# Jason 3 and Sentinel-6 Michael Freilich Tandem Phase

## Instrument Processing:
## **Measurement and Retracking**

*Francois Boy [CNES]*
*Phil Callahan [NASA/JPL]*
*Jean-Damien Desjonqueres [NASA/JPL]*
*Alejandro Egido [NOAA]*
*Walter H.F. Smith [NOAA]*
*Marco Fornari [ESA]*
*Cristina Martin-Puig [EUMETSAT]*

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# POS4 Tandem phase results in a nutshell

- **POS-4 quality assessment vs requirements**:
  - **Altimeter LR range noise** ([1.2, 1.5, 2.4, 3.2] cm at [1, 2, 5, 8] m SWH):
    - Side-A: [1.25, 1.44, 1.93, 2.41]
    - Side-B: [1.24, 1.45, 1.94, 2.41]
  - **Altimeter HR range noise** ([0.7, 0.8, 1.3, 2.0] cm at [1, 2, 5, 8] m SWH):
    - Side-A: [0.62, 0.75, 1.46, 2.42]
    - Side-B: [0.62, 0.75, 1.45, 2.43]
  - **Altimeter HR SWH** (Uncertainty < 15 cm + 5% of SWH): same effects of vertical waves motion observed on both Side-A and Side-B.

# Evolutions Foreseen

## Classification of evolutions in those:

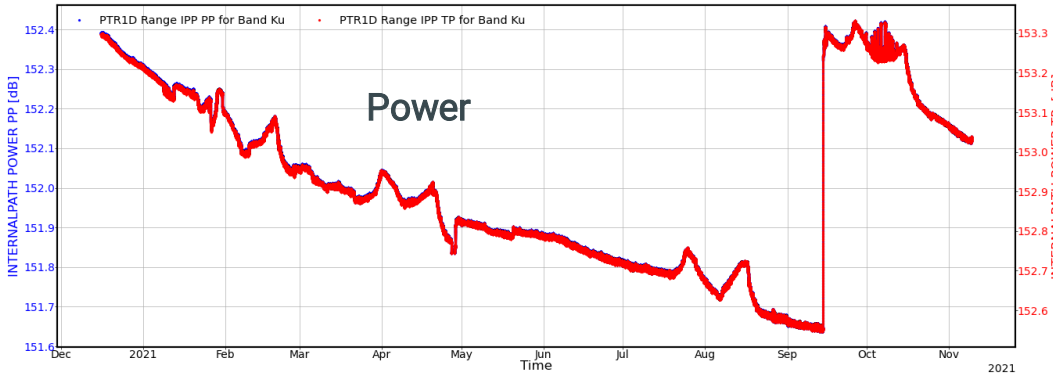
- **To improve LR and HR GMSL trend**
  1. Numerical Retracking
  2. Range Walk
  3. Use of ECHO CAL as main CAL1 instrument correction

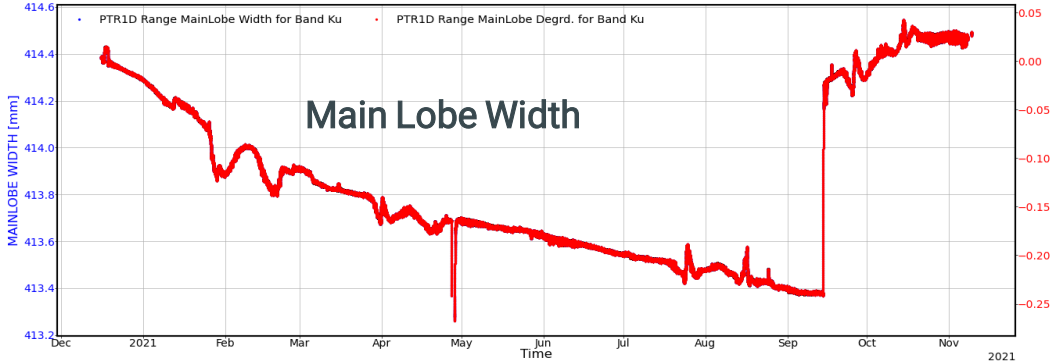
- **To improve HR SWH estimates**
  4. Use of reduced stack in L1B → Stack Doppler ambiguities effect
  5. Cancellation of Vertical Velocity effects

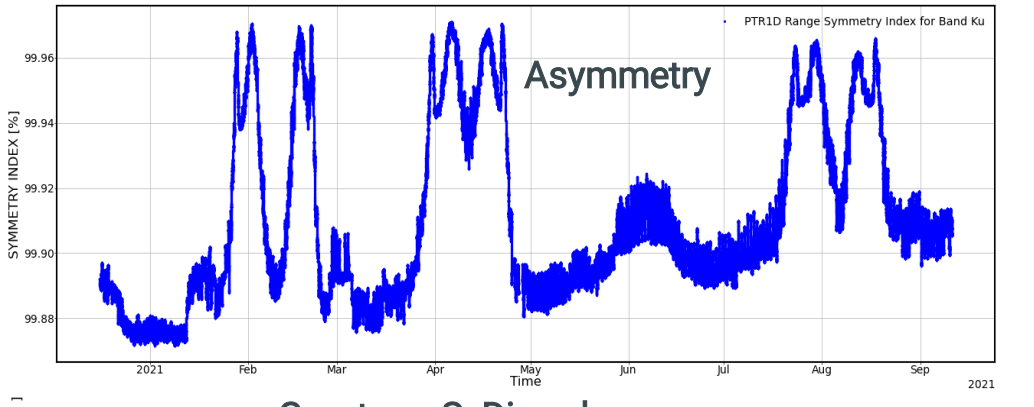
# Evolution: Improving LR and HR GMSL ➔ Numerical Retracking and Range Walk

- As observed on previous SARM altimeters,
  - POS4 Tx power drops
  - It comes with **PTR main lobe width and asymmetries drift**

- Within specifications(@instrument level) but strong GMSL impact with current PDAP implementation
  - LR/Brown and HR/SAMOSA make Gaussian assumption for PTR modelling
  - Deviation between in-flight PTR and Gaussian function is compensated using a static LUT
  - As PTR shape drifts in time, the correction is not optimal ➔ **LR GMSL impacted by +0.75mm/y (sideA)**
  - in HR mode, on top of the PTR shape evolution, it has been reported (Aublanc et al. 2020-OSTST) the necessity to apply the range walk (L1 correction)➔ **HR GMSL impacted by +2.5mm/y (total, sideA)**




Courtesy: S. Dinardo

# Evolution: Improving LR and HR GMSL ➔ Numerical Retracking and Range Walk

- **PDAP EVOLUTIONS FORESEEN FOR GMSL:**

1. Implementation of **the CZT range walk** in the L1B Delay-Doppler processing (Guccione et al. 2008, Pierre Rieu S3VT 2020, Dinardo et al. 2022 in prep)

2. Implementation of a **numerical retracking** both in LR & HR modes (Boy et al. 2016, Tourain et al. 2021)

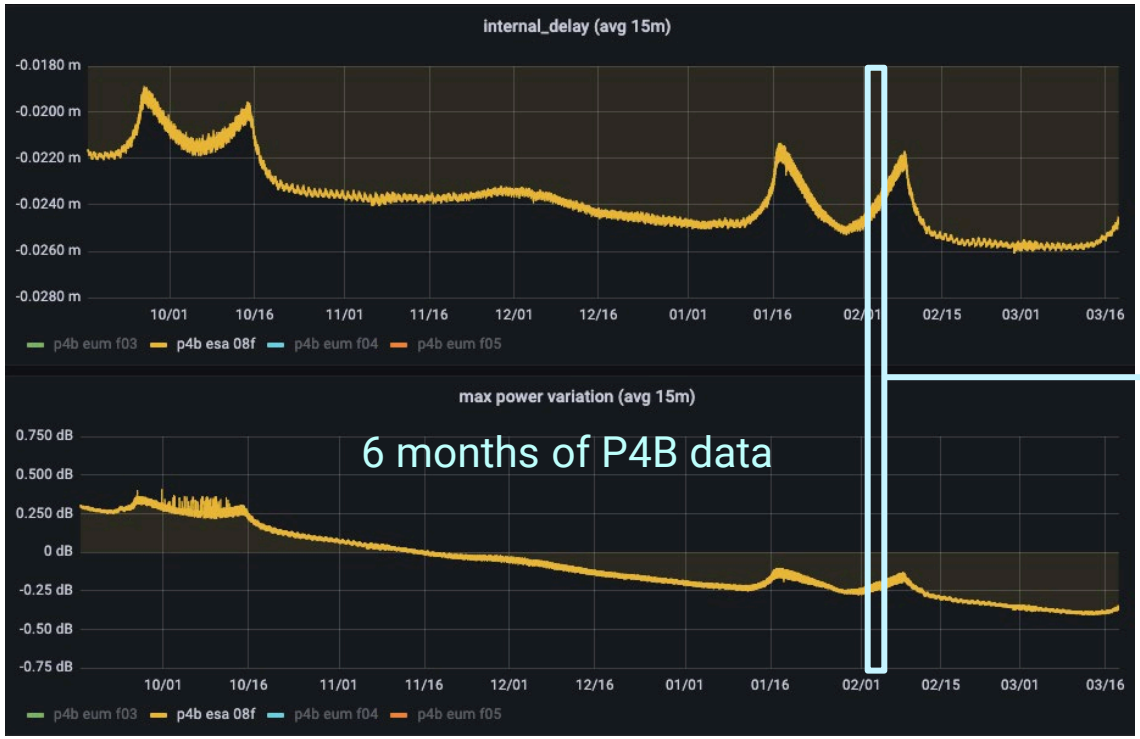
    - Use of a **frequency-based model** to speed up computation (**Buchhaupt et al., 2018**)

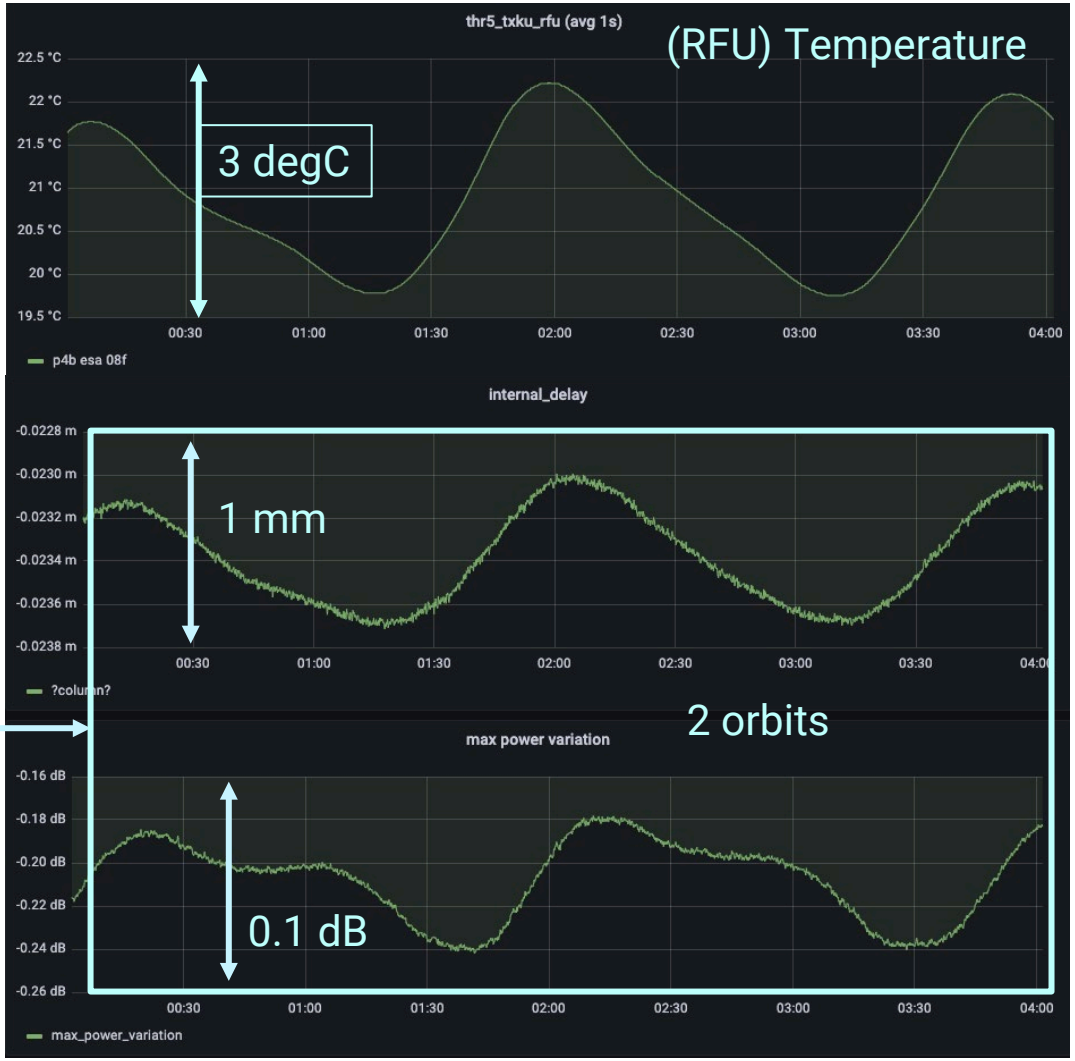
3. Use of the **ECHO-CAL** as main CAL1 instrument correction source (high rate calibrations)

# Evolution: Improving LR and HR GMSL ➔ Use of ECHO CAL

## ECHO CAL – INNOVATION FROM POS4 IN S6MF

- P4 instrument has an embedded cal1 pulse within the science measurement → ECHO CAL
- It detects both the long term, and the short term instrument impulse response (IR) evolutions along the orbit → IR dependency on temperature



# Evolution: Improving LR and HR GMSL ➔ Evolutions test results

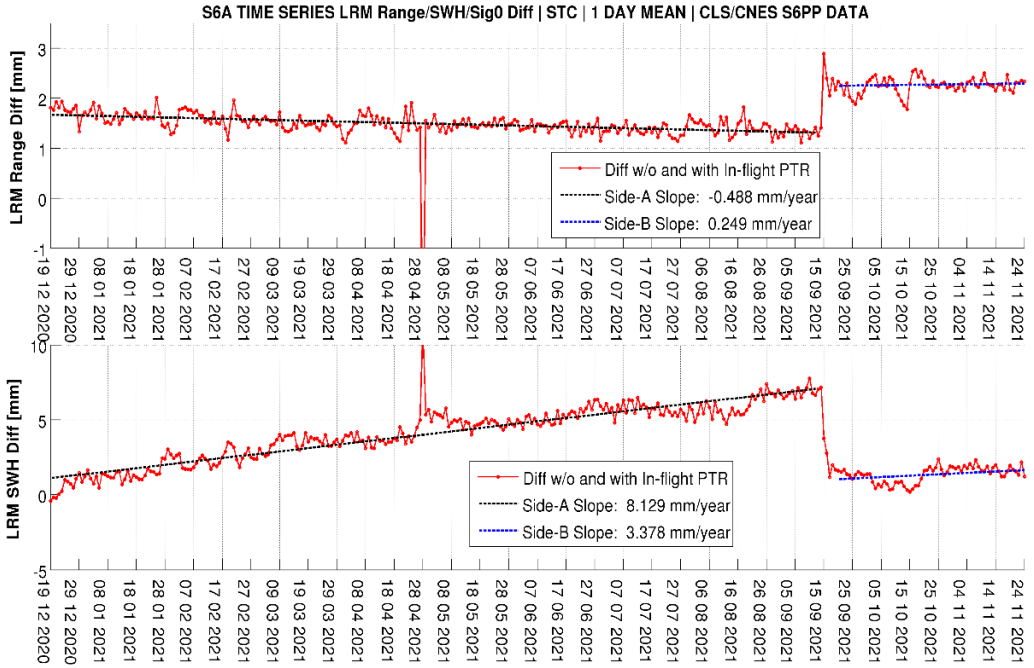
## Validation: Prototyping using CNES/CLS S6PP

- LR: range and SWH impacts of PTR shape evolution:
  (Side A) -0.48mm/y in range – 3% 8,1mm/year in SWH = 0,75mm/year
- HR: additional drift due the range walk omission
  (Side A) -1.75mm/year

## Publications: Salvatore Dinardo (CLS)

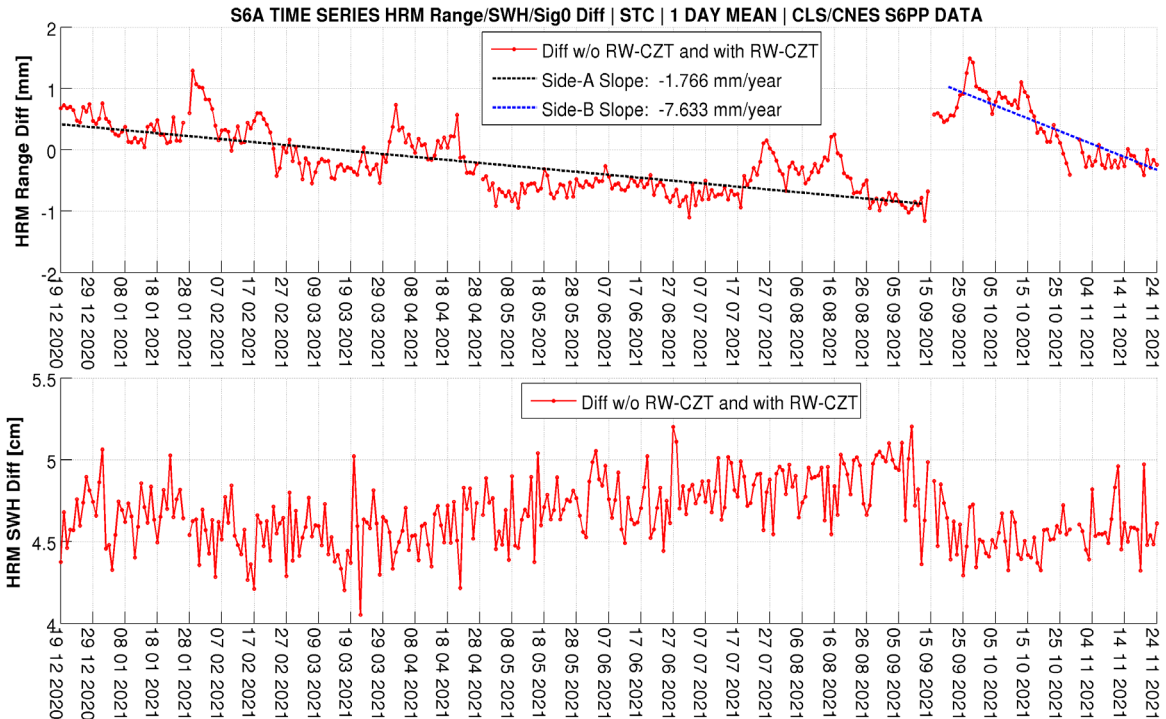
- In-Flight Calibration and Performances Monitoring (submitted)
- Main Scientific Results from S6PP LRM and UF-SAR chains in the first year of the mission (in prep)

### (LR) differences between w/o and with NR




Courtesy: S. Dinardo

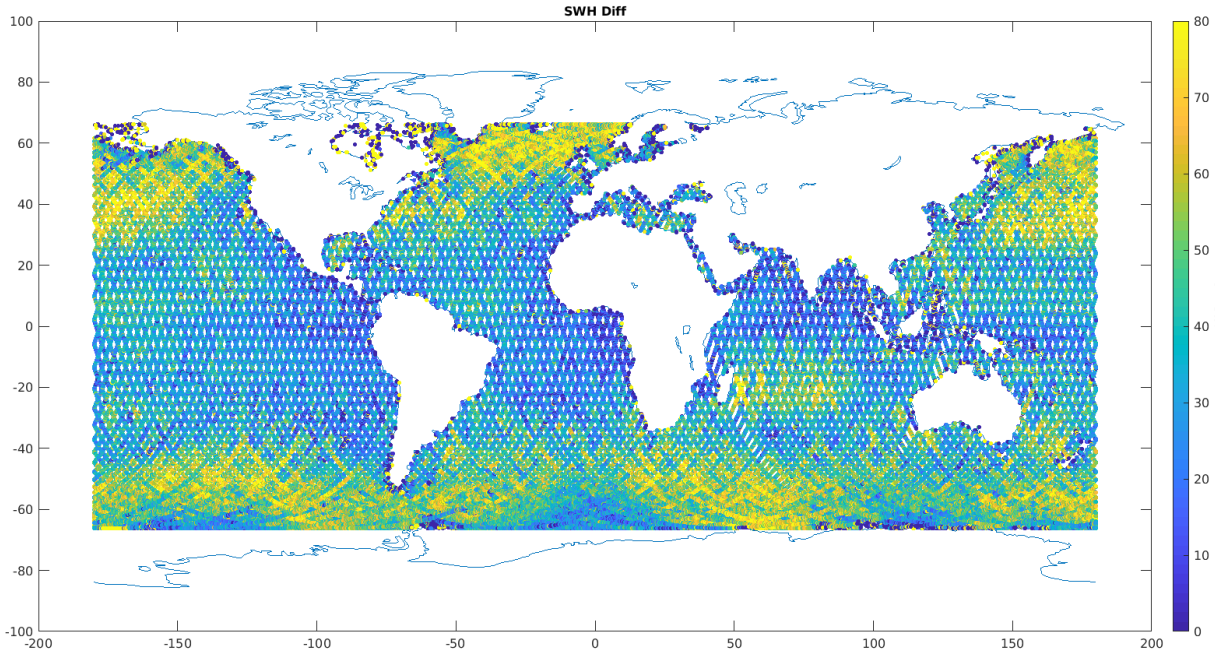
### (HR) differences between w/o and with RW

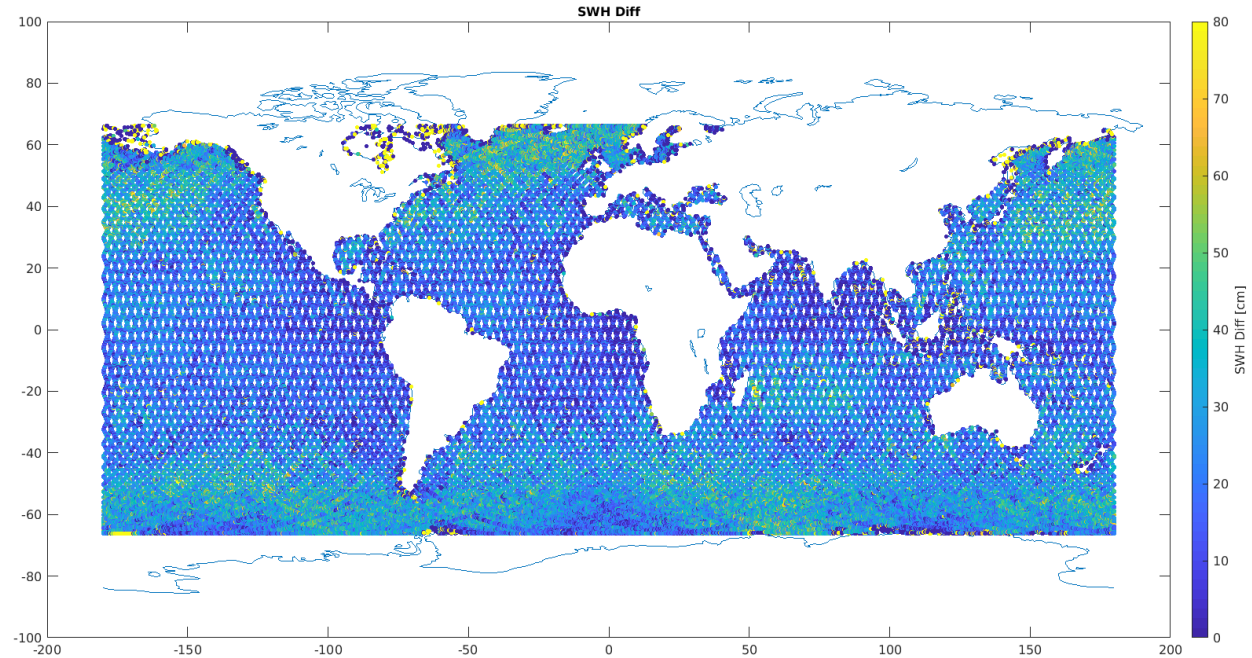


# Evolution: Improving HR SWH Estimates ➔ VV effects

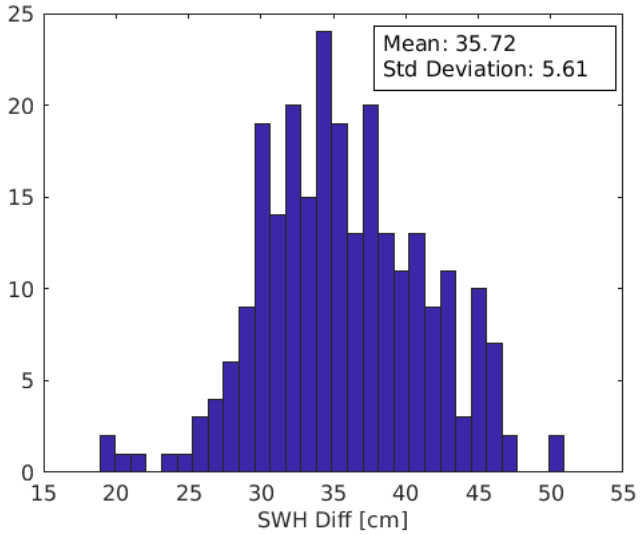
- We already showed during S6VT that the discrepancies between the Sentinel-6/MF LR and HR SWH measurements can be attributed to the ocean waves' vertical motion.
- **PDAP EVOLUTIONS FORESEEN FOR SWH:**
  - Cancellation of Doppler Ambiguities within the stack by using less stack Doppler beams to form the multi-looked L1B waveform
    - Simple L1 configuration tuning: recent results from testing this in reprocessing campaign are available hereafter.
  - Cancellation of VV effects using a more sophisticated methodology derived by NOAA team, and already tested by CNES team with their S6PP.
    - Use or numerical retracker + LUT table. Results also available hereafter.

# Evolution: Improving HR SWH Estimates ➔ VV effects



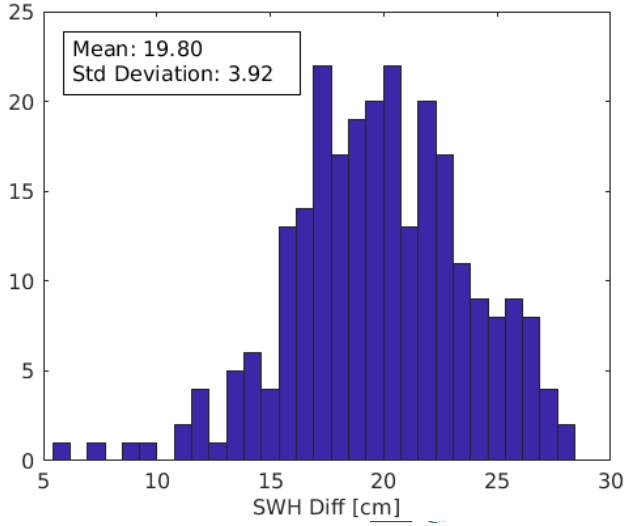

SWH SAR – LRM ORIGINAL




Current PDAP with L1 configuration set to use 322 looks instead of full stack

~ 16 cm improvement in LR/HR agreement

SWH SAR – LRM 322 looks




**By:** M.Meloni [EUMETSAT]

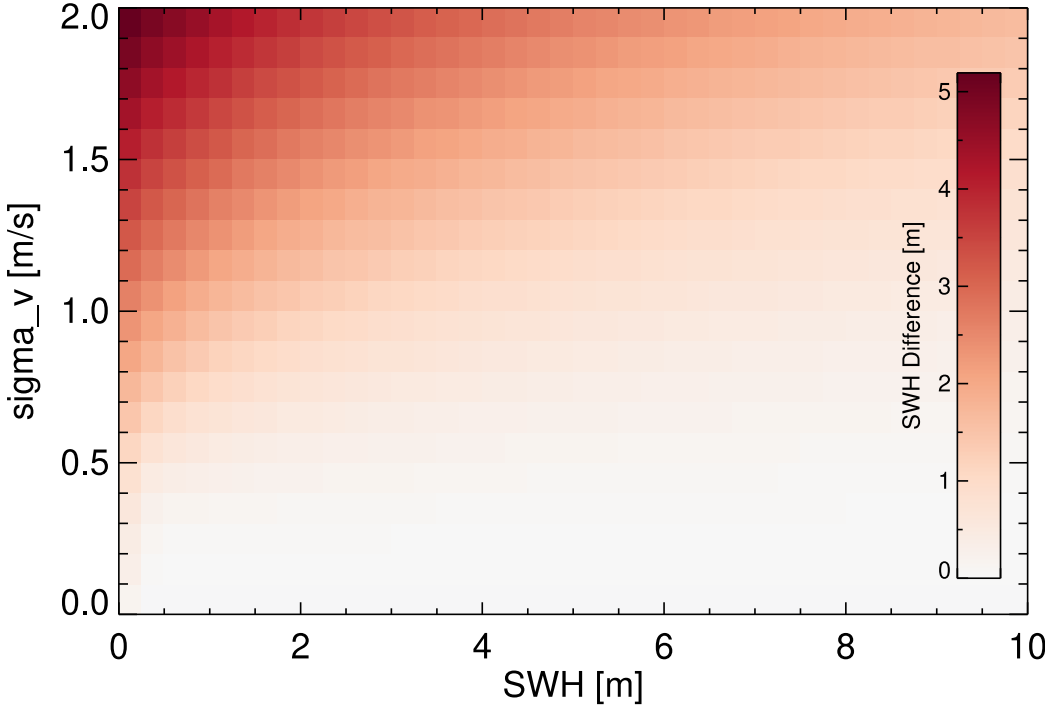
# Evolution: Improving HR SWH Estimates ➔ VV effects

- We have generated a look up table correction for the HR SWH measurements, that depends on the LR SWH (Hs) and mean wave period, T02 (from wave model).
- The application of this correction highly reduces the biases between the HR and LR SWH measurements and cleans up the SWH spectrum.
- Applying this correction is essential for the consistency of the HR and LR datasets.

- Assuming deep-water waves and that the dispersion relationship applies, we can compute sv for unidirectional waves, bypassing the use of any spectrum of any further assumptions, as:

$$T_{02} = 2\pi\sqrt{\frac{M_0}{M_2}} = \frac{\pi}{2}\frac{H_s}{\sigma_v}$$

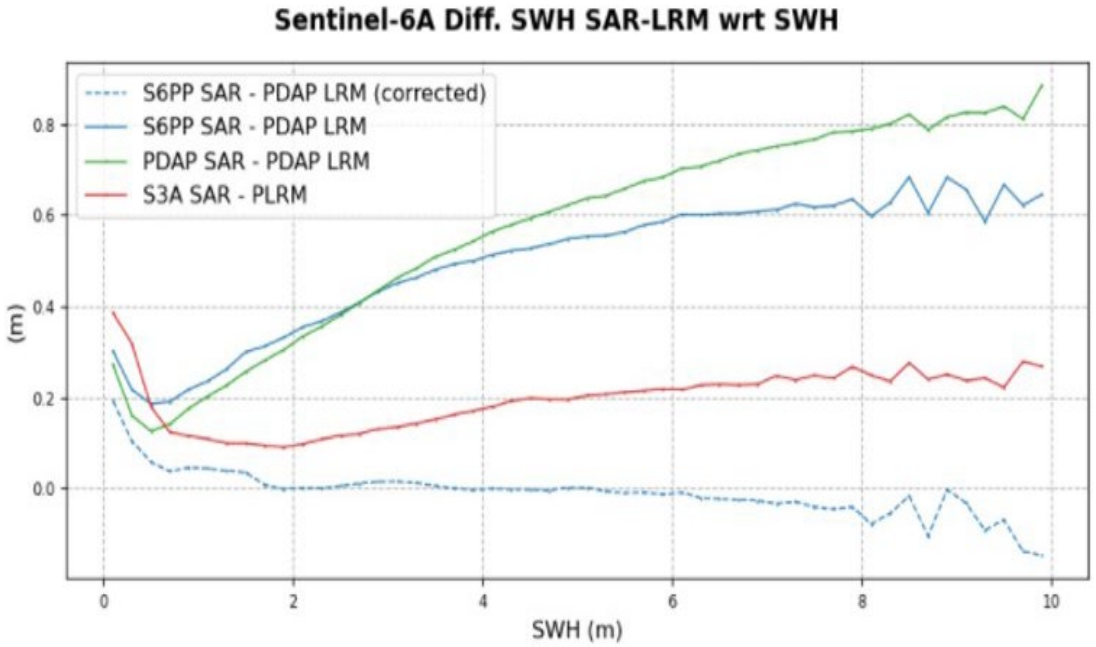
- We computed the HR SWH correction through numerical simulations of Sentinel-6/MF delay/Doppler maps.
- Based on these simulations, we were able to compute a correction for the SWH sea state dependent bias as a function of SWH and the standard deviation of waves vertical velocities ($s_v$).

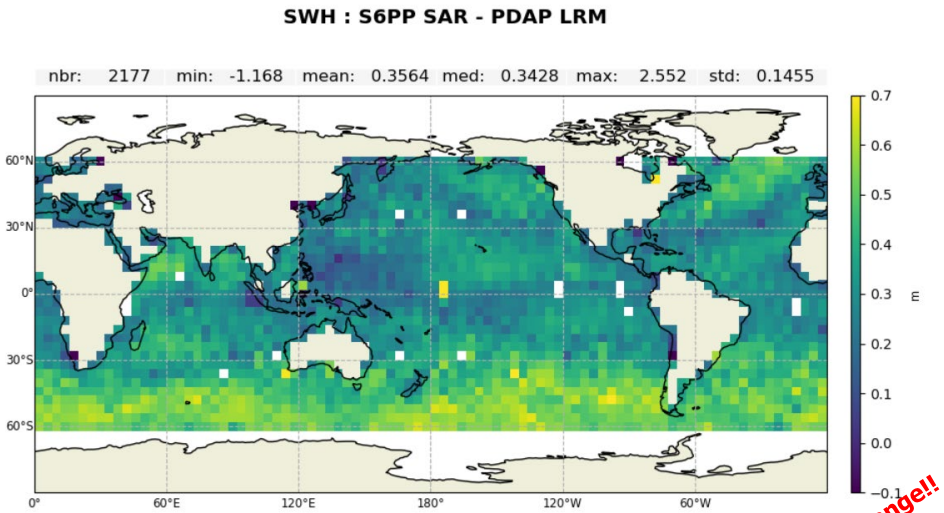


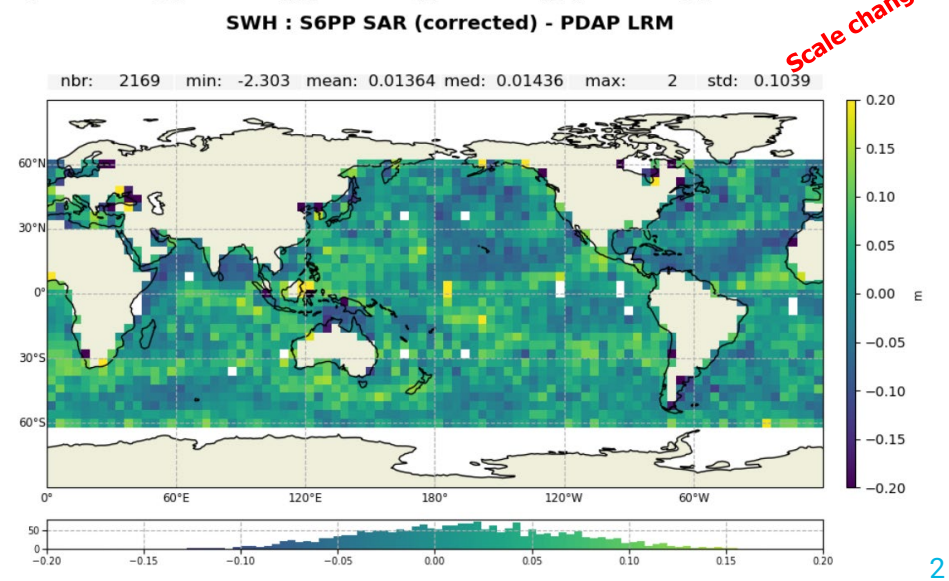
# Evolution: Improving HR SWH Estimates ➔ VV effects

## LUT assessment using CNES' S6PP

- The SWH LUT Correction drastically reduces HR SWH bias with respect to the LR mode data over the open ocean.
  - The results here presented derive from CNES's S6PP using a frequency domain fast convolution numerical retracking approach [Buchhaupt, 2018].
  - $s_v$ is computed based on the Meteo France WAve Model (MFWAM) mean wave period.
  - PDAP presents an additional bias, which is still under investigation.

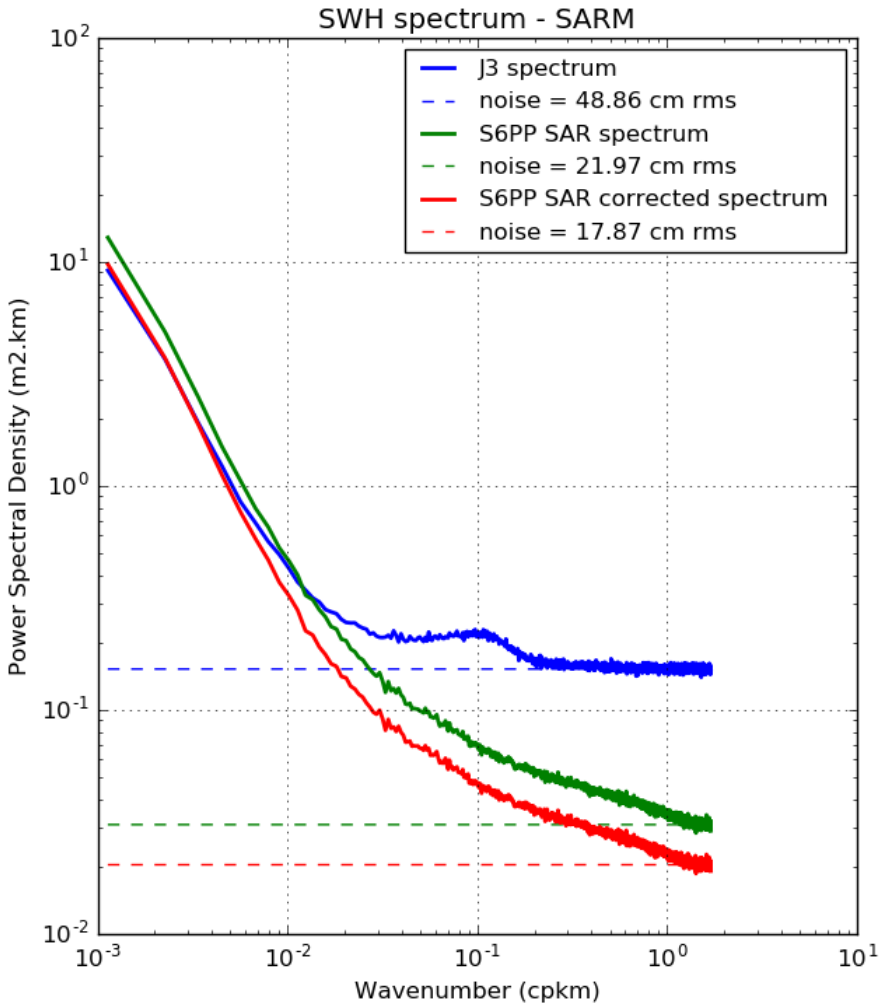


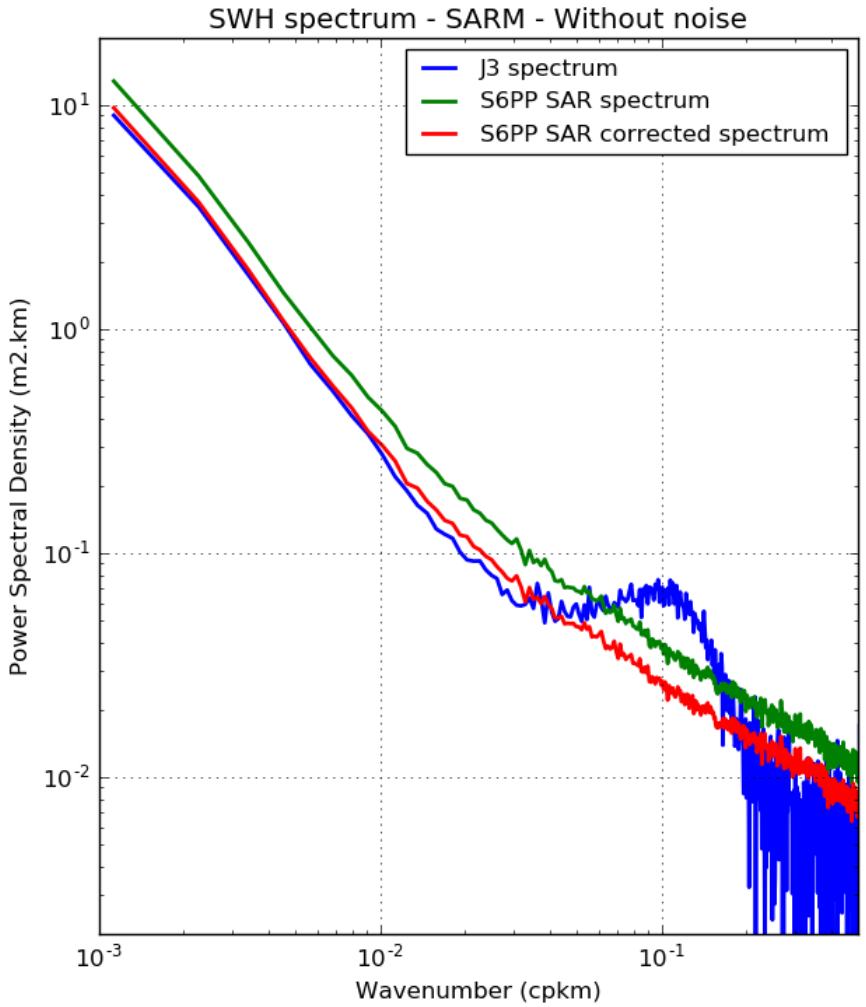



# Evolution: Improving HR SWH Estimates ➔ VV effects

- The analysis of the SWH spectrum shows that the application of the SWH LUT Correction reduces the noise level, and makes the longer wavelengths to be in agreement with J3.



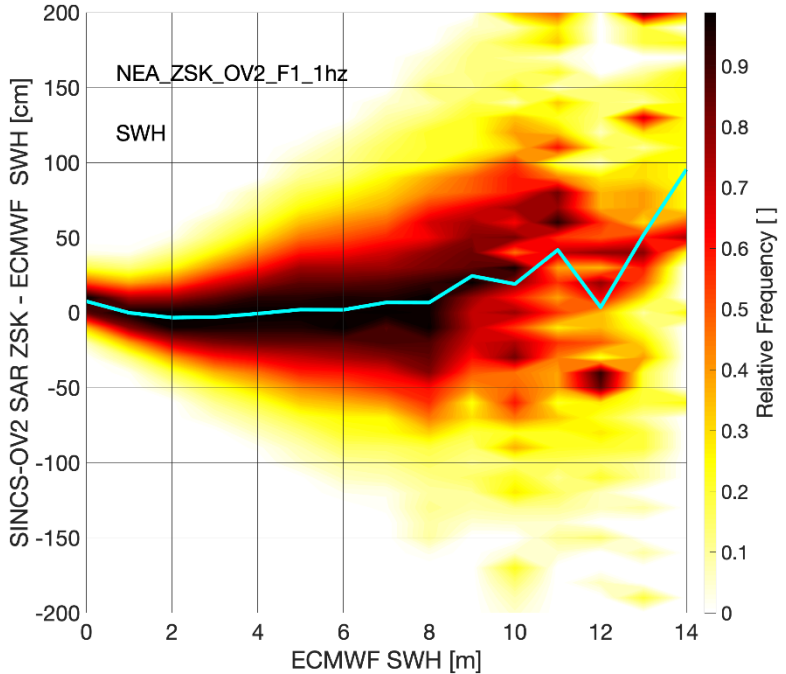
# Evolution: Improving HR SWH Estimates ➔ Possible Day-3 Evolution

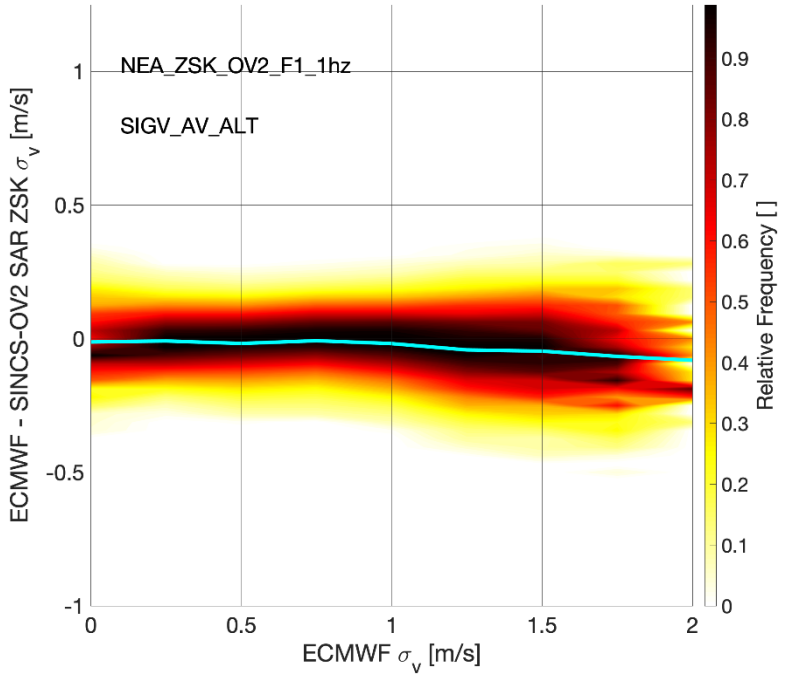
- At NOAA-LSA have implemented a physical retracker for the joint estimation of SSH, SWH, sigma-0, and standard deviation of waves vertical velocities (sigma-V); full derivation and results to be published in the following paper, currently under preparation:

**Conditional Sea Surface Statistics and Their Impact on Geophysical Sea Surface Parameters Retrieved From SAR Altimetry Signals**

Christopher Buchhaupt, Alejandro Egido, Walter H. F. Smith, and Luciana Fenoglio

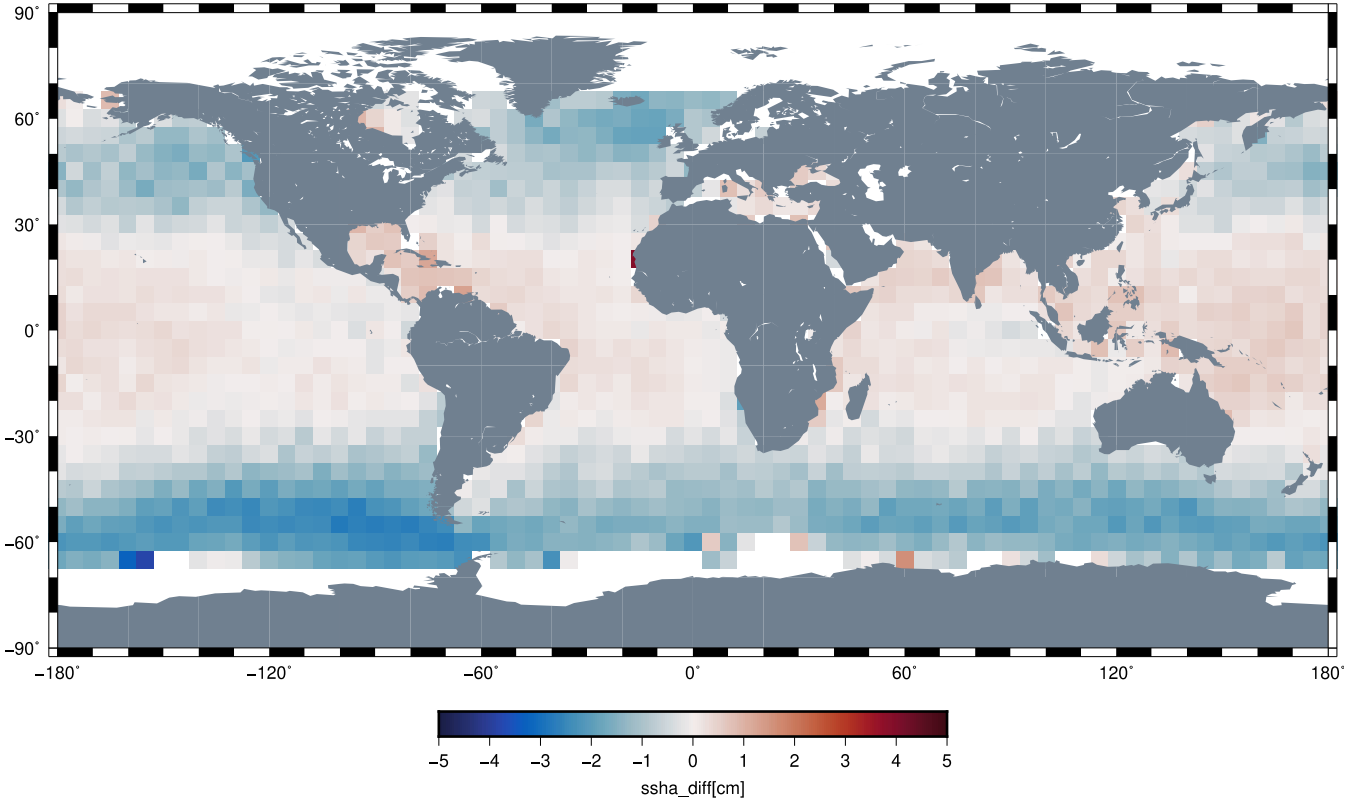
- The results, obtained with CryoSat-2 SAR mode data over the North-East Atlantic, show excellent consistency with SWH and sigma-V data when compared to ECMWF ERA-5 model.



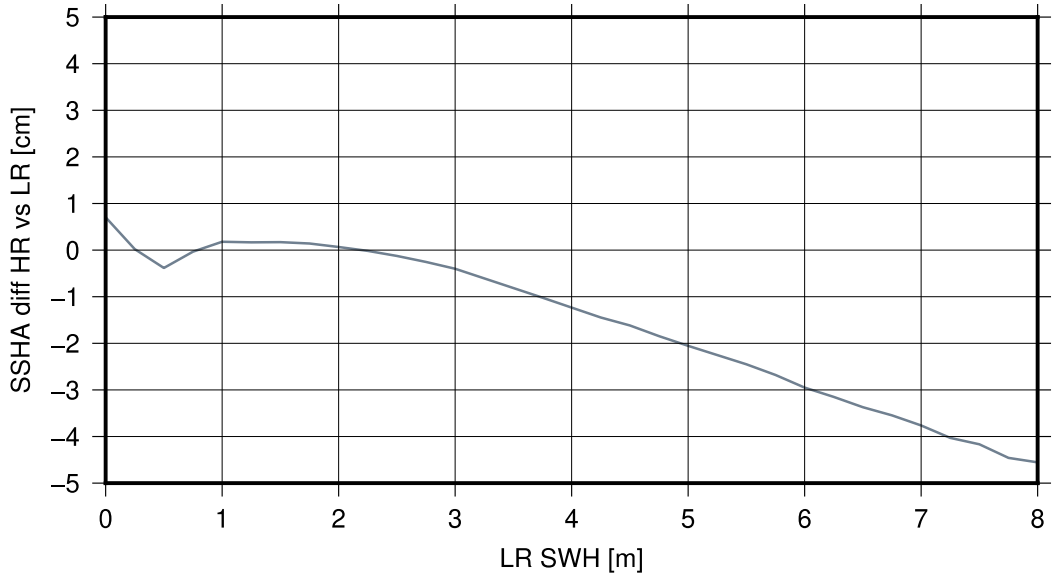



# Evolution: Improving HR SSHA Estimates

## HR - LR SSHA difference

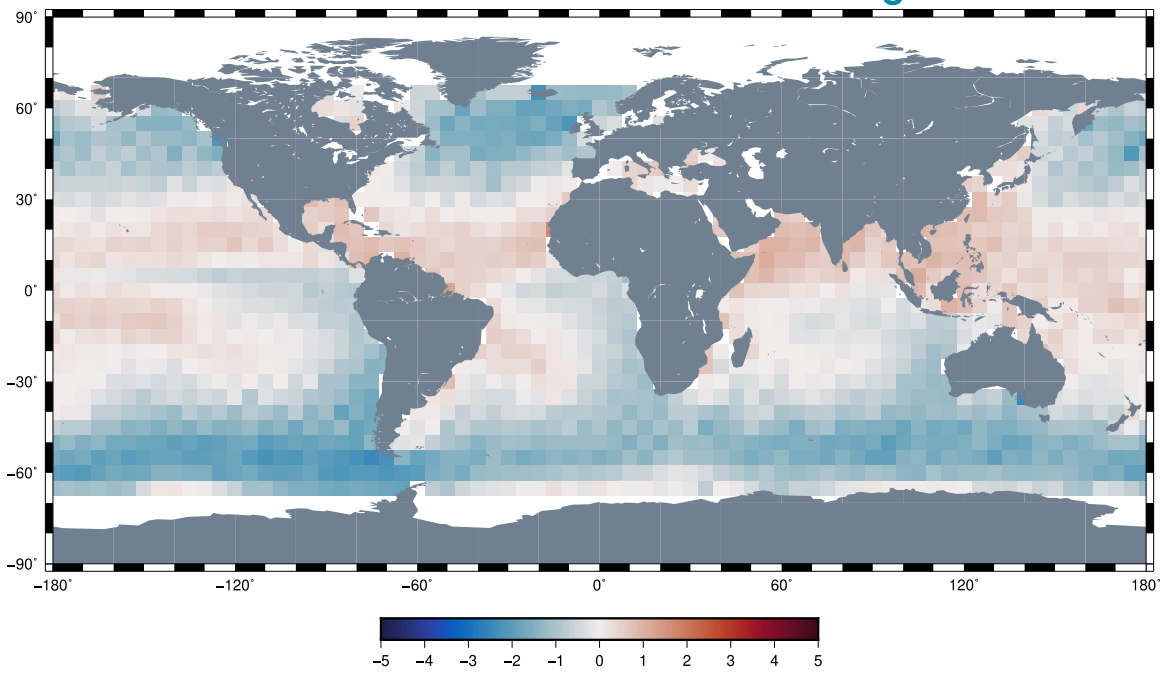



## HR - LR SSHA differences vs SWH

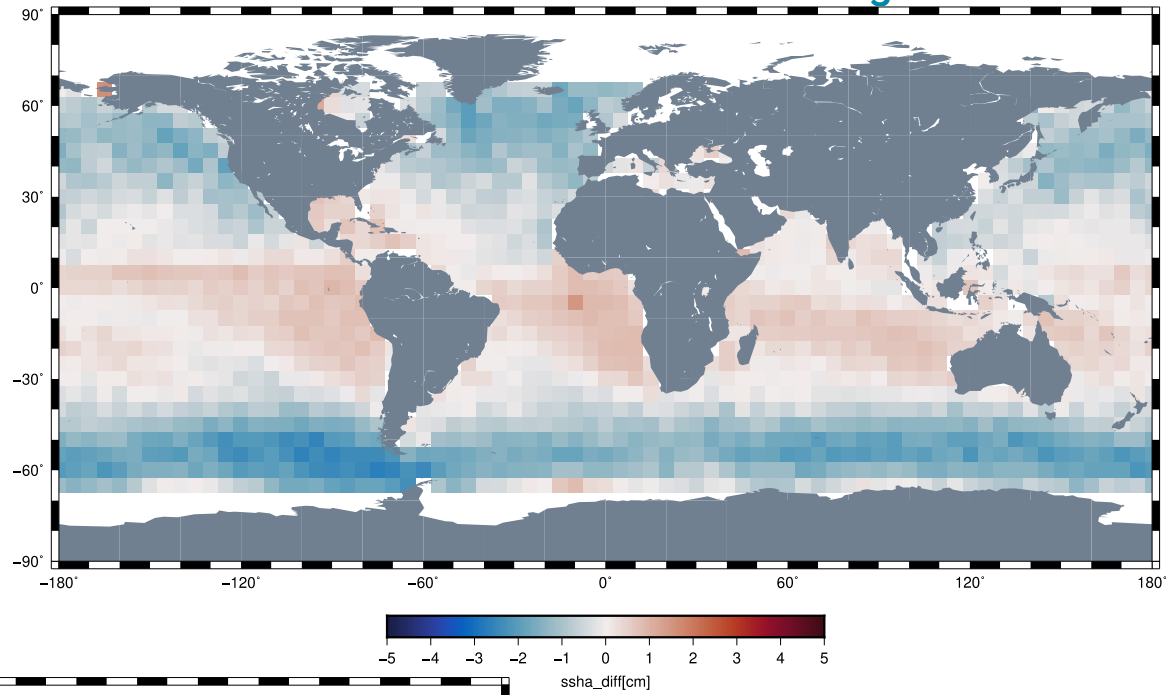


# Evolution: Improving HR SSHA Estimates

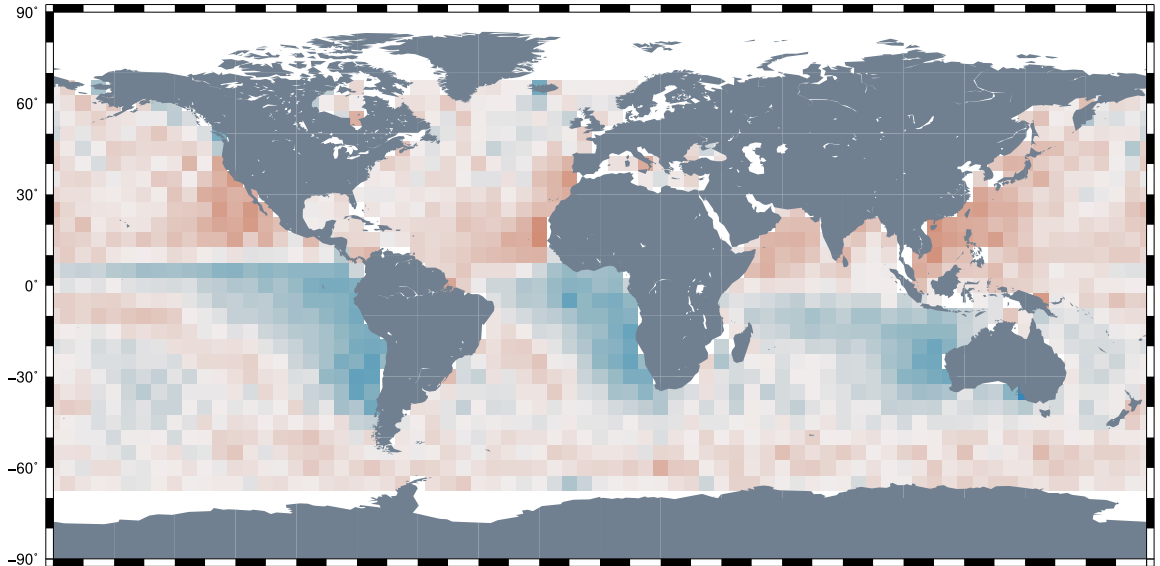
## HR - LR SSHA difference - Ascending




## HR - LR SSHA difference - Descending

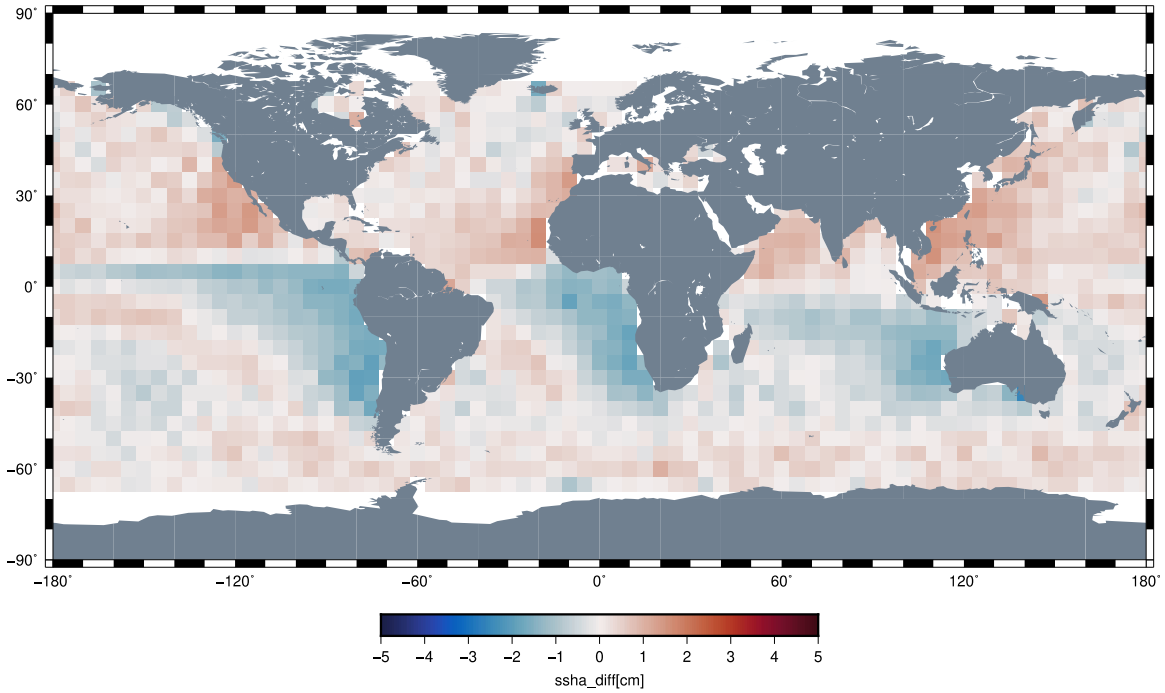



## HR - LR SSHA difference [Ascending – Descending]

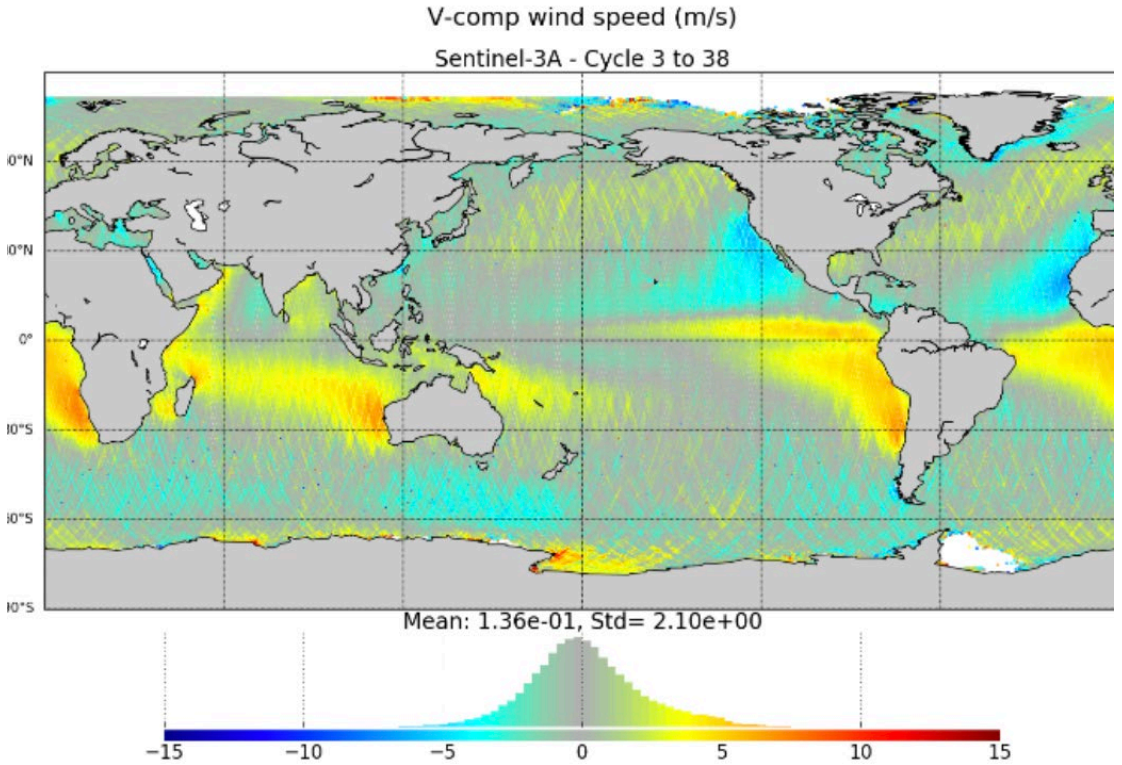


# Evolution: Improving HR SSHA Estimates

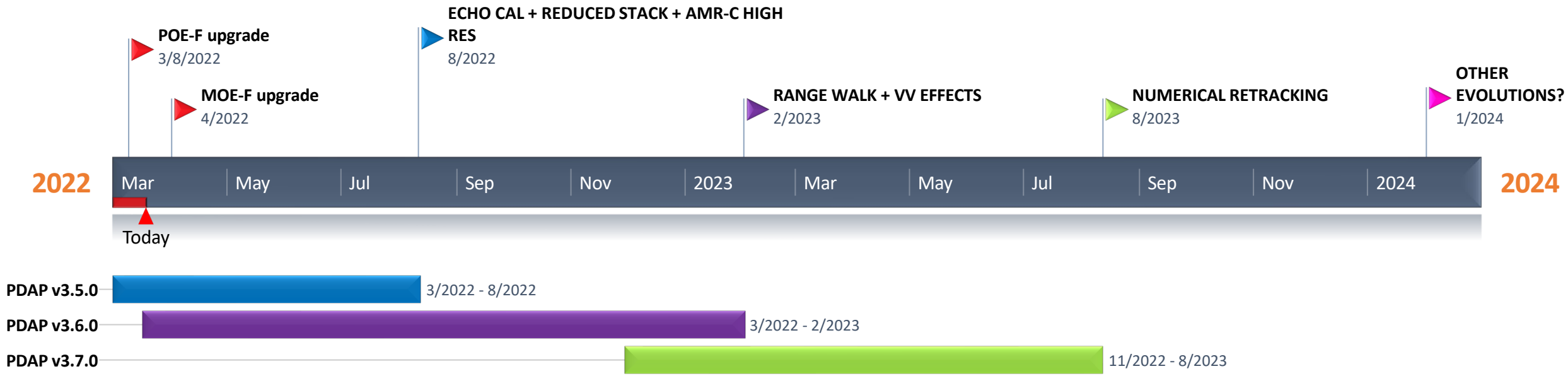
- The differences between HR and LR SSHA for ascending and descending passes has also been observed by CNES/CLS on S3A data.
- CNES/CLS have shown that this effect has strong correlation with **meridional wind component**.
- At this moment the effect of up-wind vs down-wind on the SAR waveform is not understood. Further investigation is needed.




HR vs LR SSHA difference
[Ascending – Descending]




**Meridional Winds. Image Credit, CLS.**
**Raynal, et al., S3VT Meeting #5, 7-9 May 2019, ESA/ESRIN, Frascati, Italy**




**IMPORTANT NOTE:**

These are all approximate dates.

# Thank you!

Questions are welcome.