SMOS Cal/Val activities

Raffaele Crapolicchio and SMOS Cal team

Directorate of Earth Observation Programmes
Mission Management & Ground Segments Department
Sensor Performance, Products and Algorithm Section

Content

- SMOS (Soil Moisture Ocean Salinity) mission overview.
- Interferometry concept.
- SMOS payload calibration.
- Calibration results.
- Brightness temperature image validation results.
- Conclusions.

SMOS Mission

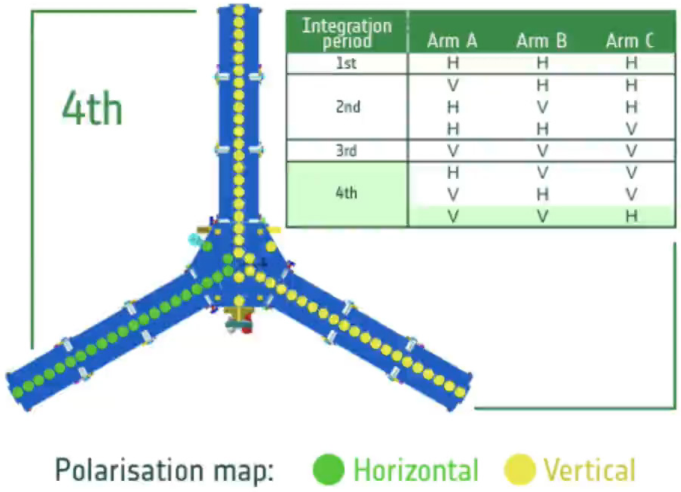
- Soil Moisture Ocean Salinity (**SMOS**) mission was launched on 2nd November 2009. ESA/CNES **Earth Explorer** Mission.
- The mission is in excellent status, operation extended up to **2021**.
- Main objective: global observations of **soil moisture** and **sea surface salinity** to improve our knowledge of the **water cycle** and to contribute to better weather and extreme-event forecasting and seasonal-climate forecasting.
- Additional objective: **sea-ice monitoring**
- **Land products**: soil moisture, soil state (freeze/thaw), vegetation optical depth.
- **Sea products**: surface salinity, sea ice thickness, winds.

For more see SMOS multimedia book

https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/smos/multimedia-book

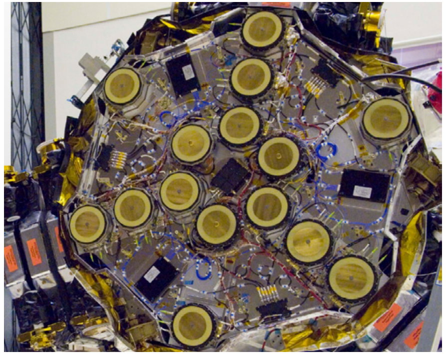
SMOS Mission

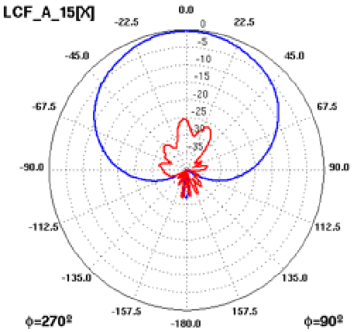
- The payload of **SMOS** consists of the Microwave Imaging Radiometer using Aperture Synthesis (**MIRAS**) instrument, a passive microwave **2-D interferometric full polarization radiometer**, operating at 1.413 GHz (wavelength of 21 cm) within the protected 1400-1427 MHz band. A full polarimetry measurement is acquired in four integration period i.e. 4.8 seconds.
- The SMOS mission is based on a **sun-synchronous** orbit (dusk-dawn **6am/6pm**) with a mean altitude of 758 km and an inclination of 98.44°.
- SMOS orbit has a **149-days** repeat cycle with a 18-days sub-cycle and a revisit time of 3 days.

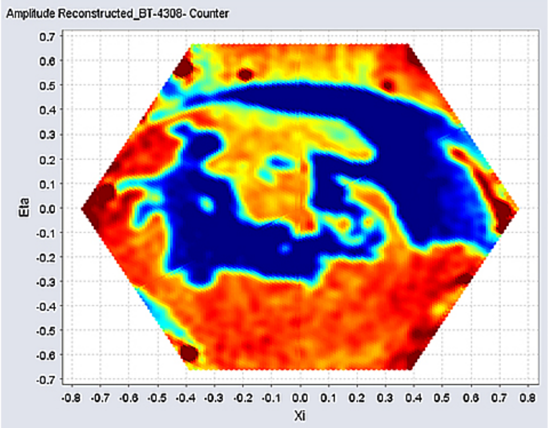


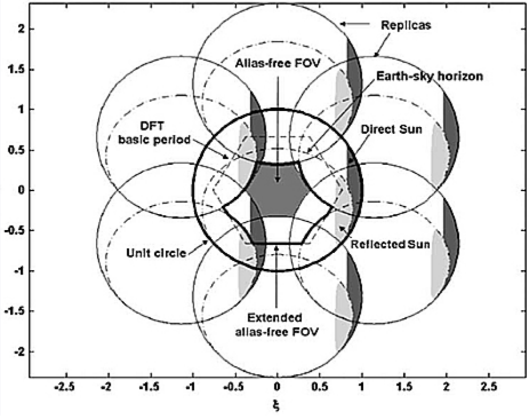
SMOS Mission

- The **MIRAS** instrument antenna array is formed by three arms 120° apart, with 23 equally spaced **LICEF** (Lightweight Cost-Effective Front-end) receivers each. Due to antenna size (diameter equal to 16.5 cm) and frequency wavelength (21 cm at L-band) the instrument's field of view (FoV) is large and includes full **Earth-disk** and part of the surrounding **Sky**. The **Y-array** configuration leads to an hexagonal sampling of the spatial frequency domain. Antenna spacing is 0.875 wavelengths. Part of the FoV is affected by **aliasing**. The alias-free FoV can be suitably extended over regions where the Sky alias is present to obtain an extended alias-free FoV (EAF-FoV).







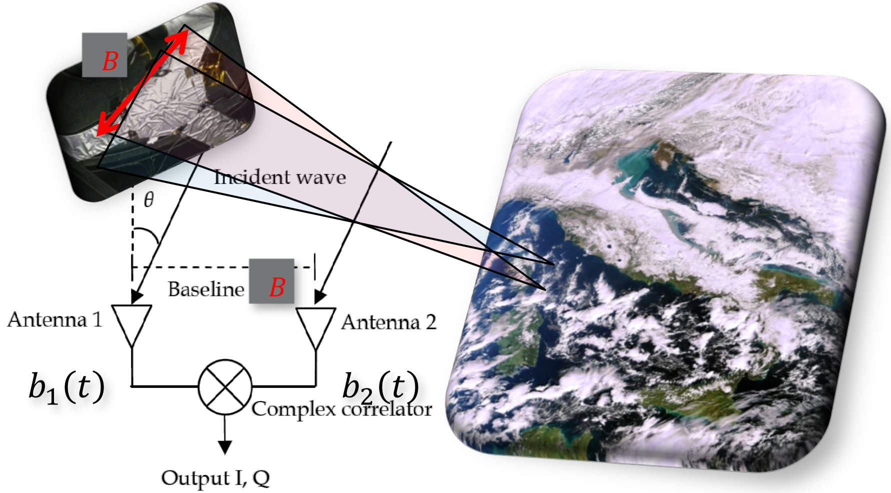


First interferometer L-Band measurements from Space

Interferometry approach:
two receivers with distance B (baseline)

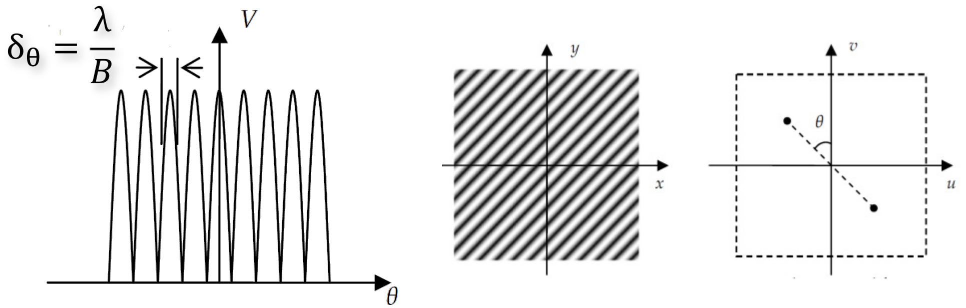
Visibility function:

$$V_{1,2}(\theta) = \frac{1}{2}\langle b_1(t) \otimes b_2(t)^* \rangle$$



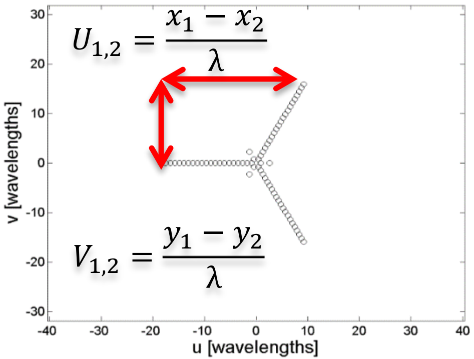
Two receivers Interferometer detects signal from **one** single direction in space: one **space frequency**.

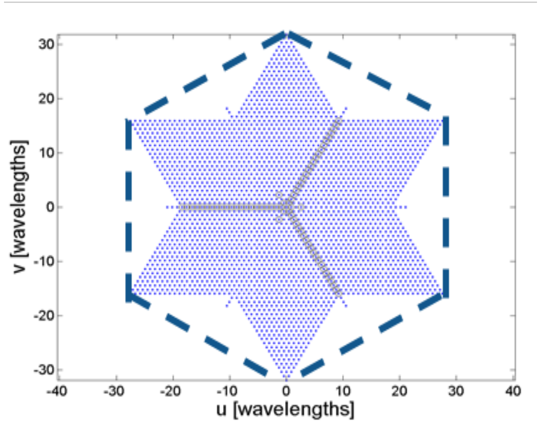
To measure several space frequency we need several baselines

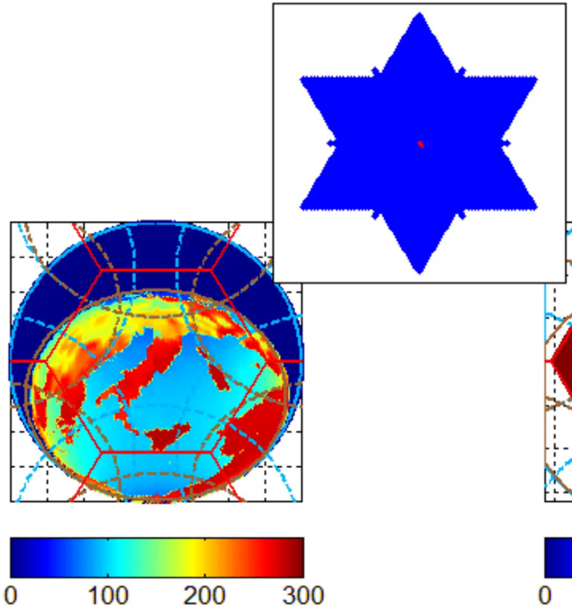


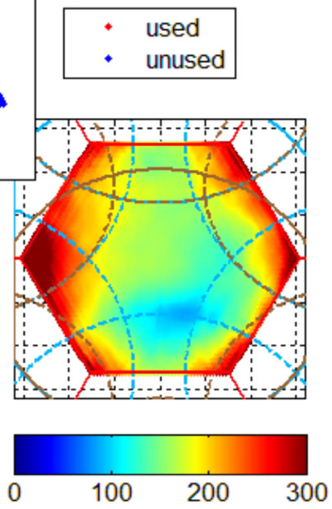
First interferometer L-Band measurements from Space

From receivers coordinates X, Y to baseline space U,V (**space frequency**)









First interferometer L-Band measurements from Space

MIRAS fundamental equation relates the visibility function to the Brightness temperature of the scene. **Corbella** term do not apply to radio astronomy equation.
Assuming all **antenna patterns** identical (F) and no **decorrelation effect** (r) among all the receivers the fundamental equation is a Fourier Transformation.
Brightness temperature in the antenna frame can be computed by apply the IFT to the **calibrated visibility**.

$$V_{12}^{pq}(u_{12}, v_{12}, w_{12} = 0) \stackrel{\Delta}{=} \frac{1}{k_B \sqrt{B_1 B_2} \sqrt{G_1 G_2}} \cdot \frac{1}{2}\left\langle b_1^p(t) \ b_2^{q^*}(t)\right\rangle =$$

$$= \frac{1}{\sqrt{\Omega_1 \Omega_2}} \iint_{\xi^2+\eta^2 \le 1} \frac{\left(T_{pq}(\xi,\eta) \boxed{- T_{rec}\delta_{pq}}\right)}{\sqrt{1-\xi^2-\eta^2}} \boxed{F_{n\,p1}(\xi,\eta) F_{n\,q2}^{*}(\xi,\eta) \tilde{r}_{12}\left(-\frac{u_{12}\xi + v_{12}\eta}{f_0}\right)} \exp\left(-j2\pi(u_{12}\xi + v_{12}\eta)\right) d\xi d\eta$$

$$(\xi,\eta) = (\sin\theta\cos\varphi, \sin\theta\sin\varphi)$$

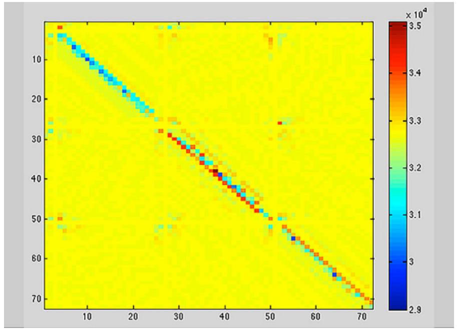
$$V(u,v) = F\left[T(\xi,\eta)\right]$$

MIRAS calibration

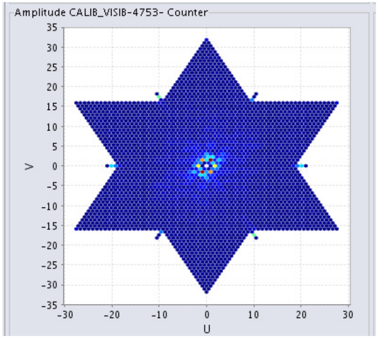
MIRAS data calibration requires to convert the digital correlation counts integrated over 1.2 second interval into calibrated visibility function (Interferometer calibration as result of the L1A processing).
MIRAS image retrieval requires to invert the MIRAS instrument transfer function (which is not a simple IFT) to convert calibrated visibility into calibrated image (Image reconstruction as result of the L1B processing).

Image geolocation is the result of the L1C processing

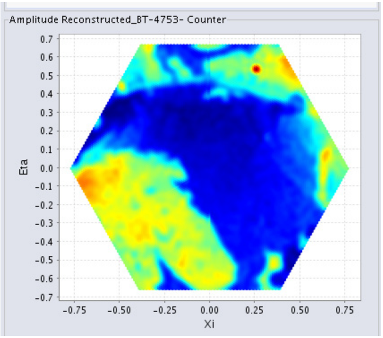
L0

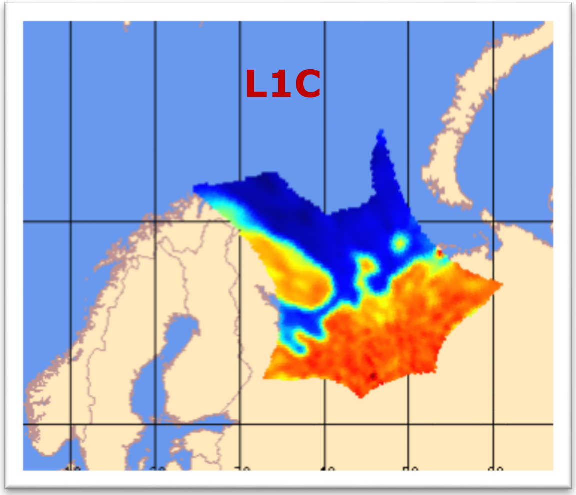


L1A



L1B

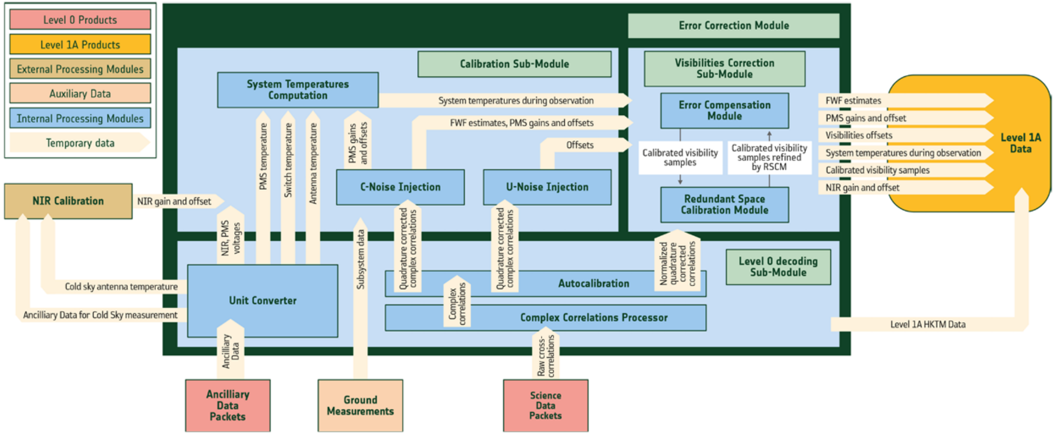




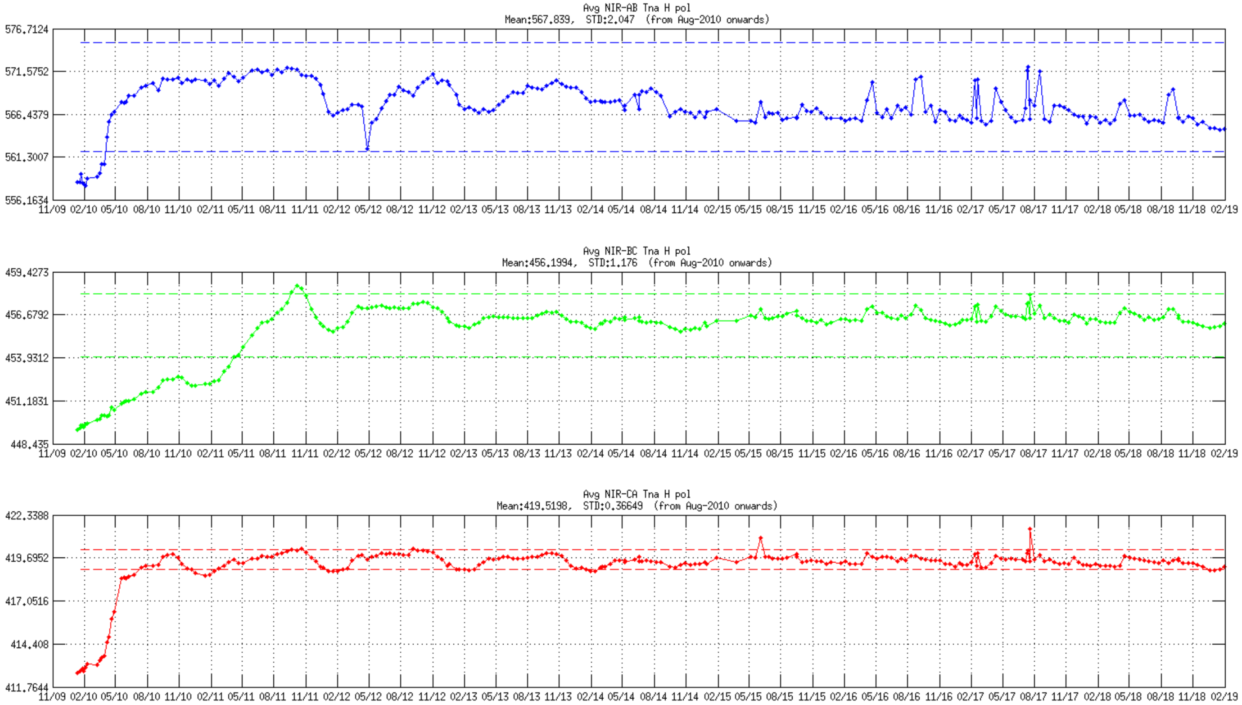
MIRAS calibration: visibility function

Visibility function calibration consist in the calibration of the total power radiometer (LICEF): gain and offset, in the computation of the visibility offset and in the computation of the decorrelation function amplitude. Such calibrations are performed every 8 weeks (every 1 week for the radiometer offset). Three Noise Injection Radiometers (NIR) provide the reference noise calibration for the LICEF. Internal uncorrelated noise source is used for the visibility offset.

NIR calibration is performed every two weeks using Cosmic Microwave Background (CMB) radiation.



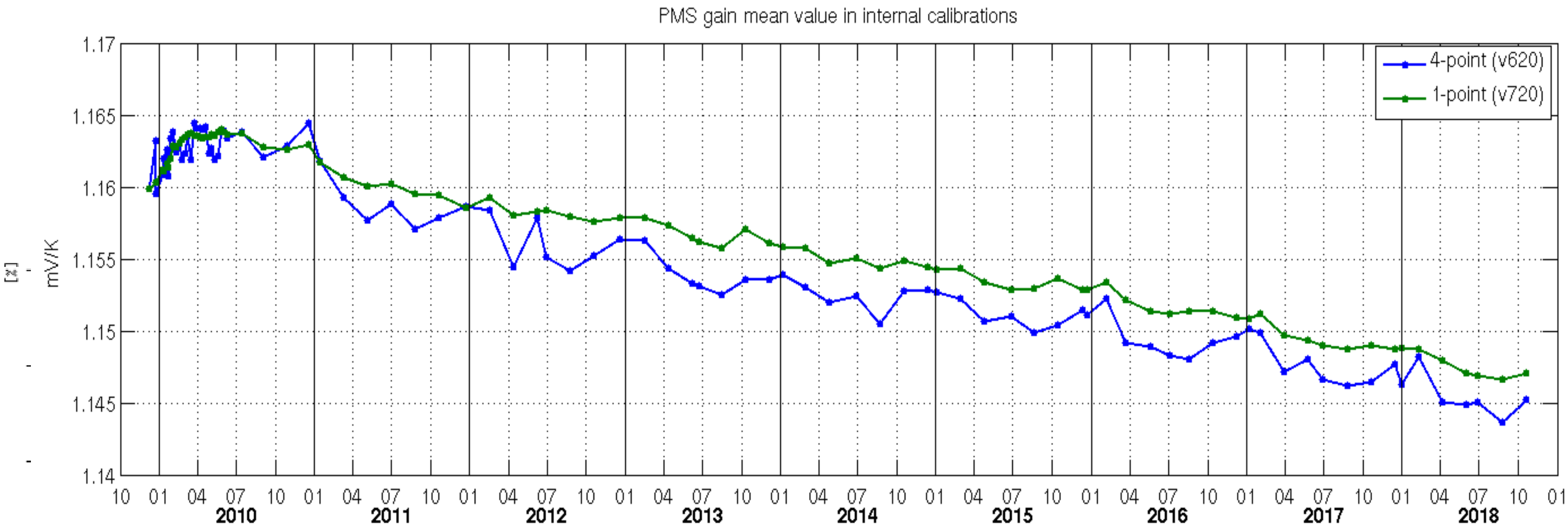
NIR calibration: results



NIR CA stability within 1K

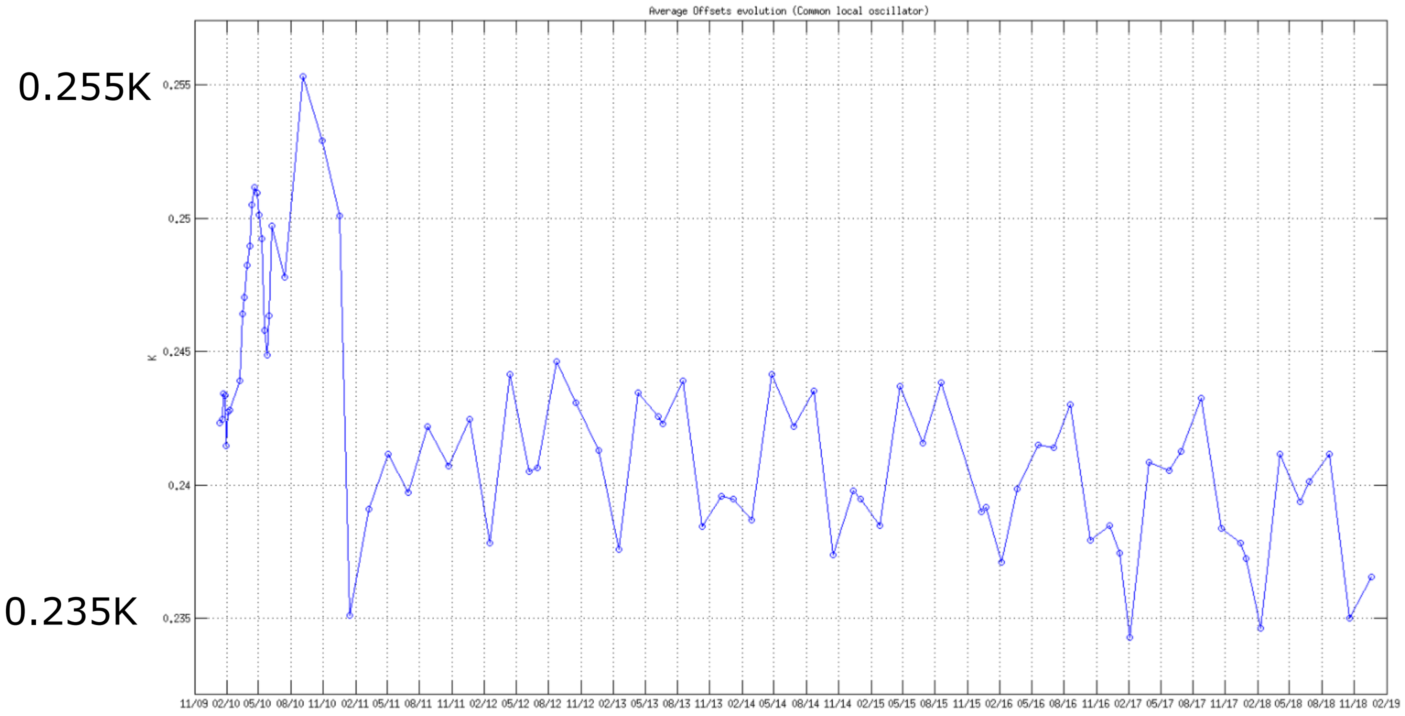
Noise Injection Radiometers (NIRs) internal diode noise temperature (Tna) evolution since the beginning of the mission for the three NIR unit: AB (blue), BC (green) and CA (red). At the beginning of the mission Tna has evolved differently among the three NIR units until October 2014 when warm-NIR calibration was introduced. The unit CA has shown to be more stable, since beginning of the mission, hence is the only one used for brightness temperature absolute calibration.

LICEF calibration: results



LICEF gain calibration evolution maximum 5%, on average less than 1%

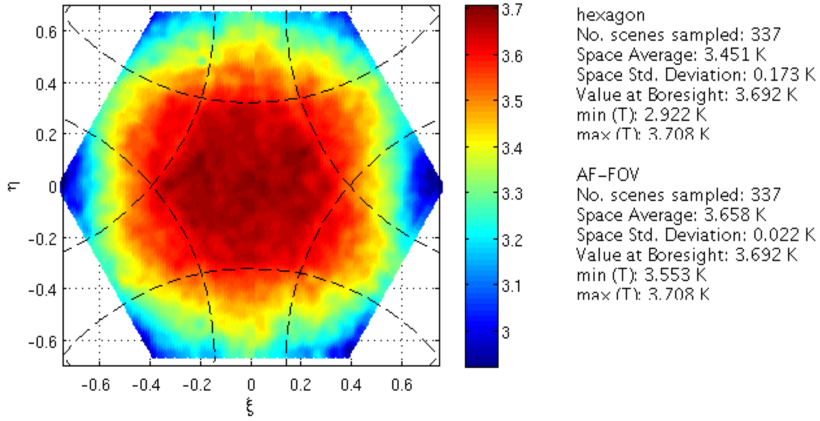
Visibility offset: results

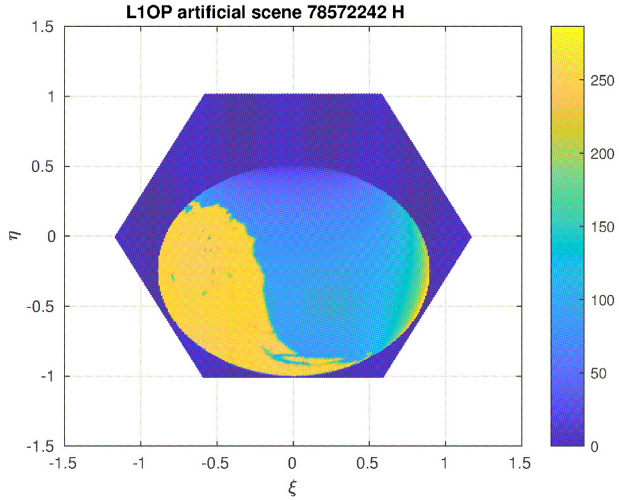


Average visibility offset (LICEF sharing the same LO)within 0.02K

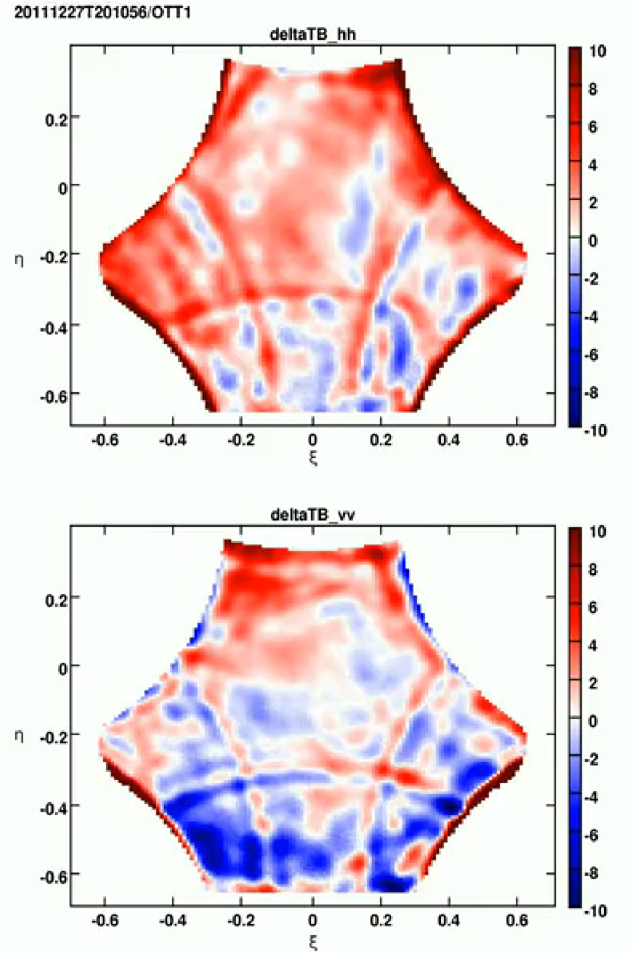
MIRAS calibration: image reconstruction

Image reconstruction consist in removal of spatial biases by Flat Target Transformation correction obtained during sky manoeuvre (CMB), removal of external sources, removal of decorrelation effects (fringe washing function calibration) and inversion of the instrument model (antenna patterns). To further reduce bias in the image, the contribution of an artificial scene, as close as possible to the observed one, is removed from the calibrated visibility before image reconstruction and then and added back to obtain the calibrated brightness temperature.





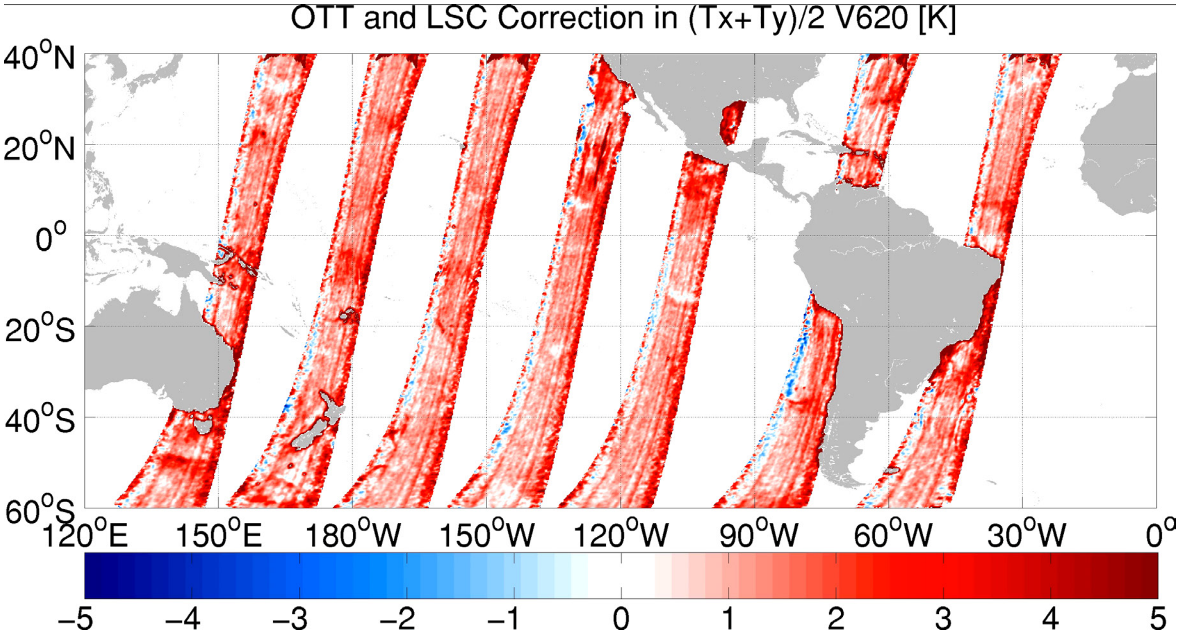
Spatial biases results



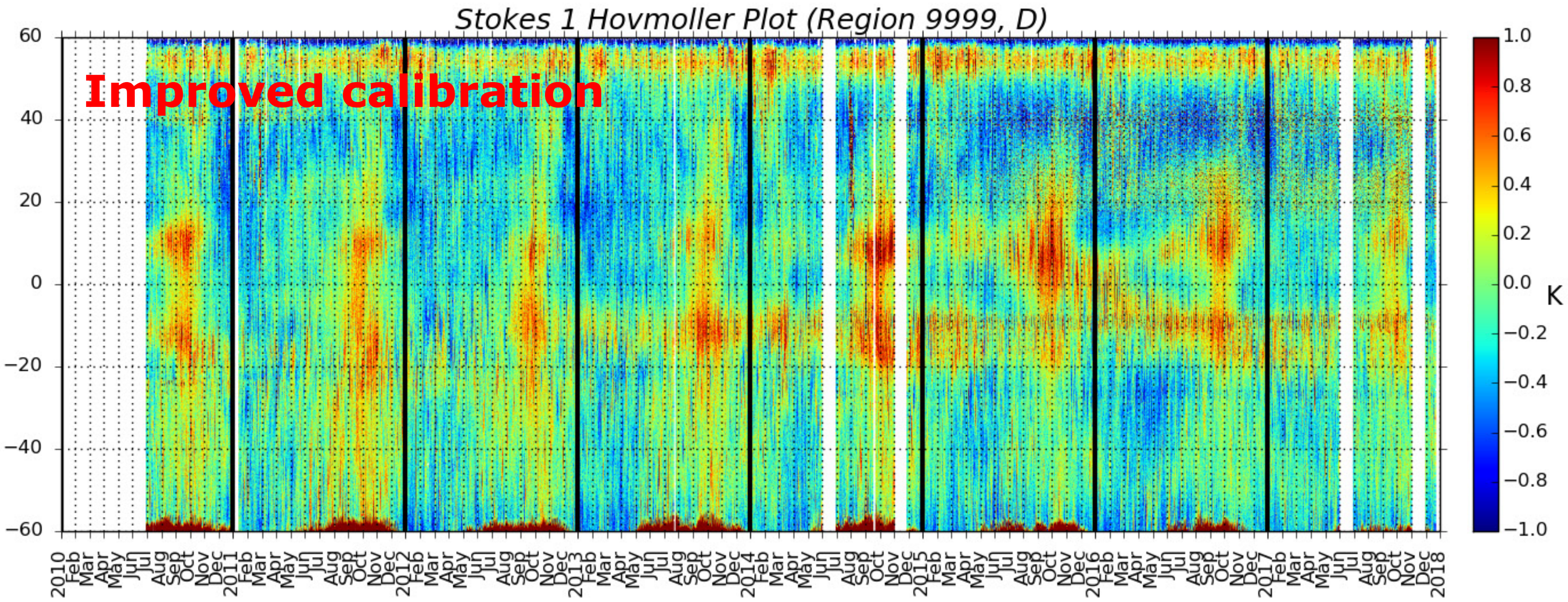
Spatial brightness temperature biases over Ocean scene from January 2012 to January 2015. Ascending passes horizontal (upper) and vertical (lower) polarization. This Spatial brightness temperature biases shall be removed (OTT correction) before sea surface salinity retrieval.

Spatial biases results

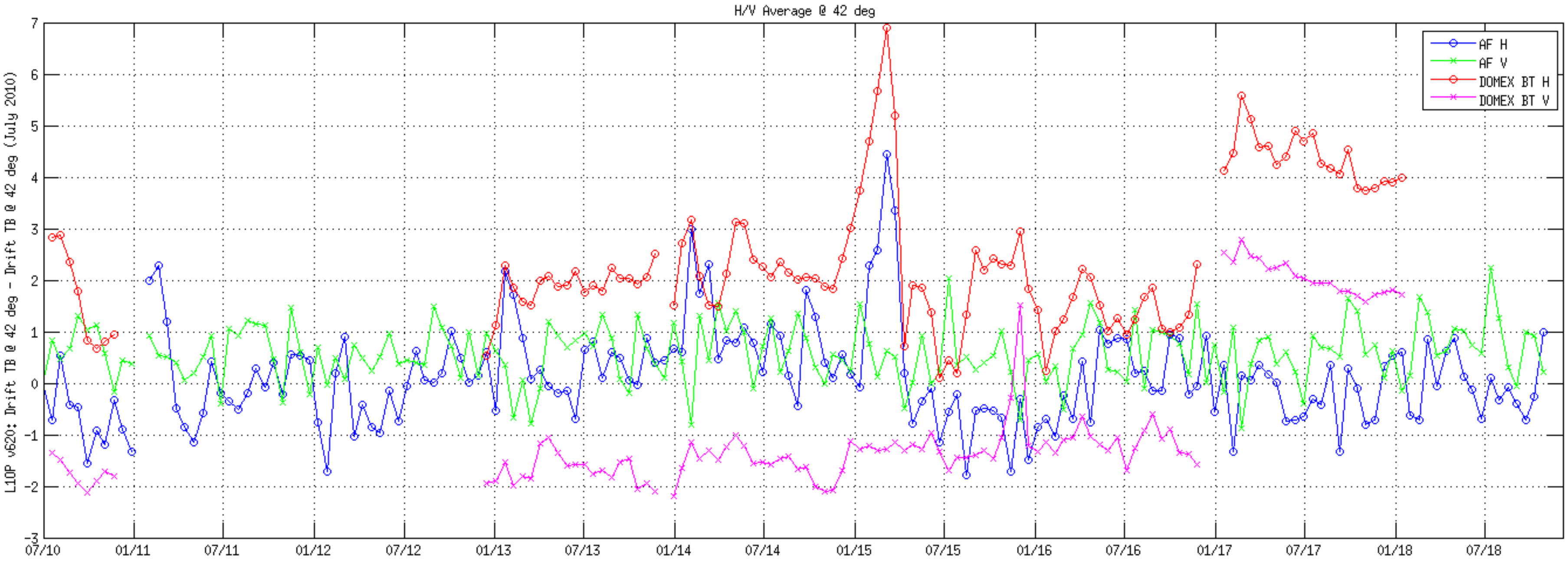
Spatial brightness temperature biases are significantly modified by the presence of land in the instrument field of view. This land-sea contamination effect (LSC correction) shall be removed before the sea surface salinity retrieval.



Brightness temperature stability (Pacific Ocean)

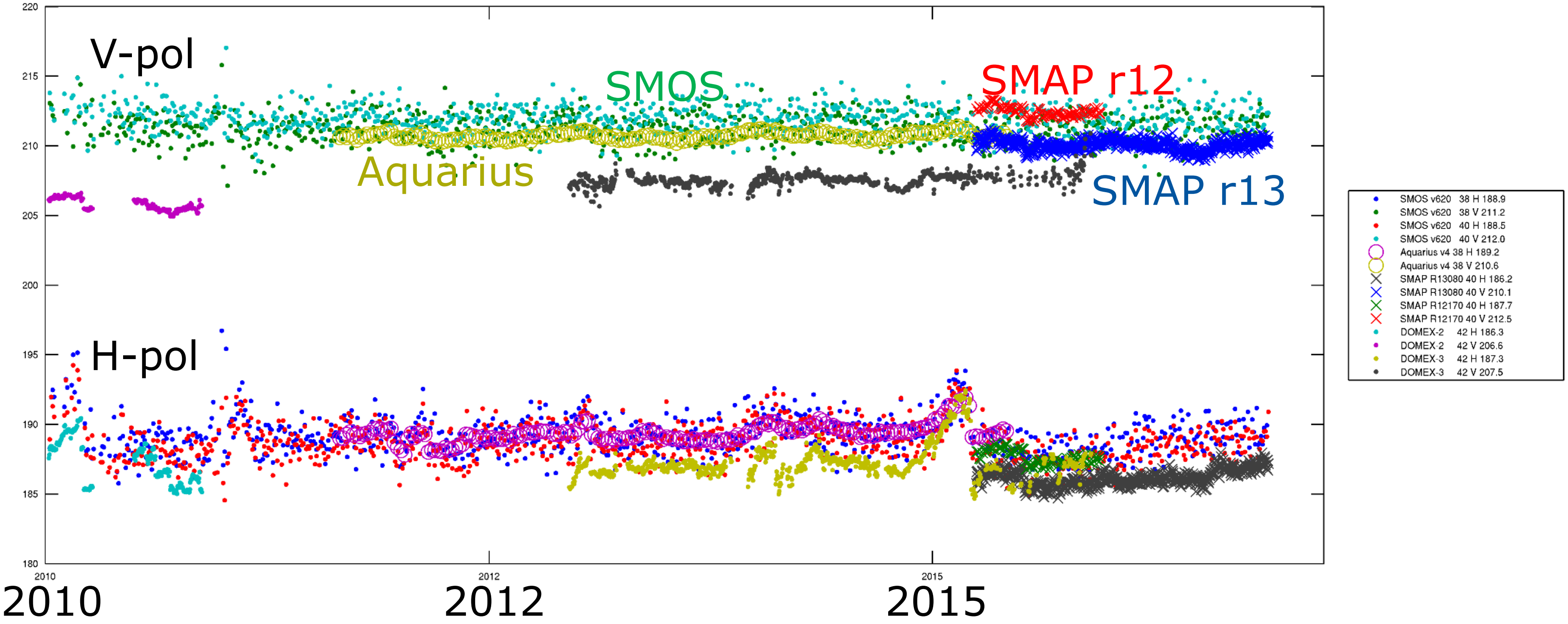


Brightness temperature stability (Antarctica, Dome-C)



SMOS brightness temperature evolution in vertical polarisation is very well correlated with in-situ measurements, stability, since the beginning of the mission, is within about 1K. The brightness temperature in horizontal polarisation is less stable and impacted by geophysical condition at surface level as confirmed by DOMEX measurement evolution. Slightly different values for DOMEX 2017 dataset are due to a new three loads calibration schema used for data processing. Differences in vertical and horizontal polarisation top of atmosphere absolute value between SMOS and DOMEX measurements are under investigation.

Brightness temperature stability over Antarctica (SMOS, SMAP and Aquarius)



Conclusions

- An overview of the SMOS (Soil Moisture Ocean Salinity) mission and MIRAS instrument calibration has been presented.
- MIRAS calibration has been stable since June 2010 (after commissioning phase).
- Brightness temperature stability within 2K. To be further reduced with next L1 processor foreseen by end 2019.
- Brightness temperature spatial biases not negligible for sea surface salinity must be corrected at L2.
- Comparison of brightness temperature over Antarctica shows good agreement among L-band missions: Aquarius, SMAP and SMOS.
- Calibration team outlook (> 2020):
  - Further reduce image spatial biases
  - Improvements for external sources corrections (galaxy, Sun glint and direct)
  - Radio Frequency Interference (RFI) mitigation