Land Modelling and Land Data Assimilation activities at ECMWF

presented by J.N. Thépaut

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Land surface model current status (38R1)

2007/11	2009/03	2009/09		2010/11	2011/11	2012/06

- **Hydrology-TESSEL**

  Balsamo et al. (2009)
  van den Hurk and Viterbo (2003)

  Global Soil Texture (FAO)

  New hydraulic properties

  Variable Infiltration capacity & surface runoff revision

- **NEW SNOW**

  Dutra et al. (2010)

  Revised snow density

  Liquid water reservoir

  Revision of Albedo and sub-grid snow cover

- **NEW LAI**

  Boussetta et al. (2011)

  New satellite-based

  Leaf-Area-Index

- **SOIL Evaporation**

  Balsamo et al. (2011),

  Albergel et al. (2012)

- **H_2O / E / CO_2**

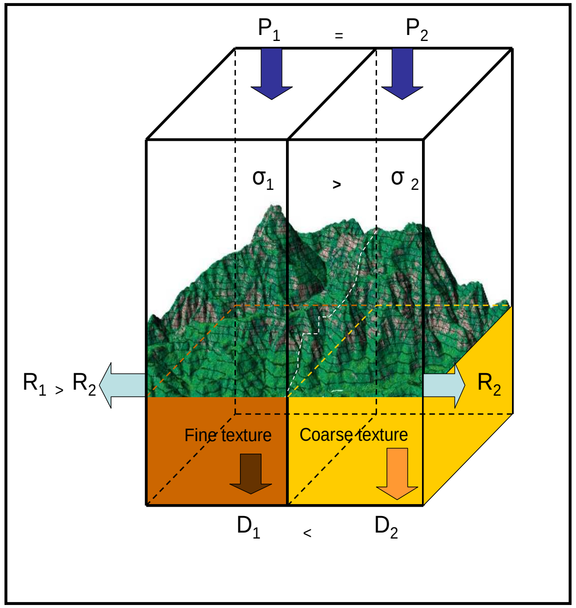
  CHTESSEL Carbon /

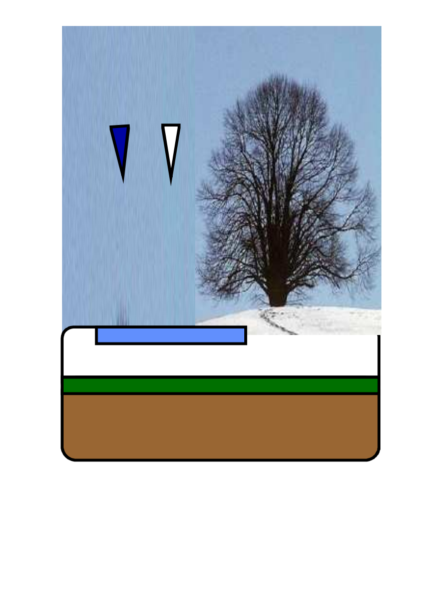
  Energy / Water cycles

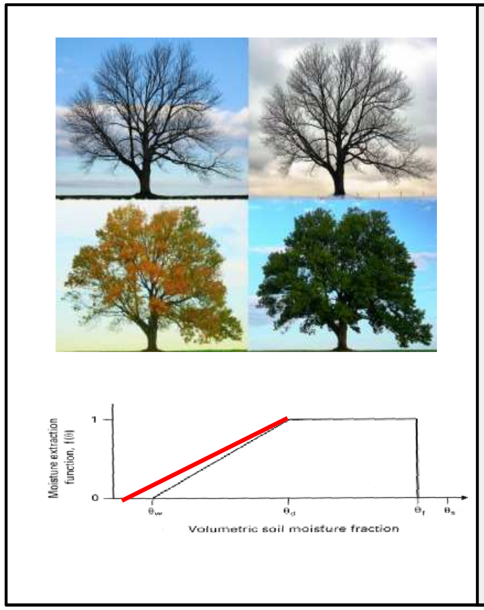
  at the surface (GEOLAND-2

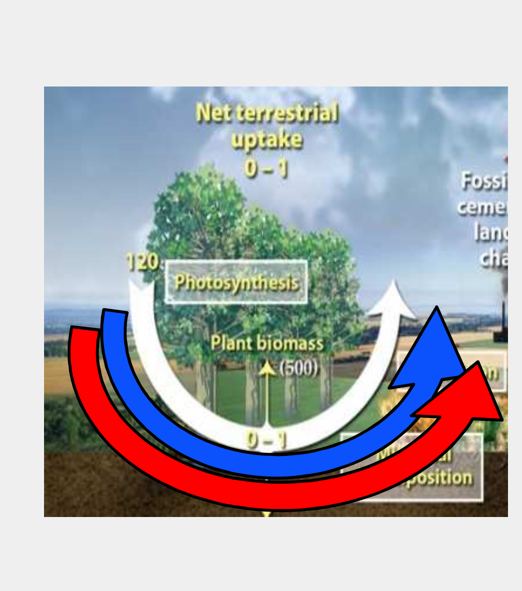
  based & GMES funded)

  Calvet et al. (1998)
  Jarlan et al (2007)
  Boussetta et al. (2010, 2012)

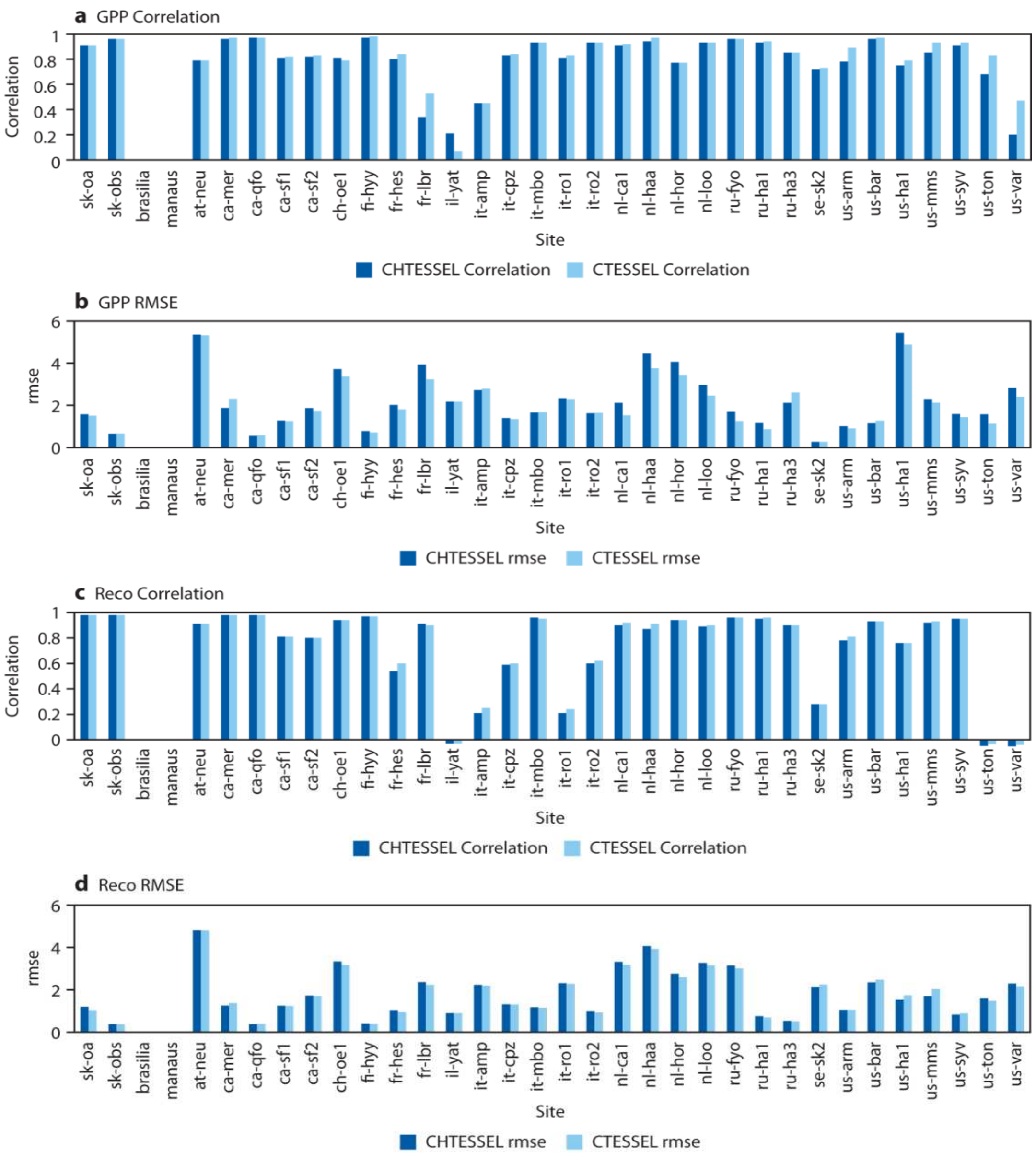








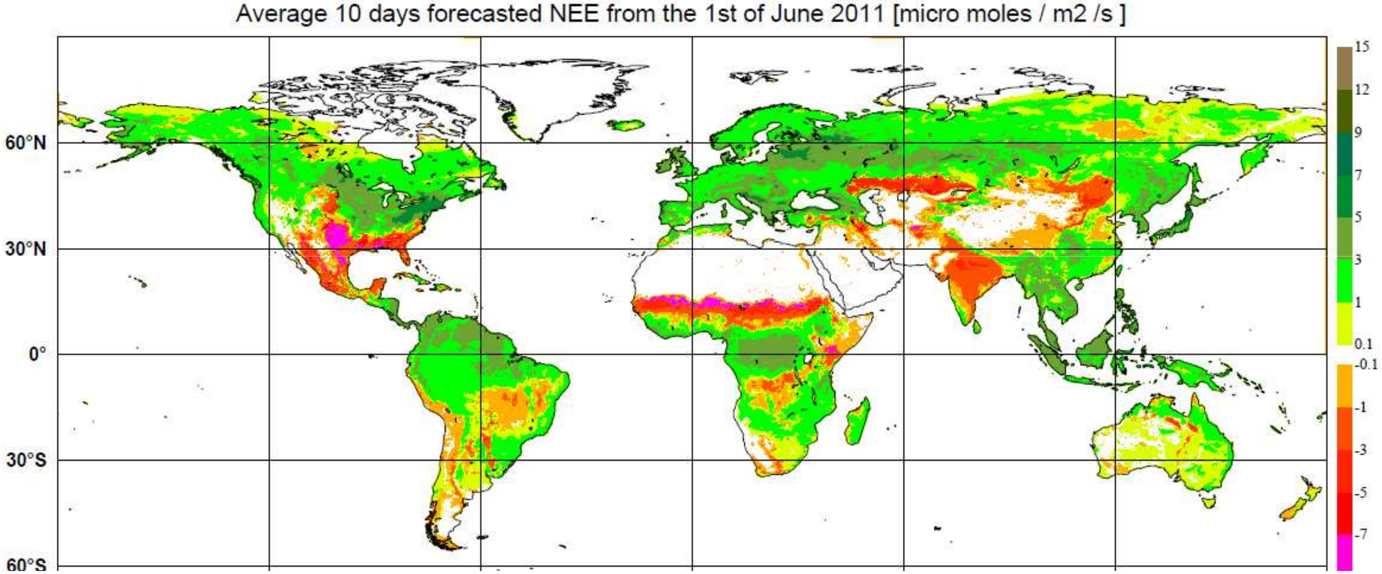
Operational CO2 fluxes in IFS



Comparison to FLUXNET sites for GPP (Gross Primary Production, CO_2 uptake) and Reco (Ecosystem respiration, CO_2 release)

- **CO_2 fluxes are operationally produced at ECMWF since November 2011 by the CHTESSEL scheme (Boussetta et al. 2012, ECMWF TM 675)**
- **The CO_2 and evapotranspiration processes are treated modularly.**
  - **CTESSEL** **$CO_2 \rightarrow Et$**
  - **CHTESSEL** **$\rightarrow CO_2$ $\rightarrow Et$**
- **This enables optimisation of CO_2 for the atmospheric composition model (MACC-2)**
- **Approach validated w. in-situ observations**

Operational CO2 fluxes in IFS (II)



Example of Average 10 days forecasted NEE from the 1st of June 2011 extracted from the pre-operational run (e-suites) [micromoles/m2/s] – Operational from November 2011

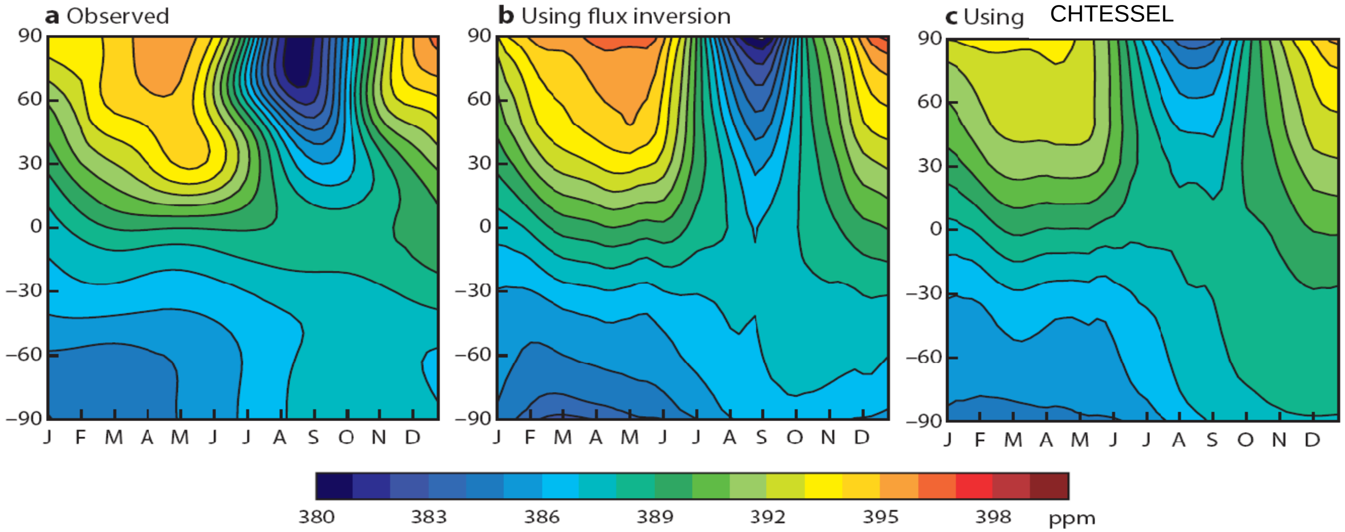


Figure 6 Validation of modelled CO_2 against observations: (a) the processed marine boundary layer surface flask observations from GLOBALVIEW-CO2, (b) the results using optimized fluxes from a flux inversion, and (c) the results using C-TESSEL CO_2 fluxes.

Application of CHTESSEL in the MACC-2 (GMES-Atmosphere) for the simulation of global CO2 compared to observations and to flux-inversion (a-posteriori) methods.

The advantage of CHTESSEL is the availability of CO2 fluxes in Real-Time for monitoring purposes

Peuch and Engelen, 2012 ECMWF, Newsletter 132

Modelling sub-grid lakes

- A feasibility study on the validity of the tiling approach for lakes (A. Manrique-Sunen, 2012, ECMWF TM 683)

Meteorological forcing: ERA-Interim reanalysis

Model was run for the year 2006, doing 3 iterations

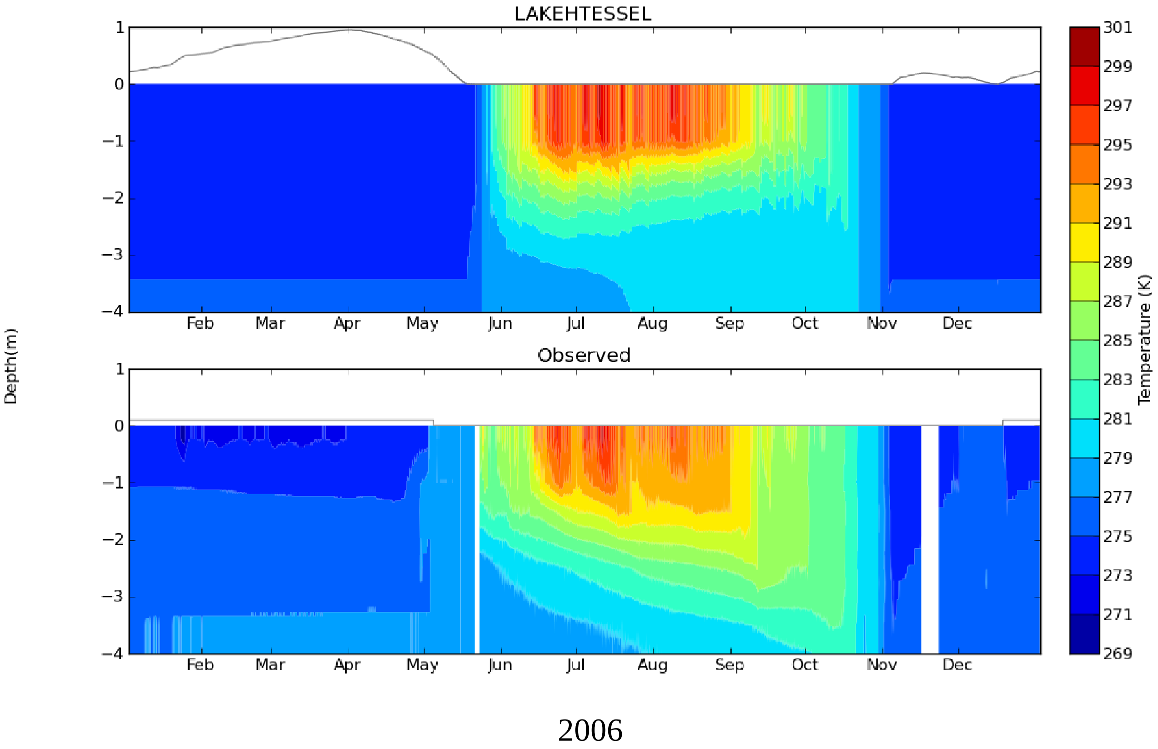
LAKEHTESSEL

Lake: Full coverage of inland water
Lake depth = 4 m
Water extinction coefficient = 3 m^{-1}

HTESSEL

Forest: Full coverage of high vegetation
Vegetation type: Evergreen needleleaf trees
Soil type: Medium texture

Modelling sub-grid lakes (II)

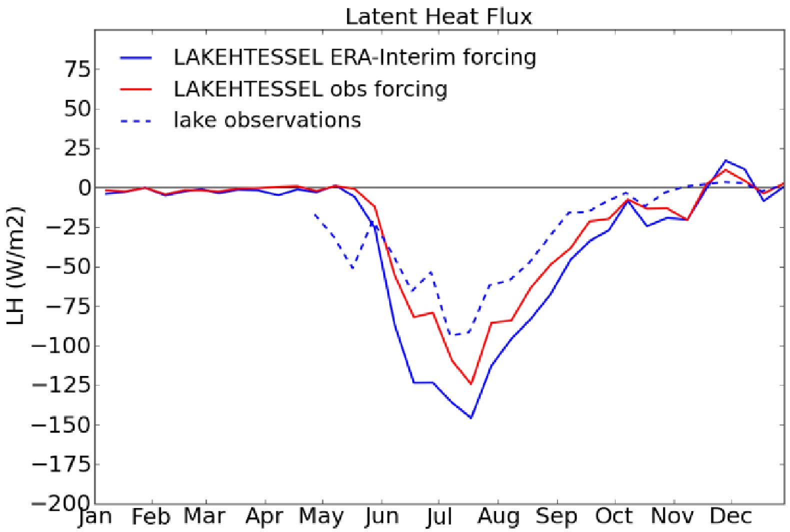


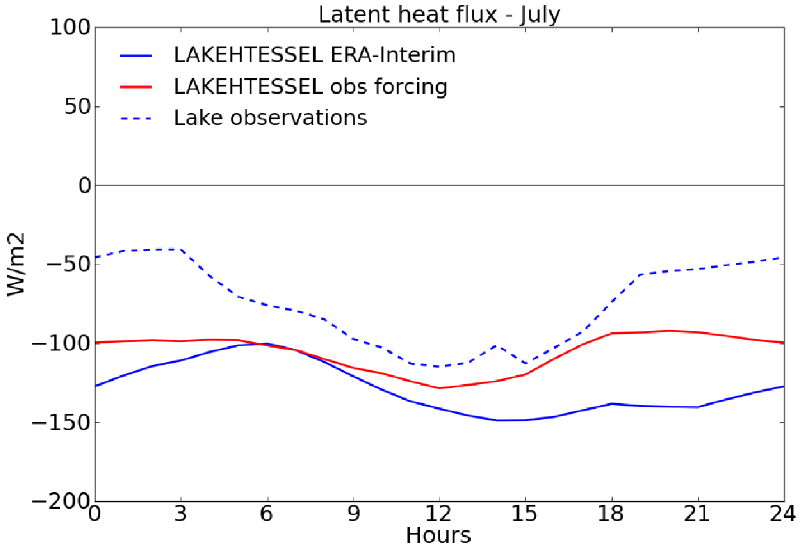
Comparison of FLake (Mironov et al. 2010) model output as provided by the LAKEHTESSEL model version, in an offline experiment for an instrumented lake site:

A. Manrique Suñen et al (2012)

- Surface temperature very well reproduced → relevant for NWP
- Deepening of the mixed layer from July to August underestimated (simplified model)
- Model's ice-covered period overestimated → underline the importance of initialization for NWP purposes.

Modelling sub-grid lakes (III)





Evaluation of the tiling method shortcomings:

The assumption of well-blended atmosphere is triggering an overestimation of latent heat

Seasonal cycle:
The use of observed forcing reduces the RMSE in evaporation from 32 W m-2 to 19 W m-2

Diurnal cycle for July:
The evaporation is reduced, but errors remain at night. The model's transfer coefficients might not be appropriate for a calm situation

A. Manrique Suñen et al. 2012, ECMWF TM 683

ERA-Interim/Land dataset

- An addition to ERA-Interim dataset obtained with HTESSEL offline simulation forced by the ERA-Interim meteorological forcing with GPCP-calibrated precipitation (as described Balsamo et al. 2012, ERA-Report, 13)

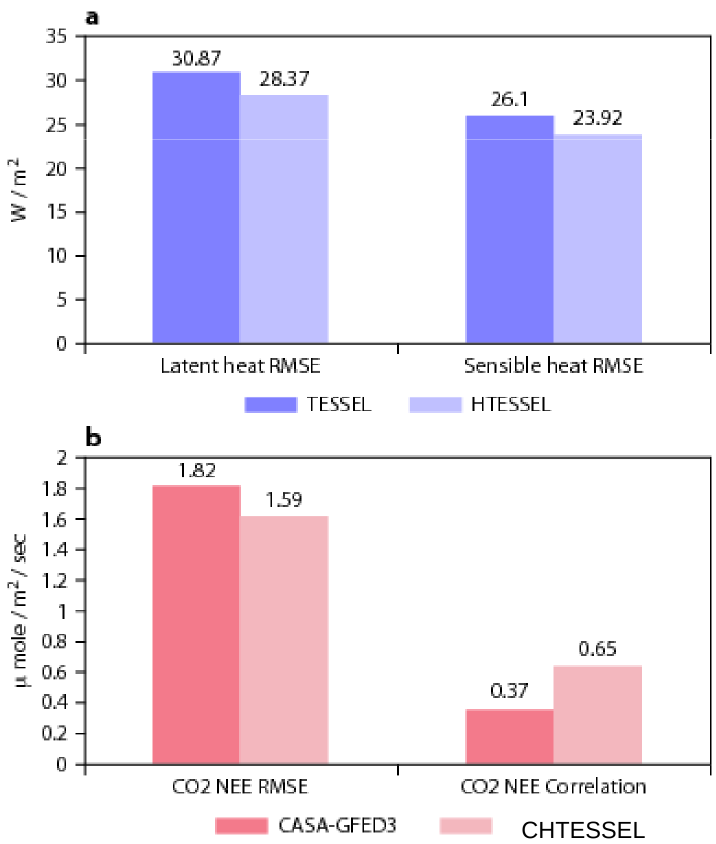


Figure 1: Mean errors over 36 stations with hourly data from FLUXNET & CEOP networks (decadal-averages) in 2006 for HTESSEL, TESSEL scheme versions (with latent and sensible heat fluxes RMSE shown in (a)) and HTESSEL and CTESSEL (with net ecosystem exchange RMSE and correlation shown in (b)).

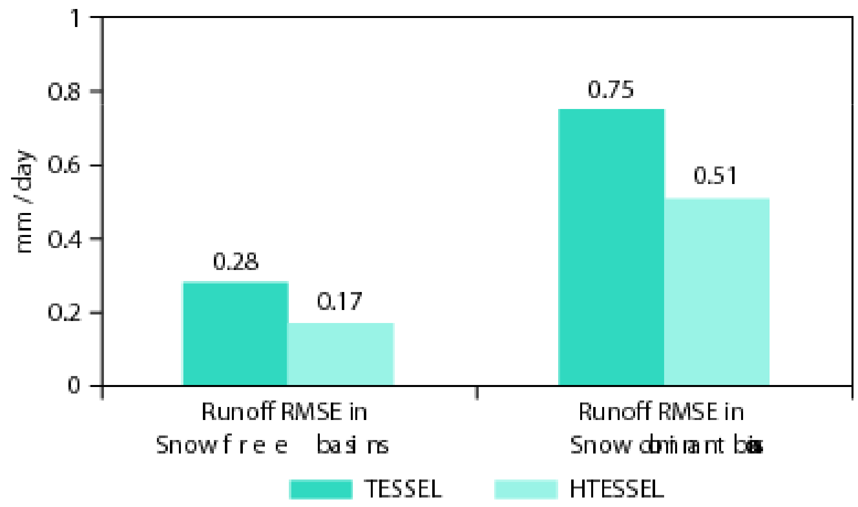


Figure 2: Runoff root-mean-square error (RMSE) for GSWP2 global offline land simulations (1986–1995) verified with GRDC monthly river discharge observations on mainly snow-free basins (North-East and Central Europe) and snow-dominated basins (Yukon, Podka, Lena, Tom, Ob, Yenisei, Mackenzie, Volga, Irtish and Neva).
The mean RMSEs are area-weighted and show the TESSEL and HTESSEL scheme versions.

Validation of H_2O / E / CO_2 cycles

Land Surface Analysis

- Operational NWP
- Objective of high quality surface and near surface weather products
- Land Surface Model: H-TESSEL **(Balsamo et al., ECMWF NewsLetter 2011)**
- Land Data Assimilation (**de Rosnay et al. 2011, ., ECMWF NewsLetter 2011**)

- Snow depth analysis

- **New 2D Optimum Interpolation (OI) (operational)**
- **Ground data (SYNOP and other NRT data)**
- **High resolution NESDIS/IMS snow cover data**
  (de Rosnay et al., Surv. Geophys., in review, 2012)

- Soil Moisture analysis

- **Simplified Extended Kalman Filter (EKF) (Operational)**
- **Uses screen level parameters analysis**
  Drusch et al. GRL (2009)
  de Rosnay et al. QJRMS (2012)

- Satellite data related to Soil Moisture

METOP-ASCAT (Operational)
de Rosnay et al., 2012

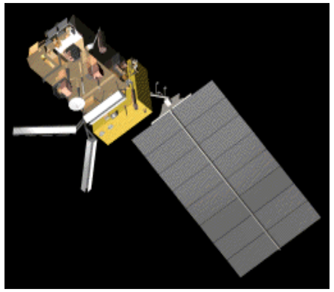
SMOS Monitoring
Sabater et al., TGRSL 2011

ASCAT data assimilation

- Validation activities (EUMETSAT H-SAF)

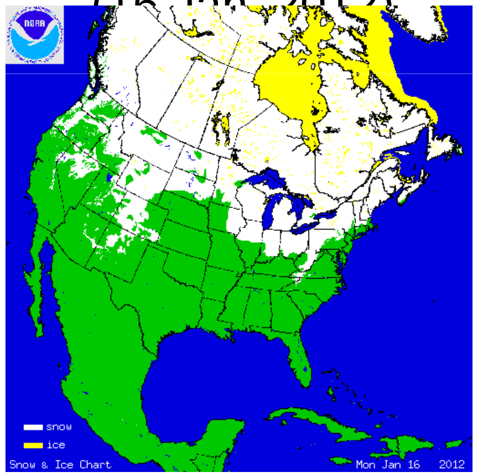
Albergel et al. RSE 2012

ASCAT



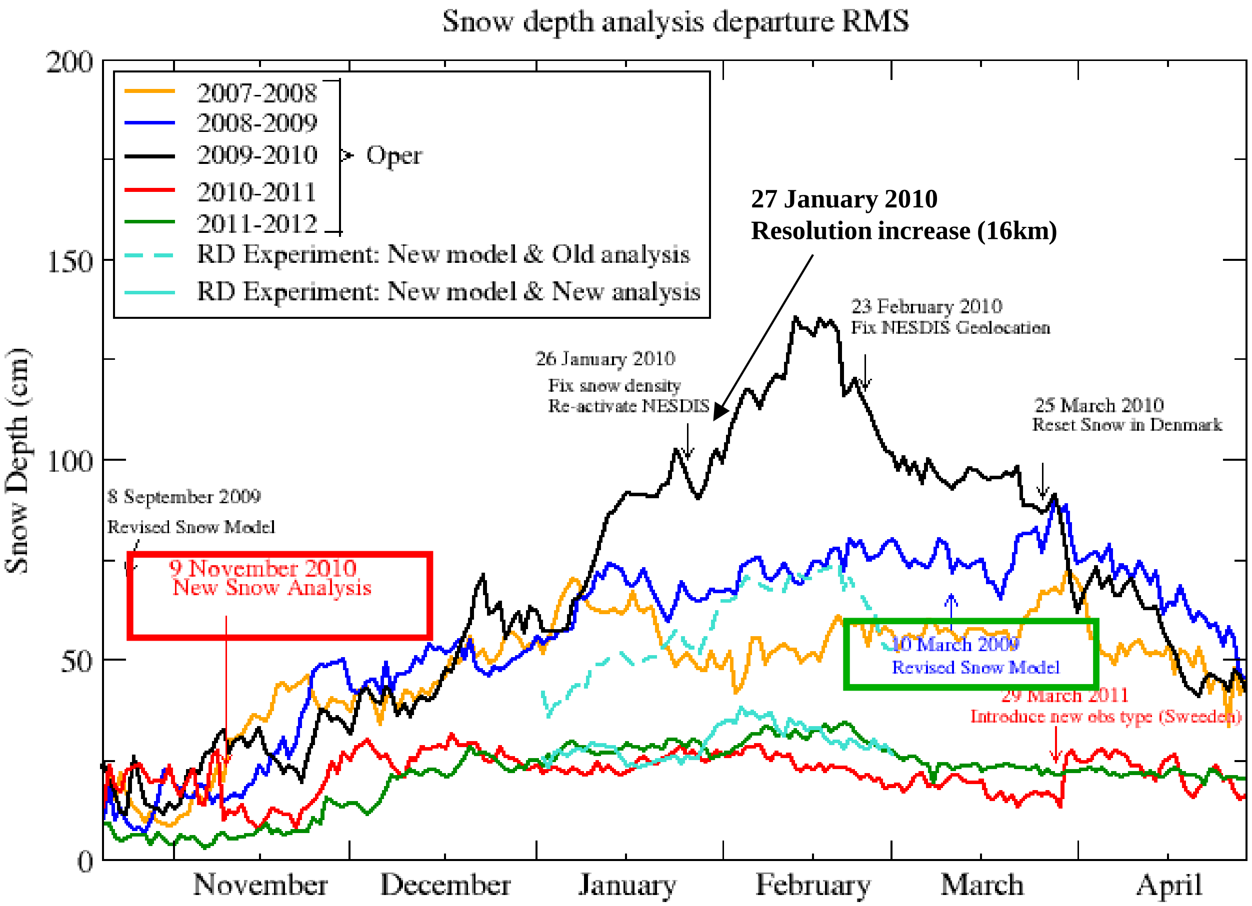
SMOS

NESDIS/IMS snow cover
(16 Jan 2012)



Snow depth analysis

Operational Snow Depth
Analysis departure (Observations minus Analysis) RMS
from 2008 to 2012



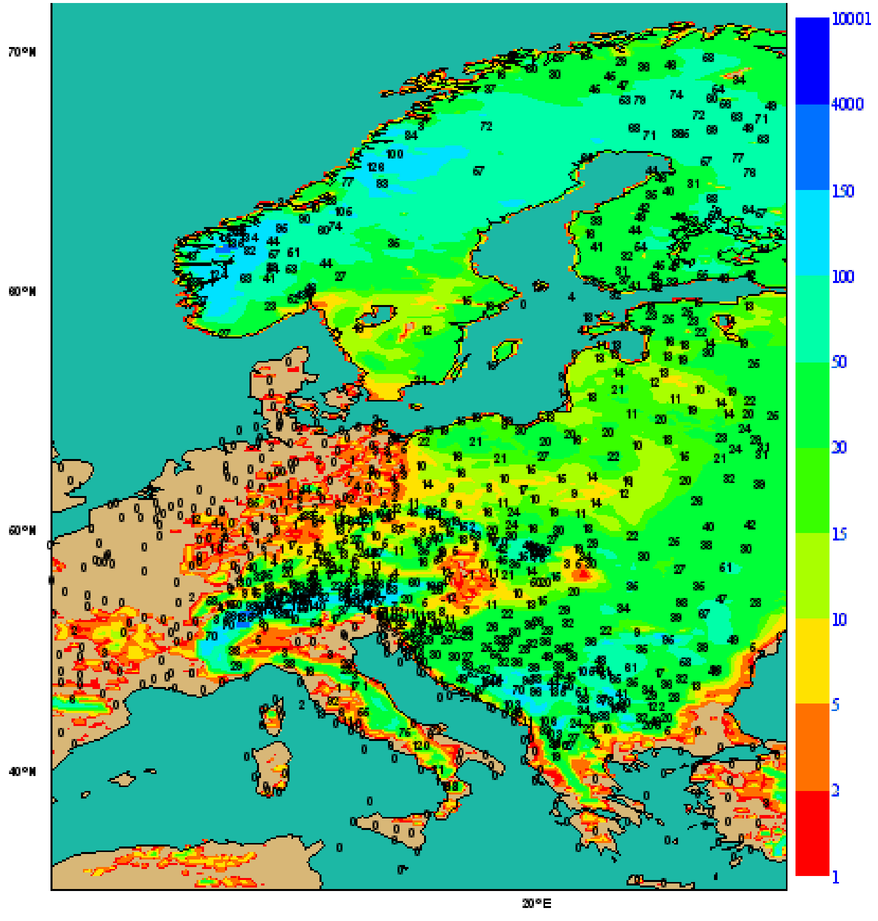
Major improvement in the Operational Snow Depth analysis From November 2010

Consistent Improvement for the entire winters 2010-2011 and 2011-2012

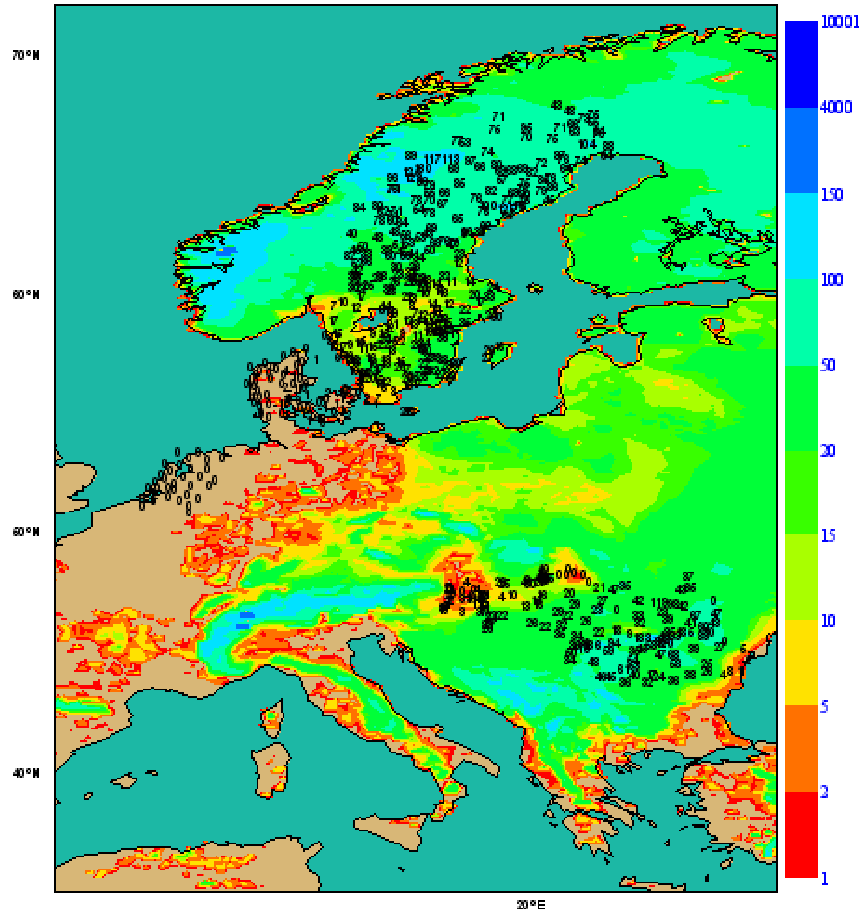
Snow Analysis

- TAC 2010: MS requested to improve availability of Snow depth data
- Dec 2010 new data from Sweden. ECMWF update of acquisition and DA to use additional snow data
- Status in 2012: Sweden, Romania, The Netherlands, Denmark, Hungary, ongoing contacts with Norway and Bulgaria

SYNOP 20120216



Additional snow data



Simplifed EKF soil moisture analysis

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

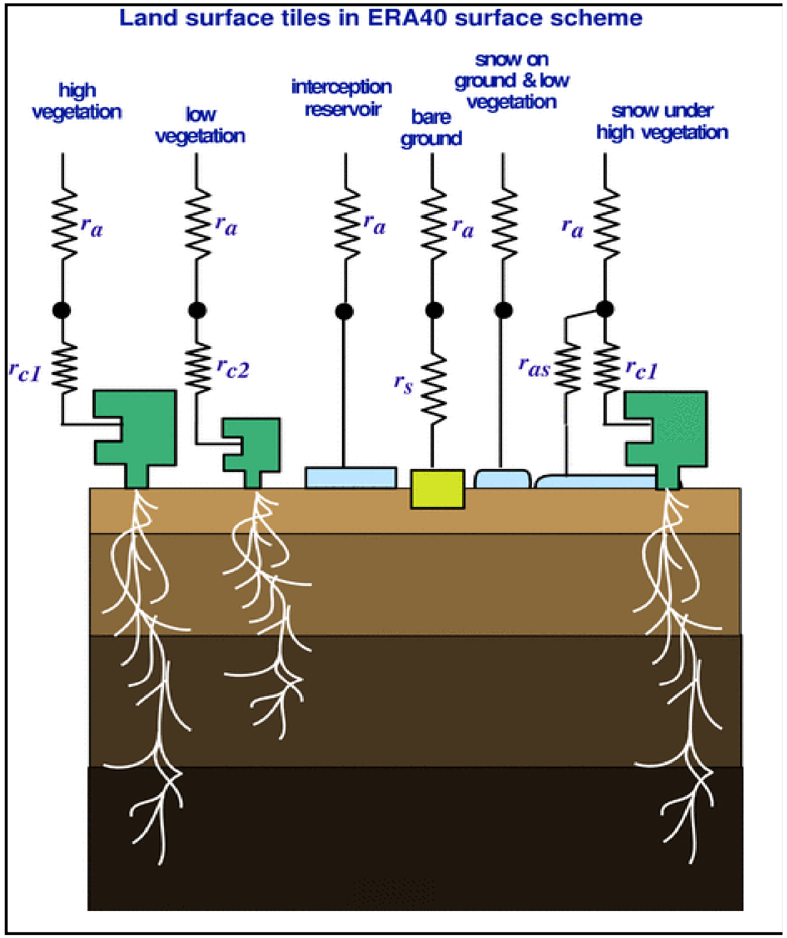
$$\boldsymbol{x}_a = \boldsymbol{x}_b + \boldsymbol{K}\,(\boldsymbol{y} - \mathcal{H}[\boldsymbol{x}_b])$$

$\boldsymbol{x}$ 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).

Observations used:

- **Operational**: Conventional SYNOP observations **(T2m, RH2m)**
- **Research**: Satellite data **ASCAT, SMOS**

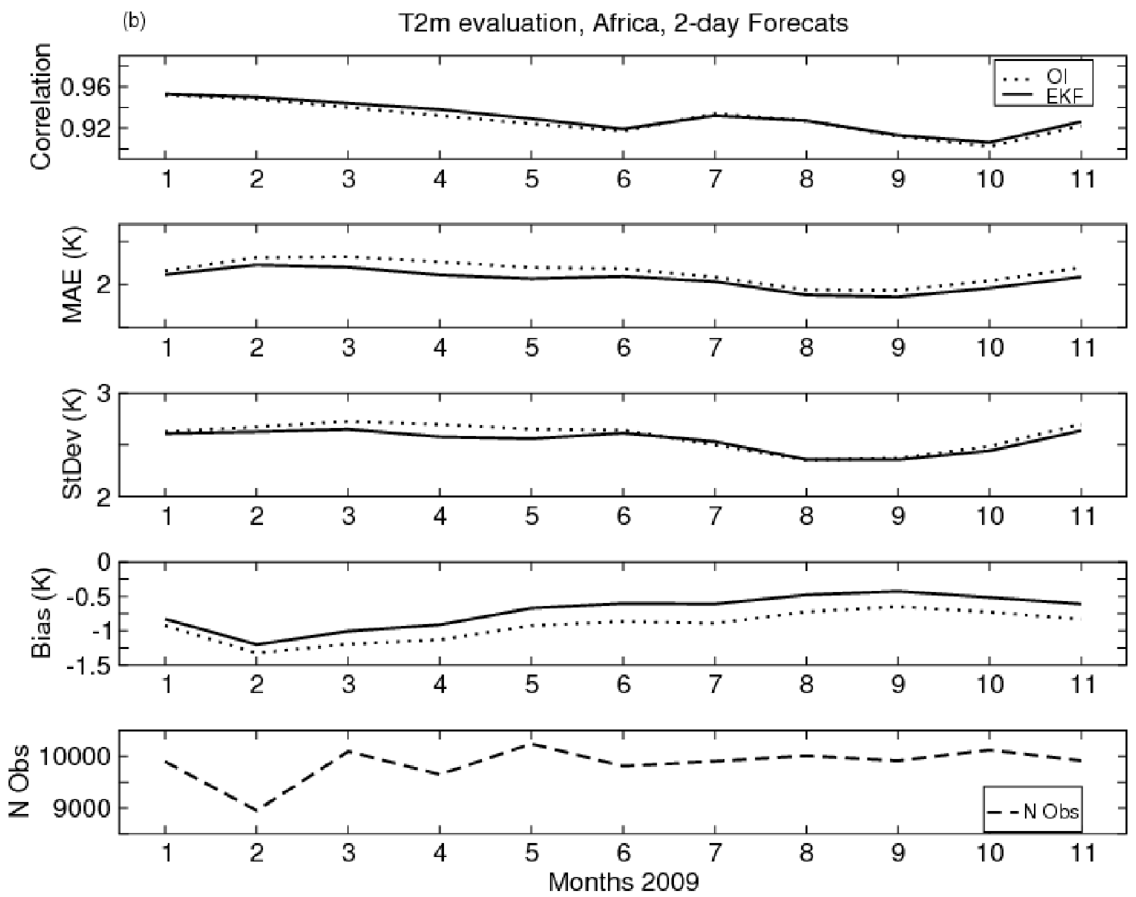
Simplified EKF corrects the trajectory of the Land Surface Model



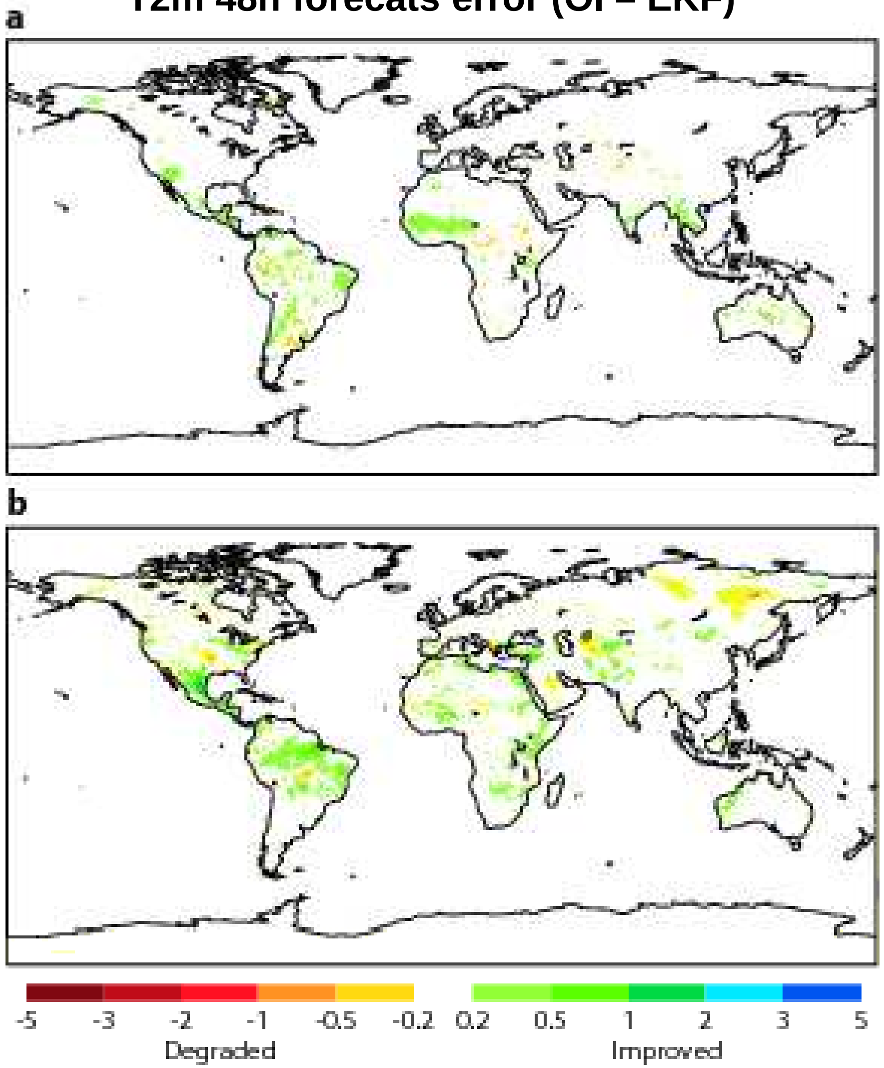
de Rosnay et al., ECMWF News Letter 127, 2011
de Rosnay et al., QJRMS in press, 2012

ECMWF

T2m 48-h Forecast Evaluation



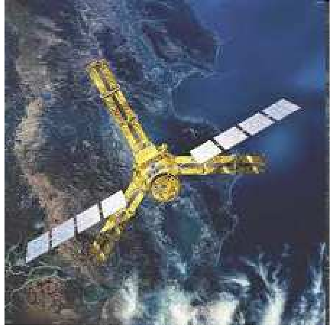
T2m 48h forecats error (OI – EKF)



(de Rosnay et al, QJRMS, in press, 2012)

- EKF improves analysis and FC of Soil Moisture and Screen level parameters
- EKF LDAS enable the use of satellite data for the surface

Use of passive microwave data: SMOS

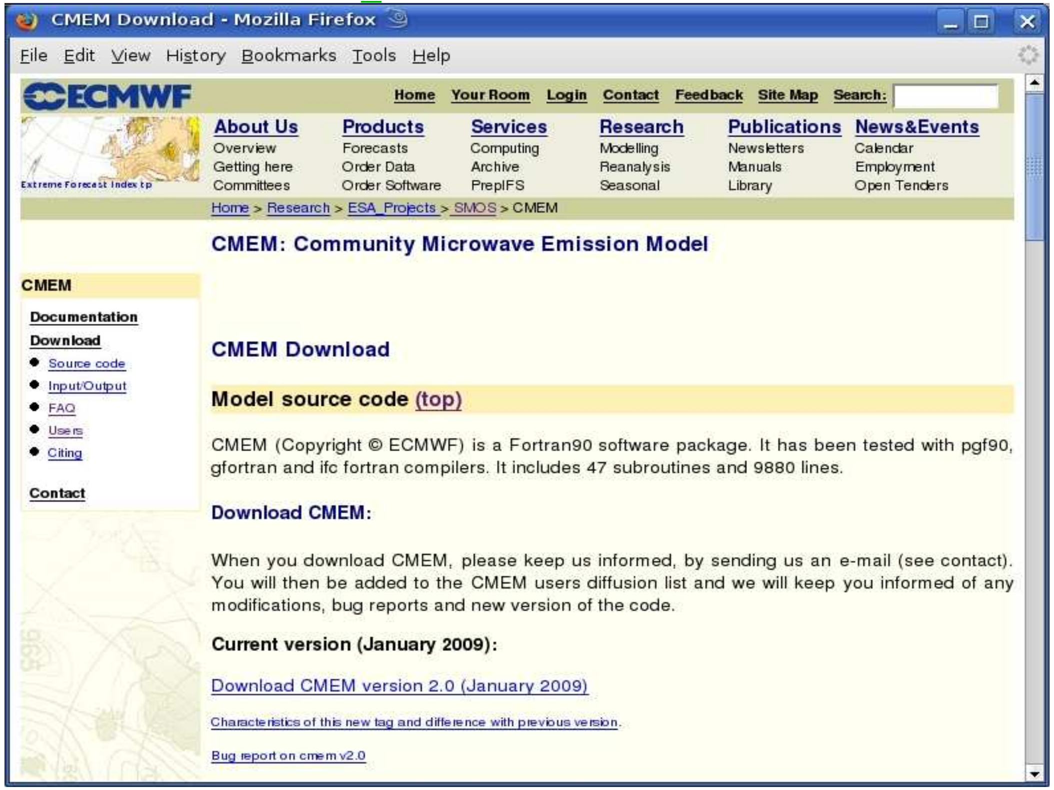


- SMOS: multi-angular L-band TB – optimal for SM sensing
- ECMWF Community Microwave Emission Model (CMEM)

  → Forward operator for SMOS
- Ongoing: Bias correction and Data Assimilation

CMEM

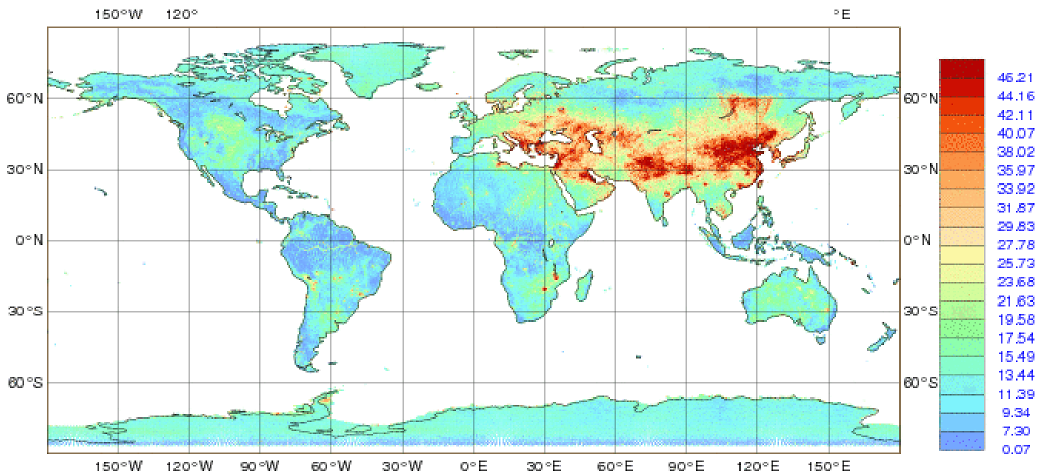
http://www.ecmwf.int/research/ESA_projects/SMOS/cmem/cmem_index.html



SMOS Monitoring

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

SDV of TB (K) FG departure (OBS-Model)
December 2011-January 2012



Muñoz Sabater et al. TGRS, 2011

Also used at CMC, CSIRO, GSFC, Météo-France etc
Drusch et al. JHM, 2009
de Rosnay et al. JGR, 2009

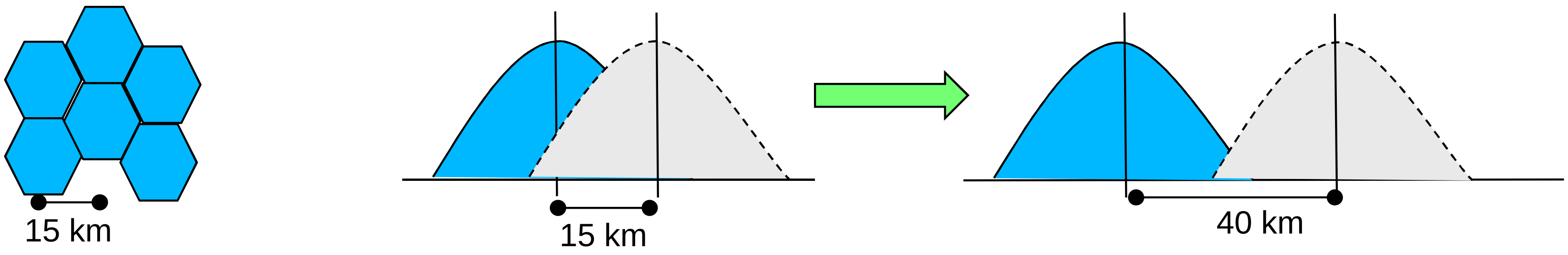
SMOS Thinning and NRT light product

- ► Current monitoring suite based on 6 angles (10, 20, 30, 40, 50, 60 ($\pm\Delta\Theta = 0.5$))
- ► Conversion of SMOS DGG to ECMWF reduced GG (next cycle) → it enables the use of light NRT product & avoid horizontal correlations,

ECMWF reduced Gaussian Grid	Number of nodes	% of DGG grid	% of DGG over land (threshold = 50%)
T159	35.718 (100%)	1.36%	10.452 (0.4%)
T511	348.528 (100%)	13.3%	101.197 (3.9%)
T799	843.490 (100%)	32.2%	244.428 (9.32%)

~ SMOS resolution (T511) — *~ 400 MB*

NRT light product



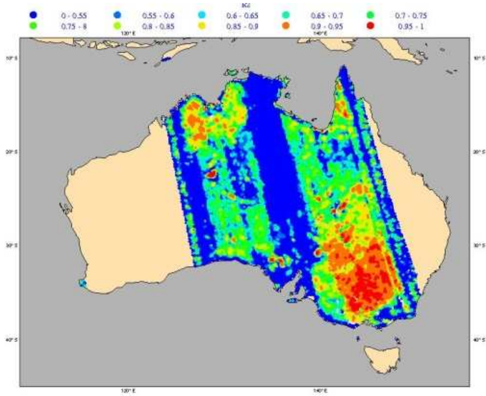
- ► Thinning also to reject data contaminated (or suspicious) by RFI from BUFR space.

Muñoz Sabater et al. ESA Tech Note, SMOS Phase II - WP1200 , 2011

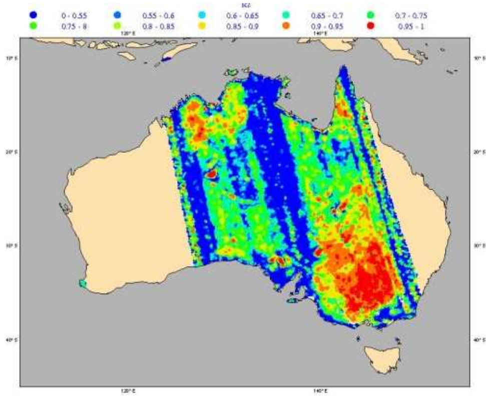
SMOS Thinning and NRT light product

r^2= 0-0.5 | r^2 | r^2= 0.95-1

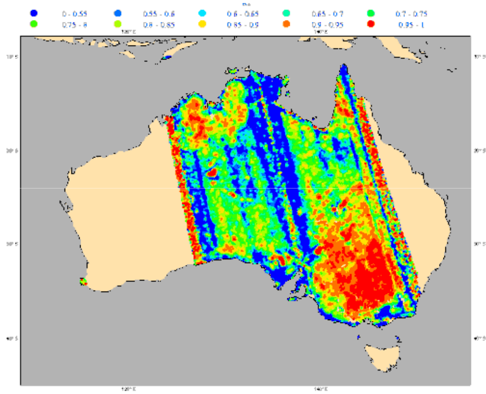
No bin



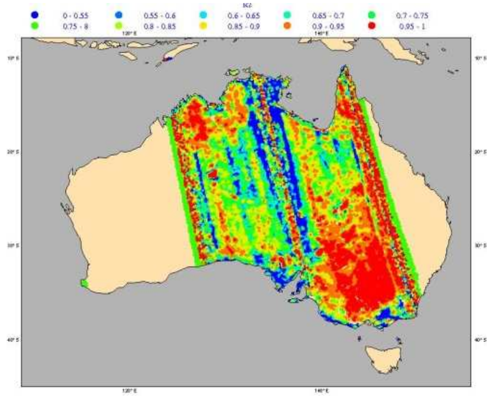
Bin - 0.5



Bin - 1

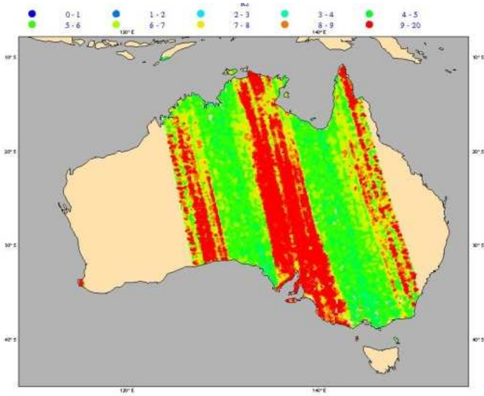


Bin - 2

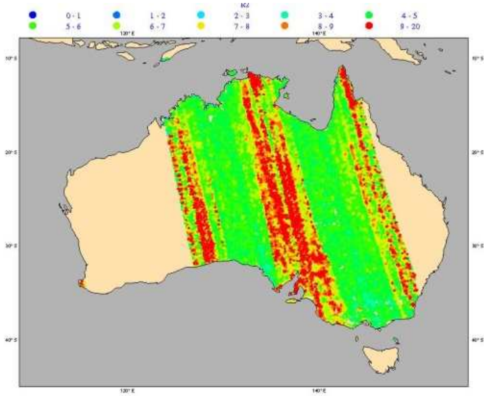


STD = 0-1 K | STD | STD = 9-20 K

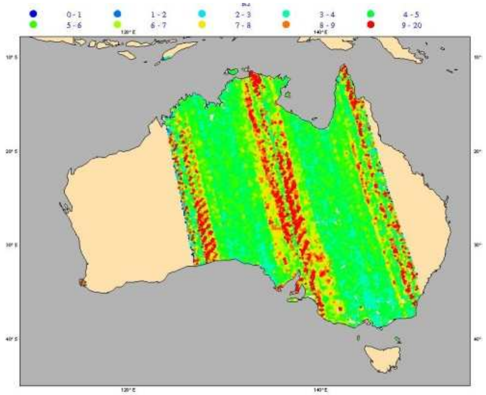
No bin



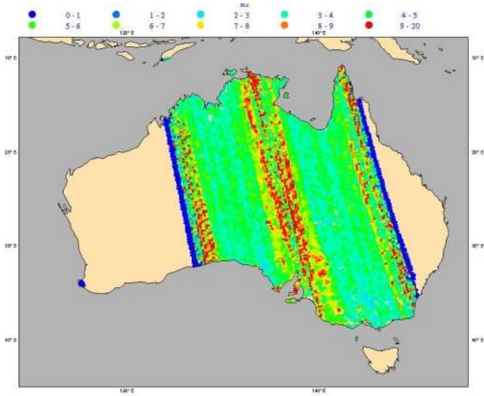
Bin - 0.5



Bin - 1



Bin - 2



Muñoz Sabater et al. ESA Tech Note, SMOS Phase II - WP1200 , 2011

Active microwave data: ASCAT

Advanced Scatterometer on MetOP (launched in 2006)
Continuity of ERS/SCAT (1-1992; 2-1996)

Active microwave instruments operating at C-band (5.2GHz)

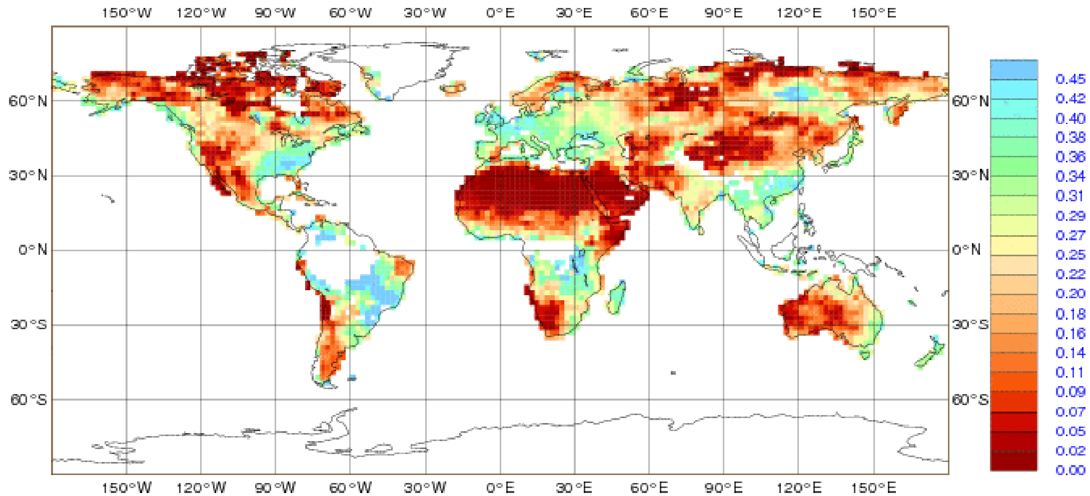
Surface soil moisture index (ms) based on the TUWien retrieval scheme (Wagner et al. 1999)

ASCAT operational EUMETSAT SM product

ASCAT Monitoring

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

Soil Moisture Monitoring Dec2011-Jan2012



ASCAT Root Zone soil moisture

Production chain based on an Extended Kalman Filter (EKF) approach

(de Rosnay et al., QJRMS, 2012)

ECMWF Atmospheric conditions

SYNOP
T2m RH2m

ASCAT CAF
Surface SM

EKF
Soil Moisture
Analysis

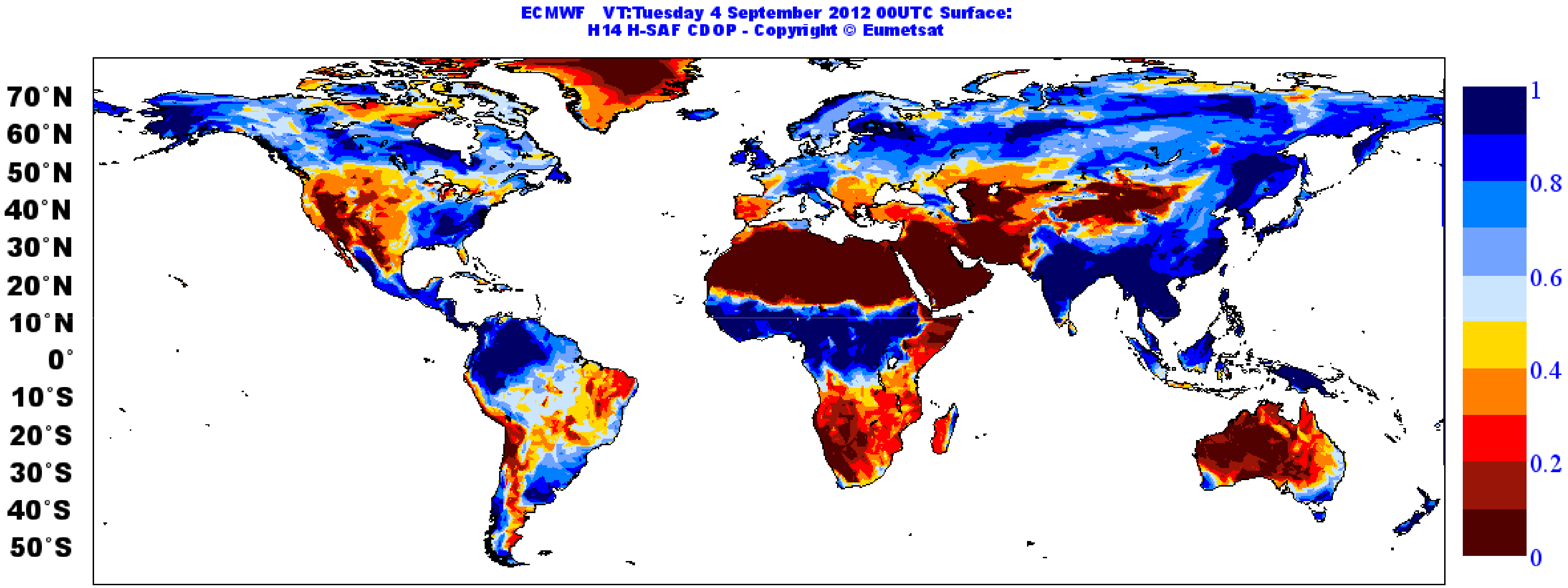
SM-DAS-2:
Soil Moisture Profile

The EUMETSAT Network of Satellite Application Facilities

H SAF
Support to Operational Hydrology and Water Management

EUMETSAT H-SAF product SM-DAS-2 (H14)

ASCAT Root Zone soil moisture SM-DAS-2



SM-DAS-2:
- **Daily Soil Moisture product valid at 00:00 UTC**
- **Daily Global coverage**

The EUMETSAT Network of Satellite Application Facilities

H SAF Support to Operational Hydrology and Water Management

H-14: Operational H-SAF since July 2012;

Contact: hsafcdop@meteoam.it

ECMWF

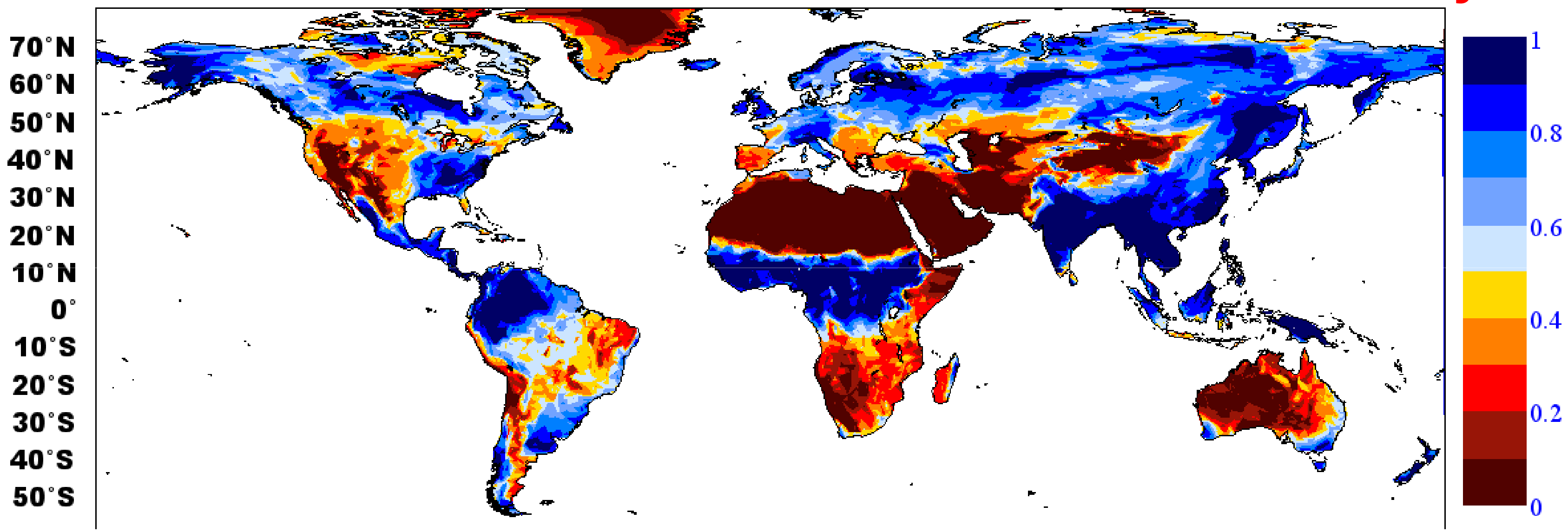
ASCAT Root Zone soil moisture SM-DAS-2

Available on 4 soil layers

04 September 2012

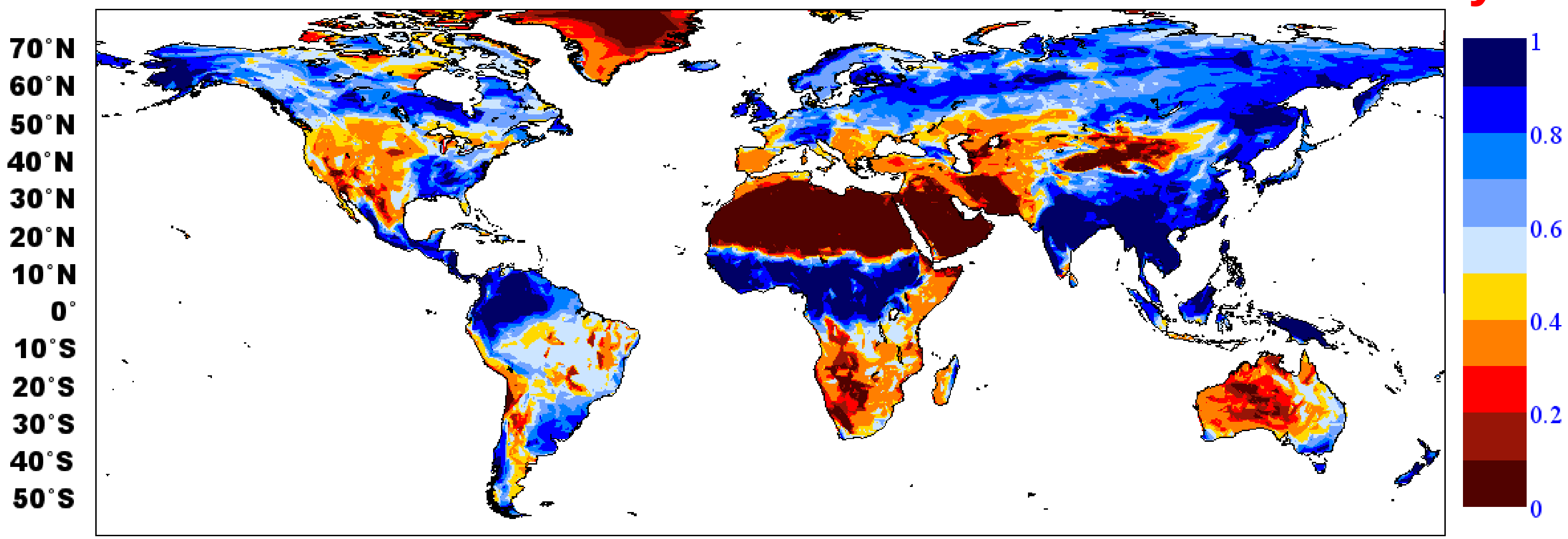
Layer 1 (0-7cm)

ECMWF VT:Tuesday 4 September 2012 00UTC Surface:
H14 H-SAF CDOP - Copyright © Eumetsat



Layer 2 (7-28cm)

ECMWF VT:Tuesday 4 September 2012 00UTC Surface:
H14 H-SAF CDOP - Copyright © Eumetsat



H SAF
Support to Operational Hydrology and Water Management

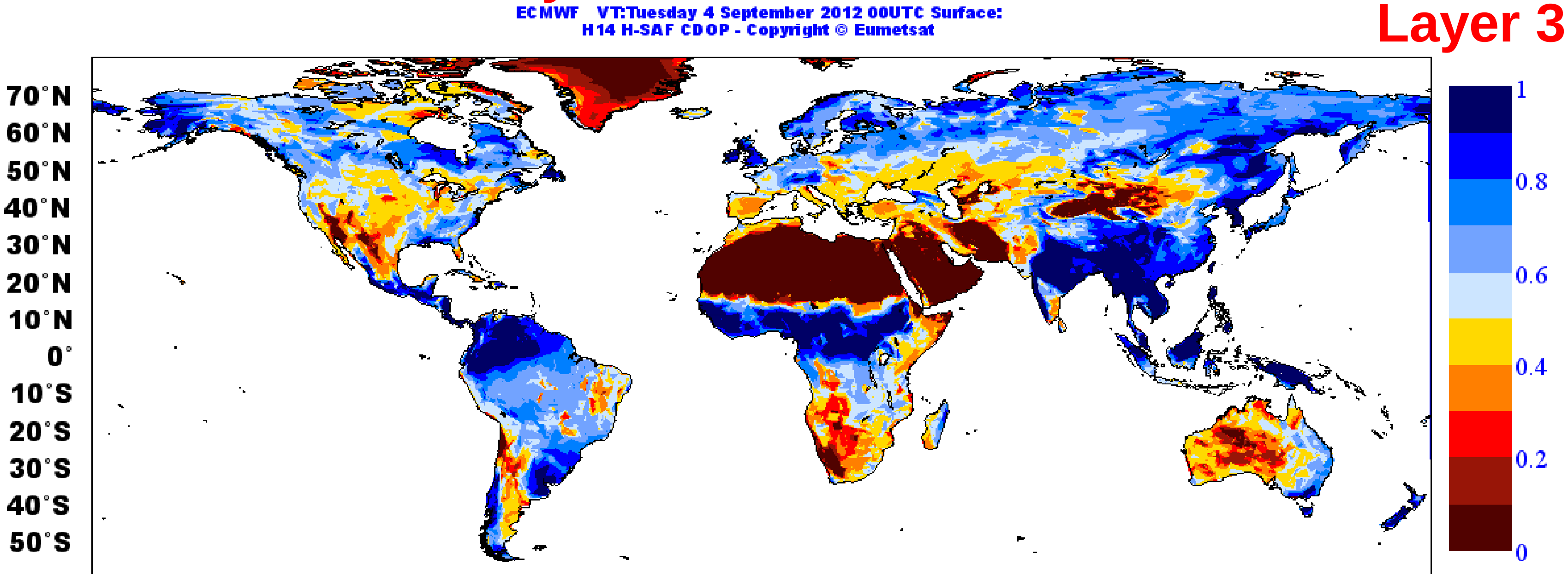
ECMWF

ASCAT Root Zone soil moisture SM-DAS-2

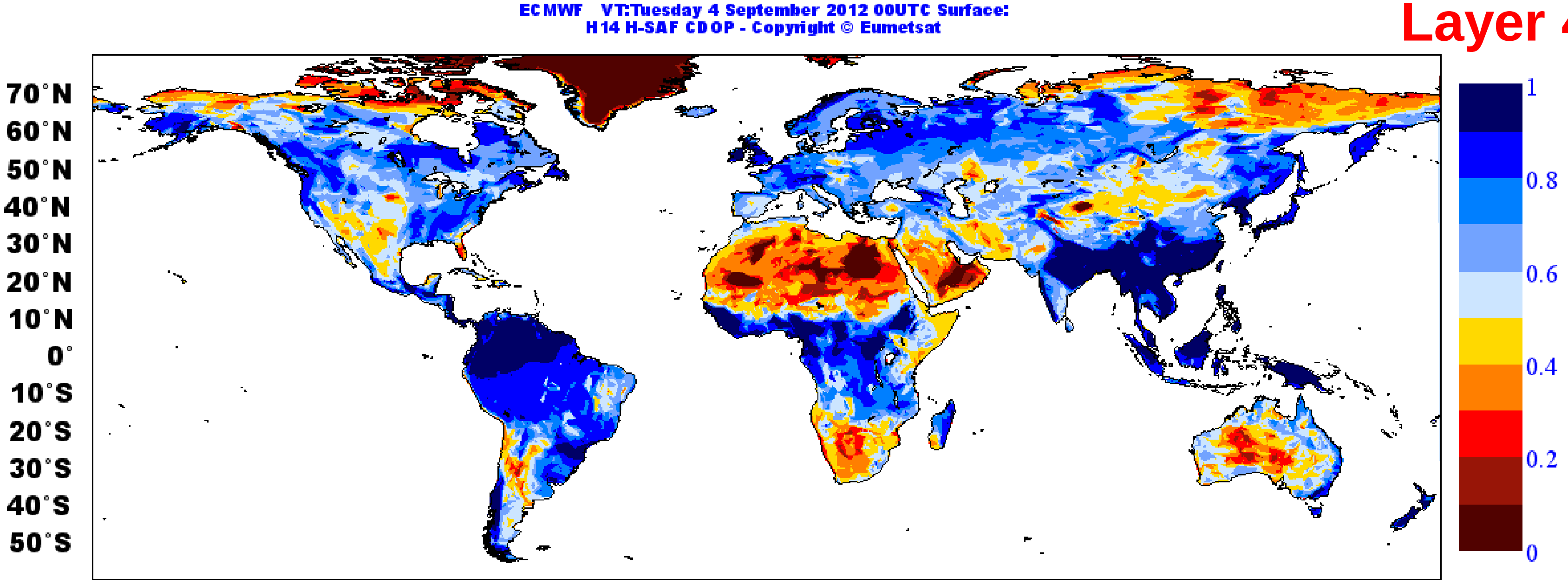
Available on 4 soil layers

04 September 2012

Layer 3 (28-100 cm)



Layer 4 (1-3 m)



H SAF
Support to Operational Hydrology and Water Management

ECMWF

Soil Moisture products Evaluation

- Within H-SAF evaluation and comparison of H14, ASCAT and SMOS Validation against more than 200 stations across 4 continents

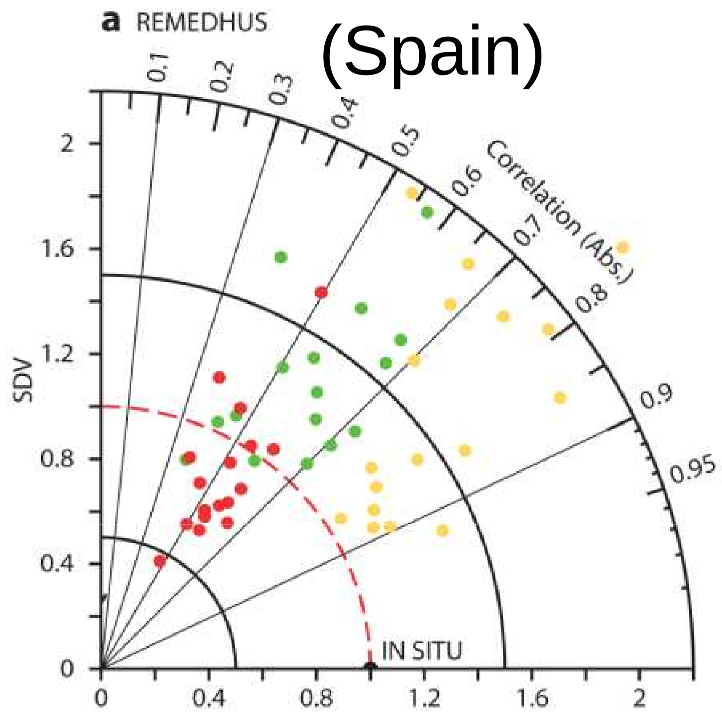
	SM-DAS-2	ASCAT L2	SMOS L2
Correlation	0.70	0.53	0.54
Bias (index)	-0.05	-0.07	0.12
RMSD (index)	0.23	0.25	0.24

- Global evaluation SM-DAS-2 / ASCAT / SMOS: Albergel et al., RSE 2012
  SM-DAS-2 best capture soil moisture dynamics,
  lowest bias and lowest RMSD

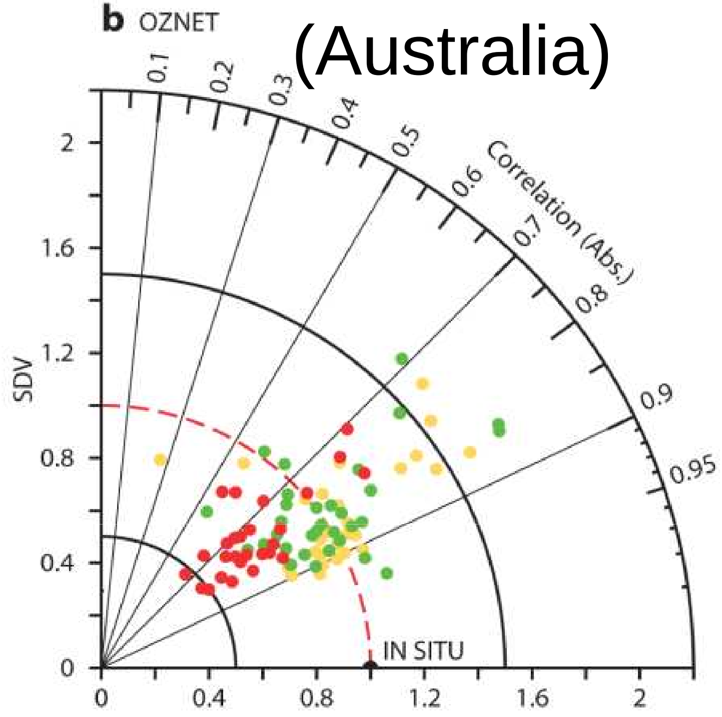
The EUMETSAT Network of Satellite Application Facilities
H SAF Support to Operational Hydrology and Water Management

- Global comparison : Gruhier et al, H-SAF VS11_02:
http://www.ecmwf.int/research/EUMETSAT_projects/SAF/HSAF/ecmwf-hsaf/index.html

(Spain)

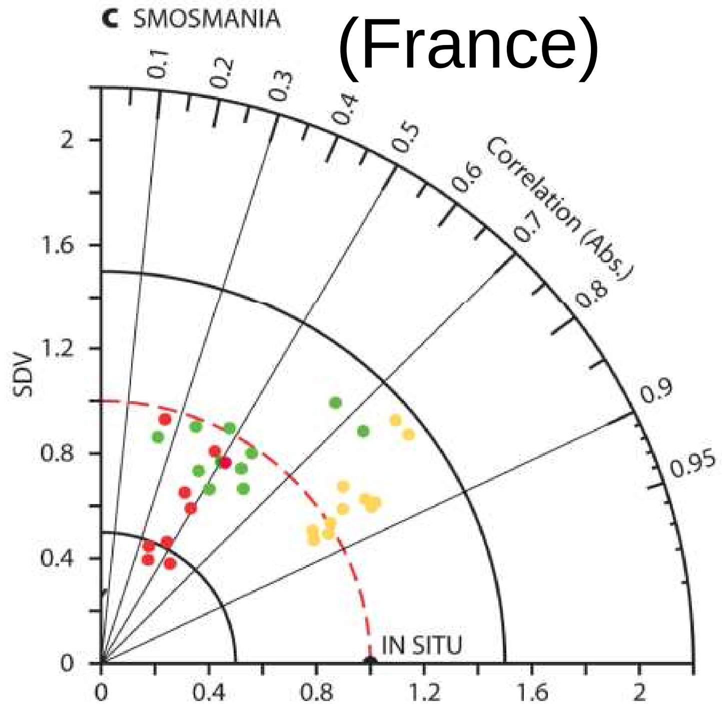


(Australia)



Soil Moisture Evaluation

(France)



Evaluation against
situ surface soil moisture

SM-DAS-2
ASCAT
SMOS

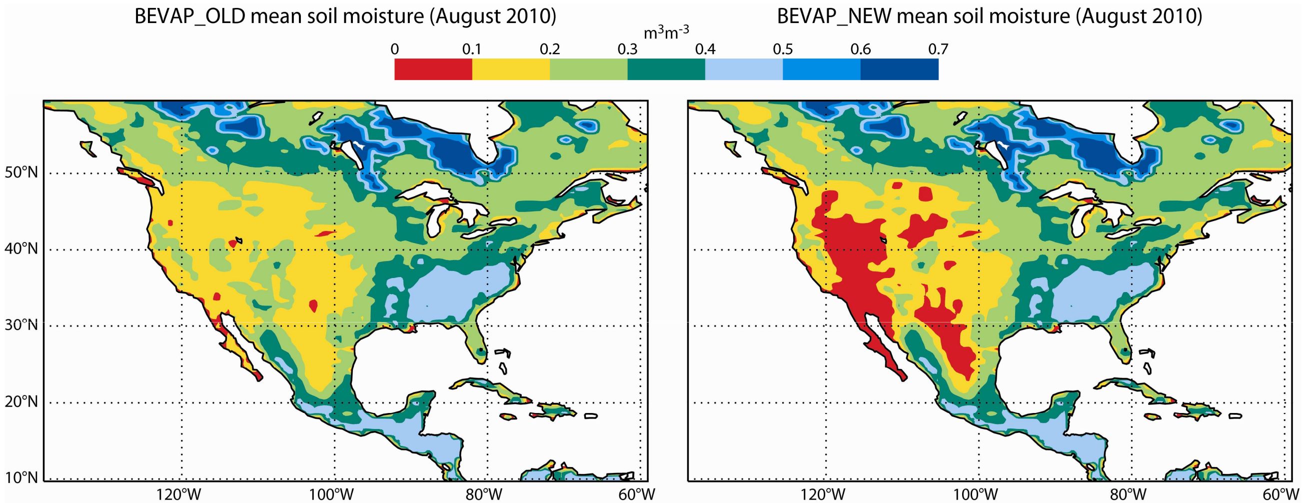
Albergel et al, RSE 2012

The EUMETSAT Network of Satellite Application Facilities

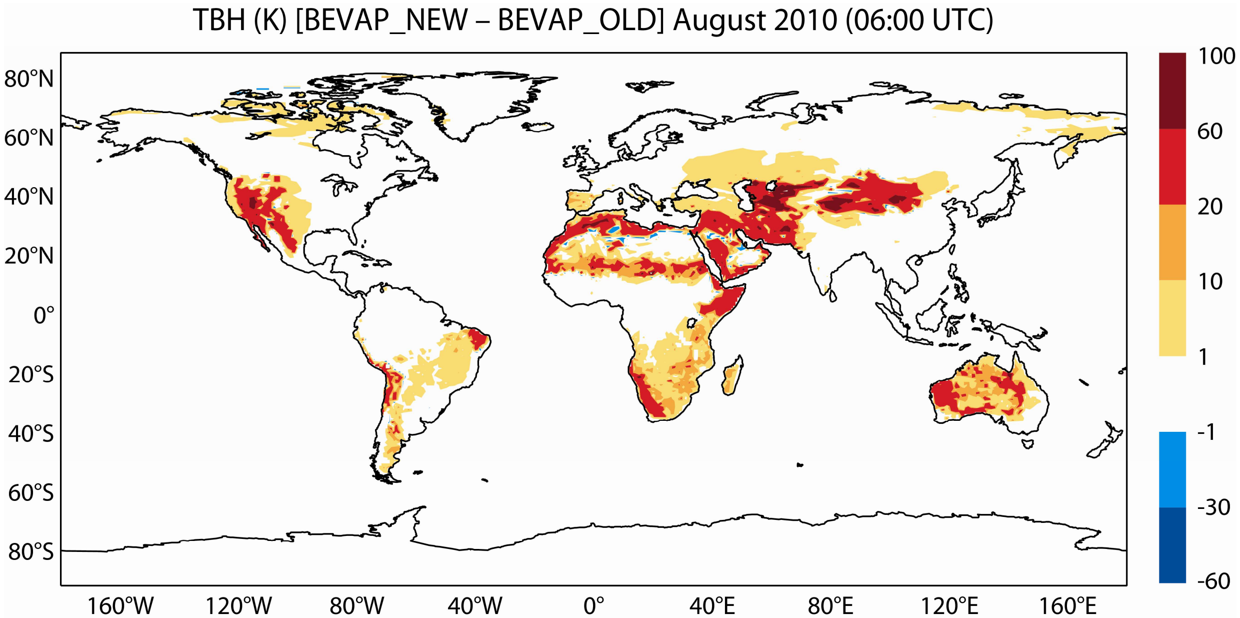
H SAF Support to Operational Hydrology and Water Management

ECMWF

Use of in situ soil moisture at ECMWF



Soil Moisture (m^3m^{-3})



Simulated SMOS TB (K)

Albergel et al.. Hydrol. Earth Syst. Sci. Discuss., 2012.

Summary LSM

- **Land surface modelling at ECMWF includes natural land carbon fluxes (CO_2)**
  - A step towards more comprehensive treatment of surface processes
  - Enabling interaction with atmospheric composition modelling (MACC-2)
- **The land surface modelling upgrades have been consistently introduced in all ECMWF forecasting and reanalysis products (ERA-Interim/Land dataset, Balsamo et al. 2012).**
  - ERA-Interim/Land is used for the initialization of the seasonal System-4 re-forecasts and for the monthly forecasting with positive impact on the anomalies.
- **The current model status is documented in publications (completed this year by the bare-soil evaporation, Albergel et al.2012 and CTESSEL implementation, Boussetta et al. 2012).**
  - New observations such as SMOS have shown potential for model validation.
  - In-situ observation networks such as FLUXNET (for land fluxes) and ISMN (for soil moisture) were crucial to trigger studies and validate model improvements.

Summary LDAS

- **Operational Land Data Assimilation at ECMWF → NWP model initialization**
- **New snow analysis from November 2010**
    - OI, uses ground data and 4km NESDIS/IMS

    → strong positive impact on snow depth and on atmospheric forecasts
- **New EKF Soil Moisture analysis :** improves SM and screen level analysis and forecasts; flexible for future developments (soil and snow temperature, + satellite data)

- **ASCAT SM monitoring and data assimilation**

- New ASCAT soil moisture bias correction
- Importance of pre-processing and noise filtering on DA results
- ASCAT DA experiments using new BC: slight positive impact on FC and SM

- **SMOS monitoring, and DA developments (EKF and Bias correction)**
- **Validation**: similar quality of SMOS L2 and ASCAT L2 SSM products;
- **SMAP** (Soil Moisture Active and Passive) NASA mission to be launched in 2014