WP3: DEFINITION OF NEW DATA PRODUCTS AND PROCESSING CHAINS

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TASKS

- WP3 Participants: CLS, DHI, DTU, Starlab, UNEW
- WP3 Leader : CLS

- WP3 objective: Definition of new data products and processing chains that
  - utilize the full potential of the SAR-mode
  - form the basis for new innovative Copernicus products and applications that are not considered or implemented in the Copernicus services yet
  - adress the different surface targets of the Sentinel-3 topography measurements (open oceans, coastal seas, sea ice, in-land water in rivers and lakes, soil moisture, and snow water equivalent)
  - meet the needs of the different users (complementing the ESA Sentinel-3 L2 data products, and enabling the end users to get an easy access to specific higher-level information they need)

- WP3 activities
  - Task 3.1: Definition and design of ocean data products ***[CLS, Starlab, DTU, UNEW]***
  - Task 3.2: Definition and design of land data products ***[CLS, UNEW, Starlab, DHI, DTU]***
  - Task 3.3: Specific products dedicated to applications ***[CLS]***
  - Task 3.4: Data product formats and dissemination services ***[CLS, DTU]***
  - Task 3.5: Specification and development of dedicated processing chains ***[CLS]***

DELIVERABLES STATUS

- Data Product Definition Document (DPDD)
  D3.1 – **submitted**
- Data Product User Manual (DPUM)
  D3.2 – **submitted**
- Algorithm Theoretical Baseline Document (ATBD)
  D3.3 – **submitted**
- SAR Mode for Ocean Corrections Theoretical Basis Document (OCTBD)
  D3.4 – **submitted**

Available on the LOTUS's website at http://www.fp7-lotus.eu/Publications/Deliverables

Definition and design of ocean data products

- To define and design Level-2 data products over ocean
  - High-resolution along-track geophysical quantities derived from the WP1 refined algorithms
  - Geophysical corrections to derive ocean geophysical parameters
- To define Level-3 data products over ocean
  - Along-track data are corrected and/or intercalibrated (multi-mission)
  - Resolution and sampling are optimised wrt Level 2 products
- To define Level-4 data products
  - Multi-mission gridded data
  - Not generated (not taking benefit of the SAR-mode along-track resolution)

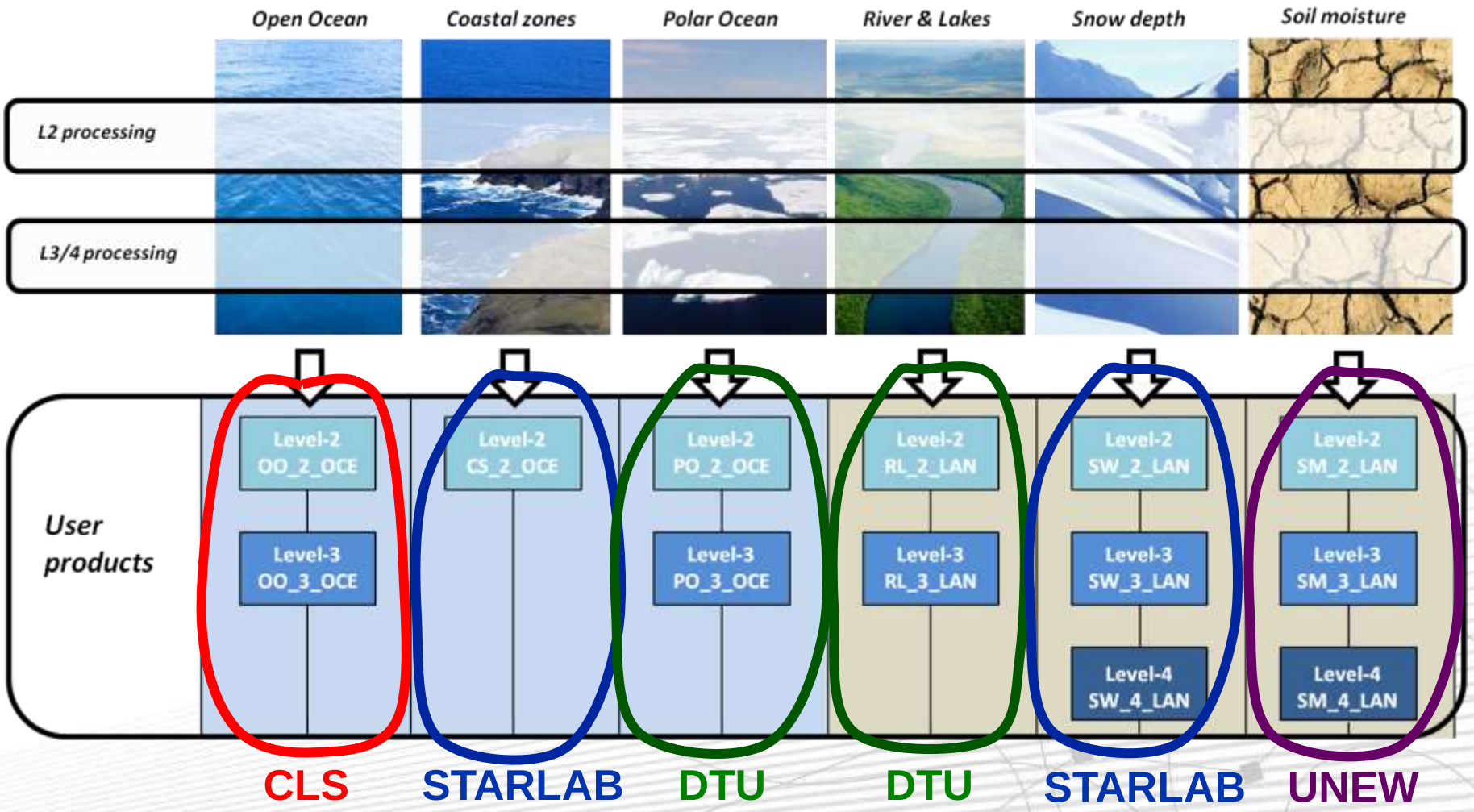
➔ **Product description in backslides**

Definition and design of land data products

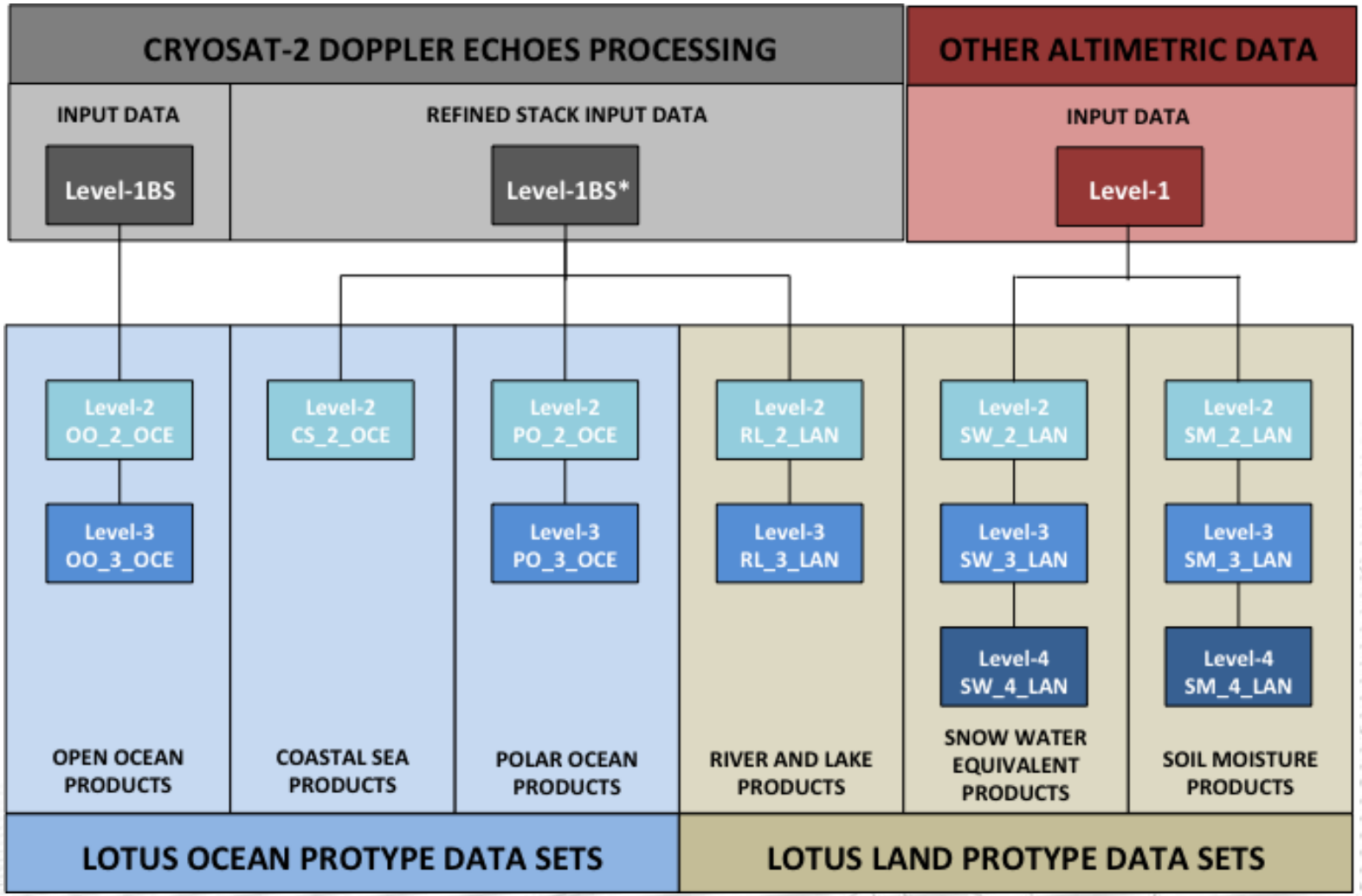
- To define and design Level-2 data products over land
  - Along-track water level derived from the WP2 refined algorithms
  - Land-water mask value and geophysical corrections
  - Not for release for snow depth and soil moisture (too noisy)
- To define Level-3 data products over land
  - Extracting most relevant observations on the hydrology basins and time series at virtual stations
  - Filtered snow depth estimates
  - Along-track soil moisture mean estimates (SMMEs)
- To define Level-4 data products
  - Time series (SMME and snow depth)

➔ **Product description in backslides**

USER PRODUCTS



PRODUCTS GENERATION



USER PRODUCT LIST

User product type	Level	Description
OO_2_OCE	2	1Hz and 20Hz SIRAL CryoSat-2 parameters (SAR/PLRM) over Open Ocean
OO_3_OCE	3	Cross-calibrated SIRAL CryoSat-2 parameters (SAR/PLRM) over Open Ocean
CS_2_OCE	2	20Hz SIRAL CryoSat-2 parameters (SAR/PLRM) over Coastal areas
PO_2_OCE	2	1Hz and 20Hz SIRAL CryoSat-2 parameters (SAR/PLRM) over Polar Ocean
PO_3_OCE	3	Cross-calibrated SIRAL CryoSat-2 parameters (SAR/PLRM) over the Polar Ocean (using global arc cross calibration)
RL_2_LAN	2	20Hz SIRAL CryoSat-2 parameters (SAR/PLRM) over in-land Rivers and Lakes
RL_3_LAN	3	Edited 20Hz SIRAL CryoSat-2 parameters (SAR/PLRM) over in-land Rivers and Lakes and time series at virtual stations
SW_2_LAN	2	Not for release
SW_3_LAN	3	20Hz filtered Snow Depth estimates
SW_4_LAN	4	Snow depth time series
SM_2_LAN	2	Not for release (data too noisy for 20Hz spatial resolution to be useful)
SM_3_LAN	3	Along-track soil moisture mean estimates (SMMEs) at spatial resolutions determined by data high frequency variation and locations bounded by DREAM extents
SM_4_LAN	4	Time series for each SMME

PRODUCTS CORRECTIONS AND MODELS

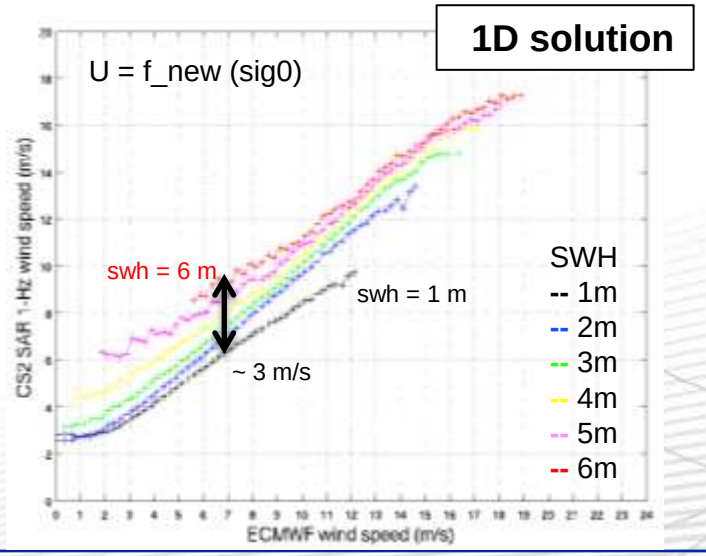
- Standard models (ECMWF, GIM, GOT4.8, MOG2D, ..) are used to compute corrections then derive ocean geophysical parameters from SAR-mode

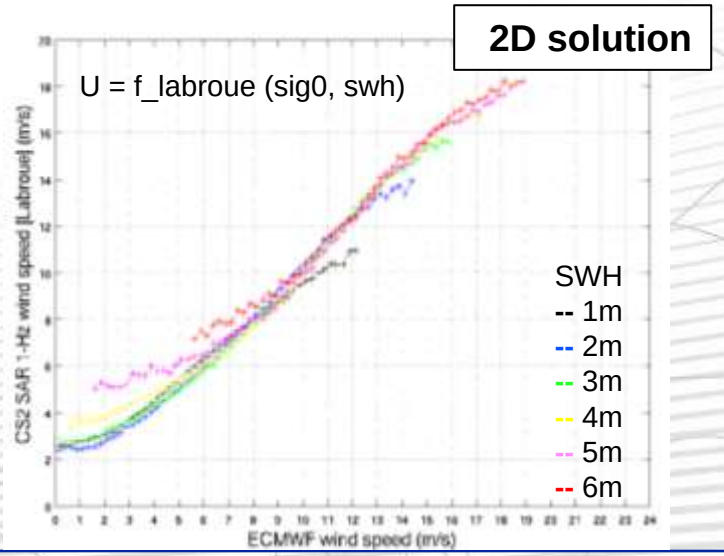
Parameter	Description
Dry Troposphere	Model dry tropospheric correction is computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag. A dry tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for dry tropospheric range delays of the radar pulse. From European Center for Medium Range Weather Forecasting
Wet Troposphere	Model wet tropospheric correction is computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag. A wet tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for wet tropospheric range delays of the radar pulse. From European Center for Medium Range Weather Forecasting
Ionosphere	GIM ionospheric correction from NASA/JPL must be added (negative value) to the instrument range to correct this range measurement for ionospheric range delays of the radar pulse.
Ocean tide and loading tide	Geocentric ocean tide height (solution 1): GOT4.8 from GSFC Includes the loading tide and equilibrium long-period ocean tide height. The permanent tide (zero frequency) is not included in this parameter because it is included in the geoid and mean sea surface.
Solid Earth tide	Solid earth tide height is calculated using Cartwright and Taylor tables and consisting of the second and third degree constituents. The permanent tide (zero frequency) is not included. From Cartwright and Edden [1973] Corrected tables of tidal harmonics J.Geophys. R. Astr. Soc., 33, 253-264.
Pole tide	Computed from Wahr [1985] Deformation of the Earth induced by polar motion J. Geophys. Res. (Solid Earth), 90, 9363-9368.
Combined atmospheric correction	Also known as high frequency fluctuations of the sea surface topography which contains the combined atmospheric corrections (from MOG2D model + inverse barometer)
Sea State Bias	A sea state bias correction must be added (negative value) to the instrument range to correct this range measurement for sea state delays of the radar pulse. The SAR CryoSat-2 sea state bias cannot be directly calculated within restricted areas. The LRM sea state bias produced from a non-parametric method applied at crossovers is used to derive the sea state bias in SAR mode.
Mean Sea Surface CLS	MSS_CNES_CLS-2011: mean sea surface height above T/P reference ellipsoid from CLS/CNES 2011
Mean Sea Surface DTU	MSS_DTU10: mean sea surface height above T/P reference ellipsoid from DTU 2010
Mean Dynamic Topography	MDT_CNES-CLS09_v1.1: mean dynamic Topography above the geoid from CLS/CNES
Geoid	Height above the T/P reference ellipsoid based on the 1996 earth gravity model from NASA/GSFC
Bathymetry	Ocean depth or land elevation based on the digital topographic model 2000 from NASA/GSFC

HIGH-WIND SPEED FOR SARM

- Derived from a non-parametric wind speed estimation based on Labroue and Tran's [2007] 2D model used in Envisat mission. This choice is motivated by:
  - Previous experiences with Ku-band data indicating that 2D models (sigma0 and SWH) provide better estimations of wind speed than 1D model. SWH is used as a proxy for long-wave roughness (unrelated to local winds)
  - Better reduction of the SWH dependence with Labroue and Tran's estimates

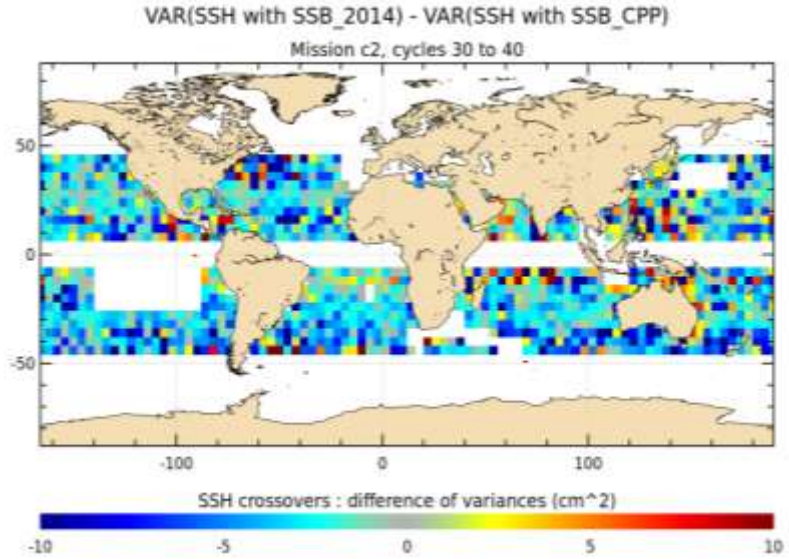
  To apply this Envisat algorithm, small absolute backscattering (and wave height) bias has to be corrected by aligning CryoSat to Envisat parameters

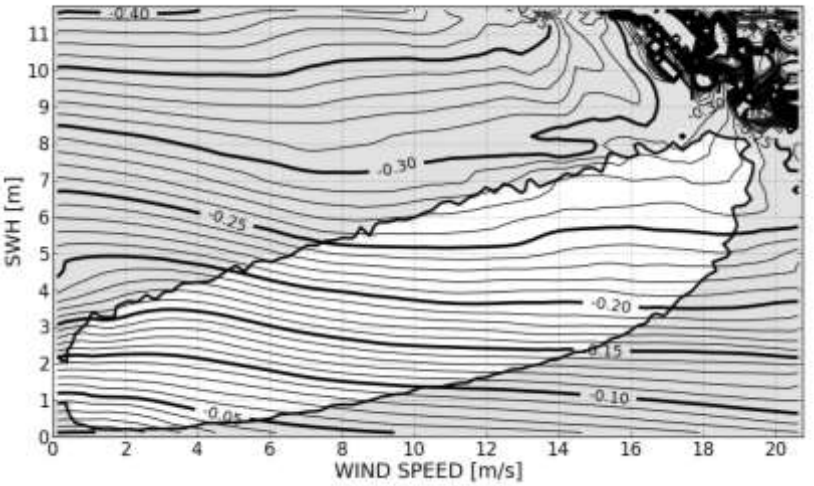




SEA STATE BIAS MODEL FOR SARM

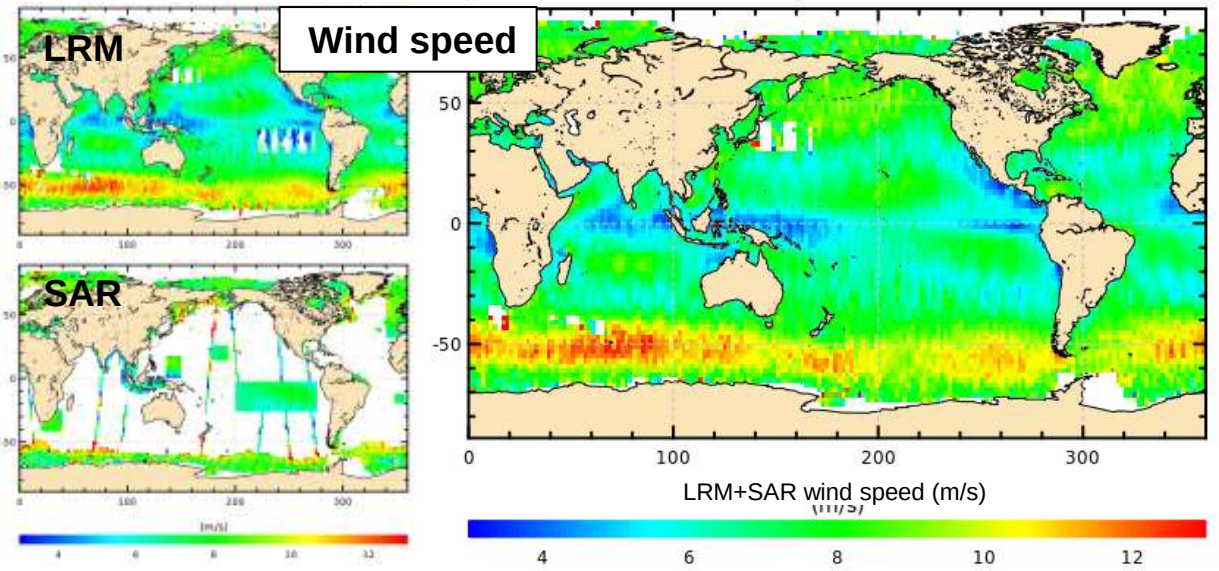
- Added to instrument range to correct for sea state delays of the radar pulse
- The SARM SSB strategy consists in:
  - computing a SSB model from a non parametric solution fitted on LRM CPP data (showing better performances than those of a SSB computed with constant value of 7 m/s),
  - then, correcting this model by a term corresponding to the range differences between PLRM and SAR estimates computed in the 2D (SWH, wind speed) domain (by assuming that LRM and PLRM SSB models are the same within a constant bias)
- SARM SSB corrections are applied at low rhythm (because of low SWH variation) then copied down to 20-Hz rate



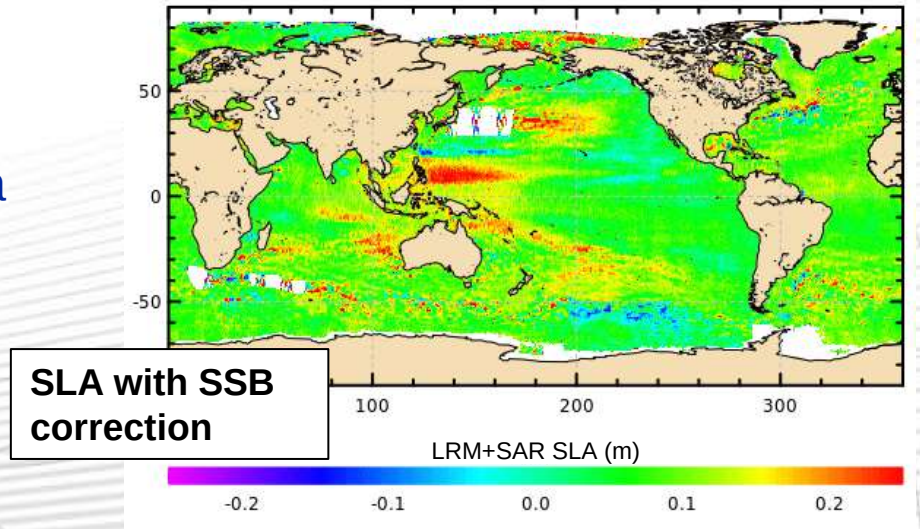


HIGH-WIND AND SSB MODEL FOR SARM

- Maps of LRM and SAR-mode wind speed computed with the Labroue and Tran's algorithm and map of merged data
  No apparent bias between LRM and SAR values

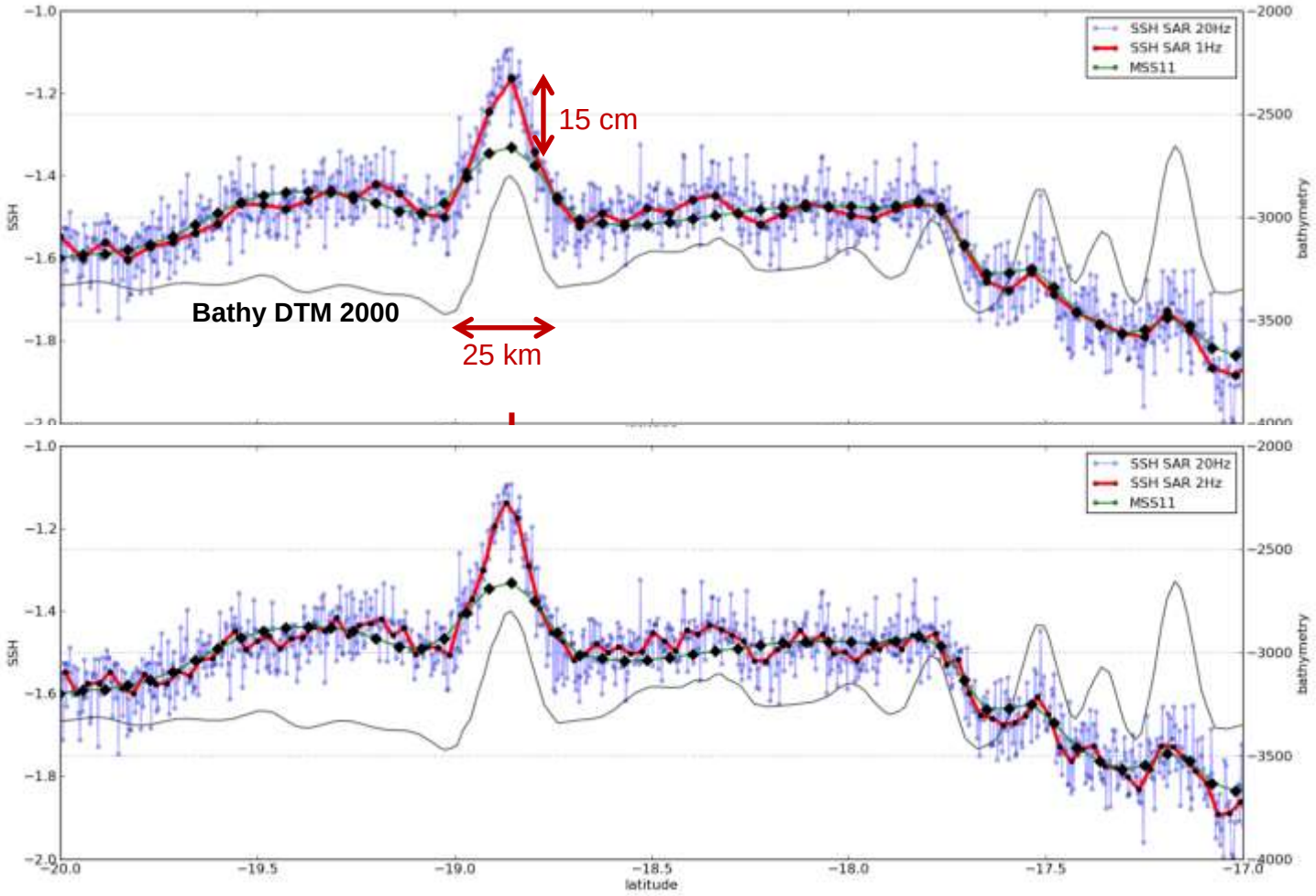


- Map of merged SLA shows very good agreement between LRM and SAR modes data



To define innovative products dedicated to specific applications

- Lower sampling and resolution (5-Hz, 2-Hz, 1-Hz) adapted to end-users have been studied to assess the potential of SARM measurements for detecting small open ocean structures (e.g., unrevealed MSS features)



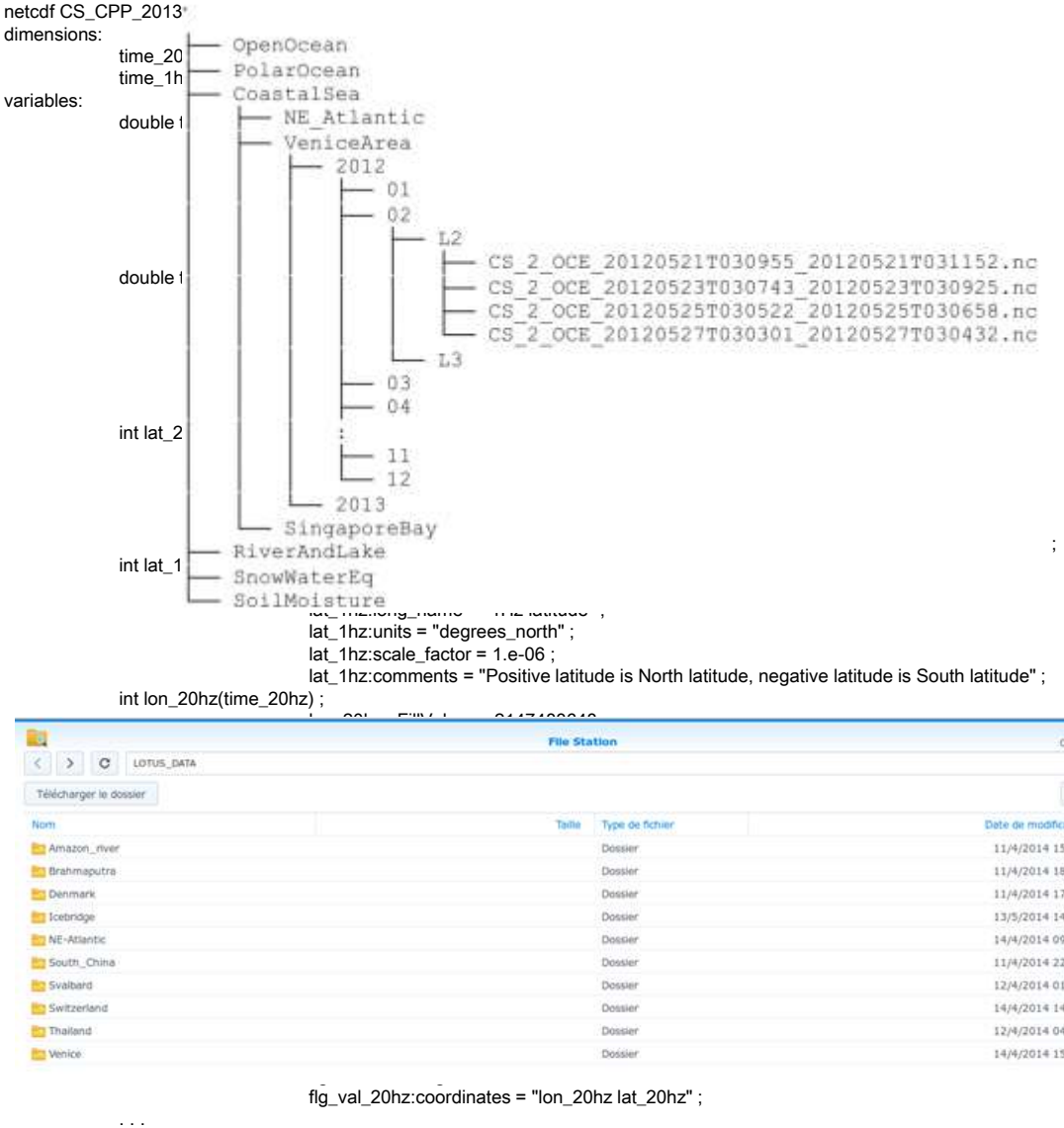
- A sea mount already present in MSS CLS11 is better detected with Cryosat-2 SAR data
- Same structure with same magnitude and width observed one year later (369 d repeat cycle)
- 5-Hz SSH is still noisy but structures are better delineated
  (➔ **L3 open ocean data)**
- 2-Hz SSH is cleaner and more accurate than conventional data also improve resolution wrt 1Hz

S. Labroue, M. Raynal, P. Schaeffer, T. Moreau, A. Ollivier, F. Boy, N. Picot, *"Linking Conventional and SAR Altimetry with Cryosat-2: An assessment over the whole mission"*, OSTST 2014, Konstanz

Data product formats

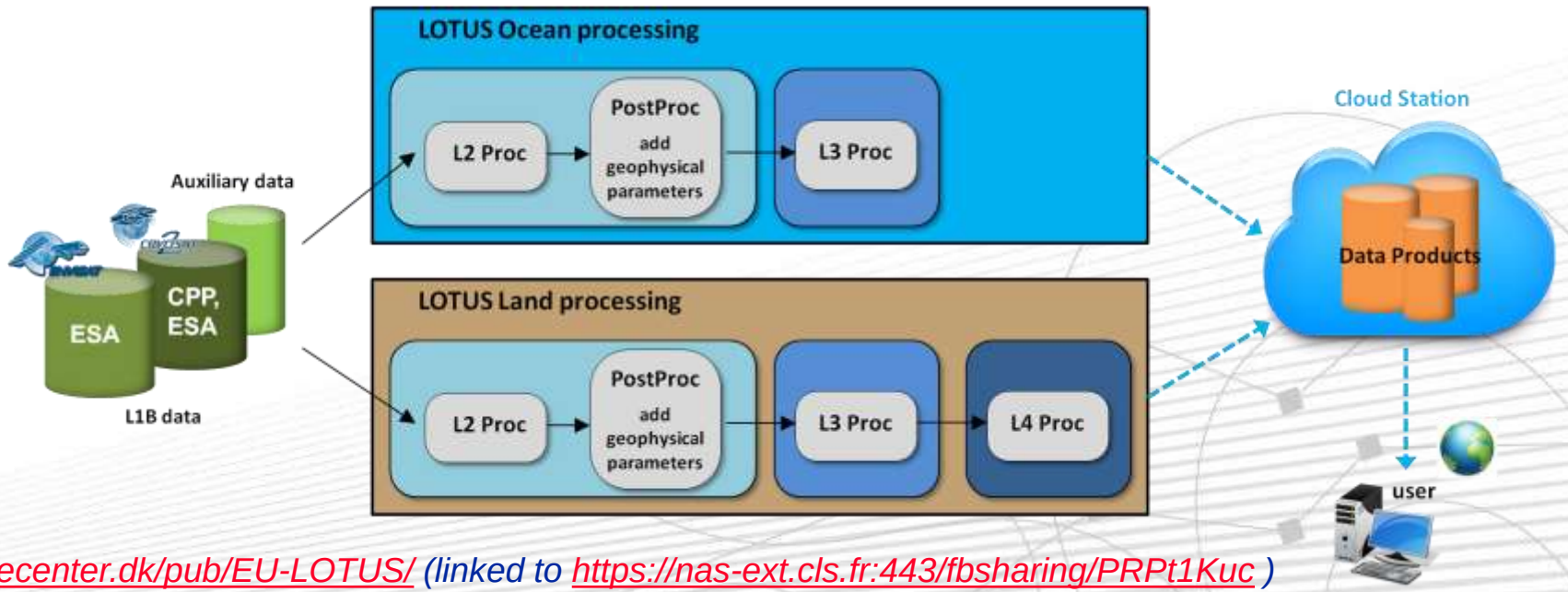
- To ensure easy use of the data and high performance data access services, products are:
  - encoded in standard format (netCDF)
  - split into files with one file per pass
  - organized into different targets and processing levels in order to implement a packaging scheme suited to archiving and dissemination to users

- Each product package contains:
  - geophysical information retrieved by the new algorithms
  - and the associated auxiliary parameters (orbital information, environmental/geophysical corrections, models, land/water mask,..)



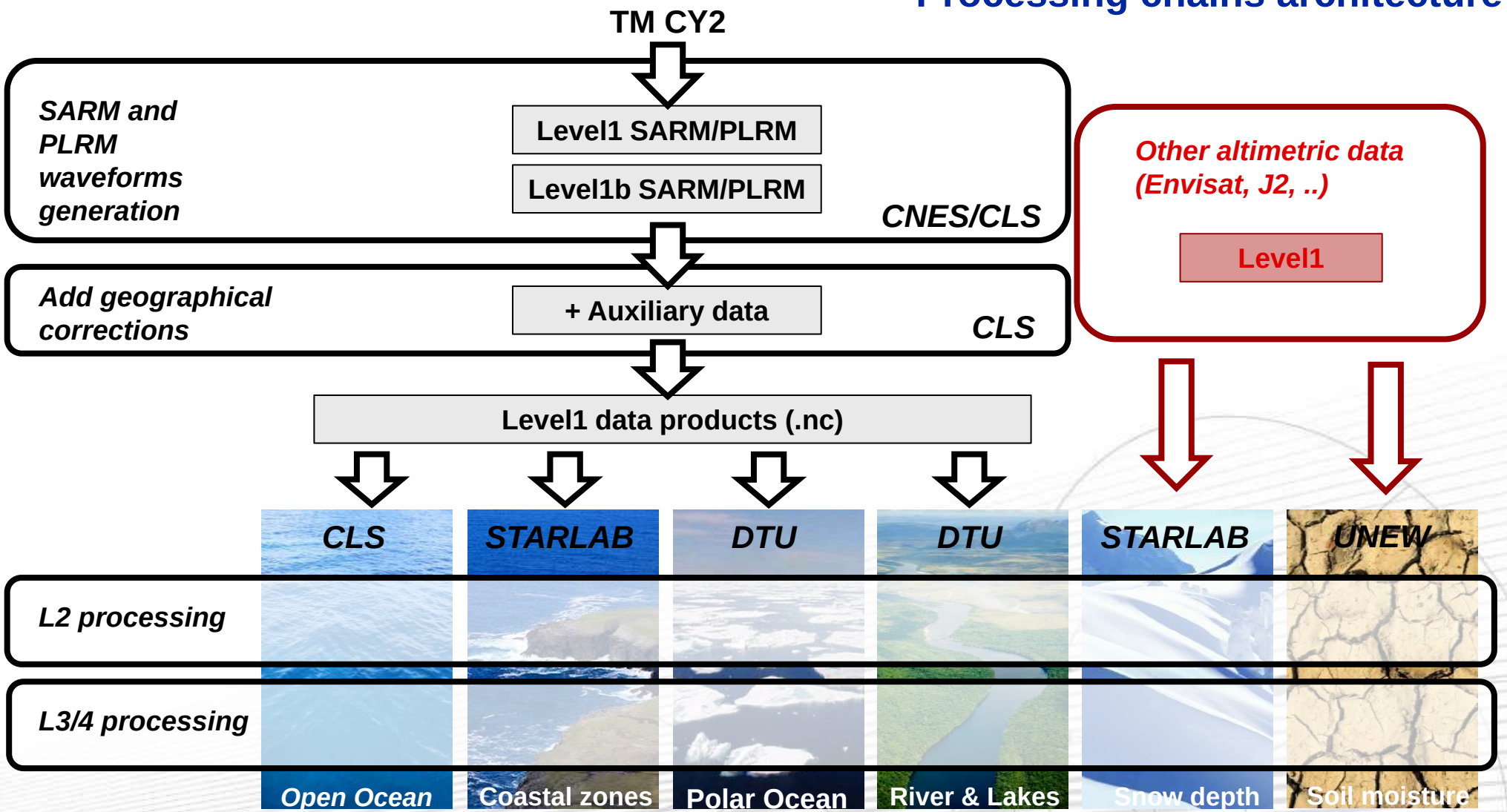
Dissemination services

- Users are able to browse, select, gather datasets according to their needs without any complex technical procedure
- Cloud services (like a dropbox) advantages:
  - No fee for large data usage (unlike Dropbox)
  - Offer syncing data between devices
  - Administrators can setup privilege settings (password) and an expiration date on the link



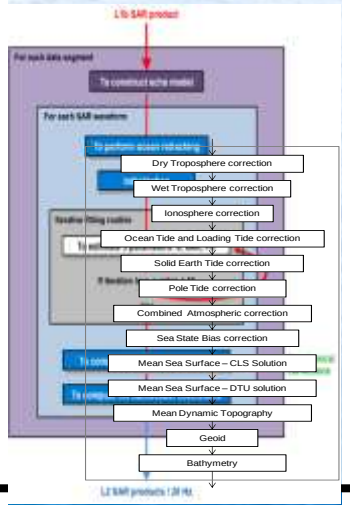
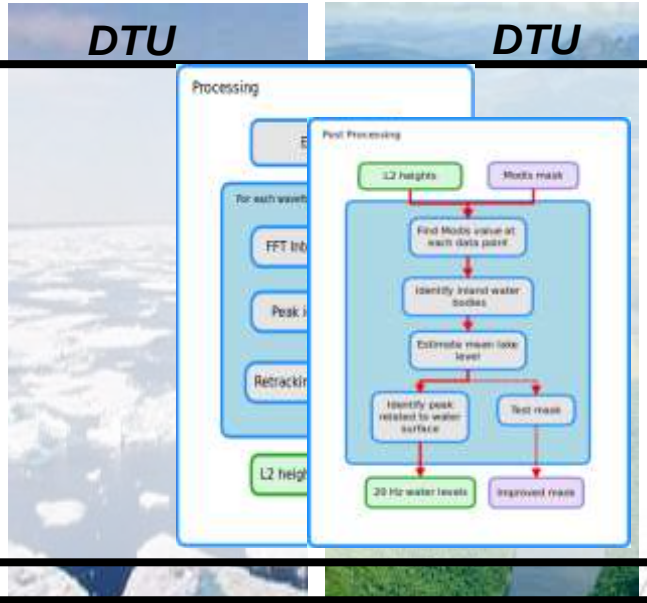
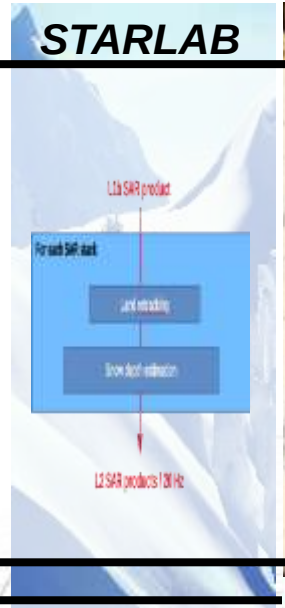
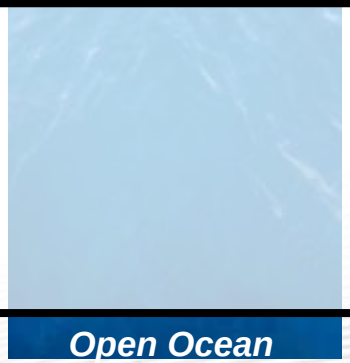
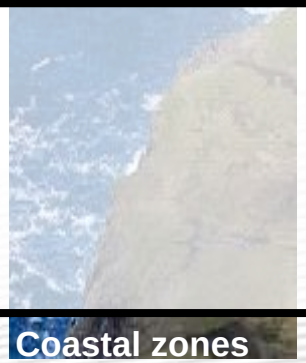
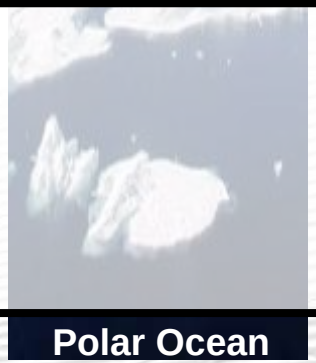
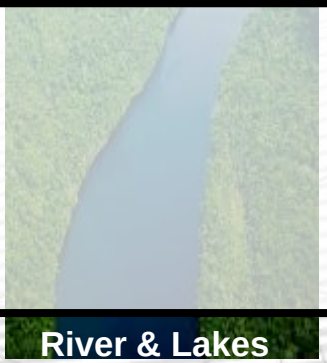
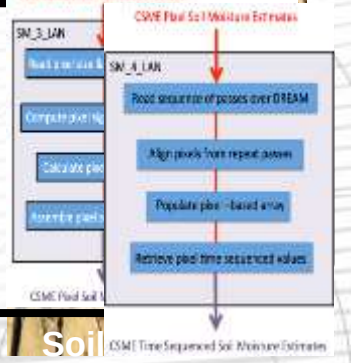
ftp://ftp.spacecenter.dk/pub/EU-LOTUS/ (linked to https://nas-ext.cls.fr:443/fbsharing/PRPt1Kuc)

Processing chains architecture



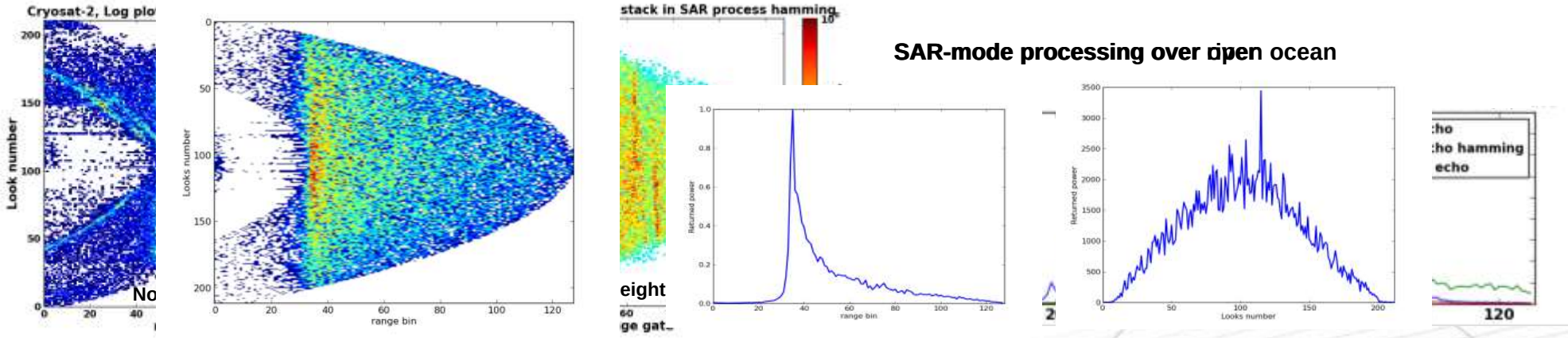
Processing chains architecture

Level1 data products (.nc)

	CLS	STARLAB	DTU	DTU	STARLAB	UNEW
L2						
L3/4						
	Open Ocean	Coastal zones	Polar Ocean	River & Lakes	Snow depth	Soil

Specification and development of dedicated processing chains

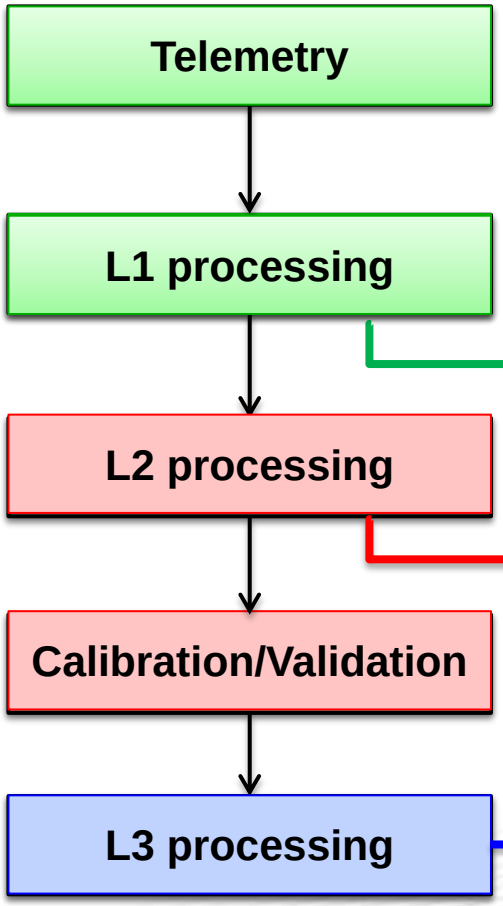
- Level-0 to Level-1BS processing chain (CPP) developed (➔ **v14**) and tested for different processing (with/no weighting function and oversampling method)



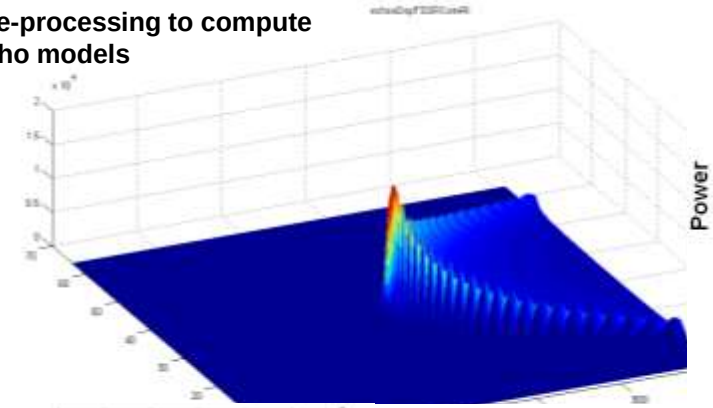
- Implementation of the Level-1BS to Level-2 (and Level-3) processing for open ocean:
  - To retrack SARM ocean waveforms and estimate geophysical parameters
  - To retrack the distribution of power among looks in the stack and estimate the model parameters
  - To analyse the Level-2 ocean data derived from the two retracked signals
  - To generate Level-3 ocean data at 5-Hz (correcting Long Wave Error computed from J2 and Saral)
- Computation of the corrections are implemented
- Improved computational process with parallel processing (reducing the cpu time)

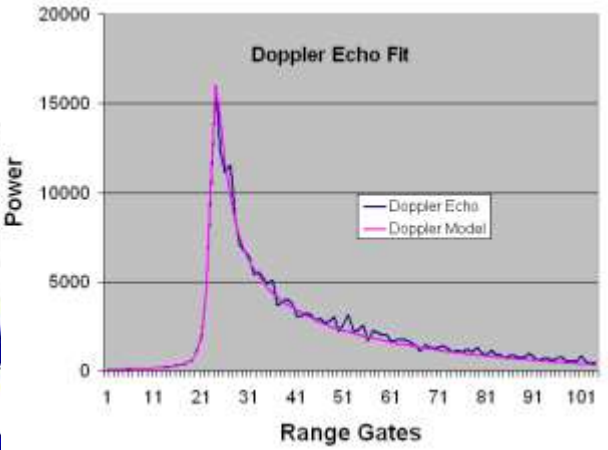
PROCESSING DEVELOPMENTS

- Development of the prototype chain from L0 to L3

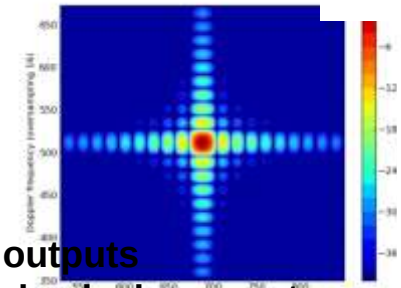


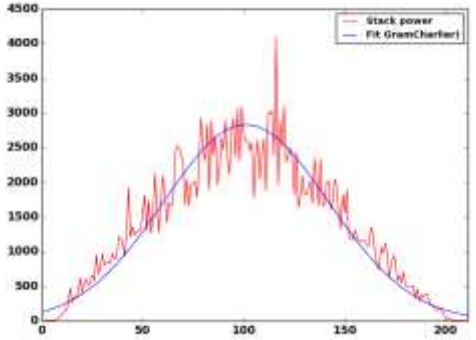
Pre-processing to compute echo models





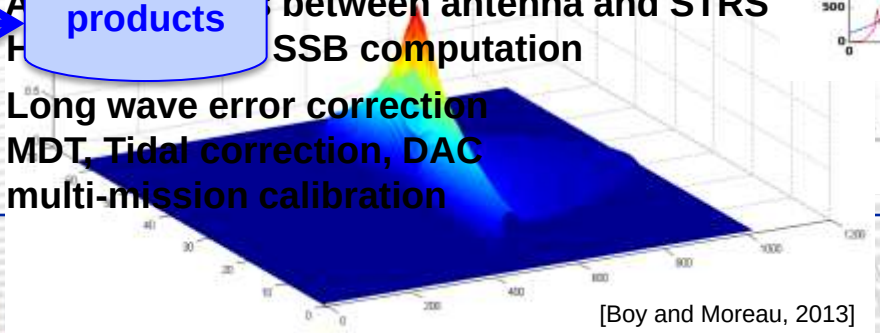
L2 products

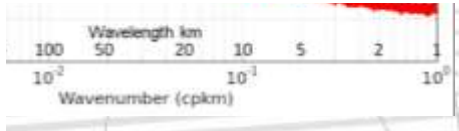




- Waveform retracking outputs
- D… of geophysical parameters
- C… orrections (iono, tropo,..)
- A… between antenna and STRS
- H… SSB computation
- Long wave error correction
- MDT, Tidal correction, DAC
- multi-mission calibration

L3 products





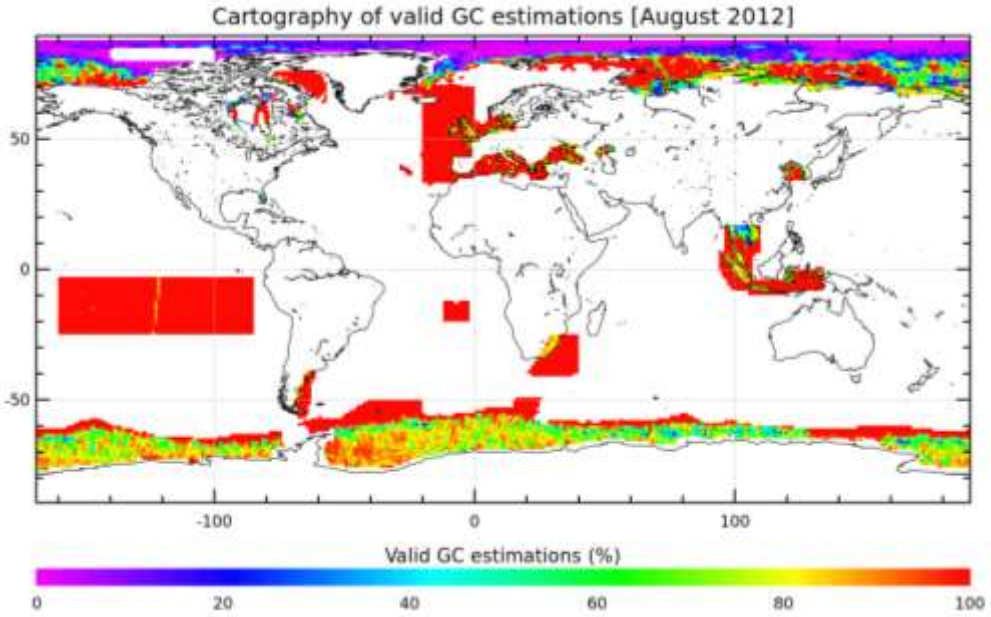
[Boy and Moreau, 2013]

SOFTWARE VALIDATION

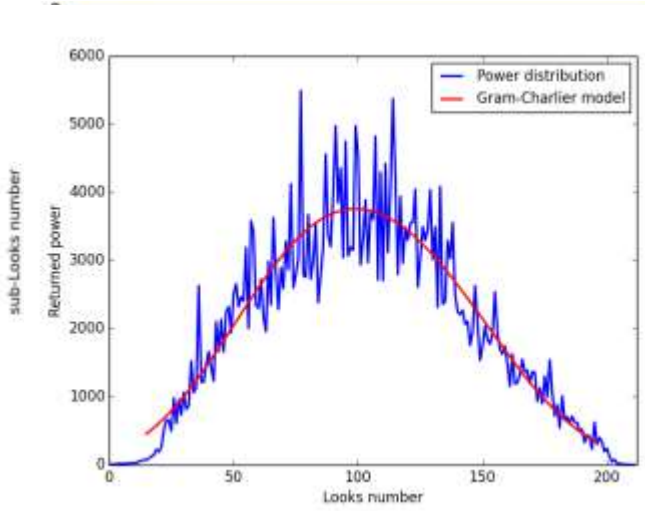
- Two years of Cryosat-2 data using the Cryosat processing prototype (CPP v14)
  - Full LRM and SARM coverage (No SARin)
  - Period from May, 2012 to April, 2014
- Several metrics are presented in WP4 Task 4.5
  - Cross calibration with Jason-2
  - Focus on the LRM / PLRM transition
  - Assessment of long wavelength errors based on comparison with PLRM data colocalised with SARM data
  - Assessment of residual errors linked to key parameters for the SAR processing that would suggest potential error in modelling

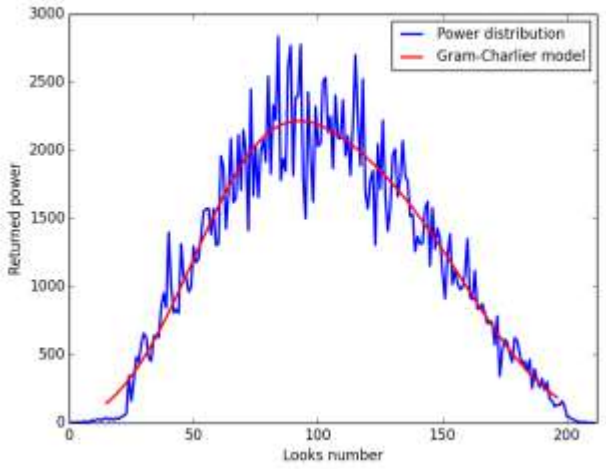
  ➔ **Fully validating L0 to L2 PLRM/SARM processing**
- Star-Tracker pitch bias validation
  - To assess the accuracy of off nadir angles from STR to be used as input parameter of SARM retracking algorithms

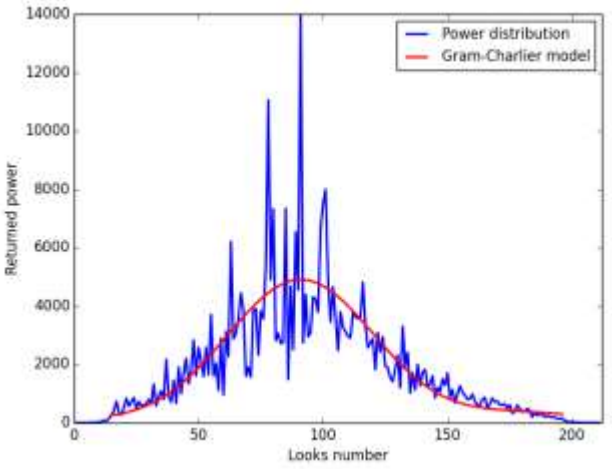
STR PITCH BIAS VALIDATION



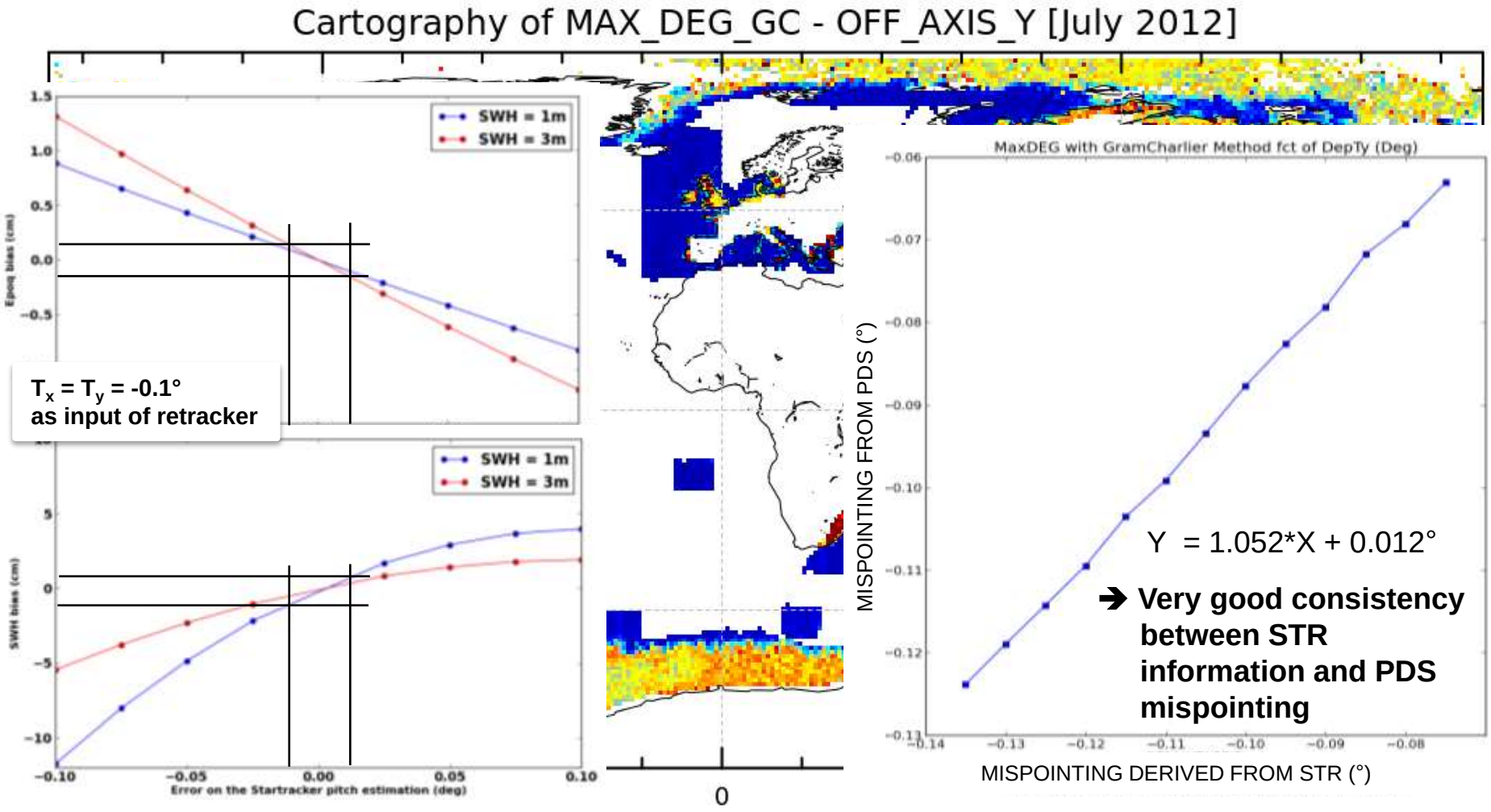
- Asymmetrical distribution of power in stack due to the off-nadir antenna pointing requires the use of a distorted Gaussian-shape model
  ➔ **Gram Charlier series**
- Basic moments are derived from a best fitting curve process with a misfit confidence value
- The maximum of the Gram-Charlier fit is the measurement of the pitch







STR PITCH BIAS VALIDATION



BACK SLIDES

PRODUCT DESCRIPTION: OO_2_OCE

Parameter	Instr. Operation Mode	Description
1Hz/20Hz Surface Height	PLRM/SAR	Distance of the satellite from the reference surface, so: (corrected) Height = Altitude – Range - Corrections Where Corrections = altimeter ionospheric correction + model dry tropospheric correction + radiometer wet tropospheric correction+ sea state bias correction + solid earth tide height + geocentric ocean tide height solution1 (GOT solution) + geocentric pole tide height + combined corrections from MOG2D model The sea surface height anomaly (SSHA) is defined here as the altitude minus the corrected range minus the Mean Sea Surface (MSS) and minus known geophysical effects. Instrumental corrections are included
1Hz/20Hz Significant Wave Height	PLRM/SAR	It is the average wave height, trough to crest, of the one-third largest waves in a particular geographic location. In conventional altimetry, it is computed from the slope of the return radar pulse (the gradient of the leading edge of the radar echo, known as the leading-edge slope), after reflection on the surface.
1Hz/20Hz Backscatter coefficient	PLRM/SAR	The backscatter coefficient, sigma0, is computed from the power of the altimeter's return pulse. AGC corrections included
1Hz/20Hz Wind speed	PLRM/SAR	Wind speed is calculated from the mathematical relationship with the backscatter coefficient and the significant wave height.
1Hz/20Hz Mispointing	PLRM	Square of the off-nadir angle is derived from the waveform (deviation of boresight from nadir). Variations of this parameter can reveal actual platform mispointing, if any, but can also reveal waveform contamination by rain or by sea-ice.

Parameter	Instr. Operation Mode	Description
Sea Level Anomaly	PLRM/SAR	Sea Level anomaly edited, filtered and sub-sampled at 5 Hz. An empirical adjustment on Jason-2 is applied to correct Cryosat-2 from long wavelength errors.

Parameter	Instr. Operation Mode	Description
20Hz Surface Height	SAR	Distance of the satellite from the reference surface, so: (corrected) Height = Altitude – Range – Corrections Where Corrections = altimeter ionospheric correction + model dry tropospheric correction + radiometer wet tropospheric correction + sea state bias correction + solid earth tide height + geocentric ocean tide height solution1 (GOT solution) + geocentric pole tide height + combined corrections from MOG2D model The sea surface height anomaly (SSHA) is defined here as the altitude minus the corrected range minus the Mean Sea Surface (MSS) and minus known geophysical effects. Instrumental corrections are included
20Hz Significant Wave Height	SAR	It is the average wave height, trough to crest, of the one-third largest waves in a particular geographic location. In conventional altimetry, it is computed from the slope of the return radar pulse (the gradient of the leading edge of the radar echo, known as the leading-edge slope), after reflection on the surface.
20Hz Backscatter coefficient	SAR	The backscatter coefficient, sigma0, is computed from the power of the altimeter's return pulse. AGC corrections included
20Hz Minimum Distance to Coast	SAR	Minimum distance from nadir point to coastline
20Hz Minimum Across Track Distance to Coast	SAR	Minimum across-track distance from nadir point to coastline
20Hz GOF	SAR	Goodness of fit between SAR L1b Waveform and Model, defined as GOF = sqrt(Sum(Wf(i)^2 – Model(i))^2)

Parameter	Instr. Operation Mode	Description
1Hz/20Hz Surface Height	PLRM/SAR	Distance of the satellite from the reference surface, so: (corrected) Height = Altitude - Range - Corrections Where Corrections = altimeter ionospheric correction + model dry tropospheric correction + model wet tropospheric correction + sea state bias correction + solid earth tide height + geocentric ocean tide height solution1 (GOT solution) + geocentric pole tide height + combined corrections from MOG2D model The sea surface height anomaly (SSHA) is defined here as the altitude minus the corrected range minus the Mean Sea Surface (MSS) and minus known geophysical effects. For the Polar Ocean, the DTU10MSS should be preferred as it has no voids. Instrumental corrections will be included
1Hz/20Hz Significant Wave Height	PLRM/SAR	It is the average wave height, trough to crest, of the one-third largest waves in a particular geographic location. In conventional altimetry, it is computed from the slope of the return radar pulse (the gradient of the leading edge of the radar echo, known as the leading-edge slope), after reflection on the surface.
1Hz/20Hz Backscatter coefficient	PLRM/SAR	The backscatter coefficient, sigma0, is computed from the power of the altimeter's return pulse. AGC corrections included
1Hz/20Hz Wind Speed	PLRM/SAR	Wind speed is calculated from the mathematical relationship with the backscatter coefficient and the significant wave height.
1Hz/20Hz Mispointing	PLRM	Square of the off-nadir angle is derived from the waveform (deviation of boresight from nadir). Variations of this parameter can reveal actual platform mispointing, if any, but can also reveal waveform contamination by rain or by sea-ice.

Parameter	Instr. Operation Mode	Description
Sea Level Anomaly	PLRM/SAR	Sea Level anomaly edited, filtered and sub-sampled at 5 Hz. An empirical adjustment on Jason-2 is applied to correct Cryosat-2 from long wavelength errors.

Parameter	Instr. Operation Mode	Description
20Hz Water levels/surface heights	SAR	Distance of the satellite from the reference surface, so: (corrected) Height = Altitude – Range - Corrections Where Corrections = altimeter ionospheric correction + model dry tropospheric correction + modelled wet tropospheric correction + solid earth tide height + ocean loading tide + geocentric pole tide height. Instrumental corrections are included
20 Hz Mask value	SAR	Value that indicates the underlying surface type; water =1, land=0
Mean water level	SAR	Robust estimate of the along-track mean water level. This value is only returned if a water body contains 5 or more measurements otherwise the value 99999 is returned

Parameter	Instr. Operation Mode	Description
Filtered 20Hz Water levels	SAR	A subset of data product RL_02_LAN. Water levels have been filtered out by applying land-water mask. An automatic outlier detection routine has been applied to the data.
Time series	SAR	Ready to use time series at virtual stations for the demo data sets.

Parameter	Instr. Operation Mode	Description
20Hz Backscatter coefficient	SAR/LRM	Radar backscattering coefficient estimated by retracking the SAR or LRM waveform and applying required corrections

Parameter	Instr. Operation Mode	Description
Filtered 20Hz Snow depth	SAR/LRM	Snow depth estimates filtered to remove outliers.

Parameter	Instr. Operation Mode	Description
Time Series	SAR/LRM	Snow Depth Time Series

Parameter	Instr. Operation Mode	Description
20Hz Backscatter coefficient	PLRM/SAR	The backscatter coefficient is computed by retracking each waveform to obtain corrected peak power and then calculating the backscatter, applying required corrections.

Parameter	Instr. Operation Mode	Description
Filtered and averaged along-track surface soil moisture estimates	PLRM/SAR	A series of along-track averaged surface soil moisture values (as % soil moisture) for each pass over each DREAM.

Parameter	Instr. Operation Mode	Description
Time series	PLRM/SAR	The soil moisture community requires time series at spatially collocated locations, thus a time series for each along-track-averaged SSME is foreseen, derived from the repeat passes. The long repeat cycle of Cryosat2 severely constrains this dataset.