Response to referee 2 (referee remarks are given in italics)

1. Title: *It does not reflect the first objective (estimate extreme marine phenomena) and a big part of the study. That should be accounted for in the manuscript title.*

We have reformulated the title:

Assessment of extreme hydrological conditions in the Bothnian Bay, Baltic Sea and the impact of the nuclear power plant "Hanhikivi-1" on local thermal regime

2. Introduction:
- Adding some information about the number of already producing and proposed NPPs in the Gulf of Bothnia or in the Baltic Sea would emphasize the real dimension and importance of the issue under study.
-
We have edited and extended the introduction (see response to referee 1) including the sixth paragraph (P2, L16-19):

At present, there are five operating NPPs on the shores of the Baltic Sea: two Swedish (Forsmarks NPP, the electric capacity of 3210 MW, Oskarshamns, 2308 MW), two Finnish (Loviisa NPP, 1020 MW, Olkiluoto NPP, 1760 MW) and one Russian (Leningrad NPP, 4000 MW). Two of them (Forsmark and Olkiluoto) are located on the coast of the Bothnian Sea. On January 19, 2016, the construction of NPP "Hanhikivi-1" with the capacity of 1200 MW was started. This event had been preceded by examination of hydro-meteorological conditions in the area of construction, which included not only the estimation of extreme conditions in the vicinity of Peninsula Hanhikivi (Pyhäjoki municipality) in the Bothnian Bay in the Baltic Sea, but also the possible impact of future power plant on the marine environment in this area.

The second objective could be better formulated: "rather than an estimation of the adverse thermal effect of NPP on marine environment" what it is done is estimate its impact on the hydrological (temperature field) conditions, as written in the title. An impact on the marine environment is a much wider concept.

We have reformulated the purpose of this study (p.2, line 25 - p.2, line 26):

The purpose of this study was two-fold: 1) to estimate the possible extreme marine phenomena in this region (wind waves, sea level changes); 2) to estimate the impact of the NPP on the local thermal regime in the future.

3. Methods:
-The models are described correctly and in detail, however I would advise to include a paragraph describing the modelling approach prior to individual model description. For example, in the current version the Hanhikivi domain is described without information on how it is connected to the larger Bothnian bay domain (P4L4-7). It is later that these details are provided. I would suggest the inclusion of a scheme (flow diagram) with indication of the models, information flows, boundary conditions,domains, etc.

We will insert in the beginning of the second section ”**2 Methods”** (after P2L28) the following text and add Figure 1-2 with flow diagram:

When evaluating extreme hydro-meteorological conditions in the study area of the sea an empirical approach based on statistical analysis of the available time series of individual characteristics (wind speed, sea level, water temperature, ice cover characteristics, and others) is traditionally used. This approach has at least two obvious limitations: 1) the accuracy of such estimates is highly dependent on the duration of the observation period; 2) it cannot be used for areas where such data is not available. In this paper we propose a method of extreme hydrological conditions estimation in the study area based on mathematical modeling of the general ocean circulation. In the present study, the extreme hydrological conditions in the area of the future NPP "Hanhikivi-1" are estimated in the Bothnian Bay in the Baltic Sea. The general scheme of the calculation is as follows: 1) to perform a model run to simulate the general circulation for the entire Bothnian Bay on the coarse grid for the selected period (from 2010 to 2015 with repetion 2 times of the 2010 year under one and the same external forcing), including the cold (2010) and the warm (2014) years, in the situation of the absence of the NPP; the model performance is verified through the quality of simulation of temperature and sea ice area fields; 2) to assess the extreme possible sea level in the NPP area on the basis of runs on the coarse grid. For this purpose the real situations of extreme storm surges during the selected time period were chosen 3) to assess the impact of the NPP on the temperature and sea ice fields around it on the basis of performing the calculations in the case of the absence of the NPP ("background" scenario) and its presence ("predictive" scenario); runs are performed on the nested (fine) grid covering the neighborhood of the NPP for both cold and warm years; 4) to assess the largest wind waves by performing the numerical experiments first on the coarse grid, and then on the fine grid with the prescribing boundary conditions from the solutions on the coarse grid.

The general scheme of numerical experiments is shown in Figure 1-2. The models used and the details of the above numerical experiments are specified below.

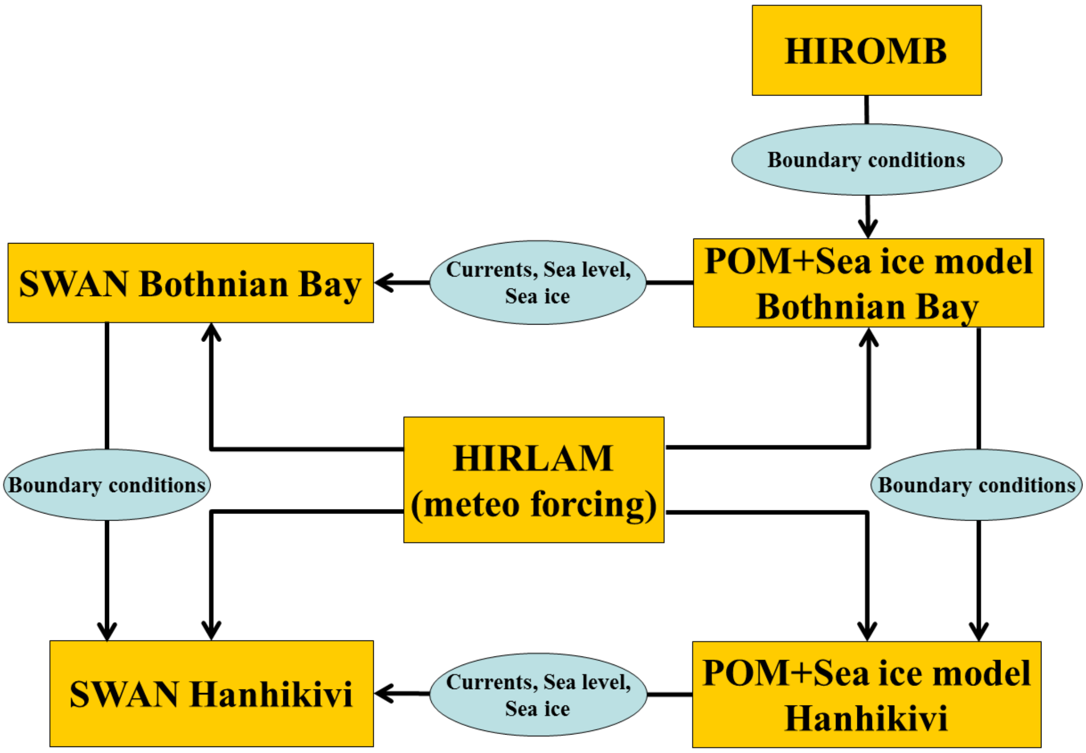


Figure 1-2. The general scheme of the model calculations

-Models output is validated in the following periods: 5-7/12/2015 (sea level) 18-19/01/2010 and 06/2010 (temperature), unknown dates (sea ice), 2013-2014 (wind waves). I am sure that there is a good reason to be so, but authors do not provide it. I would suggest including an additional paragraph explaining the validation strategy and the limitations posed by available data. Also, some general information on the runs used for validation purposes (duration, spin-up time) would be desirable.

We pointed out the dates for sea ice figure 4 to the figure caption (see that figure below). Duration and spin-up time of basic run have been pointed out in our response to previous comment.

See also our response to the comment 2 of the referee 1. We rewrote a part of section 2.6 **Verification of the models** (from p.6, line 21 to p.8, line 10), replaced Figure 2 by a new one, added new Figure 3.1 and two new Tables. In particular, we described our verification strategy in the beginning of the section 2.6:

Taking into account the main objective of this study - to estimate extreme values of the sea level and height of wind waves in the vicinity of NPP Hankikivi-1 and estimate the maximum thermal pollution produced by the NPP, the proposed model is verified with respect to sea level, significant wave height, sea water temperature and sea-ice area against all available observational data for the selected period 2010- 2015. This data includes data on sea level at 6 stations (Ratan, Furuogrund, Kalix, Kemi, Raahe, Pietarsaari) on the shores of the Gulf of Bothnia (ftp://myocean.smhi.se/Core/INSITU_BAL_NRT_OBSERVATIONS_013_032/history/mooring/), vertical temperature profiles for hydrographic stations BO3, F3 (data from BED) and PP5 (Fennovoima report, 2014), and data on the significant wave height at the stations PP2 and PP4 (Fennovoima report, 2013), the average monthly data on the area of the ice cover (http://www.aari.ru/).

- Despite the better agreement with data, it seems that POM presents a more diffusive thermocline than HIROMB (see Fig. 3). May it be caused by the fact that HIROMB is assimilating observations?

The reviewer is absolutely right: HIROMB, unlike POM, is assimilating observational data that allows the temperature changes in the thermocline to be better reproduced. A more detailed comparison of the results of these two models in comparison with data is given in response to the comment № 2 from the reviewer 1. It will be inserted at the end of section 2.6(after p.9, line 11):

Summarizing the above, we can say that the proposed modeling system based on the POM, allows at least not worse than the best model of the Baltic Sea HIROMB, to reproduce the principal characteristics of hydrodynamic regime (level, water temperature, altitude wind waves, sea ice) on the coarse grid and gives considerably better description of the temperature field on the fine grid. An advantage of POM important for the prognostic runs is the fact that the POM unlike HIROMB is not assimilating observational data.

4. Results:

-It seems that SWH near the NPP location is limited by water depth (causing wave breaking). If so, then it is of capital importance to provide information about water depth used and if this water depth was considered to be affected by wind and wave setups. Authors' estimation of storm surge levels indicates sea level changes of 130 cm (Figure 2), which can cause an increase/decrease of 20-30% in water depth. Only in the Discussion section it is mentioned that all data needed by SWAM was calculated in advance by the coupled circulation model. However, that information must be clearly and detailed provided before. The place for that is Methods, as I suggested before.

As the reviewer suggested, the text describing the methods (data transferred from POM to SWAN) has been placed from the Discussion section to the Methods: from p20L2 - p20L19 to P6L21

- Figure 13 shows that changes in bathymetry were assumed for the predictive scenario. Were these variations taken into account for the estimation of extreme SWH and sea level surges?

Yes, they were. We will mention it in the text.

5. Discussion:

I think authors should strongly stress the novelty of their approach (by comparing with other approaches employed for analogous cases). Also, the potential impact on the obtained results of some missing mechanisms (e.g. interaction between waves and currents by coupling SWAM and POM).

We rewrite Conclusions section (see our response to comment 4 of the referee 1) where we stressed the novelty of our approach. We also will add to Discussion section the following text (after P21L2):

The main missing physical mechanism is the influence of the wave bottom boundary layer upon the current bottom boundary layer. The transfer of SWAN results into the POM model was not made during the computations, only from POM to SWAN. But, from our point of view, this interaction between bottom boundary layers has less impact on the final solution than the influence of meteorological forcing and model estimates of other hydrological parameters such as sea level, sea ice distribution and currents.

MINOR REMARKS:
P2L32: "allows a smooth representation of the bathymetry" instead of "allows it to represent the bathymetry smoothly"
P3L2 thermodynamic instead of thermodynamical
P3L3 "simulation of coastal and estuarine dynamics" instead of "simulations of coastal areas and estuaries dynamics"
P4L1 "SWAN was used" instead of "During all model runs SWAN was working"
P4L6 Delete "assessment of main hydrological features of the". Indeed, big part of the manuscript is focused on wave and storm surge characterization.

All these editorial comments will be taken into account

P5L10 Adding at inset with a wider geographic setting including the Gulf of Bothnia in Fig. 1 would somehow prevent confusions between the Gulf and the Bay for readers not familiar with the area of study.

It's done. The new version of Figure 1 is shown below.

P5L17 atmospheric instead of atmospherical
P5L18 atmospheric instead of atmospherical (and so on)

Will be done.

P5L22 Can authors add any reference to sustain the good agreement between HIRLAM's simulations and observations?

We made this comparison themselves and are going to replace the sentence P5L21 «Comparison of HIRLAM's results with observational data collected near the future NPP location showed their good agreement» by following text including Table 3 and new Figure 1-1

To compare HIRLAM results with measurements, observational data on the meteorological station Raahe were used. These data represent the 3-hour monitoring data on air temperature and atmospheric pressure for the period from 01.01.2010 to 31.12.2014, and on the characteristics of wind speed for the period from 22.10 .2010 to 31.12.2014. For the same period sampling similar HIRLAM characteristics were made. The model and the observed values were averaged with a daily period. Table 3 shows the statistical characteristics of the observed and model values from year to year, Figure 1-1 shows a comparison of calculated and observed mean monthly values of meteorological characteristics in 2010-2014. As seen, there is a good agreement between the model and the observed values, and thus, in the simulation of hydrodynamic regime of the Bothnian Bay near the future NPP location, atmospheric forcing calculated from HIRLAM results can be used.

Table 3 Statistical characteristics of air temperature, atmospheric pressure and wind speed in the surface layer of the atmosphere between 2010 and 2014, calculated on the average daily data

Years	Air temperature, °C		Atmospheric pressure, mb		Wind velocity, m c^{-1}	
	Observations	HIRLAM	Observations	HIRLAM	Observations	HIRLAM
	Mean annual value					
2010	2.1	2.0	1012.2	1012.6	5.5	4.7
2011	4.6	3.7	1009.0	1009.5	6.3	5.5
2012	3.1	3.2	1010.3	1010.7	5.8	6.1
2013	4.7	4.7	1010.2	1010.6	6.2	6.1
2014	5.2	5.1	1012.8	1013.0	6.1	6.1
	Minimum value					
2010	-27.4	-26.5	981.8	981.6	1.5	1.1
2011	-25.6	-26.9	969.3	970.4	1.2	0.9
2012	-24.7	-26.1	973.2	973.4	1.7	1.9
2013	-19.2	-20.1	974.9	976.1	2.0	1.0

2014	-20.0	-21.9	976.5	977.3	1.7	1.6
	Maximum value					
2010	26.0	24.7	1046.8	1046.3	11.6	13.1
2011	25.6	20.4	1037.4	1038.0	18.9	17.2
2012	20.1	20.1	1056.0	1055.7	13.2	14.6
2013	21.4	21.3	1033.6	1033.9	17.7	18.1
2014	25.8	24.7	1040.6	1040.1	14.7	15.6
	Standard deviation					
2010	11.4	12.0	11.3	11.2	2.2	2.1
2011	9.9	9.0	12.8	12.7	2.8	2.9
2012	9.7	9.9	13.0	12.9	2.3	2.5
2013	9.4	9.2	10.7	10.7	2.5	2.8
2014	8.8	9.1	11.8	11.6	2.7	2.8

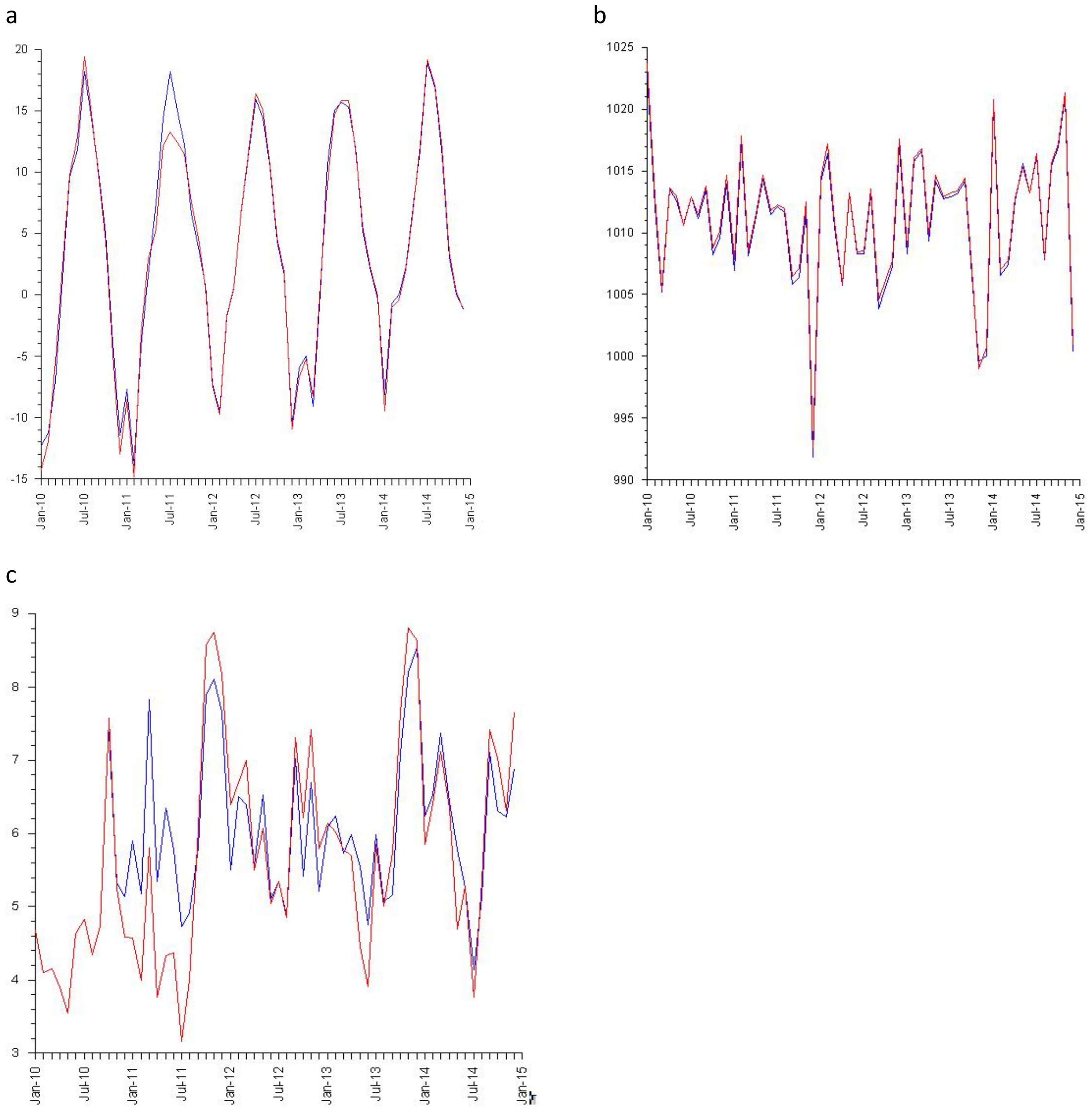


Fig. 1.1 – Temporal variability of mean monthly values of (a) air temperature (°C), (b) atmospheric pressure (mb) and (c) wind speed (m c^{-1}) in the near-surface layer of the atmosphere: calculated by HIRLAM (red curves) against observations (blue curves).

P5L24 "making" instead of "with making"
P11L4: Could it be better to say that you will estimate the maximal SWH as the asymptotic limit to increasing wind forcing?
P11L21: The wind speed was set constant and equal to 10 m/s was already written in line 12.
P12L20: "was at most 0.5-1.5 m" instead of " was 0.5-1.5 m and less"
P14L5: Use better "exceedance probability" than "repeatability"

All these editorial comments will be taken into account

P14L8: Why did authors choose those periods?

For the period under consideration 2010 -2015 just in the periods of 5-7.12.2015 and 14-16.10.2010 were observed the storm surges causing the extreme high and low sea level, respectively. The period 2010-2015 was chosen because we had data for verification of the model mainly for this period. We will be noted it in the text.

P16L2: 150 cm or -150 cm?

The referee is quiet wright: -150cm. Will be correct.

P16L2:10ˆ8 years??!! Is it correct?

Yes, this is correct.

P16L4: I think is better to be more precise. Assessing NPP impacts on the marine environment is too wide and does not correspond to the contents of the section.

We change this sentence by:

To assess the possible impacts of the NPP "Hanhikivi -1" on local thermal regime two scenario runs were performed:

P16L13: "average discharge" instead of "annual discharge"

Will be corrected.

FIGURES: Figure 1b: red line (cross-section) hardly discernible.

Here is a corrected figure 1 and caption to it.

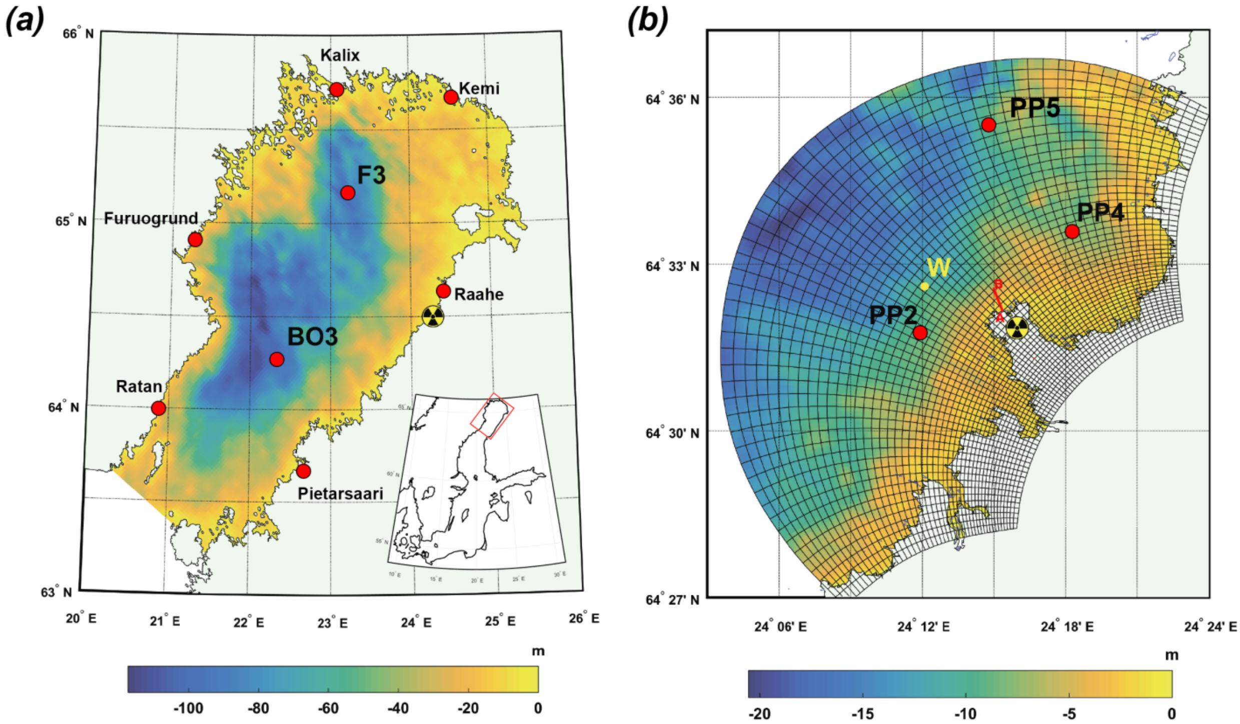


Figure 1: Bathymenty of the Bothnian Bay (a) and the area off the Hanhikivi peninsula (b). The location of the NPP, oceanographic stations (BO3, F3, PP2, PP4, PP5), coastal sites of sea-level measurements (Ratan, Furuogrund, Kalix, Kemi, Raahe, Pietarsaari) and also the position of cross-section (red line) and SWAN output point (W) are presented. The inset in fragment *a* shows the position of the Bothnian Bay in the Baltic Sea.

Figure 2: Can you indicate the location of the 4 sites in Fig 1?

Figure 2 has been modified. New Figure 2 is given in response to remark 2 of the first reviewer. Points of sea-level measurements, data from which were used in this study are shown in Figure 1a.

Figure 4: No dates are indicated. The panel b is of rather poor quality. Authors must provide equivalence between ice types and thickness in order to compare properly results and observations.

The corrected figure and caption to it are given below.

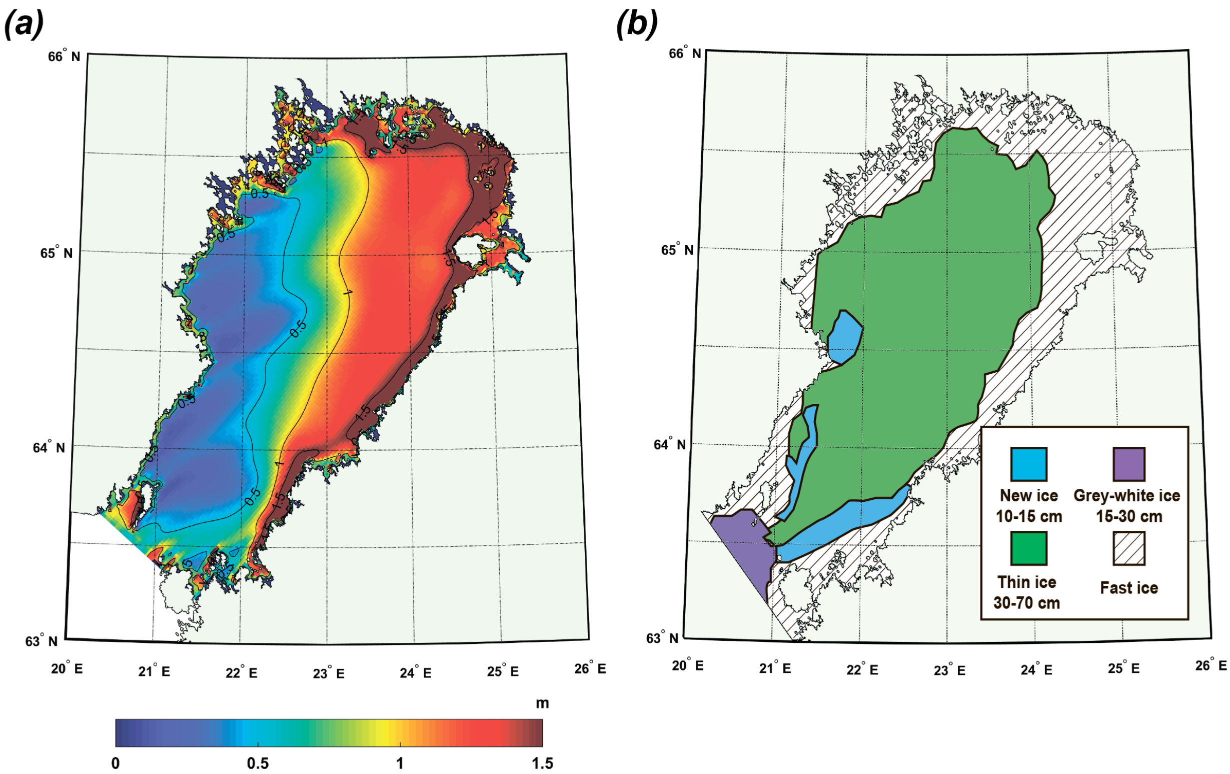


Figure 4: Modeled (a) and observed (b) distribution of sea ice thickness in the Bothnian Bay in the period 27 February to 1 March 2011. Ice map in fragment *b* is from the Arctic and Antarctic Research Institute Center "Sever" (St. Petersburg).

Figure 6: Is W the point near NPP referred to in the figure captions?

The point W is located near the NPP, the location is shown in Fig.1b

Figure 9a: Indicate NPP location. Increase font and arrow sizes within the plot.

Corrected figure is given below.

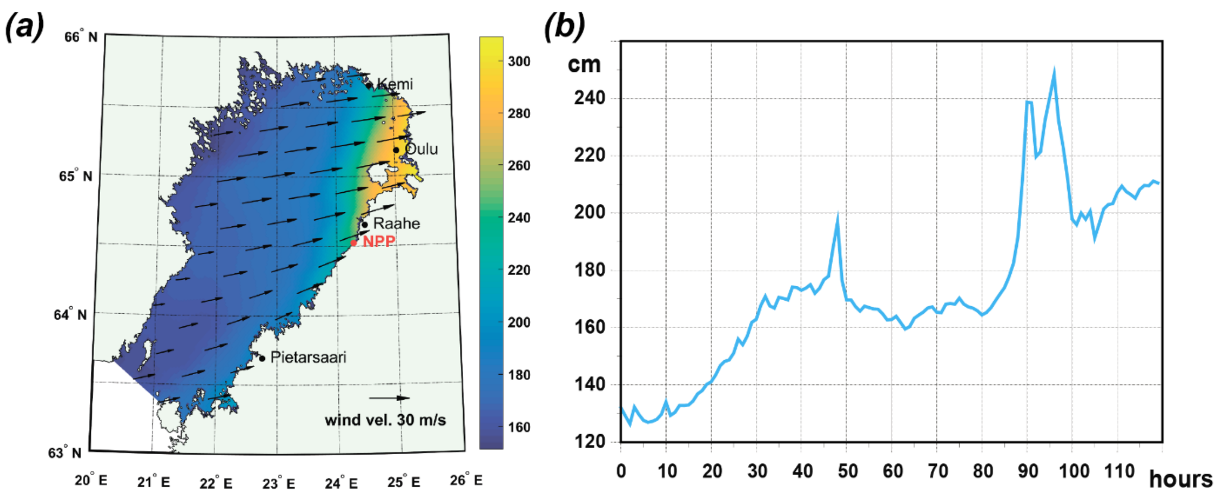
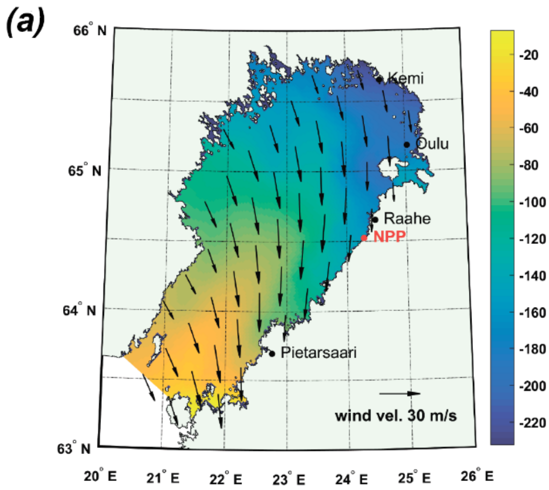
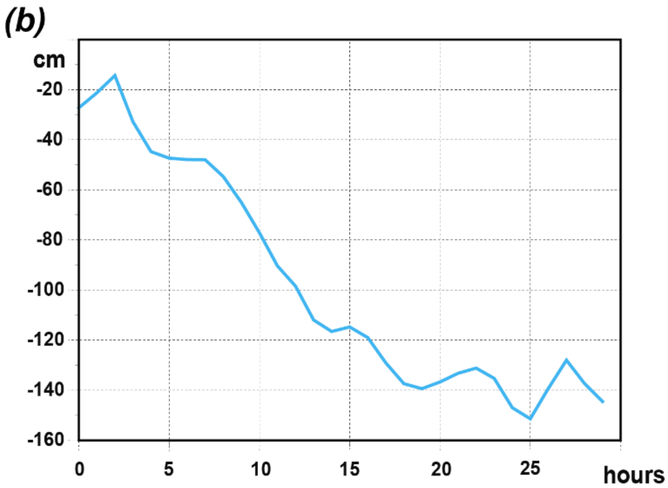


Figure 10a: Indicate NPP location. Increase font and arrow sizes within the plot.

Corrected figure is given below.



(a)
66° N
65° N
64° N
63° N
20° E
21° E
22° E
23° E
24° E
25° E
26° E
Kemi
Oulu
Raahe
NPP
Pietarsaari
wind vel. 30 m/s
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220



(b)
cm
-20
-40
-60
-80
-100
-120
-140
-160
0
5
10
15
20
25
hours