Progress towards new variational surface analyses at DWD

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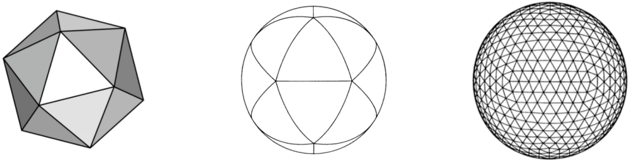
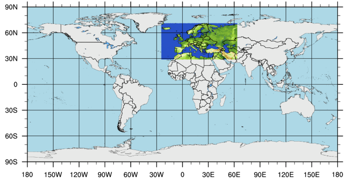
Model chain and domains at DWD

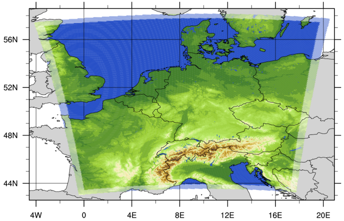
ICON

- ICOsahedral Non-hydrostatic model



- ICON-Global
  - 1 det + 40 ens
  - 13 km + 26 km
- ICON-EU
  - 2-way nested into ICON-Global
  - 6.5 km + 13 km
- ICON-D2
  - 1 det + 40 ens
  - 2 km
  - BCs from ICON-EU





Data assimilation cycle - Global+EU

- atmosphere: 3D-EnVAR + LETKF every 3 hours (global)
- surface:

deterministic analyses and increments (global + EU nest)

ensemble perturbations and mean adjustments

0	3	6	9	12	15	18	21
SMA							
SNW	SNW	SNW	SNW	SNW	SNW	SNW	SNW
SST							

Data assimilation cycle - D2 (regional)

- atmosphere: 4D-LETKF every hour
- surface:

deterministic analyses and increments

ensemble ensemble perturbations and mean adjustments

SMA

SNW SNW SNW SNW

SST

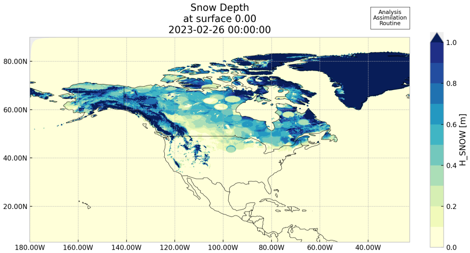
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Current surface analyses

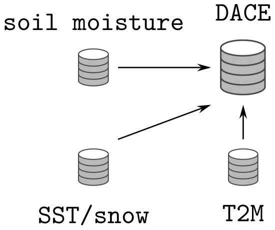
SST (Cressman)	update OSTIA SST with additional SHIP & BUOY
snow depth and fresh snow factor (Cressman)	update model first guess with · snow depth from SYNOP · temperature and precipitation from SYNOP as snow depth proxies · AFWA/AFWW snow analysis (currently not used)
T2M (2D-OI)	update model first guess with SYNOP only used in soil moisture analysis
soil moisture (1D-SEKF)	update two sets of model layers with T2M from OI using explicitly parameterized Jacobians

The need for new surface analyses

- infamous Cressman artefacts:



- scattered, non-uniform source code



The need for new surface analyses

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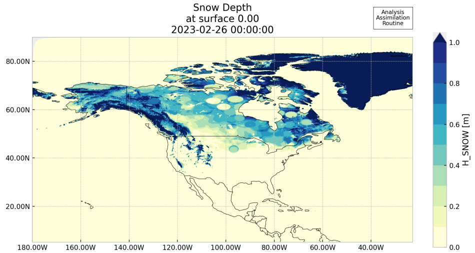

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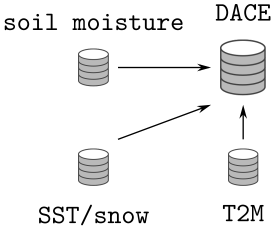

Expected benefits

- **reduce maintenance efforts** because there will be less duplicated functionality,
- **improve diagnostic and monitoring capabilities** because of shared tools for feedback files,
- **facilitate new developments** like new algorithms or additional observations

A generic ensemble-variational analysis

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Wetter und Klima aus einer Hand

- ensemble-variational analysis in our atmospheric DA system (DACE):

$$\begin{aligned}\min_{\mathbf{x}} J(\mathbf{x}) &= \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) && + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x})) \\ &= \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T\left(\mathbf{B}_{\mathrm{clim}}+\mathbf{B}_{\mathrm{ens}}\right)^{-1}(\mathbf{x}-\mathbf{x}^b) && + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x})),\end{aligned}$$

- linearize and split H into interpolation and actual observation operator
- solve in observation space (PSAS):

$$\begin{aligned}\left(\mathbf{R}+\mathbf{H}_{\mathrm{s}}(\mathbf{H}_{\mathrm{clim}}\mathbf{B}_{\mathrm{clim}}\mathbf{H}_{\mathrm{clim}}{}^{\mathrm{T}}+\mathbf{H}_{\mathrm{ens}}\mathbf{B}_{\mathrm{ens}}\mathbf{H}_{\mathrm{ens}}{}^{\mathrm{T}})\mathbf{H}_{\mathrm{s}}{}^{\mathrm{T}}\right)\mathbf{z} &= \mathbf{y}-\mathbf{H}_{\mathrm{s}}\mathbf{H}_{\mathrm{det}}\mathbf{x}_{\mathrm{b}} \\ \mathbf{x}_{\mathrm{a}}-\mathbf{x}_{\mathrm{b}} &= (\mathbf{I}_{\mathrm{clim}}\mathbf{B}_{\mathrm{clim}}\mathbf{H}_{\mathrm{clim}}{}^{\mathrm{T}}\mathbf{H}_{\mathrm{s}}{}^{\mathrm{T}}+\mathbf{I}_{\mathrm{ens}}\mathbf{B}_{\mathrm{ens}}\mathbf{H}_{\mathrm{ens}}{}^{\mathrm{T}}\mathbf{H}_{\mathrm{s}}{}^{\mathrm{T}})\mathbf{z}\end{aligned}$$

- the code for this was isolated and made independent of the ”atmospheric code” by Thomas Hüther

⇒ available for any 1D/2D/3D ensemble-variational analysis

Using the generic variational analysis for T2M

Subroutines to implement for T2M:

`apply_H_clim`	interpolation from climatological B matrix grid to interpolation space
`apply_B_clim`	multiplication with climatological B matrix
`apply_H_climT`	adjoint of `apply_H_clim`
`apply_H_ens`	
`apply_B_ens`	
`apply_H_ensT`	
`apply_H_s`	observation operator in interpolation space
`apply_H_sT`	adjoint of `apply_HsT`
`apply_R`	multiplication with R matrix
`apply_M_inv`	CG preconditioning

Initial experiments

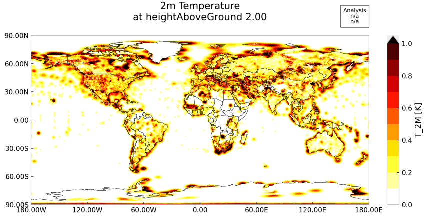
- compare different B matrices to operational OI
- force use of same observations
- RMSE over 14 days in June 2022:

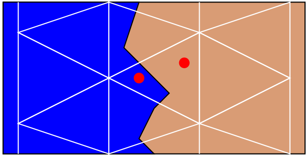
	o-f [K]	*o-a [K]*
operational OI (no minimization) separate analysis for land and water grid points	1.60	1.02
$\mathbf{B}_{\mathrm{clim}} = \mathbf{B}_{\mathrm{OI}}$ joint analysis for land and water grid points	1.62	1.17
$\mathbf{B}_{\mathrm{clim}}(i,\ j) = \exp\left(\frac{-d_{\mathrm{hor}}(i,j)^2}{2\sigma_{\mathrm{hor}}}\right) \cdot \exp\left(\frac{-d_{\mathrm{vert}}(i,j)^2}{2\sigma_{\mathrm{vert}}}\right)$ joint analysis for land and water grid points	1.62	1.18
$\mathbf{B}_{\mathrm{clim}}(i,\ j) = \mathrm{lsc}(i,\ j) \cdot \exp\left(\frac{-d_{\mathrm{hor}}(i,j)^2}{2\sigma_{\mathrm{hor}}}\right) \cdot \exp\left(\frac{-d_{\mathrm{vert}}(i,j)^2}{2\sigma_{\mathrm{vert}}}\right)$ correl. between land and water points (lsc) set to 0.5, interpolation uses only matching land/water points	1.66	1.21

Coastal points and interpolation issues

- our inital suspicion was the mixed use of land and sea points in interpolation
  - added seperate land and sea analyses
  - added option to avoid mixing land and sea points in interpolation
  - added option to control correlation between land and sea points
- did not solve the problem because we are left with less points for interpolation of observed values compared to operational OI (1 or 2 vs up to 10)

RMSD between operational OI and 2DVAR with $\mathbf{B}_{\mathrm{OI}}$





Initial experiment with full NWP suite

- replace OI for T2M with 2DVAR to gather experience
- it did not break:

Initial experiment with full NWP suite - surface verification

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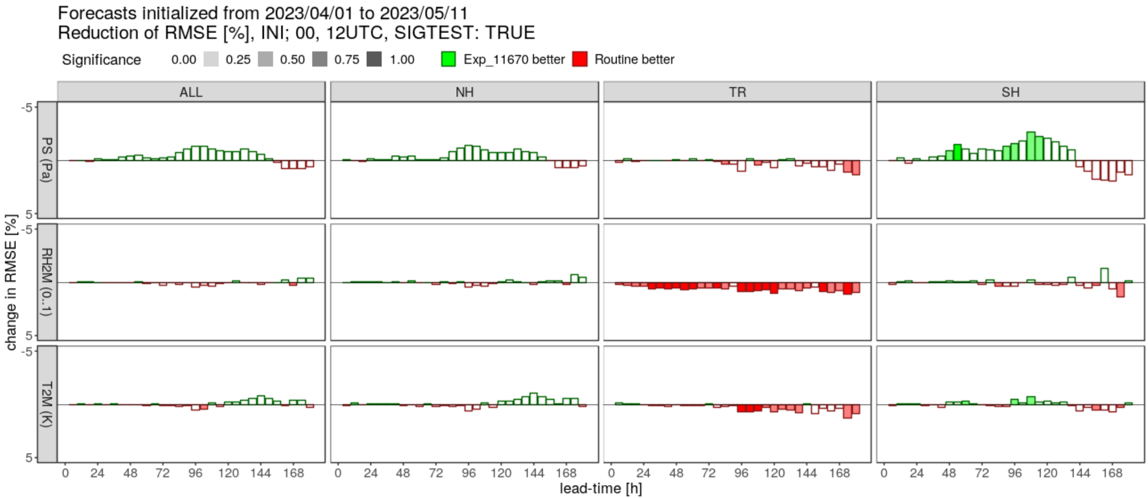

Initial experiment with full NWP suite - upper air verification

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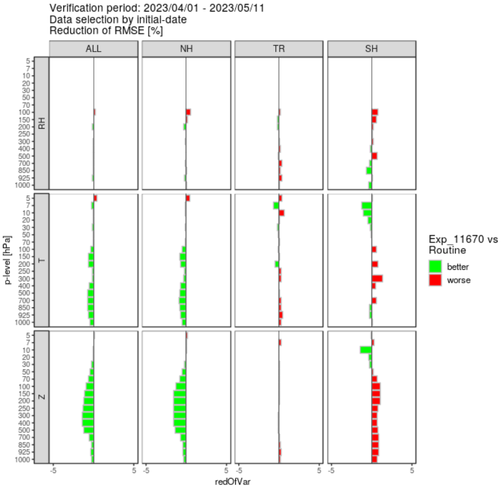

Initial experiment with full NWP suite - increments

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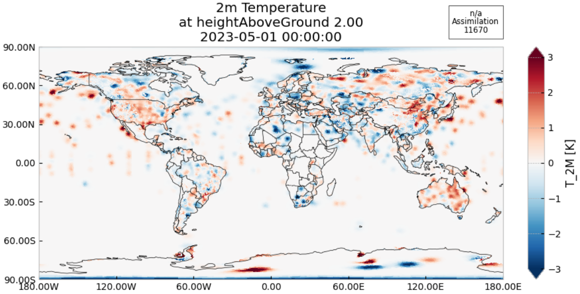
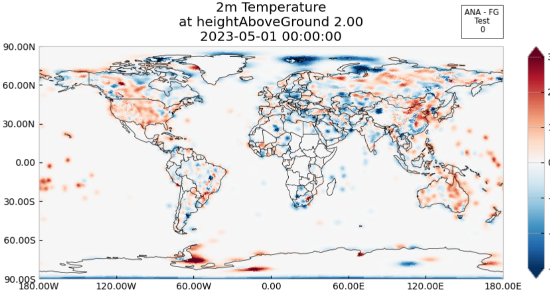
OI



2DVAR



Initial experiment with full NWP suite

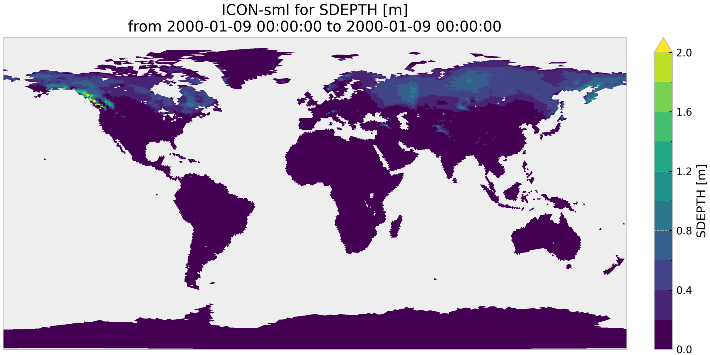
- replace OI for T2M with 2DVAR to gather experience
- it did not break

But … we use ~30 % more observations in the 2DVAR.

⇒ Understand and adjust existing implemenation of (atmospheric) quality control to surface observations.

Initialization of seasonal predictions

- 2DVAR snow analysis for ICON-Seamless/JSBACH
- NetCDF-based I/O



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Summary and Perspectives

- replace SST, snow and T2M analysis in NWP with 2D(En)VAR
  - *ensemble*-variational analysis is already functional, but not explored yet
  - work on observation quality control
  - find appropriate settings for error covariances and length scales
- develop snow and T2M analysis for seasonal predictions with 2D(En)VAR
- explore the use of an ML-based operator from soil moisture to T2M to use in 1D(En)VAR as an alternative to the SEKF