APPENDIX I

Drill Cuttings Dispersion Modelling
Bay du Nord Development Project (Wood 2020)

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Drill Cuttings Dispersion Modelling
Bay du Nord Development Project

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9 June 2020
Wood Project #: TA1872108

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EXECUTIVE SUMMARY

Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited (Wood) has been contracted by Equinor Canada Ltd. (Equinor Canada) to complete drill cuttings dispersion modelling for the Bay du Nord (BdN) Development Project (the Project), offshore eastern Newfoundland. Equinor Canada Ltd. (Equinor) and its partner Husky Oil Operations Limited (Husky) are proposing to develop the Bay du Nord (BdN) field (which includes Bay du Nord, Bay de Verde and Bay de Verde East) and the Baccalieu discovery (collectively the Core BdN Development) offshore eastern Newfoundland for the production of oil and gas. The Core BdN Development includes offshore construction, installation, hook-up and commissioning, drilling, production operations, maintenance and decommissioning activities, as well as supporting surveys, field work, supply and servicing activities. The objective of the study is to model drill cuttings releases associated with drilling activities for the Project in support of the Environmental Impact Assessment (EIS).

Drill cuttings are the small pieces of rock, ranging in size from coarse sand to fine silts and clays, created when a drill bit penetrates rock. The material is forced up the annulus of the well hole as drilling proceeds. The composition of the drill cuttings is dependent on the stratigraphy of the area, the type of drill bit used, the type of drilling mud used and the nature of cuttings treatment applied to cuttings on the drilling installation prior to their discharge to the ocean. The drill cuttings composition together with water depth and ocean current determine the deposition of the cuttings on the seabed.

The Project will involve the drilling of multiple wells, e.g., up to 36 wells in the Code BdN Development, with a combination of production and injection wells. Wells will either be drilled using templates (multiple wells drilled in one location) or at individual well locations. Two modelling simulations are considered; drilling of one well and drilling of eight wells. Modelling of drill cuttings release from drilling of one well provides a 'representative' unit prediction of cuttings dispersion. Given that (four- and eight-slot) template drilling is anticipated for the multiple wells, a simulation with eight wells models the anticipated largest drill cuttings release for a single location.

A drilling location within the Core BdN Development Area at depth 1,170 m was chosen to model as more information is known for drilling activities associated with the Core BdN Development. The location is considered as representative, as the water depths in the Core BdN Development Area are relatively flat, ranging from approximately 1,000 to 1,200 m.

A numerical computer model, ADM, developed by Wood, employs a transport computation to simulate the advection of dispersed drill cuttings materials in three dimensions through the water column, following release into the sea, until the particles come to rest on the sea bottom. Key inputs for the model include cuttings particle characterizations and ocean currents. The primary outputs are predictions of the deposition pattern of released drill cuttings on the seabed (e.g., weight, density, thickness of cuttings).

With the potential to drill at any time during the year, stochastic simulations are employed that consider ocean current conditions over an entire year. The stochastic analysis calculates statistics that include the P25, P50 (median), P75, P95 and P100 (maximum) thicknesses, and the probability (25, 50, 75, 95, or 100%, respectively) that thickness at a given location is above predicted no effect thresholds (PNET) (1.5 mm or 6.5 mm) to assist in the environmental assessment of potential biological effects of drill cuttings deposition.

The modelling for the drilling of one well simulation includes 53 deterministic model runs, each starting seven days apart from 1 January to 31 December, are included. With the longer drilling program duration on the order of 395 days for the eight well model simulation, a total of eight deterministic simulations was chosen, with each start date 45 days apart in the calendar year. In this way the annual variation in currents is incorporated. A variety of cuttings particle size distributions (PSD) based on the literature and empirical data from Equinor Canada were modelled to study the effect of different PSD and cuttings particle settling velocity on cuttings dispersion and settling on the seabed. A total of five input PSD were considered:

- ('0') Base case, estimated for the Bay du Nord field, with assumed flocculation of cuttings particles
- ('A') Base case, estimated for the Bay du Nord field, with no flocculation assumed: the smaller cuttings are assumed to stay disaggregated as separate particles and not flocculate to form larger particles with faster settling
- ('B') Troll A Platform (from a Norwegian continental shelf well), average PSD
- ('C') Troll A Platform maximum PSD
- ('D') Nedwed (a source of cuttings distributions for use in the absence of site-specific settling velocity data)

Ocean currents were characterized for the model with measurements available from a current mooring equipped with Acoustic Doppler Current Profiler (ADCP) and Recording Current Meter (RCM) instruments at a location CM-2 about 10 km to the northwest of the drill cuttings modelling location in the Core BdN Development Area. The CM-2 mooring was part of an Equinor Canada met-ocean monitoring program from July 2014 to May 2016 in the northern Flemish Pass in a water depth of 1,120 m. A continuous hourly time series of currents for depths 23, 150, 794 and 1,156 m was assembled from the 2014-2016 measurement record to represent the current profile and are assumed to be representative over the 16 km x 16 km model grid centered in the Core BdN Development Area.

<u>One Well Drilling Simulations</u>

Model results are presented for all five input PSD simulations for drilling of one well with a total cuttings volume of 898 m^3. These include:

- illustration of the individual model run outputs underlying the stochastic analysis (cross-sections of cuttings thickness vs. distance);
- tables of amount of cuttings material settled and median and maximum thickness vs. distance;
- plan view maps of median (most likely) cuttings thickness about the wellsite; and
- plan view maps showing the probability of thickness being above the PNET values of 1.5 mm and 6.5 mm.

The median total cuttings thickness for each of the five input simulations reaches the 6.5 mm PNET value at distances of 45 to 70 m from the wellsite and reaches a PNET value of 1.5 mm at 70 to 90 m away. These thresholds are reached nearer and faster with input PSDs that have higher compositions of coarser materials, and farther and later with the base case with no flocculation PSD. Considering the maximum thicknesses, the PNET value of 6.5 mm is reached from about 80 to 170 m away from the wellsite, in all five input scenarios, and the 1.5 mm threshold is largely reached at from about 140 to 200 m away. Overall, the PNET values of interest are reached faster with the Troll A Platform maximum PSD ('C') inputs given the greater composition of coarser materials, and reached latest with the Nedwed ('D') PSD with a larger percentage of slower settling particles.

For the two Bay du Nord base case simulations, just less than two thirds of the cuttings material settles within the 16-km model grid domain, most of this within 2 km. The remaining unsettled material includes the finer silts and clays with settling times of about two weeks or longer at a distance of almost 60 km or more (especially for the clays in the no flocculation input); these results are for a horizontal current input of 5 cm/s.

While the two base case simulations estimate about 3 to 5.8 percent material settling at the wellsite, the two Troll A Platform PSD simulations result in much greater material at the wellhead, on the order of 27 to 34 percent with the Nedwed simulation yielding a similar 32 percent. This is due to the much greater amount of larger SBM cuttings particles (medium sand and larger) which will settle out within several hours from release near the sea surface. Further indication of this mass of larger cuttings material is provided by the noticeably increased amount of material predicted to settle in the 2-23 km range. Over this distance interval, most of the unsettled material for either of the base case simulations will remain higher in the water column, while some of the larger SBM cuttings material will have had a chance to settle. Overall, with the Nedwed simulation just 1 percent of the cuttings material fails to settle within the 16 km model domain, while 14.4 and 7 percent of the two Troll A Platform sensitivity runs fail to settle. These three simulations therefore represent those for which the largest amounts of material are predicted to settle; however, the corresponding thicknesses over these distances (2-23 km) in these simulations are similarly small as with the two base case simulations.

Considering all five simulations, median (most likely) cuttings thicknesses are predicted to range from about 170 to 1,900 mm at the wellsite to 9 to 25 mm out to 100 m. Outside of 100 m, median thicknesses are less than 1 mm and beyond 1 km, values are generally less than 0.1 mm. Maximum thicknesses similarly drop rapidly after about 100 m. Considering all five simulations, maximum cuttings thicknesses are predicted to range from about 200 to 1,900 mm at the wellsite and to about 140 to 330 mm out to 100 m. From 100 to 200 m, maximum thicknesses range from 5 to 17 mm. Maximum thicknesses are 2 mm or less farther than 200 m away; the one exception is the no flocculation simulation with values of 5 to 7 mm.

In all five simulations, median cuttings thicknesses are on the order of 10 mm or greater within about 100 m of the wellsite and then generally rapidly fall to values of less than 1 mm. The one exception to this being the base case, no flocculation simulation (‘A’), where median thicknesses up to several millimetres are predicted up to about 2 km to the southwest.

The stochastic analysis yields the probability that the initial cuttings thickness at any given location will be greater than the PNET values of 1. 5 or 6.5 mm. While the base case with no flocculation (‘A’) simulation shows a greater than 5% probability of seeing above 1.5 mm within 500 m and out to just over 1 km to the southwest, the indication from the other four simulations is that the probability of exceeding 1.5 mm outside about 150 m is less than five percent. All simulations indicate the same general picture that the probability of exceeding 6.5 mm outside about 100 to 120 m is less than five percent.

Eight Well Drilling Simulations

Based on review of the one well dispersion results, two input scenarios were carried forward for the eight well simulation to further acknowledge some uncertainty for the predictions. On the assumption that flocculation of the smallest cuttings particles is more likely than no flocculation occurring, the base case with flocculation (‘0’) was selected as one input condition. Given that the three remaining input scenarios yield fairly similar predictions of the distribution of thickness with distance from the wellsite the Troll A Platform Average PSD (‘B’) input scenario was selected as being an appropriate second representative.

Predictions for drilling of eight wells, with either PSD input, indicate median total cuttings thicknesses outside of about 200 m or less from the wellsite do not exceed 5 mm. Outside of 200 m, median thicknesses for the base case with flocculation (‘0’) predictions do not exceed 1 mm, while for the Troll A Platform average PSD (‘B’) predictions patches of up to 1 mm extend 500 m to the southwest and 800 m, and in some places 1 km to the south-southwest. In the immediate vicinity of the wellsite, the initial thickness predictions, after over one year's drilling of eight wells, are over 1 m: for the base case with flocculation ('0') the estimated median thickness is about 2,600 mm, while for the Troll A Platform average PSD ('B') simulation it is about 11,700 mm.; however, slumping of these cuttings material will occur to reduce these values to more on the order of one or, for the Troll A Platform simulation, several metres. Further, this does not consider the weathering of these larger cuttings piles over the long drilling period for eight wells. In this way, the predictions presented for the eight well simulations are quite conservative. The main observation is that a considerable amount of cuttings material is predicted, over the course of the drilling period, to initially settle in the immediate vicinity of the wellhead template.

The median total cuttings thicknesses are predicted to reach the 6.5 mm PNET at distances of about 90 to 100 m (i.e., thicknesses are greater than 6.5 mm at closer distances) and reach the 1.5 mm PNET shortly after at about 120 m. The maximum predicted thicknesses first reach the 6.5 mm PNET at distances of about 120 to 140 m (Troll A Platform and base case, respectively) and reach the 1.5 mm PNET shortly after at about 200 m.

The stochastic analysis yields the probability that the initial cuttings thickness at any given location will be greater than the PNET values of 1. 5 or 6.5 mm. Both input scenarios considered for the eight well simulation, base case with flocculation ('0') and Troll A Platform average PSD ('B'), indicate a greater than 15 percent probability of seeing cutting thicknesses above 1.5 mm within about 180 to 200 m, with some potential, for the cuttings thicknesses to exceed 1.5 mm as far as 1 km; however, at less than a 15 percent probability of occurrence. Both input predictions show virtually identical predictions for the probability likelihoods for the 6.5 mm PNET, that there is a greater than 15 percent probability that cuttings thicknesses will be greater than 6.5 mm within about 100 to 120 m of the wellsite with no likelihood (based on the eight stochastic runs completed for a given eight well simulation) of exceeding 6.5 mm outside of that range.

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1.0 INTRODUCTION

Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited (Wood) has been contracted by Equinor Canada Ltd. (Equinor Canada) to complete drill cuttings dispersion modelling for the proposed Bay du Nord (BdN) Development Project (the Project), offshore eastern Newfoundland.

1.1 Background

Equinor Canada and its partner Husky Oil Operations Limited (Husky Energy) are proposing to develop the BdN field (which includes Bay du Nord, Bay de Verde and Bay de Verde East) and the Baccalieu discovery (collectively the Core BdN Development) offshore eastern Newfoundland for the production of oil and gas (Figure 1-1). The Project includes offshore construction, installation, hook-up and commissioning, production operations and maintenance, drilling and decommissioning activities, as well as supporting surveys, field work, supply and servicing activities. In addition to the Core BdN Development, the Project may also include potential future development activities. Hence, the Project includes the Core BdN Development and potential future development.

The Project includes the drilling, testing, and eventual decommissioning of wells within the Project Area, using one or more drilling installations. Over the course of the anticipated duration of the Core BdN Development, between 10 to 30 wells could be drilled, with specific wellsite locations being selected as planning and design activities progress. Up to 20 additional development wells may be drilled if potential future development activities occur. Additional details of the Project are contained in Chapter 2 of the Environmental Impact Statement (EIS).

Drill muds used for drilling operations are likely to be a combination of water-based muds (WBM) and synthetic-based muds (SBM). WBM are used for the initial sections of the well before the riser is installed. WBM and cuttings are discharged at the seabed in accordance with the, Offshore Waste Treatment Guidelines (OWTG) (NEB et al 2010). SBM are used for the deeper sections of the well after the riser is installed. Drill mud and cuttings are then returned to the drilling installation in a closed loop system, where the drilling fluids and cuttings are separated; the cuttings are treated prior to discharge overboard and the drilling fluids are recycled for reuse.

Drill cuttings are the small pieces of rock, ranging in size from coarse sand to fine silts and clays, created when a drill bit penetrates rock. The material is forced up the annulus of the well hole as drilling proceeds. The composition of the drill cuttings is dependent on the stratigraphy of the area, the type of drill bit used, the type of drilling mud used and the nature of the cuttings treatment applied prior to discharge to the ocean. The drill cuttings composition along with the water depth the released cuttings materials will settle over and ocean current determine the deposition of the cuttings on the seabed.

A numerical computer model, developed by Wood, employs a transport computation to simulate the advection of dispersed drill cuttings materials in three dimensions through the water column, following release into the sea, until the particles come to rest on the sea bottom. Key inputs for the model include cuttings volumes, release locations (e.g., at the seabed or from the drilling rig, near the sea surface) and rates of discharge, particle size distributions (or characterizations) (PSD) and ocean currents. The primary outputs are predictions of the deposition pattern of released drill cuttings on the seabed (e.g., weight, density, thickness of cuttings).

1.2 Objectives

The objective of this study is to model drill cuttings release associated with drilling activities for the Project. The modelling results support the Project Environmental Impact Assessment (EIS).

The Project will involve the drilling of multiple wells, e.g., up to 36 wells in the Code BdN Development, with a combination of production and injection wells. Wells will either be drilled using templates (multiple wells drilled in one location) or at individual well locations. Two modelling simulations are considered for drilling of one well and for drilling of eight wells. Modelling of drill cuttings release from drilling of one well provides a 'representative' unit prediction of cuttings dispersion. Given that (four- and eight-slot) template drilling is anticipated for the multiple wells, a simulation with eight wells models the anticipated largest drill cuttings release for a single location.

A modelling location within the Core BdN Development Area was chosen as more information is known for drilling activities associated with the Core BdN Development. Should future development drilling activities occur, additional modelling may be required depending on the location. One drilling location is considered as representative, as the water depths in the Core BdN Development Area are relatively flat, ranging from approximately 1,000 to 1,200 m. The model location (Site 1) is located within the NAFO Fisheries Closure Area and is representative of drilling in this Special Area (see Chapter 12 of the EIS).

With the potential to drill at any time during the year, stochastic simulations are employed that consider ocean current conditions over an entire year. Results presented include cuttings footprints and statistics on percent of material settled and median and maximum cuttings thicknesses.

This report presents details of the model inputs (Section 2.0), methods (Section 2.0), outputs (Section 4.0) and results (Section 5.0).

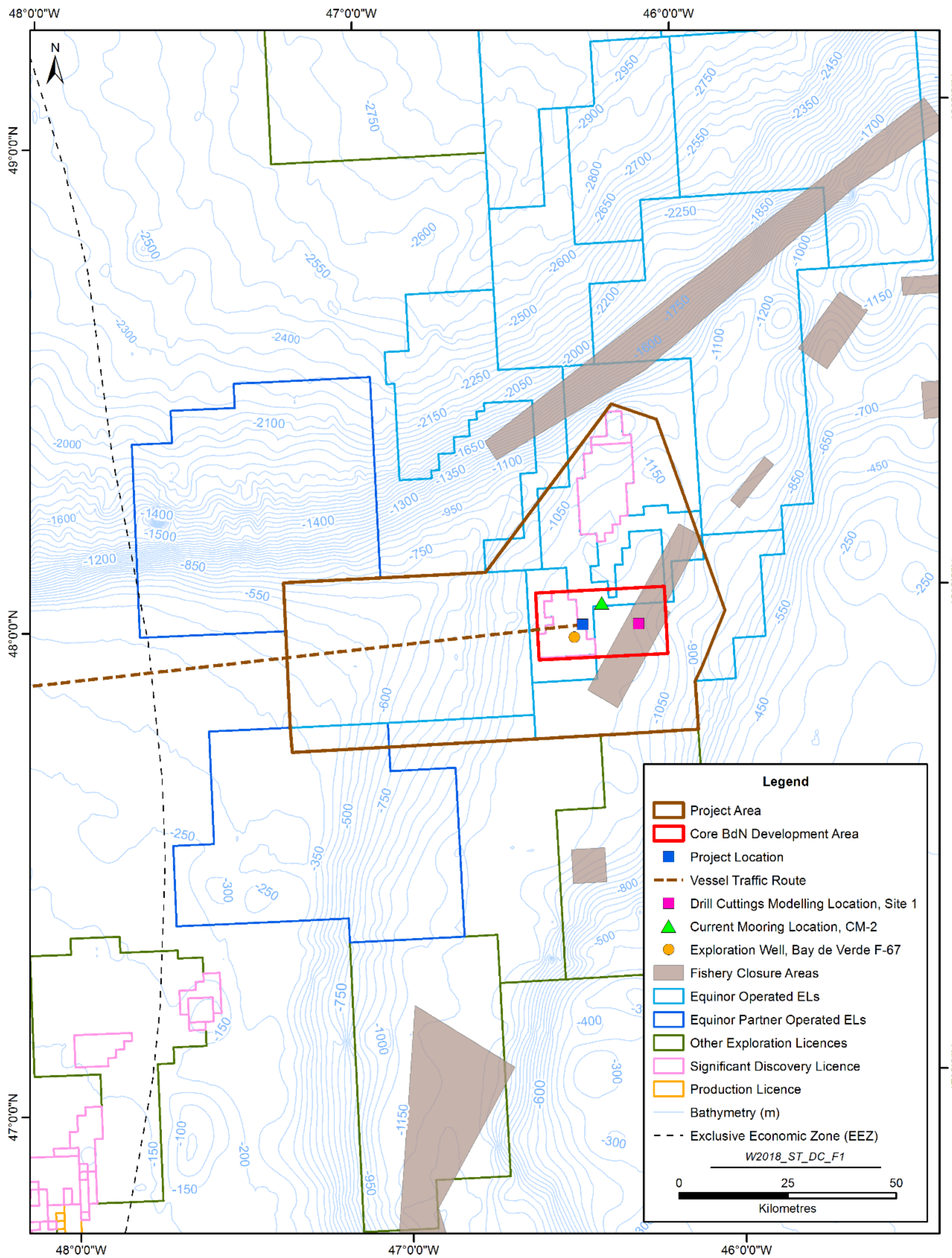

Figure 1-1 Project Area, Drill Cuttings Modelling and Current Mooring Location

2.0 MODEL METHOD

2.1 Advection-Diffusion Algorithm

The analysis of drill cuttings discharges is accomplished using the AMEC (now Wood) Advection Dispersion Model (ADM). The ADM is an advection-diffusion numerical computer model where the dispersion of cuttings released from a single point is governed by advection and turbulent diffusion in the horizontal and vertical planes. The ADM was developed based on corporate experience and modelling algorithms including those from the Terra Nova (Hodgins and Hodgins 1998) and White Rose (Hodgins and Hodgins 2000) cuttings fate modelling studies, and has been used for numerous offshore operators including the Hebron Project Comprehensive Study Report modelling study (AMEC 2010) and Hebron Project Environmental Assessment Amendment (Amec Foster Wheeler 2017a), and the White Rose Extension Project (now West White Rose Project) (AMEC 2012, Amec Foster Wheeler 2016).

In the model, the governing transport-diffusion equation is solved using a particle tracing technique. Sets of discrete cuttings particles are released over time with each particle having an associated mass. A transport computation is employed to simulate the advection of the dispersed drill cuttings materials in three dimensions through the water column following release into the sea, until the particles come to rest on the sea bottom. For the purposes of predicting their physical deposition on the seabed, the cuttings are considered as a composition of particle types or sizes, typically sand, silt and clay. These particle sizes are assumed to be generally representative of the materials likely to be encountered in the area and generated using water-based muds (WBM) or synthetic-based muds (SBM).

At any given time, a cuttings particle is assumed to be subject to independent displacing forces due to the ocean current and to a settling velocity that is constant for a given particle type. A term to model turbulent diffusion is added to the total change in position (displacement). For each time step the displacements are calculated and added to yield a new particle position. Vector additions are computed over each successive time step until the simulation terminates with deposition on the sea bottom (which may be some time after well drilling has terminated).

A model grid is used to encompass the drilling area and possible domain for the deposition of the cuttings. The model tracks the fate and deposition of the particles. In addition to each particle's path, the weight of material is tracked. This is the primary particle attribute. After completion of a model run, when all particles have settled, or have reached the model grid boundaries (in which case, they are taken to have drifted outside the domain and are tabulated as 'lost'), each particle is binned in one of the model grid cells and the total weight and thickness of materials are calculated for each grid cell. These spatial cuttings thickness footprints are the primary model output.

The transport (and spatial extent) and fate of the cuttings are modelled as a function of time. A given sequence of wells, with each well employing a schedule of drilling with associated cuttings release, is employed to simulate the release as a function of time (days). For each day for which materials are released, and for each different size class of material of an assumed particle size distribution (PSD), i.e., the coarse sand to silt and clay in the PSD in Section 3.2 tables, a collection of particles are discharged. Particles are assigned a weight apportioned on the number of days of drilling discharge and the volume of cuttings associated with the particular well section (i.e., Table 3-2). A time step is assigned appropriate for the geographic scale and model grid of the study area and the ambient current conditions. It is also necessary to choose time steps appropriate for each of the different particle types which exhibit a range of settling velocities. At each time step in the model (Table 2-1), a new location for a given particle is calculated.

Table 2-1: Model Time Steps for Cuttings Particles

Cuttings Particle Class	6 COARSE SAND	5 MEDIUM SAND	4 FINE SAND	3 V. FINE SAND	2 COARSE-MEDIUM SILT	1 FINE SILTS-CLAYS
Particle Parameter						
Time Step, Δt (s)	20	20	40	60	600	600
# Particles per Δt	1	1	2	3	30	30
# Steps per day	4,320	4,320	2,160	1,440	144	144

The path of each cuttings particle released is tracked by calculating at each new time step, n+1, its position (x,y,z) based on its position at the previous time step, n, as given by equations (1) to (3).

$$x_{n+1} = x_n + u \times \Delta t + x' \times Rx \quad (1)$$

$$y_{n+1} = y_n + v \times \Delta t + y' \times Ry \quad (2)$$

$$z_{n+1} = z_n + w \times \Delta t + z' \times Rz \quad (3)$$

where

- x = the particle position in the east-west horizontal distance (m)
- y = the particle position in the north-south horizontal distance (m)
- z = the particle position, or depth, in the vertical distance (m) (depth positive downwards)
- u = east-west component of the ocean current (m/s)
- v = north-south component of the ocean current (m/s)
- Δt = time step for the given particle type (s)
- w = settling velocity for the given particle type (m/s), e.g., Table 3-7, Table 3-10, Table 3-12
- Rx, Ry, Rz= random numbers in the range [-1,1]

and where the x′×Rx terms, and similarly for y and z, are included to simulate an element of turbulence in the current drift of the particles. The turbulent part of the flow field arises from subgrid scale motions that are not resolved in the tidal+non-tidal current data and lead to a random diffusion of particles within the grid. For a particle which moves a distance that is a uniformly distributed random displacement (hence R in [-1,1]) in the range (-x′, …, x′) in time step Δt its solution of the diffusion equation gives x′,y′=(6AhΔtp)1/2, with Ah a turbulent eddy diffusivity coefficient set=0.1 m^2/s. The model integration time step Δt depends on settling velocity. Values for x′ for coarse sand to fine silts and clays range from 6 m to 46.5 m. For example, at any time for a coarse particle, the x′Rx term might range from -6 m to 6 m. Grid cell sizes simply determine where particles are within the grid, and for example, in which grid cell they are placed when they reach the seabed but have no effect on the diffusion. There is a similar treatment for y′Ry. The z′ component is a uniformly distributed random displacement in the vertical, in the range $\pm 0.05 * w * \Delta t$, i.e., an uncertainty of $\pm$5% in the distance fallen each time step.

A grid of the seabed is used in the model to track the spatial extent of the cuttings depositions. The model grid is a Cartesian grid of size 2000x2000 centred at the drill cuttings scenario location (i.e., at the wellhead) and extending out a finite distance both in X (or East-West) and Y (or North-South) directions. A grid cell size of 16 m provides coverage out to 16 km (i.e., a 16-km radius). The model assumes a uniform water depth of 1,170 m.

The following parameters are calculated for each grid cell, with cuttings thickness, T, being of primary interest.

$$C = W \times 1000 / A \qquad (4)$$

$$T = C / \gamma \qquad (5)$$

$$OC = OCinitial \times W / (A \times h \times (1-n) \times \gamma s) \qquad (6)$$

where

- W = cuttings (dry) weight (kg)
- C = cuttings density (g/m^2)
- T = cuttings thickness (mm)
- OC = oil concentration on cuttings (mg/kg)
- A = area of one grid cell (m^2)
- γ = in situ bulk density (1,850 kg/m^3)
- OCinitial = initial oil concentration
- h = sediment mixing depth (0.08 m)
- n = seabed porosity (0.4)
- γs = specific weight of cuttings (3,112 kg/m^3 for WBM cuttings; 2,596 kg/m^3 for SBM cuttings)

The approach for calculating T and OC follows that employed by Hodgins and Hodgins (2000). The oil concentration on cuttings (OC), is the weight of material times its initial concentration, divided by the volume of an assumed thin benthic layer in which the cuttings are assumed to settle and mix with the seabed sediments. Oil concentration is only applicable where SBM are discharged during drilling. All cuttings are assumed to be adequately treated to reclaim oil as required by present regulations. Oil content on cuttings produced during drilling with SBM, OCinitial is set to 7.4 g / 100 g, equal to 6.9 g / 100 g oil on wet solids, as per the OWTG (NEB et al. 2010).

2.2 Deterministic and Stochastic Analyses

The basic ADM model simulation run is of a deterministic nature in the sense that ocean current measurements or hindcasts are used. For example, with a current speed and direction time series record a cuttings discharge scenario for a well drilled on a given date draws on the corresponding historical current time series record as the simulation proceeds in time. The outcome is the same each time the simulation is run.

To gain statistical significance in the interpretation of the model output predictions, numerous deterministic simulations, i.e., individual runs of ADM, are used. These cover a greater range of input conditions, e.g., as in a Monte Carlo approach. The result is termed a stochastic or 'probabilistic' simulation. In this way, a large number of separate simulations, each for the same assumed drilling program (i.e., amount of drill cuttings material released from all well hole sections) are completed with the differences being the currents of the receiving ocean, that serve as a primary model input are selected at random from the ocean current profile time series record(s).

For the modelling for the drilling of one well simulation 53 deterministic model runs are included. Each run starts seven days apart, i.e., run 1 start on 1 January, run 2 starts on 8 January, run 3 starts on 15 January, … , run 53 starts on 31 December. Each run releases the same amount of drill cuttings over the same length of time (see Section 3.1); however, the ocean currents used as input to the model are different, offset by seven days corresponding to each new start date (i.e., 1 Jan, 8 Jan, … 31 Dec). In this way, the inherent annual variation in ocean currents is considered. One year of currents as described in Section 3.3 is used. The set of 53 separate cuttings footprint grids – one from each of the 53 runs - are then post-processed to yield one grid of the cuttings statistics as described below with values calculated over all grid cells that recorded any deposition.

To assist in the assessment of potential biological effects of drill cuttings deposition, predicted no effect threshold (PNET) values, are also calculated by the post processing associated with the stochastic analysis of deterministic runs.

Previous studies indicate that sedimentation and burial effects from drill muds and cuttings on benthic invertebrates have mainly been localized to the vicinity of a drill cuttings pile area (Neff et al 2000; Holdway 2002; Schaanning et al 2008; Trannum et al 2010; Gates and Jones 2012; Larsson et al 2013; Cordes et al 2016; Tait et al 2016). An average burial depth threshold of 6.3 mm is considered to be the predicted no effect threshold (PNET) for non-toxic sedimentation based on benthic invertebrate species tolerances to burial, oxygen depletion and change in sediment grain size (Kjeilen-Eilertsen et al 2004; Smit et al 2006; 2008). However, as some species may be more susceptible to shallower burial depths, an average PNET burial depth of 1.5 mm is suggested to be a more conservative approach to assessing drilling discharges (Kjeilen-Eilertsen et al 2004). Burial effects on invertebrates are also predicted to occur between depositions at 1.5 mm to 6.5 mm sediment thickness, as evidenced by damage to *L. pertusa* coral observed with deposited drill cuttings of 6.5 mm (Larsson and Purser 2011) and reduced sediment reworking by invertebrates occurring with deposition of WBM drill cuttings of 2.5 mm (Trannum 2017). Given that species may be susceptible to different thresholds, both the 1.5 and 6.5 mm thresholds are considered in this study.

The stochastic analysis post processing calculates thickness and probability values as follows for each model grid cell.

Thicknesses

Values of the P25, P50 (median), P75, P95 and P100 (maximum) thicknesses as well as count of the number of non-zero thickness values are calculated. The Pj values are the thicknesses, such that j percent of the simulations with thicknesses > 0 mm in a location have thicknesses below this value; (100-j) percent have thicknesses above this value. For example, P25 is the value such that 25 percent of all model runs with cuttings thickness >0 mm in a location (grid cell) have thicknesses below this value, while 75 percent of the model runs have thicknesses above P25. A P25 value of 1 mm means that 25 percent of the time the thickness will be less than 1 mm and the other 75 percent of the time the thickness will be greater than 1 mm. P50 is equal to the median, the value for which half of the simulations with thicknesses > 0 mm have thicknesses below this value and half have thicknesses above this value. The P95 value is the value such that (just) five percent of the model runs have a thickness greater than this value. A P100 value corresponds to the maximum.

Probabilities

The probability that thickness is above 1.5 mm or 6.5 mm, abbreviated to Pr1.5 and Pr6.5 is calculated for every model grid cell location. The values of 1.5 mm and 6.5 mm are selected in line with introduction of the PNET above. For example, at a given location, a value of Pr1.5 equal to 11% at a given location indicates that in about 6 of the 53 (11.3%) simulations the thickness exceeded 1.5 mm. For example, plotting of the Pr1.5 value over the entire model grid results in the probability distribution of total cuttings thicknesses exceeding 1.5 mm. For any particular probability value of interest, e.g., five percent, the distribution plot for which 1.5 mm is exceed five percent of the time or greater can be seen. With the longer drilling program duration on the order of 395 days for the eight well model simulation (Section 3.1), a total of eight deterministic simulations was chosen, with each start date 45 days apart in the calendar year. In this way the annual variation in currents is incorporated. Given the reduction in the number of individual deterministic runs available for the stochastic analysis – eight runs as opposed to 53 runs for one well - the lowest probability level that can be readily calculated is 12.5 percent corresponding to 1 of 8 deterministic runs. This is reported as a probability level of 15 percent in the PNET figures in Section 5.2.5. This is 'low likelihood' level is slightly greater than that one would associated with five percent similarly used for the one well stochastic analysis results; however, with the annual variation in currents better incorporated in the longer duration eight well runs, the confidence levels are likely similar.

2.3 Assumptions

The following model inputs are estimates for the BdN project:

- cuttings volumes
- release location (near seabed and near sea surface)
- discharge schedule
- particle characterization (i.e., percentage of sands and fines)

Additional assumptions include:

- cuttings enter the sea in a relatively disaggregated form with sand materials remaining disaggregated in their fall to the seabed. The presence or absence of flocculation of cuttings fines is considered through of several input sensitivity simulations (Section 3.2).
- ocean currents are assembled based on nearest available measurements, from the CM-2 current mooring measurements, and are assumed representative of conditions at and near the drilling location. Modelled predictions from the DFO WebDrogue Canadian East Coast Ocean Model (CECOM) model (DFO 2015a) and WebTide tidal prediction model (DFO 2015b)) and the gridded hindcast HYbrid Coordinate Ocean Model (HYCOM) (HYCOM 2018)) data set presented for comparison to justify this assumption (Section 3.3.1).
- the dispersion model does not consider processes at the benthic boundary layer. This could include resuspension of cuttings with the potential for sediment mobilization based on current speed, e.g., clays and fines potentially mobilizing at lower current speeds, sands requiring higher speeds to move. Breakup of flocculates might be expected to reduce near-bottom concentrations, i.e., particles resuspend and are advected away by the ambient currents. Bioturbation is another process and difficult to quantify for the intensity and rate of reworking that might take place at any of the locations. These post-depositional processes are difficult to model and data are scarce. The implications of not modelling these processes can result in over-prediction of benthic impacts (IOGP 2016); predicted thicknesses are likely conservative in the sense that subsequent resuspension and further transport would likely render the thicknesses smaller.

3.0 MODEL SIMULATION INPUTS

This section presents a summary of key elements of the drilling program considered in modelling of the release of drill cuttings to the sea: drill cuttings modelling location, drill cuttings volumes and drilling schedule (Section 3.1), characterization of the drill cuttings material needed as input for the ADM cuttings dispersion model (Section 3.2) and description of the ocean currents also required for model input (Section 3.3).

3.1 Drilling Cuttings Modelling Location, Volumes and Drilling Schedule

The modelling location in the Core BdN Development Area, "Site 1" is shown in Figure 1-1 and listed in Table 3-1.

Table 3-1: Drill Cuttings Modelling Location

Location	Latitude (N)	Longitude (W)	Water Depth (m)
Site 1	47° 57' 31.8"	46° 12' 40.9"	1,170

The modelling of cuttings dispersion from drilling of both a single well and drilling of eight wells with template is considered in this study.

Estimated drill cuttings volumes (per one well and per eight wells with template) together with release locations – the point at which cuttings material is modelled to enter the sea - are presented in Table 3-2. For the BdN Project, well design is ongoing, with various options under considerations. A well design with maximum associated drill cuttings is selected for the cuttings modelling. One well yields approximately 898 m^3 of drill cuttings material comprised of 518 m^3 WBM (and barite) cuttings and 380 m^3 SBM cuttings.

Given that (four- and eight-slot) template drilling is anticipated for multiple wells, the modelling also considers the release of cuttings from eight wells, as a maximum cuttings release simulation. For each well for the eight well template drilling the WBM cuttings volumes are the same as a single well, while a single intermediate section yields 96 m^3 of SBM cuttings and a reservoir section yields 87 m^3 of SBM cuttings volume. As a result, completion of eight wells yields 5,608 m^3 of cuttings, or an average of 701 m^3 per well (Table 3-5). Release locations are assumed the same for both one well and eight wells.

Table 3-2: Drill Cuttings Volumes per Well, One Well

Well Hole Section	Hole Size	Depth (m) (MD MSL) [1]	Cuttings Volume (m^3) [2]	Release Location
	One Well			
Conductor	**42" (1067 mm)**	1,245	118	Seabed [3]
Surface	**26" (660 mm)**	1,905	400	Seabed [3]
Intermediate 1	**17.5" (445 mm)**	3,485	270	Subsea [4]
Intermediate 2	**12.25" (311 mm)**	4,204	60	Subsea [4]
Reservoir or Production	**8.5" (216 mm)**	4,721	50	Subsea [4]
Total WBM cuttings			518	
Total SBM cuttings			380	
Total cuttings			898	

1. MD is measured depth, datum MSL is mean sea level
2. Cuttings volumes include a washout factor which varies with the formation and section: WBM mud has a higher outwash factor than SBM, and typical range is 10 or 20%.
3. WBM cuttings from conductor and surface sections are released estimated at 0.2 m above the seabed assuming a Cuttings Treatment System (CTS) employed with 10" (0.25 m) outlet hose resting on the seabed, both for single well and for template drilling. WBM cuttings includes 167 $m^3$of barite, apportioned between the 42" and 26" sections: about 38 and 129 m^3 respectively. Specific weight for drill cuttings is assumed to be 2,596 kg/m^3 and for barite 4,198 kg/m^3.
4. SBM (Paradril-IA LV) cuttings from intermediate and reservoir sections are released from the MODU at an estimated 14 m below the sea surface.

Table 3-3: Drill Cuttings Volumes per Well, Eight Wells

Well Hole Section	Hole Size	Depth (m) (MD MSL) [1]	Cuttings Volume (m^3) [2]	Release Location
Conductor	**42" (1067 mm)**	1,245	118	Seabed [3]
Surface	**26" (660 mm)**	1,905	400	Seabed [3]
Intermediate	**17.5" (445 mm)**	3,485	96	Subsea [4]
Reservoir or Production	**8.5" (216 mm)**	4,721	87	Subsea [4]
Total WBM cuttings			518	
Total SBM cuttings			183	
Total cuttings			701	

1. MD is measured depth, datum MSL is mean sea level
2. Cuttings volumes include a washout factor which varies with the formation and section: WBM mud has a higher outwash factor than SBM, and typical range is 10 or 20%.
3. WBM cuttings from conductor and surface sections are released estimated at 0.2 m above the seabed assuming a Cuttings Treatment System (CTS) employed with 10" (0.25 m) outlet hose resting on the seabed, both for single well and for template drilling. WBM cuttings includes 167 $m^3$of barite, apportioned between the 42" and 26" sections: about 38 and 129 m^3 respectively. Specific weight for drill cuttings is assumed to be 2,596 kg/m^3 and for barite 4,198 kg/m^3.
4. SBM (Paradril-IA LV) cuttings from intermediate and reservoir sections are released from the MODU at an estimated 14 m below the sea surface.

A drilling discharge schedule is established for the modelling to simulate over what periods of time the cuttings are released to the sea. While detailed well drilling schedules for the Project have not been finalized, discharge schedules have been estimated as presented in Table 3-4 and Table 3-5 for one and eight well drilling. Drilling times for drilling of one well are estimated at 45 to 85 days of one well, and up to 395 days for the eight well drilling. The essential information for the model simulation is the number of days over which the cuttings from each well hole section are modelled to be released to the sea. This is presented in Table 3-4 and Table 3-5 for one well and eight well (template) drilling. As each activity is completed, cuttings for that section are released to the sea, e.g., in Table 3-4, for drilling of the surface section, cuttings are released over a period of three days; drilling from two intermediate sections is simulated to occur over a total of 10 (6+4) days. The cuttings are therefore released over a total of 20 days during which time the ocean currents will vary (Section 2.1, equations 1 to 3).

Table 3-4: Drill Cuttings Discharge Schedule, 1 well

Activity	# Days Discharge	Total # Days Cuttings Discharge
Conductor: drilling	2	2
Surface: drilling	3	5
Intermediate 1: drilling	6	11
Intermediate 2: drilling	4	15
Reservoir: drilling	5	20

Table 3-5: Drill Cuttings Discharge Schedule, 8 wells

Activity	# Days Discharge	Total # Days Cuttings Discharge
Conductor drilling (1)	2	2
Surface drilling (1)	5	7
Conductor drilling (2)	2	9
Surface drilling (2)	5	14
Conductor drilling (3)	2	16
Surface drilling (3)	5	21
Conductor drilling (4)	2	23
Surface drilling (4)	5	28
Conductor drilling (5)	2	30
Surface drilling (5)	5	35
Conductor drilling (6)	2	37
Surface drilling (6)	5	42
Conductor drilling (7)	2	44
Surface drilling (7)	5	49
Conductor drilling (8)	2	51
Surface drilling (8)	5	56
Intermediate drilling (8)	6	62
Reservoir drilling (8)	8	70
Intermediate drilling (7)	6	76
Reservoir drilling (7)	8	84
Intermediate drilling (6)	6	90
Reservoir drilling (6)	8	98
Intermediate drilling (5)	6	104
Reservoir drilling (5)	8	112
Intermediate drilling (4)	6	118
Reservoir drilling (4)	8	126
Intermediate drilling (3)	6	132
Reservoir drilling (3)	8	140

Activity	# Days Discharge	Total # Days Cuttings Discharge
Intermediate drilling (2)	6	146
Reservoir drilling (2)	8	154
Intermediate drilling (1)	6	160
Reservoir drilling (1)	8	168

3.2 Drill Cuttings Particle Size Distribution

A particle size distribution (PSD) characterization of the drill cuttings released during the drilling program is required in the dispersion model (Section 2.1) in order to predict their settling in the ocean prior to being initially deposited on the seabed, or drifting outside the model geographical domain.

The actual compositions of the drill cuttings will depend on rate of penetration, rotary table speed, hydraulics, bit selection, geology of the well, and, for SBM cuttings, how the cuttings treated onboard the drilling installation (e.g., shale shakers, cuttings dryers, or centrifuges).

Base Case

The primary (or base case) estimate of cuttings particle size distribution is based on laser diffraction data by Weatherford Laboratories of cuttings samples, from the Bay de Verde F-67 well (F-67) in 2014, which is within the Core BdN Development Area (Figure 1-1). This location near Bay du Nord is at a water depth of about 1,200 m and about 15 km from the model location Site 1 (Figure 1-1). Cuttings samples from the F-67 well consist of two samples at lag depth 2,700 m and two samples at lag depth 3,300 m. These depths are representative of proposed BdN intermediate 2 and reservoir sections (Table 3-2), therefore, the mean of the upper two samples (2,700 m) are assumed to characterize the intermediate sections and the mean of the lower two samples (3,300 m) is assumed for the reservoir section. The intermediate section characterization is also assumed for the conductor and surface sections to be drilled with WBM. These are the same characterizations which were assumed for the drill cuttings dispersion modelling (Amec Foster Wheeler 2017b) as part of the Flemish Pass Exploration Drilling Program – Environmental Impact Statement, Appendix G (Statoil 2017).

With the inclusion of barite with the WBM cuttings (Table 3-2, note 3) a barite particle size distribution is incorporated. Estimates of barite PSD are taken from the North Sea, Troll A Platform well (Frost et al 2014).

The particle size distributions (PSD) are presented in Table 3-6 and list for each particle size class (from 6 to 1, range from coarse to fine), the particle diameter and measured weight percent material. For example, for the 'WBM cuttings, ADM 42" and 26" well sections table' entry) 8.9 percent (1.1+0.1+0.3+7.5) is assumed sand (coarse to very fine) with 91.9 percent assumed fine silts and clays.

Given the Troll A Platform barite particles PSD (Frost et al 2014) consists of nine particle size classes, a mapping of these nine to the six size classes employed in the ADM software was completed as is discussed below.

Table 3-6: Cuttings and Barite Particle Size Distribution, Bay du Nord Base Case

Cuttings Particle Classes	6 COARSE SAND	5 MEDIUM SAND	4 FINE SAND	3 V. FINE SAND	2 COARSE-MEDIUM SILT	1 FINE SILTS-CLAYS
Particle diameter (mm)	0.595	0.297	0.149	0.074	0.031	0.005
Estimated weight percent material (original data sources)						
Bay de Verde F-67 (2,700 m) cuttings particles	0.1	0.1	0.5	3.9	28.0	67.4
Bay de Verde F-67 (3,300 m) cuttings particles	1.5	0.9	2.5	5.9	19.0	70.2
Troll A Platform, Barite particles	3.1	0.0	0.0	15.0	44.0	38.0
Estimated weight percent material (applied in ADM)						
WBM cuttings, 42" and 26" well section [1]	1.1	0.1	0.3	7.5	33.2	57.9
SBM cuttings, 17.5", 12.25" well sections [2]	0.1	0.1	0.5	3.9	28.0	67.4
SBM cuttings, 8.5" well section [3]	1.5	0.9	2.5	5.9	19.0	70.2

1. The WBM cuttings 42" and 26" sections use the average of the Bay de Verde F-67 2,700 m PSD and the Troll A Platform barite particles PSD, weighted by the estimated amounts of WBM cuttings volume (351 m^3) and barite volume (167 m^3) (see Table 3-2), e.g., the estimated weight percent material for Class 3, 'V. Fine Sand' = (3.9x351)/(351+167) + (15.0x167)/(351+167)=7.5 percent
2. The SBM cuttings 17.5" and 12.25" intermediate sections assume the Bay de Verde F-67 2,700 m PSD
3. The SBM cuttings 8.5" reservoir section assumes the Bay de Verde F-67 3,300 m PSD

In addition to the percent compositions shown in Table 3-6, the associated particle settling velocities are also essential for the deposition modelling. It is assumed that the cuttings will enter the sea in a relatively disaggregated form. The model considers the sand materials will remain disaggregated in their fall to the seabed. Particle settling velocities, w, are estimated from the particle diameter using the following relationships, from Sleath (1984):

$$w = 4.2\sqrt{D},\ D > 0.0001\ m \qquad (7)$$

$$w = 92\ \times 10^4\ D^2, D \leq 0.0001\ m \qquad (8)$$

where

- w is the settling velocity in m/s and D is particle diameter in m.

There is a tendency for smaller particles to clump and form aggregate particles called flocs or aggregates. An increase in the flocculation process can result from the presence of drilling fluid chemicals which cause particles to become sticky and result in larger-sized particles with increased settling velocities. The fine sediments (silts and clays with size < 0.063 mm) tend to aggregate into flocs that settle with speeds on the order of 1 mm/s and this has been observed across a range of environments (e.g., Hill and McCave, 2001). In the absence of an in-field ocean monitoring program or laboratory studies of cuttings samples in sea water to measure settling velocities, two settling velocity characterizations are assumed for the base case cuttings PSD in an attempt to bracket the potential dispersion of the small silt- and clay-sized particles: one with flocculation assumed and one with no flocculation.

Table 3-7 lists, for each particle type, its diameter and associated predicted settling velocity. For the base case with flocculation simulation, designated as '0', the smaller class 2 and 1 particles (coarse-medium silt, fine silts-clays) are assumed to aggregate into flocs and settle with constant speeds of 0.002 and 0.001 m/s. These values are estimated following review of the work of Tedford et al. (2003) where approximations there considered a fast settling (of flocs) of 0.005 m/s assumed for early stages of discharge, followed by a slowing to 0.0001 m/s (for floc breakup when the bottom stress exceeds a threshold), and finally a larger settling of 0.001 m/s (when the bottom stress falls back below that threshold). For the base case (BC) with no flocculation simulation, designated as 'A', the settling velocities are those estimated with equations (4) and (5) with the result that the smaller class 2 and class 1 particles (coarse-medium silt, fine silts-clays) are assumed to settle with constant speeds of 0.001 and 0.00002 m/s. Assuming the class 1 particles settling at speeds two orders of magnitude smaller than the flocculation case results in much greater dispersion of these tiny particles.

Table 3-7: Cuttings Settling Velocity – Bay du Nord Base Case, with flocculation ('0'), no flocculation ('A')

Cuttings Particle Classes	6 COARSE SAND	5 MEDIUM SAND	4 FINE SAND	3 V. FINE SAND	2 COARSE-MEDIUM SILT	1 FINE SILTS-CLAYS
Particle diameter (mm)	0.595	0.297	0.149	0.074	0.031	0.005
Settling velocity (m/s) – base case with flocculation ('0')	0.102	0.072	0.051	0.005	0.002	0.001
Settling velocity (m/s) – base case - no flocculation ('A')	0.102	0.072	0.051	0.005	0.001	0.00002

Given that the (base case) cuttings PSD and settling velocities reported in Table 3-6 and Table 3-7 are estimates it was deemed appropriate to consider several additional characterizations, both in terms of PSD and the percent composition and cuttings settling velocities, as follows:

- Troll A Platform (designated as 'B' and 'C' for ADM model runs). PSD based on wells drilled on the Norwegian continental shelf as reported in Frost et al (2014). Cuttings distributions are provided for average and maximum PSD) and for barite particles.
- Nedwed (designated as 'D' for ADM model runs). General categories of cuttings are identified for WBM cuttings, WBM solids (bentonite and barite) and NAF (nonaqueous drilling fluid, i.e., SBM) cuttings (Nedwed, 2004). Cuttings distributions are provided for use in the absence of site-specific settling velocity data. For each of these three categories solids classes are used to characterize the material percent composition and settling velocities.

While six particle size or solids classes are available in the ADM model, each with an associated particle diameter, the Troll A Platform (Frost et al 2014) and Nedwed (2004) data report a greater number of solids classes, from 8 to 14. As described below, the Troll A Platform and Nedwed PSD were 'mapped' to six classes for implementation in ADM. Corresponding settling velocities for the Troll and Nedwed PSD to use in the model were estimated based on the particle diameters with equations (7) and (8).

Troll A Platform

The implementation of the Troll A Platform average PSD ('B') data set is presented in Table 3-8 and Figure 3-1. Six particle size or solids classes are implemented in ADM. The resolution of the Troll A Platform 'average PSD' data set consists of 14 classes (Frost et al 2014). The correspondence of solids class with particle diameter ranges and assumed particle diameter for use in the model is shown at the top of Table 3-8 which presents the six solids classes ranging from largest particle size class 6 'V. Coarse Sand' to smallest particle size class 1 'Fine Silts-Clays'. This class 6 has a larger particle diameter than that assumed for the '6 Coarse Sand' for the base case noted above since the Troll A Platform 'original' (Frost et al 2014) PSD covers these larger particle sizes.

Similarly, resolution of the Troll A Platform PSD for smaller particles is increased by replacing the base case PSD (Table 3-6) classes 1 to 3, which each represent a frequency fraction of 10 percent, with introduction of a new class 2 'Coarse Silt' which covers a particle diameter range of 0.06 to 0.09 mm. Given this diameter is larger than the smaller diameters of the Troll A Platform barite particles, e.g., 0.001 to 0.010 for classes 1 to 3, amounts of 10 percent were taken from classes 1 and 3 and added to this new class 2 resulting in a class 1:2:3 apportionment of 0:30:10 percent. In a similar manner 10 percent of the frequency fraction of original classes 4 to 6 that cover 0.11 to 0.40 mm were moved to class 3 to better align with the assumed particle diameters to be used in the model.

The resulting implementation for the Troll A Platform average PSD ('B') is illustrated in Figure 3-1 which shows the percent composition for each of the (original) 14 classes together with the resulting mapping (approximation) to the six classes for the model. For example, the original Troll A Platform particle settling velocities range from 0.0011 m/s for class 1 (at 10 percent composition) to 0.2485 m/s for class 6 (original class 14) (at 1 percent). The mapped PSD for model implementation, 'Average PSD (ADM)' shown in orange, has settling velocities which range from 0.0052 m/s for class 2 (at 30 percent composition) to 0.1485 m/s for class 6 (at 1 percent). These (orange) values are those reported in the Troll A Platform Average PSD row in Table 3-8.

With the addition of barite to the WBM cuttings discharge (Table 3-2, note 3) a similar mapping (approximation) of the nine (barite particles) solids classes from Troll A Platform to six for ADM was implemented as shown in Figure 3-2 and Figure 3-3. Figure 3-2 shows the percent composition for each of the (original) nine barite classes, in green, together with the resulting mapping (approximation) to the six classes for the model, in grey. For example, the original Troll A Platform barite PSD consisted of the range of 11 percent class 1 for particle diameter 0.001 to 0.002 mm (a mean value of 0.0015 mm is shown in the figure) to 1 percent class 9 for particle diameter 0.158 to 0.300 mm (a mean value of 0.229 mm is shown in the figure). With the resultant mapping to the six particle size classes established above for the Troll A Platform Average PSD (Table 3-8) amounts of barite particles (from the original Troll A Platform source, Frost et al 2014, Table 3) are distributed just to four of the solids classes, with no contribution to classes 4 and 5. Figure 3-3 shows the relationship between the Troll A Platform barite PSD derived settling velocities and particle diameters and corresponding values implemented in the ADM model.

To estimate the PSD for the 42" and 26" well sections (drilled with WBM), a weighted (by volume amount of WBM cuttings particles and added barite particles) average of the Troll A Platform Average PSD and Barite particles distributions was calculated: this is reported as row 'ADM 42" and 26" well sections' in Table 3-8. The resulting Troll A Platform, Average PSD in Table 3-8 is used in the model for the 17.5", 12.25", 8.5" well sections (drilled with SBM), e.g., 30 percent composition of coarse silt at an assumed particle diameter of 0.05 mm.

Table 3-8: Cuttings and Barite Particle Size Distribution – Troll A Platform, Average PSD ('B')

Cuttings Particle Classes	6 V. COARSE SAND	5 COARSE SAND	4 MEDIUM SAND	3 FINE SAND	2 COARSE SILT	1 FINE SILTS-CLAYS
Troll A Platform Particle Solids Class	11-14	7-10	4-6	3	2	1
Particle diameter range (mm)	1.0 - 4.0	0.4 – 1.0	0.11 – 0.40	0.09 - 0.11	0.06 – 0.09	0.01 – 0.06
Particle diameter (mm)	2.0	0.595	0.297	0.149	0.05	0.005
Estimated weight percent material (original data sources)						
Troll A Platform, Average PSD cuttings particles	9.0	31.0	20.0	10.0	30.0	0.0
Troll A Platform, Barite particles	0.0	3.0	0.0	0.0	59.0	38.0
Estimated weight percent material (applied in ADM)						
WBM cuttings, 42" and 26" well sections	6.1	22.0	13.5	6.8	39.3	12.3
SBM cuttings, 17.5", 12.25", 8.5" well sections	9.0	31.0	20.0	10.0	30.0	0.0

Source: SPE168328 (Frost et al 2014, Table 3)

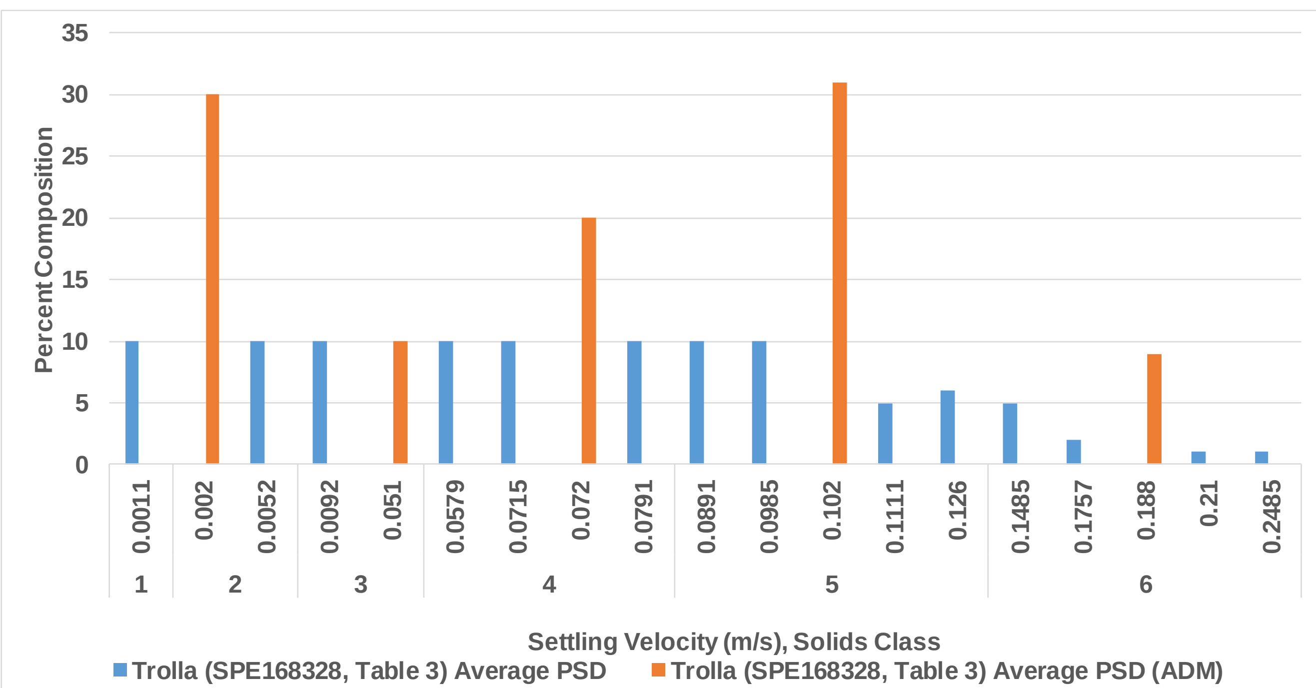

Figure 3-1 Cuttings PSD – Troll A Platform, Average PSD ('B'), Original and ADM

Figure 3-2 Barite PSD – Troll A Platform, Original and ADM

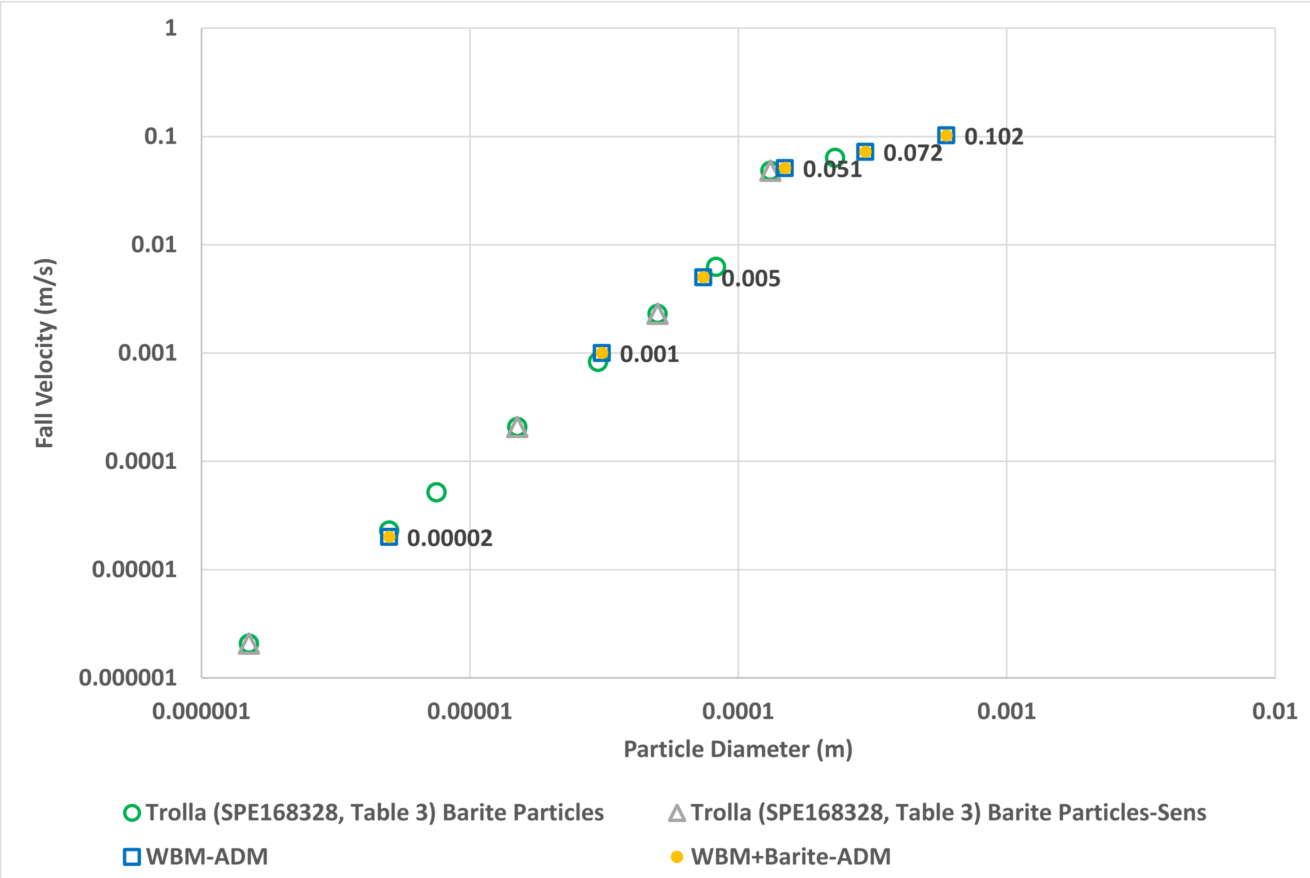

Figure 3-3 Barite Settling Velocity Distribution, Troll A Platform and ADM Implementation

The implementation of the Troll A Platform maximum PSD ('C') data set is presented in Table 3-9 and Figure 3-4. The resolution of the Troll A Platform 'maximum PSD' data set consists of 10 classes (Frost et al 2014). The correspondence of solids class with particle diameter ranges and assumed particle diameter for use in the model is shown at the top of Table 3-9 which presents the six solids classes ranging from largest particle size class 6 'V. Coarse Sand' to smallest particle size class 1 'Fine Silts-Clays' consistent with the classes defined above for the Troll A Platform average PSD ('B') PSD in Table 3-8. Note that while the particle diameter ranges are different here for the maximum PSD than presented for the average PSD, the same particle diameters are assumed for the six classes. The smallest of the Troll A Platform maximum PSD characterization, with size range 0.045 to 0.125 mm, is larger than the class 1 'Fine Silts-Clays' established for the Troll A Platform average and barite particles PSD of Table 3-8 and therefore there is no Troll A Platform maximum contribution in that class; however, class 1 is retained to accommodate the barite particles and their inclusion for the WBM cuttings characterization in the same manner as that employed previously.

The resulting implementation for the Troll A Platform maximum PSD ('C') is illustrated in Figure 3-4 which shows the percent composition for each of the (original) 10 classes together with the resulting mapping (approximation) to the six classes for the model.

For example, the original Troll A Platform maximum PSD particle settling velocities range from 0.0033 m/s for class 2 (original class 1), for particles in the range 0.045 to 0.125 mm (at 11.8 percent composition) to 0.46 m/s for class 6) (at 5.4 percent). The mapped PSD for model implementation, 'Maximum PSD (ADM)' shown in orange, has settling velocities which range from 0.002 m/s for class 2 (at 17.4 percent composition) to 0.188 m/s for class 6 (at 71.9 percent). These (orange) values are those reported in the Troll A Platform Maximum PSD row in Table 3-9.

Table 3-9: Cuttings and Barite Particle Size Distribution – Troll A Platform, Maximum PSD ('C')

Cuttings Particle Classes	6 V. COARSE SAND	5 COARSE SAND	4 MEDIUM SAND	3 FINE SAND	2 COARSE SILT	1 FINE SILTS-CLAYS
Troll A Platform Particle Solids Class	7-10	6	5	4	1-3	-
Particle diameter range (mm)	1.0 - 16.0	0.5 – 1.0	0.25 – 0.5	0.125 - 0.25	0.045 – 0.125	0.01 – 0.06
Particle diameter (mm)	2.0	0.595	0.297	0.149	0.05	0.005
Estimated Weight Percent Material (original data sources)						
Troll A Platform, Maximum PSD	71.9	7.3	2.0	1.4	17.4	0.0
Troll A Platform, Barite particles	0.0	3.0	0.0	0.0	59.0	38.0
Estimated weight percent material (applied in ADM)						
WBM cuttings, 42" and 26" well sections	48.7	5.9	1.3	1.0	30.8	12.3
17.5", 12.25", 8.5" well sections	71.9	7.3	2.0	1.4	17.4	0.0

Source: SPE168328 (Frost et al 2014, Table 3)

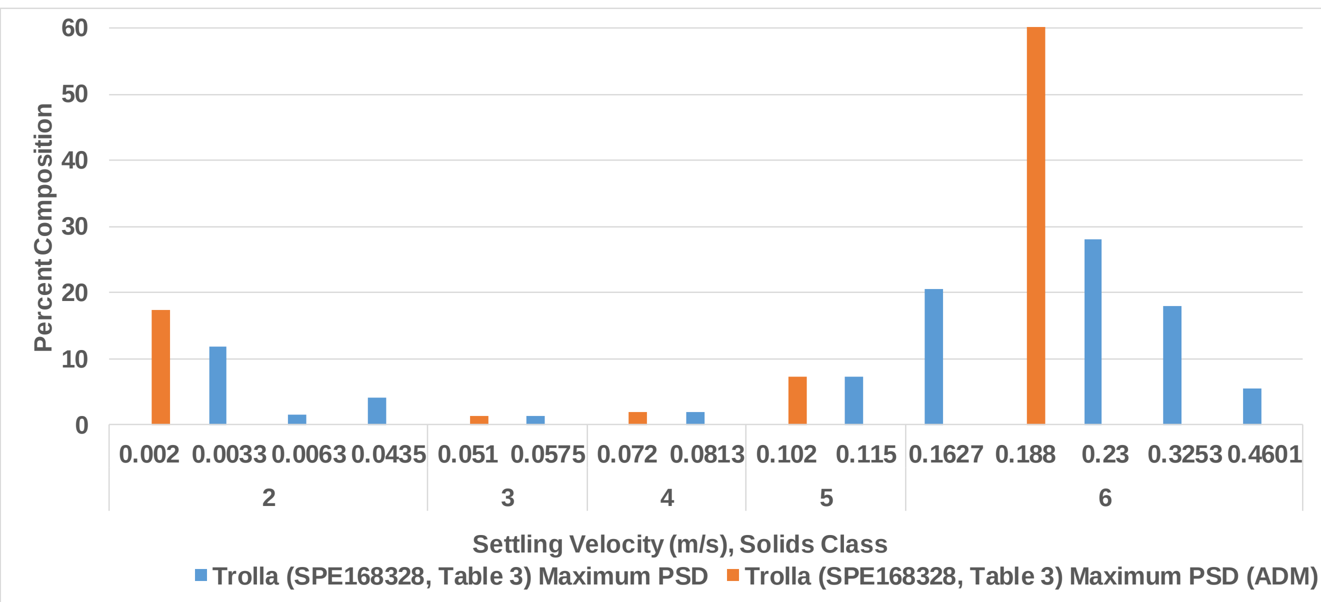

Figure 3-4 Cuttings PSD – Troll A Platform, Maximum PSD ('C'), Original and ADM

The Troll A Platform settling velocities are presented in Table 3-10, with the same values used for both average and maximum PSD characterizations. No flocculation is assumed for the (class 1) fine silts-clays.

Table 3-10: Cuttings Settling Velocity – Troll A Platform, Average and Maximum PSD ('B' and 'C')

ADM Particle Solids Class	6 V. COARSE SAND	5 COARSE SAND	4 MEDIUM SAND	3 FINE SAND	2 COARSE SILT	1 FINE SILTS-CLAYS
Assumed Particle diameter (mm)	2.0	0.595	0.297	0.149	0.05	0.005
Settling Velocity (m/s)	0.188	0.102	0.072	0.051	0.002	0.00002

Nedwed

A similar mapping of solids classes was applied for the Nedwed PSD data sets and is presented in Table 3-11. It is noted the classes are reported simply as 6 to 1 (larger to smaller particle size) with no size descriptors: it is the estimated weight percent material and associated settling velocities that are relevant for the ADM model implementation. The original (Nedwed 2004) solids classes included classes 1 to 9 for slower to faster *WBM cuttings*, and classes 1 to 10 and classes 1 to 8 for faster to slower (opposite to the WBM cuttings ordering) *WBM solids* and *NAF cuttings* (SBM) respectively. The corresponding settling velocities, as originally reported in Nedwed (2004) mapped to the six ADM model classes are presented in Table 3-12.

Table 3-11: Cuttings Particle Size Distribution – Nedwed ('D')

Cuttings Particle Classes	6	5	4	3	2	1
Estimated Weight Percent Material (original data source)						
Nedwed WBM Cuttings	25.0	31.0	20.0	3.0	7.0	14.0
Nedwed WBM Solids (barite particles)	0.0	0.0	1.0	56.0	28.0	15.0
Nedwed NAF Cuttings (SBM)	91.0	5.2	3.8	0.0	0.0	0.0
Estimated weight percent material (applied in ADM)						
WBM Cuttings, 42" and 26" well sections	16.9	21.0	13.9	20.1	13.8	14.3
SBM Cuttings, 17.5", 12.25", 8.5" well sections	91.0	5.2	3.8	0.0	0.0	0.0

Source: Nedwed, 2004, Tables 1, 4 and 2 for "WBM Cuttings", "WBM Solids (barite)" and "NAF Cuttings (SBM)"

Table 3-12: Cuttings Settling Velocity – Nedwed ('D')

	Cuttings Material, Solids Class					
	6	5	4	3	2	1
Settling Velocity (m/s)	0.2817	0.1333	0.0313	0.00165	0.000276	0.000017

3.3 Ocean Currents

Together with particle settling velocities, horizontal current is the other key factor in determining how far cuttings may disperse, so it is important to employ a good characterization of the local current behaviour as a driving force for the model. Since the cuttings will settle through the water column, a characterization of the currents as a function of water depth is required.

Having a good temporal coverage of the current data record, i.e., all months of the year, allows application of the drilling well sequences and provides some statistical reliability of conclusions drawn from analysis of the current data; i.e., that annual conditions are accounted for. The regularity of temporal resolution, i.e., time spacing between current values is essential due to the structure of the advection calculations in the model.

Ocean current measurements are available from a current mooring equipped with Acoustic Doppler Current Profiler (ADCP) and Recording Current Meter (RCM) instruments at location CM-2, in the northern Flemish Pass, about 10 km to the northwest of the drill cuttings modelling location (Figure 1-1). The CM-2 mooring was part of an Equinor met-ocean monitoring program from July 2014 to May 2016 in the northern Flemish Pass in a water depth of 1,120 m (Amec Foster Wheeler 2015).

A continuous, hourly, time series of currents for depths 23, 150, 794 and 1,156 m was assembled from the 2014-2016 measurement record to represent the current profile for this area. A description of the full 2014 to 2016 (with measurement gaps) CM-2 deployment is provided in Chapter 5 of the BdN EIS (Equinor 2018).

The model advects the cuttings particles using the currents from the depth bin corresponding to the depth the particles have settled to at each model time step, e.g.,

- 'surface-mid', 0 to 90 m: use 23 m bin
- 'mid-deep', 90 to 475 m: use 150 m bin
- 'deep-bottom', 475 to 980 m: use 794 m bin
- 'bottom', 980 m to bottom: use 1,156 m bin

Monthly and annual current statistics for the four selected depths are presented in Table 3-13. Mean, standard deviation and maximum current speeds, and the direction of maximum current speed and most frequent direction are reported. Monthly mean current speeds range from 12 cm/s in August to 29 cm/s in May near-surface at 23 m while near the seabed speeds are much-reduced, ranging from 4 cm/s in December to 12 cm/s in July at 1,156 m. Monthly maximum current speeds range from 44 cm/s in August to 91 cm/s in April near-surface at 23 m while near the seabed values range from 12 cm/s in December to 23 cm/s in September at 1,156 m.

Table 3-13: Monthly and Annual Current Statistics, CM-2 Northern Flemish Pass

Mean (cm/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
23 m	21	20	24	25	29	15	22	12	24	27	22	16	21
150 m	14	17	13	13	15	8	14	8	8	9	10	9	11
749 m	8	9	6	7	7	7	12	7	8	8	8	4	8
1,156 m	7	8	6	7	7	6	12	7	9	7	8	4	7

SD (cm/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
23 m	11	11	16	17	12	9	11	8	13	19	11	8	14
150 m	6	9	7	7	6	4	7	6	4	4	5	5	7
749 m	4	4	3	4	3	4	4	4	6	4	3	2	4
1,156 m	4	4	3	3	3	4	4	4	5	4	3	2	4

Maximum (cm/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
23 m	68	69	85	91	57	51	63	44	70	81	79	47	91
150 m	35	43	43	35	31	22	35	30	19	19	31	25	43
749 m	23	23	14	22	18	22	23	20	24	18	18	15	24
1,156 m	18	20	15	17	17	19	22	19	23	17	16	12	23

Direction of Max (deg to)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
23 m	159	172	156	228	150	147	267	198	27	266	186	257	228
150 m	201	254	129	178	175	113	158	167	42	176	209	196	129
749 m	176	186	274	231	198	147	236	37	211	211	196	215	211
1,156 m	153	231	153	271	134	191	190	173	207	181	176	178	207

Most Frequent Direction (to)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
23 m	SSE	S	S	E	S	ESE	WSW	SSW	NNE	SSW	S	WSW	S
150 m	SSW	SSW	SSW	NNE	S	ESE	SSW	SSW	NNE	SSW	SSW	WSW	SSW
749 m	SSW	SSW	WSW	SSE	SSW	SSW	SSW	SSW	WSW	SSW	SSW	SSW	SSW
1,156 m	S	SSW	WSW	S	SSW	SSW	SSW	SSW	WSW	S	S	SSW	SSW

As reported in Table 3-13 and illustrated in the annual current roses presented in Figure 3-5 the predominant annual current direction is to the south for the 23 m depth and to the south-southwest higher depths. While the south-southwest is the predominant direction for many depths and months, as illustrated in the monthly current roses in Figure 3-6 to Figure 3-9 currents are commonly experienced throughout the southwest and southeast quadrants in most months, while in September at the 23 and 150 m depths currents are predominantly to the northeast quadrant.

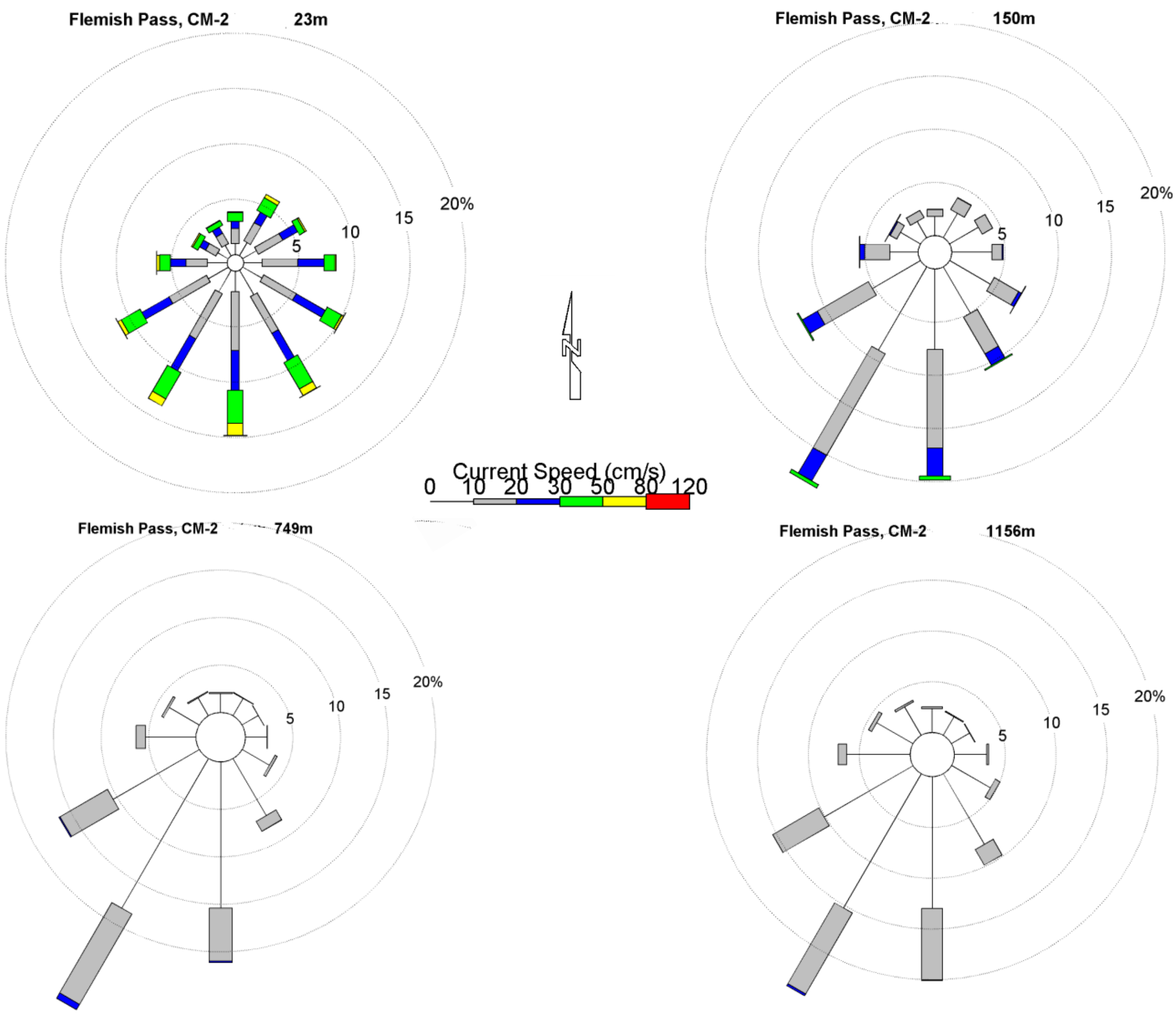

Figure 3-5 Annual Current Roses, CM-2 Northern Flemish Pass, 23, 150, 794, 1,156 m

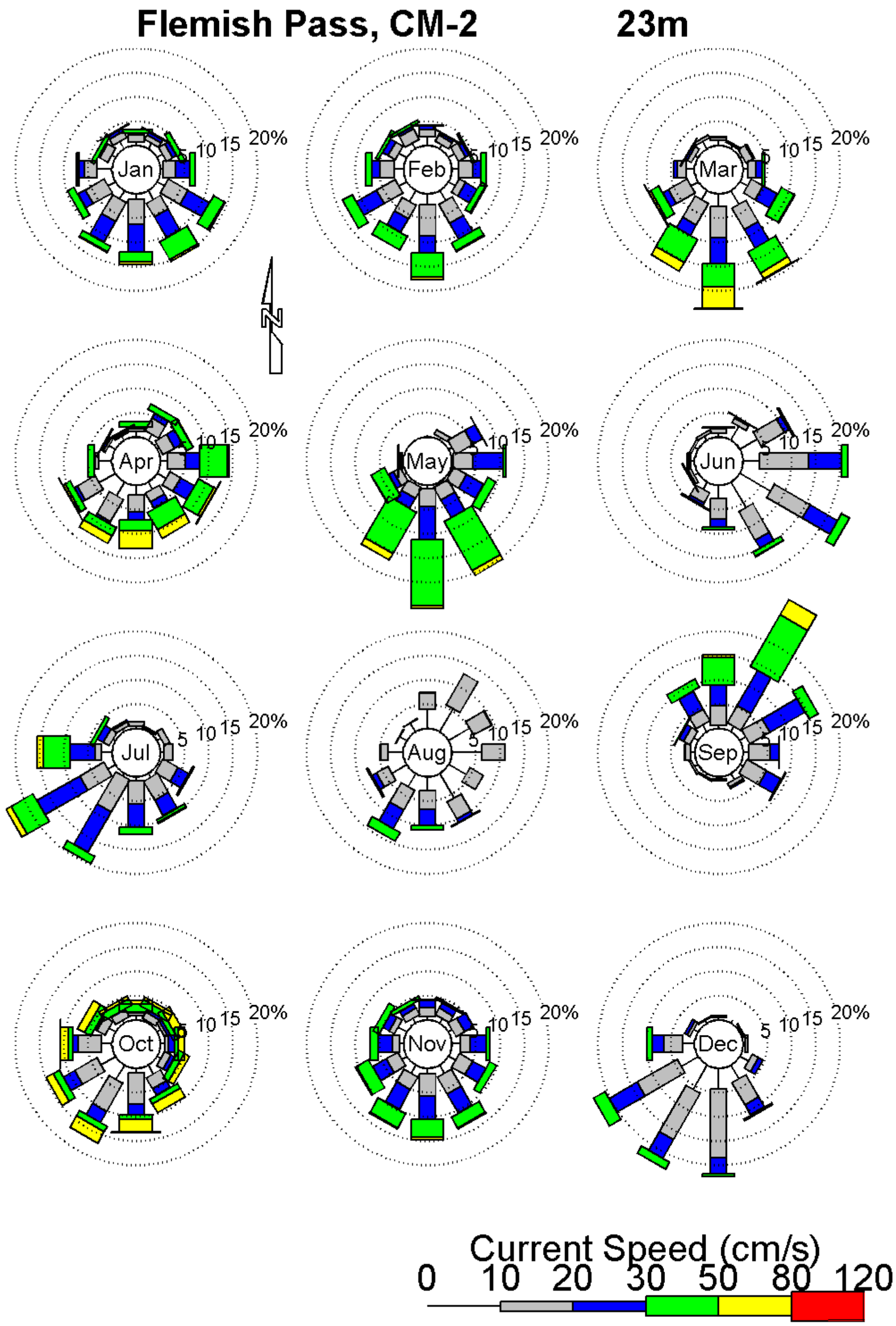

Figure 3-6 Monthly Current Roses, CM-2, Northern Flemish Pass, Near-Surface, 23 m

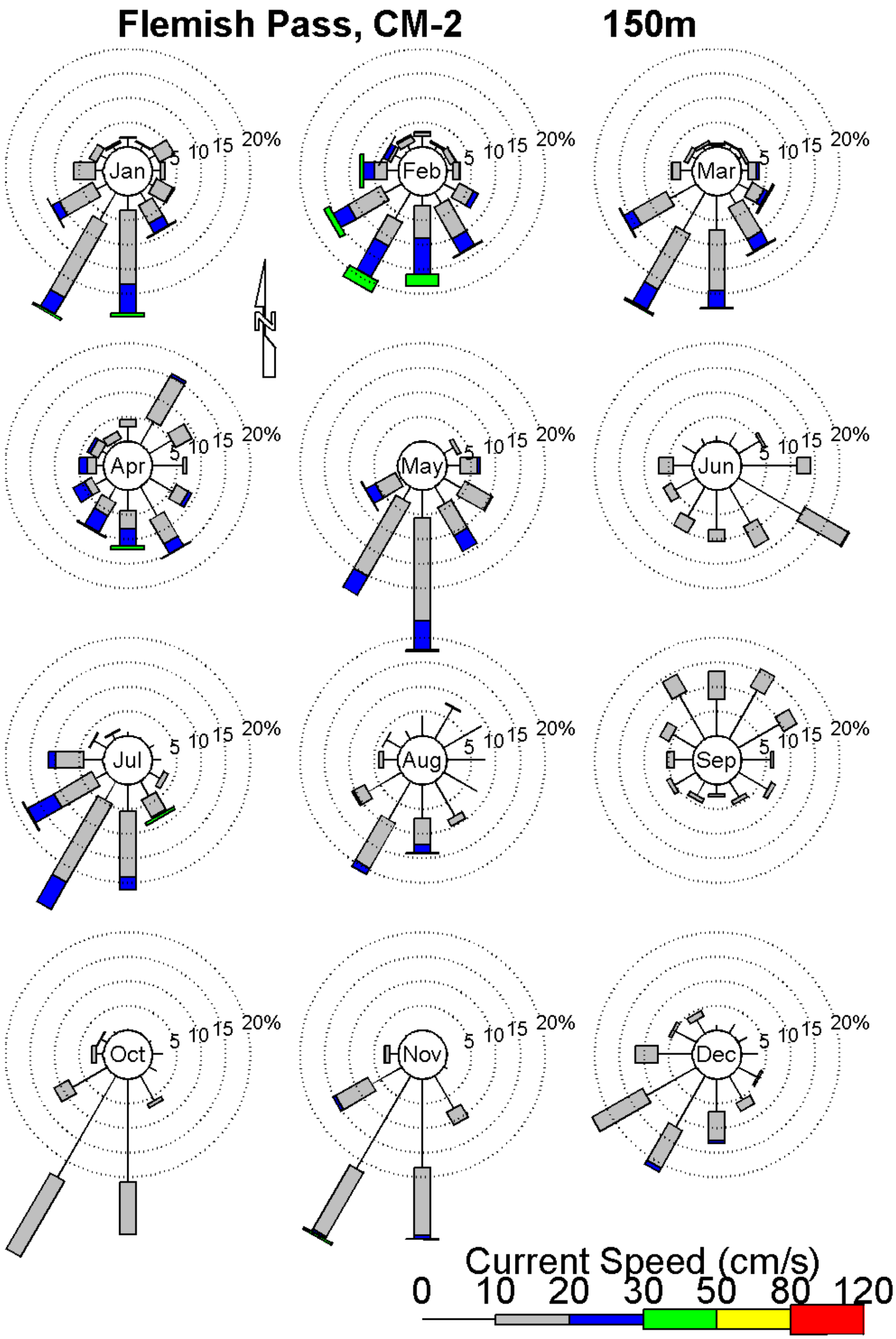

Figure 3-7 Monthly Current Roses, CM-2, Northern Flemish Pass, Surface-Mid, 150 m

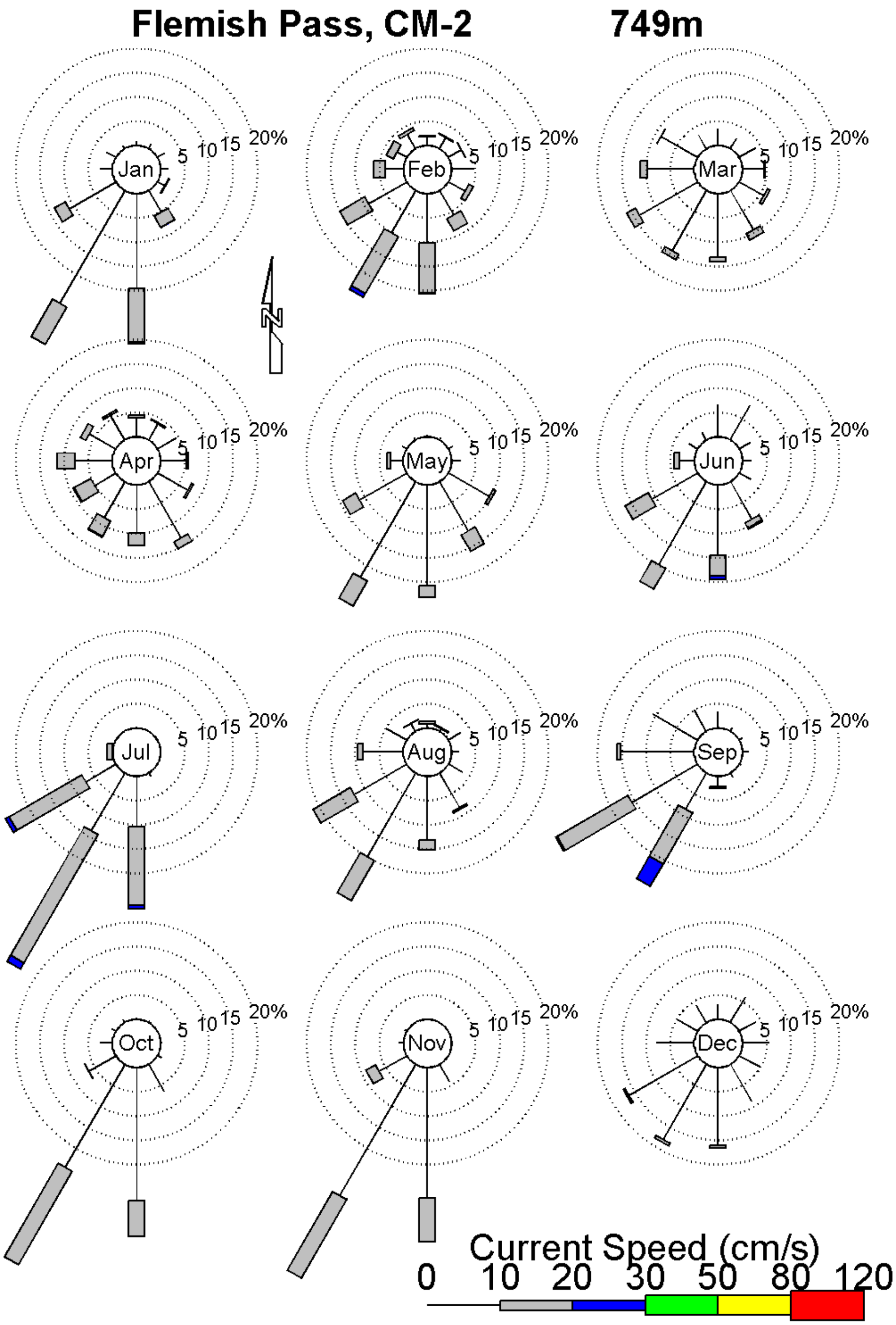

Figure 3-8 Monthly Current Roses, CM-2 Northern Flemish Pass, Mid-Deep, 794 m

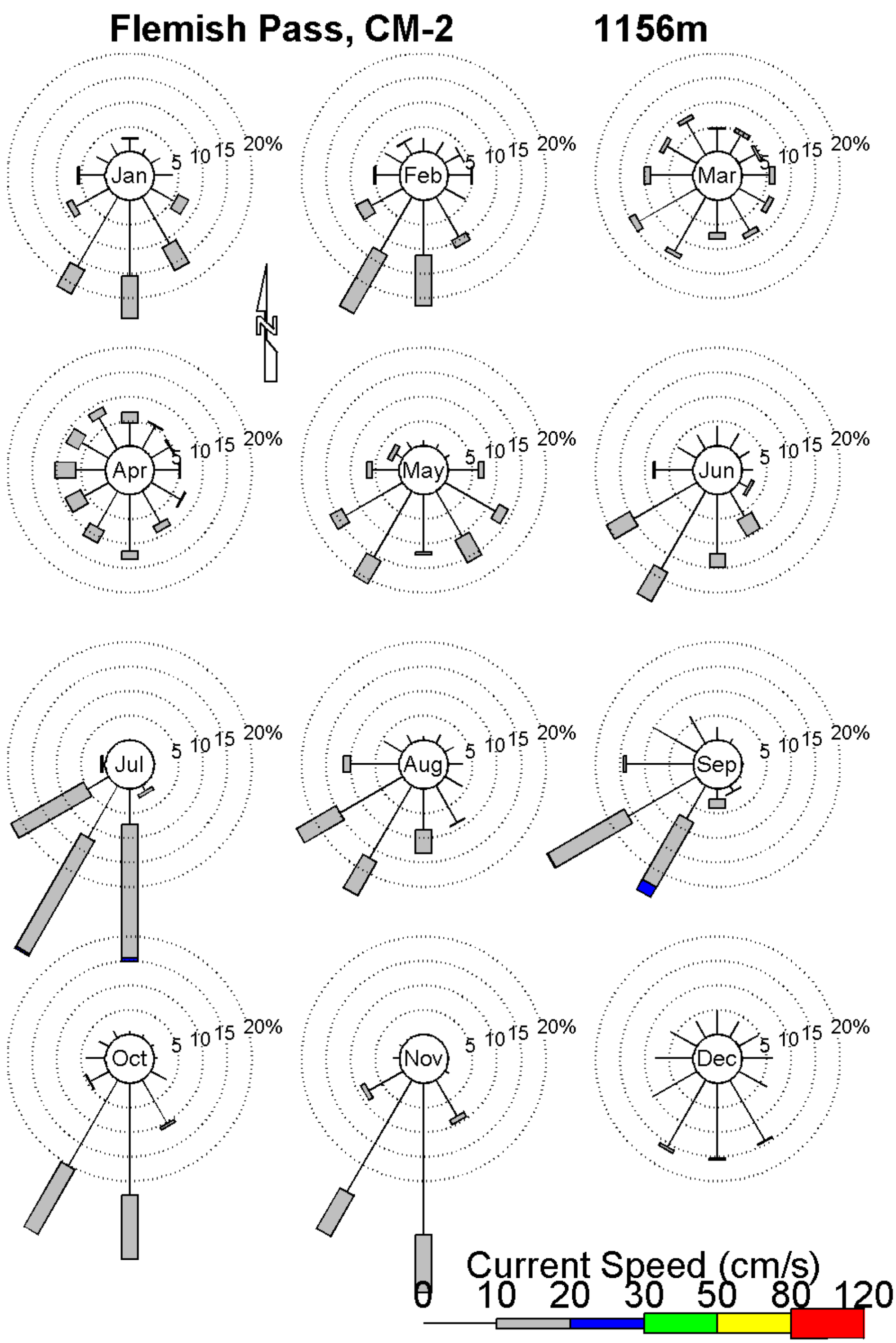

Figure 3-9 Monthly Current Roses, CM-2 Northern Flemish Pass, Near-Bottom, 1,156 m

3.3.1 Current Comparisons

This section presents comparisons of the CM-2 measurements with two modelled data sources: predictions from the DFO WebDrogue Canadian East Coast Ocean Model (CECOM) (DFO 2015a) and WebTide tidal prediction model (DFO 2015b) and the gridded hindcast HYbrid Coordinate Ocean Model (HYCOM) (HYCOM 2018) data set.

CECOM

The assumption for currents being fairly uniform over the 16 km x 16 km modelled domain (where 16 km is the approximate distance east from the modelling location Site 1 to the Project Area boundary) is verified in Figure 3-10 to Figure 3-13 which present winter and summer CECOM surface and 1,000 m depth current grids. The figures show the locations of the CM-2 current measurements and the modelling location, Site 1.

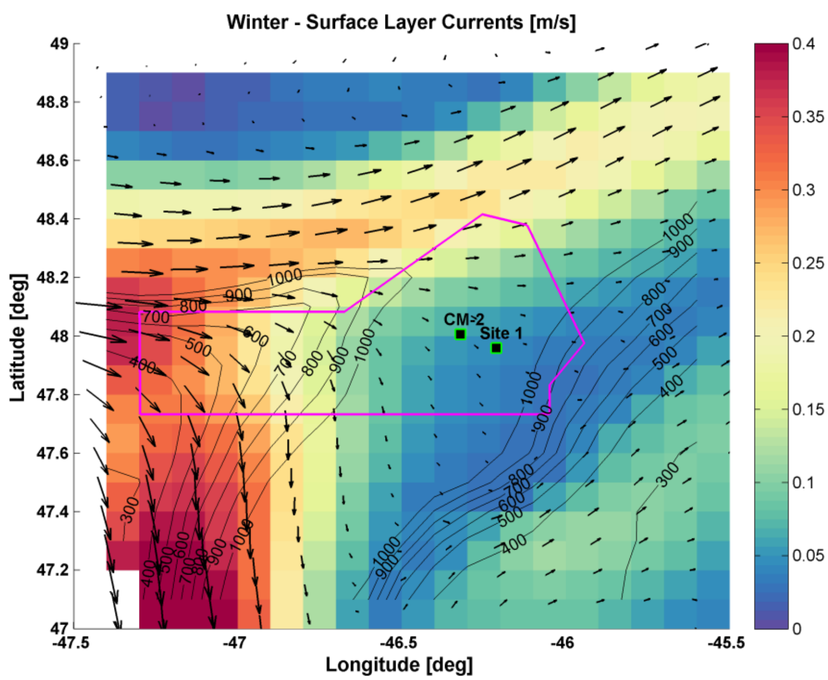

Figure 3-10 Surface Currents, Winter, CECOM

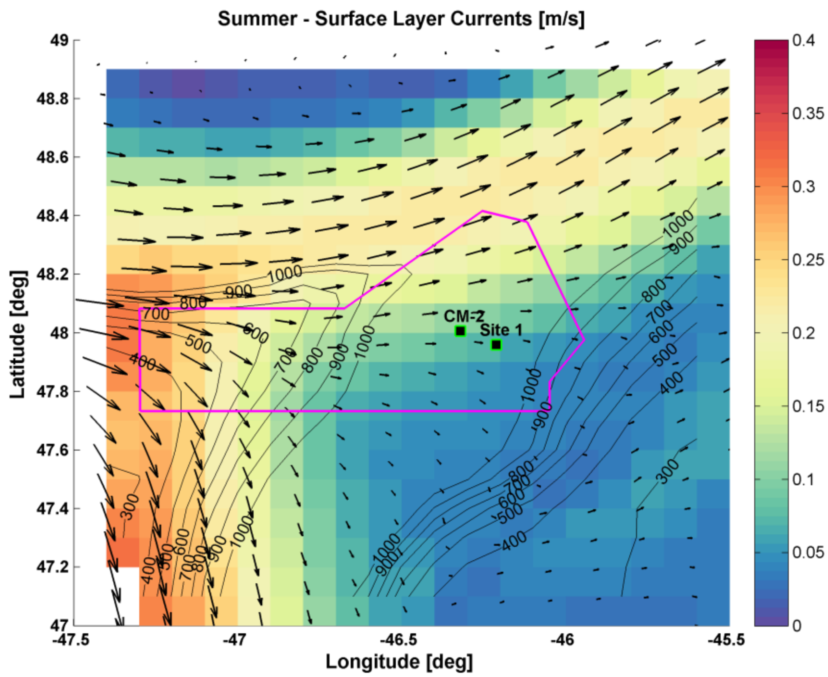

Figure 3-11 Surface Currents, Summer, CECOM

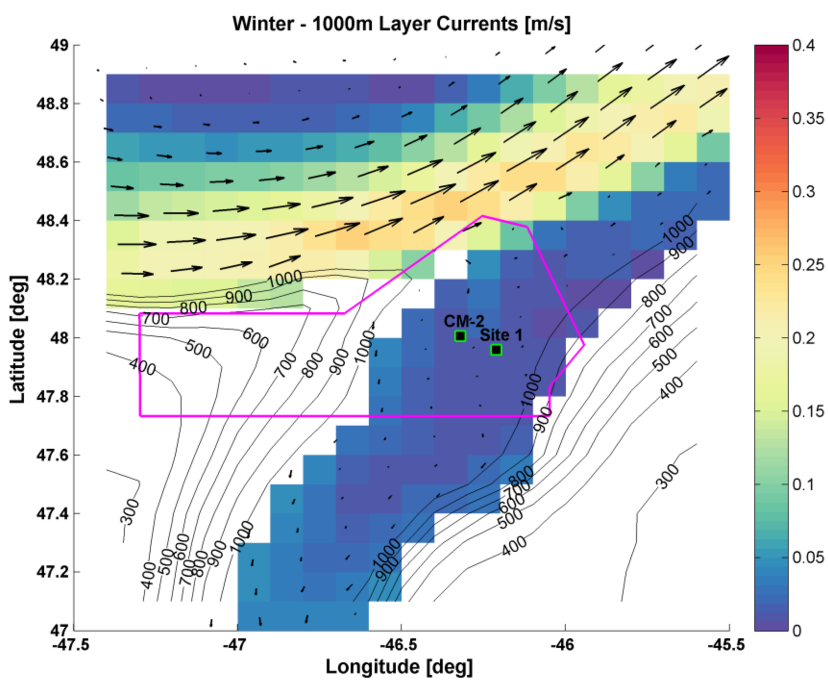

Figure 3-12 1,000 m Currents, Winter, CECOM

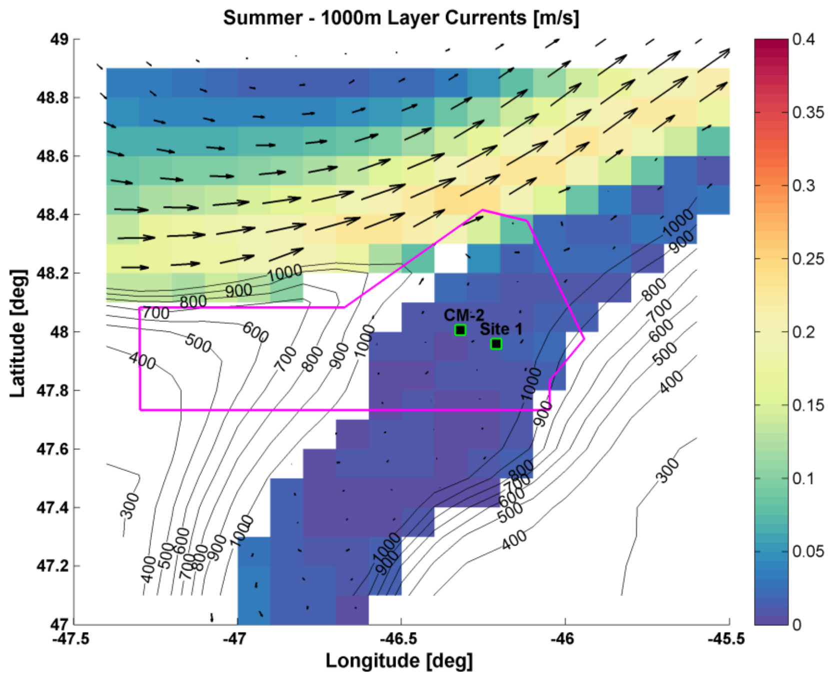

Figure 3-13 1,000 m Currents, Summer, CECOM

HYCOM

A seven-year (2006-2012) record of HYCOM daily current hindcasts was obtained[1] for a location at 47.9432°N, 46.4336°W, 11km southwest of CM-2 and 16.7 km west of the drill cuttings modelling location. Figure 3-14 presents HYCOM annual current roses. In comparison with the year of CM-2 measurements, the HYCOM shows an increase in southerly currents for most depths otherwise quite similar directional distributions. HYCOM depths of 25, 150, 800 and 1,000 m are selected to correspond to the four CM-2 depths shown in Figure 3-14.

[1] from Matt Horn, RPS ASA, gratefully acknowledged

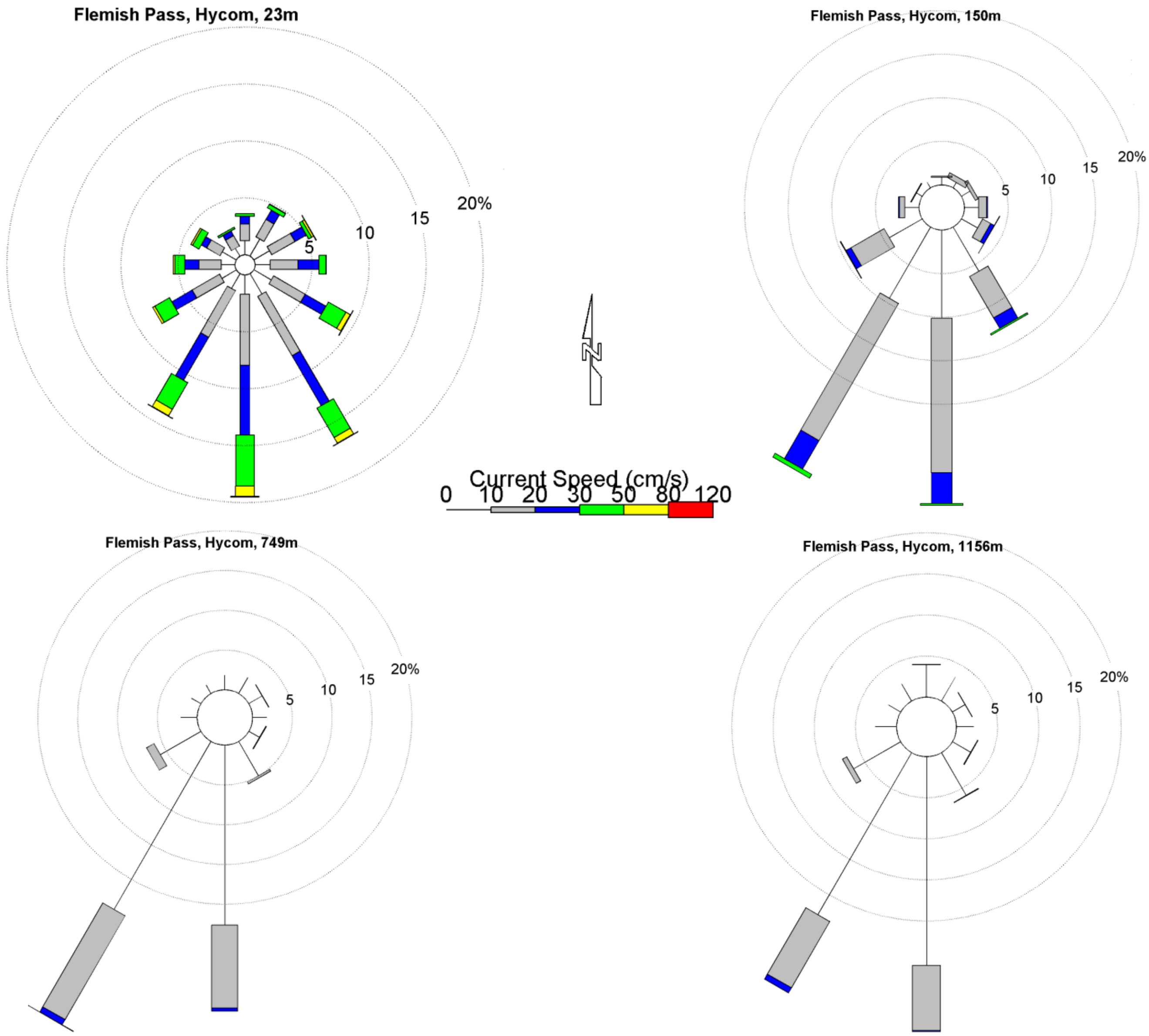

Figure 3-14 Annual Current Roses, HYCOM, 23, 150, 794, 1,156 m

The interannual variability in mean and maximum current speed for surface (25 m) and bottom (1,000 m) is shown in Table 3-14.

Table 3-14: Monthly and Annual Current Statistics Comparison, CM-2 and HYCOM

25 m Mean (cm/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	23	17	21	25	19	17	16	22	31	28	19	28	22
2007	25	20	25	26	36	29	27	17	12	16	14	23	23
2008	28	19	16	33	17	20	15	23	12	27	18	23	21
2009	20	19	16	14	16	16	13	21	36	36	24	20	21
2010	25	25	21	16	20	19	25	11	21	29	33	24	22
2011	23	17	16	19	15	13	15	13	36	38	27	27	22
2012	24	17	14	14	23	19	18	16	17	17	28	20	19
2006-2012 Mean	24	19	18	21	21	19	18	18	24	27	23	24	21
CM-2	21	20	24	25	29	15	22	12	24	27	22	16	21

25 m Maximum (cm/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	49	33	40	37	52	28	32	42	57	88	39	62	88
2007	68	42	52	42	57	68	58	39	34	35	28	56	68
2008	63	31	38	58	42	35	27	83	32	59	36	38	83
2009	47	45	35	41	32	38	29	64	87	84	62	40	87
2010	65	42	52	28	39	44	48	34	54	74	70	63	74
2011	50	44	38	51	26	36	34	24	75	74	64	37	75
2012	55	49	30	31	49	31	34	41	34	50	59	50	59
2006-2012	68	49	52	58	57	68	58	83	87	88	70	63	88
CM-2	68	69	85	91	57	51	63	44	70	81	79	47	91

1,000 m Mean (cm/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	7	7	5	6	3	4	6	4	5	13	5	8	6
2007	10	13	10	6	6	5	8	6	3	11	5	10	8
2008	5	7	3	7	3	5	10	8	6	4	3	5	5
2009	6	6	4	4	4	4	5	7	6	9	10	7	6
2010	11	10	8	8	7	6	5	8	5	6	7	8	7
2011	10	10	8	5	3	3	10	5	8	10	16	6	8
2012	7	4	4	3	3	4	6	4	3	6	8	8	5
2006-2012	8	8	6	5	4	4	7	6	5	9	8	7	6
CM-2	7	8	6	7	7	6	12	7	9	7	8	4	7

1,000 m Maximum (cm/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	16	16	13	11	6	8	13	13	10	23	10	18	23
2007	19	23	20	9	10	11	18	13	6	21	9	18	23
2008	14	17	6	15	6	13	16	11	10	9	10	8	17
2009	13	14	8	8	10	9	10	10	15	16	20	13	20
2010	16	17	16	15	13	11	12	18	16	17	17	18	18
2011	17	16	15	10	5	5	20	10	14	17	30	15	30
2012	14	9	9	6	8	10	14	8	7	17	16	15	17
2006-2012	19	23	20	15	13	13	20	18	16	23	30	18	30
CM-2	18	20	15	17	17	19	22	19	23	17	16	12	23

At 25 m, monthly mean current speeds differ by as much as 24 cm/s in a given month (September) over the seven HYCOM years; however, the average of the HYCOM years and the CM-2 measurement year monthly mean are both 21 cm/s. The standard deviation of monthly speed over the seven years is 6.3 cm/s compared with a value of 4.5 cm/s for the year of CM-2. Monthly maximum speeds over the seven HYCOM years can similarly vary widely, by up to 59 cm/s for a given month (August); however, the annual monthly maximum speeds between the HYCOM and CM-2 records are comparable at 88 and 91 cm/s respectively. The standard deviations of monthly maximum speeds over the seven HYCOM years and for the one year of CM-2 are the same at 15.4 cm/s.

At 1,000 m, monthly mean current speeds differ by as much as 13 cm/s for a given month (November) over the seven HYCOM years; however, the average of the HYCOM years and the CM-2 measurement year monthly mean are 6.4 and 7.4 cm/s respectively. The standard deviation over the seven years is 2.7 cm/s compared with a value of 1.7 cm/s for the year of CM-2. Monthly maximum speeds over the seven HYCOM years vary from 6 to 21 cm/s (November); the annual monthly maximum speeds between the HYCOM and CM-2 records are 30 and 23 cm/s respectively. The standard deviations of monthly maximum speeds over the seven HYCOM years and for the one year of CM-2 are 4.7 and 3.1 cm/s respectively.

These comparisons illustrate that while there are some interannual variability in the speeds, as would be expected, the one-year CM-2 record, besides being measurements (compared with hindcasts) provide, by virtue of comparable annual monthly mean, maximum, and standard deviation values, a faithful overall representation of currents which might be expected at Bay du Nord.

4.0 MODEL SIMULATION OUTPUTS

The ADM modelling was completed in two steps, with a set of deterministic runs followed by a stochastic analysis as described in Section 2.2.

During each deterministic run, the model tracks and outputs separately, the WBM cuttings, SBM cuttings and total (WBM plus SBM cuttings) deposition results and outputs an x,y grid of the model domain with the following variables calculated for each grid cell:

- x, y, origin of cell (km), relative to discharge (x,y,z) origin
- range (km) and bearing (°T) from origin
- and for each of WBM cuttings, SBM cuttings, and total (WBM+SBM) cuttings:
- total weight of cuttings (kg)
- cuttings density (g/m^2)
- cuttings thickness (mm)
- oil concentration on cuttings (mg/kg)
- number of particles of each of the six types (coarse, medium and fine sand, silt and clay).

A run log file is also output which echoes key model inputs and reports the total weight of cuttings (WBM and SBM) deposited on the seabed and the amount of any cuttings which drift outside the model grid.

For the stochastic simulations, the post-processing was limited to the total cuttings deposition grids in order to address the primary requirement to assess total thicknesses for PNET investigation. During the stochastic processing, the total cuttings dispersion footprint outputs of the N (N= 53 for the one well simulations; N=8 for the eight well simulations) simulations are summed (and normalized to align with the total amounts of material simulated to be released) to yield ‘probabilistic’ or stochastic predictions. The thickness and probability parameters output are listed in Section 2.2.

5.0 RESULTS

This section presents drill cuttings dispersion modelling results for simulation of the drilling of one well and drilling of eight wells for the BdN Project. The model predictions consist of total cuttings thickness distributions about the wellsite and the probabilities that thicknesses exceed PNET values of interest, at any particular distance from the wellsite, for assessment of potential biological effects. With the model's stochastic analysis approach, illustration is provided of the underlying deterministic predictions, with the stochastic analysis output thickness and probability statistics being the primary modelling results presented.

The drilling of one well includes consideration of five input scenarios to assess the anticipated possible range of cuttings particle size distributions (PSD). These results are presented in Section 5.1.

Given that (four- and eight-slot) template drilling is anticipated for multiple wells for the Core BdN Development Project, the modelling also considers the release of cuttings from eight wells, as a maximum cuttings release simulation. For modelling of the eight wells, two of the five input scenarios used for the one well are selected to further acknowledge some uncertainty for the PSD characterizations and associated cuttings thickness distribution predictions. These results are presented in Section 5.2. Both Sections 5.1 and 5.2 are similarly structured in the sets of results presented and discussed.

5.1 One Well Model Simulation

This section presents results from model simulation of drilling discharges of one well. As described in Section 3.2, five input particle size distributions (PSD) are employed to assess the range of cuttings characterization (e.g., cuttings particle sizes and associated percentages) and particle settling behaviour which might be possible (Section 3.2). The five PSD modelled are as follows, with the IDs '0', 'A', 'B', 'C' and 'D' used routinely to facilitate identification and labelling of the various data products:

- ('0') Base case, flocculation
- ('A') Base case, no flocculation (the smaller cuttings are assumed to stay disaggregated as separate particles and not to flocculate to form larger particles with faster settling)
- ('B') Troll A Platform average PSD
- ('C') Troll A Platform maximum PSD
- ('D') Nedwed

The results presented in this section include:

- illustration of the individual (deterministic) model run outputs underlying the stochastic analysis (Section 5.1.1)
- cross-sections of total cuttings thickness vs. distance for different statistics (e.g., the median or maximum thickness) in relation to 1.5mm and 6.5mm PNET values (Section 5.2.2)
- tables of a) how much material settles vs. distance and b) median and maximum cuttings thickness vs. distance, both for select distance range bins (Section 5.2.3)
- plan view maps of median (most likely) total cuttings thickness by distance from the wellsite (Section 5.2.4)
- plan view footprint maps showing the probability of thickness being above the 1.5 mm and 6.5 mm PNET values (Section 5.2.5)

5.1.1 Deterministic Model Runs (One Well)

Results are presented for eight of the 53 separate deterministic runs to illustrate the different outputs and underlying predictions used in the stochastic analysis (Section 2.2). Each separate run is the result of modelling the release of the cuttings from drilling of one well, with the difference being the assumed start day for drilling. As a result, a different set of ocean current inputs are used. Each figure shows the predicted total cuttings thickness footprint after completion of one well. Every sixth (of the 53) run was selected arbitrarily for illustration. The run number (from one of the 53 deterministic runs) and well start date are labelled in the upper left-hand corner of each plot panel. For example, the first run shown, number 6 (of 53) starts on 5 February and uses input currents beginning in February; the second run shown, number 12 (of 53) starts on 19 March and uses currents beginning in March. The figures are intended to provide an illustration of the sort of similarity, and variation, for a given input scenario (i.e., '0', 'A', 'B', 'C' and 'D'), recognizing it is the stochastic analysis and output thickness and probability statistics (Section 2.2) that are the primary modelling results and that are discussed in Sections 5.1.2 to 5.1.5.

Due to the rapid settling of cuttings particles in the first simulation, "base case with flocculation (0)", the total cuttings thickness footprints (mm) are quite similar and confined to the immediate vicinity of the wellsite[2] and with variation in current direction having little effect (Figure 5-1). While for the other simulations (Figure 5-2 to Figure 5-5), the greatest thicknesses are also typically seen at the wellsite, by contrast, with increased drift of the finer silt and clay-sized particles, there is a greater range of cuttings distribution seen about the wellsite, with thicknesses of several millimetres seen within 1 km of the wellsite. Given the short distance of 0.2 m the cuttings particles have to settle it does not take long for material to settle nearby. Fines-sized particles that settle at 0.001 m/s will fall that distance (0.2 m) in about three minutes. The length of time and hence distance for the smaller cuttings particles to settle will be greater under the base case without flocculation ('A').

Even with different PSDs for the Troll A Platform average PSD ('B') (Table 3-8) and Troll A Platform maximum PSD ('C') (Table 3-9), the cuttings thickness footprints near the wellsite are similar (Figure 5-3 and Figure 5-4 respectively). This is due to larger particles all settling rapidly and there being similar proportions of each, with sand-sized particles for Troll A Platform average PSD ('B') accounting for about 70 percent (Table 3-8) and a similar 82 percent for the Troll A Platform maximum PSD ('C') (Table 3-9).

Illustrations of the 16 km model grid results for the base case without flocculation ('A') and Nedwed ('D') simulations are shown in Figure 5-6 and Figure 5-7. Both simulations show far field dispersion of the cuttings, generally at thicknesses below 0.1 mm and widely distributed to potentially any direction, although primarily to the southwest and southeast quadrants.

[2] While a cuttings transport system (CTS) is planned, and may be some distance from the wellhead, the model origin is assumed to be that location of the CTS discharge, and for ease of reference is termed the wellsite in presentation of the results.

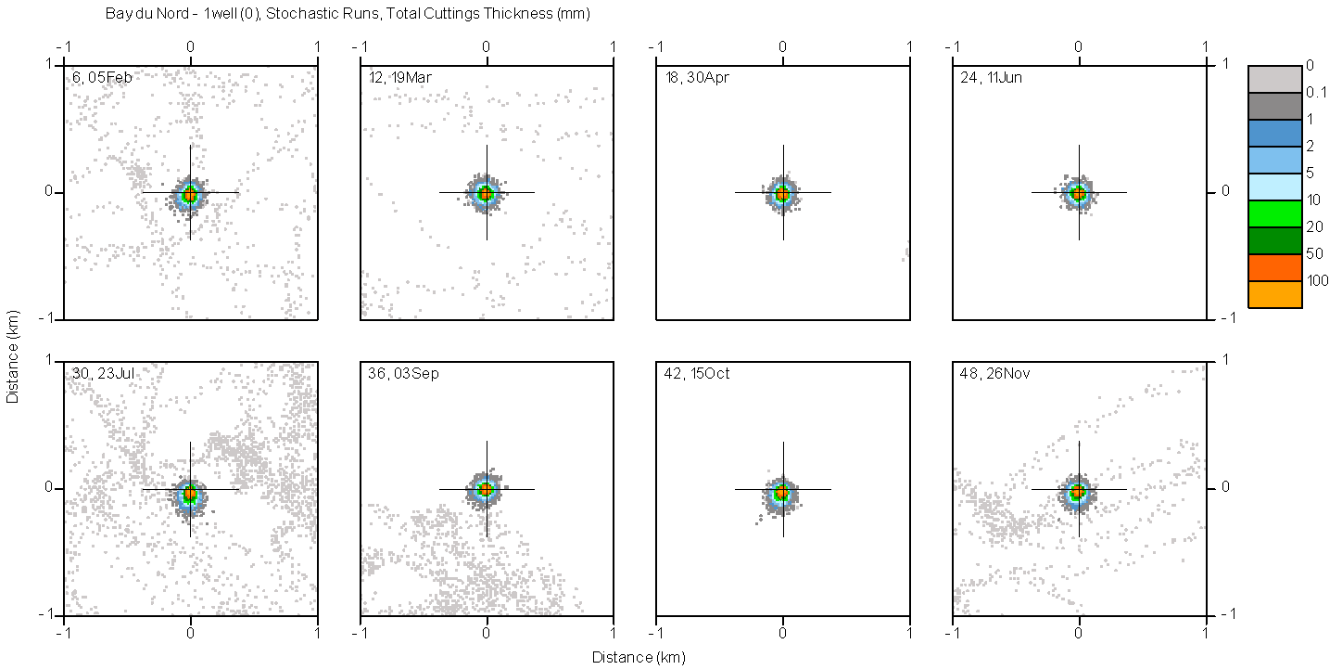

Figure 5-1 Base Case, with Flocculation ('0'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, One Well Simulations, 1-km View

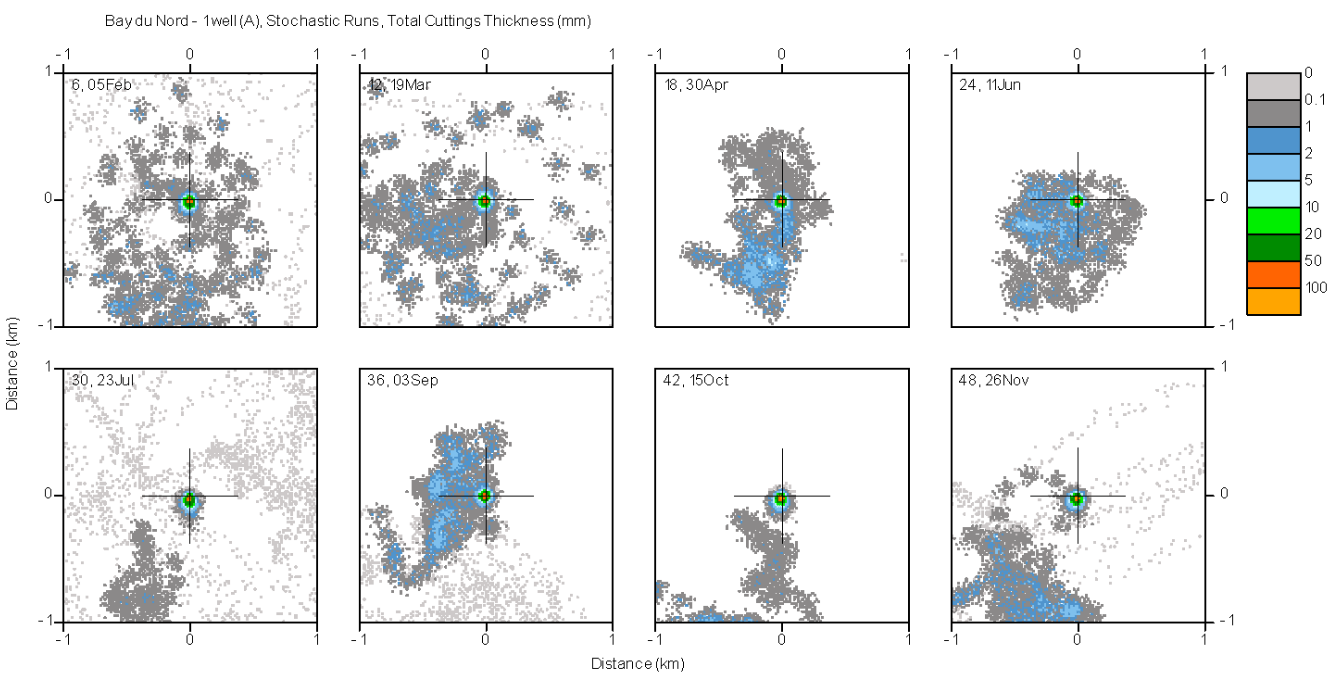

Figure 5-2 Base Case, no Flocculation ('A'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, One Well Simulations, 1-km View

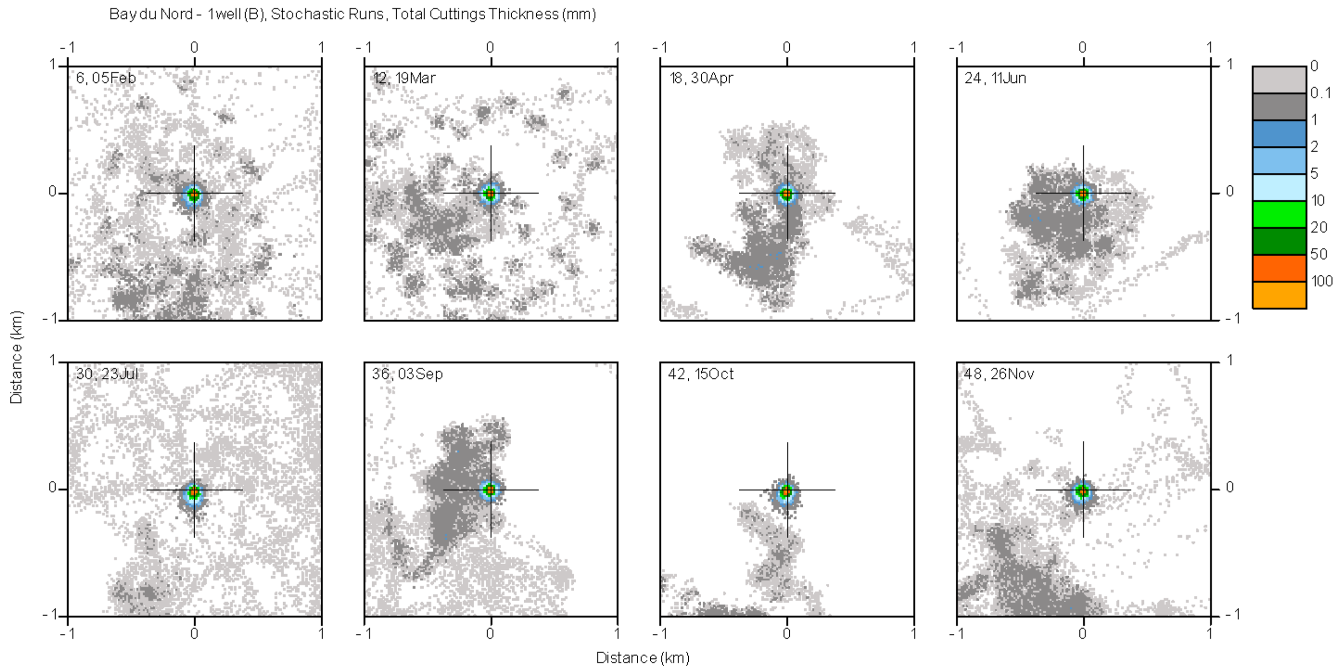

Figure 5-3 Troll A Platform, Average PSD ('B'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, One Well Simulations, 1-km View

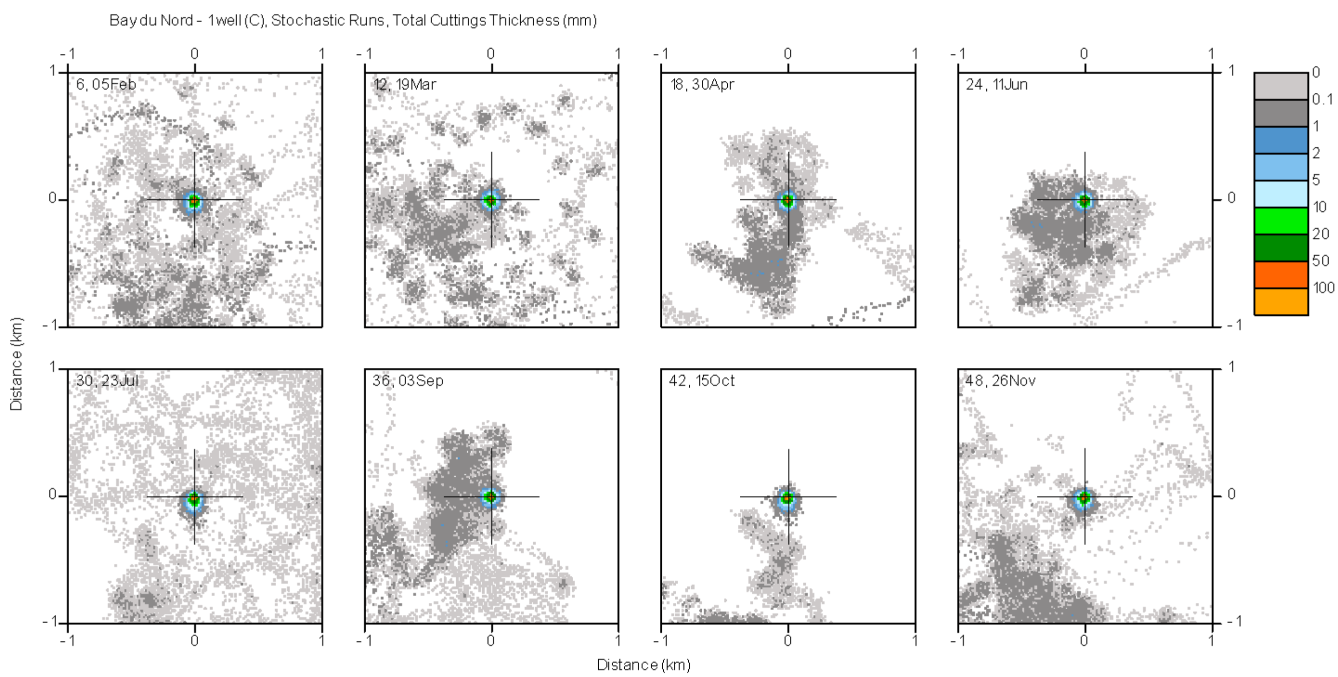

Figure 5-4 Troll A Platform, Maximum PSD ('C'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, One Well Simulations, 1-km View

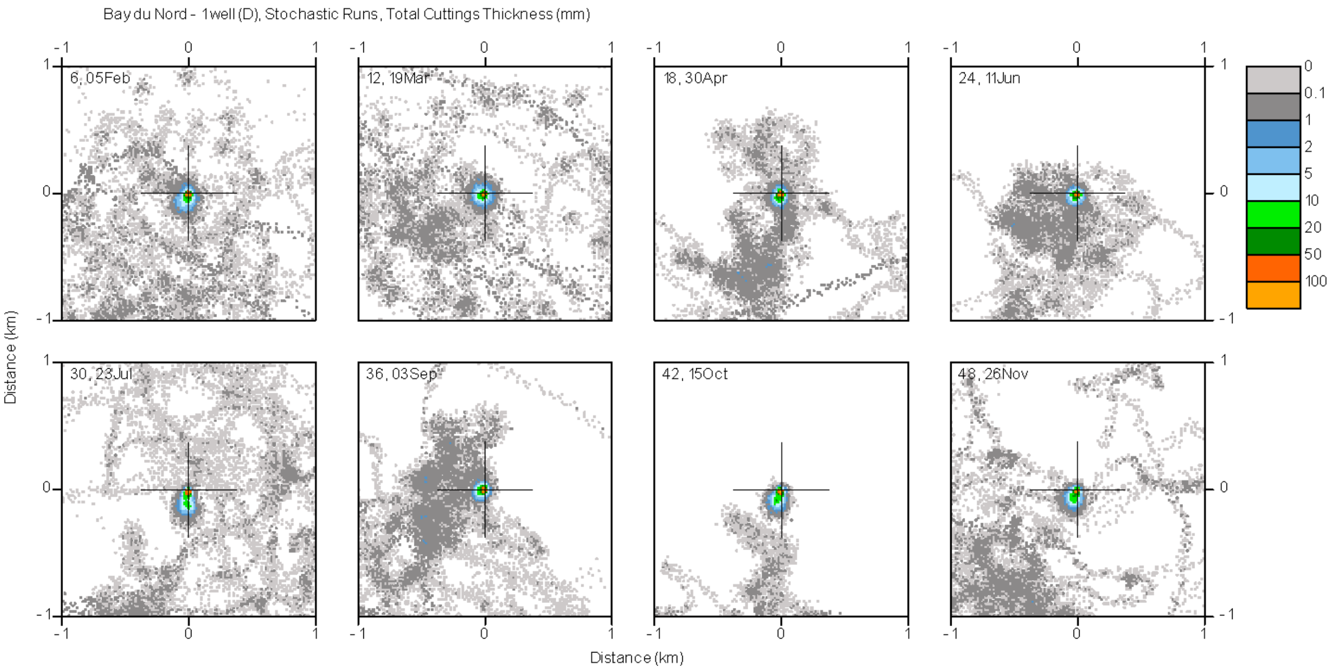

Figure 5-5 Nedwed ('D'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, One Well Simulations, 1-km View

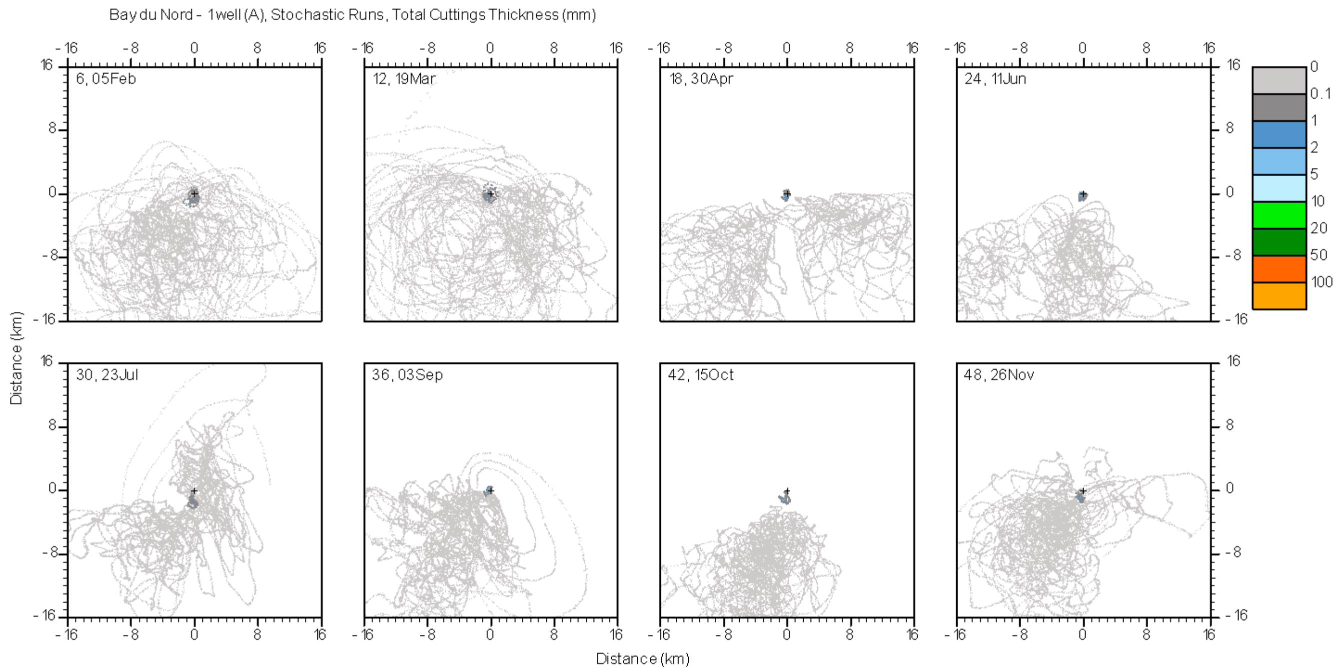

Figure 5-6 Base Case, no Flocculation ('A'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, One Well Simulations, 16-km View

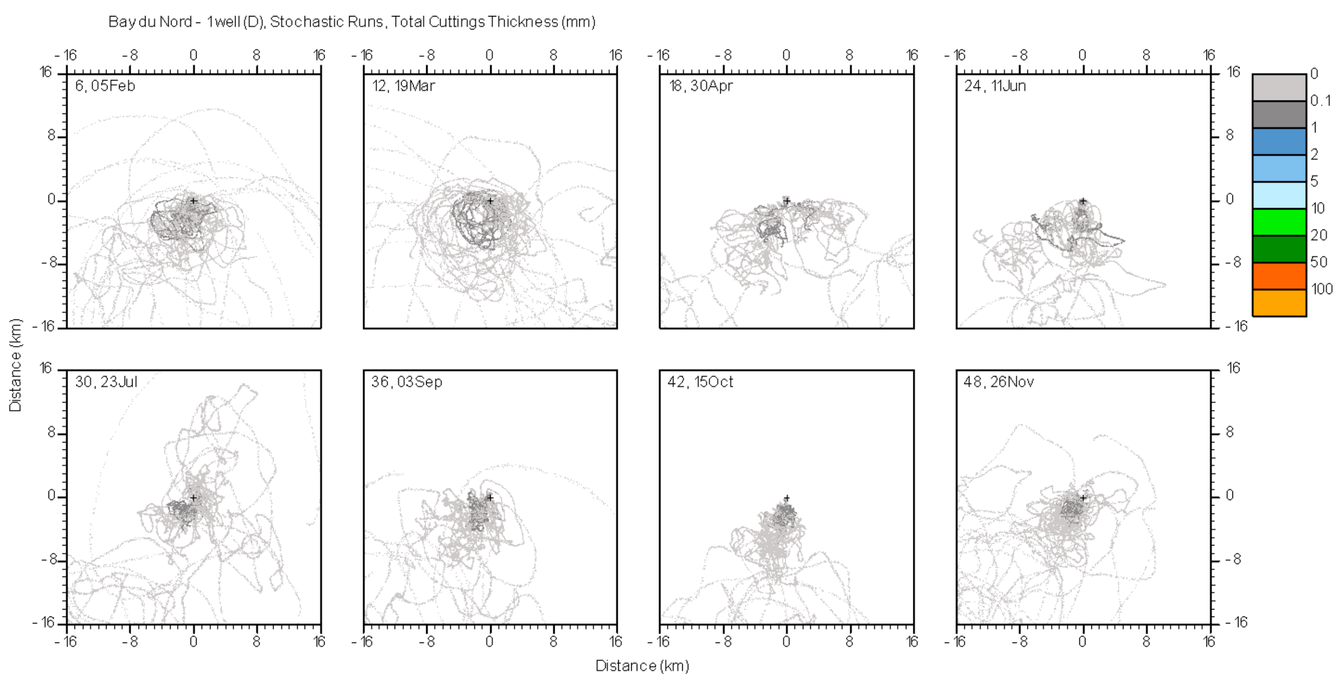

Figure 5-7 Base Case, Nedwed ('D'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, One Well Simulations, 16-km View

5.1.2 Cross-Sections of Total Cuttings Thickness by Distance (One Well)

Cross-sections of the total (WBM+SBM) drill cuttings footprints are presented to show at what distance any thickness thresholds of interest, e.g., the predicted no effect threshold (PNET) thicknesses, might be reached. Results are shown for the two base case PSD simulations, with ('0') and without ('A') flocculation, to illustrate the different thickness statistics calculated with the model, and to compare the thickness predictions for all five input PSD simulated.

Figure 5-8 shows the total cuttings thickness, for the base case, with flocculation ('0'). The P25, median (P50), P75, P95 and maximum (P100) thickness statistics versus horizontal distance from the wellsite are shown. It is noted that the statistics are calculated based on just the model output grid cells that have a non-zero thickness and considering all 53 deterministic runs (Section 2.2). The average of all grid cell values for a given statistic is the value plotted, e.g., the median is calculated as the average of all median thicknesses for a given distance; the P95 is taken as the average of all P95 thickness values. The exception is the maximum which is taken as the maximum of any thicknesses for the given distance of interest. These statistics quantify the thicknesses in those instances when one or more of the deterministic runs predicts some cuttings deposition (above zero), at a given distance. The PNET thicknesses for burial, 1.5 mm and 6.5 mm are drawn in pink. To permit viewing on a logarithmic scale, the values at the origin (wellsite, x=0) are plotted at a distance of 0.01 km.

As shown in Figure 5-8, the total cuttings thickness predictions decrease with distance from the wellsite. The maximum (P100) thickness shown in Figure 5-8 ranges from 428 mm at the wellsite (shown as distance 10 m away), to about 16 mm at 100 m, to less than 0.5 mm just past 200 m. These are the maximum predicted thicknesses from any of the 53 deterministic runs at the noted distance, and not one continuous thickness profile that was predicted in any of the 53 simulations. Each of the other statistics similarly indicate the corresponding P25, P50, or P75 thickness statistic for any particular distance. The median (P50) thickness ranges from 320 mm at the wellsite, to about 1.3 mm at 100 m, to 0.09 mm at 200 m. At a given distance, half of the predicted thicknesses greater than 0 mm will be below the noted value and half will be above, e.g., at 100 m, half of the predicted (non-zero) thicknesses will be less than 1.3 mm while half will be greater than 1.3 mm. At distances closer than 100 m, the median is larger than 1.3 mm. By comparison, at 100 m, the P25 thickness value is about 0.8 mm, indicating 25 percent of thickness predictions at this distance will be less than 0.8 mm and 75 percent will be greater than 0.8 mm.

Considering the PNET values of interest, the P25 thickness falls below 6.5 mm at a distance of about 64 m; the median (P50) thickness falls below 6.5 mm at a distance of about 72 m; the P95 thickness falls below 6.5 mm at a distance of about 88 m; and for the maximum (P100) thickness, the PNET thickness of 6.5 mm is reached at about 110 m (and therefore exceeding 6.5 mm at 100 m distance with a value of about 16 mm in the thickness range of 10 to 20 mm) and falls below 6.5 mm at distances farther than about 120 m from the wellsite.

Considering the lower PNET of 1.5 mm, the P25 thickness falls below 1.5 mm at a distance of about 86 m; the median (P50) thickness falls below 1.5 mm at a distance of about 96 m; the P95 thickness falls below 1.5 mm at a distance of about 125 m; and the maximum (P100) thickness reaches and falls below 1.5 mm between about 160 and 190 m. By 200 m, the predicted maximum thickness is 1 mm or less. The P75 thickness falls below 1.5 mm at about 105 m distance from the wellsite. This means that at 105 m, the P75 thickness value is about 1.5 mm, and indicates 75 percent of (non-zero) thickness predictions at this distance will be less than 1.5 mm and 25 percent will be greater than 1.5 mm.

In contrast to these thickness statistics, based on all non-zero thickness values, the thickness probabilities, as presented in Section 5.1.5, report on the likelihood of a thickness threshold being exceeded, which is based on all 53 deterministic runs, not just when there are non-zero thicknesses (Section 2.2).

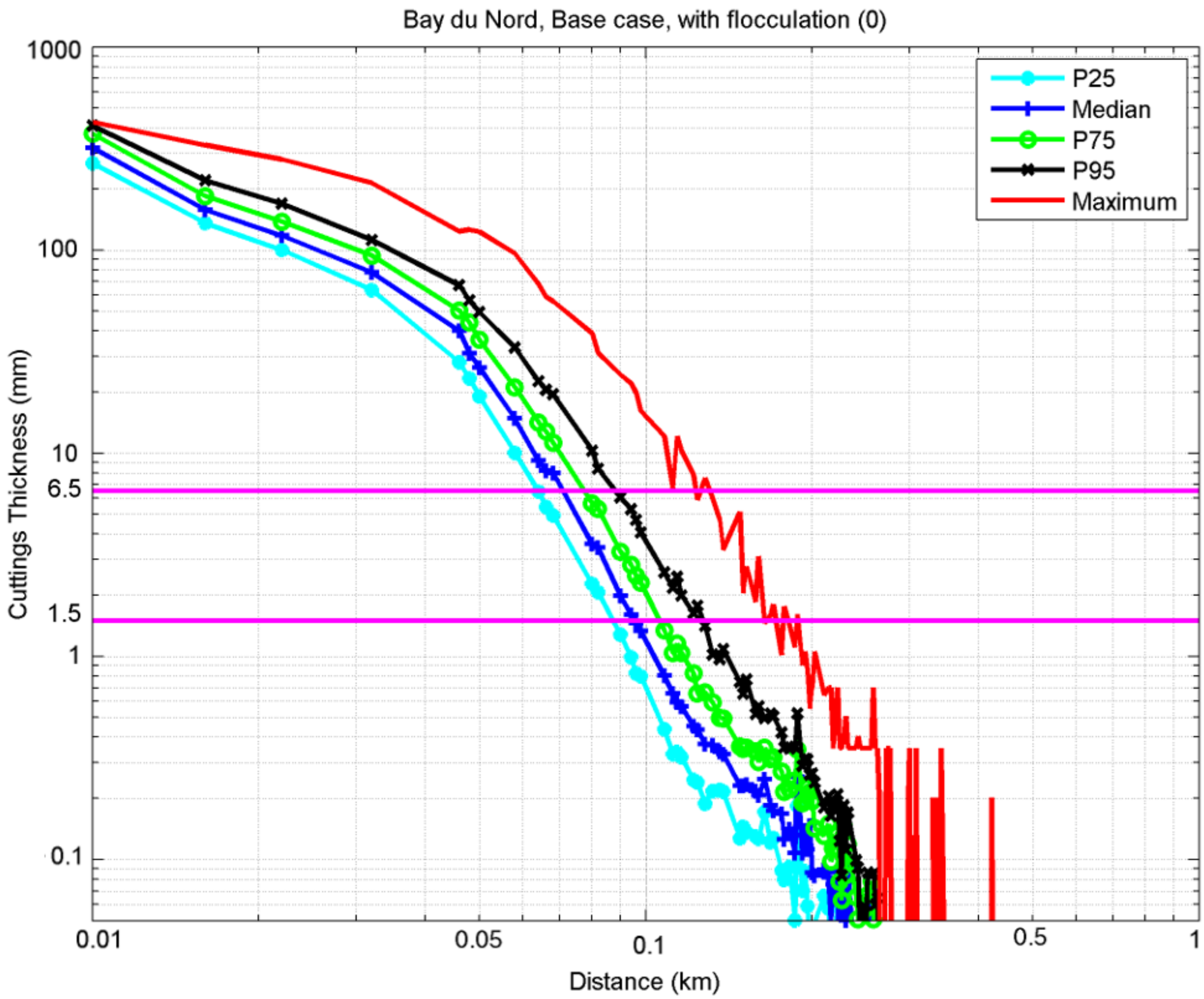

Figure 5-8 Base Case, with Flocculation, Total Cuttings Thickness

A similar presentation in Figure 5-9 reports thickness statistics for the base case, no flocculation ('A') simulation. With material initially settling more slowly than in the flocculation simulation ('0'), thicknesses here are somewhat less close in to the wellsite. For example, the maximum thickness (P100) predicted at 100 m away is about 7 mm, with corresponding median (P50), P75 and P95 values at 100 m being 0.9, 1.48 and 2.6 mm respectively. By contrast, at farther distances under the no flocculation case the thicknesses tend to persist somewhat farther, e.g., the median thickness for the base case with flocculation is about 0.09 mm at 200 m (Figure 5-8) whereas, with no flocculation, the median thickness is about 0.4 mm or slightly above out to about 600 m (Figure 5-9).

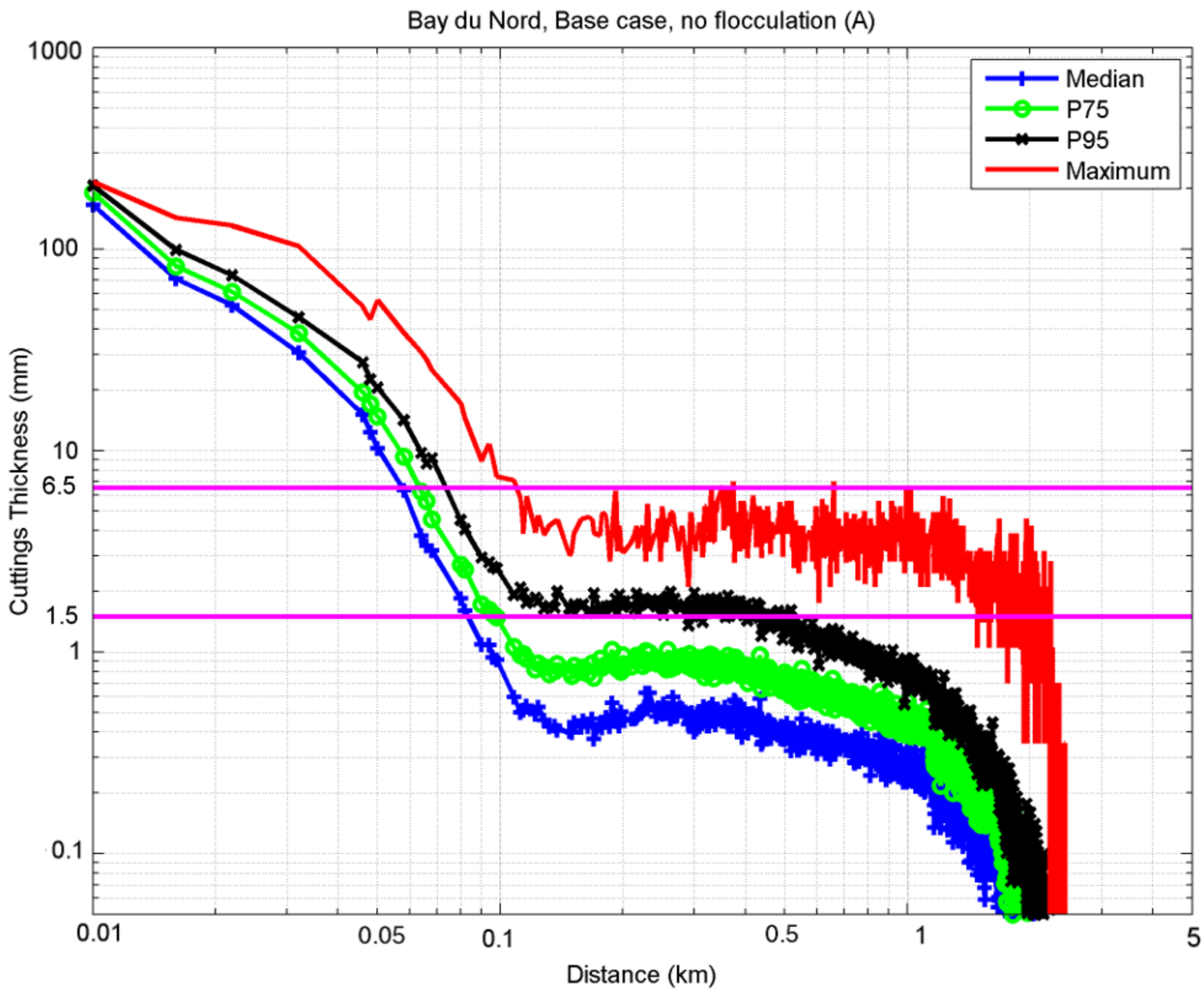

Figure 5-9 Base Case, no Flocculation, Total Cuttings Thickness

The median and maximum thickness predictions, by distance, are shown in Figure 5-10 and Figure 5-11 for all five input simulations. In terms of the PNET values of interest, the median thickness reaches the 6.5 mm threshold value at from 47 to 70 m, for all five of the input simulations, while the median thickness reaches the 1.5 mm value at 75 to 95 m away from the wellsite, again, for all five input simulations. These thresholds are reached nearest with the Nedwed ('D') inputs given the greater composition of coarser materials, and farther away with the base case with flocculation inputs ('0').

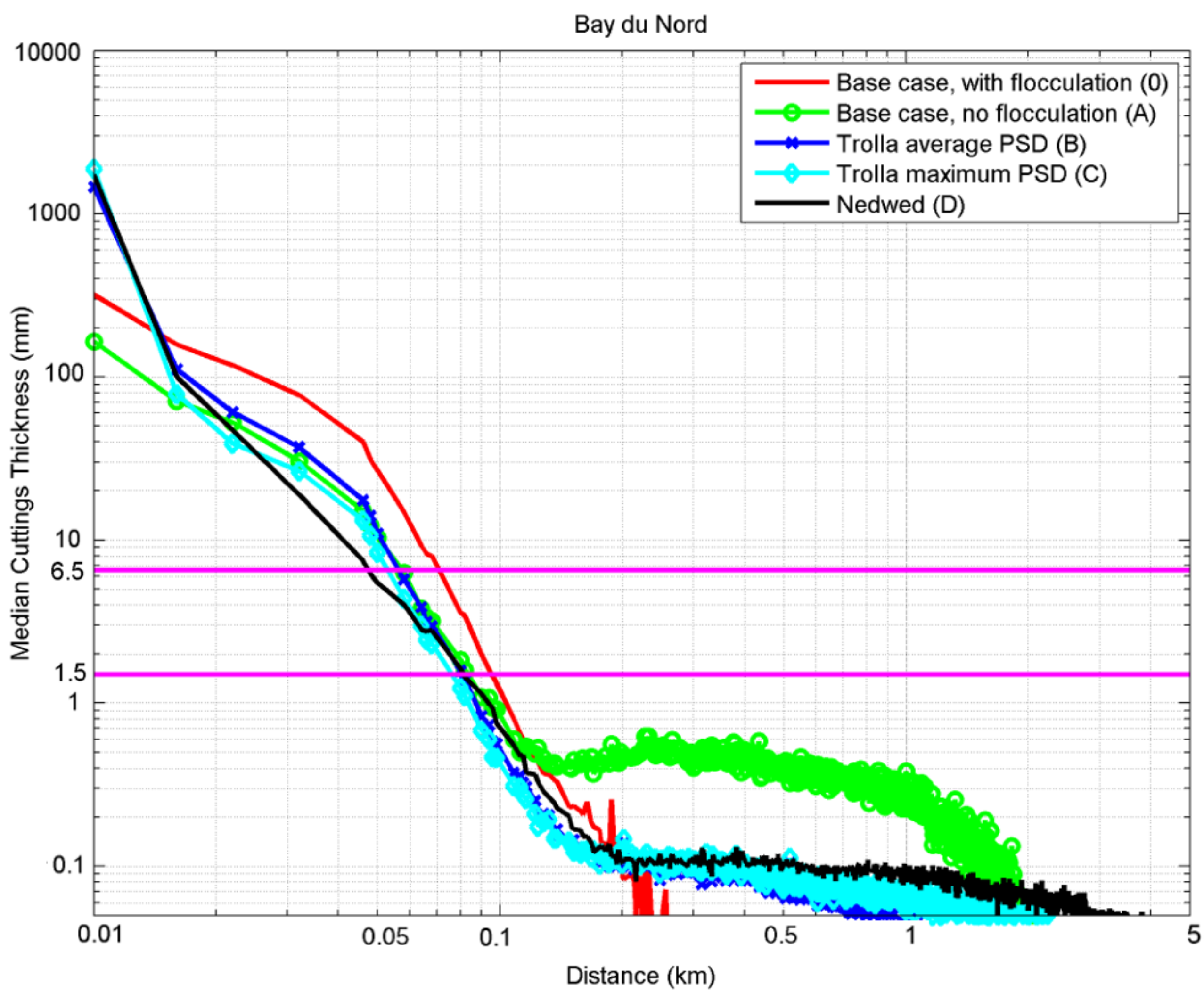

Figure 5-10 Median Total Cuttings Thickness

Considering the maximum thicknesses (Figure 5-11), the PNET value of 6.5 mm is reached from about 80 to 170 m away from the wellsite, and the 1.5 mm threshold is largely reached at from about 140 to 200 m away, with the observation that some thickness predictions from the Nedwed ('D') rise back up to 1.5 mm up to almost 4 km away. These are very spotty occurrences however and occur in only one of the 53 simulations. This is indicated in Figure 5-22 (lower right-hand panel), albeit faintly, with sparse grey pixels which report a few scattered locations where thicknesses may be above 1.5 mm; however, these are all with a low (less than five percent) likelihood. Overall, the thresholds of interest are reached soonest with the Troll A Platform maximum PSD ('C') inputs given the greater composition of coarser materials, and latest with the Nedwed ('D').

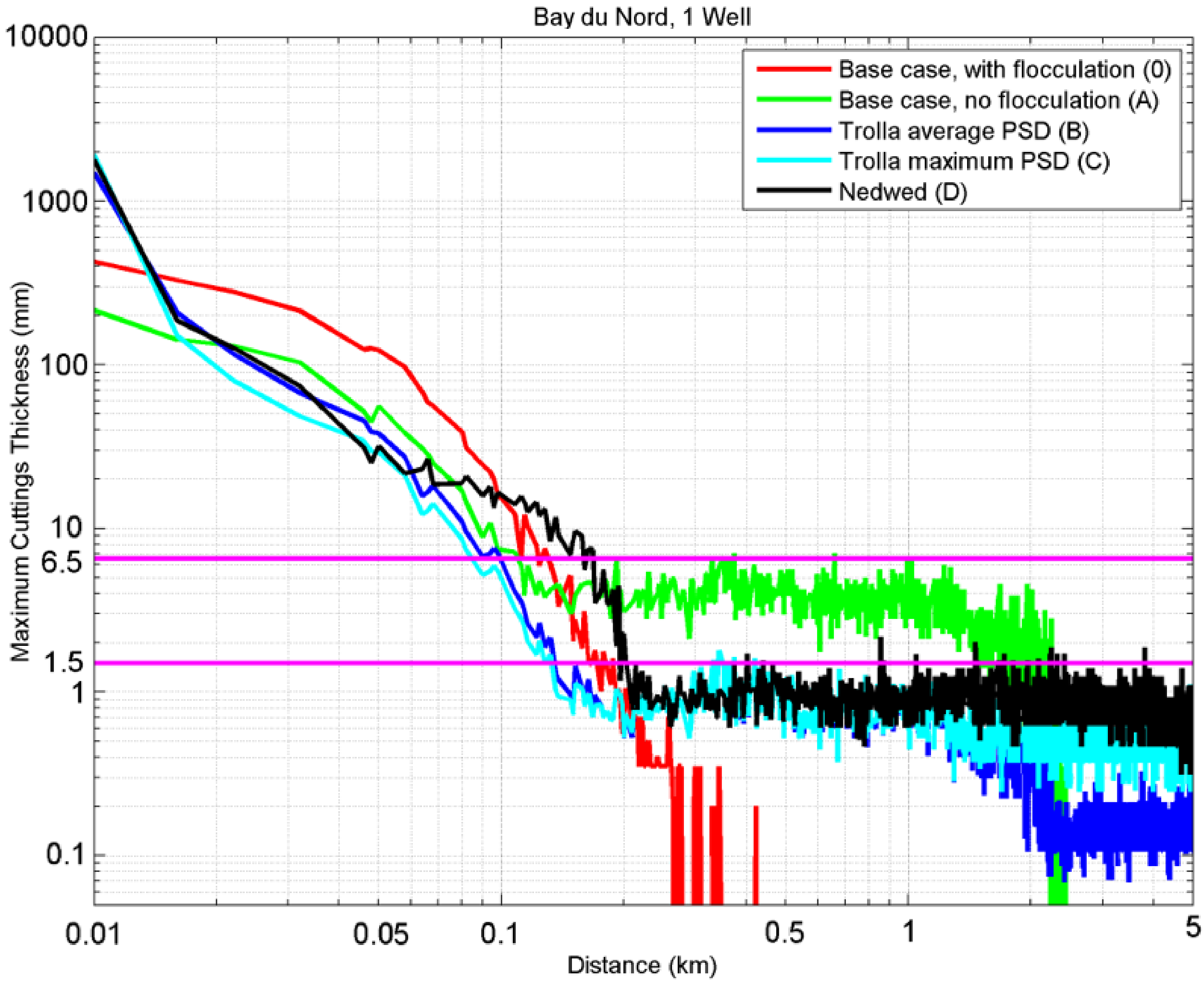

Figure 5-11 Maximum Total Cuttings Thickness

5.1.3 Cuttings Material Settled, Median and Maximum Thickness by Distance (One Well)

With cuttings from drilling the upper two well sections with WBM all being released close to the seafloor there is little time for these cuttings to be transported large distances by the ambient currents before particles settle on the sea floor. Conversely SBM cuttings, treated and released near the sea surface (14 m assumed, see Table 3-2) will have a large depth of about 1,170 m to settle and over this time will be more widely dispersed.

The amounts of total (WBM+SBM) cuttings material modelled to settle for selected distances from the wellsite (origin) are presented in Table 5-1. For the two Bay du Nord base case simulations, just less than two thirds of the material settles within the 16 km model grid domain, most of this within 2 km. The remaining unsettled material will include the finer silts and clays with settling times of about two weeks or (especially for the clays in the no flocculation scenario) at a horizontal current of 5 cm/s drift a distance of almost 60 km. As a result, SBM cuttings will be widely dispersed due to the currents before reaching the seabed in these deep waters.

While the two base case simulations estimate about 3.0 and 5.8 percent material settling at the wellsite (in terms of the model, this is in one 16 m x 16 m grid cell), the two Troll A Platform PSD simulations result in much greater material at the wellhead: about 27 percent for the Troll A Platform average PSD (26.5 percent at wellsite; 27.4 percent in the 10-100 m range), and from about 20 to 34 percent for the Troll A Platform maximum PSD (34.4 percent at wellsite; 19.7 percent in the 10-100 m range)

The Nedwed simulation yields similar estimates of about 20 to 32 percent (31.5 percent at wellsite; 20.1 percent in the 10-100 m range). This is due to the much greater amount of larger SBM cuttings particles (medium sand and larger, classes 4 to 6, e.g., Table 3-6, Table 3-8, Table 3-11) assumed which will settle out within several hours from release near the sea surface.

Further indication of this mass of larger cuttings material is provided by the noticeably increased amount of material predicted to settle in the 2-23 km range for Troll A Platform and Nedwed simulations. Over this distance interval, most of the unsettled material for either of the base case simulations will remain higher in the water column, while some of the larger SBM cuttings material will settle. Overall, with the Nedwed simulation just 1 percent of the cuttings material fails to settle within the 16 km model domain, while 14.4 and 7 percent of the two Troll A Platform sensitivity runs fail to settle. These three simulations therefore represent those for which the largest amounts of material are predicted to settle; however, the corresponding thicknesses over these distances (2-23 km) in these simulations are similarly small as with the base case simulations (Table 5-2, Table 5-3).

Table 5-1: Total Cuttings Material Settled (%) by Distance from the Wellsite

	Distance from Wellsite								
Simulation	**Wellsite**	**10-100m**	**100-200m**	**200-500m**	**500m-1km**	**1-2km**	**2-5km**	**5-23km**	**Unsettled**
	% Material Settled								
'0' Base case, flocculation	5.8	54.7	1.5	0.03	<0.01	0.01	0.05	0.3	37.6
'A' Base case, no flocculation	3.0	23.0	2.3	10.1	14.4	9.0	0.3	0.3	37.6
'B' Troll A Platform, average PSD	26.5	27.4	0.9	2.2	3.3	2.8	5.4	17.0	14.4
'C' Troll A Platform, maximum PSD	34.4	19.7	0.8	2.3	3.8	5.1	14.4	12.5	7.0
'D' Nedwed	31.5	20.1	2.0	2.6	5.4	10.8	21.5	5.1	1.0

Note: due to rounding some row totals may not exactly equal 100.

Summaries of median and maximum cuttings thicknesses with distance are presented in Table 5-2 and Table 5-3. Median thicknesses are calculated as the average of all median thickness values for a given 'distance from wellsite' range. Only those sea bottom model grid cells with cuttings deposition, i.e., non-zero median thickness values are considered. Cells with no cuttings deposits are not considered. The maximum thicknesses are the one largest thickness observed in each 'distance from wellsite' bin. Maximum total cuttings thicknesses are located at the wellsite (origin). The statistics are calculated considering all 53 deterministic runs completed for the one well simulations.

Considering all five simulations, median cuttings thicknesses are predicted to range from about 170 to 1,900 mm at the wellsite to 9 to 25 mm out to 100 m. Outside of 100 m, median thicknesses are less than 1 mm and beyond 1 km, values are generally less than 0.1 mm. Slumping of the larger cuttings piles will occur as well as weathering over time.

Maximum thicknesses similarly drop rapidly after about 100 m. Considering all five simulations, maximum cuttings thicknesses are predicted to range from about 200 to 1,900 mm at the wellsite and to about 140 to 330 mm out to 100 m. From 100 to 200 m, maximum thicknesses range from 5 to 17 mm. Maximum thicknesses are 2 mm or less farther than 200 m away; the one exception is the no flocculation simulation with values of 5 to 7 mm.

Table 5-2: Median Cuttings Thickness (mm) by Distance from the Wellsite

	Distance from Wellsite							
Simulation	**Wellsite**	**10-100m**	**100-200m**	**200-500m**	**500m-1km**	**1-2km**	**2-5km**	**5-23km**
	Cuttings Thickness (mm)							
'0' Base case, flocculation	320	24	0.3	<0.01	<0.01	<0.01	<0.01	<0.01
'A' Base case, no flocculation	165	10	0.5	0.5	0.3	0.1	<0.01	<0.01
'B' Troll A Platform, average PSD	1,458	12	0.2	0.1	0.1	0.02	0.02	0.02
'C' Troll A Platform maximum PSD	1,891	9	0.2	0.1	0.1	0.1	0.04	<0.01
'D' Nedwed	1,729	9	0.2	0.1	0.1	0.1	0.05	<0.01

Note: slumping of the larger cuttings piles near the wellsite will likely occur resulting in smaller thicknesses.

Table 5-3: Maximum Cuttings Thickness (mm) by Distance from the Wellsite

	Distance from Wellsite							
Simulation	**Wellsite**	**10-100m**	**100-200m**	**200-500m**	**500m-1km**	**1-2km**	**2-5km**	**5-23km**
	Cuttings Thickness (mm)							
'0' Base case, flocculation	428	329	14	1	<0.01	<0.01	<0.01	<0.01
'A' Base case, no flocculation	215	143	7	7	7	7	5	<0.01
'B' Troll A Platform, average PSD	1,492	207	6	2	1	1	1	0.5
'C' Troll A Platform maximum PSD	1,918	150	5	2	1	1	1	1
'D' Nedwed	1,784	186	17	2	2	2	2	1

Note: slumping of the larger cuttings piles near the wellsite will likely occur resulting in smaller thicknesses.

5.1.4 Cuttings Footprint Maps, Median Thickness (One Well)

Plan view footprint maps of the cuttings thickness about the wellsite are presented in Figure 5-12 to Figure 5-19 for all five input scenarios. The P50 median (most likely) thickness statistics are presented for all scenarios, while the P95 thicknesses are also shown for the two base case simulations ('0' and 'A') to illustrate how the median and P95 compare.

For any one of the 53 completed deterministic runs not all areas (cells of the model grid) will have the reported thickness; however, the stochastic analysis indicates that the thickness reported there is the median value, likely to be exceeded half of the time. The median, or P95, thicknesses shown would not be produced by the drilling of any one well, rather they are thickness statistics for each cell calculated across all simulations, and hence provide some 'bounds' on the possible thickness outcomes at any one location.

In the figures, circles are drawn at select distances to assist in the interpretation of the results. For the 1 km view plots of Figure 5-12 and Figure 5-13 for the base case) circles are drawn with radius of 100 m, 500 m and 1 km. For the 2.5 km view plots of Figure 5-14 to Figure 5-16, Figure 5-18 and Figure 5-19 circles are drawn with radius of 500 m, 1 km and 2 km. Figure 5-17, which shows a 'zoomed-in' 500 m scale, circles are drawn with radius 100 and 200 m.

For example, in Figure 5-12, for the base case with flocculation ('0') simulation, the median thickness within 100 m of the wellsite is predicted to generally be 5 mm or above. The 5 mm thickness areas extend slightly to the south and then fall below 0.1 mm within about 200 m. The companion illustration of the P95 thickness for the base case with flocculation ('0') in Figure 5-13 shows a largely similar distribution though with greater thicknesses of 10 to 50 mm reaching to a distance of 100 m from the wellsite. A similar pattern to that seen for the median for thicknesses falling below 0.1 mm within about 200 m is evident for the P95 thickness. This indicates that outside of about 100 to 200 m from the wellsite, the median and P95 thickness values are comparable for the base case with flocculation ('0') simulation.

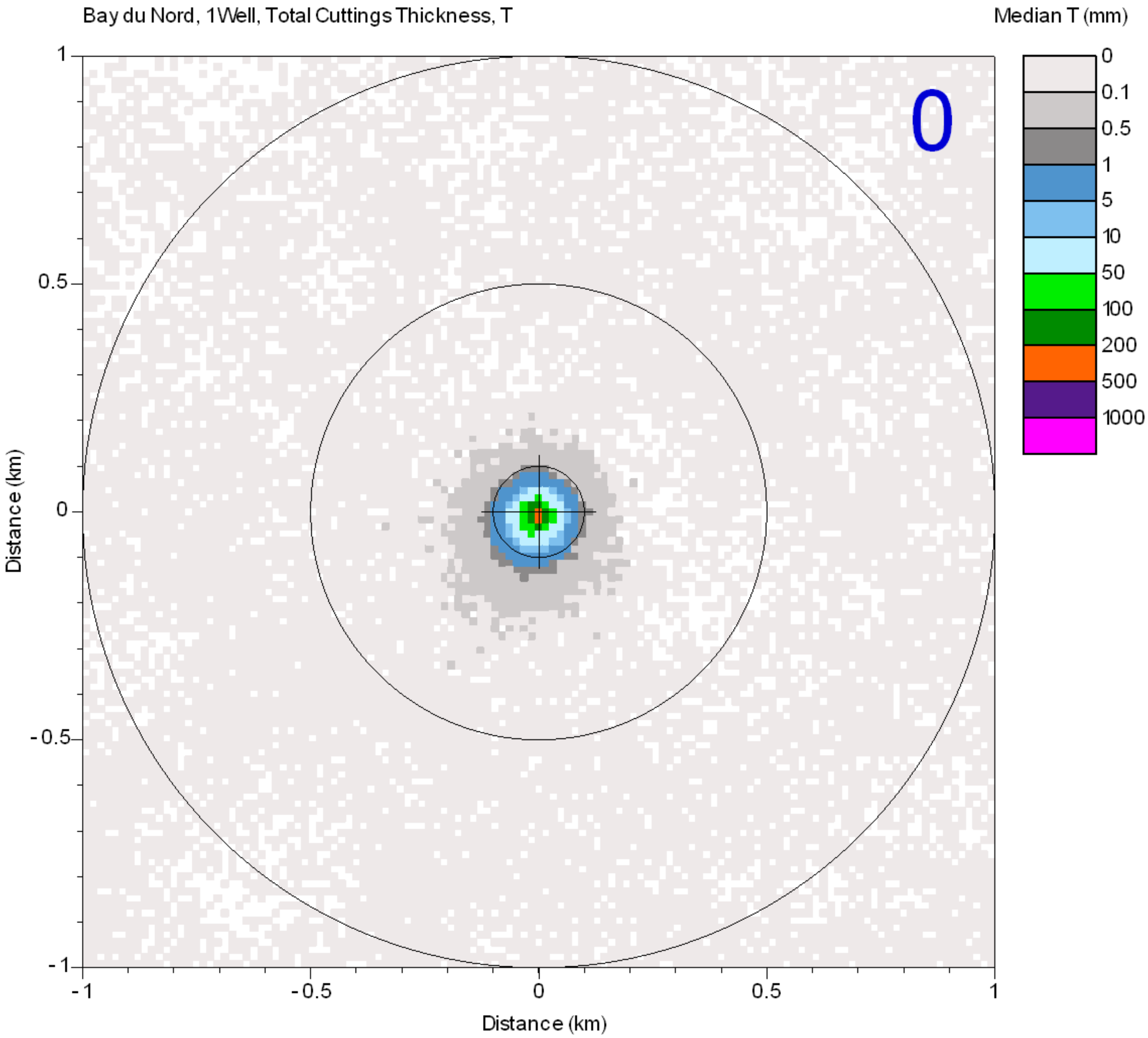

Figure 5-12 Base Case, with Flocculation ('0'), Median Total Cuttings Thickness, 1 km view

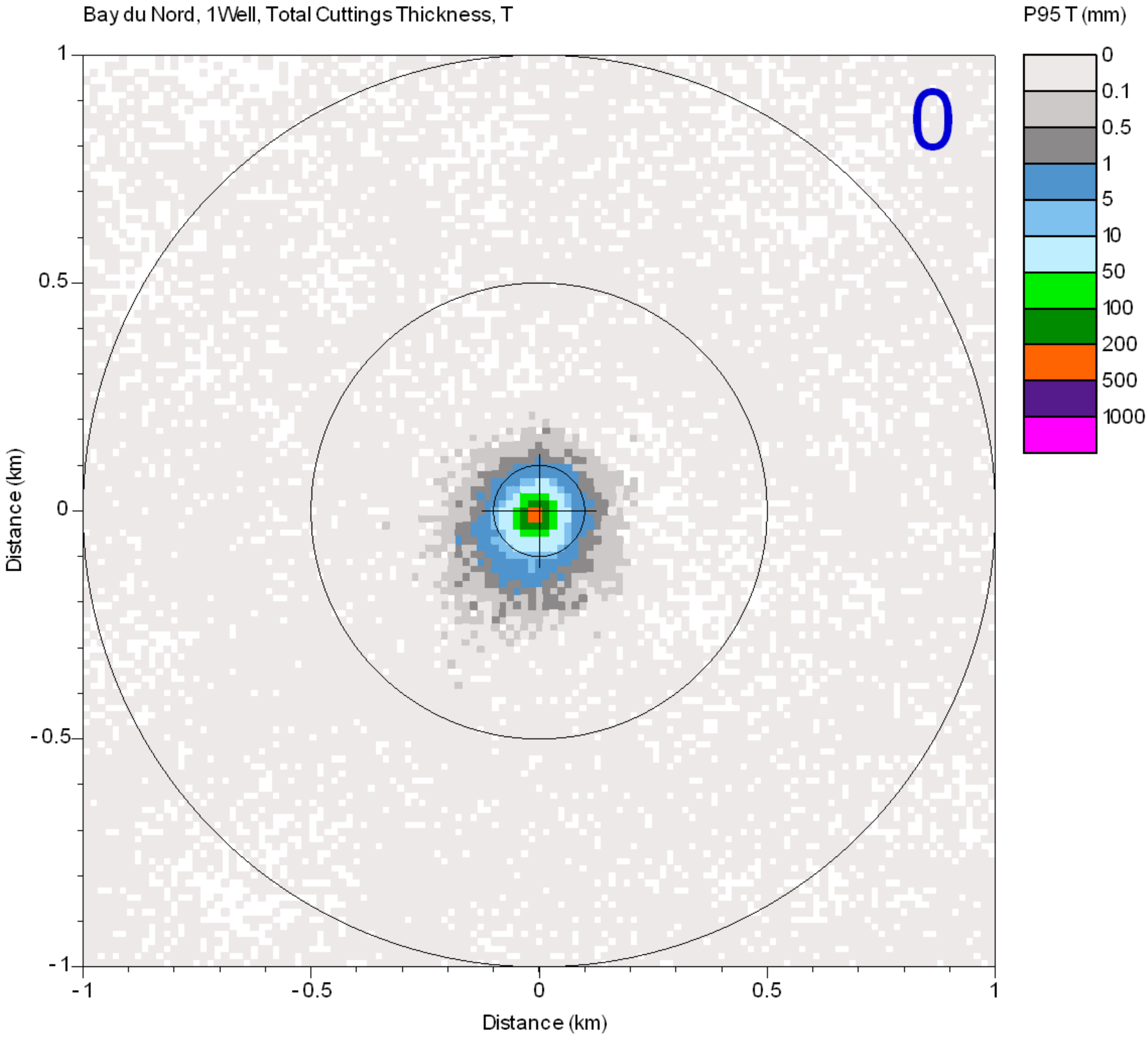

Figure 5-13 Base Case, with Flocculation (‘0’), P95 Total Cuttings Thickness, 1 km view

For the base case with no flocculation (‘A’) simulation shown in Figure 5-14, the median thickness within about 100 m of the wellsite is predicted to be 5 mm or above. Patches with median thickness as large as 5 mm are located about 1.7 to 2 km to the southwest but for the most part median thicknesses outside of the first 100 m remain at or below 1 mm and generally below 0.1 mm. The companion illustration of the P95 thickness for the base case with no flocculation (‘A’) in Figure 5-15 shows a similar distribution outline or boundary but with a noticeably greater area reporting thicknesses in the 1 to 5 mm range. In this way, should the PNET of 1.5 mm be of interest, the distances at which that threshold is exceeded would be greater; however, the key observation is that these P95 values represent only the largest of predicted values (in the sense that 95 percent of predicted thicknesses will be below this) and not as likely to be encountered as the median for example.

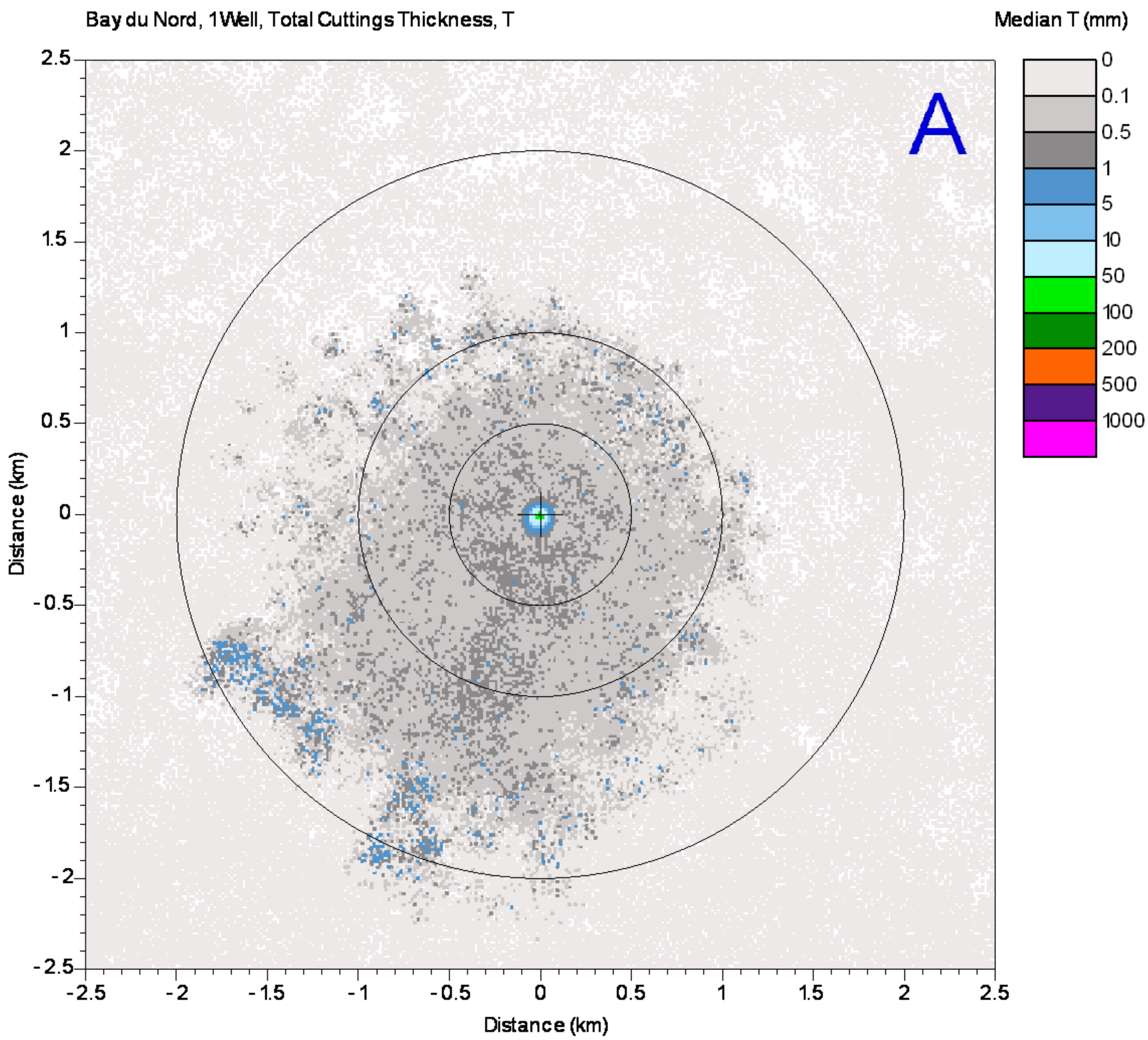

Figure 5-14 Base Case, no Flocculation ('A'), Median Total Cuttings Thickness, 2.5 km view

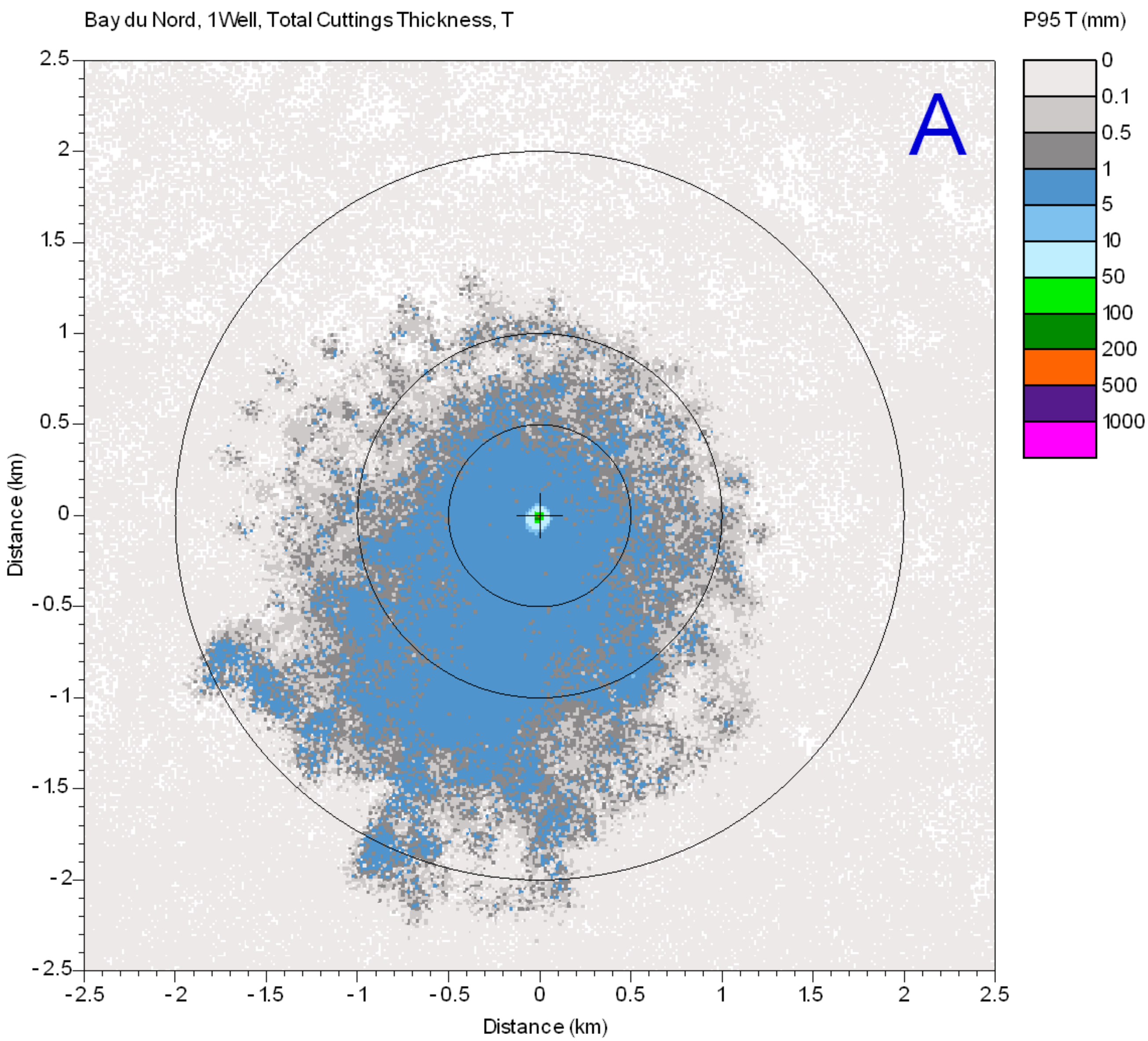

Figure 5-15 Base Case, no Flocculation ('A'), P95 Total Cuttings Thickness, 2.5 km view

Figure 5-16 presents the results of the Troll A Platform average PSD ('B') simulation. Circles are shown at a radius of 500 m, 1 km and 2 km. A 2.5 km scale is used for comparison with the base case no flocculation ('A') simulation. As with the base case with flocculation ('0') simulation, any thicknesses of 5 mm or greater are confined to within about 100 m. This is consistent with the bulk of the cuttings material settling within these distances: as reported in Table 5-1 about 50 percent of the material for all simulations except the base case no flocculation ('A') settle within 100 m: for ('A') 26 percent of the material settles within 100 m. A 'zoomed-in' 500 m view for the Troll A Platform average PSD ('B') simulation is shown in Figure 5-17 Troll A Platform, Average PSD ('B'), Median Total Cuttings Thickness, 500 m view. Here the 100 m and 200 m radius circles are shown. With the short distance for material to settle at the wellsite most of the material is 'piled' up within the one wellsite grid cell of 16 m x 16 m with a median thickness of 1,456 mm predicted there (Table 5-2). At immediately neighbouring grid cells, median total cuttings thicknesses are between 50 and 100 mm (Table 5-2).

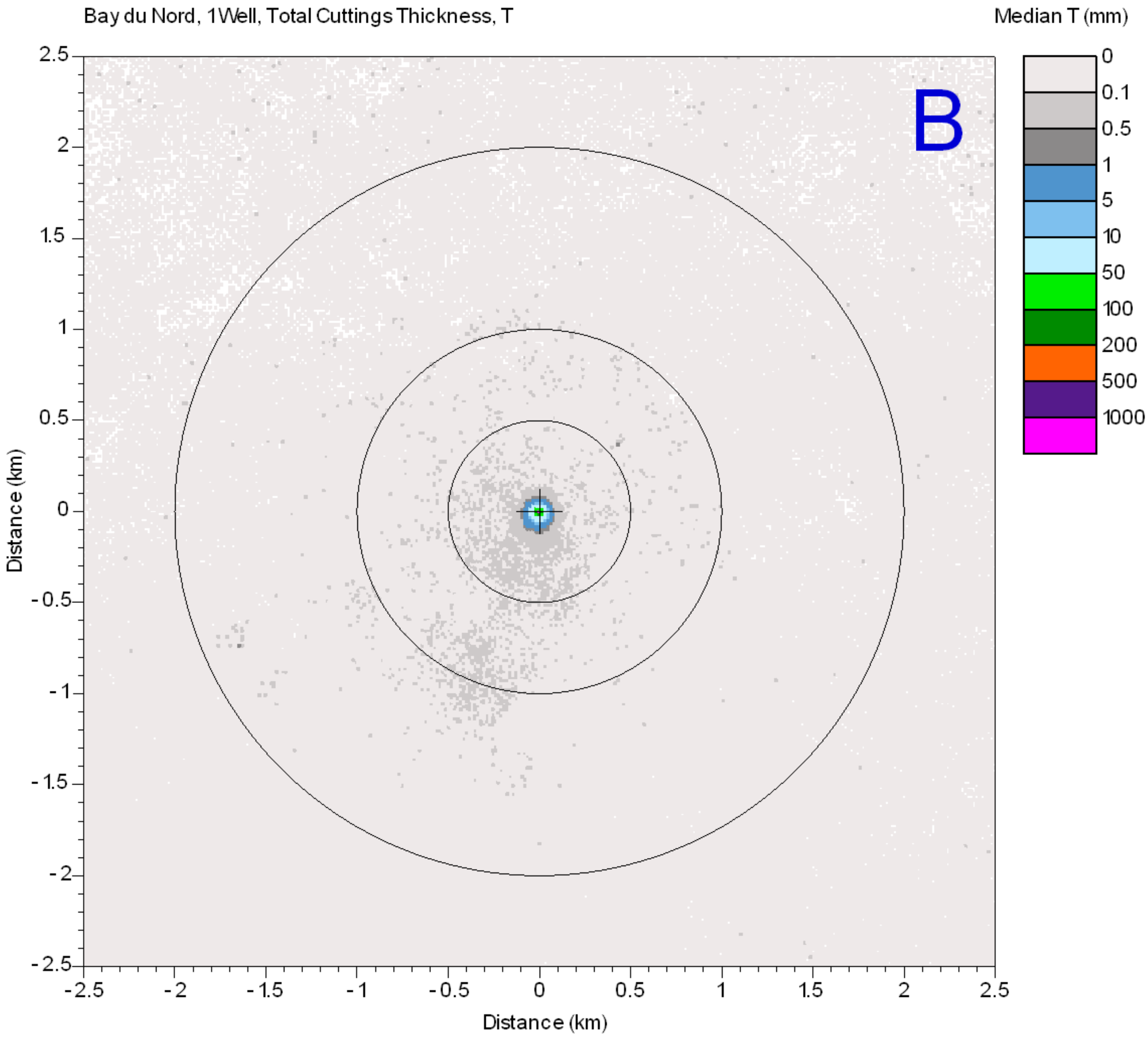

Figure 5-16 Troll A Platform, Average PSD ('B'), Median Total Cuttings Thickness, 2.5 km view

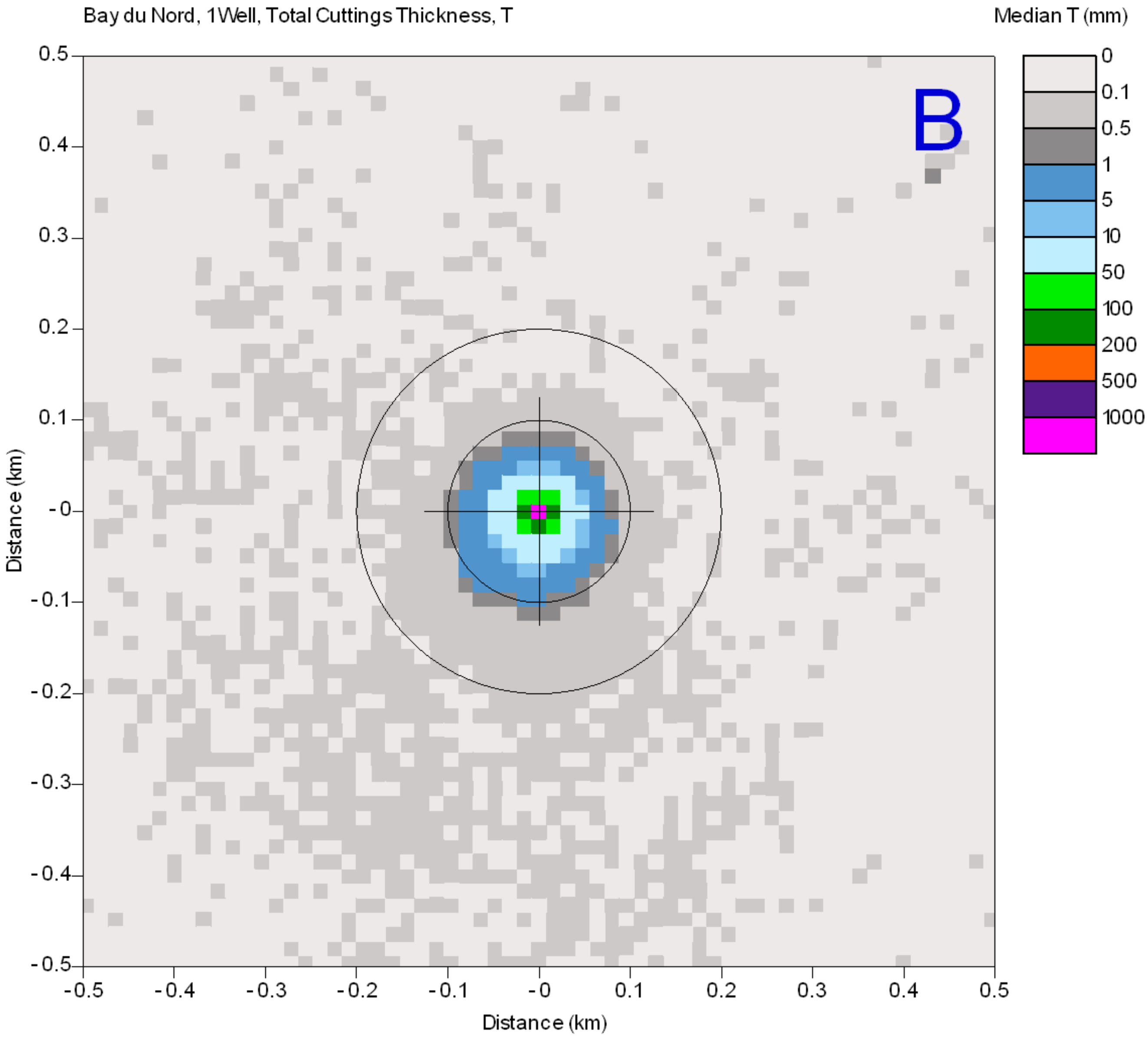

Figure 5-17 Troll A Platform, Average PSD ('B'), Median Total Cuttings Thickness, 500 m view

Figure 5-18 presents the results of the Troll A Platform maximum PSD ('C') simulation with median total cuttings thickness shown. Circles are shown at a radius of 500 m, 1 km and 2 km. The cuttings thickness pattern is similar to that for the Troll A Platform average PSD ('B') simulation with any thicknesses greater than 5 mm being confined to within about 100 m of the wellsite. Scattered areas which report median thicknesses up to 0.5 mm are seen at greater distances as for Troll A Platform average PSD ('B') simulation though over a somewhat larger area and at greater distances out to 2. 5 mm and beyond. As reported in Table 5-2 median total cuttings thicknesses beyond 2 km are calculated to be 0.4 mm with a maximum value of 1 mm (as indicated by several darker grey 0.5 to 1.0 mm grid cells pixel).

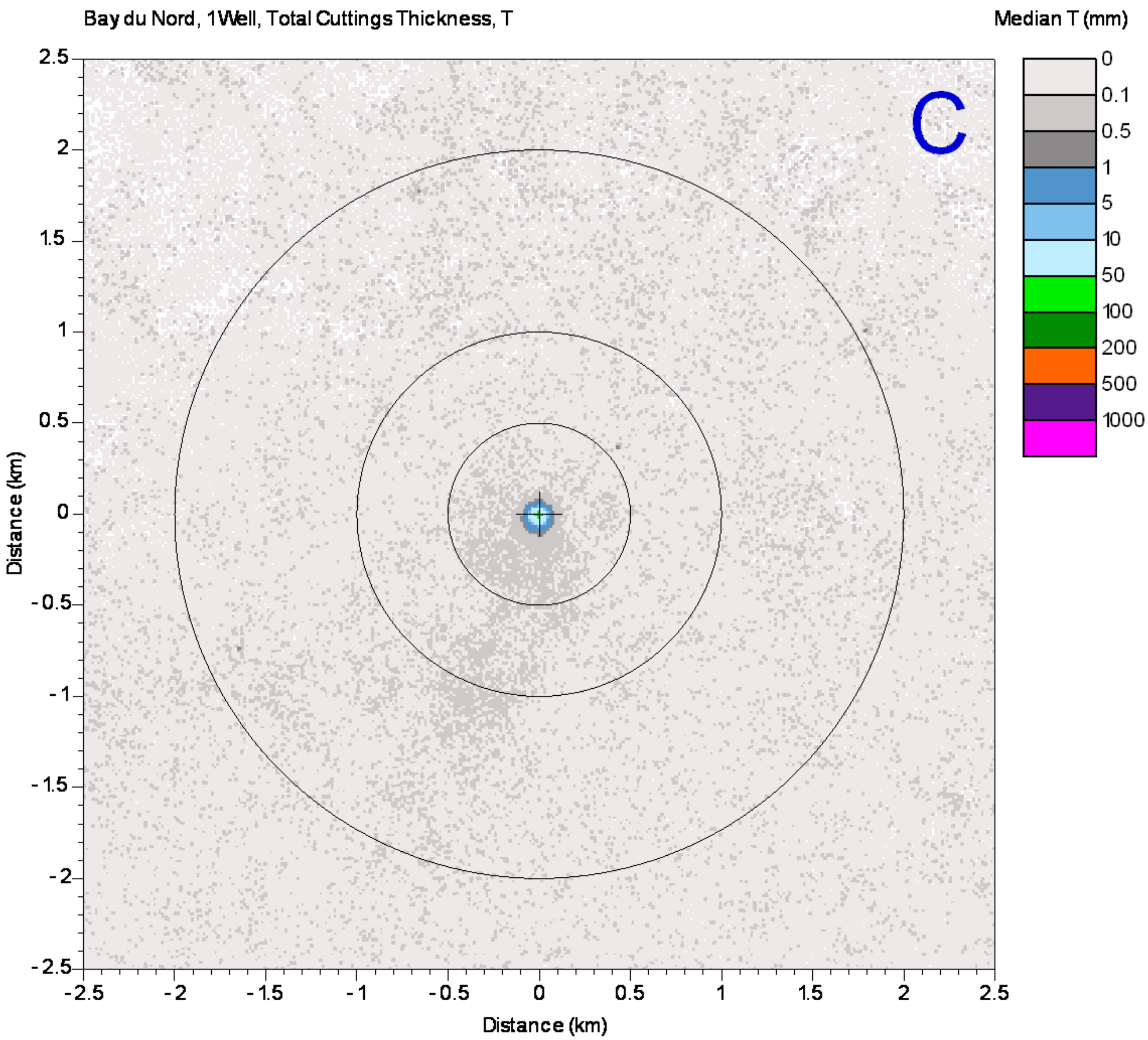

Figure 5-18 Troll A Platform, Maximum PSD ('C'), Median Total Cuttings Thickness, 2.5 km view

Figure 5-16 presents the results of the Nedwed ('D') simulation with median total cuttings thickness shown. Circles are shown at a radius of 500 m, 1 km and 2 km. The cuttings thickness patterns are very to those of the Troll A Platform ('B' and 'C') simulations with cuttings thickness being greater than 5 mm within about 100 to 120 m of the wellsite and then scattered areas of median thicknesses up to 0.5 mm at greater distances. As reported in Table 5-2 median total cuttings thicknesses beyond 2 km are calculated to be 0.5 mm with a maximum value of 2 mm.

Overall, it is noted, for all five simulations, the median thicknesses are on the order of 10 mm or greater within about 100 m and then generally rapidly fall to values of less than 1 mm. As noted above the one exception is for the base case, no flocculation simulation ('A'), with median thicknesses up to 5 mm up to about 2 km (Table 5-2) to the southwest.

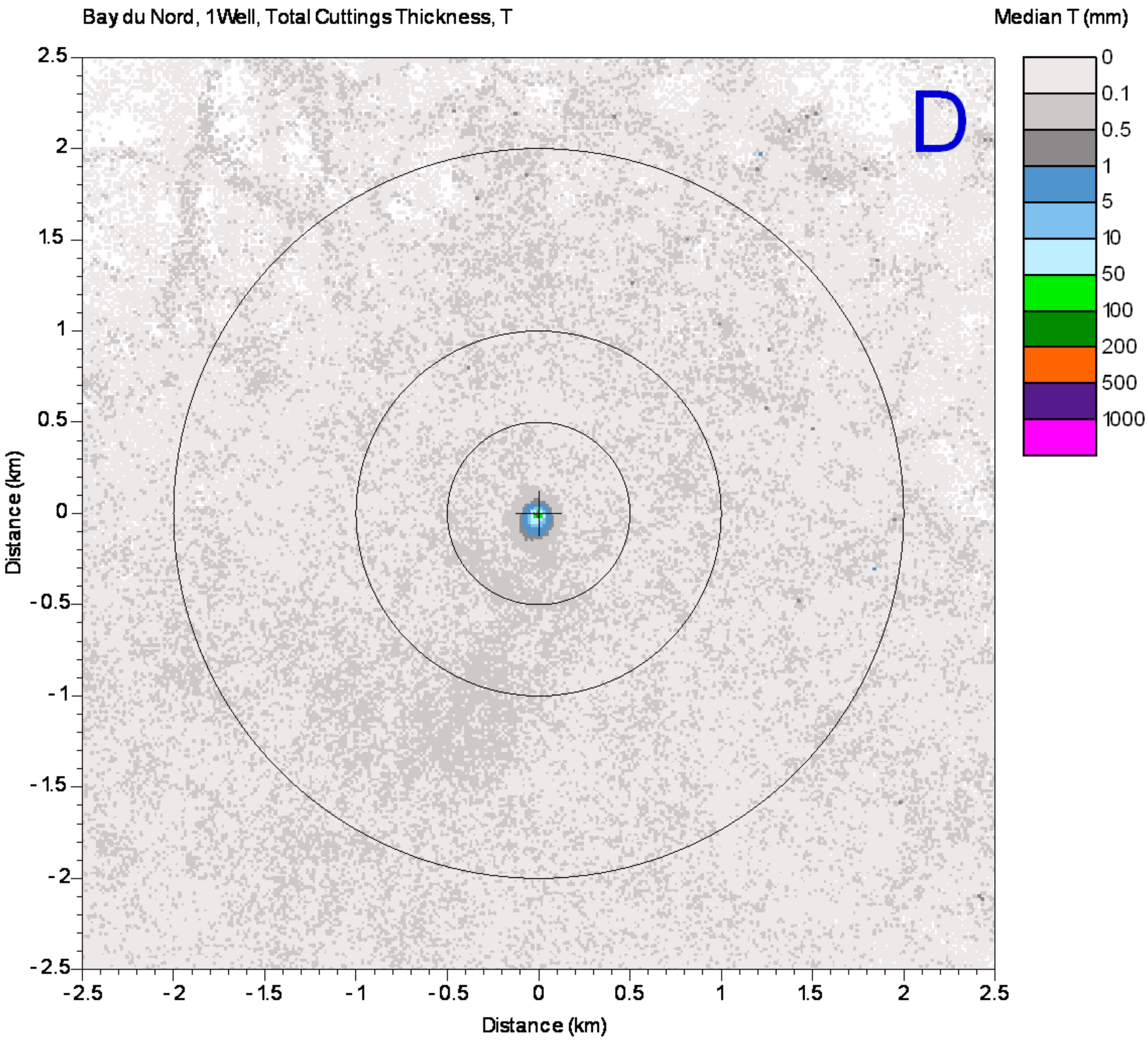

Figure 5-19 Nedwed ('D') Median Total Cuttings Thickness, 2.5 km view

5.1.5 Probability of Exceeding PNET of 1.5 mm and 6.5 mm (One Well)

The stochastic analysis yields the probability that the initial cuttings thickness at any given location will be greater than the PNET values of 1.5 mm and 6.5 mm.

To illustrate the probability range for thicknesses exceeding a given threshold, in this case the 1.5 mm PNET, results are first shown for the two base case PSD simulations, with ('0') and without ('A') flocculation (Figure 5-20 and Figure 5-21). Following this, the probabilities of exceeding both PNET values of 1.5 mm and 6.5 mm are shown for all five input PSD simulated (Figure 5-22 and Figure 5-23) and at two probability levels that a threshold is exceeded: a high likelihood of exceedance of greater than five percent, and a low likelihood of exceedance of less than five percent.

Figure 5-20 and Figure 5-21 show the probability of total cuttings thickness exceeding 1.5 mm for the two base case simulations. Probability scales of 0, 5, 10, 25, 50, 75, 95 and 100 percent are shown. Circles are drawn at a radius of 100, 200 and 500 m, 1 km and 2 km distance from the wellsite.

Both simulations (Figure 5-20 and Figure 5-21) show a very high probability (95 percent or greater as shown in the orange model grid cells) of the total cutting thickness exceeding 1.5 mm within about 50 to 100 m from the wellsite base case with flocculation simulation ('0') and within about 40 to 80 m for the base case no flocculation simulation ('A'). This is consistent with greater settling occurring closer to the wellsite with flocculation and hence (slightly) increased thicknesses for all deterministic model runs (Section 2.2). Figure 5-20 shows an above average likelihood (greater than 50 percent, as shown in the green model grid cells) of exceeding the threshold at distances to about 120 m for the base case with flocculation simulation ('0') while in Figure 5-21 for the base case no flocculation simulation ('A') within about 100 m for the same greater than 50 percent probability level.

To estimate the distances at which the predicted total cuttings thicknesses may exceed a given PNET thickness of interest at a high confidence (given the stochastic approach) two probability thresholds are shown. A range of zero to five percent corresponding to areas with a low (5 percent or less) likelihood of exceeding the thickness threshold of interest are shown in Figure 5-18 and Figure 5-19 in grey, while a range of 5 to 100 percent corresponds to any likelihood greater than five percent (shown in magenta or purple as noted below). In other words, there is a high (95 percent) likelihood that the PNET thickness would not be exceeded outside the magenta (or purple) areas.

Figure 5-22 shows the cuttings footprint plots, for the 1.5 mm PNET, showing two areas, those in magenta with a greater than five percent probability of thicknesses exceeding 1.5 mm and those in grey with a less than five percent probability. Circles are drawn at a radius of 500 m, 1 km and 2 km. While the base case with no flocculation ('A') simulation shows a greater than five percent probability of seeing above 1.5 mm within 500 m and out to just over 1 km to the southwest, the indication from the other four simulations is that the probability of exceeding 1.5 mm outside about 150 m is less than five percent. The Troll A Platform maximum PSD simulation result is not shown but is virtually identical to that of the Troll A Platform average PSD ('B').

Figure 5-23 shows the cuttings footprint plots, for the 6.5 mm PNET, showing two areas, those in purple with a greater than five percent probability of thicknesses exceeding 6.5 mm and those in grey with a less than five percent probability. Circles are drawn at a radius of 500 m and 1 km. All four input scenario simulations indicate the same general probability picture that the probability of exceeding 6.5 mm outside about 100 to 120 m is less than five percent. The Troll A Platform maximum PSD simulation not shown is virtually identical to those of the Troll A Platform average PSD B).

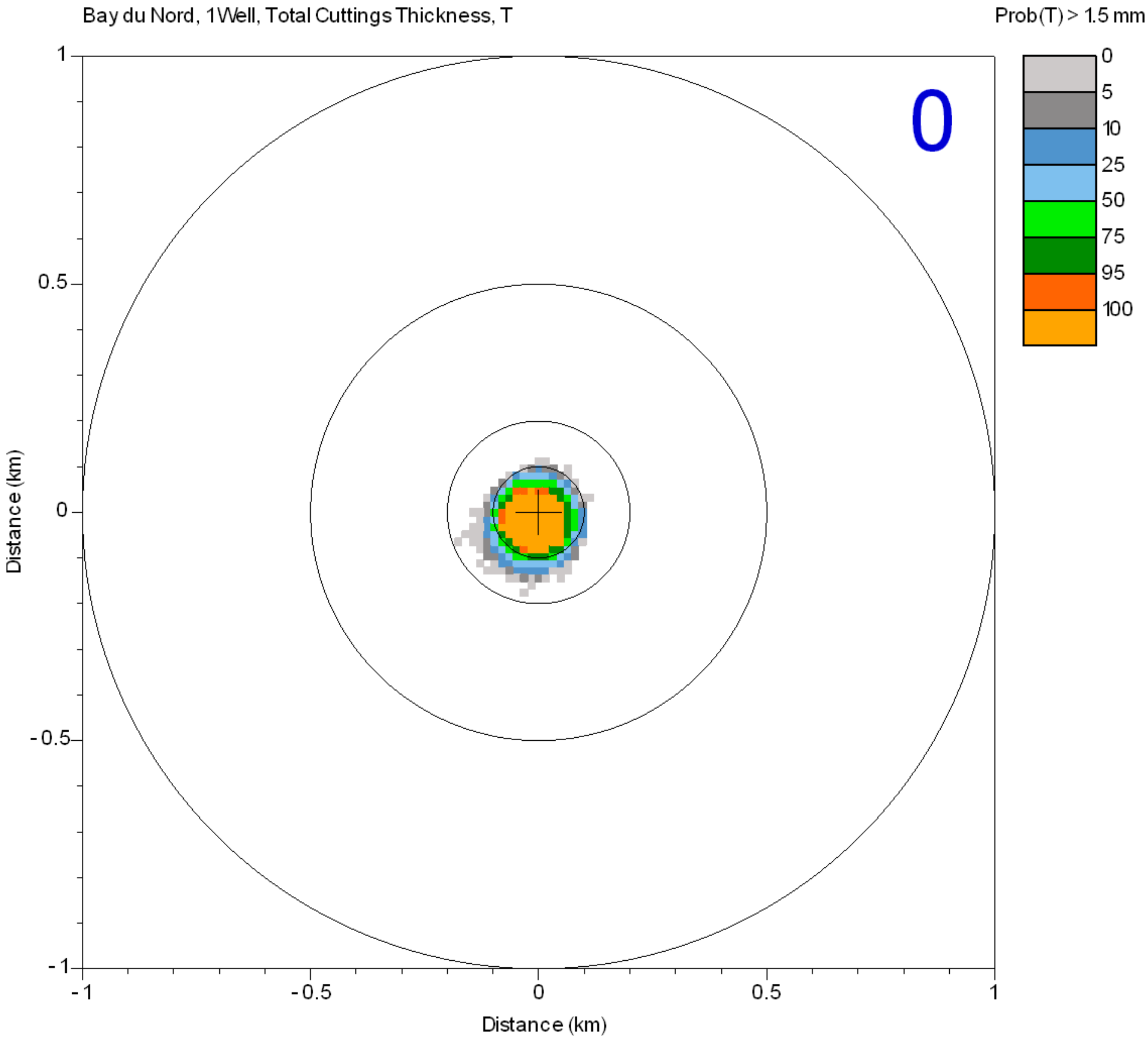

Figure 5-20 Probability of Total Cuttings Thickness Exceeding 1.5 mm, Base Case with Flocculation ('0'), 1 km view

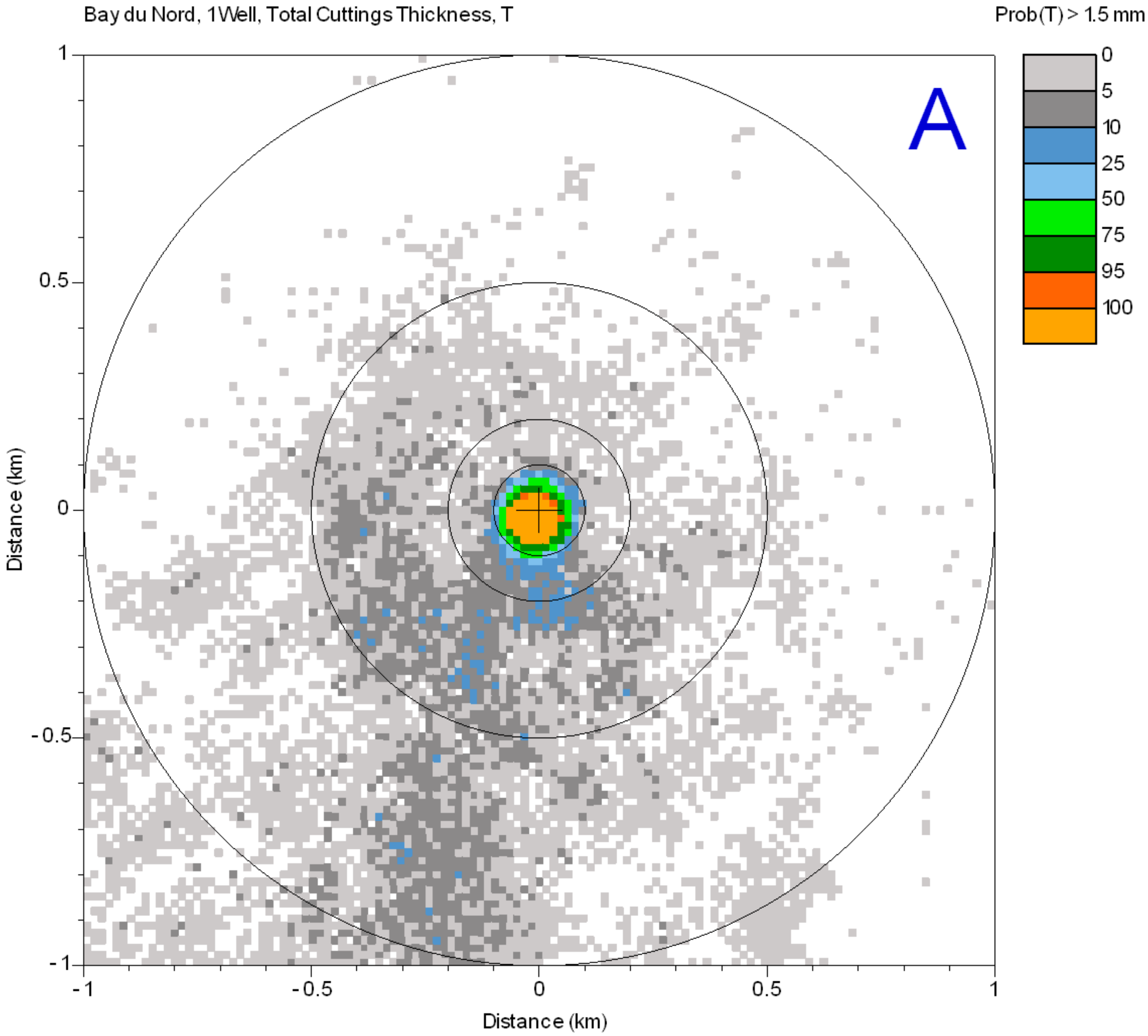

Figure 5-21 Probability of Total Cuttings Thickness Exceeding 1.5 mm, Base Case no Flocculation ('A'), 1 km view

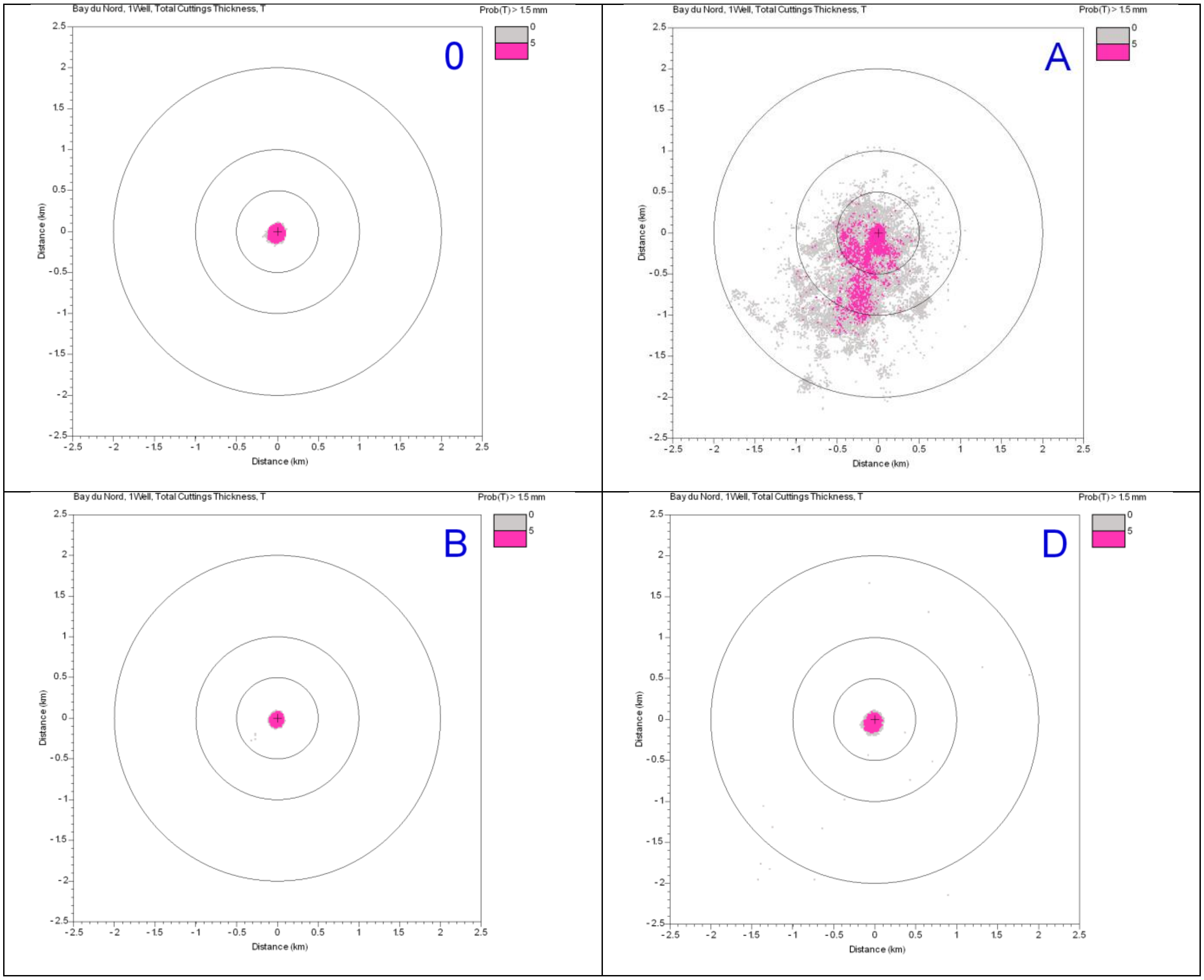

Figure 5-22 Probability of Total Cuttings Thickness Exceeding 1.5 mm greater than 5% (magenta) and less than 5% (grey). One Well Simulations shown are: Base Case with ('0'), and without ('A') flocculation, Troll A Platform Average PSD ('B') and Nedwed ('D'), 2.5 km view

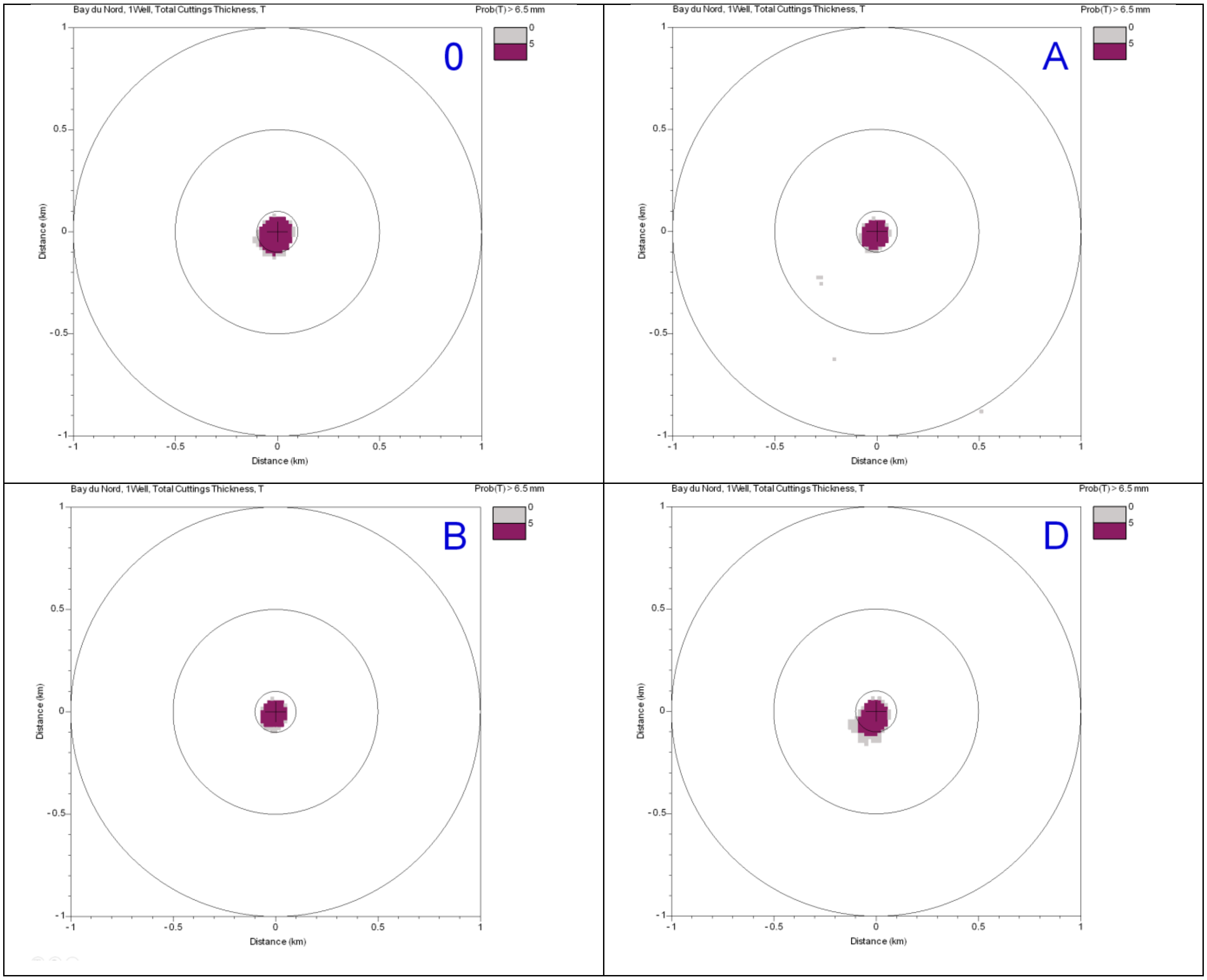

Figure 5-23 Probability of Total Cuttings Thickness Exceeding 6.5 mm greater than 5% (purple) and less than 5% (grey). One Well Simulations shown are: Base Case with ('0'), and without ('A') flocculation, Troll A Platform Average PSD ('B') and Nedwed ('D'), 1 km view

5.2 Eight Well Model Simulation

Based on review of the one well dispersion results, two input scenarios were carried forward for the eight well simulation to further acknowledge some uncertainty for the predictions. On the assumption that flocculation of the smallest cuttings particles is more likely than no flocculation ('A') occurring, the base case with flocculation ('0') was selected as one input condition. Given that the three remaining input scenarios yielding fairly similar predictions of the distribution of thickness with distance from the wellsite (e.g., Figure 5-10 for a cross-section view, Table 5-2 and Table 5-3 for thickness statistics) the Troll A Platform Average PSD ('B') input scenario was selected as being an appropriate representative. Therefore, results for eight well simulation for the base case flocculation ('0') and Troll A Platform Average PSD ('B') input scenarios are presented in this section.

The presentation of results follows the same sequence as in Section 5.1 for the one well simulations:

- illustration of the individual (deterministic) model run outputs underlying the stochastic analysis (Section 5.2.1)
- cross-sections of total cuttings thickness vs. distance for different statistics (e.g., the median or maximum thickness) in relation to 1.5mm and 6.5mm PNET values (Section 5.2.2)
- tables of a) how much material settles vs. distance and b) median and maximum cuttings thickness vs. distance, both for select distance range bins (Section 5.2.3)
- plan view maps of median (most likely) total cuttings thickness by distance from the wellsite (Section 5.2.4)
- plan view maps showing the probability of thickness being above the 1.5 mm and 6.5 mm PNET values (Section 5.2.5)

5.2.1 Deterministic Model Runs (Eight Wells)

All eight of the individual deterministic model run outputs that were input to the stochastic analysis for the ('0') Base case, flocculation and ('B') Troll A Platform, average PSD input scenarios are presented in Figure 5-24 and Figure 5-25. The well start dates are labelled in the upper left hand corner of each plot panel.

Predicted total cuttings thicknesses for the base case with flocculation ('0') (Figure 5-24) are greatest at the wellsite and within about 100 m and are consistently less than 0.1 mm farther away. There is also a general consistency in the overall thickness distributions between each of the eight deterministic runs. This is not unexpected given that, even with the simulated staggered drilling start dates (45 days apart) for each of the deterministic runs, each run will generally experience the full annual variation in ocean currents as each of the numerous well hole sections is drilled and cuttings discharged (Table 3-5).

Similar consistency in the total cuttings thickness distributions for each of the eight deterministic model runs is seen for the Troll A Platform Average PSD ('B') input scenario (Figure 5-25) as well. The two ('0' and 'B') predicted distributions are also quite similar with the primary difference being, for Troll A Platform Average PSD ('B') (Figure 5-25), there are large areas of thickness above 1 mm and also some patches with thicknesses up to 2 mm, generally to the southwest.

As illustrated below, this has the effect on the distances to PNET for median and maximum thicknesses (Sections 5.2.2, 5.2.3 and 5.2.4), in that the Troll A Platform Average PSD ('B') scenario simulation thicknesses extend greater distances, though with less of an effect for the probability of exceeding those thresholds for a five percent likelihood (Section 5.2.5), i.e., both input scenarios yield similar estimates of 'distance to PNET' with the same high degree of likelihood.

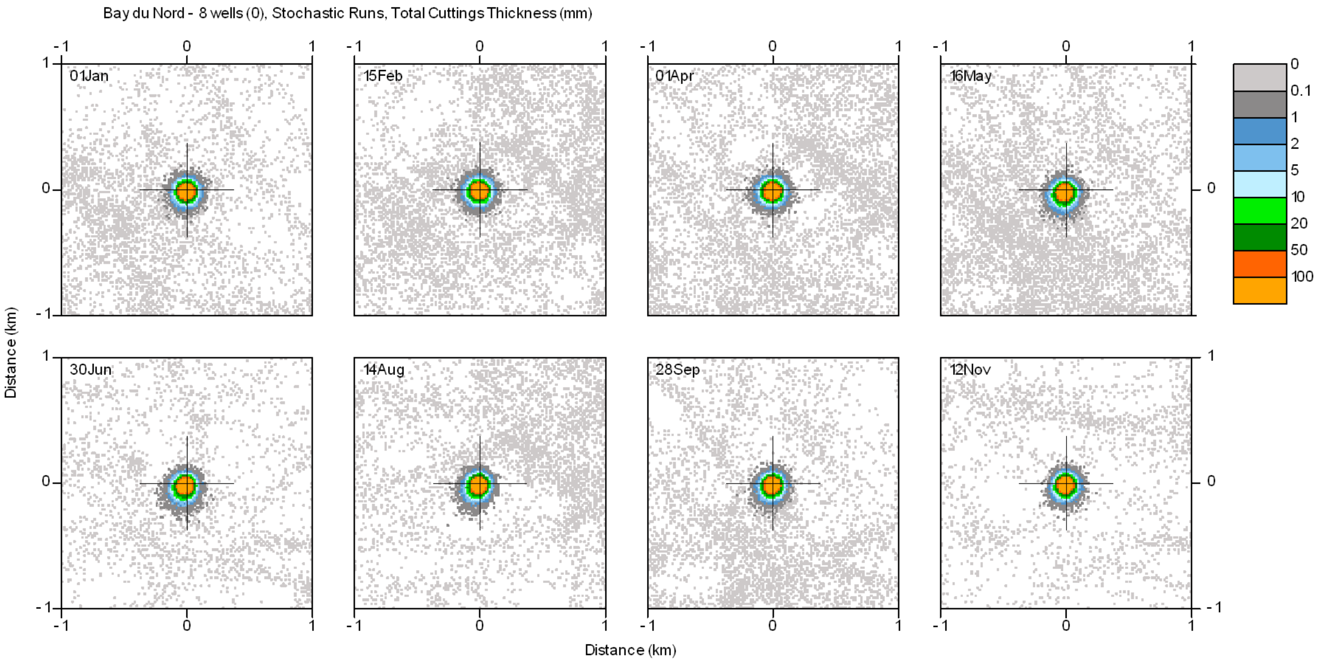

Figure 5-24 Base Case, with Flocculation ('0'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, Eight Well Simulation, 1-km View

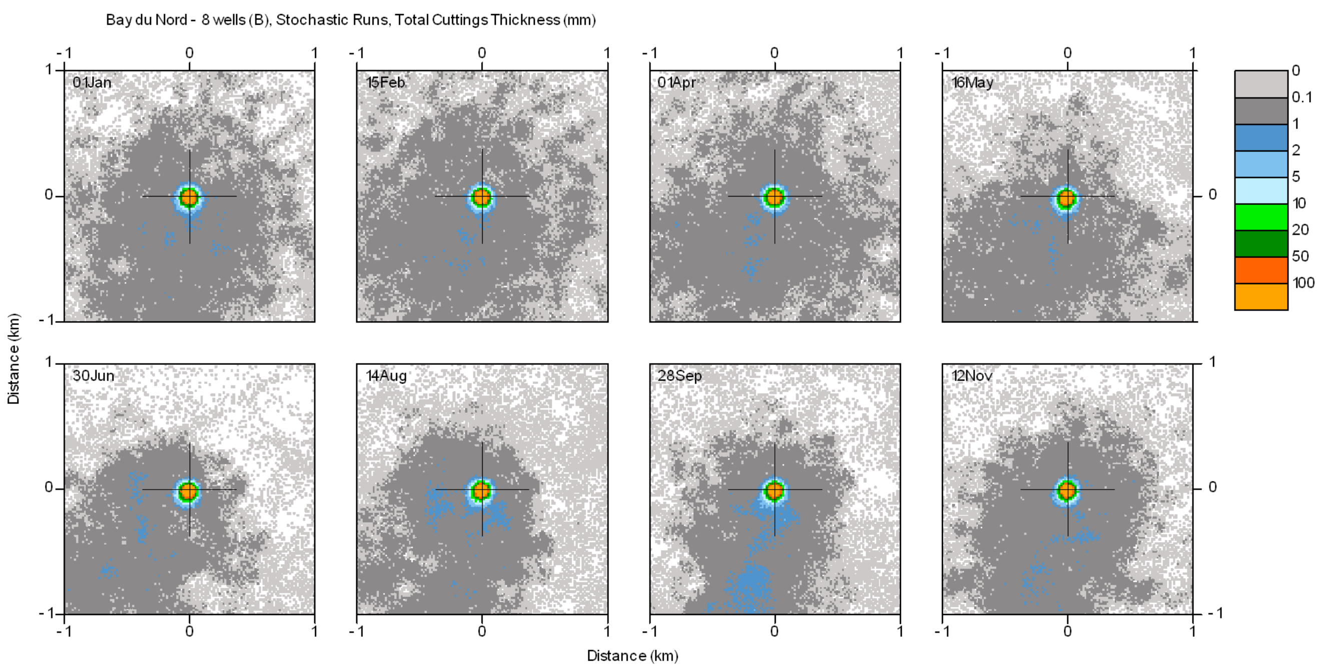

Figure 5-25 Troll A Platform Average PSD ('B'), Total Cuttings Thickness (mm) for Eight Deterministic Runs, Eight Well Simulation, 1-km View

5.2.2 Cross-Sections of Total Cuttings Thickness by Distance (Eight Wells)

Cross-sections of the total (WBM+SBM) drill cuttings footprints are presented to show at what distance any thickness thresholds of interest, e.g., the predicted no effect threshold (PNET) thicknesses, might be reached. Results are shown for the base case with flocculation ('0') and Troll A Platform average PSD ('B') eight well simulations.

Figure 5-26 shows the total cuttings thickness, for the base case, with flocculation ('0'). The P25, median (P50), P75, P95 and maximum (P100) thickness statistics versus horizontal distance from the wellsite are shown. It is noted that the statistics are calculated based on just the model output grid cells that have a non-zero thickness and considering all eight deterministic runs (Section 2.2). The average of all grid cell values for a given statistic is the value plotted, e.g., the median is calculated as the average of all median thicknesses for a given distance; the P95 is taken as the average of all P95 thickness values. The exception is the maximum which is taken as the maximum of any thicknesses for the given distance of interest. These statistics quantify the thicknesses in those instances when one or more of the deterministic runs predicts some cuttings deposition, at a given distance. The PNET thicknesses for burial, 1.5 mm and 6.5 mm are drawn in pink. To permit viewing on a logarithmic scale, the values at the origin (wellsite, x=0) are plotted at a distance of 0.01 km.

Figure 5-26 shows that the P25, median, P75 and P95 thickness statistics are quite similar for the base case with flocculation ('0') simulation with values as large as about 2,682 mm (Table 5-5) (noting that slumping and weathering of the material will result in lower thicknesses) near the wellsite, falling to about 190 to 280 mm at 50 m distance and crossing the PNET of 6.5 mm at about 105 to 120 m and reaching the 1.5 mm PNET at about 130 to 150 m. This close grouping of these statistics indicates an overall consistency in the underlying eight deterministic runs. The maximum thickness reports values of about 560 mm at 50 m distance, reaching the 6.5 mm PNET at about 140 m and reaching the 1.5 mm PNET at about 190 to 200 m.

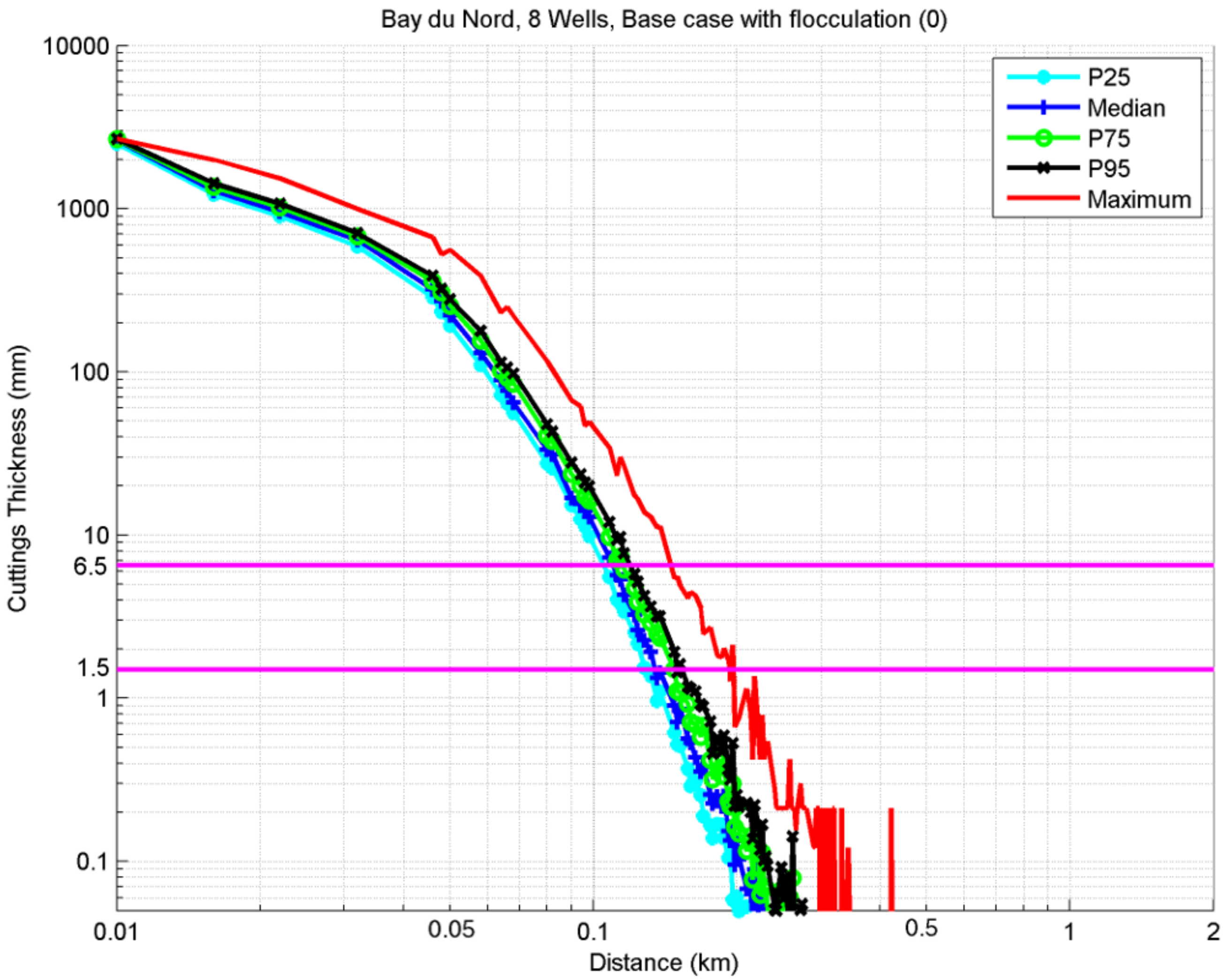

Figure 5-26 Eight Wells, Base Case, with Flocculation ('0'), Total Cuttings Thickness

A similar cross-section of total cuttings thickness for the Troll A Platform average PSD ('B') eight well simulation is shown in Figure 5-27. The P25, median, P75 and P95 thickness statistics are again quite similar with values as large as about 11,700 mm (Table 5-5) (noting that slumping and weathering of the material will result in lower thicknesses) near the wellsite, falling to about 80 to 112 mm at 50 m distance, crossing the PNET of 6.5 mm at about 90 to 100 m and reaching the 1.5 mm PNET at about 120 to 140 m. Again, the close values of these statistics indicate an overall consistency in the underlying eight deterministic runs. The maximum thickness reports values of about 200 mm at 50 m distance, reaching the 6.5 mm PNET at about 120 m and reaching the 1.5 mm PNET at about 170 m.

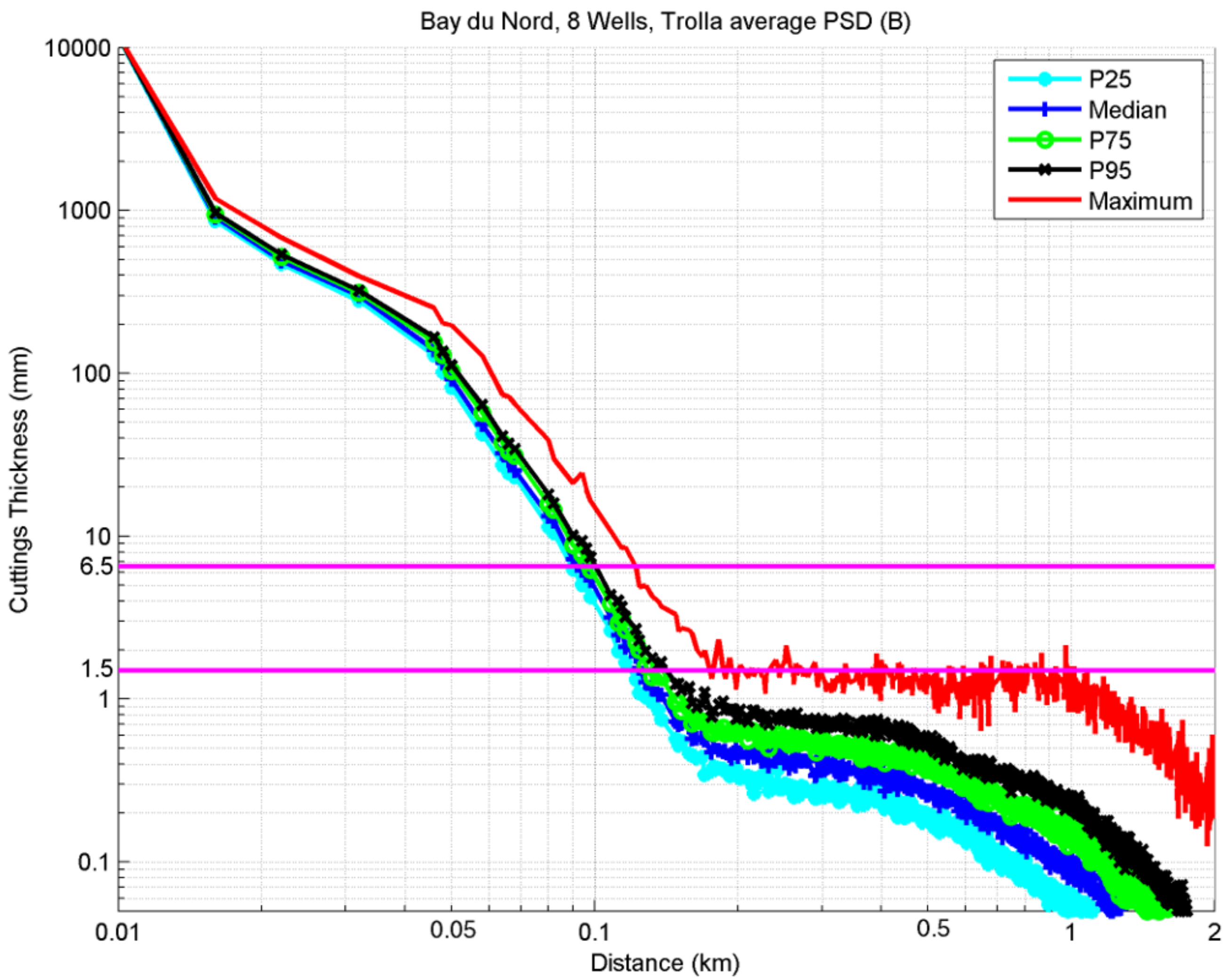

Figure 5-27 Eight Wells, Troll A Platform Average PSD ('B') Total Cuttings Thickness

Figure 5-28 shows the median and maximum thicknesses with distance from the wellsite for the base case with flocculation ('0') and Troll A Platform average PSD ('B') eight well simulations. Median thicknesses are above the

PNET of 6.5 mm distances near the wellsite and drop to 6.5 mm at distances of about 90 m and 100 m for the Troll A Platform and base case, respectively. The 1.5 mm PNET is reached shortly after at about 120 m for both input scenarios ('0' and 'B'). The maximum predicted thicknesses are above the PNET of 6.5 mm up to about 120 m and 140 m (Troll A Platform and base case, respectively) and reach the 1.5 mm PNET shortly after at about 200 m. As indicated by the Troll A Platform average PSD maximum thickness line hovering about the 1.5 mm PNET for distances out to 1 km, there is at least one of the eight deterministic runs with thicknesses at that value; however, as evidenced by the corresponding Troll A Platform average PSD median line, thicknesses are more likely to remain below 1.5 mm. The base case, with flocculation ('0') results indicates lower initial thicknesses at the wellsite than for the Troll A Platform average PSD ('B') but somewhat larger thicknesses then consistently out to about 150 m after which Troll A Platform average PSD ('B') are again larger but at the distance for which median thicknesses are quite low at 0.5 mm or below.

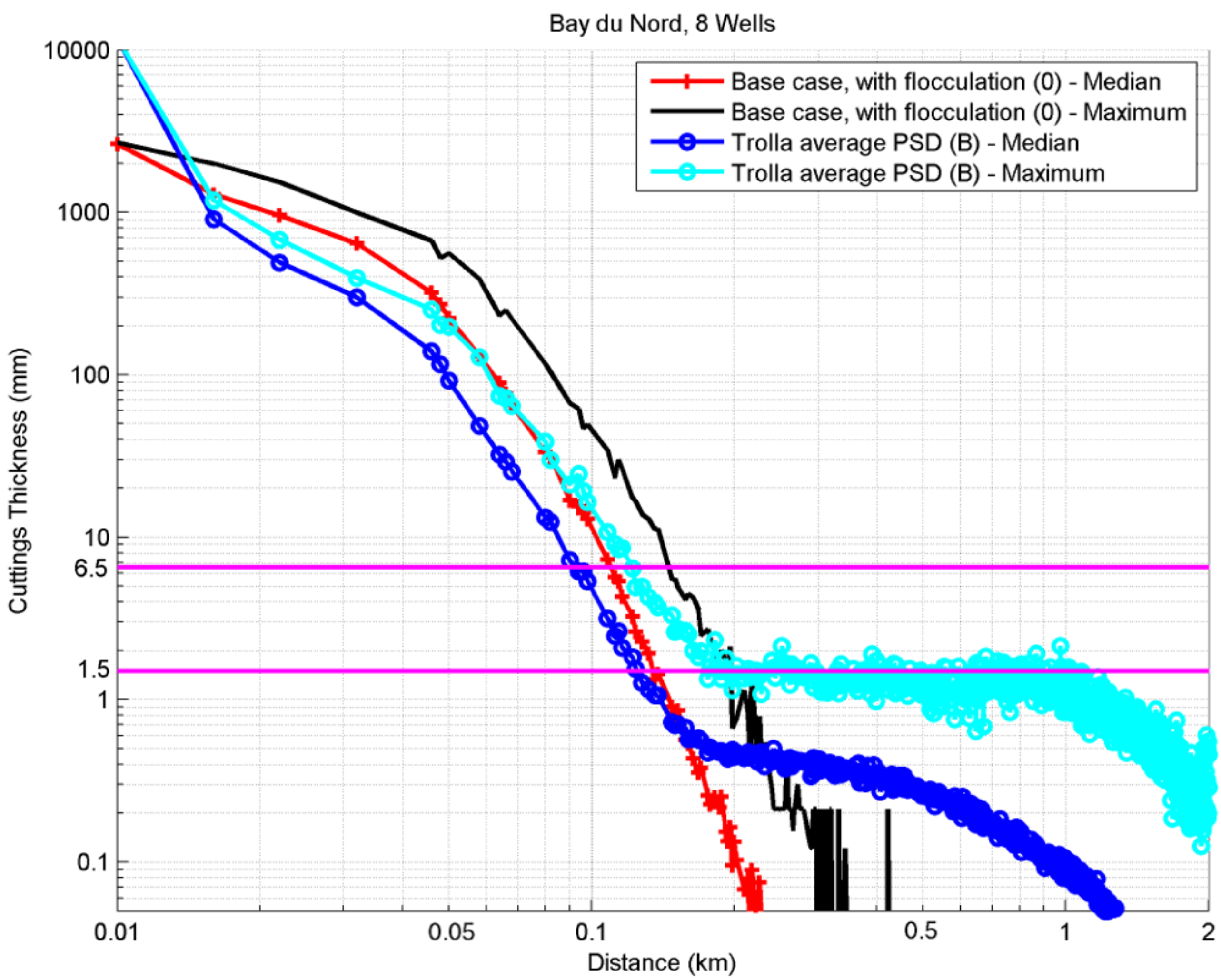

Figure 5-28 Eight Wells, Base Case, with Flocculation ('0') and Troll A Platform Average PSD ('B') Total Cuttings Thickness

5.2.3 Cuttings Material Settled, Median and Maximum Thickness by Distance (Eight Wells)

Since all WBM cuttings are predicted to settle within the model domain any unsettled material will be SBM cuttings. Since there is a smaller volume of SBM cuttings per well under the eight well simulation (Table 3-2) the corresponding percentages of material remaining unsettled are less than with the one well simulations (Table 5-1).

The amounts of total (WBM+SBM) cuttings material modelled to settle for selected distances from the wellsite (origin) are presented in Table 5-4. For the base case with flocculation ('0') eight well simulation about 75 percent of the cuttings material is predicted to settle within 100 m of the wellsite, compared with about 67 percent for the Troll A Platform average PSD ('B'). Just over two percent of the remaining cuttings material is predicted to initially settle within the model domain (out to distances of about 23 km) with a further 22 percent being highly dispersed SBM cuttings released from the sea surface for the base case ('0'). By comparison, the remaining material for the Troll A Platform average PSD ('B') simulation is predicted to settle at about 13 percent between 200 m and 5 km and about 10 percent past 5 km and almost 9 percent of the total cuttings material (all SBM cuttings) predicted not to settle in the model domain.

Slumping of the larger cuttings piles near the wellsite will occur resulting in smaller thicknesses. This is especially true given a drilling duration of over one year for drilling and release of cuttings materials for eight wells with the effects of weathering of the cuttings piles.

Table 5-4: Total Cuttings Material Settled (%) by Distance from the Wellsite, Eight wells

	Distance from Wellsite								
Simulation	Wellsite	10-100m	100-200m	200-500m	500m-1km	1-2km	2-5km	5-23km	Unsettled
	% Material Settled								
'0' Base case, with flocculation	7.2	68.1	1.9	<0.01	<0.01	0.0	0.1	0.4	22.3
'B' Troll A Platform, average PSD	33.1	34.1	1.1	2.7	4.0	2.8	3.4	10.1	8.7

Note: due to rounding some row totals may not exactly equal 100.

Summaries of median and maximum cuttings thicknesses with distance are presented in Table 5-5 and Table 5-6. Median thicknesses are calculated as the average of all median thickness values for a given 'distance from wellsite' range. Only those sea bottom model grid cells with cuttings deposition, i.e., non-zero median thickness values are considered. The maximum thicknesses are the one largest thickness observed in each 'distance from wellsite' bin. Maximum total cuttings thicknesses are located at the wellsite (origin). The statistics are calculated considering all eight deterministic runs completed for the eight well simulations.

Consistent with the greater amount of material predicted to settle in the immediate vicinity of the wellsite for the Troll A Platform average PSD ('B') simulation (due to a larger proportion of larger sand-sized cuttings compared with the base case – see Table 3-6 and Table 3-8) cuttings thicknesses are predicted to be measurably larger. The predicted median thicknesses for Troll A Platform average PSD ('B') at the wellsite are 11,699 mm compared with 2,633 mm for the base case, although slumping of these large cuttings piles will occur as well as weathering over time. In the 10 to 100 m range Troll A Platform average PSD ('B') thicknesses range from a median of 100 mm to a maximum of 1,180 mm, while for the base case the corresponding median and maximum thicknesses are 200 mm and 1,993 mm. Outside of 100 m, median thicknesses are 2 mm or less for the base case with flocculation ('0') and 1 mm or less for Troll A Platform average PSD ('B'). Maximum thicknesses of 46 mm and 14 mm are predicted for the base case and Troll A Platform average PSD in the 100 to 200 m range; beyond 1 km, maximum thicknesses are 1 mm for the base case, 2 mm for Troll A Platform average PSD.

Table 5-5: Median Cuttings Thickness by Distance from the Wellsite, Eight wells

	Distance from Wellsite							
Simulation	**Wellsite**	**10-100m**	**100-200m**	**200-500m**	**500m-1km**	**1-2km**	**2-5km**	**5-23km**
	Cuttings Thickness (mm)							
'0' Base case, with flocculation	2,633	199	2	<0.01	<0.01	<0.01	<0.01	<0.01
'B' Troll A Platform, average PSD	11,699	100	1	0.4	0.2	<0.01	<0.01	<0.01

Note: slumping of the larger cuttings piles near the wellsite will likely occur resulting in smaller thicknesses.

Table 5-6: Maximum Cuttings Thickness by Distance from the Wellsite, Eight wells

	Distance from Wellsite							
Simulation	**Wellsite**	**10-100m**	**100-200m**	**200-500m**	**500m-1km**	**1-2km**	**2-5km**	**5-23km**
	Cuttings Thickness (mm)							
'0' Base case, with flocculation	2,682	1,993	46	1	<0.01	<0.01	<0.01	<0.01
'B' Troll A Platform, average PSD	11,725	1,180	14	2	2	2	0.7	0.1

Note: slumping of the larger cuttings piles near the wellsite will likely occur resulting in smaller thicknesses.

5.2.4 Cuttings Footprint Maps, Median Thickness (Eight Wells)

Figure 5-29 and Figure 5-30 present plan view maps of the median (most likely) cuttings thickness about the wellsite for the eight well model simulations completed with the two input scenarios: base case with flocculation ('0') and Troll A Platform average PSD ('B'), in the same manner as figures for the one well simulations (Section 5.1.4). Circles are drawn in the figures at distances of 200 m, 500 m and 1 km to assist in interpretation of the results. For both input scenarios, median thicknesses outside of about 200 m or less do not exceed 5 mm. Outside of 200 m, median thicknesses for the base case with flocculation ('0') predictions (Figure 5-29) do not exceed 1 mm, while for the Troll A Platform average PSD ('B') predictions (Figure 5-30) patches of up to 1 mm extend 500 m to the southwest and 800 m, and in some places 1 km to the south-southwest.

In the immediate vicinity of the wellsite, the initial thickness predictions, after over one year's drilling of eight wells, are over 1 m: for the base case with flocculation ('0') the estimated median thickness is about 2,600 mm, while for the Troll A Platform average PSD ('B') simulation it is about 11,700 mm.; however, as noted in Section 5.2.3, slumping of these cuttings material will occur and reduce these values to more on the order of one or, for the Troll A Platform simulation, several metres. Further, this does not consider the weathering of these larger cuttings piles over the long drilling period for eight wells. In this way, the predictions presented for the eight well simulations are quite conservative. The main observation is that a considerable amount of cuttings material is predicted, over the course of the drilling period, to initially settle in the immediate vicinity of the wellhead template.

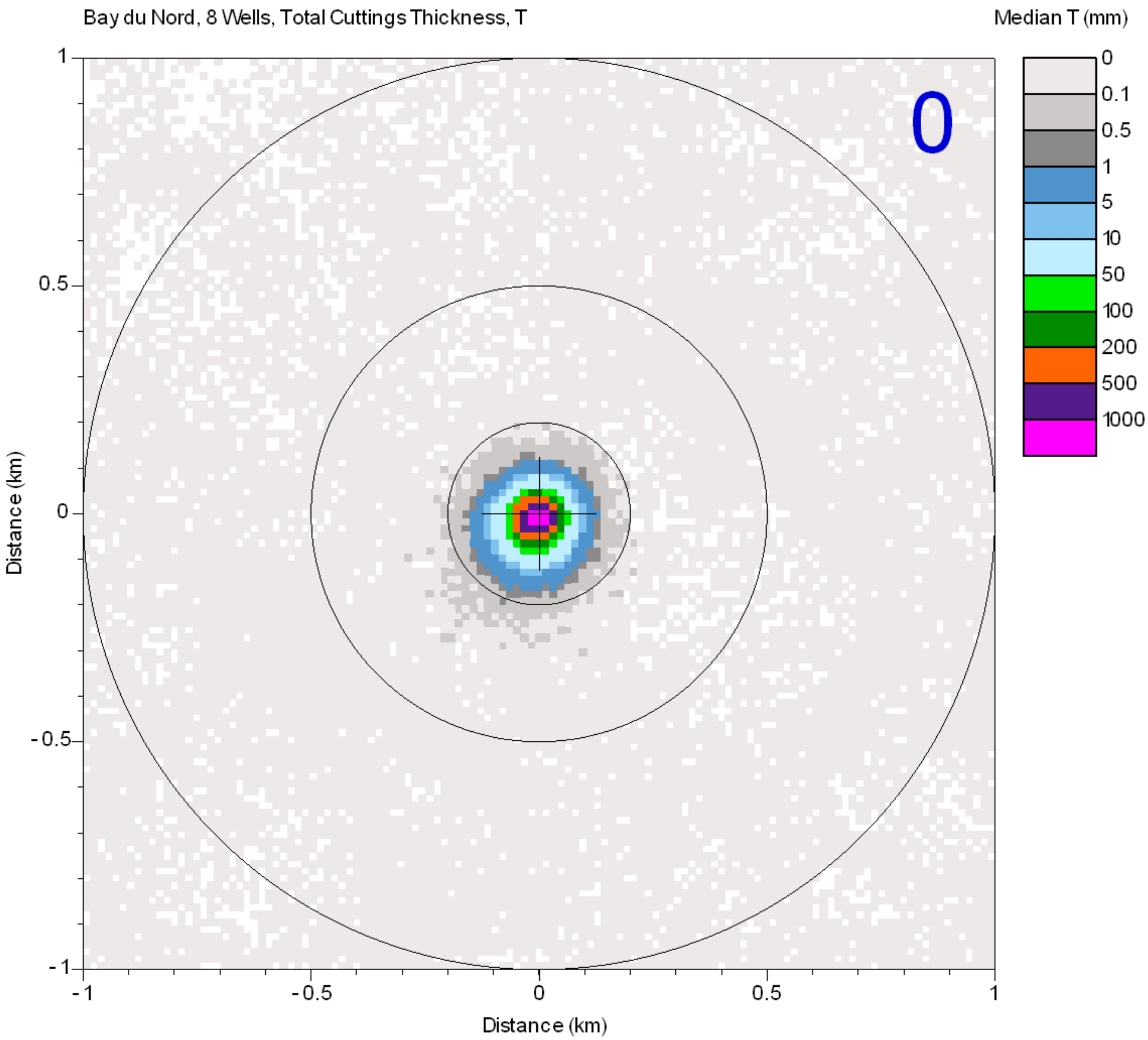

Figure 5-29 Median Total Cuttings Thickness, Eight Wells, Base Case with Flocculation ('0'), 1 km view

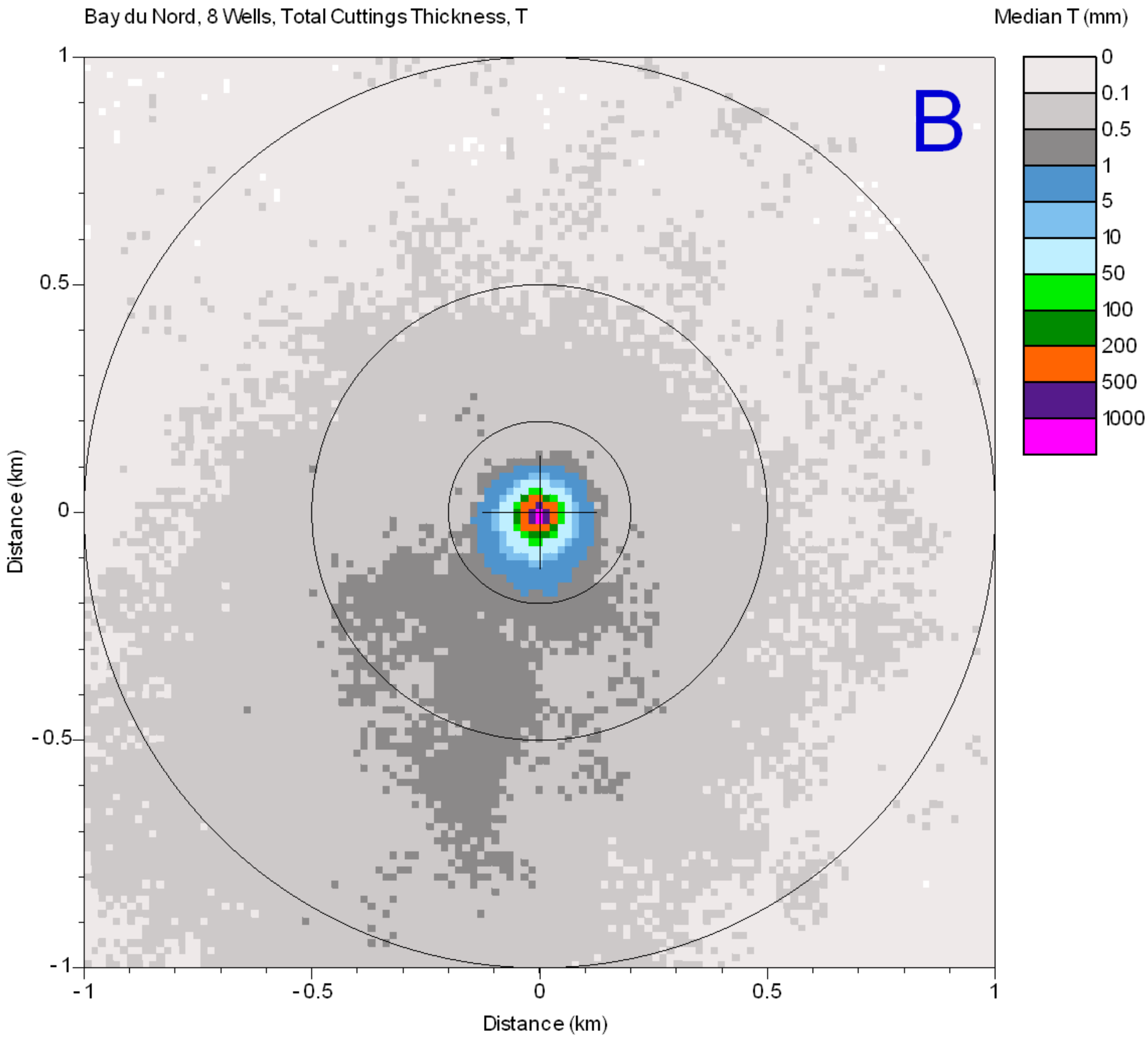

Figure 5-30 Median Total Cuttings Thickness, Eight Wells, Troll A Platform Average PSD ('B'), 1 km view

5.2.5 Probability of Exceeding PNET of 1.5 mm and 6.5 mm (Eight Wells)

The stochastic analysis yields the probability that the initial total cuttings thickness at any given location will be greater than the PNET values of 1. 5 mm and 6.5 mm. Figure 5-31 to Figure 5-34 present plan view maps of the probability of total cuttings thicknesses exceeding the PNET values of 1.5 mm and 6.5 m. Results are shown for the eight well model simulations completed with the two input scenarios: base case with flocculation ('0') and Troll A Platform average PSD ('B'), in the same manner as Section 5.1.5, although with a probability threshold of 15 percent as opposed to five percent reported for one well simulations. This is due to there being eight simulations for a stochastic simulation or analysis so that the lowest probability that can be readily inferred is 1/8 or about 15 percent. Circles are drawn at a radius of 200 m, 500 m and 1 km.

To estimate the distances at which the predicted total cuttings thicknesses may exceed a given PNET thickness of interest at a high confidence (given the stochastic approach) two probability thresholds are shown. A range of zero to 15 percent corresponds to areas with a low (15 percent or less) likelihood of exceeding the thickness threshold of interest and is shown in grey, while a range of 15 to 100 percent corresponds to any likelihood greater than 15 percent and is shown (in magenta or purple as noted below). In other words, there is a high (85 percent) likelihood that the PNET thickness would not be exceeded outside the magenta (or purple) areas.

Figure 5-31 and Figure 5-32 show the cuttings footprint plots, for the 1.5 mm PNET, for the base case with flocculation ('0') and Troll A Platform average PSD ('B') simulations. Both input scenarios, base case with flocculation ('0') and Troll A Platform average PSD ('B'), show a greater than 15 percent probability of seeing total cuttings thicknesses above 1.5 mm within about 180 to 200 m. The Troll A Platform average PSD ('B') results (Figure 5-32) show, with the scattered grey grid cells to the southwest, some potential, for the cuttings thicknesses to exceed 1.5 mm as far as 1 km; however, these are all at less than a 15 percent probability of occurrence.

Figure 5-33 and Figure 5-34 similarly show the probability of initial total cuttings thicknesses exceeding a 6.5 mm PNET: areas in purple showing where there is a greater than 15 percent probability of thicknesses exceeding 6.5 mm and those in grey with a less than 15 percent probability. In other words, there is a high (85 percent) likelihood that the 6.5 mm thickness threshold would not be exceeded outside the purple areas. Both predictions ('0' and 'B') show virtually identical predictions, i.e., there is a greater than 15 percent probability that cuttings thicknesses will be greater than 6.5 mm within about 100 to 120 m of the wellsite and no likelihood (based on the eight stochastic runs completed for a given eight well simulation).

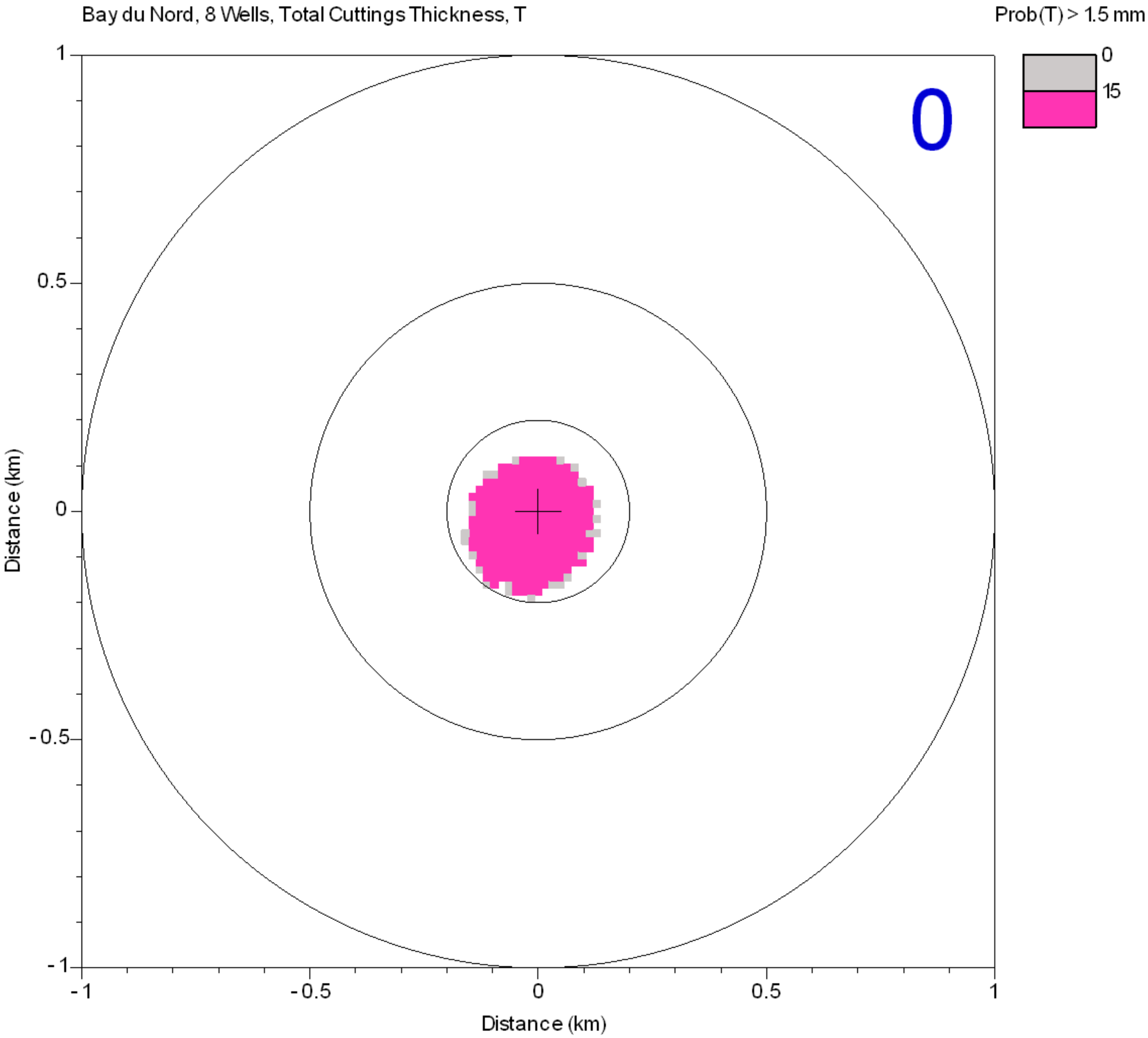

Figure 5-31 Probability of Total Cuttings Thickness Exceeding 1.5 mm greater than 15% (magenta) and less than 15% (grey), Eight Well Simulations, Base Case, with Flocculation ('0'), 1 km view

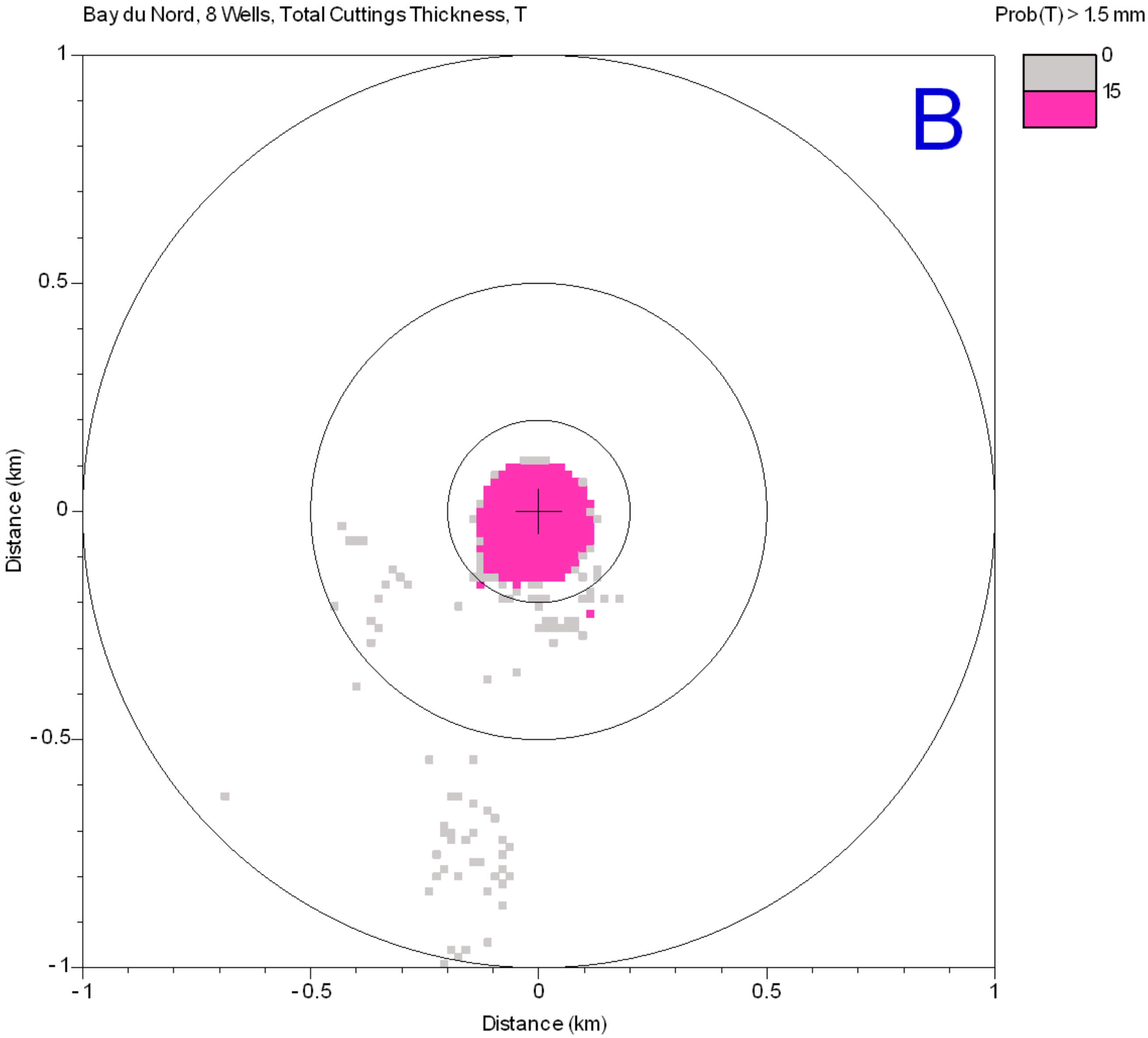

Figure 5-32 Probability of Total Cuttings Thickness Exceeding 1.5 mm greater than 15% (magenta) and less than 15% (grey), Eight Well Simulations, Troll A Platform Average PSD ('B'), 1 km view

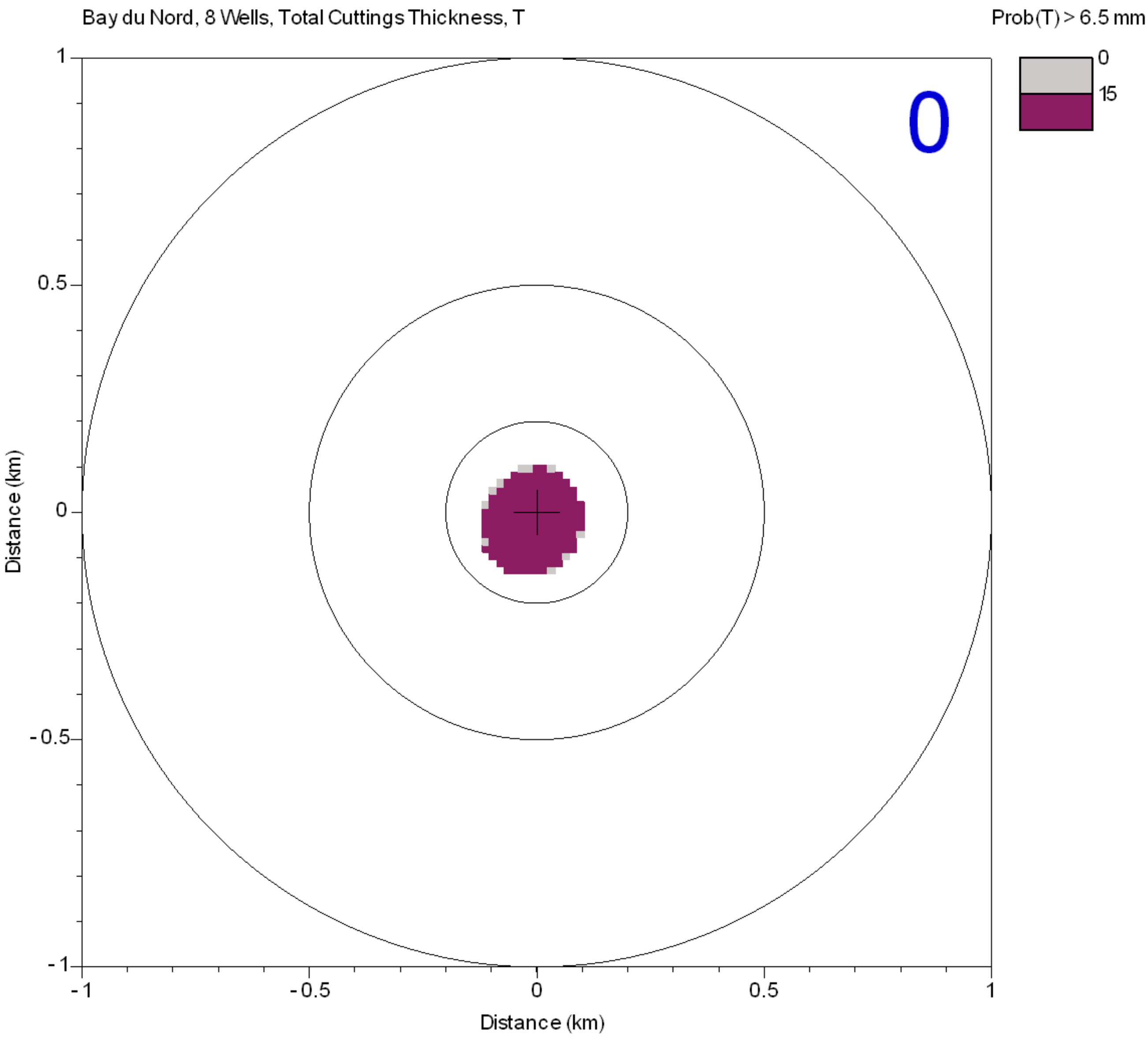

Figure 5-33 Probability of Total Cuttings Thickness Exceeding 6.5 mm greater than 15% (purple) and less than 15% (grey), Eight Well Simulations, Base Case, with Flocculation ('0'), 1 km view

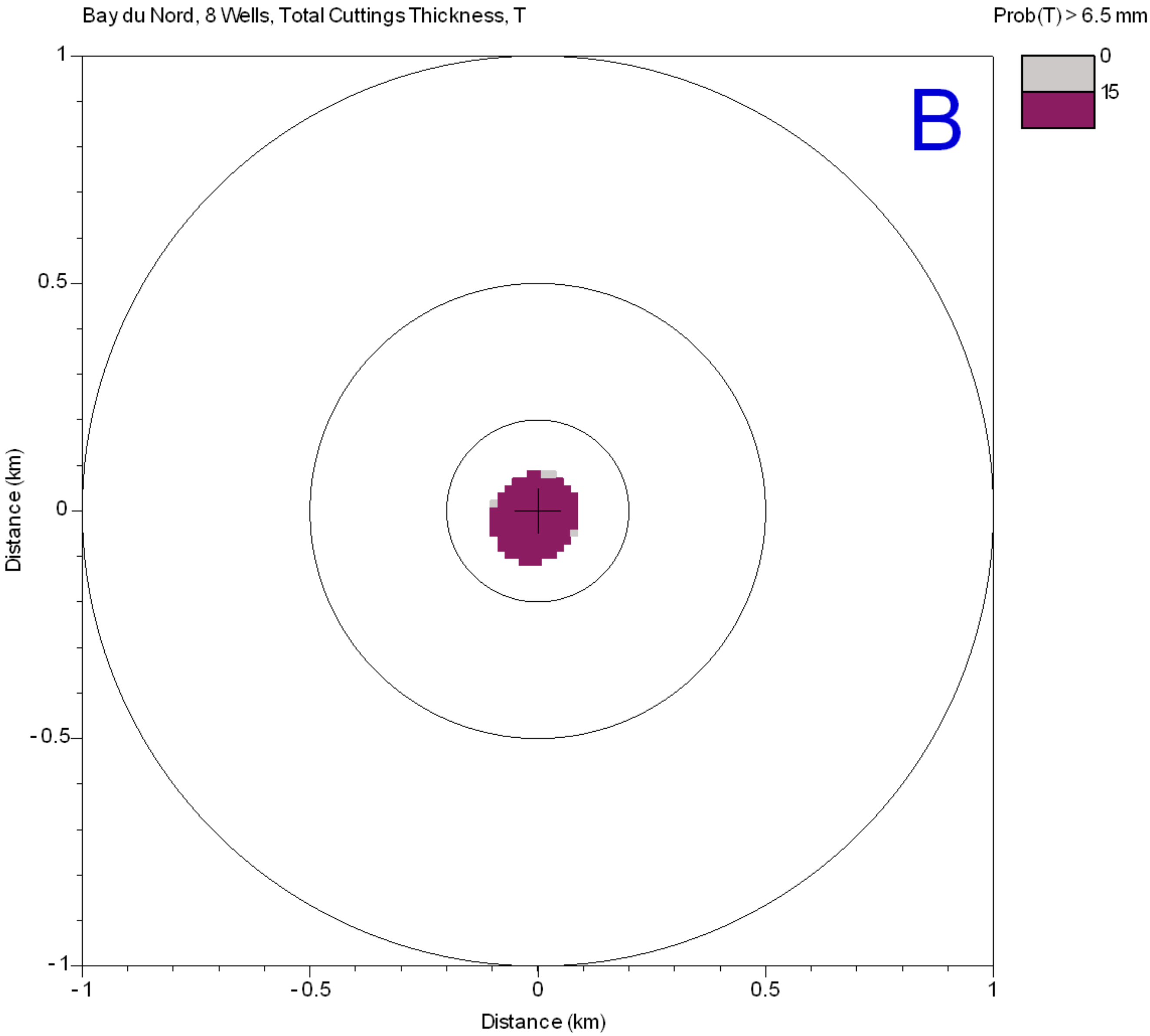

Figure 5-34 Probability of Total Cuttings Thickness Exceeding 6.5 mm greater than 15% (purple) and less than 15% (grey), Eight Well Simulations, Troll A Platform Average PSD ('B'), 1 km view

PNET Thickness Limits

Estimates of the footprint areas with total cuttings thicknesses above the PNET thicknesses are shown in Figure 5-35. The base case, with flocculation ('0') and Troll A Platform average PSD ('B') eight well simulations are shown. For each simulation the total areas (calculated as the number of model grid cells with total cuttings thickness greater than the noted threshold, 1.5 mm or 6.5 mm, multiplied by the cell area of 256 m^2) for each of the eight deterministic runs are shown.

The estimated area for which total cuttings thicknesses are greater than 1.5 mm for the base case, with flocculation ('0') ranges from 0.051 km^2 to 0.059 km^2 and averages 0.055 km^2 (about 235 m square). The corresponding estimated area for which total cuttings thicknesses are greater than 1.5 mm for the Troll A Platform average PSD ('B') simulations is comparable to the base case with flocculation ('0') ranges from 0.045 km^2 to 0.067 km^2 and averages 0.050 km^2 (about 225 m square).

The estimated area for which total cuttings thicknesses are greater than 6.5 mm for the base case, with flocculation ('0') ranges from 0.034 km^2 to 0.038 km^2 and averages 0.036 km^2. The corresponding estimated area for which total cuttings thicknesses are greater than 6.5 mm for the Troll A Platform average PSD ('B') simulations ranges from 0.025 km^2 to 0.028 km^2 and averages 0.026 km^2.

Considering the average of both simulations, an estimate of the total area for which total cuttings thicknesses are predicted to be greater than 1.5 mm is 0.053 km^2 (about 230 m square), while the corresponding total area for thicknesses greater than 6.5 mm is 0.031 km^2 (about 176 m square).

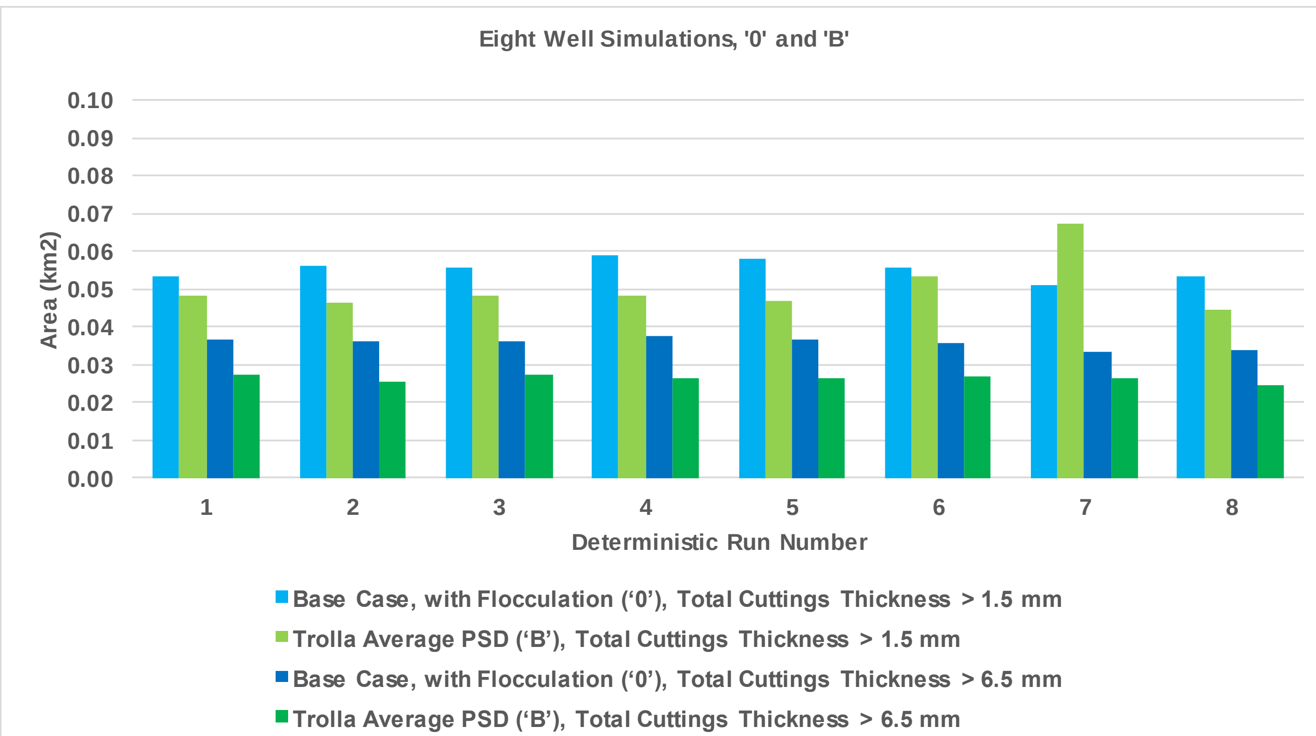

Figure 5-35 Total Cuttings Thickness Areas above PNET Thresholds. Deterministic runs 1 to 8 shown for both Eight Well Simulations, Base Case, with Flocculation ('0') and Troll A Platform Average PSD ('B')

6.0 CLOSURE

This report presents the data and methods used to model drill cuttings release for production drilling at Bay du Nord, offshore eastern Newfoundland. Model simulations for drilling of one well and from eight wells are considered. Results presented include total cuttings thickness footprints, cross-sections of total cuttings thickness, statistics of the percent of material settled and median and maximum total cuttings thicknesses, and probability estimates of thicknesses exceeding predicted no effect threshold (PNET) values of interest.

Yours sincerely,

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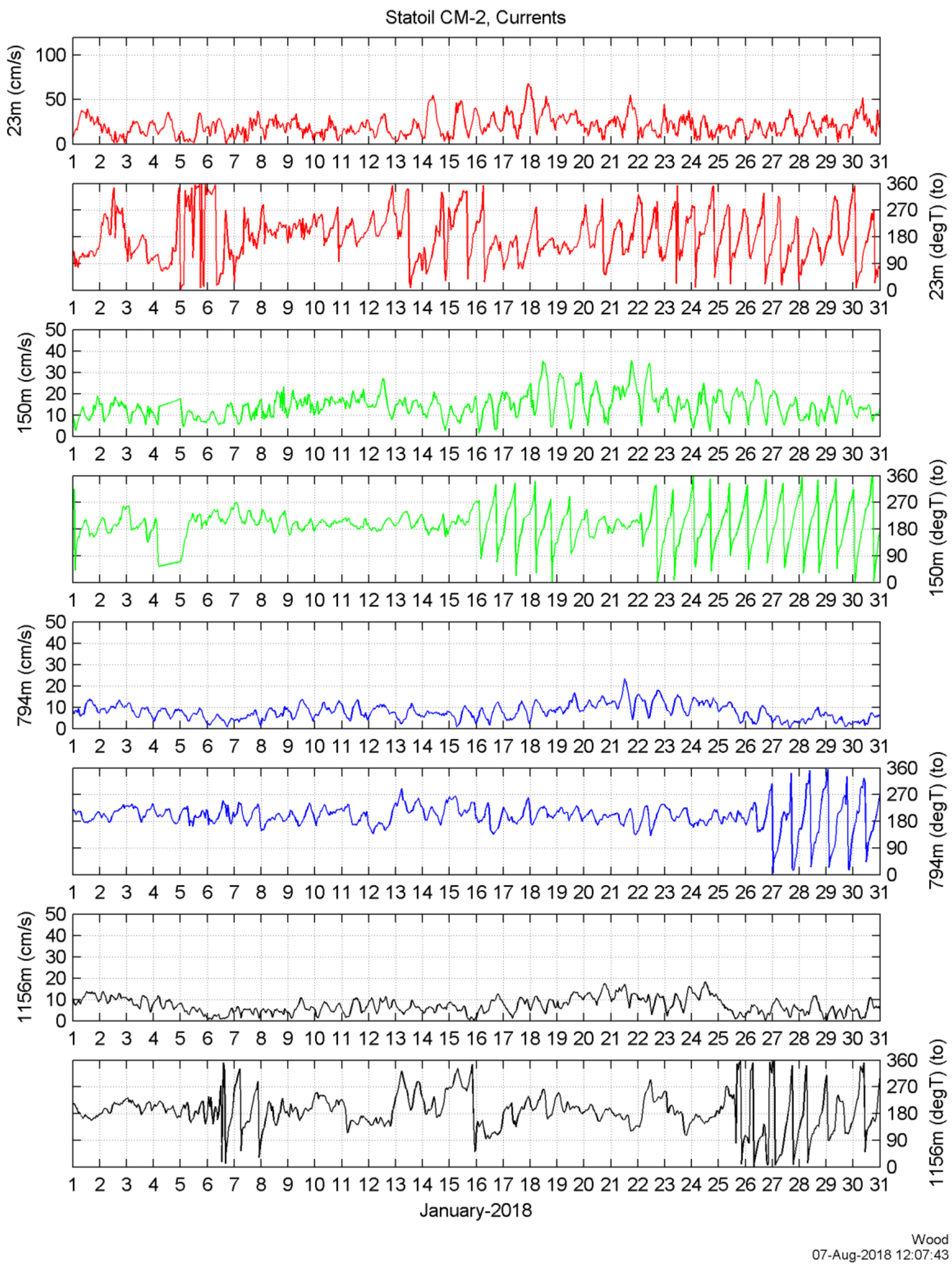
APPENDIX A: OCEAN CURRENTS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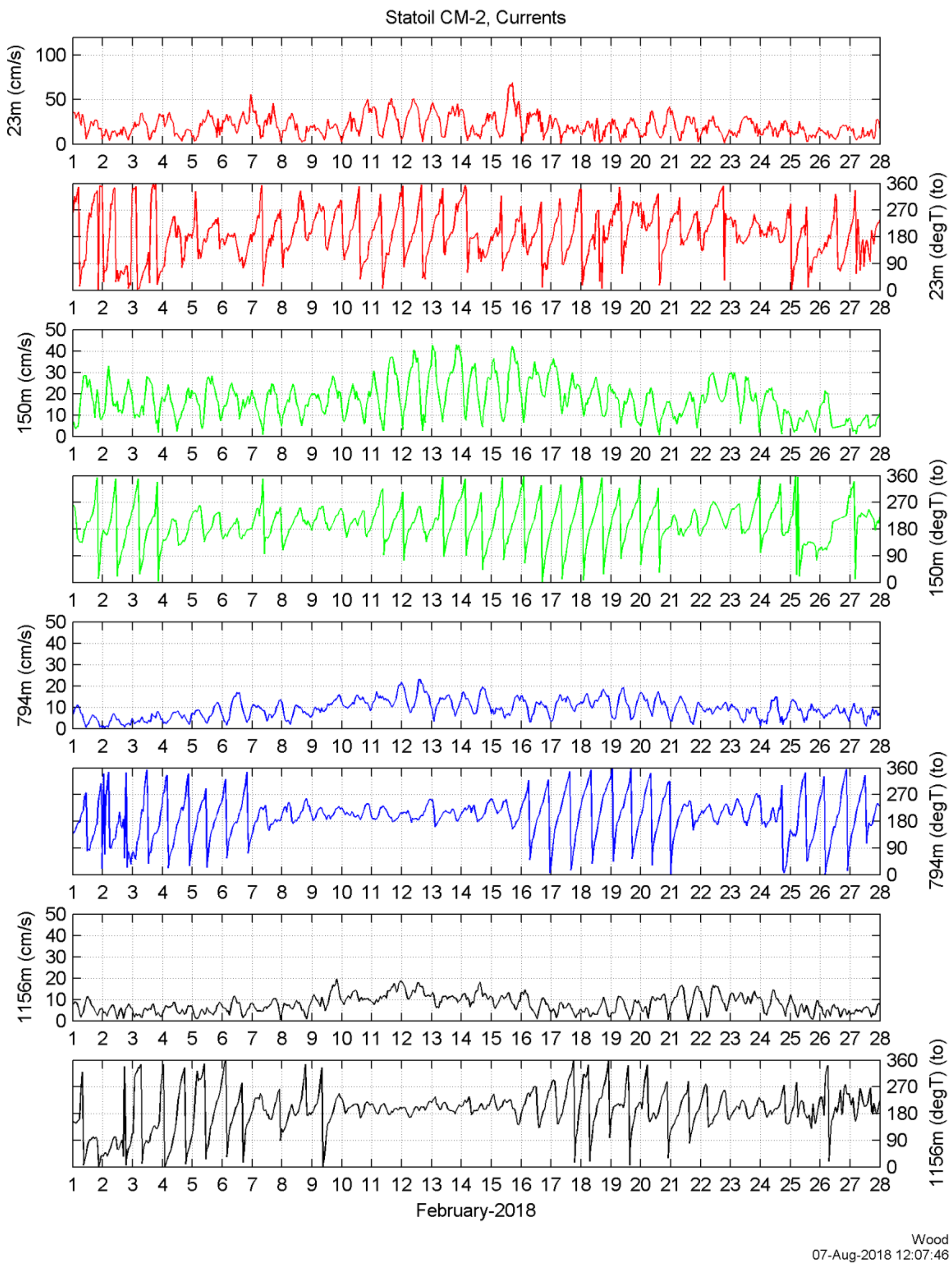
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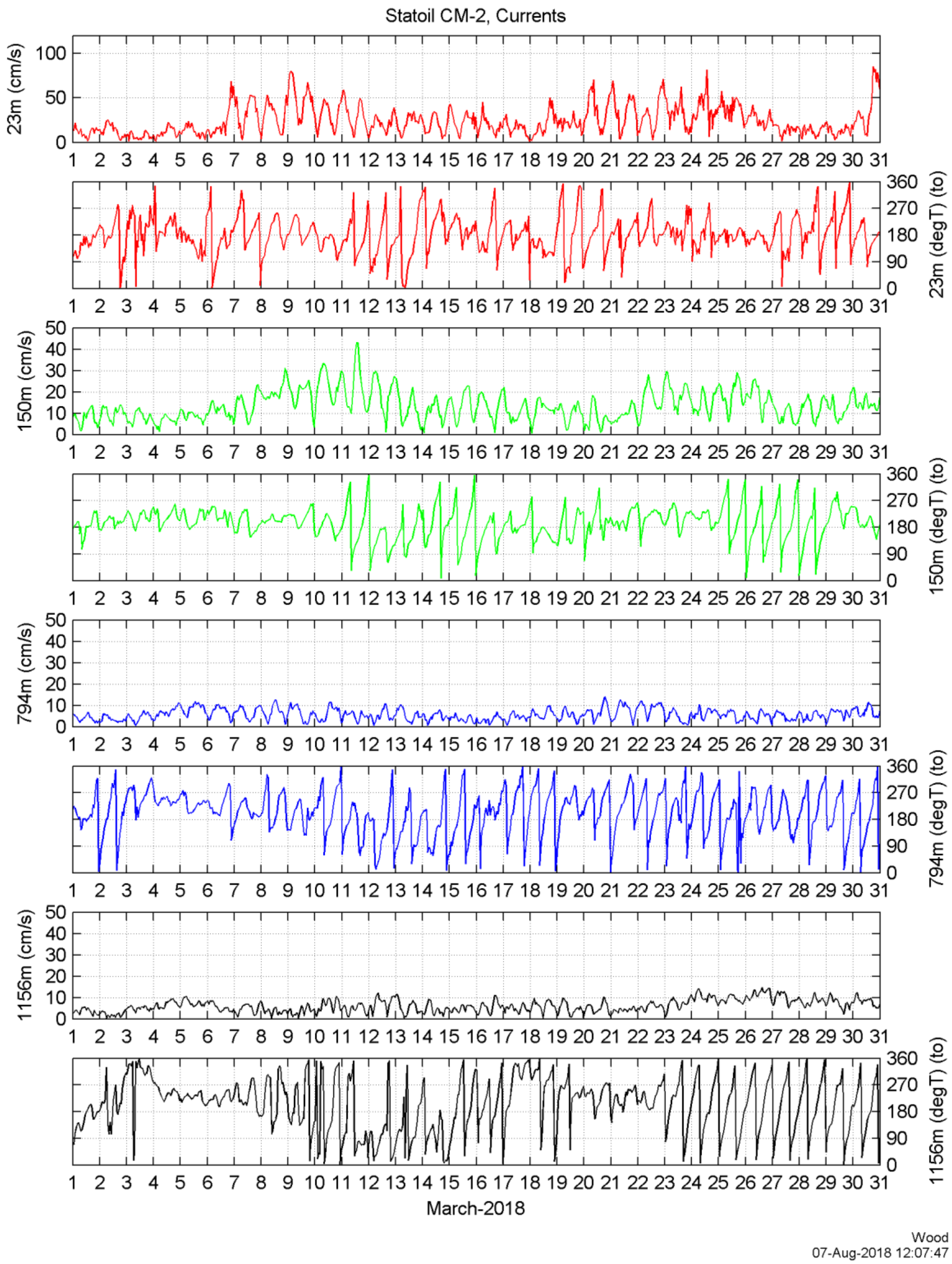
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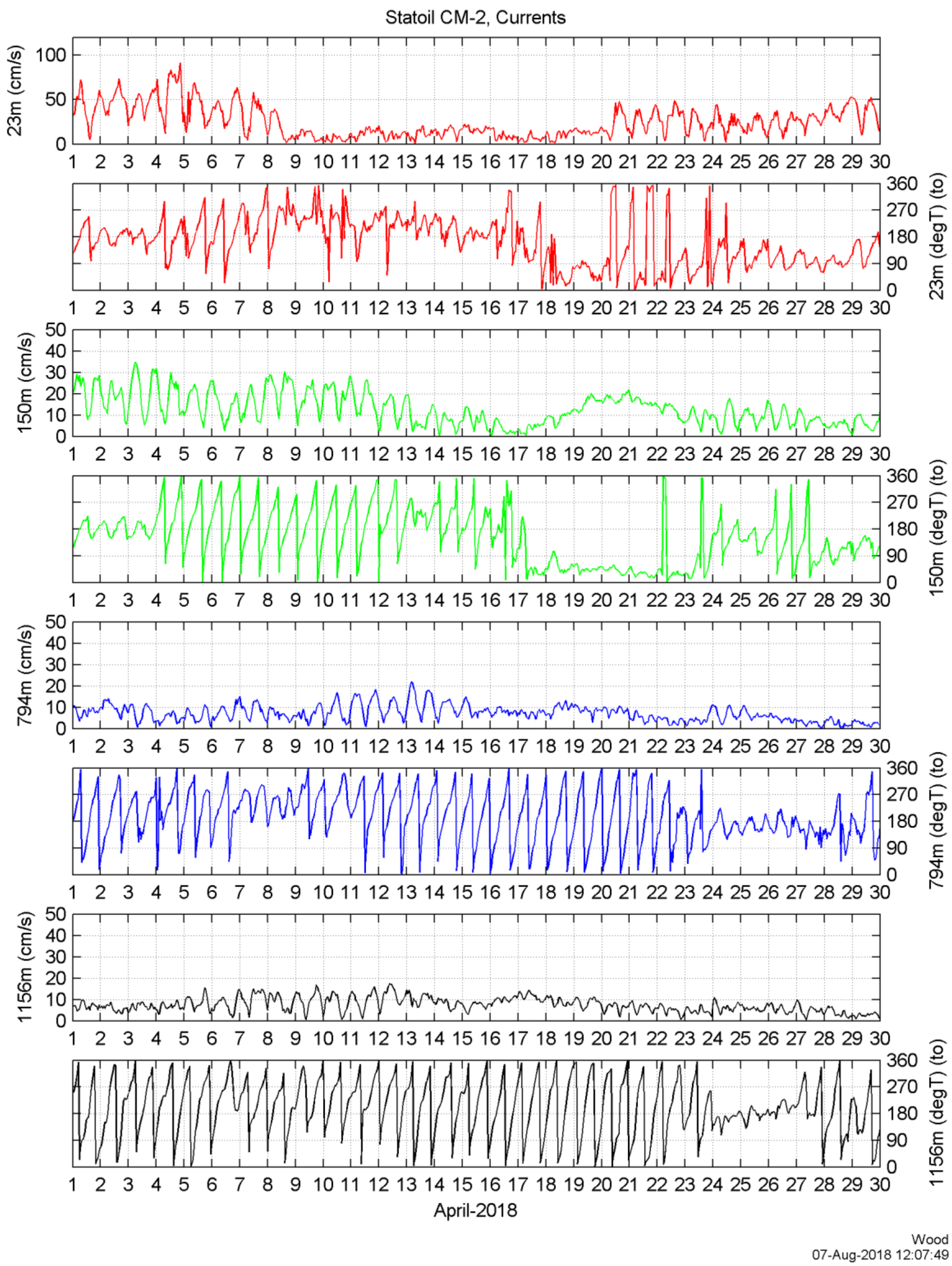
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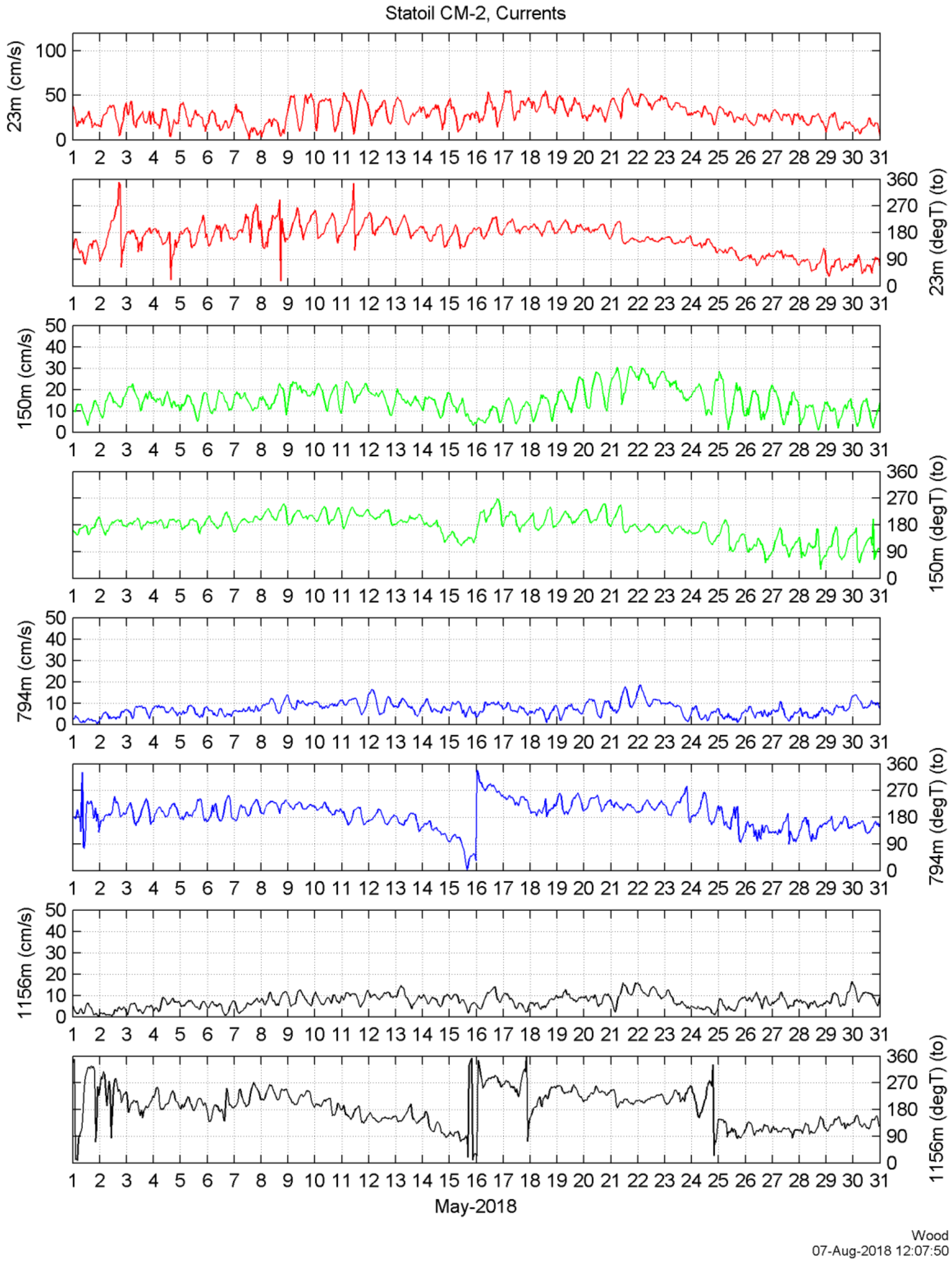
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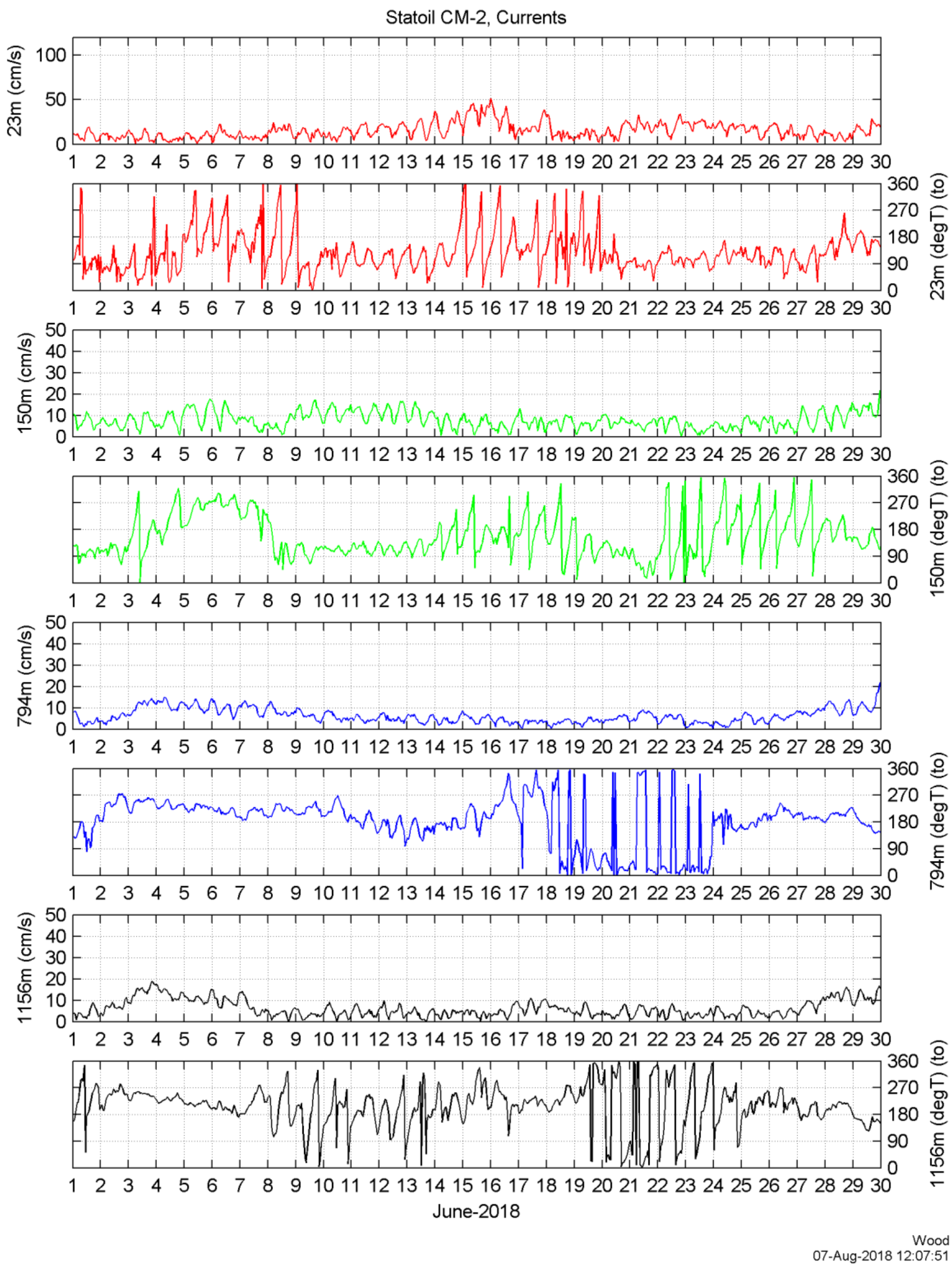
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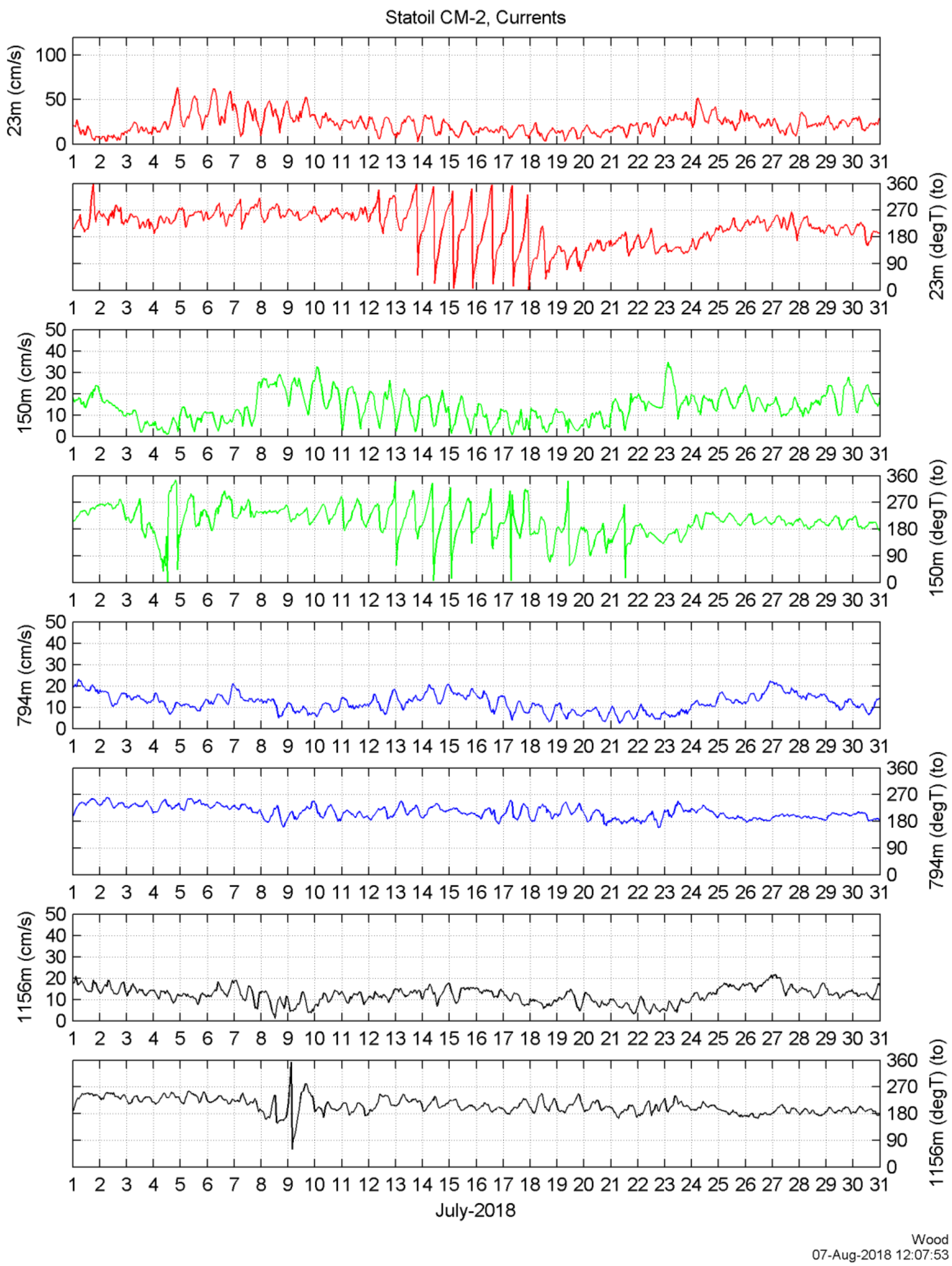
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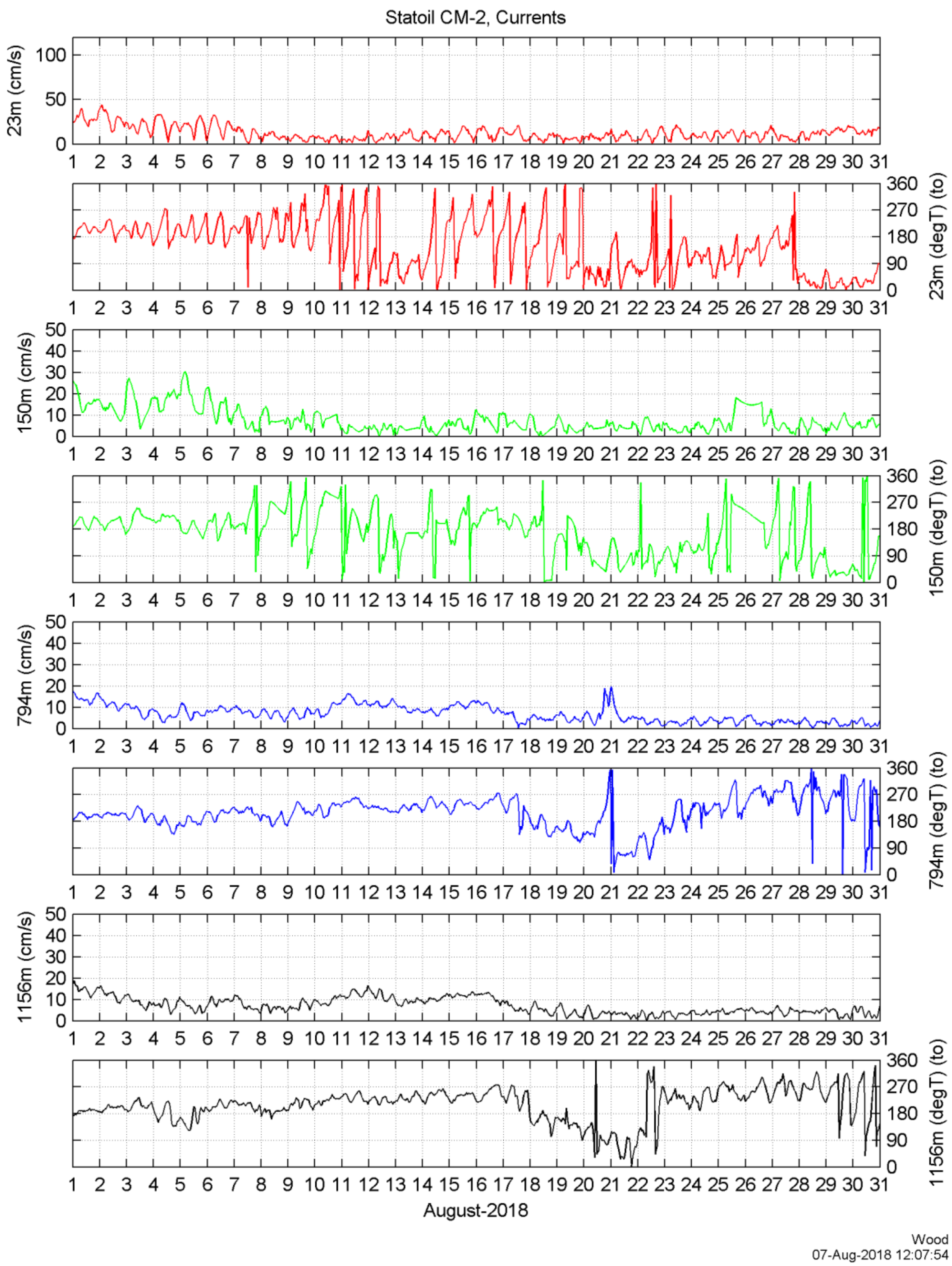
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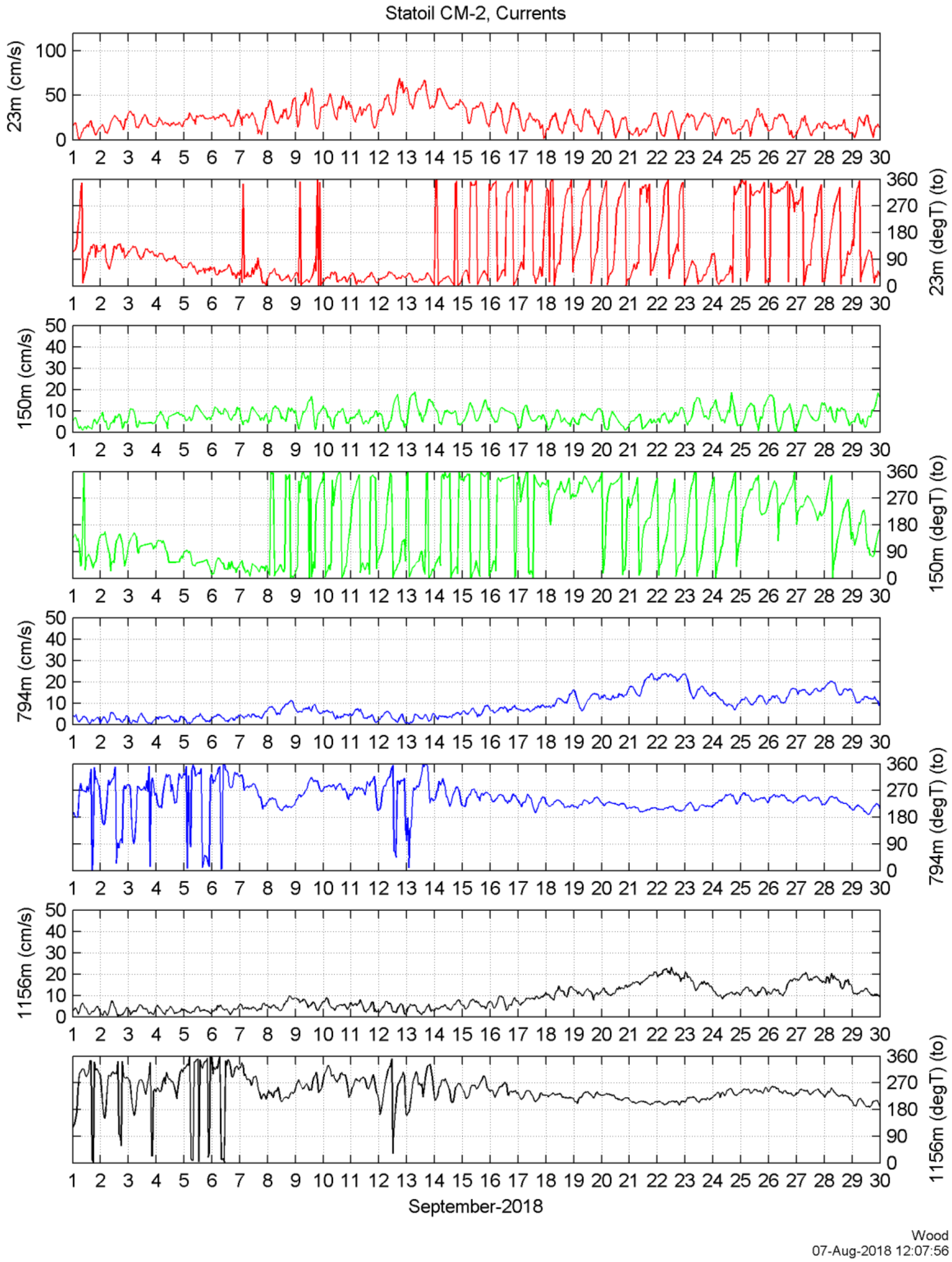
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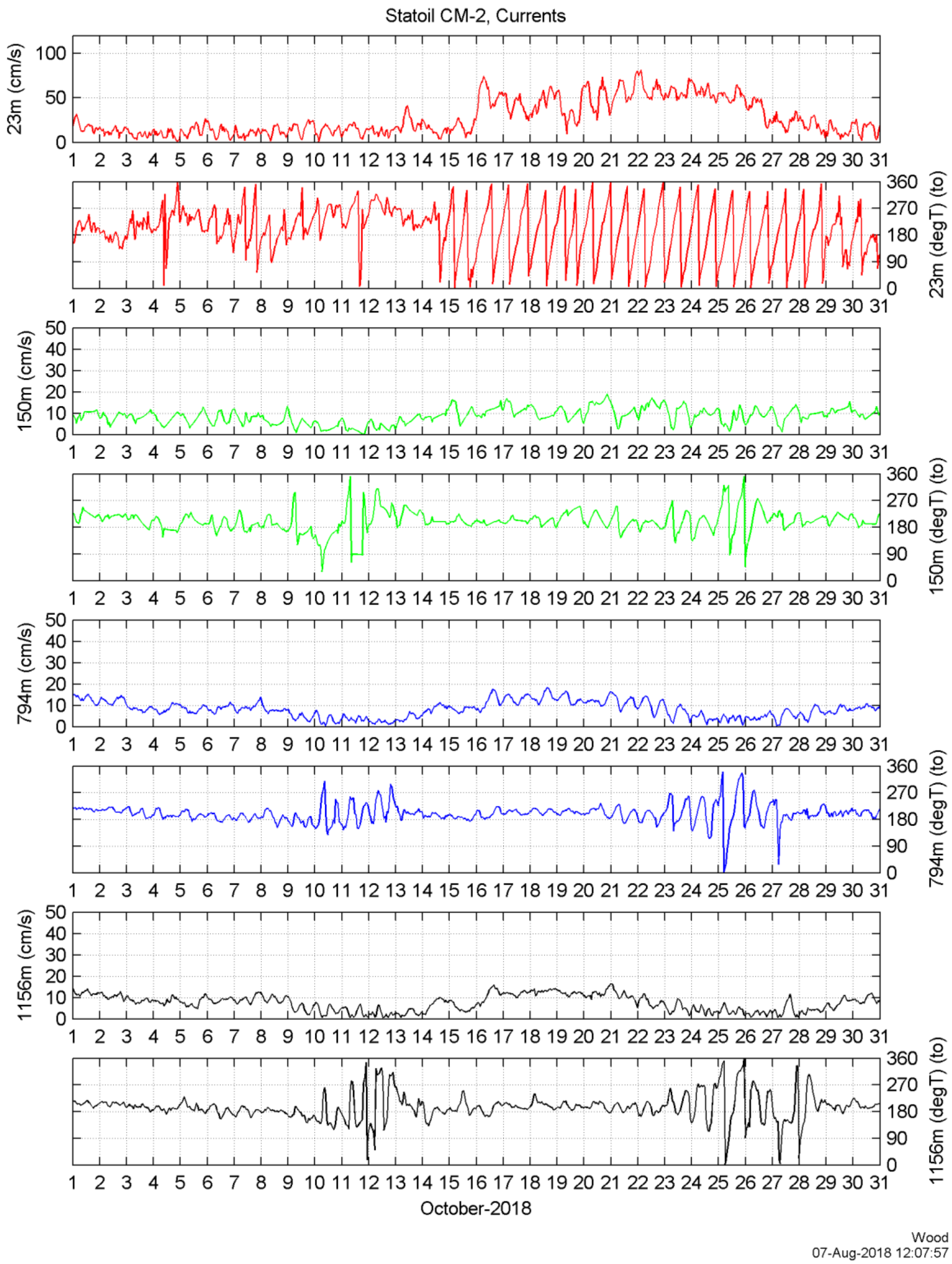
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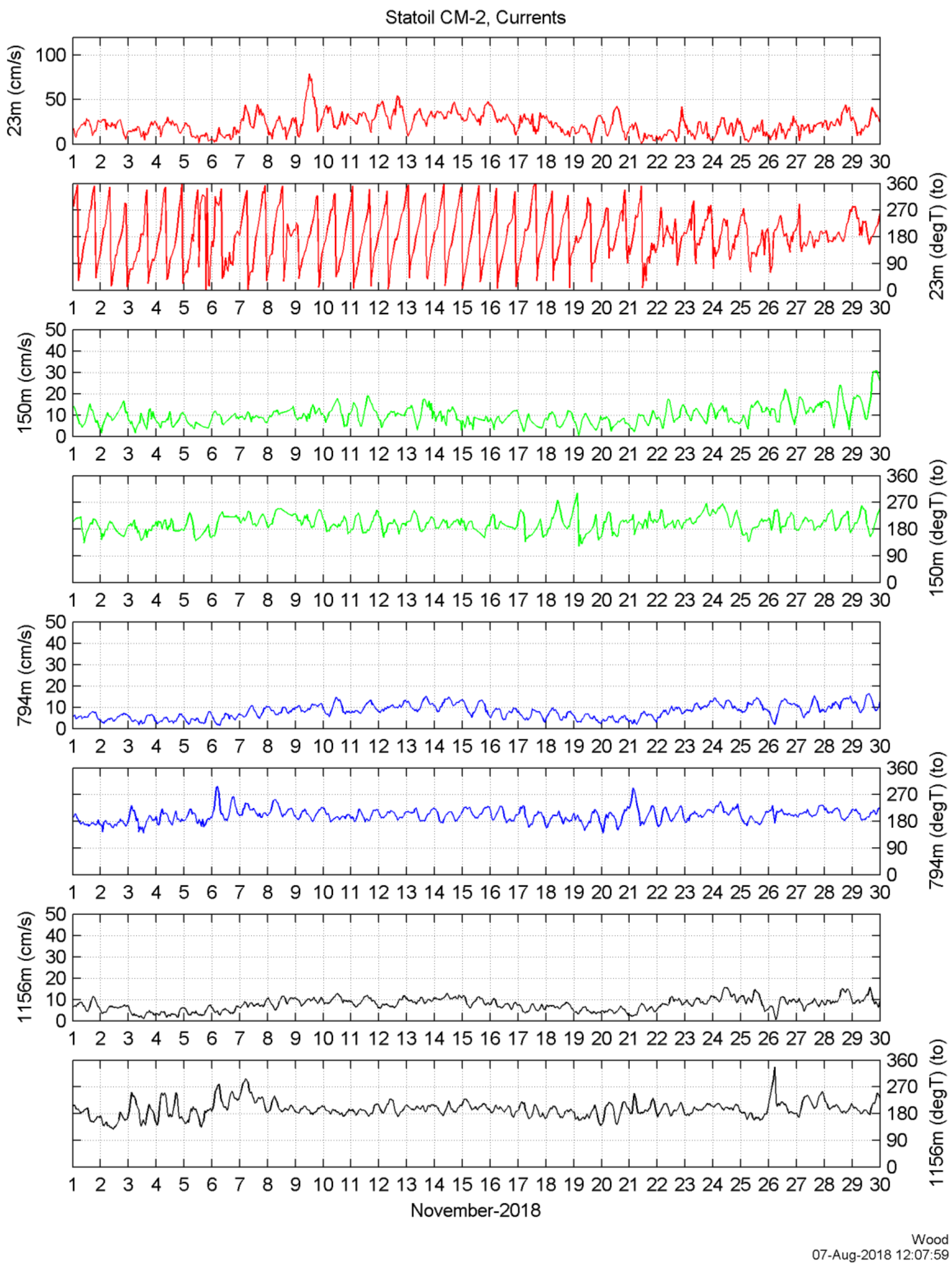
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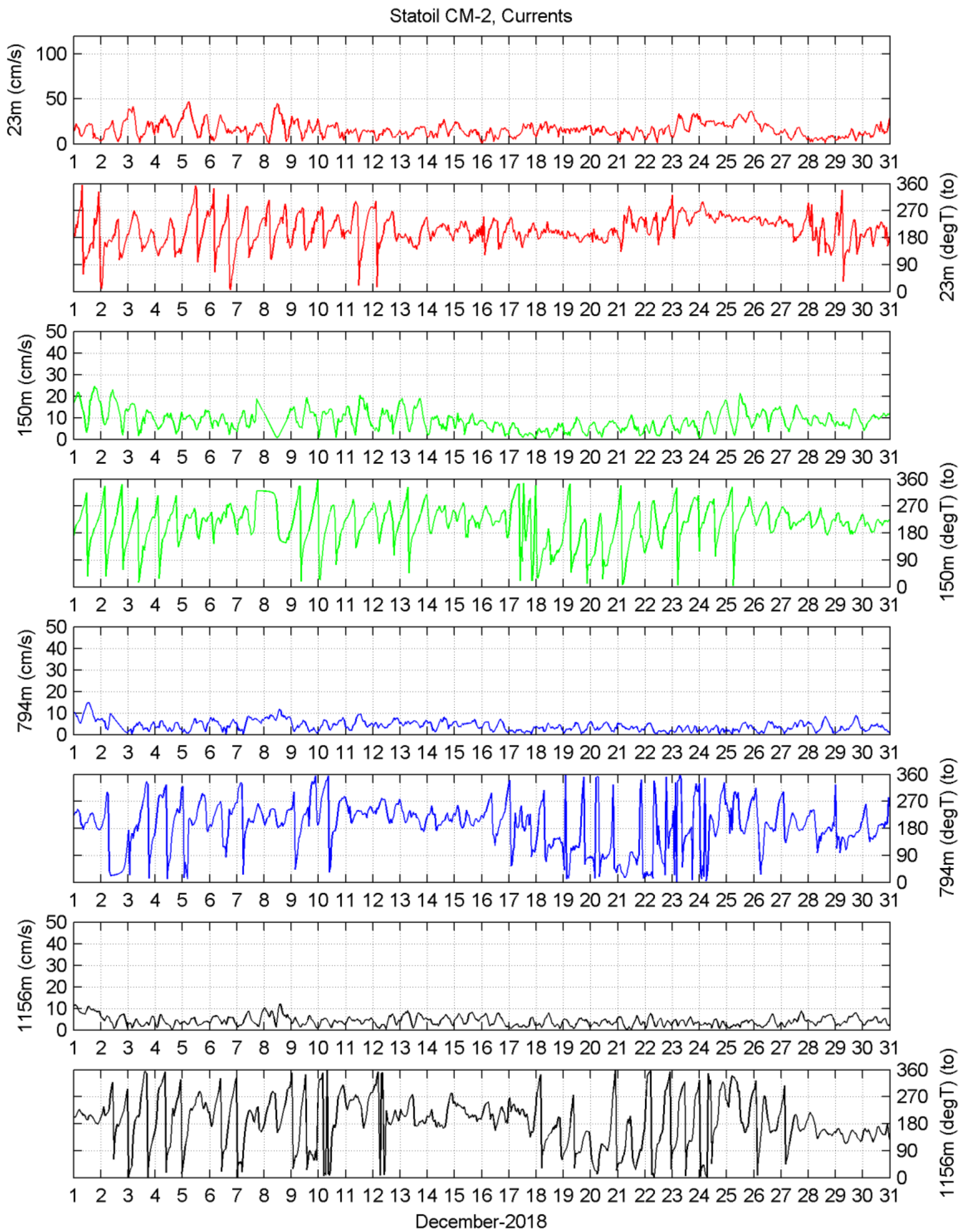
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