Surface analysis at DWD: Status and plans

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Outline

- Short review surface analysis at DWD
- New development of 2D-Var for T2m, Snow, and SST
- Use of external NOAA snow depth analysis in data sparse regions.
- Issue with zero snow depth reports instead of missing over NE-China
- Summary

DWD snow depth analysis

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General Problem in DA: Minimization of cost functional

$$J = (X - X^B) B^{-1} (X - X^B) + (Y^{obs} - HX)^T O^{-1} (Y^{obs} - HX)$$

Background (Obs – Model fc)

$$\nabla J = 0$$

Analysis update equation (model space)

$$X^A = X^B + K(Y^{obs} - HX^B) \qquad K = \frac{BH^T}{HBH^T + O}$$

Analysis, Background, Gain (weight), Obs.-Increments

Cressman with Successive Correction

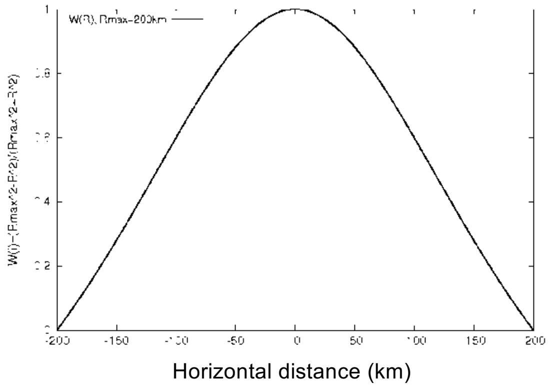
$$f_i^A = f_i^B + \sum_k w_k h_k D_k \qquad f_i^B = f_{i-1}^A$$

$$D_k = f_k^O - f_k^B$$

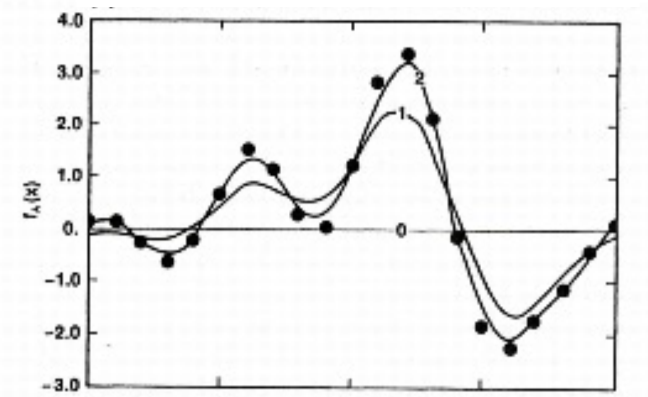
$$w_k = \max\left(0, \frac{(R_{\max}^2 - R_k^2)}{(R_{\max}^2 + R_k^2)}\right)$$

$$h_k = \max\left(0, \frac{(Z_{\max}^2 - Z_k^2)}{(Z_{\max}^2 + Z_k^2)}\right)$$

Weight function in successive correction method



2nd Iteration improves Analysis



2d var (z,t) soil moisture analysis

Cost function penalizes deviations from observations and initial soil moisture content

$$J = (w - w_b)^T B^{-1} (w - w_b) + (T_{2m} - T_{2m}{}^{obs})^T O^{-1} (T_{2m} - T_{2m}{}^{obs})$$

$$\nabla J = 0$$

Analysed soil moisture depends on T2m forecast error and sensitivity ∂T2m/∂w

$$w_{ana} = w_b + (\Gamma_{T2m}{}^T O^{-1} \Gamma_{T2m} + B^{-1})^{-1} \Gamma_{T2m}{}^T O^{-1} \underbrace{(T_{2m}{}^{obs} - T_{2m}(w_b))}_{T2m\ fc\ error}$$

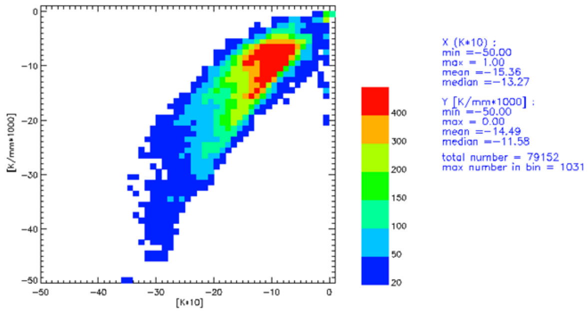
$$\Gamma_{T2m} = \frac{\partial T_{2m}(12:00, 15:00)}{\partial w(0:00)}$$

Parameterisation for Sensitivity dT2m/dw

In previous SMA for regional model sensitivity was calculated by two extra model forecast runs
In ICON it is derived from Surface energy balance and Penman type equation

$$\frac{\partial T_{2m}}{\partial w_k} = \frac{\overline{r_a}}{\rho c_p} \left(\frac{\alpha}{1-\alpha} \right) \frac{Lhfl}{(r_a + r_f)} \frac{1}{f_{LAI}} (1 - \frac{r_s}{r_{s,\max}}) \frac{r_s}{w_{root} - w_{pwp}} \frac{dz_{k,root}}{z_{root}}$$

dT2m/dw
Param / explicit variation



No further need for additional model runs!

2d-Var for surface analysis

- Based on code base for atmospheric 3d-EnVar analysis DACE (Data Assimilation Coding Environment).
- Same data structures, parallelisation, observation processing
- New representation of operators as abstract interfaces for flexible implementation of different grids and methods

2d-Var for surface analysis

Minimisation of cost function

$$J(x) = (x - x^b)^T B^{-1} (x - x^b) + (y - Hx)^T R^{-1} (y - Hx)$$

$$\nabla J = 0$$

Solution for x in model space

$$x^a - x^b = BH^T (HBH^T + R)^{-1} (y - Hx^b)$$

Rearrange to solve minimisation efficient in observation space

$$\underbrace{(R + HBH^T)}_{A} \underbrace{(BH^T)^{-1}(x - x^b)}_{z} = \underbrace{y - Hx^b}_{b}$$

A is symmetric and positiv definit. Linear equation system can be solved iteratively by standard conjugate gradient method to find solution for z that minimizes J in observation space .

2d-Var for surface analysis

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Solution for state variable in model space obtained by post multiplication

$$x^a - x^b = BH_{spec}^T z$$

$$B = H_{clim}^T B_{clim} H_{clim} + H_{ens}^T B_{ens} H_{ens}$$

B lives in a common „interpolation space“ for B_{clim} and B_{ens}, e.g. on climatological or ensemble or any other appropriate grid.
H_{spec}, transforms B from interpolation to observation space.

No operation in full model resolution required. Only for calculation of observation equivalent $\mathrm{H}X_b$ model gridpoints around obs-locations are involved.

2d-Var for surface analysis

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Analysis increments in model space can be finally calculated directly by operation between z in observation space and B_{clim} and B_{ens} represented in model space. No transformation to interpolation space necessary.

$$x_a - x_b = \underbrace{(I_{clim} B_{clim} H_{clim}^T + I_{ens} B_{ens} H_{ens}^T) H_{spec}^T}_{BH^T \text{ (dim(obs) x dim(model))}} z$$

First implementation in 2D-Var Gauss type B matrix representation

$$b_{ij} = \sigma_b \, exp[-\frac{dist_h^2}{2\sigma_h^2}] \, exp[-\frac{dist_v^2}{2\sigma_v^2}]$$

Code implementation

All operators provided by abstract interfaces between different data types, defined procedures adressed via function pointers

➢ Allows flexible implementation of new methods and grids

Test version ready, runs on low resolution 80 km grid

Next steps (2 years)

- Code consolidation, single obs. Experiments, debugging, parameter tuning (localisation, error estimates)
- Monitoring against Routine analysis
- Testing in experiment, further development
- Replacement of present OI-T2m Analysis when scores are o.k.
- Development of 2d-Var for snow and SST analysis

Use of external NOAA snow depth analysis

Why using external NOAA snow depth analysis ?

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- Regions with sparse observations show pathologic pattern

➡

  - Effect from relativ simple combination of model first guess and distance weighted average of surrounding observations in Cressman analysis
  - Also observed less pronounced by CMC and weakly in ECMWF snow analysis.
  - Circular pattern in snow depth do generally not affect snow cover fraction (do not affect T_S and scores).
  - However unrealistic and ugly.

- Several national american observation networks do not report data to GTS

Use of external NOAA snow depth analysis

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- Possible solution: Blend analysis in data sparse regions
  - NOAA snow analyis contains the snow data from the national networks.

    ⇒

  - Good for the moment. 2d Var analysis should work better without external snow depth.
  - IMS snow mask is planned to be used as additional observation with proxy snow depth.

How is it done?

NOAA snow depth is used as additional obs with weight 1

First guess *Synop obs*

h_snow(ana) = w(fg) sh(fg) + sum[w(obs)*sh(obs)]

NOAA snow depth: limited increment added to fg

+ [sh(fg)+ (min(max(sh(noaa)-sh(fg), hmin), hmax) *w(noaa)]

w(noaa)=1 (no distance from analysed gpt)

- Scaling
  h_snow = h_snow / (wsnow(fg) + sum[wsnow(obs)] + wsnow(noaa))

Increased snow cover in western USA

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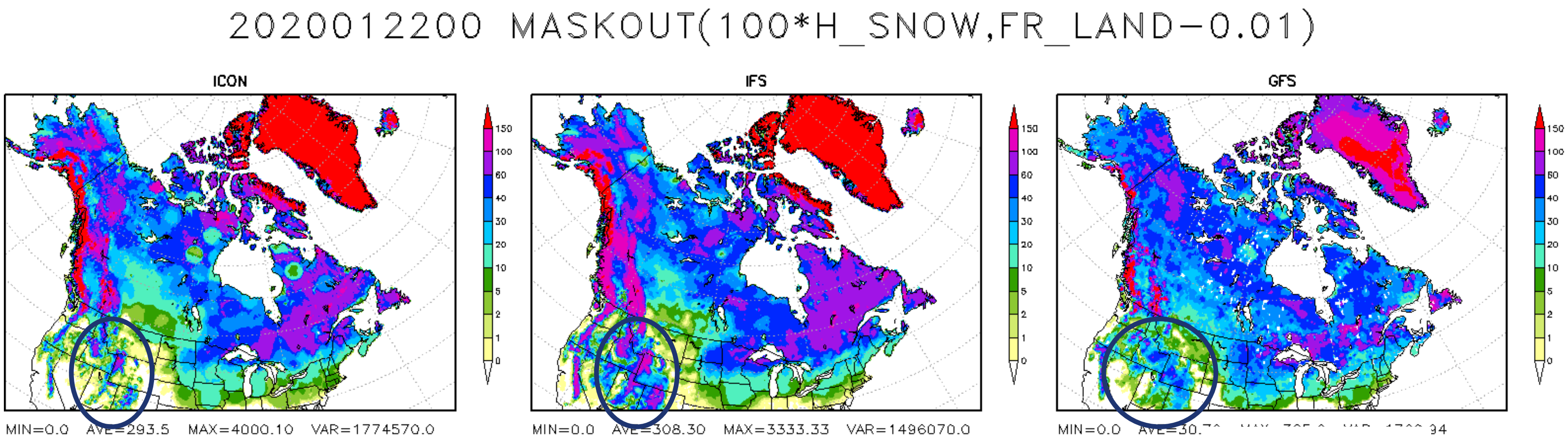

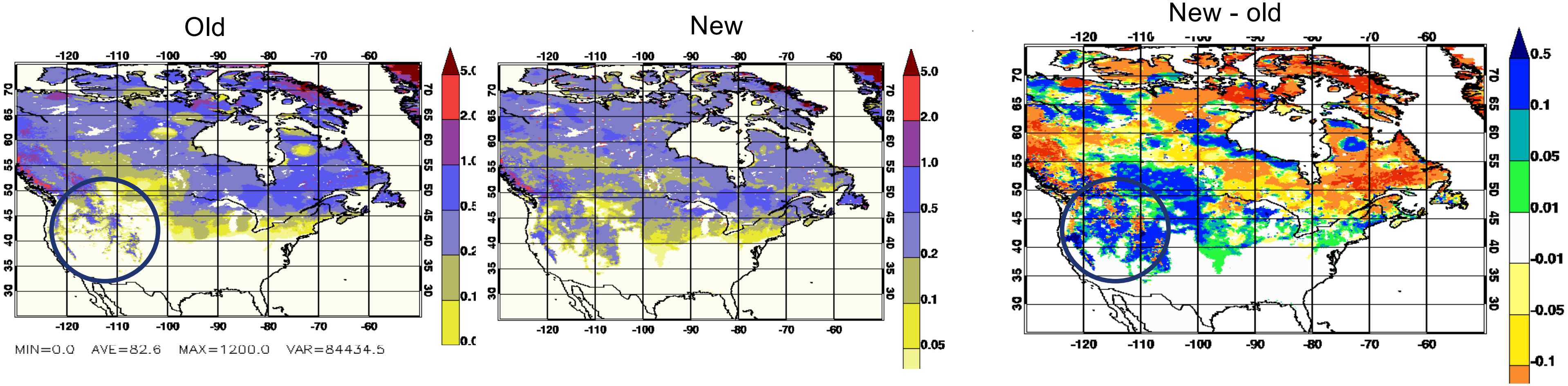

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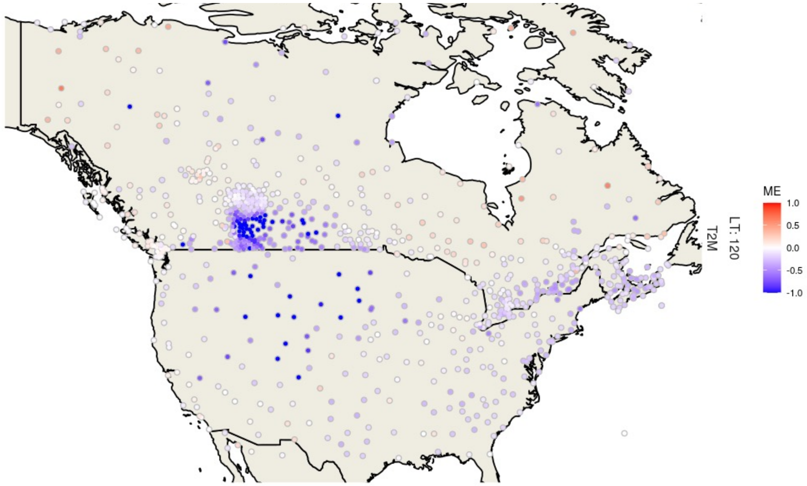
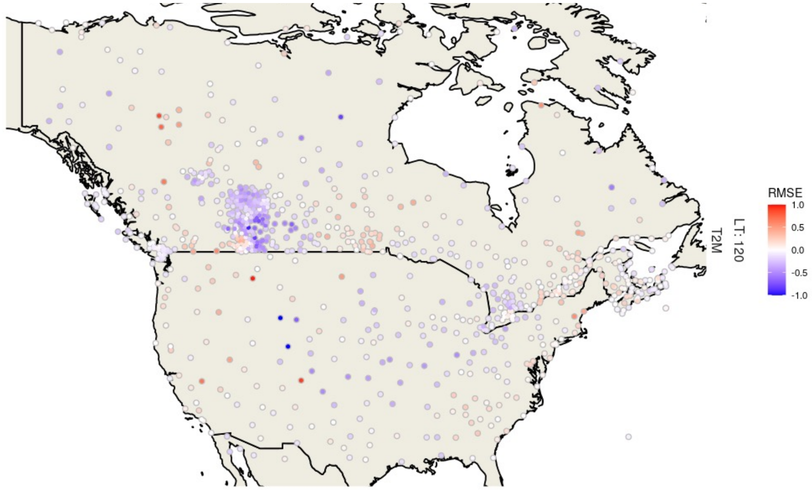
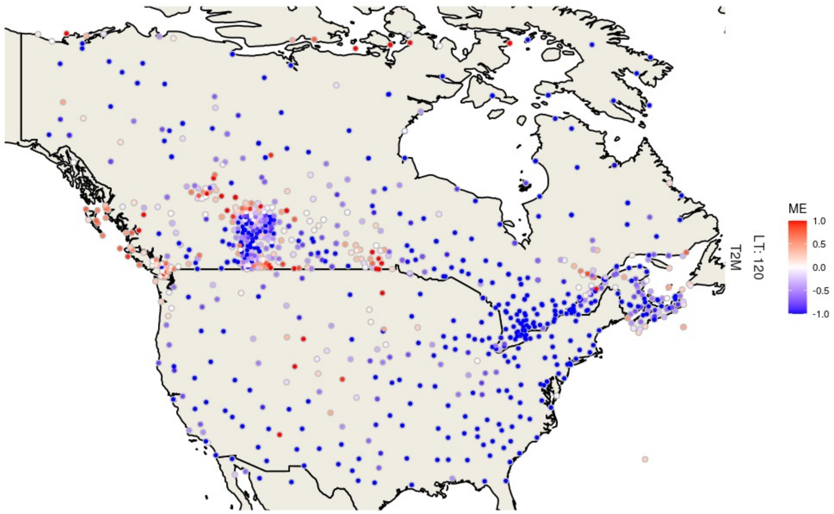
T2M ME reduction 11145-11142



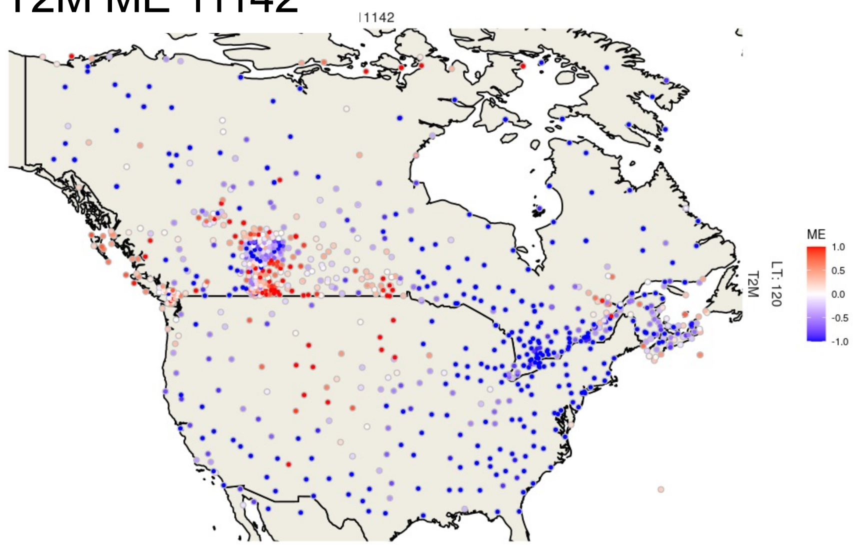
T2M RMSE reduction 11145-11142



T2M ME 11145



T2M ME 11142



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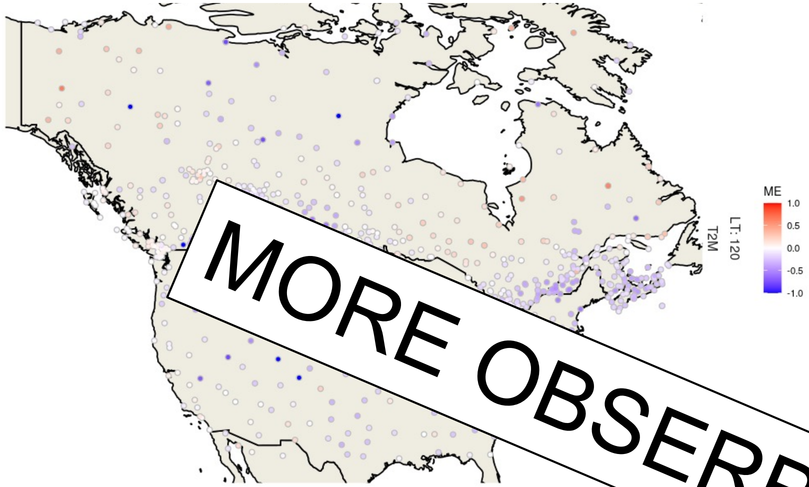
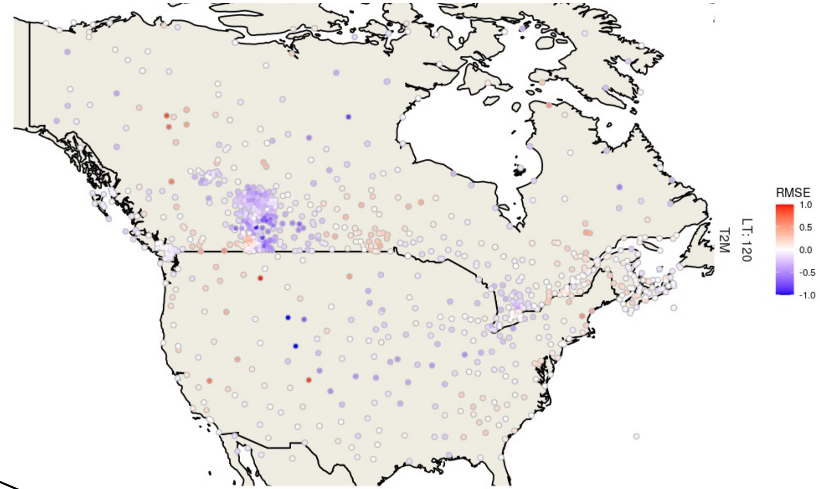
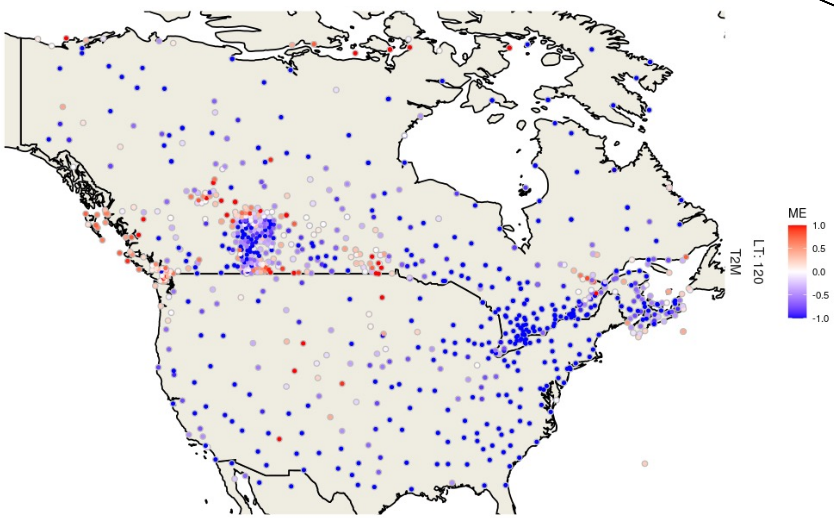
T2M ME reduction 11145-11142



T2M RMSE reduction 11145-11142



T2M ME 11145



T2M ME 11142

MORE OBSERBATIONS NEEDED

Missing snow cover over North Eastern China due to zero snow depth reports instead of missing value.

Missing Snow in NE-China

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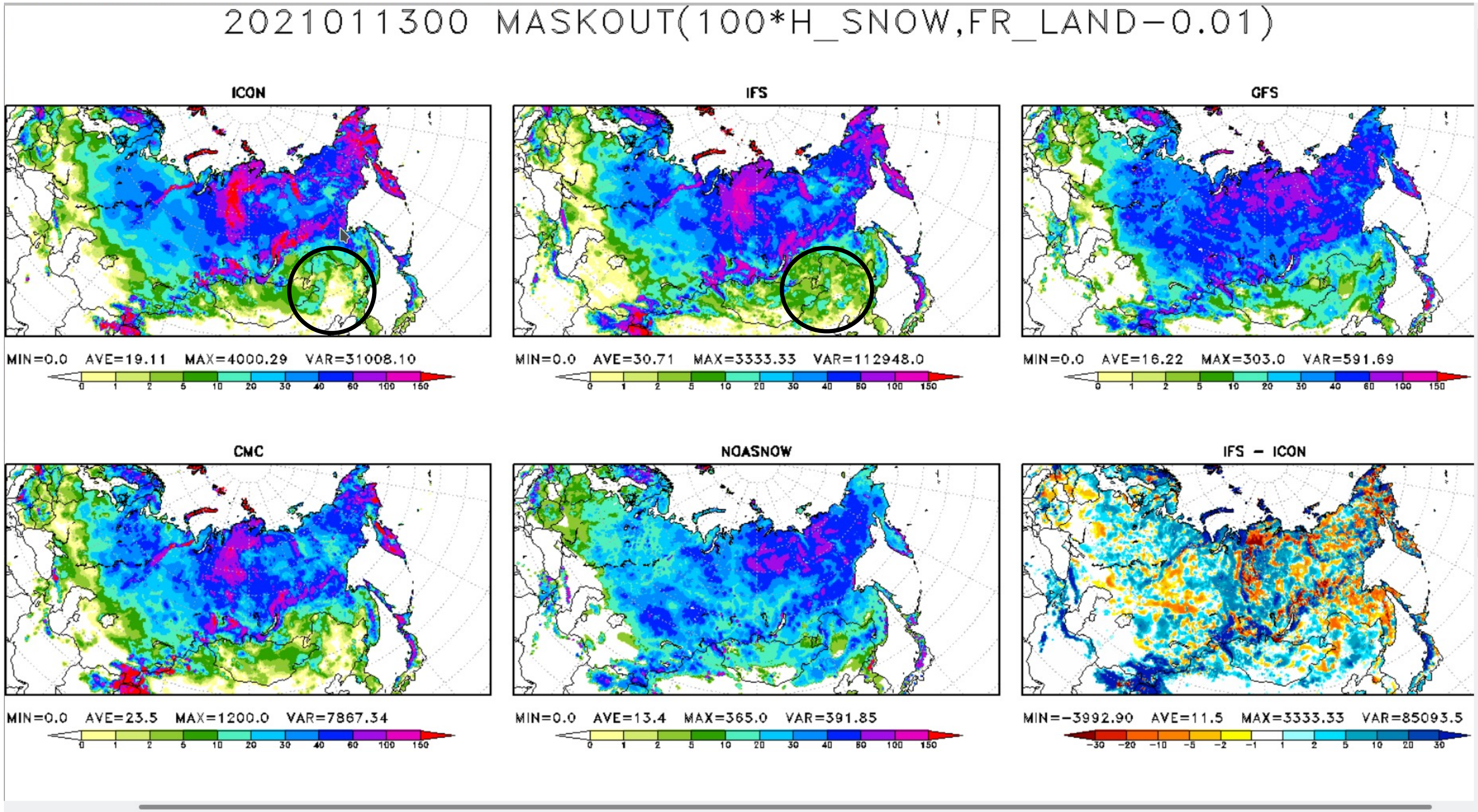

Zero snow depth in North Eastern China but Mongolei snow covered

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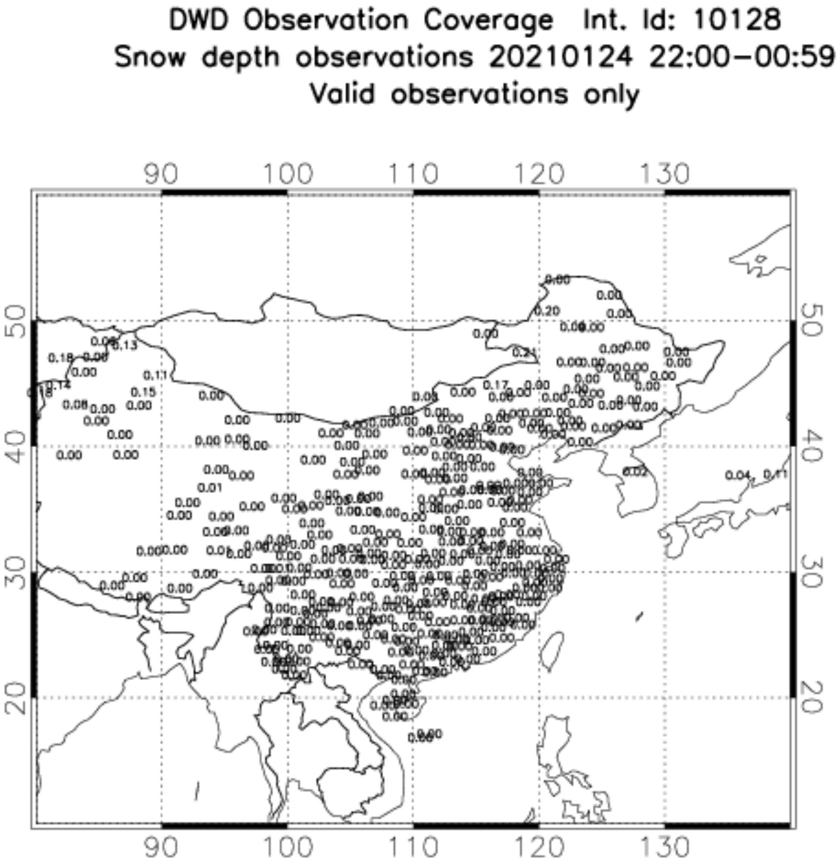
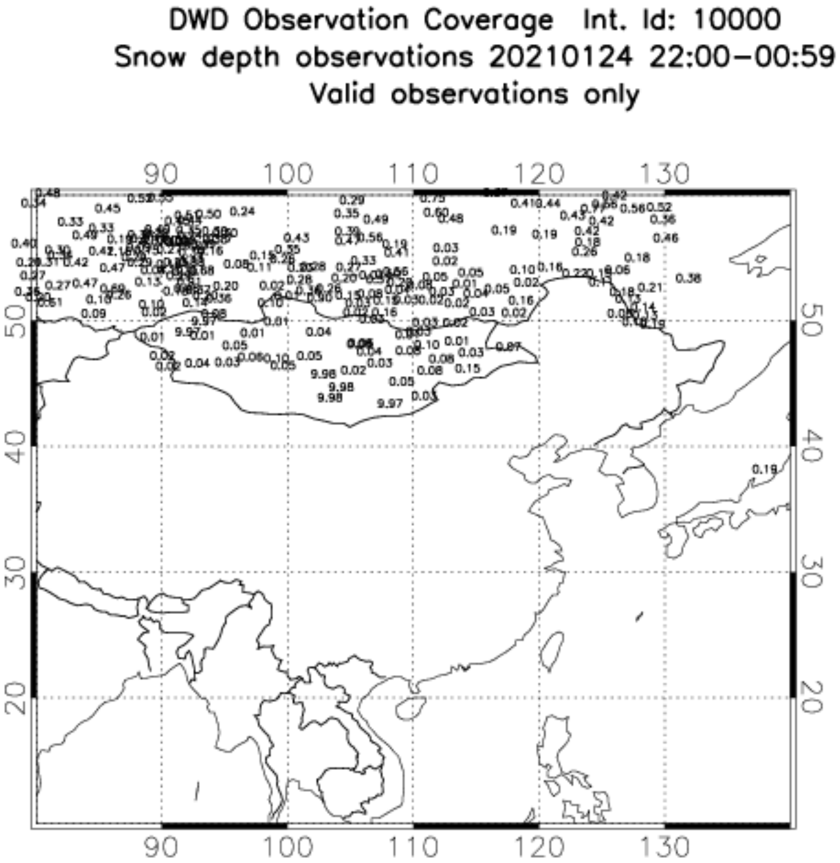
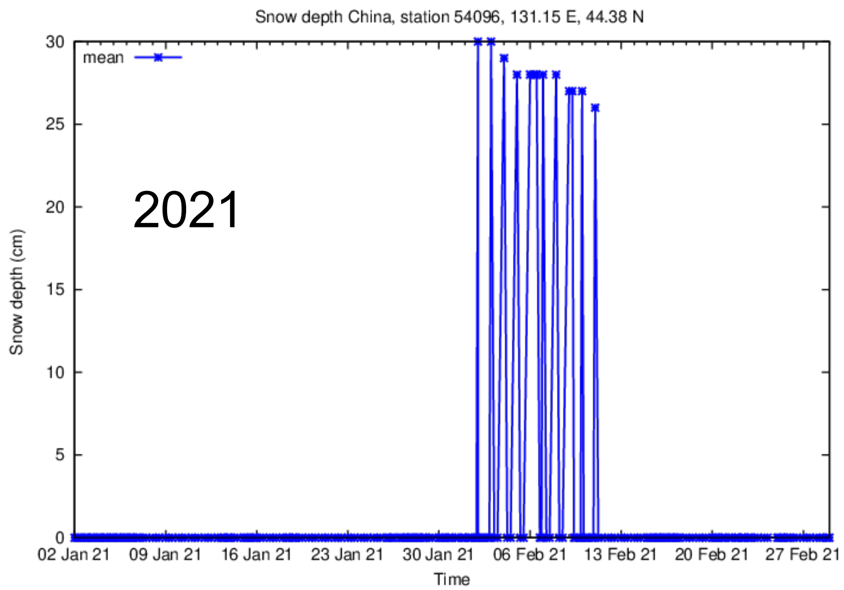
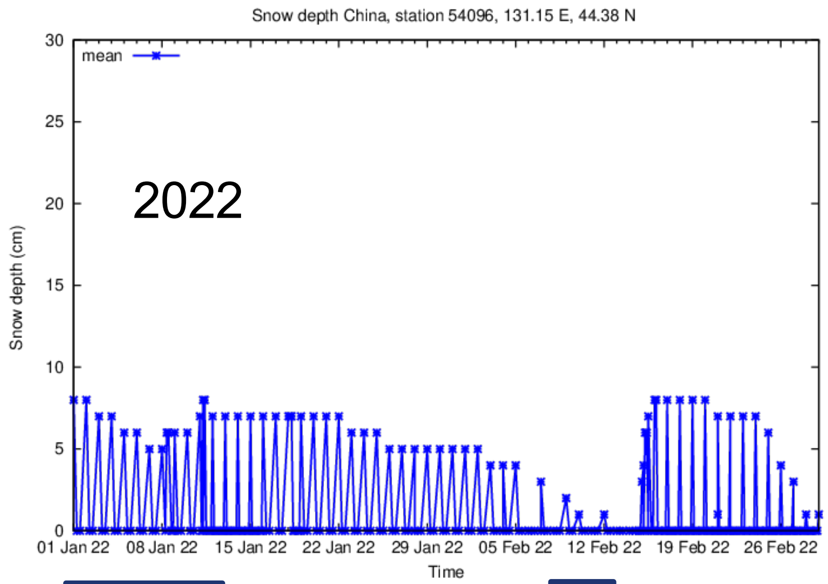




Snow depth report at selected station





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54096	2021020506	10128	131.15	44.38	000567	0.0	-9.00	0.00
54096	2021020512	10128	131.15	44.38	000567	0.0	-11.20	0.00
54096	2021020600	10128	131.15	44.38	000567	28.0	-11.10	0.00
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00054096	2022010700	10128	131.15	44.38	000567	5.0	-17.70	0.00
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00054096	2022011106	10128	131.15	44.38	000567	0.0	-16.20	1.80
00054096	2022011109	10128	131.15	44.38	000567	8.0	-17.30	1.90

Summary zero snow depth issue

Zero snow depth reports found in case of missing value or instrument failure at automatic measurement stations in NE-China.

Issue reported to CMA, problem fixed for 0:00 UTC but only for short period.

Zero snow depth measurements in the region were then explicitly discarded in the analysis. No further attempt was made during the last year. 0:00 UTC measurements now fixed, problem remains for other times.

Satellite measurements help to stabilze the analysis but problem is masked, and probably corrupt measurements are not recovered. Action might be taken to exchange information between the Met Services about such occurences e.g. by sharing a blacklist.

Summary

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- New 2d-Var surface analysis package based on DACE is developed. First version for T2m analysis runs on low resolution grid. Snow and SST analysis will come later.
- NOAA snow depth analysis is used in data sparse regions. Removes pathological patterns in ICON snow analysis over Northern America.
- Zero snow depth reported instead of missing value in NE-China. Observations rejected in the analysis.
  Action desired to exchange information e.g. common blacklist ?

Other issues and devolopments

- Wrong zero snow depth reported in old TAC format over Finland
- Dynamic parameter tuning by exploiting information from temporal filtered T2m increments. Model-DA coupling for further improvement of near surface parameter.
- SST analysis: additional run for 0:00 UTC assimilation to make earlier use of Ostia from previous date.
  Reduced data cutoff to prevent redundant use of observations.

ECMWF lead for the medium range, DWD for short range near the surface

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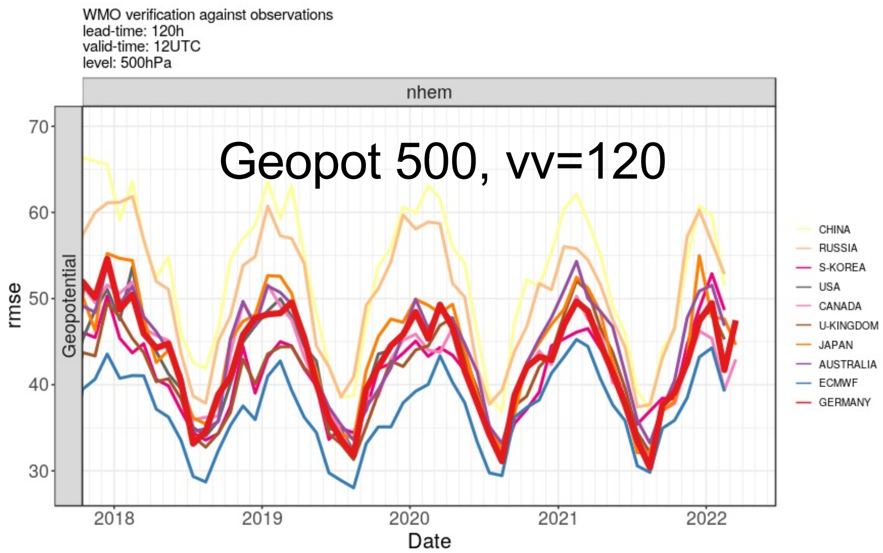

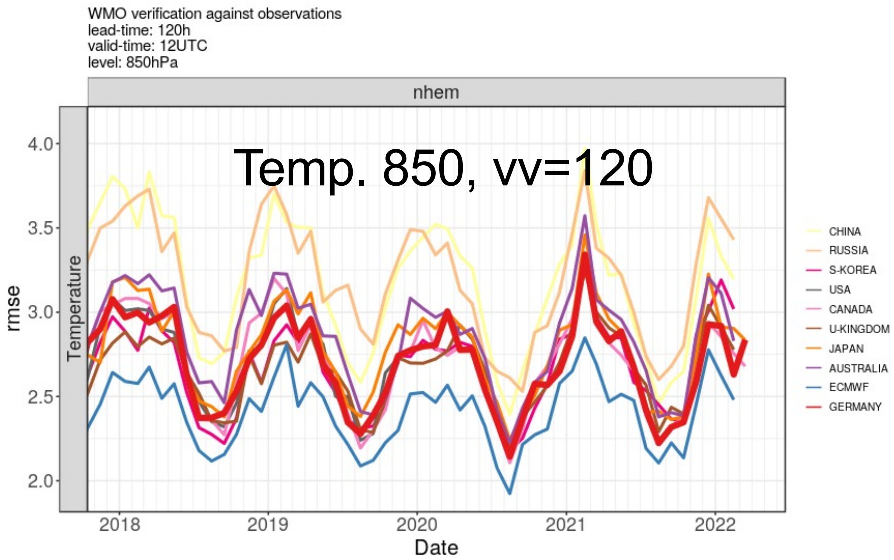

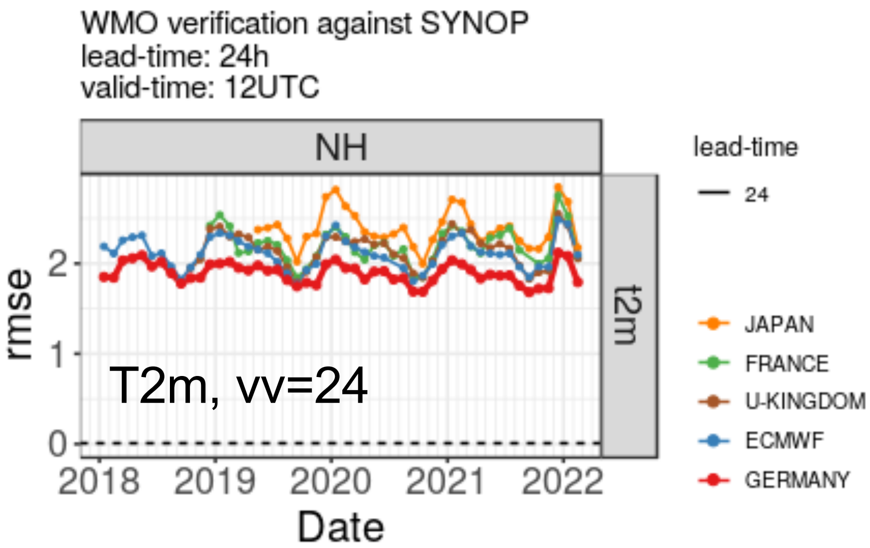

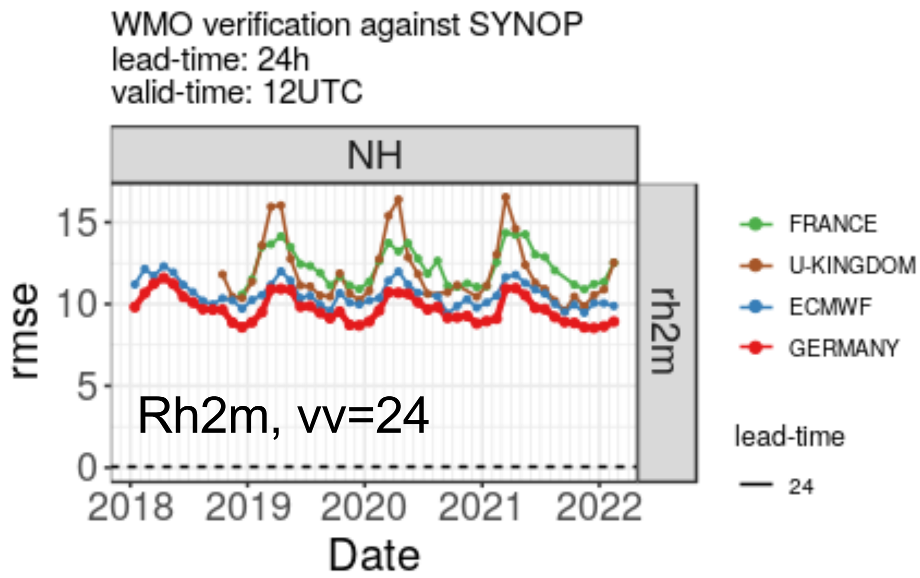

Operational Snow Products

The **Air Force Weather Agency (AFWA)** snow depth is estimated daily by merging satellite-derived snow cover data with daily snow depth reports from ground stations.

Snow depth reports are updated by additional snowfall data or decreased by calculated snowmelt.

The **Interactive Multisensor Snow and Ice Mapping System (IMS)** snow cover product is a snow cover analysis at 4-km resolution manually created by looking at all available satellite imagery, several automated snow mapping algorithms, and other ancillary data.

Regions covered by cloud during the 24-hour analysis period take lower resolution passive microwave data and surface observations into account where possible. There are no missing values over the mapped region.

Circular patterns in snow depth analysis (also observed weaker in CMC analysis)

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