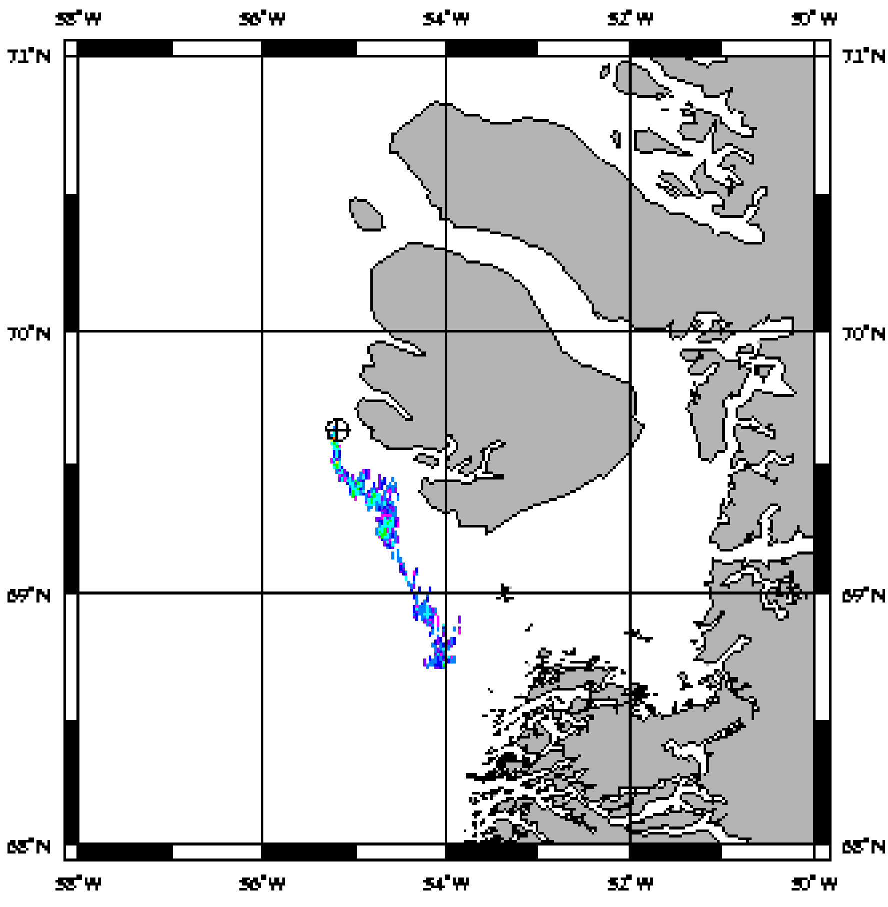
Ministry of Transport and Energy

Technical Report 06-06

Oil drift and fate modelling at Disko Bay

Jacob W. Nielsen, Nicolai Kliem, Martin Jespersen, and Bettina M. Christiansen



Copenhagen 2006

Colophon

Serial title:
Technical Report 06-06

Title:
Oil drift and fate modelling at Disko Bay

Subtitle:

Author(s):
Jacob W. Nielsen, Nicolai Kliem, Martin Jespersen, and Bettina M. Christiansen

Other contributors:

Responsible institution:
Danish Meteorological Institute (JWN, NK, BMC), Danish National Environmental Research Institute (MJ)

Language:
English

Keywords:
Oil drift, Modelling, Disko, Greenland

Url:
www.dmi.dk/dmi/tr06-06

ISSN:
1399-1388 (online), 0906-897x (print)

Version:

Website:
www.dmi.dk

Content:

Abstract

One-month simulations of hypothetical oil spills on the West Greenland shelf region off Disko Island results in estimates of the region affected, and the maximum skin layer thickness and oil concentration to occur under different wind conditions.

Resumé

Månedslange simuleringer af hypotetiske oliespild i det grønlandske shelfområde vest for Disko Øen resulterer i en vurdering af hvilket område der påvirkes, den maksimale tykkelse af oliefilm på overfladen, og de højeste koncentrationer af olie, der opnås

1 Introduction

This report deals with oil drift simulations in the region between West Greenland and Baffin Island, focusing on the shelf region off Disko Island and Disko Bay. The calculations are done with an oil drift model, which simulates the physical and chemical processes a hypothetical oil spill undergoes during the first days after the oil has been released into sea water, and subsequently calculates the drift of the oil for an extended period. Prerequisites for the oil drift model are detailed knowledge of the surface wind and the 3-dimensional motion of the sea, as obtained from the operational numerical weather prediction model HIRLAM, and the semi-operational ocean model HYCOM, respectively.

A number of spill conditions and sites have been prescribed by the Danish National Environmental Research Institute, in order to represent envisaged oil spill conditions. A number of study periods within the design year medio 2004 – medio 2005, with a wide range of wind conditions, have been selected by the Danish Meteorological Institute.

The work has been funded by the Danish National Environmental Research Institute (NERI) as part of the cooperation between NERI and the Bureau of Minerals and Petroleum, Greenland Home Rule, on developing a Strategic Environmental Impact Assessment of oil activities in the Southeastern Baffin Bay.

2 DMI oil drift and fate model

Since the 1990'ies, DMI has run an operational oil drift forecasting service for the North Sea – Baltic Sea. In recent years this service has been extended by application of an oil drift and fate model (below referred to as DMOD), that in addition to passive advection simulates a number of chemical processes, collectively termed 'oil weathering'. The model applies surface winds and 3-dimensional ocean motion (horizontal and vertical current) in order to calculate the drift of the oil. DMOD has been developed specifically for this region by the Bundesamt für Seeschiffahrt und Hydrographie (BSH) in Germany.

In the present project DMOD has been generalised and set up for West Greenland waters. The forcing fields are obtained from the DMI large-scale numerical weather prediction (nwp) model Hirlam-T, which covers all of the arctic and sub-arctic region, and the general 3-D hydro-dynamical (hd) ocean model HYCOM (HYbrid Coordinate Ocean Model), developed by the University of Miami and the Los Alamos National Laboratory.

DMOD runs decoupled from the weather and ocean models. With an extensive archive of HYCOM output data files, any period may be selected for spill studies once the drift model sub-region is properly defined.

The processes handled by DMOD are passive drift of oil, horizontal spreading, horizontal and vertical dispersion (by turbulent and buoyant motion), evaporation, emulsification (uptake of sea water), and settling on the bottom or at the shore. Dissolution and oxidation (by sunlight) are considered less important and are not included. Biodegradation is assumed to be important on long timescales only and is also not modelled. The oil will either settle or stay in the water phase, and the only way oil can disappear from the simulations is by evaporation or emigration out of the model domain.

For a given spill, the oil is released into sea water at a fixed location (latitude, longitude, depth) either as an instantaneous release or at a fixed rate during a specified time interval. The ambient water temperature influences both weathering and spreading processes. The environment is represented by water of constant temperature and density.

A brief summary of processes modelled by DMOD is given below. A detailed description of the processes and parameterizations are given in [1].

Oil particles

An oil spill is represented by a large number of particles, each of which has mass, volume and composition that change due to evaporation and emulsification processes. The total release may be envisaged as a particle 'cloud'. Each oil particle represents a fraction of the total release; this can be quite a large amount of oil, depending on the magnitude of the release. A particle can not be subdivided but is treated as an entity, unable to interact with other particles. It is assumed to have a disc-like shape, with an area and thickness that increase and decrease respectively, as the oil spreads out horizontally. The particle thickness at the time of its release is 3 cm.

Oil composition

An oil particle is composed of 7 groups of hydrocarbon compounds and a residuum (tar). The initial composition constitutes an oil type. DMOD has 8 pre-defined oil types: 4 different crude oils and 4 fuel oils. The density of the oil is the weighted mean of the density of each compound. The composition, and the physical properties of the oil, changes with time due to weathering processes (see below).

Drift

The oil particles drift passively with the ocean current. In a shallow surface layer the horizontal current is modified by adding a wind-induced logarithmic velocity profile, which at the surface takes its maximum value of 3% of the wind speed. Both current and wind velocity are subject to turbulent motion, modelled as random processes scaled by the velocity itself. Turbulence and sub-grid scale motion are further modelled by random walk, by giving the particles a small motion on top of the passive drift, so that all particles do not experience exactly the same drift vector. This spreads out the particle cloud with time, even in total absence of wind or sea current.

The oil slick

Each oil particle gradually spreads out due to gravity/viscous forces and surface tension. The slick spreads out in three phases: initially the radius r increases by buoyancy-inertia forces, then, as the slick grows thinner, the spreading moves into a buoyancy-viscous regime, and the final stage is governed by viscosity and surface tension. The oil slick thickness decided which spreading phase is active. The slick area depends on the (strictly theoretically based) slick radius as $A=\pi r^2$. The limiting area (and thus thickness) of the slick depends on total spill volume as A [m^2] = $10^5 V^{3/4}$ [m^3]. Under constant wind, an instantaneous spill takes an asymmetric disk-like shape, elongated in the wind direction, while a continuous spill will resemble smoke from a chimney.

Weathering

An oil particle undergoes weathering processes that begin to act immediately or shortly after its release. Weathering processes is the collective term for oil spreading, evaporation, dispersion (vertical and horizontal), emulsification (uptake of sea water) and dissolution. These processes depend on the ambient water temperature and density, and the oil's chemical composition and physical properties (density, viscosity, maximum evaporation and pour point), and they change the composition, shape and total volume of an oil particle. Volatile components evaporate from oil at the sea surface, water is added through emulsification until saturated (when two thirds of the particle is water), and the oil particle, being buoyant relative to sea water, displaces itself vertically and spreads out horizontally. The buoyant motion is modelled as a random process, dependent on a theoretical droplet size probability distribution. The downward mixing of surface waves is parameterized as a function of wind speed. The oil particles to be mixed down are selected by a random process that sets in when the wind speed exceeds 5 m/sec, and involves more and more particles as the wind speed increases. An oil slick resting at the surface will thus gradually be disperged in windy weather. For further information on oil in sea water and weathering processes, see, e.g., [3,4].

Settling and emigration

Once released, an oil particle is tracked throughout the entire simulation period. When a particle sinks to the sea bed or reaches the shore (the model does not distinguish between the two), it settles and ceases to be active. The particle can not re-suspend or be washed off-shore again. The weathering processes are also assumed to come to a halt. The particle may also drift out of the model domain, and thereby cease to be active. All particles (active and inactive) are part of the statistical description of the total release or spill outlined below.

Oil in ice-covered waters

DMOD does not explicitly take oil-sea ice interaction into account. Implicitly, however, both the hd model and the nwp model include a formulation of sea ice. Ocean current fields and surface wind are thus influenced by the ice present in those models, and this information is passed on to the drift model. Information about the ice cover itself is, however, not passed on. At low ice concentration, the oil will simply drift and spread along with the ice floes. In this case of free or nearly free ice drift, the presence of ice does not strongly influence the drift and spreading of oil. As the ice concentration increases, the floes begin to interact. The movement of the ice then no longer directly reflects the prevailing wind and current, but the drift model will advect and spread the oil even in completely ice-covered waters. In such a situation the presence of ice hampers the drift, so the model will overpredict the drift and spreading of the oil.

Drift model output

An oil drift simulation results in time series of mean position of the oil slick, total volume and area, and a percentage distribution of oil at the surface, disperged vertically (in the water column), settled and evaporated, plus the total water uptake. The position and composition of each oil particle are recorded. The oil slick may thus be tracked as the average position of all particles, or by mapping out all particles geographically at any given time after the initial release. It should be noted that the mean position may end up on land, e.g. if a spill drifting past an island splits up in two branches. Also, in case of a continuous release of oil, taking place over several days, the mean position does not give an adequate description of the spill situation. In such cases, particle mapping is a better approach.

Gridding

The oil particle cloud is gridded onto the DMOD model region and resolved in the vertical into a 0.05 m surface (skin) layer and a number of subsurface layers. The grid cell area is approx. 1 km² (1/120º latitude by 1/48º longitude). The depth of a particle locates it in one single layer (the vertical particle extent is of the order of mm or less, and therefore disregarded). Horizontally, a particle is treated as a square. It may cover more than one grid cell, and it may cover a grid cell only partly. The thicknesses of all particles covering a grid cell fully or partly, weighted by the fraction of the cell the particle covers, are added up, resulting in an oil thickness for that cell.

Slick thickness and oil concentration

The oil thickness can be directly converted into an oil volume per area: a thickness of 1 mm corresponds to a volume of 1000 m³/km². For the surface skin layer, the accumulated thickness is the gridded result. Conversion into oil concentration in subsurface layers is less straightforward. When a surface slick of 1 mm thickness is mixed down, the resulting concentration will depend on the mixing depth. Mixing a 1mm slick down to 10m depth results in a concentration of 100,000 ppb total hydrocarbon (TH) in the top 10m. From the DMOD output, however, there is no simple or obvious way of telling whether an oil particle located at depth origins from below (subject to buoyant rise) or from above (subject to wave-induced downward mixing). Therefore, in this study a particle is assumed only to pollute the layer in which it resides. The water content in the particles are subtracted before the accumulated oil thickness is divided by the layer thickness, resulting in a mean concentration in that layer. It is thus implicitly assumed that the oil is evenly distributed over the layer in question. To some extent, the resulting concentration depends on the vertical subdivision of the water column.

Validity

The advective-dispersive part of the drift model has been proven to give excellent results, provided the forcing data (wind and current maps) has high quality. In two cases in the Danish Domestic Waters, an oil spill caused by an accident at sea resulted in pollution of coastal stretches. Both timing and extent was well predicted by DMOD (see [4]). The oil weathering part is theoretically based, and the DMOD implementation has, to the authors knowledge, not been tested against field data. The same is true for the oil concentrations resulting from gridding and post-processing.

3 Model setup

The nwp and hd forcing models, HIRLAM and HYCOM respectively, are described in detail in [2]. While the weather model is running operationally at DMI, the ocean model has been set up specifically for this study to cover the North Atlantic and the Arctic Sea with a nested high resolution domain covering Greenland waters. Output from both models are interpolated onto the mesh of the oil drift model DMOD in time steps of one hour.

The DMOD grid covers the region 72-50ºW, 65-75ºN (depicted below) with a latitude/longitude resolution of 0.25º/0.10º, respectively (approx. 10 km). The model has 12 layers, with layer interfaces located at 1, 5, 10, 15, 20, 30, 50, 75, 100, 500, 1000 and 1500 m depth. The gridded current velocities represent the average velocity of the layer in question. The particle advection velocity is found by bi-linear interpolation in the DMOD data cube. This velocity is thus doubly (wind speed: triply) interpolated from the basic data.

The time step for all DMOD processes (as described above) is one hour. While fully adequate for chemical processes, this may be considered an upper limit for advective processes in flow with a strong tidal component and for vertical displacement by buoyancy forces.

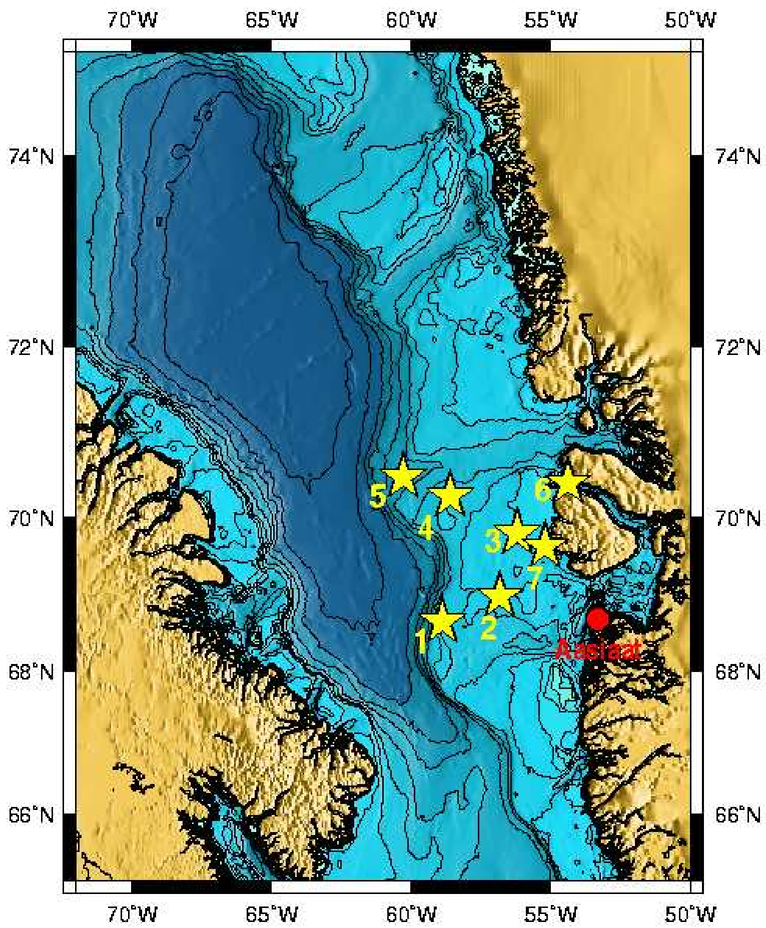


Figure 1 Model domain and bathymetry. Stars indicate oil spill positions. The wind station Aasiaat, indicated by a red circle, is located at the south coast of Disko Bay. The near-terminal sites 6-7 are located at the Vaigat between Disko Island and Nuussuaq Peninsula, and at the west coast of Disko Island, respectively.

4 Simulations

The sites of hypothetical oil spills are all located in the shelf area west of Disko Island, at the west coast of Greenland (68ºN to 71ºN). Seven spill locations have been selected as indicated on the map above and in Table 1, representing releases at potential offshore well drilling or oil production platforms (location 1-5), and spills from tankers near a potential oil terminal (location 6-7). Sites 1 and 5 are located near the shelf break; sites 2, 3, and 4 on the shelf proper. For each of the offshore spill sites we simulate a continuous spill taking place either at the surface (0 m depth) or at the sea bed. For the two oil tanker sites we simulate a surface spill only. Furthermore, for all spill sites instantaneous surface spills are simulated. These simulations are repeated for a number of wind conditions, as described in the next section. The length of each simulation period is fixed at 30 days, in order to simulate the spreading of the oil until concentrations are low, or until the oil has settled on shore. The total number of simulations is 114.

Site no.	Longitude	Latitude	Depth (m)
1	58.8723 W	68.6628 N	321
2	56.8115 W	68.9972 N	201
3	56.1807 W	69.7621 N	130
4	58.5865 W	70.2514 N	318
5	60.2702 W	70.4852 N	683
6 (T)	54.3662 W	70.4172 N	414
7 (T)	55.1837 W	69.6315 N	79

Table 1 Oil spill sites. T = tanker spill near a potential oil terminal.

For continuous spills oil is released at a constant rate during the first ten days of the simulation period. The amount of oil released is fixed at 3,000 t/day, totalling 30,000 tons. For instantaneous spills, the amount of oil released is 15,000 tons. A crude oil of type “Statfjord” with a density of 886.3 kg/m³ (a North Sea crude oil, see Table 2 for composition) is chosen to represent oil in this region. This is a medium oil type, lighter than sea water, which will evaporate about one third during the first 24 hours of a surface spill. The ambient water temperature is climatological, taken from Levitus and ranging from 6ºC in August to -1ºC in January-April. The density of sea water is fixed at 1026 kg/m³.

Fraction	1	2	3	4	5	6	7	8
Description	C_6-C_{12} Paraffin	C_{13}-C_{25} Paraffin	C_6-C_{12} Cyclo-paraffin	C_{13}-C_{23} Cyclo-paraffin	C_6-C_{11} Aromatic	C_{12}-C_{18} Aromatic	C_9-C_{25} Naphtheno-aromatic	Residual Incl. Hetero-cycles
Percentage	15	13	14	12	7	3.5	3.5	32

Table 2 Fraction of different compounds for the selected crude oil. The oil fractions 1,3, and 5 (36% in total) will evaporate in less than two days if the oil is in contact with the atmosphere. Fractions 2,4,6 and 7 are volatile on longer timescales, while the tar residuum persists.

5 Wind periods

Six 10-days wind periods have been selected within the design year July 2004 – June 2005. The periods are chosen on basis of observations at the wind station; Aasiaat (04220) located at the southern tip of Disko Bay (68.7ºN, 53.3ºW, position indicated on map). The five first periods represent dominating wind from different directions (see Table 3). The indicated wind direction is represented during the first days of the period, but may shift later on. The first few days are considered most important after an oil spill release, especially at tanker spills near terminal sites, since this decides whether the oil settles on shore or escapes to sea. While period 1-5 represent moderate wind speeds, the sixth period has spells of strong southerly wind.

Appendix A contains wind rose graphics and statistics of the wind speed and direction frequency, for the full design year and for each month in the design year. Appendix B contains wind rose graphics and statistics for each of the six wind periods, and 10-days average wind velocity maps produced by the nwp model.

Period no.	Starting at: (UTC time)	Wind conditions Aasiaat	Wind conditions Off-shore
1	07-Jul-2004 20	SW	weak
2	13-Aug-2004 04	N	SSE
3	16-Nov-2004 04	E	SE
4	03-Jan-2005 21	S	N
5	10-Jun-2005 12	W	weak SE
6	28-Jan-2005 00	Strong wind	S

Table 3 10-days wind periods chosen on basis of observations at Aasiaat wind station (04220).

The observed mean wind conditions at Aasiaat are found not to be representative for the off-shore surface wind conditions as described by the nwp model. The 10-days averages show that due to topographic features, the local wind at Aasiaat may run counter to the general off-shore wind direction. This is the case for wind period 2, 4, and 5, while for case 3 and 6 the general flow pattern also applies to Aasiaat. For period 1, the off-shore wind is too weak to assign a typical wind direction.

The full simulation length is 30 days. The wind conditions during the last 20 days of the simulations have not been studied in detail, or used to select the periods.

6 Results

The basic output of a simulation is an hourly particle location and property table. Spill statistics is generated by averaging over all particles, and gridding results in oil concentration/thickness maps. Appendix C contains maps of the maximum oil slick thickness in the surface skin layer attained at any time during the 30 days of simulation. Only surface spill cases are shown. The continuous bottom spill cases are not shown, but are very similar to the continuous surface spill cases.

Some general features of the oils spill simulations are discussed below.

Surface versus bottom release

Due the fast buoyant rise of the oil, it quickly ends up at the surface, and there is thus not much difference in surface conditions between a continuous surface and a continuous bottom release.

Downward mixing

In calm weather the oil stays in a skin layer at the surface, and the oil is mixed down only during periods of strong wind. A maximum of about 20% of the oil is temporarily mixed down. The average mixing depth is usually just a few metres, with a maximum of 12 metres. The maximum mixing depth of an oil particle is 10-34 metres, depending on the wind period.

Oil thickness

A typical skin layer thickness after 10 days is 0.4-0.6 mm for continuous release, but only 0.05-0.15 mm for instantaneous release, when the oil on average has had longer time to spread out and the total amount released is only half. After 30 days the mean skin layer thickness has decreased to 0.01-0.05 mm in every case.

Oil composition

The total water content converges towards two thirds for all oil particles, except when they settle very quickly (the particle composition is then fixed). All volatile components, about 36% of the oil, evaporates during the first day or two after the oil has been released or has surfaced. The final volume is thus about double the spill size.

Mean drift

The maximum displacement of the oil is about 375 km away from the release site in ten days, and the preferred drift directions are alongshore, north and south. In 30 days, oil may be found as much as 580 km from the release site.

Spreading

As indicated in section 2, the time dependency of the slick radius and area is calculated using a theoretical formulation for the radius increase. The spread depends on the time oil has resided in sea water, which (during the first 10 days) on average is twice as large for the instantaneous spill as for the continuous spill. This leads to larger area and radius for instantaneous spills. The slick area after 10 days is 100-500 km², equivalent to a disc with a radius of 5-6 km in case of a continuous spill, and 10-12½ km in case of an instantaneous spill. After 30 days, the slick radius has increased to 20-25 km, and the slick typically covers an area of 1,500-2,000 km² of very irregular shape. In practice, the oil will form isolated patches within this area, with regions of high concentration interspersed with regions with no oil at a given time. This means that the area actually covered with oil is smaller than the indicated figured. The model gives no indication of how much smaller.

Settling

In the off-shore releases (sites 1-5) almost none of the oil particles settle on the sea bed or the coast during the first ten days. Continuous bottom release from site 1 and 5 (shelf-break sites) settle none or less than 1% on the sea bed. The tanker surface spills (bottom releases not simulated) result in everything from a few percent to almost all of the oil to settle on shore. For the continuous release, 17-64% of the oil released at Vaigat (site 6) settles on shore, while 0-37% from Disko Island (site 7), the exact amount depending strongly on wind conditions. Only in the case of easterly wind (period 3) is Disko Island or Vaigat not polluted. For the instantaneous release, the settled amount may be larger or smaller, depending on the wind direction just after the release time.

Percentage of total spill on coast after 10 days							
Site	**Release**	**period 1**	**period 2**	**period 3**	**period 4**	**period 5**	**period 6**
6	ins	100	67	0	100	50	91
6	con	64	28	17	38	19	64
7	ins	0	1	0	0	70	45
7	con	26	3	0	7	37	21
Percentage of total spill on coast after 30 days							
Site	**Release**	**period 1**	**period 2**	**period 3**	**period 4**	**period 5**	**period 6**
2	ins	20	0	0	0	0	0
2	con	1	0	0	0	0	0
3	ins	31	0	0	0	0	0
3	con	40	0	0	0	0	1
6	ins	100	100	0	100	100	93
6	con	100	100	35	76	76	66
7	ins	58	3	0	0	79	51
7	con	62	4	2	7	69	21

Table 4 Amount of oil (%) settled on shore 10 days and 30 days after spill from near-coastal platform or tanker spill near oil terminal. None of the spills from far off-shore platforms (sites 1,4,5) reach the shore within 30 days.

After 30 days, the spills farthest off-shore (site 1, 4, and 5) still have not reached any coast and no further bottom settling has taken place. In wind case 1 (westerly wind), spills from site 2 and 3 wash partly onshore, as indicated in Table 4. The instantaneous Vaigat (site 6) spill largely ends up on shore, except when immediately blown offshore (wind period 3). From the continuous spill, one to two thirds settle on shore, while the rest of the oil escapes to open sea. From the Disko Island spill (site 7), 20-80% ends up on shore in the on-shore (westerly) wind cases, while in other wind directions most of the oil escapes to sea.

Oil concentration

The oil concentration resulting from the simulations depend on the fineness of the post-processing gridding method. The oil in a grid box is assumed to be spread out evenly over the box volume, and the larger the box, the lower the concentration. While vertical mixing can be assumed effective (the box depth/length ratio is 1/100), a too coarse horizontal gridding easily results in spurious mixing. The selected gridding fineness of 1km² is considered adequate; finer gridding will not change the results.

When downward mixing results in subsurface contamination, the whole layer down to the mixing depth is affected in reality. This feature is not represented by the model, resulting in an overestimation of the concentration in the polluted layer. Furthermore, in real life a subsurface contamination decays rather slowly. In the model, the decay is represented by a sudden lift of the oil particle back to the surface, leaving a non-polluted layer behind. These two features should be kept in mind when applying model results.

The highest concentration is found in the top metre of the water column, with a gradual decrease towards the sea bed. The highest value at any depth is found in the case of an continuous bottom release, when the surface level momentarily reaches almost 80,000 ppb. Layers below the maximum mixing depth are obviously only affected in case of a bottom release, and the maximum level is of the order of 10,000 ppb. Oil released at depth does not evaporate until surfaced, which accounts for the higher levels relative to surface releases. For surface releases, the oil concentration (50,000-60,000 ppb at the surface) drops off quickly with depth to disappear below 30m. The maximum skin layer thickness in case of a continuous release is 2-2½ mm, as opposed to 16½ mm for the instantaneous release, when more oil particles are located at the same spot so their thicknesses add up.

Depth	**continuous bottom release**	**continuous surface release**	**instantaneous surface release**
Skin	2,371	2,558	16,589
<1m	77,807	61,245	46,524
1-5m	31,714	17,430	20,685
5-10m	29,716	14,645	8,746
10-15m	26,033	7,460	6,506
15-20m	25,678	4,183	4,820
20-30m	18,508	1,483	1,273
30-50m	11,264	0	282
50-75m	13,548	0	0
75-100m	12,836	0	0
100-500m	2,476	0	0
500-1000m	1,791	0	0
1000-1500m	0	0	0

Table 5 Maximum skin layer thickness (µ) and oil concentration (volume ppb TH) during day 0-10.

Theoretical and practical experience

The discussion to follow is based on [3]. When oil is released continuously into sea water, the resulting oil slick has been found to reach a typical thickness of 0.1mm. The downward mixing due to waves and turbulence is found to be effective down to a depth of 15-20m. Maximum concentration is in the range of 1,000-10,000 ppb TH, but about 40 km away from the source down to the background level of <5 ppb. When the supply of oil is cut, the concentration falls to a few hundred ppb in about 24 hours. Theoretical values are about three times higher, because in practice the oil emulsifies in concentrated regions, thereby lowering the concentration in the rest of the water mass. A theoretical blow-out of 4,800 t/d will result in an oil slick thickness of about 2mm at the blow-out site, in reasonable accordance with Table 5. Mixing down to 20m from a small slick gives maximum concentrations of 24,000 ppb. The extreme values in Table 5 are somewhat higher, but in reasonable accordance with this.

7 Examples

In this section a total of 5 cases are singled out for detailed description. All cases were run for wind period 3: easterly wind at Aasiaat and south-easterly off-shore (cf. Appendix B).

Case 1: Continuous bottom spill from platform (site 4)
Case 2: Continuous surface spill from platform (site 4)
Case 3: Instantaneous surface spill from platform (site 4)
Case 4: Continuous surface spill from tanker near oil terminal (site 6)
Case 5: Instantaneous surface spill from tanker near oil terminal (site 6)

Case 1-3 Spill from platform (site 4)

The release point is located about 150 km west of Disko Island. The simulated oil statistics is shown in Figure 2. The top panel shows a continuous bottom release (317 m depth), the middle panel a continuous surface release, and the bottom panel an instantaneous surface release. In none of the simulations does any oil settle on the sea bed or at the coast. The total water uptake converges toward two thirds, while 36% of the oil evaporates. These processes roughly take place during the first two days. 60-65% of the oil ends up at the surface, even when released at large depth. Oil released at the sea bed quickly rises to the surface, and up to 10% is re-disperged during periods with strong wind.

The spill size is shown in Figure 3. The total volume and area grow approximately linearly with time during the first 10 in case of a continuous release. The final volume is more than double the total amount of oil released (30t), even considering the loss of oil due to evaporation, due to the large uptake of sea water. This is important for oil combating purposes, since the oil-water mixture is rather stable, but less important for the oil concentration. The area affected by the release can be converted to a disc of 6 km radius after 10 days. Volume and area are a little larger for the bottom release than for the surface release. In the case of an instantaneous release, the total oil volume reaches a maximum after ~24 hours, when the water uptake process rolls faster than evaporation. The total volume triples, but during the next day or so the volatile components disappear and we again end up with a total volume of twice the released amount. However, the total area covered after 10 days is about four times as large as for the continuous release (converted to a disc of 11-12 km radius). The reason for this is that the average residence time is twice as large as for the continuous spill, so the oil has had more time to spread out. After the release has terminated, the area and radius growth rates of the spill methods are similar.

The spill particle distribution at day 10 is shown in Figure 4. The oil has drifted approximately 235 km to the north, maintaining an almost constant distance to the Greenland coast. There does not seem to be much difference between a continuous bottom and surface release. As a result of the spill, the oil lies in a long narrow band extending from the source point northwards. The instantaneous spill has drifted away from the source point and forms a north-south elongated slick of about 90 km length and 20 km width.

Figures 5 and 6 show the surface slick thickness after 5, 10, 20 and 30 days, for the continuous and instantaneous surface spill, respectively. The spreading of the oil results in a steady decrease of the thickness of the oil film (and thereby the potential for polluting the water masses below). After 10 days we still have values in the 0.1-0.25mm range, but after 20 days the level has fallen below 0.025mm everywhere, and below 0.01mm in most of the affected region. Assuming a mixing level of 10m, this corresponds to a potential oil concentration of 1,000 ppb TH. The continuous spill results in a vary long narrow band of oil, extending further and further away from the source point. The band broadens only very slowly, and towards the end of the simulation it has broken up into segments. The instantaneous spill is a more well-defined patch that gradually elongates to more than 150 km extent, and, much like the continuous case, has become patchy towards the end of the simulation.

Figure 7 shows the time development of the maximum surface slick thickness, for the two types of surface release. The instantaneous spill starts out as a thick slick (3cm at day 0), but ends up as a thin film of less than 0.05mm everywhere. The continuous spill never exceeds 1½ mm thickness, but ends up with a maximum thickness about twice that of the abrupt spill.

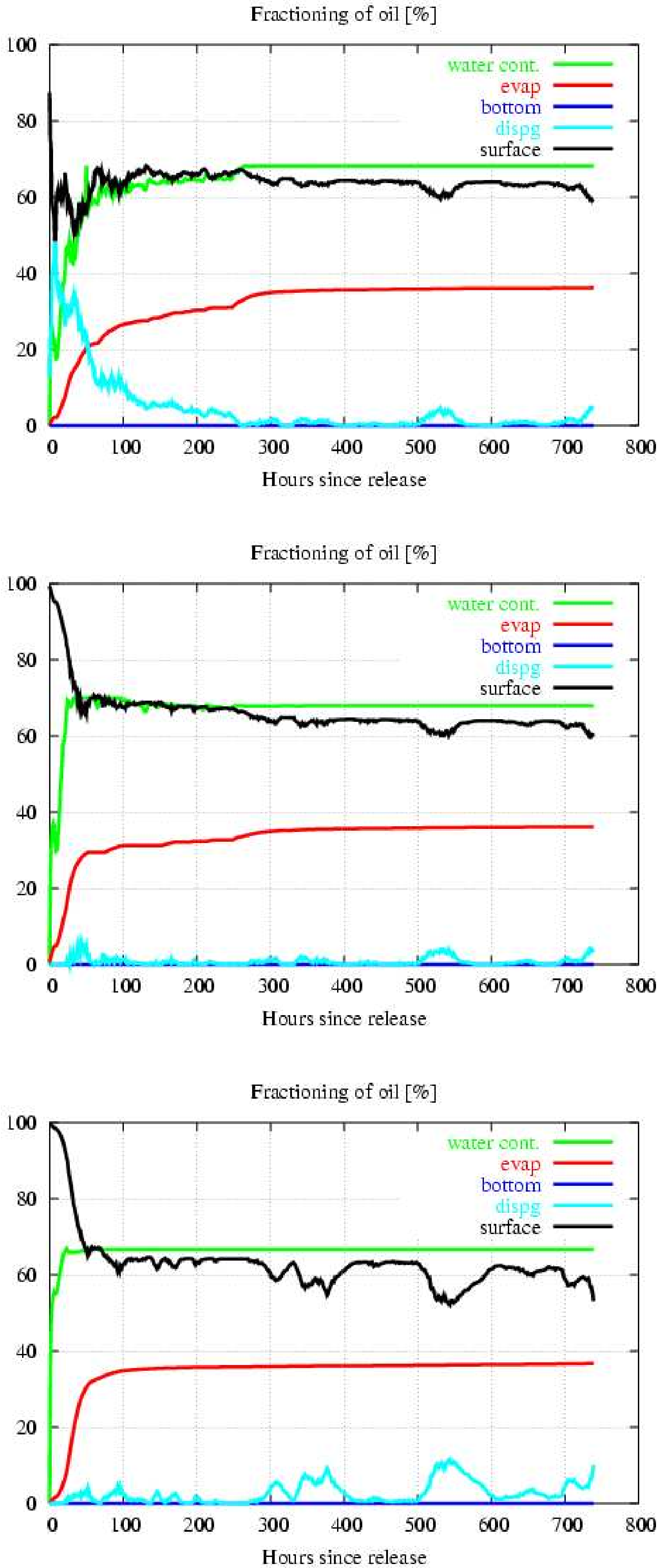


Figure 2 Oil statistics for off-shore oil spill. Top panel: continuous bottom spill; centre panel: continuous surface spill; bottom panel: instantaneous surface spill.

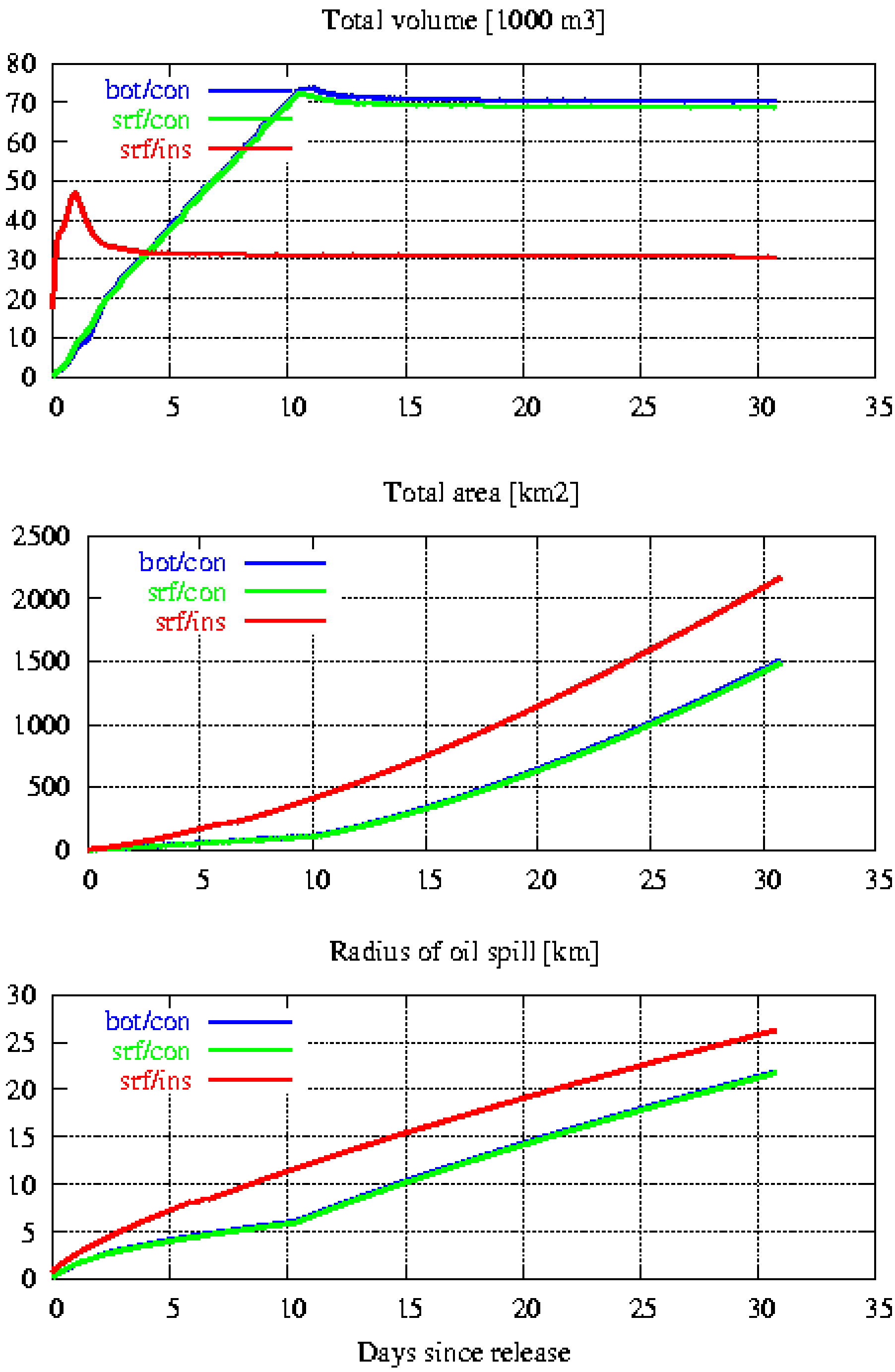


Figure 3 Size development of off-shore oil spill. Blue: continuous bottom spill; green: continuous surface spill; red: instantaneous surface spill.

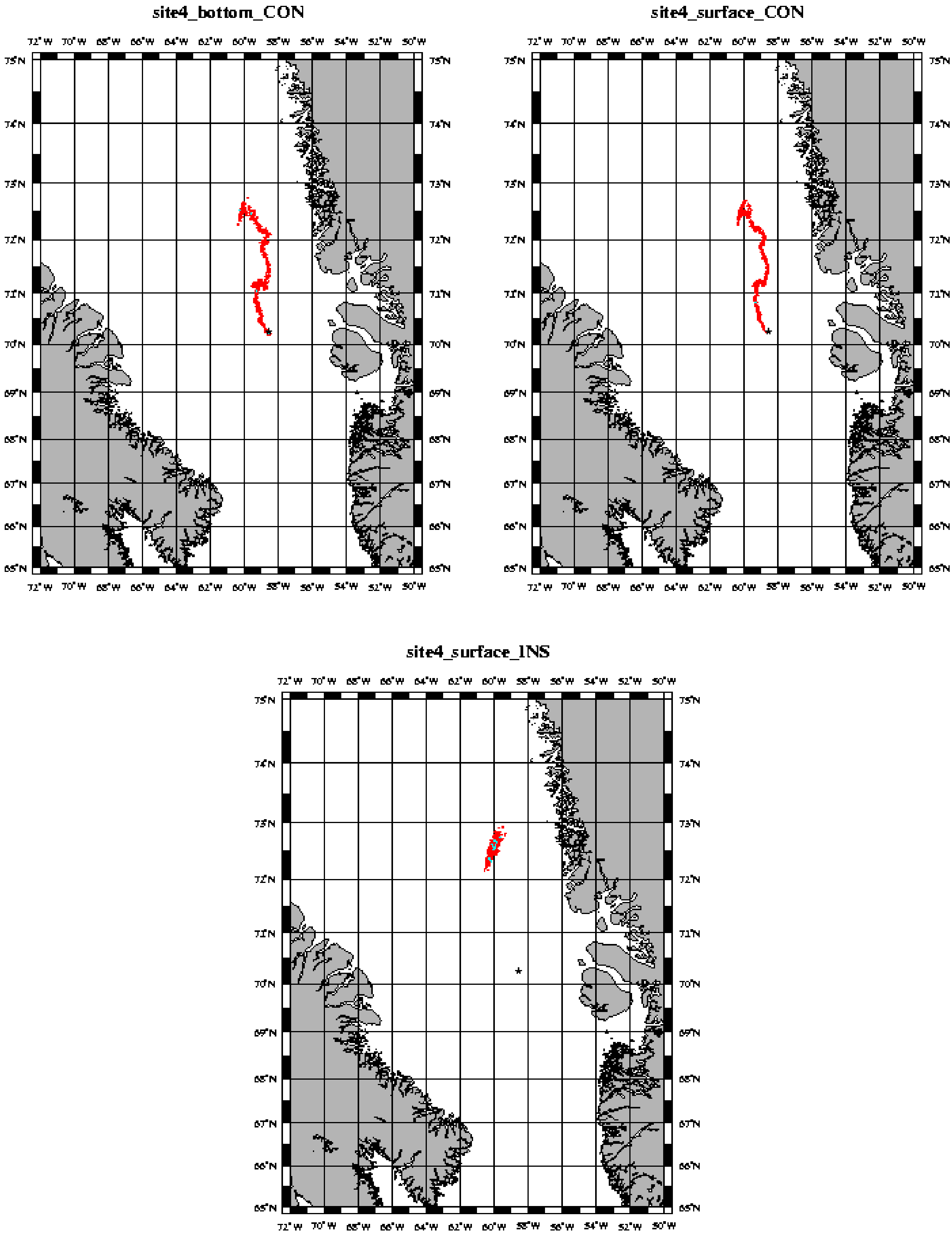


Figure 4 Off-shore oil spill. Snapshot after 240 hours. Dots indicate oil particles (red: surface, cyan: subsurface, yellow: settled) and the spill site is located at the black star. Top panel, left: continuous bottom spill; top panel, right: continuous surface spill; bottom panel: instantaneous surface spill.

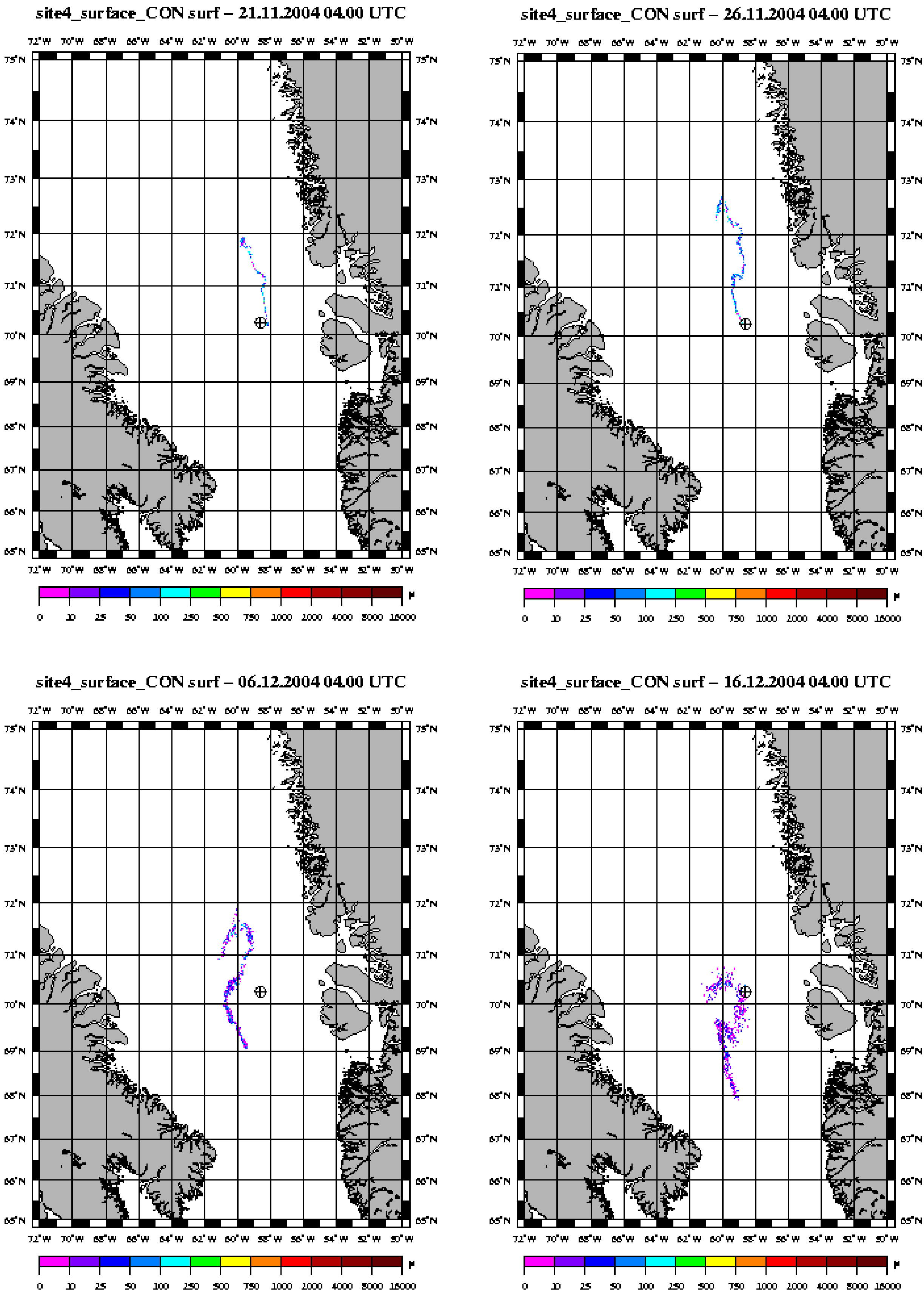


Figure 5 Thickness and position of surface oil slick in case of a continuous platform spill, after 5, 10, 20 and 30 days.

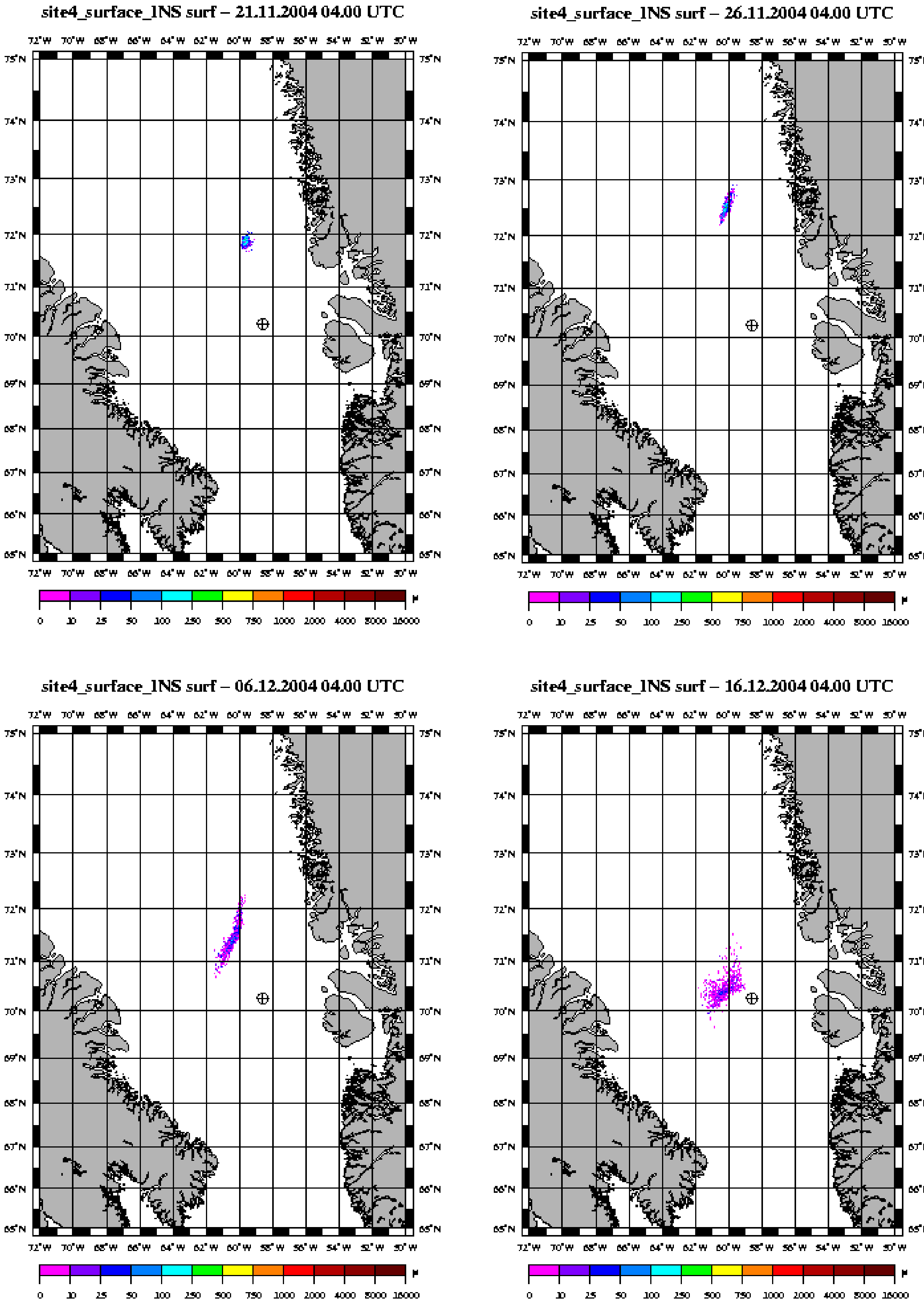


Figure 6 Thickness and position of surface oil slick in case of an instantaneous platform spill, after 5, 10, 20 and 30 days.

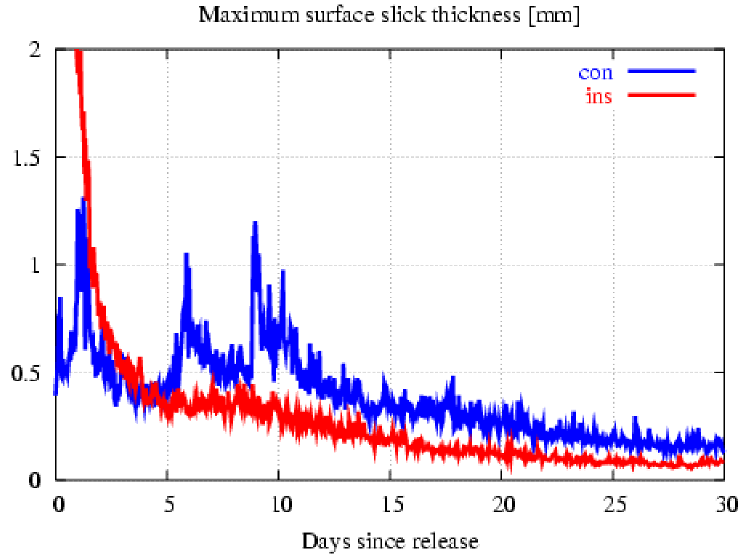


Figure 7 Maximum surface slick thickness for surface oil spills at site 4.

Case 4-5: Spill from tanker near oil terminal (site 6)

The release point is located in the western end of the sound between Disko Island and Nuussuaq Peninsula, north of Disko Island. The simulated oil statistics is shown in Figure 8. The top panel shows a continuous surface release, and the bottom panel an instantaneous surface release. The evaporation and emulsification processes run along the same lines as for the off-shore release. The total water uptake converges toward two thirds, and 36% of the oil evaporates during the first two days. For the continuous release, 35-40% of the oil ends up on the shores of the Nuussuaq Peninsula, while another 35-40% stays at the surface in a narrow band extending 250 km northwards along the west coast of Greenland. Due to coastal settling which takes place near the release point during spells of westerly wind, the band is broken up into segments. For the abrupt release no oil settles and so the amount of oil at the surface is larger. The oil is mixed down several times during periods with strong wind; this effect is stronger for the instantaneous release when up to 21% of the oil leaves the surface, about five times as much as for the continuous release.

The spill size is shown in Figure 9. During the first ten days the total volume and area grow approximately linearly with time in case of a continuous release. When the wind turns westerly, the oil settles at the same rate at released, at so the total volume temporarily ceases to grow. This happens on two occasions, at day 5 and day 9 after the initial release. After 10 days, the final volume is 50% larger than the total amount of oil released, but then oil begins to settle in large amounts. The area affected by the release can be converted to a disc of 5-6 km radius after ten days. In the case of an instantaneous release, the total oil volume reaches a maximum after 1-1½ days, much along the same lines as for the off-shore release.

The spill particle distribution after 10 days is shown in Figure 10. The oil drifts approximately 275 km to the north, maintaining a rather short distance to the Greenland coast. As a result of the steady spill, the oil lies in a long narrow band extending from the source point northwards. The band is broken into segments due to settling of oil on the Nuussuaq Peninsula. The instantaneous spill drifts away from the source point and forms a north-south elongated slick of about 80 km length and 20 km width.

Figures 11-12 show the surface slick thickness after 5, 10, 20 and 30 days, for the continuous and instantaneous surface spill, respectively. The general pattern does not differ much from the platform release, with slick thickness falling below 0.01mm almost everywhere from day 20-30. The patchiness of the continuous spill is larger for reasons indicated above.

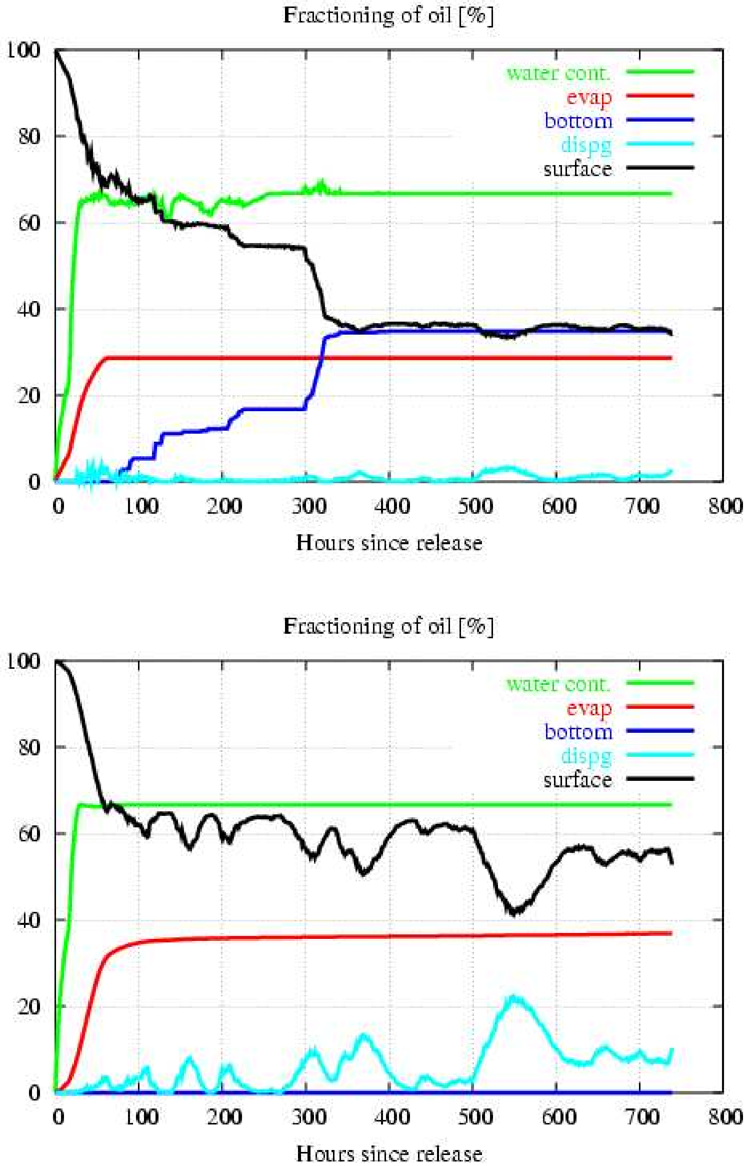


Figure 8 Oil statistics for oil spill from tanker near terminal. Top panel: continuous surface spill; bottom panel: instantaneous surface spill.

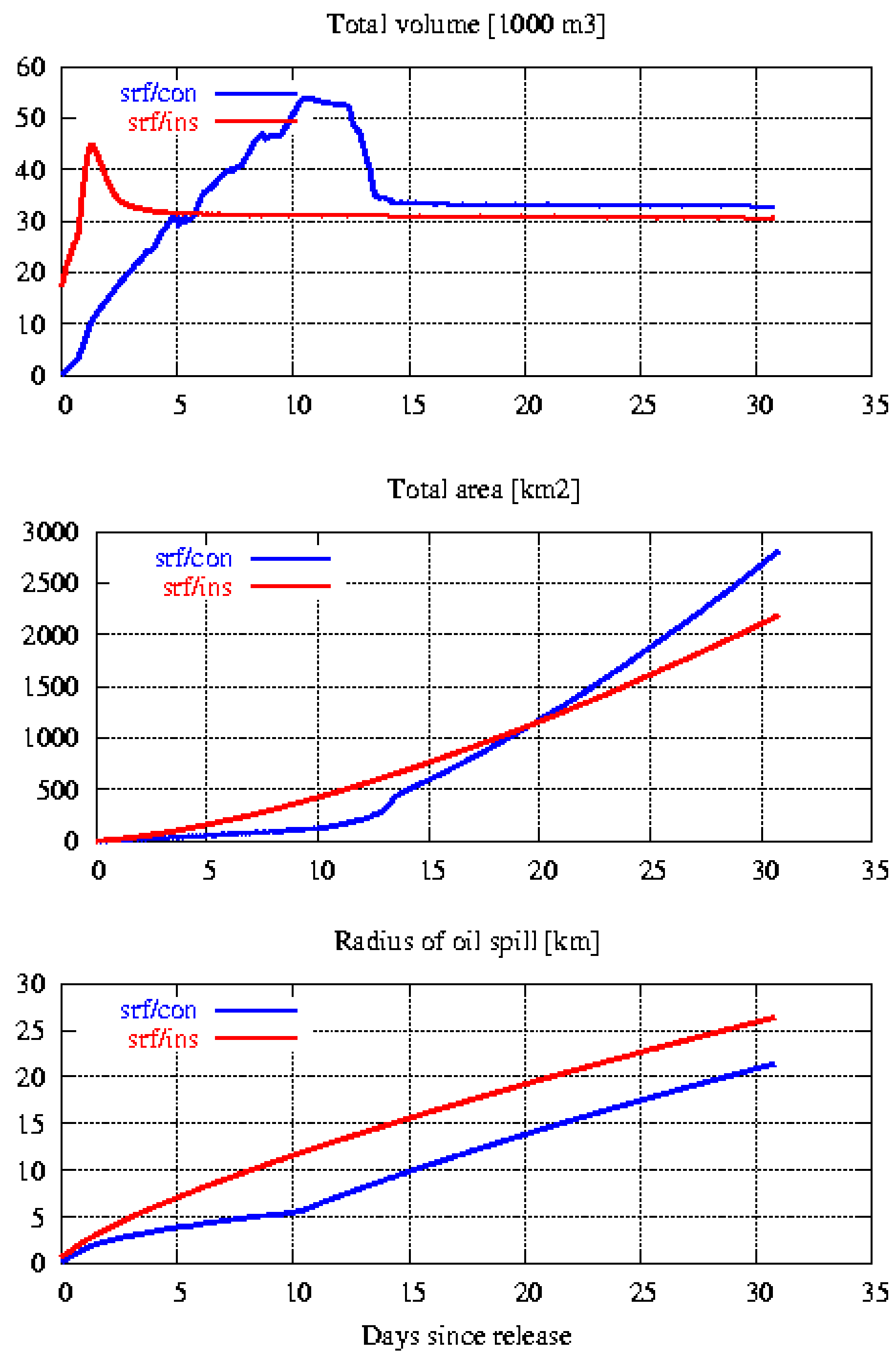


Figure 9 Size development of oil spill from tanker near oil terminal. Blue: continuous surface spill; red: instantaneous surface spill.

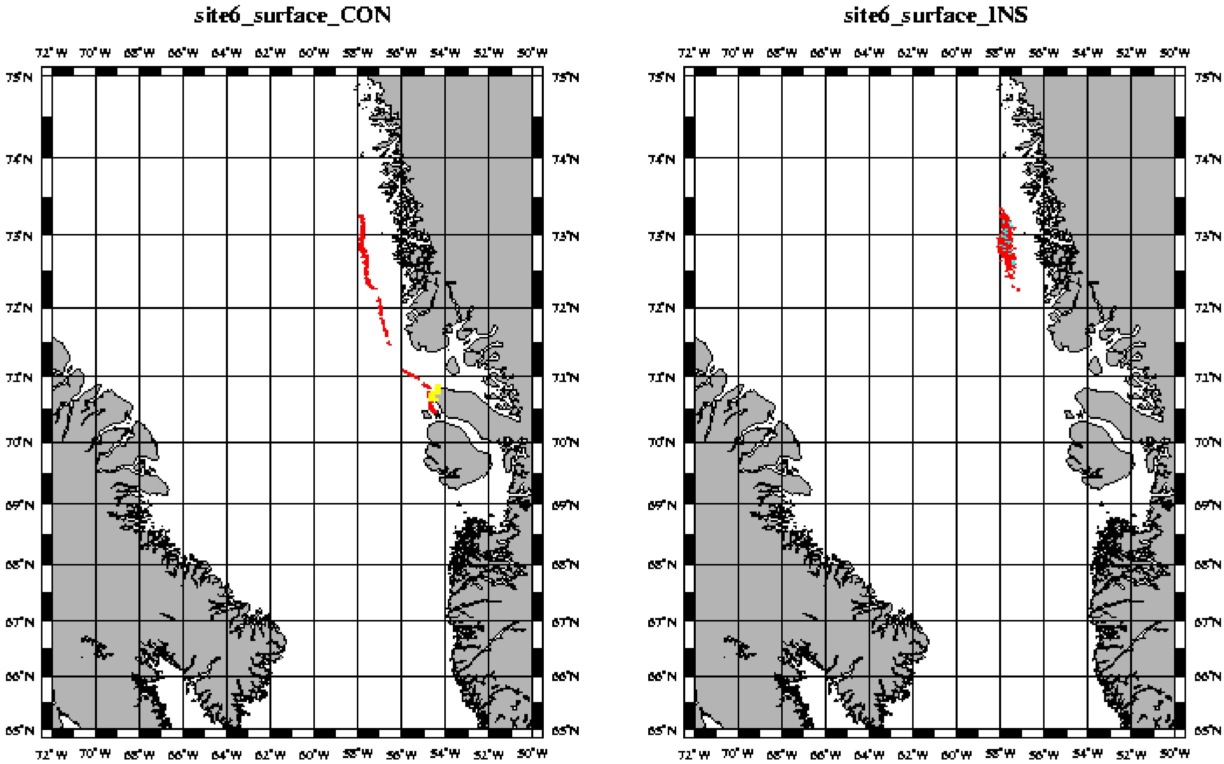


Figure 10 Oil spill from tanker near oil terminal. Snapshot after 240 hours. Dots indicate oil particles (red: surface, cyan: subsurface, yellow: settled) and the spill site is located at the black star. Left panel: continuous surface spill; right panel: instantaneous surface spill.

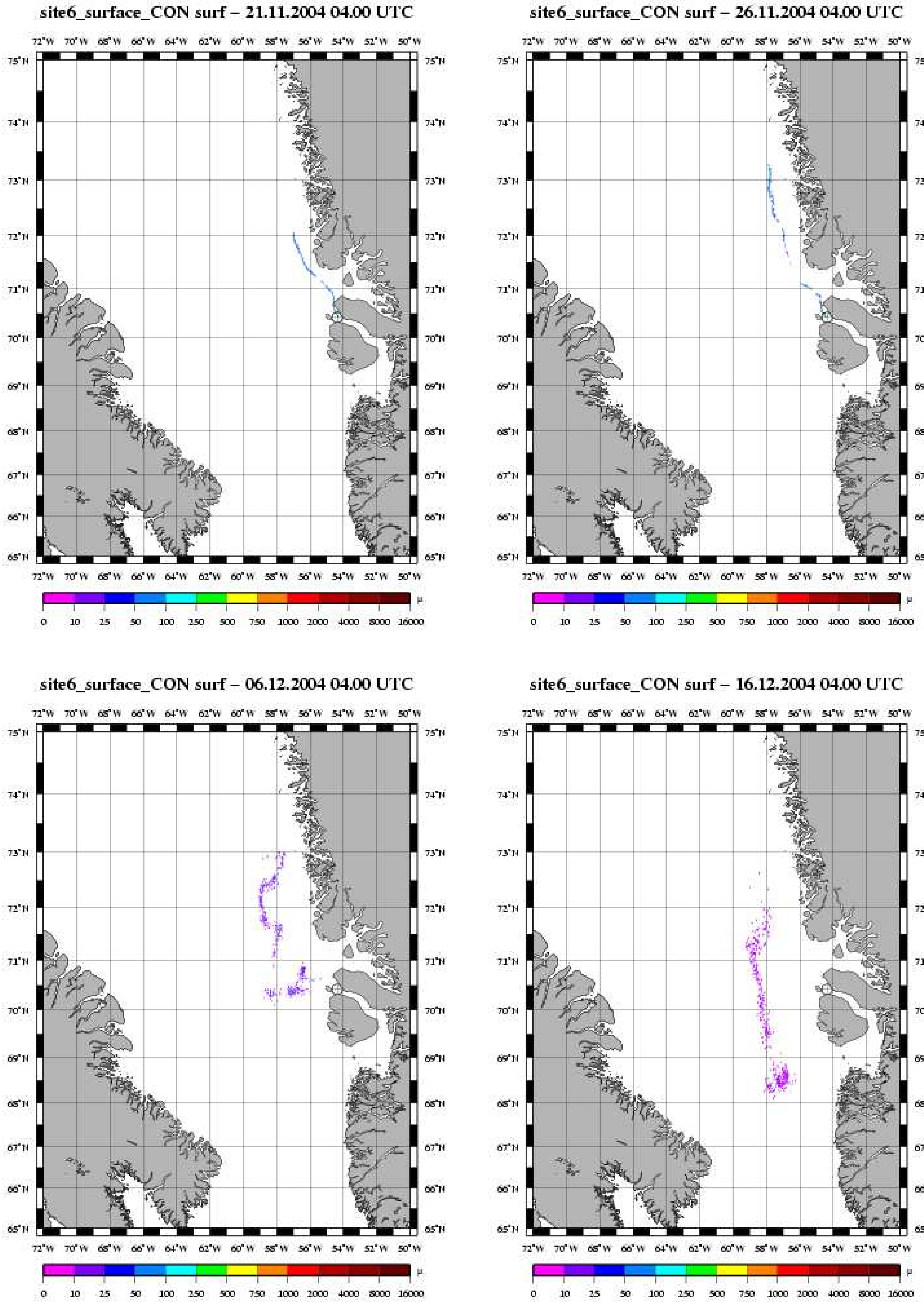


Figure 11 Thickness and position of surface oil slick in case of a continuous spill from near-shore tanker, after 5, 10, 20 and 30 days.

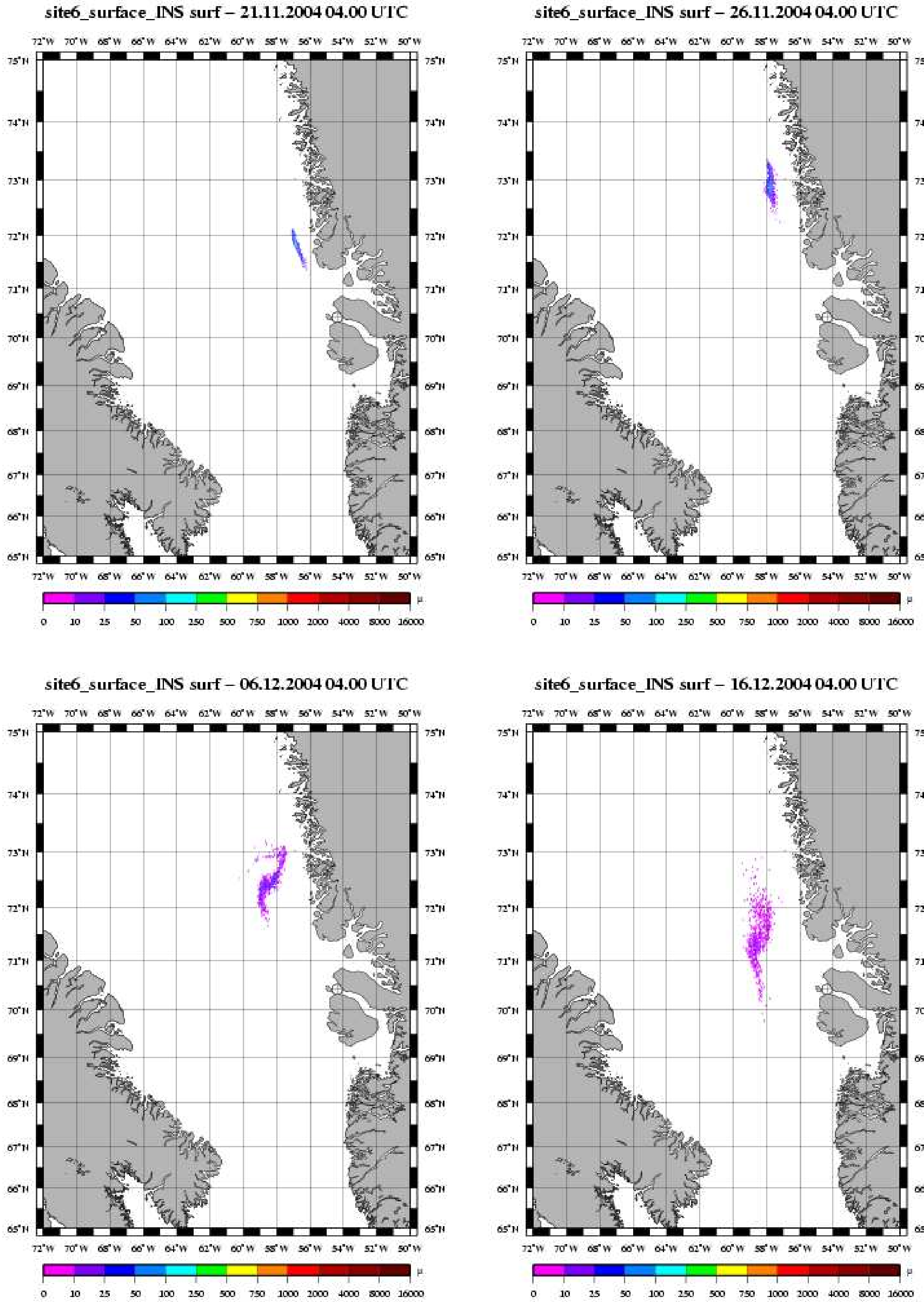


Figure 12 Thickness and position of surface oil slick in case of a continuous spill from near-shore tanker, after 5, 10, 20 and 30 days.

Conclusion

A total of 114 one-month oil drift simulations have been carried out. The simulations result in hourly tables of position and properties of a cloud consisting of 1000 oil particles. Proper averaging results in bulk spill time series. A careful gridding technique is applied, resulting in oil slick thickness and concentration maps.

By tracking all particles, the relative amount of oil settling on shore, and the shore affected, is calculated. When the spill is located far off-shore, the coast is not affected in any of the chosen wind conditions. Near-shore spills will result in coastal pollution under unfavourable wind conditions, and spills from tanker transport to/from oil terminals will usually pollute the coast, except under very lucky wind conditions. The polluted stretch may include the Vaigat, southern parts of Disko Bay, the west coast of Disko Island, and up to 100 km north and south of the Disko Bay area.

The maximum oil concentrations peak at 75,000 (ppb TH). While being in the right order of magnitude, this is perhaps a bit larger than what one would expect. Modelled concentrations may be two to three times larger than observed values, due to tar ball formation which concentrates part of the oil in small regions. For the region affected in each case, typical maximum values range up to 250 ppb which is considered reasonable.

References

[1] S. Dick and K.C. Soetje, 1990: An operational oil dispersion model for the German Bight. Deutsche Hydrographische Zeitschrift, Ergänzungsheft Reihe A, nr. 16. Bundesamt Für Seeschiffahrt und Hydrographie, Hamburg.

[2] M.H. Ribergaard and N. Kliem, 2006: HYCOM for the North Atlantic, with special emphasis on West Greenland Waters. Techn. Rep 06-07, Danish Meteorological Institute, Denmark.

[3] J.A. Børresen, 1993: Olje på havet. Gyldendal.

[4] B.M. Christiansen, 2003: 3D Oil Drift and Fate Forecasts at DMI. Techn. Rep. No. 03-36, Danish Meteorological Institute, Denmark.

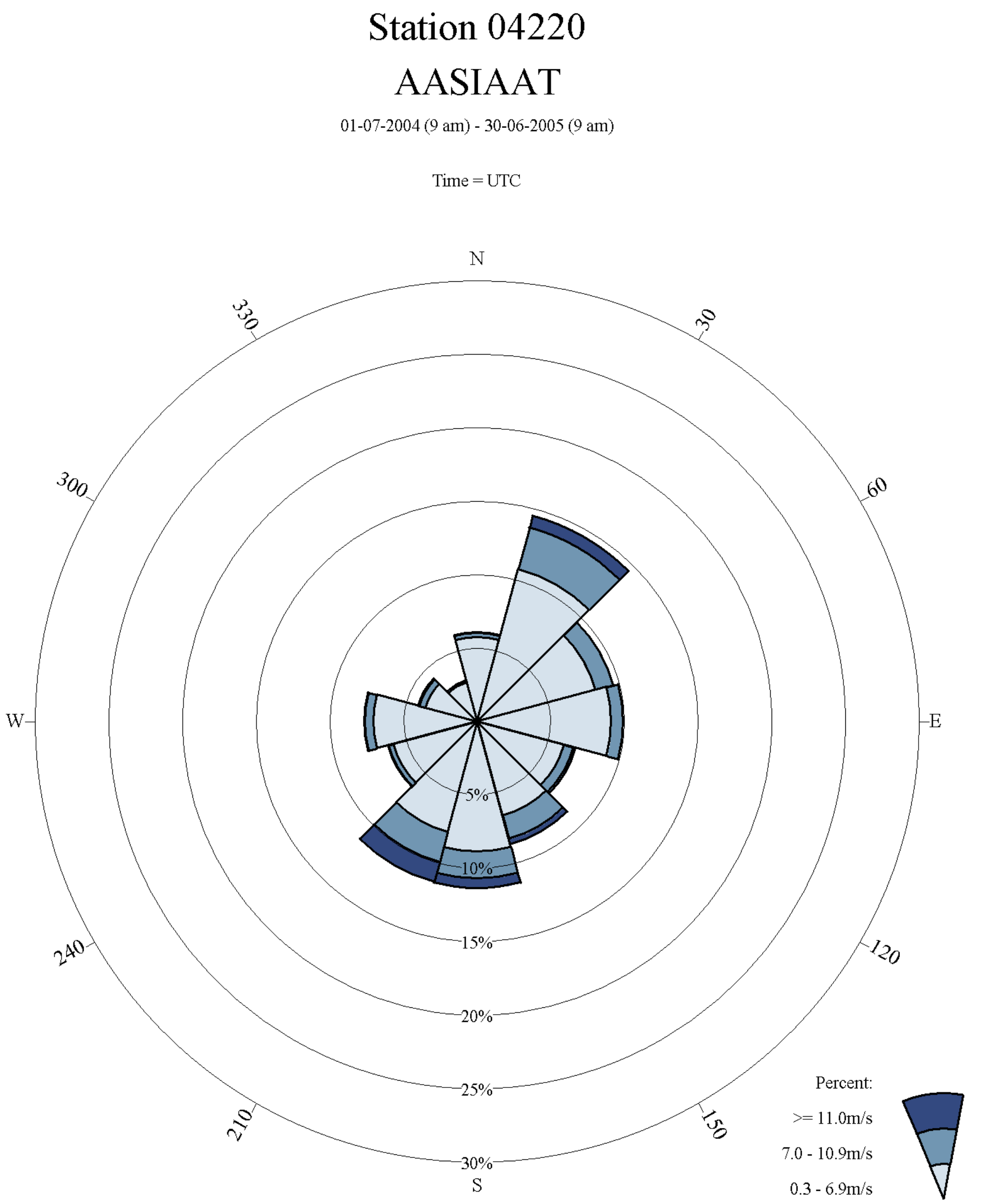
Previous reports

Previous reports from the Danish Meteorological Institute can be found at:

http://www.dmi.dk/dmi/dmi-publikationer.htm

Appendix A. Monthly surface wind statistics

The standard statistics and wind roses presented below are based on hourly wind recorded at the weather station Aasiaat, located at the southern tip of Disko Bay (68.7N, 53.3W). The statistics is done for the full study year (July 2004 – June 2005), and for each calendar month of that year.

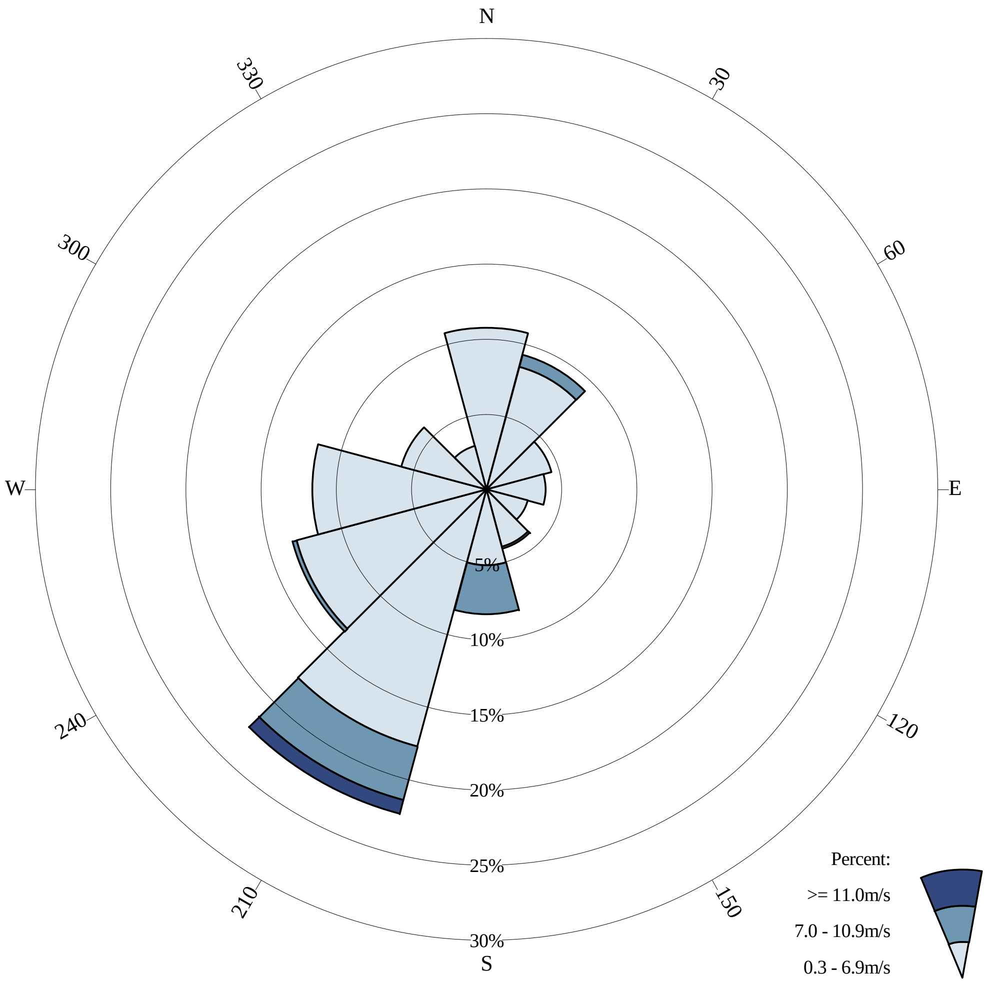


	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	6.1	14.5	9.6	9.9	6.9	8.6	11.4	11.3	6.3	7.7	4.2	2.9	99.4
% 0.3-6.9m/s	5.8	10.8	8.3	9.1	6.1	6.6	8.9	7.8	5.9	7.0	3.7	2.8	82.8
% 7.0-10.9m/s	0.2	2.9	1.3	0.8	0.7	1.7	1.8	2.1	0.3	0.6	0.4	0.1	13.0
% >= 11.0m/s	0.1	0.8	0.0	0.0	0.1	0.4	0.7	1.4	0.0	0.0	0.1	0.0	3.7
Mean wind speed	3.0	5.4	4.6	4.0	4.0	4.9	5.0	6.0	3.5	3.7	4.0	3.2	4.5
Max wind speed	15.4	20.6	11.8	9.8	13.4	15.4	22.7	22.1	11.8	11.8	12.9	9.3	22.7

Number of observations = 8672 Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 50 = 0.6%
Observations with calm/varying wind direction are not used in the statistics

Figure 13 Wind statistics at Aasiaat for the design year from July 1 2004 to June 30 2005.

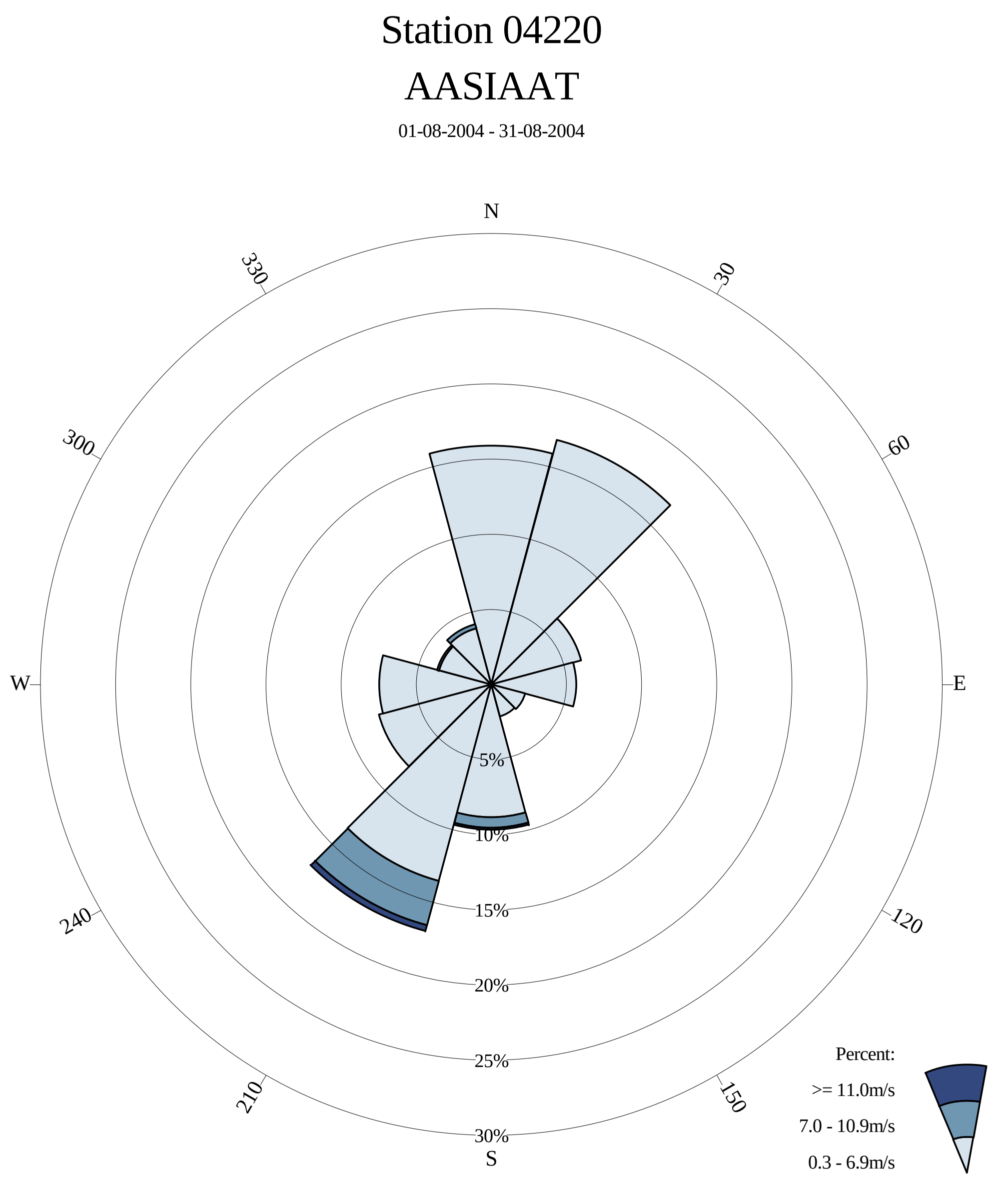
Station 04220
AASIAAT
01-07-2004 - 31-07-2004



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	10.8	9.3	4.5	4.0	2.9	4.1	8.3	22.3	13.4	11.6	5.9	3.0	99.9
% 0.3-6.9m/s	10.8	8.4	4.5	4.0	2.9	4.0	5.0	17.7	13.1	11.6	5.9	3.0	90.7
% 7.0-10.9m/s	0.0	0.8	0.0	0.0	0.0	0.1	3.3	3.7	0.3	0.0	0.0	0.0	8.2
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0
Mean wind speed	2.7	4.2	3.0	3.4	2.6	3.0	5.6	5.1	3.0	2.7	2.5	2.1	3.7
Max wind speed	5.7	9.3	5.1	5.7	5.7	8.2	10.3	15.4	7.2	4.6	4.6	3.6	15.4

Number of observations = 734
Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 1 = 0.1%
Observations with calm/varying wind direction are not used in the statistics

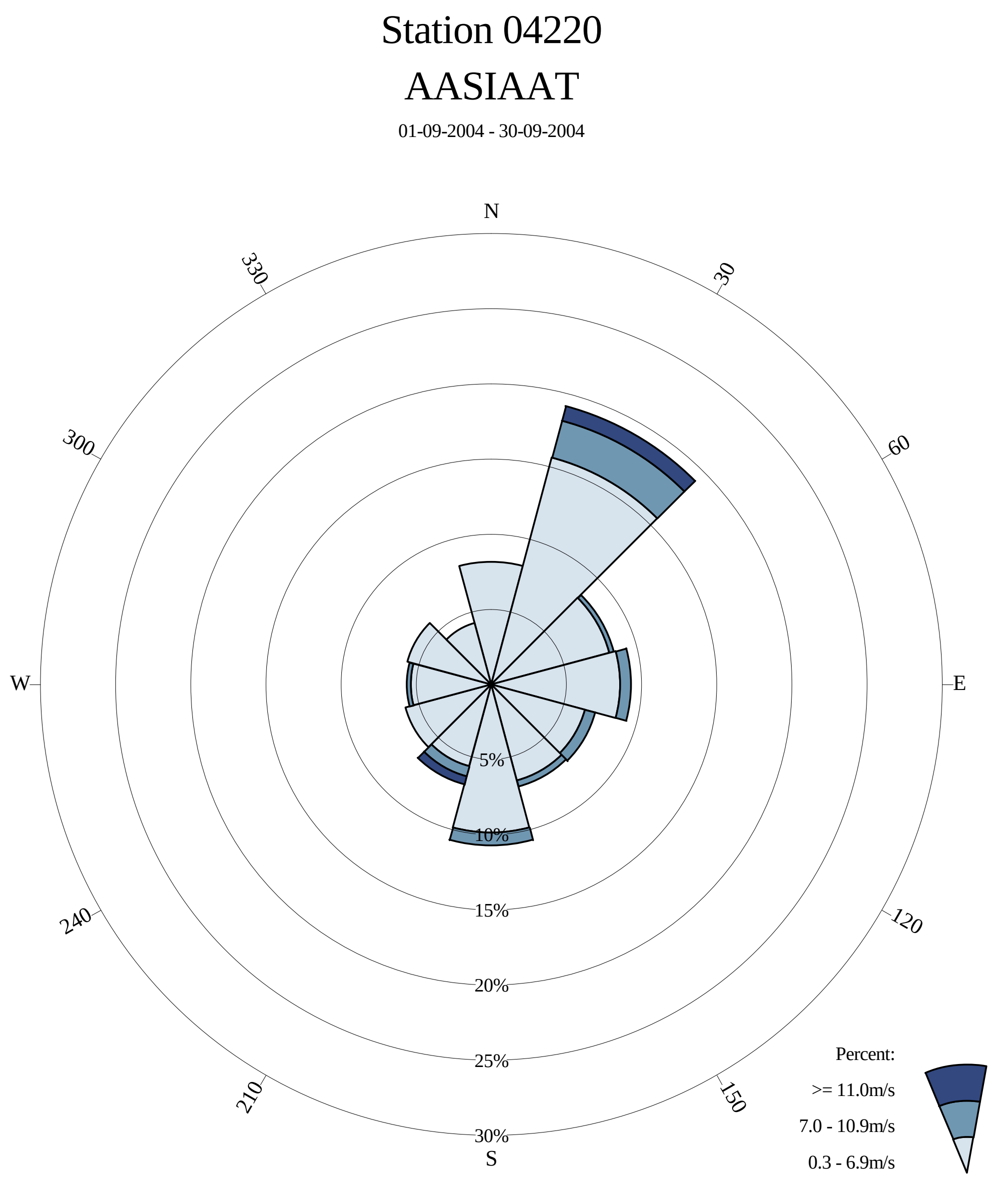
Figure 14 Wind statistics at Aasiaat for July 2004.



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	15.9	16.9	6.2	5.7	2.3	2.2	9.7	17.0	7.7	7.5	3.7	4.1	98.9
% 0.3-6.9m/s	15.9	16.9	6.2	5.7	2.3	2.2	8.8	13.5	7.7	7.5	3.6	3.9	94.2
% 7.0-10.9m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.7	3.0	0.0	0.0	0.1	0.3	4.1
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.6
Mean wind speed	2.2	2.9	2.6	2.6	1.9	3.2	4.2	5.1	2.7	3.3	3.7	2.9	3.3
Max wind speed	6.2	6.7	6.2	6.2	5.7	5.1	11.3	12.4	5.7	6.2	7.2	7.7	12.4

Number of observations = 724
Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 8 = 1.1%
Observations with calm/varying wind direction are not used in the statistics

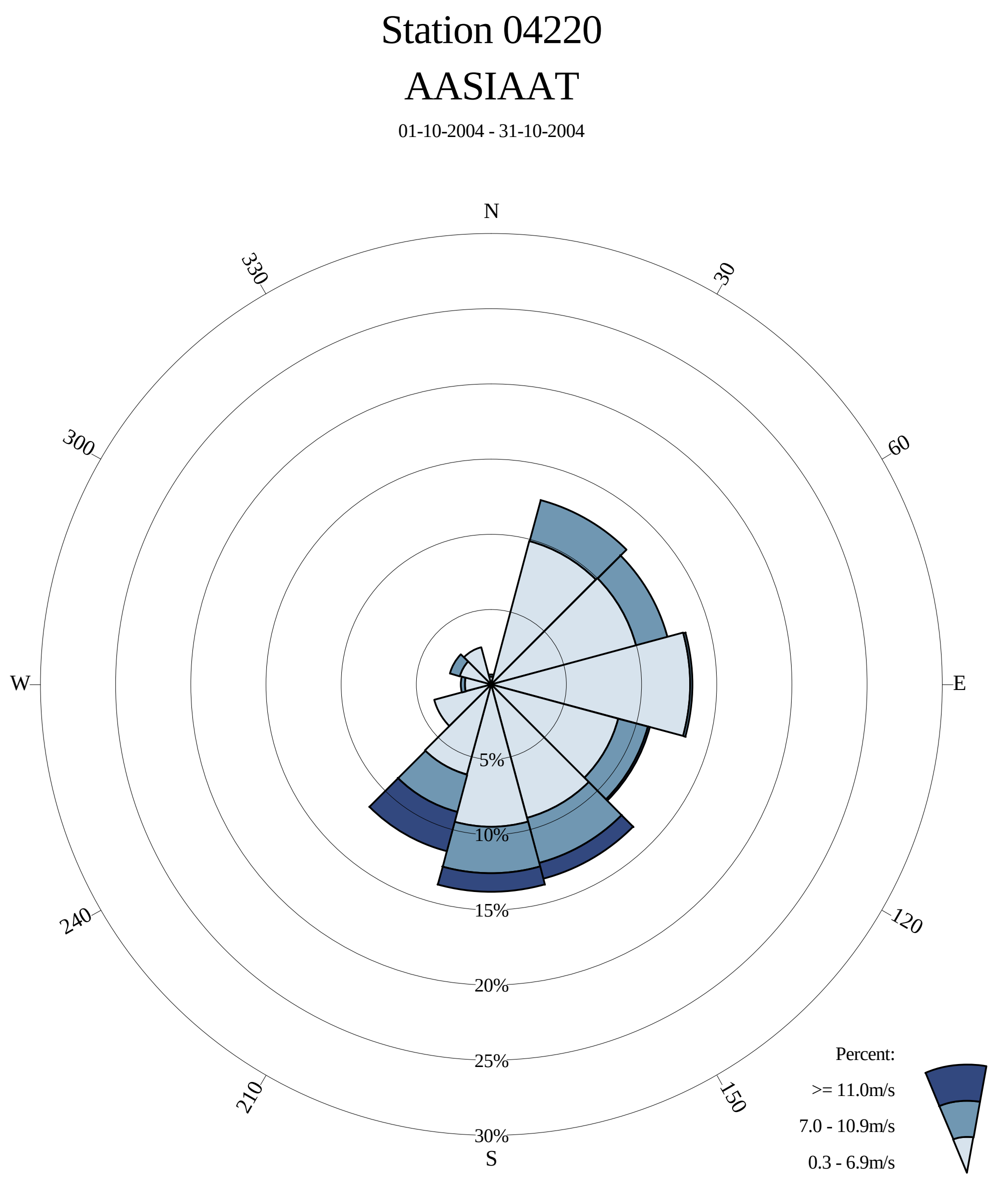
Figure 15 Wind statistics at Aasiaat for August 2004.



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	8.2	19.2	8.5	9.3	7.2	7.0	10.7	6.9	5.9	5.6	5.8	4.2	98.5
% 0.3-6.9m/s	8.2	15.6	8.2	8.6	6.5	6.6	9.9	5.6	5.9	5.4	5.8	4.2	90.4
% 7.0-10.9m/s	0.0	2.5	0.3	0.7	0.7	0.4	0.8	0.7	0.0	0.3	0.0	0.0	6.5
% >= 11.0m/s	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	1.5
Mean wind speed	2.7	4.6	3.6	3.1	3.1	3.0	3.5	4.4	2.6	2.8	3.6	2.9	3.5
Max wind speed	5.1	14.9	7.2	8.2	8.8	10.3	10.3	13.4	5.7	8.2	6.7	6.2	14.9

Number of observations = 710
Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 11 = 1.5%
Observations with calm/varying wind direction are not used in the statistics

Figure 16 Wind statistics at Aasiaat for September 2004.

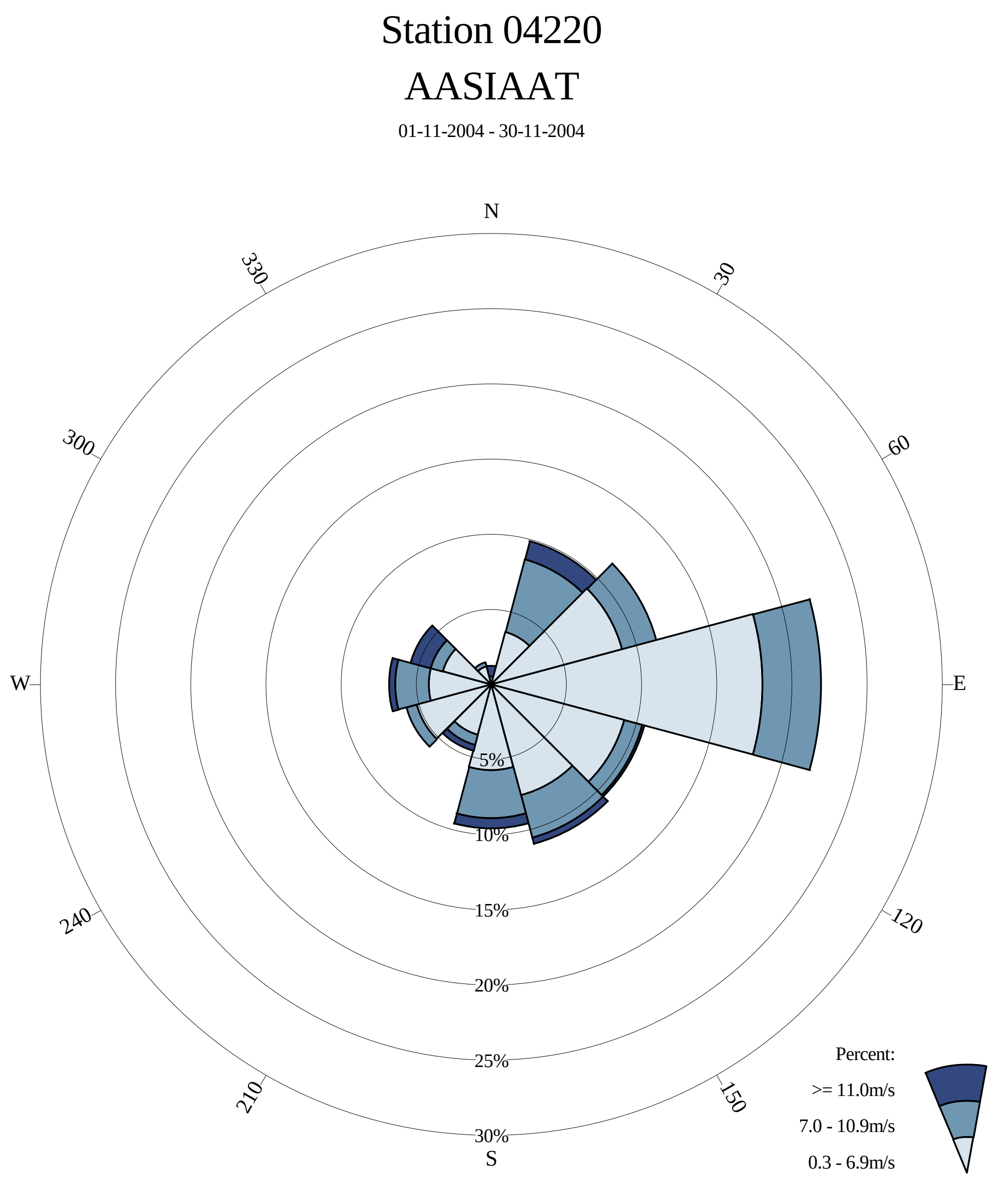


	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	0.7	12.7	12.2	13.4	10.9	13.4	13.8	11.5	3.9	2.0	2.8	2.6	99.9
% 0.3-6.9m/s	0.5	9.9	10.0	13.2	8.8	9.2	9.5	6.2	3.9	1.8	2.2	2.6	77.7
% 7.0-10.9m/s	0.1	2.8	2.2	0.1	2.0	3.1	3.1	2.6	0.0	0.3	0.7	0.0	17.0
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.1	1.1	1.2	2.7	0.0	0.0	0.0	0.0	5.1
Mean wind speed	3.2	5.3	4.7	3.7	4.4	6.0	5.6	7.0	3.7	3.4	4.8	4.4	5.1
Max wind speed	8.8	10.3	8.8	7.7	11.3	13.4	15.4	22.1	6.7	8.8	8.2	6.7	22.1

Number of observations = 740
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 1 = 0.1%
Observations with calm/varying wind direction are not used in the statistics

Source: DMI

Figure 17 Wind statistics at Aasiaat for October 2004.



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	1.3	9.9	11.4	21.9	10.6	11.0	9.6	4.6	5.8	6.8	5.6	1.5	99.9
% 0.3-6.9m/s	0.1	3.6	9.0	18.1	9.2	7.6	5.7	3.5	5.1	4.2	3.3	1.3	70.7
% 7.0-10.9m/s	0.4	5.0	2.4	3.9	1.3	2.9	3.2	0.7	0.7	2.2	0.8	0.3	23.8
% >= 11.0m/s	0.7	1.3	0.0	0.0	0.1	0.4	0.7	0.4	0.0	0.4	1.4	0.0	5.4
Mean wind speed	10.6	8.3	5.5	4.6	4.4	5.6	6.3	5.6	4.4	6.3	7.0	4.9	5.7
Max wind speed	15.4	14.4	10.3	9.3	11.3	15.4	17.0	18.0	8.2	11.8	12.9	9.3	18.0

Number of observations = 720

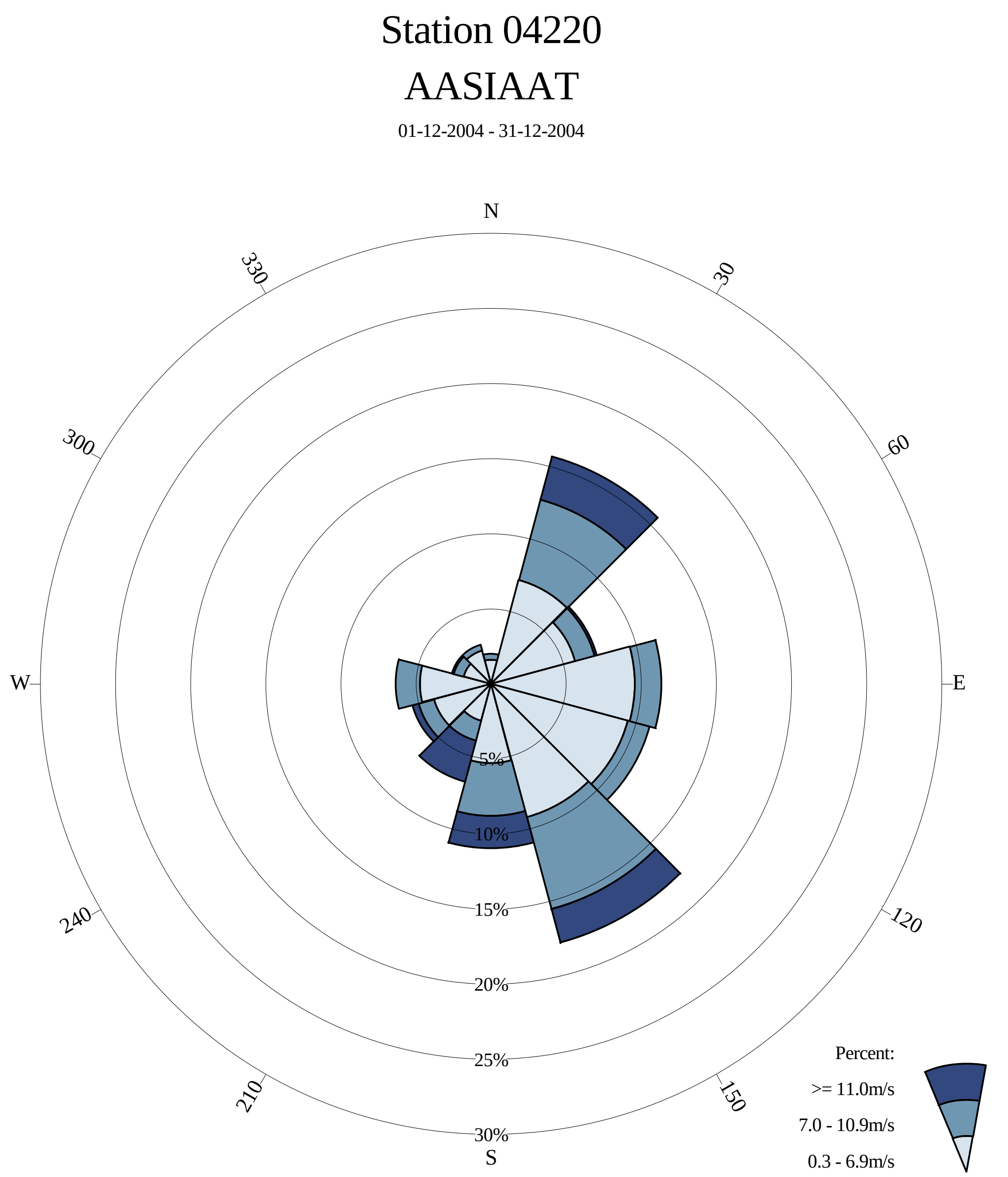
Source: DMI

Calm defined as wind speed <= 0.2m/s

Number of observations with calm/varying wind direction: 1 = 0.1%

Observations with calm/varying wind direction are not used in the statistics

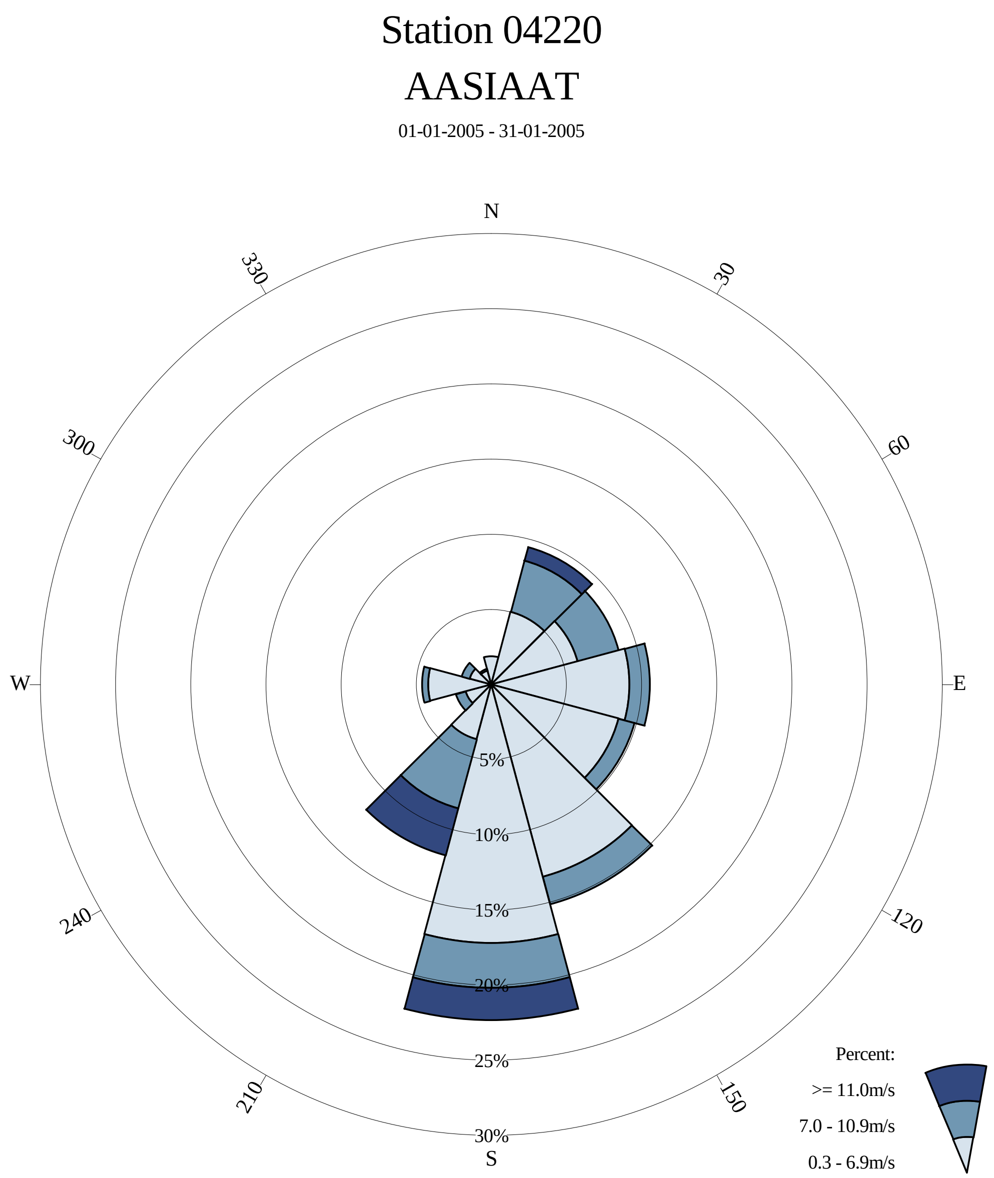
Figure 18 Wind statistics at Aasiaat for November 2004.



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	2.0	15.7	7.3	11.4	10.9	17.8	10.9	6.8	5.4	6.4	2.7	2.7	100.0
% 0.3-6.9m/s	1.6	7.2	5.8	9.6	9.5	9.2	5.3	2.6	3.9	4.7	1.9	2.3	63.5
% 7.0-10.9m/s	0.4	5.5	1.4	1.8	1.5	6.4	3.5	1.4	1.1	1.6	0.7	0.4	25.5
% >= 11.0m/s	0.0	3.0	0.1	0.0	0.0	2.3	2.2	2.8	0.4	0.0	0.1	0.0	10.9
Mean wind speed	5.4	7.9	5.2	4.8	4.5	6.7	7.1	9.4	5.8	5.7	5.8	5.5	6.3
Max wind speed	8.8	17.0	11.8	9.3	10.3	14.4	17.5	19.0	11.8	10.8	11.8	7.2	19.0

Number of observations = 740
Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 0 = 0.0%
Observations with calm/varying wind direction are not used in the statistics

Figure 19 Wind statistics at Aasiaat for December 2004.



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	1.9	9.5	8.8	10.6	9.9	15.2	22.3	11.8	2.4	4.6	2.0	1.1	100.0
% 0.3-6.9m/s	1.9	5.0	6.0	9.2	8.8	13.3	17.2	3.8	1.8	4.2	1.5	0.9	73.5
% 7.0-10.9m/s	0.0	3.5	2.8	1.4	1.1	1.9	3.0	4.7	0.7	0.4	0.5	0.1	20.2
% >= 11.0m/s	0.0	0.9	0.0	0.0	0.0	0.0	2.2	3.2	0.0	0.0	0.0	0.0	6.4
Mean wind speed	4.0	7.1	5.5	4.8	4.4	4.6	5.9	8.7	4.3	4.5	5.6	4.9	5.7
Max wind speed	5.7	17.0	10.8	8.2	9.3	10.3	22.7	20.1	10.3	8.8	8.8	7.2	22.7

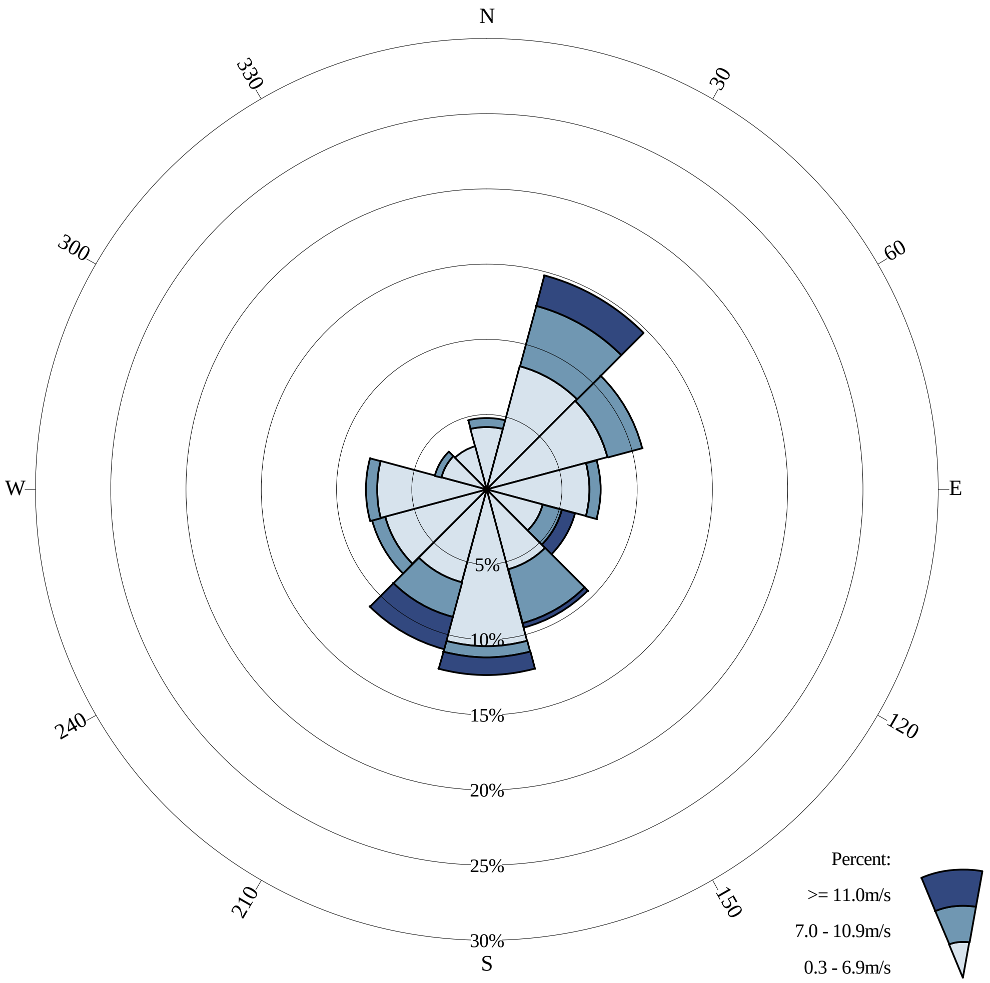
Number of observations = 739 Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 0 = 0.0%
Observations with calm/varying wind direction are not used in the statistics

Figure 20 Wind statistics at Aasiaat for January 2005.

Station 04220

AASIAAT

01-02-2005 - 28-02-2005



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	4.8	14.7	10.7	7.6	6.1	9.5	12.4	11.0	7.9	8.0	3.6	3.0	99.3
% 0.3-6.9m/s	4.2	8.5	8.3	6.8	3.9	5.5	10.4	6.4	7.0	7.3	3.1	3.0	74.4
% 7.0-10.9m/s	0.6	4.2	2.4	0.7	1.3	3.7	0.7	2.4	0.9	0.7	0.4	0.0	18.2
% >= 11.0m/s	0.0	2.1	0.0	0.0	0.9	0.3	1.2	2.2	0.0	0.0	0.0	0.0	6.7
Mean wind speed	2.9	6.6	5.2	3.6	5.8	5.9	5.0	7.2	4.2	4.3	3.2	2.5	5.2
Max wind speed	9.8	20.6	10.3	8.8	13.4	12.4	19.6	21.6	9.8	9.3	8.8	6.7	21.6

Number of observations = 672

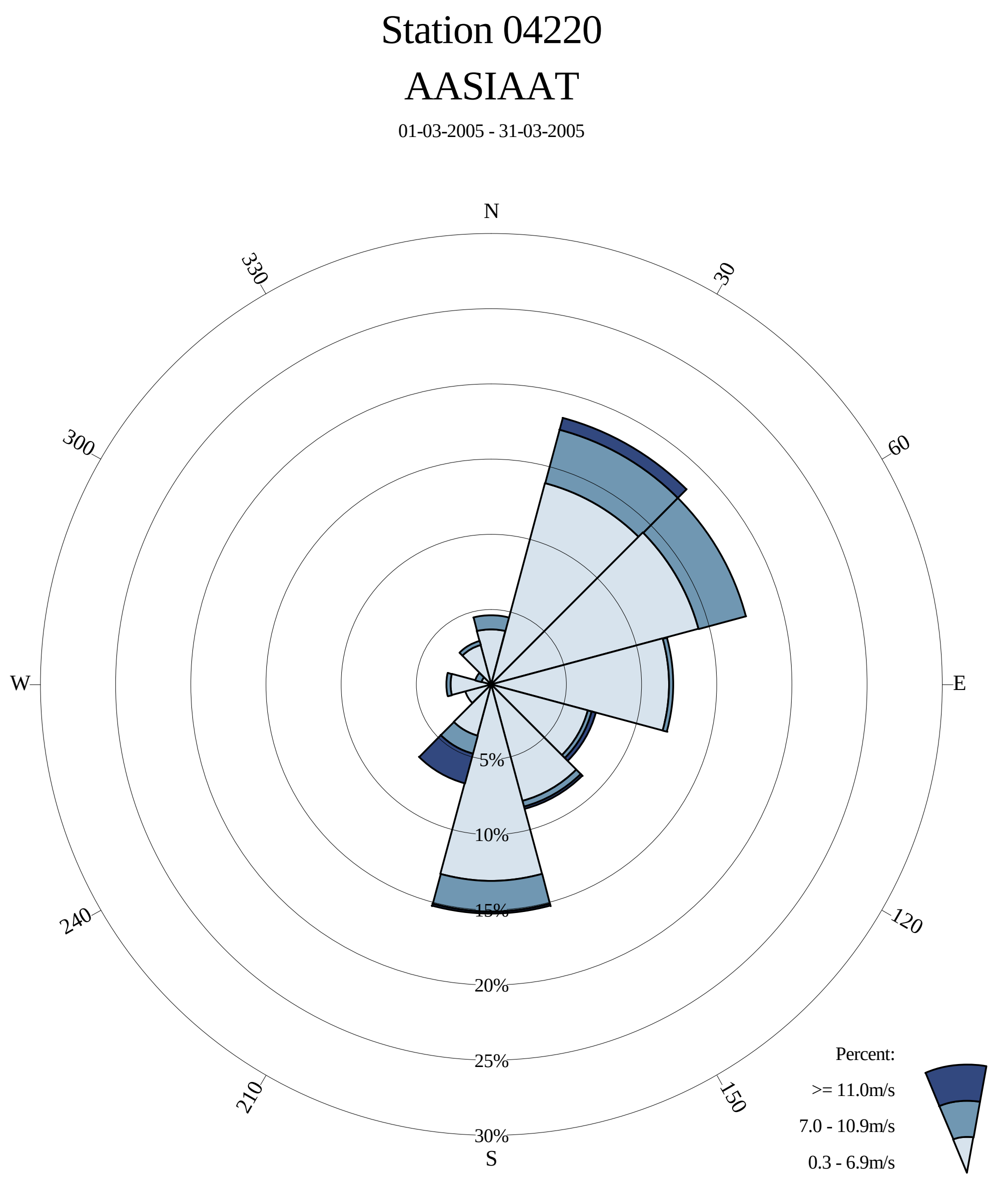
Source: DMI

Calm defined as wind speed <= 0.2m/s

Number of observations with calm/varying wind direction: 5 = 0.7%

Observations with calm/varying wind direction are not used in the statistics

Figure 21 Wind statistics at Aasiaat for February 2005.



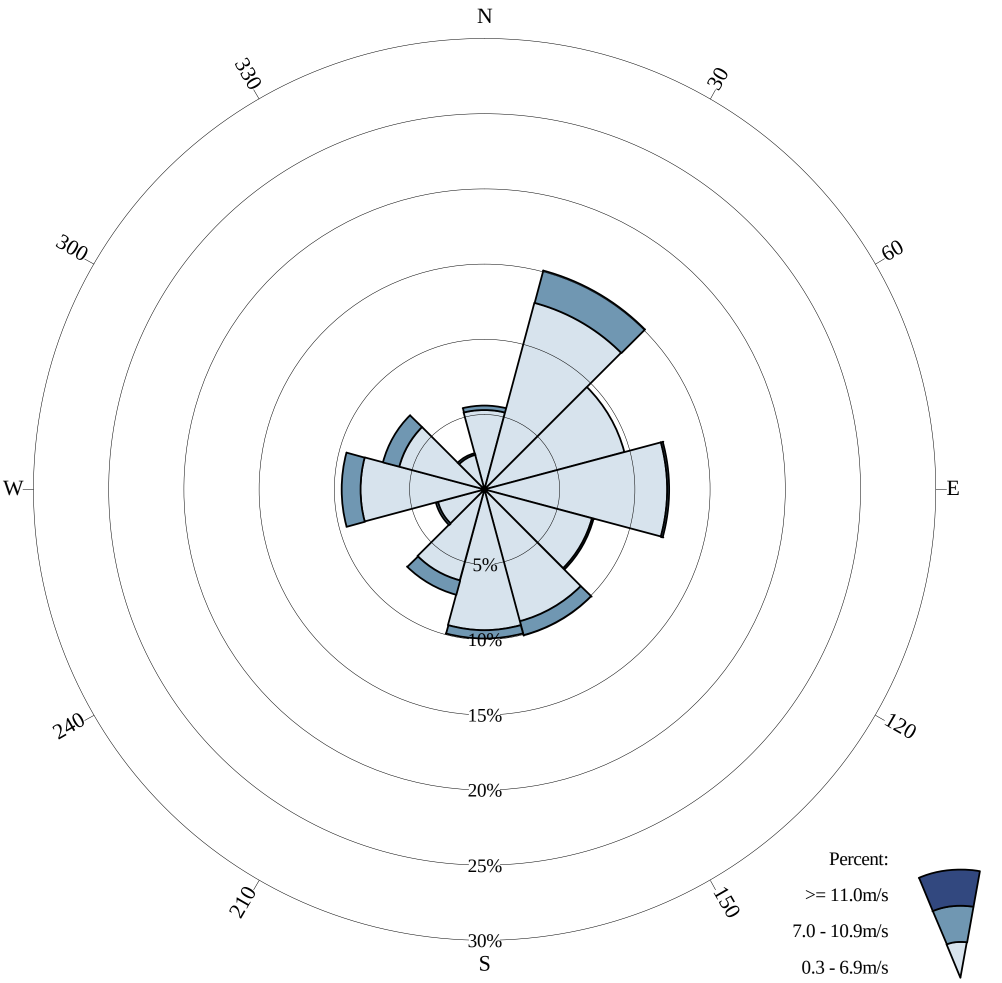
	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	4.6	18.4	17.6	12.1	7.2	8.6	15.2	6.8	1.8	3.0	1.1	3.0	99.3
% 0.3-6.9m/s	3.7	13.9	14.3	11.8	6.7	8.0	13.1	3.5	1.8	2.7	0.7	2.7	82.9
% 7.0-10.9m/s	1.0	3.7	3.3	0.3	0.3	0.4	2.0	1.2	0.0	0.3	0.4	0.3	13.1
% >= 11.0m/s	0.0	0.8	0.0	0.0	0.3	0.1	0.1	2.0	0.0	0.0	0.0	0.0	3.4
Mean wind speed	4.1	5.3	5.4	4.1	3.8	3.6	4.4	7.9	3.2	4.1	5.4	4.1	4.8
Max wind speed	9.8	12.9	9.8	9.8	12.9	11.3	13.4	22.1	6.7	7.7	10.8	8.2	22.1

Number of observations = 735 Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 5 = 0.7%
Observations with calm/varying wind direction are not used in the statistics

Figure 22 Wind statistics at Aasiaat for March 2005.

Station 04220
AASIAAT

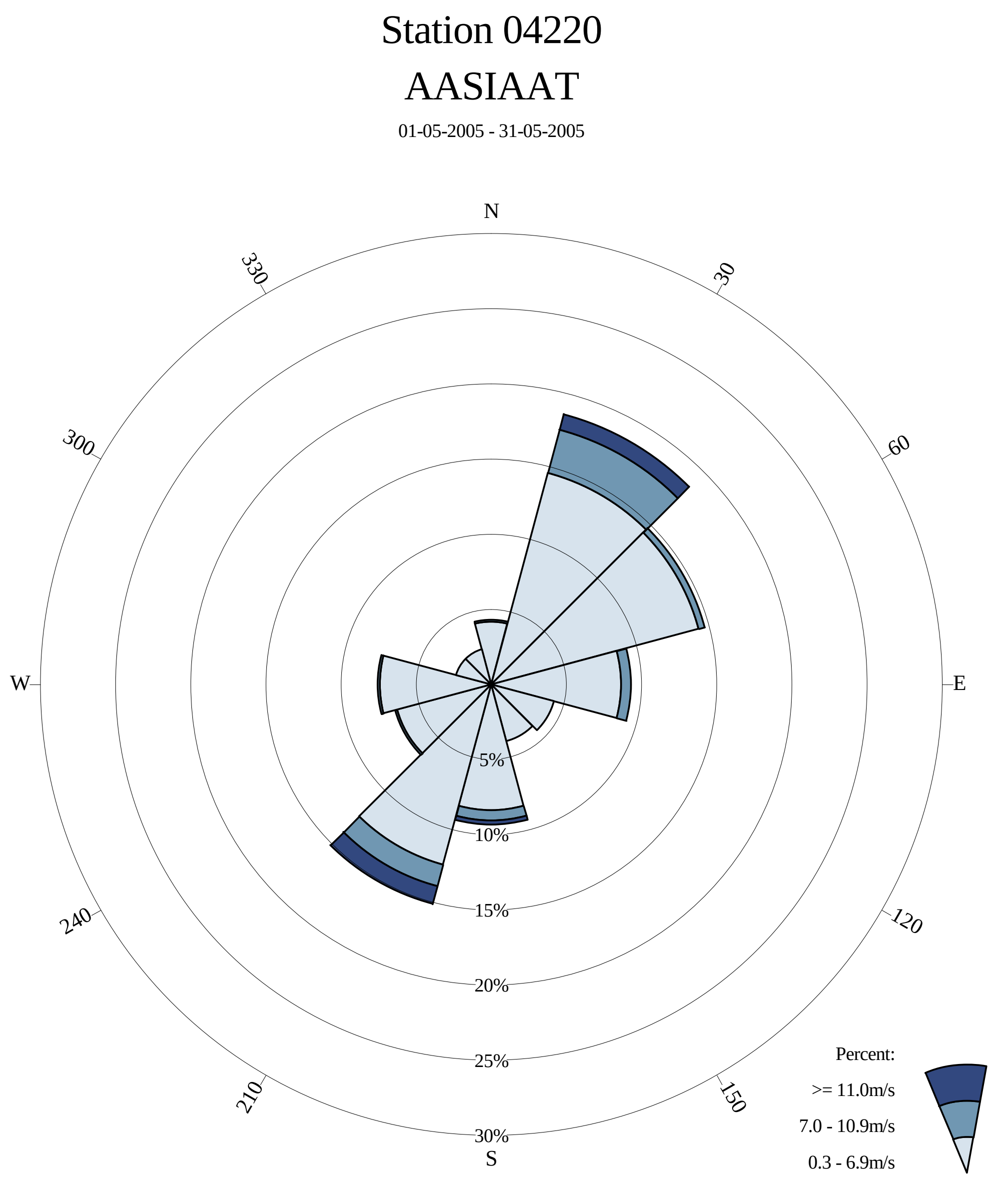
01-04-2005- 30-04-2005



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	5.6	15.1	9.6	12.3	7.5	10.1	9.9	7.3	3.4	9.5	7.0	2.5	99.7
% 0.3-6.9m/s	5.3	12.8	9.6	12.2	7.4	9.1	9.4	6.3	3.2	8.2	5.9	2.4	91.8
% 7.0-10.9m/s	0.3	2.2	0.0	0.1	0.1	1.0	0.6	1.0	0.1	1.3	1.1	0.1	8.0
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean wind speed	4.1	4.8	3.8	3.7	3.3	3.8	3.4	3.8	2.5	4.4	4.6	3.1	3.9
Max wind speed	8.2	8.8	6.7	7.7	7.2	10.8	9.8	8.8	7.2	10.8	10.8	8.2	10.8

Number of observations = 716 Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 2 = 0.3%
Observations with calm/varying wind direction are not used in the statistics

Figure 23 Wind statistics at Aasiaat for April 2005.



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	4.3	18.6	14.7	9.3	4.3	3.9	9.3	15.1	6.6	7.6	2.4	2.4	98.7
% 0.3-6.9m/s	4.2	14.6	14.3	8.6	4.3	3.9	8.4	12.4	6.5	7.4	2.4	2.4	89.5
% 7.0-10.9m/s	0.1	3.0	0.4	0.7	0.0	0.0	0.7	1.5	0.1	0.1	0.0	0.0	6.6
% >= 11.0m/s	0.0	1.1	0.0	0.0	0.0	0.0	0.3	1.2	0.0	0.0	0.0	0.0	2.6
Mean wind speed	2.5	5.1	3.8	3.5	2.3	2.6	4.0	4.9	3.3	3.1	2.4	1.8	3.9
Max wind speed	7.2	14.4	7.7	7.2	6.2	5.1	12.4	15.4	10.8	7.2	4.1	3.1	15.4

Number of observations = 741

Source: DMI

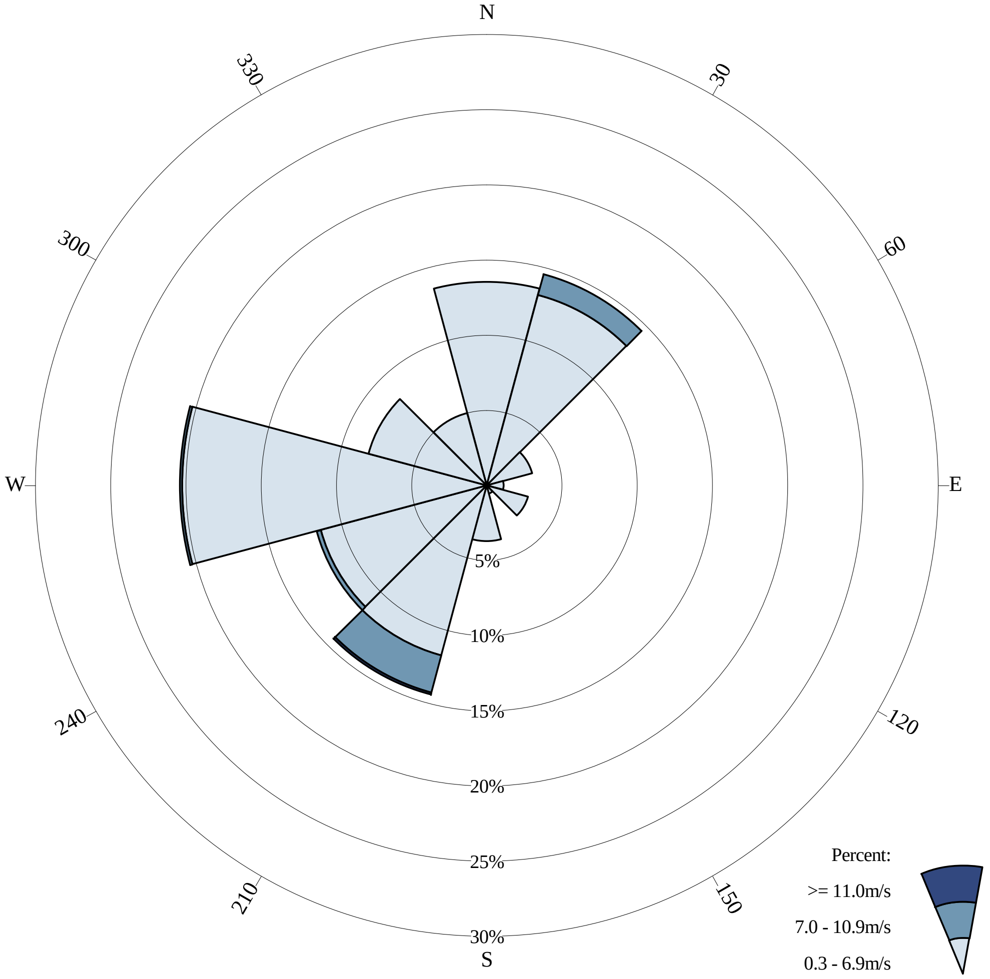
Calm defined as wind speed <= 0.2m/s

Number of observations with calm/varying wind direction: 10 = 1.3%

Observations with calm/varying wind direction are not used in the statistics

Figure 24 Wind statistics at Aasiaat for May 2005.

Station 04220
AASIAAT
01-06-2005 - 30-06-2005



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	13.6	14.6	3.1	1.1	2.9	0.6	3.7	14.4	11.7	20.4	8.1	5.0	99.1
% 0.3-6.9m/s	13.6	13.1	3.1	1.1	2.9	0.6	3.7	11.7	11.4	20.3	8.1	5.0	94.6
% 7.0-10.9m/s	0.0	1.4	0.0	0.0	0.0	0.0	0.0	2.6	0.3	0.1	0.0	0.0	4.4
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1
Mean wind speed	2.6	4.2	4.1	3.7	4.2	1.0	2.6	4.8	3.2	2.8	2.2	1.8	3.3
Max wind speed	5.7	8.8	6.7	5.1	6.2	1.5	5.1	11.8	8.2	7.2	4.1	3.6	11.8

Number of observations = 701
Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 6 = 0.9%
Observations with calm/varying wind direction are not used in the statistics

Figure 25 Wind statistics at Aasiaat for June 2005.

Appendix B. Simulation period wind statistics

The wind statistics for the simulation periods is done for the first ten days of each period.

The mean wind fields are based on the DMI nwp model Hirlam-T short-range (0-6 hour) predicted surface wind used to force the hydro-dynamical ocean model HYCOM, and further used as input to the drift model DMOD.

The standard statistics and wind roses presented below are based on hourly wind recorded at the weather station Aasiaat, located at the southern tip of Disko Bay (68.7N, 53.3W).

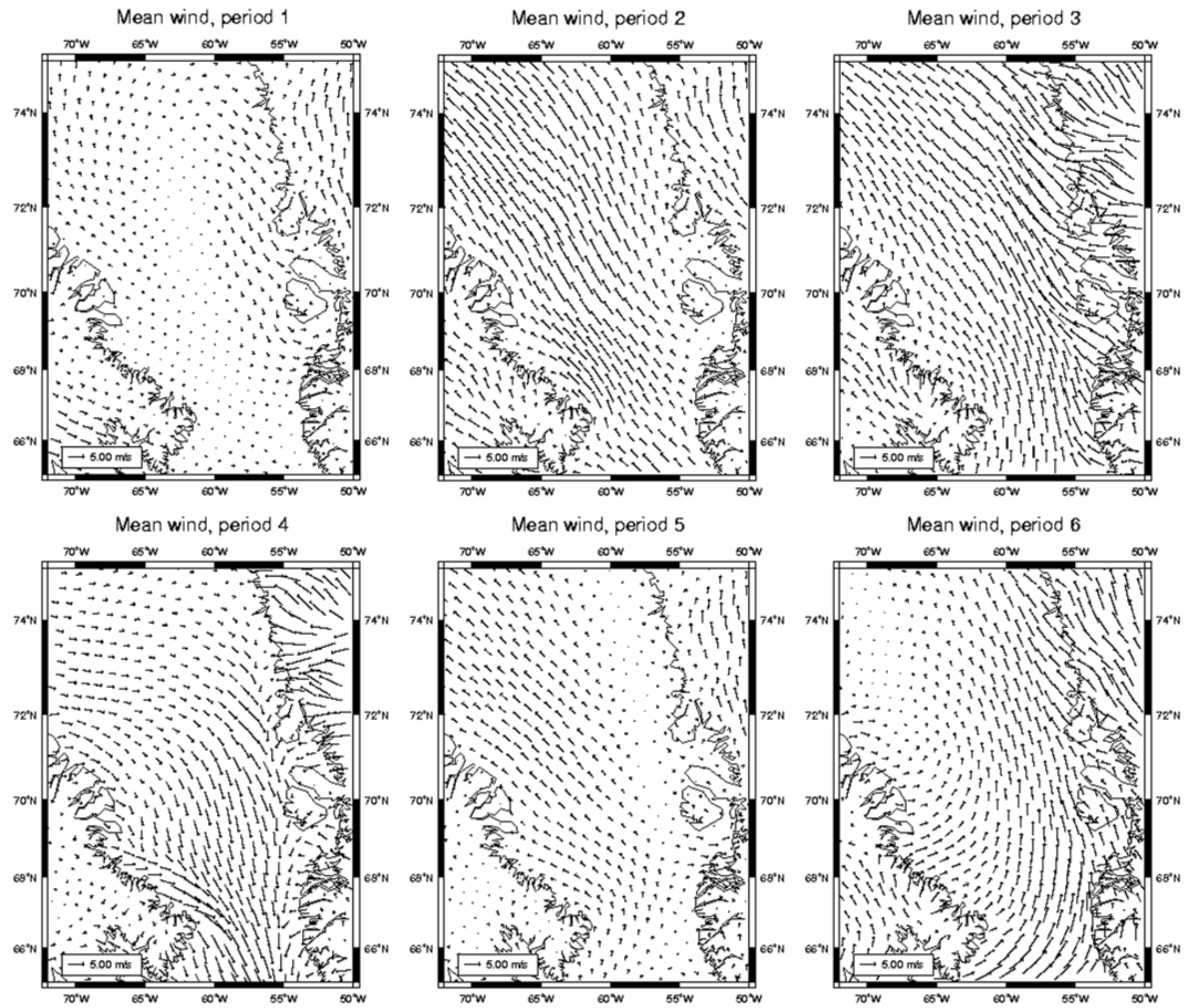


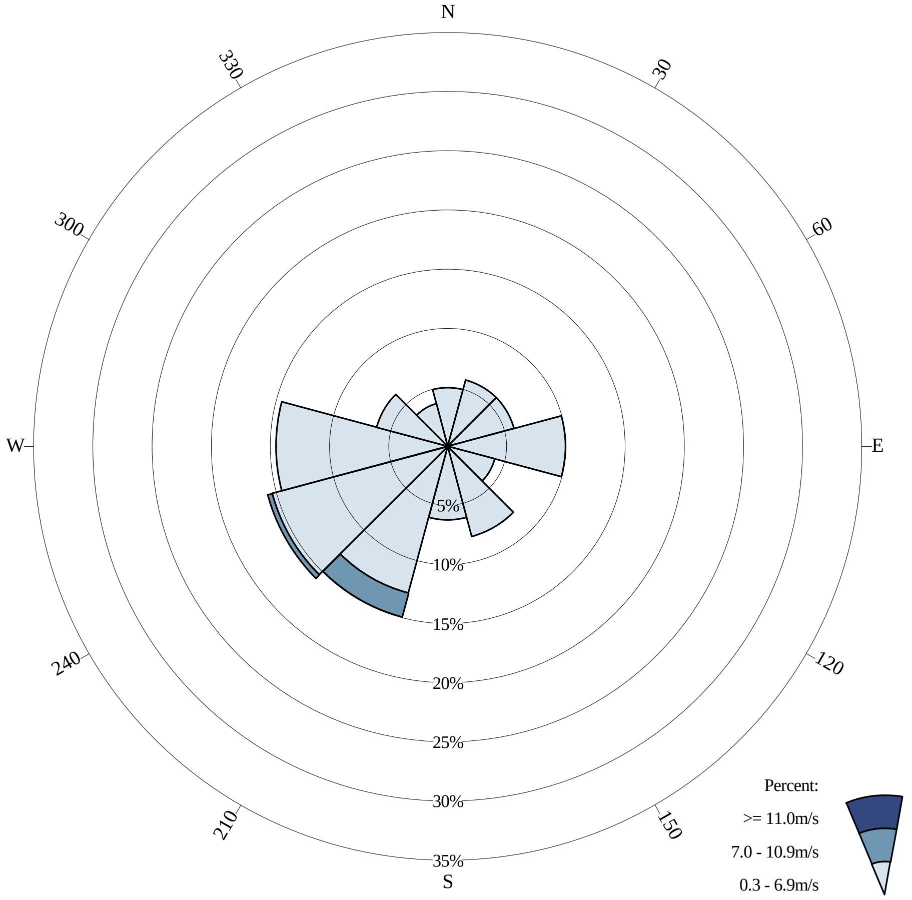
Figure 26 Mean surface wind fields for each of the six ten-days wind periods.

Station 04220

AASIAAT

07-07-2004 (8 pm) - 17-07-2004 (8 pm)

Time = UTC



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	5.0	5.8	5.8	10.0	4.1	7.9	6.2	14.9	15.8	14.5	6.2	3.7	100.0
% 0.3-6.9m/s	5.0	5.8	5.8	10.0	4.1	7.9	6.2	12.9	15.4	14.5	6.2	3.7	97.5
% 7.0-10.9m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.4	0.0	0.0	0.0	2.5
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean wind speed	1.5	2.8	3.1	3.6	2.3	2.9	3.3	3.6	3.1	2.4	2.1	2.0	2.9
Max wind speed	2.6	5.7	5.1	5.7	4.1	5.1	6.2	8.2	7.2	4.1	3.1	3.1	8.2

Number of observations = 241 Source: DMI

Calm defined as wind speed <= 0.2m/s

Number of observations with calm/varying wind direction: 0 = 0.0%

Observations with calm/varying wind direction are not used in the statistics

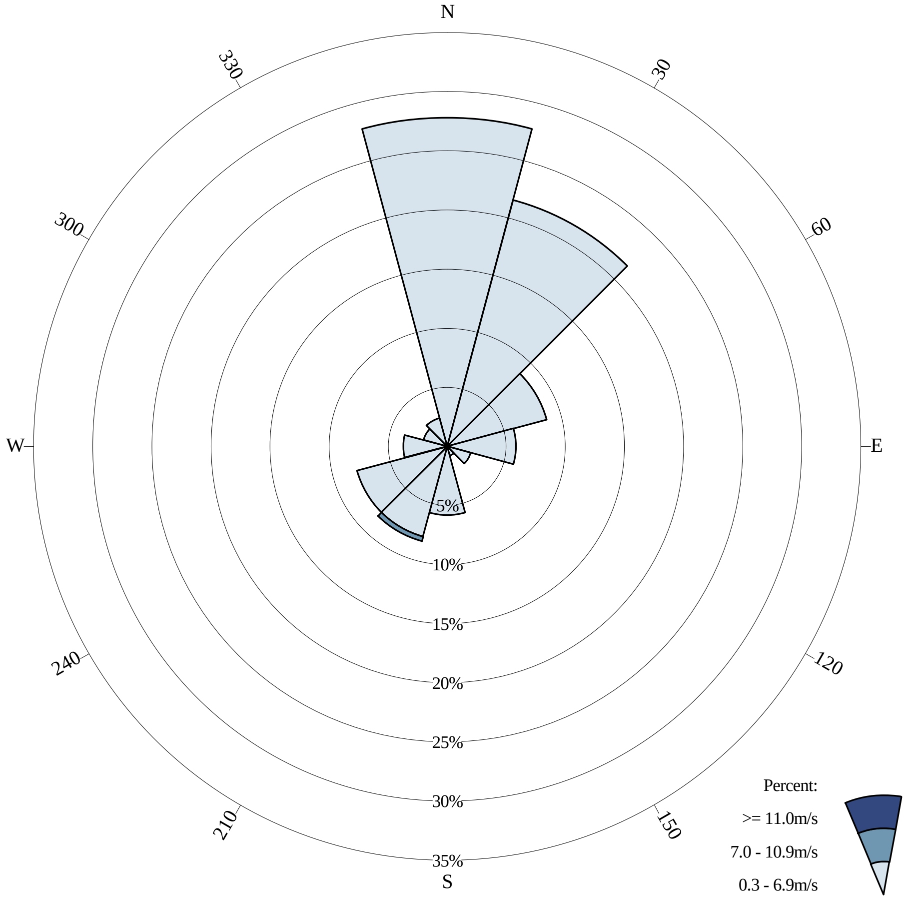
Figure 27 Statistics for wind period 1 (day 1-10)

Station 04220

AASIAAT

13-08-2004 - 23-08-2004

Time = UTC



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	27.8	21.6	8.7	5.8	2.1	0.8	5.8	8.3	7.9	3.7	2.1	2.5	97.1
% 0.3-6.9m/s	27.8	21.6	8.7	5.8	2.1	0.8	5.8	7.9	7.9	3.7	2.1	2.5	96.7
% 7.0-10.9m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean wind speed	2.0	2.3	2.0	2.0	1.0	1.3	2.0	3.0	1.6	1.9	1.2	1.1	2.1
Max wind speed	4.1	5.1	3.1	3.6	1.5	1.5	3.6	8.2	3.6	3.1	2.1	1.5	8.2

Number of observations = 241 Source: DMI

Calm defined as wind speed <= 0.2m/s

Number of observations with calm/varying wind direction: 7 = 2.9%

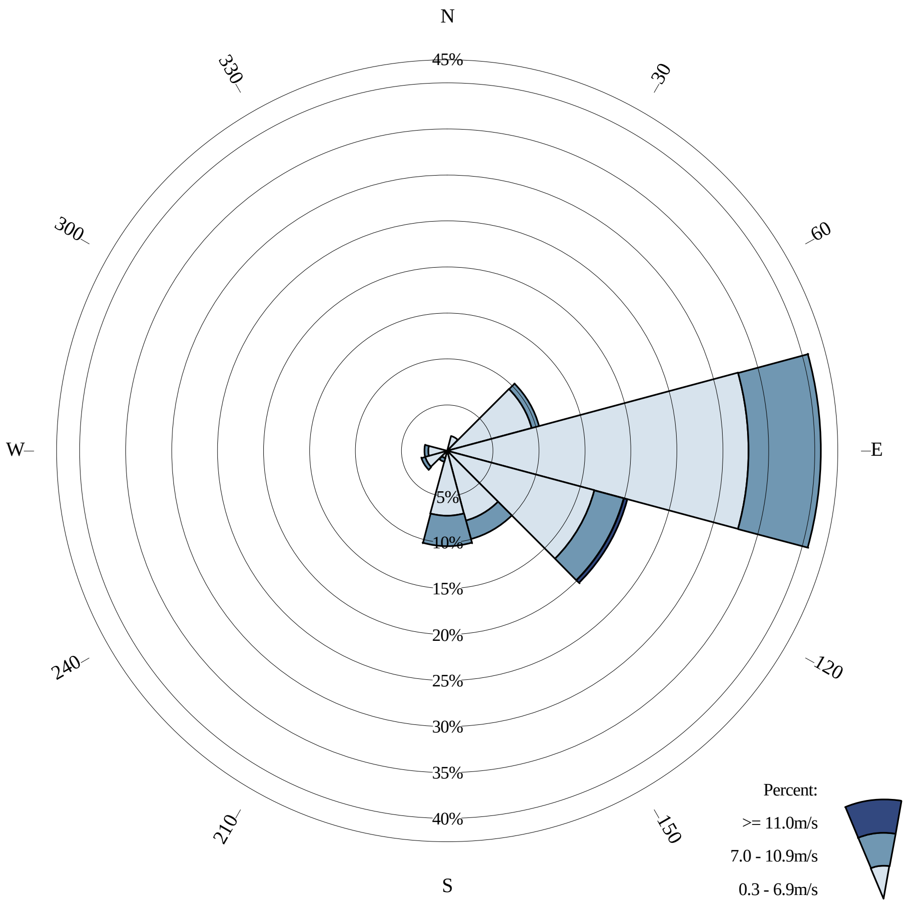
Observations with calm/varying wind direction are not used in the statistics

Figure 28 Statistics for wind period 2 (day 1-10)

Station 04220
AASIAAT

16-11-2004 (4 am) - 26-11-2004 (4 am)

Time = UTC



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	0.0	1.7	10.4	40.7	20.3	10.0	10.4	1.2	2.9	2.5	0.0	0.0	100.0
% 0.3-6.9m/s	0.0	1.7	9.5	32.8	16.6	7.9	7.1	0.8	2.5	2.1	0.0	0.0	80.9
% 7.0-10.9m/s	0.0	0.0	0.8	7.9	3.3	2.1	3.3	0.4	0.4	0.4	0.0	0.0	18.7
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Mean wind speed	0.0	6.3	4.8	4.7	4.9	4.4	5.6	4.5	3.9	4.7	0.0	0.0	4.8
Max wind speed	0.0	6.7	7.7	9.3	11.3	10.3	10.3	8.8	7.7	7.2	0.0	0.0	11.3

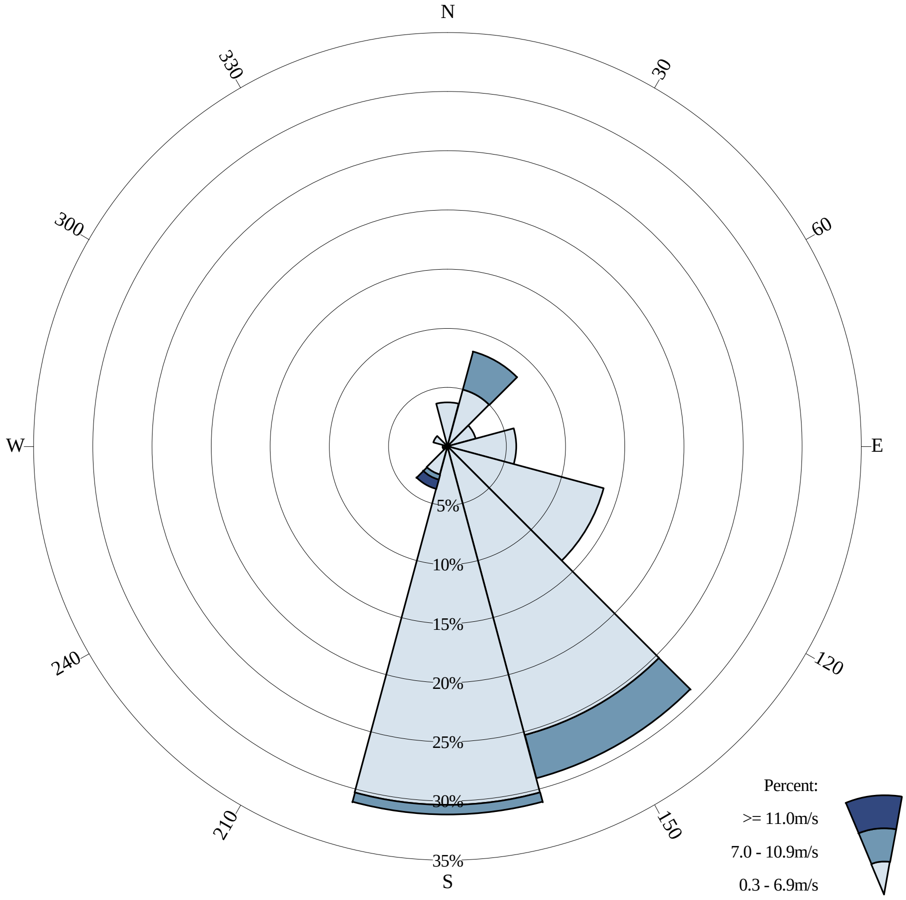
Number of observations = 241
Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 0 = 0.0%
Observations with calm/varying wind direction are not used in the statistics

Figure 29 Statistics for wind period 3 (day 1-10)

Station 04220
AASIAAT

03-01-2005 (9 pm) - 13-01-2005 (9 pm)

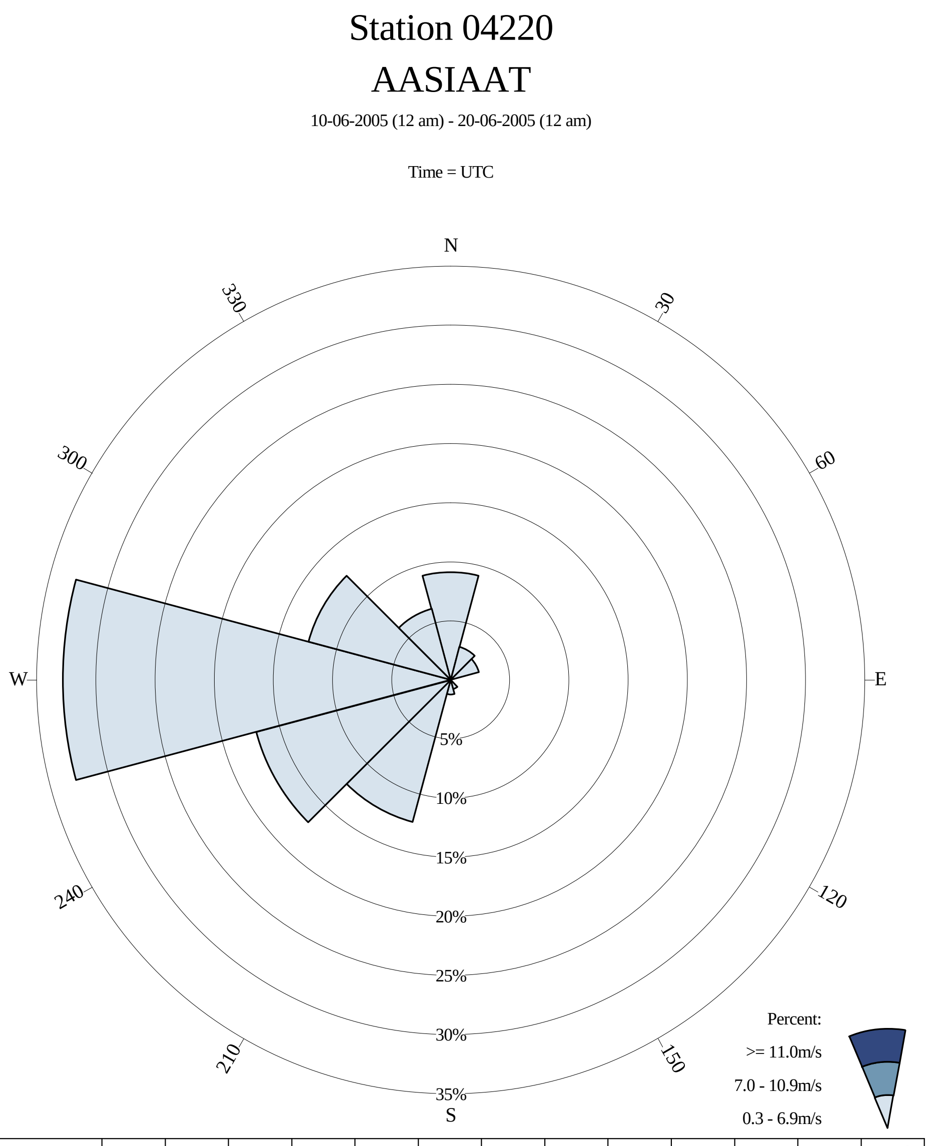
Time = UTC



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	3.7	8.3	2.5	5.8	13.7	29.0	31.1	3.7	0.4	0.4	1.2	0.0	100.0
% 0.3-6.9m/s	3.7	5.0	2.5	5.8	13.7	25.3	30.3	2.5	0.4	0.4	1.2	0.0	90.9
% 7.0-10.9m/s	0.0	3.3	0.0	0.0	0.0	3.7	0.8	0.4	0.0	0.0	0.0	0.0	8.3
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.8
Mean wind speed	4.4	6.5	3.7	3.6	3.8	4.9	4.8	6.0	3.6	1.5	4.5	0.0	4.8
Max wind speed	5.7	10.3	5.7	6.2	6.2	10.3	7.2	13.4	3.6	1.5	5.7	0.0	13.4

Number of observations = 241 Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 0 = 0.0%
Observations with calm/varying wind direction are not used in the statistics

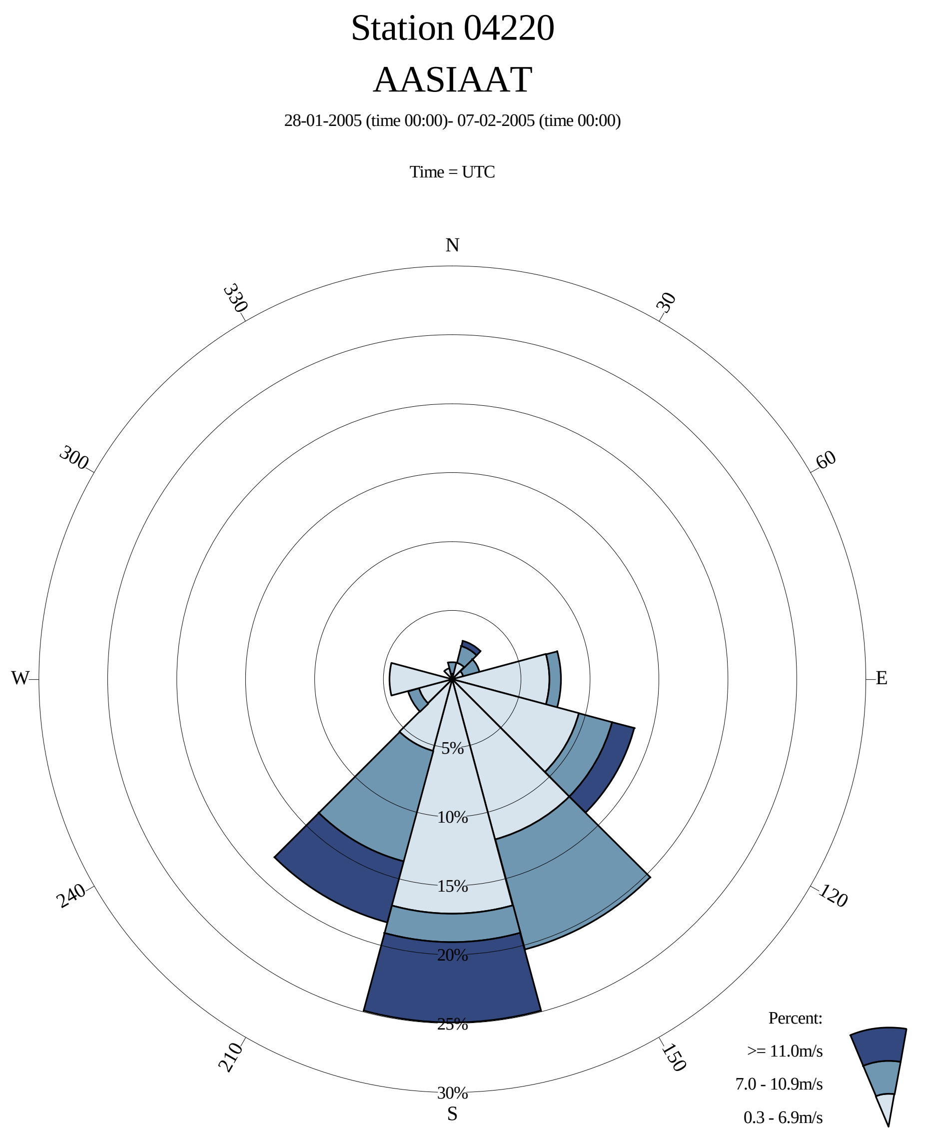
Figure 30 Statistics for wind period 4 (day 1-10)



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	9.1	2.9	2.5	0.0	0.0	0.8	1.2	12.4	17.0	32.8	12.4	6.2	97.5
% 0.3-6.9m/s	9.1	2.9	2.5	0.0	0.0	0.8	1.2	12.4	17.0	32.8	12.4	6.2	97.5
% 7.0-10.9m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% >= 11.0m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean wind speed	2.3	2.4	3.3	0.0	0.0	1.0	2.7	3.2	2.7	2.4	2.1	1.5	2.5
Max wind speed	5.7	4.6	4.1	0.0	0.0	1.5	4.1	5.7	6.7	4.1	3.6	3.6	6.7

Number of observations = 241 Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 6 = 2.5%
Observations with calm/varying wind direction are not used in the statistics

Figure 31 Statistics for wind period 5 (day 1-10)



	N	30	60	E	120	150	S	210	240	W	300	330	Total
%	1.2	2.9	2.1	7.9	13.7	20.3	24.9	18.3	3.3	4.6	0.0	0.8	100.0
% 0.3-6.9m/s	0.4	1.2	0.8	7.1	9.5	12.0	17.0	5.4	2.5	4.6	0.0	0.8	61.4
% 7.0-10.9m/s	0.8	1.2	1.2	0.8	2.5	8.3	2.1	8.3	0.8	0.0	0.0	0.0	26.1
% >= 11.0m/s	0.0	0.4	0.0	0.0	1.7	0.0	5.8	4.6	0.0	0.0	0.0	0.0	12.4
Mean wind speed	7.7	7.3	8.0	4.0	5.9	6.0	7.2	9.4	4.6	4.6	0.0	5.4	6.7
Max wind speed	9.8	11.3	10.8	8.2	13.4	10.8	22.7	20.1	8.2	6.2	0.0	6.7	22.7

Number of observations = 241 Source: DMI
Calm defined as wind speed <= 0.2m/s
Number of observations with calm/varying wind direction: 0 = 0.0%
Observations with calm/varying wind direction are not used in the statistics

Figure 32 Statistics for wind period 6 (day 1-10)

Appendix C. Maximum surface layer oil thickness

For each of the 7 spill sites, the maximum oil slick thickness in the surface skin layer attained at any time during the 30 days of simulation is mapped. All six wind periods are included. Only surface spills are shown. Bottom spills are very similar to the continuous surface spills.

Note that the figures does not represent the oil slick at a given time, but shows the area that at any time during the simulation has been covered by oil.

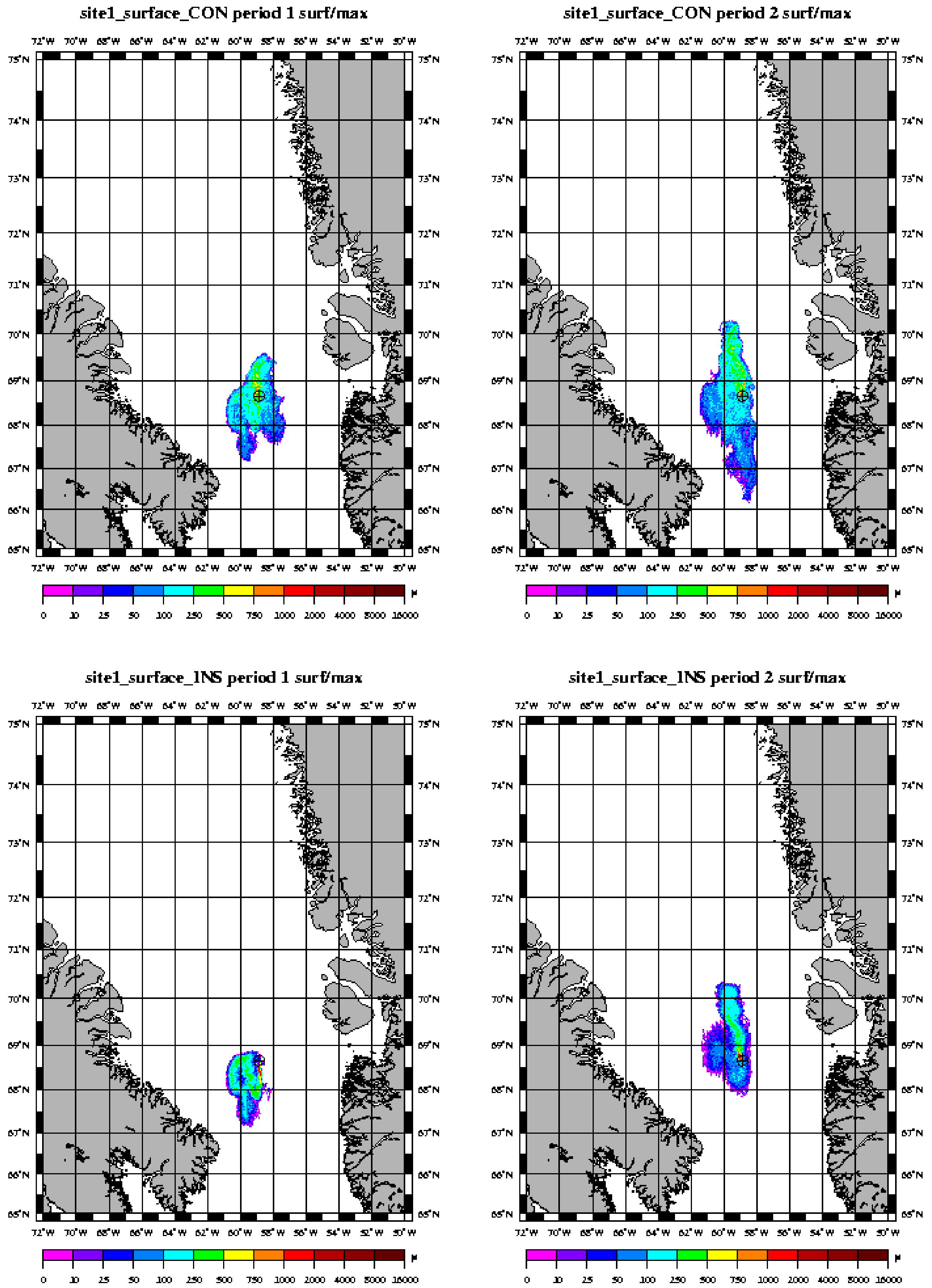


Figure 33 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 1 for wind period 1-2.

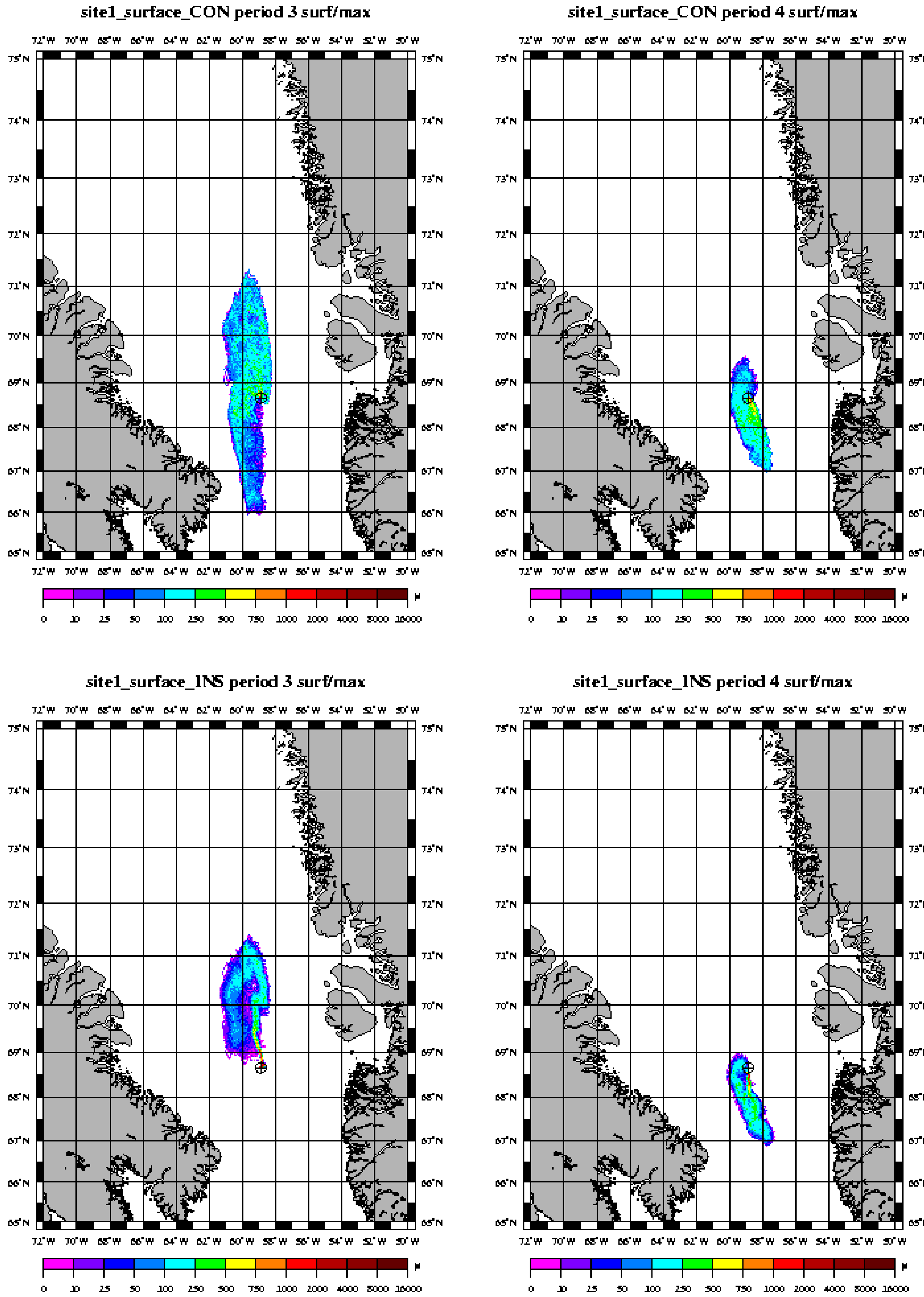


Figure 34 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 1 for wind period 3-4.

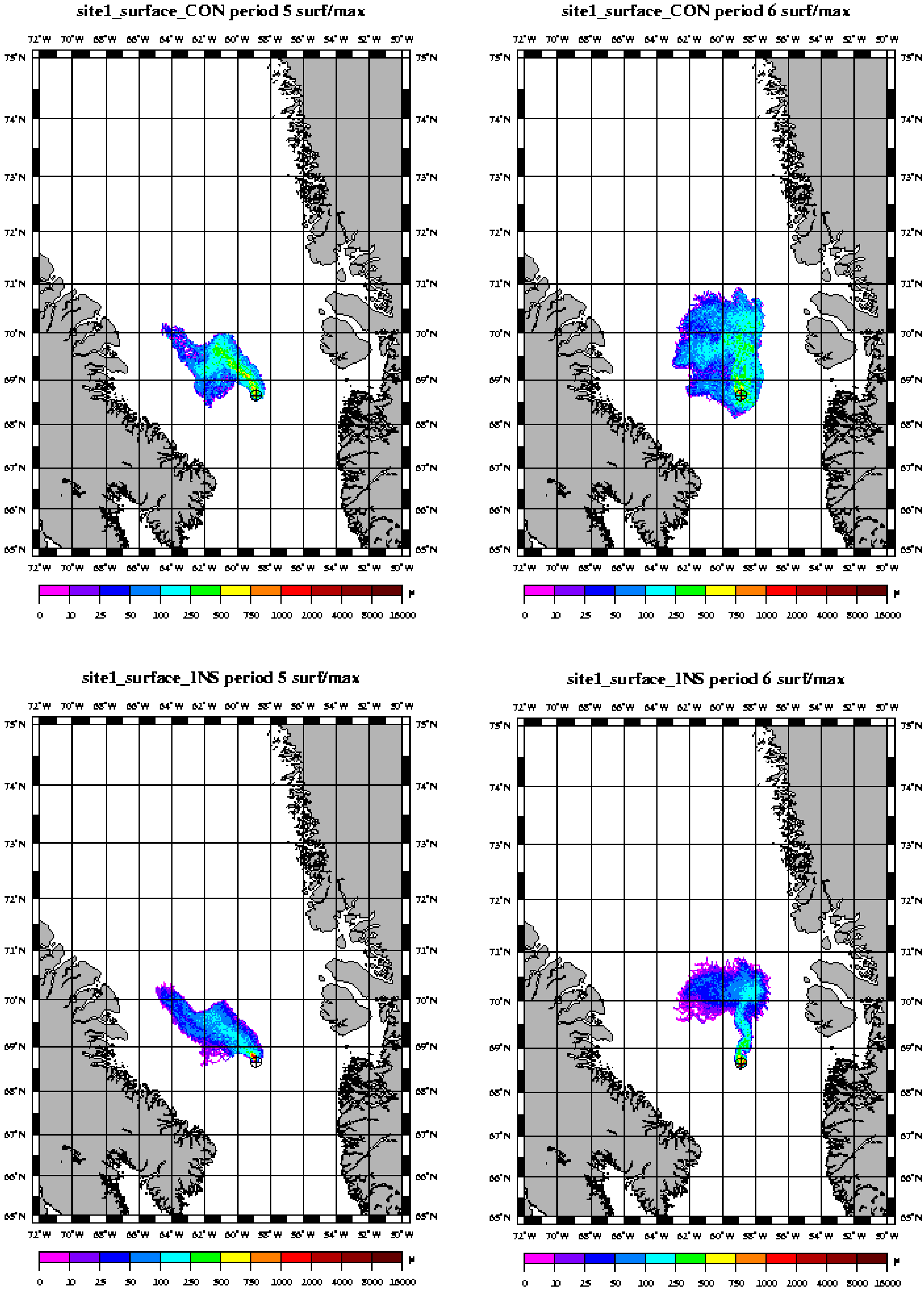


Figure 35 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 1 for wind period 5-6.

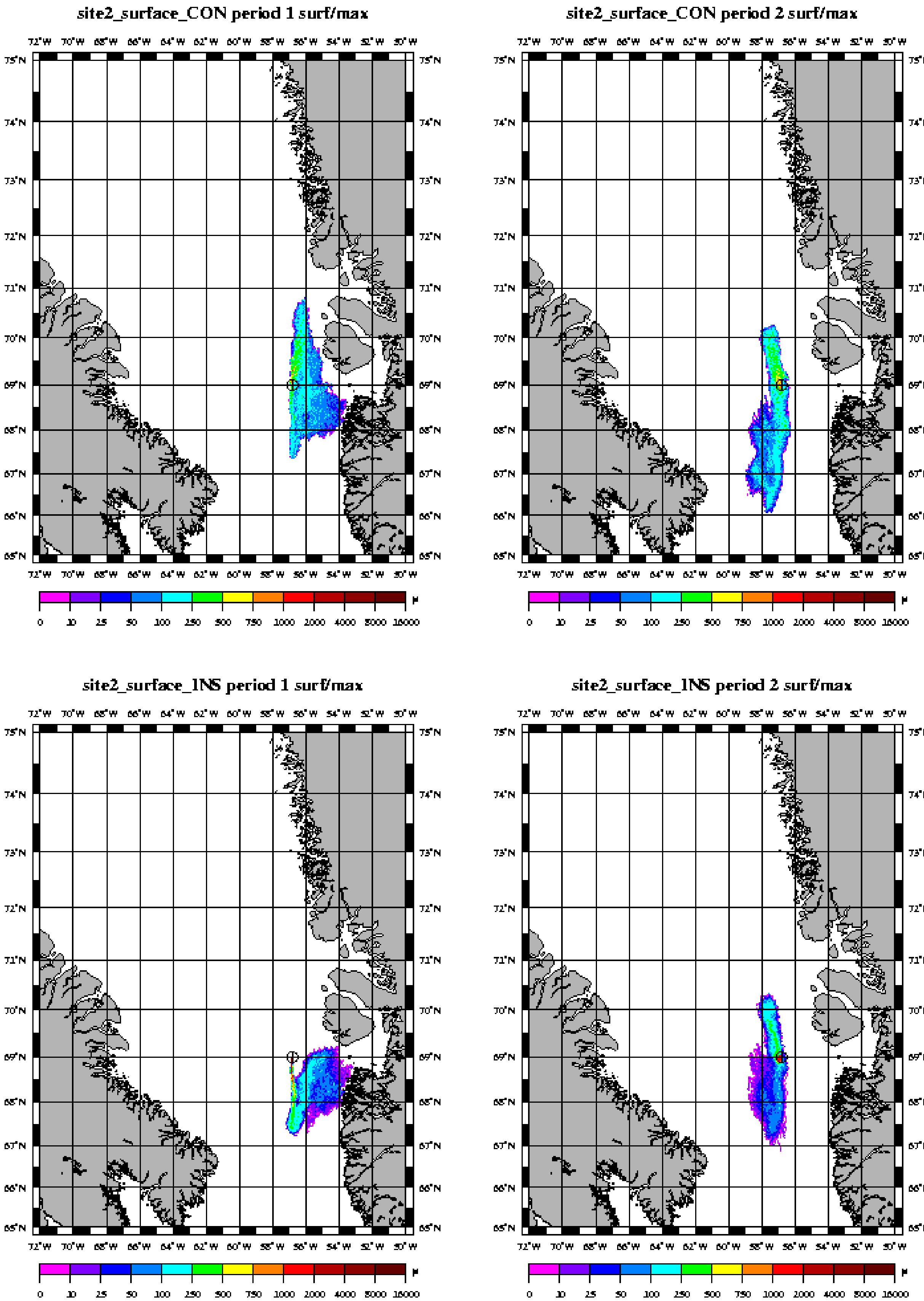


Figure 36 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 2 for wind period 1-2.

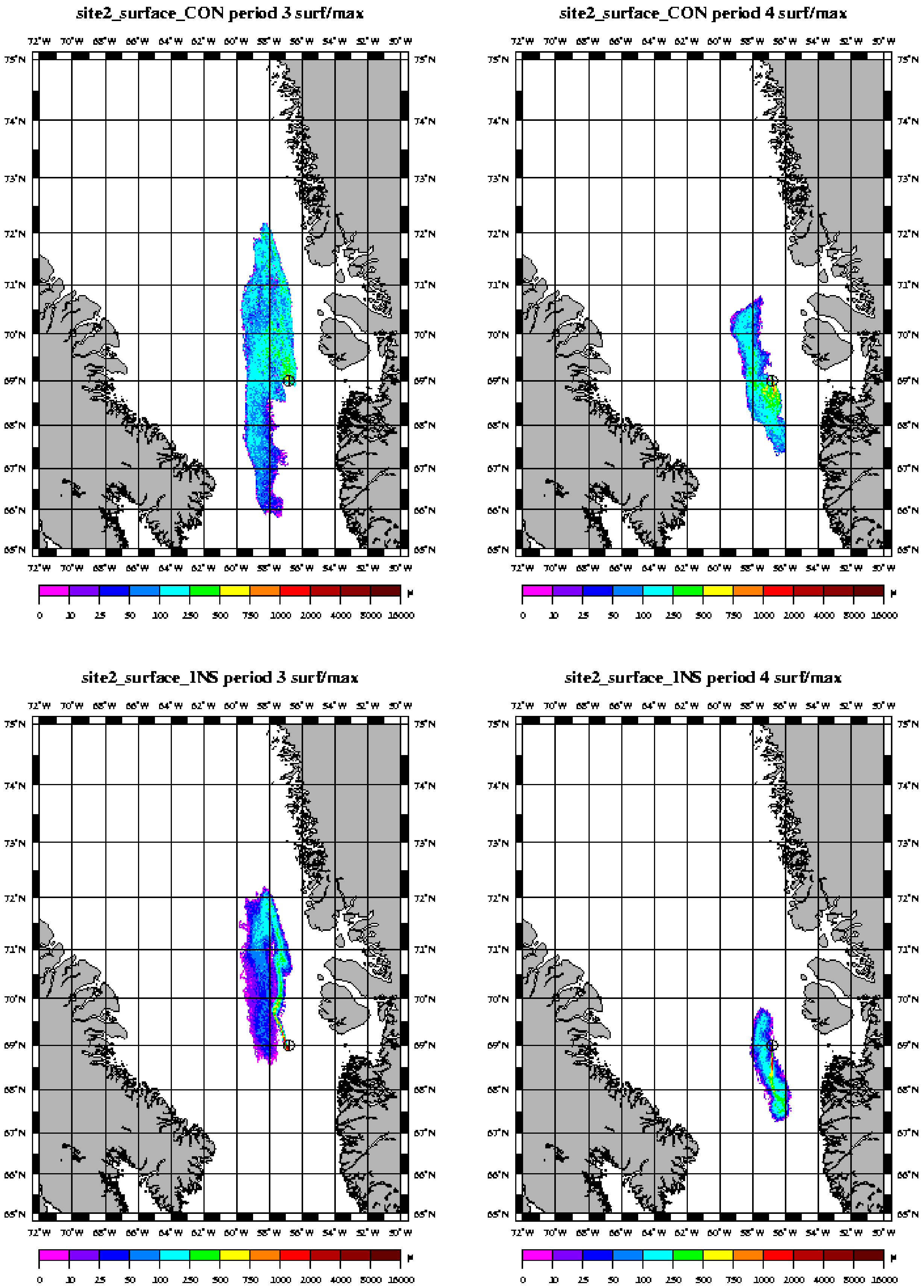


Figure 37 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 2 for wind period 3-4.

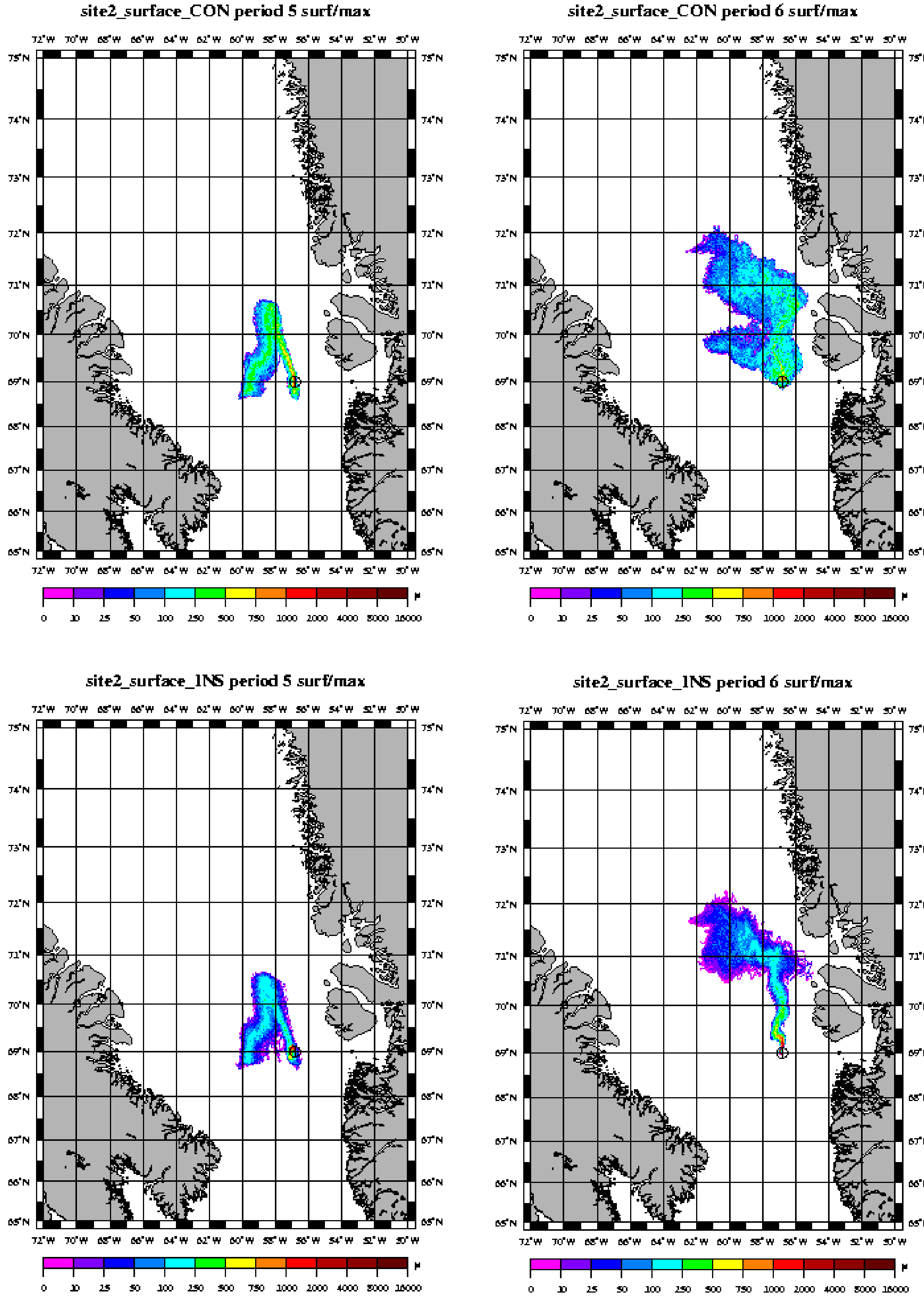


Figure 38 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 2 for wind period 5-6.

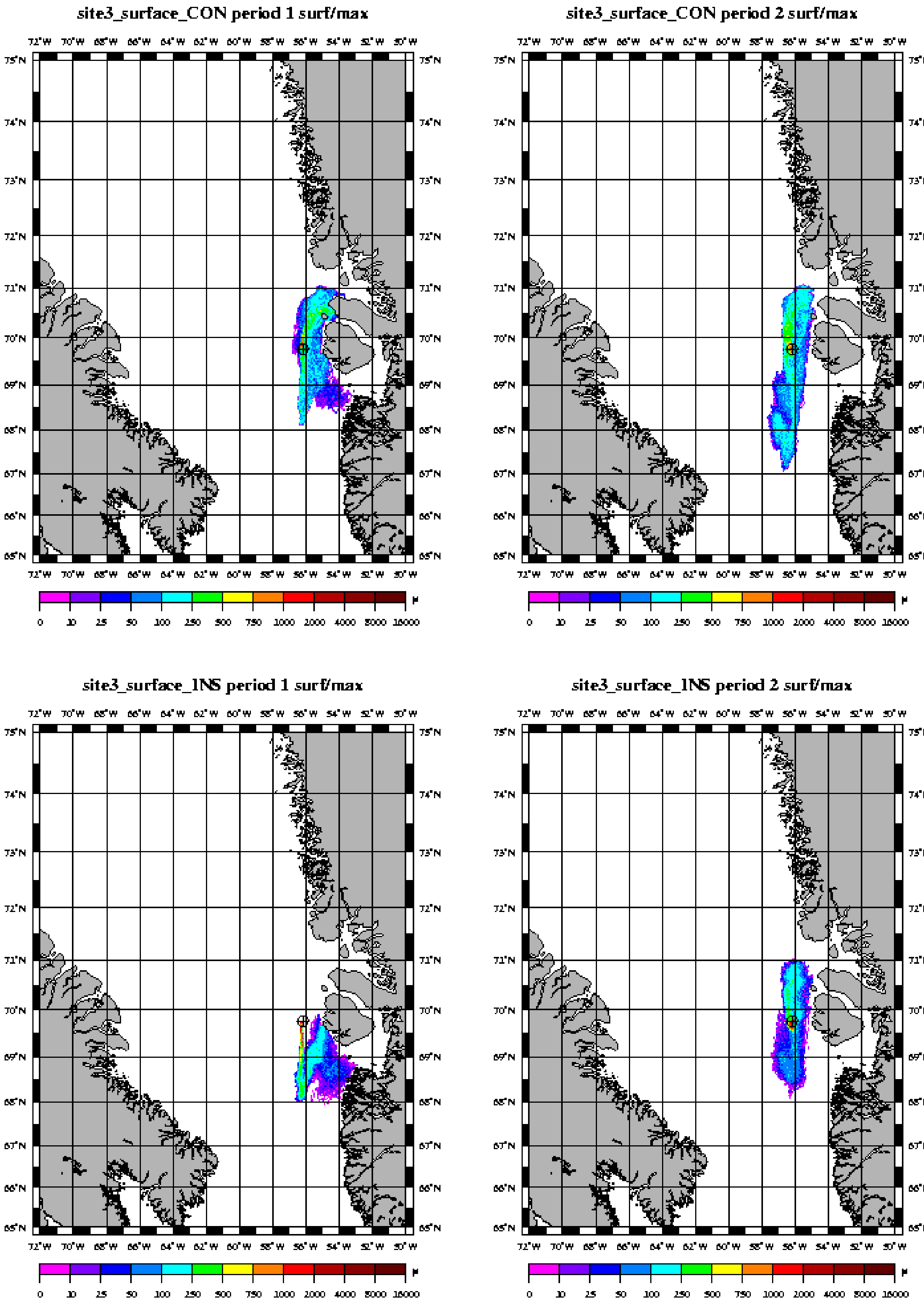


Figure 39 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 3 for wind period 1-2.

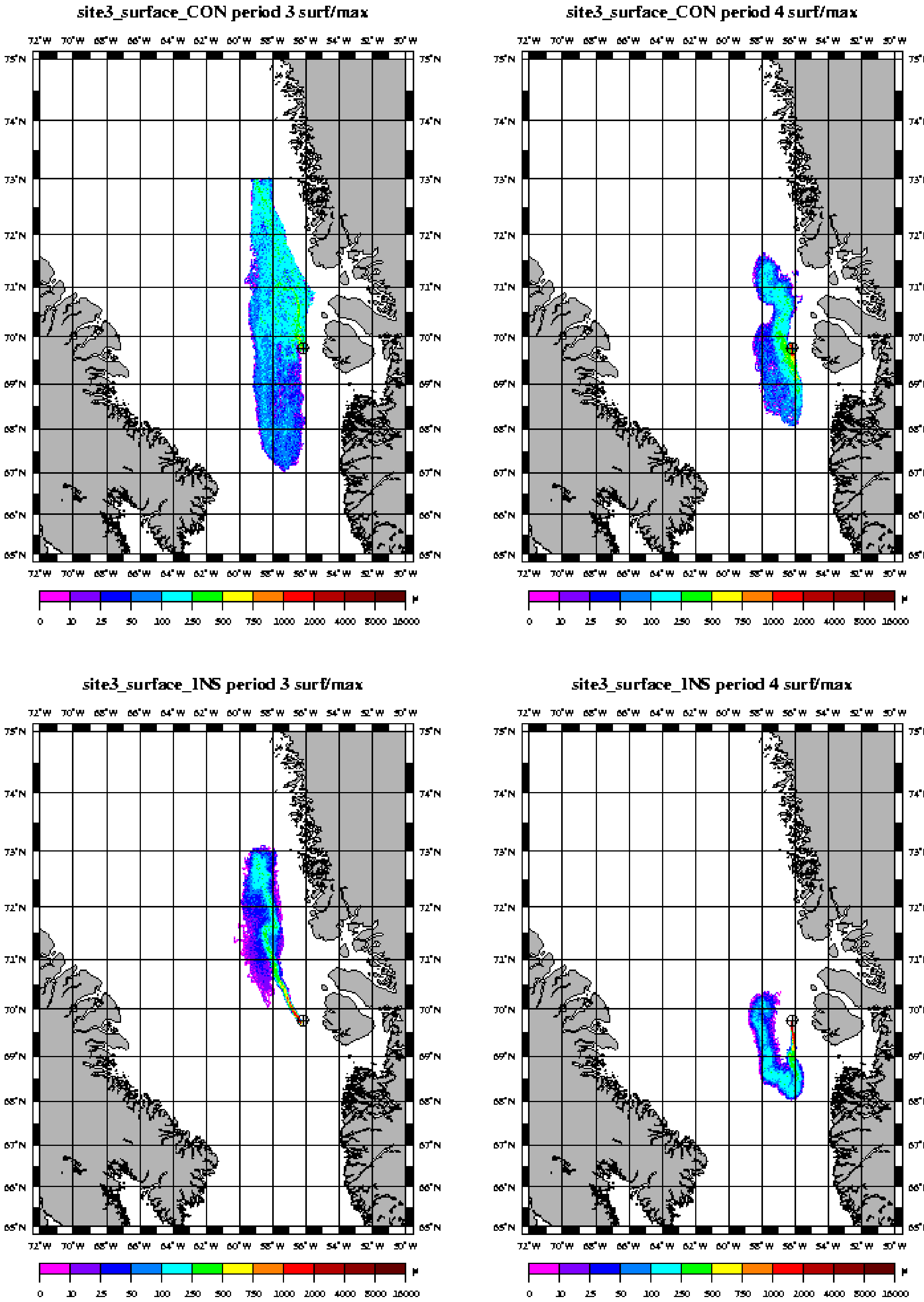


Figure 40 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 3 for wind period 3-4.

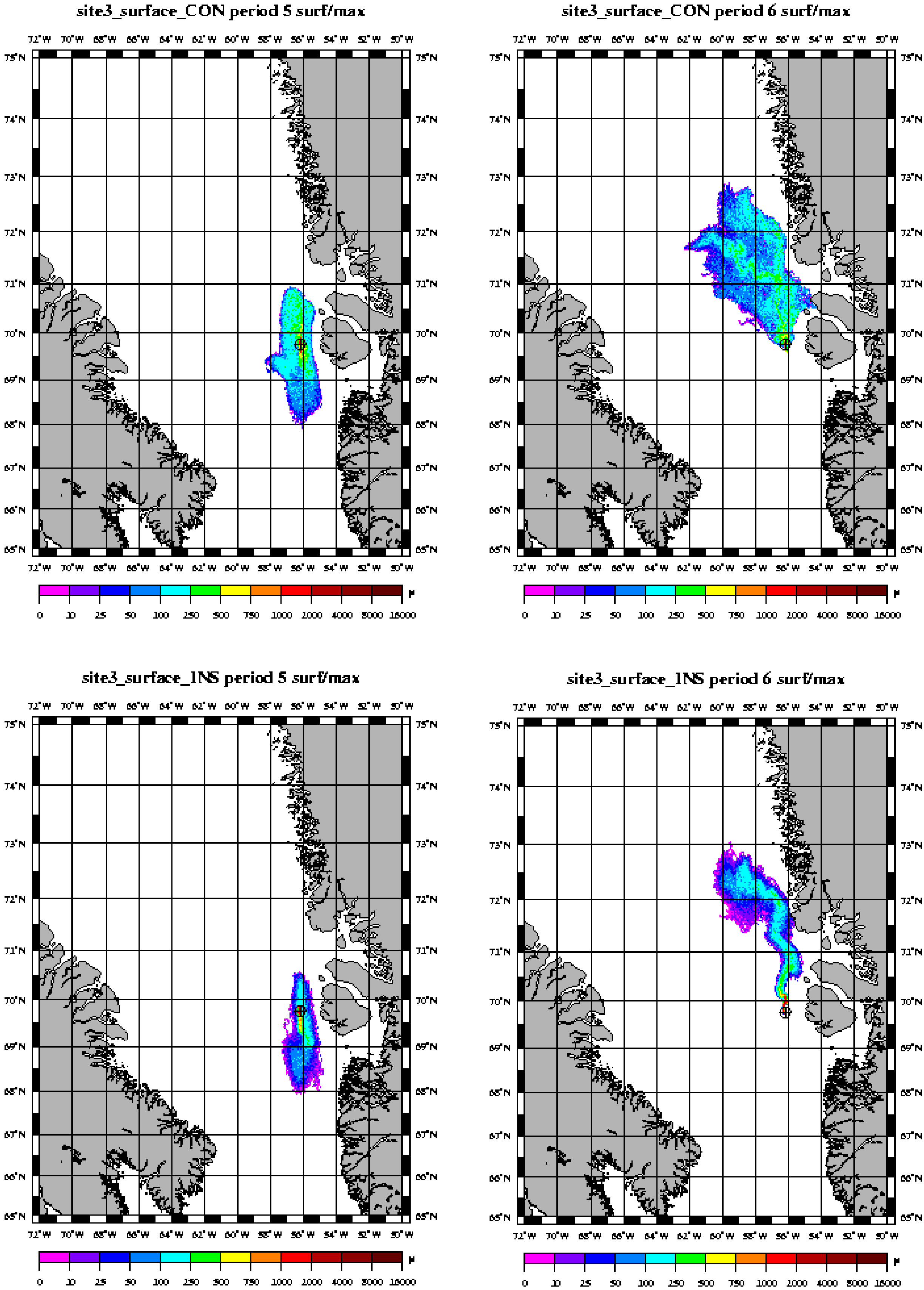


Figure 41 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 3 for wind period 5-6.

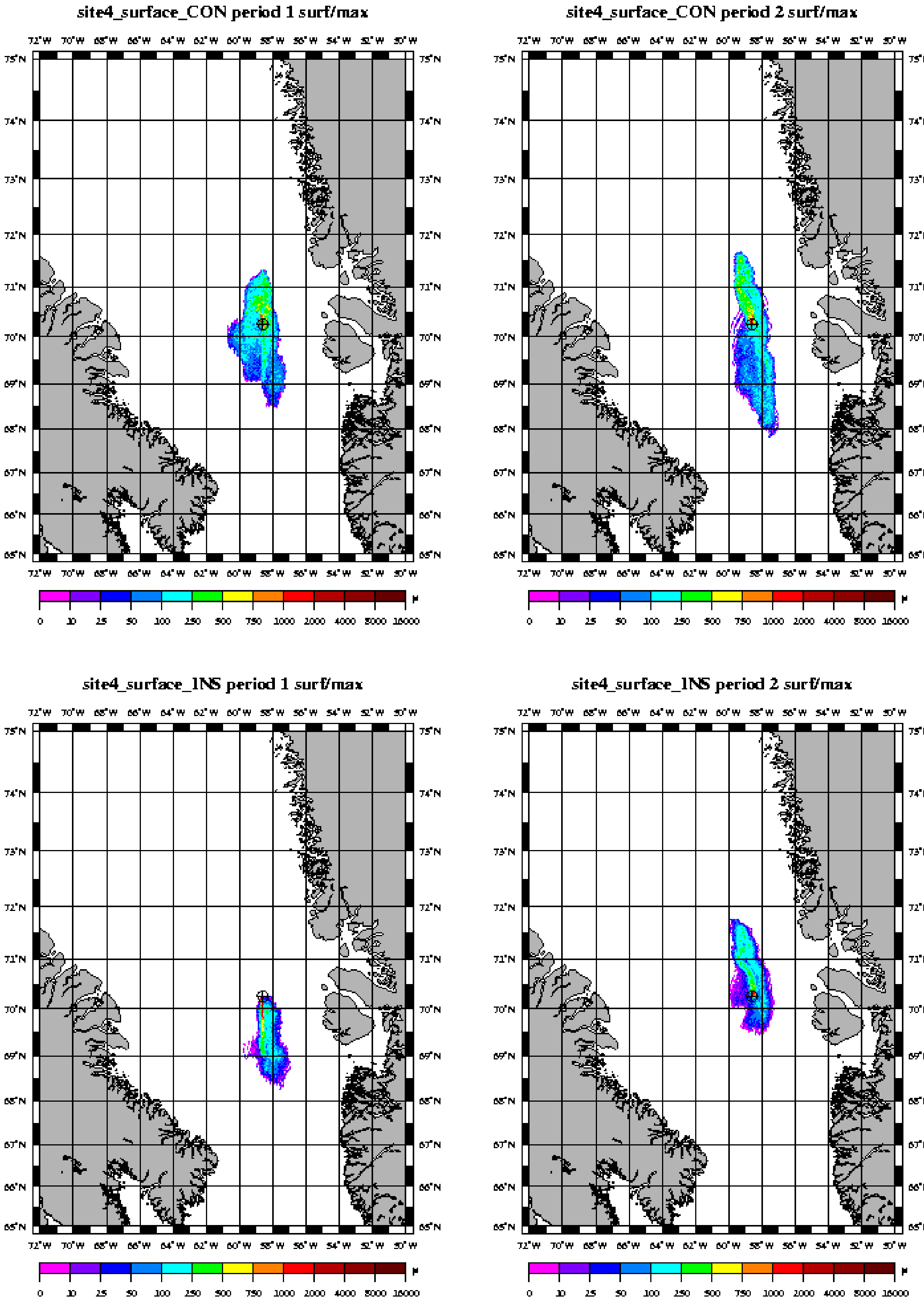


Figure 42 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 4 for wind period 1-2.

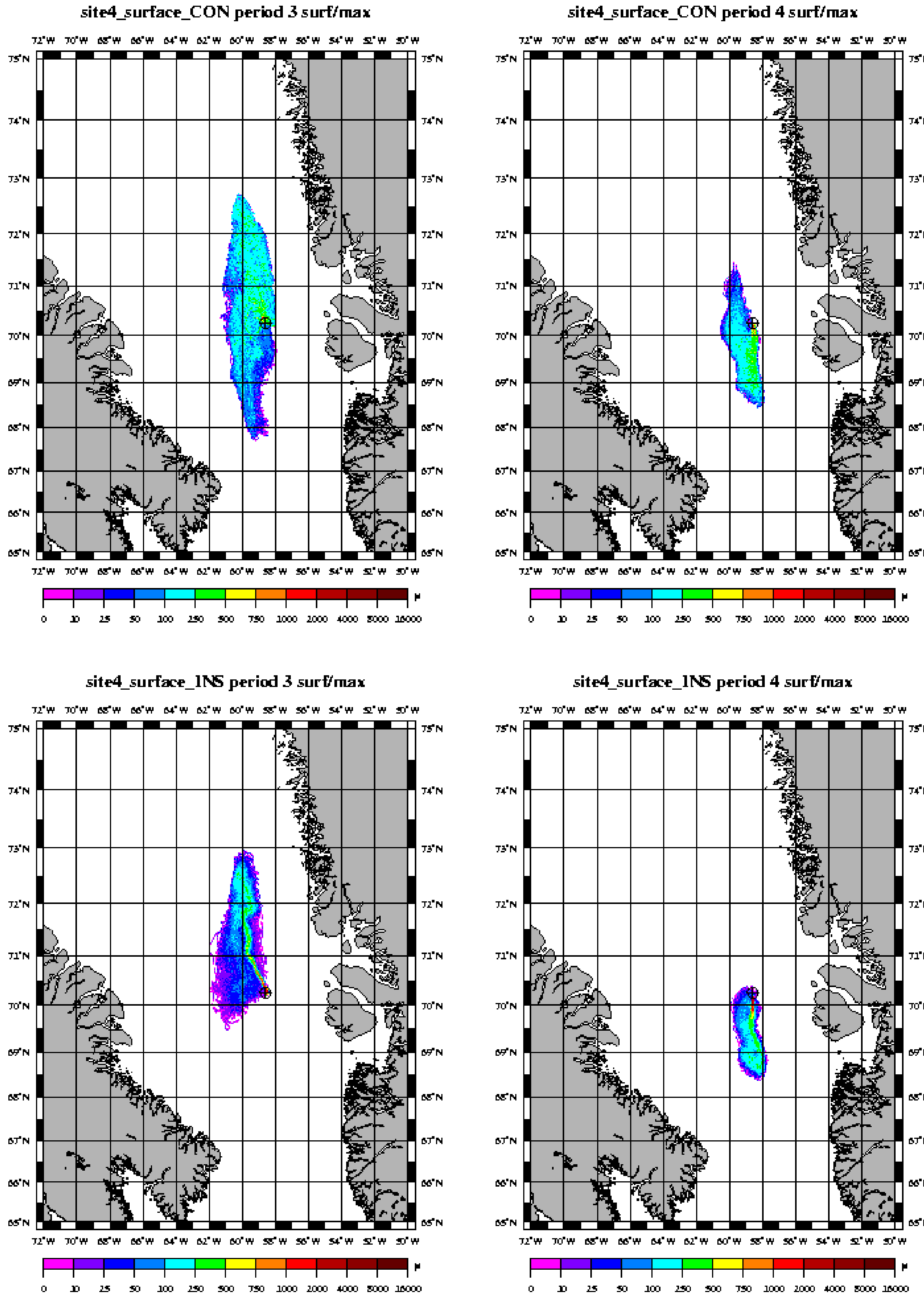


Figure 43 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 4 for wind period 3-4.

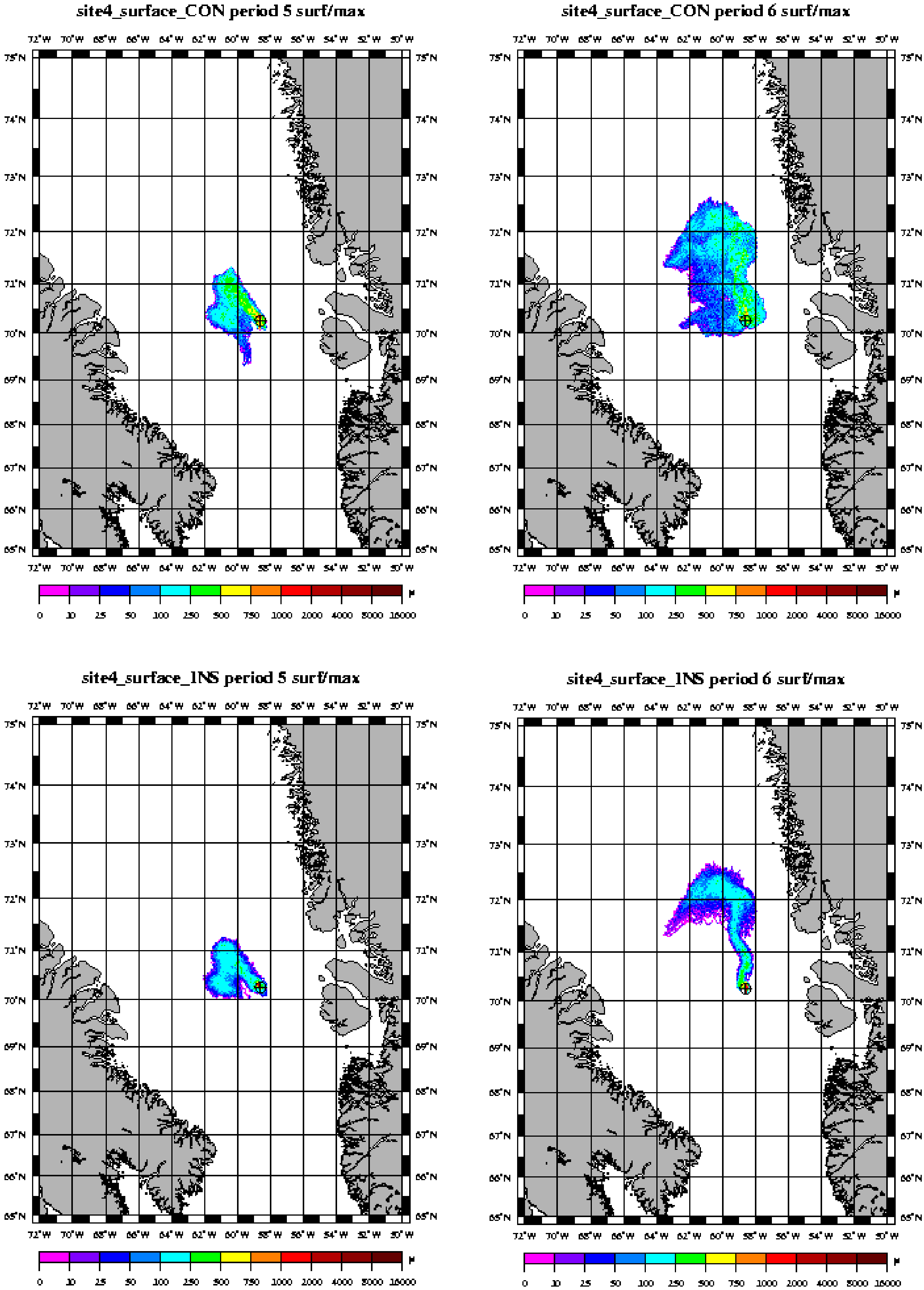


Figure 44 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 4 for wind period 5-6.

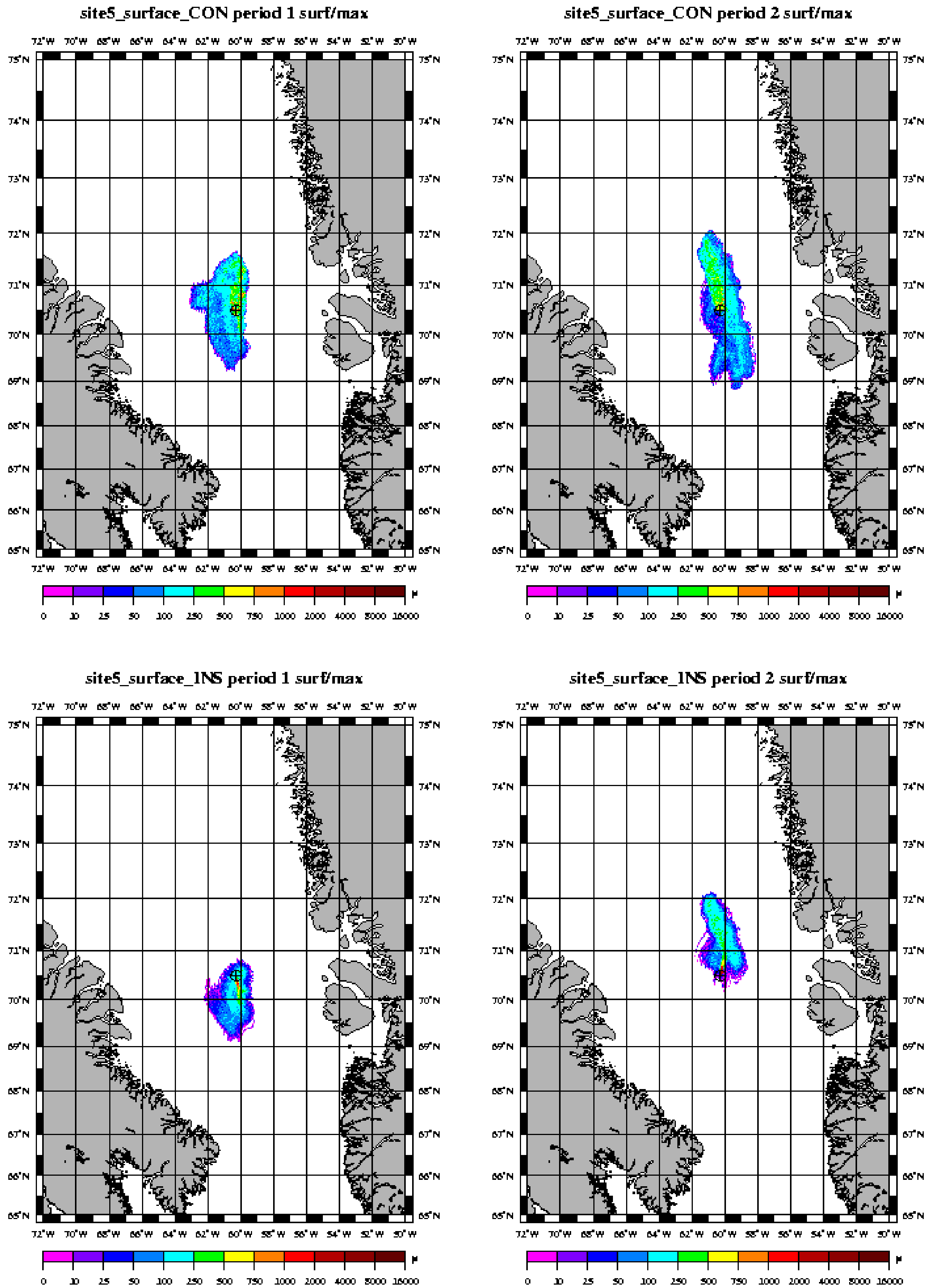


Figure 45 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 5 for wind period 1-2.

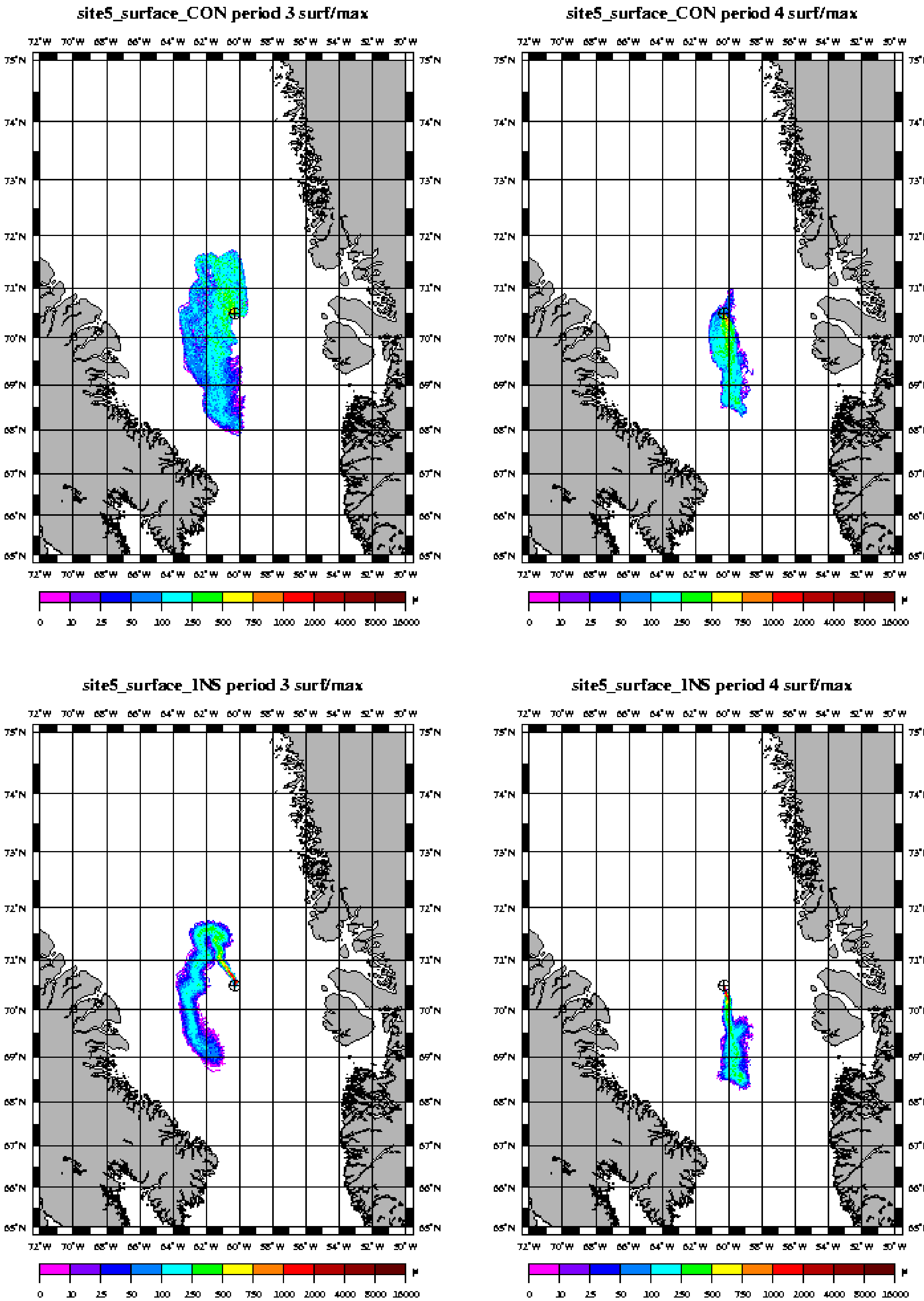


Figure 46 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 5 for wind period 3-4.

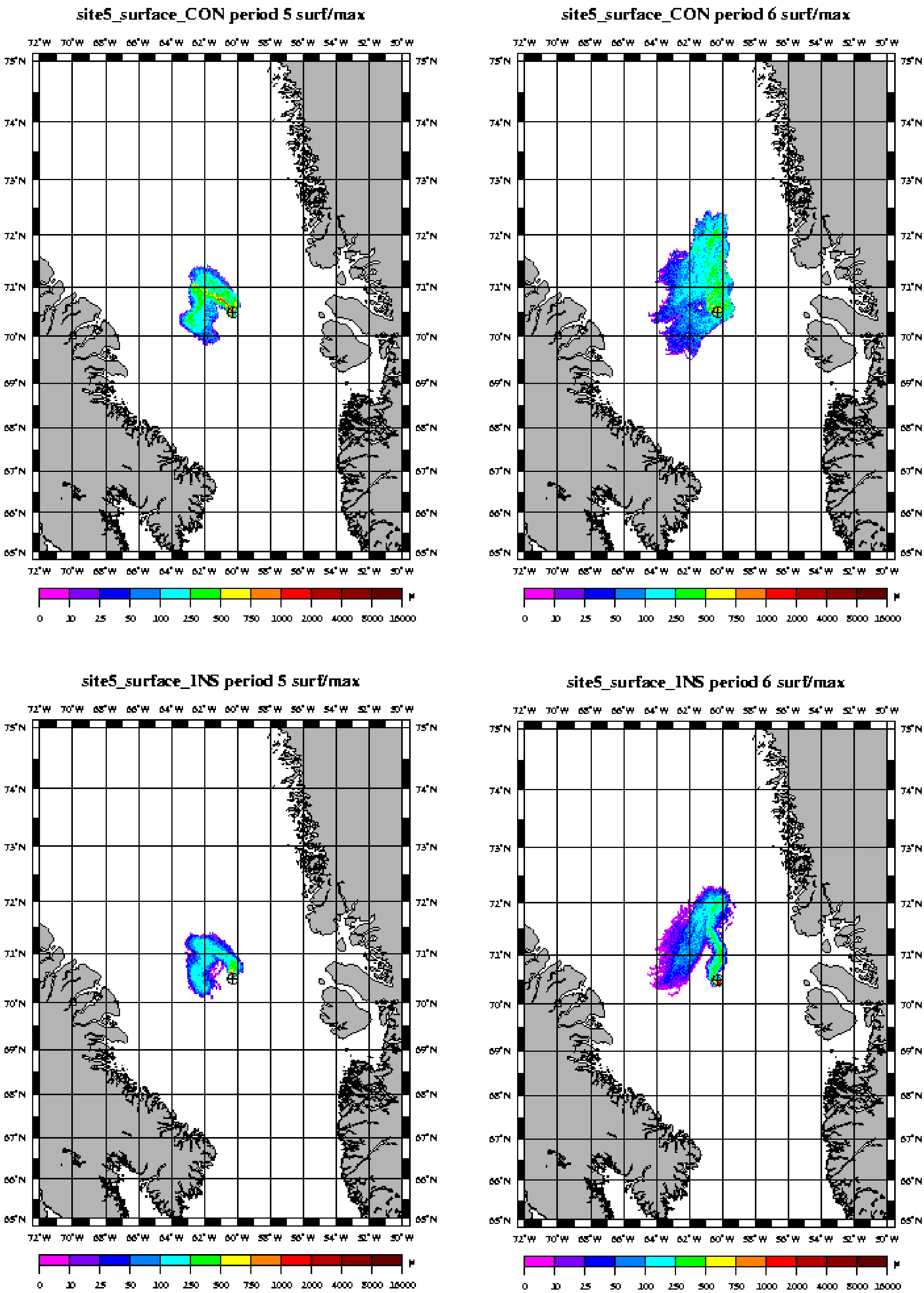


Figure 47 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 5 for wind period 5-6.

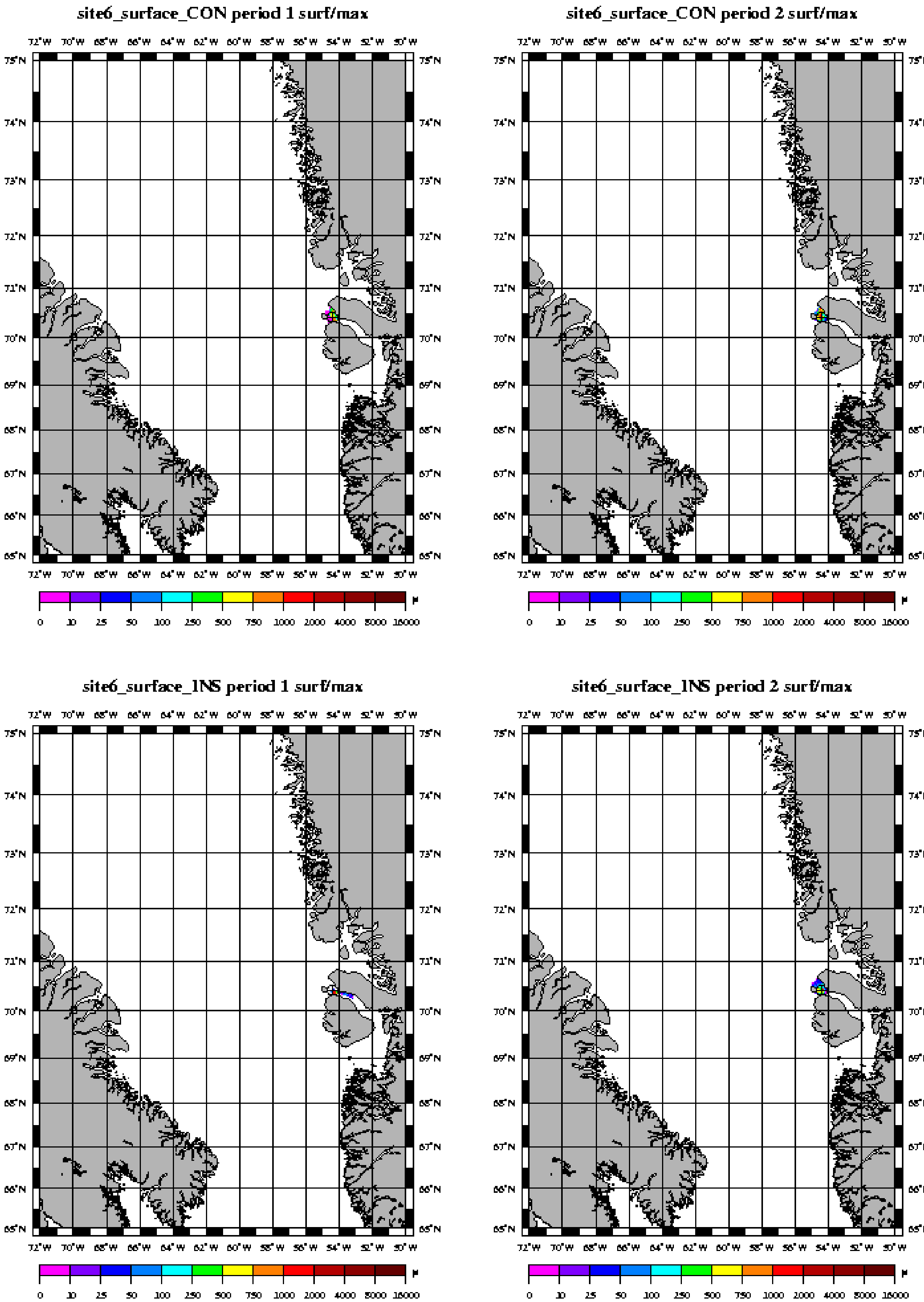


Figure 48 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 6 for wind period 1-2.

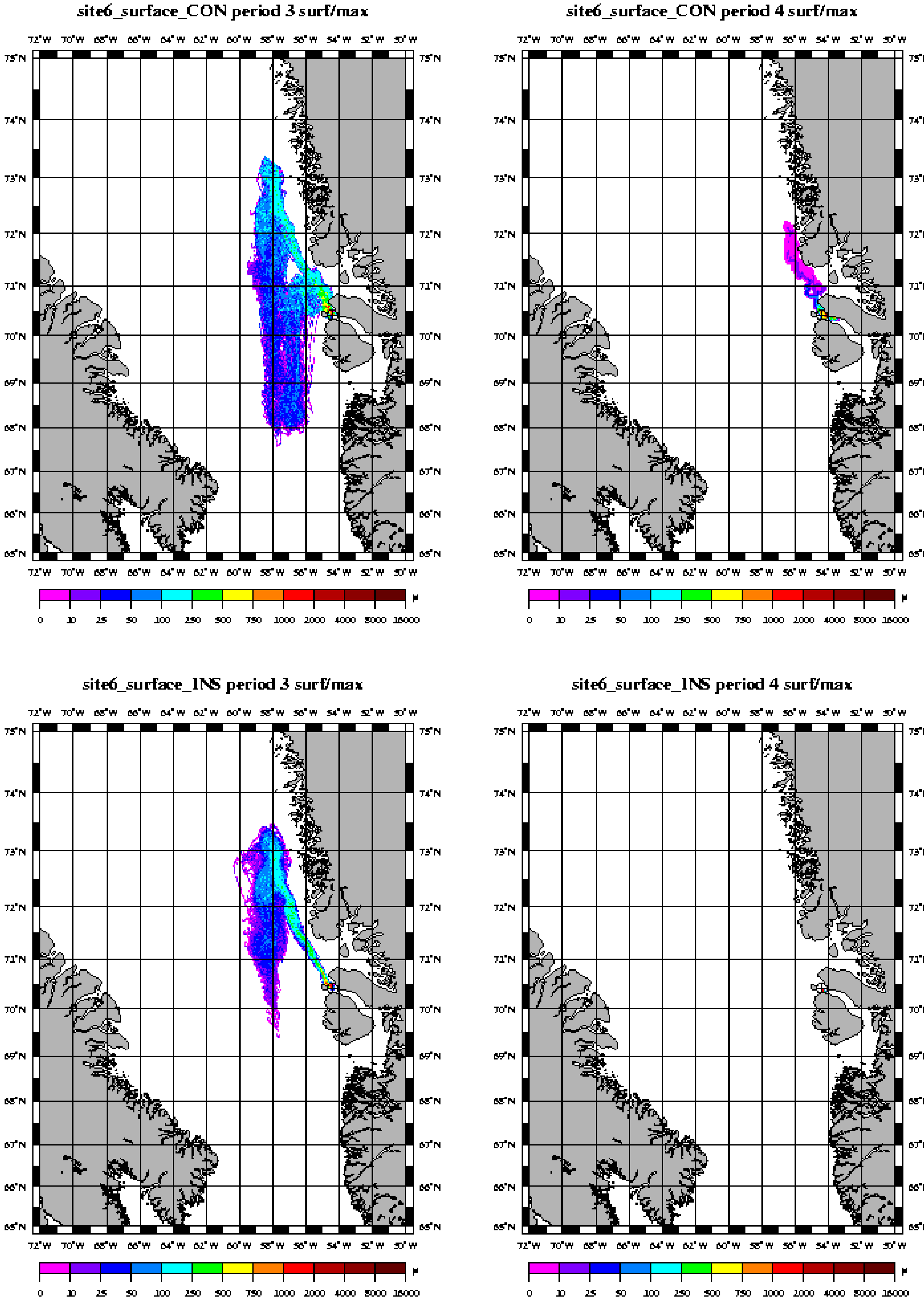


Figure 49 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 6 for wind period 3-4.

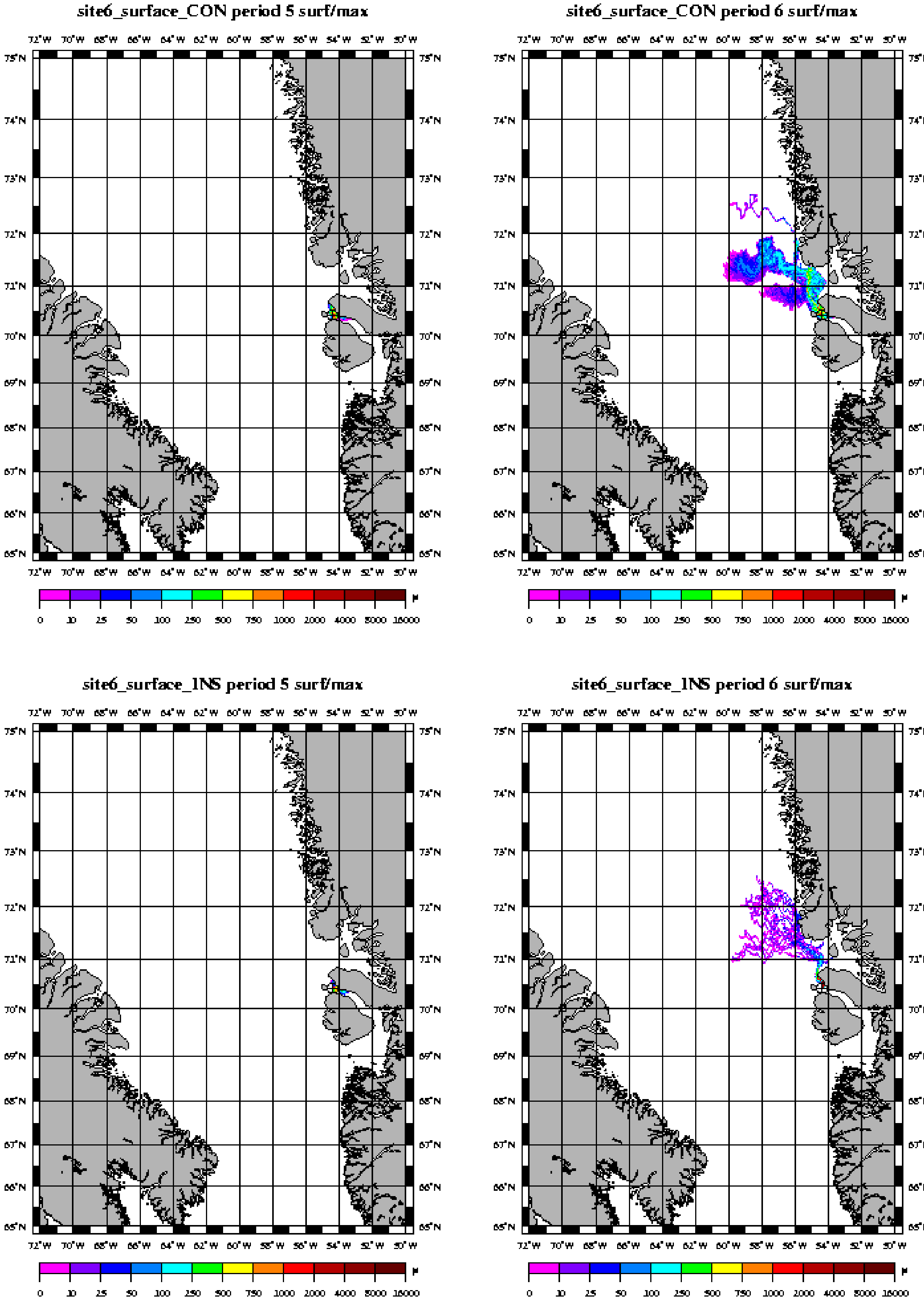


Figure 50 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 6 for wind period 5-6.

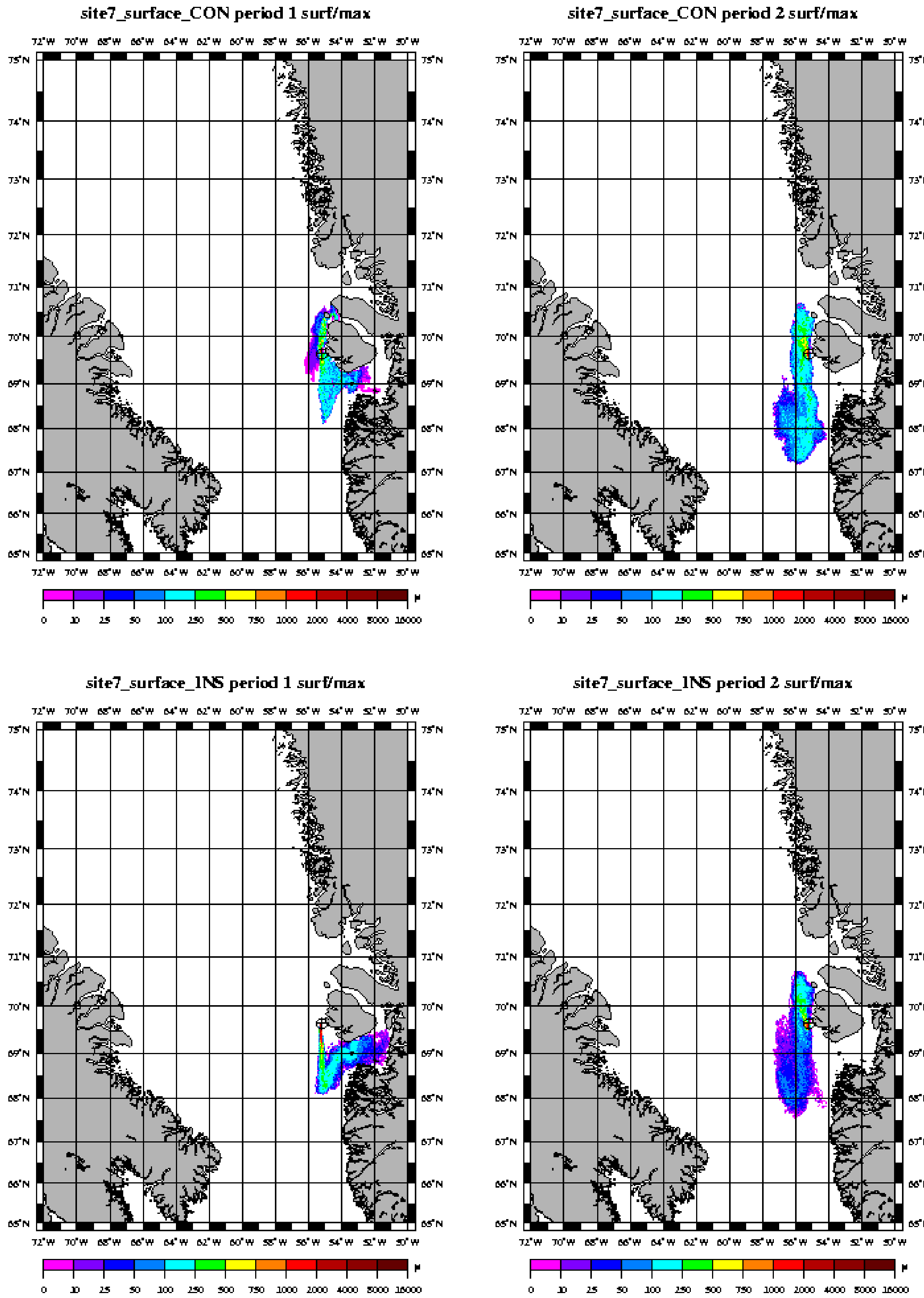


Figure 51 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 7 for wind period 1-2.

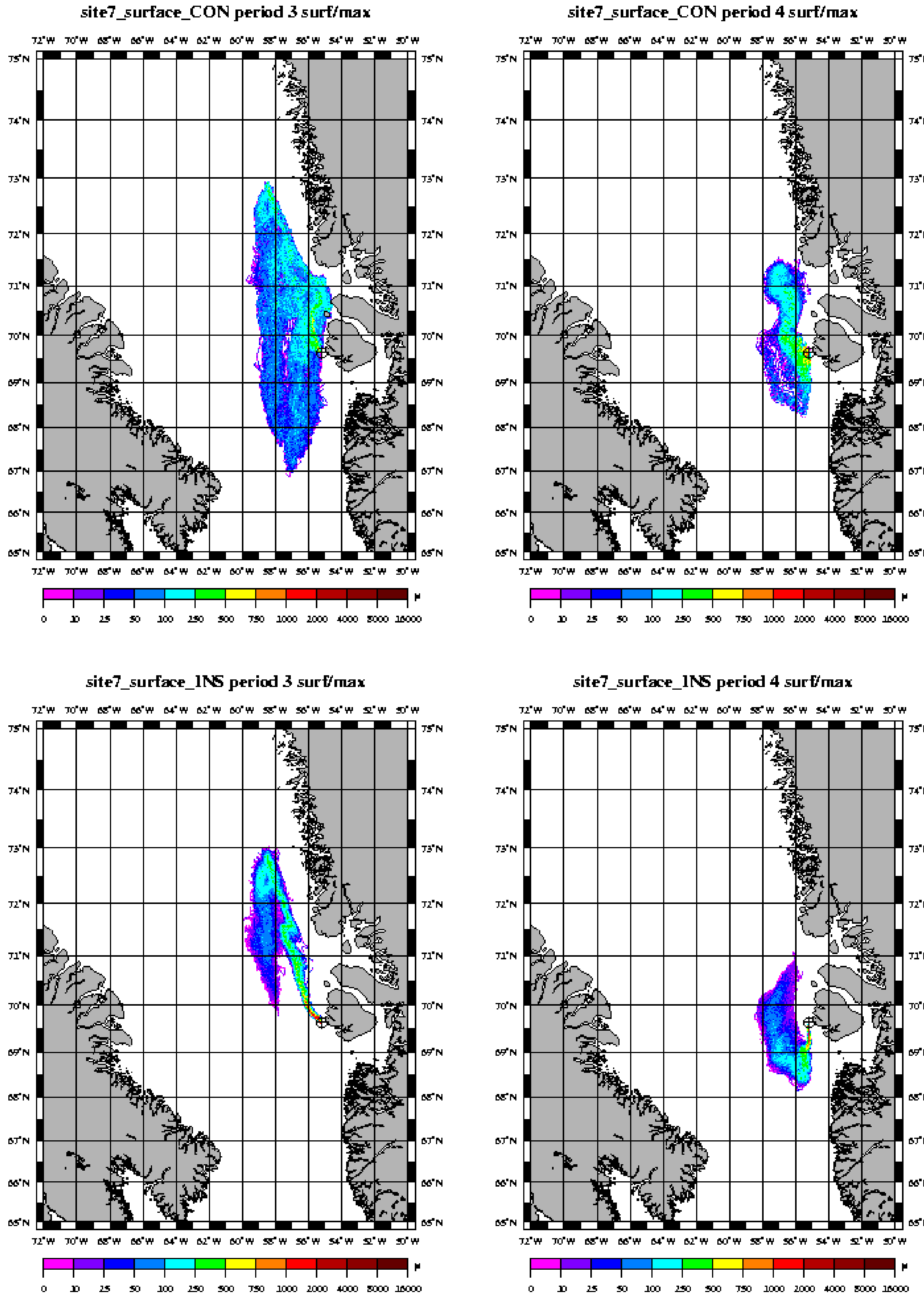


Figure 52 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 7 for wind period 3-4.

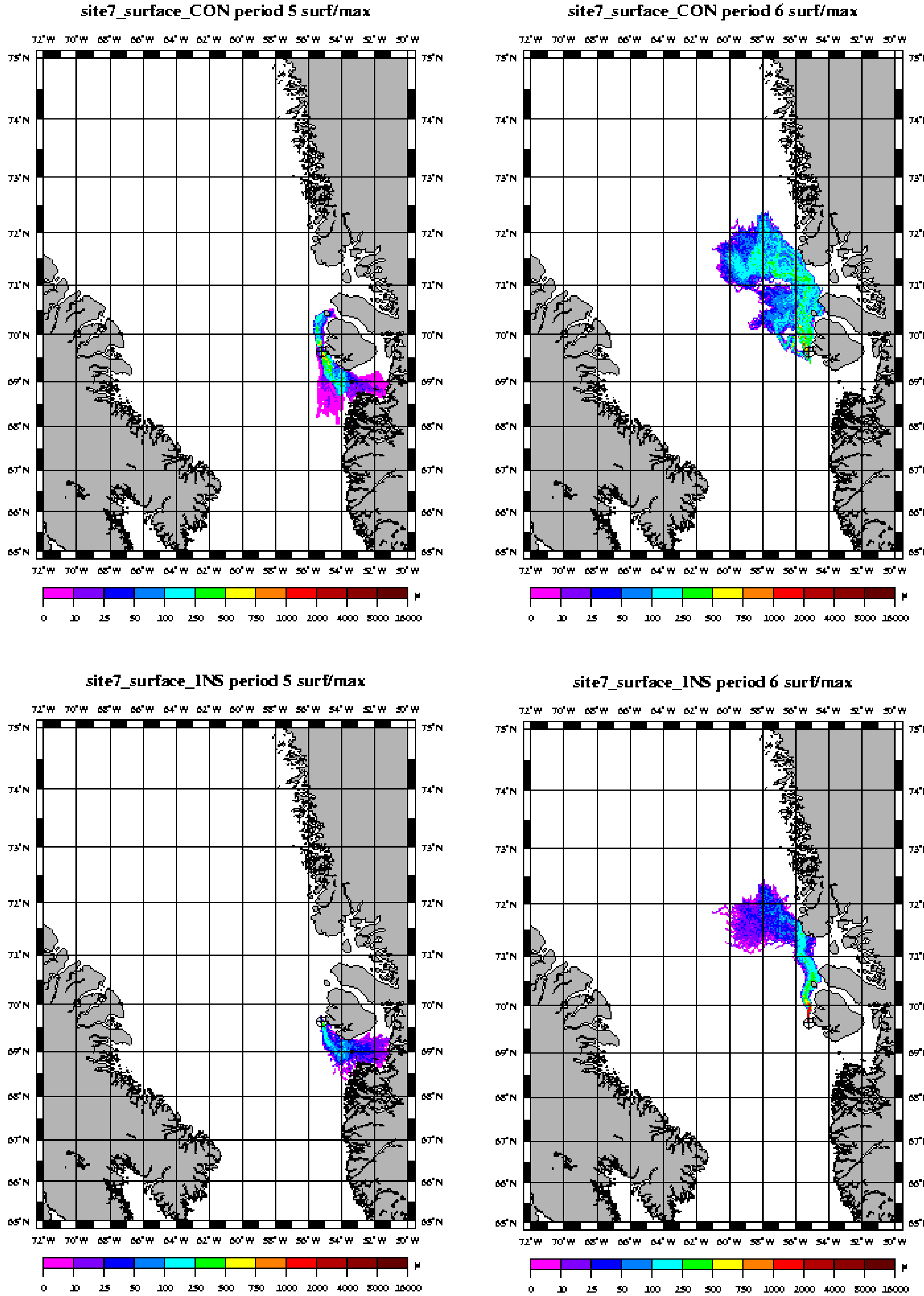


Figure 53 Maximum surface layer thickness for instantaneous (left) and continuous (right) surface spills at location no. 7 for wind period 5-6.