Snow analysis for NWP at Meteo France and recent developments for land surface analysis

Camille Birman, Jean-François Mahfouf and GMAP...

All Staff Meeting, 1-4 April 2019, Madrid, Spain

Outline

- Current land surface data assimilation system
- Snow analysis:
  - AROME model
  - ARPEGE model
  - First steps toward the use of satellite observations
- Future plans for the assimilation system over land and preliminary steps towards coupled assimilation: Diagnostics using ARPEGE EDA for surface analysis
- Conclusions and future work

Land surface data assimilation system

- Météo France global model ARPEGE and limited area model AROME are coupled to the surface modelling platform SURFEX.

- Each grid point is divided into 4 tiles which have their own prognostic variables (and analysed variables):

  - Nature: ISBA-3L (3 layers) for NWP (Noilhan and Mahfouf, 1996; Boone et al., 1999), prognostic variables in the three superficial layers (liquid and solid fractions for soil water content, SWE for snow on the ground) → : T_s, T_2, T_3, w_g, w_2, w_3.

  - Town: TEB (Masson, 2000) → T_{roof}, T_{wall}, T_{road}

  - Lake → LST (FLake)

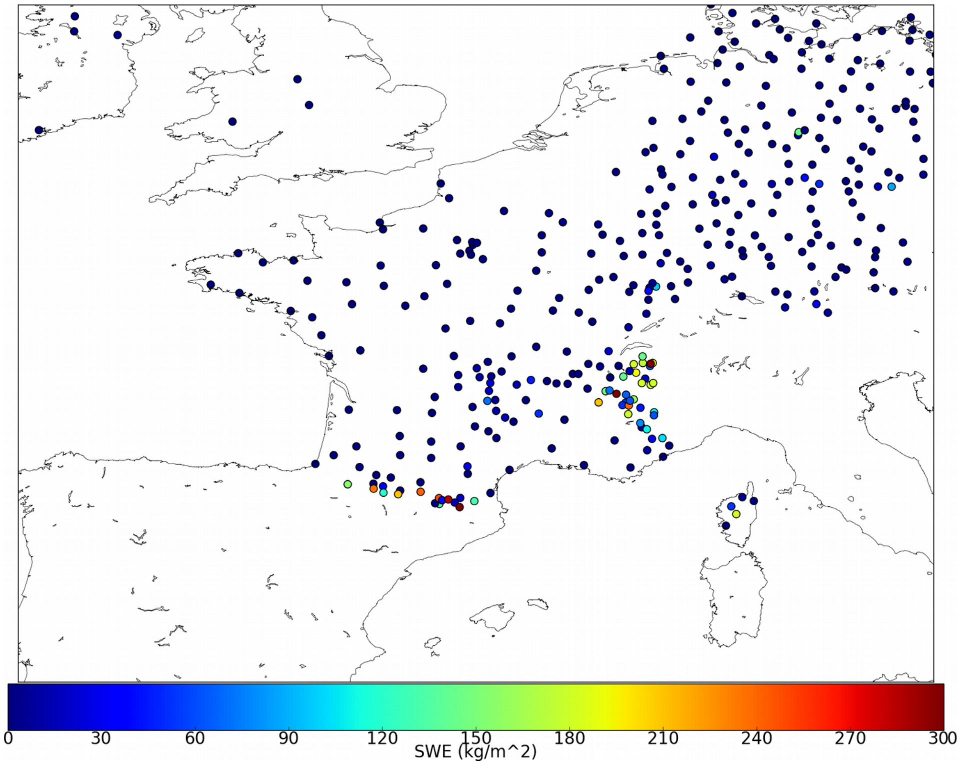
  - Sea → SST (CMO 1D)

- We use screen level observations of T_{2m} and RH_{2m} to compute gridded analysed fields using 2D Optimal Interpolation (OI) (CANARI)

- 1D OI scheme using the increments of T_{2m} and RH_{2m} (Giard and Bazile, 2000) to obtain increments of soil temperature and moisture T_s, T_2, w_g, w_2.

Snow analysis

- Snow analysis over plains: necessary to correct for insufficient snow melt in the model
  - Period of study during February-March 2018 and January-February 2019

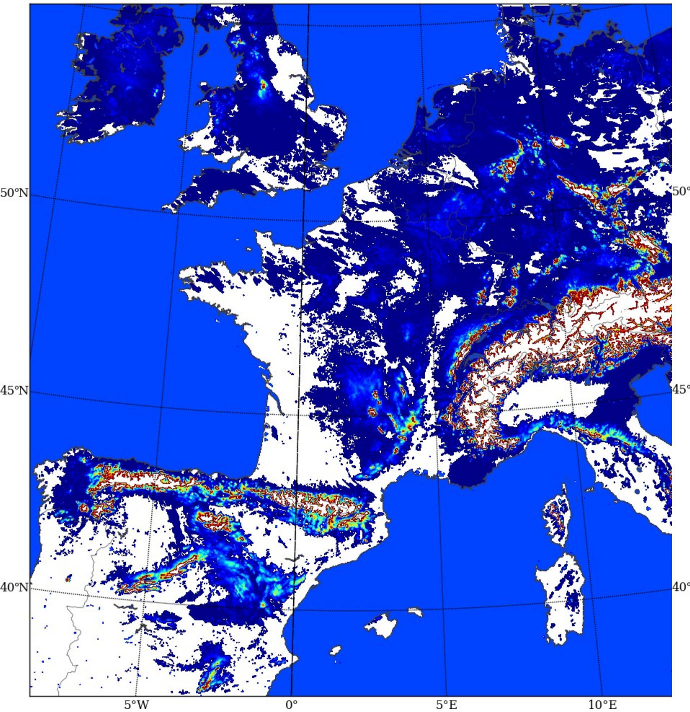


Snow depth observations over the AROME-France domain

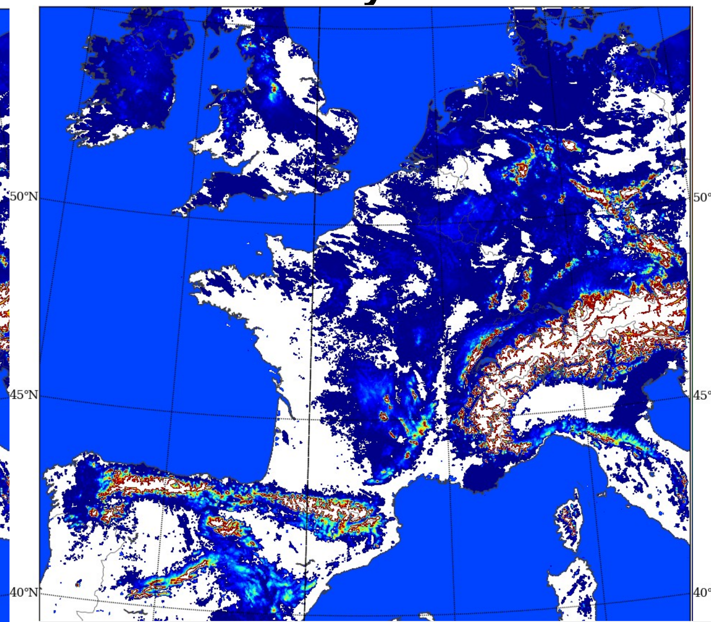
- Heterogeneous observation network over the AROME-France domain
- Snow analysis performed using CANARI 2D OI
- Transfer of snow increments into SURFEX
- Prognostic variable: SWE → use of model density to transform snow depth observations into snow water equivalent for the assimilation
- Tuning of observation and background errors and length scale

Snow analysis: case study on 12th February 2018, 12:00

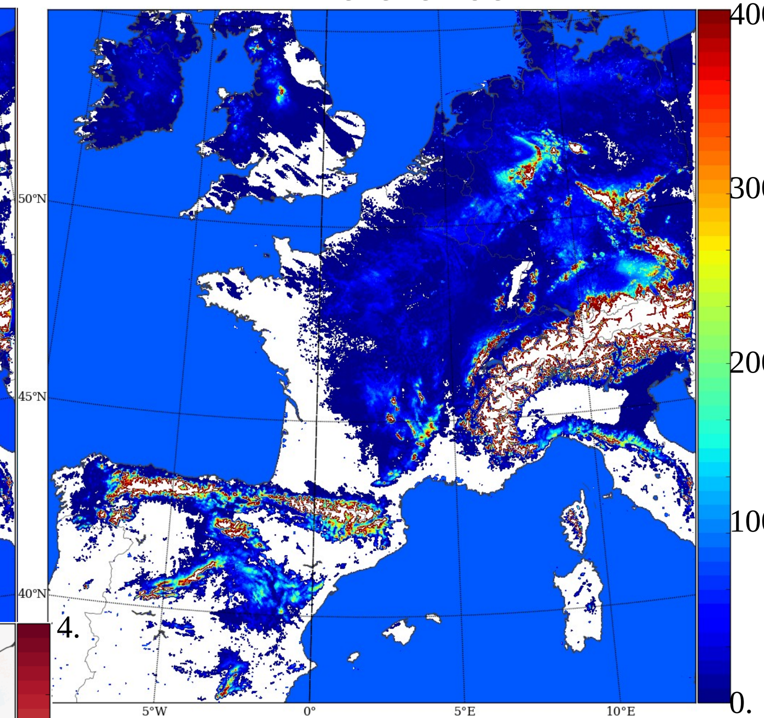
Background



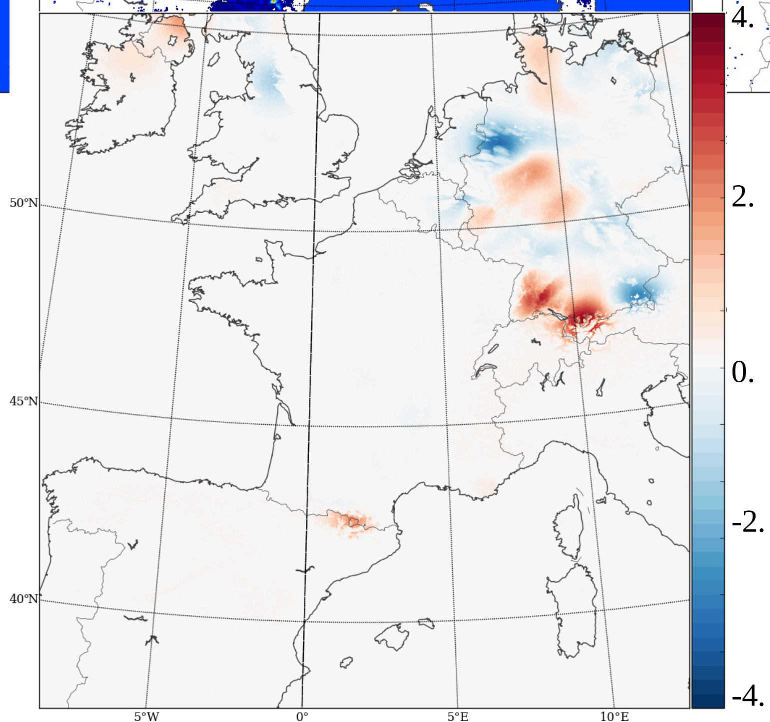
Analysis



Reference



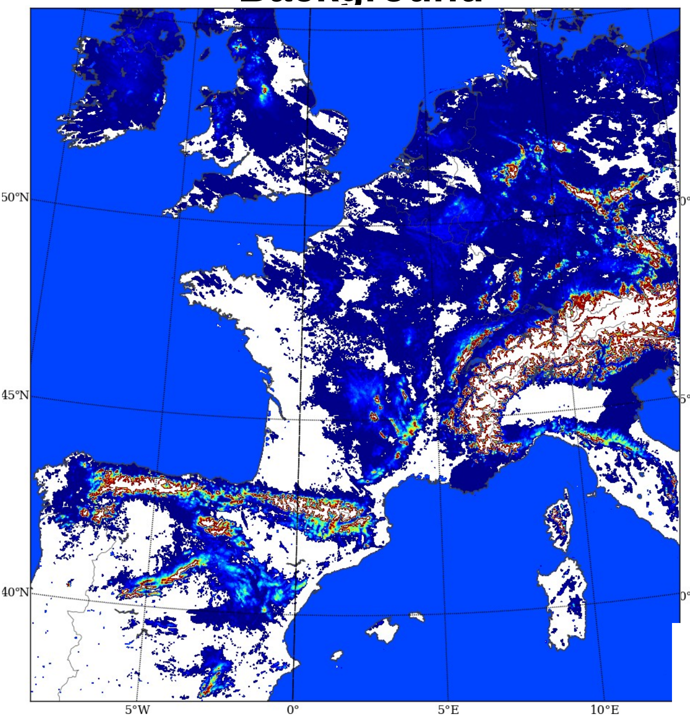
Analysis Increment (σ_o = 5 kg/m²)



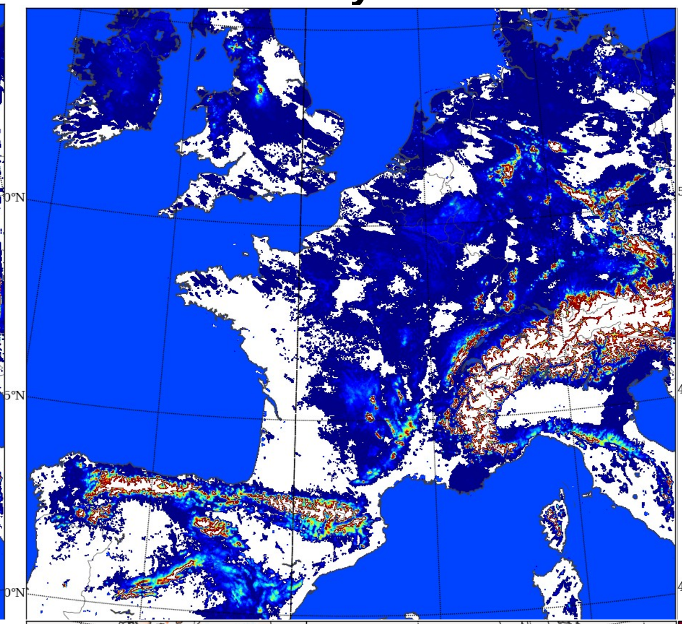
(kg/m²)

Snow analysis: case study on 12th February 2018, 12:00

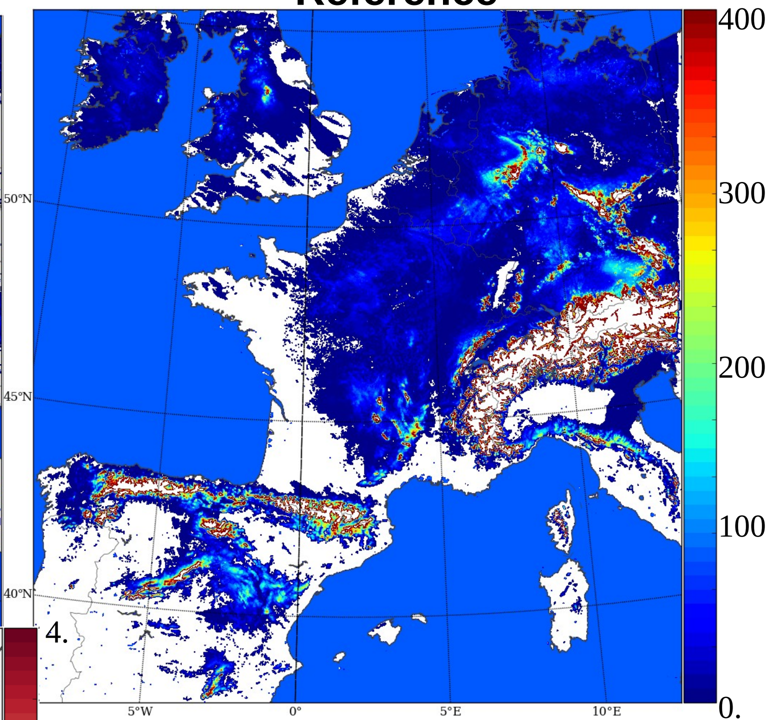
Background



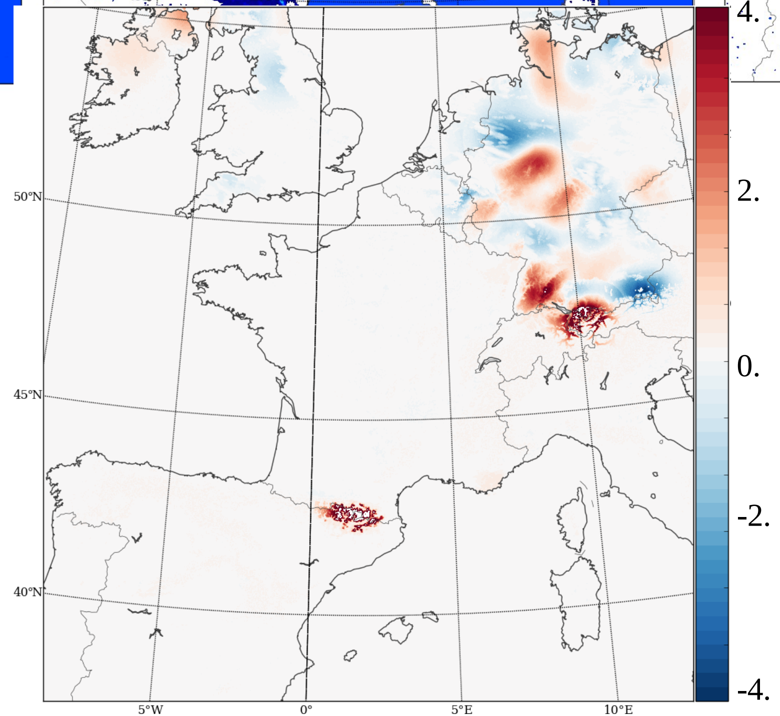
Analysis



Reference



Analysis Increment (σ_o = 2 kg/m²)

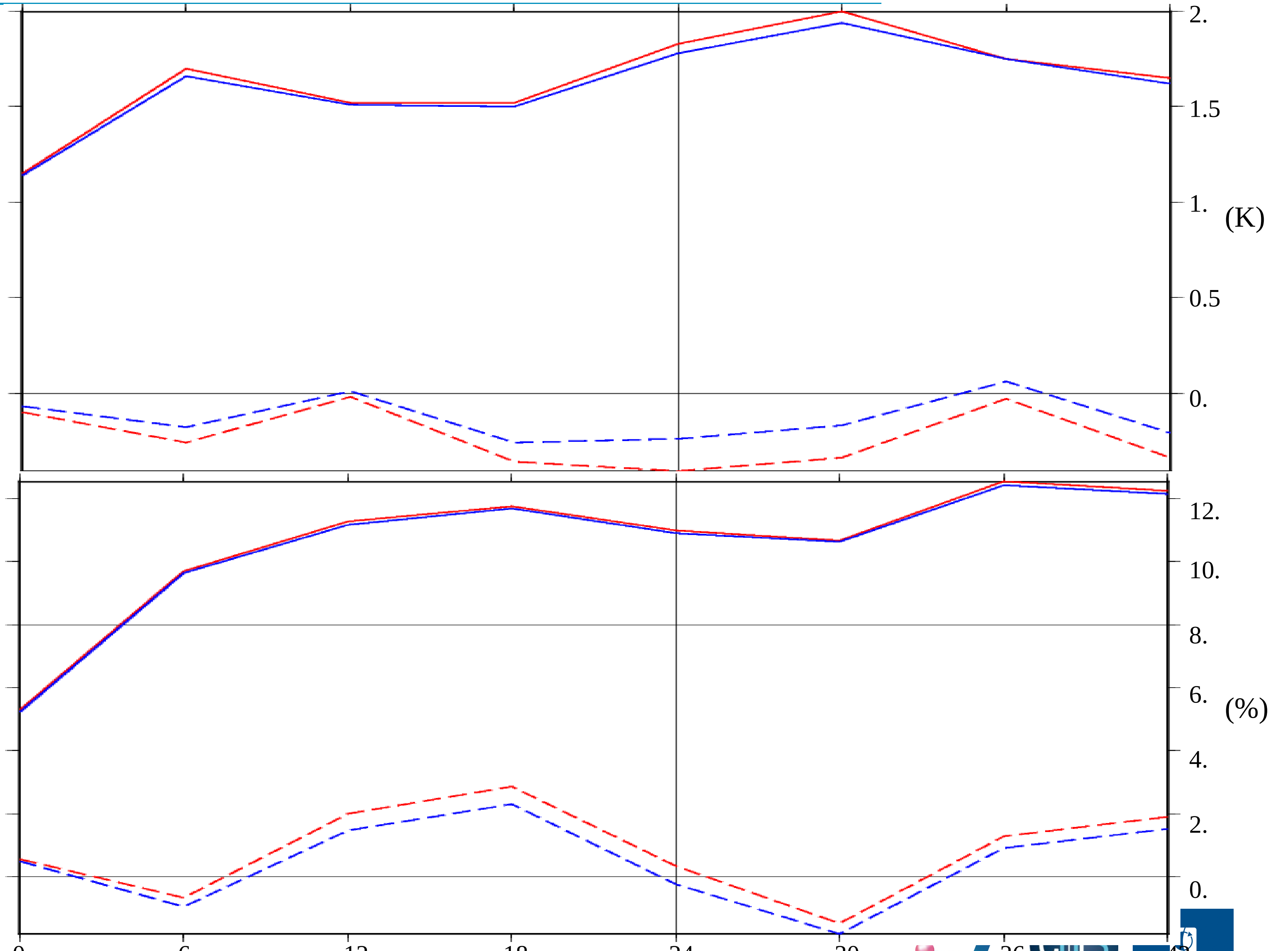


(kg/m²)

Snow analysis: bias and MSE on February 2018 with respect to Synop stations

T2m
(σ_o = 2 kg/m²)

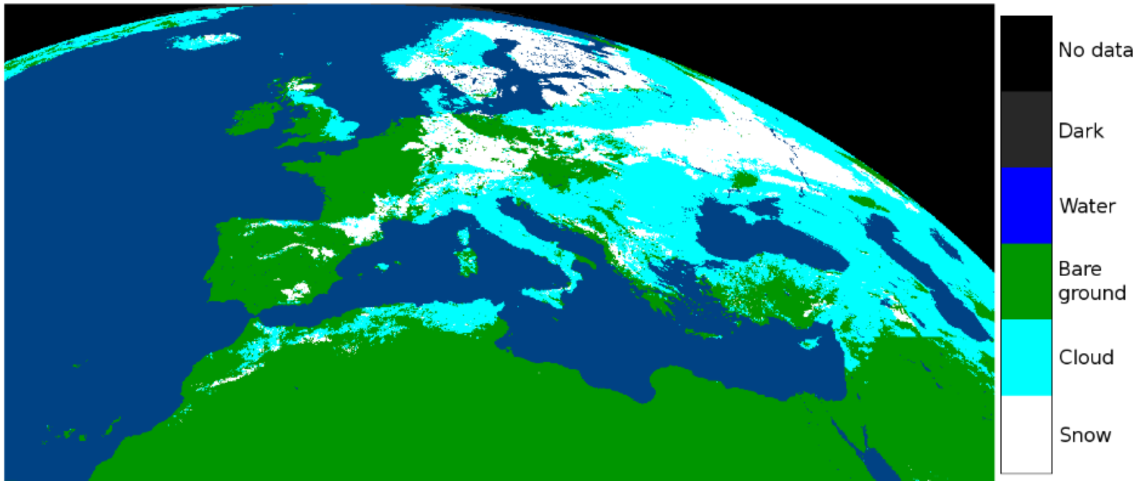
Hu2m
(σ_o = 2 kg/m²)



Bias (dashed line) and Mean Square Error (solid line) of 2 metre temperature and 2 metre relative humidity forecasts as a function of the forecast range, with snow analysis and without snow analysis

Snow analysis: use of satellite observations

- Daily snow product H10 from H-SAF (http://hsaf.meteoam.it/snow.php)
  - Resolution 0.05° over Europe, computed from SEVIRI multichannel analysis



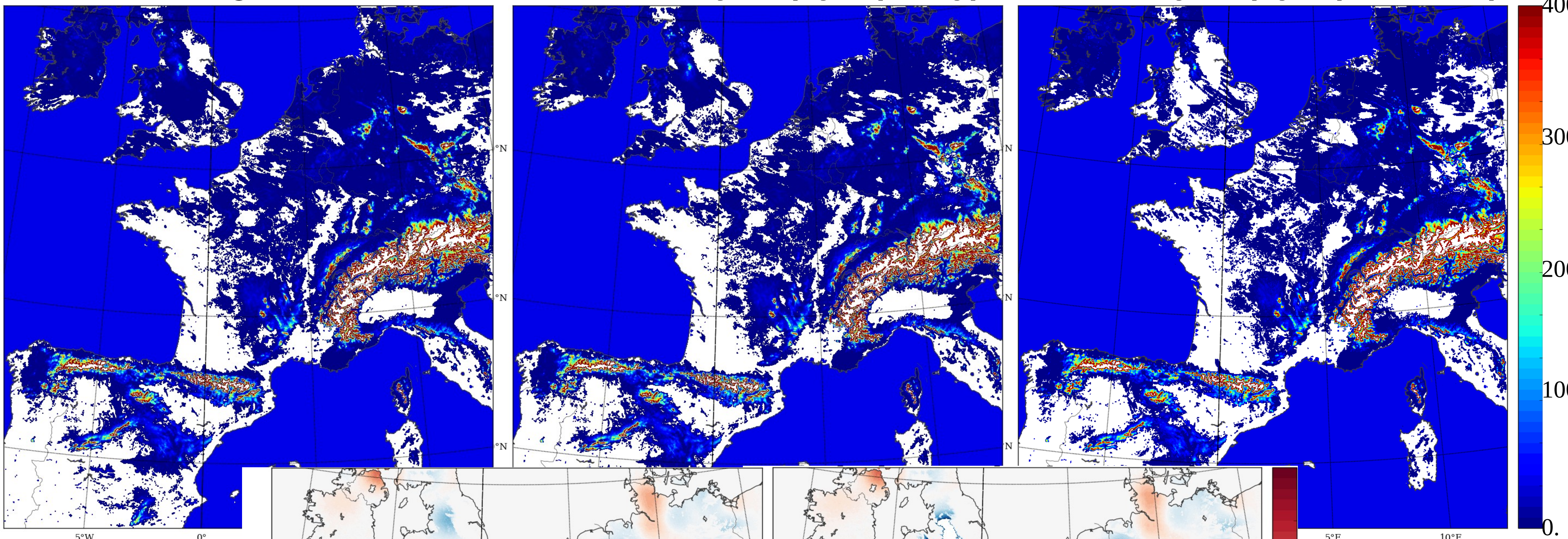
H-SAF H10 snow product on March 9, 2010

- The snow mask (values 0 or 1) is converted into values that can be ingested in the assimilation :
  - 0 kg/m² (no snow) or 5 kg/m² (snow on the ground)

- Tuning of observation errors and length scale:
  - σ_o = 8 kg/m² (H-SAF) instead of 5 kg/m² (Synop)
  - d = 5 km (H-SAF) instead of 50 km (Synop)

Snow analysis: case study on 12th February 2018, 12:00

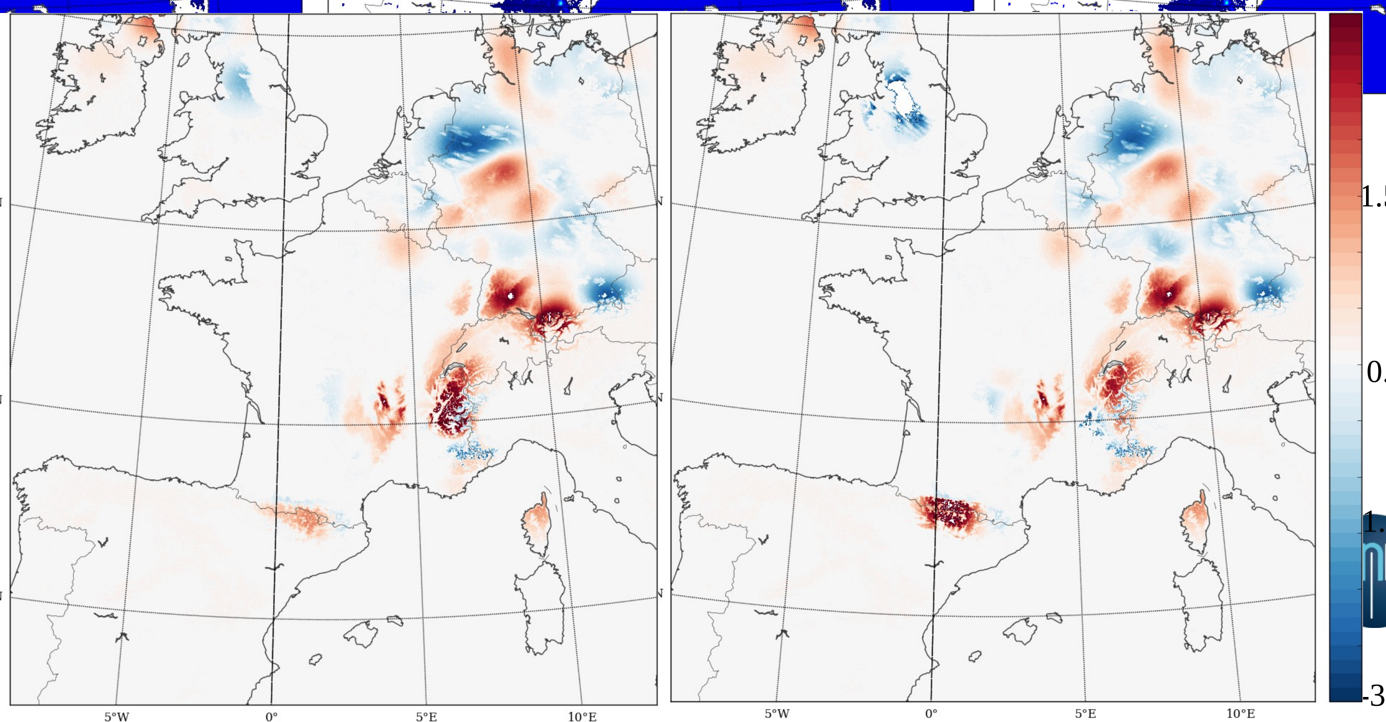
Background **Analysis (Synop only)** **Analysis (Synop + H-SAF)**



Analysis Increment

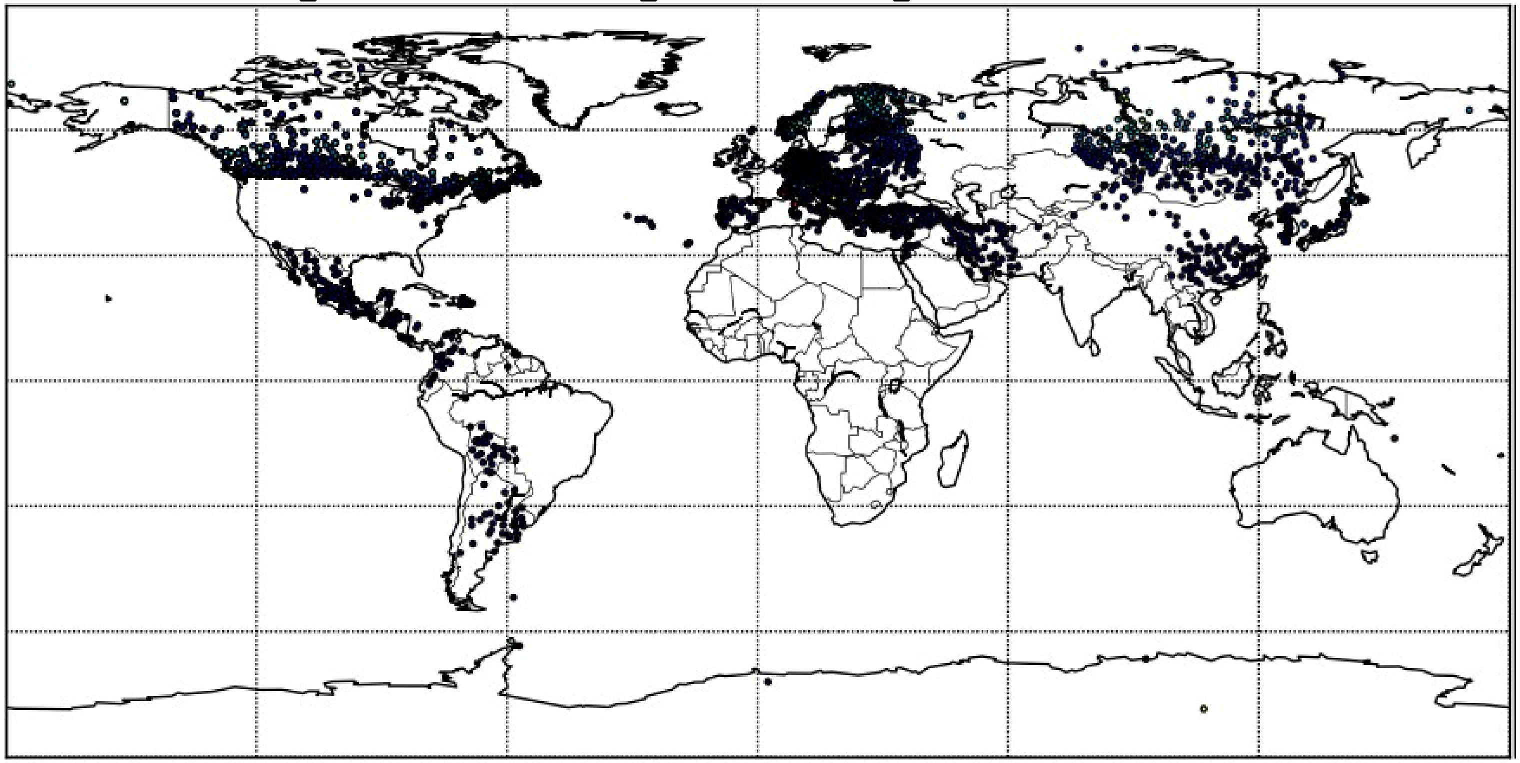
Synop only

Synop + H-SAF



Snow analysis in ARPEGE

- Synop stations: heterogeneous coverage over the globe



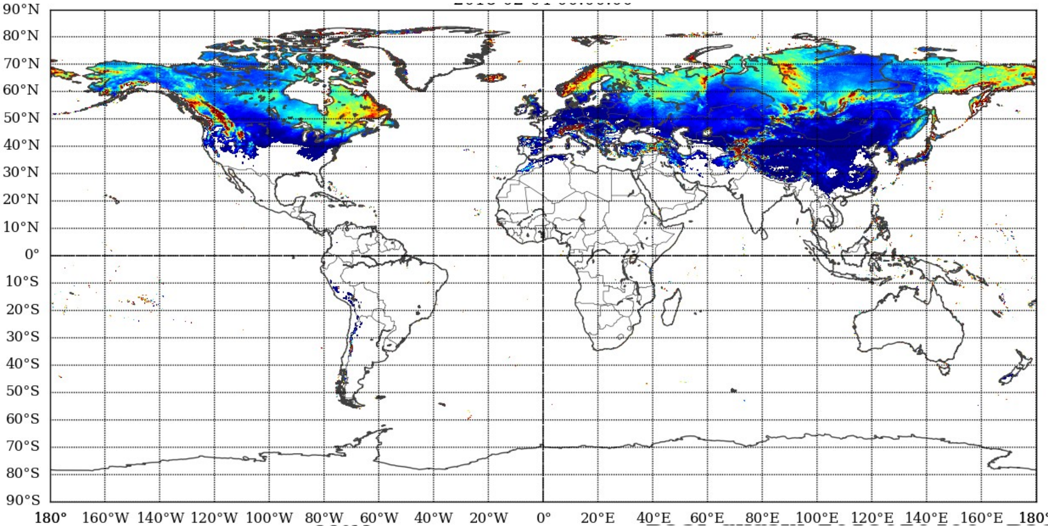
- Same principle as in AROME: 2D-OI with a struture function accounting for the distance and the difference of elevations between observation and grid point

- Tuning of observation errors and length scale:

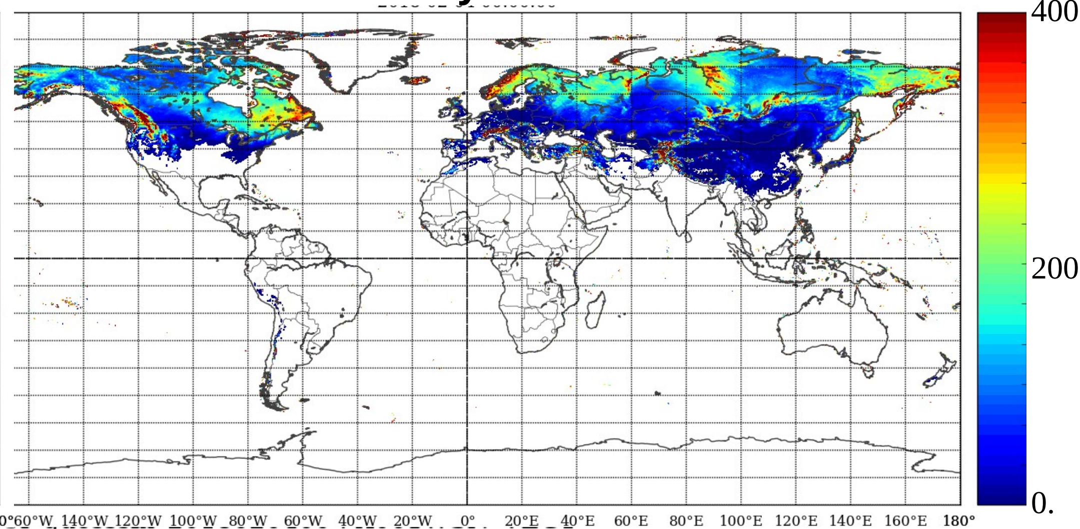
  - σ_o = 5 kg/m², d = 100 km

Snow analysis: case study on 4th February 2018, 00:00

Background

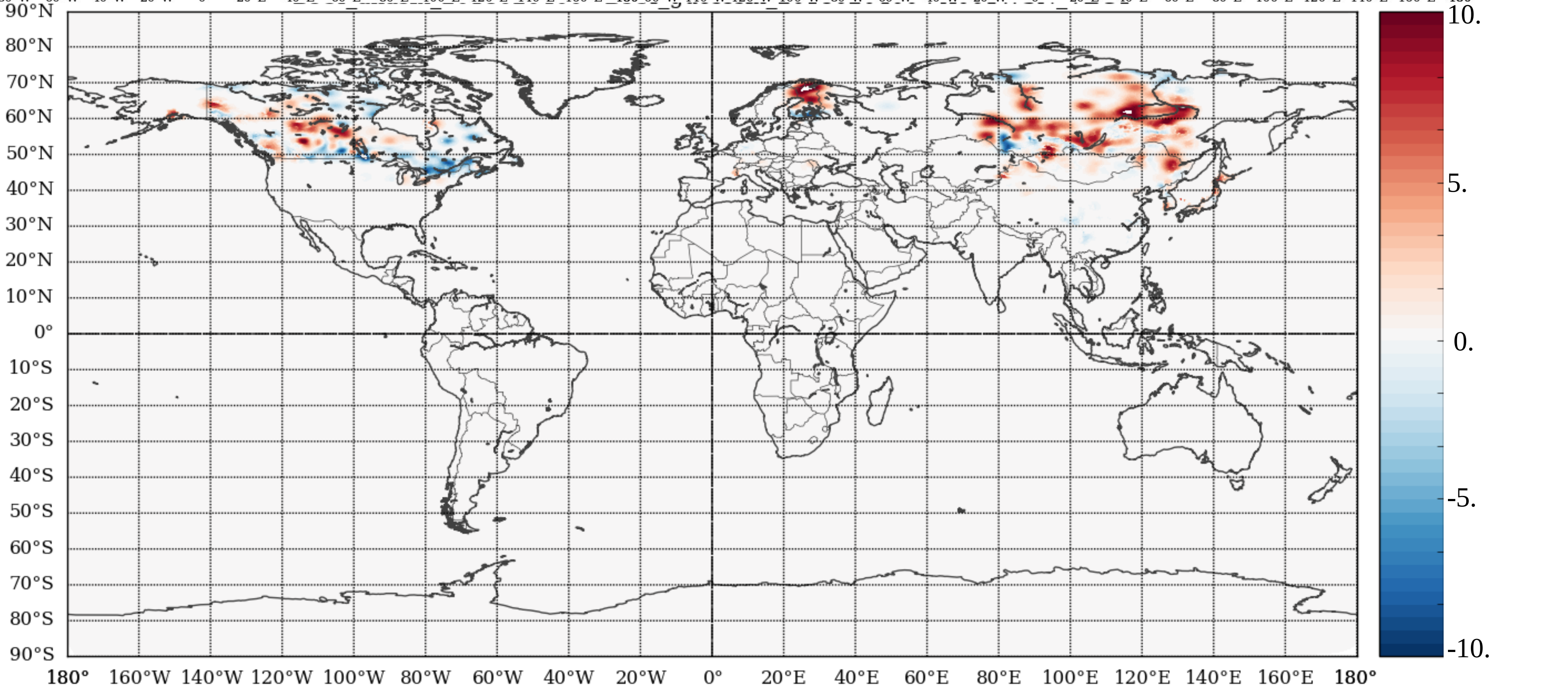


Analysis



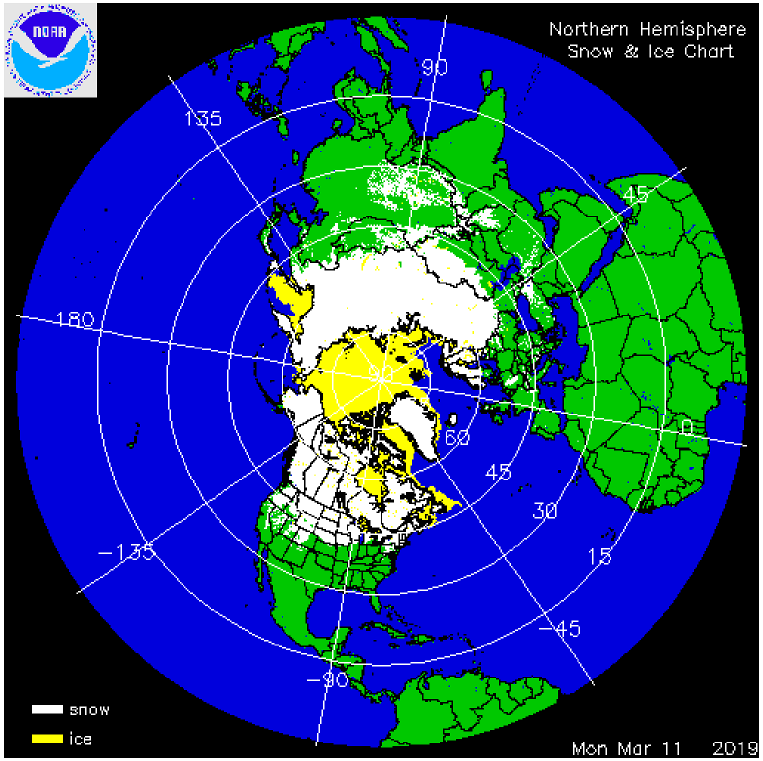
Analysis Increment

(kg/m²)



Snow analysis in ARPEGE: use of satellite data

- IMS NOAA-NESDIS snow product over Northern Hemisphere: derived from AVHRR, AMSU, GOES/Imager, Himawari (AHI), Meteosat (SEVIRI)
- Daily product, 4 km resolution
- The snow mask (values 0 or 1) is converted into values that can be ingested in the assimilation :
  - 0 kg/m² (no snow) or 5 kg/m² (snow on the ground)
- Thinning of observations: ~1 observation every 30 km is kept
- Tuning of observation errors and length scale:
  - σ_o = 8 kg/m² (IMS) instead of 5 kg/m² (Synop)
  - d = 10 km (IMS) instead of 100 km (Synop)

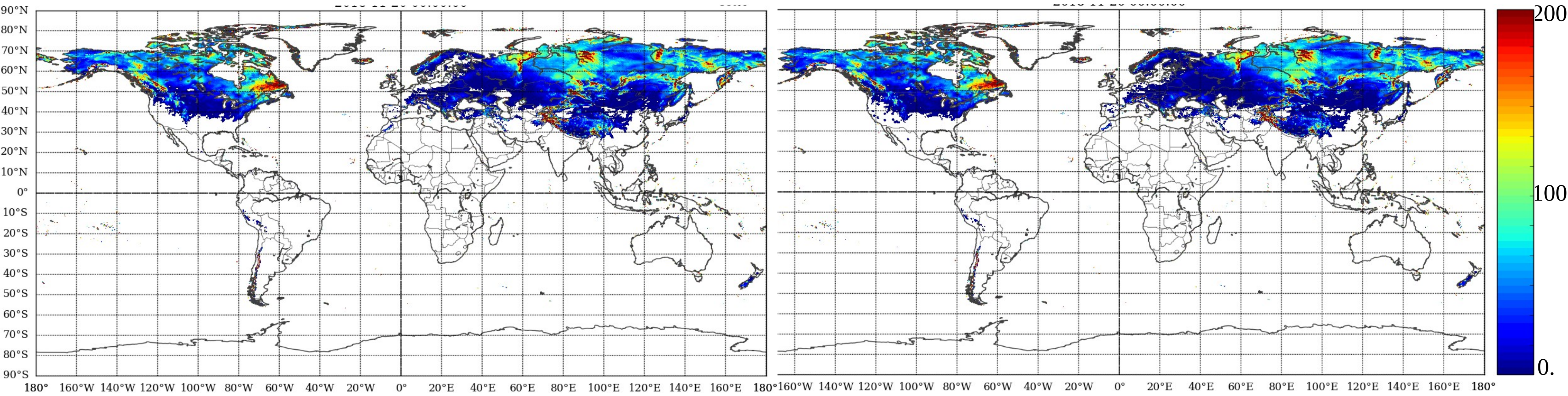


IMS snow and ice product over Northern Hemisphere on March 11, 2019

Snow analysis: case study on 20th November 2018, 00:00

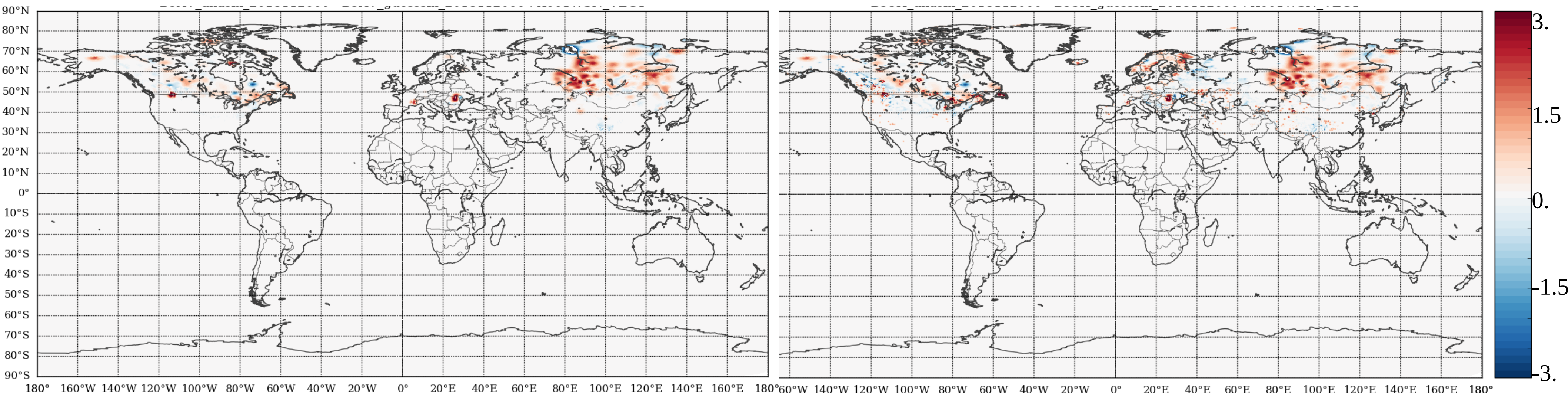
Analysis

Synop only | Synop + IMS



Analysis increment (kg/m²)

Synop only | Synop + IMS



Diagnostics using ARPEGE EDA for surface analysis

- Optimal interpolation coefficients:
  - Covariances between the forecast errors of T_{2m} and RH_{2m} and the perturbed soil moisture values w_g and w_2 were obtained from a set of 100 single column model integrations where the initial soil moisture content was perturbed.

$$w^a - w^b = \alpha(T^o - T^b) + \beta(RH^o - RH^b)$$

$$\alpha = \frac{\sigma_w}{\Phi\sigma_T}\left\{\left[1 + \left(\frac{\sigma^o_{RH}}{\sigma^b_{RH}}\right)^2\right]\rho_{T,w} - \rho_{T,RH}\rho_{RH,w}\right\}$$

$$\beta = \frac{\sigma_w}{\Phi\sigma_{RH}}\left\{\left[1 + \left(\frac{\sigma^o_{T}}{\sigma^b_{T}}\right)^2\right]\rho_{RH,w} - \rho_{T,RH}\rho_{T,w}\right\}$$

$$\Phi = \left[1 + \left(\frac{\sigma^o_{T}}{\sigma^b_{T}}\right)^2\right]\left[1 + \left(\frac{\sigma^o_{RH}}{\sigma^b_{RH}}\right)^2\right] - \rho^2_{T,RH}$$

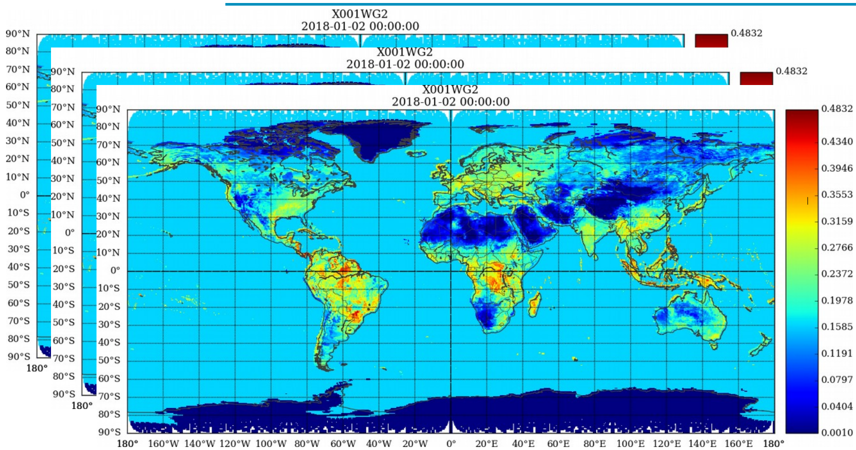
- Kalman filter approach:

$$\Delta \mathrm{x} = \mathrm{BH}^{\mathrm{T}}(\mathrm{HBH}^{\mathrm{T}} + \mathrm{R})^{-1}\Delta \mathrm{y}$$

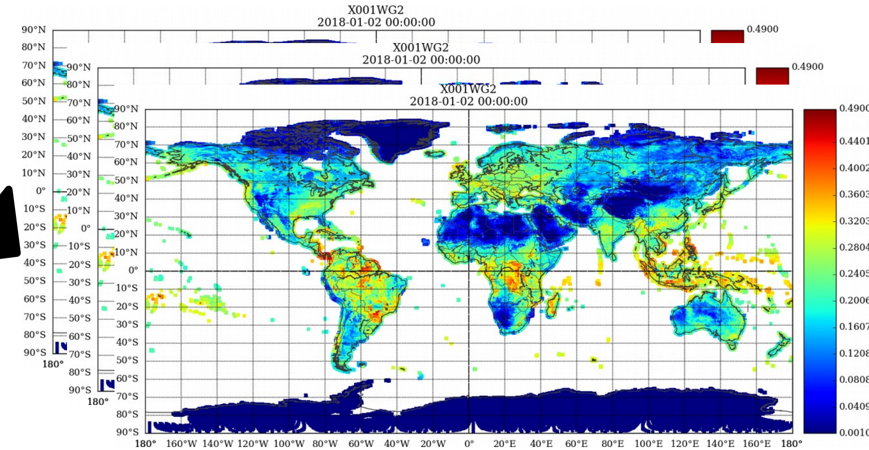
- Use of EDA (AEARP, 25 members) to compute standard deviations and covariances between surface variables and observed variables.

$$\Delta \mathrm{x} = \mathrm{cov}(\mathrm{x}^b,\mathrm{y}^b)\left[(\mathrm{cov}(\mathrm{y}^b,\mathrm{y}^b) + \mathrm{cov}(\mathrm{y}^o,\mathrm{y}^o)\right]^{-1}\Delta \mathrm{y}$$

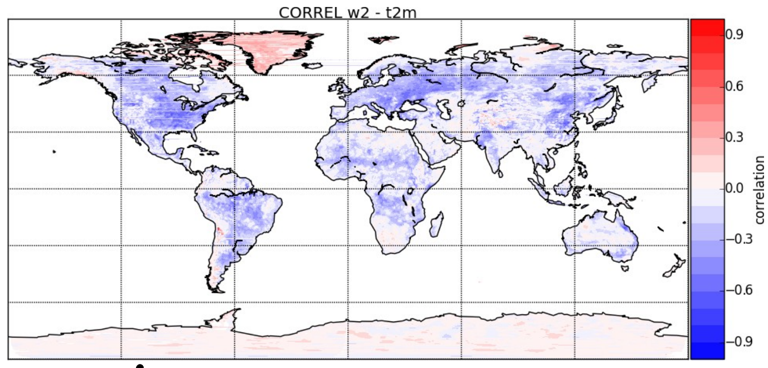
Diagnostics using ARPEGE EDA for surface analysis



Surface fields at **low resolution** from EDA
(25 members)



Surface fields at **high resolution**
(25 members)



Correlations and standard deviations at **high resolution**

Soil analysis

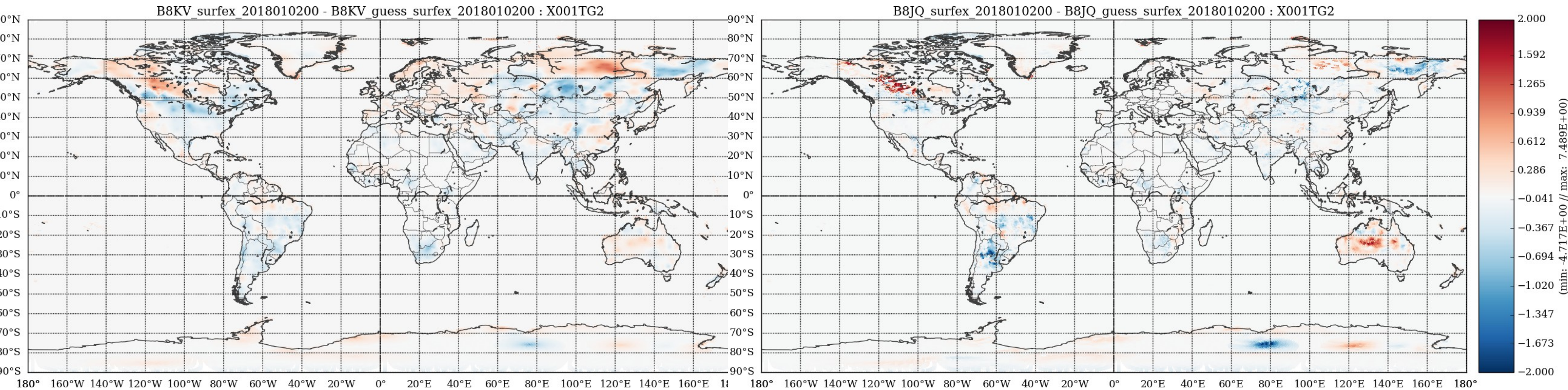
Diagnostics using ARPEGE EDA for surface analysis

- Cycling of analysed surface fields computed from the EDA over assimilation cycles: increments in the 2nd layer of the soil at first analysis time (20180102H00)

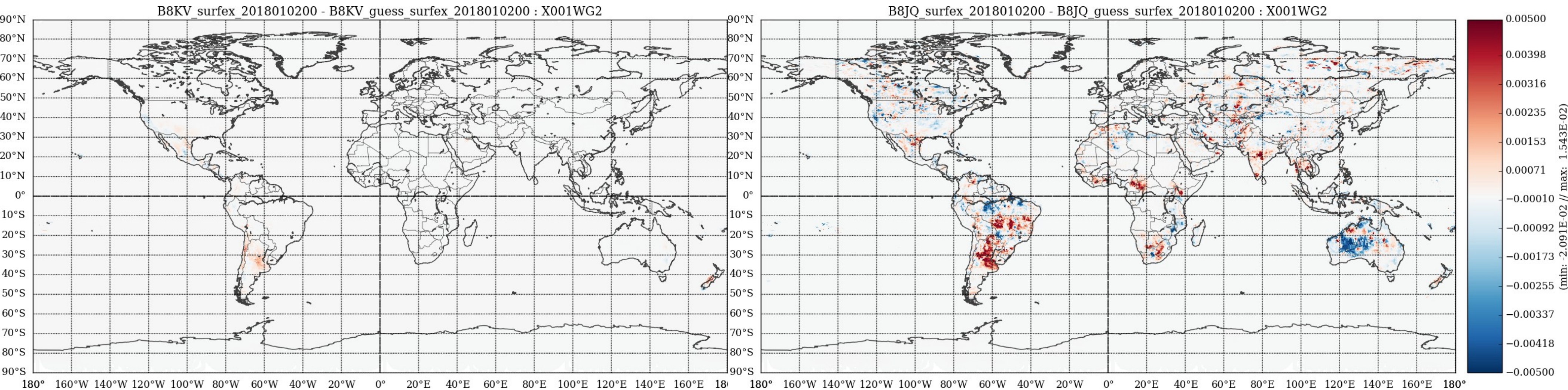
OI increments

TG2

EDA increments



WG2



Conclusions and future work

- Snow analysis in AROME and ARPEGE models with a 2D Optimal Interpolation, using Synop observations
- Improvement of the land surface data assimilation system: ensemble methods (EnKF, particle filter…) and use of atmospheric ensembles produced by ensemble data assimilation systems (AEARP → global model ARPEGE, AEARO → limited area model AROME)
- Assimilation of satellite products, in particular for surface temperature (PhD Zied Sassi) and for snow (Nesdis-IMS snow cover product for ARPEGE, H-SAF products for AROME)
- Future plans for the assimilation of soil moisture products (soil moisture product from ASCAT, and/or from L-band sensors SMOS/SMAP), and albedos (LSA-SAF products)

Land surface assimilation system

- Météo France global model ARPEGE and limited area model AROME are coupled to the surface modelling platform SURFEX, which represents the exchanges between the atmosphere and the surface.

- Each grid box is divided into 4 tiles for nature, sea, lake and town fractions. The 4 tiles recieve the same atmospheric forcing and the surface fluxes computed on each tile are averaged over the grid box.

- The 4 tiles have their own prognostic variables (and analysed variables):

  - Nature: ISBA-3L (3 layers) for NWP (Noilhan and Mahfouf, 1996; Boone et al., 1999), prognostic variables in the three superficial layers (liquid and solid fractions for soil water content, SWE for snow on the ground) → : T_s, T_2, T_3, w_g, w_2, w_3.

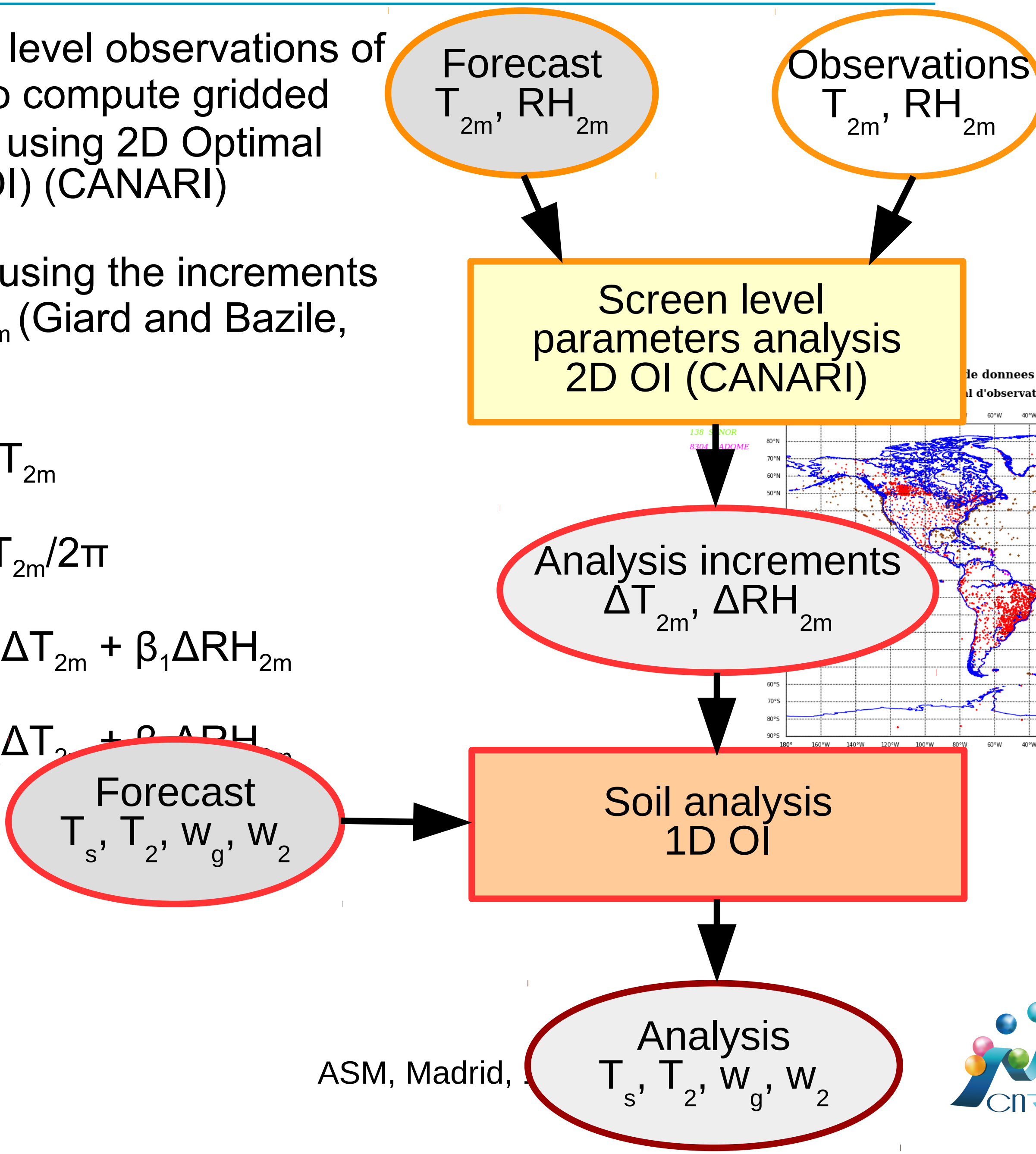
  - Town: TEB (Masson, 2000) → T_{roof}, T_{wall}, T_{road}

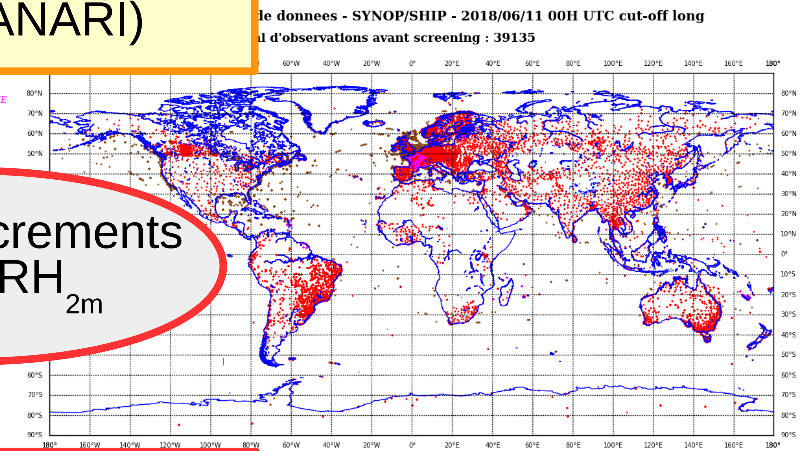
  - Lake → LST (FLake)

  - Sea → SST (CMO 1D)

Land surface assimilation system

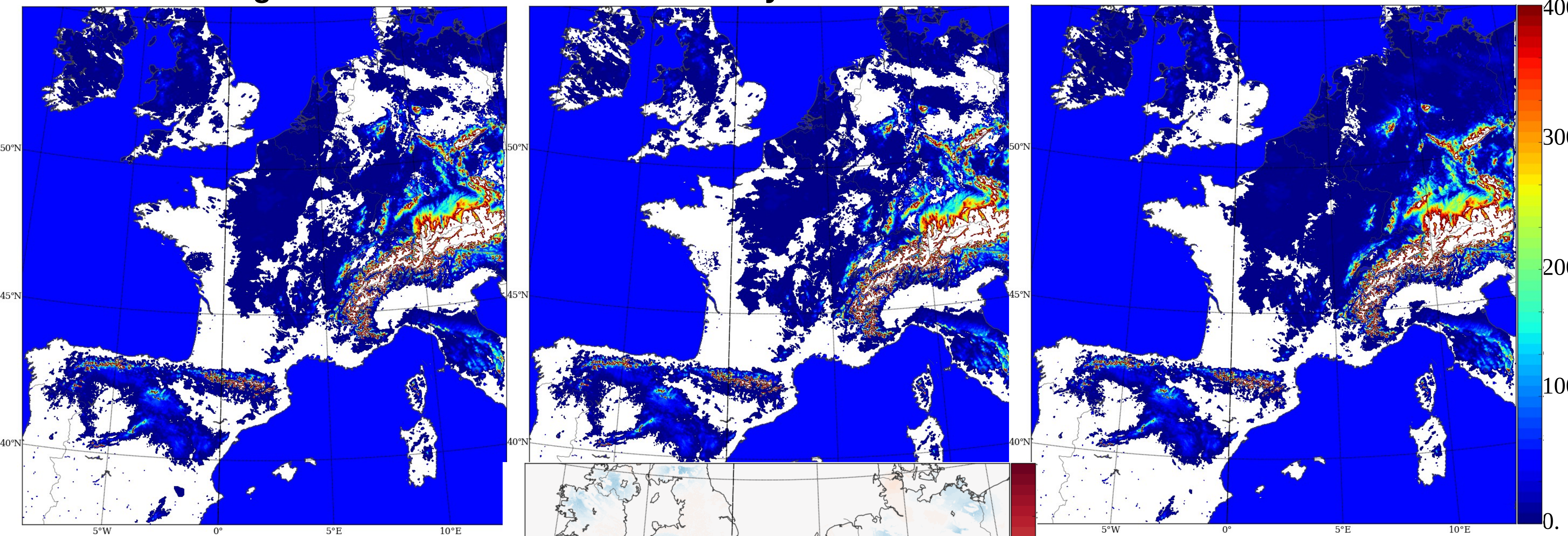
- We use screen level observations of T_{2m} and RH_{2m} to compute gridded analysed fields using 2D Optimal Interpolation (OI) (CANARI)
- 1D OI scheme using the increments of T_{2m} and RH_{2m} (Giard and Bazile, 2000):
  - $\Delta T_s = \Delta T_{2m}$
  - $\Delta T_2 = \Delta T_{2m}/2\pi$
  - $\Delta w_g = \alpha_1 \Delta T_{2m} + \beta_1 \Delta RH_{2m}$
  - $\Delta w_2 = \alpha_2 \Delta T_2$ …



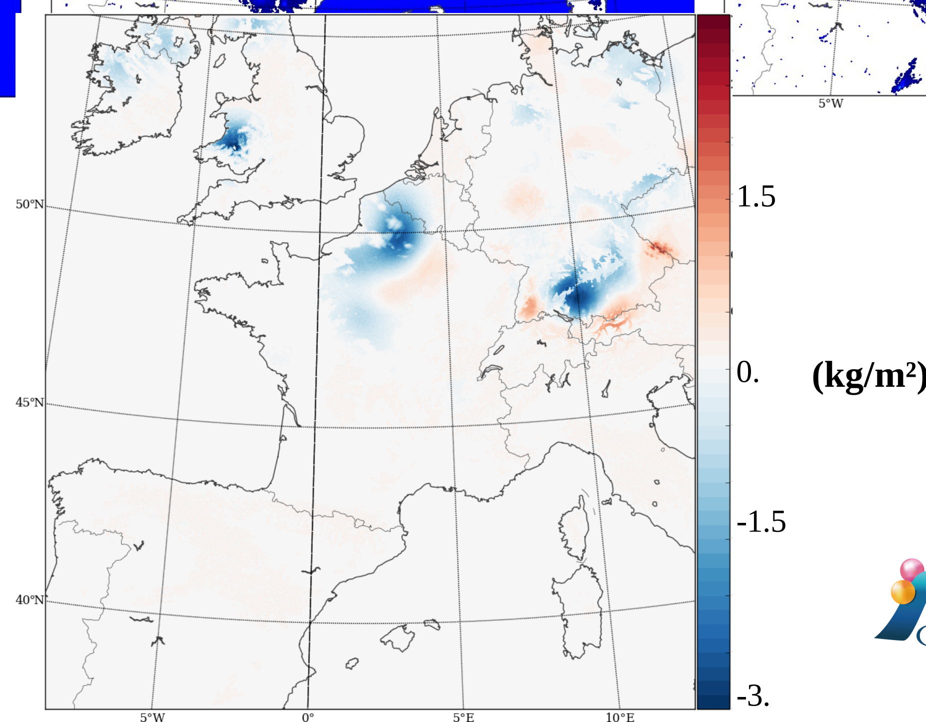


Snow analysis: case study on 22th January 2019, 12:00

Background | **Analysis** | **Reference**



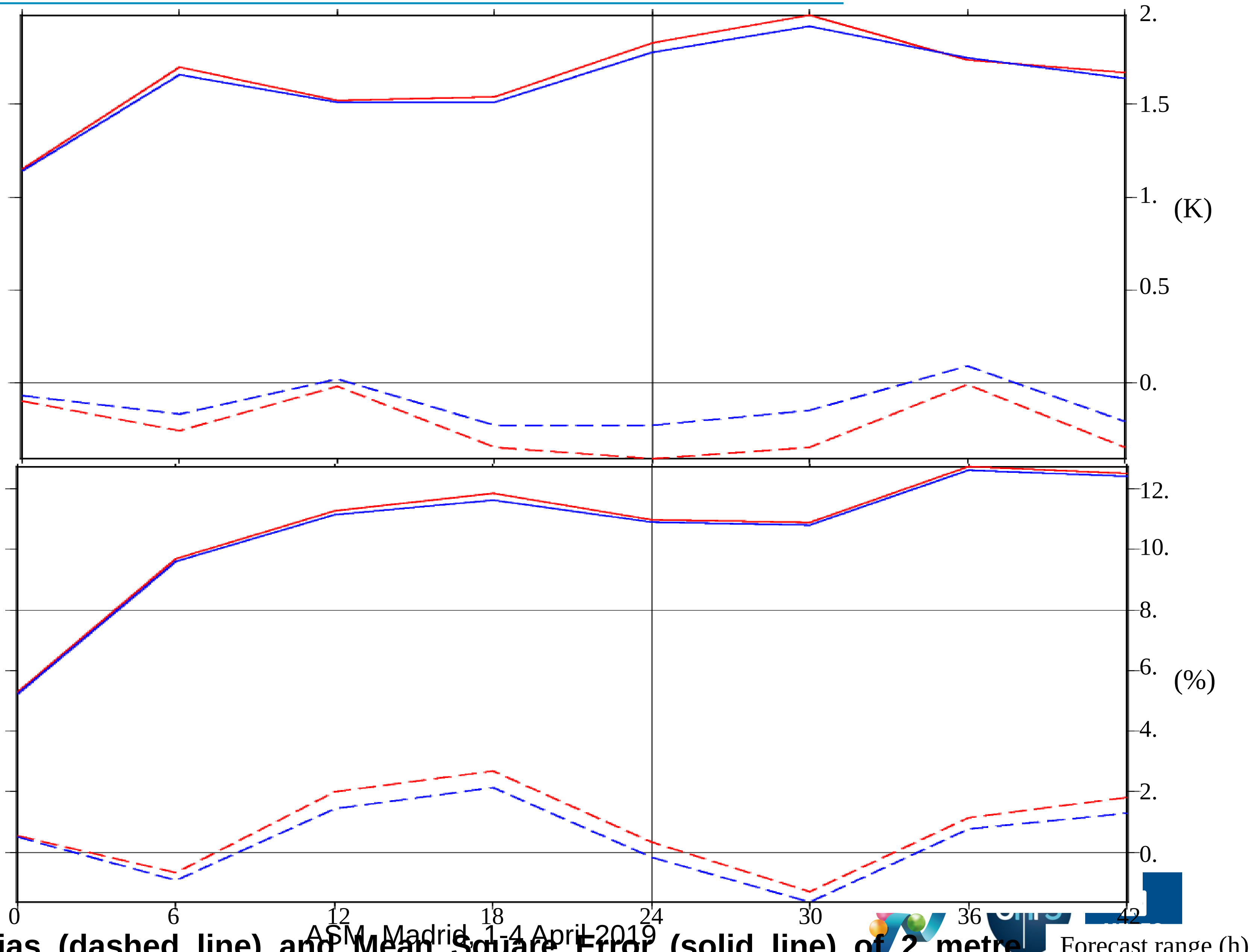
Analysis Increment (σ_o = 5 kg/m²)



Snow analysis: bias and MSE on February 2018 with respect to Synop stations (9 simulations)

T2m
(σ_o = 5 kg/m²)

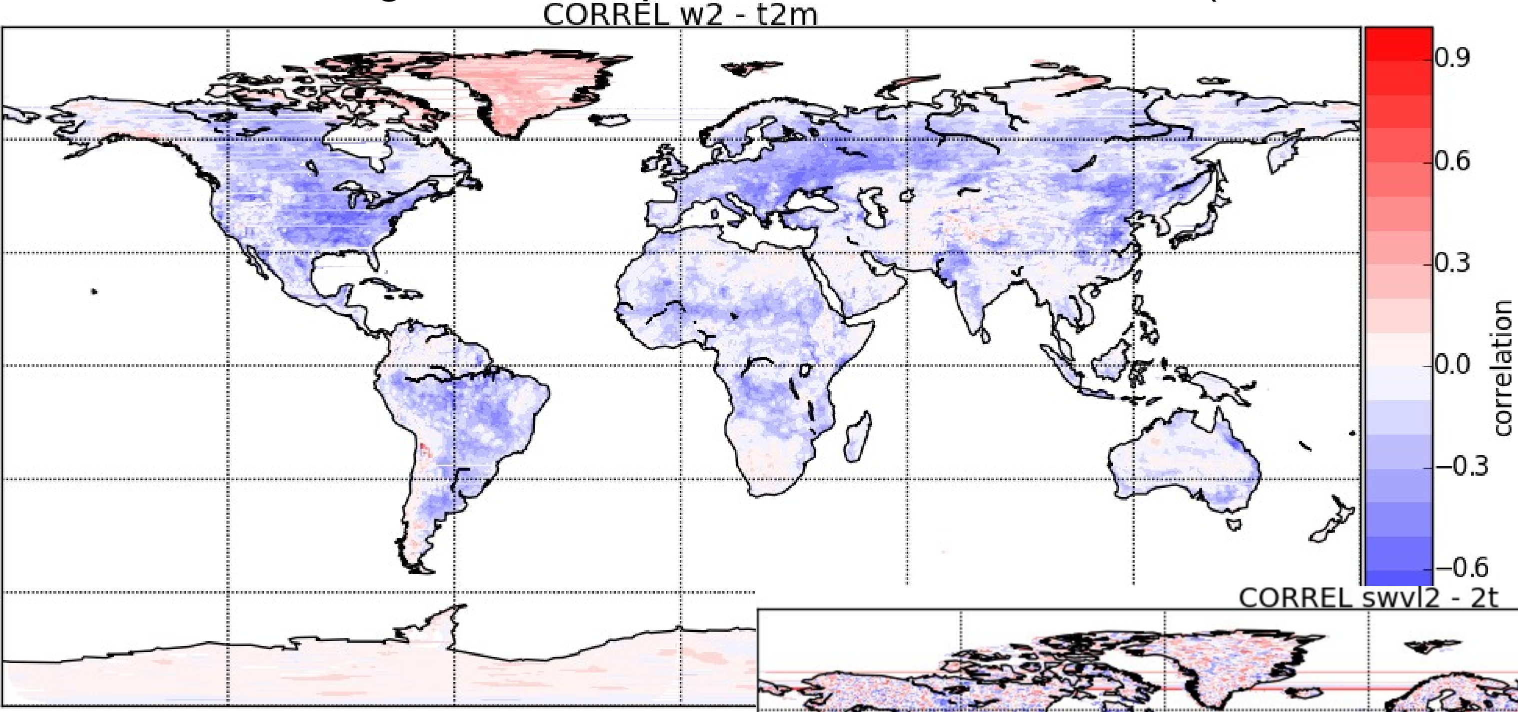
Hu2m
(σ_o = 5 kg/m²)



Bias (dashed line) and Mean Square Error (solid line) of 2 metre temperature and 2 metre relative humidity forecasts as a function of the forecast range, with (blue) and without (red) snow analysis

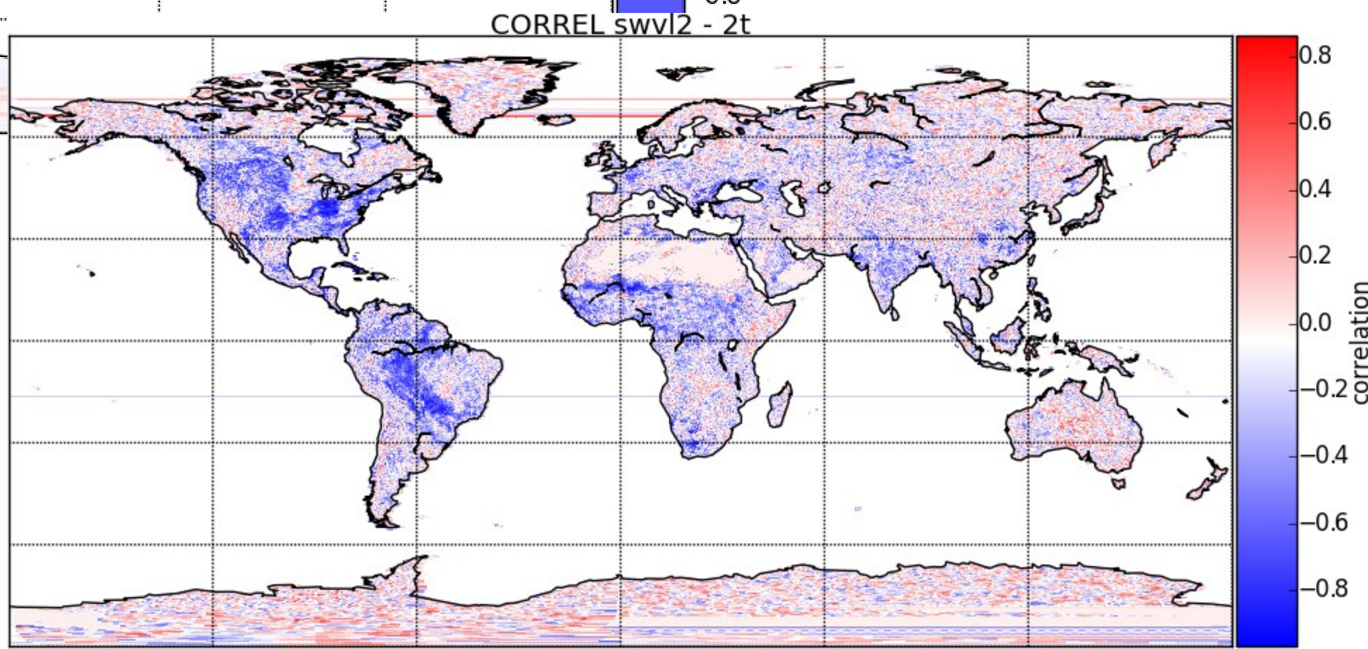
Diagnostics using ARPEGE EDA for surface analysis

- Diagnostics on a summer period (August 2017): Correlations between w_2 and T_{2m} averaged ove the period. Coll. with ECMWF (Patricia de Rosnay)



AEARP

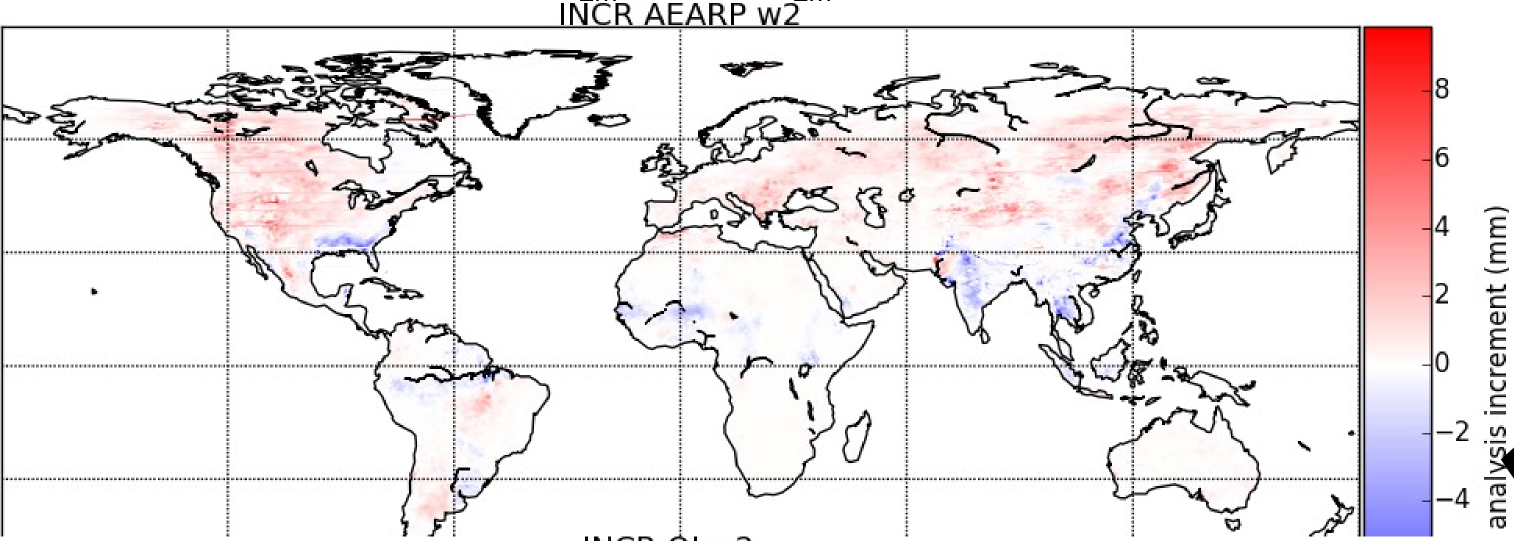
Correlations between w2 and T2m computed over a 3-weeks period (August 2017, all analysis times)



EDA ECMWF

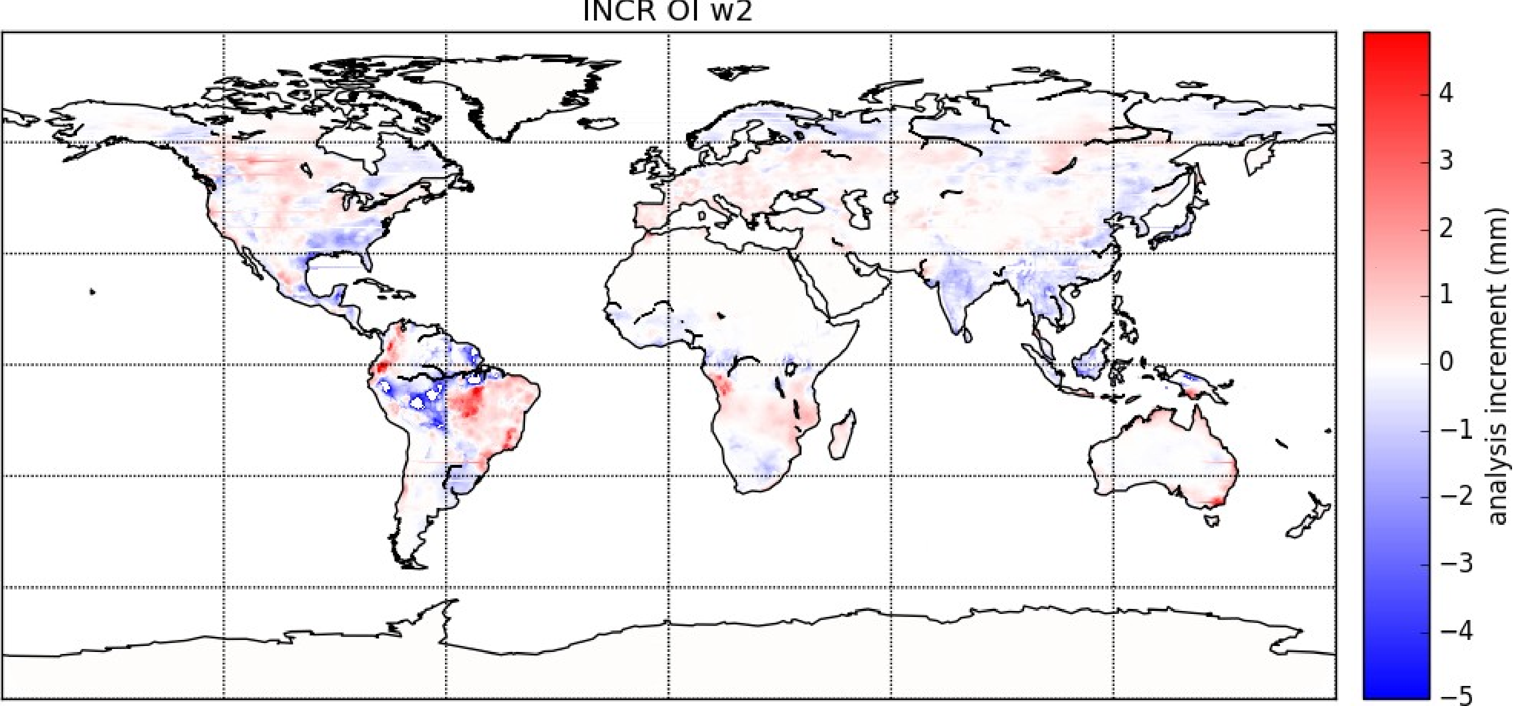
Diagnostics using ARPEGE EDA for surface analysis

- Analysis increments for soil variables and comparison with OI increments (operationnal T_{2m} and RH_{2m} increments)



Mean w2 increments during August 2017 using EDA

X 2



Mean w2 increments during August 2017 using OI

Conclusions and future work

- Analysis of surface parameters: snow depth, precipitation (2D optimal interpolation), ...(LAI); improvement of analysis techniques, in particular in areas of complex orography (MESCAN)
- Improvement of the land surface data assimilation system: ensemble methods (EnKF, particle filter…) and use of atmospheric ensembles produced by ensemble data assimilation systems (AEARP → global model ARPEGE, AEARO → limited area model AROME)
- Assimilation of satellite products, in particular for surface temperature (PhD Zied Sassi), for soil moisture (soil moisture product from ASCAT, and/or from L-band sensors SMOS/SMAP), for snow (snow cover products Nesdis-IMS/H-SAF product/Modis?) and for albedos (products from LSA-SAF)