Use of satellite soil moisture information for Nowcasting-Short Range NWP forecasts

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(Third and final year of the research fellowship)

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in collaboration with German Weather Service (DWD)

EUMETSAT

H SAF

H-SAF ASCAT product

COMET NWP System

KENDA-LETKF algorithm

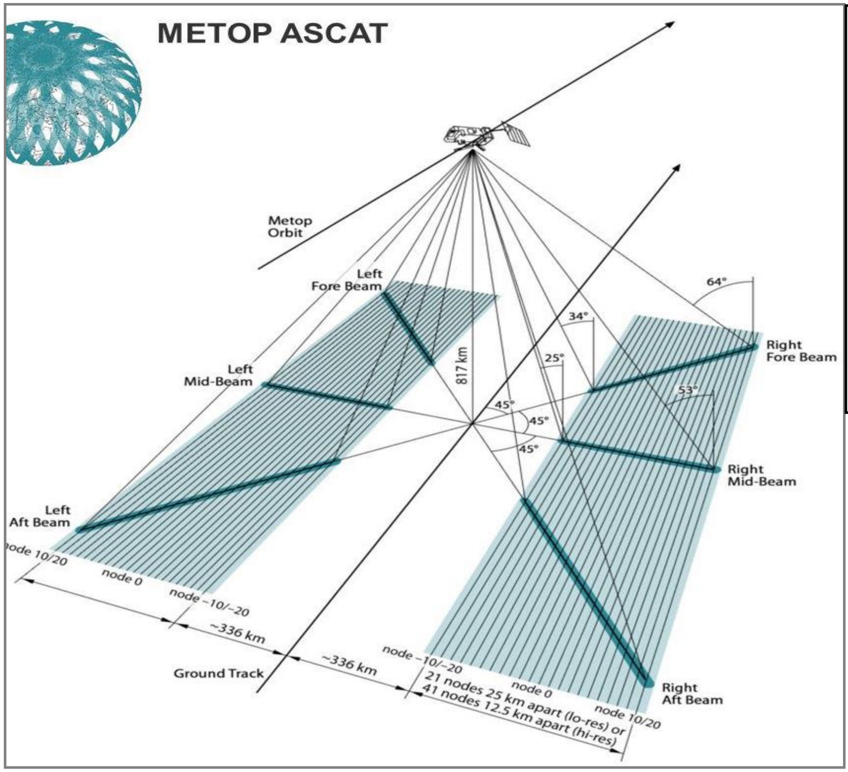
Use of
satellite soil moisture data
into an
high-resolution short range forecasting model
with an
ensemble based data assimilation system

→

- ✓ *Influence of low level atmospheric variables*
- ✓ *Direct soil moisture analysis*

H-SAF ASCAT soil moisture products

Advanced Scatterometer ASCAT soil moisture data (H16 product) provided by EUMETSAT within the H-SAF project, one of the 8 EUMETSAT SAFs, led by the Italian Air Force Met Service



- frequency: 5.3 GHz (microwave C-band)
- VV polarization
- Able to provide a triplet of electromagnetic backscattering coefficients σ_0 for each swath
- 25 km resolution
- 2 sets of 3 antennas
- It covers two 550 km wide swaths
- Daily global coverage of 82%
- Soil moisture retrievals in the first 2 cm below the soil

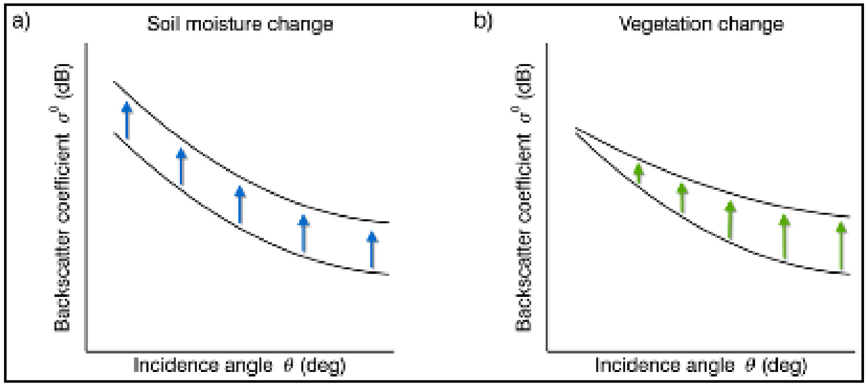
H-SAF ASCAT soil moisture products

σ_0 affected by:

- soil moisture content
- incidence angle
- land cover (vegetation)
- surface roughness

Soil moisture measurements are obtatained from the backscattering coeffiecient through a CHANGE DETECTION ALGORITHM (TU Wien)

1. The relationship between the backscattering coefficients and the surface soil moisture content is linear.
2. The backscattering coefficient depends strongly on the incidence angle.

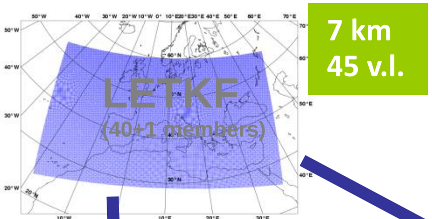


3. An increase in soil moisture simply shift the backscattering-angle of incidence curve upwards, while a change in vegetation affects its shape. For sparse vegetation, the curve tends to drop off rapidly, while for fully grown vegetation it becomes less steep.

COMET Operational Numerical Weather Prediction System

Ensemble Data Assimilation:

Operational since June 2011

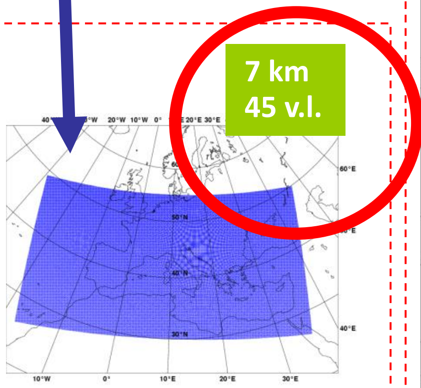


ECMWF

Boundary Conditions

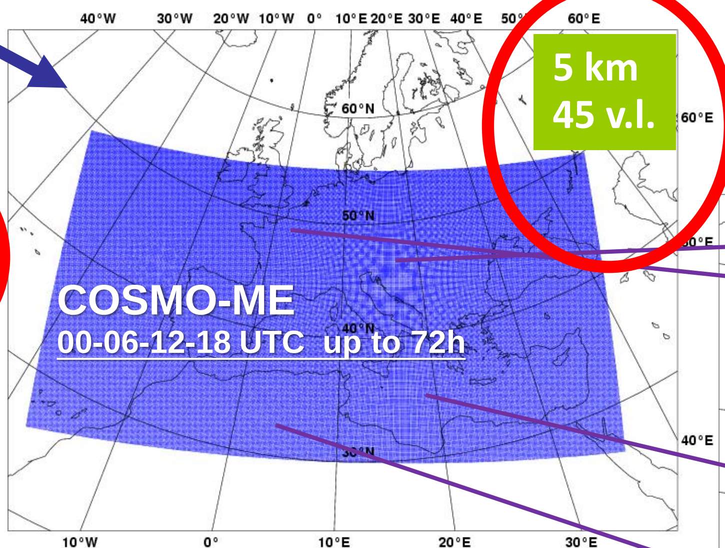
LETKF analysis ensemble (40+1 members) every 6h using RAOB (also 4D), PILOT, SYNOP, SHIP, BUOY, Wind Profilers, AMDAR-ACAR-AIREP, MSG3-MET8 AMV, MetopA-B scatt. winds, NOAA/MetopA-B AMSUA/MHS and NPP ATMS radiances+ Land SAF snow mask, IFS SST analysis once a day

Ensemble Prediction System:

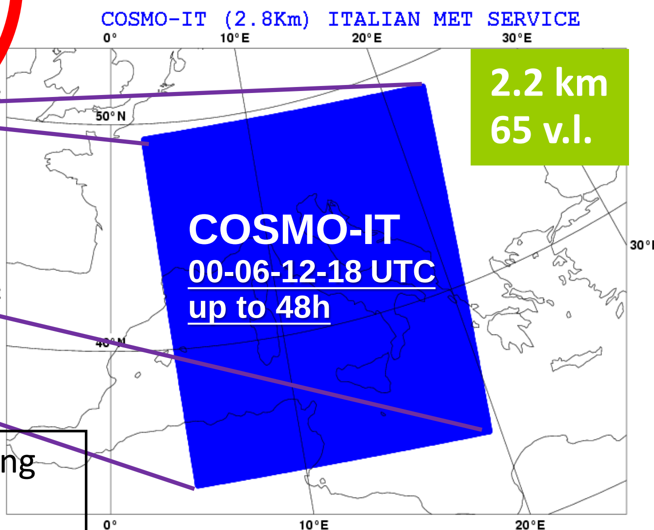


Local Area Modeling:

COSMO-ME (5km) ITALIAN MET SERVICE



COSMO-IT (2.8Km) ITALIAN MET SERVICE



COSMO: **Co**nsortium for **S**mall-scale **Mo**deling (Germany, Switzerland, Italy, Greece, Poland, Romania, Israel and Russian

COSMO KENDA

COSMO: Consortium for **S**mall-scale **Mo**deling (Germany, Switzerland, Italy, Greece, Poland, Romania, Israel and Russian)

KENDA
(**Km-Scale Ensemble-Based Data Assimilation**)

The main FOCUS of the KENDA project has been on the algorithmic development of the LETKF

↓

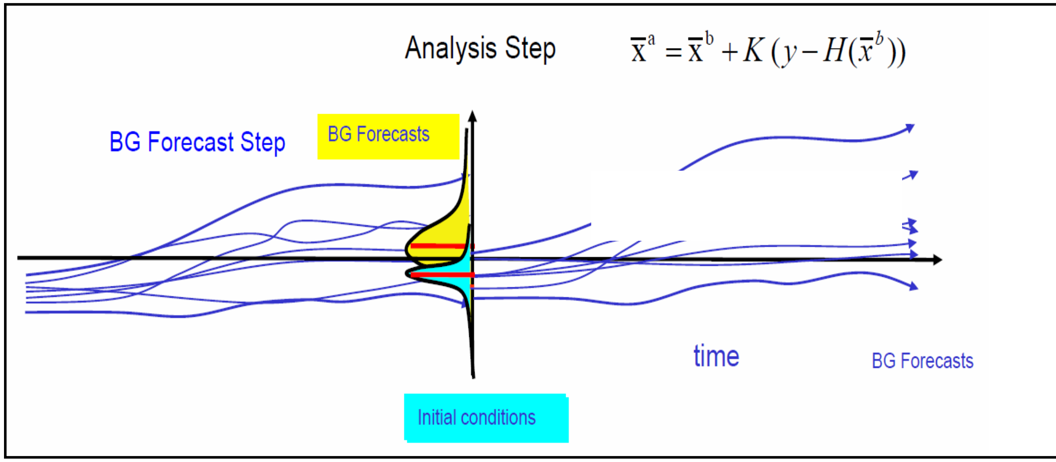
Assimilation of conventional observations and (work in progress) high resolution remote sensing data (**ASCAT soil moisture**)

Ensemble-based Data Assimilation

DA : initial conditions (**analysis**) of the NWP model produced through a statistical combination of observations and short-range forecast data

Ensemble data assimilation

Ensemble-based assimilation algorithms use Monte-Carlo techniques. As an approximation, the initial probability density function for the atmospheric state is randomly sampled (from the distribution of N ensemble members). Thereafter, the effects of chaos, model error, and observations are simulated



Local Ensemble Transform Kalman Filter

- Ensemble Kalman Filter (EnKF) is an approximation to the KF in that background-error covariance P_b is estimated from a finite ensemble of forecasts x_b (so P_b is flow dependent and varies with time).

$$\mathbf{P}^b = \frac{1}{m-1}\mathbf{X}^b\left(\mathbf{X}^b\right)^T \qquad X_b = x_b - \overline{x}_b$$

- Analysis computed separately for each grid point selecting only the observations in the vicinity. The observation error covariance R elements are modified by distance-dependent localization factors so that far- away observations have large errors

Results: observation increment statistics

The transformed ASCAT soil moisture observations has to be compared to the equivalent model values

OBSERVATION INCREMENTS:

$$(y - H(\bar{x}^b))$$

- **difference between the obs value and its model equivalent value (ensemble mean)**
- first guess values linearly interpolated in time
- 2 options investigated for the choice of the soil type to assign to an ASCAT observation:

  - nearest grid point
  - average on the 9 nearest grid points

- model values calculated using the COMET-LETKF system
- Quantity directly used in the LETKF algorithm

Because of the assumption of no bias and gaussianity for the ensemble-based DA, their distribution in terms of bias and symmetry will be analyzed

Feedback file composition in MEC

- The **Model Equivalent Calculator** (MEC) applies the observation operators used in the data assimilation scheme (Nudging, EnVar, LETKF) to model forecasts (COSMO, ICON, ICON-LAM, IFS) and stores the results in verication files (NetCDF feedback le format). These data is intended to be used for verication of the forecasts with respect to observations.

- MEC is responsbile for the creation of the feedback files (observation increment) for all the variables in the COSMO model.

- MEC code has been entirely developped and written by the German Weather Service DWD

•Before the MEC integration, soil moisture feedback file creation procedure was done with our own specific routine (not COSMO official).

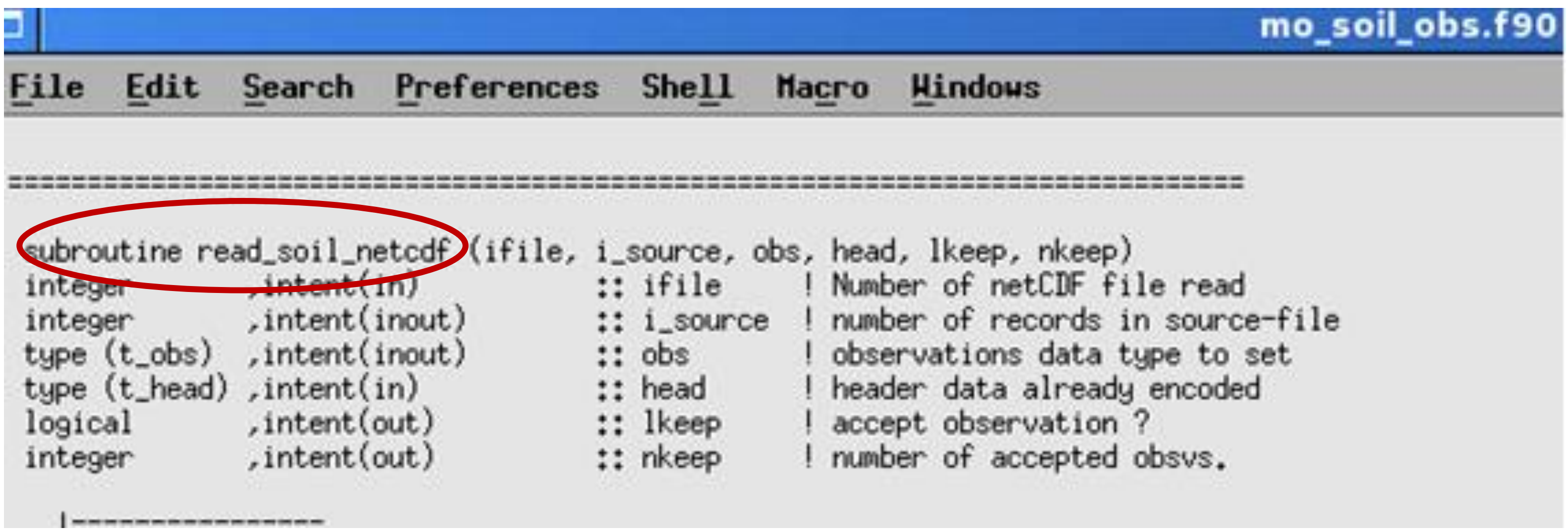
Implementation of soil moisture feedback file creation procedures into the Model Equivalent Calculator

Feedback file composition in MEC

Three main subroutines are necessary

Subroutine read_soil_netcdf:

here soil moisture input oservations (cdfin file) are read




```
==========================================================================
subroutine read_soil_netcdf (ifile, i_source, obs, head, lkeep, nkeep)
 integer       ,intent(in)        :: ifile     ! Number of netCDF file read
 integer       ,intent(inout)     :: i_source  ! number of records in source-file
 type (t_obs)  ,intent(inout)     :: obs       ! observations data type to set
 type (t_head) ,intent(in)        :: head      ! header data already encoded
 logical       ,intent(out)       :: lkeep     ! accept observation ?
 integer       ,intent(out)       :: nkeep     ! number of accepted obsvs.

   !----------------
```

Feedback file composition in MEC

Subroutine check_store_soil

Here quality checks are performed for the soil moisture observations

```
mo_soil_obs.f90
File  Edit  Search  Preferences  Shell  Macro  Windows
!==============================================================================

subroutine check_store_soil (spot, obs, lkeep, nssm, nsmpf, nsmq, neesm, nsnco, nflsf, niawf,ntoco, nicep, nrfd )
type(t_spot)     ,intent(inout)  :: spot     ! report derived type
type(t_obs)      ,intent(inout)  :: obs      ! observations derived type

!type(t_obs_block)  ,intent(inout),optional :: ybs     ! observation data type
```

Quality Control before assimilation of ASCAT soil moisture DATA

Soil moisture cannot be estimated if the fraction of dense vegetation, open water, snow/frozen soils, mountains, sand dunes and/or wetlands dominates the scatterometer footprint

ASCAT data is rejected where:

- *snow:* the analysed snow amount is greater than 0.05 kg/m^2
- *frost:* the 2m Temperature analysis is below 275.15 K
- *wetlands:* the inundation and wetland amount has a value greater than 15%
- *mountains:* the topographic complexity has a value greater than 20%
- *ASCAT estimated error:* the error in the ASCAT surface soil wetness is estimated to be greater than 7% (Met Office) or 8% (ECMWF). This check rejects ASCAT data from regions with dense vegetation and sand dunes.
- Ens.mean Observation Increments > 2.5 σ
  (σ estimated from 1 year statistics for each soil type)

Feedback file composition in MEC

Subroutine process_soil:

Here the observation incremens (observation – model equivalents) are created

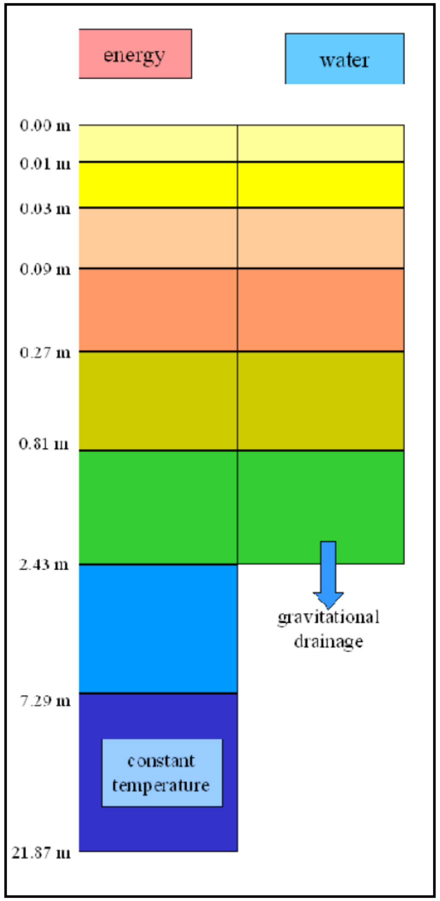
mo_soil_obs.f90

File Edit Search Preferences Shell Macro Windows

```
!=================
! module variables
!=================

subroutine process_soil (task, spot, obs, atm, cols, xi, y, Jo, Jo_atm, &
                         state)
integer          ,intent(in)              :: task    ! what to do
type(t_spot)     ,intent(inout),optional  :: spot    ! SPOT observations
```

COSMO TERRA_ML model: overview



Layer structure of the ML soil model

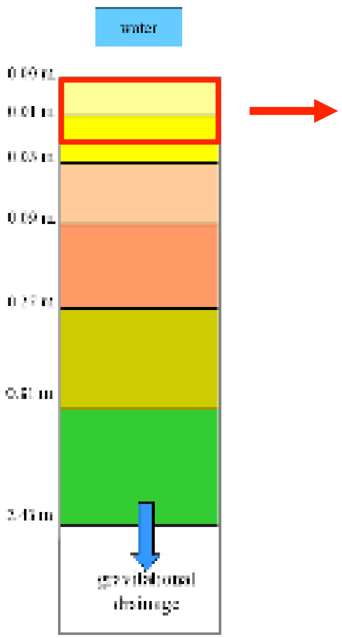
TASK: to predict Temperature and water content at the ground, by the simultaneous solution of a separate set of equations which describe various thermal and hydrological processes within the soil

soil type	1 ice	2 rock	3 sand	4 sandy loam	5 loam	6 loamy clay	7 clay	8 peat
volume of voids w_{PV} [1]	-	-	0.364	0.445	0.455	0.475	0.507	0.863
field capacity w_{FC} [1]	-	-	0.196	0.260	0.340	0.370	0.463	0.763
permanent wilting point w_{PWP} [1]	-	-	0.042	0.100	0.110	0.185	0.257	0.265
air dryness point w_{ADP} [1]	-	-	0.012	0.030	0.035	0.060	0.065	0.098

- **Most parameters of the soil model strongly depend on soil texture**
- **Five types are distinguished: sand, sandy loam, loam, loamy clay, clay**
- **Three special soil types are considered additionally: ice, rock and peat**
- **Hydrological processes in the ground are not considered for ice and rock**

Transformed SOIL MOISTURE

- H-SAF ASCAT derived Soil Moisture: **degree of saturation** (%) in the first 2 cm of soil
- COSMO TERRA_ML model soil moisture: **liquid water content** (m H2O) in the various model layers



layer structure of the hydrological part of the COSMO TERRA_ML soil model

To compare observed and model values the model values are transformed (to have quantities independent from the thickness of the layers) in **volumetric water content** (m^3/m^3) in the first 2 cm

+

NEED TO RESCALE THE SATELLITE OBS TO THE MODEL VALUES

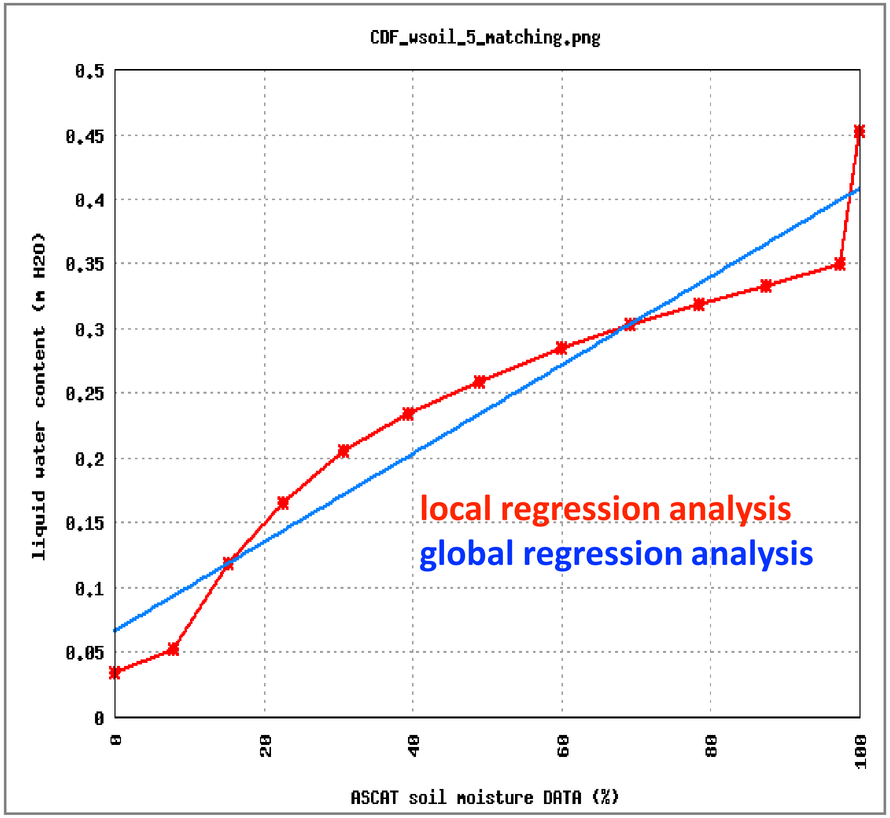
- CDF matching method
- Normalization methods

CDF matching

ECMWF approach

To scale the ASCAT derived soil moisture to the model climatology so that the <u>cumulative distribution functions</u> (CDF) of satellite and model soil moisture match.

- **1 year time series of ASCAT and model SM data (january 2015 - january 2016)**



This method doesn't allow deriving "correct" soil moisture. Rather it removes differences between satellite observations and model data by ensuring statistical consistency.

- **Linear regression analysis of ASCAT data plotted against model data**

2 options investigated:

- global regression analysis
- local regression analysis

$$\omega_{obs} = max\left(0, a + b\frac{\theta_{obs}}{100}\right)$$

b slope, a intercept

Normalization Method

UKMO approach

$$\omega_{obs} = \omega_{ADP} + \frac{\theta_{obs}}{100}(\omega_{PV} - \omega_{ADP})$$

$$\omega_{obs} = \omega_{ADP} + \frac{\theta_{obs}}{100}\left(\frac{\omega_{PV} + \omega_{FC}}{2} - \omega_{ADP}\right)$$

soil type	1 ice	2 rock	3 sand	4 sandy loam	5 loam	6 loamy clay	7 clay	8 peat
volume of voids w_{PV} [1]	-	-	0.364	0.445	0.455	0.475	0.507	0.863
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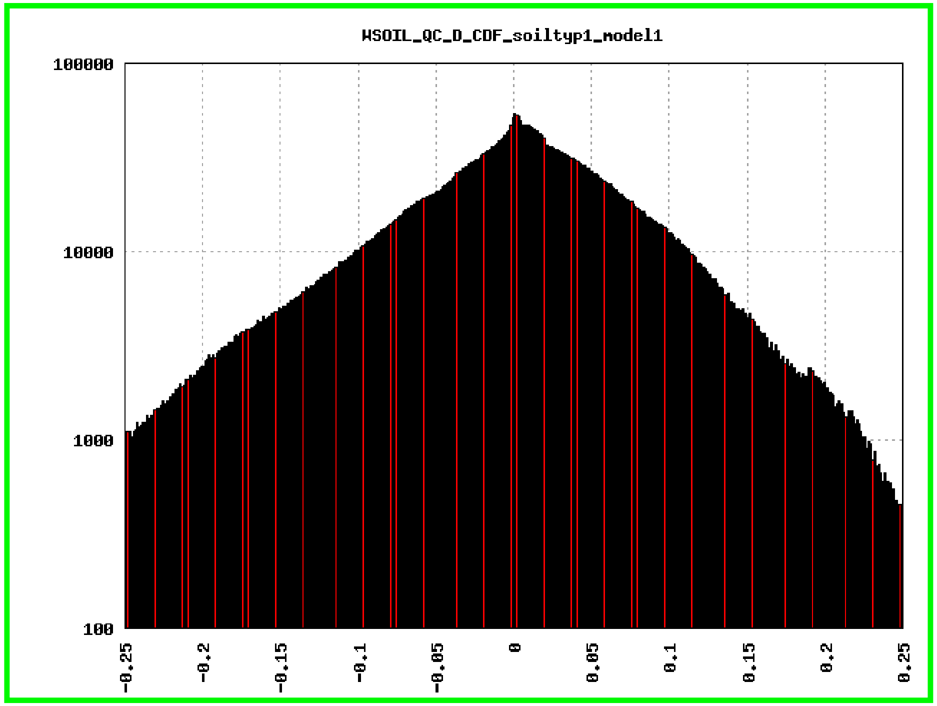
Soil parameters values in the COSMO TERRA_ML soil model
8 different soil types: ice, rock, sand, sandy loam, loam ,loamy clay, clay

Volume of voids: maximum possible volume of water that the soil can hold
Field capacity: amount of soil moisture held in the soil after excess water has drained away and the rate of downward movement has decreased.
Wilting point: the minimal amount of water the plant requires not to wilt
Air Dryness point: minimum possible amount of water that can remain in the soil

Evaluation of results (CDF)

Chosen method :

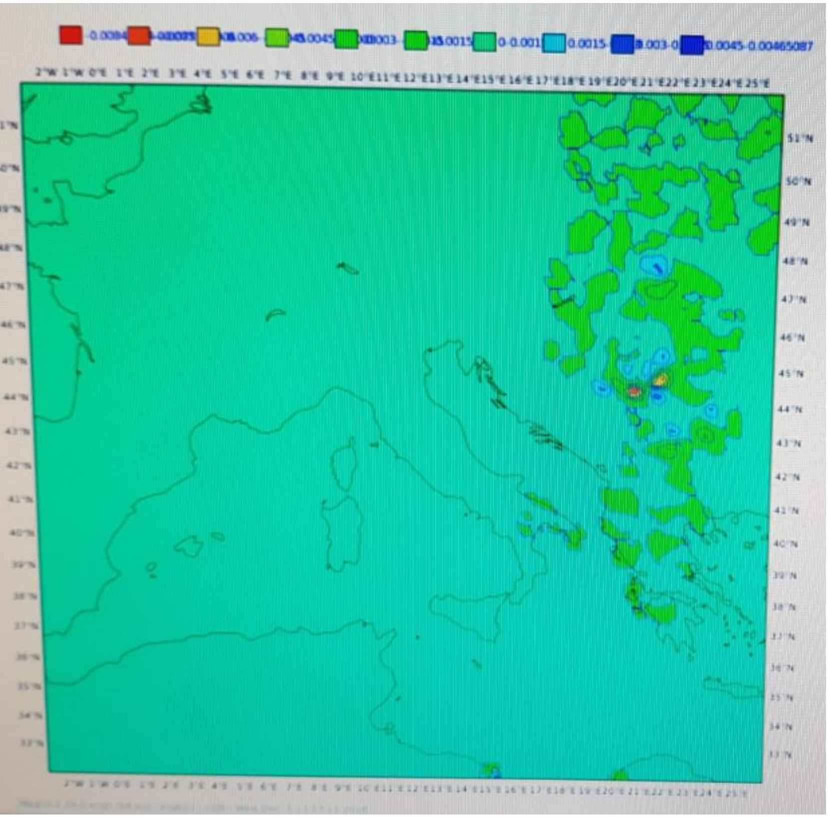
Local regression + soil type of the nearest grid point

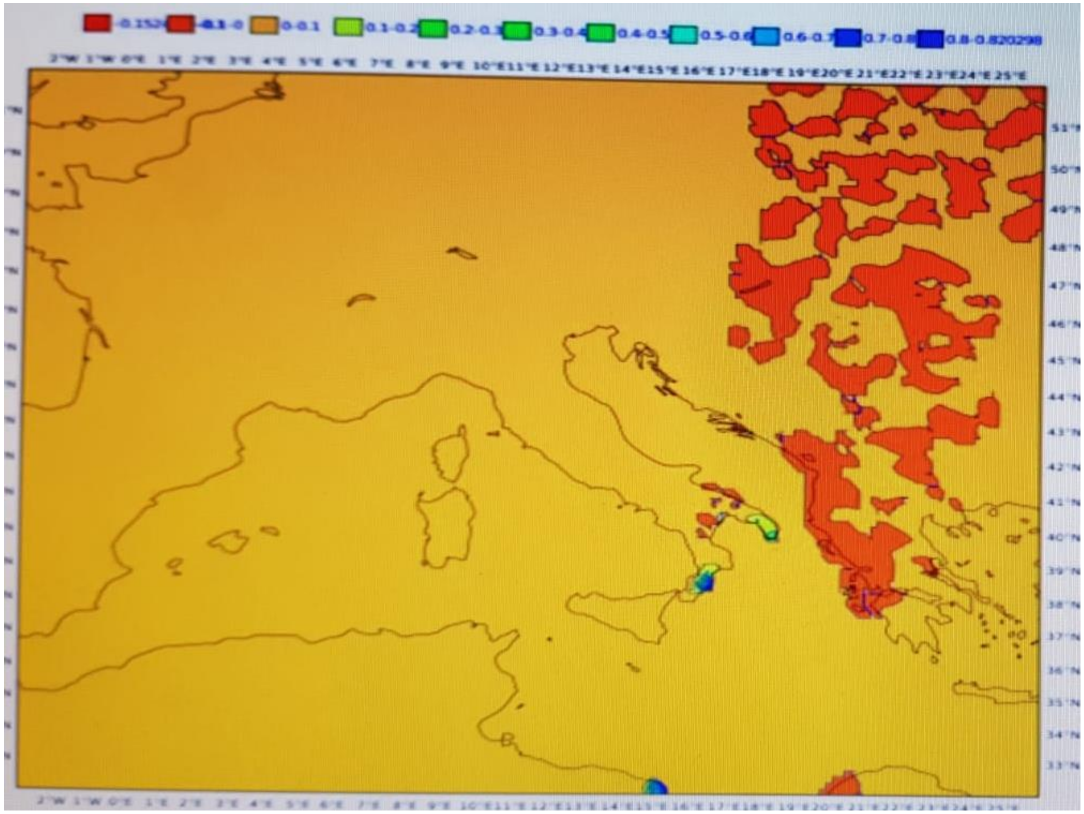


bias: 0.0008242
stdv: 0.0840188
symm: -0.3009857

Feedback file composition in MEC

Some of the problems we had passing from the old comet routine to MEC :





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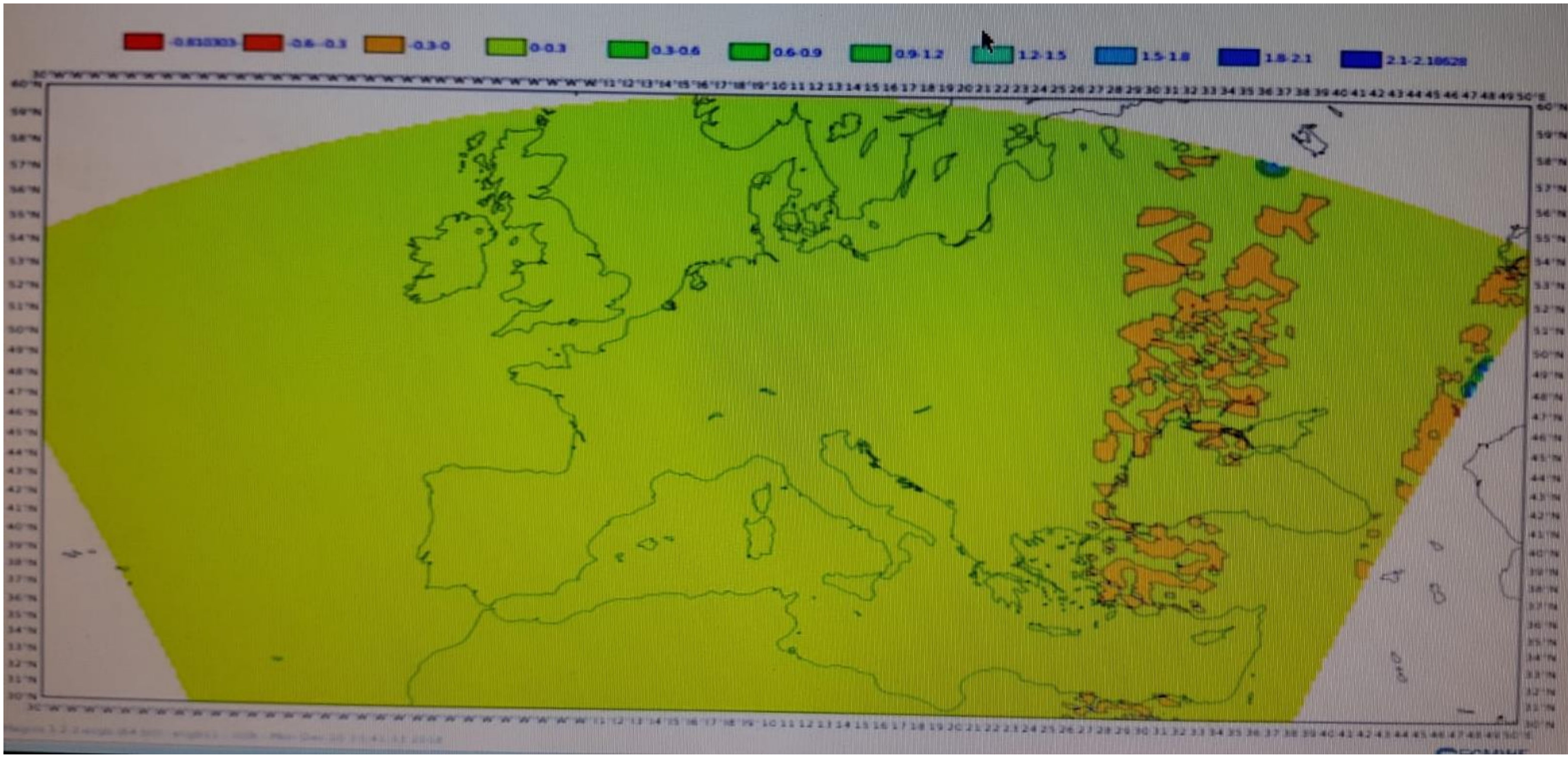


Feedback file composition in MEC

Soil moisture feedback file composition in MEC works now both for:

•KENDA - COSMO-ME

•KENDA - COSMO-IT

KENDA soil moisture assimilation (COSMO-ME)

TEST 1 ***:soil moisture observations influence ONLY the low level atmospheric variables*** :
l_soil_ana = false , horizontal localization (~100 km) , vertical localization (10 lower levels)

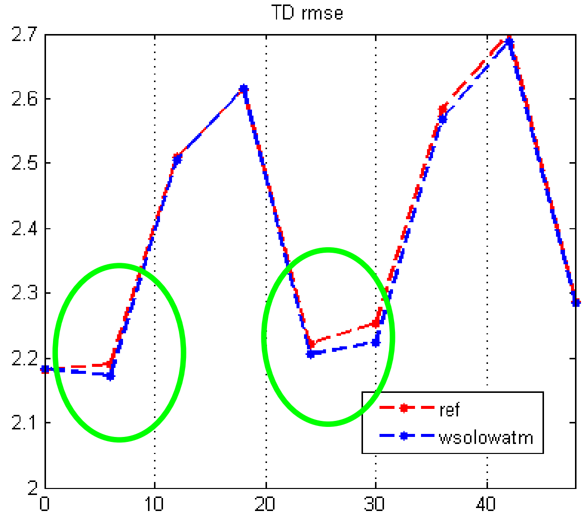
TEST 2 ***:soil moisture observations influence BOTH the low level atm***
+ soil variables (l_soil_ana = true , 100km, 10 lower levels)

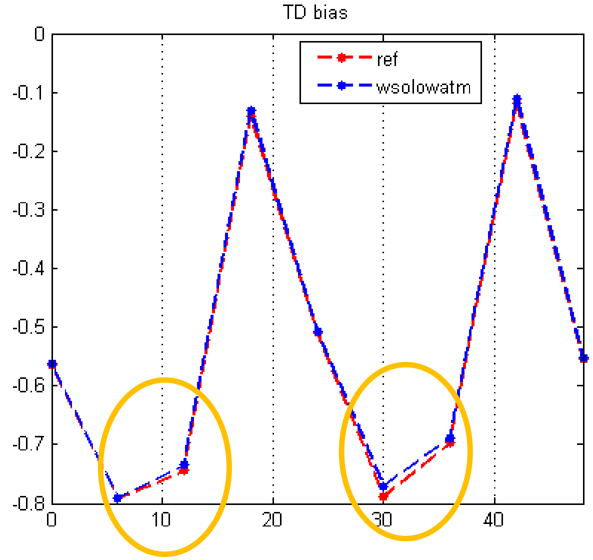
TEST 3 ***:as TEST2 but wso analysis without rh2m T2m observation***

KENDA@10km (COSMO-ME) pre-operational test suite
coarse grid (rf=2,nzr=40)
6h-data assimilation cycle
e_o= 2 x BUFR estimated error (suggested by P. De Rosnay ECMWF→ to be estimated by Desroziers statistics after data assimilation cycle)
from 22 jun 2016 to 23 jul 2016
(selected period for TS test cases in SRNWP-EPS project)

TEST-1

Verification results with respect SYNOP observations
from 22 jun 2016 to 23 jul 2016

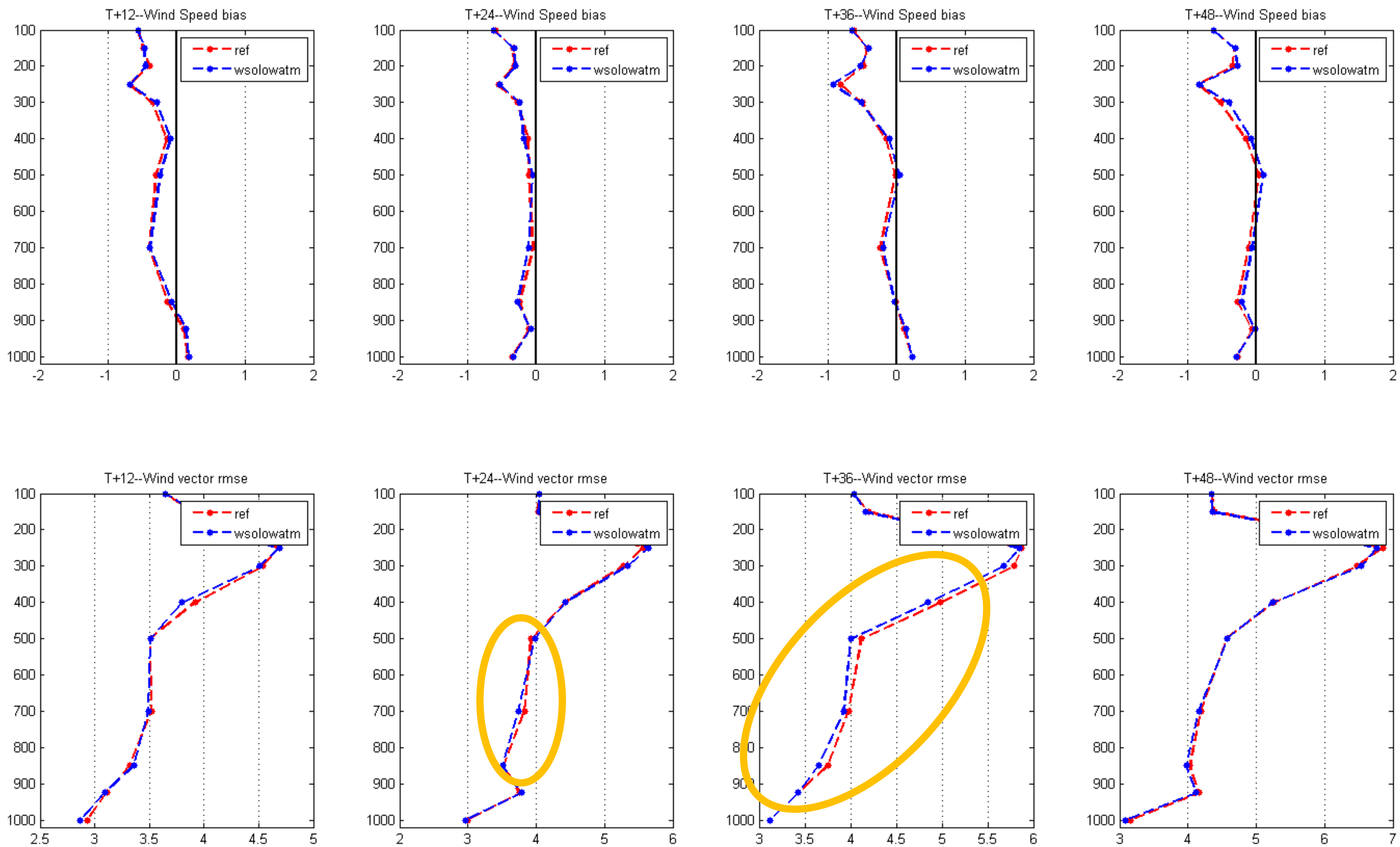




Synop
2m dew point temperature:
A little improvement of rmse and bias is observed
No impact for other variables

TEST-1

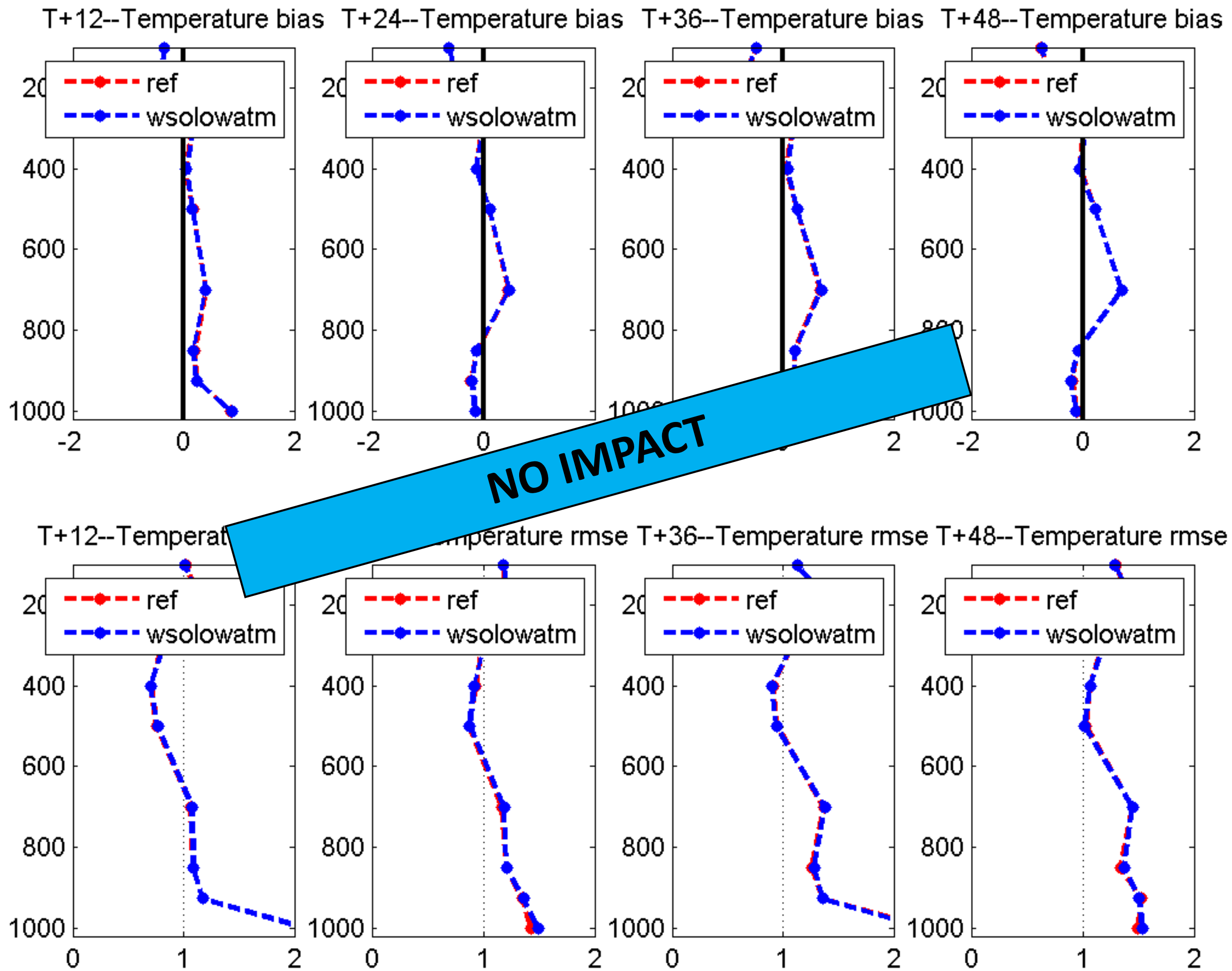
WIND: Verification results with respect TEMP observations from 22 jun 2016 to 23 jul 2016



A little improvement in rmse is observed

TEST-1

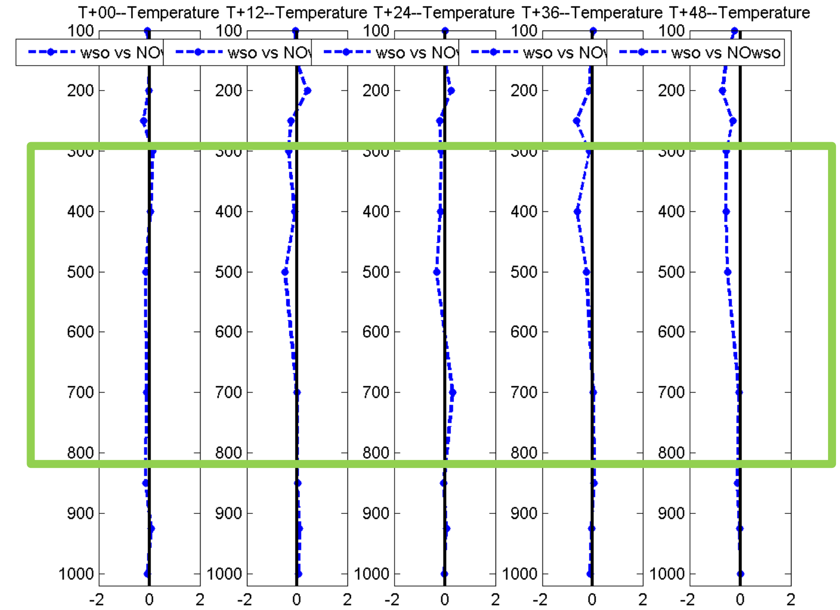
TEMPERATURE: Verification results with respect TEMP observations
from 22 jun 2016 to 23 jul 2016



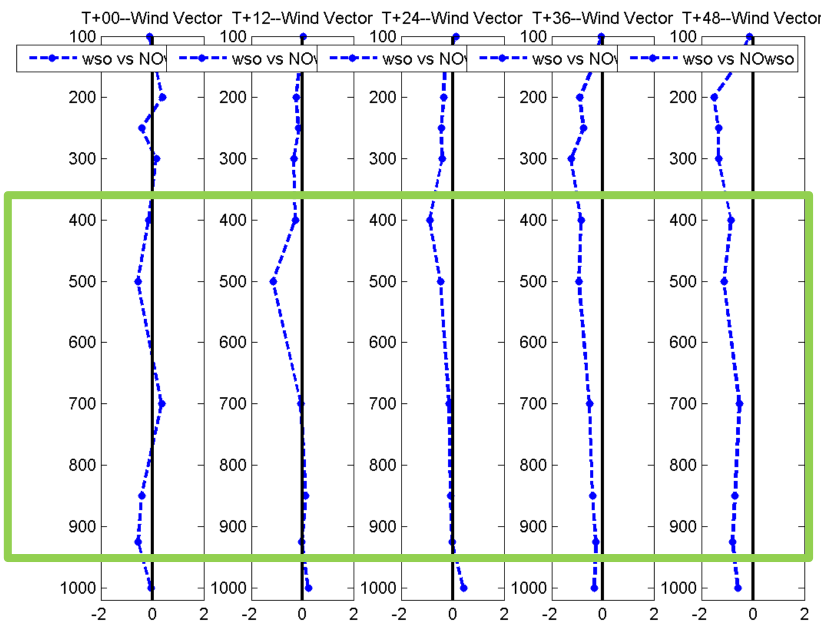
TEST-1

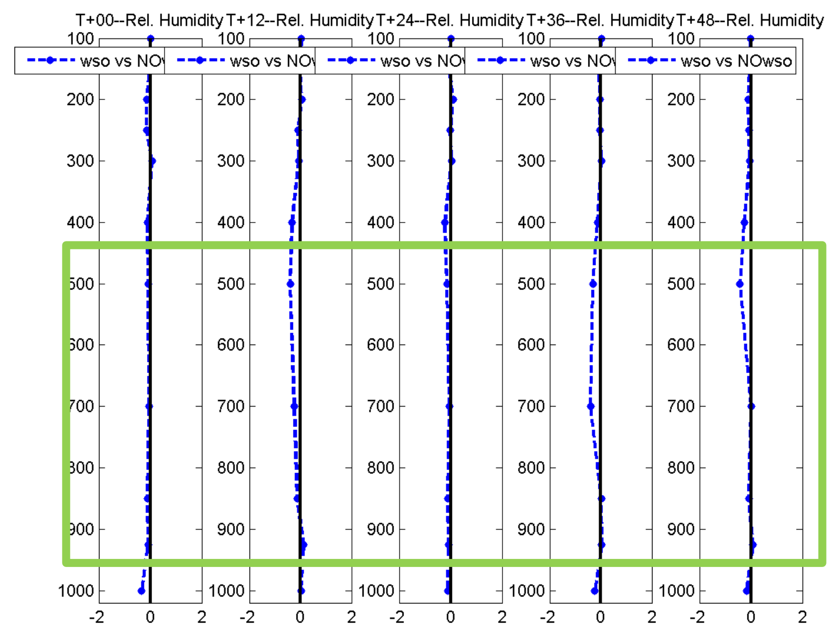
Forecast verification results

Relative difference (%) in RMSE,
computed **against IFS analysis**, with respect to reference run
(NO soil moisture observations)
for 00 UTC COSMO forecasts from 22 jun 2016 to 23 jul 2016
negative value = positive impact



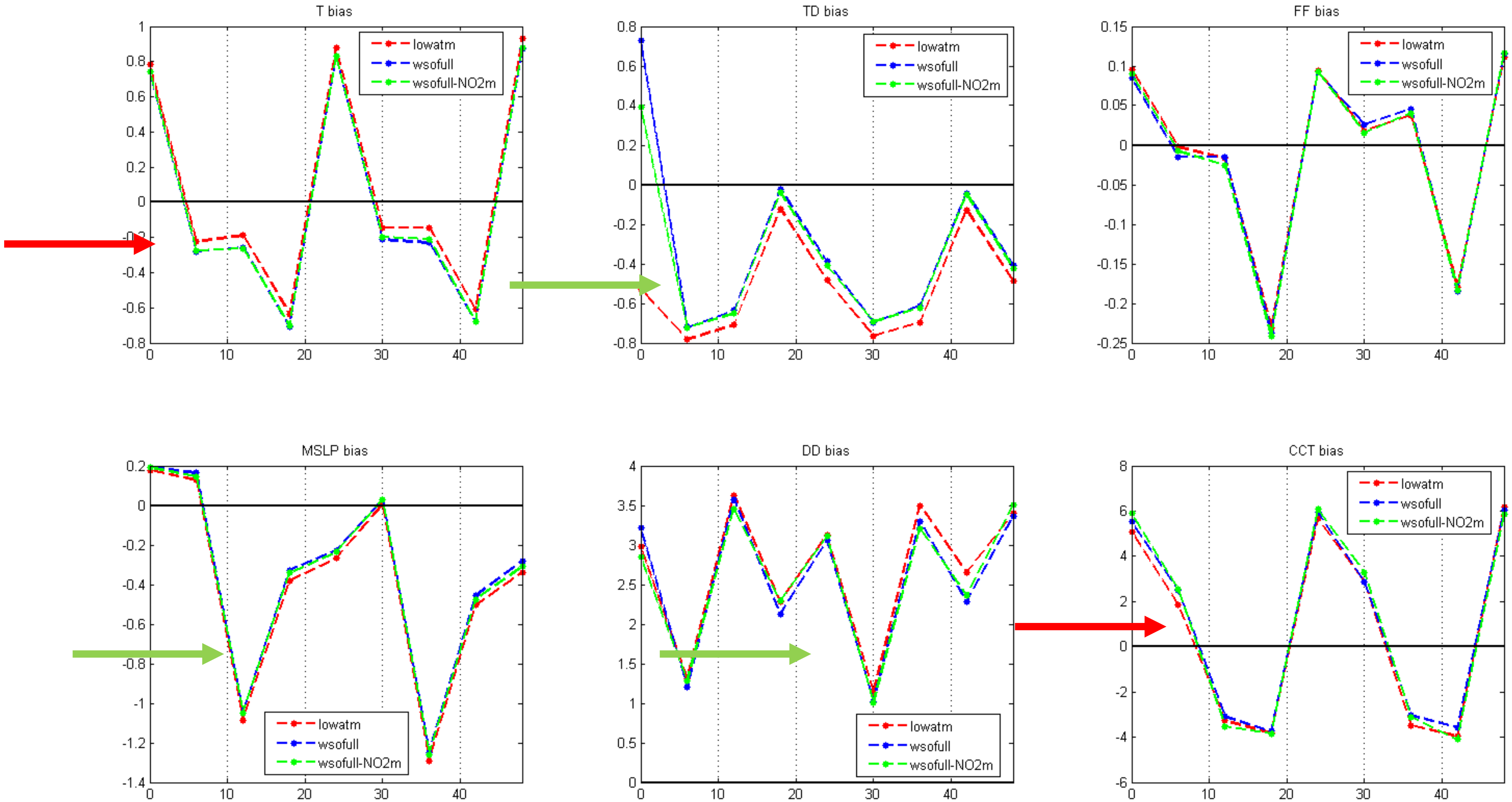
A *small* positive impact is observed on the whole column for all variables and for all forecast steps





Verification results with respect SYNOP observations from 22 jun 2016 to 23 jul 2016

Increase/decrease of bias

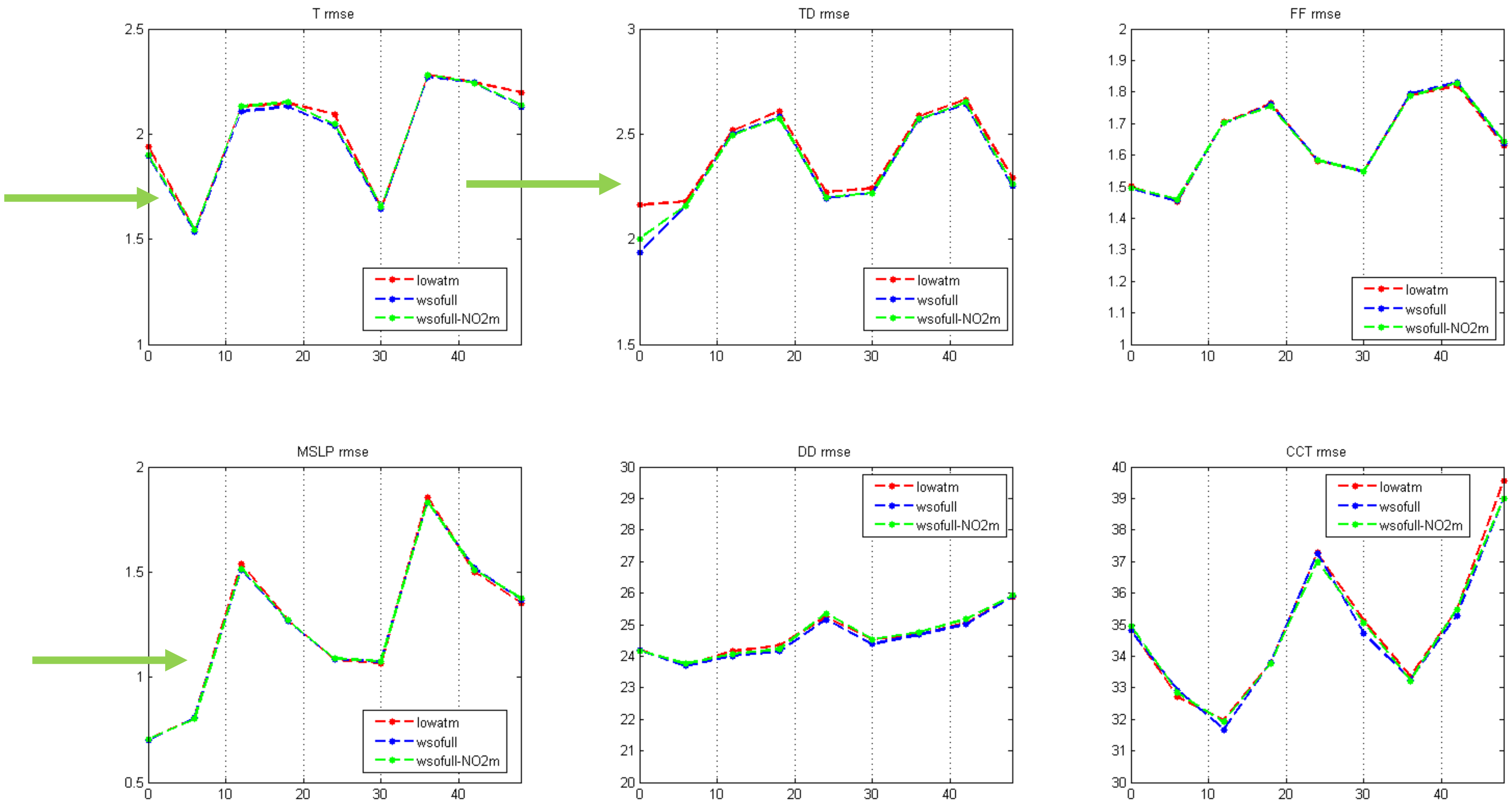


lowatm (**TEST1**) wso full (**TEST2**)

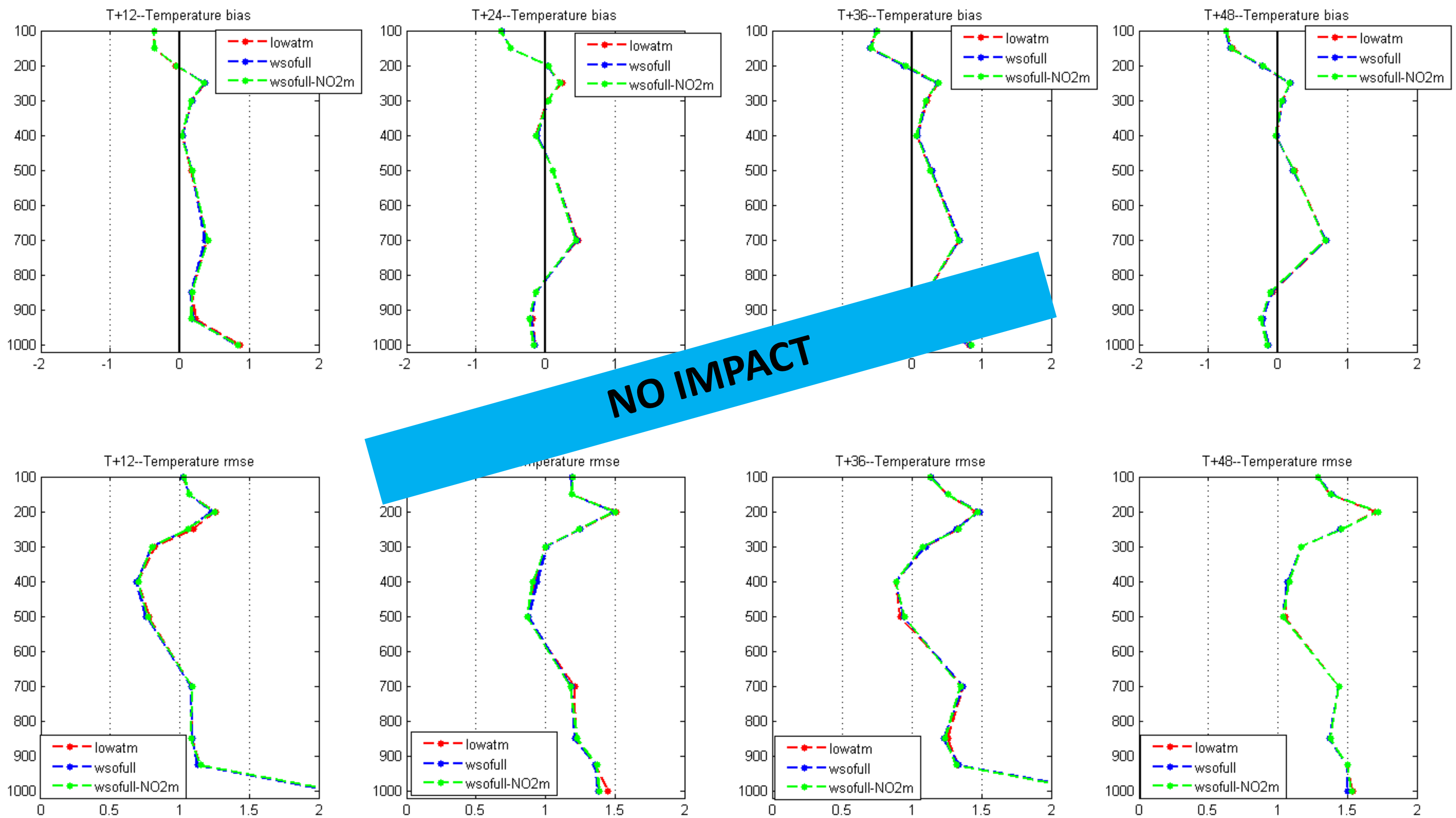
wso full (without influence of T2m,RH2m) (**TEST3**)

Verification results with respect SYNOP observations from 22 jun 2016 to 23 jul 2016

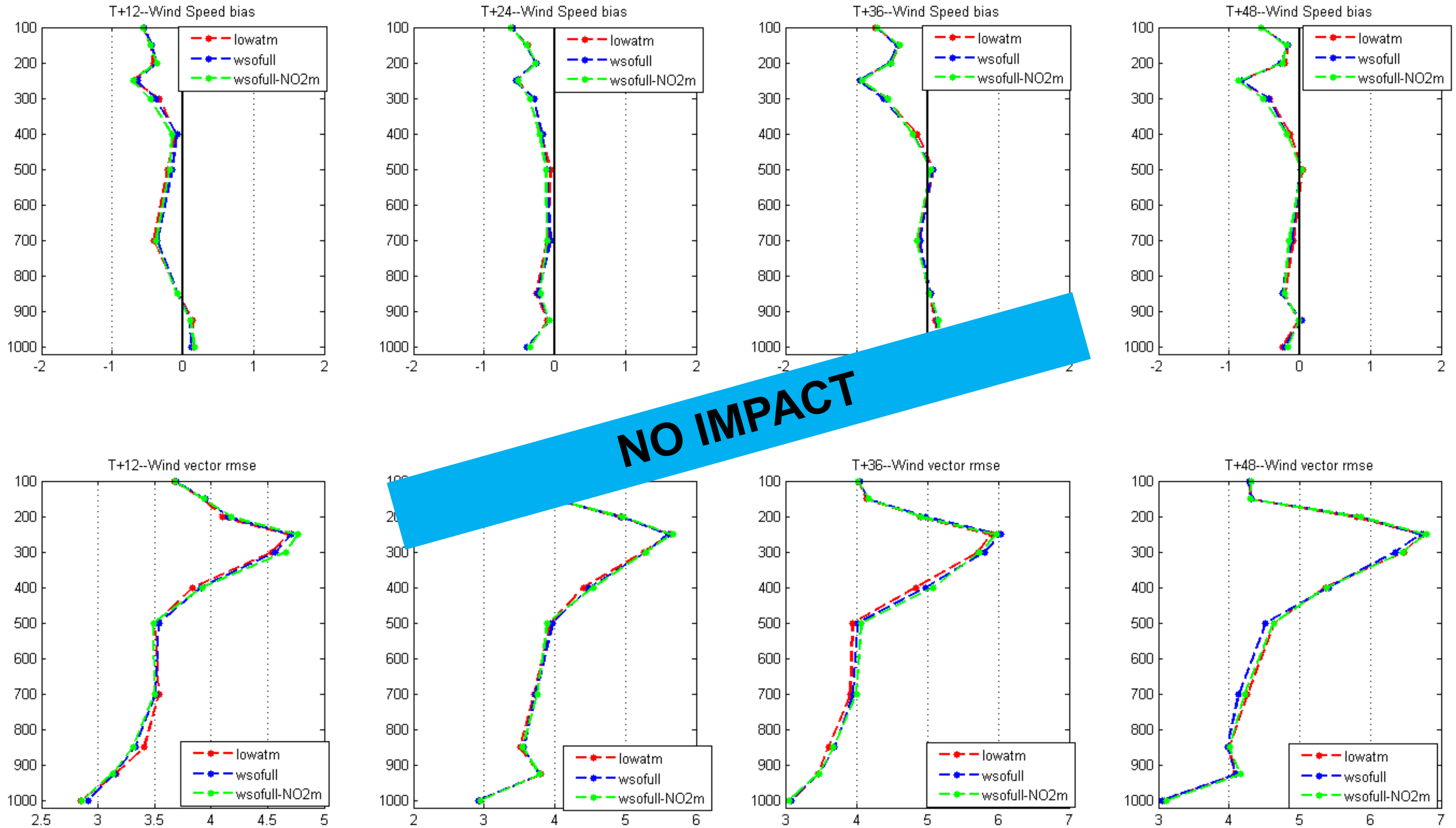
SMALL REDUCTION OF RMSE



Verification results with respect TEMP observations
from 22 jun 2016 to 23 jul 2016



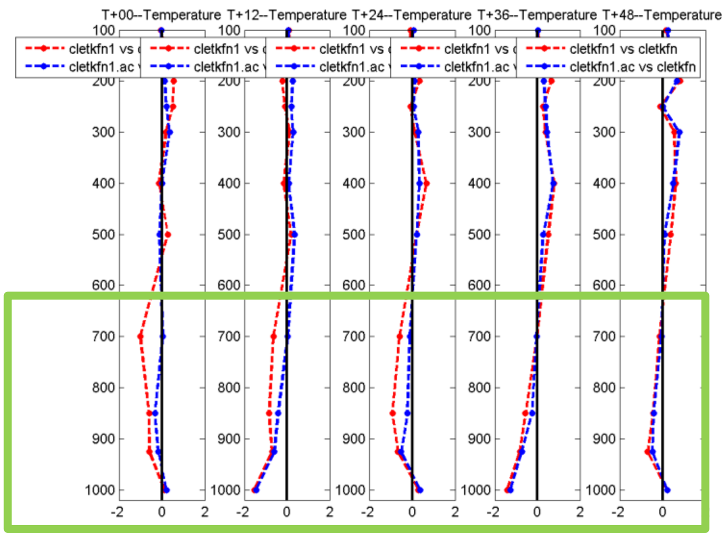
Verification results with respect TEMP observations from 22 jun 2016 to 23 jul 2016

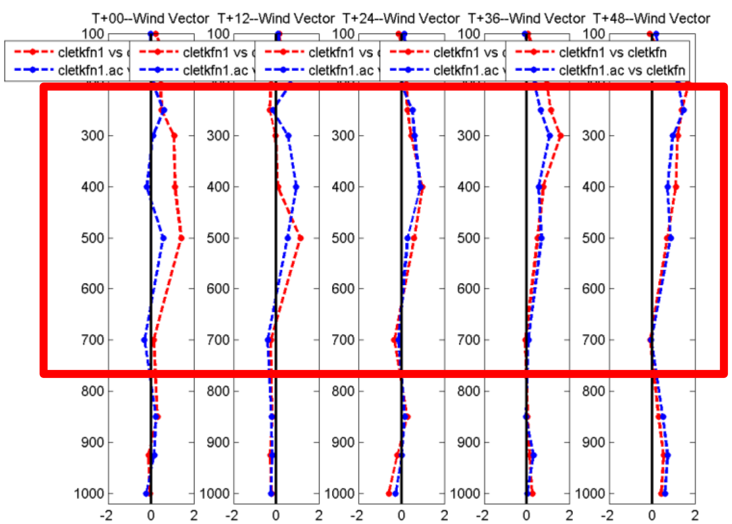


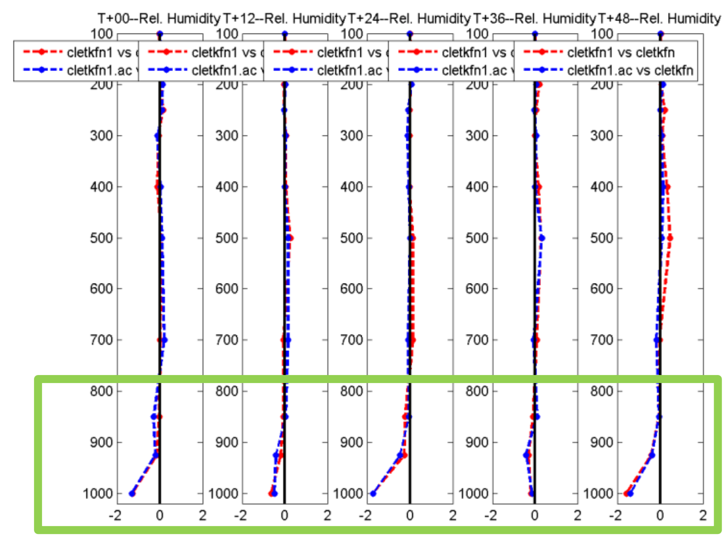
Forecast verification results

Relative difference (%) in RMSE,
computed **against IFS analysis**, with respect to TEST1 run
(wso influence only low atm)
for 00 UTC COSMO forecasts from 22 jun 2016 to 23 jul 2016
negative value = positive impact

TEST2 **TEST3**







KENDA soil moisture assimilation (COSMO-IT)

- Thanks to MEC we can now use the the soil moisture assimilation also for the COSMO-IT (2.2km resolution)

- It would be ideal to test the KENDA soil moisture assimilation for COSMO-IT in the summer time (more important influence of soil moisture on the system because of stronger convection mechanisms).

  Due of unavailability of data for the last summer, the next summer will be waited to have enough data in order to run a month test validation

Thank you

Aknowledgments

- Andreas Rhodin (DWD)
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- Harald Anlauf (DWD)
- Francesca Marcucci (COMET)
- Valerio Cardinali (COMET)