Spray-icing forecasting in Northern Norway

ASSW 2023

Vienna, 21 February 2023

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What is sea-spray icing?

Saline-water icing caused mainly by:

- **Wave-ship interaction** (this provides the highest water amount)

  -> considered the most important source of water

- **Wind-driven icing** (droplets ripped off from the wave crests)

Atmospheric water sources like:

- **snow**, **freezing fog** and **freezing rain** may also contribute to icing on ships.
- particularly the combination of **snow** and **sea spray** may be important

Official U.S. Navy photo NH 98517 from the U.S. Navy Naval History and Heritage Command

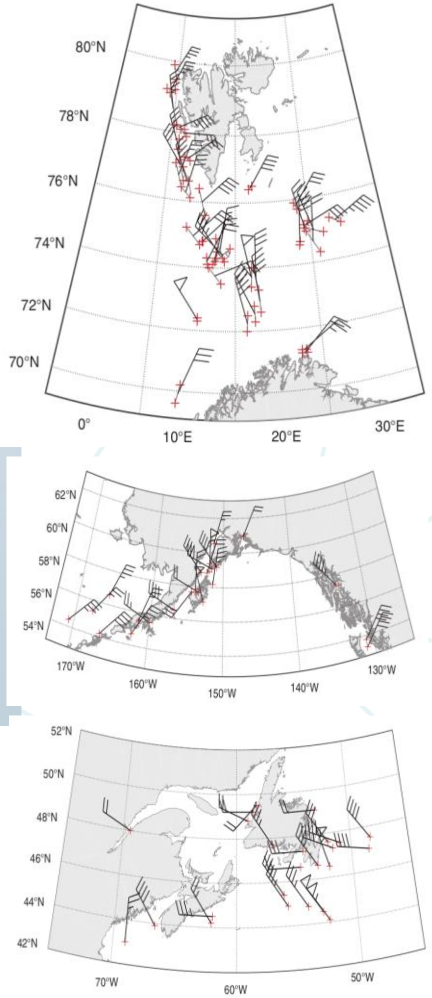
Photo: ✝ Heidi Nilima Monsen, 26.05.2018

Photo: Sveinung Løset

[Samuelsen et al. (2015)]

[Samuelsen, 2018]:

Unique ship-icing data from Norway, Alaska, Eastern Canada



Tf = -4 deg C in the mean, due to salt expulsion the Tf is lower than out in the sea

$$T_f = -54.1126\left(\frac{S_b}{1000 - S_b}\right), S_b \in [0, 124.7] \text{ ppt}$$

Spray-icing model for ships (MINCOG)

Atmospheric variables

Ocean-wave variables

Ocean variables

Ship variables

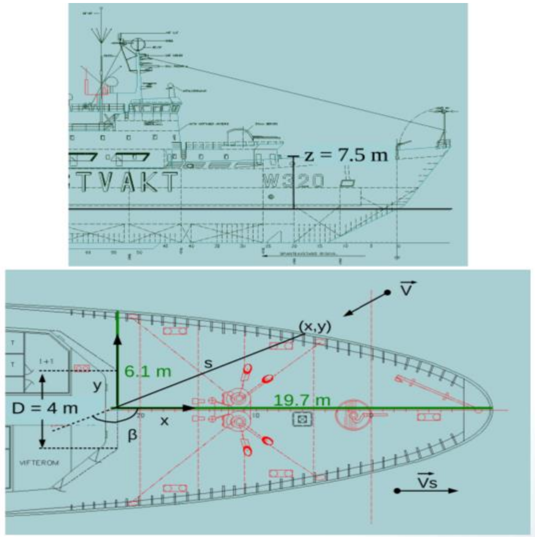
$$R_w = (\vec{V}_d \cdot \vec{n}_1)\ l_{wc} N t_{dur}$$

Spray-flux calculation

Icing-rate calculation

$$Q_f = Q_c + Q_e + Q_d + Q_r$$

Using reference ship: KV Nordkapp



Above view/side view KV Nordkapp.

$$\frac{dh}{dt} \times 0.7 L_f \rho_i = f\left(T_a, p, R_H, T_{\mathrm{sp}}(\mathrm{SST}, T_d), \vec{V}, \vec{V}_s, \downarrow \mathrm{LW/SW}, R_w, T_s(S_b)\right)$$

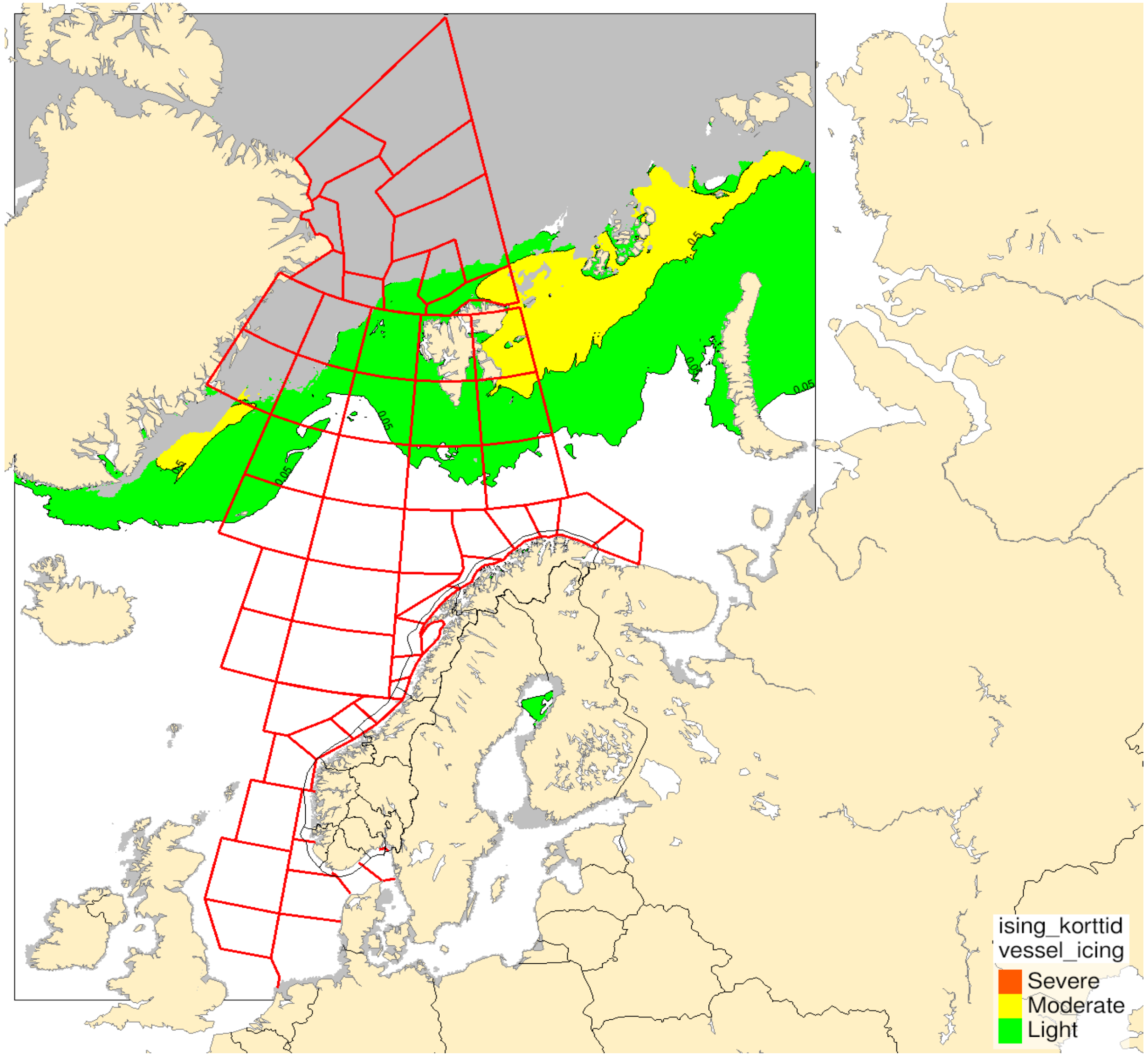
$$R_w = f\left(\vec{V}, \vec{V}_s, H_s, P_s, \vec{c}(D_p, D_w, P_s), z\right)$$

$$S_b = \frac{S_w}{1 - 0.7n}, \quad T_s = -54.1126 \left(\frac{S_b(n)}{1000 - S_b(n)}\right)$$

More details:
Samuelsen et al., 2017

Operational system used at MET Norway

2016/2017 -> October 2021 larger domain -> Running twice every day at 00 and 12 UTC: finished 0930 UTC and 2130 UTC



Latest forecast available here:
https://thredds.met.no/thredds/catalog/vesselicinglatest/catalog.html

Freely available archive from September 2019 -> :
https://thredds.met.no/thredds/catalog/vesselicing/catalog.html
Somewhat unstable production, particularly in the beginning. More stable after the update in October 2021.

Visual output is available on Barentswatch:
https://www.barentswatch.no/bolgevarsel/

Atmospheric input

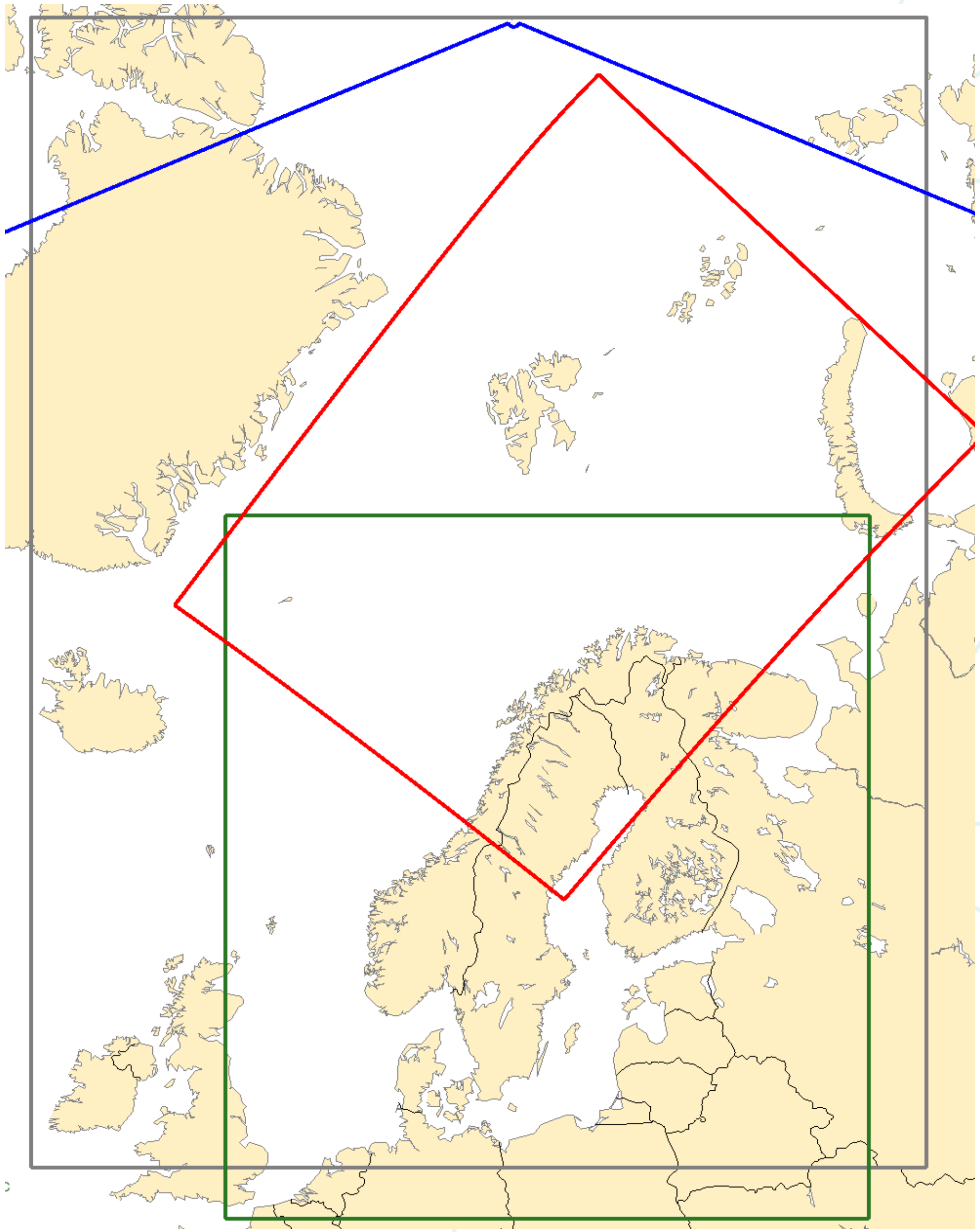
Arome Arctic 2.5 km +
MEPS 2.5 km +
ECMWF
(AA first, then MEPS, finally ECMWF)

- Wind speed 10 m (U10m)
- Temperature 2 m (T2m)
- Relative humidity 2 m (RH2m)
- Mean-sea-level pressure (MSLP)

Some assumptions:

- Incoming shortwave radiation (SW) = 0
- Incoming longwave radiation (LW) equal to:
- 0.7 * sigma * T^4 (approximation)

May consider adding radiation directly from the model, but more verification of radiation data is needed.



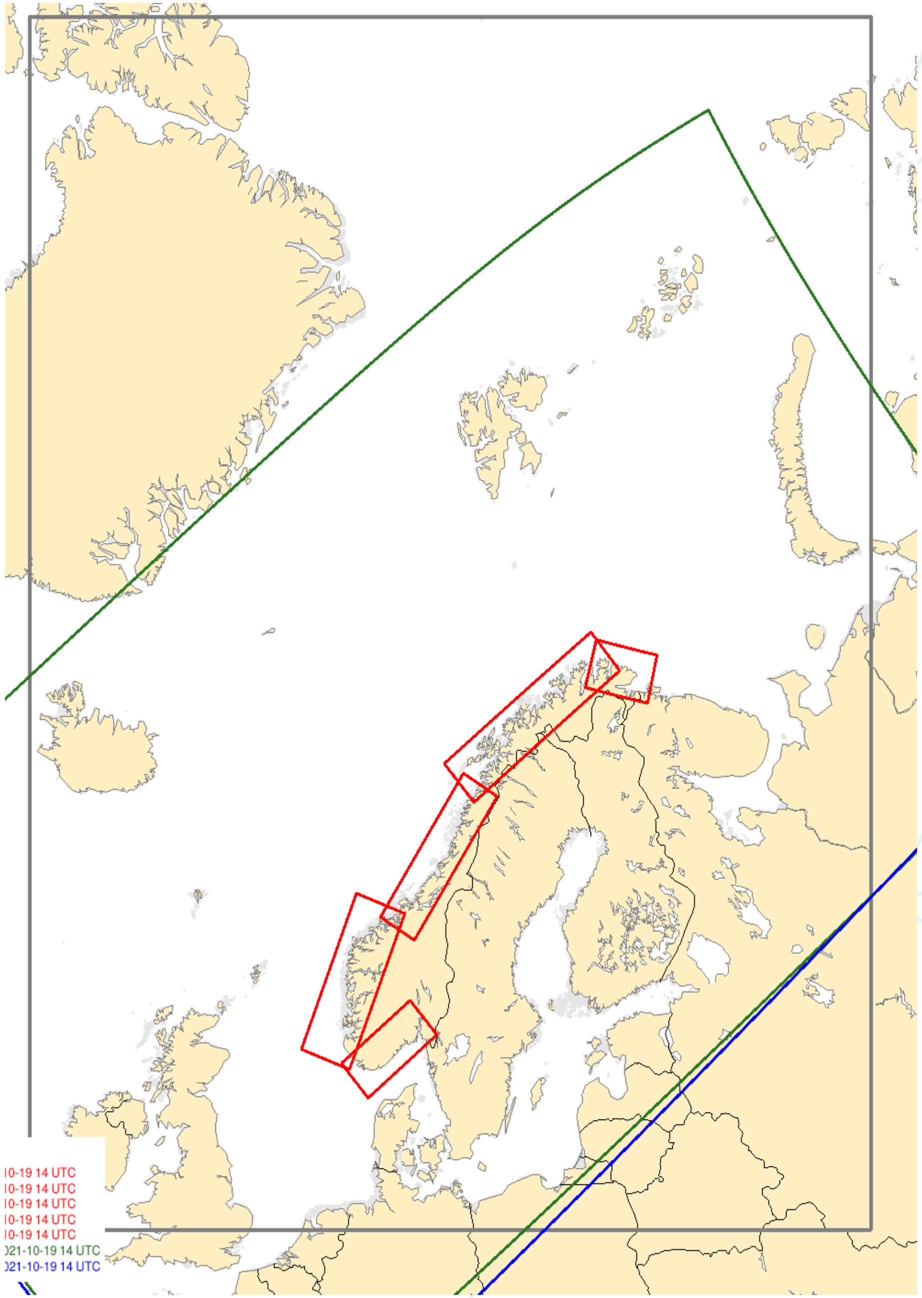
The models are interpolated and merged to a common grid of 2.5 km grid spacing.

Wave models

Wam 800 m (5 models, MEPS wind) +
Wave Watch 4 km (ECMWF + MEPS wind) +
Wam 3 km (ECMWF wind)

- Sig. wave height (Hs)
- Mean wave period (Ps)

(Ideally we want to take the wave spectrum and the energy of the waves hitting the ship better into account, but we are not currently doing that)



The models are interpolated and merged to a common grid of 2.5 km grid spacing.

Ocean models

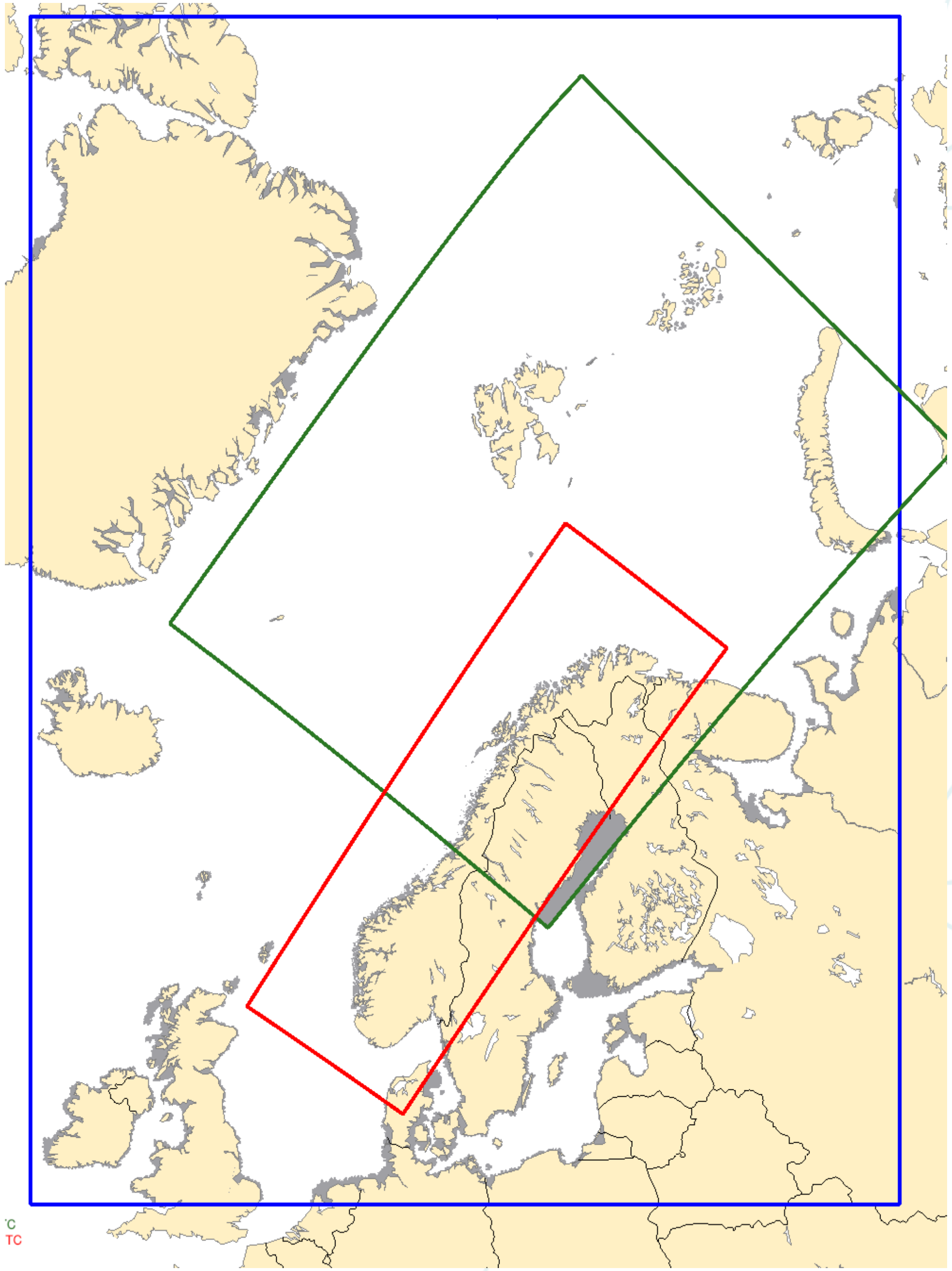
Norkyst 800 m +

Barents 2.5 km +

Topaz5

- Sea-water salinity (Salt)
- Sea-ice concentration (undefined above 40 % ice-concentration, no sea ice in Norkyst 800 m) (IC)
- Depth (for wave-speed calculation) (Dp)
- Sea-surface temperature (SST) (may also be extracted from Arome/IFS)

Salinity is important when there is large variation in it, e.g. in Bottenviken where there is low salinity



The models are interpolated and merged to a common grid of 2.5 km grid spacing.

Forecaster warnings based on the model output in 2021/2022

22 warnings issued on the coast/in the fjords of mainland Norway in 2021 and in 2022

This is a high number. Most warnings are normally issued further north.

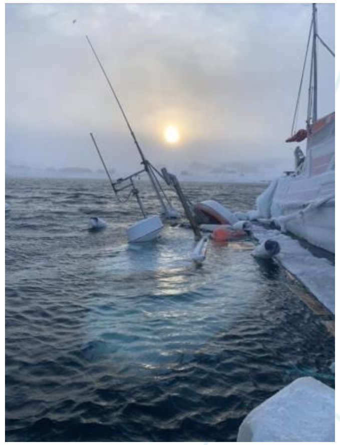
2021

Ukenr.	Startdato	Evt. sluttdato	Farevarsel	Observasjoner?
1	07.01.2021	08.01.2021	1	
1	08.01.2021	10.01.2021	1	
2	11.01.2021	12.01.2021	1	
3	20.01.2021	20.01.2021	1	
3	21.01.2021	22.01.2021	2	2?
3	21.01.2021	22.01.2021 k	1	
3	23.01.2021		1	
3	23.01.2021	(24.01.2021)	1	1?
4	29.01.2021	30.01.2021	1	
5	05.02.2021	10.02.2021	1	0/1?
7/8	21.02.2021	23.02.2021	2	2?
7/8	21.02.2021	23.02.2021	2	2?
8	**22.02.2021**	**23.02.2021**	1	2?
8	23.02.2021	23.02.2021	1	
10	09.03.2021	12.03.2021	1	1?
11	19.03.2021	19.03.2021	1	1?
47/48	28.11.2021	30.11.2021	1	1?
48/49	04.12.2021	08.12.2021	1	
49	06.12.2021	08.12.2021	1	
49	09.12.2021	10.12.2021	1	
51	22.12.2021	23.12.2021	1	

2022

	Startdato	Evt. sluttdato	Farevarsel	Observasjoner?
1	03.01.2022	06.01.2022	1	1?
1	07.01.2022	08.01.2022	1	
2	10.01.2022	12.01.2022	1	
3	22.01.2022	23.01.2022	1	
5	01.02.2022	03.02.2022	1	
5	03.02.2022	04.02.2022	1	
5	03.02.2022	05.02.2022	1	**2?**
5	04.02.2022	06.02.2022	1	
6	13.02.2022	13.02.2022	1	
8	23.02.2022	24.02.2022	1	
8	25.02.2022	26.02.2022	1	
10	07.03.2022	08.03.2022	1	
12	25.03.2022	26.03.2022	1	1
17	26.04.2022	27.04.2022	1	1
17	27.04.2022	28.04.2022	1	

Hammerfest, Photo: iFinnmark/private



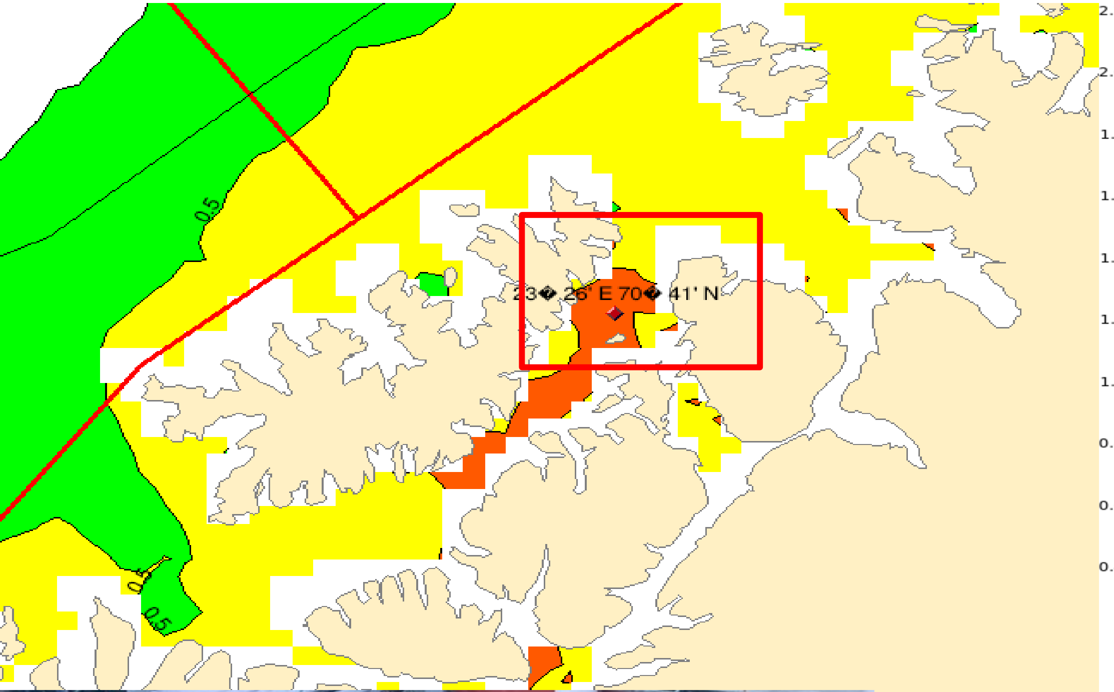
Torsvåg, Photo: Audun Mathiassen

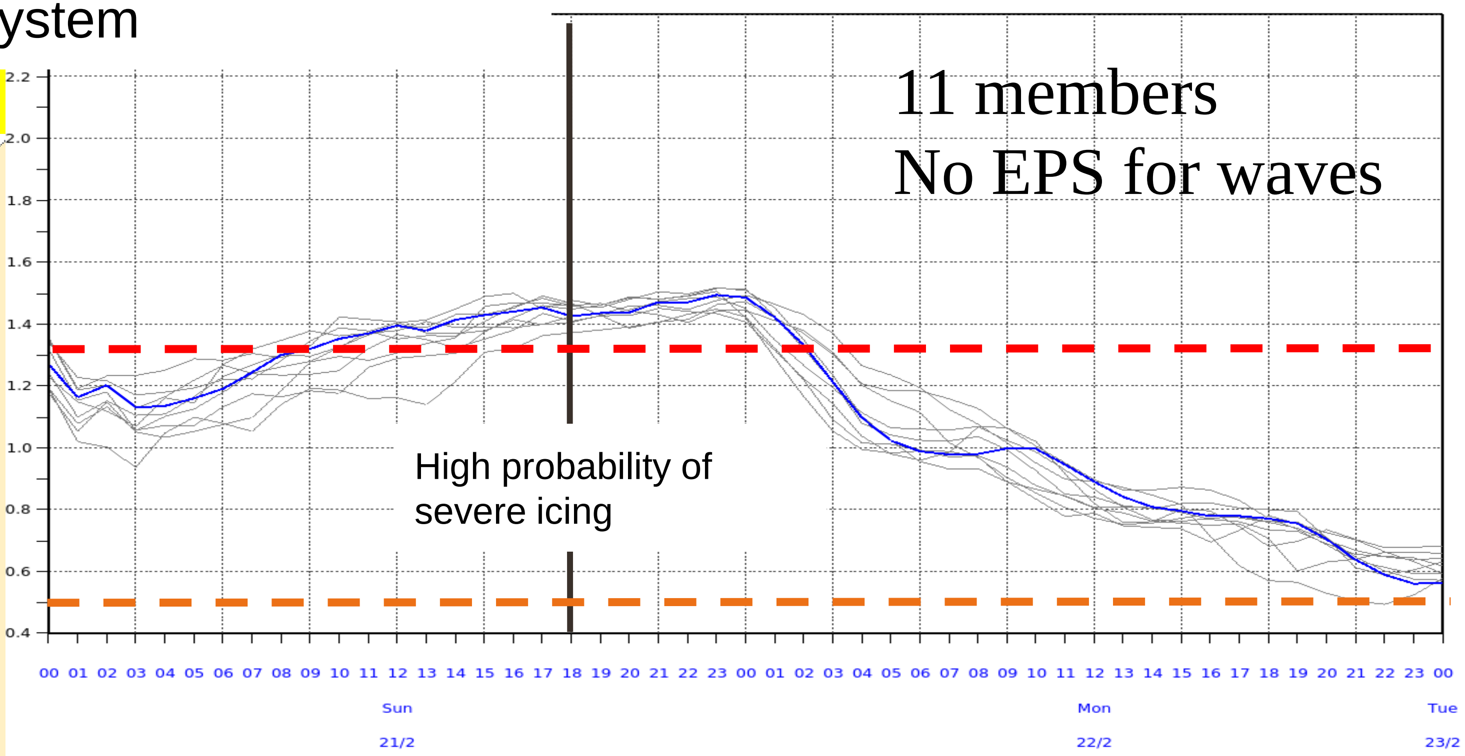
26 April 2022. Spray and snow icing.
Photo: Redningsselskapet

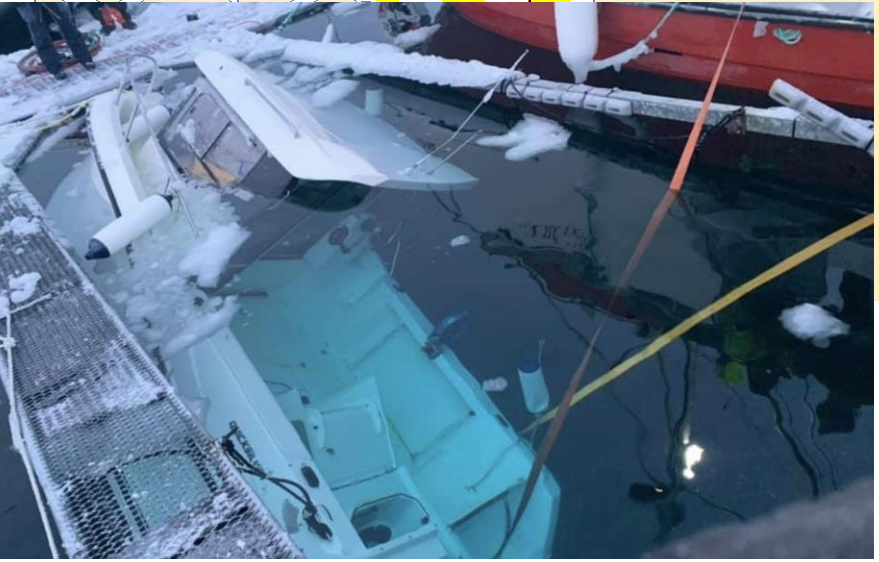
Dyrøy, Photo: Cecilie Larsen

3 warnings of severe icing in 2021

Testing out EPS of icing for the operational system







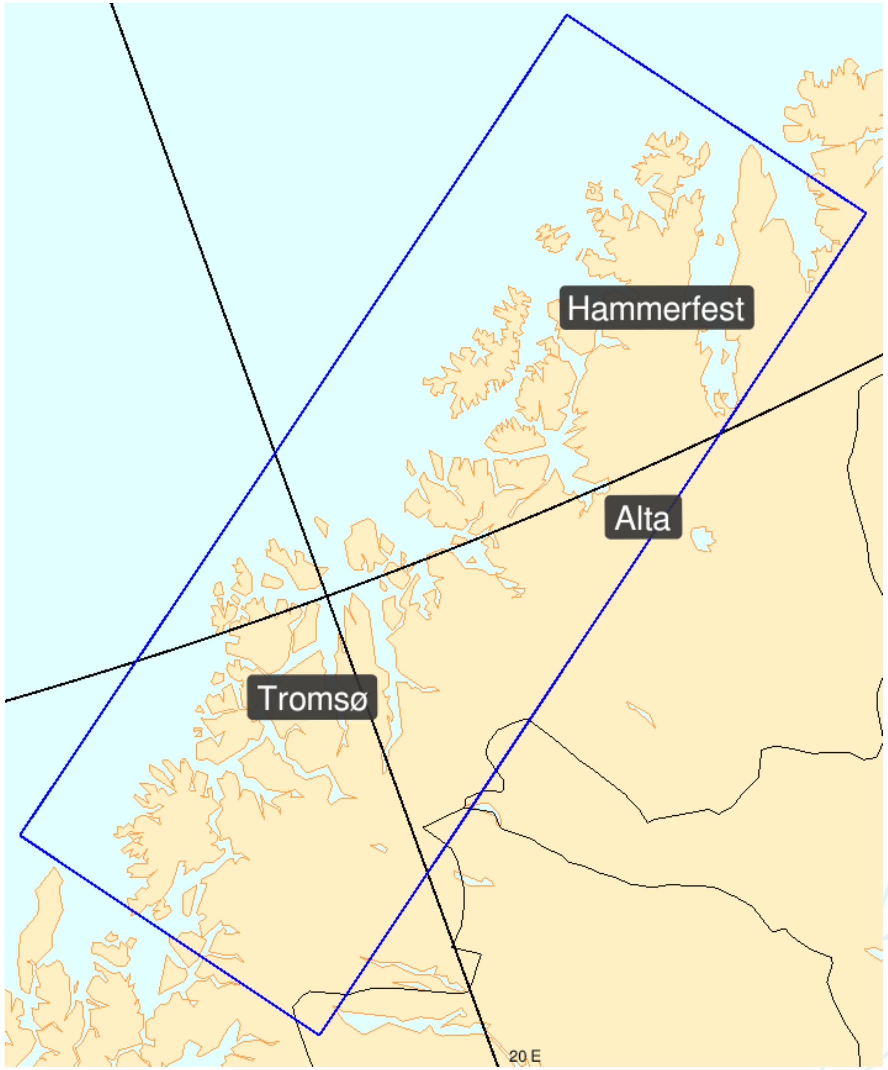
Hammerfest, Photo: iFinnmark/private

Hakkstabben, Photos: Merete Bergly

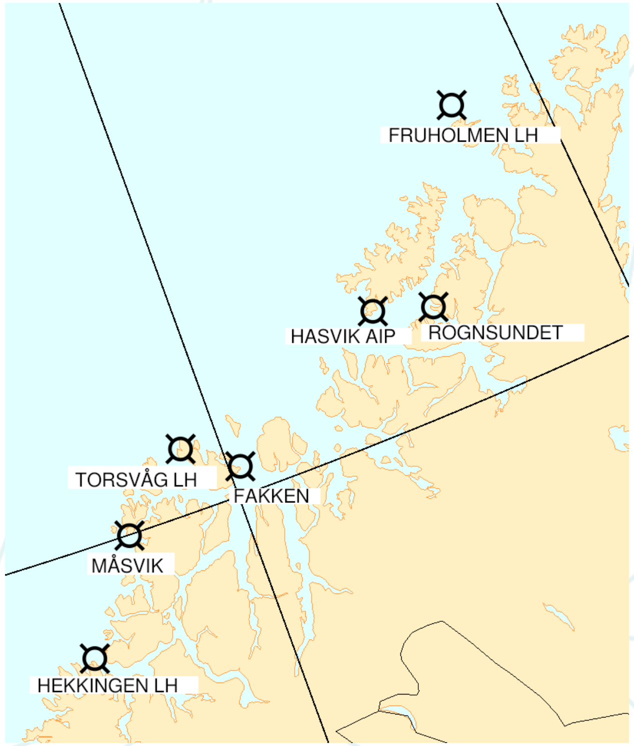
Experiments with hectometric atmospheric Harmonie-AROME modelling

Arome Troms Finnmark 300 m (ATF300m)

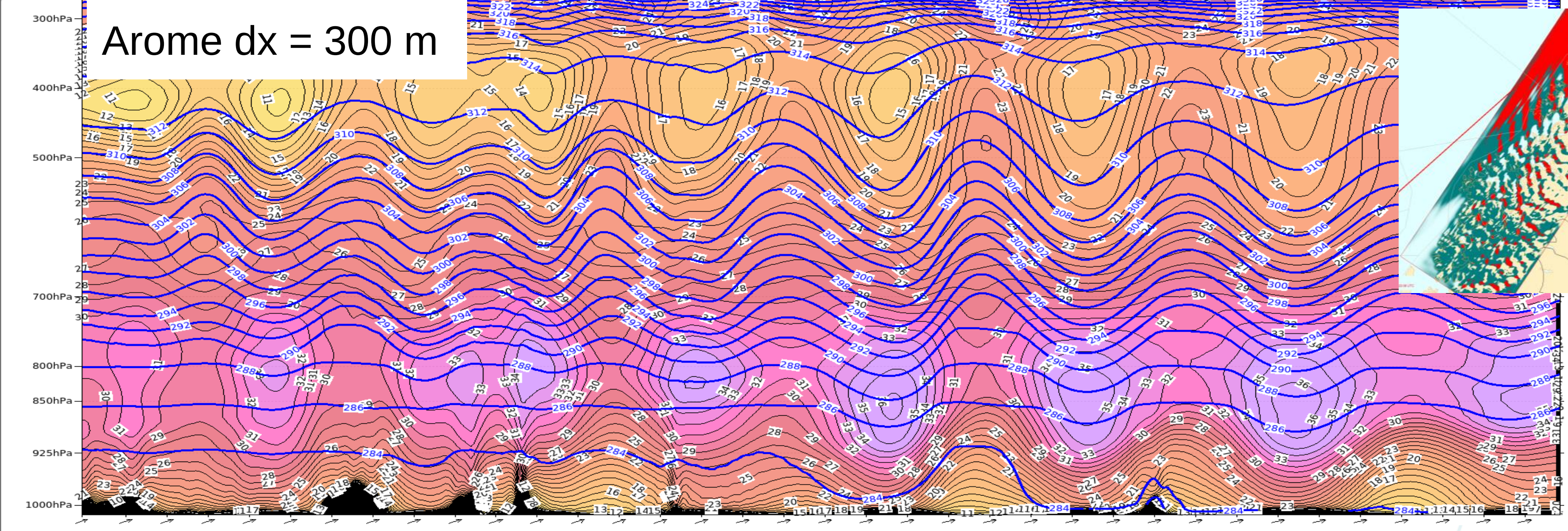
- Δx = **300 m**, 90 vertical layers, Cubic grid
- Δt = 5 s (2-4 s when crashed)
- IFS-ECMWF Highres boundaries
    - CY43h2.1
    - double precision
    - 6 hour cycling
    - +12h forecast at 00 UTC and 12 UTC
    - no surface or upper-air DA
        - Canari run to update SST and sea ice
- Run from 1 January 2022 until 30 September 2022
- Icing is calculated using this atmospheric model run, and otherwise the operational settings for waves and ocean parameters
- Notice that there is no wave calculation using high-resolution atmospheric input

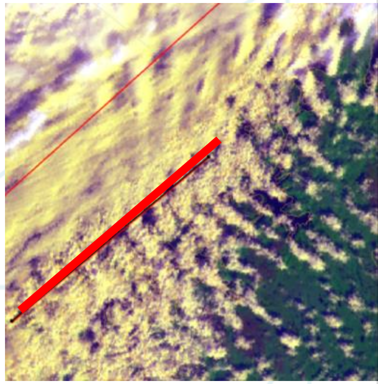


7 coastal observations applied for icing verification

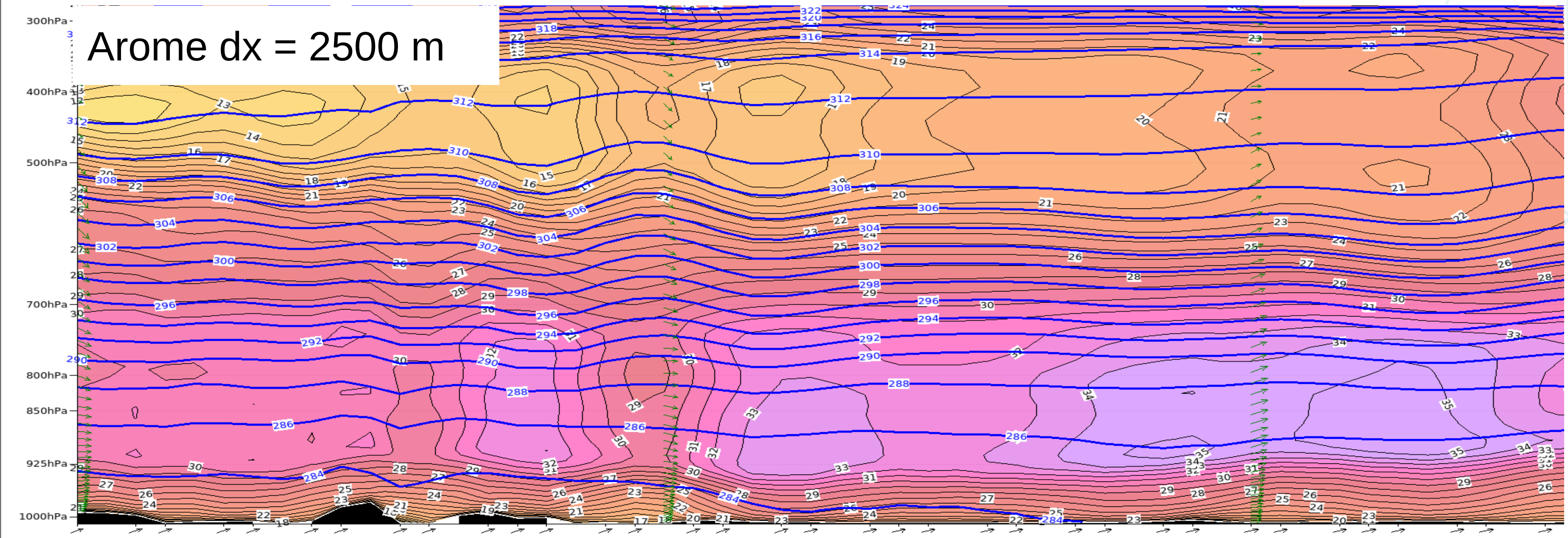


Arome dx = 300 m





Arome dx = 2500 m

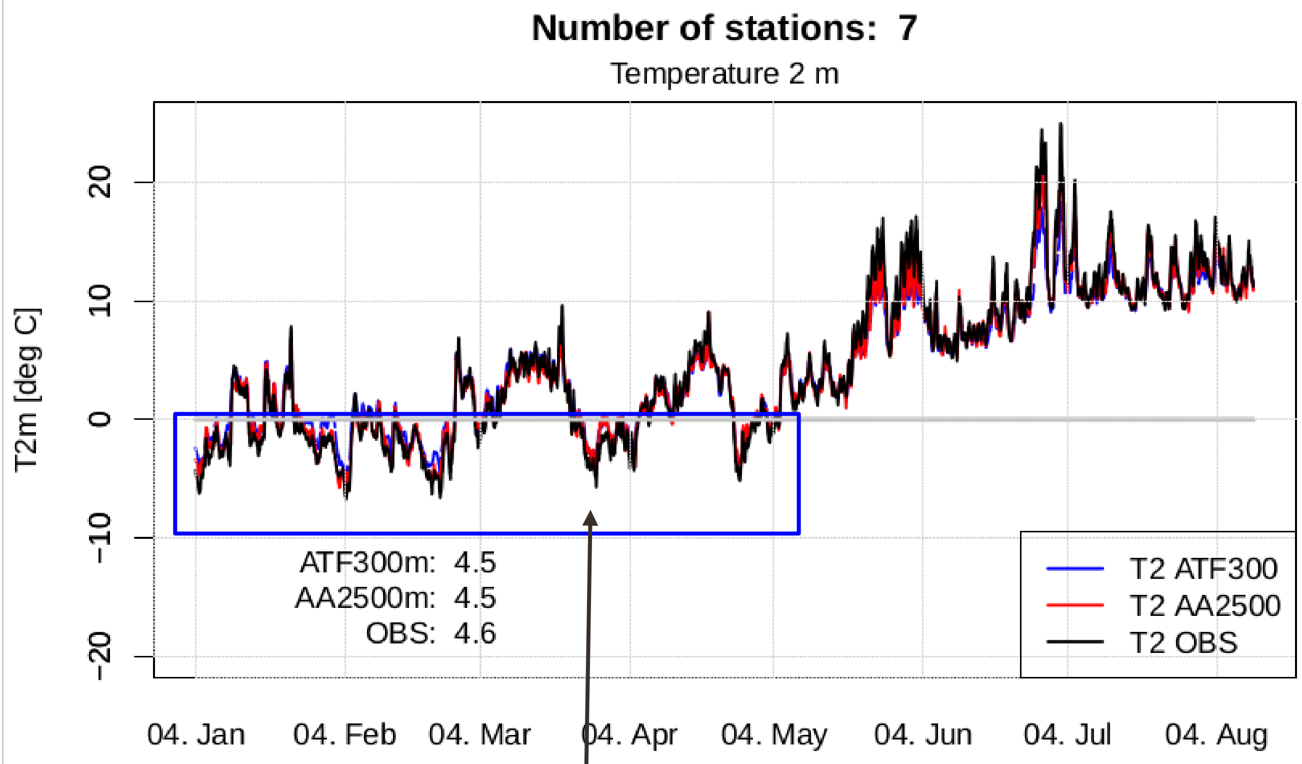


23 August 2022

- Potential temperature
- Wind speed

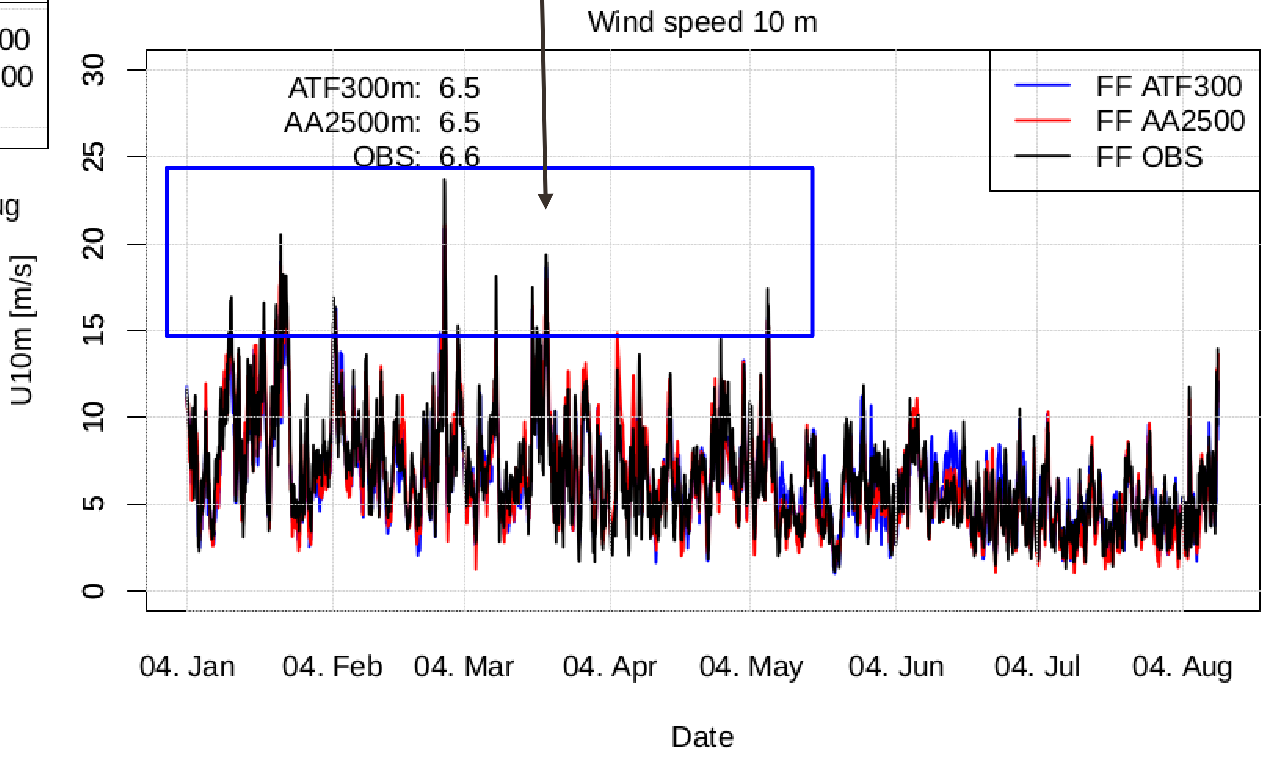
The Arome 300 model is resolving mountain waves and other high-resolution wind phenomena considerable better!

Weather conditions during 4 January to 11 August 2022

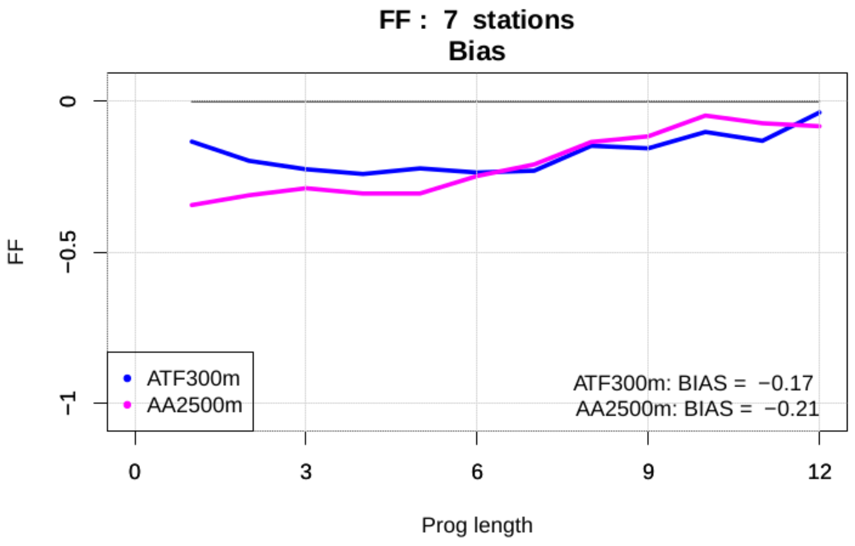


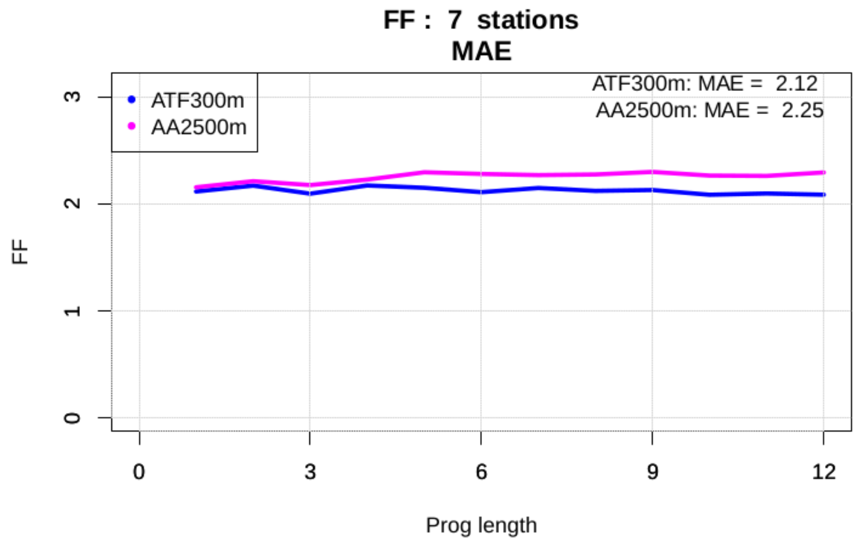
Periods of freezing (in the mean of 7 coastal stations) until the beginning of May!

Periods of strong winds above 15 m/s (in the mean of 7 coastal stations) until the beginning of May!

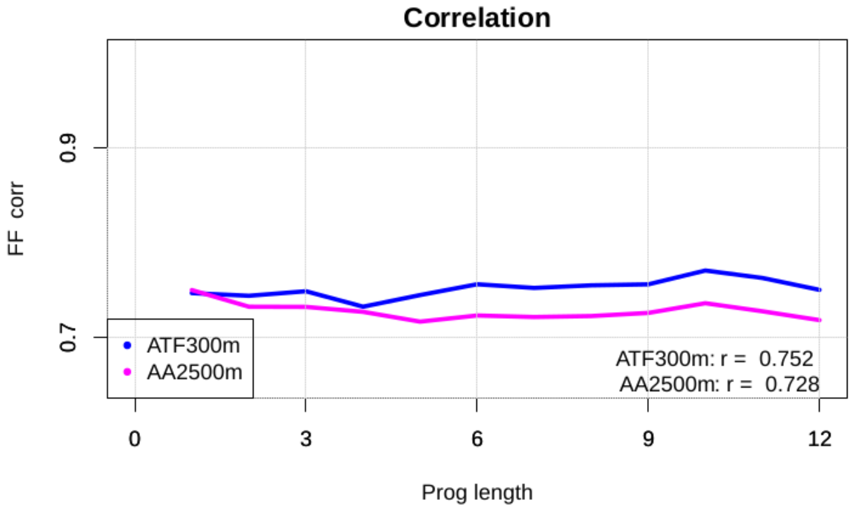


General verification - wind speed 10 m





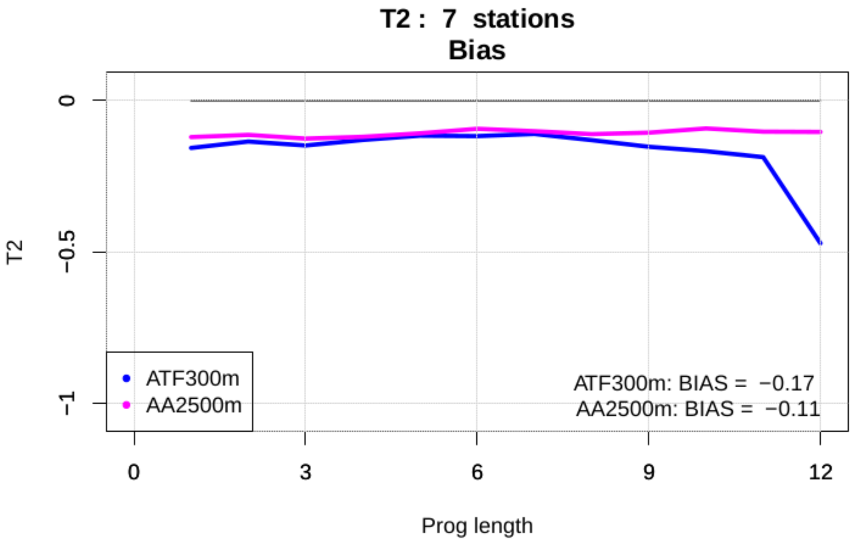
Verification period is 4 January 2022 until 11 August 2022.

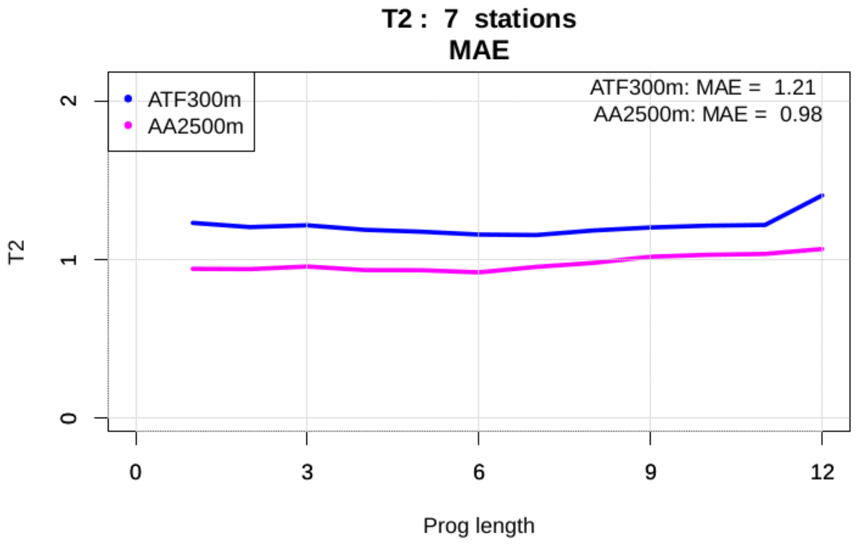


Better BIAS
Better MAE
Better Correlation

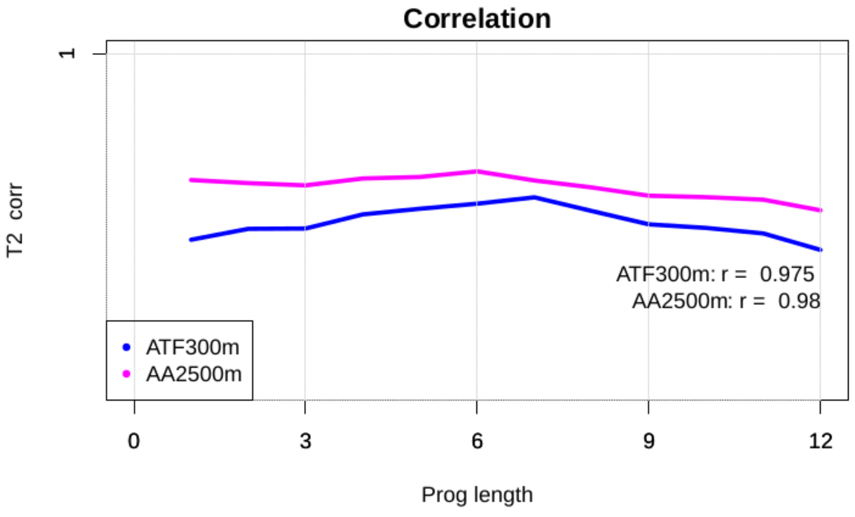
Photo: Bernt Aksel Jensen, 23.08.2022

General verification - temperature 2 m





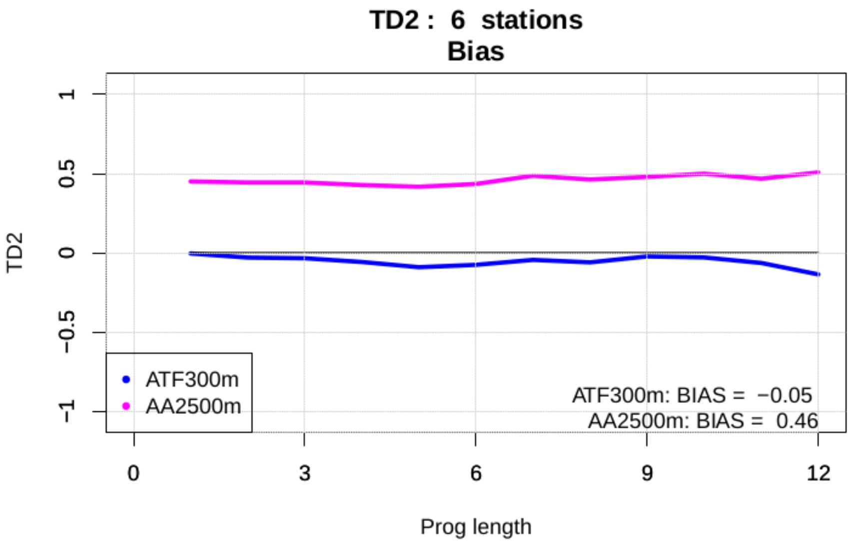
Verification period is 4 January 2022 until 11 August 2022.

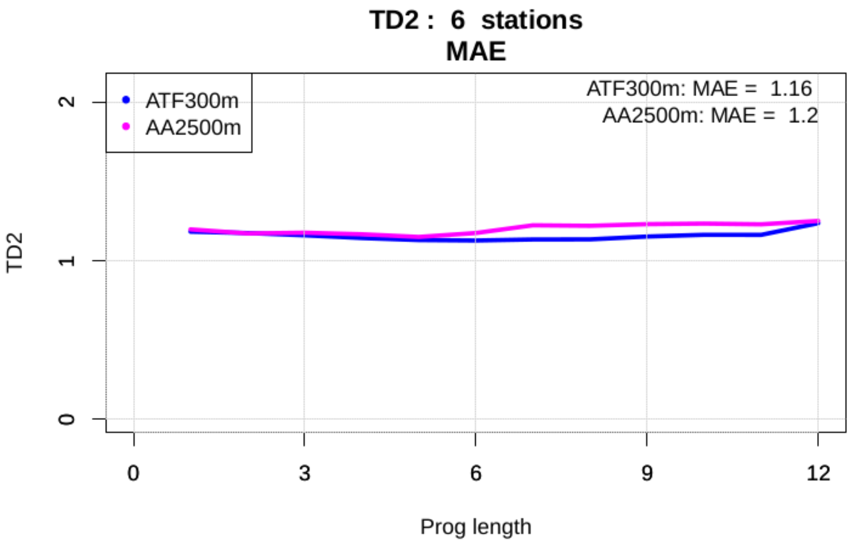


Worse BIAS
Worse MAE
Worse Correlation

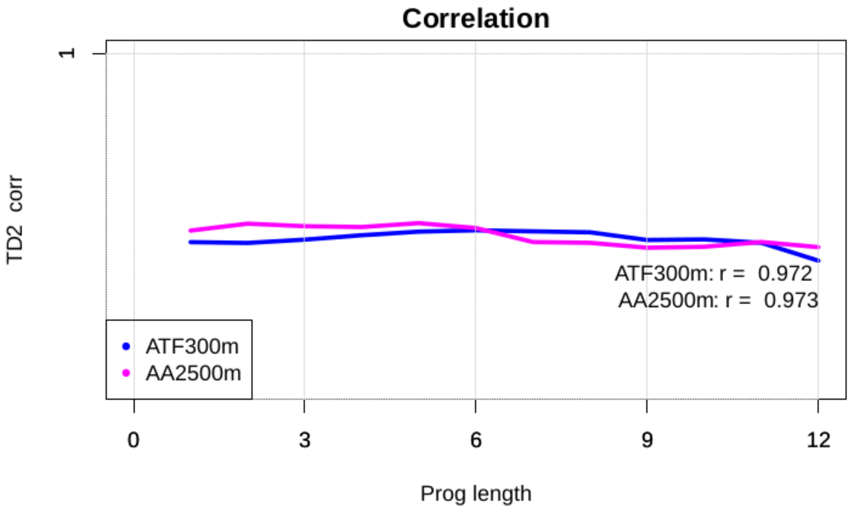
Photo: Eirik Mikal Samuelsen, 05.02.2022

General verification - dew-point temp. 2 m





Verification period is 4 January 2022 until 11 August 2022.



Better BIAS
Better MAE
Similar Correlation

Photo: Eirik Mikal Samuelsen, 11.06.2022

Simplified MINCOG model in order to make proxy observations

Simplifications (most critical assumptions are marked with **boldface)**:

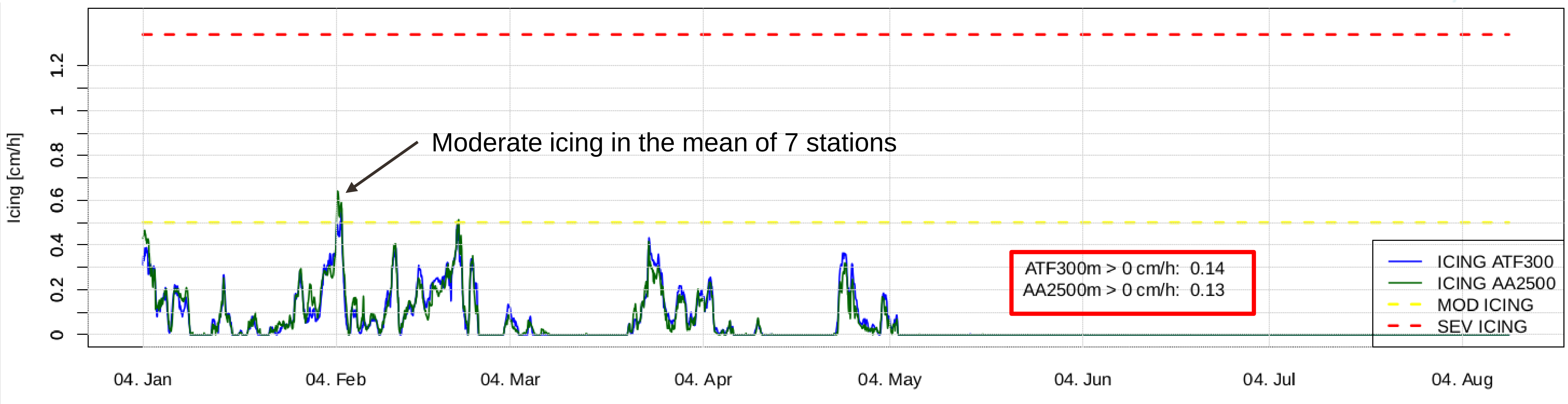
- **Constant Tf = -4 deg C, in order to save computation time**
- Constant spray duration and spray freq.
- Simple weighting of incoming spray temp. = 0.8 x SST + 0.2 x Ta
- Spray speed equal to relative wind in along ship direction
- Constant angle between wind and ship, wave and ship, deep water approximation applied for wave speed calculation.

As observations of icing the following are applied:

- Obs of U10, T2m, RH2m and MSLP from the 7 coastal stations
- ATF300m data applied when there is lack of observations
- Hs, Ps, SST: model data from the operational settings are applied (at a nearby grid point at sea)

Icing “observations” are therefore calculated using partly observed values.

Icing from 4 January 2022 - 11 August 2022

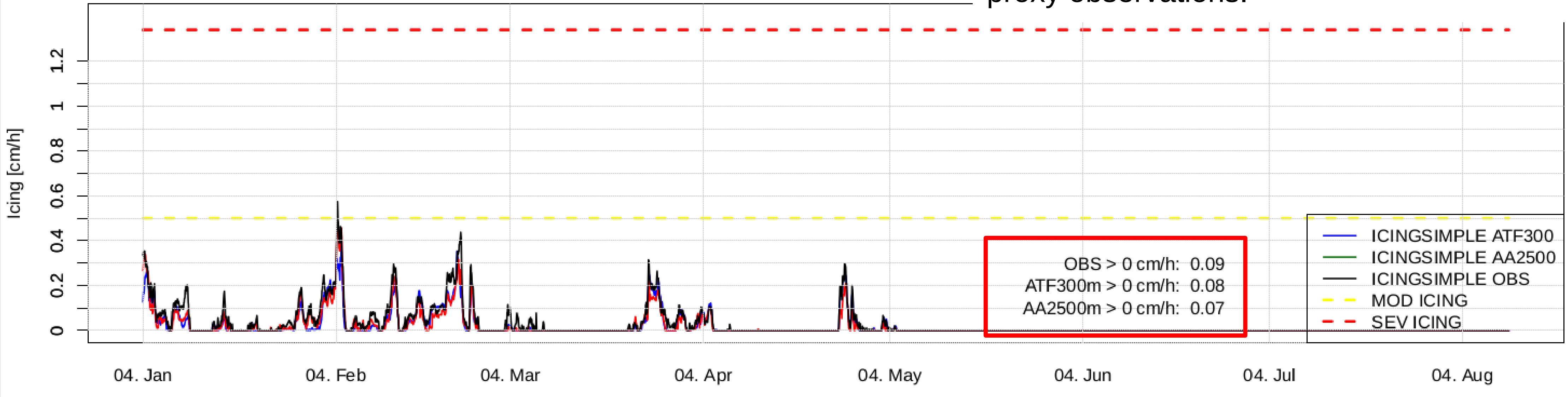


Date

The full model has higher icing rates than the simplified model.
ATF300 m has higher icing rates which is closer to the proxy observations.

Number of stations: 7

Icing rate



Conclusions

- The operational MINCOG icing model of MET Norway has been routinely run twice a day since 2016, and archived data is available from September 2019
- The model seems to work good for issuing general icing warnings despite the fact that it is developed for a specific ship type at a specific position. It has clearly improved ship-icing forecasting in Norway compared to the previously-applied Overland model.
- EPS of icing is also started to be tested out
- Using ATF300 m as input to MINCOG provides higher icing rates closer to the proxy observations compared to using the operational Arome Arctic 2.5 km model as input to MINCOG.
- Next step would be run ocean-wave models with input from Arome 300 m winds in some of the cases of 2022 to see whether model performance is further improved when applied in MINCOG.

Questions/comments?

eiriks@met.no

SPRICE web page:
https://uit.no/project/sprice

For a thorough description of the ship-icing models currently applied in operational weather forecasting:
[Samuelsen (2017)](#)

dx = 300 m
atmospheric input