Retracking range, SWH, sigma-naught, and attitude in CryoSat conventional ocean data

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Special thanks to M. Fornari & R. Cullen

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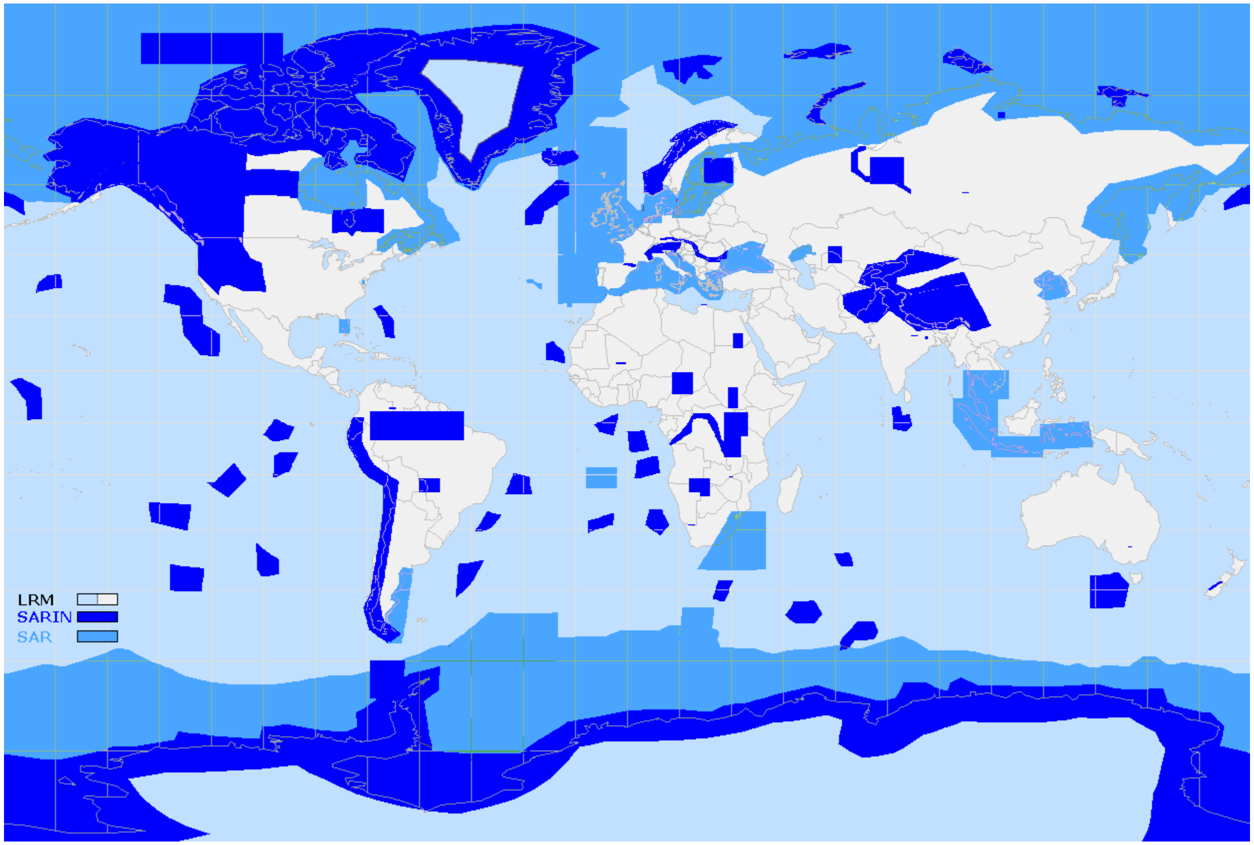
CryoSat-2 LRM Mode Products



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

LRM Products:

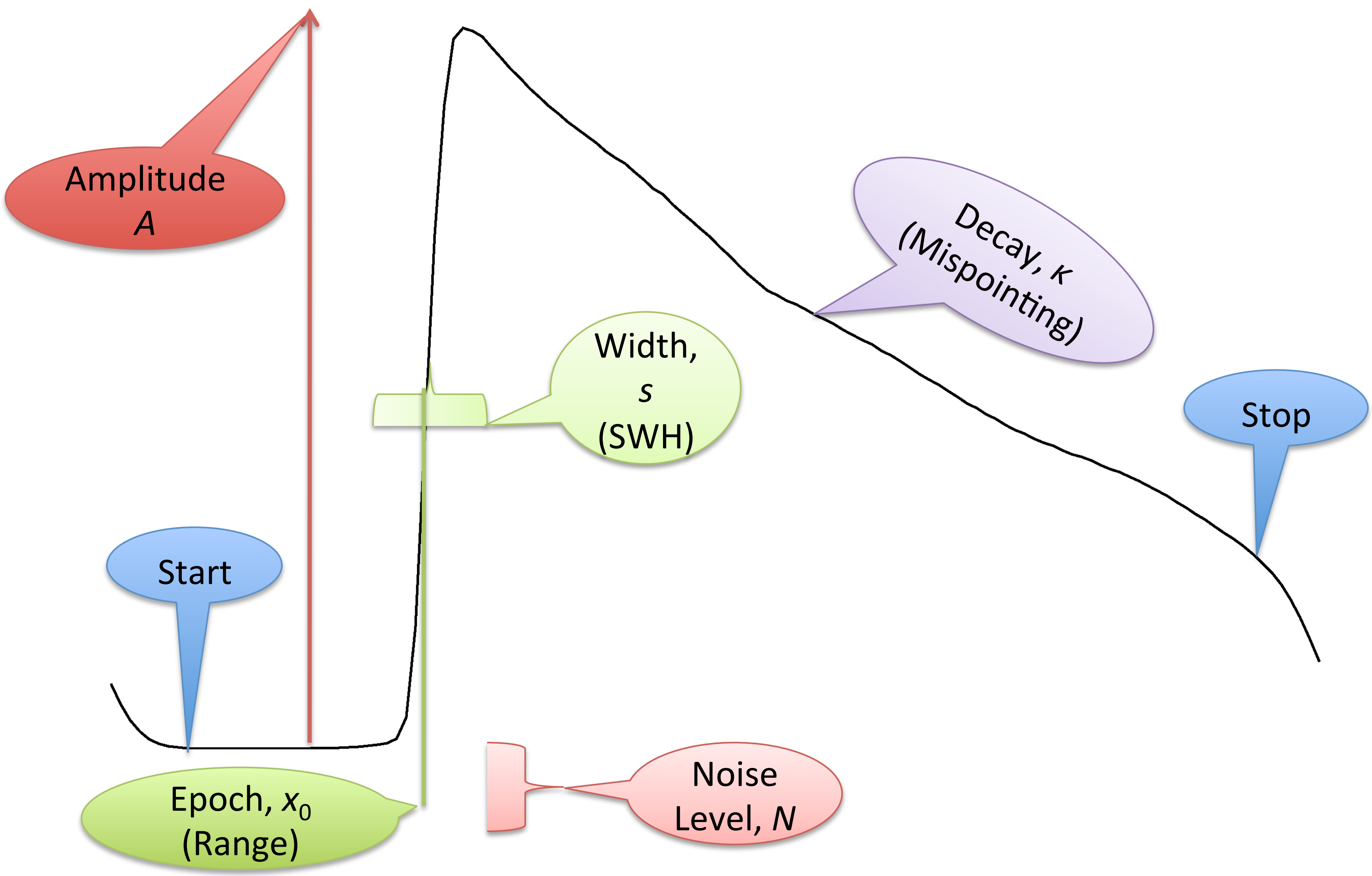
- FDM (Fast Delivery Mode) = short latency, DORIS DIODE or predicted orbit, predicted meteo & ancillary data.
- "LRM" = Final version, precise orbit, analyzed meteo, etc. (final "GDR").

Level L1b = Has waveform and geophysical corrections, but no derived quantities (range, SWH, σ^0) ➔ no sea surface height, wind speed (U_{10}), wave height, backscatter, etc.

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

We build all our results from <u>L1b</u> FDM and LRM waveform products, <u>not Level 2.</u>

CS2 LRM mean waveform



Elliptical antenna pattern

Classical "Brown model" theory for the expected waveform shape assumes a circular antenna pattern.

CryoSat2's antenna pattern is slightly elliptical.

If we average CS2's beam width over all azimuths, then the azimuthally averaged half-power beam width is the harmonic mean of the major and minor elliptical HPBWs.

We retrack CS2's waveforms with a circular beam theory using the azimuthally averaged HPBW.

This is a good approximation for conventional LRM waveforms.

This would be wrong for SAR/SARIN waveforms.

Wingham & Wallace [2010] have developed the full theory for the elliptical antenna. Their paper supports our belief that the circular approximation is a good one in our case.

Retracker options

Retracker allows selection of any or all of these parameters to be fitted:

1) Epoch, x_0
2) Width, s
3) Amplitude, A
4) Mispointing, $\kappa(\xi^2)$, ξ is off-nadir angle
5) Noise level, N

Any of these can be free parameters to be fitted, while others are held fixed.

$\kappa(\xi^2)$ can use 0th, 1st, or 2nd order approximation of Bessel function $I_0(z)$.

$I_0(z) = 1$, [MacArthur]

$I_0(z) = \exp(z^2/4)$, [Rodriguez]

$I_0(z)$ = two terms in exp() [Amarouche et al.]

Example:
"MLE3" would be first 3 parameters, and 1st order approximation.
"MLE4" would be first 4 parameters, and 2nd order approximation.
"RED3" would be first 3 parameters, 1st order approximation, and fewer gates fitted.

Retracker search features

Retracker iterative search requires these steps:

1) Initialization (by given or default values)
2) Interative update using Modified Gauss-Newton steps
3) Stopping criteria for success and failure

Initialization can supply "known" values (e.g., *off-nadir angle given from star trackers*, or along-track smoothed prior estimates, as in Sandwell & Smith two-pass method).

Iteration is solved by QR decomposition of column-balanced Jacobian (MLE3&4 use QR with column pivoting).

Stopping criteria for success/failure (in unweighted case) are MLE-like (A^2-normalized change in Mean Quadratic Error $< 5 \times 10^{-4}$ for 3 iterations = success).

Example:
To behave as MLE3 or MLE4, initialize with default values and proceed as above.

Default initializations MLE-like

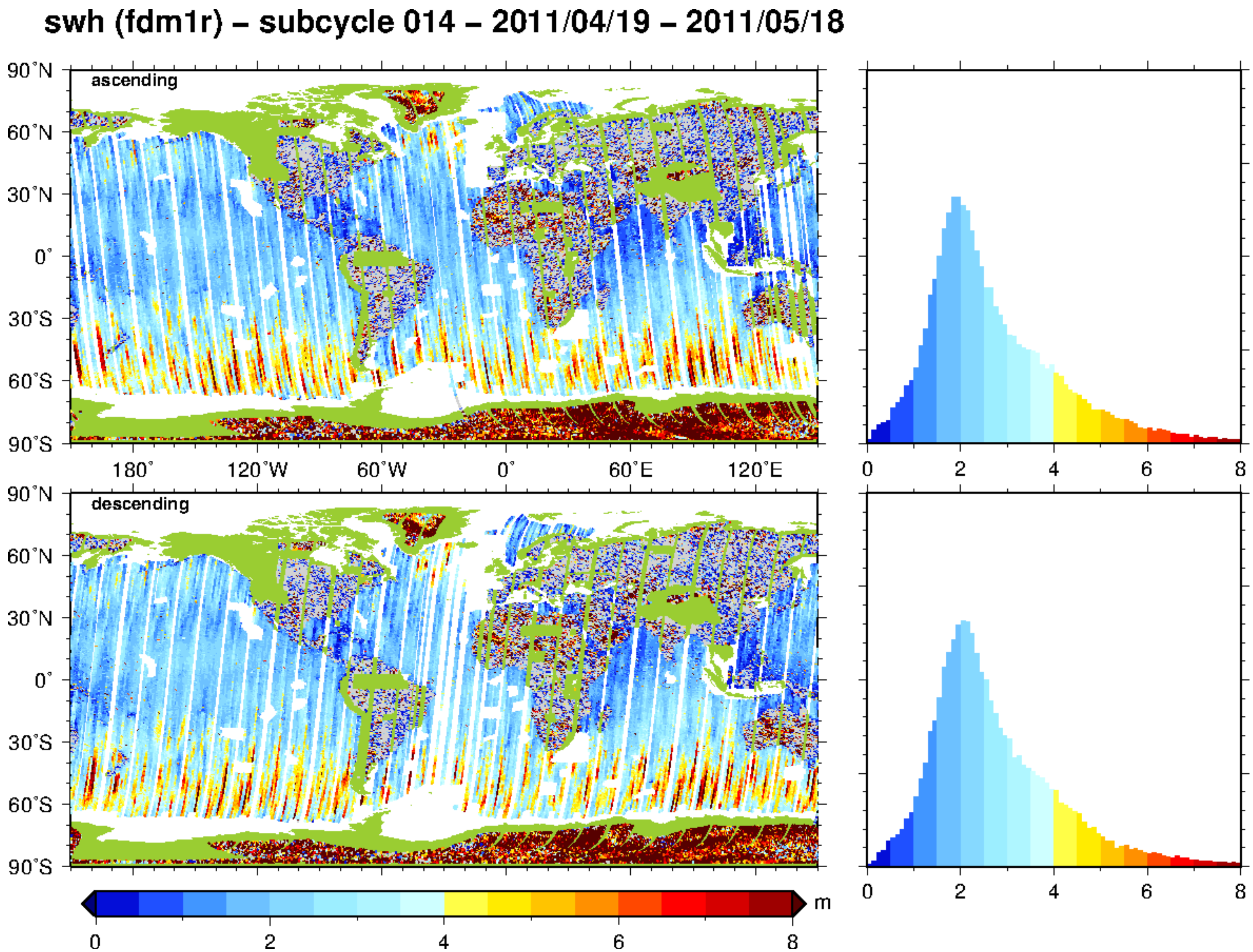
Initialization of search may default to these values:

1) Epoch, x_0: set to normal track point.
2) Width, s: set equivalent to SWH = 2 m.
3) Amplitude, A: set to Max(waveform)
4) Mispointing, $\kappa(\xi^2)$, ξ is off-nadir angle: set to $\xi = 0$.
5) Noise level, N: set to average of first five gates used.

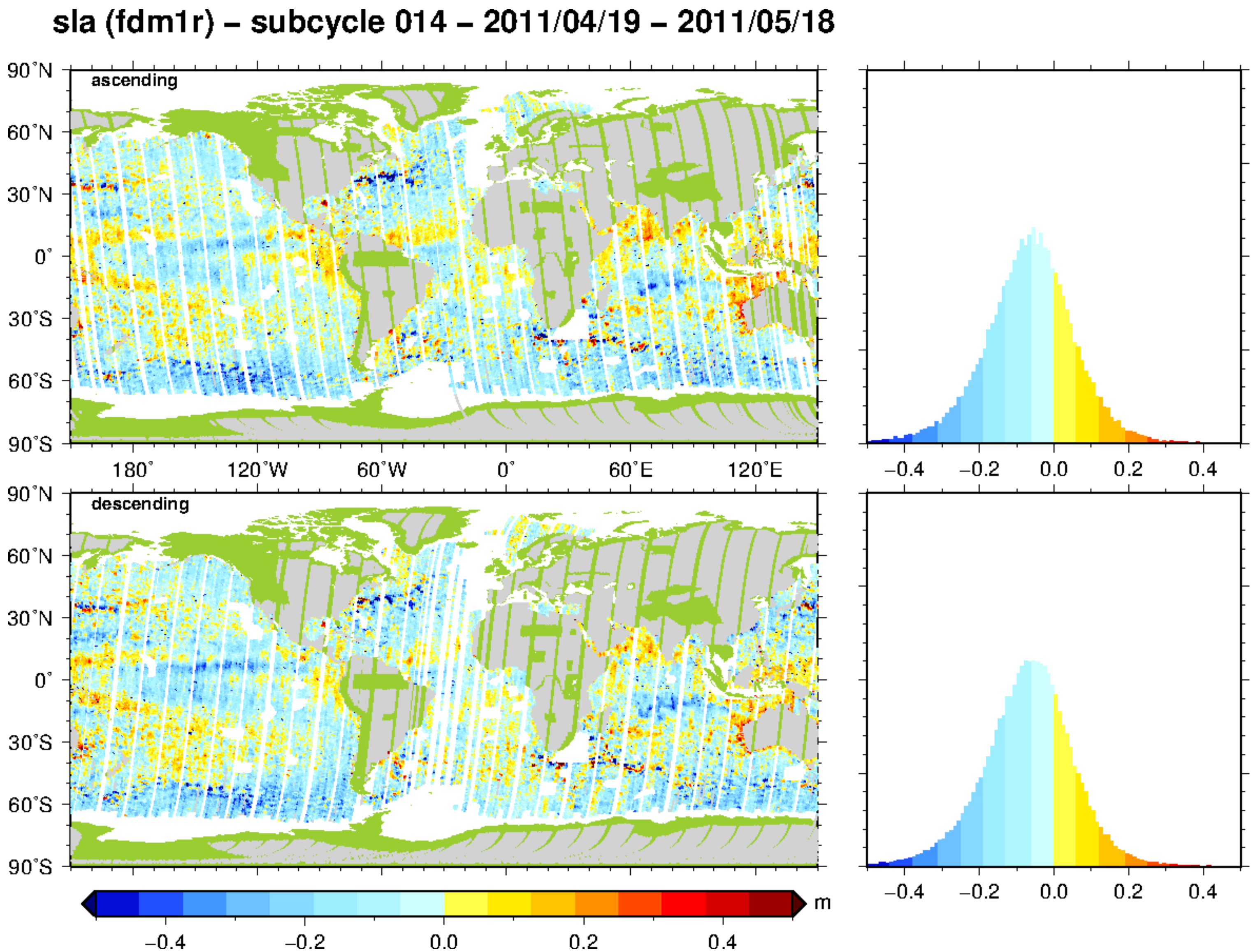
For CryoSat2, we fit the middle 104 of the 128 gates, as is done also for Jason.
Laurent P. said in Coastal meeting we should make this 106 and 126, I think.

Our first attempt was to replicate MLE3 assuming $\xi = 0$.

CS2 SWH (MLE3, $\xi = 0$)

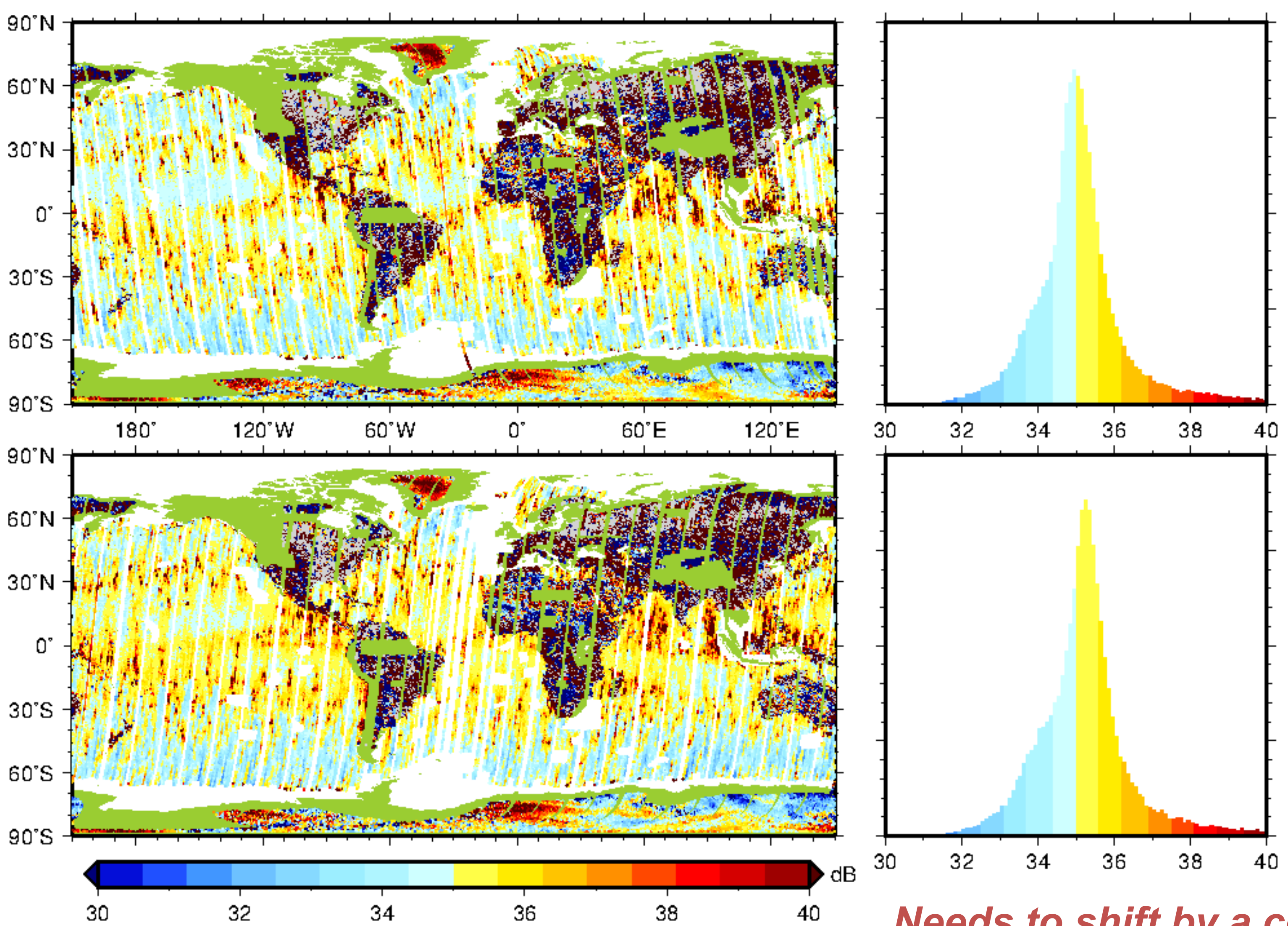


CS2 SLA (MLE3, $\xi = 0$)



CS2 σ^0 (MLE3, $\xi = 0$)

Note Asc/Dsc Asymmetry



Needs to shift by a constant

Making a guess at σ^0

From Orbit

Constant, unless raining

From Retracker

$$(1.47) \qquad \ell\left(\frac{P_R}{P_T}\right) = \ell(\sigma_0) + C - \ell(L) - 30\log_{10}\left(\frac{h'}{h_N}\right) + \frac{10}{\ln(10)}\left[\frac{-4}{\gamma}\sin^2\xi + \frac{k_j s}{2}\right] + \ell\left(\frac{A}{A_N}\right)$$

Target Amplitude Maintained by AGC

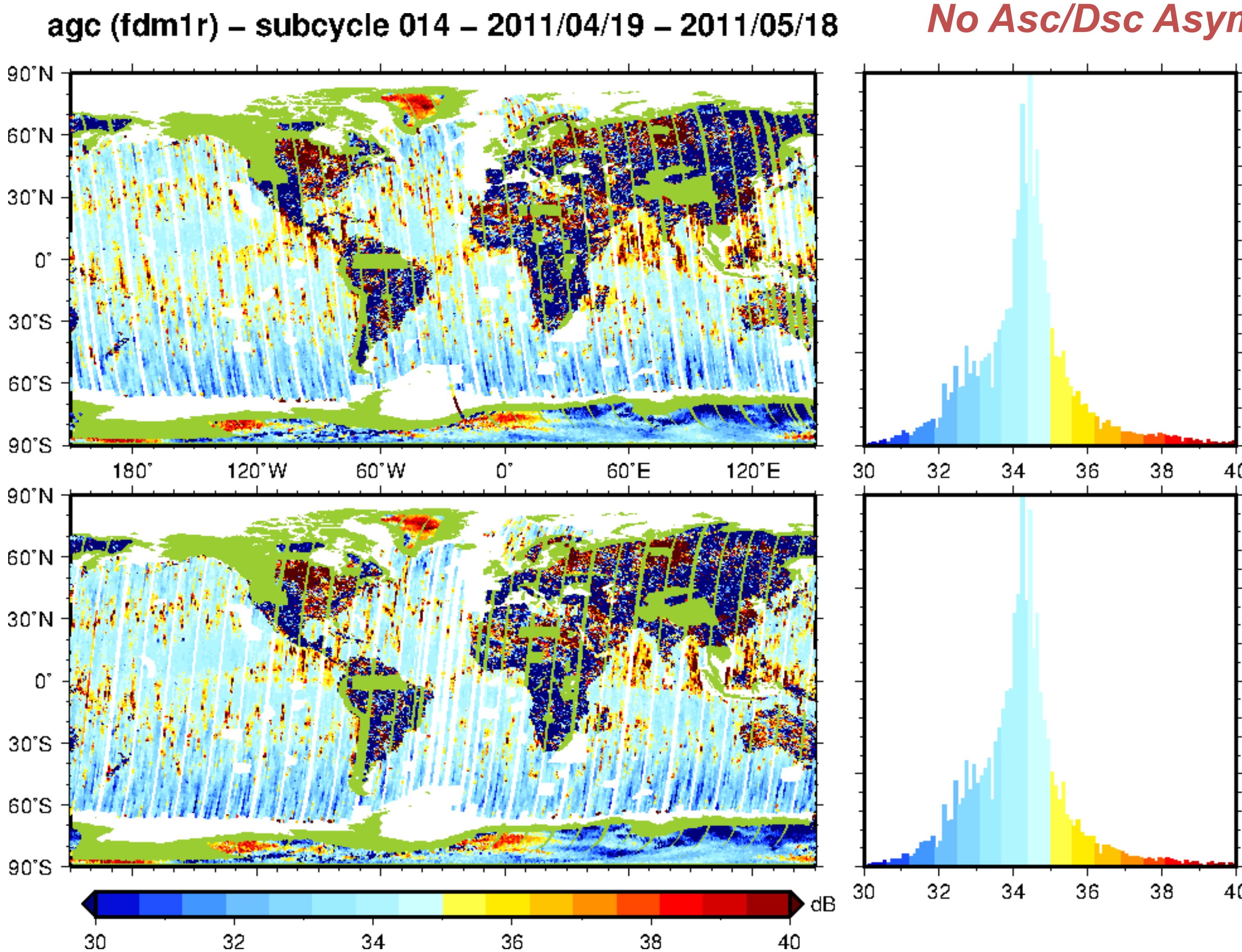
in which

$$(1.48) \qquad C = \ell\left(\frac{c\pi\lambda^2 G_0^2 A_N T}{(4\pi h_N)^3 \eta}\right)$$

σ^0 is mainly given by a constant, *C*, (+/-?) AGC (is AGC an amplification or an attenuation?) (AGC or 62 – AGC ?). Retracking yields small (< 1 dB) corrections to apply to refine σ^0. We had to guess the system constant, *C*, and get the sign right, in order that the histogram would not be inverted.

CS2 *AGC* is not asymmetric

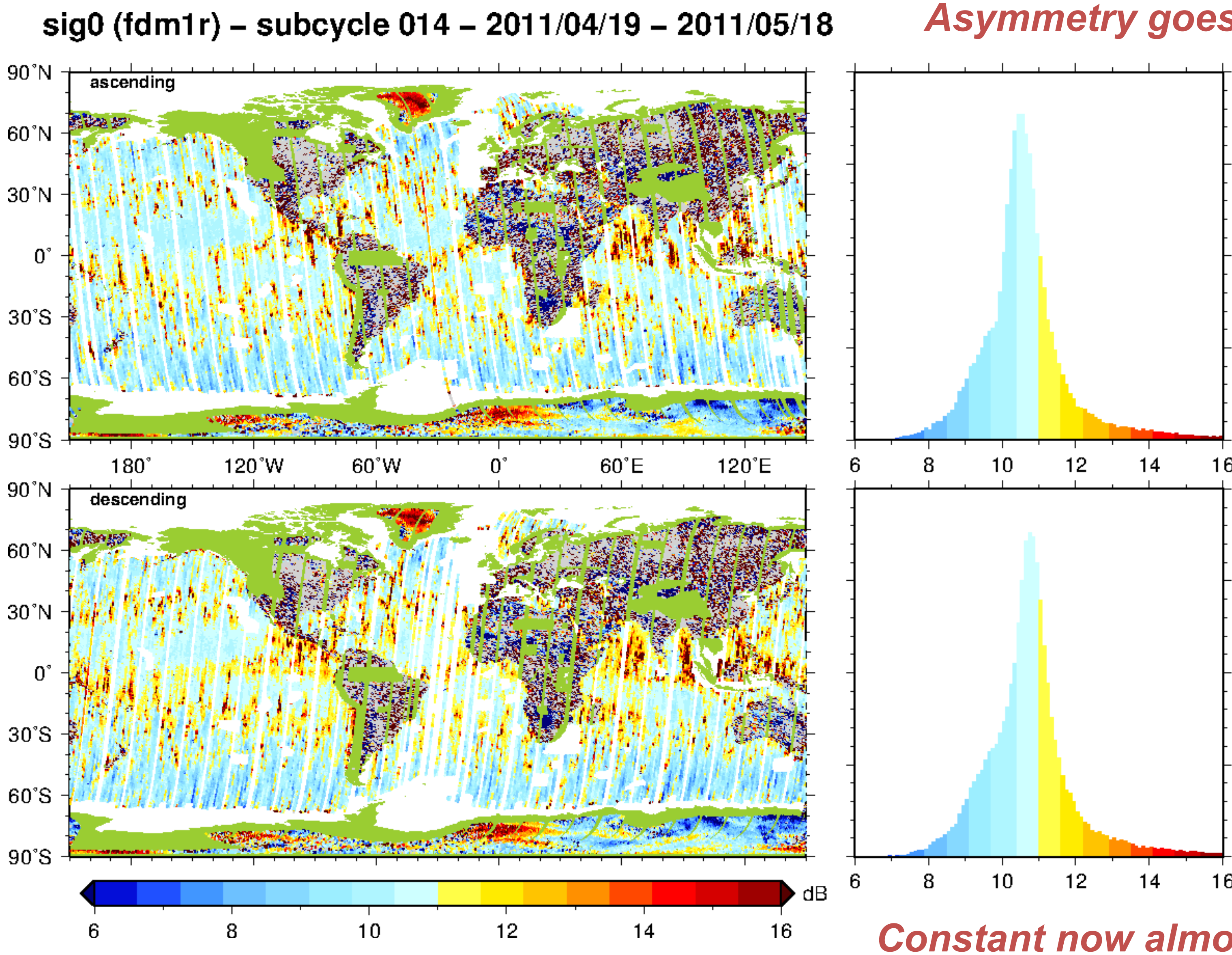
No Asc/Dsc Asymmetry



Chasing down the asymmetry

- We introduced the ascending / descending asymmetry in σ^0 either through the orbit height, or by neglecting to correct for mispointing, since we initially assumed $\xi = 0$.
- So next we tried fitting the off-nadir angle as a free parameter (MLE4-like).
- You will see that this fixes the asymmetry problem.

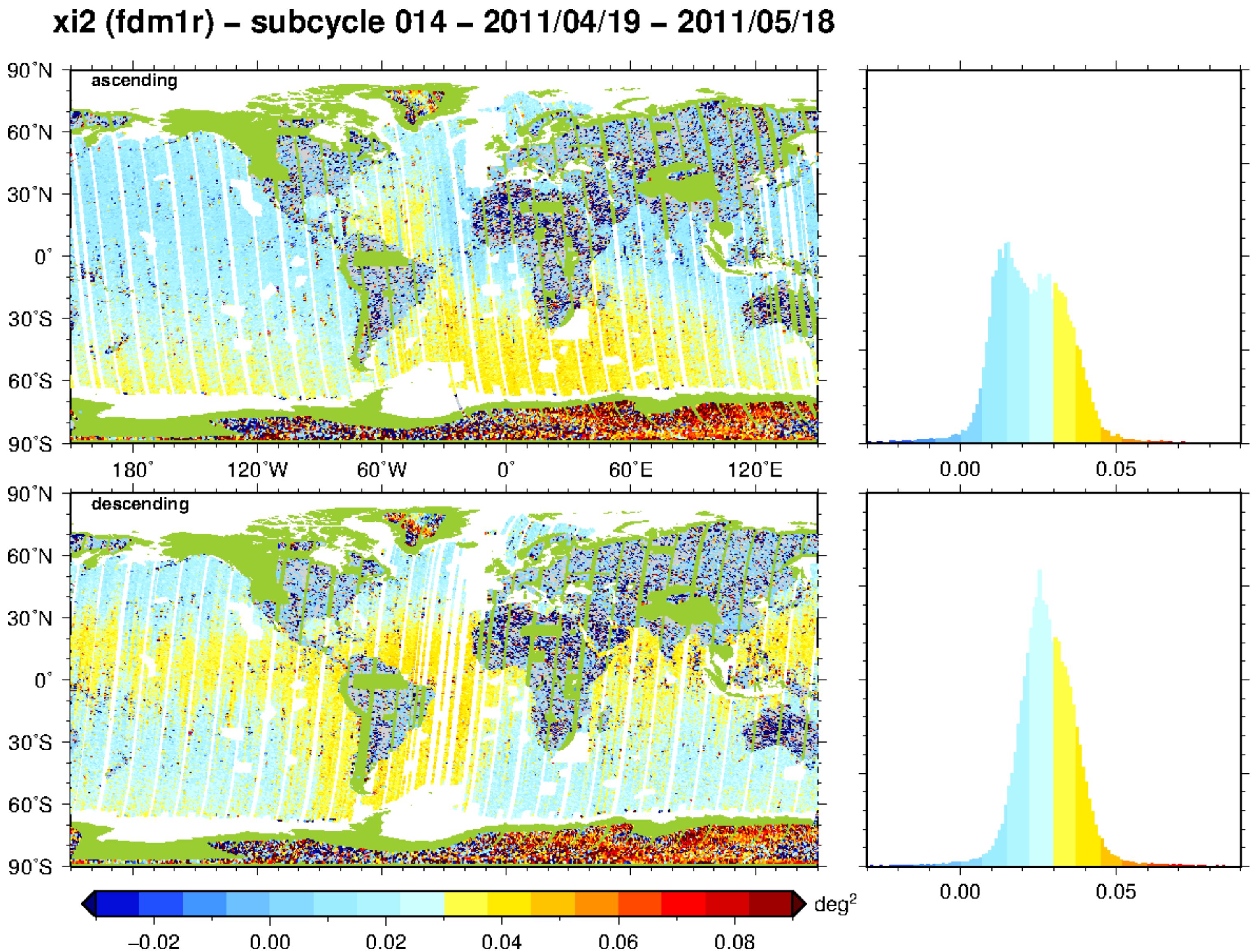
CS2 σ^0 (MLE4, ξ = free)



Asymmetry goes away

Constant now almost right

CS2 ξ^2 from retracker (MLE4)

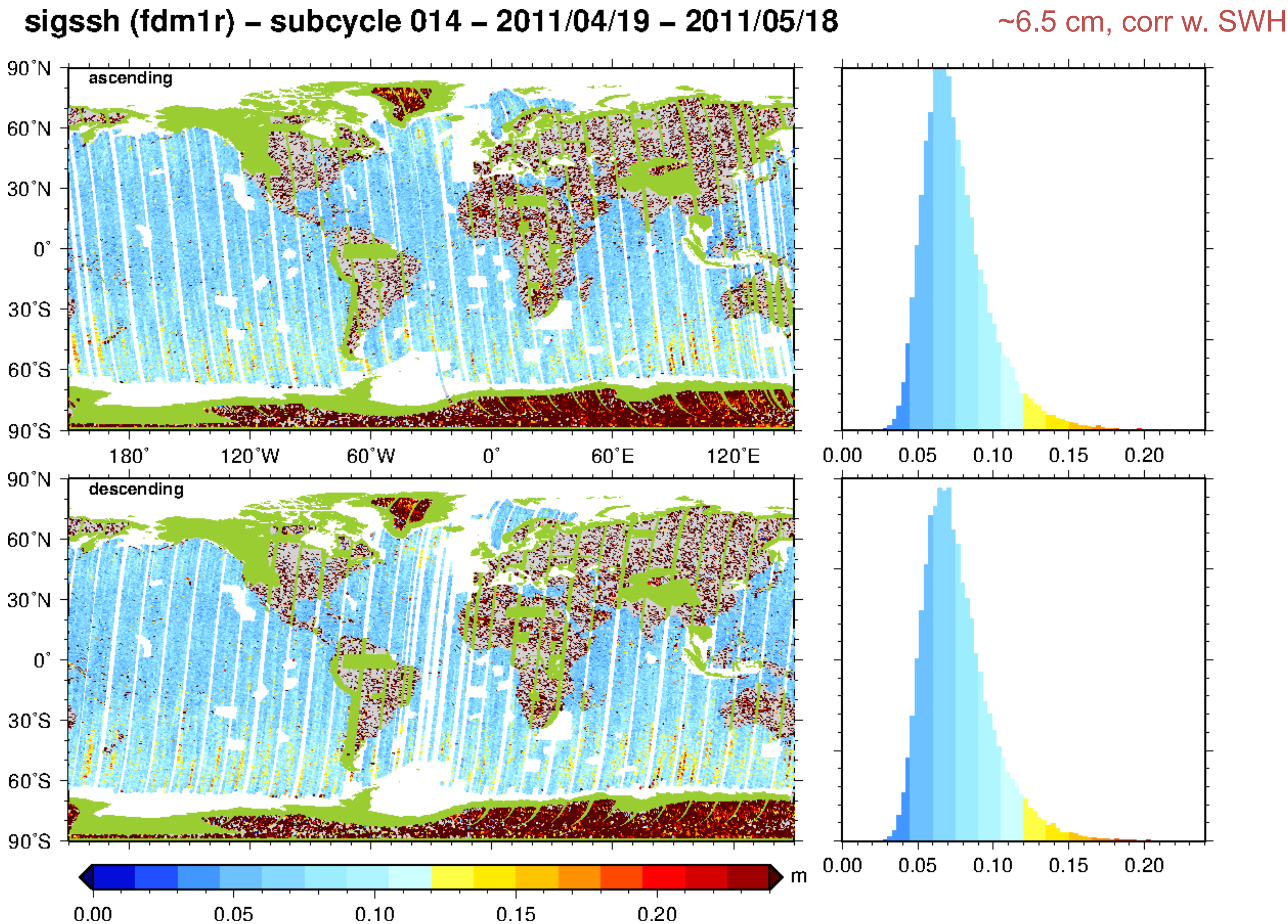


But freedom in ξ has a price!

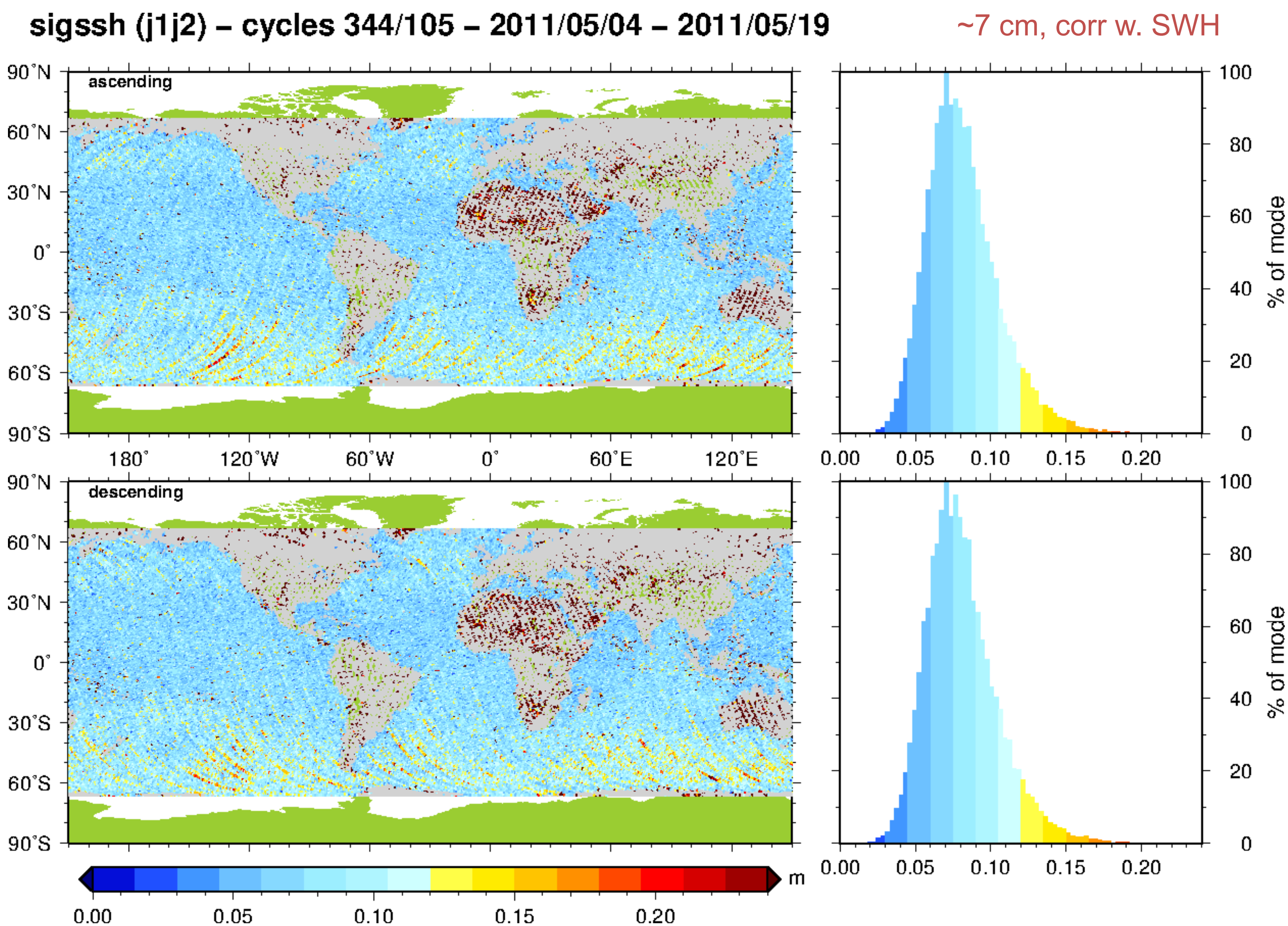
The 1-Hz averaged SSH is found by fitting a straight line to twenty values of 20-Hz (orbit – range). The standard deviation of the residuals around the line we call here σ_{SSH}. This number represents the random noise in range.

Range noise goes up, and is more dependent on SWH, with freedom in ξ.

CS2 σ_{SSH} from MLE4 (ξ = free)

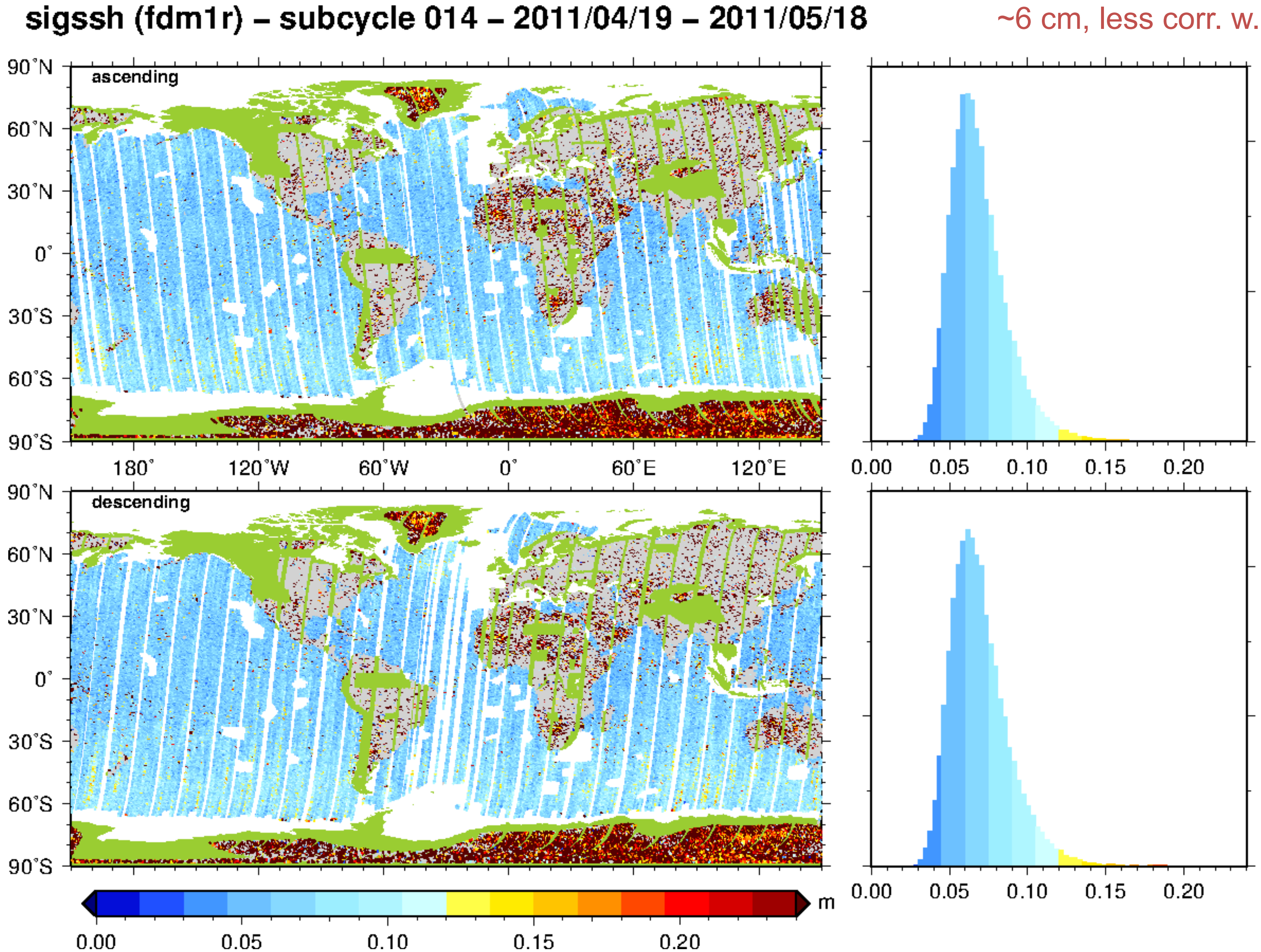


J-1&J-2 σ_{SSH} from MLE4



CS2 σ_{SSH} from MLE3

~6 cm, less corr. w. SWH

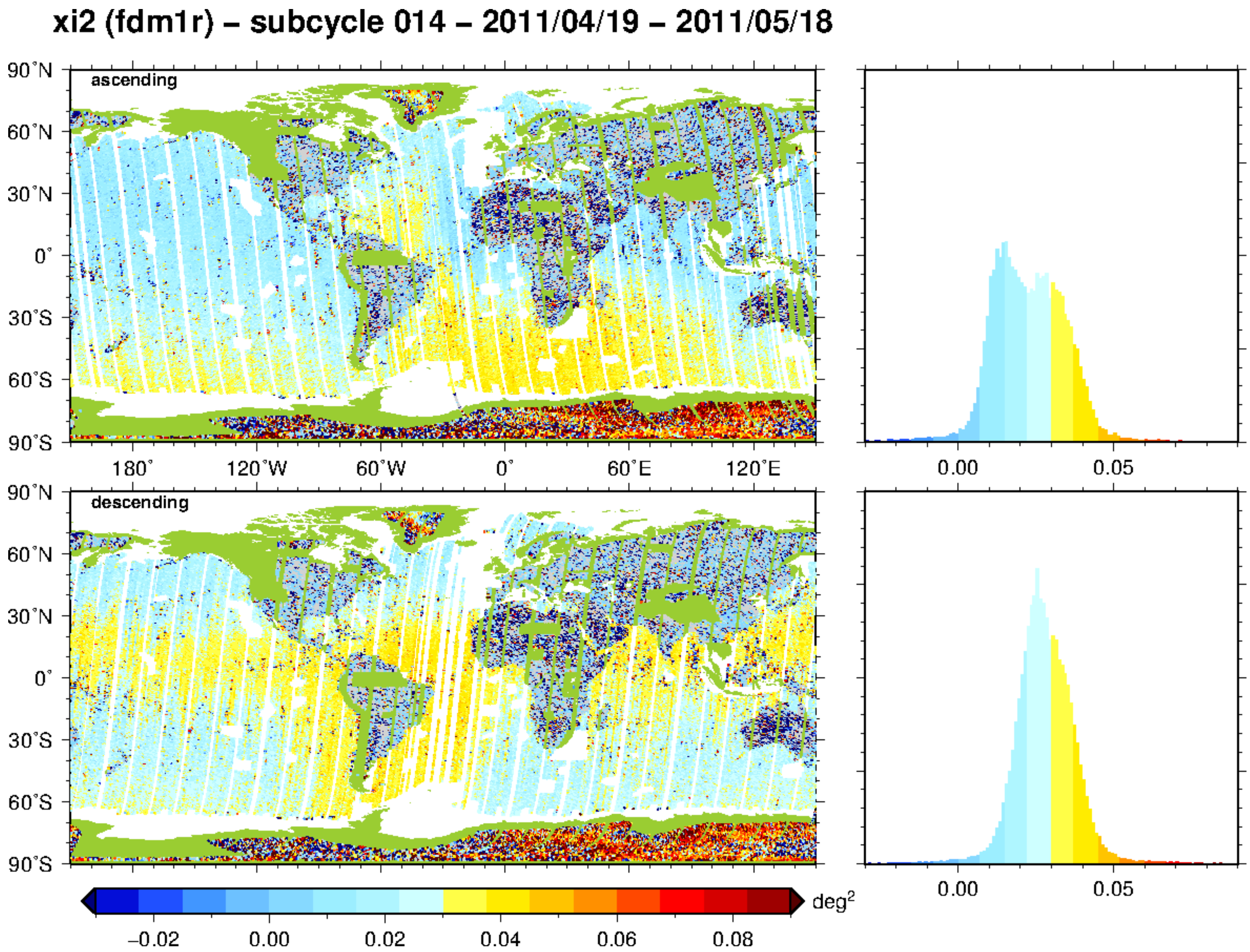


Solution: a priori ξ

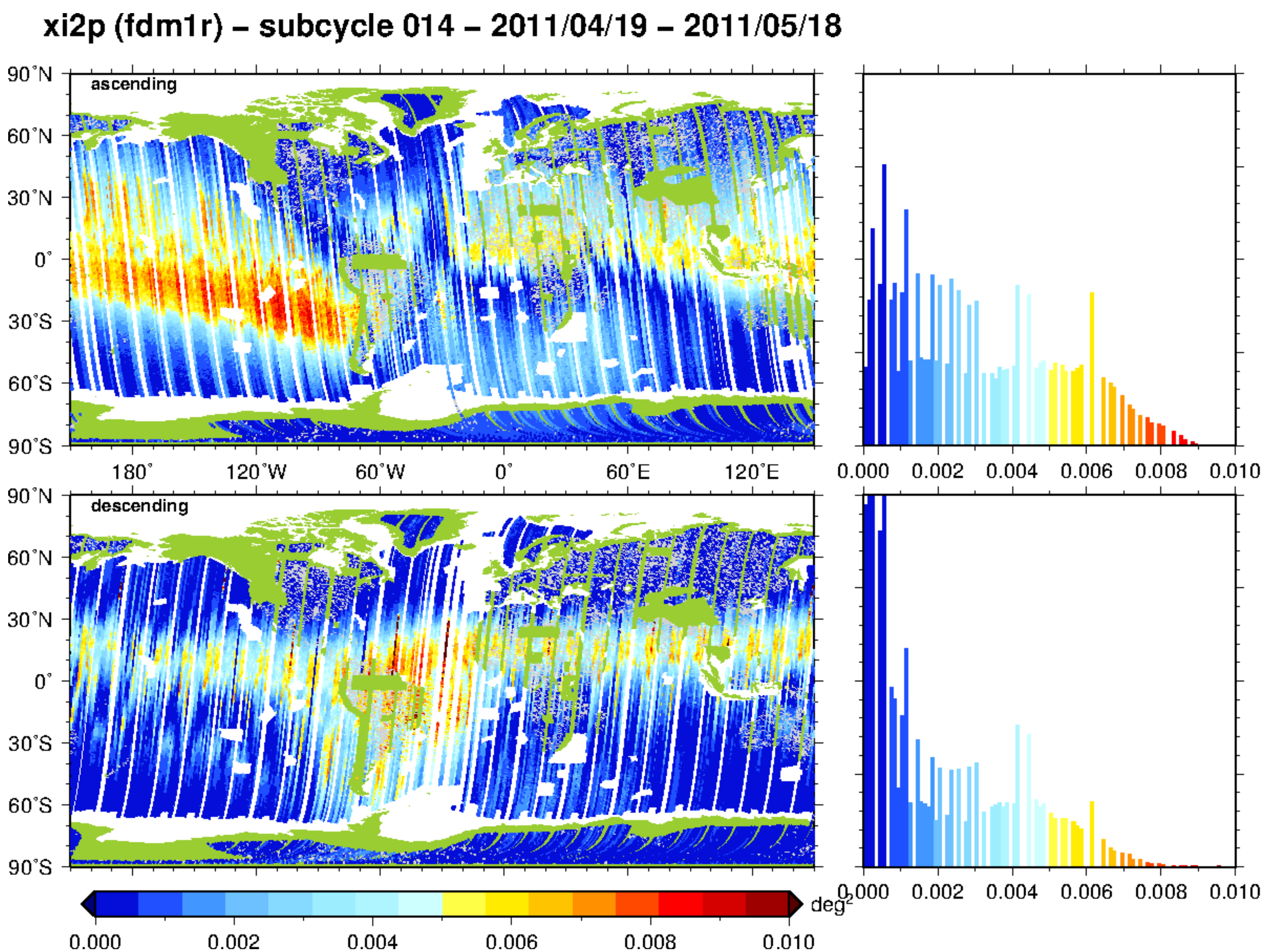
We next tried using MLE3, holding ξ fixed to an *a priori* value determined from the platform attitude found from star trackers.

This data is given in the FDM and LRM L1b product.

CS2 ξ^2 from retracker (MLE4)



CS2 ξ^2 from star trackers



Platform attitude biases

We fit a model for platform bias of the form

$\xi^2 = (\text{pitch} - \text{bias}_P)^2 + (\text{roll} - \text{bias}_R)^2$.

Assumptions: negligible thermal flexures; negligible biases between star trackers.

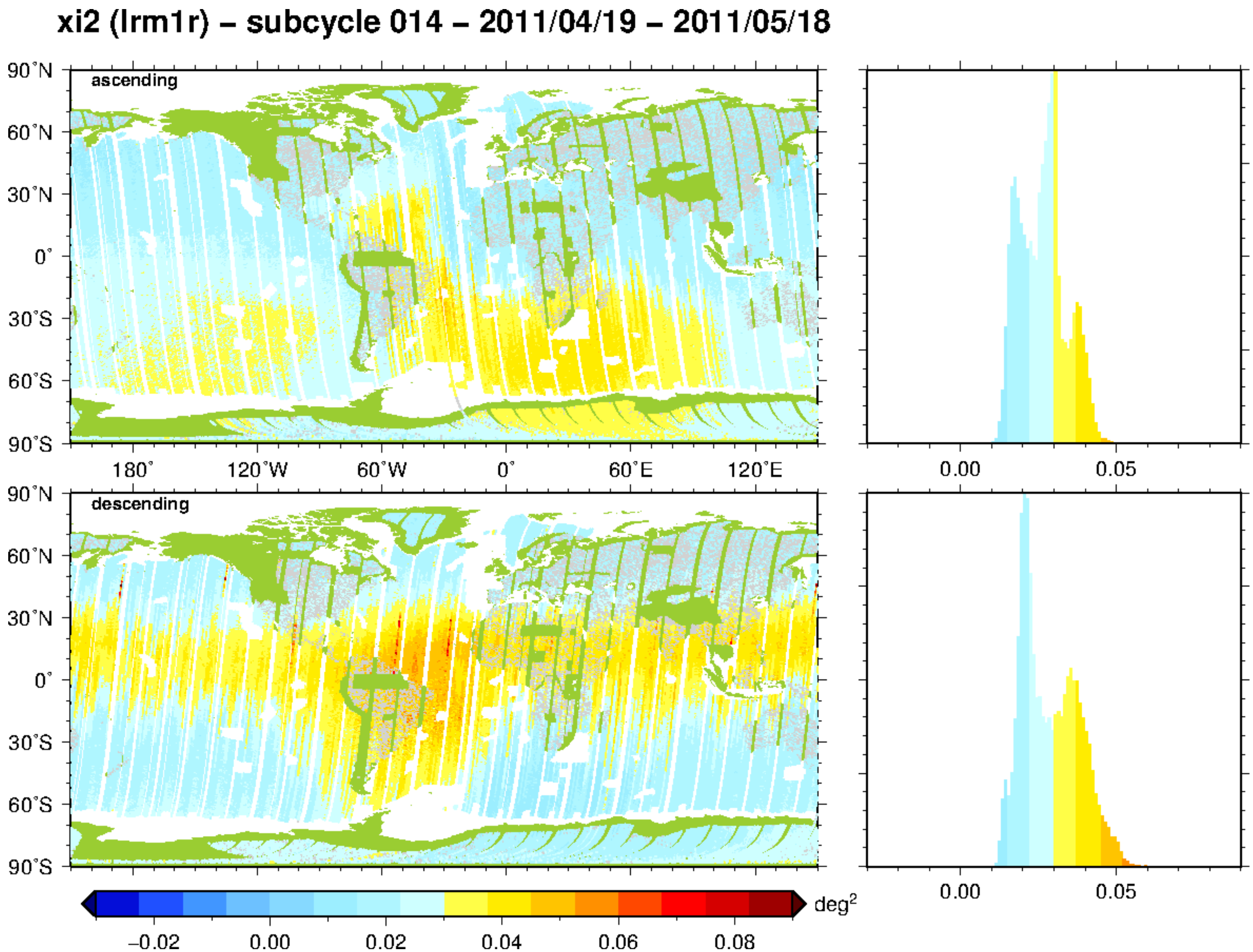
We found we had to do this using the LRM L1b, not the FDM L1b, because of FDM orbit problems that noticeably affect pitch estimates.

We estimate:

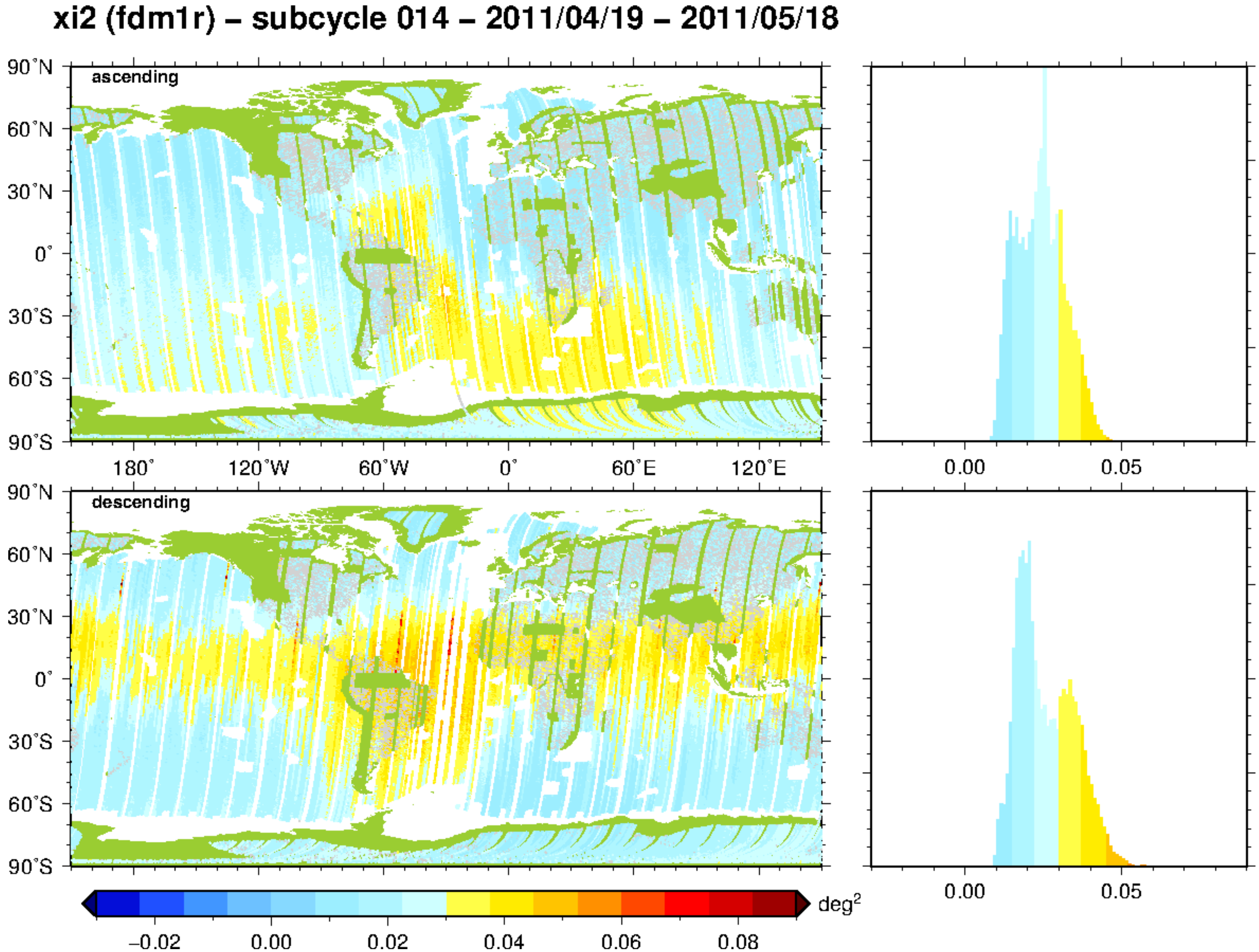
Pitch bias: +0.0962 degrees.

Roll bias: +0.0848 degrees.

CS2 ξ^2 from adj. stars, LRM



CS2 ξ^2 from adj. stars, FDM



FDM orbit challenges

The FDM uses a DORIS orbit if it exists when the pass segment is processed. If not, FDM uses a predicted orbit.

The predicted orbit has height errors of meters but is interpolated at the correct time.

The DORIS orbit has accurate enough (for NRT) height, but is interpolated at the wrong time; delta_UT1 should be ~0.266 sec but is set to 0.

This huge timing bias causes an apparent pitch of (360˚/6000s)x0.266s = 0.016˚.

Conclusions

We are producing SWH, σ_0, U_{10}, and SSH by retracking FDM and LRM L1b waveforms.

Our product compares well with J1, J2, E, though there are *ad hoc* values that could be tuned.

Range precision of CS2 appears superior to J1&2 when both are retracked with MLE4.

With a good orbit 1 to 3 days behind real time we could make an I-GDR.

Our product depends only on the L1b data at ESRIN ftp; we are not proposing upstream changes.