Exploitation of the full SAR-mode signal for different applications

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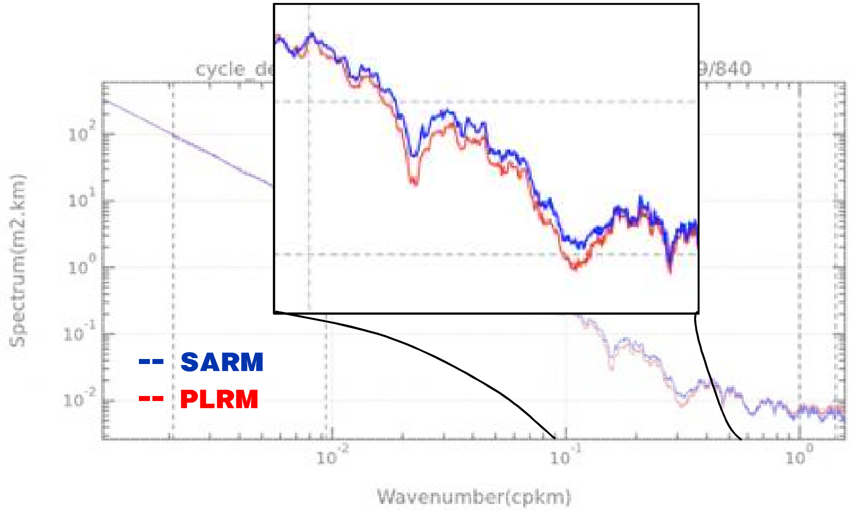
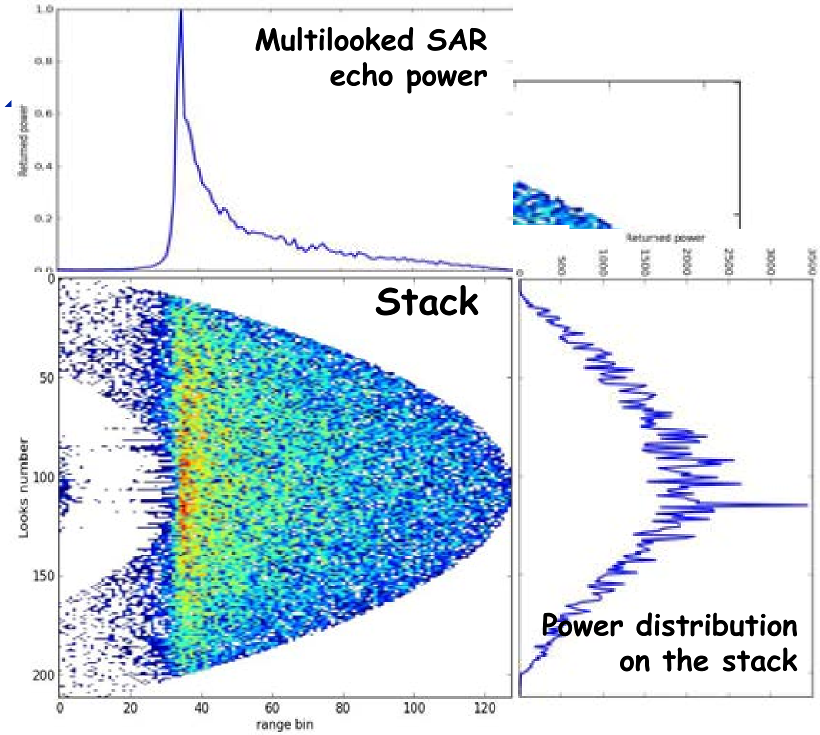
SAR ALTIMETRY IN OPEN OCEAN

- Spectral analysis for sigma0 shows more energy in the SAR PSD particularly between 2-10 km (< LRM footprint size), due to the reduced footprint

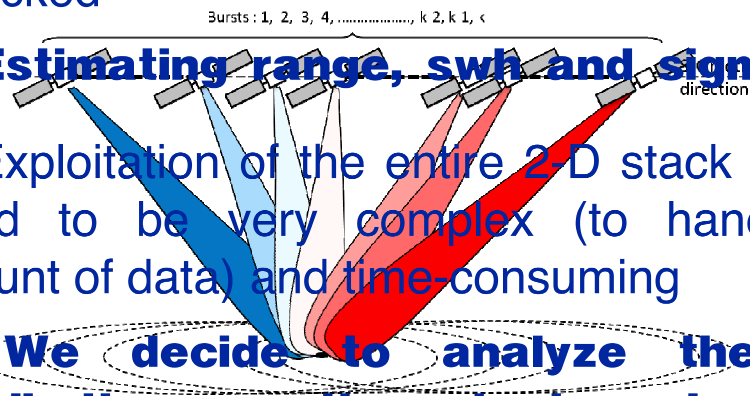
➔ **Enhanced resolution allows to capture smaller scales roughness (that needs to be better characterized)**





- But only 1-D SAR echo power (averaging different looks in the stack) wrt distance are retracked

- SARM measurements consist of:



➔ **Estimating range, swh and sigma0**

- Exploitation of the entire 2-D stack has been found to be very complex (to handle huge amount of data) and time-consuming

➔ **We decide to analyze the power distribution on the stack wrt different look angles and see which information of interest may be extracted about the ocean surface**

CONTENT

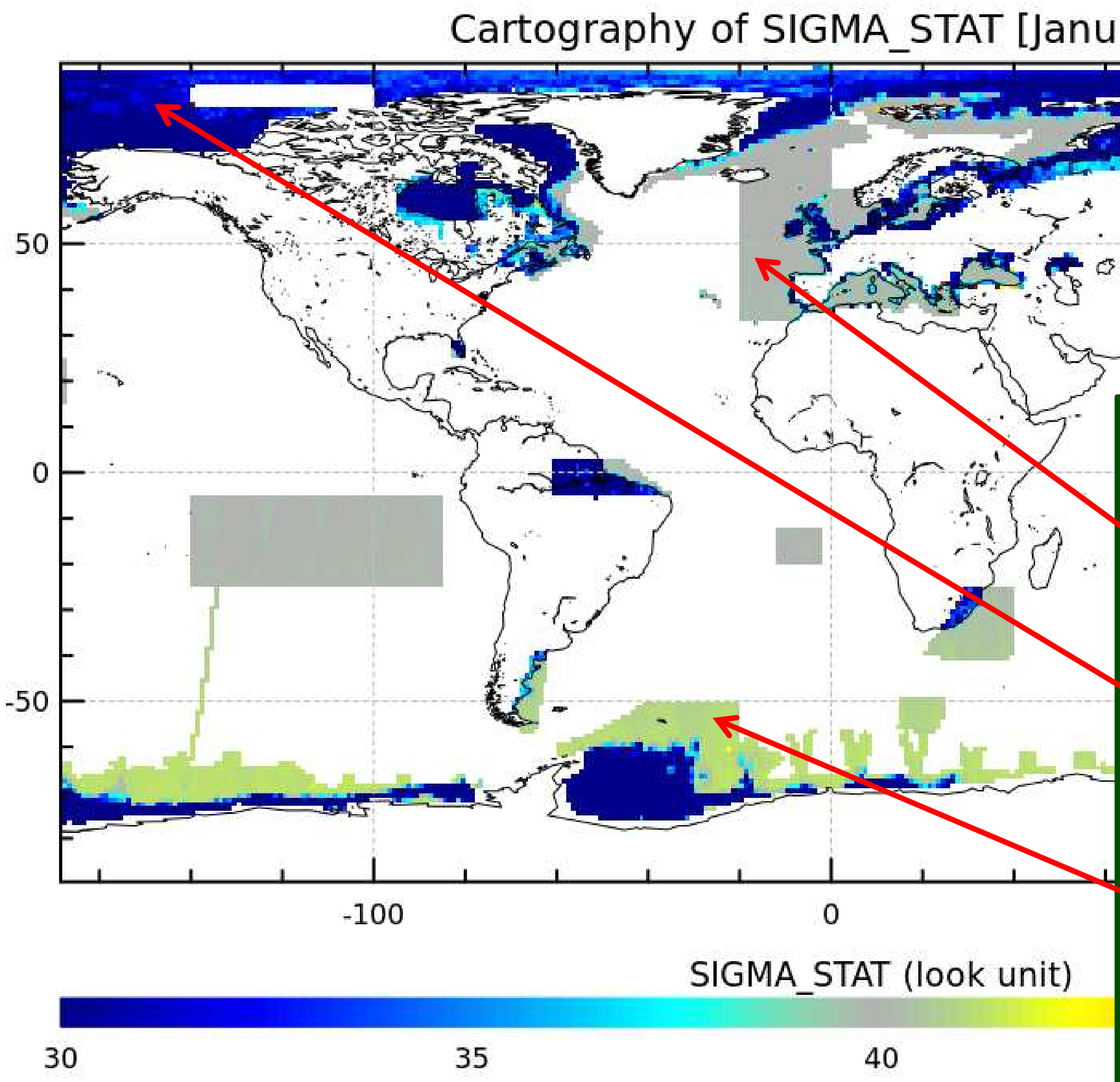
- Analysis of Power Distribution on the Stack (PDS) from SARM CPP measurements over ocean:
  - understanding,
  - limitations and,
  - simulation

- Development of a PDS retracking algorithm for ocean surfaces

- Analysis of the PDS estimates: moments of the PDS with statistical and retracking method

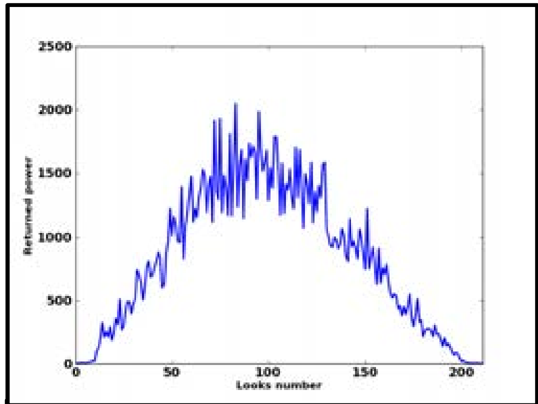
This study is undertaken in the framework of the lotus project and through CNES contract

STATISTICAL ANALYSIS OF THE PDS : STD

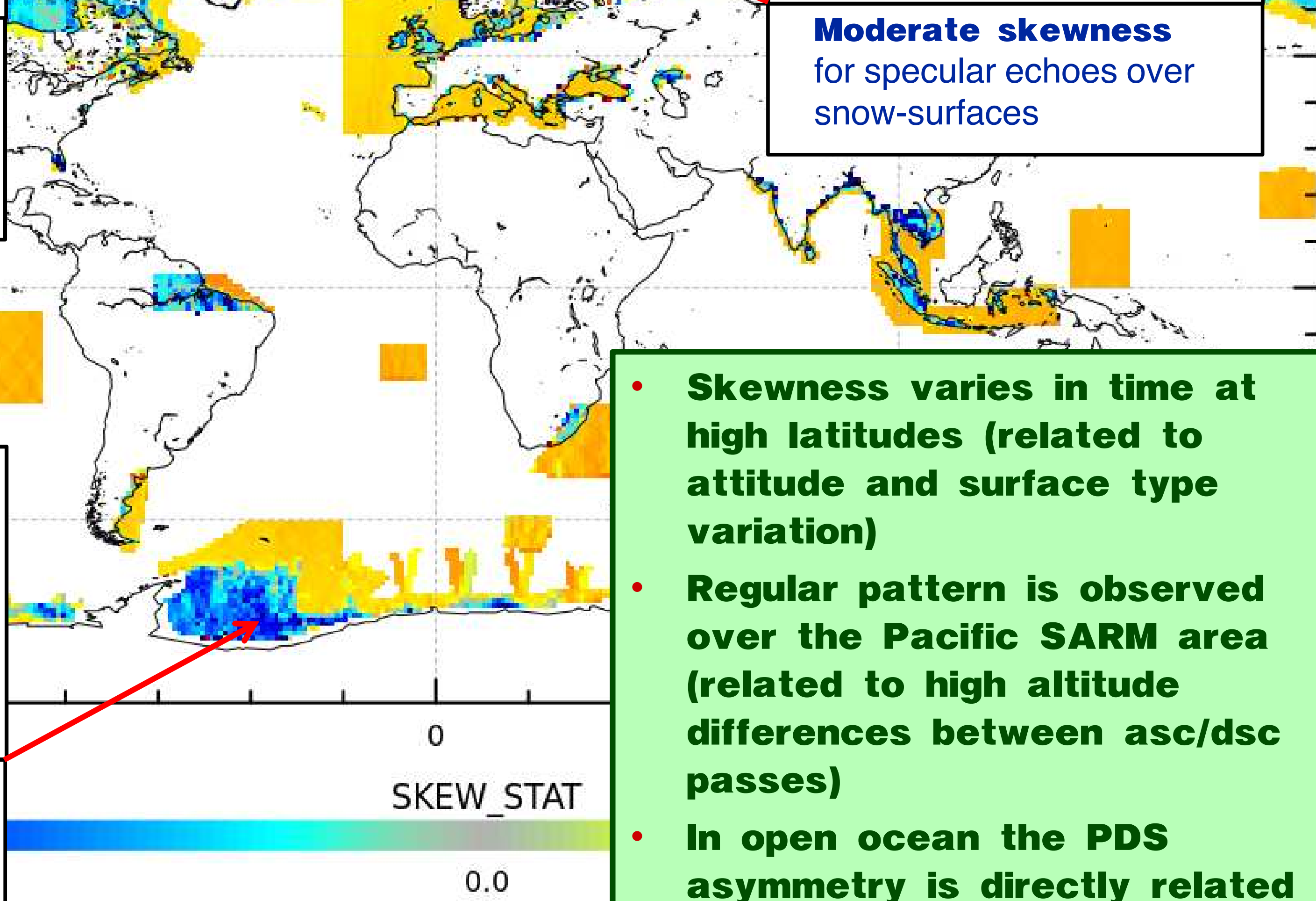


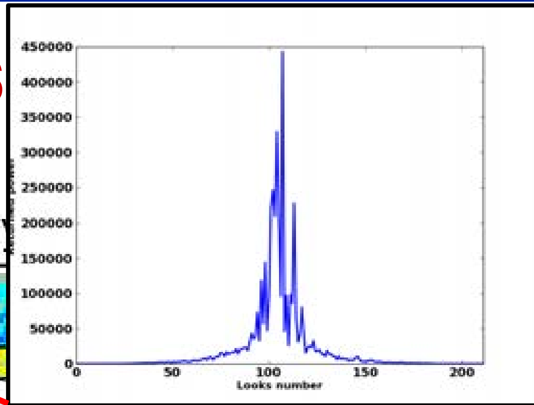
- **STD informs about the surface roughness**
  - **Rougher scattering surface over open ocean (almost steady std)**
  - **very narrow shape of the PDS over polar ocean and land (very low std values)**
- **Slightly wider PDS are however observed in open ocean regions and periods where wind and waves are however supposed to be low**

TATISTICAL ANALYS ... S :
... ESS

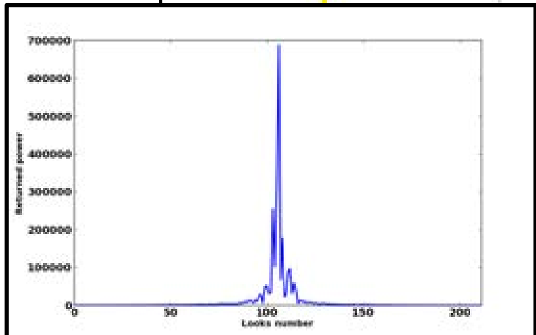


Skewness ˜ 0.1-0.15 (over open ocean) only sensitive to the off-nadir along-track antenna gain pattern ~0.1°





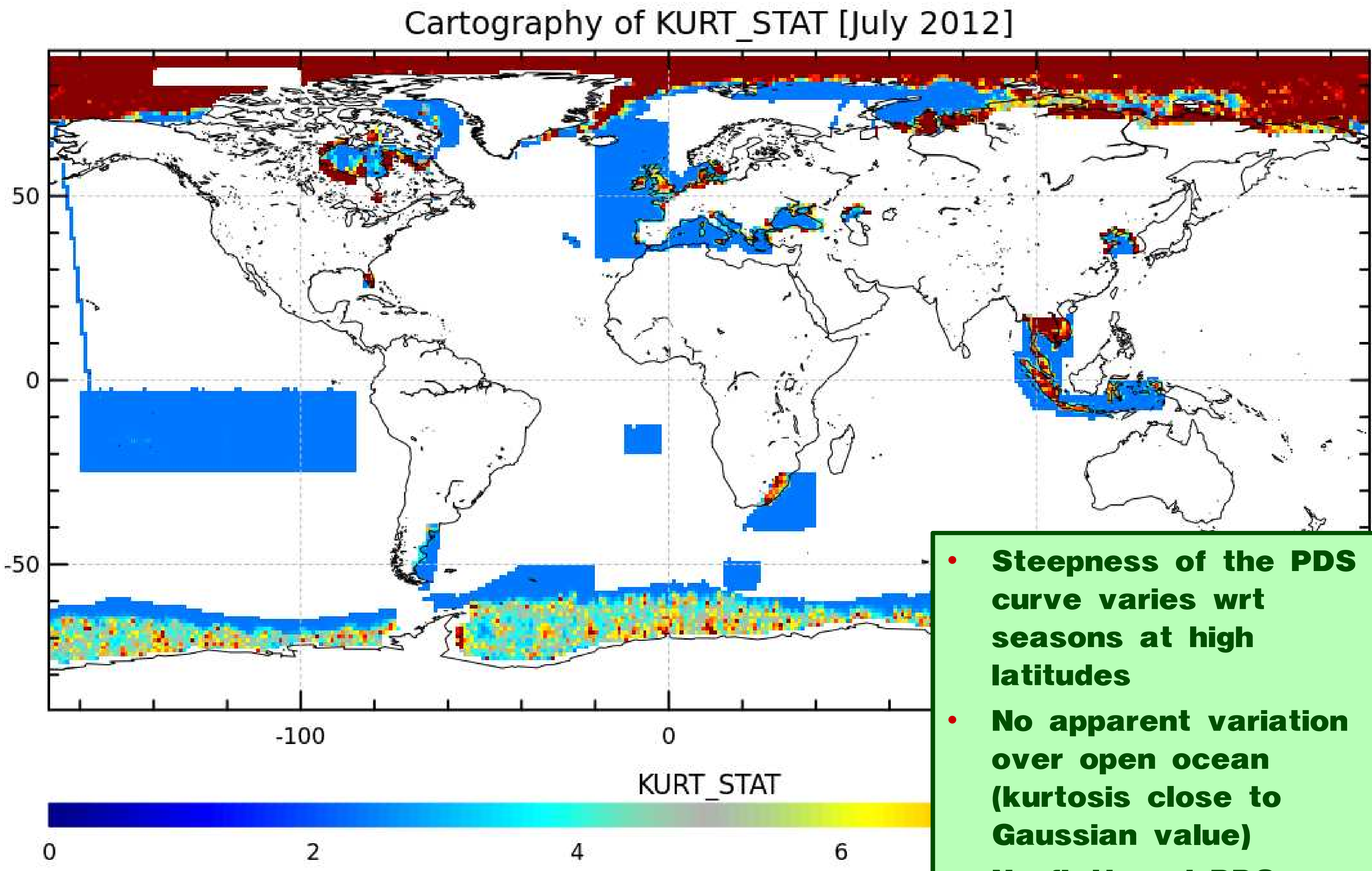
Moderate skewness for specular echoes over snow-surfaces



High negative skewness for specular echoes over mirror-like surfaces

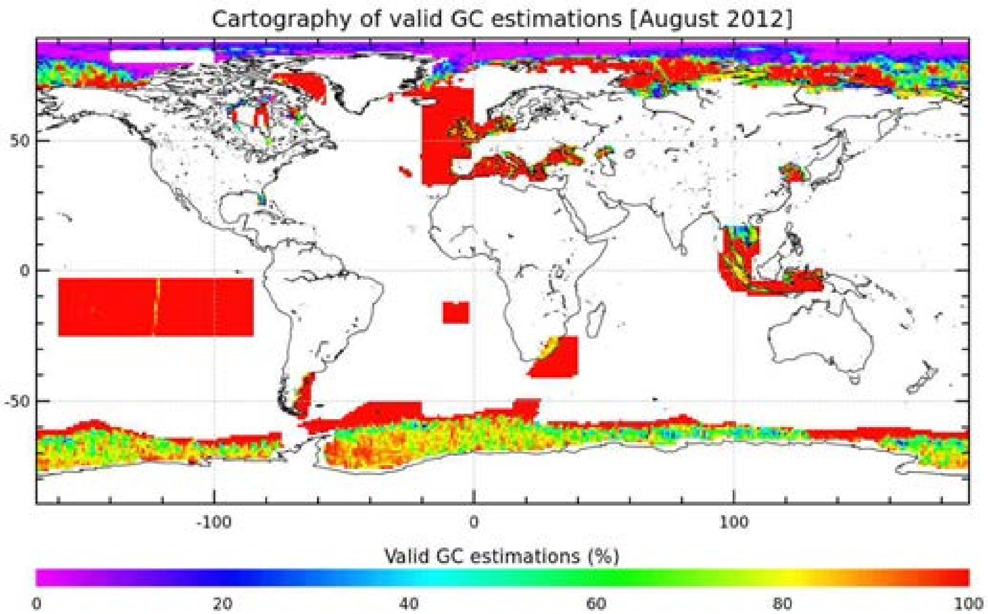
- **Skewness varies in time at high latitudes (related to attitude and surface type variation)**
- **Regular pattern is observed over the Pacific SARM area (related to high altitude differences between asc/dsc passes)**
- **In open ocean the PDS asymmetry is directly related to the along-track antenna**

STATISTICAL ANALYSIS OF THE PDS : KURTOSIS



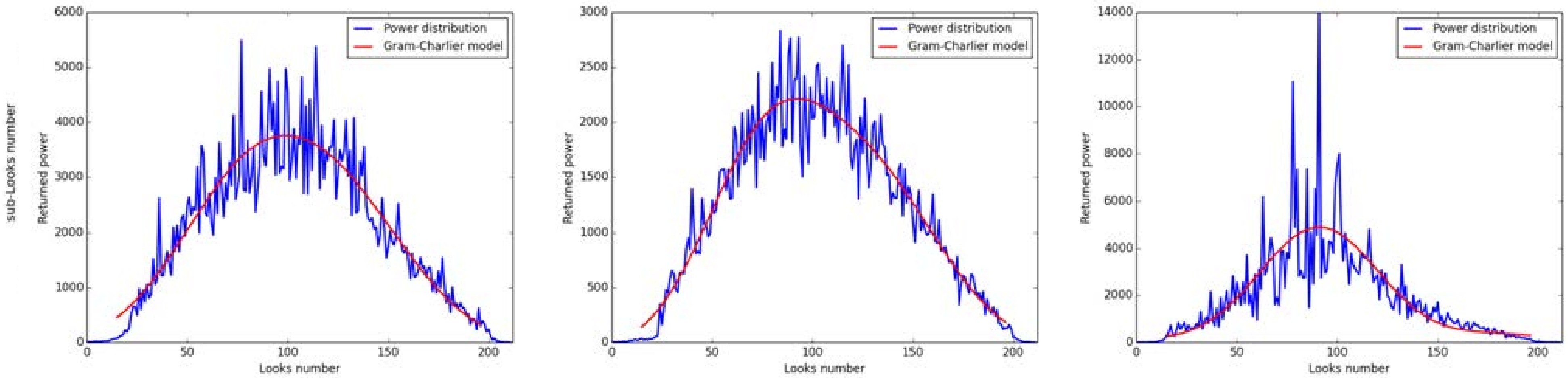
- **Steepness of the PDS curve varies wrt seasons at high latitudes**
- **No apparent variation over open ocean (kurtosis close to Gaussian value)**
- **No flattened PDS curve**

PDS RETRACKING



- Asymmetrical distribution of power in stack due to the off-nadir antenna pointing requires the use of a distorted Gaussian-shape model

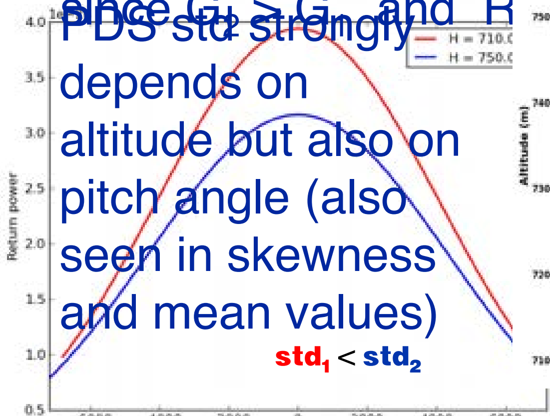
  ➔ **Gram Charlier series**
- Basic moments are derived from a best fitting curve process with a misfit confidence value
- The maximum of the Gram-Charlier fit is the measurement of the pitch

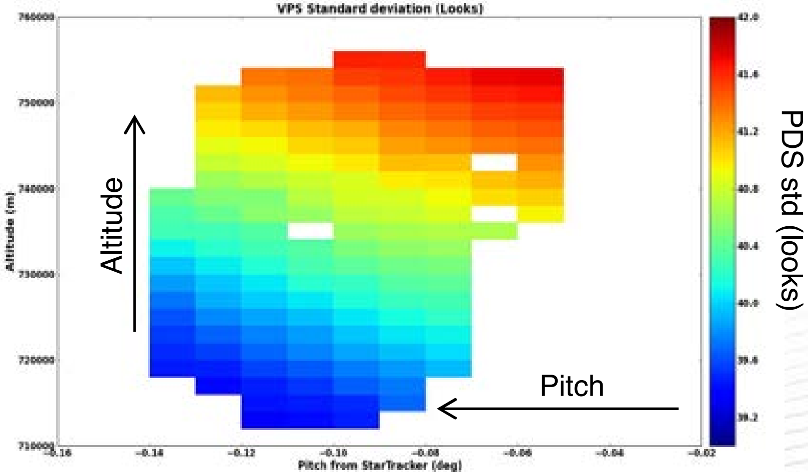


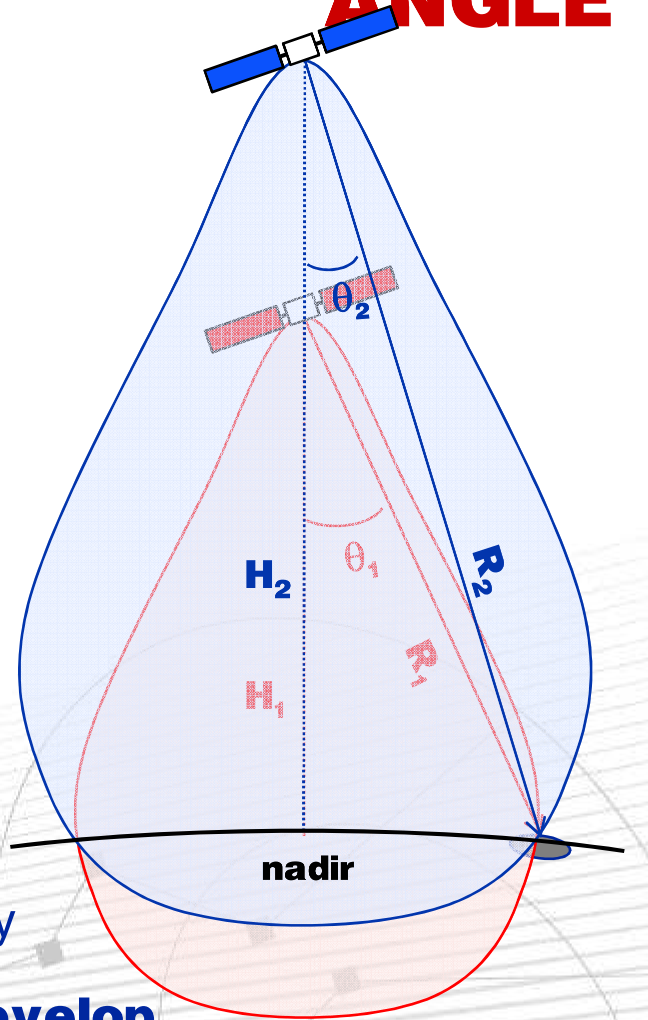
SENSITIVITY TO ALTITUDE AND PITCH ANGLE

- **Return power P_r is proportional to G^2/R^4**
  - R distance altimeter-surface
  - G the antenna gain $G(\theta) = G_0 \exp\left[-8\ln 2\left(\frac{\sin\theta}{\sin\theta_{-3dB}}\right)^2\right]$

- At the same surface point **if $H_2>H_1$ then $P_{r2} \neq P_{r1}$** since $G_1 > G_2$ and R
- On real data, the PDS std strongly depends on altitude but also on pitch angle (also seen in skewness and mean values)







- No dependency on roll angle and negligible on radial velocity

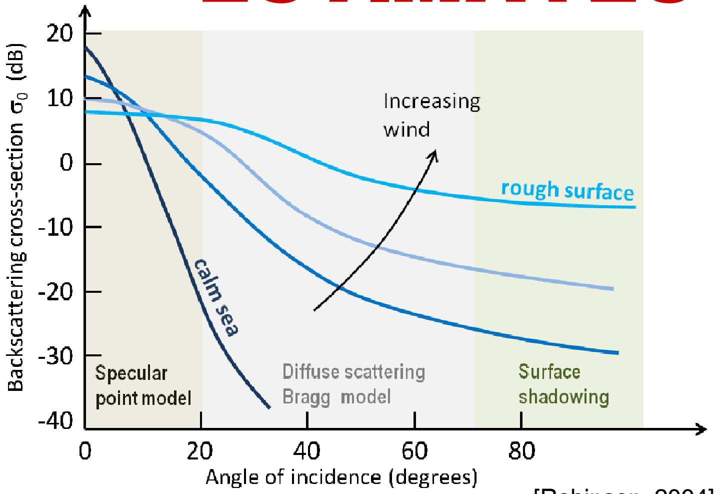
➔ **On-going investigations are attempting to develop a model accounting for pitch and altitude**

ANALYSIS OF PDS RETRACKING ESTIMATES

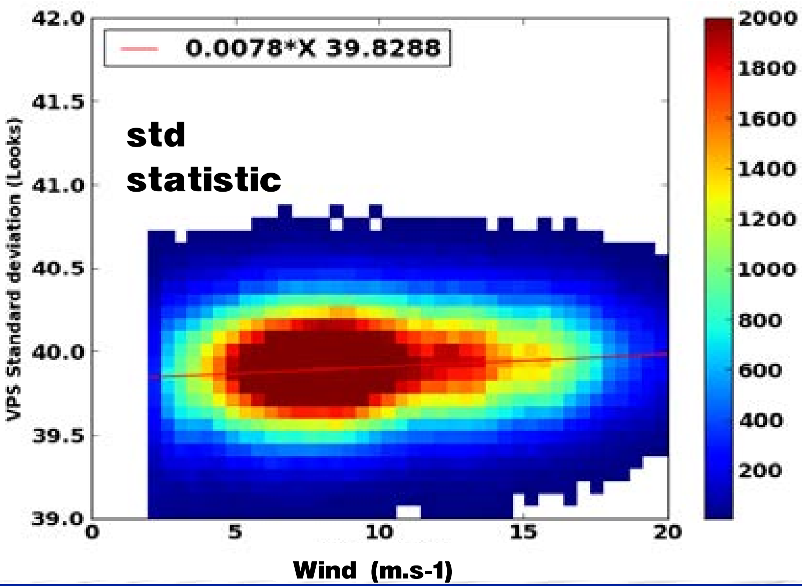
The dominant environment factor responsible for sea surface roughness is the wind

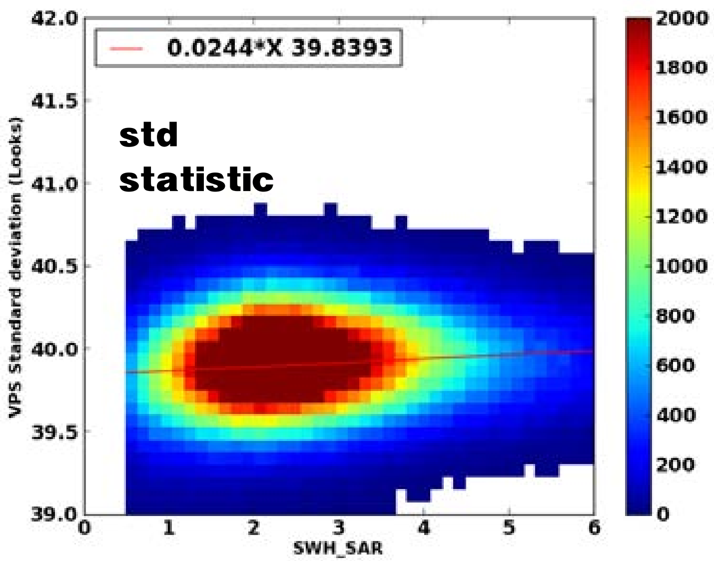
Surface roughness analysis done at constant pitch and altitude over ocean to compensate the altitude and pitch effects

- Mean square slope given by the PDS std increases linearly with wind speed (➔ dependency may be used to compute wind from PDS estimates) but poor correlation because of the variability of the retracking
- Low dependency with wave height



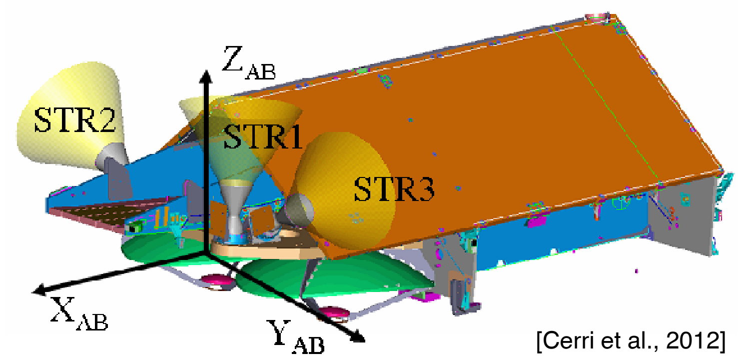
[Robinson, 2004]



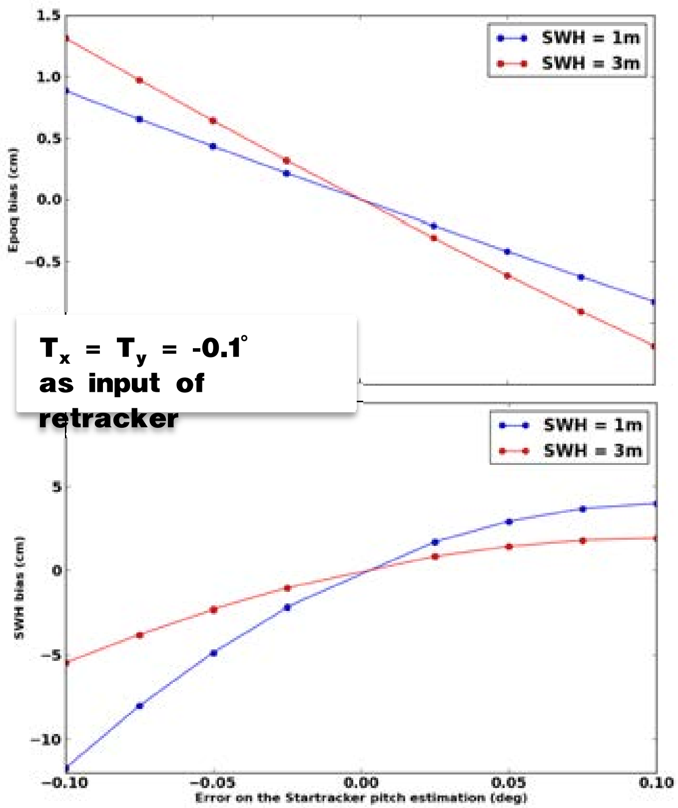


ANTENNA POINTING ISSUE

- In CPP products, off nadir angles seen by the altimeter are derived from:
  - satellite platform measurements (roll/pitch) provided by CNES POD (after STR quaternion transformation), and
  - angular biases computed between the STR boresight and the altimeter electromagnetic axis



[Cerri et al., 2012]

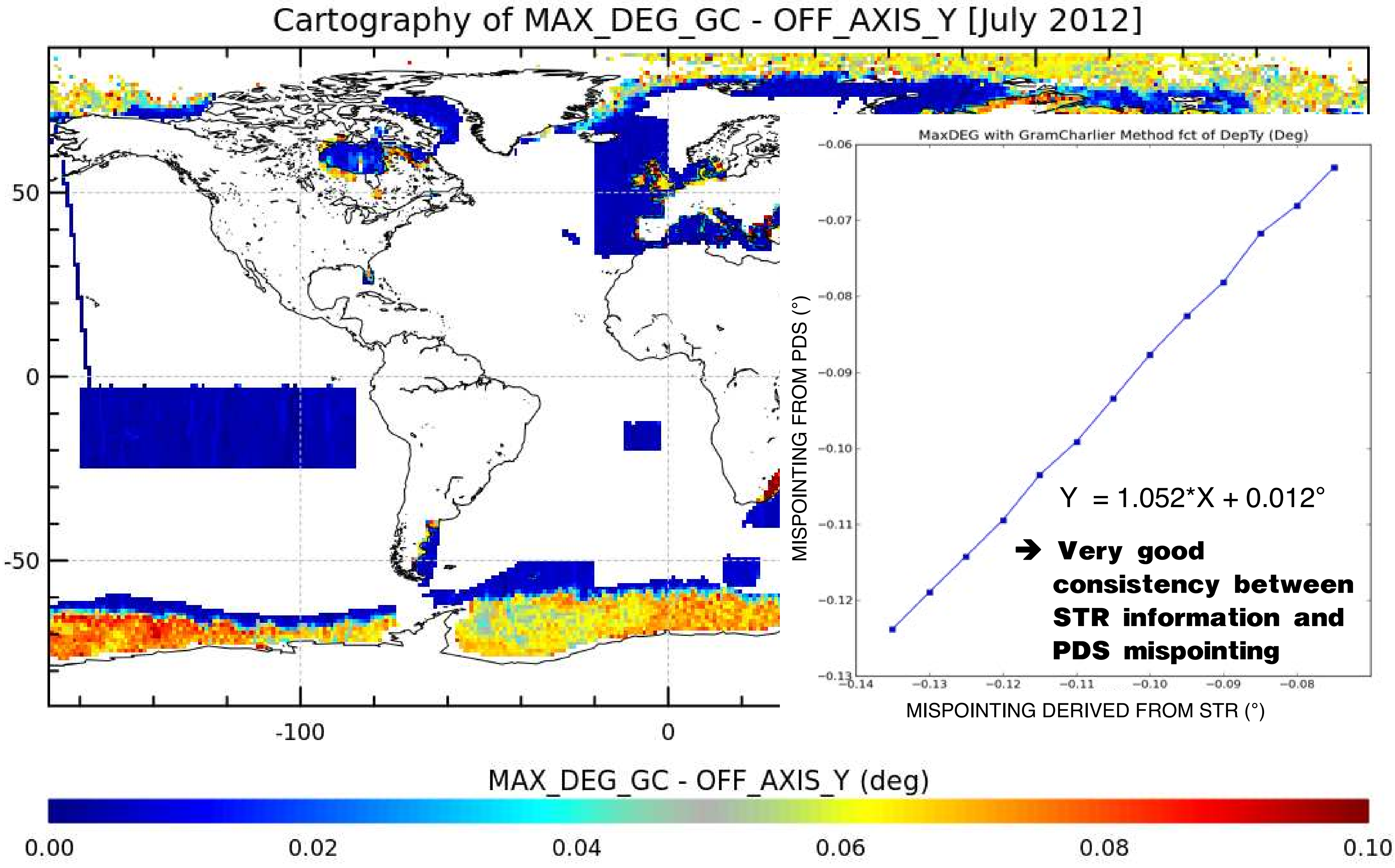


- Non-negligible error on range and SWH estimates wrt inaccurate knowledge of mispointing angles (due to imprecise pitch/roll angles or to incorrect adjusted angular biases) are determined

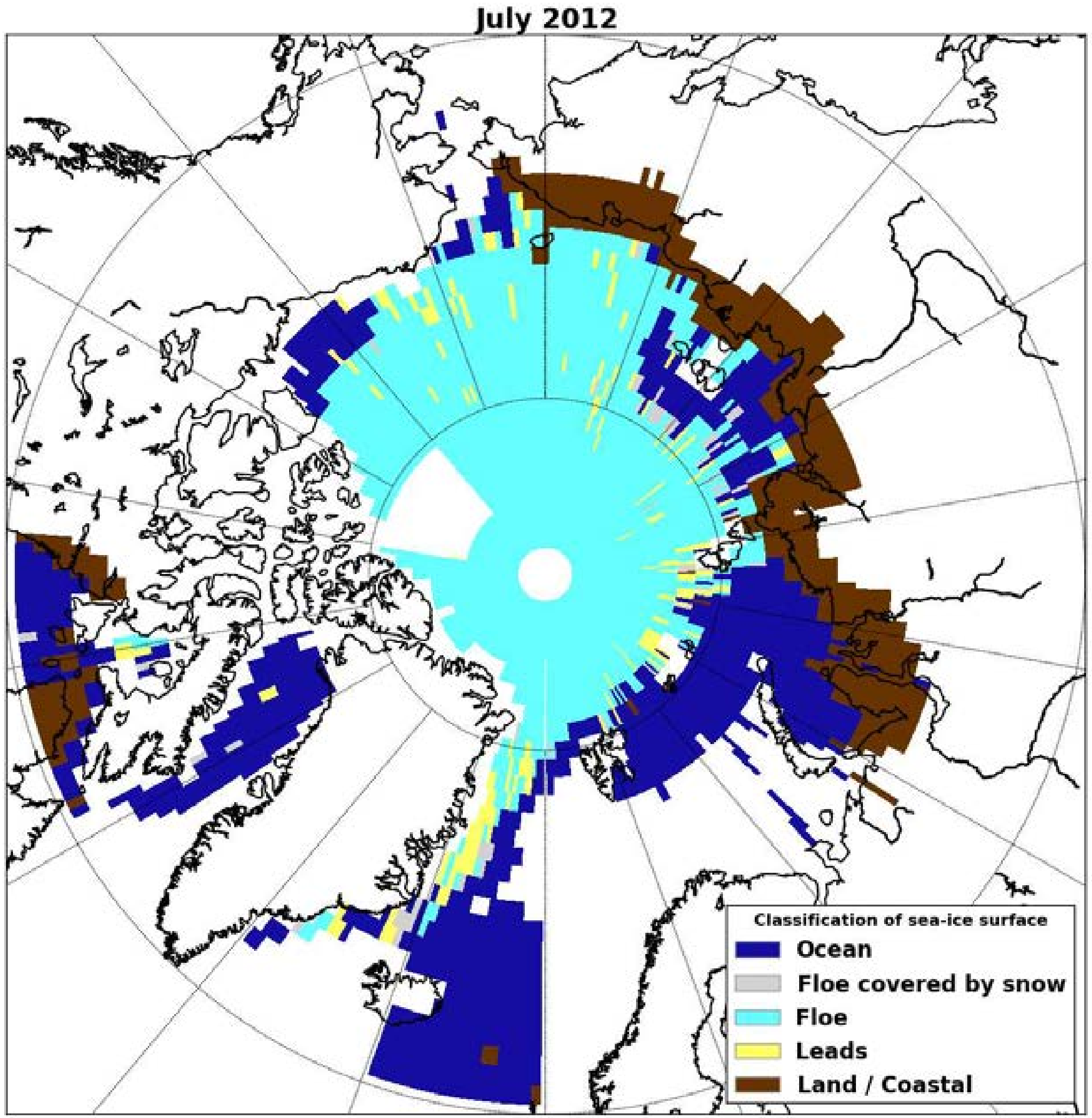
➔ **raising the need of accurate off nadir angles as input parameter of a 3-parameters SAR retracking module**

Note that the S-3 attitude determination error is defined below 10μrad (2σ) per axis (~6E-4°) while the Cryosat-2 one is higher (≤130μrad) since no gyros are on-board.

COMPARISON OF ALONG-TRACK MISPOINTING ANGLES



PDS CLASSIFICATION



CONCLUSIONS

- ✓ Power Distribution on Stack from SARM CPP data has been analyzed over 6 months

→ **Information of interest may be extracted (pitch bias of the star tracker, roughness and wind speed, classification of PDS shapes to be added in higher level products for the final user)**

- ✓ However the particular Cryosat-2 satellite with un-steady satellite orbit and off-axis angle strongly impacts the PDS shape leading to difficult interpretations (which should not be the case with Sentinel-3)

- ✓ Gram-Charlier model gives adequate description of the measured return power, more probable than for a Gaussian distribution

- ✓ The full CPP database (2-3 years) will permit to identify entire seasonal variation and annual trend

PERSPECTIVES

- To adjust the Gram-Charlier model to make it more robust (particularly over polar ocean) and to improve its correlation with geophysical parameters (wind speed)
- Analysis of the Power Distribution on Burst would permit to eliminate those oceanic waveforms that are contaminated by land and ice returns (application to coastal regions, ocean polar and in-land waters)
- To cross-compare with Ka-band Altika products, with moderate resolution imaging spectroradiometer (MODIS) and high resolution SAR imaging to assess the consistency of the SARM altimeter findings
- The exploitation of the PDS will also provide valuable information on both ice-sheet stability and sea-ice coverage

THANK YOU !!

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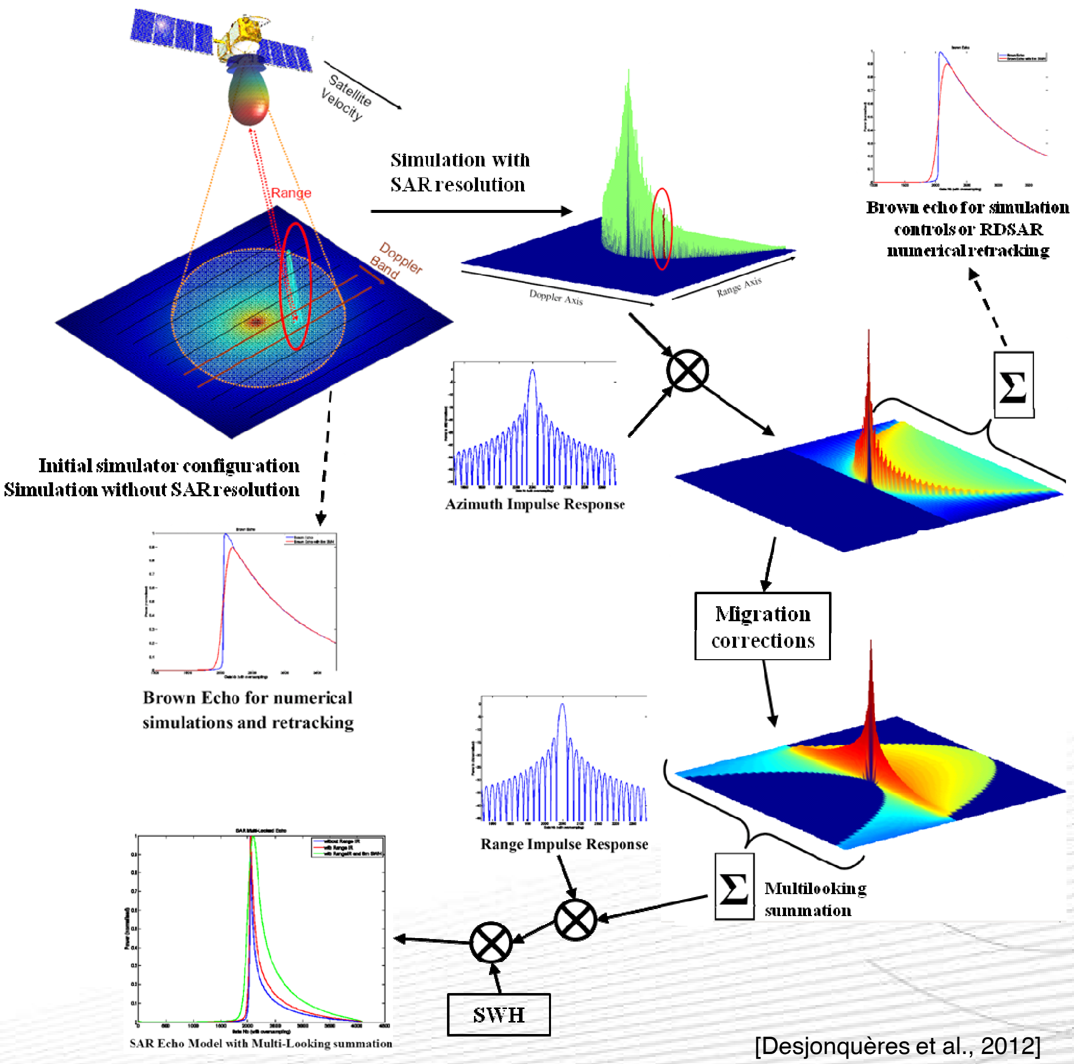
AMPLITUDE NUMERICAL SIMULATOR



[Desjonquères et al., 2012]

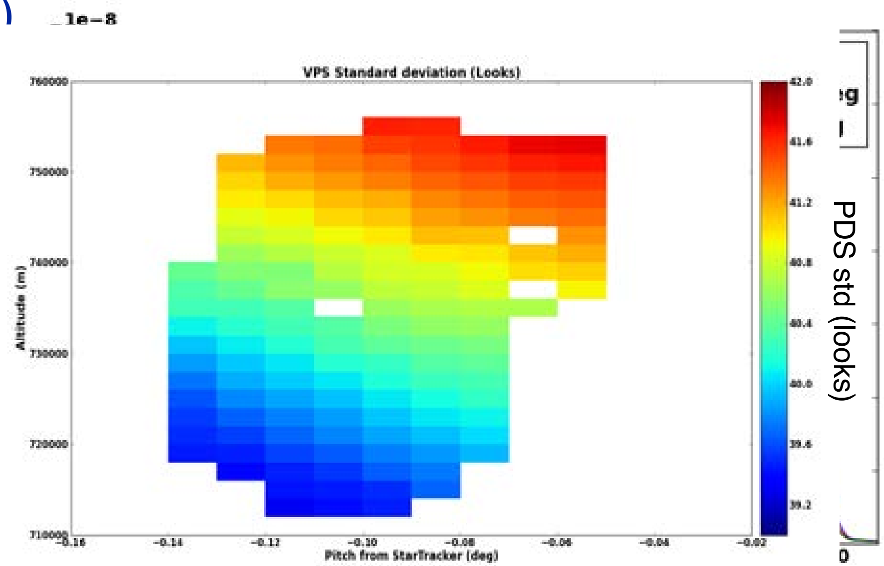
The simulator mimics the altimeter response in SAR mode (taking into account the real elliptical antenna pattern and a real point target response)

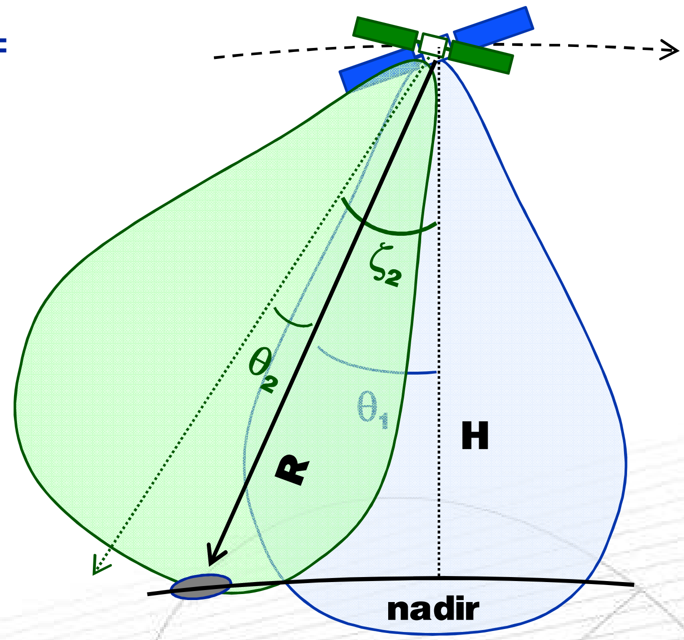
Major processes of the SAR simulator are in sequence:

- The power return signals are computed for each point of gridded surface then sorted by Doppler band and accumulated in the appropriate range gates of the waveforms.
- To convolve FSSR with AIR and RIR of the radar (approximated by a sinc² function)
- To correct Doppler bands in range to compensate the slant range migration,
- To sum (multilooking) Doppler beam waveforms (looks) from the same surface to finally form the SAR echo model for a flat sea surface
- To finish, the simulator convolves the previous result with the PDF of the significant wave height.

SENSITIVITY TO PITCH ANGLE

- At same point surface and same satellite altitude **if $\zeta_2 \neq \zeta_1$ then $P_{r2} \neq P_{r1}$** since $G_2 \neq G_1$ (but $R_2 = R_1$)

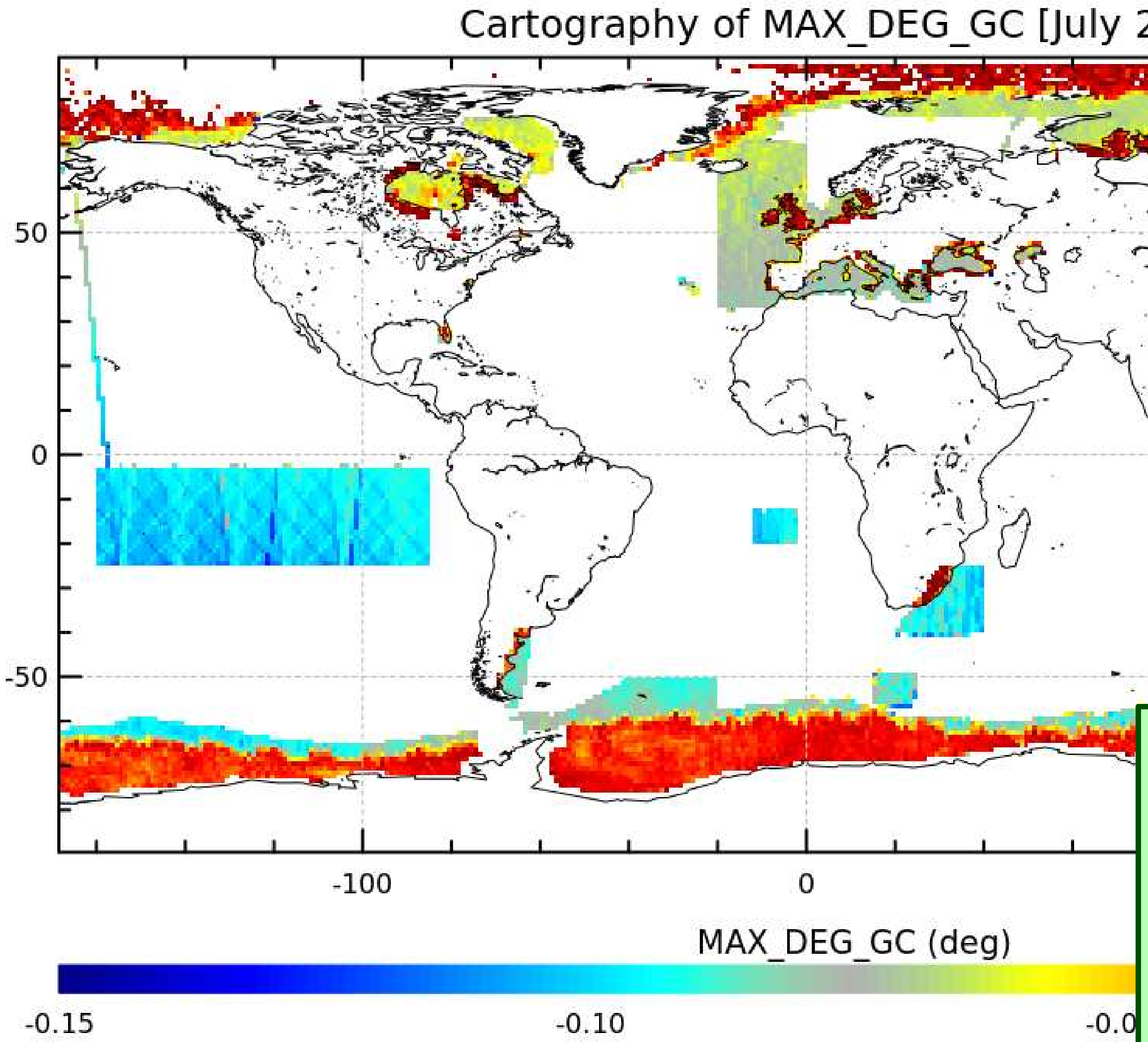




- On real data, low dependency of the PDS std on pitch angle is observed (also seen in skewness values)
- No dependency found on roll angle and negligible on radial velocity

➔ **Surface roughness analysis will be done at constant altitude and constant pitch angle over ocean to compensate both effects**

ANALYSE OF THE ALONG-TRACK MISPOINTING ESTIMATES



- **The along-track antenna off-axis measurement is only reliable over open ocean (where the radar backscattering σ_0 is almost constant in the nadir angular sector)**