The continuity of L-band observations with an increased spatial resolution: the SMOS-HR concept

N. Rodriguez-Fernandez (1), E. Anterrieu (1), J. Boutin (2), G. Picard (3), T. Pellarin (3), J. Vialard (2), F. Vivier (2), A. Al Bitar (1), P. Richaume (1), A. Mialon (1), T. Amiot (4), C. Cheymol (4), T. Decoopman (5), A. Kallel (5), Y.H. Kerr (1)

(1) CESBIO, Toulouse, France
(2) LOCEAN, Paris, France
(3) IGE, Grenoble, France
(4) CNES, Toulouse, France
(5) Airbus Defence and Space, Toulouse, France

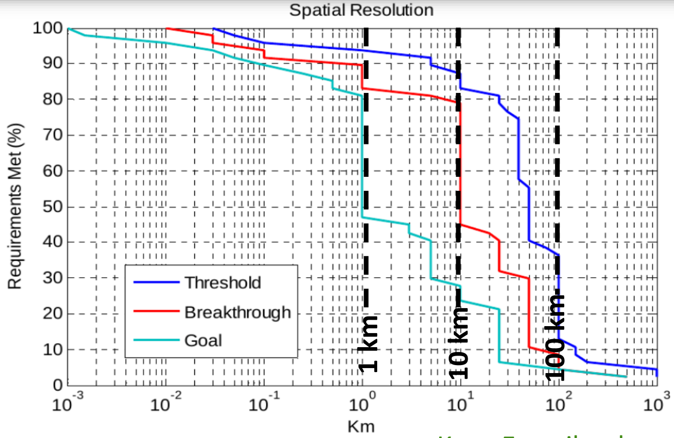
SMOS and L-band observations

- **SMOS** (2009-)
  - Synthetic aperture of ~7.5 m: **resolution of 25-50 km**
  - **Multi-angular (0-60º)**

    → simultaneous estimation of soil moisture and **vegetation optical depth (biomass)**
- Other L-band missions
  - SMAP (2015-), Aquarius (2011-2015)
- Large number of applications beyond soil moisture and ocean salinity

Community study of land, ocean and cryosphere research and operational applications (ESA funded)

- 10 km will be a breakthrough for many applications while 1 km will be the ideal value
- Temporal sampling < 3 days

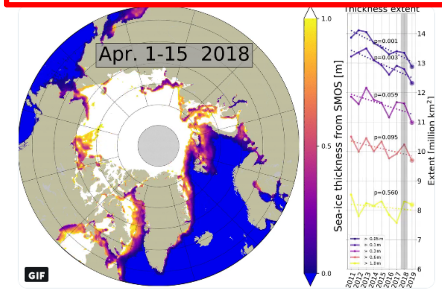


Kerr, Escorihuela et al. 2020

SMOS L-band data and the cryosphere

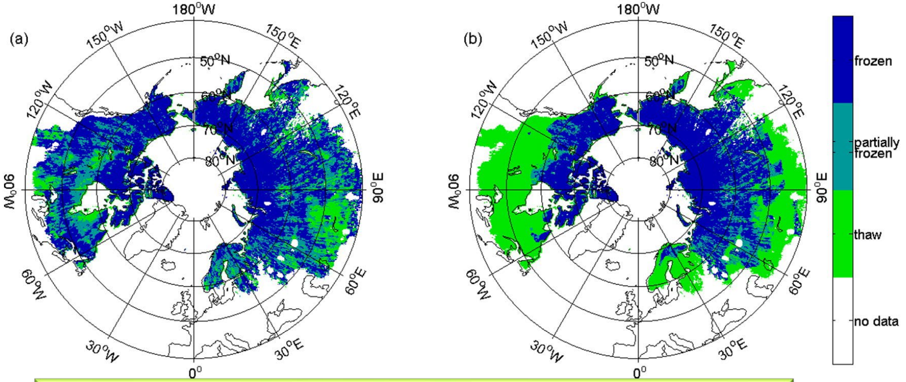
Lars Kaleschke
@seaice_de
Following

ESA's Soil Moisture and Ocean Salinity (SMOS) missions objective was not to measure the sea ice thickness but it worked out very well. Now data collected over 9 years clearly shows a trend in Arctic sea ice extent while the area covered with ice >1m has no significant trend.



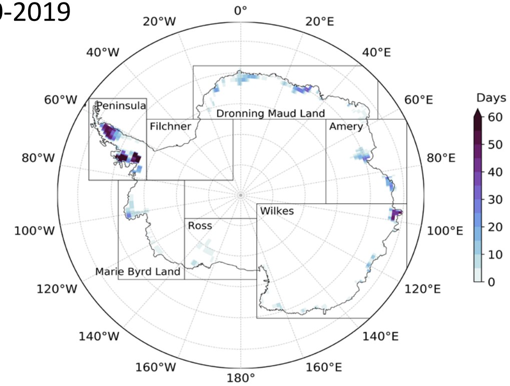
Sea ice contamination in the Arctic affects the estimation of salinity (Supply et al. 2022, RSE)

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

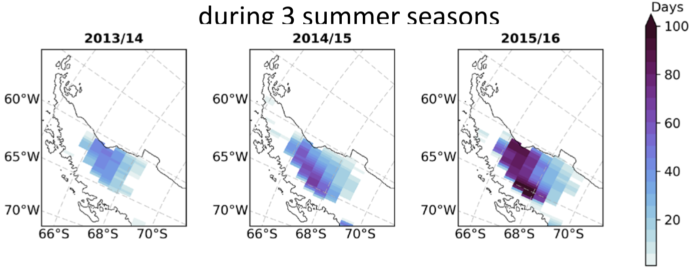


Higher resolution needed (complex land cover)

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 needed to monitor melting events close to the coast

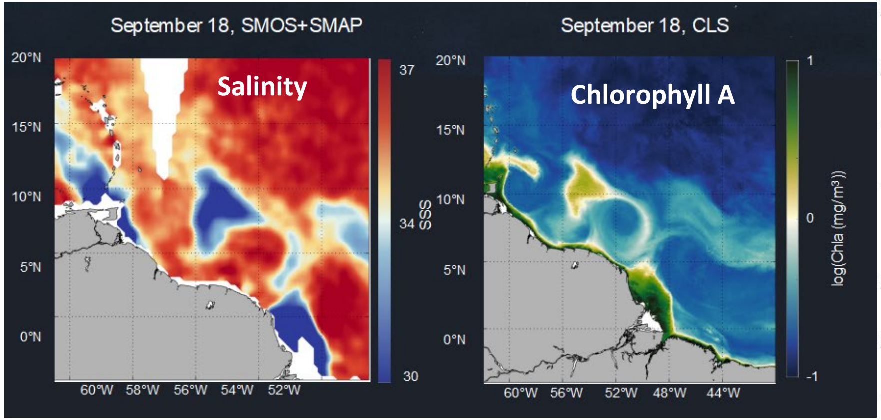
Ocean applications and L-band new generation requirements

Boutin et al. Poster Tuesday 18:20

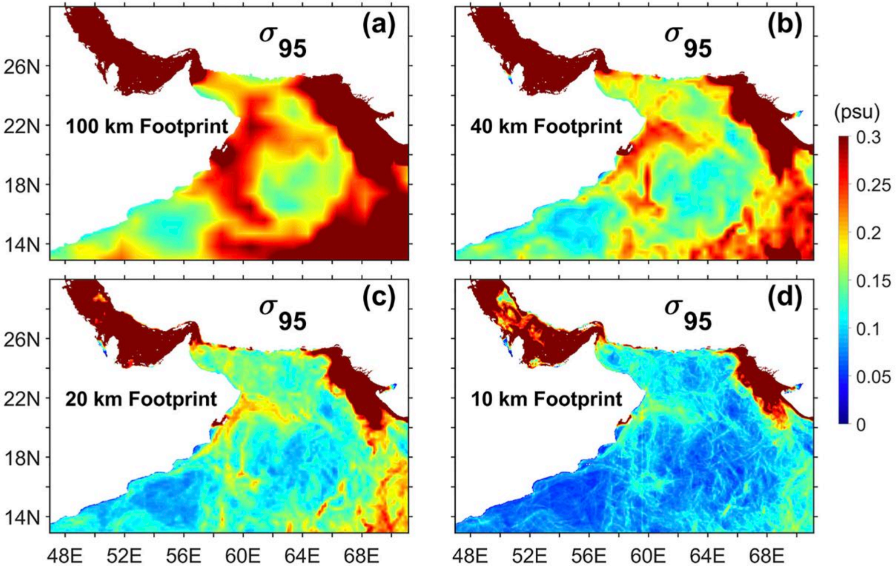
- **High resolution is also needed for ocean studies: river plumes, meso-scale physics, coastal regions, ...**

Salinity spatial variance (D'Addezio et al. 2019, RSE):

70 % for 50 km footprints
85 % for 20 km footprings
95 % for 10 km footprints



Olivier et al. (2022, Biogeosci. Discussions)



Soil moisture and vegetation optical depth applications

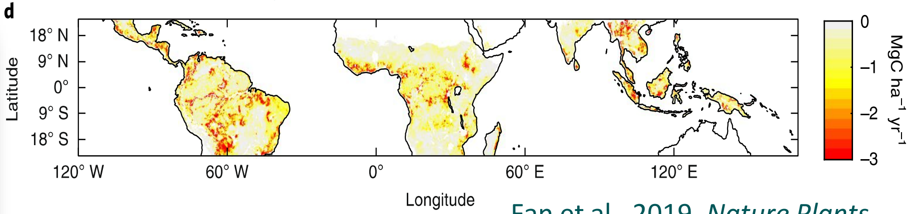
Table 3
Applications that would benefit from soil moisture information on different spatial scales. The requirements level is indicated from high (+++) to low (+).

	Low spatial resolution (≥25km)	Medium spatial resolution (10km, 5km)	High spatial resolution (≤1km)
NWP	++	+++	++
Climate modelling	+++	+++	+
Watershed based runoff modelling	+	+++	++
Precipitation/ Evapotranspiration estimation	+++	+++	+++
Landslide prediction	+	++	+++
Flood forecasting	+	++	+++
Drought monitoring	+++	+++	+++
Precision agriculture		+	+++
Erosion modelling		+	+++

Peng et al. (2021)

- **ECMWF NWP global models resolution: 9 km**

Pantropical carbon stocks evolution



Fan et al., 2019, *Nature Plants*

- L-band observations allow to study the **coupling of the water and carbon cycles** thanks to the vegetation optical depth (VOD)
- **Multi-angular observations** are needed for a proper estimation of VOD
- Spatial resolutions of <10 km will also allow biomass monitoring at regional scale

SMOS, SMOS-HR, SMOS-Next

Multi-angular capabilities + high spatial resolution → large interferometer array

1st generation

SMOS

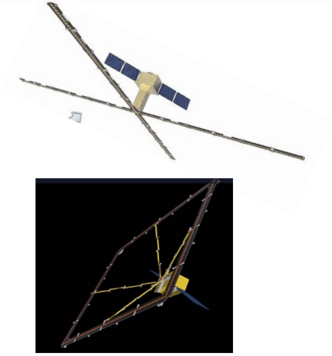
Launched in 2009

Resolution 40km

Sensitivity 2K

69 antennae

Three 4.5 m arms



2nd generation

SMOS-HR

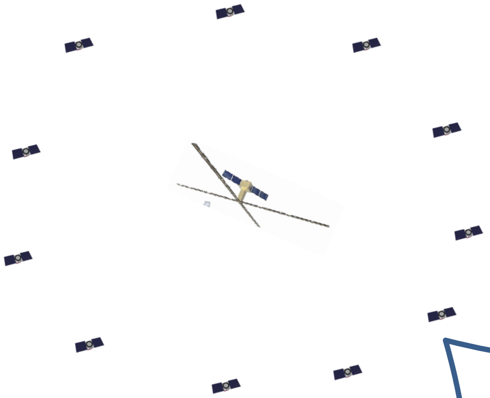
Phase A ongoing

Resolution better than 15 km

Sensitivity 2K

> 200 antennae

Four 8.5 m long arms



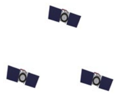
3rd generation

SMOS-Next

Resolution 4km

Sensitivity 2K

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



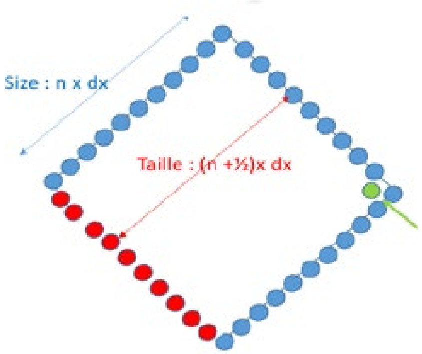
ULID

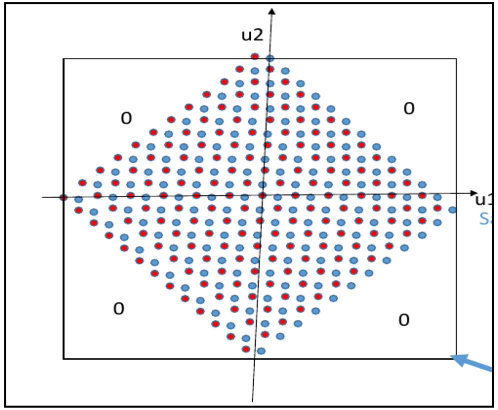
demonstrator

SMOS vs SMOS-HR: reducing the aliasing

- The fourth arm antennae (red) could be redundant …
- … but if the position of the antenna in this arm are modified in a quincunx way the spatial frequencies coverage is improved : interlacing a shifting grid

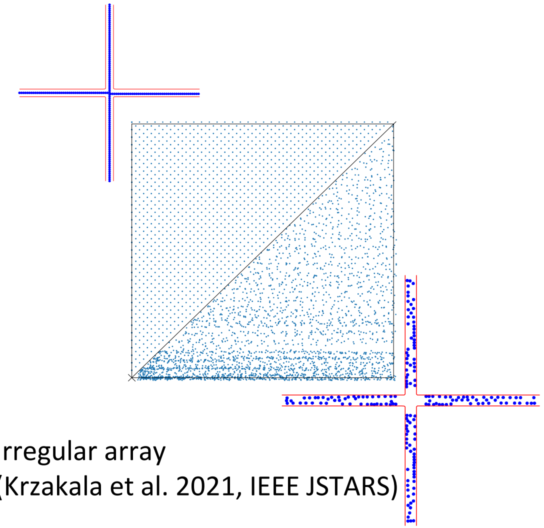
- Reduction of the aliasing in reconstructed images





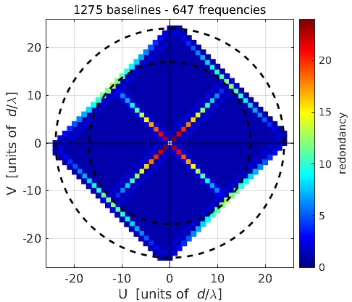
Patent FR3071068 (Kerr et al. 2019)

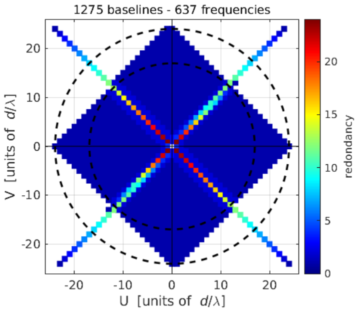
- Complete irregular layouts were also tested
  - Possible to calibrate
  - Would require new imaging algorithms
  - Many constrains for actually building the such a system

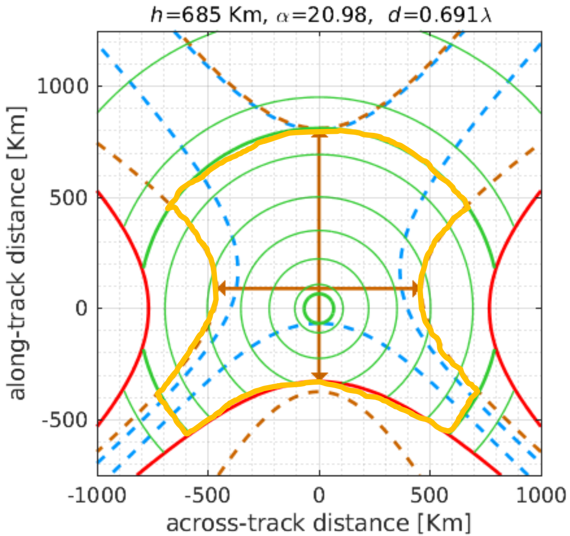


Irregular array
(Krzakala et al. 2021, IEEE JSTARS)

Spatial frequencies sampling and field of view







Earth alias-free field of view for angles < 55º

Antennae power patterns. RFI mitigation

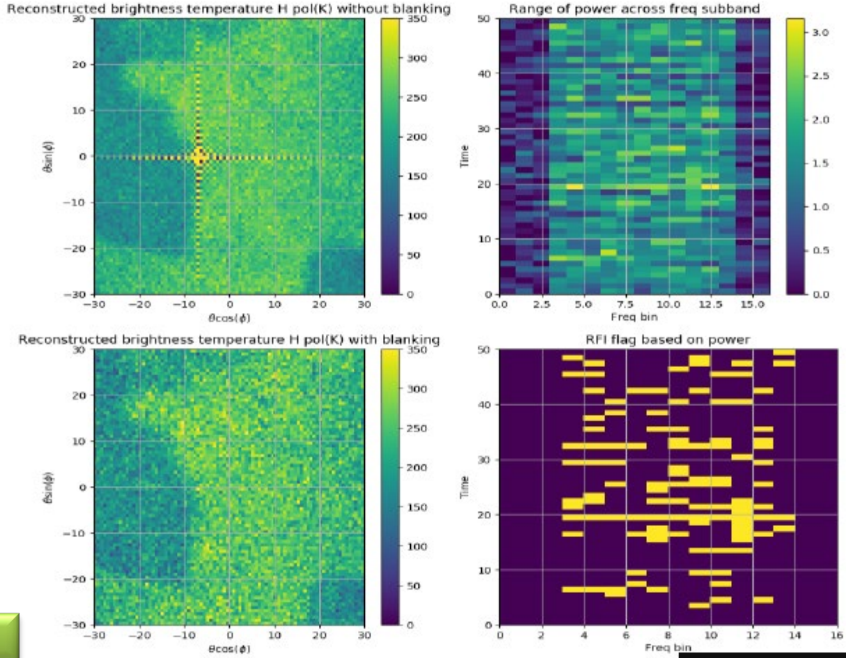
Challenge: similarity of the antenna patterns once they are located in the payload arms close to other antennas

Band width : 21 MHz Jeannin et al.

RFI filtering in 1-1.5 MHz sub bands Patent WO/2021/001408

Image reconstruction in 5 MHz sub-bads

Anterrieu (2021, CESBIO report)



E. Anterrieu (CESBIO), A. Bornaud (CNES),
L. Costes (Airbus DS)

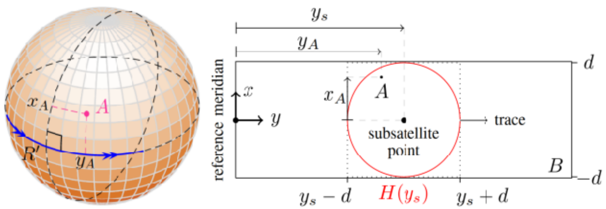
Kallel et al. Poster Tuesday 18:16

SMOS-HR (Phase A) versus SMOS

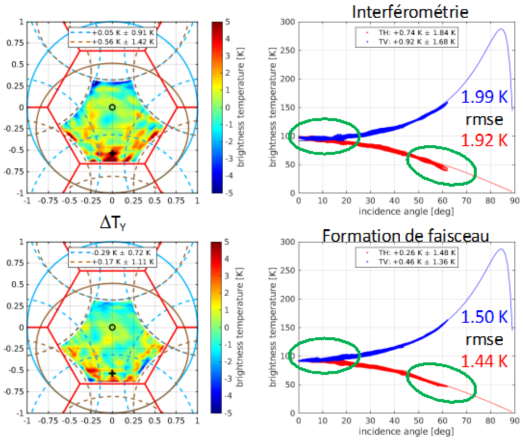
Parameter	SMOS	SMOS-HR
Array shape	Y-shape 4.5 m arms	cross-shape **8.3 m arms**
Longest baseline	7.5 meters	**12 meters**
Orbit height	758 km	680 km
Resolution after apodisation	27-50 km	**15-20 km**
Number of antennas/baselines	69/2346	167/13861
Antenna spacing / visibilities sampling	0.875 λ / 0.875 λ	**0.956 λ / 0.675 λ**
Effective swath/revisit time	1150 km / 3 days max	920 km / 3 days max
Tilt/ Incidence angle range	32.5º / 0-60º	20º / 0-55º
Band / Sub-bands RFI filtering / sub-bands imaging	19 Mhz / - / -	21 MHz / 1-1.5 MHz/ 5 MHz
Polarization	full-pol, alternative acquisitions	**Full-pol simultaneous acquisitions**
Quantization/Correlation/Effective integration time	1 bit / 0.7 x integration time	**8 bits / 2 bits / 0.9 x integration time**
Radiometric sensitivity: single snapshot/geophysical retrievals	3 K / ~ 1 K	1.7 - 3 K / < 1 K

Cheymol et al.
Poster Thursday 18:00

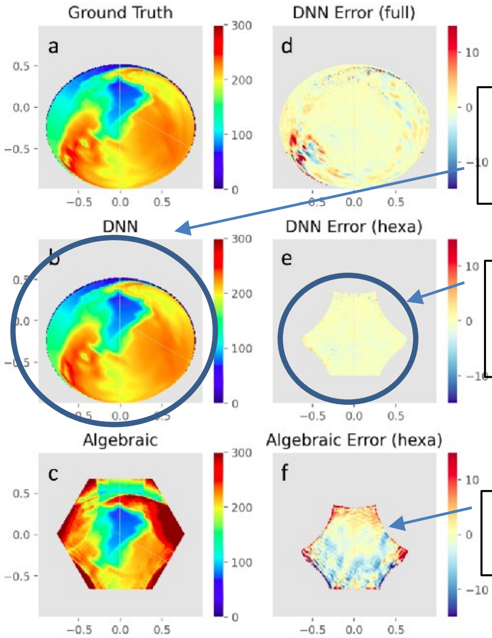
Image reconstruction



Multi-snapshot reconstruction (Dunitz et al. 2021, IEEE CAMA)



Digital beam forming (Anterrieu et al. *2022, Remote Sensing*)



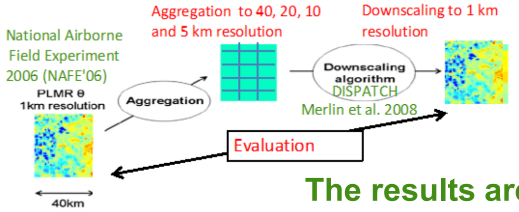
DL: Image with almost no aliasing

DL: less noise in the alias-free region

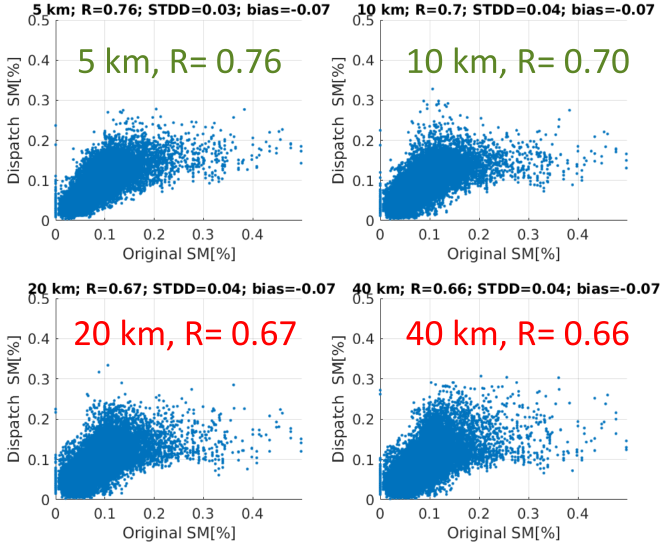
Classical imaging

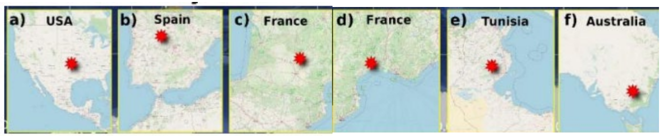
Deep learning
Faucheron et al.
Poster Friday 13:14

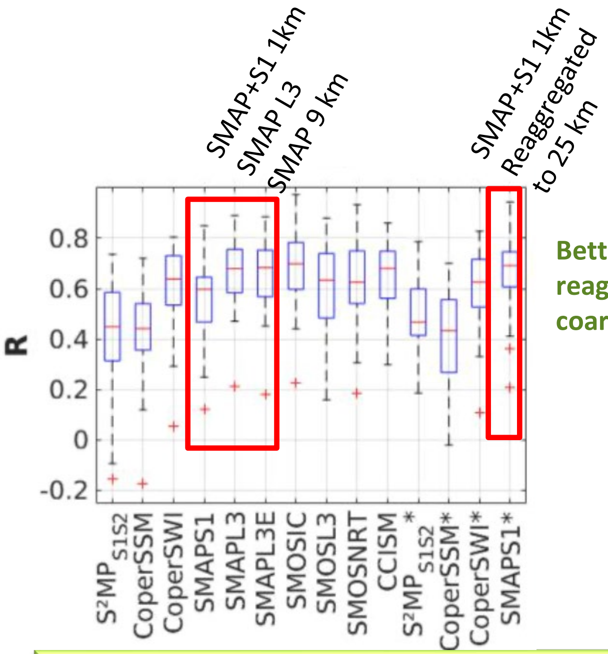
Downscaling or oversampling cannot replace native high resolution



The results are significantly better when the initial resolution goes from 40 to 5 km







Better results when reaggregated to coarse resolution

Madelon et al. Poster Friday 12:48

Rodriguez-Fernandez et al. *in prep*

Summary

- **SMOS is almost 13 year old. Working well but a follow up should be prepared**
- **SMOS-HR is a SMOS follow-up project under Phase A study at CNES**
- **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**