A consistent wave hindcast using NCEP's Climate Forecast System Reanalysis

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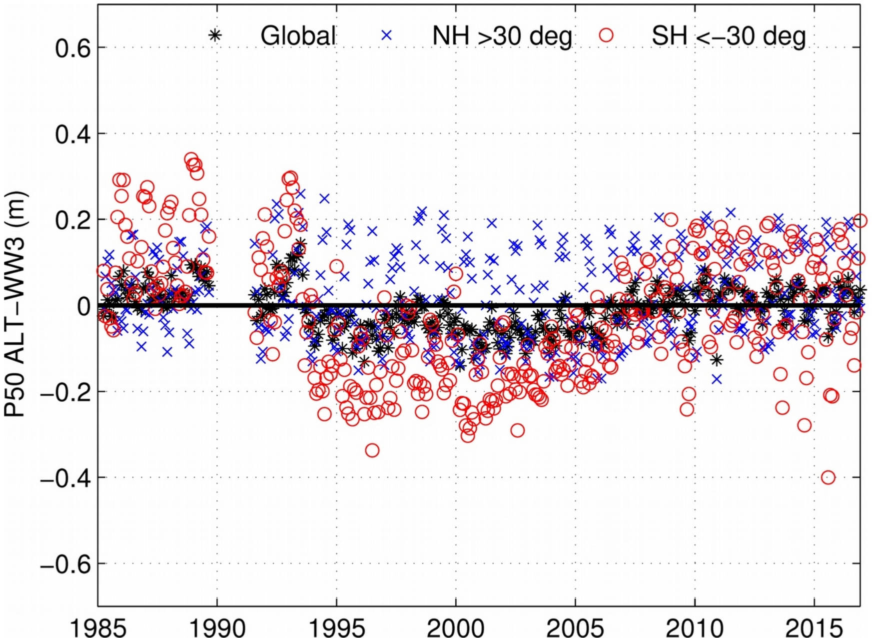
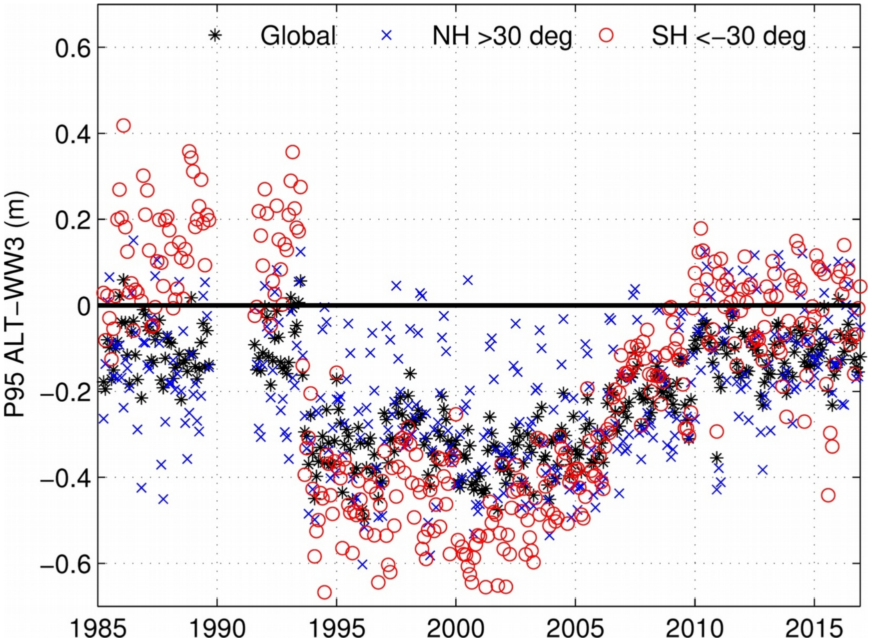
1 Introduction
Why CFSR?

-Not the best choice for climate studies…
- many changes in errors:
  - 1994 step change (SSM/I)
  - increasing trend 2004-2009
  - 2011-2016 v2
  - difference in NH and SH

P50 : WAVEWATCH-ALT



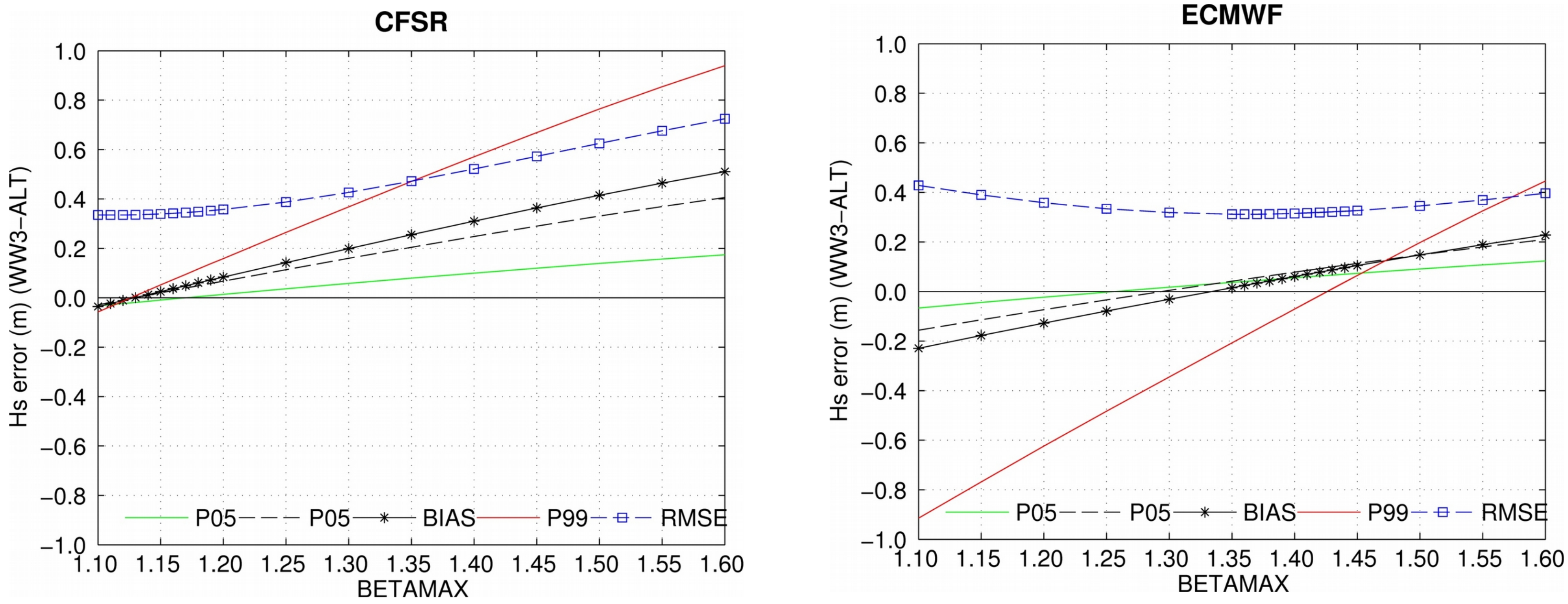
P95 : WAVEWATCH-ALT



1 Introduction
Why CFSR?

-U10 is higher than observations, however we can calibrate the wave model (BETAMAX)

1-degree global errors (2015) – colocated with altimeters



Janssen (2004) : atmos→ocean (wave growth)

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

1 Introduction
Objective

<u>Wave hindcasts/reanlysis</u>

- **ERA-Interim is consistent but underestimates extreme Hs**
- **CFSR captures large sea states but is inconsistent in time**
  - **NCEP (*Chawla et al.*, 2013); Ifremer (*Rascle and Ardhuin*, 2013)**
  - **GOWv2- extremes reasonably captured (*Perez et al.*, 2017)**
- **JRA55?**
- **ERA5 soon!**

For climate studies: a consistent time series is essential!

- **Especially when studying inter-annual variability, trends, extremes using statistical extrapolation**

Objective → Create a consistent wave hindcast that resolves high sea states

Outline

1) Introduction - Why CFSR?

2) Proposed Correction

3) Independent verification with buoys and seismic

4) Conclusion and outlook

2

Methods

-Proposed Correction

2 Methods
Datasets: ALT

Hs and U10 from altimeters

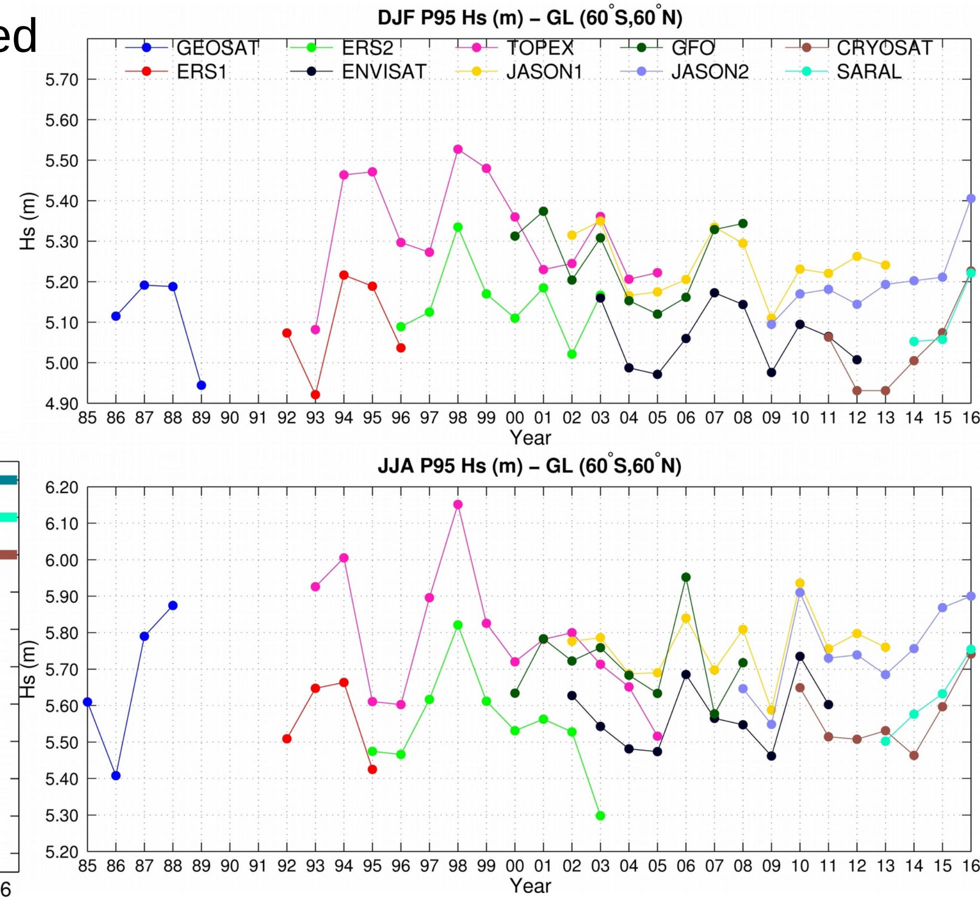
-Near continuous coverage since mid-1985

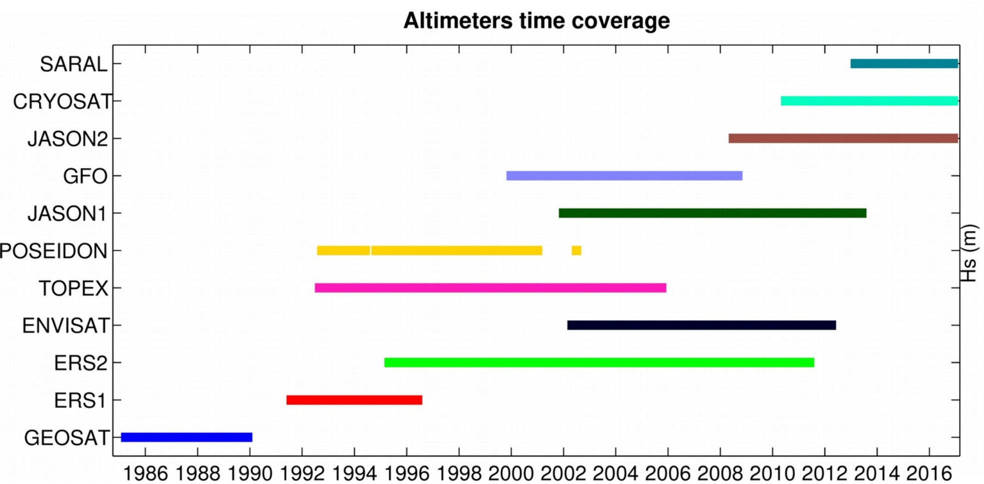
-Calibrated (to buoys) and quality controlled

-Relatively consistent in time

-ESA CCI will revisit...

Altimeters-Hs P99 : platforms <8% difference !





Queffeulou and Croize-Fillon, 2016

2 Methods
Proposed Correction

-U10 and Hs residuals are similar as function of latitude

-Correction applied to U10 for each month as a function of the P95 Hs residuals

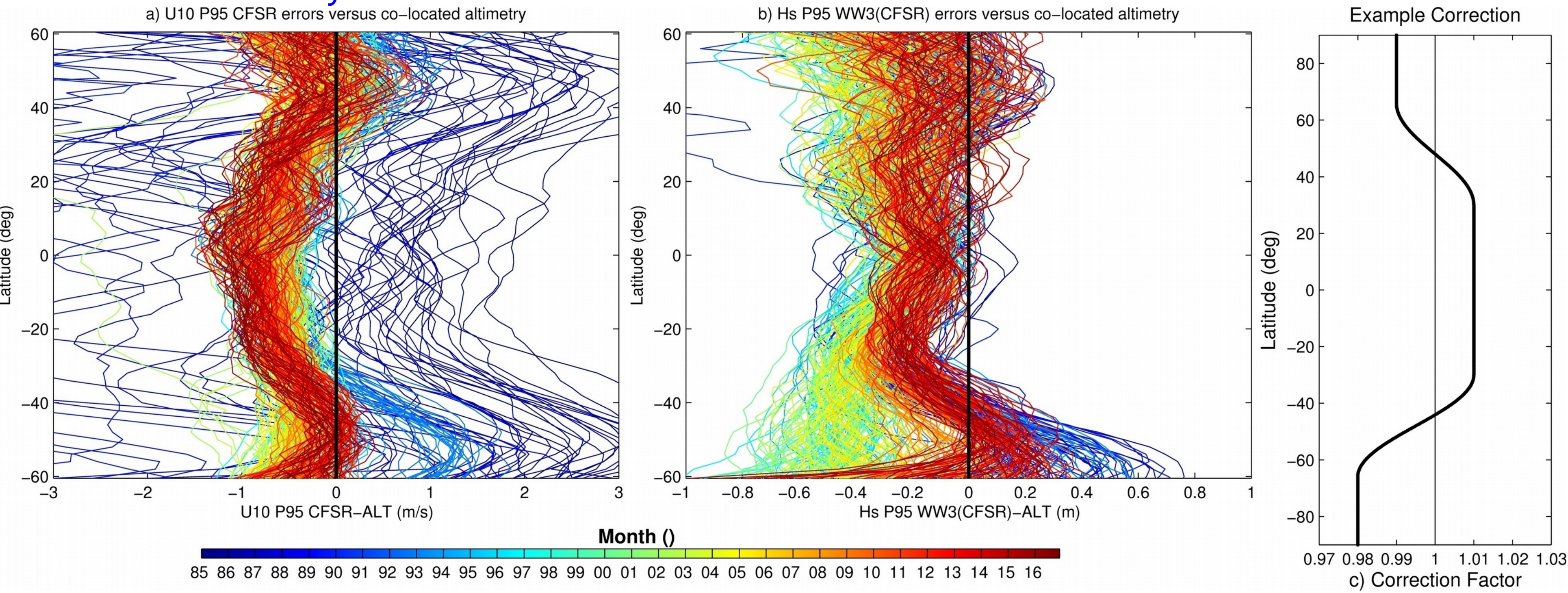
-To counter-act the U10/Hs errors we propose the following as function of latitude

$$C(y_i) = \begin{cases} F_g, & y_i < |15°| \\ F_g + F_j\left[\frac{1}{2}\left(1 - cos\left(\frac{\pi}{N-1}(i-I)\right)\right)\right], & |15°| \le y_i \le |65°| \\ F_g + F_j, & y_i > 65° \end{cases}$$

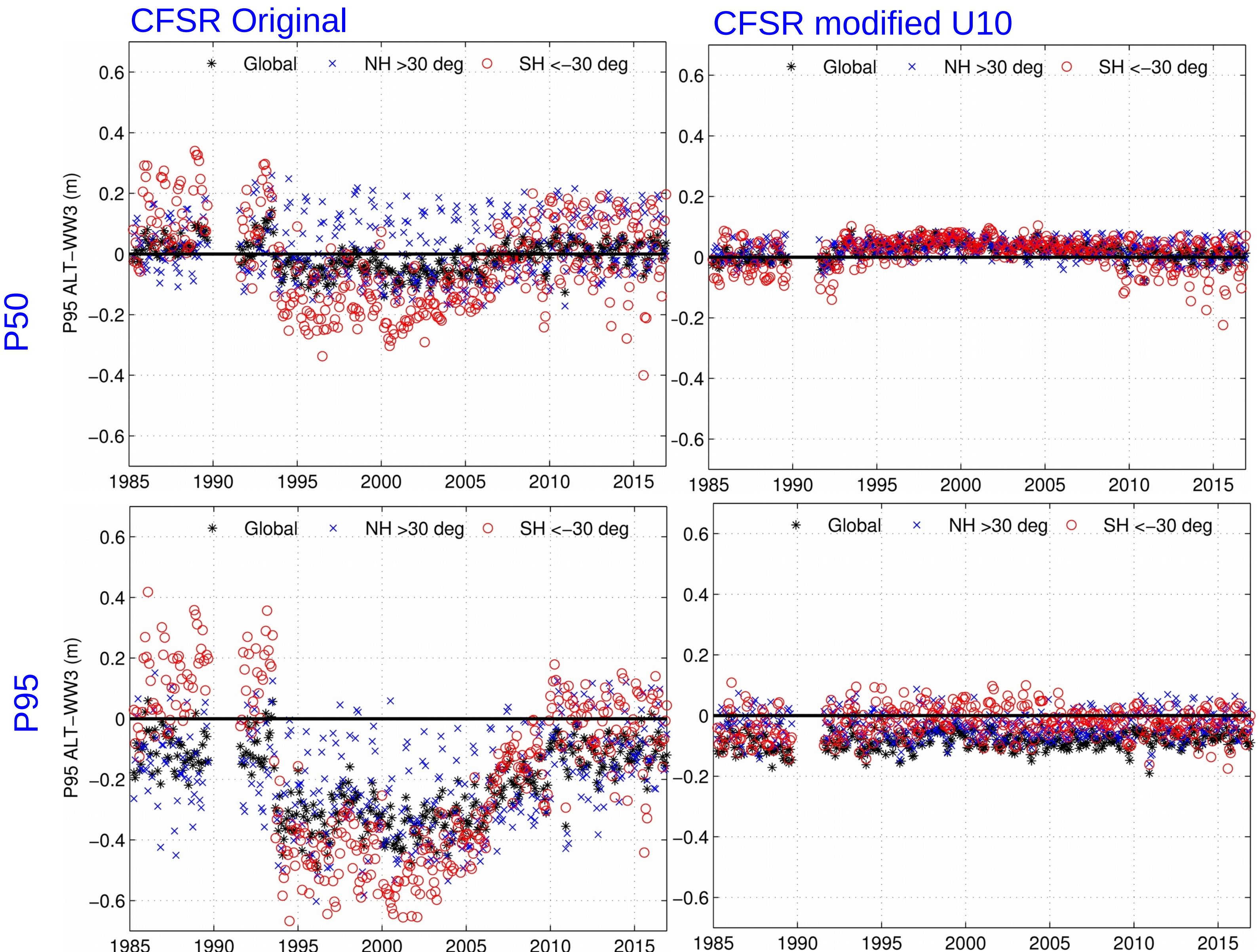
ΔHs_{P95} > 30 N/S

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

U10 & Hs monthly differences a function of latitude



2 Methods
Before & After

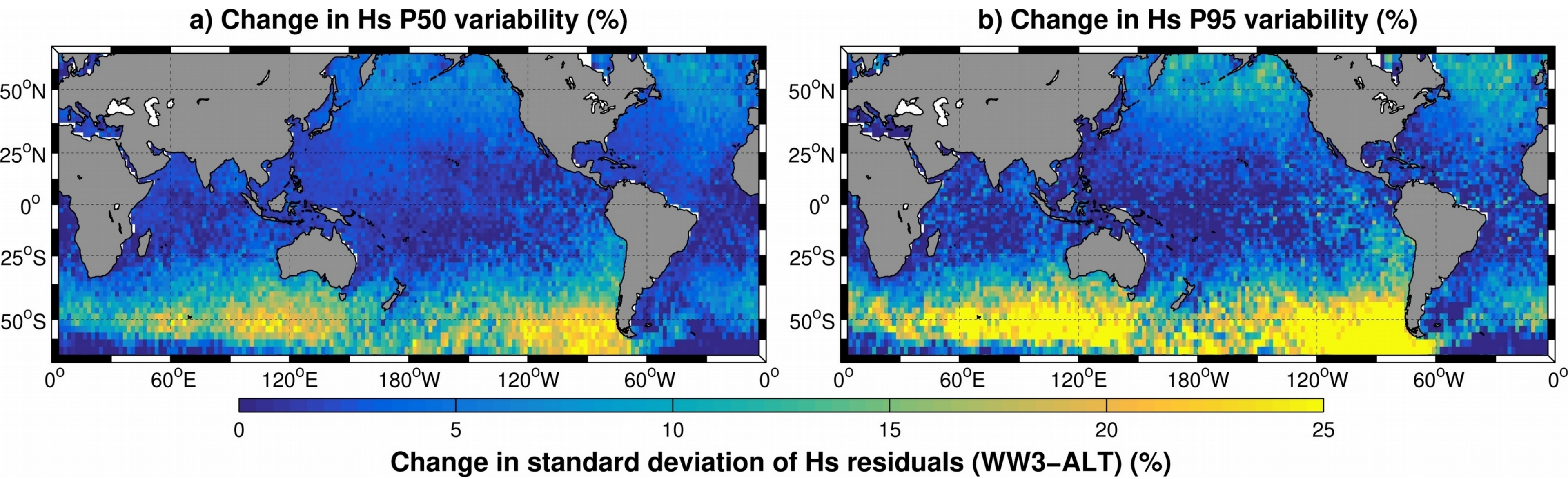


2 Methods
Before & After

Spatial view of change in Hs residuals

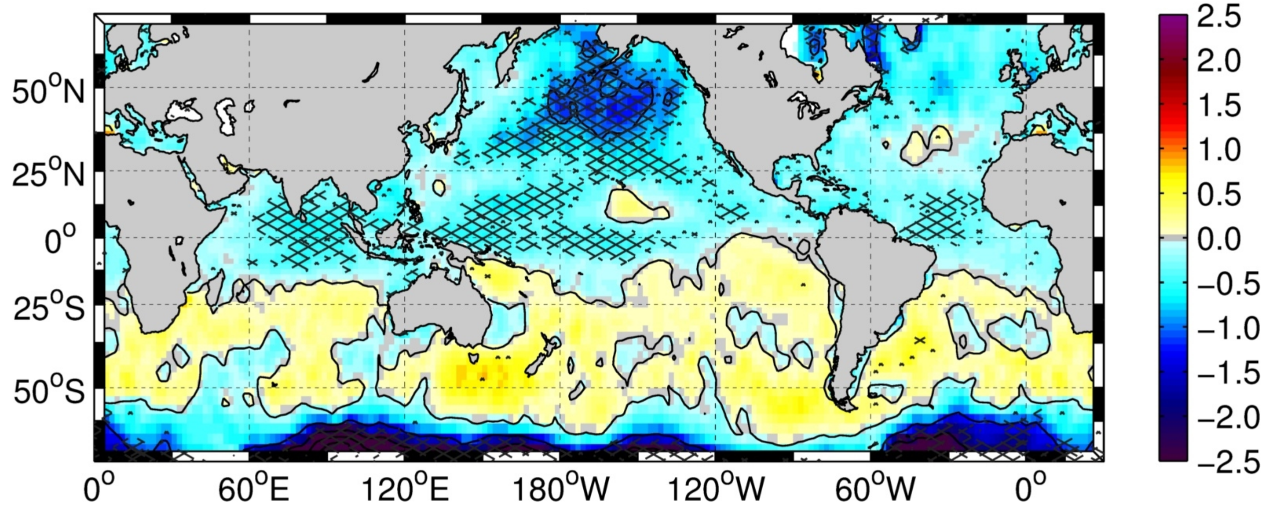
-largest changes in the extra-tropics especially SH
<3% change in the tropics
>25% change in P95

$$\Delta\sigma = \frac{\sigma_{v,ORG} - \sigma_{v,MOD}}{\sigma_{v,ORG}} \times 100 \qquad \sigma_v = \sqrt{\frac{\sum_{k=1}^{M}\left((v_{k,WW3} - v_{k,ALT}) - \overline{(v_{k,WW3} - v_{k,ALT})}\right)^2}{M-1}}$$



2 Methods
Trend verification

Sen's Slope ALT 1985–2015 (cm/yr)

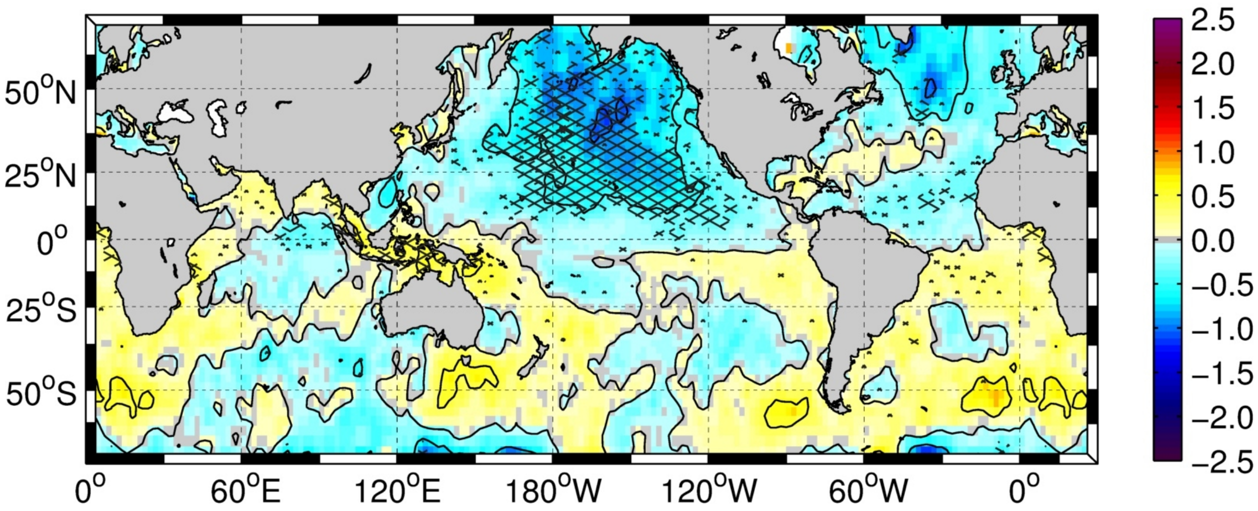


Trend of monthly averaged Hs (cm/yr)

-WW3 and ALT agree!

-Disagree in N. Indian Ocean – high variability

Sen's Slope WW3 1985–2015 (cm/yr)



3

Verification

-Buoys

-Seismic

3 Verification Buoys

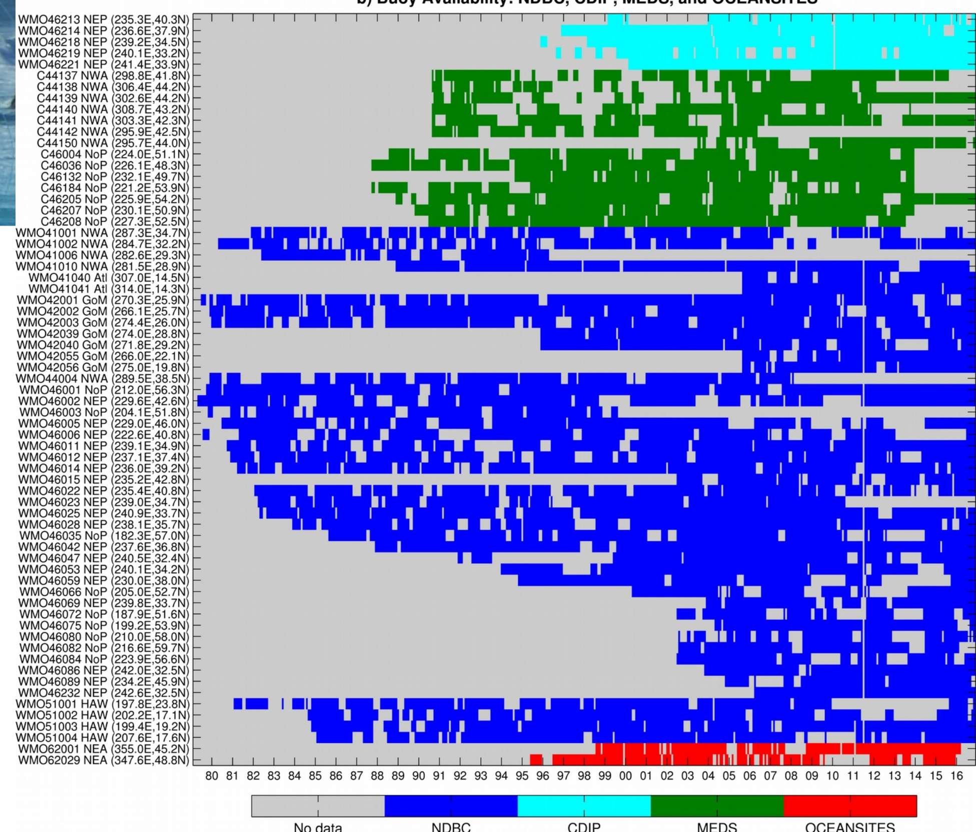
Hs from moored buoys

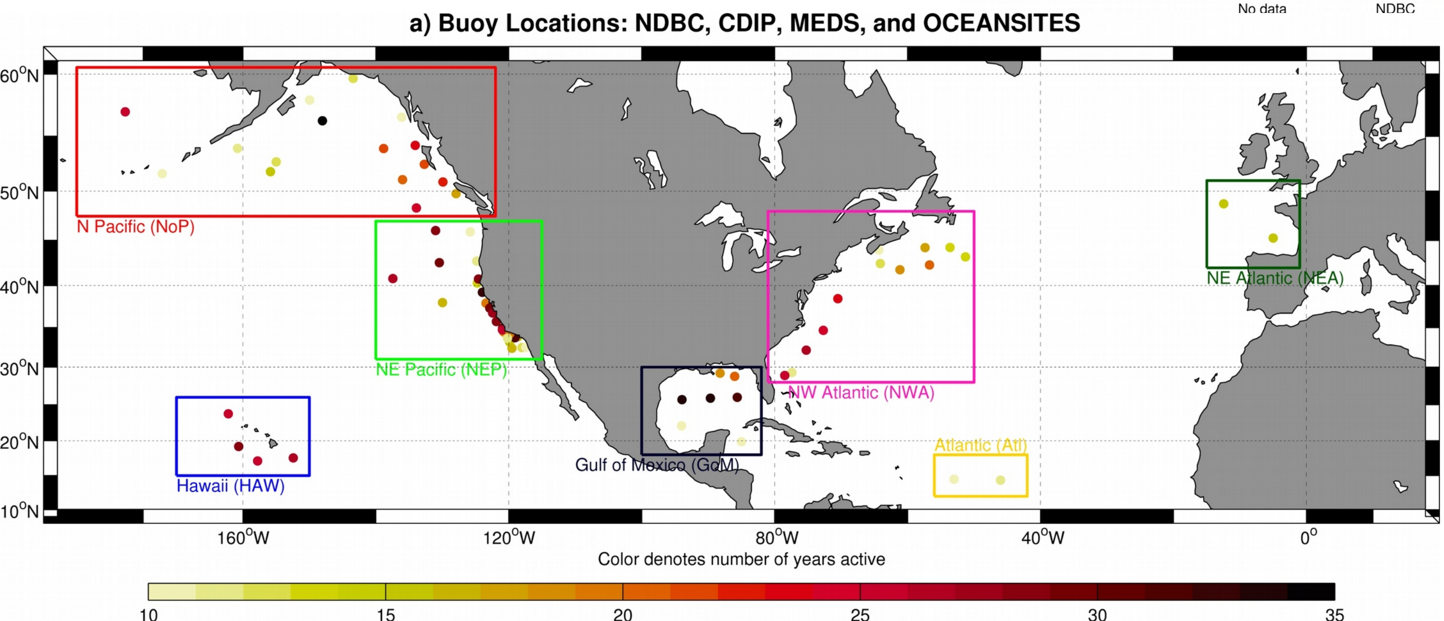
-NDBC, CDIP, MEDS, OCEANSITES

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

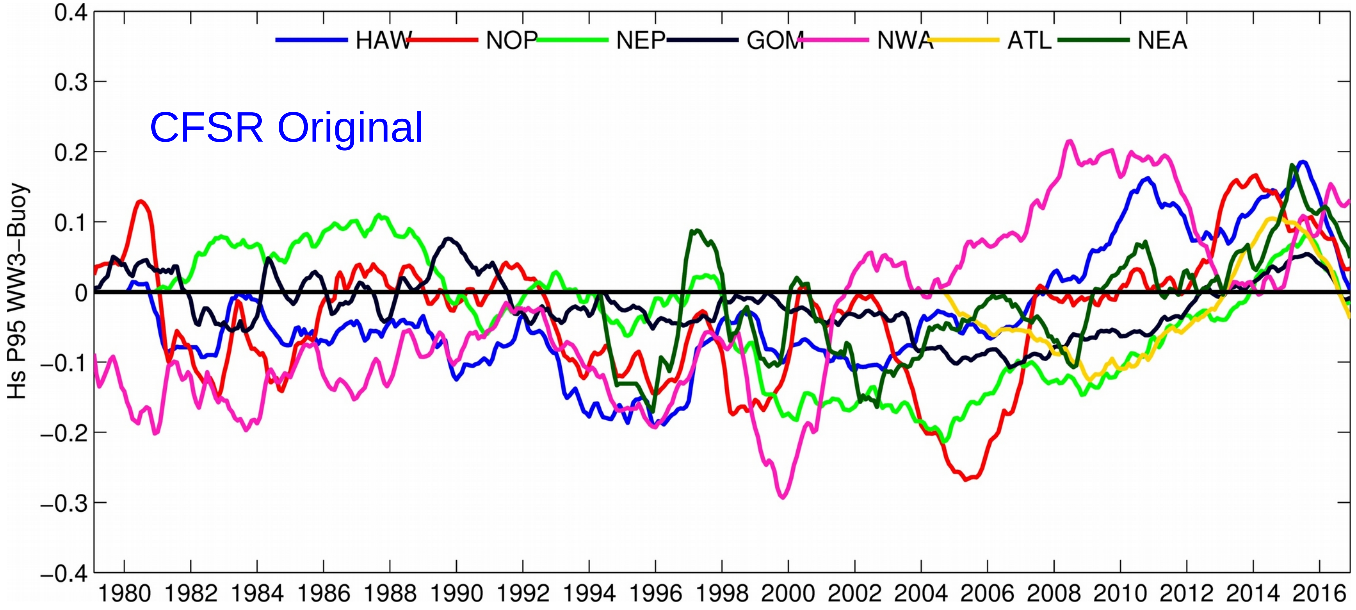
-limited to NH

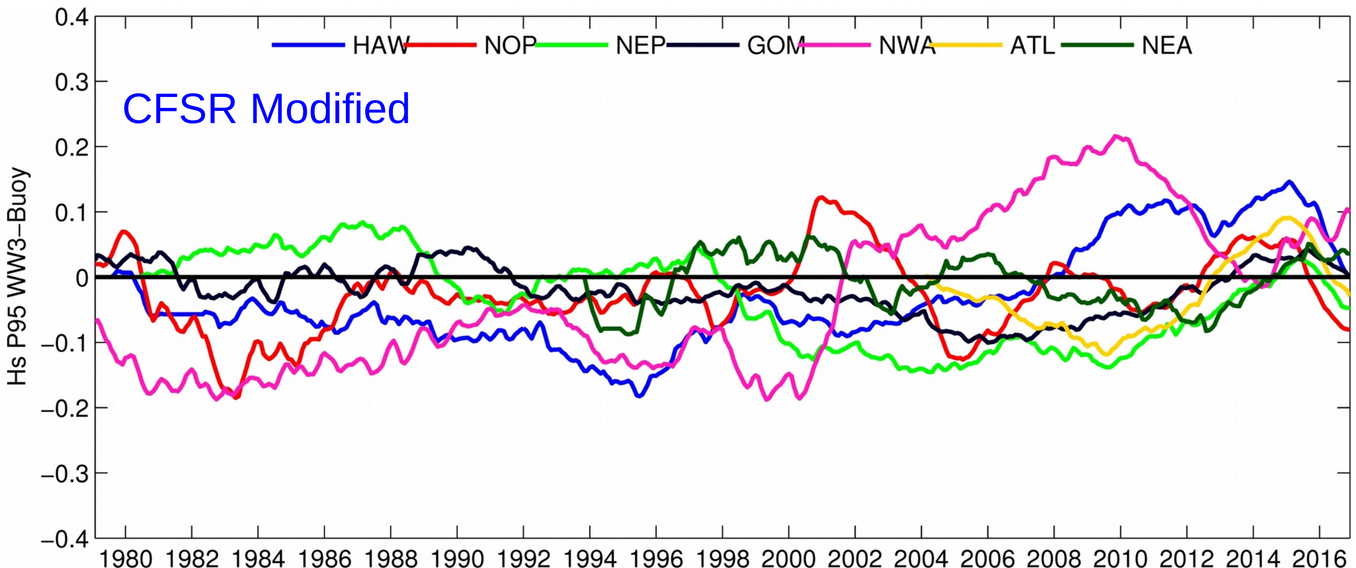
-Consistent in time… not so much





3 Verification Buoys





P95 Hs difference: model – buoy

After correction
-variability reduces
-trend 2010-2016 reduces

-dominant features within buoy residuals persist in both datasets

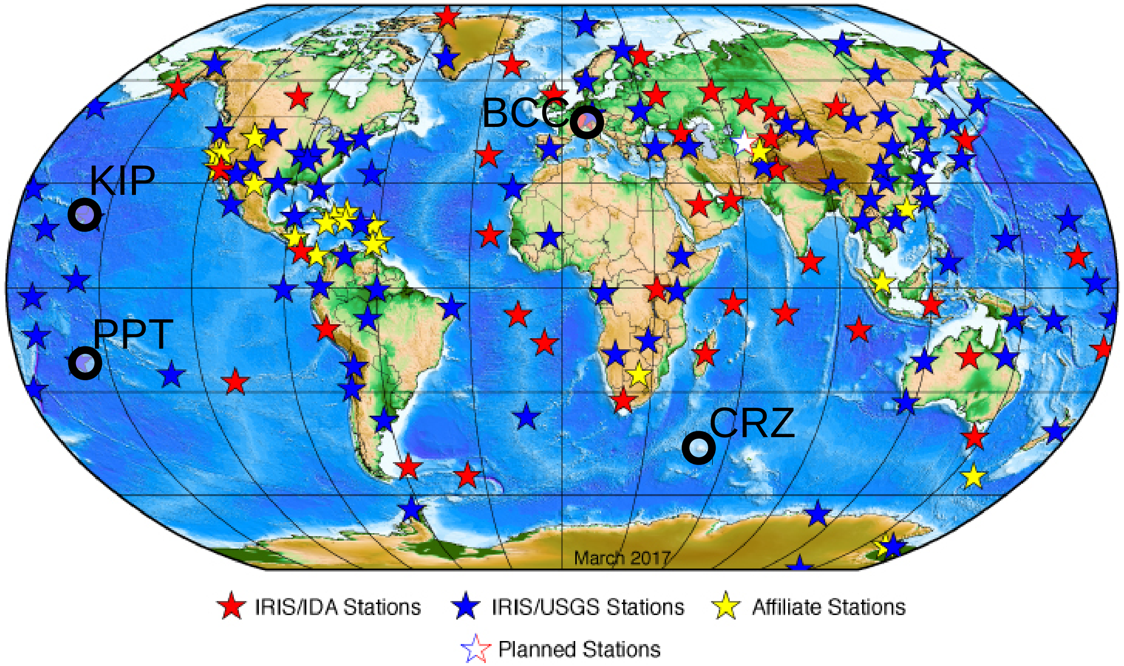
3 Verification
Seismic Stations

-Numerous seismic stations worldwide

-Many digital records extend back several decades

-Data exist in the SH!

-Many more stations exist



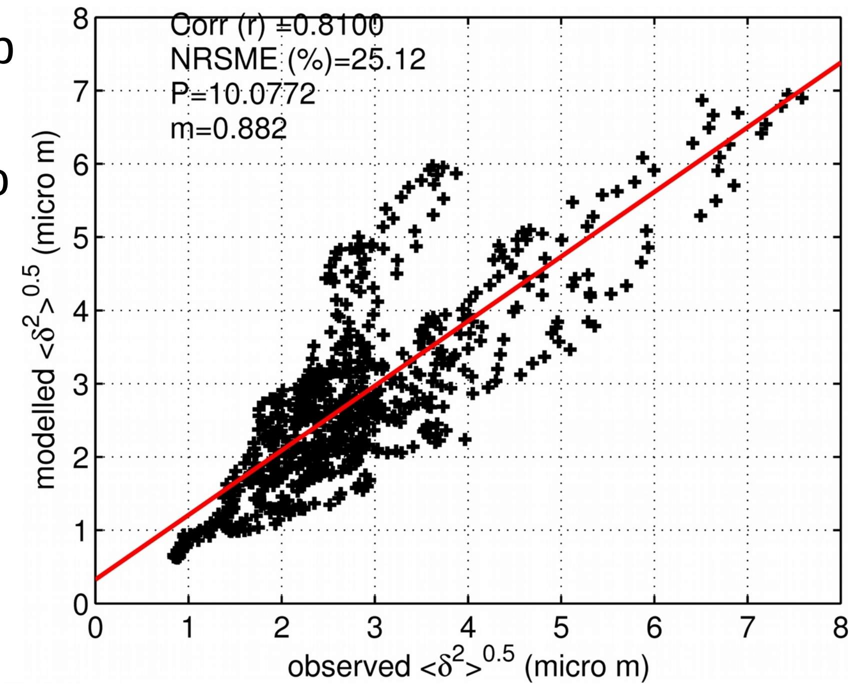
3 Verification
KIP example

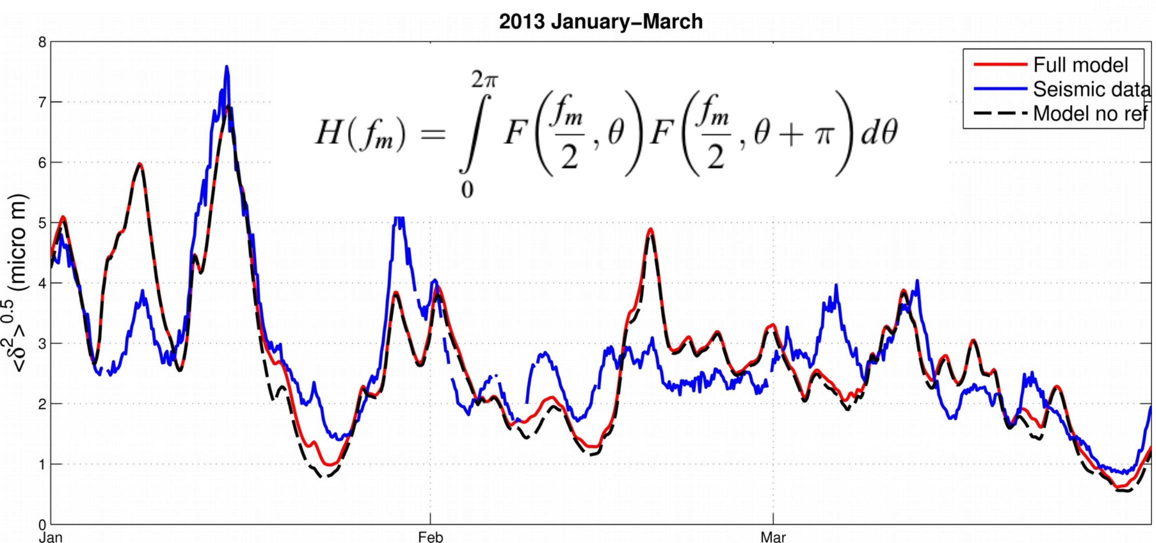
-E(f) are required globally to estimate the overlap integral (equal wavelength, opposing directions

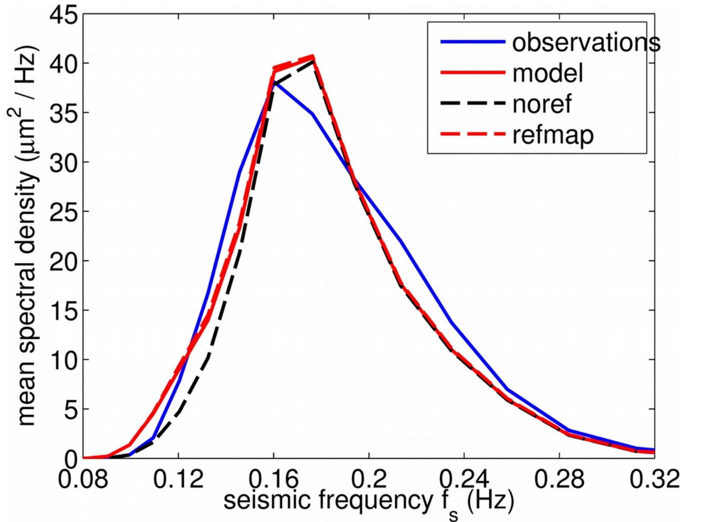
-Seismic energy from the model is propagated to the station (a function of the Earth's crust)

-2 model runs: w/ and w/o reflection are needed to best estimate the Earth's displacement at the seismic station (response is linear)

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



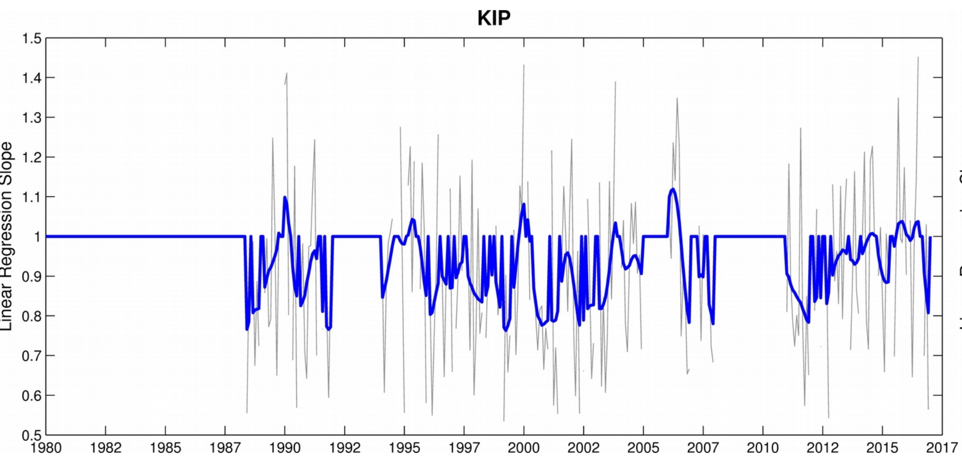


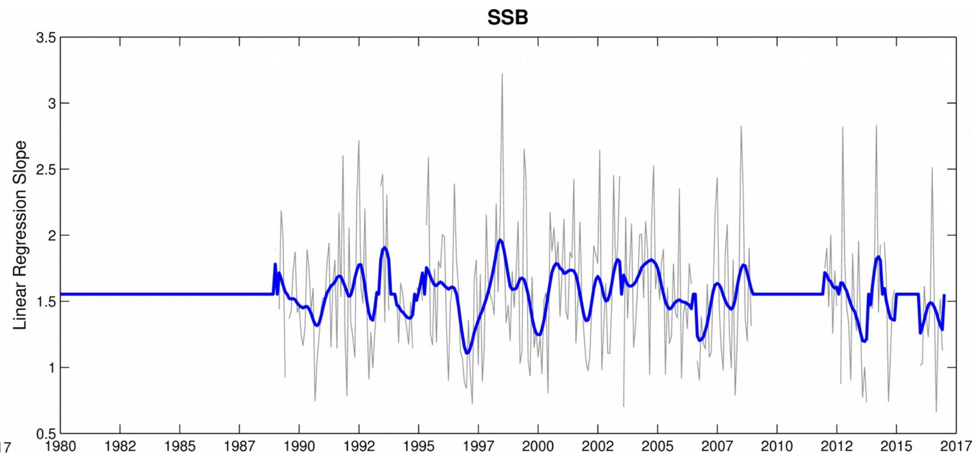


3 Verification

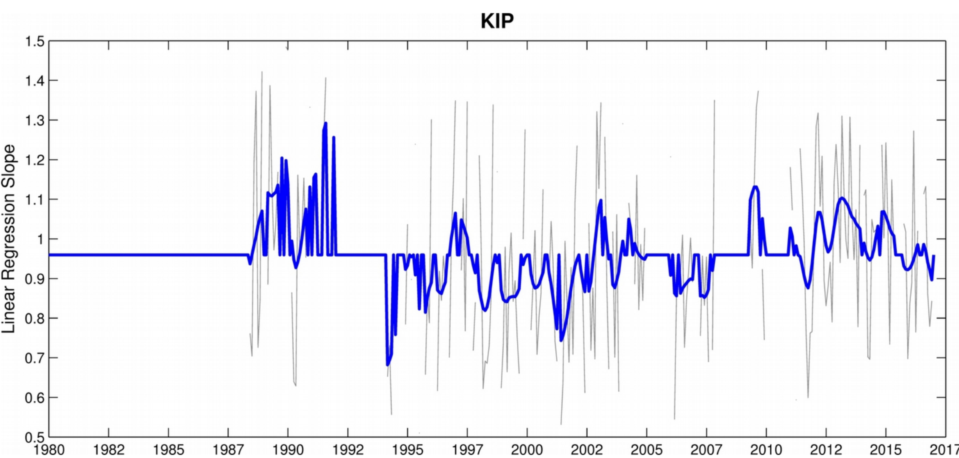
Seismic stations

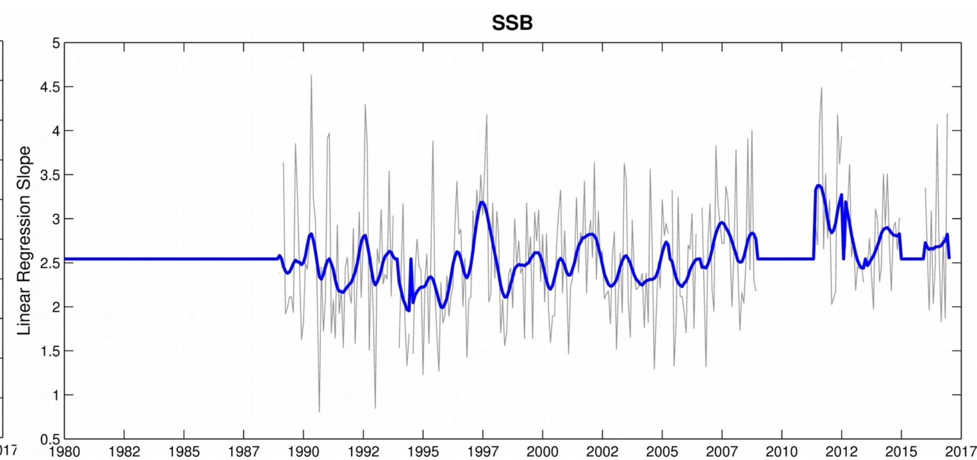
6<T<26 s : far-field waves





1.4<T<6 s : local waves – related to winds





3 Verification

Seismic stations

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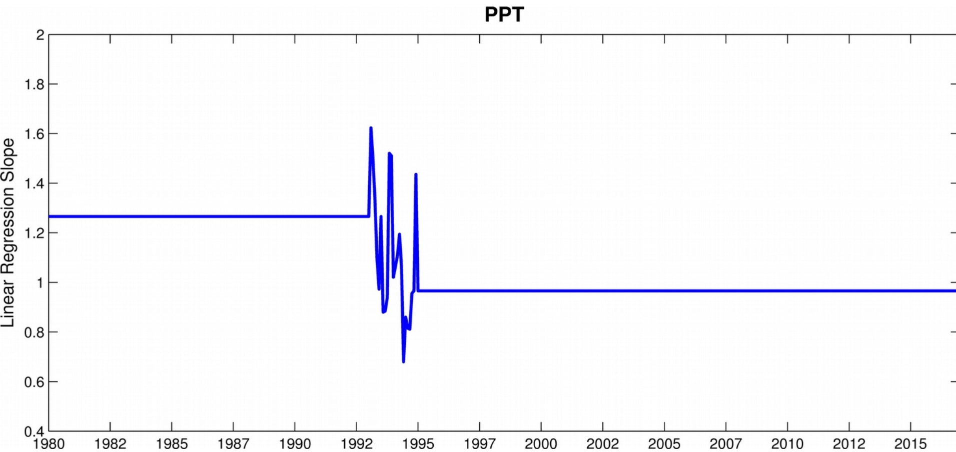

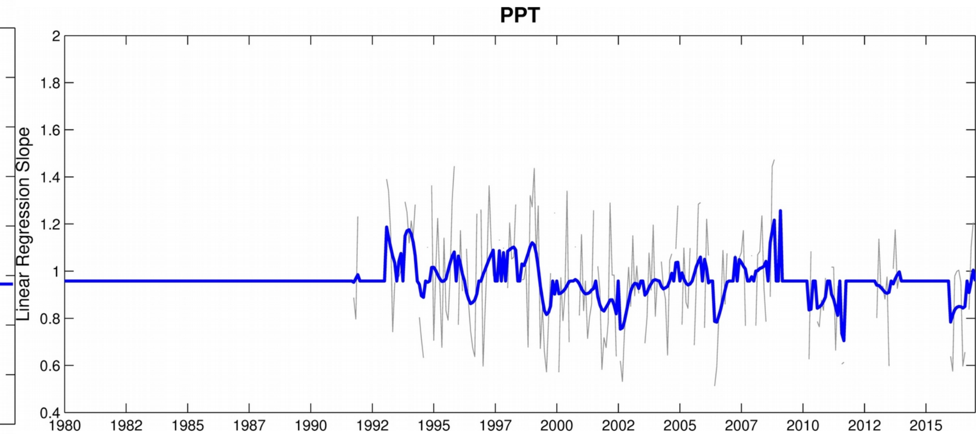

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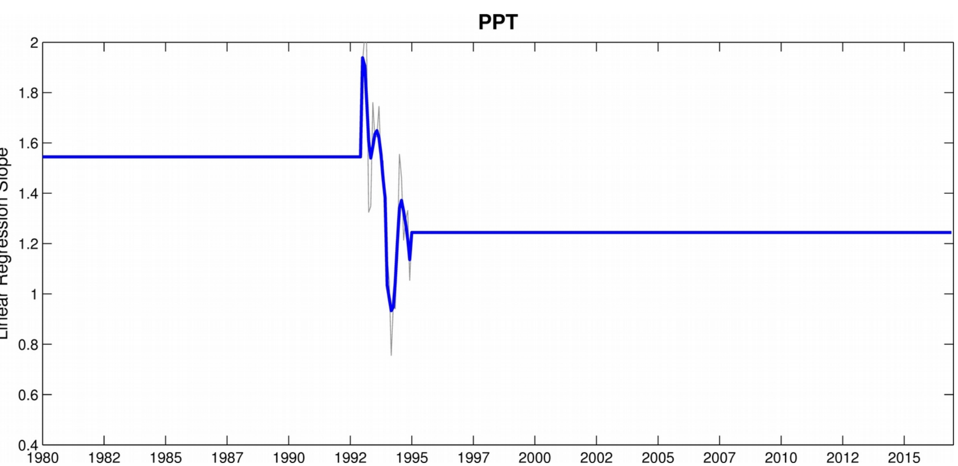

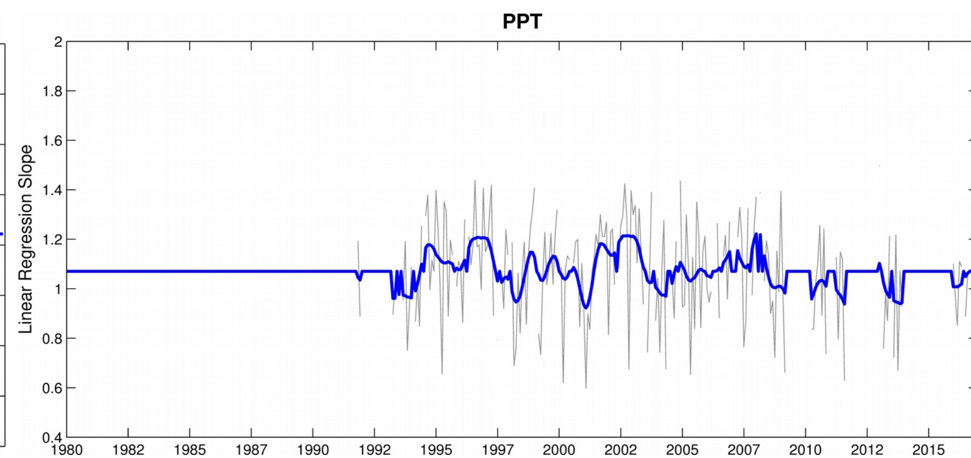

4

Conclusion & Outlook

4. Conclusion

- Proposed modification of U10 reduces Hs biases as a function of time with respect to altimeters

- Verification with buoys – (subtle) reduction in residuals as function of time. The changes in buoy hull and sensor type needs to be considered!

- Verification with seismic stations – NH relatively consistent; at PPT change in 1994 is reduced

4. Outlook

Discussion

- 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: buoys, satellite, seismic,

Future Plans

- Assess consistency with more seismic data!
- Improve underestimation of Hs extremes
- Give a renewed look at the inter-annual variability wave climate with a consistent hindcast

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5. SAR observations of TCs

-Now have the ability to observe TCs in real-time: based on the forecasted track

-Development of a GMF to estimate high winds using cross-polarization (HV) that does not saturate under extreme winds (like L-band radiometers)

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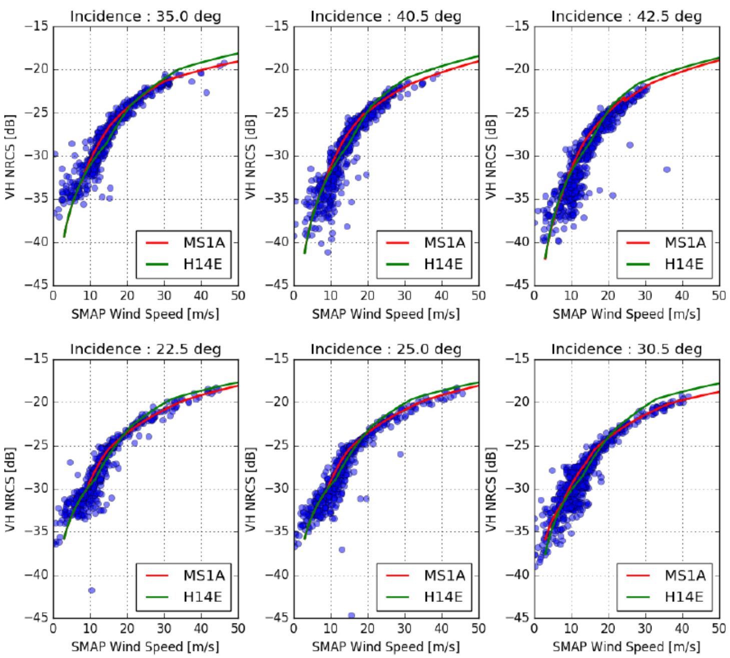
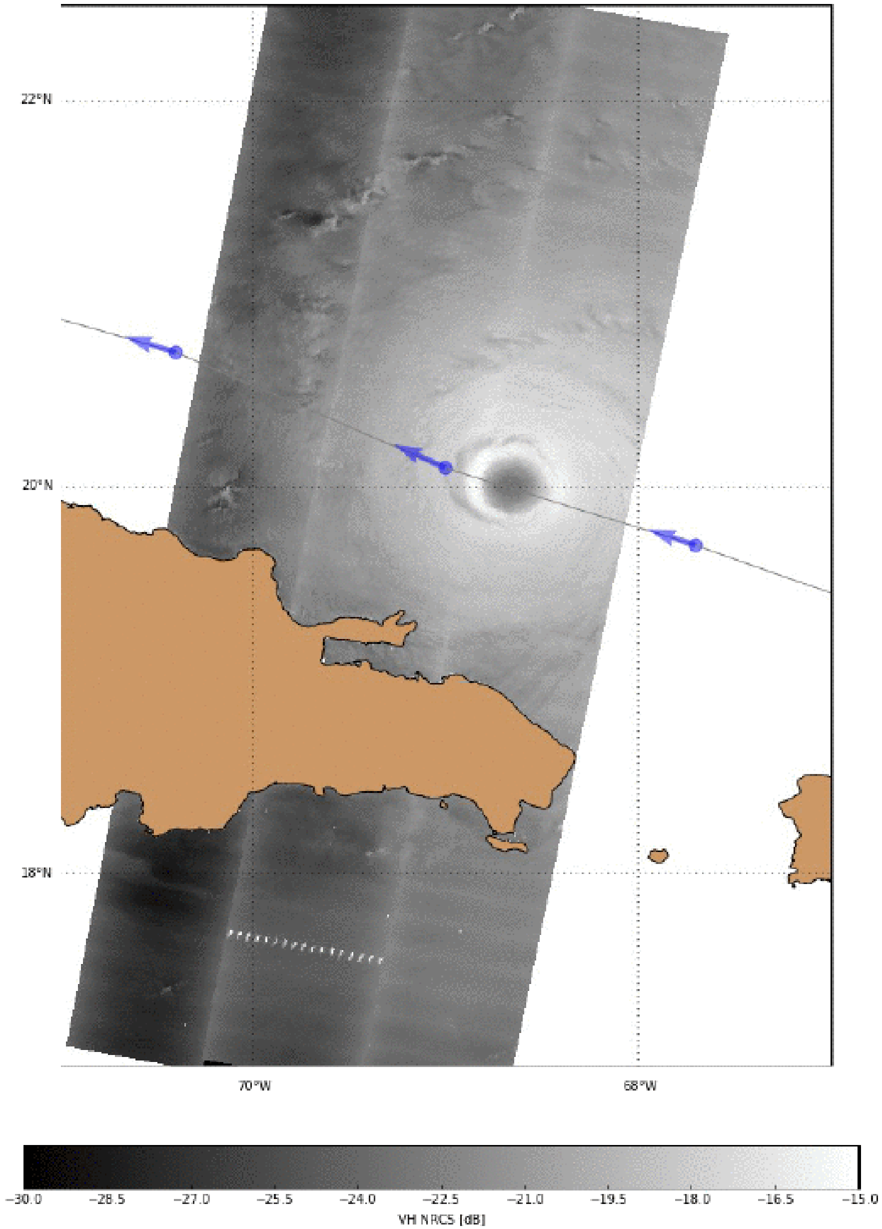
GMF developed for L-band radiometer



#IrmaHurricane2017



Sentinel-1