Improving altimetry's non-tidal high frequency ocean de-aliasing correction through the inclusion of daily GRACE updates

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Theory behind our Research

Background:

Jason uses the "DAC" ocean de-aliasing model during processing (Mog2D ocean model + inverted barometer).

No model is perfect. Errors in the model will alias into errors in sea surface height product.

Research Questions:

Over which areas, spatial wavelengths, and frequency bands can GRACE add value to DAC?

Can we supplement DAC with GRACE swath data to make a better altimetry de-aliasing model?

Technique Used:

Altimetry – GRACE residual will be non-zero:
- Non-pressure ocean signals & local effects.
- Non-ocean gravity signals.

If GRACE is detecting real ocean mass signal:

$$var(Alt - GRACE) < var(Alt)$$

If GRACE is more accurate than the model:

$$var(Alt - GRACE) < var(Alt - model)$$

Using this logic, we can determine where GRACE improves the model.

We use an EOF analysis to separate out the portions of the GRACE signal which are real vs noise, keeping only those safe to add to the de-aliasing model.

# GRACE: RL05 CSR "Daily" Swath Series

Mascon series (40000+ blocks; 120 km across):

- Geoid anomalies estimated along varying GRACE ground tracks.

- Observed every 1-2 days (polar) to 4-5 days (equatorial).

- Older local data and newer neighboring data used to optimally fill gaps.

- Regularized using GRACE only (no models).

- Reduced north/south striping and decorrelated land/ocean mascons.

This is an older series (Release-5 GRACE) which we are updating:

- We are in the process of updating to Release-6, including GRACE Follow-On data, but creating the new series is computationally intensive.

- Preparation of the GRACE/GFO tracking data is complete.

- Currently incorporating improvements found from this analysis.

- GRACE-FO RL06 swath solution processing will begin January 2021 and take 2-3 months to complete.

- GRACE RL06 swath solution processing will begin March 2021 and take 7-9 months to complete.

- The remainder of this will be completed using other GRACE funds.

Example day: 1 Jan 2006
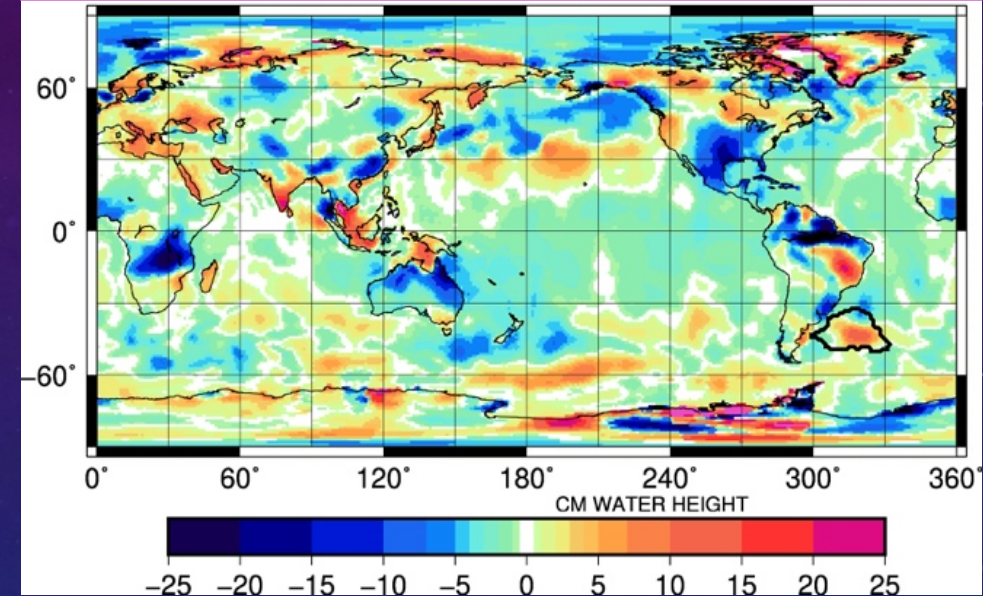
Time series over the Argentine ocean basin
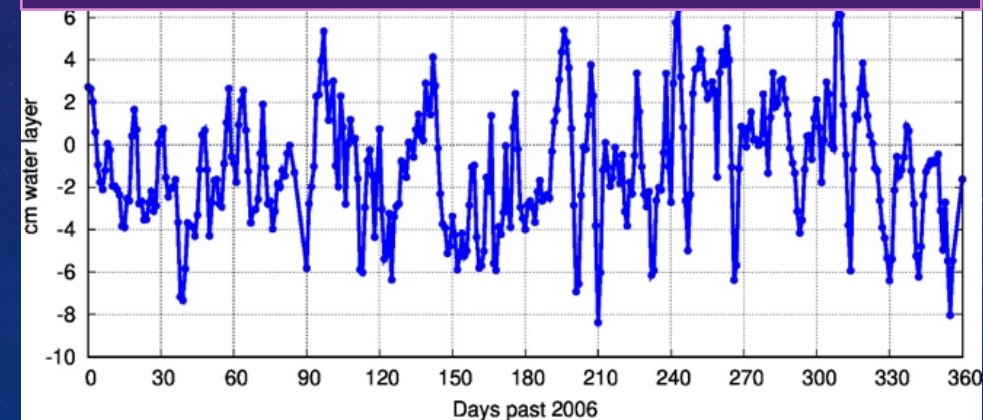
DATA ALONG JASON GROUND TRACKS ONLY: GRACE VS DAC BY FREQUENCY BAND

We compared Jason altimetry to the non-IB DAC and the CSR swath data, over three frequency bands (labeled per figure).
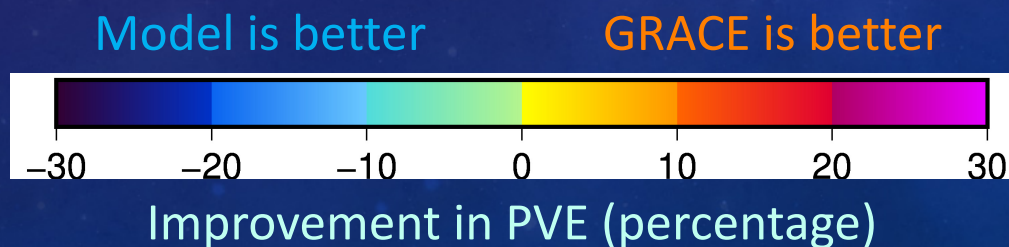
CSR swath fits Jason altimetry better than non-IB DAC does:
- For periods > 15 days.
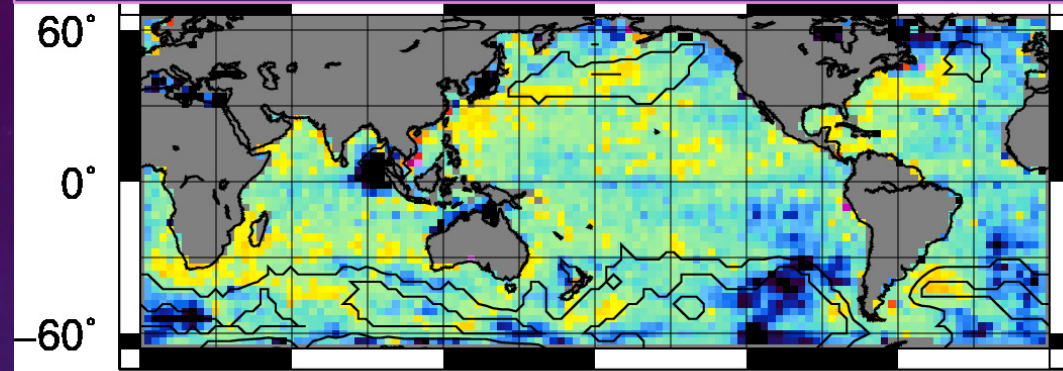- Across high-signal areas (the southern ocean).

Jason's current de-aliasing model is better:
- For periods < 10 days.
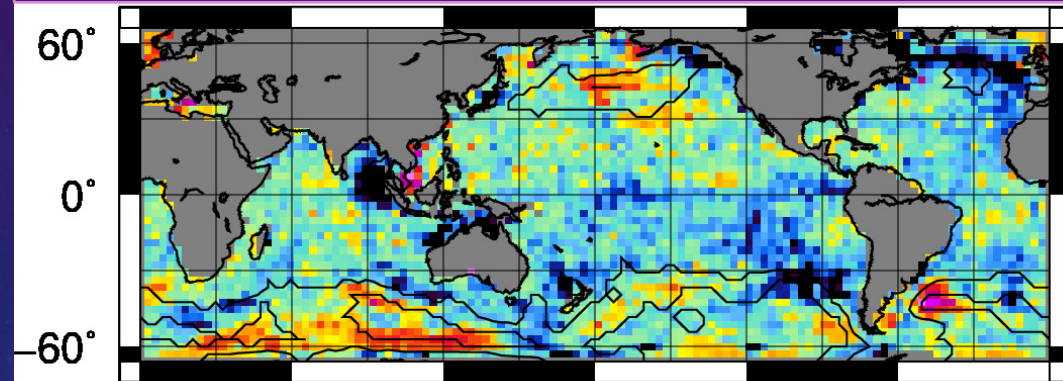- Across the equatorial regions and Atlantic.

The GRACE swath series *can* be used to improve the altimetry de-aliasing model in the 10-20 day band!

Model is better   GRACE is better

Improvement in PVE (percentage)
-30   -20   -10   0   10   20   30
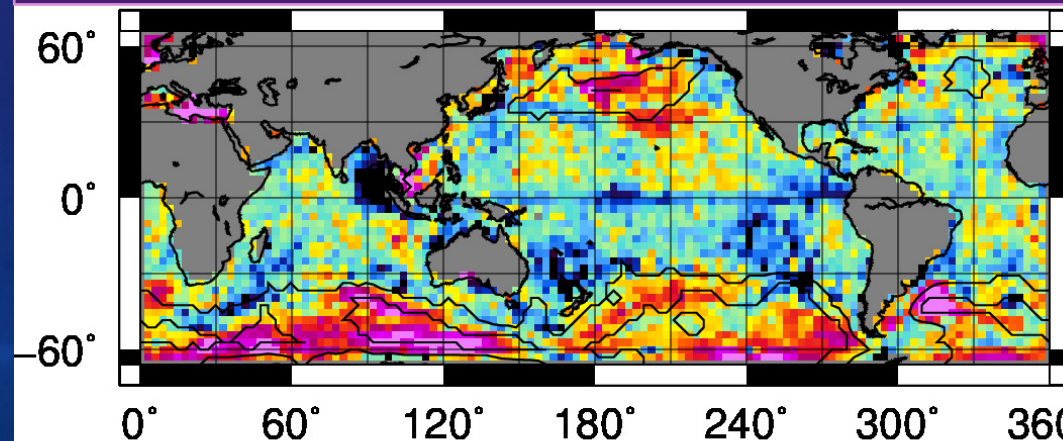
Using EOF Modes to Create a Combined Model

Three Series:

- Jason Altimetry: Smoothed with a 300km filter and averaged to daily, 1°x 1° gridded resolution.
- CSR Swath Data: All standard corrections applied. GAD (GRACE ocean de-aliasing model) restored.
- HF* = DAC – IB: The actual Jason de-aliasing model without the all-frequencies IB product was not available.
  - Created an alternate by removing the IB product used in the CSR swath data. Some IB differences will remain as errors.

Processing to create sub-20-day data: done identically on each series

- 6 parameter fit used to remove annual, semi-annual, trend, and bias.
- Windowing is used to create a band-pass effect, keeping only the signals in the 10-20 day band.

Computed EOF mode maps and time-series from HF* model for 2004-2014 in the Southern Ocean

- Did an EOF reconstruction using HF* EOF maps and the CSRswath and Altimetry data to get comparable time-series.
- Computed a least-squares scaling factor to scale up/down HF* to best match CSRswath for each mode.
- Used and EOF reconstruction of altimetry to determine for which modes GRACE and the scaled HF* were beneficial.
- The southern ocean was chosen because our previous results showed GRACE could provide the largest benefits there.

Goal: To make a combination of HF*+GRACE and/or scaled HF* which is better than either component alone.

Scaled Reconstruction: Southern Ocean, Mode 1

Map of the first mode (top figure) and partial time-series for that mode (bottom figure):

- CSRswath matches Altimetry better than HF* does in terms of frequencies, not merely amplitudes.

- Generally, the HF* model matches altimetry equally well when altimetry sees smaller quasi-periodic variations, but does not increase in amplitude enough during times when altimetry and CSRswath see larger variations.

- A simple scaling does not improve the fit very much.

Similar results occur for all other early modes.

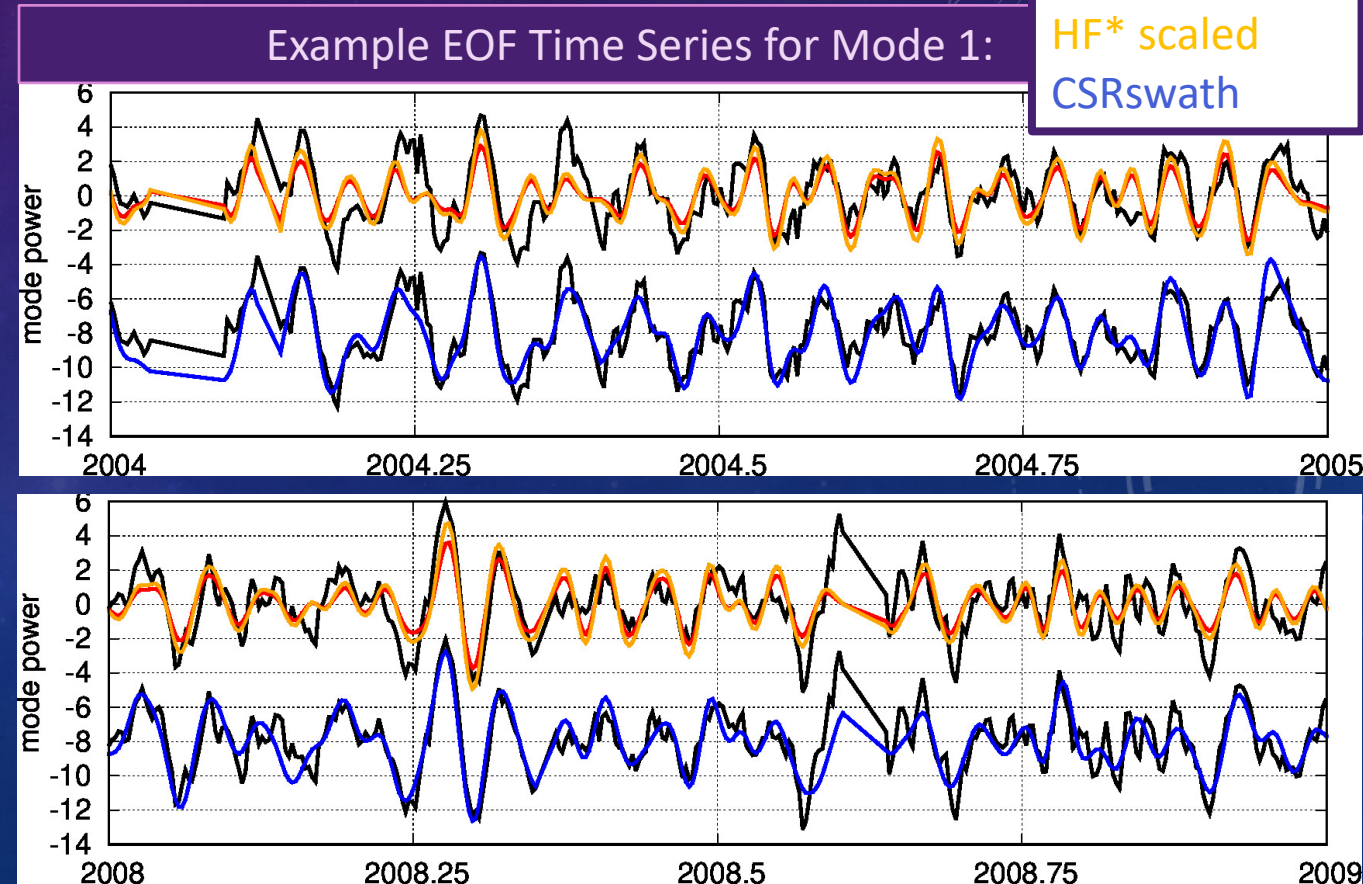(Offset has been applied to the CSRswath time-series, to aid in legibility.)

Spatial Map of Mode 1 from HF*

RELATIVE MAP OF MODE POWER
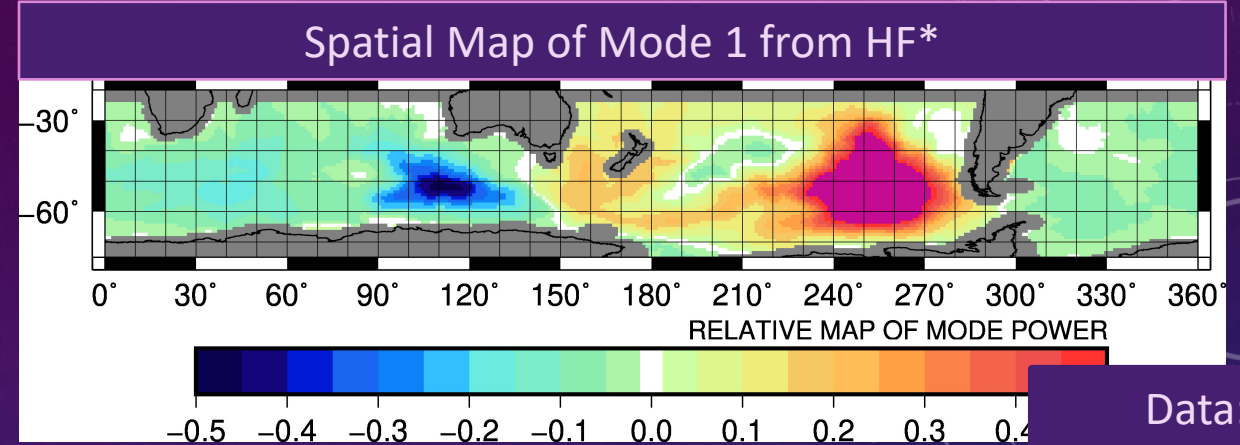
Data:
Jason ("truth")
HF* unscaled
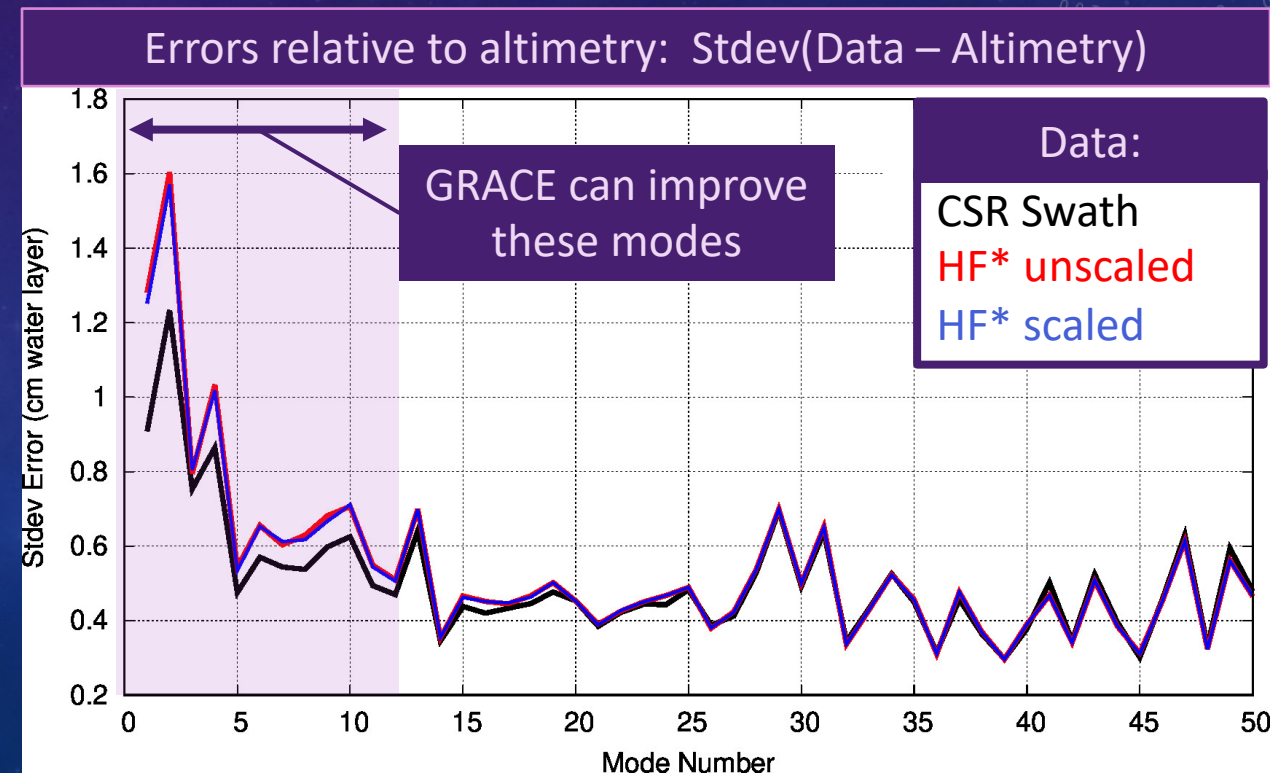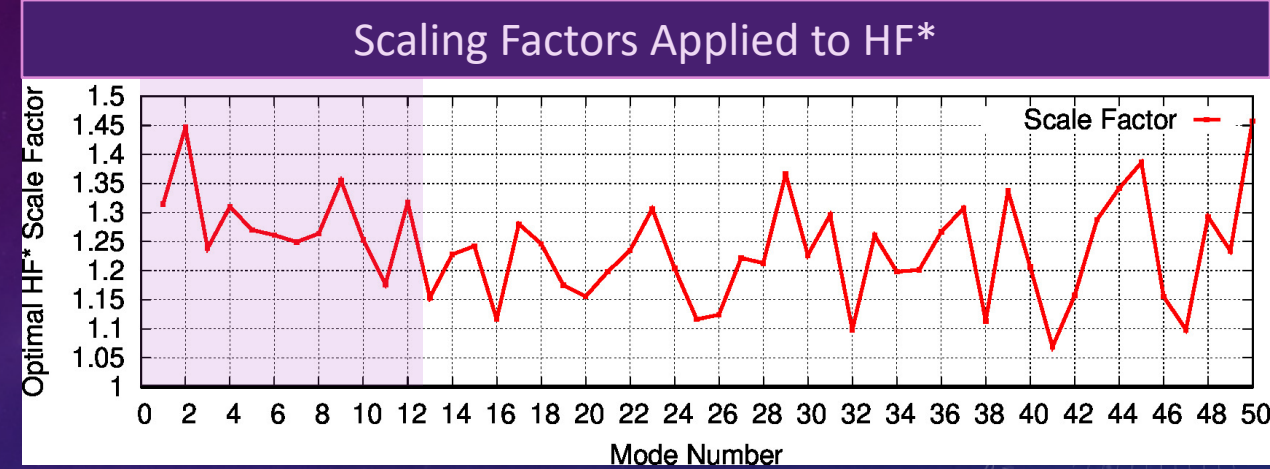HF* scaled
CSRswath

Example EOF Time Series for Mode 1:

Results in the Southern Ocean, Based on HF* 10-20 Day Band

CSRswath better explains altimetry than the HF* model does for at least the first 12 modes.

- The optimal scaling factors (top figure) always increase the amplitude of the HF* signal.

- But a comparison with altimetry (bottom figure) shows that simple scaling of the HF* model makes a small improvement, not nearly as much as using GRACE itself.

- This suggests that the difference isn't merely amplitude, but that GRACE is seeing different time-variable patterns in the southern ocean than HF*, and that those GRACE patterns are more often correct (according to altimetry).

After mode ~12, the difference between CSRswath and HF* drops, such that replacing these HF* modes with CSRswath will give little benefit.

Scaling Factors Applied to HF*

Errors relative to altimetry: Stdev(Data – Altimetry)

GRACE can improve these modes

Data:
CSR Swath
HF* unscaled
HF* scaled

USING THESE EOFS TO IMPROVE THE DE-ALIASING MODEL

We replace the first ~12 modes of the model with CSRswath, leaving other parts of the HF* signal unchanged.

- We had ideally hoped to use GRACE to estimate a scaling, then simply scale up the model. But that doesn't help.

- Using GRACE directly means the results won't be usable (reliably) near coastlines, or when GRACE doesn't exist.

- But it's clear that the use of GRACE in this way can augment the model without adding in GRACE noise.

It's possible that some EOF modes correlate with something physical – winds, etc. – which can be measured. In which case, those mode(s) could be replaced with that correlated timeseries, when GRACE doesn't exist.
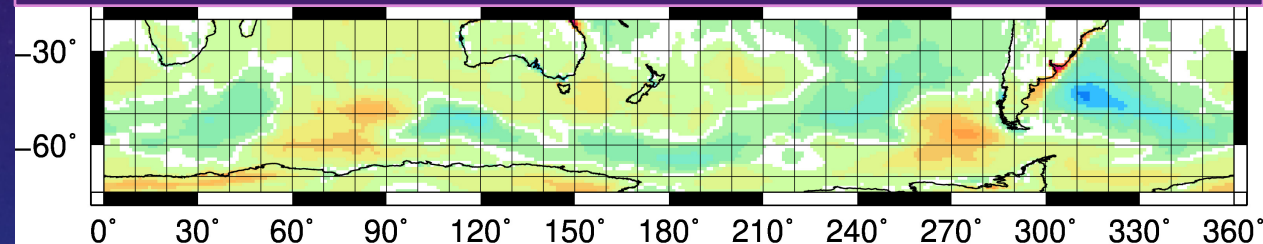
- We plan to investigate this in the next few months.

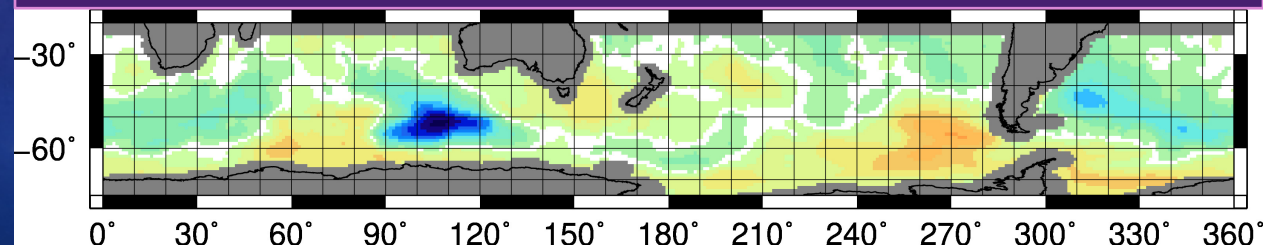One example day (10-20 day band only):
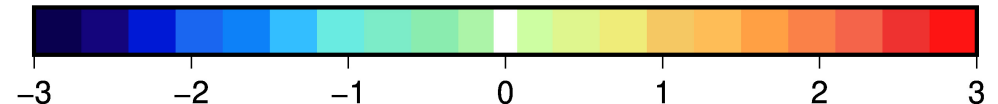
First 50 modes of CSR Swath
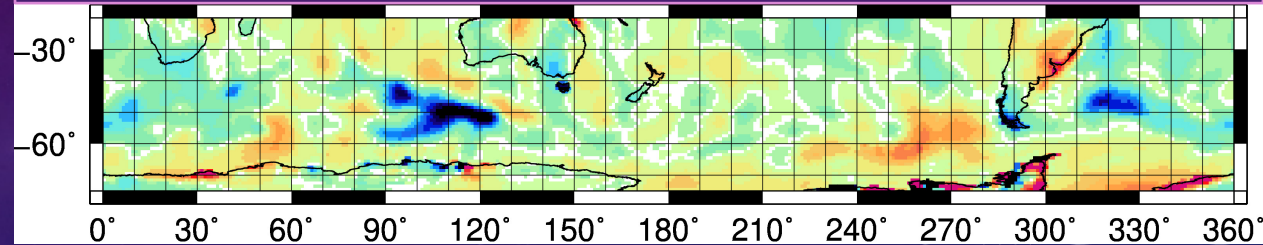
The original model HF*



The new model (EOF recombination)

CM WATER HEIGHT

CONFIRMATION OF IMPROVEMENT VIA JASON ALTIMETRY

A higher percent of altimetry's variance is explained by the new model than any other (plots to right).
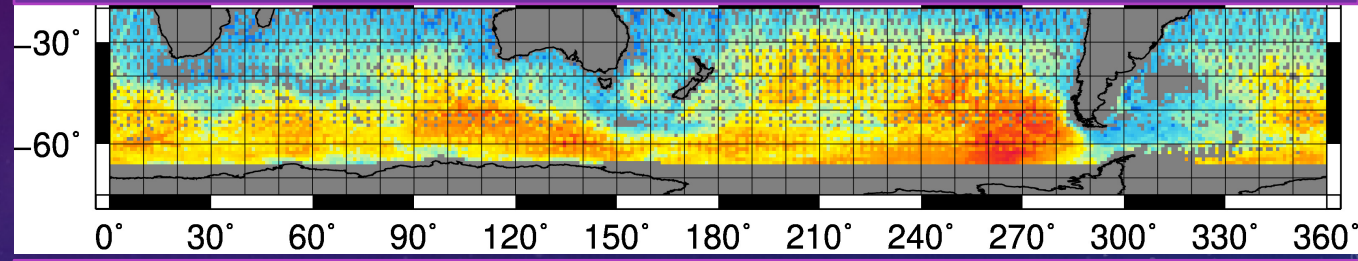
The plot below is the difference of the HF* and new model plots, showing in red the places where the new model improves upon the original HF* Jason de-aliaser.
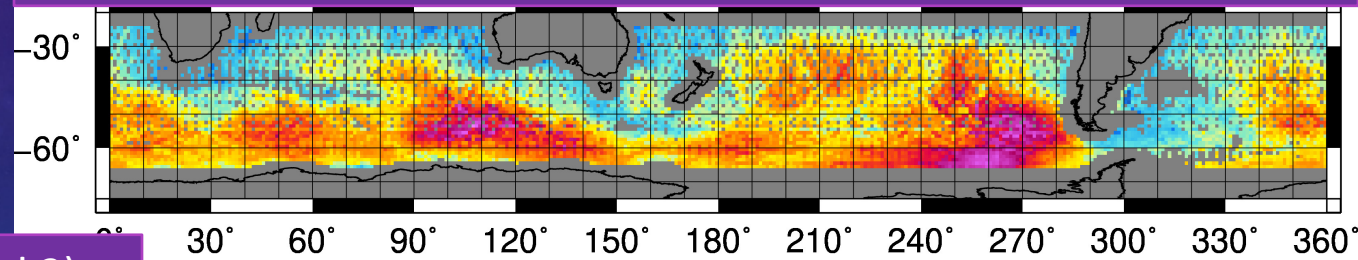
- Typically, adding GRACE gives a 10-30% improvement.

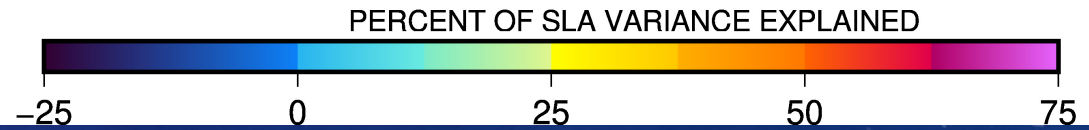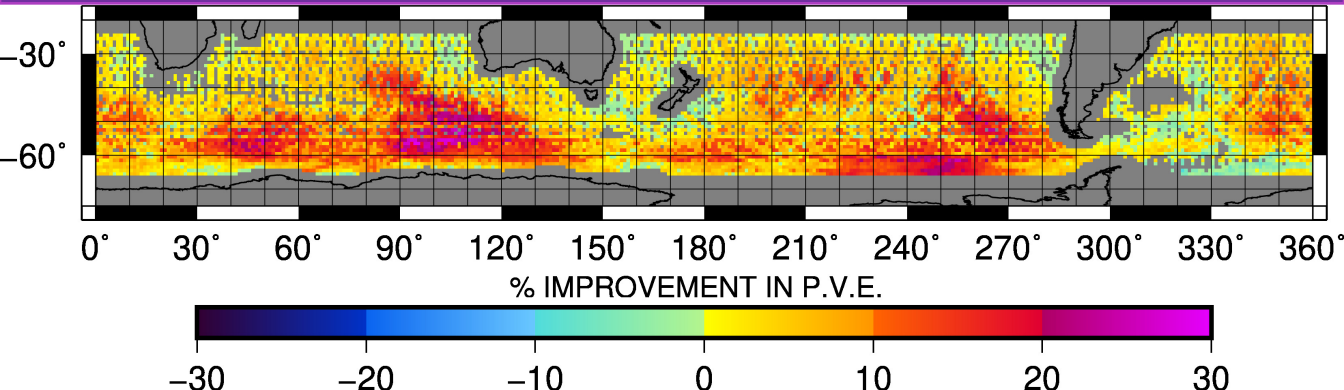**% of Altimetry explained by original CSR Swath (10-20day band)**
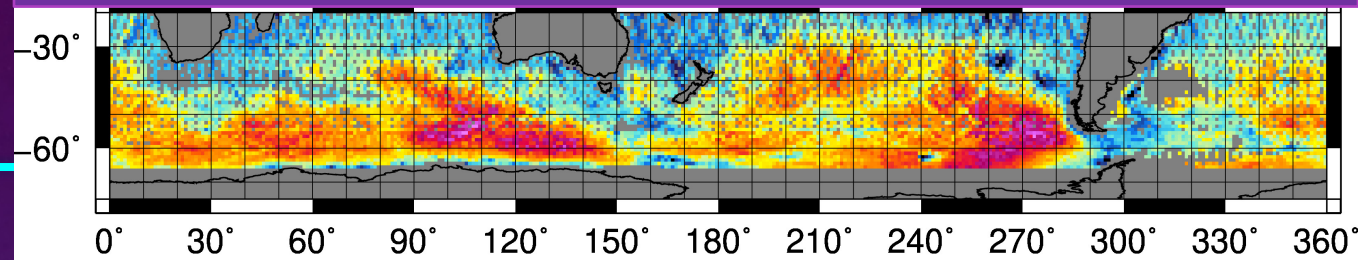
% of Altimetry explained by original HF* model (10-20day band)

% of Altimetry explained by new model (10-20day band)

PERCENT OF SLA VARIANCE EXPLAINED

% Improvement in the new model (difference of plots 2 and 3)

% IMPROVEMENT IN P.V.E.

Replacing the first 12 modes of HF* with their CSRswath-reconstructed time-series results in a new model which is more like Jason altimetry than either GRACE or the original HF* model is alone, in the southern ocean.

Continuing Work

Covid threw off our schedules badly this year, but there are a few things we would like to accomplish:

- The creation of Release-6 "daily" mascons will be happening during the coming year.

- We will repeat this analysis over other areas of the ocean.

  - We see small improvements in the North Pacific and few to none in the North Atlantic, based on our prior findings.

  - We are interested to see what the ocean signals in the Arctic look like, since that is an area with small GRACE errors but probably large model errors. Unfortunately, Jason doesn't cross the Arctic, so proof of success may be hard.

- We hope to search for a correlation of the first few EOF modes in the southern ocean with physical causes, which could be used to fill in for missing GRACE data, or merely to inform future model creators.

Published work on this subject:

- Bonin and Save. "Evaluation of Sub-Monthly Oceanographic Signal in GRACE Daily Swath Series Using Altimetry." Ocean Science. 2020.

Thank you for your time!

- If you have questions or comments, please send us a note.