# Comparison between SMOS observations and ECMWF reanalysed brightness temperatures:

## Long term monitoring and multi-year global analysis

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# SMOS forward modelling for Numerical Weather Prediction applications

- Objective: Use SMOS Brightness Temperature (TB) data to initialise soil moisture to improve surface and near-surface weather forecasts
- Ingredients:
  - SMOS Near Real Time TB data (Kerr et al.)
  - Atmospheric model (ECMWF IFS doc 2014), coupled to the Land Surface Model H-TESSEL (Balsamo et al., JHM 2009)
  - **Community Microwave emission modelling platform (CMEM)** to simulate TB as seen by SMOS (Drusch et al., JHM 2009, de Rosnay et al., JGR 2009, Munoz-Sabater et al., IJRS 2011, Parrens et al., RSE 2014)
- Method: Data Assimilation
  - Bias Correction (de Rosnay et al., in prep): the purpose of data assimilation is to correct the model random errors. So, bias correction ensures obs and model are unbiased (remove systematic errors).
  - Extended Kalman Filter soil moisture analysis (de Rosnay et al QJRMS, 2013), adapted to ingest SMOS data (Muñoz Sabater et al. in prep & next talk).

# ECMWF Land Surface Data Assimilation System (LDAS)

## Initialisation of the land surface model prognostic variables for operational NWP

➢ **Snow depth and density**

• 2D Optimal Interpolation (OI) using *in situ* SYNOP & NESDIS/IMS snow cover data

➢ **Snow and Soil Temperature**

• 1D OI using *in situ* SYNOP data

More on the ECMWF LDAS:

- **Web:software.ecmwf.int/wiki/display/LDAS/LDAS+Home**
- **(de Rosnay et al, Surv. Geophys. 2014**

➢ **<u>Soil Moisture</u>**

• **Approach:**

Simplified Extended Kalman Filter (EKF)

• **Observations**:

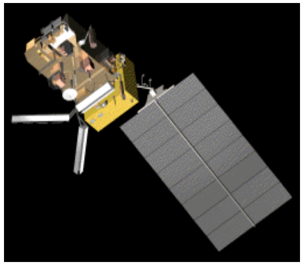
*in situ:* T2m, RH2m (SYNOP) and

Satellite: **SMOS TB, ASCAT SM, SMAP** (dvpt)

-> Numerical Weather Prediction

-> Root zone soil moisture retrieval

ASCAT



SMOS

SMAP

# Simplifed EKF soil moisture analysis

**Method:**

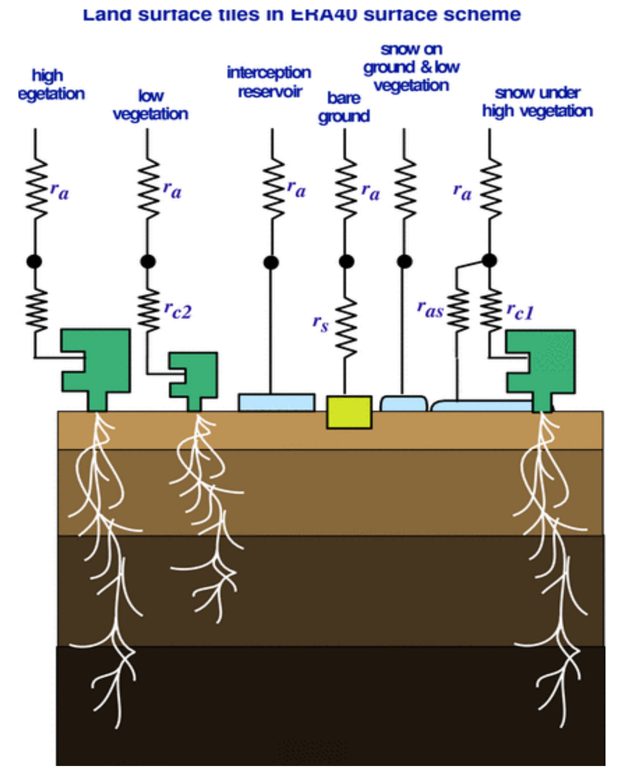
For each grid point, analysed soil moisture state vector $\boldsymbol{\theta}_a$:

$$\boldsymbol{\theta}_a = \boldsymbol{\theta}_b + \boldsymbol{K}\,(\boldsymbol{y} - \mathcal{H}[\boldsymbol{\theta}_b])$$

$\boldsymbol{\theta}$ background soil moisture state vector,
$\mathcal{H}$ non linear observation operator
$\boldsymbol{y}$ observation vector, $\boldsymbol{K}$ Kalman gain matrix

Used for operational NWP since Nov. 2010
(de Rosnay et al., QJRMS 2013)

Simplified EKF corrects the trajectory of the Land Surface Model

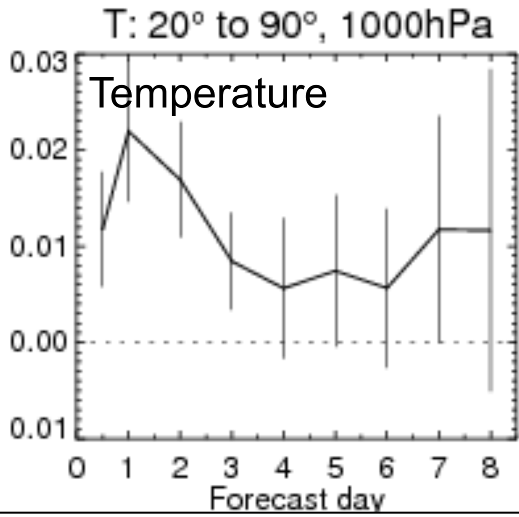



**Observations:**

- ➢**Operational NWP**:
  - Conventional SYNOP observations **(T2m, RH2m)**
  - ASCAT-A/B data assimilation
- ➢**Operational Monitoring:** SMOS, ASCAT-A/B
- ➢EUMETSAT operational: SM-DAS-2 (Albergel et al., RSE 2012, Pellarin et al ECMWF H-SAF report 2013, Alyaari, RSE 2014)
- ➢**Research developments:**

- SMOS forward modelling and bias correction
- SMOS TB Data Assimilation (Muñoz Sabater et al.)
- SMOS NN SM data assimilation to be tested (Rodriguez et al)
- SMAP implementation

# Impact of soil moisture data assimilation on weather forecasts

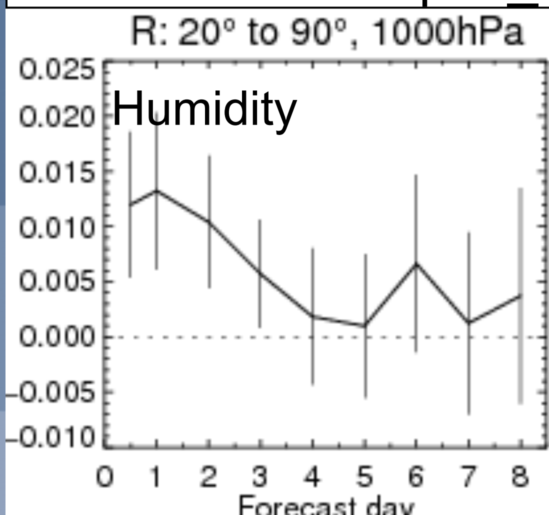



Jun-Jul 2012

CTRL: operational EKF

Open_Loop: No EKF SM analysis

RMSE of 1000hPa forecasts
Normalised diff Open_Loop (No data assimilation) – CTRL (EKF)




Positive values:
Open_Loop has larger errors than CTRL EKF

- Significant positive impact of EKF soil moisture analysis on humidity & temperature
- Consistent soil moisture improvement

# Monitoring soil moisture at ECMWF

| Operational | Operational | Research development |
|---|---|---|
| **Active microwave data:**<br>**ASCAT** C-band (5.2GHz)<br>**On METOP A & B**<br>**NRT Surface soil moisture**<br><br>Operational product | **Passive microwave data:**<br>**SMOS** L-band (1.4 GHz), multi-angular<br>**NRT Brightness Temperature (xx,yy)**<br>Dedicated soil moisture mission | **Active and Passive:**<br>**SMAP** L-band<br><br>Max 12h latency for L1C Brightness Temp. (H,V)<br>Dedicated soil moisture mission |

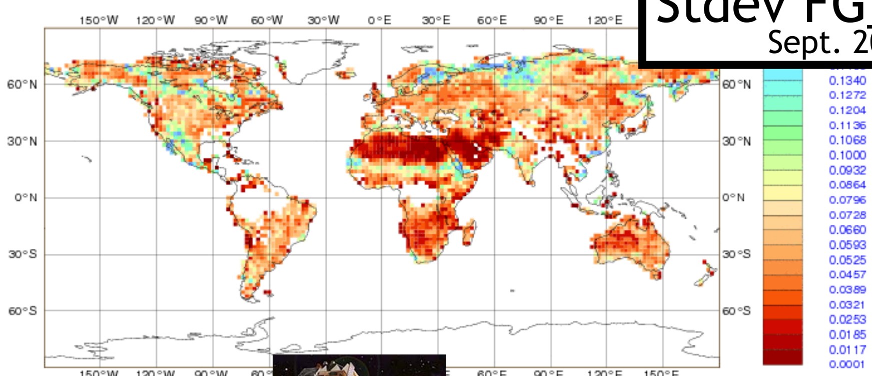
STATISTICS FOR SOIL MOISTURE FROM METOP-B/ASCAT

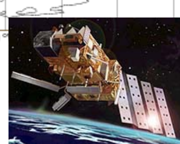
STATISTICS FOR RADIANCES FROM FROM SMOS

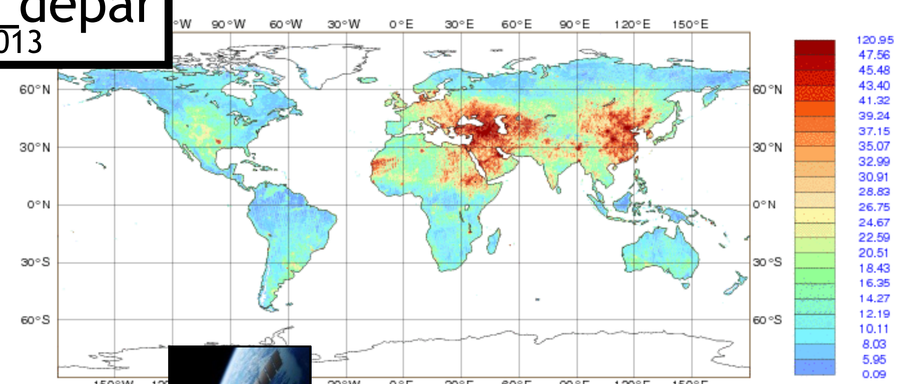
Operational Monitoring of surface soil moisture related satellite data:

**ASCAT** soil moisture ($m^3m^{-3}$) **SMOS** Brightness temperature (TB) (K)

Stdev FG_depar
Sept. 2013






# SMOS/CMEM intercomparison & bias correction

**Observations**

SMOS NRT TB (reproc v505)

Convert to grib
Superobing
Reduced Gaussian grid

Quality Control ensures:
Water Fraction < 5%
Radio. Accuracy < 4K
AFOV
No RFI (flag)
Faraday Rotation

Output:
TBxx, TByy, Faxx,…
Angles: 30, 40, 50

**Model**

ECMWF input:
SM, ST, Tair, Tskin
Land cover, LAI, texture

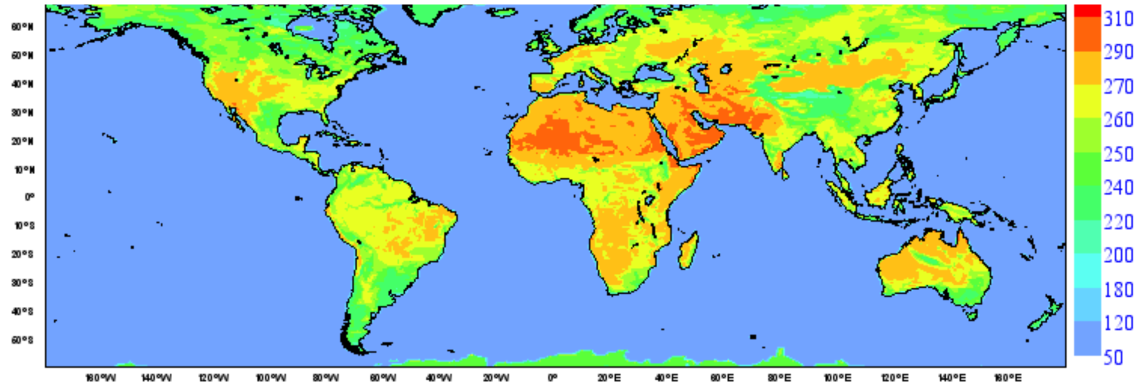
CMEM -> Simulate TBh,v
Reduced Gaussian grid
Resolution T511

Quality Control ensures:
No snow
T2m > 273K
Slope < 4%

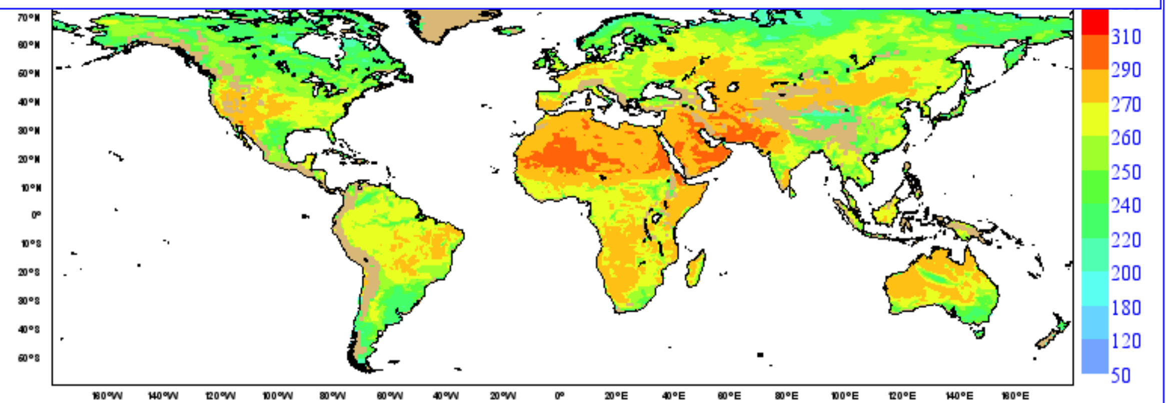
Output:
TBh, TBv, Faraday rotation
—>TBxx, TByy
Angles: 30, 40, 50

1- CMEM Intercomparison at 40° → best H-TESSEL/CMEM configuration
2- Monthly CDF matching for TBxx, TByy at 30°, 40°, 50°

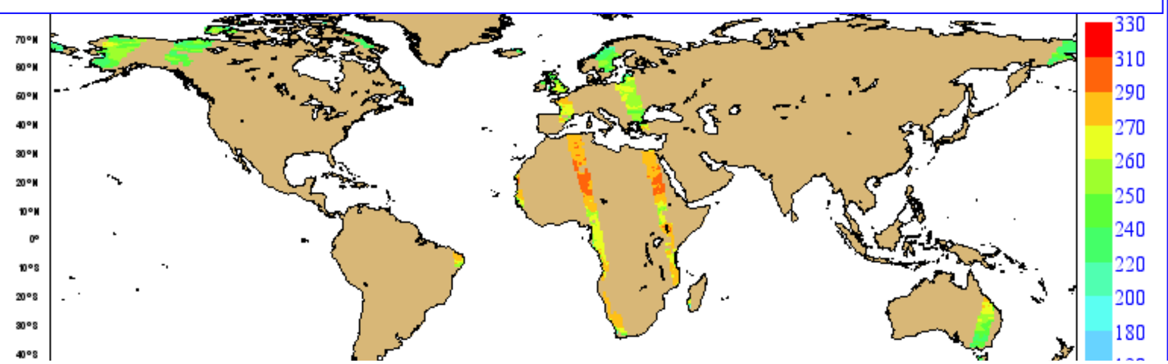
# ECMWF CMEM Simulations




**Simulated TBh TOA**
**01 July 2010 at 06 UTC**




Quality control (land-sea mask, orography, soil freezing, snow cover)

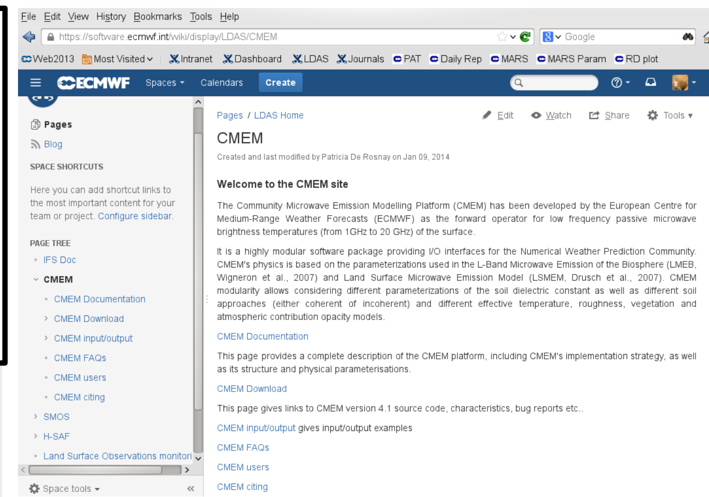



Match availability of SMOS data and apply Faraday rotation -> TBxx

# Passive microwave: CMEM forward model

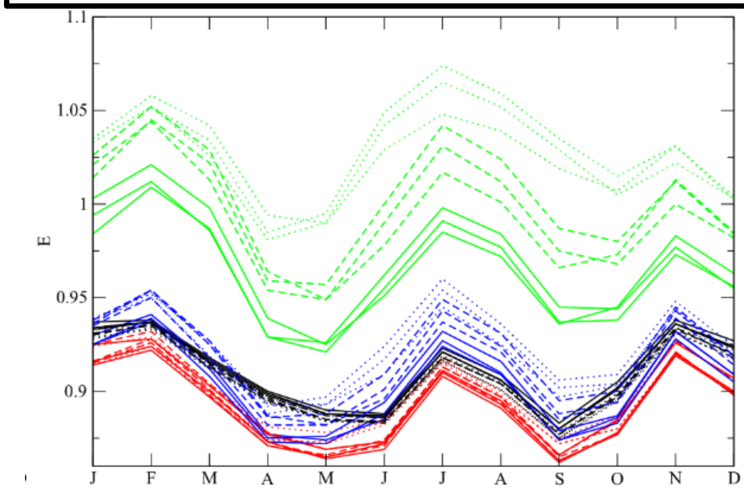
- ➢ Community Microwave Emission Modelling platform (CMEM) used as SMOS and SMAP forward operator
- ➢ Modular structure allows the use of a range of parameterisations of soil dielectric properties, soil roughness and vegetation opacity

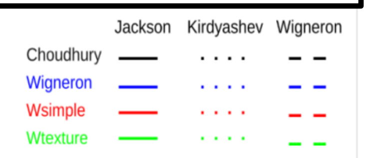
https://software.ecmwf.int/wiki/display/LDAS/CMEM




**CMEM_ECMWF comparison with SMOS TB 40 degrees data:**
- 3 dielectric models
  (Dobson, Mironov, Wang)
- 3 vegetation opacity models
  (Jackson, Kirdyashev, Wigneron)
- 4 roughness models
  (Choudhury, Wigneron, Wsimple, Wtexture)

} 36 configurations




(d) TBH

**Evaluation Metrics:**
RMSE, R, Bias, SDV, uRMSE, E (normalized uRMSE)

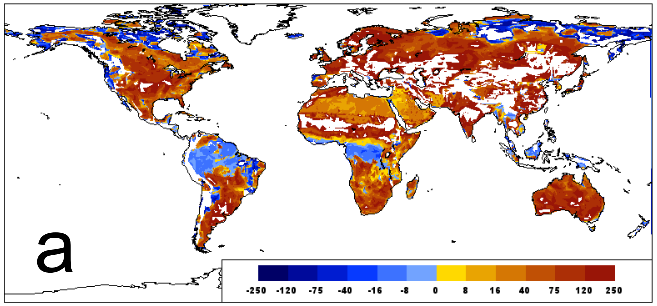
**Best CMEM configuration:**
**Dielectric: Wang and Schmugge ; Mironov**
**Vegetation opacity: Wigneron 2007**
**Roughness: Wigneron et al. 2001 (Wsimple)**

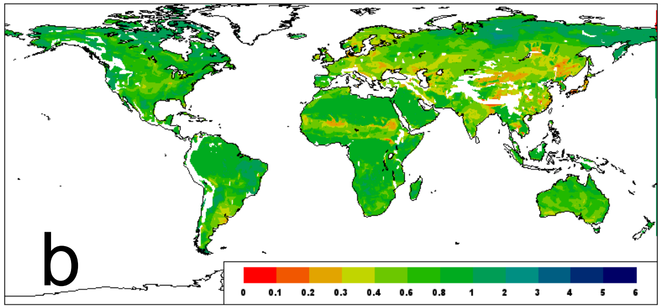
# ECMWF Bias correction for SMOS DA

CDF-matching matches mean and variance of two distributions
Used to match climatologies of observed SMOS TB and ECMWF

$$TB^*_{SMOS} = a + b\, TB_{SMOS}$$
$$\text{with } a = \overline{TB}_{ECMWF} - \overline{TB}_{SMOS}\, (\sigma_{ECMWF} / \sigma_{SMOS})$$
$$b = \sigma_{ECMWF} / \sigma_{SMOS}$$

Matching parameters computed on each grid point and for each month




**New revised CDF matching:**

- Based on ECMWF re-analysis of CMEM TB (using ERA-Interim forcing & latest version of IFS 41r1, implemented May 2015)
- Long term data sets: January 2010 – March 2014
- Computed at T511 (closest to SMOS resolution)
- Monthly CDF: 3-months moving window
- Multi-angular and dual pol CDF

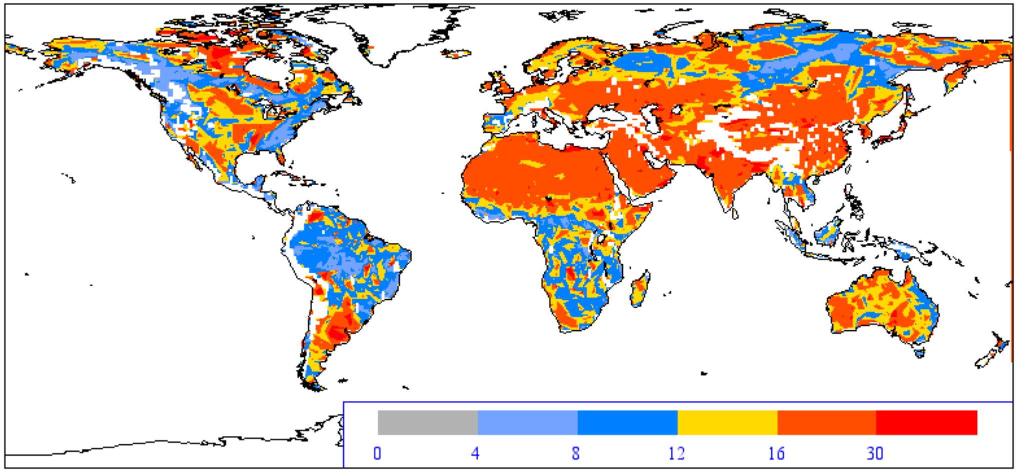
# First guess departure statistics

**2012**

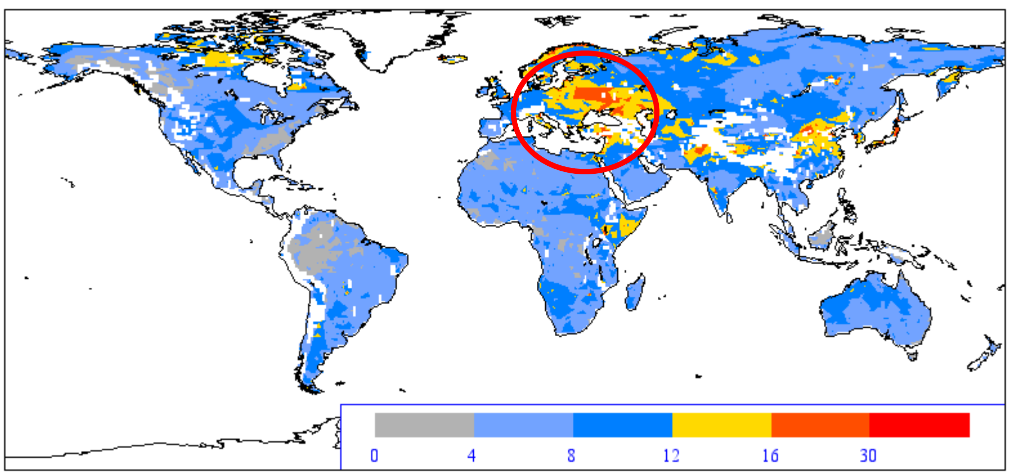
Comparison between SMOS Obs and ECMWF Model

RMSD (K)

TBxx, 40 degrees




**Before bias correction (17.7K)**




**After bias correction (7.5K)**

Low residual RMSD, except in RFI affected areas
More info: CESBIO SMOS blog
http://www.cesbio.ups-tlse.fr/SMOS_blog/

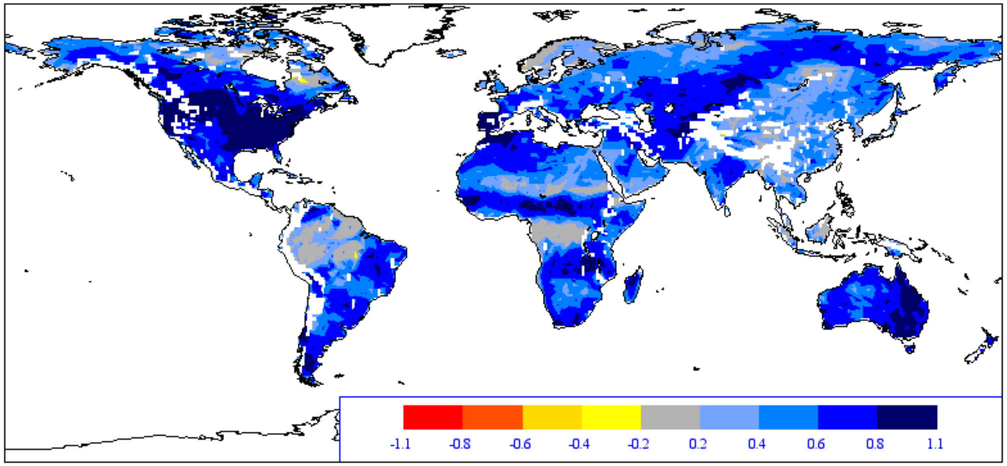
# First guess departure statistics

**2012**

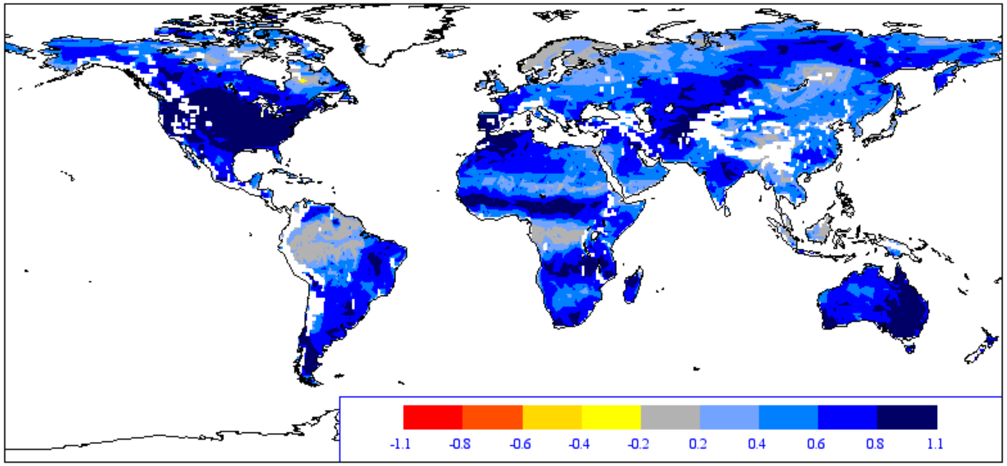
Comparison between SMOS Obs and ECMWF Model

Correlation

TBxx, 40 degrees




**Before bias correction (0.54)**



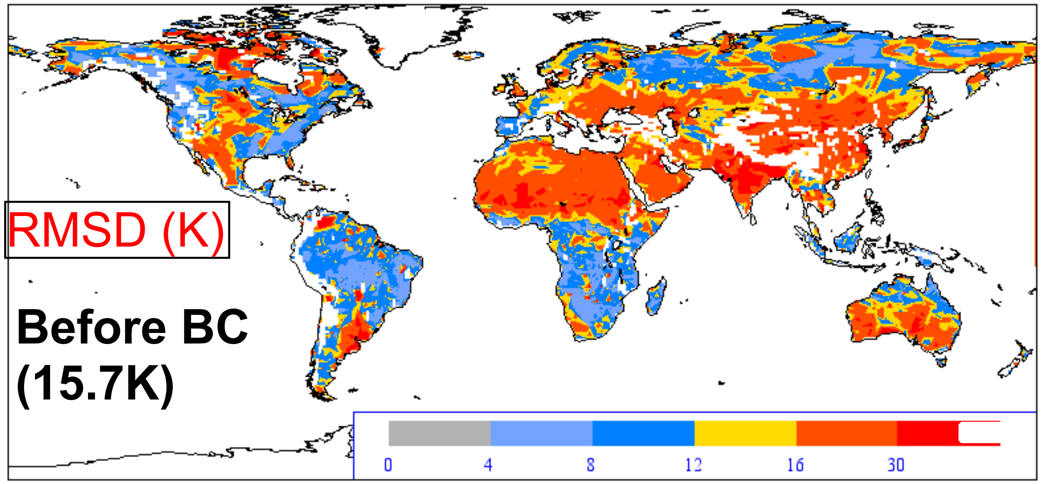

**After bias correction (0.59)**

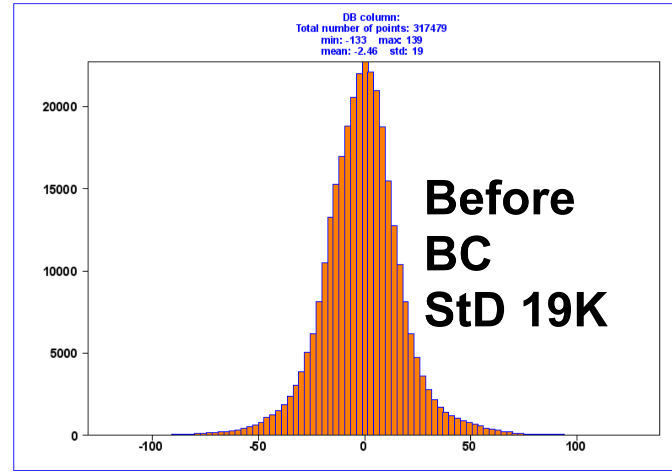
Seasonal bias correction
→ improve annual cycle consistency between model and observations

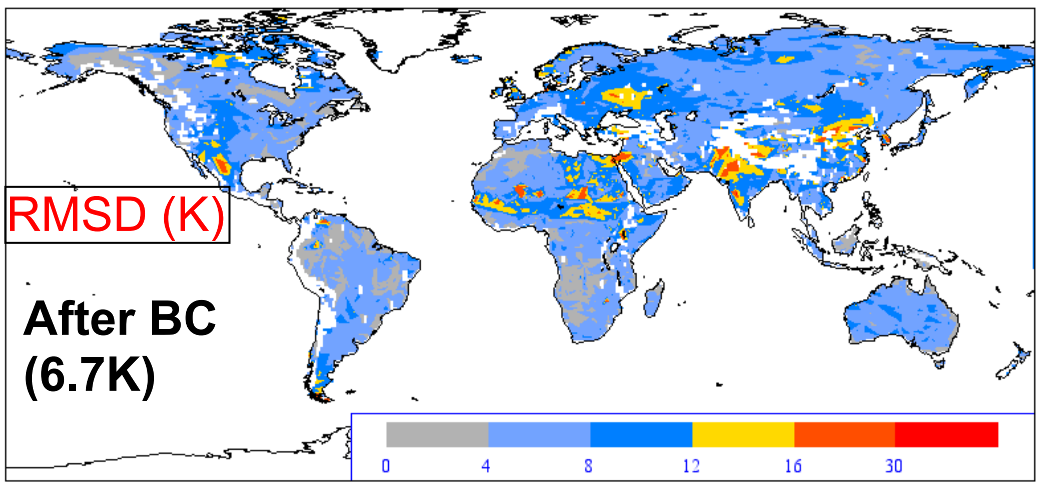
# First guess departure statistics

**July 2012**

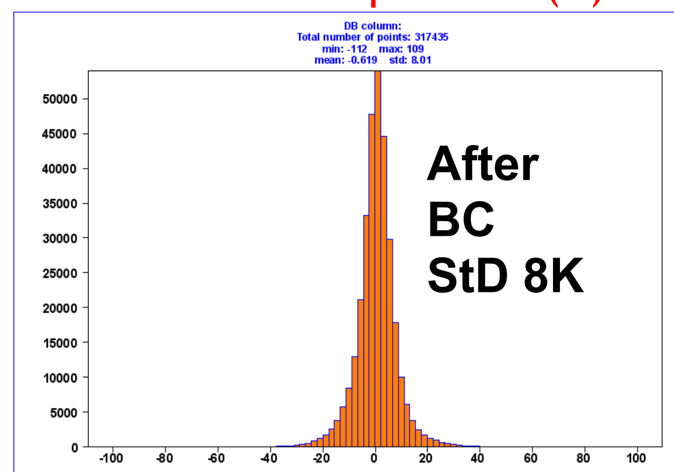
Comparison between SMOS Obs and ECMWF Model




First Guess Departure (K)




Monthly evaluation: first guess departure RMSD 6.7K for July

# First guess departure statistics

Comparison between SMOS Obs and ECMWF Model for 2012

| Angle | R | | RMSE(K) | | Bias (O-B) | | |
|---|---|---|---|---|---|---|---|
| | *XX* | *YY* | *XX* | *YY* | *XX* | *YY* | |
| *30* | *0.54* | *0.56* | *17.1* | *15.5* | *-0.6* | *-1.0* | Before BC |
| *40* | *0.54* | *0.51* | *17.7* | *14.6* | *-1.3* | *0.5* | |
| *50* | *0.47* | *0.48* | *19.7* | *13.4* | *-5.9* | *-0.8* | |
| *30* | *0.59* | *0.61* | *7.5* | *7.3* | *0.5* | *0.3* | After BC |
| *40* | *0.59* | *0.56* | *7.5* | *7.8* | *0.6* | *0.3* | |
| *50* | *0.53* | *0.52* | *8.5* | *8.2* | *0.5* | *0.1* | |

- **Before BC, larger RMSE for xx than yy; fixed after BC.**
- **After BC, RMSE lower than 8K except in RFI affected areas**
- **Seasonal BC improves mean, rmse and corr.**
- **FG_depar Stdev after BC ~ 8K**

**—> Suitable for data assimilation**

# Long term comparison between SMOS NRT TB and ECMWF CMEM TB re-analysis

Long term comparison between:
- SMOS NRT TB for 2010-2013 (proc v505)
- ECMWF-CMEM re-analysis using latest surface model and parameters

| | RMSE (K) | R | Anomaly R |
|---|---|---|---|
| *2010* | *8.68* | *0.545* | *0.277* |
| *2011* | *8.03* | *0.565* | *0.285* |
| *2012* | *7.78* | *0.567* | *0.302* |
| *2013* | *7.40* | *0.595* | *0.315* |

Table: Global mean statistics, after bias correction, considering xx and yy pol and 30,40,50 degrees incidence angles.

**→ Consistent improvement of agreement between SMOS and ECMWF reanalysis from 2010 to 2013.**
**→ SMOS TB data quality improvement**

# Summary and future plans

- ➢ Dvpts to use of SMOS data to initialise soil moisture for NWP
- ➢ Forward operator CMEM to project the model background (soil moisture) into the observation space (TBxx and Tbyy)
- ➢ Best CMEM configuration: Wang and Schmugge dielectric model; Wigneron et al 2001 for the soil roughness; Wigneron et al. 2007 for the vegetation optical thickness
- ➢ Data assimilation goal: reduce model random errors -> bias correction (BC) to remove systematic errors.
    - ➢ Model RMSD before BC ~16K (systematic errors), after BC ~8K (random errors).
- ➢ Used for SMOS TB data assimilation (see J. Muñoz Sabater next talk)
- ➢ Ongoing & very near future ECMWF activities:
    - SMOS SM NRT processor implementation (ECMWF/CESBIO)
    - SMOS Neural Network soil moisture data assimilation (N. Rodriguez)
    - CMEM improvements in desert areas (M. Lange ECMWF/DWD)
    - SMOS wind speed and sea ice investigation
    - SMAP implementation