Enhanced spatial resolution of satellite salinity measurements: the SMOS-HR (High Resolution) mission

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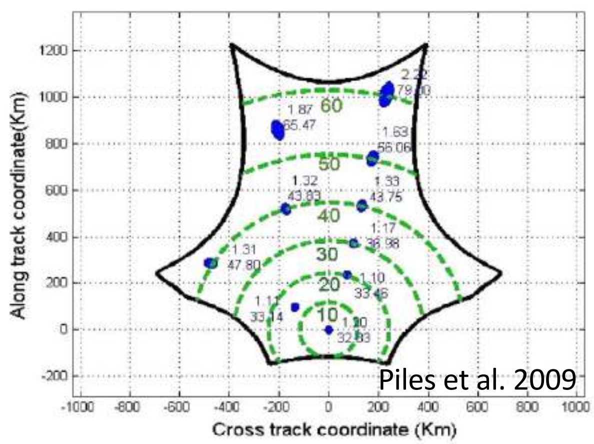
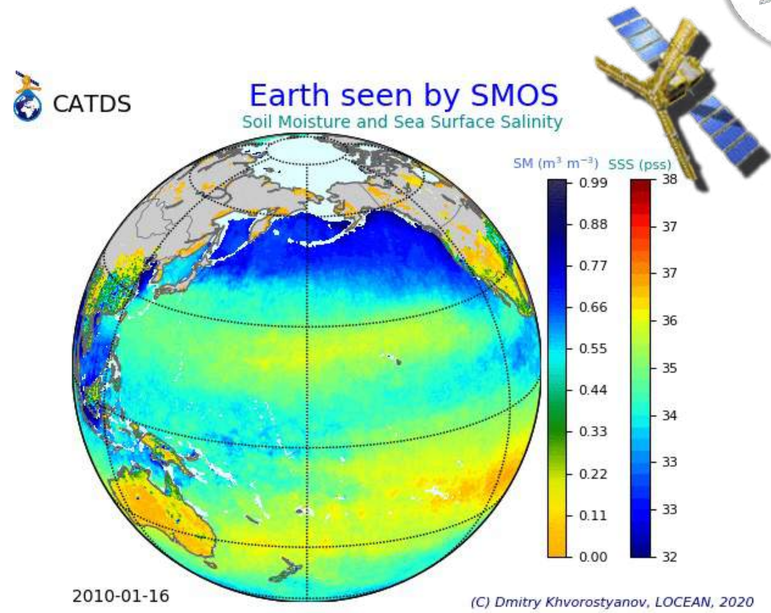
SMOS and L-band observations

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



Piles et al. 2009



- Other L-band missions
  - SMAP (2015-), Aquarius (2011-2015)
- Large number of applications beyond soil moisture and ocean salinity

Soil moisture and vegetation optical depth applications

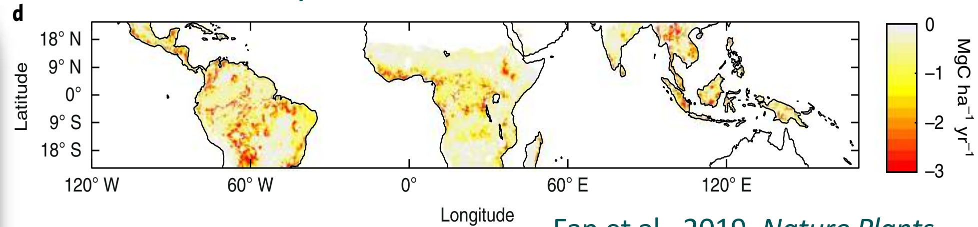
Table 3
Applications that would benefit from soil moisture information on different spatial scales. The requirements level is indicated from high (+++) to low (+).

	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

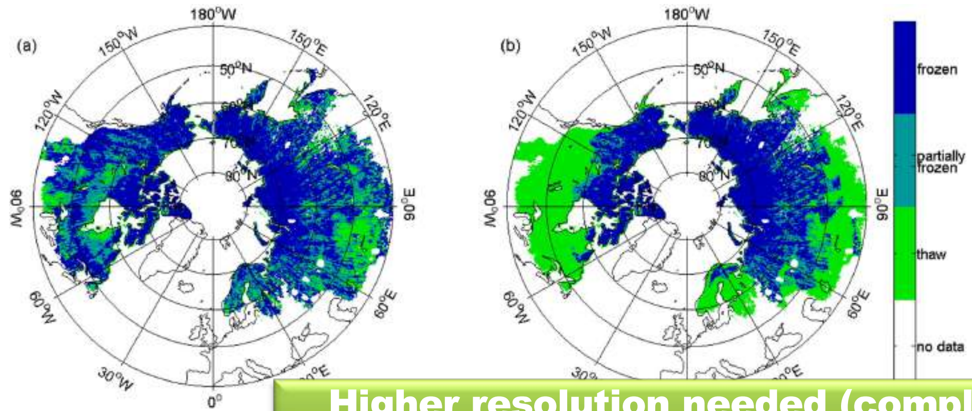


Fan et al., 2019, *Nature Plants*

- 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 L-band data and the cryosphere

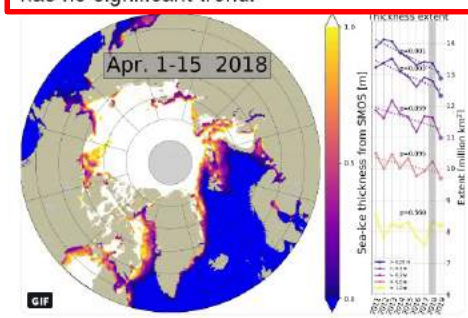
Soil freeze/thaw. Rauitiainen et al. (2016, RSE)



Higher resolution needed (complex land cover)

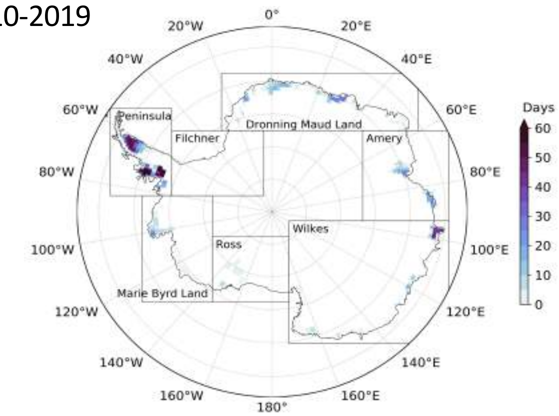
Lars Kaleschke
@seaice_de

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.

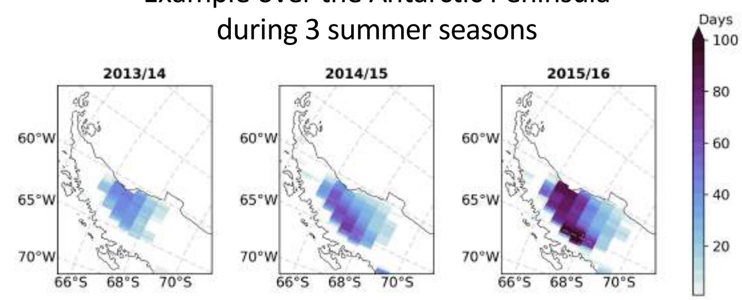


Sea ice contamination in the Arctic affects the estimation of salinity (Supply et al. 2022, RSE)

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.

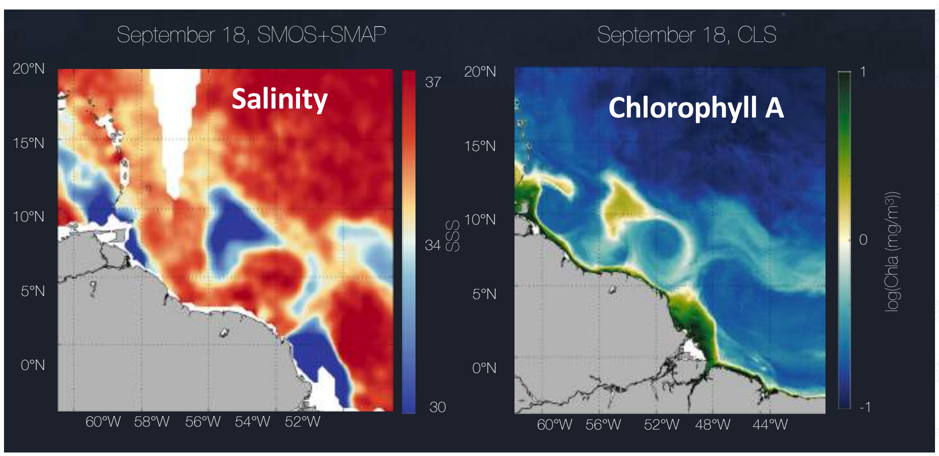
Higher resolution needed to monitor melting events close to the coast

Ocean applications

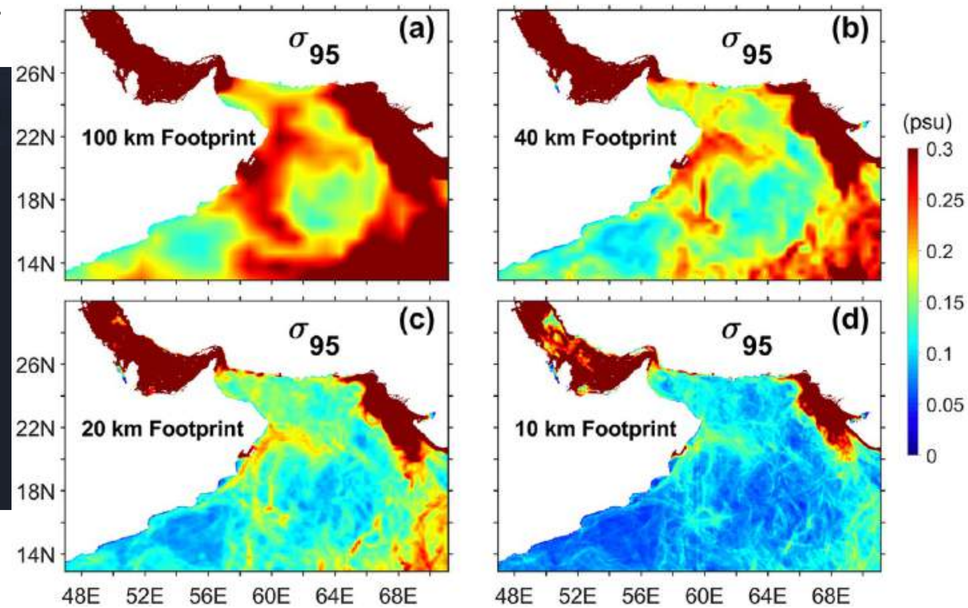
- **High resolution is also needed for ocean studies: river plumes, meso-scale physics, coastal regions, ...**

Salinity spatial variance (D'Addezio et al. 2019, RSE):
70 % for 50 km footprints
85 % for 20 km footprings
95 % for 10 km footprints

Previous presentations this week by: A. Supply, G. Alory, J. Boutin...



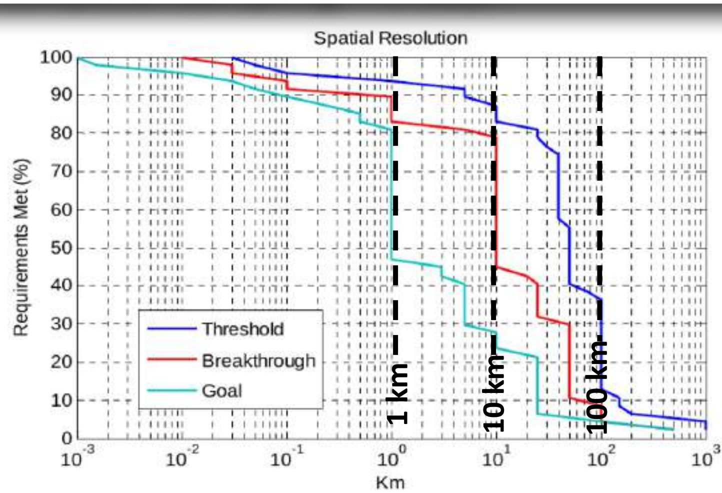
Olivier et al. (2022, Biogeosci. Discussions)

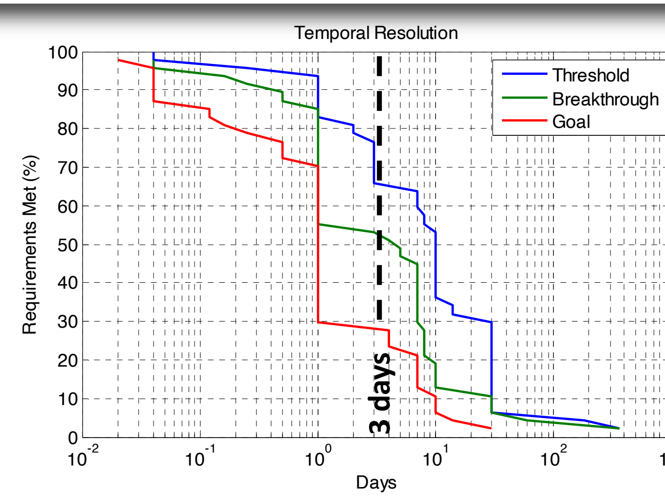


Summary of requirements

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

- While 1 km will be the ideal value for many applications, 10 km will be a breakthrough with respect to the current generation of sensors
- Temporal sampling < 3 days





Kerr, Escorihuela et al. 2020

SMOS, SMOS-HR, SMOS-Next

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

1st generation

SMOS

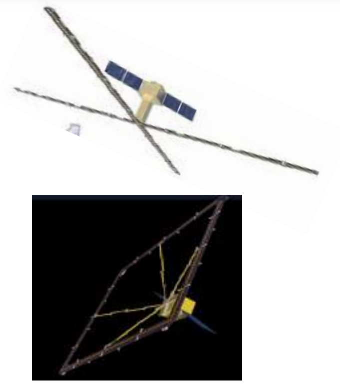
Launched in 2009

Resolution 40km

Sensitivity 2K

69 antennae

Three 4.5 m arms



2nd generation

SMOS-HR

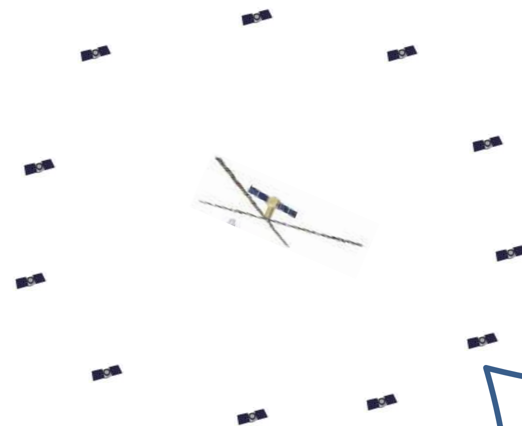
Phase A ongoing

Resolution better than 15 km

Sensitivity 2K

> 200 antennae

Four 8.5 m long arms



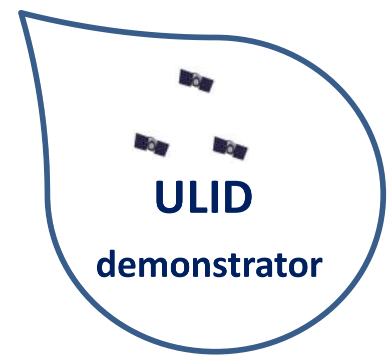
3rd generation

SMOS-Next

Resolution 4km

Sensitivity 2K

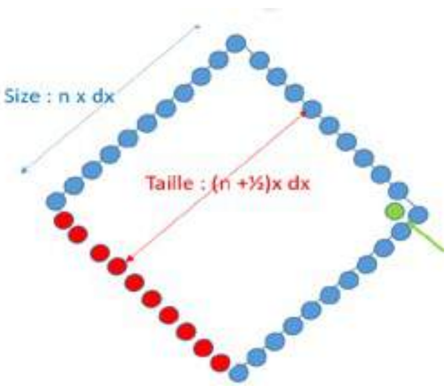
Hub SMOS-HR like satellite
and > 50 nano-satellites ULID like

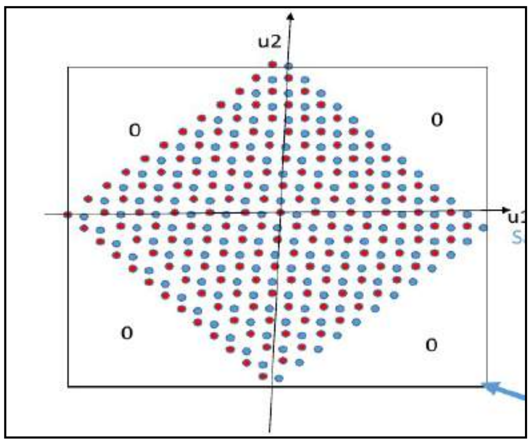


SMOS vs SMOS-HR: reducing the aliasing

- 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

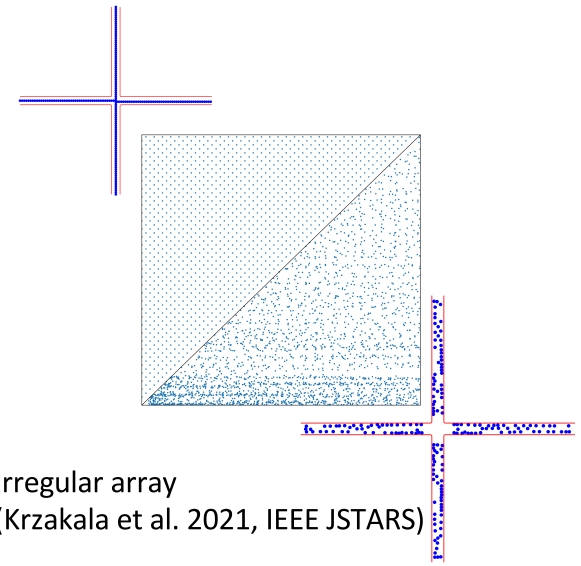
- Reduction of the aliasing in reconstructed images





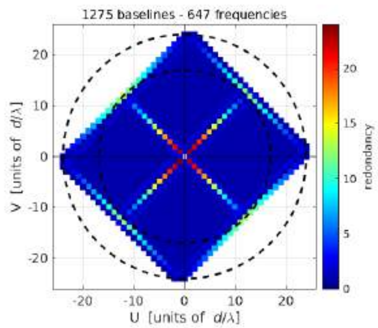
Patent FR3071068 (Kerr et al. 2019)

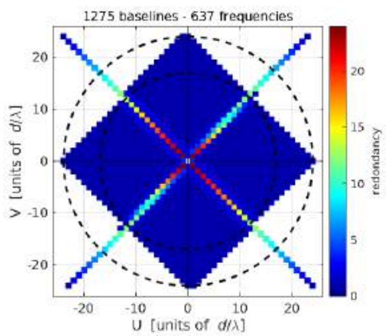
- Complete irregular layouts were also tested
  - Possible to calibrate
  - Would require new imaging algorithms
  - Many constrains for actually building the such a system

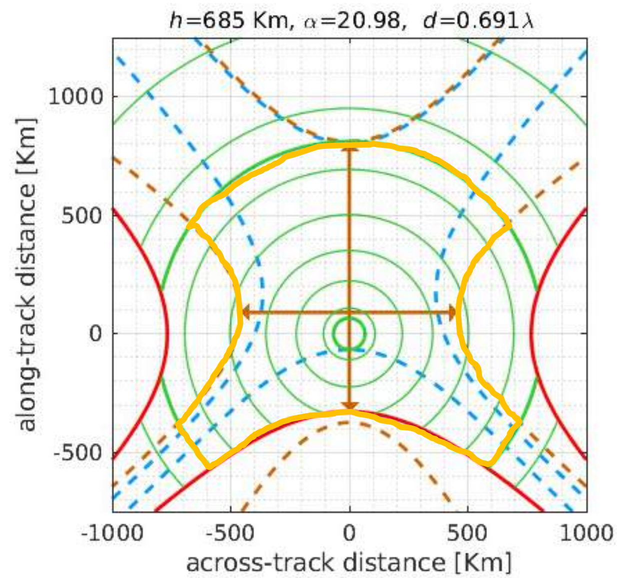


Irregular array
(Krzakala et al. 2021, IEEE JSTARS)

Spatial frequencies sampling and field of view







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

Antennae power patterns. RFI mitigation

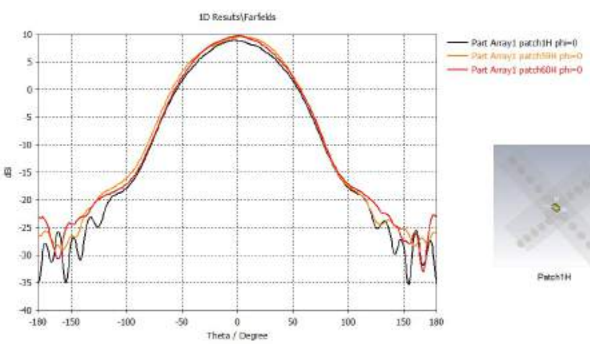
Band width : 21 MHz Jeannin et al.

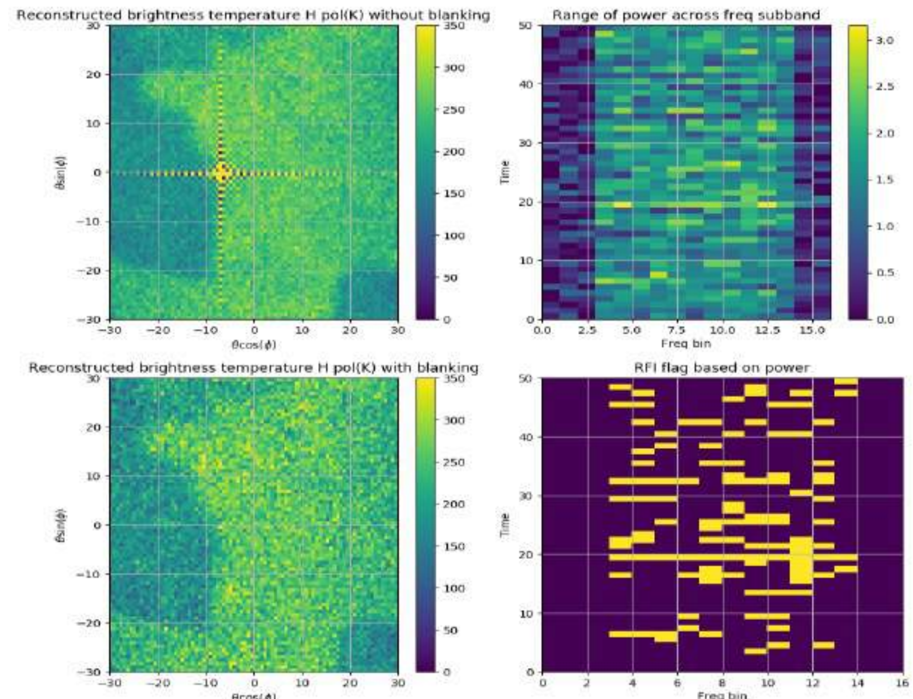
RFI filtering in 1-1.5 MHz sub bands Patent WO/2021/001408

Image reconstruction in 5 MHz sub-bads

Anterrieu (2021, CESBIO report)

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



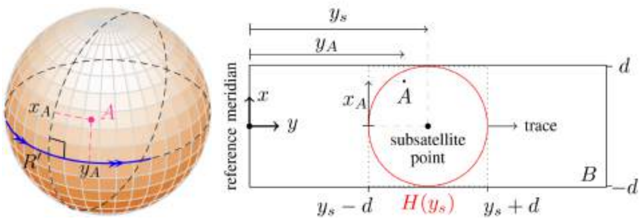


E. Anterrieu (CESBIO), A. Bornaud (CNES),
L. Costes (Airbus DS)

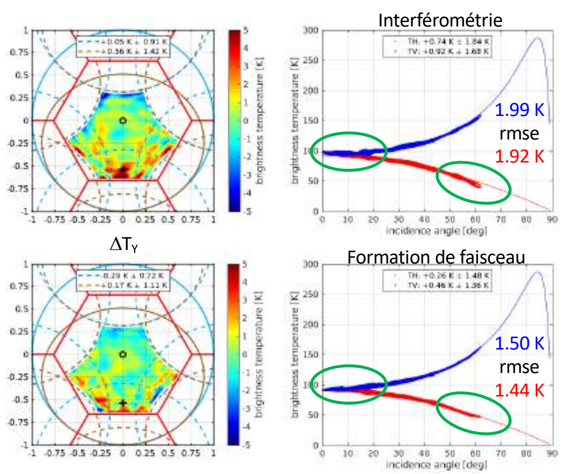
SMOS-HR (Phase A) versus SMOS

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	1.4 – 2.6 K / < 1 K

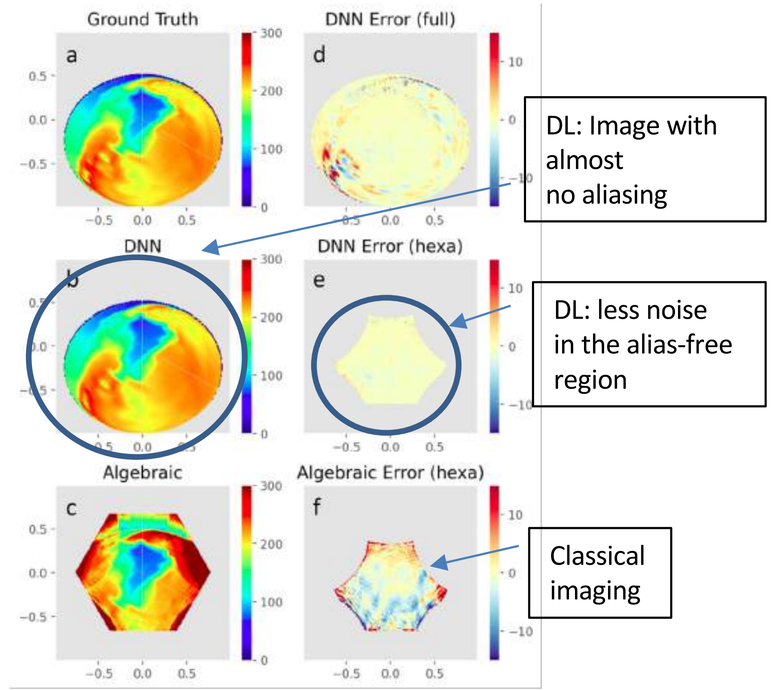
Image reconstruction



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

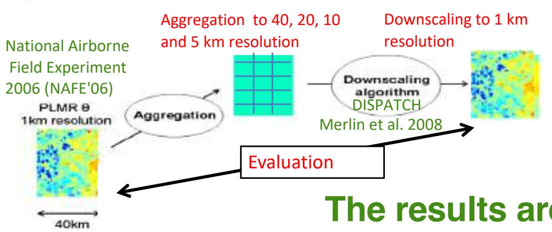


Digital beam forming (Anterrieu et al. *2022, Remote Sensing*)

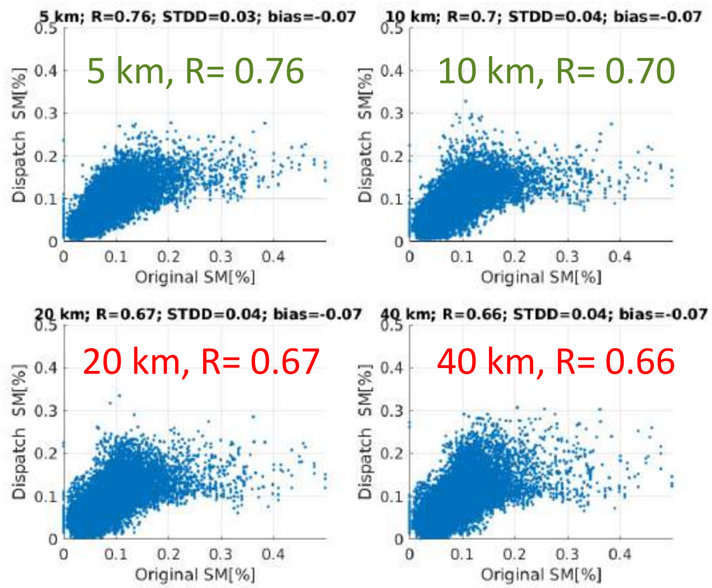


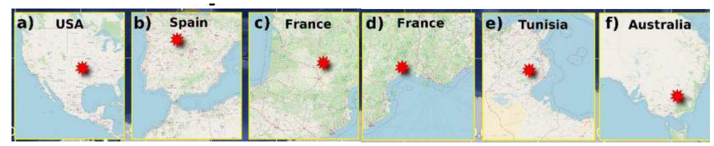
Faucheron et al. *in prep*

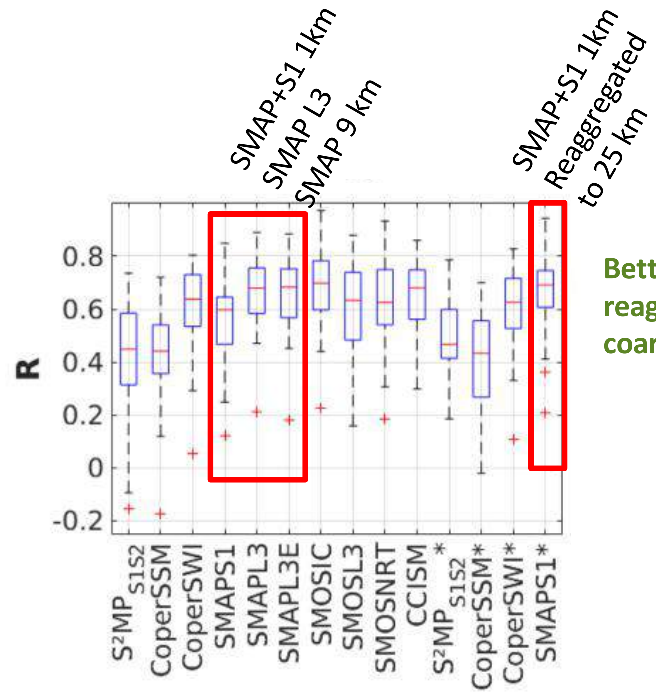
Downscaling or oversampling cannot replace native high resolution



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







Better results when reaggregated to coarse resolution

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**
  - **No clear scenario for Phase B**
  - **Open to collaborations : ESA, NASA, China…**
- **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**

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