Modified CFSR wave hindcast (1979-2016): Coherency between a wave hindcast, altimeters, buoys, and seismic measurements

Justin Stopa[1] and Fabrice Ardhuin[1]

[1]Laboratoire d'Océanographie Physique et Spatiale, Brest, France

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Outline

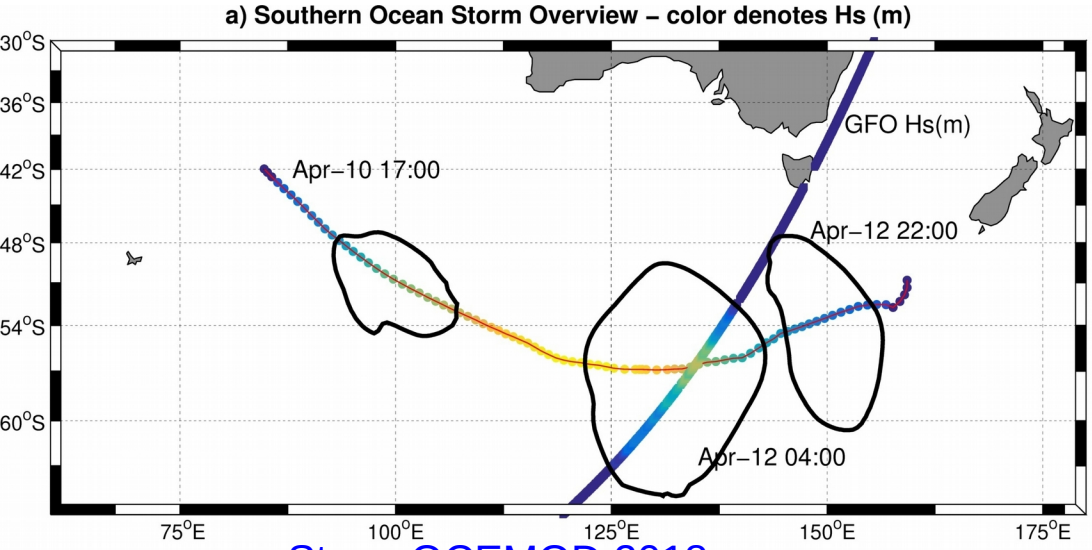
1) Introduction - Why CFSR?
2) Proposed correction using altimeters
3) Verification with buoys and seismic
4) Conclusion
5) Discussion - consistency

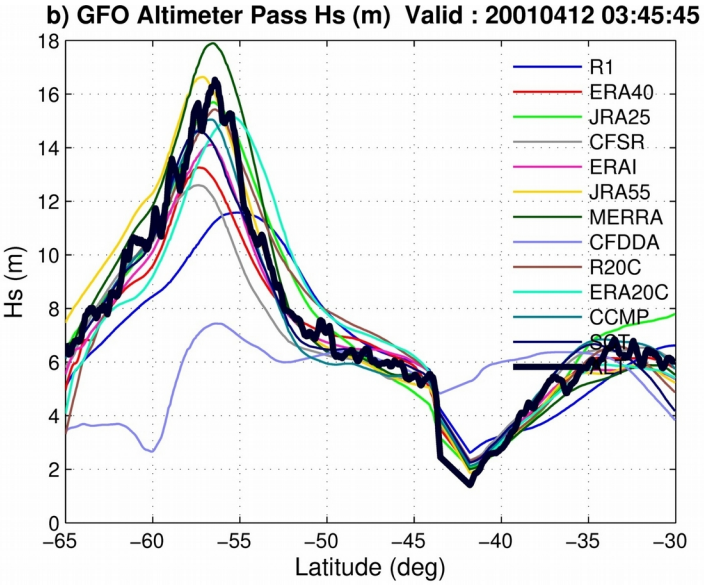
1 Introduction
Why CFSR?

-Various hindcasts using different forcing are calibrated (Betamax varied)
-After calibration – average sea states are similar; large waves (Hs>10 m) are very different! Janssen (2004)

$$\mathcal{S}_{in}(k,\theta) = \frac{\rho_a}{\rho_w}\frac{\beta_{\max}}{\kappa^2}\mathrm{e}^Z Z^4 \left(\frac{u_\star}{C}+z_\alpha\right)^2 \cos^{p_{in}}(\theta-\theta_u)\sigma N(k,\theta)$$

-CFSR performs well (other good ones: ERAI, JRA55,...):
(+) best match with Tm02, smallest errors for large sea states,
(-) precision could be improved, positions of storms often wrong, can underestimate peak Hs of events (example: CFSR Hs =12, ALT Hs=16 m)
-Example storm in SO: Hs at peak ranges 8<Hs<18 m





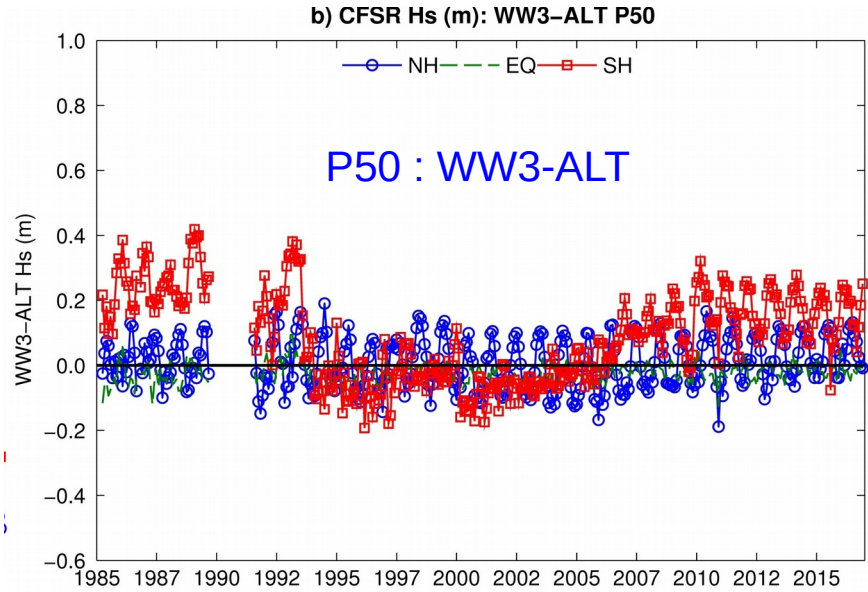
Stopa OCEMOD 2018

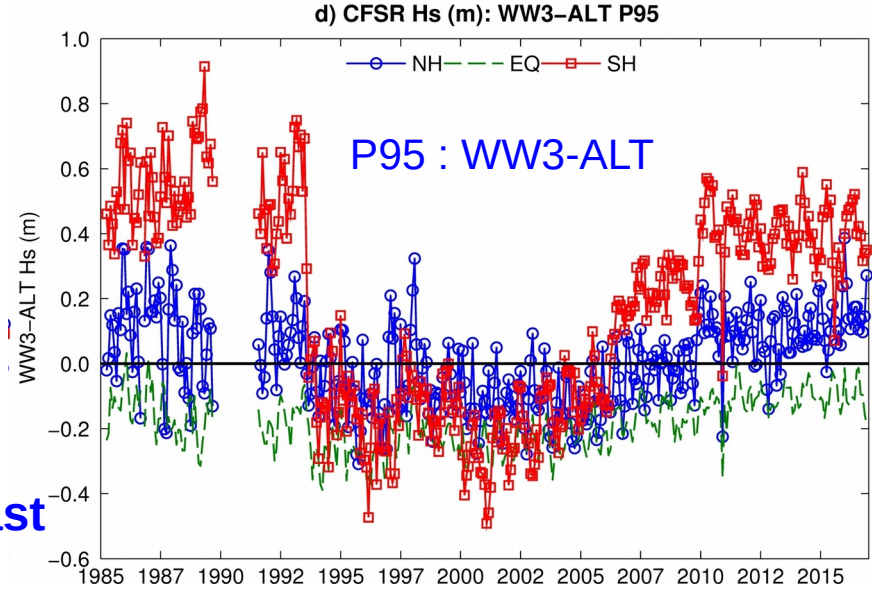
1 Introduction
Why CFSR?

-Highest resolution in time and space (0.2-0.3 deg,1 h)

-Inconsistent in time perhaps not so different than others: ERAI, JRA55,...

Many changes in WW3-ALT residuals:
-1994 step change (SSM/I) (Chawla et al., OCEMOD 2013; Rascle and Ardhuin OCEMOD 2013)
-increasing trend 2004-2009
-2011-2016 v2
-difference in NH and SH
-discrepancies in NH not previously noted





Objective → Create a consistent wave hindcast

2

Methods

-Proposed Correction

2 Method
Altimeter Database

Hs and U10 from altimeters

-Near continuous coverage since mid-1985

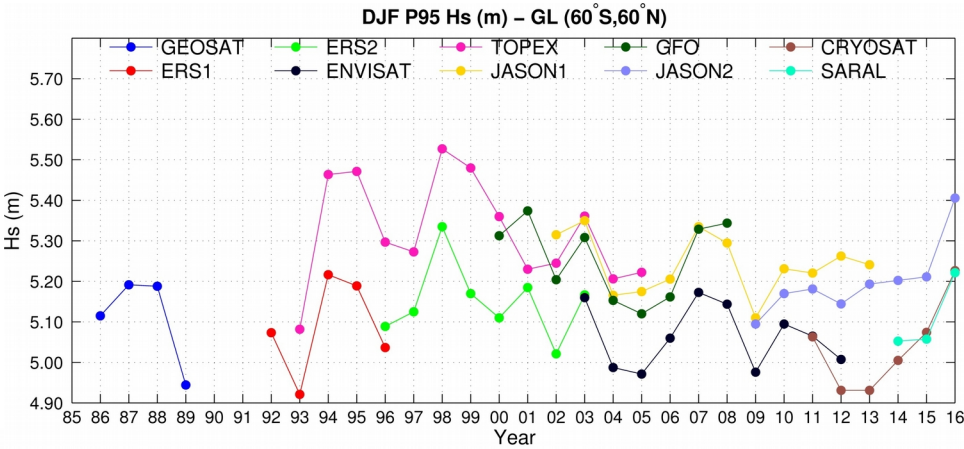
-Important: cross-calibrated between platforms (Young et al., JTECH 2017)

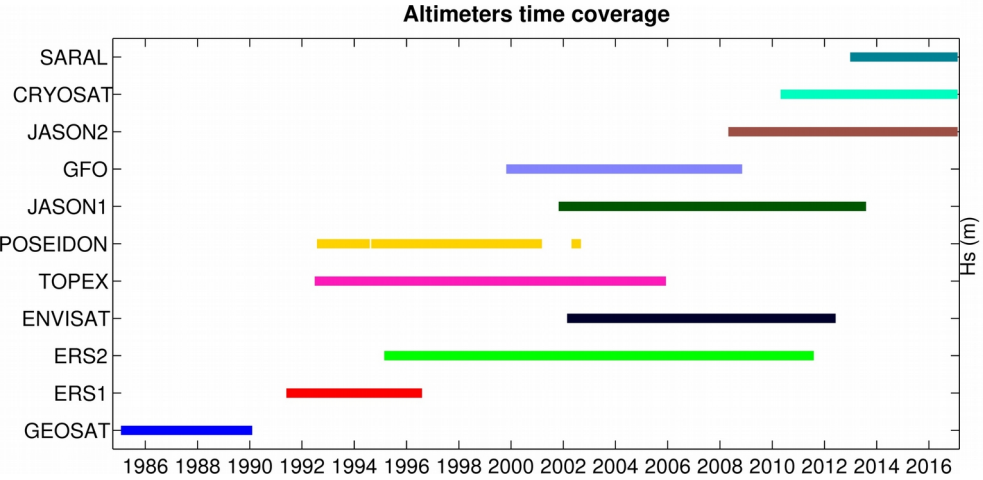
-Biases corrected using buoys

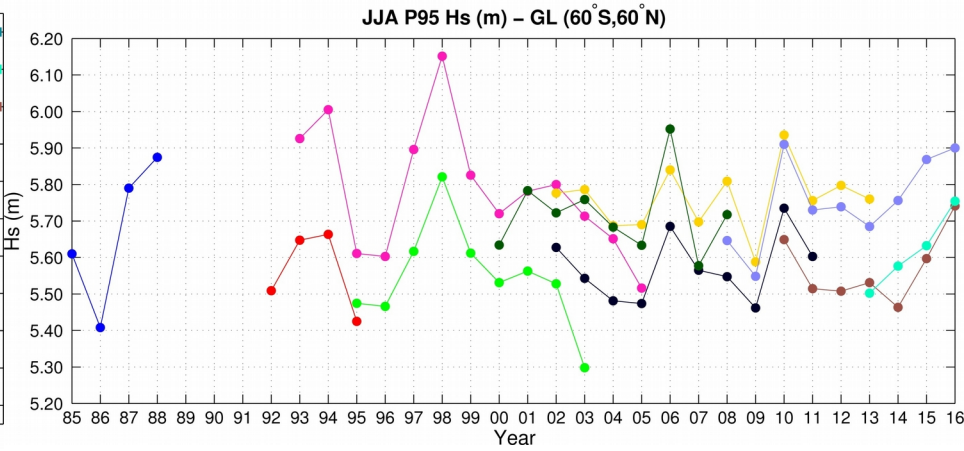
-We expect relatively consistent in time so we use as a reference for a correction

-ESA CCI will revisit...

Altimeters-Hs P99 : platforms <8% difference !







Queffeulou and Croize-Fillon, 2016

2 Method
Proposed Correction

-U10 and Hs residuals are similar as function of latitude

-Correction applied to U10 (u,v) for each month as a function of the P95 Hs residuals

-To counter-act the U10/Hs residuals we propose the following:

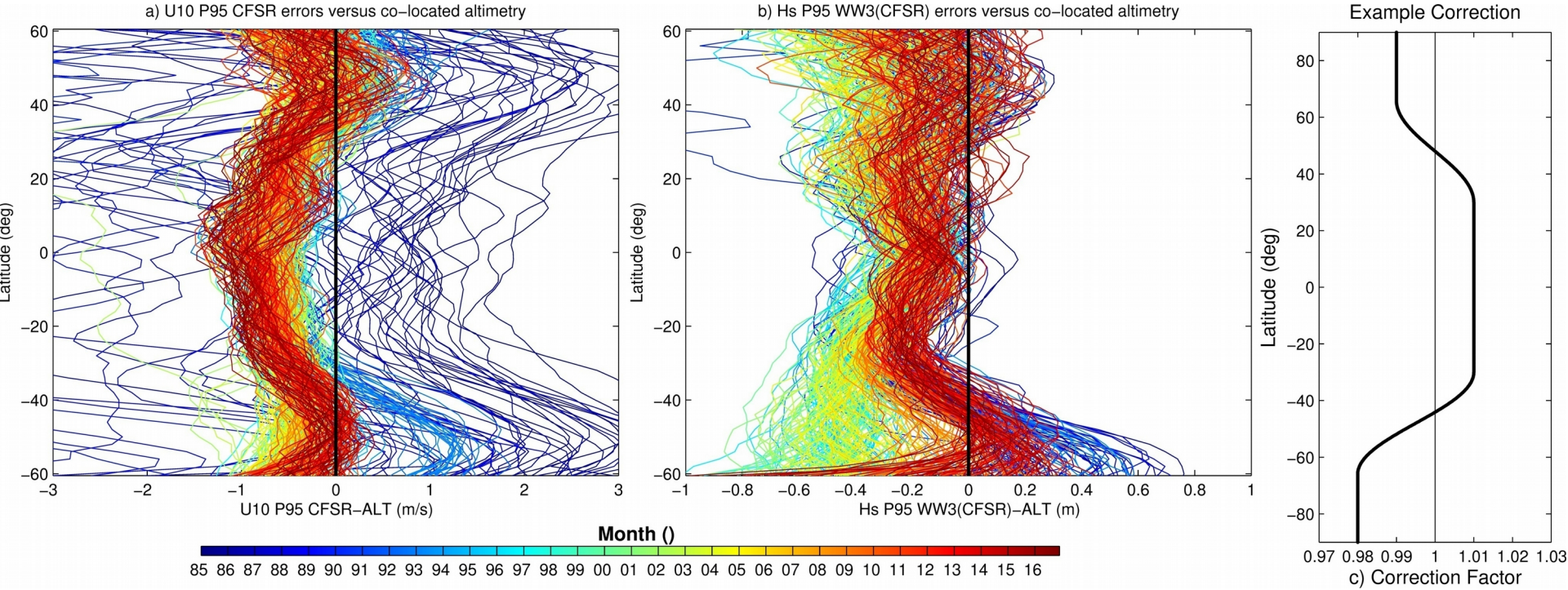
$$C(y_i) = \begin{cases} F_g, & y_i < |15^\circ| \\ F_g + F_j\left[\frac{1}{2}(1 - cos\left(\frac{\pi}{N-1}(i-I)\right)\right], & |15^\circ| \le y_i \le |55^\circ| \\ F_g + F_j, & y_i > 55^\circ \end{cases}$$

$$F_j = 1 - \frac{\Delta H_{s,P95}}{f_j\sqrt{2}}$$

ΔHs_{P95} per region : NH, EQ, SH

$$(\Delta H_{s,P95} = H_{s,P95,WW3} - H_{s,P95,ALT})$$

$$F_g = 0.018 \times (\overline{\Delta H_{s,P95}}) + 0.015$$



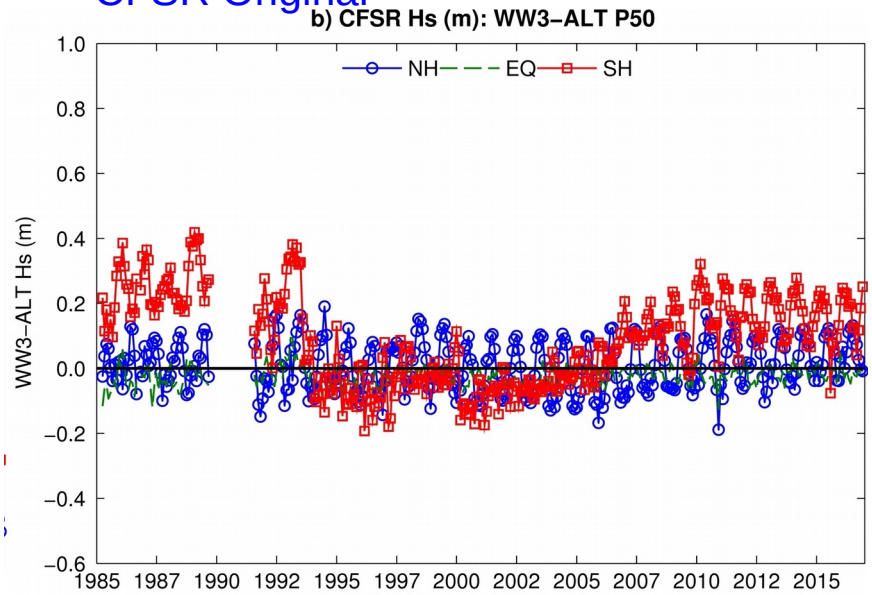
2 Method
Before & After

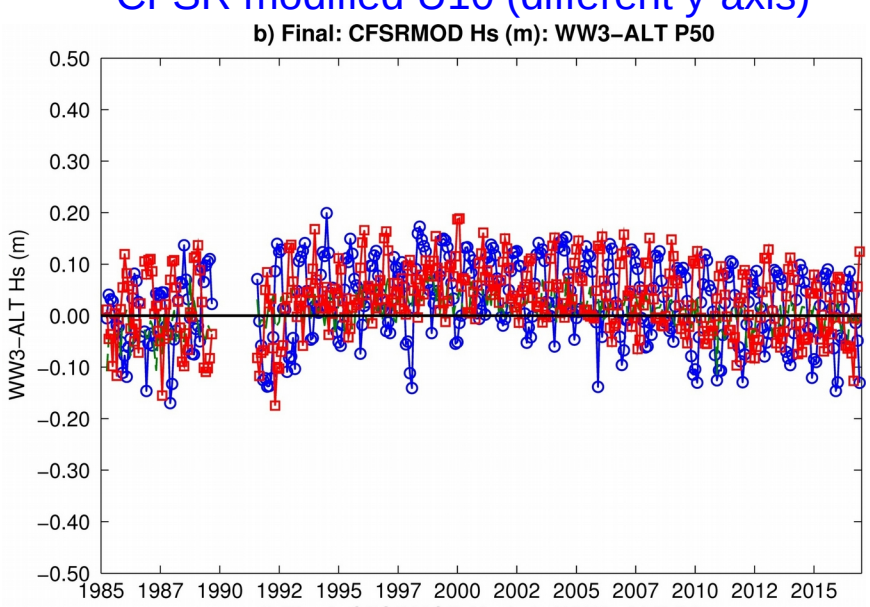
CFSR Original

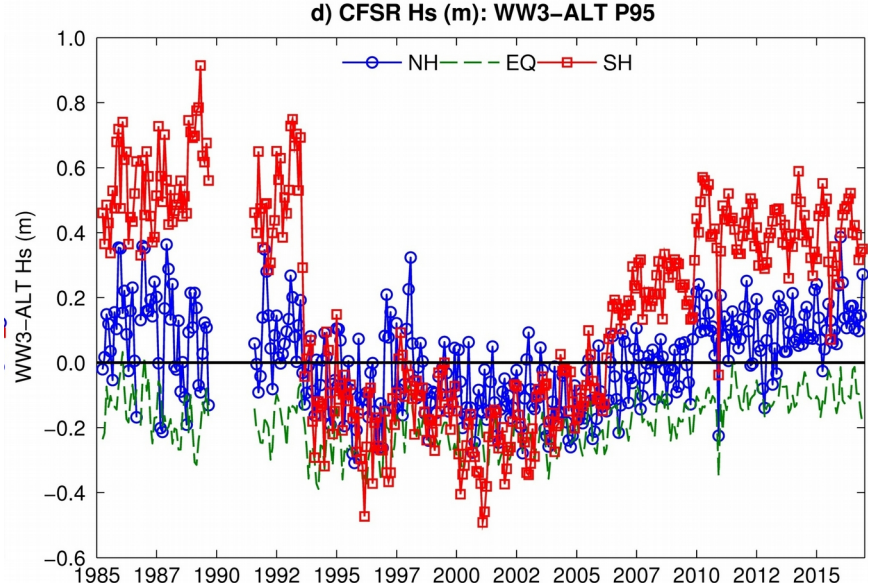
CFSR modified U10 (different y-axis)

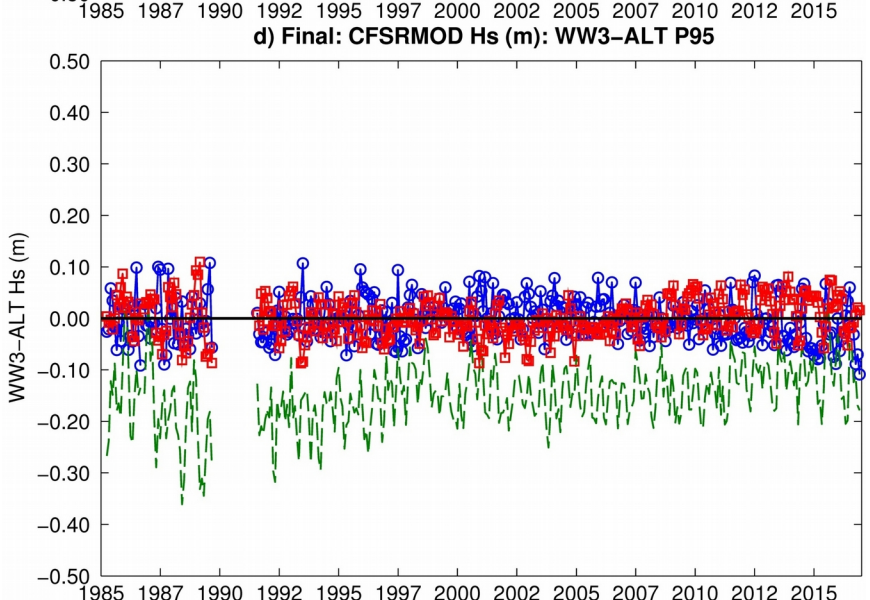
P50

P95





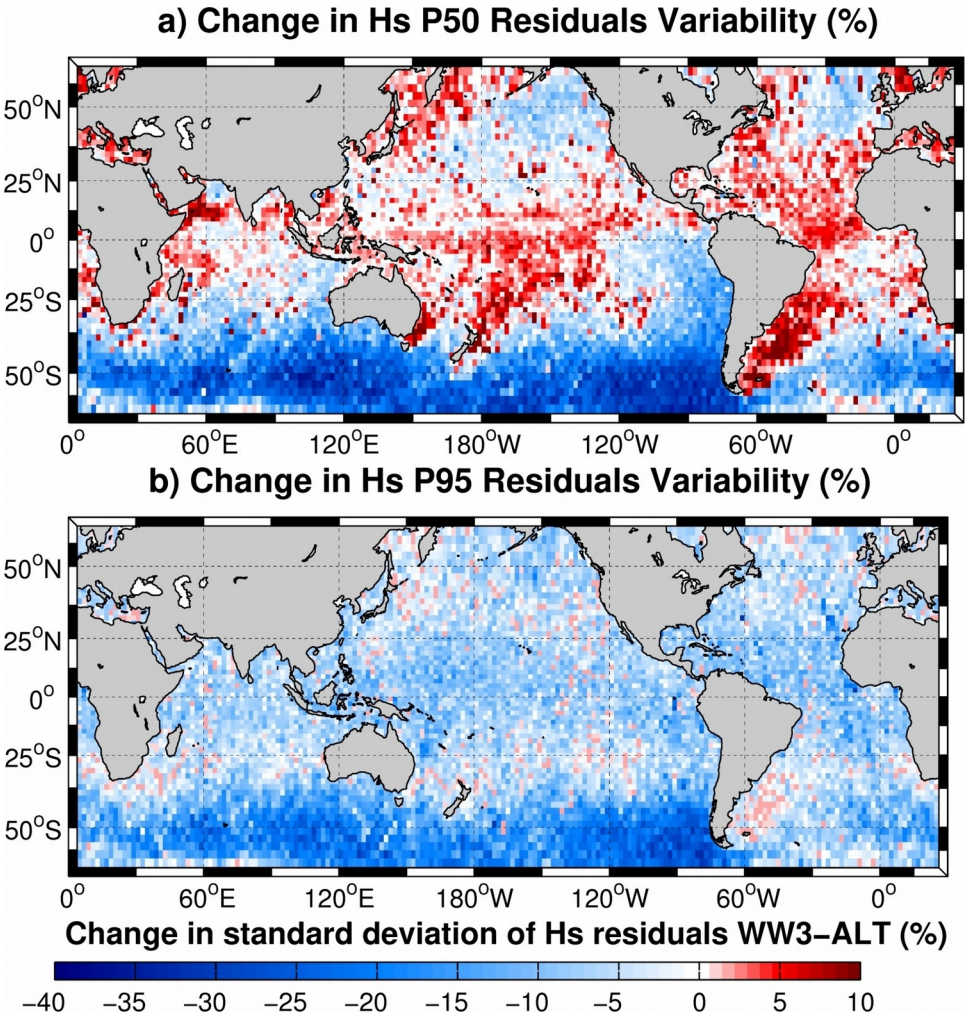




2 Method
Before & After

-Strong seasonality in the Hs residuals… reduces after correction
-Near EQ – underestimating Hs

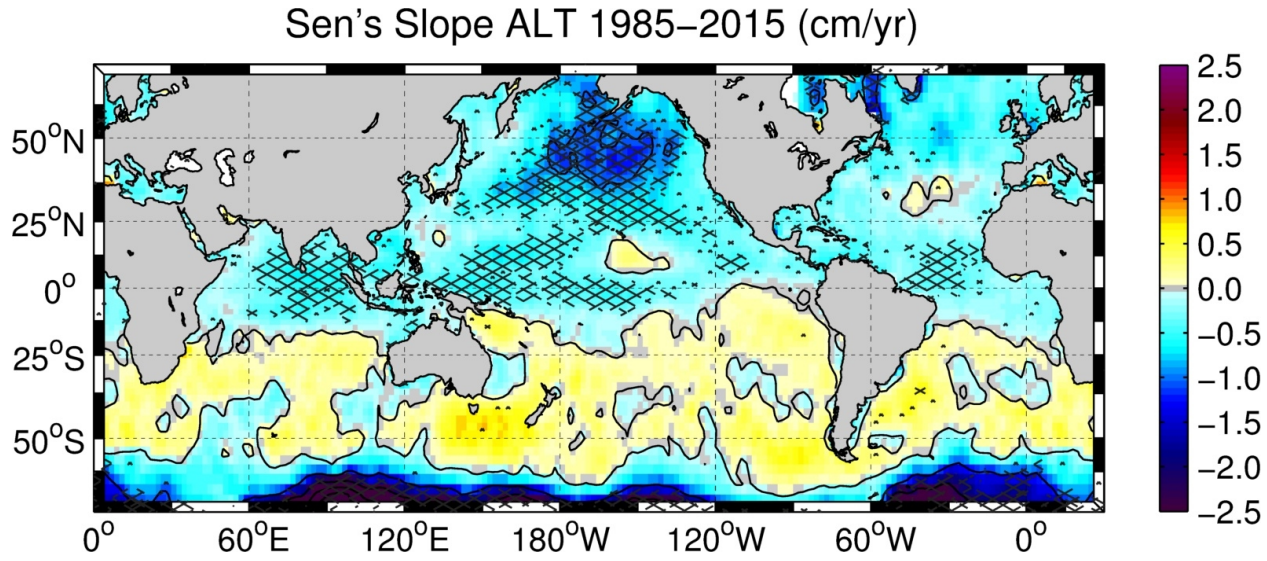
Change in variability of the Hs residuals
P50 – strong reduction in SO, some increase mostly < 10 %
P95 – strong reduction in SO, mostly reducing across the global ocean

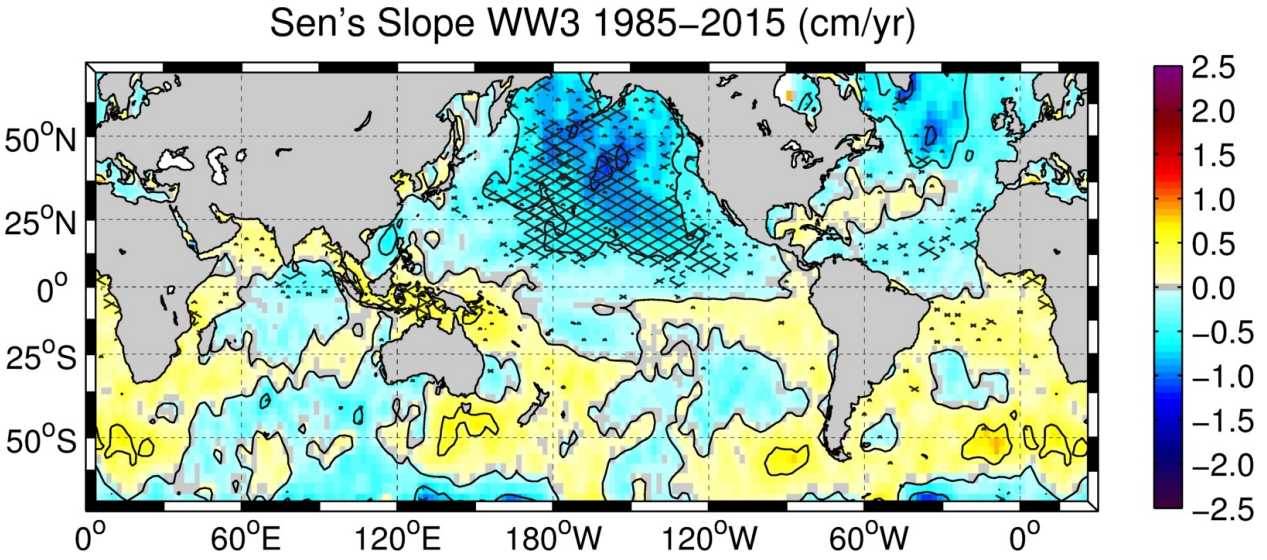


$$\sigma_v = \sqrt{\frac{\sum_{k=1}^{M}\left((v_{k,WW3} - v_{k,ALT}) - \overline{(v_{k,WW3} - v_{k,ALT})}\right)^2}{M-1}}$$

$$\Delta\sigma = \frac{\sigma_{v,MOD} - \sigma_{v,ORG}}{\sigma_{v,ORG}} \times 100$$

2 Methods
Trend verification





Trend of monthly averaged Hs (cm/yr)

-WW3 and ALT agree!

-Disagree in N. Indian Ocean – high variability

3

Verification

-Buoys

-Seismic

3 Verification Buoys

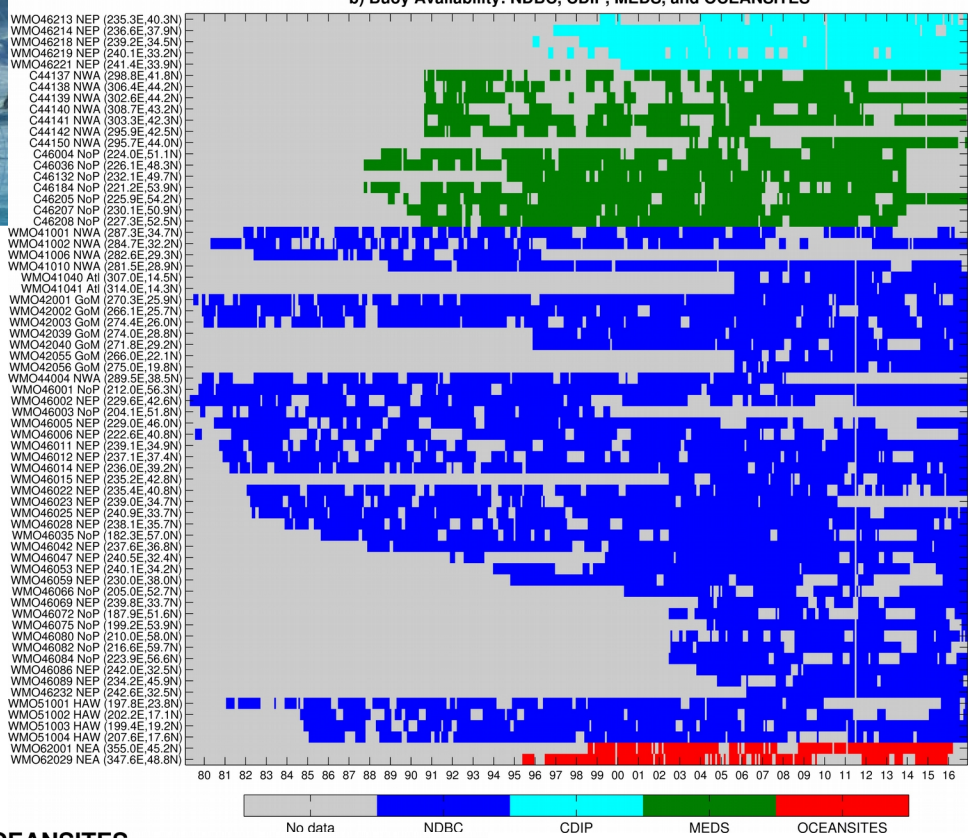
Hs from moored buoys

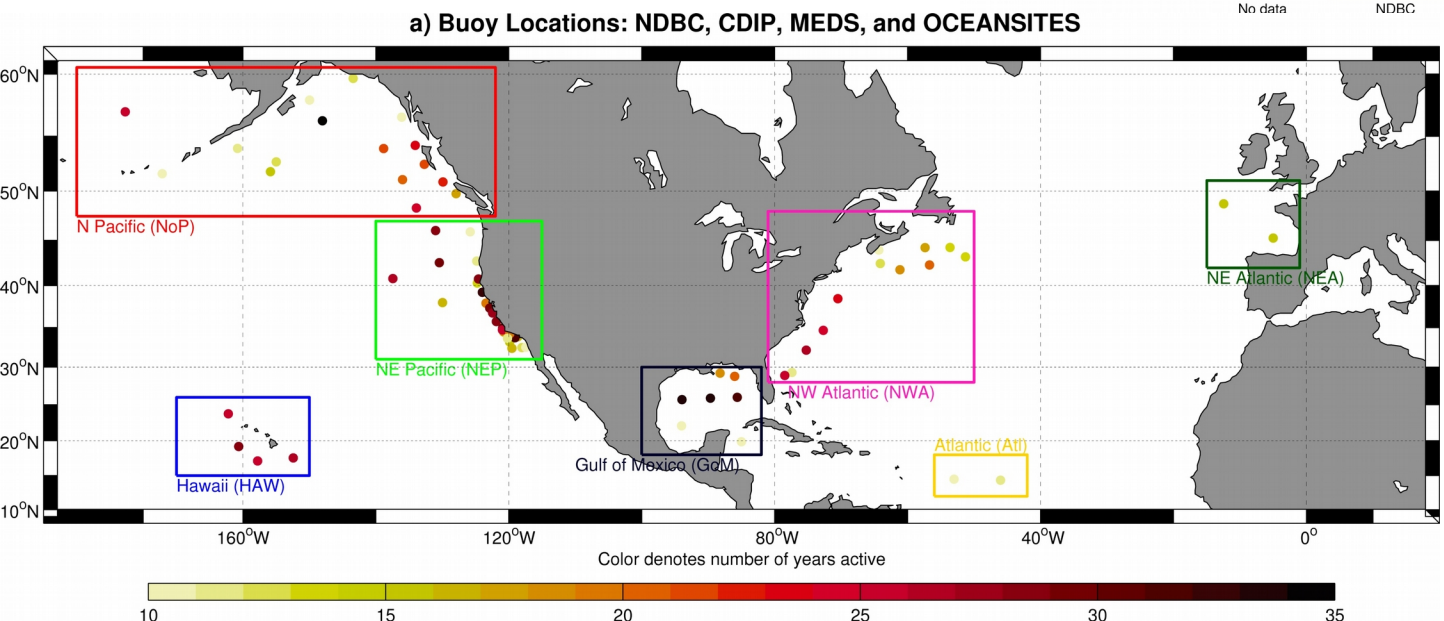
-NDBC, CDIP, MEDS, OCEANSITES

-Deep water (>200 m), far from coastlines >50 km and >10 years of data

-limited to NH, few data in the 1980s

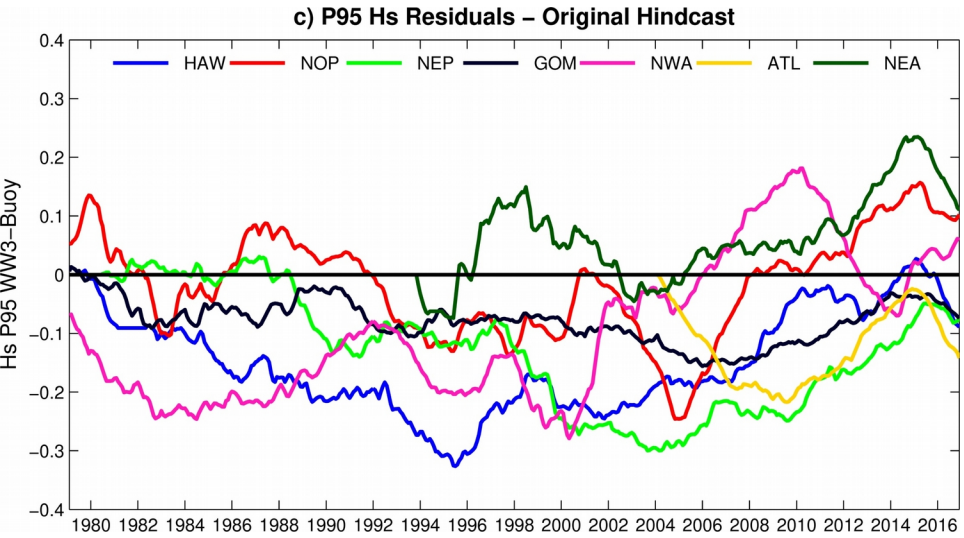
-numerous hull and payload changes...



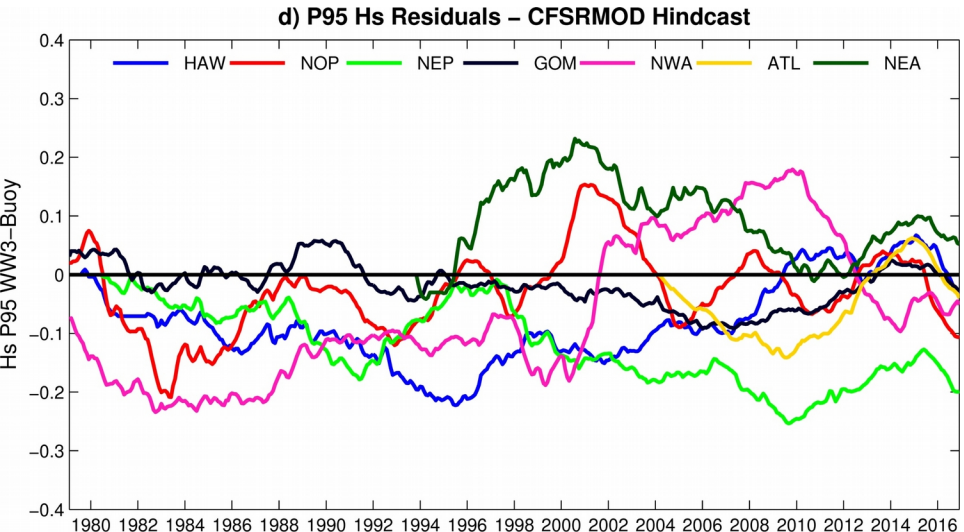


3 Verification Buoys

CFSR Original



CFSR Modified



P95 Hs residuals (WW3-buoy) per region

After correction
-not much difference… <5% change in the variability
-biases mostly reduce
-trend 2010-2016 reduces

-dominant features of buoy residuals persist before and after correction

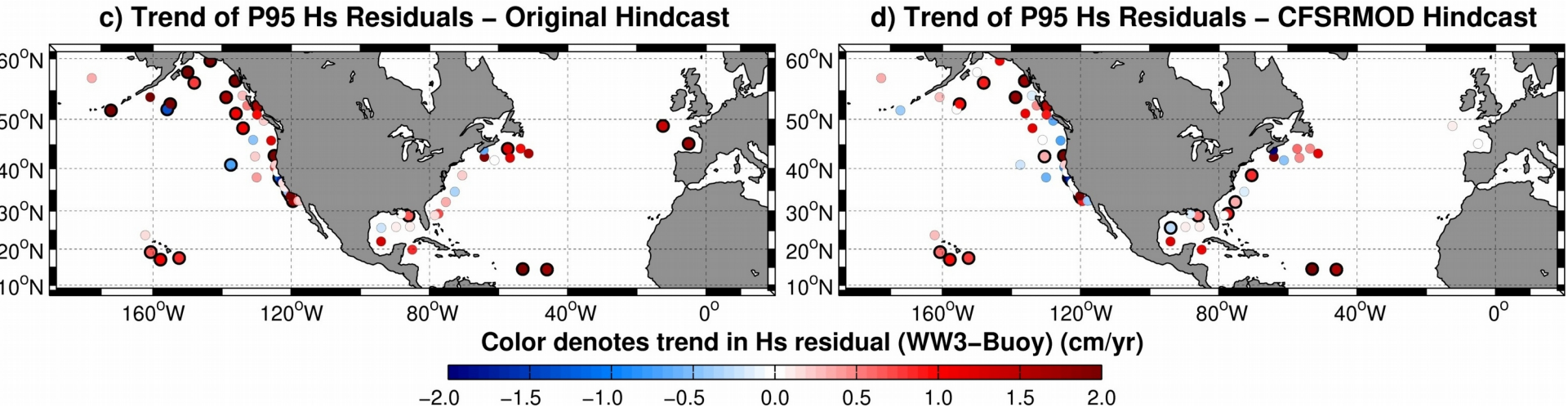
3 Verification Buoys

Sen's slope computed per monthly time series with MK test (dark circles CI 95%)

-37 (55%) trend of Hs residual reduces
-22 (32%) not significant
-9 (13%) trend of Hs residual increases

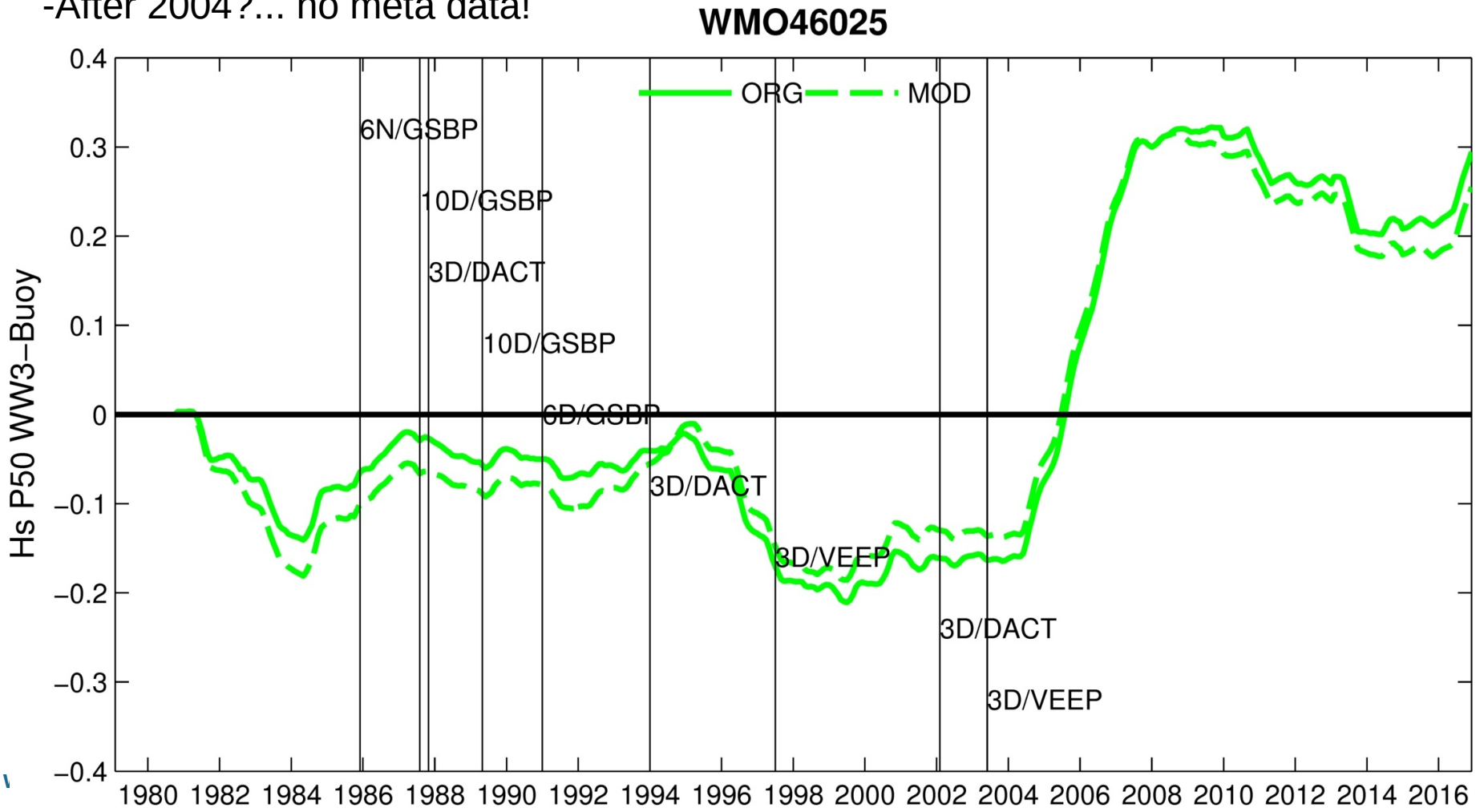
-Some buoys have same features after correction (e.g. buoys near Hawaii)

-Generally an improvement after correction… but it is subtle



3 Verification Buoys

-Meta data from NDBC 46025 in NEP (West of Santa Monica)
-No clear change in modified hindcast
-Residuals might be caused by changes in hulls and payloads
-After 2004?... no meta data!



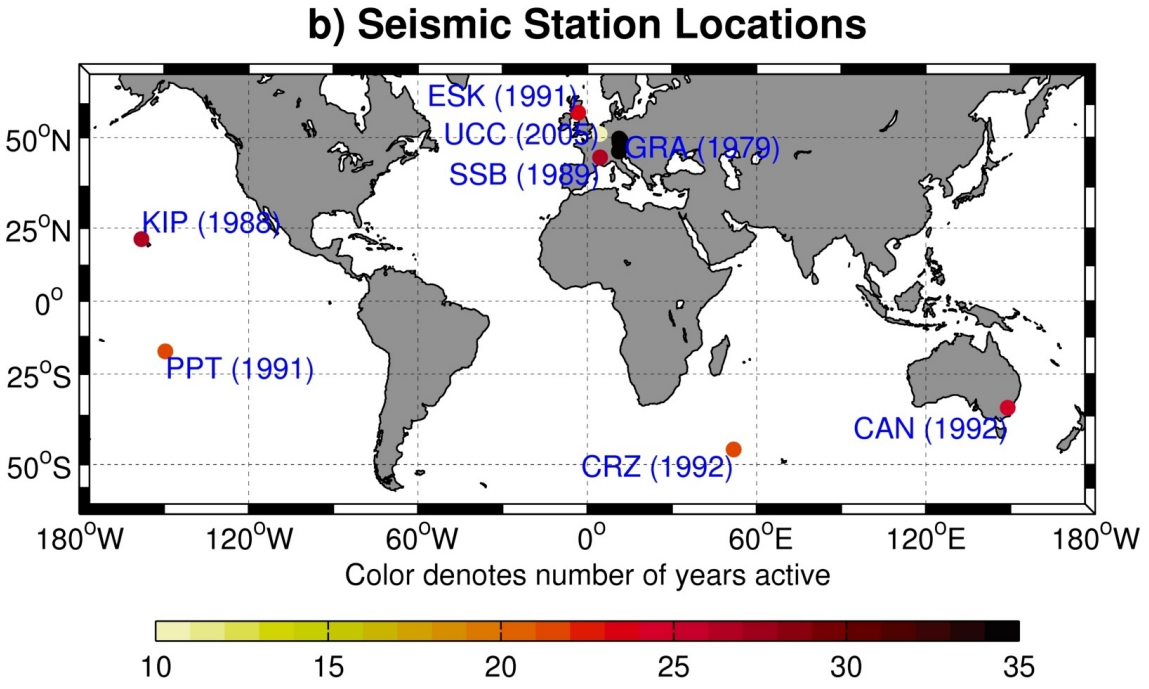
3 Verification
Seismic Stations

-Focused on these stations but there many seismic stations worldwide (GSN, GEOSCOPE)

-Many digital records extend back several decades

-Data exist in the SH!

-Stations CRZ, CAN, PPT are highly valuable data



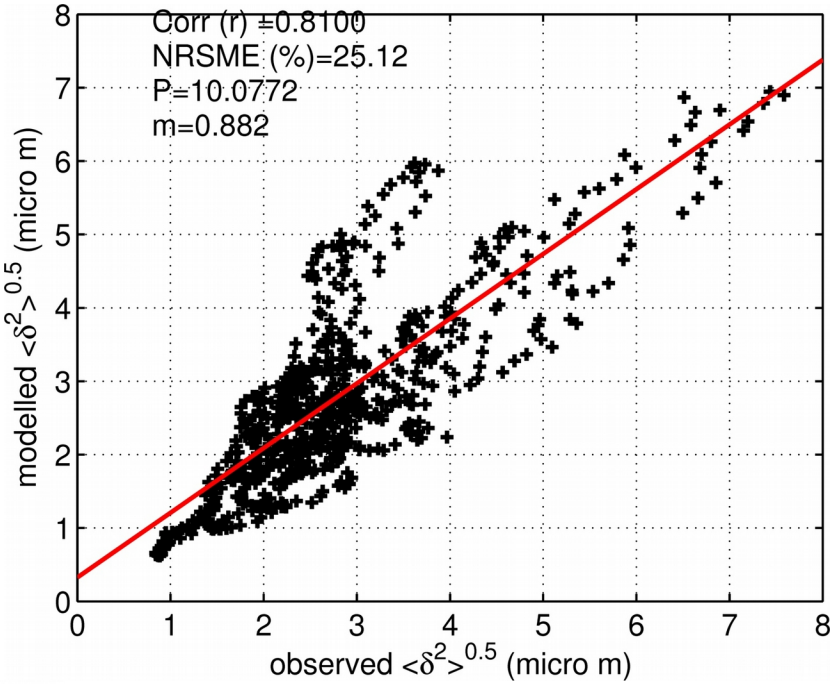
3 Verification
KIP example

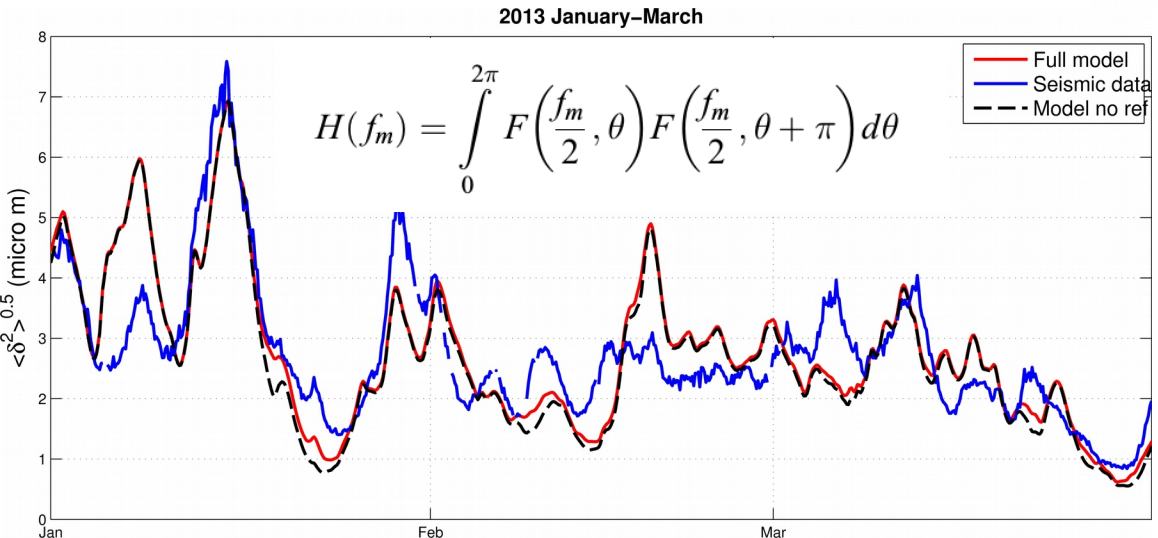
-E(f) are required globally to estimate the overlap integral (equal wavelength, opposing directions)

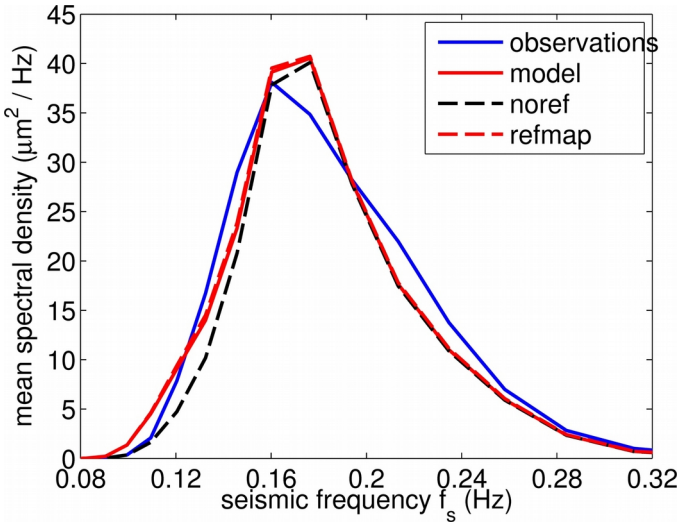
-Seismic energy from the model is propagated to the station (a function of the Earth's crust)

-Use a global reflection to estimate the Earth's displacement at the seismic station… response is linear

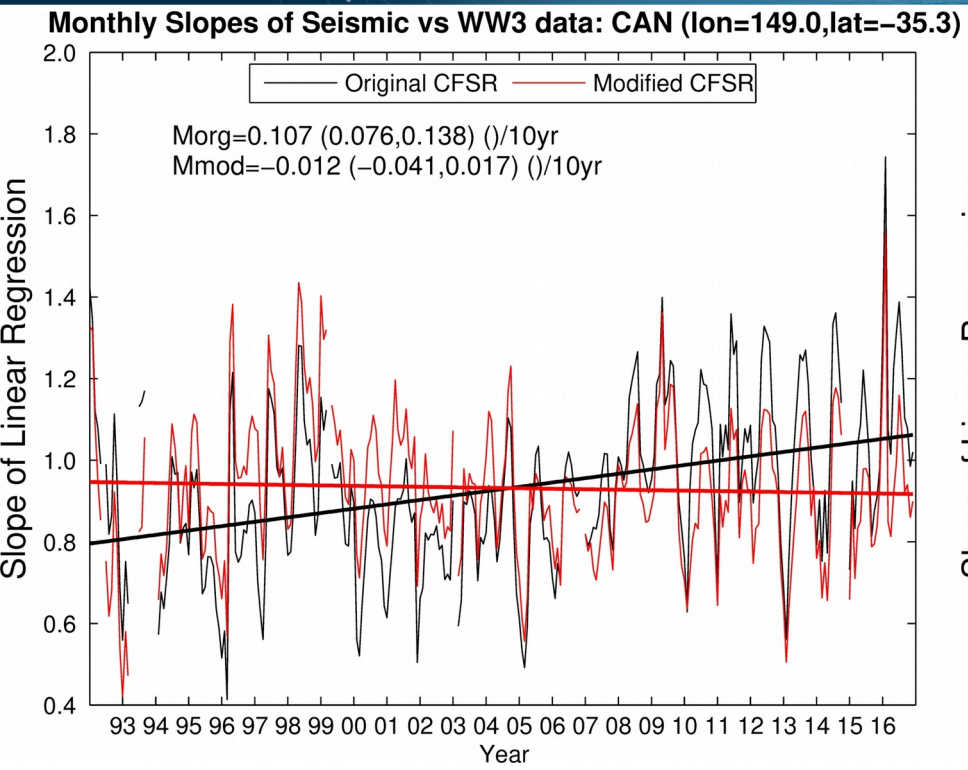
-Longuet-Higgins (1950); Hasselmann (1963); Ardhuin and Herbers (2013)

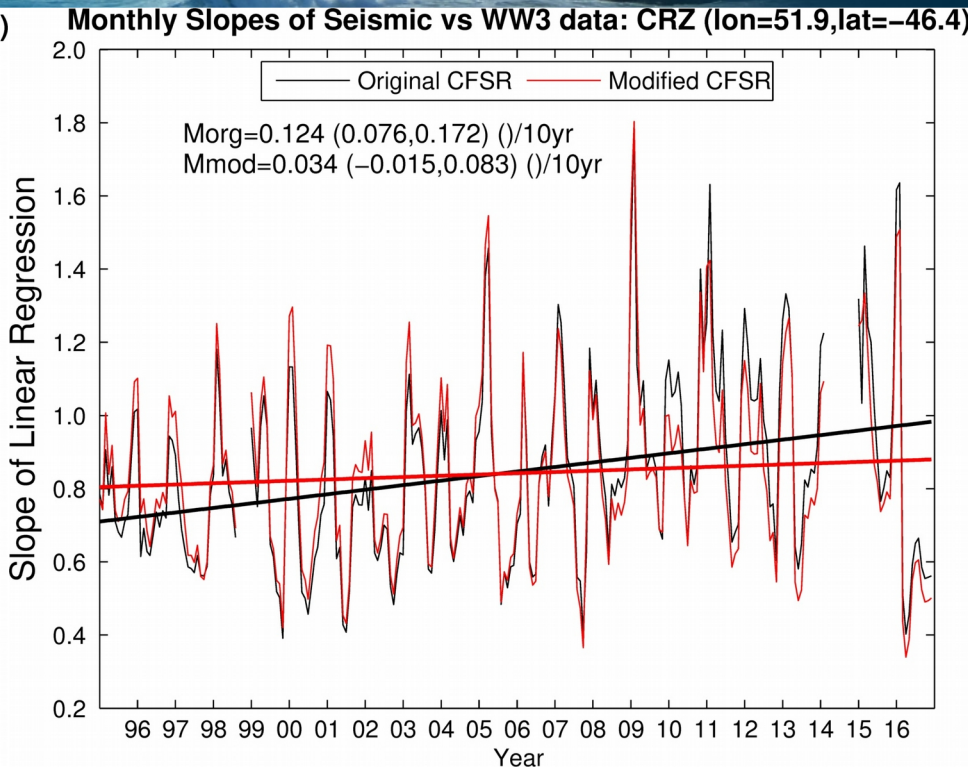






3 Verification
Examples: CAN and CRZ



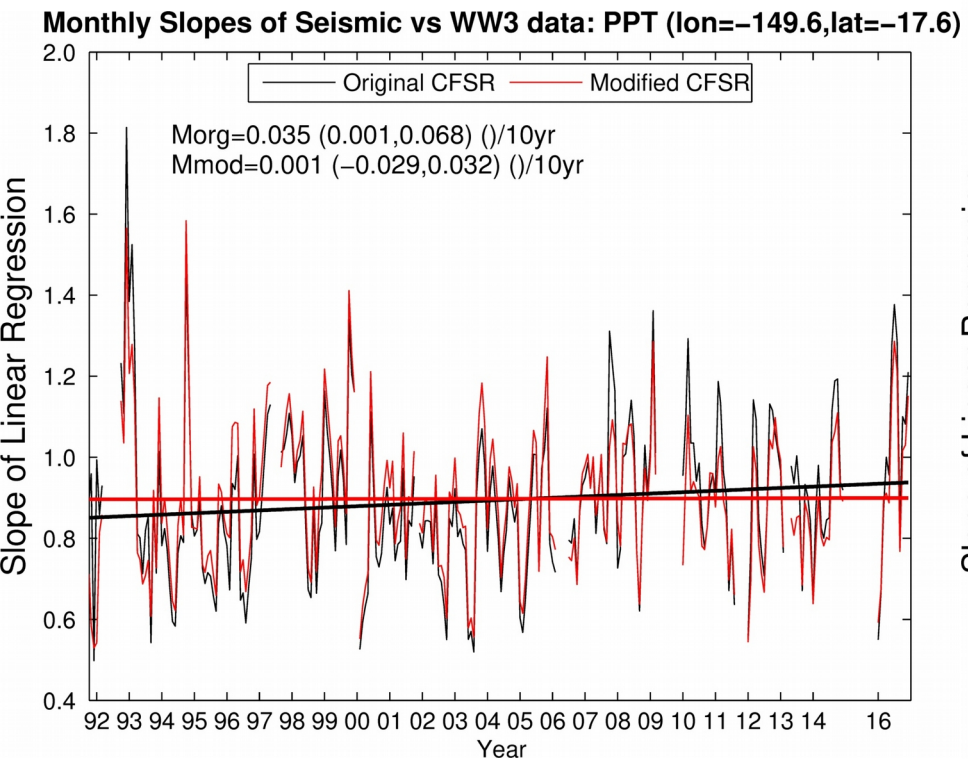


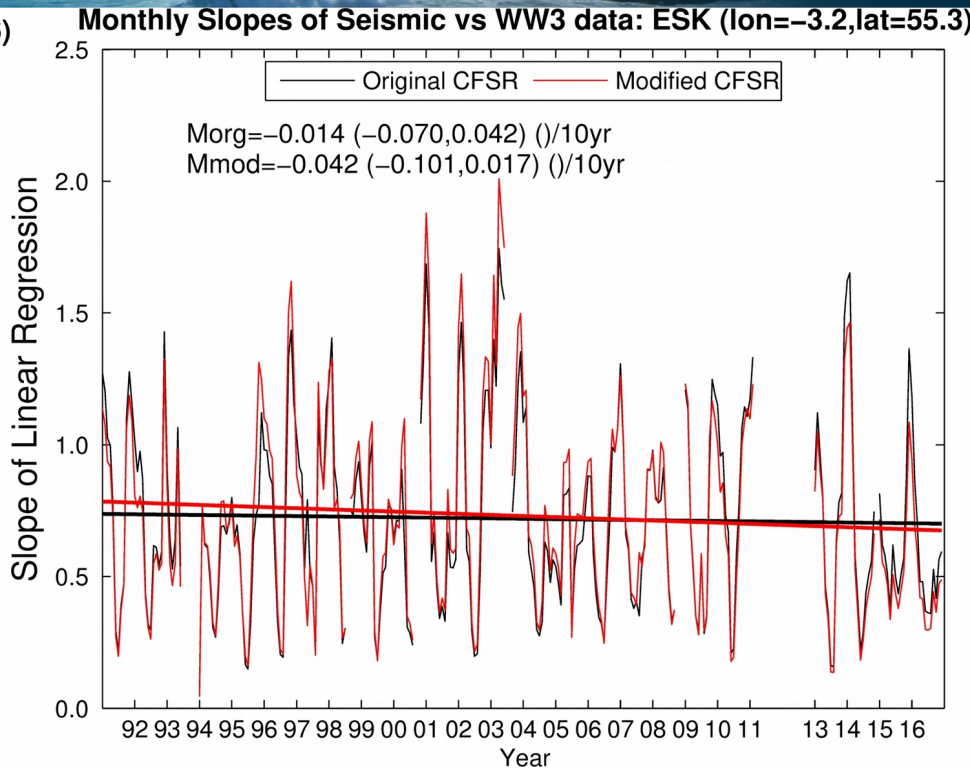
-In both cases the homogeneity of the hindcast improves (slope reduces)

-Most convincing evidence showing the improvement of the modified CFSR hindcast

-Suggests the altimeters are consistent and the correction created over these large regions is adequate

3 Verification
Examples: PPT and ESK





-PPT: improvement in homogeneity but not statistically significant

-ESK: degradation in homogeneity but not statistically significant

-Other stations in NH: only subtle improvements and not statistically significant

4

Conclusion & Discussion

4. Conclusion

- Proposed modification created from Hs residuals applied to CFSR U10 reduces Hs biases as a function of time

- Verification with buoys – only subtle improvements of hindcast homogeneity; changes in buoy hull and sensor might be dominating the residuals

- Verification with seismic stations – SH wave hindcast homogeneity improved; NH minimal change in homogeneity

5. Discussion

- Having a consistent merged satellite dataset (Hs,U10) is key - ESA CCI

- What is causing the seasonality in the Hs residuals?
  - Possible reasons: Air-sea stability errors; Errors with CFSR; Air density effect in the wind input; Errors in swell

- Data consistency: What source can we trust (to measure Hs~1 cm/yr)?
  - Merged altimeters (conceivable): platform cross calibration
  - Seismic (possibly): sea state over large area
  - VOS (Vika? Sergey?): sparse sampling in SH and extremes
  - Wave hindcasts (not so much): quantity and quality of satellite observations assimilated changes with time
  - Buoys (not so much): too many changes in hull and sensors

Email: justin.stopa@ifremer.fr, stopa@hawaii.edu