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Preliminary results on all-sky MHS data assimilation in the AROME-ARCTIC NWP system

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Preliminary results on all-sky MHS data assimilation

Content

- Context & motivation
- DA experiments
- Fg departures / radiance simulations
- Overall forecast scores
- Case study: Mesoscale low pressure February 2023

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Preliminary results on all-sky MHS data assimilation

Context & motivations

Microwave observations have been assimilated in all-sky conditions for a decade at ECMWF:

=> Geer (2013) and Baordo and Geer (2016) obtained twice the impact of a clear-sky approach with significant improvement on the wind forecast when they assimilated SSMI/S in all-sky conditions.

=> extended to many other MW instruments: MHS, GMI, MWHS-2, ATMS, AMSU-A …
Geer et al., 2014; Lean et al., 2017; Lawrence et al., 2018; Bormann et al., 2021; Ducan et al., 2022 among many others

Since then, many other centres, including MET Norway & DMI, are working together on implementing the all-sky approach.

Initial developments to enable the assimilation of cloudy/rainy radiances in HARMONIE-AROME have been integrated in the cycle 46 (Azad and Randriamampianina, 2022).

Preliminary results on all-sky MHS data assimilation

All-Sky Scientific Background

1) Radiances are **thinned/superobbed** => to provide more representative observations & save computing resources (– emoslib ECMWF software).

2) Advanced observation operator (**RTTOV-SCATT**) to improve the simulation of cloudy/rainy radiances

=> 'Tuned' bulk optical properties (liquid & solid hydrometeors) to improve scattering radiative transfer

+ Radiances are then computed in both clear sky and all-sky subcolumn

and the weight given by an 'effective' cloud fraction

3) A **dynamic observation error** to mitigate 'representivity' errors

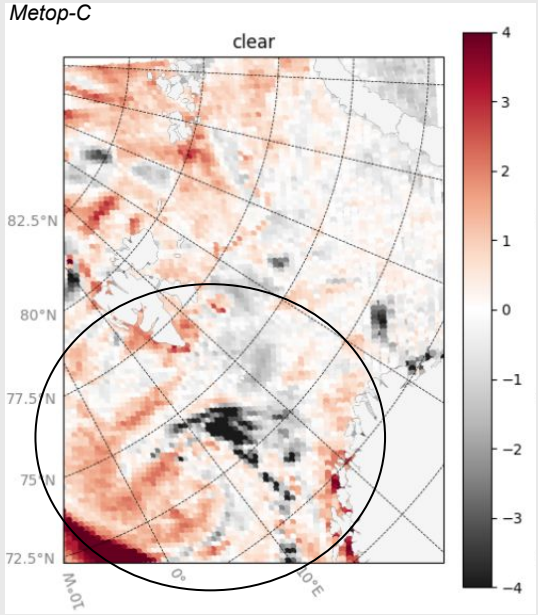
=> the model cannot simulate clouds and precipitations with the right intensity and/or location:

the error is inflated as a function of a 'symmetric' cloud predictor

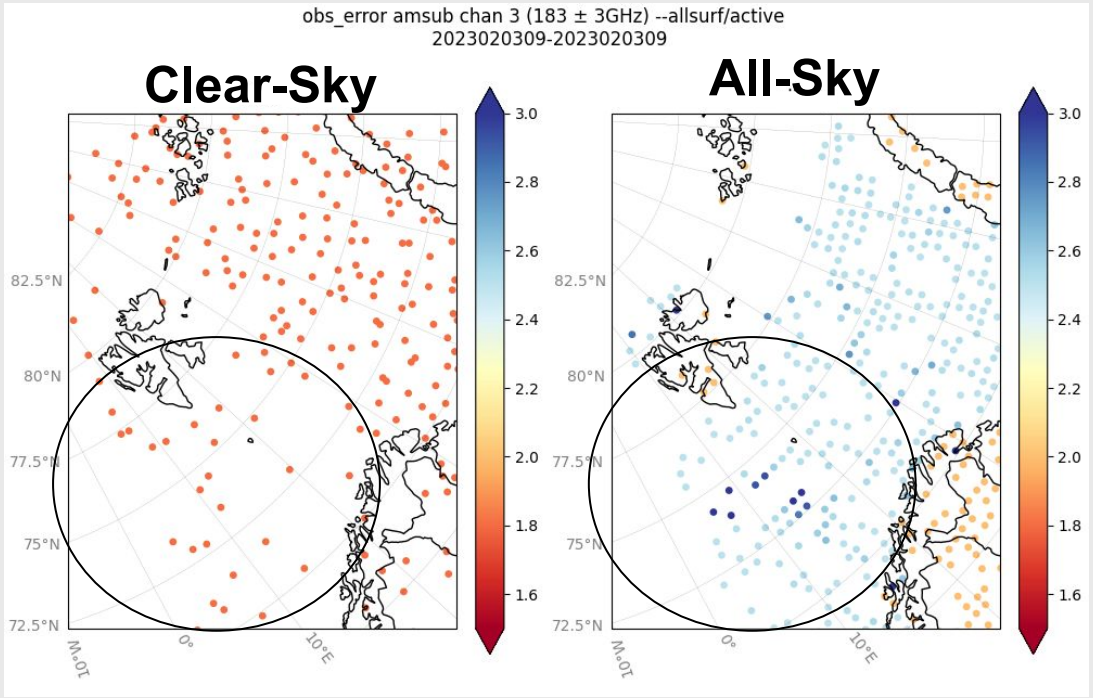
Preliminary results on all-sky MHS data assimilation

All-Sky Scientific Background

MHS FG departures
(all available obs)



Assumed observation errors in the system (actives)



=> Cloudy/rainy observations associated with large departures rejected in clear sky but active in all-sky

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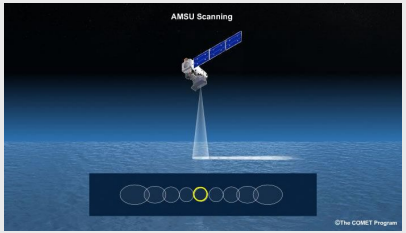
MW radiance observations

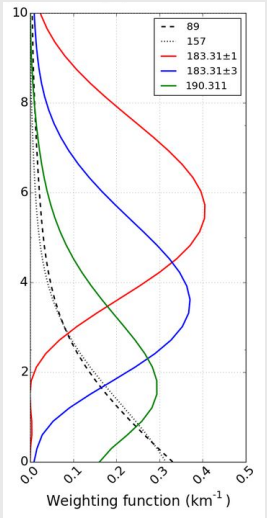
The Microwave Humidity Sounder (**MHS**) is a cross-track scanning instrument that observes the Earth with variable zenith angle and size field of view.

Onboard polar-orbiting platforms: Metop-B & -C and NOAA-19



MHS (Arctic)

Weighting function



Channel 3

Channel 4

Channel 5

Channel 1,2

Edel et al., 2019

=> Designed to provide valuable information on the upper, mid & lower tropospheric and surface humidity.

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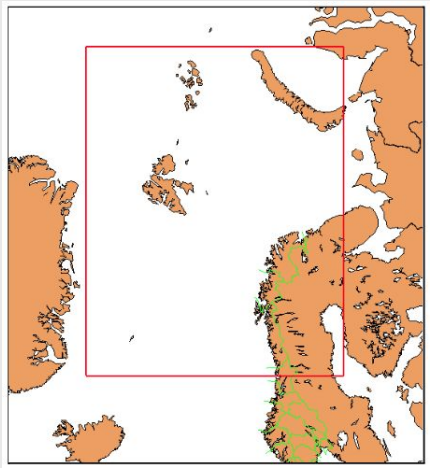
Preliminary results on all-sky MHS data assimilation

Context & motivations

Operational usage of clear-sky MHS (thin80km) in AROME-Arctic (cy43)

Channel usage	**Channel Idx**	**Frequency [GHz]** Vertical/Horizontal polarisation	**OPER Assimilation**
Emissivity retrieval	1	89.0 V	no
Cloud screening (FGd)	2	157.0 V	no
Upper tropospheric humidity	3	183.311±1 H	All surfaces/clear
Mid-upper tropospheric humidity	4	183.311±3 H	All surfaces/clear
Mid-lower tropospheric humidity	5	190.311 V	Ocean & sea-ice/clear (over land if lat<55N)

Domain



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DA experiments

Preliminary experiments with only conv+MHS were run beforehand showing some encouraging results.

Full observing system setup (cy46):

Clear-sky = AROME-ARCTIC 3D-Var + Conv & AMSU-A & MHS (clear-sky)
+SCAT, IASI, ATMS, MWHS-2

All-sky = same as clear-sky but MHS in all-sky

Period: 1 month spin-up + 2 months
(winter & summer)

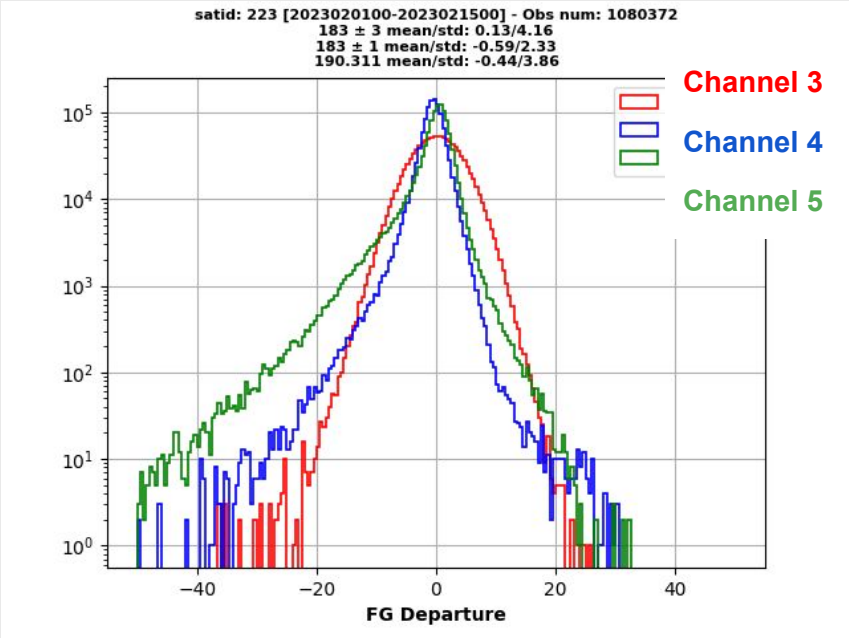
Preliminary results on all-sky MHS data assimilation

First-Guess departures

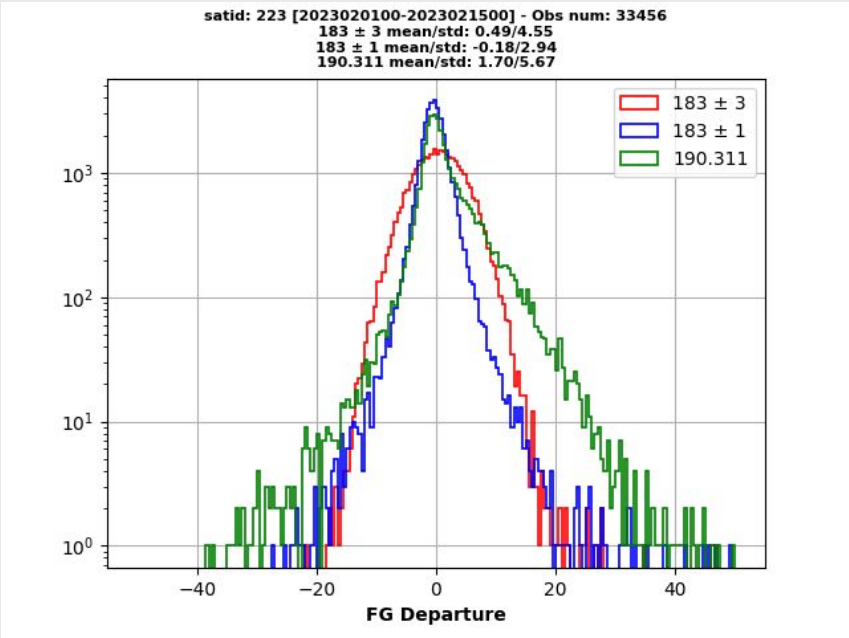
Histograms of Observations - simulations (ECMA) 1-15 Feb - NOAA19

=> Similar results for Metop B & C

Clear-Sky



All-Sky



Preliminary results on all-sky MHS data assimilation

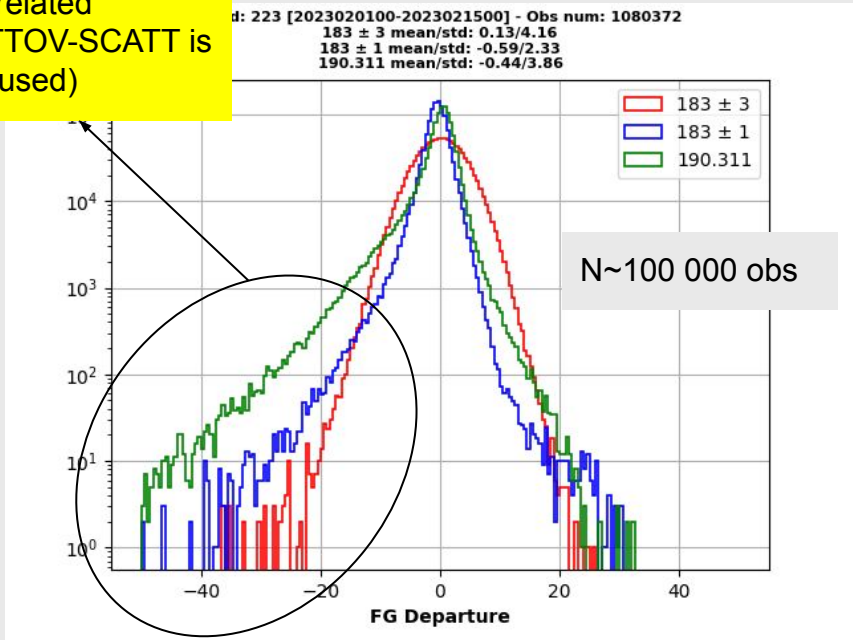
First-Guess departures

Histograms of Observations - simulations (ECMA) 1-15 Feb - NOAA19

=> Similar results for Metop B & C

Clear-Sky

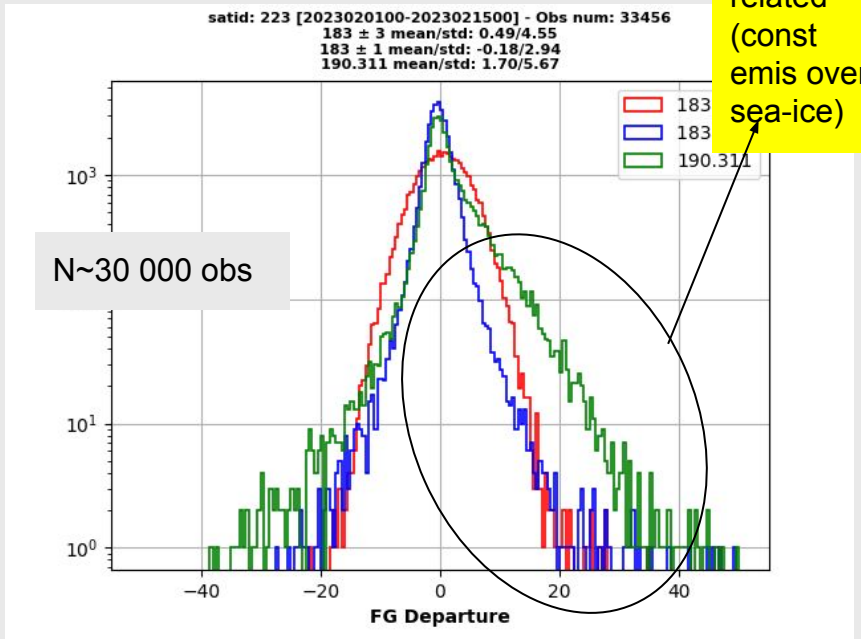
RT related (‘RTTOV-SCATT is not used)



N~100 000 obs

All-Sky

SURF related (const emis over sea-ice)



N~30 000 obs

Preliminary results on all-sky MHS data assimilation

First-Guess departures

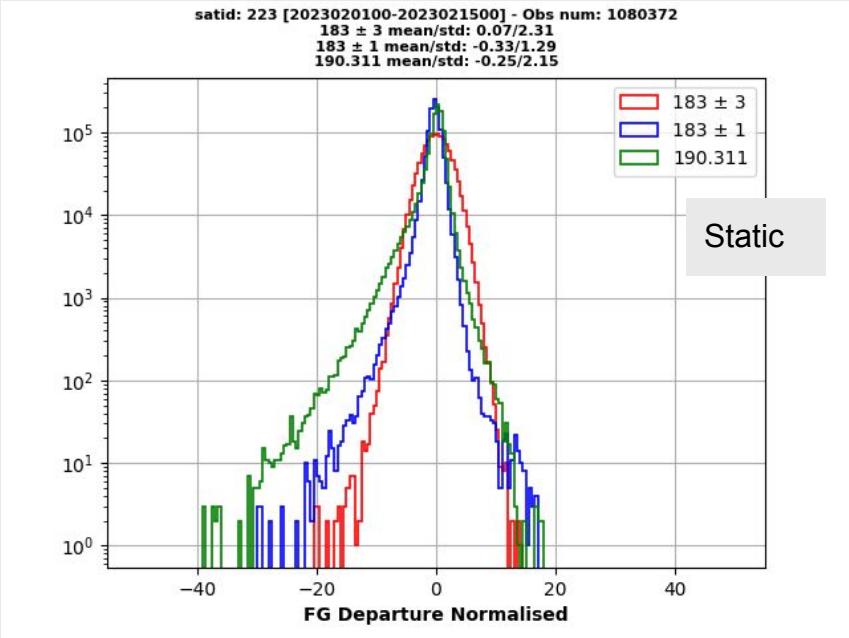
Histograms of Observations - simulations (ECMA) 1-15 Feb - NOAA19

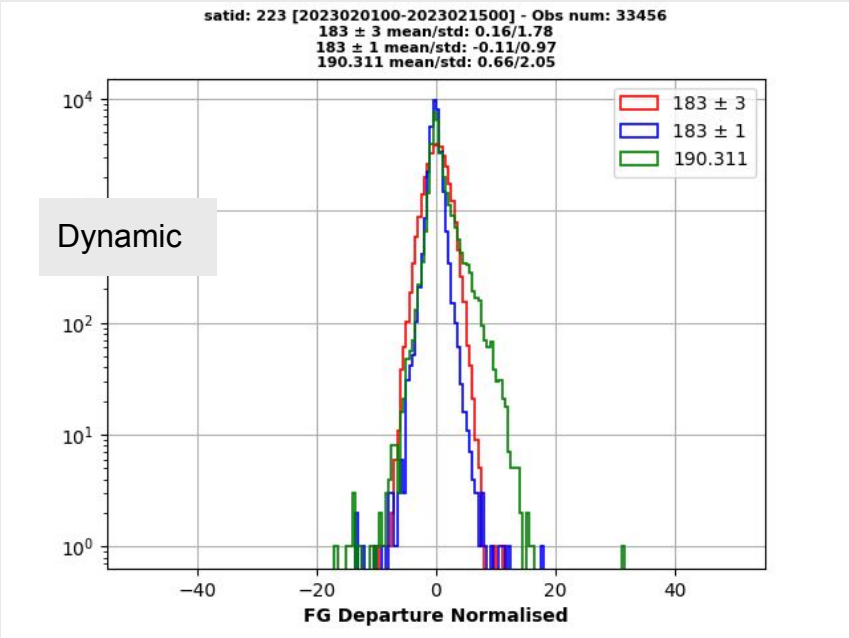
=> Similar results for Metop B & C

Clear-Sky

Normalized by the obs error

All-Sky

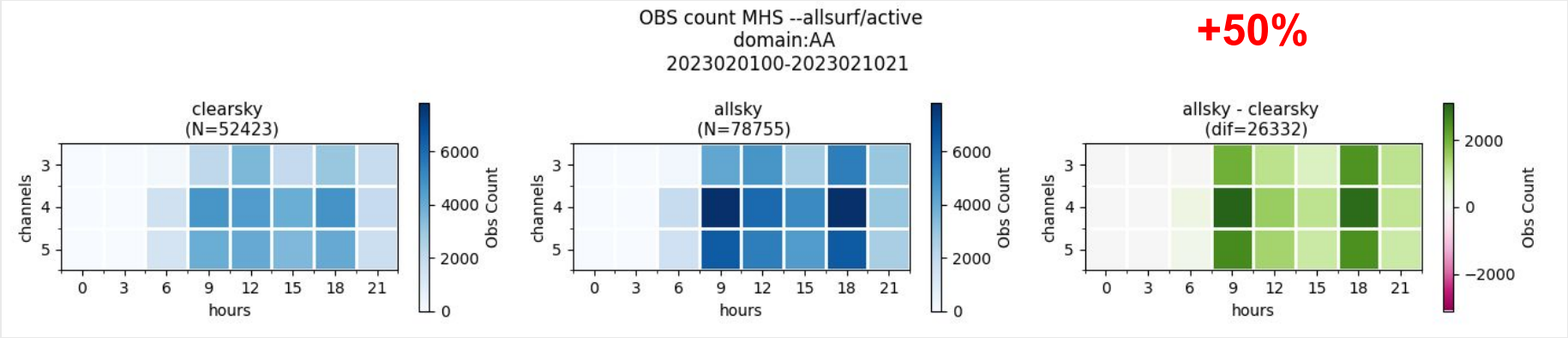




Preliminary results on all-sky MHS data assimilation

First-Guess departures

Even if the setup is not optimal (pre-thinning & emissivity over sea-ice),
all-sky permits to significantly increase the amount of active observations:



=> Forecast impact …

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Preliminary results on all-sky MHS data assimilation

Overall forecast scores: Upper-air

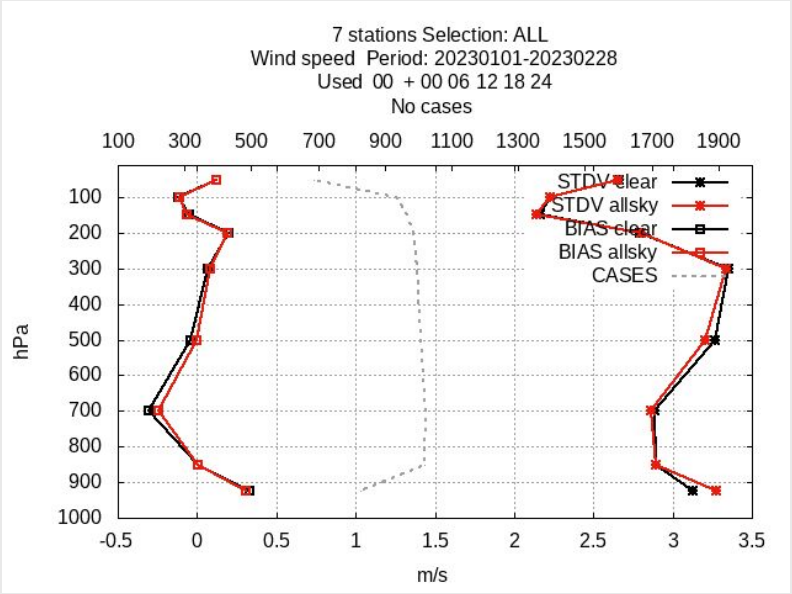
Jan-Feb 2023

clear-sky

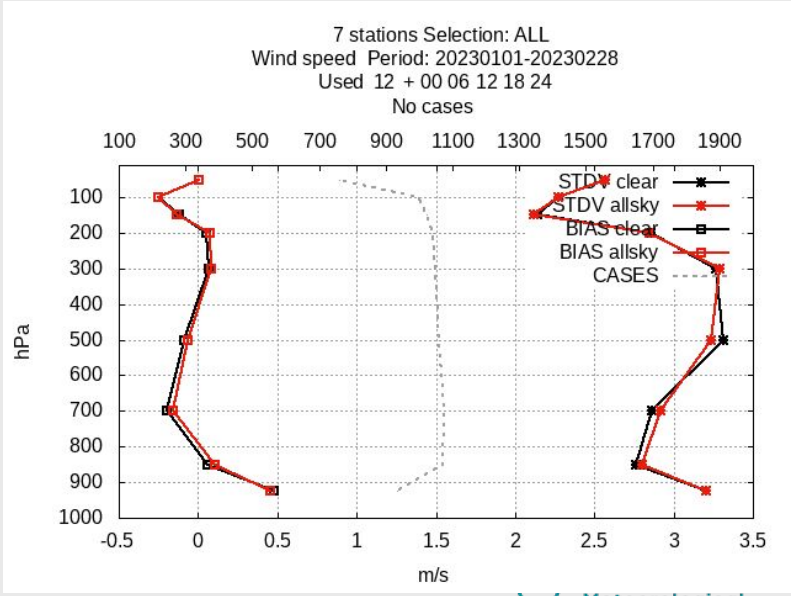
all-sky

Wind speed

Initial time = 00h



Initial time = 12h



=> overall neutral impact for temperature, humidity and wind speed + others

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Preliminary results on all-sky MHS data assimilation

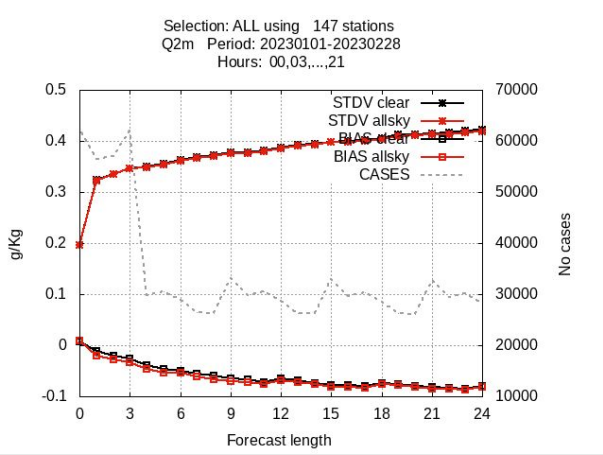
Overall forecast scores: Surface

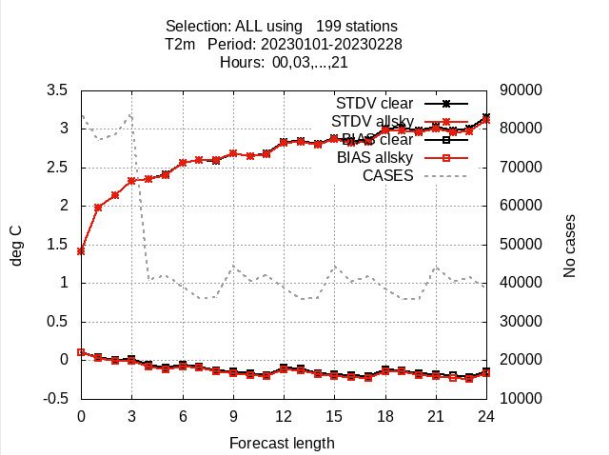
Jan-Feb 2023

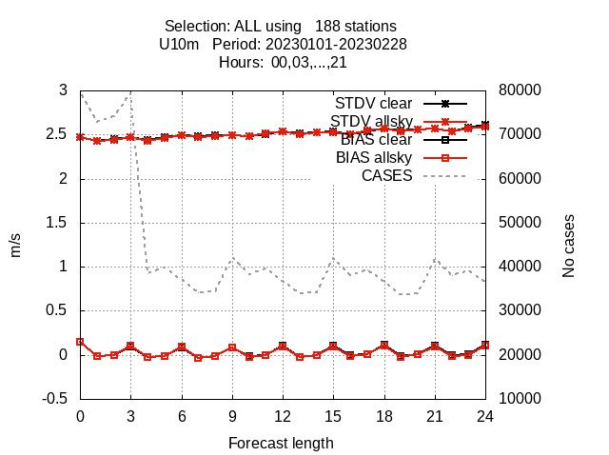
clear-sky

all-sky

Q2m **T2m** **U10m**







Neutral impact against most of surface observations except …

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Preliminary results on all-sky MHS data assimilation

Overall forecast scores: Surface

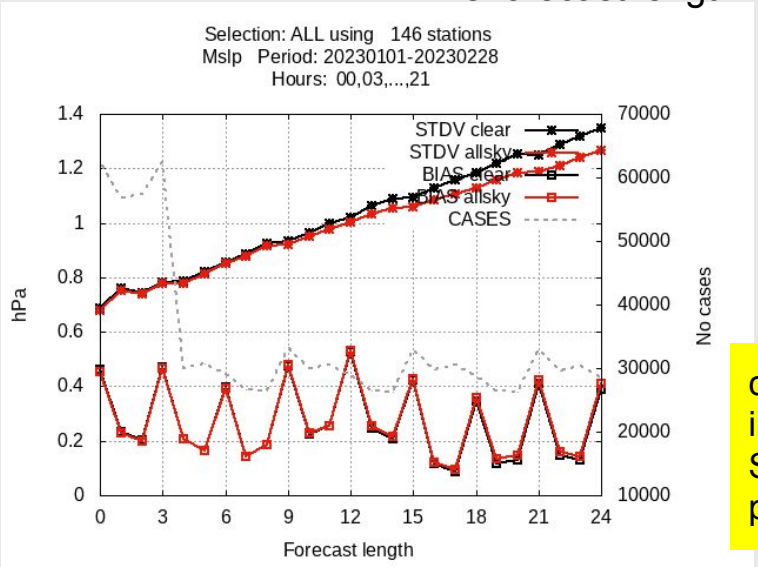
Jan-Feb 2023

clear-sky

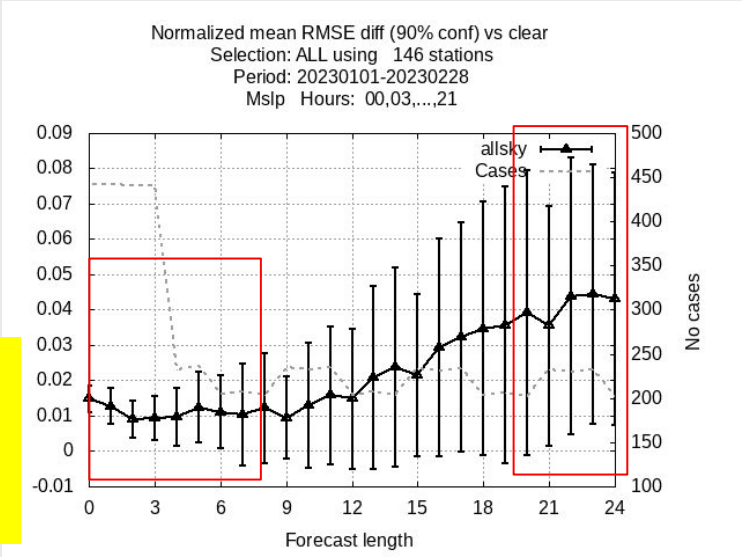
all-sky

Mean Sea Level Pressure

vs forecast length



continuous improvement & Significant positive impact



Neutral impact against most of surface observations except MSLP !

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Preliminary results on all-sky MHS data assimilation

Overall forecast scores: Surface

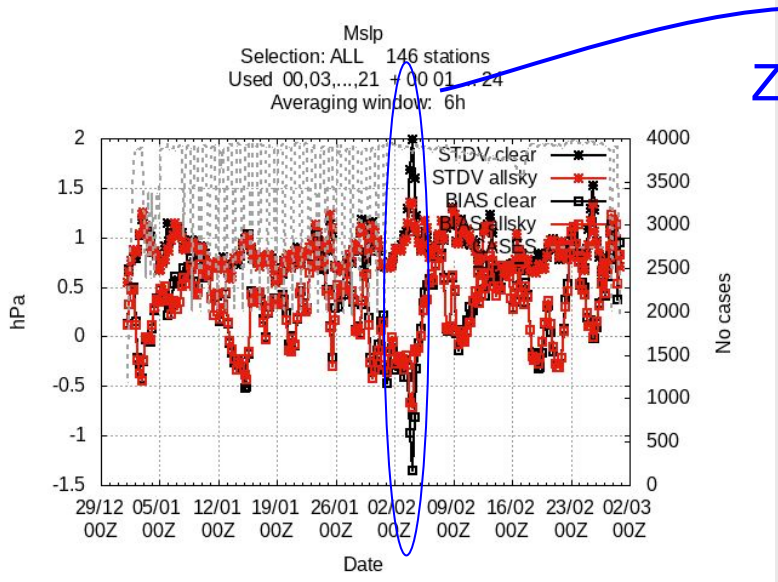
Jan-Feb 2023

clear-sky

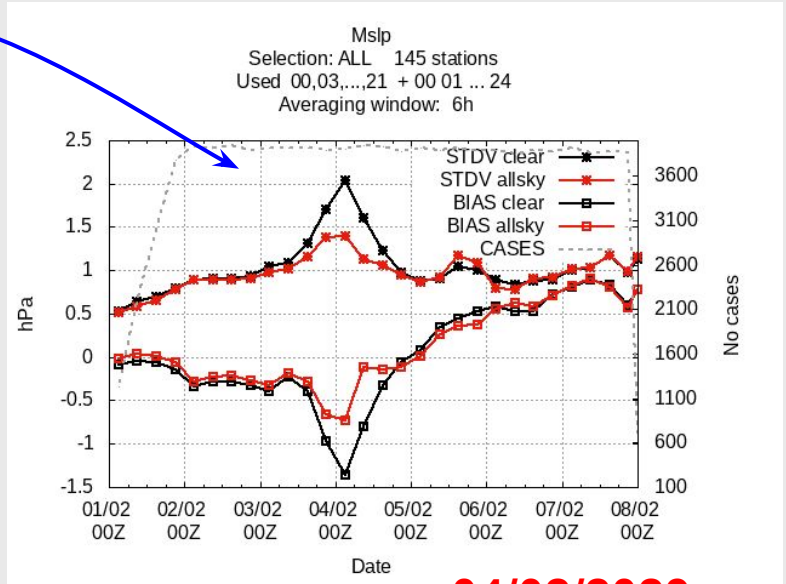
all-sky

Mean Sea Level Pressure

Time-series



Zoom in



04/02/2023

Neutral impact against most of surface observations except MSLP !

Preliminary results on all-sky MHS data assimilation

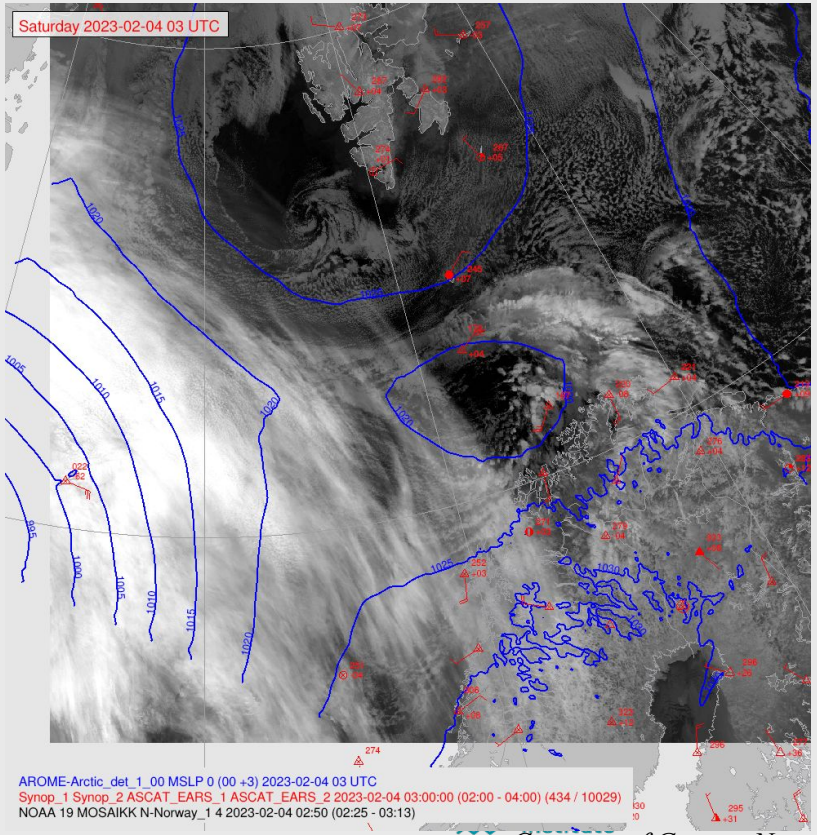
Case Study

Synoptic situation on the 04/02/2023 - 03UTC:

- a small low, **bordering to a polar low**, but not very intense, position approximately 72.3N and 19.0E
=> classify as a mesoscale circulation, i.e. less intense than a polar low.

There is a ship crossing northwards and partly against the wind west of the center, measuring at most 35 knots (17 m/s) and a pressure of some 2 hPa lower than the AROME-Arctic 00-run from the 4th.

It was not expected to give sufficient wind to justify a polar low forecast (> 41 knots) but still a good illustration in our period.

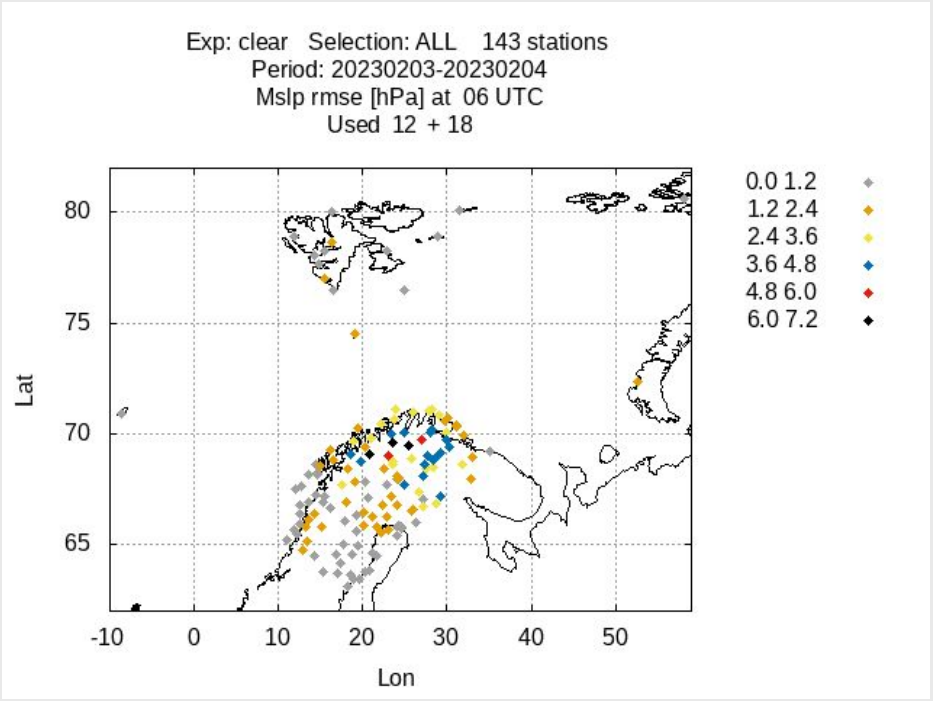


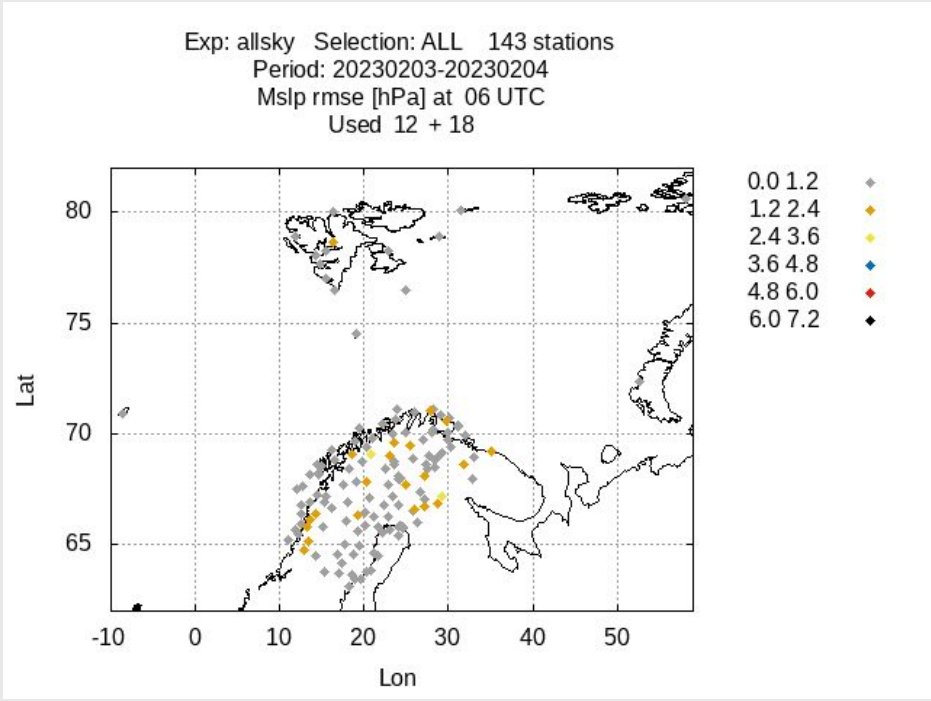
Courtesy of Gunnar Noer

Preliminary results on all-sky MHS data assimilation

Case Study

Forecast for 4/2 at 06UTC based on previous analysis 3/2 - 12UTC & 18UTC





=> also valid at 00h & for T2m, Q2m & Uwind

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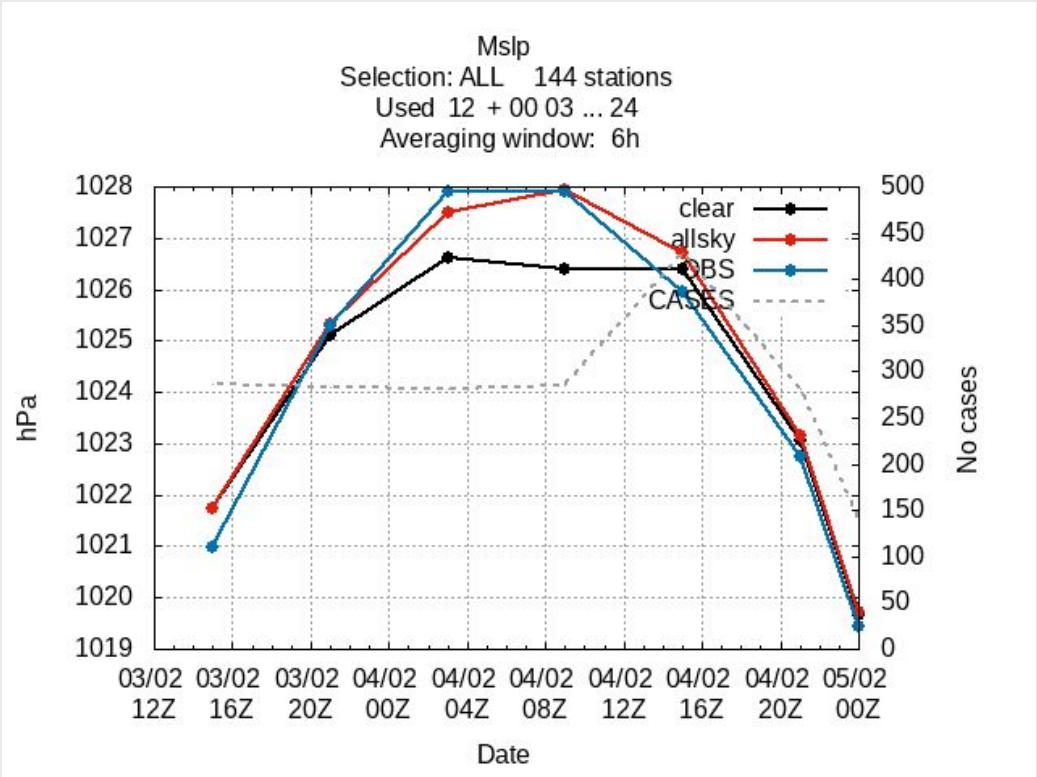
Case Study



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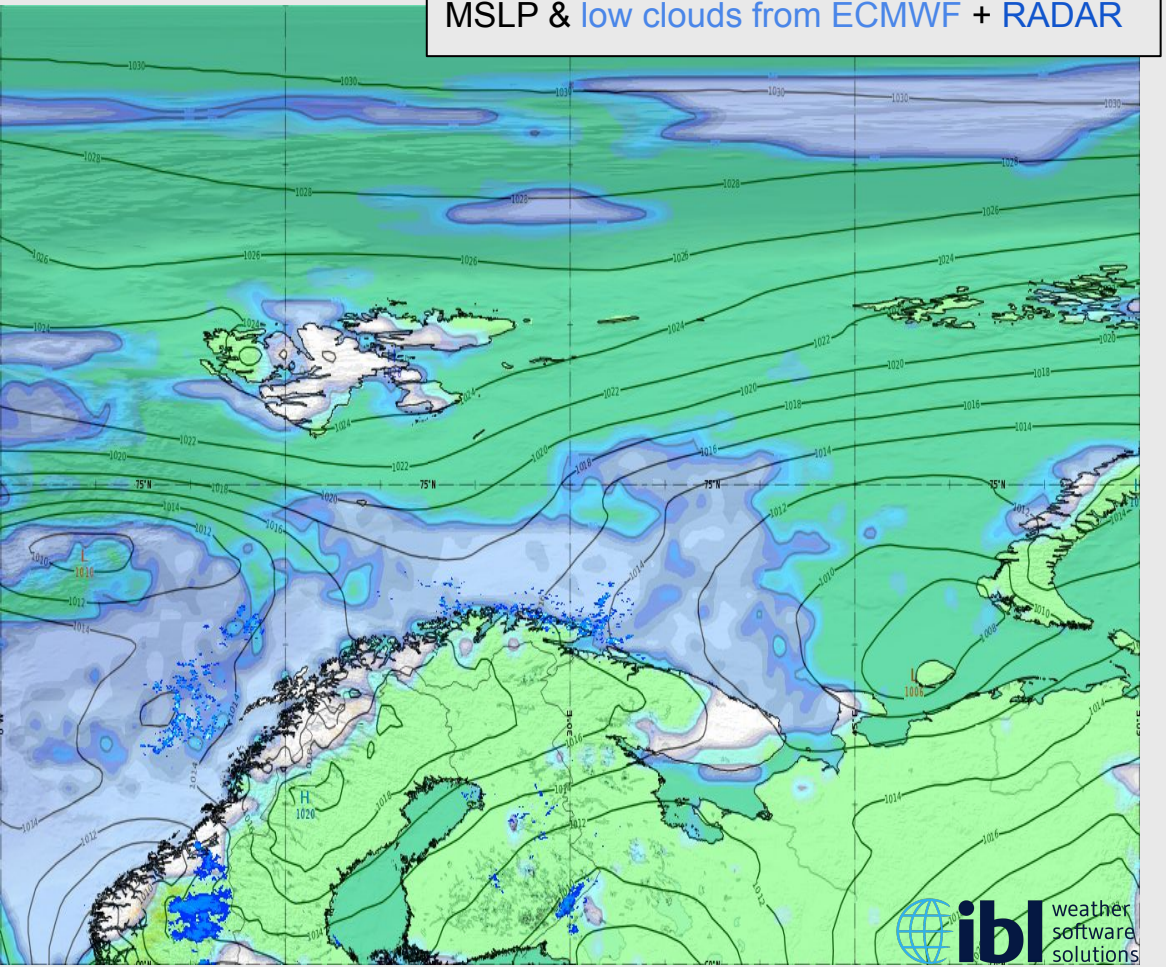
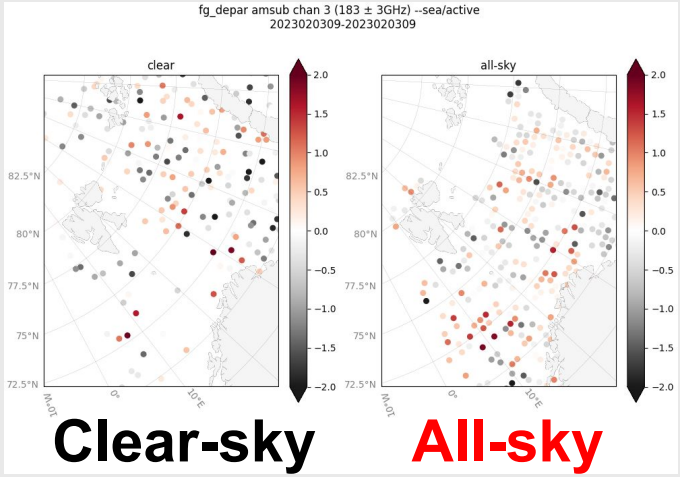
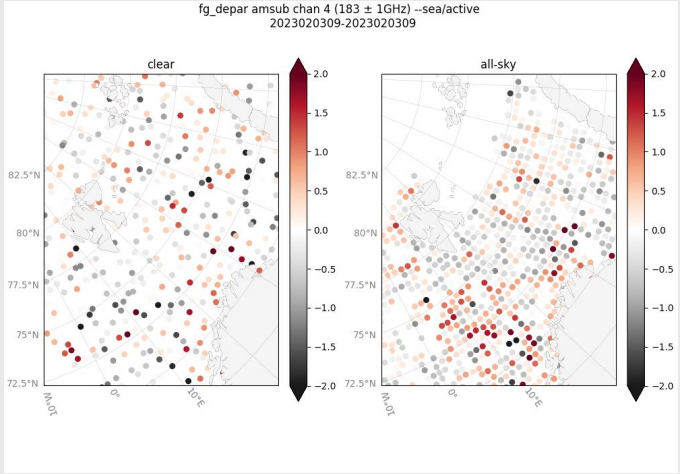
03/02 - 09UTC

MSLP & low clouds from ECMWF + RADAR



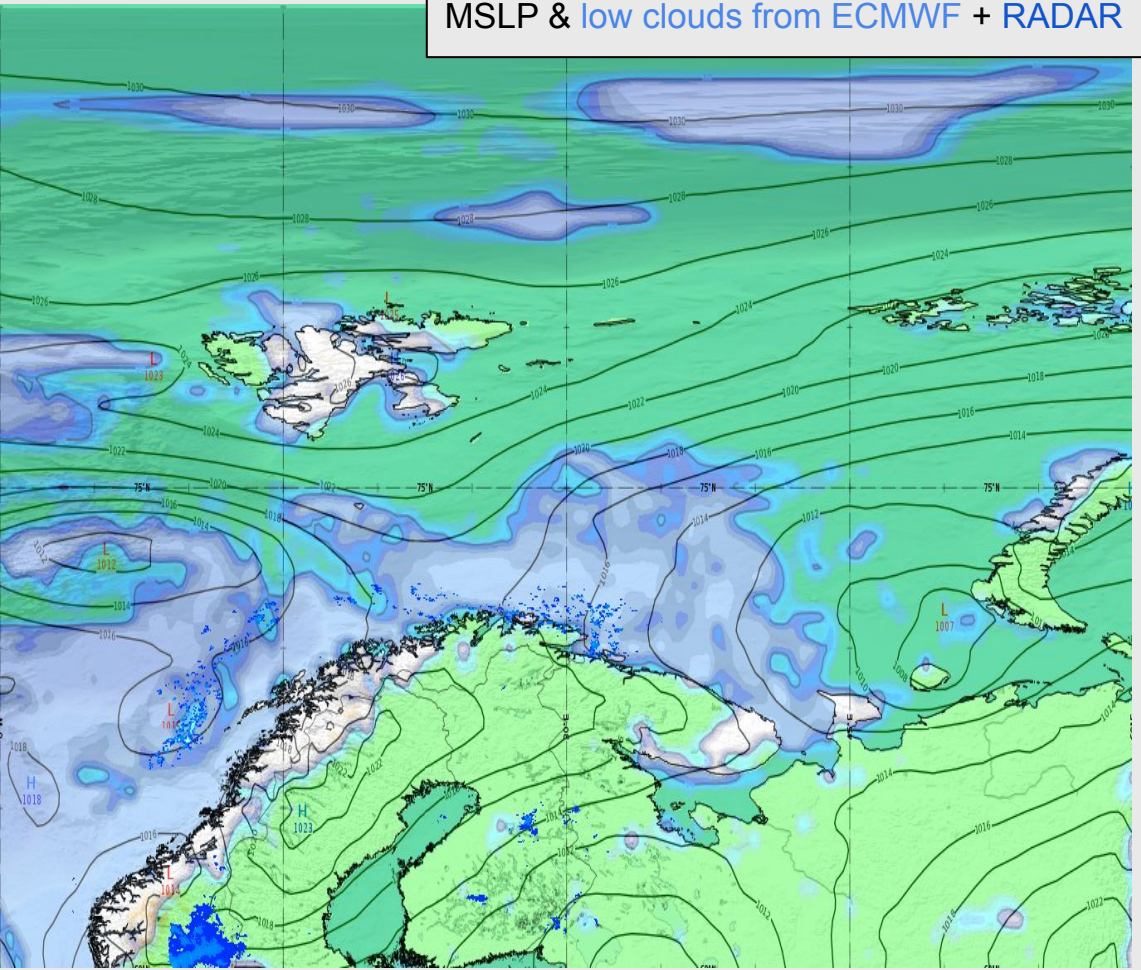
FG departures
(normalised by obs error)



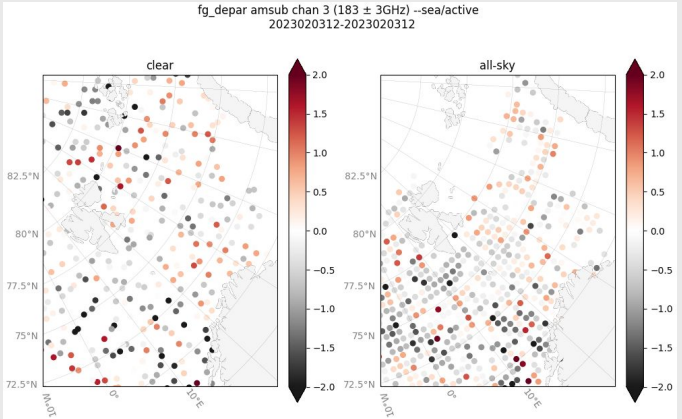


03/02 - 12UTC

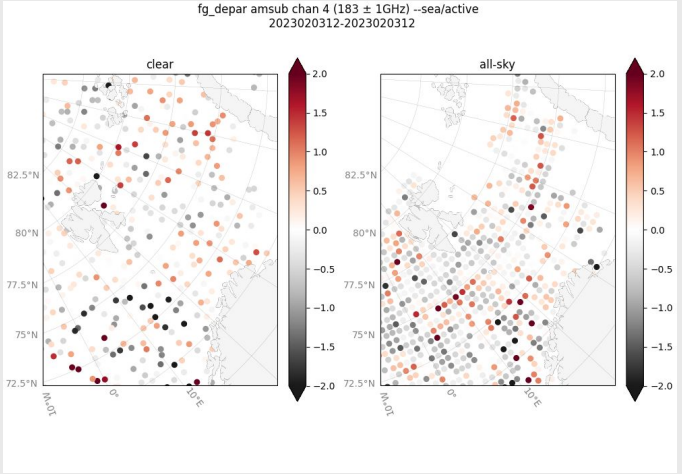
MSLP & low clouds from ECMWF + RADAR



FG departures
(normalised by obs error)

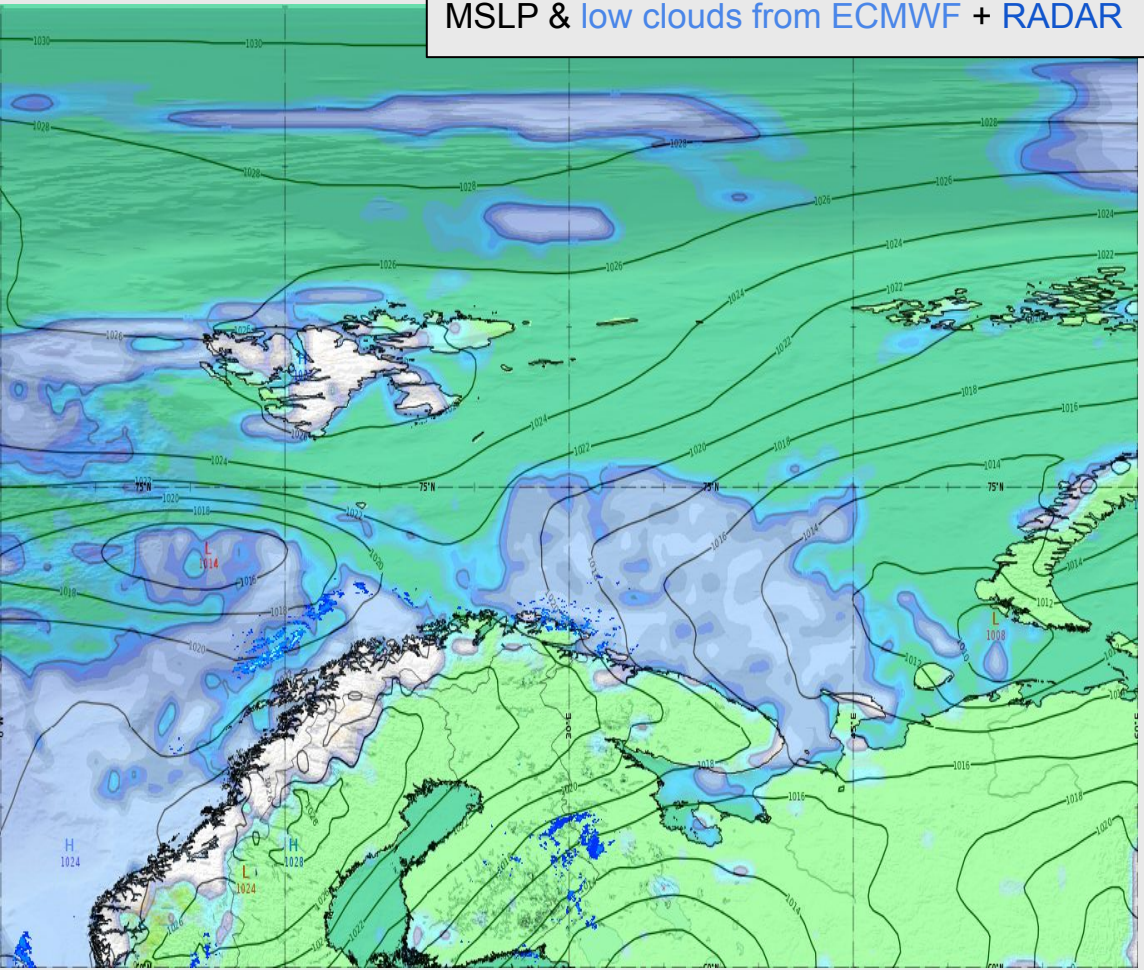


Clear-sky **All-sky**

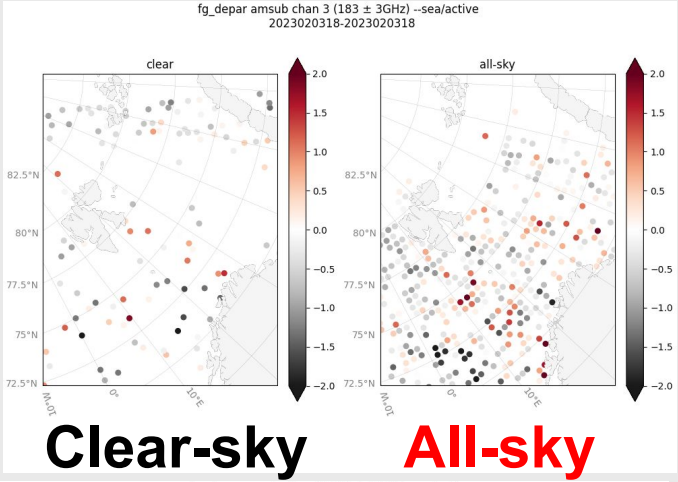


03/02 - 18UTC

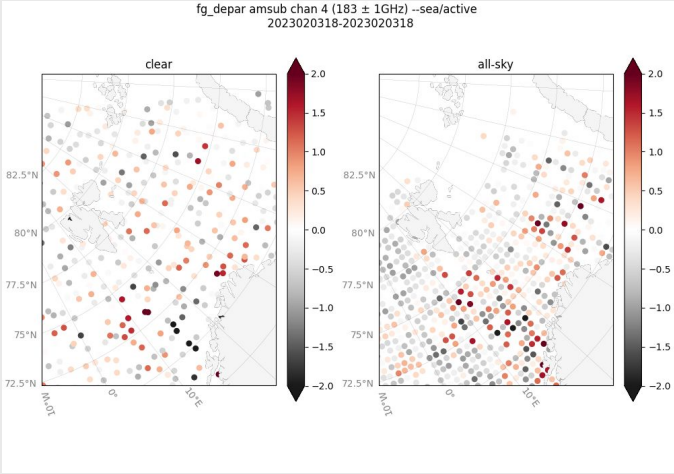
MSLP & low clouds from ECMWF + RADAR



FG departures
(normalised by obs error)



Clear-sky **All-sky**



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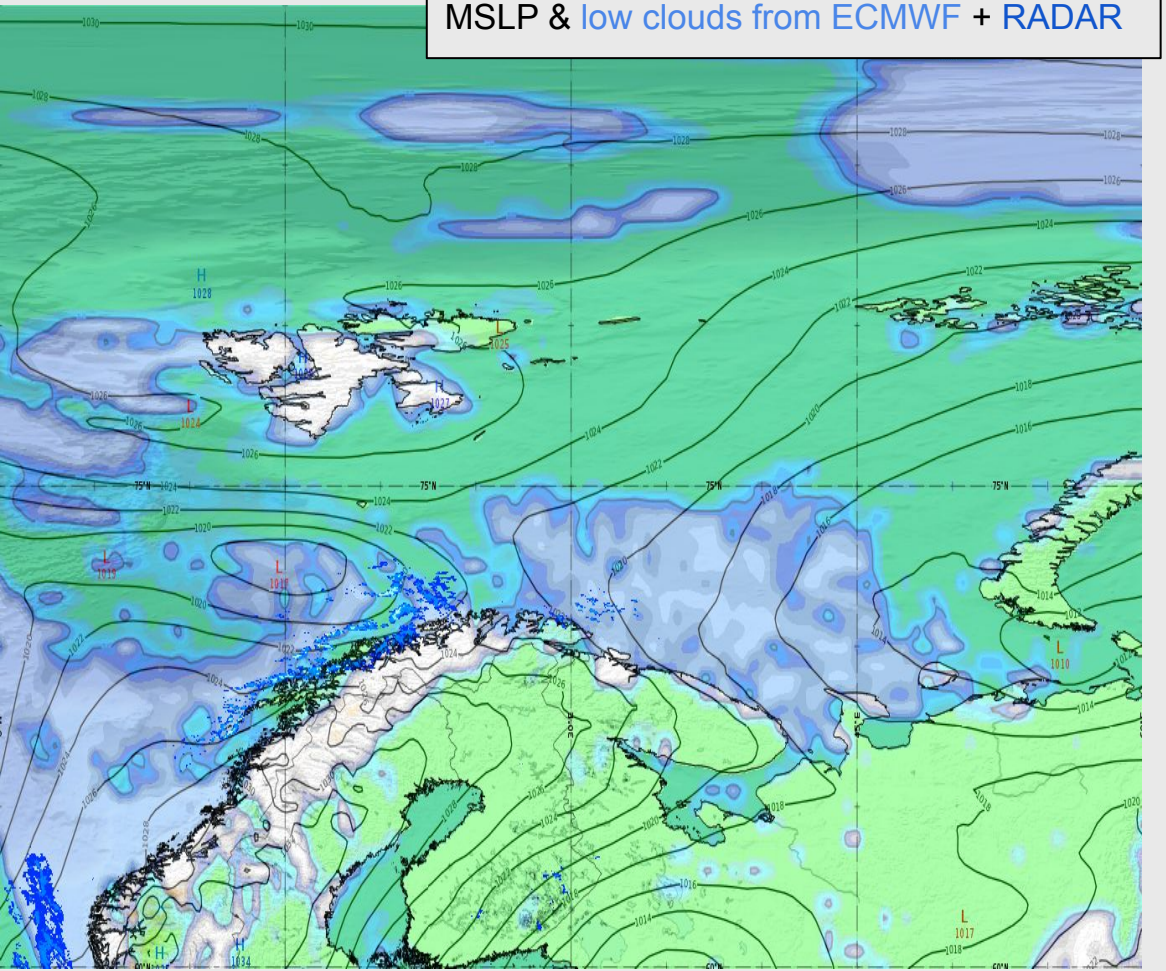
04/02 - 00UTC

MSLP & low clouds from ECMWF + RADAR



FG departures
(normalised by obs error)

No MHS data

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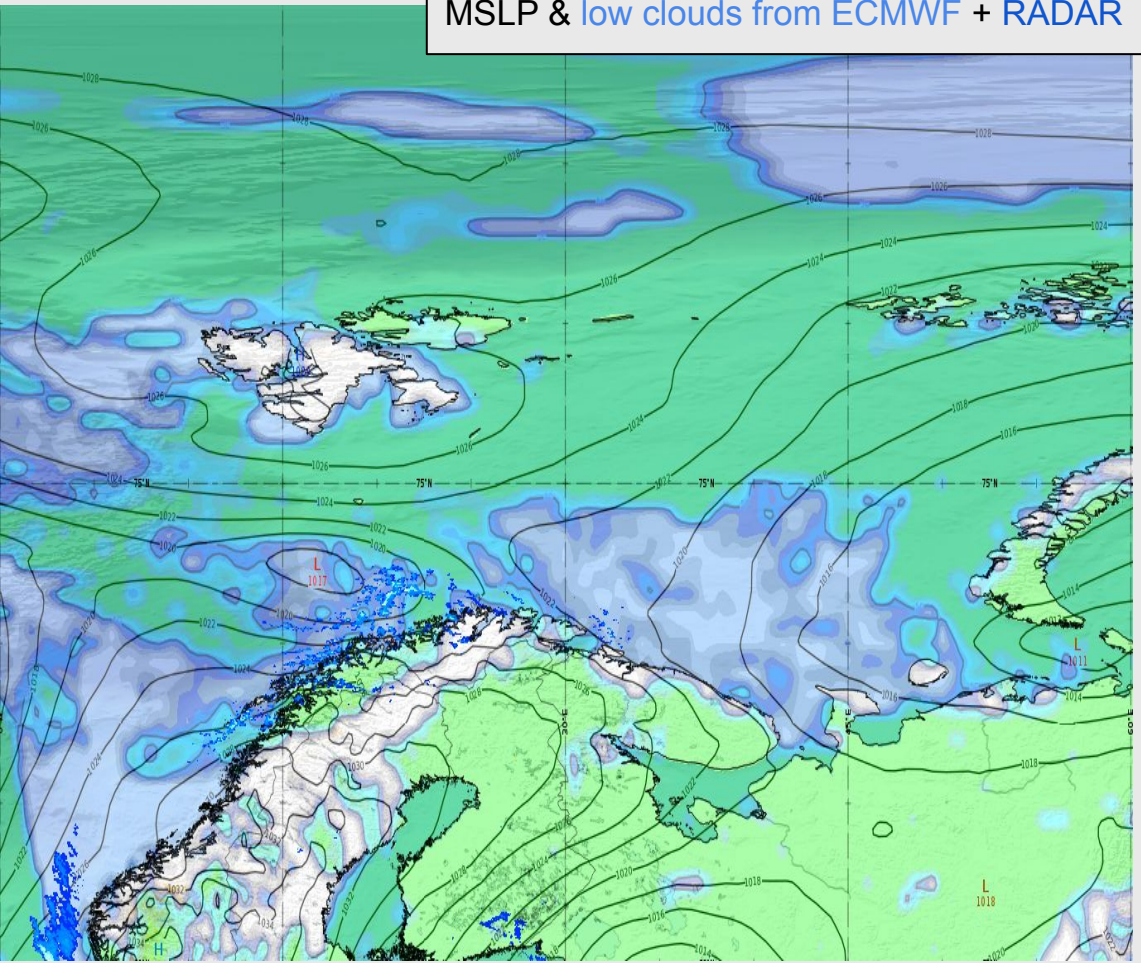
04/02 - 03UTC

MSLP & low clouds from ECMWF + RADAR



FG departures
(normalised by obs error)

No MHS data

Norwegian Meteorological Institute

ibl weather software solutions

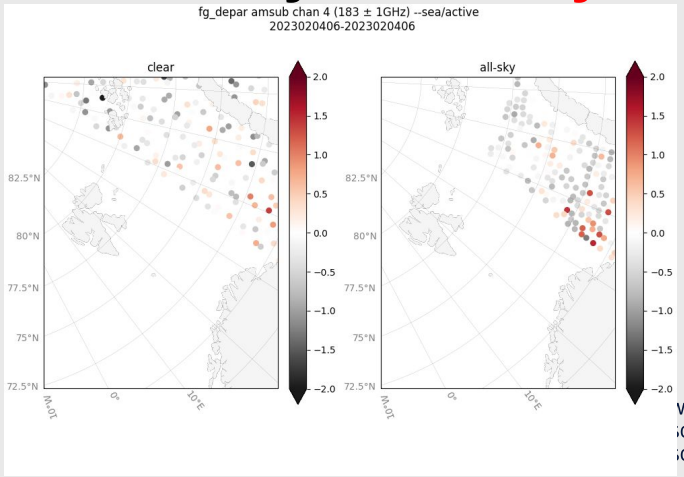
04/02 - 06UTC

MSLP & low clouds from ECMWF + RADAR

FG departures
(normalised by obs error)

No channel 3 MHS data

Clear-sky **All-sky**



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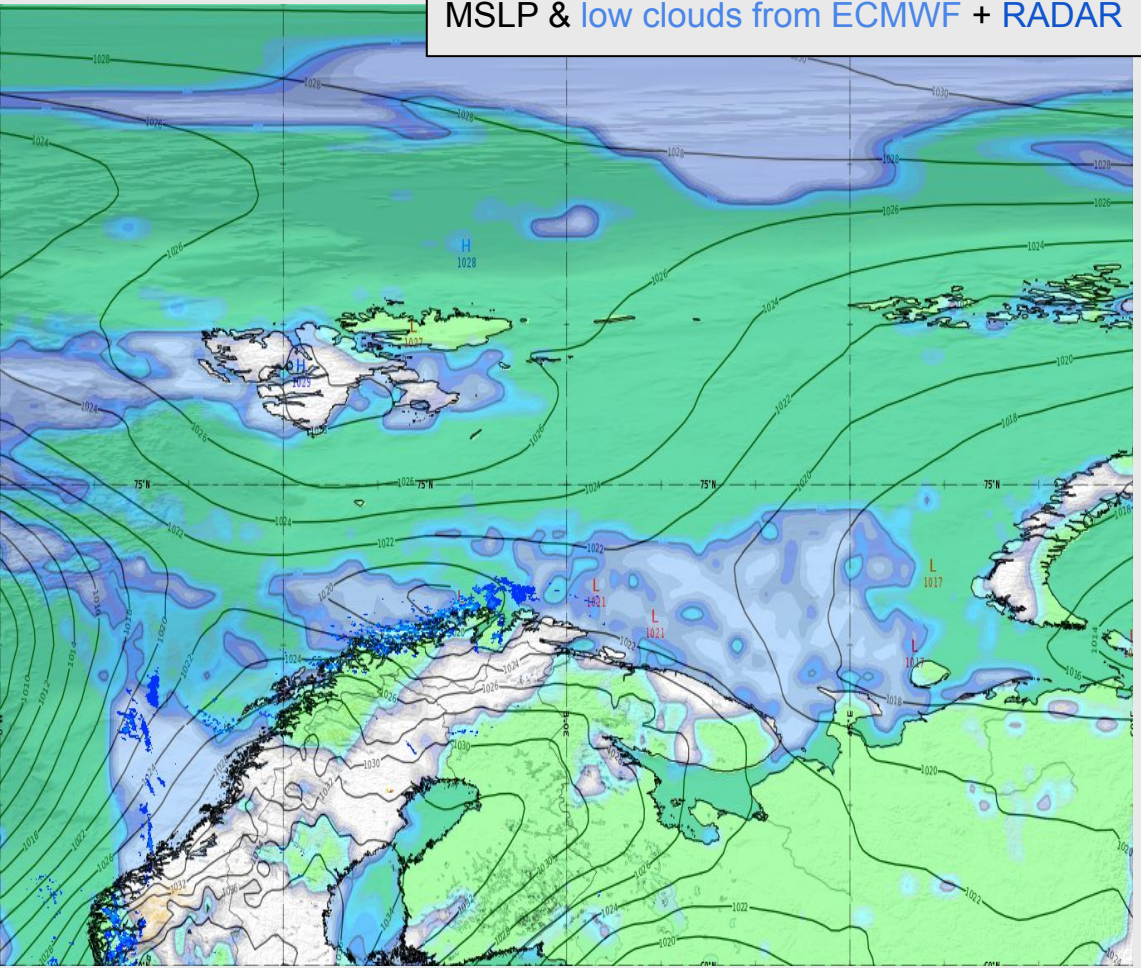
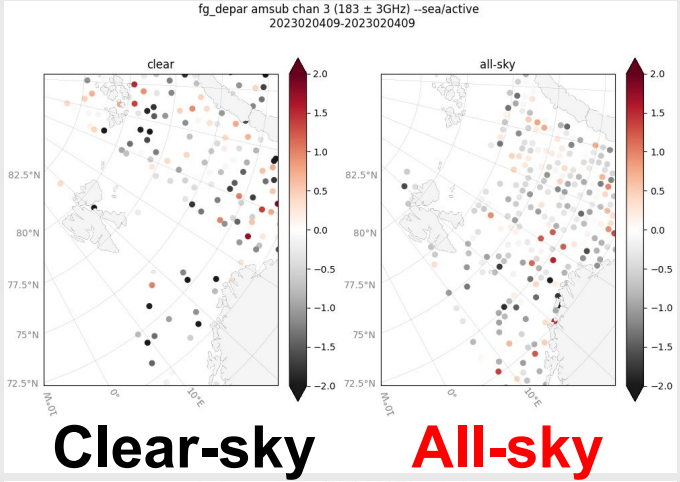
04/02 - 09UTC

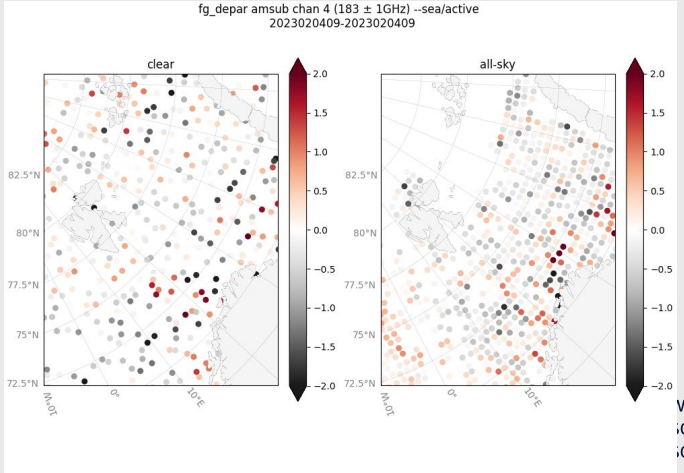
MSLP & low clouds from ECMWF + RADAR



FG departures
(normalised by obs error)



Clear-sky **All-sky**



weather
software
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Preliminary results on all-sky MHS data assimilation
Conclusions

Main results:

- All-sky has been setup in cycle 46 and we managed to run it for MHS !

- Fg departures are improved thanks to :
  - RTTOV-SCATT
  - Dynamic obs error giving a more realistic weight to the simulation

=> The all-sky approach consistently improves the number of assimilated observations with respect to the clear-sky approach.

Forecast scores overall neutral but positive sometimes (case study)

=> Large scale structures seem better constrained with all-sky

(consistent with Alan's papers)

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Preliminary results on all-sky MHS data assimilation

Conclusions & future works

Developments from Rooholad are available (but incomplete) in cycle 46

More work to do for verification & optimization of the all-sky assimilation:

- Reviewing thinning/superobbing to increase the coverage of satellite observations within the AROME-ARCTIC domain (emoslib) - not included in github config
- Surface related issue: dynamical emissivity retrieval should be activated over sea-ice
- Reviewing dynamical observation error (scattering index) for optimal use over the AROME-ARCTIC domain

\+ Extend to other microwave instruments …

Radiance DA people, we need your help :)

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Thank you

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Back-up slides

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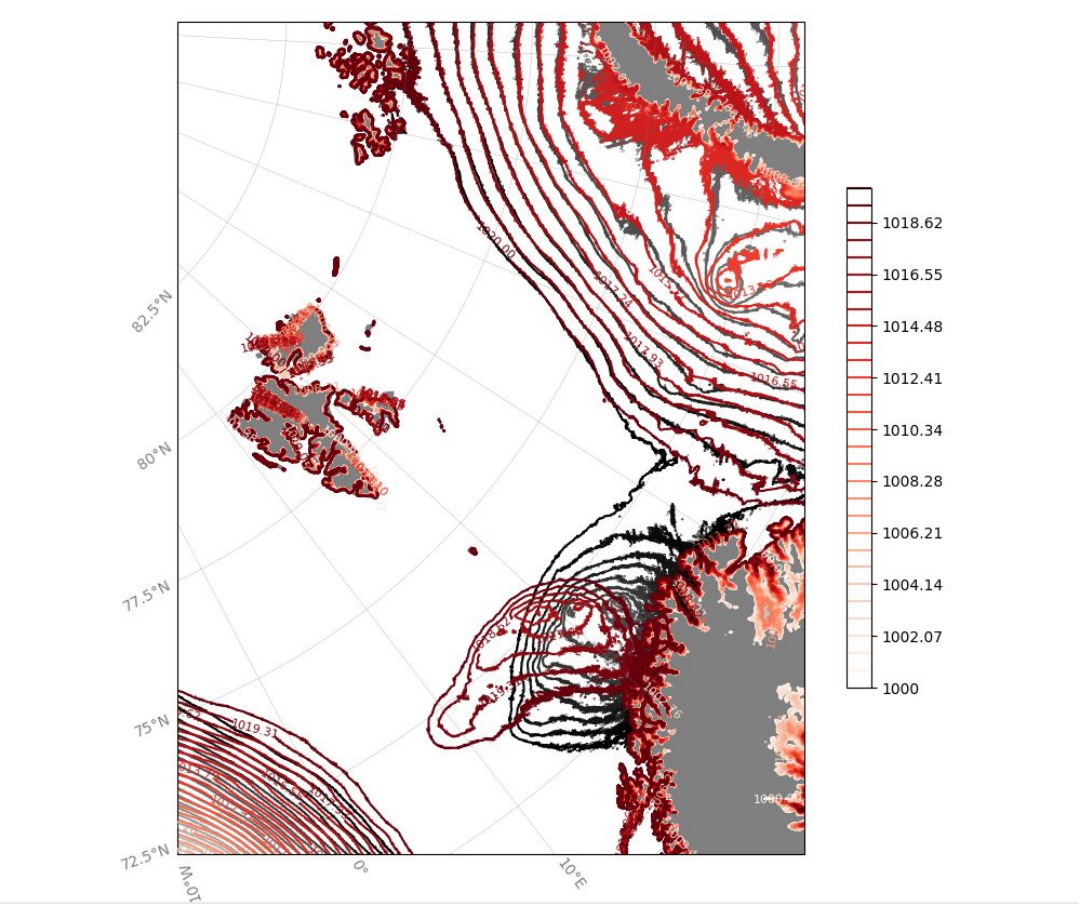
Clear
All-Sky



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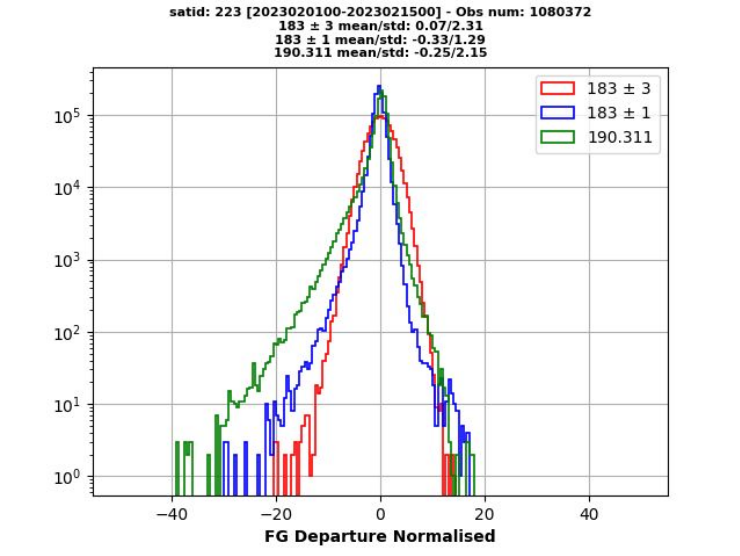
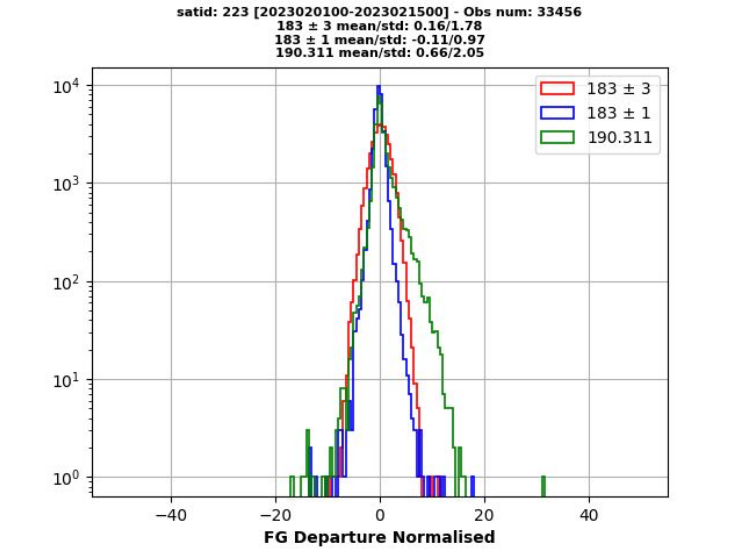
All obs (ECMA) 1-15 Feb - **NOAA19**

Clear-Sky

FG Departures normalised respect to the observation error

All-Sky





Norwegian Meteorological Institute

Preliminary results on all-sky MHS data assimilation
Assimilated Obs 1-15 Feb - METOP-B

Clear-Sky

CH 3

CH 5

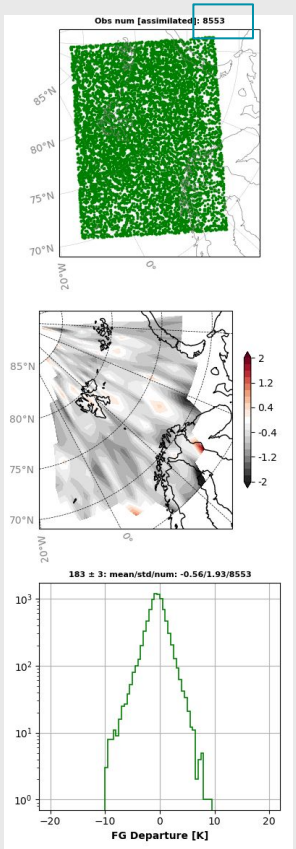
All-Sky

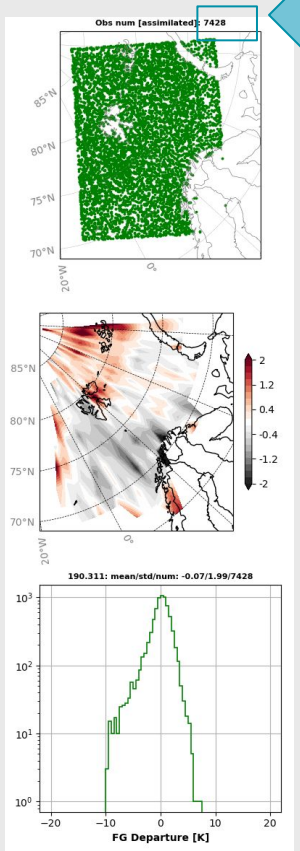
CH 3

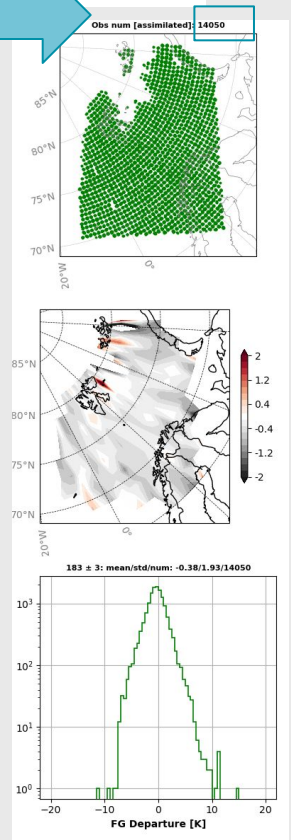
CH 5

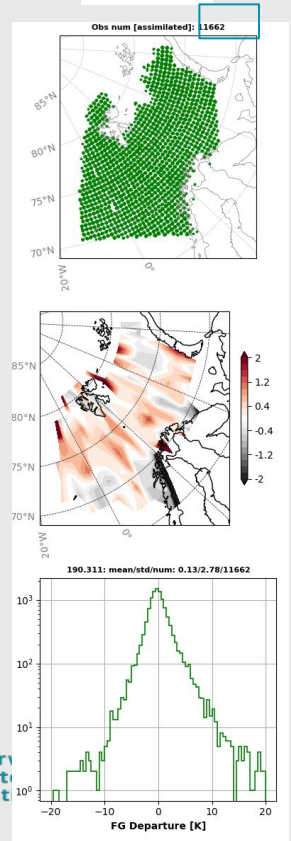
Larger number of assimilated observations

Mean FG
Binned on 2 x 2 grid



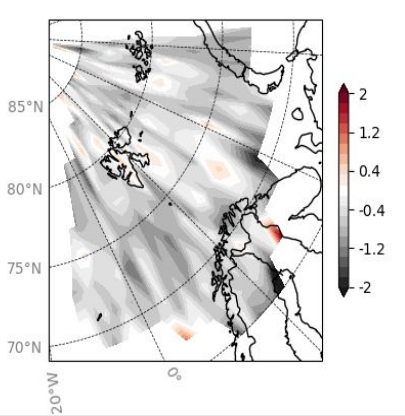


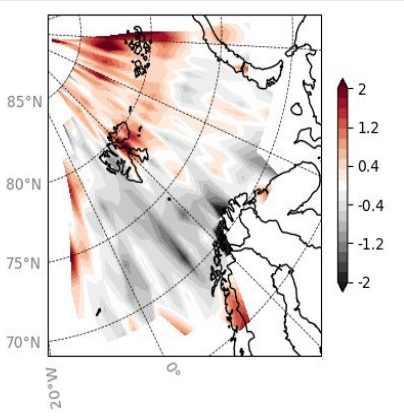




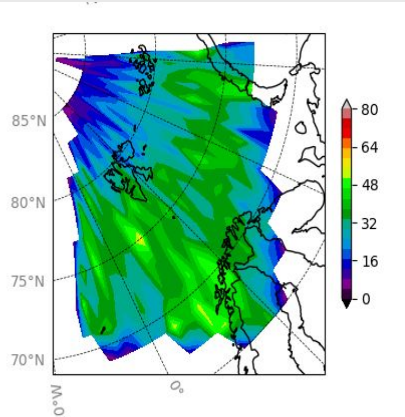
Preliminary results on all-sky MHS data assimilation

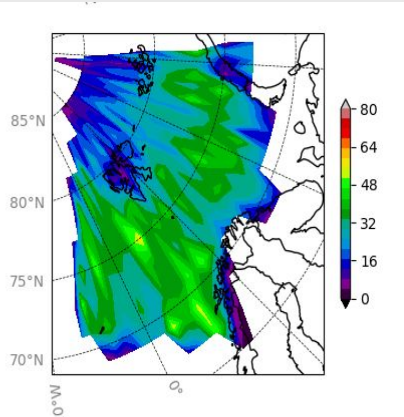
Assimilated Obs 1-15 Feb - **METOP-B**





Mean FG
Binned on 2 x 2 grid





Counts in Bins

Norwegian Meteorological Institute

Preliminary results on all-sky MHS data assimilation

Overall forecast scores: Upper-air

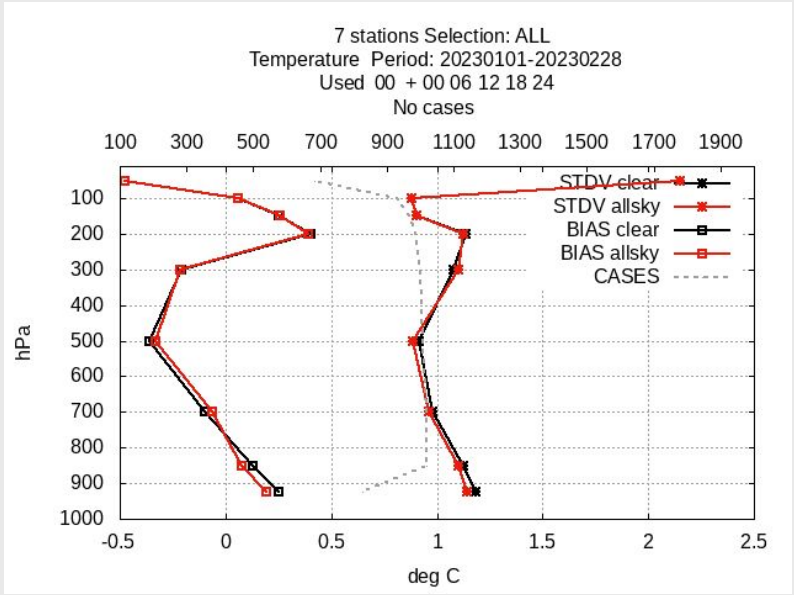
Jan-Feb 2023

clear-sky

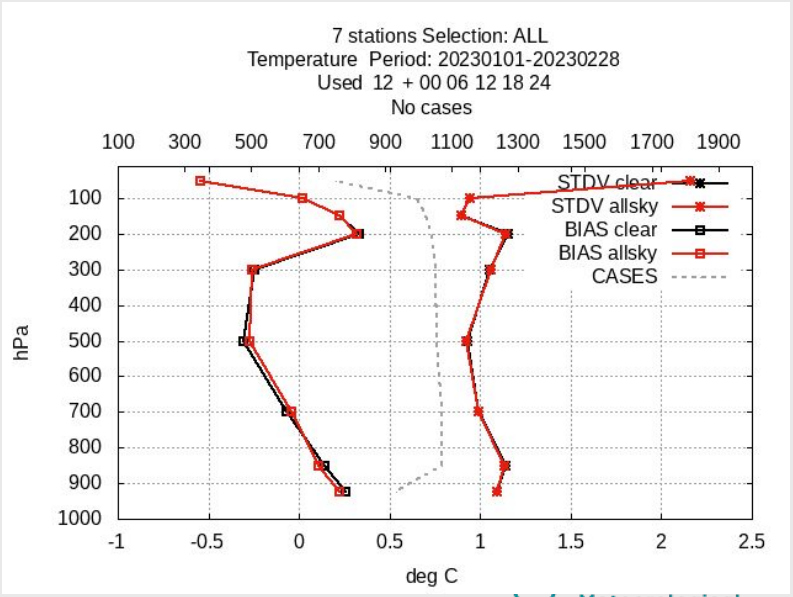
all-sky

Temperature

Initial time = 00h



Initial time = 12h



=> overall positive impact for temperature

Meteorological Institute

Preliminary results on all-sky MHS data assimilation

Overall forecast scores: Upper-air

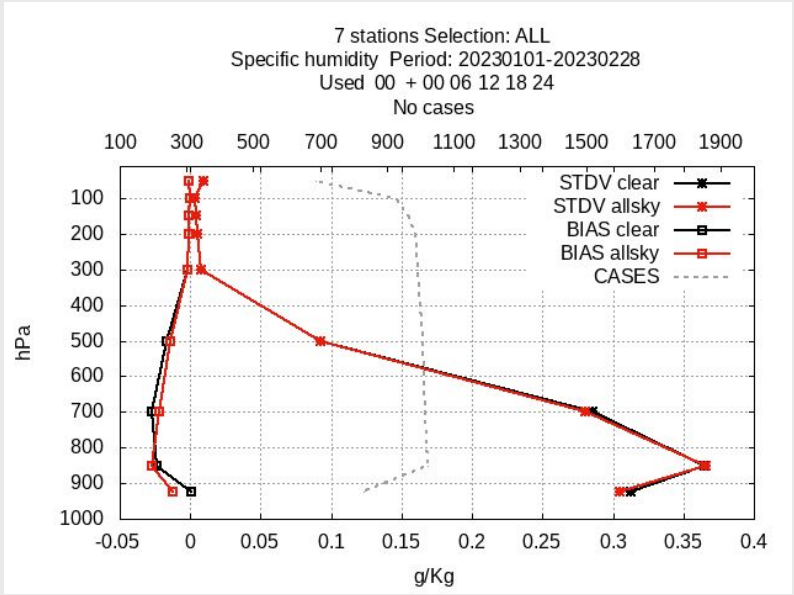
Jan-Feb 2023

clear-sky

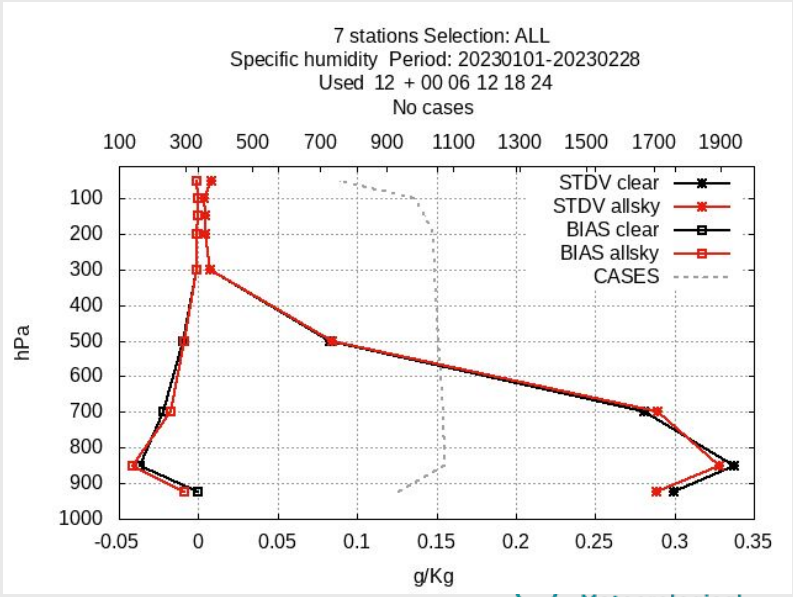
all-sky

Specific humidity

Initial time = 00h



Initial time = 12h



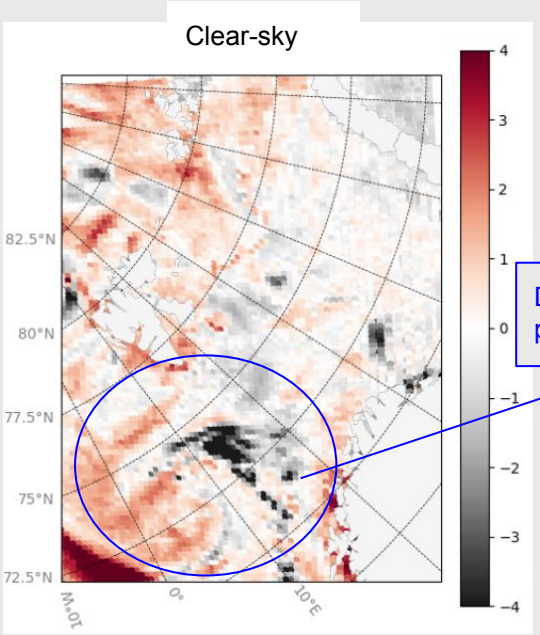
=> overall positive impact for temperature, humidity (bias surface)

Meteorological Institute

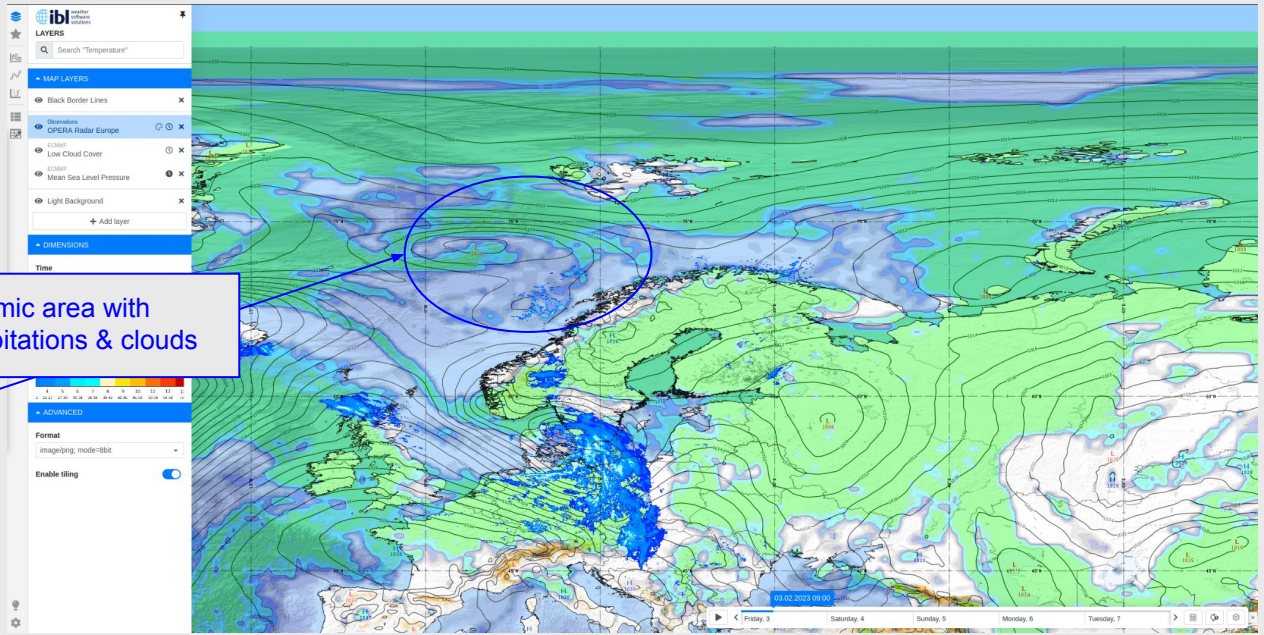
Preliminary results on all-sky MHS data assimilation
Case Study

Benefits of MHS data from previous cycles (03/02/2023 - 09UTC) ?

MHS FG departures
(chan 5 - available)



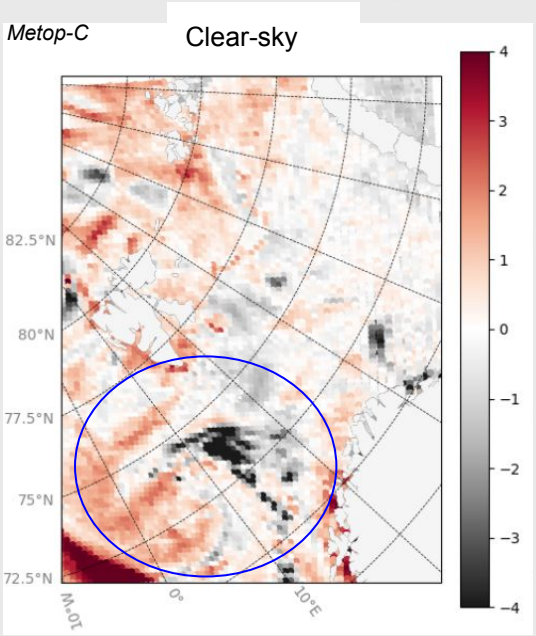
MSLP & low clouds from ECMWF + RADAR

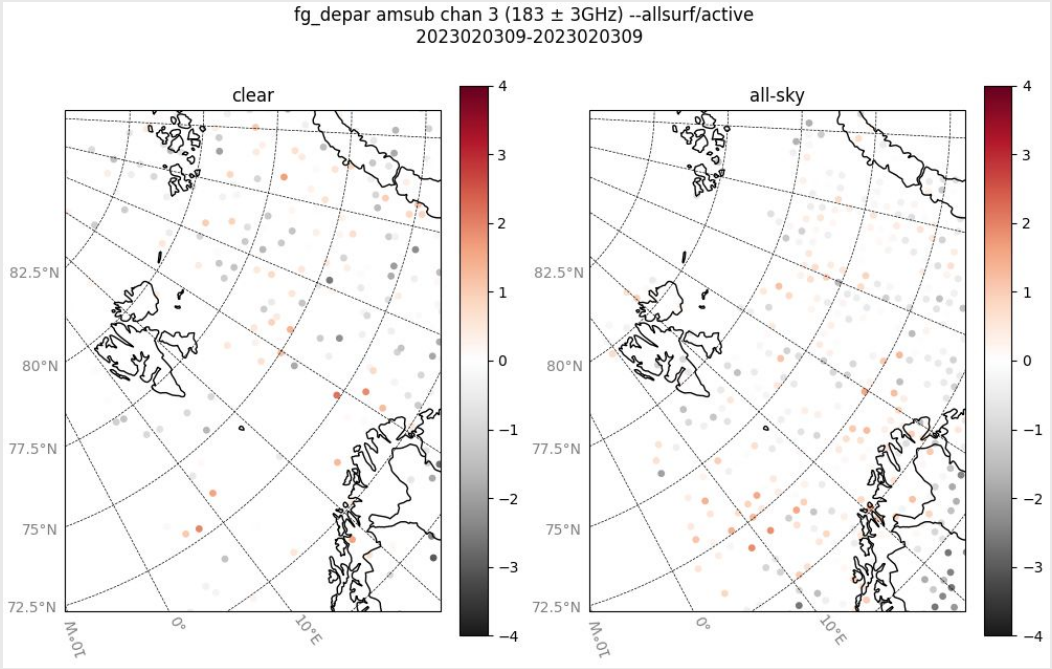


Preliminary results on all-sky MHS data assimilation
Case Study

Benefits of MHS data from previous cycles (03/02/2023 - 09UTC) ?

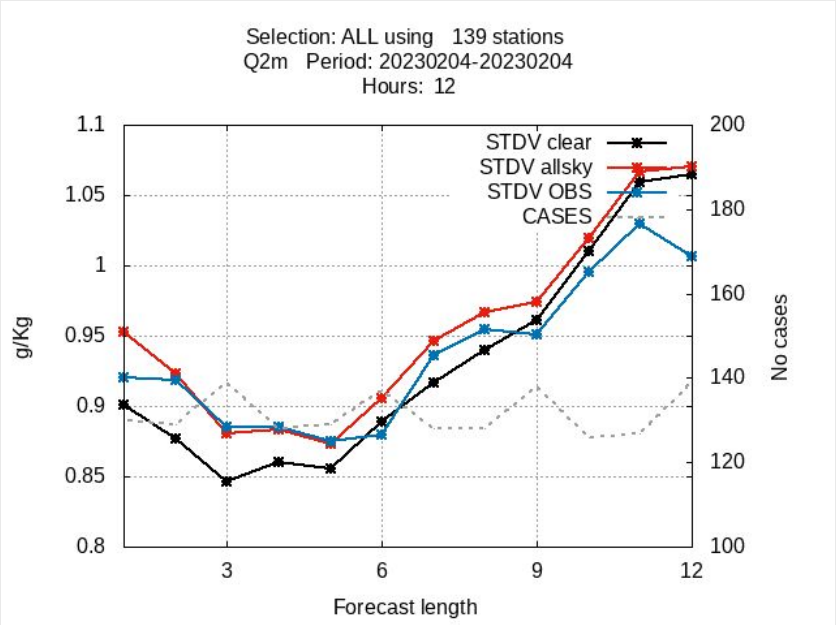
MHS FG departures
(chan 5 - available)





Preliminary results on all-sky MHS data assimilation

Case Study



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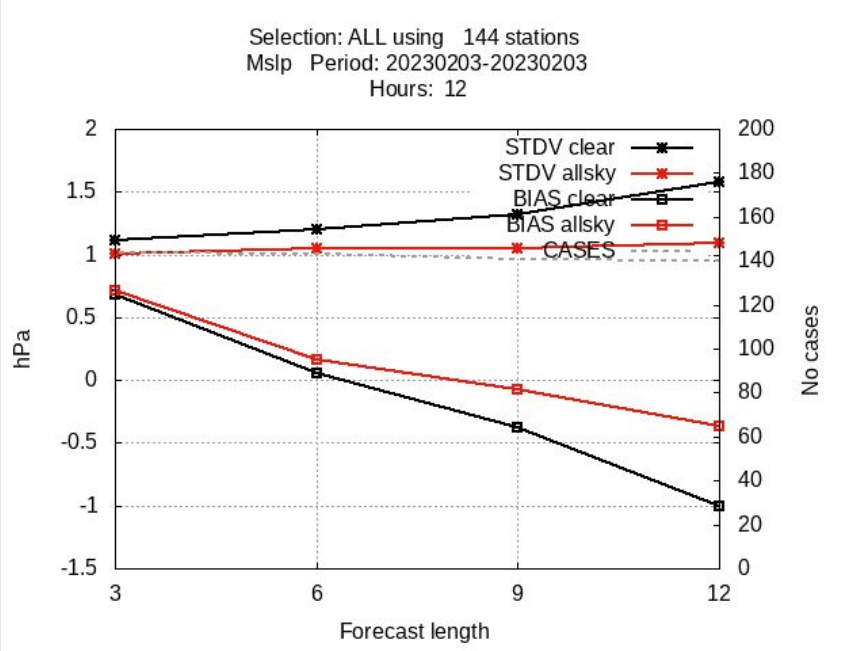
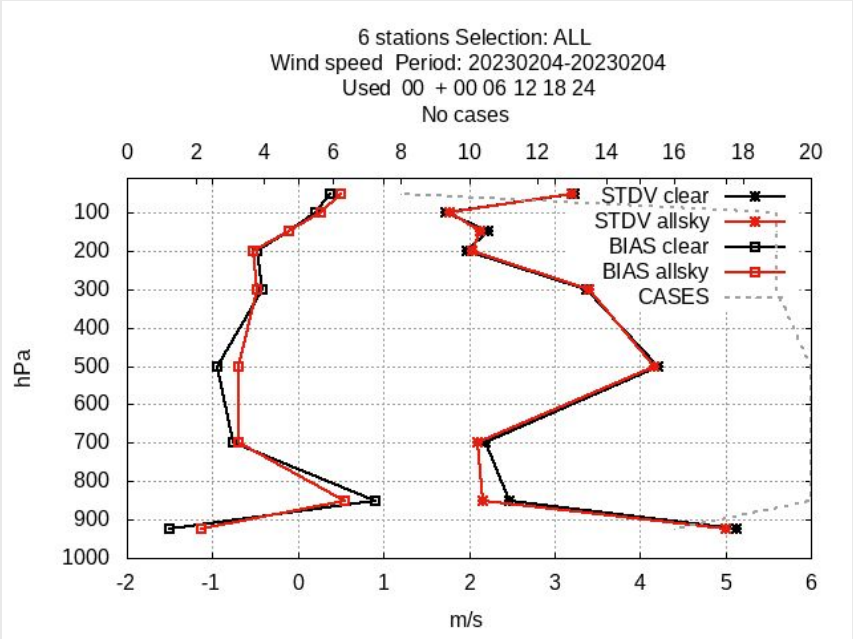
Preliminary results on all-sky MHS data assimilation

Case Study

Clear-sky

All-sky





Short-range forecast based on 03/02 at 12UTC

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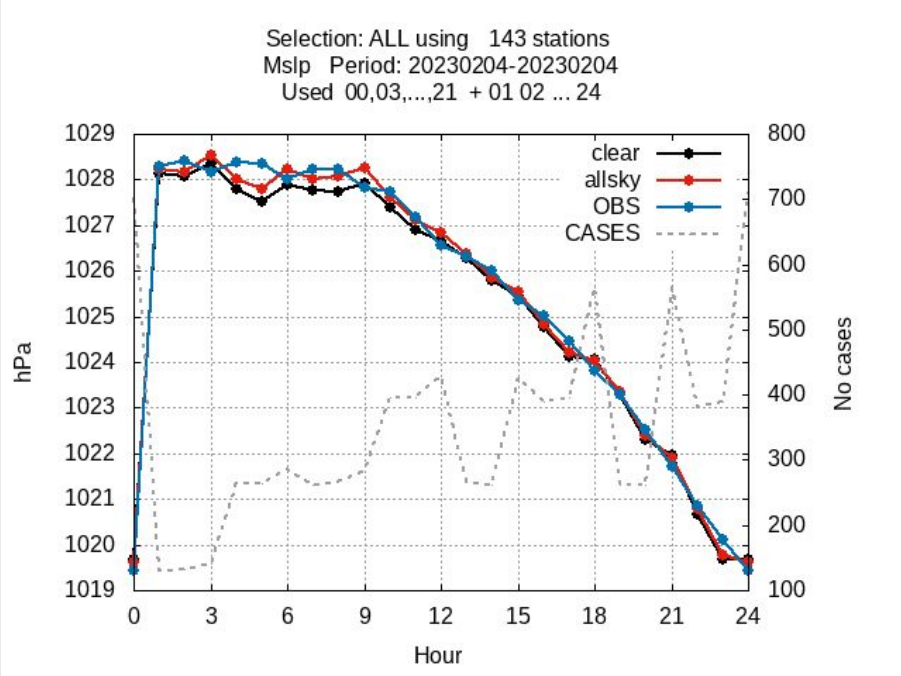


Norwegian Meteorological Institute

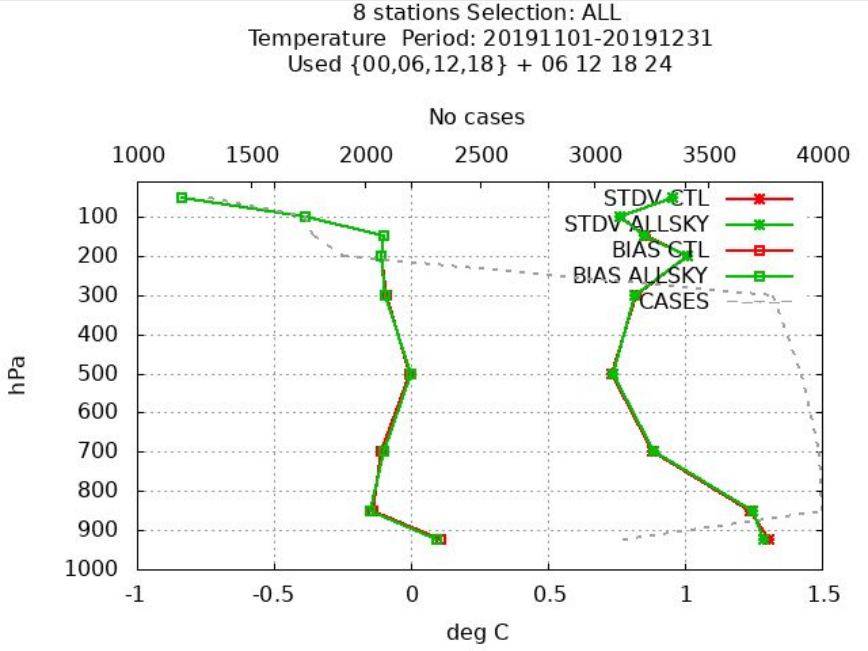
Preliminary results on all-sky MHS data assimilation

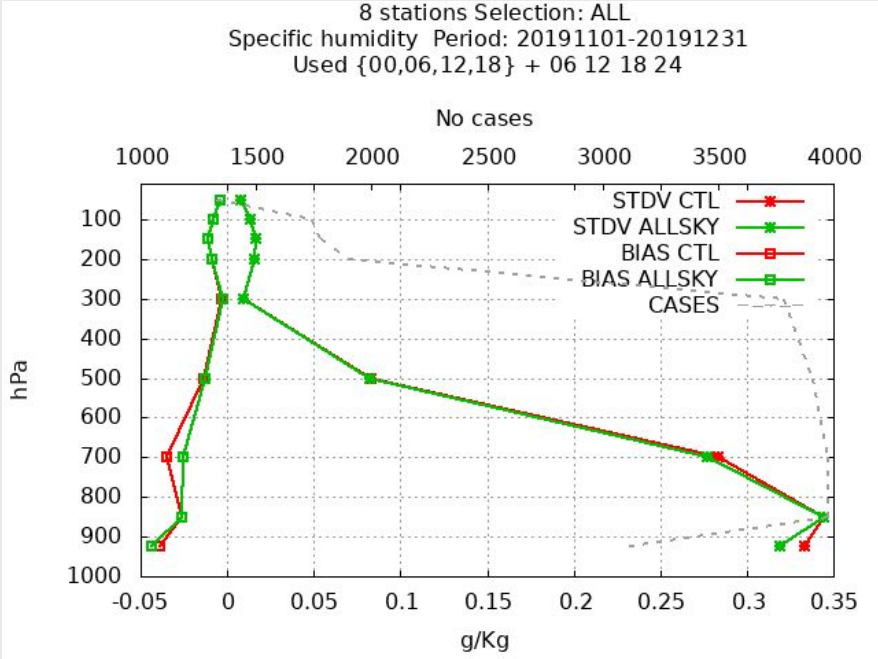
Overall forecast scores: Conv + MHS only setup

CTL

ALL-SKY

Nov-Dec 2019

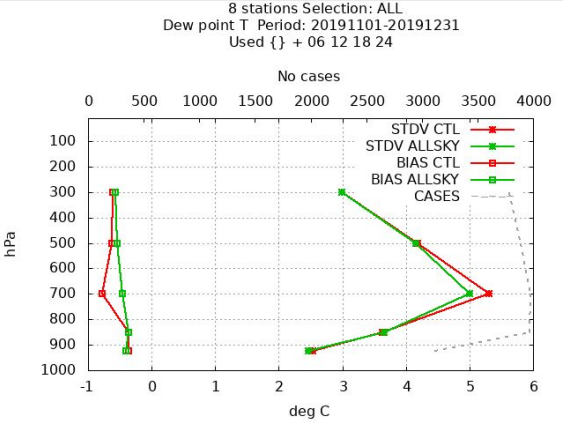


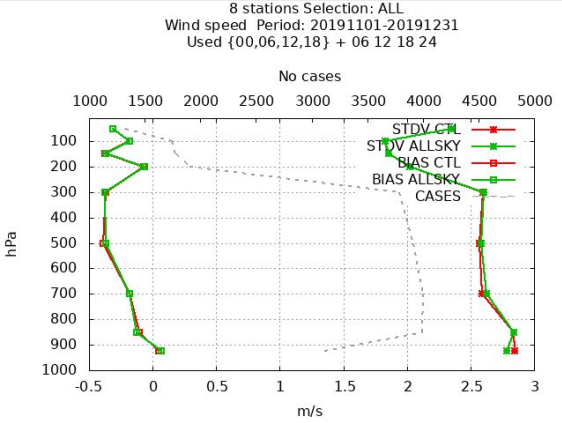


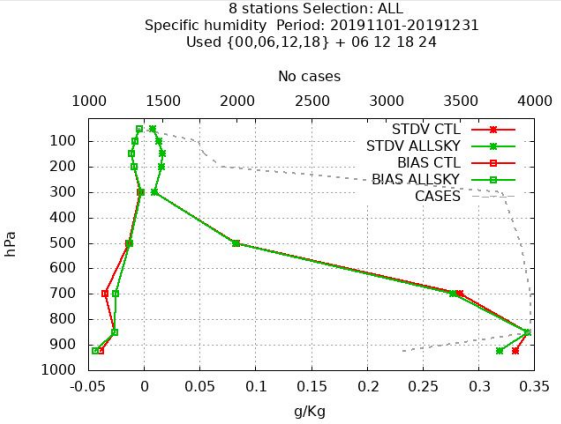
Preliminary results on all-sky MHS data assimilation

Overall forecast scores: Conv + MHS only setup

Nov-Dec 2019

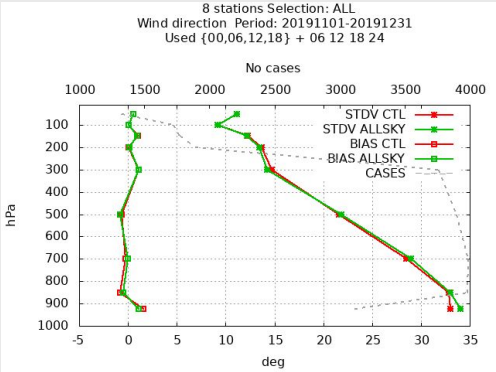


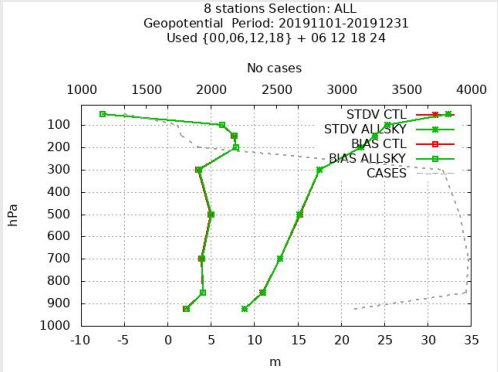




CTL

ALL-SKY





Norwegian Meteorological Institute

Preliminary results on all-sky MHS data assimilation

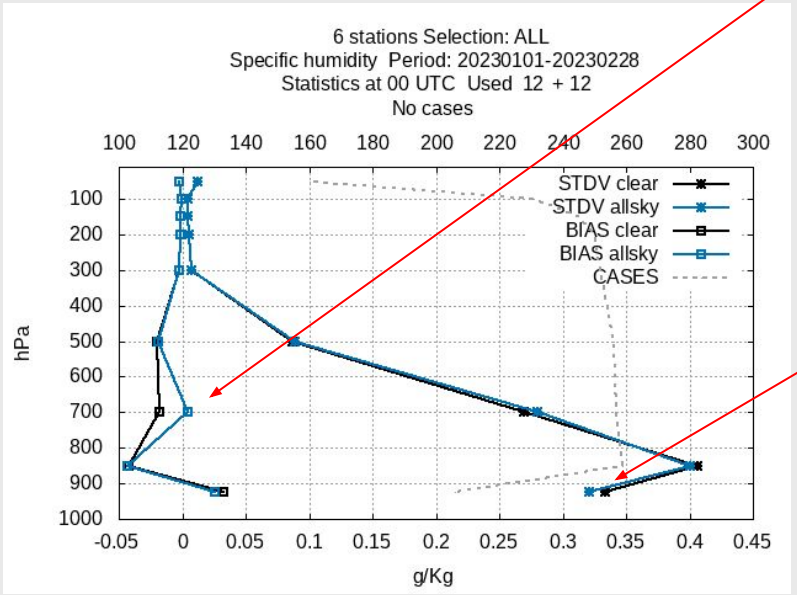
Overall forecast scores: Full observing system setup

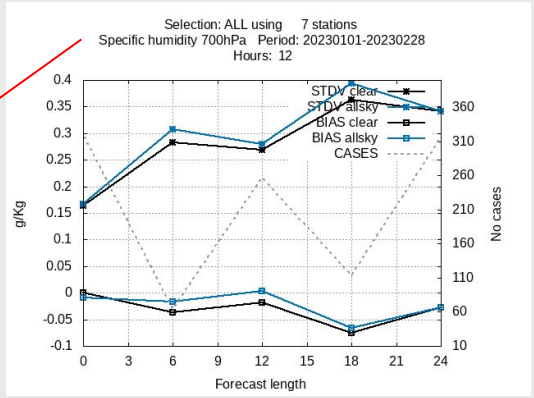
Jan-Feb 2023

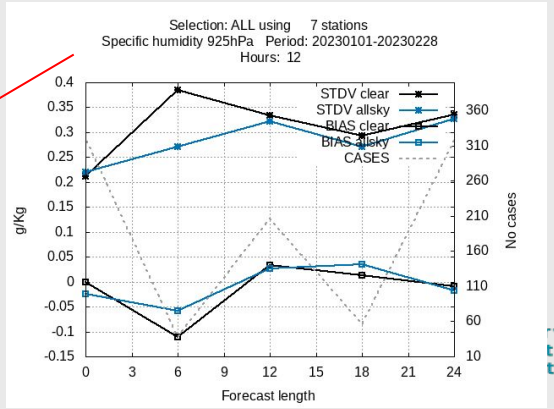
CTL

ALL-SKY

Initial time = 12h







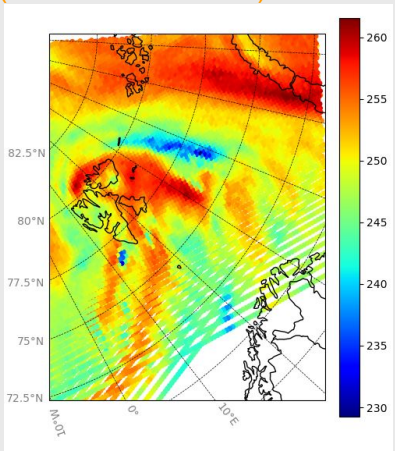
Norwegian Meteorological Institute

Optimizing the use of Microwave observations over Arctic

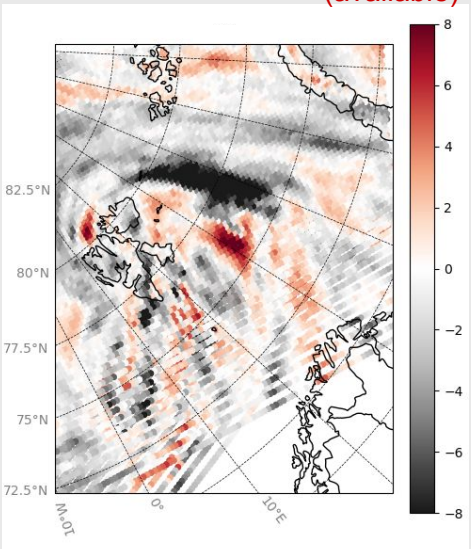
All-sky assimilation DA (ongoing work)

=> All-sky double the number of observations and most dynamically active area (cloudy/rainy area) are better constrained

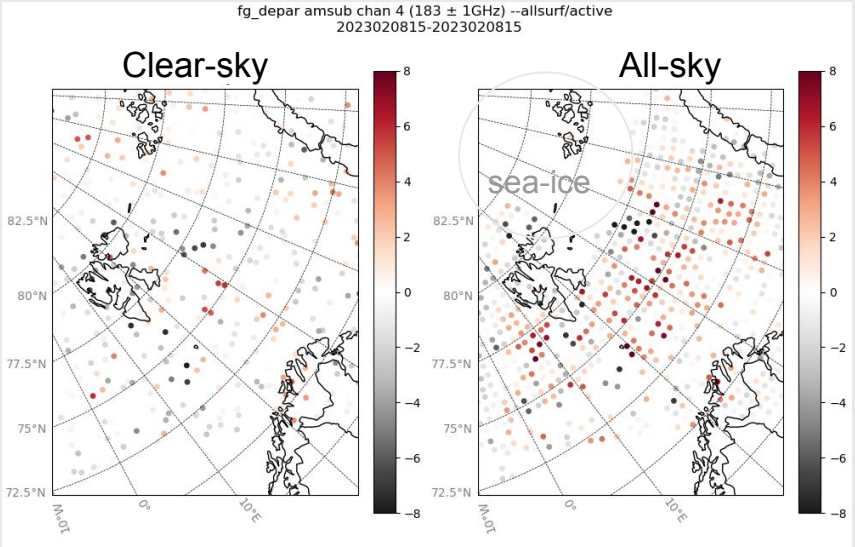
BT observations
(08/02/2023-15UTC)



Observations - Background
(available)

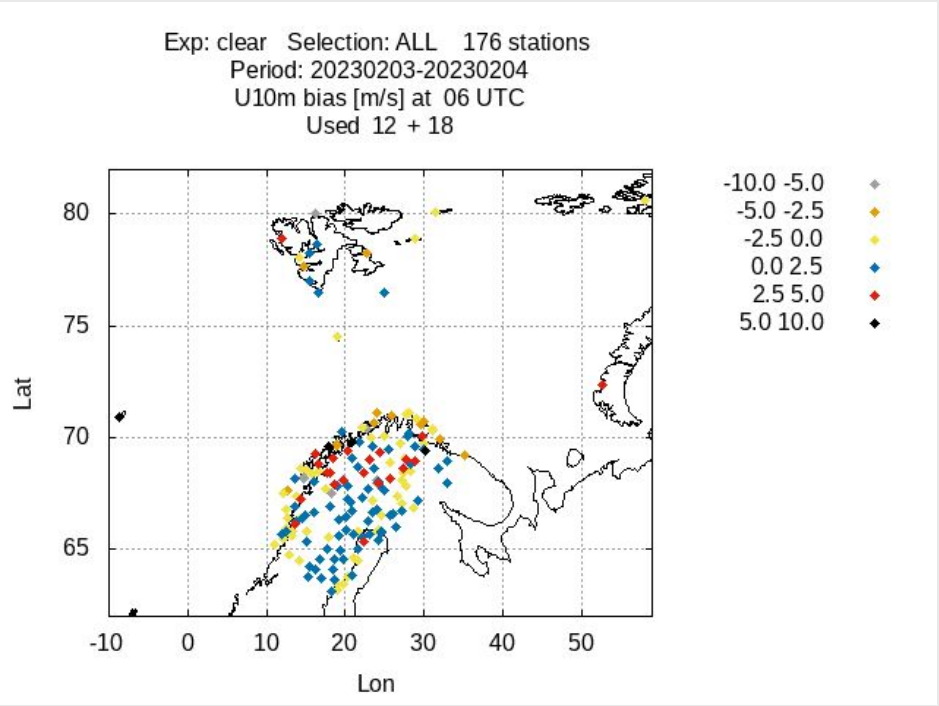


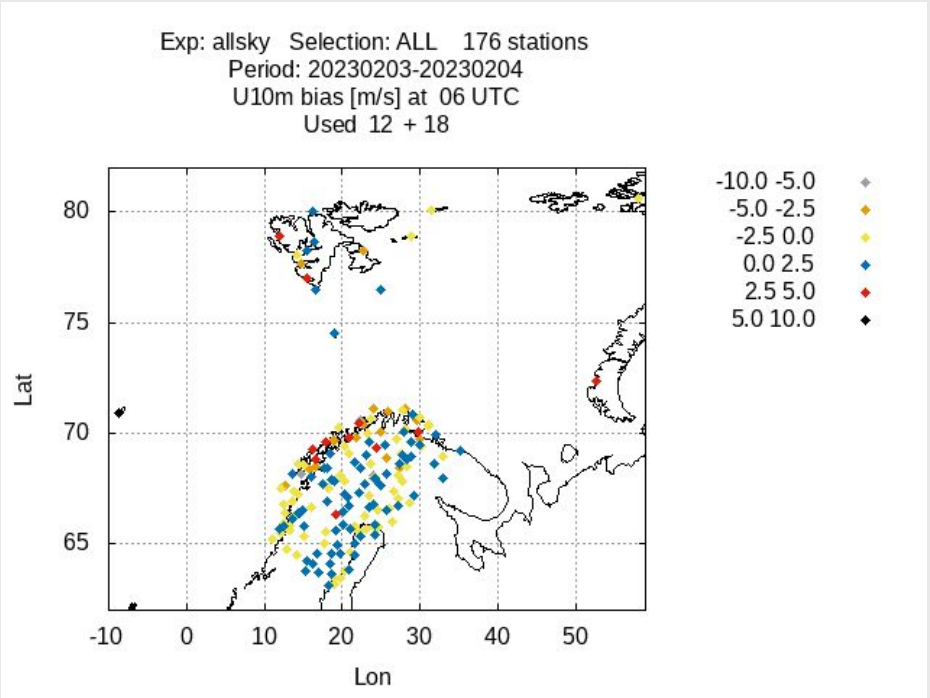
Observations - Background
(actives)



Preliminary results on all-sky MHS data assimilation

Case Study





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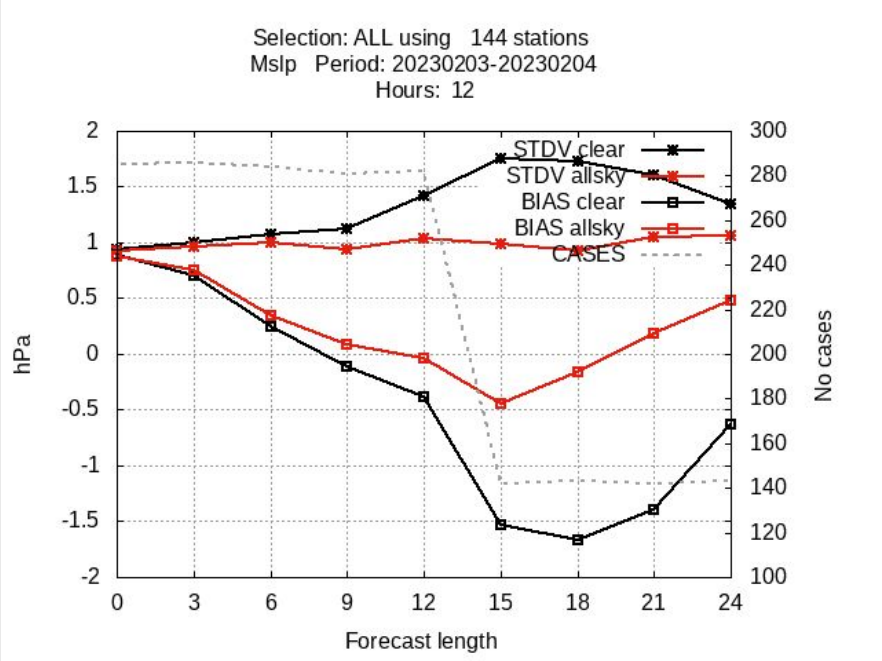
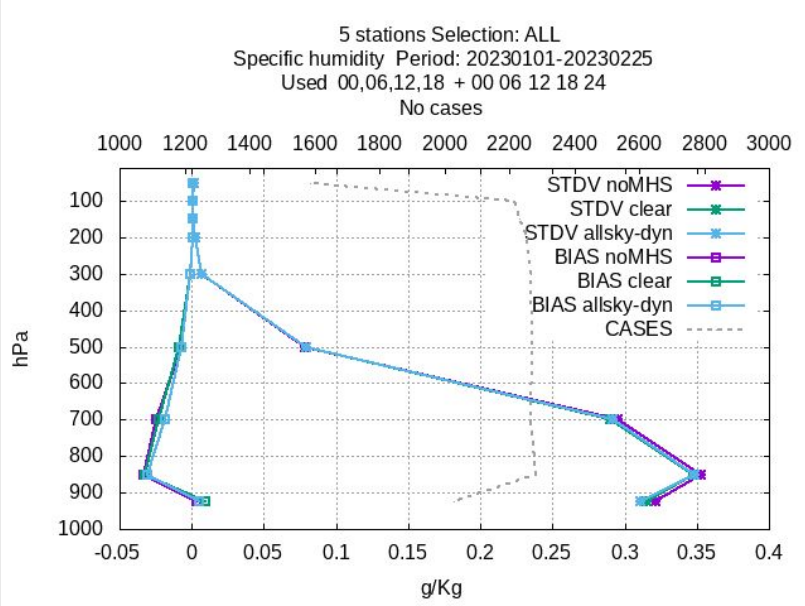


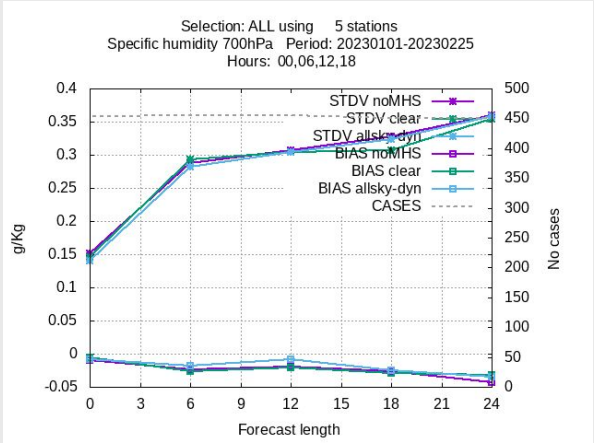
Norwegian Meteorological Institute

Optimizing the use of Microwave observations over Arctic

All-sky assimilation DA (ongoing work)

=> Forecast impact still neutral to positive on humidity and neutral to negative for other parameters …



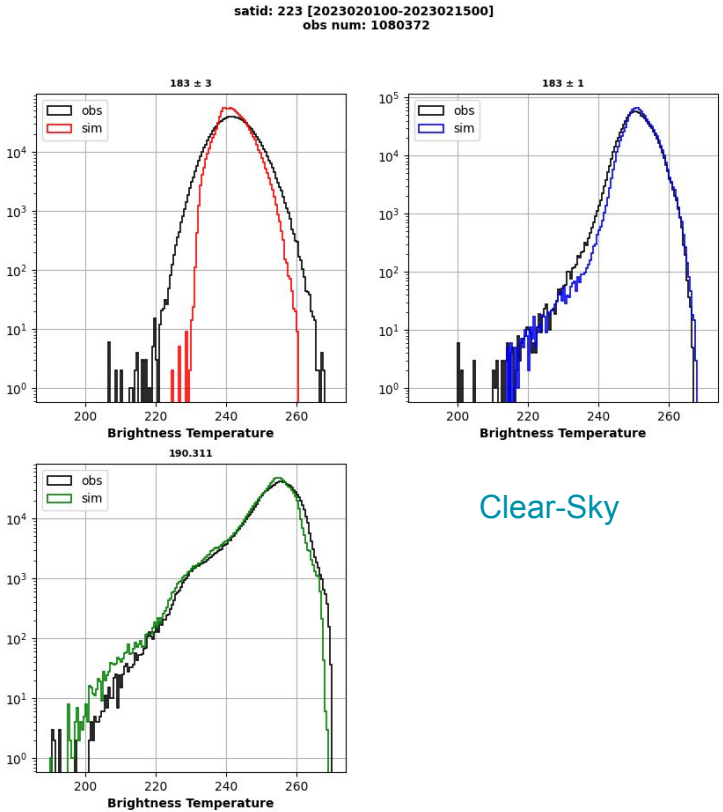


Norwegian Meteorological Institute

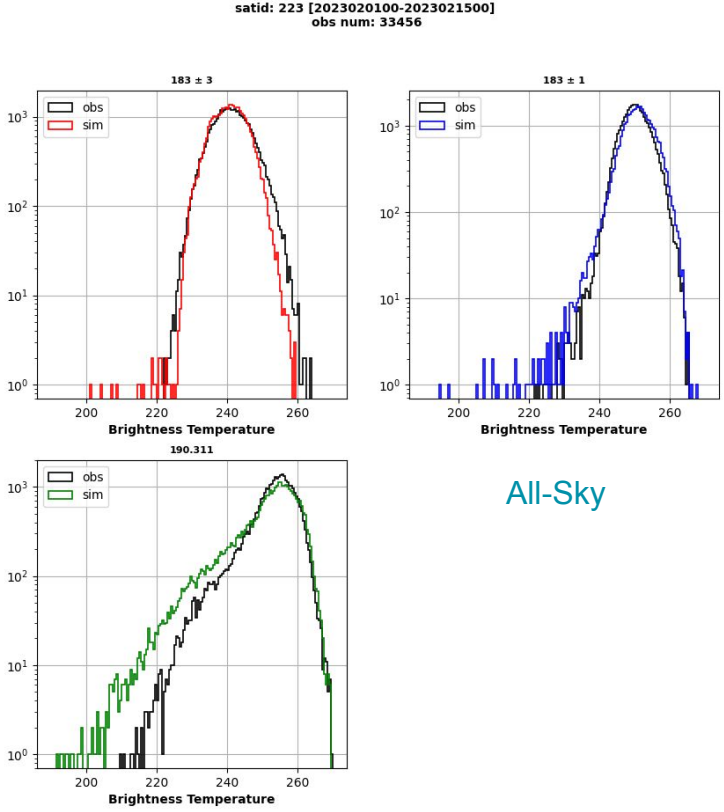
Preliminary results on all-sky MHS data assimilation

All obs (ECMA) 1-15 Feb - **NOAA19**

Observed VS Simulated BT



Clear-Sky



All-Sky