4D-LETKF Data Assimilation in a WAVEWATCH III® Wave Model Ensemble

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ABSTRACT

Challenges in wave data assimilation into models are diverse. The evolution of wave energy spectra under wind forcing quickly loses memory of initial conditions [1]. The aim of this work is to build a system that efficiently performs a wave height assimilation cycle in a global wave model ensemble, including the joint use of wave and wind observations, and an improved sea surface wind analysis. The most widely available wave data provide a measure of total energy. Global data coverage is provided by satellite altimeters, which small number and lack of swath conspire against an even spatial distribution. We explore here how flow-dependent uncertainties contribute to overcome this drawback. Conventional wave observations from buoys are usually too near the coast to be relevant in global assimilation. They are used here as an independent source of information for validation.

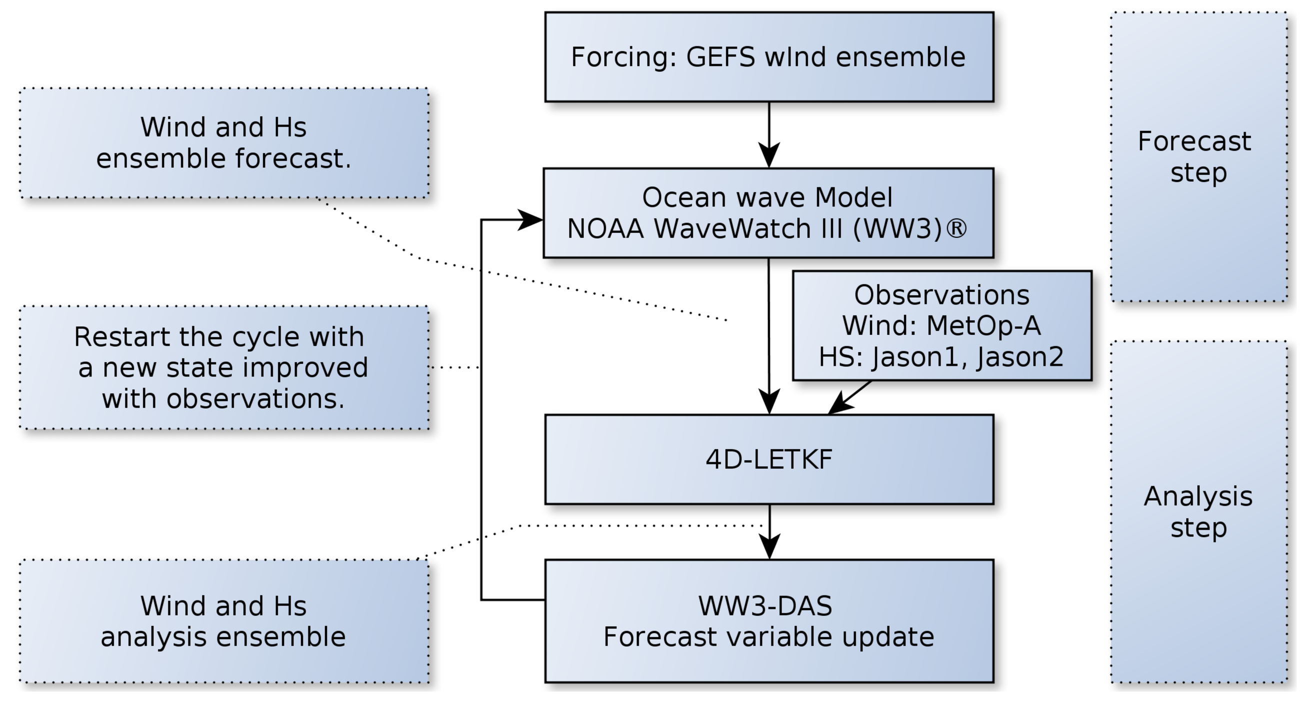


figure 1

The NOAA/NCEP GEFS fields drive a global WAVEWATCH III®[2] wave model ensemble. We get observed significant wave heights from satellite altimeters on Jason 1 and Jason 2 and vector winds from the ASCAT scatterometer on MetOp-A. A 4D-LETKF assimilation system based on T. Miyoshi's code [3] produces analyzed significant wave height (hs) and surface wind fields. The latter enhance the driving wind fields in the wave hindcasts, while the significant wave height analyses scale the initial wave energy spectra in the wave model, with no further considerations.

We developed an object-oriented system to handle observations, which main skill is to easily add new sources of data (Figure 5). Following current trends, we worked with Phyton, an updated and versatile language, with friendly graphics, date management, encoding/decoding libraries (matplotlib, matplotlib.basemap, datetime, netcdf4-python). We succeeded in implementing an efficient and feasible in computing time, wave data assimilation system (Figure 1).

WAVEWATCH III®

The **WAVEWATCH III®** forecast variable is the wave energy (action) spectrum, represented in the 4-dimensional space (lat, lon, frequency, direction). Energy at every point in the model is discretized in 25 frequencies and 24 directions. The spatial resolution is 1º x 1º. Figure 2 illustrates the 2-D wave energy spectrum together with the Hs field, which results from equation 1.

$$hs(lat,lon)=4\sqrt{\sqrt{E(f,\sigma,lat,lon)dfd\theta}}$$

equation 1

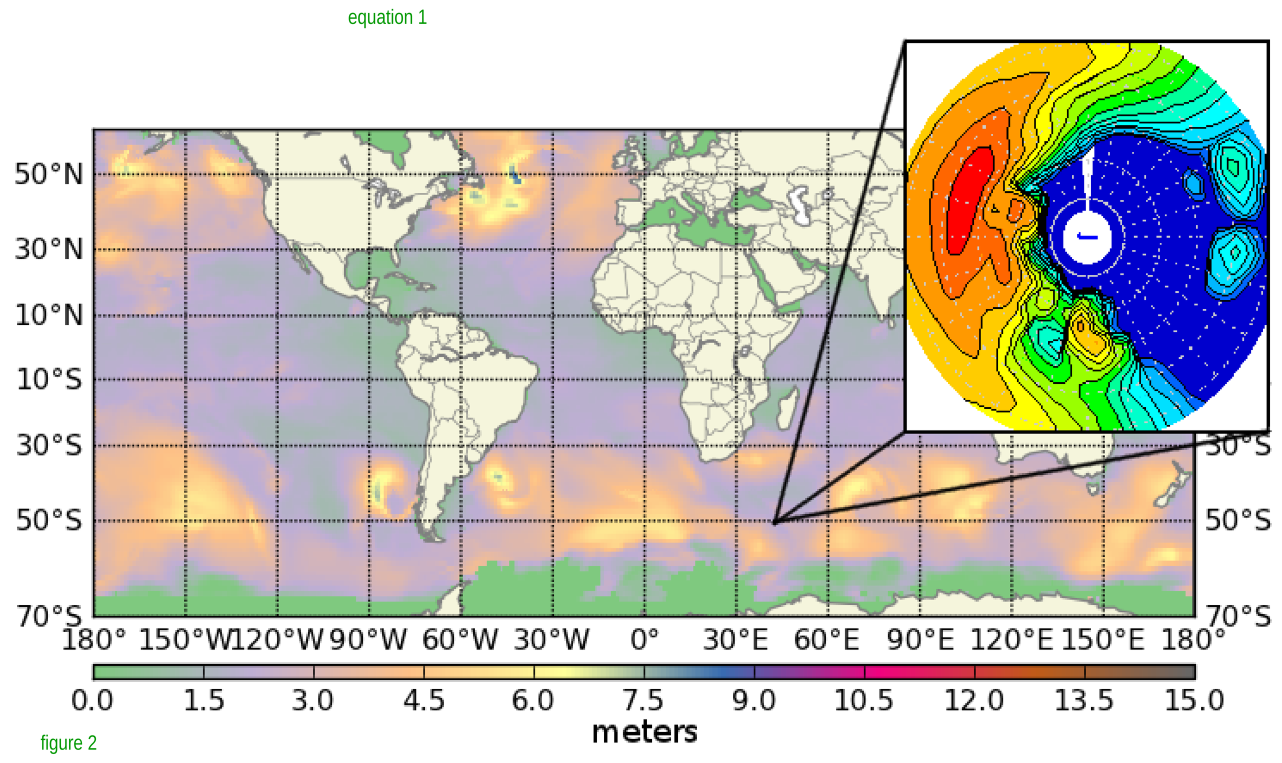


figure 2

OBSERVATIONS Jason1, Jason2 and MetOp A

We get observations from two altimeters on Jason 1 and Jason 2. They produce along-track Hs observations (figure 3). The scaterometer ASCAT on MetOpA produces wind vector data in a swath (figure 4). We use the coarse 25 km resolution for the latter. In figure 6 we show the number of observations in the analysis time period (December 2012).

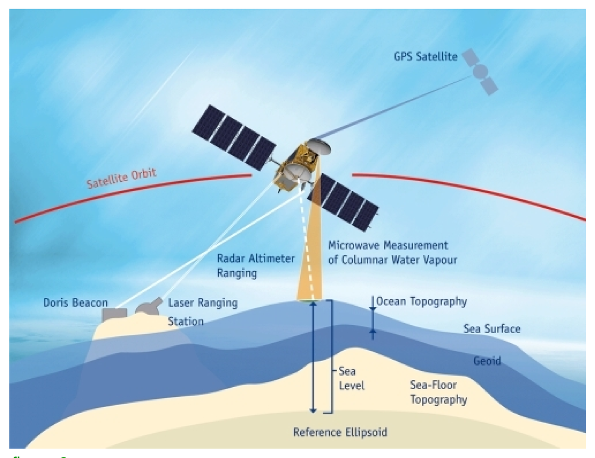


figure 3

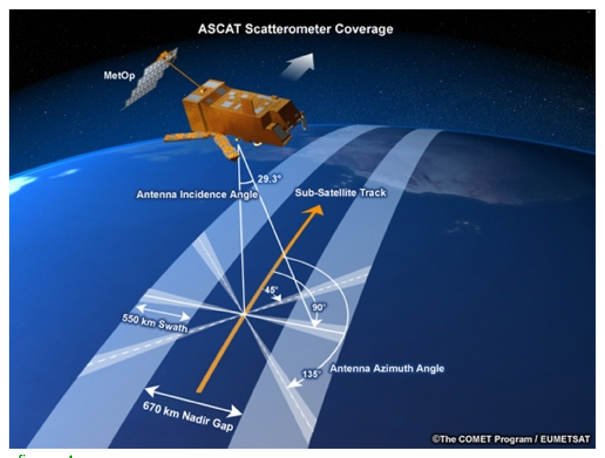
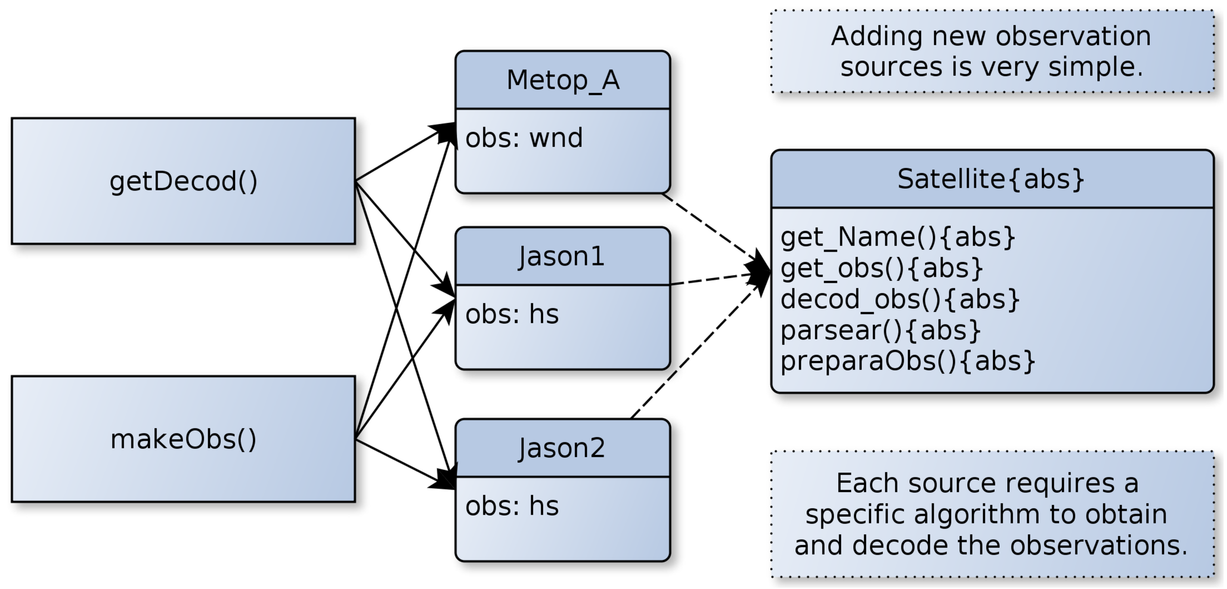


figure 4



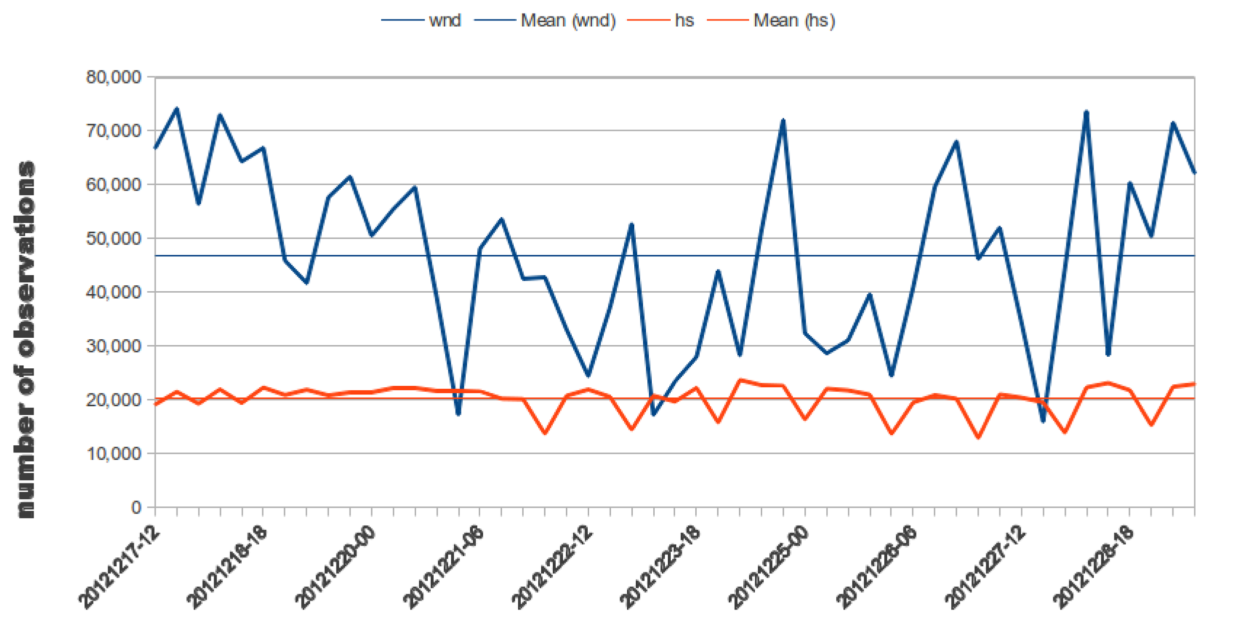


figure 6

4D-LETKF implementation for WW3

We adapted the code to analyse Hs and vector wind, including cyclic global domain. Observations are discarded following (equation 2), where ***x*** is the model value at the obs location, ***rms*** is the "root mean square error" provided with the observation. The influence of an observation is half Its value at a distance σ_{obs}, where σ_{obs} is 7º (~700km), according to the weigth function in equation 3. is used to localize the obs in time $(\sigma_{obsTime}=1)$.

$$|obs-H(\bar{x})|>0.1\,rms_{obs}+0.3|H(\bar{x})|$$

equation 2

$$W(dist)=e^{\frac{-dist^2}{2}\sigma_{obs}^2}$$

equation 3

We use an additive inflation factor of **0.2** and a multiplicative inflation factor of **1.1**. We use a **20 members ensemble.**

WW3 DATA ASSIMILATION STEP: swell + wind sea

The forecast variable in WWIII is the wave energy (E), while we get Hs from the analysis (equation 1). Here, we adapted the approach updated as in ECMWF (2013), except that we do not make any assumptions on wind duration. Equation 4 shows the spectrum update, where f is frequency, while the f superscript denotes forecast. A and B are calculated (equation 5 and 6) separately for swell and windsea.

$$E^a=AE^f(Bf,\theta)$$

equation 4

Swell

$$B=\left(\frac{H^a_{sw}}{H^f_{sw}}\right)^{0.5}\qquad A=B\left(\frac{H^a_{sw}}{H^f_{sw}}\right)^2$$

equation 5

Wind Sea

$$B=\left(\frac{U^a}{U^f}\right)^{0.3518}\left(\frac{H^f_{ws}}{H^a_{ws}}\right)^{0.6759}$$

$$A=\left(\frac{H^a_{ws}}{H^f_{ws}}\right)^{1.363}\left(\frac{U^a}{U^f}\right)^{0.394}$$

equation 6

RESULTS

In figure 7 we present the average observational departure from the background ensemble mean vs. the assimilation cycle (6-hour).

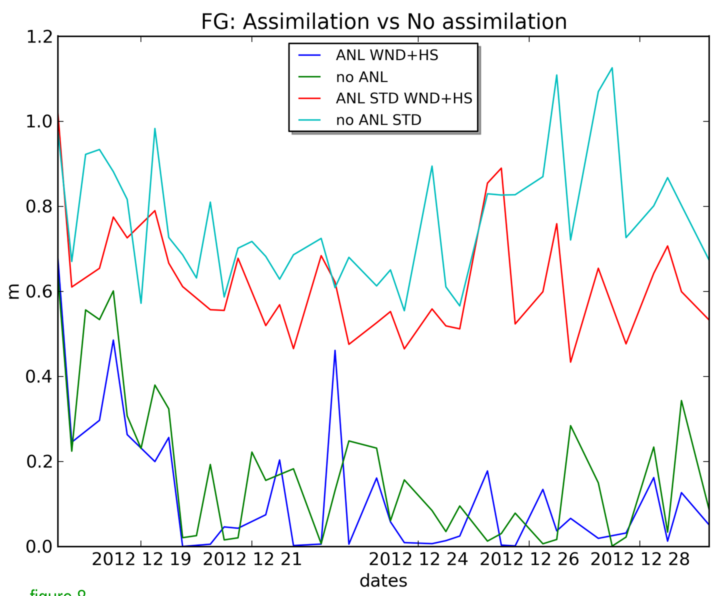


figure 8

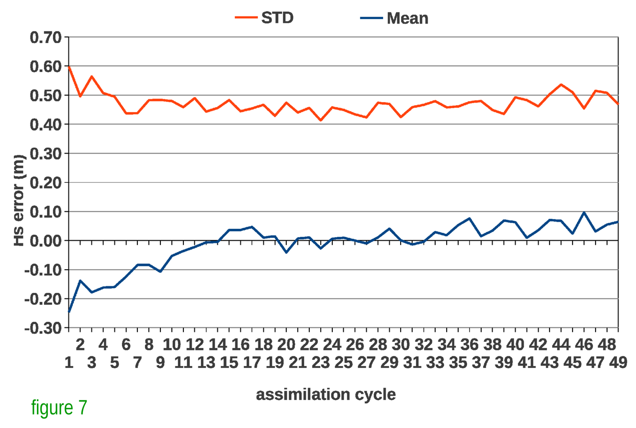


figure 7

In Figure 8 we show the average observational departure mean and spread from 2012 12 17 to 2012 12 19 (with and without assimilation). The error is lower in the run with assimilation (blue-red) with respect to the run without assimilation (green-turquoise).

Figure 9 shows satellite tracks, Hs output and measurements from buoys: Hawaii (51100), Australia (56006) and North Pacific Ocean (46208 and 46184) which are independent sources of verification.

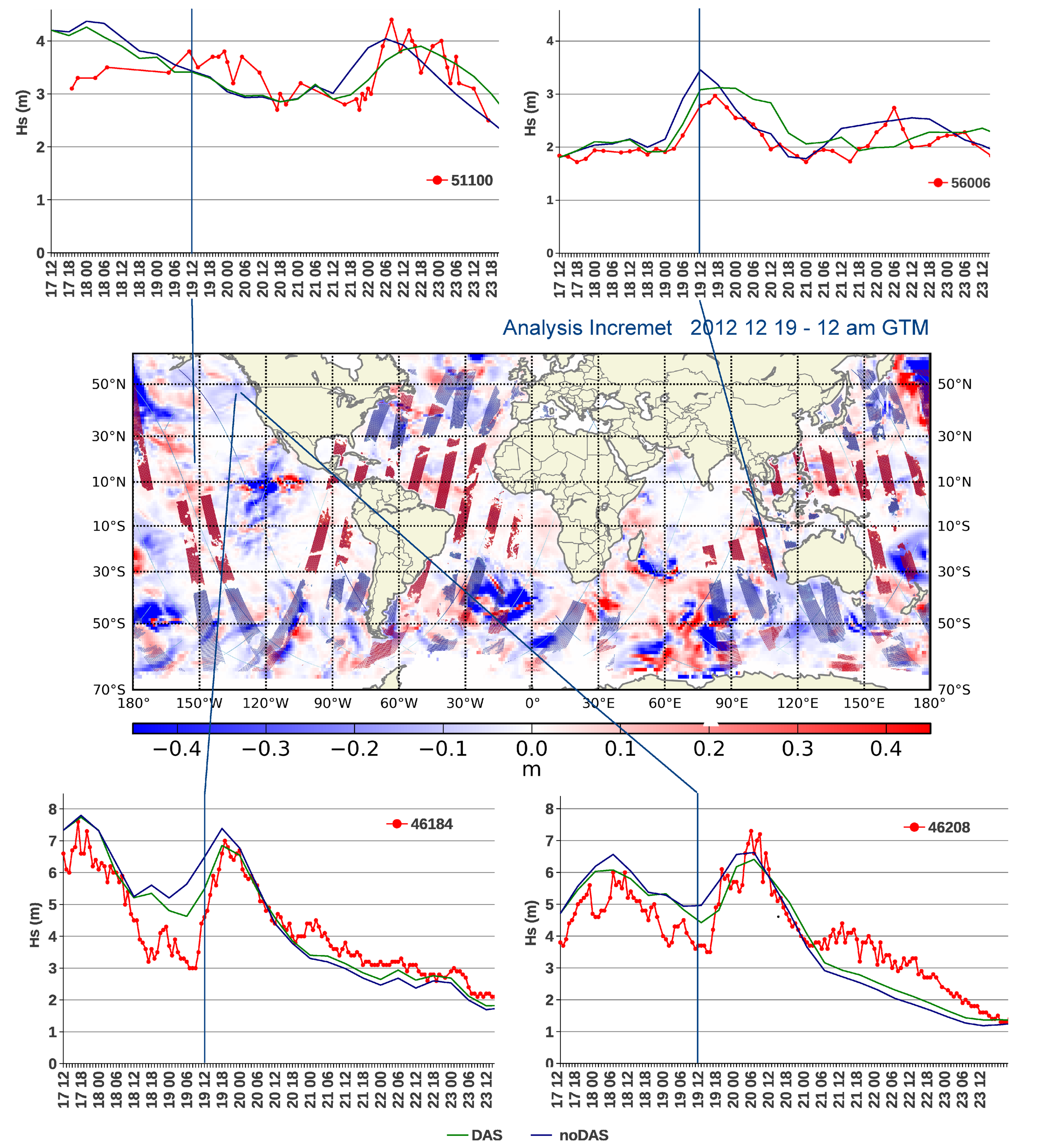


figure 9

ACKNOWLEDGMENTS

·Jason 1 and Metop-A data were obtained from the Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the NASA Jet Propulsion Laboratory, Pasadena, CA. http://podaac.jpl.nasa.gov.

·Jason 2 data were obtained from NOAA's Ocean Data Archive(NODC) http://www.nodc.noaa.gov

·The GEFS vector wind are obtained through the THORPEX Interactive Grand Global Ensemble TIGGE http://tigge.ecmwf.int/

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