Effect of swell and wind-waves on the altimeter-derived estimates

Analyzing real and simulated data

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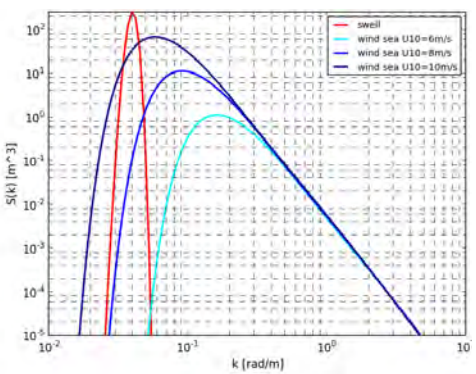
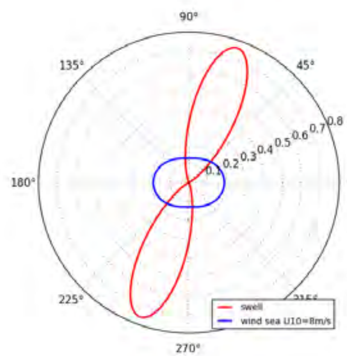
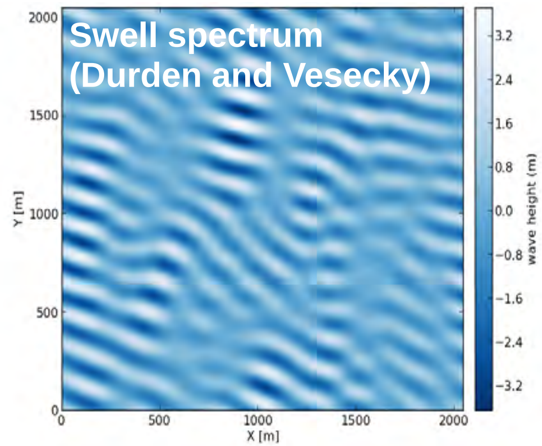
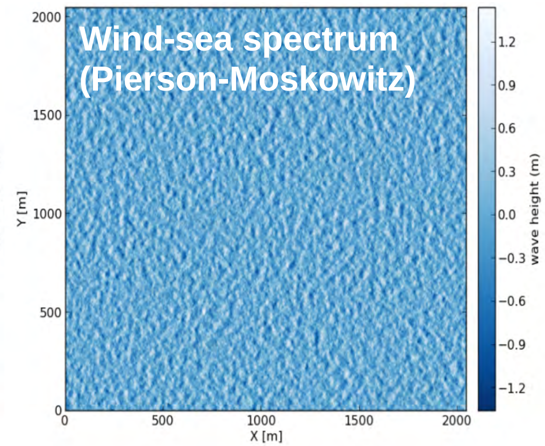
  - R&D on SAR-mode sensitivity (and LRM) to long waves
  - Analyze of impact of wind-sea on LRM in CFOSAT project









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- First evidence of impact of swell on real SAR altimetry data by *Aouf et Phalippou* [2015]
  - Showing Cryosat-2 wave height estimates likely biased by ocean swell (most noticeably for longest waves and swell fields propagating in a direction parallel to the satellite track)

SEA STATE: WAVE HEIGHT AND PERIOD

- Wave conditions are frequently represented by **Hs** and **Tm**

$$m_x = \iint f^x S(f,\varphi)\, df\, d\varphi$$

m_x : x – order moment

S : wave height spectrum

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ϕ : wave direction

Significant wave height: ***Hs = 4 sqrt(m0)***

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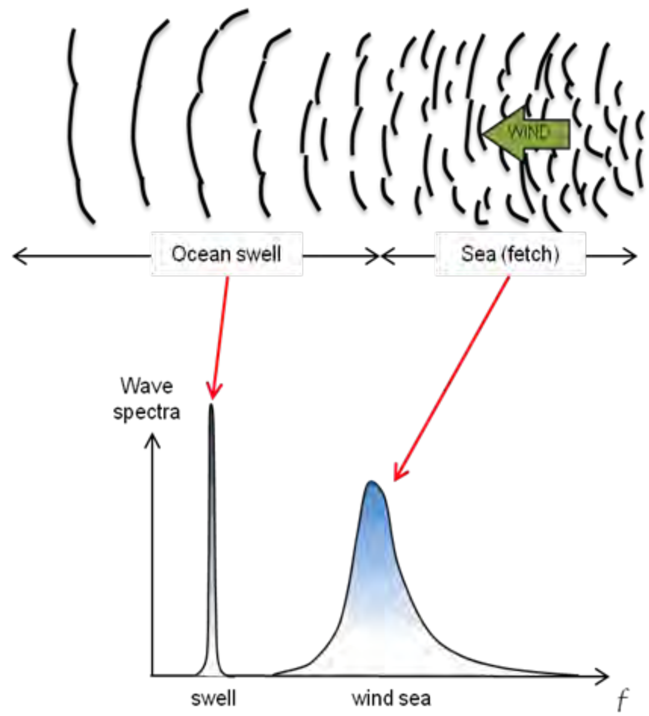
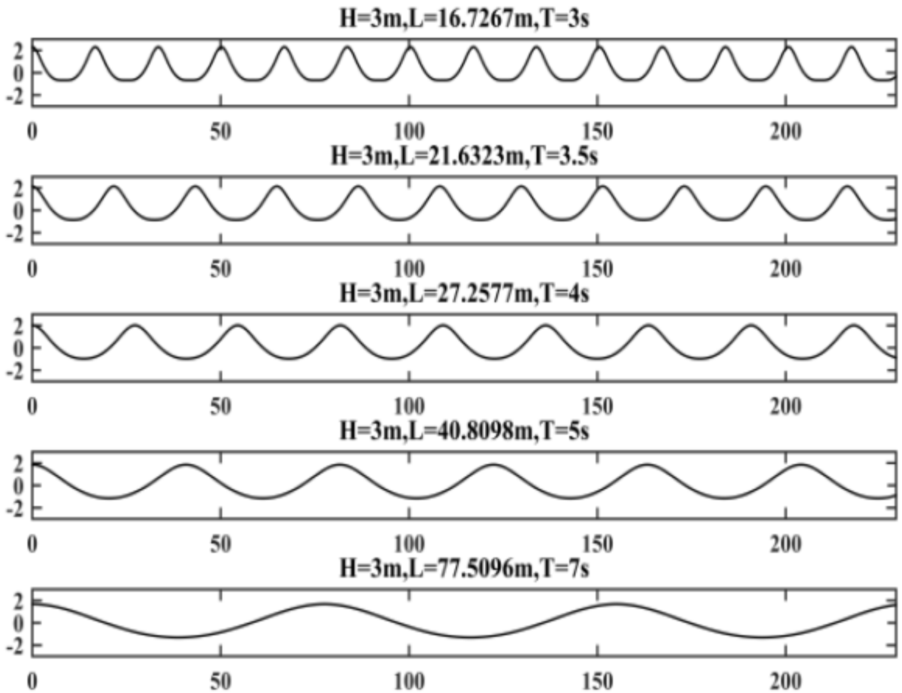
- In altimetry, **processing design (retracking) only considers wave height (pdf based on Hs), ignoring Tm**
- With increasing spatial resolution (from 10km to 300m in SAR-mode), **radar measurements shall become sensitive to long wavelength wave periods** (i.e. swell)



SEA STATE: WAVE HEIGHT AND PERIOD

- For a given Hs (or Tm respectively) sea surface may have different aspects **which may result in different altimetry radar returns**

fixed Hs, variable T



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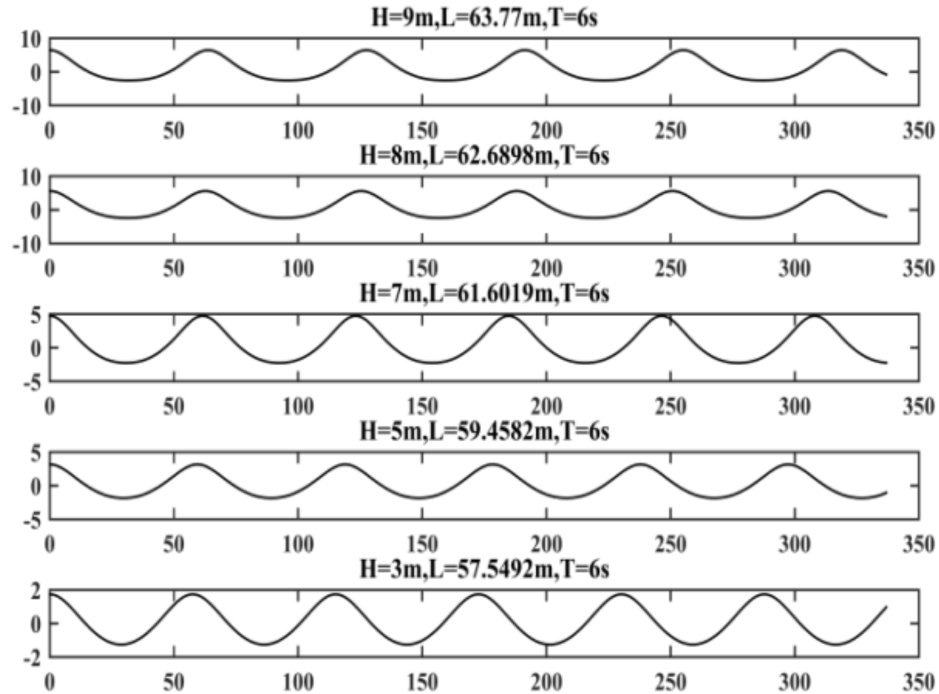

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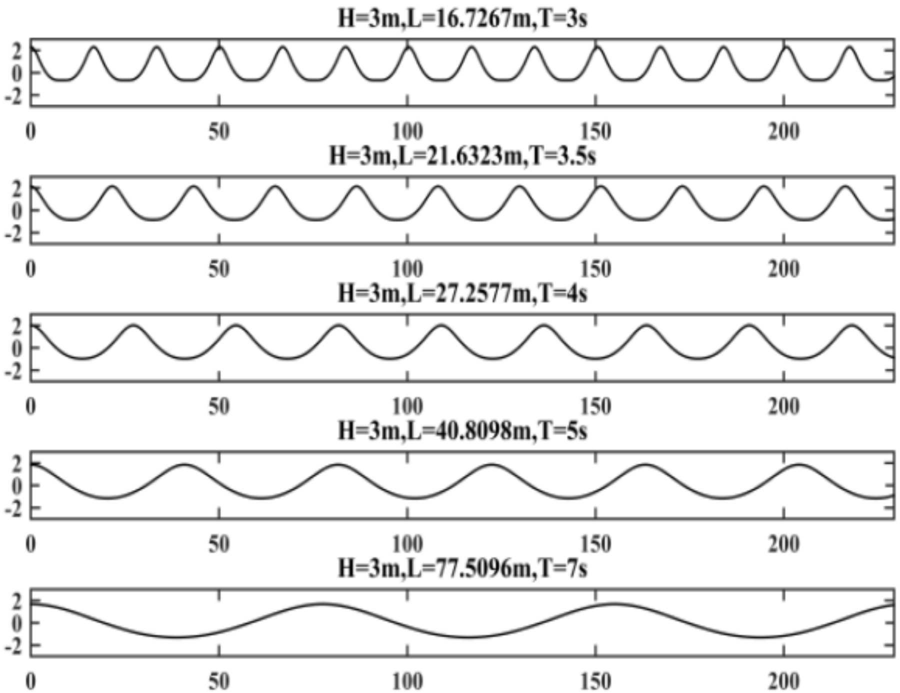

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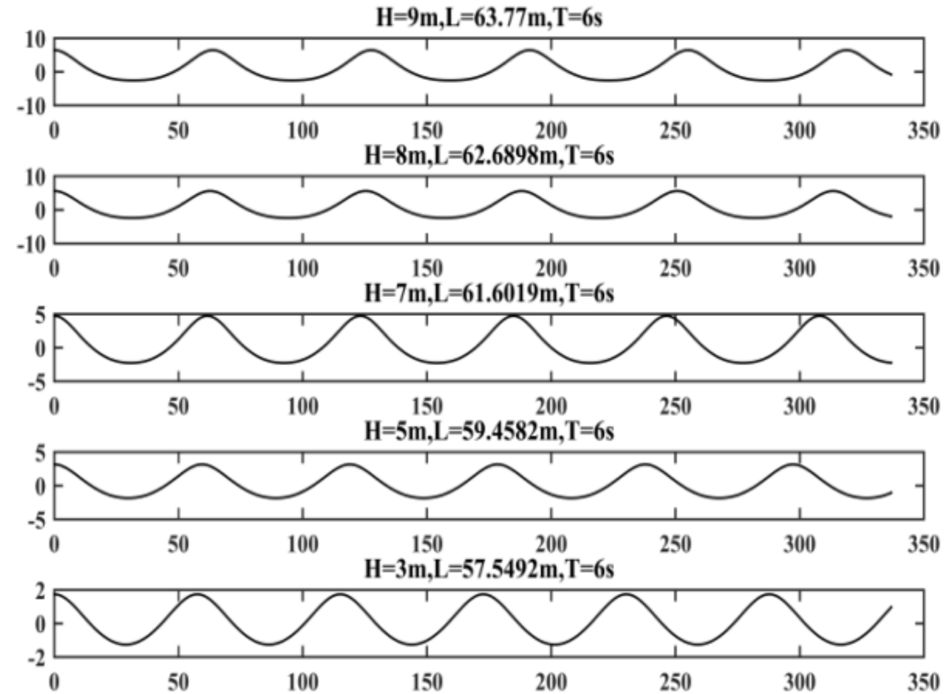
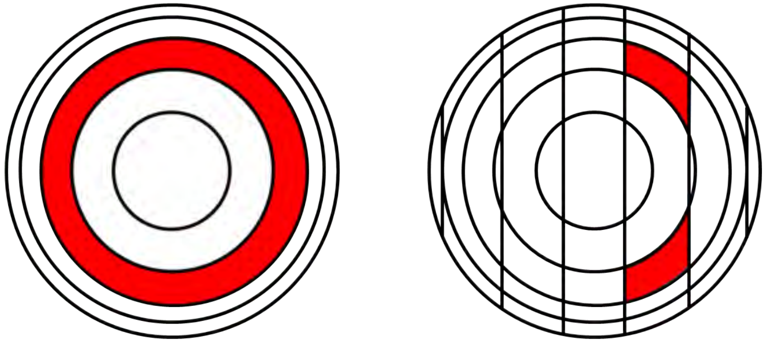


- In addition, ocean surface is complex with mixing wave systems (crossing swell fields and wind sea). **Two wave fields with the same Hs and Tm may also be different in detail.**

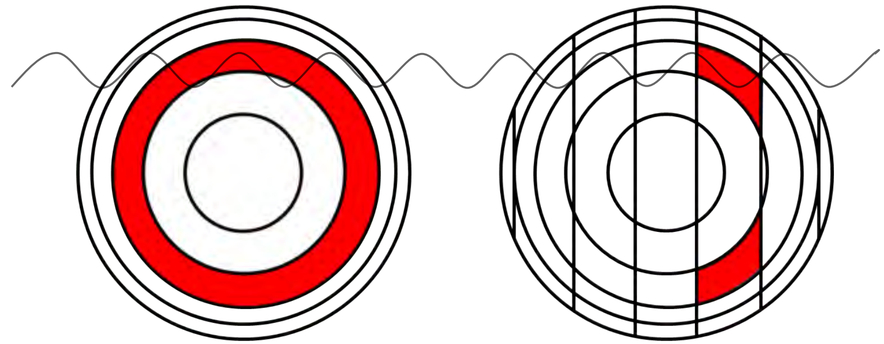
SIMULATION STUDIES



Conventional altimetry (LRM)

Delay/Doppler altimetry

- Doppler echo shapes are distorted, and retrieved parameters altered



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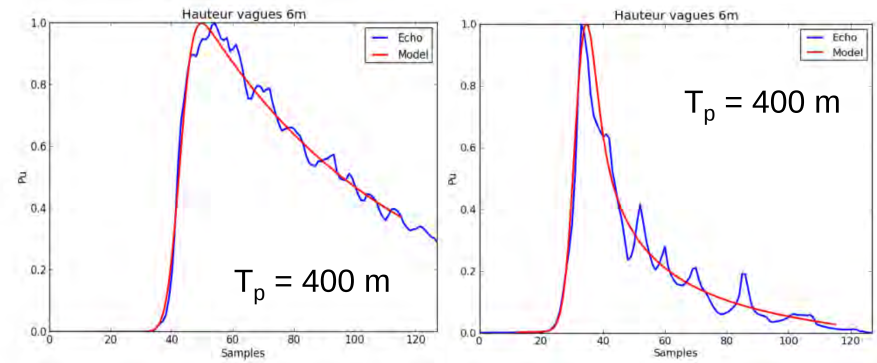

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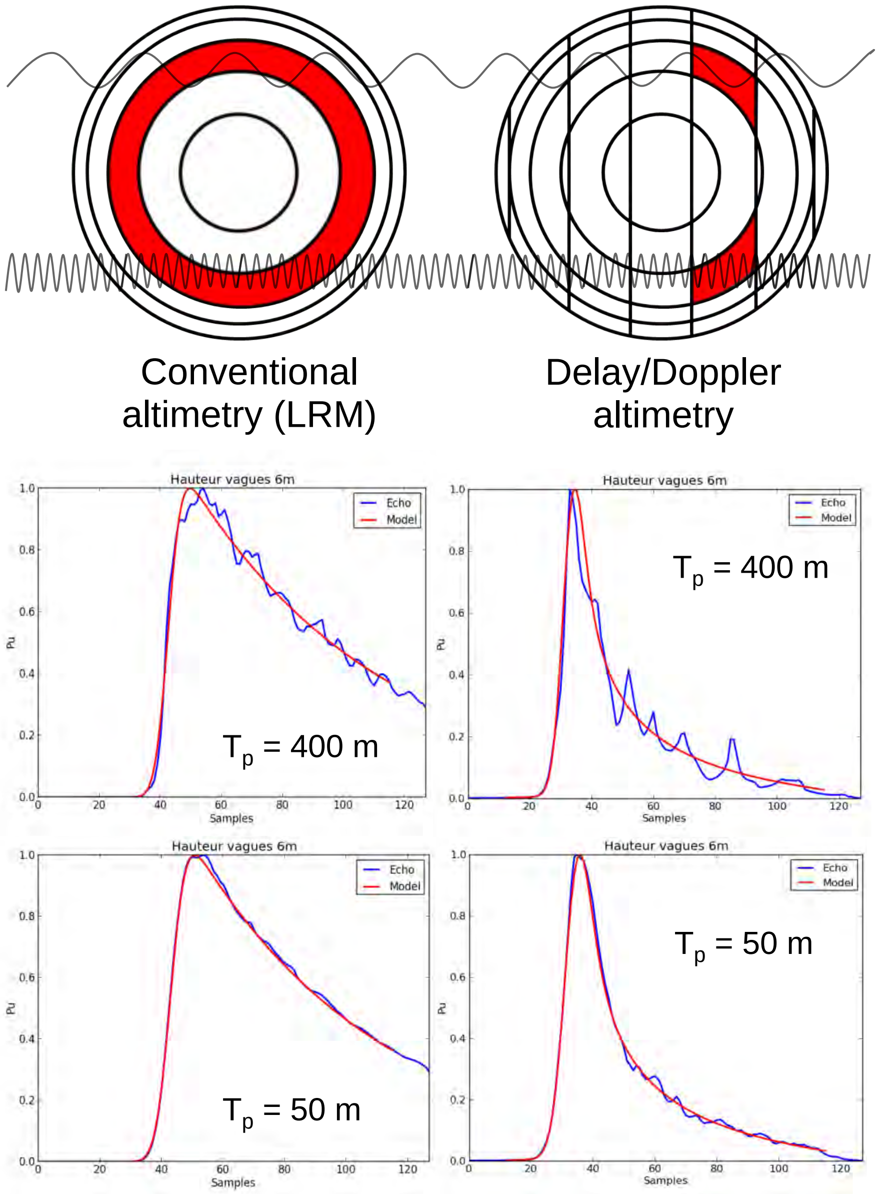

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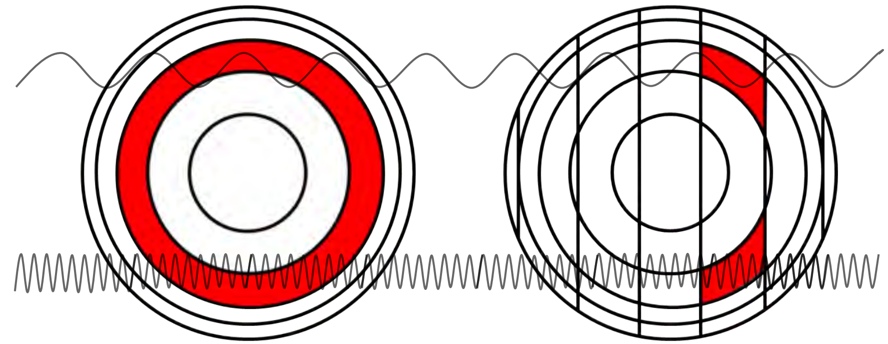

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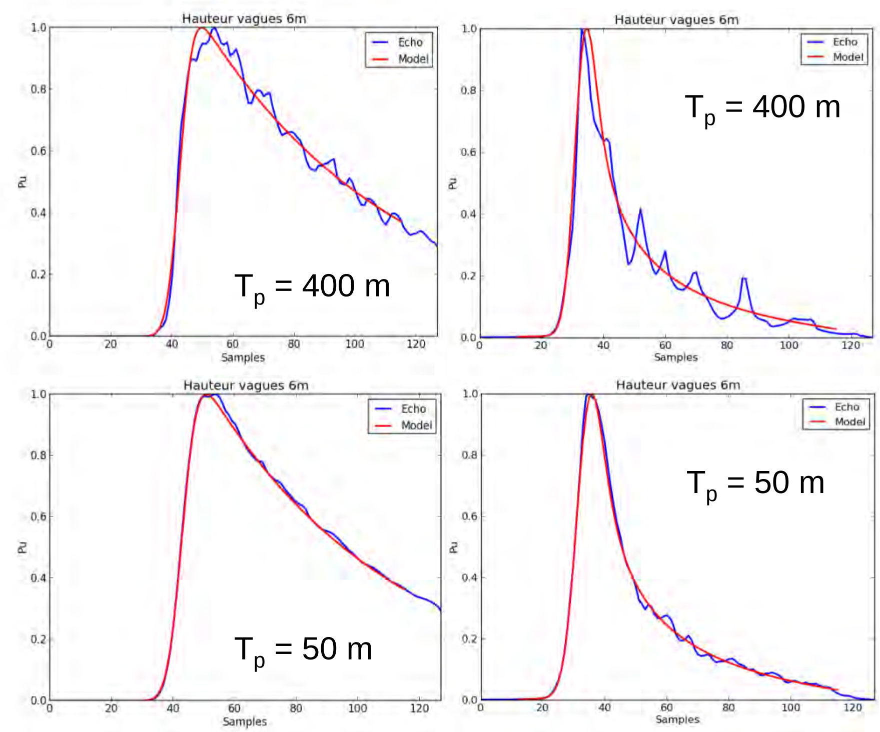

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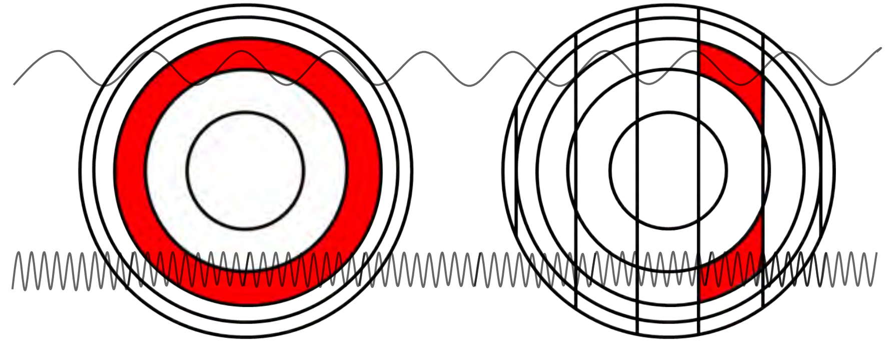

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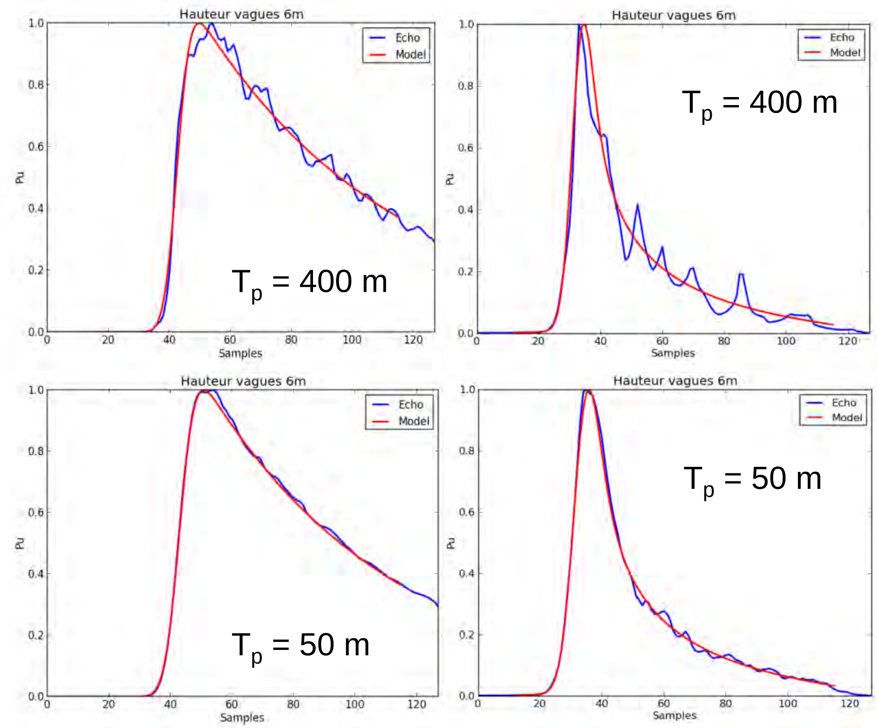

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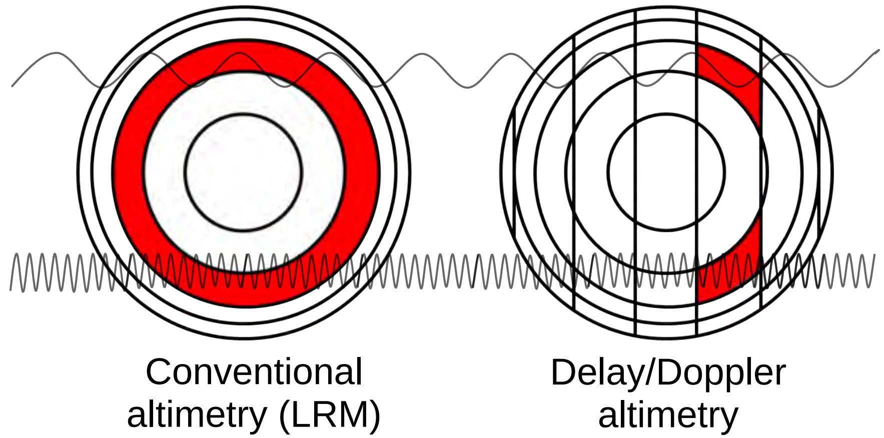

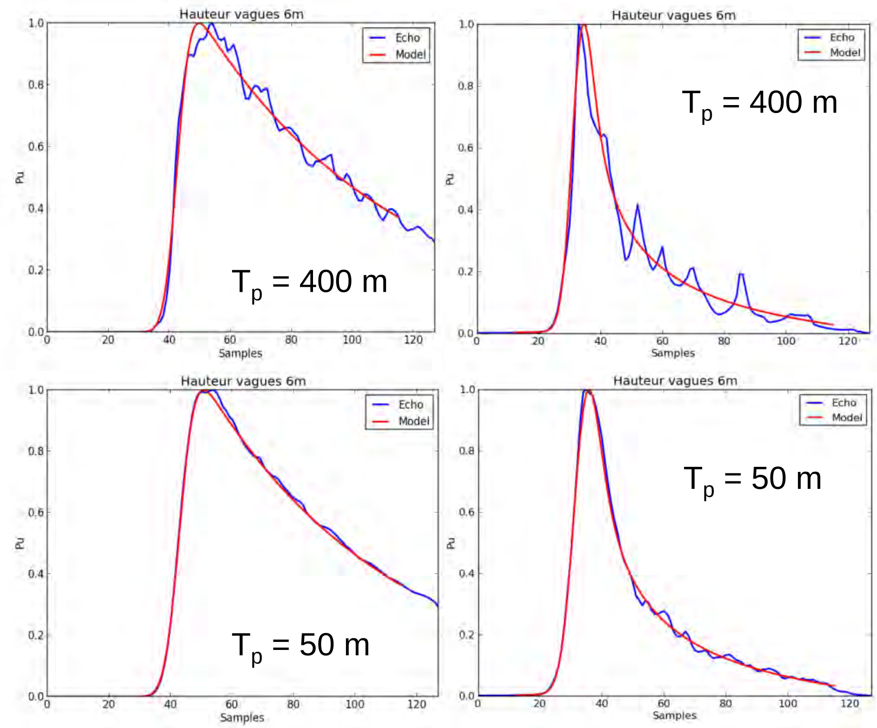

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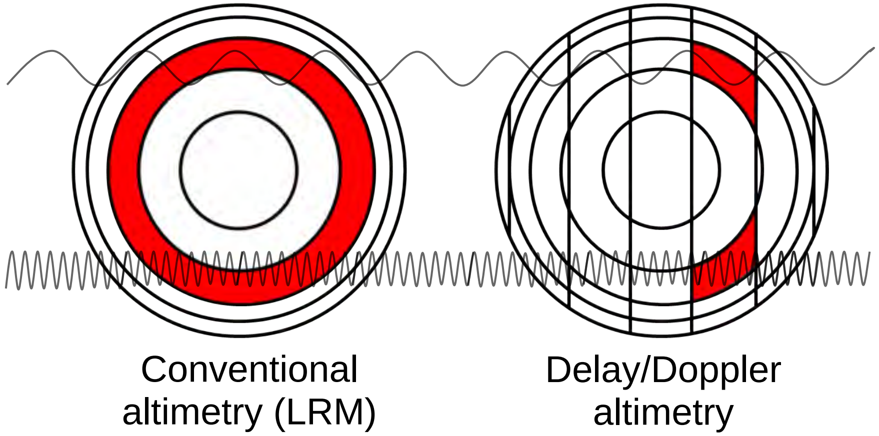

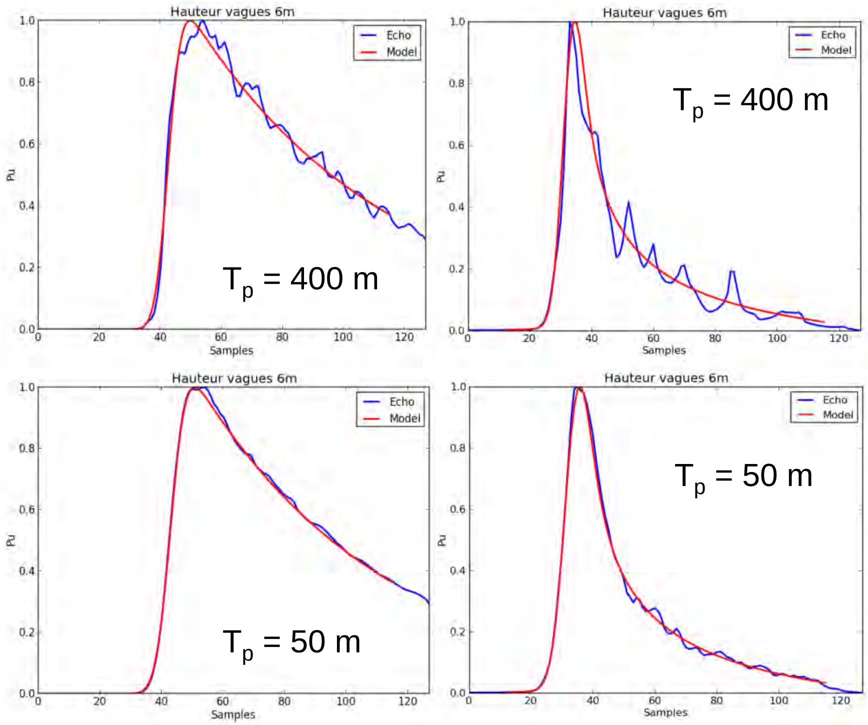

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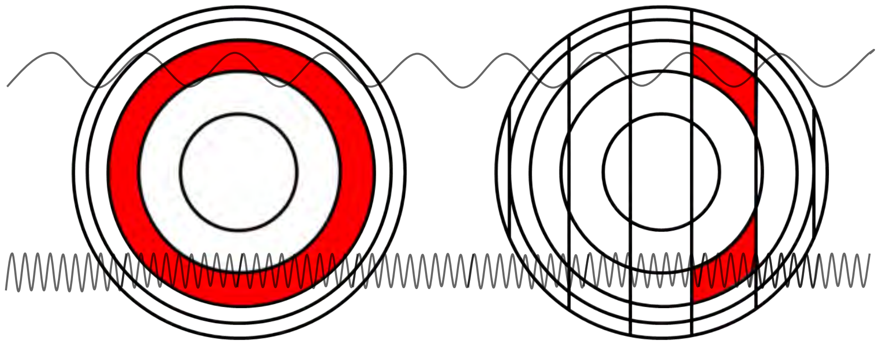
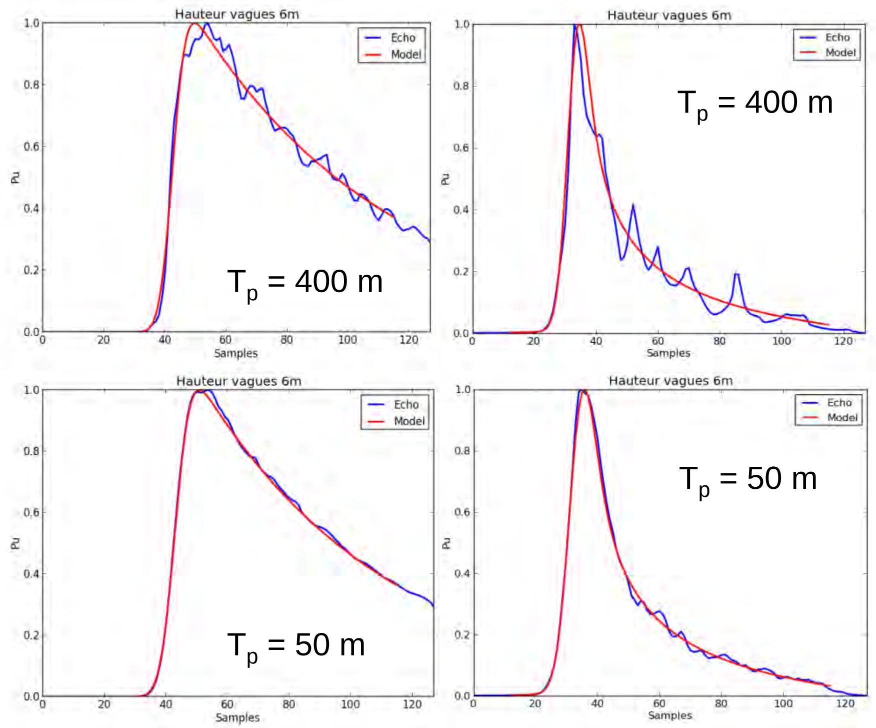
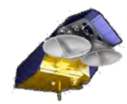
➔ To identify these effects with real data and characterize impacts on surface altimeter parameters

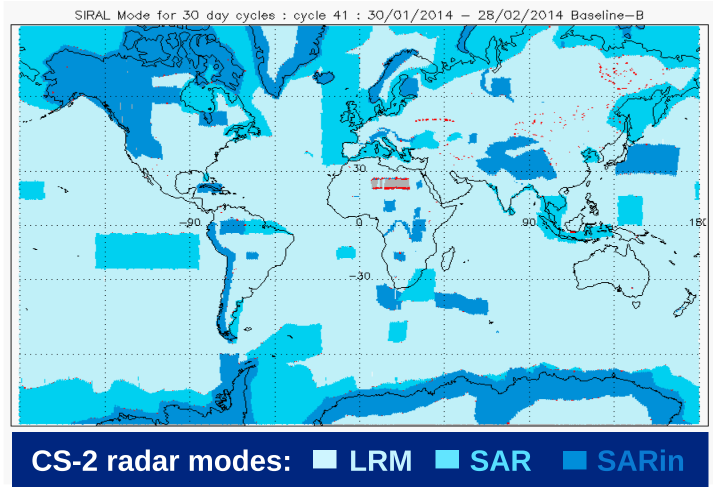




- **8-months of altimeter data in open ocean from may to december 2015**
  - **Jason-2**
    Low Resolution Mode (LRM)
    @ 1-Hz/20-Hz

  - **Cryosat-2 in SAR mode**
    SAR mode and LRM-like (PLRM)
    processed by CNES CPP
    @ 1-Hz/20-Hz





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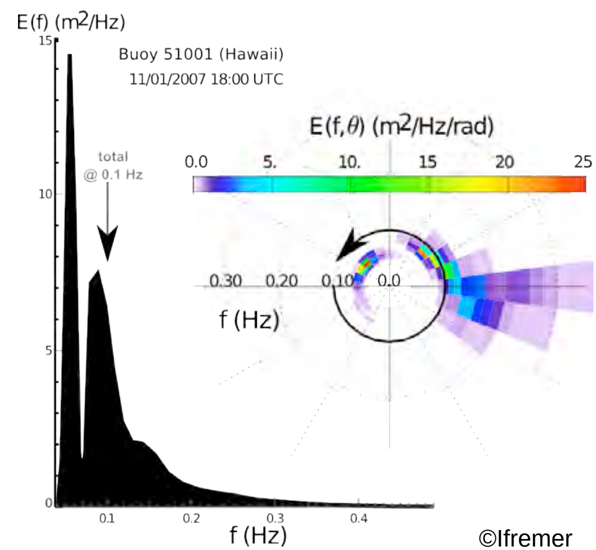
- **IFREMER WaveWatch3 products**
  - Global 0.5°x0.5° wave grid
  - ECMWF surface wind forcing / 3-hours step
    (with no altimetric data assimilation)
  - Fields used:
    - Hs
    - Tm (mean wave period)
    - Partitions: wind-sea; swell#1; swell#2; swell#3
      Hs, Dir, Tp (peak period)



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DATASETS DESCRIPTION

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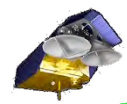

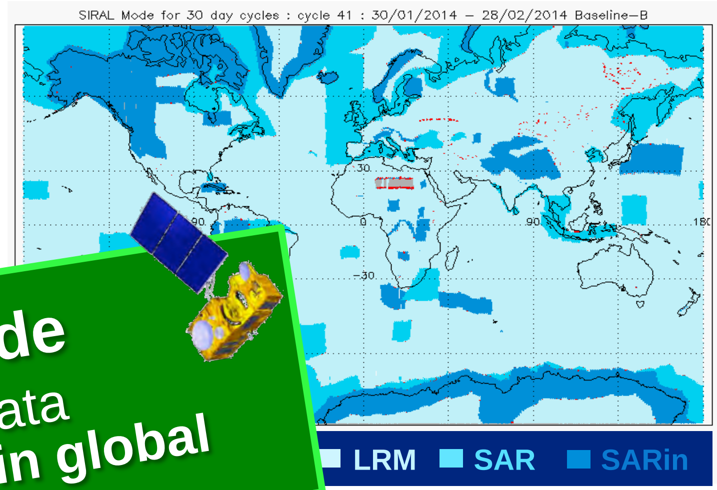

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+ Sentinel-3A in SAR mode

One-month (april 2016) of data processed by CNES S3PP **in global**

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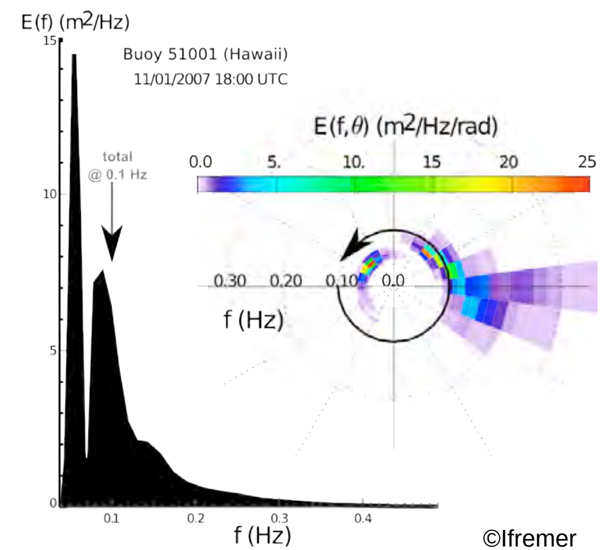

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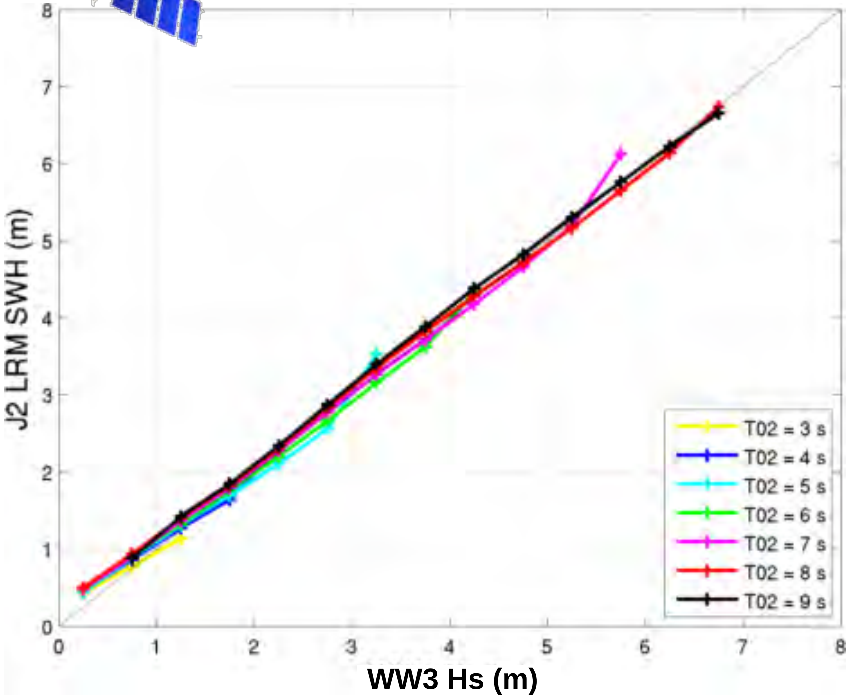
J2 SWH vs WW3 Hs



- Good agreement between altimeter and WW3 Hs values

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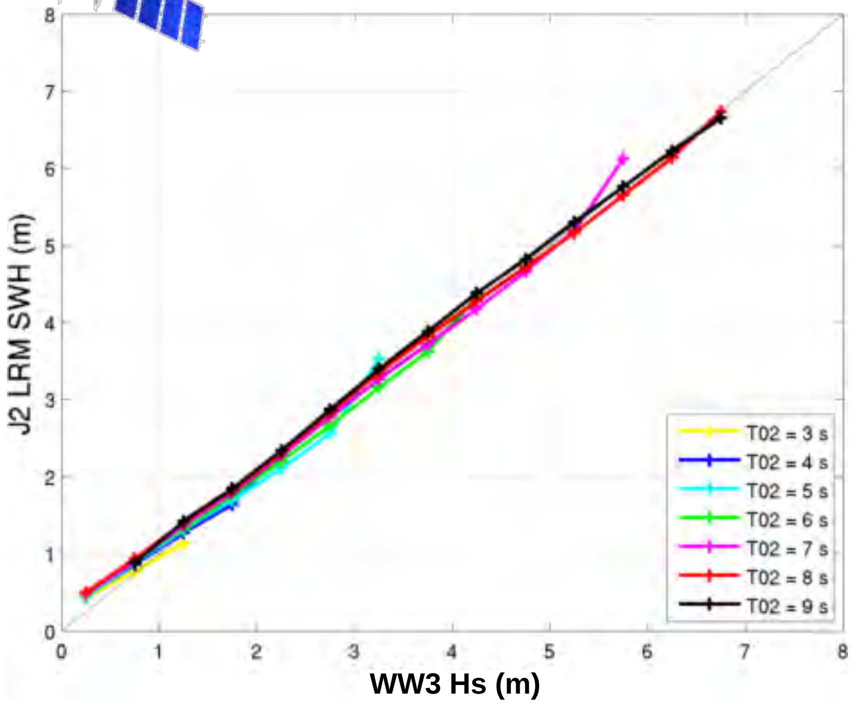
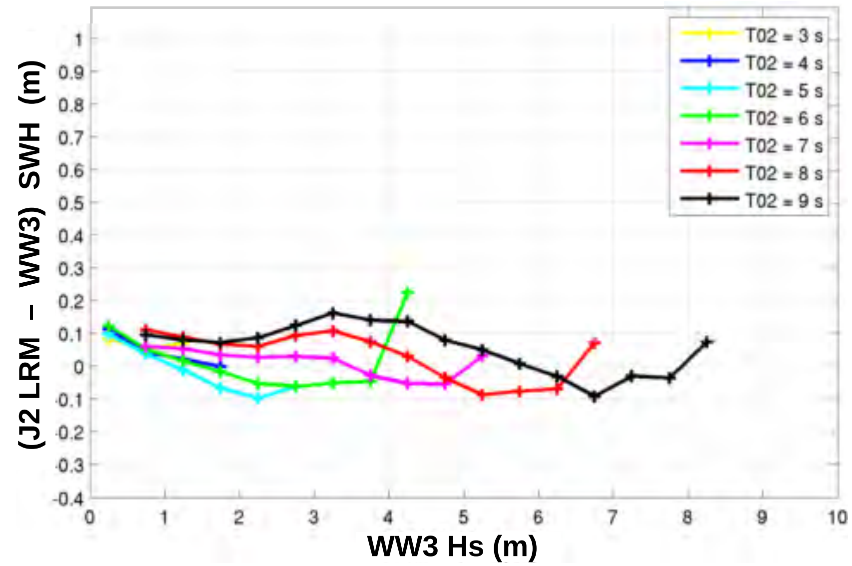


- Good agreement between altimeter and WW3 Hs values
- But their difference reveal features depending on wave period values

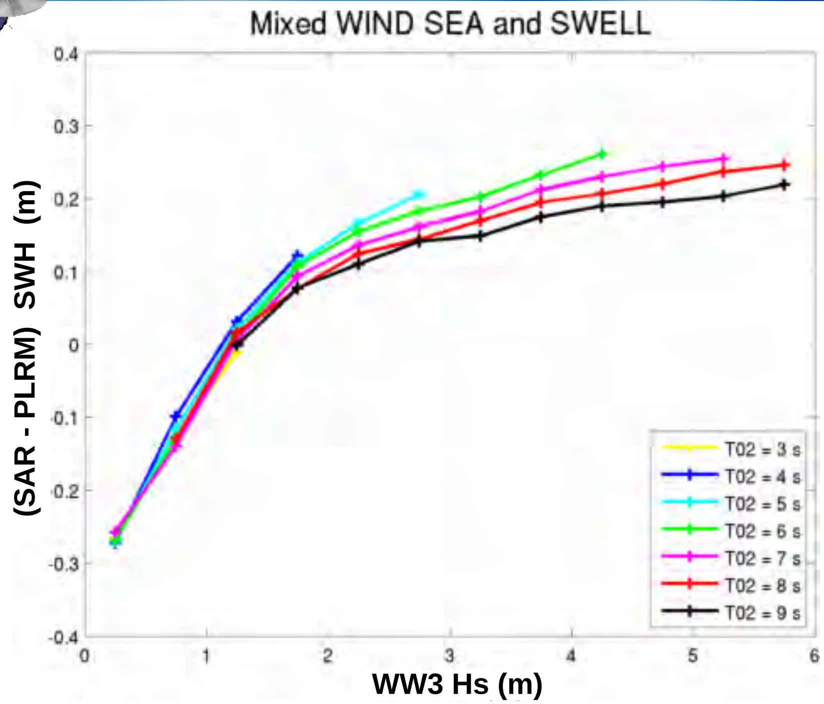
➔ May impact wind/SSB computation

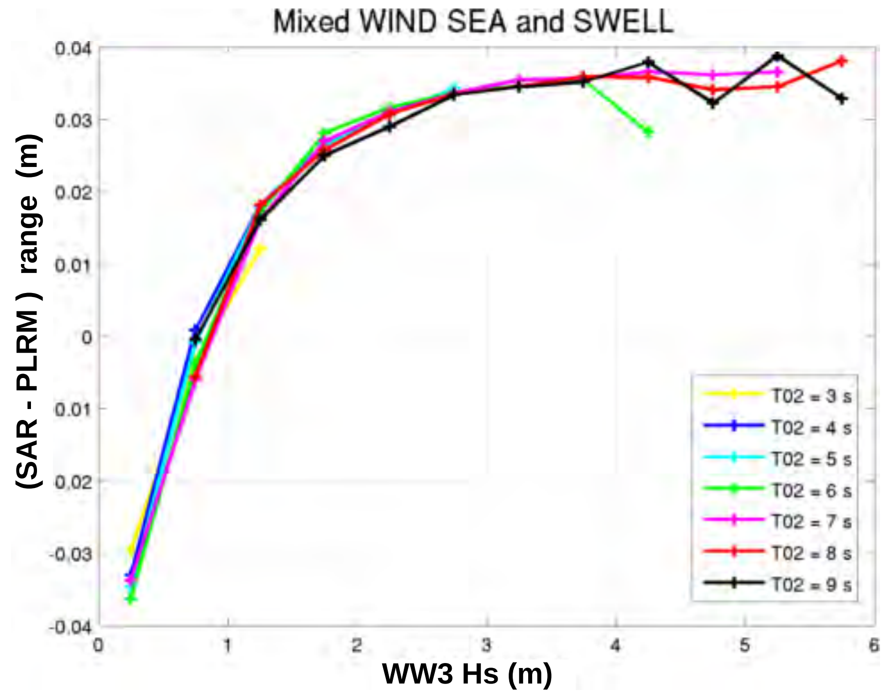
➔ Analyse over longer time period, separate wave systems and geographical regions to better understand these trends

➔ Analyse the consistency of WW3 as a reference (by comparing with SAR imagery estimates for example)



CS2 SARM vs PLRM ESTIMATES





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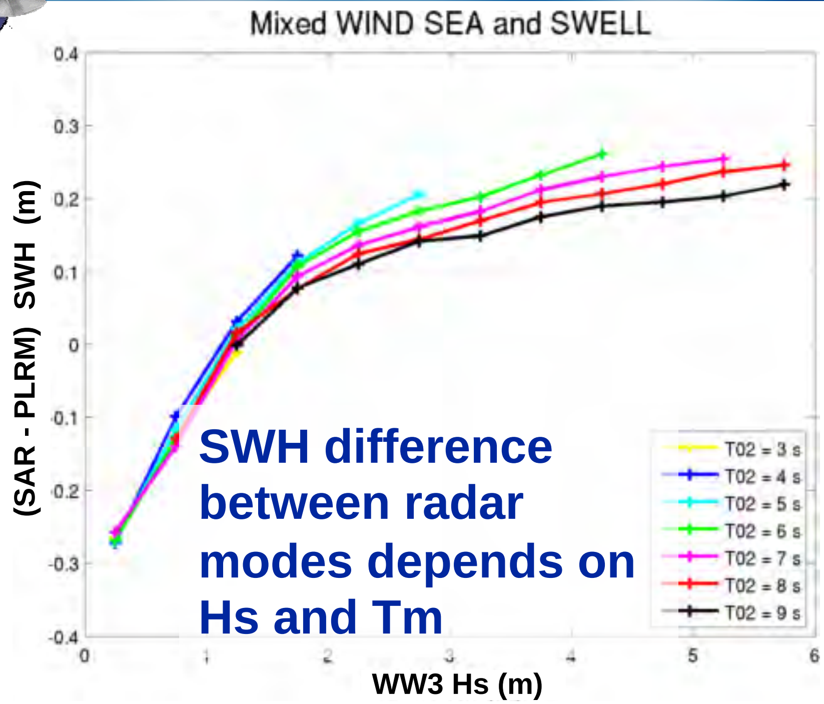

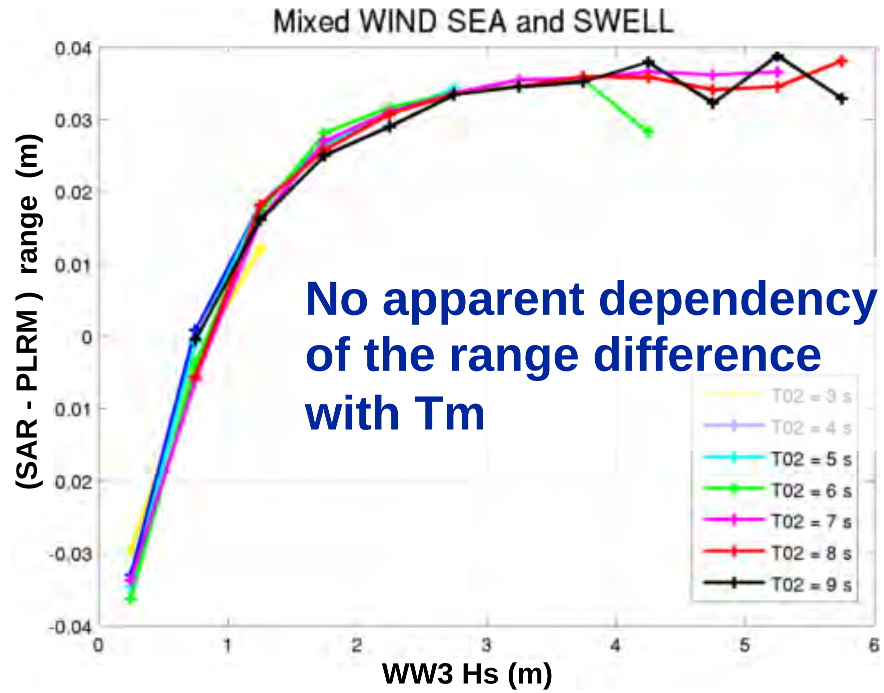

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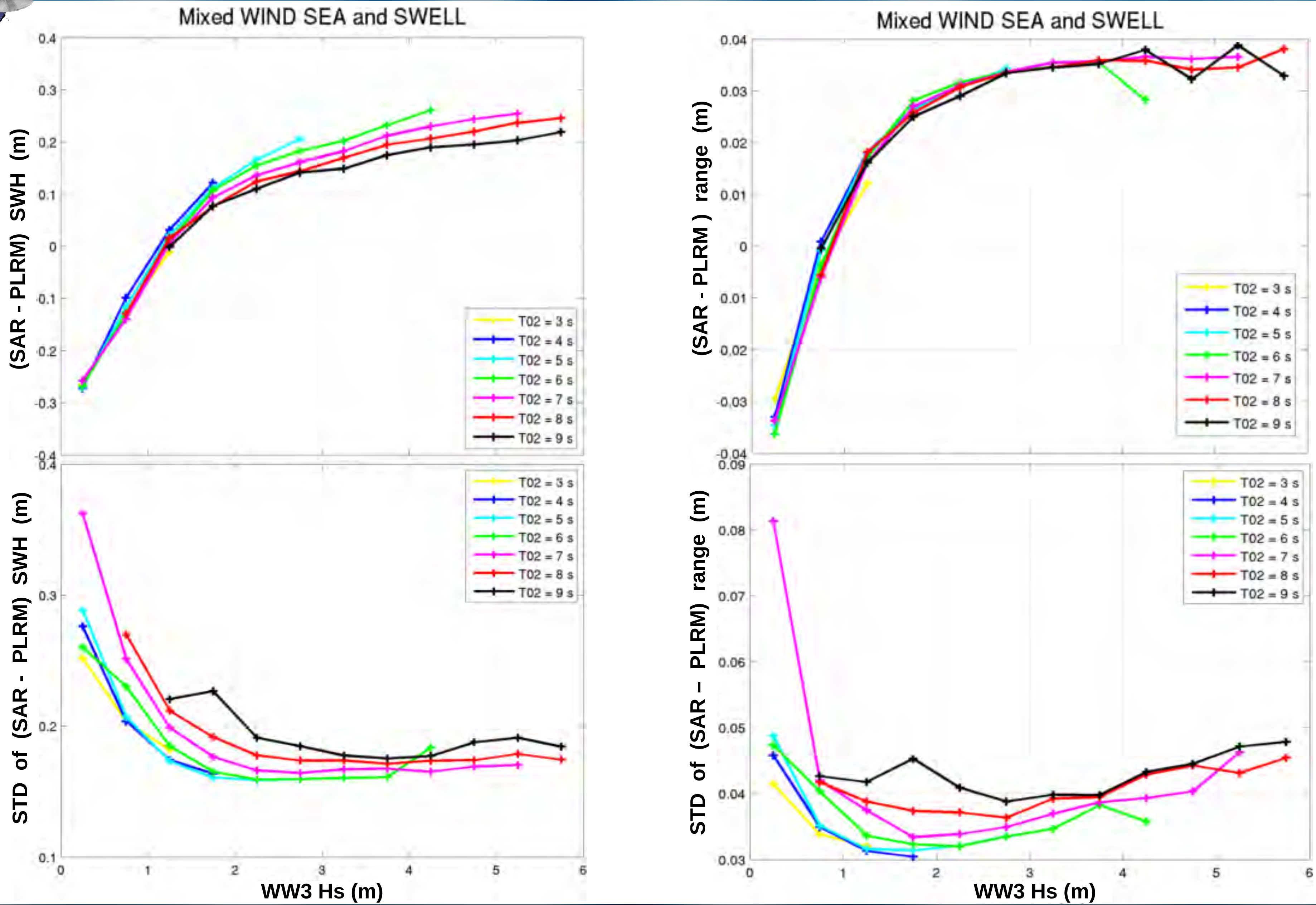

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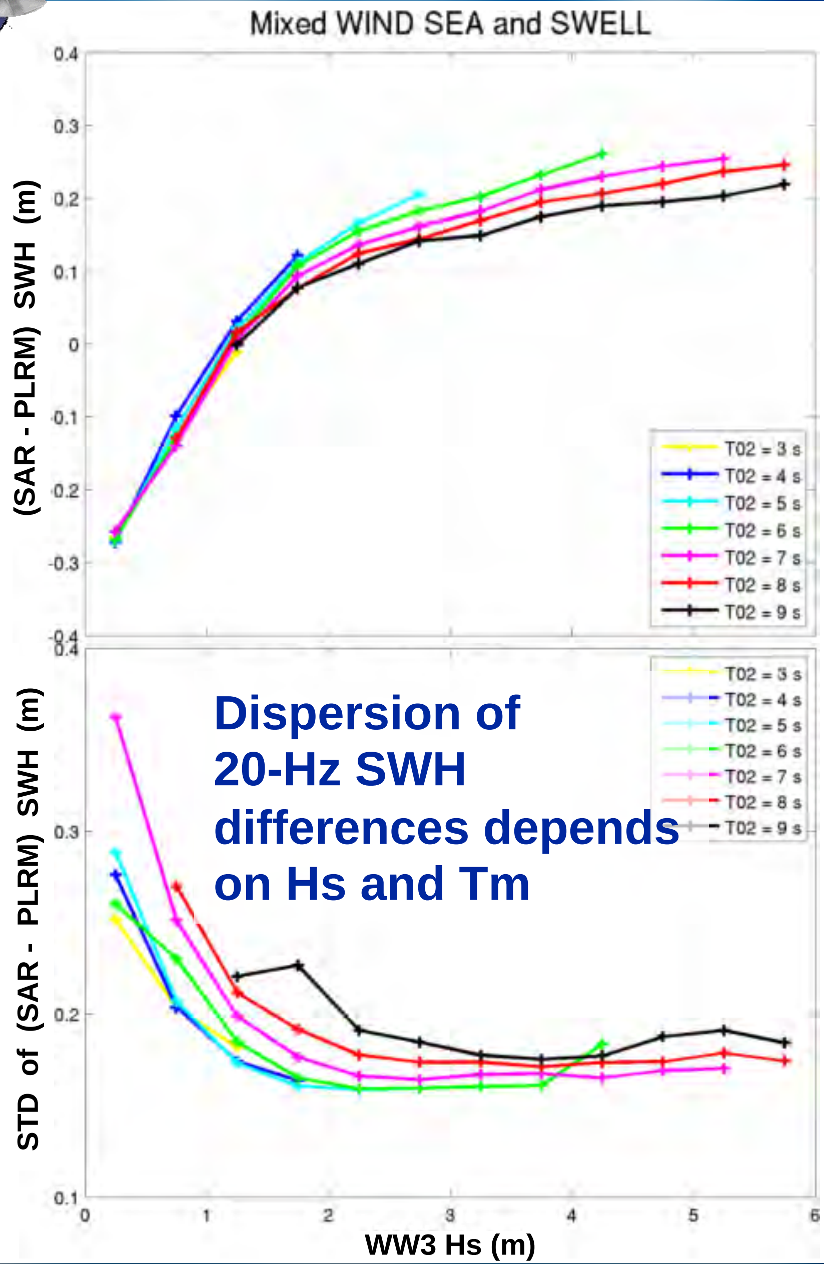
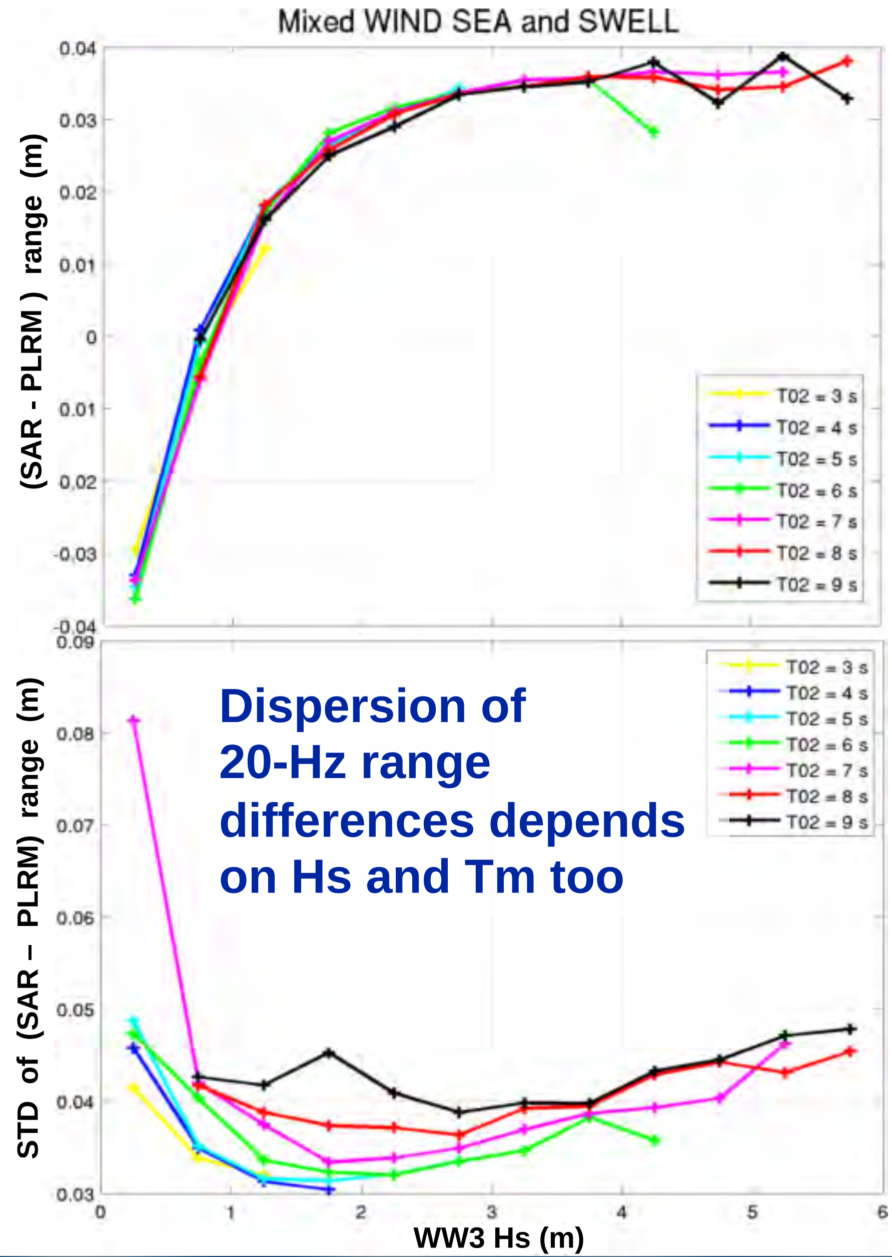
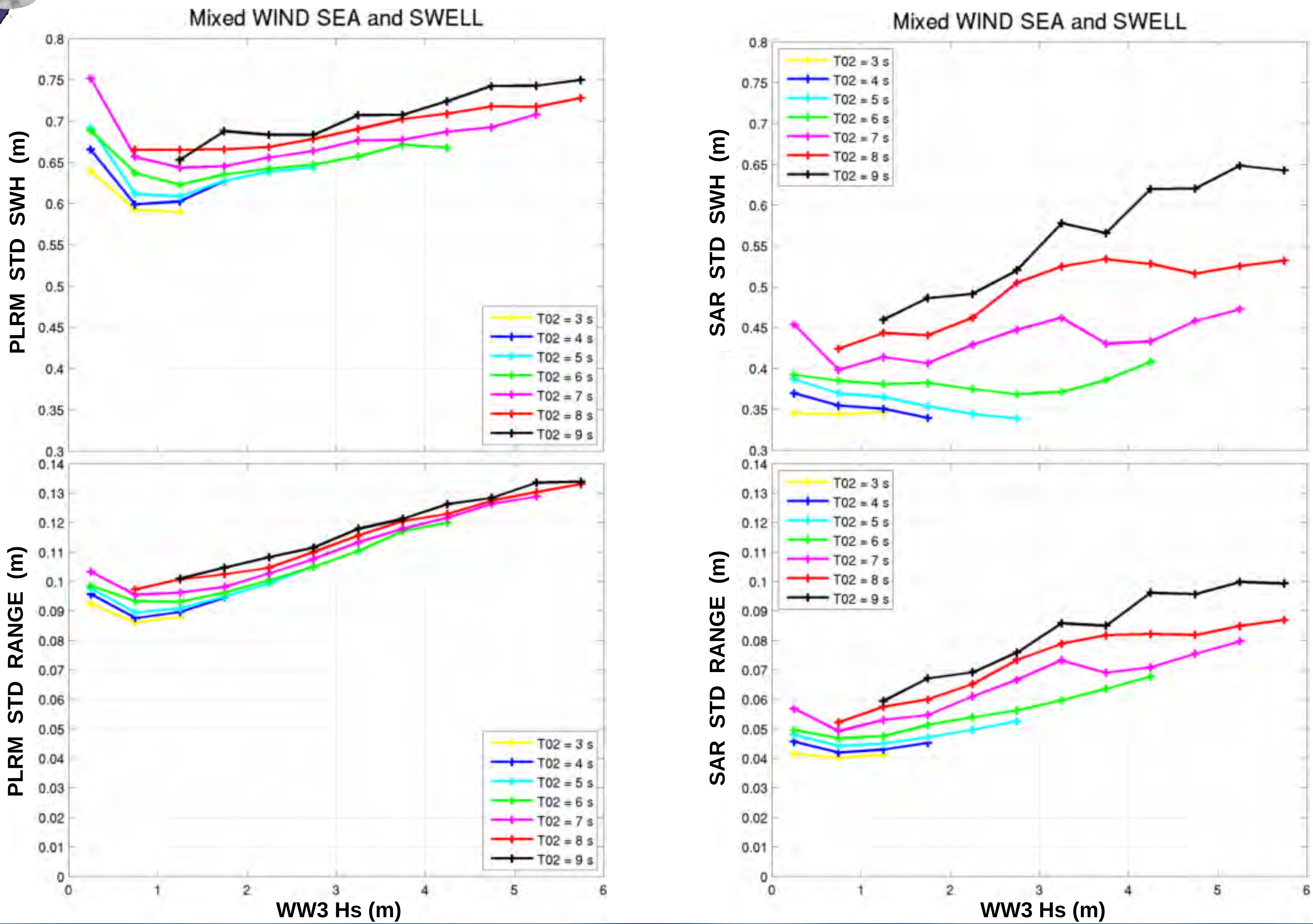


Dispersion of 20-Hz SWH differences depends on Hs and Tm



Dispersion of 20-Hz range differences depends on Hs and Tm too

CS2 SARM AND PLRM STD



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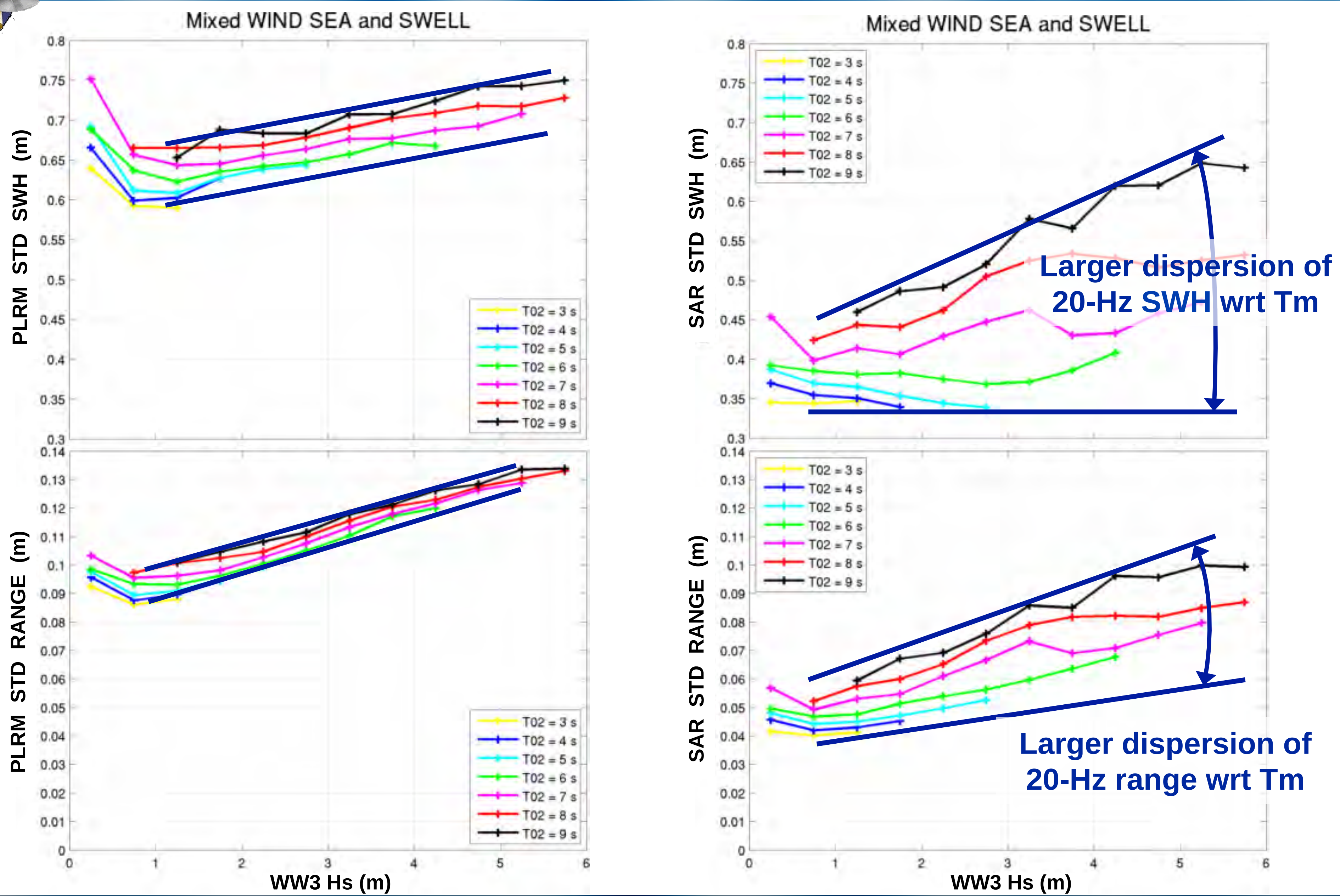

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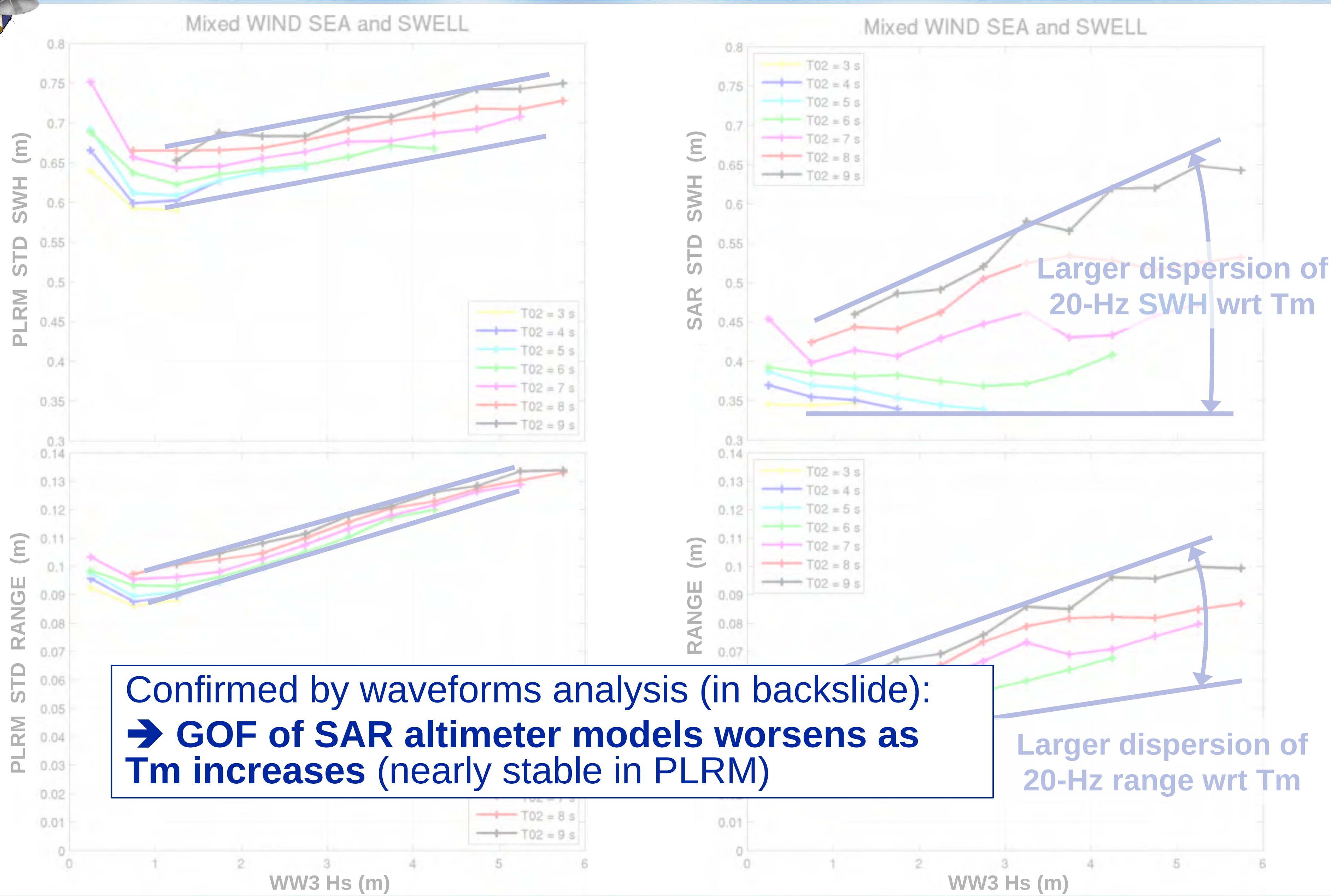
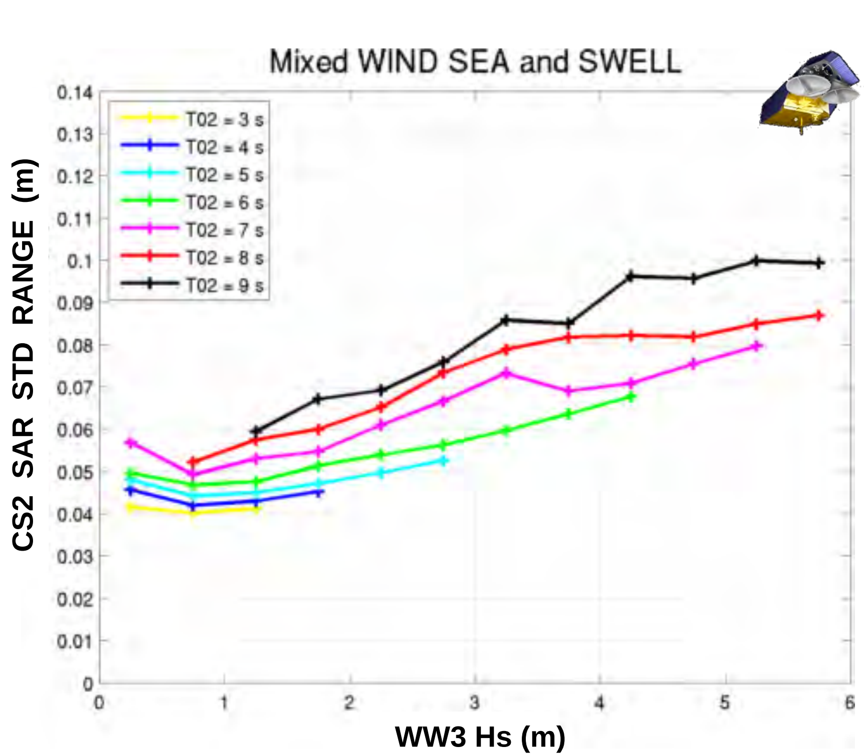
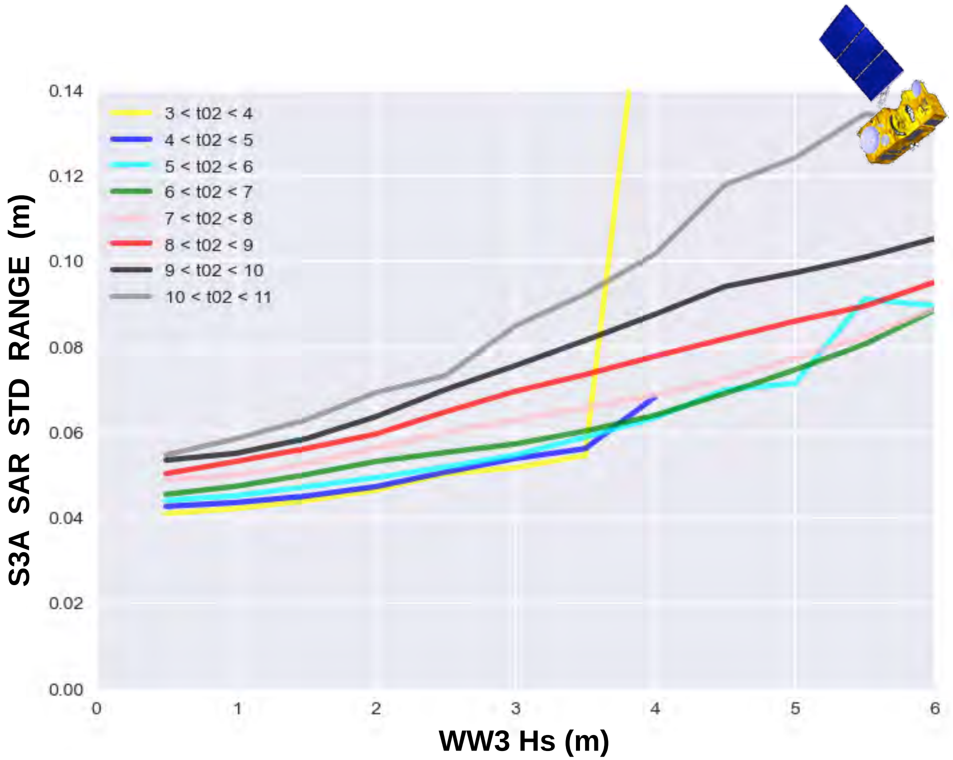


Confirmed by waveforms analysis (in backslide):
➔ **GOF of SAR altimeter models worsens as Tm increases** (nearly stable in PLRM)

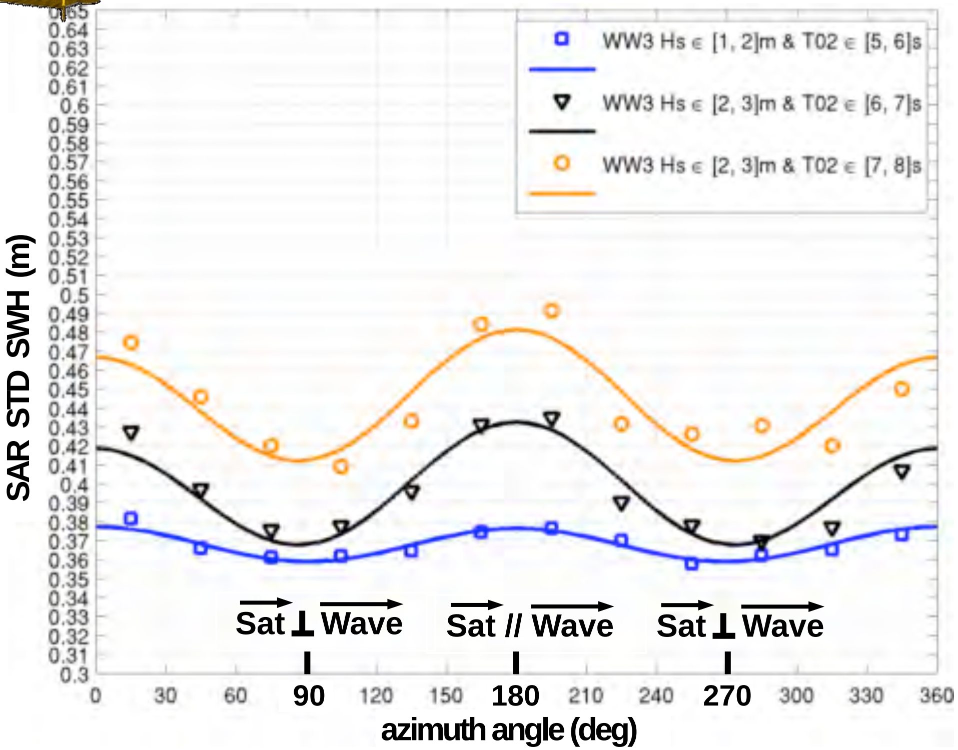
CS2 AND S3A SARM RANGE STD

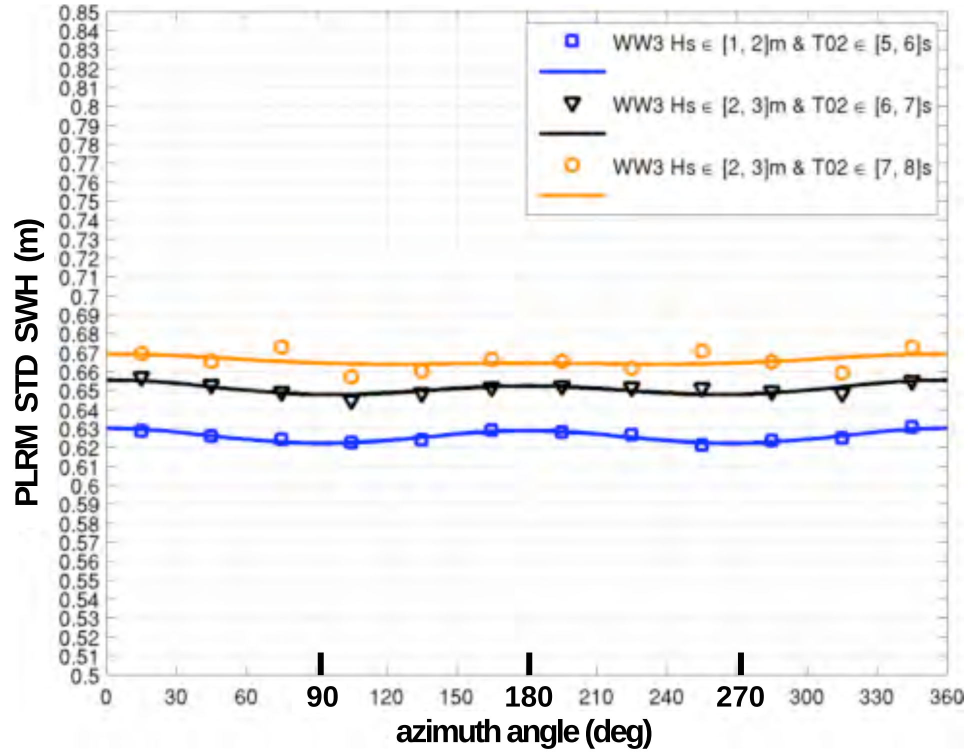




- Dependence of 20-Hz range std on Tm confirmed with S3A data in SAR-mode
- Much less significant dependency of 20-Hz range std on Tm observed in S3A P-LRM data (in backslide)

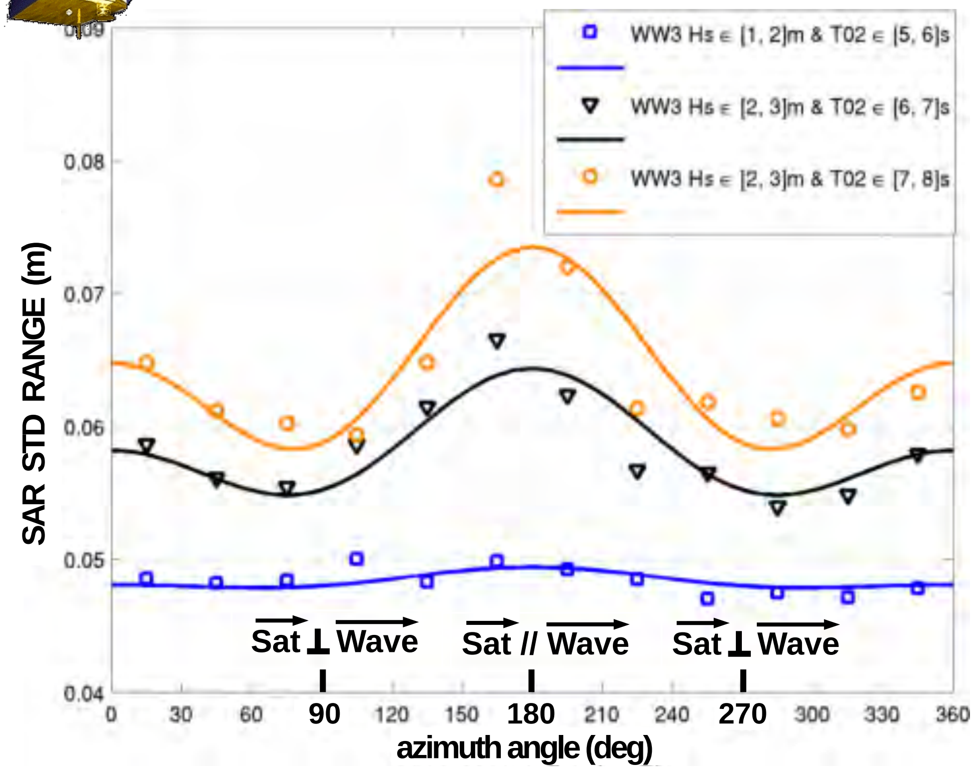
CS2 SWH STD wrt DIRECTION

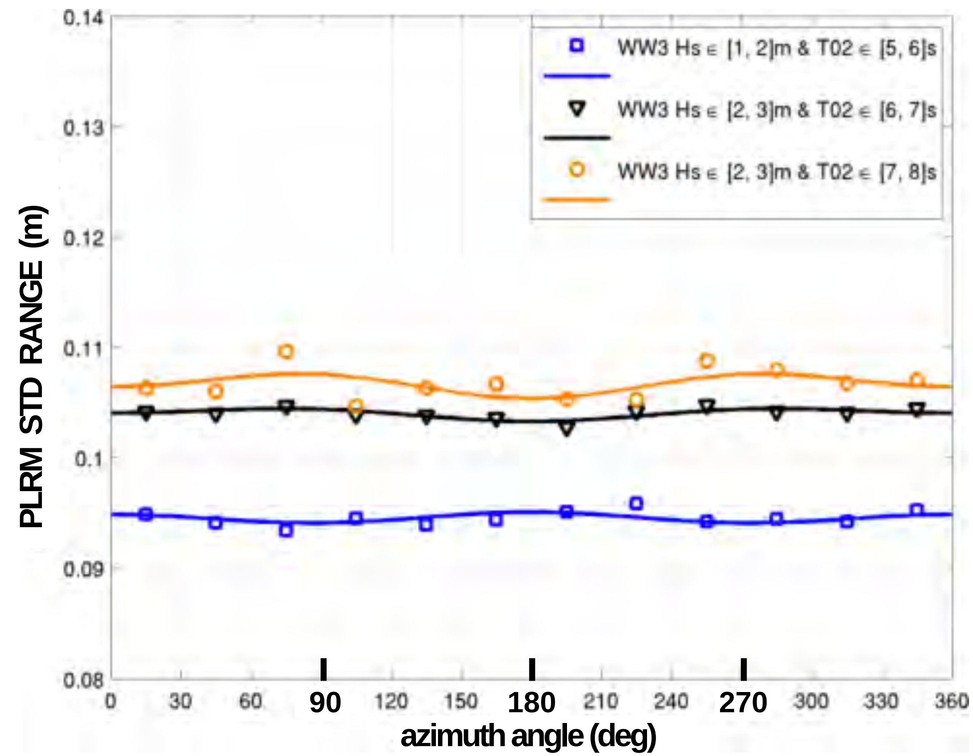




- **20-Hz SWH std sensitive to wave direction in SAR-mode**
  but no apparent dependency of SWH measurements in direction (in backslide)
- Higher dispersion (over 7km) for wave propagation parallel to satellite ground track displacement
- No angular effect on 20-Hz SWH std in P-LRM (cylindrical symmetry)

CS2 RANGE STD wrt DIRECTION





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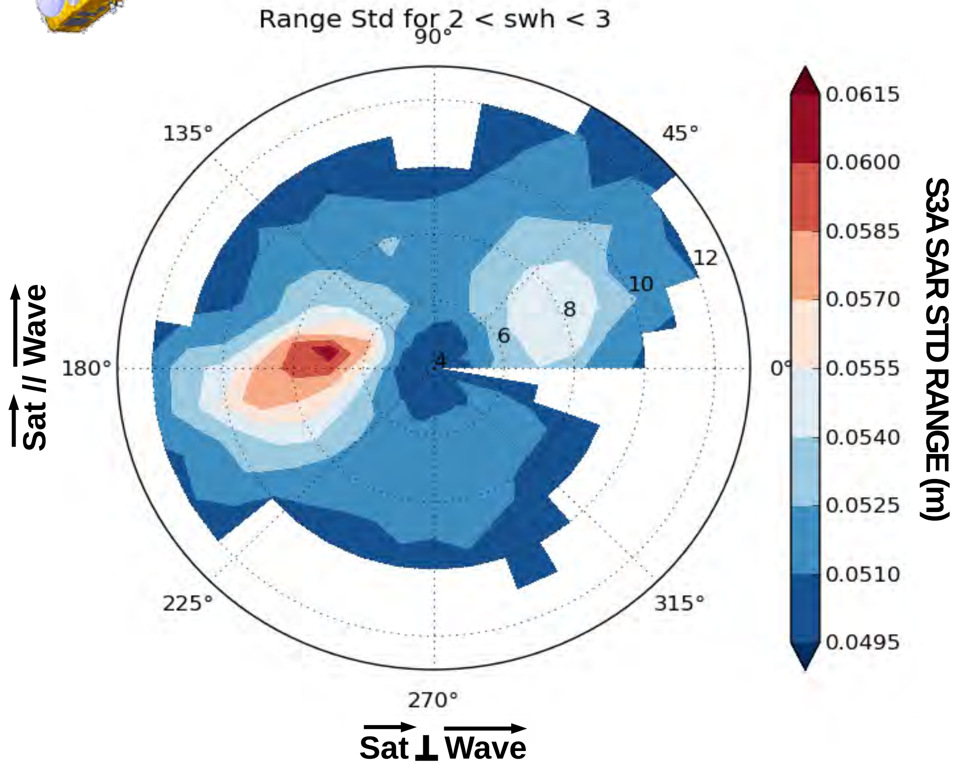
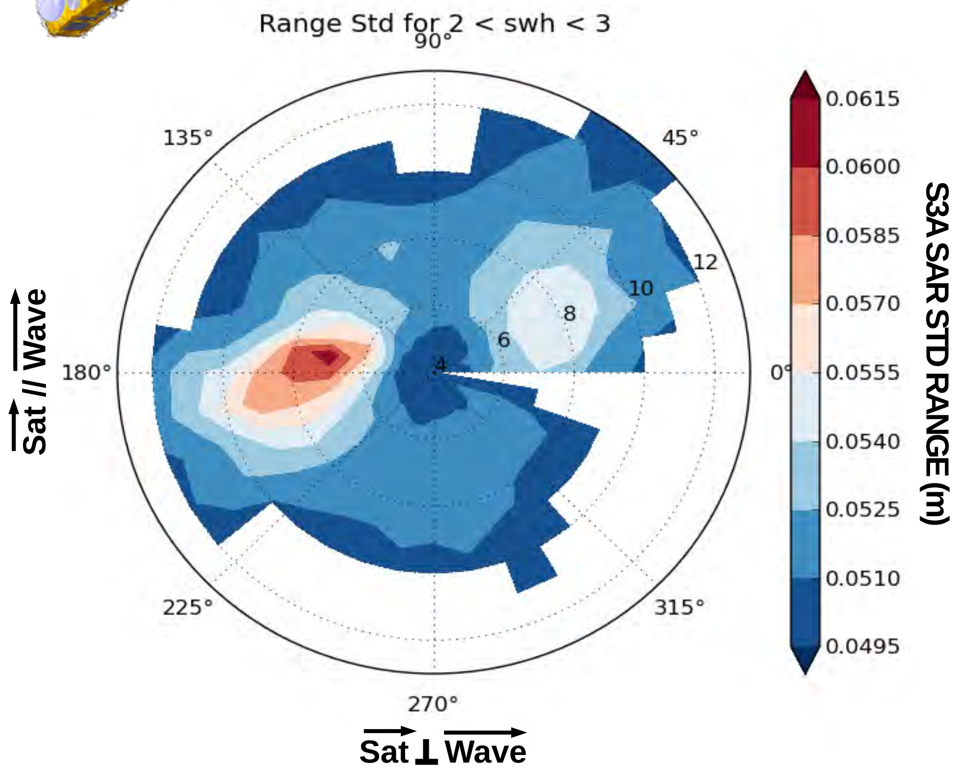
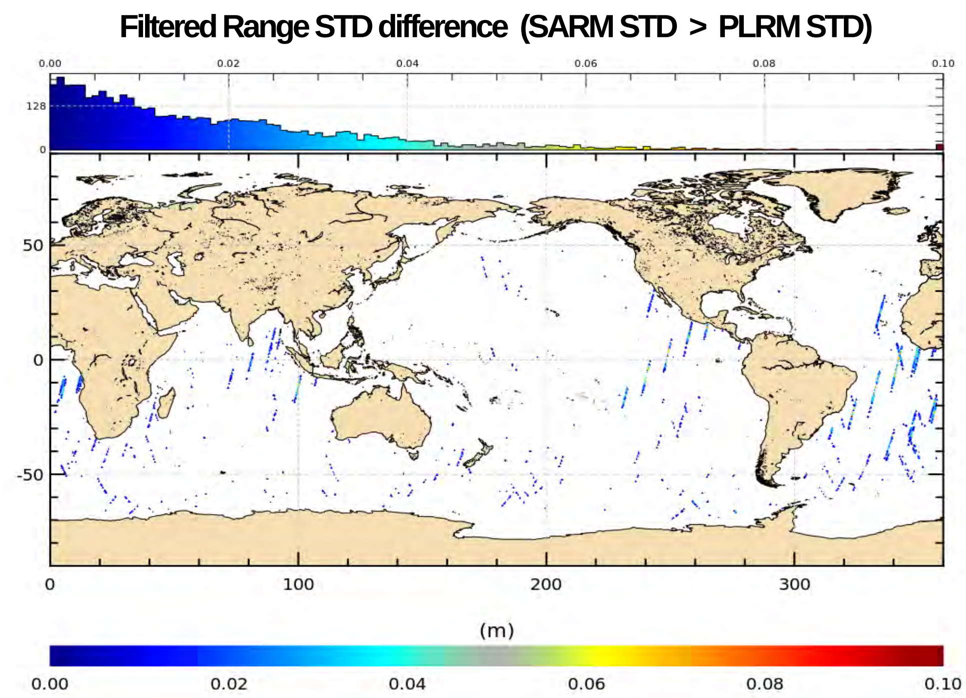
S3A RANGE STD wrt DIRECTION



- 20-Hz range std sensitivity to Tm and wave direction in SAR-mode confirmed with S3A data

S3A RANGE STD wrt DIRECTION

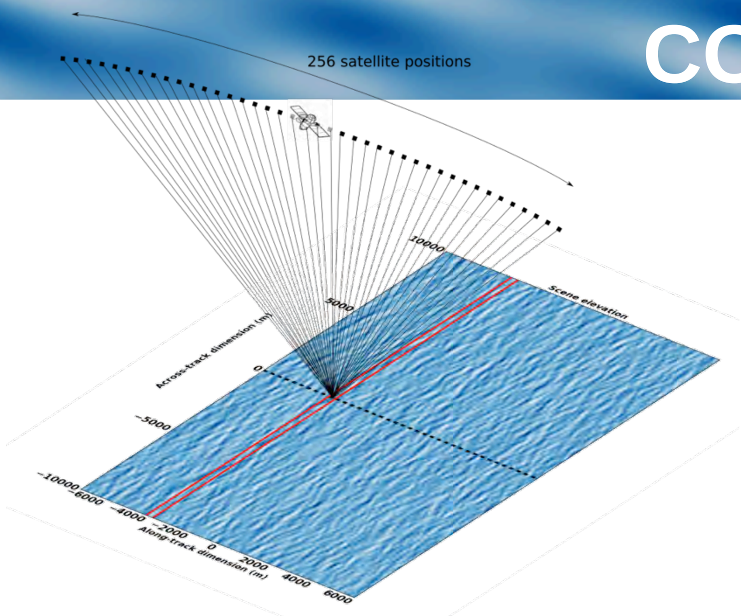




- 20-Hz range std sensitivity to Tm and wave direction in SAR-mode confirmed with S3A data

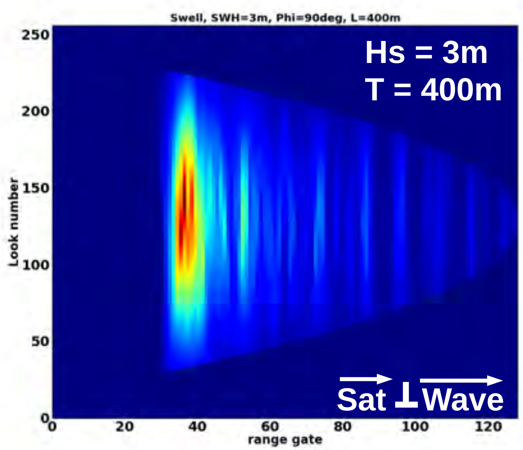
- Occurrences of 20-Hz range std in SARM greater than in PRLM are observed for waves propagating parallel to orbit track over long segments

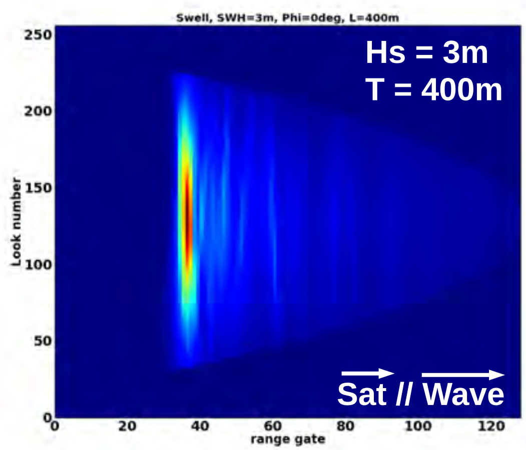
COMPLEMENTARY SIMULATIONS

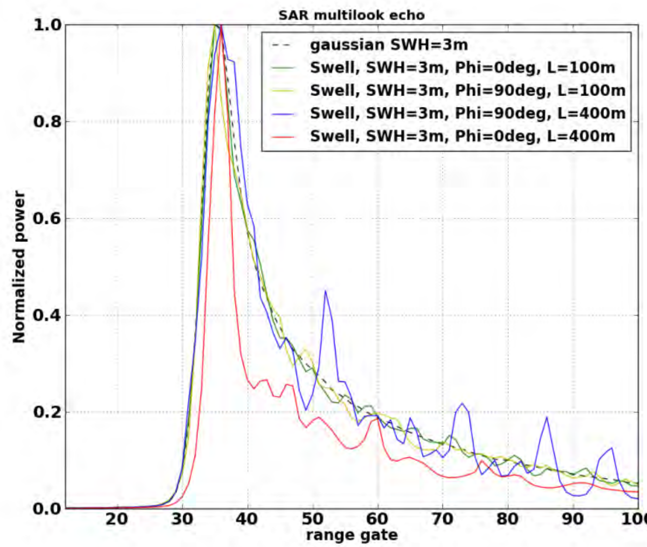


- Use an *end-to-end* radar altimeter simulator able to generate waveforms in SAR and conventional modes for any instrumental configuration and different scenario of waves system

  ➔ **To study the dispersion of 20-Hz SARM and LRM measurements and dependencies**

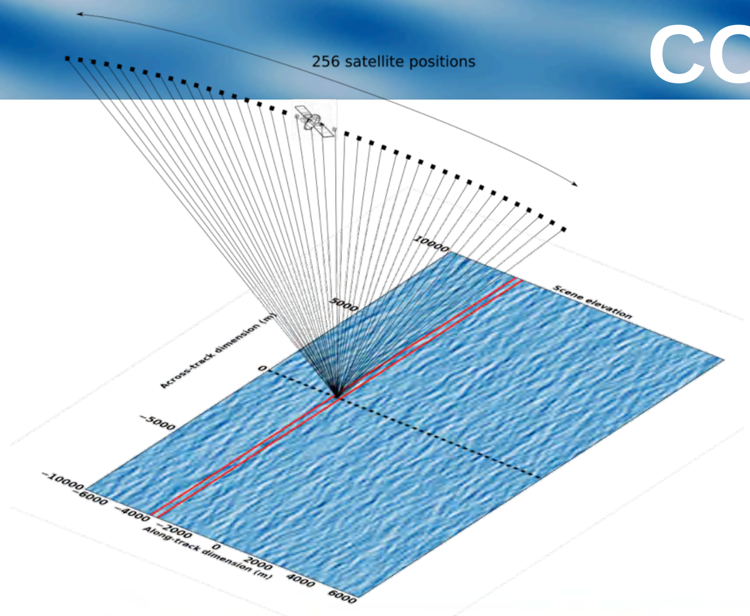






- Shape of Doppler power echoes impacted by the wave period and Hs, but also the direction

COMPLEMENTARY SIMULATIONS



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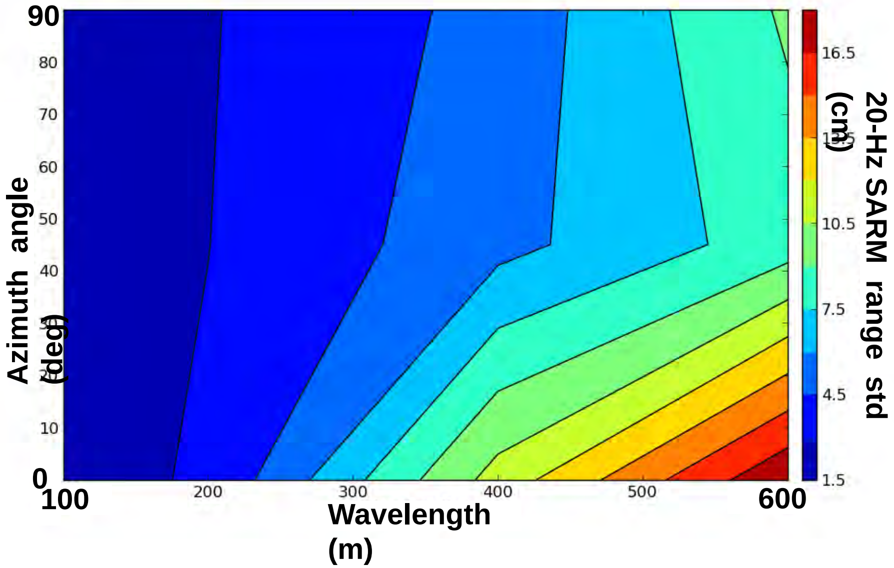
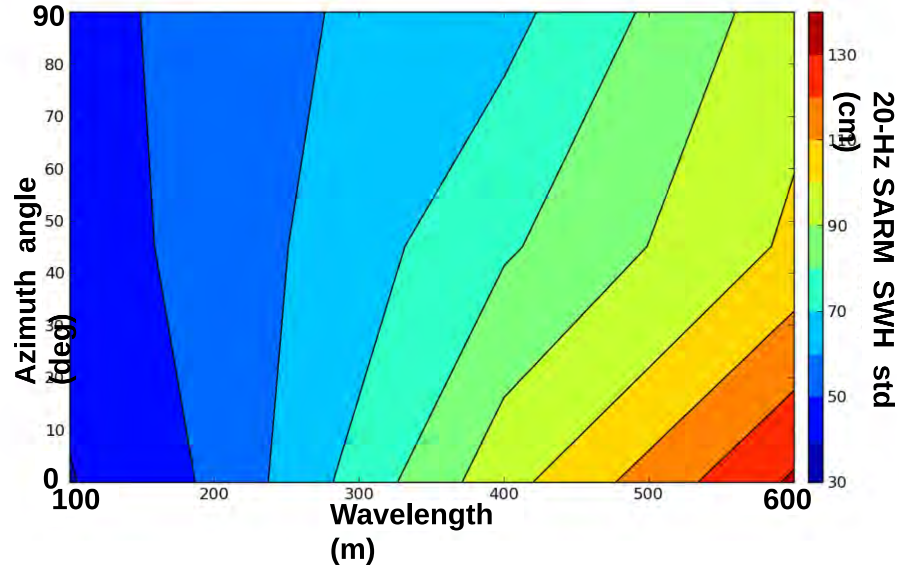


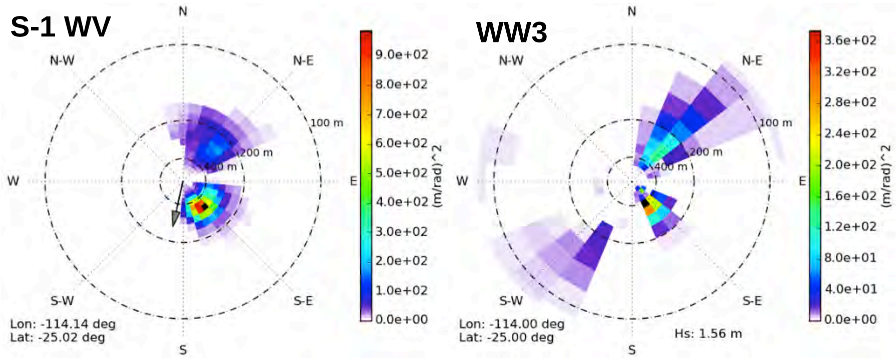


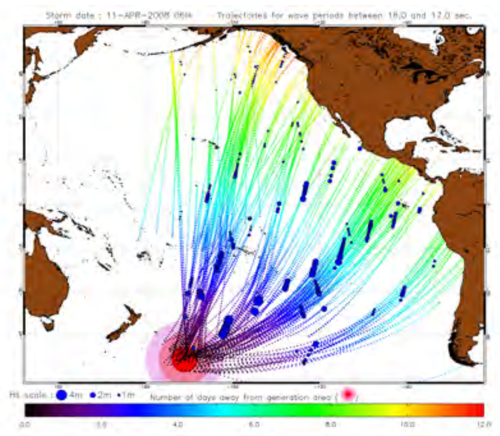
- Simulations confirm the sensitivity of SARM measurements (in dispersion) to waves period and direction while no impact is observed on LRM (not shown here)

CONCLUSIONS & PERSPECTIVES

- **Impact of swells and wind-waves on the altimeter-derived estimates has been clearly identified at small scale (in terms of dispersion over 7km)**

- Triple colocation alti/WW3/S-1 to assess their consistencies is on-going





- Use of indirect SAR (S-1) measurements by propagating synthetic swell fields may be considered where static colocations with S-1 are not available

- To analyze sea state effects on Ka-band altimeter configurations (Altika)

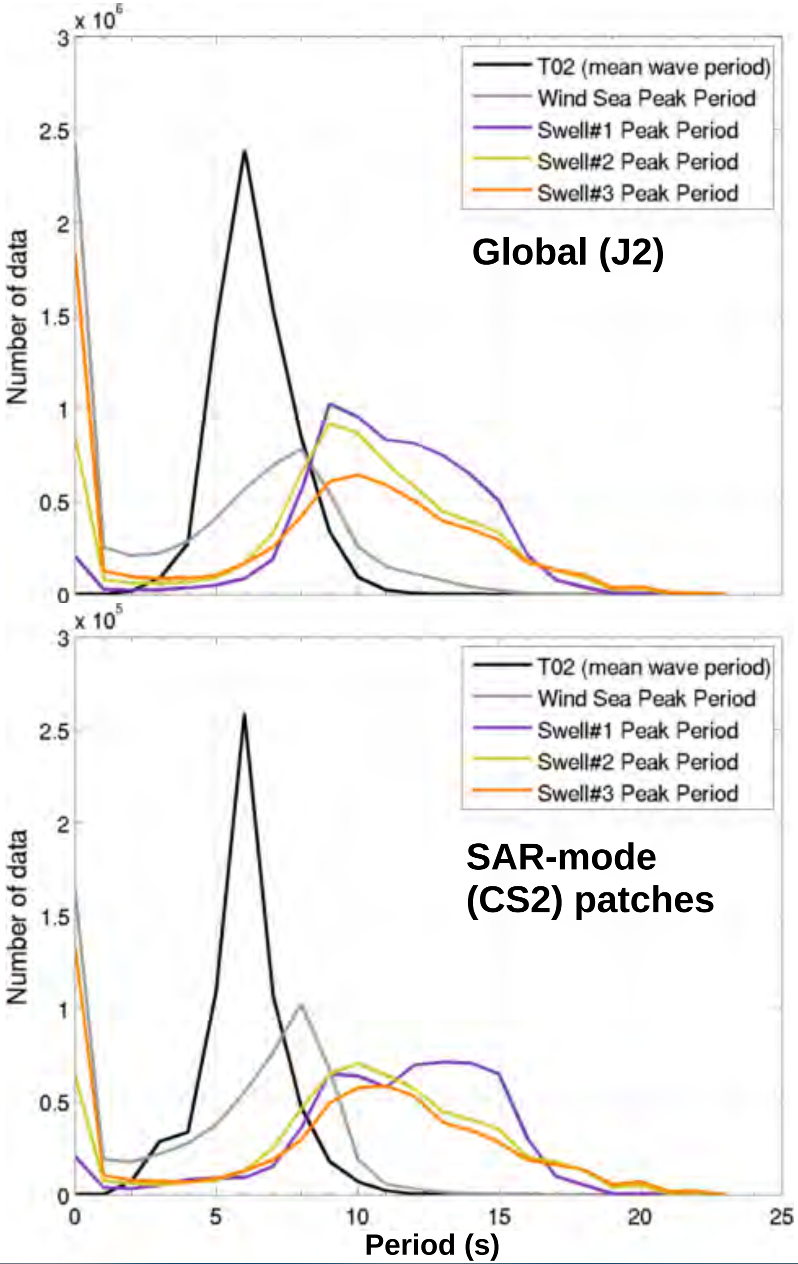
- **A more thorough study of this issue is planned to be done with Sentinel-3A data to better characterize those effects and biases, and to reveal any potential anomalies in SAR (and LRM) altimetry data and in the sea level content**

- The results of this analysis soon in:
  "*Impact of swell and wind-waves on SAR altimeter-derived estimates*",
  Moreau et al. [in preparation]

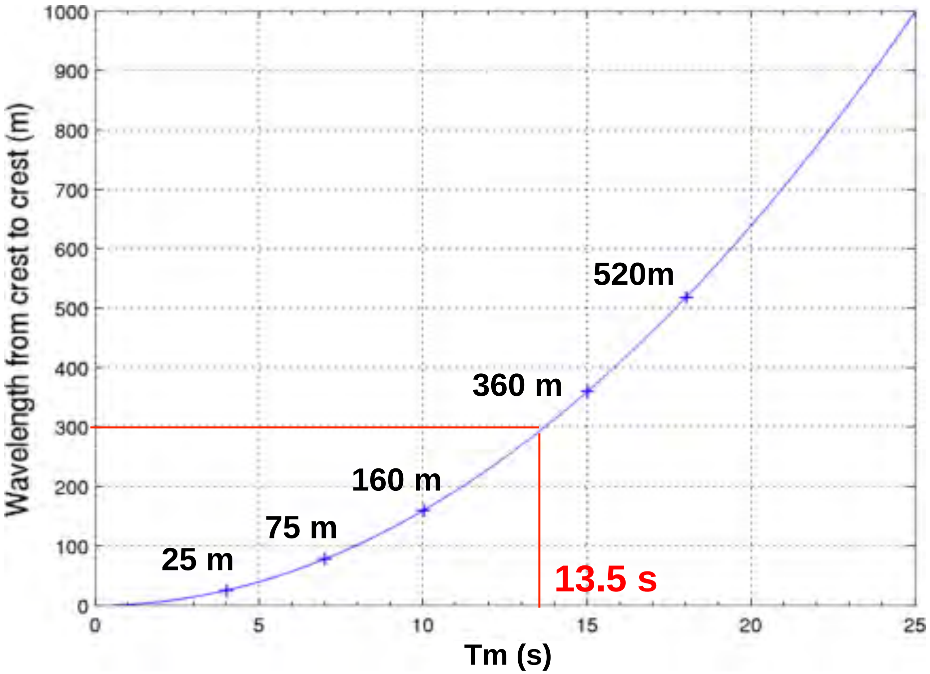
THANK YOU !!

tmoreau@cls.fr

WW3 MODEL: WAVE PERIOD AND WAVELENGTH

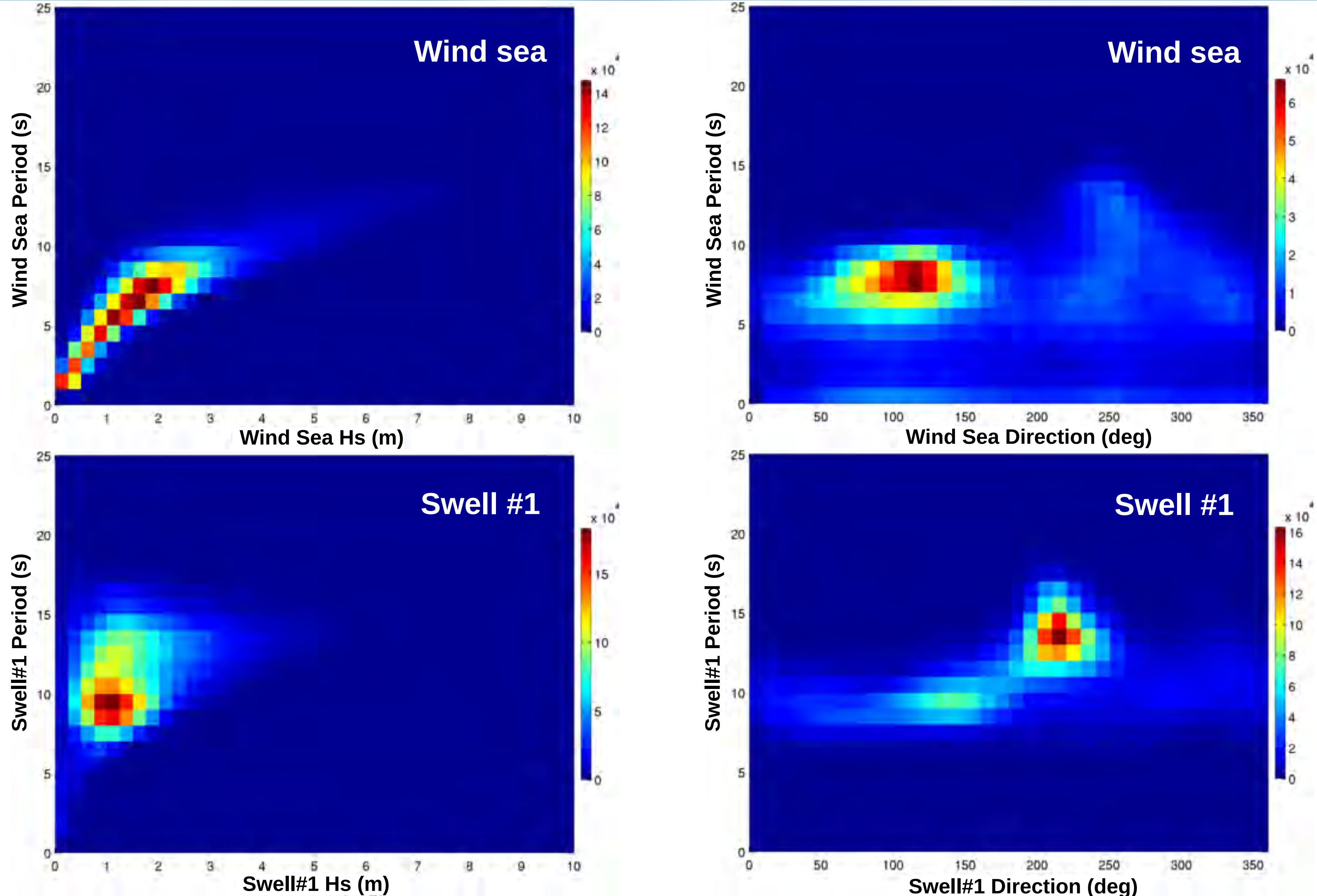


- Tpeak swell > Tpeak wind-sea
- Tm is lower than individual Tpeak
- Deep water: L ~ 1.6 Tm^2



- Tm of 13.5s corresponds to SAR altimeter resolution ~ 300 m

WAVE SYSTEMS FROM WW3 MODEL



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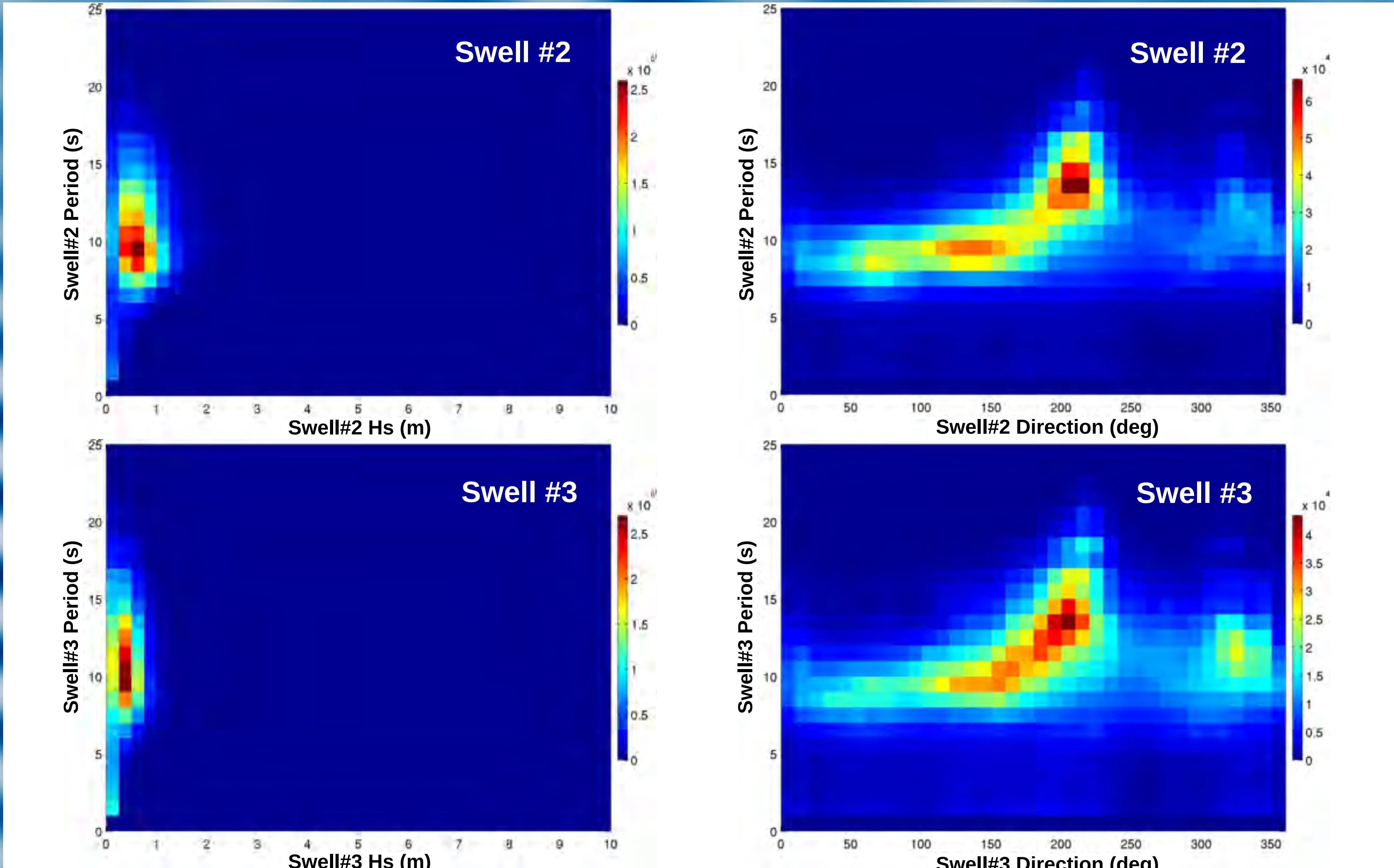
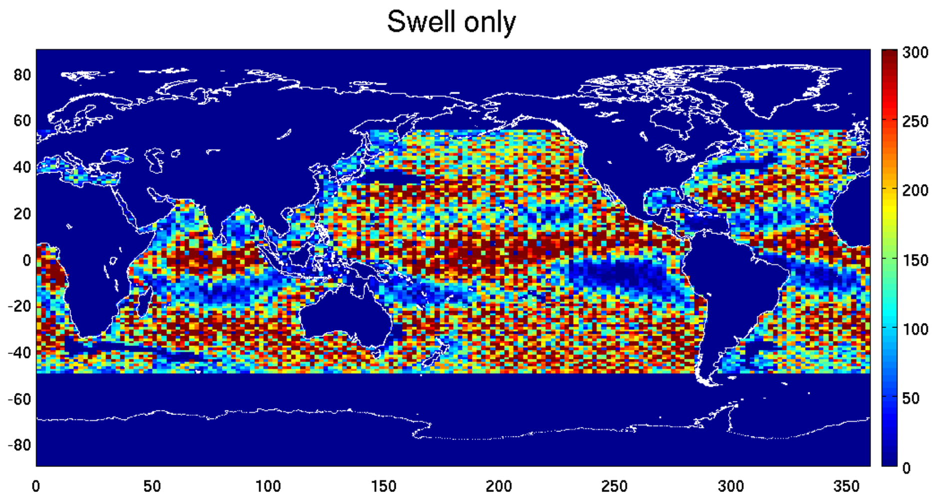
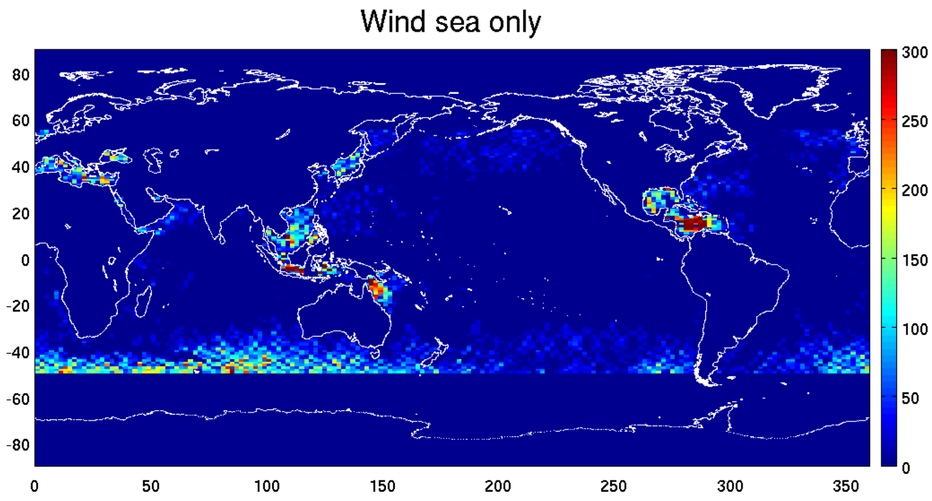
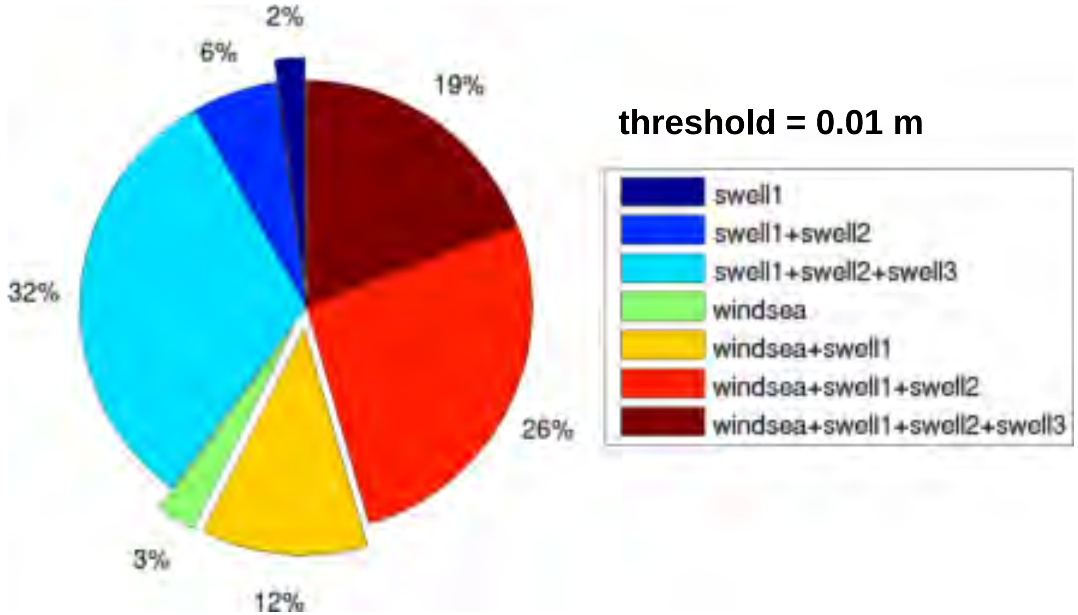


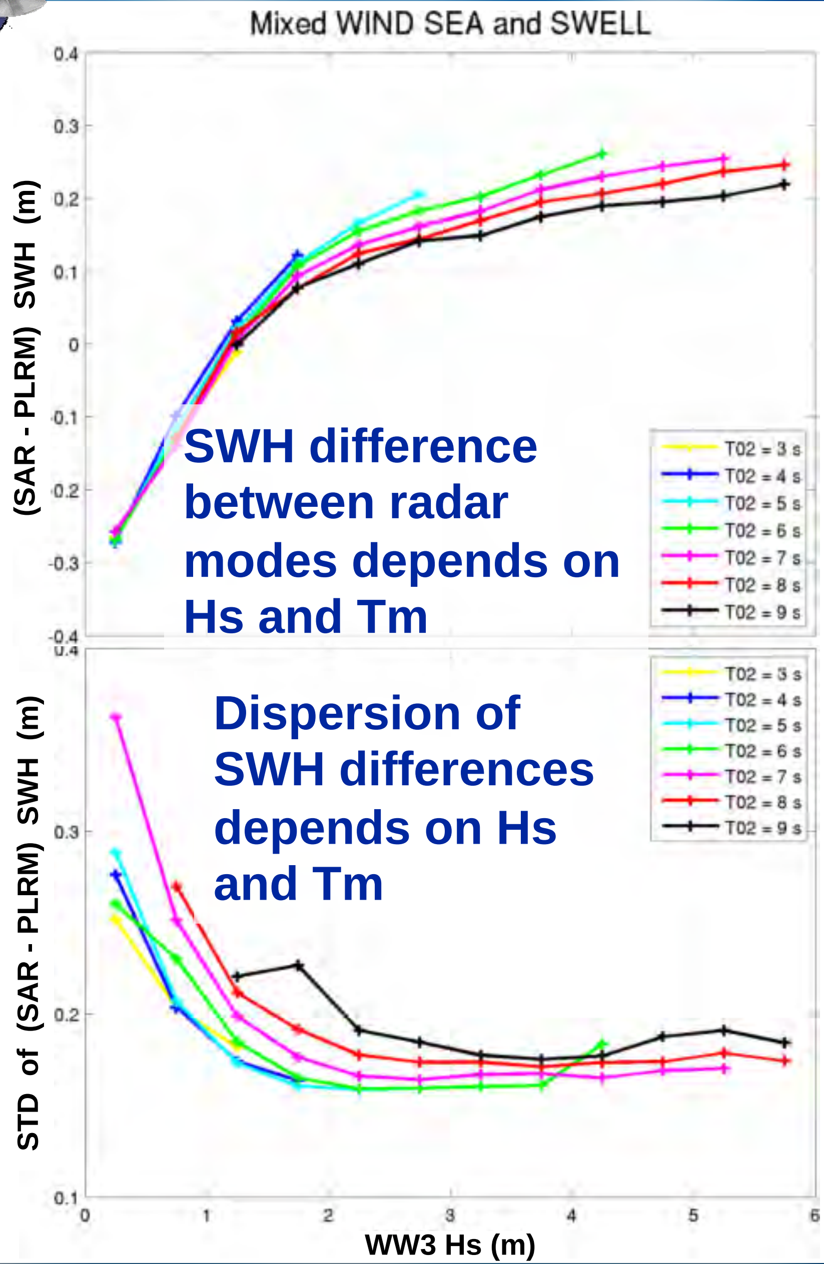
WAVE SYSTEMS FROM WW3 MODEL

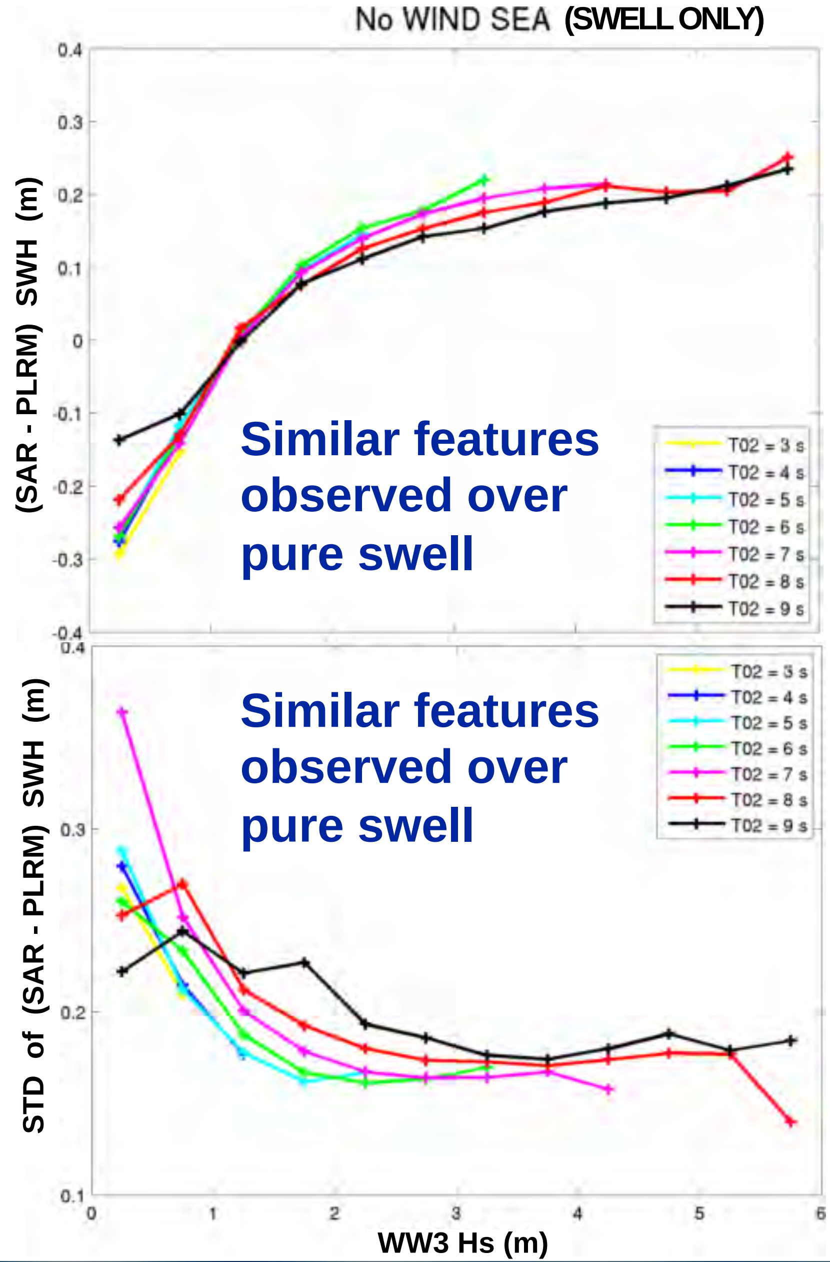




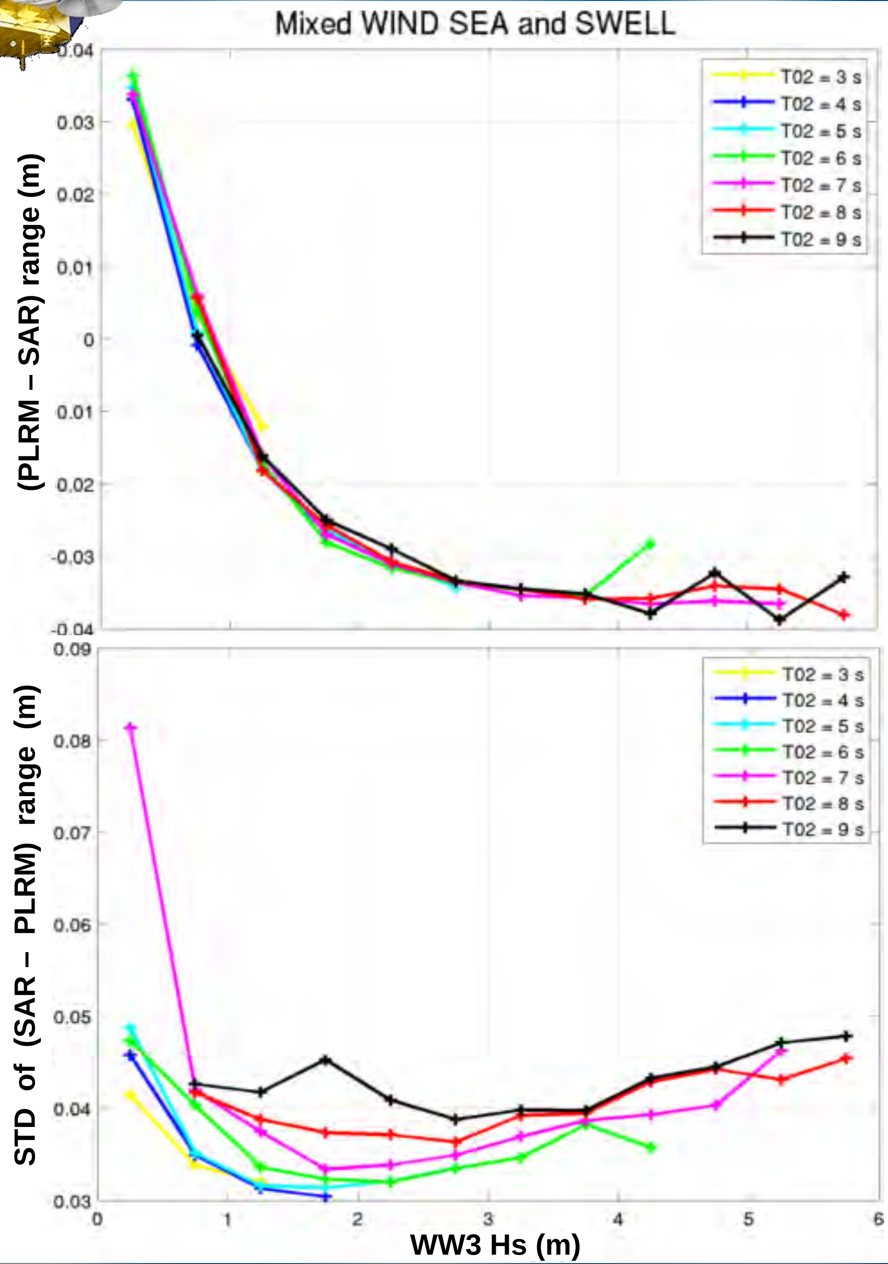


CS2 SWH SARM vs PLRM

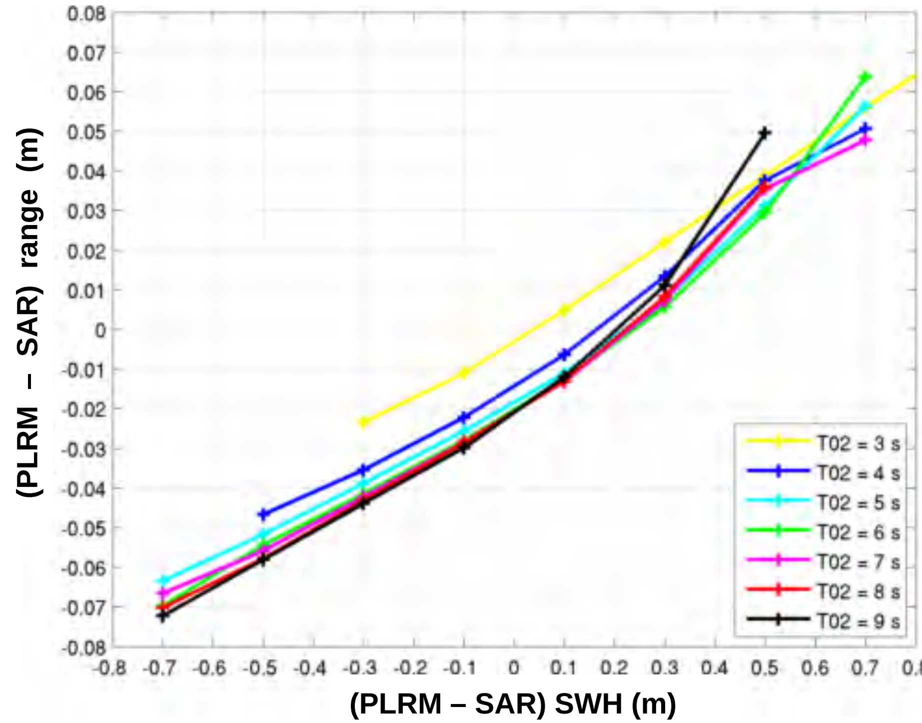




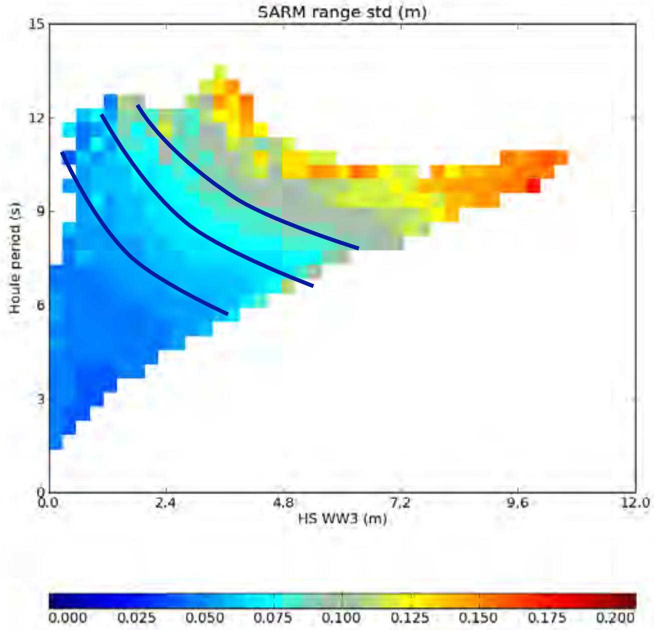
EFFECT ON RANGE

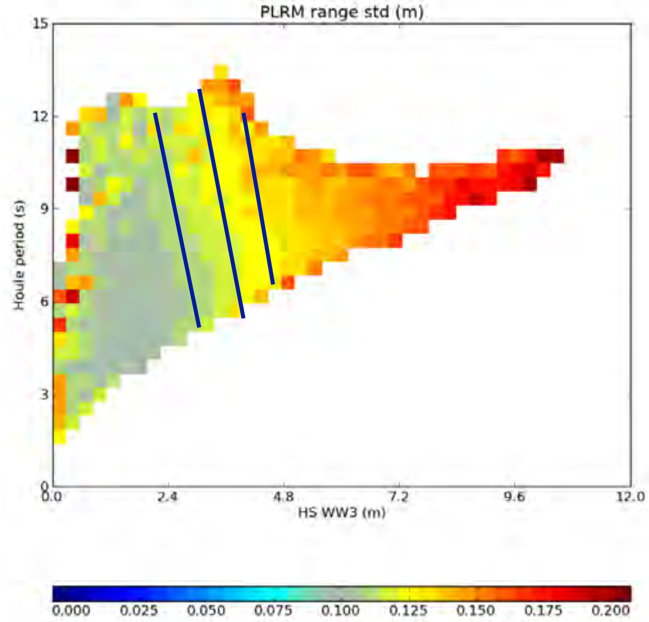


- **No apparent dependency of the range difference on the wave mean period values**
- But the dispersion of their difference depends on the wave period
- Correlation observed between range difference and SWH difference

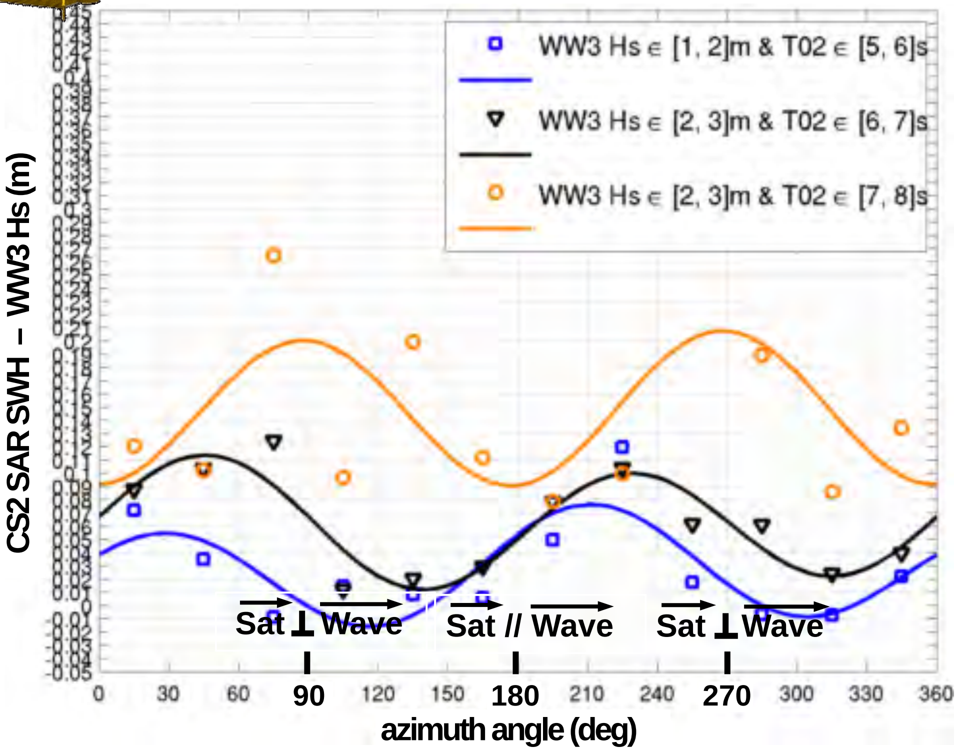


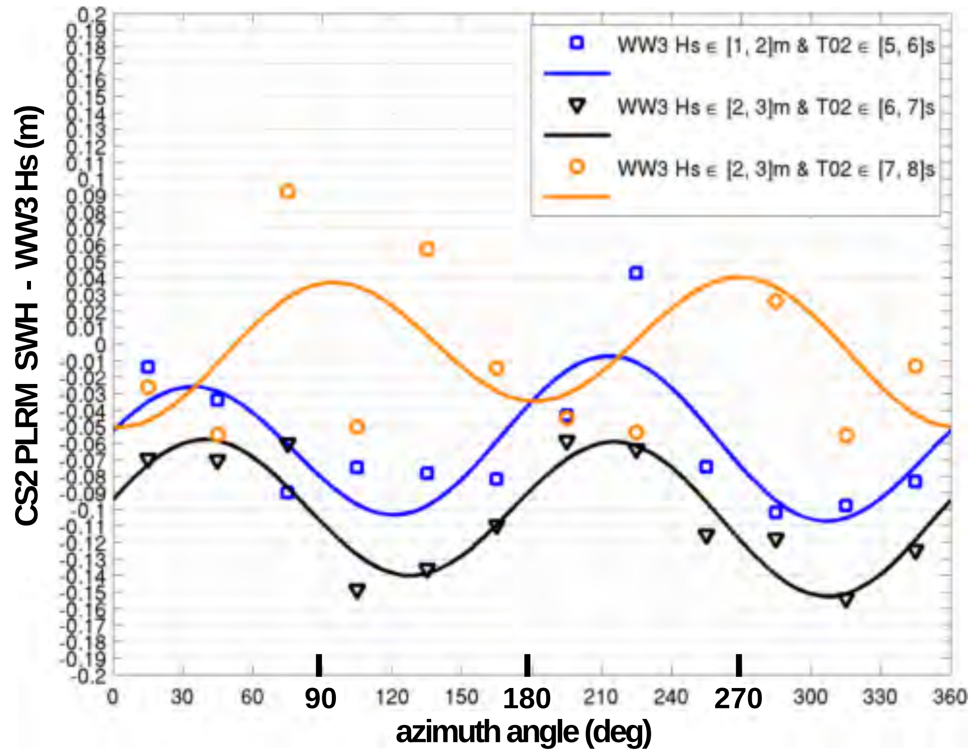
S3A SARM AND P-LRM RANGE STD





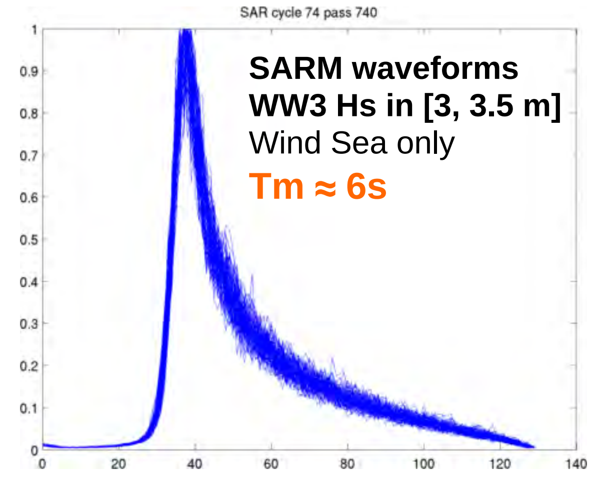
CS2 SWH vs WW3 Hs wrt DIRECTION

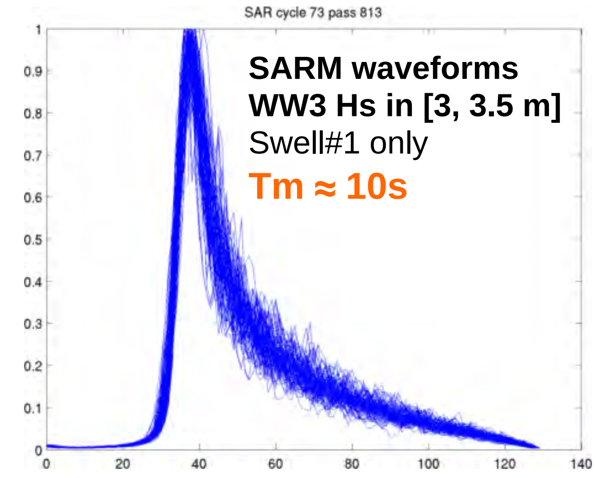




- No apparent dependency of SWH (and range) measurements in direction

WAVEFORMS ANALYSIS





- **Higher waveform amplitude dispersion in SAR-mode as Tm increases**
- **GOF of the SAR altimeter models worsens as Tm increases** (nearly stable in PLRM)
- **Larger SARM SWH and SLA std as Tm increases** (almost unchanged in PLRM)