ESA'S SOIL MOISTURE AND OCEAN SALINITY MISSION - *Status and Perspectives*

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4th Workshop on Remote Sensing and Modeling of Surface Properties | 2016

ESA's EO MISSIONS

SMOS mission operations confirmed until 2017 by both ESA and CNES

Mission overview and performance

- Mission objectives
- Technical status of satellite platform/payload
- Over view on data product
- Data quality: Level 1 (Tb) and Level 2 (SM and SSS)
- RFI status

THE MISSION:
OBJECTIVES & SCIENCE REQUIREMENTS

The mission objective is to provide global measurements of two key variables in the water cycle - soil moisture and ocean salinity.

THE MISSION

Launch - 2 November 2009

m; inclination of
, polar, sun-
ar, dusk-dawn
t cycle, 3-day

en ESA (overall
ground segment
responsible for

ging Radiometer
nstrument, is a
interferometric
-Band (1.4GHz,
21cm); 69 antennas are equally distributed over the 3 arms and the central structure.

The scie

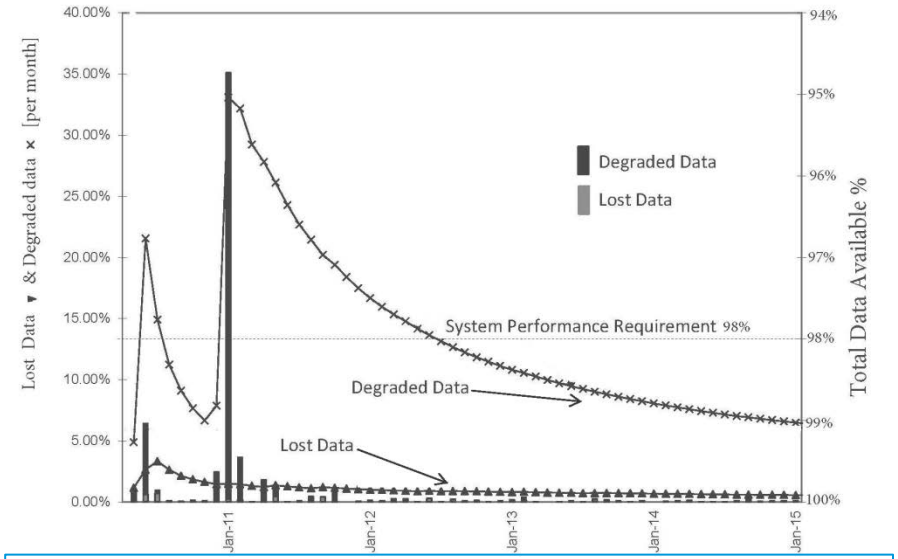
Soil Moisture	
Ocean salinity	

For operations phase till 2017, mission objectives were extended to include:

1. SMOS brightness temperatures, soil moisture, and ocean salinity observations shall be analysed with respect to geophysical **processes related to the water cycle occurring on time scales exceeding the nominal mission lifetime** of 3 (5) years.
2. Daily **sea ice thickness** estimates based on MIRAS observations shall be provided for the Northern Hemisphere with a spatial resolution of 10.000 km^2 up to maximum values of 50 cm.

OVERALL TECHNICAL STATUS
SATELLITE AND GROUND SYSTEMS

Platform and payload



- Platform fully operational, all sub-systems in good health and no sign of degradation (remaining propellant sufficient for another 120 years in orbit!)
- Payload status & performance excellent after ~6 years of operations with some well-identified anomalies with recovery procedures in place.
- **High data availability**
  - Overall mission performance **~99%**
  - Calibration: 1.68% of observations

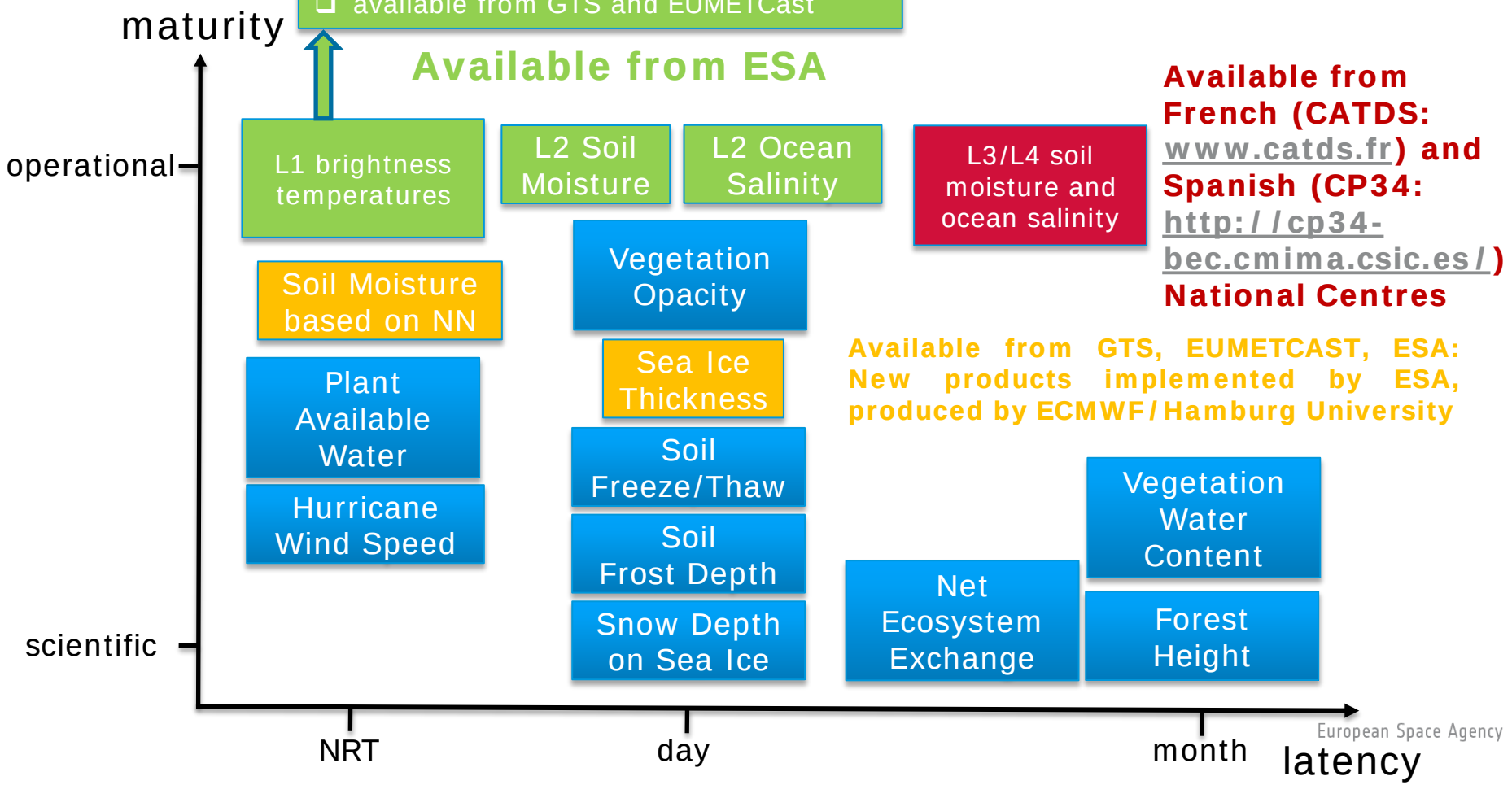
Very reliable ground segment operations

- Ground segment continuously acquires and processes data up to level 2 (soil moisture and ocean salinity) in 99% of time and provides brightness temperatures (and soil moisture from autumn 2015) in NRT.
- Data available to science users within 1-3 days from sensing, for NRT within 3 hours from sensing (~90% of time).
- 2nd reprocessing campaign completed, with level 1 reprocessed data already being available to users since May 2015. Level 2 SM and SSS reprocessed data released on 4 March 2016.

SMOS is in excellent technical conditions. No technical limits exist to operate the mission beyond 2017.

SMOS DATA PRODUCTS

- NRT L1 TB: BUFR (ECMWF)
- NRT L1 TB LIGHT (full angular resolution, reduced grid, only land coverage, no averaging of TB in antenna frame)
- available from GTS and EUMETCast



Available from French (CATDS: www.catds.fr) and Spanish (CP34: http://cp34-bec.cmima.csic.es/) National Centres

Available from GTS, EUMETCAST, ESA: New products implemented by ESA, produced by ECMWF/Hamburg University

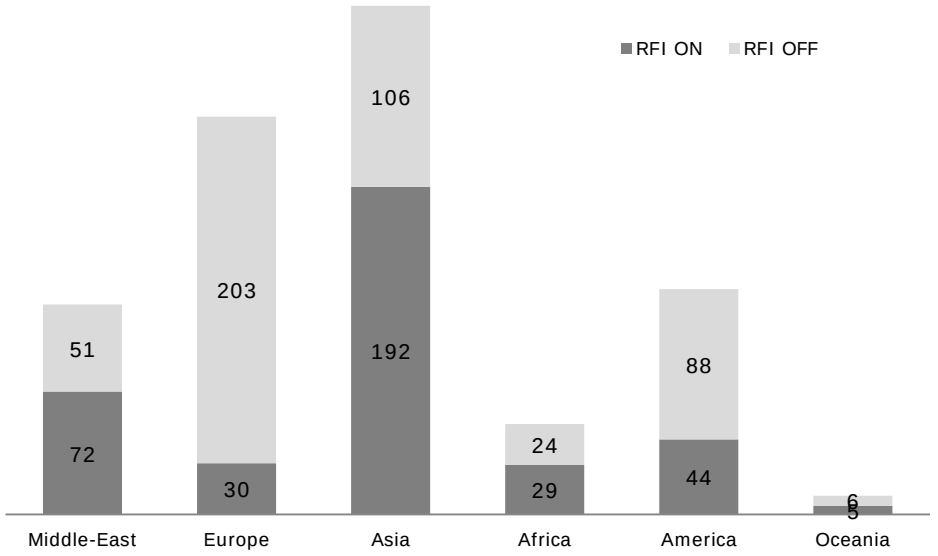
DATA QUALITY
LEVEL 1 BRIGHTNESS TEMPERATURES

MAIN IMPROVEMENTS AT LEVEL 1

- Significant improvements regarding drifts/stability and spatial biases in new Level 1 processor.
- New processor implements correct computation of the 4th Stokes parameter and improved RFI flagging.
- Remaining problem: land-sea contamination :

$(T_x+T_y)/2$	Previous Level 1 (V5)	Current Level 1 (V6)
Orbital stability, latitudinal slope	6.9 mK/lat deg	4 mK/lat deg
Seasonal stability	0.38 K	0.16 K
Long term stability: yearly drift	–0.18 K/year	–0.03 K/year

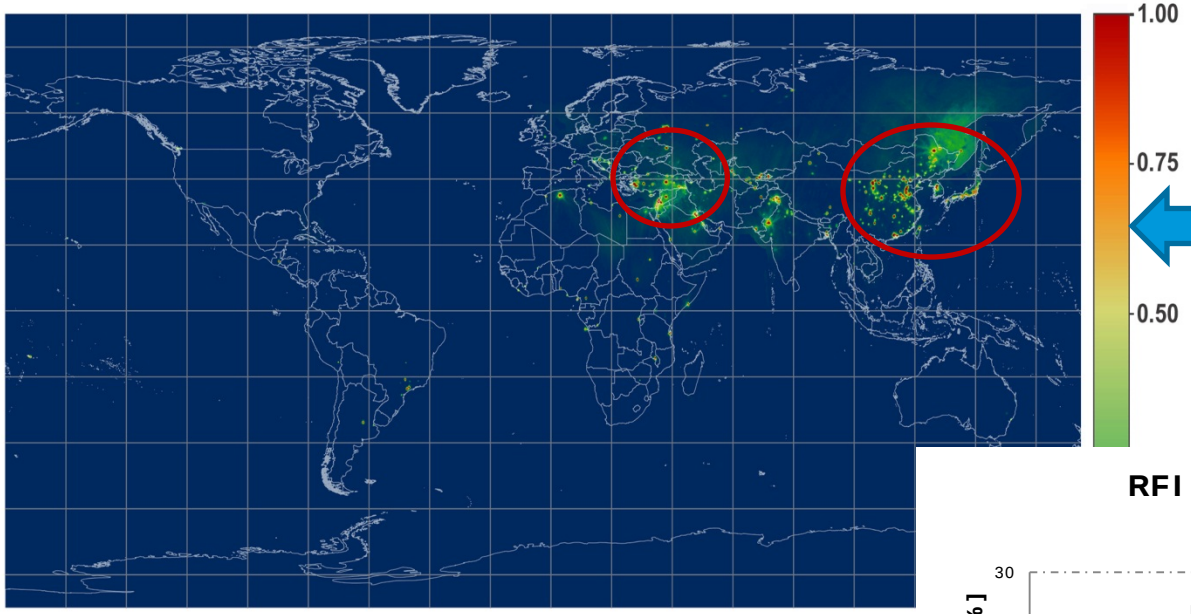
SMOS RFI Worldwide (Jul 2015)



RFI CONTAMINATION MUCH REDUCED

Status July 2015: 850 RFI sources being detected worldwide and 478 of these RFI sources (58%) being identified and not operating anymore in the protected band.

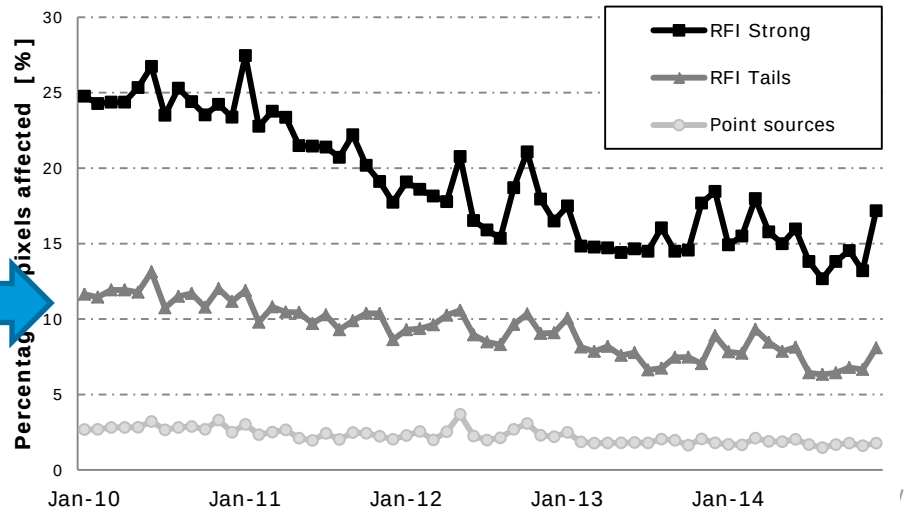
RFI DETECTION AND MITIGATION



RFI contamination worldwide much reduced but still present in middle East and Asia (in particular China and Japan).

RFI presence over land masses

Percentage of the number of SMOS pixels over land affected by RFI for the 5 years of SMOS in orbit. Pixels flagged with strong RFI have decreased by 11% over the mission life time due to successfully switching off strong sources.



New RFI flagging in L1 v6

SOIL MOISTURE

Mission objective over land - To provide global volumetric soil moisture estimates with an accuracy of 0.04 m^3m^{-3} at a spatial resolution of 35-50 km and a temporal sampling of 1-3 days → **Reached.**

Applications over land

Land Surface Hydrology

- ❑ High-accuracy surface soil moisture (CESBIO)
- ❑ Root zone soil moisture (CESBIO, ECMWF)
- ❑ High-resolution/downscaled soil moisture (BEC)
- ❑ Flood forecasting (Univ. Gent)
- ❑ Evapotranspiration (Univ. Gent)
- ❑ Weather forecasting (ECMWF, Env. Canada, UK Met.)
- ❑ Essential Climate Variable (INRA, CESBIO, Transmissivity)

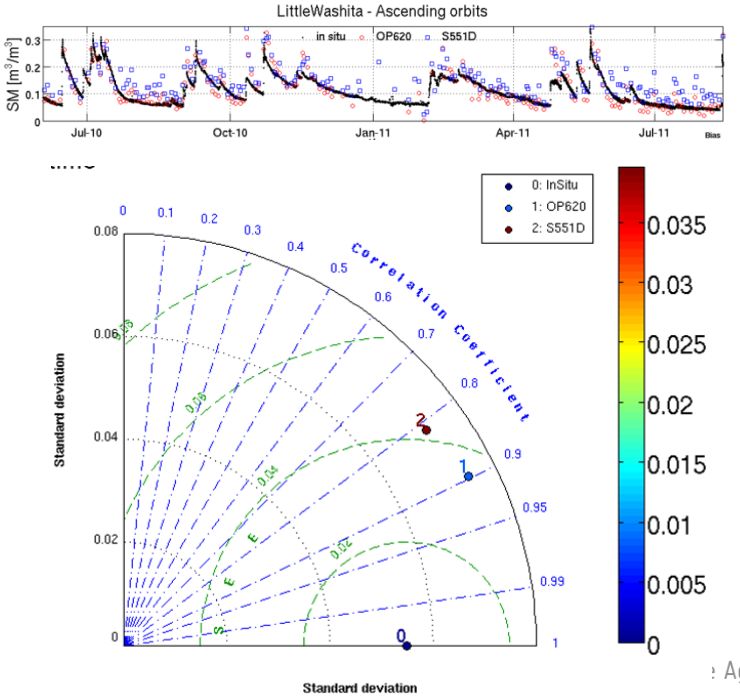
Carbon and Vegetation

- ❑ Net Ecosystem Exchange (FASTOPT)
- ❑ Fire risk monitoring (Diputació de Barcelona)
- ❑ Wetlands and rivers (CESBIO)
- ❑ Vegetation water content (Lund Univ.)

Food and Feed

- ❑ Crop Yield (Uni. Iowa)
- ❑ Drought monitoring (USDA, CESBIO)
- ❑ Crop Explorer (FAO/USDA)

Continued validation of L2 soil moisture product



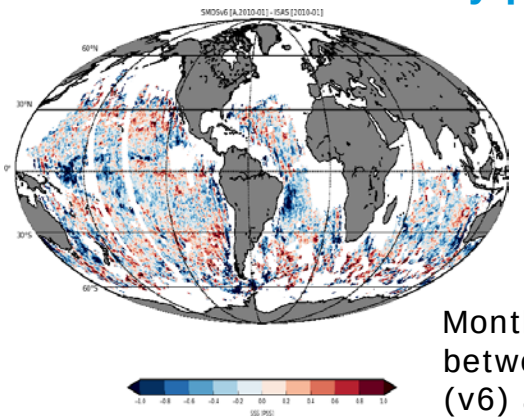
SEA SURFACE SALINITY

Mission objective over ocean - To provide global ocean salinity estimates with an accuracy of 0.1 practical salinity scale units for a 10-30 day average for an open ocean area of 200 x 200 km^2 → **product accuracy constantly improved and approaching targeted values**

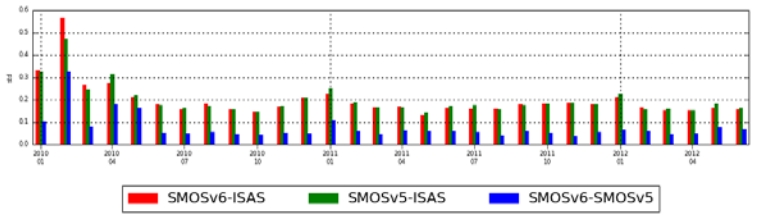
Applications over ocean

- Ocean-Atmosphere interactions
  - Detecting Upwelling and barrier layers (LEGOS, IFREMER)
  - Monitoring freshwater river plumes (IFREMER, Univ. of Maryland)
  - Monitoring precipitation-induced signals (LOCEAN, Univ. Washington, NUIG)
  - Characterizing SSS variability in high evaporation zone - subtropical gyres (SPURS-experiment)
- Ocean circulation and modelling
  - Characterizing mesoscale variability of SSS (and density) in frontal structures, eddies (LOCEAN, IFREMER, JPL)
  - Monitoring key oceanic thermohaline circulation processes: Gulf Stream (IFREMER)
  - Detecting Tropical Instability Waves - TIW (LOCEAN, JPL)
  - Assimilating SMOS in OGCM (Univ. Hamburg, Mercator, UK MetOffice)
- Climate change studies
  - Large-scale SSS anomaly related to climate indexes - ENSO and IOD (LOCEAN, BEC, Univ. S. Carolina)
- Marine Biology / Biogeochemistry
  - Ocean Acidification (Univ. Exeter, PML, IFREMER)
- Numerical Weather Prediction
  - Hurricane/storm tracking and intensity forecasting (IFREMER, UK MetOffice)

Continued validation of L2 sea surface salinity product



Monthly difference between SMOS (v6) and ISAS SSS



SPURS–N. Atlantic – 2011 averaged accuracy: **0.17 psu**

THIS WORKSHOP: SMOS CONTRIBUTION

Retrievals of surface parameters based on SMOS data

- Soil moisture
- Sea surface salinity
- Sea ice thickness
- Soil moisture in NRT → **see presentation N. Rodriguez-Fernandez**
- Severe winds over ocean
- Vegetation optical depth/water content
- Freeze and thaw

Land surface assimilation schemes

- Numerical weather prediction (L1 TB, SM) → **see presentation P. de Rosnay / N. Rodriguez-Fernandez**
- Stream flow prediction (L3 SM)
- Net Ecosystem Exchange: Carbon assimilation scheme (L3 SM)
- Evapotranspiration model (VOD)

CRYOSPHERE

Mission objective (extension phase) - Daily sea ice thickness estimates based on MIRAS observations shall be provided for the Northern Hemisphere with a spatial resolution of 10.000 km2 up to maximum values of 50 cm. → **Reached.**

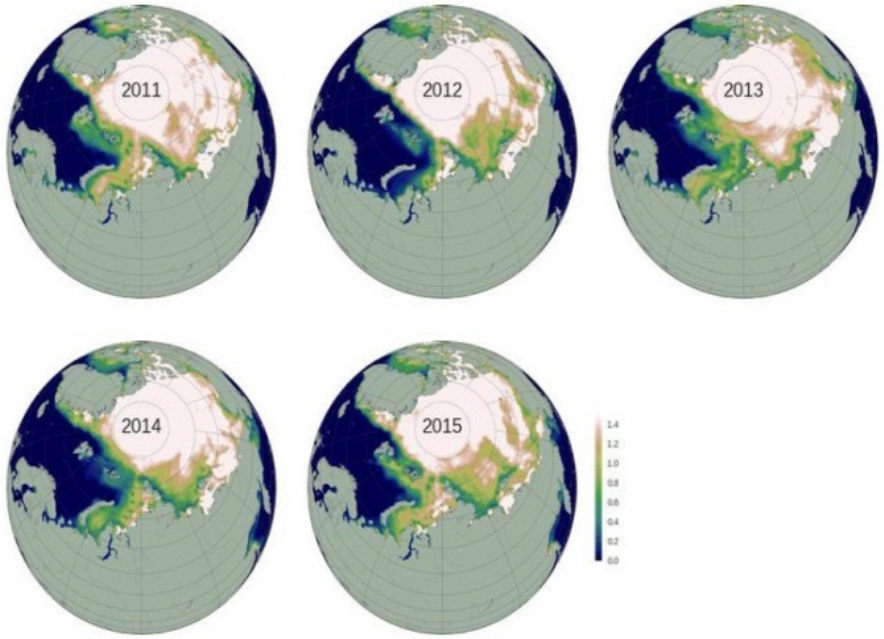
Applications over cryosphere

Sea Ice
- ❑ thickness (UHH)
- ❑ snow depth (UHH)

Land Ice
- ❑ internal ice temperature (IFAC)
- ❑ bedrock topography (DTU)
- ❑ surface characteristics (LGGE)

Ice Shelve
- ❑ ice temperature (UHH)
- ❑ marine ice (UHH)
- ❑ iceberg tracking (PAS)

Terrestrial Cryosphere
- ❑freeze / thaw state (FMI)
- ❑snow density/ground permittivity (GAMMA RS)
- ❑temperature gradient

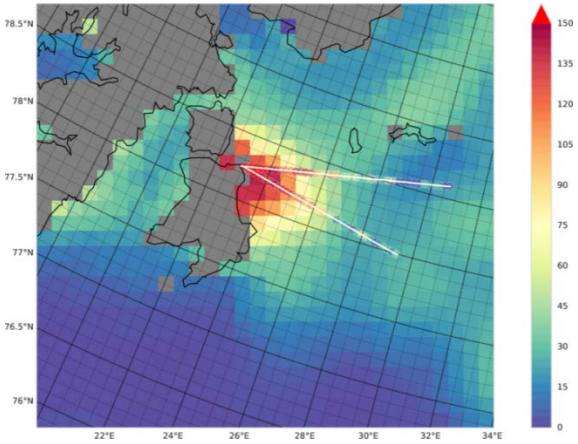


SMOS derived sea ice thickness for February and March (average) from 2011 to 2015. Credit: University of Hamburg, ESA.

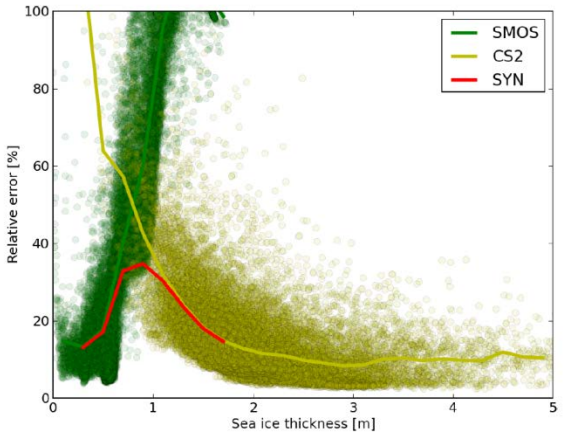
SEA ICE THICKNESS

smosice
support to science element

esa



Validation of sea ice thickness product: SMOS sea ice thickness and airborne laser scanner (ALS) ice thickness (both in cm) on 24 March 2014 in the Barents Sea. Credit: University of Hamburg, Alfred Wegener Institute, ESA.



- SMOS brightness temperatures can be used to retrieve sea ice thickness up to ~ 0.5-1m
- Semi-empirical retrieval based on TB intensities:
  - Using thermodynamic and radiative transfer model
  - Accounts for ice temperature (surface air temperature from JRA-25 Re-Analyse) and ice salinity (SSS from weekly climatology)
- Complementary with ESA's CryoSat data.
- Validated in Arctic campaign in March 2014.
- Operational users have signalled interest and using data already (DMI, MetNo, ECMWF).
- Daily maps generated by University of Hamburg and disseminated with latency of 24 hours, since winter season 2010/11 till now through: http://icdc.zmaw.de

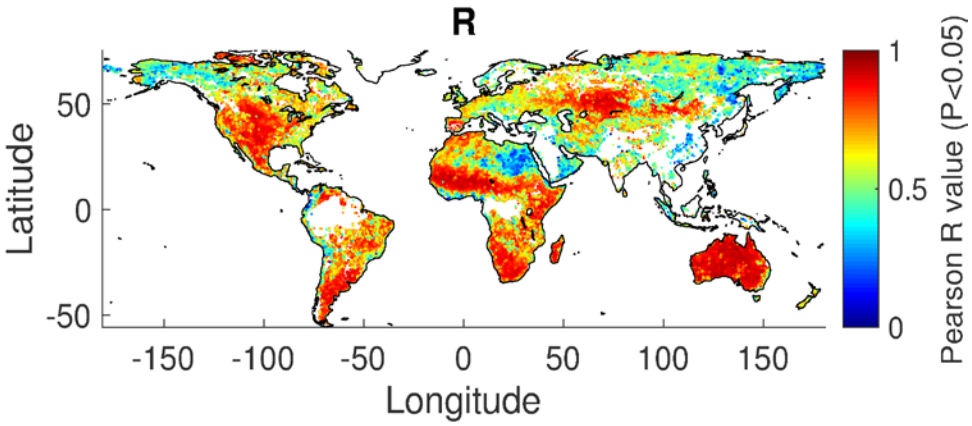
Synergy ice product based on SMOS and CryoSat data, combining both sensors' skill

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

European Space Agency

SOIL MOISTURE IN NRT

New Soil Moisture data product available in **Near-Real-Time** for operational application



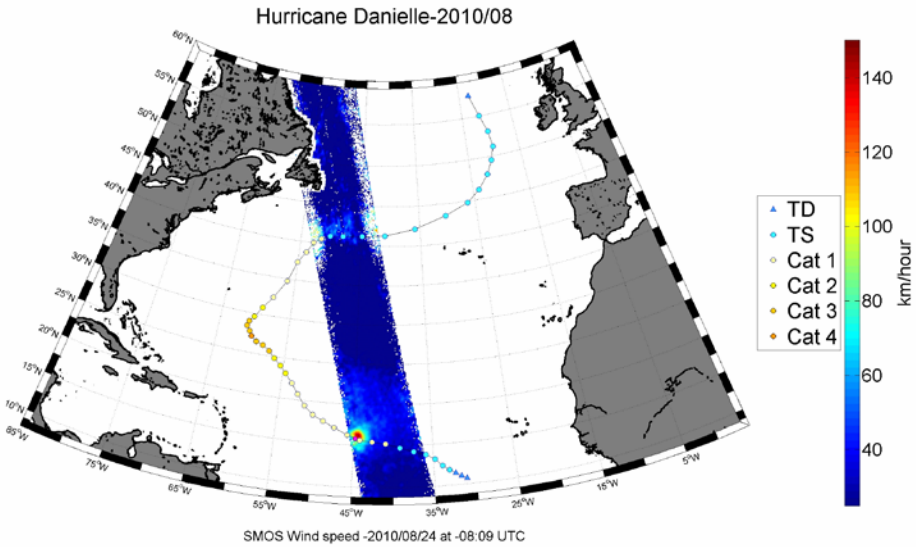
Local temporal correlation (Pearson R coefficient) between the SMOS NRT soil moisture data and the SMOS level 3 soil moisture data from CATDS. Credit: CESBIO, ESA.

- Developing a fast retrieval for a NRT Level 2 Soil Moisture product based on Neural Networks
- Important for Numerical Weather Prediction and operational hydrology
- Input data = Tb in NRT
- Training data set = SMOS Level 2 (geophysical) soil moisture data product
- Processing at ECMWF based on algorithm by CESBIO/Estellus
- Product available from ESA since March 2016; from GTS and Eumetcast from April 2016+

→ **see presentation N. Rodriguez-Fernandez**

SEVERE WINDS

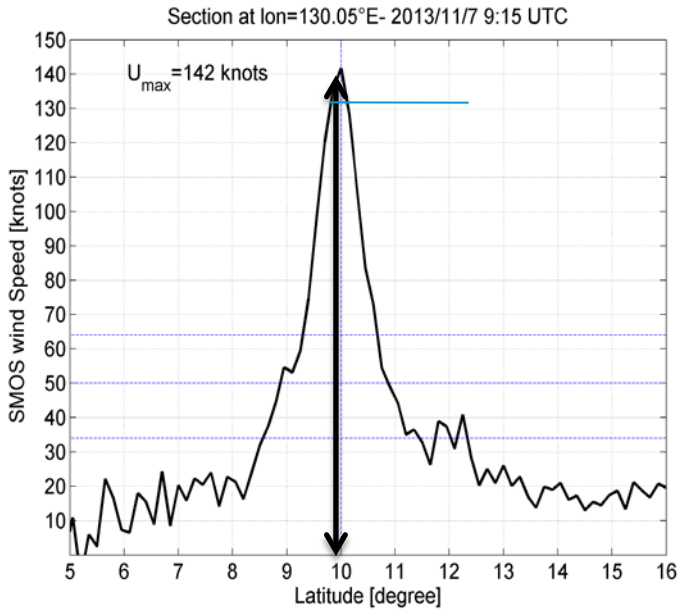
smos+ storms
support to science element
esa



- Emissivity from ocean in microwave increases with increased wind speed (and thus surface roughness/foam).
- **SMOS can measure up to 70-80 m/s with an accuracy of ~5 m/s**
- Scatterometer data saturate at U~30 m/s (Hurricane force)
- Very promising for improving Tropical Cyclone intensity forecasts.

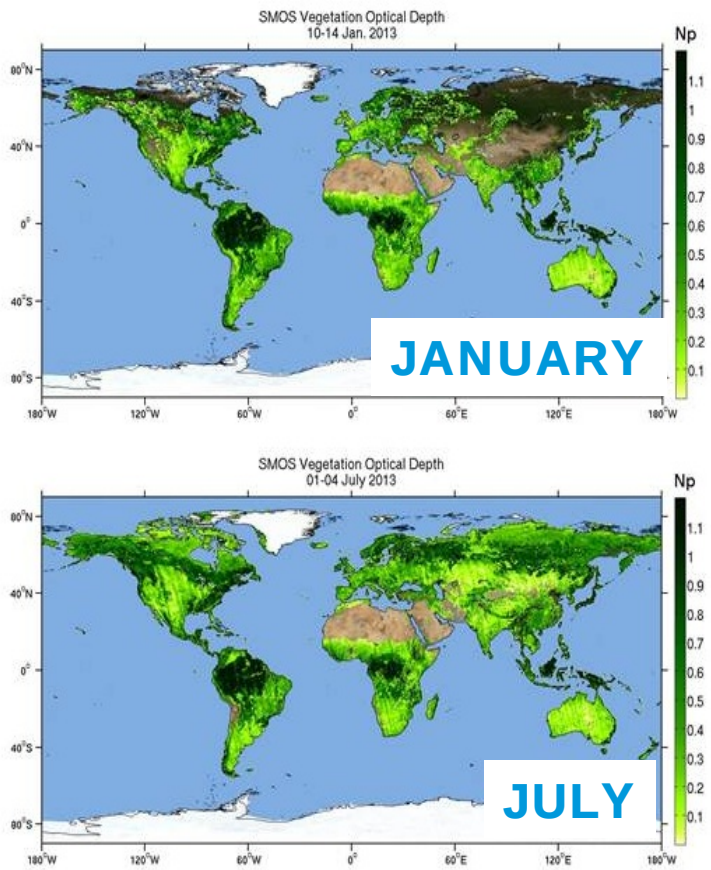
NEW

- Global Tropical Cyclone & Extra-Tropical Cyclone storm catalogue and database from 2010 till now available
- Working with UK Metoffice on analyses of SMOS data assimilation impact on Met Office modeled storm track & intensity forecasts



ce Agency

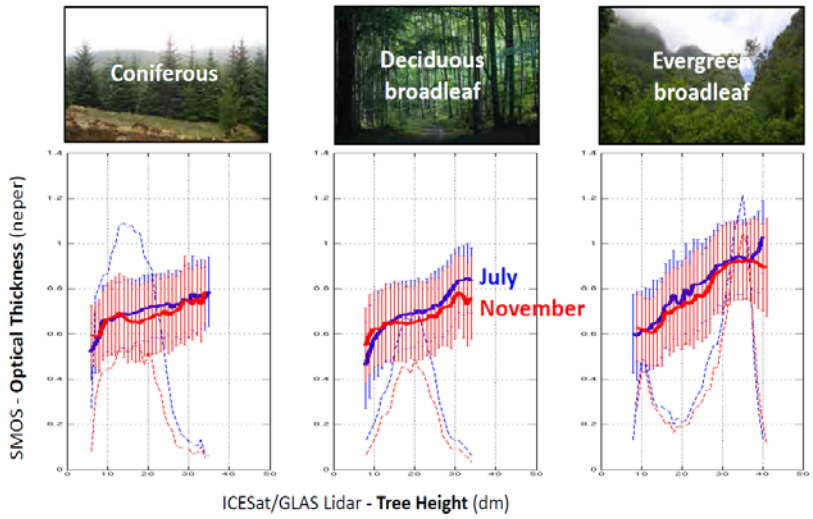
VEGETATION OPTICAL DEPTH



Monthly vegetation optical depth derived from SMOS data for January (top) and July (bottom) 2013. Seasonal differences in vegetation are well visible. Credit: CESBIO, ESA.

- SMOS 'sees' the vegetation layer as a homogeneous cloud of vegetation elements, air, and water (in and on the vegetation)
- **Vegetation Optical Depth (VOD) is a measure of the transmissivity of the vegetation layer** = transparency of the layer for electromagnetic radiation at a given frequency
- **Potential applications:** Agriculture: plant available water, stress/drought monitoring; Terrestrial biosphere and carbon modelling; Climate studies; Landscape ecology

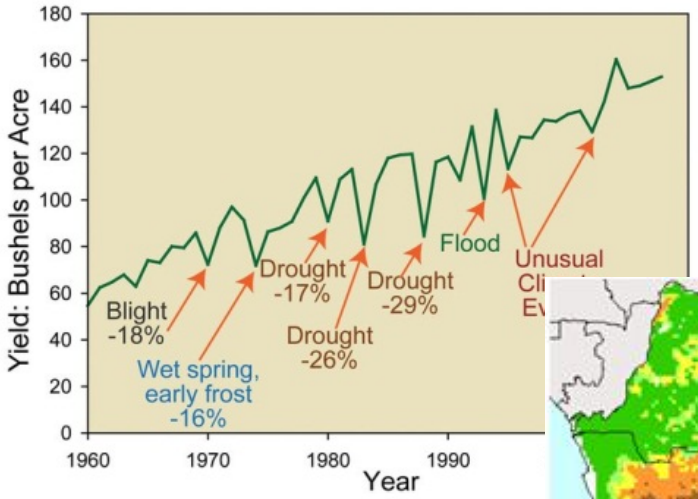
Optical thickness over forests



Rahmoune, R., Ferrazzoli, P., Singh, Y., Kerr, Y., Richaume, P., Al Bitar, A. SMOS Retrieval Results Over Forests: Comparisons With Independent Measurements. J-STARS ,2014

Comparing VOD and tree height (LIDAR): "validation" and improving representation of forested areas in L2 processor

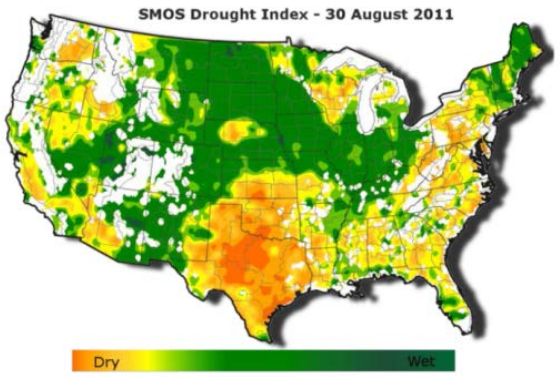
SMOS DATA FOR FOOD SECURITY

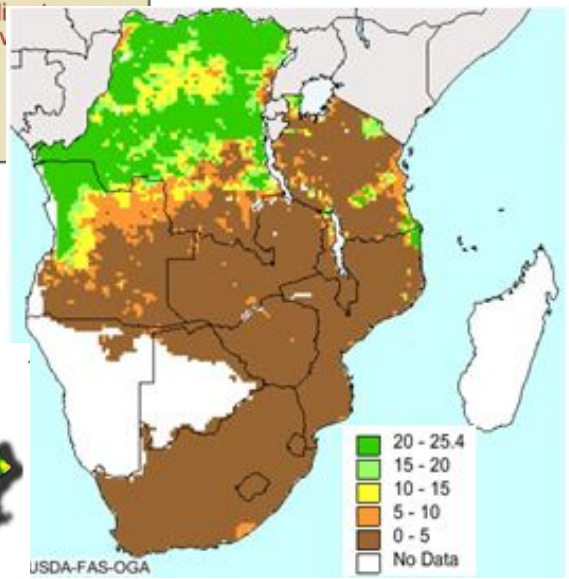


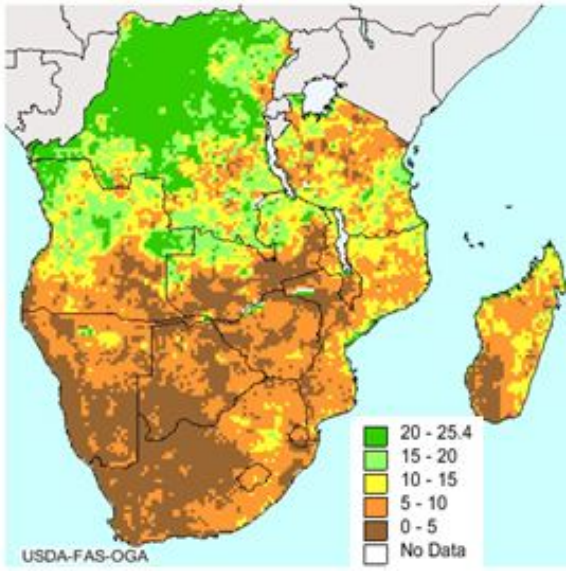
Credit: USDA FAS

SMOS data used to predict drought and improve crop yield by US Department of Agriculture, Crop Explorer website: http://www.pecad.fas.usda.gov/cropexplorer/

From Root Zone moisture to Drought Index







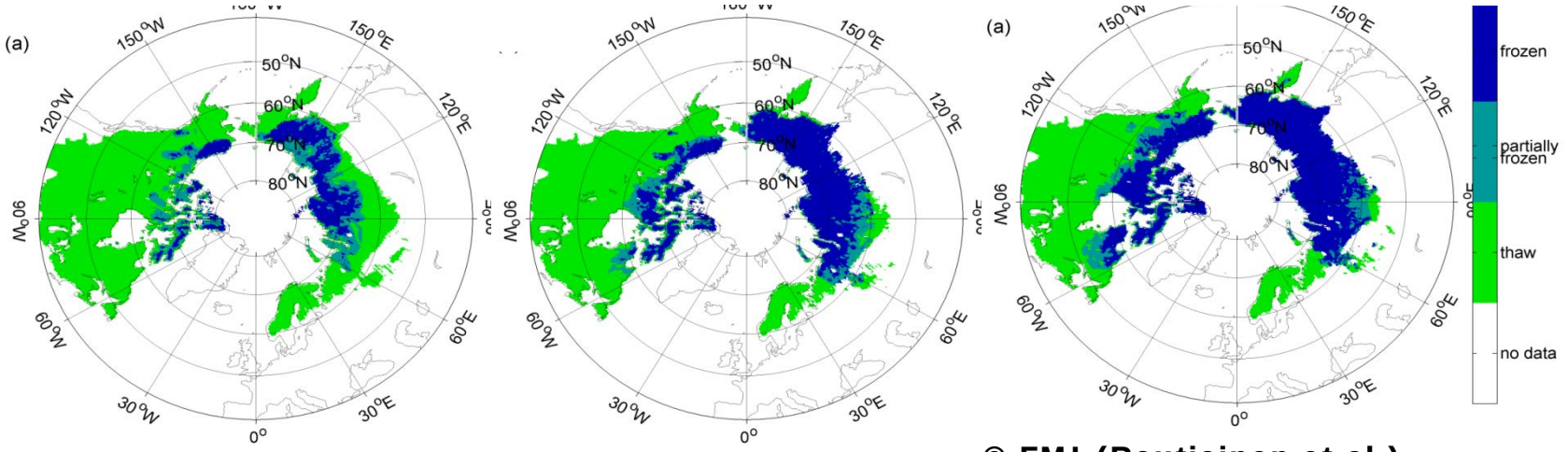
Credit: USDA FAS, Soil moisture in southern Africa in mid-April 2014.

FREEZE AND THAW

10 Oct 2015

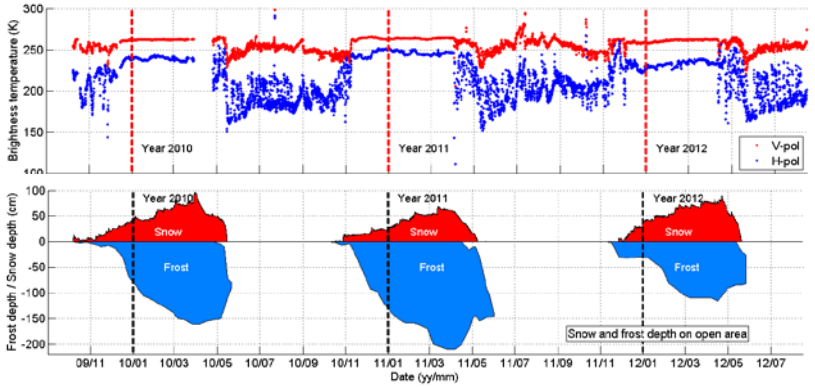
20 Oct 2015

30 Oct 2015



© FMI (Rautiainen et al.)

- Retrieval based on empirical change detection algorithm using 3 years of ground based L-Band observations and in-situ measurements (e.g. soil frost tube observations)
- Product now available!
  - Daily product
  - Coverage: Northern Hemisphere EASE grid projection
  - Three soil state categories “frozen”, “partially frozen”, “thaw” and one “no data” category
  - Currently available 6 years: 2010-2015
  - Will be accompanied with quality estimation flag (pixel-wise)
  - Work continues to make the product operational(updates with 1-2 days latency)



Rautiainen, K., Parkkinen, T., Lemmetyinen, J., Schwank, M., Wiesmann, A., Ikonen. J., Derksen, C., Davydov, S., Davydova, A., Boike, J., Langer, M., Drusch, M., Pulliainen, J., (2016) SMOS prototype algorithm for detecting autumn soil freezing, Remote Sensing of Environment, in press

THIS WORKSHOP: SMOS CONTRIBUTION

Retrievals of surface parameters based on SMOS data

- Soil moisture
- Sea surface salinity
- Sea ice thickness
- Soil moisture in NRT → **see presentation N. Rodriguez-Fernandez**
- Severe winds over ocean
- Vegetation optical depth/water content
- Freeze and thaw

Land surface assimilation schemes

- Numerical weather prediction (L1 TB, SM) → **see presentation P. de Rosnay / N. Rodriguez-Fernandez**
- Stream flow prediction (L3 SM)
- Net Ecosystem Exchange: Carbon assimilation scheme (L3 SM)
- Evapotranspiration model (SM)

SMOS in DATA ASSIMILATION

new observation systems — novel measurements

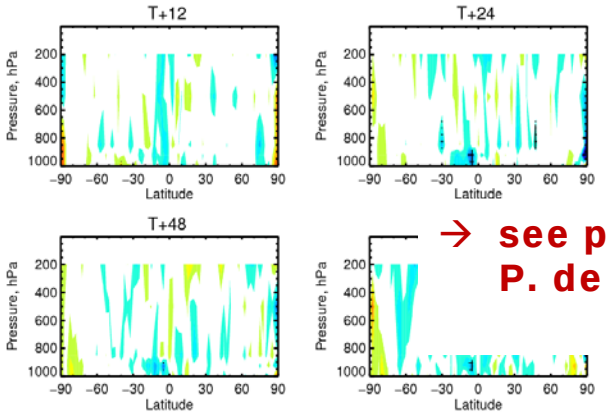
↓ data assimilation ↓

high quality analyses and improved initial conditions

↓ forecast ↓

increased predictive skill — improved risk mitigation — societal benefit

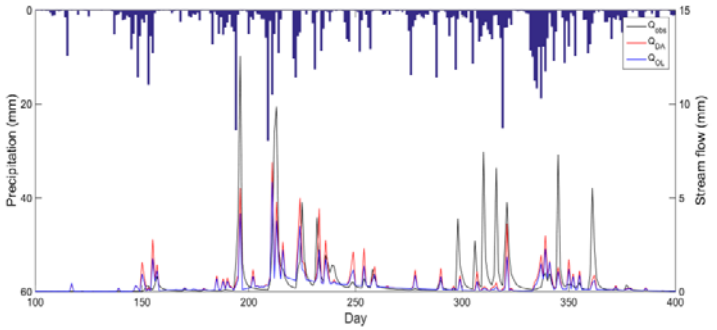
NWP – ASSIMILATING SMOS TB



→ see presentation P. de Rosnay /

Assimilating SMOS TB improves the soil moisture analysis. The impact on weather is neutral to positive (blue) (ECMWF)

PREDICTING STREAMFLOW



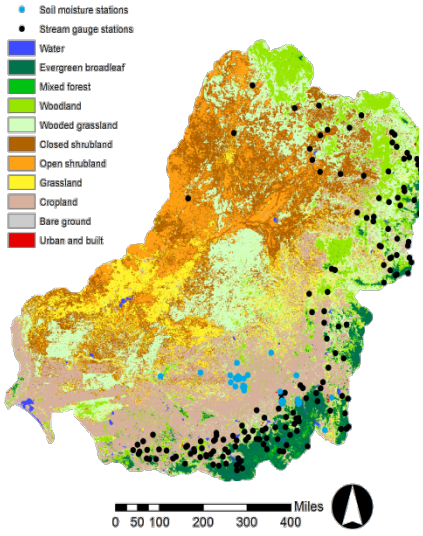
The impact on stream flow is positive. (U. Gent)

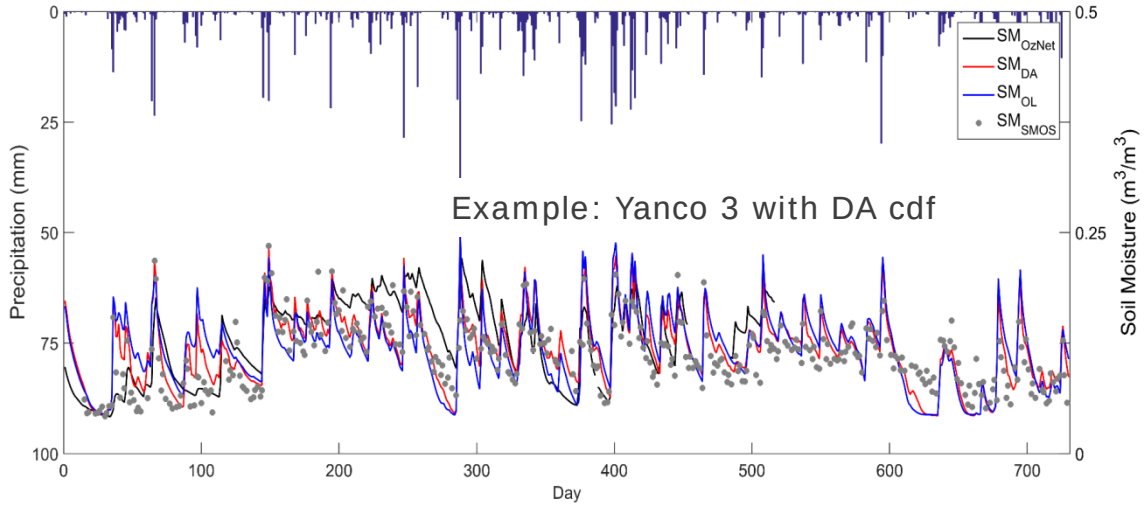
STREAM FLOW PREDICTION

smos+hydrology
support to science element

esa

Assimilate SMOS soil moisture into a the variable infiltration capacity (VIC) model to predict stream flow



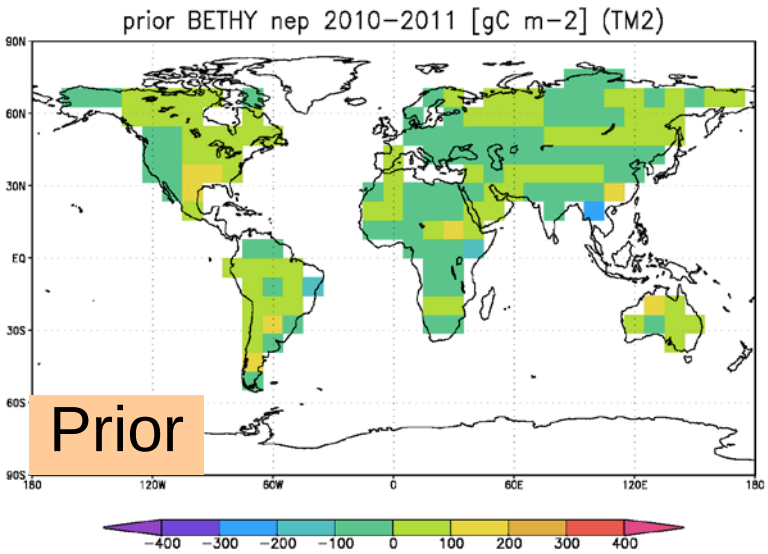


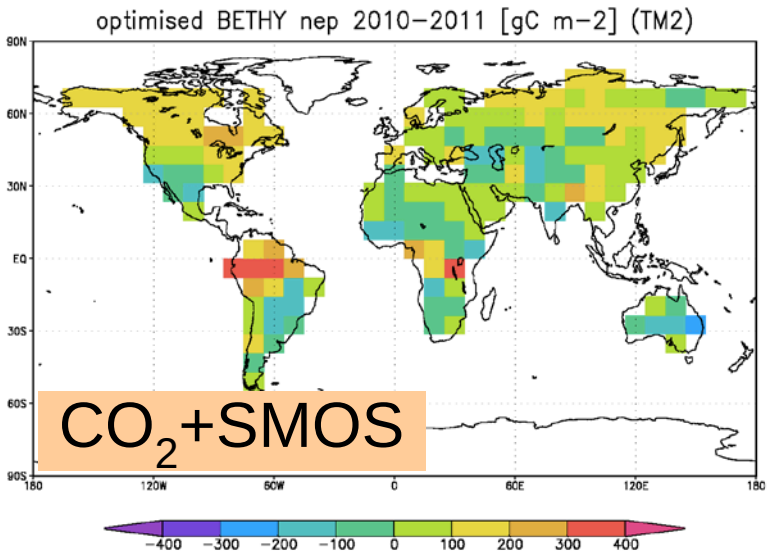
All stations:

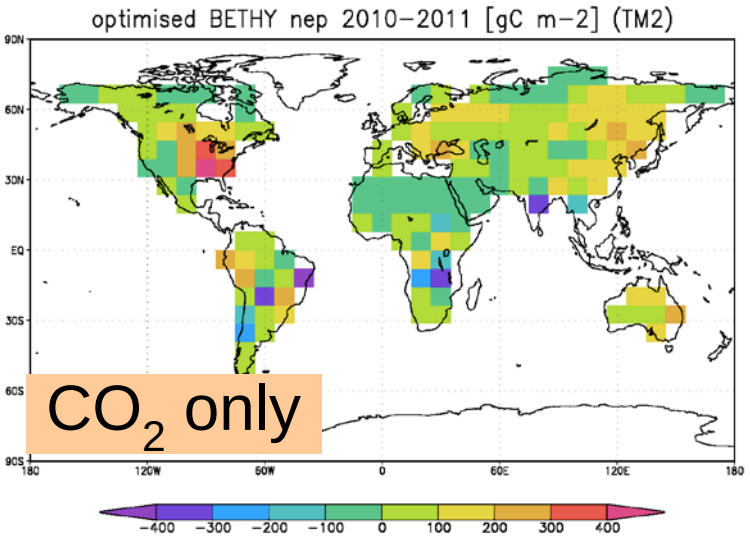
SM record	RMSE *cdf* (m^3/m^3)	R *cdf* (-)
VIC OL	0.058	0.549
VIC DA *mean*	0.045	0.713
VIC DA *var*	0.048	0.677
VIC DA *cdf*	0.048	0.686

SMOS adds skill to the soil moisture analysis. Assimilating SMOS improves stream flow prediction.

NET ECOSYSTEM EXCHANGE
IMPACT ON NEP





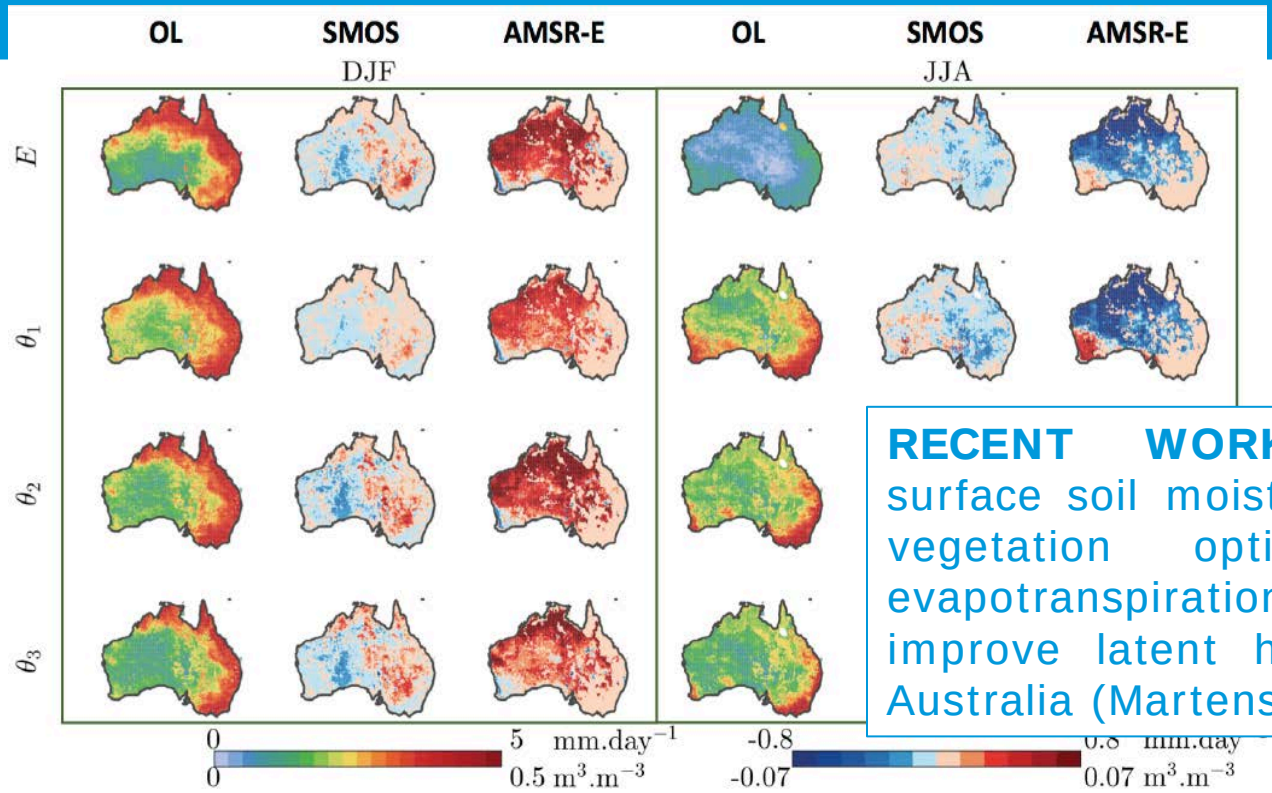


Credit: T.Kaminski et al, 2015

Impact of SMOS: better water balance in models and maintaining the skill of atmospheric CO2 analysis, detectable differences in carbon fluxes

RECENT WORK: Assimilating SMOS surface soil moisture into a carbon assimilation scheme built around a terrestrial biosphere model was found to improve global CO_2 flux estimates (Scholze et al., RSE special issue on SMOS, 2016).

EVAPOTRANPIRATION



RECENT WORK: Assimilating SMOS surface soil moisture and AMSR-E derived vegetation optical depth into an evapotranspiration model was found to improve latent heat flux estimates over Australia (Martens et al., 2015).

Conclusions

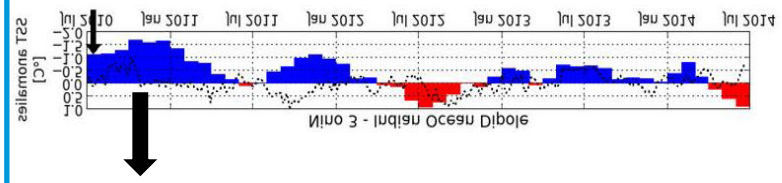
- ✓ SMOS assimilation leads to **better root-zone soil moisture** in GLEAM
- ✓ Difficult to assess the **impact on evaporation** due to ground data scarcity
- ✓ Performance of **SMOS observations higher than AMSR-E** over Australia
- ✓ A constant quality factor and simple algorithm appears to perform well

Miralles et al., 2015

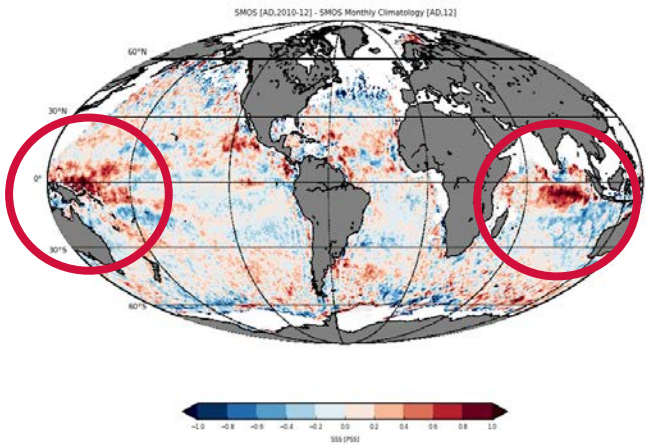
SMOS DATA POTENTIAL FOR CLIMATE CHANGE

Mission objective (extension phase) - SMOS brightness temperatures, soil moisture, and ocean salinity observations shall be analyzed with respect to geophysical processes related to the water cycle occurring on time scales exceeding the nominal mission lifetime of 3 (5) years. → **on-going.**

Detecting El Niño / La Niña



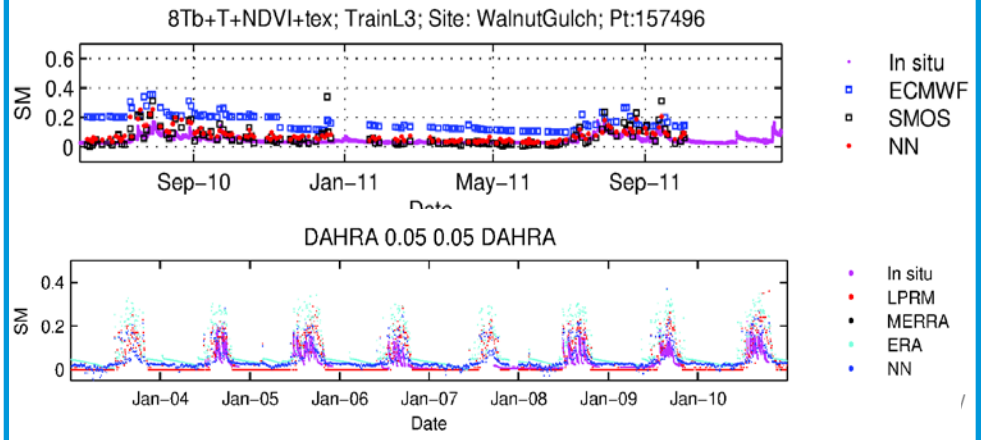
December 2010: La Niña



Credit: LOCEAN

Creating long-term data sets

TOP: Training neural network on SMOS L2 soil moisture data and using AMSR-E brightness temperatures as input. **BOTTOM**: Applying trained neural network to AMSR-E data retrospectively. Credit: CESBIO



SMOS FOLLOW-ON & L-BAND CONTINUITY

REQUIREMENTS COLLECTION FROM THE SCIENCE/OPERATIONAL COMMUNITY

- Recommendations from science workshops indicate clear need for L-Band continuity (Living Planet, SMOS-Aquarius WS etc)
- ISSI forum on "Continuity of microwave observations in L-band for operational and climate applications"
- Regular interaction with EUMETSAT community

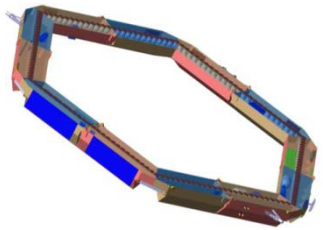
INTERNATIONAL COLLABORATION

- Close collaboration with the counterpart L-Band missions: Aquarius and SMAP teams
- CEOS virtual constellation

Way forward towards L-Band continuity to be identified over coming years

PREPARING MISSION CONCEPTS

- SMOS follow-on concept: SMOSOps and SUPER MIRAS (ESA led)
- SMOS NEXT (CNES led)
- STSE study on concept for future water cycle mission



SMOS CONTRIBUTING TO ECVS

Soil moisture and ocean salinity have been defined as Essential Climate Variables (ECV) by GCOS in its second Adequacy Report to the UN Framework Convention on Climate Change (UNFCCC) on the global climate observing systems

BUILDING UP OPERATIONAL USER COMMUNITY

- Operational application for SMOS data in NWP (ECMWF, proven) and hydrological forecasting (on-going), working with WMO
- Availability of SMOS L1 data in NRT
- Two new data products for operational applications: sea ice thickness (available since 2014) and L2 soil moisture NRT data product to be released in July
- New or further operational data products: vegetation, hurricane tracking, freeze/thaw etc

MAIN MESSAGES

- ESA's SMOS mission provides global observations of brightness temperature, soil moisture and ocean salinity since 2009 supporting a wide range of scientific and operational applications.
- Data products are available in near-real time: brightness temperatures and soil moisture.
- New products include:
  - *Sea ice thickness*
  - *Soil moisture in NRT based in NN*
  - *Severe winds over ocean*
  - *Vegetation Optical Depth*
  - *Freeze and thaw*
- SMOS data (TB, SM) have been assimilated for
  - *NWP*
  - *Stream flow prediction*
  - *Net Ecosystem Exchange*
  - *Evapotranspiration/latent heat flux*
- A variety of operational applications can be addressed with SMOS data: NWP, flood prediction, drought and forest fire monitoring, food security, ship routing, severe wind tracking.
- SMOS operations have been extended to 2017 by both ESA and CNES.
- SMOS is in excellent technical conditions, with high data availability (~99%). No technical limits exist to operate the mission beyond 2017.
- **Summary of mission performance, recent scientific results, new product and application in RSE special issue on SMOS, to be released April 2016.**

THANK YOU

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