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Jason-2 Validation Test Report (VTR): Validation of Sea Surface Height Anomaly Precision and Accuracy for Mesoscale Applications

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14. ABSTRACT

The Jason-2 satellite altimeter was launched on June 20, 2008. The mission is a joint NASA/NOAA/CNES/EUMETSAT project that will transition altimeter satellite observations to operational status. Initial data began to be released in July 2008 and contain the information necessary to construct sea surface height anomaly (SSHA) observations from a long term mean. To apply the Jason-2 observations within ocean environment models, the data must meet precision and accuracy requirements. The source for the requirements is taken to be the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Operational Requirements Document II (IORD-II), which contains threshold and objective requirements for SSH observations for both the Department of Defense and Department of Commerce. The accuracy and precision of the Jason-2 satellite data meet the IORD-II thresholds for Mesoscale observations through comparisons to the Jason-1 data, comparisons of the Jason-2 data at ground track cross-over points as well as high pass noise floor evaluations. For the DoD Basin scale requirements, the Jason-2 satellite meets thresholds as well as the Jason-1 satellite.

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Executive Summary

The Jason-2 satellite altimeter was launched on June 20, 2008 at 3:46 AM EDT. The satellite and payload are similar to Jason-1 and covers the same ground tracks. The satellite was maneuvered to an orbit such that it passed over the same ground points as the Jason-1 satellite 55 seconds later. Initial data began to be released in July 2008 in the form of the Operational Geophysical Data Records (OGDRs). The OGDRs along with additional ancillary data contain the information necessary to construct sea surface height anomaly (SSHA) from a long term mean.

The SSHA provides measurement of surface pressure on the ocean due to large scale (> ~20km horizontally) circulation structures. The internal ocean thermal variations associated with these circulation structures change sound speed profile (SSP) that affects acoustic propagation. In addition, water velocities throughout the water column are altered by the geostrophic balance with the varying pressure gradients. Because the mesoscale front and eddy features that change circulation and associated SSHA are nondeterministic, forecasting of the ocean environment for Navy applications through numerical models integrating the equations of motion forward in time requires continuous observations to correct model state trajectories toward the observed.

To apply Jason-2 observations within ocean forecast systems run by the Naval Oceanographic Office (NAVO), the data must meet precision and accuracy requirements. The source for the requirements is taken to be the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Operational Requirements Document II (IORD-II), which contains threshold and objective requirements for SSH observations for both the Department of Defense and Department of Commerce. Requirements for NPOESS IORD-II were provided by the Commander of Naval Meteorology and Oceanography Command (CNMOC) in collaboration with researchers at the Naval Research Laboratory (NRL), and the IORD-II is vetted and signed by the Joint Requirements Oversight Council (JROC). The altimeter sensor that would provide SSH observations was descoped from NPOESS during the Nunn-McCurdy program review. Since that time, the Navy has worked to mitigate possible data discontinuity issues by leveraging similar sensors. This is a critically necessary effort as satellite altimeter observations are the only global coverage observations of sufficient density to constrain an ocean forecast system. Without a continuing stream of observations, climatology becomes a superior estimate to a numerical model for mesoscale features after about 30 days from initial data outage.

Accuracy and precision of the Jason-2 satellite is demonstrated to meet the IORD-II thresholds for mesoscale observations through sensor noise evaluations, comparisons to the Jason-1 data and through comparisons of the Jason-2 data at points where the ground track crosses itself as well as high pass noise floor evaluations. For the DoD Basin scale requirements, the Jason-2 satellite meets thresholds as well as the Jason-1 satellite when evaluations are performed using methods that provide an upper bound on errors. Global requirements apply only to DoC and are not evaluated here.

Based on these evaluations contained in this report, the Validation Test Panel recommends Jason-2 data for operational use in Navy numerical model prediction systems.

Manuscript approved August 26, 2008.

Altimeter Sea Surface Height parameter definitions

The altimeter instrument has been developed to provide an accurate measurement of the transit time of a pulse limited radar chirp emitted by the satellite, reflected by the ocean surface, and returned to the satellite. Several techniques are used within the satellite hardware to allow a small ocean footprint simultaneously with a small transmitter/receiver antenna and a low power requirement (Chelton et al. (2001). The altimeter measurement is intended to represent an area larger than wind driven waves and ocean swell but smaller than typical large scale ocean features ranging from twenty to thousands of kilometers. The radar pulse footprint varies in size depending on the satellite altitude and the ocean wave height. Higher wave heights reflect the radar pulse further from the sub-satellite point. In calm seas, the ocean area reflecting the radar pulse has a diameter of about 3 km, and this increases up to 10 km in areas with waves of 15 m amplitude for the TOPEX/Poseidon altimeter. This is the across-track footprint size. One second temporal averaging causes the footprint to be elongated in the along-track direction.

The quantity measured by the altimeter instrument is the satellite range (R , Figure 1), which must be corrected for effects on the radar pulse propagation speed and the reflecting surface roughness. The corrected satellite range together with satellite orbital height above the reference ellipsoid (O) provides the sea level height above the reference ellipsoid (SL)

$$SL = O - \ R + A \tag{1}$$

where A represents corrections to the measured range. For oceanographic purposes, the sea surface height above the ocean rest state (SSH) is of importance. If G is the geoid height above the reference then

$$SSH = O - (R + A) - G \tag{2}$$

Often the geoid height is unknown or contains substantial errors. These errors may be avoided by examining only sea level changes from one time to another or deviations from a long time period mean. The sea surface height anomaly ($SSHA$) is

$$SSHA = SSH - MDH = SL - (G + MDH) \tag{3}$$

where MDH is the mean dynamic height or height above the geoid due to the time-averaged ocean circulation.

Within altimeter data sets, usually the altimeter range is provided assuming that the medium has no effect, and corrections to the range are provided. These corrections are represented by the variable A in equation 1. The major atmospheric corrections are the dry troposphere, wet troposphere, and ionosphere corrections. The dry troposphere correction accounts for changes in propagation speed due to the total dry air mass. The total air mass is obtained from surface pressure and is reliably estimated by global numerical weather prediction systems. The wet troposphere correction accounts for the total precipitable water effect on propagation speed. The spatial scales over which the water vapor content changes are relatively small, and small errors in weather prediction systems can lead to large errors in altimeter range. A majority of satellite altimeter instruments incorporate a water vapor radiometer to measure the water vapor content, which provides an accurate propagation delay correction. The ionospheric correction accounts for path delays due to the total electron count (TEC) below the satellite. Several methods have been used to measure the path delay due to ionospheric effects. The Jason altimeters measure

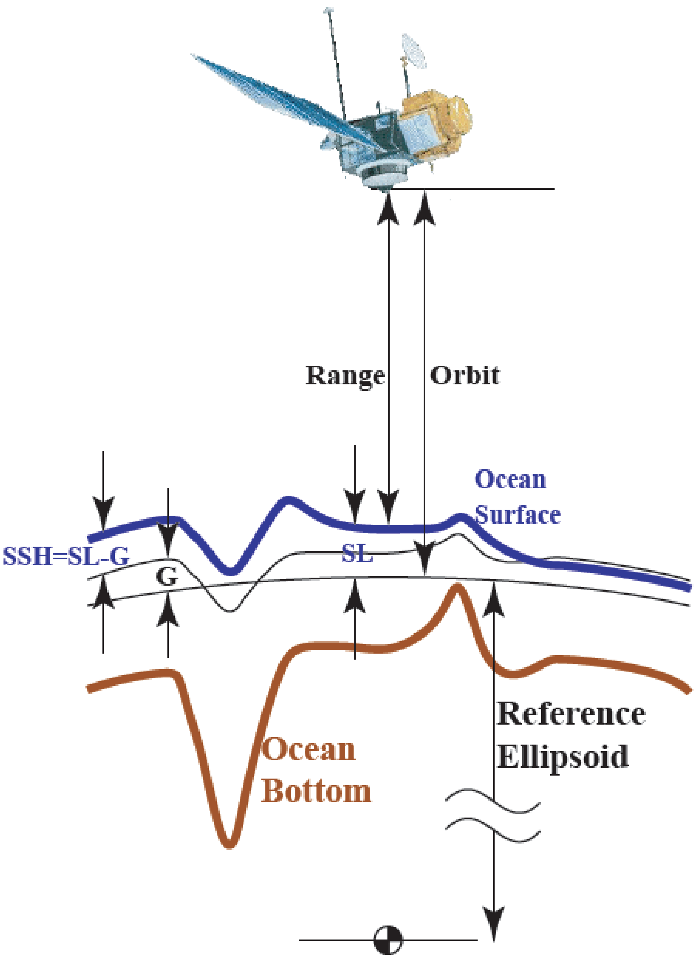

Figure 1. The altimeter measures the range R between the satellite and ocean surface by measuring the round-trip travel time of a radar pulse. Knowledge of the satellite distance (O) relative to the reference ellipsoid allows computation of the sea level (SL), and knowledge of the geoid (G) provides the sea surface height (SSH).

range at two frequencies each of which are affected differently by the TEC thus providing a direct TEC measurement (Fu et al., 1994). Other techniques include DORIS, which measures the TEC between the satellite and ground stations. Using the TEC computed by GPS signal measurements, global ionospheric maps are also constructed for satellites that have no onboard method of measuring the TEC.

An accurate measure of distance from the ocean surface to the satellite is of little consequence without accurate positioning of the satellite relative to fixed reference surface. Usually, the fixed surface is the reference ellipsoid defined as having a semi-major axis of

6378136.3 m and a flattening of 1/298.257. The satellite position relative to the reference ellipsoid must be known with accuracy better than the amplitude of the ocean signal of interest. Orbit solution accuracy is very important to the application of altimeter data.

NPOESS IORD-II SSH requirements

The Environmental Data Records (EDRs) for NPOESS cover space, atmosphere, land and ocean environment observations. All are provided in a similar format with thresholds and objectives. The thresholds are requirements that the contractor is required to meet, and objectives are values that the contractor is asked to meet if possible. The EDRs were intended to be achievable within technical capabilities available or available in the near term when they were written, which was during the late 1990s. For SSH, these requirements can be met with present technology.

Most of the NPOESS instruments are imagers with swath information provided by rotating instruments with axes orientated either in the direction toward the earth center or in the direction of the satellite velocity. Most of the EDR information is specified in terms of instruments that collect data in this manner.

The SSH EDR did not fit the standard definitions for other NPOESS EDRs because the imagers are expected to return radiances at specified frequencies within cells. The altimeter operation is very different and includes many corrections for radar propagation delay effects. Thus, there are specific definitions and requirements for the SSH EDR in the IORD-II provided in the glossary. The NPOESS IORD-II EDR thresholds and objects as well as the glossary terms are provided here and discussed. It is necessary to understand the implications of the definitions with respect to the SSH observations to determine if Jason-2 observations meet the NPOESS requirements.

The NPOESS IORD-II requirements of section 4.1.6.6.7 are provided in table 1. There are three different scales described as mesoscale, basin scale and global scale under accuracy and latency. Note that global scale is required by Department of Commerce only. For Navy applications, there is no requirement to demonstrate that data meets the accuracy, precision and latency criteria for global scale.

Beginning with the first requirement in the SSH EDR, Horizontal resolution for the altimeter is based on the along-track 1 second averaging. With a typical wave height, the footprint size is about 8 km. This footprint size is dependent on the sea state. During a 1 second period, the satellite will advance about 6.5 km along track providing an along-track averaging bin of about 15 km. The horizontal reporting interval defines the periodicity of the sampling. For the altimeter instrument, 20 samples per second are provided by Jason-1 and Jason-2. This leads to less than 1 km reporting interval, which meets the threshold requirement, and this data has been verified in the OGDRs provided from NOAA.

The closest point to shore is a function of the altimeter footprint size and how the observation is corrupted as radar signal reflection from land deviates from the expected returned ocean signal.

Measurement accuracy and precision typically relates to the bias and non-bias error in observation. For the altimeter, these definitions are changed to be able to account for the error within the instrument and the errors in propagation path delay corrections. The bias or long term errors in the instrument do not affect Navy applications as bias is removed from data returned from each satellite orbit during operational processing. The measurement precision is defined in the NPOESS IORD-II as:

4.1.6.6.7 Sea Surface Height/Topography (DOC)/(DoD). Sea surface height is the topography of the ocean surface with respect to the Earth's reference ellipsoid in a well-maintained terrestrial reference frame. Its variability is associated with mesoscale, basin scale, and global scale (DOC only) ocean phenomena. The requirements below apply under both clear and cloudy conditions. Note: following terminology is altimeter-specific. See Glossary Part II for terms and definitions specific to Sea Surface Height.

Systems Capabilities	Thresholds	Objectives
a. Horizontal Resolution		
1. Satellite Nadir Resolution	15 km	2 km
2. Horizontal Reporting	1 km	0.2 km
3. Closest Point to Shore	10 km	3 km
b. Measurement Precision	3 cm	2 cm
c. Measurement Accuracy		
1. Mesoscale	6 cm	4 cm
2. Basin Scale	5 cm	3 cm
3. Global Scale	4 cm	2 cm
d. Exact Repeat Period	20 days	10 days
e. Equatorial Track Spacing	<=165 km	<=50 km
f. Latency		
1. Mesoscale	24 hr	3 hr
2. Basin Scale	3 days	2 days
3. Global Scale	3 months	2 months
g. Geographic Coverage	66S to 66N latitude	85S to 85N
h. Long Term Stability (after calibration)	1 mm yr-1	0.5 mm yr-1

Table 1, the NPOESS IORD-II SSH requirements.

"Measurement Precision (For Sea Surface Height EDR)

The standard deviation from a linear fit to data at the Horizontal Reporting Interval within the Nadir Resolution cell. Precision does not include measured range corrections (wet troposphere, ionosphere), model-based corrections (dry troposphere, sea state bias), or radial orbit determination.", NPOESS IORD-II, G-II-7.

Note that errors in corrections are not included in the precision. It based on sensor errors only. During the processing from Jason-1 and Jason-2 satellite download data to GDRs, the reporting interval is processed to 1/20 s. The cell size is based on these 20 samples combined into one. To do this, a linear fit is made to the 20 samples. The RMS of the 20 samples about the linear fit provides an estimate of instrument noise in the 1 second interval (about 6.5 km along track). There is an assumption that correction values and errors in correction values do not deviate from a linear trend over a one second time period. Thus it is possible to verify the instrument precision by evaluation of the RMS about the linear trend. The expected error in the 1 second reported SSH value will be 1/sqrt(20) times the RMS of the 20 samples about the linear trend given that the 20 samples contain uncorrelated errors.

Measurement accuracy for most NPOESS instruments has the standard expected definition or distribution about the true value. However, for the altimeter, there is a definition provided in the glossary:

"Measurement Accuracy (For Sea Surface Height EDR)

Based on an average over the Nadir Resolution cell. Accuracy includes radial orbit determination as well as measured range corrections (wet troposphere, ionosphere) and model-based corrections (dry troposphere, sea state bias). The required accuracy and timeliness for Coastal/Mesoscale may be obtained by high-pass filtering the sea height profiles to remove radial orbit error, which has scales greater than 10,000 km.", NPOESS IORD-II, G-II-6.

The accuracy for SSH includes all corrections for propagation path delay effects, and it restricts the contributing errors from orbit solution to only those at short wavelength (less than 10,000 km). In addition, the errors are based on an average over the nadir cell resolution of 15km, which permits filtering data along track to scales longer than 15km. This particular definition is provided within the IORD-II due to the uniqueness of SSH observation, which relies on having an accurate estimate of the satellite altitude above the reference ellipsoid. The accuracy consideration is strongly coupled with the latency requirements. One of the largest influences on orbit solution accuracy has been the calculation of satellite ephemeris based on observations in either position or velocity. As latency increases, the number of observations available in the orbit solution processing increases. Thus, the coupling between measurement accuracy and latency is very important for SSH observations.

NPOESS requirements include restrictions on the possible orbits:

4.1.5.5. Orbital Characteristics for Sea Surface Height Measurement (DoD). For the purpose of Sea Surface Height measurement, the sensor will be flown in an orbit allowing a ground track repeat of ± 1 km.

The exact repeat orbit is a requirement for Jason-2. The satellite will overfly the original TOPEX/Poseidon ground track to within 1km, and active maneuvers will be conducted to maintain this positioning. Due to the orbit selection for Jason-2, the satellite does not meet the Exact Repeat Period and Equatorial Track Spacing requirements. The 10 day repeat period leads to a ground track spacing of about 340 km at the equator. This is much larger than the typical spatial scales of mesoscale features and does not meet the IORD-II equatorial track spacing requirement. This report only validates the accuracy and precision of the system for mesoscale requirements.

Sensor noise level estimation (NPOESS Precision)

Errors in the altimeter range observation are estimated by examining the high frequency range measurements. The intent is to reduce the examination time interval (or distance along the ground track) to the point where expected variations in true range and propagation path delays are essentially linear in time. The one second reporting intervals cover 6.5 km along the ground track for Jason-2. Over this distance, ocean features have little curvature in SSH. Atmospheric water vapor and atmospheric pressure have little curvature as well as the total electron content in the ionosphere. The geoid is certain areas of extreme slope may have curvature that could deviate significantly from the linear trend. The initial assumption is that over 6.5 km, geophysical features cause a linear trend in range from the ocean surface to the satellite.

The high rate sampling of 20 samples per second is used to estimate the instrument noise level. A linear fit is constructed to the high rate data, and the RMS residual between the data and linear fit is computed every second. Thus, every second a measure of the instrument noise level is computed. Because deviations of geophysical properties from the linear assumption over 6.5 km only add to this value, the error estimate based on the high rate data is an upper bound of the noise level. That is, the instrument noise is equal to or less than the noise level computed by this method. If the noise level computed is below the requirements, then the true instrument noise level is below the required values.

For this computation, the Jason-2 OGDR data set is used covering a 14 day time period 05Aug2008 to 19Aug2008 (14 days total). The resulting data set contains 824,582 individual one second observations. Of these, 521,388 are over water with no sensor flags set in the OGDR. The variance of the 20 high rate range observation deviations from a linear fit are constructed (HR^2). This observed variance divided by the expected variance is a chi squared variable with 20 degrees of freedom (χ^2_{20}). The expected value (denoted by <>) of $<\chi^2_{20}>$ is 20. Thus $<HR^2 / v^2> =20$, and $v^2=<HR^2>/20$. With 521,388 realizations of χ^2_{20}, an accurate estimate of $<HR^2>$ can be made. Figure 2 shows the distribution of the values of HR^2 from the data set covering 14 days. The mean value is 0.007705 m^2. This translates to a sensor precision level of 1.96 cm RMS noise, which meets the NPOESS IORD-II requirements of 3 cm for threshold and 2 cm for objective RMS noise.

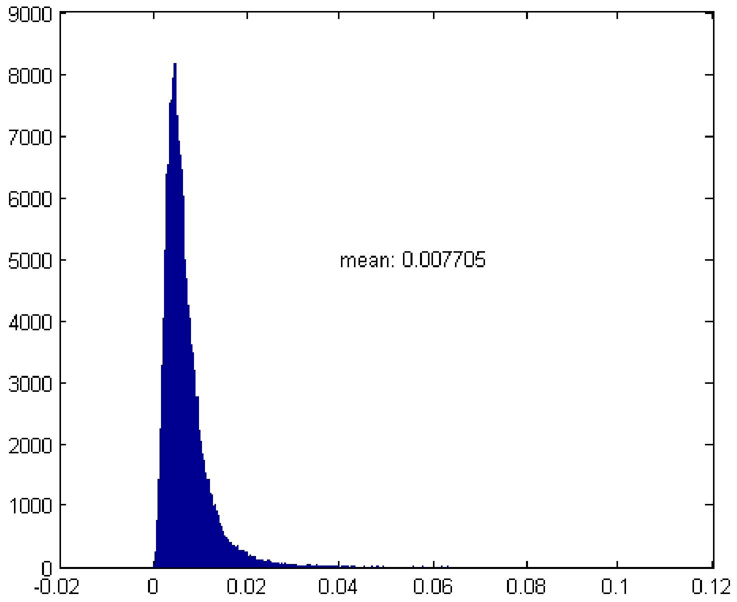

Figure 2: The distribution of number of samples of the HR^2 values from 14 days of Jason-2 observations provides a mean of 0.007705 m^2, which implies an RMS noise of 1.96 cm.

System noise level estimation (NPOESS Accuracy)

The NPOESS accuracy estimation is based on inclusion of all geophysical corrections and orbit solution estimation as well as the associated errors. These evaluations are conducted over the time period 20Jul2008 through 04Aug2008. During this time period both Jason-1 and Jason-2 were operating with Jason-2 trailing Jason-1 by 55 minutes. The evaluations are conducted by comparison of the Jason-1 SSHA and the Jason-2 SSHA, which provides validation of Jason-1 relative to a known system. In addition, the SSHA difference at points where each satellite crosses itself is computed for a self consistency check. The Jason-1 and Jason-2 SSHA are processed by ALPS. This system consists of several independent stages shown in Figure 3.

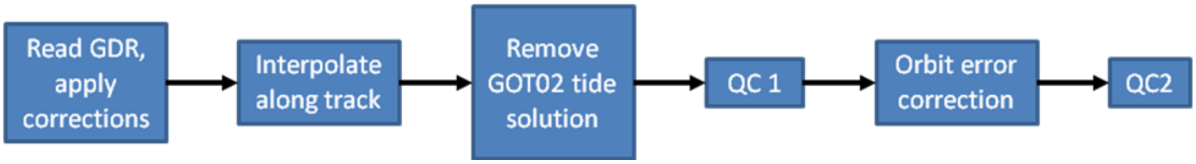

Figure 3: Functional processing blocks within ALPS.

The Read program reads the binary GDR data sets from the available satellites and different sensor variants of the available GDRs. Initial flags on the GDRs are used to determine if the SSHA values to be derived will be of use. In particular, land contamination, ice contamination and other sensor problems are identified in the GDR, and the SSHA is immediately flagged as bad. Several other quantities in the GDR are checked as well. The number of good high rate values must be greater than 15, and the rms variability of the high rate values about a linear trend must be less than 15 cm. Automatic gain control (AGC) is used as a QC parameter. SSHA values with AGC more than 3.5 standard deviations from the mean are flagged as suspect. The program quality controls corrections by comparing each geophysical correction value obtained by direct sensing (water vapor, ionosphere and em-bias in the case of Jason-1 and Jason-2) to neighboring values. The necessary corrections are then applied to the range and together with the orbit solution the SSH is computed. If necessary corrections have been flagged, the SSHA is flagged as well. In the latest version, the CLS mean sea surface (CLMSS) is interpolated spatially to each observation point and removed to provide an initial estimate of SSHA.

The corrections that are applied to both the Jason-1 and Jason-2 data sets are:

- Wet troposphere, derived by 3-channel onboard microwave radiometer on both satellites used to correct for water vapor in the atmosphere changing the propagation speed of the radar pulse

- Dry troposphere, based on surface atmospheric pressure from global meteorological models

- Inverse barometer, using atmospheric pressure and an assumption of instantaneous stationary response to pressure loading to change the water level
- Pole tide, to correct for the earth rotation axis precession and nutation, which causes the ellipsoidal shape of the earth to appear as a tide
- Solid earth tide, to correct for gravitational effects on the solid earth
- Ionosphere, measured by the dual frequency altimeter on Jason-1 and Jason-2 corrects the Ku band for propagation speed delays due to electron content in the lower ionosphere
- EM-bias, electromagnetic bias accounts for troughs of ocean waves being better reflectors than crests and thus the SSHA observation is biased low. This quantity is derived using the observed significant wave height
- Geoid, the CLS mean sea surface interpolated to each observation point

EM-bias, ionosphere and wet troposphere correction outlier detection are conducted by first smoothing each correction using a 3 second boxcar smoother, then computing the RMS difference between the original observations and the smoothed and finally flagging original values that are more than 6 standard deviations from the smoothed values. After this, the EM-bias and wet troposphere corrections are smoothed along track using a 3 point average. The ionosphere correction is smoothed using a 4 point average.

The satellites are in an exact repeat track, though they do not sample at the same points along the ground track from one repeat cycle to the next. Thus it is necessary to interpolate the data along the ground track to reference points for each satellite. During this process quality control is applied to the data to ensure no suspect values are used in the interpolation procedure. Any suspect values are flagged. The interpolation along track is a quadratic using the 3 observation points closest to the reference point. If the 3 closest observation points are too far from the reference point, the interpolated value is flagged. Several steps are used in determining the 3 closest points, and SSHA may be flagged during any of these steps.

The Goddard Ocean Tide 2000 tide solution for the 8 primary tide constituents is subtracted from all processed data. No values are flagged during this stage.

The QC1 step first removes the long term deviation from the CLSMSS at each reference ground track point. This step constructs SSHA values that represent deviations from a long term mean of 1991-2007 for all altimeter data sets. A QC step is performed by smoothing the SSHA along track, computing the difference of the original and smoothed data and flagging values more than 3 standard deviations from the smoothed.

The orbit error correction step is conducted separately on portions of data that cover one entire satellite revolution starting at the southernmost extent of the satellite orbit. Each orbit of data is corrected iteratively. During each iteration, an outlier detection is made, the orbit error estimated and evaluation of the RMS variability of the orbit of data used to determine if the track is being corrected. In each iteration the outlier limits and of the RMS of the data are reduced. The orbit correction is estimated as a 1 cycle per orbital revolution sinusoid through a least squares fit to the data with a weighting provided by historical RMS variability at each reference ground track point. The RMS test conducted within each iteration is an evaluation of the RMS of the data contained within the one orbit of data. This is a gross error check to test convergence of the iterative solution. If the RMS is not less than the limit (which starts large and reaches 16 cm by the end of the iterations), the entire orbit of data is flagged as suspect. After the iterations, a final QC is conducted by evaluating the SSHA at each ground track point to the historical SSHA variability at that point. The orbit correction amplitude for each orbit of data from Jason-1 and Jason-2 are shown in Figure 4.

The QC2 portion is a gross error check. Values rarely are flagged at this point. Note that throughout this data flow SSHA may be flagged for many different reasons at each step. Data is not removed from the processing stream, only flagged. In addition, the first time a data point is flagged for a particular reason, the identification is not changed. Subsequent evaluations may also have determined to remove the point, but the original identification is not changed. Thus it is possible to determine the point at which data was first determined to be suspect. Flagged points are examined between Jason-1 and Jason-2 in Appendix A. From the evaluations of spatial distribution of flagged data, there appears to be no significant difference between the system performance of each.

The difference of Jason-2 minus Jason-1 processed SSHA is shown in Figure 5 The global bias between the two is 0. 2 mm, and the standard deviation of the difference is 3.19 cm. If the error characteristics of the two systems are the same, this implies that each system has an error level of 2.26 cm RMS. This compares well with the sensor error level providing system precision of 1.96 cm RMS. The 2.26 cm RMS level meets both the NPOESS threshold and objectives for system accuracy level.

Evaluations of the Jason-2 minus Jason-1 differences in the applied corrections are presented in Appendix B. Generally, the instrument-derived differences are spatially white noise with little bias. There are several corrections that show large correlations along track. These are due to differences in the model products used to provide the corrections during the GDR construction. The reason they use different products is because of the latency. The Jason-2 OGDR has a latency of a few hours while the Jason-1 IGDR has a latency of 2 days. Thus, the Jason-2 dry troposphere correction based on atmospheric model sea surface pressure uses a model forecast, while the Jason-1 correction is based on a period much closer to the model analysis time. Similarly, the pole tide for Jason-2 is based on an Earth rotation axis forecast while the Jason-1 pole tide is based on observations of the axis closer to the satellite sampling time. Mean and RMS values of Jason-2 minus Jason-1 correction differences and significant wave height and wind speed are given in table 2.

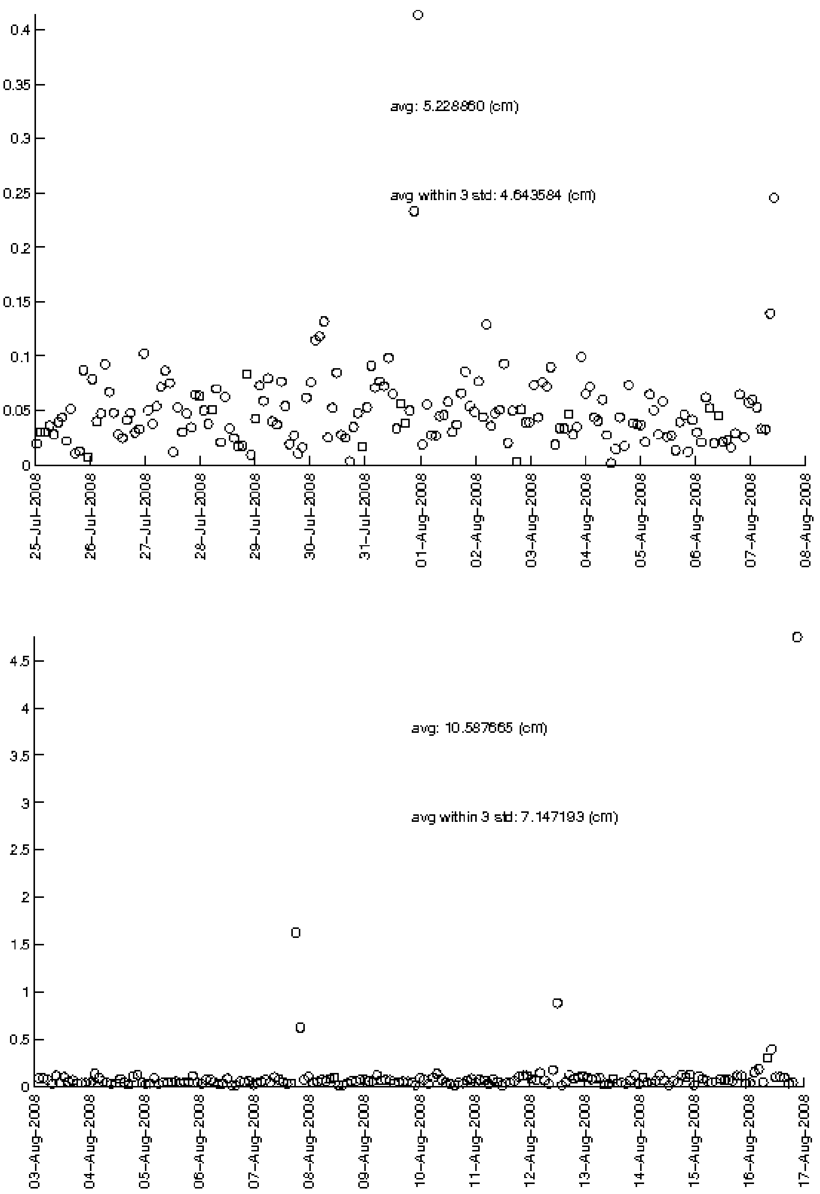

Figure 4: Amplitude (m) of orbit corrections applied to Jason-1 (top) and Jason-2 (bottom).

A second estimate of system accuracy is provided by each altimeter separately through examination of the difference of SSHA at points where the ground track crosses itself. The difference here is that there is an added source of difference between the two observations due to ocean circulation- and wind-driven SSHA changes. The longest time between the two observations at a crossover point is about 5 days. Any ocean driven SSHA changes will add to the system noise. Thus, the values computed here represent and upper bound on the system performance. The crossover RMS values are based on 14,000 crossover observations during the period. The crossover RMS differences for Jason-1 are 7.68 and for Jason-2 are 7.76. As these are RMS of differences, and assuming that the error characteristics are the same along ascending and descending passes over the crossover point, the RMS system errors for Jason-1 are 5.43 cm and for Jason-2 are 5.49 cm. These both meet the threshold requirements for mesoscale accuracy.

Beyond the inclusion of Jason-2 processing, there have been additions to the ALPS system from the present operational version 3 to the new version 4. In particular, the CLSMSS is removed from the SSH observation within the “read” program. Quality control limits have also changed. An evaluation of ALPS processing accuracy between version 3 and 4 is therefore also necessary. This evaluation was conducted by retrieving the ALPS output binary files from the NAVOCEANO version 3 system and then processing the same input Jason-1 IGDR data files on the NRL version 4 system. The RMS crossover differences are computed for each. The data included Jason-1 cycle 244 track 3 through cycle 245 track 187 (23Aug2008 22:03 to 06Sep2008 23:20 GMT). The crossover RMS of the operational version 3 system is 7.6 cm. The crossover RMS of the version 4 system is 7.4 cm. Assuming that the errors removed from version 3 to version 4 are uncorrelated to the remaining errors, the RMS of the removed errors is about 1 cm (sqrt(7.6*7.6/2-7.4*7.4/2)). Thus the new version 4 system produced lower error levels than the version 3 system.

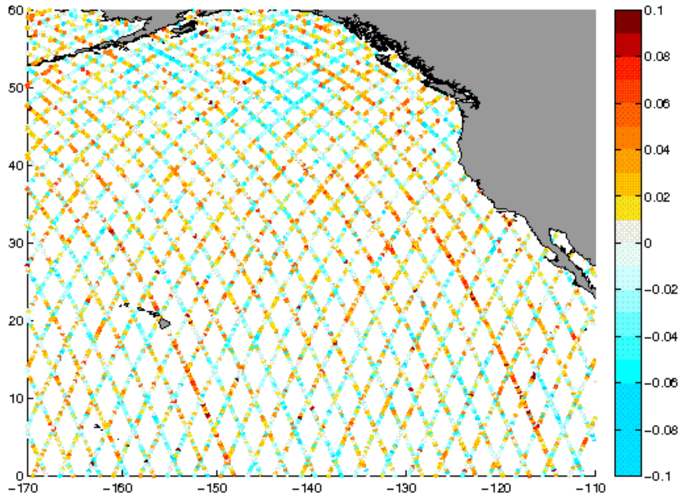

Figure 5: The SSHA difference of Jason-2 minus Jason-1 with color bar range of -0.1 to 0.1 m. This is after processing through the full ALPS with outlier detection and orbit correction. Globally, the bias is 0.0002 m, and the standard deviation is 3.19 cm. If error characteristics are equivalent between the two systems, the error of each is then 2.26 cm.

Property	Mean (cm)	RMS (cm)
SSHA	0.002	3.19
Significant Wave Height	-1.18	18.6
Wind Speed	-0.23 (m/s)	0.40 (m/s)
Ionosphere	-0.90	3.28
Wet Troposphere	0.35	0.42
Dry Troposphere	0.02	0.22
Inverse Barometer	-0.01	0.94
EM-Bias	0.15	1.35
Pole Tide	0.001	0.01
Solid Earth Tide	0.001	0.01

Table 2: The mean and RMS values of Jason-2 minus Jason-1 correction and geophysical value differences over the globe during a 14 day period 20Jul2008 through 04Aug2008. As these are differences, an estimate of the error level in either one assuming equivalent error levels are the values here divided by the square root of 2.

Data availability and coverage

Data coverage is evaluated on an orbit-by orbit basis with two metrics. The first is the fraction of all possible reference ground track points that contained data not flagged as suspect. It is possible that only half an orbit of data was returned from the satellite and so while the satellite data is good, it may appear to not be performing well. Thus, a second metric is fraction of data returned that is good. Both these are shown in Figure 6 for Jason-1 and Figure 7 for Jason-2.

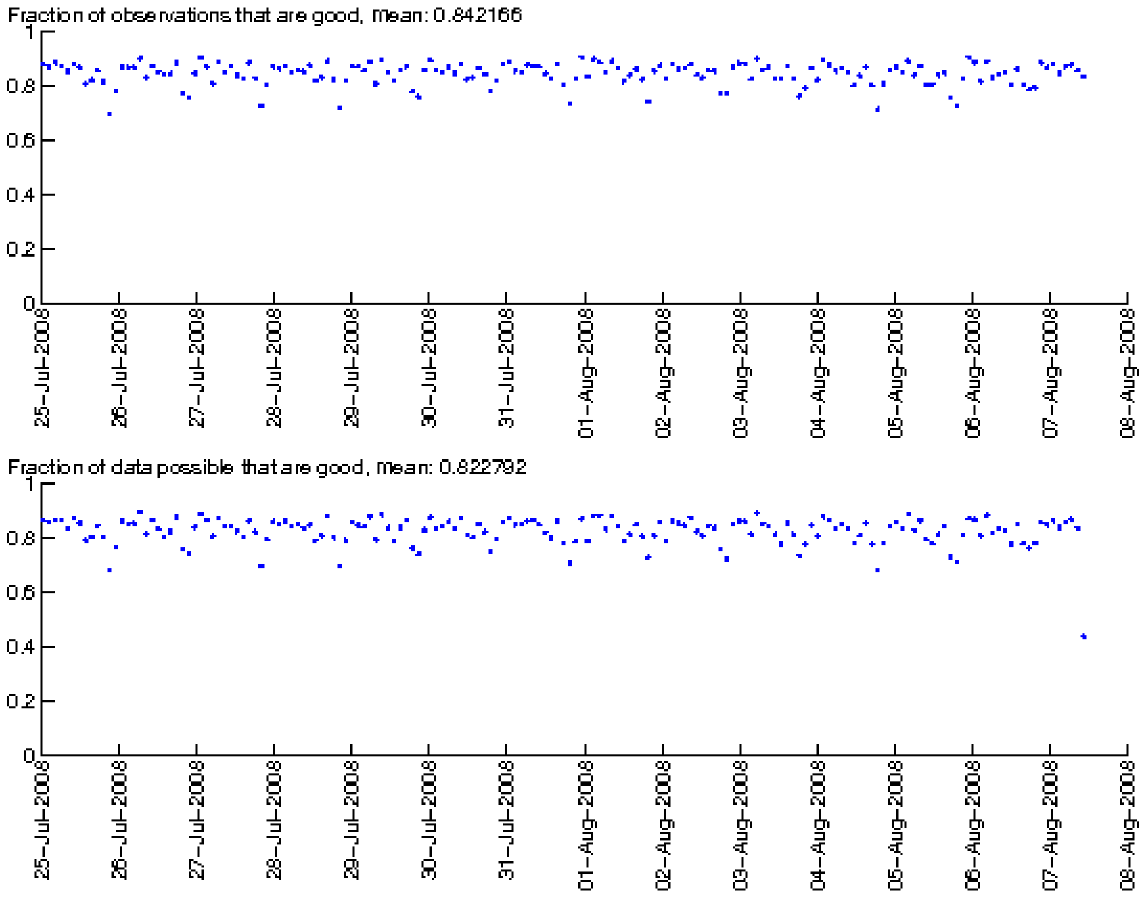

Figure 6: Jason-1 fraction of observations that are good (top) and fraction of all possible reference ground track points that contain good data (bottom). The last point on the right is an example of a partial orbit of data.

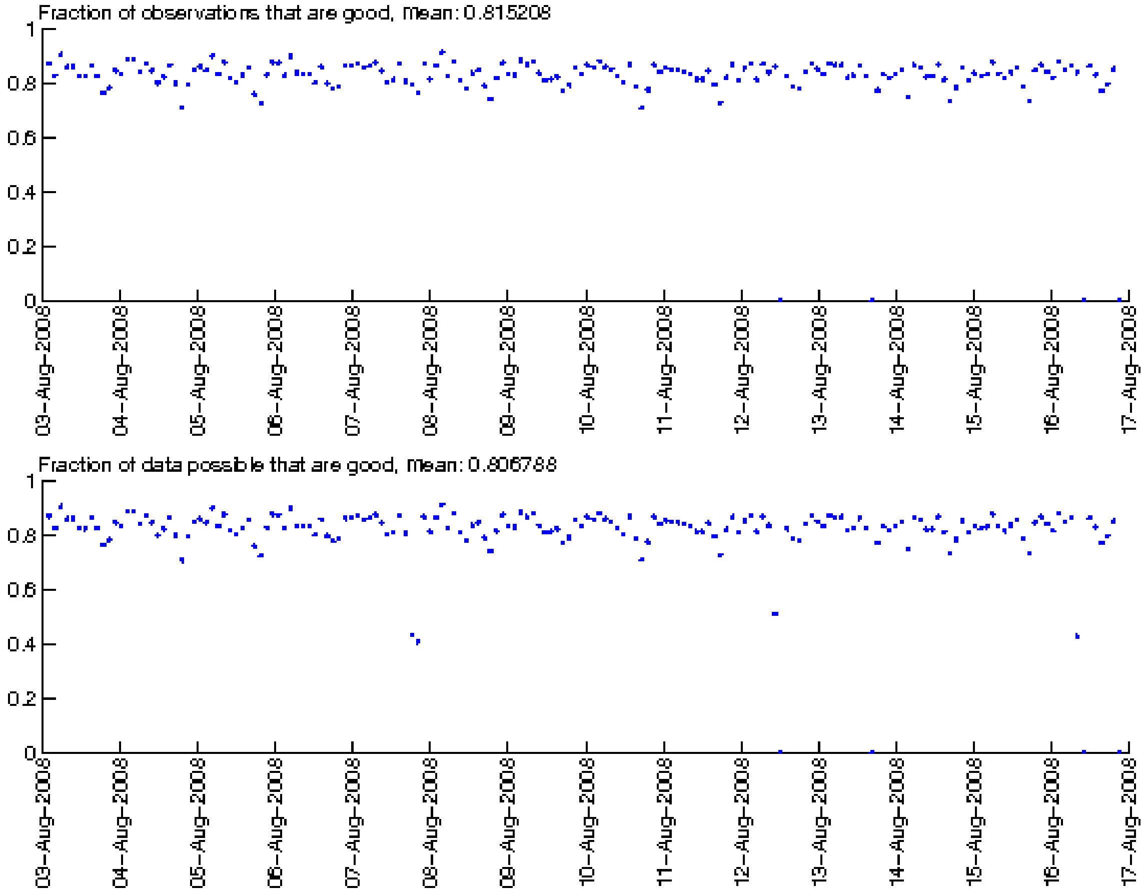

Figure 7: Jason-2 fraction of observations that are good (top) and fraction of all possible reference ground track points that contain good data (bottom).

Appendix A: Evaluation of Jason-1 and Jason-2 observations flagged as suspect during processing

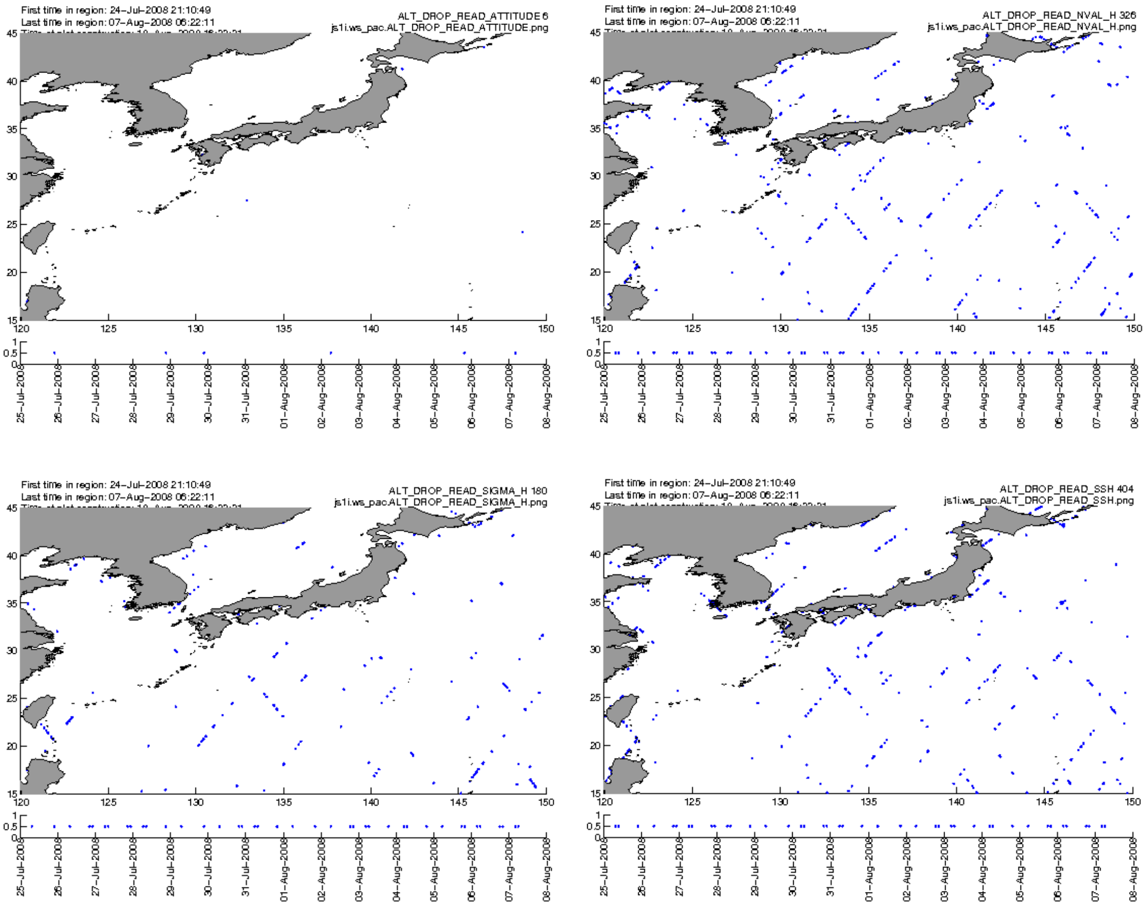

Figure A1: Jason-1 points flagged by the Read program for attitude (based on waveform) (top left), number of high rate values too low (top right), rms of high rate values too high (lower left), and for flagged as bad SSH on the GDR (lower right). The time line shows when the points were flagged. For all these, flagging is spread throughout the area and throughout time, indicating random suspect values

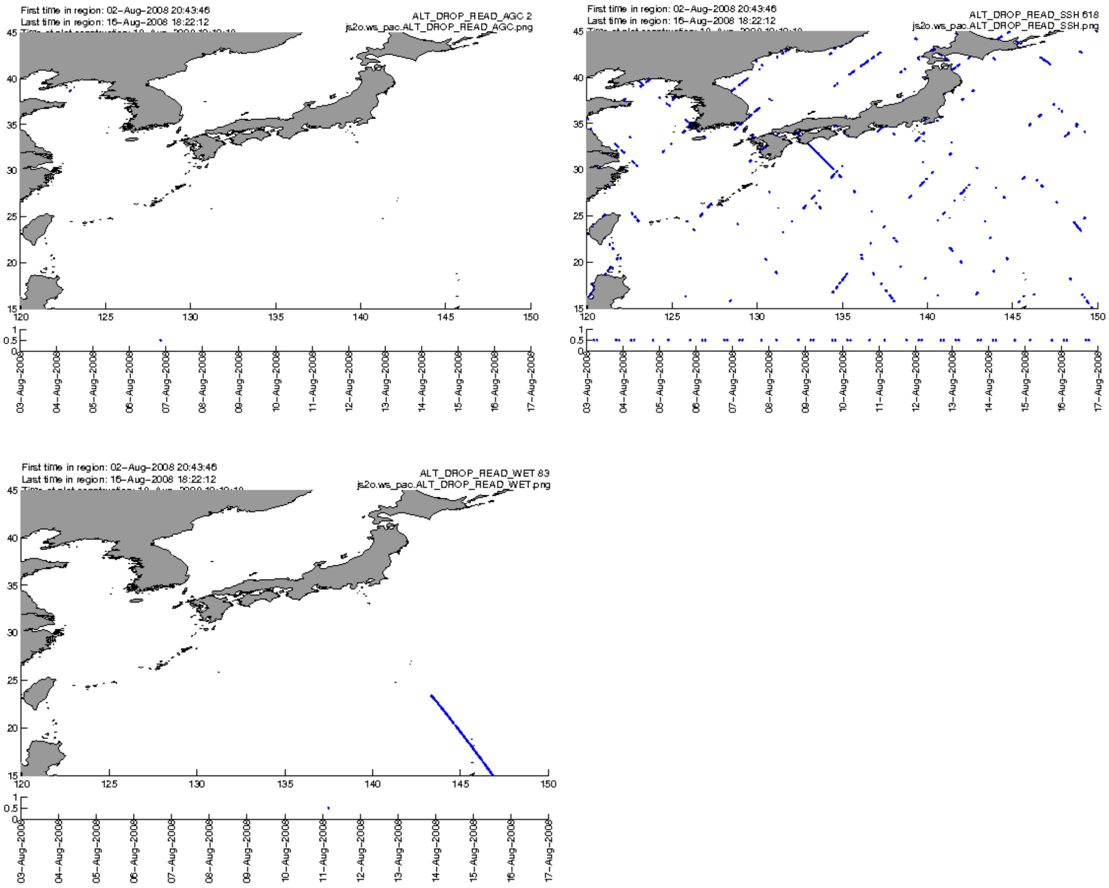

Figure A2: Jason-2 points flagged by the Read program for suspect AGC values (top left), GDR flagged values (top right), and missing wet troposphere corrections (bottom) left. The time line shows when the points were flagged. For all these, except for the wet troposphere correction, flagging is spread throughout the area and throughout time, indicating random suspect values.

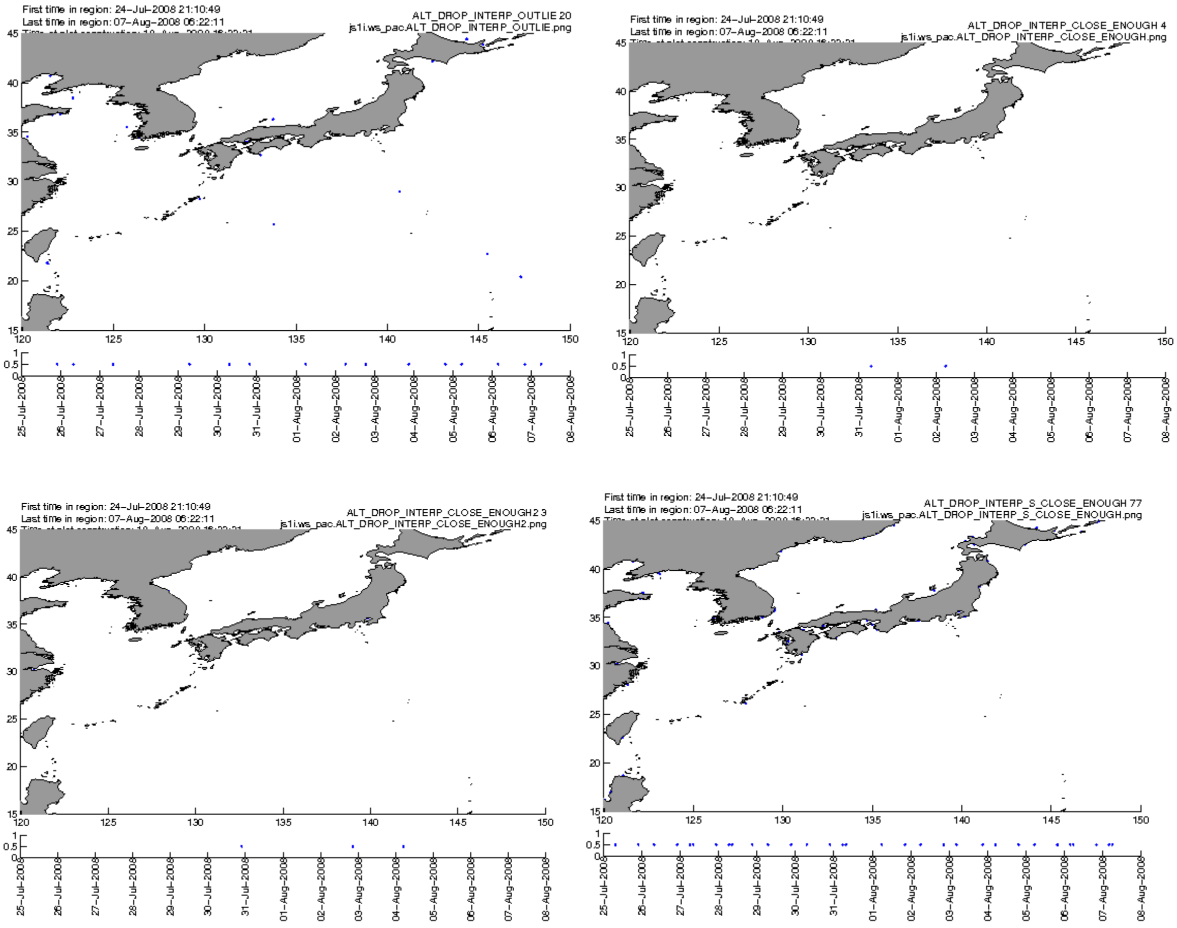

Figure A3: Jason-1 points flagged by the Interp program for initial outlier detection (top left), the first check for points close enough for interpolation (top right), the second check (lower left) and third check (lower right). The time line shows when the points were flagged. For all these flagging is spread throughout the area and throughout time, indicating random suspect values.

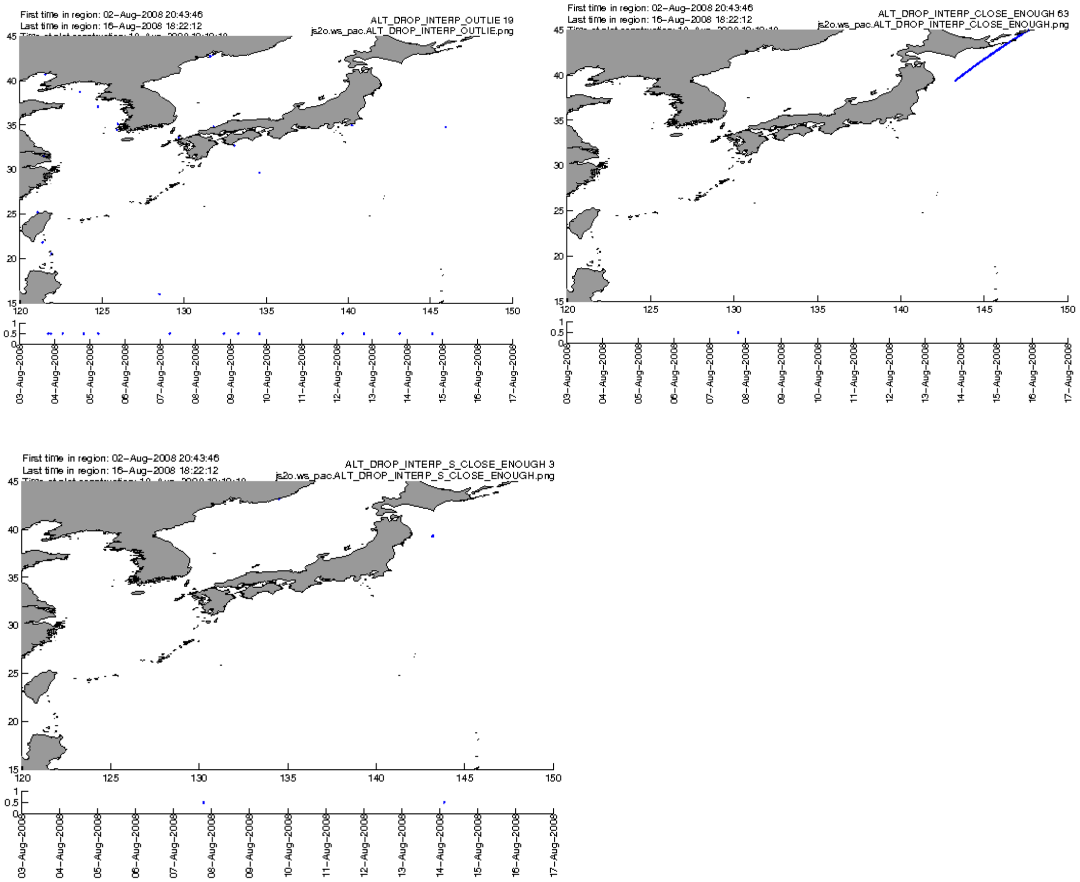

Figure A4: Jason-2 points flagged by the Interp program for initial outlier detection (top left), the first check for points close enough for interpolation (top right) and third check (lower left). The time line shows when the points were flagged. For all these flagging is spread throughout the area and throughout time, indicating random suspect values.

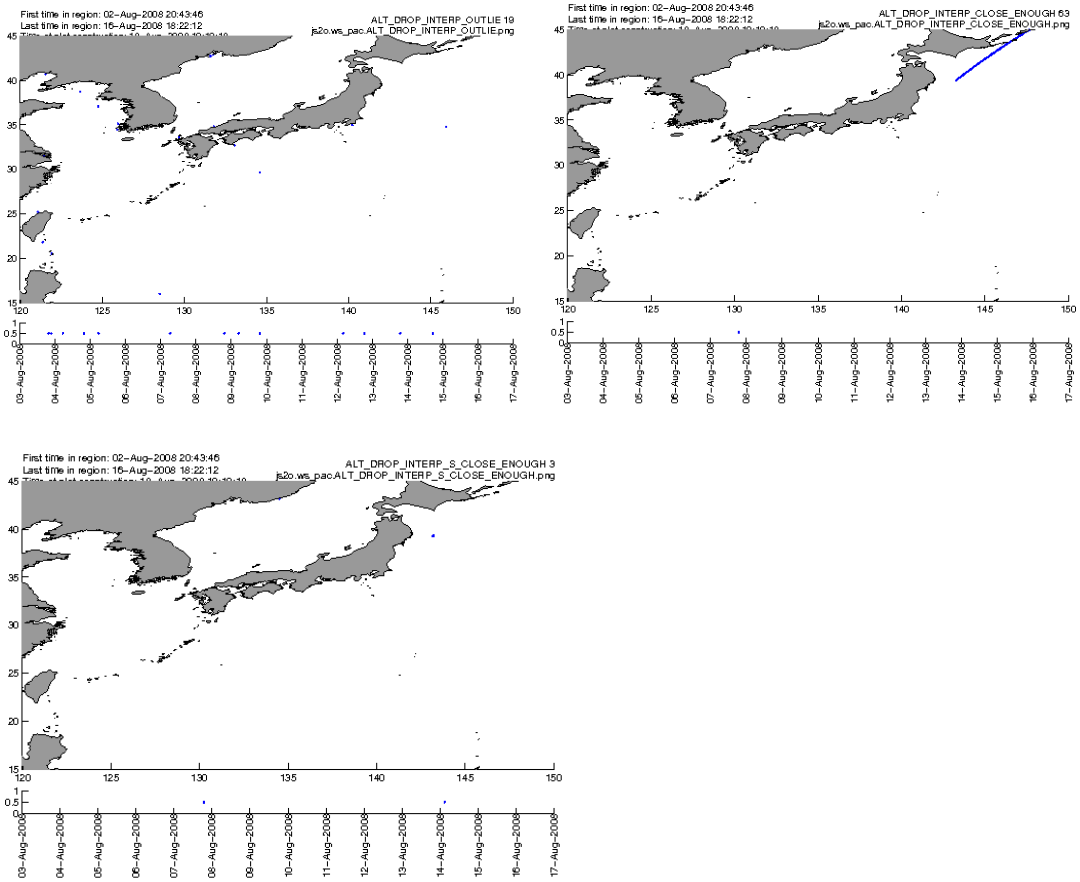

Figure A5: Jason-2 points flagged by the Interp program for initial outlier detection (top left), the first check for points close enough for interpolation (top right) and third check (lower left). The time line shows when the points were flagged. For all these flagging is spread throughout the area and throughout time, indicating random suspect values.

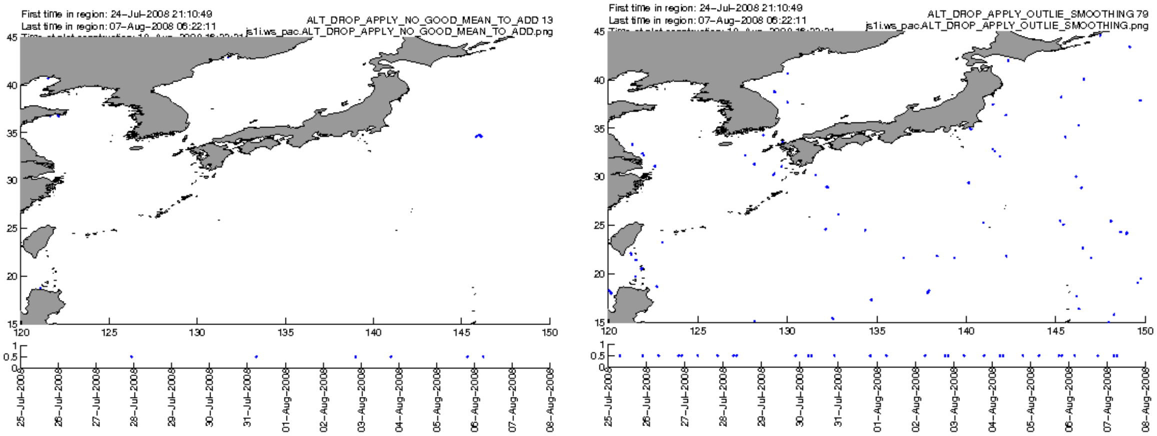

Figure A6: Jason-1 points flagged by the first QC program for points with no good historical mean (top left) and points flagged by the along track smoothing outlier detection (top right). For all these flagging is spread throughout the area and throughout time, indicating random suspect values.

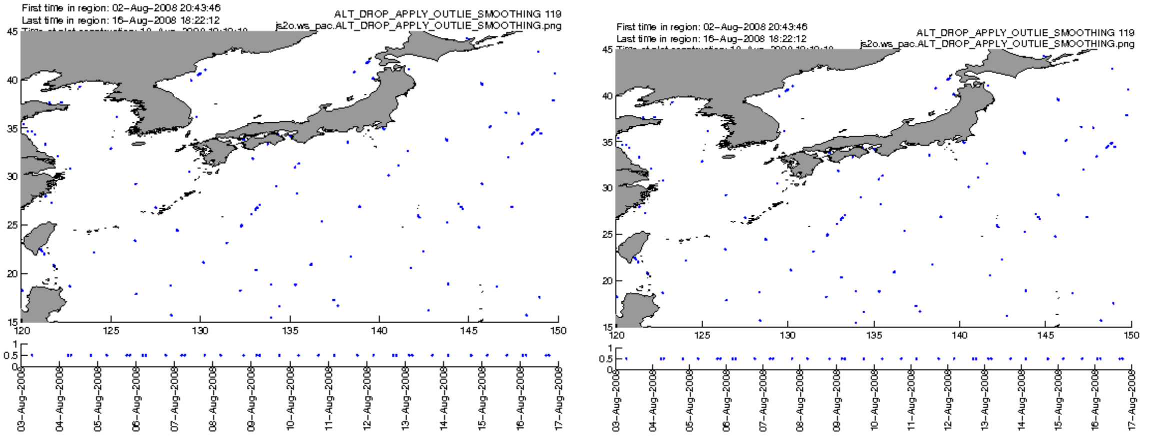

Figure A7: Jason-2 points flagged by the first QC program for points with no good historical mean (top left) and points flagged by the along track smoothing outlier detection (top right). For all these flagging is spread throughout the area and throughout time, indicating random suspect values.

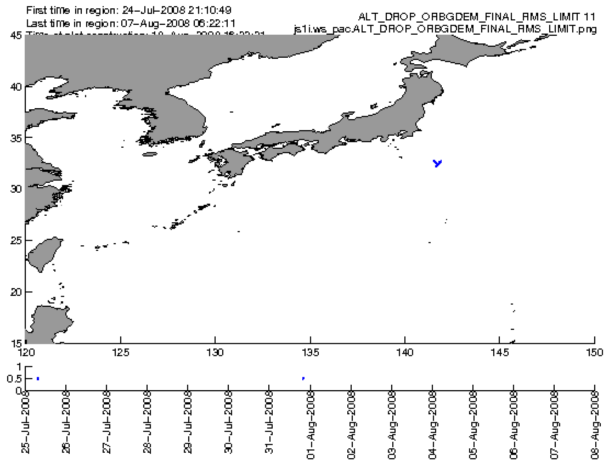

Figure A8: Jason-1 points flagged by the orbit correction program for points that were outside historical variability. For all these flagging is spread throughout the area and throughout time, indicating random suspect values.

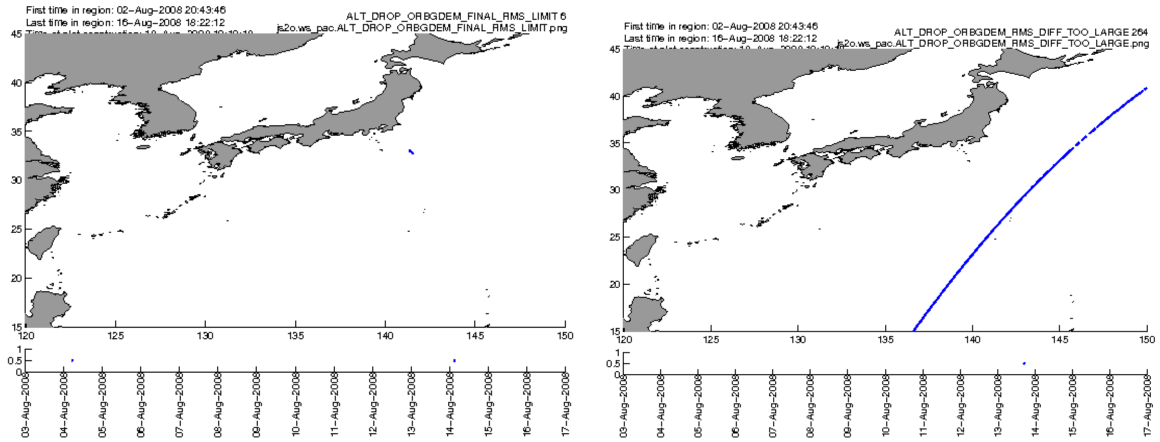

Figure A9: Jason-2 points flagged by the orbit correction program for points that were outside historical variability (left) and for which an orbit correction did not converge within the along track RMS limit (right). For all these flagging is spread throughout the area and throughout time, indicating random suspect values.

Appendix B: Evaluation of differences in Jason-2 minus Jason-1 correction fields

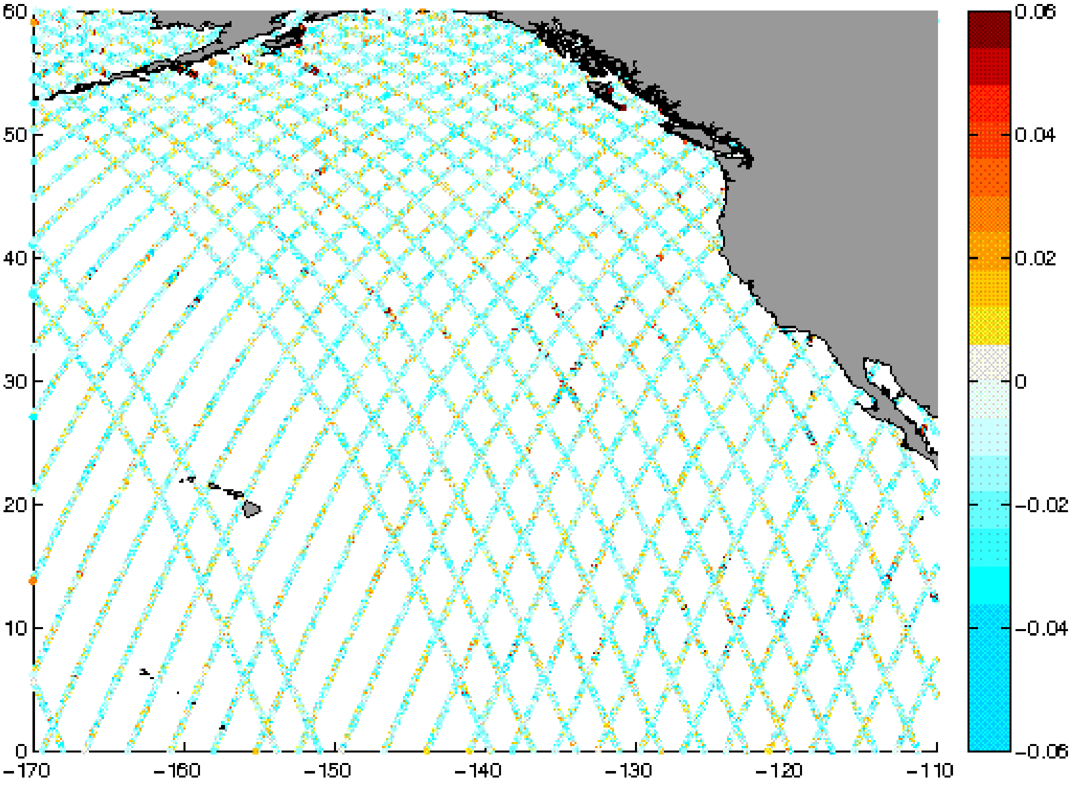

Figure B1: Jason-2 minus Jason-1 ionosphere correction differences in meters.

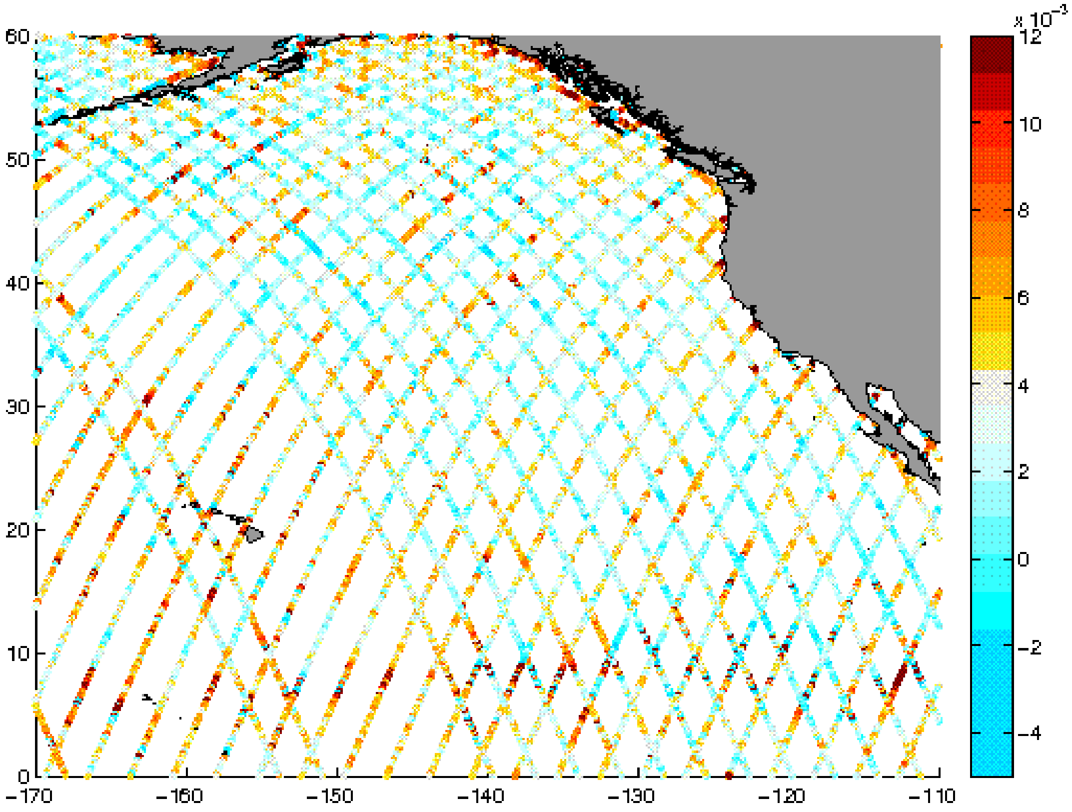

Figure B2: Jason-2 minus Jason-1 wet troposphere correction differences in meters.

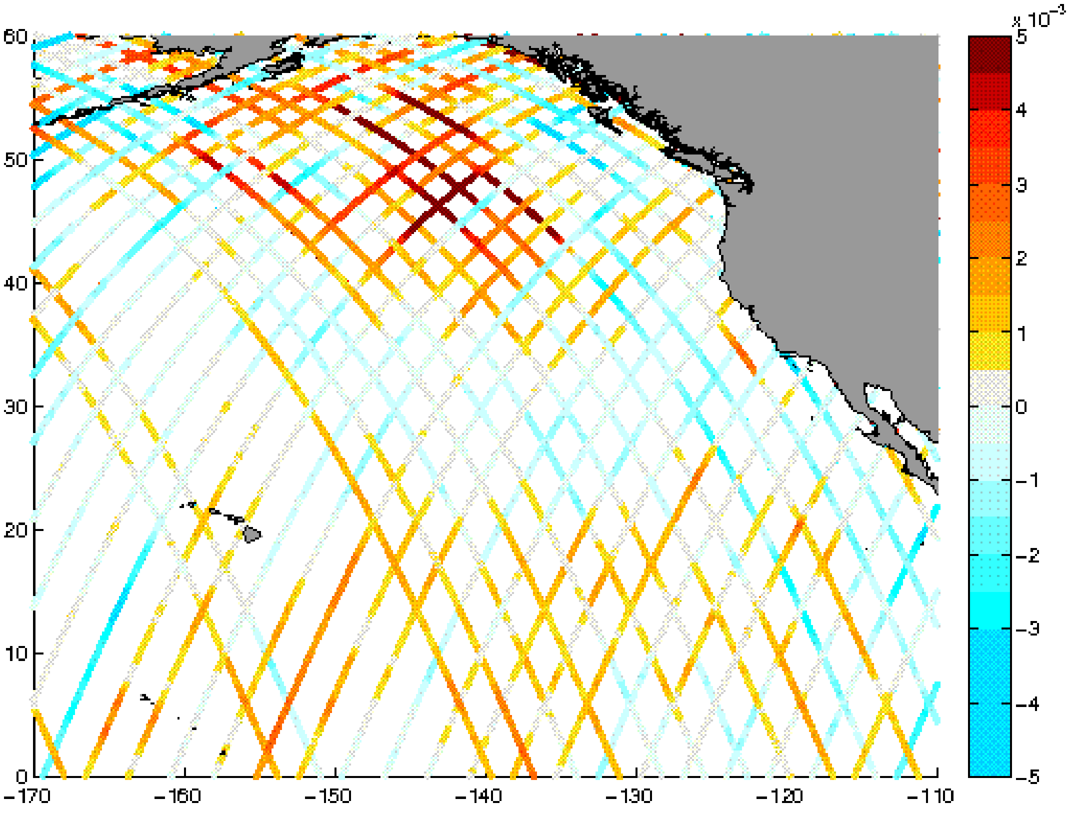

Figure B3: Jason-2 minus Jason-1 dry troposphere correction differences in meters.

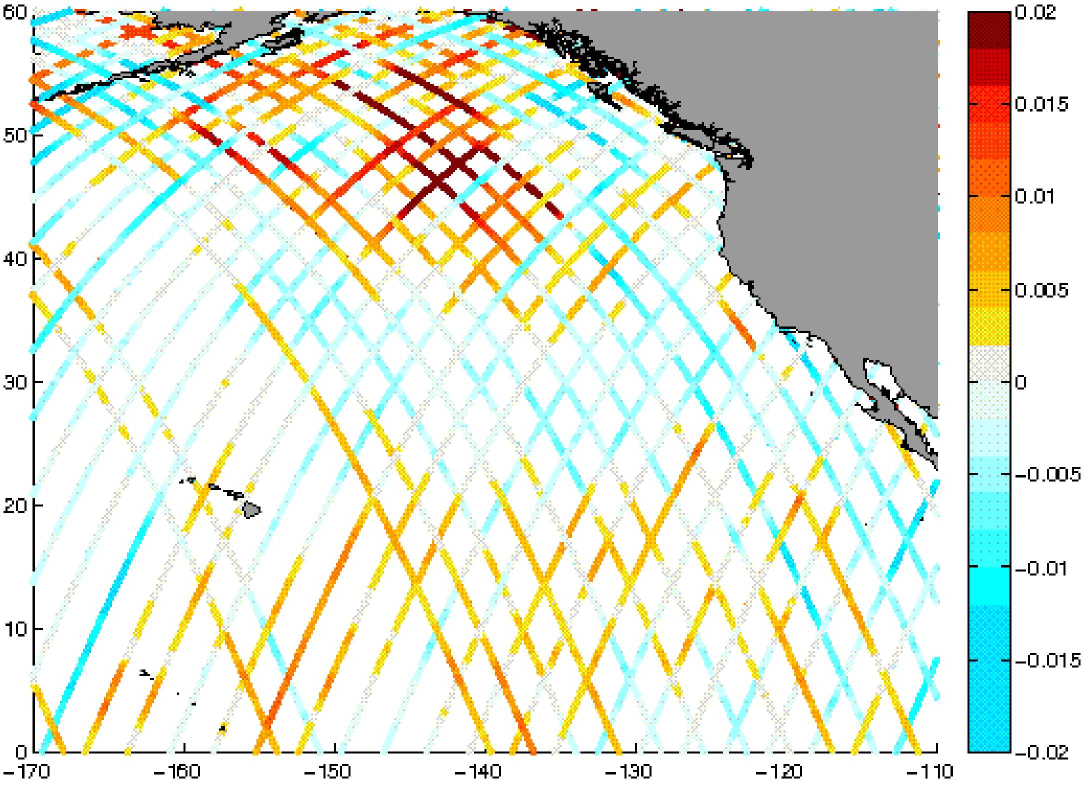

Figure B4: Jason-2 minus Jason-1 inverse barometer correction differences in meters.

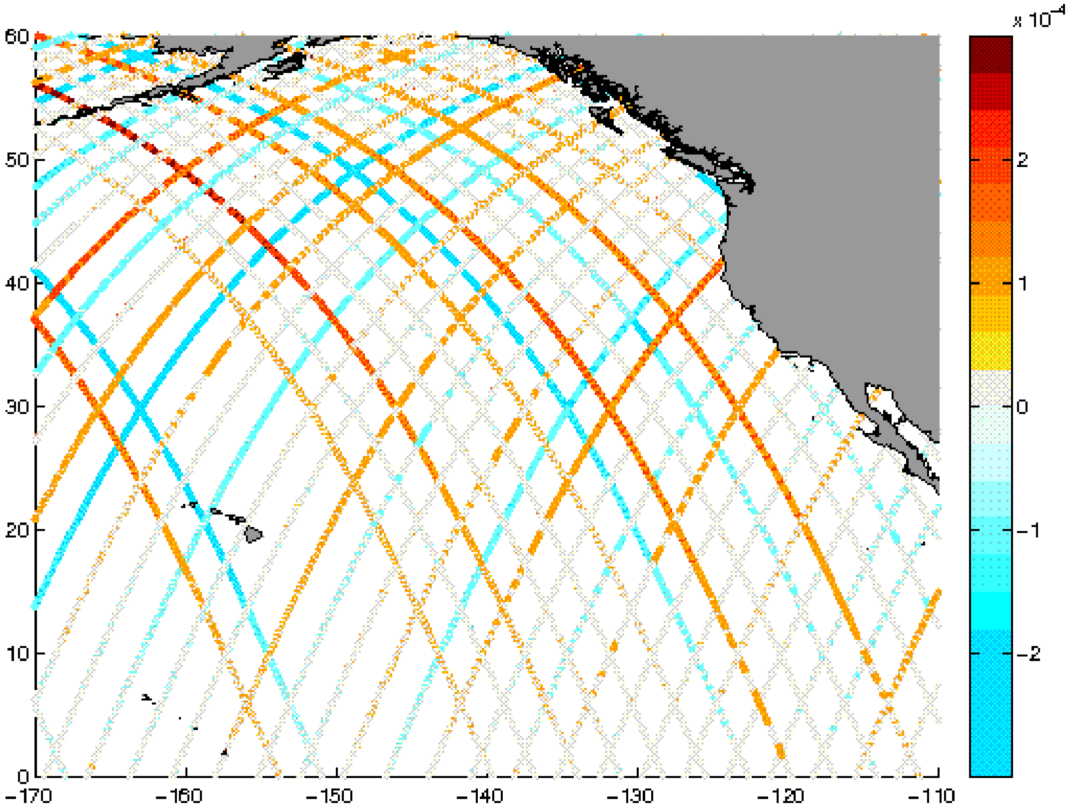

Figure B5: Jason-2 minus Jason-1 pole tide correction differences in meters.

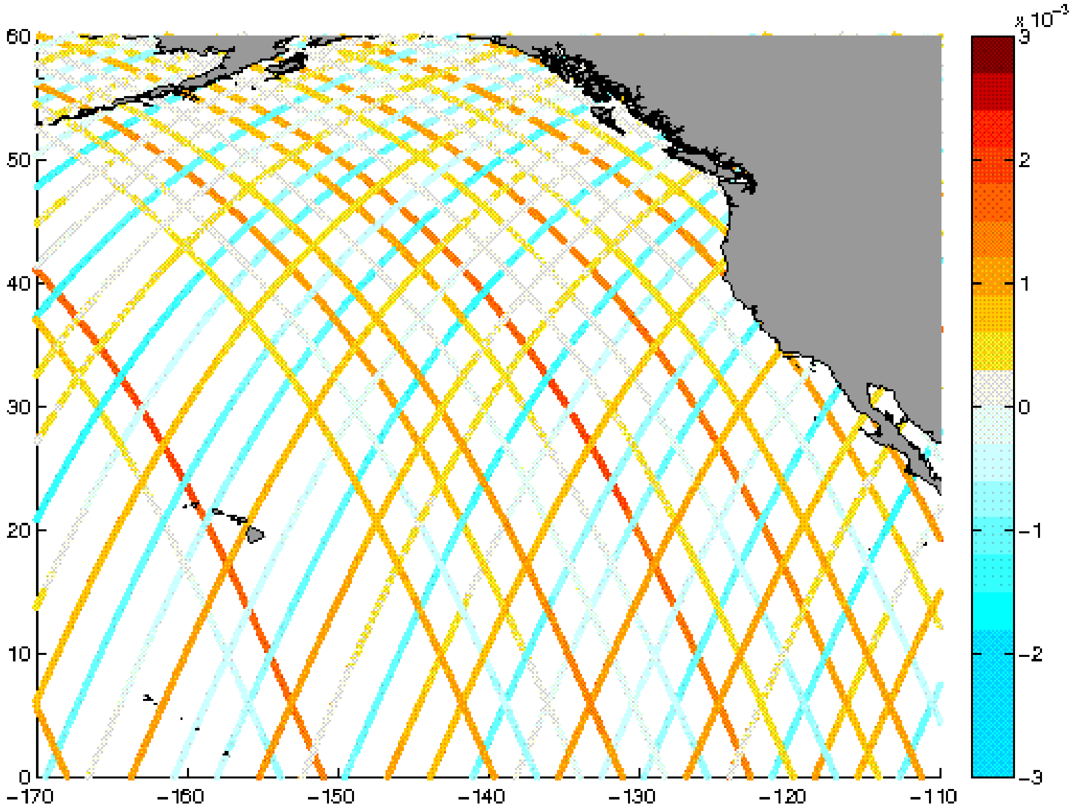

Figure B6: Jason-2 minus Jason-1 solid earth tide correction differences in meters.