Validation of Retracked CryoSat Data Over Open Oceans

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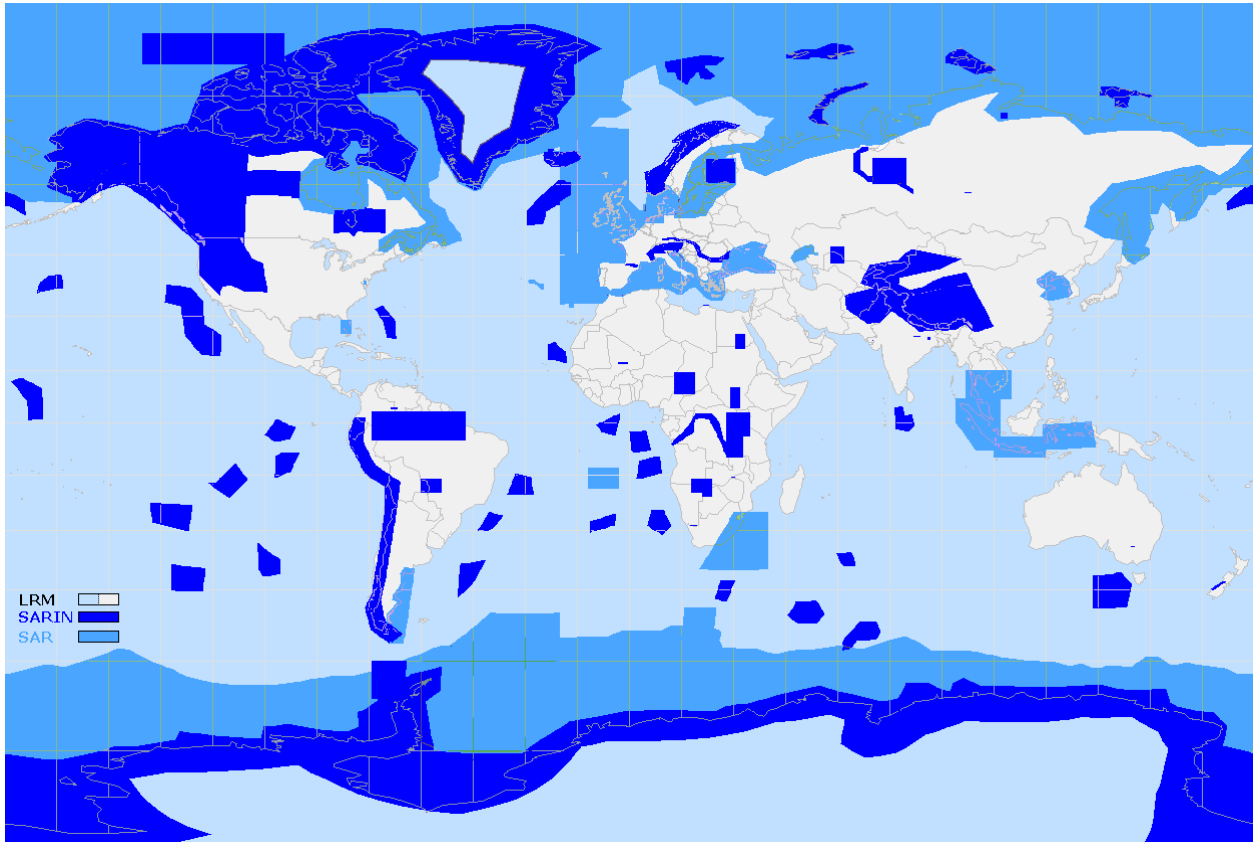
Motivation and Overview

- Born out of NRT needs
  - NOAA wanted to compute near-realtime winds and waves from CryoSat-2 for 2011 Hurricane season.
  - Existing ESA Fast-Delivery Level 2 product had vastly incorrect backscatter and SWH estimates.
  - At NOAA we built our own retracker for the Level 1B waveform data (See *Walter*'s Instrument Processing talk for details).
  - We are now delivering winds and waves hourly to the National Hurricane Center (See *Walter*'s NRT talk for details).
- Validation
  - Winds and wave compare well with Jason and Envisat.
  - We managed to *reverse engineer* the errors in the Level 2 product (See also *Marc Naeije*'s poster).
  - We determined a sea state bias model.
  - Sea surface height now compares *very* favourably to Jason-2 and Envisat.

CryoSat-2 LRM Mode Products



- **LRM** (Low Rate Mode) = Operates as a conventional altimeter.

LRM Products:

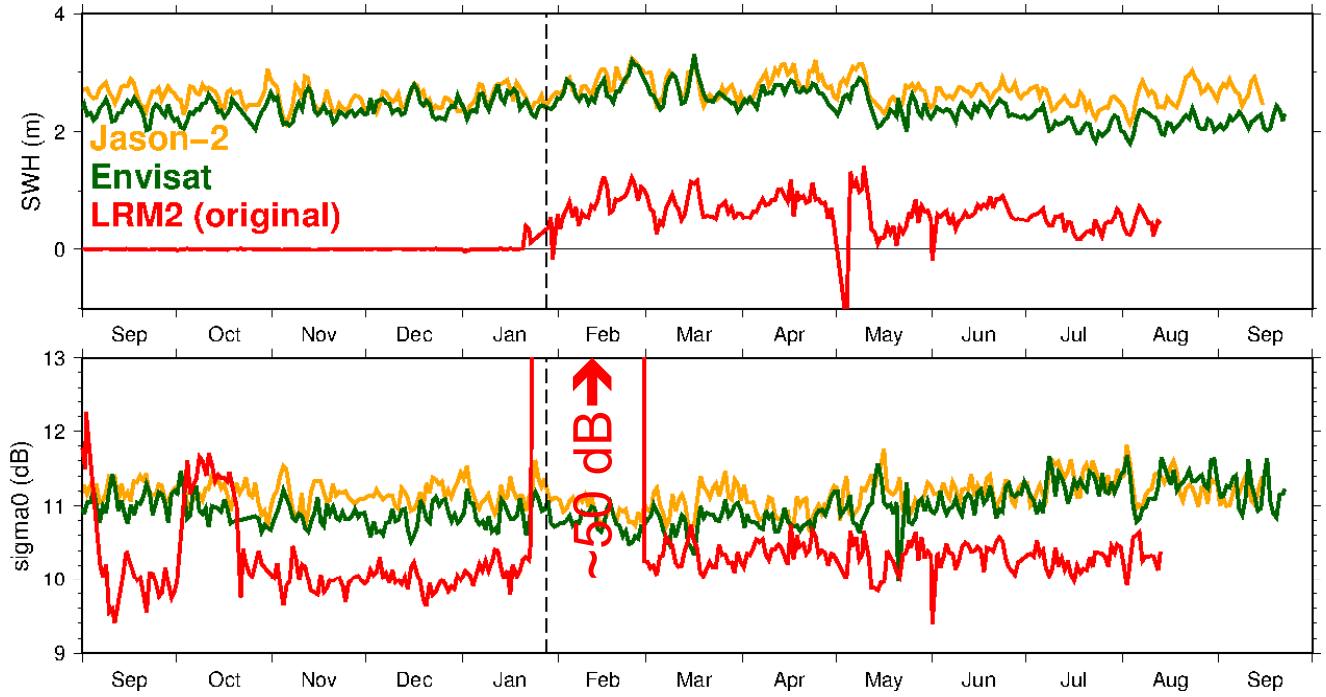
- **FDM** (Fast Delivery Mode) = < 1-day latency, DORIS DIODE or predicted orbit, predicted meteo & ancillary data.
- **LRM** = Final version, precise orbit, analyzed meteo, etc. (“GDR”).

Level L1b = Has waveform and geophysical corrections, but no derived quantities (range, SWH, backscatter) ➔ no sea surface height, wind speed, wave height, backscatter, etc.

Level 2 = No waveform; has geophysical corrections and derived quantities.

Why Retracking?

- Why not use Level 2?
  - FDM and LRM L2 data are seriously flawed, among others:
  - Significant Wave Height is zero, negative, or far too low.
  - Backscatter (and hence wind speed) is high where it should be low and vice versa; and for a month as high as 50 dB, instead of ~10 dB.

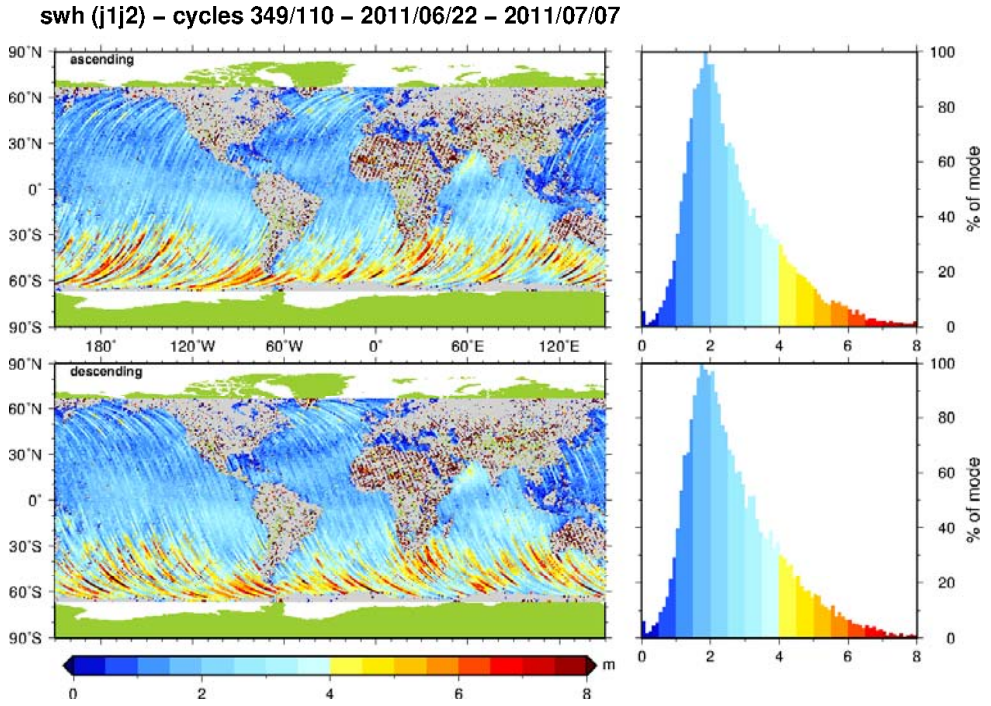


What Retracking?

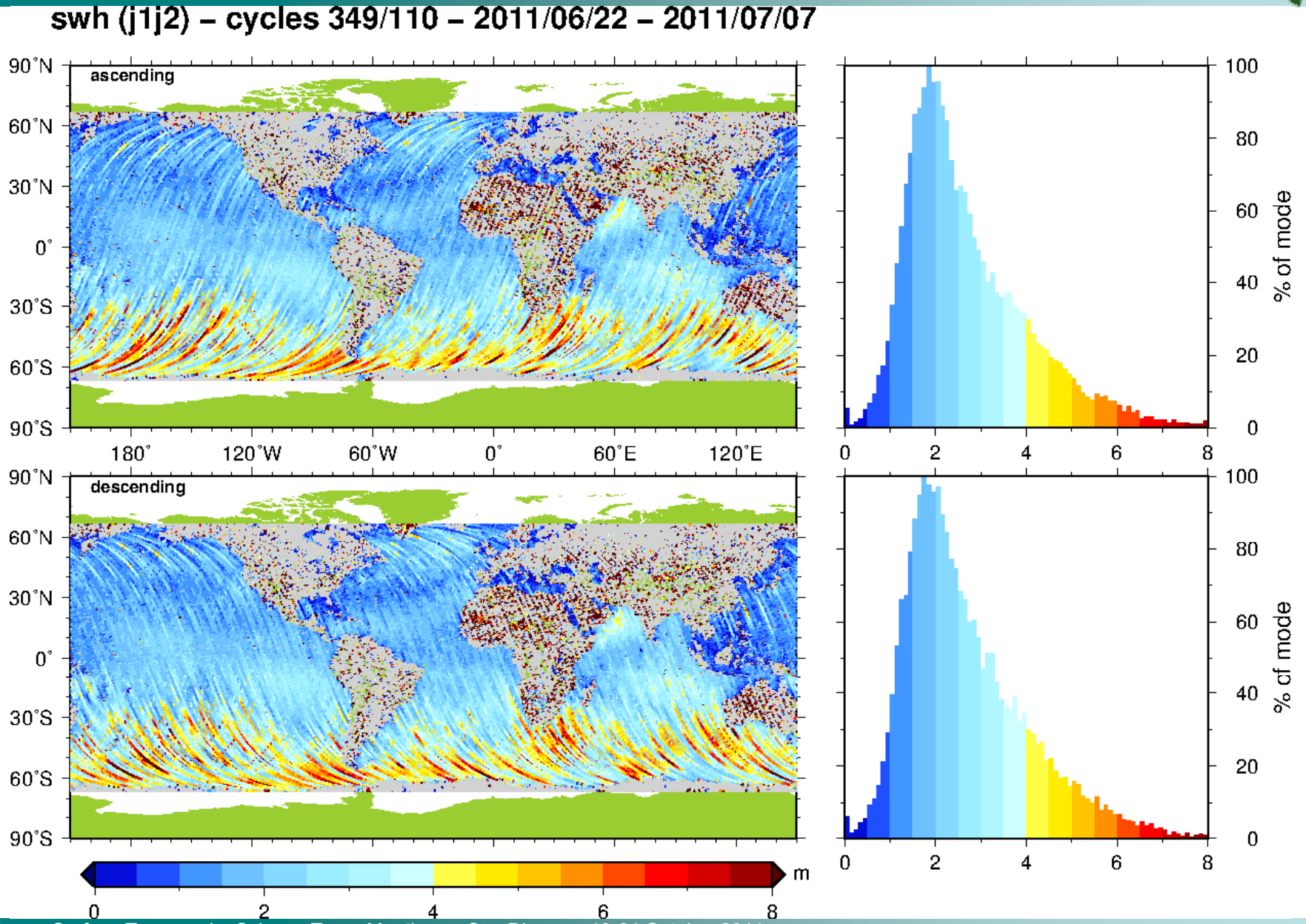
- Retrack Level 1 waveforms
  - Daily download FDM and LRM L1B data from ESA
  - Retrack waveforms to compute our own wave height, backscatter, range (MLE3-type retracker)
  - Takes approximately 1 minute per day of data
  - Merge data files (few to tens of minutes normally) into passes and subcycles of 29 days (à la GDR) in **RADS**
  - Use additional geophysical corrections from L1B
  - Overwrite and add common RADS geophysical corrections
    - **SSB** (that we determined ourselves)
    - Latest MSS models (DTU10, CNES-CLS11), geoid
    - Tides (FES2004, GOT4.9)
    - NCEP meteo, GPS and NIC iono, MOG2D IB
    - Off-line orbits from Delft, ESOC, CNES
  - Compute wind speed from backscatter (Abdalla)
  - Compute sea level anomalies from orbit - range - corrections

Results and Validation

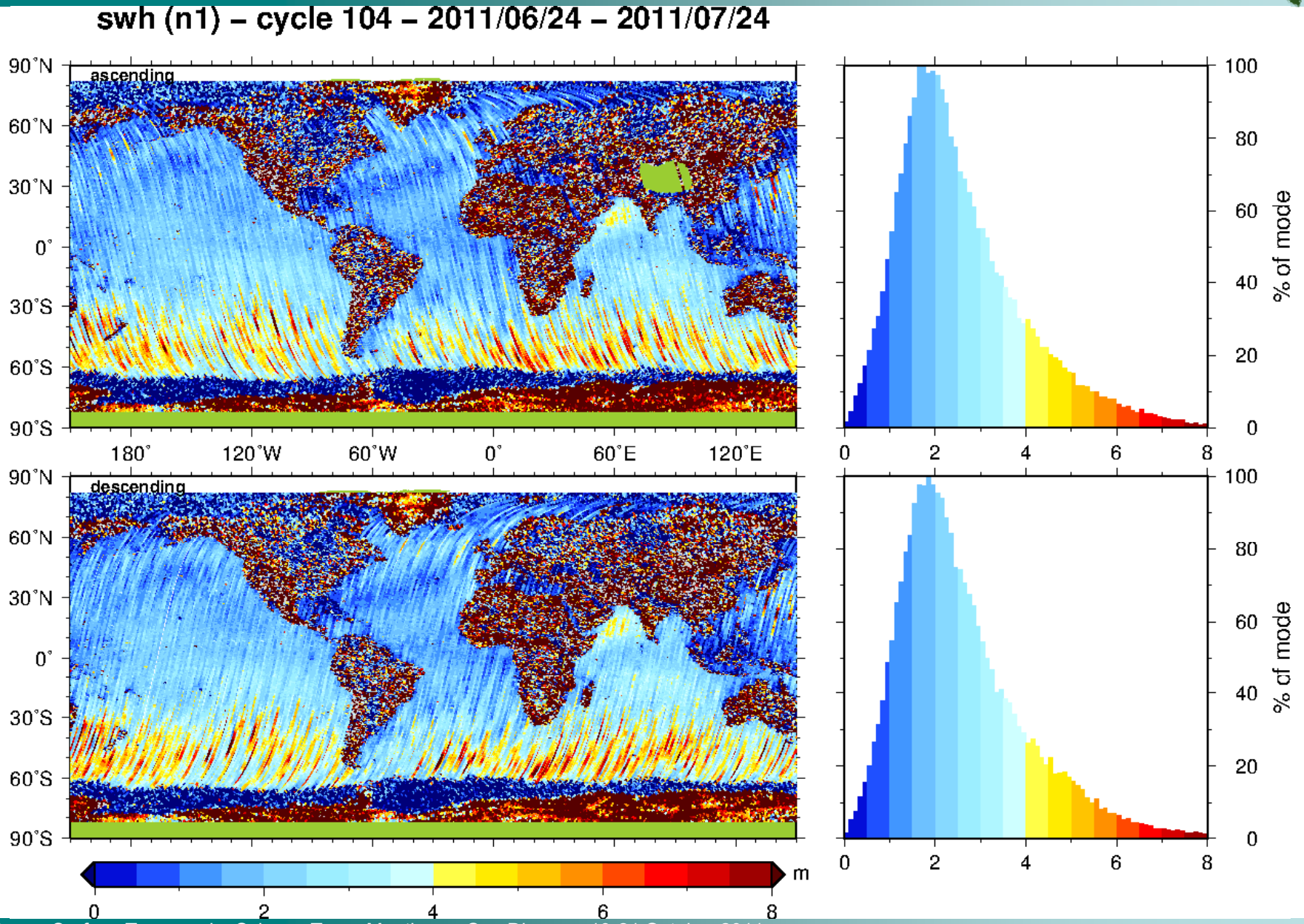
- Cycle maps
  - All data (ocean and land)
  - Ascending and descending separately
  - Two overlapping cycles of Jason-1 and -2 (15 days total)
  - One cycle of Envisat (30 days)
  - One subcycle of CryoSat (29 days)
- Histograms
  - “Good” ocean data only
  - Normalised by mode



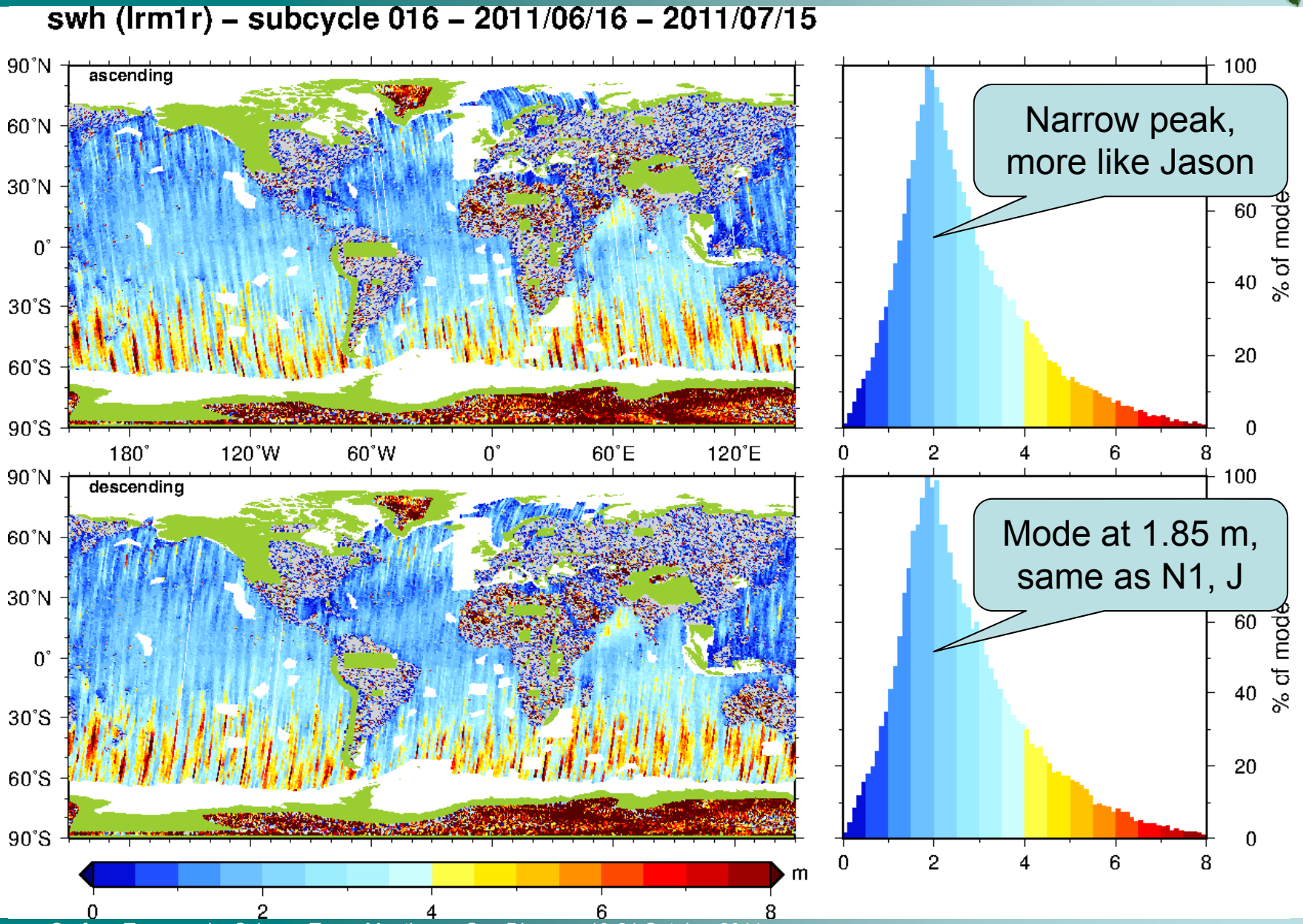
Jason – Significant Wave Height



Envisat – Significant Wave Height

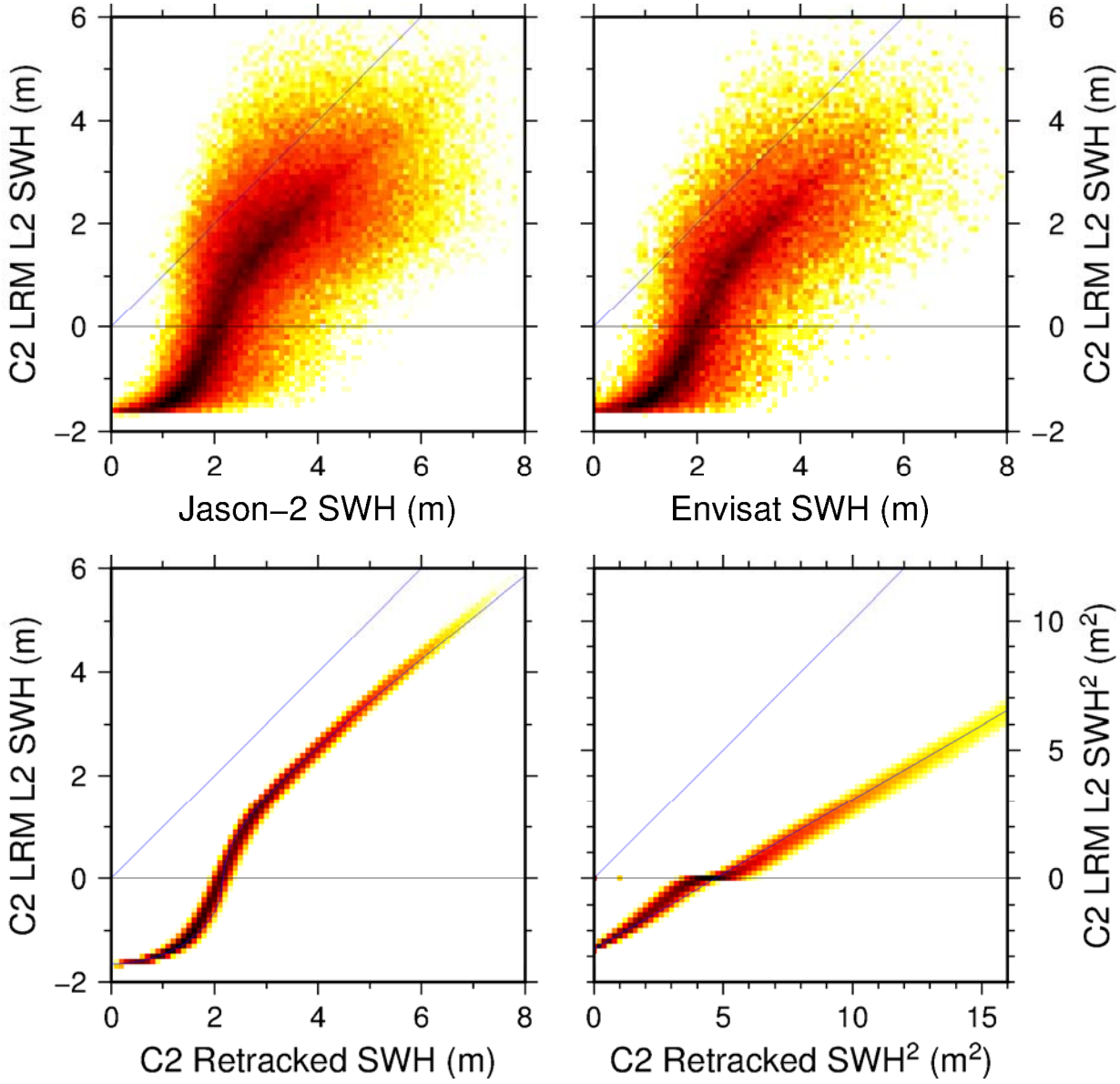


CryoSat L1b – Significant Wave Height



SWH in CryoSat Level 2

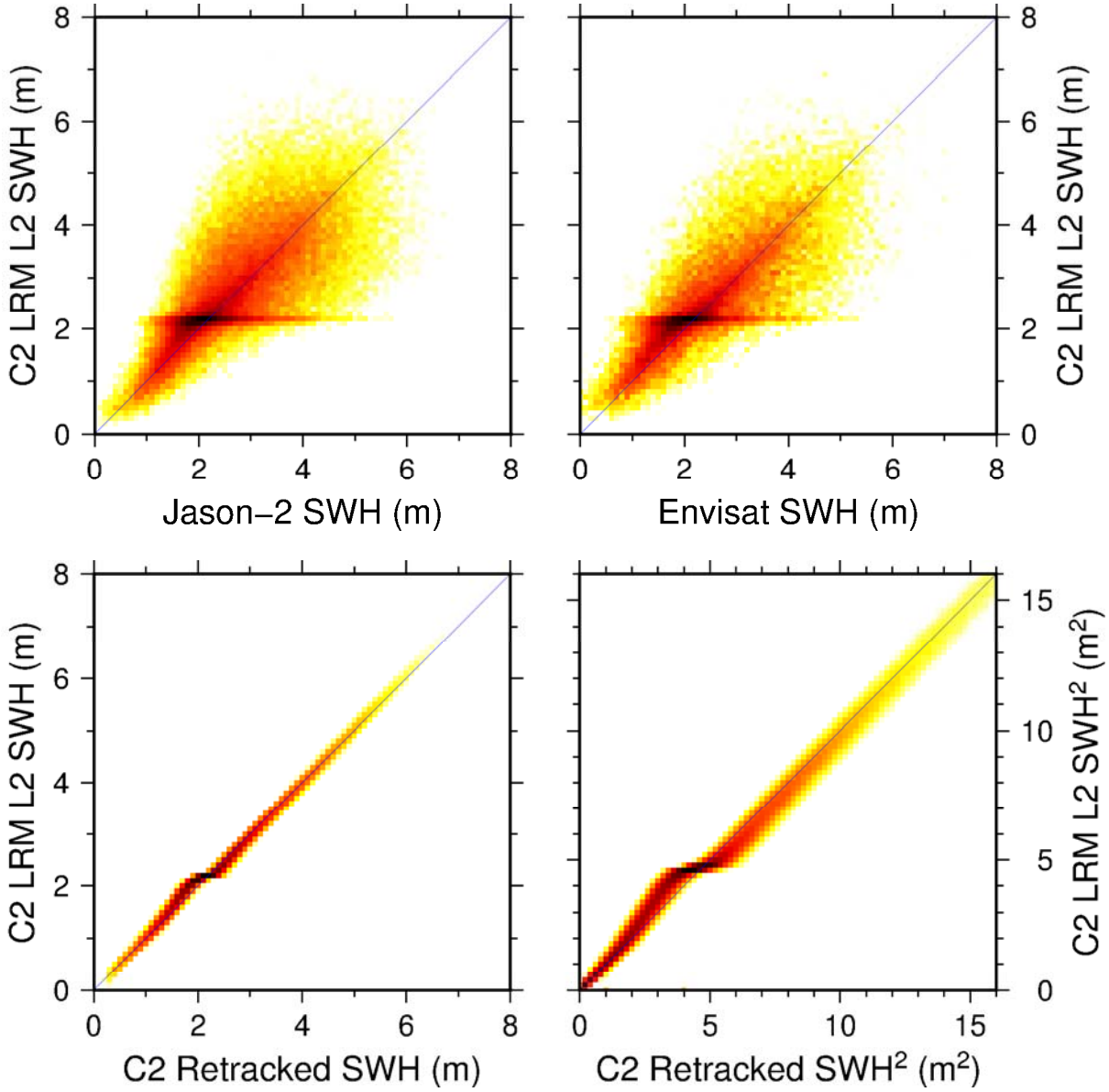
- Comparison with J2, N1 and retracking
  - **Negative** at low wave height: $-\sqrt{(-SWH^2)}$
  - Thanks ESA for keeping negative SWH!
  - **Too low** at high wave height
  - **Trend** in SWH^2 comparison



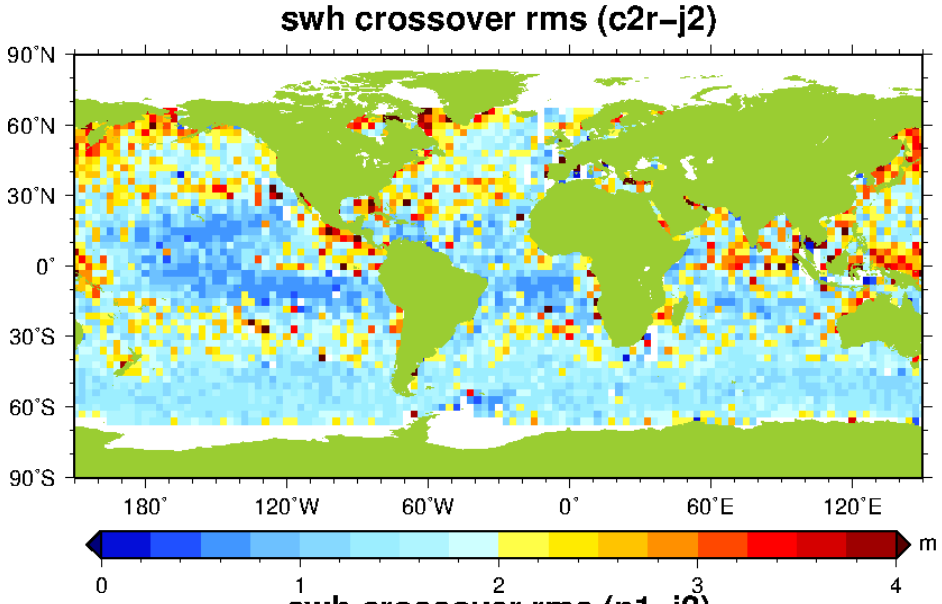
SWH in CryoSat Level 2

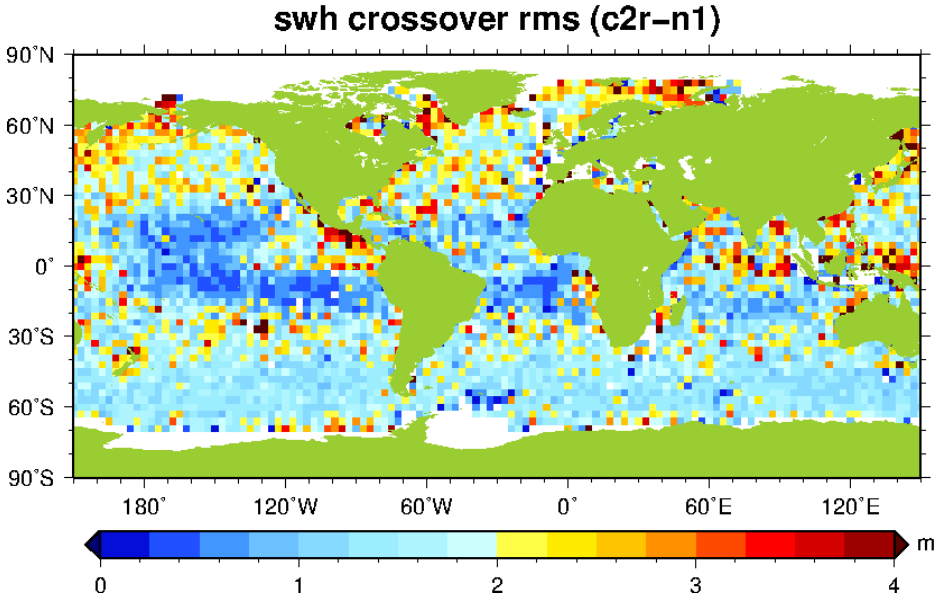
- After undoing trend in SWH^2
  - **SWH** lines up better
  - **Discontinuity** where SWH used to be 0
  - **Trend** correction:

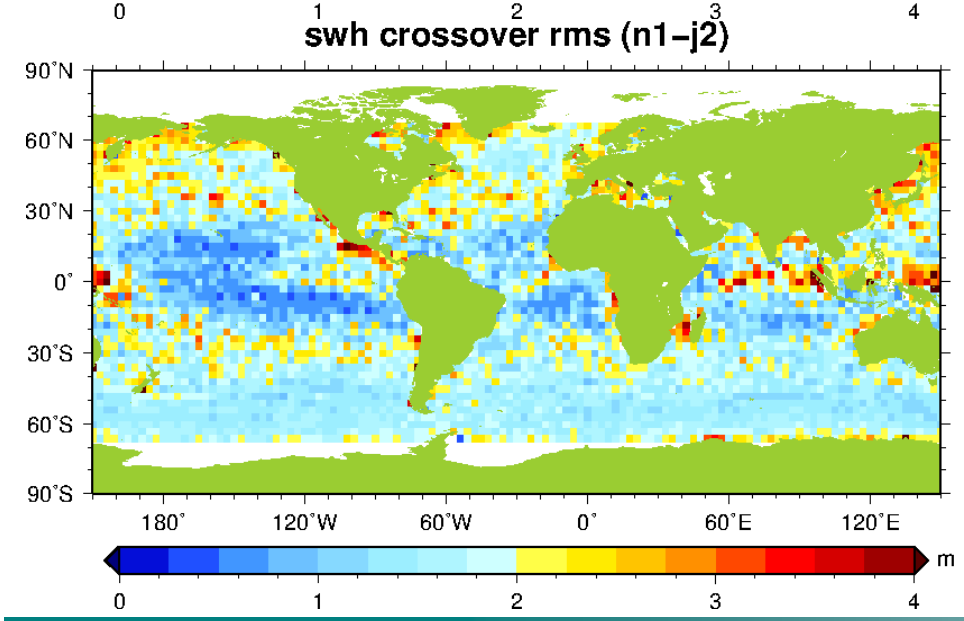
$SWH^2 := (SWH^2 + 2.7124) / 0.5777$



SWH Crossover Comparisons

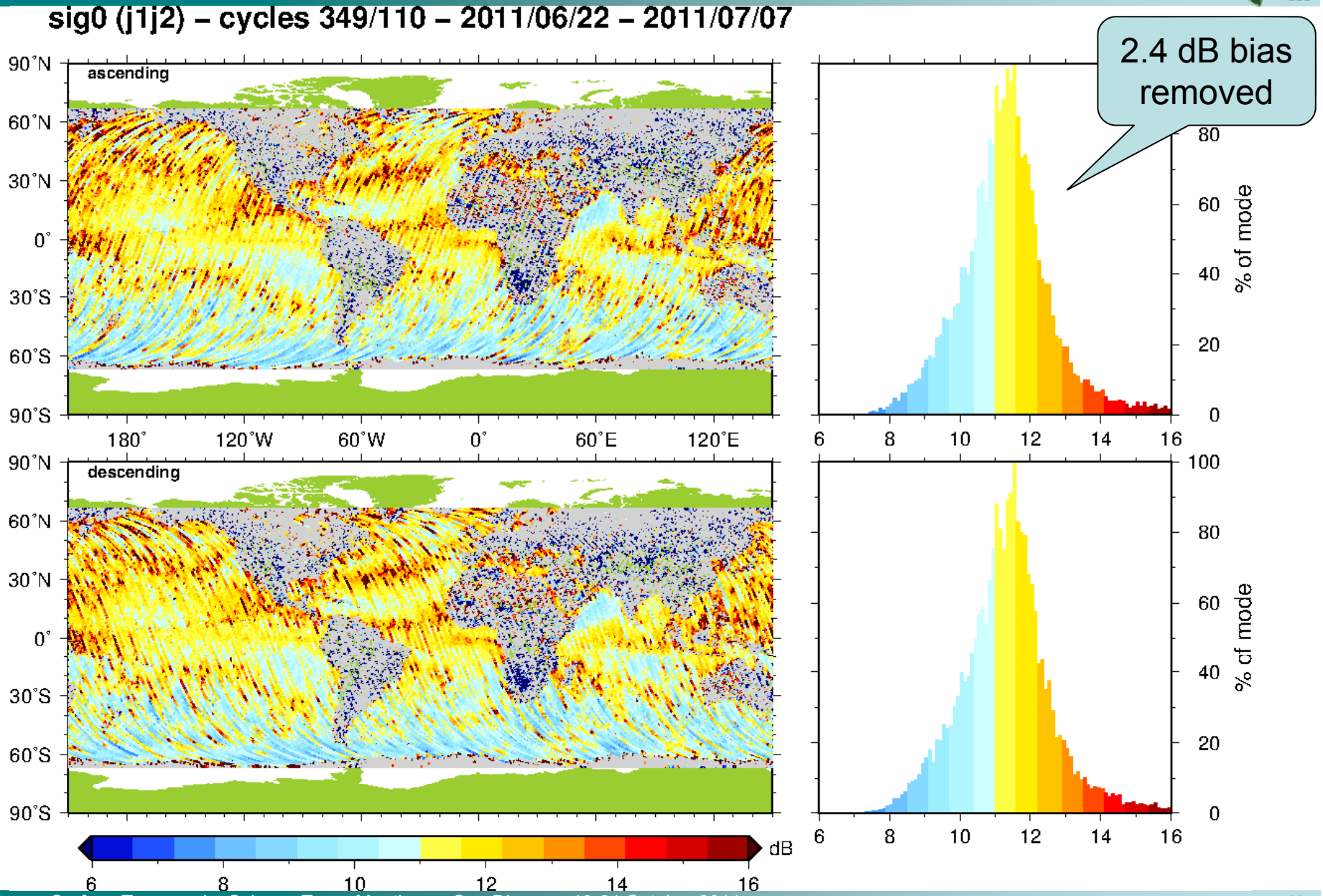




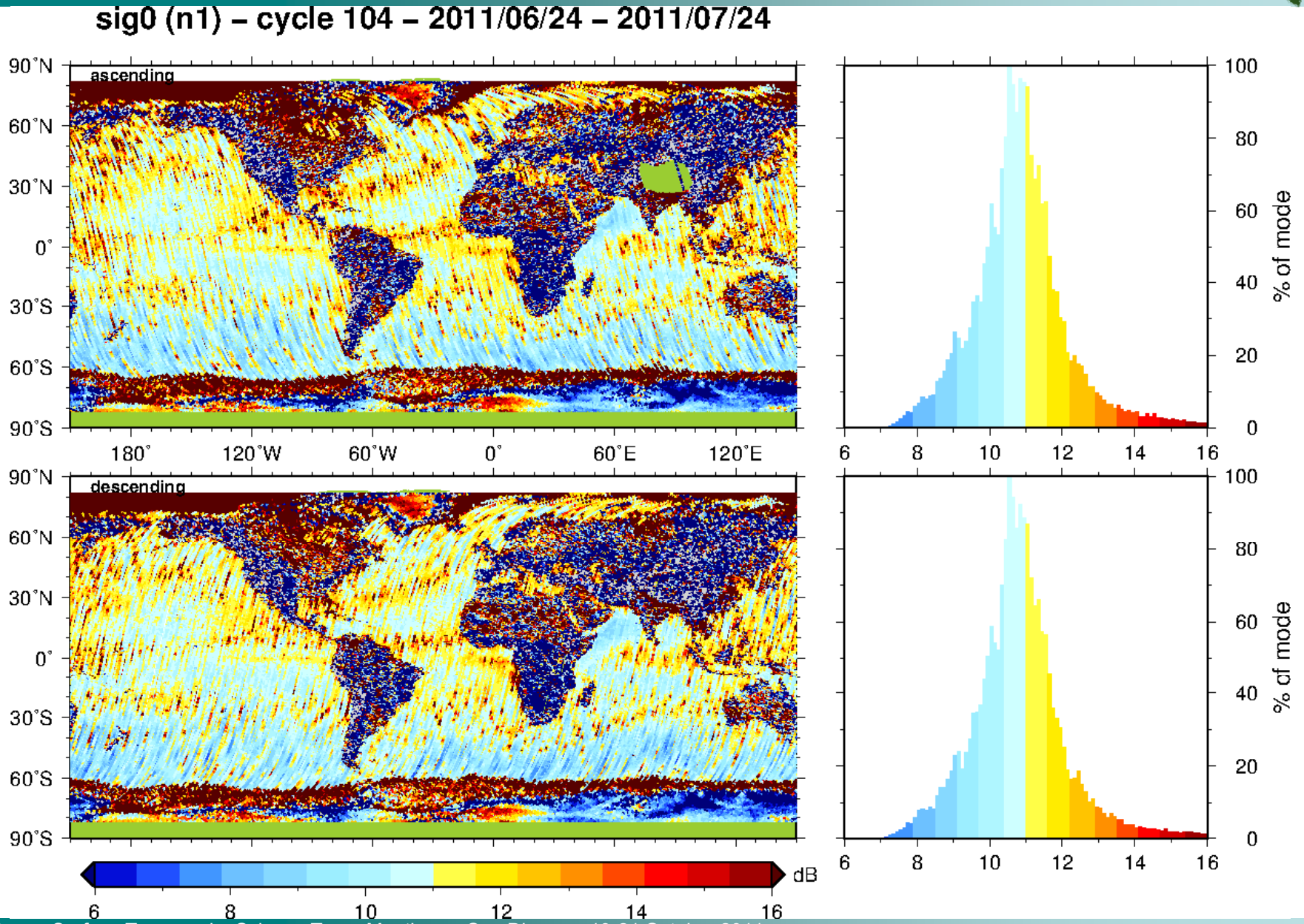


SWH (m)	Mean	Std
LRM1R – Envisat	+0.110	1.180
LRM2F – Envisat	+0.087	1.171
LRM1R – Jason-2	+0.101	1.250
LRM2F – Jason-2	+0.071	1.243
Envisat – Jason-2	–0.006	1.266

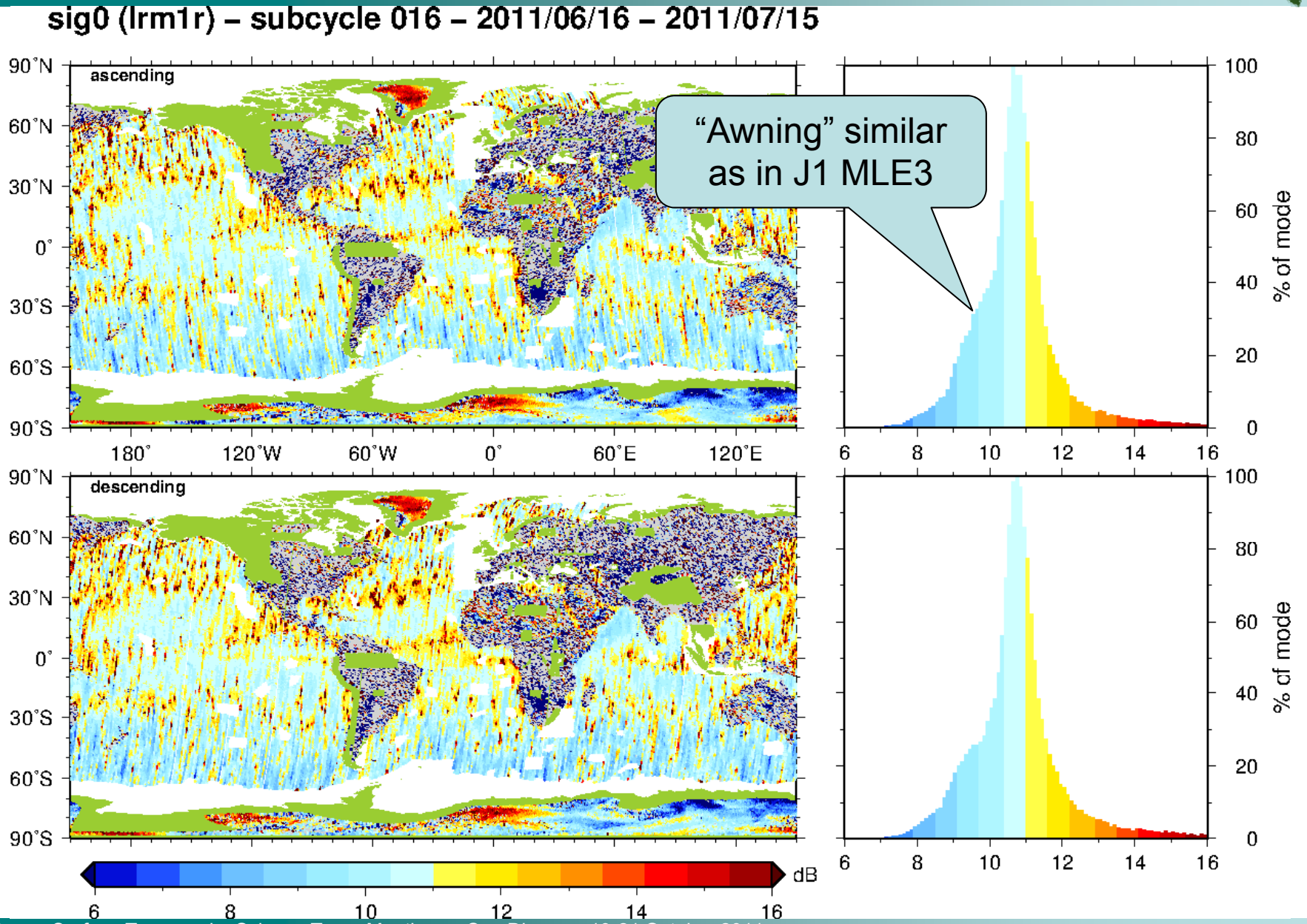
Jason – Backscatter



Envisat – Backscatter

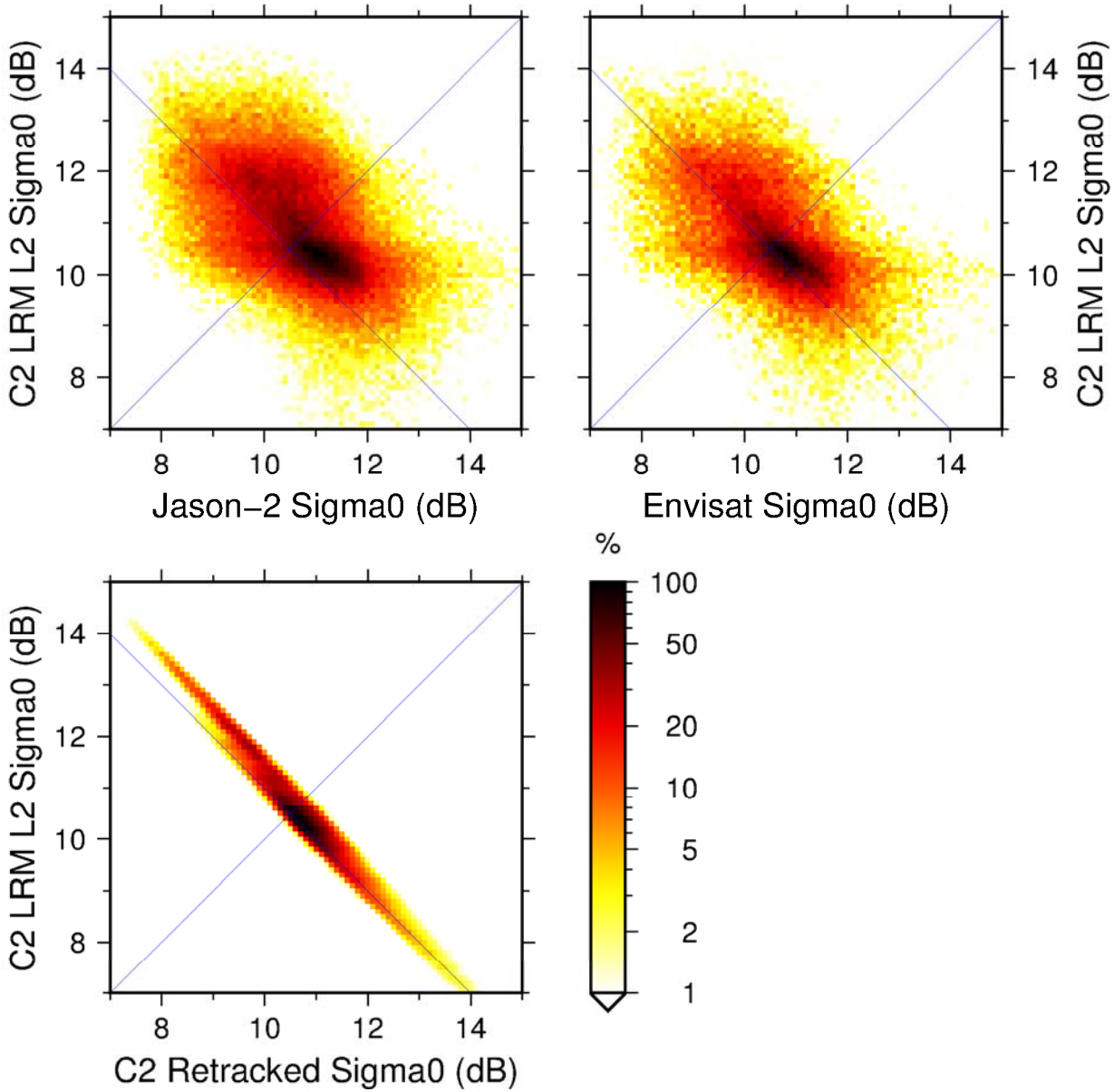


CryoSat L1b – Backscatter



Backscatter in Level 2

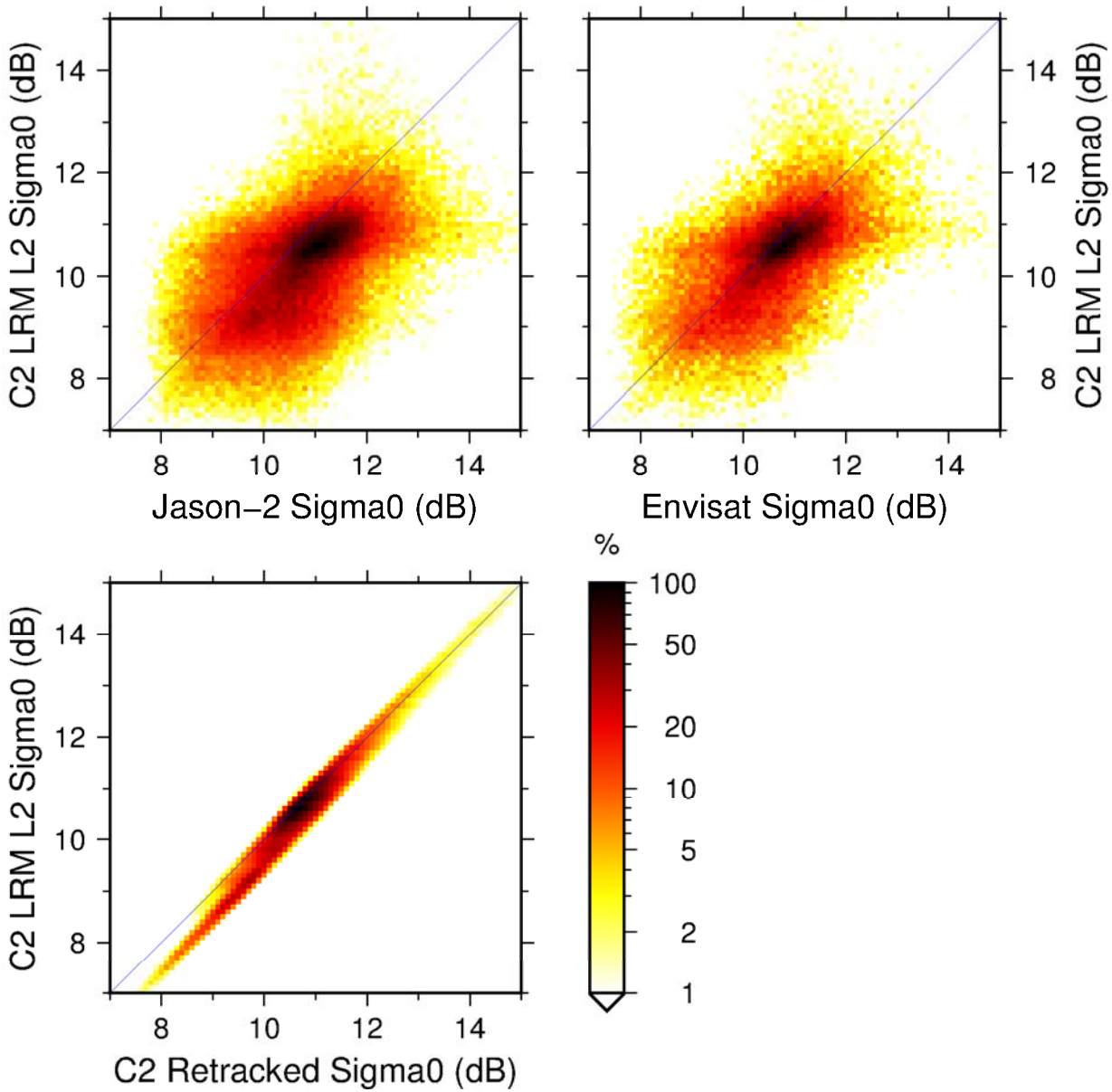
- Comparison with J2, N1 and retracking
  - **Trend** is 1 : –1 instead of 1 : 1
  - **Offset** of 21 dB



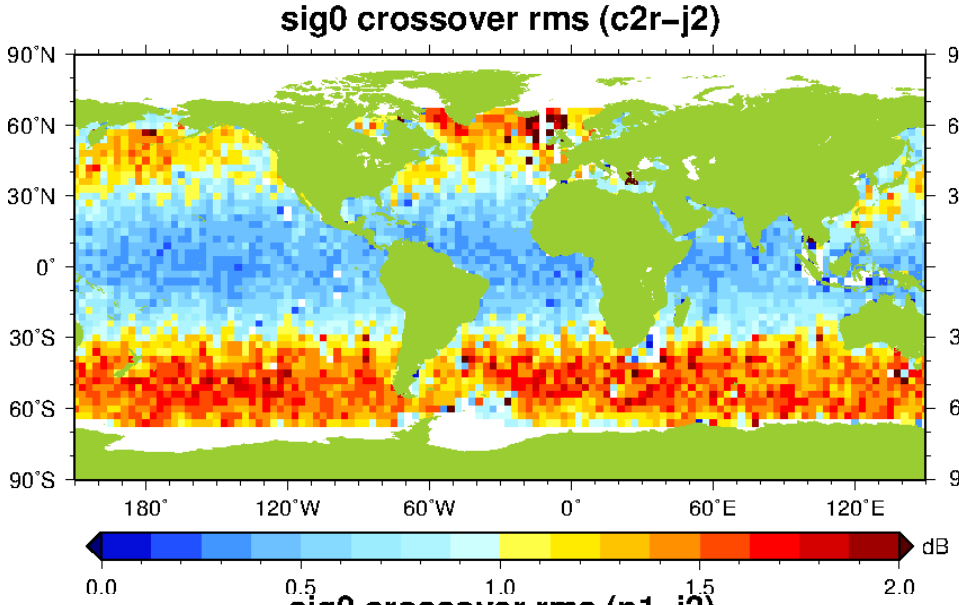
Backscatter in Level 2

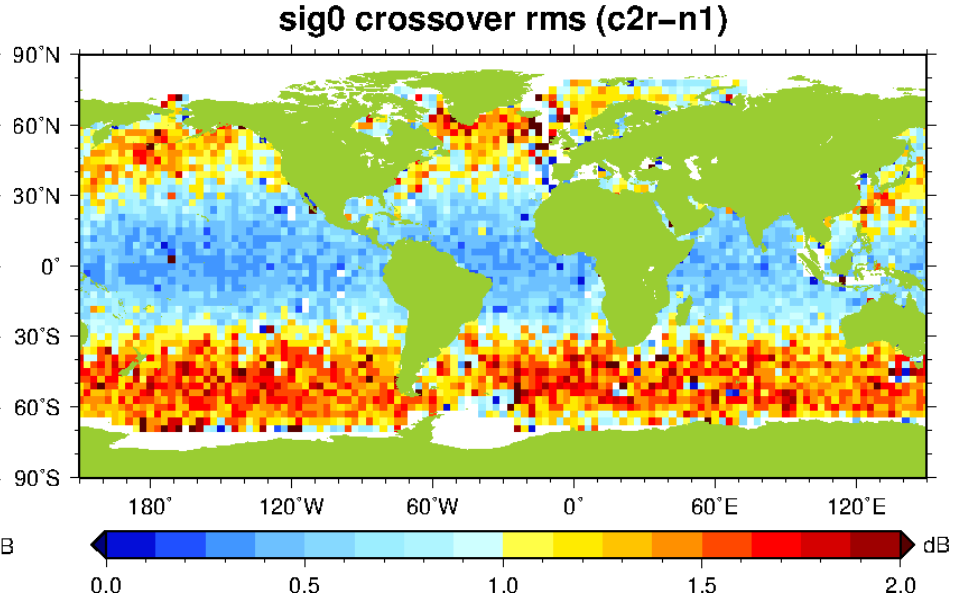
- After undoing trend in backscatter
  - **Backscatter** lines up better
  - **Discontinuity** where SWH used to be 0
  - **Trend** correction:

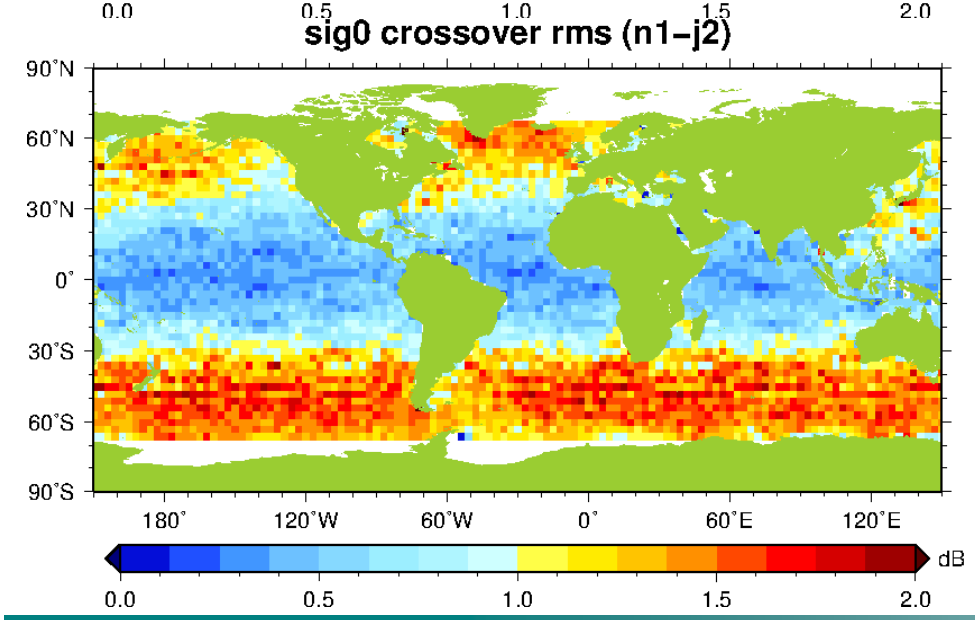
sigma0 :=
21 – sigma0



Backscatter Crossover Comparisons

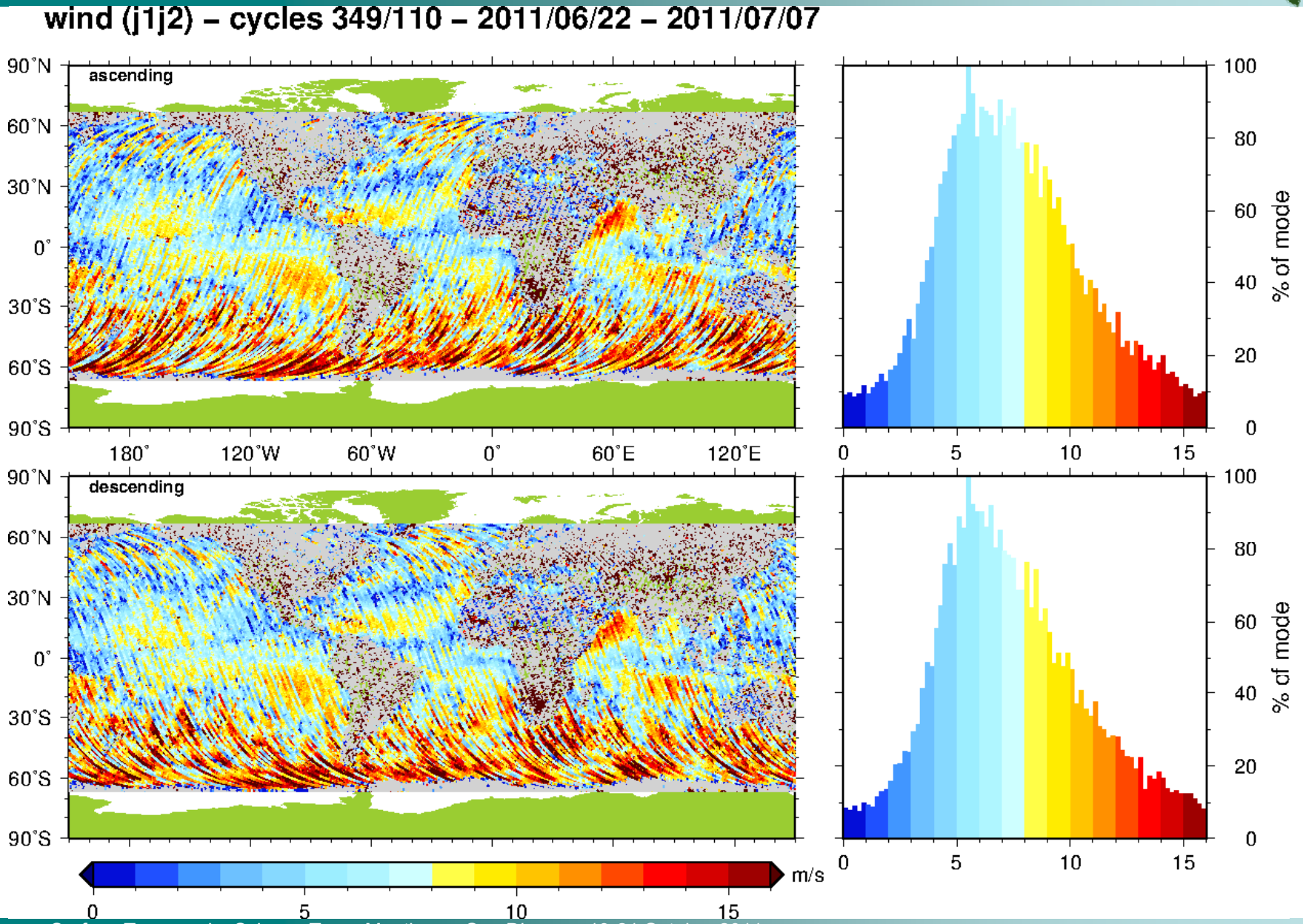




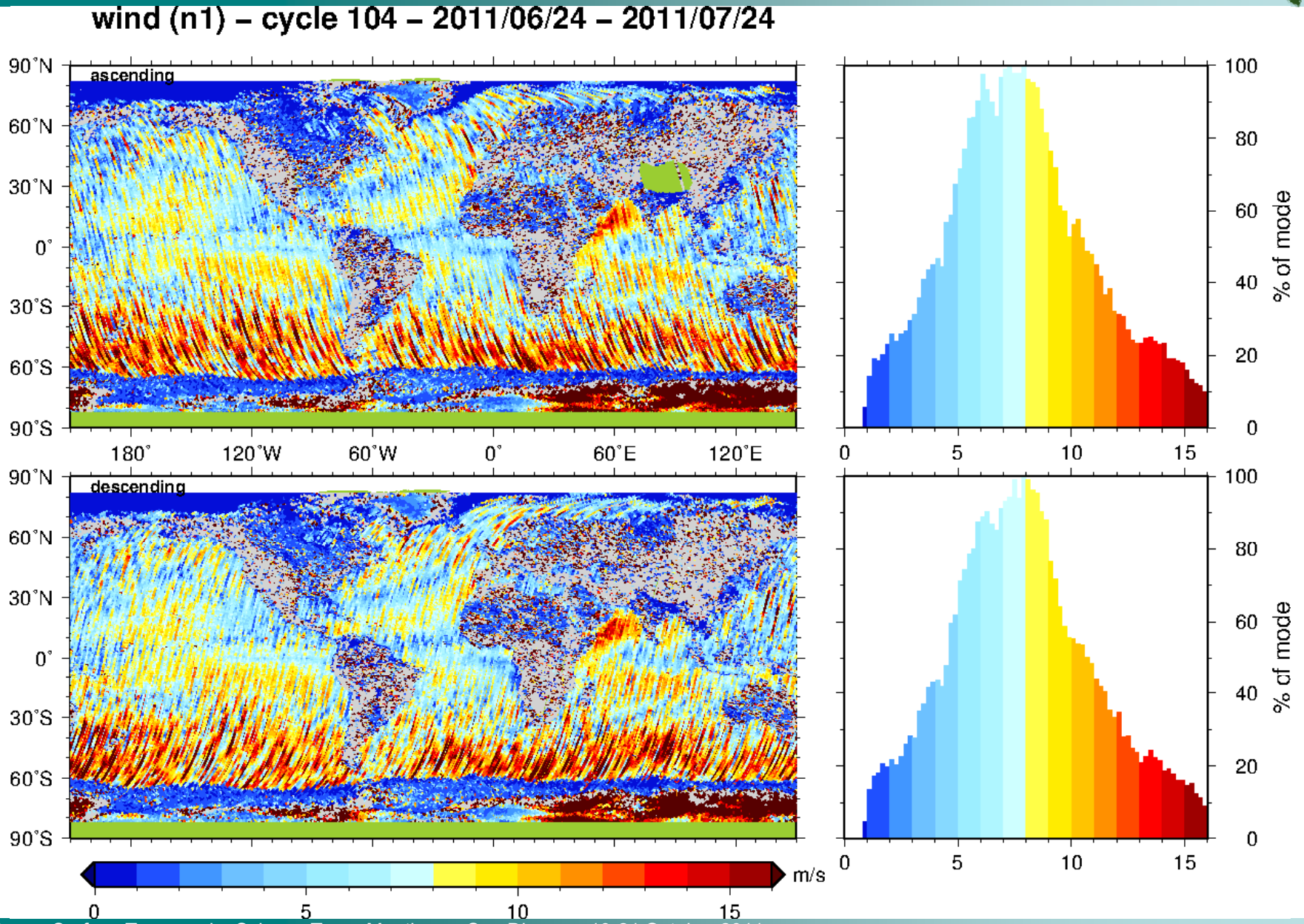


Backscatter (dB)	Mean	Std
LRM1R – Envisat	–0.014	1.875
LRM2F – Envisat	–0.213	1.907
LRM1R – Jason-2	–0.282	1.789
LRM2F – Jason-2	–0.535	1.826
Envisat – Jason-2	–0.301	1.784

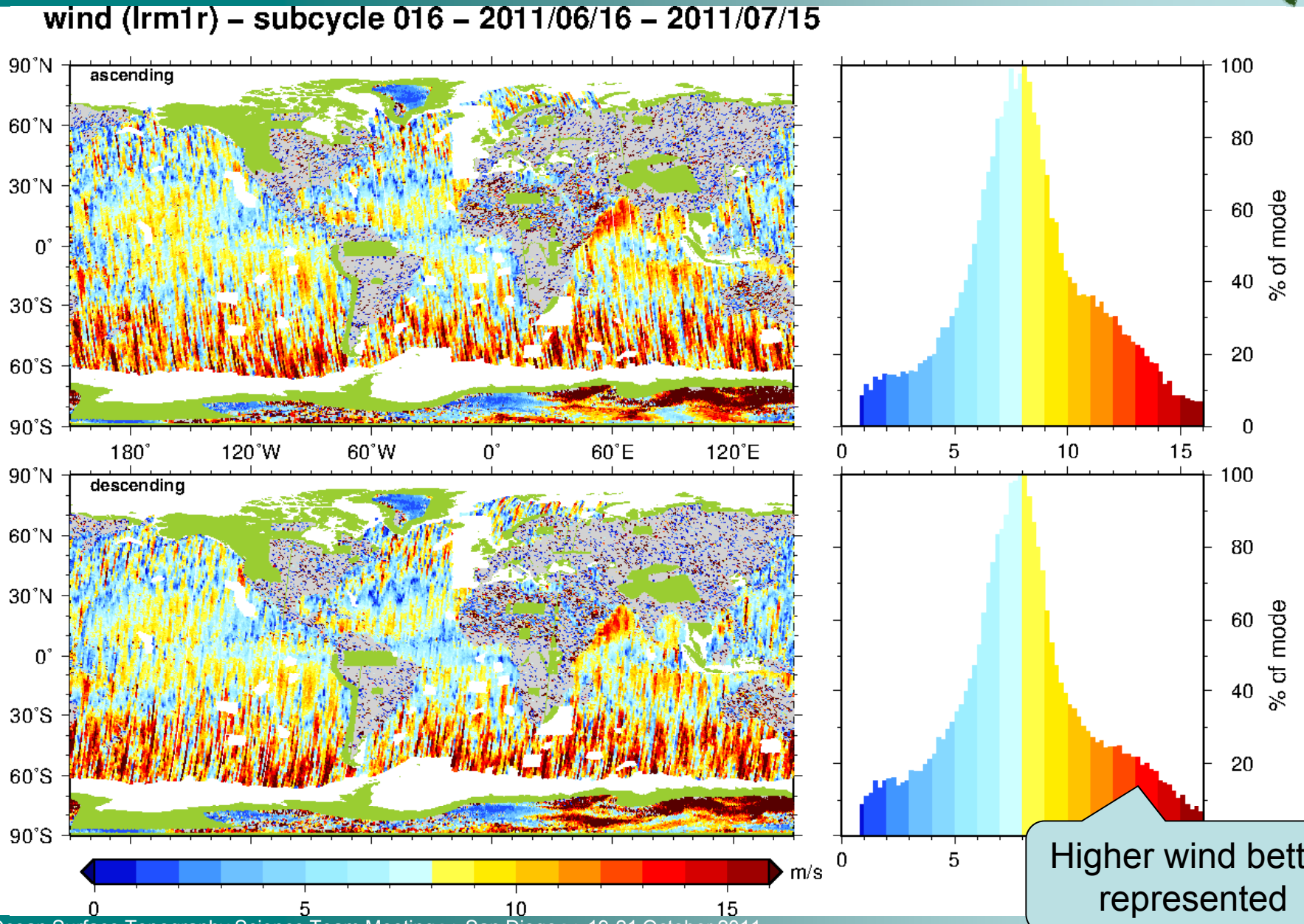
Jason – Wind Speed (Collard)



Envisat – Wind Speed (Abdalla)



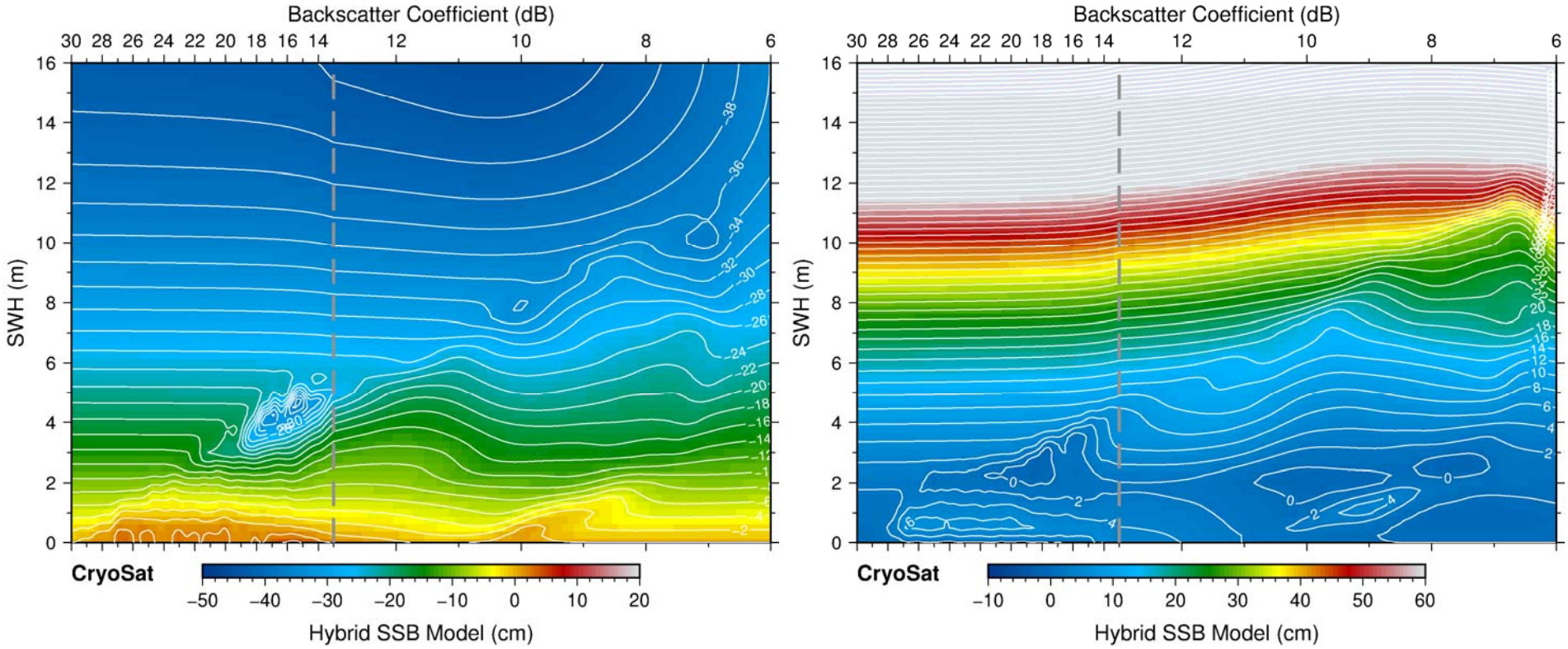
CryoSat L1b – Wind Speed (Abdalla)



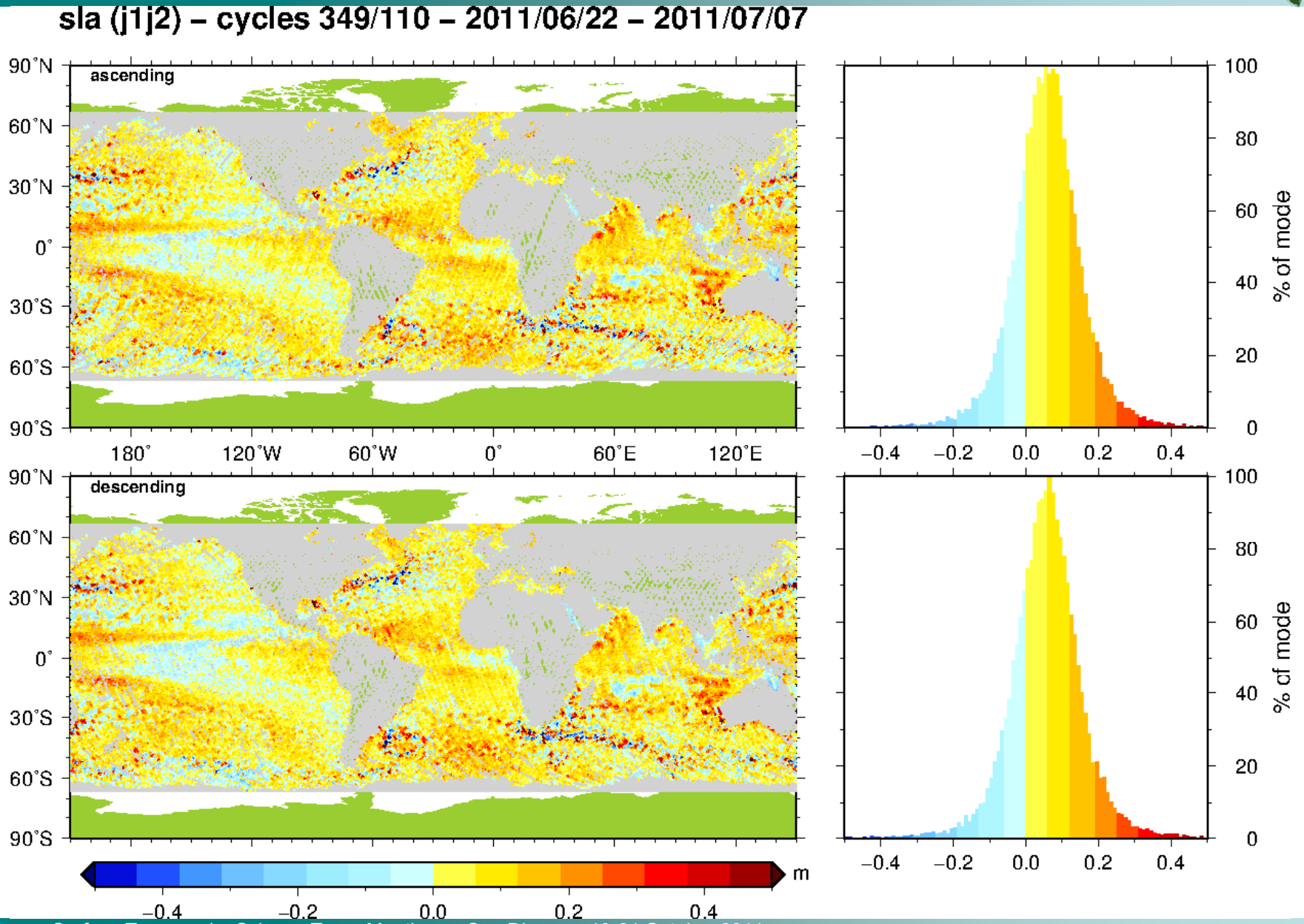
Higher wind better represented

Hybrid Sea State Bias Model

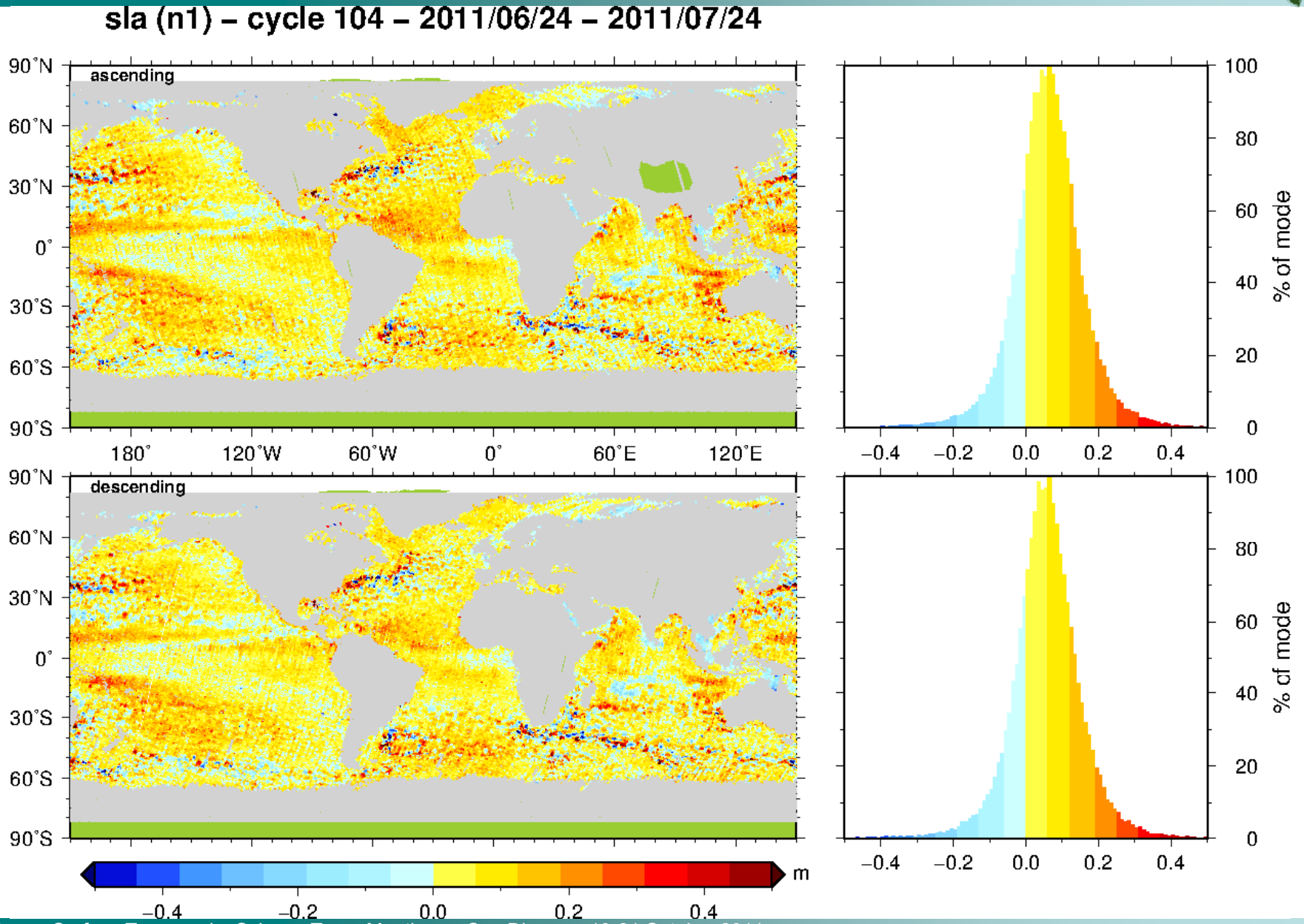
- Direct method, enhanced
  - Sea level anomalies gridded in sigma0-SWH space
  - Fit BM4 model: SSB = [a_0 +] SWH (a_1 + a_2 SWH + a_3 U + a_4 U^2)
  - Blend in residuals
  - L1B Retracked (~ –3.5% SWH) L2 has “wrong” sign! (but works)



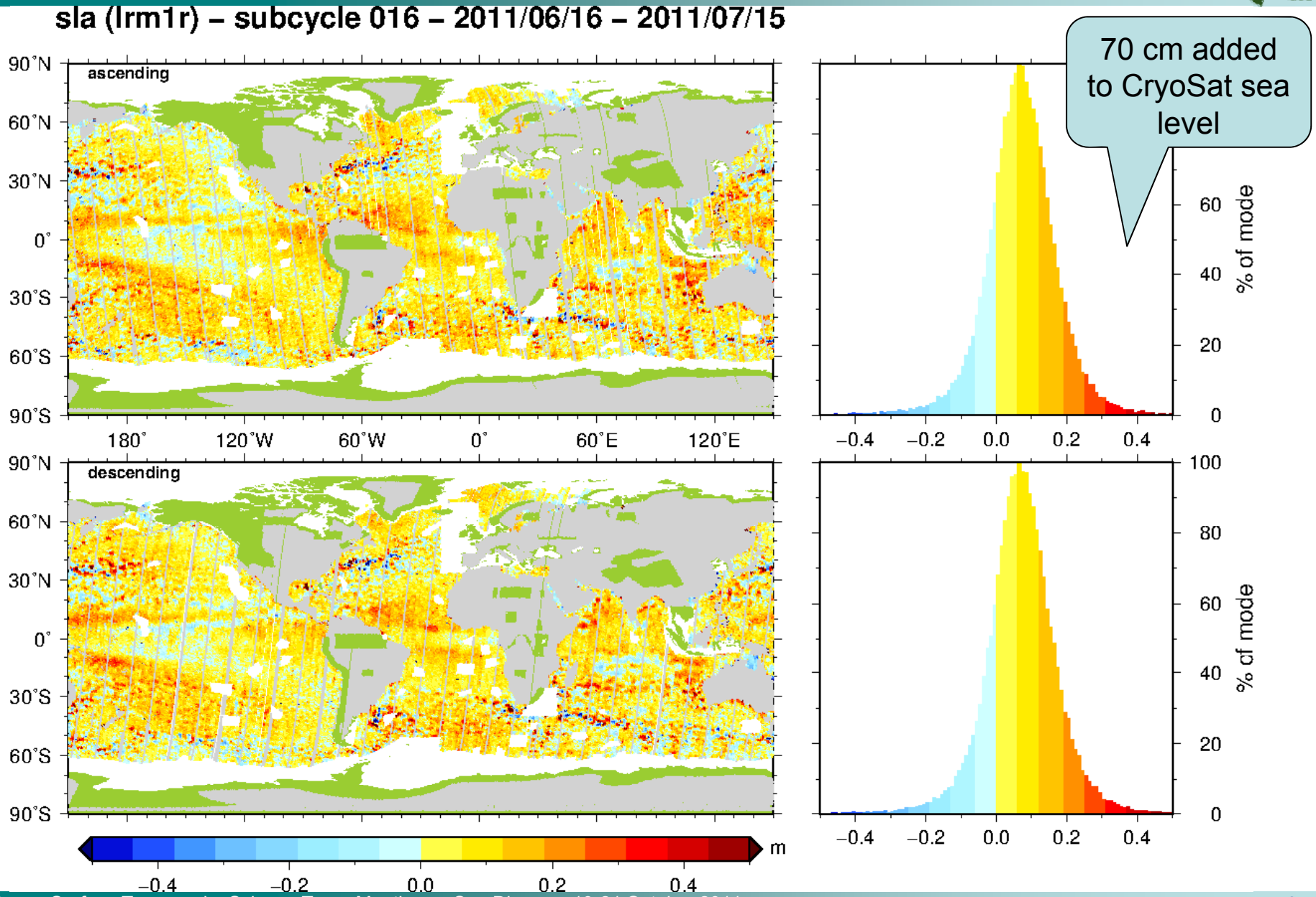
Jason – Sea Level Anomaly



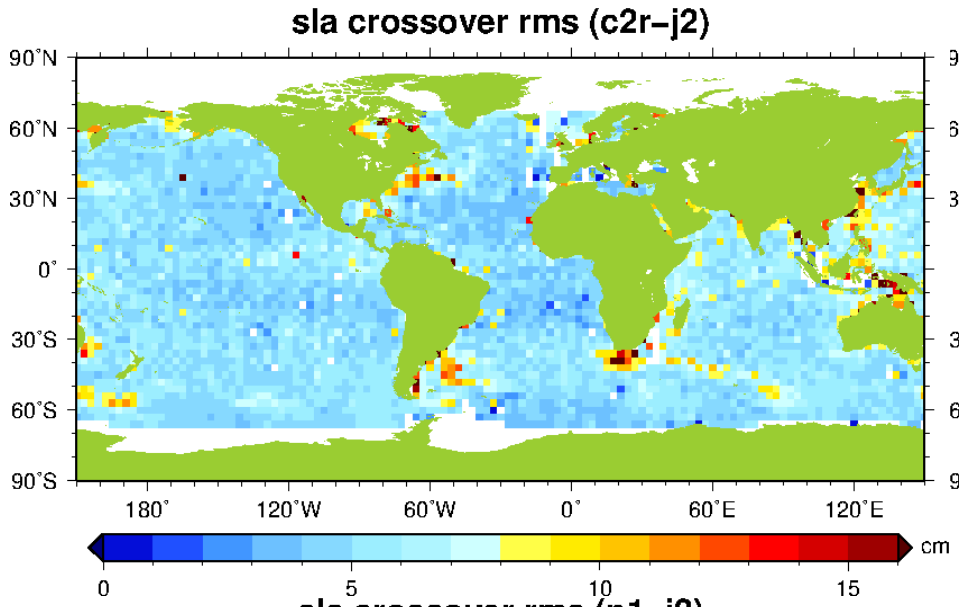
Envisat – Sea Level Anomaly

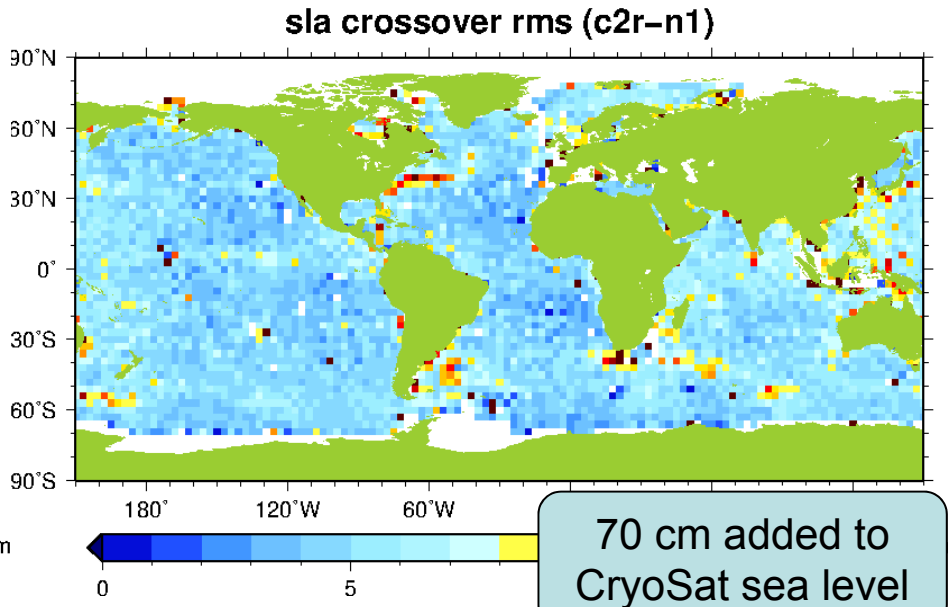


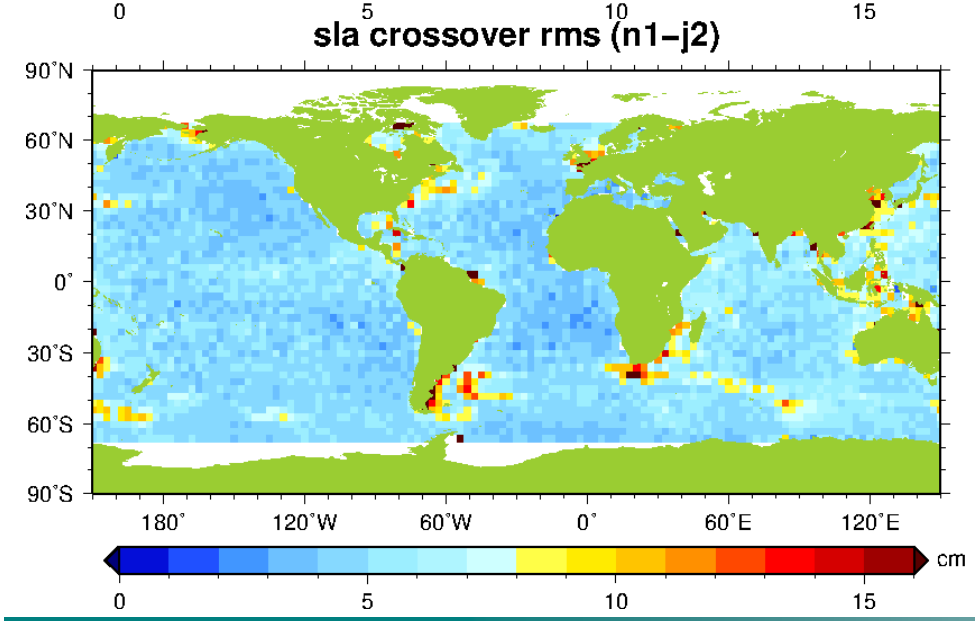
CryoSat – Sea Level Anomaly



Sea Level Crossover Comparisons







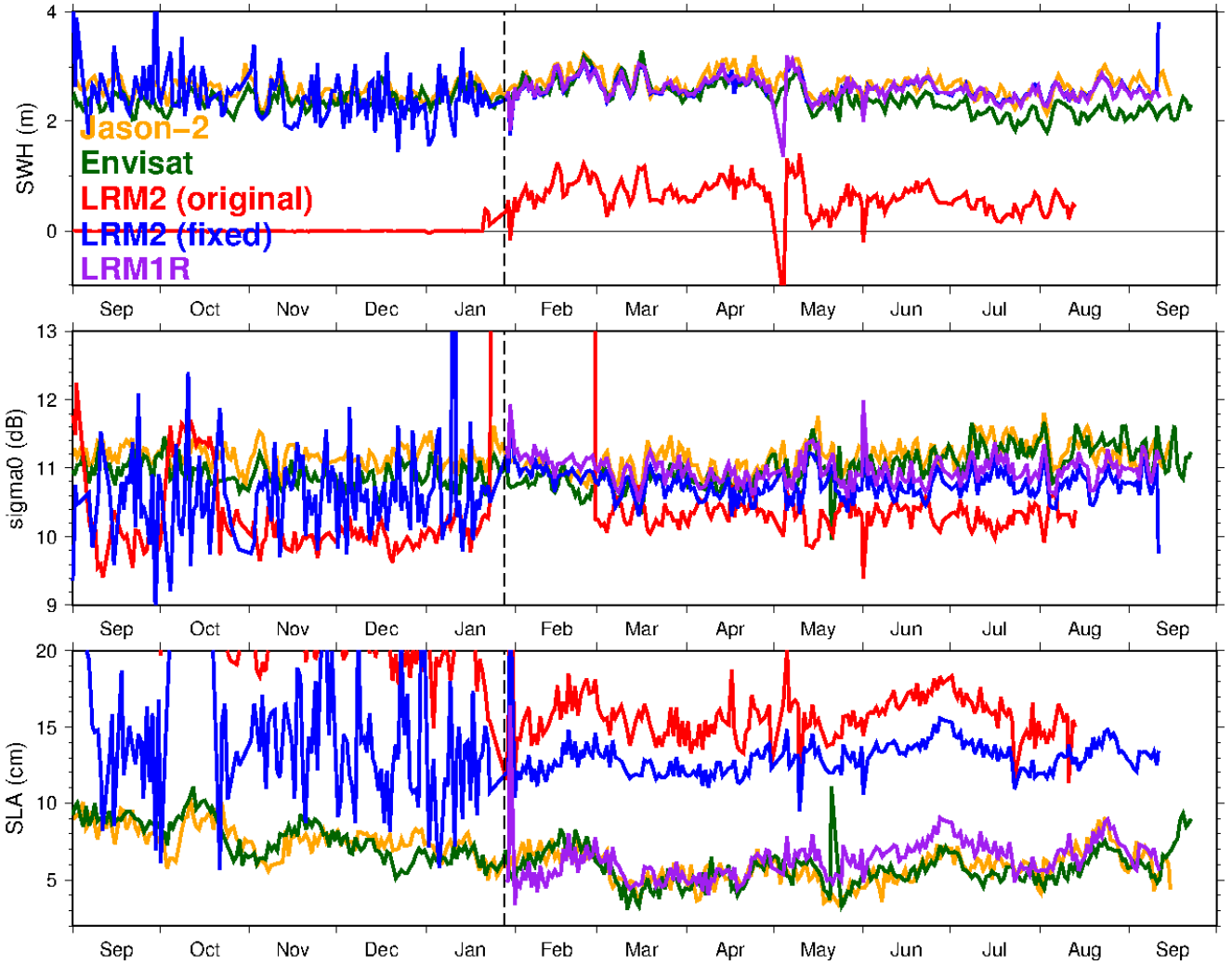
70 cm added to CryoSat sea level

Sea level (m)	Mean	Std
LRM1R – Envisat	+0.29	5.49
LRM2F – Envisat	+7.18	5.36
LRM1R – Jason-2	+0.07	5.56
LRM2F – Jason-2	+6.97	5.44
Envisat – Jason-2	–0.28	5.37

Time Series of Means

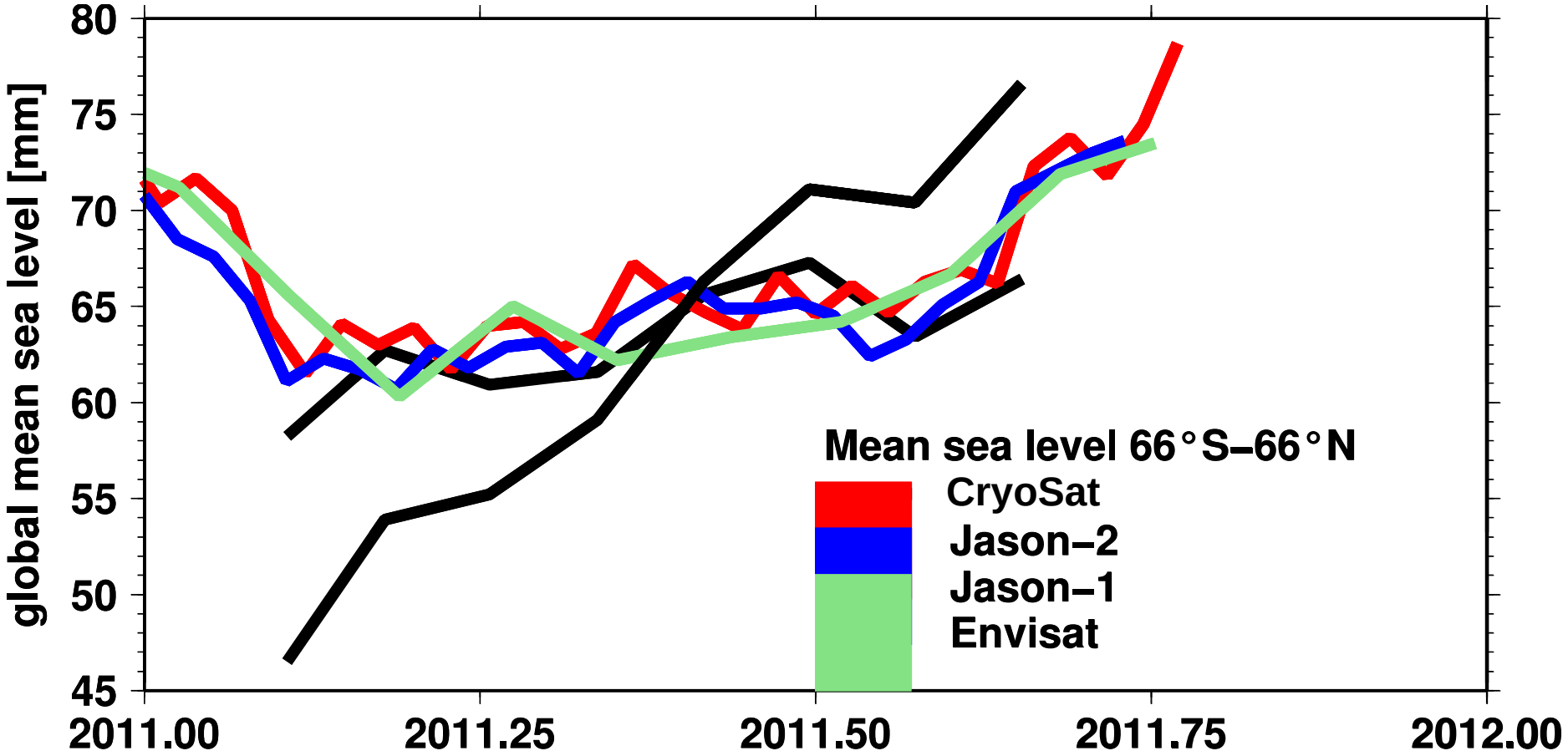
Improved

- Since 28 Jan
- Level 2 now close to Level 1B retracked
- Except bias of about 7.5 cm in range
- Slightly high sea level trend
- Probably due to missing USO correction



CryoSat-2 Mean Sea Level

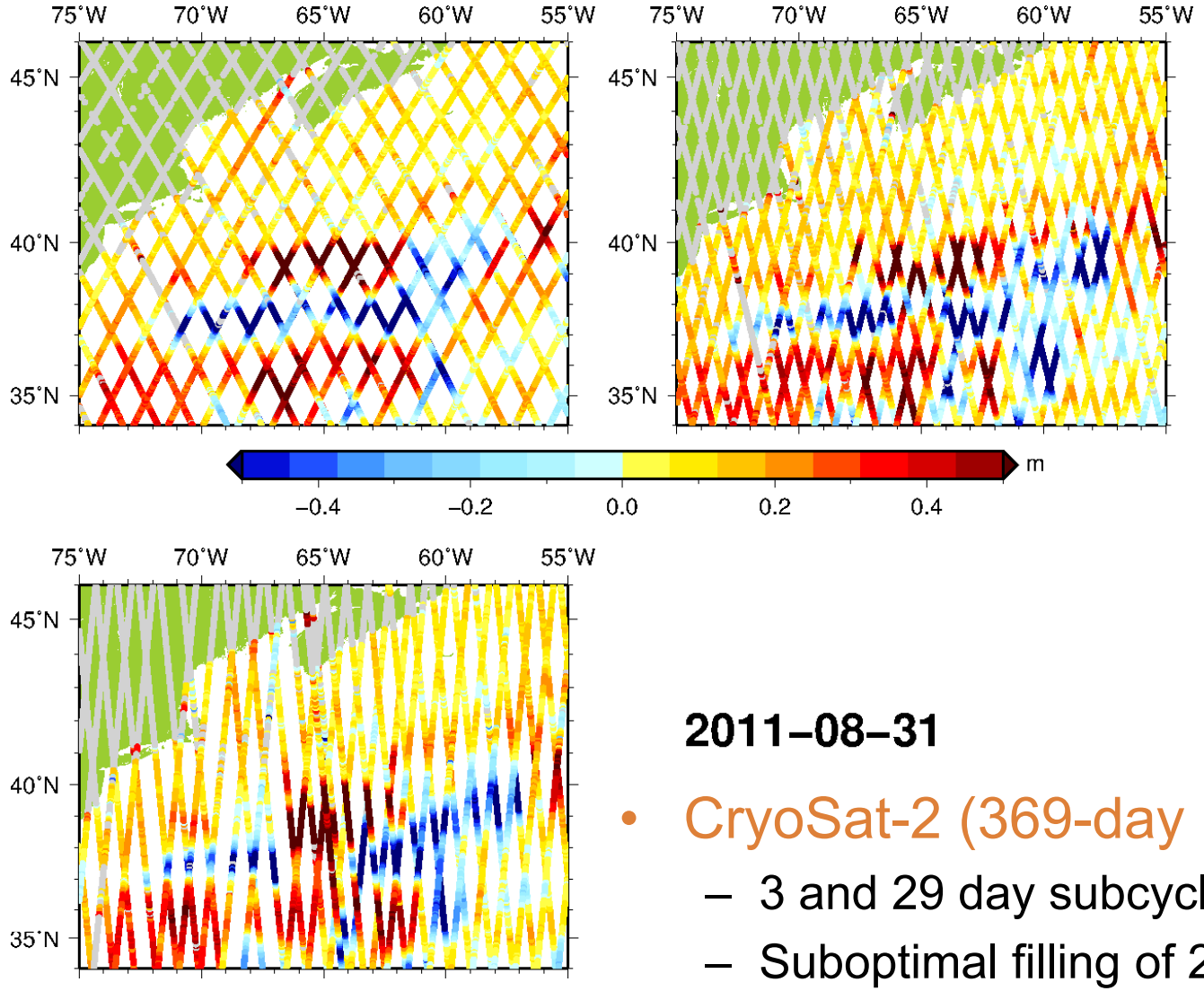
Seven months of mean sea level from CS show a significant drift (~40 mm/year) compared to J1, J2, and Envisat.



Recipe to Upgrade LRM Level 2

- Backscatter
  - Make sigma0 = 21 – sigma0
- Wave height
  - Determine SWH^2 = sign(SWH) * SWH^2
  - Make SWH^2 = (SWH^2 + 2.7124) / 0.5777
  - Take square root.
- Sea state bias
  - Interpolate our hybrid model.
- Final CNES orbit
  - We get a bit better results when interpolating the POE orbit ourselves. Also need to fix 8.2 ms timing bias.
- Geophysical corrections
  - Have not validated all geophysical corrections.

Coastal Coverage



2011–08–31

- CryoSat-2 (369-day repeat)
  - 3 and 29 day subcycle
  - Suboptimal filling of 29-day pattern

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.
  - 20-Hz noise is around 6 cm RMS.
  - Crossovers with Jason-2 shows accuracy slightly better than Envisat.
- LRM Level 2 data
  - Backscatter and SWH need to be adjusted
  - New SSB model applied
  - Orbits need to be reinterpolated
  - After that, L2 data is comparable accuracy to retracked data
- To RADS
  - NOAA is ready to distribute both products through RADS, pending approval by ESA.