Surface data assimilation activities in the HIRLAM consortium

LACE DA Working Days 2016

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Outline

SMHI

- Introduction
- Surface data assimilation for nature tile
  - MESCAN
  - EKF and EnKF activities
  - Snow data assimlation
- SST and Sea ice
- Lakes
- Town
- Plans for the future

Introduction

SMHI

•The current operational HARMONIE-AROME configuration setup of the ALADIN-HIRLAM NWP system is cy38 (cy40), utilizing the SURFEX v7.2 (v7.3) for the surface. It describes the physical models for natural landsurface (nature), urbanized areas (TEB), lakes and oceans, as represented by 4 different tiles. Each gridpoint is subdivided into these tiles.

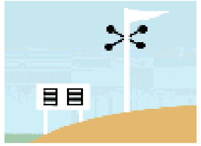
•For the landsurfacetile we use the option 3-L (Force restore, 2 layers temp, 3 water, ice) and D95 (Douville) snowscheme (1 layer, prog. SWE, albedo, density). It is configured to use a three-layer force-restore formulation for surface variables and the D95 snow scheme.

•Most activities initialization of the nature tile (soil temperature and surface as well as snow), but there are activities also for initializing other tiles.

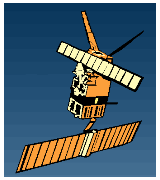
Introduction

SMHI

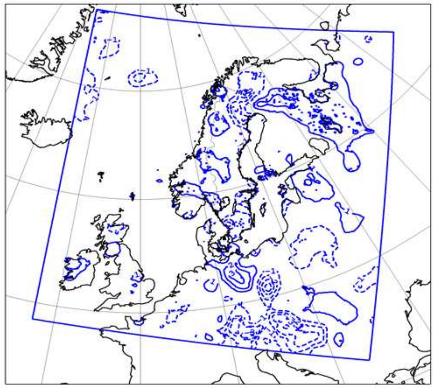
HARMONIE-AROME Surface Data Assimilation for Nature Tiles



(Snow,T_{2m}, RH_{2m})



CANARI



Snow

T_s, w_g

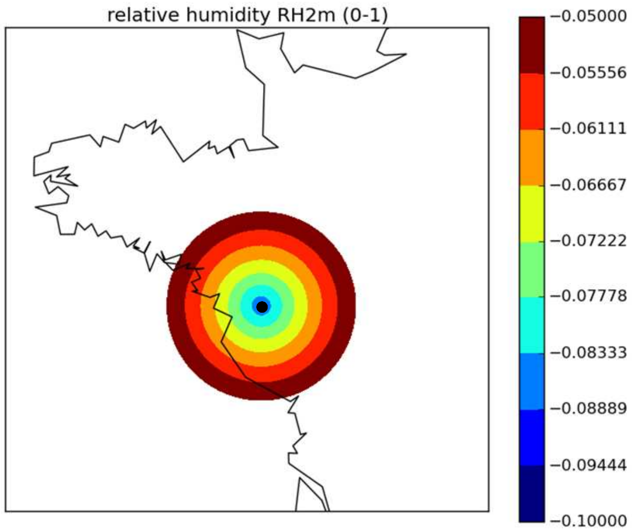
T_2, w_2

OI, EKF, EnKF

Horizontally varying background error statistics

Impact of one single SYNOP Relative Humidity observation at the 2 meters height unit (%). The observation is located close to the west coast of France and the observed relative humidity is approximately 15 % less than the corresponding model value.

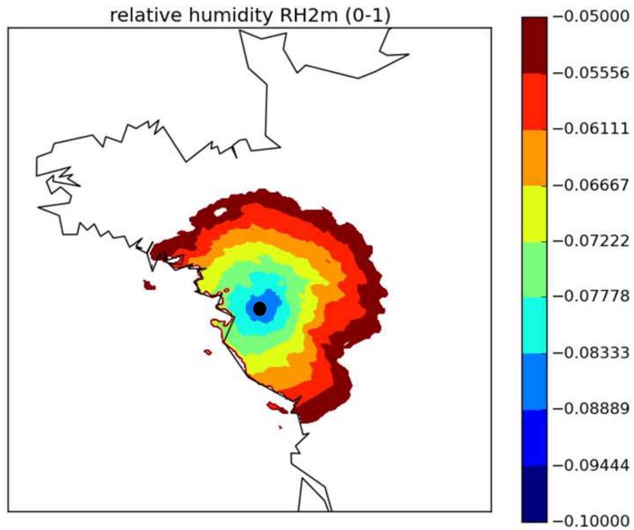
Current Method




```
ro12=exp(-r/2a)
```

a – 85 km

Improved Method



$$Corr(r_{ij}, d_p, d_z) = 0.5\left[e^{-\frac{r_{ij}}{L}} + \left(1 + \frac{2r_{ij}}{L}\right)e^{-\frac{2r_{ij}}{L}}\right] \cdot F_p(d_p)F_z(d_z)$$

L – 195 km
(vertical correlation scale ~500m)

Default HARMONIE-AROME configuration surface data assimilation for nature tile

(Mahfouf, 1991 ; Giard and Bazile, 2000)

$$w_g^a = w_g^b + \alpha_1 (T_{2m}^a - T_{2m}^b) + \alpha_2 (RH_{2m}^a - RH_{2m}^b)$$

$$w_2^a = w_g^b + \beta_1 (T_{2m}^a - T_{2m}^b) + \beta_2 (RH_{2m}^a - RH_{2m}^b)$$

$$T_s^a = T_s^b + \mu_1 (T_{2m}^a - T_{2m}^b) + \mu_2 (RH_{2m}^a - RH_{2m}^b)$$

$$T_2^a = T_2^b + \nu_1 (T_{2m}^a - T_{2m}^b) + \nu_2 (RH_{2m}^a - RH_{2m}^b)$$

$$T_s, w_g$$

$$T_2, w_2$$

In MetCoOp HARMONIE-AROME configuration we have changed the parameter v_1 from 1/(2*pi) to 1/2. An associated change in the snow scheme is needed in order to prevent spurious feedback effects during spring snow-melting.

•EKF formulation

Analysis

$$\mathbf{x_a}^t = \mathbf{x_b}^t + \mathbf{BH}^T(\mathbf{HBH}^T + \mathbf{R})^{-1}(\mathbf{y}_o^t - \mathcal{H}(\mathbf{x_b}^t))$$

$$\mathbf{H}_{ij} = \frac{\partial \mathbf{y}_i}{\partial \mathbf{x}_j} \qquad \mathbf{H}_{ij} \simeq \frac{\mathbf{y}_i(\mathbf{x} + \delta x_j) - \mathbf{y}_i(\mathbf{x})}{\delta x_j}$$

$$\mathbf{A} = (\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1}$$

Propagation

$$\mathbf{x_b}^{t+1} = \mathcal{M}(\mathbf{x_a}^t)$$

$$\mathbf{B}^{t+1} = \mathbf{M}\mathbf{A}^t\mathbf{M}^T + \mathbf{Q}$$

•EnKF formulation

$$\mathbf{BH}^T \approx \overline{(\mathbf{x_b} - \overline{\mathbf{x_b}})(\mathcal{H}(\mathbf{x_b}) - \overline{\mathcal{H}(\mathbf{x_b})})^T}$$

$$\mathbf{HBH}^T \approx \overline{(\mathcal{H}(\mathbf{x_b}) - \overline{\mathcal{H}(\mathbf{x_b})})(\mathcal{H}(\mathbf{x_b}) - \overline{\mathcal{H}(\mathbf{x_b})})^T}$$

$$\overline{\mathbf{x}} = \frac{1}{N}\sum_{i=1}^{N} \mathbf{x}_i \qquad \overline{\mathbf{x}\mathbf{y}^T} = \frac{1}{N-1}\sum_{i=1}^{N} \mathbf{x}_i\mathbf{y}_i^T$$

EKF and EnKF activities

•EnKF

+ Solves for mean, no assumption about higher order terms.

+ Suffice to compute h(x), no need to explicitly specify **H**.

+ Only need to be able to advance model in time.

+ Same approach for upper air and surface (and ocean).

+ Easy to extend to 4D (asynchronous obs).

- Al pdf:s are assumed to be Gaussian.

- Few ensemble members can lead to spurious correlations.

EKF

+ **B** not estimated from ensemble - no spurious errors.

- Cannot afford dynamic **B** with horizontal correlations.

- Hard to use asynchronous obs.

- Approximating linear **H** with perturbations may cost more than EnKF.

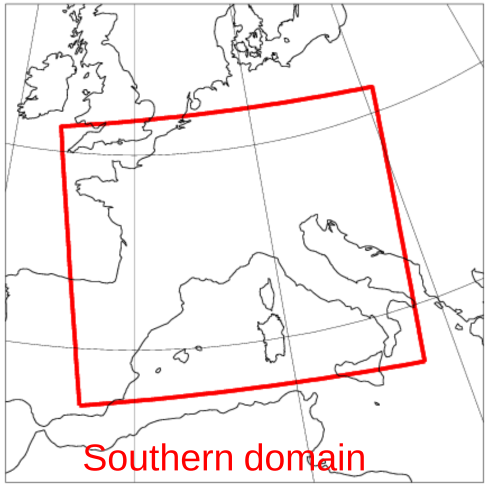
- Linearisation can result in unbounded error.

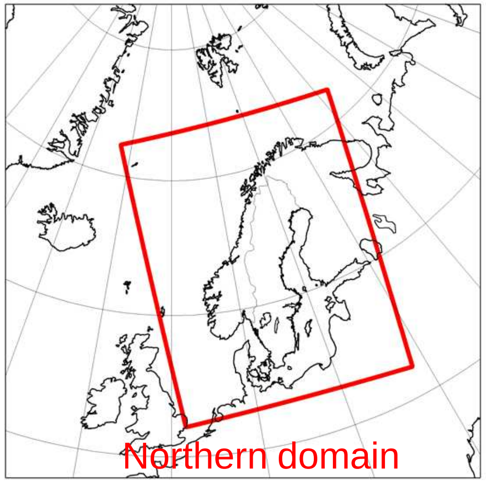
- Central forecast not equal to mean for non-linear system.

EKF activities

IMPREX modelling and data assimilation

Applying the ALADIN-HIRLAM NWP system with HARMONIE-AROME configuration including data assimilation as input for hydrological models and as a reference evaluation of data assimilation developments. Horizontal grid-distance of the HARMONIE-AROME configuration is 2.5 km and 65 vertical levels.





For southern domain forecasts 4 times a day with 3h output frequency up +48 h for cases:

- 12-19 June 2013
- 21-28 July 2013
- 22-25 June 2014
- 28 June-5 July 2014
- (24 July-1 Aug 2014)

For Northern domain forecasts 4 times a day with 3h output frequency up to +60h for cases:

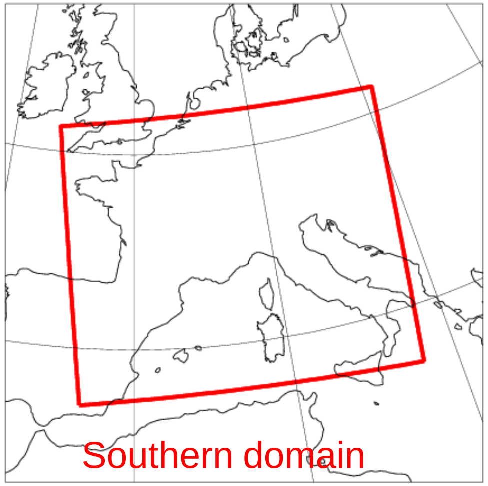
- Exact dates TBD

In addition to HARMONIE-AROME configuration runs with improved data assimilation will be carried out for some cases.

EKF activities

SMHI

Southern HARMONIE-AROME configuration domain, Case 1, 12-19 June 2013

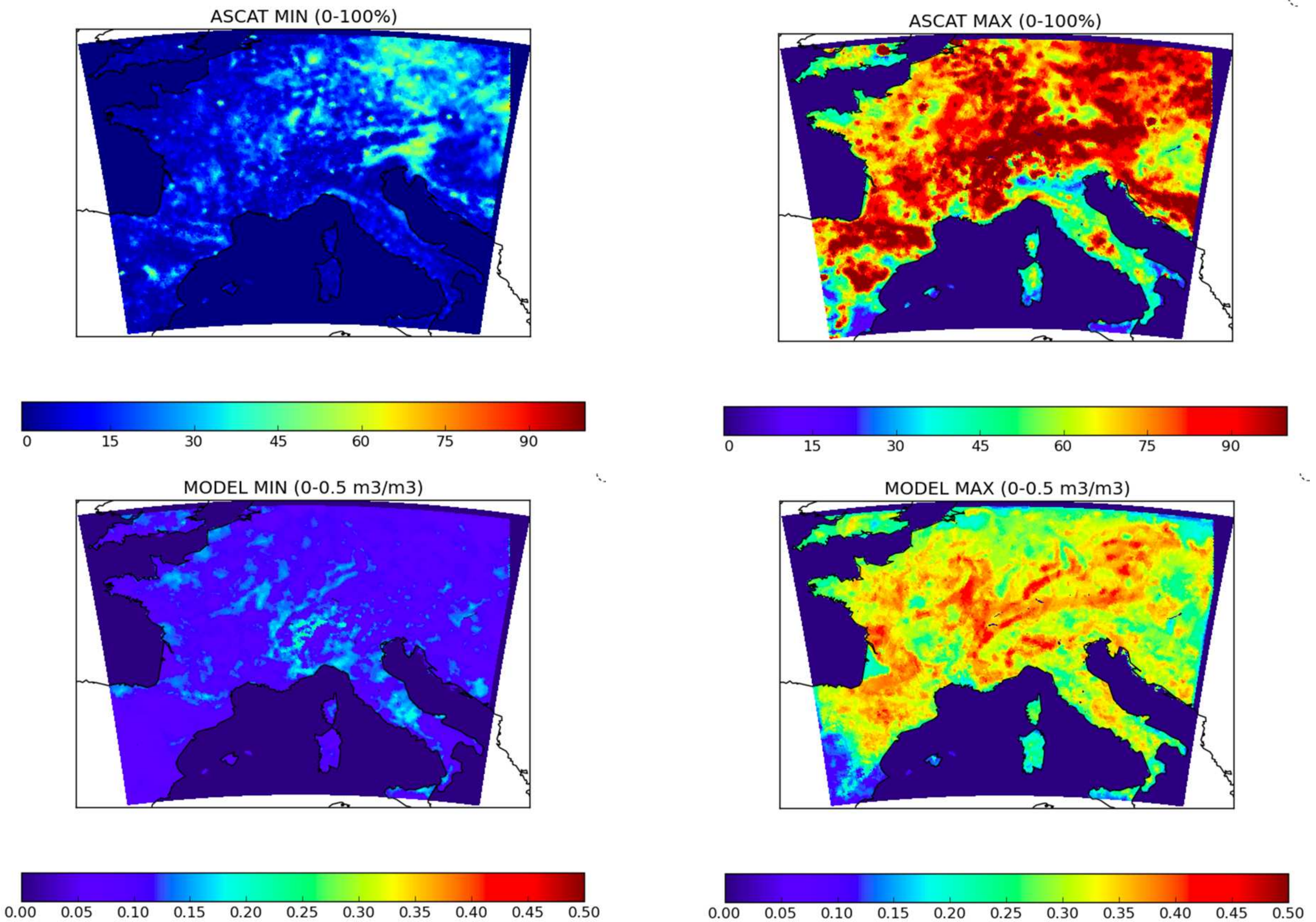


- 3D-Var, CANARI+OImain (T2m, RH2M)
- 3D-Var, MESCAN+OImain (T2m,RH2m)
- 3D-Var, MESCAN+EKF (T2m,RH2m)
- 3D-Var, MESCAN+EKF (T2m, RH2M, ASCAT)

Investigate impact of improved surface data assimilation.

EKF activities

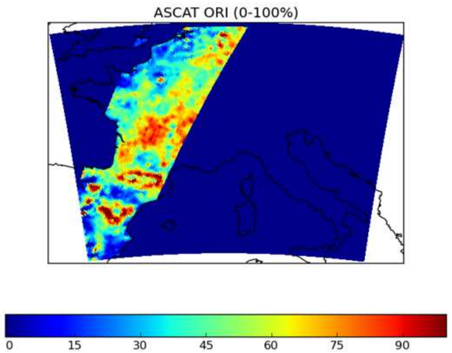
Based on 2 months ASCAT METOP-A (METOP-B) and model data wg1 maximum and minimum ASCAT METOP-A (METOP-B) and model data were calculated for each grid-point.

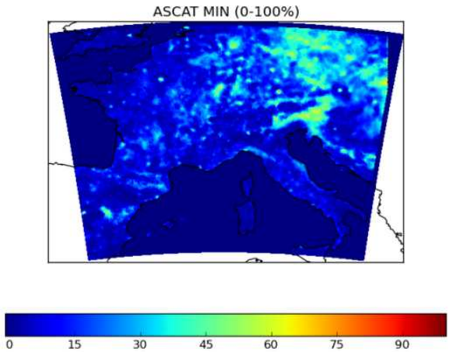


EKF activities

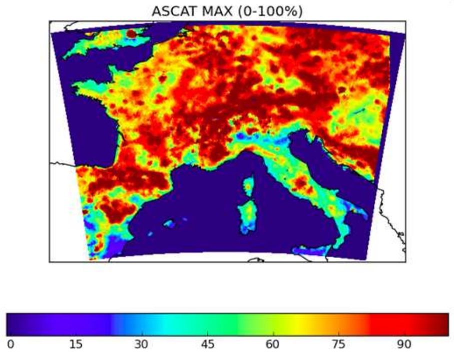
Processing and conversion of ASCAT derived soil moisture product
Illustartion for ASCAT METOP-A at 20130614 09 UTC

Derived Product (%) (in top layer)



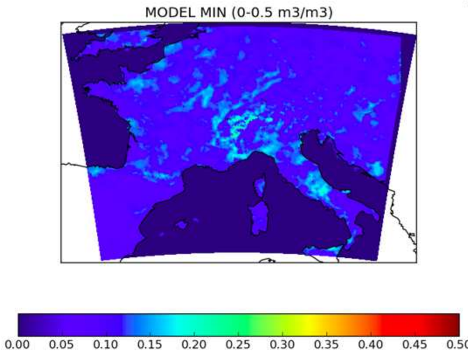


Ascatmin

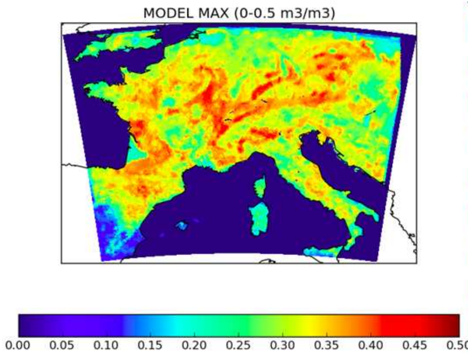


Ascatmax

$$Ascatout = Modmin * \frac{Modmax - Modmin}{Ascatmax - Ascatmin} \text{*(Ascatraw-Ascatmin)}$$



Modmin



Modmax

Transformed Product (m3/m3 Model uppermost layer)

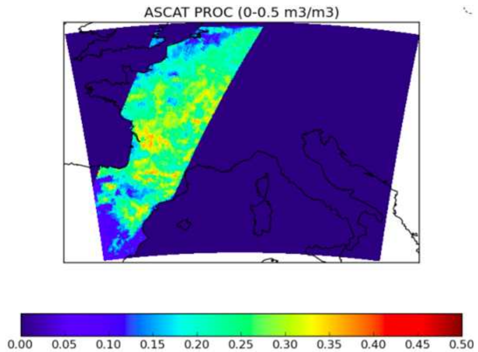
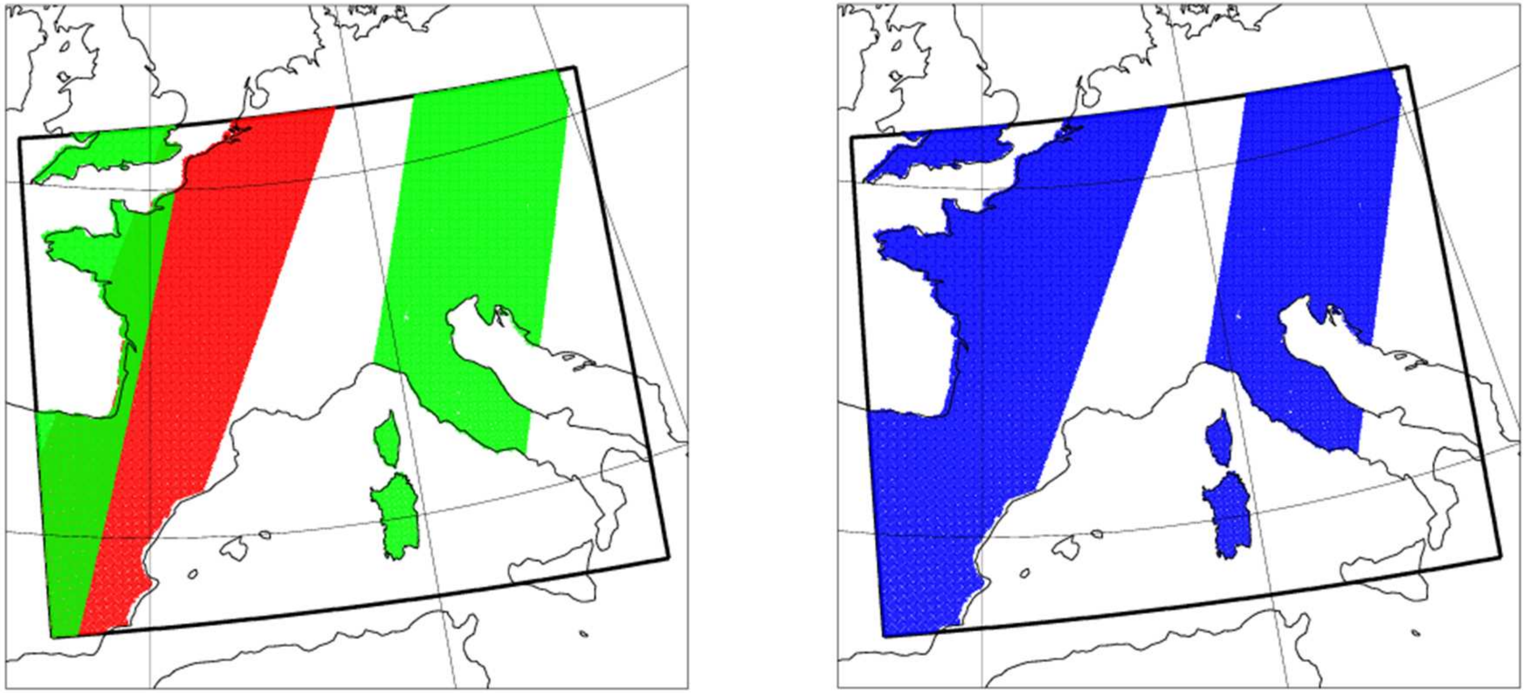


ILLUSTRATION OF SCATTEROMETER DATA COVER AND MERGING 2014061409

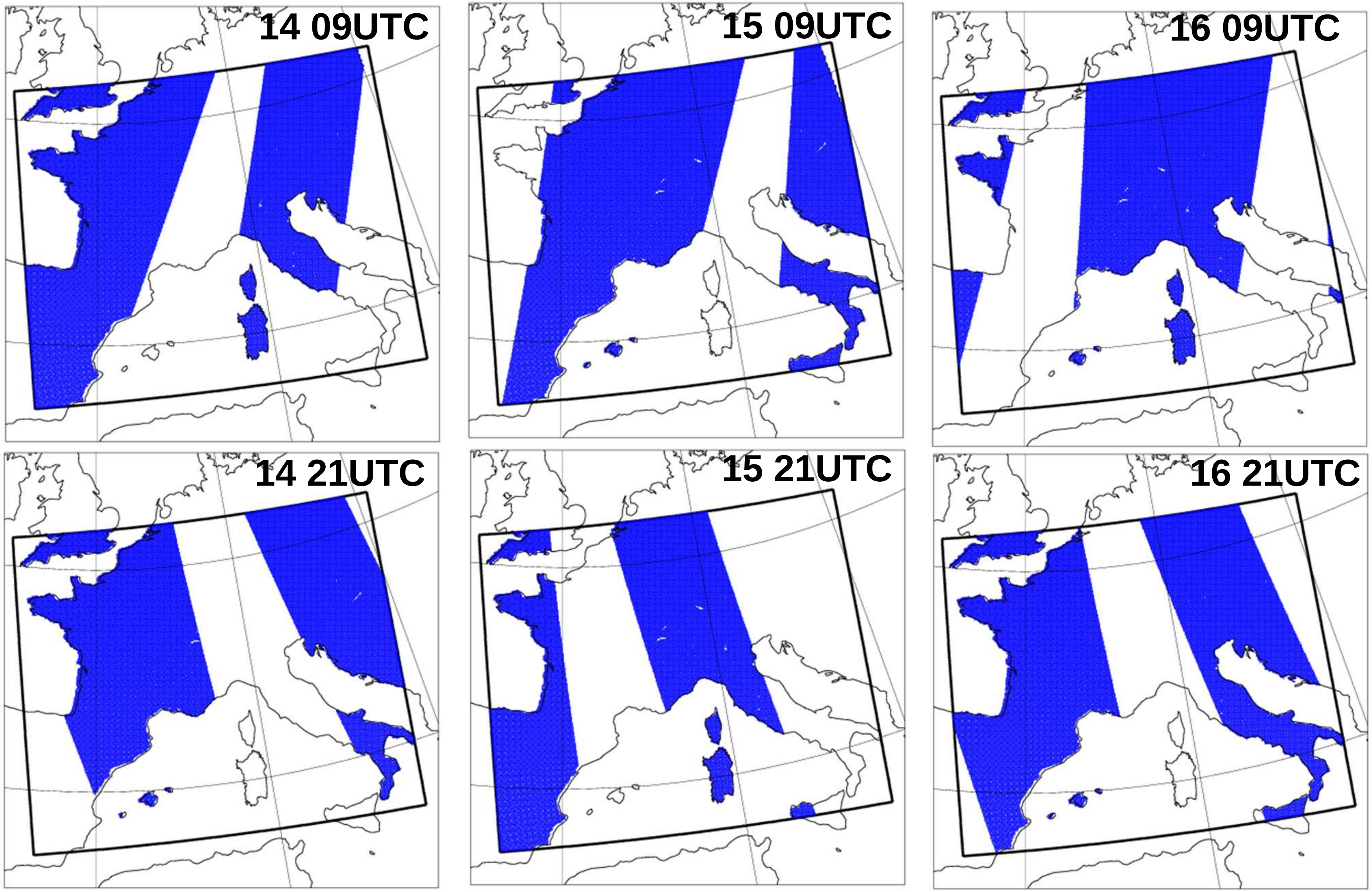
ASCAT METOP-A, ASCAT METOP-B, ASCAT COMBINED



EKF activities

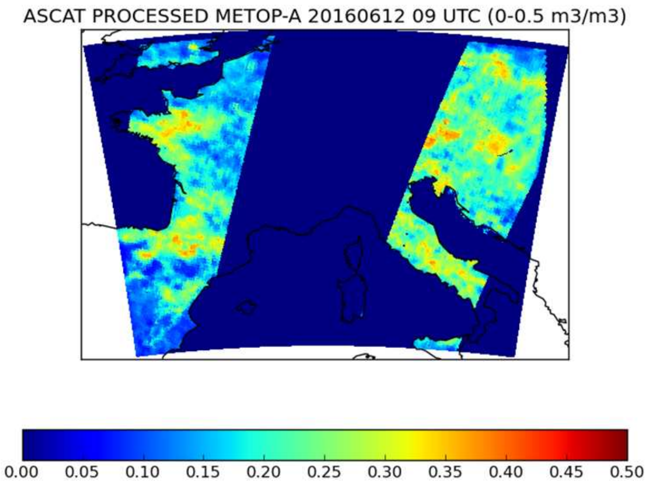
SMHI

ASCAT DATA COVERAGE

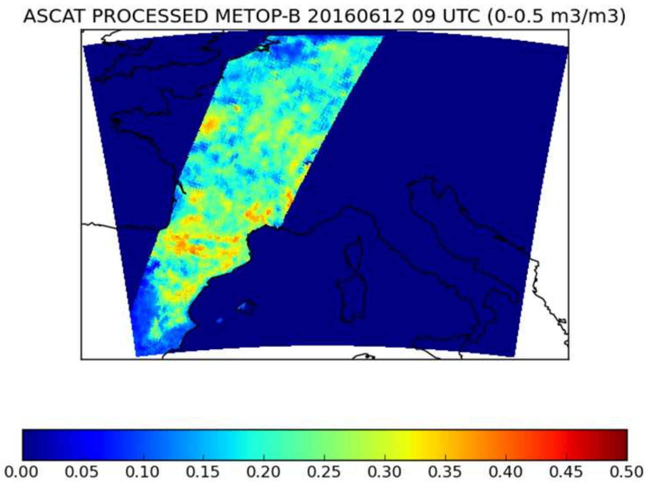


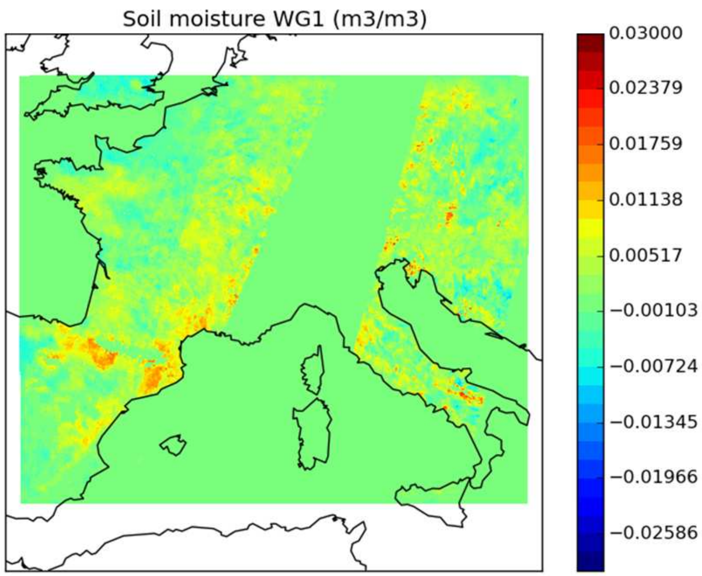
EKF activities

Surface Data Assimilation of ASCAT data using EKF



INDATA
20160612
09 UTC





EKF based surface data assimilation WG1 increments 20160612 09 UTC

EKF activities

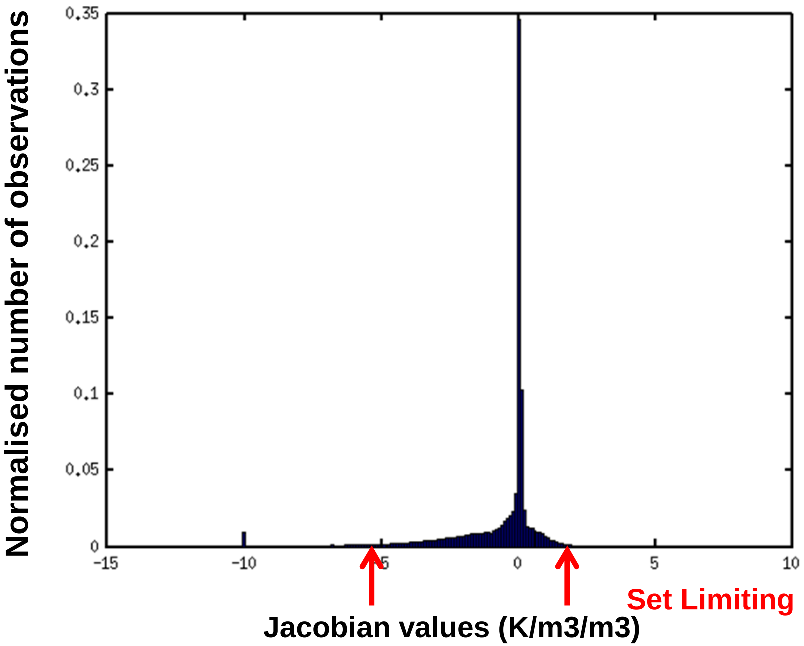
SMHI

Tuning of the EKF system needed

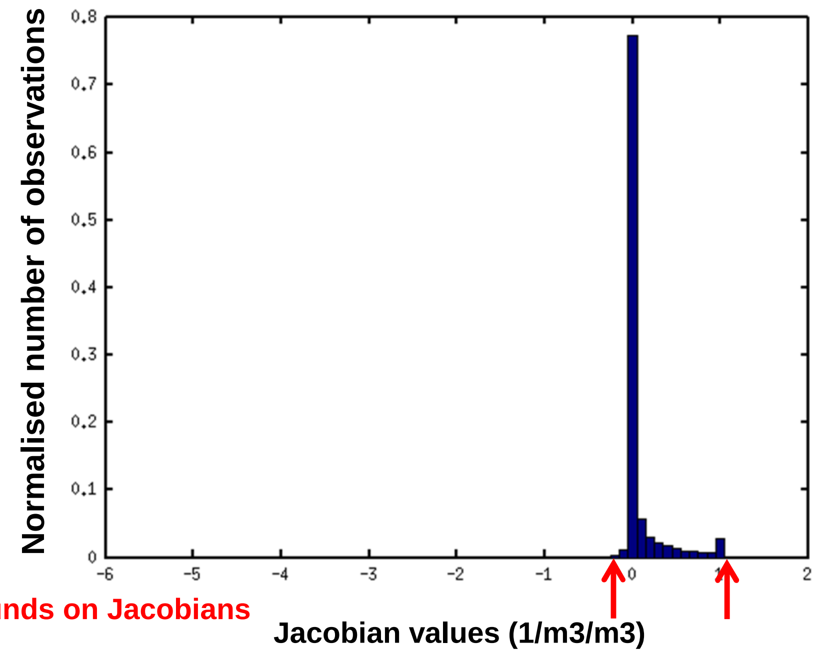
- Error specification
- Handling of large and noisy Jacobians

$$\mathbf{H}_{ij} \simeq \frac{\mathbf{y}_i(\mathbf{x} + \delta x_j) - \mathbf{y}_i(\mathbf{x})}{\delta x_j}$$

dT2m/dT1



dRH2m/dwg1



Set Limiting bounds on Jacobians

Remote sensing data and observation operators

Sentinel-1/SAR-C: wet snow, snow extent, (dry snow?)
- S1A_EW_GRDM_1SDH
- Extra Wide swath mode VV+VH and HH+HV, ca 25 x 80 m
- MEMLS3&a

GCOM-W1/AMSR2
soilm (7 Ghz), deep (10, 19 GHz), moderate (37 GHz), shallow snow (89 GHz)
- L1SGRTBR
- Level 1R V,H, ca 40 x 60 km
- Community Microwave Emission Modelling Platform (CMEM): 1 – 20 Ghz
- FASTEM + RTTOV?

SMOS/MIRAS, L band 1.4 GHz: soil moisture
- MIR_SCL[FD]1C
- Level 1C Land Science Measurements product, dual (or full) polarization, ca 50 x 50 km, ISEA 4-9 hexagonal grid
- CMEM + FASTEM (water)?

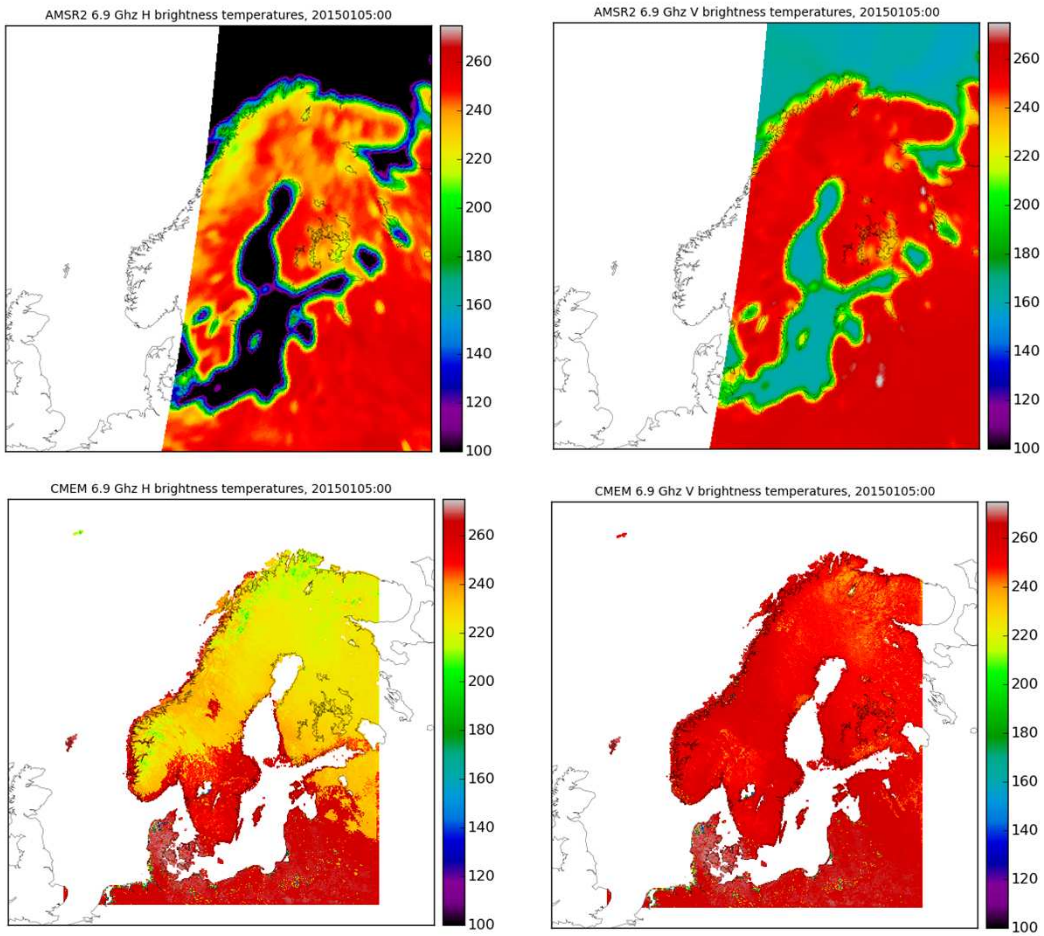
Observation operator for Radiances AMSR2 level 1C, 6.9 GHz

H brightness temperatures

V brightness temperatures

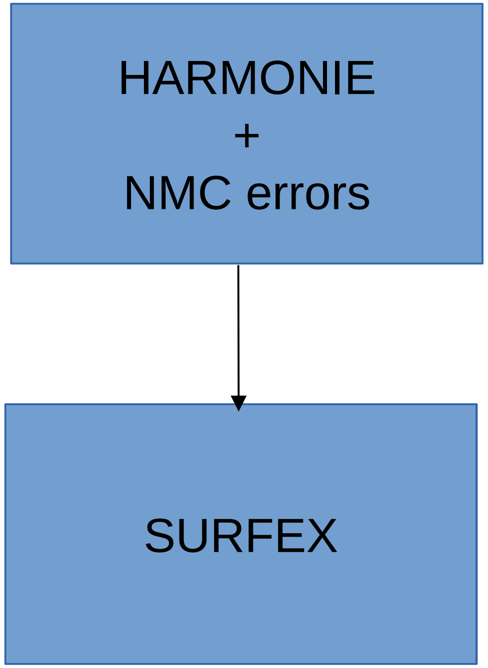
Observed radiances

model counterparts derived with observation operator



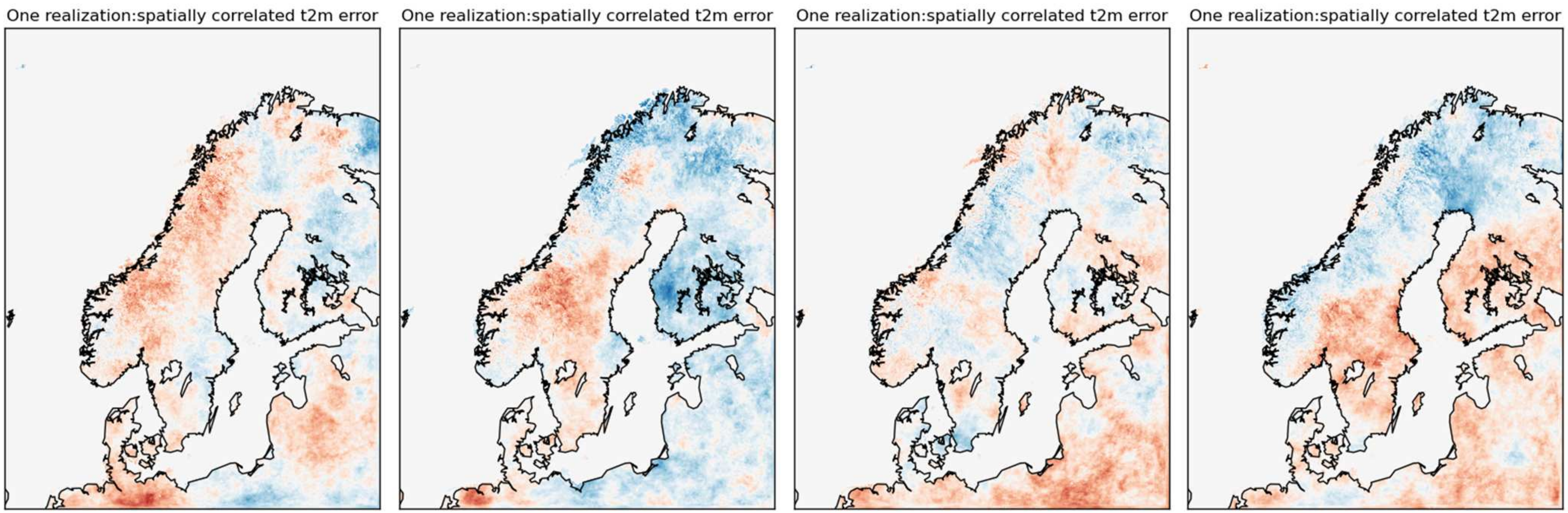
EnKF activities

Spatially correlated errors in the forcing



$$
\begin{aligned}
x_k &= fc_{48} - fc_{24} (m \, x \, 1) \\
X &= [x_1, \ldots, x_n] (m \, x \, n) \\
B &= X X^T (m \, x \, m) \\
B_s &= X^T X = E_s D_s E_s^T (n \, x \, n) \\
X E_s (X E_s)^T &= X X^T = B \\
&= E_l D_s E_l^T \quad , \quad E_l = X \hat{E}_s (m \, x \, n) \\
z &= E_l D_s^{1/2} e \quad , \quad e \in N(0, I) \\
E\{z z^T\} &= E_l D_s E_l^T = B
\end{aligned}
$$

Four examples of spatially correlated t2m errors (z)



These are not fc48-fc24 differences, but samples drawn using

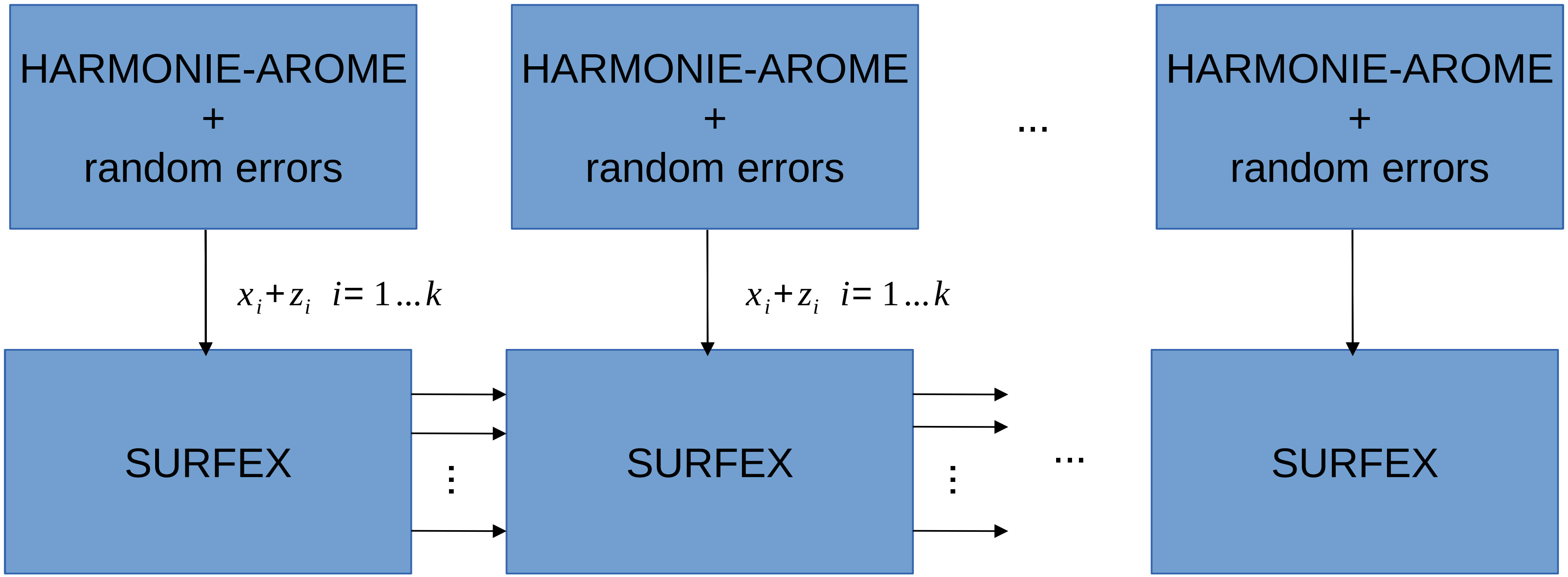
$$z = E_l D_s^{1/2} e, \quad e \in N(0, I)$$

$$z = E_l D_s^{1/2} e, \quad e \in N(0, I)$$

NMC statistics from 20140401-1231; m =nx*ny*npar,n=1000.

EnKF ongoing work

Creating an initial SURFEX ensemble (spin-up)



How many members (k) are called for?
How long time do we need to run to spin up a sufficiently rich ensemble?

Snow Data Assimilation

- A visiting student at FMI, Maxime Quenon, has published a report on “Visual and Statistical Analysis of Snow Cover” where snow extent (SE) and Snow-Water Equivalent (SWE) simulated by cy38h1.2 HARMONIE-AROME-SURFEX has been compared with SYNOP snow depth, MetOp and MSG SE and Globsnow SWE. Report available via hirlam.org.

- Next step is to utilize the satellite SE product H-SAF. Other possible sources of satellite snow-related information are H-SAF SWE, based on microwave data (similar to Globsnow), and L-SAF albedo.

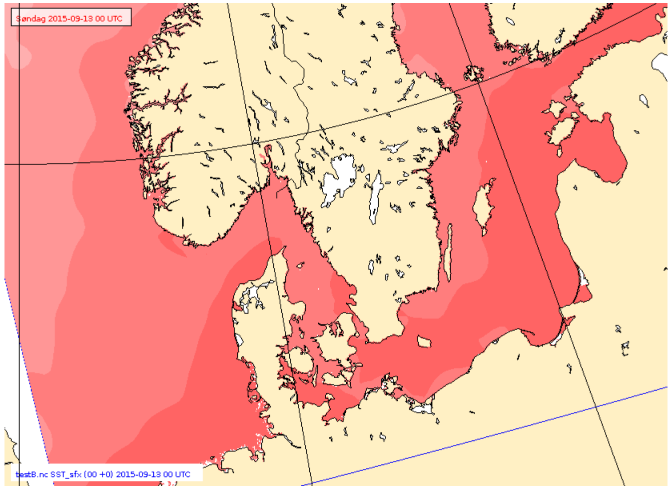
- The question of combining all the different sources in the process of assimilation, taking into account the available background fields and possible observation operators, needs further studies and possibly more advanced methods than straight-forward optimal interpolation.

- It seems reasonable to start from simple combination of H-SAF SE, current SYNOP and first guess SWE. This has been done in ECMWF and at UKMO and, based on Cryo Risk satellite data, by Mariken for CANARI. Early work with L-SAF albedo has been reported by Jure Cedilnik.

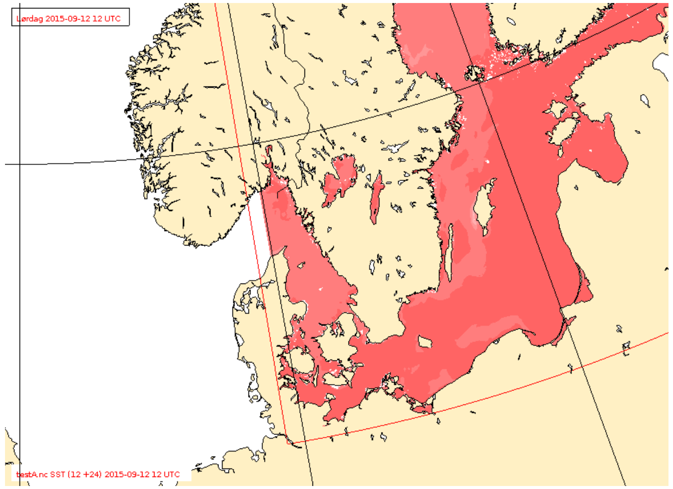
SST and Sea Ice

SST in Baltic Sea from oceanography model HIROMB (later NEMO)

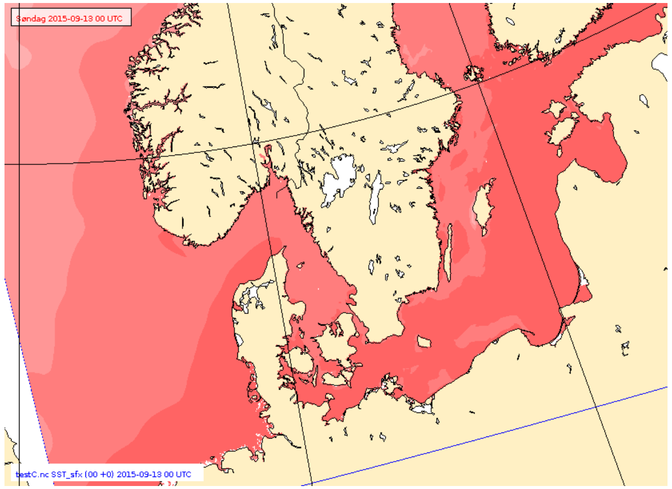
ECMWF SST



HIROMB SST



Combined SST



Sea ice modelling and DA

SMHI

Since cy38h1.2 the "Simple Ice" model (SICE) by Yurii Batrak (MetNorway) is running operationally in the HARMONIE-AROME configuration. SICE uses the SURFEX diffusion soil scheme with ice characteristics. The HIRLAM intention is to make SICE an official contribution to SURFEXv9.

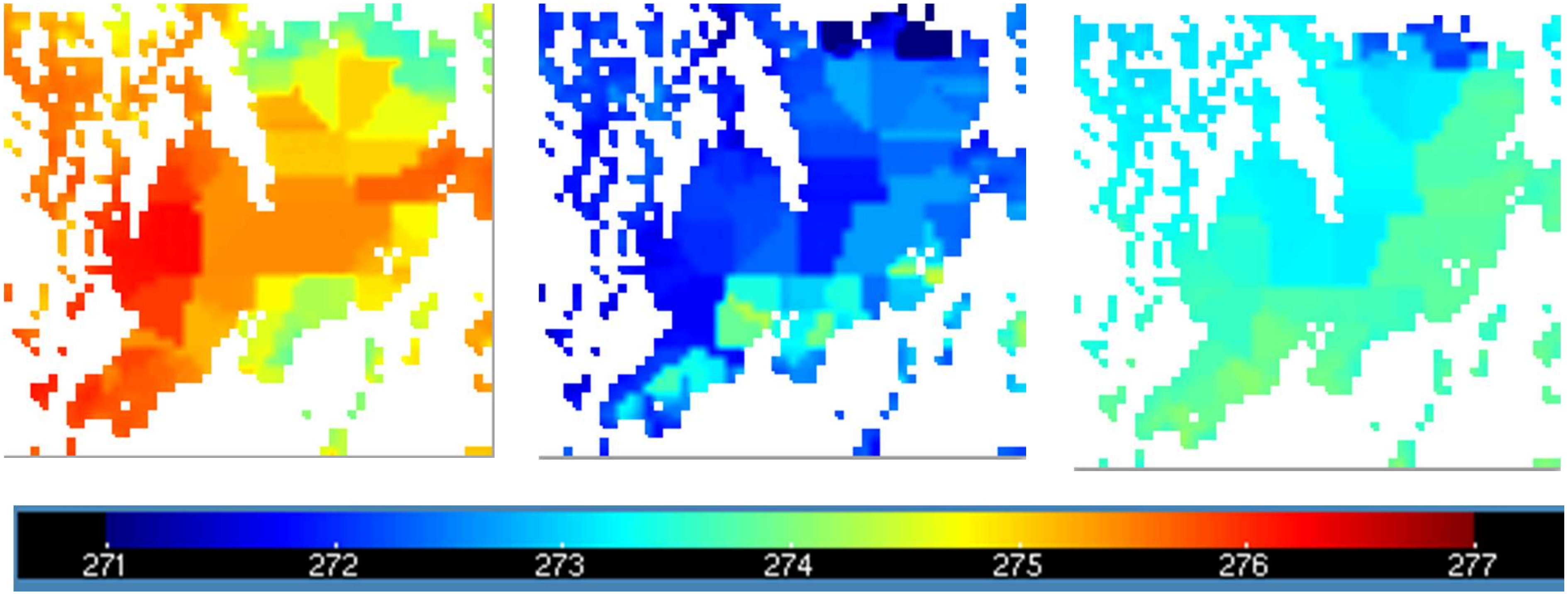
Before SICE was used any sea ice was given an initial temperature in SURFEX PREP which was kept constant during the forecast. Now, we have prognostic sea-ice temperature.

However, there are no assimilation methods available for sea-ice conditions yet (sea-ice temperature, ice extent, ….). Possible satellite products exist and also buoy data from sea-ice mass balance (SIMBA) and we need EKF assimilation methods to utilize such data. Work on this is included in our Rolling Plan for surface activities.

Lakes

Current approach: TS_WATER as extrapolated from TG2

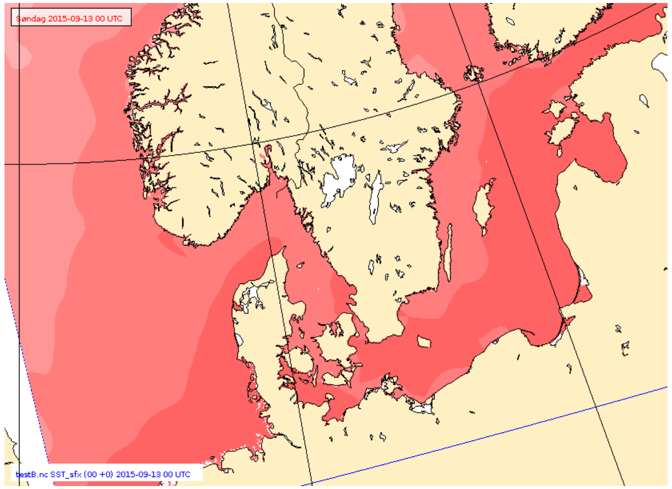
10/2 25/2 5/3



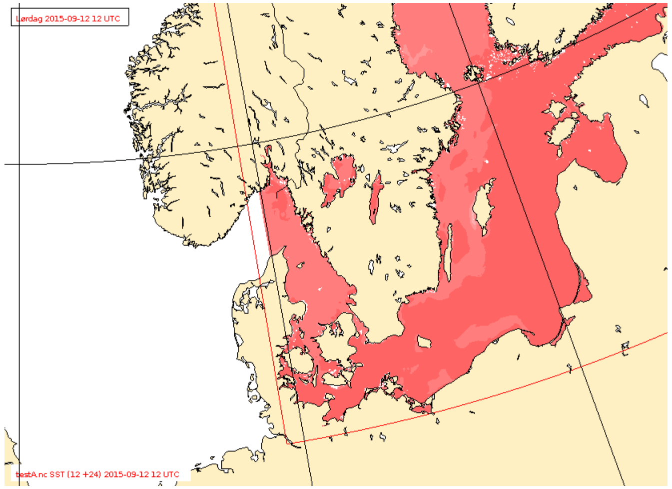
Lakes

SST in Baltic Sea from oceanography model HIROMB (later NEMO)

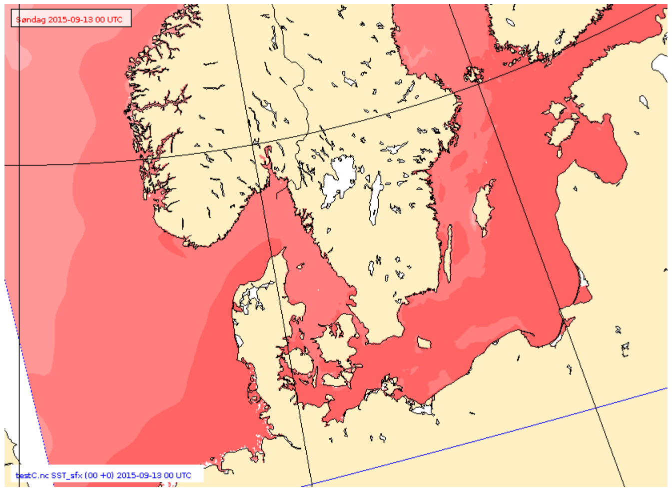
ECMWF SST



HIROMB SST



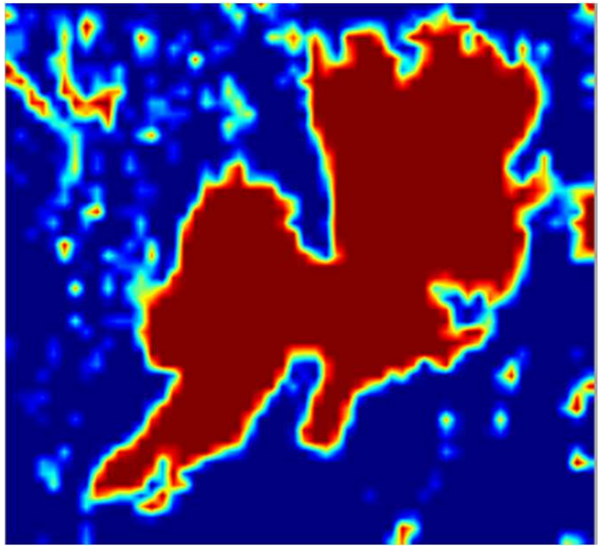
Combined
SST

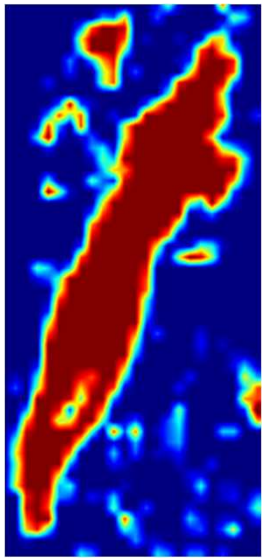


Note HIROMB also applied for Swedish big lakes.

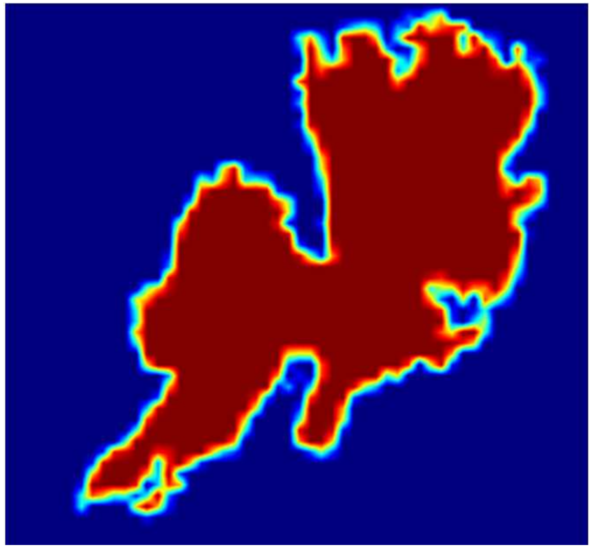
Lakes

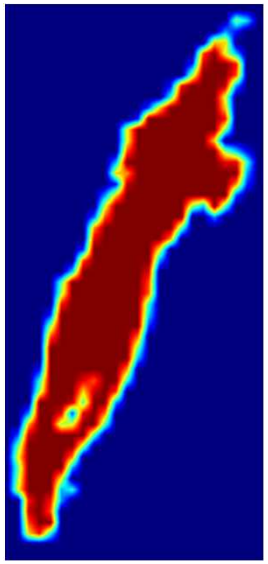
FRAC_WATER → FRAC_SEA Done in climate generation step





Select gridpoints using a polygon. Could possibly be more connected to the HIROMB grid



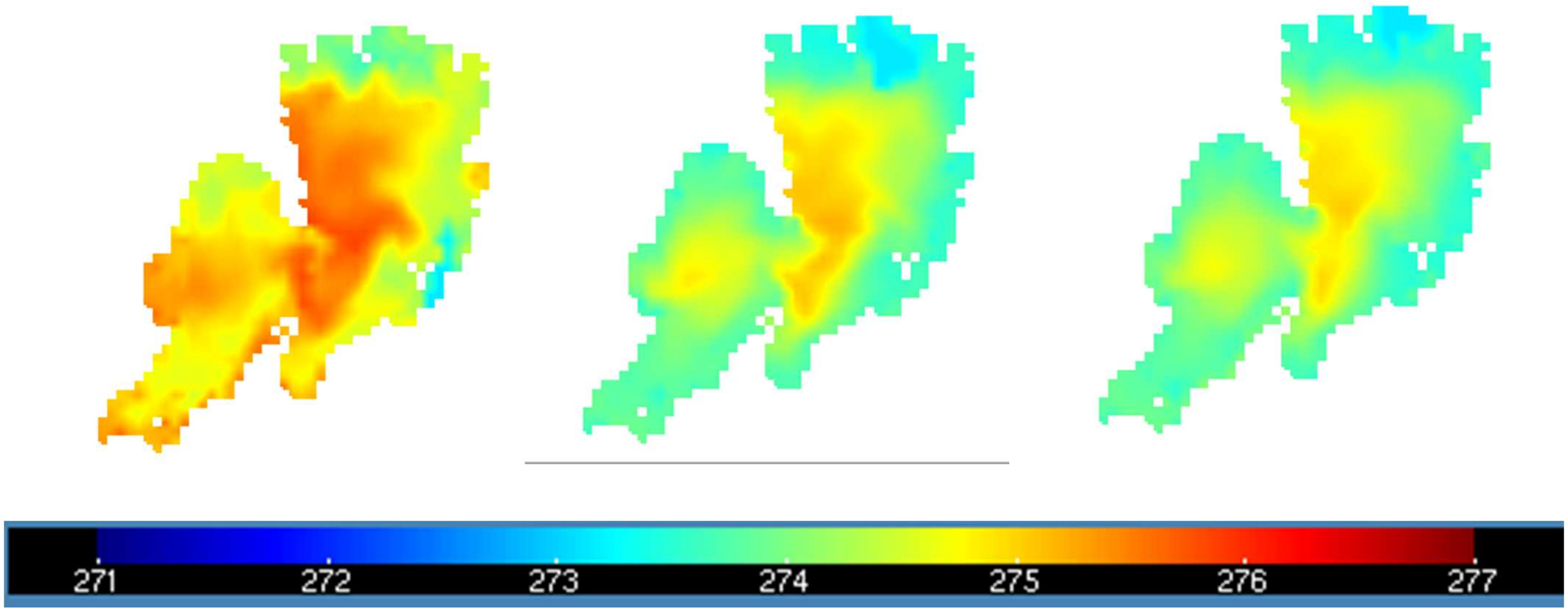


Lakes

SMHI

SST from HIROMB

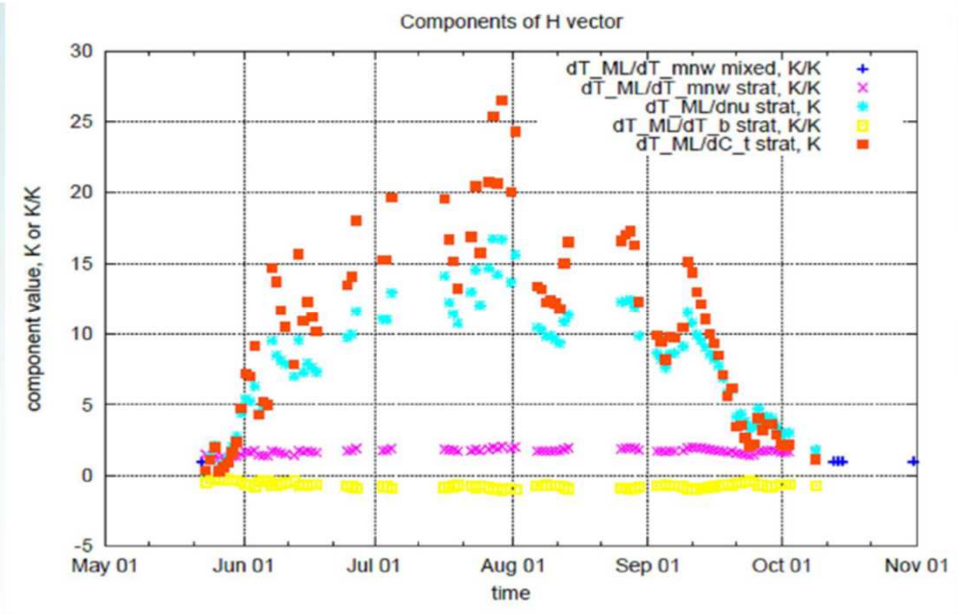
10/2 25/2 5/3

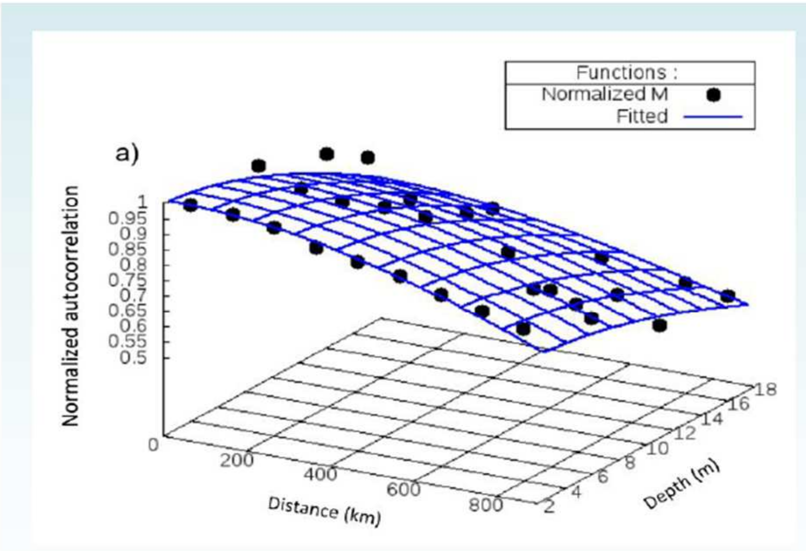


FLake modelling an DA

Currently we are working on making the lake model FLake operational in cy40h. Now it will run in so called “peaceful coexistence” without data assimilation.

In parallel Ekaterina Kourzeneva (FMI) is working on EKF assimilation methods for lakes using a 2D setup of SURFEX7.3. Here the Global Lake Data Base (GLDB) v3.1 is used. Studies are done of EKF Jacobian behaviour and of structure functions for lake surface temperature from observations (SYKE and MODIS), including dependency from the difference in the lake depth.





Town

TEB-TOWN ENERGY BALANCE MODEL

- Measurements confirm urban heat island.
- TOWN is represented by 3 surfaces: 1 WALL, 1 ROOF, 1 ROAD, each composed of several layers.
- ROAD temperature level three updated with information from SYNOP T2m measurements: Ta=(To-Tbg)/2*pi:

```
sm_mlind@n503:/home/harmonie/tags/harmonie-40h1.1.rc.1/src/surfex/ASSIM

File Edit View Search Terminal Help
File Edit Options Buffers Tools Help
! Screen-level innovations

ZT2INC(:) = PT2M_O(:) - ZTCLS(:)

IF ( NPRINTLEV > 0 ) WRITE(*,*) 'Mean T2m increments over TOWN ',SUM(ZT2INC)/KI


! Temperature analysis of TOWN points

WHERE (ZTRD3(:)/=XUNDEF)
  ZTRD3(:) = ZTRD3(:) + ZT2INC(:)/(2.0*XPI)
END WHERE
!

WRITE(*,*) 'Mean T_ROAD3 increments over TOWN ',SUM(ZT2INC)/KI

! Update modified variables
XT_ROAD(:,3)=ZTRD3  ! T_ROAD3

IF (LHOOK) CALL DR_HOOK('ASSIM_TEB_N',1,ZHOOK_HANDLE)
!
-UU-:%%--F1  assim_tebn.F90   78% L85    (Fundamental)------------------------------------------
```

Plans for the future

Planned Short and Long Term HARMONIE-AROME SURFACE Model Enhancements

- Sub-division of SURFEX nature tile into two patches: open land and forest (time-scale less than one year).

- Application of multilayer diffusion scheme and multilayer snow scheme (possibility to apply in CY 43/SURFEXv8, t-version released but h-version not ready yet).

Associated surface data assimilation developments are needed.

- SODA/OI already adopted to two patches, but not yet EKF
- EKF (and later EnKF) to be adopted to multilayer diffusion scheme and multilayer snow scheme.

Plans for the future

Plans for the Future

•Further evaluation of MESCAN and EKF/EnKF and assimilation of satellite based snow-cover products/radiances.

• How to best represent uncertainties in forcing/initial state for surface EnKF?

• Treatment of sea/lakes and frozen soil in radiance observation operators

• Handling of scale differences between satellite data and model data.

•On the longer term extension of EnKF from 1D to 3D and investigate alternatives to CANARI/MESCAN (like EnKF or En2DVar)?

•Data assimilation for FLake and ice.