Doppler Oceanography from Space

From science to technology and applications

10 -12 October 2018 Brest (France)

Analysis of Doppler signals from nadir altimeters over ocean

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Delay-Doppler Altimetry

Launched in 2016, Sentinel-3A has been measuring oceans, land, ice to monitor and understand large-scale global dynamics and to provide critical information for marine operations, and more.

On-board S3A, **the SRAL instrument is a Ku-Band Delay-Doppler altimeter** (also called SAR altimeter):

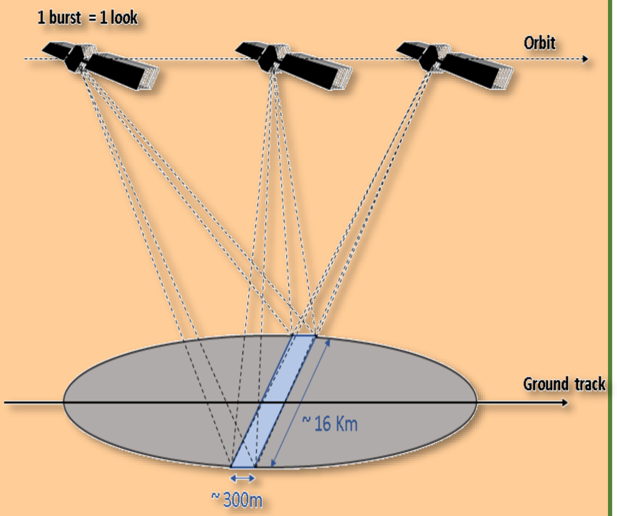
- **Nadir** looking instrument
- **Doppler capability** (coherent pulses) – Bdop = 15kHz
- **High PRF** (18kHz)
- Closed-bursts chronogram

The Doppler bandwidth is used through an unfocused SAR processing to improve the instrument azimuth resolution (~320m). Then multi-looking is applied for speckle noise reduction (**High resolution** altimetry vs conventional/low resolution altimetry (Jason's missions)

Higher performances wrt conventional altimetry and better meso-scale signals observation.

Unfocused SAR (SAR mode)

[Raney, 1998]



- Coherent processing on a burst (3.5ms)
  ➔ **Along-track resolution ~ 300 m**
- Multi-looking (sum of independent looks)
  ➔ **Noise level reduction**

Rationale

In preparation of SKIM mission,

what can we learn from nadir altimeter doppler signals?

A priori, **not so much**…

- Nadir looking instrument
- Not designed to measure surface velocities
- Wave orbital motion should be averaged

So, we should see **only the satellite velocity**…!

However, our curiosity has led us to look.

Phase of radar altimeter signals

After deramping and range compression, the resulting signal S_i, acquired by a radar altimeter at time η on a nadir point scaterrer can be approximated as:

$$S_i(\underbrace{\tau_R}_{\text{Time delay (fast-time)}},\underbrace{\eta}_{\text{Slow time}}\ ) \approx G\ sinc[\ \underbrace{B}_{\text{Bandwidth}}\ (\tau_R - \underbrace{\tau(\eta)}_{\text{two-way travel time}})] . \exp\left(2\pi j\ \overbrace{(\underbrace{f_c}_{\text{Carrier frequency}}\tau(\eta))}^{\text{Relative Range Phase}} + \overbrace{\frac{1}{2}\underbrace{\alpha}_{\text{Chirp rate}}\tau(\eta)^2}^{\text{Residual Video Phase}}\right)$$

RVP << 1
Can be negligible

S_{i+1} , acquired at time η + PRI, can be expressed as:

$$S_i(\tau_R, \eta + PRI\ ) \approx G\ sinc[\ B\ (\tau_R - \tau(\eta + PRI)] . \exp(2\pi j\ (f_c \tau(\eta + \mathrm{PRI}))$$

$$With\ \tau(\eta + PRI) = \tau(\eta) + 2 * RadiaVelocity * PRI/c$$

Before range compression, S_{i+1} can be aligned in range wrt S_i (with 2*RadVel*PRI/c phase rotation in range). With this correction can be written as:

$$S_i(\tau_R, \eta + PRI\ ) \approx G\ sinc[\ B(\tau_R - \tau(\eta)] . \exp(2\pi j f_c \tau(\eta) + 4\pi j f_c * RadVel * PRI/c)$$

Pulse-pair processing on radar altimeter pulses

We apply a pulse-pair processing to two consecutive radar pulses.

The measured phase can be expressed as:

$$\Phi = \arg(\, S_i S_{i+1}^{*})$$

$$\Phi = -4\pi f_c * RadVel * PRI/c$$

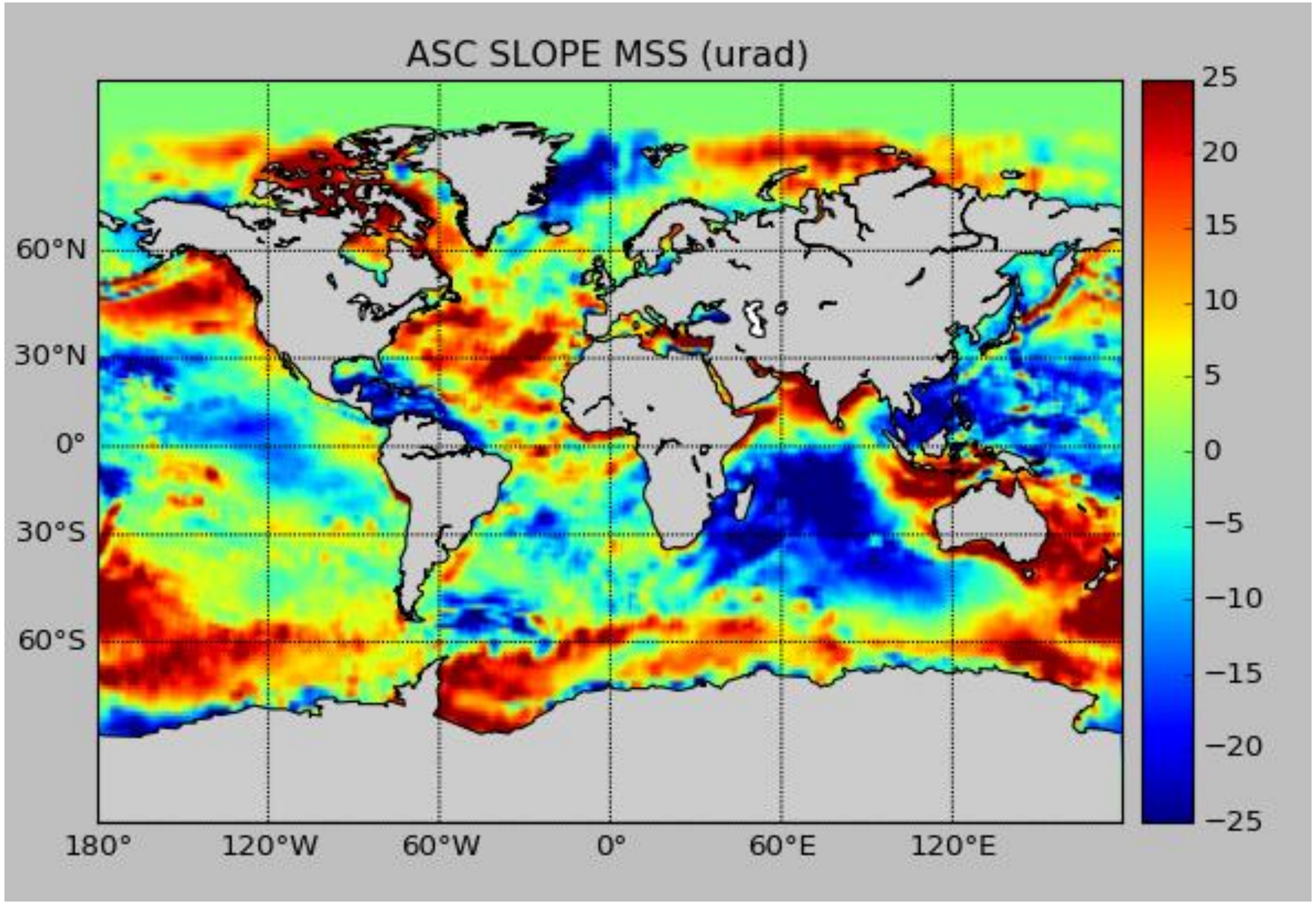
$$\Phi = -4\pi f_c * RadVel * PRI/c$$

This gives directly the Doppler Frequency of the signal S_i

$$\mathrm{F} = -2 * f_c * RadVel/c = -f_d$$

The Doppler anomaly is the deviation between the measured frequency and the Doppler from the satellite velocity.

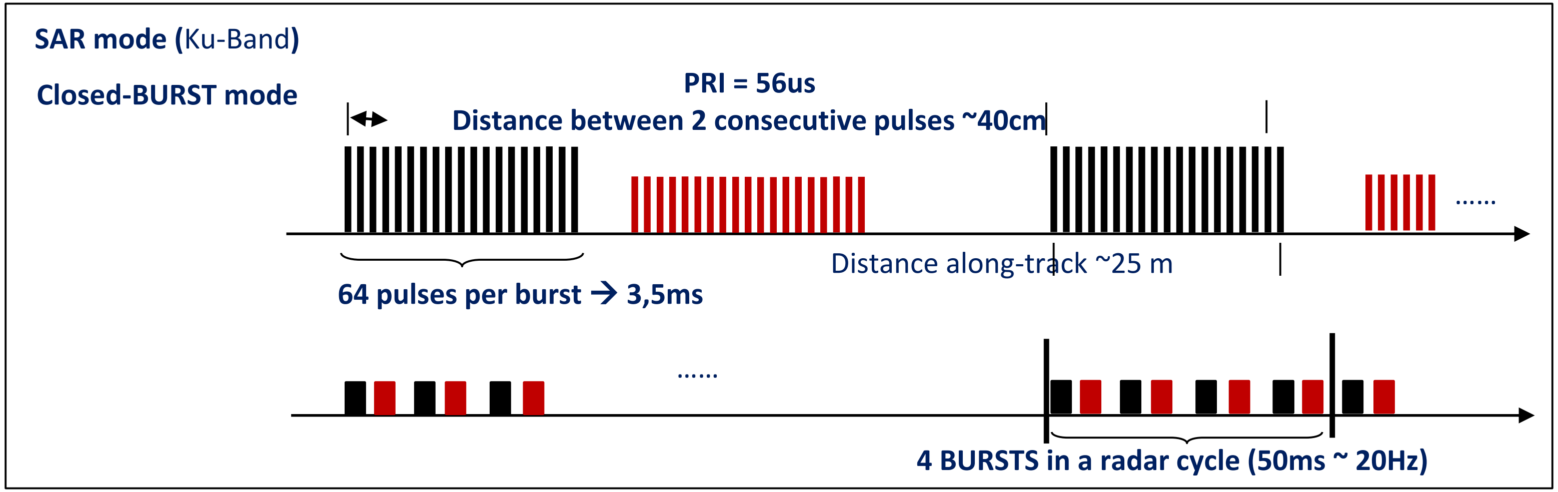
Don’t forget the Mean Sea Surface Slopes !



50urad = 15Hz

Application on Sentinel-3/SRAL SARM data

S3/SRAL SARM Chronogram:



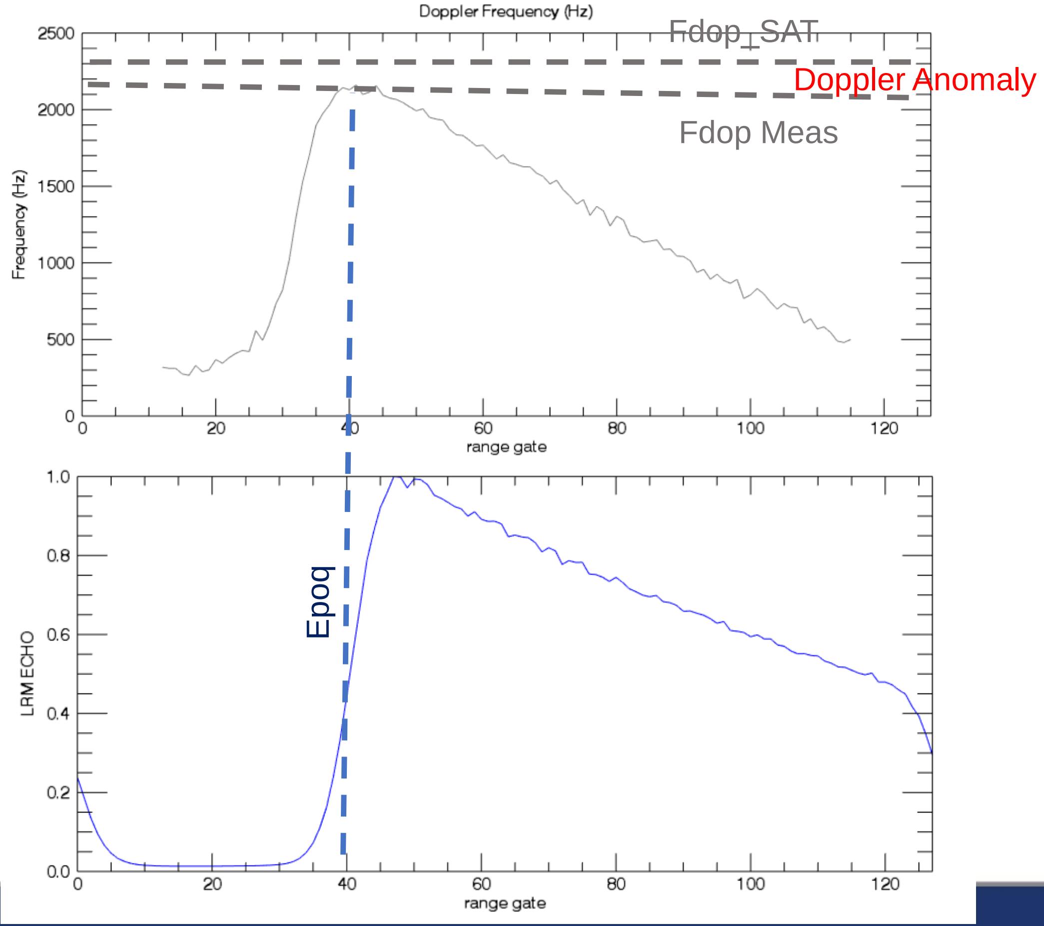
For each radar cycles:

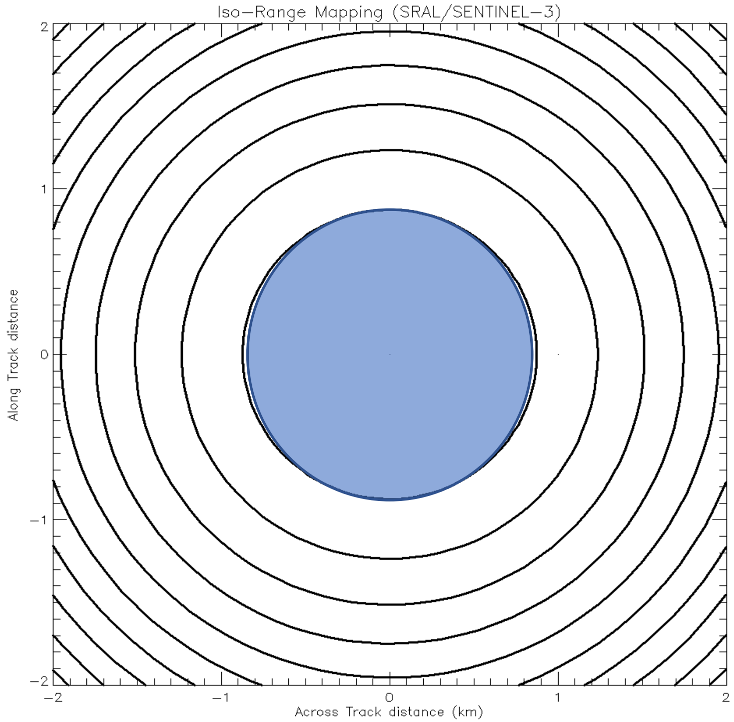
- Pulses are **calibrated** (corrected for all instrumental phase)
- **Range compressed**
- **Pulse-pair** technique is applied on 63 pairs in each burst (total of 252 phase signals on 128 gates)
- All PP phase signals are **averaged through the cycle**
- The phase is measured **@ *epoq* gate** (given by the retracking of Doppler power echoes) – linear interpolation is used
- The theoretical **Doppler frequency is removed** to get the **Doppler anomaly**

Application on Sentinel-3/SRAL SARM data

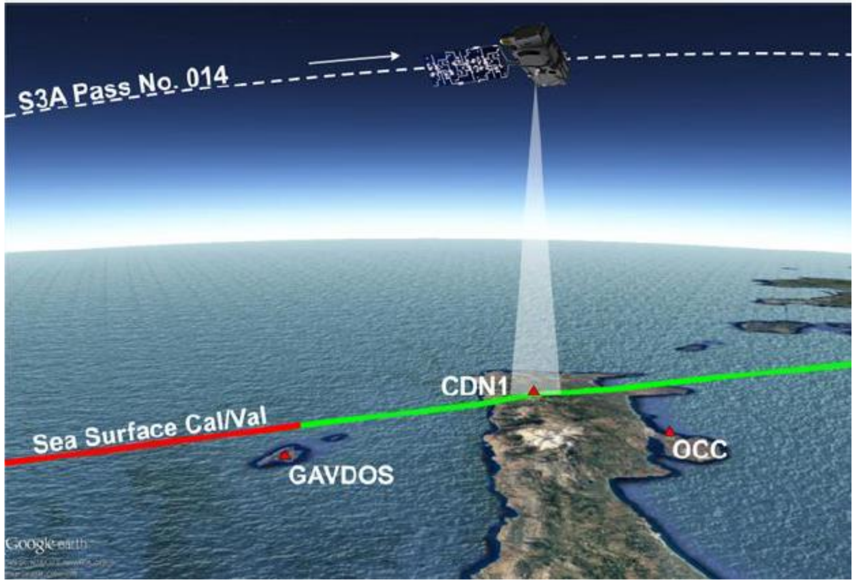
Over ocean, we intend to measure the **doppler anomaly** on the first range cell.

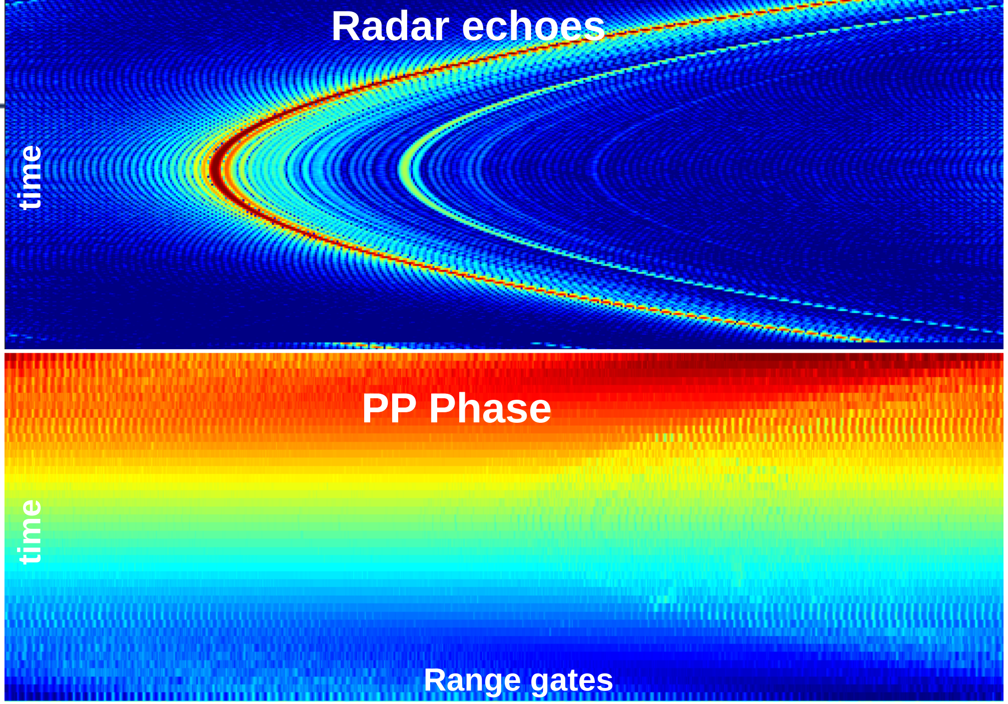
Epoq is given by the **retracking** of the altimetry echo.

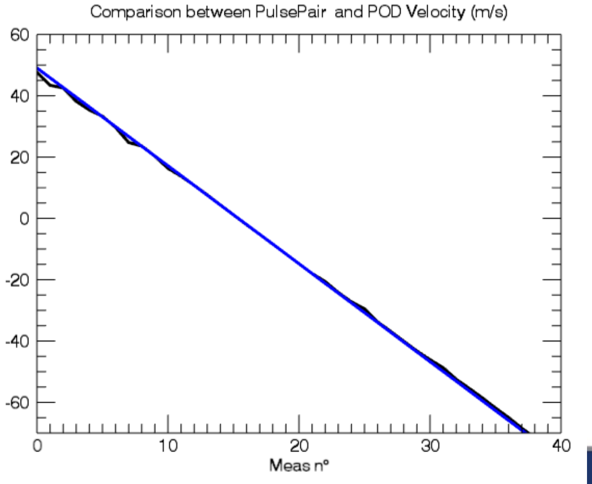


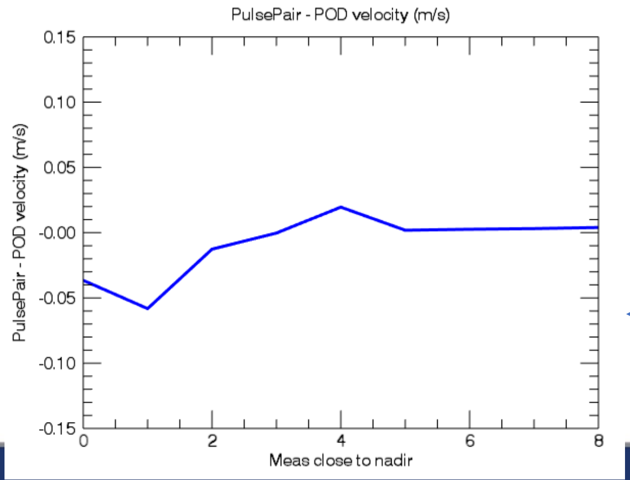


Validation over the transponder







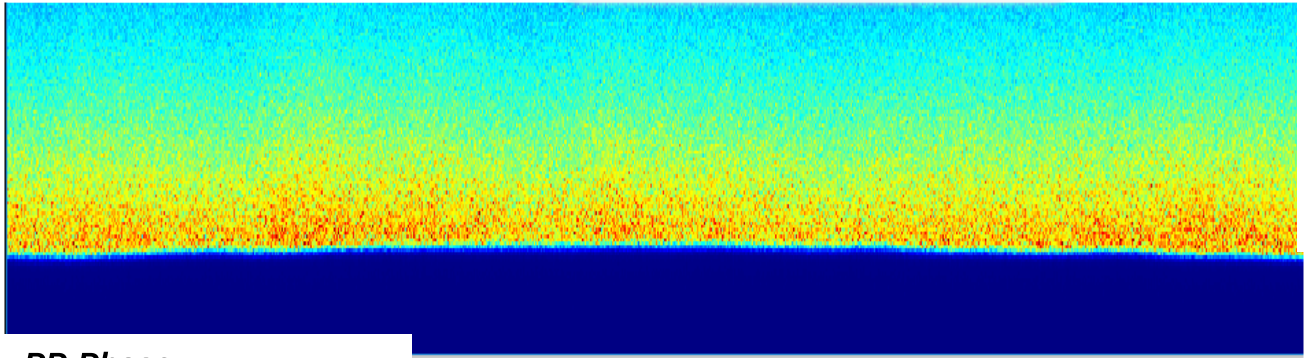


Good precision and accuracy close to nadir

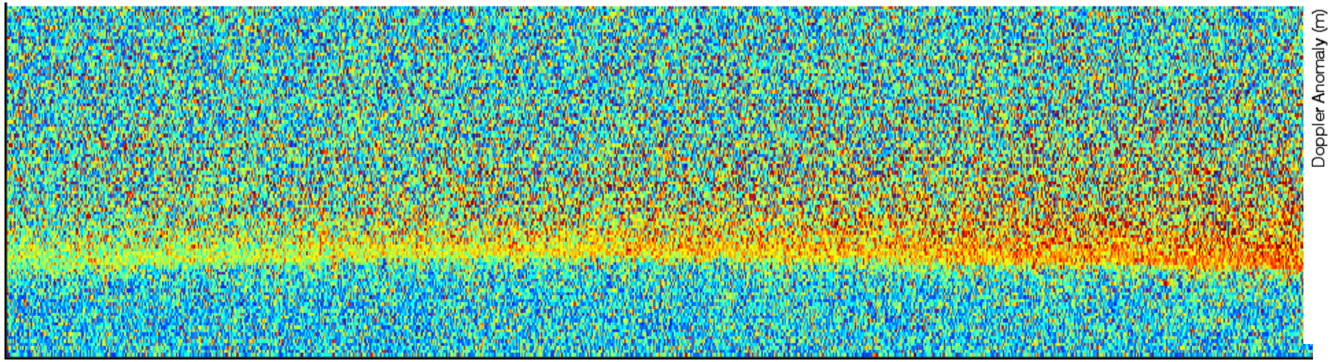
Application over ocean – 1st case

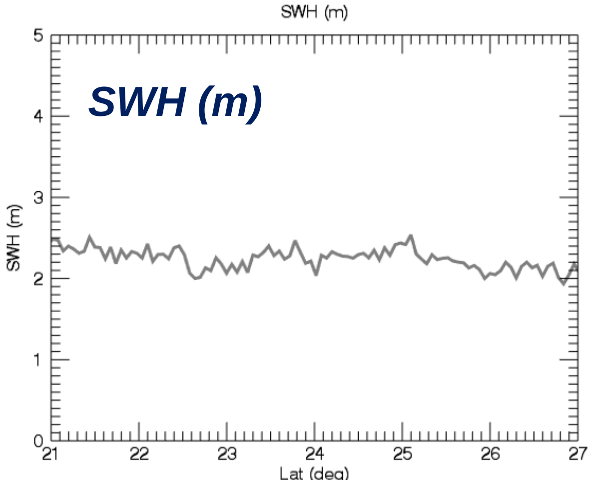
Normal SWH ~ 2,5m
Normal Sig0 ~ 13dB
RadVel ~ 6,5 m/s

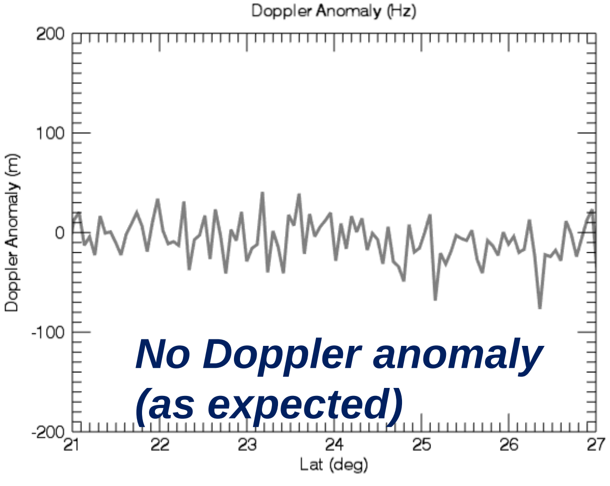
Echoes



PP-Phase



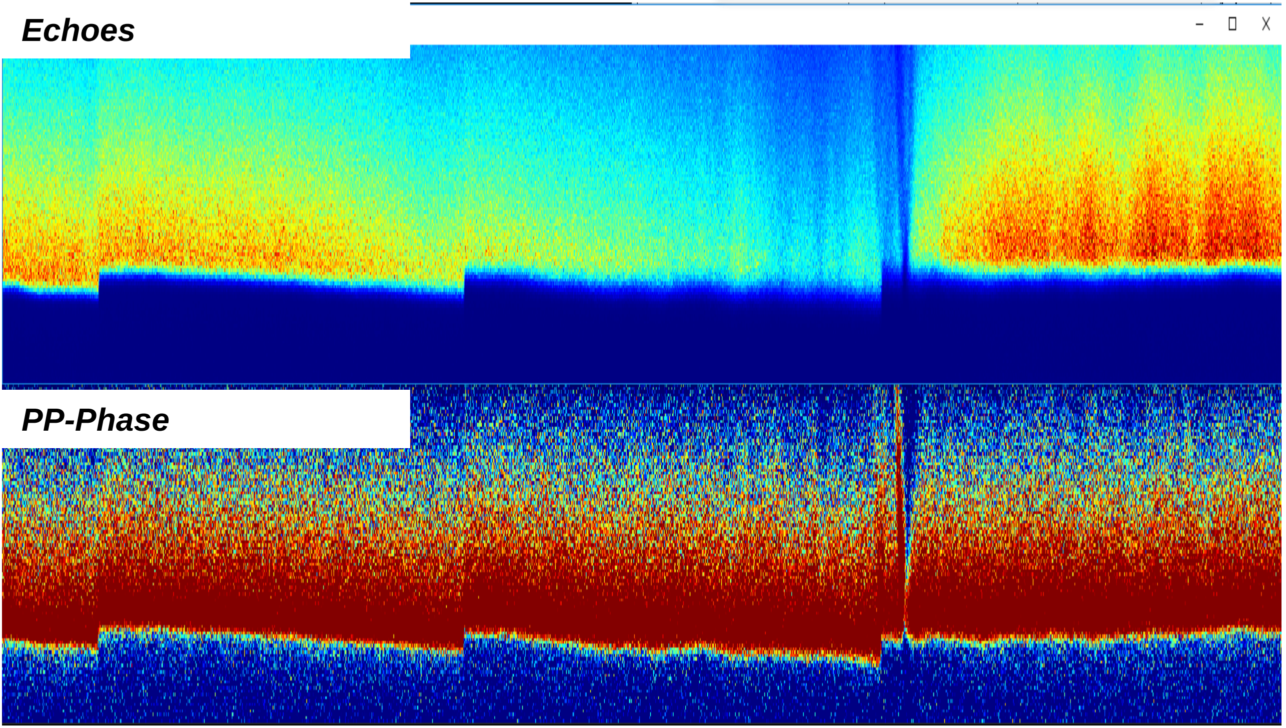


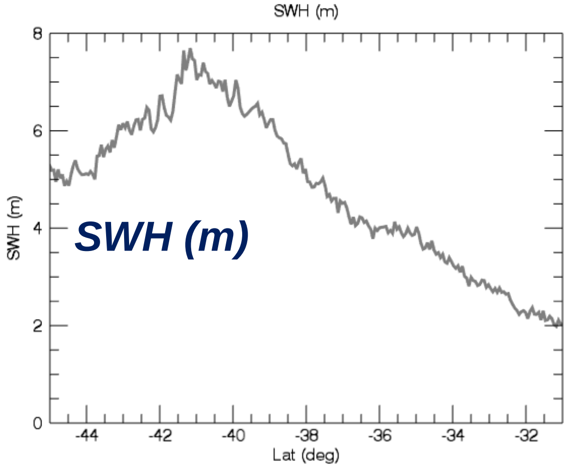


No Doppler anomaly (as expected)

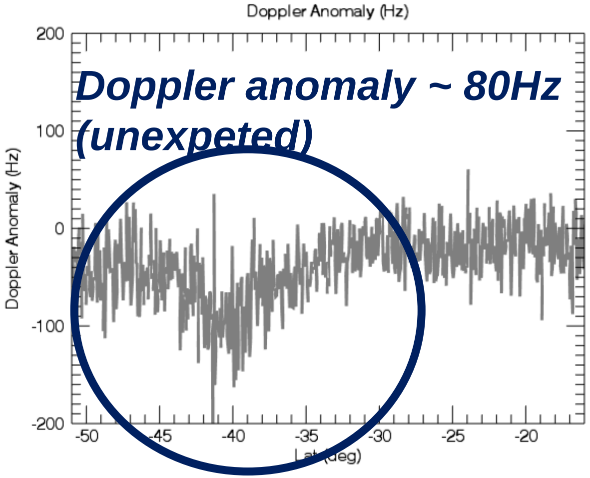
Application over ocean – 2nd case

High & Normal SWH ~ 8m&3m
Low Sig0 ~10db
RadVel ~ 20 m/s





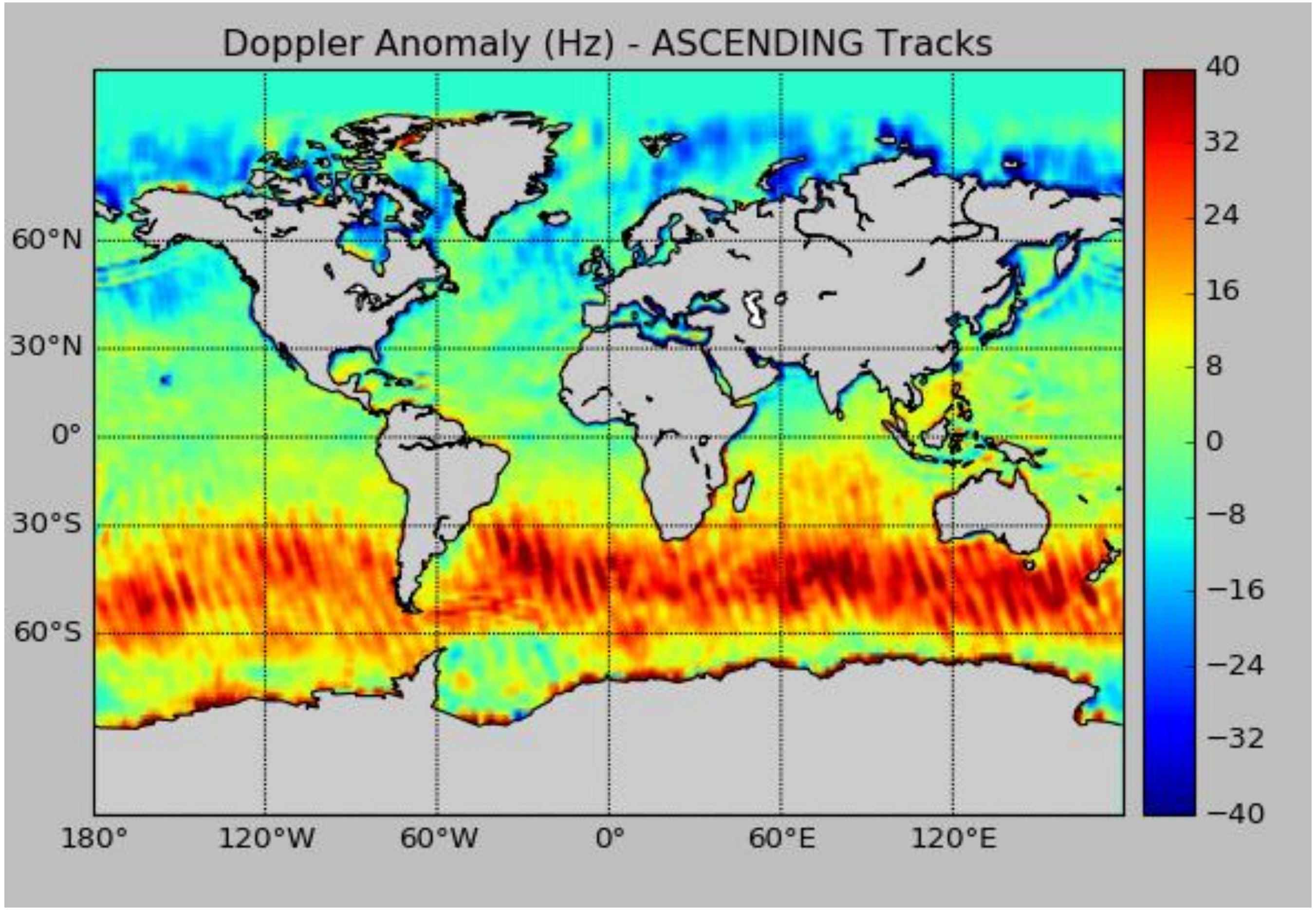
SWH (m)



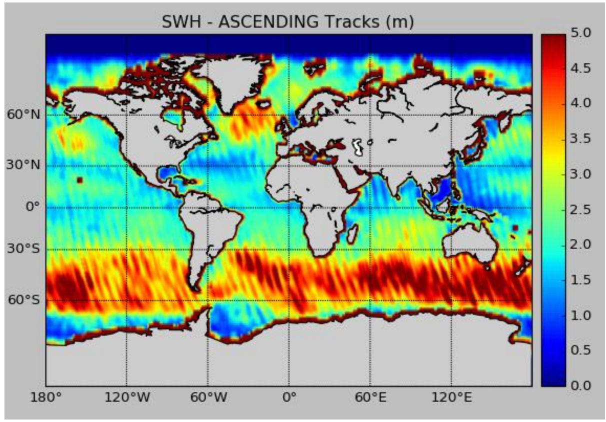
Doppler anomaly ~ 80Hz (unexpeted)

Application over ocean – Global – ASC TRACKS

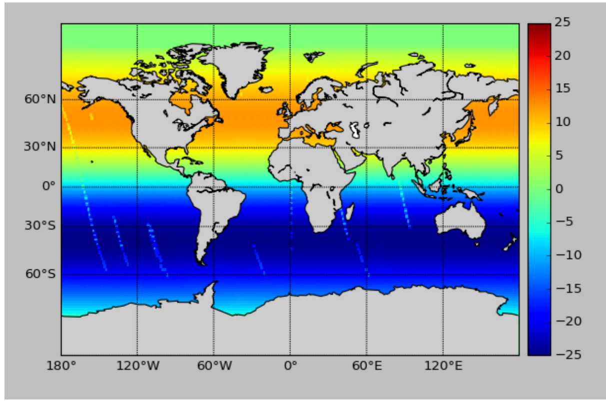
Doppler anomaly (Hz)



SWH (m)

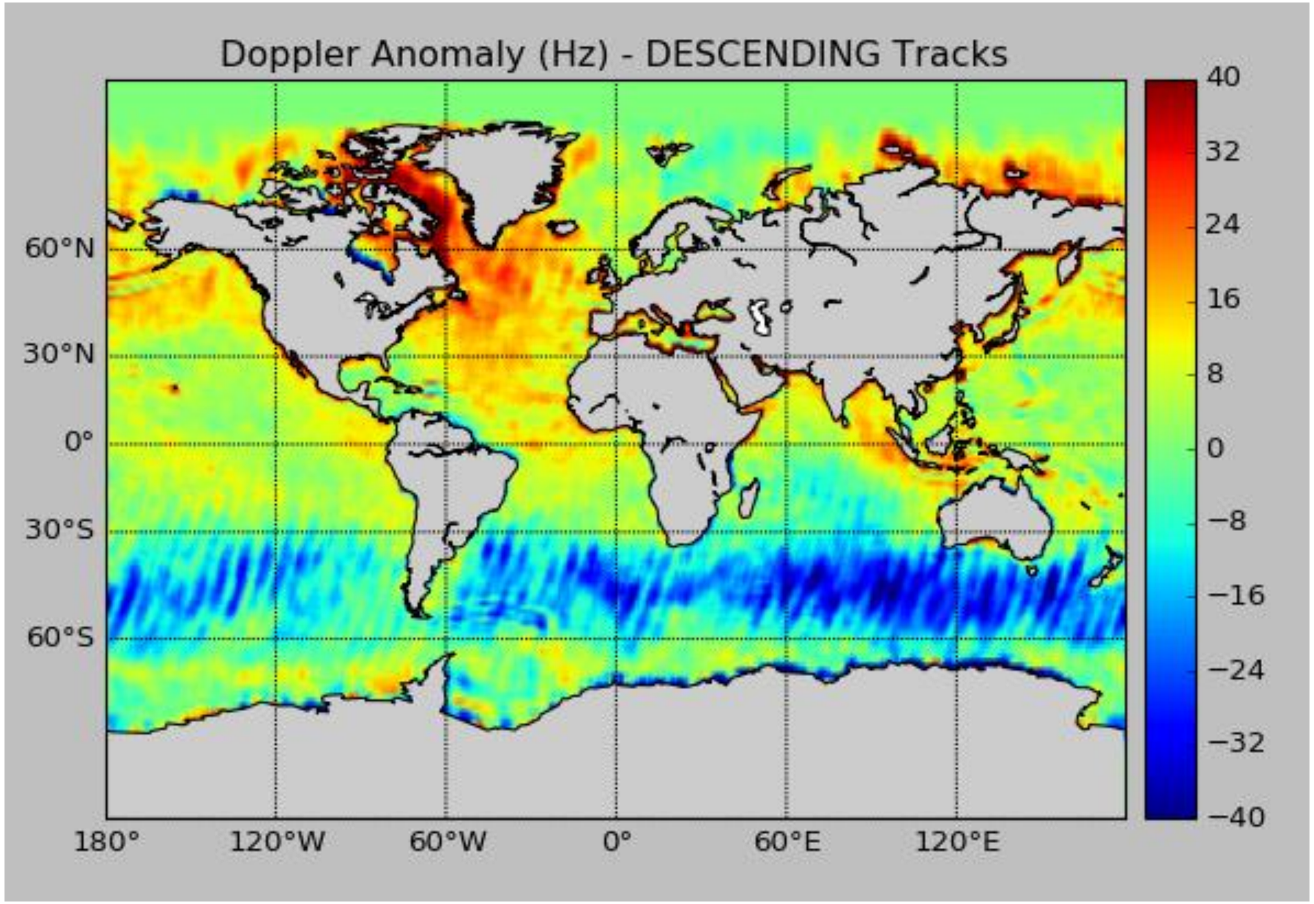


Radial velocity (m/s)

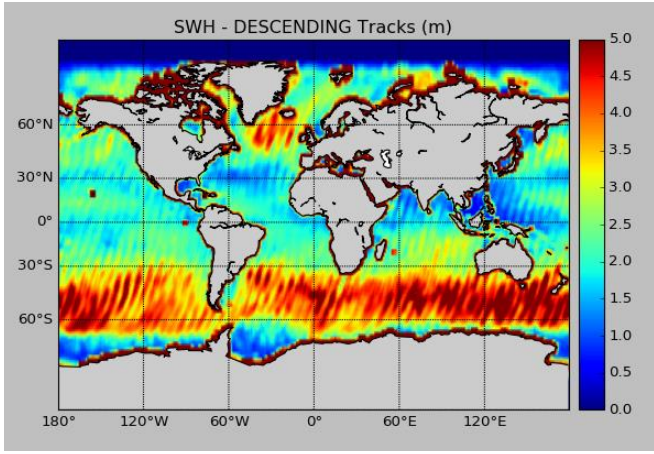


Application over ocean – Global – DESC TRACKS

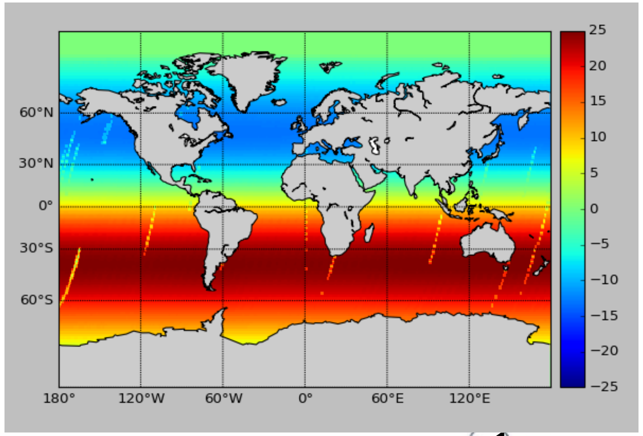
Doppler anomaly (Hz)



SWH (m)



Radial velocity (m/s)



Conclusion & Perspectives

what can we learn from Doppler signals of nadir altimeter?

More than expected!

Clear Doppler anomalies (up to 50Hz) are observed over ocean @ nadir:

- Correlated to high SWH (elsewhere, the Doppler anomaly is almost null)
- Sign of Doppler anomaly depends on sign of radial velocity (or tracks direction)
- The measured Doppler is always lower than the Doppler from satellite velocity
- Correlated to wind speed?

What's the origin of this effect?
Is it applicable/transferrable to SKIM?

More investigation is planned is the coming weeks to bring answers:

- Investigating the PP algorithm implementation
- Processing more data
- Comparison with models (WW3)
- Using simulator

Thank you