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WIND FORECASTS FOR ROCKET & BALLOON LAUNCHES AT THE ESRANGE SPACE CENTER

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ROLE OF WEATHER ON ROCKET & BALLOON OPERATIONS

Weather is the most important factor governing rocket & balloon operations (Kingwell et al., 1991; Wetzel et al., 1995). Most relevant meteorological phenomena for rocket & balloon operations:

- ✓ **LIGHTNING**: electrical surges can lead to loss of control and even destruction of rocket. Also hazardous to ground crews during launch and routine site operations. Rockets can themselves trigger lightning strikes;
- ✓ **WIND**: major issue when rocket is taken to launchpad, when shelter of launch tower is removed, and during burning phase when rocket is near the surface and its relative velocity is low. Vertical wind shear important for balloon ascent;
- ✓ **TURBULENCE**: turbulence, in particular that arising from vertical wind shear, can lead to unacceptable stresses on key structural elements of the rocket;
- ✓ **TEMEPERATURE**: excessively high or low temperatures can cause damage to components of rocket and affect performance of personnel and equipment during launch and routine site operations. Variations in temperature lapse rate can lead to sharp changes in balloon buoyancy during ascent phase.

WIND is most relevant factor for launches at ESC and is the focus of this work.

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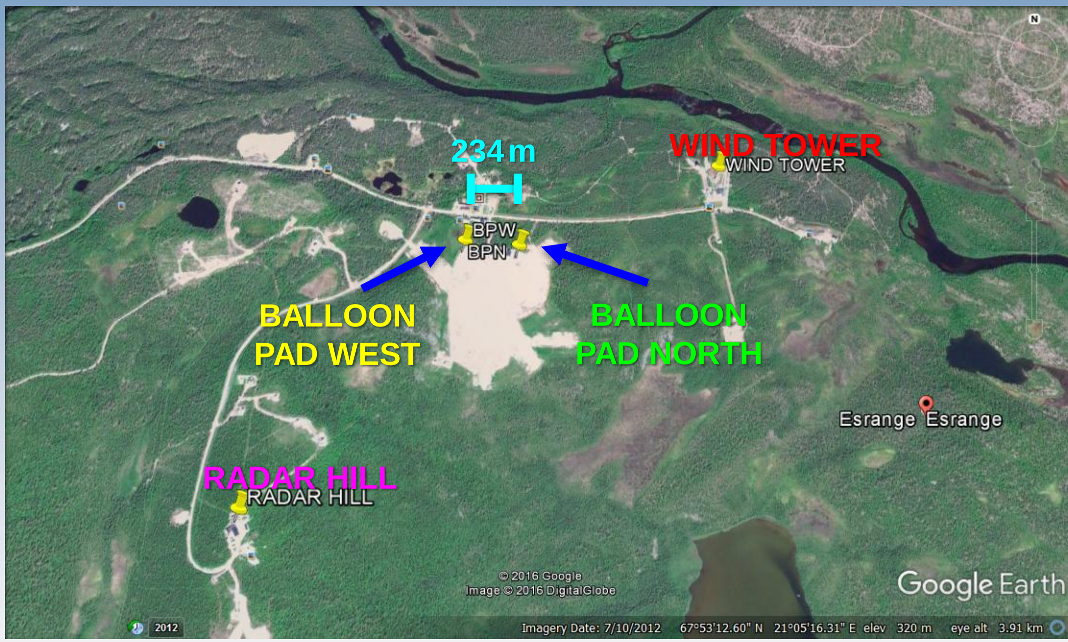
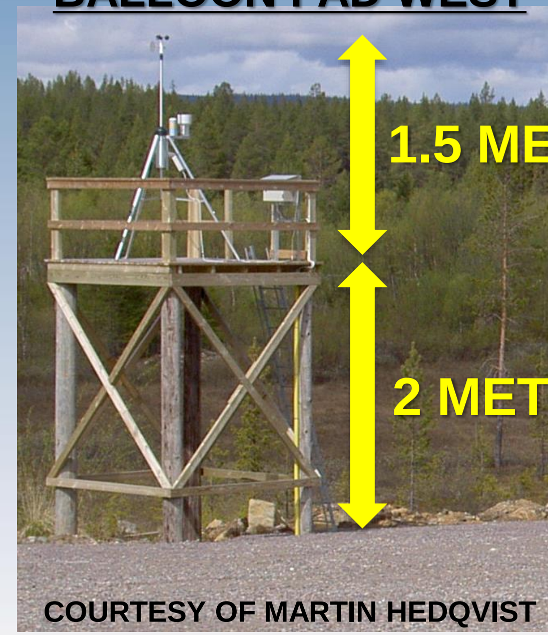
ESRANGE SPACE CENTER (WEATHER SENSORS)



BALLOON PAD WEST



- **RADAR HILL (RH)**: horizontal wind direction & speed + temperature @ 40 m AGL;
- **BALLOON PAD WEST (BPW)**: horizontal wind direction & speed @ ~3.5 m AGL + Pressure, Temperature, Dewpoint Temperature and Relative Humidity @ ~3 m AGL;
- **BALLOON PAD NORTH (BPN)**: horizontal wind direction & speed @ 20 m AGL;
- **WIND TOWER (WT)**: horizontal wind direction & speed @ 10, 25, 45, 65, 85, 100 m AGL.

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WEATHER RESEARCH AND FORECASTING (WRF) MODEL

- *"Community Model"*: free and shared resource developed by National Center for Atmospheric Research (NCAR) in collaboration with other institutions

- WRF Version 1.0 released in December 2000; current release is Version 4.0 available since June 2018

- WRF is suitable for use in wide range of applications including:
  - Idealized simulations (e.g. convection, sea breeze, squall lines, etc.);
  - Regional climate research;
  - Polar climate research (PolarWRF);
  - Coupled-model applications;
  - Chemistry-related applications (WRF-CHEM);
  - Planetary atmosphere research (PlanetWRF);
  - Real-time NWP.

- WRF is used by academic atmospheric scientists, forecast teams at operational centers and application scientists.

WRF's Website: http://www.wrf-model.org/index.php
Download WRF: http://www2.mmm.ucar.edu/wrf/users/download/get_source.html

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EXPERIMENTAL SETUP

- Hindcasts (model run for past events and output compared with observations) conducted to evaluate model performance & find optimal configuration. Utility of WRF wind forecasts for go/no-decision for two sounding rockets also tested.
- WRF run for **6 × 5-day periods** (2 in summer, 2 in winter, 1 in spring and 1 in autumn) representative of atmospheric conditions typically seen at the ESC.
- Forecasts produced by the **GFS (Global Forecast System)** run by US' National Weather Service (NWS) **freely available online in near real-time** used to generate initial & boundary conditions for WRF runs. GFS forecasts initialized every 6 h (00, 06, 12 and 18 UTC) and run up to 16 days into future. **Forecast data available in format readily ingested into WRF**.
- WRF run in 4-nest configuration with innermost grids centered on the ESC with resolution of **1 km** and output stored every **10 min**. 4-nest configuration found to give best compromise between quality of model forecasts and time taken to run WRF. **60 vertical levels, roughly 30 in lowest 1 km**.
- 5-day forecast run takes 1.5 days with 96 CPUs (2 nodes) @ High Performance Computing Center North (HPC2N) Abisko cluster → **forecast available for pre-flight meeting** (2 days before launch) & **final decision** (1 day before launch).

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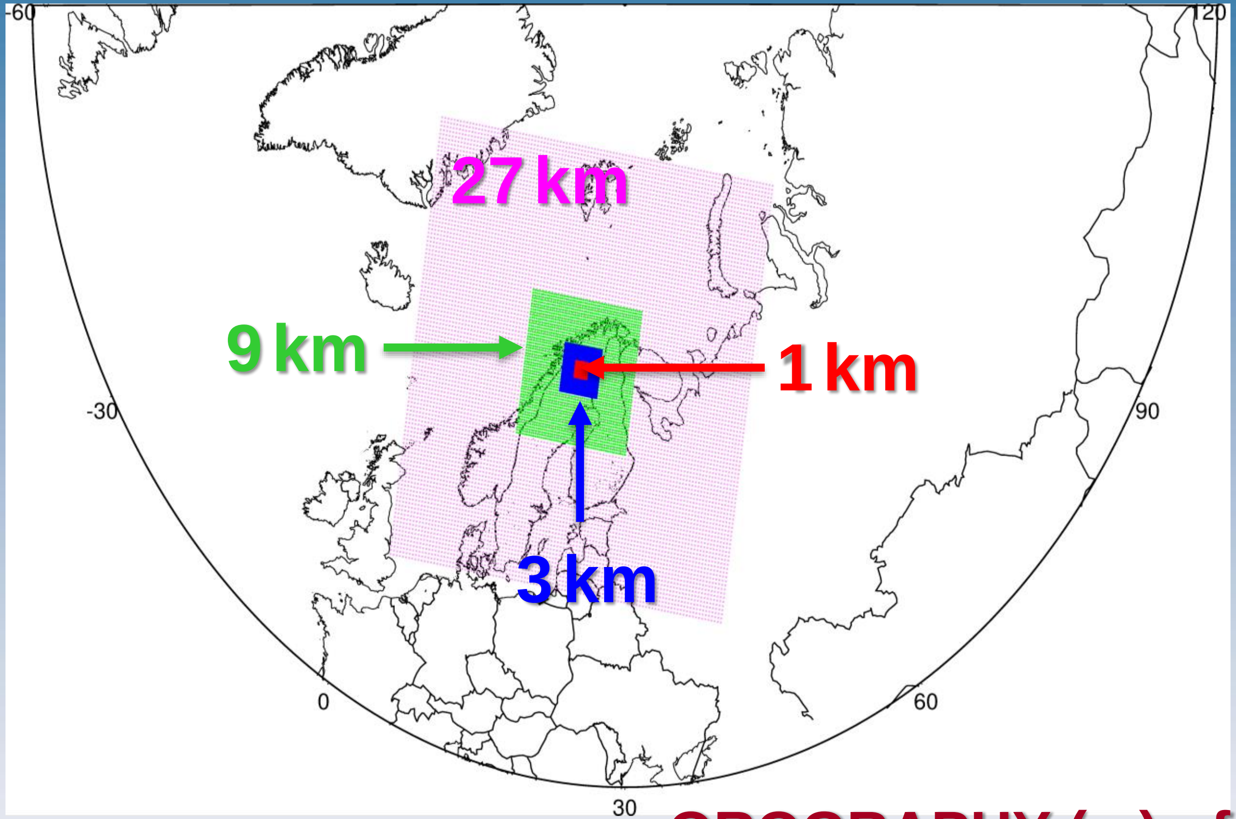
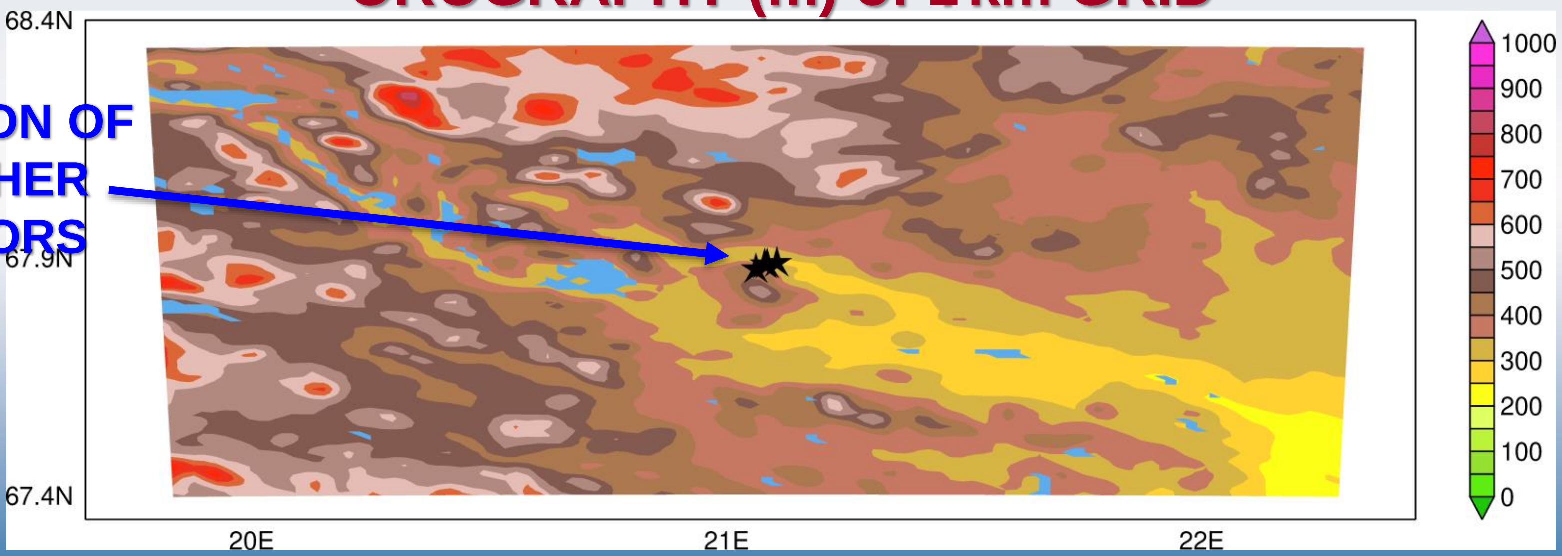


OROGRAPHY (m) of 1 km GRID



LAUNCH CRITERIA (WRF PERFORMANCE)

LAUNCH CRITERIA FOR 2 SOUNDING ROCKETS (MARTIN BYSELL, ESC):

VSB-30: Maximum horizontal wind speed / direction variation of 1.8 m s^{-1} / 25º

IO: Maximum wind horizontal speed / direction variation of 2.7 m s^{-1} / 65º

REFERENCE: Schafer (Wea. Forecast., 1990)

FORECAST	OBSERVED	
	YES	NO
YES	HITS (YY)	FALSE ALARMS (YN)
NO	MISSES (NY)	CORRECT REJECTIONS (NN)

PROBABILITY OF DETECTION (POD): $$\frac{HITS}{HITS+MISSES} = \frac{YY}{YY+NY}$$

FALSE ALARM RATE (FAR): $$\frac{FALSE\ ALARMS}{FALSE\ ALARMS+HITS} = \frac{YN}{YN+YY}$$

CRITICAL SUCCESS INDEX (CSI): $$\frac{HITS}{HITS+MISSES+FALSE\ ALARMS} = \frac{YY}{YY+NY+YN}$$

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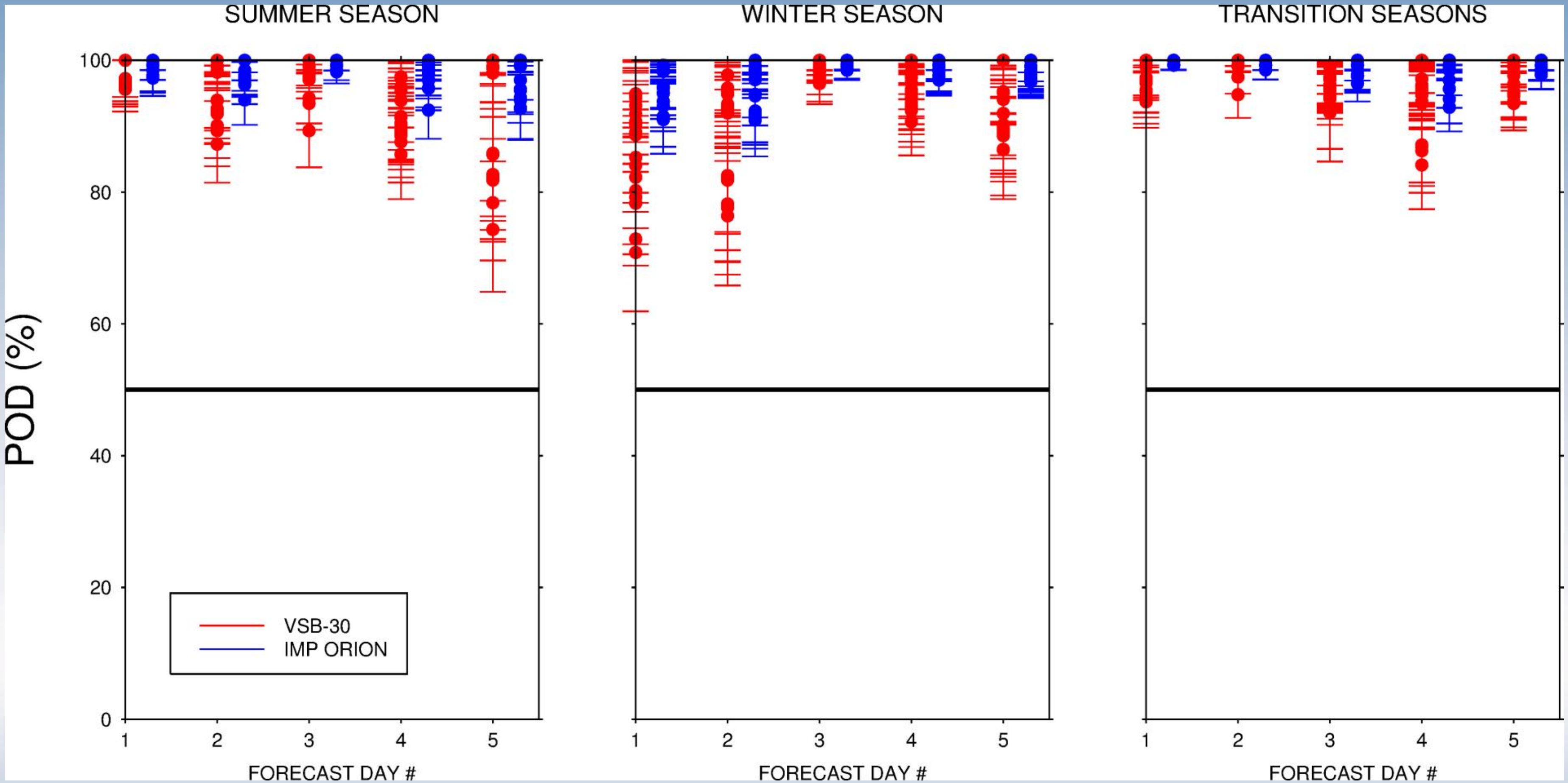
LAUNCH CRITERIA (WRF PERFORMANCE)



PODs always higher than **~65%** for **VSB-30** and **~85%** for **Improved Orion** → At least in 2/3 of time when there are good conditions for launch, WRF gives useful forecast → WRF wind forecasts can be used for guidance into go/no-go decision for launch of VSB-30 & IO.

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CONCLUSIONS

- WRF capable of simulating weather conditions at ESC during 6 × 5-day periods in winter, summer and transition seasons. 5-day runs with 2 nodes at the Abisko HPC2N cluster take 1.5 days → **WRF forecasts can be made available to pre-flight meeting & final decision time allowing for better planning of event**.

- When launch criteria of two of most commonly launched vehicles at ESC is considered, PODs always exceed 65% with FARs generally below 50% → **WRF wind forecasts can be used for purpose of guidance into the go/no-go decisions at least for VSB-30 & IO sounding rocket launches at ESC**.

- Balloon pads located at lower elevations compared to shallow hill where radar is found → cold air accumulates in valley in winter → temperature differences can reach 30ºC with lapse rates as steep as 160ºC km^{-1}: large but not as extreme as those found e.g. in Kevo Valley (Finland) where lapse rates of 500ºC km^{-1} have been reported in Pepin et al. (2009).

PUBLICATION

Fonseca, R. M., Martín-Torres, J., Andersson, K., 2018: Wind Forecasts for Rocket and Balloon Launches at the Esrange Space Center using the WRF Model. *Wea. Forecast.*, **33**, 813-833.

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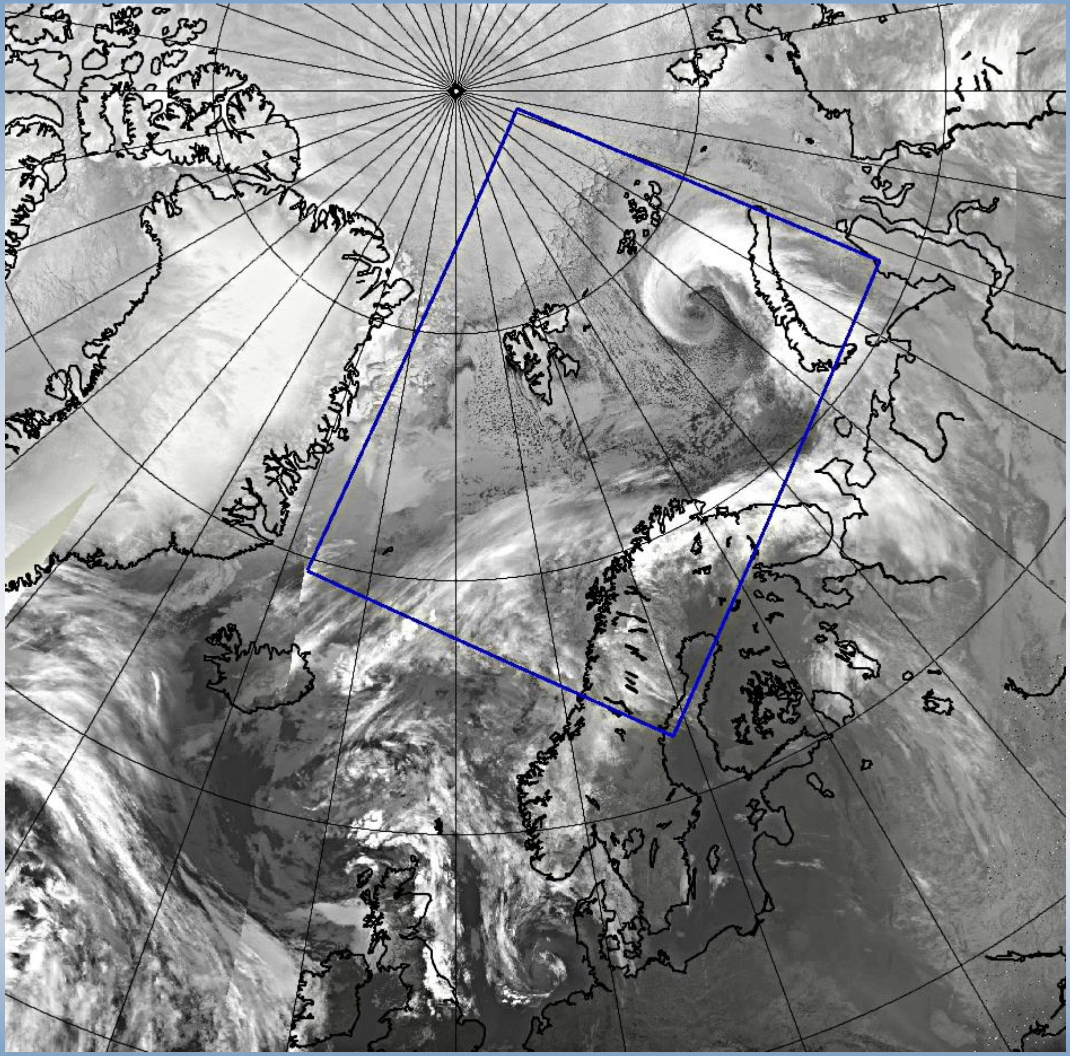
AROME – ARCTIC FORECASTS



On website below, 2.5 km hourly forecasts over blue domain (AROME-ARCTIC) are available ~3 h after real-time and are initialised every 6 h (00, 06, 12 and 18 UTC)

http://thredds.met.no/

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