

# Soil Moisture and Ocean Salinity High Resolution (SMOS-HR) mission

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Equipe Projet



- (1) CESBIO, Toulouse, France
- (2) LOCEAN, Paris, France
- (3) IGE, Grenoble, France
- (4) CNES, Toulouse, France
- (6) Airbus DS, Toulouse, France
- (7) LEGOS, Toulouse, France
- (8) LOPS, Brest, France
- (9) Mercator, Troulouse, France
- (10) Acri-ST, France

Equipe TOSCA



# The SMOS mission



- SMOS was launched in November 2009
- Array of 69 antennas used in interferometric mode to synthesize an aperture of ~7.5 m: **resolution of 25-50 km**
- L-Band (1.4 GHz), full polarization and multi-angular (0-60°)
- Almost 12 years old... we need to prepare a follow-up
- Need of higher spatial resolution for some applications

# Soil moisture applications and users requirements



Table 3

Applications that would benefit from soil moisture information on different spatial scales. The requirements level is indicated from high (+++) to low (+).

	Low spatial resolution ( $\geq 25\text{km}$ )	Medium spatial resolution (10km, 5km)	High spatial resolution ( $\leq 1\text{km}$ )
NWP	++	+++	++
Climate modelling	+++	+++	+
Watershed based runoff modelling	+	+++	++
Precipitation/ Evapotranspiration estimation	+++	+++	+++
Landslide prediction	+	++	+++
Flood forecasting	+	++	+++
Drought monitoring	+++	+++	+++
Precision agriculture		+	+++
Erosion modelling		+	+++



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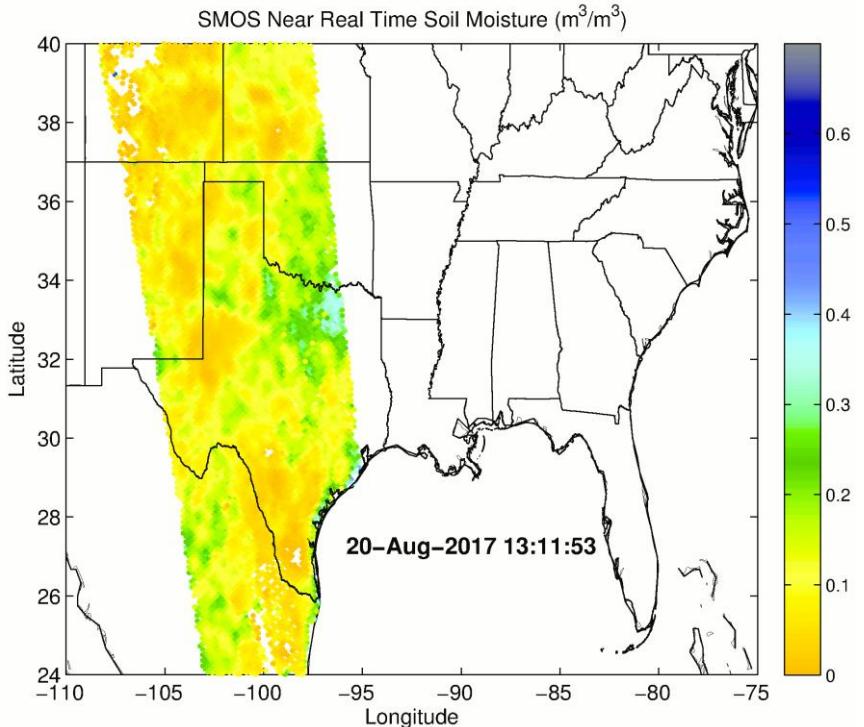
journal homepage: [www.elsevier.com/locate/rse](http://www.elsevier.com/locate/rse)

Review

A roadmap for high-resolution satellite soil moisture applications – confronting product characteristics with user requirements

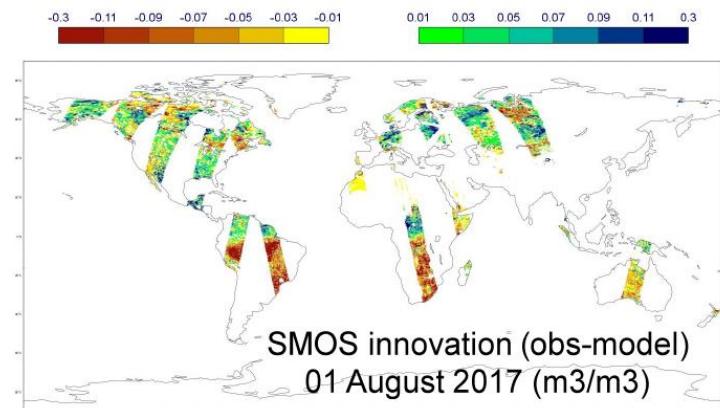
Jian Peng <sup>a,b,c,\*</sup>, Clement Albergel <sup>d,1</sup>, Anna Balenzano <sup>e</sup>, Luca Brocca <sup>f</sup>, Oliver Cartus <sup>g</sup>, Michael H. Cosh <sup>h</sup>, Wade T. Crow <sup>h</sup>, Katarzyna Dabrowska-Zielinska <sup>i</sup>, Simon Dadson <sup>c,j</sup>, Malcolm W.J. Davidson <sup>k</sup>, Patricia de Rosnay <sup>l</sup>, Wouter Dorigo <sup>m</sup>, Alexander Gruber <sup>n</sup>, Stefan Hagemann <sup>o</sup>, Martin Hirschi <sup>p</sup>, Yann H. Kerr <sup>q</sup>, Francesco Lovergine <sup>e</sup>, Miguel D. Mahecha <sup>b</sup>, Philip Marzahn <sup>r</sup>, Francesco Mattia <sup>e</sup>, Jan Pawel Musial <sup>i</sup>, Swantje Preuschmann <sup>s</sup>, Rolf H. Reichle <sup>t</sup>, Giuseppe Satalino <sup>e</sup>, Martyn Silgram <sup>u,2</sup>, Peter M. van Bodegom <sup>v</sup>, Niko E.C. Verhoest <sup>w</sup>, Wolfgang Wagner <sup>m</sup>, Jeffrey P. Walker <sup>x</sup>, Urs Wegmüller <sup>g</sup>, Alexander Loew <sup>r,3</sup>

# Soil Moisture in Near Real-Time and Numerical Weather Prediction



Harvey effects using the ESA NRT product  
(Rodriguez-Fernandez et al. (2017, HESS))

- **SMOS neural network SM assimilation at ECMWF operational since 2019**
  - *De Rosnay et al. (2018, IGARSS), Rodriguez-Fernandez et al. (2019, Rem. Sens.)*
- **Global state-of-the-art forecasts are already running at 9 km ...**



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Flood forecasting	+	++	+++
Drought monitoring	+++	+++	+++
Precision agriculture		+	+++
Erosion modelling		+	+++



**soil moisture**

**cci**



**SCO**

**SPACE CLIMATE OBSERVATORY**



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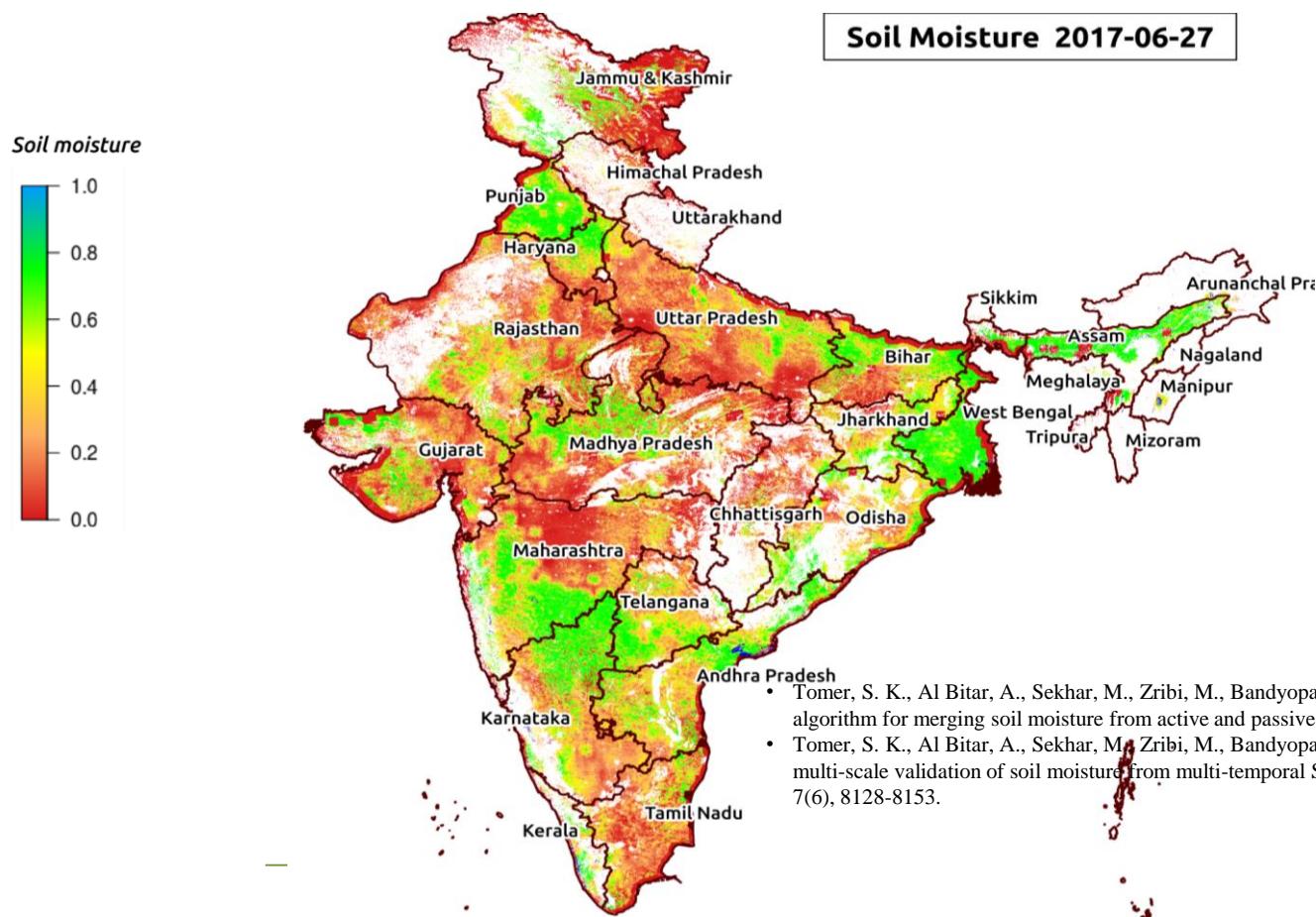
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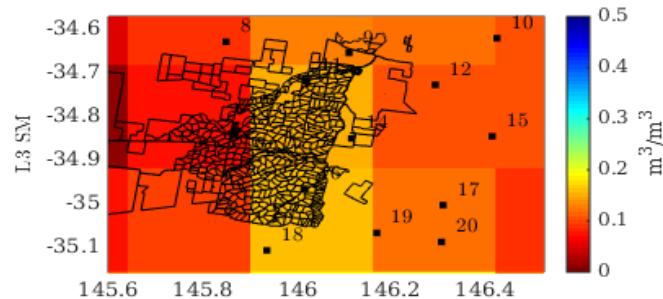
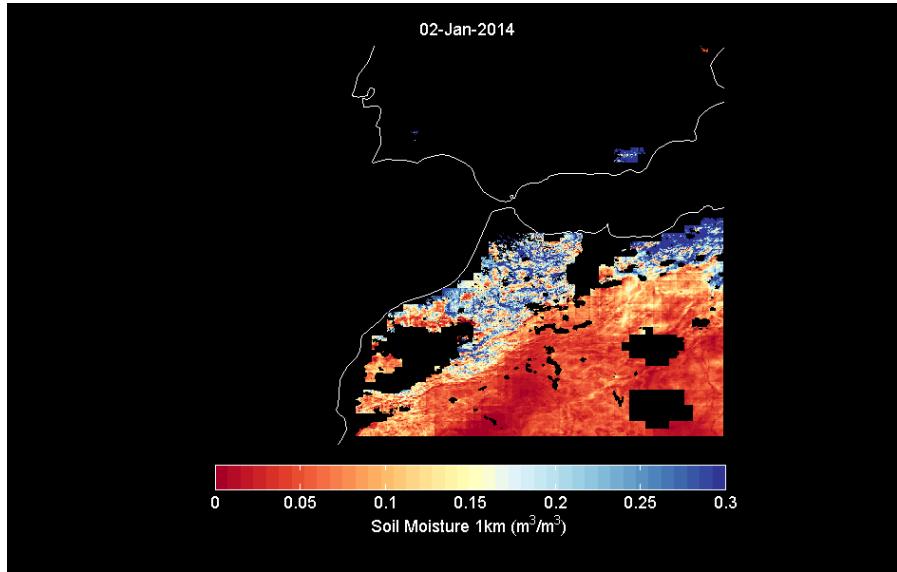
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# MAPSM SMOS+S1 500 m



- Tomer, S. K., Al Bitar, A., Sekhar, M., Zribi, M., Bandyopadhyay, S., & Kerr, Y. (2016). MAPSM: A spatio-temporal algorithm for merging soil moisture from active and passive microwave remote sensing. *Remote Sensing*, 8(12), 990.
- Tomer, S. K., Al Bitar, A., Sekhar, M., Zribi, M., Bandyopadhyay, S., Sreelash, K., ... & Kerr, Y. (2015). Retrieval and multi-scale validation of soil moisture from multi-temporal SAR data in a semi-arid tropical region. *Remote Sensing*, 7(6), 8128-8153.

# SMOS & Dispatch : SM at 1 km

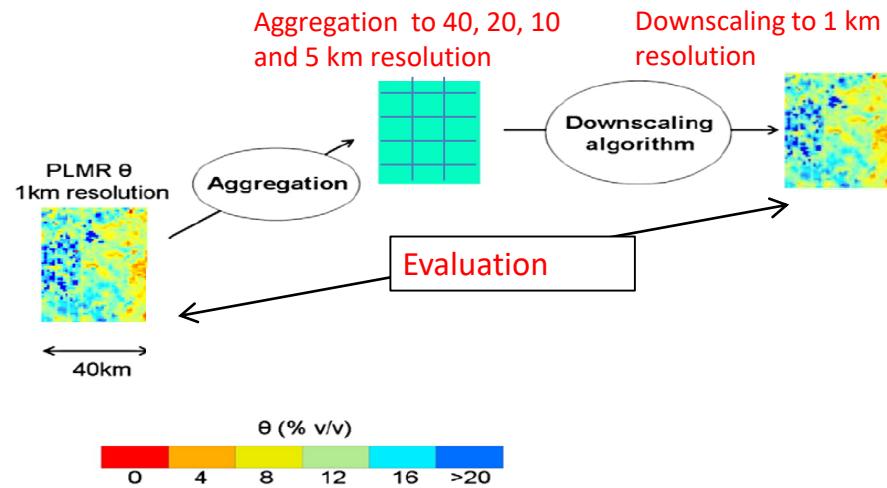


Merlin, Molero et al

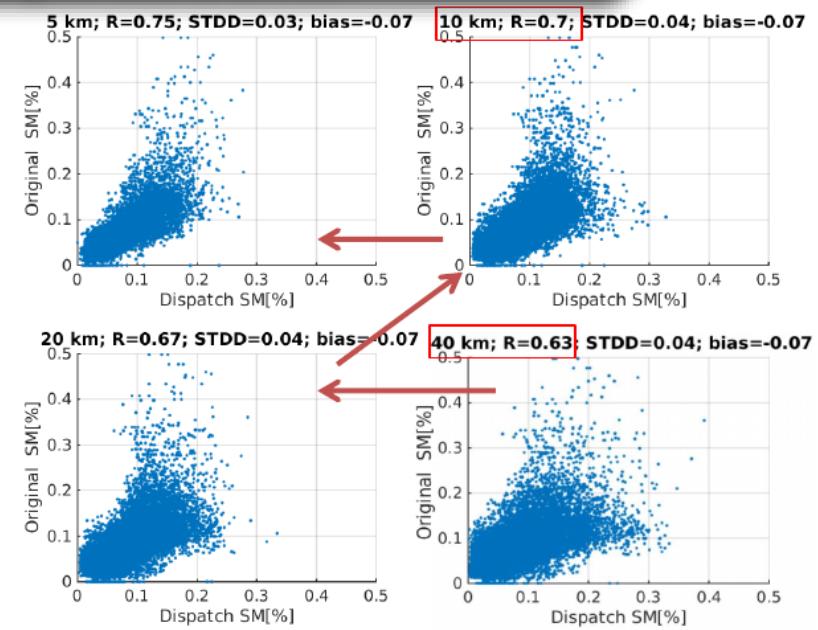
# Native resolution counts, also for downscaling !



- L-band brightness temperature from the National Airborne Field Experiment 2006 (NAFE'06) over the Yanco site in Australia
- Aggregating NAFE'06 PLMR data to 5, 10, 20 and 40 km
- Downscaling to 1 km using MODIS data and the DISPATCH algorithm (Merlin et al. 2008, 2010, 2012)
- Evaluate the downscaled data as a function of the initial resolution
- The results are significantly better when the initial resolution goes from 40 to 5 km



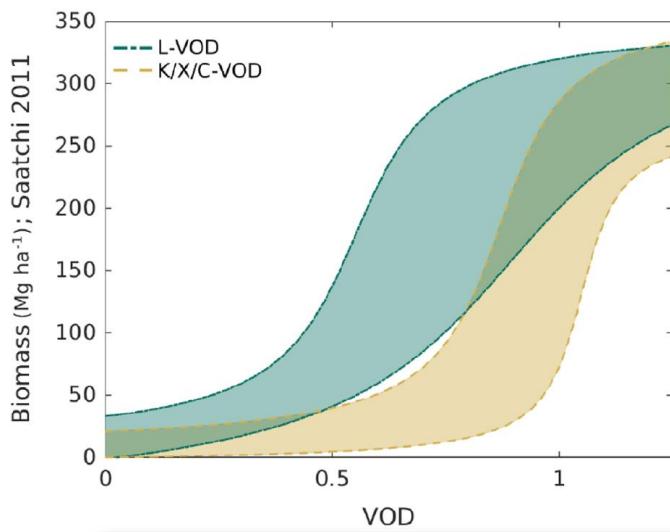
Rodriguez-Fernandez, Merlin et al. *in prep*



# Coupling water and carbon cycles

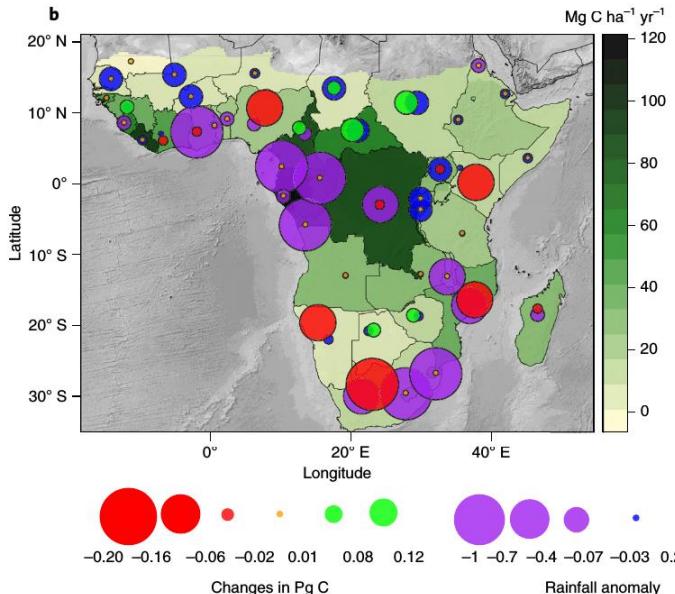


L-band VOD vs AGB relationship  
*Rodriguez-Fernandez et al. (2018, Biogeosciences)*

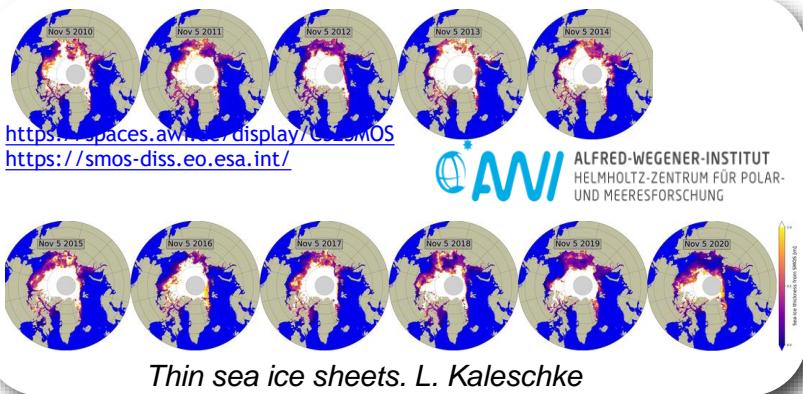


**L-VOD:**  
sensitivity to biomass without saturation

SMOS revisit time allows to study the evolution of C-stocks using L-VOD  
*Brandt et al. (2018, Nature E&Evo)*



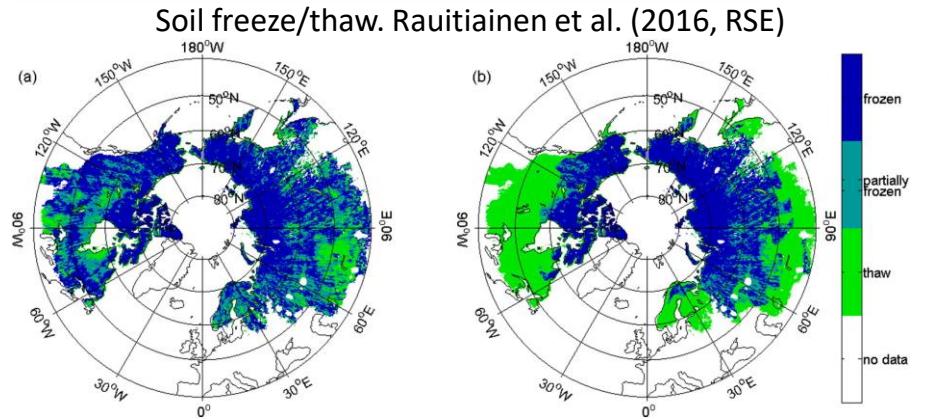
# High resolution L-band is needed to study the cryosphere



<https://spaces.awi.de/display/CSMOS>  
<https://smos-diss.eo.esa.int/>

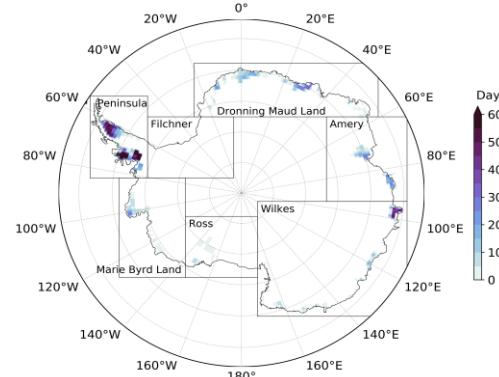
ALFRED-WEGENER-INSTITUT  
HELMHOLTZ-ZENTRUM FÜR POLAR-  
UND MEERESFORSCHUNG

Thin sea ice sheets. L. Kaleschke

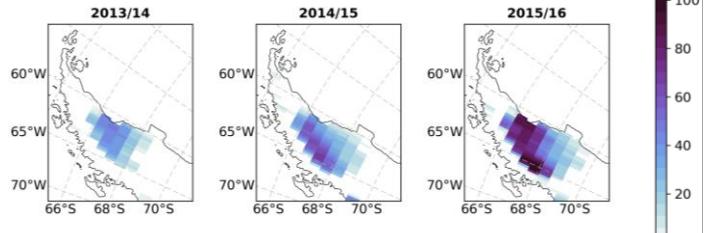


Soil freeze/thaw. Rautiainen et al. (2016, RSE)

Mean annual duration of the melt season between 2010-2019



Example over the Antarctic Peninsula during 3 summer seasons



Leduc-Leballeur et al., 2020,, *The Cryosphere*.

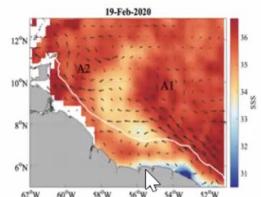
# Higher resolution is also needed for ocean studies



Slide by J. Boutin

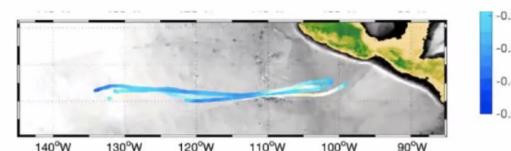
SMOS CATDS maps widely used for studying Sea Surface Salinity (SSS) variability :  
>50 papers in open litterature in 2019-2021 (<https://www.catds.fr/Publications>)

Freshwater plumes



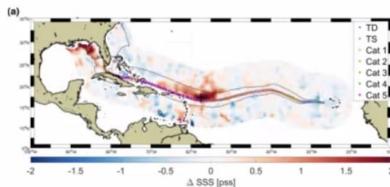
Export of freshwater towards open ocean  
Reverdin et al. 2021

Mesoscale variability



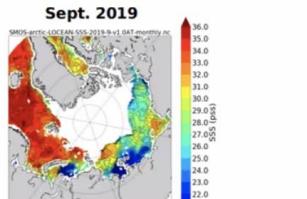
SSS anomalies associated with eddies  
Hasson et al. 2019

Tropical cyclones



Haline wake of cyclones  
Reul et al. 2021

Arctic Ocean



SSS variability in Arctic Ocean  
Supply et al. 2020

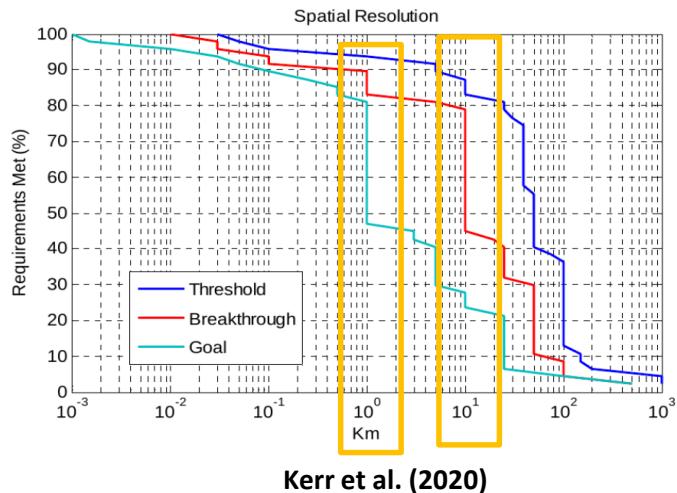
Large scale variability, Data Assimilation, ....

# L-band new generation requirements



- Community-contributed study of land, ocean and cryosphere research and operational applications
- Number of applications increases strongly when the spatial resolution is 10 km (breakthrough) or 1 km (goal)

- Temporal sampling (revisit) <3 days
- Sensitivity ~1 K



# SMOS and follow-ups



1<sup>st</sup> generation

## SMOS

Launched in 2009

Resolution 40km

Sensitivity 2K

69 antennae

3 6 m arms



2<sup>nd</sup> generation

## SMOS-HR

Phase 0 successfully finished (2019)

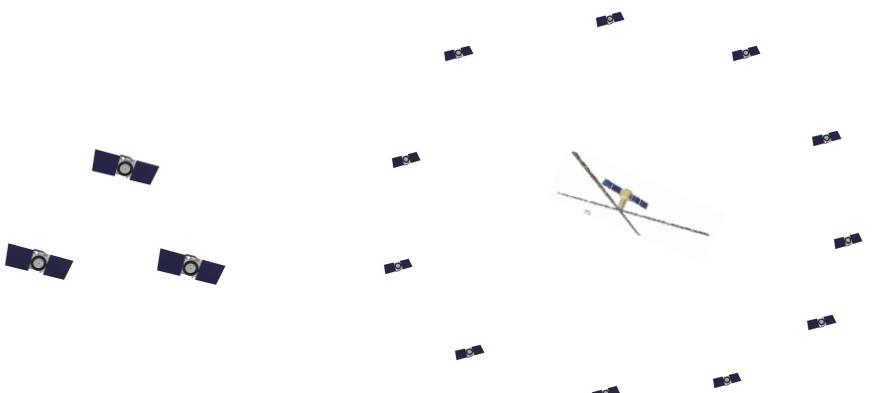
Phase A started end of 2020

Resolution 10-15 km

Sensitivity 2K

~200 antennae

~10 m long arms



## ULID

Bridging phase (2020-2021)

Demonstrator, Not products

3 antennae

Not connected and formation flying

3<sup>rd</sup> generation

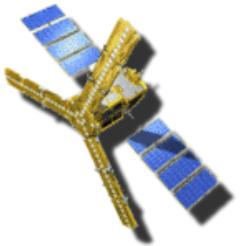
## SMOS-Next

Resolution 4km

Sensitivity 2K

Hub SMOS-HR like satellite  
and > 50 nano-satellites ULID like

# SMOS-HR concept at the end of the Phase 0 study

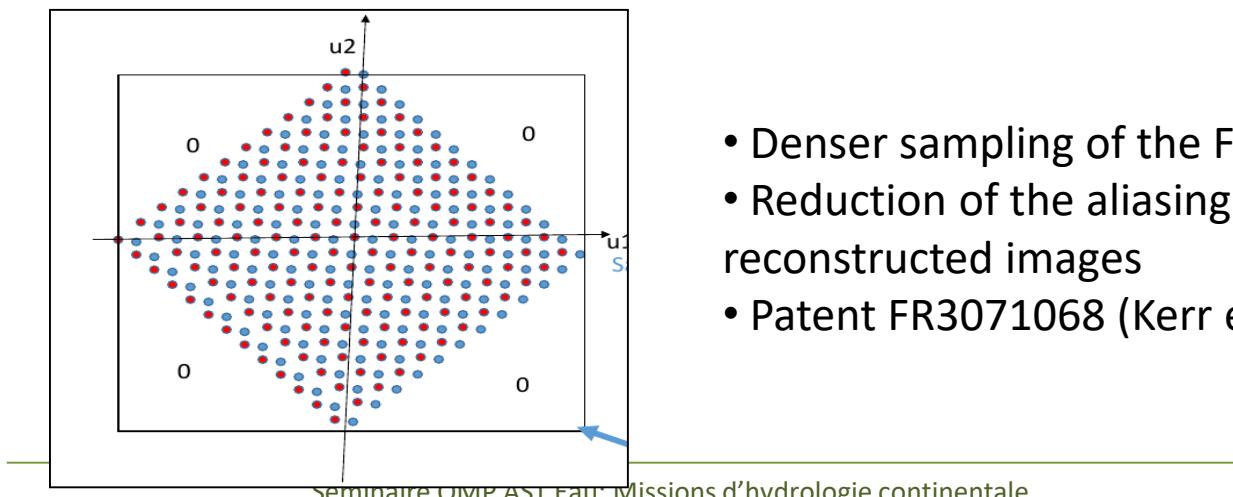
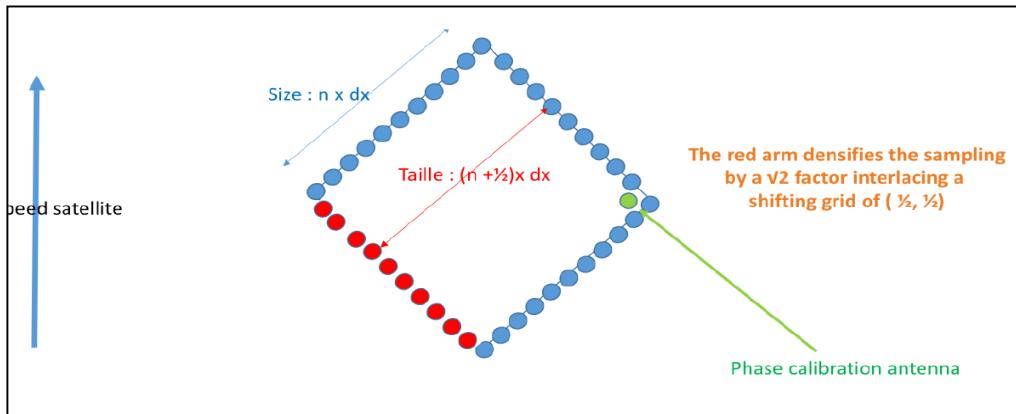


**Phase 0 study completed in 2019 at CNES by CESBIO and AIRBUS Defence and Space**

- **A resolution of 10 km at L-band implies an antennas of 17 meters size**
- **Aperture synthesis:**
  - **Array configuration: a four arms cross with 12 meters arms (with 231 antennas)**
- **Cartesian grid sampling that allow to implement a patented method to increase the spatial frequency sampling density (patented concept, Kerr et al. 2019)**

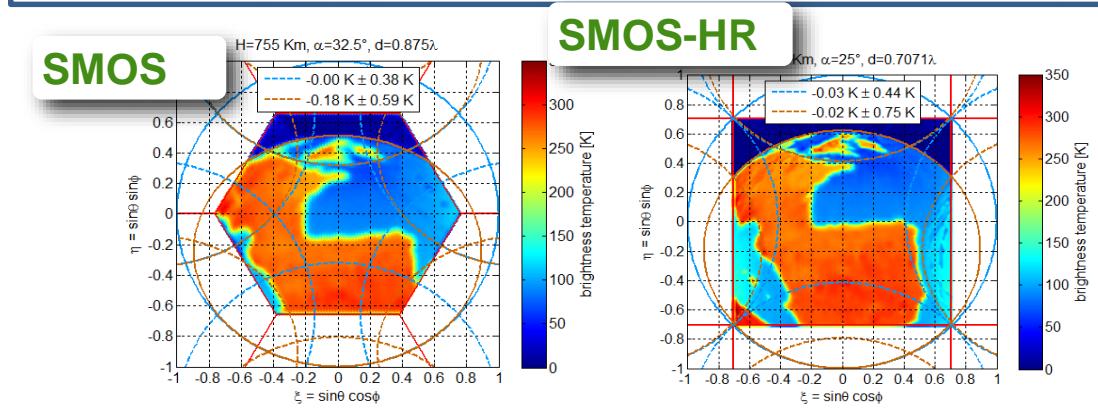
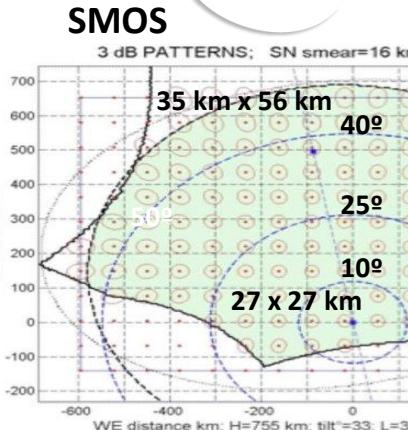
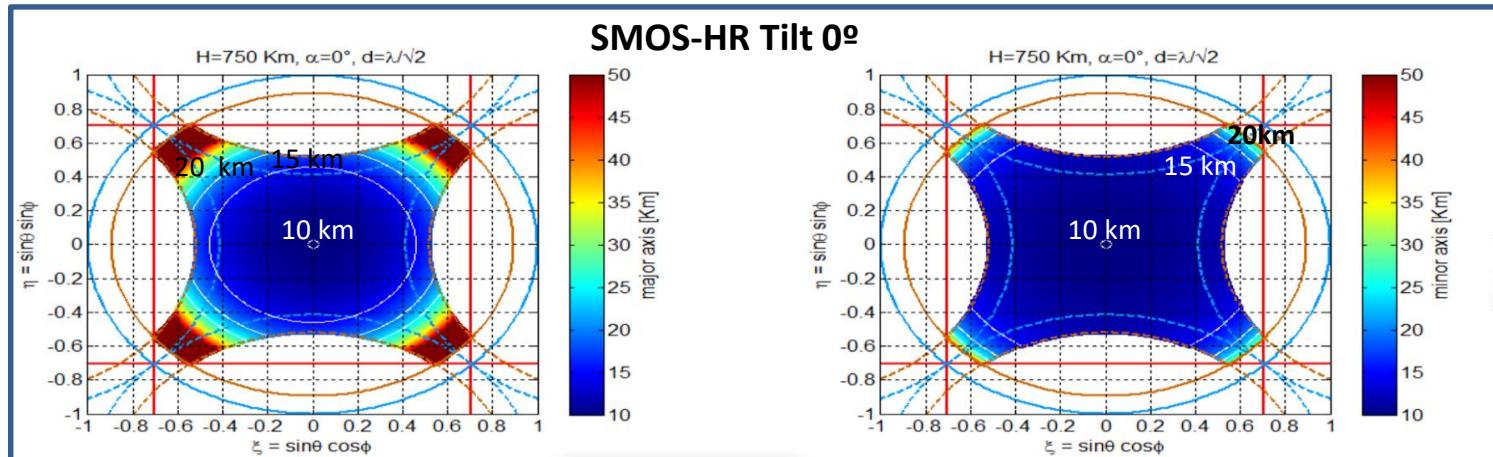
**Currently starting the Phase A study at CNES**

# SMOS vs SMOS-HR: reducing the aliasing



- Denser sampling of the Fourier plane
- Reduction of the aliasing in reconstructed images
- Patent FR3071068 (Kerr et al. 2019)

# Reconstruction algorithms



Waldteufel et al. 2004

Anterrieu et al. *in prep*

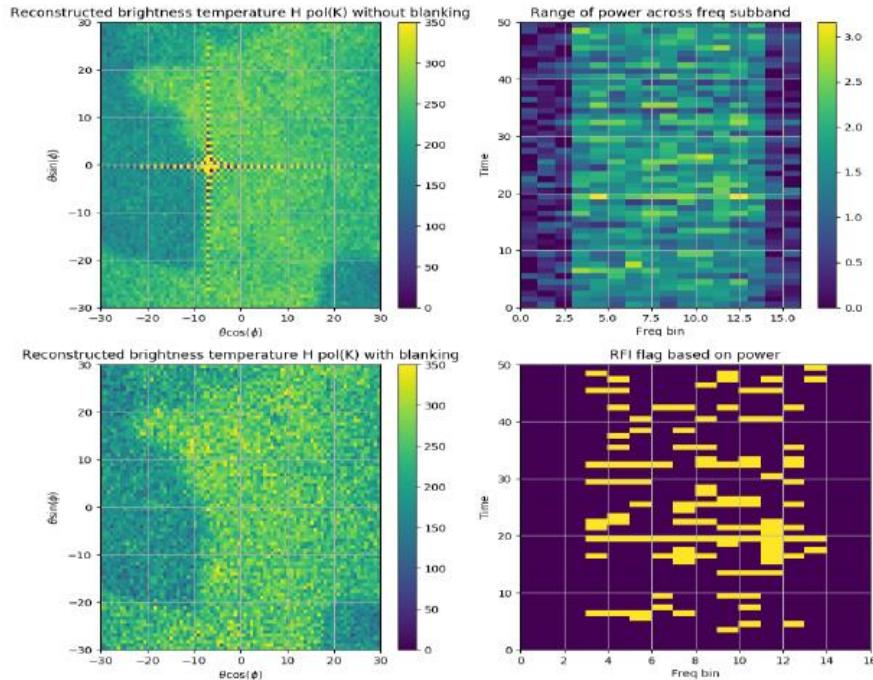
# Advanced RFI mitigation



Radio frequency interference, human-made emission, even in protected bands



## RFI detection and handling



Jeannin et al.



# SMOS-HR versus SMOS

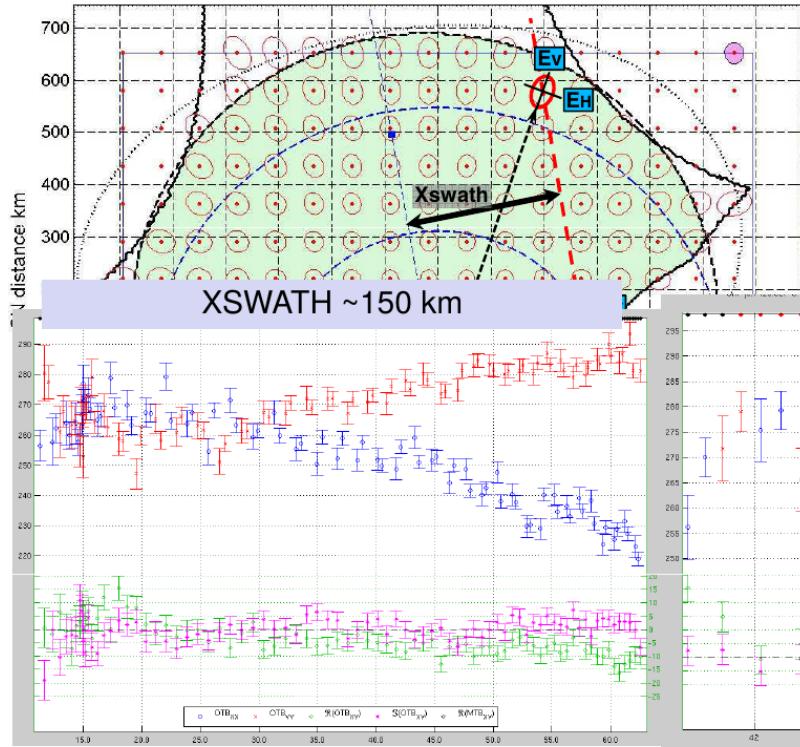


Parameter	SMOS	SMOS-HR
Array shape	Y-shape 4.5 m arms	Square-shape 12 m side, 8.48 m half diagonal
Longest baseline	7.7 meters	17 meters
Resolution after apodisation	27-50 km	10-15 km
Number of antennas/baselines	69/2346	231/26565
Antenna spacing / visibilities sampling	$0.875 \lambda / 0.875 \lambda$	<b><math>1 \lambda / 0.7 \lambda</math></b>
Effective swath/revisit time	~ 1150 km / 3 days max	920 km / 3 days max
Incidence angle range	0-60°	0-40° (tilt 0°) / 0-60° (tilt 25°)
Polarization	full-pol, alternative acquisitions	<b>Full-pol simultaneous acquisitions</b>
Sub-bands/RFI filtering at instrument level	1 / No	<b>Many/yes</b>
Quantization/Effective integration time	1 bit / 0.7 x integration time	<b>several bits / ~ integration time</b>
Radiometric sensitivity for a single snapshot	1.5 K	2 K
Radiometric sensitivity for geophysical retrievals	< 1 K	< 1 K

# Many observations of a footprint in subsequent snapshots



## The SMOS observation system



Each 1.2s a snapshot is taken and form an image of BT pixels having a surface size.



Non uniform surfaces are observed  
BTs include variable fractions of  
different types of emissions weighted  
by the antenna pattern

These "pixels" are however a bit unusual:  
XSWATH ~580 km

P. Richaume

## New concept and how they fit the requirements

- The colour code is red below 33%, orange between 33 and 50% and green above 50%.

Table 3: description of how the different mission fulfil the users' requirements ¶

Mission	Spatial resolution			Revisit			Radiometric accuracy					
	km	% req satisfied	days	% req satisfied	K	% req satisfied						
	T	B	G		T	B	G		T	B	G	
SMOS/SMAP	40	75	31	6	3	78	53	28	1	62	43	32
CIMR	65	38	10	5	1	95	85	70	0.1	90	69	66
Hexagon	25	81	35	20	3	78	53	28	0.5	71	60	38
SMOS-HR	10	87	80	25	3	78	53	28	0.5	71	60	38

Table 3 depicts the different mission (with SMOS-SMAP as a kind of yardstick) and how they fulfil the users' requirements as depicted in Figure 3 to Figure 5. For each category the first column corresponds to the expected actual values and the following three the Threshold (T), breakthrough (B) and goal (G) degree of satisfaction. ¶

# Summary



- **SMOS** is almost 12 year old. Working well but a follow up should be prepared
- **SMOS-HR** is a SMOS follow-up project at CNES
  - Phase 0 study was successfully completed in 2019 at CNES by CESBIO and AIRBUS Defence and Space
  - Phase A just started
  - The goal is to ensure the continuity of L-band observations while increasing the spatial resolution by at least a factor of 2 ... while preserving or improving the radiometric sensitivity

