Data assimilation and use of observations at the United Weather Centres

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Isabel Monteiro

Team Leader of Data Asimilation and Use of Observations

United Weather Centres (UWC)

Outline

United Weather Centres

- Overview
- Developments
- Looking at (and to) the future

United Weather Centres

Overview

Common reference and operations

United Weather Centres

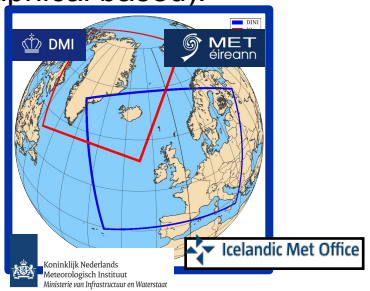
Reference HARMONIE-AROME:

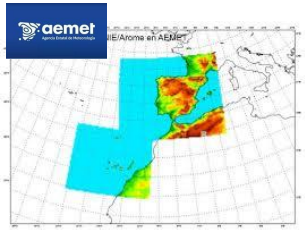
- Upper air: 3D-Var scheme. → **4D-Var**
- Surface OI (canari+SODA).
- Extensive use of observations.
- Climatological background error covariance matrix (B-matrix).
- Forecast model: AROME Physics.
- Model top at 10 hPa.
- Several regional domains (over Europe).
- ECMWF IFS, boundary conditions.
- Horizontal grid resolution 2.5 km, 65 verticals levels

How we organize ourselves for operations:

Details: posters Eoin Whelan and Javier Calvo

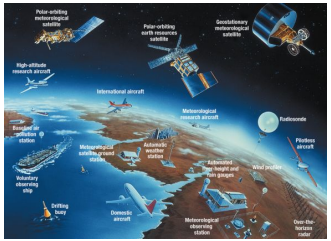
- Sub-consortiums for operations (geographical based).
- Upper air: 3D-Var scheme.
- Diverse use of observations.
- Horizontal grid resolution ~ km
- Vertical levels 65 to 90

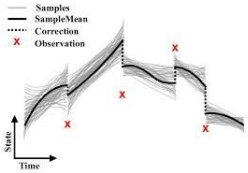


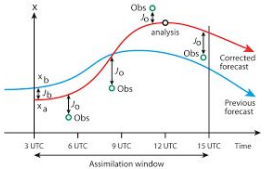


How we organize ourselves for research and development:

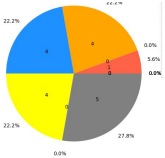
United Weather Centres



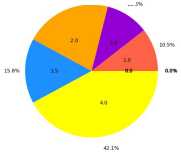




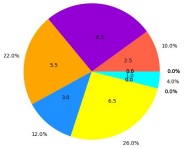
Radar/GNSS



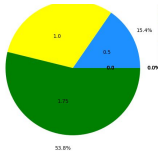
Insitu



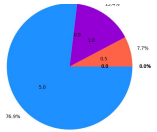
Satellite



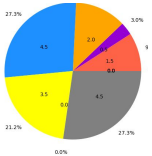
Pre-processing



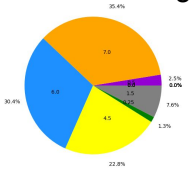
Nowcasting



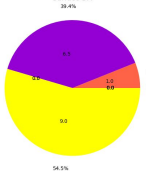
Ens. based /EDA



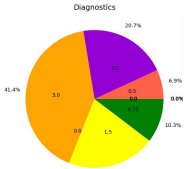
Variational algo.



Surface DA

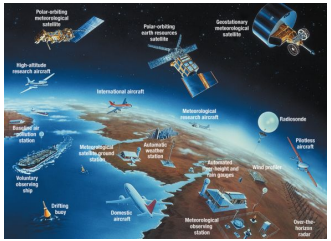


Diagnostics



How we organize ourselves for research and development:

United Weather Centres



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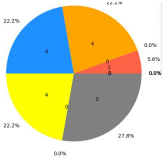
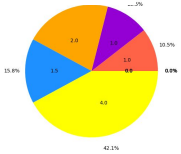
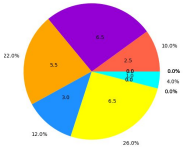


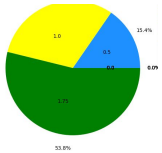
Insitu



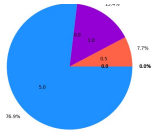
Satellite



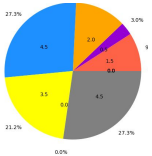
Pre-processing



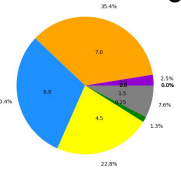
Nowcasting



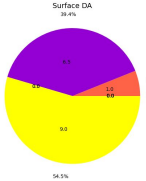
Ens. based /EDA

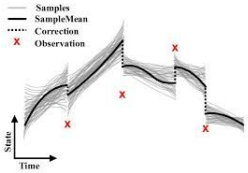


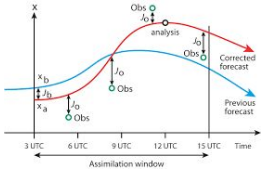
Variational algo.

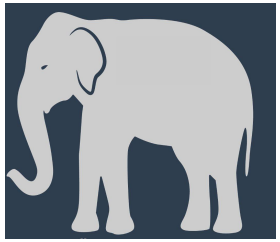


Surface DA

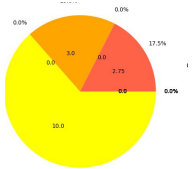




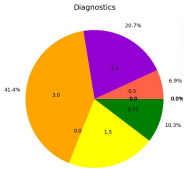




AI/ML



Diagnostics

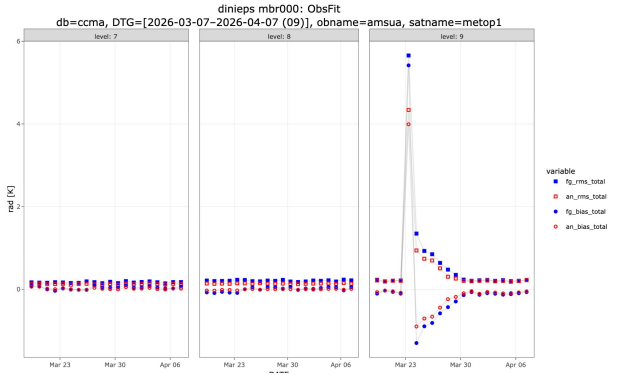


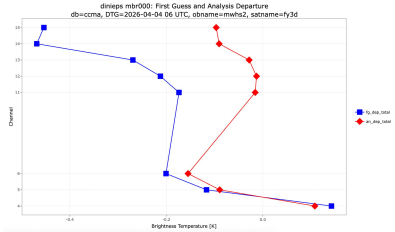
Are we actually progressing? Obsmon WW, 23-26 March at SMHI

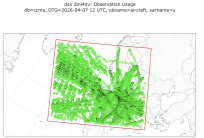
Eoin Whelan (eoin.whelan@met.ie), David Schönach, Martin Ridal, Ahto Mets, Medi Esagh

United Weather Centres

- Install obsmon on **different platforms** (RHEL 9, RHEL 10, Atos, Ubuntu containers).
- **Documentation improved** See https://github.com/Hirlam/obsmon/issues/49
- **More comprehensive tests** using GitHub Actions
- Make a **stand alone backend** that can write either **SQLite** or **parquet** files.
  - The new (prototype) tool uses Python and *odbcon* framework
  - ODB-API (defunct: to be replaced by ODB-tools) used to produce ODB2 file
  - Converts ODB-2 data files to either SQLite or parquet.
- **Test reading one big SQLite file** to speed up the reading.
  - obsmon is quite attached to the pre-defined directory/file structure







The future of obsmon:

Staff resources an ongoing challenge

Is a larger overhaul feasible? Are other solutions available?

MET éireann · SMHI · Estonian Environment Agency | WEATHER · FINNISH METEOROLOGICAL INSTITUTE

ACCORD

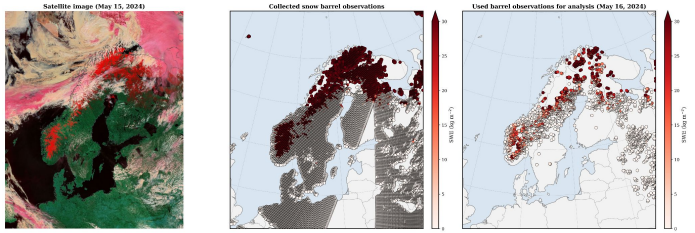
United Weather Centres

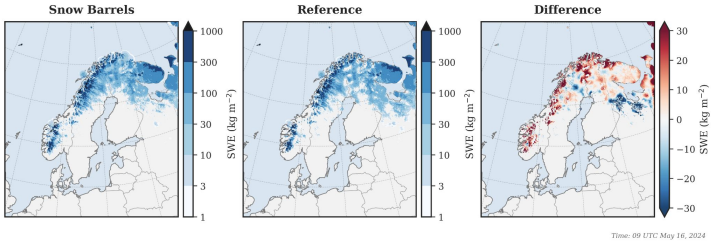
Developments

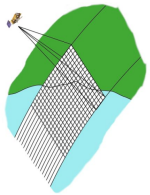
Assimilation of satellite snow extent observations: snow barrels

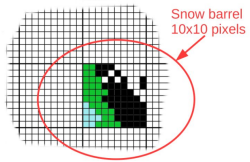
Mikael Hasu, Niilo Siljamo, Ekaterina Kurzeneva, Laura Rontu

- Direct **satellite snow data assimilation is challenging** due to resolution mismatch with NWP grids
- ***Snow barrels*** aggregate **10 × 10 satellite pixels** to better match model grid scales
- Each barrel stores **time, location**, and a **snow-class distribution**
  - Classes: *snow, no snow, partial snow, water, unclassified*
- **Usage in analysis:**
  - Data from the **previous day** used in the **morning snow analysis**
  - Barrels applied **only when conflicting** with the model first guess
- **Pseudo-observations:**
  - Fixed snow depth range **0–10 cm**, scaled by snow fraction
  - Example: 100/100 snow pixels → 10 cm, 50/100 → 5 cm
- SWE derived using **monthly climatological snow density**
- **Assimilation:** Combined with **SYNOP observations** and **background**









In file (example):
20191024 1107 66.9386 174.6436 0 19 0 29 44 8

Patrick Samuelson talk, Wednesday

FINNISH METEOROLOGICAL INSTITUTE

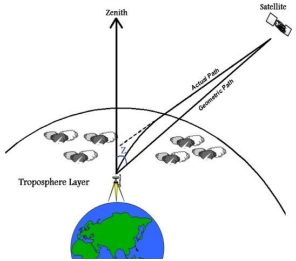
Assimilation of data from GNSS ZTD and GNSS STD

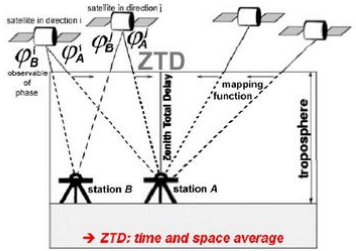
Jana Sánchez (jsancheza@aemet.es), M. Ridal (martin.ridal@smhi.se) M. Dahlbom, S. de Haan and J. M P. de Gracia

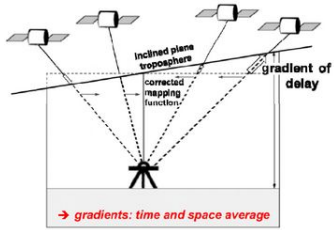
- **GNSS Zenith Total Delay** (GNSS ZTD), provide an estimative of the total water vapor in the air column above a GNSS receiver, **operational** at **MetCoOp** and **AEMET**
  - Whitelists are being updated. More regular updates are wanted
  - Switch from ASCII to BUFR is ongoing

- **GNSS Slant Tropospheric Delay** (GNSS STD) provide 3D, high-resolution information about water vapor structure,assimilation is under development in UWC.
  - Observation error, thinning and similar need tuning (not the same as ZTD)
  - A limitation is the reduced number of observations available

- **Plans**: assimilation of **ZTD gradients. VarBC for STD**



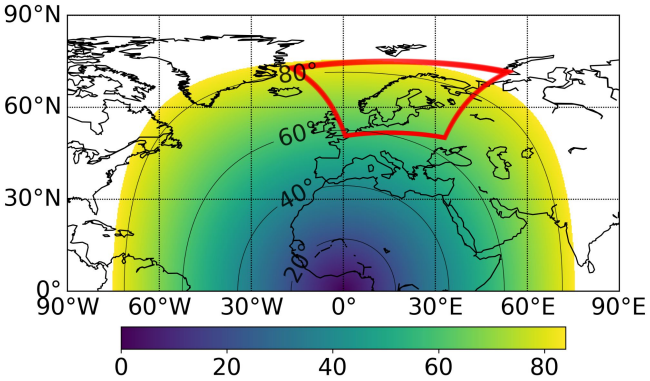


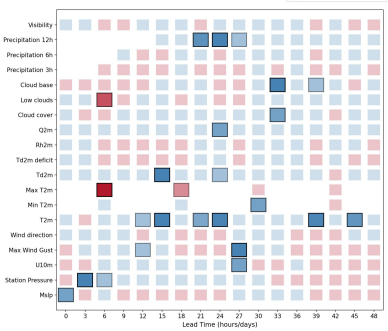


SEVIRI and FCI, taking advantage of frequent IR observations David Schönach (david.schonach@fmi.fi)

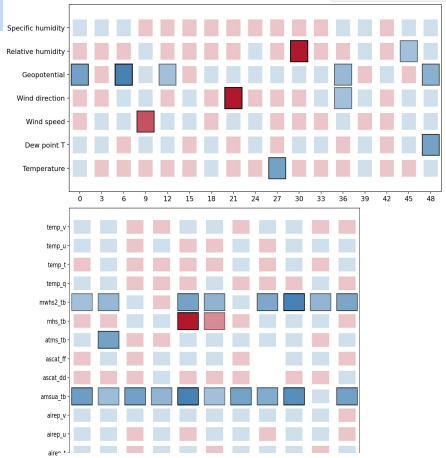
United Weather Centres

SEVIRI





Surface: ref vs seviri
RMSE diff = ref - seviri
2026022000 - 2026030800
00, 12 UTC



Upper Air: ref vs seviri
RMSE diff = ref - seviri
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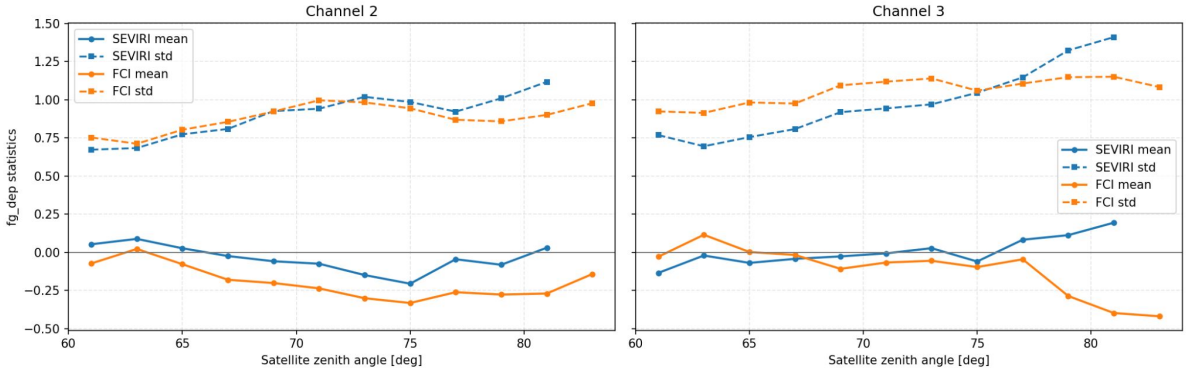
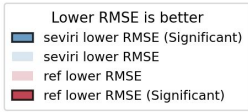
00, 12 UTC

FCI





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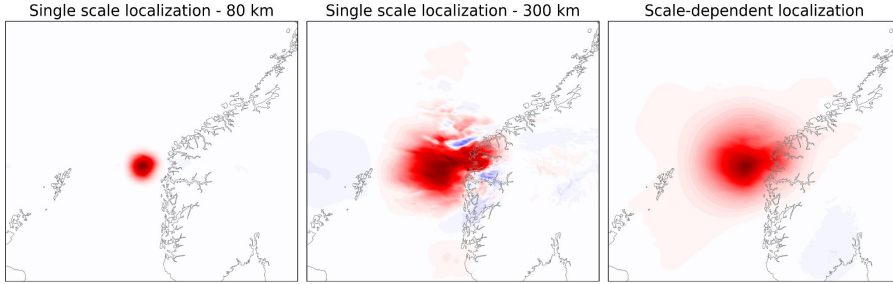
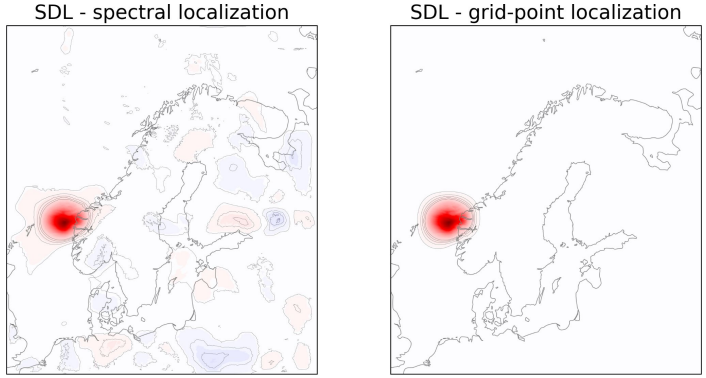
3D-EnVar Scale Dependent Localization - Benjamin Menetrier (benjaminm@met.no)

United Weather Centres

- **SDL** is a powerful method to **remove sampling noise** from ensemble-based covariances while retaining large-scale covariances (top fig.):
  - left: narrow localization → no large-scale signal
  - center: broad localization → small-scale noise
  - right: **SDL** → **large-scale** signal **without small-scale noise**
- SDL is implemented in CY49, but we needed it in CY46.
- HARMONIE can be i**nterfaced with the SABER library** for background error modeling, from CY46.
- **SABER** is very flexible, its SDL **includes CPU** and **memory optimizations**.
- **SABER** has several **localization options** (bottom fig.):
  - left: SDL with spectral localization → large-scale noise because of spectral truncation
  - right: SDL with grid-point localization → no more large-scale noise





Norwegian Meteorological Institute

Continue to push operations forward

Maria Diez (mdiezm@aemet.es), Jana Sánchez

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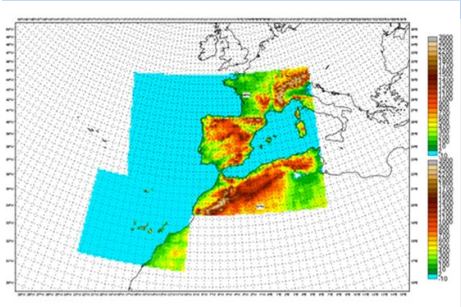


Operational AIB/AIC

2,5 km, 3h cycle. (cycle 43h2.1.1)

Conv + radar + GNSS ZTD + Satellite:

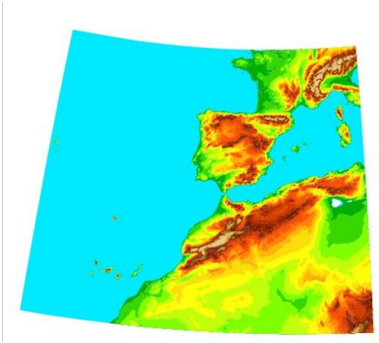
Seviri: WV channels (only over sea),

METOP-B &METOP-C: AMSU-A, MHS, IASI & ASCAT

Nowcasting AIN

1,25 km, 1h cycle. (cycle 43h2.1.1)

Conv + radar + GNSS ZTD + MODE-S EHS (only wind) + Satellite: Seviri: WV channels (only over sea).



Pre-Operational big domain AIBC

2,5 km, 3h cycle. (cycle 46h1.1.1)

Conv + radar + GNSS ZTD + Satellite:

Seviri: WV channels,

METOP-B & METOP-C: AMSU-A (low peak channels), MHS, IASI & ASCAT,

NOAA-20 & NOAA-21: ATMS & CrIS ; Soumi-NPP (only ATMS),

FY-3D & FY-3E: MWHS-2

Next future:

- Update **nowcasting suite** to cycle 46 over the Iberian peninsula and Canary Islands
- Finish the setup for the assimilation of **FCI**
- Assimilate **ASW** radiances
- Prepare all the suites for **IRS** assimilation.

Details Maria Diez talk on **Friday**

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Looking at (and to) the future

Arctic Weather Satellites and domains over the Arctic..

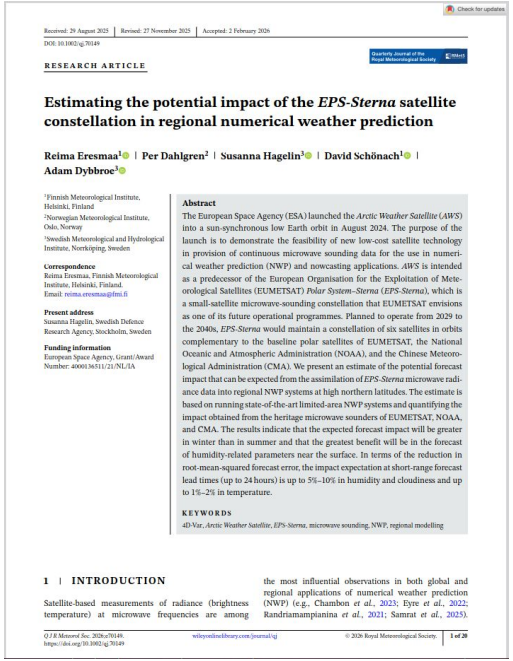
Reima Eresmaa (reima.erasmaa@fmi.fi) and Stephanie Guedj (stephanieg@met.no)

United Weather Centres

- The **EPS-Sterna** constellation **impact** study (presented at ASW2024) in **HARMONIE-AROME 4D-Var** was published recently in **QJRMS**: doi.org/10.1002/qj.70149.

- There was a **reassessment based on real AWS measurement data in 2025**
  - See report D6 at arctic-weather-satellite.org/publications.html
  - The AWS impact is broadly in line with the impact of the MW sounders on Metop-B - hence, the conclusions of the QJRMS article remain valid

- MetCoOp has been monitoring **AWS in a pre-operational run since 17th February 2026** and is currently evaluating the impact of active assimilation



Received: 29 August 2025 | Revised: 27 November 2025 | Accepted: 2 February 2026
DOI: 10.1002/qj.70149
RESEARCH ARTICLE

Estimating the potential impact of the *EPS-Sterna* satellite constellation in regional numerical weather prediction

Reima Eresmaa[1] | Per Dahlgren[2] | Susanna Hagelin[3] | David Schönach[1] | Adam Dybbroe[3]

[1]Finnish Meteorological Institute, Helsinki, Finland
[2]Norwegian Meteorological Institute, Oslo, Norway
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Funding information
European Space Agency, Grant/Award Number: 4000136511/21/NL/IA

Abstract
The European Space Agency (ESA) launched the *Arctic Weather Satellite* (*AWS*) into a sun-synchronous low Earth orbit in August 2024. The purpose of the launch is to demonstrate the feasibility of new low-cost satellite technology in provision of continuous microwave sounding data for the use in numerical weather prediction (NWP) and nowcasting applications. *AWS* is intended as a predecessor of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) *Polar System–Sterna* (*EPS-Sterna*), which is a small-satellite microwave-sounding constellation that EUMETSAT envisions as one of its future operational programmes. Planned to operate from 2029 to the 2040s, *EPS-Sterna* would maintain a constellation of six satellites in orbits complementary to the baseline polar satellites of EUMETSAT, the National Oceanic and Atmospheric Administration (NOAA), and the Chinese Meteorological Administration (CMA). We present an estimate of the potential forecast impact that can be expected from the assimilation of *EPS-Sterna* microwave radiance data into regional NWP systems at high northern latitudes. The estimate is based on running state-of-the-art limited-area NWP systems and quantifying the impact obtained from the heritage microwave sounders of EUMETSAT, NOAA, and CMA. The results indicate that the expected forecast impact will be greater in winter than in summer and that the greatest benefit will be in the forecast of humidity-related parameters near the surface. In terms of the reduction in root-mean-squared forecast error, the impact expectation at short-range forecast lead times (up to 24 hours) is up to 5%–10% in humidity and cloudiness and up to 1%–2% in temperature.

KEYWORDS
4D-Var, *Arctic Weather Satellite*, *EPS-Sterna*, microwave sounding, NWP, regional modelling

1 | INTRODUCTION

Satellite-based measurements of radiance (brightness temperature) at microwave frequencies are among the most influential observations in both global and regional applications of numerical weather prediction (NWP) (e.g., Chambon *et al.*, 2023; Eyre *et al.*, 2022; Randriamampianina *et al.*, 2021; Samrat *et al.*, 2025).

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In preparation for MTG-IRS reconstructed radiances.

Isabel Monteiro (isabel.monteiro@knmi.nl), Maria Diez and David Schönach

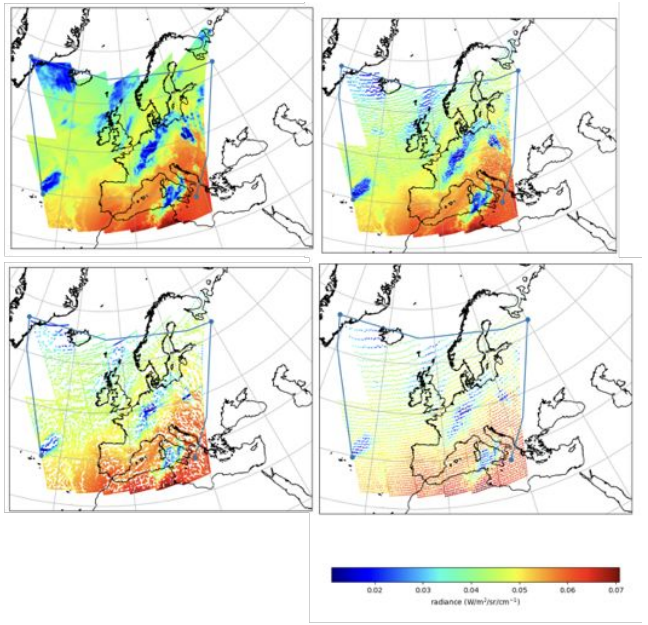
United Weather Centres

Objective: Test EUMETSAT test data in CY49 HARMONIE-AROME 4D-Var

Pre-processing - IRSPP: NWPSAF IRSPP reconstructed radiances.

- Only LAC4 and selected dwells are fetched
- Channel selection and thinning at IRSPP level- collaboration with Météo-France.

Code developments are technically tested.



To do (with real data):

- Implement the cloud detection scheme (based on the McNally & Watts, using LWIR band, similar to CrIS).
- Observation errors
- Final channel selections

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MW all-sky, using cloud and precipitation information in HARMONIE-AROME 4D-Var

Reima Eresmaa (reima.eresmaa@fmi.fi), Stephanie Guedj (stephanieg@met.no), Máté Mile, P. Dahlgren, I. Monteiro

Goal: implementing **MW all-sky assimilation route** using the same approach as ECMWF in their 4D-Var.

- HARMONIE-AROME HARMONIE-AROME **control vector:** temperature and humidity, but **no hydrometeors.**
- The **observation operator** requires **cloud and precipitation profiles**: these are diagnosed from the control vector information using the 4D-VAR HARMONIE-AROME **simplified linear physics** code.
- .The work is conducted in a CYCY49 development branch of HARMONIE-AROME.HARMONIE-AROME.

Recent progress (2026):

- Implementing a necessary **pre-thinning** step to reduce the amount of input BUFR data to a manageable level.
- Implementing a **technically-functioning interface to retrieve the diagnostic hydrometeor profiles** at observation locations from the 4D-Var linear physics code.

Next steps:

- Demonstrating meaningful analysis increments in single-observation experiments
- Extending the functionality to humidity sounders other than MHS

Successfully extracting information from spatial dense observations

José Faundéz Alarcon (josemanuel.faundezalarcon@smhi.se) and Jelena Bojarova

United Weather Centres

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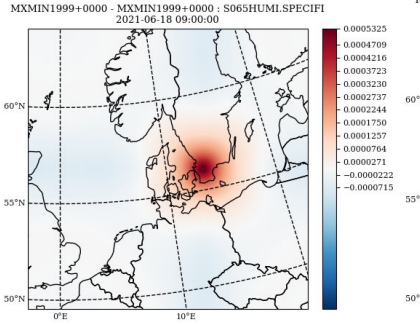
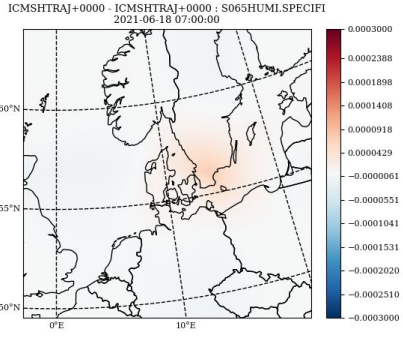
- Experiments carried out to evaluate the capabilities of our system to integrate the observations from a drone data collection campaign.
- Sensors collected temperature, humidity and pressure during a vertical flight.
- The observations have been treated as radiosondes and assimilated using **3DVAR** and **4DVAR**

3DVAR increments

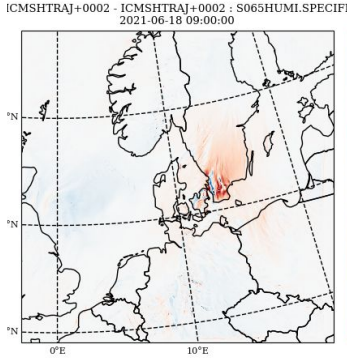


@ Analysis time

4DVAR increments



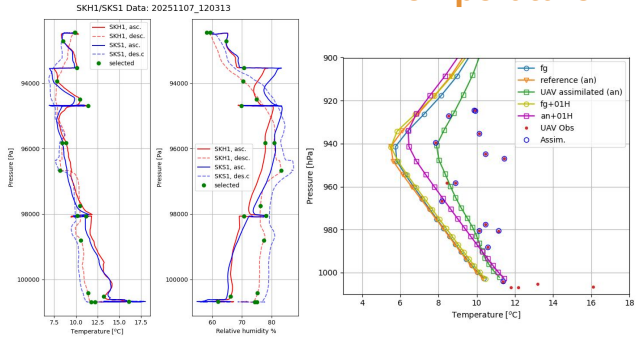
@ beg. 4dvar window



@ Analysis time

Specific humidity

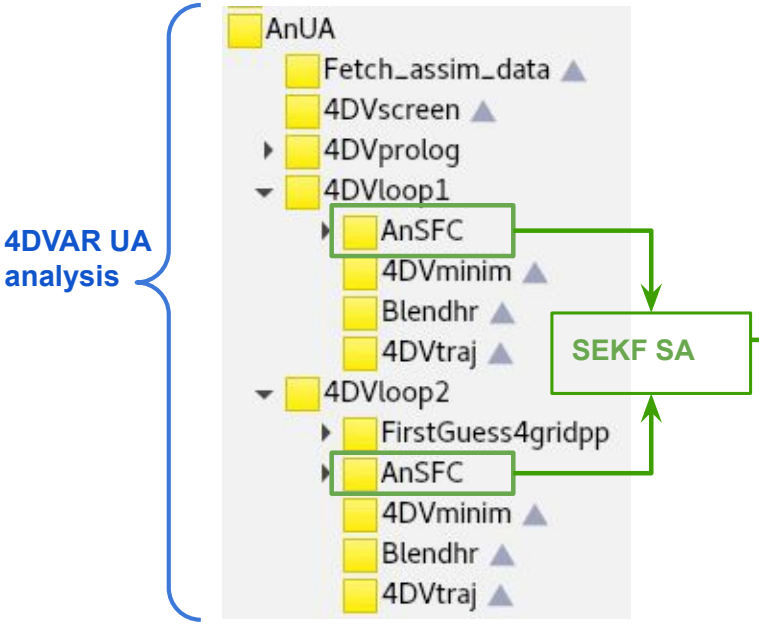
Temperature



Example of campaign measurements from National Research Project **"BÄVER"** (*Better Weather Forecast for Unmanned Vehicles*) funded by ***Swedish Transport Agency***

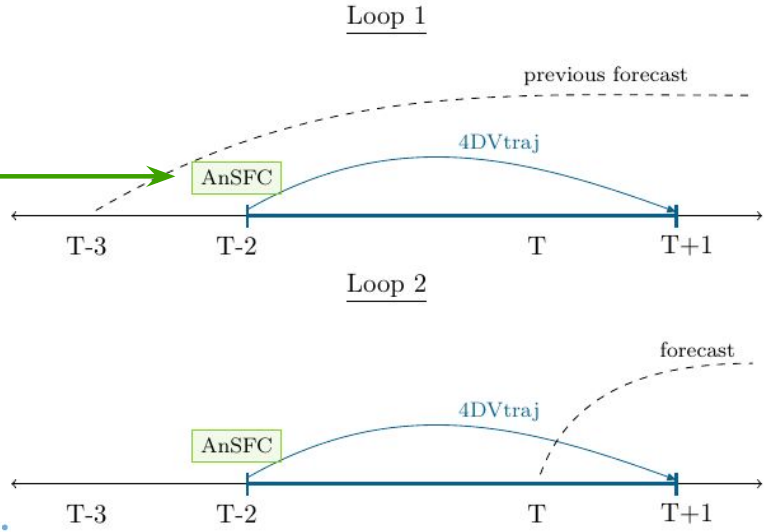
Surface upper air coupling - Jelena Bojarova (jelena.bojarova@smhi.se) , José Faundéz Alarcon

through 4DVAR outer loop functionality



- **Coupling strategy:** different assimilation schemes for upper-air and surface, but within the same DA window.
- The sequential update of the fields through the outer loops allows information exchange between the systems.
- Coupled trajectory (short forecast) enhances initial state balancing

At the beginning of 4DVAR window



Skin-temperature analysis - Jelena Bojarova (jelena.bojarova@smhi.se) ,José Faundéz Alarcon

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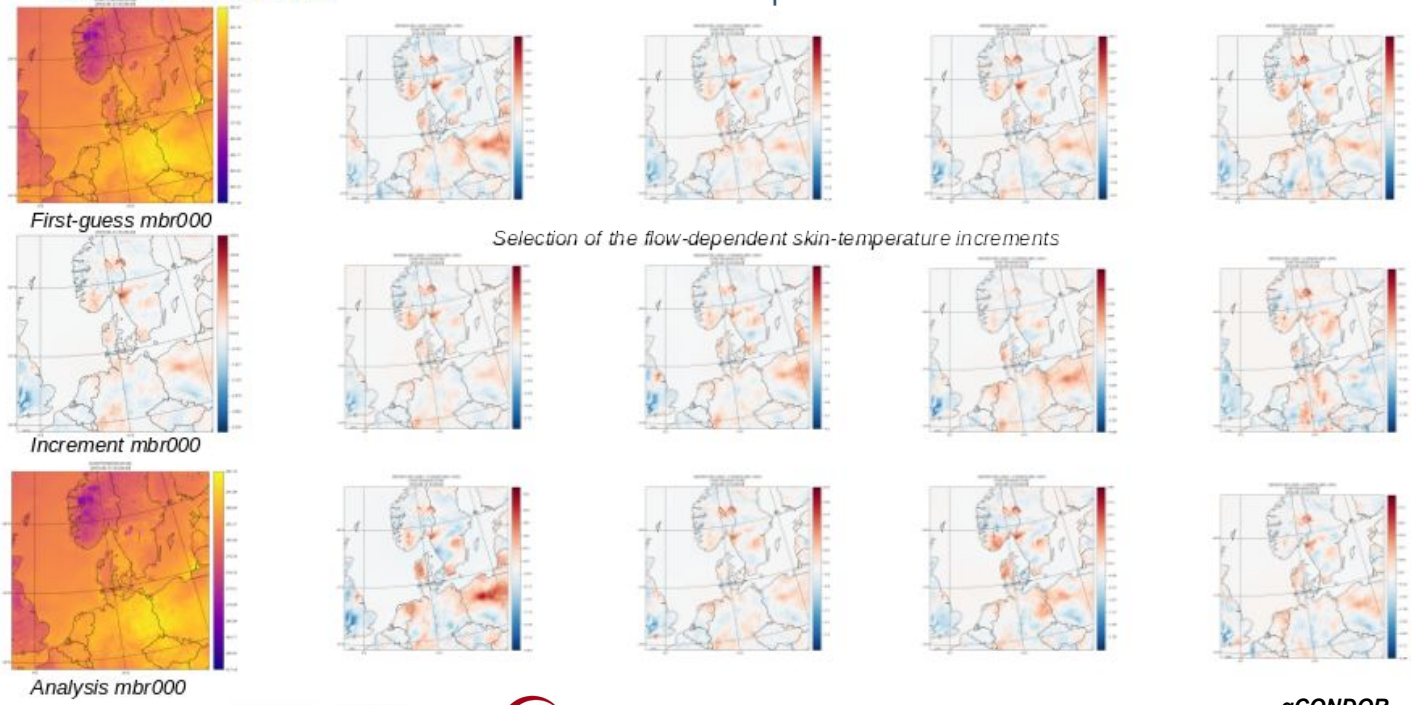
Task WP2.3 : illustration of the skin-temperature increments



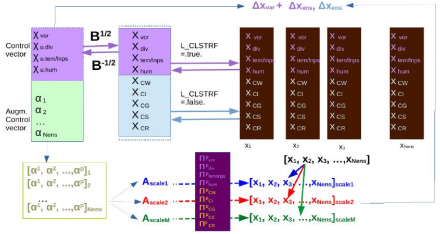


Illustration of ***HybridEnVar*** scheme extended to provide flow-dependent skin-temperature analysis using ***BREND*** (randomization of B-matrix covariance in ensemble mode) ensemble generation scheme

20 ensemble members are used in Hybrid3DEnVar scheme

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Funded by the European Union

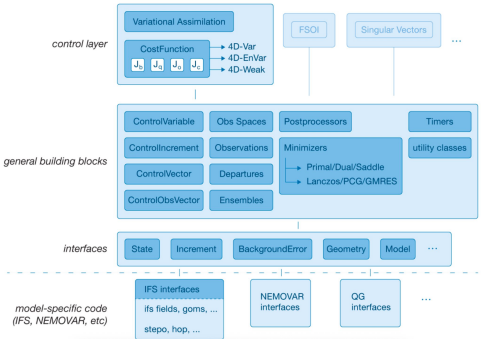
Coordinated ECMWF

eRISE

qCONDOR (*Swedish National Space Agency*)

2025

- **3D-EnVar:** Scheme testing at an operational domain. Starting long experiments using CY46.
- **LAM 4D-Var** - one loop resolution: basic functionality confirmed (against MASTERODB).



2026 (so far)

- **3D-EnVar:** Scale Dependent Localization from OOPS in CY49. First comparisons with the SABER implementation.
- **LAM 4D-Var (CY49):** 2 outer loops, at different resolution. Possible to run long forecasts. MASTERODB comparison led to several bug fixes.
- **Use of observations:**

  Tested: Conventional; AMSU-A, Mode-S, ATMS.

  Ongoing: SEVIRI, FCI, ASCAT, Radar, IASI/CrIS

  To do: MTG-IRS, GNSS, AMV.

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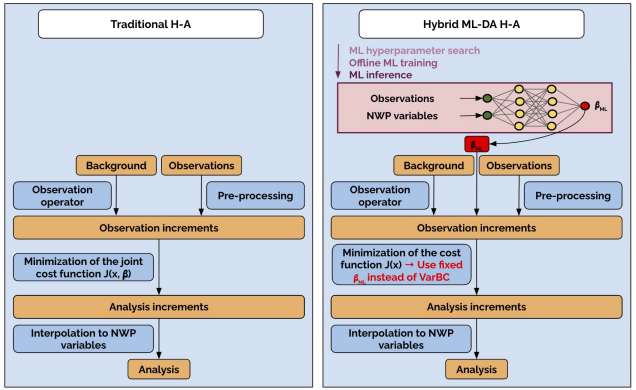
- **ML bias correction within variational DA (completed)**

  Objectives:

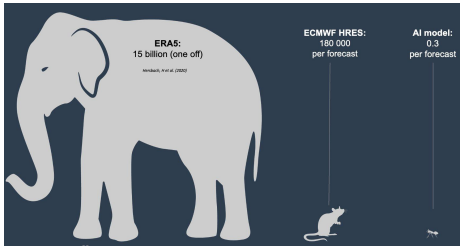
  - Shorten spin up phases in LAMs
  - Transfer knowledge from one domain to another



- **Prototype for the emulation/replacement of the full DA scheme (starting)**

  Objectives:

  - Use all observations, alleviate thinning
  - Assimilation of challenging observations
  - High temporal and spatial resolution
  - Fast computation of x_a for (re)analysis datasets



Wrap up and priorities

Continue collaborating to improve data assimilation in the HARMONIE-AROME reference system, in order to better serve operations and users.

Priorities:

- Local installation of **OOPS** based on CY49
- Surface data assimilation.
- Revisit the B-matrix formulation.
- Take full advantage of 4D-Var:
  - Use cloud and precipitation contaminated observations (satellite).
  - MTG-IRS and frequent observations

Integrate ML into DA s:

- Solve problems that we were never able to solve.
- Outperform “conventional” DA
- Contribute to the advance of data driven weather-models

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Thanks for your attention

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Backup slides

The United Weather Centres

United Weather Centres

- **Brings together NMSs of 11 countries** to collaborate in providing the **best possible regional short-range NWP forecasts**.
- **Participants** are members or acceding **members of the ACCORD** Consortium focusing on research in NWP.
- **ACCORD** develops a non-hydrostatic convection-permitting model based predicting system. **HARMONIE-AROME,** which is **one of Canonical System Configurations (CSC)** of the ACCORD,
- **Developed and used in the HIRLAM/UWC** projects and will continue to be developed and used in **UWC**.
- UWC encompasses **3 Groupings** that are running **HARMONIE-AROME operationally:** MetCoOp, UWC West and the operational system for a Southern European domain maintained by AEMET.
- **UWC builds upon** the three values: **Collaboration**, **Innovation** and **Partnerships**.

Icelandic Met Office

MET éireann

Lietuvos hidrometeorologijos tarnyba

aemet Agencia Estatal de Meteorología

LATVIJAS VIDES, ĢEOLOĢIJAS UN METEOROLOĢIJAS CENTRS

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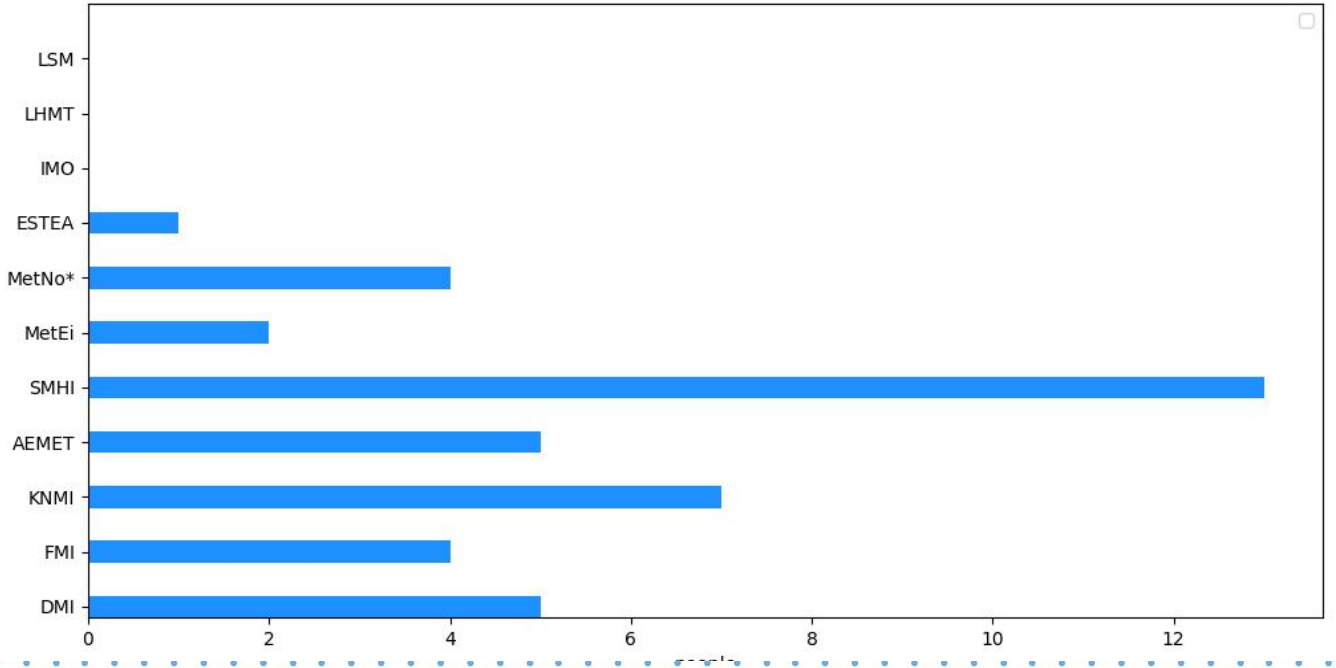
HIRLAM

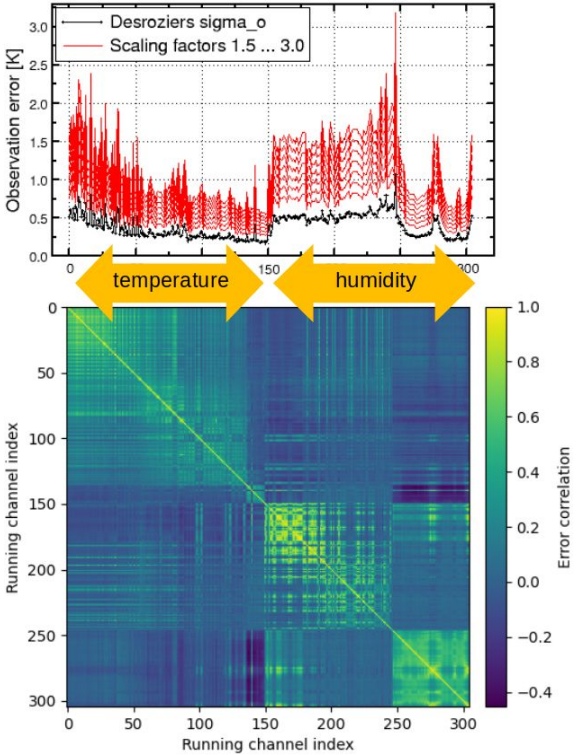
Data Assimilation, Use of Observations & Surface Data Assimilation - UWC

41 (or 39*) = 39(or 37*) (DA&UO) + 2 (SU) scientists and developers



Understanding IASI and CrIS spectral error correlations - Reima Eresmaa (reima.eresmaa@fmi.fi)

- The operational setups assimilate 40–60 channels with an “ad hoc” observation error covariance specification
- We aim to provide more realistic error covariance matrices to enhance the impact. The approach follows the method of Bormann et al. (2016): doi.org/10.1002/qj.2774.
- We have used the Desroziers method to diagnose the spectrally-correlated errors in subsets of 305 (IASI) and 215 (CrIS) channels
- We are running experiments to find the optimal empirical scaling factors that maximize the impact of data
- However: we still limit the active assimilation to 144 (IASI) and 87 (CrIS) channels



RADAR work in UWC

Martin Ridal, Jana Sánchez, Mats Dahlbom, Günther Haase

United Weather Centres

- NIMBUS radar data have been evaluated in HARMONIE-AROME for UWC three domains.
- Still some NIMBUS data cannot be processed by HARMONIE-AROME
  - Missing metadata
  - Missing fields
- Encourage OPERA members to provide missing quantities and metadata

Future work in UWC:

- Build in checks in prepopera.py to handle all varieties of files from NIMBUS
- **MetCoOp:** Continue testing additional radar data from NIMBUS in the Southern part of the domain.
- **UWC-W**: Solve the issues with single radars and put radar assimilation back to active in operational runs
- **AEMET**: Currently using BALTRAD operationally but NIMBUS 15 min data is prepared to be switched on in the next operational cy46 cycle

- **MetCoOp:**

Assimilation of AWS in AROME-Arctic - Stephanie, Per and Mate

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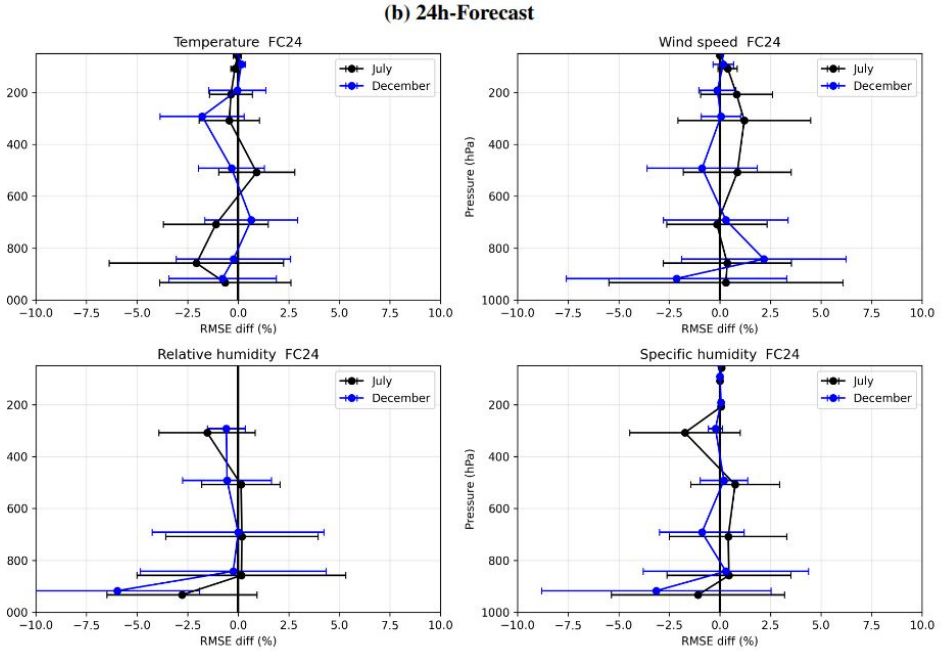
Norwegian Meteorological Institute

- Assimilation test of T an Q AWS channels were run on 2 seasons: July and December 2025

- Overall neutral to positive impacts :
  - Improvement of the fit to other obs (up to 0.6% for MW and 3% for IR)
  - Significant improvements of the humidity between 900 and 700 hPa and close to the surface (about 1% to surface and 3 to 6% to radiosondes observations).

- AROME-Arctic has been monitoring AWS in a preoperational run since 26th November 2025. No clear plans on the operational implementation (low priority apparently…)

  => Paper in preparation (to be submitted)



Example of campaign measurements from National Research Project
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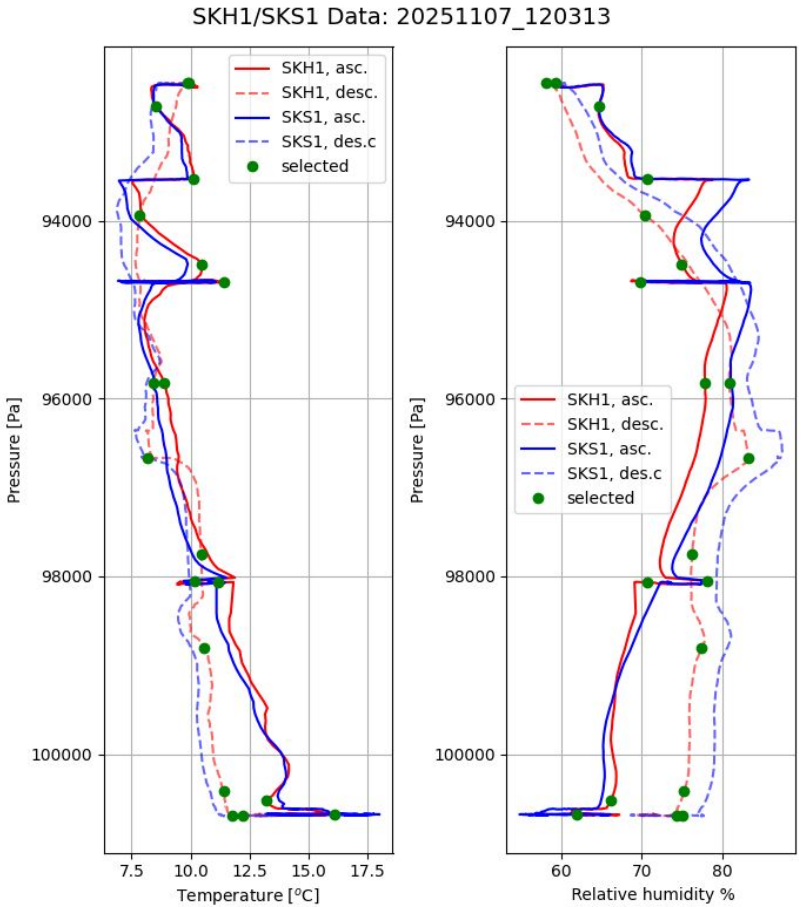
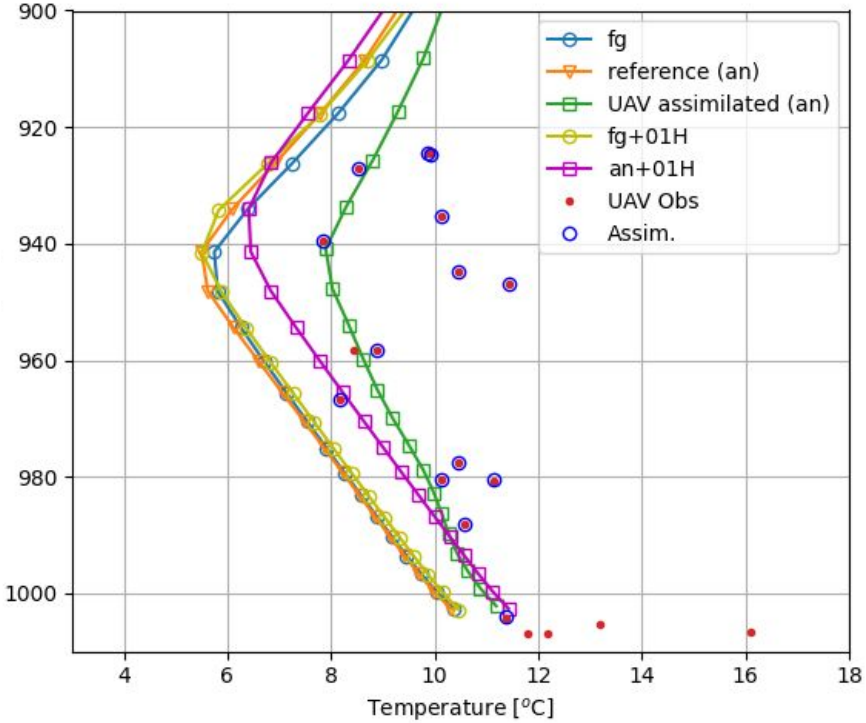


Temperature



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Upper Air: ref vs seviri
RMSE diff = ref - seviri
2026022000 - 2026030800
00, 12 UTC