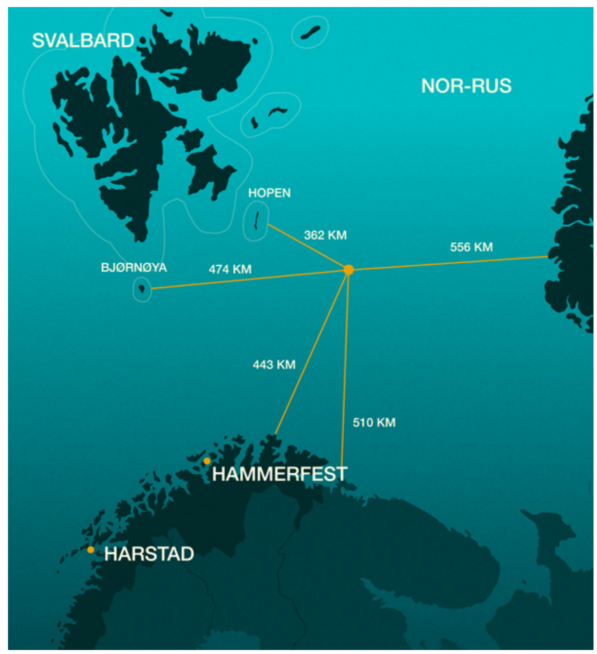
Miljørisiko og oljevernberedskap i Barentshavet sørøst

Barents Sea Exploration Collaboration (BaSEC) er et industrisamarbeid for å forberede leteoperasjoner i Barentshavet. Barentshavet har vært åpent for petroleumsaktivitet siden 1980, men industrien beveger seg nå inn i nye områder av dette havområdet. BaSECs siktemål er derfor å koordinere operatører og komme med anbefalinger om tiltak som kan danne grunnlag for sikker og effektiv letevirksomhet i Barentshavet. BaSEC har 17 medlemmer, alle operatører på norsk sokkel. BaSEC bygger sine rapporter på beste tilgjengelige kunnskap og på den brede erfaring disse 17 selskapene har fra operasjoner i Barentshavet, andre steder på norsk sokkel og i andre områder med tilsvarende forhold.

Sammendraget dekker tre rapporter om tre tema: miljørisiko, oljevernberedskap og status for oljevern i is. De tre rapportene er laget med utgangspunkt i blokk 7435/9 som inngår i lisens PL859. Rapportene ble utarbeidet i forkant av vårens tildelinger i 23. konsesjonsrunde. Lisensgruppen som nå har ansvaret for lisens PL859 vil utarbeide miljørisikoanalyser når de bestemmer seg for hvor og når man skal bore letebrønner i denne lisensen.



Figur 1: Lokalisering av brønn for miljørisikoanalysen

Blokk 7435/9 ligger midt i Barentshavet med stor avstand til land. Nærmeste landområde er Hopen som er 380 km unna, det er 440 km til fastlandet (Nordkapp) og ca. 500 km til Bjørnøya. Dette er en viktig forutsetning for de vurderingene som gjøres i miljørisikoanalysen. I tillegg er det viktig å merke seg de funn som er gjort i BaSECs rapport om «Fysisk miljø i Barentshavet sørøst», som ble offentliggjort tidligere i 2016. Videre har rapporten brukt en generell sannsynlighet for utblåsning på 0,014 % eller 1 gang per 7092 letebrønner. Det er forventet at denne risikoen vil være lavere ved senere analyser på grunn av reservoarenes lave trykk og lave temperatur.

Rapporten er laget av DNV GL og har anvendt best tilgjengelige data, slik som Seapop og SEATRACK for å kunne si noe om risikoen ved en eventuell oljeutblåsning. Anerkjente analyseverktøy som OSCAR for oljedriftsimulering er også brukt. Rapporten har også for første gang gjennomført en dynamisk simulering av olje i drift i forhold til den marginale issonen og vurdert sårbarheten til dyrelivet i området definert som polarfronten.

Hovedfunnene knyttet til miljørisiko ved en oljeutblåsning fra blokk 7435/9 kan oppsummeres med at:

- Oljen fra en utblåsning vil ikke nå land
- Så lenge aktiviteten foregår i henhold til myndighetenes krav om en 50 kilometers buffersone er det svært lite sannsynlig at oljen fra en eventuell utblåsning vil nå inn i iskantsonen
- En oljeutblåsning vil i hovedsak påvirke sjøfugl på åpent hav – det er mer enn 70 % sannsynlighet for ingen skade og inntil 30 % sannsynlighet for en skade hvor bestanden vil være gjenvunnet i løpet av 1-3 år
- Det er ikke funnet bestandseffekter på sjøpattedyr eller på fisk
- Eksisterende oljevernutstyr vil kunne benyttes med betydelig effekt

Hvor stor er sannsynligheten for en oljeutblåsning?

Selv om Barentshavet ligger langt mot nord, viser erfaring og kunnskapen om geologien i området at det ikke er mer komplisert å bore der enn andre steder på sokkelen. I Barentshavet er det ikke høyt trykk i reservoarene, i motsetning til enkelte steder i Nordsjøen og i Norskehavet. Det lave trykket innebærer at det er liten sannsynlighet for en ukontrollert utblåsning. En eventuell utblåsning vil derfor ha et begrenset skadepotensiale.

I denne rapporten har BaSEC likevel, basert på relevant historisk statistikk, brukt en generell frekvens risiko for oljeutblåsning tilsvarende 1 utblåsning for hver 7092 letebrønn. Dette tilsvarer en sannsynlighet for utblåsning på 0,014 prosent. Det antas at dette er en høyere risiko enn den man vil se i de forskjellige boremålene i de tildelte lisensene.

Siden 1969 er det boret om lag 1500 letebrønner totalt på norsk sokkel, hvorav ca. 130 brønner i Barentshavet.

Vil oljen kunne nå kysten?

Leteblokk 7435/9 i Barentshavet sørøst (en del av lisens PL859) ligger 380 km fra nærmeste landområde på Hopen og hele 440 km nord for fastlandet på Finnmarkskysten. Avstanden til den maritime grensen mellom Norge og Russland er 30 km. En eventuell oljeutblåsning ved leteboring i området vil derfor ikke nå kysten.

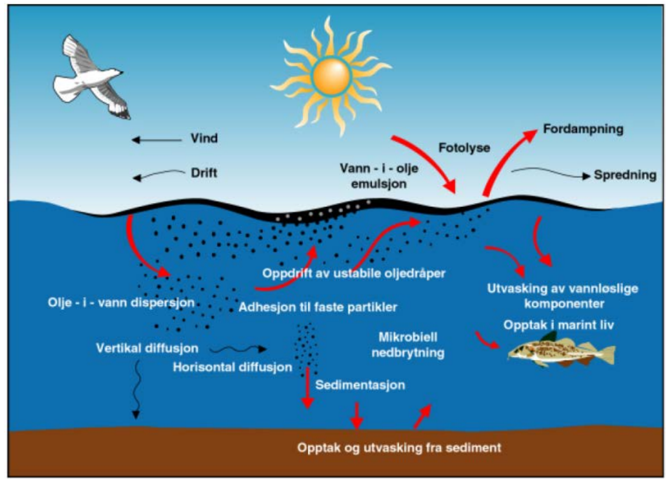
Skrugard-olje, som er oljetypen valgt for området ved blokk 7435/9, har en relativt kort levetid – 2 døgn – på sjøen ved mye vind og høye bølger, men kan holde seg en drøy uke på havoverflaten under rolige værforhold.

Fordampningen og nedblandingen ved en eventuell oljeutblåsning eller et eventuelt oljeutslipp, starter like etter oljen legger seg på havoverflaten. Da iverksette tre prosesser fra naturens side som alle bidrar til at oljeflaket brytes opp og forsvinner.

Første fase. De lette delene av oljen fordamper. Hvor fort det skjer, avhenger av værforhold og oljens konsistens. Forventet olje i Barentshavet sørøst kjennetegnes ved å være lett. Konsistensen gjør at fordampingen vil skje raskere der enn i de fleste andre havområder.

Andre fase. Oljen blandes ut med vann. Dette kan øke volumet på oljeflaket selv om konsentrasjonen av olje synker.

Tredje fase. Den viktigste prosessen er den naturlige oppløsningen av oljen. Oppløsningen skjer i hovedsak ved at vind og bølger brekker opp oljeflaket i små oljedråper. Jo større bølger og jo kraftigere vind, desto fortere brytes oljeflaket opp. Disse dråpene blandes så inn i vannet under havoverflaten. Ganske raskt synker da konsentrasjonen av giftige stoffer til under nivået som påvirker levende organismer. På det tidspunktet kan ikke lenger oljen skade livet i havet.



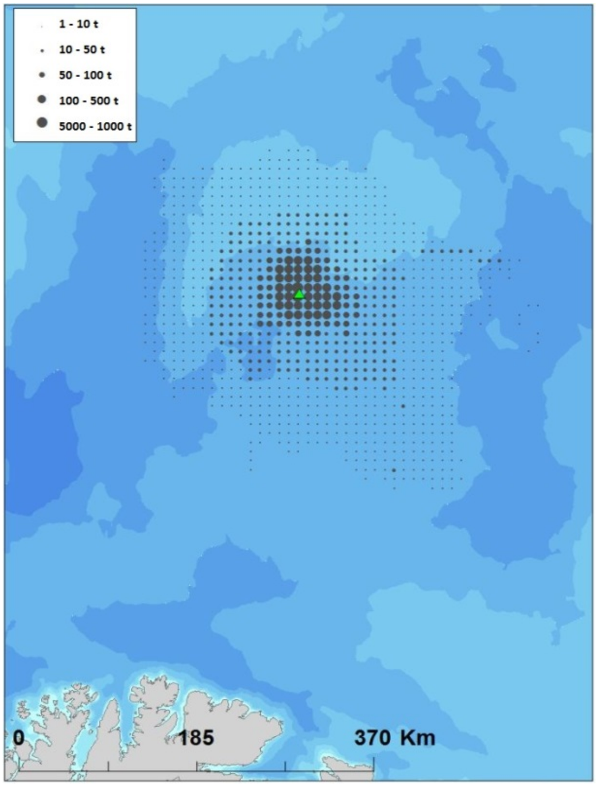
Figur 2: Naturlig nedbryting av olje på havoverflaten. Kilde: SINTEF

Antatt levetid på overflaten for olje i Barentshavet sørøst er fra to dager til en drøy uke.
I tillegg til dette vil det være oljeverntiltak som tar opp olje fra havoverflaten og/eller øker nedbrytingen av oljen i vannet. Det er strenge krav til å være forberedt på slike situasjoner, og alle operasjoner i Barentshavet har og vil ha en god beredskap for oljevern.

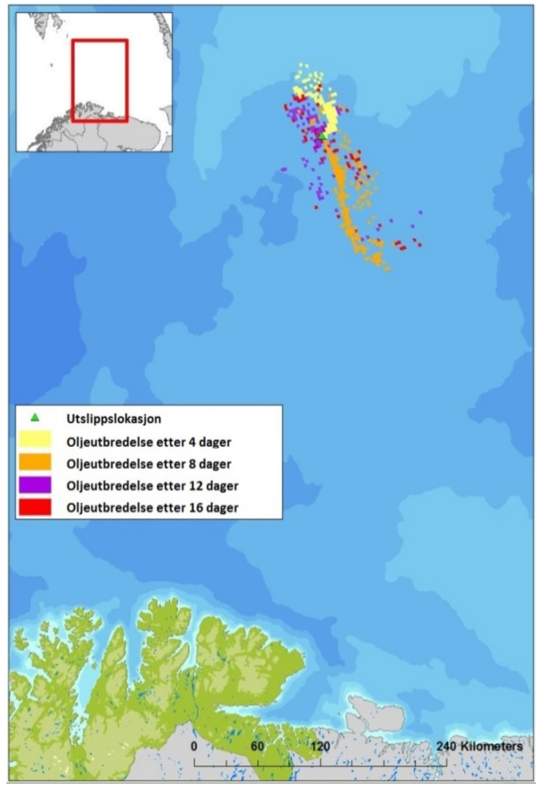
Oljedriftsberegninger viser at oljen fra en utblåsning er forventet å bre seg inntil 100 km fra utslippspunktet, men at oljen i noen tilfeller kan drive så langt som 200-250 km på havet før den er fordampet og nedblandet i vannmassene. Jo lengre oljen kommer vekk fra utblåsningspunktet, jo mindre er konsentrasjonen av oljen og mulige miljøeffekter avtar i takt med reduksjon i konsentrasjon.

Figur 3 (på neste side) viser hvor oljemengdene fra en utblåsning i blokk 7435/9 i hovedsak kan havne. Et enkeltutslipp vil dekke et mye mindre område, men vil ikke gå utenfor det merkede området. Figuren er en simulering av hvor et stort antall oljeutslipp kan drifte under ulike historiske vind- og strømforhold.

Figur 4 (på neste side) viser hvordan et enkeltutslipp vil bevege seg over en 16-dagers periode. Dette er en tilfeldig utvalgt simulering.



Figur 4: Vektet oljemengde i tonn per 10x10km ved en overflateutblåsning



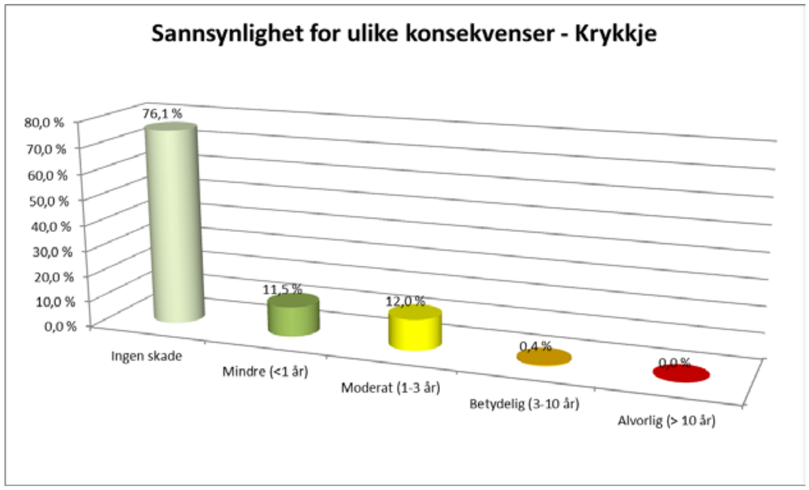
Figur 3: Utbredelse av olje på havoverflaten over en periode på 16 døgn i en tilfeldig valgt utblåsningssimulering

Vil oljen kunne nå iskanten?

Oljedriftsberegningene som er utført for blokk 7435/9 i lisens PL859 viser at det er svært lite sannsynlig at olje driver inn til en iskant som er mer enn 50 km unna. Beregningene viser en samvariasjon som gjør at selv om man forventer at olje kan drive 100 km så driver den som regel i samme retning som isen, dvs. når isen rykker sørover driver også oljen sørover og når isen trekker seg tilbake vil oljen drive nordover igjen.

Overgang fra åpent hav til islagt hav (iskanten) har variabel karakteristikk fra dag til dag, fra måned til måned og fra år til år. Forvaltningsplanen for Barentshavet og Lofoten benytter derfor en definisjon på iskanten som det området hvor mer enn 15 % av havflaten er dekket av sjøis i mer enn 30 % av dagene i april. Typisk ser man da på sannsynlighet basert på mange år med historiske isutbredelser (10-30 år med data). Blokk 7435/9 ligger cirka 150 km sør for det iskantområdet etter denne definisjonen. Regelverket tilsier at dersom iskanten kommer nærmere enn 50 km fra borelokasjonen skal en leteboringsoperasjon settes på vent inntil isen igjen er mer enn 50 km unna.

Hvordan vil en oljeutblåsning påvirke sjøfugl og sjøpattedyr på havet?



Figur 5: Sannsynlighet for effekt på krykkje

Analysene som er utført for blokk 7435/9 viser at det er sjøfugl som vil kunne bli mest berørt. Dette inkluderer arter som krykkje, lunde og polarlomvi. Selv om enkeltindivider vil kunne dø er det beregnet at det er over 70 % sannsynlighet for at en eventuell oljeutblåsning ikke vil medføre skade (mer enn 1 % tap) på sjøfuglbestandene i Barentshavet. Det er mindre enn 1 % sannsynlighet for å få en betydelig miljøskade, som vil medføre 3-10 års restitusjonstid for bestanden av krykkje i Barentshavet (se figur 6).

Beregningene er utført basert på data fra Seapop (seapop.no) som har utarbeidet kart som viser artenes utbredelse på åpent hav om sommeren, høsten og vinteren.

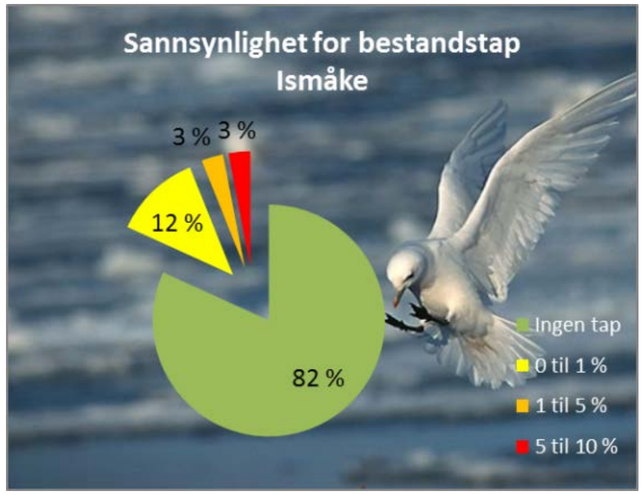
Generelt kan vi si at det er svært stor variasjon i hvilke konsekvenser en oljeutblåsning vil få for sjøfugl og sjøpattedyr avhengig av værforholdene når et utslipp skjer og hvor mye sjøfugl og sjøpattedyr det er i området. Konsekvensen vil også variere med hvor sårbare ulike individer er for olje, men også hvor sårbare ulike bestander er i forhold til en nedgang i populasjonen.

Et annet usikkerhetsmoment er Polarfronten – skillet mellom varmt atlantisk vann og kald arktisk vann og hvilke biologiske ressurser som finnes der. Datasettene er for grove til å fange opp større tettheter av fugl i polarfronten. Hvis man likevel analyserer en utblåsningseffekt på en hel bestand som skulle befinne seg i umiddelbar nærhet av utblåsningen, forventer vi at bestandstapet fremdeles er på under 10 %. Bestanden vil da i løpet av 1-3 år gjenvinne størrelsen. Dette er innenfor det som på norsk sokkel er en akseptabel risiko. Igjen er det viktig å huske på at sjansen for en utblåsning i seg selv er på 0,014 %.

Hvordan vil en oljeutblåsning påvirke dyrelivet i iskanten?

Borelokasjonen ligger et stykke unna iskanten, og det er beregnet en lav sannsynlighet for at olje vil berøre iskanten ved en eventuell oljeutblåsning. Det forventes derfor ikke at dyrelivet i iskanten vil bli vesentlig berørt. Oljen i denne delen av Barentshavet har relativt kort levetid (2 døgn) på sjøen ved mye vind og høye bølger. Den kan holde seg i en drøy uke på havoverflaten under rolige værforhold.

Beregninger utført for ismåke viser at selv i vinter- og vårsesongen, hvor iskanten er nærmest borelokasjonen, så er det ved en utblåsning mer enn 80 % sannsynlighet for at man ikke får konsekvenser på ismåkebestanden (se figur 7). Det er generelt lite spesifikke datasett tilgjengelig som viser utbredelsen av dyrelivet i iskantsonen. For å vurdere mulige konsekvenser på sjøfugl ble det derfor opparbeidet et datasett på utbredelse av ismåke, en høyarktisk art som har tilhold i isfylte farvann hele året. Datasettet er dynamisk og viser utbredelsen i områder med 20 til 50 % is.



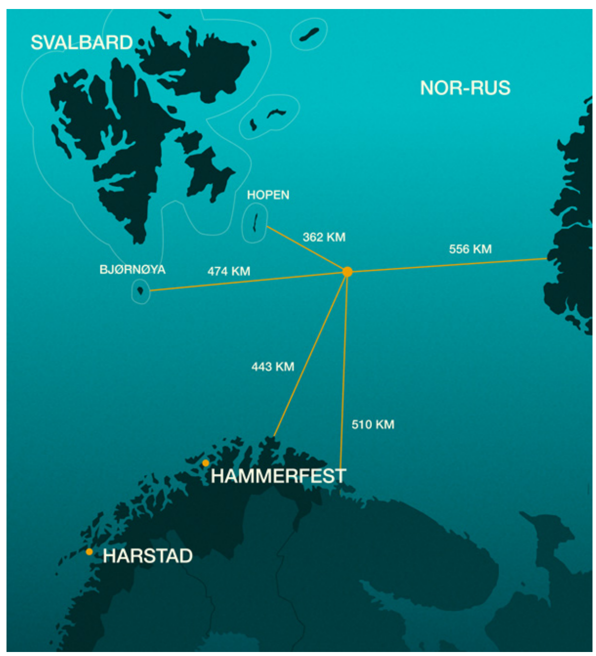
Figur 6: Sannsynlighet for bestandstap av ismåke

Dataene om ismåke baserer seg på GPS-logger-studier i SEATRACK. Dette er et helhetlig og langsiktig overvåkings- og kartleggingsprogram for norske sjøfugler. Datasettet kan også være relevant for andre arter i den marginale issonen slik som for eksempel sel.

Hvordan vil en oljeutblåsning påvirke dyrelivet i kyst- og strandsonen?

Risikoen for en utblåsning er på 0,014 %. I og med at borelokasjonen i blokk 7435/9 er mer enn 380 km fra nærmeste landområde på Hopen og mer enn 440 km fra Finnmarkskysten, så vil ikke olje fra en eventuell utblåsning leve så lenge på havoverflaten at den vil kunne nå land. Det vil derfor ikke være noen bestandseffekter på dyrelivet i kyst- og strandsonen.

Oljen i denne delen av Barentshavet har relativt kort levetid (2 døgn) på sjøen ved mye vind og høye bølger. Den kan holde seg en drøy uke på havoverflaten under rolige værforhold. Enkelte sjøfuglarter, som for eksempel lunde kan fly så langt som 100 km ut fra hekkekolonien for å finne mat. Individer av enkeltarter som er basert langs land forventes derfor i svært begrenset grad å bli påvirket av en utblåsning fra denne blokken.



Figur 7: Lokalisering av brønn for miljørisikoanalysen

Hvordan vil en oljeutblåsning påvirke fisk og livet i havet?

Ved en eventuell oljeutblåsning vil bølger føre til at noe av oljen naturlig blandes ned i vannsøylen. Det vil imidlertid være en rask fortynning i tid og rom i av de giftige oljekomponenter i vannsøylen som kan gi effekter på livet i havet. Det er først og fremst fiskeegg- og larver som er mest sensitive for oljepåvirkning. Det er ikke vist til særlig stor konsentrasjon av fiskeegg- og larver i området rundt borelokasjon 7435/9 og modellerte oljekonsentrasjoner i vannsøylen er lave. Det vil kunne være dødelighet av egg- og larver i nærområdet 20-30 km rundt en utblåsning, men dette forventes ikke å føre til målbare konsekvenser for fiskebestander i Barentshavet.

Det er i cirka 250 meters vanndyp på borelokasjonen og skulle en utblåsning skje på sjøbunnen og ikke på overflaten, forventes det allikevel at gass og reservoartrykk vil føre oljen raskt opp til overflaten for så å spres på samme måte som et overflateutslipp.

Hvilken effekt kan vi forvente av oljevernberedskap i dette området?

En oljevernberedskapsanalyse er utført for et utblåsningsscenario fra blokk 7435/9 i lisens PL859. Størst beregnet effekt har en kombinasjon av mekanisk opptak med lensesystemer og dispergering fra fly. En slik kombinasjon vil kunne redusere oljen på overflaten med inntil 75 % under optimale forhold i løpet av de første fem dagene. Av de vurderte teknikkene er det mekanisk opptak som viser størst potensiale i iskonsentrasjon opp til 30 %. Det vurderes imidlertid som svært lite sannsynlig at et eventuelt oljesøl vil nå iskanten.

På tross av lav sannsynlighet for oljepåslag i is, tar studien for seg ulike beredskapsteknikker både i åpent hav og i isfylte farvann. Den belyser hvilke teknikker som kan fungere best på en eventuell utblåsning i dette området. Dette omfatter både mekanisk opptak med både konvensjonelle og aktive lensesystemer, kjemisk dispergering både fra fly og fra fartøy, brenning og undervannsdispergering. I tillegg er det sett på et konsept for et fartøy som kan utføre flere typer oljeverntiltak i isfylte farvann opp til 30 % iskonsentrasjon.

Målet er at flest mulig av disse beredskapsteknikkene er tilgjengelige og kan benyttes basert på hvilke forhold det til enhver tid er rundt utslippet. Beredskapen vil være sammenlignbar med effektiviteten andre steder på norsk sokkel. Den viktigste forskjellen er at forskjellen i effekt mellom sommer og vinter er større enn på andre deler av sokkelen. Dette skyldes blant annet lysforhold.

Flere øvelser har blitt utført i Finnmark vinteren 2015. En øvelse ble også gjennomført i iskanten senvinteren 2015. Øvelsene har gitt verdifull informasjon og erfaringer om norsk oljevernberedskap i kaldt klima og is, og underbygger de utførte beregninger. Øvelsen demonstrerte bl.a. at et vanlig NOFO-system kan settes ut og opereres etter dagens prosedyrer. Anti-is middel (glykol) kan benyttes på sentrale komponenter for å motvirke ising.

For isfrie farvann er eksisterende og tilgjengelige løsninger på norsk sokkel for oljedeteksjon dekkende, men datakommunikasjon kan være en begrensende faktor så langt nord. Tiltak for å forbedre digital kommunikasjon fra skip viser gode resultater, og digitale downlink-systemer fra fly fungerer også godt.

Dersom et oljeutslipp skulle drive inn i Russisk farvann er det etablert en overenskomst mellom Norge og Russland angående samarbeid om bekjempelse av oljeforurensning i Barentshavet. I medhold av avtalen er det utarbeidet en felles Norsk-Russisk beredskapsplan for oljevernaksjoner i Barentshavet. Planen regulerer samarbeid mellom myndigheter i de to landene når det gjelder aksjoner mot oljeutslipp, gjennomføring av øvelser og jevnlige møter.

Oil spill contingency analysis for exploration drilling in the Barents Sea South-East

Statoil ASA

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EXECUTIVE SUMMARY

The Barents Sea Exploration Collaboration (BASEC) - a joint effort including Statoil ASA, Eni Norge, Lundin Norway, OMV and ENGIE - has conducted a damage-based environmental risk analysis (ERA) and an oil spill contingency analysis (OSCA) for a potential drilling operation in block 7435/9 (part of the 23rd licencing round). The results from the main part of the study are presented in separate reports. The following report presents the output from the oil spill contingency part. The results of the OSCA provide the basis for an operational assessment of these response measures, documented in a separate *Oil Spill Response Status Document.*

The exploration well is located in the South-Eastern part of the Barents Sea, approximately 440 km from mainland Norway. The water depth at location is 228 meters MSL.

Topside dimensioning release scenario had a rate of 2735 Sm^3/d with duration of 9 days, for a subsea release the values were 1730 Sm^3/d and 16 days, respectively. Skrugard crude oil was selected as reference oil.

Standard oil spill response measures as well as future concepts were selected for both open water response as well as response in the marginal ice zone, including

- mechanical recovery with passive and active boom systems
- aerial and vessel-based dispersion application
- in-situ burning
- subsea dispersion.

The aim of the OSCA was to assess the effect of different numbers and types of response systems as well as the effect of shorter response times using a second standby-vessel. Open water response was modelled with SINTEF's oil spill model OSCAR, while oil in ice calculations were performed with DNV GL's Oil spill response calculator (ORCA).

The modelling results for the reference scenario (no oil spill response measure) indicate that by the end of simulation (24 days topside blowout, 31 days subsea blowout) the oil primarily has dispersed naturally, evaporated, and biodegraded in the water column. A limited fraction (0.5-3 %) remains on the water surface. No stranding is observed.

In general, all response measures showed a greater effectiveness on topside blowout than on subsea blowout as more surface oil is available to be collected, burned or dispersed. The use of a second stand-by vessel in order to shorten response times had marginal additional effect on the fraction of recovered or dispersed oil.

For **mechanical recovery**, the recovered oil fraction is higher during summer compared to winter season. An increasing the number from one to five mechanical recovery systems results in a further increase in the degree of recovered oil up to 30 - 35 %. Active mechanical recovery systems can contribute to a faster and higher recovery of surface oil than passive systems due to their higher encounter rate.

Chemical dispersion is according to the model a suitable strategy for reducing the amount of Skrugard surface oil. The use of dispersants will mainly lead to an increase in oil in the water column, especially in the biodegraded fraction. Dispersants applied using 5 vessels showed according to the model to be more effective on reducing surface oil compared to distributing the same amount of dispersant fluids using one aircraft. However, in combination with mechanical recovery, aerial dispersion had a higher effect in reducing the fraction of oil on surface than the combination of dispersant vessels and mechanical recovery.

In-situ burning can be operational feasible for a topside scenario but less for a subsea scenario, however the oil properties (high and rapid water uptake) impede most likely to the efficiency of the burn.

Subsea dispersion has according to the model limited effect on reducing oil on surface, mainly due to the low water depth of the spill location, resulting in a rapid raise of the oil droplets to the water surface.

For an **oil spill within the marginal ice zone**, mechanical recovery was calculated to be the most feasible strategy but a combination with chemical dispersion and in-situ burning could potentially broaden the operational window when operating on fresh oil in such areas.

In general, response measures primarily aim reduce the fraction of oil on surface and limit/prevent the amount of oil to impact seabirds, marine mammals and shoreline habitats. The study showed that reduction of population loss probability is strongly linked to the reduction of surface oil. Response measures with a high ability to decrease oil on surface within the first days contribute also most to a reduction in population loss probability.

The study showed that by using combination of several response techniques and implementing new response systems to the “toolbox”, the operational time window for effective response operations can be can be widened and the environmental damage and impact can be reduced.

DEFINITIONS AND ABBREVIATIONS

Biodegradation	The breaking down of substances by microorganisms, which use the substances for food and generally release harmless by-products such as carbon dioxide and water.
Boom	A temporary floating barrier used to contain an oil spill. Conventional/passive boom systems are usually towed in U- or J-formation by two vessels. Active boom systems can be towed at higher operational speeds by one vessel.
Chemical dispersion	Oil spill response strategy which involves the application of oil dispersants to help breaking oil into small droplets.
Contingency plan	A document that describes a set of procedures and guidelines for containing and cleaning up oil spills.
cP	Centipoise
Crude oil	Naturally occurring liquid mixture of hydrocarbons found in reservoirs in the bedrock and extracted as raw materials in the petroleum industry.
Dispersants	Chemicals that are used to break down spilled oil into small droplets.
Dispersion	A dispersion is a system in which particles are dispersed in a continuous phase of a different composition (or state).
Deployment	Strategic placement of equipment and personnel
DOR	Dispersant to oil ratio
Encounter rate	Rate at which a response system encounters an oil slick. It includes three components: sweep width, encounter speed, and oil film thickness.
Emulsion	A mixture of small droplets of oil and water.
Emulsification:	The formation of a mixture of two liquids, such as oil and water, in which one of the liquids is in the form of fine droplets and is dispersed in the other.
Evaporation	The physical change by which any substance is converted from a liquid to a vapour or gas.
Environmental resources	Seabirds, marine mammals, fish and shoreline habitats
Environmental risk	Refers to a product of the probability of an accident to occur and the environmental consequences expressed as restitution time
Environmental vulnerability	The capacity of an environmental resource to cope with different pressures

ERA	Environmental risk assessment
Fate	The outcome; the fate of an oil spill is what happens to the oil.
Influence area	Oil/chemical affected area (a number of grid cells) which the radius of the area is defined from the relevant product and mass category
Ice-concentration	Defined according to the WMO nomenclature; i.e. as the percentage of the sea surface covered by ice.
In-situ burning	In situ burning, or ISB, is a technique sometimes used by people responding to an oil spill. In situ burning involves the controlled burning of oil that has spilled from a vessel or a facility, at the location of the spill.
Key species	A species that is critical for maintaining the relationship of an ecosystem
Marginal ice zone	The marginal ice zone is as defined as the area with more than 30 % probability of more than 15 % ice concentration.
Natural dispersion	Dispersion (see *dispersion*) of oil due to the effect of breaking waves.
Oil slick	A layer of oil floating on the surface of water.
Oil spill contingency system	System used in oil spill contingency operations- such as a system for application of chemical dispersants (usually one boat or aircraft) or a system for mechanical recovery (usually includes one OR-ship and a towing boat, including boom and skimmer equipment).
Oil spill response	Measure implemented in the acute phase of an oil spill with the aim of preventing the spreading of the oil.
OR vessel	Oil recovery ship. The main ship in a mechanical oil recovery system, containing storage tank and equipment such as skimmer and boom.
OSCA	Oil Spill Contingency Analysis
OSCAR	Oil Spill Contingency and Response model (SINTEF).
Pour point	The pour point of a liquid is the temperature at which it becomes semi solid and loses its flow characteristics.
Recovery system	A system for mechanical recovery of oil, which normally includes one OR-ship and a towing boat, including boom and skimmer equipment.
Response time	Time a response system needs until it is on scene and start the operation. This includes mobilization time, transit time, and deployment time of equipment.
System capacity	Anticipated recovery rate in m^3/d for a response system, including contact time, encounter rate etc.
Skimmer	Device used to remove oil from water surface.

Viscosity	Having a resistance to flow; substances that are extremely viscous do not flow easily.
Vulnerability	The ability of an environmental resource to deal with types of exposure
Vulnerability for oil	The ability of an environmental resource to deal with oil pollution
Vulnerability value	Relative ranking of resource vulnerability
Water column	An imaginary cylinder of water from the surface to the bottom of a water body; water conditions, temperature, and density vary throughout the water column.
Weathering	Action of the wind, waves, and water on a substance, such as oil, that leads to disintegration or deterioration of the substance.

1 INTRODUCTION

1.1 Objective

This Oil Spill Contingency Analysis (OSCA) covers an exploration drilling in the Barents Sea, with special focus on a potential well location in block 7435/9 in the Barents Sea 23rd licencing round area. The project is initiated by the Barents Sea Exploration Collaboration (BaSEC), a joint effort between Statoil ASA, Eni Norge, Lundin Norway, OMV and Engie to solve operational task tied to exploration in the Barents Sea. More recently several additional companies have joined BaSEC. This analysis is a preparation for a potential drilling campaign to point out potential environmental challenges related to petroleum activity in the area. The present study is one out of three separate studies carried out by DNV GL; the first being an *Environmental Risk Assessment* (DNV GL, 2015a) and the third being an *Oil Spill Response Status Document* (DNV GL, 2015b).

The aim of the OSCA is to assess the effect of different oil spill response measures for relevant oil spill scenarios. Response measures both for open water response as well as in the marginal ice zone in ice concentrations up to 30% were identified. The results of this OSCA provide the basis for an operational assessment of these response measures, documented in the *Status Document* (DNV GL, 2015b).

1.2 Scenario description

The defined scenario is an exploration drilling operation in the north-eastern part of the Norwegian economic zone of the Barents Sea (Figure 1-1) using a semi-submersible drilling rig. The water depth at the location is 228 meters MSL.

The potential blowout scenarios are described in (Solberg, 2015). A blowout during drilling may occur if a reservoir is penetrated while well pressure is in underbalance with the formation pore pressure, followed by a loss of well control. The blowout release path may be through open hole, drill pipe and annulus, each with a corresponding probability.

According to the NOROG guideline (NOROG, 2013) weighted rate and duration were used respectively for topside and subsea release. More information related to the oil spill contingency analysis is given in Table 1-1.

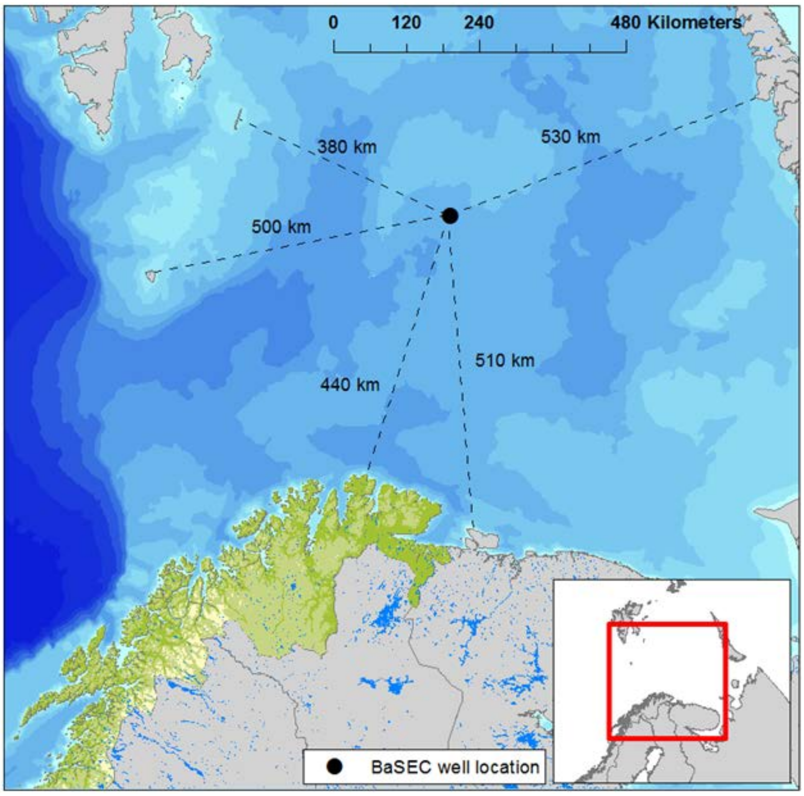


Figure 1-1 *Location and distances from nearest land areas from the well location in block 7435/9.*

Table 1-1 *Information applied in the oil spill contingency analysis.*

Blowout location	74,375° N; 35,833° E
Analysis period	Annual, presented as two seasons: summer (March – August) and winter (September - February)
Water depth	228 m
Shortest distance to shore	Ca. 440 km
Fluid type (reference fluid)	Skrugard Crude Oil
Crude oil density	871 kg/m^3
Type of scenarios	Topside and subsea blowout
Rates used in oil spill contingency analysis	Topside: 2735 Sm^3/d (weighted rate) Subsea: 1730 Sm^3/d (weighted rate)
Durations used in oil spill contingency analysis	Topside: 9 days (weighted duration) Subsea: 16 days (weighted duration)

1.3 Oil type and characteristics

Oil spilled into sea undergoes different weathering processes due to the influence of weather conditions. Chemical and physical parameters change which influence oil drift and the efficiency of contingency measures.

This chapter gives a general overview of parameters influencing oil properties which are important for oil spill response. In this study, Skrugard crude oil is chosen as a reference oil type. The oil characteristics are gathered from the oil weathering study for the oil type, carried out by SINTEF in 2012 (Øksenvåg, 2012).

Skrugard oil is a highly biodegraded, naphthenic oil with a medium density and a low content of wax and asphaltenes compared to other Norwegian crude oils. Spilled at sea, the oil will rapidly be lowered to ambient water temperature. In high sea conditions the oil is predicted to have limited time at the sea surface due to evaporation and natural dispersion (~48 hours), but it may be more persistent in calmer weather, (>5 days).

Some of the key characteristics for Skrugard crude oil are presented in Table 1-2.

Table 1-2 *Key characteristics for Skrugard crude oil.*

Parameter	Value
Oil density [kg/m^3]	871
Maximum water content at 5/10 °C [volume%]	80
Viscosity, fresh crude at 5 °C (10 s^{-1}) [cP]	32
Wax content [weight%]	1.89
Asphalt content [weight%]	0.05

1.3.1 Important physical and chemical oil parameters related to oil spill response

Density

Specific gravity (kg/m^3) is one of the most central physical oil parameters. It is of great importance for how the oil performs in the sea, both on the surface as well as in the water column. For example, lighter oil types will reach the surface faster given a subsea blowout, and distribute as a thinner oil film over a larger surface area, compared to heavier oil types. Skrugard crude oil is classified as a medium crude oil with a medium density (Table 1-3)

Table 1-3 *Density for Skrugard oil compared to other Norwegian oil/condensates (Øksenvåg, 2012)*

	Skrugard	Troll B	Statfjord A	Norne	Grane
Density [kg/m^3]	871	892	827	863	942

Viscosity

Viscosity is a measure of a liquid's ability to resist deformation by shear or tensile stress. High viscosity gives viscous (thick) liquids and low viscosity gives thin liquid oils. This is an important parameter to ensure that response vessels are equipped with proper recovery equipment to collect the oil.

Oil viscosity is given in centipoise (cP). Norwegian crude oils normally range from 10 cP for fresh to several thousand cP for weathered oils. Heavy and extra heavy oils have viscosities from 2000 cP and higher.

Oil and water emulsions are generally more viscous than the original crude oil. Viscosity increases rapidly with enhanced water content. Formation of emulsions is a result of weathering processes on the sea surface. Lighter oil compounds are removed from the oil by evaporation; results in more viscous oil with a higher concentration of heavier compounds. Higher wind intensity speeds up the weathering process and thereby contributes to higher viscosity values. Above a certain threshold the wind forces the majority of the oil down in the water column. Emulsion viscosity continues to increase in calm weather or after stranding. The emulsion might end up as a semi solid material. Oil viscosity is strongly related to temperature, where lower temperatures results in higher viscosity.

A viscosity of 1000 cP is as assumed to be the lower limit for when a traditional mechanical recovery system can effectively operate. Below this threshold recovery is achievable but with limited effect. Upwards the recovery is equipment dependent, at 20 000 cP emulsion will not flow freely into and through the mechanical uptake systems which results in reduced recovery efficiency. Around 15 000 cP hi-wax skimmers usually replace traditional skimmers (Leirvik et al. 2001).

Figure 1-2 shows that Skrugard crude oil has a relatively low viscosity compared to other oil types of the Norwegian shelf.

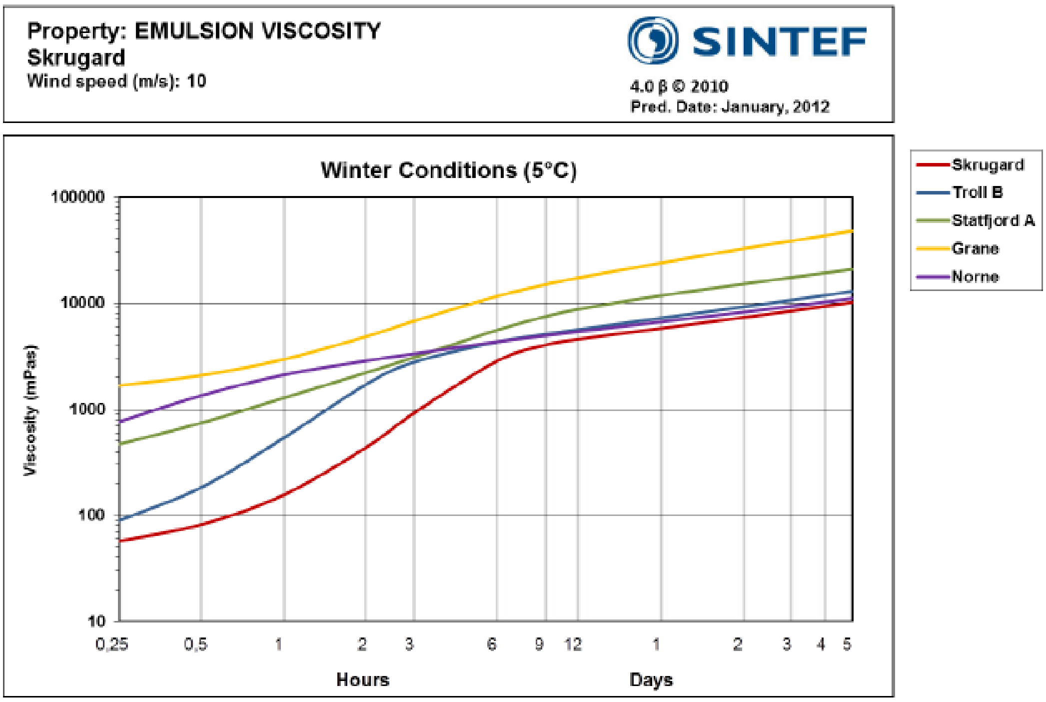


Figure 1-2 *Predicted emulsion viscosity at 5 °C and 10 m/s wind speed for Skrugard crude oil, compared with other Norwegian oils (Øksenvåg, 2012).*

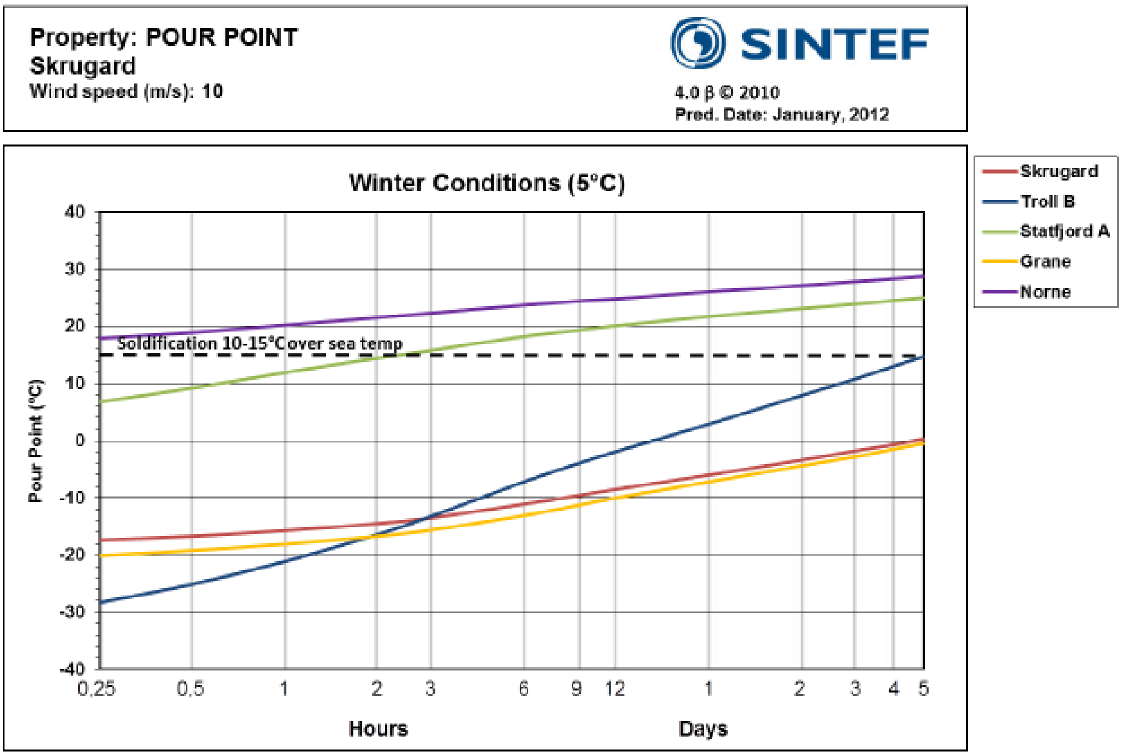


Figure 1-3 *Predicted pour point at 5 ℃ and 10 m/s wind speed for Skrugard crude oil, compared with other Norwegian oils (Øksenvåg, 2012).*

Pour point

For oil types where a high viscosity is not an obstacle, solidification on water surface might be a limiting factor which is known to start at a pour point 10-15 °C above the sea temperature. Pour point is the temperature at which the oil stops flowing in a laboratory under calm conditions and cooling. Fresh crude oil with high wax content has a pour point around 30 °C, however, low viscous oil might have a pour point down to -40 °C. Pour point depends on the oil's wax content and the amount of light components that are able to keep the waxes dissolved in the oil.

Figure 1-3 shows that Skrugard has, as Grane and Troll B, a low wax content, and will not solidify at the given release scenario. This is due to their low wax content. Norne has a very high content of wax and Statfjord a medium content of wax, both resulting in high pour points. This might cause a solidification quite rapid after an oil release at sea (Øksenvåg, 2012).

Flash point –fire / explosion hazard

This is the lowest temperature at which gas or fume from the oil can ignite. This indicates if there is a fire or explosion hazard working with specific oil at a specific time. The most common crude oils have a flash point between -30 °C and -40 °C. Weathering processes as evaporation and emulsification increase the flash point over time. The greatest risk of fire and explosion is therefore right after the spill has started. Calm wind and high temperature contributes to a high degree of evaporation and accumulation of condensates on the surface. Oil in contact with sea water rapidly cools off to the ambient water temperature. The highest risk of fire and explosion is related to oils with flash point below sea temperature.

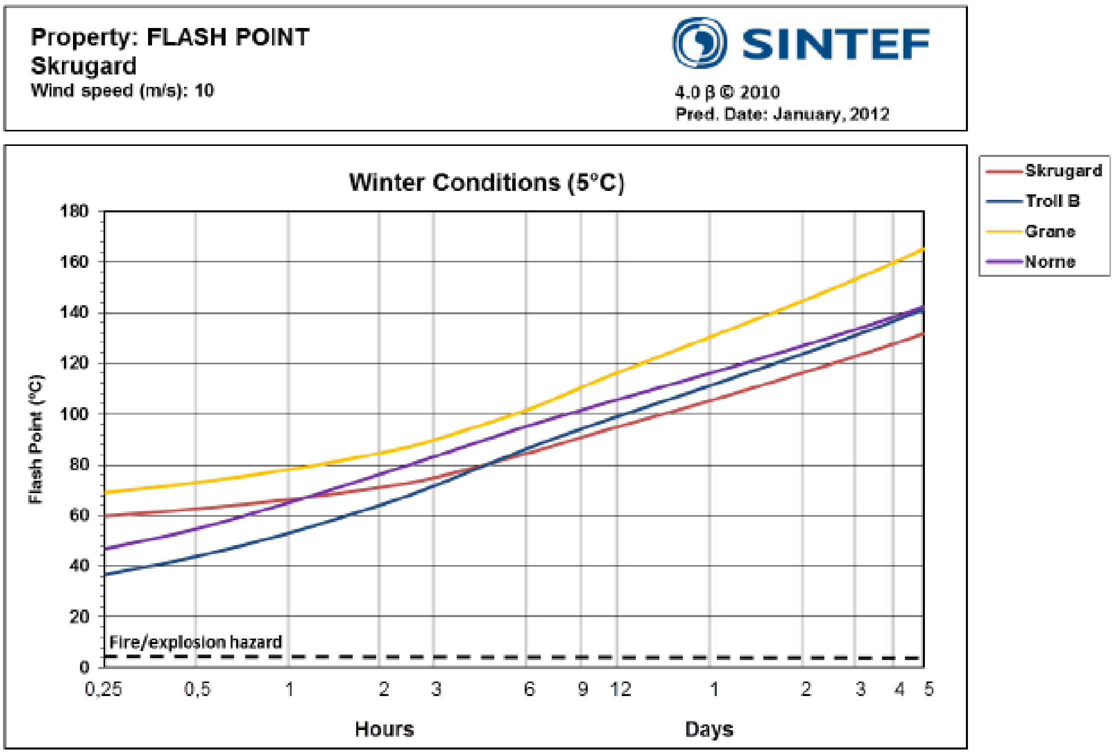


Figure 1-4 *Predicted flash point at 5 °C and 10 m/s wind speed for Skrugard crude oil, compared with other Norwegian oils (Øksenvåg, 2012).*

As a safety measure all vessels used in oil spill contingency have a flash point limitation of 60 °C, to ensure safe and secure storage of recovered oil. The immediate fire and explosion danger results in a limited amount of oil being recovered in the first hours after an oil spill has started. The oil type's flash point might therefore affect when oil recovery vessels can move into and operate in close vicinity to the spill location.

According to SINTEF's weathering study (Figure 1-4), the flash point of the Skrugard oil will be well above sea temperature at all sea states for both summer and winter conditions (Øksenvåg, 2012).

Water content – Emulsion formation

The total amount of oil on the sea surface is usually reduced due to evaporation and natural dispersion in the initial stages of weathering. However, water mixed into the oil can increase its volume considerably, forming stable oil-water-emulsions.

Skrugard emulsifies relatively rapid on the sea surface, both under winter and summer conditions, and forms w/o emulsion with high water content, as illustrated in Figure 1-5.

When no mechanical energy is applied and the stable oil-water-emulsion will nearly lose no water after 24 hours settling. Emulsion breaker is, however, effective and will make the water settle out from the emulsion (Øksenvåg, 2012).

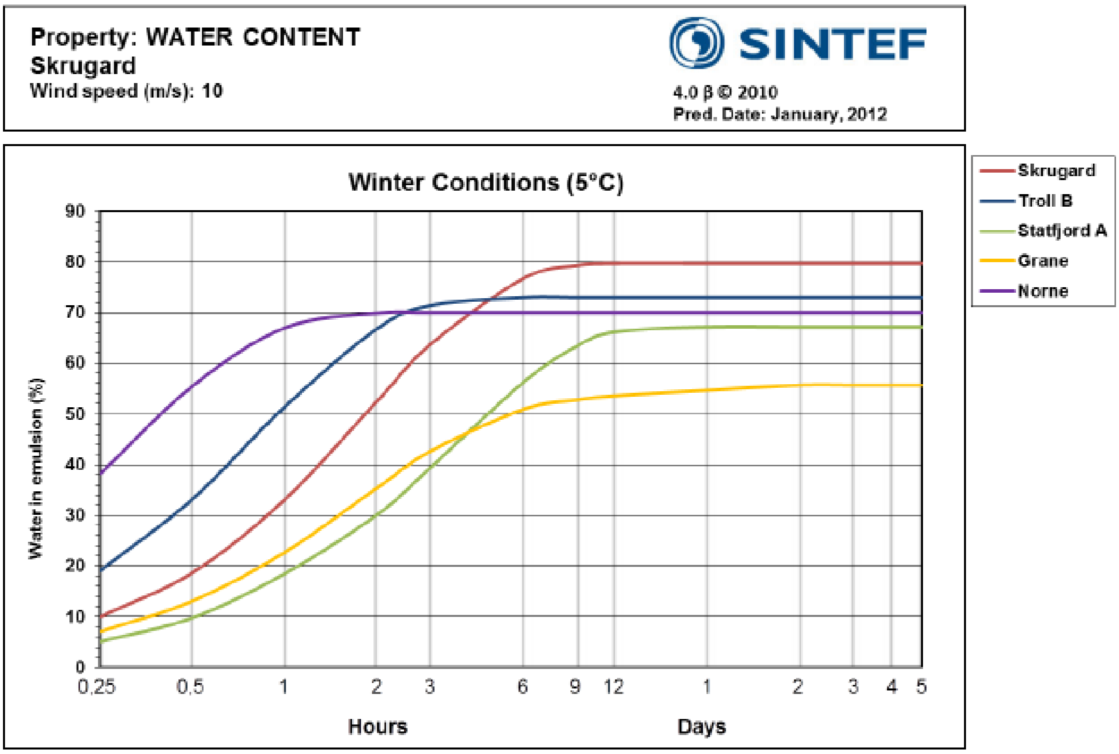


Figure 1-5 *Predicted water content for Skrugard crude oil at 5 ℃ and 10 m/s wind speed compared with other Norwegian oils (Øksenvåg, 2012).*

Oil film thickness

Oil film thickness is of great importance for oil recovery. Oil types with low oil density and viscosity will spread more evenly on the surface and eventually create thin oil films. In addition to the oil's physical and chemical properties, will also affect the release point the thickness of the oil film. Subsea blowouts and blowouts typically result in thinner surface oil films compared to topside oil spills.

Oil drifting at the sea surface will normally appear as scattered flakes after a while. The properties of the flake depend on oil type, drift time in combination with environmental and weather conditions. The thickest part of the oil flake is normally restricted to a limited part of the flake. A rule of thumb is that 90 % of the oil is concentrated within 10 % of the total flake area. This implies that oil outside this will be relatively thin (Sørheim et al., 2011).

In general will mechanical recovery-systems have very low or no efficiency when oil film thickness is below 0.1-0.2 mm, even if specialised equipment made for thin oil film is used (NOROG, 2013).

Use of chemical dispersions

The effectiveness of a chemical dispersant agent on an oil film is dependent on many factors such as oil type, weathering degree, and environmental conditions. The *window-of-opportunity* is usually relatively small as dispersants do not function on weathered oil slicks.

Dispersant screening studies showed that based on the viscosity of the Skrugard emulsions, it has a good potential for chemical dispersion, both during winter and summer conditions, however, with a limited time window (Øksenvåg, 2012). The wind condition affects the window of dispersibility with lower wind speed (2 m/s) providing a window of 2-3 days something which is reduced to 2-3 hours at a wind speed of 15 m/s. Table 1-4 shows the time window for chemical dispersibility of the Skrugard oil, based on the SINTEF's weathering study.

When the oil is expected to have reduced dispersibility, additional energy by use of e.g. thrusters, firefighting systems and man overboard boats, or the use of a higher dosage rate and repeated dispersant application, may increase the effectiveness.

Table 1-4 *Time window for chemical dispersibility of Skrugard crude oil under winter (5 °C) and summer conditions (10 °C) and different wind speeds. Green color indicates that the oil is dispersible; yellow indicates reduced chemical dispersibility and red indicates low/poor chemical dispersibility. Summarized based on results from SINTEF's weathering study (Øksenvåg, 2012).*

Season		Time window for chemical dispersibility of Skrugard crude oil										
(Temp.)	Hours	1	2	3	6	9	12	24	48	72	96	120
	Days	0,04	0,08	0,13	0,25	0,38	0,50	1,00	2,00	3,00	4,00	5,00
Winter (5 °C)	**Wind**											
	2 m/s											
	5 m/s											
	10 m/s											
	15 m/s											
	Wind											
Summer (10 °C)	2 m/s											
	5 m/s											
	10 m/s											
	15 m/s											

1.4 Oil spill response concepts

The aim of the OSCA was to assess:

- the effect of different response options incl. type and number of systems,
- the effect of response times on the recovery of oil,
- the effect of existing oil spill response strategies as well as future potential response measures.

For that, one topside and one subsea blowout scenario was modelled in OSCAR with a selection of various response measures. Based on discussions involving BaSEC work group, NOFO and DNV GL, existing oil spill response strategies as well as potential future response measures were identified.

Table 1-5 provides an overview of the response measures. A detailed description of each response measure/concept can be found in the *Status document* (DNV GL, 2015b). Response measures in open waters as well as within the marginal ice zone and ice concentrations up to 30 % have been selected.

Table 1-5 *Overview of response concepts used in the OSCA.*

Response measure		Response strategy	Short system description
0 ***Reference scenario***		none	No response measures implemented- reference scenario
MechP ***Current response systems***		Open water **mechanical** recovery with **passive** boom system	Response measure MechP equals a modern OR stand-by or supply vessel with detection capacity (IR and oil radar), an open water containment boom and a high capacity skimmer and primary storage capacity (NOFO system). Towing vessels for could be daughter crafts or a second vessel (eg. fishing vessel/NOFO Pool).
MechA ***Future concept***		Open water **mechanical** recovery with **active** boom system	Response measure MechA equals an open water containment and recovery system (Response measure MechP), but operates an active boom system (e.g CB6/CB8/MOS Sweeper) with a high capacity skimmer and primary storage capacity.
DispV ***Current response systems***		Open water **vessel** based **dispersion** system	Response measure DispV equals a modern OR stand-by or supply vessel equipped for chemical dispersion. The concept consists of detection capacity (IR and oil radar), spray booms and dispersant fluid.
DispA ***Current response systems***		Open water **aerial dispersion** system	Response measure DispA equals a fixed-wing dispersant aircraft (e.g. *OSRL Boing 727*) for aerial dispersant application. The system has a dispersant capacity of 17.5 m^3 and a range of 2,500 nautical miles in five hours.
DispS ***Future concept***		**Subsea dispersion**	Response measure DispS will be used for a subsea blowout scenario injecting chemical dispersants into wellhead.
ISB ***Future concept***		Open water **in-situ burning** system	Response measure ISB equals a future response concept for In Situ Burning in open waters. The measure is based on a modern OR stand-by or supply vessel with oil detection capacities (IR and oil radar) and carries an additional ISB kit with fire booms and a surface ignition system. Towing vessels could be daughter crafts or fishing vessels.
IceRV ***Future concept***		Multipurpose **response vessel** for **ice concentrations up to 30%.**	Response measure IceRV equals a multipurpose vessel system equipped for combating oil in the marginal ice zone. The system is primarily set up for operations in ice up to 30 % concentration and comprises of kits for 1) mechanical recovery, 2) ISB and 3) dispersant application in ice. **NOTE: this response measure has not been modelled but assessed quantitatively in a calculator tool.**

1.4.1 Response configuration set-up

Each response measure as described in Table 1-5 was set-up with several system configurations as presented in Table 1-6. A complete list of all input parameters for each response measures used in the model can be found in Appendix A. Input parameters were set and discussed of the BaSEC work group, NOFO and DNV GL.

Except for the subsea dispersion scenario (DispS) and aerial dispersion (DispA) 1, 2 and 5 systems were applied in the setups in combination with different response time for first system (labelled a and b respectively).

Response measure DispA was modelled with 1 and 2 aircrafts (same response time).

Response measure DispS was modelled for the subsea scenario only.

Furthermore, the effect of the combination of mechanical recovery and dispersion application was analysed in four different combinations (Table 1-7).

Table 1-6 *Set-up and system configuration for the different response measures used in the OSCA. The number in the scenario name indicates the number of systems while the letters **a** and **b** refer to the response time set-up.*

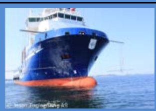
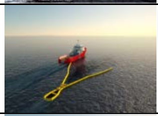
	Response measures set-up					
						
Scenario name	**MechP**	**MechA**	**DispV**	**DispA**	**DispS**	**ISB**
1	1 Standby vessel	1 Standby vessel	1 Standby vessel	1 Aircraft	Yes	1 Standby vessel
2a	1 Standby vessel 1 NOFO system	1 Standby vessel 1 NOFO system	1 Standby vessel 1 NOFO system			1 Standby vessel 1 NOFO system
2b	2 Standby vessels	2 Standby vessels	2 Standby vessels	2 Aircrafts		2 Standby vessels
5a	1 Standby vessel 4 NOFO systems	1 Standby vessel 4 NOFO systems	1 Standby vessel 4 NOFO systems			1 Standby vessel 4 NOFO systems
5b	2 Standby vessels 3 NOFO systems	2 Standby vessels 3 NOFO systems	2 Standby vessels 3 NOFO systems			2 Standby vessels 3 NOFO systems

Table 1-7 *Combined response strategy set-ups.*

Combination name	Response configuration	
Comb1	 	3 MechP systems 2 DispV systems
Comb2	 	3 MechP systems 1 DispA system
Comb3	 	3 MechA systems 2 DispV systems
Comb4	 	3 MechA systems 1 DispA system

1.4.2 Response times

The response times of existing NOFO vessels were used:

Name of NOFO system	Name of tug boat	Response time (hours)
Standby vessel	---	2
Goliat	RS Sørvær	26
Hammerfest 1	RS Båtsfjord	34
Hammerfest 2	RS Vadsø	54
Hammerfest 3	RS Ballstad	54
Aircraft		24

Response times for the vessels were calculated based on the following assumptions:

- 14 knots sailing speed for OR vessels and 20 knots for tug vessels.
- 2 h mobilisation time for tug vessels
- 1 h for boom deployment for both OR and tug vessels
- 1 h initiation of contingency plan
- 1 hour mobilisation time for Haltenbanken
- 4 h mobilisation time for Goliat
- 10 h mobilisation time for Hammerfest 1
- 30 h mobilization time for Hammerfest 2 and 3
- 36 h mobilisation time for tug vessels from NOFO pool.

2 OIL SPILL RESPONSE IN OPEN WATERS

2.1 Methodology – response modelling

All scenarios were modelled with SINTEFs Oil Spill Contingency and Response (OSCAR) model (version 6.2.).

In this chapter the oil drift modelling methodology, model limitations, processing of results and model input parameters are described.

2.1.1 OSCAR model set up

OSCAR is a 3-dimensional particle model that calculates and records the drift behaviour and fate of oil particles while taking processes like e.g. surface spreading, slick transport, suspension in water column, emulsification and other weathering characteristics, or coastal habitat interactions into consideration. Response measures can be entered in the model by altering the configuration in OSCAR. Available response resources in OSCAR are mechanical recovery systems with the use of booms and skimmers and chemical dispersant applied by vessels, helicopters or airplanes.

The OSCAR model was set up for a topside and a subsea blowout scenario applying different response strategies as described in section 1.4. All model specific parameters are listed in Appendix A.

OSCAR accepts input both as two- and three-dimensional current data from hydrodynamic models, and single point or gridded wind data from meteorological models. In this study current data collected in the period 1998-2005 with a resolution of 4×4 km is utilized. The dataset is produced by Institute of Marine Research (IMR) and further processed by SINTEF. It contains both surface and water column currents. Historical wind data is provided by The Norwegian Meteorological Institute (MI) in 75×75 km resolution and three hours sampling intervals.

Due to the location of the exploration well it is chosen to incorporate a dynamic gird with daily mean ice concentrations for the period 1998-2005 from the Nordic Seas 4 km numerical hindcast archive (SVIM, ftp://ftp.met.no/projects/SVIM-public/SVIMresults) in the oil drift modelling. The data is imported to OSCAR from a NetCDF-formate. This dataset is used in the modelling to take into account possible effects of sea ice within the influence area after a spill from the well. Sea ice may affect the general weathering of the oil, the spread of oil at the sea surface, evaporation and down-mixing, but also how the oil moves in different ice concentrations. OSCAR uses an algorithm for oil spreading in partially ice covered waters, where for instance ice concentrations > 30 % will have a great impact on oil movement and weathering. The modelling is performed in alignment with the current recommendations in the guideline (Norsk olje og gass, 2014).

As the OSCAR does not comprise a function for oil in ice recovery, no operational effect is calculated for ice concentrations > 0 %. Oil in ice recovery is addressed by using a calculator tool (see chapter 3.1).

For this analysis, all scenarios were modelled stochastically for an 8-year-period (1998-2005) with 40 simulations/ year. Stochastic simulations have the advantage compared to single simulations that they cover the whole simulation period, release and response parameters being constant while climatic data fluctuates.

The modelling time was for set to 24 days (topside blowout) and 31 days (subsea blowout) in order to follow the fate of the oil 15 days after the end of the blowout duration.

2.1.2 Subsea dispersion modelling

In general, subsea dispersion is a response technique that enhances the natural dispersion of oil by creating a higher number of oil droplets that are small enough to be permanently captured in the water column and subsequently biodegraded. Chemical dispersion may be used if it is found that the effects of dispersants are less harmful to the environment than other measures.

The application of subsea dispersion at the wellhead is modelled in OSCAR by lowering the interfacial between oil and water by a factor 200. This is consistent with SINTEF's breakup experiments using Corexit 9500 at DOR of 2 % (Socolofsky et al., 2015). Model results and some sensitivity studies indicated that the effectiveness of subsea dispersion may significantly alter the amount of surface oil and even lower it more, depending on the effectiveness of the subsea dispersion.

2.1.3 In-situ burning modelling

SINTEF's OSCAR model has currently not a build-in function to model in-situ burning (ISB) as a response measure. However, for this analysis the simulation of ISB was approached by using mechanical recovery systems in the analysis and replacing the mechanical boom characteristics, skimmer capacities and turnaround times with relevant data for ISB operations.

Input parameter and their references can be found in Appendix A.

2.1.4 Results produced in the OSCA

Mass balance figures

The main modelling result in an OSCA is the mass balance data. The mass balance shows the fate of the oil at a certain time after the release.

From the beginning of a release to the end of the simulation the oil particles are exposed to natural weathering processes and/or human influence such as response measures. The oil can e.g. evaporate into the atmosphere, disperse into the water column, settle on the sea bed, biodegrade in the water column, drift on the surface or reach shore. In case of response measures being modelled some of the oil may be recovered. This parameter directly quantifies how well the specified recovery systems have worked in a simulation. Categories and corresponding terms used in OSCAR are described in Table 2-1. When referring to oil in water column it comprises dispersed, dissolved, and degraded oil.

It should be noted that not all states are absolute, meaning that an oil particle can change back and forth throughout the simulation period between for example being on the surface or in the water column. This highly depends on weather conditions.

Mass balance represents fractions of released oil, and not oil emulsion. A mass balance that states 30 % recovered oil refers to 30 % of the total amount of released oil. The conversion from mass to oil emulsion depends on the oil's- capability of water uptake; high water content will result in several times the mass compared to the original oil spill volume.

Table 2-1 *Definition of the physical and spatial states in the oil mass balance generated by OSCAR.*

Name of physical or spatial state	Definition
Surface	Fraction of oil on the sea surface
Dispersed	Fraction of oil dispersed in the water column. Note that he model does not distinguish between naturally and chemically dispersed oil
Dissolved	Fraction of oil that is dissolved in the water column
Stranded	Fraction of oil that has stranded
Evaporated	Fraction of oil that has evaporated
Degraded	Fraction of oil that has been biologically degraded
Collected	Fraction of oil that has been recovered by mechanical recovery systems
Out of grid	Fraction of oil that has ended up in the sediments at the sea bottom

Population loss after response measures

The effect of oil spill response strategies on environmental resources was addressed by calculating the probability of population loss, for a selected number of pelagic seabird species, prior to and after implementation of oil spill response measures. The species selected for the calculations are the species with highest environmental risk identified in the ERA study carried out for the BaSEC project (DNV GL, 2015a). The resources are representatives from the pelagic seabird VEC group: *Black-legged Kittiwake*, *Atlantic Puffin*, and *Brunnich's Guillemot*.

Population loss for the different oil drift simulations are calculated using the following loss categories: < 1%, 1-5 %, 5-10 %, 10-20 %, 20-30 % and more than 30 % of the total population. Please refer to the ERA-report for a detailed methodology description.

Population loss was calculated for all scenarios.

2.2 Results and Discussion

In the following chapter the results from the OSCA for each scenario and response measure are presented in form of mass balance figures at the end of the simulation and selected mass balances over time. All mass balance figures are enclosed in Appendix B. For the topside scenarios the calculated effect of the response measures on the probability of population loss is also included.

The results provide a discussion basis for the *Status document* (DNV GL, 2015b) in which the operational feasibility of the response measures is further assessed.

2.3 No response measures (reference scenario)

Key findings for the fate of the oil given a topside and subsea scenario:

- The majority of the oil will either have dispersed, evaporated or biodegraded at the end of the simulation (24 and 31 days respectively).
- Only a small amount of oil is modelled to remain at the sea surface at the end of the simulation: 1-3 % during a topside blowout after 24 days and 0.5-1 % in case of a subsea blowout after 31 days.
- No stranding of oil is calculated.

Topside scenario

The mass balance over time showing the fate of the oil during the simulation period for the topside scenario is illustrated in Figure 2-1.

During summer season (March - August) the fraction of oil on surface is high early in the release phase (76 %) something which is decreasing throughout the release period (49 % after 4 days, 34 % after 9 days) and further continuous to reduce until the end of the simulation (3 % after 24 days). At this point, the majority of the oil has dispersed naturally (46 %), evaporated (37 %) and degraded (11 %). There is no stranding of oil.

Due to harsher weather conditions during winter season (September - February), the fraction of surface oil is expected to be reduced faster compared to the summer season from 59 % (1 day after blowout) to 17 % (9 days) down to 1 % at the end of the simulation (24 days). The oil will be dispersed and evaporated during that period.

The final mass balance results are presented together with the subsea scenario in Figure 2-3.

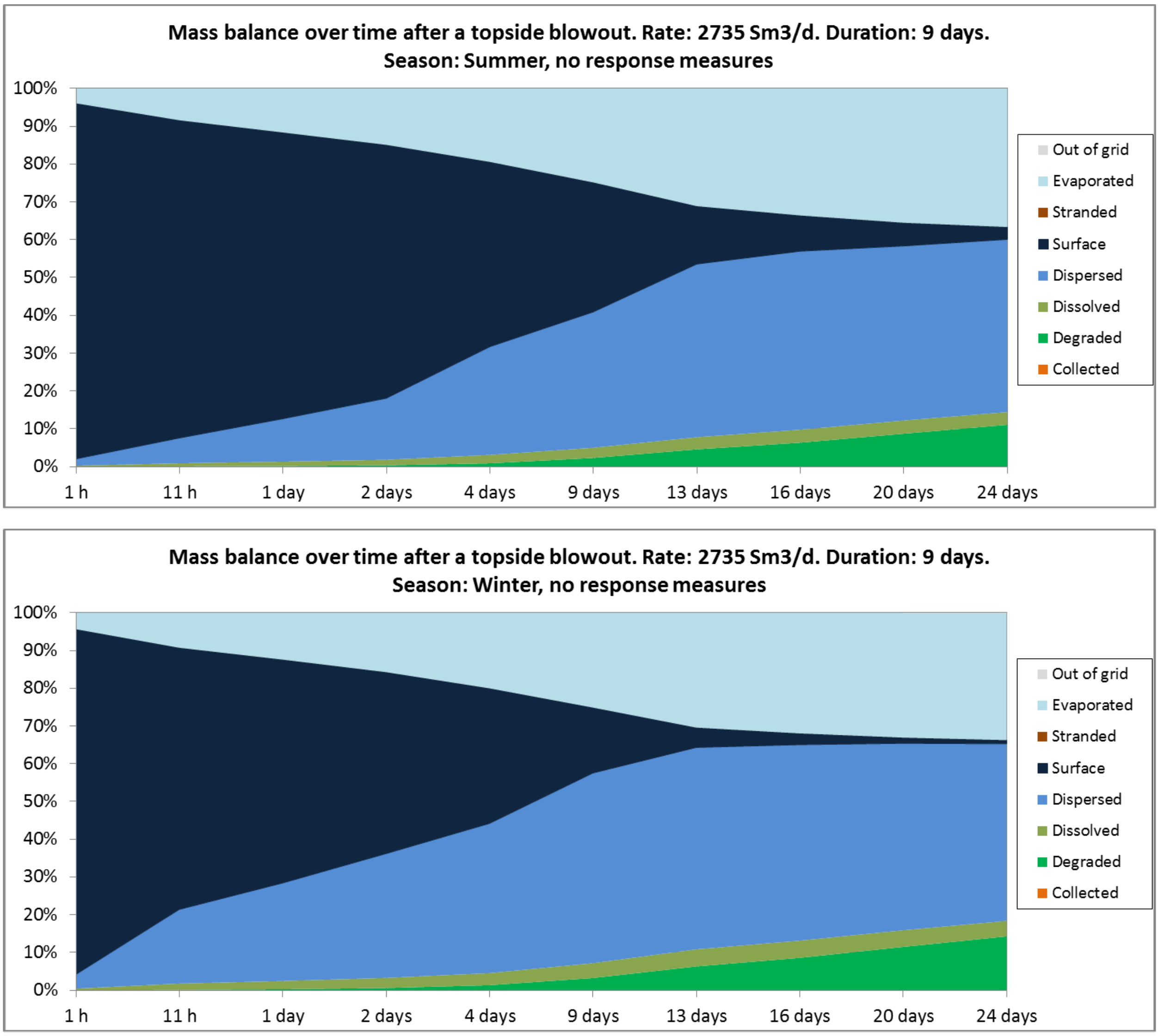


Figure 2-1 *Mass balance over time for a topside blowout of 2735 Sm^3/day Skrugard crude oil with no response measures during summer season (top) and winter season (bottom). Note that the x-axis is non-linear.*

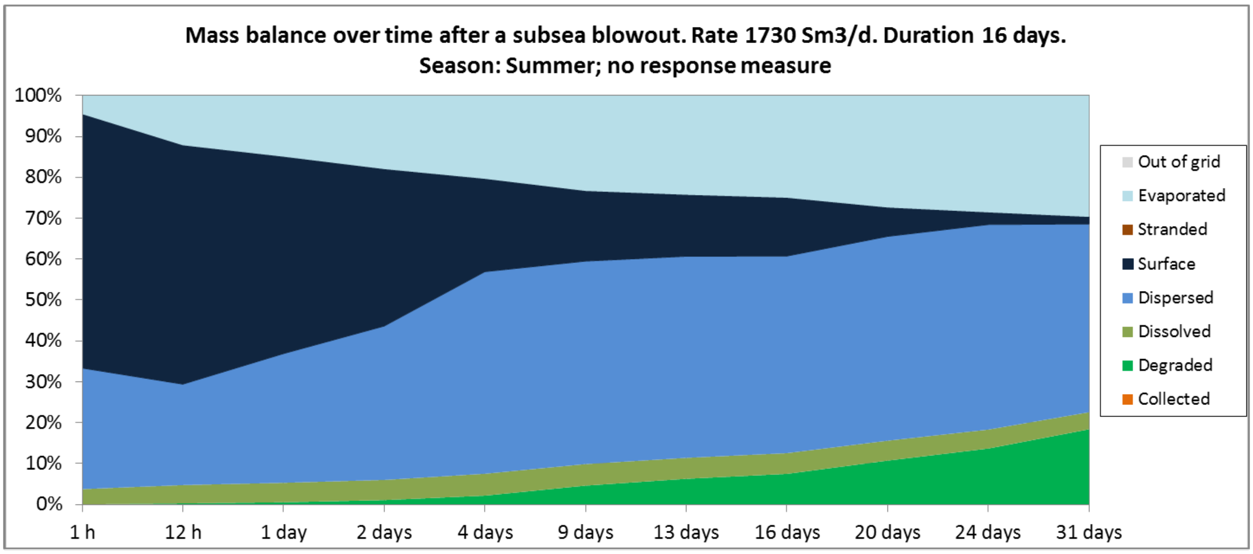
Subsea scenario

The mass balance over time showing the fate of the oil during the simulation period for the subsea scenario is illustrated in Figure 2-2.

During summer season (March - August) the fraction of oil on surface is high early in the release phase (48 %) something which is decreasing throughout the release period (23 % after 4 days, 14 % after 16 days) and further continuous to reduce until the end of the simulation (2 % after 31 days). At this point, the majority of the oil has dispersed naturally (46 %), evaporated (30 %) and degraded (18 %). There is no stranding of oil.

Due to harsher weather conditions during winter season (September - February), the fraction of surface oil is expected to be reduced faster compared to the summer season from 32 % (1 day after blowout) to 7 % (16 days) down to 0.5 % at the end of the simulation (31 days). The oil will be dispersed and evaporated during that period.

The final mass balance results are presented in Figure 2-3.



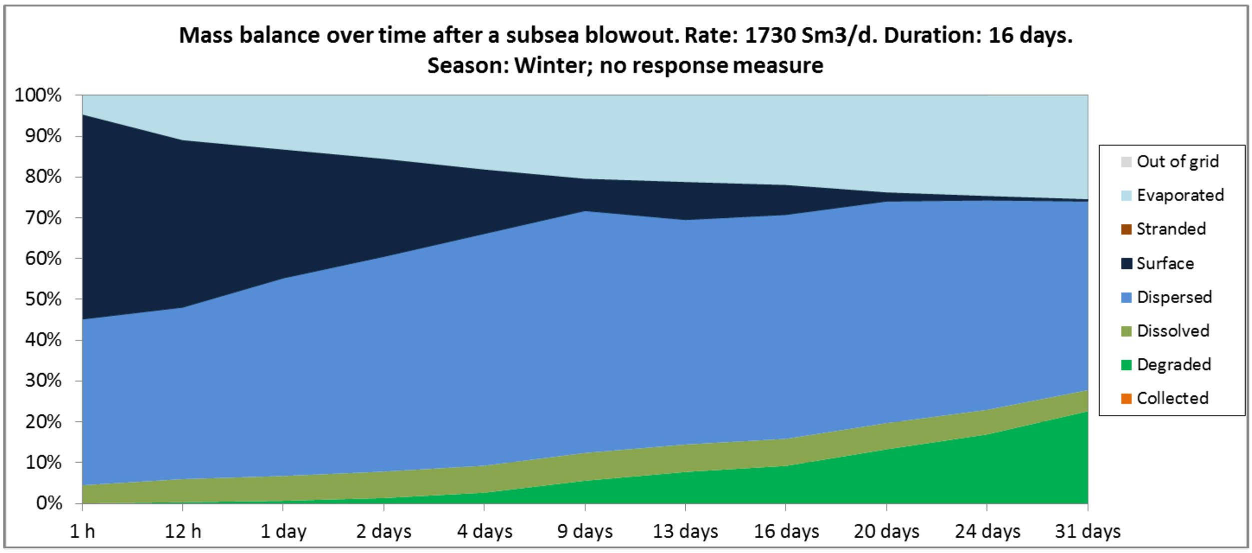
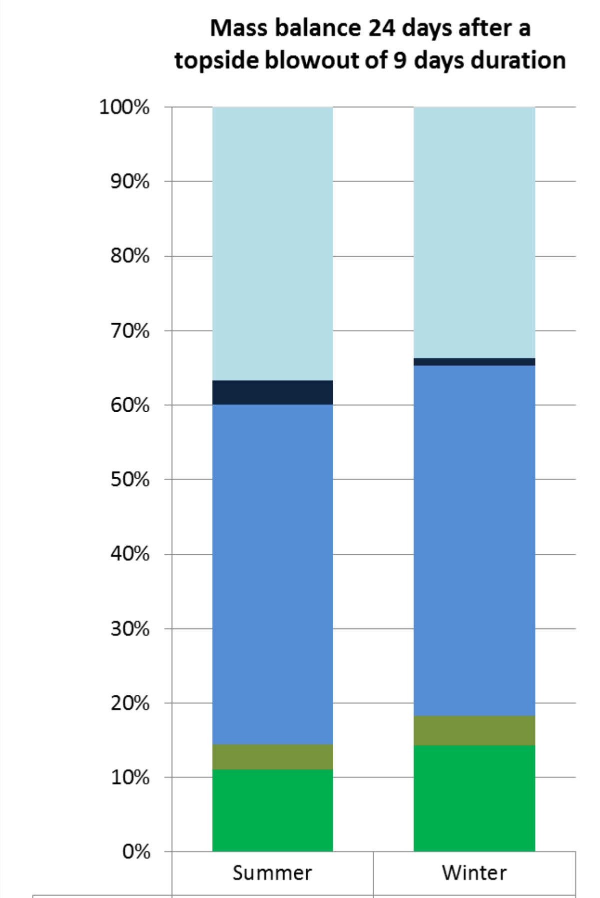
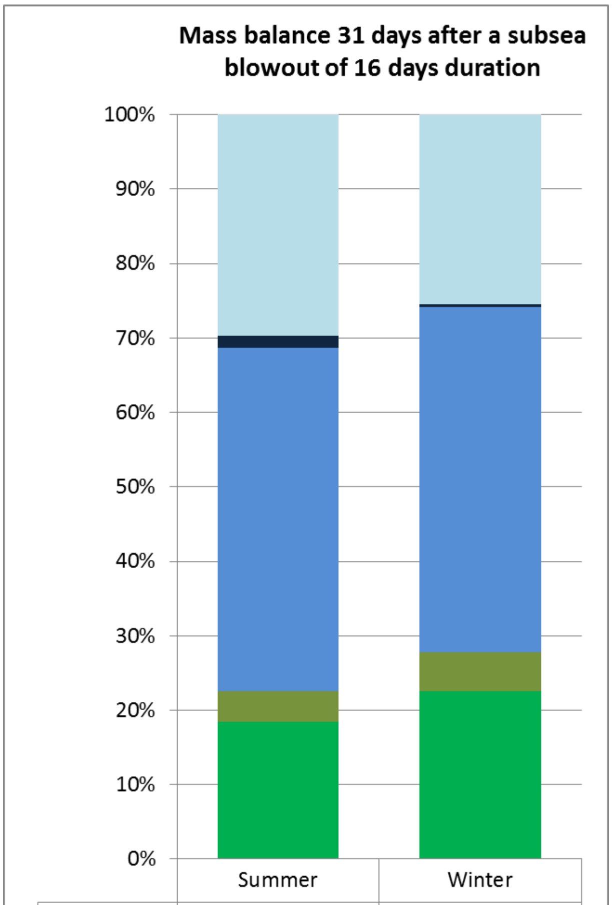


Figure 2-2 *Mass balance over time for a subsea blowout of 2730Sm^3/day Skrugard crude oil with no response measures during summer season (top) and winter season (bottom). Note that the x-axis is non-linear.*



	Summer	Winter
Out of grid	0,0 %	0,0 %
Evaporated	36,7 %	33,7 %
Stranded	0,0 %	0,0 %
Surface	3,2 %	1,0 %
Dispersed	45,7 %	46,9 %
Dissolved	3,4 %	4,1 %
Degraded	11,1 %	14,3 %
Collected	0,0 %	0,0 %



	Summer	Winter
Out of grid	0,0 %	0,0 %
Evaporated	29,7 %	25,4 %
Stranded	0,0 %	0,0 %
Surface	1,7 %	0,5 %
Dispersed	46,1 %	46,3 %
Dissolved	4,2 %	5,2 %
Degraded	18,4 %	22,6 %
Collected	0,0 %	0,0 %

Figure 2-3 *Mass balance after a topside (left; 9 days duration) and a subsea blowout (right; 16 days duration) and 15 days following time.*

2.4 Open water mechanical recovery with passive boom systems

Key findings for mechanical recovery with passive boom systems:

- Mechanical recovery is more effective for the topside scenario than the subsea scenario with a maximum oil recovery of 24 % vs. 3 %.
- Fraction of recovered oil is twice as high for summer season compared to winter season in the topside scenario, but remains the same in the subsea scenario.
- Overall surface oil reduction compared to the reference scenario at the end of the simulation due to mechanical recovery is ≤ 1 percentage point.
- Additional mechanical recovery systems will increase amount of recovered oil from 7 to 24 % and reduce probability of population loss.
- Additional effect of shorter response time (2nd standby-vessel) is limited as < 1 percentage point more oil will be recovered.

Topside scenario

The fate of the oil as mass balance is a key output from oil spill contingency modelling. Figure 2-4 and Figure 2-5 shows the effect and the efficiency of mechanical recovery with various numbers of passive boom systems and different response times compared to the reference set-up – simulation without oil spill response (0).

There are differences in mass balance between summer and winter season. This is due to different weather conditions which affect the oil's weathering characteristics as well as the effectiveness of the response measures. During the winter season the wind is more intense, the waves are higher, the temperature is lower and the time period of operational light is reduced compared to the summer season.

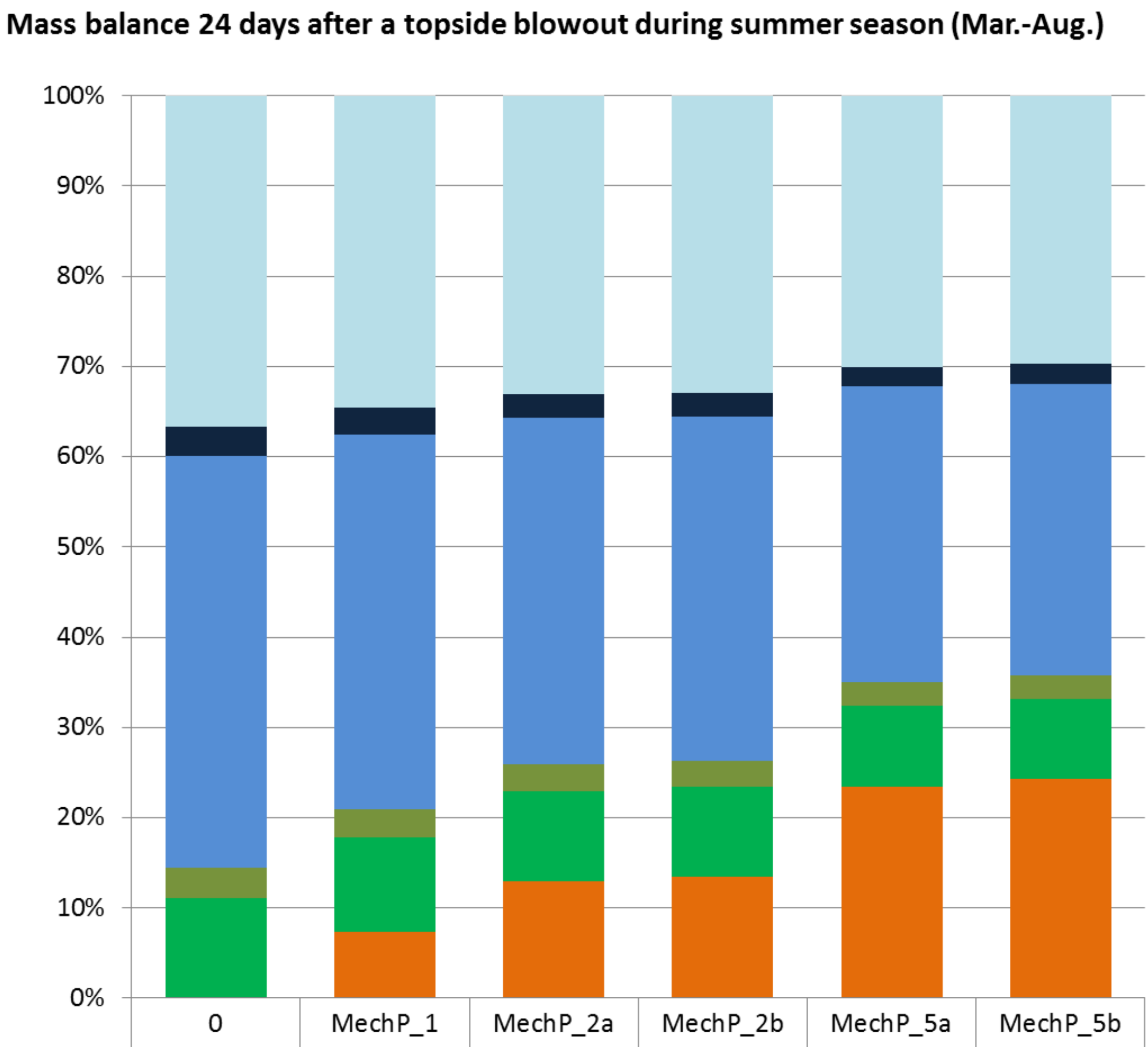
The fraction of recovered oil from the sea surface is an important result in the oil spill contingency modelling. The mass balance indicates increased oil recovery from the surface by using additional mechanical recovery vessels, independent of season. With one recovery vessel (MechP_1) 7 % of the oil is recovered, whereas 5 recovery vessels (MechP_5a) would recover 23 % in summer season (3 % and 12 % in winter season respectively). The fraction of recovered oil is thus twice as high for summer compared for winter season. However, the increased oil recovery is considerably larger than the accompanied reduction of oil on sea surface (0.2-1 percentage points). The additional increase in oil recovery is primarily oil that otherwise would have ended up in the naturally dispersed category.

The use of a second standby-vessel in order to shorten the response times has no significant effect regarding the overall mass balance at the end of the simulation (24 days). The additional amount of recovered oil is calculated to be < 1 percentage point. This is most likely due to the long duration of the spill.

Figure 2-6 shows the mass balance over time for scenario MechP_5a and MechP_5b. It can be seen that within the first 4 days, more oil will be recovered from the water surface using 2 standby-vessels. However, after 4 days the amount of recovered oil starts to level out between the scenarios. After 13 days the fraction of recovered oil remains more or less constant until the end of the simulation ranging between 23 % (scenario 5a) and 24 % (scenario 5b).

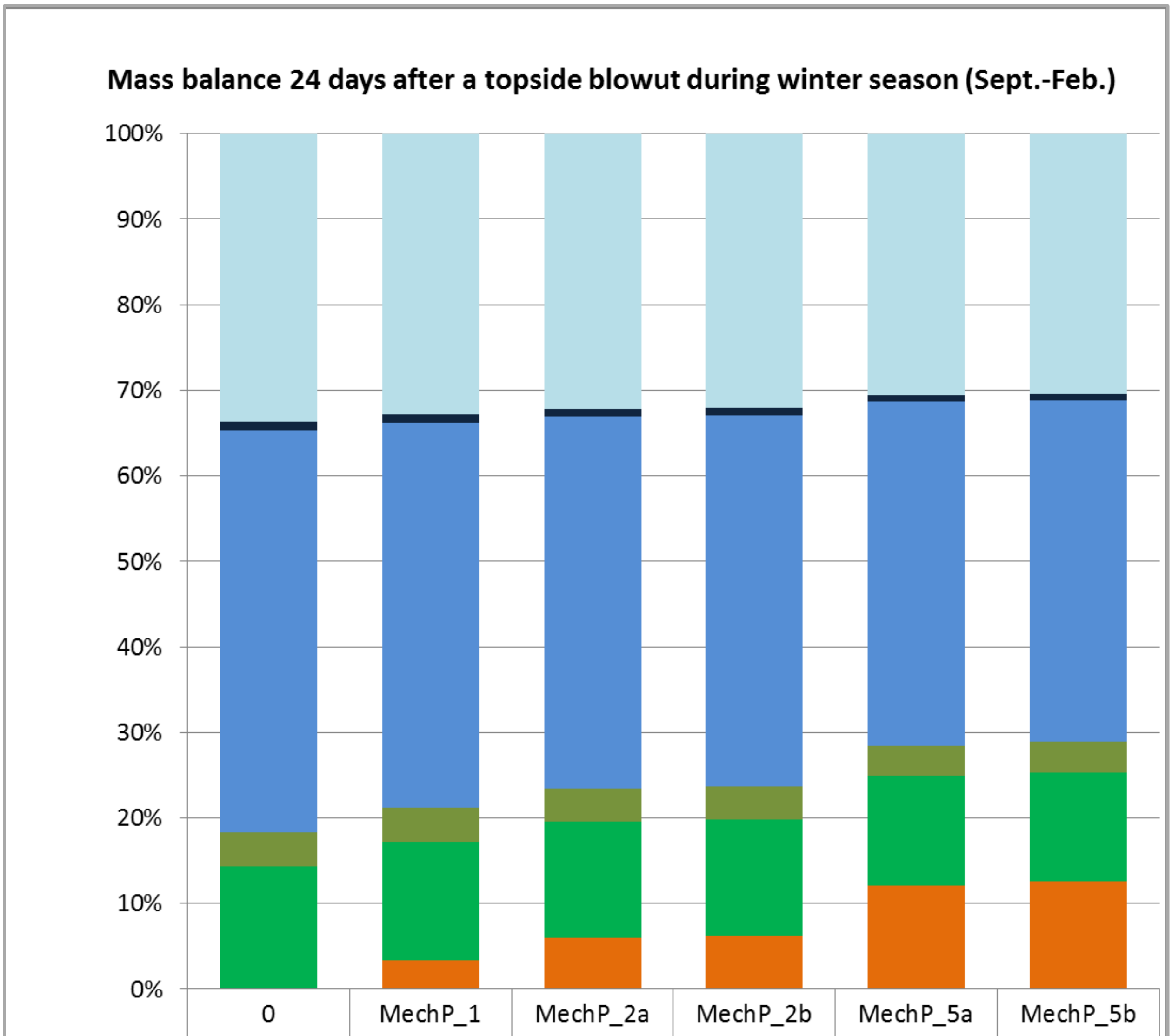
Based on results from the ERA for the exploration well of this study (DNV GL, 2015a), pelagic sea birds are the most affected species; hence a reduction of surface oil should be the main aim during an oil spill operation. The calculation of the probability of population loss for seabirds gives an indication on the performance of a certain response measure.

Figure 2-7 compares the calculated probability of population loss for response measure MechP_5a and MechP_5b for three selected seabird species. In general, the results show a positive reduction in population loss probability by implementing mechanical recovery systems with best effect for the species *Brunnich's Guillemot* and *Atlantic Puffin* during summer. The 1-5% population loss category e.g. is reduced from 13 % probability to 6 % for *Brunnich's Guillemot*. Using a second standby-vessel in the response strategy can lead to some further reduction in population loss probability, however the effect is limited. For *Atlantic Puffin* during winter time the population loss is marginal higher for response measure MechP_5b than MechP_5a. The cause of this minor difference is a result of model inaccuracies as the faster response time will change the further drift and spread of oil and occasionally this could lead oil to an area with more seabirds although the recovered oil amount is increased with shorter response time.



	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	34,6 %	33,1 %	32,9 %	30,1 %	29,8 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,9 %	2,6 %	2,6 %	2,2 %	2,2 %
Dispersed	45,7 %	41,5 %	38,4 %	38,1 %	32,8 %	32,3 %
Dissolved	3,4 %	3,1 %	2,9 %	2,9 %	2,6 %	2,6 %
Degraded	11,1 %	10,5 %	10,0 %	9,9 %	9,0 %	8,9 %
Collected	0,0 %	7,3 %	13,0 %	13,5 %	23,4 %	24,3 %

Figure 2-4 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the summer season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	32,8 %	32,1 %	32,0 %	30,5 %	30,4 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	0,9 %	0,9 %	0,8 %	0,8 %
Dispersed	46,9 %	45,0 %	43,5 %	43,4 %	40,2 %	39,9 %
Dissolved	4,1 %	4,0 %	3,9 %	3,8 %	3,6 %	3,6 %
Degraded	14,3 %	13,9 %	13,6 %	13,5 %	12,8 %	12,8 %
Collected	0,0 %	3,4 %	6,0 %	6,3 %	12,0 %	12,5 %

Figure 2-5 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the winter season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*

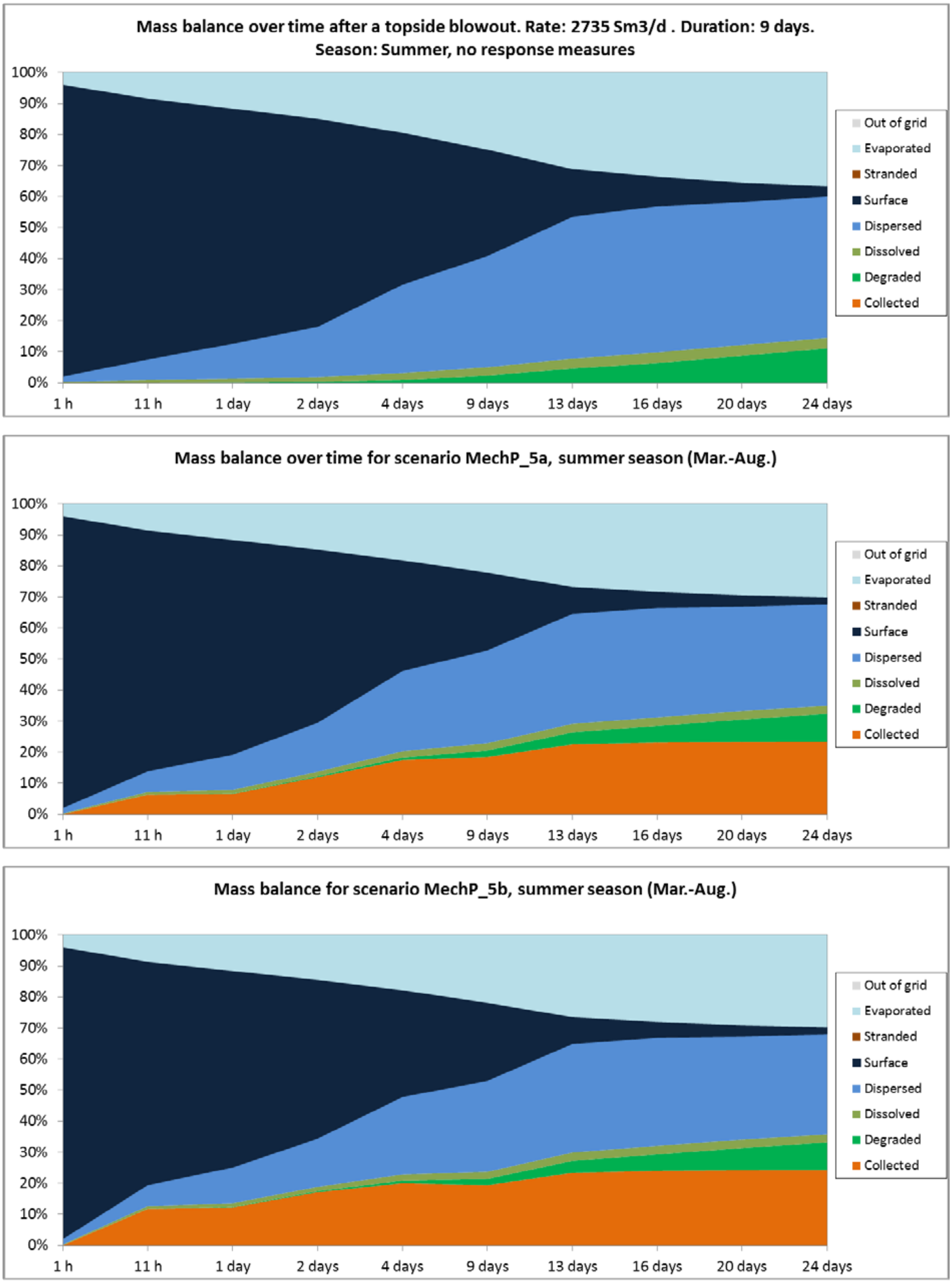


Figure 2-6 *Mass balance over time for a topside blowout in the summer season with no response measures and with 5 mechanical passive recovery systems. Strategy MechP_5a consists of 1 standby-vessel with a response time of 2 hours and 4 response vessels with response times of 26, 34, 54,and 54 hours. Strategy MechP_5b consists of 2 standby-vessels with a response time of 2 hours and 3 response vessels with response times of 26, 34, and 54 hours. Note that the x-axis is non-linear.*

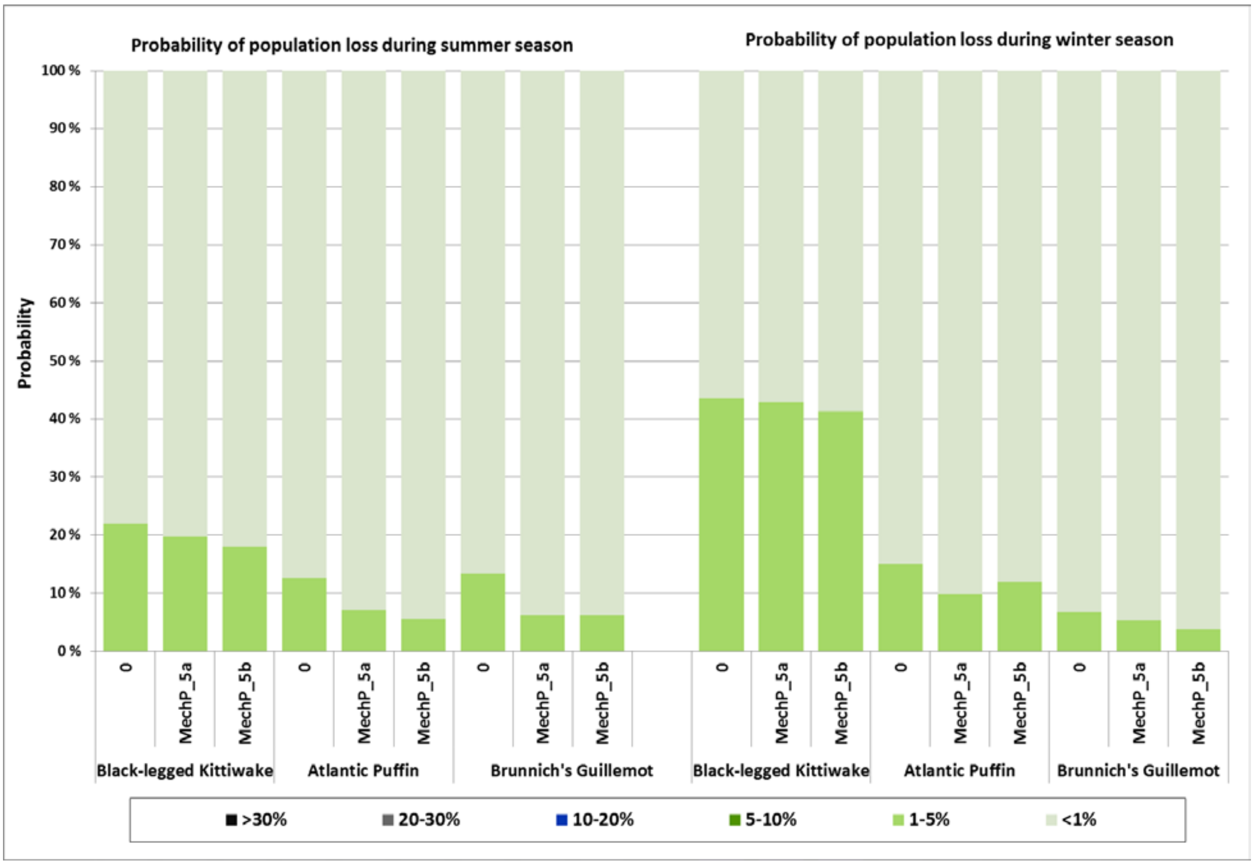


Figure 2-7 *Probability for population loss for three selected seabird species given a topside blowout, for summer (left) and winter season (right). Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

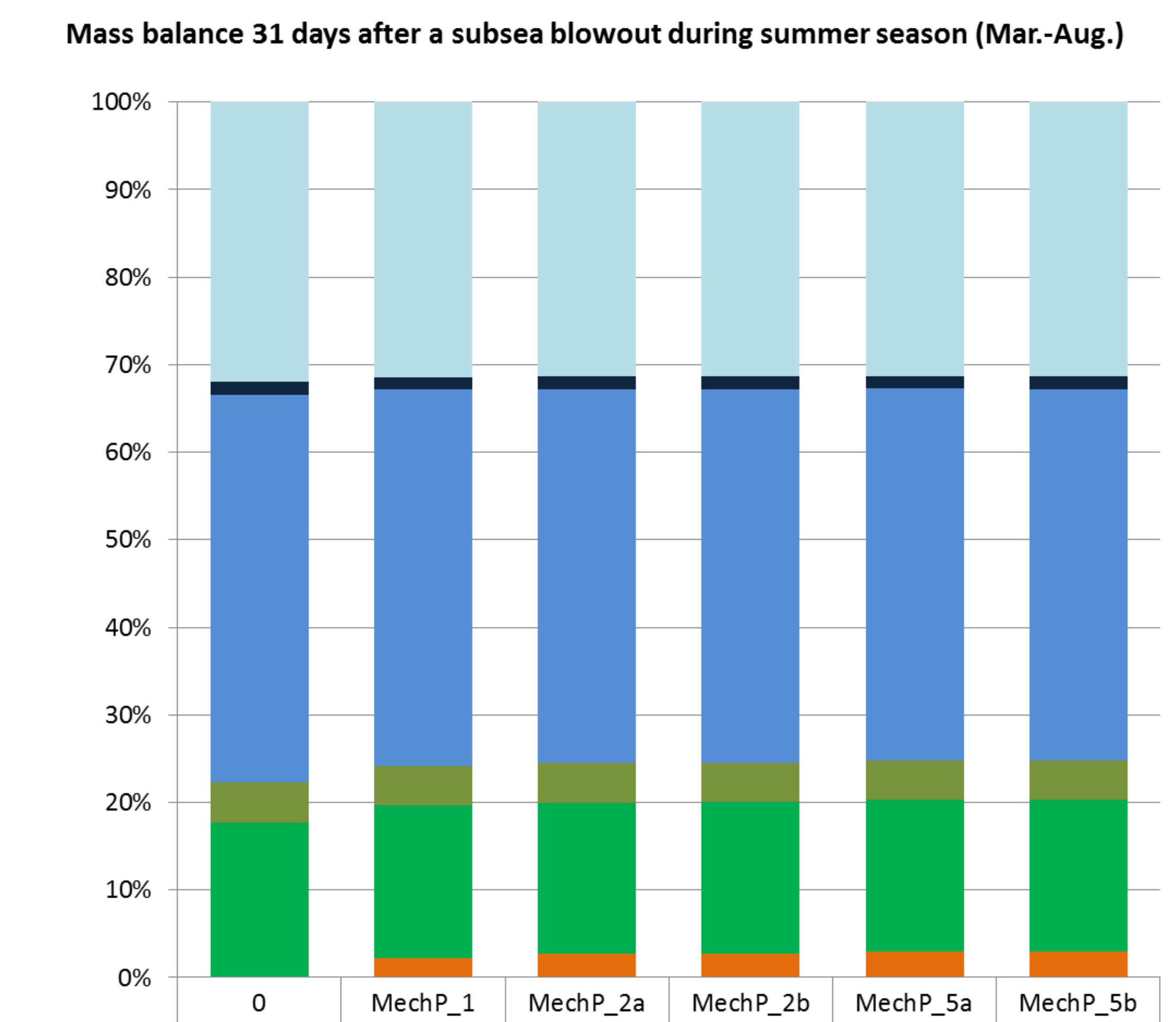
Subsea scenario

Figure 2-8 and Figure 2-9 shows the mass balance at the end of the simulation (31 days) for a subsea blowout.

There are no big differences in mass balance between summer and winter season. The mass balance indicates increased oil recovery from the surface by using additional mechanical recovery vessels, independent of season, however with limited effect. With one recovery vessel (MechP_1) 2 % of the oil is recovered, whereas 5 recovery vessels (MechP_5a) would recover 3 %.

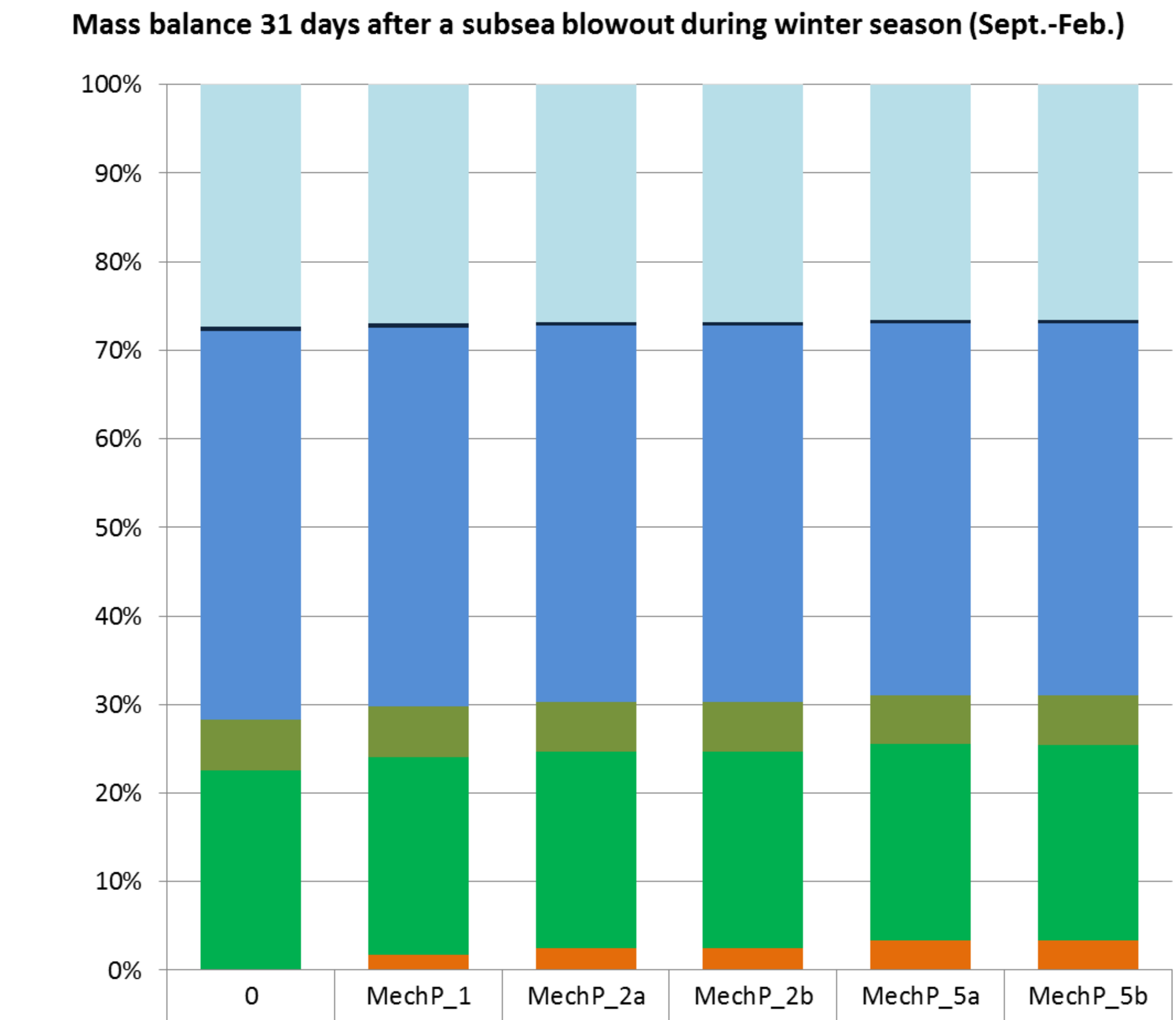
There is no reduction in oil on surface at the end of the simulation (31 days) by adding response measures compared to the reference scenario. Thus, oil recovery is primarily oil that otherwise would have ended up in the naturally dispersed category.

The use of a second standby-vessel in order to shorten the response times has no significant effect regarding the overall mass balance at the end of the simulation.



	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,4 %	31,4 %	31,4 %	31,3 %	31,3 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,4 %	1,4 %	1,4 %	1,5 %	1,5 %
Dispersed	44,2 %	42,9 %	42,6 %	42,6 %	42,4 %	42,4 %
Dissolved	4,7 %	4,6 %	4,6 %	4,6 %	4,6 %	4,6 %
Degraded	17,6 %	17,4 %	17,3 %	17,3 %	17,3 %	17,2 %
Collected	0,0 %	2,3 %	2,7 %	2,7 %	3,0 %	3,0 %

Figure 2-8 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the summer season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	26,9 %	26,8 %	26,8 %	26,5 %	26,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,5 %	0,4 %	0,4 %	0,4 %
Dispersed	43,9 %	42,9 %	42,4 %	42,4 %	41,9 %	41,9 %
Dissolved	5,7 %	5,6 %	5,6 %	5,6 %	5,6 %	5,6 %
Degraded	22,6 %	22,3 %	22,2 %	22,2 %	22,1 %	22,1 %
Collected	0,0 %	1,8 %	2,5 %	2,5 %	3,4 %	3,4 %

Figure 2-9 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the winter season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*

2.5 Open water mechanical recovery with active boom systems

Key findings for mechanical recovery with active boom systems:

- Mechanical recovery is more effective for the topside scenario than the subsea scenario with a maximum oil recovery of 55 % vs. 5 %.
- Fraction of recovered oil is 15 percentage points higher for summer season compared to winter season in the topside scenario.
- Overall surface oil reduction compared to the reference scenario at the end of the simulation due to mechanical recovery is < 2 percentage points.
- Additional mechanical recovery systems will increase amount of recovered oil from 25 % to 55 % and reduce probability of population loss.
- Additional effect of shorter response time (2nd standby-vessel) is limited as < 3 percentage points more oil will be recovered.

Topside scenario

The fate of the oil as mass balance oil is a key output from oil spill contingency modelling. Figure 2-10 and Figure 2-11 shows the effect and the efficiency of mechanical recovery with various numbers of active boom systems and different response times compared to the reference set-up – simulation without oil spill response (0).

There are differences in mass balance between summer and winter season. This is due to different weather conditions which affect the oil's weathering characteristics as well as the effectiveness of the response measures. During the winter season the wind is more intense, the waves are higher, the temperature is lower and the time period of operational light is reduced compared to the summer season.

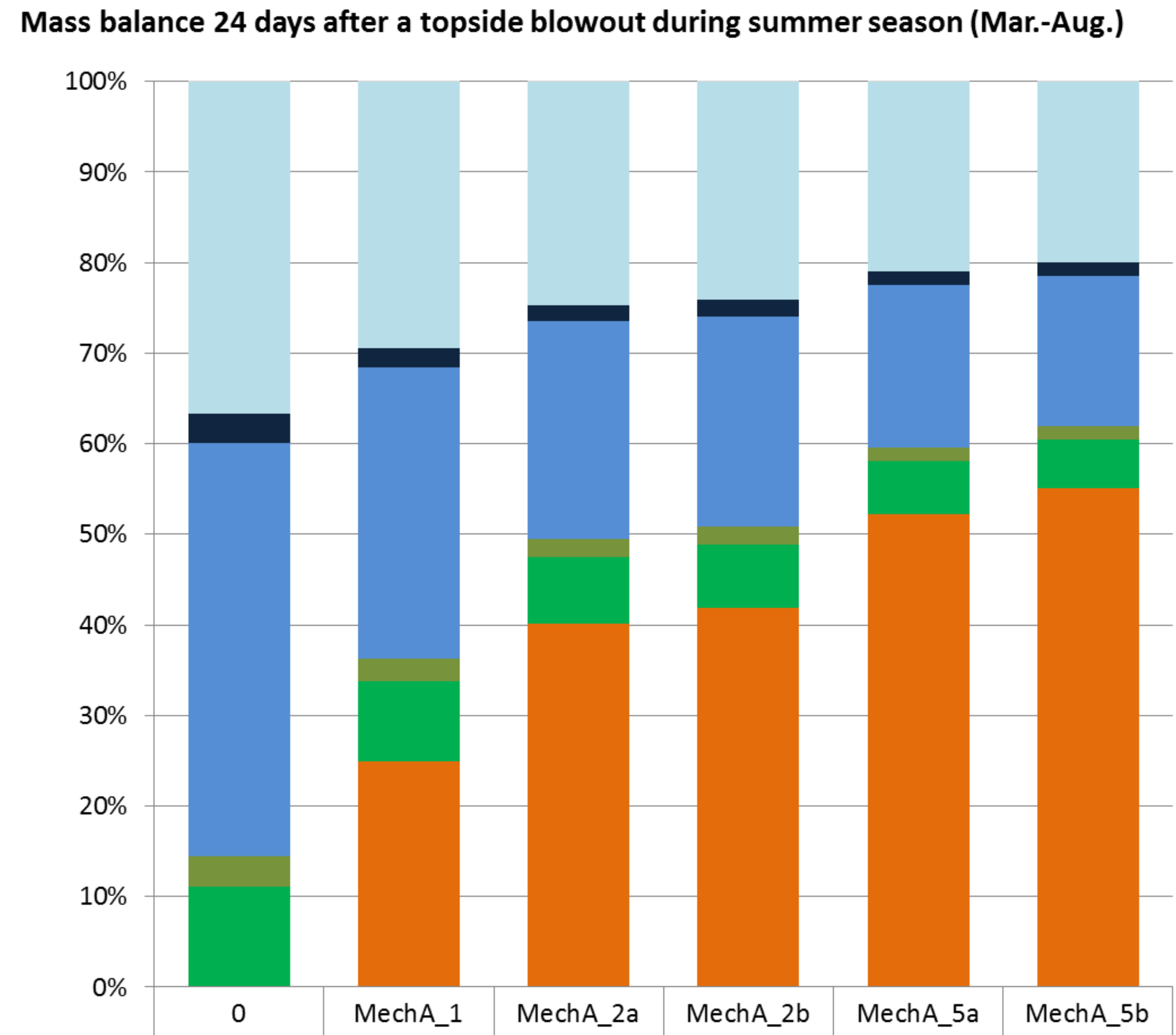
The fraction of recovered oil from the sea surface is an important result in the oil spill contingency modelling. The mass balance indicates increased oil recovery from the surface by using additional mechanical recovery vessels, independent of season. With one recovery vessel (MechA_1) 25 % of the oil is recovered, whereas 5 recovery vessels (MechP_5a) would recover 55 % in summer season (14 % and 40 % in winter season respectively). The fraction of recovered oil is 11 -15 percentage points higher in summer compared to winter season. However, the increased oil recovery is considerably larger than the accompanied reduction of oil on sea surface (0.4 - 2 percentage points). The additional increase in oil recovery is primarily oil that otherwise would have ended up in the naturally dispersed category.

The use of a second standby-vessel in order to shorten the response times has some limited effect regarding the overall mass balance at the end of the simulation (24 days). The additional amount of recovered oil is calculated to be around 3 percentage points for a response strategy with 5 systems. This is most likely due to the long duration of the spill.

Figure 2-12 shows the mass balance over time for scenario MechA_5a and MechA_5b. It can be seen that within the first 9 days, more oil will be recovered from the water surface using 2 standby-vessels. However, after 9 days the amount of recovered oil starts to level out between the scenarios. After 13 days the fraction of recovered oil remains more or less constant until the end of the simulation ranging between 52 % (scenario 5a) and 55 % (scenario 5b).

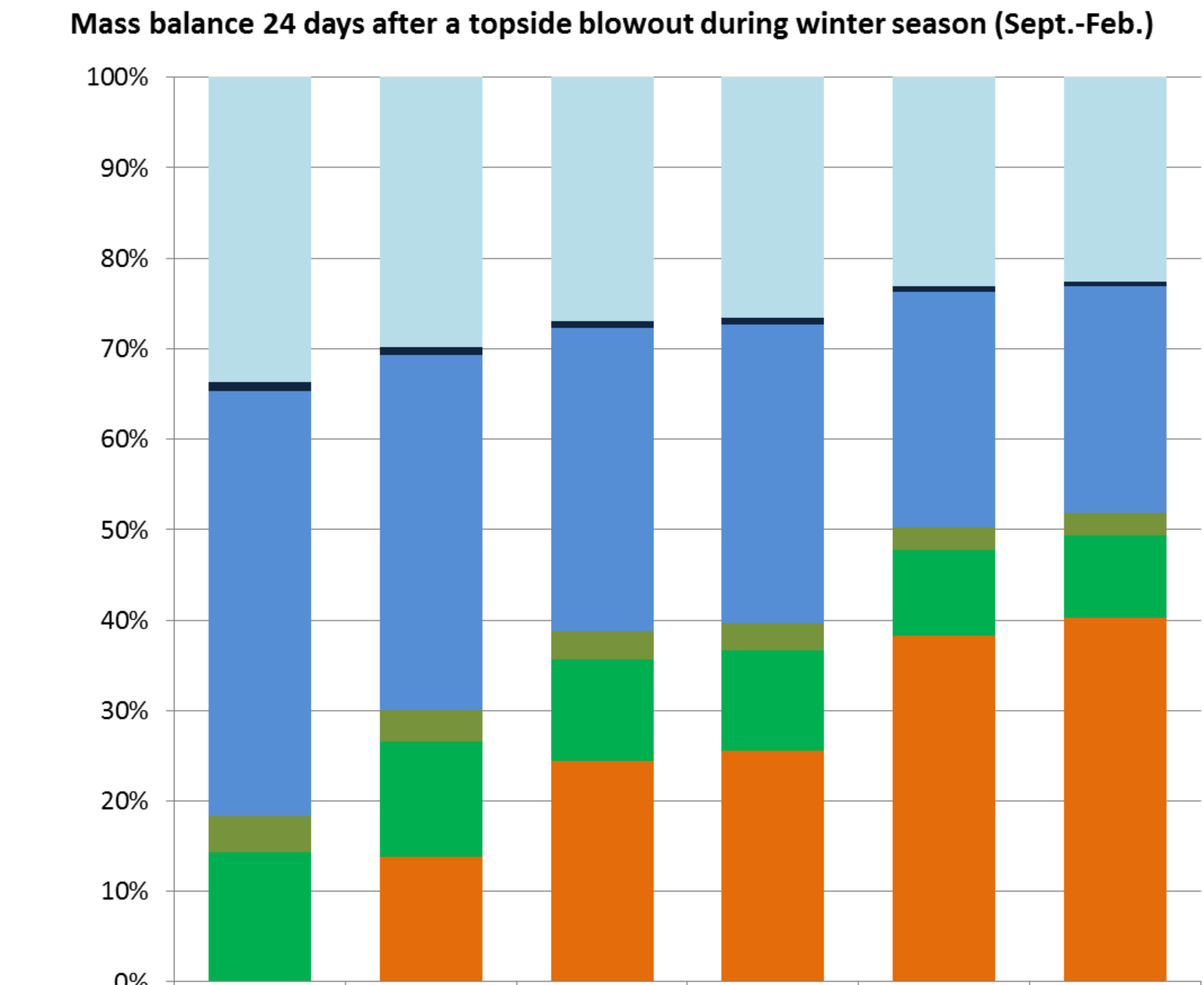
Based on results from the ERA for the exploration well of this study (DNV GL, 2015a), pelagic sea birds are the most affected species; hence a reduction of surface oil should be the main aim during an oil spill operation. The calculation of the probability of population loss for seabirds gives an indication on the performance of a certain response measure.

Figure 2-13 compares the calculated probability of population loss for response measure MechA_5a and MechA_5b for three selected seabird species. In general, the results show a positive reduction in population loss probability by implementing active mechanical recovery systems. It can be seen that those systems will lead to a reduction in the 1-5% population loss category. For the *Atlantic Puffin* during summer season and the *Brunnich's Guillemot* in the winter season, there is a total shift to category < 1%. Using a second standby-vessel in the response strategy does not lead to a further reduction in population loss probability.



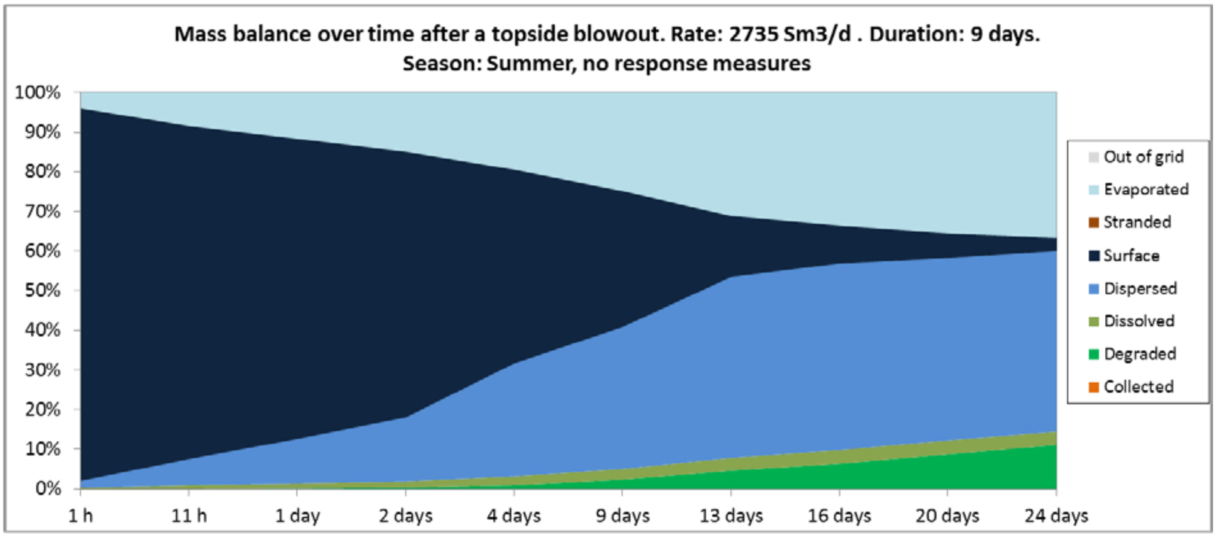
	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	29,4 %	24,7 %	24,1 %	21,0 %	20,0 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,2 %	1,8 %	1,8 %	1,6 %	1,5 %
Dispersed	45,7 %	32,1 %	24,1 %	23,3 %	17,9 %	16,6 %
Dissolved	3,4 %	2,5 %	2,0 %	1,9 %	1,5 %	1,4 %
Degraded	11,1 %	8,8 %	7,3 %	7,1 %	5,9 %	5,5 %
Collected	0,0 %	24,9 %	40,1 %	41,8 %	52,2 %	55,0 %

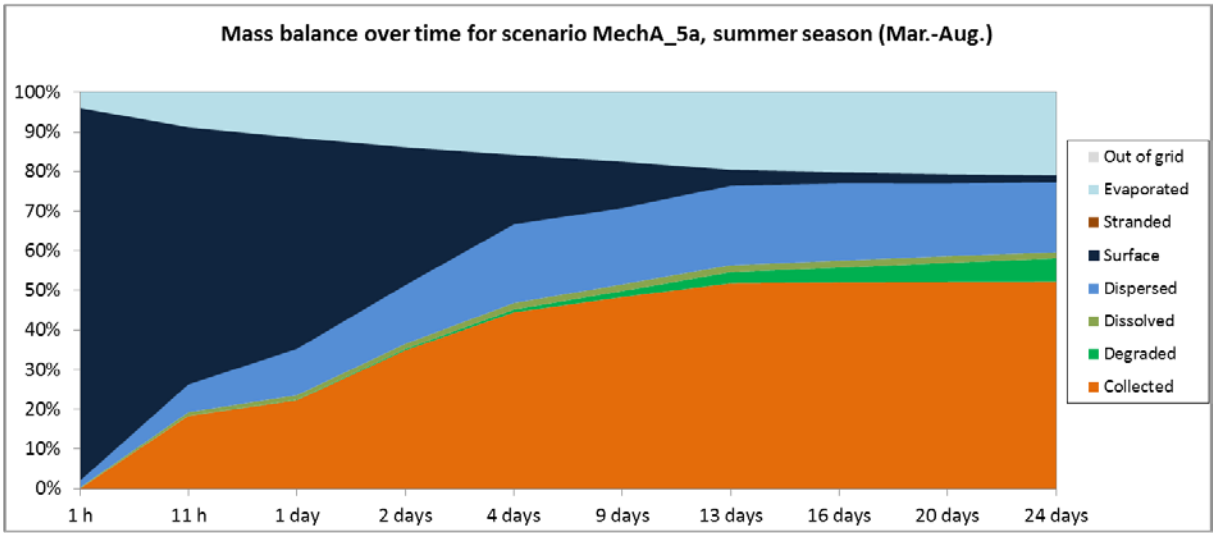
Figure 2-10 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the summer season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	29,8 %	26,9 %	26,6 %	23,1 %	22,5 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,8 %	0,7 %	0,7 %	0,6 %	0,6 %
Dispersed	46,9 %	39,3 %	33,5 %	33,0 %	26,0 %	25,0 %
Dissolved	4,1 %	3,5 %	3,1 %	3,1 %	2,5 %	2,4 %
Degraded	14,3 %	12,6 %	11,3 %	11,1 %	9,4 %	9,1 %
Collected	0,0 %	13,9 %	24,4 %	25,5 %	38,3 %	40,3 %

Figure 2-11 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the winter season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*





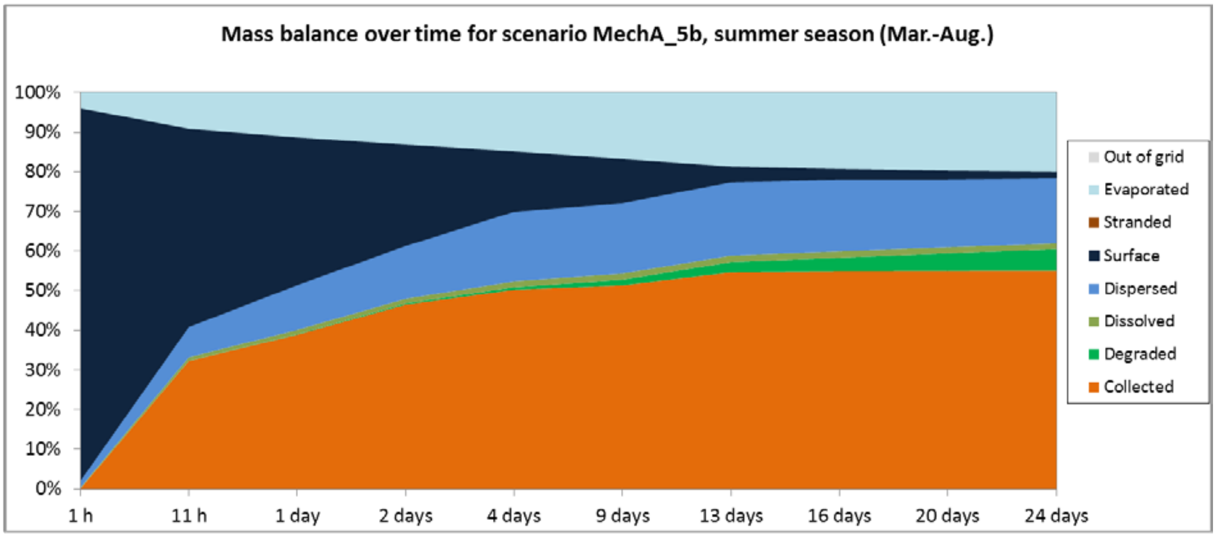


Figure 2-12 *Mass balance over time for a topside blowout in the summer season with no response and with 5 mechanical active recovery systems. Strategy MechA_5a consists of 1 standby-vessel with a response time of 2 hours and 4 response vessels with response times of 26, 34, 54,and 54 hours. Strategy MechA_5b consists of 2 standby-vessels with a response time of 2 hours and 3 response vessels with response times of 26, 34, and 54 hours. Note that the x-axis is non-linear.*

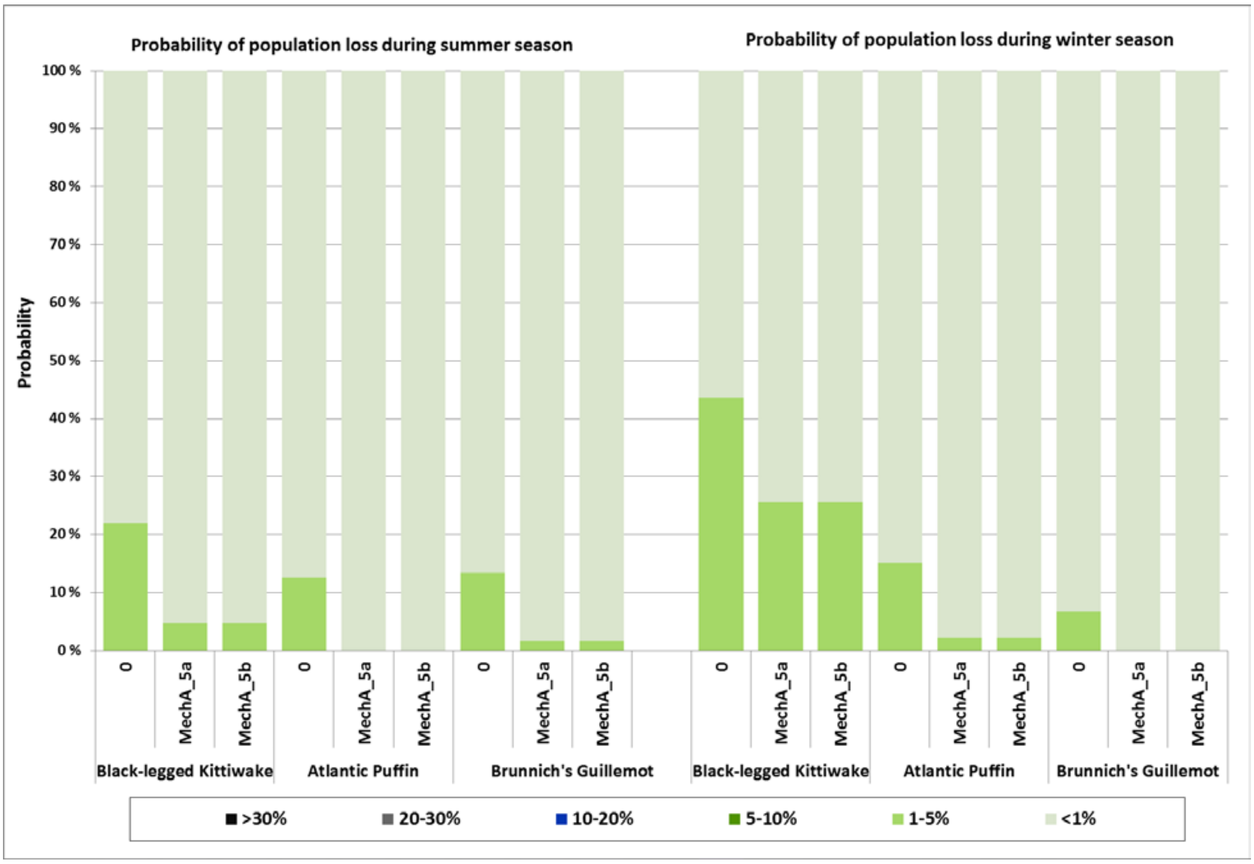


Figure 2-13 *Probability for population loss for three selected seabird species given a topside blowout, for summer (left) and winter season (right). Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

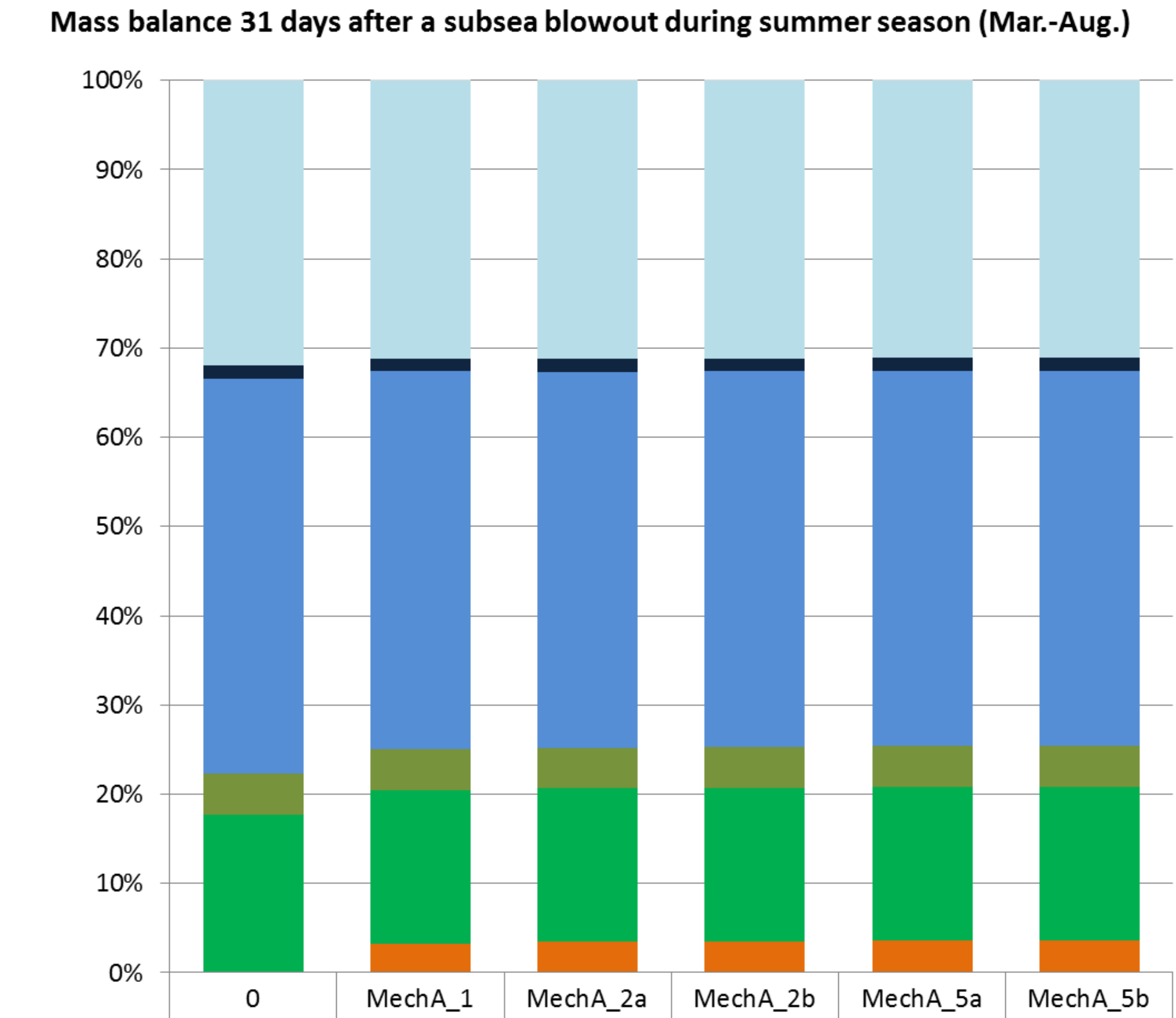
Subsea scenario

Figure 2-14 and Figure 2-15 show the mass balance at the end of the simulation (31 days) for a subsea blowout.

There are no large differences in mass balance between summer and winter season. The mass balance indicates a limited increase in oil recovery from the surface by using additional mechanical recovery vessels during summer season (increase of 0.4 percentage points). During winter season the oil recovery can be increased by 1.8 percentage points by moving from one (MechA_1) to 5 recovery vessels (MechP_5b).

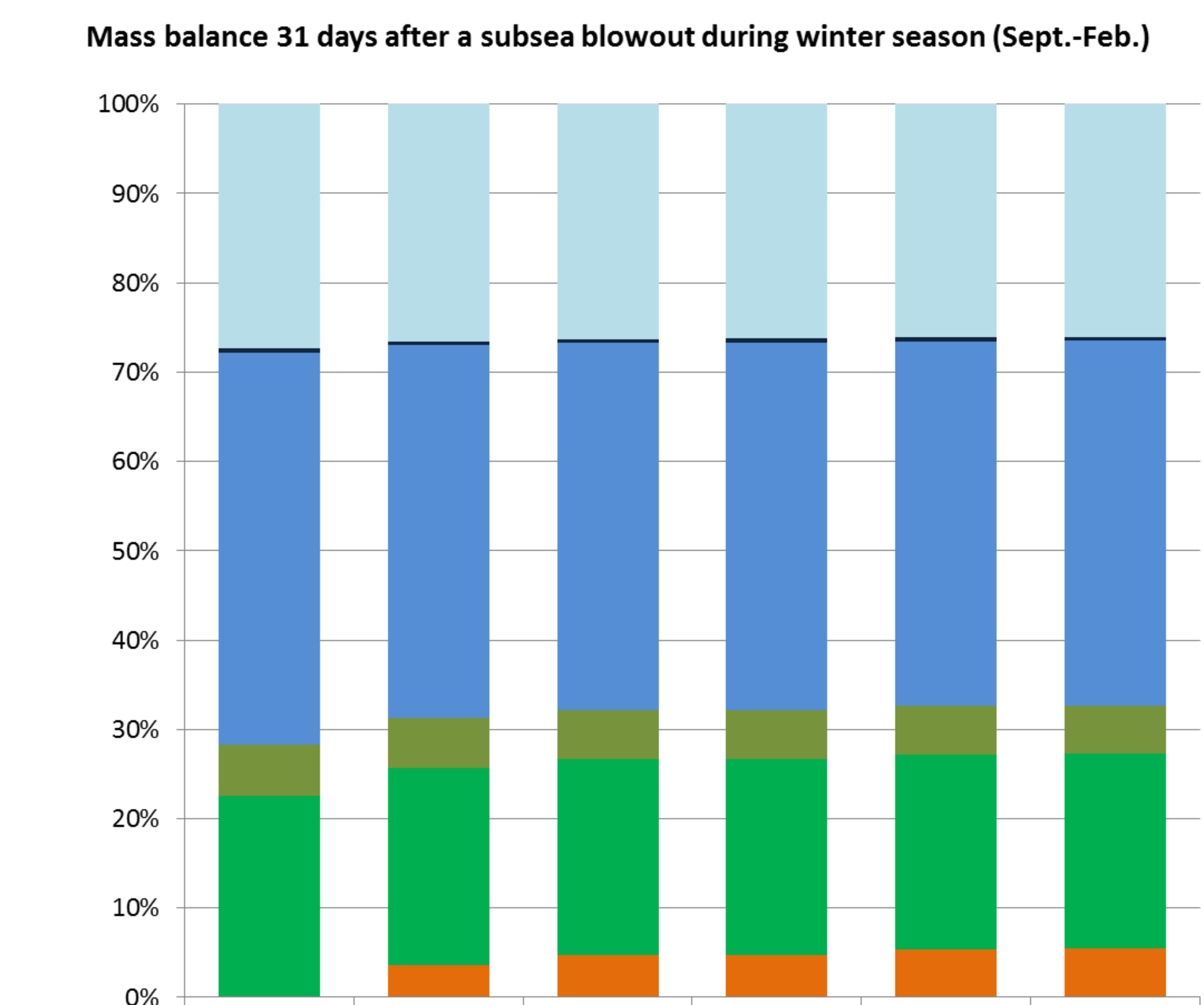
The implantation of response measures does not reduce the fraction of surface oil. Recovered oil is primarily oil that otherwise would have ended up in the naturally dispersed category.

The use of a second standby-vessel in order to shorten the response times has no effect regarding the overall mass balance at the end of the simulation.



	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,2 %	31,2 %	31,1 %	31,1 %	31,1 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,4 %	1,5 %	1,5 %	1,5 %	1,5 %
Dispersed	44,2 %	42,4 %	42,1 %	42,1 %	42,0 %	42,0 %
Dissolved	4,7 %	4,6 %	4,5 %	4,5 %	4,5 %	4,5 %
Degraded	17,6 %	17,3 %	17,2 %	17,2 %	17,2 %	17,2 %
Collected	0,0 %	3,2 %	3,5 %	3,5 %	3,6 %	3,6 %

Figure 2-14 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the summer season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	26,5 %	26,2 %	26,2 %	26,1 %	26,1 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,4 %	0,4 %	0,4 %	0,4 %
Dispersed	43,9 %	41,8 %	41,2 %	41,2 %	40,8 %	40,8 %
Dissolved	5,7 %	5,5 %	5,5 %	5,5 %	5,5 %	5,5 %
Degraded	22,6 %	22,1 %	21,9 %	21,9 %	21,8 %	21,8 %
Collected	0,0 %	3,6 %	4,7 %	4,7 %	5,4 %	5,4 %

Figure 2-15 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the winter season. 0 indicates no mechanical recovery systems in use; strategy 1 indicates 1 recovery system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*

2.6 Vessel based open water dispersion system

Key findings for vessel based dispersion system:

- Vessel based dispersion systems are only effective for the topside scenario as the mass balance remains the same for the subsea scenario compared to the reference scenario..
- Adding chemical dispersions will increase the amount of oil in the water column from 60 % to 75 %, while the fraction of surface and evaporated oil will be reduced.
- Overall surface oil reduction compared to the reference scenario at the end of the simulation due to vessel dispersion is < 1.5 percentage points.
- Additional dispersion systems will increase amount of oil in water column from 60 % to 75 % and reduce probability of population loss by 17 percentage points during summer season.
- Additional effect of shorter response time (2nd standby-vessel) is limited, but can lead to further reduction of probability of population loss.

Topside scenario

A positive effect by using chemical dispersants as an oil spill contingency strategy appears primarily as an elevated fraction of dispersed oil in the mass balance. Figure 2-16 and Figure 2-17 show the effect and the efficiency of vessel based dispersion systems with various numbers of systems and different response times compared to the reference set-up – simulation without oil spill response (0).

There are some, but limited differences in mass balance between summer and winter season due to different weather conditions which affect the oil's weathering characteristics as well as the effectiveness of the response measures.

By applying chemical dispersions to an oil slick, more oil will degrade and dissolve in the water column. The mass balance shows that during summer season, the fraction of biodegraded oil increases from 11 % (no response measures) to 17 % with one dispersion vessel up to 29 % with 5 dispersion vessels. The amount of dissolved oil increases up to 4 %, while the amount of evaporated and dispersed oil will be reduced. The amount of oil on surface can be decreased by 1.5 percentage points in the overall mass balance by using vessel based dispersion systems.

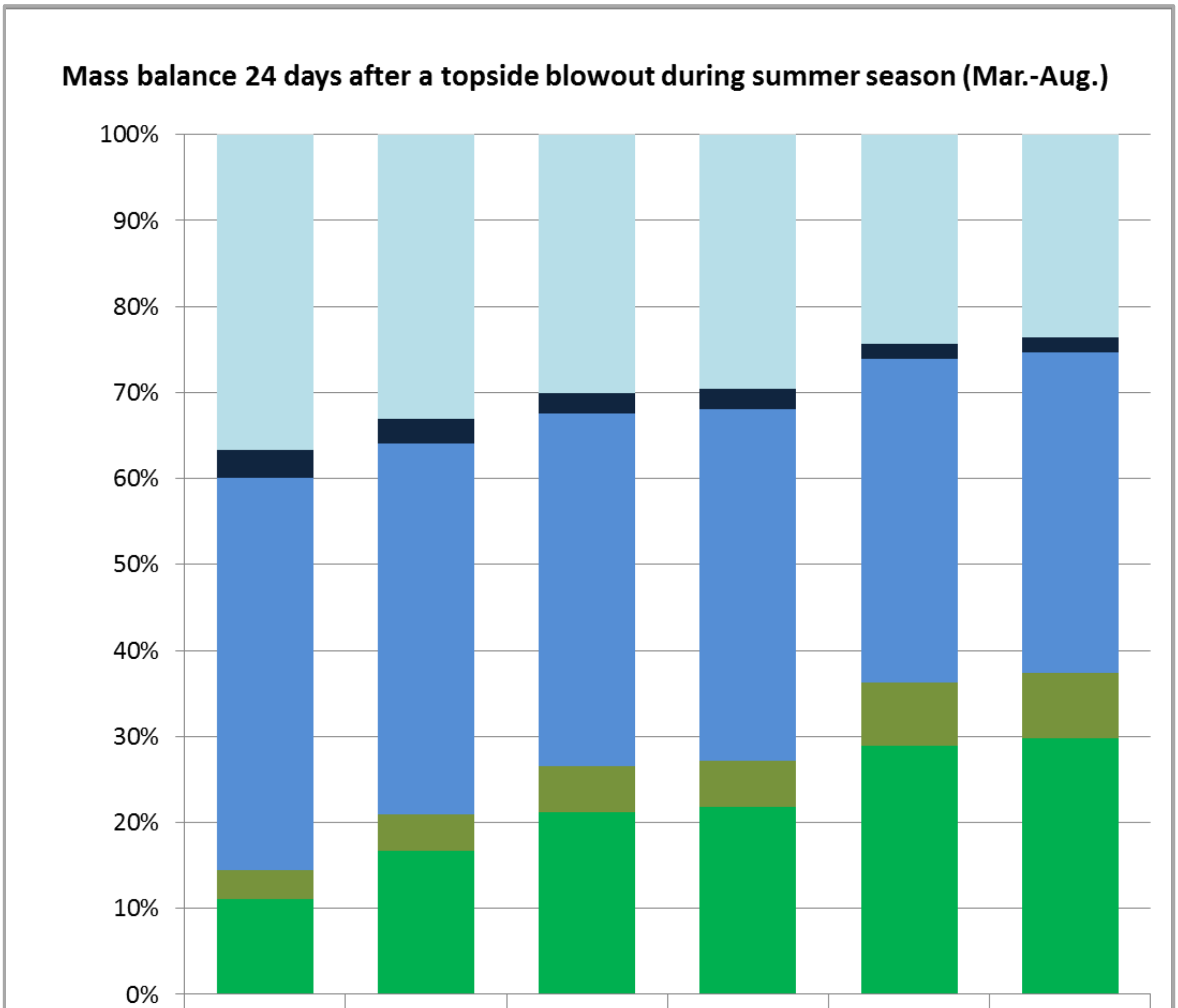
The use of a second standby-vessel in order to shorten the response times has some limited effect regarding the overall mass balance at the end of the simulation (24 days). The additional amount of degraded or dissolved oil is less than 1 %. This is most likely due to the long duration of the spill.

Figure 2-18 shows the mass balance over time for scenario DispV_5a and DispV_5b. It can be seen that within the first 4 days, more oil will be removed from the water surface using 2 standby-vessels. However, after 4 days the amount of recovered oil starts to level out between the scenarios. After 13 days the fraction of surface oil decreases constant until 2 % at the end of the simulation for both response set-ups.

The results indicate that chemical dispersion is an applicable strategy on the Skrugard crude oil.

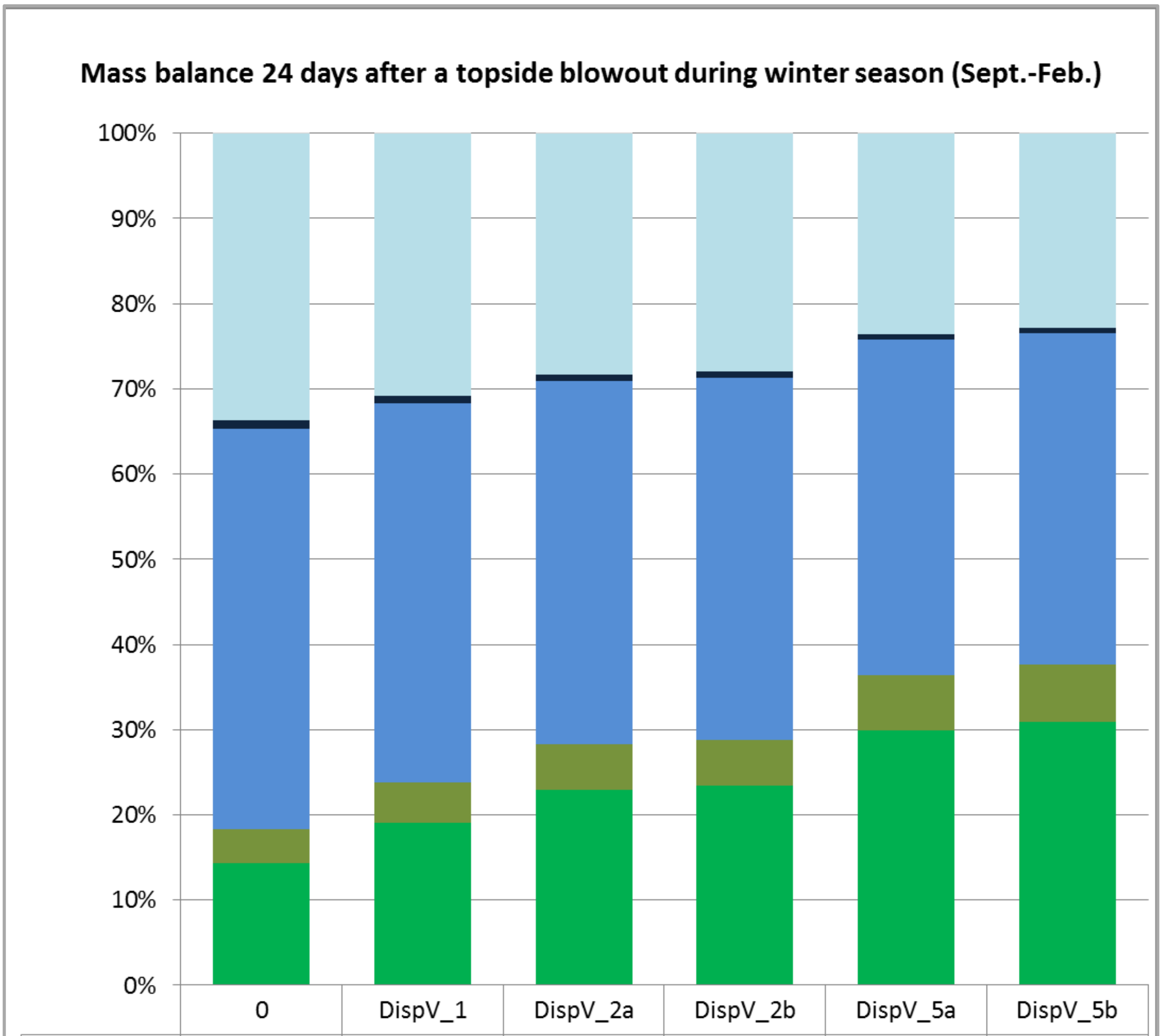
Based on results from the ERA for the exploration well of this study (DNV GL, 2015a), pelagic sea birds are the most affected species; hence a reduction of surface oil should be the main aim during an oil spill operation. The calculation of the probability of population loss for seabirds gives an indication on the performance of a certain response measure.

Figure 2-19 compares the calculated probability of population loss for response measure DispV_5a and DispV_5b for three selected seabird species. In general, the results show a positive reduction in population loss probability by using chemical dispersions with a good effect for all species during both summer and winter season. The 1-5 % population loss category can be reduced from 44 % probability to 20 % for *Black-legged Kittiwake* during winter season. Using a second standby-vessel in the response strategy can lead to a further reduction in population loss probability for *Black-legged Kittiwake* and *Atlantic Puffin, e.g. from 27% to 20 % in the 1-5 % population loss category for Black-legged Kittiwake during winter season*. No additional effect can be observed for *Brunnich's Guillemot*.



	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	33,1 %	30,1 %	29,5 %	24,3 %	23,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,8 %	2,4 %	2,4 %	1,8 %	1,7 %
Dispersed	45,7 %	43,1 %	41,1 %	40,8 %	37,7 %	37,3 %
Dissolved	3,4 %	4,3 %	5,2 %	5,4 %	7,3 %	7,5 %
Degraded	11,1 %	16,7 %	21,2 %	21,8 %	28,9 %	29,8 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

Figure 2-16 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the summer season. 0 indicates no vessel based dispersion systems in use; strategy 1 indicates 1 dispersion system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	30,8 %	28,3 %	27,9 %	23,6 %	22,9 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	0,7 %	0,7 %	0,6 %	0,6 %
Dispersed	46,9 %	44,5 %	42,7 %	42,5 %	39,3 %	38,9 %
Dissolved	4,1 %	4,7 %	5,3 %	5,4 %	6,6 %	6,7 %
Degraded	14,3 %	19,1 %	22,9 %	23,4 %	29,9 %	30,9 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

Figure 2-17 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the winter season. 0 indicates no vessel based dispersion systems in use; strategy 1 indicates 1 dispersion system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*

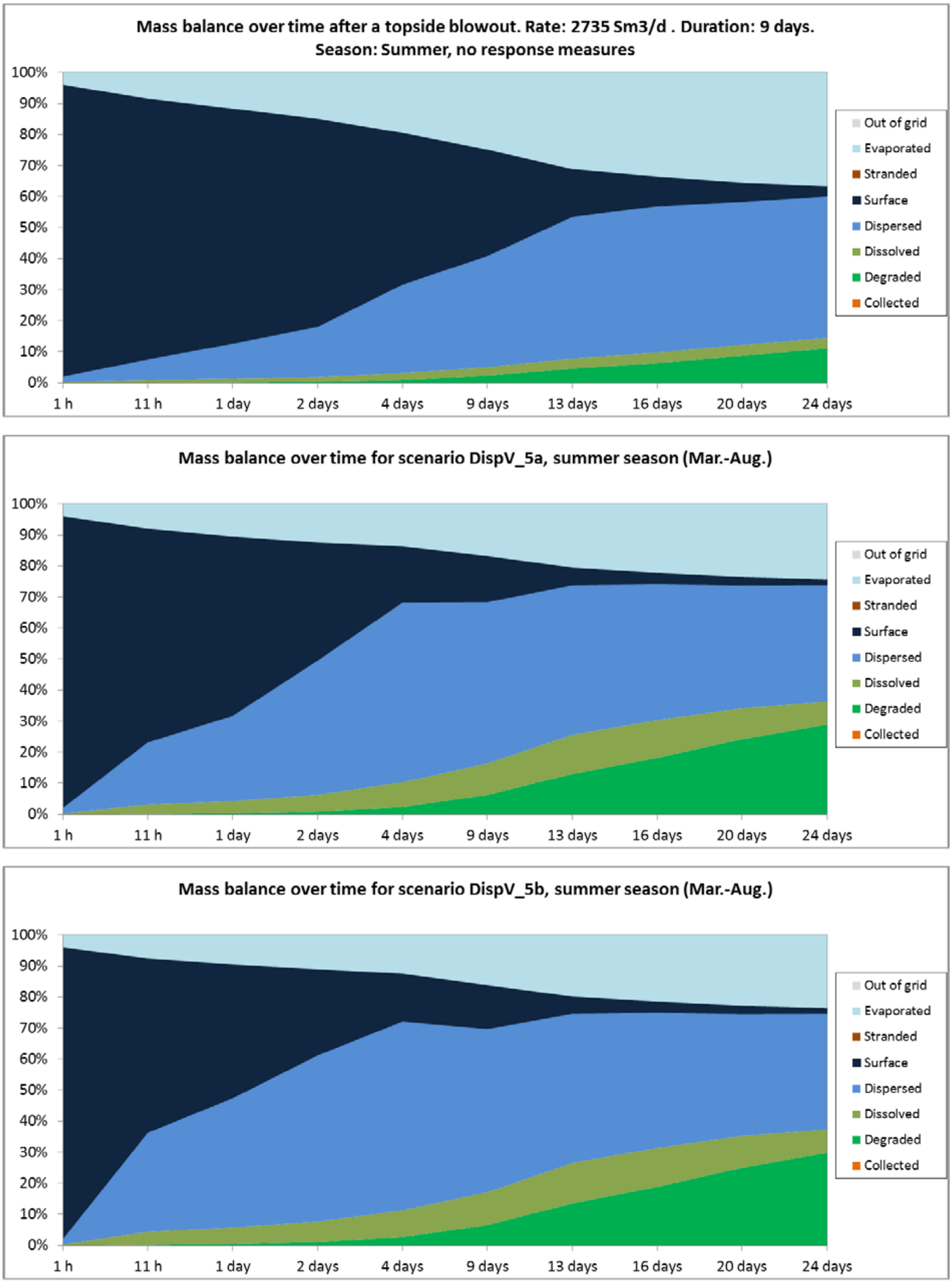


Figure 2-18 *Mass balance over time for a topside blowout in the summer season with no response measures and with 5 vessel based dispersion systems. Strategy DispV_5a consists of 1 standby-vessel with a response time of 2 hours and 4 response vessels with response times of 26, 34, 54,and 54 hours. Strategy DispV_5b consists of 2 standby-vessels with a response time of 2 hours and 3 response vessels with response times of 26, 34, and 54 hours. Note that the x-axis is non-linear.*

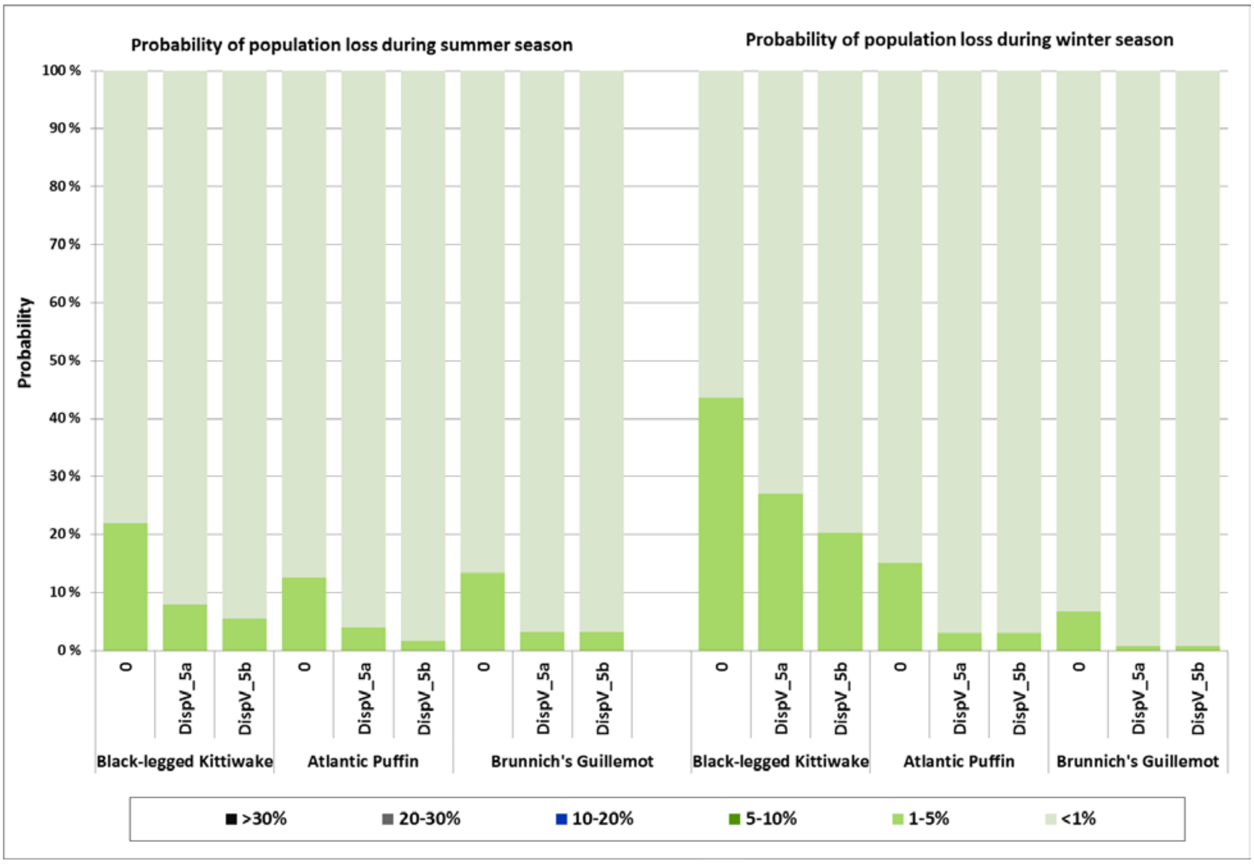


Figure 2-19 *Probability for population loss for three selected seabird species given a topside blowout, for summer (left) and winter season (right). Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

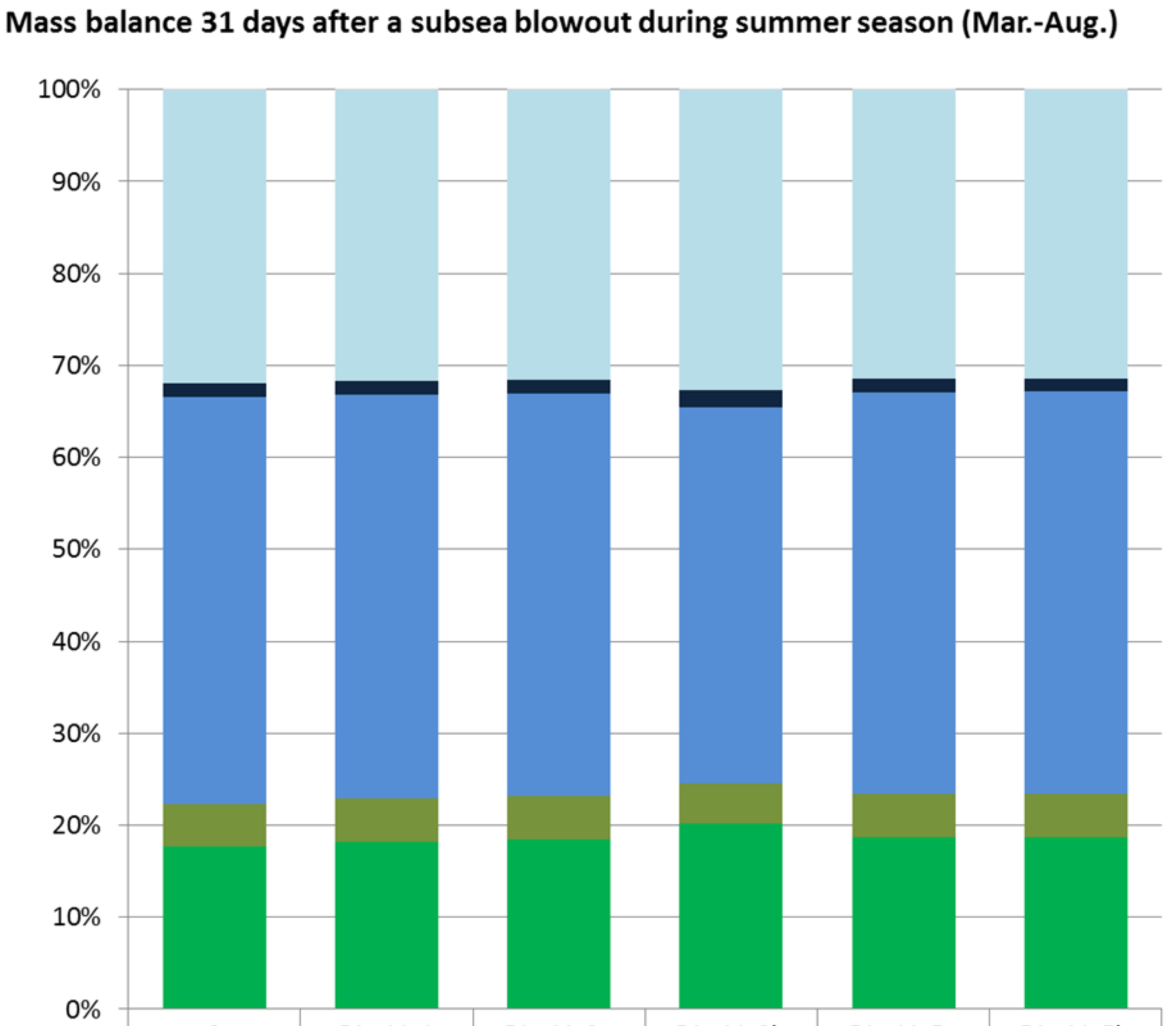
Subsea scenario

Figure 2-20 and Figure 2-21 show the mass balance at the end of the simulation (31 days) for a subsea blowout.

The fraction of surface oil is higher during summer as in winter season; however differences in the mass balance are limited.

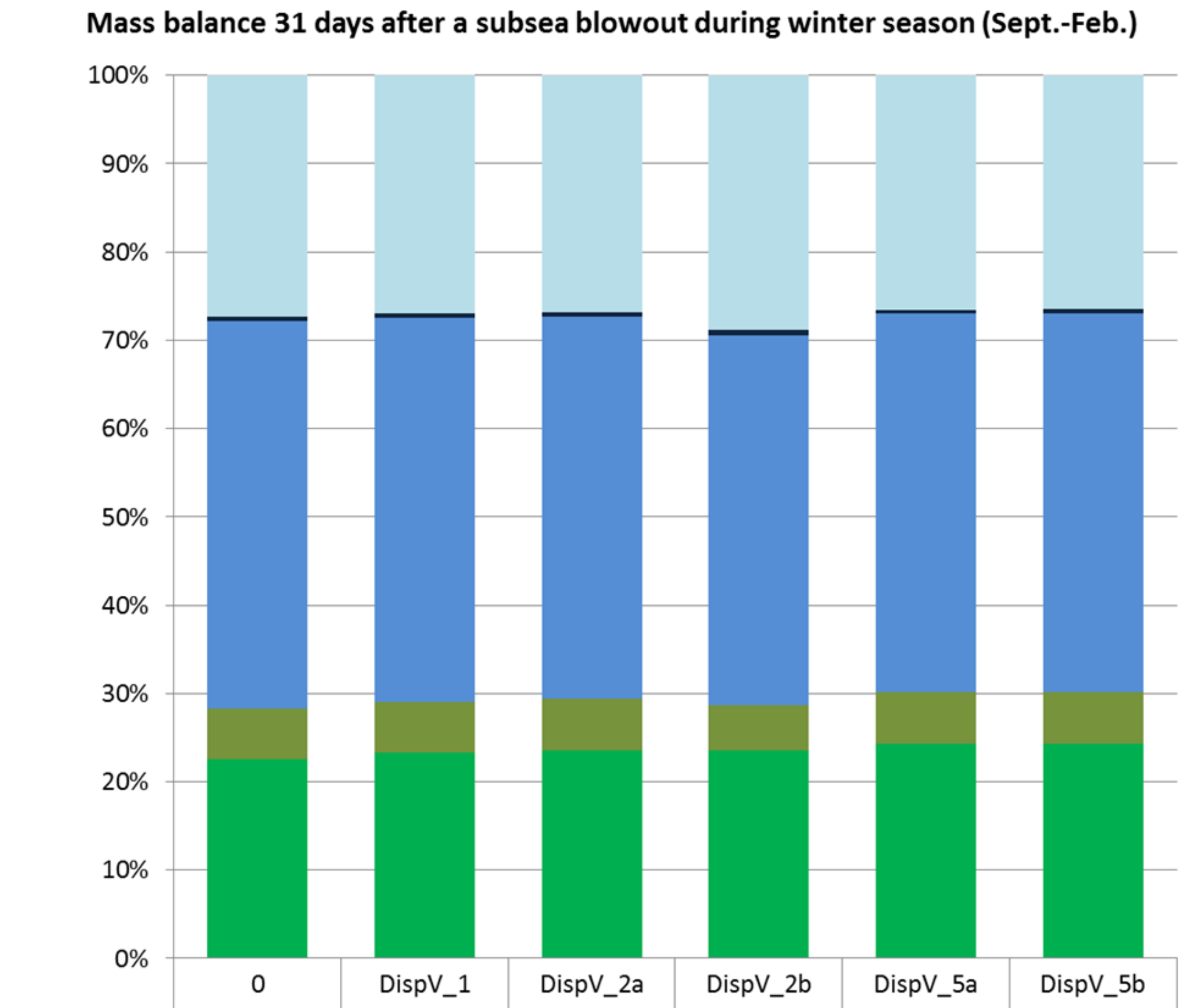
There is no reduction in oil on surface by adding vessel based dispersion systems compared to the reference scenario. The amount of degraded oil is only slightly higher (1-2 percentage points) compared to the reference scenario. Thus, the effect of vessel based dispersion systems is limited given a subsea scenario.

The use of a second standby-vessel in order to shorten the response times has no effect regarding the overall mass balance at the end of the simulation.



	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,7 %	31,6 %	32,7 %	31,5 %	31,4 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,5 %	1,5 %	1,9 %	1,4 %	1,4 %
Dispersed	44,2 %	43,9 %	43,7 %	40,9 %	43,7 %	43,6 %
Dissolved	4,7 %	4,8 %	4,8 %	4,3 %	4,8 %	4,8 %
Degraded	17,6 %	18,2 %	18,4 %	20,2 %	18,6 %	18,7 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

Figure 2-20 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the summer season. 0 indicates no vessel based dispersion systems in use; strategy 1 indicates 1 dispersion system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,1 %	0,1 %	0,0 %	0,1 %	0,0 %
Evaporated	27,3 %	27,0 %	26,8 %	28,8 %	26,5 %	26,5 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,4 %	0,6 %	0,4 %	0,4 %
Dispersed	43,9 %	43,5 %	43,3 %	41,9 %	42,9 %	42,9 %
Dissolved	5,7 %	5,8 %	5,8 %	5,0 %	5,9 %	5,9 %
Degraded	22,6 %	23,3 %	23,6 %	23,6 %	24,2 %	24,3 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

Figure 2-21 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the winter season. 0 indicates no vessel based dispersion systems in use; strategy 1 indicates 1 dispersion system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*

2.7 Aerial based open water dispersion system

Key findings for aerial dispersion systems:

- Aerial based dispersion systems are only effective for the topside scenario. Their operational feasibility is limited by high seas states and darkness in winter time.
- Adding chemical dispersions will increase the amount of oil in the water column from 60 % to 70%, while the fraction of surface and evaporated oil will be reduced.
- Overall reduction of surface oil at the end of the simulation compared to the reference scenario is < 1 percentage point.
- An additional aerial dispersion system will lead to a higher decrease of surface oil within the first few days; however its performance is limited due to available amount of dispersant fluid.
- Probability of population loss can be reduced by maximum 8 percentage points using aerial dispersion, but effect is limited.

Topside scenario

A positive effect by using chemical dispersants as an oil spill response strategy appears primarily as an elevated fraction of dispersed oil in the mass balance. Figure 2-22 and Figure 2-23 shows the effect and the efficiency of one and two aerial dispersion systems compared to the reference set-up – simulation without oil spill response (0).

There are some differences in mass balance between summer and winter season due to different weather conditions which affect the oil's weathering characteristics as well as the effectiveness of the response measures.

By applying chemical dispersions to an oil slick, more oil will degrade and dissolve in the water column. The mass balance shows that during summer season, the fraction of biodegraded oil increases from 11 % (no response measures) to 24 % for both response strategies. The amount of dissolved oil increases up to 6 %, while the amount of evaporated and dispersed oil will be reduced. The amount of oil on surface can be decreased by 1 percentage point in the overall mass balance by using aerial dispersion systems.

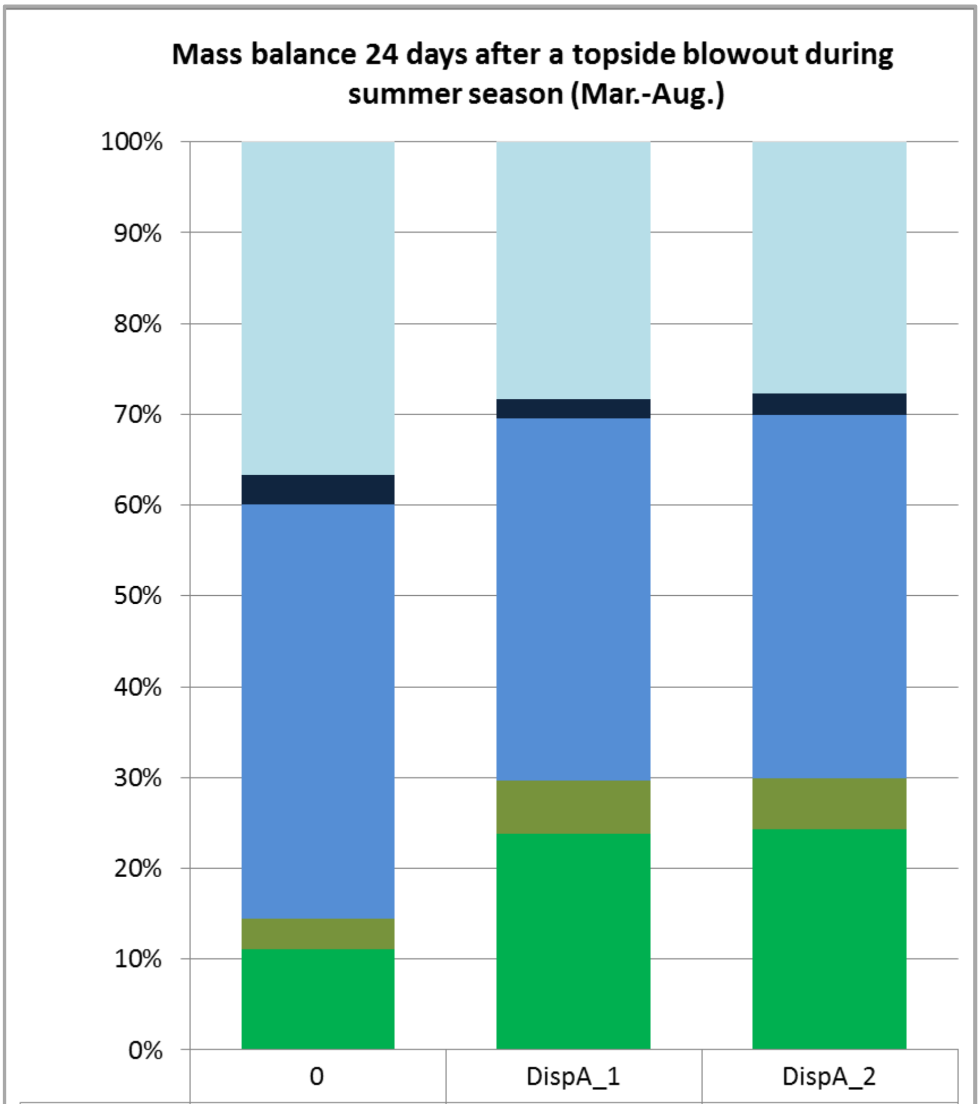
The use of a second airplane in order to shorten the response times and to be able to treat more oil in the dispersion window has no effect regarding the overall mass balance at the end of the simulation (24 days). The operation is limited by available dispersant agent capacities (see below).

Figure 2-24 shows the mass balance over time for scenario DispA_1 and DispA_2. It can be seen that after 1 day with the start of the aerial dispersion and within the first 4 days, more oil will be removed from the water surface using 2 aircrafts. There is an increase in surface oil at day 9. This is due to the fact that both aircrafts have used up the available amount of dispersant fluid in Norway (517 m^3, status as per October 2015) while the oil discharge is ongoing. The oil will be dispersed naturally until the end of the simulation. After 13 days the amount of recovered oil starts to level out between the strategies. After 13 days the fraction of surface oil decreases constant until 2 % at the end of the simulation for both response set-ups.

The results indicate that chemical dispersion is an applicable strategy on the Skrugard crude oil.

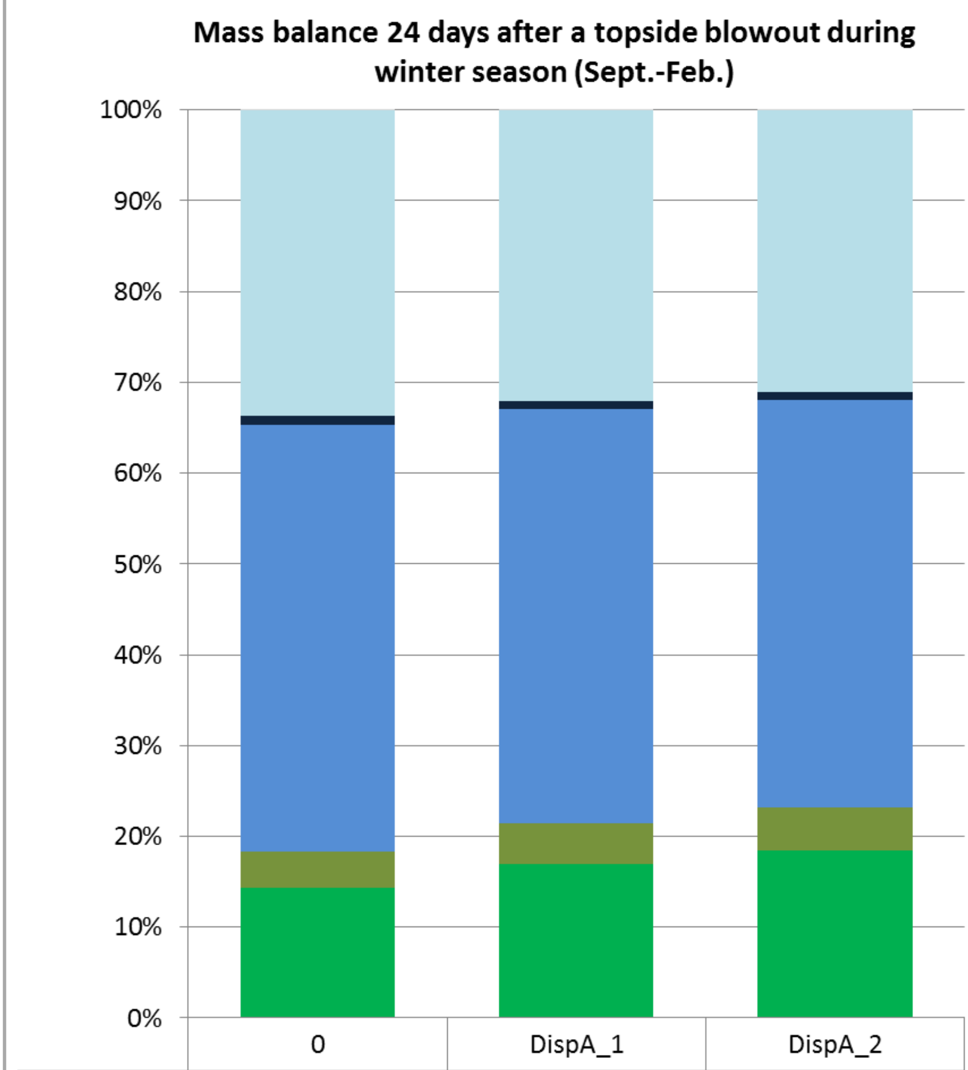
Based on results from the ERA for the exploration well of this study (DNV GL, 2015a), pelagic sea birds are the most affected species; hence a reduction of surface oil should be the main aim during an oil spill operation. The calculation of the probability of population loss for seabirds gives an indication on the performance of a certain response measure.

Figure 2-25 compares the calculated probability of population loss for response measure DispA_1 and DispA_2 for three selected seabird species. In general, the results show a positive reduction in population loss probability by using aerial dispersion with best effect for the species *Brunnich's Guillemot* during summer. The 1-5 % population loss category is reduced from 13 % probability to 6 % for *Brunnich's Guillemot*. Using a second airplane in the response strategy can lead to some further reduction in population loss probability, however the effect is limited.



	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	28,4 %	27,7 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,1 %	2,4 %
Dispersed	45,7 %	39,8 %	39,9 %
Dissolved	3,4 %	6,0 %	5,7 %
Degraded	11,1 %	23,7 %	24,3 %
Collected	0,0 %	0,0 %	0,0 %

Figure 2-22 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the summer season. 0 indicates no aerial dispersion systems in use; strategy 1 indicates 1 airplane, strategy 2 indicates 2 airplanes with the same response times.*



	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	32,0 %	31,1 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	0,9 %
Dispersed	46,9 %	45,5 %	44,8 %
Dissolved	4,1 %	4,5 %	4,7 %
Degraded	14,3 %	17,0 %	18,4 %
Collected	0,0 %	0,0 %	0,0 %

Figure 2-23 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the winter season. 0 indicates no aerial dispersion systems in use; strategy 1 indicates 1 airplane, strategy 2 indicates 2 airplanes with the same response times.*

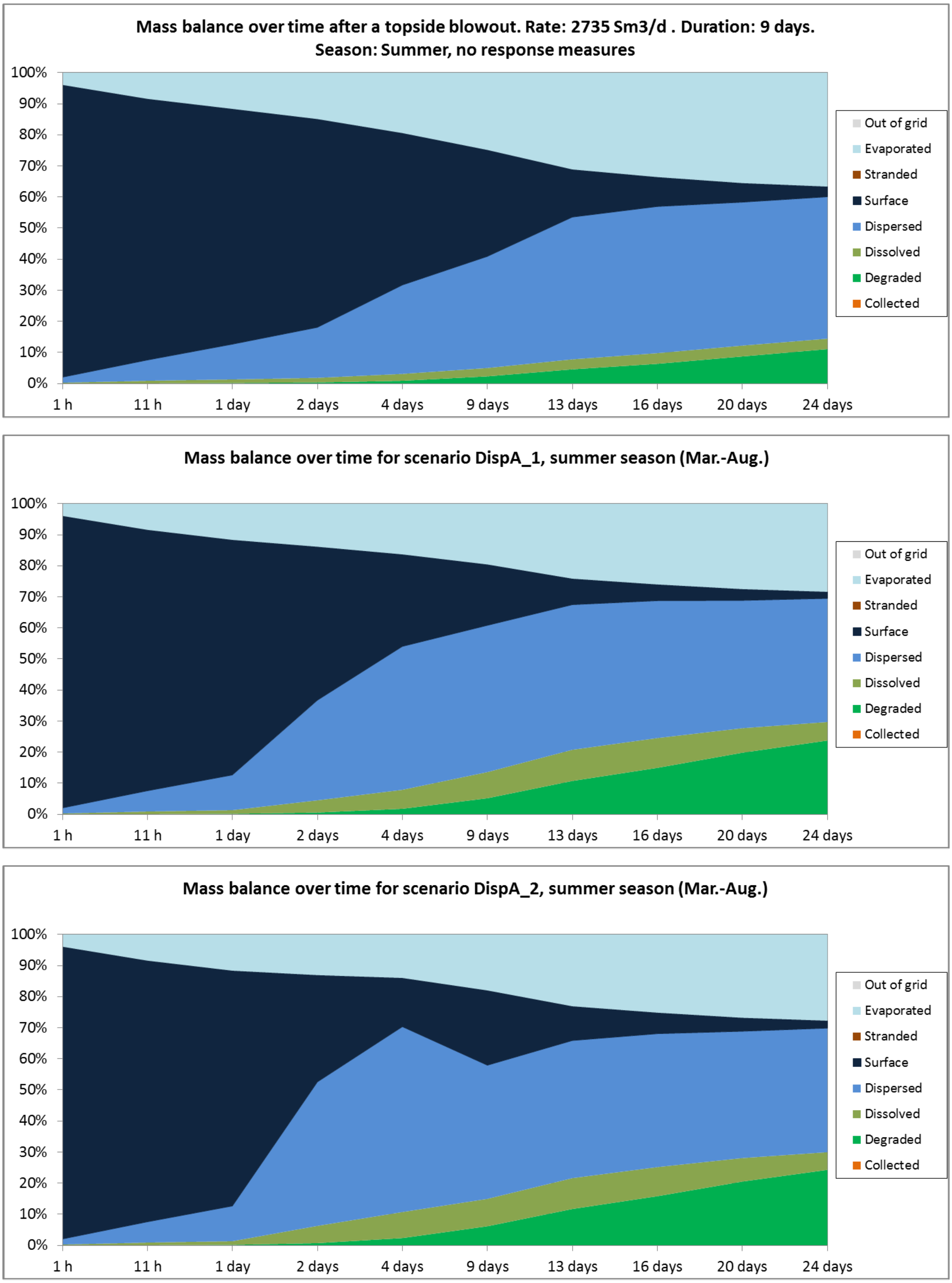


Figure 2-24 *Mass balance over time for a topside blowout in the summer season with no response measures (top), 1 (middle) and 2 (bottom) aerial dispersion systems. The response time for both systems is 24 hours. Note that the x-axis is non-linear.*

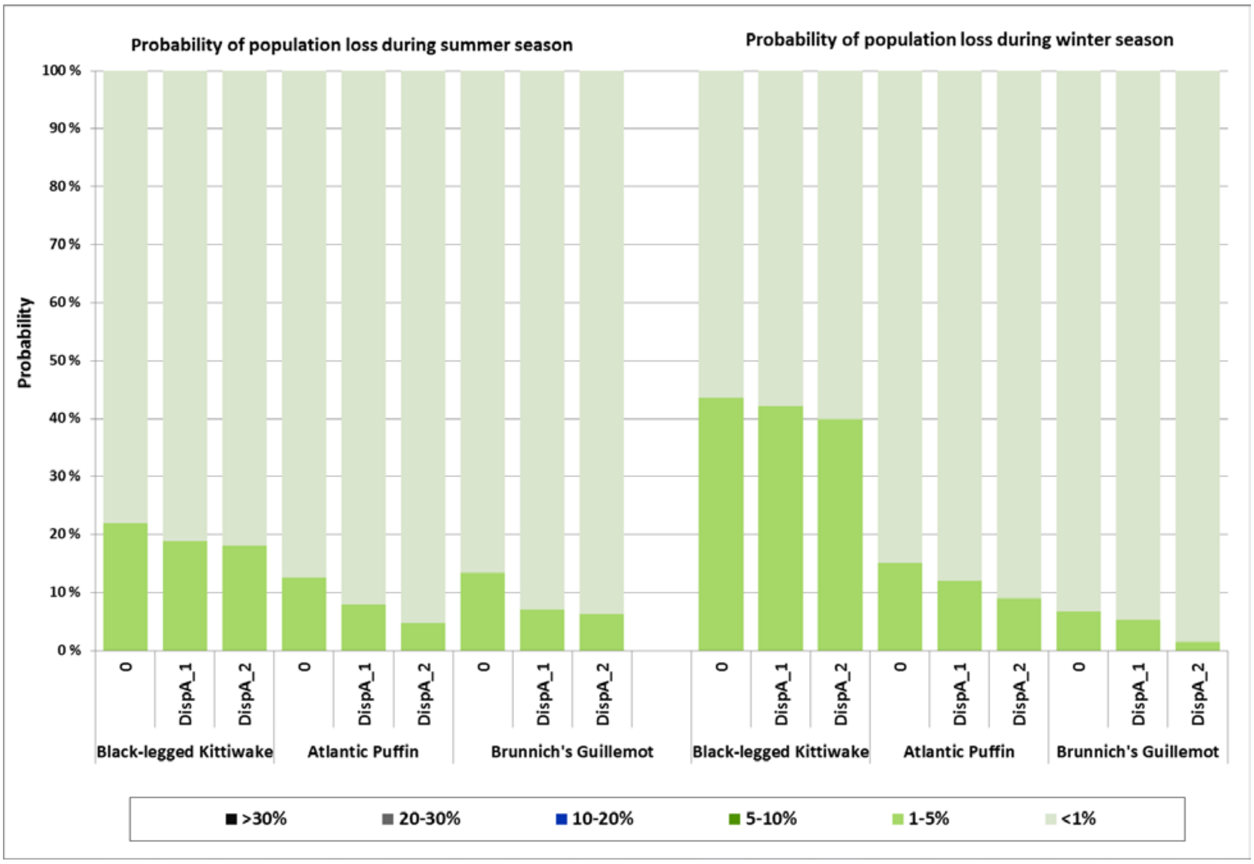


Figure 2-25 *Probability for population loss for three selected seabird species given a topside blowout, for summer (left) and winter season (right). Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

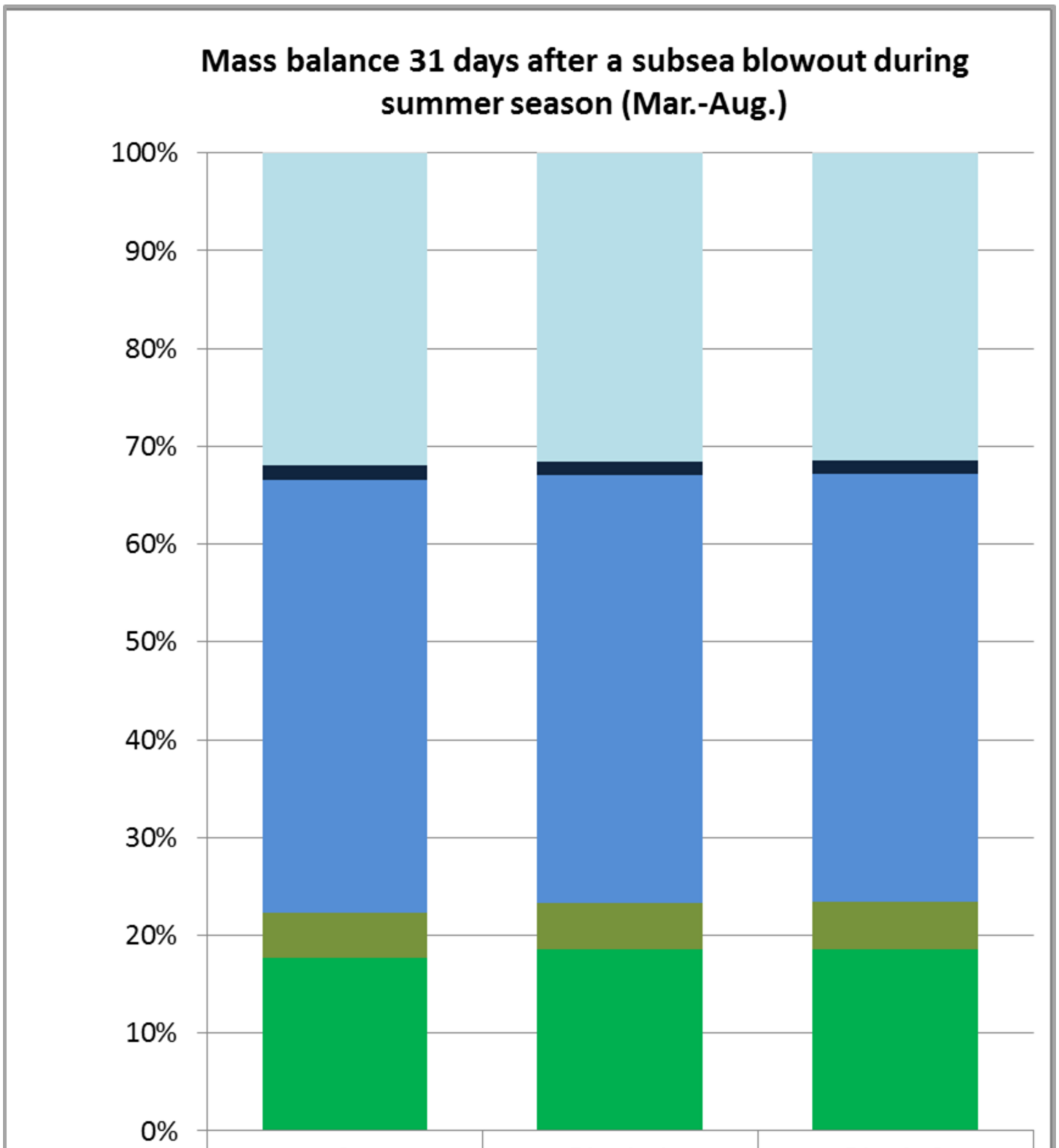
Subsea scenario

Figure 2-26 and Figure 2-27 show the mass balance status at the end of the simulation (31 days) for a subsea blowout.

The fraction of surface oil is higher during summer as in winter season; however differences in the mass balance are limited.

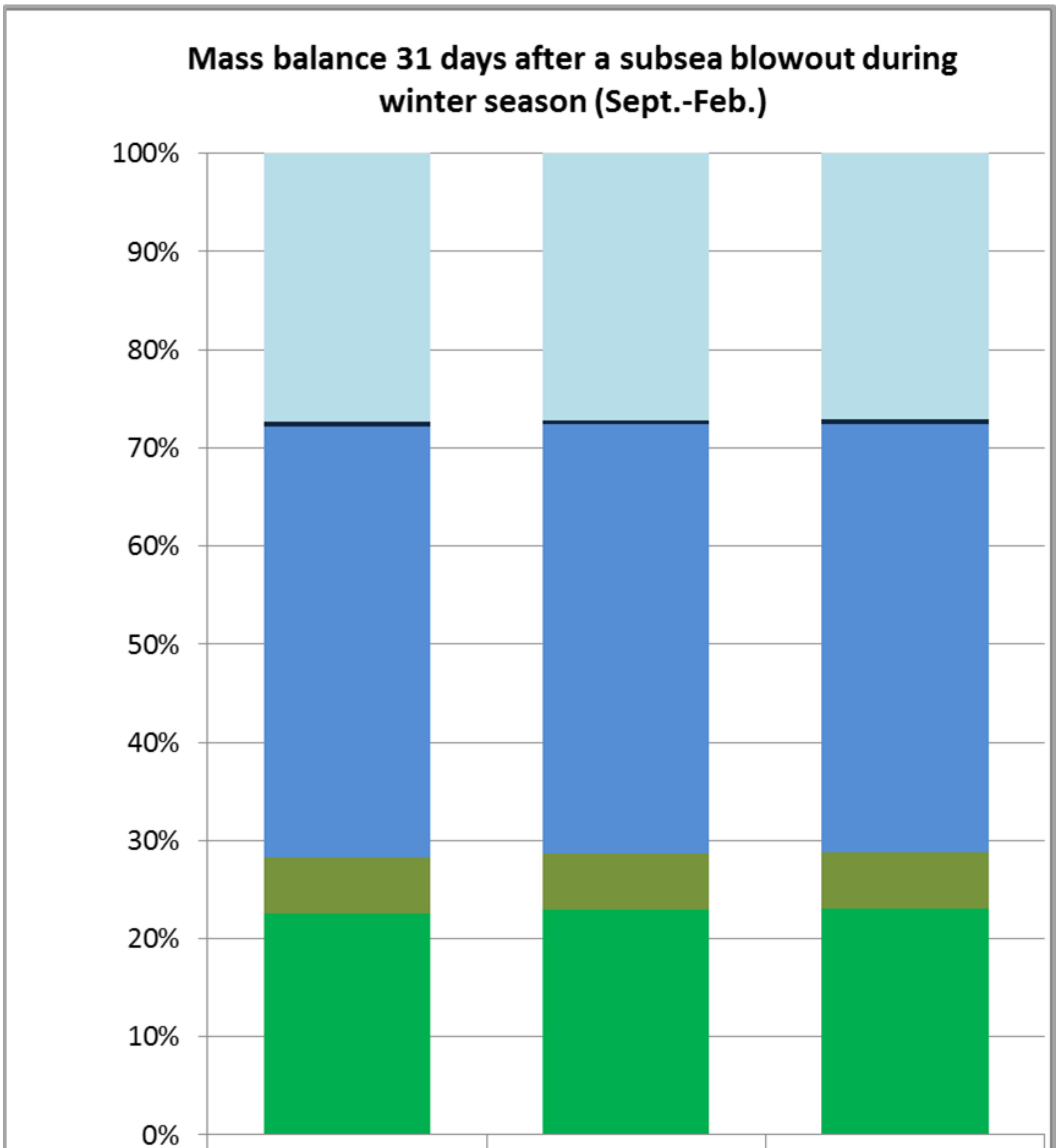
There is no reduction in oil on surface by adding aerial dispersion systems compared to the reference scenario. The amount of degraded oil is only slightly higher (< 1 percentage point) compared to the reference scenario. Thus, the effect of aerial dispersion systems is limited given a subsea scenario.

The use of a second aircraft has no effect regarding the overall mass balance at the end of the simulation.



	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,5 %	31,5 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,4 %	1,4 %
Dispersed	44,2 %	43,7 %	43,7 %
Dissolved	4,7 %	4,8 %	4,8 %
Degraded	17,6 %	18,5 %	18,6 %
Collected	0,0 %	0,0 %	0,0 %

Figure 2-26 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the summer season. 0 indicates no aerial dispersion systems in use; strategy 1 indicates 1 airplane, strategy 2 indicates 2 airplanes with the same response times.*



	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	27,1 %	27,1 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,4 %
Dispersed	43,9 %	43,7 %	43,6 %
Dissolved	5,7 %	5,7 %	5,8 %
Degraded	22,6 %	22,9 %	23,0 %
Collected	0,0 %	0,0 %	0,0 %

Figure 2-27 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during the winter season. 0 indicates no aerial dispersion systems in use; strategy 1 indicates 1 airplane, strategy 2 indicates 2 airplanes with the same response times.*

2.8 Subsea dispersion

Key findings for subsea dispersion:

- Subsea dispersion as a response measure has a limited effect on reducing surface oil as the mass balance is similar to the reference scenario. The relatively short distance between seabed and water surface and a rapid uplift of the oil limits the time period for the oil being dispersed in the water column.
- Using subsea dispersion will lead to an elevated fraction of oil in water column from 67 % to 77 %, while surface and evaporated oil will be reduced.
- An effect of subsea dispersion by reducing the fraction of surface oil is mainly observed within the first four days due to the higher fraction of not weathered, dispersible oil on the water surface.

A positive effect using chemical dispersants as an oil spill response strategy appears primarily as an elevated fraction of biodegraded oil in the mass balance. Figure 2-28 shows effect and efficiency of subsea dispersion compared to reference set-up.

There are some differences in mass balance between summer and winter season as more oil is dispersed and degraded during winter season. This is due to different weather conditions which affect the oil's weathering characteristics as well as the effectiveness of the response measures.

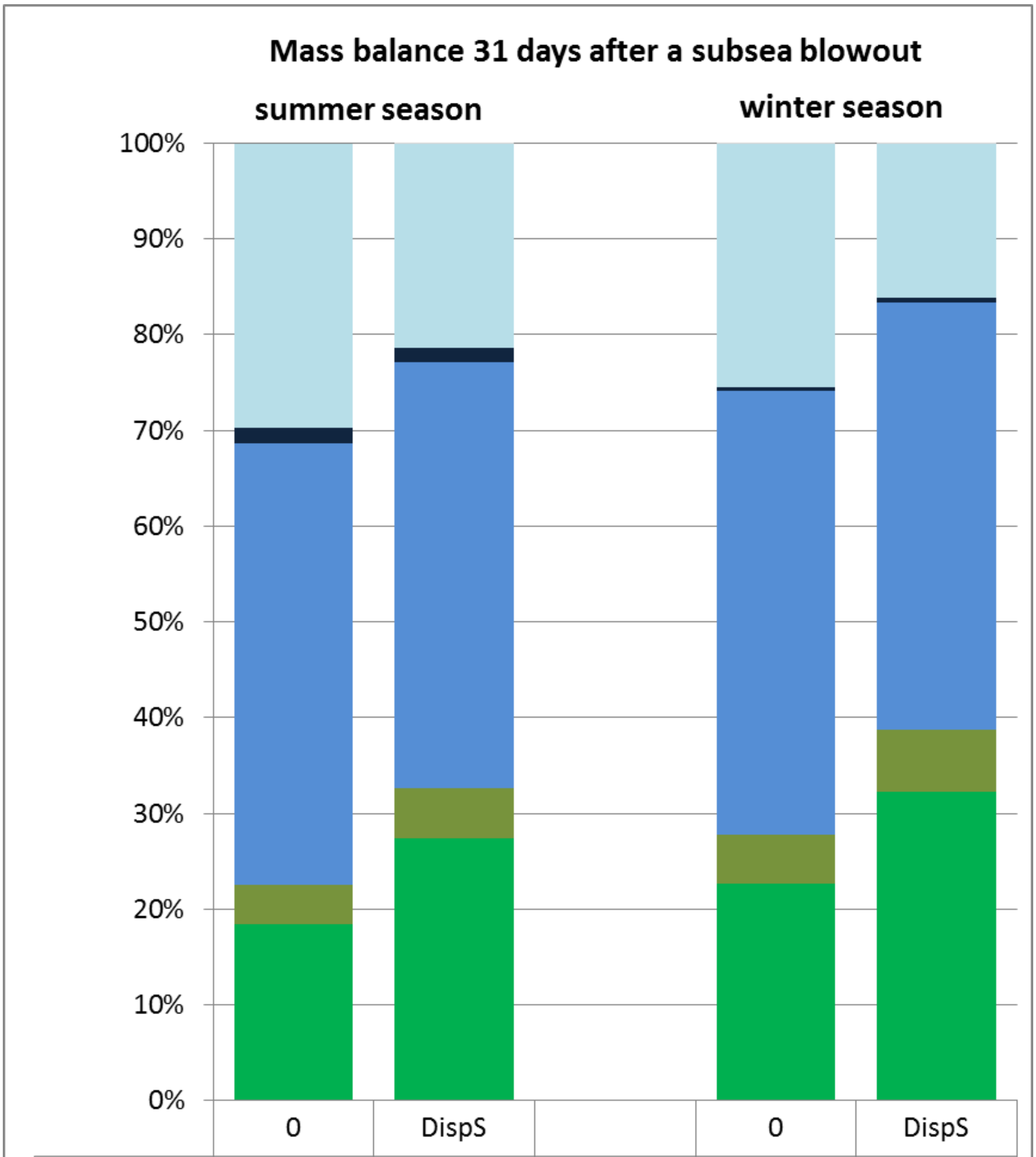
Applying chemical dispersions to a subsea blowout plume will increase the fraction of degraded oil in the water column. The mass balance shows that at the end of the simulation (24 days) during summer season the fraction of biodegraded oil increases from 18 % (no response measures) to 27 %. The fraction of surface oil is reduced by 0.2 percentage points by adding dispersion into a subsea wellhead.

Figure 2-29 shows the mass balance over time for scenario DispS. According to the model, the fraction of surface oil will be reduced immediately upon adding dispersion compared to use of no response measures (36 % vs. 58 % after 12 hours, respectively). The effect decreases after 4 days and after 9 days the amount of surface oil starts to level out between no response measure and subsea dispersion. This is due to an increased fraction of weathered oil towards the end of the simulation, meaning that the contribution from fresh oil will be less compared to the early phase of the release.

Based on results from the ERA for the exploration well of this study (DNV GL, 2015a), pelagic sea birds are the most affected species; hence a reduction of surface oil should be the main aim during an oil spill operation. The calculation of the probability of population loss for seabirds gives an indication on the performance of a certain response measure.

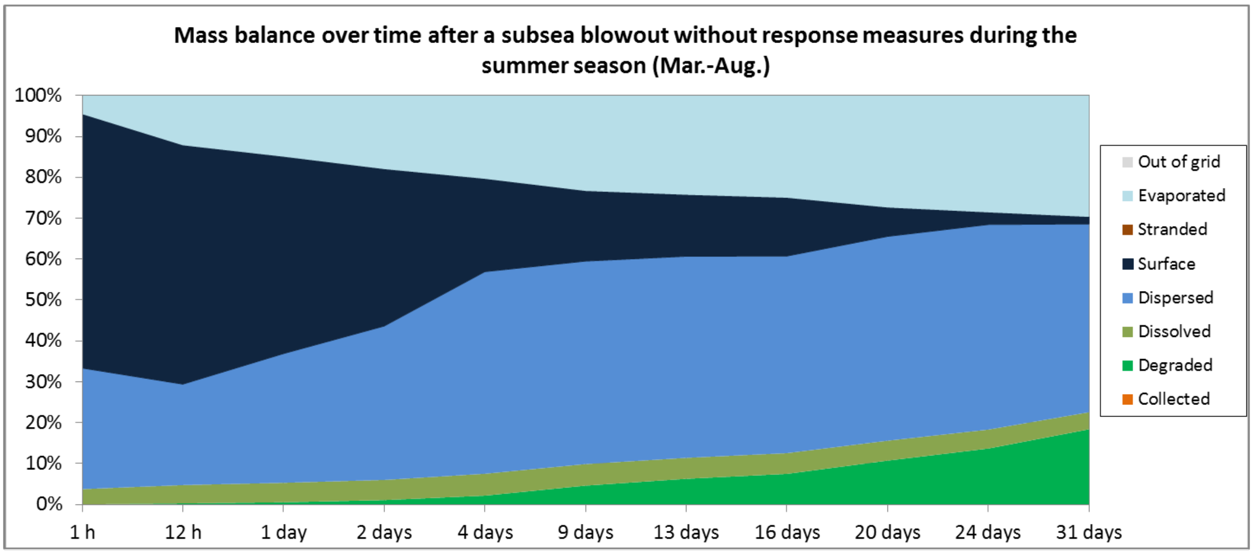
Figure 2-30 shows population loss probability calculations with and without the effect of subsea dispersion for three selected seabird species. The results indicate marginal reductions, which can be resulted by the ERA-methodology as it uses relatively broad mass categories.

Subsea dispersion as a response measure is most feasible at great water depth. During a subsea blowout, a plume of small oil droplets, gas bubbles and entrained water will initially rise rapidly in the form of a buoyant plume, with the gas providing the dominant source of lift and buoyancy. Studies showed that at oil and gas releases from subsea blowouts in water less than 500 meters depth, the gas is not likely to totally dissolve in the water and the buoyant plume of gas and oil is likely to rapidly arrive at the sea surface (IPIECA-IOGP, 2015). The water depth at the blowout location of this study is 228 m MSL. Single simulation for this study showed that the first droplets will arrive at the sea surface after ~10 minutes. The relatively short distance between seabed and water surface thus limits the contact period between oil and dispersion particles which ultimately will affect the effectiveness of subsea dispersion as a response strategy.



	0	DispS		0	DispS
Out of grid	0,0 %	0,0 %		0,0 %	0,0 %
Evaporated	29,7 %	21,3 %		25,4 %	16,2 %
Stranded	0,0 %	0,0 %		0,0 %	0,0 %
Surface	1,7 %	1,5 %		0,5 %	0,4 %
Dispersed	46,1 %	44,6 %		46,3 %	44,7 %
Dissolved	4,2 %	5,2 %		5,2 %	6,4 %
Degraded	18,4 %	27,4 %		22,6 %	32,3 %
Collected	0,0 %	0,0 %		0,0 %	0,0 %

Figure 2-28 *Mass balance 31 days after a subsea blowout with 16 days duration and 15 days following time during summer (March – August) and winter season (September – February). 0 indicates no response measures; strategy DispS indicates subsea dispersion.*



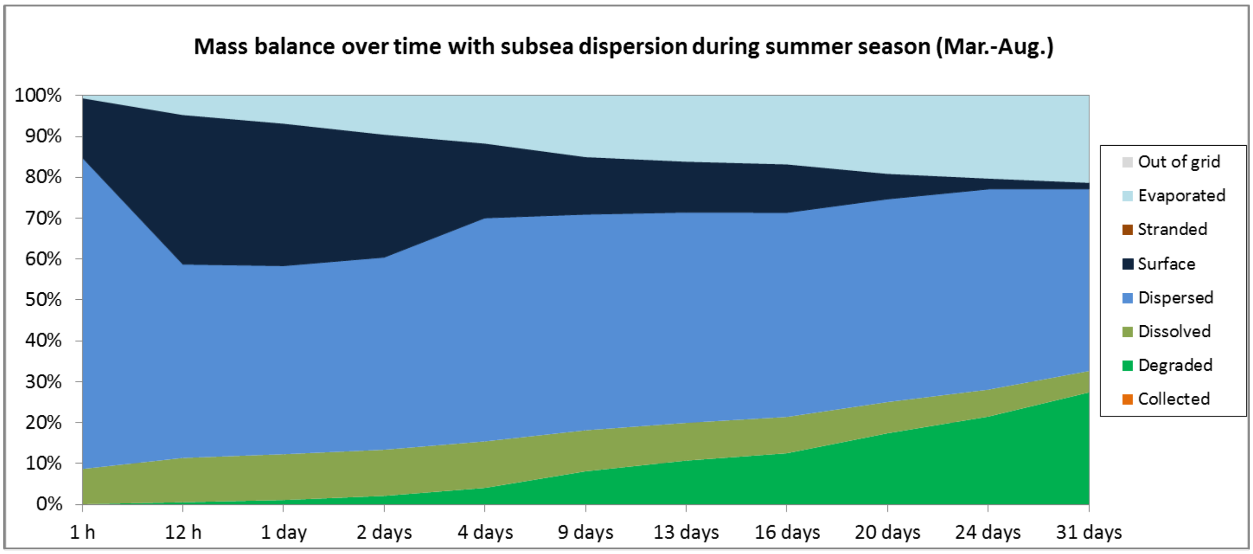


Figure 2-29 *Mass balance over time for a subsea blowout in the summer season with no response measures (top) and subsea dispersion (bottom) as a response measures. Note that the x-axis is non-linear.*

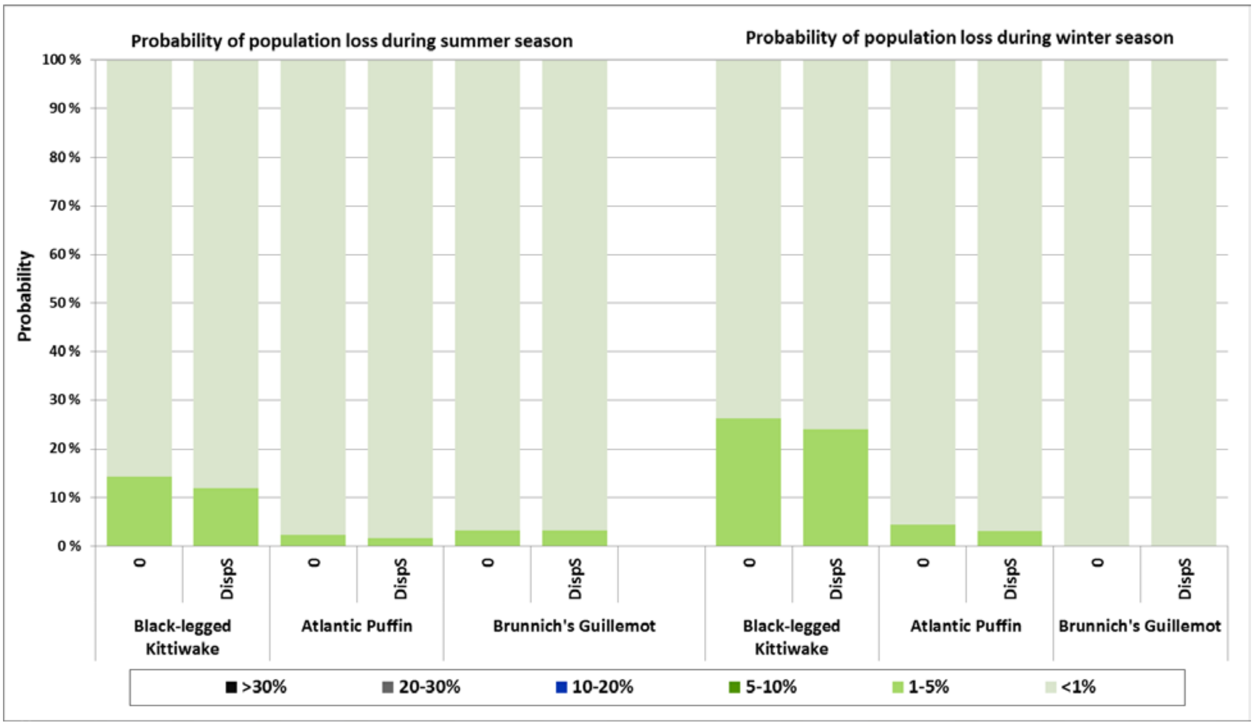


Figure 2-30 *Probability for population loss for three selected seabird species given a subsea blowout, for summer (left) and winter season (right). Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

2.9 Open water in-situ burning

Key findings for in-situ burning systems:

- ISB can be operational feasible for a topside scenario but less for a subsea scenario, however the oil properties (high water uptake) impede most likely to the efficiency of the burn.
- Fraction of burned oil is much higher for summer season compared to winter season (19 % vs. 2 %).
- Overall surface oil reduction at the end of the simulation compared to the reference scenario through ISB is < 1 percentage point.
- Additional ISB systems will increase amount of burned oil from 6 % to 19 % burned oil.
- Additional effect of shorter response time (2nd standby-vessel) is limited as ≤ 1 percentage point more oil will be burned.
- The calculated effect on population loss is with 1 -4 percentage points reduction marginal.

Topside scenario

As the OSCAR model has currently not a build-in function to model in-situ burning (ISB) as a response measure, the simulation of ISB was approached by using mechanical recovery systems in the analysis by applying relevant data for ISB operations to a mechanical recovery system, e.g. replacing the mechanical boom characteristics with fire-boom characteristics and skimmer capacities with an average burn rate. The traditional recovered oil category is replaced with a "burned oil" fraction. However, one has to note that the results represent the operational feasibility of this response measure. The efficiency of the burn itself (e.g. difficult ignition due to water uptake of the oil) will not be taken into account in the model. The weathering study of the oil will provide additional information and has to be considered in the discussion.

Figure 2-31 and Figure 2-32 show the effectiveness of ISB given different numbers of "burn systems" and different response times compared to the reference set-up.

During summer season, the ISB systems can operate and burn oil from the sea surface to some degree, while the operational feasibility of ISB is hampered during winter season. This is due to different weather conditions which affect the oil's fate as well as the effectiveness of the response measures. During the winter season the wind is more intense, the waves are higher, the temperature is lower and the time period of operational light is reduced compared to the summer season. ISB was set in model to be active only during periods of daylight.

The mass balance indicates that the implementation of more systems increases the amount of oil gathered and available for burning during summer season. The harsh weather conditions as well as darkness during winter season results in that the effect of the strategy is limited during winter. Five ISB vessels (ISB_5a) would burn 18 % in summer season, but only 2 % in winter season.

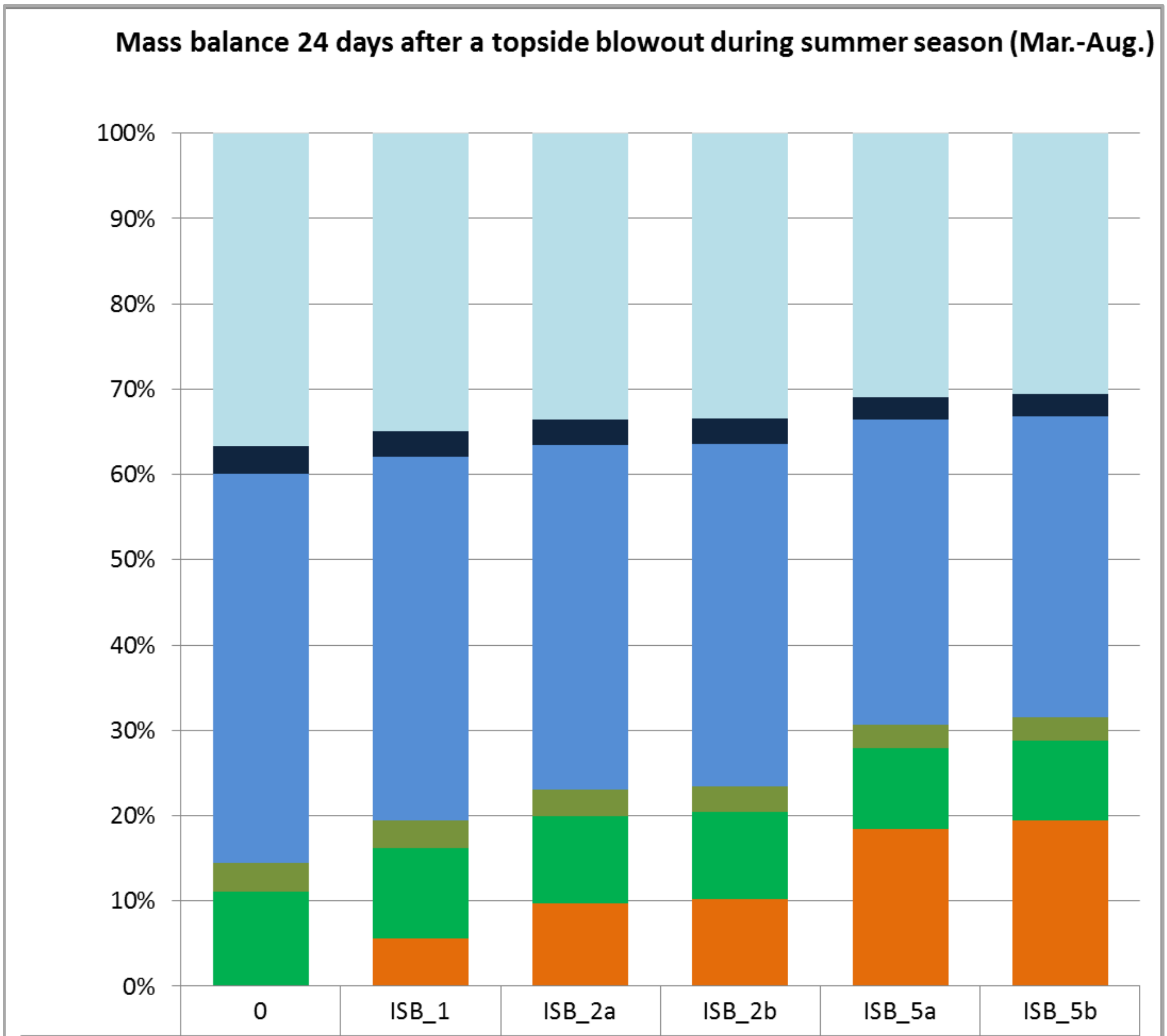
The use of a second standby-vessel in order to shorten response time has no significant effect regarding the overall mass balance at the end of the simulation (24 days). The additional amount of burned oil is calculated to be 1 percentage point for 5 systems during summer conditions. This is most likely due to the long duration of the spill.

Figure 2-33 shows the mass balance over time for scenario ISB_5a and ISB_5b. Within the first 4 days more oil can be burned and removed from the water surface using 2 standby-vessels. However, after 4 days when all response systems are in place and fully operative, the amount of burned oil is the same and remains constant until the end of the simulation ranging between 18 % (scenario 5a) and 19 % (scenario 5b).

Based on results from the ERA for the exploration well of this study (DNV GL, 2015a), pelagic sea birds are the most affected species; hence a reduction of surface oil should be the main aim during an oil spill operation. The calculation of the probability of population loss for seabirds gives an indication on the performance of a certain response measure.

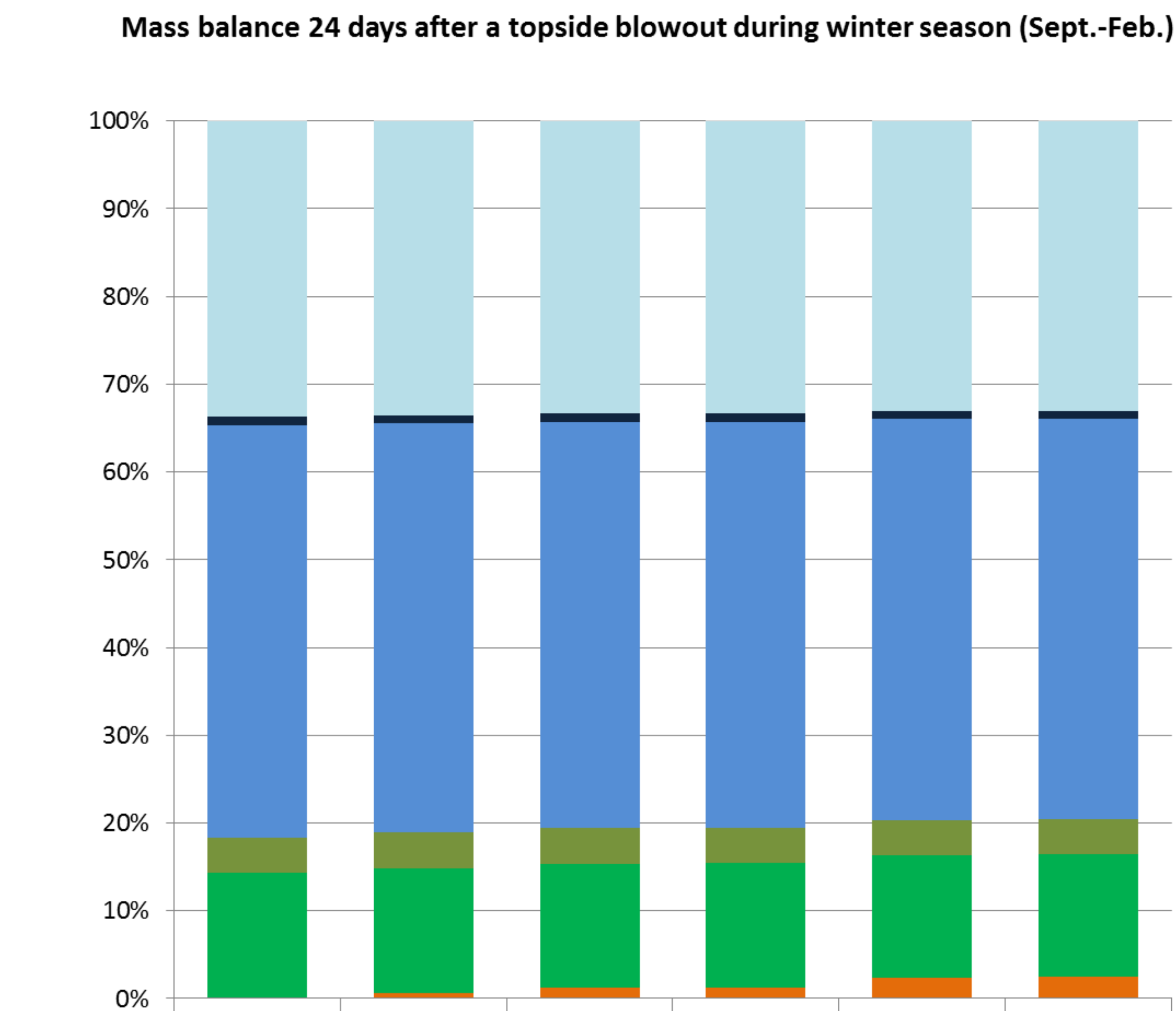
Figure 2-34 compares the calculated probability of population loss for response measure ISB_5a and ISB_5b for three selected seabird species. There is only a limited reduction in population loss probability by using ISB as a response measure with best effect for the species *Brunnich's Guillemot* and *Atlantic Puffin* during summer season. Both species could be reduced from 13 % to maximal 9 % probability in the 1-5 % population loss category. Using a second standby-vessel in the response strategy does in most cases not lead to a further reduction in population loss probability.

In general, the ignitability of an oil slick is highly dependent on its water content. ISB has usually its best performance on fresh oil, with a water content < 25 % (ARPEL, 2006). SINTEF's weathering study of the Skrugard crude oil (Øksenvåg, 2012) reports a water uptake of 50 % within >24 hours, depending on wind speed. Single simulations confirmed a high water uptake within 24 hours. Thus, ISB as a response strategy for Skrugard oil is likely to have a low efficiency.



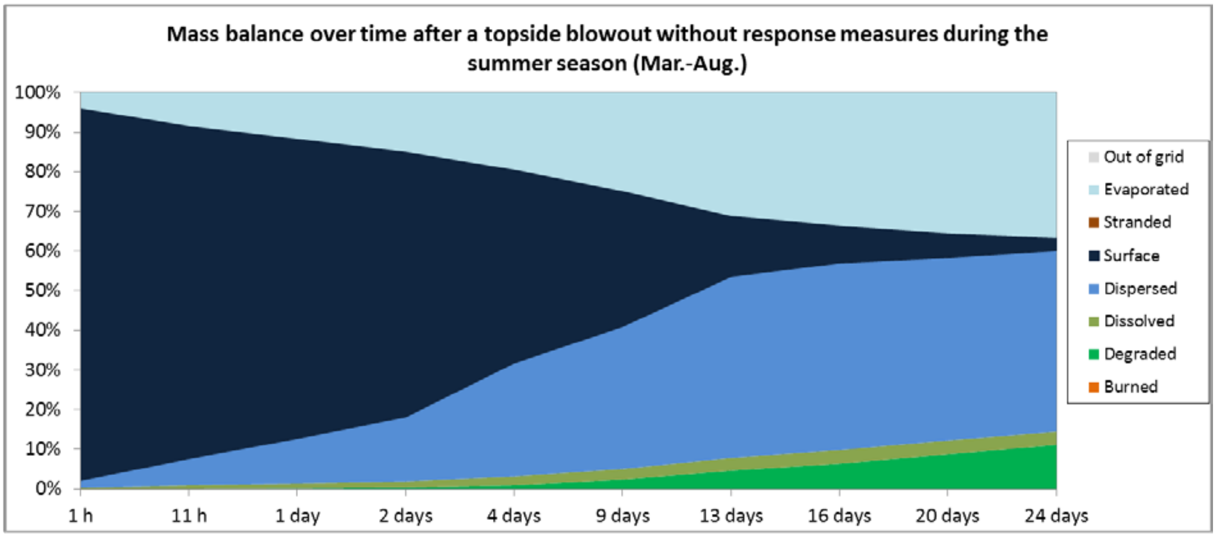
	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	34,9 %	33,6 %	33,4 %	30,9 %	30,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	3,1 %	2,9 %	3,0 %	2,6 %	2,7 %
Dispersed	45,7 %	42,7 %	40,4 %	40,1 %	35,8 %	35,2 %
Dissolved	3,4 %	3,2 %	3,1 %	3,1 %	2,8 %	2,8 %
Degraded	11,1 %	10,6 %	10,2 %	10,2 %	9,5 %	9,4 %
Burned	0,0 %	5,6 %	9,7 %	10,2 %	18,4 %	19,4 %

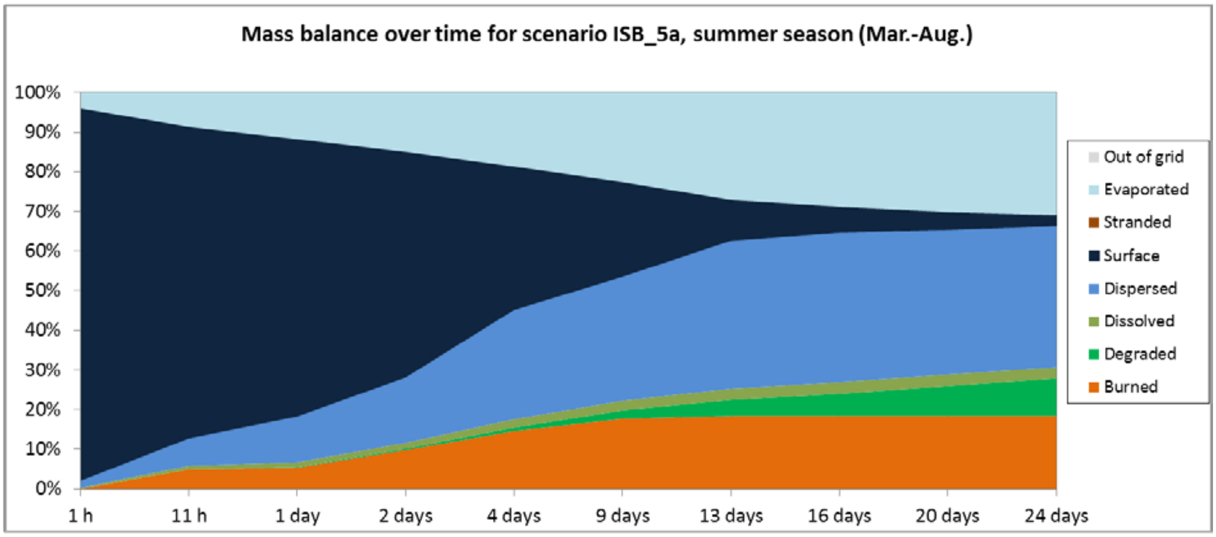
Figure 2-31 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the summer season. 0 indicates no in-situ burning systems in use; strategy 1 indicates 1 ISB system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	33,5 %	33,3 %	33,3 %	33,0 %	33,0 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	1,0 %	0,9 %	0,9 %	0,9 %
Dispersed	46,9 %	46,6 %	46,3 %	46,3 %	45,6 %	45,6 %
Dissolved	4,1 %	4,1 %	4,1 %	4,1 %	4,0 %	4,0 %
Degraded	14,3 %	14,2 %	14,1 %	14,1 %	14,0 %	14,0 %
Burned	0,0 %	0,7 %	1,2 %	1,3 %	2,3 %	2,4 %

Figure 2-32 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the winter season. 0 indicates no in-situ burning systems in use; strategy 1 indicates 1 ISB system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*





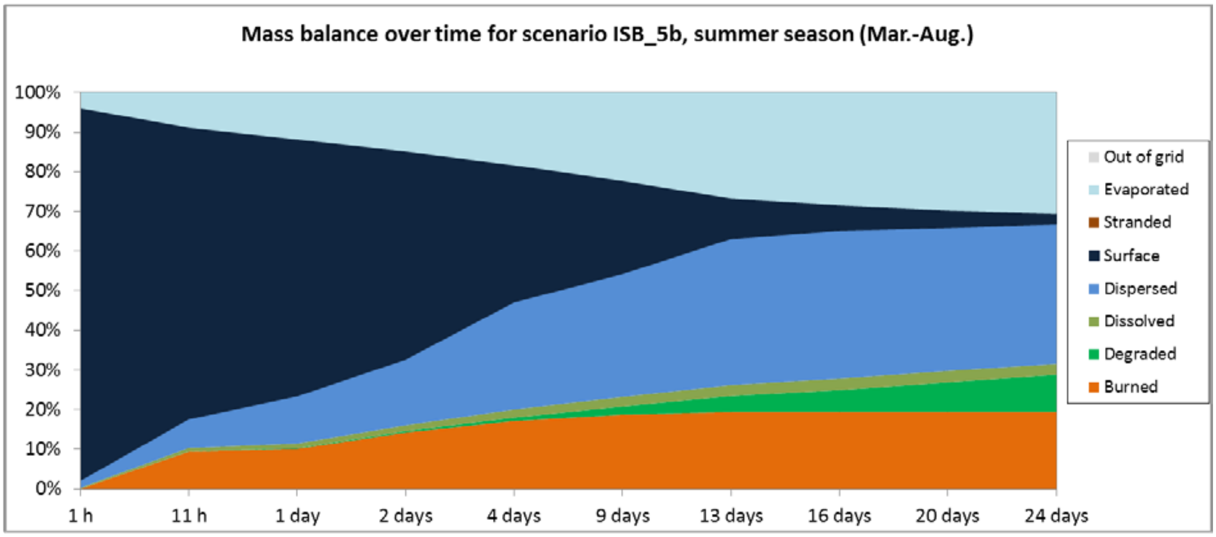


Figure 2-33 *Mass balance over time for a topside blowout in the summer season with no response measures and with 5 ISB systems. Strategy ISB_5a consists of 1 standby-vessel with a response time of 2 hours and 4 response vessels with response times of 26, 34, 54,and 54 hours. Strategy ISB_5b consists of 2 standby-vessels with a response time of 2 hours and 3 response vessels with response times of 26, 34, and 54 hours. Note that the x-axis is non-linear.*

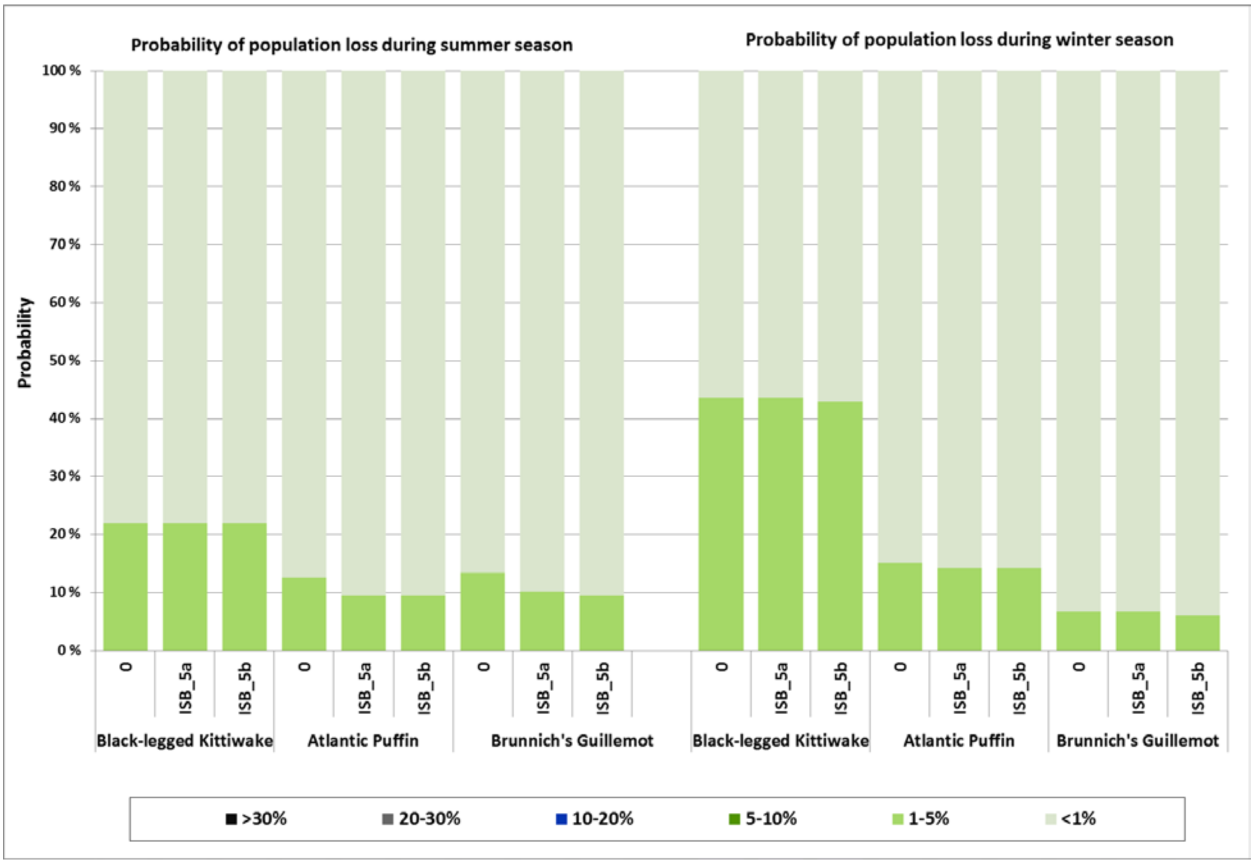


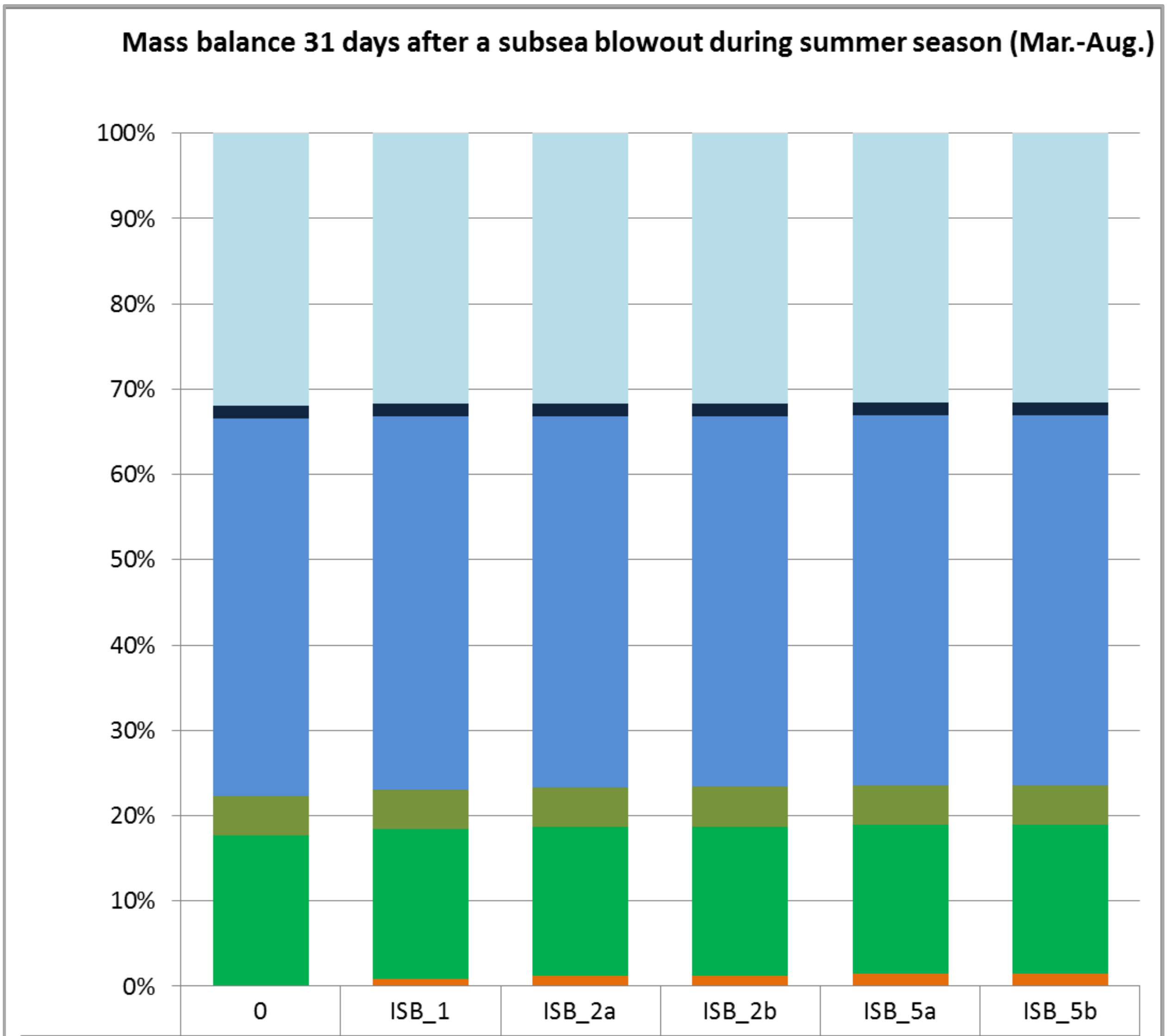
Figure 2-34 *Probability for population loss for three selected seabird species given a topside blowout, for summer (left) and winter season (right). Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

Subsea scenario

Figure 2-35 and Figure 2-36 show the mass balance at the end of the simulation (31 days) for a subsea blowout.

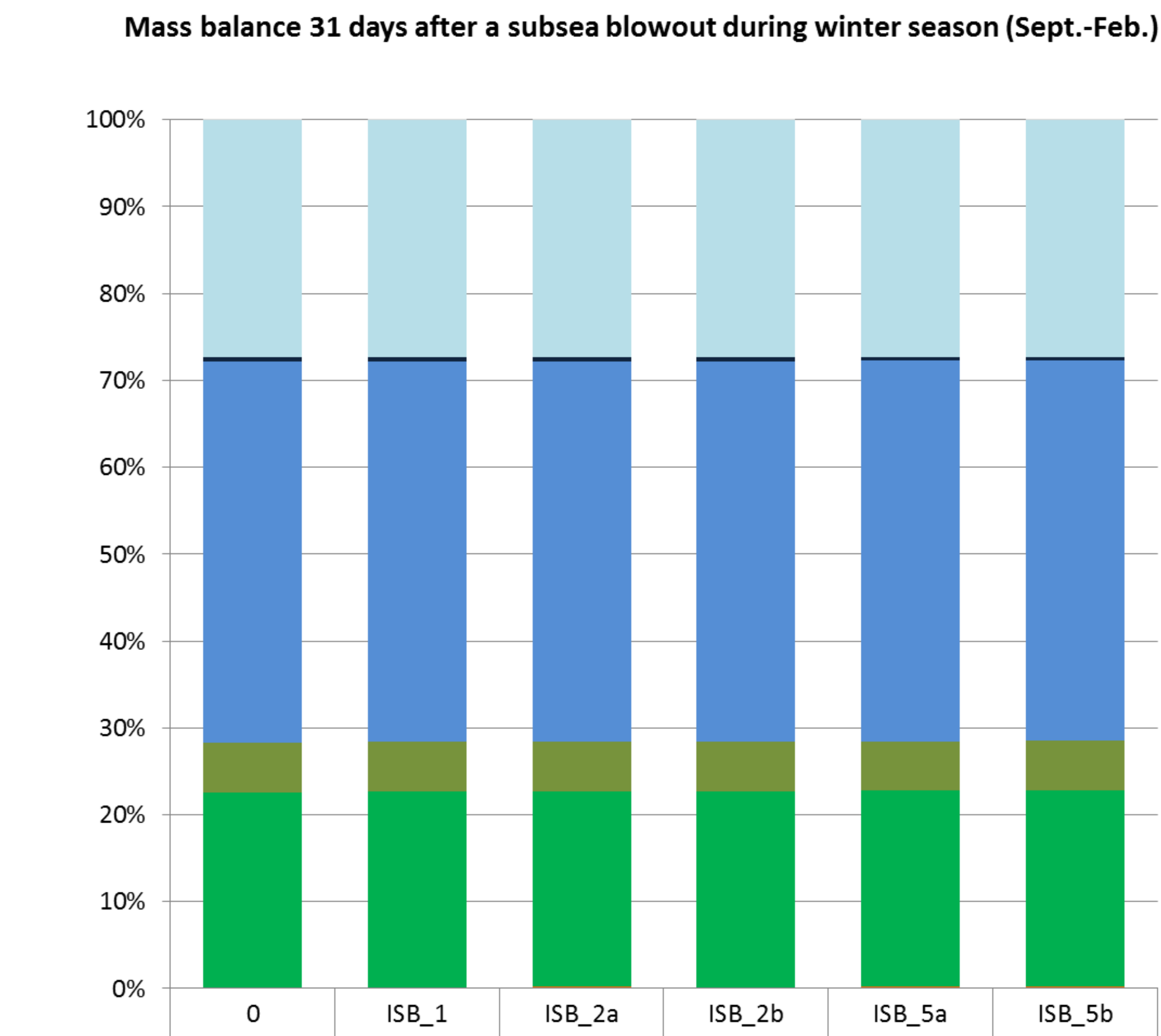
In general, ISB strategy is strongly ineffective independent of season and number of systems applied.

The performance of ISB is greatly dependent on the oil's ability of water uptake. IN general, oil gets difficult to ignite if the water content is > 30 %. Skrugard crude oil has a high water uptake (see chapter 1.3) and ISB is thus not a feasible strategy for a subsea release.



	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,8 %	31,6 %	31,7 %	31,6 %	31,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,5 %	1,5 %	1,5 %	1,5 %	1,5 %
Dispersed	44,2 %	43,7 %	43,5 %	43,4 %	43,4 %	43,3 %
Dissolved	4,7 %	4,6 %	4,6 %	4,6 %	4,6 %	4,6 %
Degraded	17,6 %	17,5 %	17,5 %	17,5 %	17,5 %	17,5 %
Burned	0,0 %	0,8 %	1,2 %	1,2 %	1,4 %	1,5 %

Figure 2-35 *Mass balance 31 days after a topside blowout with 16 days duration and 15 days following time during the summer season. 0 indicates no in-situ burning systems in use; strategy 1 indicates 1 ISB system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*



	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	27,3 %	27,3 %	27,3 %	27,2 %	27,2 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,5 %	0,5 %	0,5 %	0,5 %	0,5 %
Dispersed	43,9 %	43,8 %	43,8 %	43,8 %	43,8 %	43,8 %
Dissolved	5,7 %	5,7 %	5,7 %	5,7 %	5,7 %	5,7 %
Degraded	22,6 %	22,6 %	22,5 %	22,5 %	22,5 %	22,5 %
Burned	0,0 %	0,1 %	0,2 %	0,2 %	0,3 %	0,3 %

Figure 2-36 *Mass balance 31 days after a topside blowout with 16 days duration and 15 days following time during the winter season. 0 indicates no in-situ burning systems in use; strategy 1 indicates 1 ISB system, strategy 2a and 5a indicates in total 2 and 5 systems with one standby-vessel; while strategy 2b and 5b has two standby-vessels.*

2.10 Combined open water techniques

Key findings for combined mechanical and dispersion systems:

- Combinations of different response strategies have a positive effect in both reducing oil on surface and population loss probability.
- Best effects are obtained using active mechanical recovery systems combined with aerial dispersion.

The topside scenario has been modelled with a set of different combinations of mechanical recovery systems and dispersion systems with the following strategies:

Comb1 = 3 passive mechanical recovery systems + 2 vessel based dispersion systems
Comb2 = 3 passive mechanical recovery systems + 1 aerial dispersion system
Comb3 = 3 active mechanical recovery systems + 2 vessel based dispersion systems
Comb4 = 3 active mechanical recovery systems + 1 aerial dispersion system

Figure 2-37 and Figure 2-38 show the mass balance of these systems compared to the reference set-up – simulation without oil spill response (0).

There are some differences in mass balance between summer and winter season due to different weather conditions which affect the oil's weathering characteristics as well as the effectiveness of the response measures.

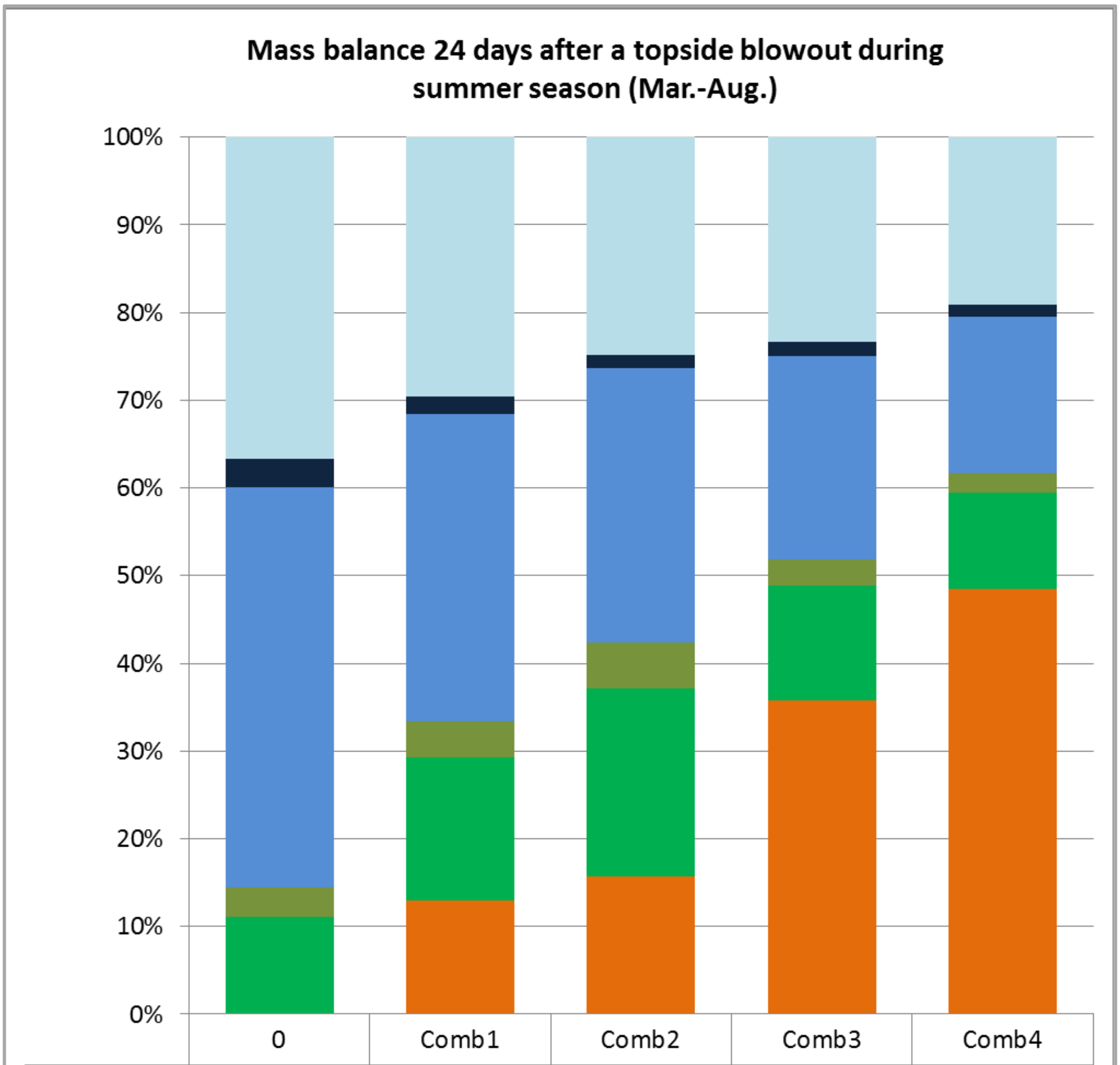
The highest amount of recovered oil (48 %) is achieved by the active mechanical recovery systems in response measure *Comb4*, whereas *Comb2* results in the highest increase of degraded oil (21 %), showing the positive effect of aerial dispersion.

The reduction of surface oil at the sea surface is an important criterion in oil spill contingency. The overall mass balance indicates that with the implementation of a response measure, the oil in surface would be reduced by > 1.5 percentage points. Thus, recovered and chemically dispersed oil recovery is primarily oil that otherwise would have ended up in the naturally dispersed category.

Analysing the mass balance results (Figure 2-39) it appears that the majority of the response combinations can contribute significantly in reducing the surface oil fraction immediately after a release has been initiated.

Based on results from the ERA for the exploration well of this study (DNV GL, 2015a), pelagic sea birds are the most affected species; hence a reduction of surface oil should be the main aim during an oil spill operation. The calculation of the probability of population loss for seabirds gives an indication on the performance of a certain response measure.

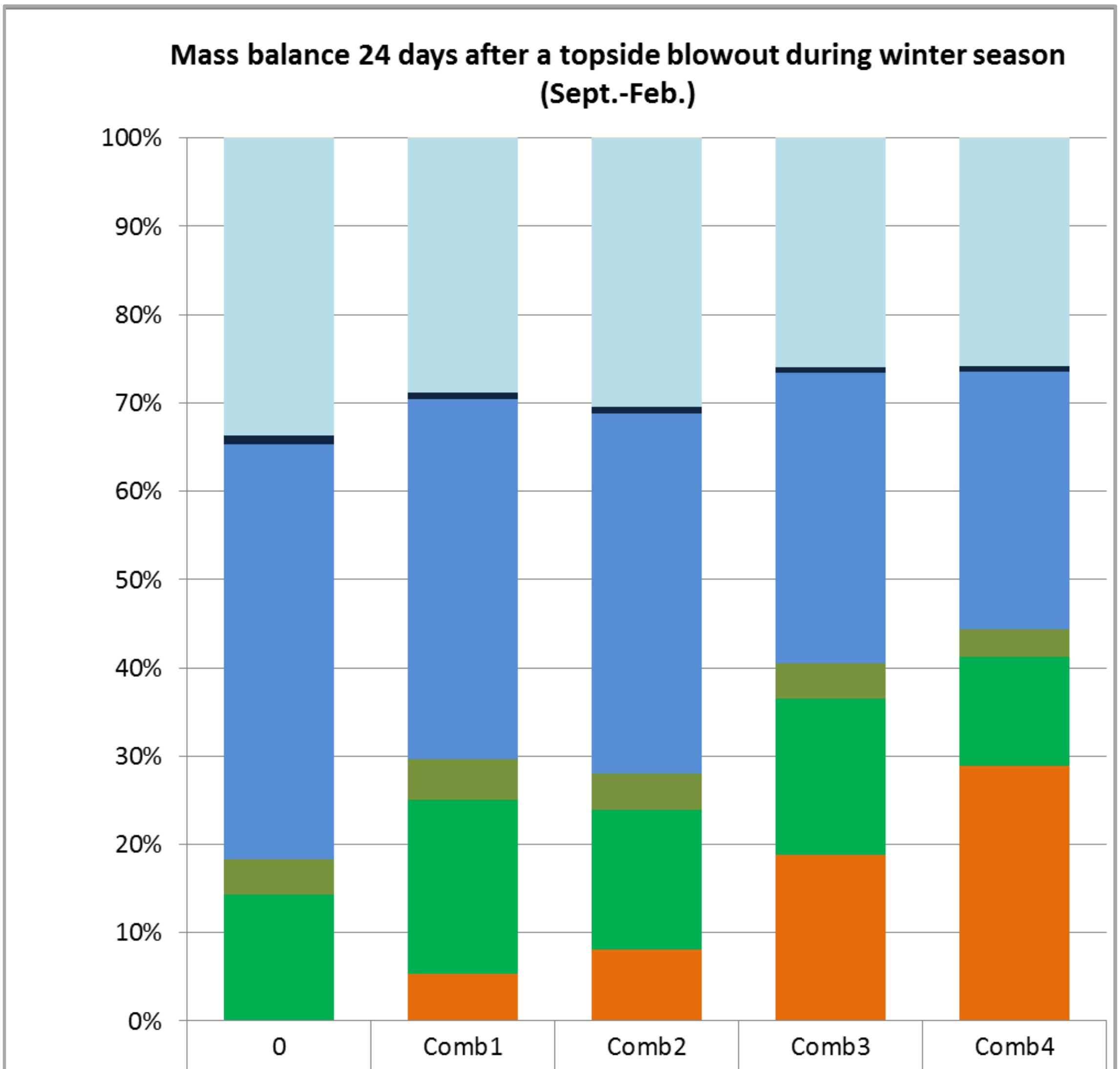
Figure 2-40 compares the calculated probability of population loss for response measure for all combinations for three selected seabird species. In general, the results show a positive effect on population loss by using a combined response strategy. The best effect results by the combination of active recovery systems and aerial dispersion. It can be seen that this combination will lead to high a probability reduction in the 1-5 % population loss category. For the *Atlantic Puffin* during summer season and the *Brunnich's Guillemot* in the winter season, there is a total shift to category < 1 %.



	0	Comb1	Comb2	Comb3	Comb4
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	29,6 %	24,9 %	23,4 %	19,1 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,1 %	1,5 %	1,5 %	1,4 %
Dispersed	45,7 %	35,0 %	31,2 %	23,2 %	17,8 %
Dissolved	3,4 %	4,0 %	5,3 %	3,0 %	2,3 %
Degraded	11,1 %	16,4 %	21,4 %	13,1 %	10,9 %
Collected	0,0 %	13,0 %	15,7 %	35,7 %	48,5 %

Figure 2-37 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the summer season with the following response strategies:*

0 = no response measures
Comb1 = 3 passive mechanical recovery systems + 2 vessel based dispersion systems
Comb2 = 3 passive mechanical recovery systems + 1 aerial dispersion system
Comb3 = 3 active mechanical recovery systems + 2 vessel based dispersion systems
Comb4 = 3 active mechanical recovery systems + 1 aerial dispersion system



	0	Comb1	Comb2	Comb3	Comb4
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	28,8 %	30,4 %	25,9 %	25,9 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,7 %	0,8 %	0,6 %	0,6 %
Dispersed	46,9 %	40,7 %	40,7 %	32,9 %	29,1 %
Dissolved	4,1 %	4,7 %	4,1 %	4,0 %	3,1 %
Degraded	14,3 %	19,6 %	15,9 %	17,6 %	12,4 %
Collected	0,0 %	5,4 %	8,0 %	18,8 %	28,8 %

Figure 2-38 *Mass balance 24 days after a topside blowout with 9 days duration and 15 days following time during the winter season with the following response strategies:*

0 = no response measures
Comb1 = 3 passive mechanical recovery systems + 2 vessel based dispersion systems
Comb2 = 3 passive mechanical recovery systems + 1 aerial dispersion system
Comb3 = 3 active mechanical recovery systems + 2 vessel based dispersion systems
Comb4 = 3 active mechanical recovery systems + 1 aerial dispersion system

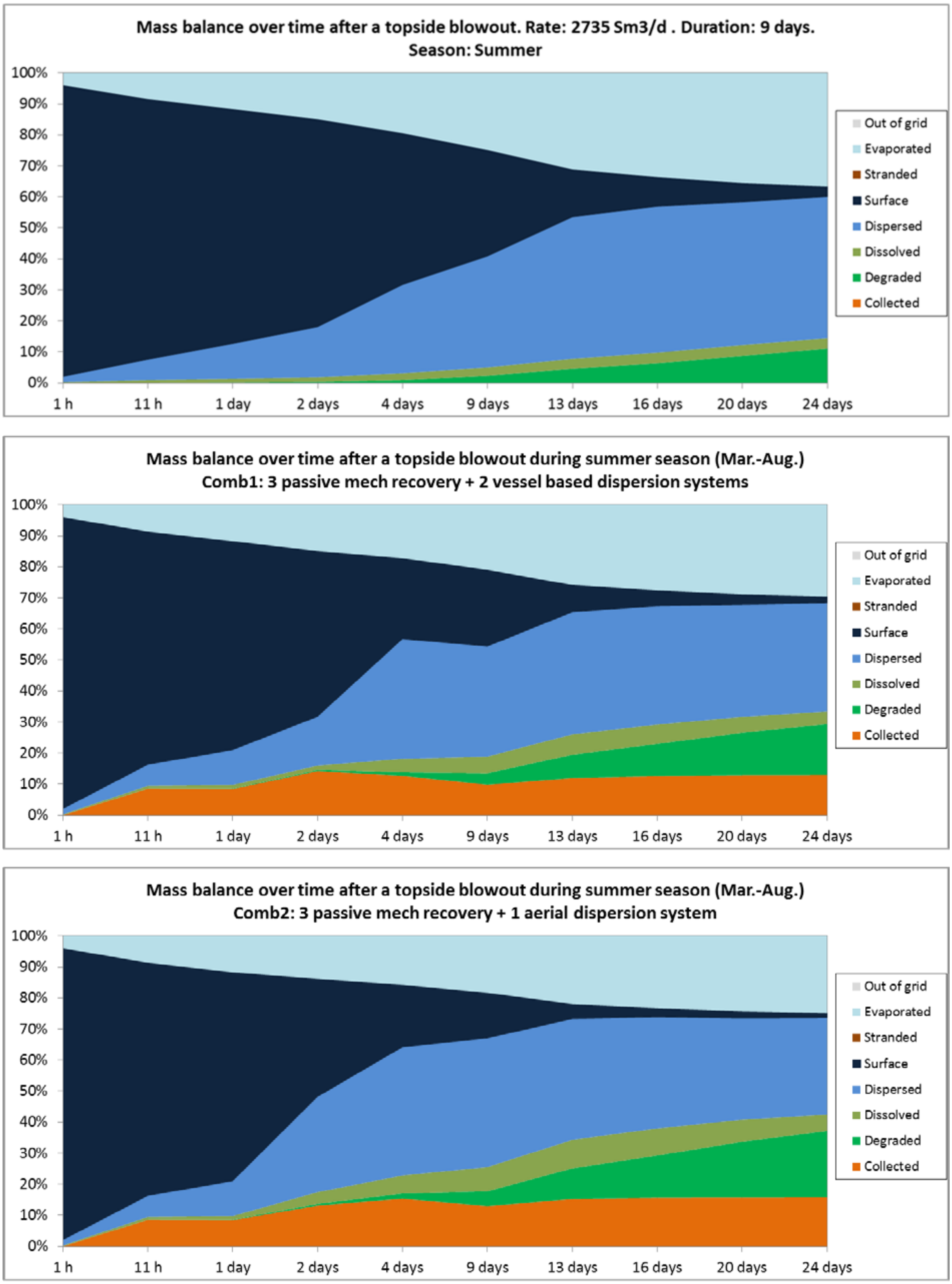
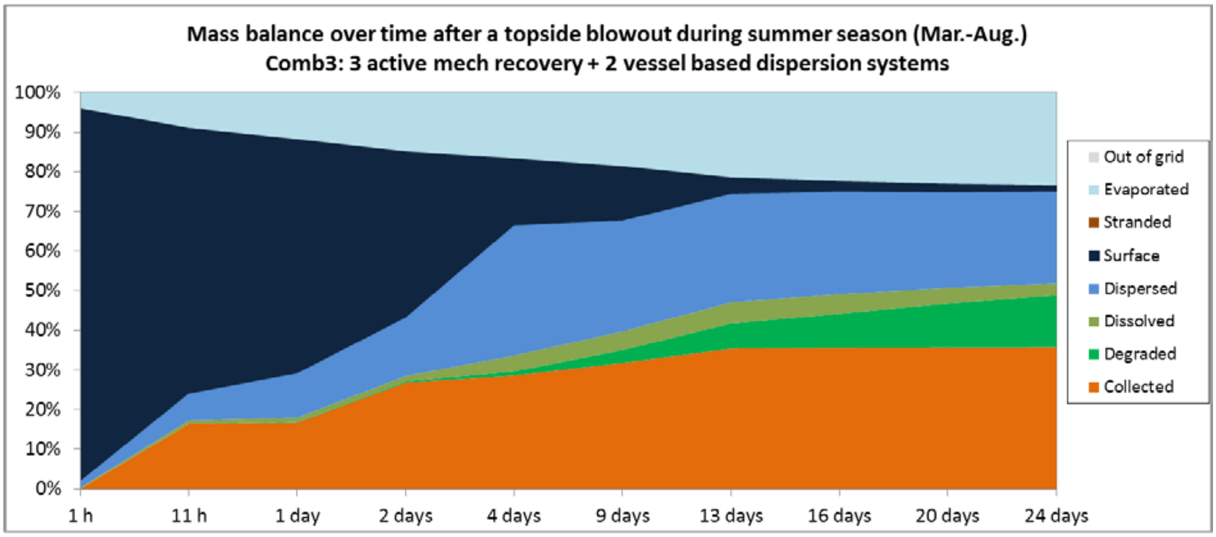


Figure 2-39 *Mass balance over time for a topside blowout in the summer season with no response measures and with different response combinations. Note that the x-axis is non-linear.*



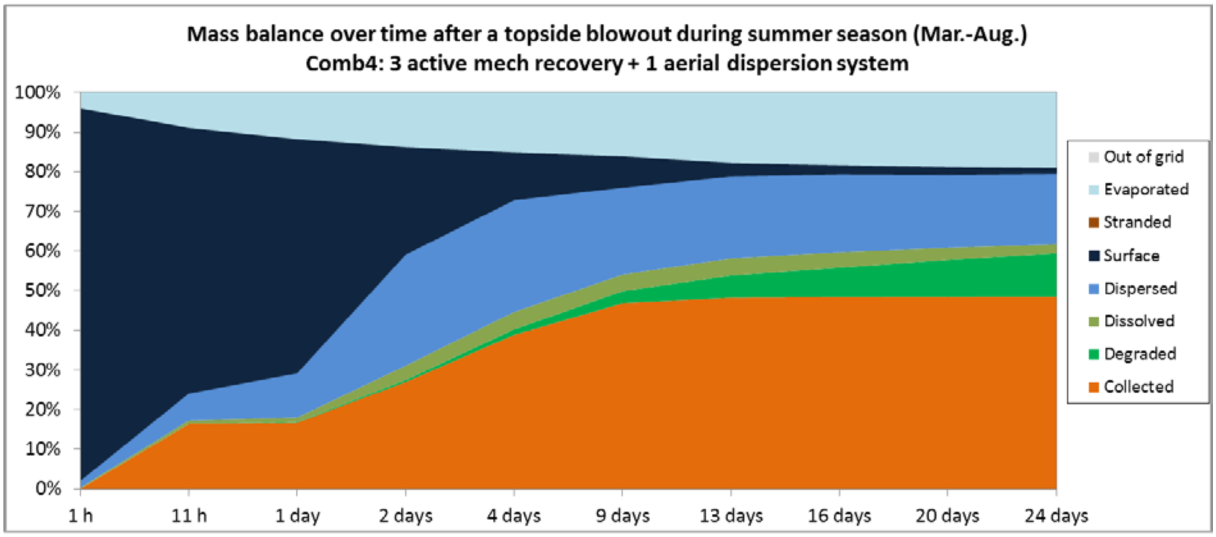


Figure 2-39 (continued) *Mass balance over time for a topside blowout in the summer season with no response measures and with different response combinations. Note that the x-axis is non-linear.*

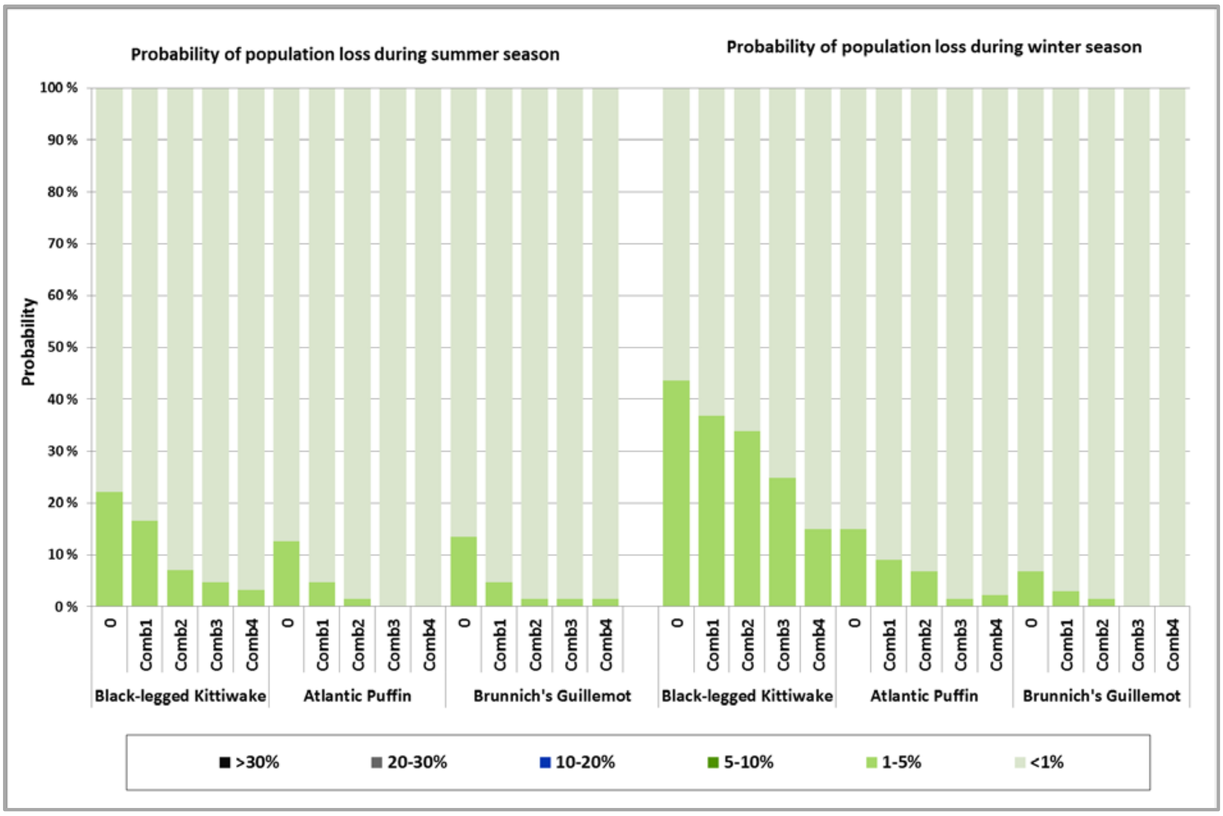


Figure 2-40 *Probability for population loss for three selected seabird species given a topside blowout, for summer (left) and winter season (right). Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

2.11 Comparison and evaluation of open water response strategies

In case of an oil spill, a good oil spill response strategy is important in order to mitigate the environmental damage and impact. In general, response measures primarily aim to reduce the fraction of oil on surface and limit/prevent the amount of oil to reach coastal waters and shoreline. This can be achieved either by mechanical recovery of the surface oil, by applying chemical dispersions or by igniting the oil slick. To overcome operational challenges of oil spill response and to widen the operational time window it can be from advantage to be able to use the complete "toolbox" of response measures rather than focussing on one single response strategy.

Table 2-2 summarizes the key findings from the OSCA. The modelled response measures were evaluated based on their ability to reduce the probability of population loss (on pelagic seabirds at risk). A response measure was considered as *positively effective* (orange colour) if the response measure reduced the population loss probability by ≥ 10 percentage points. Yellow colour illustrates response measures which reduced the population loss probability by 5-10 percentage points.

As the OSCA revealed, response measures are most effective given a topside spill and during summer season.

All response measures contributed to a reduction in the surface oil fraction throughout the release phase (Figure 2-41), with *Comb4* - the combination of aerial dispersion and active mechanical recovery systems - as the most efficient. In-situ burning (ISB_5a) and passive mechanical recovery systems (MechP_5a) displayed marginal effect.

These findings are also reflected in the calculated probability of population loss (Figure 2-42). Response measures with a high ability to decrease oil on surface within the first days, as active mechanical recovery systems, contribute greatest to a reduction in population loss probability.

Active mechanical recovery systems have a higher encounter rate than passive systems as they are able to operate under operational speeds up to 4 knots. Passive systems usually operate up to 0.7 knots. This higher operational speed results in a higher encounter rate and thus a higher oil recovery, even if their swath width is smaller (50 m) than those of passive systems (130 m).

Results showed furthermore that the use of chemical dispersion is also a feasible response strategy on the Skrugard oil. The use of 5 dispersion vessels showed to have a better effect on reducing population loss than application of the same amount of dispersant fluids by one aircraft, most likely due to the ability to operate on different oil slicks at the same time. However, in combination with mechanical recovery (Comb3 and Comb4) aerial dispersion can contribute to a faster decrease of oil on surface and a reduction in population loss. These findings underline the advantage of combining different response strategies in order to reach the best possible effect.

The effect of shortened response time s by using a second stand-by vessel was limited due to the long duration of the spill. Earlier studies have also shown that response time is mostly a sensitive parameter on short spill durations (DNV GL, 2012).

A further, more detailed assessment on the operational feasibility of each response measure can be found in the *Status document* (DNV GL, 2015b).

Table 2-2 *Key results from the OSCA after a topside blowout and a subsea blowout and implementation of various response measures. (--) indicates no modelled/calculated results. (Orange color) = positively effective response measures, reduces population loss probability by ≥ 10 percentage points. (Yellow color) = response measures which reduce the population loss probability by 5-10 percentage points.*
**Oil in water column = sum of dispersed, dissolved and biodegraded oil.*

Modelled effect of response measure at the end of the simulation (24 and 31 days)					
Response measure		**Topside scenario summer**	**Topside scenario winter**	**Subsea scenario summer**	**Subsea scenario winter**
No response – main oil behaviour -	*Oil in water column**	***60 %***	***65 %***	***67 %***	***72 %***
	Remaining oil on surface	***3.2 %***	***1.0 %***	***1.7 %***	***0.5 %***
	Stranded oil	***0 %***	***0 %***	***0 %***	***0 %***
MechP	*Max. oil recovery*	*24 %*	*12 %*	*3 %*	*3 %*
	Min. % remaining oil on surface	*2.2 %*	*0.8 %*	*1.5 %*	*0.4 %*
	Max. reduction in population loss	*7 percentage points*	*5 percentage points*	*--*	*--*
MechA	*Max. oil recovery*	*55 %*	*40 %*	*4 %*	*5 %*
	Min. % remaining oil on surface	*1.5 %*	*0.6 %*	*1.5 %*	*0.4 %*
	Max. reduction in population loss	*17 percentage points*	*18 percentage points*	*--*	*--*
DispV	*Max. % oil in water column*	*75 %*	*76 %*	*67 %*	*73 %*
	Min. % remaining oil on surface	*1.7 %*	*0.6 %*	*1.4 %*	*0.4 %*
	Max. reduction in population loss	*17 percentage points*	*23 percentage points*	*--*	*--*
DispA	*Max. % oil in water column*	*70 %*	*68 %*	*67 %*	*72 %*
	Min. % remaining oil on surface	*2.4 %*	*0.9 %*	*1.4 %*	*0.4 %*
	Max. reduction in population loss	*8 percentage points*	*6 percentage points*	*--*	*--*
DispS	*Max. % oil in water column*	*--*	*--*	*77 %*	*83 %*
	Min. remaining oil on surface	*--*	*--*	*1.5 %*	*0.4 %*
	Max. reduction in population loss	*--*	*--*	*2 percentage points*	*2 percentage points*
ISB	*Max. % burned oil*	*19 %*	*2 %*	*2 %*	*0.3 %*
	Min. % remaining oil on surface	*2.7 %*	*0.9 %*	*1.5 %*	*0.5 %*
	Max. reduction in population loss	*4 percentage points*	*1 percentage point*	*--*	*--*
Comb1	*Max. % recovered and oil in water column*	*68 %*	*70 %*	*--*	*--*
	Min. remaining oil on surface	*2.1 %*	*0.7 %*	*--*	*--*
	Max. reduction in population loss	*9 percentage points*	*7 percentage points*	*--*	*--*
Comb2	*Max. % recovered and oil in water column*	*75 %*	*69 %*	*--*	*--*
	Min. % remaining oil on surface	*1.5 %*	*0.8 %*	*--*	*--*
	Max. reduction in population loss	*15 percentage points*	*10 percentage points*	*--*	*--*
Comb3	*Max. % recovered and oil in water column*	*75 %*	*73 %*	*--*	*--*
	Min. % remaining oil on surface	*1.5 %*	*0.6 %*	*--*	*--*
	Max. reduction in population loss	*17 percentage points*	*19 percentage points*	*--*	*--*
Comb 4	*Max. % recovered and oil in water column*	*80 %*	*73 %*	*--*	*--*
	Min. % remaining oil on surface	*1.4 %*	*0.6 %*	*--*	*--*
	Max. reduction in population loss	*19 percentage points*	*29 percentage points*	*--*	*--*

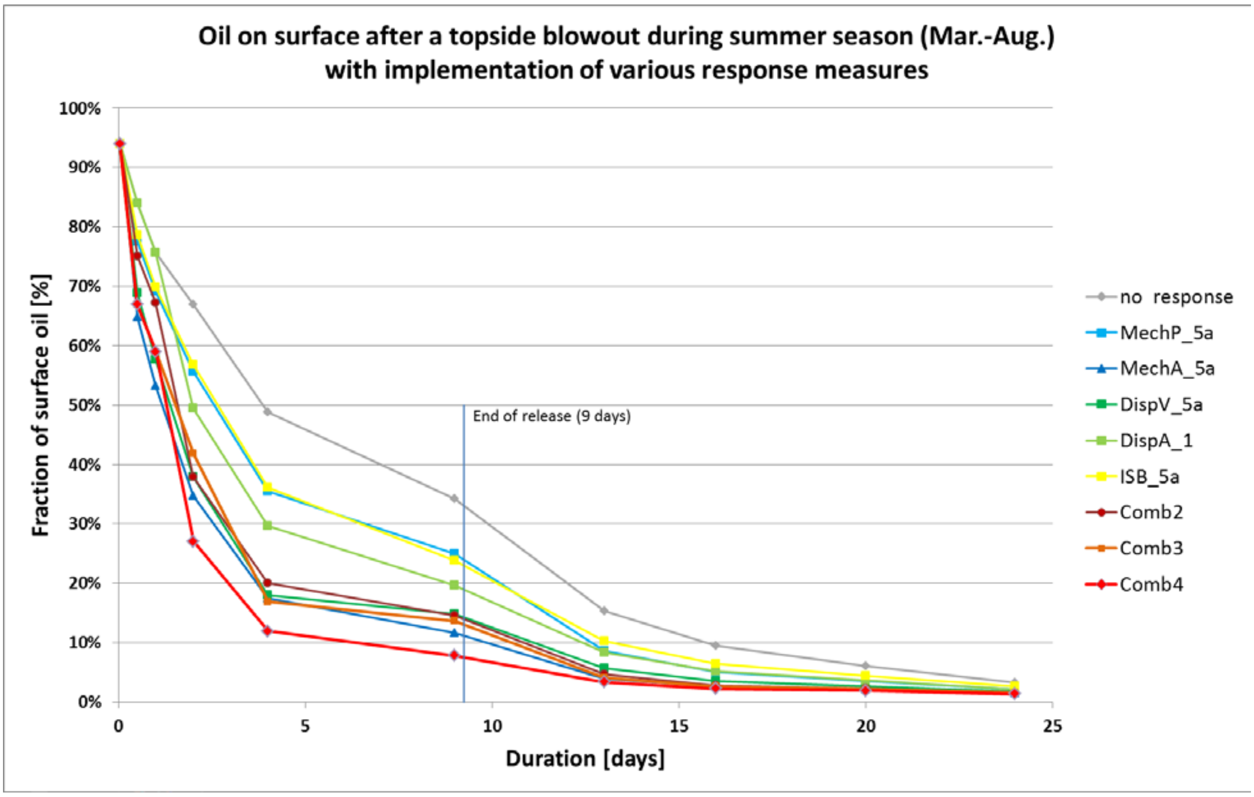
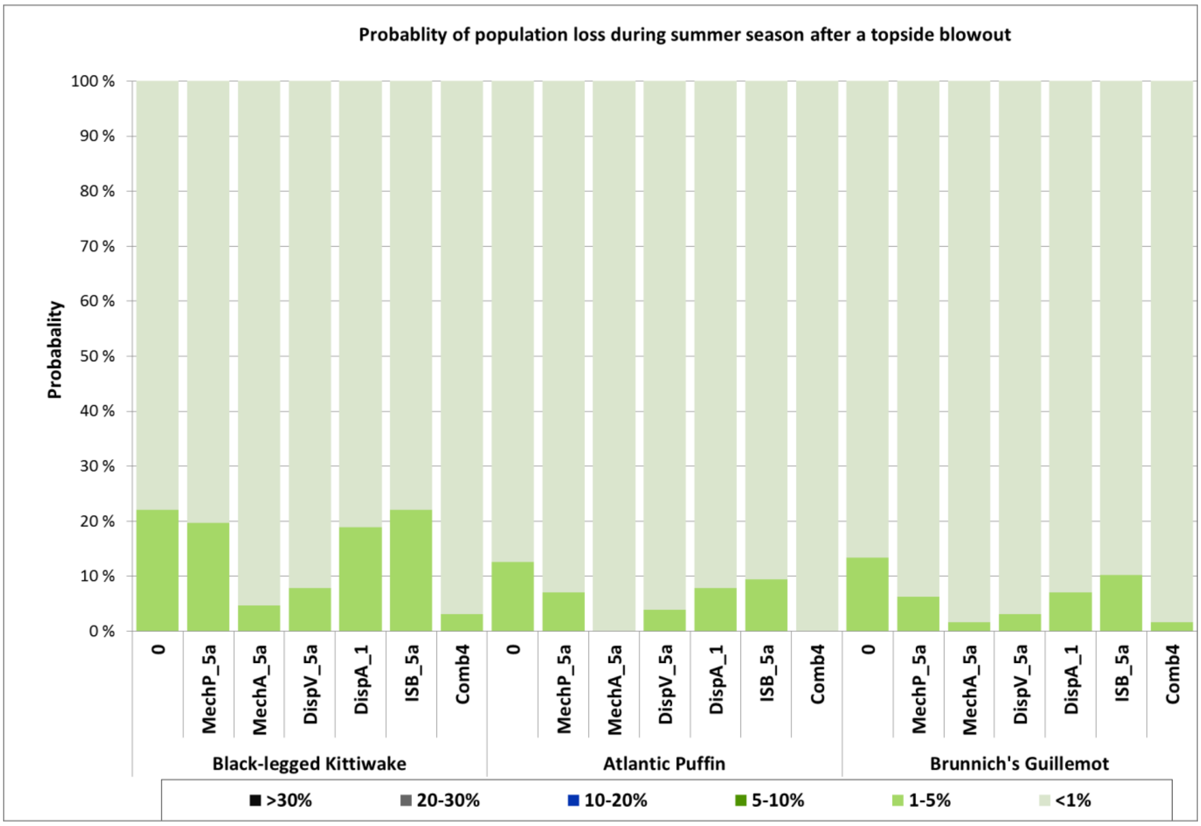


Figure 2-41 *Decrease of oil on surface over time during a topside blowout after implementation of various response measures.*



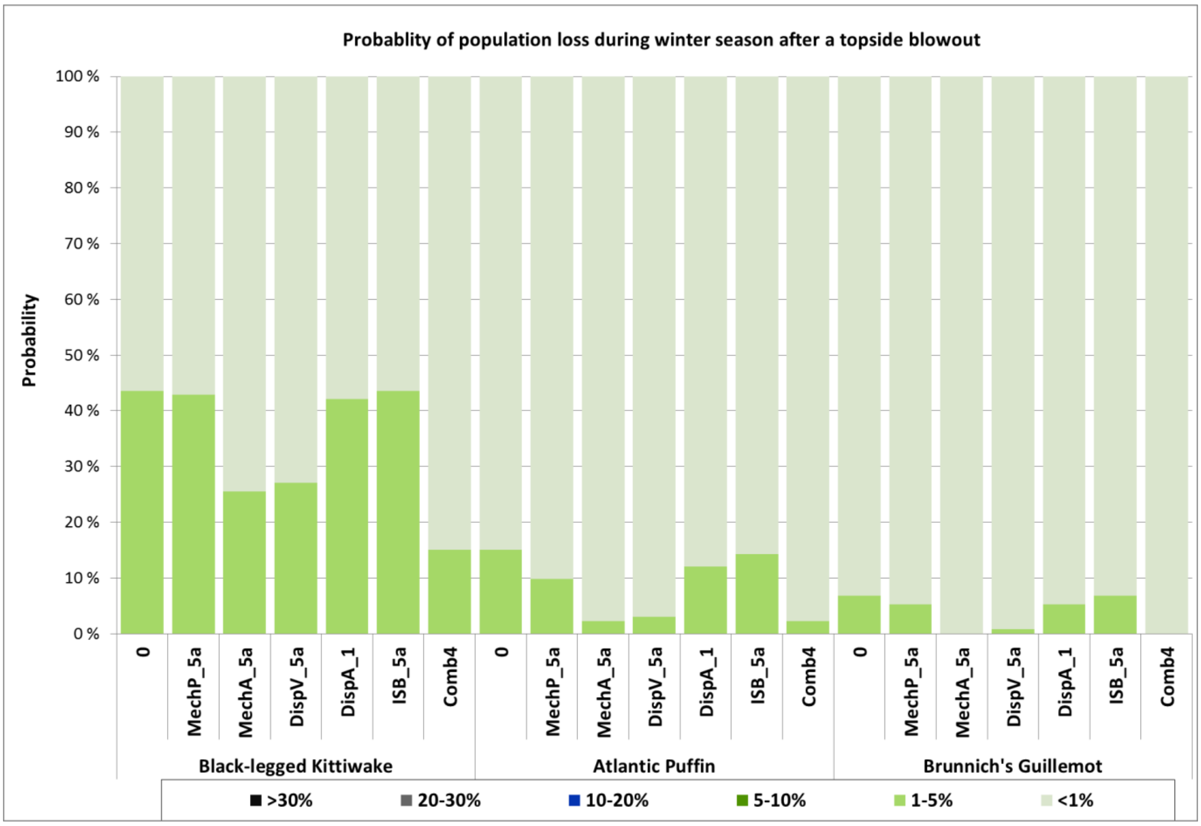


Figure 2-42 *Probability for population loss for three selected seabird species given a topside blowout, for summer (top) and winter season (bottom) after implementation of various response measures. Population loss is classified using the following categories: < 1 %, 1-5 %, 5-10 %, 10-20 %, 20-30 % and >30 %.*

3 OIL SPILL RESPONSE IN ICE-INFESTED WATERS

3.1 Methodology – Oil spill response in ice (calculation)

The complexity of oil spill response in ice is currently not an integrated part in SINTEF's OSCAR model. DNV GL has applied the in-house calculator ORCA (Oil spill response calculator) to assess the effect of oil recovery in the marginal ice zone in ice concentrations up to 30 %.

The ORCA methodology is based on the ASTM F1780-97 (2010) standard and is presented schematically in Figure 3-1.

It is based on system efficiency calculations for different response systems for mechanical recovery, dispersants and ISB systems. The effectiveness of a response system is dependent on various parameters:

1.) Oil spill scenario related parameters e.g. spill volume or oil properties

2.) system/operational related parameters e.g. system encounter rate

3.) environmental related parameters e.g. response conditions

These parameters are taken into account as reduction factors when calculating the effective system capacity. The calculation output predicts e.g. system capacities, number of systems, resources and time required for a defined scenario.

The methodology consists of several steps:

- Definition of oil spill scenario, identification of environmental data and operational reduction factors
- Definition of system configuration
- Calculation of effective system capacity with reduction factors
- Dimensioning calculations based on specific criteria and requirements

It has to be emphasised that theoretical calculations of system efficiencies is very sensitive to the assumptions and input used. The ORCA methodology rather provides a consistent base for evaluating the relative efficiency of the systems compared to each other which could differ under actual conditions.

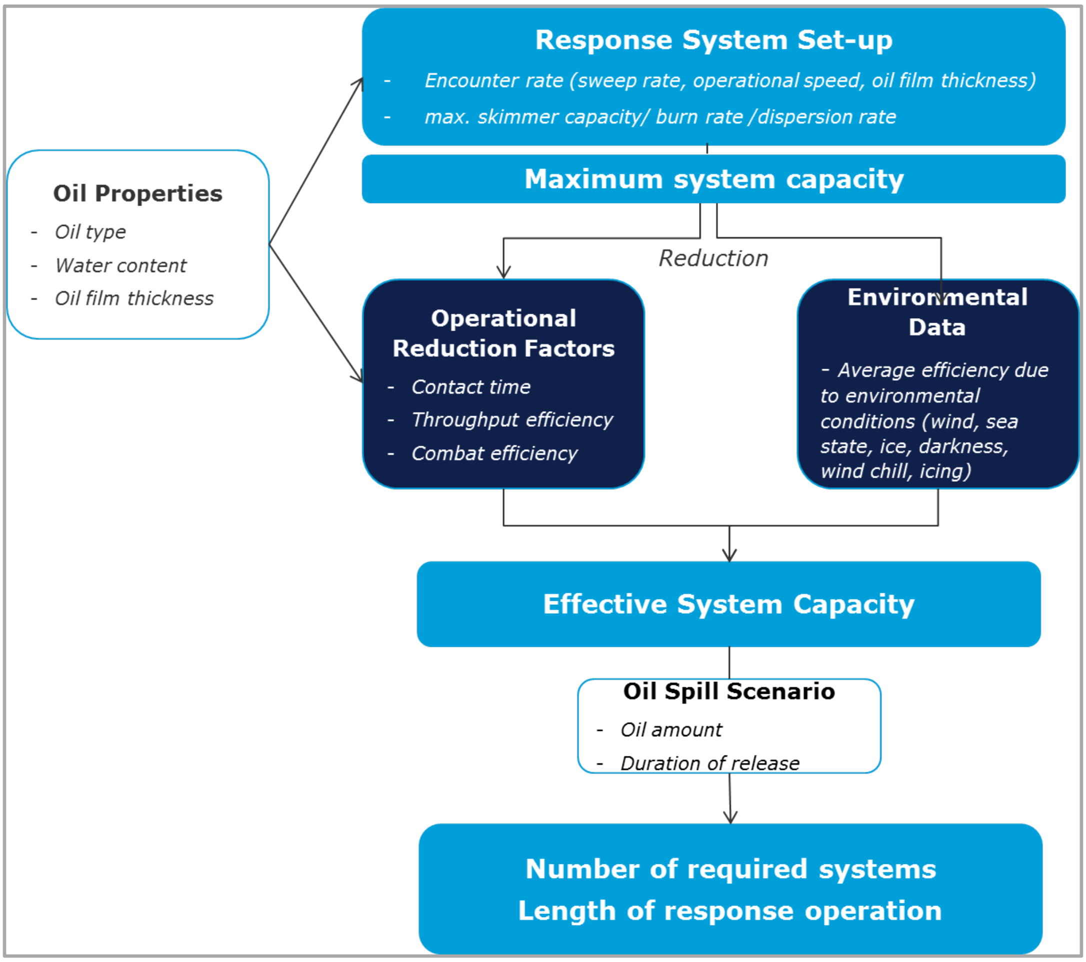


Figure 3-1 *Schematic setup of the ORCA methodology.*

3.2 Defined oil spill scenario

The possible interaction between oil and sea ice from the BaSEC well location has been described in detail in the ERA –report (DNV GL, 2015a). The overall conclusion was that the probability of surface oil entering the marginal ice zone is very small. The output from the oil drift in the OSCAR model indicates that the same metocean / weather conditions affect both surface oil and drifting sea ice. This means that one can expect a similar movement pattern for both sea ice and surface oil; when the oil drifts northward, so does the sea ice. Hits can occur only at certain times of the year (the period of the maximum ice extent or in years with more extreme ice conditions (e.g. 2003 or 2004).

To illustrate relevant oil spill capacities given different spill conditions two single simulations have been selected, one representing a topside blowout in ice (*Case 1*) and one representing a scenario where oil reaches the marginal ice zone after several days (*Case 2*).

Both case scenarios are based on the results of two single simulations from the OSCAR model for the topside blowout. From the results of the single simulations, oil volumes, water content and oil film thickness were extracted for oil particles in grid cells with ice concentrations 10-30 % and used as input for the calculations.

3.2.1 Case 1 – Topside blowout in ice

Figure 3-2 and Figure 3-3 show oil drift in ice for selected time steps throughout the simulation period. The drift model indicates that oil drifting into ice filled waters is trapped until changes in ice conditions occur.

Table 3-1 summarizes the oil behaviour during the simulation. The estimated volumes, water content and film thickness are based on oil particles within 10-30 % ice concentrations and were used as input for the ORCA tool.

Table 3-1 *Oil behaviour and scenario related input parameters for the ORCA tool.*

CASE 1: Topside blowout in ice	
Start single simulation: 05.03.2004, 10:00	
Oil behaviour	**Oil properties - Input in ORCA** ***(for oil in 10-30 % ice concentrations)***
Day 1 93 % of oil on surface - *20 % of this in ice concentrations 10- 30 %* - *60 % of this in ice concentrations > 30 %*	Total oil volume: 727 m^3 Average water content: 30 % Average oil film thickness: 2 mm
Day 2 90 % of oil on surface - *20 % of this in ice concentrations 10-30 %* - *60 % of this in ice concentrations > 30 %*	Total oil volume: 2813 m^3 Average water content: 65 % Average oil film thickness: 3 mm
Day 14 8 % of oil on surface - *20 % of this in ice concentrations 10-30 %* - *55 % of this in ice concentrations > 30 %*	Total oil volume: 3063 m^3 Average water content: 80 % Average oil film thickness: 1 mm

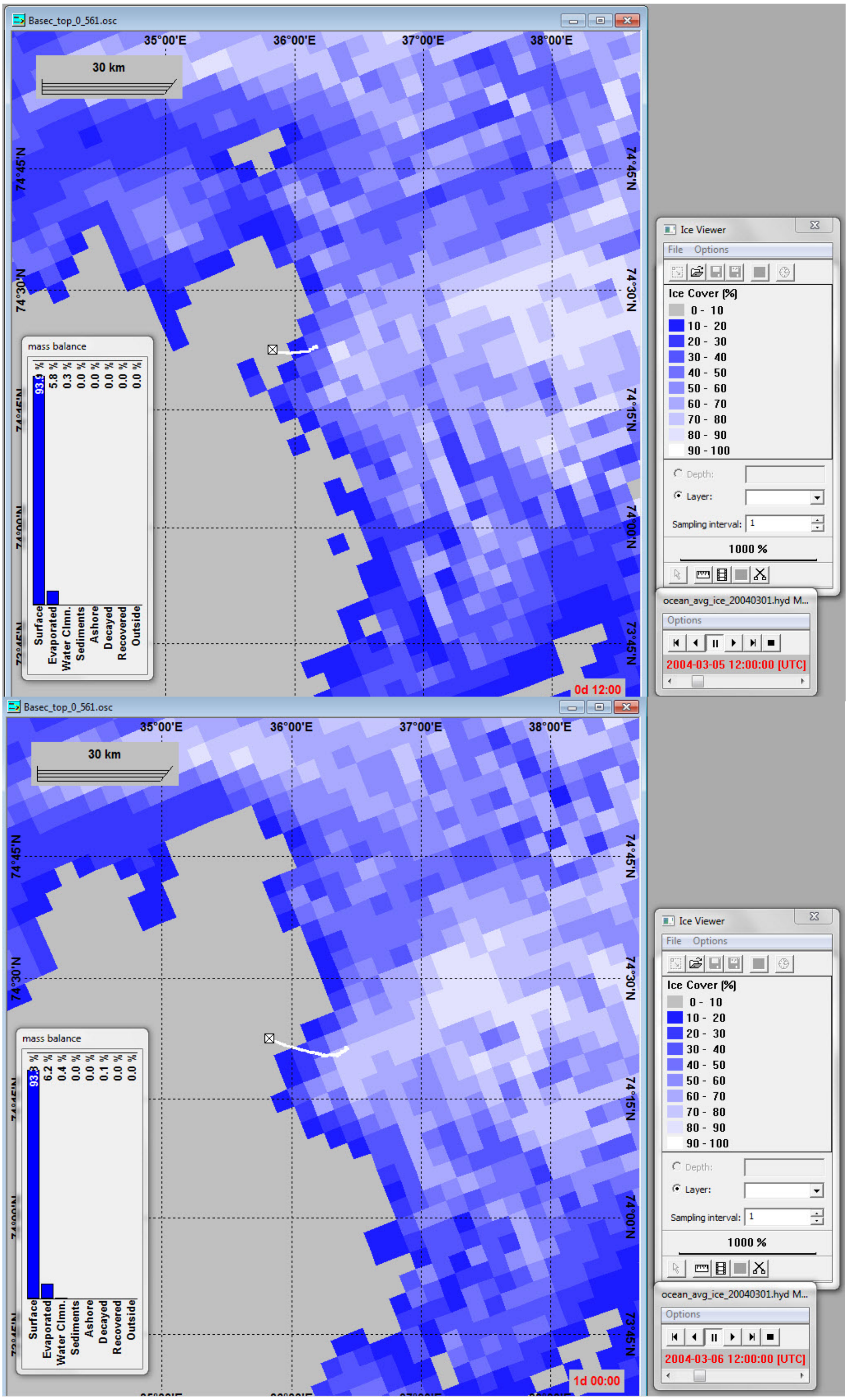


Figure 3-2 *Single simulation screenshots at 12 hours and 1 day after the initiation of the release.*

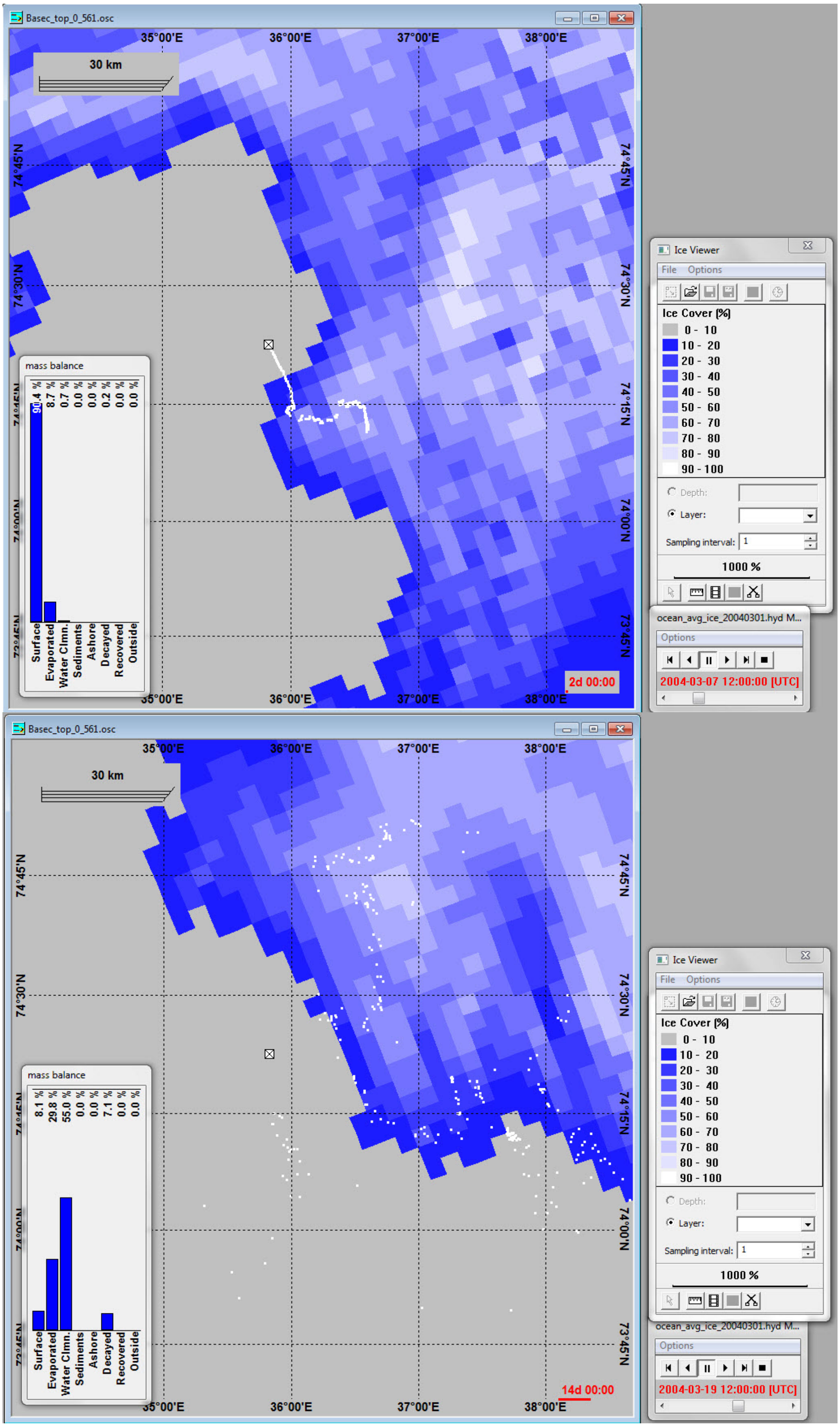


Figure 3-3 *Single simulation screenshots at 2 and 14 days after the initiation of the release.*

3.2.2 Case 2- Topside blowout with oil reaching the marginal ice zone

Case study 2 represents a topside blowout where oil reaches the marginal ice zone after several days. Figure 3-4 and Figure 3-5 show the oil drift in ice for selected days during the simulation period. The oil is spilled into open water with ice concentrations < 10 % but reaches ice concentrations of 10-30 % after day 7 in the simulation period. After 14 days 30 % of the oil on surface is trapped in ice with concentrations > 30 %.

Table 3-2 summarizes the oil behaviour during the simulation. The estimated volumes, water content and film thickness are based on oil particles within 10-30 % ice concentrations and were used as input for the ORCA tool.

Table 3-2 *Oil behaviour and scenario related input parameters for the ORCA tool.*

CASE 2: Topside blowout with oil reaching the marginal ice zone	
Start single simulation: 18.04.1999, 03:00	
Oil behaviour	**Oil properties - Input in ORCA** ***(for oil in 10-30 % ice concentrations)***
Day 7 42 % of oil on surface - *4 % of this in ice concentrations 10- 30 %* - *2 % of this in ice concentrations > 30 %*	Total oil volume: 1462 m^3 Average water content: 78 % Average oil film thickness: < 0.5 mm
Day 9 9 % of oil on surface - *4 % of this in ice concentrations 10-30 %* - *5 % of this in ice concentrations > 30 %*	Total oil volume: 403 m^3 Average water content: 78 % Average oil film thickness: < 0.5 mm
Day 14 9 % of oil on surface - *3 % of this in ice concentrations 10-30 %* - *30 % of this in ice concentrations > 30 %*	Total oil volume: 517 m^3 Average water content: 80 % Average oil film thickness: < 0.5 mm

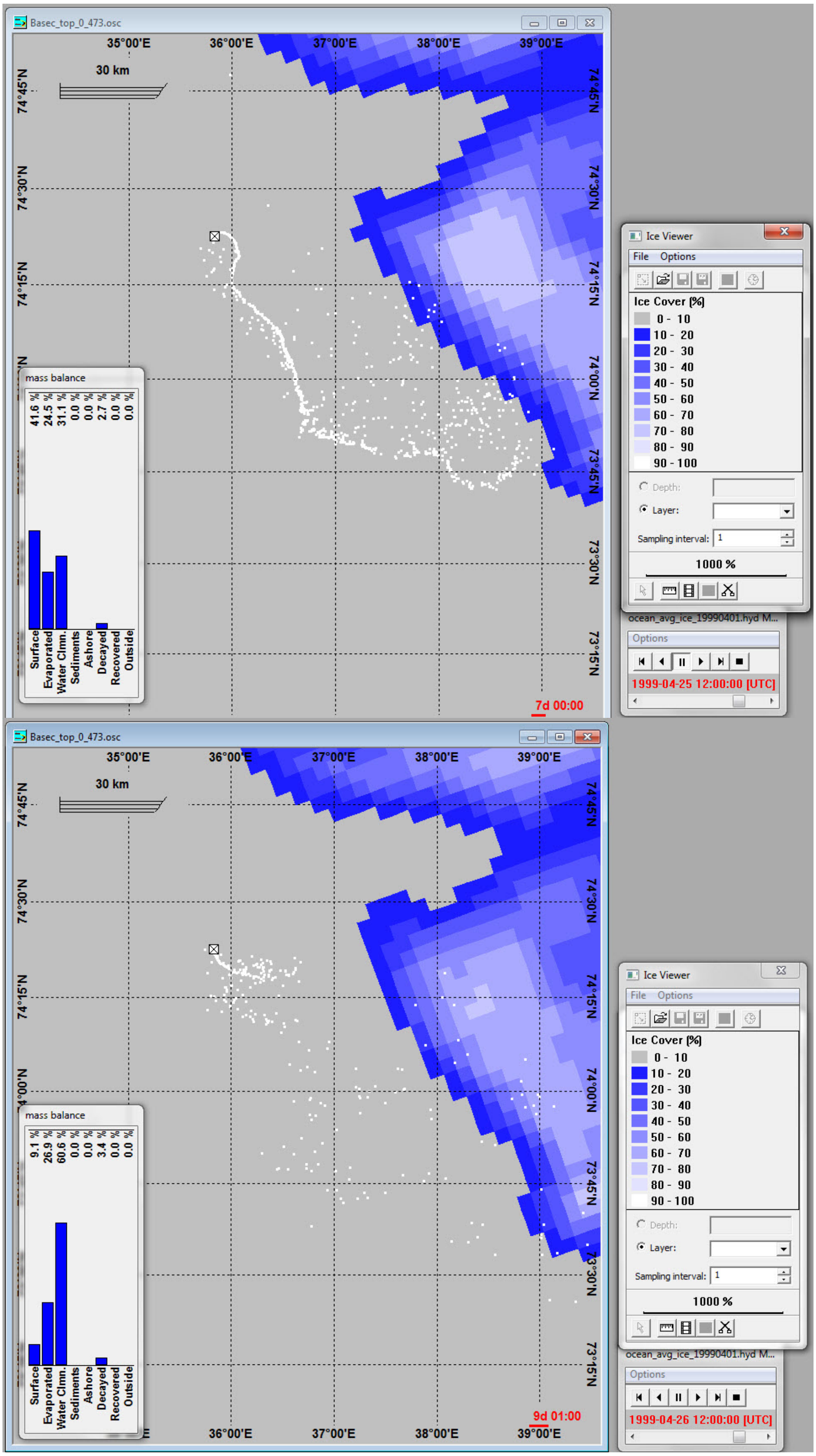


Figure 3-4 *Single simulation screenshots at 7 and 9 days after the initiation of the release.*

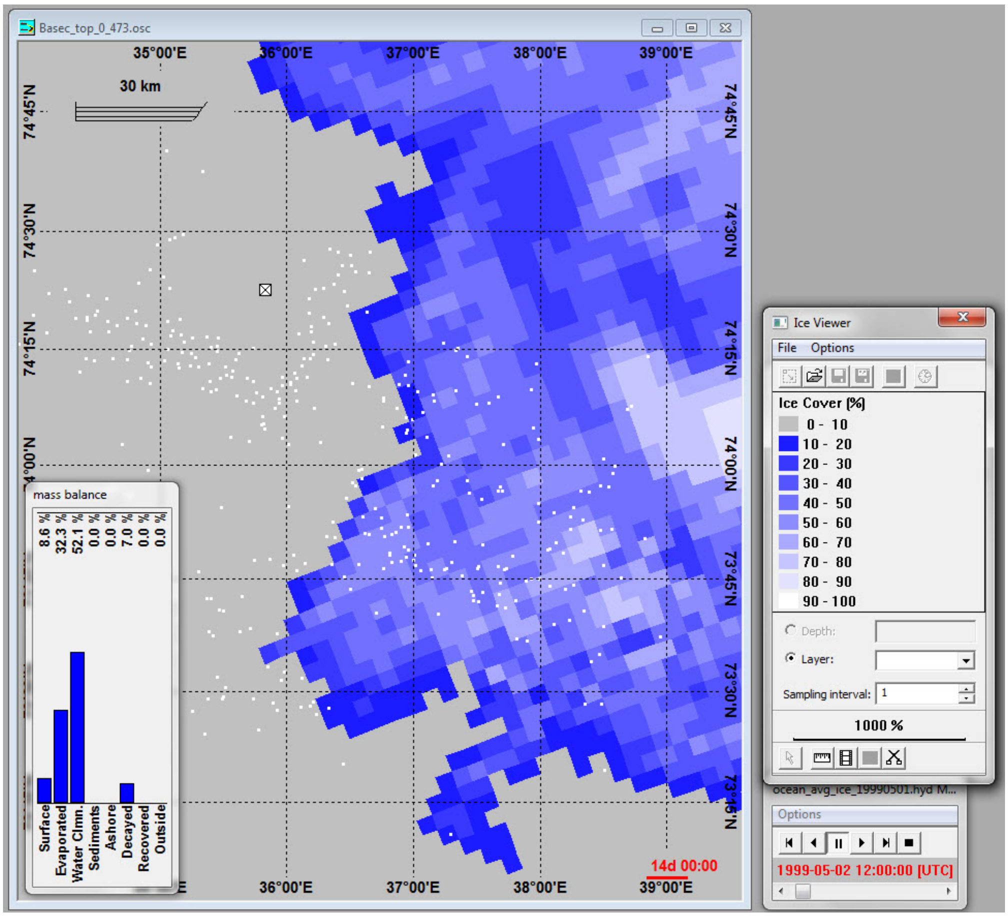


Figure 3-5 *Single simulation screenshots at 14 days after the initiation of the release.*

3.3 Calculator setup

Besides the oil spill scenario related parameters as defined in the previous chapter 3.2) which are used as input for the ORCA tool, system related input parameters as well as environmental and operational reduction factors are also defined and applied in calculator.

Defined system configuration

Table 3-3 shows the input parameter used in this study for the system set up of a multipurpose response vessel. System parameters were discussed and set in a workshop involving BaSEC work group NOFO, and DNV GL. Response measure IceRV equals a multipurpose vessel system equipped for combating oil in ice infested waters. The system is primarily set up for operations in ice up to 30 % and comprises of kits for mechanical recovery, in-situ burning and dispersant application in ice.

System capacity calculations are based on encounter rate and maximum skimmer uptake capacity (mechanical recovery), dispersion rate (dispersant application), or burn rate (in-situ burning).

Table 3-3 *System configuration for a multipurpose response vessel.*

	Mechanical recovery
Average efficiency during spring	45 %
Boom swath width	25 m
Operational speed	2 knots
Skimmer uptake capacity	100 m^3/h
Boom holding capacity	75 %
	Chemical dispersion
Average efficiency during spring	48%
Spraying width	7.5 m
Operational speed	2.5 knots
Application rate and ratio	50 l/min; 1:20
	In-situ burning
Average efficiency during spring	21%
Boom swath width	12.5 m
Operational speed	0.7 knots
Burn rate	150 m^3/h
Boom holding capacity	75%

Defined environmental data

Environmental parameter can cause limitations to oil spill recovery equipment e.g. high wind and waves causing the boom to fail or reduced effectiveness in oil recovery due to darkness. Therefore, the average efficiency of an oil spill operation due to environmental conditions is used as a reduction factor in the ORCA tool. Environmental data were obtained from DNV GL's response gap analysis performed for the Barents Sea (DNV GL, 2014). The response gap analysis evaluated the percentage of time of favourable, impaired, and ineffective response conditions during a year on a monthly basis. For the ORCA, results for the spring season (March-May) were extracted and average response efficiencies were calculated for each response measure.

Defined reduction factors

Operational reduction factors are expressed through contact time and combat efficiency. In this set-up a contact time of 25 % was used. The combat efficiency based on skimmer, dispersion and burn efficiency is oil type and properties dependent. For mechanical recovery it was set to 65 %, for dispersion to 80 % and for ISB to 85 %. The efficiency was reduced for dispersion and ISB by 50% for a water content > 35 % and was set to 0 % for a water content > 70 %.

3.4 Results and discussion

3.4.1 Case 1 – Topside blowout in ice

The calculations, based on the previously defined input data and assumptions, indicate that mechanical recovery is potentially the most effective strategy for response measure IceRV, followed by dispersion and in-situ burning (Table 3-4). The results reflect the variations in encounter rate and operational time windows among the different strategies. With increasing water content, the performance of chemical dispersion and in-situ burning decreases. At day 14 mechanical recovery is assessed to be the only effective strategy for handling oil in ice.

Calculated duration of clean-up operations using the different techniques reflects the effectiveness of the different strategies; shortest time period for mechanical recovery and longest in case of in-situ burning (Table 3-5).

Table 3-4 and Table 3-5 show furthermore that if the response techniques would be used in combination, respectively more oil could be treated and fewer days would be needed for a response operation. However, one have to keep in mind that this is a theoretical calculation by summarizing all systems capacities and assuming that the contact time would increase linear by adding another technique. In the calculations, a contact time of 25 % was used as input- meaning that the combined techniques would add up to a contact time of 75 % which might not be achievable during a real operation.

Table 3-4 *Calculated efficient system capacities for each response tactic of the IceRV.*

CASE 1		Efficient system capacity [m^3/day]			
	Water content/ Oil film thickness	*Mechanical recovery*	*Chemical Dispersion*	*In-situ burning*	*Combined techniques*
Day 1	**30 % 2 mm**	244	160	25	429
Day 2	**65 % 3 mm**	366	120	19	505
Day 14	**80 % 1 mm**	122	0	0	122

Table 3-5 *Calculated duration of a response operation for each response tactic of the IceRV.*

CASE 1		Duration of response [days]			
	Treated volume of oil	*Mechanical recovery*	*Chemical Dispersion*	*In-situ burning*	*Combined techniques*
Day 1	**727 m^3**	3	5	29	2
Day 2	**2813 m^3**	8	23	148	6
Day 14	**3063 m^3**	25	---	---	25

Capacity calculations are highly dependent on oil film thickness and contact time. The impact of oil film thickness on the effectiveness of different response techniques are illustrated in Figure 3-6. For mechanical recovery, system capacity increases with increased oil film thickness to the maximum skimmer capacity of 2400 m^3/day of the boom-skimmer-system of the IceRV. The system capacity for dispersion with spray arms from the vessel will be limited by the maximum dispersion application rate and will result in a maximum system capacity of 1440 m^3/day. The maximum system capacity of ISB is not limited by the daily maximum burn rate (3600 m^3/day) during a response operation and is more dependent on oil film thickness and encounter rate.

Calculations show a clear trend that mechanical recovery is the most efficient response strategy from day 1 onward for Case 1. This is valid for oil in ice with concentrations of < 30 %. Oil which is trapped in ice at higher ice concentrations would demand different response measures. The combination and additional use of other strategies could have the potential to broaden the operational window of an oil spill response. This is discussed in the *Status document* (DNV GL, 2015b).

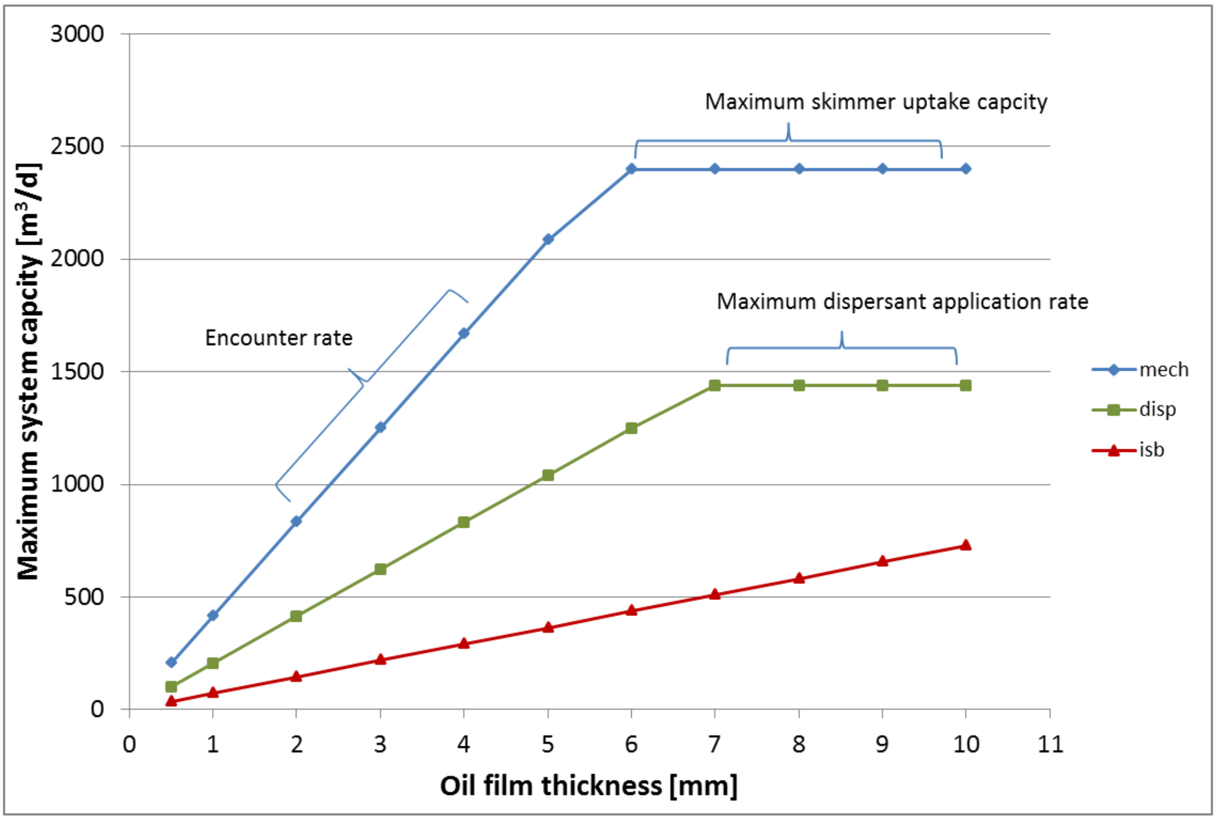


Figure 3-6 *Maximum system capacity as a function of oil film thickness for the mechanical recovery unit (mech), the chemical dispersant unit (disp) and the in-situ burning unit (ISB) of the multipurpose response vessel IceRV. The contact time is set to 25 %.*

3.4.2 Case 2 – Topside blowout with oil reaching the marginal ice zone

The calculations, based on the previously defined input data and assumptions, indicate that mechanical recovery is potentially the only effective strategy for response measure IceRV (Table 3-6). The performance of chemical dispersion and in-situ burning is not possible due to the high water uptake of the oil after day 7.

Single simulations show that in this scenario, the amount of oil in ice decreases with the time. A response operation with a multipurpose response vessel for waters with up to 30 % ice concentration would thus range between 7 and 21 days (Table 3-7). Oil which is trapped in ice at higher ice concentrations would demand different response measures. These are presented and discussed in the *Status document* (DNV GL, 2015b).

Table 3-6 *Calculated efficient system capacities for each response tactic of the IceRV.*

CASE 2		**Efficient system capacity [m3/day]**			
	Water content/ Oil film thickness	*Mechanical recovery*	*Chemical Dispersion*	*In-situ burning*	*Combined techniques*
Day 7	**78 %** **0.5 mm**	61	0	0	Not feasible
Day 9	**78 %** **0.5 mm**	61	0	0	Not feasible
Day 14	**80 %** **0.5 mm**	61	0	0	Not feasible

Table 3-7 *Calculated duration of a response operation for each response tactic of the IceRV.*

CASE 2		**Duration of response [days]**			
	Treated volume of oil	*Mechanical recovery*	*Chemical Dispersion*	*In-situ burning*	*Combined techniques*
Day 7	**1462 m^3**	24	Not feasible	Not feasible	Not feasible
Day 9	**403 m^3**	7	Not feasible	Not feasible	Not feasible
Day 14	**517 m^3**	9	Not feasible	Not feasible	Not feasible

4 CONCLUSIONS

The output and evaluation from the OSCA based on the defined inputs used in the modelling and calculations for the exploration well in block 7435/9 in the Barents Sea are:

- **Response measures are general more effective during summer season compared to the winter period.** This is due to harsher environmental conditions as well as oil properties such as viscosity or oil film thickness.
- **Response measures are more effective given a topside blowout compared to a subsea blowout.** Oil which reaches the surface after a subsea blowout is more difficult to recover/treat as it has changed its properties, e.g. increased water uptake or thinner oil film thickness.
- **Shortened response time by using a second standby-vessel has limited effect at the end of the simulation.** The additional increase of recovered or dispersed oil is < 5 % and there is no or very limited further decrease in population loss probability. The effect of shortened response time is marginal due to the long spill duration. Shorter spill durations would probably result in greater differences in the mass balance.
- **Active mechanical recovery systems have a greater capacity to recover oil from surface than passive mechanical recovery systems due to higher encounter rate.** Results showed that 5 active systems recovered more than twice the amount of oil as 5 passive systems. The high encounter rate is mostly influenced by the higher operational speed of the active systems, which is nearly 6 times higher than the operational speed of a passive system.
- **Dispersant application with 5 vessels showed to have a better effect on reducing population loss than application of the same amount of dispersant fluids by one aircraft.** Population loss could be reduced by 17 percentage points by dispersant vessels during summer season compared to 8 percentage points by aerial application. This is most likely due to the ability to operate on different oil slicks at the same time.
- **Mechanical recovery systems in combination with aircraft dispersant systems contribute to the highest decrease of oil on surface.** Surface oil could be decreased by 75 % within the first 5 days after a topside blowout in the summer season. This shows that the flexibility of the active systems plus the high efficiency of aerial dispersion is a good combination in combatting an oil spill.
- **In-situ burning in open water is regarded as a less favourable response option.** Operational feasibility is limited by high seas states and darkness in winter time. Furthermore, due to the oil properties of the Skrugard crude oil (high and rapid water uptake), the burn efficiency is assumed to be very limited.
- **Subsea dispersion has limited effect in the model.** The amount of dispersed oil in the water column was increased by 14 %, while the probability of population loss was reduced by 2 percentage points. This is most likely due to the low water depth at the release location resulting in a rapid raise of the plume to the water surface. Single simulations revealed a travel time of ~10 minutes to the water surface. Due to the methodology of modelling subsea dispersion in OSCAR there are some uncertainties in the results and these have thus to be considered with care.
- **Mechanical recovery is the most feasible response technique for an oil spill within the marginal ice zone up to 30 % ice concentration.** Due to the oil properties of the Skrugard

oil (high and rapid water uptake), the efficiency and system capacity of dispersion and in-situ burning systems will be reduced or is close to zero. The efficiency of ISB is very dependent on the oil type and properties and might be more effective on other oil types.

The study showed that by using combination of several response techniques and implementing new response systems to the “toolbox” the operational time window can be widened and the environmental damage and impact can be reduced.

5 REFERENCES

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APPENDIX A - OSCAR MODEL INPUT PARAMETERS

Model input parameters (oil spill contingency modelling)

The following tables show the **basic model parameters** for the oil spill contingency analysis with OSCAR.

Parameter	Value
Liquid/Solid particles:	5000
Dissolved particles:	2500
Surface film thickness (mm)	
Initial:	2
Thick limit:	0.1
Terminal:	0.001
Output interval (hours):	1*
Time step (hours):	1*
Number of simulations:	40
Simulation time:	Duration of release (topside: 9 days, subsea 16 days) + 15 days following time

*For the subsea dispersion scenario an output interval of 20 minutes and time step of 5 minutes was used.

RESPONSE MEASURE SETUP

The following tables present the input parameters which are to be used to define the oil spill response configurations in the OSCAR model. In OSCAR these data corresponds to the creation of a response file (.rsp).

Input values were discussed and set during a workshop between DNV GL, the BaSEC group and NOFO on the 8.7.2015.

The following color-coding is used:

- Green fields: according to NOROG guideline (standard OSCAR input)
- Orange fields: according to BaSEC workshop
- Blue fields: OSCAR internal or scenario specific

Exclusion zone		Reference / remarks
Radius (m)	2000	An exclusion zone will be added around the location of discharge to assure safety considerations. Skrugard weathering study indicates flash point to be well above the sea temperature at all sea states for both summer and winter conditions.

A.1 Response measure MechP

Input values for NOFO OR vessel –open water containment and recovery, passive system

SYSTEM			
Parameter	**Description**	**Input value**	**Reference/Remarks**
System name:	*Specify the response system's description or name*	----	Individual input.
Time to mobilize:	*Specify the amount of time needed, in hours, to mobilize system*	----	Individual input. Time to mobilize is calculated separately according to NOFO specifications.
Turnaround time: *= time to empty the onboard storage tank when it becomes full during recovery operations*	*Specify the time required (in hours) for turnaround when returning to base. This is for example the time needed to empty the onboard storage tank for a mechanical system, or for the reloading of dispersants.*	**7 hours** 5 hours for emptying + 2 hours for getting ready again (e.g.cleaning etc.)	Assuming standard offloading capacity of 300m^3/h and a 1500 m^3 storage tank (ref NOFO)
☑ Operate at night with reduced effectiveness:	*Specify the reduction in effectiveness due to darkness (0-1). 0= zero effectiveness. 1= no reduction in effectiveness.*	**0.65**	NOROG 2013, page 16 – A4 iii dependent on equipment on board
Operative before sunrise/ after sunset (hrs)	*Check if the system is operational at night (in darkness)*	0	
☑ Apply emulsion breaker with efficiency (%):	*Efficiency of emulsion breaker fluid*	**80**	Skrugard weathering study

Strategy				**Reference/remarks**
Area	Start	Stop	Method	For a priority area, the vessels will only be active inside the defined area. For an exclusion area, the vessels will not enter the defined area.
Exclusion zone	0	End of release (hrs)	Newest oil	Release duration in hours
	End of release (hrs)	-1	Nearest oil	(-1.00 = until end of simulation)

VESSEL			
Parameter	**Description**	**Input value**	**Reference/Remarks**
Vessel name:	*Select from the list. Default values for the vessel will be loaded from the response options database*	User defined	
Tankage (m^3):	*Specify the on-board holding capacity of the vessel in cubic meters.*	1500	NOROG 2013, Page 13 –A2
Cruise speed (knots):	*Specify the vessels cruising speed in knots. The cruising speed applies to movement to and from the home port and the offload barges.*	14	NOROG 2013, Page 12 –A1
Search cruising path:	*Apply X search in grid(s) to find out cruising path avoiding land cells.*	yes	
Draught (m):	*Specify the minimum water depth that the vessel can draw*	5	Confirmed by NOFO 4.11.2014

BOOM

Parameter	Description	Input value	Reference/Remarks
Boom name:	*Select from the list. Default values for the boom will be loaded from the response options database*	User defined	
Swath width (m):	*Specify the swath width in meters*	130	Workshop
Operational speed (knots):	*Specify the maximum operational speed in knots*	0.7	NOROG 2013, Page 14 –A3
Wave treshold (m):	*Specify the wave threshold for operation in meters*	4	NOROG 2013, Page 15 –A4
Effectiveness (%):	*Enter the max percentage of oil encountered that this boom will retain under optimal conditions.*	80	NOROG 2013, Page 15 –A4

SKIMMER			
Parameter	**Description**	**In-put value**	**Reference/Remarks**
Skimmer name:	*Select from the list. Default values for the skimmer will be loaded from the response options database*	User defined	
Skimmer rate (m^3/hr): *= maximum skimmer uptake capacity*	*Specify the maximum skimmer rate in cubic meters per hour*	100	workshop
Viscosity limit for flow to skimmer (cP):	*Specify the maximum viscosity (cP) that the skimmer can handle*	50000	Confirmed by NOFO 4.11.2014
Thickness limit for recoverable oil (mm):	*Specify the minimum thickness (mm) that the skimmer can handle*	0.1	Confirmed by NOFO 4.11.2014

A.2 Response measure MechA

Input values for NOFO OR vessel –open water containment and recovery –active system

SYSTEM			
Parameter	**Description**	**Input value**	**Reference/Remarks**
System name:	*Specify the response system's description or name*	----	Individual input.
Time to mobilize:	*Specify the amount of time needed, in hours, to mobilize system*	----	Individual input. Time to mobilize is calculated separately according to NOFO specifications.
Turnaround time: *= time to empty the onboard storage tank when it becomes full during recovery operations*	*Specify the time required (in hours) for turnaround when returning to base. This is for example the time needed to empty the onboard storage tank for a mechanical system, or for the reloading of dispersants.*	**7 hours** 5 hours for emptying + 2 hours for getting ready again (e.g.cleaning etc.)	Assuming standard offloading capacity of 300m^3/h and a 1500 m^3 storage tank (ref NOFO, meeting with ENI 31.1.2014))
☑ Operate at night with reduced effectiveness:	*Specify the reduction in effectiveness due to darkness (0-1). 0= zero effectiveness. 1= no reduction in effectiveness.*	**0.65**	NOROG 2013, page 16 – A4 iii dependent on equipment on board
Operative before sunrise/ after sunset (hrs)	*Check if the system is operational at night (in darkness)*	0	
☑ Apply emulsion breaker with efficiency (%):	*Efficiency of emulsion breaker fluid*	**80**	Skrugard weathering study

Strategy				**Reference/remarks**
Area	Start	Stop	Method	For a priority area, the vessels will only be active inside the defined area. For an exclusion area, the vessels will not enter the defined area.
Exclusion zone	0	End of release (hrs)	Newest oil	Release duration in hours
	End of release (hrs)	-1	Nearest oil	(-1.00 = until end of simulation)

VESSEL			
Parameter	**Description**	**Input value**	**Reference/Remarks**
Vessel name:	*Select from the list. Default values for the vessel will be loaded from the response options database*	User defined	
Tankage (m^3):	*Specify the on-board holding capacity of the vessel in cubic meters.*	1500	NOROG 2013, Page 13 –A2
Cruise speed (knots):	*Specify the vessels cruising speed in knots. The cruising speed applies to movement to and from the home port and the offload barges.*	14	NOROG 2013, Page 12 –A1
Search cruising path:	*Apply X search in grid(s) to find out cruising path avoiding land cells.*	yes	
Draught (m):	*Specify the minimum water depth that the vessel can draw*	5	Confirmed by NOFO 4.11.2014

BOOM

Parameter	Description	Input value	Reference / Remarks
Boom name:	*Select from the list. Default values for the boom will be loaded from the response options database*	User defined	
Swath width (m):	*Specify the swath width in meters*	50	Workshop
Operational speed (knots):	*Specify the maximum operational speed in knots*	4	Workshop
Wave treshold (m):	*Specify the wave threshold for operation in meters*	4	Ocean buster type
Effectiveness (%):	*Enter the max percentage of oil encountered that this boom will retain under optimal conditions.*	80	NOROG 2013, Page 15 –A4

SKIMMER			
Parameter	**Description**	**In-put value**	**Reference / Remarks**
Skimmer name:	*Select from the list. Default values for the skimmer will be loaded from the response options database*	User defined	
Skimmer rate (m^3/hr): = *maximum skimmer uptake capacity*	*Specify the maximum skimmer rate in cubic meters per hour*	100	workshop
Viscosity limit for flow to skimmer (cP):	*Specify the maximum viscosity (cP) that the skimmer can handle*	50000	Confirmed by NOFO 4.11.2014
Thickness limit for recoverable oil (mm):	*Specify the minimum thickness (mm) that the skimmer can handle*	0.1	Confirmed by NOFO 4.11.2014

A.3 Response measure DispV

Input values for NOFO OR vessel –open water dispersant system

SYSTEM			
Parameter	**Description**	**Input value**	**Reference/Remarks**
System name:	*Specify the response system's description or name*	----	Individual input.
Time to mobilize (hr):	*Specify the amount of time needed, in hours, to mobilize system*	----	Individual input. Time to mobilize is calculated separately according to NOFO specifications.
Turnaround time: *= time to empty the onboard storage tank when it becomes full during recovery operations*	*Specify the time required (in hours) for turnaround when returning to base. This is for example the time needed to empty the onboard storage tank for a mechanical system, or for the reloading of dispersants.*	**5 hours + travel time** 5 hours for loading + travel time back on forth to base	Confirmed by NOFO 4.11.2014; transit time to Hammerfest 22h, a total turnaround time: 50 hours
Number of trips	*Specify the maximum number of return trips to perform. The vehicle will always perform at least one trip.*	**----**	Individual input, vessel specific, calculated by total available dispersant fluid and tank size of vessel
☑ Operate at night with reduced effectiveness:	*Specify the reduction in effectiveness due to darkness (0-1). 0= zero effectiveness. 1= no reduction in effectiveness.*	**0.65**	NOROG 2013, page 16 – A4 iii dependent on equipment on board
Operative before sunrise/ after sunset (hrs)	*Check if the system is operational at night (in darkness)*	0	

Strategy				**Reference/remarks**
Area	Start	Stop	Method	For a priority area, the vessels will only be active inside the defined area. For an exclusion area, the vessels will not enter the defined area.
Exclusion zone	0	End of release (hrs)	Newest oil	Release duration in hours
	End of release (hrs)	-1	Nearest oil	(-1.00 = until end of simulation)

VESSEL			
Parameter	**Description**	**Input value**	**Reference/Remarks**
Vessel name:	*Select from the list. Default values for the vessel will be loaded from the response options database*	User defined	
Tankage (m^3):	*Specify the on-board holding capacity of the vessel in cubic meters.*	100	workshop
Cruise speed (knots):	*Specify the vessels cruising speed in knots. The cruising speed applies to movement to and from the home port and the offload barges.*	14	NOROG 2013, Page 12 –A1
Search cruising path:	*Apply X search in grid(s) to find out cruising path avoiding land cells.*	yes	
Draught (m):	*Specify the minimum water depth that the vessel can draw*	5	Confirmed by NOFO 4.11.2014

APPLICATION UNIT			
Parameter	**Description**	**In-put value**	**Reference/Remarks**
Unit name:	*Select an application unit from the list. Default values for the unit will be loaded from the response options database*	User defined	For NOFO OR vessel use the values given in this table
Application rate (l/min)	*Specify the application rate in liters per minute.*	120	NOROG 2013, Page 14 –A3
Tankage (0= vessels tank)	*Specify the application unit's tankage capacity in cubic meters. If the unit does not have its own tank, but uses the vessel's tank directly, then specify a zero tankage capacity here.*	0	
Spraying width (m)	*Specify the spraying width in meters*	26, for Esvagt Aurelia 34	workshop
Operational speed (knots)	*Specify the operational speed in knots*	5	NOROG 2013, Page 15 –A4

DISPERSANT			
Parameter	**Description**	**Input value**	**Reference/Remarks**
Dispersant name:	*Select a dispersant from the list. Default values for the dispersant will be loaded from the response options database*	Dasic NS	
Effectiveness (%):	*Specify the maximum effectiveness of the dispersant in percent*	83	Skrugard weathering study (SINTEF, 2012)
Viscosity limit (cP):	*Specify the maximum viscosity (cP) that this dispersant can be used*	Use database	
Thickness limit (mm):	*Specify the minimum thickness (mm) that this dispersant can be used*	0.1	
Dispersant application ratio:	*Specify the application ratio of oil to dispersant*	25	Skrugard weathering study (SINTEF, 2012)

A.4 Response measure DispA

Input values for a Boing 727 from OSRL –aerial dispersant system

SYSTEM			
Parameter	**Description**	**In-put value**	**Reference/Remarks**
System name:	*Specify the response system's description or name*	----	Individual input. The name has no influence on results
Time to mobilize (hr):	*Specify the amount of time needed, in hours, to mobilize system*	24	NOROG 2013, page 13 – A1,workshop
Turnaround time: *= time to empty the onboard storage tank when it becomes full during recovery operations*	*Specify the time required (in hours) for turnaround when returning to base. This is for example the time needed to empty the onboard storage tank for a mechanical system, or for the reloading of dispersants.*	**1.5 hours + travel time** 1.5 hours at base for loading + travel time back on forth to base	NOROG 2013, page 13 –A3 Distance to Lakselv Airport: 602 km, travel time back and forth: 3.5 h; total turnaround time: 5 h
Number of trips	*Specify the maximum number of return trips to perform. The vehicle will always perform at least one trip.*	**29/14**	Scenario set-up specific, calculated by total available dispersant fluid and tank size of aircraft- 517 m3 of dispersant fluid available (according to NOFO) – For scenario with one airplane: 29 trips. For scenario with 2 airplanes 14 trips each
☑ Operate at night with reduced effectiveness:	*Specify the reduction in effectiveness due to darkness (0-1). 0= zero effectiveness. 1= no reduction in effectiveness.*	**0**	Aircraft is only operating in summer season, according to OSRL
Operative before sunrise/ after sunset (hrs)	*Check if the system is operational at night (in darkness)*	0	

Strategy				**Reference/remarks**
Area	Start	Stop	Method	For a priority area, the vessels will only be active inside the defined area. For an exclusion area, the vessels will not enter the defined area.
Exclusion zone	0	End of release (hrs)	Newest oil	Release duration in hours
	End of release (hrs)	-1	Nearest oil	(-1.00 = until end of simulation)

VEHICLE			
Parameter	**Description**	**In-put value**	**Reference/Remarks**
Vehicle name:	*Select from the list. Default values for the vessel will be loaded from the response options database*	User defined	For Boing 727 from OSRL use the values given in this table
Cruise speed (knots):	*Specify the vehicles cruising speed in knots. The cruising speed applies to movement to and from the home port and the offload barges.*	200	NOROG 2013, page 12-A1
Wind threshold (knots)	*Specify the wind threshold for operation in knots.*	39	= 20 m/s
Endurance (hrs)	*Specify the endurance in hours. The endurance specifies the maximum time for which the vehicle can operate on each trip.*	7	

APPLICATION UNIT

Parameter	Description	In-put value	Reference/Remarks
Unit name:	*Select an application unit from the list. Default values for the unit will be loaded from the response options database*	User defined	For Boing 727 from OSRL use the values given in this table
Application rate (l/min)	*Specify the application rate in liters per minute.*	1000	OSRL
Tankage (aircrafts tank) (m^3)	*Specify the application unit's tankage capacity in cubic meters.*	17.5	NOROG 2013, page 14 – A3; OSRL says 17.5 m^3
Spraying width (m)	*Specify the spraying width in meters*	50	OSRL
Operational speed (knots)	*Specify the operational speed in knots*	140	NOROG 2013, page 14 – A3

DISPERSANT				
Parameter	**Description**	**IN-put value**		**Reference/Remarks**
Dispersant name:	*Select a dispersant from the list. Default values for the dispersant will be loaded from the response options database*	Dasic NS		OSCAR default values
Effectiveness (%):	*Specify the maximum effectiveness of the dispersant in percent*	83		NOROG 2013, page 15 –A4
Viscosity limit (cP):	*Specify the maximum viscosity (cP) that this dispersant can be used*	Use database	----	Check weathering study of oil, otherwise use default values
Thickness limit (mm):	*Specify the minimum thickness (mm) that this dispersant can be used*	0.1		
Dispersant application ratio:	*Specify the application ratio of oil to dispersant*	25		

A.5 Response measure DispS

Subsea chemical dispersion cannot be modelled directly in OSCAR, however there is a method on how to approximate the effects of subsea chemical dispersion. To model subsea chemical dispersion, the interfacial tension between oil and water in the modelling setup is adjusted by a given factor.

The normal reduction factor to adjust for subsea chemical dispersion is 200. This means reducing the original interfacial tension from 0.03 N/m to 0.00015 N/m in the setup for the Plume 3D near field model in OSCAR. Furthermore, the time interval was reduced to 5 minutes and the output interval to 1 hour in order to get a higher resolution of the results.

A.6 Response measure ISB

SINTEF's OSCAR model has currently not a build-in function to model in-situ burning (ISB) as a response measure. However, in this project the simulation of ISB was approached by replacing mechanical boom characteristics, skimmer capacities and turnaround times with relevant data for ISB operations.

Input values for NOFO OR vessel –in-situ burning system

SYSTEM			
Parameter	**Description**	**In-put value for ISB**	**Reference/Remarks**
System name:	*Specify the response system's description or name*	----	Individual input. The name has no influence on results
Time to mobilize:	*Specify the amount of time needed, in hours, to mobilize system*	----	Individual input. Response time depending on vessel type and system configuration
Turnaround time: *= time to empty the onboard storage tank when it becomes full during recovery operations*	*Specify the time required (in hours) for turnaround when returning to base. This is for example the time needed to empty the onboard storage tank for a mechanical system, or for the reloading of dispersants.*	**0**	OSCAR will not be able to model potential downtimes, as there is no oil storage which will be filled up during the simulation
☑ Operate at night with reduced effectiveness:	*Specify the reduction in effectiveness due to darkness (0-1). 0= zero effectiveness. 1= no reduction in effectiveness.*	**no**	ISB not applicable during darkness
Operative before sunrise/ after sunset (hrs)	*Check if the system is operational at night (in darkness)*	**no**	
☑ Apply emulsion breaker with efficiency (%):	*Efficiency of emulsion breaker fluid*	**no**	Not applicable

Strategy				**Reference/remarks**
Area	Start	Stop	Method	
Exclusion zone	0	-1.00	Newest oil	(-1.00 = until end of simulation); **4**

VESSEL			
Parameter	**Description**	**In-put value**	**Reference/Remarks**
Vessel name:	*Select from the list. Default values for the vessel will be loaded from the response options database*	User defined	
Tankage (m^3):	*Specify the on-board holding capacity of the vessel in cubic meters.*	unlimited	
Cruise speed (knots):	*Specify the vessels cruising speed in knots. The cruising speed applies to movement to and from the home port and the offload barges.*	14	NOFO OR vessel
Search cruising path:	*Apply X search in grid(s) to find out cruising path avoiding land cells.*	yes	
Draught (m):	*Specify the minimum water depth that the vessel can draw*	5	NOFO OR vessel

BOOM

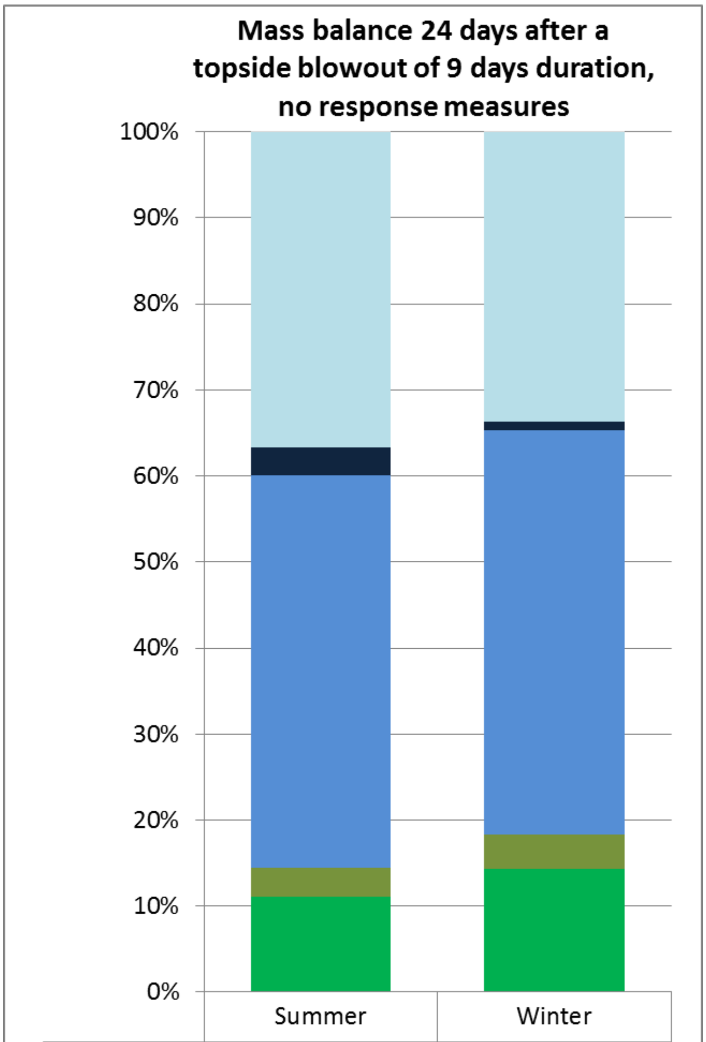
Parameter	Description	In-put value	Reference/Remarks
Boom name:	*Select from the list. Default values for the boom will be loaded from the response options database*	User defined	
Swath width (m):	*Specify the swath width in meters*	40	30-50m, workshop
Operational speed (knots):	*Specify the maximum operational speed in knots*	0.7	
Wave treshold (m):	*Specify the wave threshold for operation in meters*	1.8	workshop
Effectiveness (%):	*Enter the max percentage of oil encountered that this boom will retain under optimal conditions.*	75	Throughput Efficiency

SKIMMER			
Parameter	**Description**	**In-put value**	**Reference/Remarks**
Skimmer name:	*Select from the list. Default values for the skimmer will be loaded from the response options database*	User defined	
Skimmer rate (m3/hr): *= maximum skimmer uptake capacity*	*Specify the maximum skimmer rate in cubic meters per hour* *= Burn rate*	150	Burnrate for typical crude oil
Viscosity limit for flow to skimmer (cP):	*Specify the maximum viscosity (cP) that the skimmer can handle* *= Viscosity limit for ISB*	1500	estimated based on Skrugard weathering study—30% water content
Thickness limit for recoverable oil (mm):	*Specify the minimum thickness (mm) that the skimmer can handle* *= minimum encounter thickness*	0.1	

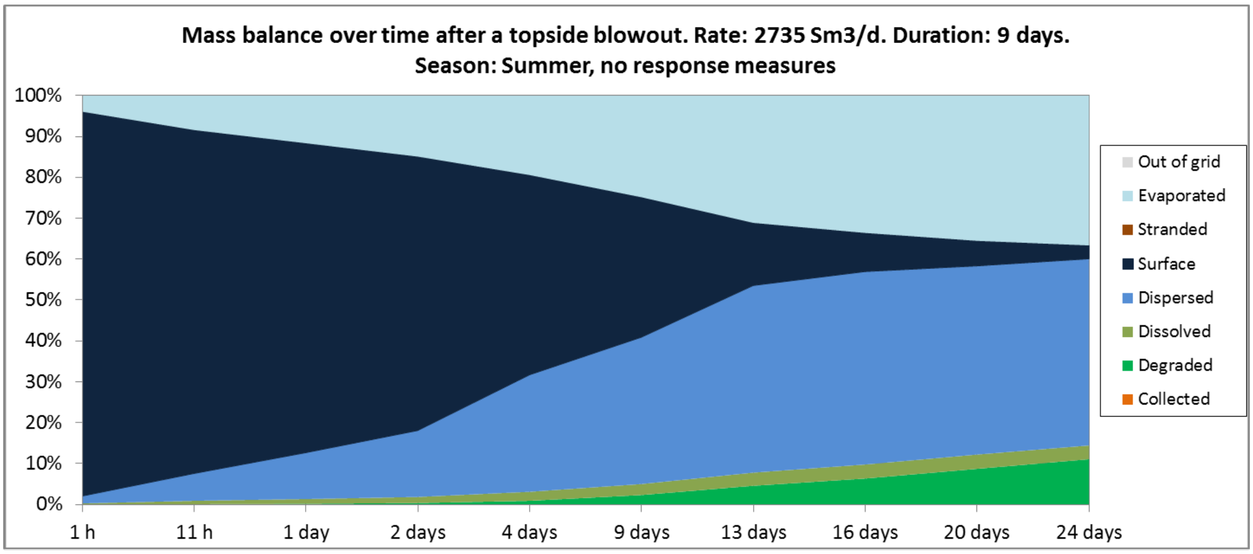
APPENDIX B – MASS BALANCE FIGURES

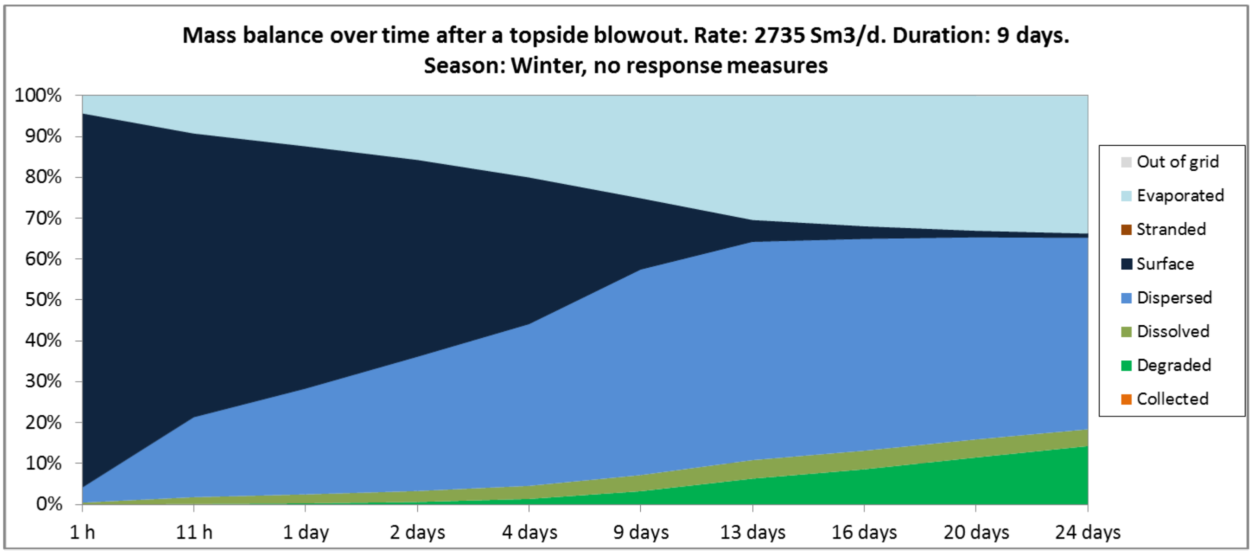
B.1 No response measures

TOPSIDE SCENARIO

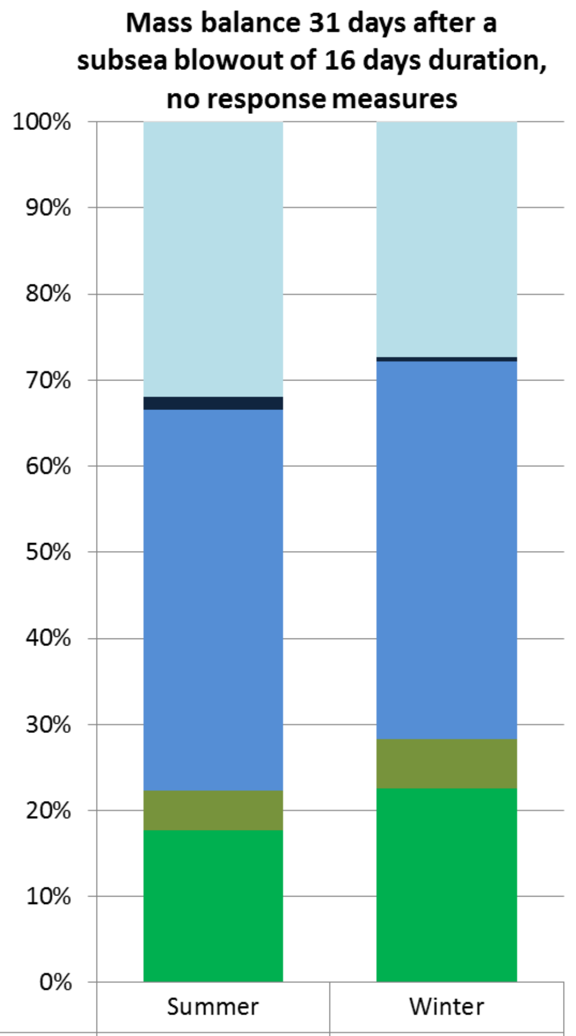


	Summer	Winter
Out of grid	0 %	0 %
Evaporated	37 %	34 %
Stranded	0 %	0 %
Surface	3 %	1 %
Dispersed	46 %	47 %
Dissolved	3 %	4 %
Degraded	11 %	14 %
Collected	0 %	0 %

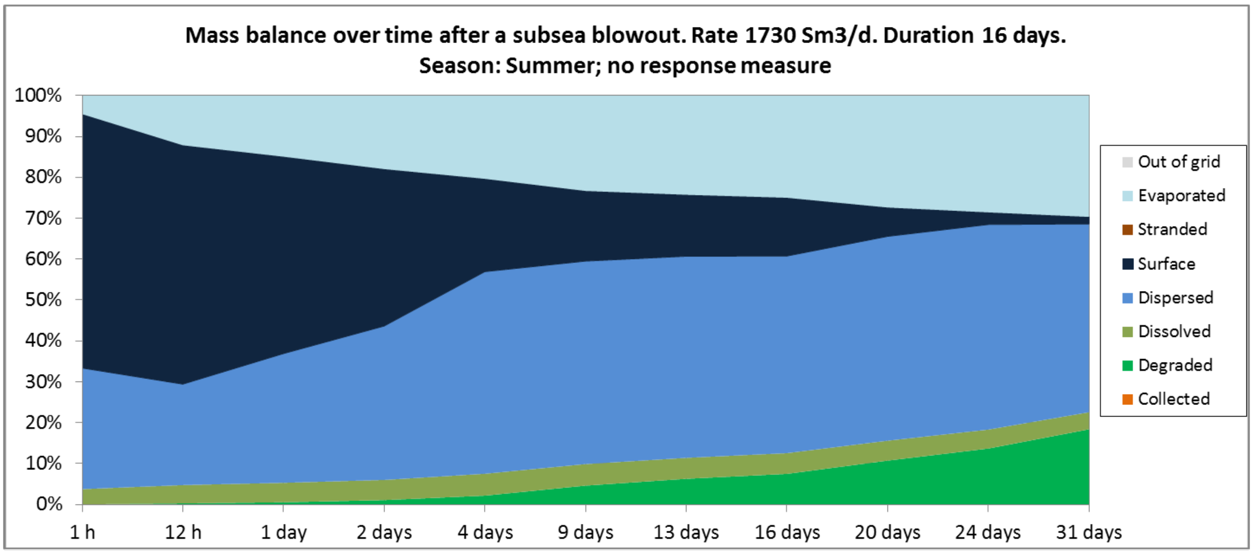

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer, no response measures
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

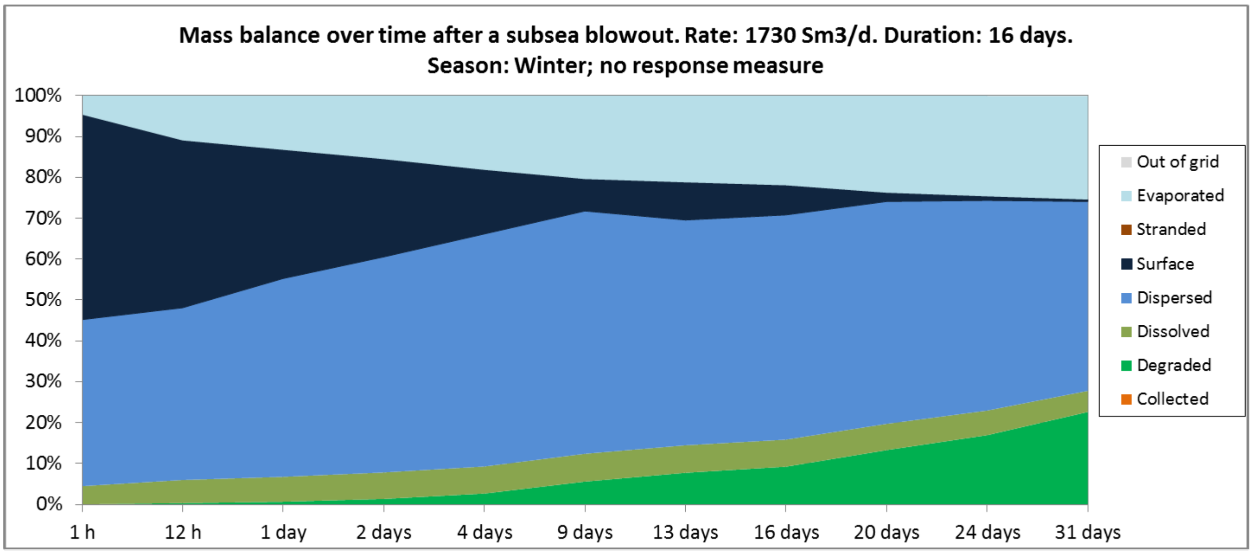

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter, no response measures
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

SUBSEA SCENARIO



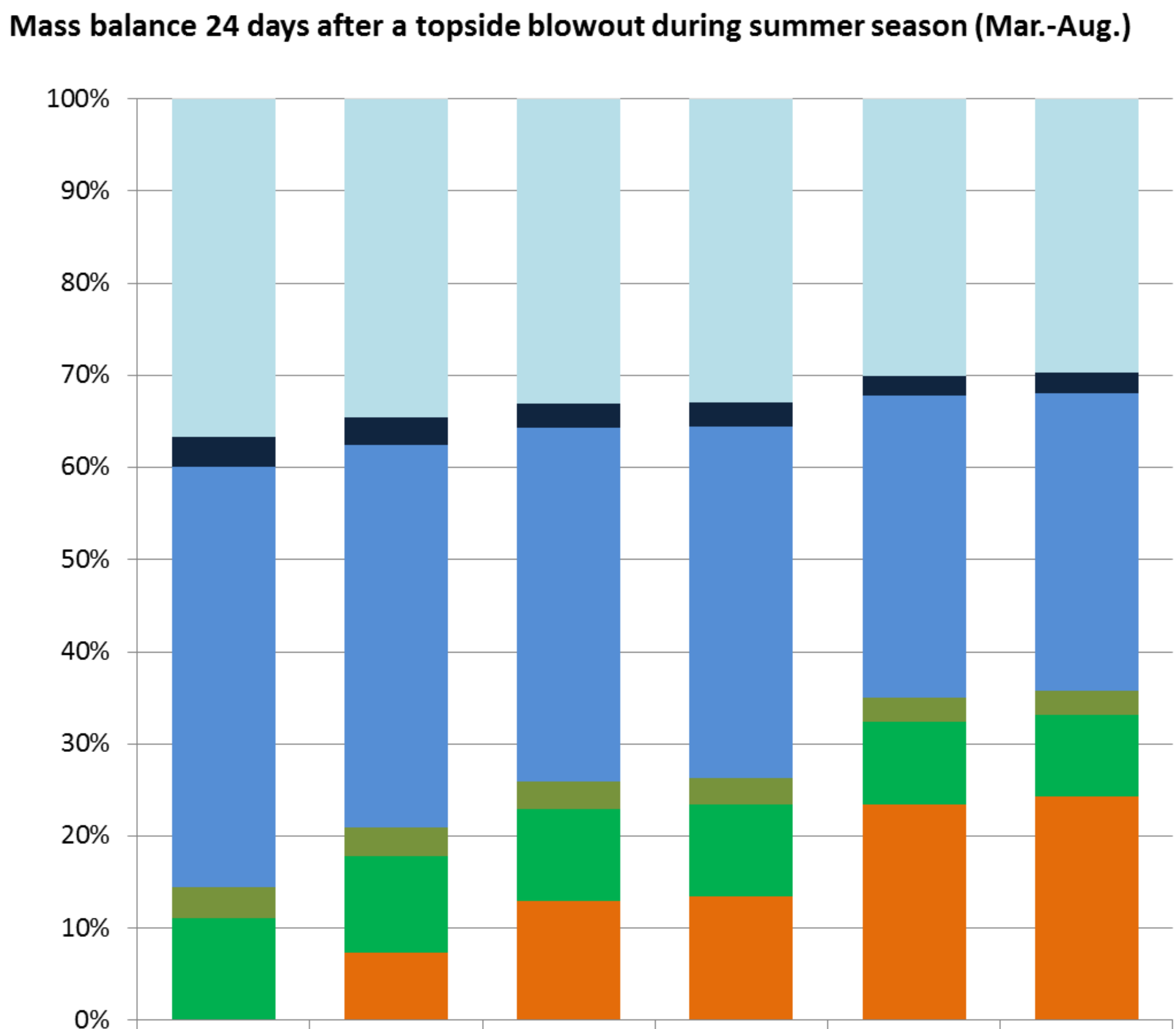
	Summer	Winter
Out of grid	0 %	0 %
Evaporated	32 %	27 %
Stranded	0 %	0 %
Surface	1 %	0,5 %
Dispersed	44 %	44 %
Dissolved	5 %	6 %
Degraded	18 %	23 %
Collected	0 %	0 %


Mass balance over time after a subsea blowout. Rate 1730 Sm3/d. Duration 16 days.
Season: Summer; no response measure
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
12 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; no response measure
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
12 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

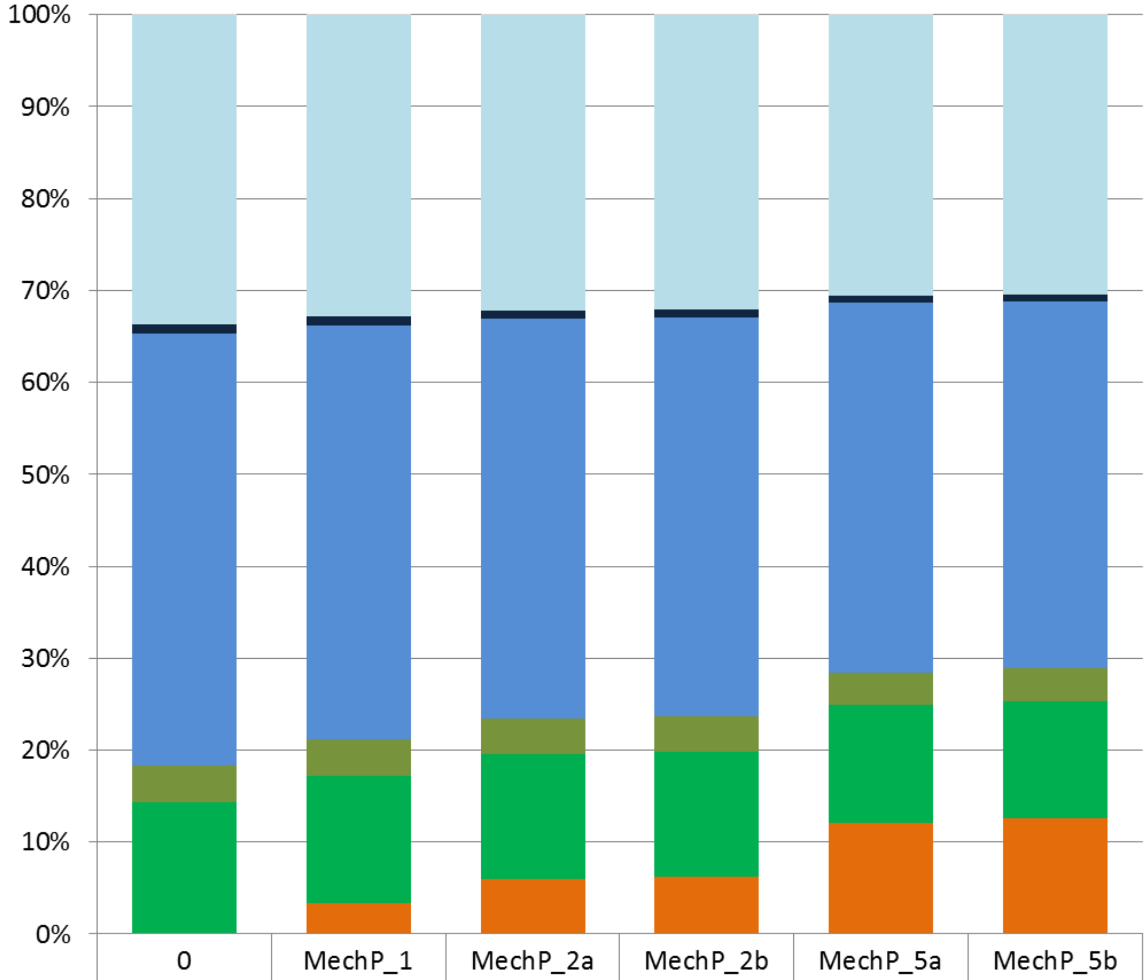
B.2 Response measure MechP

TOPSIDE SCENARIO

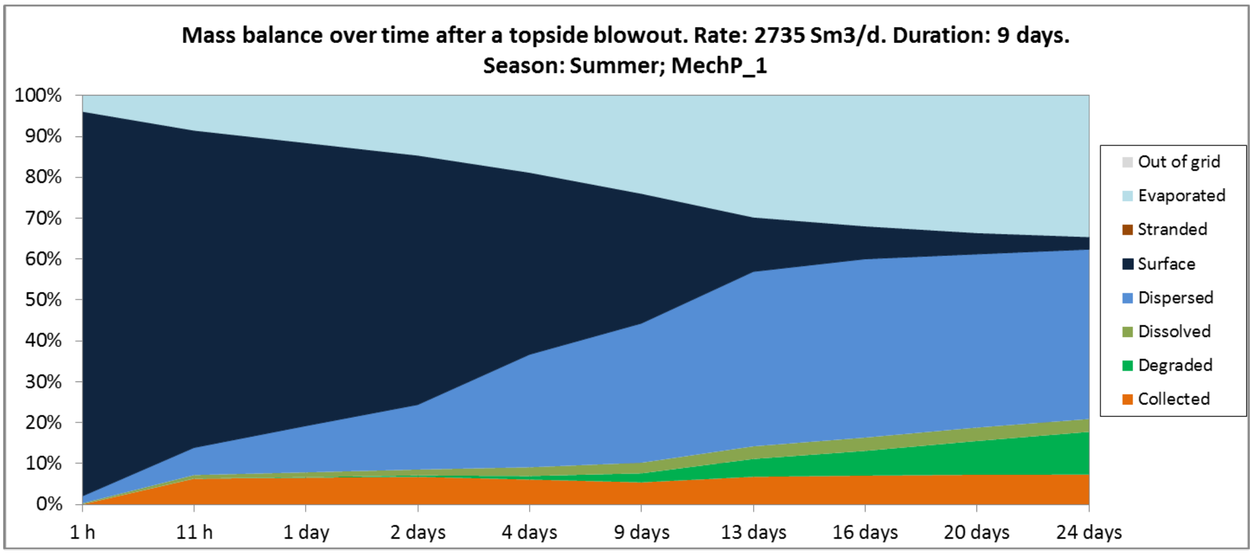


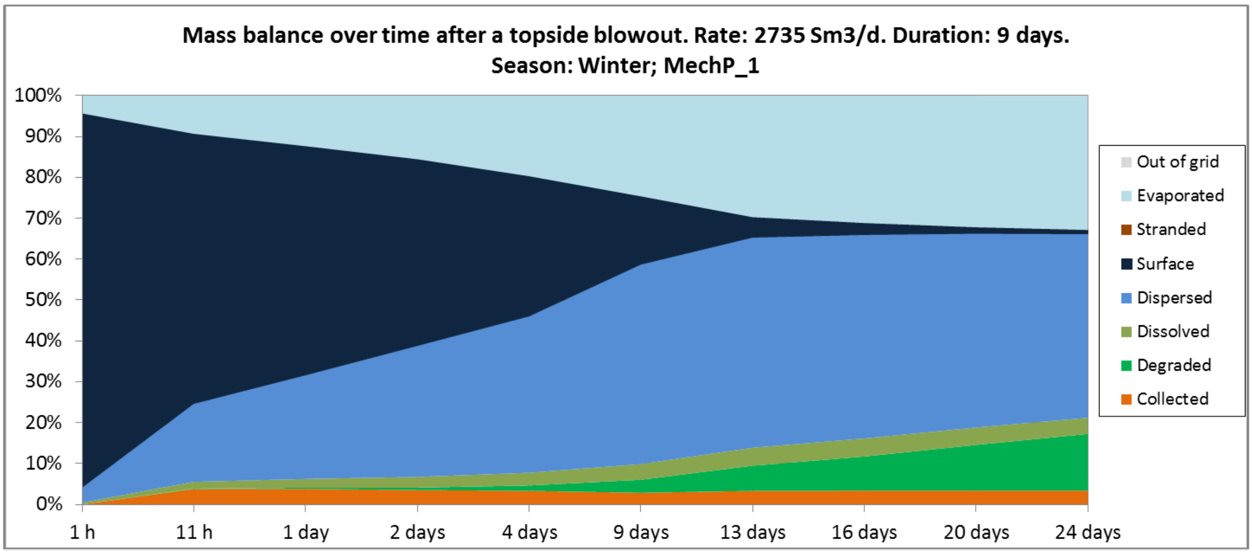
	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	34,6 %	33,1 %	32,9 %	30,1 %	29,8 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,9 %	2,6 %	2,6 %	2,2 %	2,2 %
Dispersed	45,7 %	41,5 %	38,4 %	38,1 %	32,8 %	32,3 %
Dissolved	3,4 %	3,1 %	2,9 %	2,9 %	2,6 %	2,6 %
Degraded	11,1 %	10,5 %	10,0 %	9,9 %	9,0 %	8,9 %
Collected	0,0 %	7,3 %	13,0 %	13,5 %	23,4 %	24,3 %

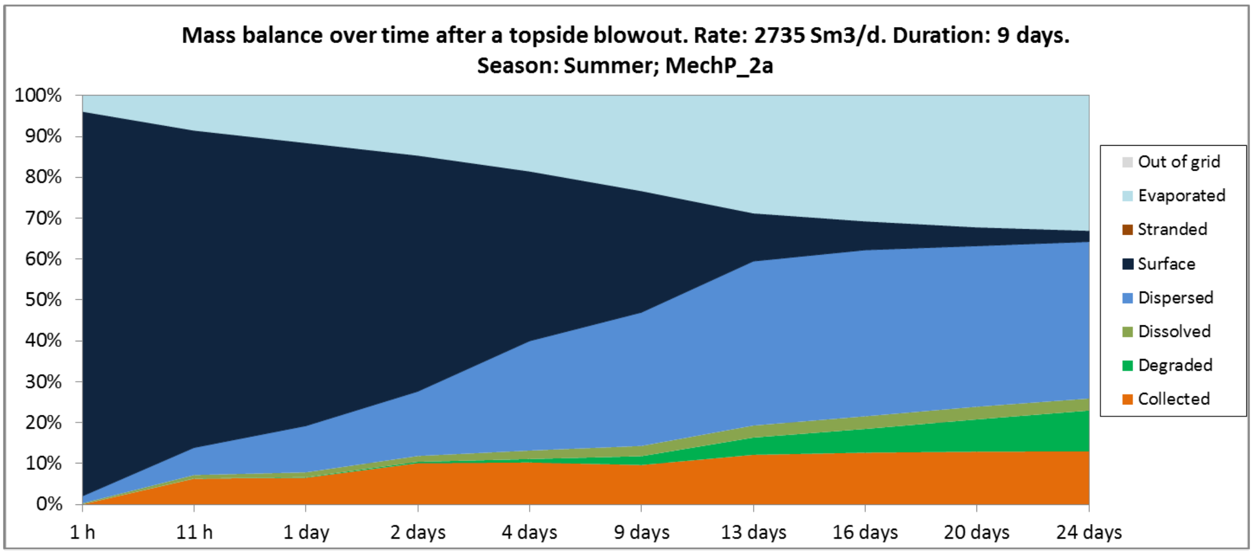
Mass balance 24 days after a topside blowut during winter season (Sept.-Feb.)

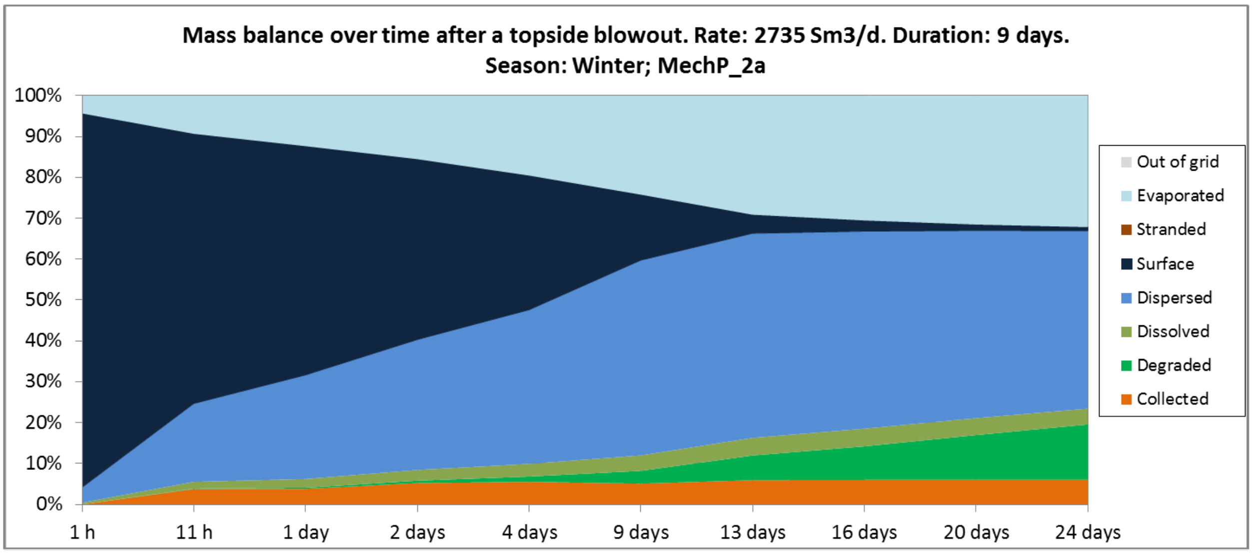


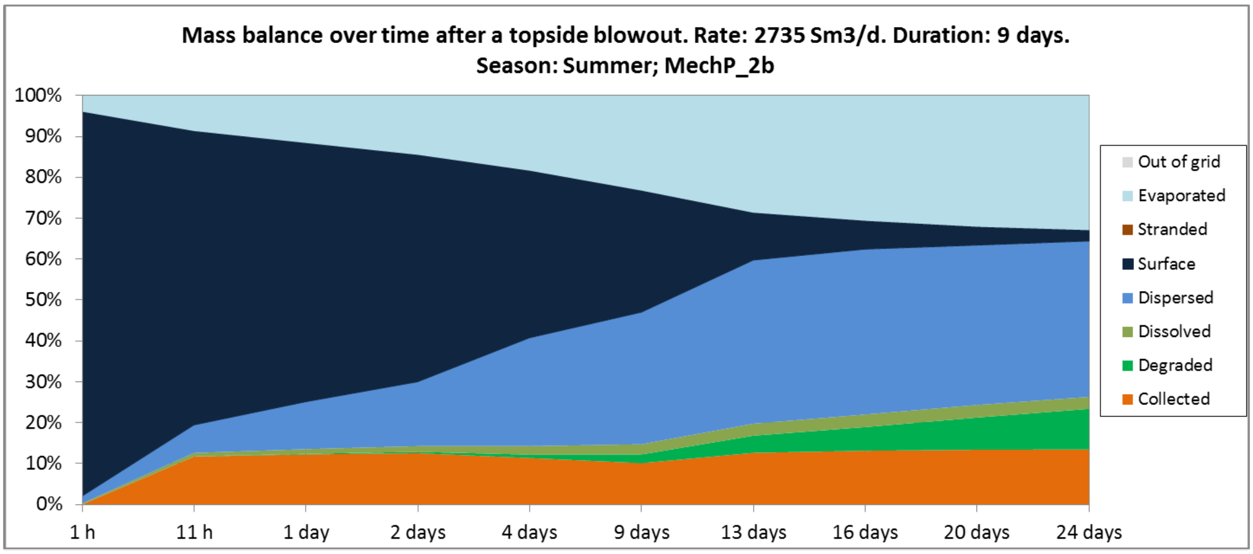
	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	32,8 %	32,1 %	32,0 %	30,5 %	30,4 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	0,9 %	0,9 %	0,8 %	0,8 %
Dispersed	46,9 %	45,0 %	43,5 %	43,4 %	40,2 %	39,9 %
Dissolved	4,1 %	4,0 %	3,9 %	3,8 %	3,6 %	3,6 %
Degraded	14,3 %	13,9 %	13,6 %	13,5 %	12,8 %	12,8 %
Collected	0,0 %	3,4 %	6,0 %	6,3 %	12,0 %	12,5 %

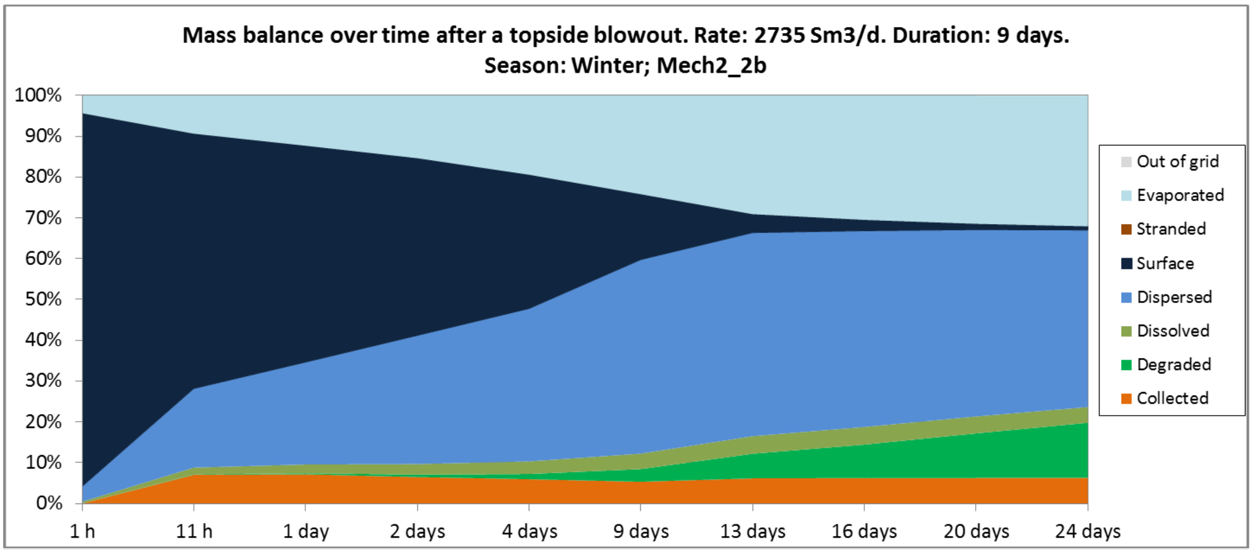

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechP_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

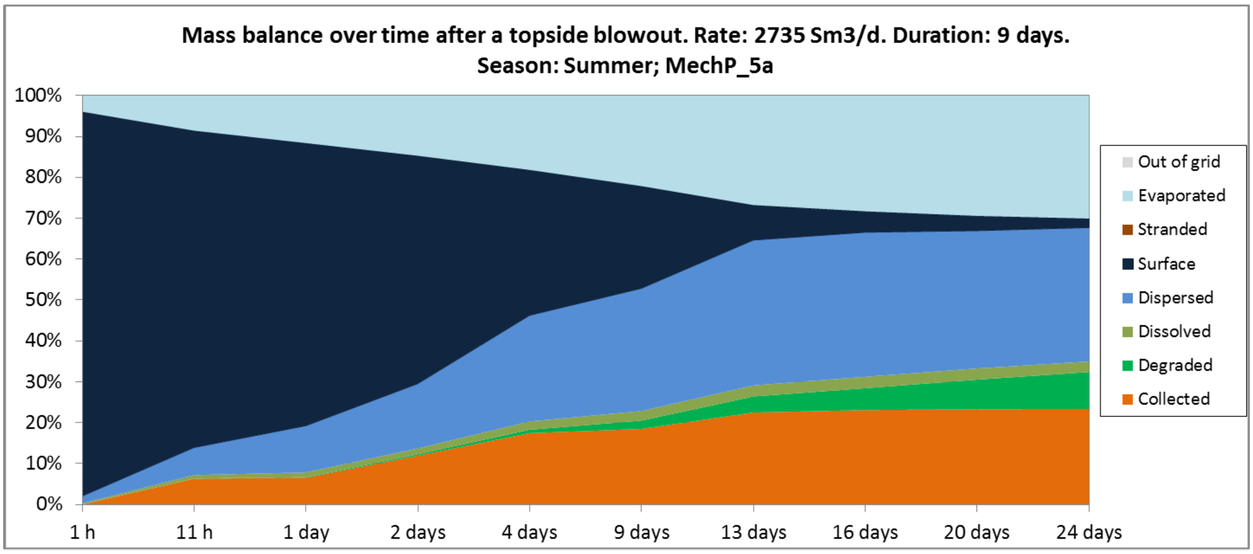

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechP_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

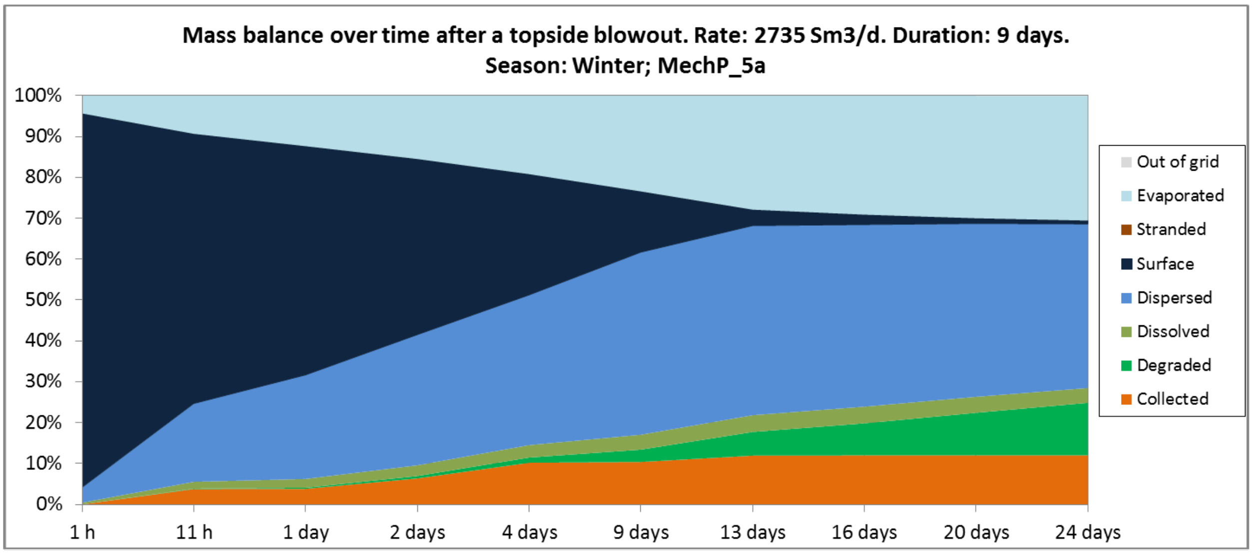

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechP_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

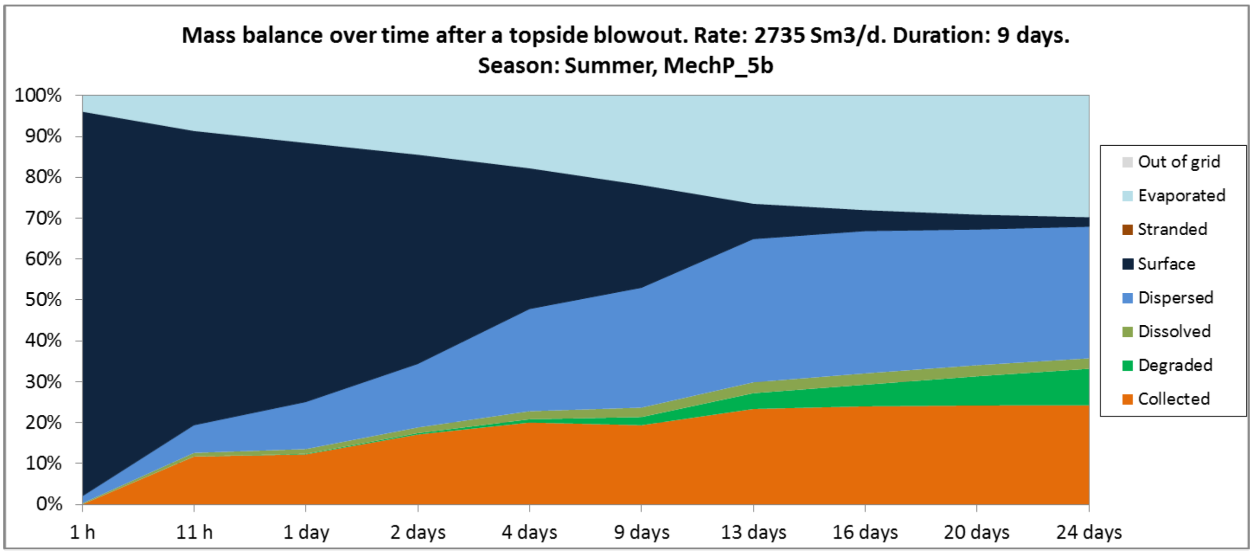

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechP_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

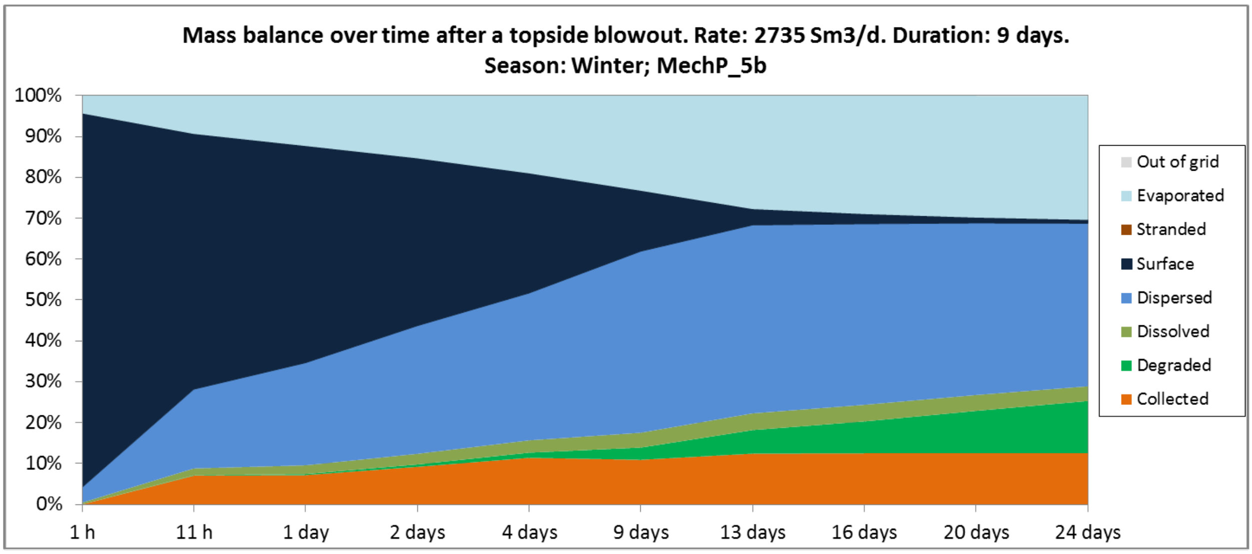

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechP_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; Mech2_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechP_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

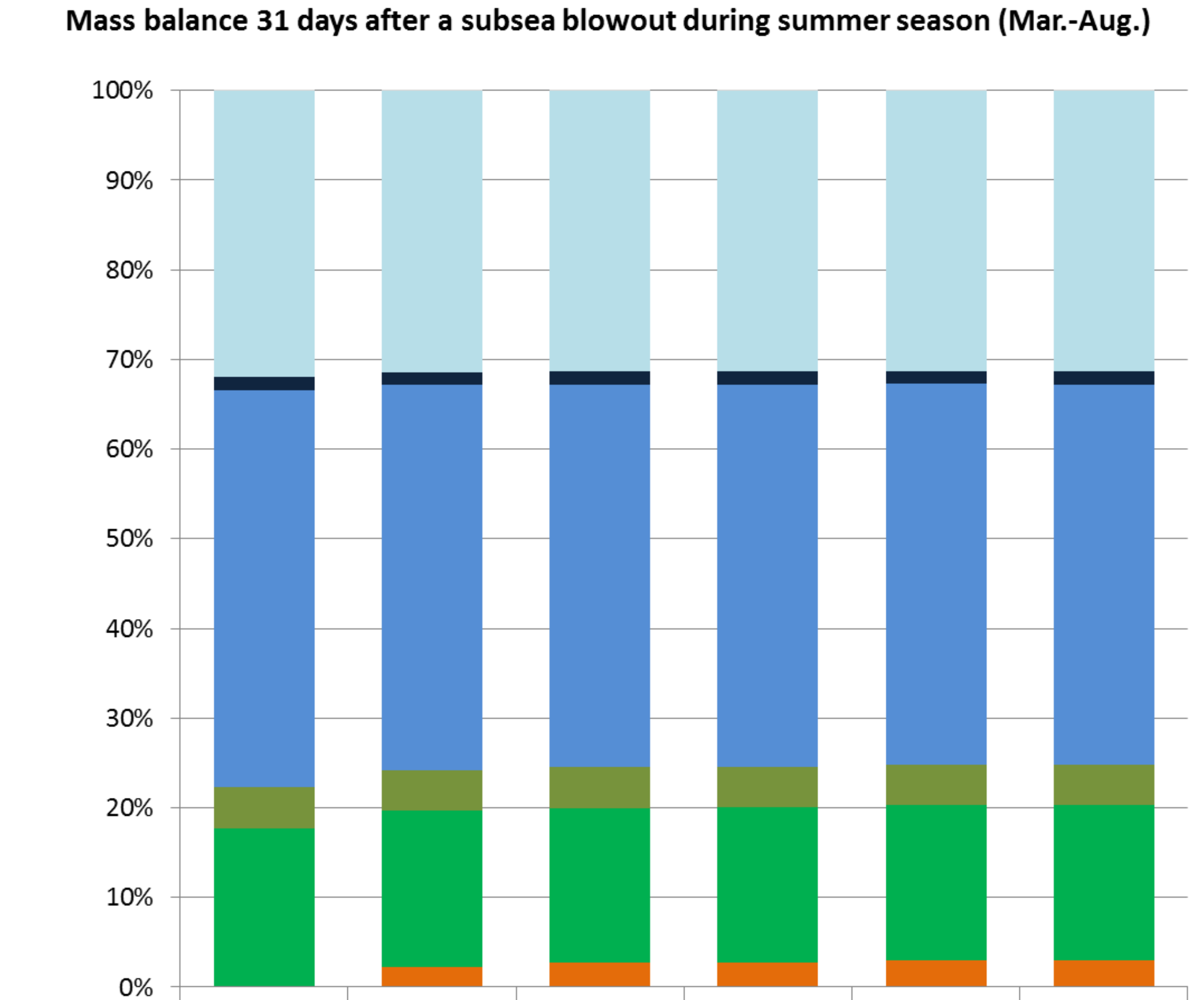

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechP_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer, MechP_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

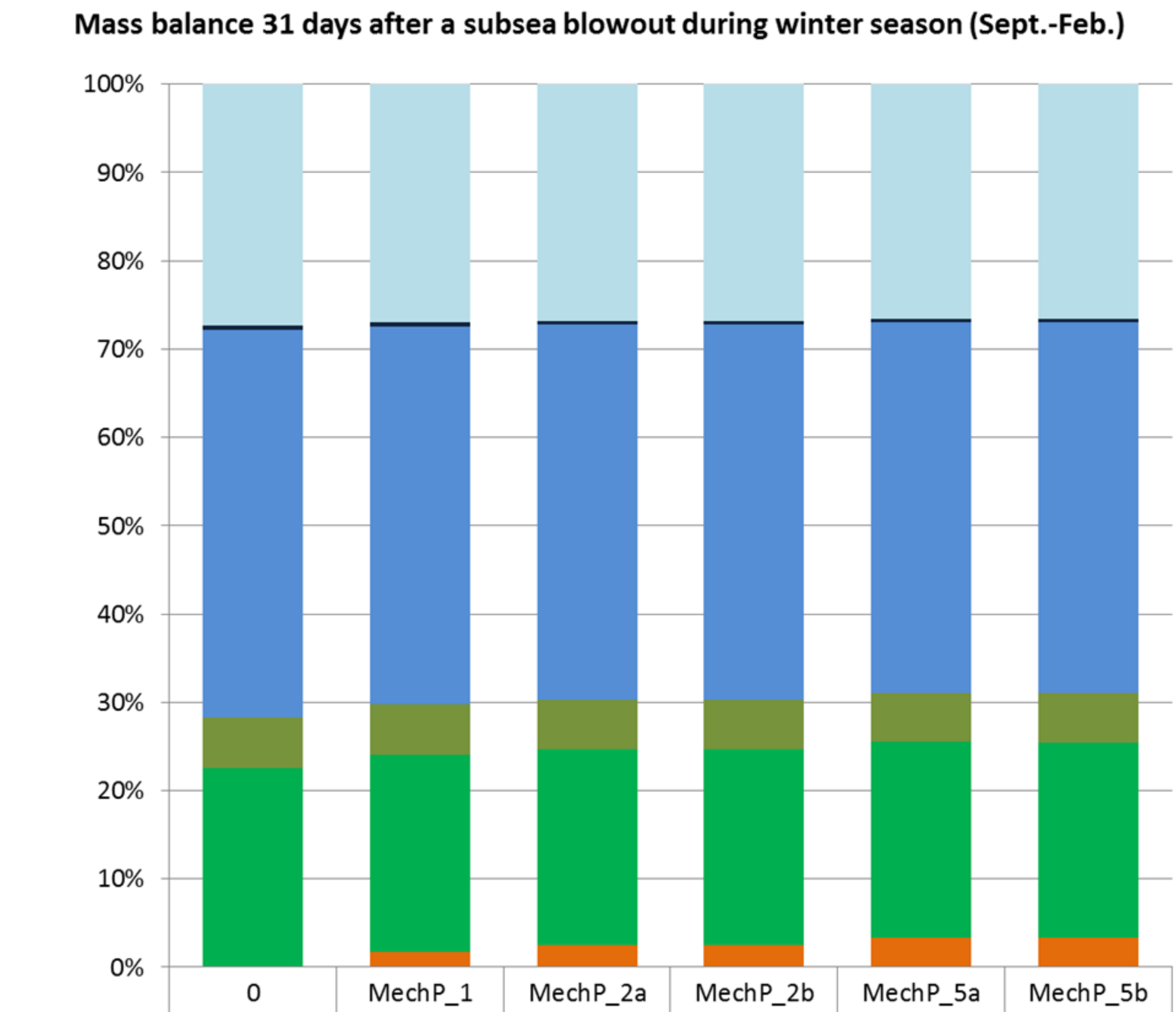


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechP_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

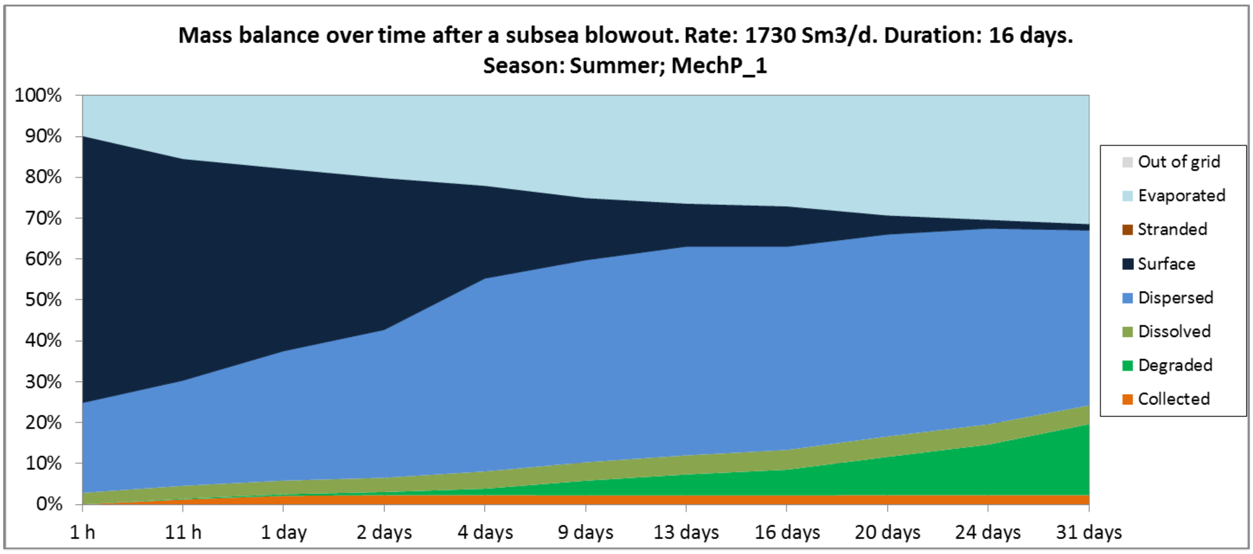
SUBSEA SCENARIO

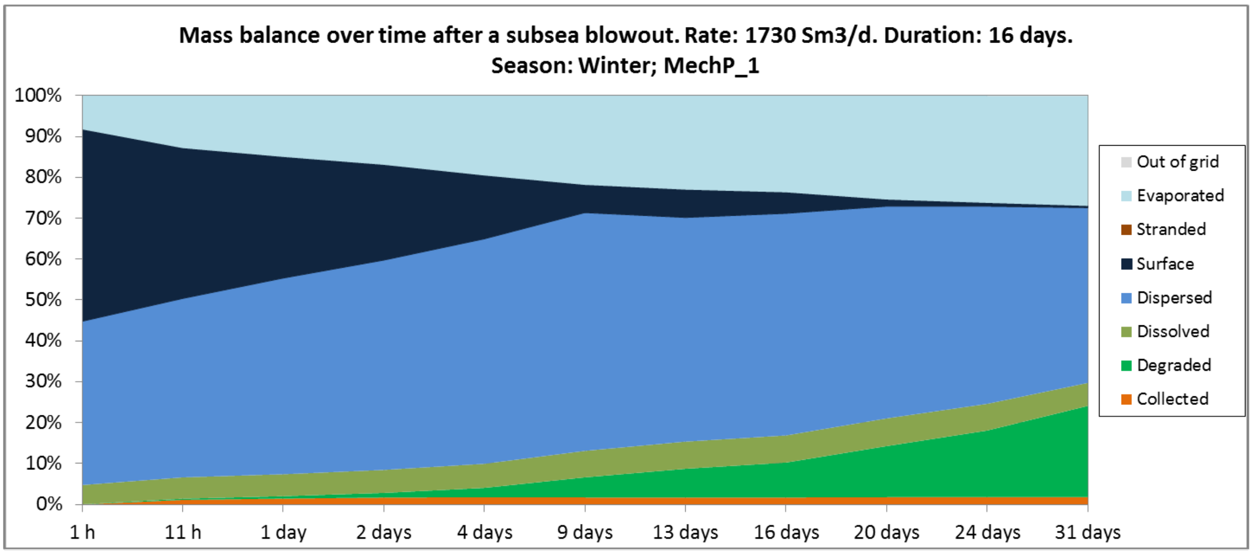


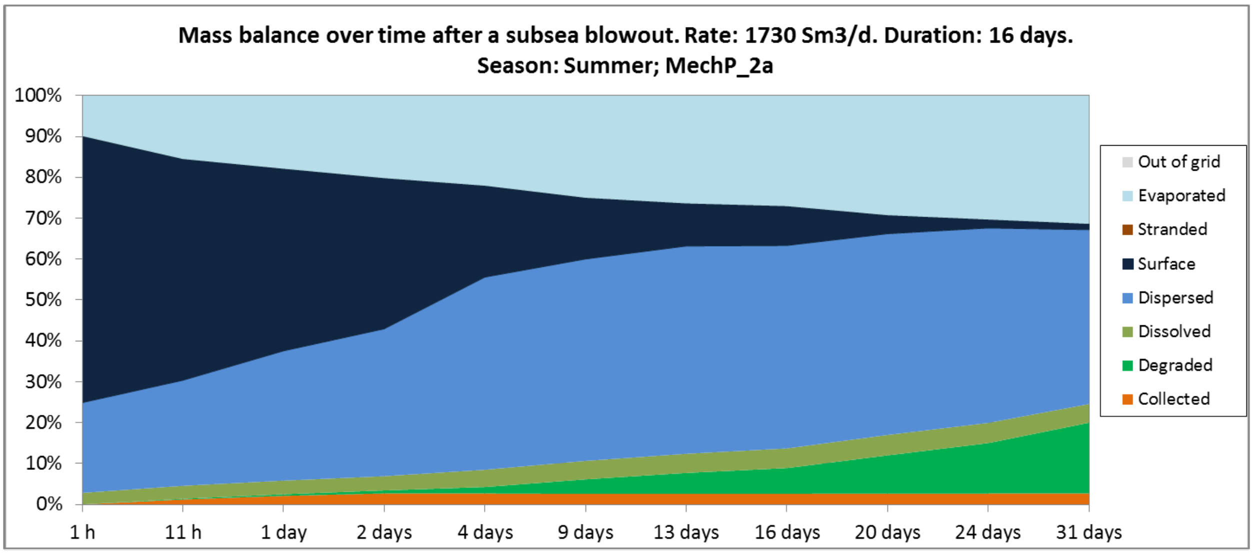
	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,4 %	31,4 %	31,4 %	31,3 %	31,3 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,4 %	1,4 %	1,4 %	1,5 %	1,5 %
Dispersed	44,2 %	42,9 %	42,6 %	42,6 %	42,4 %	42,4 %
Dissolved	4,7 %	4,6 %	4,6 %	4,6 %	4,6 %	4,6 %
Degraded	17,6 %	17,4 %	17,3 %	17,3 %	17,3 %	17,2 %
Collected	0,0 %	2,3 %	2,7 %	2,7 %	3,0 %	3,0 %

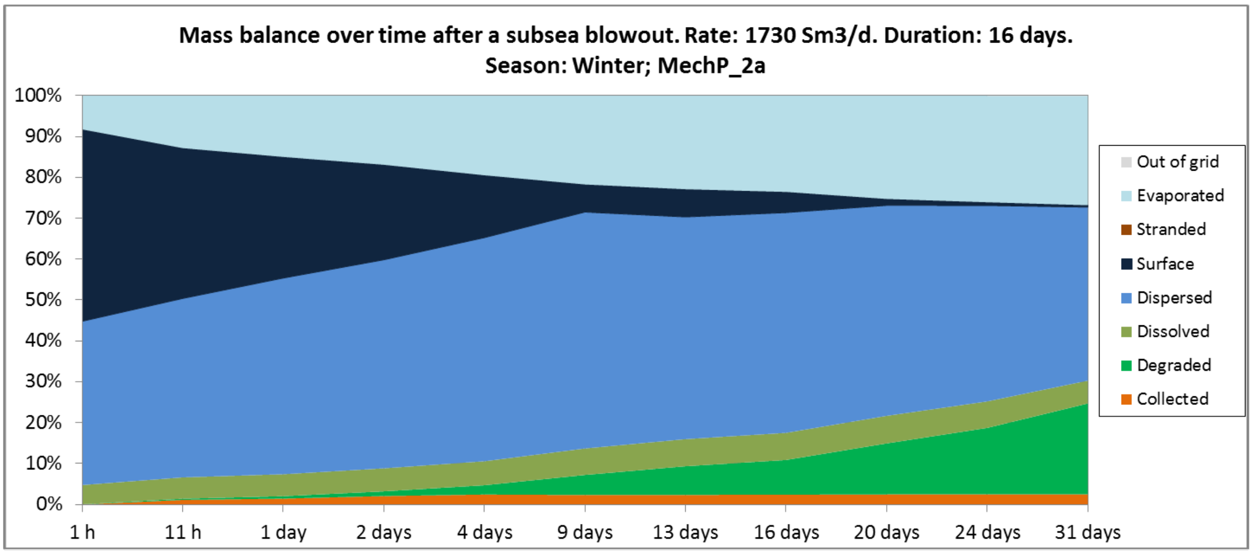


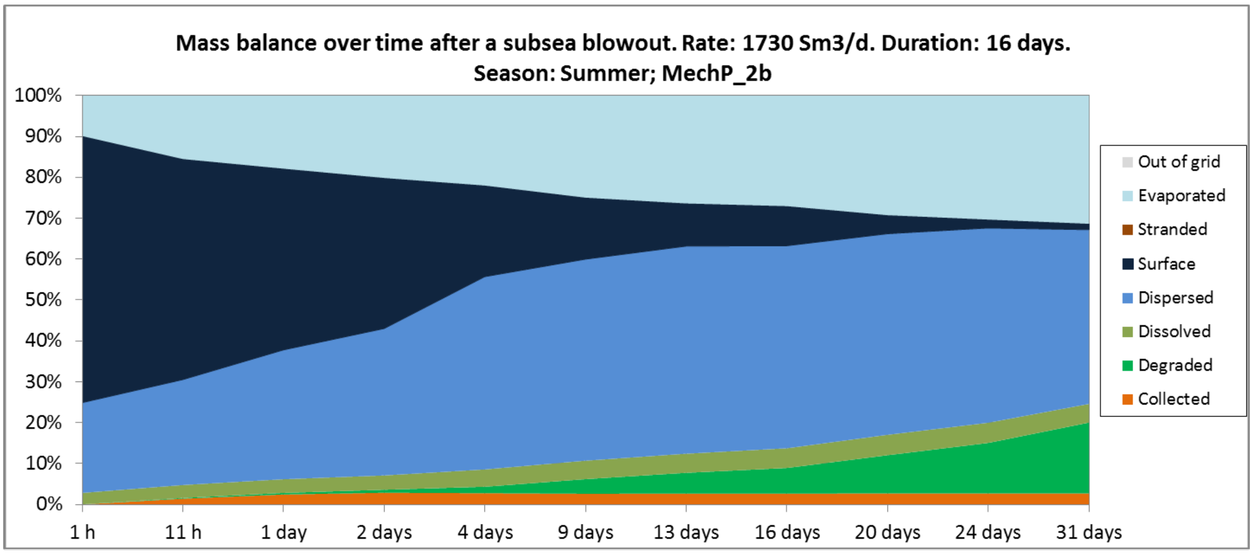
	0	MechP_1	MechP_2a	MechP_2b	MechP_5a	MechP_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	26,9 %	26,8 %	26,8 %	26,5 %	26,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,5 %	0,4 %	0,4 %	0,4 %
Dispersed	43,9 %	42,9 %	42,4 %	42,4 %	41,9 %	41,9 %
Dissolved	5,7 %	5,6 %	5,6 %	5,6 %	5,6 %	5,6 %
Degraded	22,6 %	22,3 %	22,2 %	22,2 %	22,1 %	22,1 %
Collected	0,0 %	1,8 %	2,5 %	2,5 %	3,4 %	3,4 %

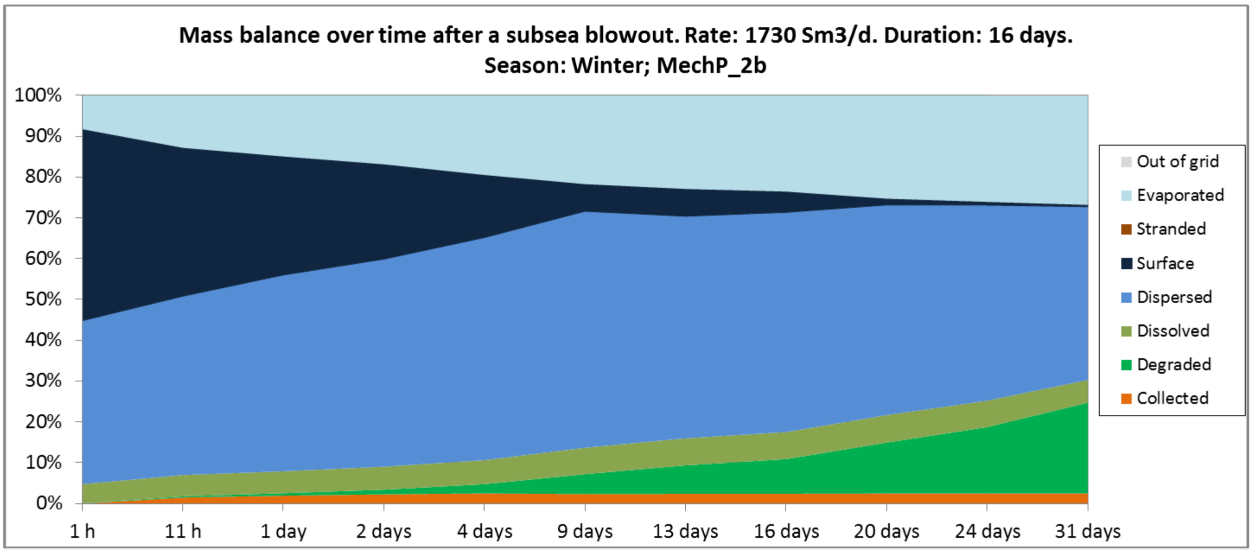

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechP_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

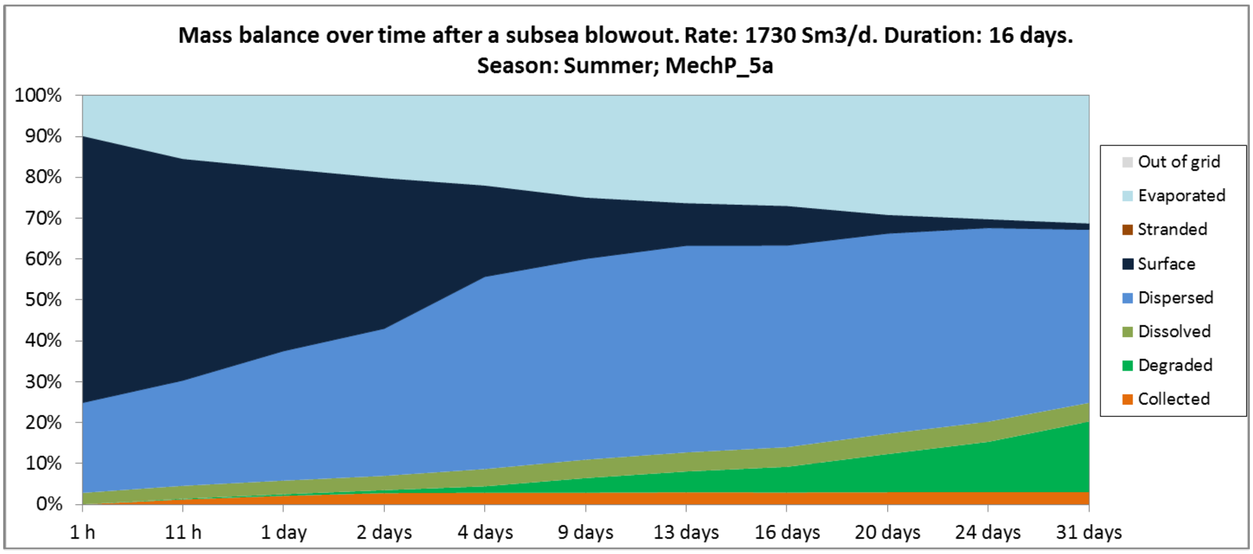

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechP_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechP_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

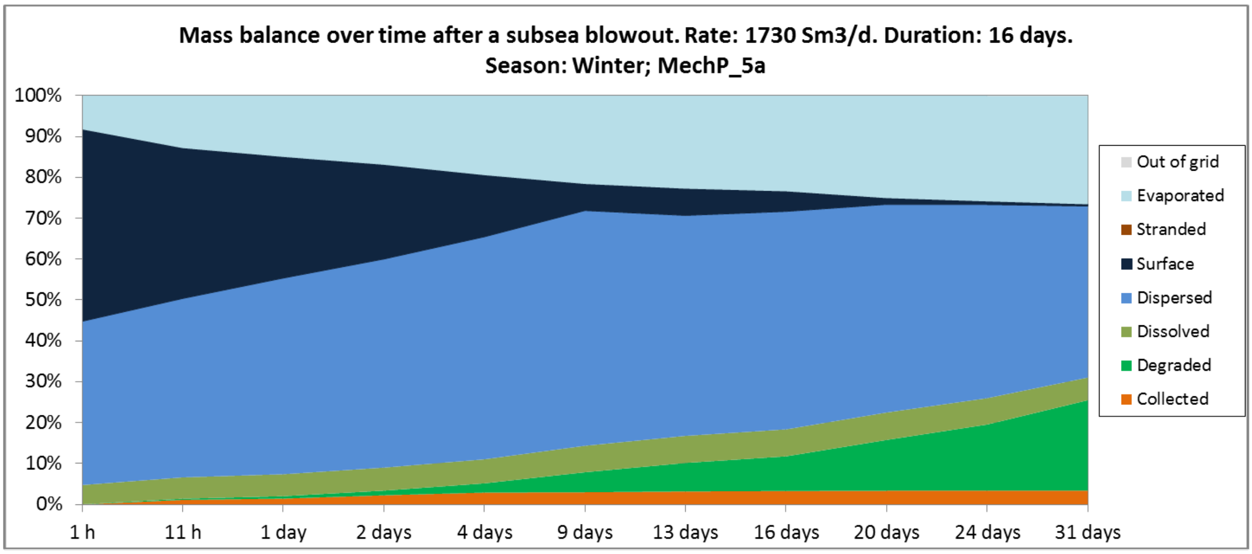

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechP_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechP_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

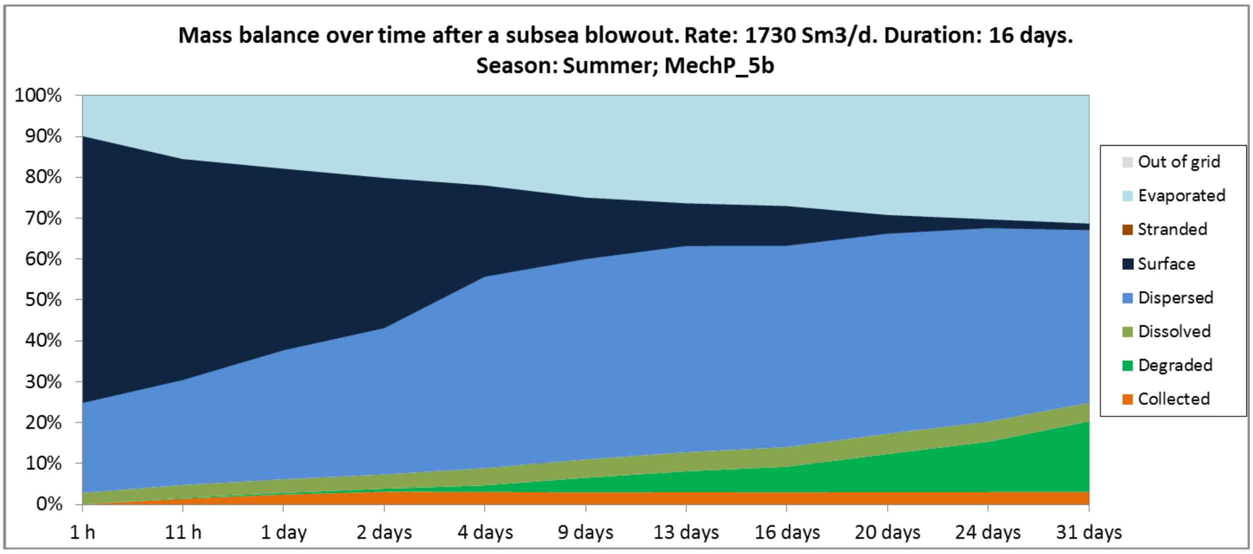

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechP_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



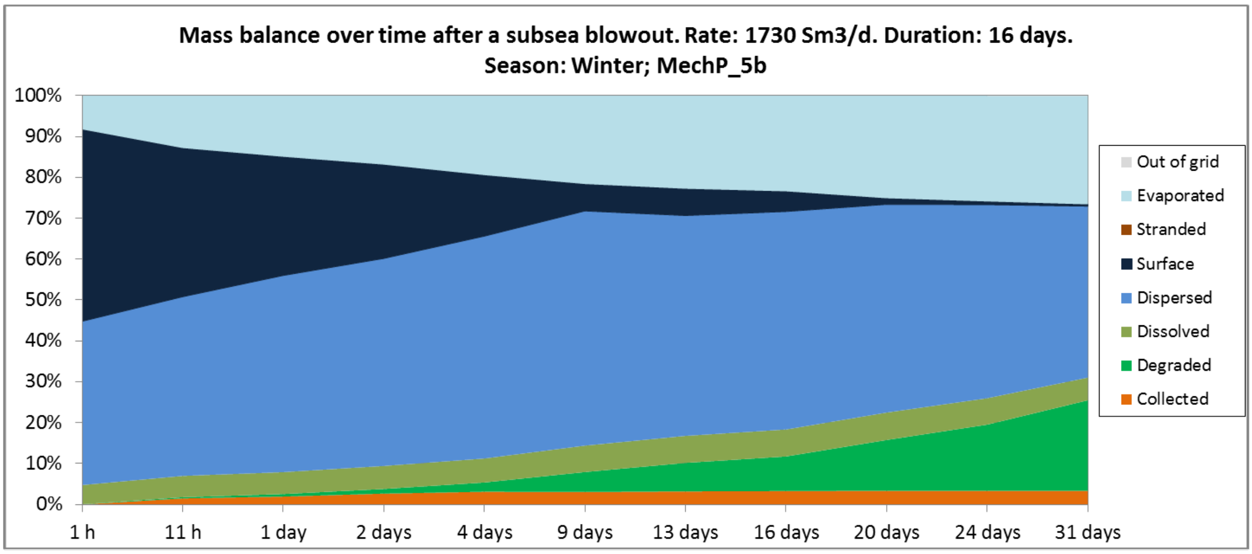
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechP_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechP_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



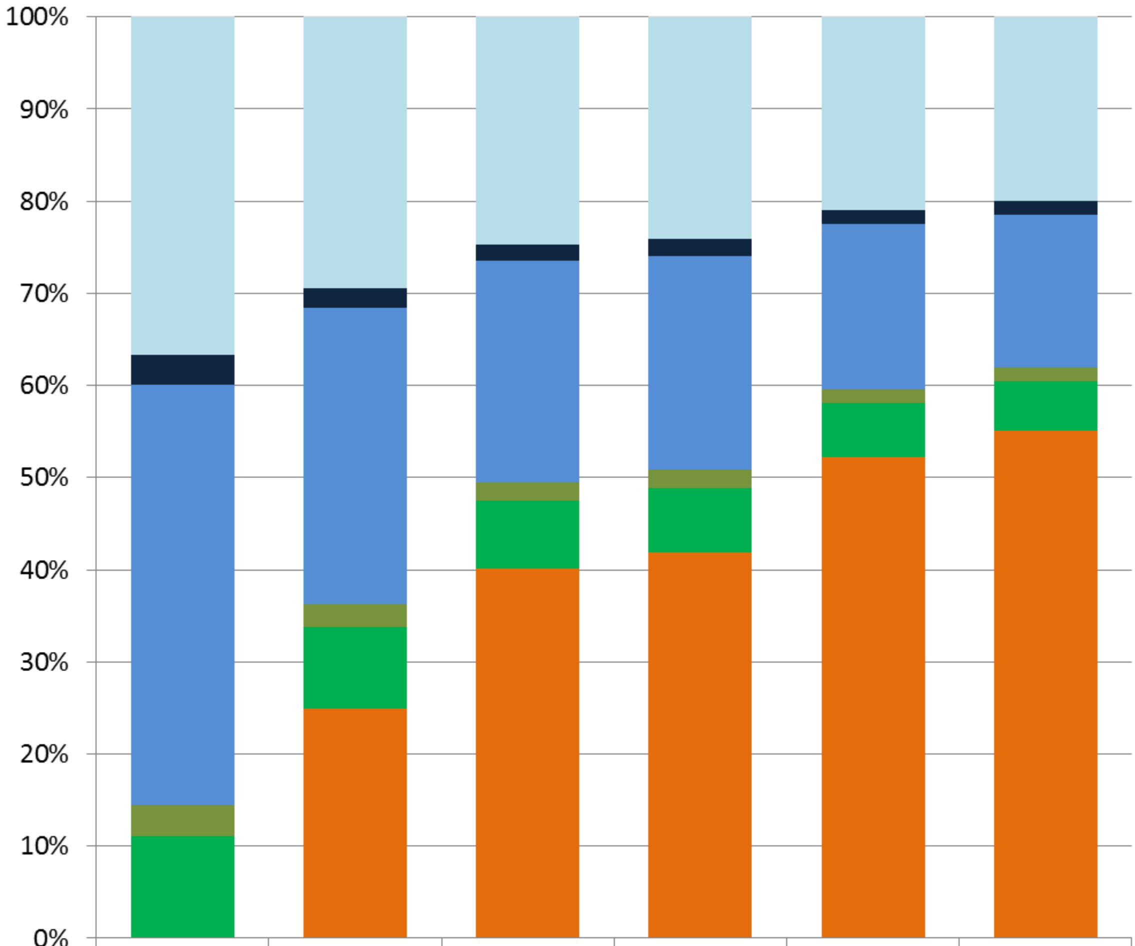
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechP_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechP_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

B.3 Response measure MechA

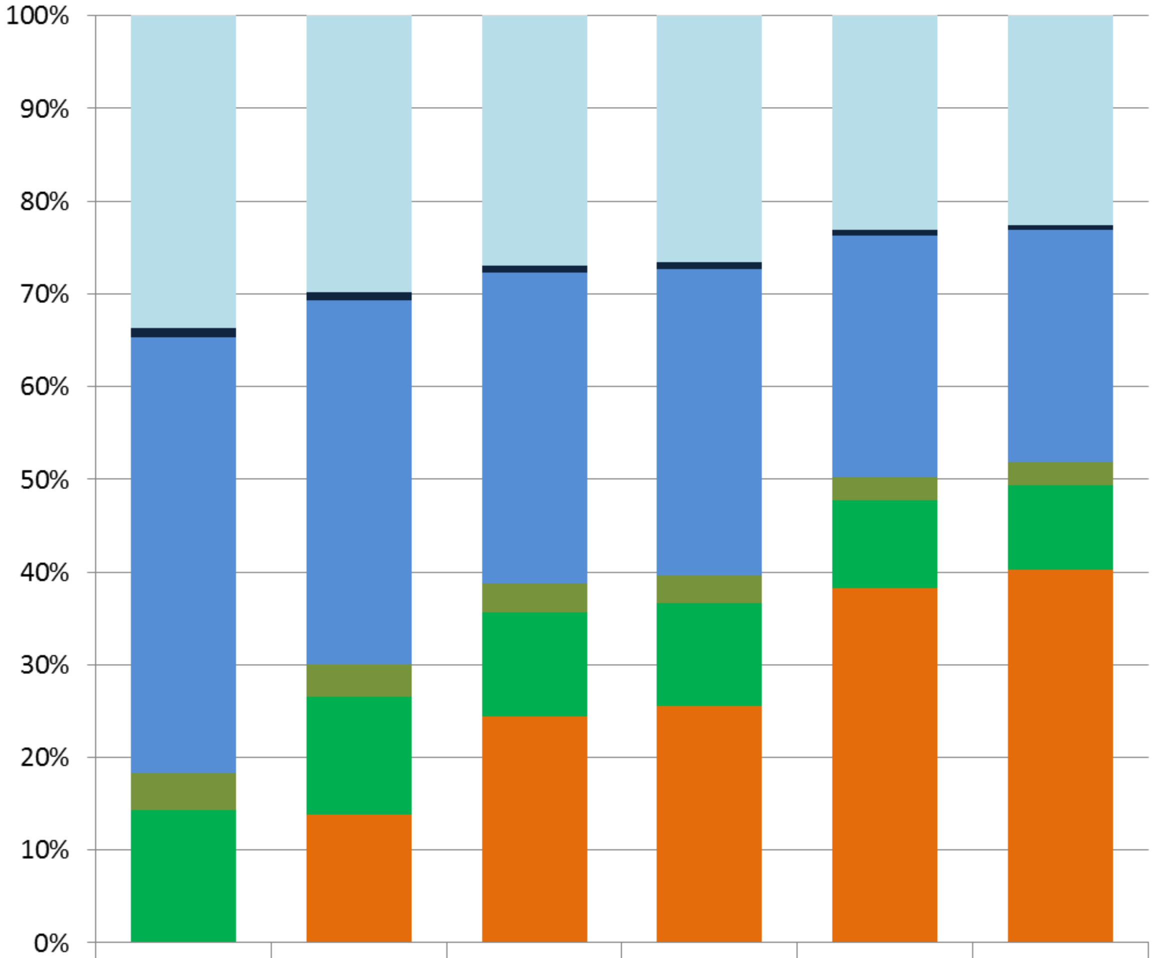
TOPSIDE SCENARIO

Mass balance 24 days after a topside blowout during summer season (Mar.-Aug.)

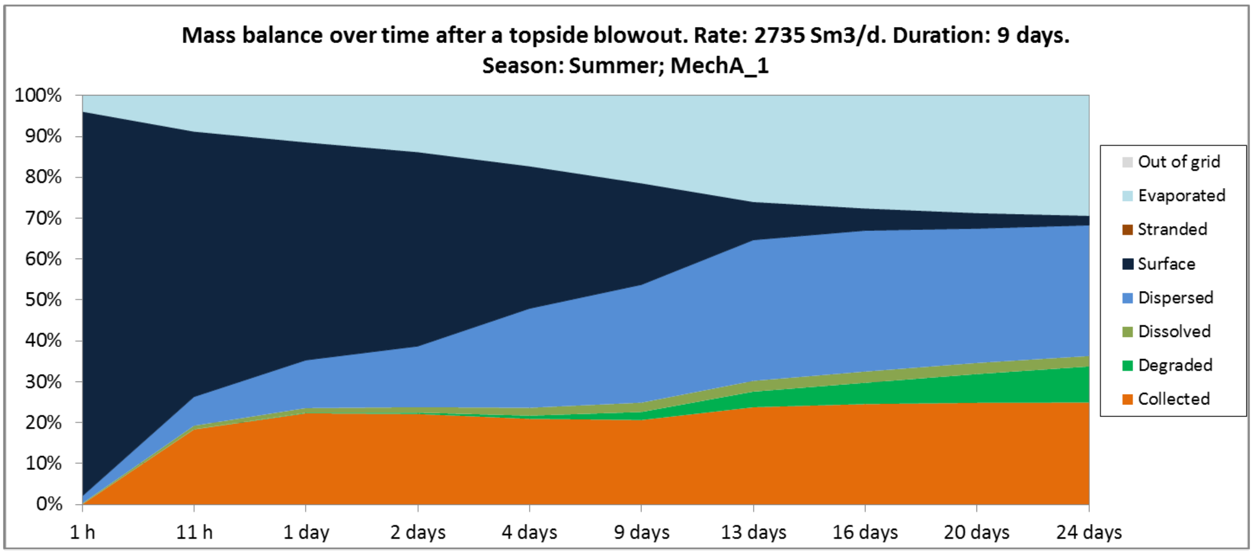


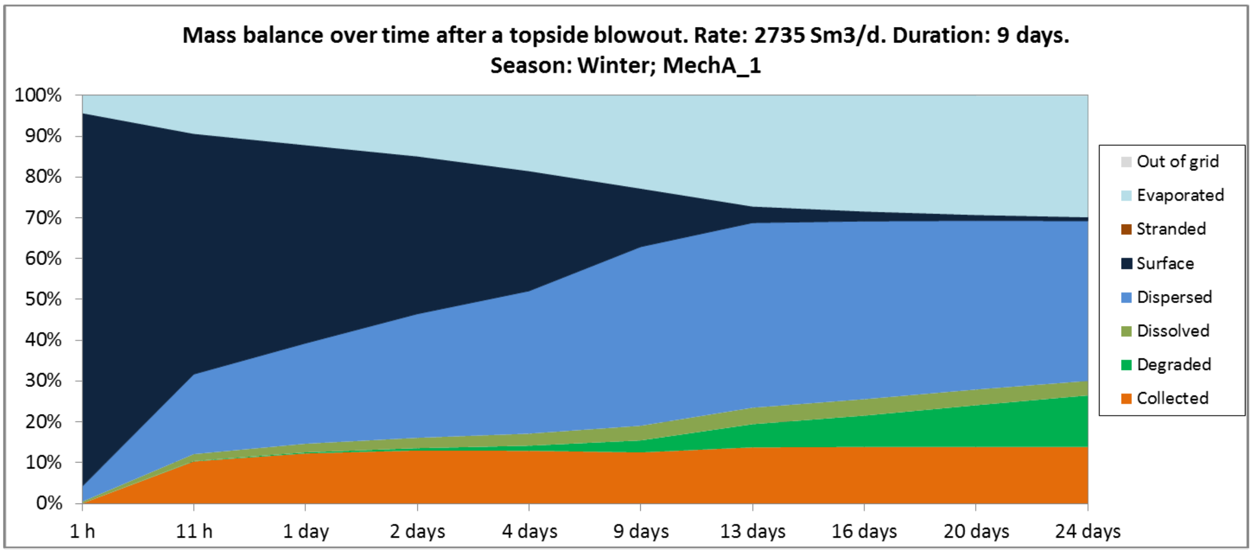
	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	29,4 %	24,7 %	24,1 %	21,0 %	20,0 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,2 %	1,8 %	1,8 %	1,6 %	1,5 %
Dispersed	45,7 %	32,1 %	24,1 %	23,3 %	17,9 %	16,6 %
Dissolved	3,4 %	2,5 %	2,0 %	1,9 %	1,5 %	1,4 %
Degraded	11,1 %	8,8 %	7,3 %	7,1 %	5,9 %	5,5 %
Collected	0,0 %	24,9 %	40,1 %	41,8 %	52,2 %	55,0 %

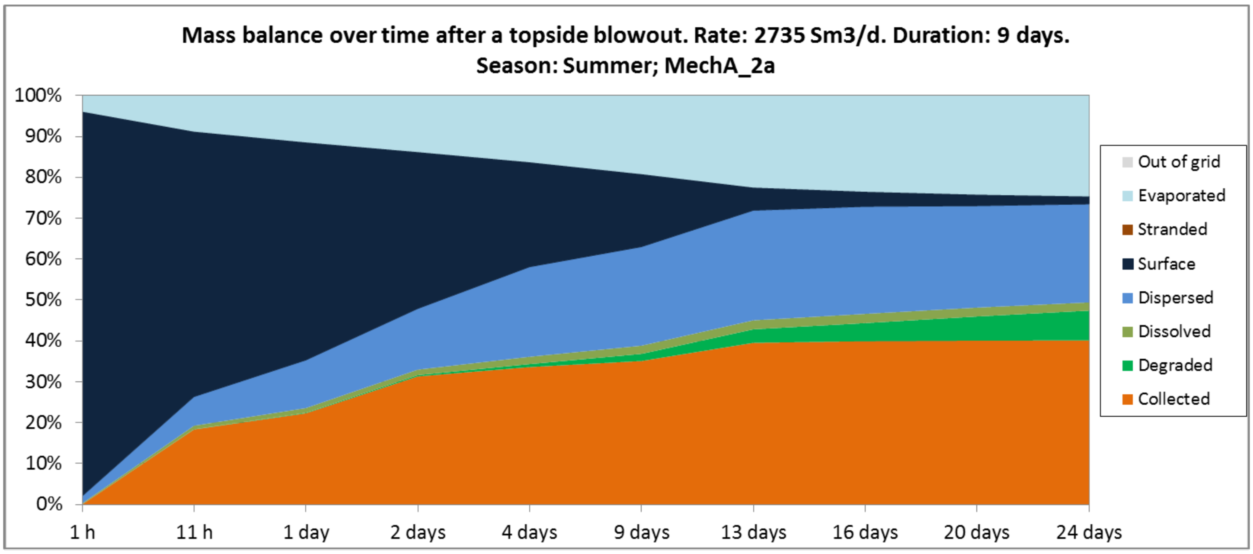
Mass balance 24 days after a topside blowout during winter season (Sept.-Feb.)

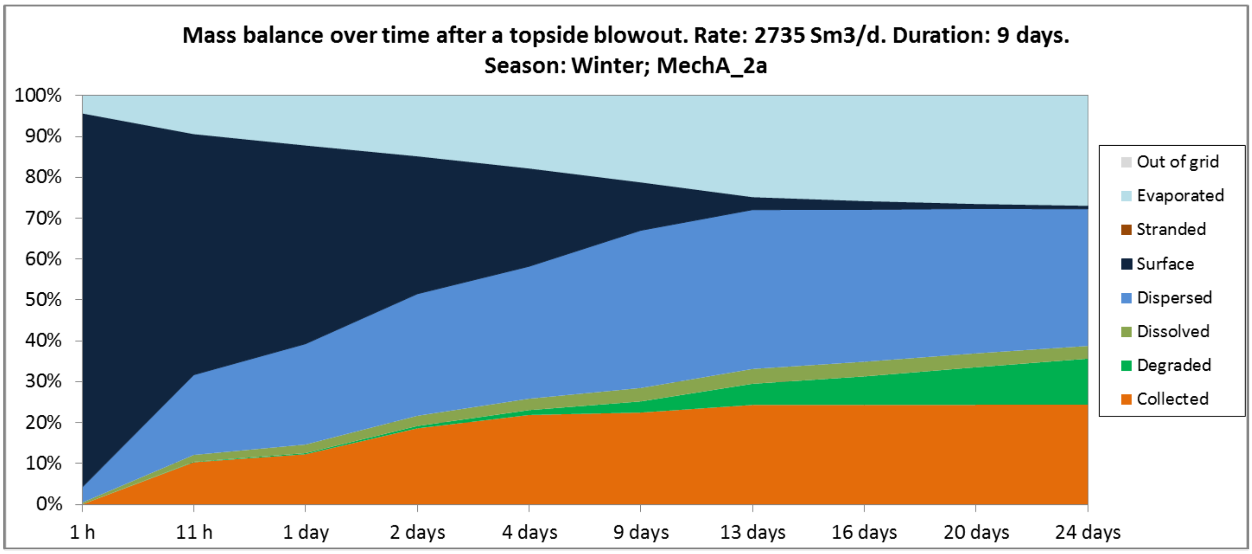


	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	29,8 %	26,9 %	26,6 %	23,1 %	22,5 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,8 %	0,7 %	0,7 %	0,6 %	0,6 %
Dispersed	46,9 %	39,3 %	33,5 %	33,0 %	26,0 %	25,0 %
Dissolved	4,1 %	3,5 %	3,1 %	3,1 %	2,5 %	2,4 %
Degraded	14,3 %	12,6 %	11,3 %	11,1 %	9,4 %	9,1 %
Collected	0,0 %	13,9 %	24,4 %	25,5 %	38,3 %	40,3 %

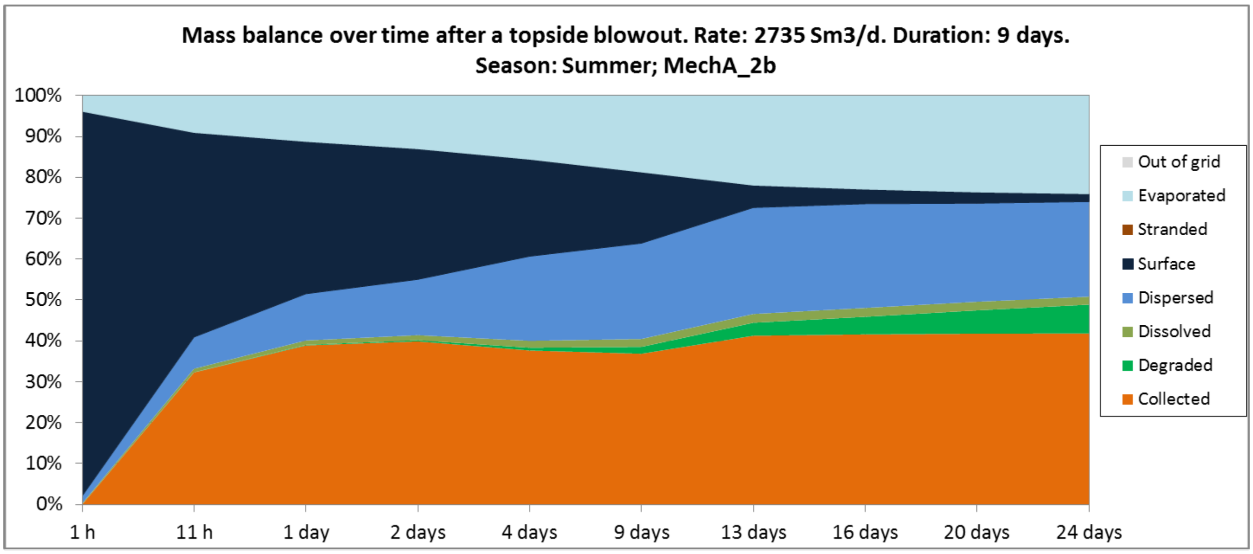

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

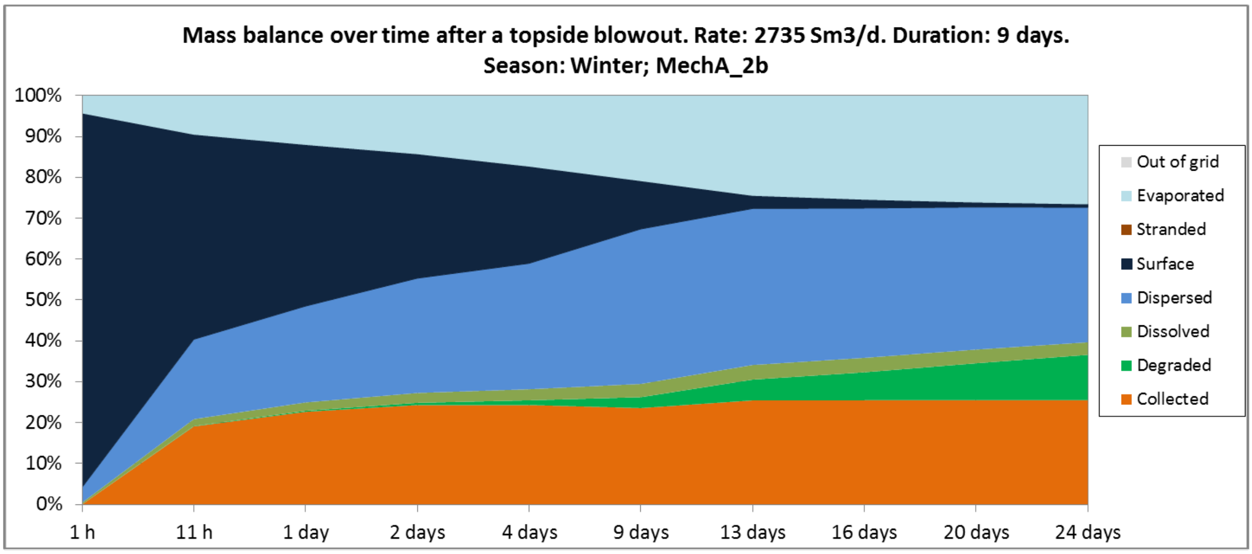

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechA_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



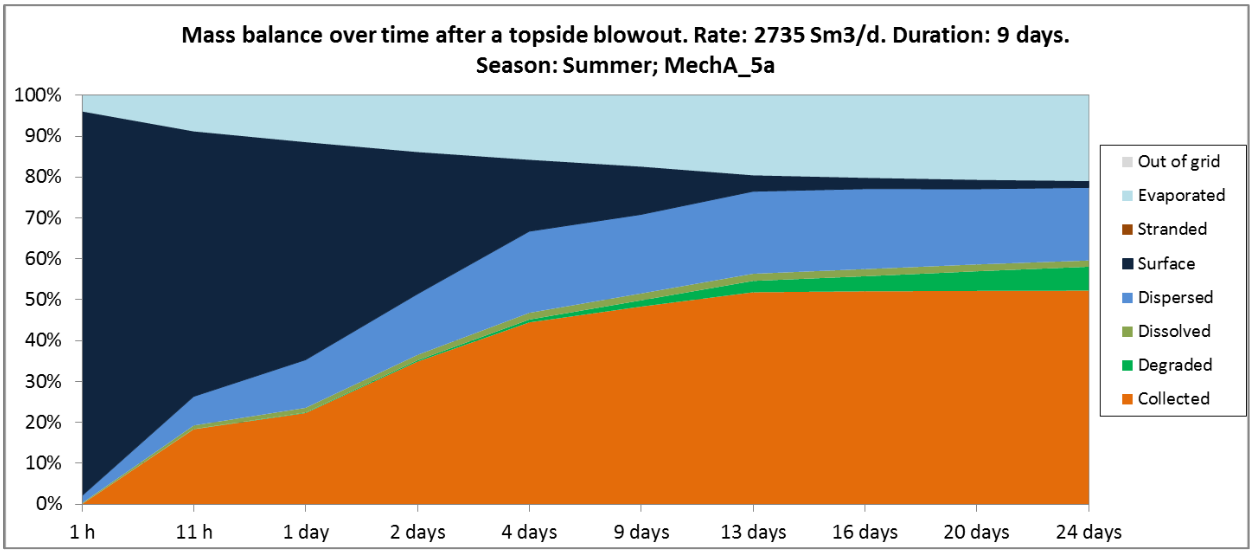
Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechA_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



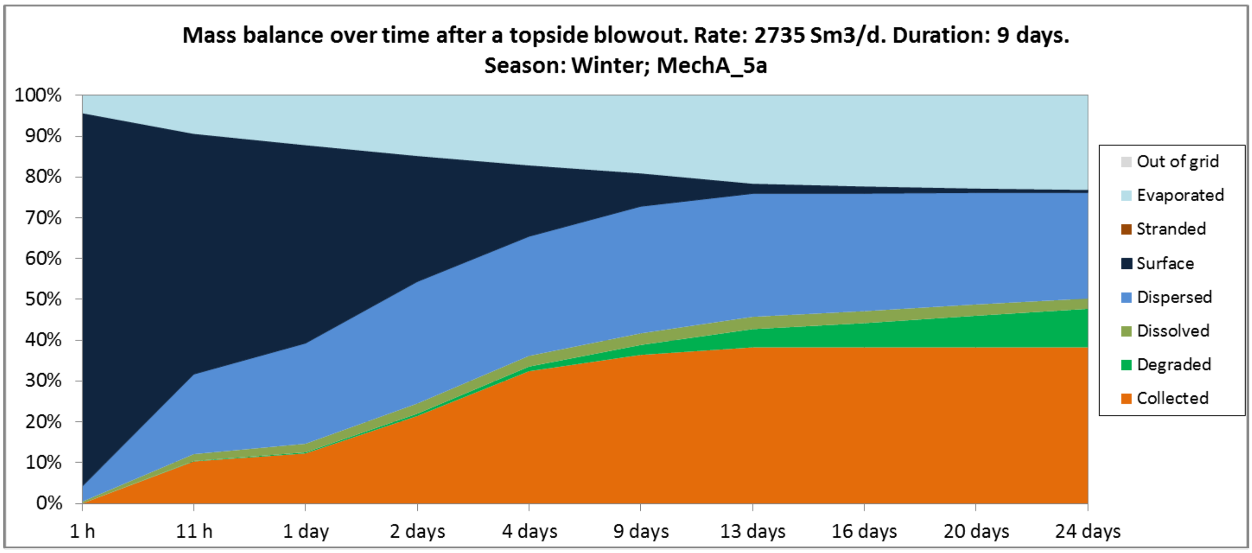
Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechA_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



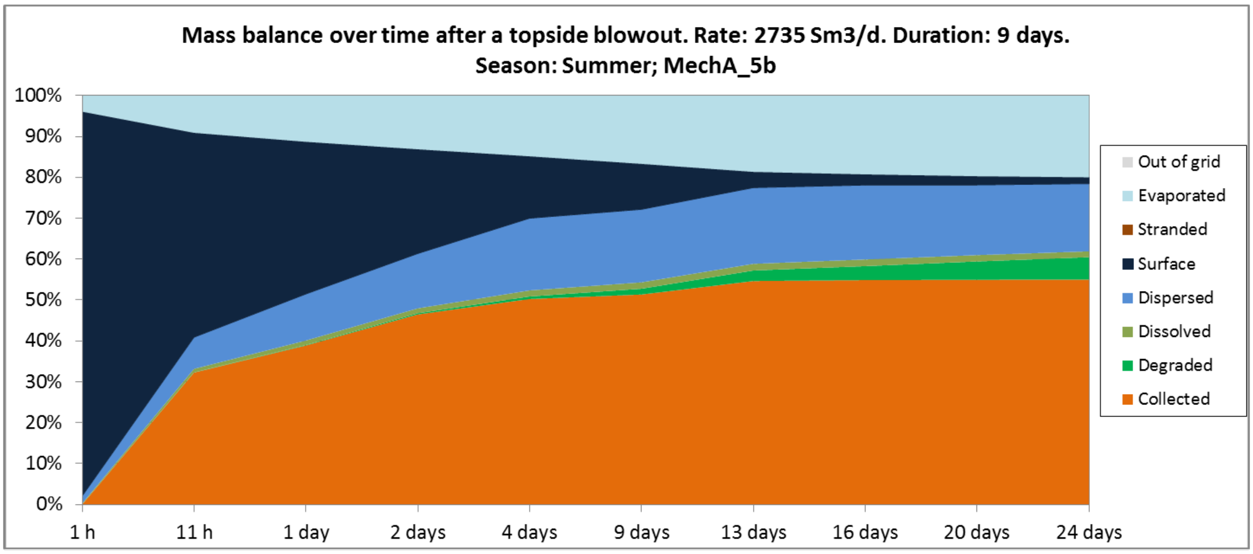
Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechA_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



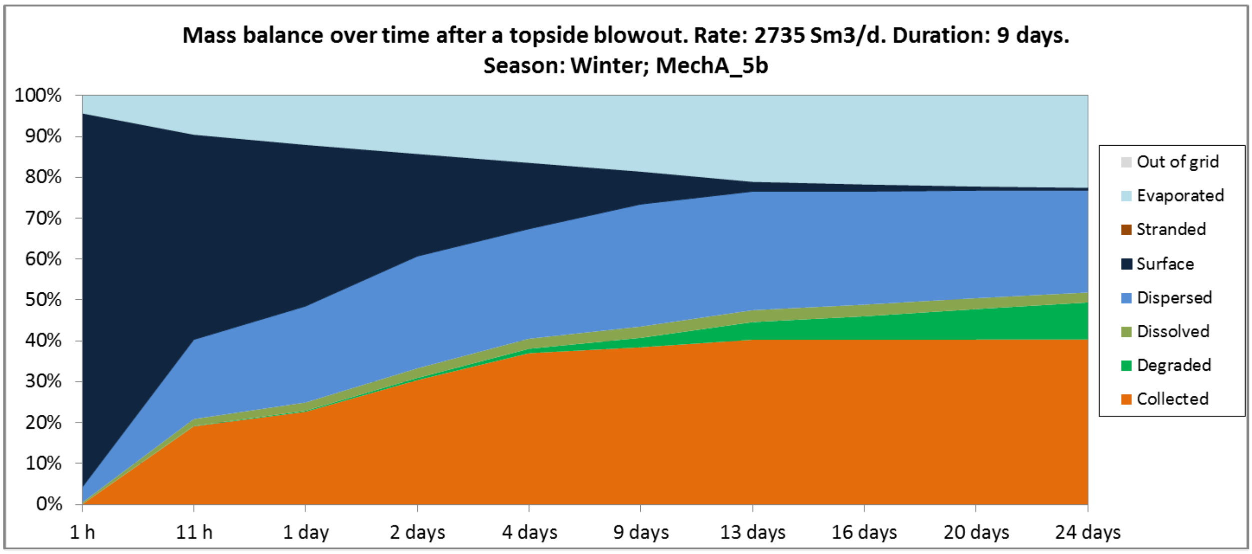
Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechA_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechA_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

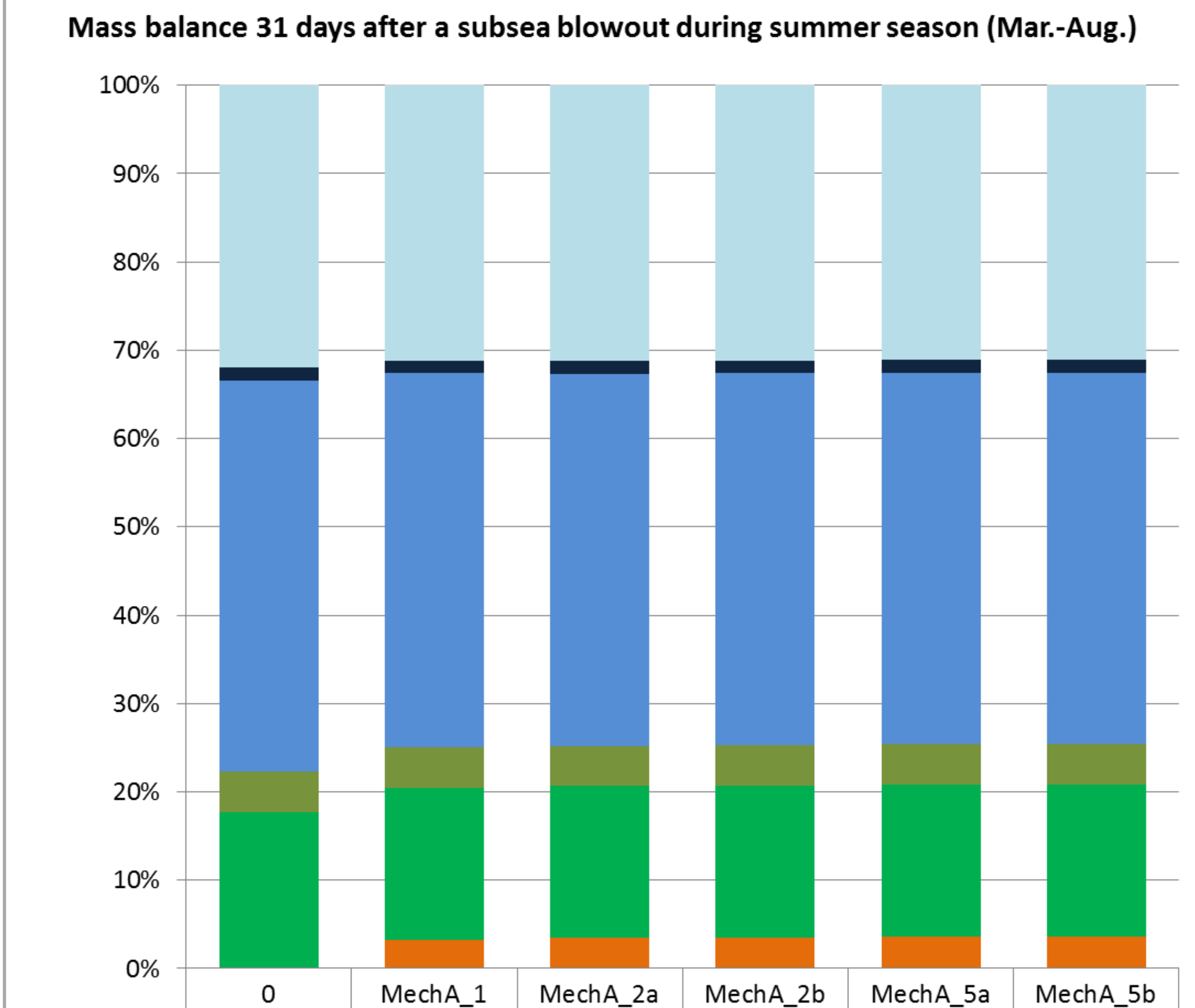


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; MechA_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

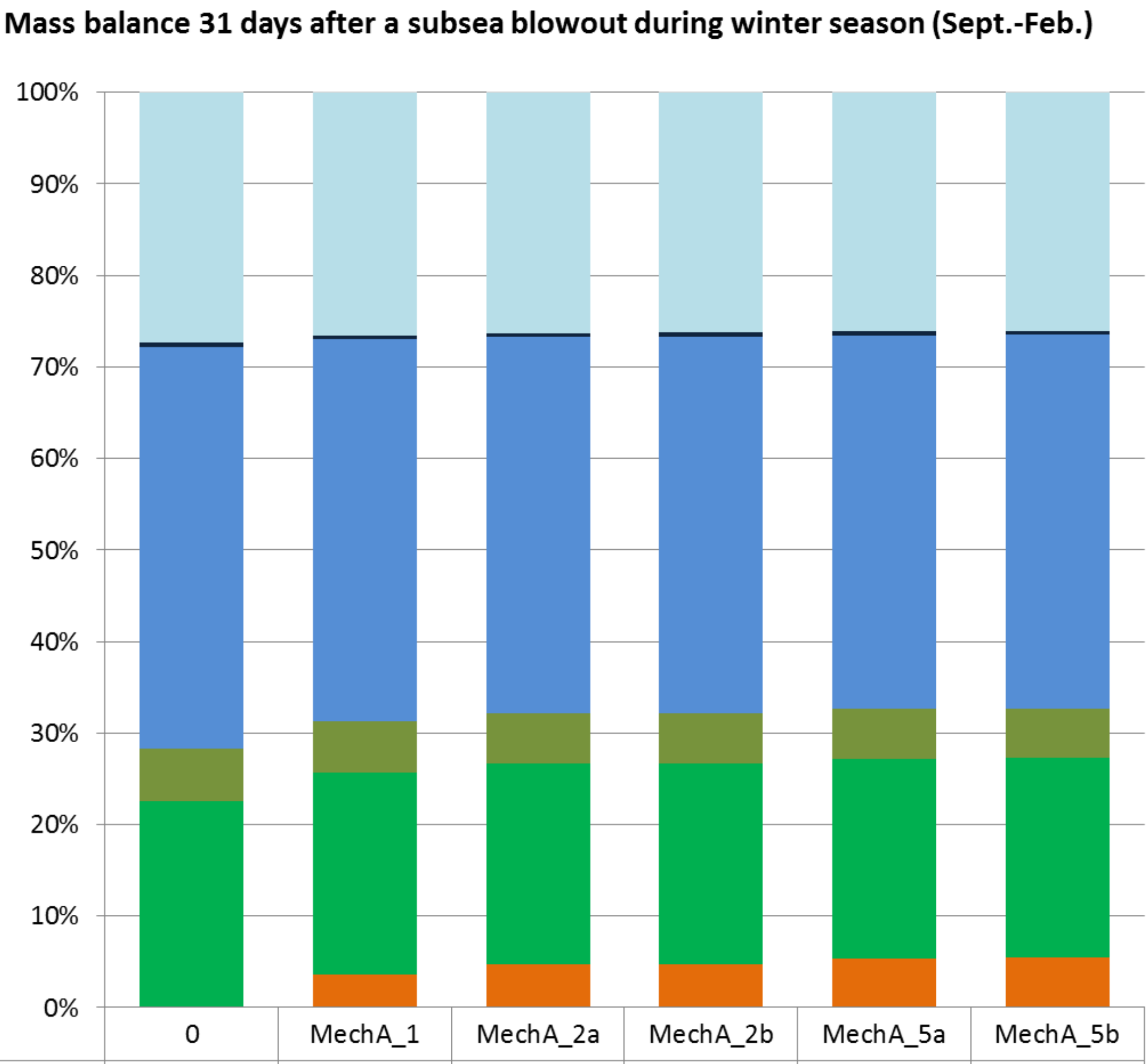


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; MechA_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

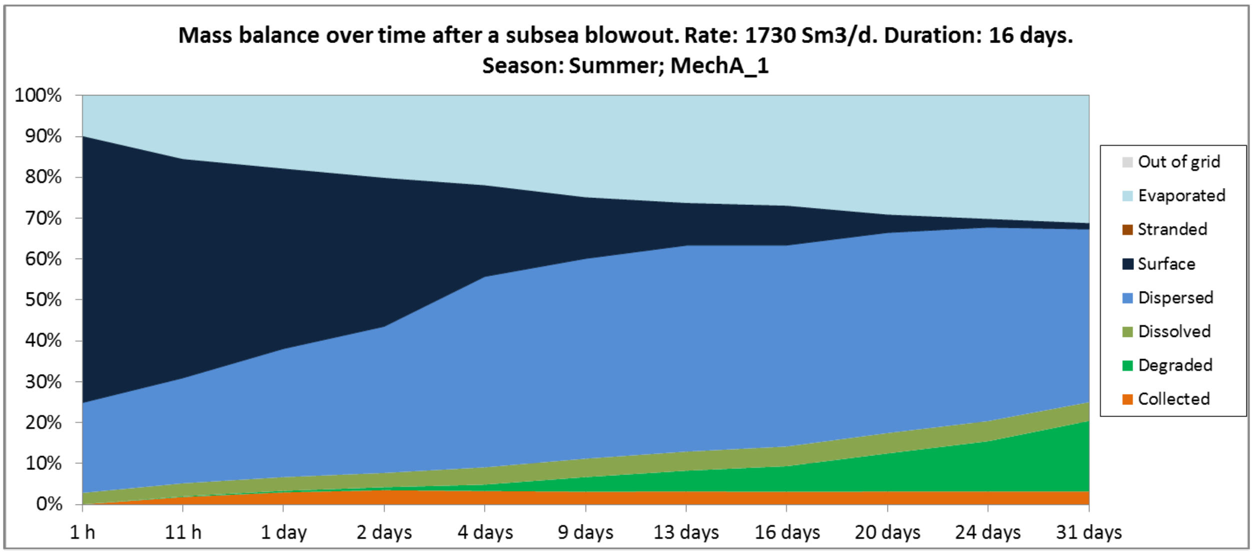
SUBSEA SCENARIO

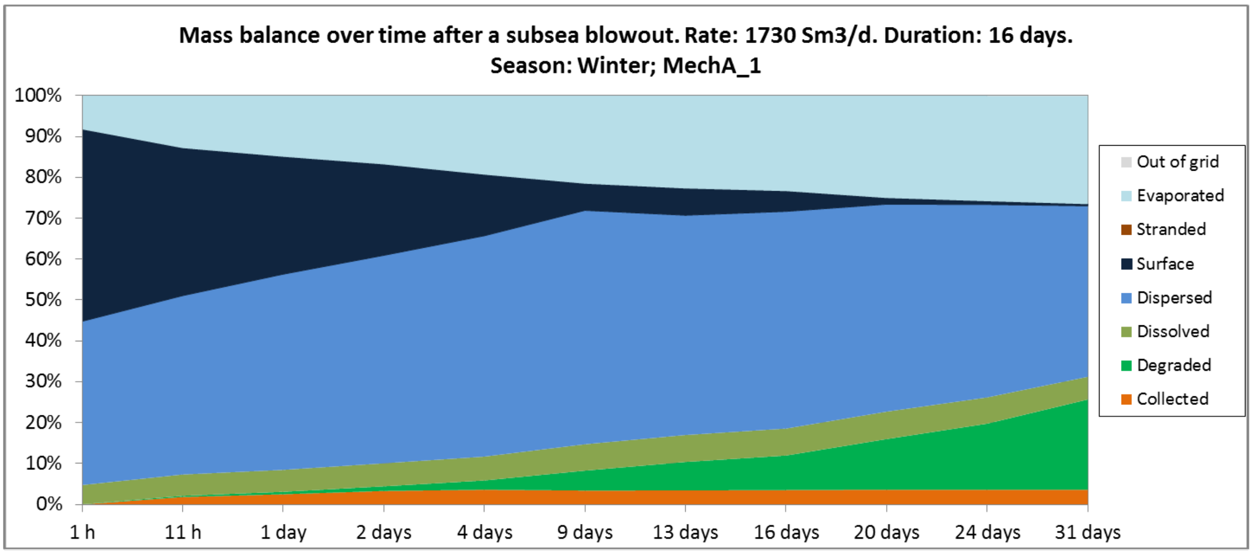


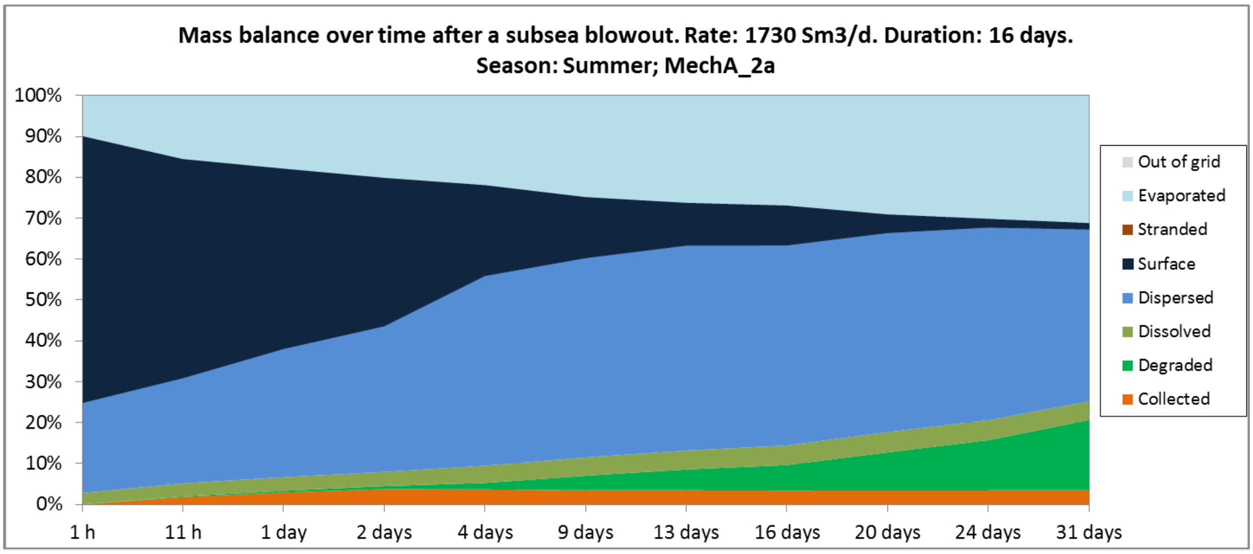
	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,2 %	31,2 %	31,1 %	31,1 %	31,1 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,4 %	1,5 %	1,5 %	1,5 %	1,5 %
Dispersed	44,2 %	42,4 %	42,1 %	42,1 %	42,0 %	42,0 %
Dissolved	4,7 %	4,6 %	4,5 %	4,5 %	4,5 %	4,5 %
Degraded	17,6 %	17,3 %	17,2 %	17,2 %	17,2 %	17,2 %
Collected	0,0 %	3,2 %	3,5 %	3,5 %	3,6 %	3,6 %

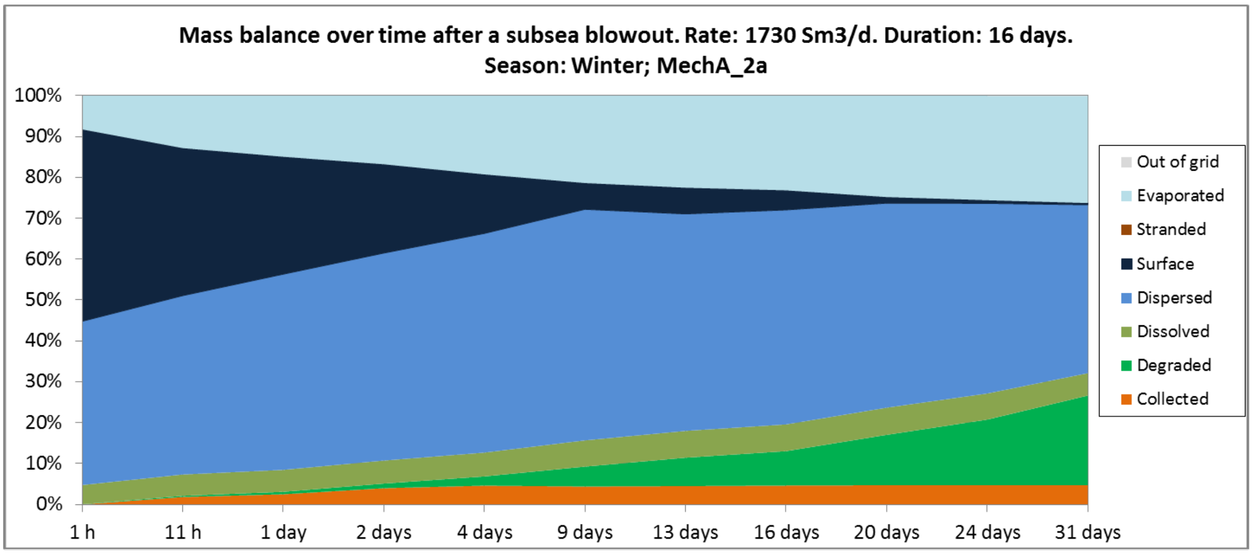


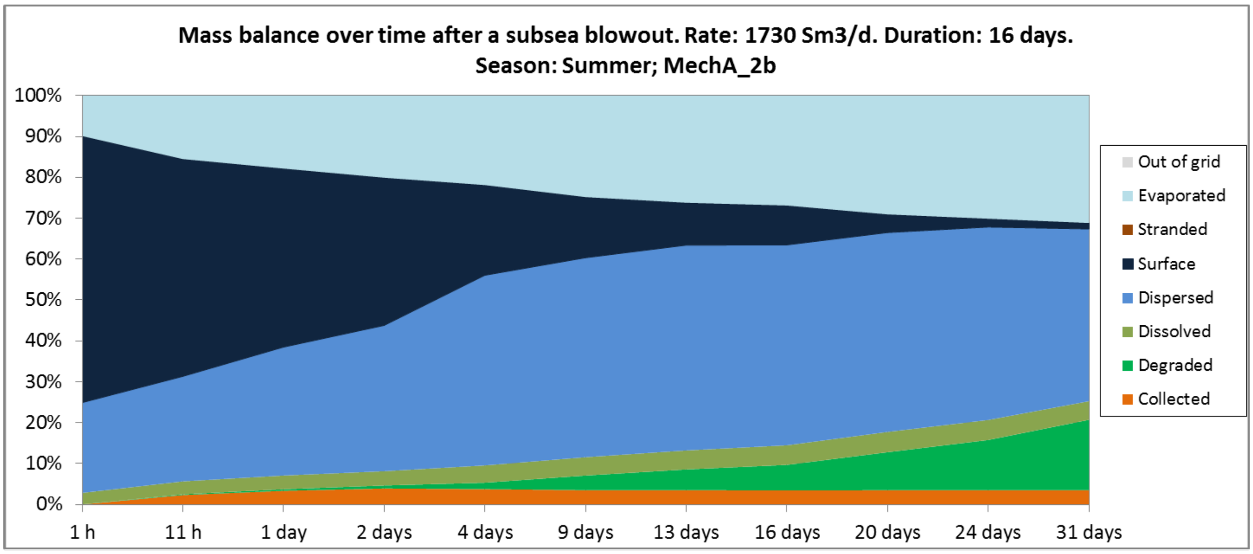
	0	MechA_1	MechA_2a	MechA_2b	MechA_5a	MechA_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	26,5 %	26,2 %	26,2 %	26,1 %	26,1 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,4 %	0,4 %	0,4 %	0,4 %
Dispersed	43,9 %	41,8 %	41,2 %	41,2 %	40,8 %	40,8 %
Dissolved	5,7 %	5,5 %	5,5 %	5,5 %	5,5 %	5,5 %
Degraded	22,6 %	22,1 %	21,9 %	21,9 %	21,8 %	21,8 %
Collected	0,0 %	3,6 %	4,7 %	4,7 %	5,4 %	5,4 %

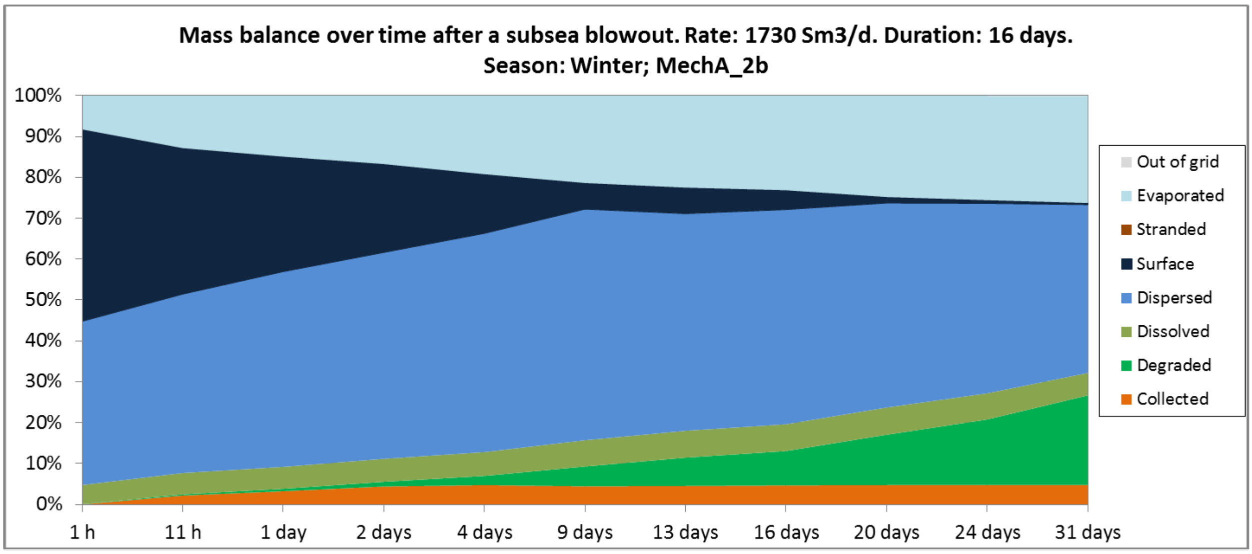

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

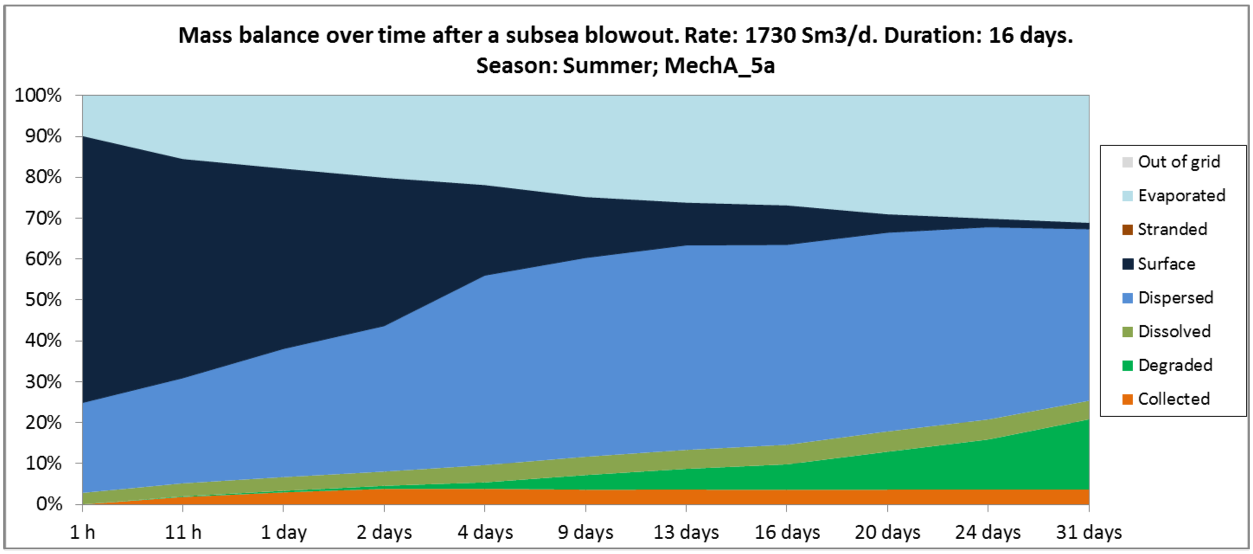

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechA_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

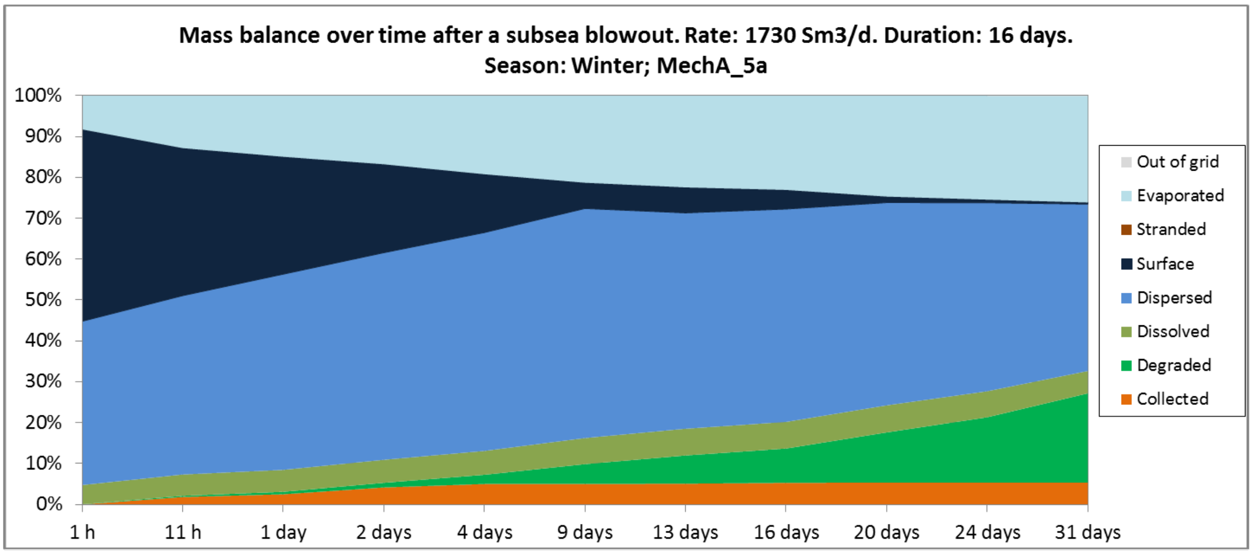

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechA_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechA_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

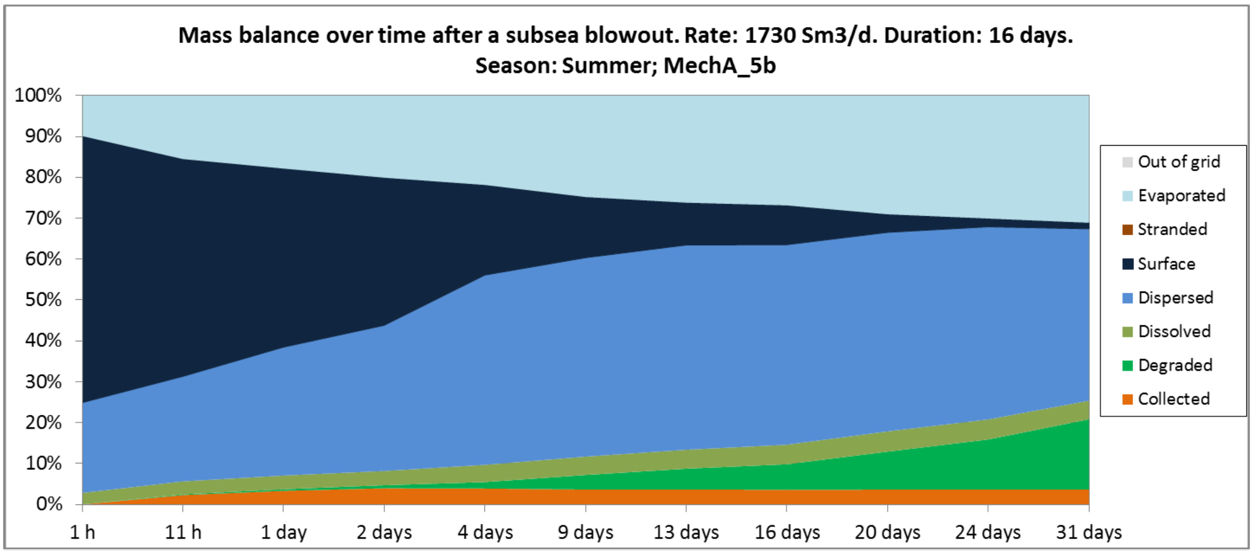

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechA_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



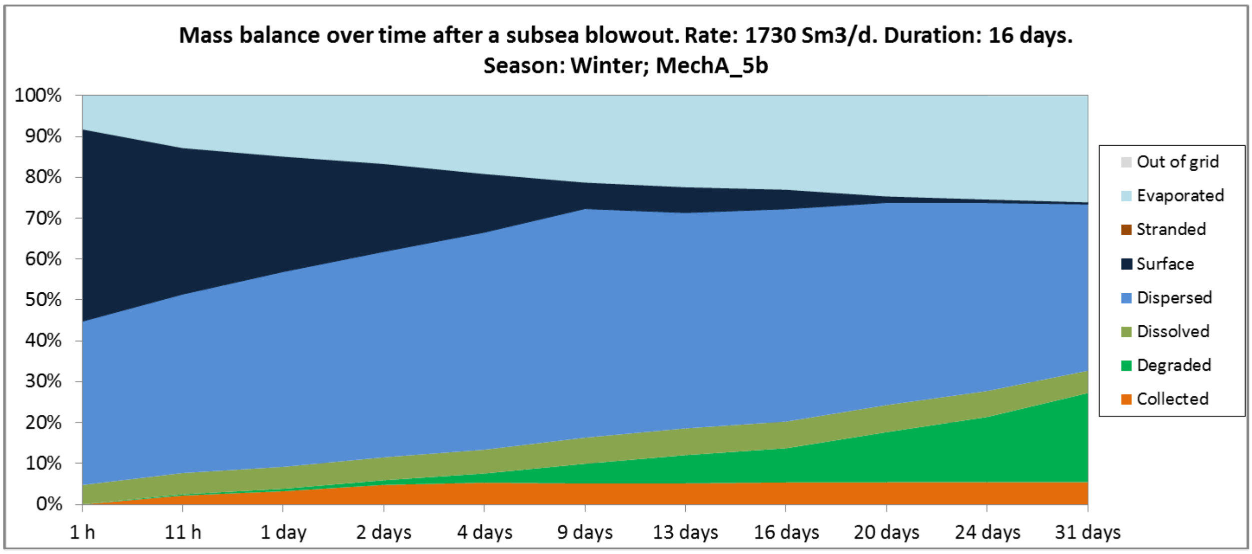
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechA_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechA_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



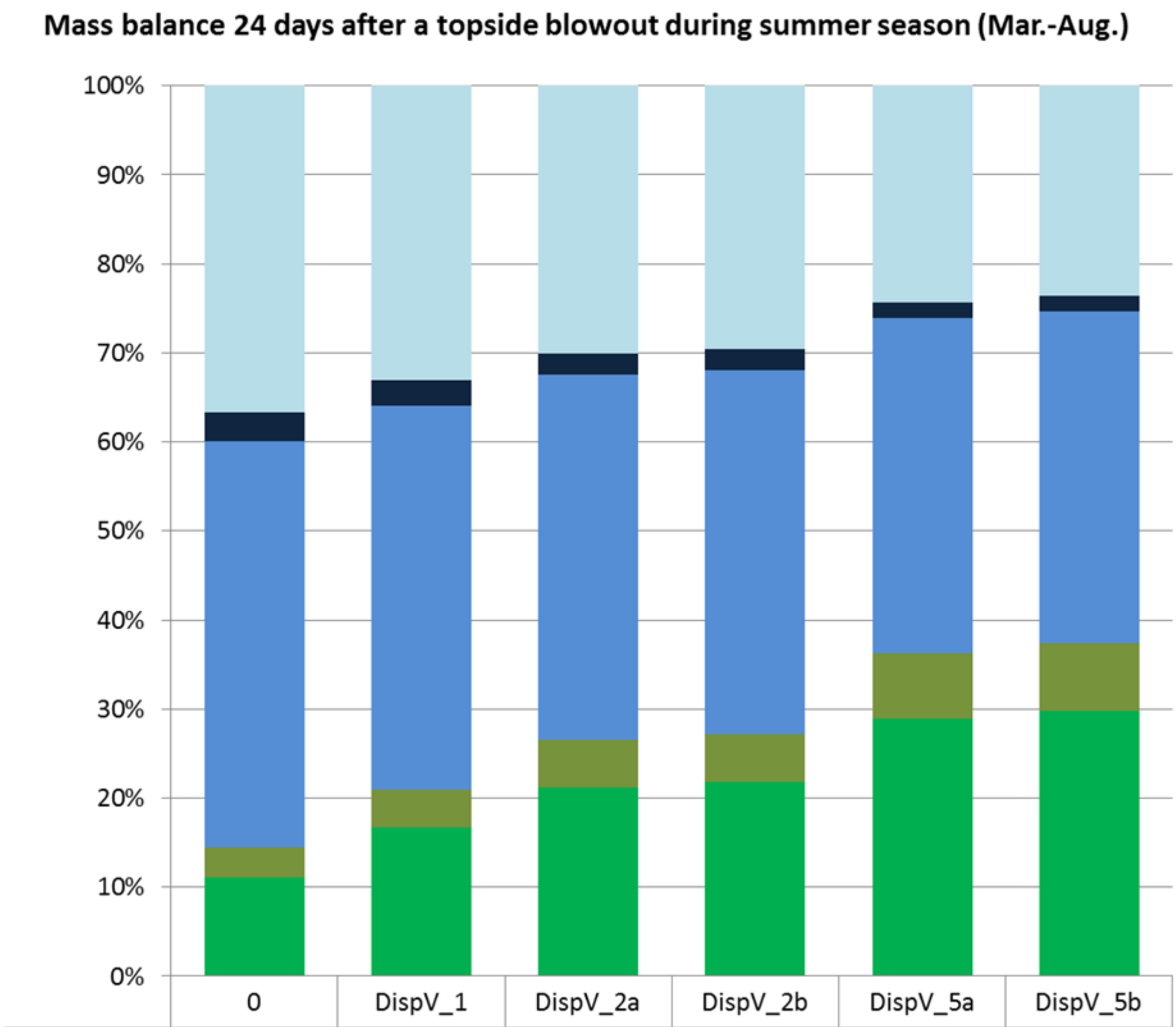
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; MechA_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; MechA_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

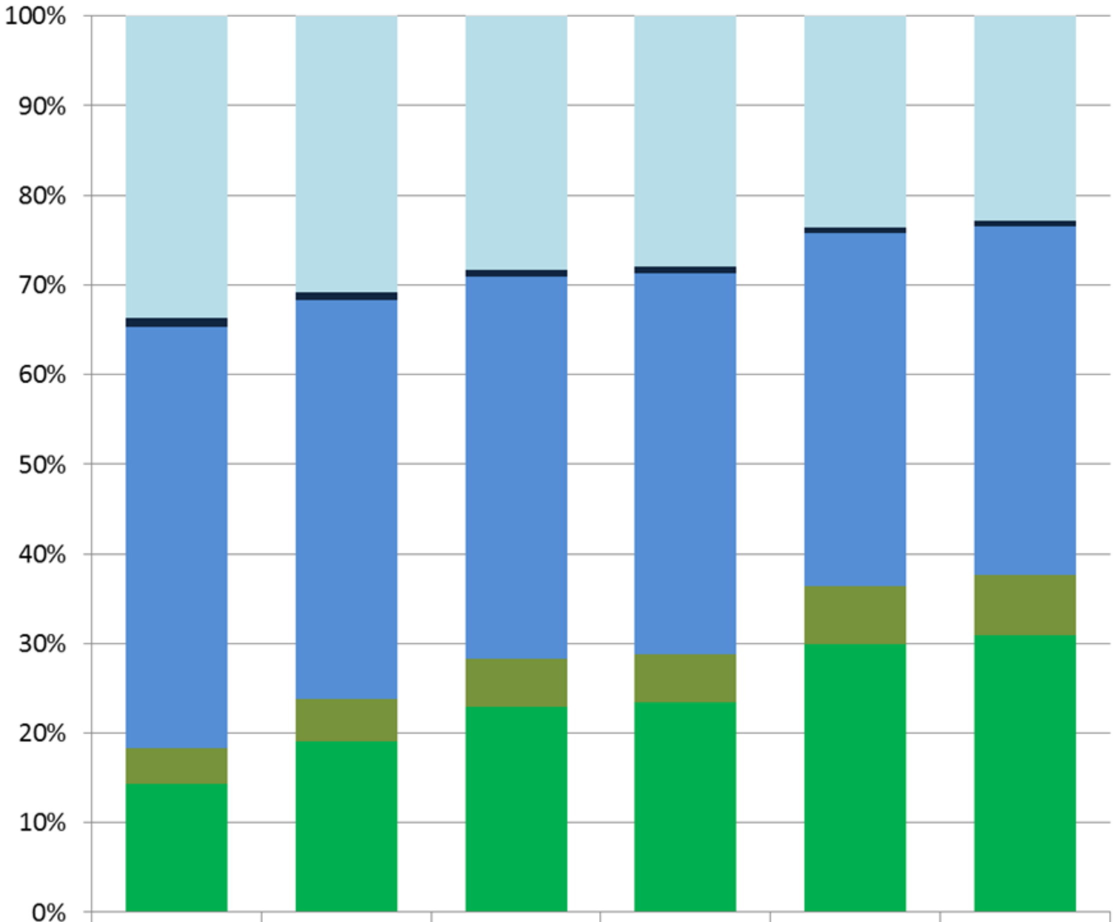
B.3 Response measure DispV

TOPSIDE SCENARIO

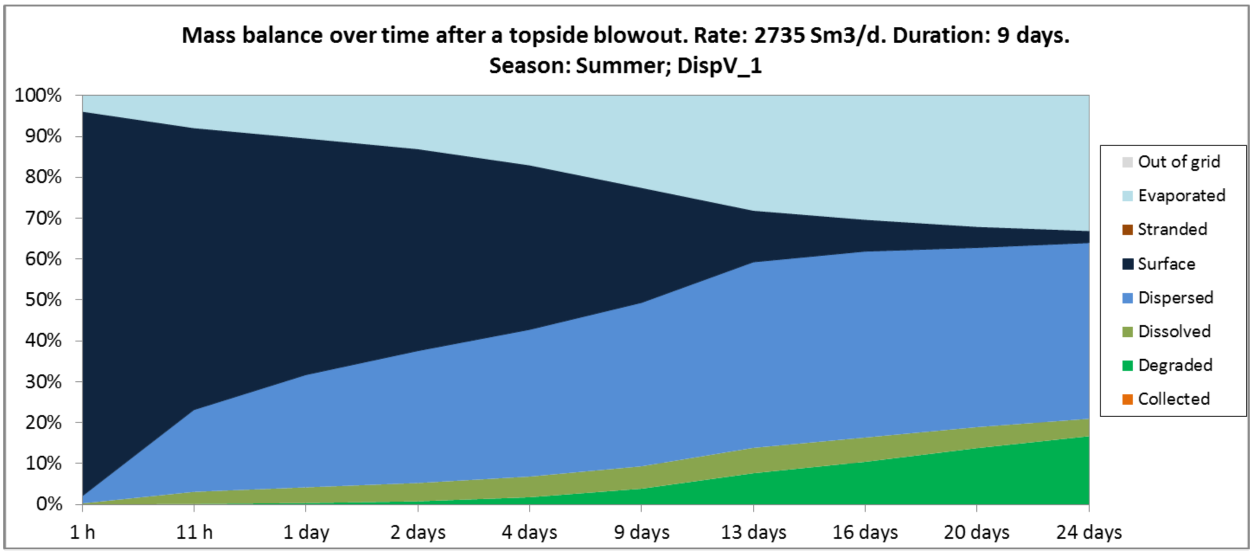


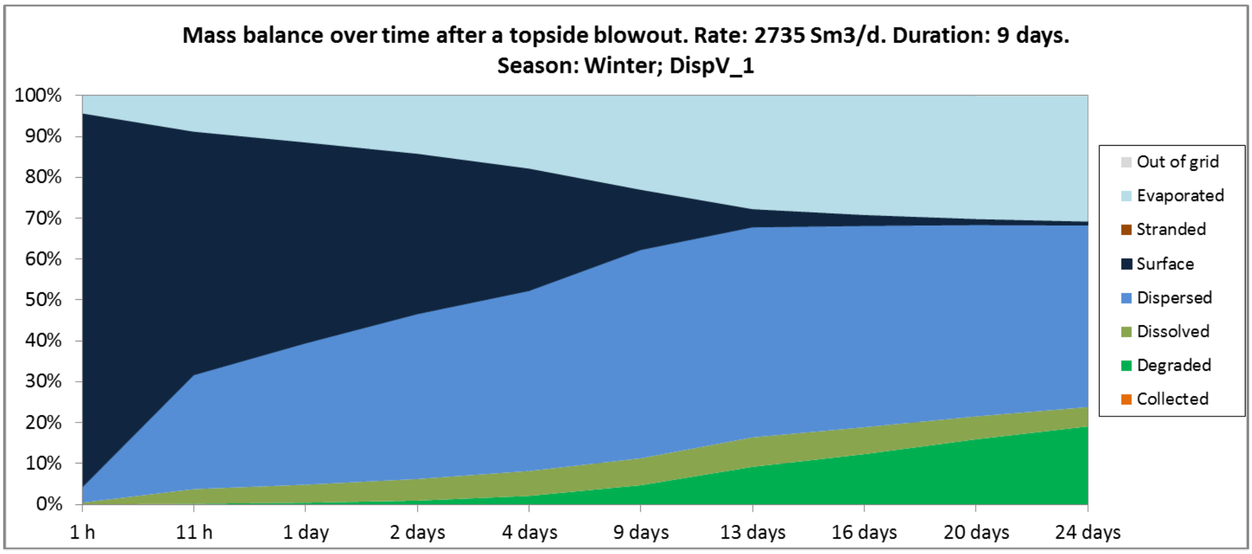
	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	33,1 %	30,1 %	29,5 %	24,3 %	23,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,8 %	2,4 %	2,4 %	1,8 %	1,7 %
Dispersed	45,7 %	43,1 %	41,1 %	40,8 %	37,7 %	37,3 %
Dissolved	3,4 %	4,3 %	5,2 %	5,4 %	7,3 %	7,5 %
Degraded	11,1 %	16,7 %	21,2 %	21,8 %	28,9 %	29,8 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

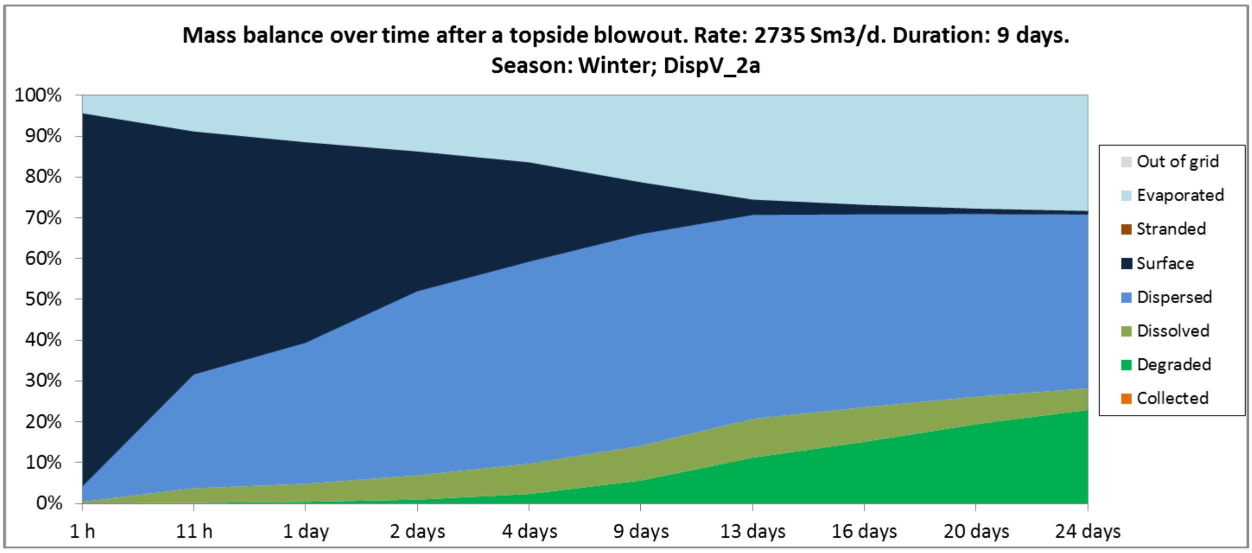
Mass balance 24 days after a topside blowout during winter season (Sept.-Feb.)

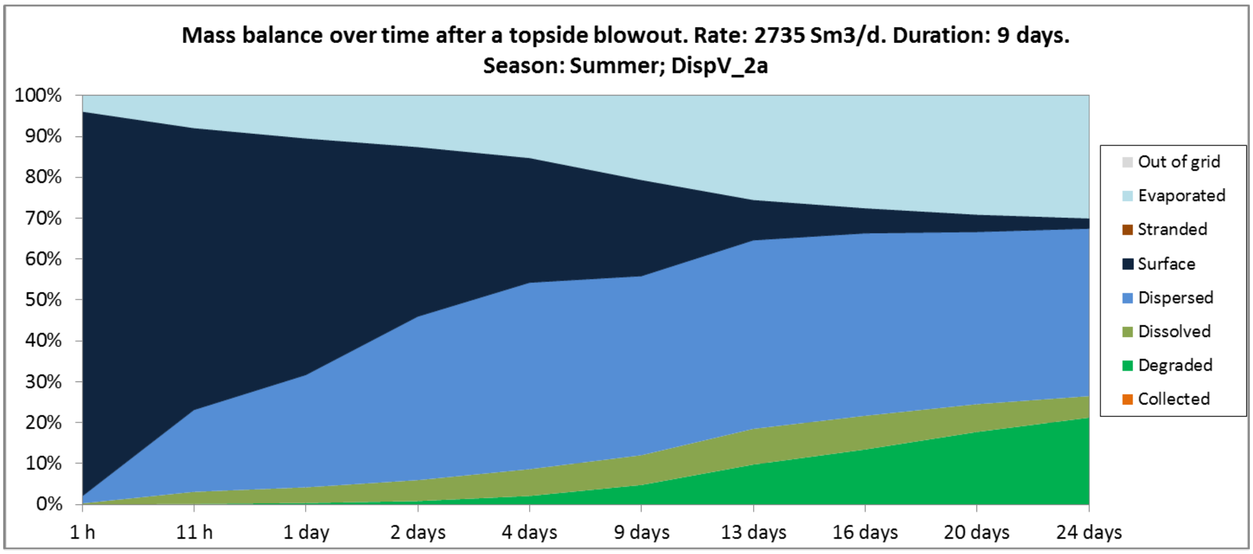


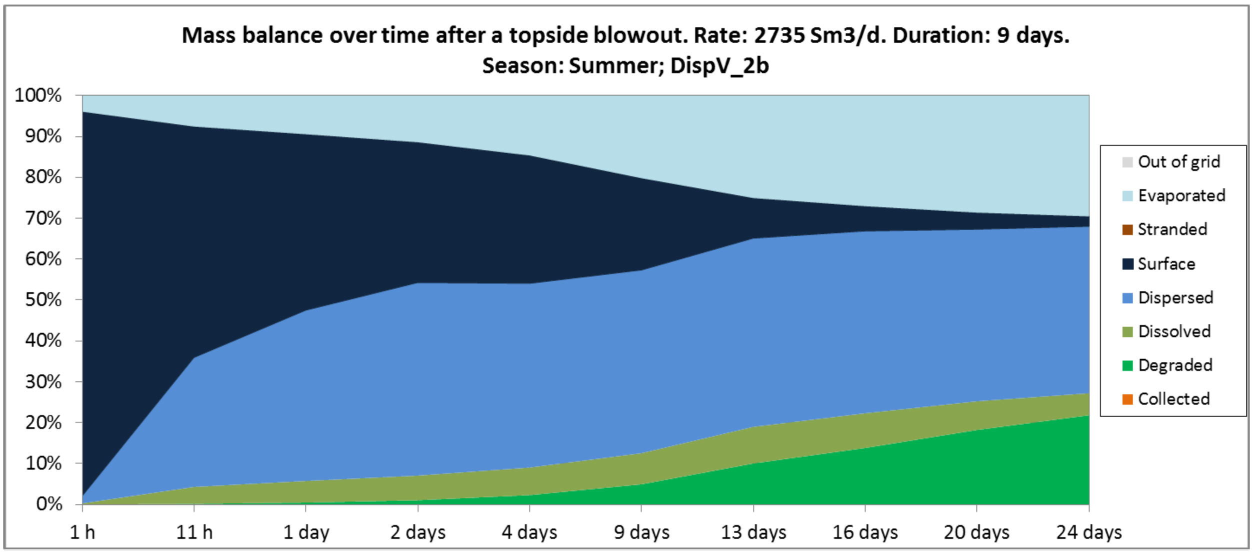
	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	30,8 %	28,3 %	27,9 %	23,6 %	22,9 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	0,7 %	0,7 %	0,6 %	0,6 %
Dispersed	46,9 %	44,5 %	42,7 %	42,5 %	39,3 %	38,9 %
Dissolved	4,1 %	4,7 %	5,3 %	5,4 %	6,6 %	6,7 %
Degraded	14,3 %	19,1 %	22,9 %	23,4 %	29,9 %	30,9 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

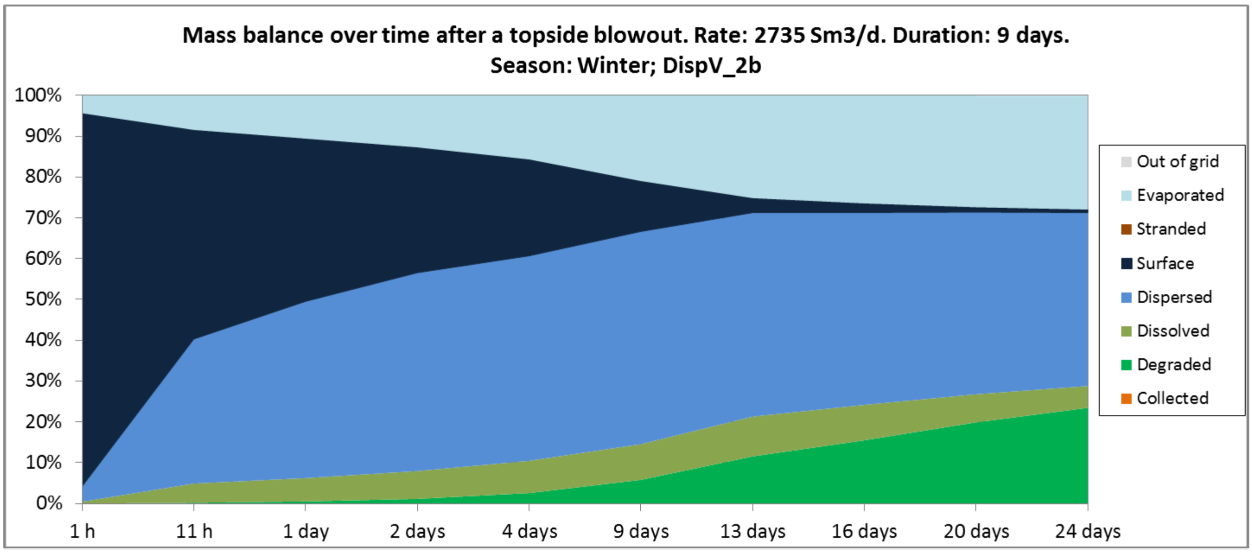

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; DispV_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

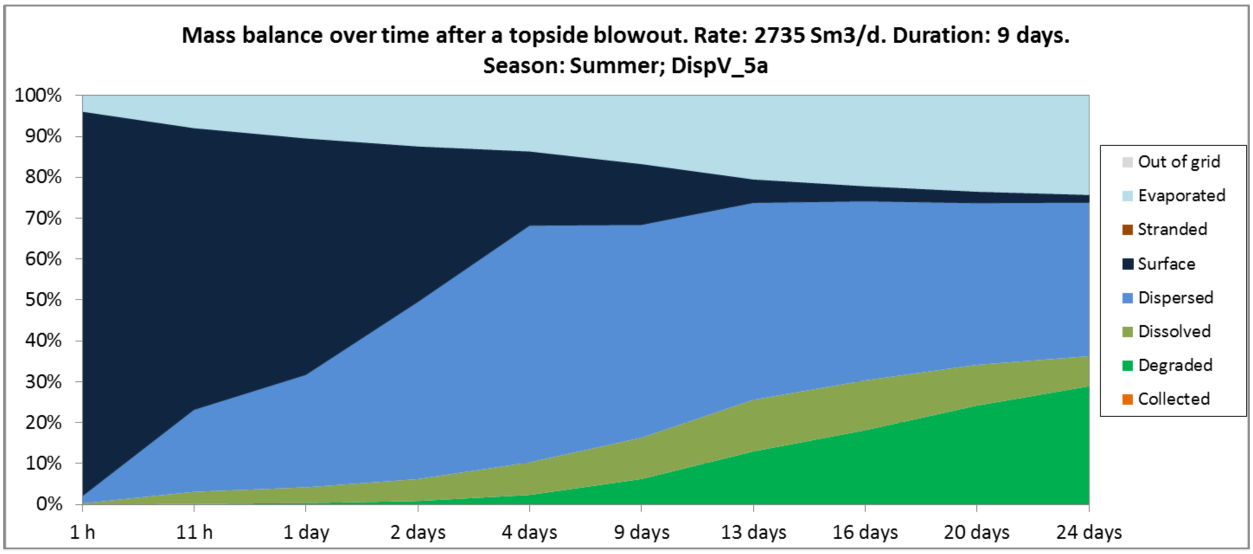

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; DispV_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

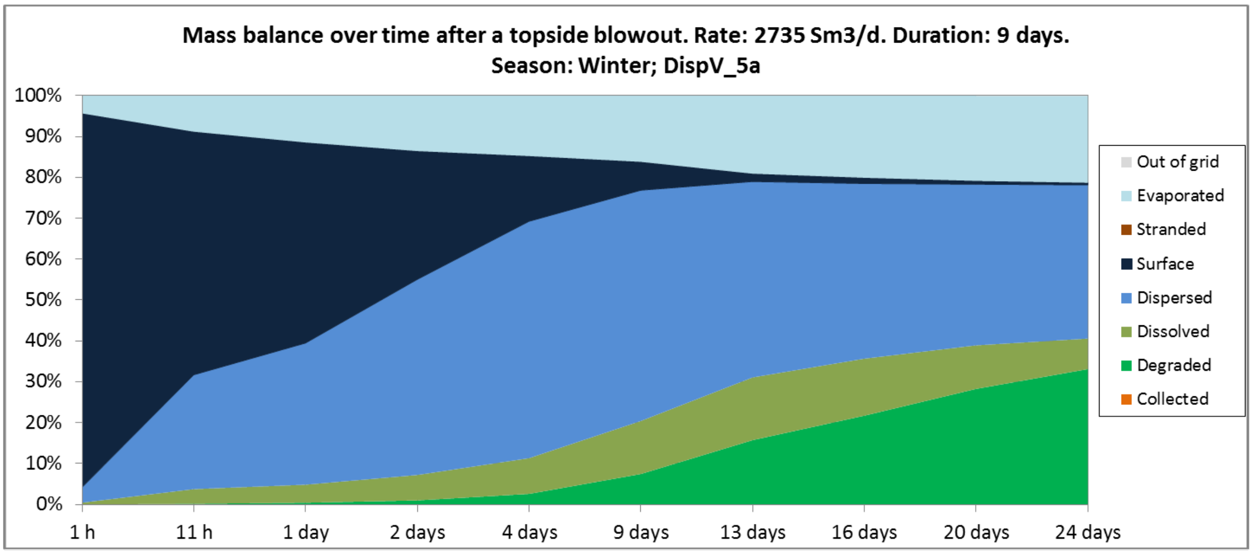

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; DispV_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

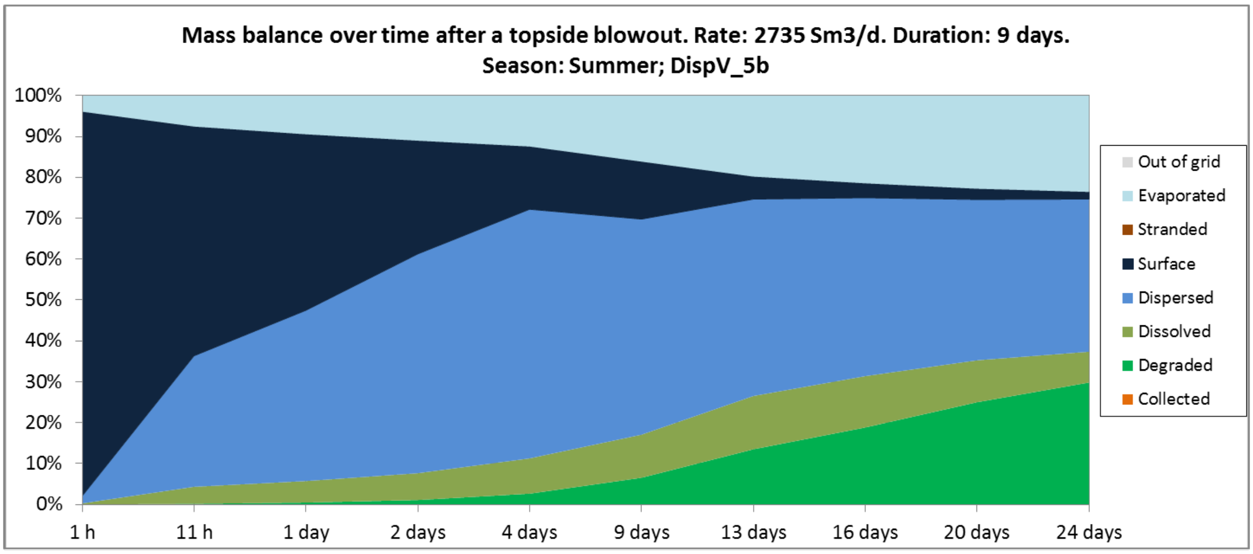

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; DispV_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

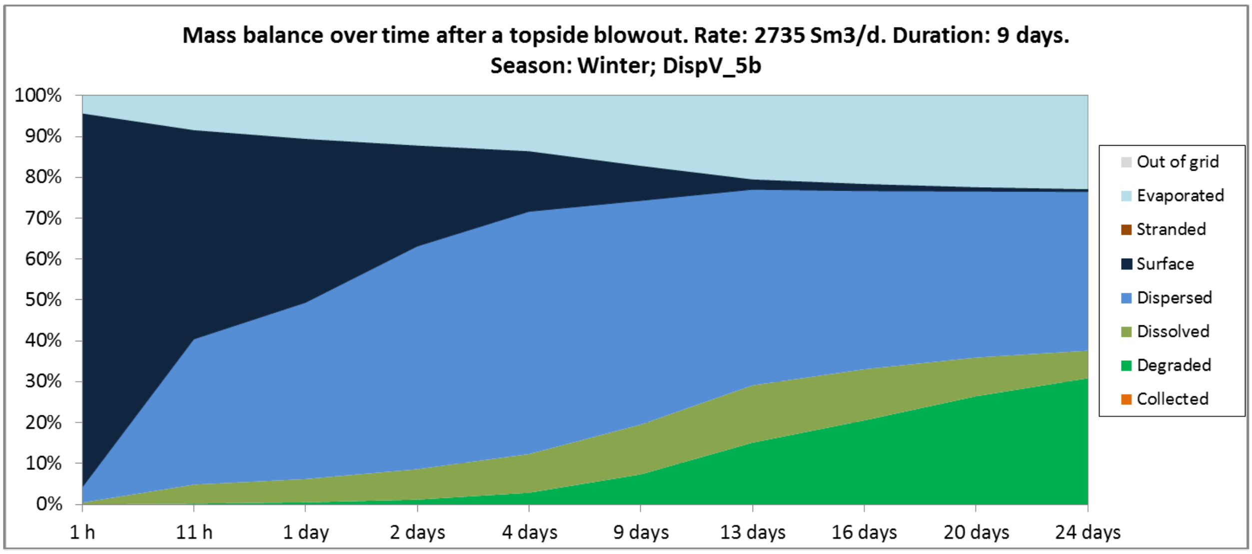

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; DispV_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; DispV_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; DispV_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

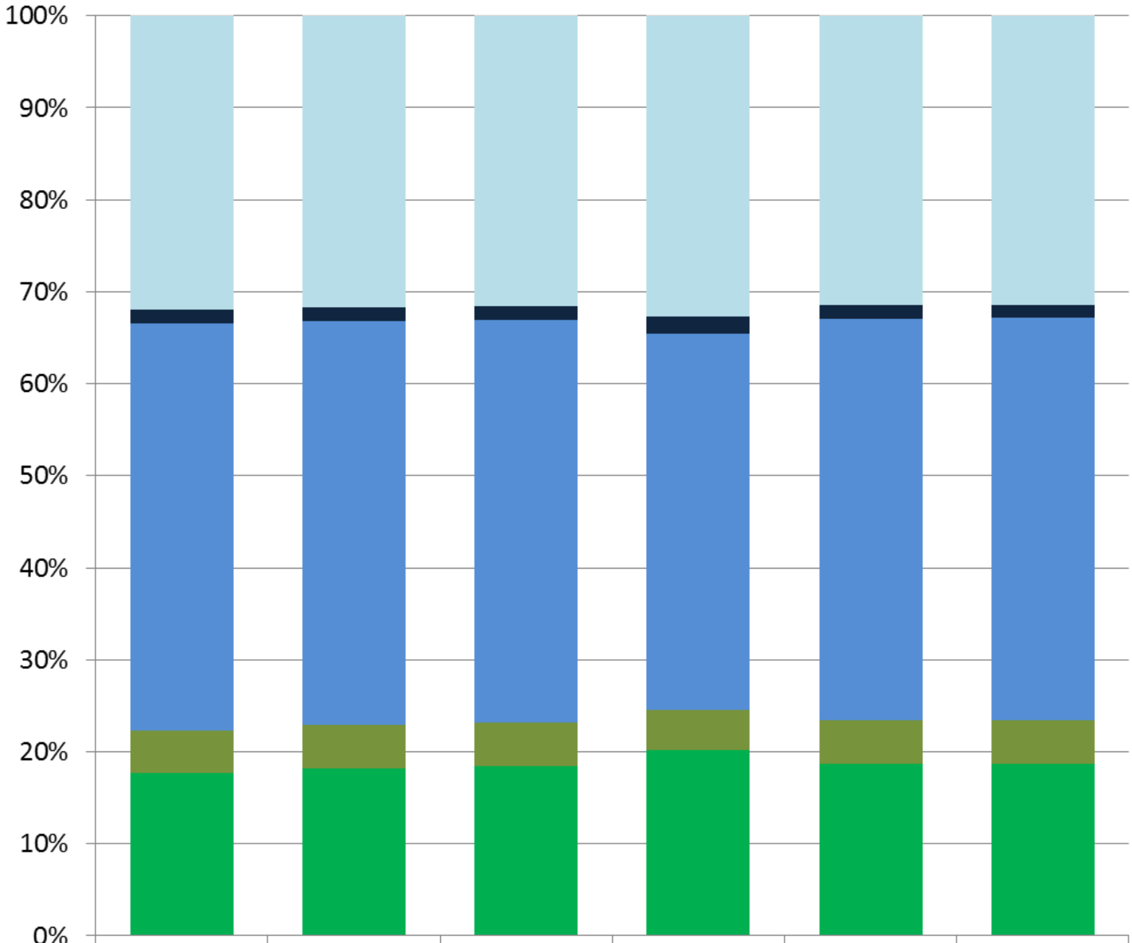

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; DispV_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; DispV_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

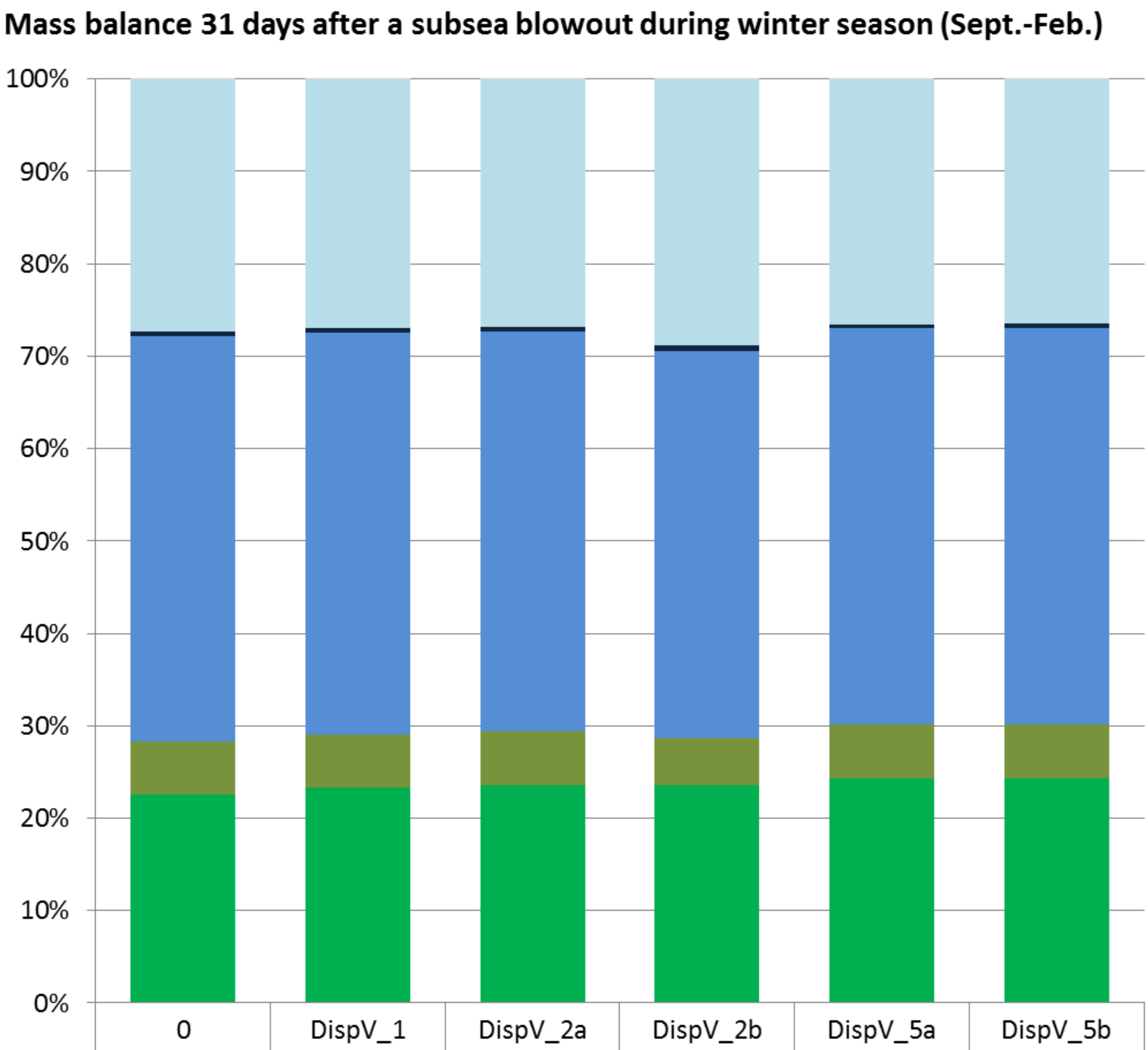

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; DispV_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

SUBSEA SCENARIO

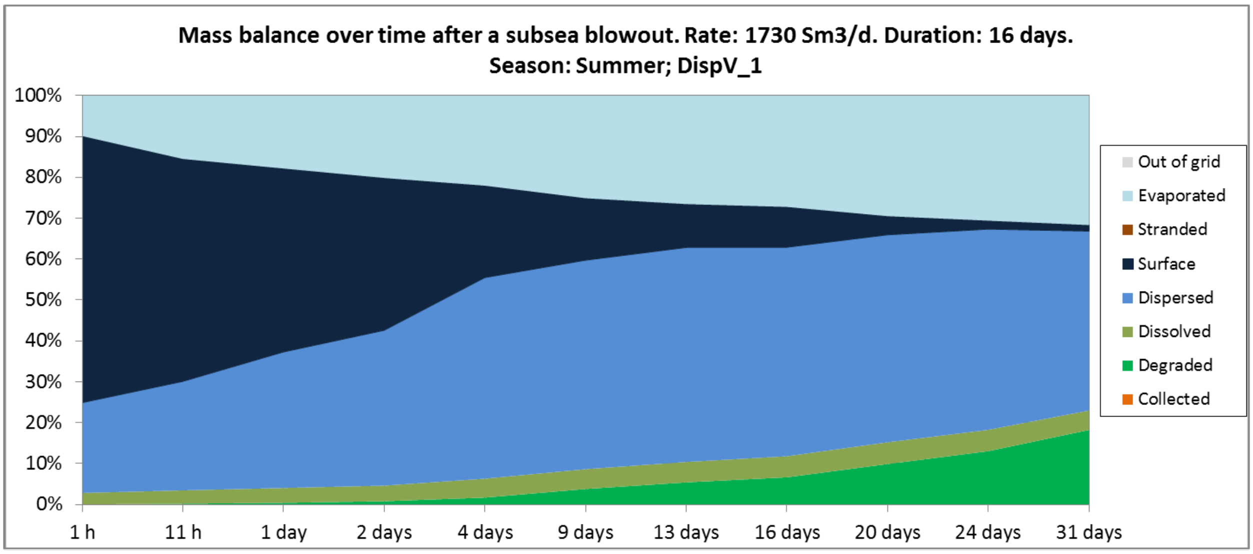
Mass balance 31 days after a subsea blowout during summer season (Mar.-Aug.)

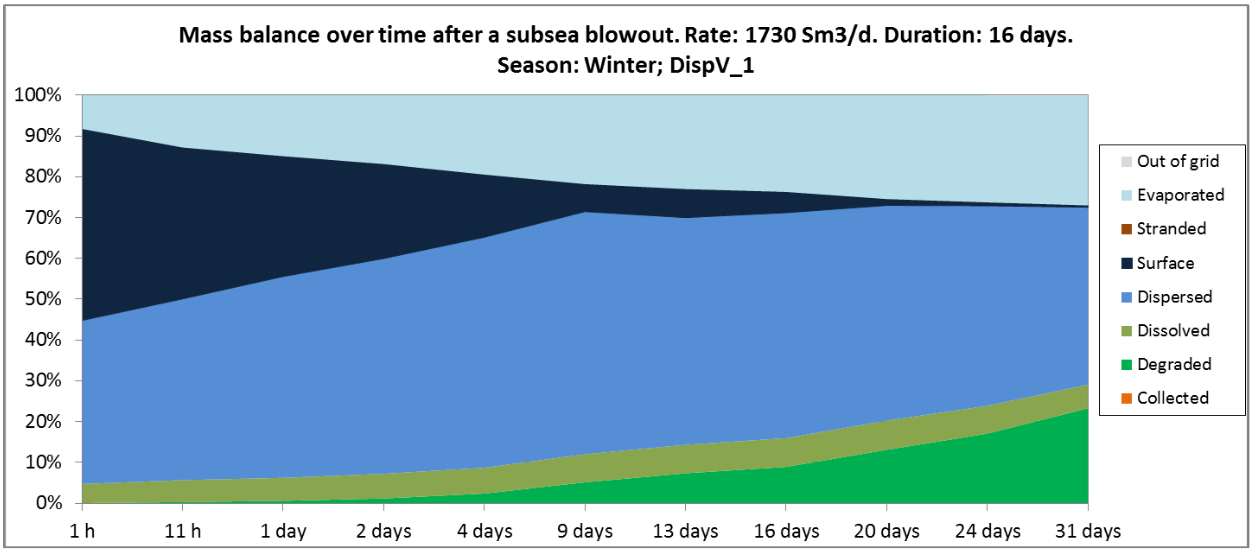


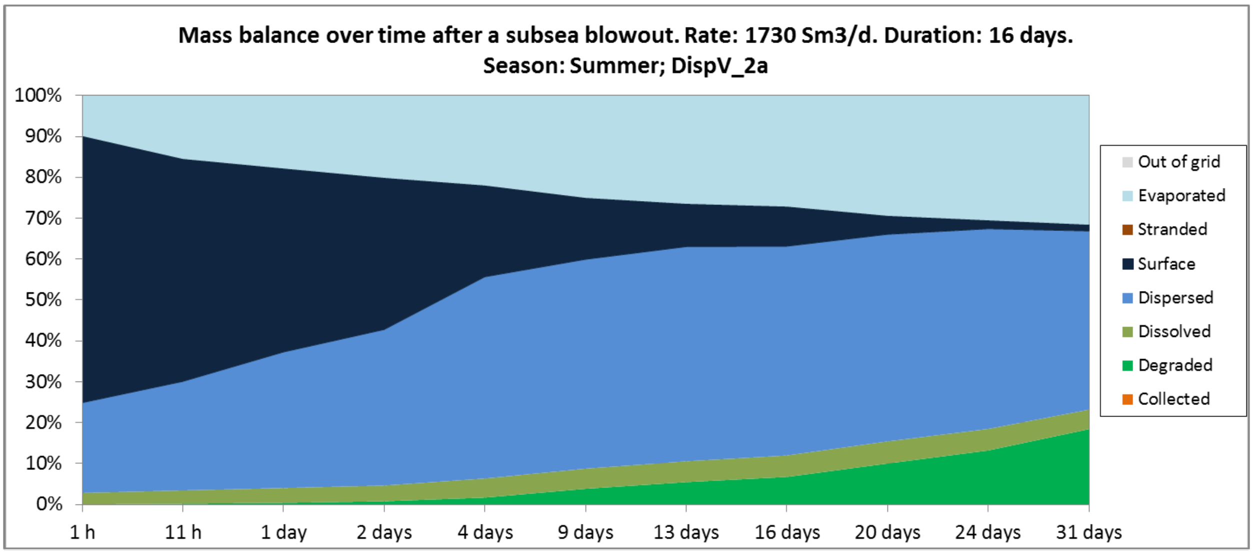
	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,7 %	31,6 %	32,7 %	31,5 %	31,4 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,5 %	1,5 %	1,9 %	1,4 %	1,4 %
Dispersed	44,2 %	43,9 %	43,7 %	40,9 %	43,7 %	43,6 %
Dissolved	4,7 %	4,8 %	4,8 %	4,3 %	4,8 %	4,8 %
Degraded	17,6 %	18,2 %	18,4 %	20,2 %	18,6 %	18,7 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

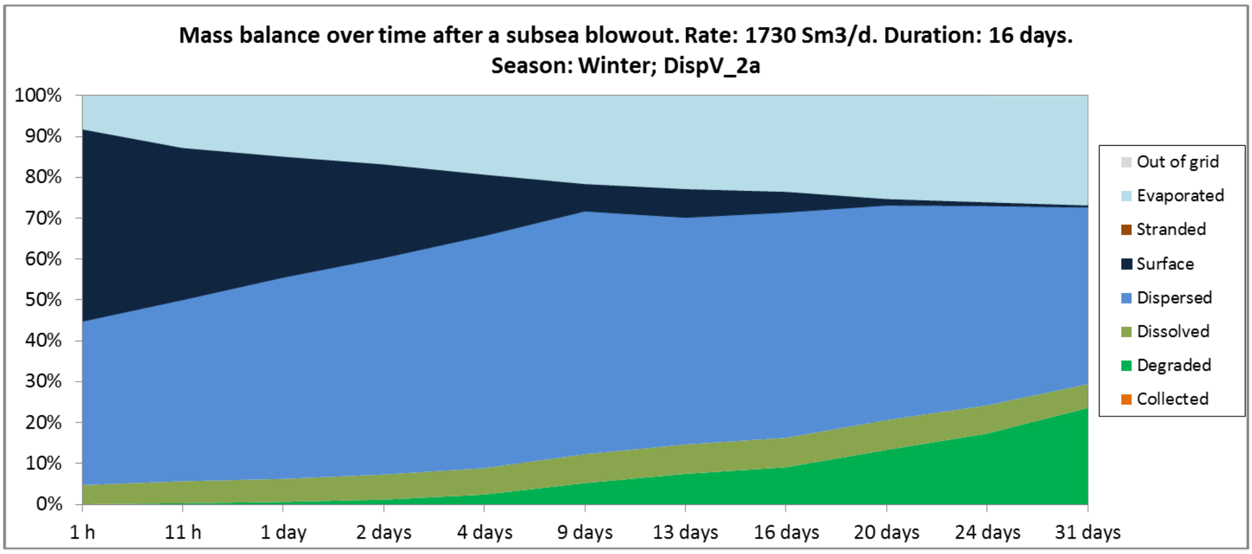


	0	DispV_1	DispV_2a	DispV_2b	DispV_5a	DispV_5b
Out of grid	0,0 %	0,1 %	0,1 %	0,0 %	0,1 %	0,0 %
Evaporated	27,3 %	27,0 %	26,8 %	28,8 %	26,5 %	26,5 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,4 %	0,6 %	0,4 %	0,4 %
Dispersed	43,9 %	43,5 %	43,3 %	41,9 %	42,9 %	42,9 %
Dissolved	5,7 %	5,8 %	5,8 %	5,0 %	5,9 %	5,9 %
Degraded	22,6 %	23,3 %	23,6 %	23,6 %	24,2 %	24,3 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %

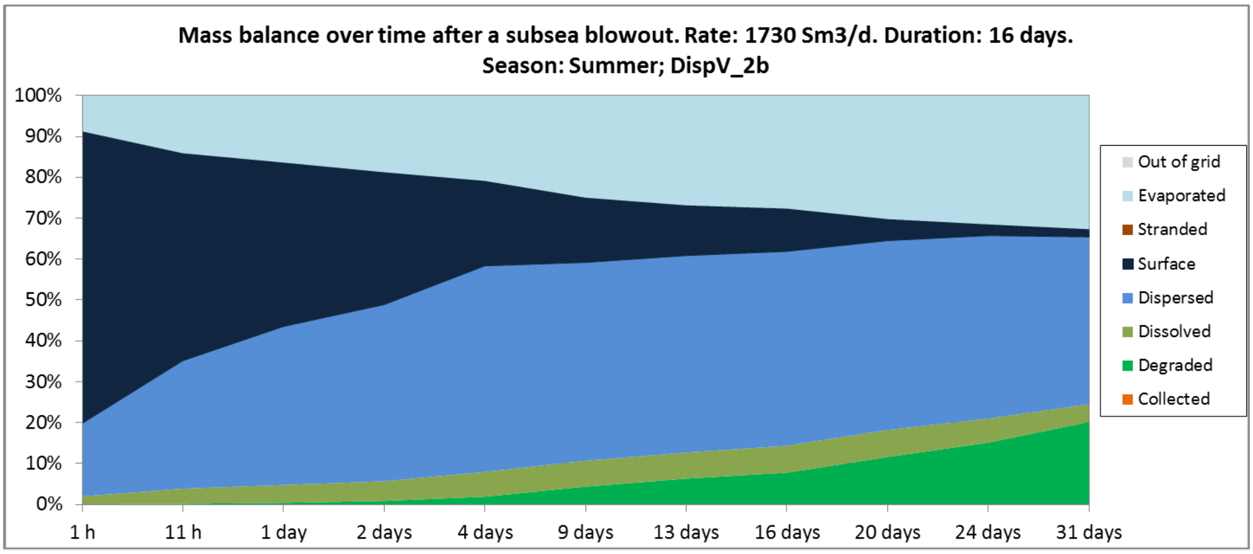

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispV_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispV_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

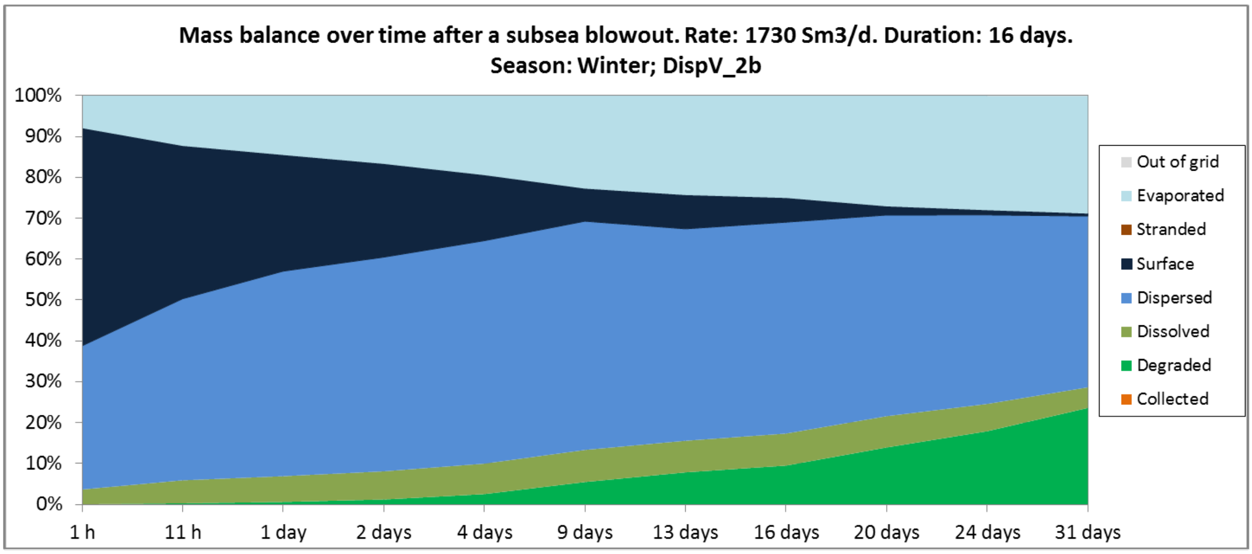

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispV_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



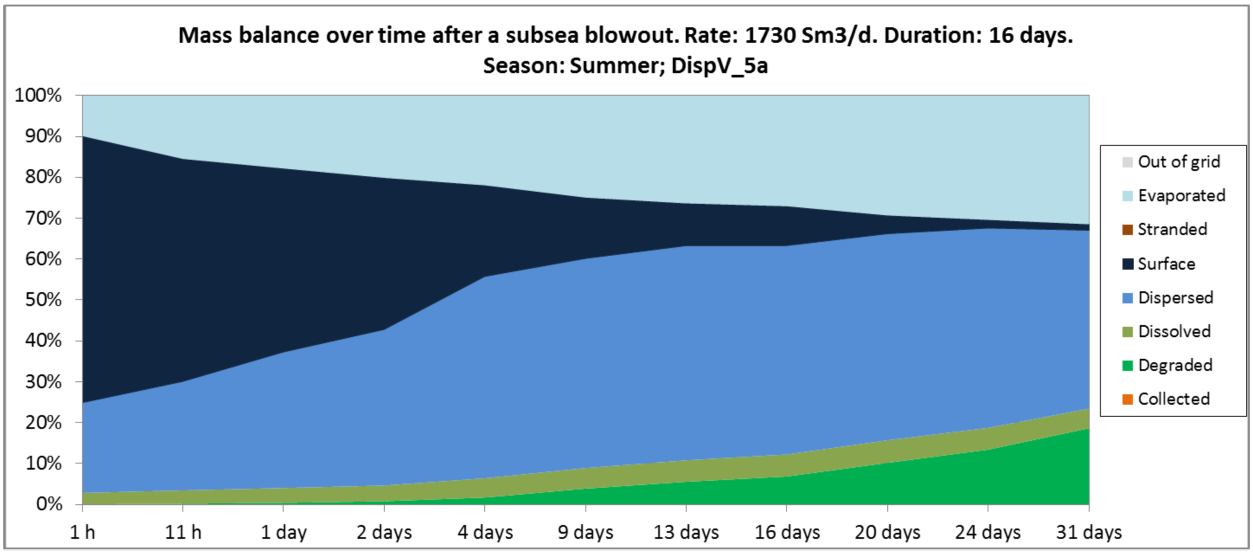
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispV_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



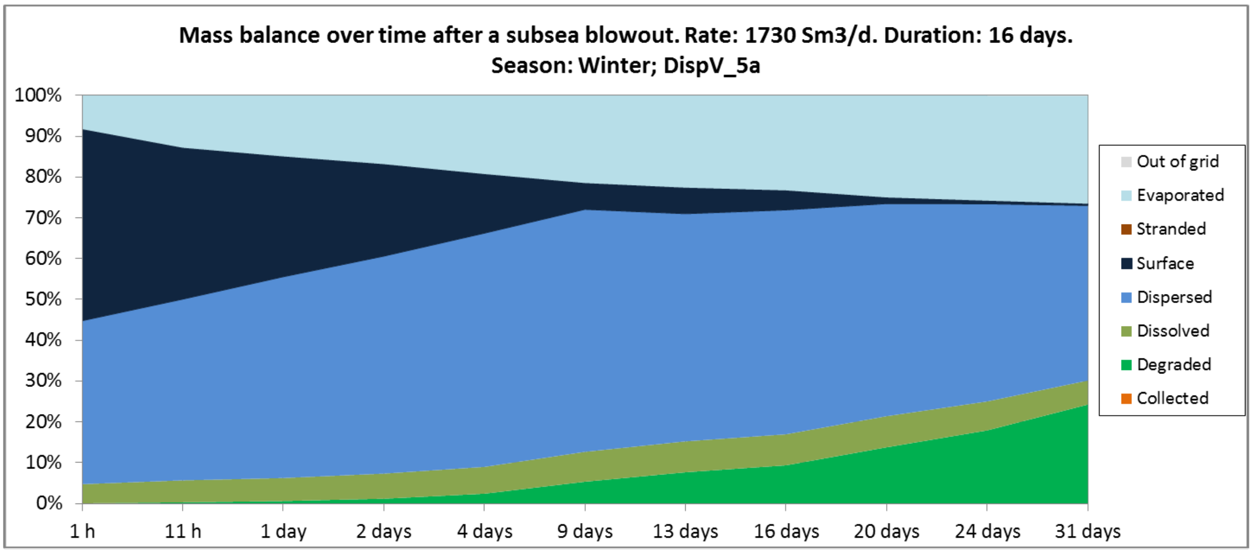
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispV_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



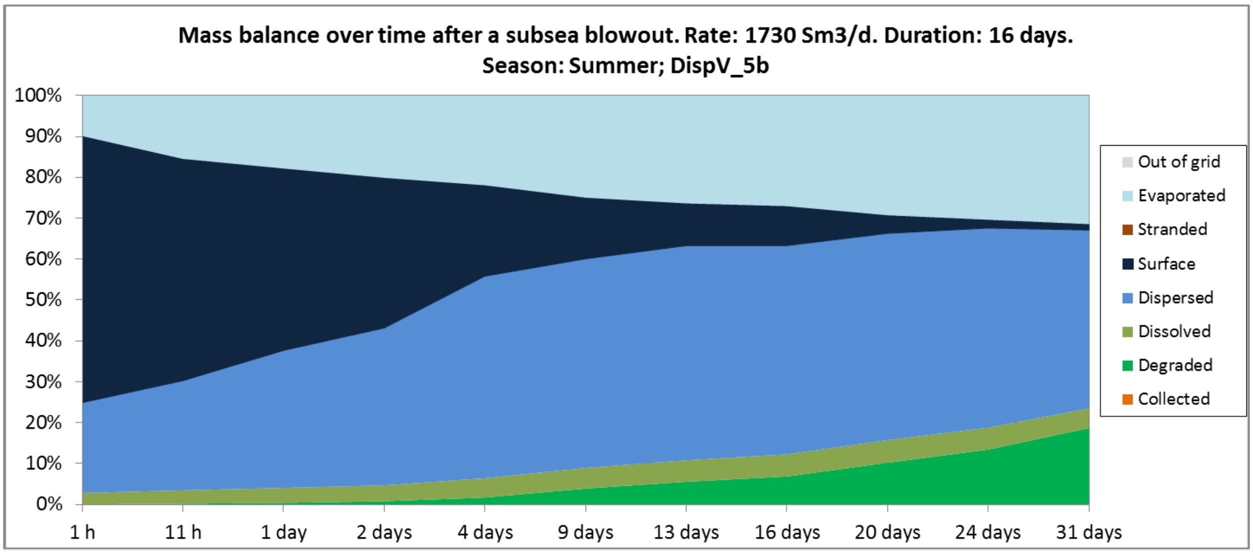
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispV_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



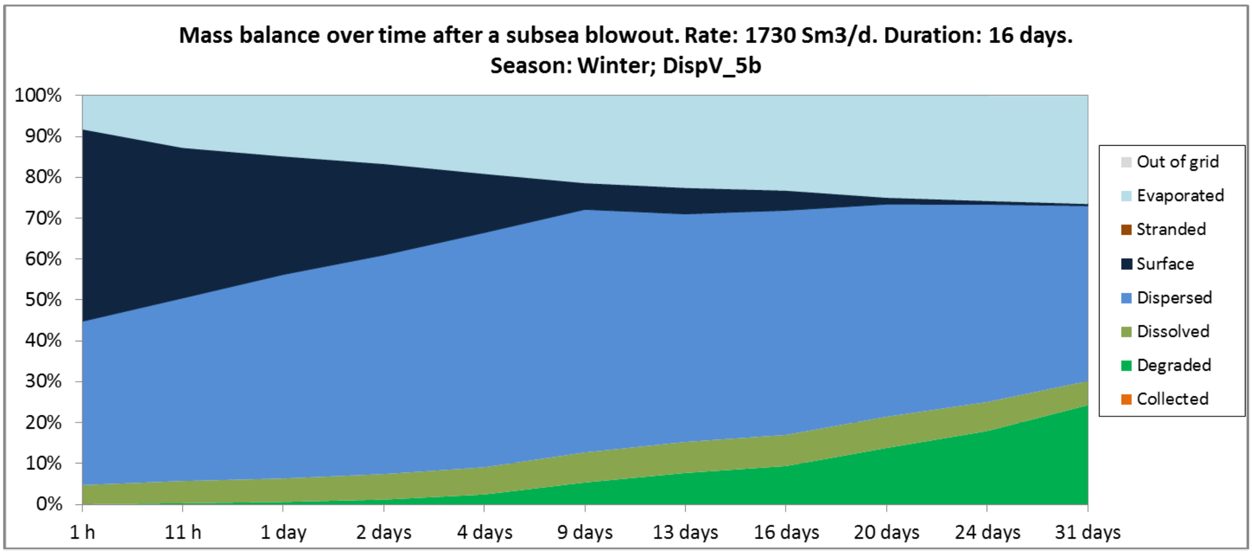
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispV_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispV_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



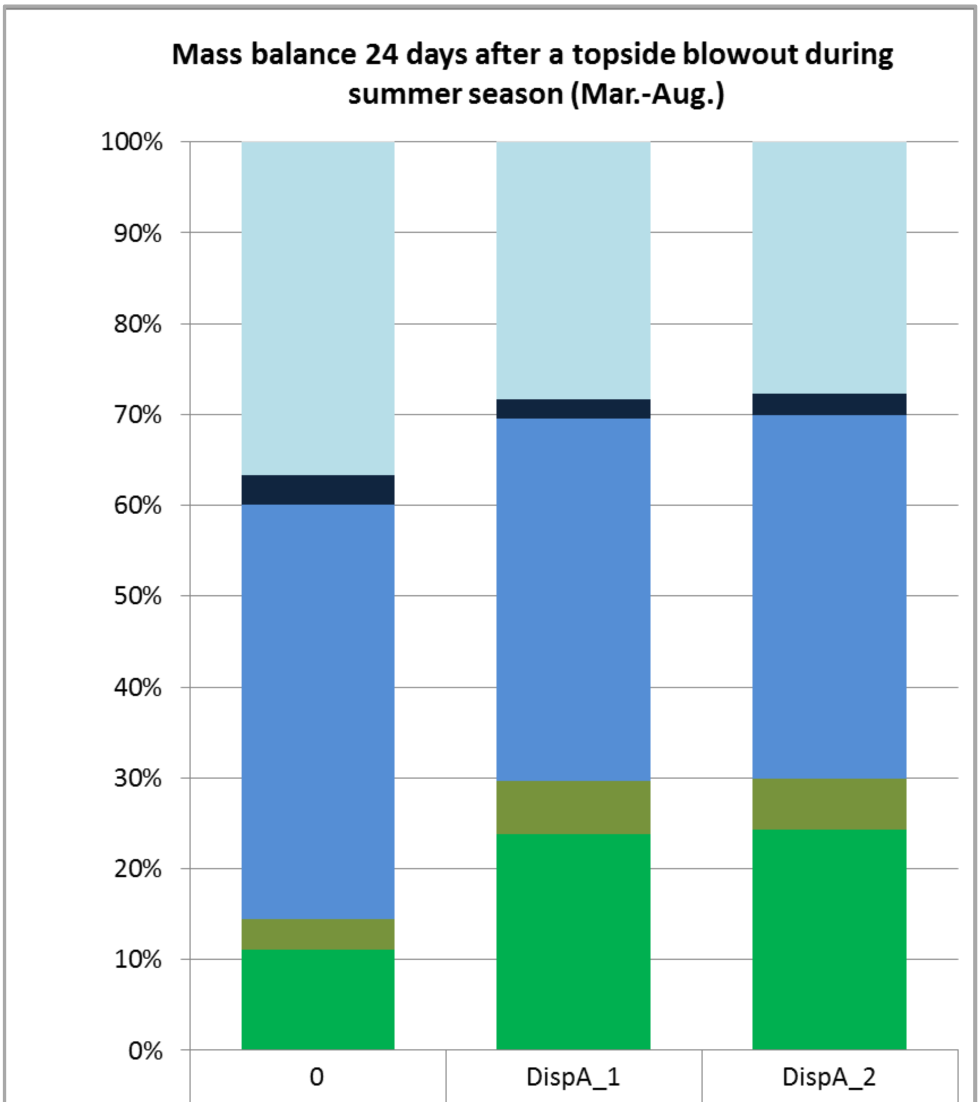
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispV_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



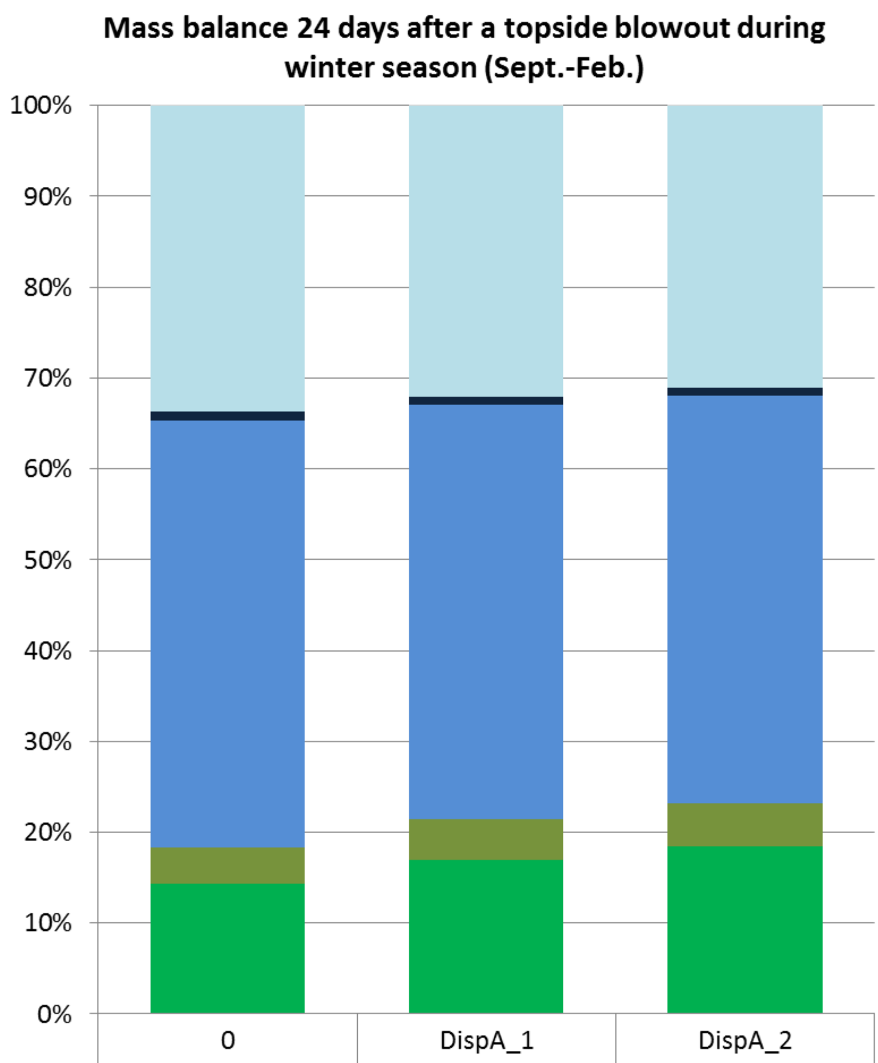
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispV_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

B.5 Response measure DispA

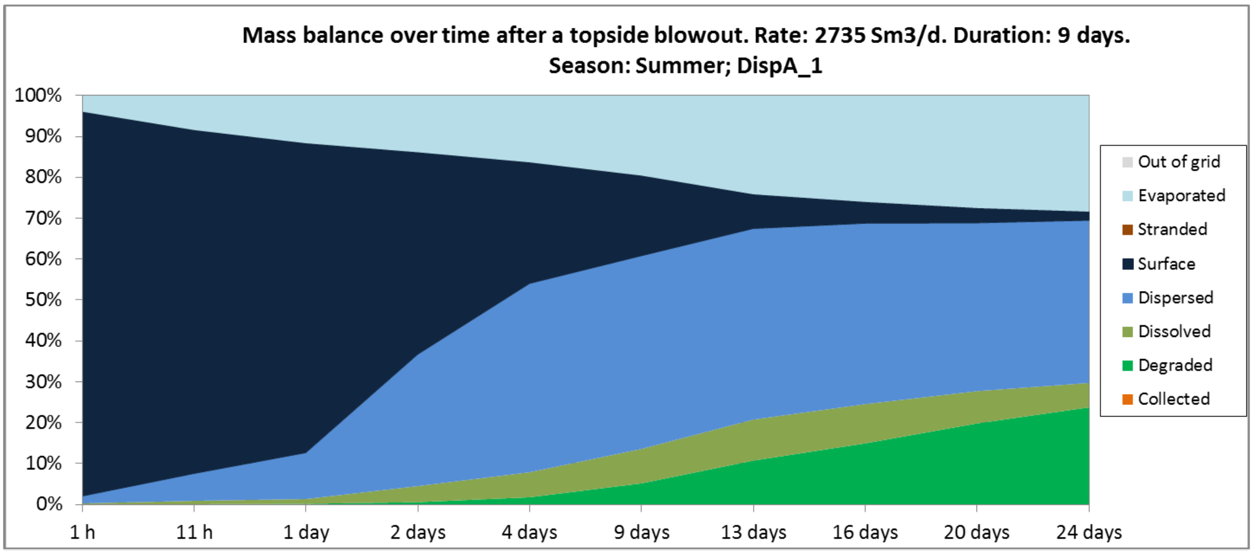
TOPSIDE SCENARIO



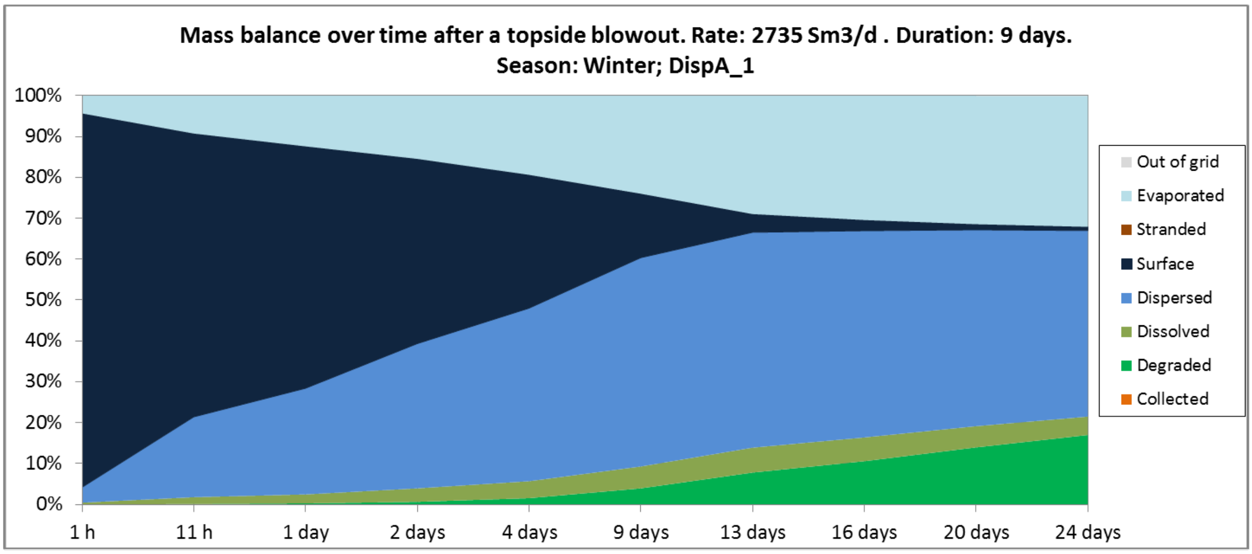
	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	28,4 %	27,7 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,1 %	2,4 %
Dispersed	45,7 %	39,8 %	39,9 %
Dissolved	3,4 %	6,0 %	5,7 %
Degraded	11,1 %	23,7 %	24,3 %
Collected	0,0 %	0,0 %	0,0 %



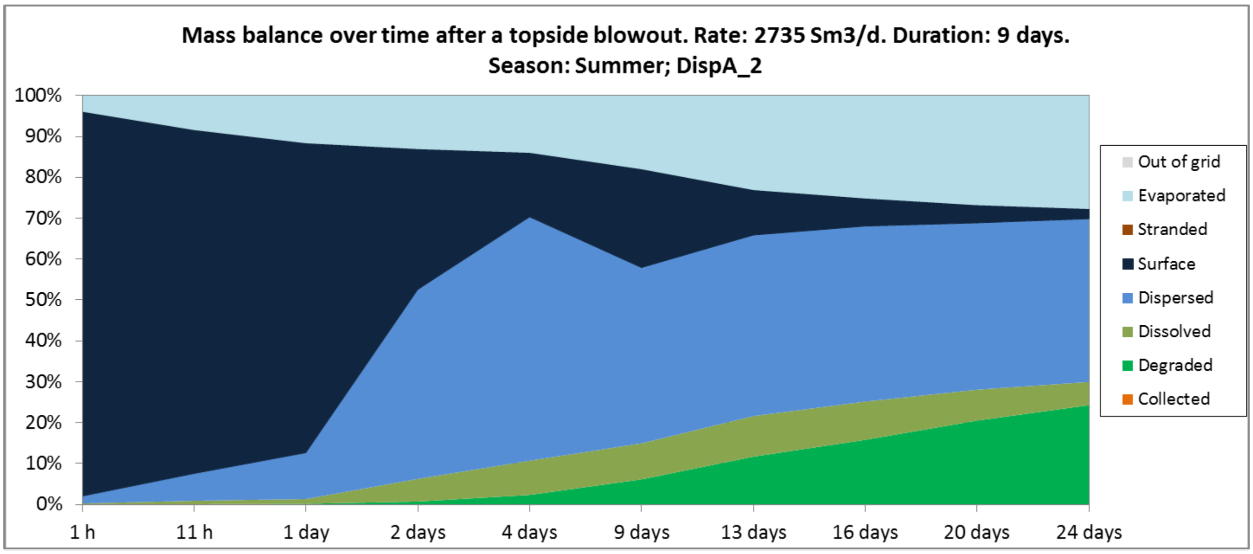
	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	32,0 %	31,1 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	0,9 %
Dispersed	46,9 %	45,5 %	44,8 %
Dissolved	4,1 %	4,5 %	4,7 %
Degraded	14,3 %	17,0 %	18,4 %
Collected	0,0 %	0,0 %	0,0 %



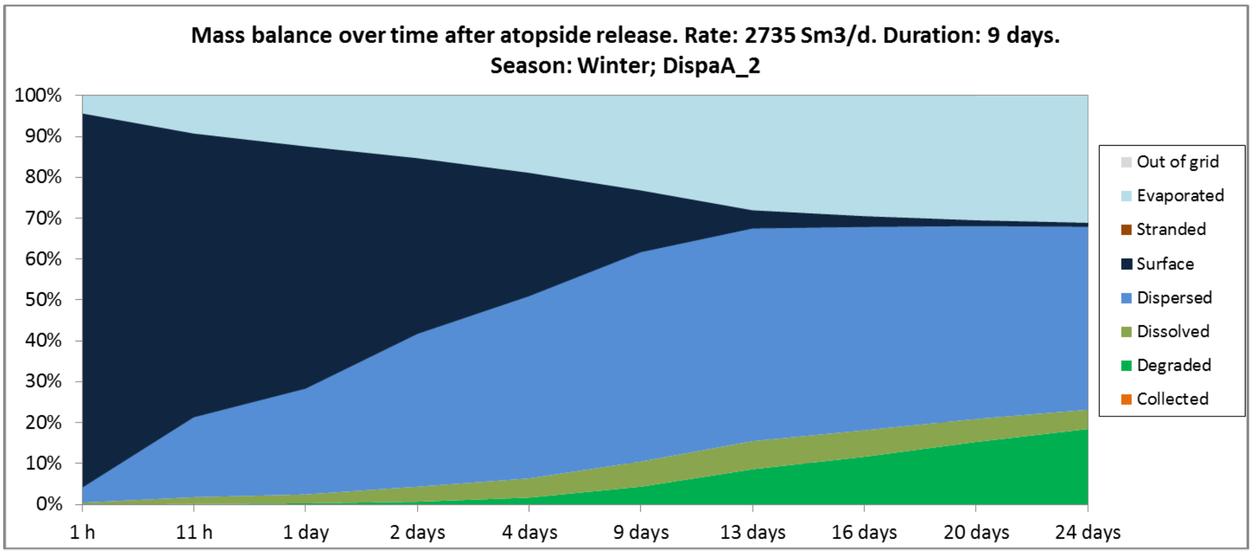
Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; DispA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



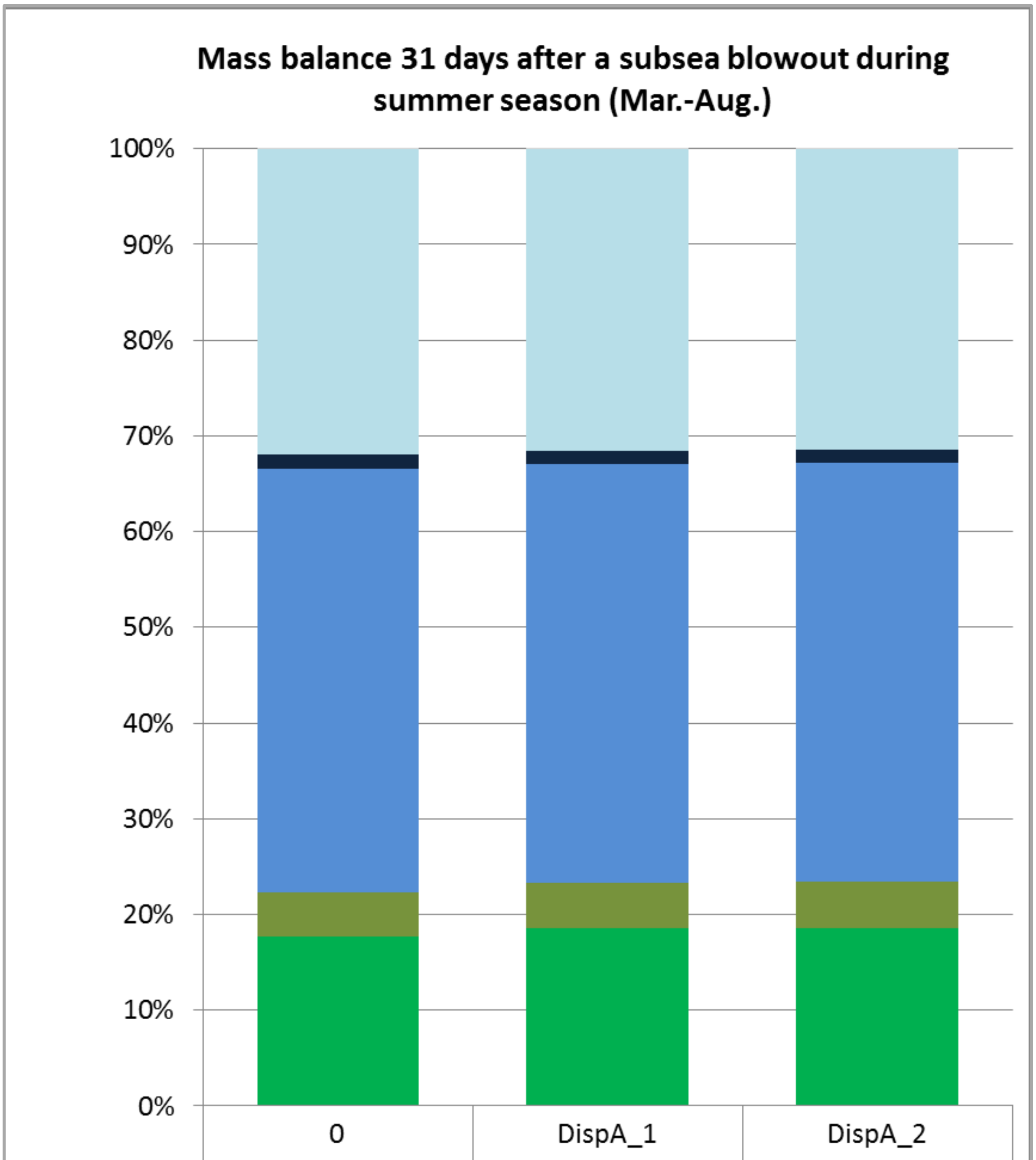
Mass balance over time after a topside blowout. Rate: 2735 Sm3/d . Duration: 9 days.
Season: Winter; DispA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; DispA_2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

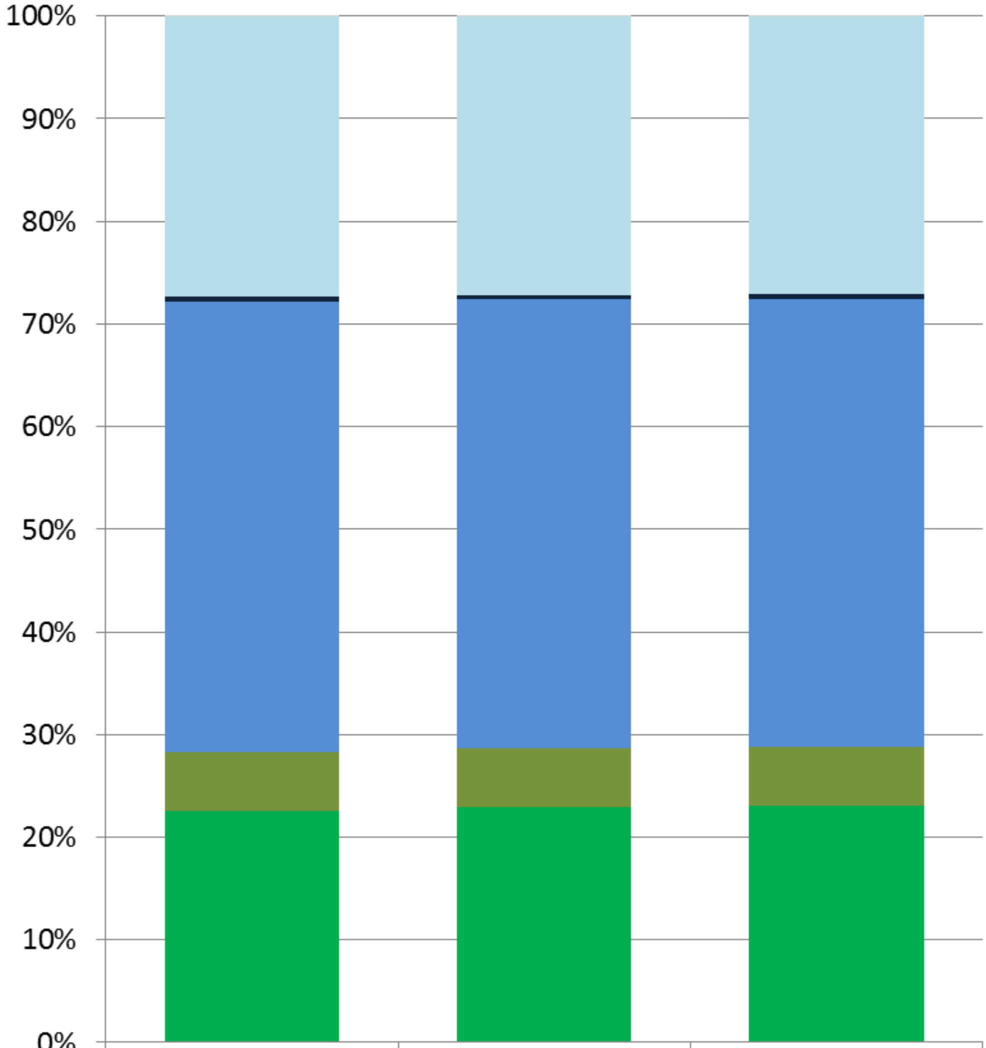

Mass balance over time after atopside release. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; DispaA_2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

SUBSEA SCENARIO

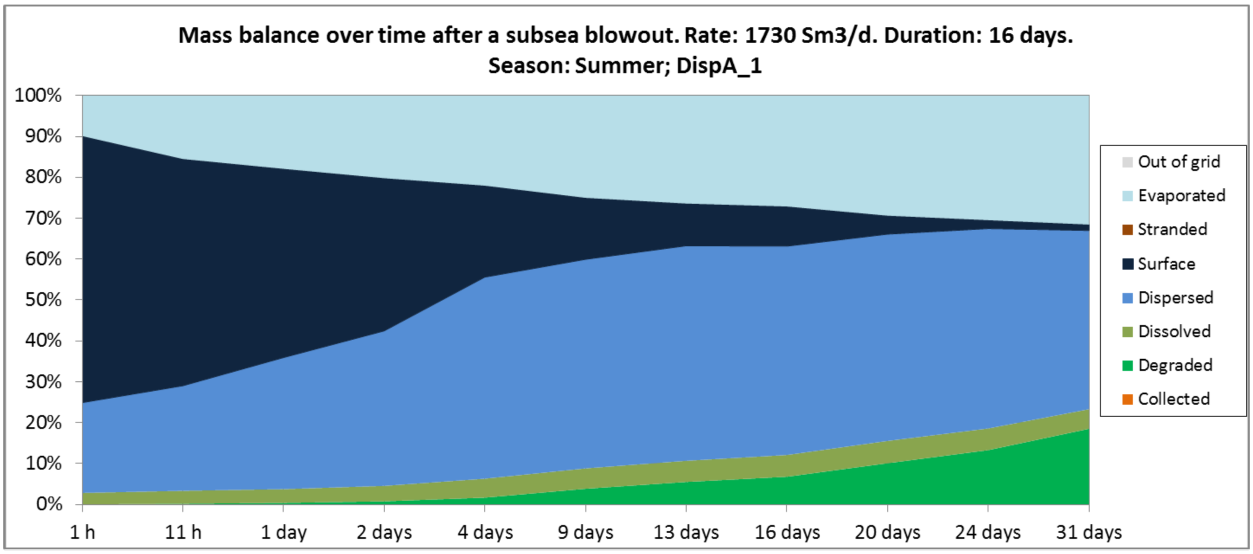


	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,5 %	31,5 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,4 %	1,4 %
Dispersed	44,2 %	43,7 %	43,7 %
Dissolved	4,7 %	4,8 %	4,8 %
Degraded	17,6 %	18,5 %	18,6 %
Collected	0,0 %	0,0 %	0,0 %

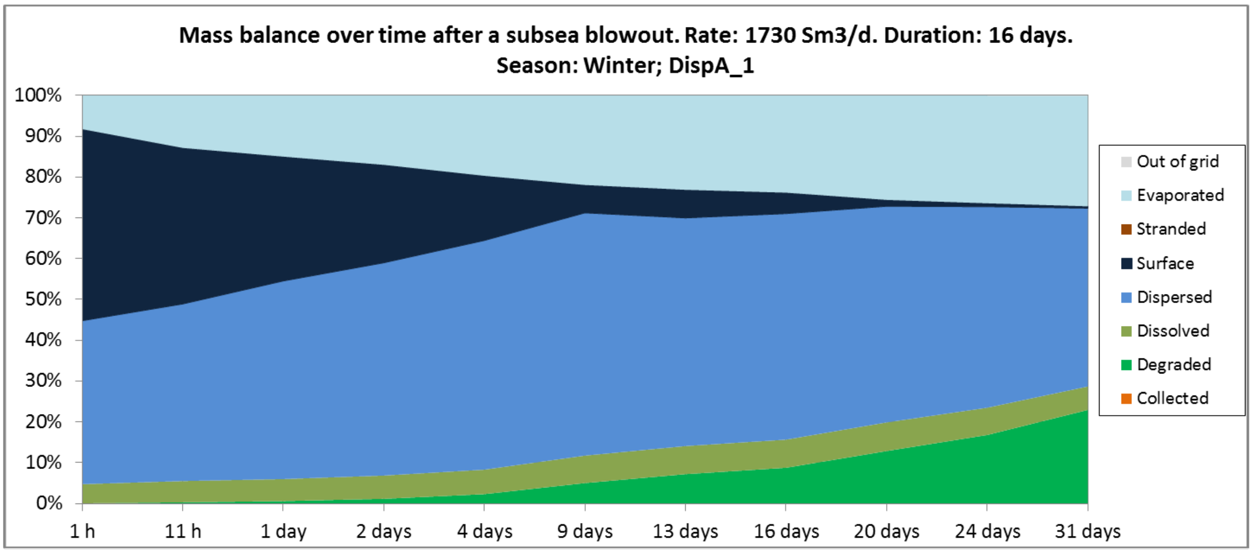
Mass balance 31 days after a subsea blowout during winter season (Sept.-Feb.)



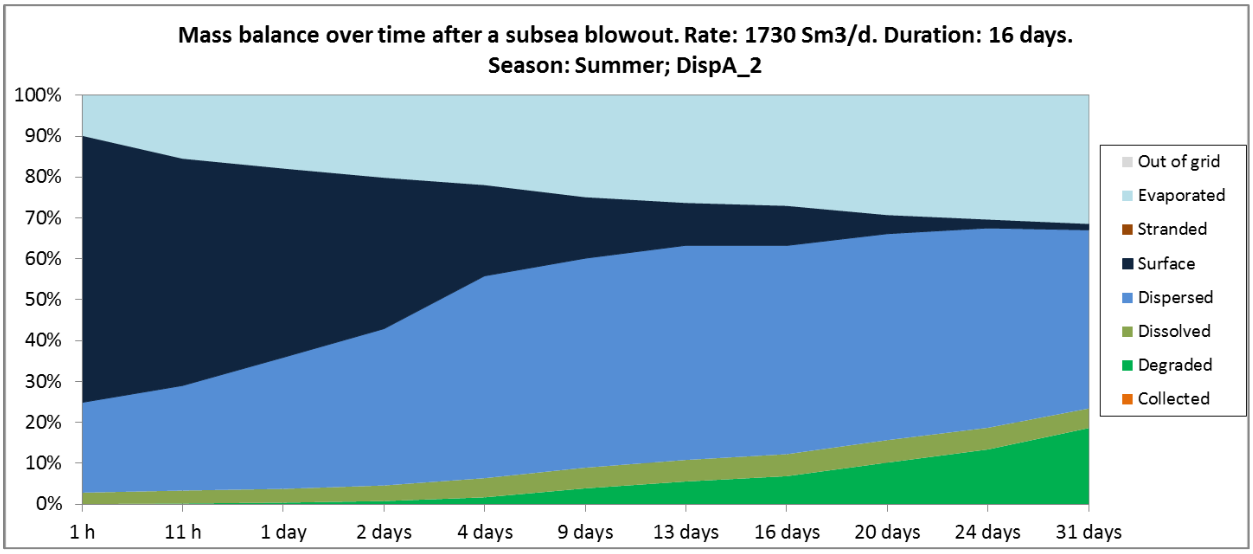
	0	DispA_1	DispA_2
Out of grid	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	27,1 %	27,1 %
Stranded	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,4 %	0,4 %
Dispersed	43,9 %	43,7 %	43,6 %
Dissolved	5,7 %	5,7 %	5,8 %
Degraded	22,6 %	22,9 %	23,0 %
Collected	0,0 %	0,0 %	0,0 %



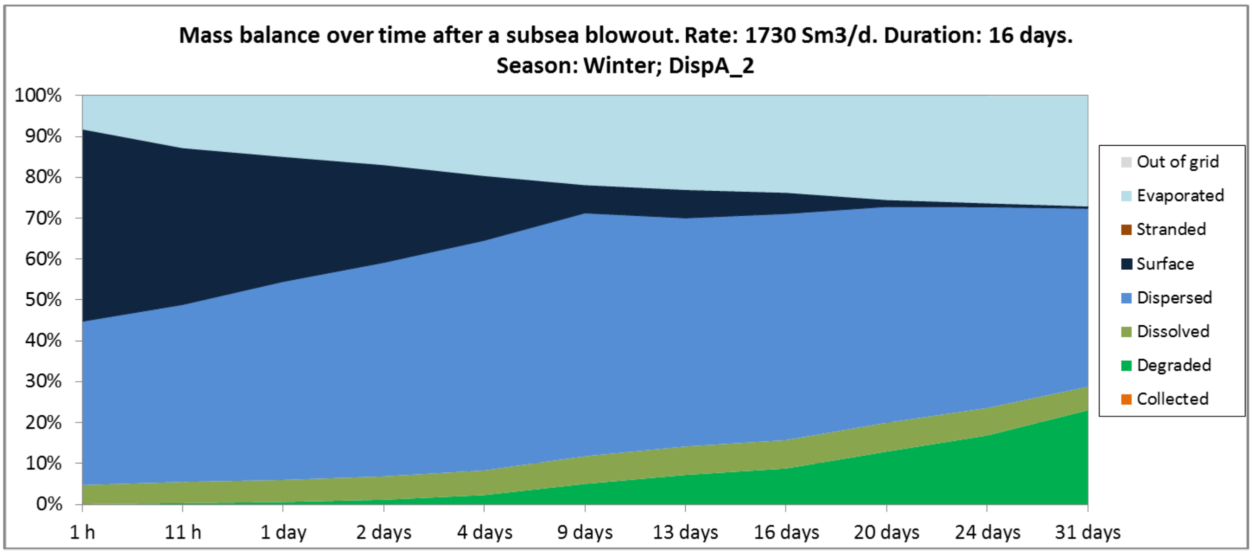
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispA_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

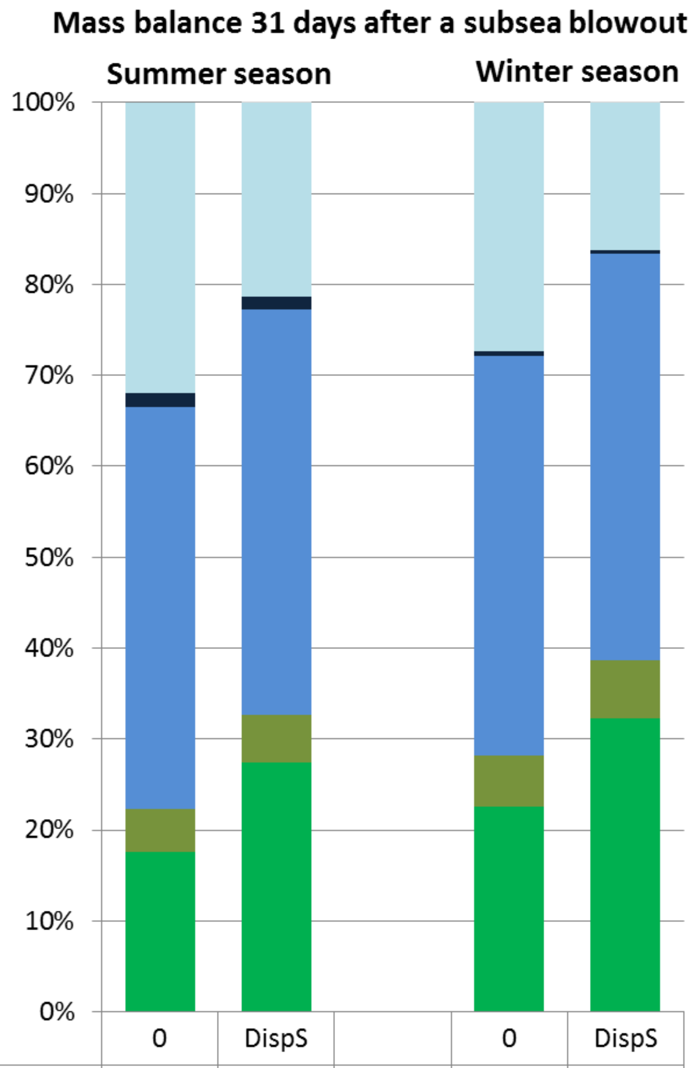


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispA_2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

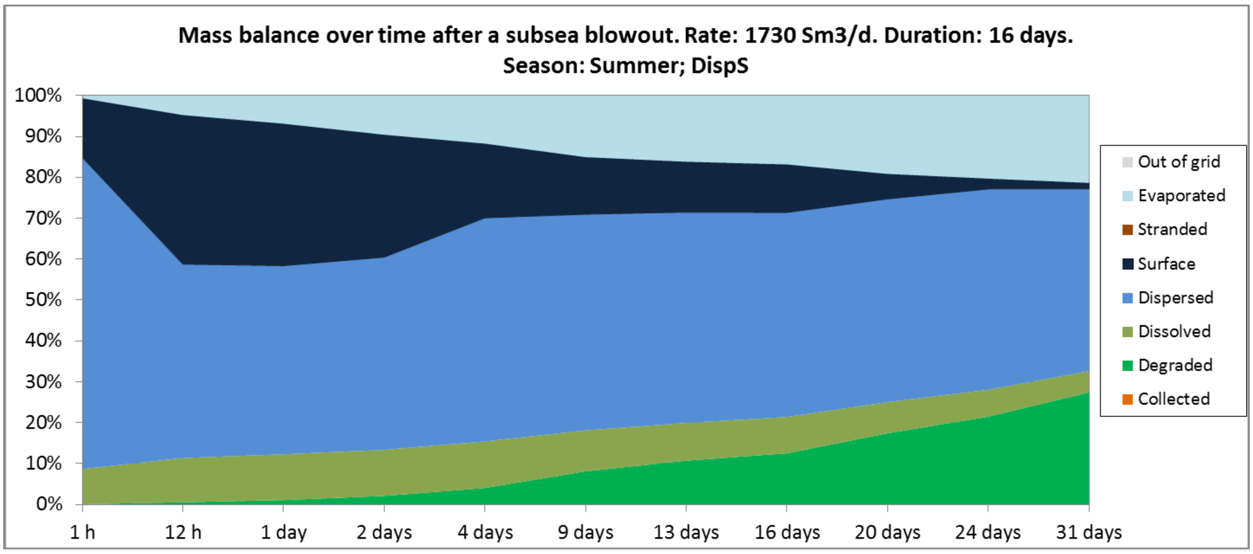

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispA_2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

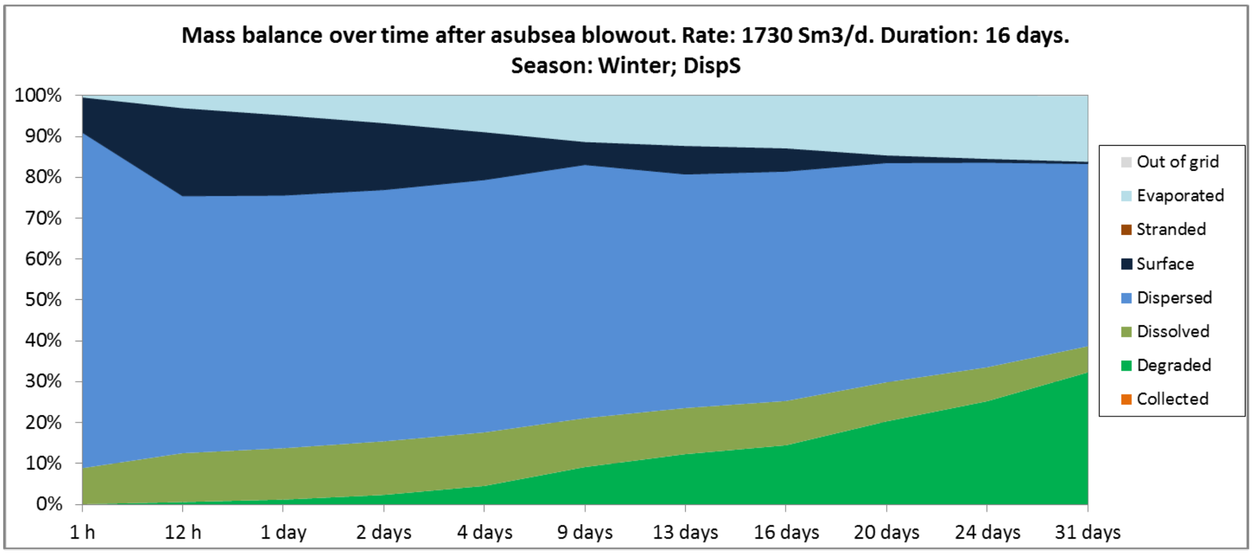
B.6 Response measure DispS

SUBSEA SCENARIO



	Summer season: 0	Summer season: DispS	Winter season: 0	Winter season: DispS
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	21,3 %	27,3 %	16,2 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,5 %	0,5 %	0,4 %
Dispersed	44,2 %	44,6 %	43,9 %	44,7 %
Dissolved	4,7 %	5,2 %	5,7 %	6,4 %
Degraded	17,6 %	27,4 %	22,6 %	32,3 %
Collected	0,0 %	0,0 %	0,0 %	0,0 %

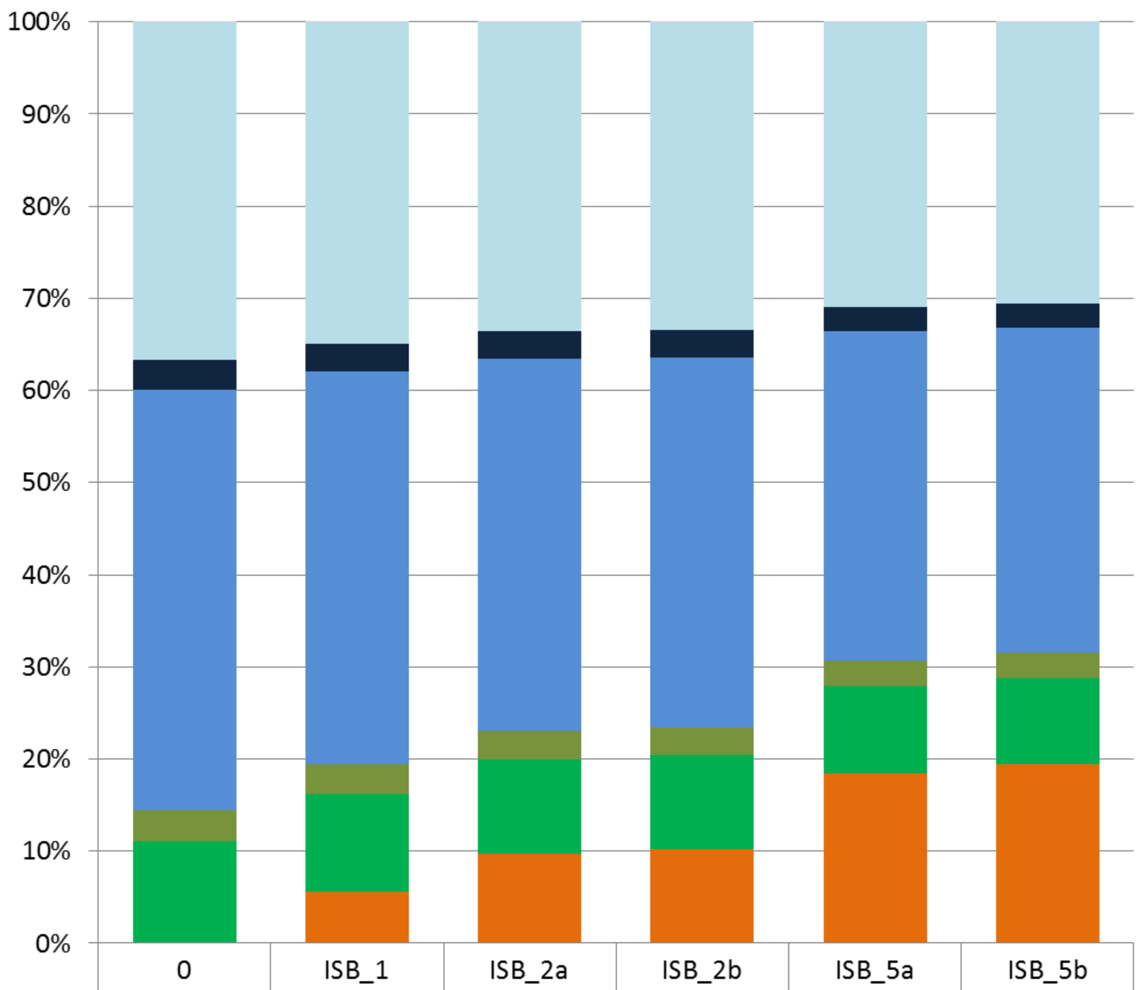

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; DispS
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
12 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after asubsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; DispS
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
12 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

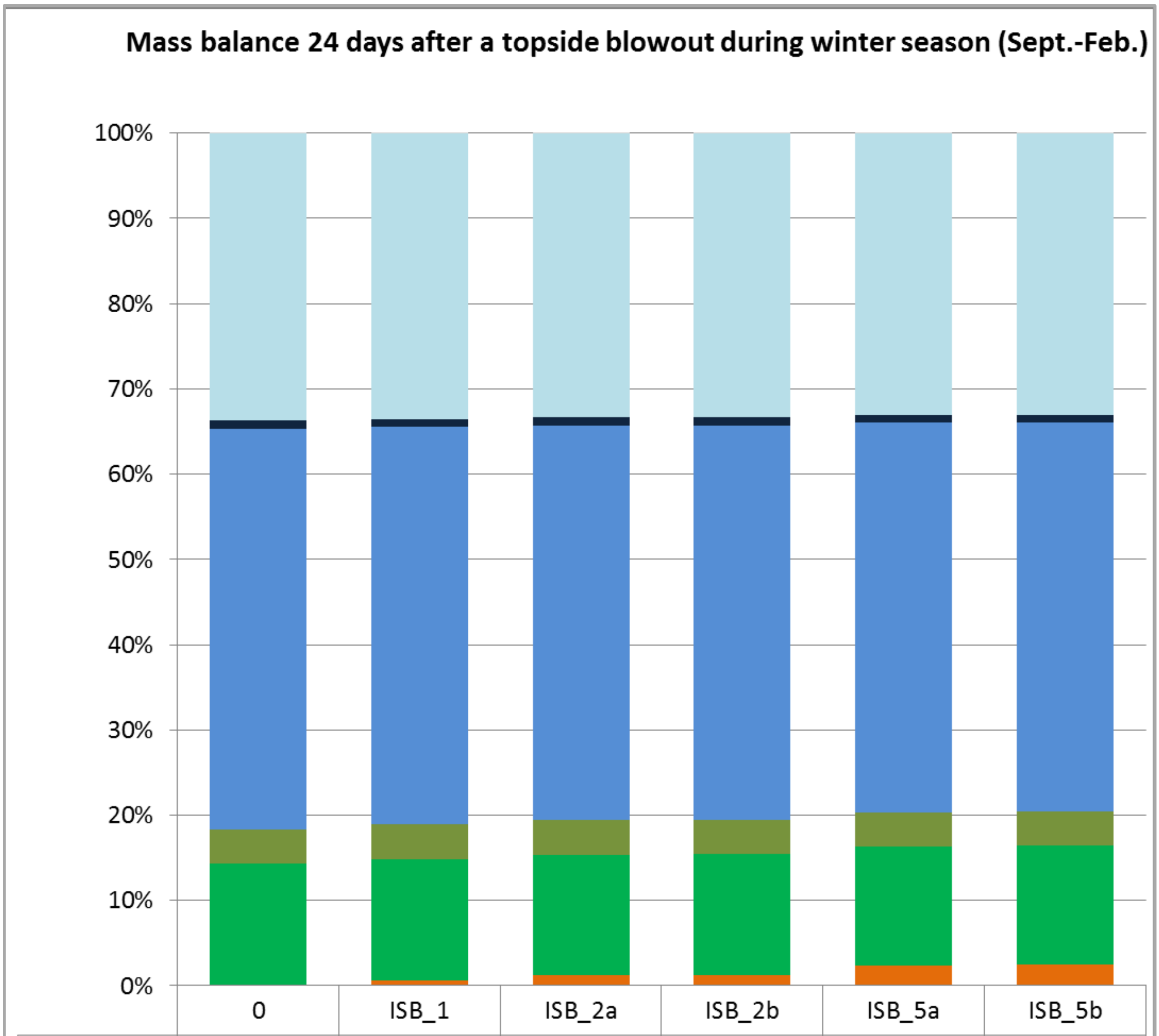
B.7 Response measure ISB

TOPSIDE SCENARIO

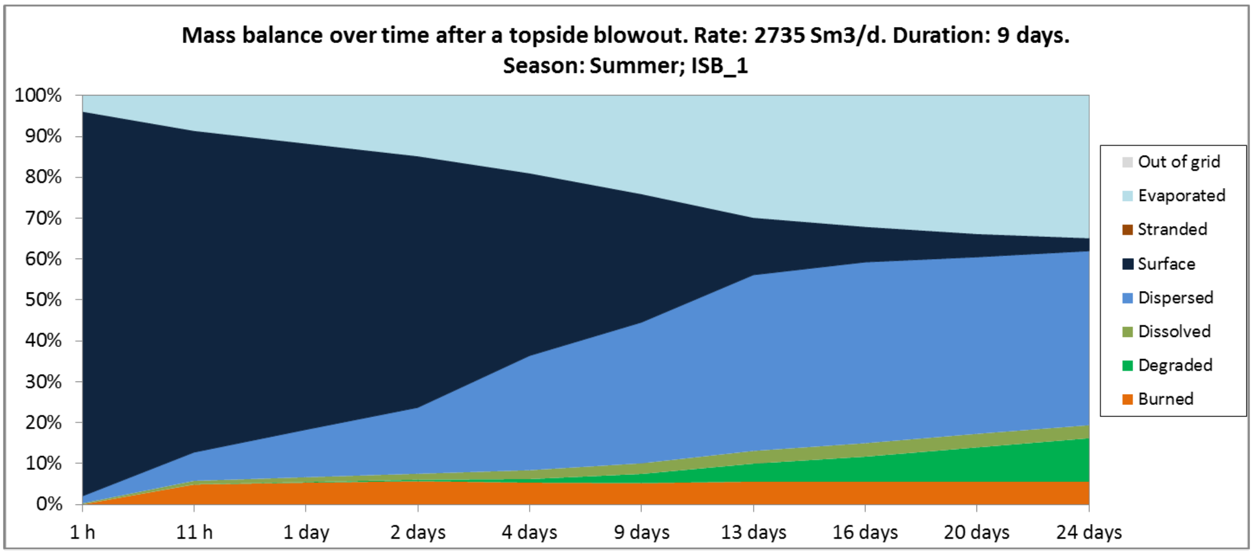
Mass balance 24 days after a topside blowout during summer season (Mar.-Aug.)

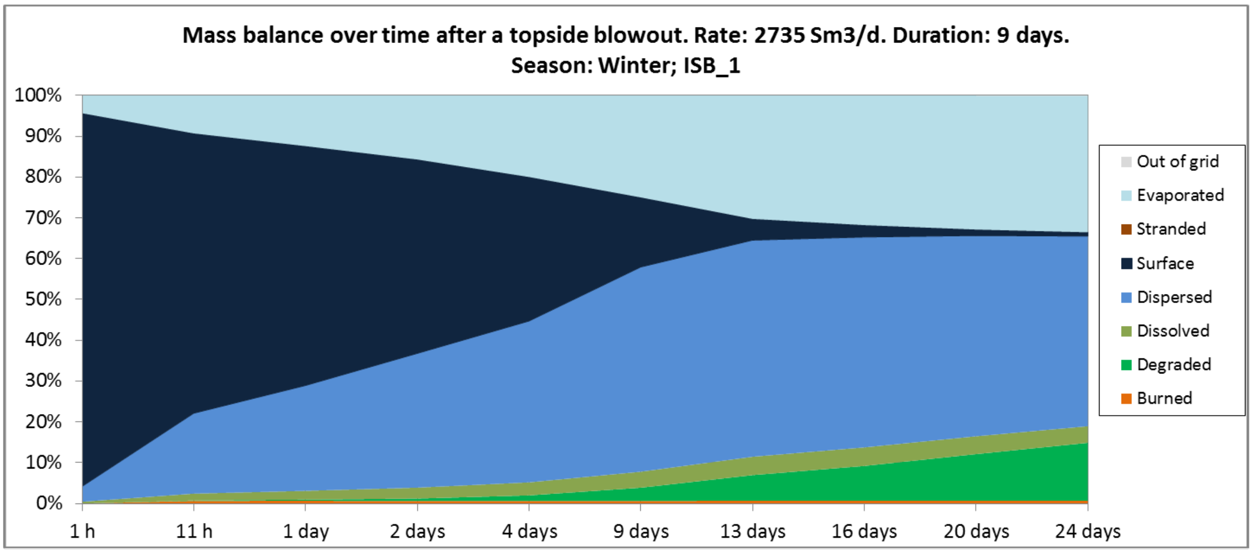


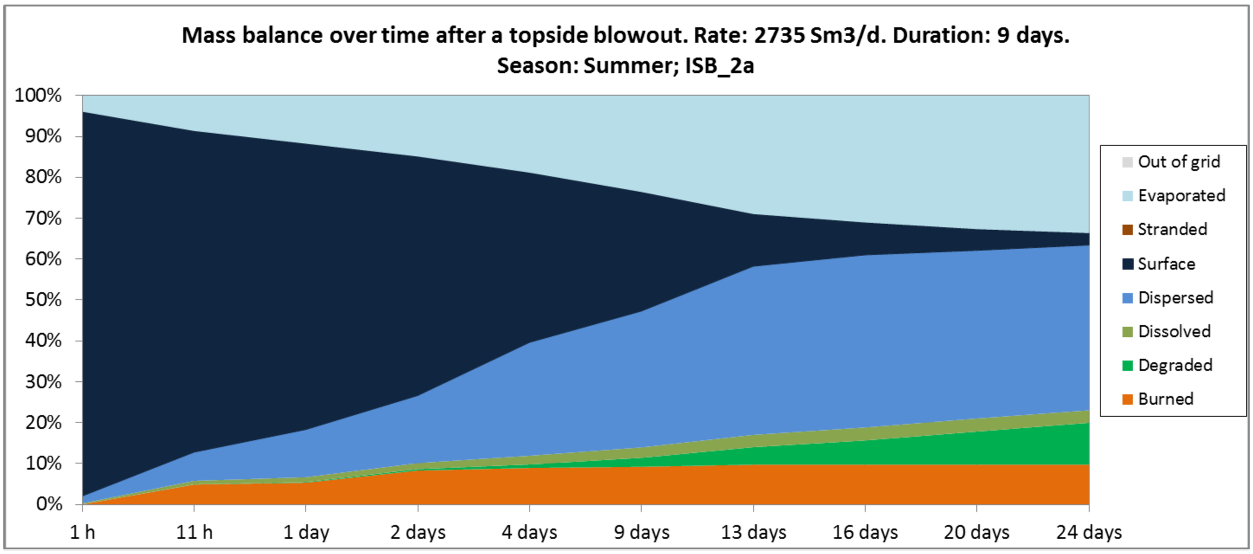
	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	34,9 %	33,6 %	33,4 %	30,9 %	30,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	3,1 %	2,9 %	3,0 %	2,6 %	2,7 %
Dispersed	45,7 %	42,7 %	40,4 %	40,1 %	35,8 %	35,2 %
Dissolved	3,4 %	3,2 %	3,1 %	3,1 %	2,8 %	2,8 %
Degraded	11,1 %	10,6 %	10,2 %	10,2 %	9,5 %	9,4 %
Burned	0,0 %	5,6 %	9,7 %	10,2 %	18,4 %	19,4 %

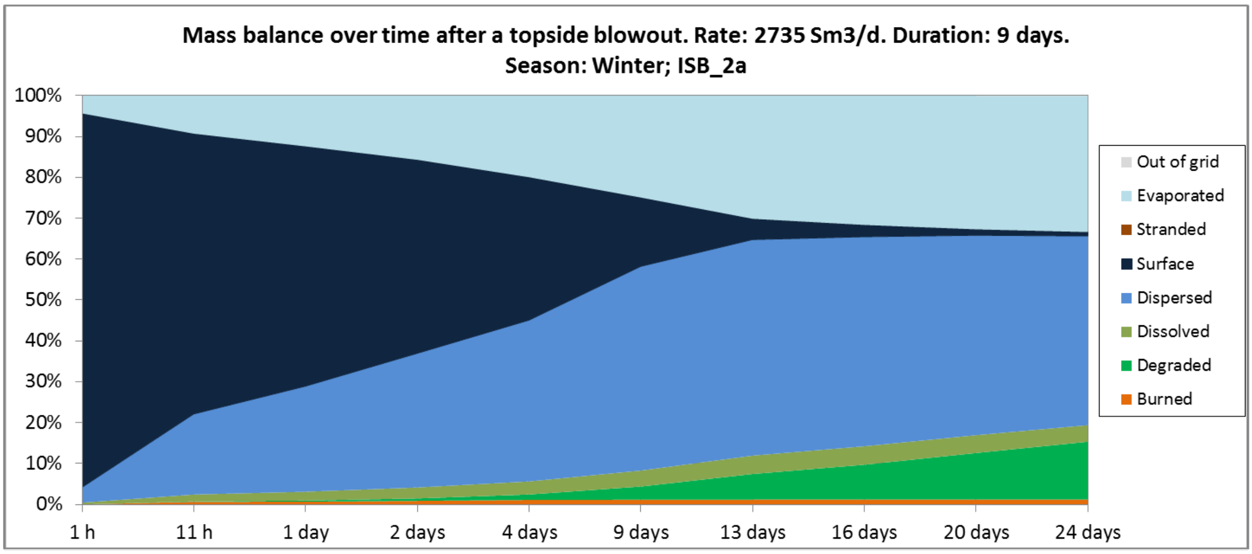


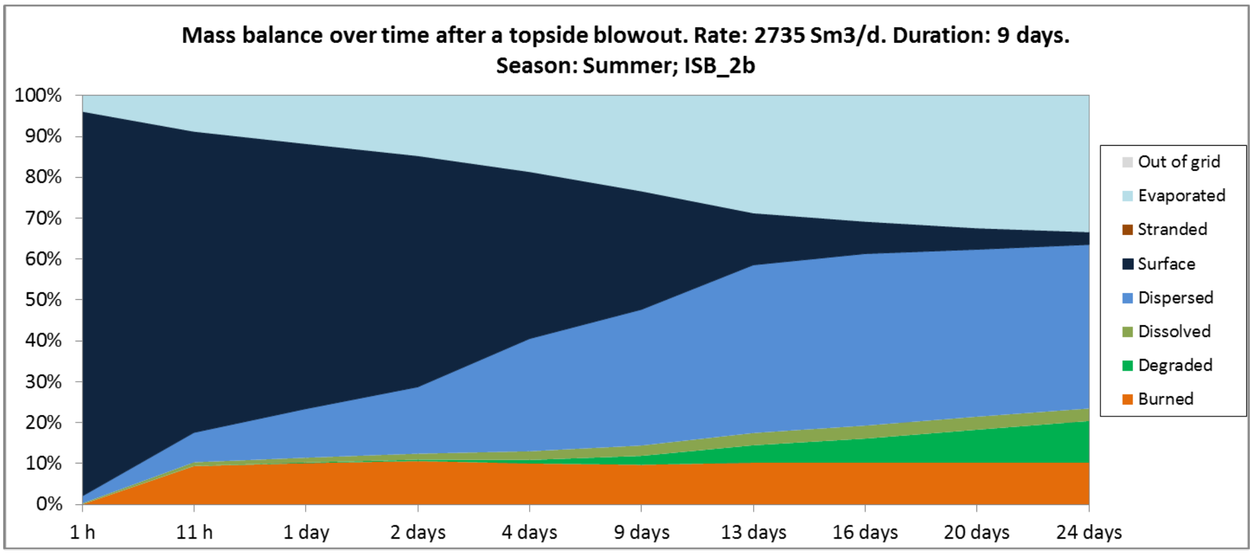
	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	33,5 %	33,3 %	33,3 %	33,0 %	33,0 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,9 %	1,0 %	0,9 %	0,9 %	0,9 %
Dispersed	46,9 %	46,6 %	46,3 %	46,3 %	45,6 %	45,6 %
Dissolved	4,1 %	4,1 %	4,1 %	4,1 %	4,0 %	4,0 %
Degraded	14,3 %	14,2 %	14,1 %	14,1 %	14,0 %	14,0 %
Burned	0,0 %	0,7 %	1,2 %	1,3 %	2,3 %	2,4 %

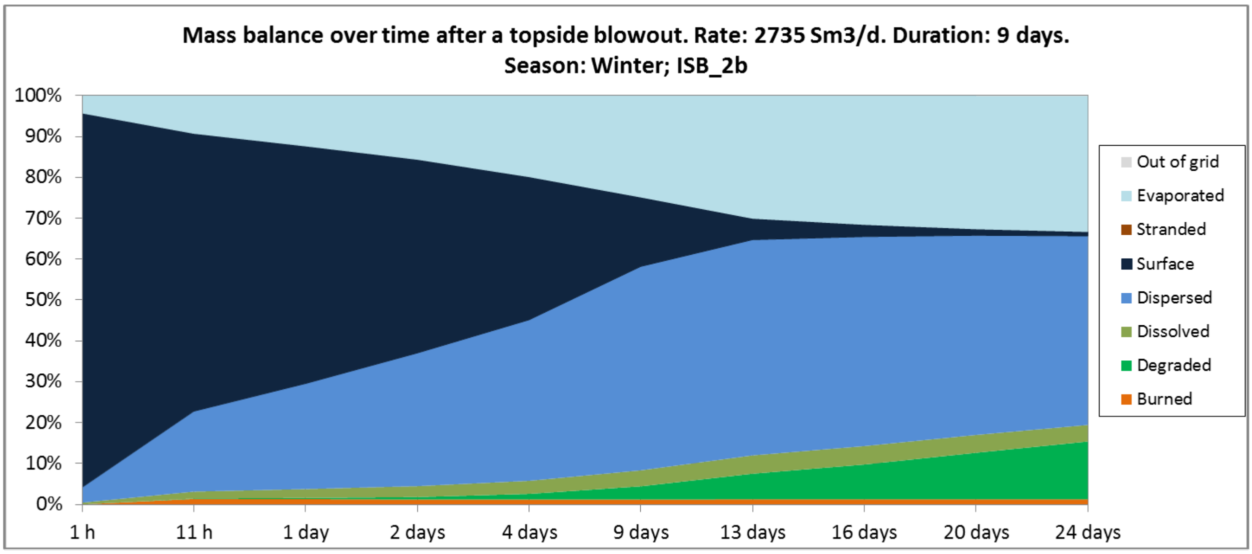

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days. Season: Summer; ISB_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

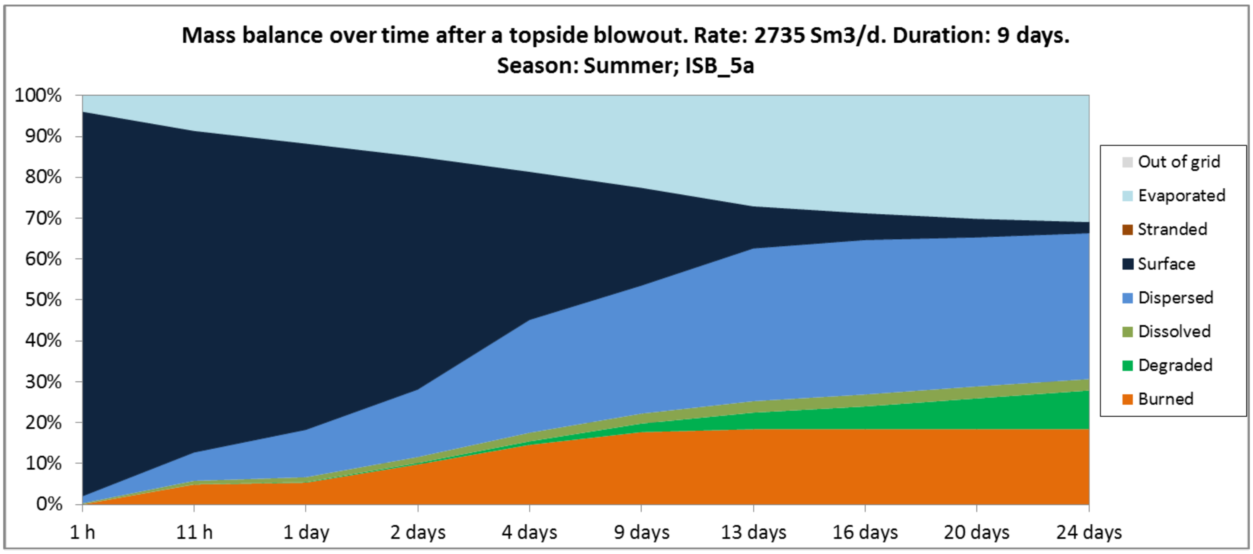

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days. Season: Winter; ISB_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

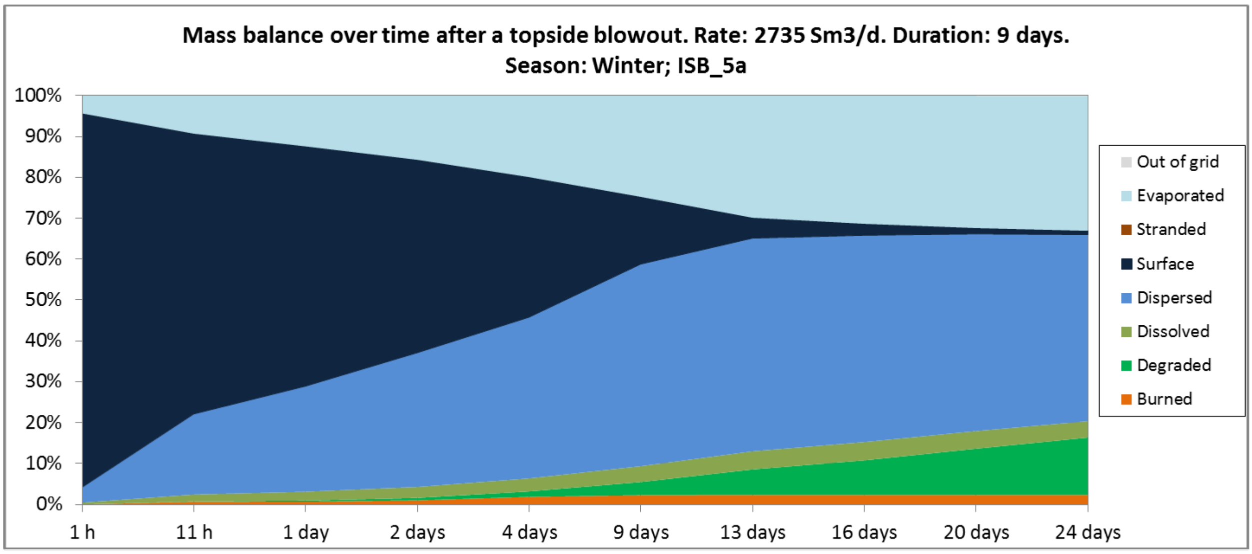

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days. Season: Summer; ISB_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

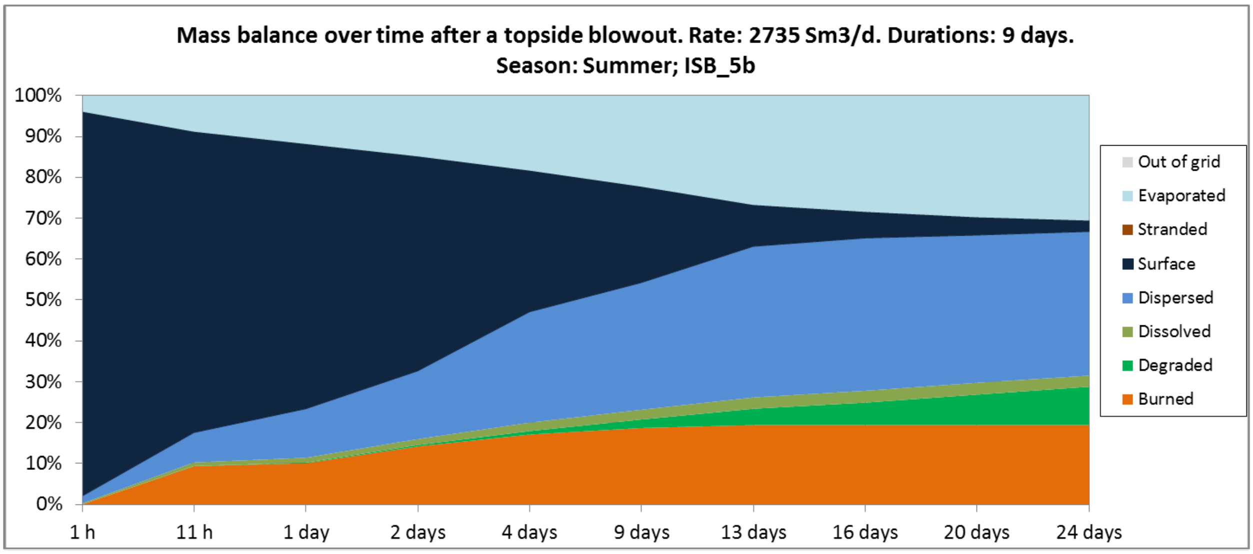

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; ISB_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

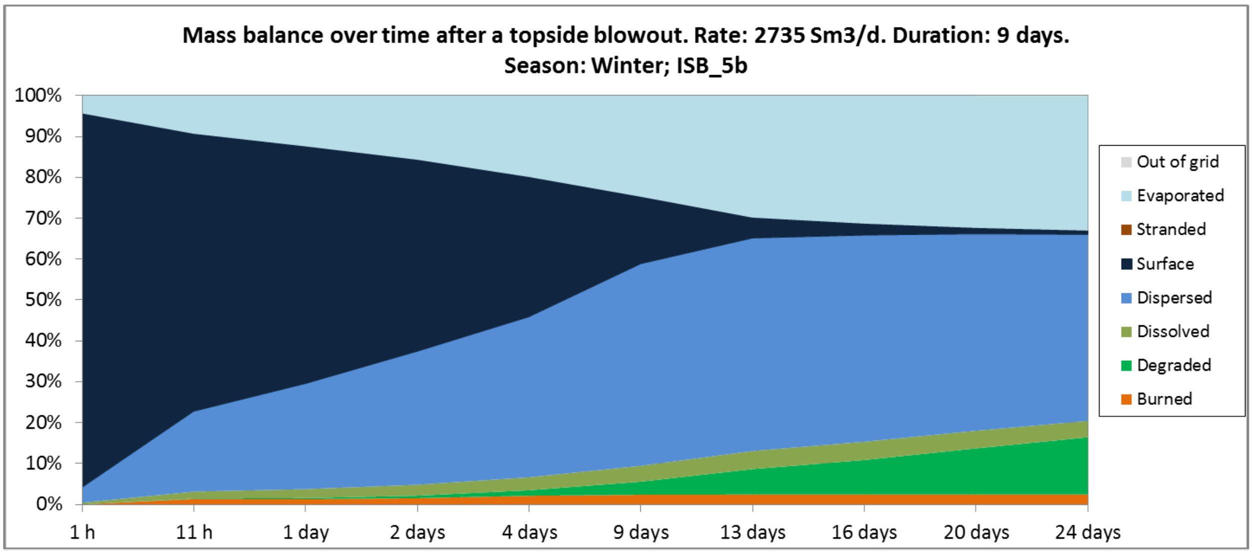

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; ISB_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; ISB_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; ISB_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

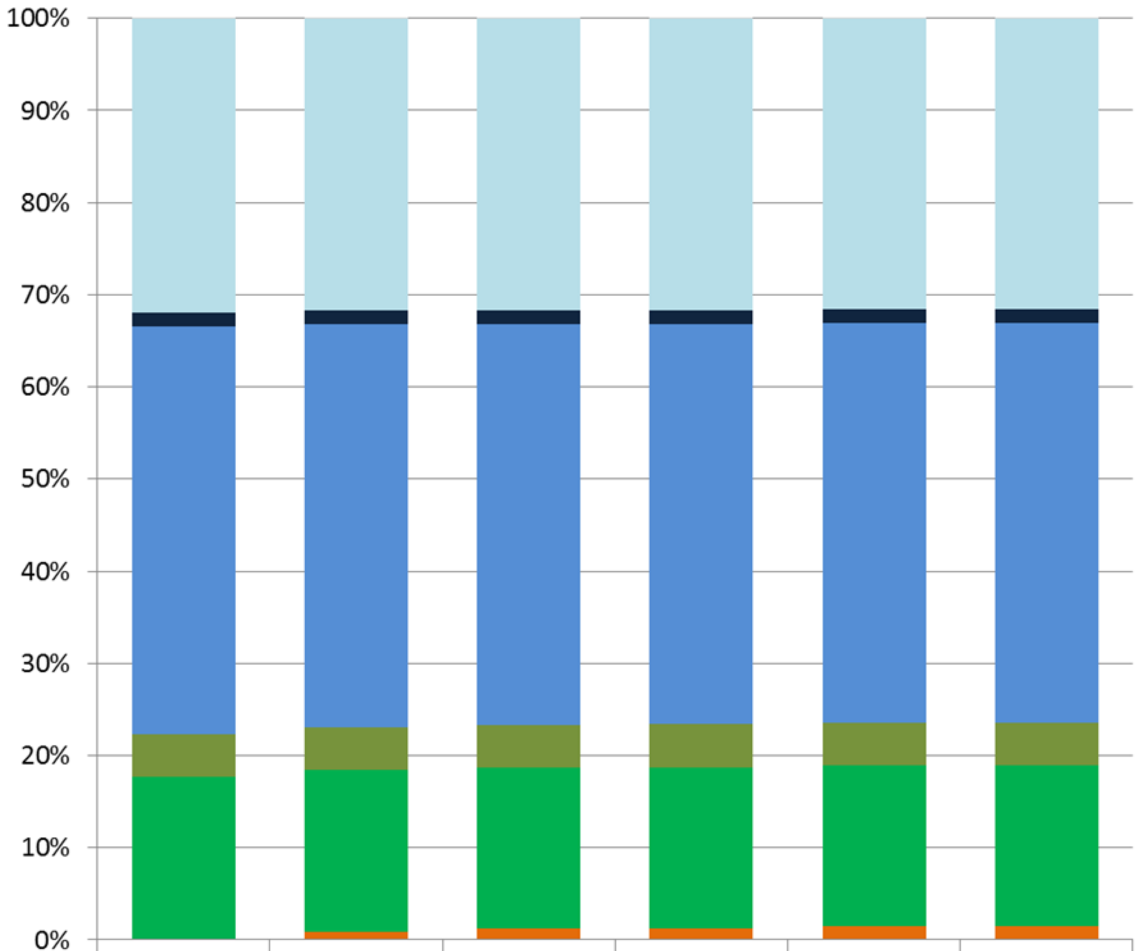

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; ISB_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Durations: 9 days.
Season: Summer; ISB_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; ISB_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

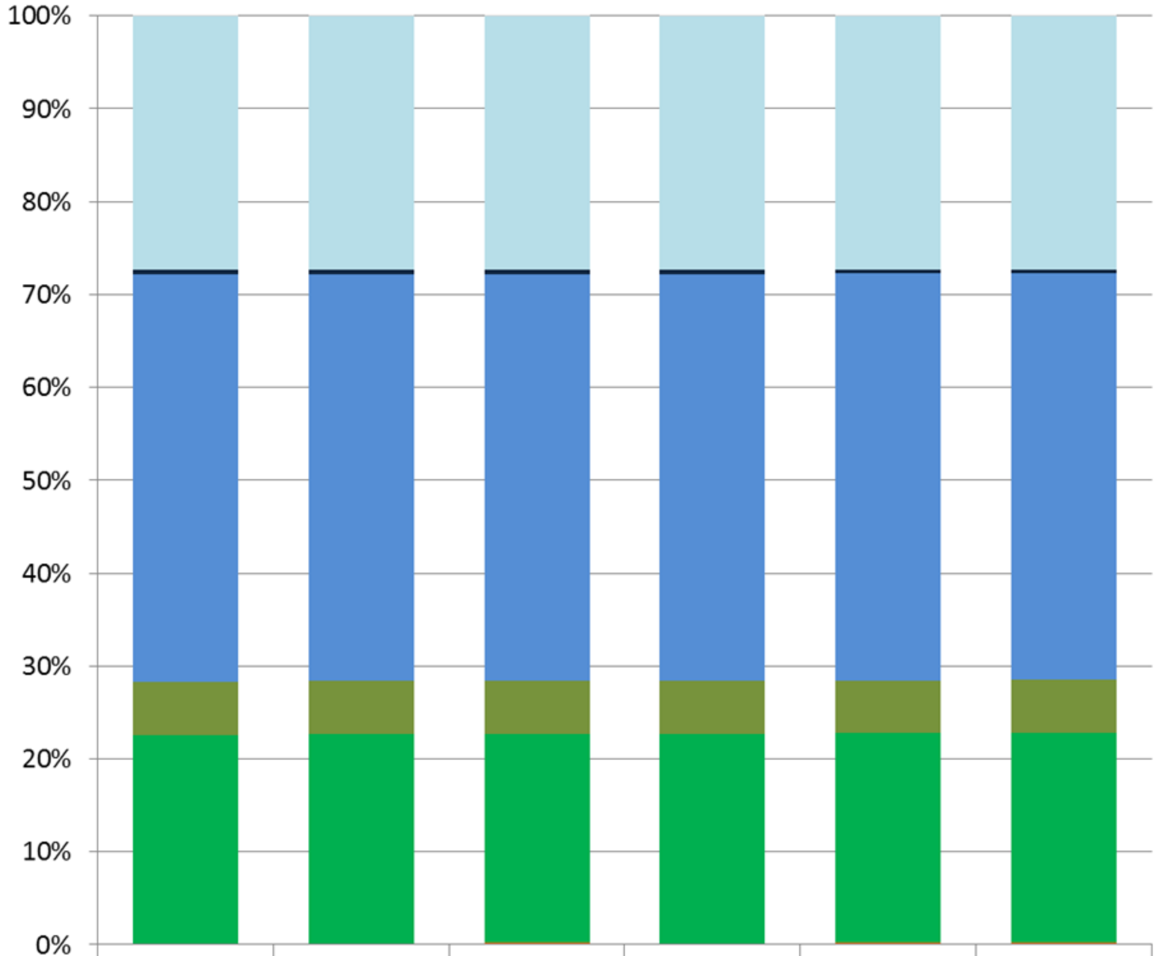
SUBSEA SCENARIO

Mass balance 31 days after a subsea blowout during summer season (Mar.-Aug.)

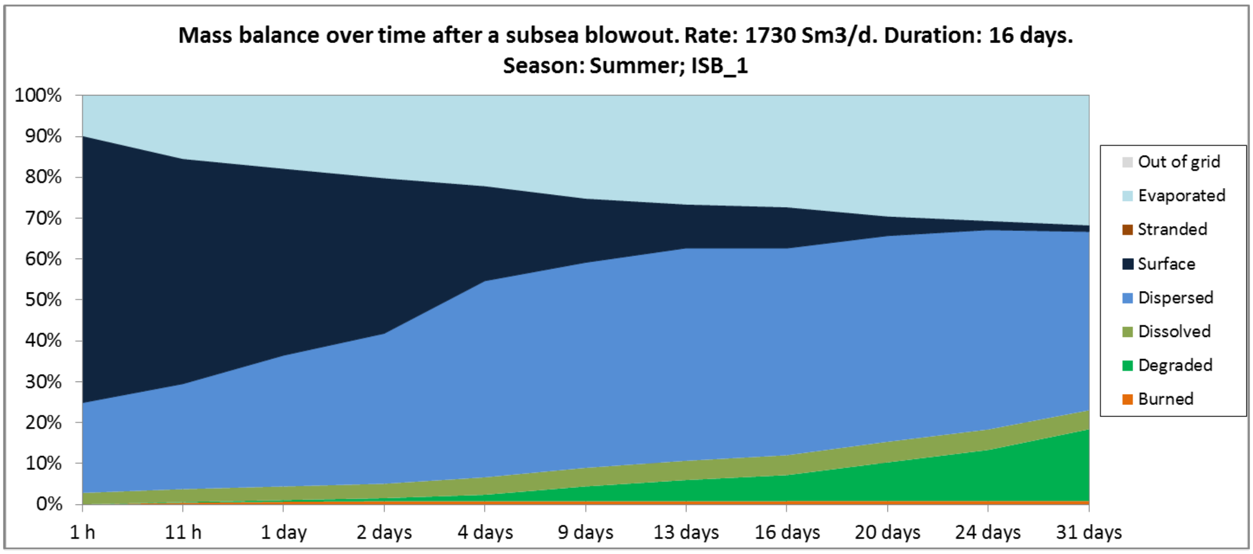


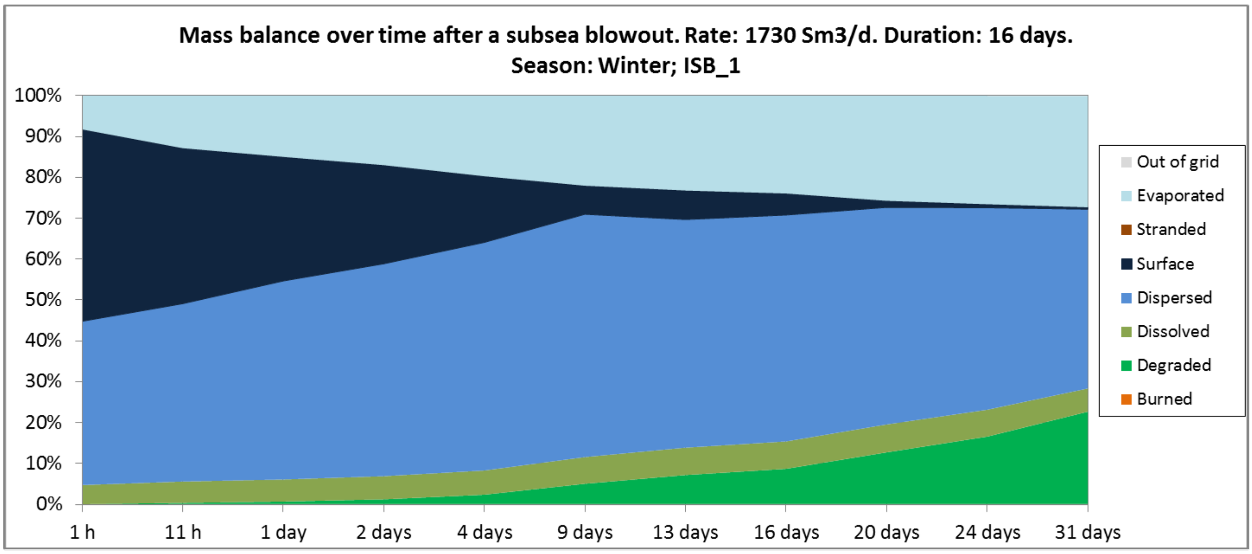
	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	32,0 %	31,8 %	31,6 %	31,7 %	31,6 %	31,6 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,5 %	1,5 %	1,5 %	1,5 %	1,5 %	1,5 %
Dispersed	44,2 %	43,7 %	43,5 %	43,4 %	43,4 %	43,3 %
Dissolved	4,7 %	4,6 %	4,6 %	4,6 %	4,6 %	4,6 %
Degraded	17,6 %	17,5 %	17,5 %	17,5 %	17,5 %	17,5 %
Burned	0,0 %	0,8 %	1,2 %	1,2 %	1,4 %	1,5 %

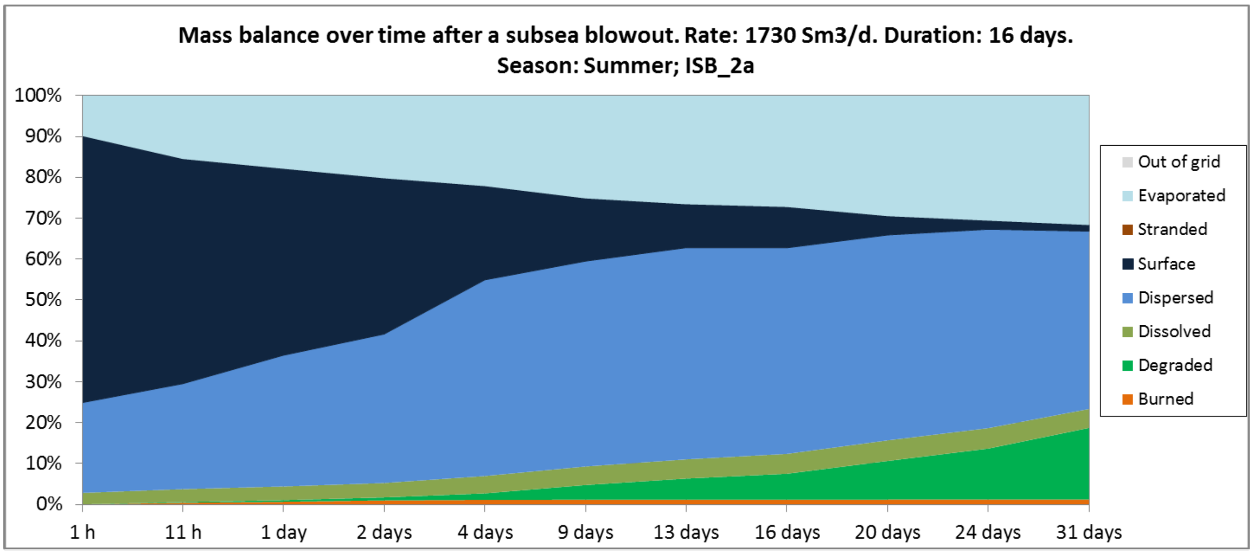
Mass balance 31 days after a subsea blowout during winter season (Sept.-Feb.)

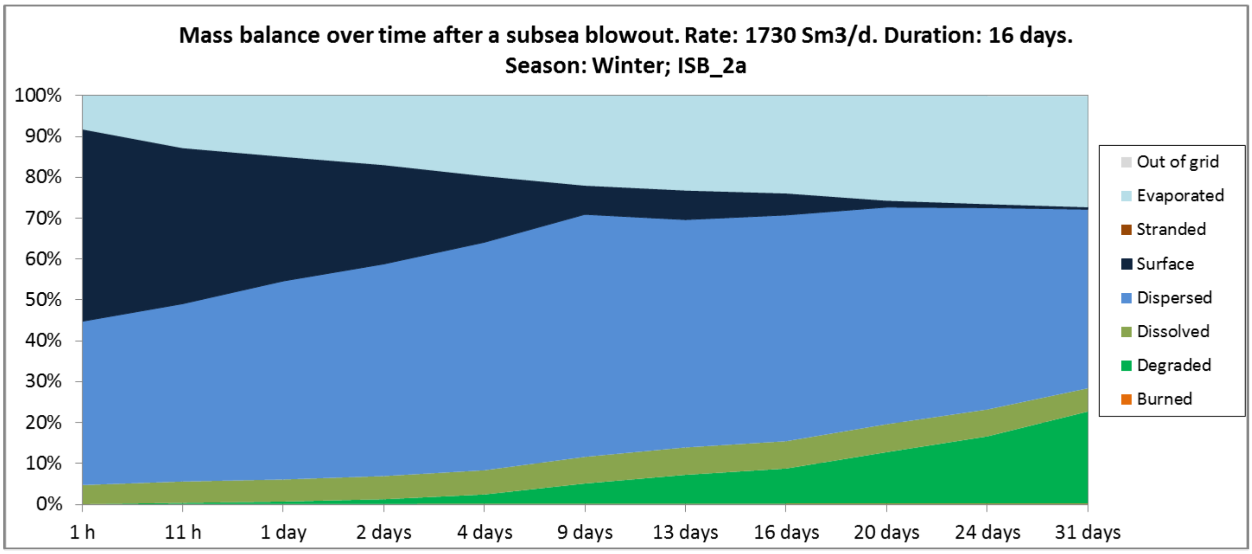


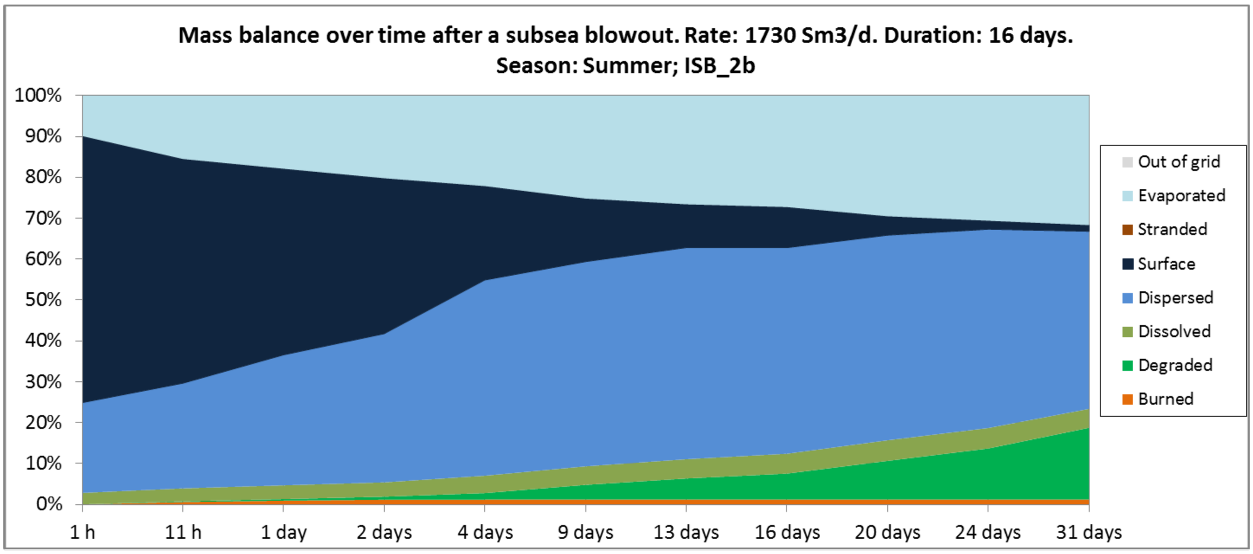
	0	ISB_1	ISB_2a	ISB_2b	ISB_5a	ISB_5b
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	27,3 %	27,3 %	27,3 %	27,3 %	27,2 %	27,2 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	0,5 %	0,5 %	0,5 %	0,5 %	0,5 %	0,5 %
Dispersed	43,9 %	43,8 %	43,8 %	43,8 %	43,8 %	43,8 %
Dissolved	5,7 %	5,7 %	5,7 %	5,7 %	5,7 %	5,7 %
Degraded	22,6 %	22,6 %	22,5 %	22,5 %	22,5 %	22,5 %
Burned	0,0 %	0,1 %	0,2 %	0,2 %	0,3 %	0,3 %

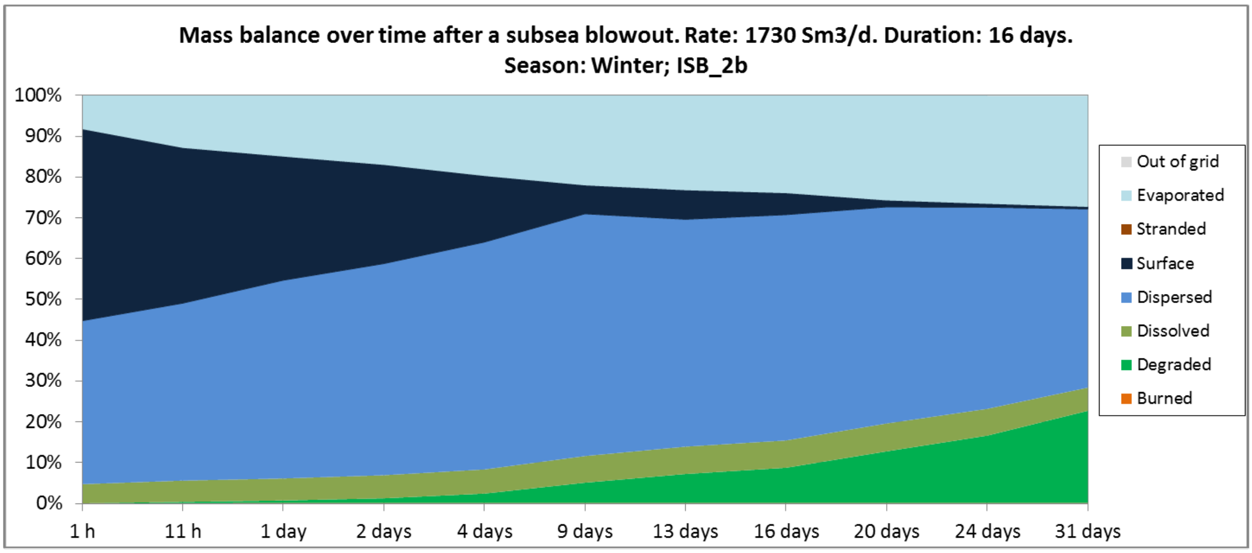

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; ISB_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

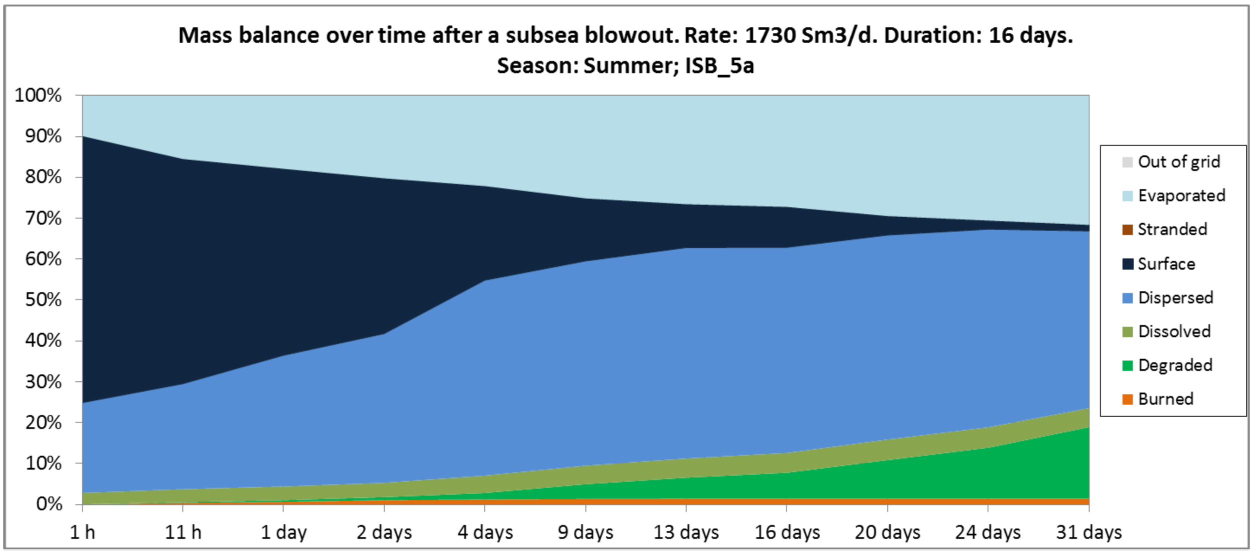

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; ISB_1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; ISB_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

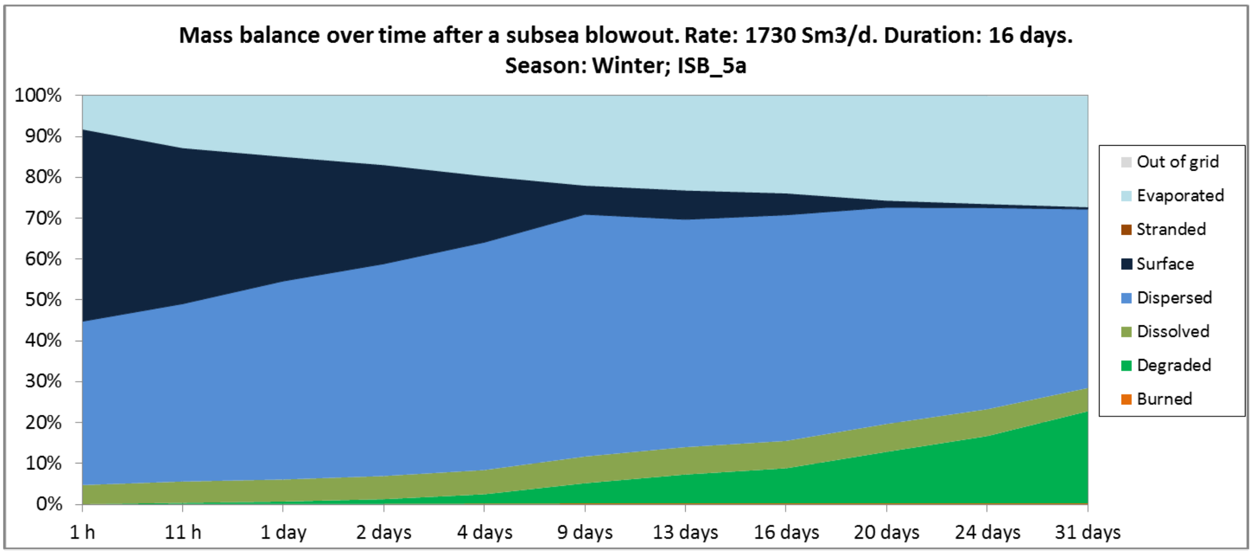

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; ISB_2a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned


Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; ISB_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

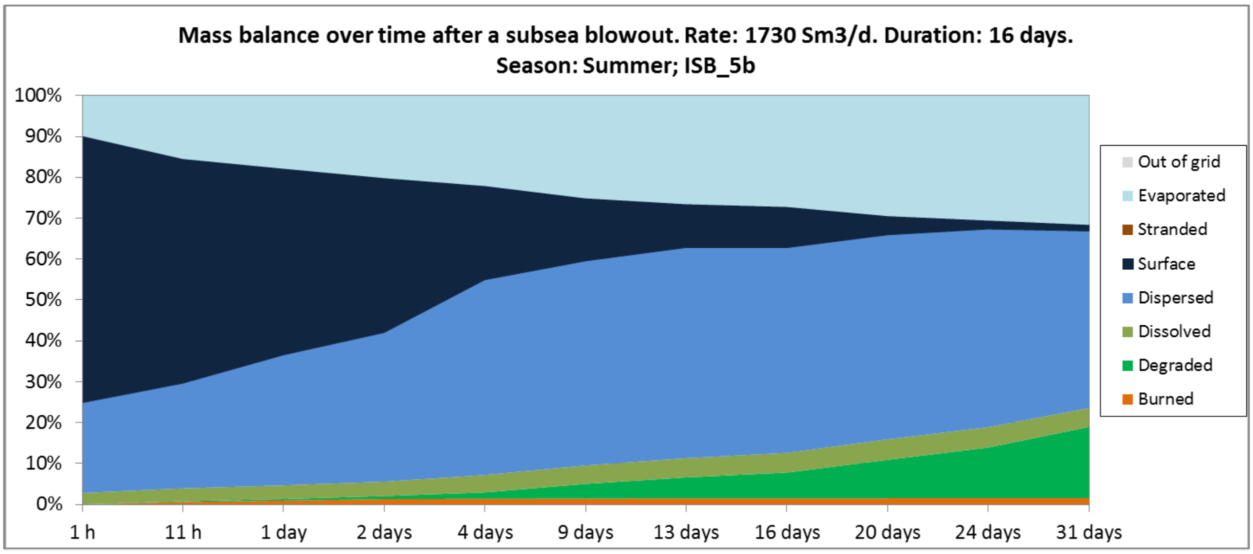

Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; ISB_2b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned



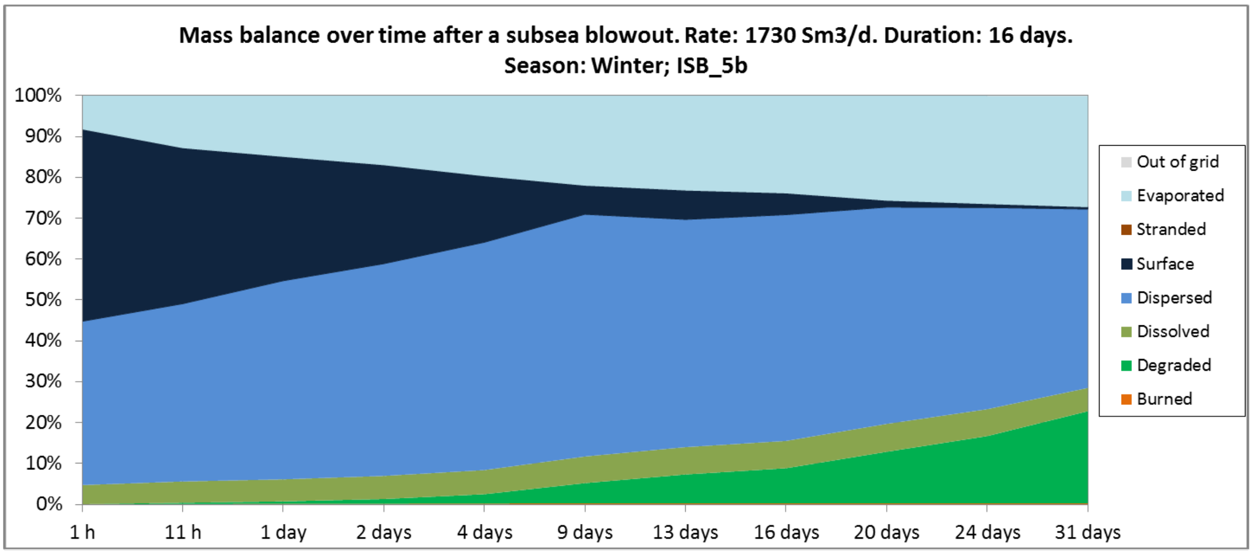
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; ISB_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned



Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; ISB_5a
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned



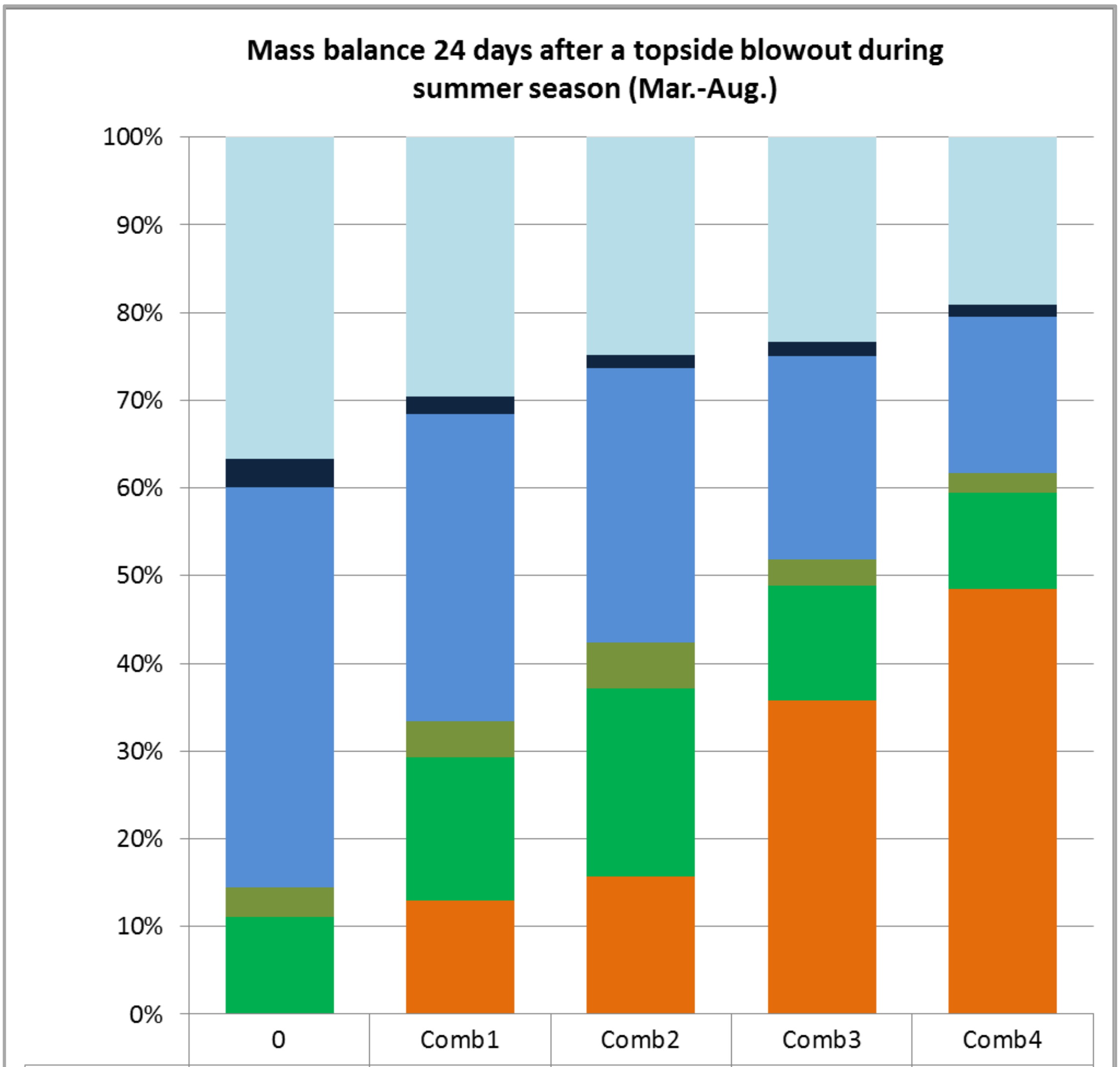
Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Summer; ISB_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned



Mass balance over time after a subsea blowout. Rate: 1730 Sm3/d. Duration: 16 days.
Season: Winter; ISB_5b
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
31 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Burned

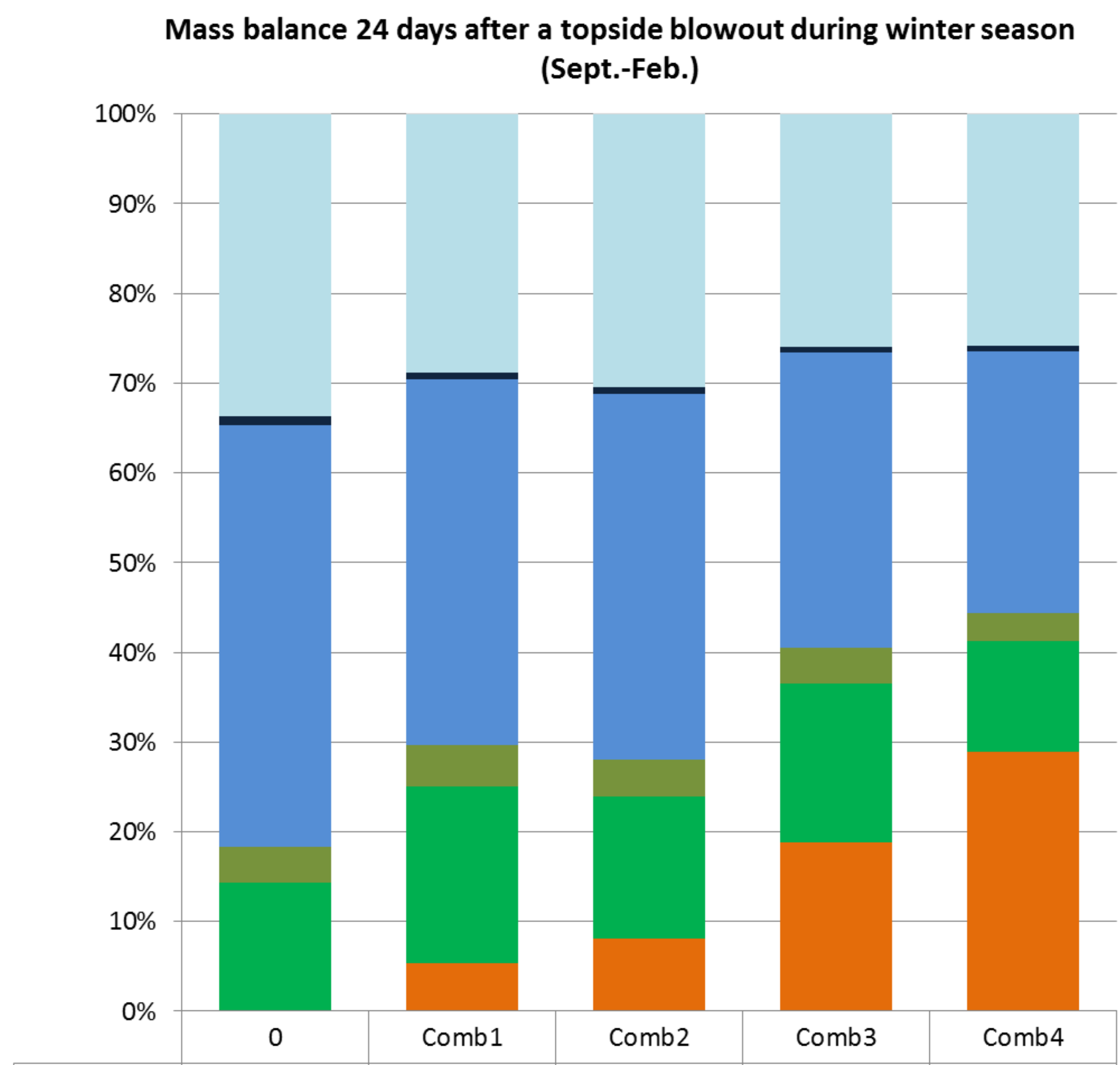
B.8 Combined response measures

TOPSIDE SCENARIO



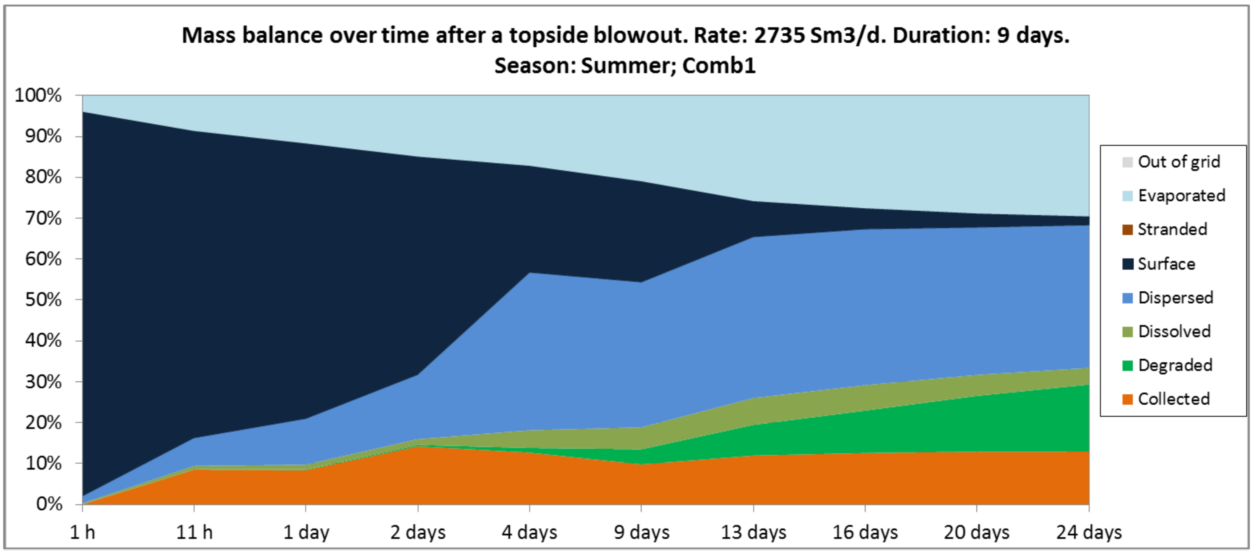
	0	Comb1	Comb2	Comb3	Comb4
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	36,7 %	29,6 %	24,9 %	23,4 %	19,1 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	3,2 %	2,1 %	1,5 %	1,5 %	1,4 %
Dispersed	45,7 %	35,0 %	31,2 %	23,2 %	17,8 %
Dissolved	3,4 %	4,0 %	5,3 %	3,0 %	2,3 %
Degraded	11,1 %	16,4 %	21,4 %	13,1 %	10,9 %
Collected	0,0 %	13,0 %	15,7 %	35,7 %	48,5 %

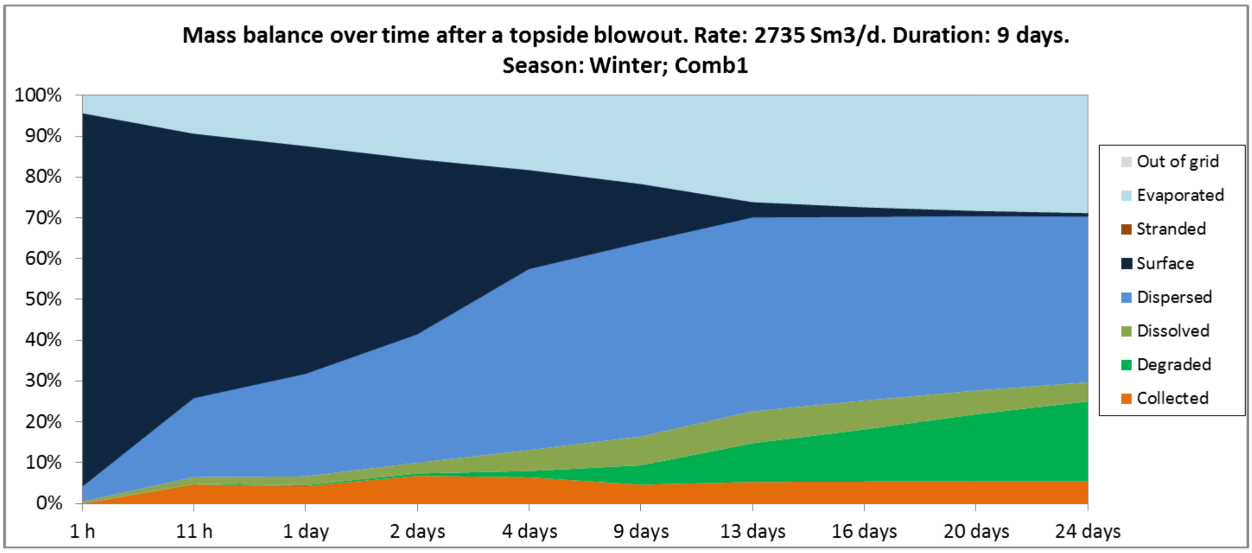
Comb1 = 3 passive mechanical recovery systems + 2 vessel based dispersion systems
Comb2 = 3 passive mechanical recovery systems + 1 aerial dispersion system
Comb3 = 3 active mechanical recovery systems + 2 vessel based dispersion systems
Comb4 = 3 active mechanical recovery systems + 1 aerial dispersion system

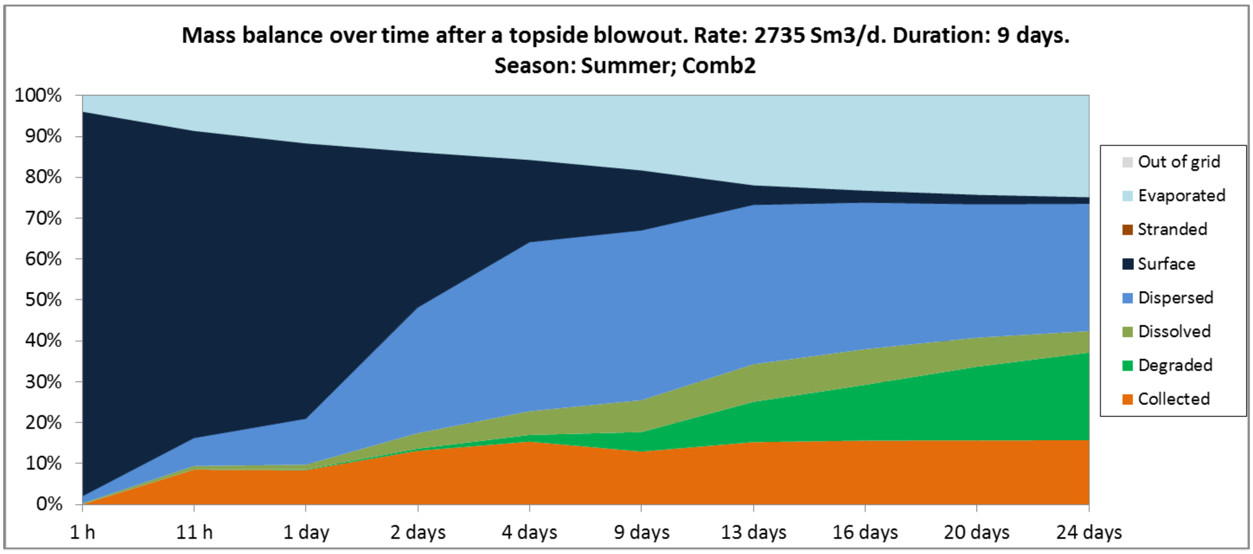


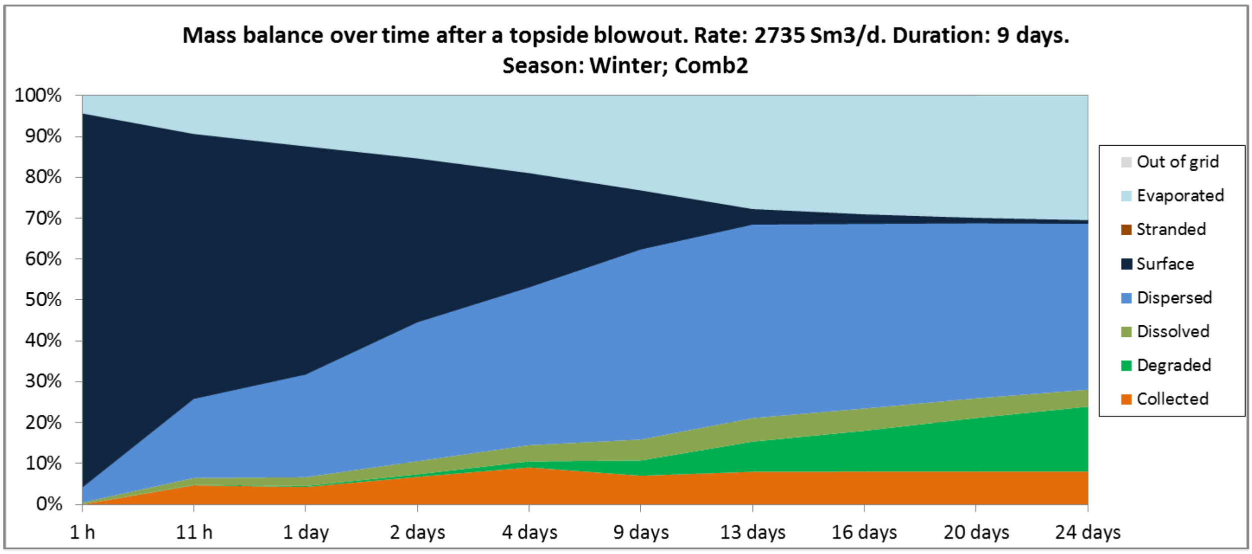
	0	Comb1	Comb2	Comb3	Comb4
Out of grid	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Evaporated	33,7 %	28,8 %	30,4 %	25,9 %	25,9 %
Stranded	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
Surface	1,0 %	0,7 %	0,8 %	0,6 %	0,6 %
Dispersed	46,9 %	40,7 %	40,7 %	32,9 %	29,1 %
Dissolved	4,1 %	4,7 %	4,1 %	4,0 %	3,1 %
Degraded	14,3 %	19,6 %	15,9 %	17,6 %	12,4 %
Collected	0,0 %	5,4 %	8,0 %	18,8 %	28,8 %

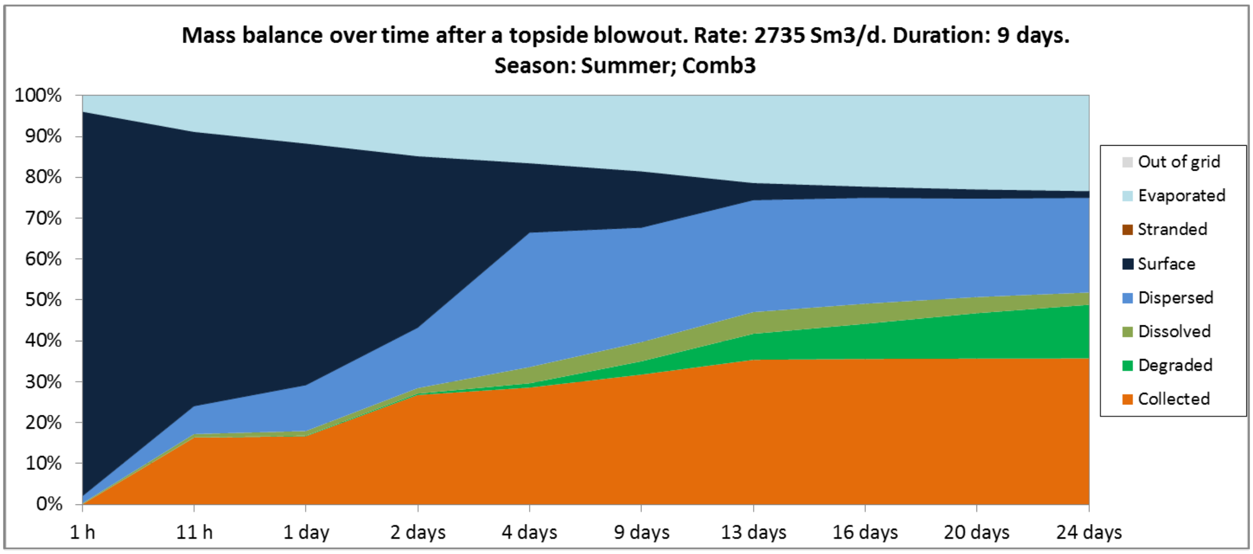
Comb1 = 3 passive mechanical recovery systems + 2 vessel based dispersion systems
Comb2 = 3 passive mechanical recovery systems + 1 aerial dispersion system
Comb3 = 3 active mechanical recovery systems + 2 vessel based dispersion systems
Comb4 = 3 active mechanical recovery systems + 1 aerial dispersion system

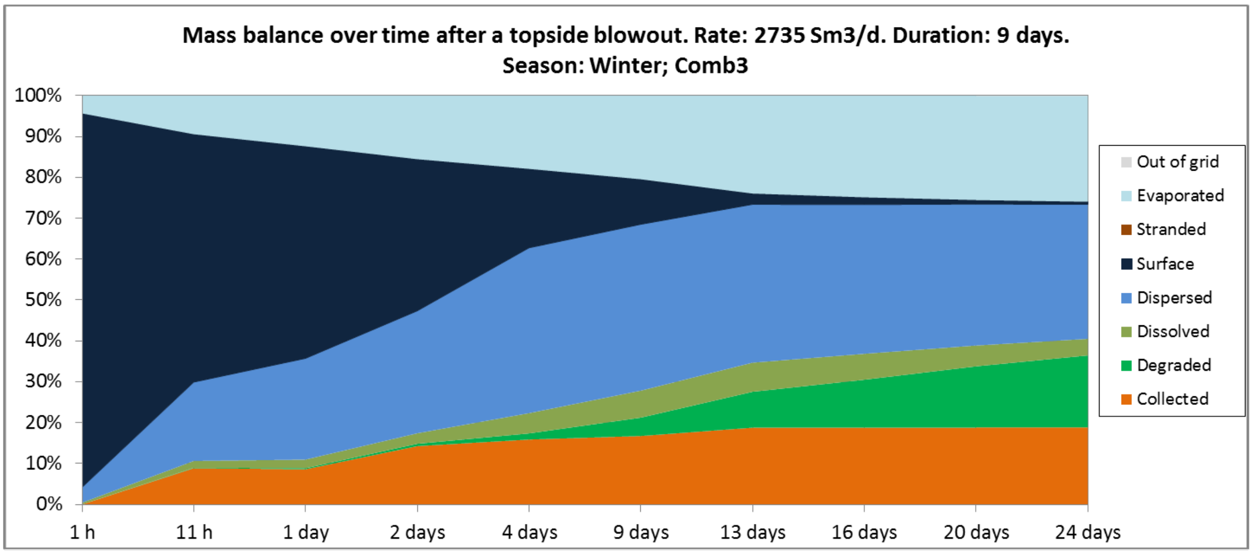

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; Comb1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

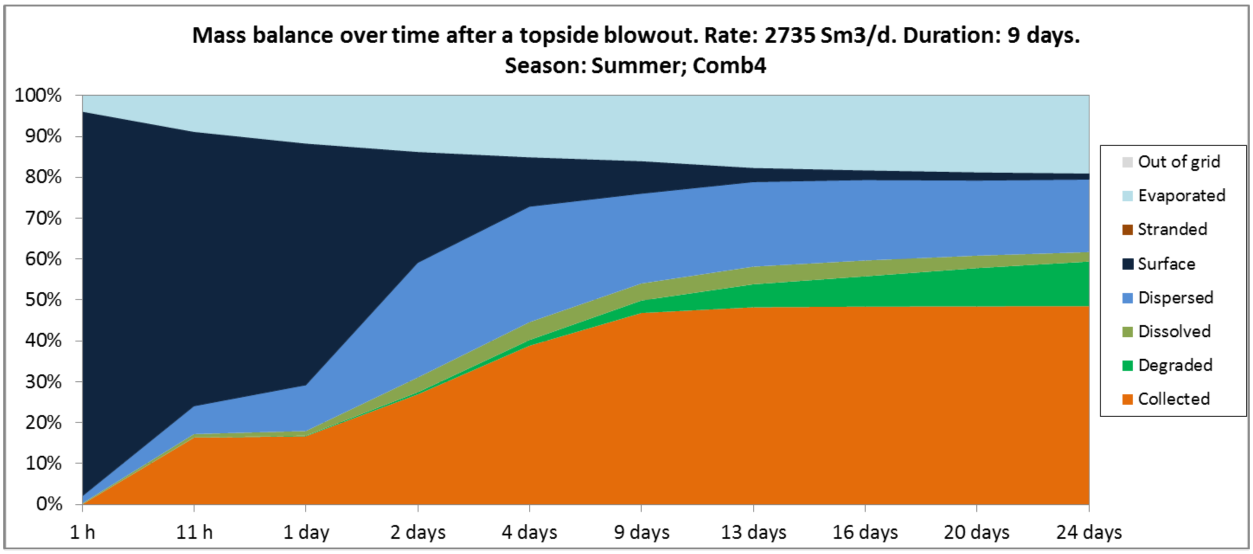

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; Comb1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; Comb2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

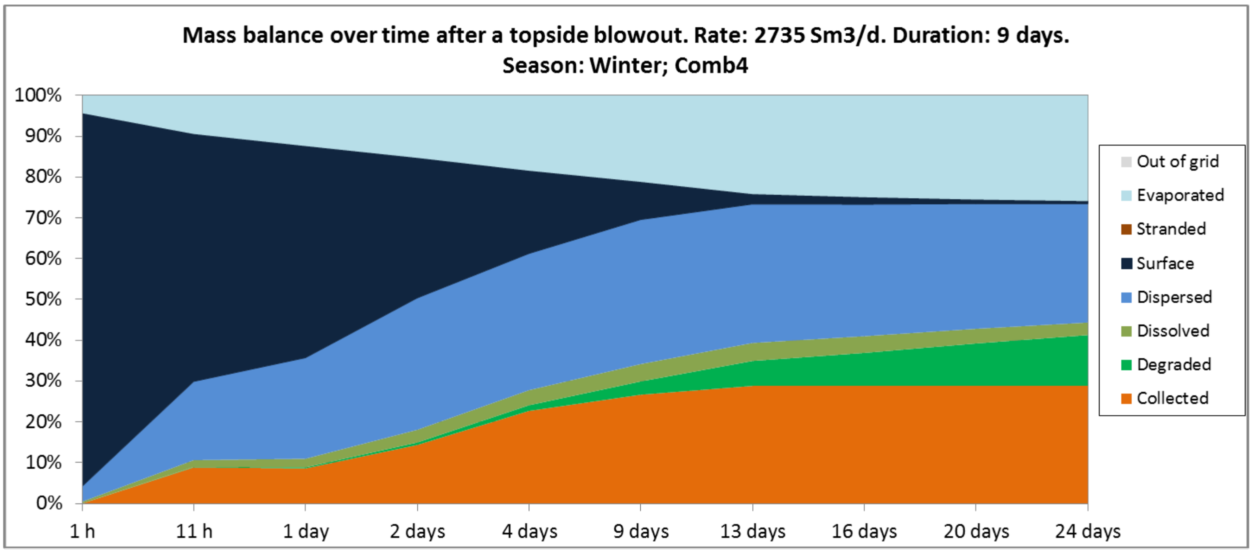

Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; Comb2
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; Comb3
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected


Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; Comb3
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Summer; Comb4
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected



Mass balance over time after a topside blowout. Rate: 2735 Sm3/d. Duration: 9 days.
Season: Winter; Comb4
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 h
11 h
1 day
2 days
4 days
9 days
13 days
16 days
20 days
24 days
Out of grid
Evaporated
Stranded
Surface
Dispersed
Dissolved
Degraded
Collected

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.