Regional Reanalysis Workshop
19-20 May 2016, Reading

High resolution land reanalysis

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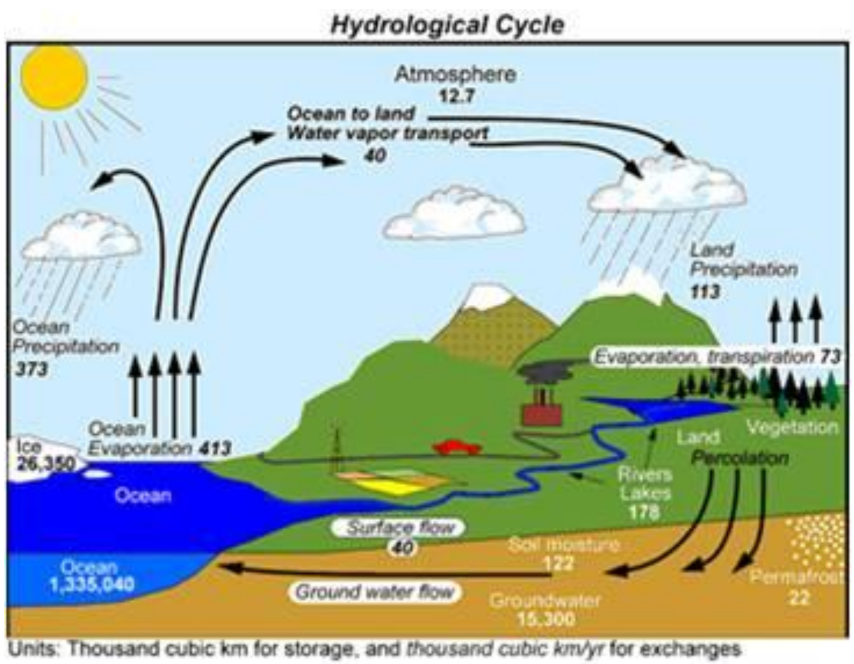
Introduction: Land Surface for Numerical Weather Prediction (NWP)

Land surfaces:

- Processes: Continental hydrological cycle, interaction with the atmosphere on various time and spatial scales
- Boundary conditions at the lowest level of the atmosphere
- Crucial for near surface weather conditions



Land surface heterogeneities → Relevance of high resolution for land surface reanalyses

Trenberth et al. (2007)

ECMWF reanalyses based on Integrated Forecasting System (IFS)

- **Model:** GCM including the H-TESSEL land surface model
    - Fully coupled land-atmosphere (for NWP, ERA-Interim, ERA5)
    - HTESSEL offline (ERA-Interim Land, ERA5L), forced by the atmospheric conditions

- **Data Assimilation:** for NWP, ERA-Interim, ERA5; weakly coupled DA
    - **4D-Var for atmosphere**
    - **Land Data Assimilation System**

Systems	Model	Coupling	Land Data Assimilation	Resolution/ Domain
NWP	IFS	yes	Yes cycle 41r2	9km/Glob
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ECMWF Land Data Assimilation System (LDAS)

Snow depth

Methods: Cressman for ERA-Interim, 2D Optimal Interpolation (OI) for NWP & for ERA5

Conventional observations: *in situ* snow depth

Satellite data: NOAA/NESDIS IMS Snow Cover Extent (daily product).

Soil moisture (SM)

Methods: - 1D Optimal Interpolation in ERA-Interim (also used at Météo-France)

- Simplified Extended Kalman Filter (EKF) for NWP and for ERA5

Conventional observations: Analysed SYNOP 2m air relative humidity and air temp.

Satellite data: Scatterometer SM for NWP (ASCAT) & for ERA5 (ERS/SCAT &ASCAT)

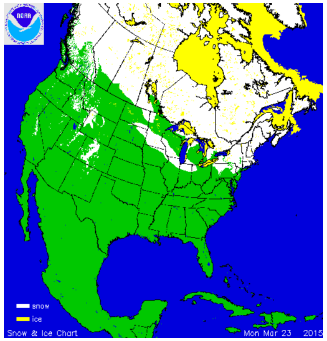
ESA SMOS brightness temperature in development, research NASA SMAP

Soil Temperature and Snow Temperature

1D-OI using analysed T2m as observation (NWP, ERA-Interim, ERA5)

Snow analysis

Revised IMS snow cover data assimilation



Impact on snow October 2012 to April 2013 (using 251 independent in situ observations)

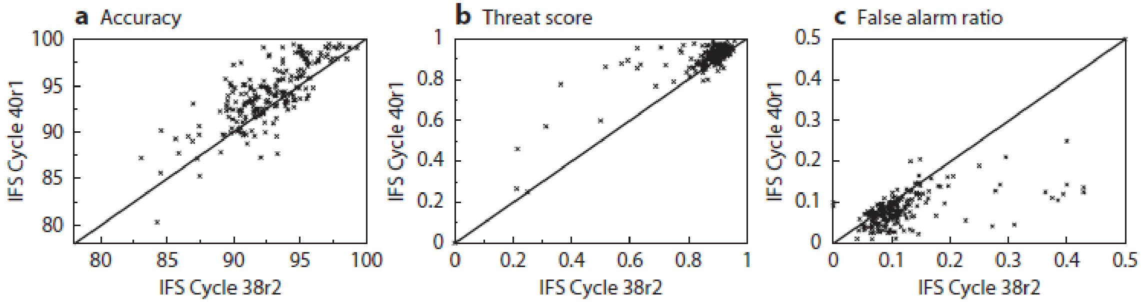
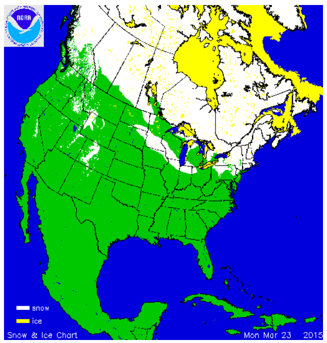


Figure 2 Snow analysis scores for the revised IFS 40r1 snow analysis versus the IFS 38r2 analysis for (a) accuracy, (b) threat score, and (c) false alarm ratio in the period October 2012 to April 2013. Each cross represents the scores computed against 251 independent in situ snow depth observations for a given date. The scatter plots show the results for each of the 212 days from 1 October 2012 to 30 April 2013. The black line represents the one-to-one line.

Snow analysis

Revised IMS snow cover data assimilation



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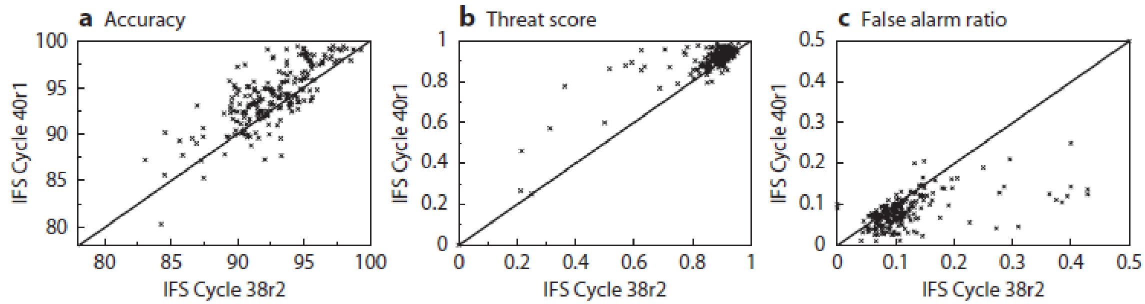

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Impact on atmospheric forecasts

October 2012 to April 2013 (RMSE new-old)

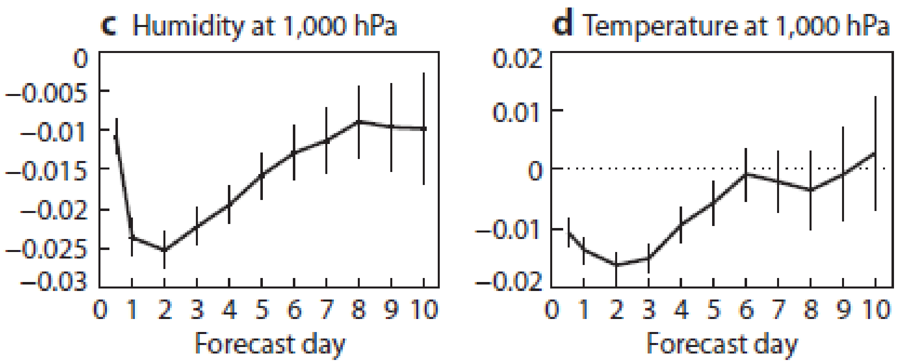


Figure 4 Impact of the revised snow analysis on the normalised root mean square error difference between IFS Cycles 40r1 and 38r2 (40r1 minus 38r2) for (a) humidity forecasts at 850 hPa;

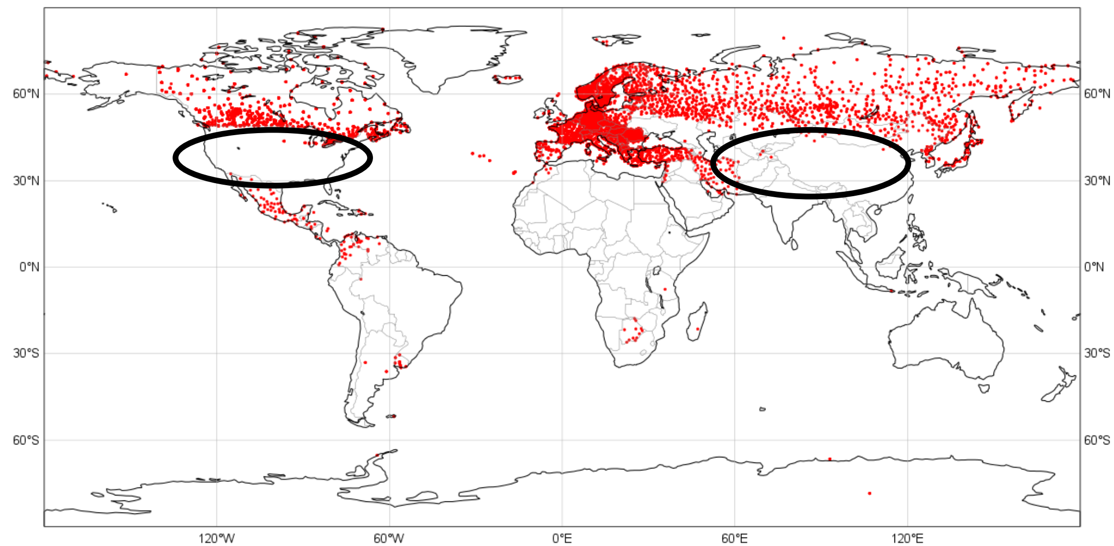
→ Consistent improvement of snow and atmospheric forecasts

Snow Observations

GTS SYNOP Snow depth availability

Status on 1 March 2016

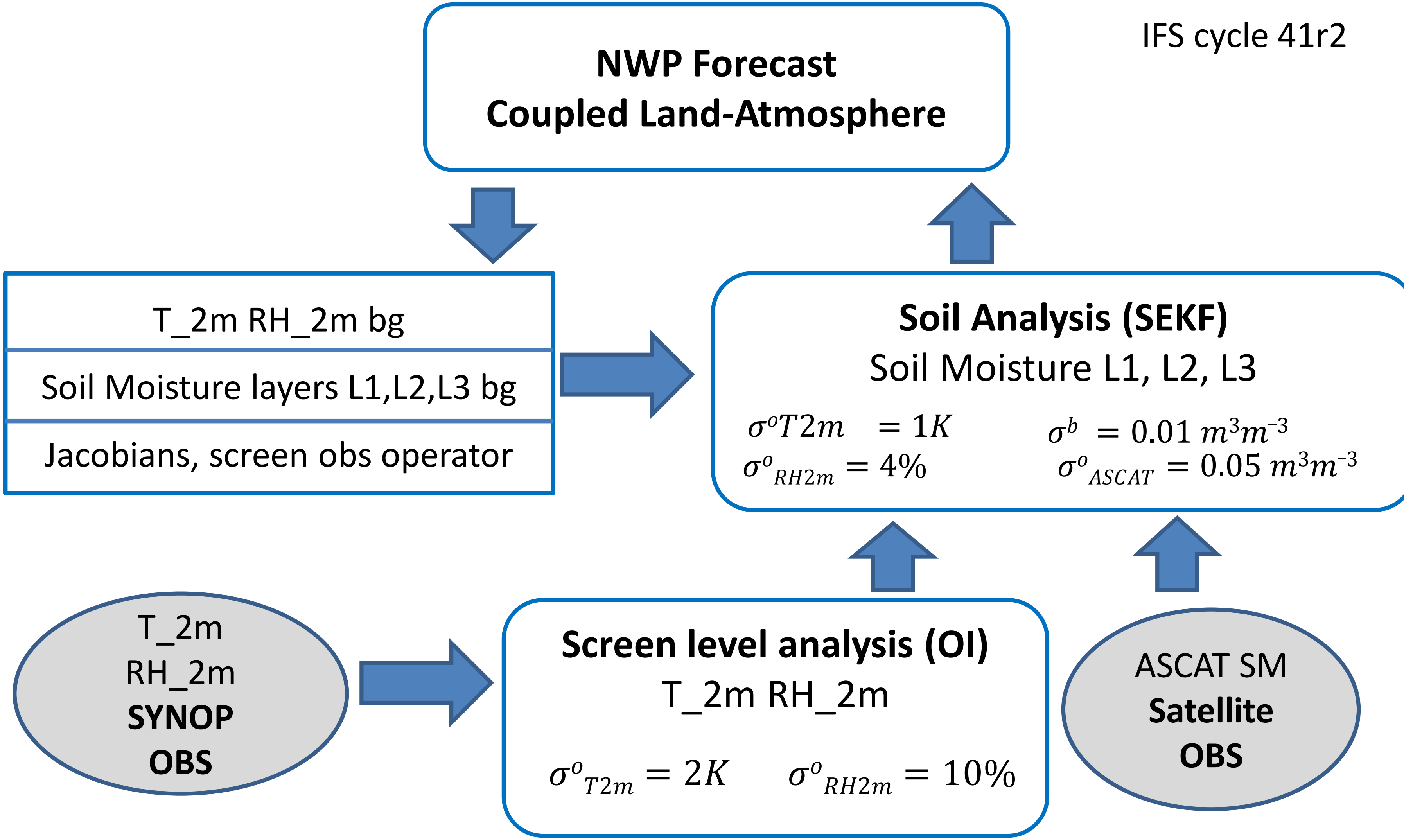
Operational snow observations monitoring
(SYNOP TAC + SYNOP BUFR + national BUFR data):
http://old.ecmwf.int/products/forecasts/d/charts/monitoring/conventional/snow/



For regional renalyses:
Some regions don't have observations!
→ Importance of regional data rescue

WMO Members States encouraged to put their snow depth data on the GTS
- BUFR template for national data approved by WMO in April 2014
- WMO GCW **Snow Watch** initiative on snow reporting, (Brun et al 2013)

Soil Analysis in the IFS

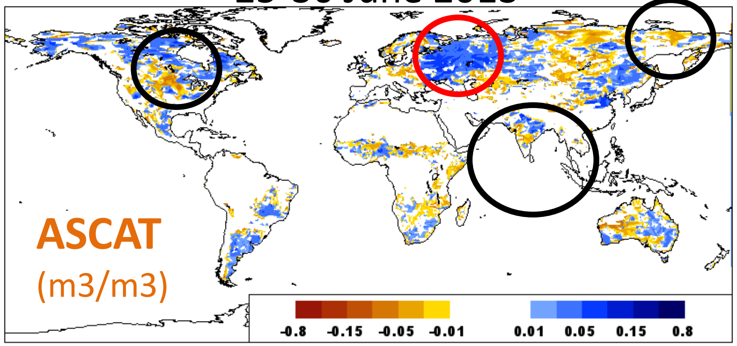


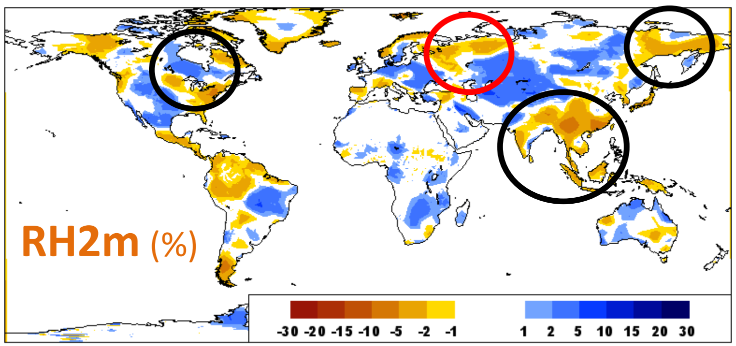
→ Operational soil moisture data assimilation: combines SYNOP and satellite data

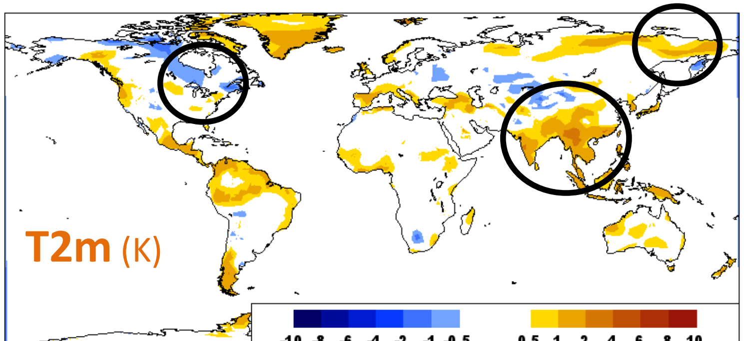
ASCAT Soil Moisture data assimilation

Innovation (Obs- model)

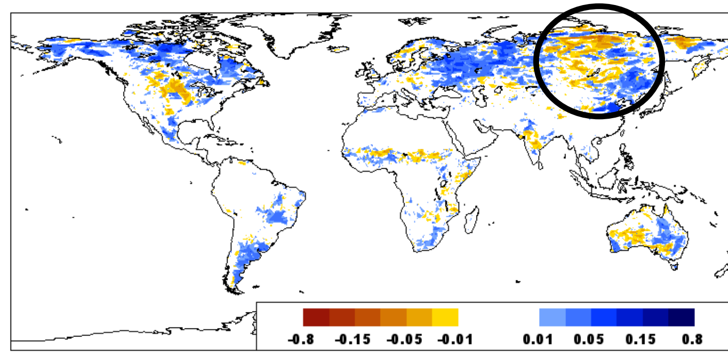
25-30 June 2013



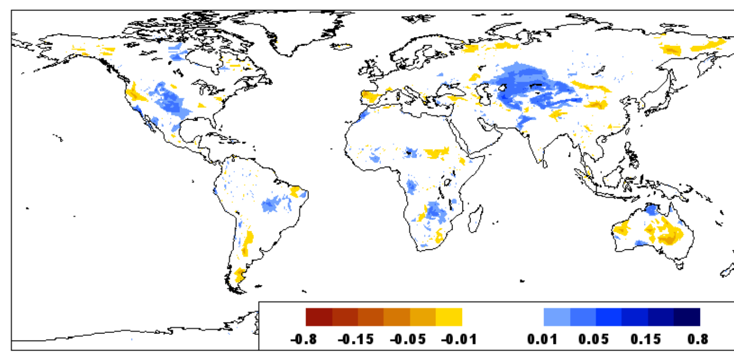




Accumulated Increments (m^3/m^3) in top soil layer (0-7cm)



Due to ASCAT



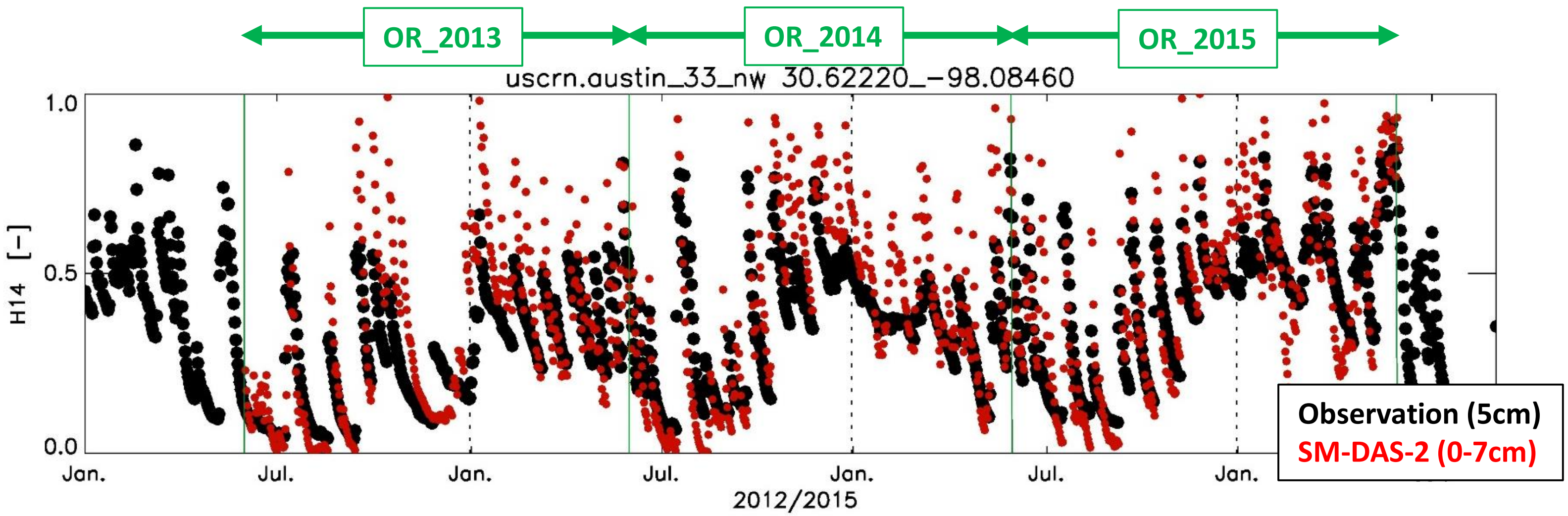
Due to SYNOP T2m and RH2m

Soil moisture validation

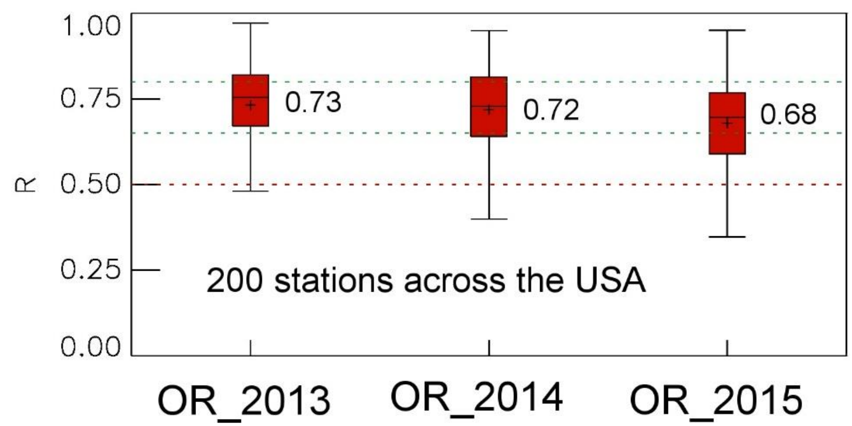
Scatterometer root zone soil moisture based on data assimilation

Against in situ stations

Surface and root zone liquid soil moisture content



Accuracy requirements for product SM-DAS-2 [R]			
Unit	**Threshold**	**Target**	**Optimal**
Dimensionless	0.50	0.65	0.80

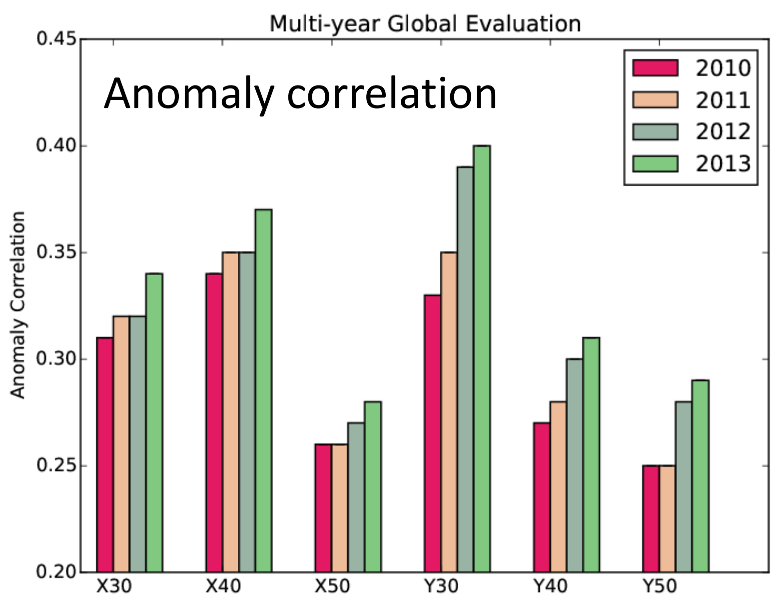


The EUMETSAT Network of Satellite Application Facilities

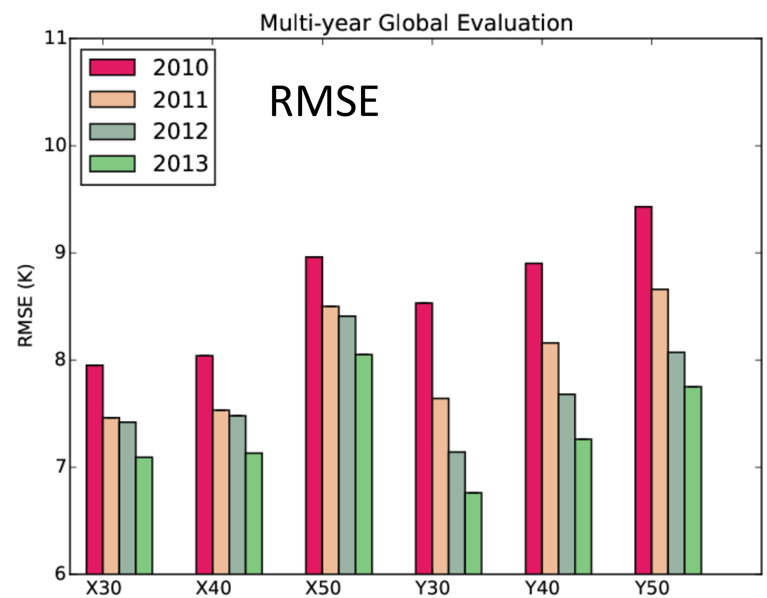
H SAF Support to Operational Hydrology and Water Management

ESA SMOS data for soil moisture analysis

- CMEM: ECMWF Community Microwave Emission Modelling Platform
  → produce reprocessed ECMWF SMOS TB for 2010-2013
- Comparison between ECMWF TB and SMOS NRT TB (both reprocessed)
- **Consistent improvement of SMOS data at Pol xx and yy, for incidence angles 30, 40, 50 degrees**



Polarisation (xx or yy) and incidence angle (30, 40, 50)



Polarisation (xx or yy) and incidence angle (30, 40, 50)

ECMWF Reanalysis ERA5
Assimilation of Scatterometer soil moisture data ERS/SCAT and MetOpA/B ASCAT

Use of EUMETSAT ASCAT-A reprocessed data (25km sampling)

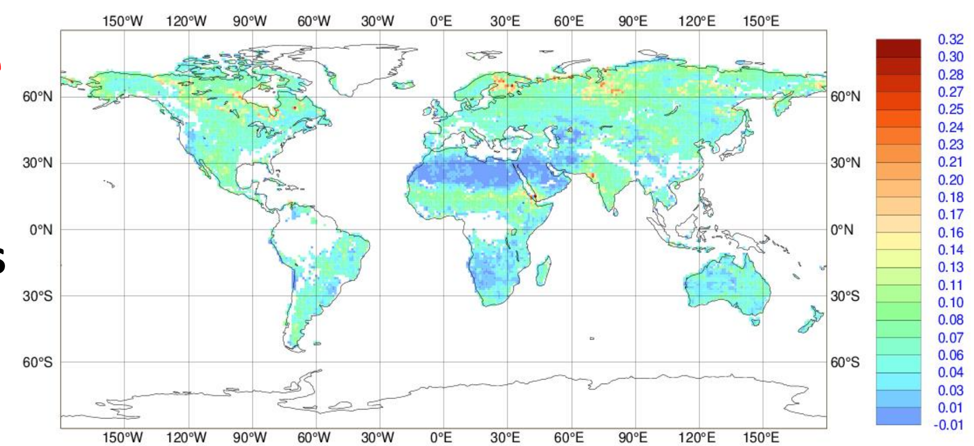
(FMA 2010)

	FG departure **Mean** m^3m^{-3}	**FG departure** **StDev** m^3m^{-3}
Using NRT ASCAT	0.013	0.05
Using Reproc ASCAT	0.006	0.044

→ Reprocessed ASCAT has reduced background departure statistics both in mean and Stdev

ERA5 production (C3S) started (will be available end of 2017)

ASCAT surface soil moisture first guess departure (Obs-Model) in m3/m3 for JJAS 2014



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Land surface model evolution (since ERA-Interim scheme) provided motivation for ERA-Interim/Land

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**

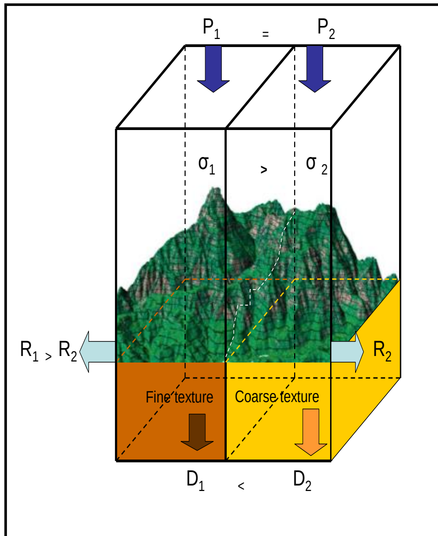
  Integration of Carbon /

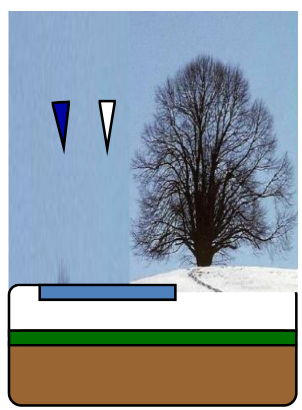
  Energy / Water cycles

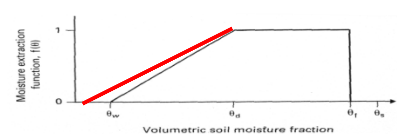
  at the surface (GEOLAND-2

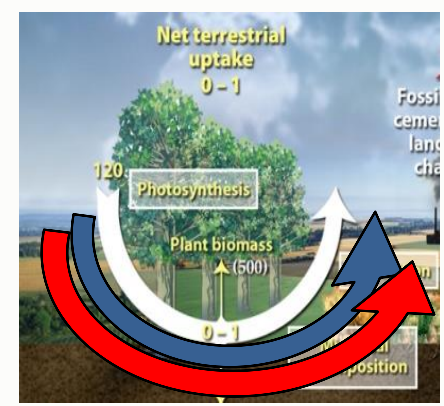
  based & GMES funded)

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









Based on ERA-Interim meteorological forcing and land surface modelling component

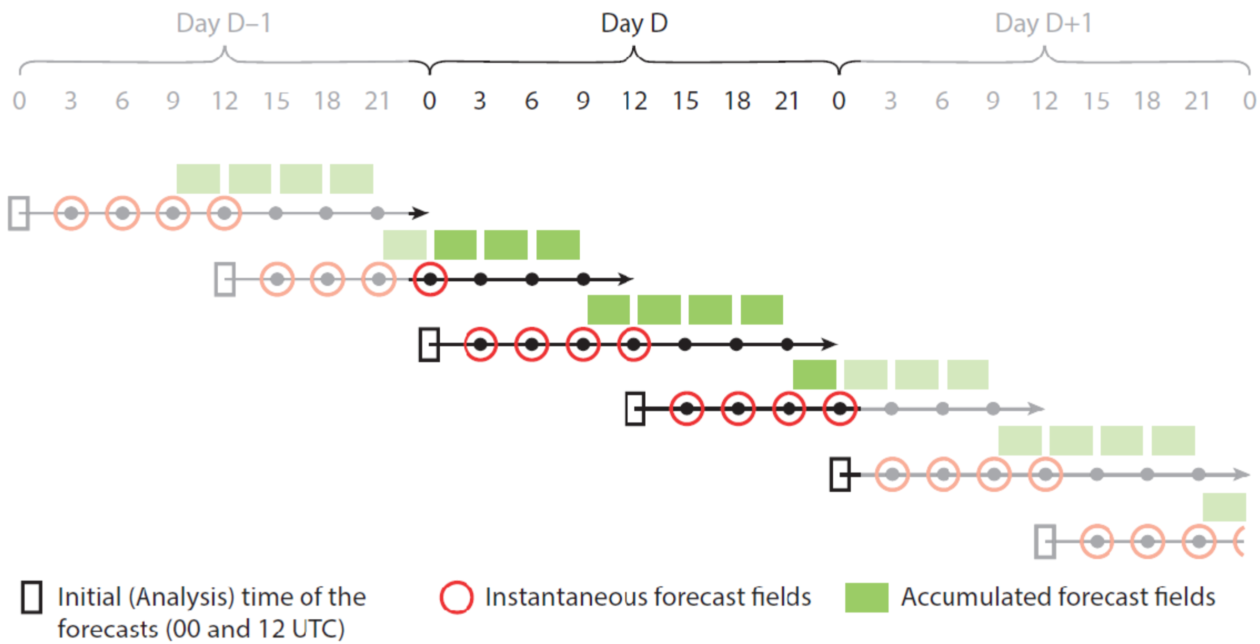


Figure 1: Schematic representation of the ERA-Interim meteorological forecasts concatenation for the creation of the 3-hourly forcing time-series used in ERA-Interim/Land for a given day. Orange circles indicate instantaneous variables valid at their timestamp: 10m temperature, humidity, wind speed, and surface pressure. Green boxes indicate fluxes valid on the accumulation period: surface incoming short-wave and long-wave radiation, rainfall, and snowfall.

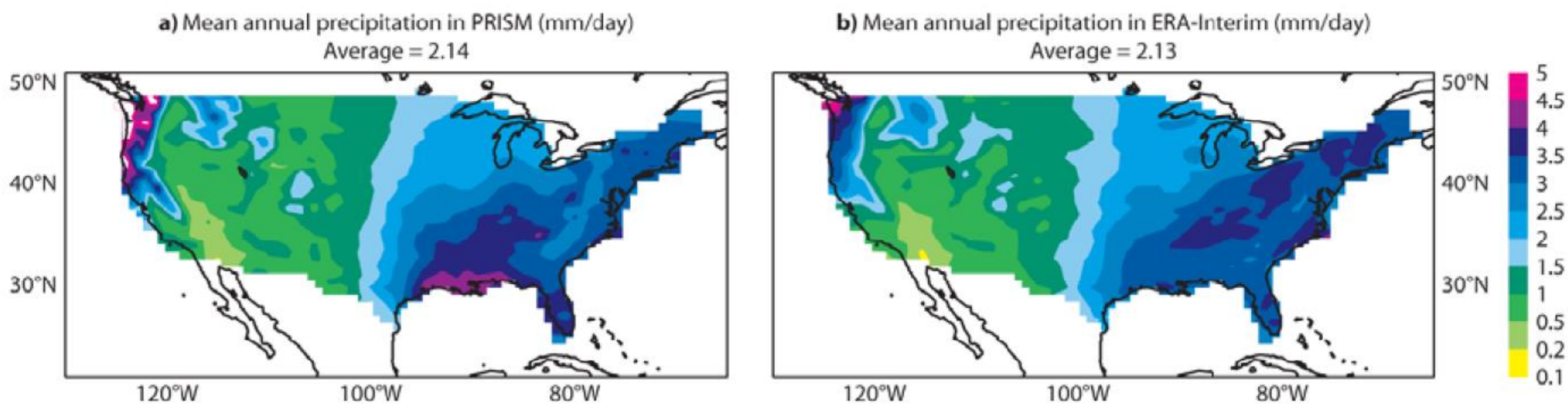
ERA-Interim/Land forcing for precipitation and radiation was validated along with a simple bias correction method using GPCPv2.0 monthly precipitation (1979-2010)

ERA-Interim/Land: forcing verification

Balsamo et al. (2010 ERA-Rep.5), Szczypta et al. 2011 (HESS)

ERA-Interim/Land precipitation and radiation (at MF) forcing were evaluated with independent dataset.

Evaluation of ERA-Interim and ERA-Interim-GPCP-rescaled precipitation over the U.S.A. ECMWF

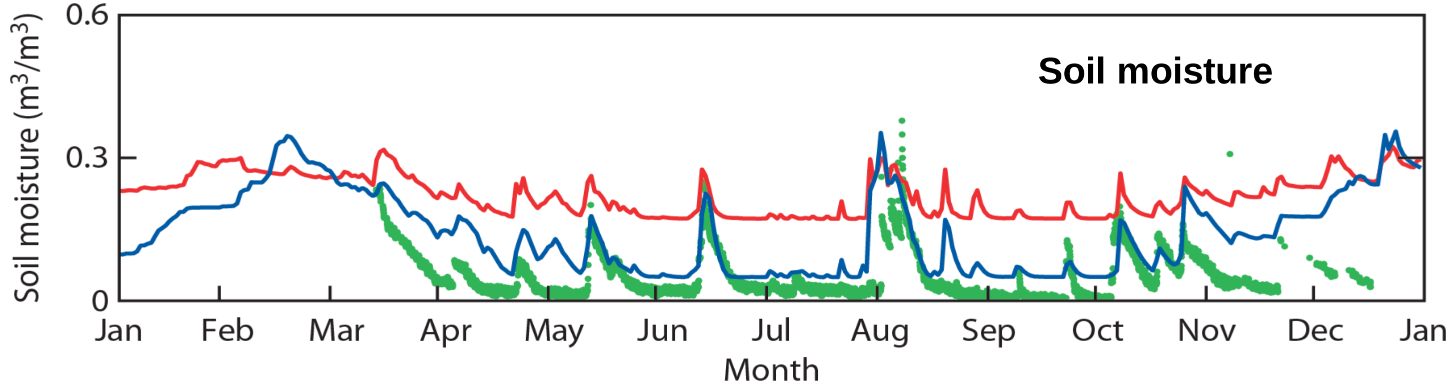


Example of the annual cumulated precipitation over US (CONUS area) vs PRISM dataset

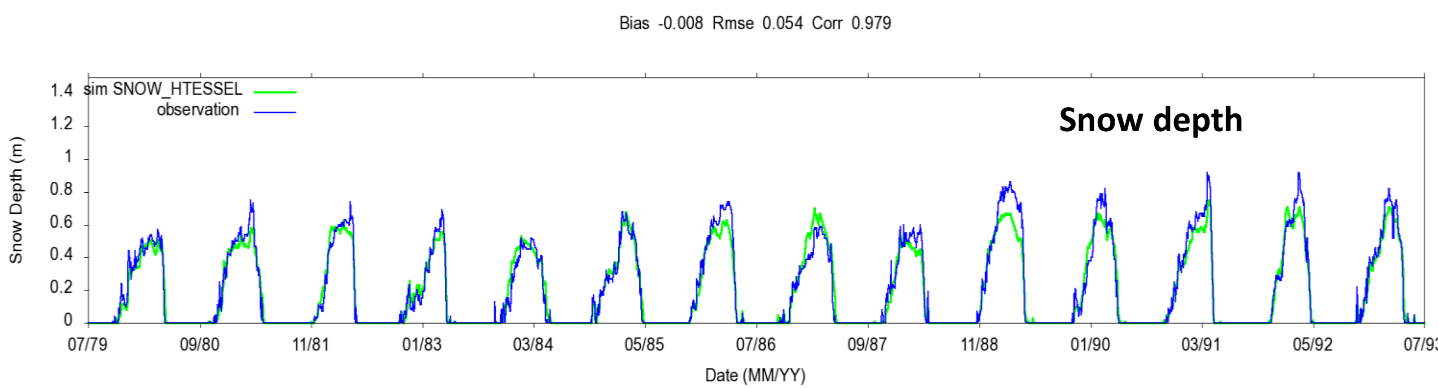
ERA-Interim/Land: storages verification

Albergel et al. (2013 JHM), Balsamo et al. (2013 HESSD)

ERA-Interim/Land integrates land surface modelling improvements with respect to ERA-Interim surface scheme and provided a balanced initial condition for the Monthly/Seasonal Re-Forecasts



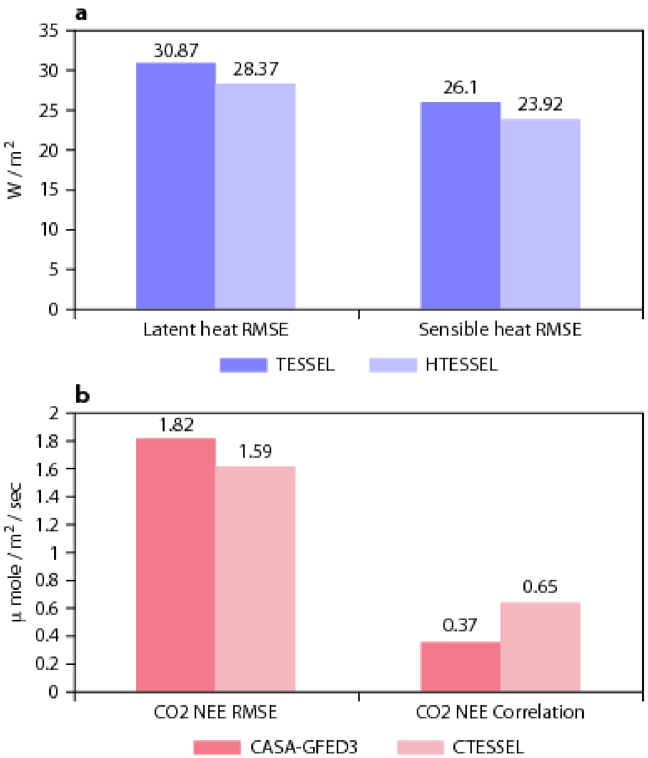
Evolution of soil moisture for a site in Utah in2010. Observations, ERA-Interim, and ERA-Interim/Land.



Evolution of snow depth for a site in Perm Siberia (58.0N, 56.5E) ERA-Interim/Land and in-situ observation between 1979 and 1993.

ERA-Interim/Land: fluxes verification

The ERA-Interim/Land fluxes are validated with independent datasets used as benchmarking.



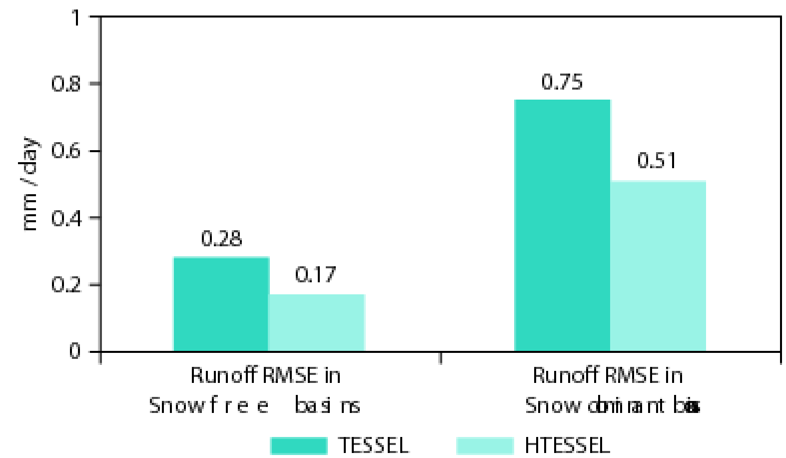
E

CO_2

GEOLAND-2 R&D support

Figure 1: Mean performance measured over 36 stations with hourly Fluxes from FLUXNET & CEOP Observations networks

Validation of H_2O / E / CO_2 cycles



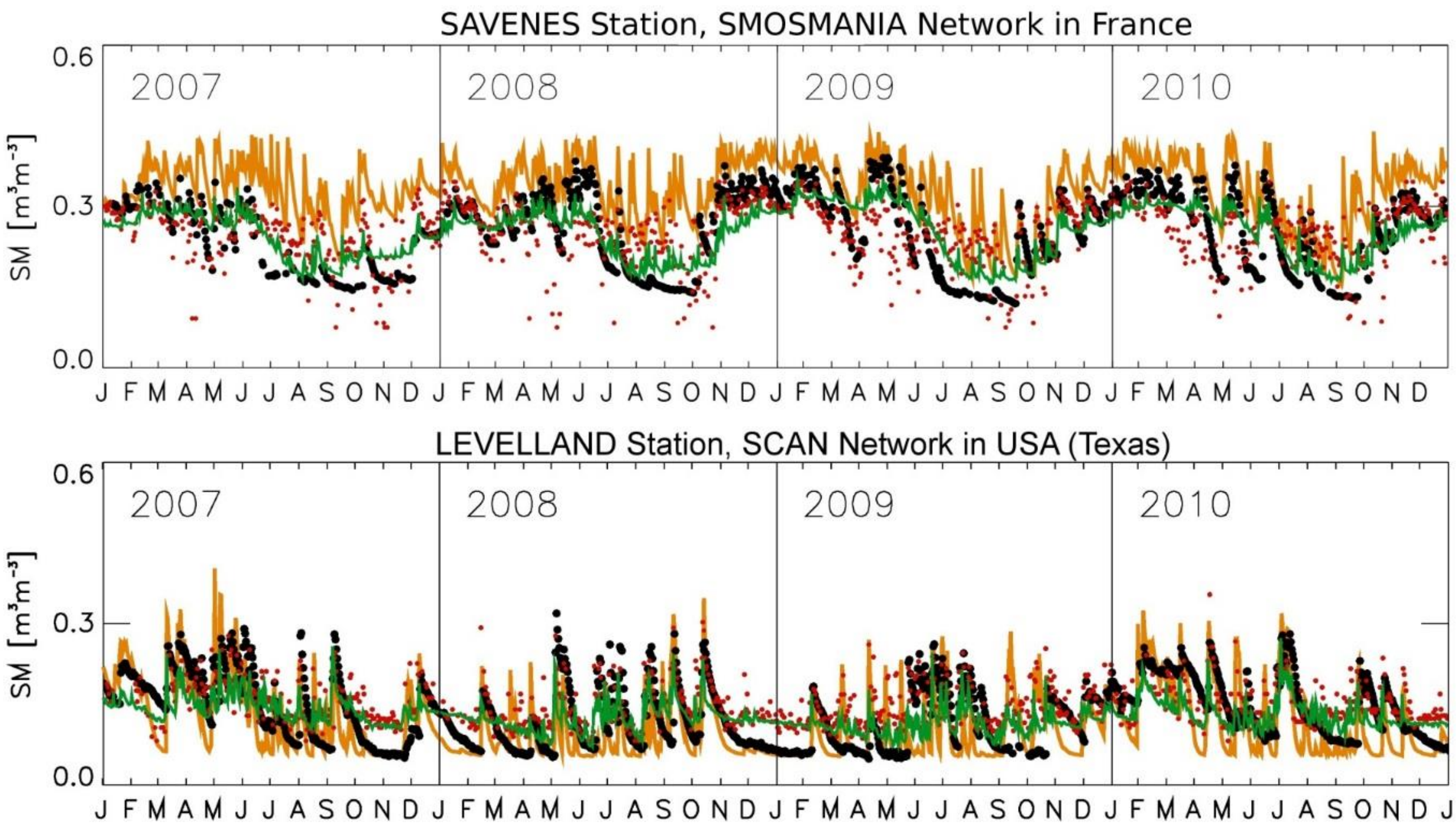
H_2O

Figure 2: Mean performance measured for the monthly rivers discharge verified with GRDC observations

Soil moisture: a globally monitored quantity (ECV)

Albergel et al. (2013)

- **In-situ:** Soil moisture observation sites are >900 stations (ISMN)

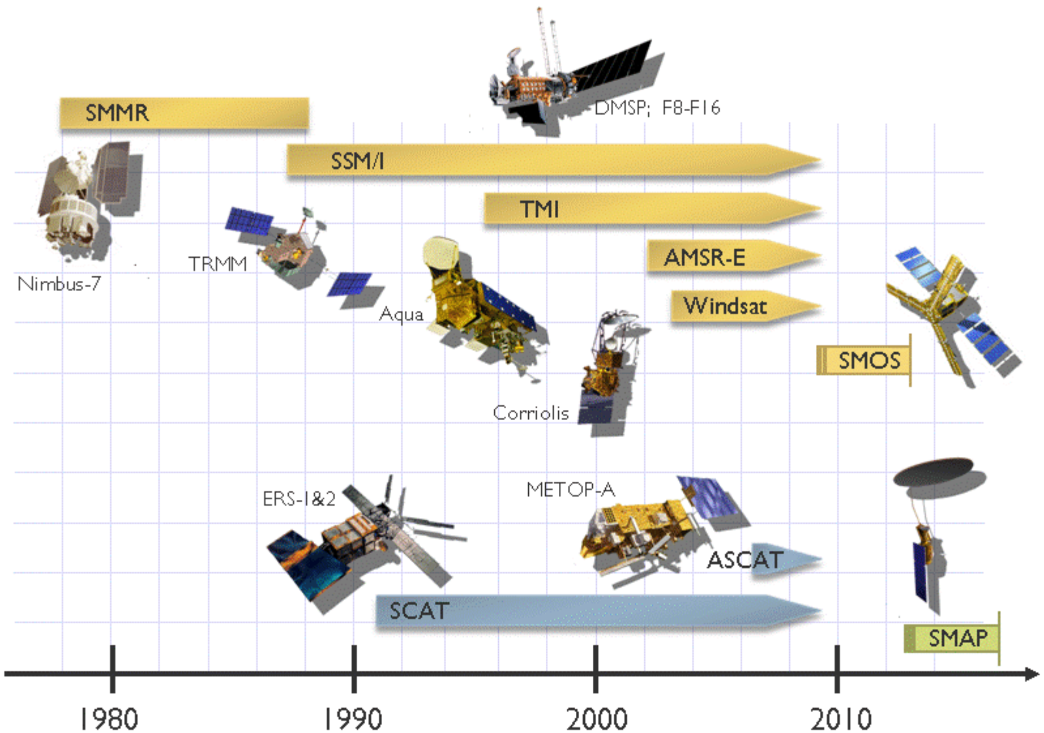


In situ (5cm) SM-MW MERRA-Land (0-2cm) ERA-Land (0-7cm)

Soil moisture remote sensing

Courtesy of Clement Albergel

- **Spatial Remote Sensing :** unique opportunity to observe SM at a global scale

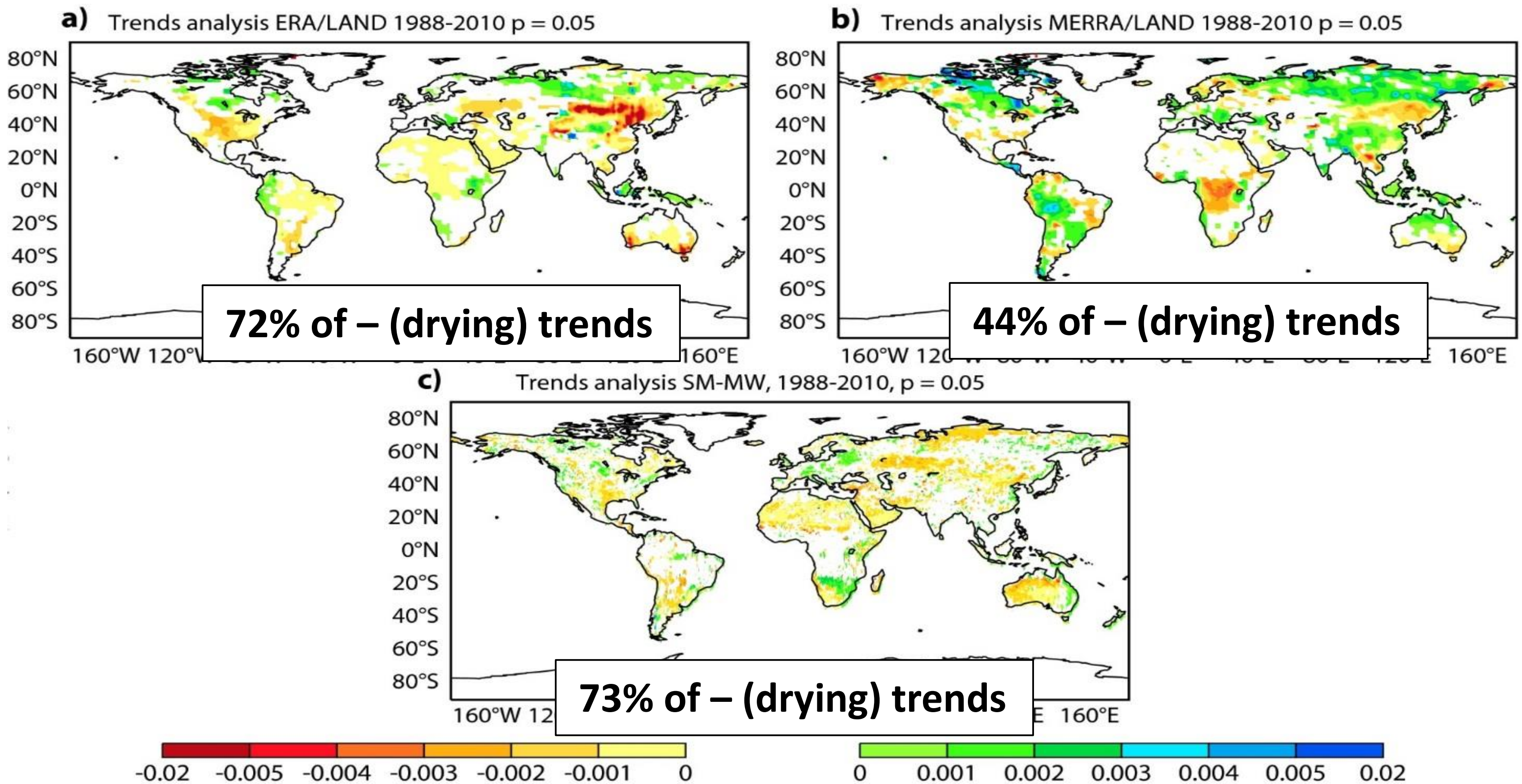


(Figure from : http://www.esa-soilmoisture-cci.org)

WACMOS and CCI Soil Moisture projects: merge data from various active and passive microwave sensors to produce the most complete and most consistent global soil moisture data record (1979-2010): SM-MW

Combining Land-reanalyses, In-situ, Remote-sensing for characterizing drying trends

Albergel et al. (2013)



1988-2010 trends in monthly surface soil moisture ($m^3m^{-3}y^{-1}$) for a) ERA-Interim/Land, b) MERRA-Land and c) SM-MW (ESA-CCI / ECV). Only significant trends (p=0.005) based on the Mann-Kendall test are shown.

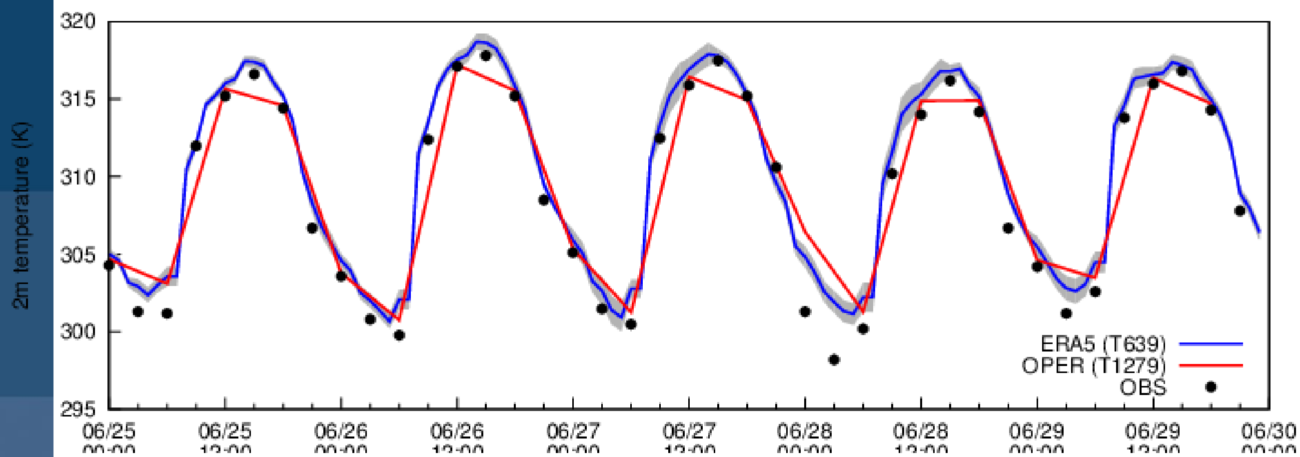
ERA-5L in a nutshell

- High-resolution land component forced by ERA5 atmospheric reanalysis
  - Running in a stand-alone suite, decoupled from the atmosphere (lower computational cost)
  - Expected resolution will follow ECMWF operational system (TCo1279 → approx. 9 km)
  - Currently under development
  - Very useful data set for the scientific land community but also for commercial applications
  - Expected start of production by the end of 2016 (ERA-5L lags behind the ERA5 production)

- Some characteristics
  - Atmospheric forcing from ERA5
  - T, Q and P fields corrected from orography height difference (lapse-rate correction)
  - Surface fields uncertainty estimated from coarser resolution 10-ensemble members run
  - Currently no assimilation implemented

- Current & future developments
  - Precipitation & lapse-rate corrections
  - Use of full interactive vegetation module
  - More realistic ensemble spread through additional perturbations
  - Possible increase to 10 soil layers (from the current 4 layers)
  - NRT production suite
  - Illustrative higher-resolution run.

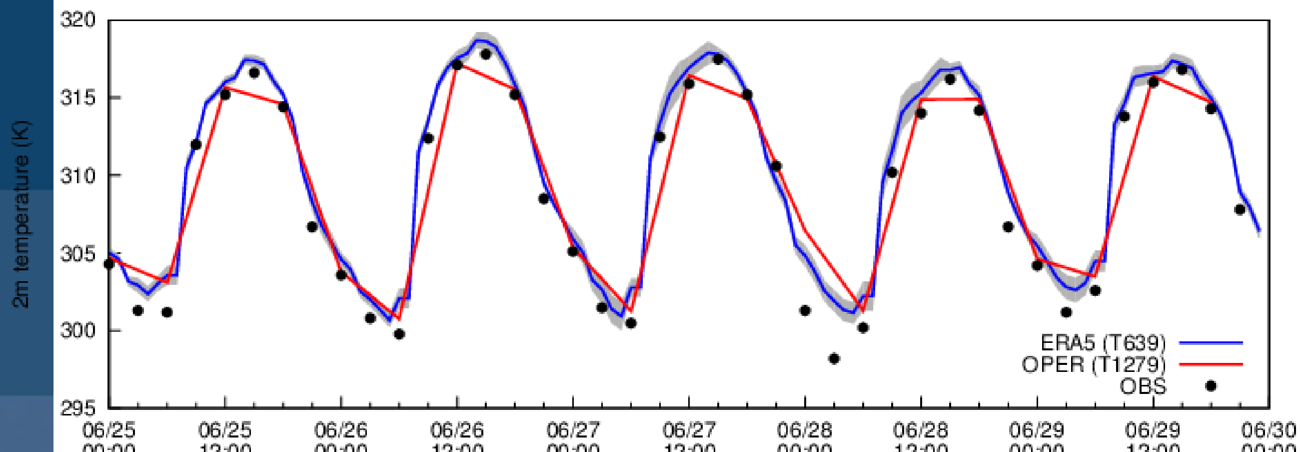
Some examples



2014 (location in the Sahara desert)

- Good description of 2m Temp by ERA5 reanalysis.
- Added value of ERA5 hourly analysis → better characterisation of the daily cycle, min & max
- Spread obtained from the ensemble

Some examples



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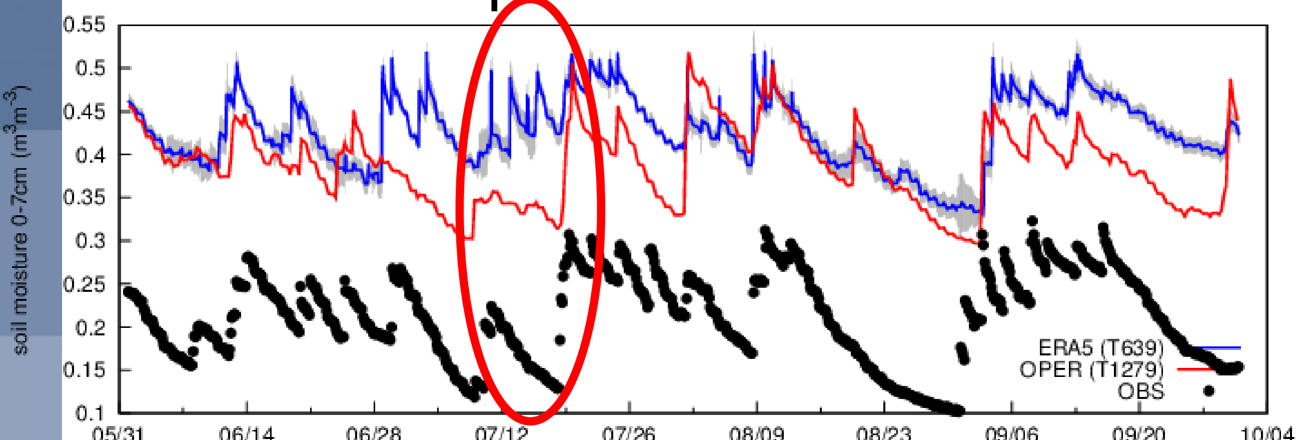
- Good description of 2m Temp by ERA5 reanalysis.
- Added value of ERA5 hourly analysis → better characterisation of the daily cycle, min & max T
- Spread obtained from the ensemble

Precipitation can be very local → discrepancy between OPER, ERA5 and OBS → potential of ERA-5L



2014 (a location of the SCAN network in US)

- But some problems with other land variables, as soil moisture → good potential of ERA-5L to reduce biases and increase correlation with obs.
- Uncertainty underestimated

Summary

ERA5L and ERA-Interim Land: Land surface model forced by the atmosphere ERA5 and ERA-Interim

- Advantages:
    - Possible to run at high resolution with low computing cost,
    - Potential to use enhanced land surface model version (e.g. increased vertical resolution in the soil)
    - Potential to run at regional scale
- Disadvantages:
    - No land data assimilation (snow, soil moisture, soil temperature), but still benefit from high quality reanalysed atmospheric conditions
    - Not integrated to the main reanalysis -> additional system to maintain and run offline
    - Potential inconsistency with the atmospheric component

ERA5, ERA-Interim Land: Integrated part of the reanalysis, LDAS and weakly coupled DA

- Advantages:
    - Consistency with atmosphere (weakly coupled DA)
    - Benefit from land surface data assimilation for snow, soil moisture and soil temperature
    - System maintenance (it is part of ERA-Interim and ERA5 already)

- Disadvantage:
    - Spatial resolution
    - Global scale approach (so can not adapt to regional scale specific needs)
    - No Flexiblility to use enhanced land surface model version

Perspectives for regional reanalysis

Merge the advantages of both approaches:

- Stand alone approach enables regional scale approach at higher resolution than the atmosphere
- Need to enhance the stand alone system to enable land data Assimilation (link to H-SAF activities)
  - improve land surface parameters
  - consistency with global coupled reanalysis

→ Consistency between the integrated land component of ERA and the high resolution regional ERA Land