CryoSat-2 Pseudo LRM Technique

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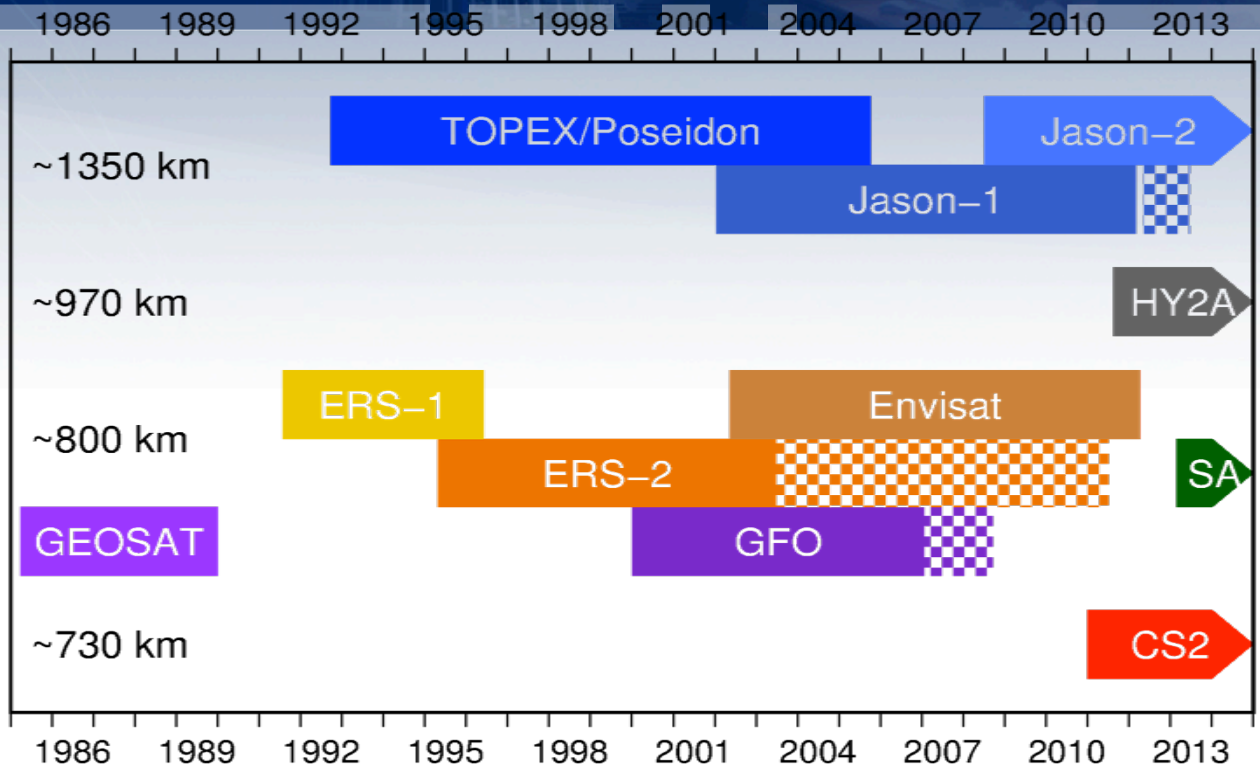
Loss of Ocean Altimeters



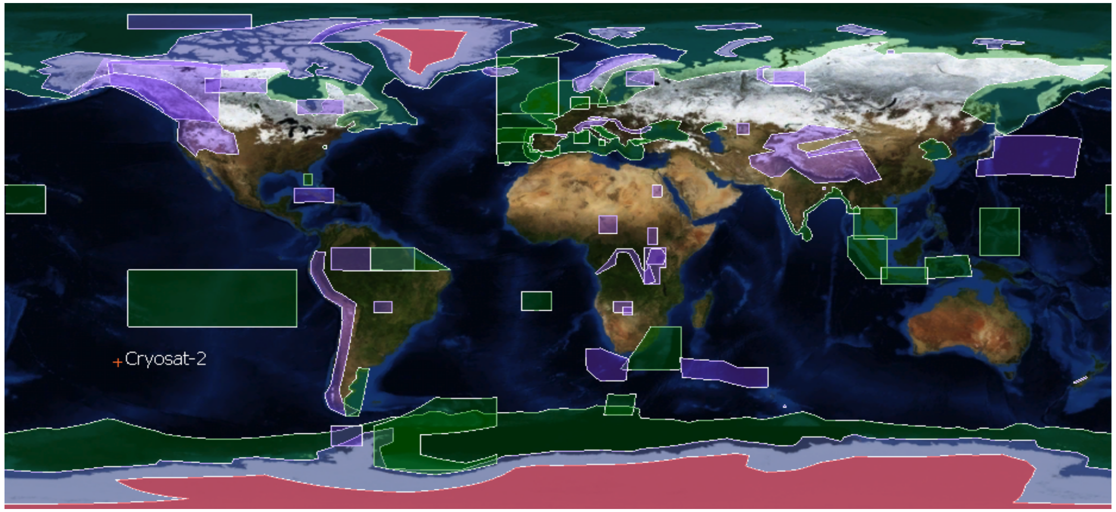
CryoSat-2 one of only 3(4) operational satellite altimeters

- April 2012: Loss of Envisat
- May 2012: Jason-1 orbit lowered to geodetic orbit after near-loss
- Feb 2013: SARAL/AltiKa launched
- June 2013: Loss of Jason-1

CryoSat-2 Operating modes

LRM

- "Conventional Altimetry"
- Fast-delivery (**FDM**) or delay-time (30-day) (**LRM**) products



SAR

- "Synthetic Aperture"
- Increased along-track resolution.
- Quite different from "conventional altimetry"
- Echoes can be *"reduced"* to LRM mode from **FBR** product

SARIN

- As SAR, but including cross-track resolution
- Not yet investigated

Retracking of CryoSat-2 (P)LRM waveforms

Following description for Baseline B only

LRM Level 1B data

- Daily download FDM and LRM L1B data from ESA

FBR Level 1A data

- Create Pseudo-LRM waveforms

Merge LRM and PLRM

- Retrack waveforms (NOAA retracker) to compute wave height, backscatter, range (MLE3-type retracker)
- Merge data files (few to tens of minutes normally) into passes and subcycles of 29 days (à la GDR)
- Insert into **RADS**

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Incorporating CryoSat-2 data into RADS (1)

Insertion into RADS

- Convert TAI to UTC
- Create 1-Hz measurements from 20-Hz

Updates

- Timing bias
  - Add –4.669112 ms (LRM), +0.520795 ms (PLRM) (accounted for)
  - Add another +0.4 ms not yet accounted for
  - Adjust orbital altitude accordingly
- Backscatter
  - LRM: Add –3.02 dB + 0.22 dB/year (since 1-May-2011)
  - PLRM: Add –3.04 dB + 0.27 dB/year (since 1-May-2011)

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Incorporating CryoSat-2 data into RADS (2)

Use some geophysical corrections from L1B

- Off-line orbits from Delft, ESOC, CNES
- Overwrite and add common RADS geophysical corrections
    - **Hybrid SSB** (that we determined ourselves)
    - Latest MSS models (DTU10, CNES-CLS11), EGM2008 geoid
    - Tides (FES2004, GOT4.8)
    - ECMWF and NCEP wet and dry tropo (operational analysed fields)
    - ERA interim wet and dry tropo
    - GIM and NIC09 ionospheric corrections
    - MOG2D dynamic atmospheric correction
    - “Reference frame offset” (constant –704 mm)
- Compute wind speed from backscatter (Abdalla)

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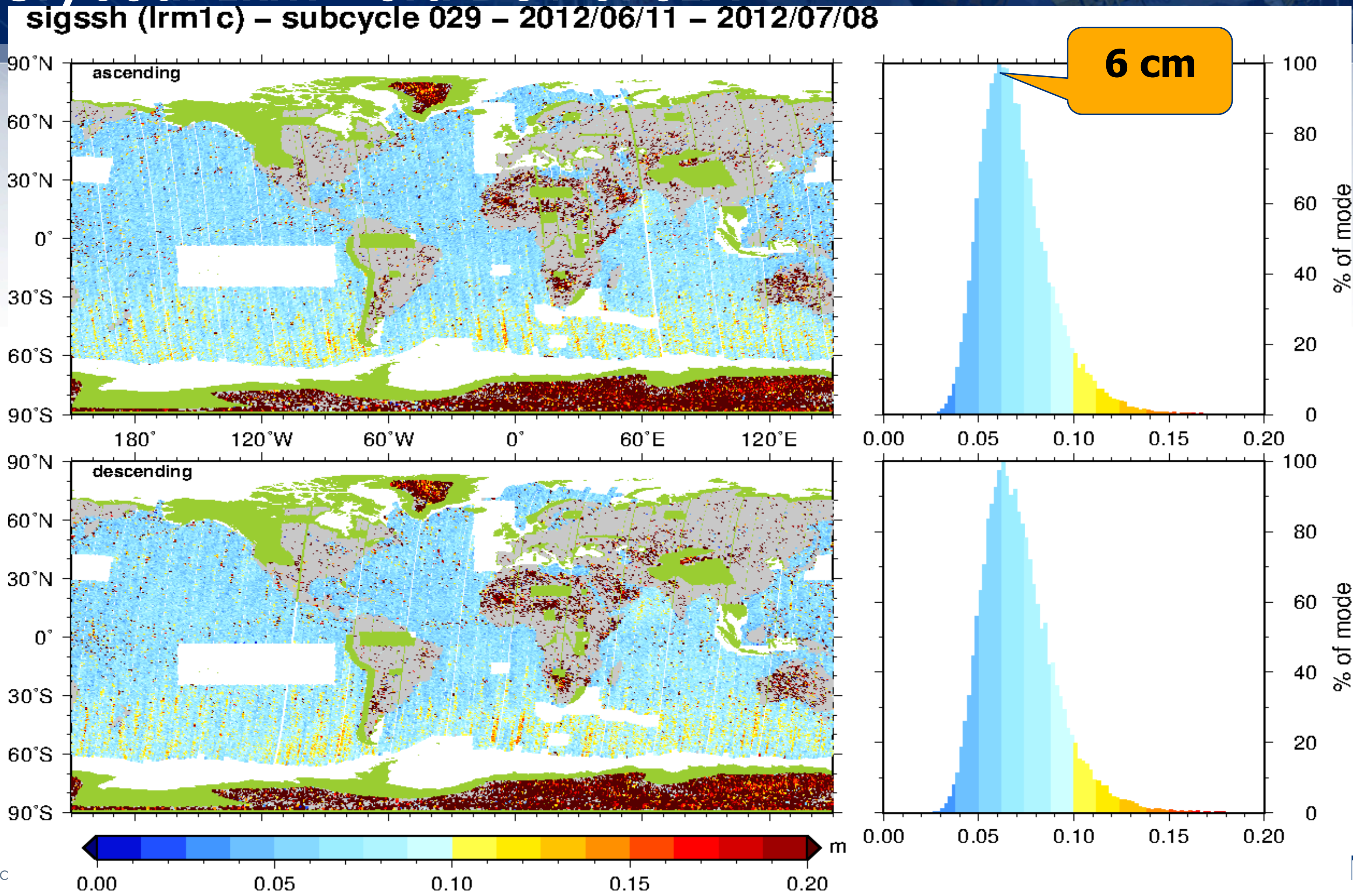
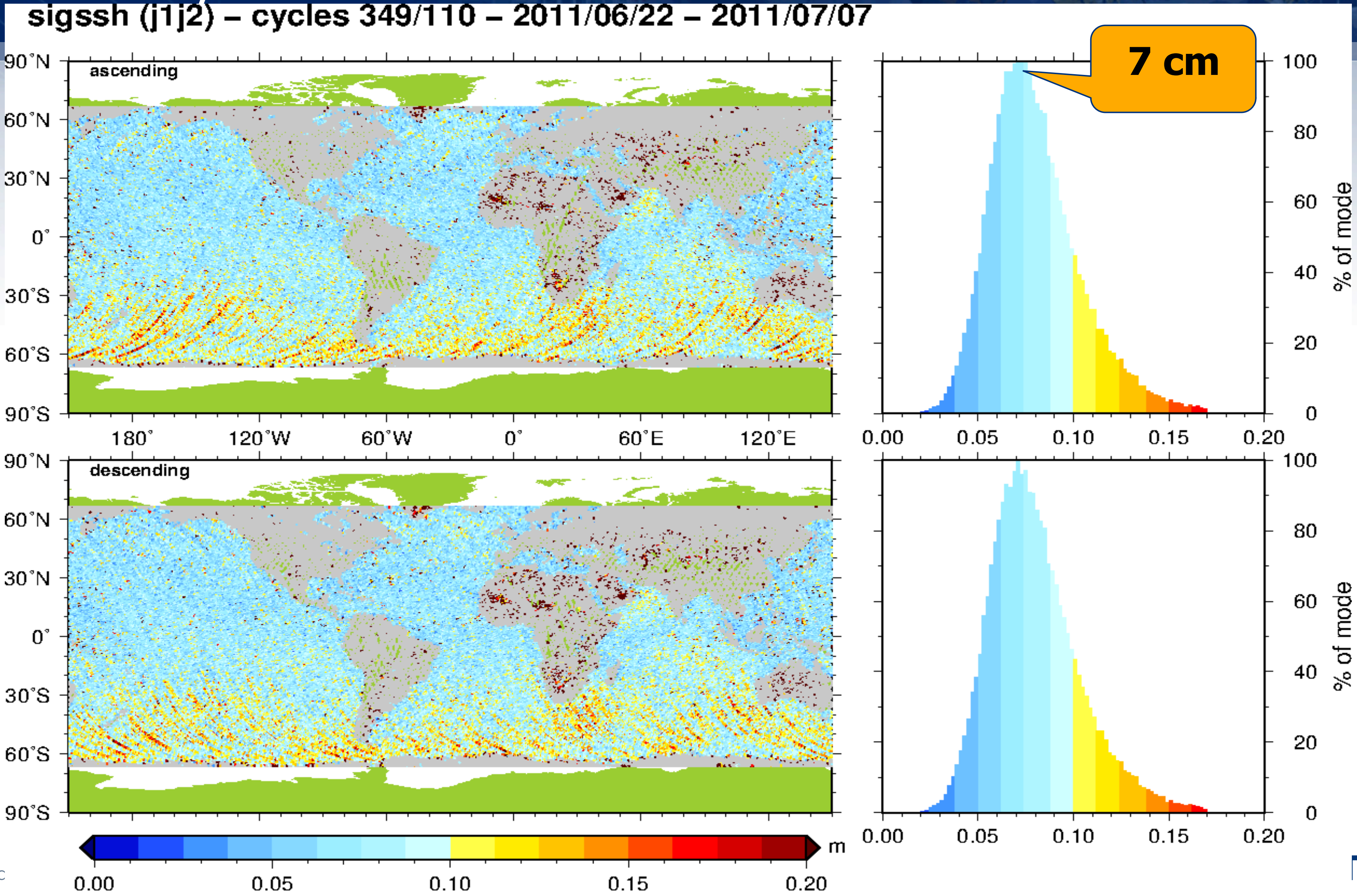
Data Selection (from RADS)

- CS2 Retracked L1B; Ja1 GDR-C; Ja2 GDR-D; Env GDR v2.1
- Create sea level anomalies, SWH, sigma0
  - CNES GDR-D orbit
  - ECMWF dry tropospheric corrections
  - CS2: ECMWF wet tropo; Other: Radiometer wet tropo
  - CS2/Env: GIM ionospheric correction; Ja1/Ja2: Dual-frequency iono
  - GOT4.8 tides, DTU10 mean sea surface
  - Reference frame offsets
    - CS2: –704 mm; Env: +448 mm; Ja1: +88 mm; Ja2: –18 mm
  - CS2/Env: Hybrid SSB; Ja1/Ja2: As on GDR
  - Backscatter (Ku)
    - CS2 (see before); Env: As on GDR
    - Ja1/Ja2: Add –2.4 dB

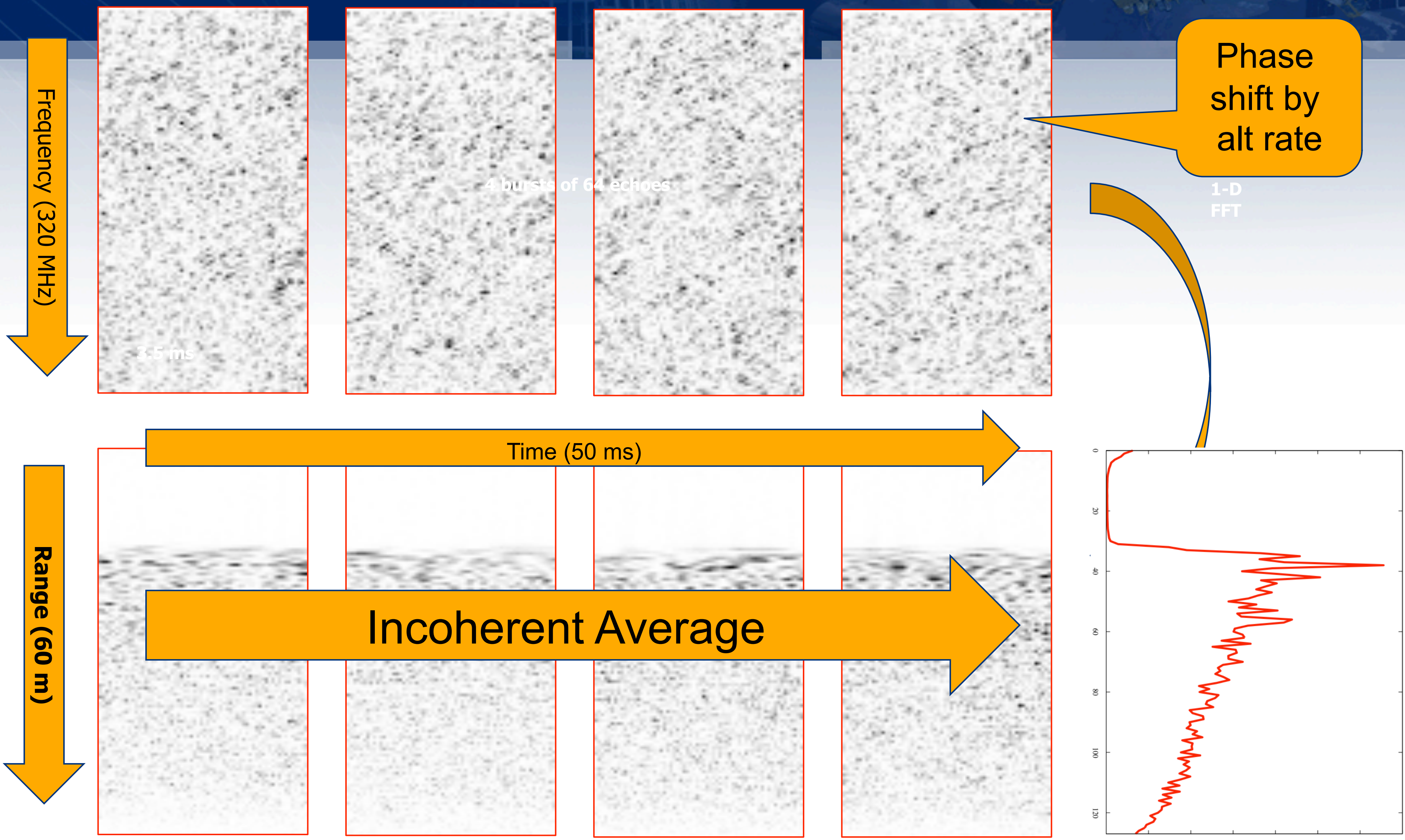
CryoSat LRM – Std Dev of SLA



Jason-1/2 – Std Dev of SLA



Construct 20-Hz PLRM Waveform



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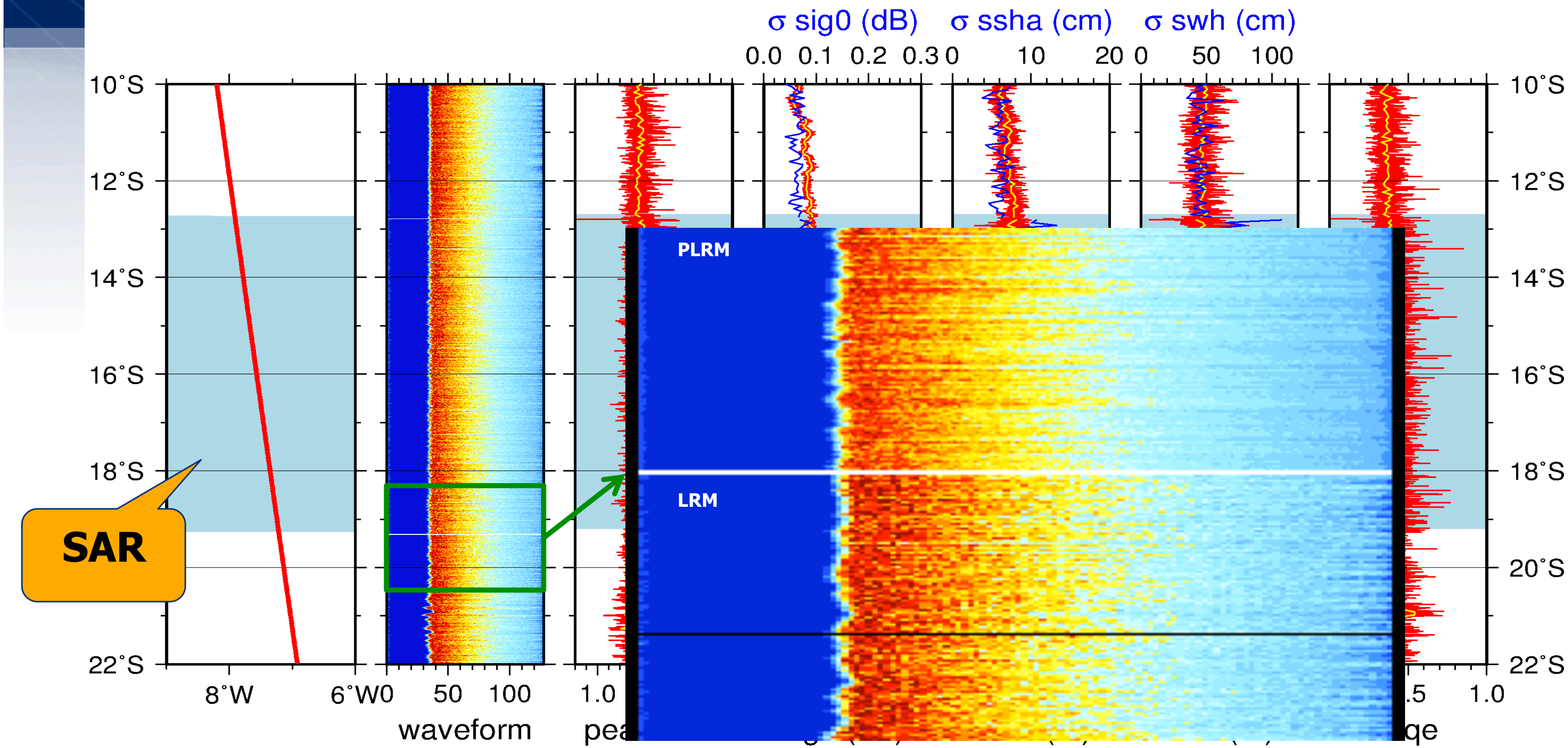
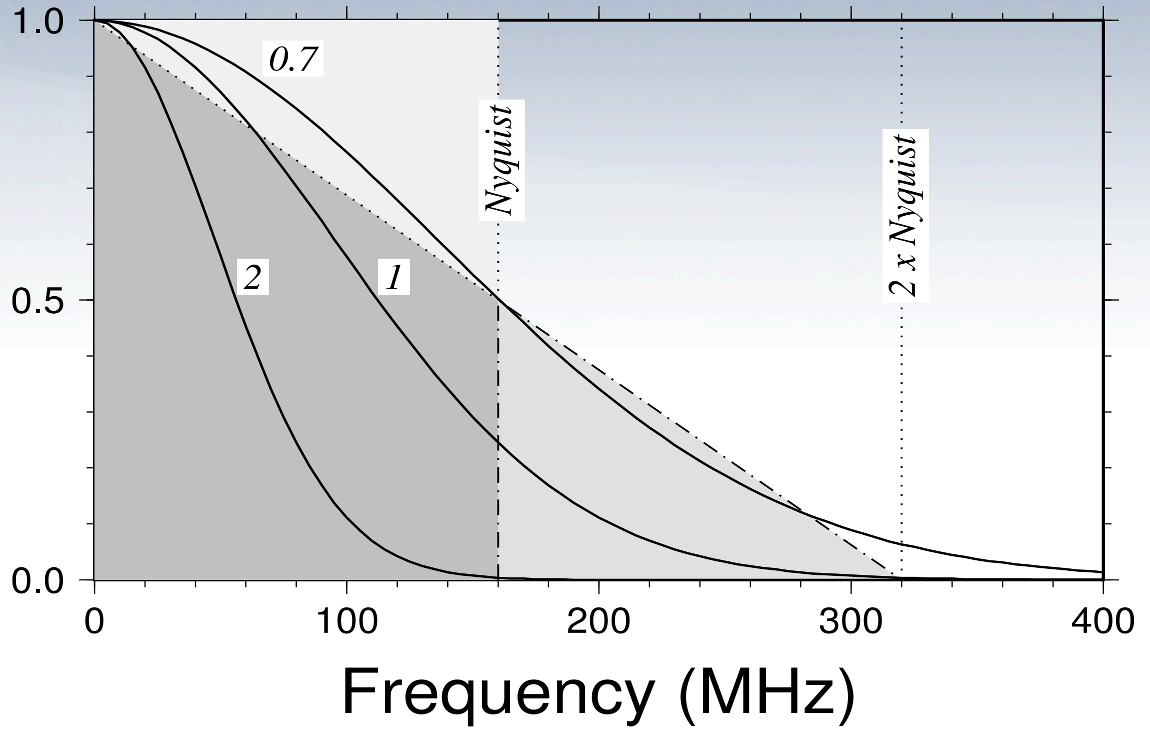
Retracking over St Helena box



Waveform consistent between LRM and PLRM

Sampling Restriction



Observation of low wave heights limited by Nyquist frequency of 160 MHz

Square magnitude should increase to 320 MHz

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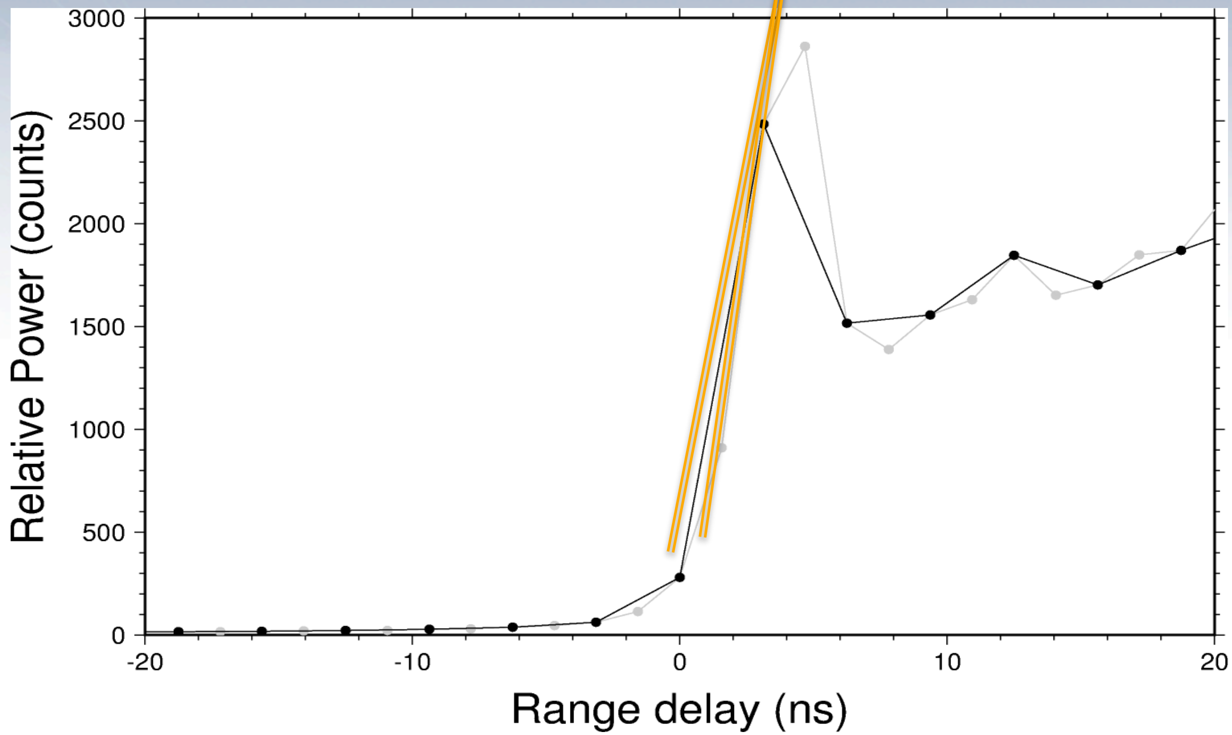
"Jensen Sampling"



Increasing wave form samples from 128 to 256 using technique after Jensen (1999)

Captures leading edge (hence SWH) better

Publication: Smith & Scharroo, *Waveform Aliasing in Satellite Radar Altimetry,* IEEE TGRS, in press

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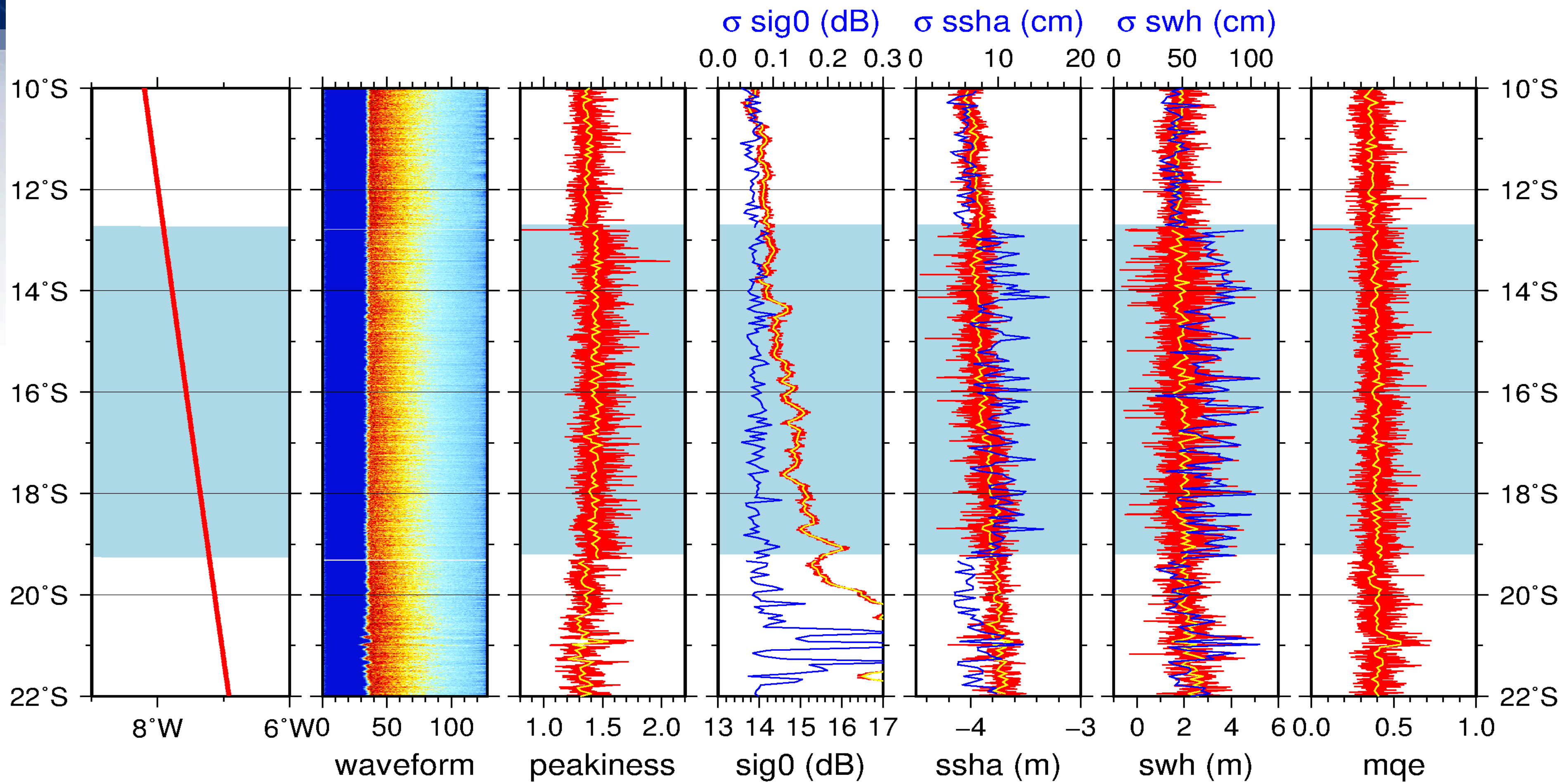
Retracking over St Helena box



“Jensen sampling” reduces SWH noise

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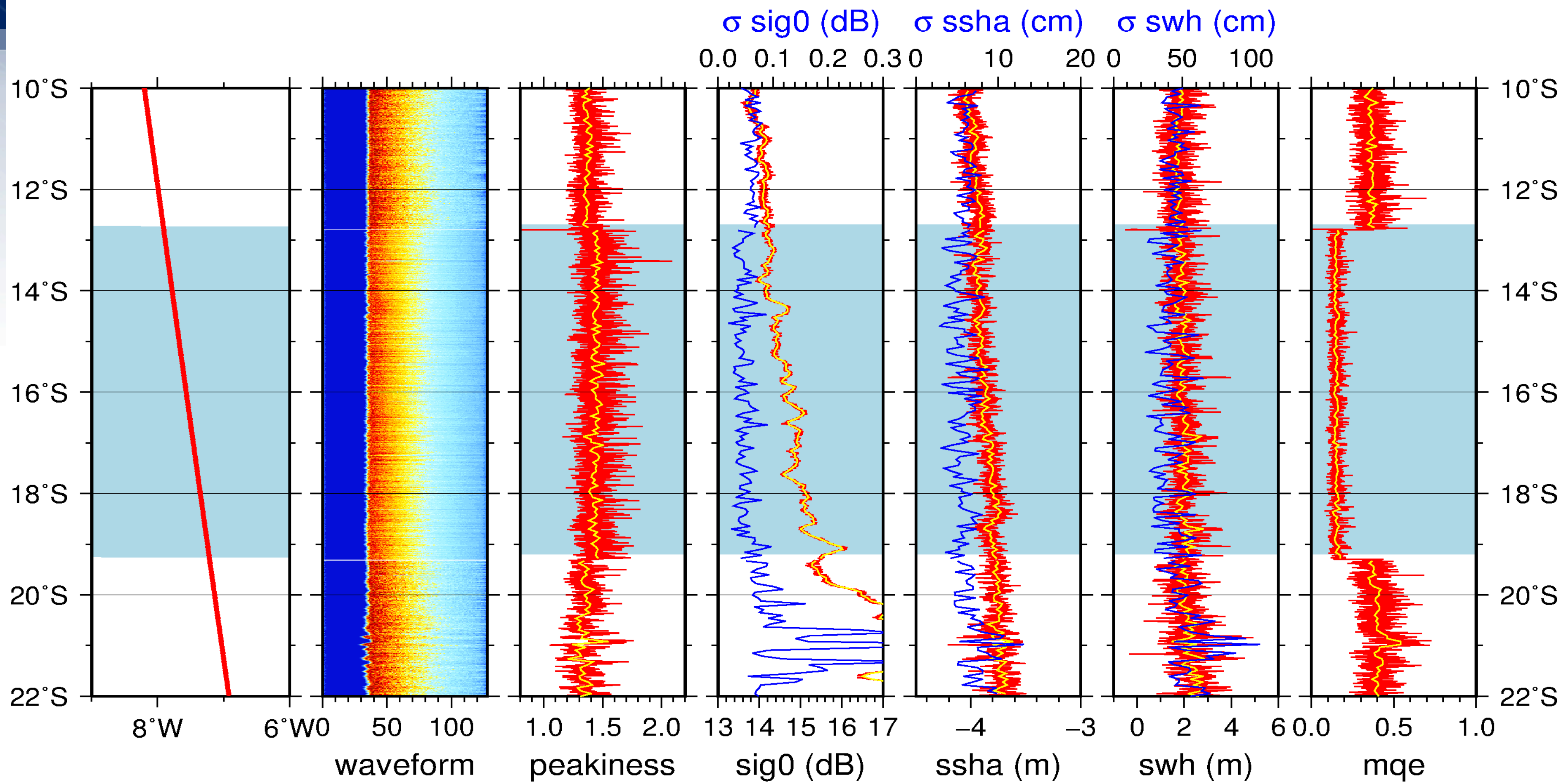
Retracking over St Helena box

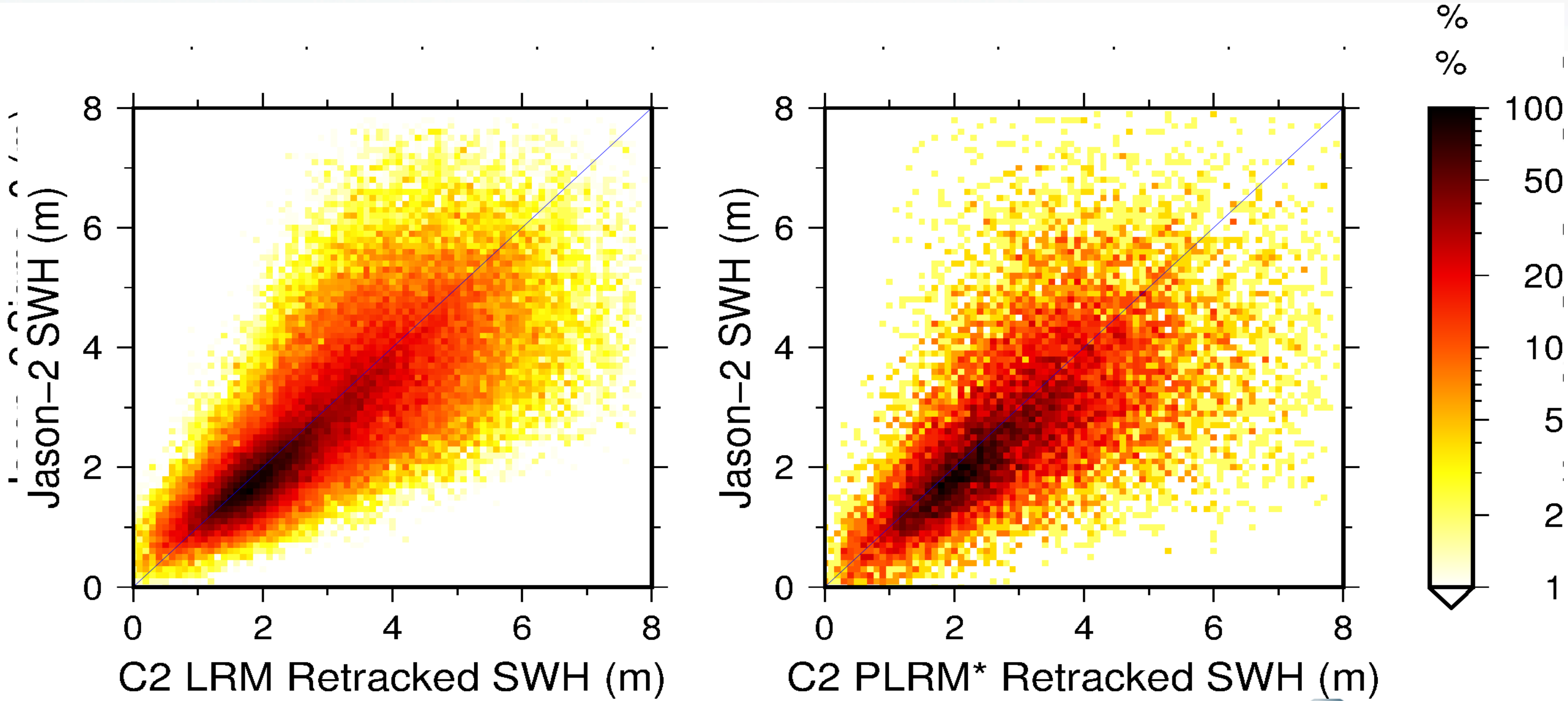


Noise reduction with ¼ + ½ + ¼ waveform averaging

Comparison with Jason-2

Crossovers Cryosat-2 vs Jason-2 (dt < 5 days)

- Too few crossovers between LRM and Pseudo-LRM for direct comparison



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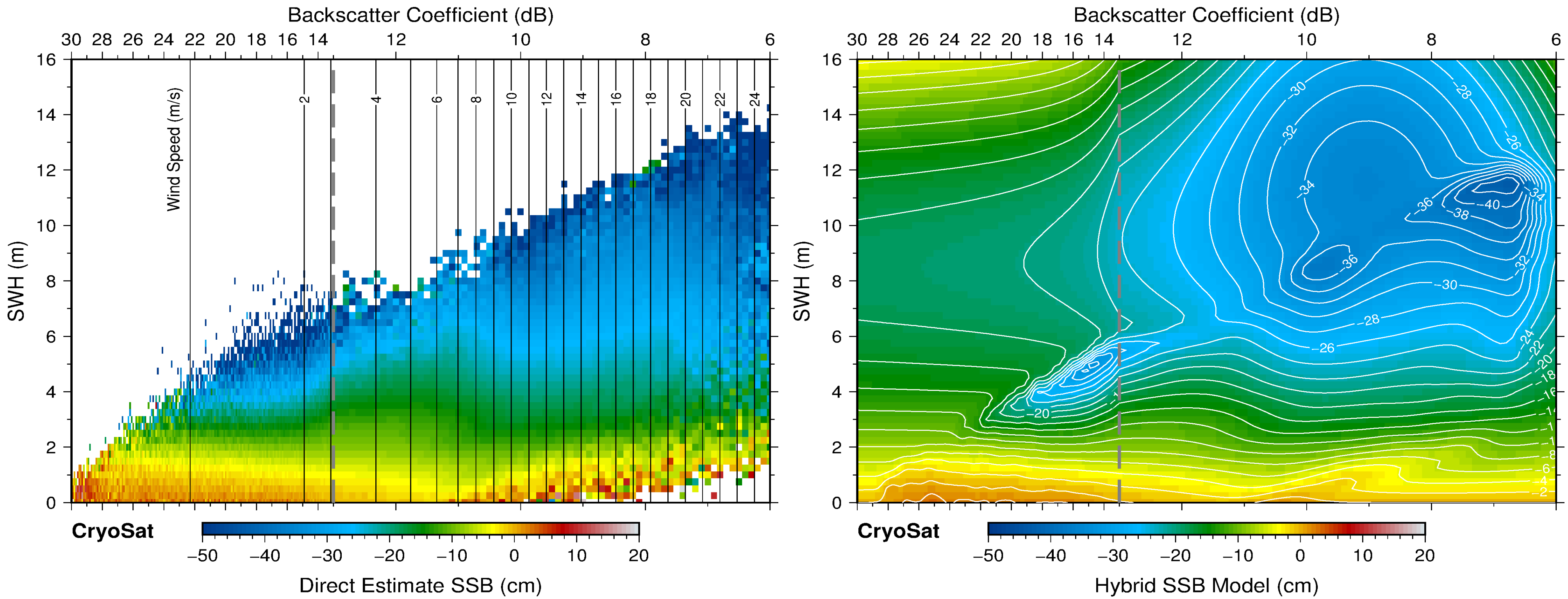
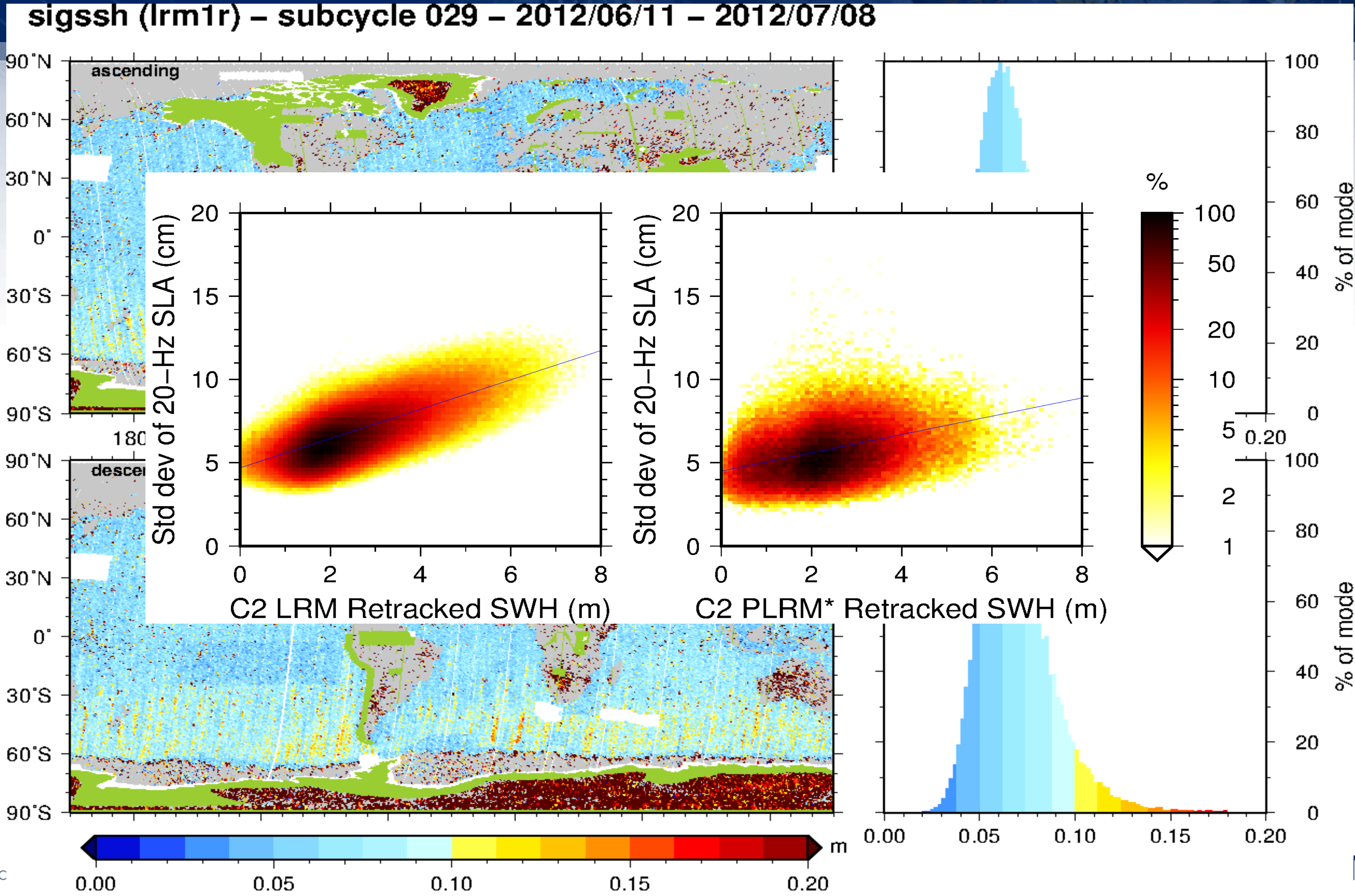
Hybrid Sea State Bias Model

Direct method, enhanced

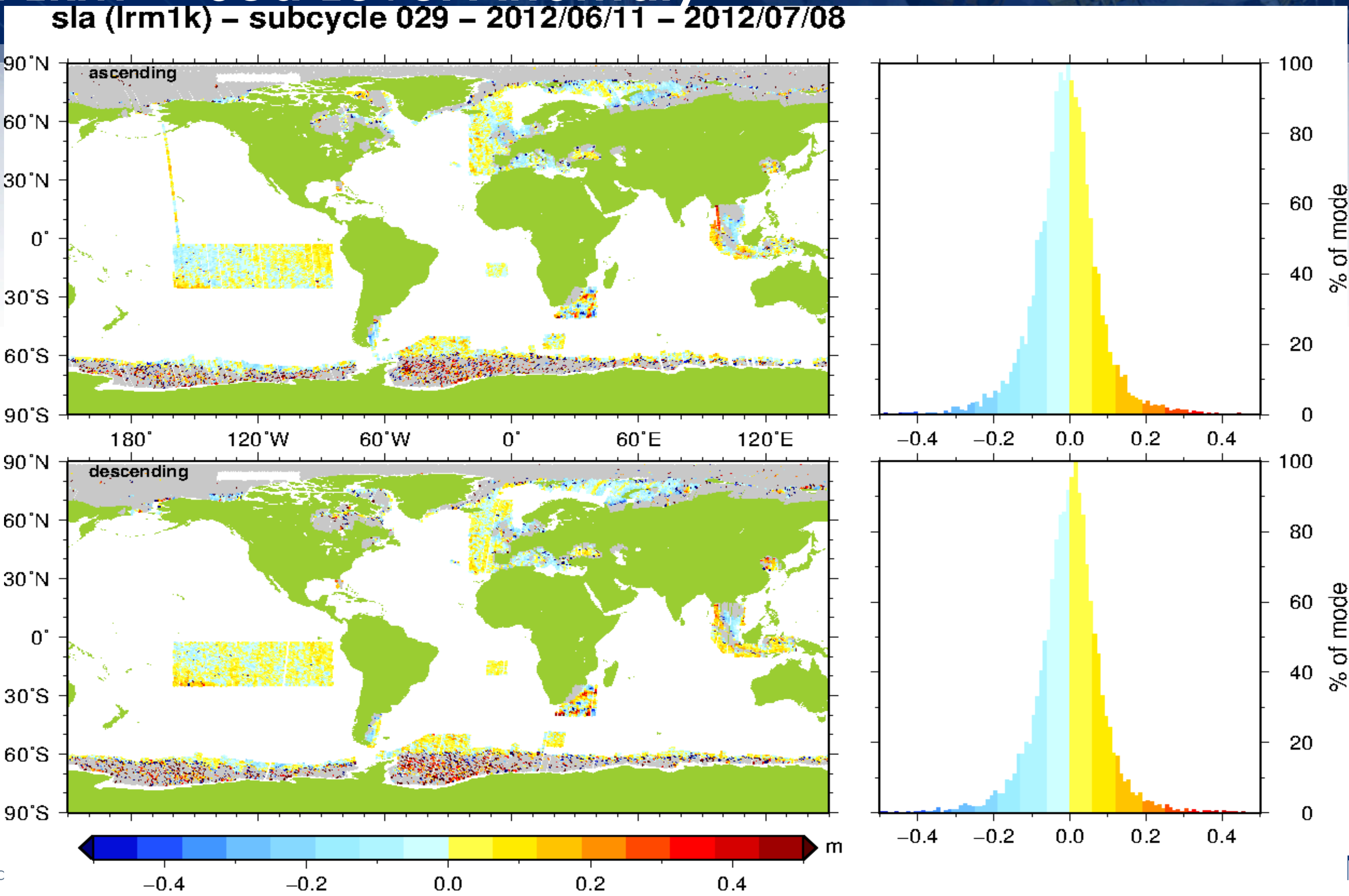
- Sea level anomalies gridded in sigma0-SWH space
- Fit BM4 model, blend in residuals
- Approximately –4% SWH



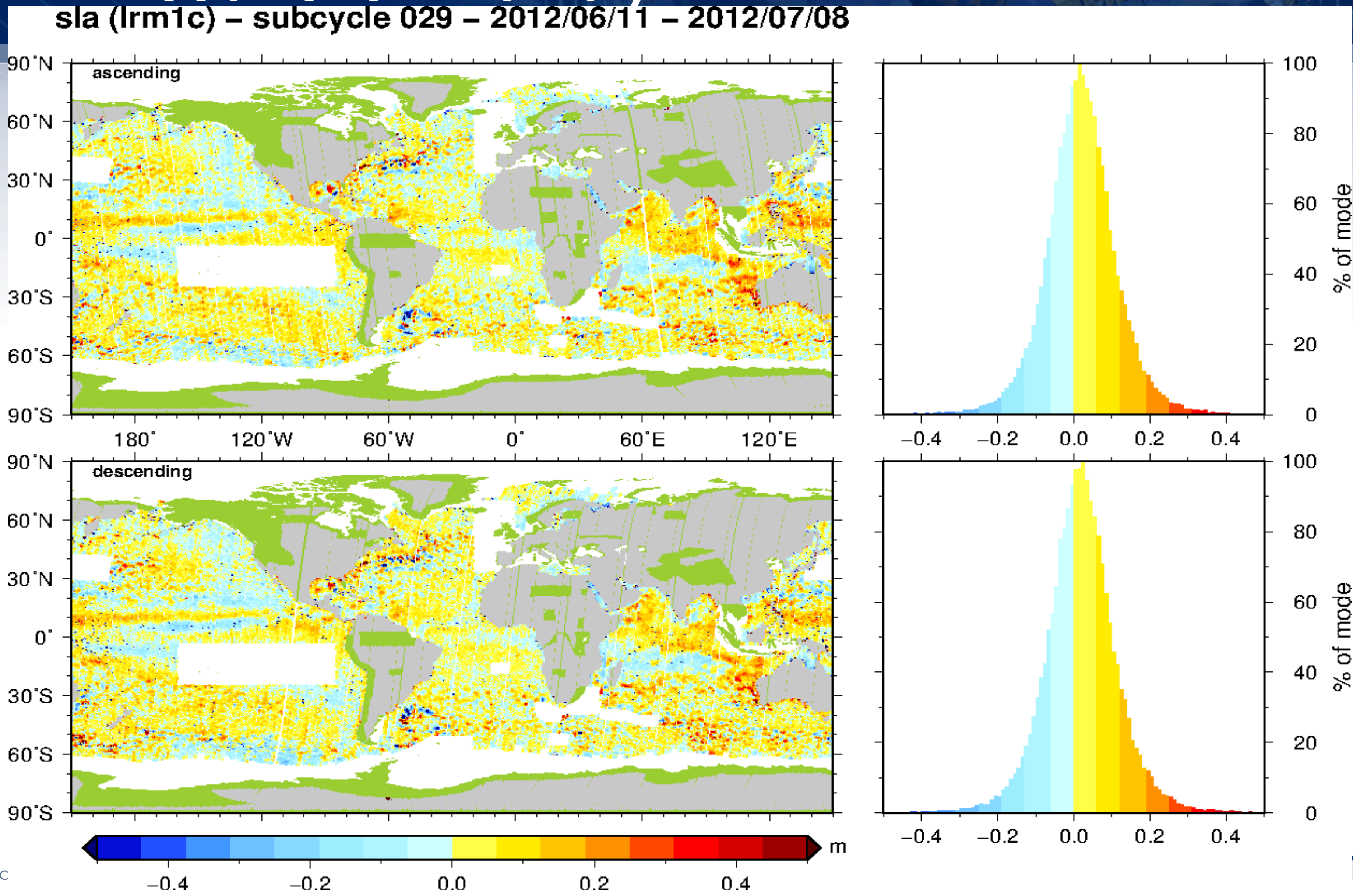
LRM+PLRM* – Std Dev Sea Level



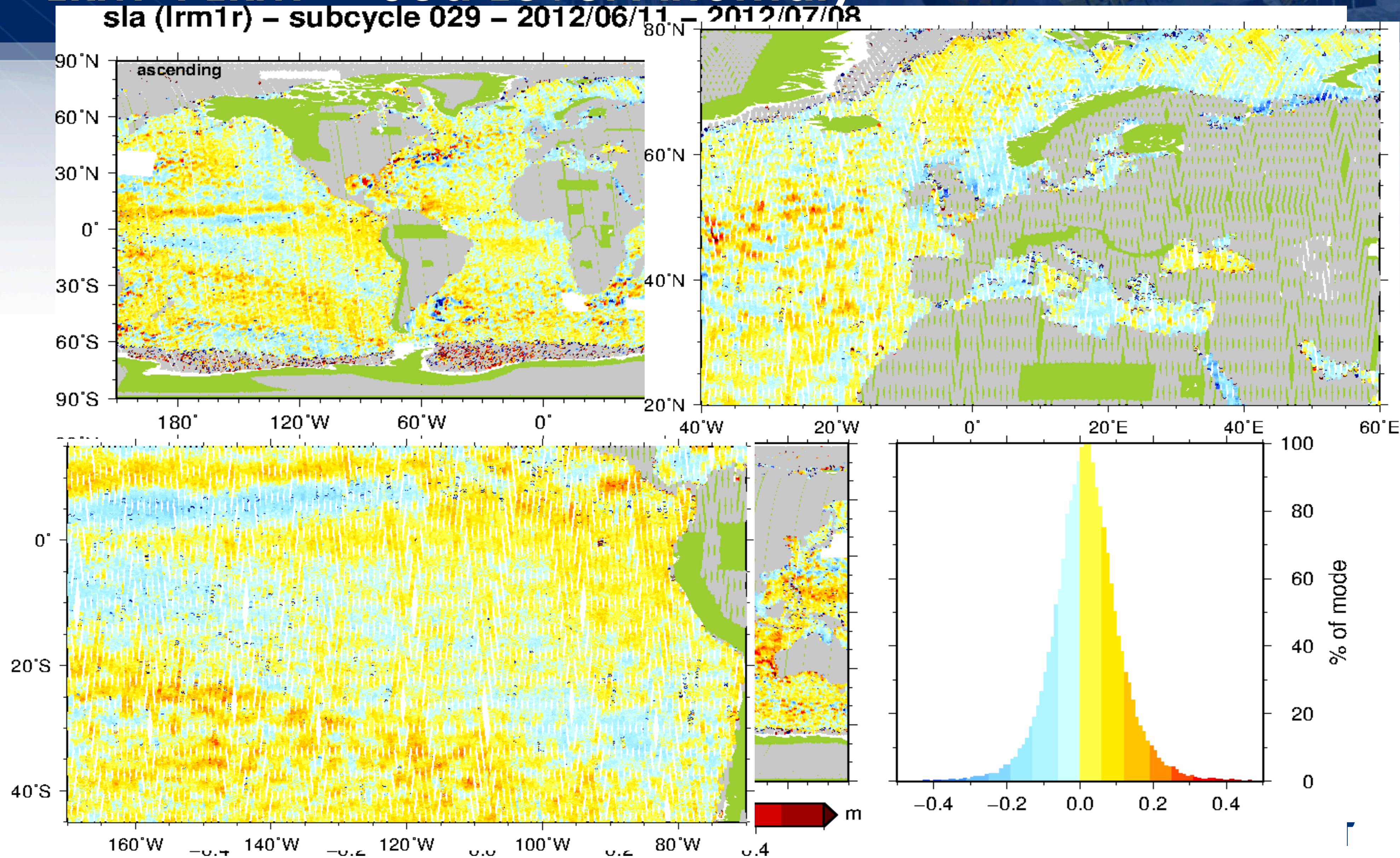
PLRM* – Sea Level Anomaly



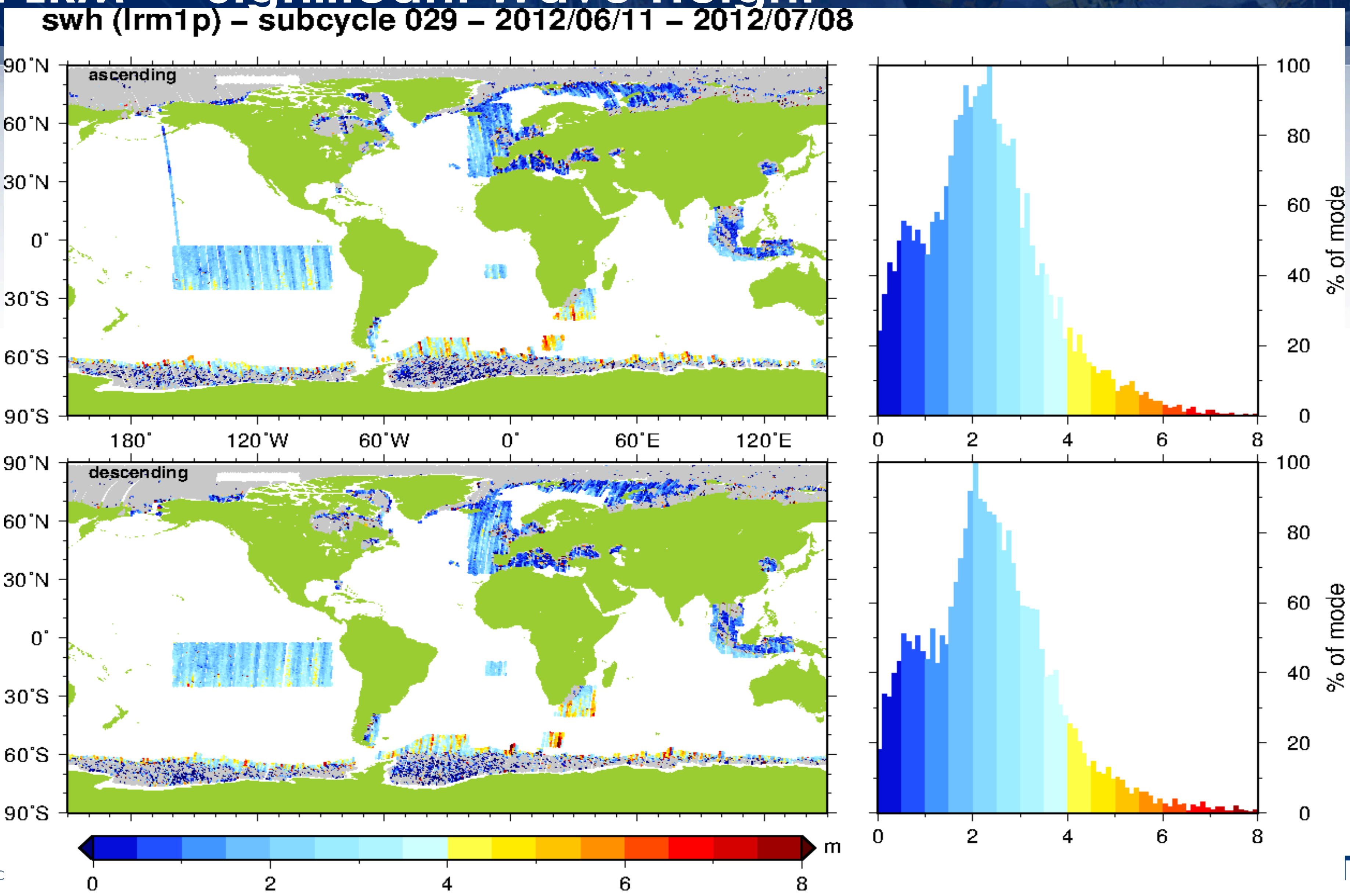
LRM – Sea Level Anomaly



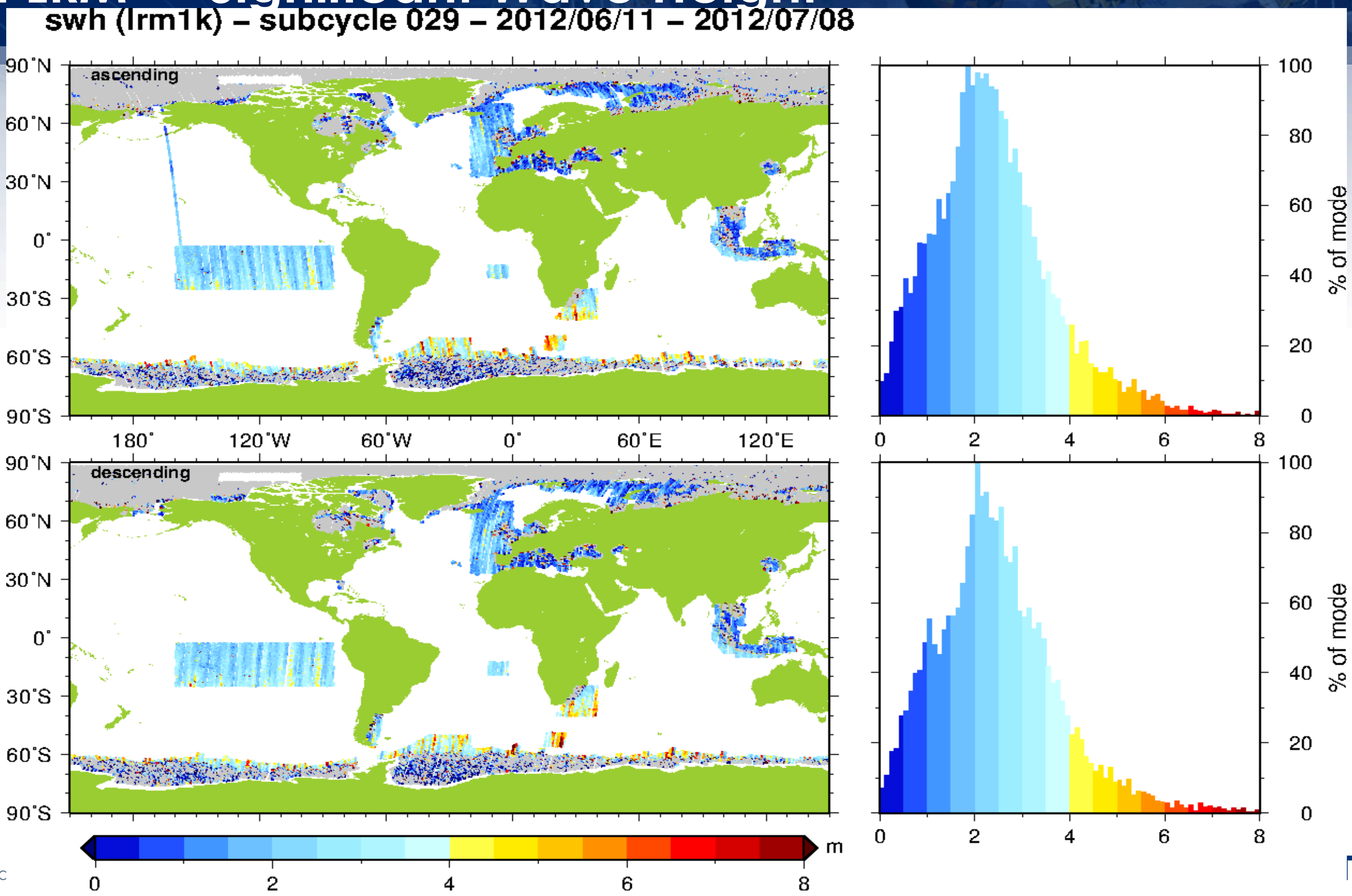
LRM+PLRM* – Sea Level Anomaly



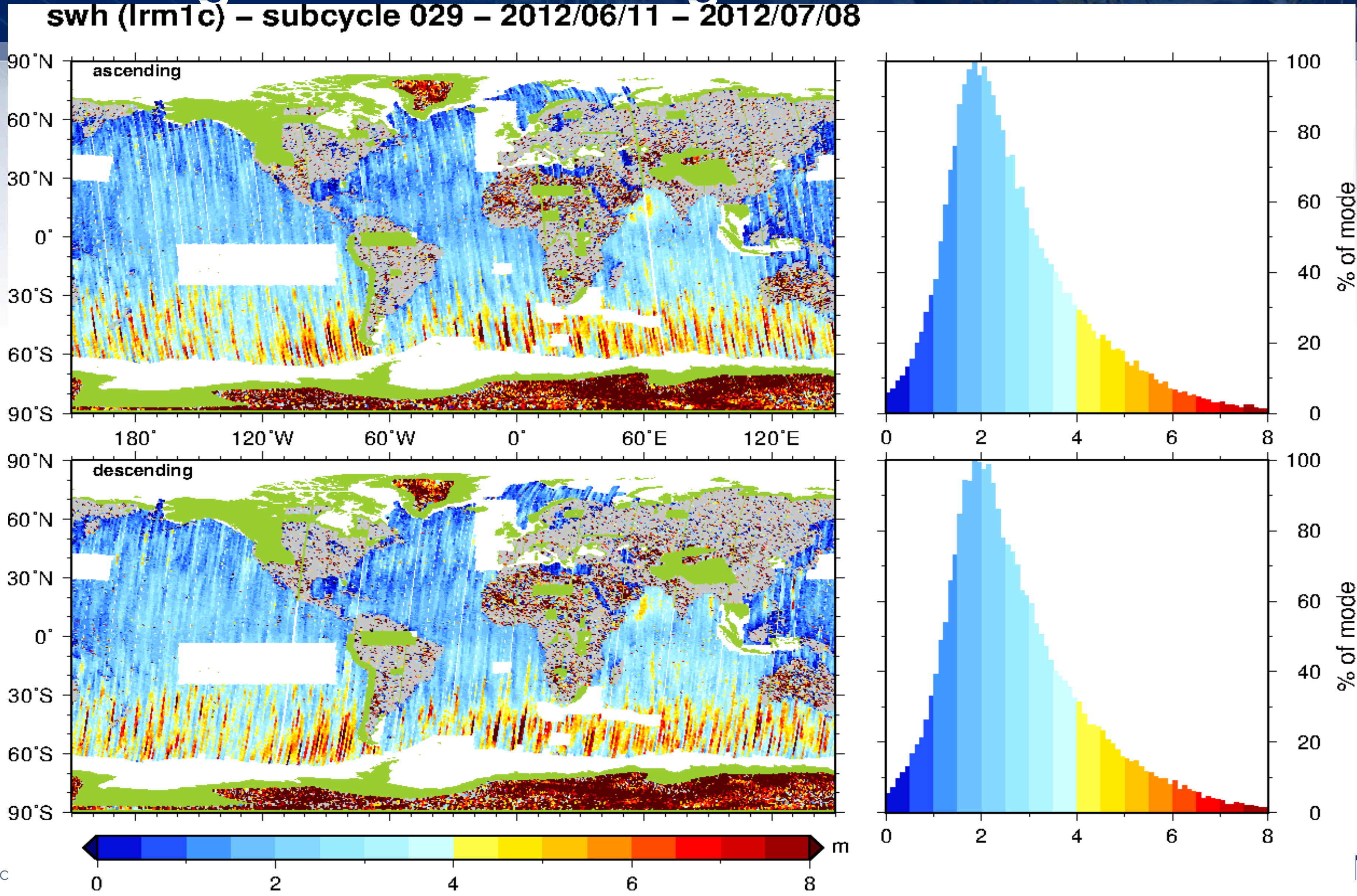
PLRM* – Significant Wave Height



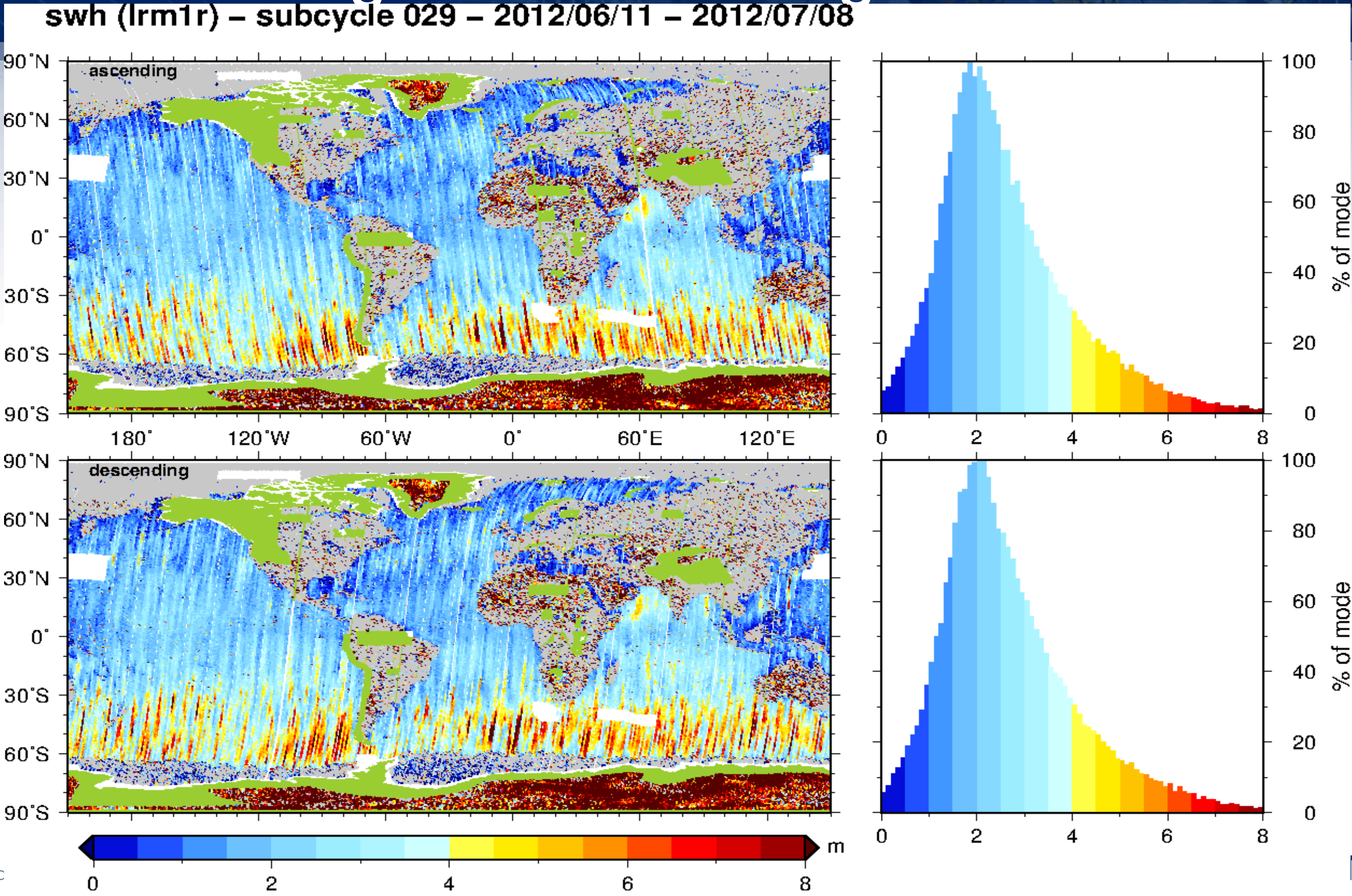
PLRM* – Significant Wave Height



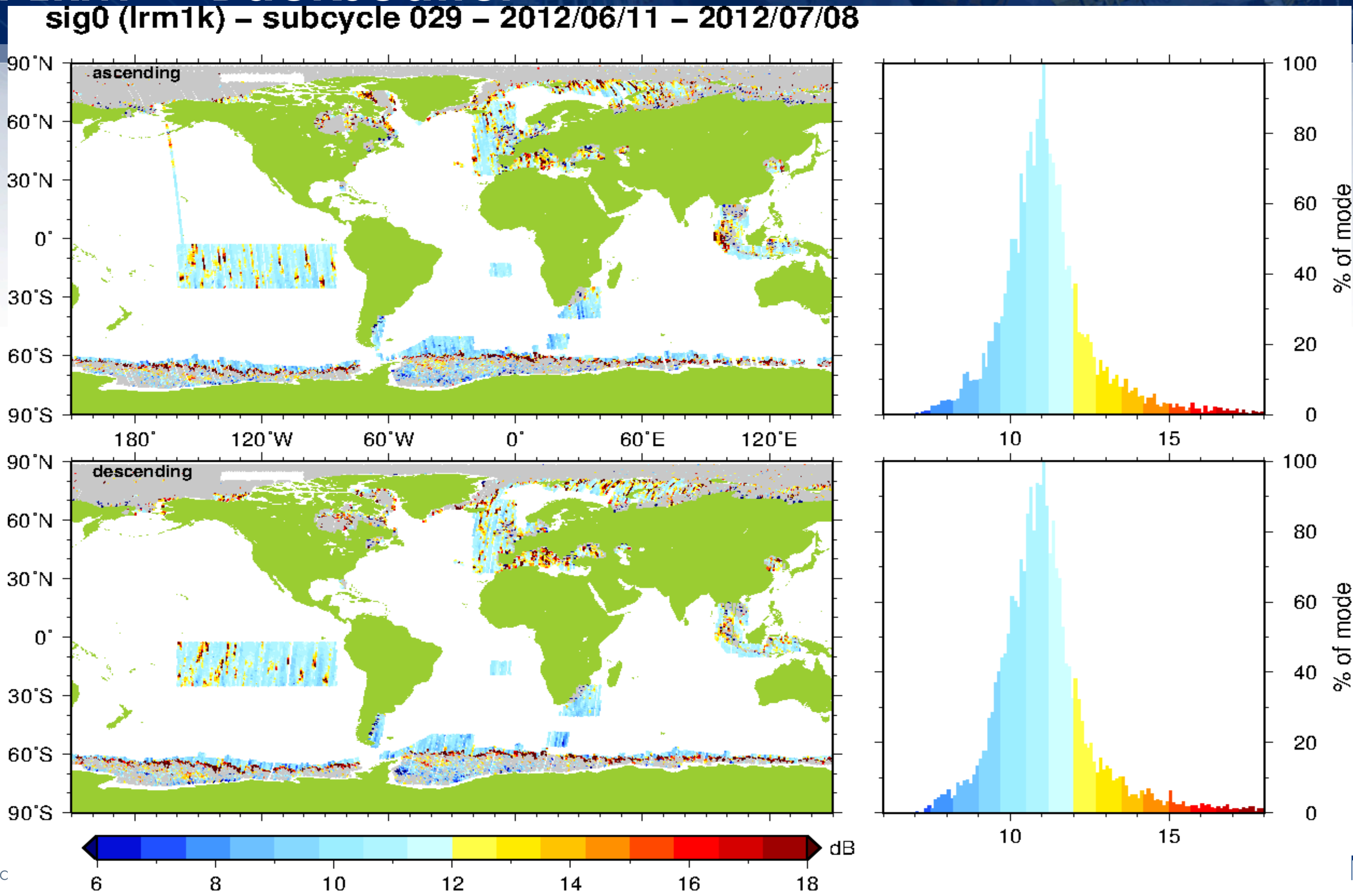
LRM – Significant Wave Height



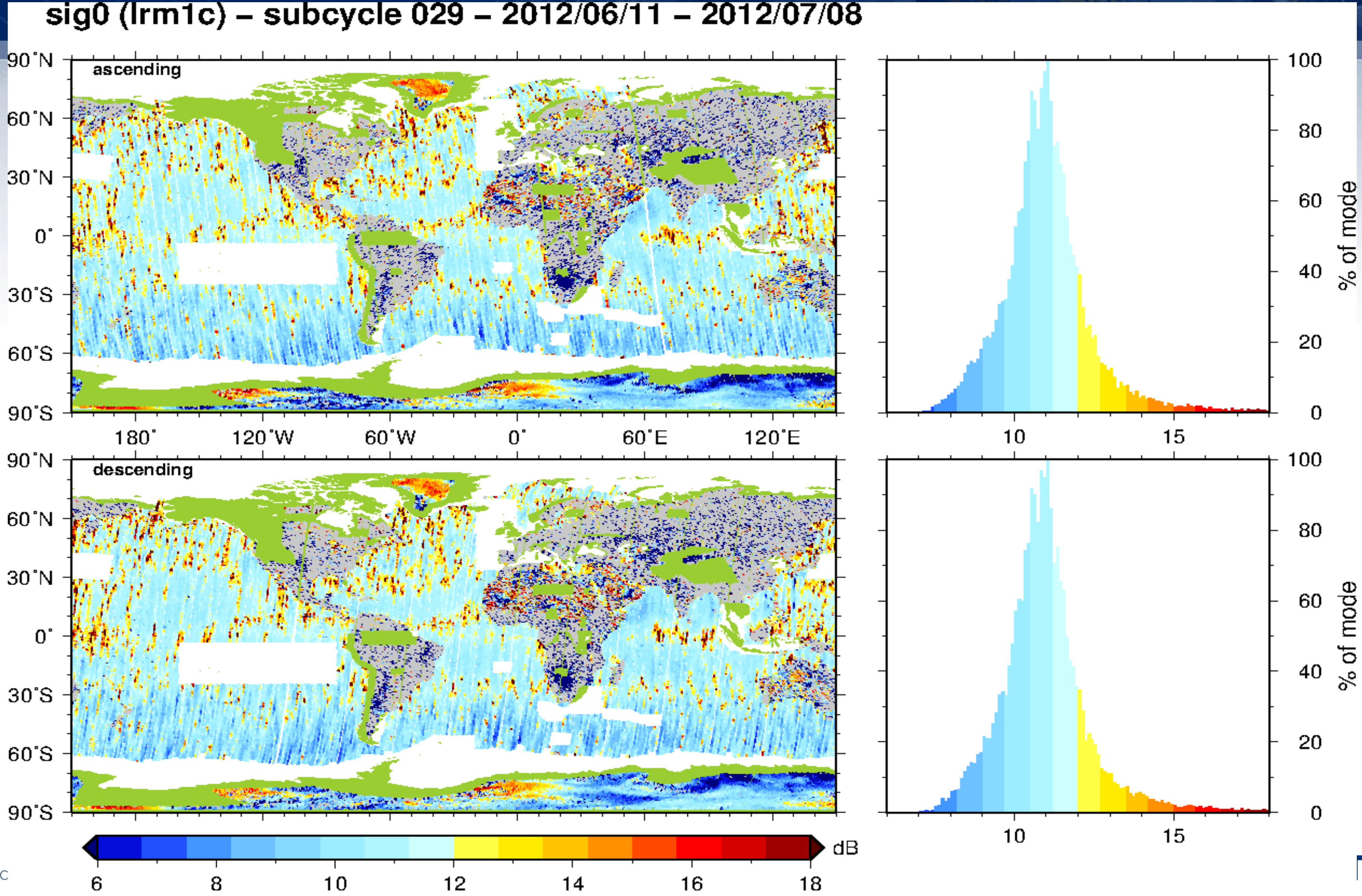
LRM+PLRM* – Significant Wave Height



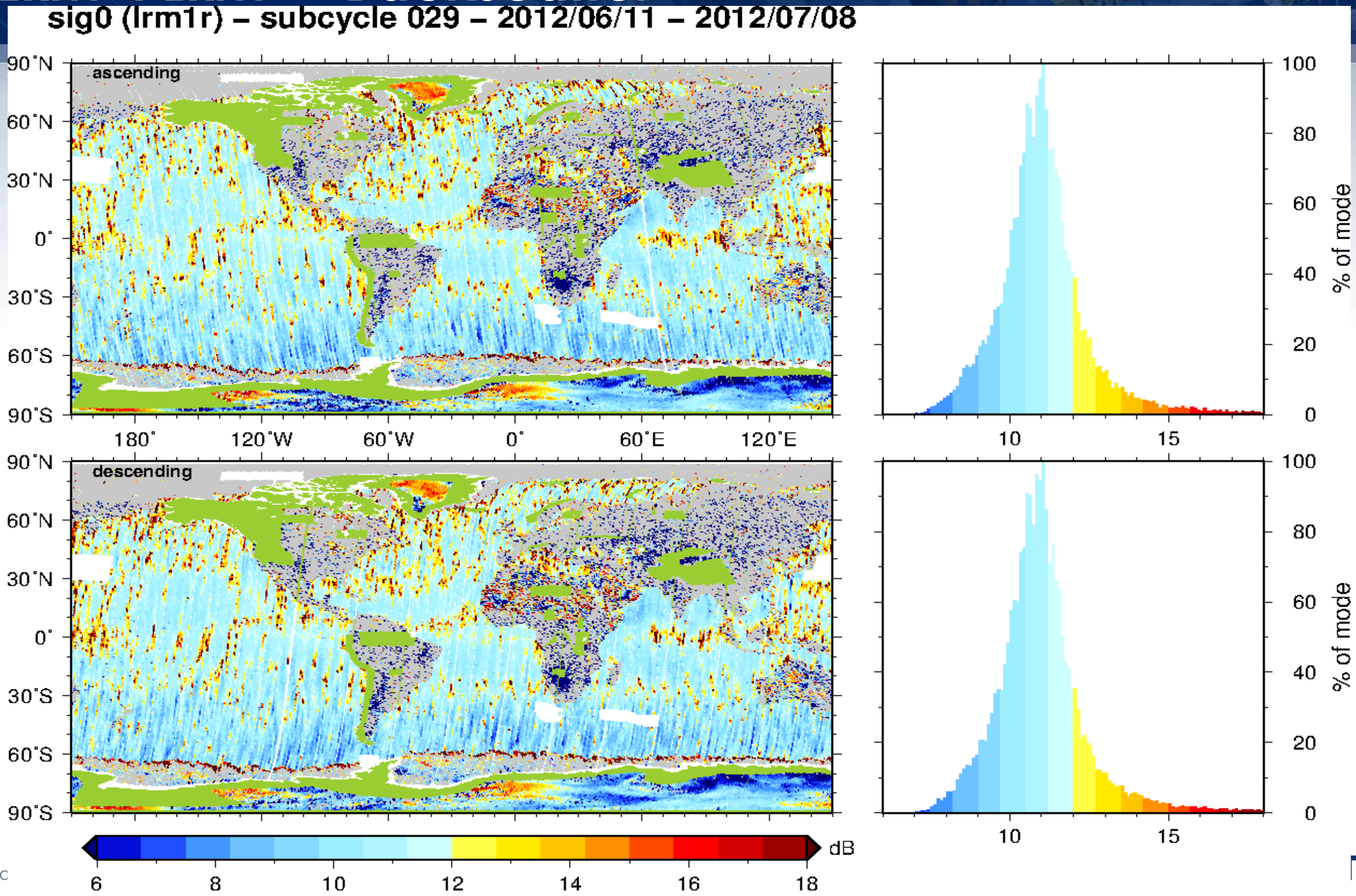
PLRM* – Backscatter



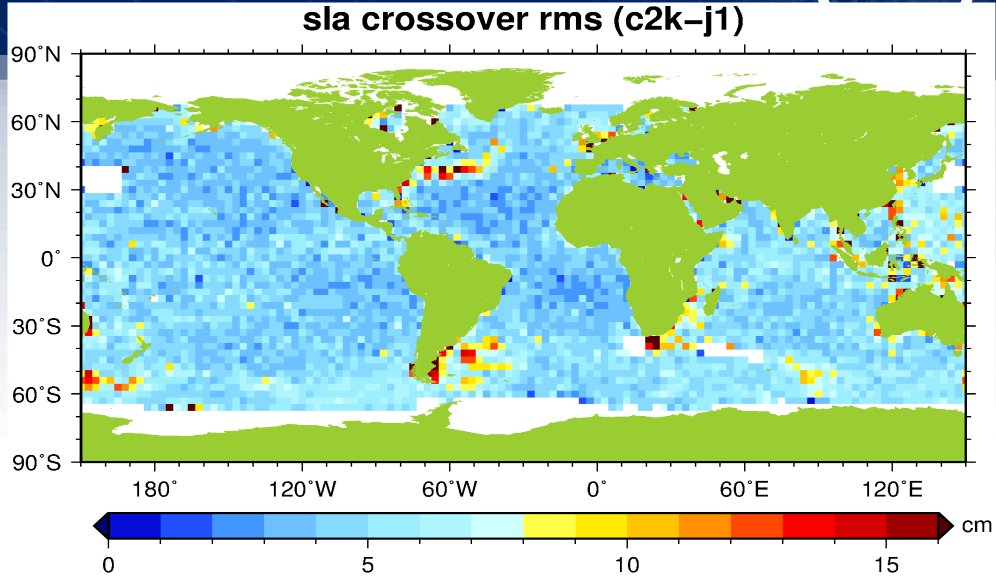
LRM – Backscatter

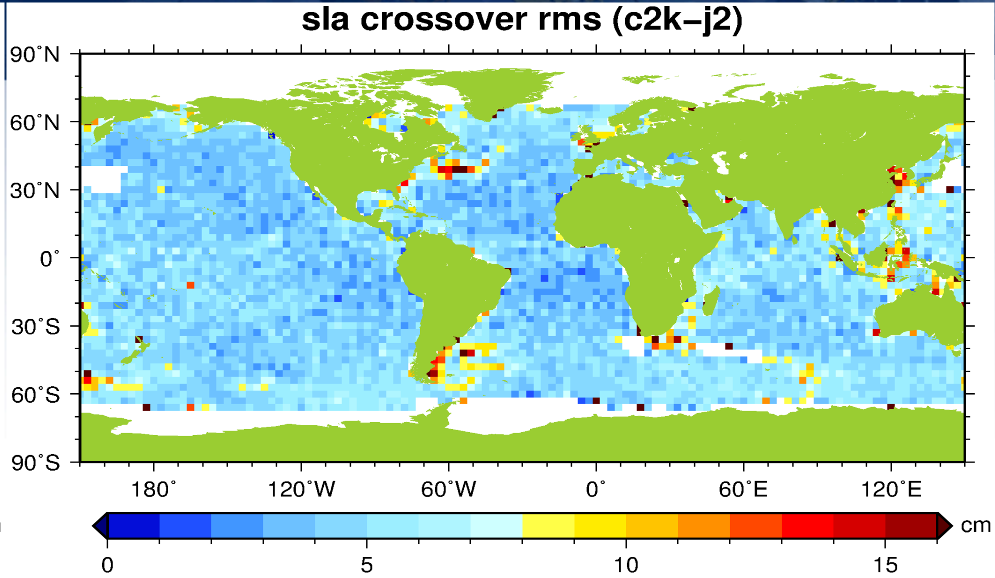


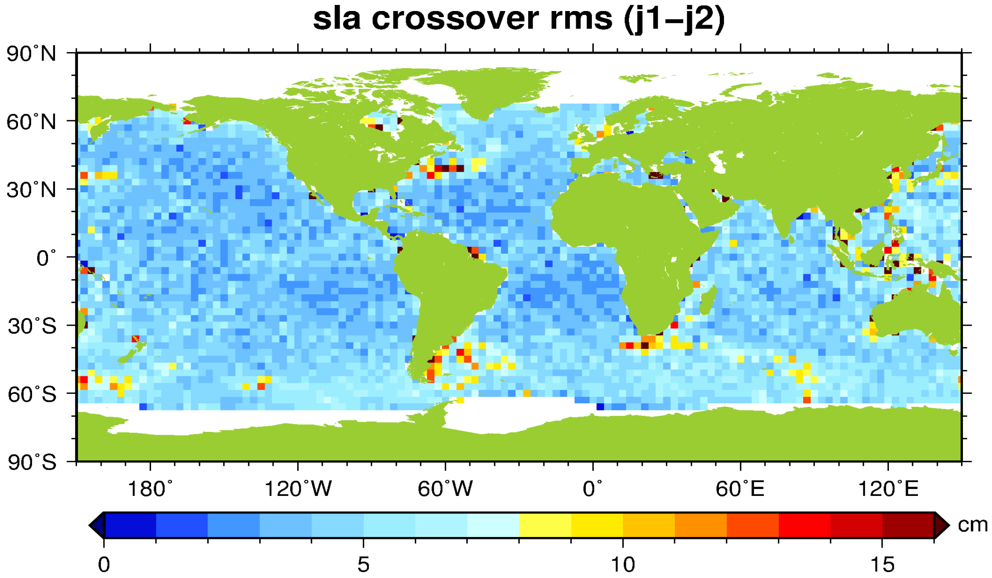
LRM+PLRM* – Backscatter



Retracked Sea Level (cm) Crossovers







	Mean	Std
LRM – Jason-1	–0.26	5.32 +1.2
LRM – Jason-2	+0.11	5.26 +1.0
PLRM* – Jason-1	+0.04	5.55 +2.0
PLRM* – Jason-2	+0.20	5.56 +2.0
Jason-1 – Jason-2	+0.32	5.18

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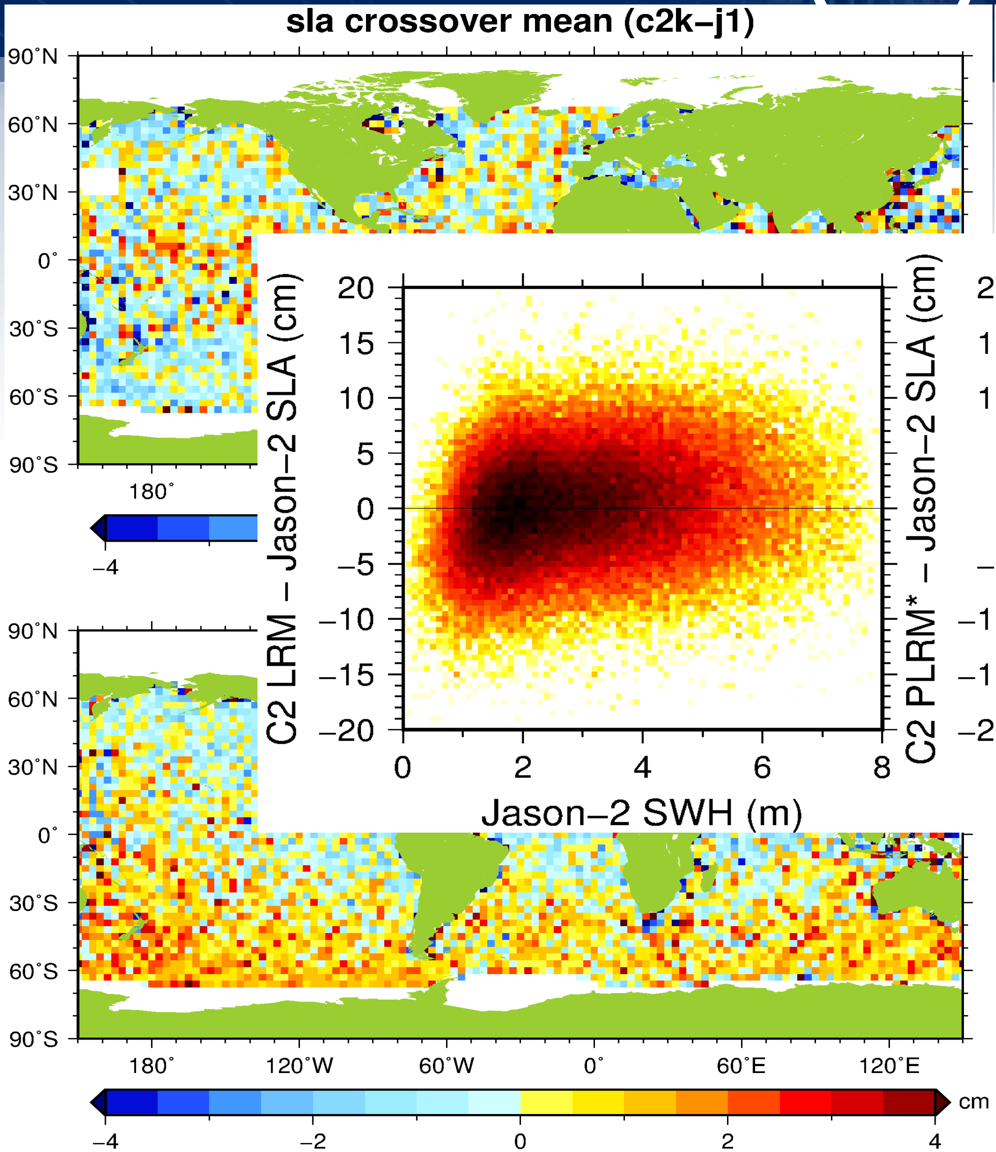
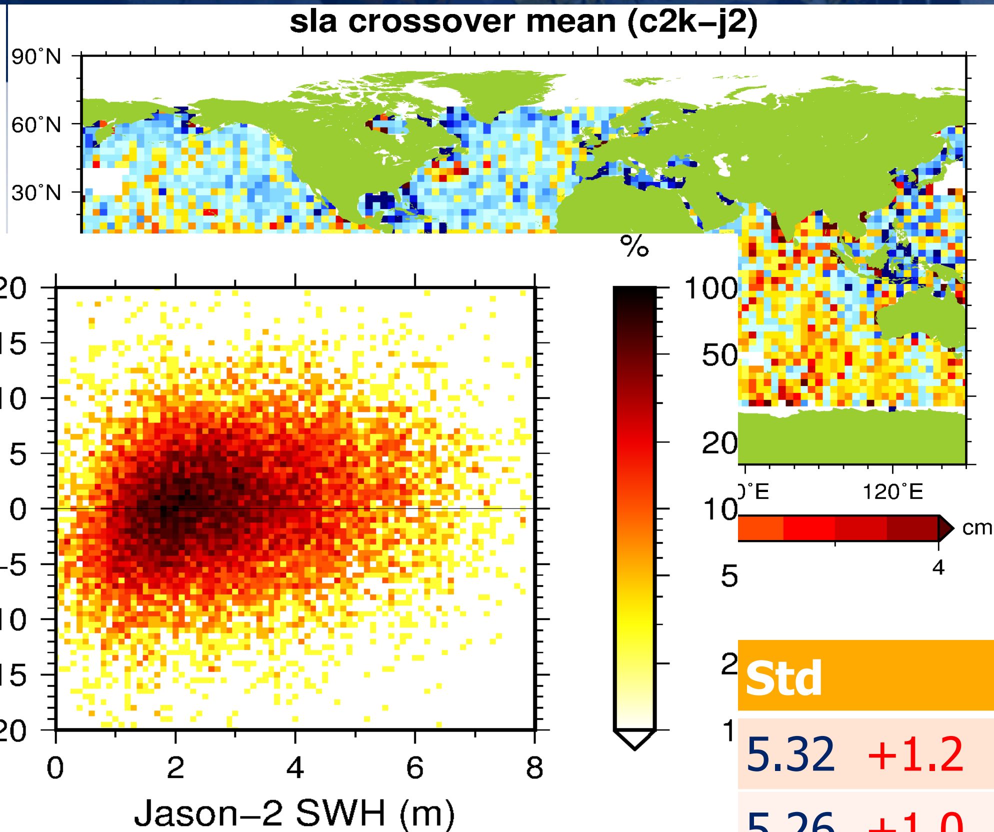
Retracked Sea Level (cm) Crossovers





		Std
		5.32 +1.2
LRM – Jason-2	+0.11	5.26 +1.0
PLRM* – Jason-1	+0.04	5.55 +2.0
PLRM* – Jason-2	+0.20	5.56 +2.0
Jason-1 – Jason-2	+0.32	5.18

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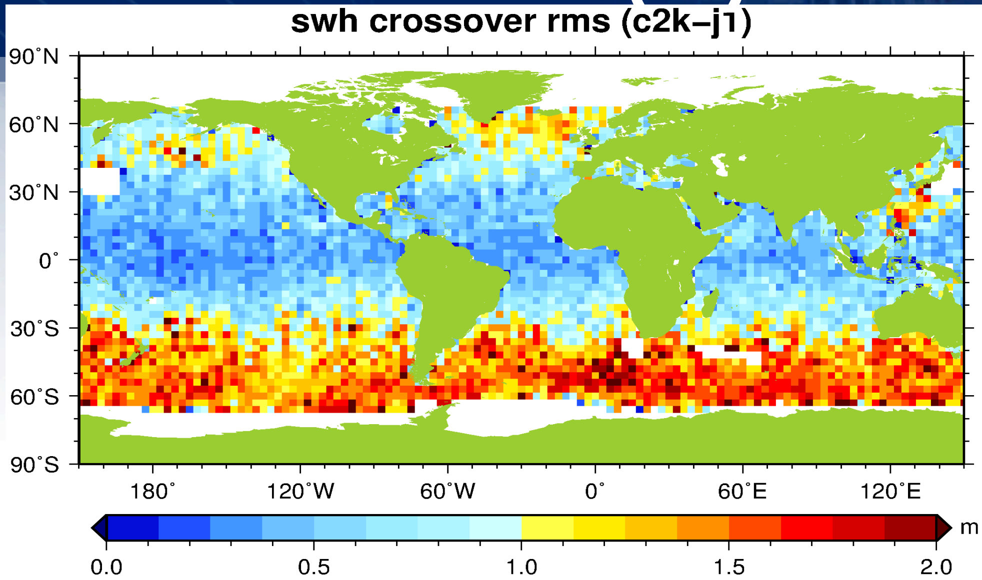
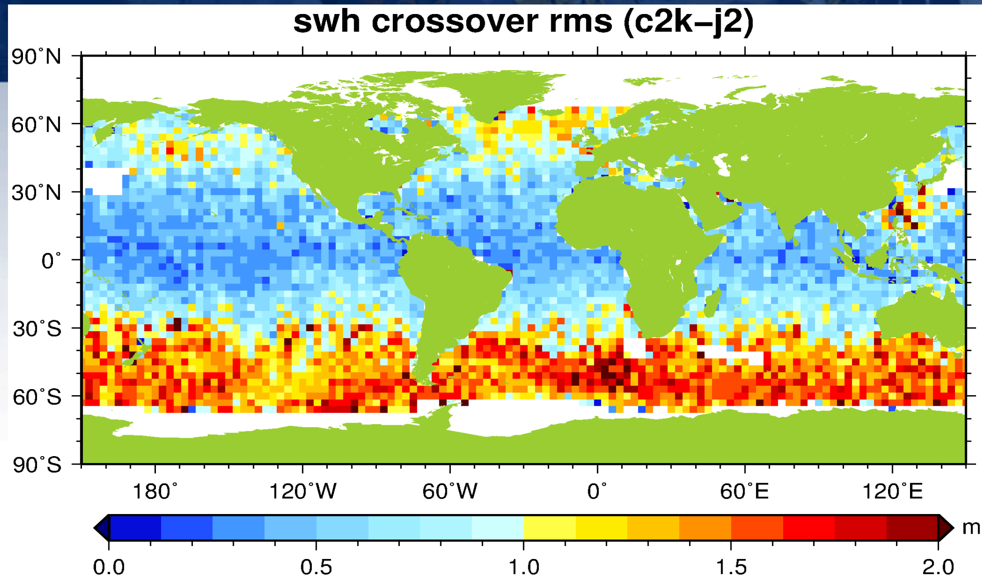
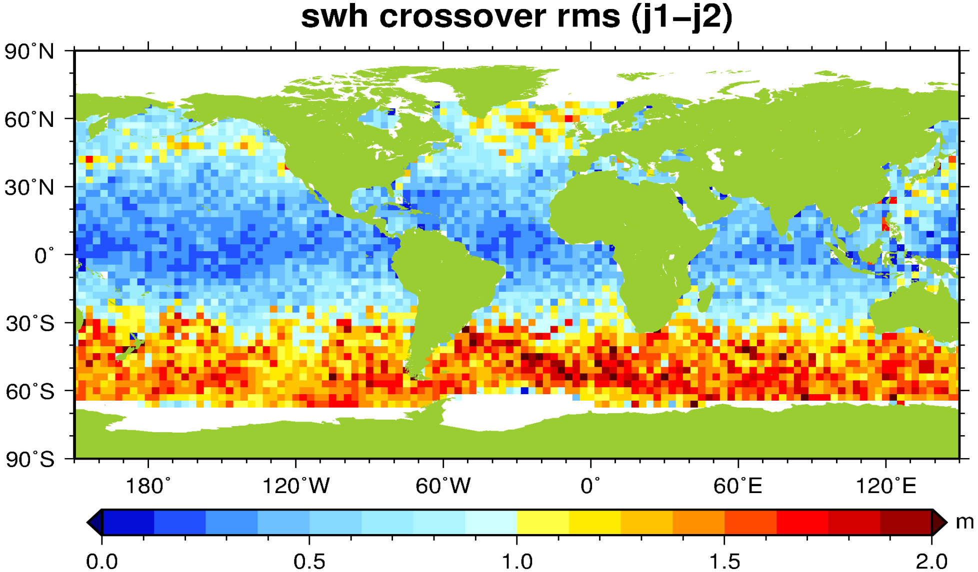
Retracked SWH (m) Crossovers

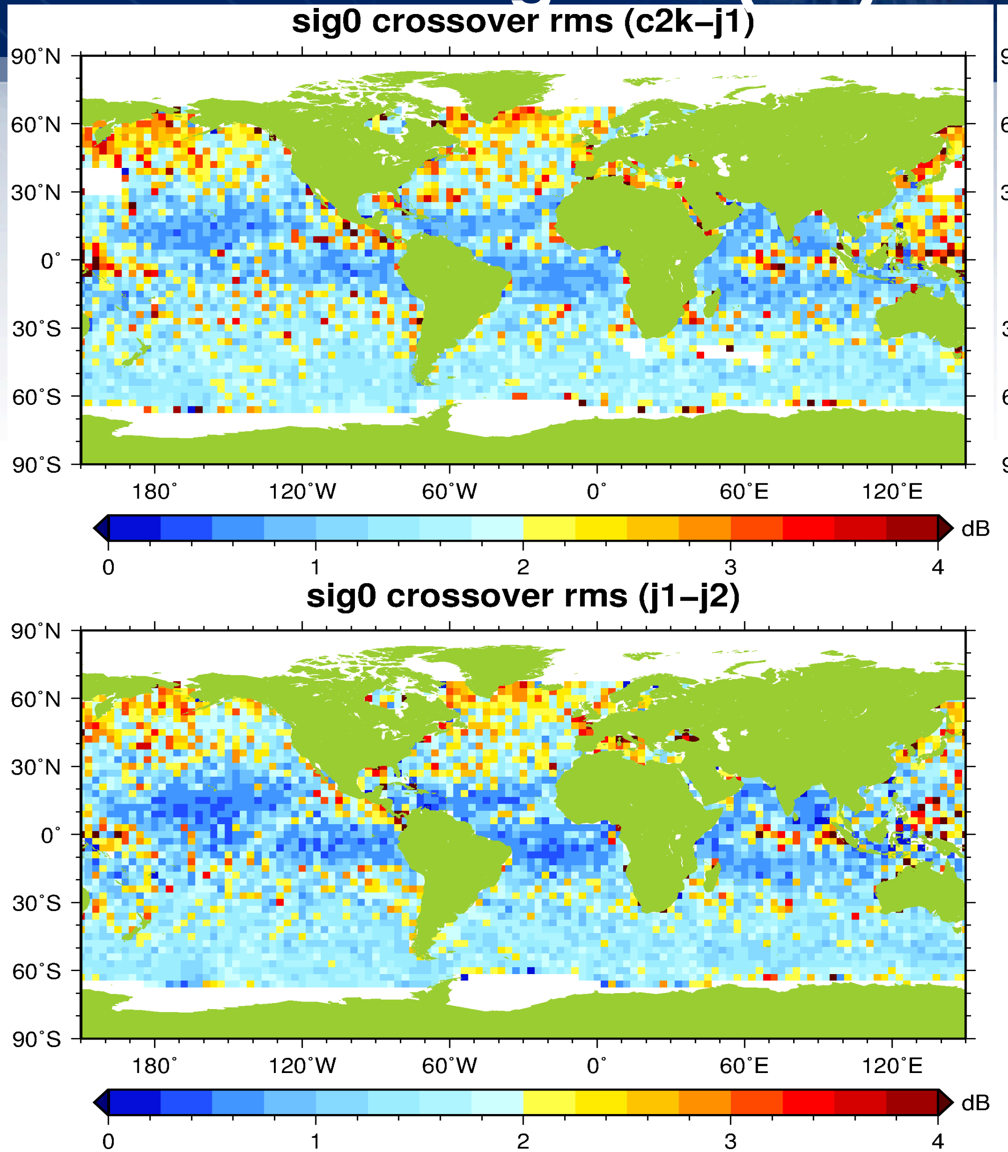






	Mean	Std
LRM – Jason-1	+0.17	1.21
LRM – Jason-2	+0.15	1.20
PLRM – Jason-1	+0.26	1.27
PLRM – Jason-2	+0.26	1.26
Jason-1 – Jason-2	–0.13	1.20

Retracked Sigma0 (dB) Crossovers



	Mean	Std
LRM – Jason-1	–0.53	1.78
LRM – Jason-2	–0.21	1.76
PLRM – Jason-1	–0.55	1.95
PLRM – Jason-2	–0.23	2.00
Jason-1 – Jason-2	+0.32	1.74

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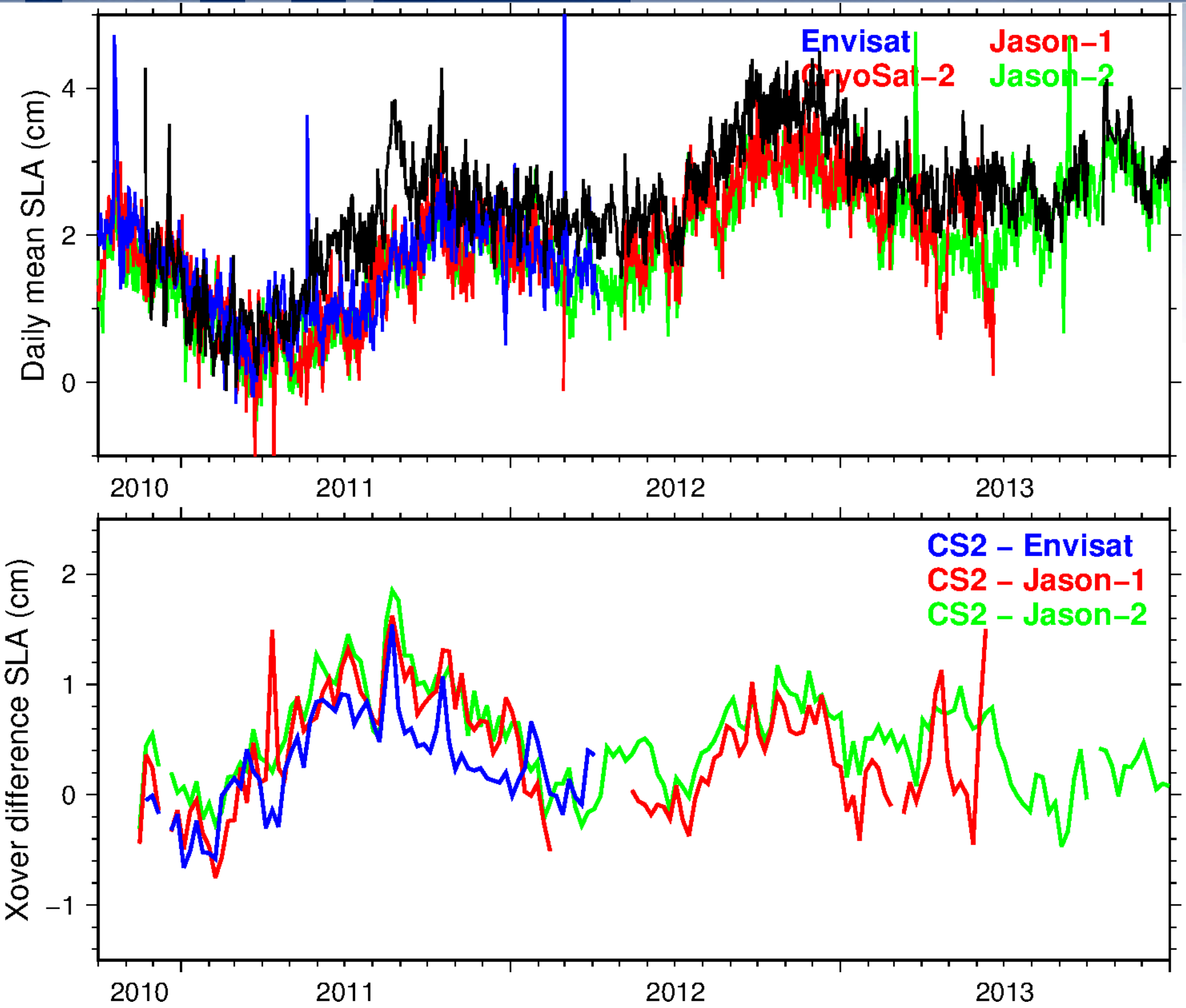
Sea Level Anomaly (LRM)

Biases

- Few mm at most

Seasonal variation

- In daily global mean
- ~500 days in xovers (Beta angle)



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Sea Level Anomaly (LRM) with same corrections

Corrections

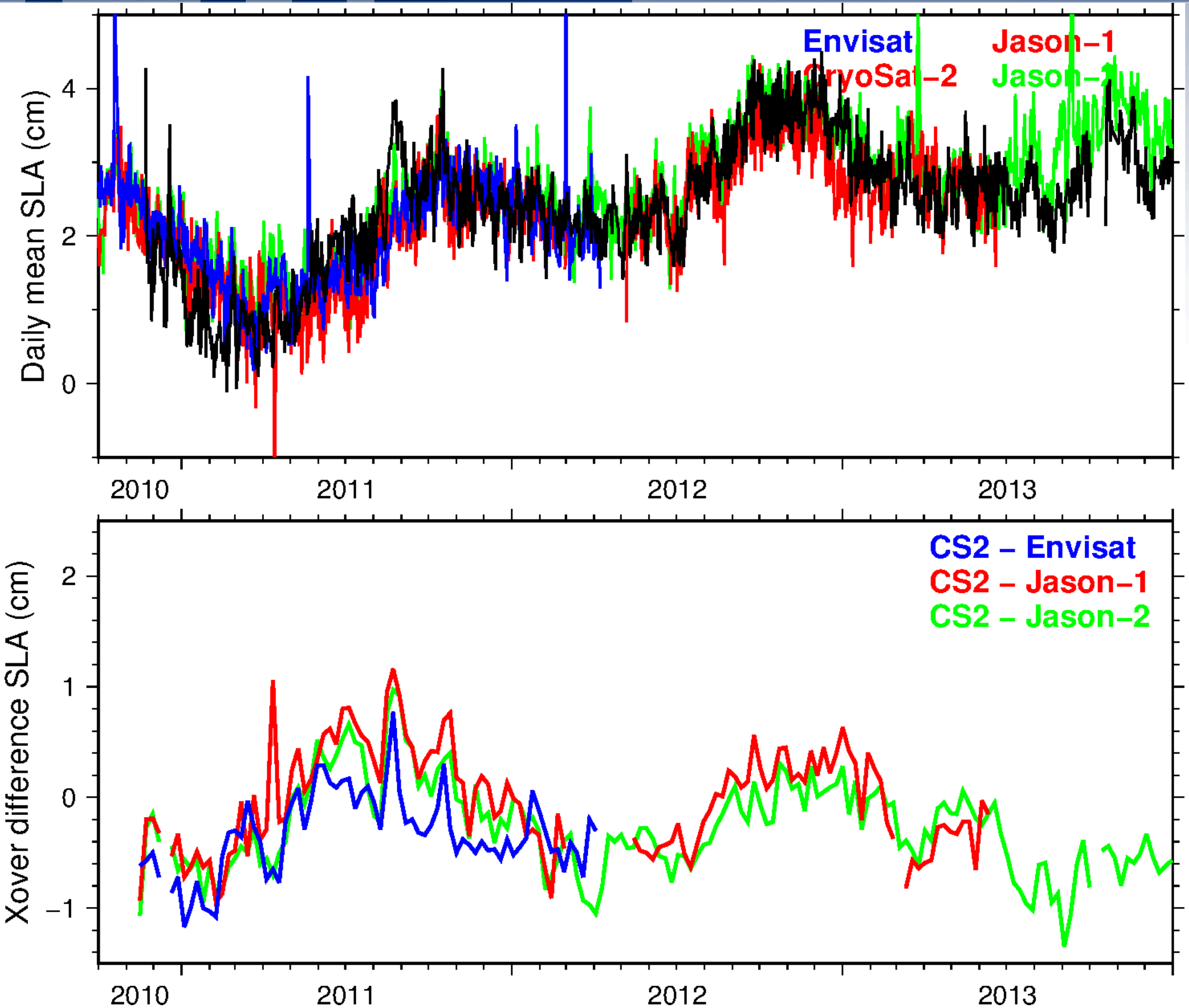
- For Env, Ja1/Ja2 also use ECMWF wet and GIM iono

Biases

- Few mm at most
- Now even closer to zero

Seasonal variation

- In daily global mean
- ~500 days in xovers



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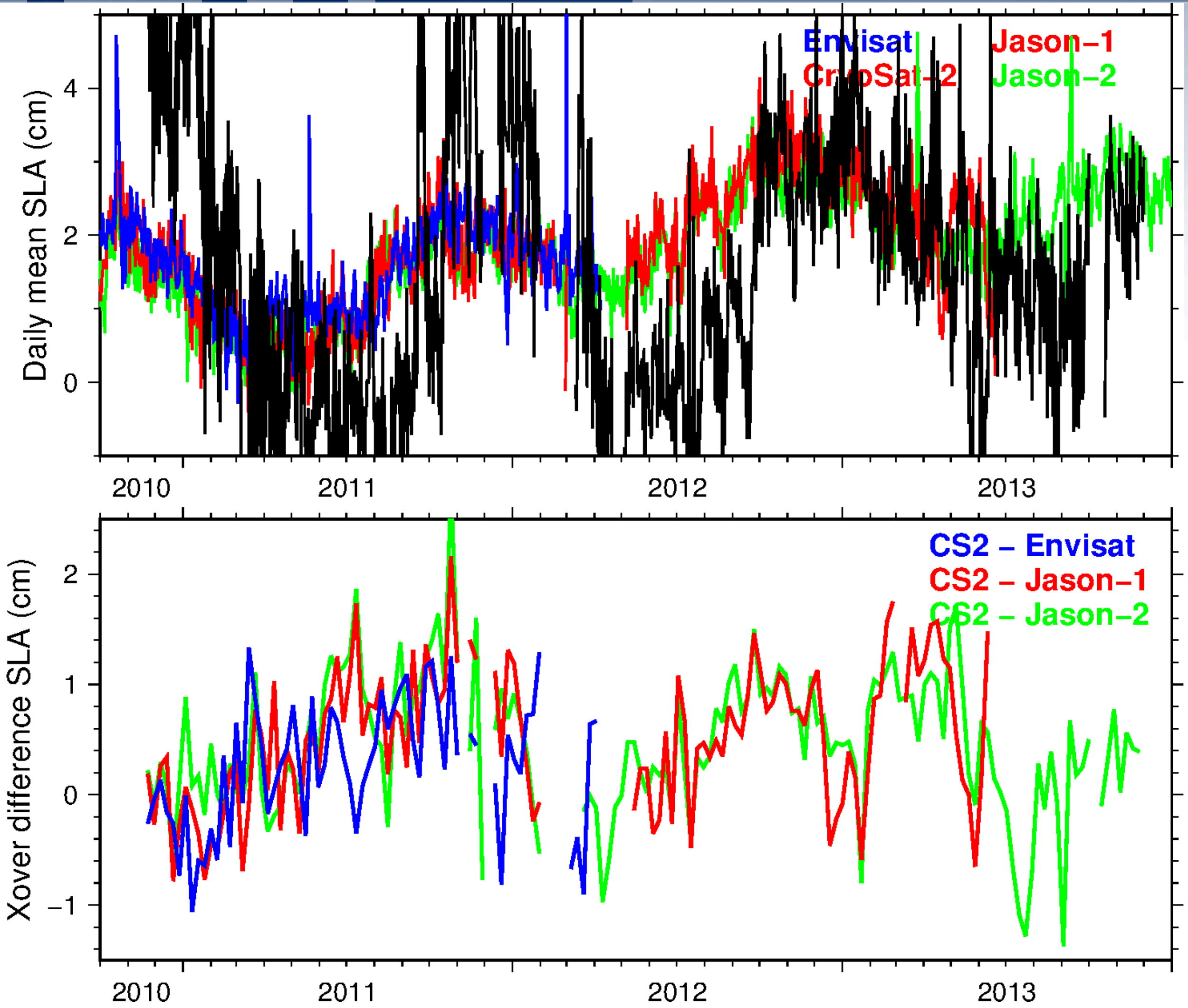
Sea Level Anomaly (PLRM)

Biases

- Few mm at most

Seasonal variation

- In daily global mean
- ~500 days in xovers



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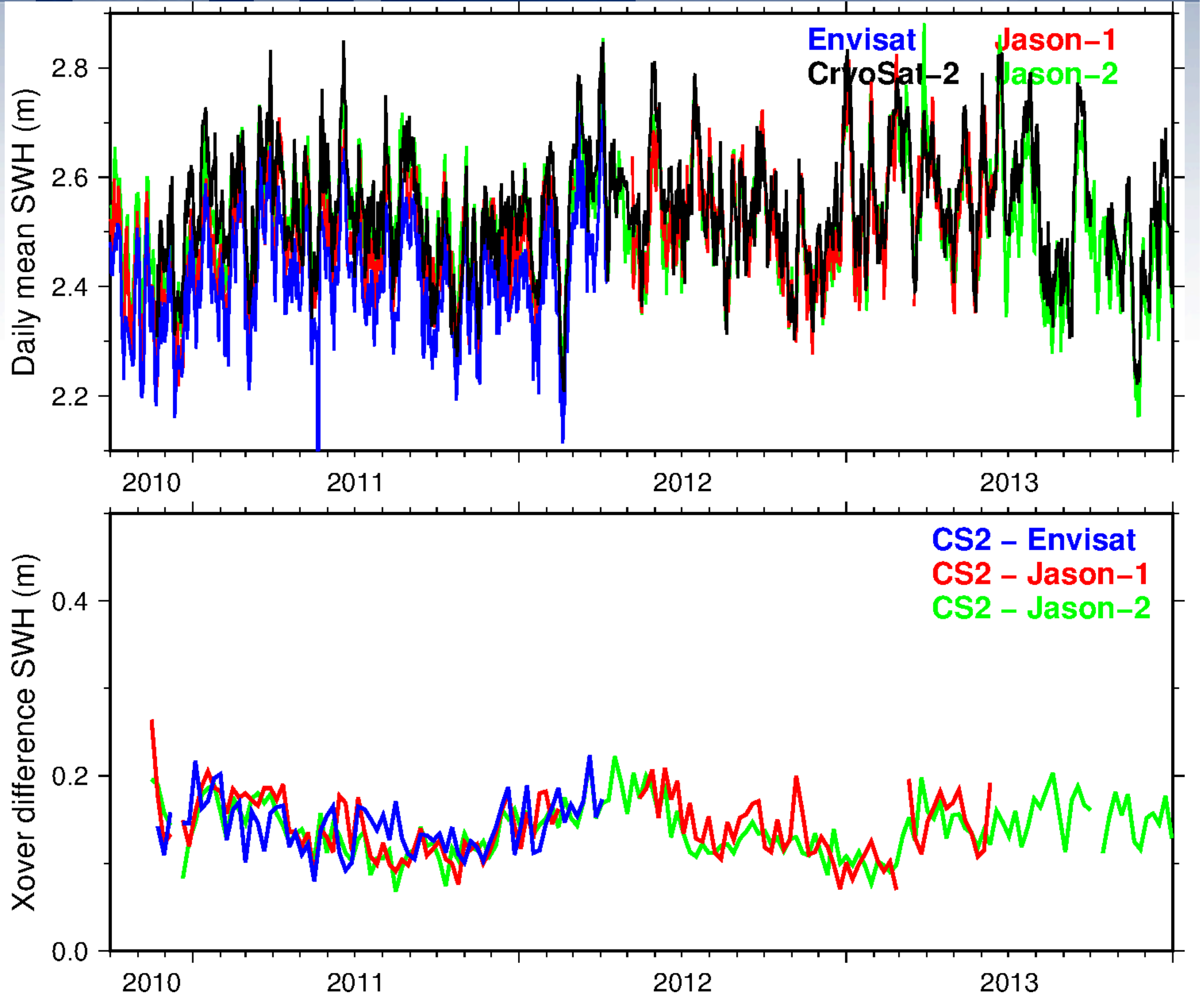
Significant Wave Height (LRM)

Biases

- Little apparent bias in global mean
- SWH xovers show CS2 is biased high by ~15 cm

Seasonal variation

- In daily global mean
- But very small in xovers



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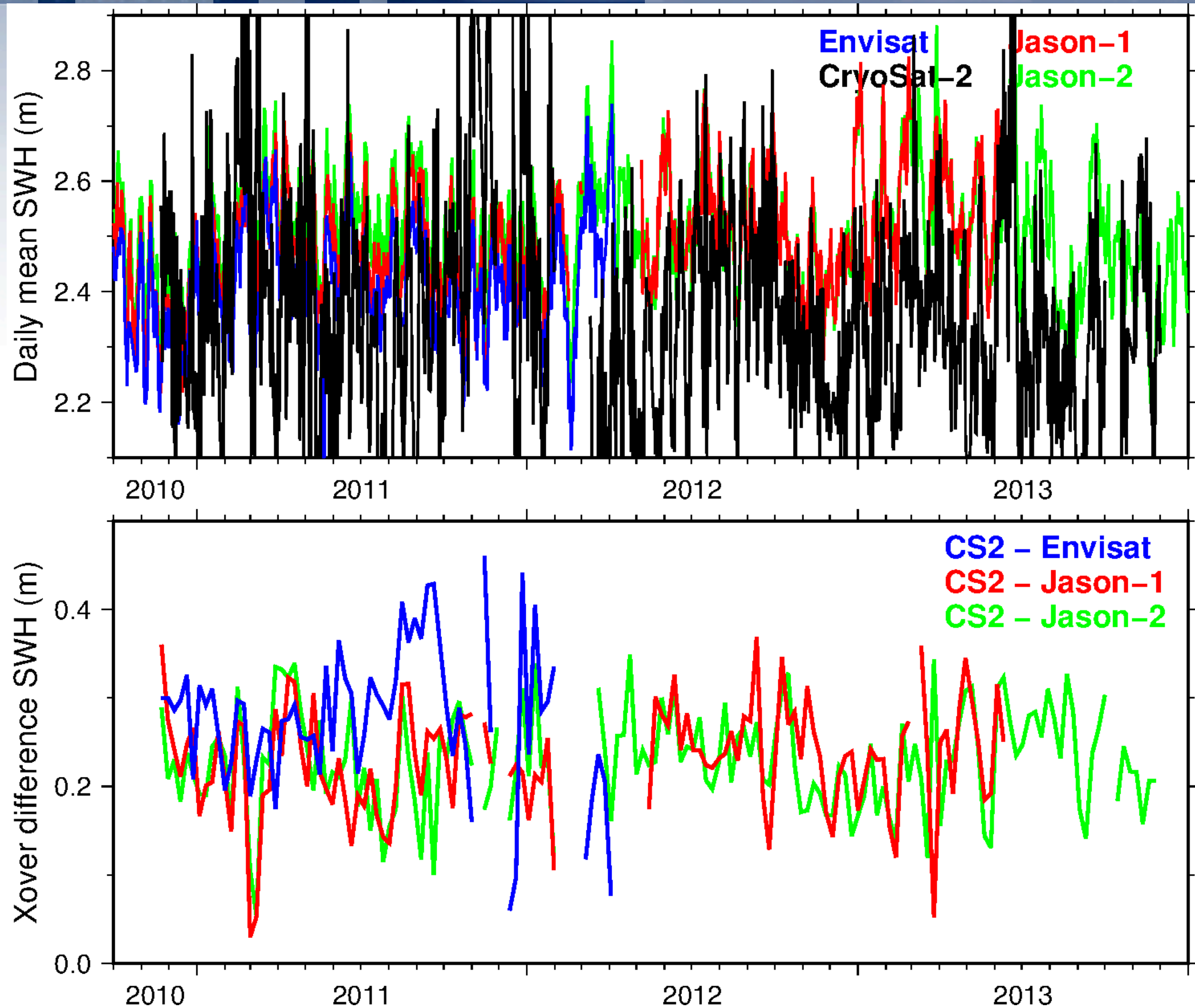
Significant Wave Height (PLRM)

Biases

- Little apparent bias in global mean
- SWH xovers show CS2 is biased high by ~20 cm

Seasonal variation

- In daily global mean
- But very small in xovers



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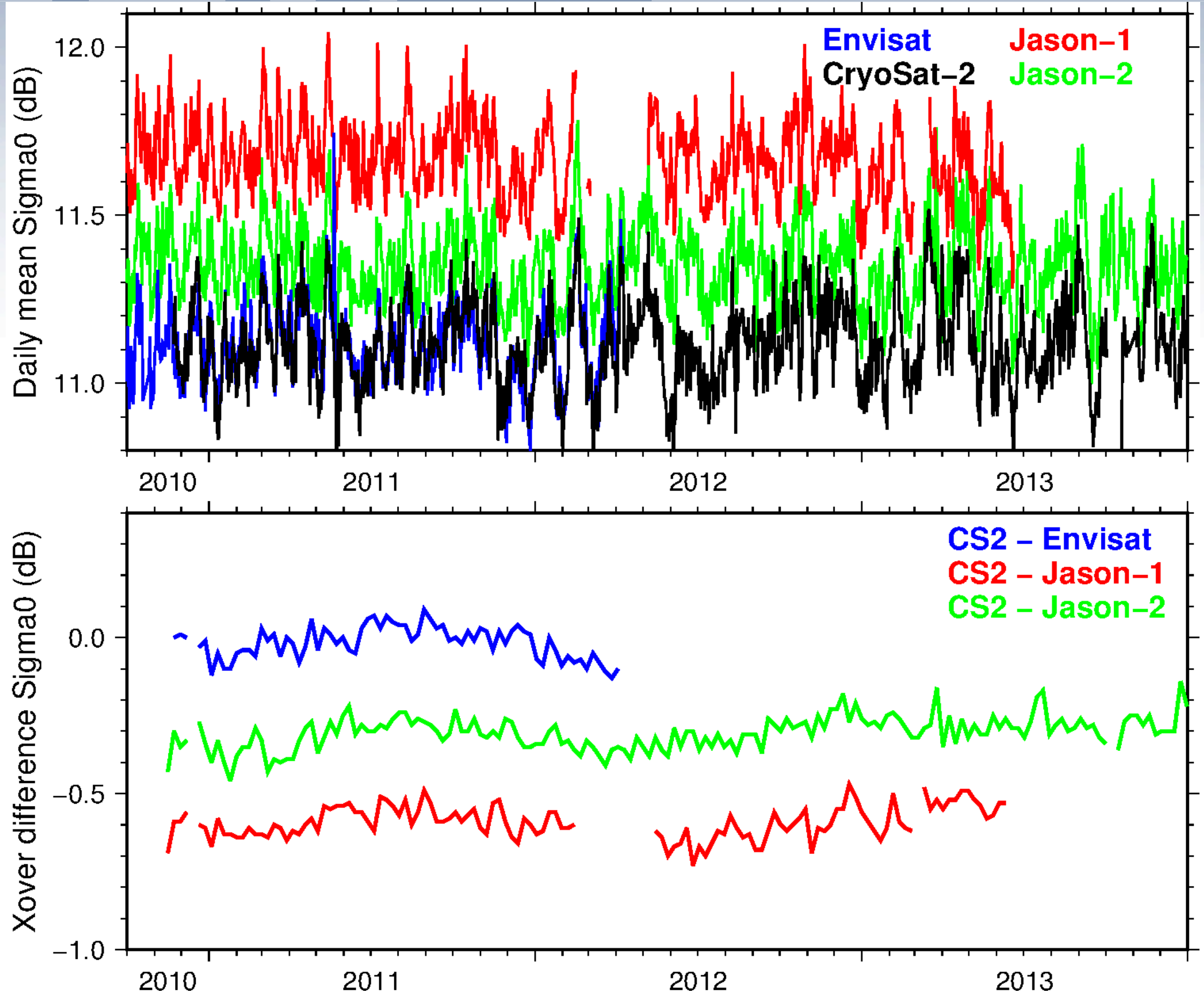
Backscatter (LRM)

Biases

- With Env: 0.0 dB
  - Abdalla wind speed model applies
- With Ja1: –0.6 dB
- With Ja2: –0.3 dB

Seasonal variation

- Very small



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Backscatter (PLRM)

Biases

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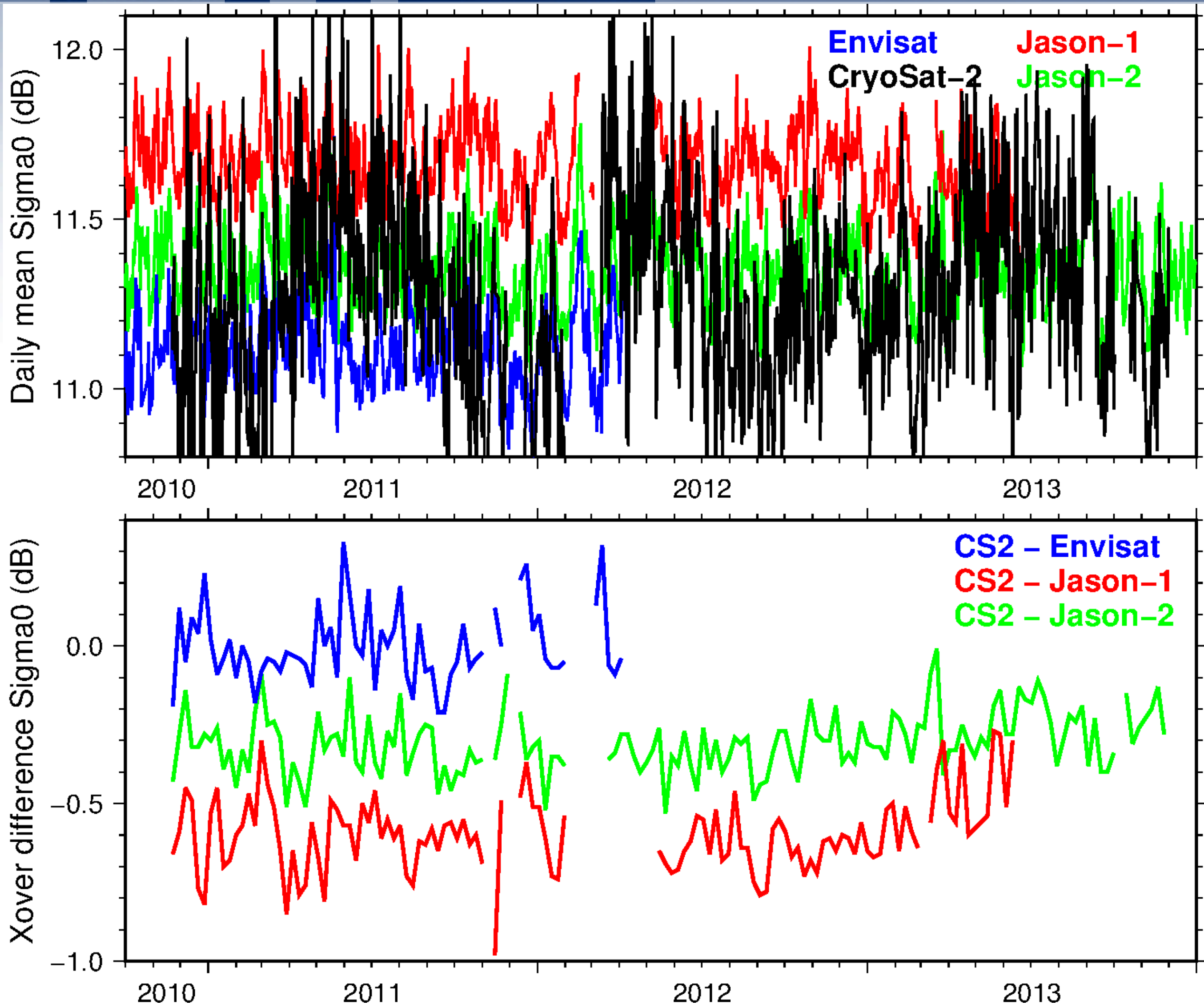
- With Ja2: –0.3 dB

Seasonal variation

- Very small



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Conclusions

Sea level anomaly

- “Reference frame offset” applied
  - CS2: –704 mm; Env: +448 mm; Ja1: +88 mm; Ja2: –18 mm
- Remaining bias few mm; some beta-angle related variation

Significant Wave Height

- CS2 biased high by about 15 cm (LRM), 20 cm (PLRM)

Backscatter coefficient

- CS2 adjusted for drift and ~–3.0 dB bias
- Jason-1/2 adjusted by –2.4 dB
- Remaining biases
  - Env: 0.0 dB, Ja1: –0.6 dB, Ja2: –0.3 dB

Conclusions

Retracked LRM L1B data

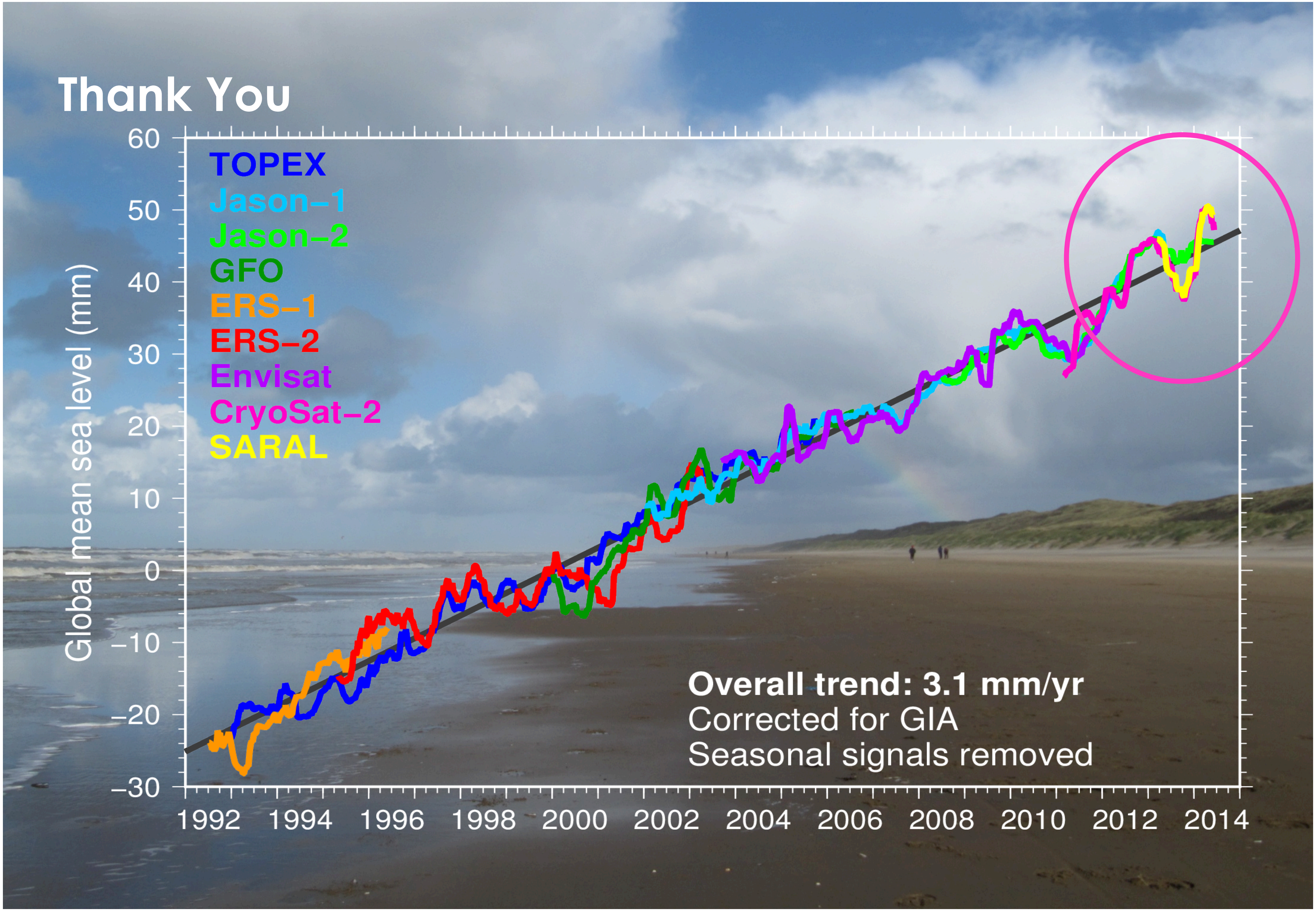
- Retracking can be performed with MLE3 with a priori off-nadir angle from star-tracker information.
- Retracked L1B data shows excellent quality.
- Crossovers with Jason-1/2 shows sea level variance only slightly higher than Jason-1/2, due to lack of radiometer & dual-frequency.

Retracked Pseudo-LRM data

- Stacking SAR echoes, 256 bins, waveform smoothing, same retracking.
- No apparent bias with LRM data.
- Higher levels of 20-Hz noise, reduced by smoothing.
- However, data quality is comparable to LRM data.

RADS

- Has distributed LRM data since October 2011.
- Has started distributing PLRM data since October 2012, when ESA data policies were relaxed.
- New PLRM data with Jensen technique uploaded this morning.



Thank You
Global mean sea level (mm)
60
50
40
30
20
10
0
−10
−20
−30
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
TOPEX
Jason−1
Jason−2
GFO
ERS−1
ERS−2
Envisat
CryoSat−2
SARAL
Overall trend: 3.1 mm/yr
Corrected for GIA
Seasonal signals removed