VALIDATION AND APPLICATIONS OF NEAR-REAL TIME ALTIMETRY DATA FOR OPERATIONAL OCEANOGRAPHY IN COASTAL AND SHELF SEAS

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ABSTRACT

Near-real time altimetry products from ENVISAT RA-2, Jason 1 and Topex/Poseidon tandem mission are validated for the North Sea and Baltic Sea region to assess the feasibility of using the data for operational purposes. The coverage of the satellite data shows that all Jason 1 and Topex/Poseidon observations in the Baltic Sea are currently discarded in the processing of the data. The spatial scales of the sea level variability are determined from a combination of satellite altimetry and tide data. The characteristic time scales are derived from hourly observations from 45 tide gauges. The near-real time data are compared against delayed satellite data and output from a 2-dimensional storm surge model to derive error estimates of 13 cm for ENVISAT, 8 cm for Jason 1 and 8.2 for the T/P tandem mission. The feasibility of using the data for operational purposes is discussed for different sub regions.

Key words: ENVISAT, satellite altimetry, validation, operational applications.

1. INTRODUCTION

In the last decade, satellite altimetry products of sea surface height (SSH) have emerged with unprecedented accuracy [1]. These products are now capable of providing the height of the sea surface with an error of only a few centimeters. However, the data processing such as the computation of very precise orbits, is very computer demanding and the accurate data products are available with a typical delay of about a month from the time of the observation. For operational purposes, a month delay in the data is too long and interim satellite products are now being delivered in near-real time (NRT), with delays from 3 hours to 3 days. This study reports on an investigation of the feasibility of using these NRT satellite altimetry data for operational purposes in the North Sea and Baltic Sea regions. The study region with the North Sea and Baltic Sea is shown in Figure 1. The ENVISAT groundtracks are overlaid. In order for the satellite data to be of use in an operational agency, several criteria have to be fulfilled for the data. Some of the important aspects to consider are:

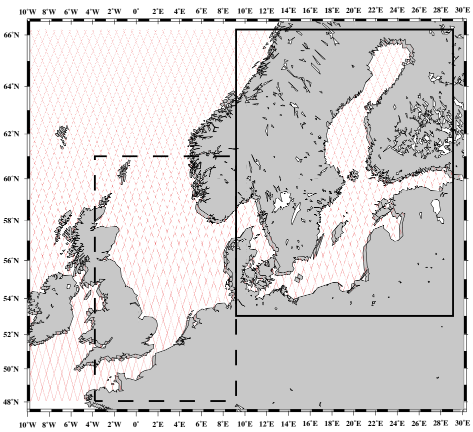

Figure 1. Study areas: North Sea (dashed line) and Baltic Sea (solid line) on top of Envisat ground tracks (red points).

- The variability of the signals
- The temporal and spatial sampling of the satellite
- The errors of the NRT satellite observations
- The spatial distribution of the model errors
- The spatial and temporal scales of the signals

The above issues will be considered in the following sections and the optimal areas for use of the satellite data will be discussed in the conclusions.

2. DATA

The data used in the investigations consist of satellite altimetry data and tidegauge measurements. Both NRT and delayed, post-processsed observations were used.

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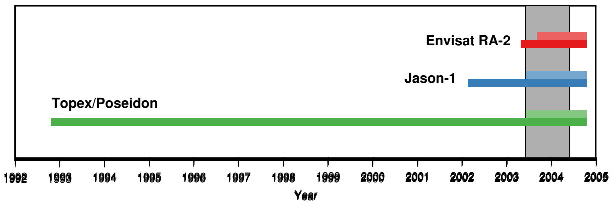

Figure 2. Temporal coverage of the altimeter data. Horizontal, colored bars indicate temporal coverage of NRT (upper, light color) and delayed (lower, dark color) altimetry data. The vertical grey bar indicates the NRT study period.

2.1. NRT Satellite Data

NRT sea surface anomalies from the ENVISAT RA-2 (EN) instrument were acquired from AVISO (Archivage, Validation et Interprétation des donnés des Satellites Océanographiques) [3]. The observations provided are sea level anomalies where tidal and inverse barometer effects have already been corrected for. The model used for the tidal correction is the CSR3.0. A subset of the data covering the North Sea and the Baltic Sea (48°N to 66.2°N and 10°W to 30°E) was extracted for the study time period 15th August 2003 to 25th May 2004. See Figure 2 for temporal coverage of the data.

NRT sea surface anomalies from the TOPEX/Poseidon (T/P) and Jason 1 (J-1) instruments were acquired from Physical Oceanography Distributed Active Archive Center (PO.DAAC) Jet Propulsion Laboratory [4] for the same area covering the time period from 6th May 2003 to 1st June 2004.

2.2. Delayed Satellite Data

Delayed, post-processed processed altimeter data were obtained from the NASA Pathfinder project. The data products consisted of 364 cycles of T/P observations and 72 cycles of J-1 data (see Figure 2). The T/P Pathfinder data have been used in this region before [2] and have an error of about 4 cm.

In order to be consistent with the tide gauge observations, tidal variations and inverse barometer effects are included in all the satellite products.

2.3. Tidegauge data

Hourly tide gauge data were obtained from about 45 tidegauge stations. Data were extracted from January 1, 1992 to June 1, 2004, if available. The positions of the tide gauges are marked with circles in Figure 3. The length of the tide gauge records demonstrate that we have very good data for most of the tide gauges, especially in the North Sea. Only a few stations in the Danish Straits have records less than 1 year.

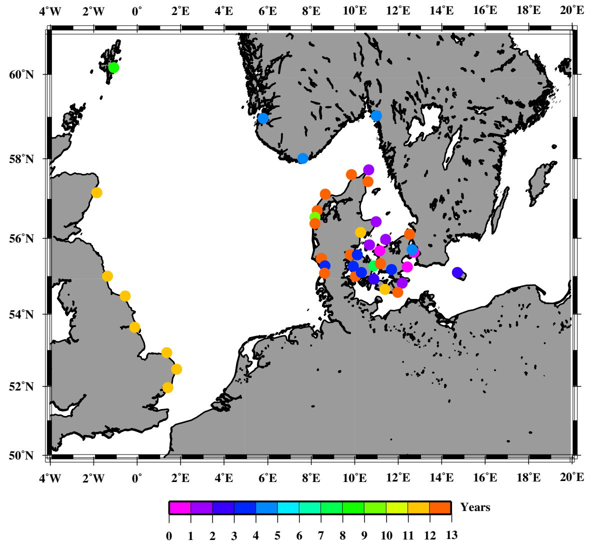

Figure 3. Tide gauge records used in this study. The colors of the circles correspond to the length of the data record in years.

Table 1. Data return percentages for the North Sea and the Baltic Sea.

Sensor/Area	North Sea	Baltic Sea
Topex/Poseidon	61	17
Jason 1	78	23
ENVISAT RA-2	23	15

3. DATA RETURN AND COVERAGE

To be able to assess the feasibility of the NRT data for operational oceanographic use, the data return and coverage was computed and mapped.

To facilitate easy comparisson between the NRT and delayed data sets, the NRT data was firstly interpolated to the nominal geopgraphical points used in the Pathfinder project dataset. A nearest neighbor interpolation was used.

The data return was computed by comparing the actual recorded observations with the theoretical number of achievable observations. See Table 1. The North Sea and Baltic Sea boundaries are indicated on Figure 1. A low overall data return for EN NRT data was noticed as well as a low return for T/P and J-1 in the Baltic Sea area. The low T/P and J-1 return was due to the lack of observations for the entire of the Baltic Sea which is also seen on the data coverage maps (Figure 4). The coverage of the datasets was assessed by computing the number of independent observations for 1-by-1 degree boxes. Independent observations are computed by counting observations from the same cycle as one observation only.

The mean number of independent observations in the North Sea has been calculated for different combinations

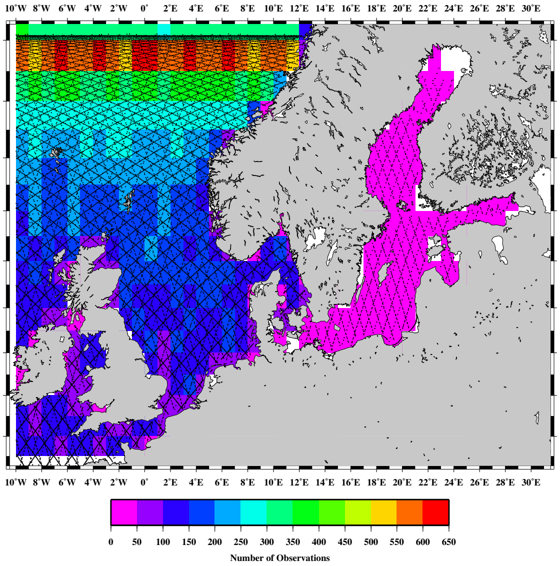

Figure 4. Number of independent NRT observations over a time period of 284 days for all three sensors combined.

of satellites. The results in Figure 5 shows the advantages of using multi satellite altimetry observations.

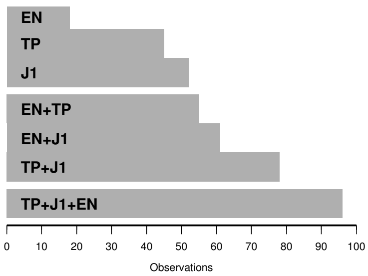

Figure 5. The average number of independent satellite observations in the North Sea for different combinations of satellites.

4. VALIDATION

4.1. 2-D storm surge model

A two dimensional storm surge model was run for 1 year, to validate the NRT satellite altimetry data and to identify areas with large model errors where satellite data have the potential of improving the performance. The model is a finite element model, MOG2D, which has spatially varying resolution from 0.5 km in the Danish Straits to 20 km in the central North Sea. The DMI-HIRLAM numerical weather prediction system was used for the meteorological forcing [5, 6]. Tides and inverse barometer effects were applied at the two open boundaries in the northern North Sea and in the English Channel.

The delayed J-1 data were used for the validation of the model. Model timeseries were extracted in every nominal satellite observation and the error statistics were thus calculated pointwise. The spatial distribution of the standard deviation of the residuals is shown in Figure 6. Areas

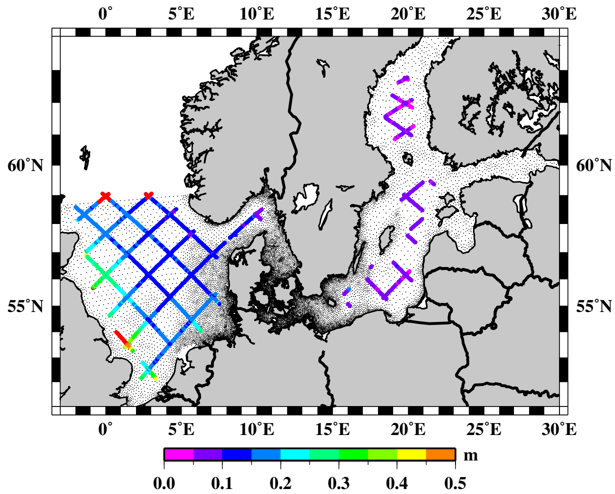

Figure 6. Pointwise standard deviation of the residuals between delayed J-1 satellite and model data. The model grid nodes are indicated with black dots.

with elevated errors are identified to be: Northern North Sea, western North Sea and parts of the southern North Sea. The Baltic Sea is seen to have small residual errors.

4.2. Errors on the NRT data

From previous studies it has been shown that the delayed Pathfinder T/P data has an accuracy of about 4 cm for this region. It is therefore possible to perform a pointwise comparison of the NRT data with the delayed data to derive a 2-dimensional spatial distribution of the NRT errors. An example of such a comparison is seen in Figure 7 and shows that the noise on the NRT data is fairly uniform throughout the region, except for the southern North Sea that tends to have slightly elevated errors. The mean standard deviation of the differences in the North Sea is 8.85 cm, which includes errors on both observations. The error estimate derived in this way, may not give an absolute error estimate on the data since the noise on the delayed data and the NRT data can be correlated. We therefore also compared all the satellite products against the 2-D model run. From the two comparisons available for each satellite we can derive the errors on the NRT products by assuming an error of 4 cm on the T/P delayed data.

The errors on the EN NRT data were calculated in the Baltic Sea in order to reduce the effect of the tidal corrections. However, inverse barometer effects may still contribute to an elevated error. The error on the EN NRT data should therefore be taken as an upper limit.

The errors derived from the comparisons are given in Table 2. As each NRT satellite product is compared twice it is possible to perform a cross validation of the derived error results. The cross check showed consistency between the error estimates for T/P and J-1. Note that the timeseries for the ENVISAT observation point are very short

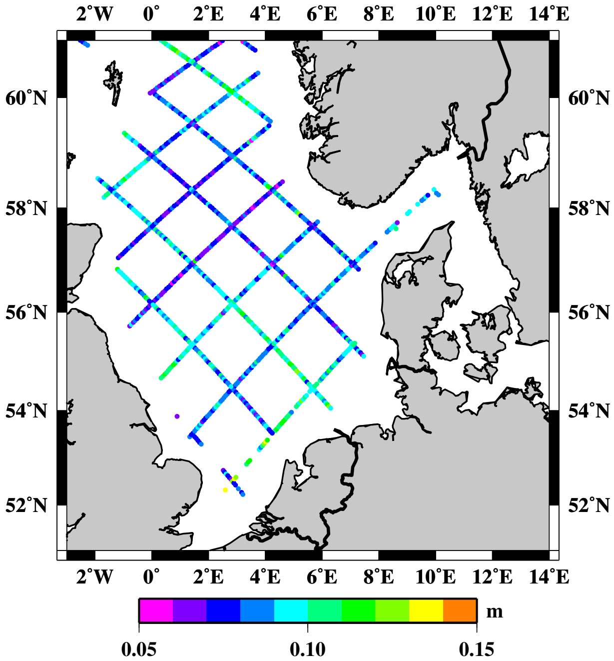

Figure 7. Standard deviation of the residuals between J-1 NRT and J-1 delayed data.

Table 2. The mean error standard deviation for the NRT satellite products in the North Sea.

Satellite	Error (cm)
Topex/Poseidon	8
Jason 1	8.2
ENVISAT	13

(typically 6-10 cycles) and the error estimate is therefore not as reliable as for T/P and J-1.

5. CHARACTERISTIC SPATIAL AND TEMPORAL SCALES

Due to the infrequent spatial and temporal sampling of the satellites, the representativeness of the satellite observations depends very much upon the spatial and temporal scales of the signals. If these scales e.g. are small, the information from the satellite data can thus only be applied at the times and positions of the measurement. This would reduce the usefulness of the data significantly.

The spatial scales of the sea level variability in the North Sea were calculated from pointwise correlations calculated between delayed T/P data and tide gauge observations. The correlation results were subsequently arranged according to the distance from the tide gauge and averaged in bins with a width of 25 km. This procedure was applied for the normal observations and for the observations where the 68 largest tidal constituents were subtracted. The spatial scales of the total sea level variability signal and for the detided sea level signal are shown in Figure 8 for the northern North Sea, the southern North Sea and the Danish Straits. The figures show that the spatial scales in general are several hundreds of kilometers. Largest spatial scales are found for the weather induced sea level variability in the northern part of the North Sea, whereas the total sea level variability in the Danish Straits display a relatively rapid decrease in the correlation.

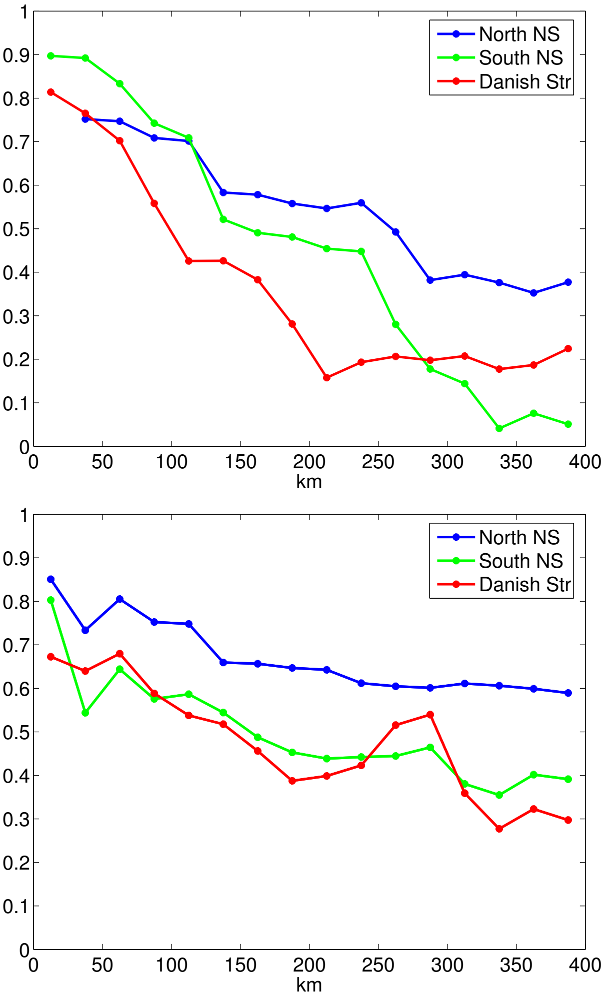

Figure 8. Correlation as a function of distance away from the tide gauges. The top figure shows the results from the total sea level signal whereas the bottom figure shows results from detided time series.

The characteristic timescales are derived from the hourly detided tide gauge observations. The auto-correlation function with a lag of up to 200 hours has been calculated for every timeseries with at least a year of data. The characteristic time scale was chosen to be the lag where the auto-correlation is equal to 0.5. The timescales of the tide gauges are shown in Figure 9. Relatively long timescales from 40-100 hours are found in the northeastern part of the North Sea and along the the Danish west coast, whereas timescales shorter than 40 hours are found along the east coast of the United Kingdom and in the Danish Straits. According to the eastermost tide gauge at Bornholm, long temporal scales may also be found for the detided sea level variability in the Baltic Sea.

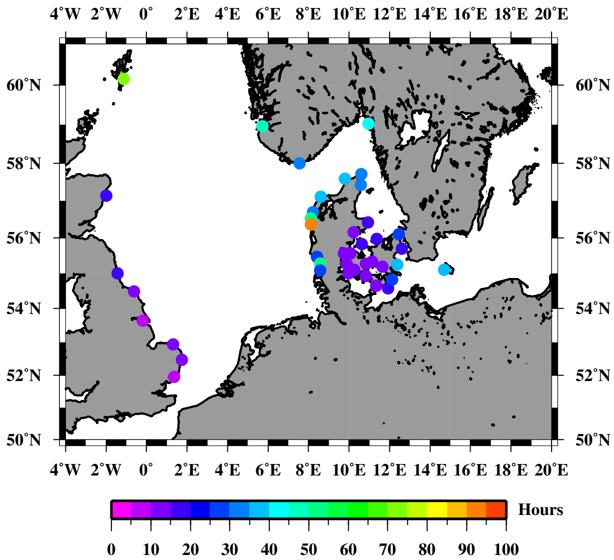

Figure 9. Characteristic time scales of the detided sea level observations.

6. DISCUSSION

From the results presented above, general statements about the feasibility of the satellite data to operational oceanography in this region can now be made. For use in the North Sea-Baltic Sea, it is essential that tidal variations and inverse barometer effects are not subtracted in the NRT EN data. Furthermore, NRT J-1 and T/P satellite data must be available for the Baltic Sea. The NRT T/P and J-1 data are currently being discarded in the Baltic Sea due to the lack of GOT99.2b tide model solutions. However, for storm surge purposes, no tidal corrections are needed. According to JPL/NASA, the T/P and J-1 NRT data processing will include Baltic Sea observations in the future (S. Desai, personal communication).

We have selected 5 areas with distinctly different characteristics. These regions differ in their potential for using satellite altimetry. The selected regions are.

- **Open boundaries in the North Sea**
  In these areas we have: Large model error, large spatial and temporal scales and good data return. The regions are therefore well suited for application of the NRT satellite altimetry data.
- **North Sea in general**
  Due to the large sea level variability and the good data return, satellite data are in general well suited for use of satellite data.
- **Danish Straits**
  Due to the low data return, the small spatial and temporal scales of the signals and the low sea level variability, the impact of satellite observations is likely to be small for this region.
- **Baltic Sea**
  As no NRT J-1 and T/P satellite data exist for this region, and only detided NRT EN data are available, no conclusive statements can be made for this area. There are indications that we have long time scales of the signals, but the variability as well as the model error is in general low. It is therefore likely that the impact of NRT satellite data will be small but further investigations and NRT J-1 and T/P data are needed in this area.

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