The Radar Altimeter Database System project RADS

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Abstract— The Radar Altimeter Database System project is part of the Netherlands Earth Observation NETwork (NEONET), an Internet facility, funded by the Dutch government, for exploitation of remote-sensing expertise and data (**http://www.neonet.nl**). In the frame of RADS, The Delft Institute for Earth-Oriented Space Research DEOS is building a data base that contains validated and verified altimeter data products that are consistent in accuracy, format, correction and reference system parameters. The availability of such a data base will attract users with less altimetry expertise like advisory councils, water management authorities and even high schools.

Much effort has been put in calibrating and validating the raw data, *i.e.* harmonization of geophysical corrections, of secondary data, and of the measurements themselves. The validation includes editing, tide experiments, radiometer-model collocation, and Rossby and Kelvin waves propagation analysis.

This paper introduces RADS, and deals with cal/val aspects and how to use/access the data.

KEYWORDS: altimetry, sea level, cal/val, El Niño

INTRODUCTION

Today, research and applications in geosciences are dependent on space-borne techniques. Techniques that require a global approach. Some of these techniques have become successful with the establishment of internationally coordinated services which handle the generation of standard products, recommendations, standards, coordinated analysis, data collection, and product and software distribution. Gradually, for other space techniques also the need for coordinated global approaches and global observation systems are being recognized. On European level the Centre for Earth Observation (CEO) works on an observation system for access to remotely sensed data. It has build the Internet infrastructure INFEO (Information on Earth Observation). As a consequence also on national levels initiatives are developed to take advantage of the need of such services. NEONET, for instance, is the Dutch answer to INFEO. In the NEONET frame DEOS thought it not only appropriate but also mandatory to build a satellite altimetry service. Many investigations have demonstrated and proven that altimetry is extremely important for geosciences, in particular geodesy, oceanography and geophysics.

DEOS' anticipation of the need for altimeter services started the RADS project: "The Radar Altimeter Database System". A data base that should consist of validated and calibrated altimeter data (sea level, wave height, wind, models and corrections) not only internally consistent but also consistent from mission to mission. This concept has also been recognized by SCOMMSA, the sub-commission on Multi-Mission Satellite Altimetry, of the CSTG, Commission for International Coordination on Space Techniques for Geodesy and Geodynamics.

In the following Sections the data processing and validation are briefly discussed followed by some words on data facilitation and concluded by an outlook.

DATA PROCESSING

Level 0 Products

For the base level, source data have been obtained from Geophysical Data Record (GDR) providers like AVISO [1] and CERSAT [2] and transformed to level 0 products with the restriction that all original information is maintained and that the format and contents are as uniform as possible. This enables replacing or isolating specific model corrections, a major research issue within DEOS and other institutes. The level 0 database contains measurements, corrections and auxiliary data at 1/s sample frequency. Basically, it represents mapping of the altimeter equation: $h_{dyn} = (H_o - H_a) - \sum_i e_i - H_g$, with h_{dyn} the sea level anomaly, H_o the orbital height with respect to the reference ellipsoid, and H_a the observed altimeter range. e_i are instrumental, environmental and geophysical corrections, and H_g is the geoid. The data are stored in separate pass (or track) files and indexed by time relative to equator crossing. A typical pass file will hold $\approx$ 2000 measurements, about 160 Kb. The enormous amount of files are kept in an hierarchical directory structure. Table 1 gives an overview of the available data within RADS. The total encompasses over 30 Gb.

Higher Level Products

Level 1 products are direct derivatives of level 0 products. We differentiate 3 sub levels, from ASCII data dumps along tracks, via collinear data, along-track interpolated, to crossover

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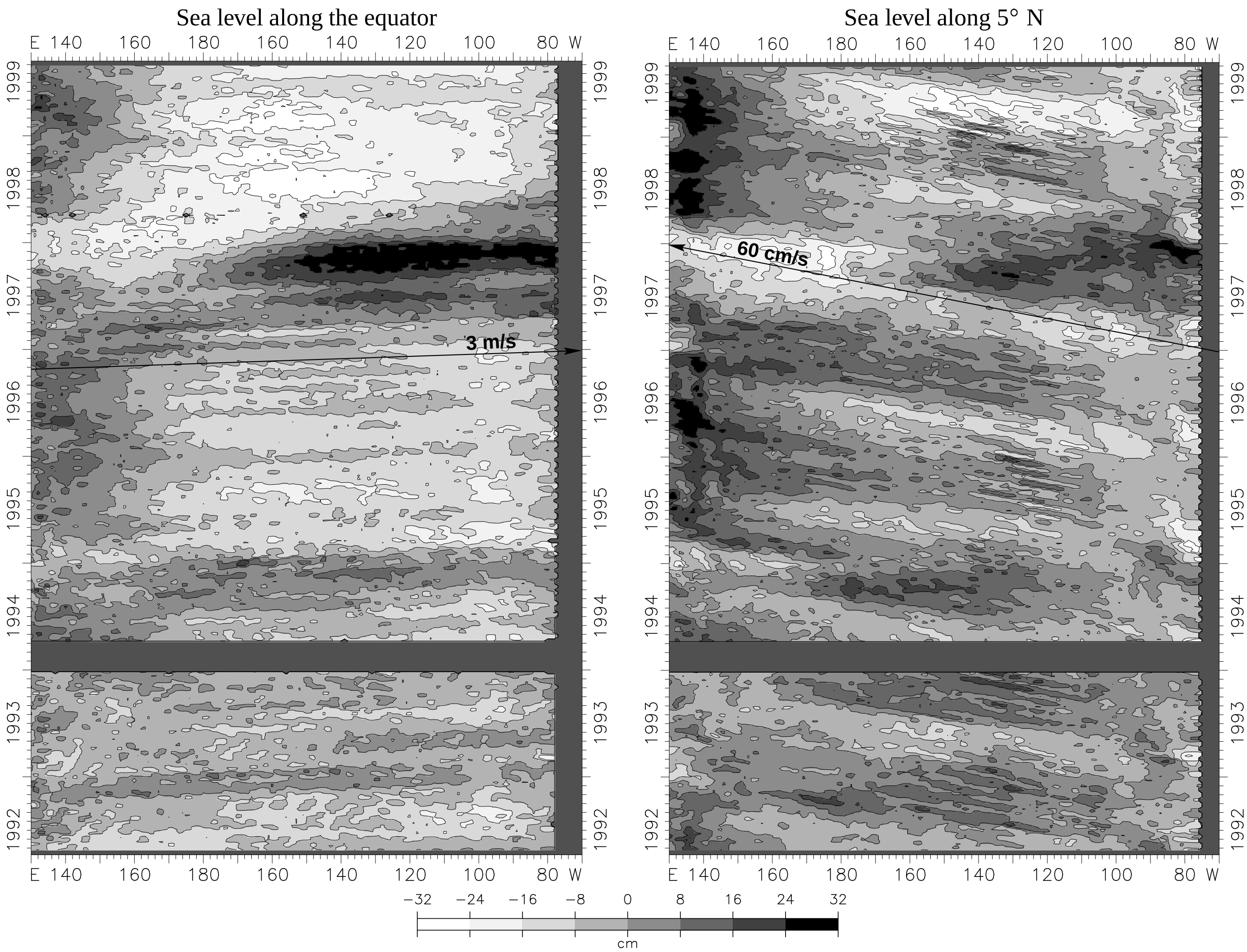

Figure 1. Time-longitude diagrams of sea level anomaly.

data, *i.e.* data generated at locations where satellite passes cross. Level 2 contains sea level anomalies interpolated to periodic (weekly) regular grids. This provides a convenient way of representing altimeter observed sea level changes. At the DEOS web site (**http://www.deos.tudelft.nl**) and the RADS server (**ftp://hocus.geo.tudelft.nl/pub**) several of such products can be found in image and movie format. From level 2 we arrive at level 3 which defines altimeter end-products like

Table 1. Altimeter data available within RADS.

System	# of passes	# of phases	Start date	Stop date
GEOSAT	45021	2	31-Mar-1985	29-Dec-1989
ERS-1	47869	7	1-Aug-1991	2-Jun-1996
TOPEX	58943	1	25-Sep-1992	25-Oct-1999
Poseidon	6080	1	1-Oct-1992	5-Sep-1999
ERS-2	44715	1	15-May-1995	11-Oct-1999

tide models, calibration models (sea state bias), models for the annual cycle and hovmuller (time-longitude) diagrams. Fig. 1 shows analyzed sea level data in the equatorial Pacific obtained from the ERS altimeters. The time-longitude diagrams show the repeated rise and fall of the 1997/98 Los Niños characterized by eastward up- and down-welling Kelvin waves along the equator traveling at roughly 3 m/s. Outside the equatorial regime most of the variability propagates westward as Rossby waves. The example of 5° N reveals wave speeds of approximately 60 cm/s.

VALIDATION OF ALTIMETER DATA

TOPEX/Poseidon data is relatively easy inserted into the RADS data base. Most of the values on the original data records are up to date and properly validated. The upgrading and merging of ERS-1 and ERS-2 altimeter data was more

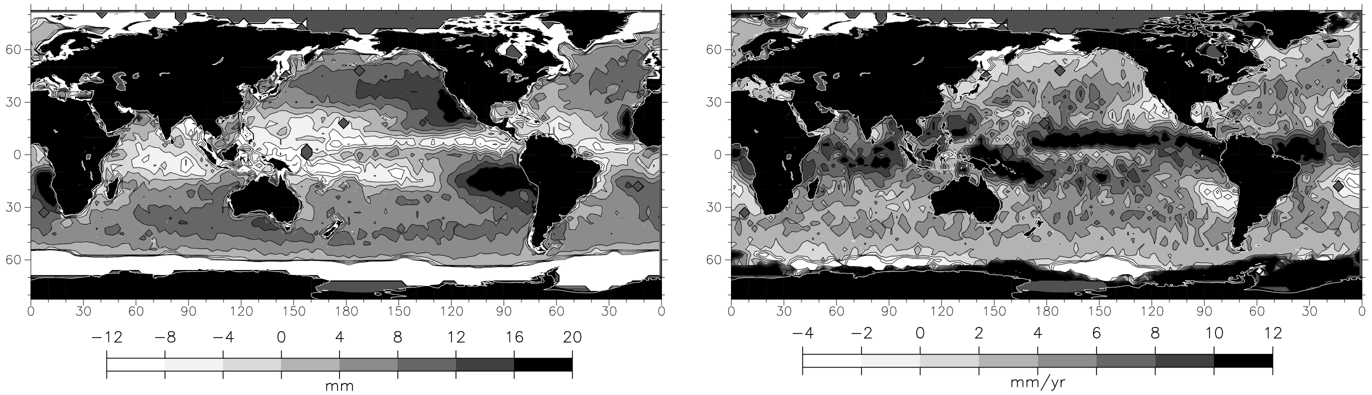

Figure 2. Mean difference wet tropo correction from ECMWF model and ERS-2 radiometer (left) and trend (right).

troublesome. A long list of adjustments to the measurements and geophysical corrections finally compiles an accurate and unified ERS data set, that meets the standards required for research in geodesy, oceanography and climate change [3]. After all data was unified, some experiments were conducted to assess the value of the new data set. This includes cross-calibration of sea level height and significant wave height, sea ice detection, and tide gauge comparisons.

ERS Data

Users of the original ERS altimeter data have to deal with three different data sets: ERS-1 prior to the launch of ERS-2, ERS-1 during the Tandem Mission, and ERS-2. To arrive at a unified multi-satellite altimeter database all the data had to be validated and upgraded to common formats and standards. A long list of re-calibration algorithms and updated geophysical corrections was the result, of which format, re-tracker (wave height, range and sea state bias), propagation corrections, orbit (time tag, radial position), and geophysical corrections are the most significant. Details can be found in [3] and [4]. Still not fully understood is the remaining difference between modeled

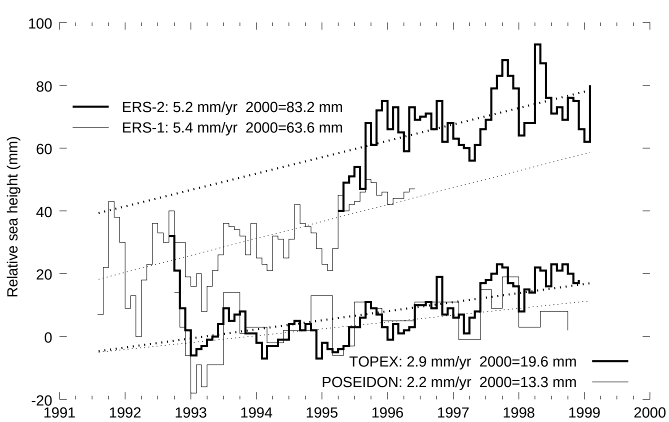

Figure 3. Monthly mean sea level height above OSU MSS96 mean sea surface model.

(ECMWF) and measured (ERS-2 Microwave Radiometer) wet tropospheric path delays. This is shown in Fig. 2: left the mean difference and right the trend in the differences over 1995-1998. Low values indicate that the modeled value is too “dry”, high values indicate that the modeled value is too “wet”. Although the larger differences in the tropics should be attributed to weaknesses in the model, at arctic latitudes the differences and trends are small (around 5 mm and 1 mm/yr, respectively).

TOPEX/Poseidon Data

As stated earlier incorporating these data was much easier, due to the fact that the original data sets have been updated and reprocessed on a regular basis. Still some updates have been applied to line the data up with RADS standards: separating the ocean and load tide, smoothing the dual-frequency based ionospheric corrections, and substituting the original geoid model for EGM96.

Sea Level Trends

After all data have been unified sea level trends according to ERS, TOPEX and Poseidon can be computed by calculating monthly mean sea levels relative to the OSU-MSS95 mean sea surface model by fitting 1 cycle/rev functions pass by pass. This is depicted in Fig. 3. The differences in the trends are likely due to differences (drifts) in the radiometers, but could also come from the altimeters themselves. This is also an unresolved issue.

FACILITATION

To obtain a set of data base requirements to be used in the RADS design, an initial Dutch users group, consisting of universities (Delft, Utrecht), institutes (NIOZ, KNMI), and industry (Delft Hydraulics, ARGOSS), was identified and consulted [5]. A preliminary breakdown shows that the interest ranges from pure science to operations, and that sea level is required mainly in a level 1 form. Obviously, tags like

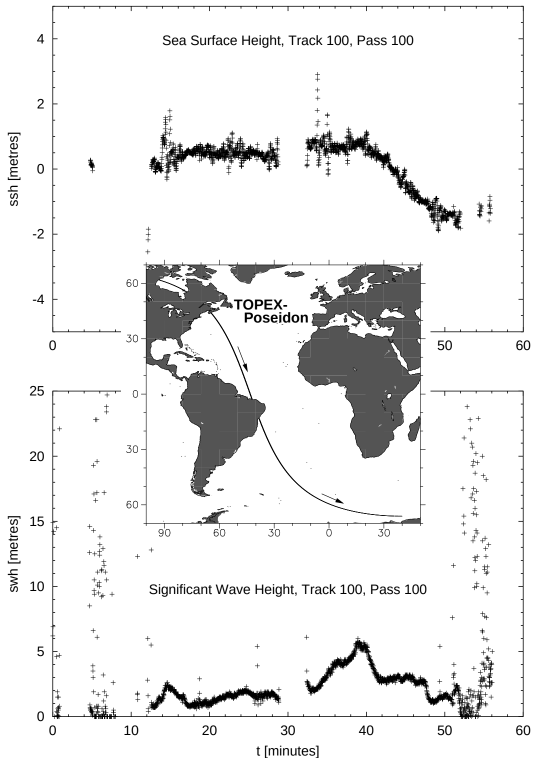

Figure 4. Sea surface height (top) and significant wave height (bottom) for TOPEX pass 100, cycle 100.

time and position are needed but more important is the measurement accuracy, especially true for assimilating altimeter data into ocean models. It was recommended that the RADS service will be continued for a period well beyond 2000, vital for research on decadal variability and global change. The requirements from the user group have been merged with the requirements set by DEOS and with requirements from previous international queries. Problems and new needs are processed during the evaluation and use of the data base by the users group and new users.

NEONET

As mentioned earlier RADS is build in the frame of NEONET. This has led to the condition that the data base should be accessible through the NEONET core software system (middle-ware and topical nodes), or at least the meta data concerning the database. In earlier versions of NEONET the information was gathered by a search robot searching the Dutch remote sensing related Internet sites. In the current version a more advanced meta data information exchange mechanism is used which requires meta data to be provided in a special format (XML). At the moment we work on automating the conversion of thousands of meta data files to this format. Meanwhile, at DEOS we have the level 0 data base on line, and interested parties already can browse the database and retrieve information of which Fig. 4 gives an example for sea surface height and significant wave height. It is retrievable from (**http://pocus.geo.tudelft.nl/˜schrama/Public/RADS-server/gtb.html**). Also a collection of higher level products is readily available from the DEOS web pages and anonymous FTP site (*c.f.* section DATA PROCESSING).

OUTLOOK

Reference [5] strongly recommends that RADS continues for years to come, especially in the frame of research on the climate like decadal variability, ENSO events, and global change (CLImate VARiability program). Also: more data will definitely contribute to improving the statistics on the dynamic behavior of sea level in general. Of course this is true, and the success of RADS not just depends on the present state of the data but even more on the continuation of the service.

On a global scale the accuracy of sea level change estimates will continue to improve by insertion of Jason and Envisat observations into the altimeter database. On regional scales the combination of TOPEX/Poseidon with ERS data and/or *in situ* data demonstrated the separability between altimeter instrument drift and sea level change. Synergy of Jason and Envisat and existing altimeter missions and other *in situ* ocean monitoring techniques will solve the calibration problem. The inclusion of new data will enhance the sampling characteristics of the altimeter data. Inter-satellite calibration will play a significant role in these studies.

Summarizing, for RADS we definitely strive for continuation, extension (not only new altimeter data but also new higher level products), improvement of quality control, linkage with other programs, and intensification of national and international contacts. We see this only as the beginning!

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