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Merged Observatory Data File (MODF) of Sodankylä Supersite: How to Deal with a Complex, Heterogeneous Environment

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**ECMWF 2nd Observational campaigns workshop,
Reading 01.07.2026**



Genesis of MODFs during YOPP

YOPP Special Observing Period (SOP):

- NH-SOP1: Northern Hemisphere, February–March 2018.
- NH-SOP2: July–September 2018
- SH-SOP: Southern Hemisphere, November–February 2018/2019

Production of Merged Observatory Data Files (MODF):

- Whitehorse: <https://doi.org/10.21343/a33e-j150>, Huang et al., 2023a;
- Iqaluit: <https://doi.org/10.21343/yrnf-ck57>, Huang et al., 2023b;
- Sodankylä: <https://doi.org/10.21343/m16p-pq17>, O'Connor, 2023;
- Utqiaġvik (Barrow): <https://doi.org/10.21343/a2dx-nq55>, Akish and Morris, 2023c;
- Tiksi: <https://doi.org/10.21343/5bwn-w881>, Akish and Morris, 2023b;
- Ny-Ålesund: <https://doi.org/10.21343/y89m-6393>, Holt, 2023; and
- Eureka: <https://doi.org/10.21343/r85j-tc61>, Akish and Morris, 2023a).



Mariani et al. (2024)

MODFs are available on the YOPP Data Portal <https://yopp.met.no>
<https://thredds.met.no/thredds/arcticdata/yoppsitemip.html>

Papers:

- Mariani et al.: Special Observing Period (SOP) data for the Year of Polar Prediction site Model Intercomparison Project (YOPPsitemIP), *Earth Syst. Sci. Data*, 16, 3083–3124, <https://doi.org/10.5194/essd-16-3083-2024>, 2024.
- Uttal, et al.: Merged Observatory Data Files (MODFs): an integrated observational data product supporting process-oriented investigations and diagnostics, *Geosci. Model Dev.*, 17, 5225–5247, <https://doi.org/10.5194/gmd-17-5225-2024>, 2024.

Earth Syst. Sci. Data, 16, 3083–3124, 2024
<https://doi.org/10.5194/essd-16-3083-2024>
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Earth System
Science
Data

Special Observing Period (SOP) data for the Year of Polar Prediction site Model Intercomparison Project (YOPPsitemIP)

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Geosci. Model Dev., 17, 5225–5247, 2024

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Geoscientific
Model Development

EGU

Methods for assessment of models

Merged Observatory Data Files (MODFs): an integrated observational data product supporting process-oriented investigations and diagnostics

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Abstract. A large and ever-growing body of geophysical information is measured in campaigns and at specialized observatories as a part of scientific, expedition and experiments. These collections of observed data include many essential climate variables (as defined by the Global Climate Observing System) but are often distinguished by a wide range of additional non-climate measurements that are designed to not only document the state of the environment but also the drivers that contribute to that state. These field data are used not only to further understand environmental processes through observation-based studies but also to provide baseline data to test model performance and to codify understanding to improve predictive capabilities. To address the considerable barrier and difficulty in utilizing these diverse and complex data for observation-model research, the Merged Observatory Data File (MODF) concept has been developed. A MODF combines measurements from multiple instruments into a single file that complies with well-established data format and metadata practices and has been designed to parallel the development of corresponding Merged Model Data Files (MMDFs). Using the MODF and MMDF protocols will facilitate the evolution of model intercomparison projects into model intercomparison and improvement projects by pairing observation and model data. “on the same page” in a timely manner. The MODF concept was developed especially for weather forecast model studies in the Arctic.

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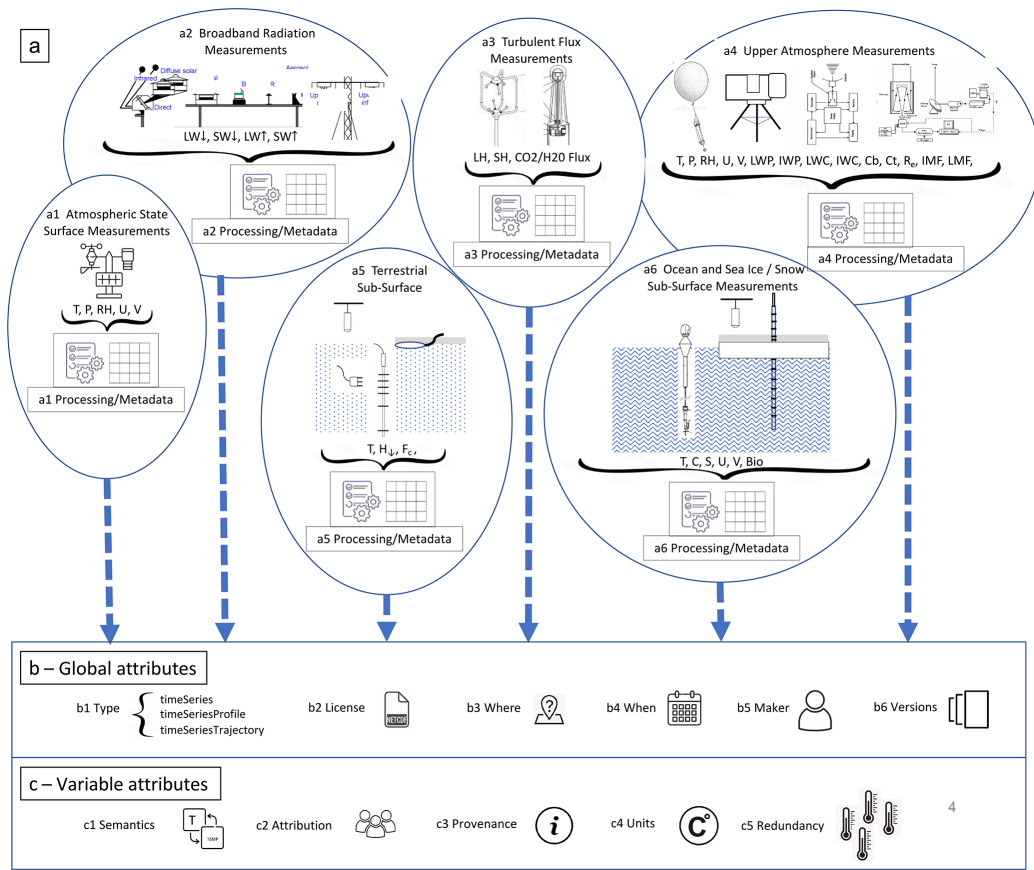
MODFs are NetCDF files

MODFs include instruments, measurements, data processing, and metadata for:

- (a1) the atmospheric state at the surface,
- (a2) broadband radiation at the surface,
- (a3) surface turbulent fluxes,
- (a4) upper-atmospheric profiles,
- (a5) the terrestrial subsurface, and
- (a6) ocean and sea-ice/snow.

This information is collected into netCDF files with specified (b) global attributes and (c) variable attributes that are compliant with FAIR principles.

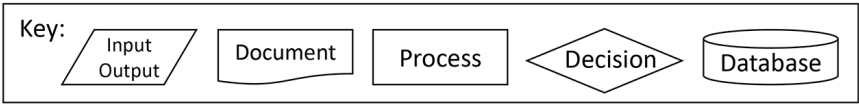
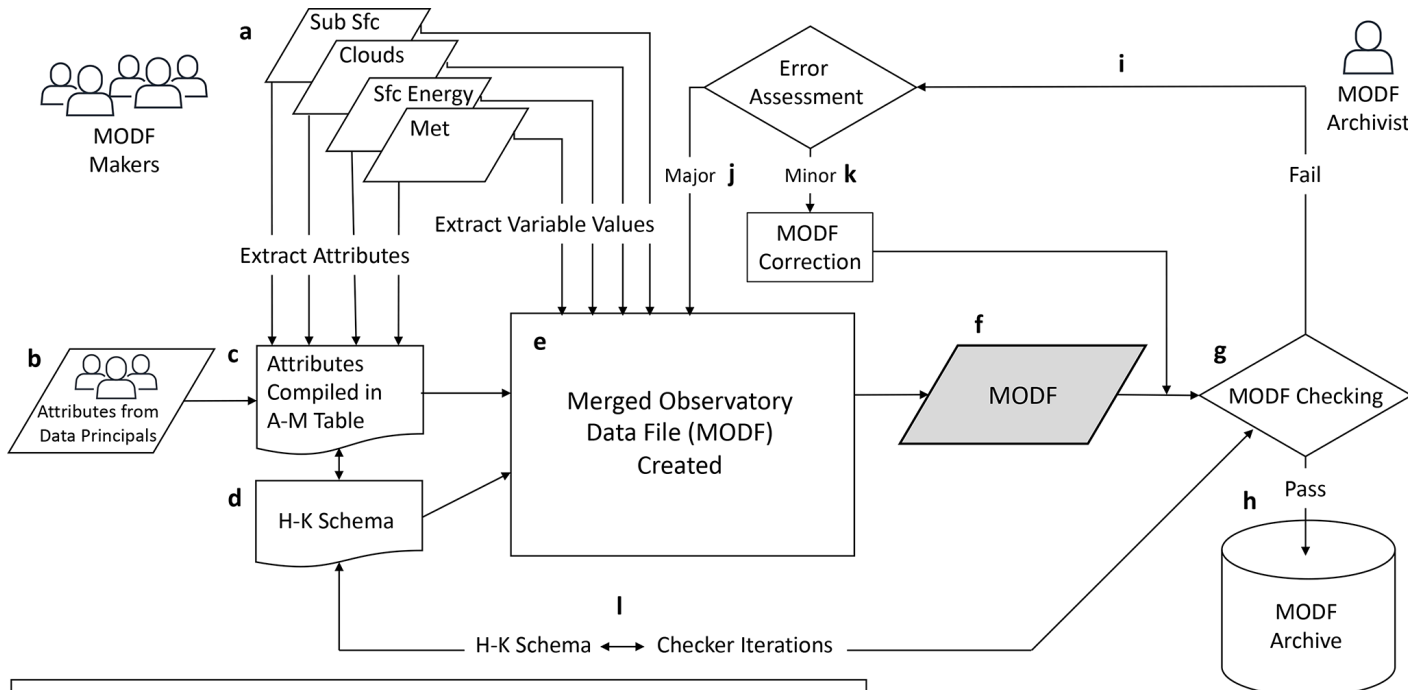
(Uttal et al., 2024)



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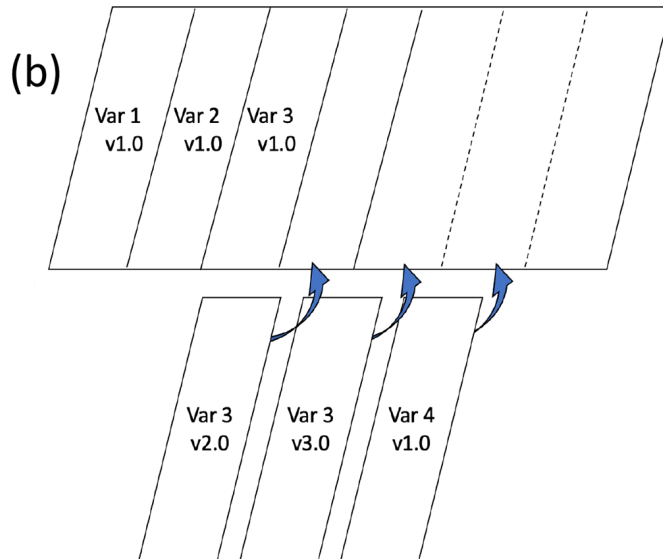
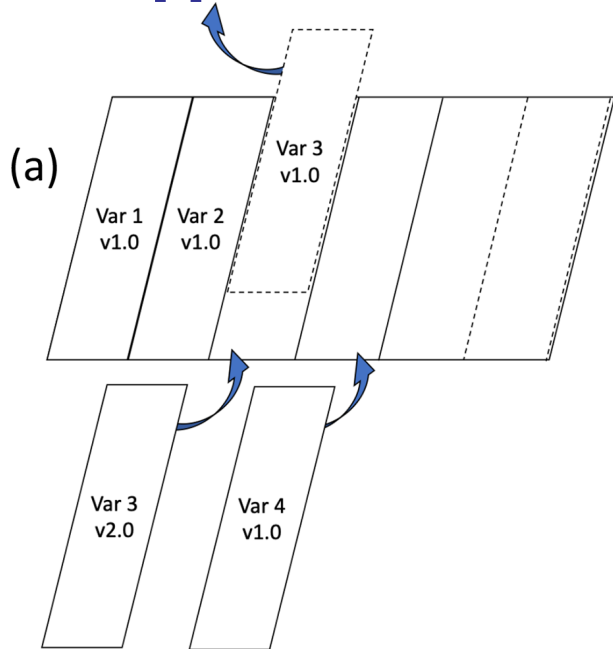
The MODF workflow process

(Uttal et al., 2024)



A-M Table: <https://doi.org/10.5281/zenodo.6780400>
H-K SchemaTable: <https://doi.org/10.5281/zenodo.6255666>
YOPPsiteMIP Archive:
https://thredds.met.no/thredds/catalog/alertness/YOPP_supersite/catalog.html

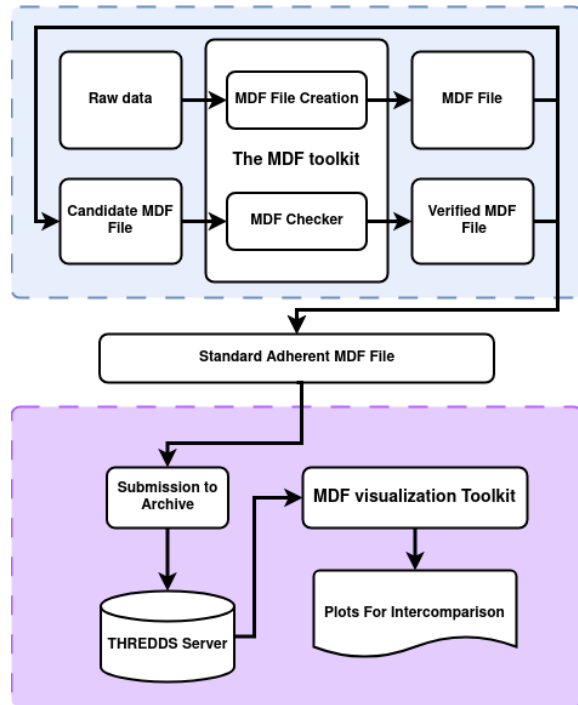
Two approaches for MODF augmentation:



Development and current status of the MDF toolbox

- Toolkits for creating, checking and visualising MDF files are available on Git¹
- The MDF creator tool works best for observational data and is being updated to accommodate model data
- Packaging is being updated
- Code for processing Sonde data and Trajectories has been developed and is being integrated
- **Goal: plug and play python package for easy MDF creation and usage**

Created by Johanna Tjernström (johanna.a.k.tjernstrom@gmail.com) for the **Svalbard Marginal Ice Zone Campaign 2025** (<https://openmetbuoy-arctic.com/svalmiz2025.html>).



Sodankylä Merged Observatory Data Files (MODFs)

- Inclusion of data from all measurement stations during the entire 2018, not just for the spring and summer Special Observing Periods (SOPs): <https://thredds.met.no/thredds/arcticdata/yoppsitemip.html>
 - MODF for single level variables and vertical profiles (towers, near-surface arrays of sensors)
 - MODF for radio soundings
- Sodankylä yearly MODFs (from 2018 until 2025) have been produced this year. They will be made available in METIS - FMI's Research Data repository (<https://fmi.b2share.csc.fi/>)



Catalog <https://thredds.met.no/thredds/catalog/YOPPSiteMIP-observations/sodankyla/catalog.html>

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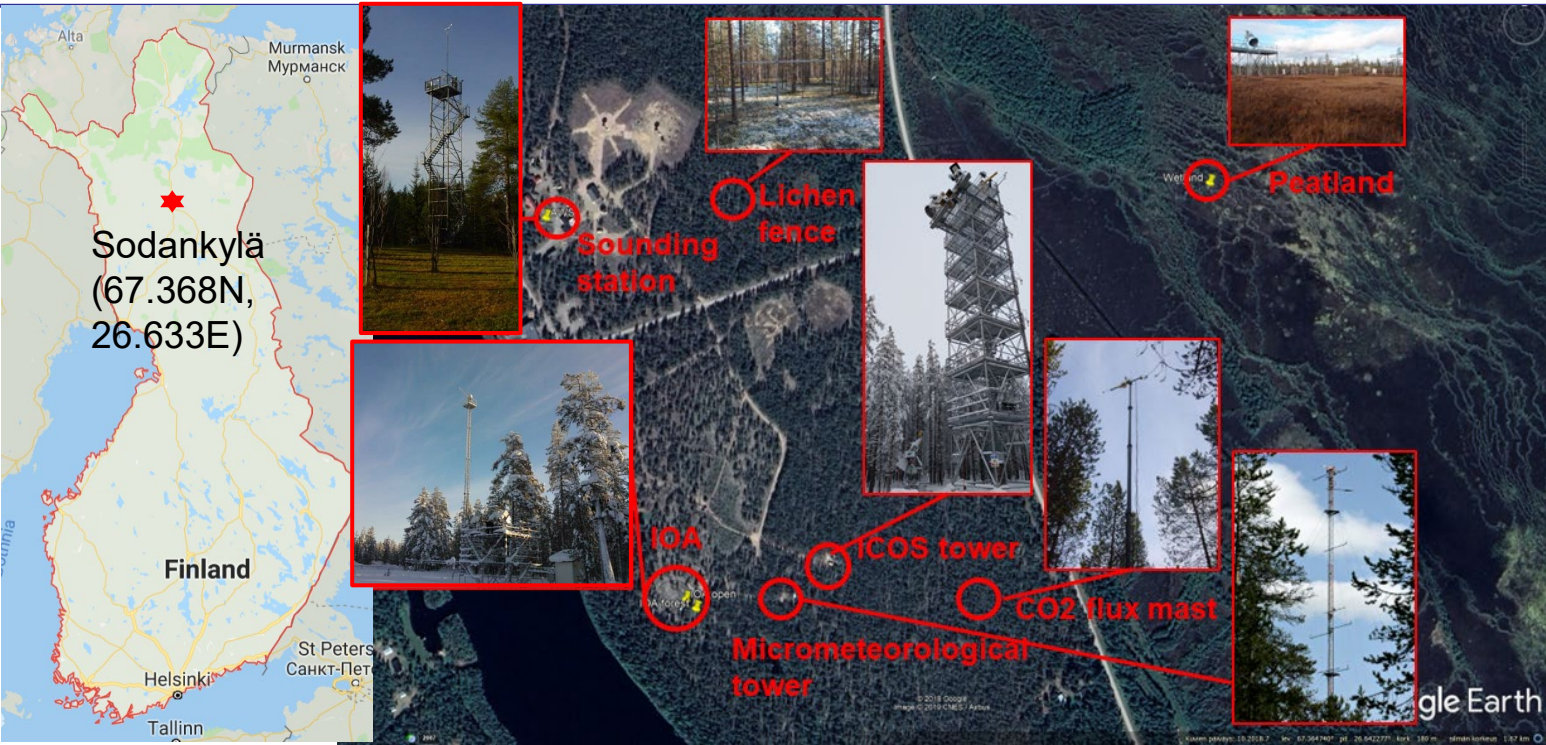
Observations for YOPP SiteMIP

This folder contains in situ observations from YOPP supersites intended for intercomparison with YOPP SiteMIP model output. This dataset is still under development and will be further updated. These data will also be discoverable in the YOPP Data Portal at <https://yopp.met.no/>. Please beware that discovery metadata in the data portal will be updated as datasets are updated. So please do not use these data for publications as of today.

Dataset

Dataset	Size	Last Modified
 sodankyla		--
sodankyla_obs_timeSeries_20180701_20180930.nc	7.499 Mbytes	2023-03-21T06:54:10Z
sodankyla_obs_timeSeries_20180201_20180331.nc	4.817 Mbytes	2023-03-21T06:53:56Z
sodankyla_obs_timeSeriesProfile_20180701_20180930.nc	21.26 Mbytes	2023-03-13T16:33:52Z
sodankyla_obs_timeSeriesProfile_20180201_20180331.nc	13.63 Mbytes	2023-03-13T16:33:51Z

Sodankylä supersite: cluster of measurement sites



Sodankylä
(67.368N,
26.633E)

Sounding station

Lichen fence

Wind Peatland

IOA

ICOS tower

CO2 flux mast

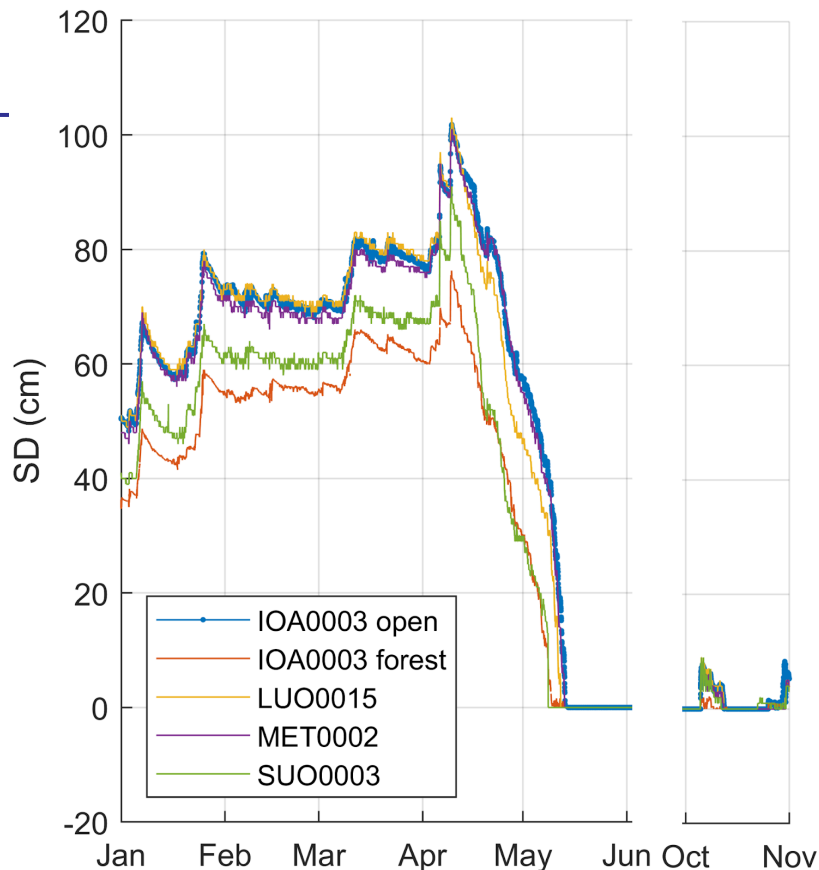
Micrometeorological tower

Google Earth

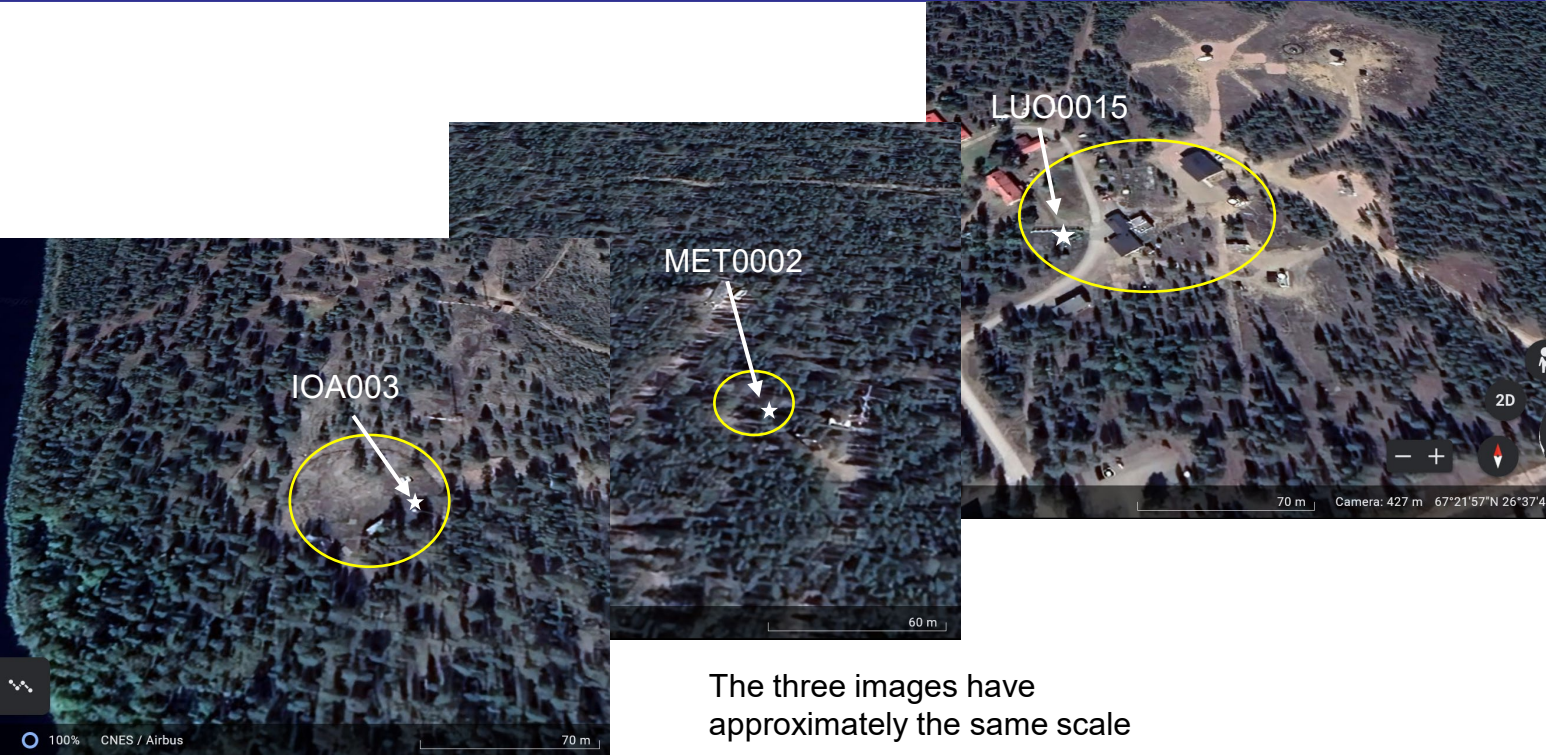
Käytetty paikoin: 10.2018.7 lev: 67.364740° pit: 26.642277° kor: 180 m sivän korkeus: 1.57 km

Spatial heterogeneity: Example from snow depth

- **Small open areas (~20-50m diameter) surrounded by forest (IOA003 open, LUO0015, MET0002):** snow is trapped there, snow depth is the largest and snow disappears last.
- **Thick forest (IOA003 forest):** snow depth is smallest because of interception by canopy.
- **Wetland (SUO003):** the open area is wide (~700 x 2500 m) hence there is not the snow trapping effect seen in the small open areas. Moreover, near-surface wind speed is larger than in small openings, causing drifting snow and enhanced snow sublimation. As a result, on wetland snow depth is smaller than in small open areas.



Instrumented small open areas:



The three images have approximately the same scale

Application 1:

Day et al., 2024. doi: 10.5194/gmd-17-5511-2024

- Assessment of the surface energy budget:
 - Models tend to underestimate the sensitivity of T2m and the surface skin temperature (or LW) to variations in radiative forcing and do not capture extreme minima in these variables.
 - For coarse-resolution models, we recommend providing variables for the different sub-tile components (bare soil, vegetation, water, ice). The more the site characteristics are matched to the correct model output, the more reliable diagnosis on the model capability to reproduce the observed physical process.



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Model evaluation paper

The Year of Polar Prediction site Model Intercomparison Project (YOPPsiteMIP) phase 1: project overview and Arctic winter forecast evaluation

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Abstract. Although the quality of weather forecasts in the polar regions is improving, forecast skill there still lags behind lower latitudes. So far there have been relatively few efforts to evaluate processes in numerical weather prediction systems using in situ and remote sensing datasets from meteorological observatories in the terrestrial Arctic and Antarctic compared to the mid-latitudes. Progress has been limited both by the heterogeneous nature of observatory and forecast data and by limited availability of the parameters needed to perform process-oriented evaluation in multi-model forecast archives. The Year of Polar Prediction (YOPP) site Model Inter-comparison Project (YOPPsiteMIP) is addressing this gap by producing merged observatory data files (MODFs) and merged model data files (MMDFs), bringing together observations and forecast data at polar meteorological ob-

servatories in a format designed to facilitate process-oriented evaluation.

An evaluation of forecast performance was performed at seven Arctic sites, focussing on the first YOPP Special Observing Period in the Northern Hemisphere (NH-SOP1) in February and March 2018. It demonstrated that although the characteristics of forecast skill vary between the different sites and systems, an underestimation in boundary layer temperature variability across models, which goes hand in hand with an inability to capture cold extremes, is a common issue at several sites. It is found that many models tend to underestimate the sensitivity of the 2 m air temperature (T2m) and the surface skin temperature to variations in radiative forcing, and the reasons for this are discussed.

Published by Copernicus Publications on behalf of the European Geosciences Union.

Application 2:

Remes et al., 2025. <https://doi.org/10.1002/qj.4941>

- Assessment of the spatial variability of near-surface air temperature at scales of tens of kilometres in the European Arctic
 - In Sodankylä, high variability is found under cold and stable conditions, with variability peaking above the surface due to spatial differences in temperature inversion development.
 - Considerable subgrid variability observed in Sodankylä accounts for a substantial portion of the difference between the model grid box value and observed point value.



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RESEARCH ARTICLE

Quarterly Journal of the
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Spatial variability of near-surface air temperature in the Copernicus Arctic regional reanalysis

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Abstract

This study investigates spatial variability of near-surface air temperature at scales of tens of kilometres in the European Arctic, using the Copernicus Arctic Regional Reanalysis (CARRA) data from 1991 to 2022. It examines factors influencing this variability, compares model-derived variability with observed subgrid variability, and evaluates its impact on model verification. Key findings reveal that spatial variability is strongly influenced by geographical features and seasonal changes. The highest seasonal spatial variability is found during winter, particularly near coasts, mountainous regions, and sea ice edges where persistent temperature gradients drive baseline variability. In contrast, in inland Scandinavia, where climatic temperature gradients are less pronounced, situation-dependent variability predominates. The study highlights these distinct patterns of variability in Ny-Ålesund, Svalbard, and Sodankylä, Finland. In Sodankylä, high variability is found under cold and stable conditions, with variability peaking above the surface due to spatial differences in temperature inversion development. The observed spatial variability largely aligns with the modeled CARRA data, particularly in terms of the relationship between baseline and situation-dependent variability. Furthermore, considerable subgrid variability observed in Sodankylä accounts for a substantial portion of the difference between the model grid box value and observed point value. These findings emphasize the importance of considering spatial variability in weather forecasting, model verification, model intercomparisons, and process studies.

KEYWORDS

Arctic, observations, reanalysis, spatial variability, temperature, verification

1 | INTRODUCTION

The Arctic climate is in rapid transition (Hanssen-Bauer et al., 2019; Isaksen et al., 2022), which poses major challenges for the environment and society. Observational

records and future climate projections indicate a further increase in temperature, including more frequent extreme weather events (Hanssen-Bauer et al., 2019; Müller et al., 2022). While our knowledge of mean climate change is reasonably well established, the understanding of the

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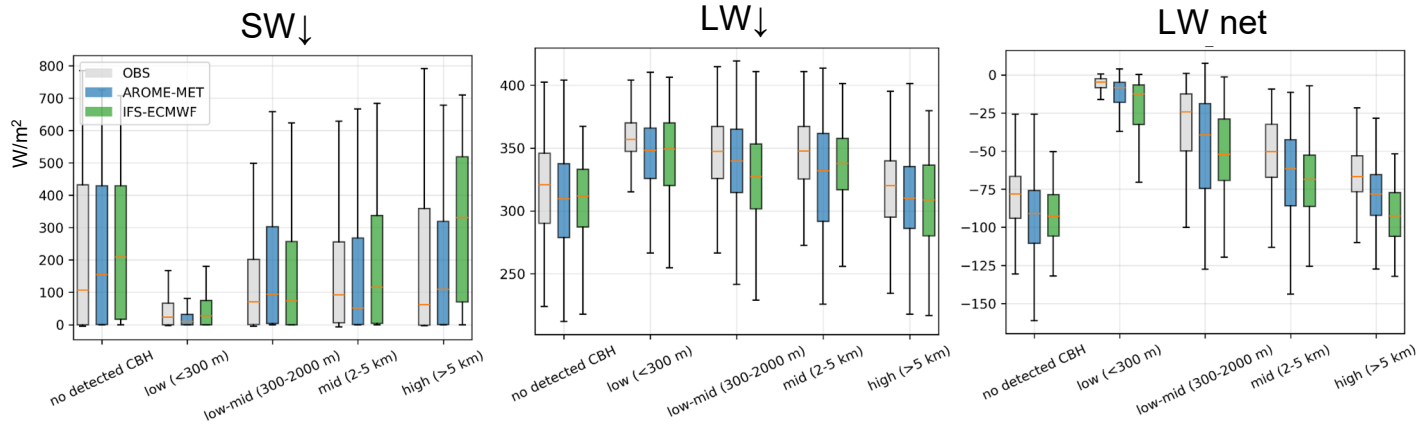
onlinelibrary.wiley.com/journal/10.1002/qj

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Application 3:

Remes et al., cloud-base-dependent radiation at Sodankylä

Sodankylä MODF observations and MMDF 2nd-day forecasts (AROME-Arctic, IFS-ECMWF) grouped by cloud-base height (CBH)



- CBH categories clearly separate the summer surface radiation regime
- Very low clouds (<300 m) decrease SW_{\downarrow} and increase LW_{\downarrow}
- Low clouds weaken longwave cooling, but net LW remains negative; models reproduce the broad behaviour despite biases

Take home messages

- MODFs and MMDFs facilitate process-oriented model evaluation
- MODFs can be created for supersite or field campaigns, enabling the access to observations to a wider community
- MODFs can integrate complex and comprehensive datasets and retain all metadata needed to interpret them. They include time series of different data types such as single-height variables and vertical profiles (towers, sub-surface or near-surface vertical arrays of sensors, radio soundings)
- Comparison of Sodankylä supersite observations with model outputs is not trivial: extreme attention should be paid to the spatial heterogeneity of the considered variables.





Thank you for your attention!



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