ECMWF SMAP Early Adopter: Preparation of SMAP monitoring

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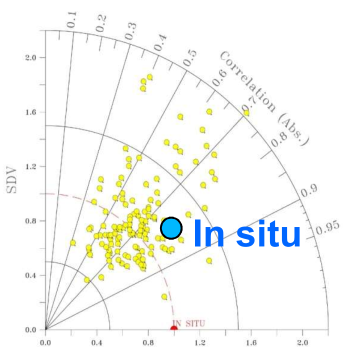
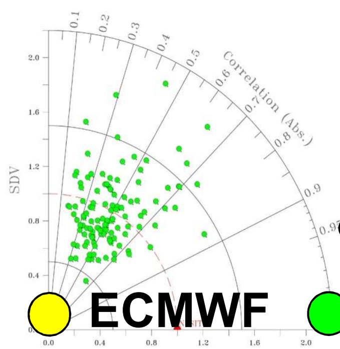
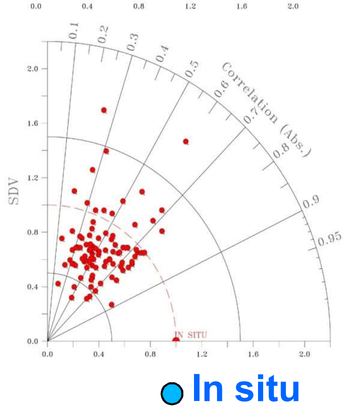
Thanks to: M. Dahoui, J. Muñoz Sabater, A. Fouilloux, I. Mallas, C. Albergel, G. Balsamo

Validation NCRS-SCAN (154 stations)

Albergel et al, 2011





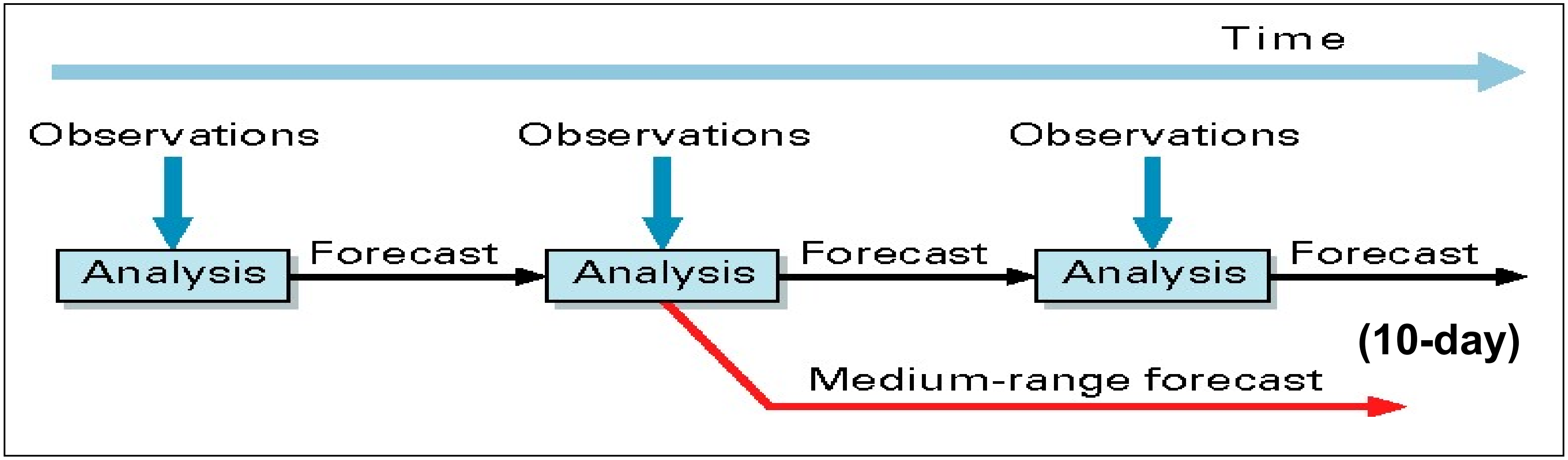


ECMWF SM-DAS-2 | ASCAT | SMOS

Correlation [-] (number of significant values)		
ECMWF	***ASCAT***	***SMOS***
0.65 (131 stations)	**0.48** (125 stations)	**0.51** (106stations)

The ECMWF Integrated Forecasting System (IFS) data assimilation system

http://www.ecmwf.int/newsevents/training/meteorological_presentations/MET_DA.html



Data Assimilation System:
Provides best possible accuracy of initial conditions to the forecast model

Analysis:
- 4D-VAR for atmosphere
- Surface analysis

- The observations are used to correct errors in the short forecast from the previous analysis time.
- Every 12 hours we assimilate 7 – 9,000,000 observations to correct the 80,000,000 variables that define the model's virtual atmosphere.
- This is done by a careful 4-dimensional interpolation in space and time of the available observations; this operation takes as much computer power as the 10-day forecast.

ECMWF Land surface data assimilation

1999	2004	2010/2011

OI screen level analysis

Douville et al. (2000)
Mahfouf et al. (2000)

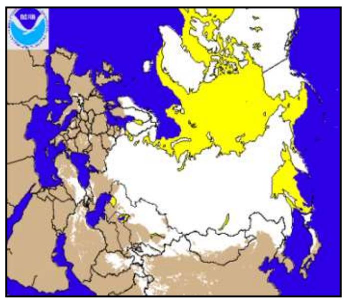
Soil moisture 1D OI analysis
based on Temperature and relative humidity analysis

SYNOP Data

Revised snow analysis

Drusch et al. (2004)

Cressman snow depth analysis using SYNOP data improved by using NOAA / NSEDIS Snow cover extend data (24km)



NOAA/NESDIS IMS

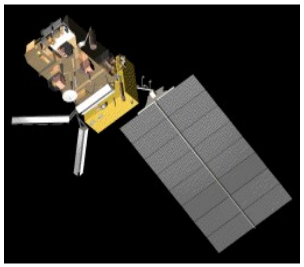
Operational

New snow analysis (11.2010)
Optimum Interpolation (OI)
High resolution NESDIS data
(de Rosnay et al., 2011)

SEKF Soil Moisture analysis (11.2010)
Simplified Extended Kalman Filter
Drusch et al. (2009)
de Rosnay et al. (2011)

Research

Use of satellite data



METOP-ASCAT
de Rosnay et al., 2011

SMOS
Sabater et al., 2011

SMAP Early Adopter

Validation activities (H-SAF)
Albergel et al. 2011

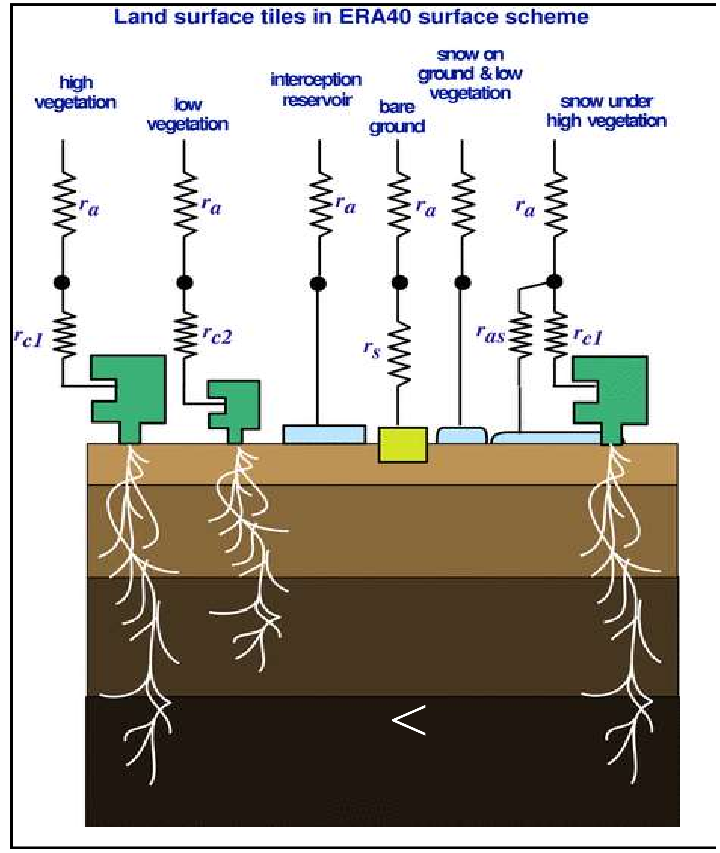
Simplifed EKF soil moisture analysis

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, fn of
H (linearsation of $\mathcal{H}$), **B** and **R** (covariance matrices of background and observation errors).

Simplified EKF corrects the trajectory of the Land Surface Model



Observations used:
- Operational: Conventional observations **(T2m, RH2m)**
- Research (ECMWF, Météo-France, BoM, CMC): Satellite data from ASCAT, SMOS, AMSR-E
- UKMO uses ASCAT in operations in a nudging data assimilation scheme

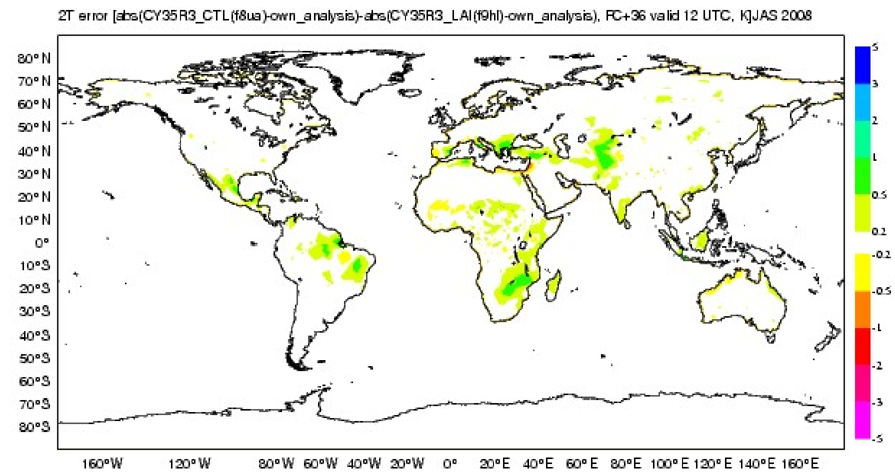
Simplified EKF: de Rosnay et al., 2011
LSM H-TESSEL: Balsamo et al., 2011

SEKF soil moisture analysis

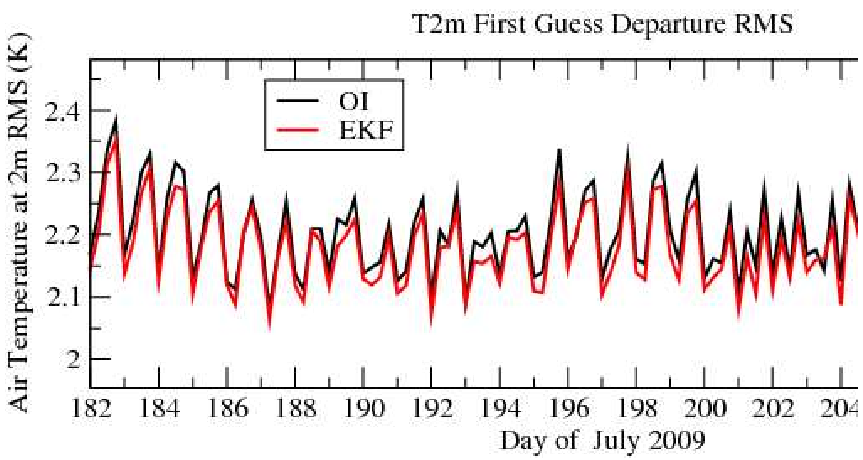
SEKF: IFS cycle 36r4

(de Rosnay et al., 2011)

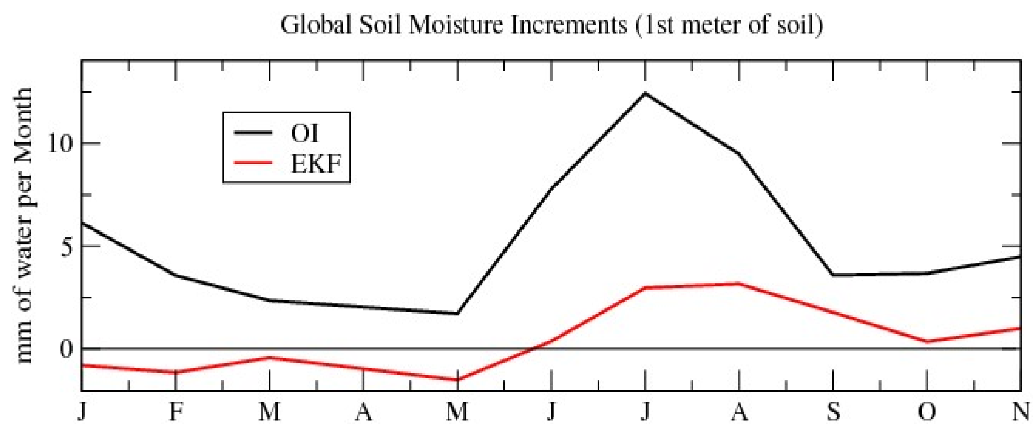
T2m error (OI-SEKF) 48h fc
→ EKF improves T2m



Global mean RMS (against SYNOP)



(de Rosnay et al, News letter article, spring 2011)



→ **Compared to the OI, the SEKF SM analysis improves screen level parameters analysis and opens the possibility to use satellite data for SM analysis**

ECMWF SMAP Early Adopter activities

- **Objective**
  - Pre-launch preparation for SMAP L1C_TB and L2_SM_A monitoring
  - Based on ECMWF satellite monitoring experience; recent developments for SMOS TB (passive) and ASCAT SSM (active)
- **Method**
  - Implement SMAP L1C_TB and L2_SM_A data in the ECMWF Integrated Forecasting System (IFS) to enable SMAP active and passive data monitoring → **develop a SMAP Observation Data Base (ODB) at ECMWF**
  - Develop bias corrections, based on SMAP SDS Testbed products

ECMWF SMAP Early Adopter activities

- **Expected results**
  - Monitoring of L1C_TB and L2_SM_A
  - Metrics: mean and StD for SSM and TB observations and first guess departure (obs-model)
- **Post launch strategy**
  - Monitoring of SMAP L1C_TB and L2_SM_A (depending on latency).
  - Update Bias correction based on real SMAP data
  - Investigate SMAP data assimilation impact on NWP forecast skills

Satellite data Monitoring at ECMWF

- Core activity at ECMWF
- Dedicated operational web page: link

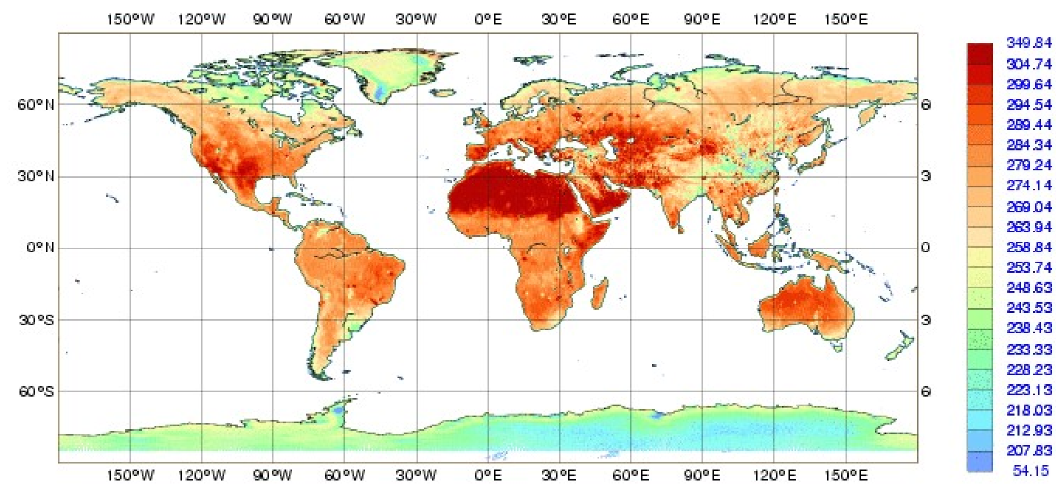
http://www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/

- Soil Moisture related satellite monitoring:
  - SMOS (Passive micriwave L-band TB)
  - ASCAT (Active microwave C-band soil moisture)

SMOS Monitoring

Soil Moisture and Ocean Salinity (launched in 2009)
Passive microwave interferometric radiometer operating at L-band (1.4 GHz)
Multi-angular measurements of Brightness Temperature (TB) (Kerr et al., 2010)

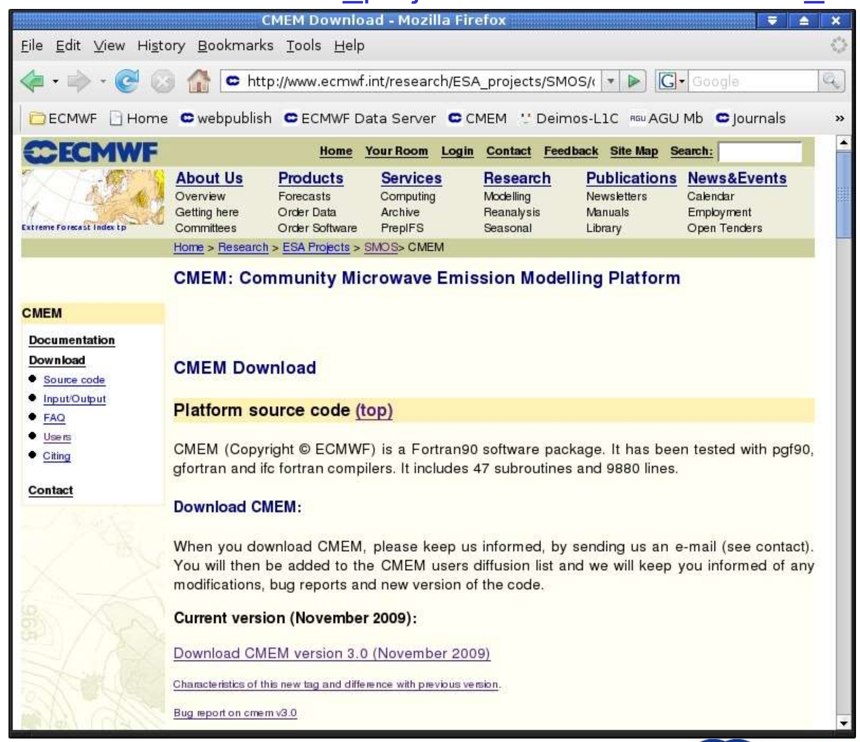
SMOS NRT TB product → ECMWF SMOS L1c TB (K) NRT Monitoring (TBV 50°) Aug. 2011



Passive microwave data: Forward Operator

- **ECMWF Community Microwave Emission Modelling Platform (CMEM)**
- I/O interfaces for the Numerical Weather Prediction Community.
- Web interface available

http://www.ecmwf.int/research/ESA_projects/SMOS/cmem/cmem_index.html



Use of SMOS and SMAP L1C_TB at ECMWF

→ Relies on CMEM forward operator implemented in the IFS

Holmes et al., 2008
Drusch et al. JHM, 2009
de Rosnay et al. JGR, 2009

SMOS Monitoring

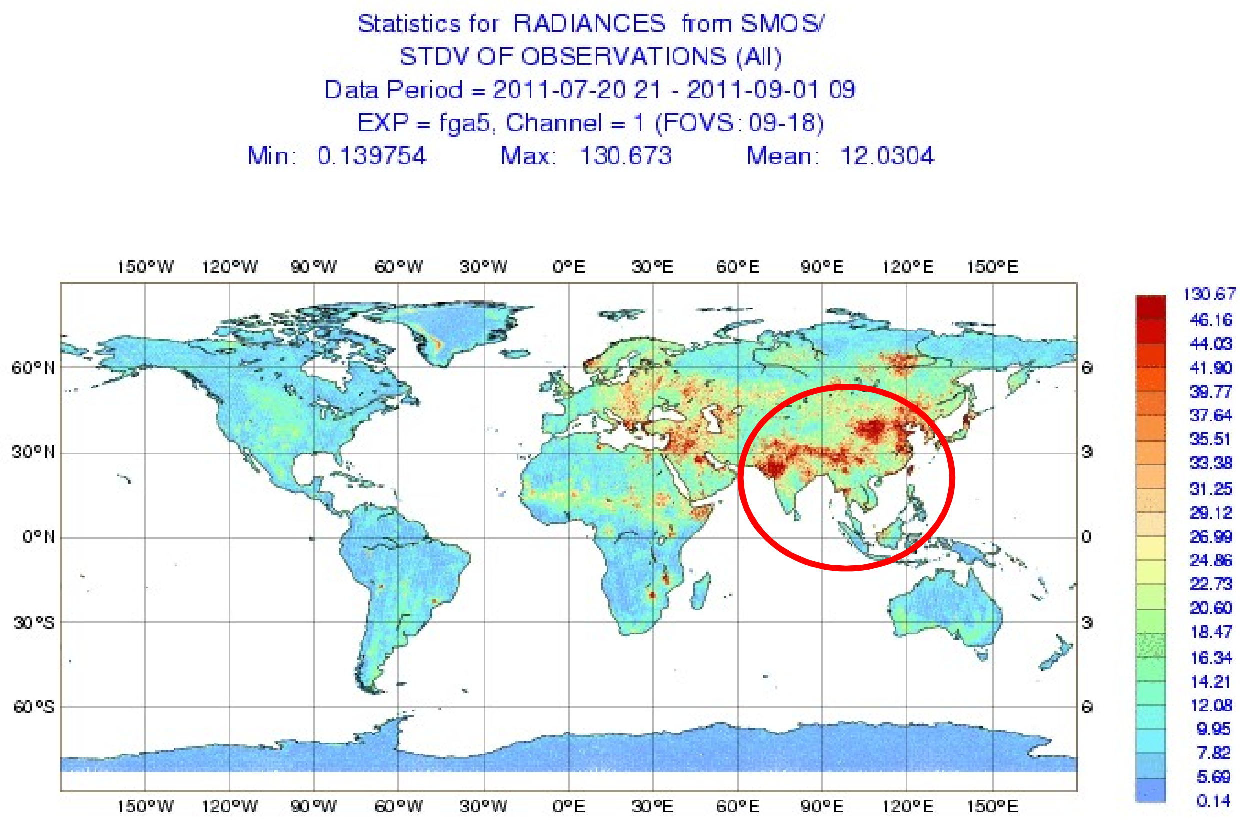
- **Routinely production of statistics with SMOS Tb, model equivalents and background departures, <u>in NRT</u>**
  - Global scale
  - Land and oceans separately,
  - Several incidence angles [**10, 20, 30, 40, 50, 60**],
  - Two polarisations states **[XX, YY]**,
  - Independently per continents and hemispheres,

- **Statistical products,**
  - Time-averaged geographical mean-fields (last 6 weeks of data),
  - Hovmoeller zonal mean fields (last 3 months),
  - Time series of area averages (last 3 months),
  - Scatter plots: background departures as function of incidence angle (last 5 weeks).

SMOS Monitoring

STD of First Guess Departure over land (Obs – Model), July-Aug 2011

RFI (Radio Frequency Interference) issues → impact on FG departures STD is large; Lots of RFI sources switched off in Europe, still an important issue in Asia.



- Continuous improvement of the data quality since the end of the commissioning phase

- August 2011: availability of a reprocessed SMOS TB data set of consistent quality

Muñoz Sabater et al., 2011

SMOS Challenges

- Earth Explorer mission → investigate multi-angular L-band data to access soil moisture information.
- Data volume, data thinning, noise filtering
- RFI issues, detecting and mitigation approaches under development (ESA)
- For NWP applications:
  - SMOS ODB developed and implemented in the IFS
  - Multi-angular monitoring implemented in Near Real Time
  - Importance of L1C_TB flag content for data pre-processing
  - New forward operator (CMEM) developed (used at ECMWF, CMC, GSFC, Météo-France and others)
  - Bias correction and forward operator calibration have to be investigated based on long enough time series of consistent quality.
  - Ongoing SMOS data implementation in the ECMWF SEKF
- For SMAP L1C_TB: use CMEM forward operator, as for SMOS

Soil Moisture Active data: ASCAT

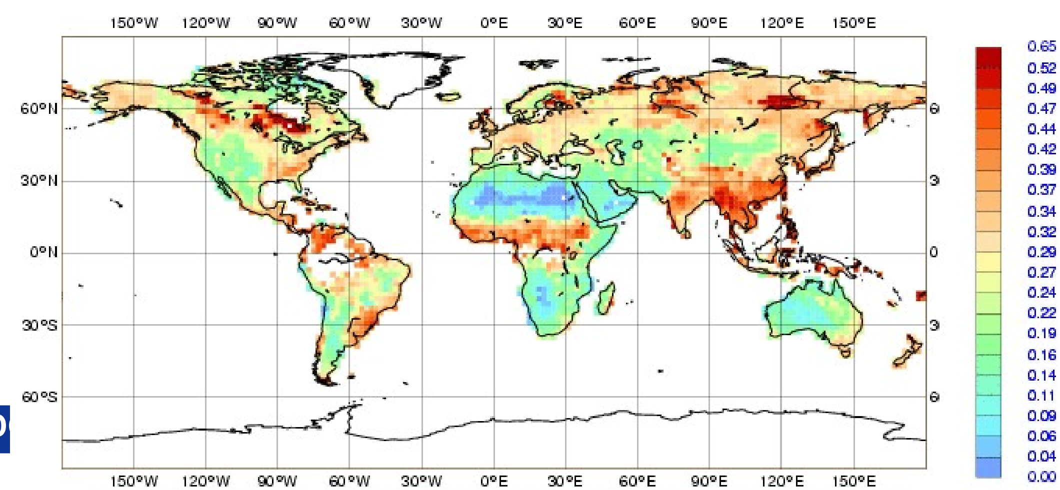
Advanced Scatterometer on MetOP (launched in 2006)

Active microwave instruments operating at C-band (5.6GHz) ~0.5-2 cm
Surface soil moisture index (ms) based on TUWien retrieval scheme (Wagner et al., 1999)

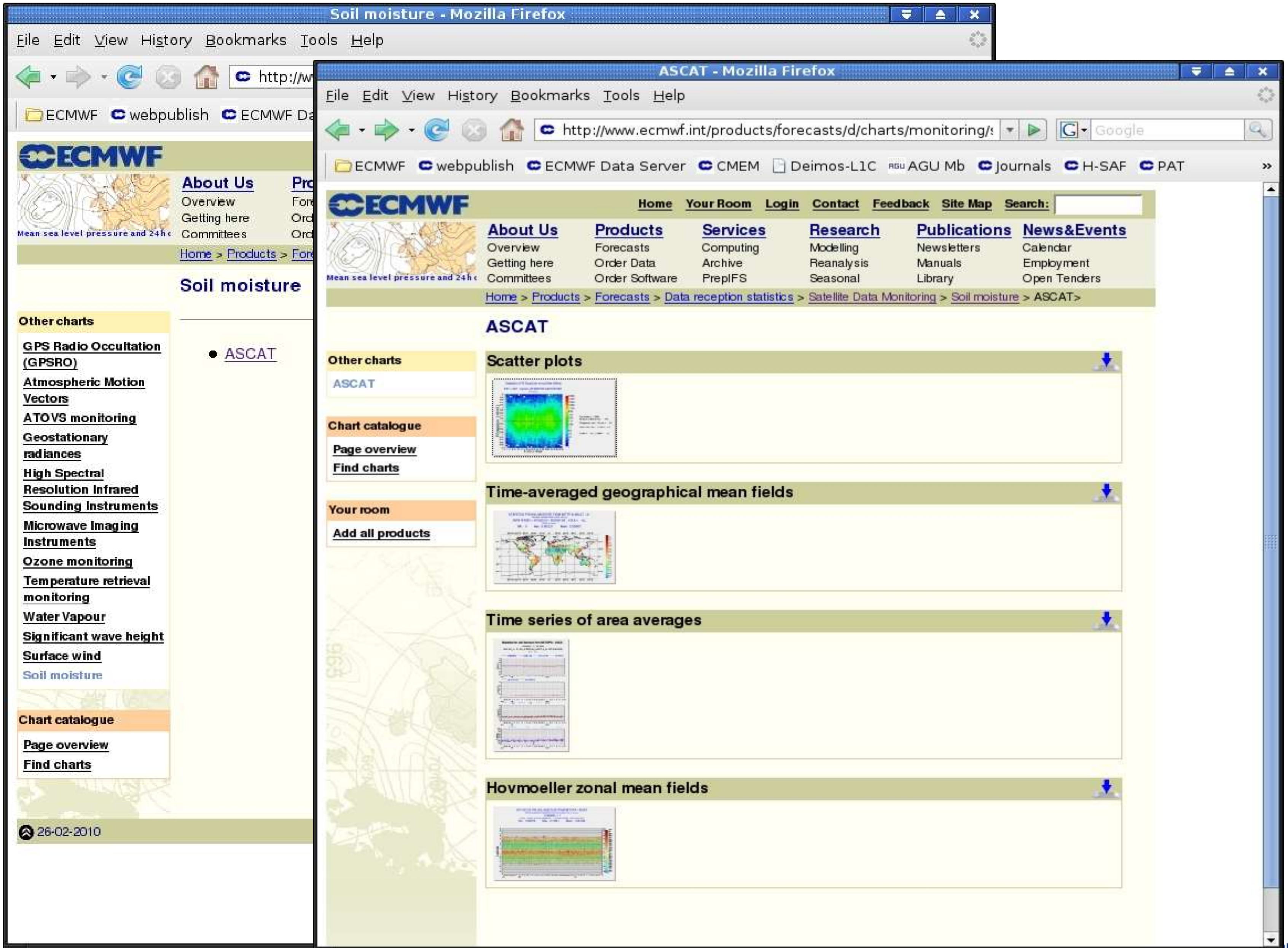
ASCAT operational SM product : NRT data and disseminated to Numerical Weather Prediction community via EUMETCAST

~50 km resampled 25km

ASCAT operational NRT SSM Monitoring Aug. 2011



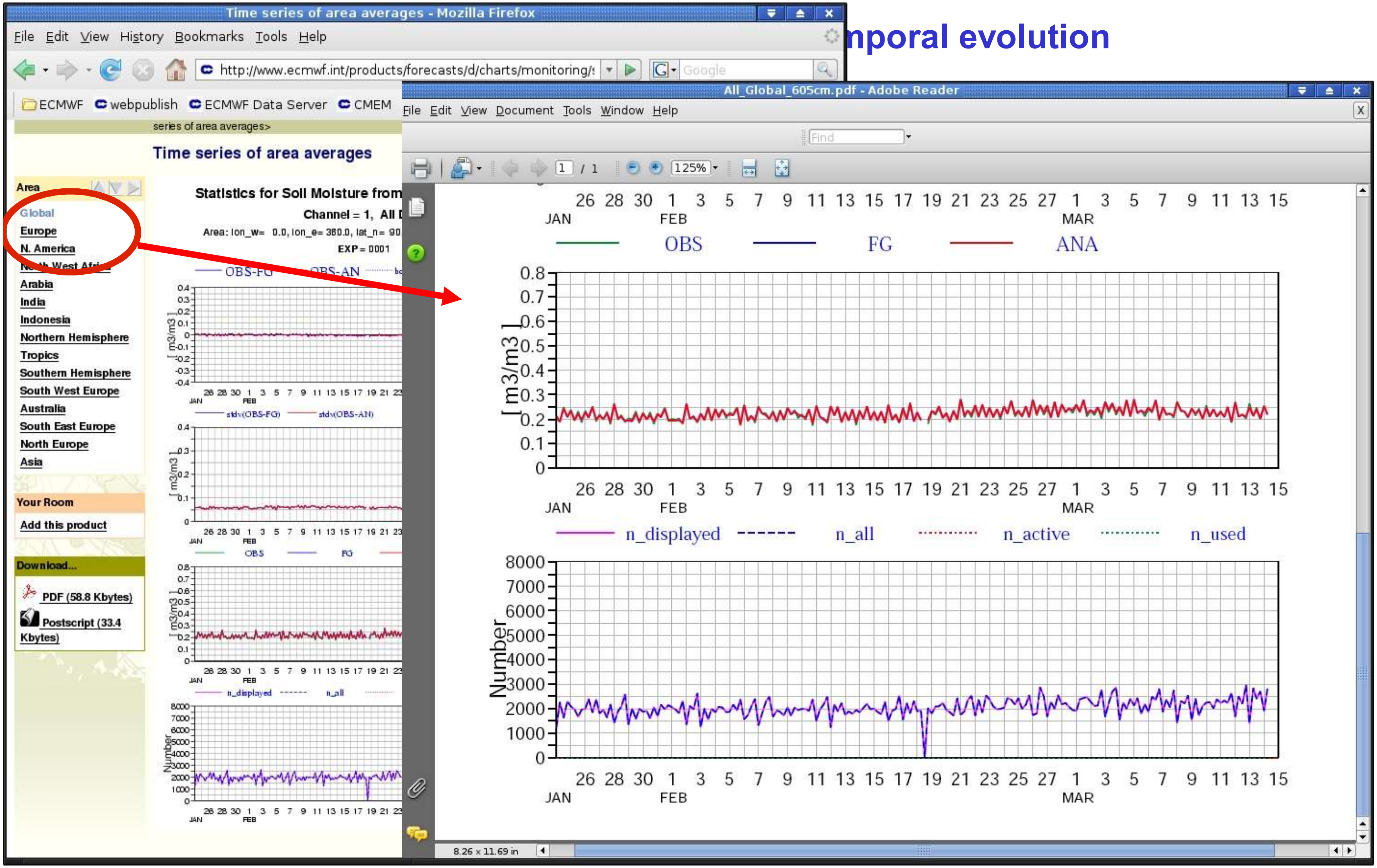
ECMWF Operational ASCAT monitoring (since September 2009)



ECMWF

ECMWF Operational ASCAT monitoring (since September 2009)

mporal evolution



ASCAT CDF matching

- ASCAT soil moisture is an Index (ms)
- Model soil moisture θ is volumetric (m^3/m^{-3})

→ **ASCAT index has to be converted to volumetric soil moisture and bias corrected**

→ **Simple Cumulative Distribution Function (CDF) matching (Scipal et al., 2008)**

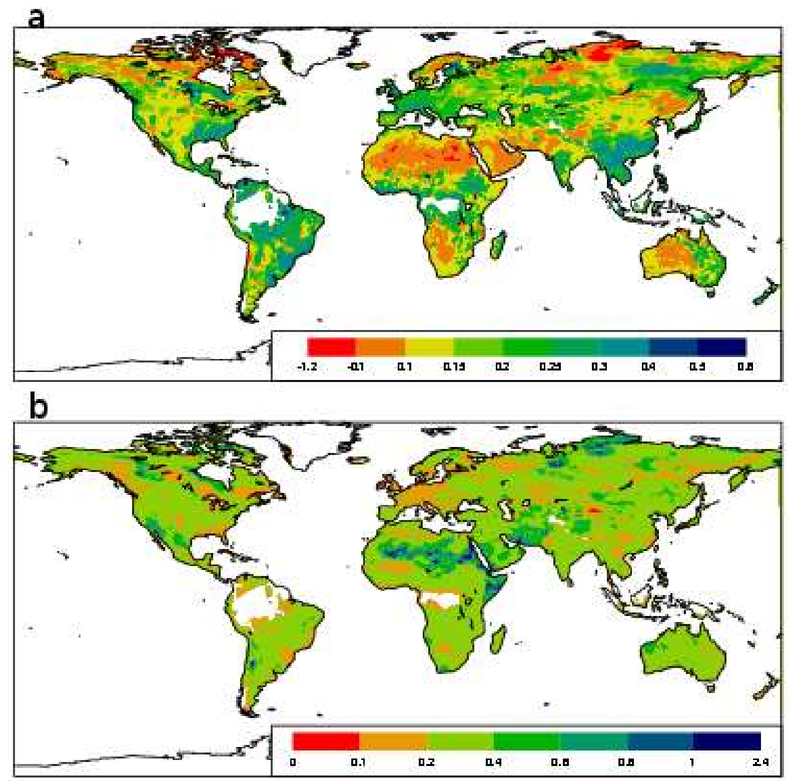
$$\theta_{ASCAT} = a + b * ms$$

a and b are CDF matching parameters computed on each model grid point separately

$$a = \overline{\theta_{ERA}} - \overline{ms} \, . \, [var(\theta_{ERA}) \, / \, var(ms)]^{1/2}$$

$$b = [var(\theta_{ERA}) \, / \, var(ms)]^{1/2}$$

CDF matching fits the data mean and variance on that of the model (ERA-Interim)
Moments are rescaled to H-TESSEL soil moisture



T1279 (16km) resolution ASCAT CDF matching parameters

Improved use of ASCAT Soil Moisture data

Improved product

18 August 2011: EUMETSAT release of improved soil moisture product

- Improved backscattering coefficient calibration (wind & SM)
- Improved soil moisture retrieval algorithm (TUWien)
  (better consistency with ERS/SCAT, lower angle dependency)

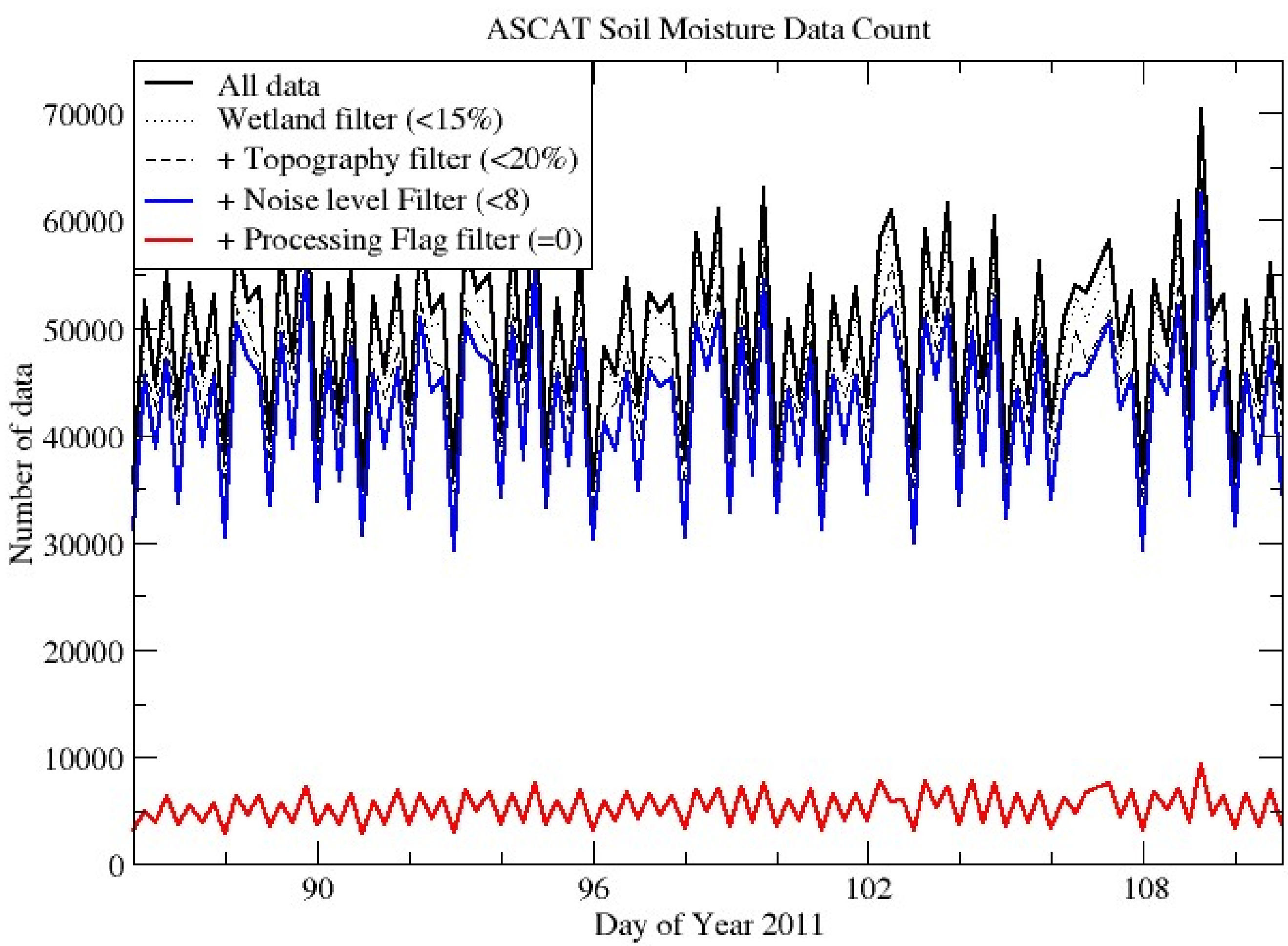
Revision of the bias correction

- Match with recent H-TESSEL version (cycle 36r4)
- Match ASCAT index to offline H-TESSEL simulations (prevent from matching to a SM climatology affected by systematic errors in precipitation in some areas)
- Account for seasonal cycle correction
- Tests with new ASCAT product

(de Rosnay et al., ECMWF Res. Memorandum)

ASCAT Soil Moisture data: pre-processing

ASCAT SM data BUFR content (per 6h) in April 2011



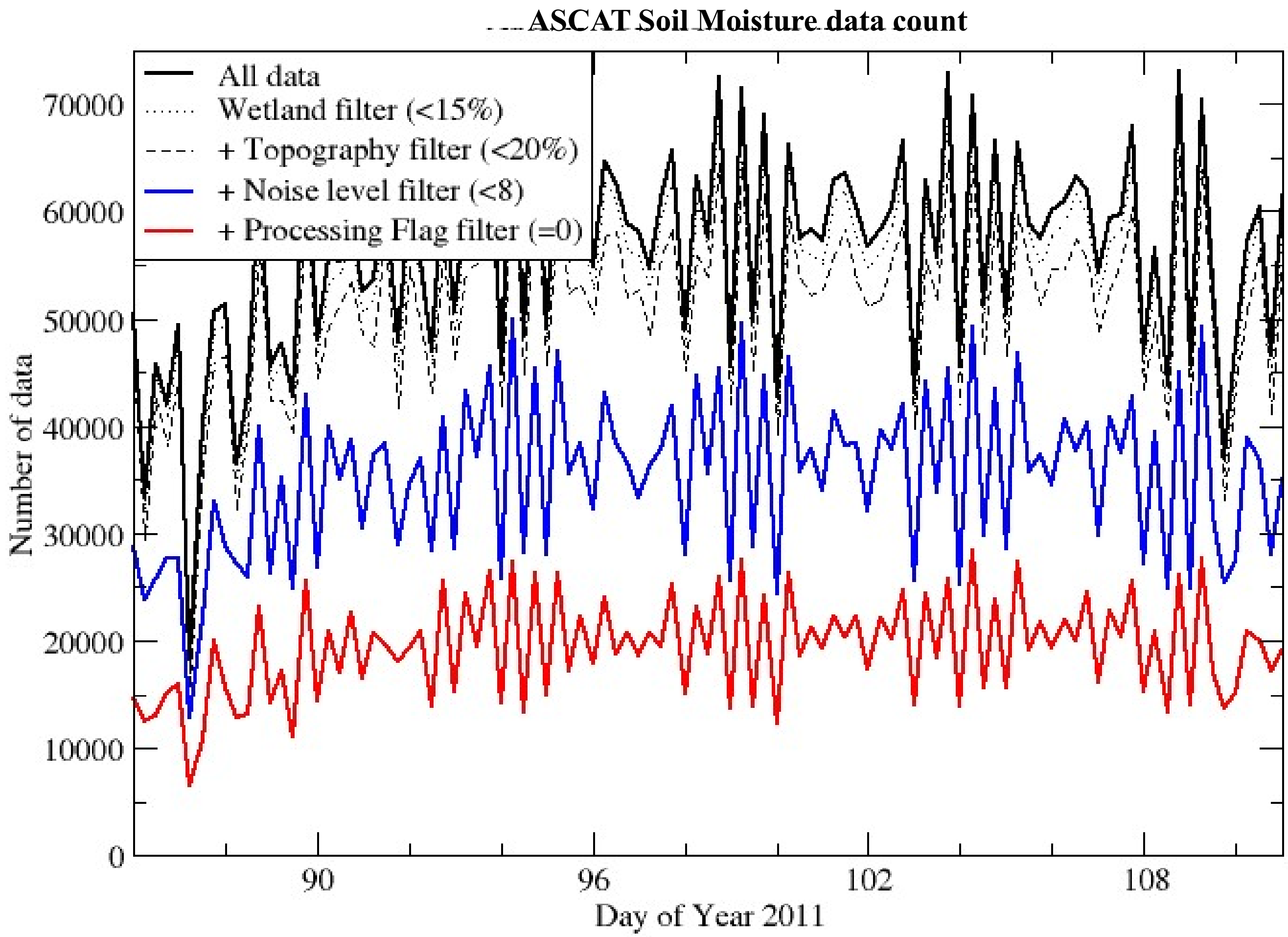
Data Thinning

ECMWF usage:
Limited number of observations remaining after pre-processing

ECMWF

ASCAT Soil Moisture data: pre-processing

New ASCAT SM test data set BUFR content (per 6h)
EUMETSAT operational product since Aug. 2011



New EUMETSAT product → Increased number of observations after pre-processing

ASCAT Bias correction revision

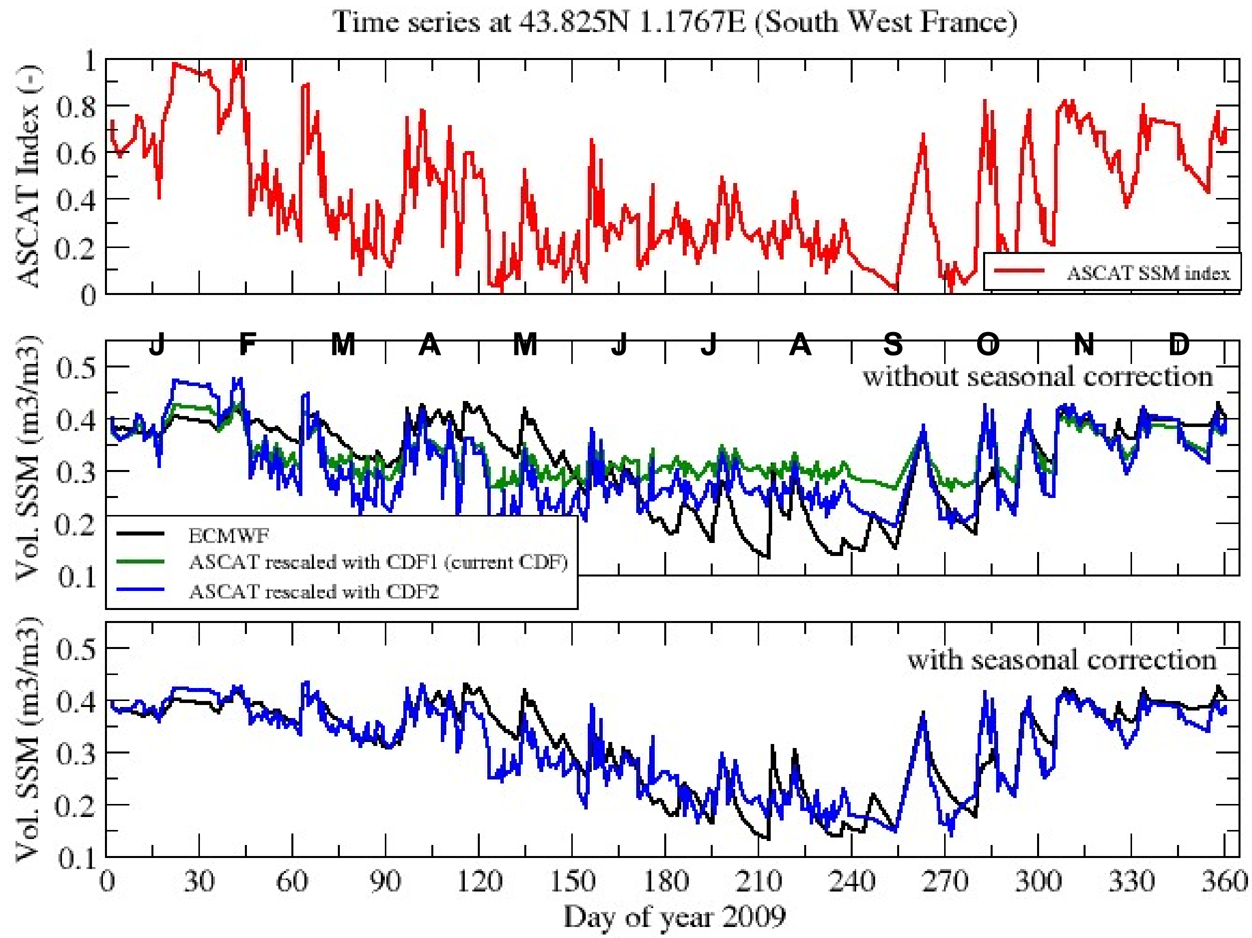
ASCAT data

ECMWF SM

OLD CDF matching

New CDF matching

New CDF matching
With seasonal
correction



Monthly CDF matching based on a 3-months moving window

Bias correction: crucial component of the data assimilation system

Used at ECMWF for - Operational ASCAT soil moisture monitoring

- ASCAT Soil Moisture data assimilation

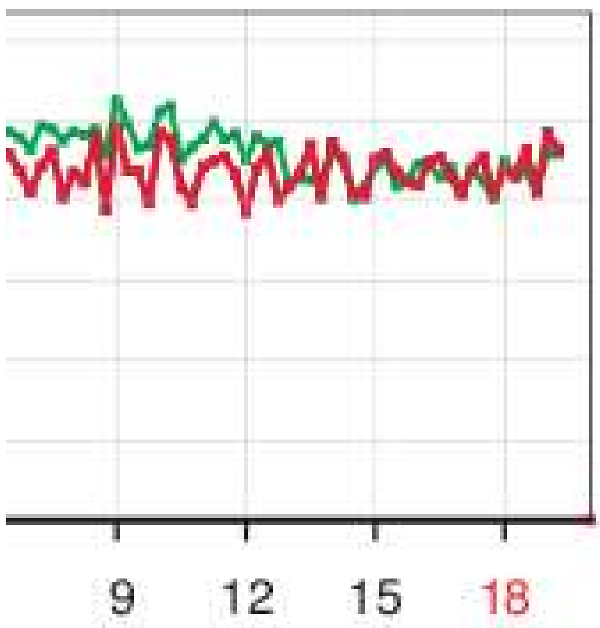
ASCAT monitoring

Esuite 37r3: new CDF matching annual

Next cycle 38r1: new CDF matching seasonal

13 September:

Improved Bias Correction:
Good agreement between ECMWF and ASCAT (global)

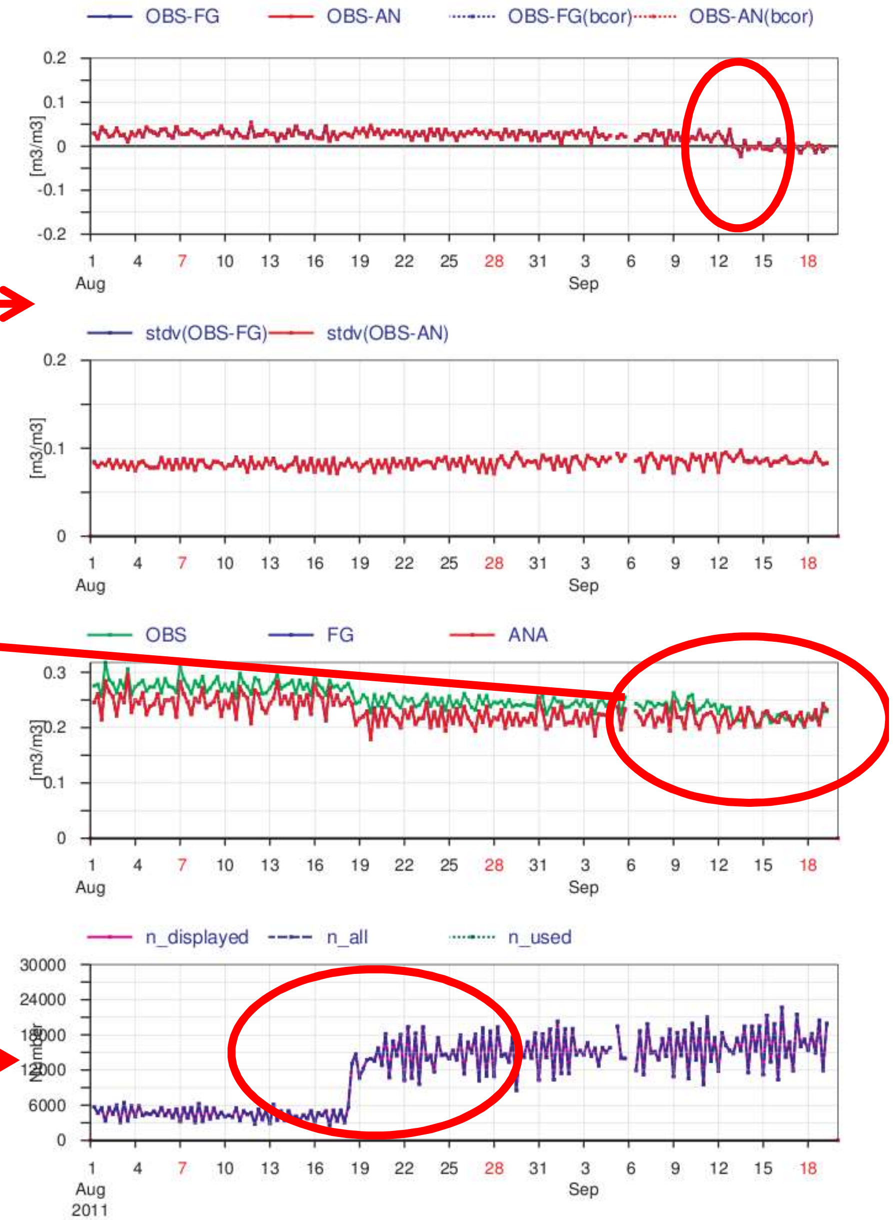


18 August:

Improved ASCAT product
More data used

Global scale:

Statistics for soil moisture from METOP-A/ASCAT
Channel =1, All data [time step = 6 hours]
Area: lon_w= 0.0, lon_e= 360.0, lat_s= -90.0, lat_n= 90.0 (over All_surfaces)
EXP = 0055



ASCAT SM data assimilation

The EUMETSAT Network of Satellite Application Facilities

H SAF Support to Operational Hydrology and Water Management

ECMWF produces the H-SAF root zone SM produ

ASCAT (surface swath) → SM-DAS (Root Zone profile global)
consistent 2008- 2010 … NRT in 2012

ECMWF Atmospheric conditions

SYNOP
T2m RH2m

ASCAT
Surface SM
Bias corrected

SEKF
Soil Moisture
Analysis
in the IFS

SM-DAS-2:
Soil Moisture
Profile

25km (T799)

4 layers:
0-7cm
7-28 cm
28-100 cm
100-289cm

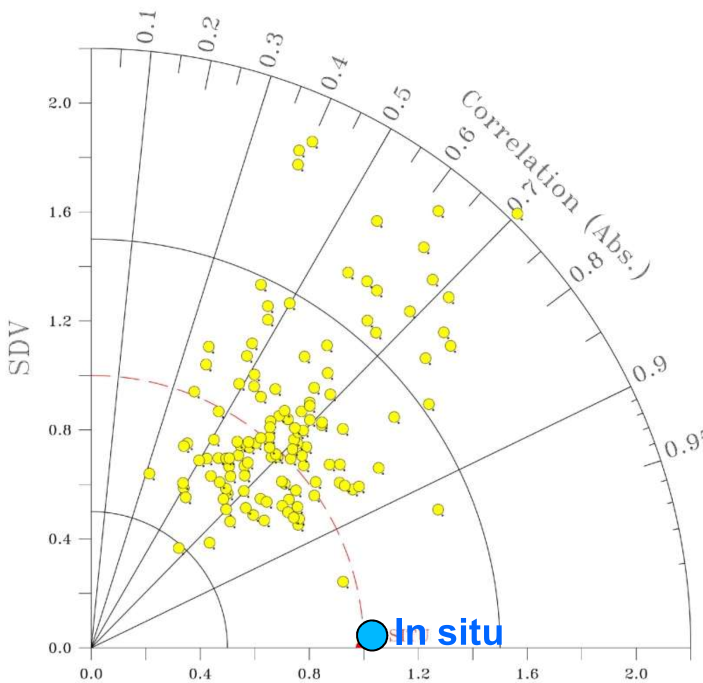
H-SAF CDOP: SM-DAS-2 Production chain

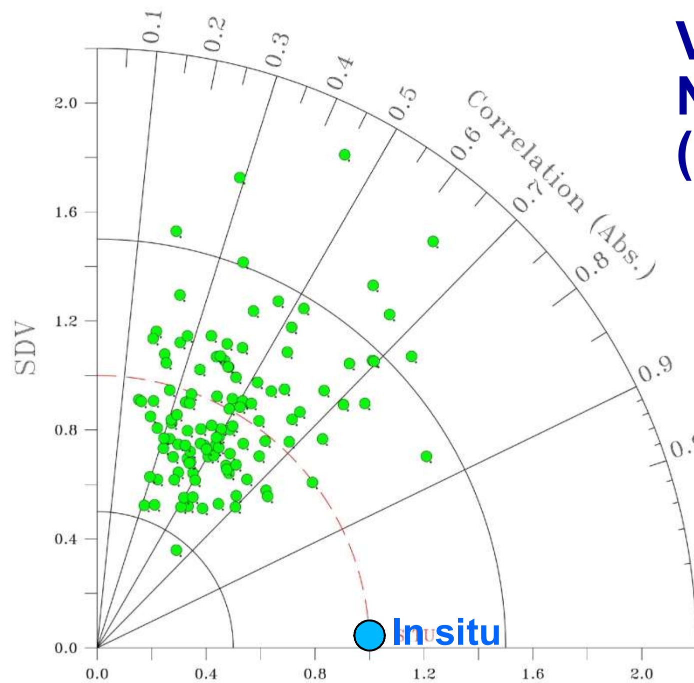
Quality Control → use data when:
- **Incidence angle: cell number € [11,26]**
- **Topographic complexity ≤ 20**
- **Wetland Fraction ≤ 15**
- **Noise level ≤ 8**

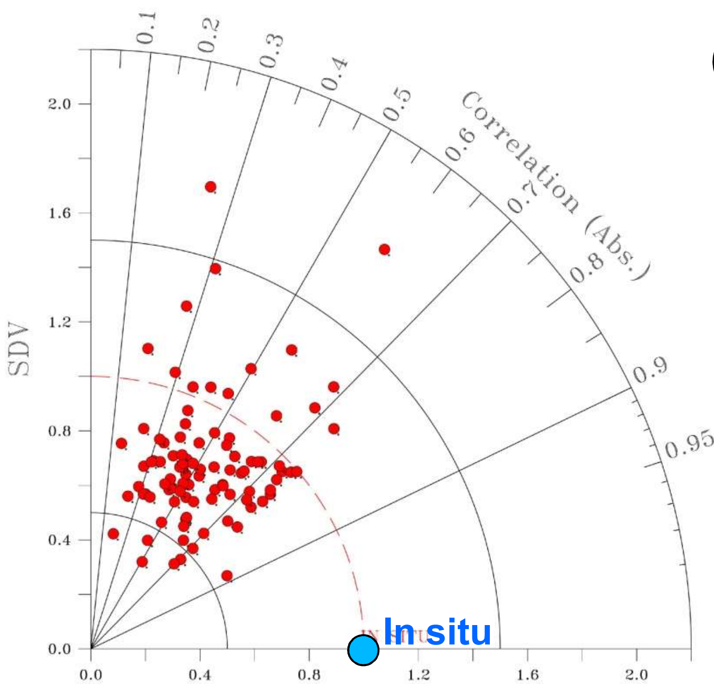
For Surface conditions:
- **Snow free**
- **T2m > 0° C**

Validation NCRS-SCAN (154 stations)

Albergel et al, 2011







ECMWF SM-DAS-2

ASCAT

SMOS

Summary

- SEKF soil moisture analysis
  - Operational at ECMWF since November 2010
  - Positive impact on T2m **and** soil moisture
- Use of Active data: ASCAT
  - Operational NRT Monitoring
  - Research data assimilation
  - Importance of quality control and pre-processing ; usage of product flags
  - Revised bias correction (CDF matching), with H-TESSEL corrected from precipitation errors and accounting for seasonal correction → ASCAT DA has a positive impact.
  - ASCAT Data Assimilation (H-SAF)→ Root zone SM
- Use of passive data: SMOS
  - Quasi NRT Monitoring
  - Challenging implementation: volume of data, new grid, strong RFI
  - Importance of pre-processing and usage of product quality flags
  - Current Bias correction development accounting for seasonal cycle correction

Summary

- **SMAP Early Adopter Activities**
  - Pre-launch preparation for SMAP L1C_TB and L2_SM_A monitoring

    Based on the **SMAP Testbed product when available**
  - SMAP ODB: will include both L1C_TB and L2_SM_A
  - SMAP L1C_TB monitoring will use CMEM and Seasonal TB Bias correction
  - SMAP L2_SM_A monitoring based on ASCAT type bias correction to rescale L2_SM_A to ECMWF SSM
  - Post launch: investigate the impact of SMAP data assimilation on NWP

More information

ECMWF SMOS web page:
http://www.ecmwf.int/research/ESA_projects/SMOS/ (link)

ECMWF H-SAF web Page:
http://www.ecmwf.int/research/EUMETSAT_projects/SAF/ (link)

ECMWF News Letter 127 (spring 2011):
http://www.ecmwf.int/publications/newsletters/ (link)

EKF: **de Rosnay P, Drusch M., Balsamo G., Albergel C. and Isaksen L.: Extended Kalman Filter soil-moisture analysis in the IFS ECMWF Newsletter no 127, spring 2011, pp12-16**

ASCAT: **de Rosnay, de Chiara, Mallas, ECMWF Research Memorandum11100, August 2011**

SMOS: **Muñoz Sabater J., de Rosnay P. and Fouilloux A.: Use of SMOS data at ECMWF; ECMWF Newsletter no 127, spring 2011, pp23-27**

H-TESSEL: **Balsamo G., S. Boussetta, E. Dutra, A. Beljaars, P. Viterbo, B. Van den Hurk, 2011: Evolution of land surface processes in the IFS, ECMWF Newsletter, 127, 17-22.**

Validation: **Albergel C., P. de Rosnay, C. Gruhier, J. Muñoz Sabater, S. Hasenauer, L. Isaksen, Y. Kerr and W. Wagner: Evaluation of remotely sensed and modelled soil moisture products using global ground-based in-situ observations, submitted to Remote Sensing of Environment, 2011**