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User requirements document for RADS/NEONET

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BELEIDSCOMMISSIE REMOTE SENSING

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Executive summary

This document describes a study that was conducted in the frame of the DEOS' Radar Altimeter Database System (RADS) project. RADS is a so-called application facility of the Dutch infrastructure for exploitation of remotely sensed data, NEONET, which is funded by the Dutch government (SRON/BCRS). This particular document deals with a description of the collection, summary, and evaluation of user requirements concerning the retrieval and use of satellite altimeter data in both research environments and operational environments. For this purpose an initial user group has been identified based on the past, present, and future cooperation of DEOS with Dutch institutes and organizations:

- RWS RIKZ, National Institute for Coastal and Marine Management of the Directorate-General of Public Works and Water Management;
- IMAU, Institute for Marine en Atmospheric research Utrecht University;
- NIOZ, Netherlands Institute for Sea Research;
- KNMI, Royal Dutch Meteorological Institute of the Ministry of Transport, Public Works and Water Management;
- ARGOSS, Advisory and Research group on Geo-Observation Systems and Services;
- WL-Delft Hydraulics, consulting and research institute for water-related issues;
- AA-ITS/DUT, Applied Analysis group, Faculty of Information Technology and Systems, Delft University of Technology;
- HME-CEG/DUT, Hydro Mechanical Engineering group, Faculty of Civil Engineering and Geosciences, Delft University of Technology.

Each member of this user group has been consulted by means of meetings and a questionnaire. In addition, DEOS itself, an inter-faculty institute, joining the sub-faculty of Geodetic Engineering and the faculty of Aerospace Engineering, both at Delft University of Technology, is considered end-user of the altimeter data. DEOS has a long tradition in earth-oriented space research, particularly altimetry research, *i.e.* altimeter data processing and applications of altimetry-related geophysical products, for its research projects as well as for training of undergraduates, graduates, and PhD students. Therefore, the requirements of 'outside' users will be merged with the 'inside' requirements. Here we specifically deal with the collection and evaluation of 'outside' requirements. The merging and implementation will be dealt with in the final RADS project report.

The main goal of the study presented in this report is to obtain a set of requirements that will be used in the design of the RADS system, fulfilling the need of highly accurate altimeter data. This data will consist of verified and validated sea levels, surface winds, and significant wave heights. Raw data already have been put on-line locally at DEOS for internal needs and special requests from outside DEOS, but in the frame of NEONET these have to be made available in an easy to use and understand format with proper documentation.

After a description of the RADS project and some background information on satellite altimetry and its use in research and operations, the questionnaire is discussed. It contains questions on a) user profile, like nature of projects, organization, and computer infrastructure, b) data requirements, like which parameters, level, resolution, and what meta data, c) general requirements, like format, software, and on-line browsing, and d) suggestions, like continuation, shortcomings, funding, etc. For a complete overview on the answers the reader is referred to Appendix A. A preliminary breakdown shows that the complete field ranging from pure science to operational work is covered, that all parties have direct access to computers and the Internet, and that predominantly sea level is required in a level 1 product form. Obviously tags like time and position are needed but the most important one is the accuracy of the measurement; this is especially true for those cases in which the altimeter data will be assimilated in ocean models, so an error bar is needed. More general requirements seem to boil down to 'highest resolution', global coverage, 'binary integers', and disclosure through HTTP/FTP (URLs) and CD-rom. Furthermore it is suggested, or actually strongly recommended, that the RADS service will be continued for a period well beyond 2000, which is vital for research on decadal variability and global change, but will also contribute to better statistics on the dynamic behavior of sea level in general.

This document is concluded by suggestions for implementing the requirements in the RADS system. As previously mentioned the first Appendix lists the answers given to the questionnaire, while the second Appendix deals with the format of the level 0 product ("raw" altimeter measurements). The third Appendix gives an impression of data coverage from the ERS-2 and TOPEX/POSEIDON missions. This information was also provided to the user group along with the questionnaire in order to show what is locally available on-line at DEOS.

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Chapter 1

Introducing RADS

1.1 Problem definition and project objectives

Satellite altimetry has a long history within the Delft institute for Earth-Oriented Space research (DEOS). Activities have been focused on the processing of satellite altimeter observations for precise orbit determination, and geodetic and oceanographic applications, and on the improvement of various environmental and instrumental correction models that are needed for these data. Numerous altimeter missions have been studied, among which GEOS-3 (1975-1978), SEASAT (1978), GEOSAT (1985-1990) and ERS-1 (1991-1995). Operational satellites of which data is used include TOPEX/POSEIDON, ERS-2, and GFO (GEOSAT follow-on), launched respectively in 1992, 1995, and 1997. In addition DEOS has a number of approved AO proposals that guarantee data flow from the T/P and ERS-2 follow-ons, JASON-1 and ENVISAT-1, both to be launched in 2000.

In the past DEOS has been redistributing corrected altimeter measurements in all kinds of formats and levels of accuracy (some of which now have outdated corrections), and from all kinds of missions, for its (inter)national project partners. These projects not only involve straightforward sea level variations, but also more specialized products from analyses like climatology. As satellite altimetry already spans a period of more than 20 years, and this number is still increasing, this has become an unsatisfying situation. Both DEOS and its present and future partners would benefit from a data base that consists of validated and verified data that is consistent throughout the data base (the whole period) in accuracy, format, correction and reference system parameters used. This would also attract new users (customers) with less expertise in utilizing altimetry if the data would be well-documented, easy accessible, and easy to use. One can think of advisory councils or local water management authorities. Consistency is also important if we want to use old data in conjunction with new data. Consider for instance the contribution of ocean and load tides to the measured sea level heights. Currently these can be modeled with an overall precision of about 3 cm, which is far better than only 5 years ago. Application of these modern tide models to older altimeter data will discard errors associated with the earlier tidal correction problems and bring the data of for instance SEASAT or GEOSAT to a higher level of accuracy, enabling researchers to study past sea level changes with unprecedented accuracy. This is not only true for the tides, it is also true for all the other corrections used in satellite altimetry, like the ionospheric and wet tropospheric correction, the EM bias, the marine gravity contribution to the measurement (geoid) and the satellite height needed to reduce the measured distance between satellite and sea surface to sea level.

NEONET, funded by the Dutch government (BCRS/SRON), is the Dutch network/infrastructure for (easy) access to earth observation products. Consequently, it was suggested that the DEOS' Radar Altimeter Database System (RADS) project could be sheltered here as a so-called Application Facility (AF): for further details on NEONET the reader is referred to `http://www.neonet.nl` or to written documentation on NEONET). Meanwhile, the proposal for building the consistent database of high precision sea levels and associated products has been approved, and the actual building is in progress. One of the main concerns of DEOS and its funding partners is the anticipation of the potential users of the data base. Therefore an initial user group was defined and consulted. Preliminary results of this consult are presented in this document. The structure of the user group, consisting of a number of Dutch universities (Utrecht, Delft), institutes (RIKZ, KNMI, NIOZ), and companies (Delft Hydraulics, ARGOSS), is based on past and present contacts of DEOS. Not unimportant is the contribution of DEOS' own background and expertise. A brief anthology, DEOS; conducted the MOCUR/BCRS project on the monitoring of ocean currents, in which for the first time a long record of altimetry was investigated spanning the GEOSAT, ERS-1/2, and TOPEX/POSEIDON missions; is also sponsored by SRON for its earth-oriented space research program and in particular ERS-1 and ERS-2 data processing activities; initiated the DATUM-1 and 2 projects together with RSW RIKZ; and is supporting ARGOSS in building a wave climate statistics facility. Recently a new BCRS project was started with Delft Hydraulics and partners from KNMI and Applied Analysis (DUT) on the assimilation of altimetry in local tide and storm surge models to be applied in the South China Sea and Indonesian waters. Moreover DEOS cooperates with the KNMI in two ALW/SRON proposals for a post-doc and PhD position, both covering the subject of data assimilation for El Niño and climate research.

1.2 Project work

The Radar Altimetry Database System (RADS) will contain the essential data required by its users at the end of the project (early 2000) and meet the integrity and quality assurance specifications as laid out in the original proposal and in the final version of this document. However, already during the project, or the building of the database, parts of the database will be available for access and evaluation.

RADS distinguishes three levels of data. Level 0 is directly based on the raw data and corrections as they are received from various organizations. These data have been calibrated and the corrections validated/verified and possibly updated. This also includes in-house computed orbit corrections. Such a database easily spans more than 40 Gb. Obviously level 1 is based on level 0 and still contains bulk information but in a compressed and easy to use form: either only a few parameters in the form of anomalies (deviations from the mean) and a small number of tags, organized in collinear tracks, or just one or two parameters interpolated to geographical grids for fixed time intervals. Level 2 products are more or less end-products based on analyses of either level 0 or level 1 information. These have very specific goals. For instance, amplitude and phase maps of selected ocean and/or load tide constituents, time-longitude maps to study wave propagation effects, seasonal amplitude and phase maps to study steric heating of the top-layer of the oceans, variability maps and trends in the sea level for climate studies. The most obvious ones will be made available directly, others are available upon request.

The work that needs to be done or actually that is in progress now is distributed over 3 so-called work packages (WPs):

- WP 1 - Management: organization and project control,
- WP 2 - Data base development and user support: developing an on-line altimeter database, feeding heterogeneous altimeter sources into one uniform database structure, merging (interpolating and testing) alternative corrections from other data sources, and maintaining documentation,
- WP 3 - Communication and quality control: helping users of the altimeter data base to access RADS, and maintaining a World Wide Web (WWW) interface consisting of browsers and specialized query programs to access the data products.

Up to now a lot of effort has been put in setting up the level 0 data base and the calibration and validation of the data used. Calibration entails both harmonization of the geophysical corrections like geoid, orbit, tides, ellipsoid, mean sea surface, and atmospheric response, of the secondary data like significant wave height, radiometer (water vapor), and ionosphere, and of the altimeter measurements themselves, like clock frequency, drift, sea state bias, altimeter bias, and temperature dependency, while validation includes geo-coding (land-sea mask), editing (data flagging), ice detection, tidal experiments, collocation radiometer with model information (ECMWF/NMC), propagation speed of Rossby and Kelvin waves, and statistical analyses. The work on on-line browsers also has been initiated.

Chapter 2

Background

2.1 Measuring sea level from space

Earth-observation satellites, also called remote-sensing satellites, are ideal platforms for watching the earth from a distance. From their orbit, they are capable of monitoring the entire globe in a relatively short period and repeating the observations in a regular manner. An example of an active sensor that can be employed on such platforms for measuring sea level is the so-called radar altimeter. By transmitting and receiving radar pulses scattered back from the sea surface this instrument can determine the distance between the satellite (radar dish) and the sea surface right beneath the satellite (nadir). This is illustrated in Figure 2.1: The range is determined from the 2-way travel time, given by the point where half of the return power is received. When the exact height of the satellite with respect to the center of gravity of the earth or any other reference level is known we can simply subtract the measured distance from this height to recover the sea level (with respect to the chosen reference level). This concept has been depicted in Figure 2.2

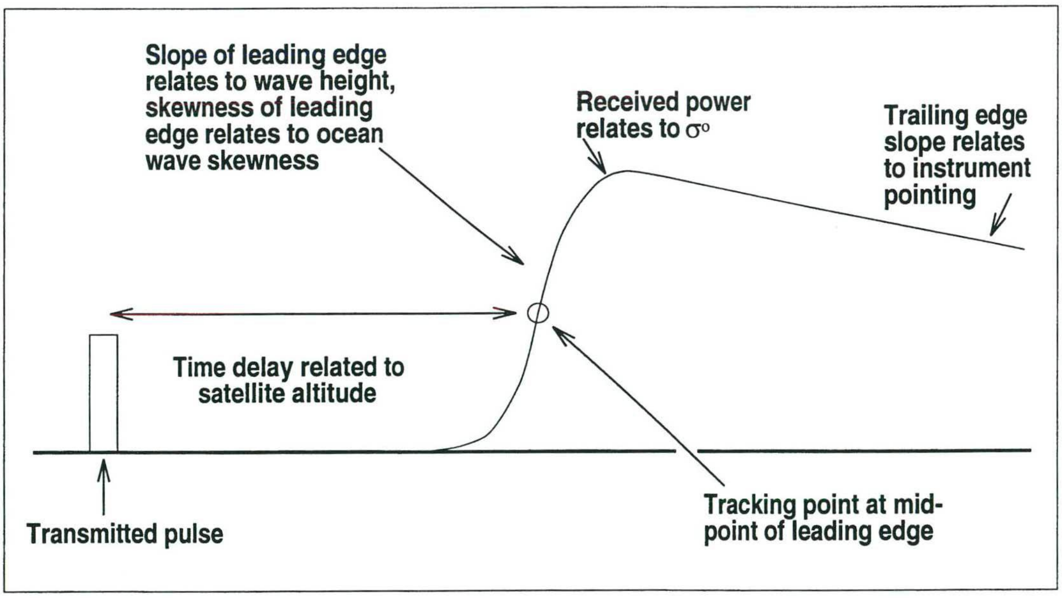


Figure 2.1 Average profile of an ocean return waveform.

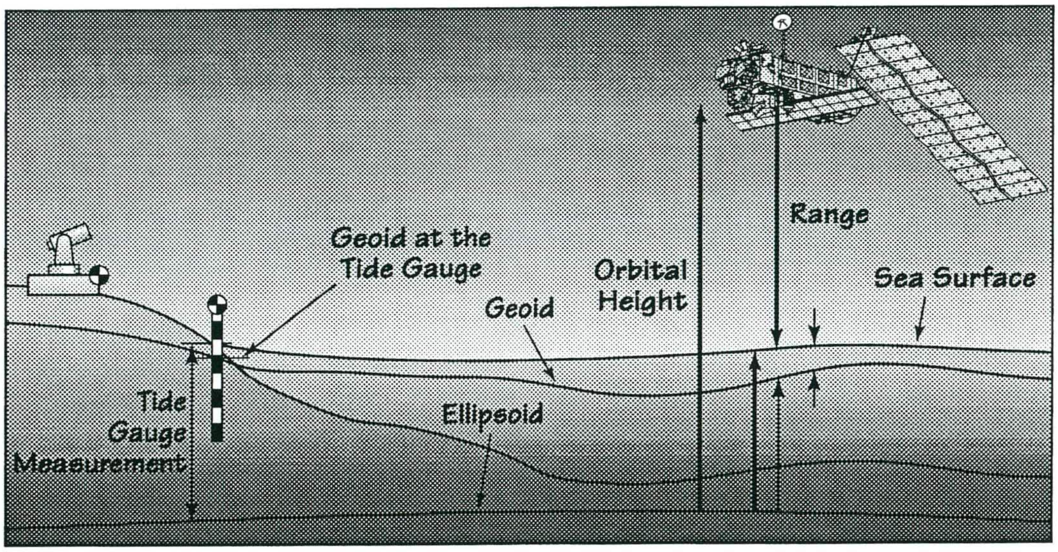


Figure 2.2 Altimeter measurement concept.

Why is it necessary to know the sea level or height of the sea surface ?

Oceanographers are interested in ocean currents expressed in terms of dynamic height or dynamic topography; this is sea level with respect to the marine geoid. The geoid is an equipotential surface that by definition is perpendicular to the local effective gravity, a combination of the gravitational acceleration and the rotation of the earth. Given a stationary balance in the oceans the sea surface topography would define the geoid. Whenever the sea level deviates from this geoid this is an indication for ocean currents, tides, wind and/or atmospheric disturbances. Now, changes on the long run can be related to changes in the climate. Clearly, the monitoring of the sea level is also important for forecasting these trends, which in turn is vital information for coastal management. The ocean currents transport water, sediment, heat, and waste. A global data base with sea level, therefore, both averaged over a longer period and the deviations from this mean, is of utmost importance for oceanography, geophysics, climate research, environmental issues, ship routing, fishery, off-shore operations, etc.

However, there is more in the altimeter measurement. The permanent or time-invariant component of the sea level, also called **mean sea surface**, provides information on the local gravity field of the earth, and by that gives a good view on the mass concentrations on or under the ocean floor. It can therefore be used for sea-mount detection or oil and gas exploration. Furthermore, the shape of the returned pulse received by the altimeter shows wave height (steepness of the leading edge) and wind speed (total power) by its relation with sea surface roughness.

2.2 From distance measurement to sea level

The radar altimeter on board of the satellite transmits a radar pulse (microwave) to the earth beneath. At the ocean surface, which covers about 70% of the total surface, the pulse is scattered and send back in the direction of the satellite. Subsequently, the pulse is received by the altimeter and the time of travel (two-way!) between sea surface and satellite is measured. It will be clear that this is also a measure of distance when the propagation speed of the wave is exactly known. Errors in the determination of the distance occur whenever the speed of the radar wave changes by its travel through the atmosphere. Free electrons, for instance, but also air molecules and water vapor will slow the wave down. So, if one takes the speed in vacuum (the speed of light) into account, the estimation of the distance will lead to an overestimation. Obviously, several corrections are necessary to reach the final goal, measuring the sea level.

2.2.1 Correcting the measurements

In the ionosphere, stretching from an altitude of about 50 to 1000 km, the effect depends on the number of free electrons and the frequency of the transmitted pulse. This can be deduced directly using a multi-frequency altimeter by comparing measurements on the same spot but with different frequencies. The effect itself can be up to 20 cm but can be estimated with 5 mm precision. In the troposphere, which starts at 0 km and ends somewhere around 15 km height, is the correction needed depending on the amount of air molecules (dry component) and water vapor (wet component). The dry component follows a model of the vertical distribution of gases in the atmosphere, and therefore depends on the air pressure at sea level and the latitude of the position of the satellite projected on the earth's surface. The total effect on average is 2.3 m, but can be determined with a precision better than 2 cm. The wet component as stated earlier depends on the water-vapor pressure and temperature at sea level. For this correction we have to rely on assumptions on the vertical distribution of the water vapor completed with meteorological measurements. Nowadays it is common practice to have a separate instrument on board of the satellite that can extract for a vertical column beneath the satellite the total mass of the water vapor and water droplets (precipitation) by measuring the radiation that is transmitted by water vapor at certain frequencies. This instrument is called a radiometer. The order of magnitude of this correction is around 40 cm, and can also be determined with a precision of 2 cm.

Another error that arises and needs to be corrected is the so-called electromagnetic bias. Here the sea surface roughness or wave height plays a dominant role. Wave troughs are somewhat flatter and less steep, and therefore give a stronger reflection of the radar signal than the wave peaks. This leads to an overestimation of the measured distance. In addition, also the interpretation of the signal is hampered when the sea surface is more rough. The total effect of sea waves on the distance determination is known as *sea state bias* and is about 5% of the significant wave height, a quantity that also can derived from the returned radar signal.

2.2.2 Referencing the measurements

The surface of the earth can be described mathematically by an ellipsoid fitting the geoid. This ellipsoid that has no real physical meaning is often used as reference from which the geoid is measured and from which the position of the satellite is determined. Due to the inhomogeneous mass distribution inside the earth the geoid will deviate locally from the reference ellipsoid (order magnitude 50 m). When there is concentration of mass on the bottom of the ocean, for example in the form of sea mountains, than the geoid will exhibit a bump in the vicinity of this mass, and vice versa a valley whenever there is a trench or trough in the ocean floor. The dynamic topography only makes out 1.5 m of the total sea level, so the actual sea surface level or topography is a good indicator of ocean bottom and sub-bottom processes. Radar altimetry can therefore be used to map bottom topography, also called bathymetry, and to help in tracking down oil and gas fields. In addition, the sea level measurements are used to improve the models for the geoid and gravity. Indeed improve, because the state-of-the-art models are yet not accurate enough to reduce the measurements to dynamic heights without error. Both the introduction of the satellite height and the geoid height give rise to an extra error source. And they are both related to each other, because the satellite orbit depends on the shape of the geoid: it responds to the spatial variations in the gravity. Fortunately, only the large-scale geoid variations are important for the precise determination of the orbit, and those are known within cm-level. At the moment the total error in the orbit determination of altimetry satellites is about 5 cm or better. The small-scale variations in the geoid though are not known at the cm-level.

2.2.3 Processing the measurements

After the altimeter measurement has been reduced to sea level or sea height it is ready to be used in all kinds of scientific studies and operational applications. Most of the time a geophysicist or oceanographer will not directly be interested in the contribution of tides. A first step in the processing of the data then will be the removal of tides using models. These models account for the vertical movement of the ocean water and earth crust due to solar and lunar attraction. Additionally, the vertical movement of the crust due to the pressure of the overlying ocean water is taken into account. The accuracy of the global models is of the order of 5 to 10 cm in the open ocean. In the coastal zones this accuracy can be drastically reduced and a local model will be needed thats is fed with local tide gauge data. Next step in the processing chain will be the removal of the radial orbit error that entered the measurement through the orbit determination of the satellite. For this purpose DEOS has developed special filter techniques that uses repeated measurements either over the same ground track (sub-satellite point projected on the earth's surface) or at places where ground tracks cross. Here differencing the measurements will eliminate all time-independent contributions, revealing time-dependent contributions of which the radial orbit error is one with a specific frequency characteristic, *viz.* one cycle per revolution.

Subsequently, the processing splits up in two paths: the geodesist or geophysicist will look at the mean of the measurements and try to remove the noise, or the varying topography due to ocean currents. Whereas the oceanographer is more interested in this noise and will try to eliminate the mean signal; he will look at the variations or standard deviation of the signal, also called the variability. This is a measure for the kinetic energy represented by the variable ocean circulation. Wherever there are eddies in motion or current patterns or fronts are changing over time, this variability will exhibit peaks.

Chapter 3

User requirements questionnaire

This chapter describes the questions that were distributed among the members of the initial RADS user community consisting of representatives of: the National Institute for Coastal and Marine Management, Directorate-General of Public Works and Water Management (RWS RIKZ); the Institute for Marine and Atmospheric Research Utrecht University (IMAU); the Netherlands Institute for Sea Research (NIOZ); the Royal Dutch Meteorological Institute (KNMI); the Advisory and Research group on Geo Observation Systems and Services (ARGOSS); WL-Delft Hydraulics (WLdelft); the Applied Analysis group, Faculty of Information Technology and Systems of Delft University (AA-ITS/DUT); the Hydro Mechanical Engineering group, Faculty of Civil Engineering and Geosciences of Delft University (HME-CEG/DUT); and the Delft Institute for Earth-Oriented Space Research, also from Delft University (DEOS/DUT). At this point in time the questionnaire should be considered as an inventory of what our core users will do with the data, what they expect of it and in what form they like to receive it. Actual technical details and implementation will be established after this round of inquiries and will be described in the final RADS project report.

3.1 User profile

1. What kind of research or application at your institute/company is or will be supported with altimetry, *i.e.* sea level, wind speed, and wave height data ?
   - indicate the type of activity, being either scientific, operational, commercial, or political (water and coast management), and
   - indicate the theme (frame), *e.g.* ocean currents, tides, mean sea surface, wind, waves, storm surges, orbit determination, etc.
2. Concisely describe in which (running or future) projects altimetry will embedded and give the goals of these projects.
3. How many people in your organization will work with the provided altimeter data and what are their qualifications (engineer, oceanographer, ...) ?
4. What facilities or infra-structure do you have at your disposal to process the altimeter data ?
   - give a list of the hardware, brand, type, speed, operating system and data storage capacity,
   - in what manner do you read and store off-line data (CD-rom, Exabyte, etc.) ? and

- what are your connections with certain networks, which type/protocol and what speed ?

3.2 Data requirements

In case of multiple projects with different type/theme or character please answer the data requirements questions separately for each project.

1. Which part of the altimeter data record is most suited for the project: sea level (sea surface height), wave height, wind speed, backscatter, etc. ?
2. In what (which) form(s) should the data be available ?
   - Low level (intermediate products):
     - level 0: the information as it is available, *i.e.* raw information with up-to-date corrections and consistent throughout the database from one altimeter mission to the other and validated against ground truth and inter-validated. It must be noted that due to the size and complexity of this data set it will not be comfortable both for the user and for the provider to put this on-line for the whole user community. If there is still a need for this comprehensive data set a proper argumentation is needed.
     - level 1a: the data in the form of anomalies with respect to a certain reference mean, in other words values along the satellite ground track (sub-satellite trace).
     - level 1b, the data in the form of crossover point data and/or crossover differences, with which for certain positions higher temporal resolution can be established than the repeat period of the satellite orbit.
   - High Level (end products):
     - level 2: semi-synoptic "images" (grids) that have to be obtained by interpolation and/or filtering in time and space.
     - level 3-4 products obtained by specific analyses, for example climatology, annual cycles, means, variability, GIF/JPEG images, ocean tides, etc.
3. When talking about level 1 and level 2 products, what is the required data density or resolution in both time and space ? Obviously, boundary conditions are given by the sampling characteristics of the satellite orbit: the repeat period, the along-track sampling resolution, and the cross-track resolution.
4. Also indicate which (geographical) regions and time periods are favorable for your research/project. Again boundary conditions are given by mission characteristics, such as inclination and operational life.
5. Are there any specific needs or wishes regarding the availability of the data ?
6. Which additional information ("tag") is absolutely necessary with the data product you are going to use; *e.g.* time, position, accuracy ? (see also the attached description of the so-called "raw" level 0 data to get a feel for what is available; this can be found in Appendix B).
7. Are there any more wishes for additional information ? One can think of geoid, mean sea surface (reference), depth, air pressure at sea level, water vapor, (skin) temperature of the sea surface, 1 or more corrections (sea state bias), orbit error correction obtained by means of crossover difference minimization

(not really needed for TOPEX/POSEIDON and most likely also superfluous for future missions such as ENVISAT and JASON), coast lines, *in-situ* data such as tide gauge data, etc. Good arguments are needed.

3.3 General requirements

1. Are there any specific demands on the format in which the data will be offered, both for the level 1 product with a preference of the provider for 'direct access' files with 'binary integers' (this is almost platform independent: only the short and long integers may need to be swapped) and for the level 2 data, which most likely will be a grid format (proprietary format, NETCDF, HDF, etc.) ?
2. Special data read subroutines and/or complete software could be put at your disposal to process level 1 data into higher level data. What is your opinion on this ?
3. What software or applications do you use and to what extent should data be readable directly by that software and/or application ?
4. Are standards needed for the intermediate and end products ? For the software ? Do we need integration with other products/measurements ?
5. Which way of data distribution would be preferred (Internet, FTP sites, CDs, tapes, on-line browsers, off-line) ? Please state your opinion.
6. What (minimal) functionality should an on-line browser have ?
7. Which meta data (information on the data) should be available on-line ?
8. In addition, should there also be more general or thematic information such as:
   - bibliography,
   - references to other groups and/or projects,
   - mission descriptions,
   - contents and quality of the available data, and/or
   - processing techniques or methodologies ?
9. Are there any other remarks or ideas on the subject of catalogue, select, and order the data ?

3.4 Suggestions for RADS: Outlook

1. Any suggestions concerning the continuation of the RADS project and the altimeter data base are welcome:
   - What are the shortcomings of the data and what should be done to tackle these ?
   - Are there future projects in which a role for altimetry is anticipated ?
   - How can the database be financially supported when the BCRS project officially ends, in other words: which (financial) policy is acceptable taken into account whether the usage of the data is scientific, operational or commercial ?
2. More suggestions concerning RADS ?

Chapter 4

User requirements: summary and evaluation

4.1 Summary

For details on the filled-in questionnaires the reader is referred to Appendix A. Here only a resume is given.

In the Profile section we notice quite a broad interest in the application of sea level data ranging from scientific background and applied research, like studies on climate variability and the prediction of Los Niños, to more operational use of the data, like wave climate statistics for the off-shore industry and predicting storm surges and spring tide water levels. Each representative in the user group has on average 2 people around him supporting altimetry (read: sea level) related activities, and also has direct access to the (inter)net through FTP and HTTP protocols (via web browsers and FTP clients).

The data requirements section shows that the main interest is sea level information, but for a number of applications also wave heights and wind speeds are required. Not surprisingly, nobody directly wants access to the level 0 data base. Though this would be technically feasible, it is certainly not practical: it is either to complex or to large for on-line retrieval. Clearly, there is a need for a compact easy to use data stream in the form of a level 1 product. Within this level the along-track anomalies are preferred over gridded data, which leaves the user the opportunity to apply own algorithms and choose references. Every partner agrees on the tags that are needed for the data, *viz.* time, position, and accuracy. The latter is underlined (not literally) because this is the only way the data can be really valued; how good is one data point with respect to the other (internal consistency) and how does it compare to data from other sources. For instance, if the altimeter data is to be assimilated in ocean models, information is needed on the (co)variances of all the incorporated data.

The responses to the general requirements questions didn't come as a surprise: Of course people want 'highest resolution' and global coverage. They also seem to agree on a format based on 'binary integers' but that really doesn't matter as long as read software is supplied that is portable to a number of computer architectures. Disclosure by preference mainly through HTTP/FTP (URLs) and for large datasets and/or slow net connections by use of CD-roms.

The response to the suggestions section was somewhat less than to the other sections, but it was on more than one occasion suggested, or even better, strongly recommended, that the altimeter data base service, as DEOS is supplying through RADS, should be continued for years to come, especially in the frame of research on decadal variability and global change, because therefore you need decades of data to come to useful conclusions. But more data will definitely also contribute to improving the statistics on the dynamic behavior of sea level in general. It was suggested that for funding, DEOS and maybe partners should talk to governmental sponsors and/or ESA, and even selling CD-roms with data could be considered.

4.2 Evaluation and suggestions for implementation

The requirements from the user group have been merged with the requirements set by DEOS and shall be merged with requirements that come from the upcoming RADS usage test cases by WL-Delft Hydraulics in the frame of the BCRS' SAT2SEA project, by the KNMI in the frame of the ALW/SRON proposals mentioned before, and by NIOZ in the frame of a CLIVARNET (SRON) proposal concerning hydrography in the North Atlantic Ocean.

Not only is the common denominator in the retrieved requirements compatible with DEOS' requirements, it also fits the more general requirements that came out of a survey taken in the frame of a CEO contract called 'Collect User Requirements from Experimental User Community on Marine Altimetry' conducted by CLS, CNES, ECMWF, GFZ, GRGS, MSSL, POL, Oceanor, Space Tec Ltd., and DEOS, in 1995. Therefore at present time no need exists to retrieve further requirements; problems and new needs concerning RADS will be processed during the evaluation and use of the data base by the user group and in the future by new users.

Suggestion for implementation:

- Bring level 1 and higher products quickly on-line (WWW), taking into account the evaluated requirements laid out in this document, not only to enable the familiarization but also stimulate usage of these products,
- Provide access in first instance through meta data (data on the data).

It goes without saying that this has to be implemented compliant to the technical frame set by the NEONET core software (at present level 1.2). Emphasis should be laid on documenting the products and the methods used to arrive at these products, on providing information on the quality of the data, and on promoting the data, *viz.* show the possibilities, attract new users (and sufficient funding!).

Acknowledgments

The RADS team wishes to thank all the members of the RADS user group for their input and support, enabling this document and a successful project. Also BCRS and SRON are acknowledged for their financial support.

Appendix *A*

User response

The answers to the questionnaire are listed by institute (not explicitly mentioned!) and the numbers refer to the numbers used in the questionnaire as discussed in Chapter 3.

1	**User Profiles**
1.1	We use altimetry observations for the determination of wind and wave climate in coastal zones and on the open ocean. We also use ocean tide models (local and global) that are based on altimetry data.
1.2	The data are used in the frame of developing a wind/wave climate system (CLAMS) and the development of a Global Wave Statistics CD-rom.
1.3	Two to three people are working on the abovementioned issues, of which 2 of them are scientist and one of them a software engineer.
1.4	Mainly working with Intel chip based personal computers (200 MHz Pentium Pros, 8 Gbytes drives). The altimeter data is down-loaded through the (inter)net (either FTP or http). The connection is very fast (10 mbit/s).
1.1	Sea level prediction for the continental shelf near the Dutch coast. Tuning models in quiet-weather situations and predicting storm surges. These are mainly research activities, but we expect it to become more operational. The research is focussed on the improvement of existing and development of new techniques for data assimilation; so data is NEEDED.
1.2	We have used altimeter data for the DATUM-2 project (BCRS) and will use it for SAT2SEA, a BCRS funded project on local tide model improvement and storm surge prediction improvement.
1.3	Two to three researchers (scientists - applied mathematical analysis).
1.4	Seems to be not very relevant: we never had any problems getting workstations, super-computers, and sufficient data storage at our disposal.
1.1	Scientific research in the field of internal tides, inertia waves, tides in shallow waters, ocean currents, and eastern boundary currents.
1.2	Altimetry can/will be used in the following research projects: ▪ spatial distribution of internal tides and inertia waves in the open ocean and in the vicinity of continental shelf breaks in search of 'wave attractors'. ▪ current research on shelf-slope currents seeking an explanation for eastern boundary currents. ▪ tides in shallow waters; comparison between satellite and *in situ* measurements. ▪ future research on large-scale eddies and currents in the North Atlantic ocean.

1.3	Two to four people (1 to 2 scientists, and 1 to 2 PhD students).
1.4	Here we have a network of SUN micro-systems; Ultra 5-60; storage 150 Gb; CD, DLT, Exabyte.

1.1	We are using and will use altimeter data for our scientific research on El Niño and the Southern Oscillation (ENSO). Additionally we may be involved in development activities for governmental organizations in Europe like ECMWF.
1.2	Project: variability of the thermocline in the tropical Pacific. In this project we pose the following questions: a) what is the role of intra-seasonal variability in ENSO ? b) is this variability modulated by ENSO ? and c) what exactly is the role of the annual or seasonal cycle ?
1.3	Two senior researchers (scientists) and 1 to 2 junior scientists.
1.4	Several: from workstations (SGI Indy, 2 Gb) to Fujitsu VPP700 plus archive at the ECMWF (Reading, UK). Preference for data distribution through the Internet, otherwise CD-rom.

2	**Data Requirements**
2.1	All measurements of the significant wave height and wind speed from all available missions that last more than a couple of months are required. From the altimeter data record wave height and wind speed are needed.
2.2	Most likely a direct derivative of level 0, *i.e.* raw data but in compact form (level 1 ?)
2.3	N/A for wave height and wind speed.
2.4	Global data from all missions.
2.5	Yes, there is a strong preference in receiving the data in the format that has been used in the CLAMS (BCRS) project.
2.6	Tags: time, position, wave height, wind speed, accuracy of both height and speed (error indication), and confidence flags.
2.7	Additional information is not needed.

2.1	The data has to be as accurate as possible and an error model or measure of accuracy should be available. We are especially interested in the sea level or sea surface height.
2.2	This doesn't really matter for our research. The only thing we need is a good description of the processing and the way the processing affects the data error structure. Mainly interested in tuples 'measurement+location+time'.
2.3	As many data as possible.
2.4	Continental shelf.
2.5	Operational forecasts require data within 9 hours (DATUM-2 project report). Presently, the added value of altimetry for such forecasts in the North Sea is limited, but it will be useful in other geographical areas.
2.6	Extra tags should be time, position, and accuracy.
2.7	All information that is needed for the proper interpretation of the supplied data, especially the coordinate and reference systems, the corrections that have been applied, and the error bars.

2.1	We need every possible item such as sea level (sea surface height), wave height, wind speed, and backscatter.
2.2	Everything from level 1 and up. Resolution of grids most likely too coarse, so along-track data would be preferred. Additionally, one should be able to define the period for averaging the data yourself, and make anomalies.
2.3	In order to solve internal tides, resolutions on the order of 5 km are needed. For temporal resolution we need data on the tide scales. Inertia waves can be solved with temporal resolutions depending on latitude: on the poles a period of 12 hours, longer periods towards the equator. Current variations and variations in internal tides are ruled by density variations, which manifest themselves on time scales of days to weeks.
2.4	To be able to compare with *in situ* data: North Sea, North Atlantic ocean, Farœr-Shetland canal, Rockall Trough, Gulf of Biscaye. For the internal tide research it could also be very useful to have measurements from elsewhere.
2.5	It would be desirable to have on-line information on the long-term mean and the actual deviations from that mean in certain areas whenever there are cruises in that area.
2.6	Position, time, height, sea-state, PLUS their accuracy.

2.7	Any additional information is useful, especially an indication of trustworthiness, but also mean sea surface, temperature, air pressure at sea level.

2.1	Sea level and probably wind speed.
2.2	Level 1 and especially level 2 products. We will contact DEOS to find out which one suits our needs/applications best.
2.3	Level 2 data: in space a couple of degrees, in time a week. Level 1 data: 1/3 degree along the satellite trail.
2.4	In time: as long as possible; this would ideally be decades. It is therefore absolutely necessary that RADS will receive continuous support for many years! In space: the tropical ocean (both Atlantic and Pacific).
2.5	No, other than that the data should be available freely for scientific research and for development work that can lead to better climate predictions.
2.6	Time (hours), location (0.1 degree), sea level height (mm), error bar (mm), and perhaps the other components like wet tropo correction, etc.
2.7	For comparison reasons it would be beneficial to also have tide gauge data available.

	General requirements
3.1	Preference for direct access data files with binary integers.
3.2	Not applicable.
3.3	We have our applications developed in-house using PV-Wave.
3.4	Standard intermediate and end products is OK.
3.5	We primarily use FTP for down-loading and CDs for reading/writing data.
3.6	No specific need for an on-line browser.
3.7	Availability of the data (for instance per satellite per sensor per month).

3.8	A Detailed description of the applied processing methods and outliers detection would be very useful.
3.9	No comments on data catalogue, browsing, selecting and ordering the data.
3.1	No preference for certain formats.
3.2	Most likely not needed, because we are interested in level 1 products.
3.3	Own software, own read subroutines.
3.4	No idea.
3.5	No special need for on-line retrieval. For our research off-line is good enough.
3.2	As long as the sub-routines are compatible with the format of the supplied data.
3.3	We program in C, Fortran, Matlab, and PV-Wave.
3.4	Likely useful.
3.5	FTP and CD.
3.7	Everything.
3.8	Yes.
3.1	Binary integers with a good documentation is preferred, both for level 1 and level 2 (gridded) data.
3.2	This is always handy, for clearing up things or as a macro or layout.
3.3	Fortran, Grads, etc: so no specific system that only can read data in one format, but very flexible.
3.4	No.
3.5	FTP-sites and HTTP sites as long as the data files are not too large (smaller than 10 Mb). For larger data sets (10 Gb) we would prefer CDs as distribution medium.
3.6	We are familiar with HTTP (WWW) based on-line browsers.

3.7	How was the data obtained, what does it mean, how can you read it ? IF any questions arise to who do we refer ?
3.8	Not necessary, but maybe useful: keep it short and simple so it will be not to much work to set it up and maintain it (keep it up-to-date).

	Suggestions
4.1	Perhaps the service can be set up like CERSAT is doing for the ERS-2 scatterometer data. CERSAT produces a reasonable homogeneous product and distribute it on CD-rom covering the entire ERS project time span (WNF product). Maybe funds can be found for such a service at the NIVR or ESA.
4.2	General comment: good initiative!
4.2	Continuity is essential for the data base. Likely, or in any case hopefully, BCRS has ideas to safeguard the continuity for RADS and NEONET in the future. Or one could think of "selling" the data to the Ministry of Transport, Public Works, and Water Management or the Ministry of Housing, Spatial Planning, and the Environment, who could renew contracts for keeping the data base up-to-date with new data.

Appendix *B*

RADS RAW altimeter files

Header file for getdata software, contains information on format and ingredients of level 0 data base.

```
**RAWINFO.INC - Include file for usage with RADS RAW
*                altimeter files
*
*
* 1. INTRODUCTION
*
* RAW altimeter files consist of 1 header record, followed
* by 'datanr' data records. All records have a length of 80
* bytes (20 words). Files can be opened with
*
*      open (unit,file=filenm,status='old',access='direct',
*     .      form='unformatted',recl=80)
*
* Then read the header and data records, filling the appropriate
* equivalenced variables.
*
*      read (unit,rec=1) rawhead
*      ( .... )
*      do i=1,datanr
*         read (unit,rec=i+1) rawinfo
*         ( .... )
*      enddo
*
* rawhead and rawinfo is where header and data records are
* captured

      integer nrawinfo
      parameter(nrawinfo=40)
      integer*2 rawinfo(nrawinfo),rawhead(nrawinfo)

* 2. HEADER
*
* Definitions of variables for the raw altimeter header
*
*     Variable  Size Explanation                          Units
*      iden      4    File type identifier                 '@RAW'
*      version   4    File version number                  char*4
*      satel     8    Name of the satellite                char*8
*      mission   4    Mission identifier                   char*4
*      sec_s     4    start time pass                      sec
*      sec_e     4    end time pass                        sec
*      sec_n     4    time of nodal passage                sec
*      usec_n    4    time of nodal passage (usec part)    usec
*      lon_n     4    longitude of the node                udeg
*      orbnr     4    absolute orbit number
*      cycnr     4    cycle number
*      passnr    4    pass number (odd=asc,even=des)
*      datanr    4    number of data records
*      cdate    20    creation date 'XX-YYY-ZZZZ 00:00:00'
*      hspare    4    if hspare .ne. 0 then extra header record
*                     exists

      character iden*4,version*4,satel*8,mission*4,cdate*20
      integer*4 sec_s,sec_e,sec_n,usec_n,lon_n
      integer*4 orbnr,cycnr,passnr,datanr,hspare
```

```
* These variables are equivalenced with the rawhead array

      equivalence ( rawhead( 1) , iden     ) ,   !C*4
     |            ( rawhead( 3) , version  ) ,   !C*4
     |            ( rawhead( 5) , satel    ) ,   !C*8
     |            ( rawhead( 9) , mission  ) ,   !C*4
     |            ( rawhead(11) , sec_s    ) ,   !I*4
     |            ( rawhead(13) , sec_e    ) ,   !I*4
     |            ( rawhead(15) , sec_n    ) ,   !I*4
     |            ( rawhead(17) , usec_n   ) ,   !I*4
     |            ( rawhead(19) , lon_n    ) ,   !I*4
     |            ( rawhead(21) , orbnr    ) ,   !I*4
     |            ( rawhead(23) , cycnr    ) ,   !I*4
     |            ( rawhead(25) , passnr   ) ,   !I*4
     |            ( rawhead(27) , datanr   ) ,   !I*4
     |            ( rawhead(29) , cdate    ) ,   !C*20
     |            ( rawhead(39) , hspare   )     !I*4


* 3. DATA RECORDS
*
* Definitions of variables for the raw altimeter data records
*
*   Time of observation, 8 bytes
*
*     sec        4    UTC seconds since 1.0 Jan 1985    sec
*     usec       4    microsecond correction            usec
*
*   Observed altimeter range and related corrections, 30 bytes
*
*     lat        4    northern latitude                 udeg
*     lon        4    eastern longitude                 udeg
*     alt1       4    orbit altitude #1                 mm
*     alt2       4    orbit altitude #2                 mm
*     altrng     4    observed range by altimeter       mm
*     drytrop    2    dry troposphere                   mm
*     wettrop1   2    wet troposphere #1                mm
*     wettrop2   2    wet troposphere #2                mm
*     iono1      2    ionosphere #1                     mm
*     iono2      2    ionosphere #2                     mm
*
*  Corrections related to the sea surface height, 20 bytes
*
*     invbaro    2    inverse barometer                 mm
*     stide      2    solid earth tide                  mm
*     otide1     2    ocean earth tide #1               mm
*     otide2     2    ocean earth tide #2               mm
*     ltide      2    load tide                         mm
*     ptide      2    pole tide                         mm
*     ssb1       2    sea state bias #1                 mm
*     ssb2       2    sea state bias #2                 mm
*     geoid      4    geoid height                      mm
*
*  Other information, 22 bytes, this is for ERS
*
*     sigrng     2    sigma altimeter range             mm
*     swh        2    significant wave height           mm
```

```
*     sigma0    2    radar backscatter                   0.01 db
*     nrval     2    Nr valid 20-Hz measurements         -
*     dalt3     2    orbit altitude #3 - #2              mm
*     tb23      2    brightness temperature 23.8 GHz     0.01 K
*     tb36      2    brightness temperature 36.5 GHz     0.01 K
*     speed     2    wind speed                          cm/s
*     flags     2    editing flags
*     altdot    2    orbit altitude rate                 mm/s
*     mssh      2    mean sea surface height - geoid     mm
*
*  Other information, 22 bytes, this is for T/P
*
*     sigrng    2    sigma altimeter range               mm
*     swh       2    significant wave height             mm
*     sigma0    2    radar backscatter                   0.01 db
*     nrval     2    valid 10 (TPX) or 20 (POS) Hz       -
*     tb18      2    brightness temperature 18 GHz       0.01 K
*     tb21      2    brightness temperature 21 GHz       0.01 K
*     tb37      2    brightness temperature 37 GHz       0.01 K
*     speed     2    wind speed                          cm/s
*     flags     2    editing flags
*     depth     2    ocean depth                         m
*     mssh      2    mean sea surface height - geoid     mm
*
      integer*2 drytrop,wettrop1,wettrop2,iono1,iono2
      integer*2 invbaro,stide,otide1,otide2,ltide,ptide,ssb1,ssb2
      integer*2 sigrng,swh,sigma0,tb18,tb21,tb37,flags,speed
      integer*2 tb23,tb36,dalt3,mssh,nrval,altdot,depth
      integer*4 sec,usec,lat,lon,alt1,alt2,altrng,geoid

* These variables are equivalenced with rawinfo. The order of the
* variables in the following is chosen such that there are no byte
* conflicts.

      equivalence ( rawinfo( 1) , sec      ) ,   !I*4
     |            ( rawinfo( 3) , usec     ) ,   !I*4
     |            ( rawinfo( 5) , lat      ) ,   !I*4
     |            ( rawinfo( 7) , lon      ) ,   !I*4
     |            ( rawinfo( 9) , alt1     ) ,   !I*4
     |            ( rawinfo(11) , alt2     ) ,   !I*4
     |            ( rawinfo(13) , altrng   ) ,   !I*4
     |            ( rawinfo(15) , geoid    ) ,   !I*4
     |            ( rawinfo(17) , drytrop  ) ,   !I*2
     |            ( rawinfo(18) , wettrop1 ) ,   !I*2
     |            ( rawinfo(19) , wettrop2 ) ,   !I*2
     |            ( rawinfo(20) , iono1    ) ,   !I*2
     |            ( rawinfo(21) , iono2    ) ,   !I*2
     |            ( rawinfo(22) , invbaro  ) ,   !I*2
     |            ( rawinfo(23) , stide    ) ,   !I*2
     |            ( rawinfo(24) , otide1   ) ,   !I*2
     |            ( rawinfo(25) , otide2   ) ,   !I*2
     |            ( rawinfo(26) , ltide    ) ,   !I*2
     |            ( rawinfo(27) , ptide    ) ,   !I*2
     |            ( rawinfo(28) , ssb1     ) ,   !I*2
     |            ( rawinfo(29) , ssb2     ) ,   !I*2
     |            ( rawinfo(30) , sigrng   ) ,   !I*2
     |            ( rawinfo(31) , nrval    ) ,   !I*2
```

```
     |          ( rawinfo(32) , swh       ) ,  !I*2
     |          ( rawinfo(33) , sigma0    ) ,  !I*2
     |          ( rawinfo(34) , tb18      ) ,  !I*2 (t/p)
     |          ( rawinfo(34) , dalt3     ) ,  !I*2 (ers)
     |          ( rawinfo(35) , tb21      ) ,  !I*2 (t/p)
     |          ( rawinfo(35) , tb23      ) ,  !I*2 (ers)
     |          ( rawinfo(36) , tb37      ) ,  !I*2 (t/p)
     |          ( rawinfo(36) , tb36      ) ,  !I*2 (ers)
     |          ( rawinfo(37) , flags     ) ,  !I*2
     |          ( rawinfo(38) , speed     ) ,  !I*2
     |          ( rawinfo(39) , depth     ) ,  !I*2 (t/p)
     |          ( rawinfo(39) , altdot    ) ,  !I*2 (ers)
     |          ( rawinfo(40) , mssh      )    !I*2
*
* The flags word for T/P is defined as follows:
*
*    0  0x0001  1=topex 0=poseidon
*    1  0x0002  1=ionosphere is ok
*    2  0x0004  1=tmr channel 21a is used
*    3  0x0008  1=tmr channel 21b is used
*    4  0x0010  1=shallow water, 0=deep water
*    5  0x0020  1=land 0=water (for the altimeter)
*    6  0x0040  1=land 0=water (for the radiometer)
*    7  0x0080  1=ice 0=water (this bit is unreliable)
*    8  0x0100  1=rain 0=no rain
*    9  0x0200  this is bit 0 in the tmr_bad word
*               (see page 131 in avi-nt-02-101-cn)
*   10  0x0400  this is bit 1 in the tmr_bad word
*               (see page 131 in avi-nt-02-101-cn)
*   11  0x0800  1=problem detected in Ku or (and) C values (TOPEX)
*   12  0x1000  1=error or possible error for poseidon altimeter
*   13  0x2000  1=attitude out of range (Poseidon only)
*   14  0x4000  1=altimeter (Topex or Poseidon) is in fine
*               tracking mode
*   15  0x8000  spare
*
* Note on T/P bit status
*
*   For some reason, bit 14 (0x4000) is not properly set when
*   the POSEIDON altimeter is on, this can only be the result of
*   the Current_Mode_1 or 2 word on the GDR's, (a problem yet to
*   fix in the gdr2raw program). It is perfectly safe to test
*   bit 14 for TOPEX.
*
* The flags word for ERS-1/2 is defined as follows:
*
*    0  0x0001  1=ERS-1 0=ERS-2 [opr6raw]
*    1  0x0002  ==0 (not used)
*    2  0x0004  ==0 (not used)
*    3  0x0008  ==0 (not used)
*    4  0x0010  1=shallow water, 0=deep water [erspatch2]
*    5  0x0020  1=land 0=water (for the altimeter) [erspatch2]
*    6  0x0040  1=land 0=water (for the radiometer) [opr6raw]
*    7  0x0080  ==0 (not used)
*    8  0x0100  ==0 (not used)
*    9  0x0200  1=23.8 GHz brightness temperature out of range
*               [opr6raw]
```

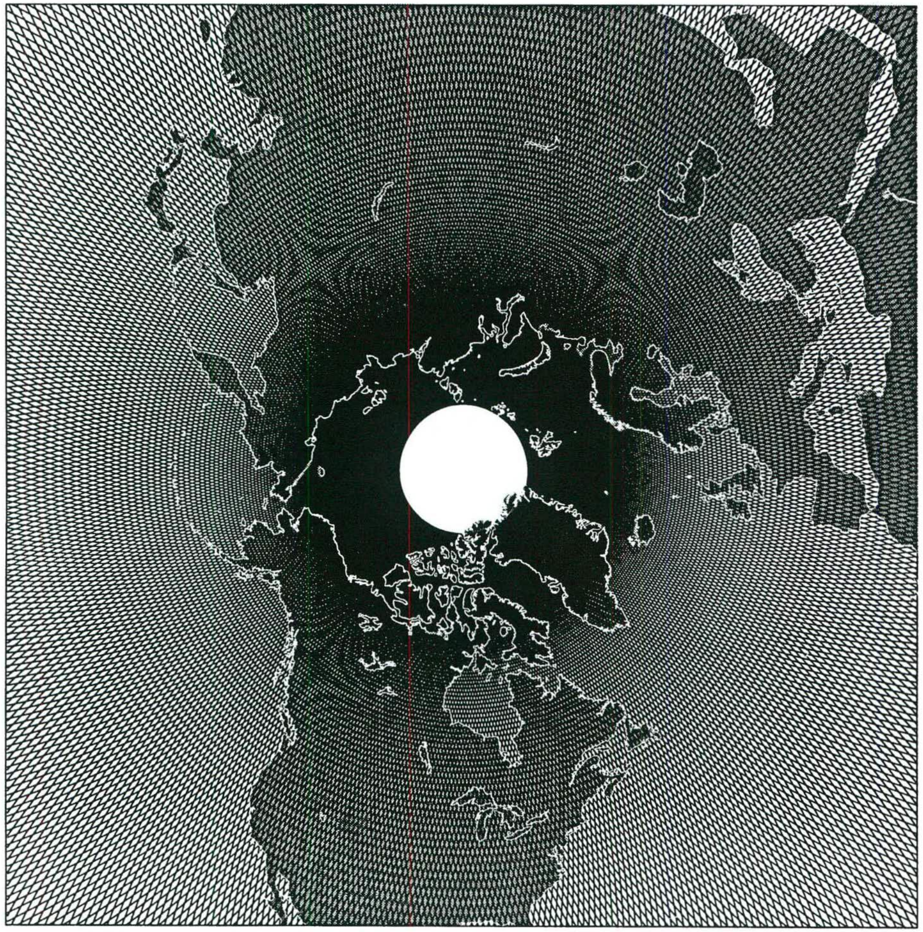
```
*    10 0x0400  1=36.5 GHz brightness temperature out of range
*               [opr6raw]
*    11 0x0800  1=bad quality of the range estimate (fatal)
*               [opr6raw]
*    12 0x1000  1=bad quality of the wave height estimate
*               [opr6raw]
*    13 0x2000  1=bad quality of the backscatter coefficient
*               estimate [opr6raw]
*    14 0x4000  1=preset tracking mode [opr6raw]
*    15 0x8000  1=bad orbit quality [opr6raw]
*
* 4. COMMON BLOCK
*
* A common block is included because all above mentioned
* variables are unsafe to pass via argument lists.
*

      common /Crawinfo/ rawhead,rawinfo

*-----------------------------------------------------------
```

Appendix C

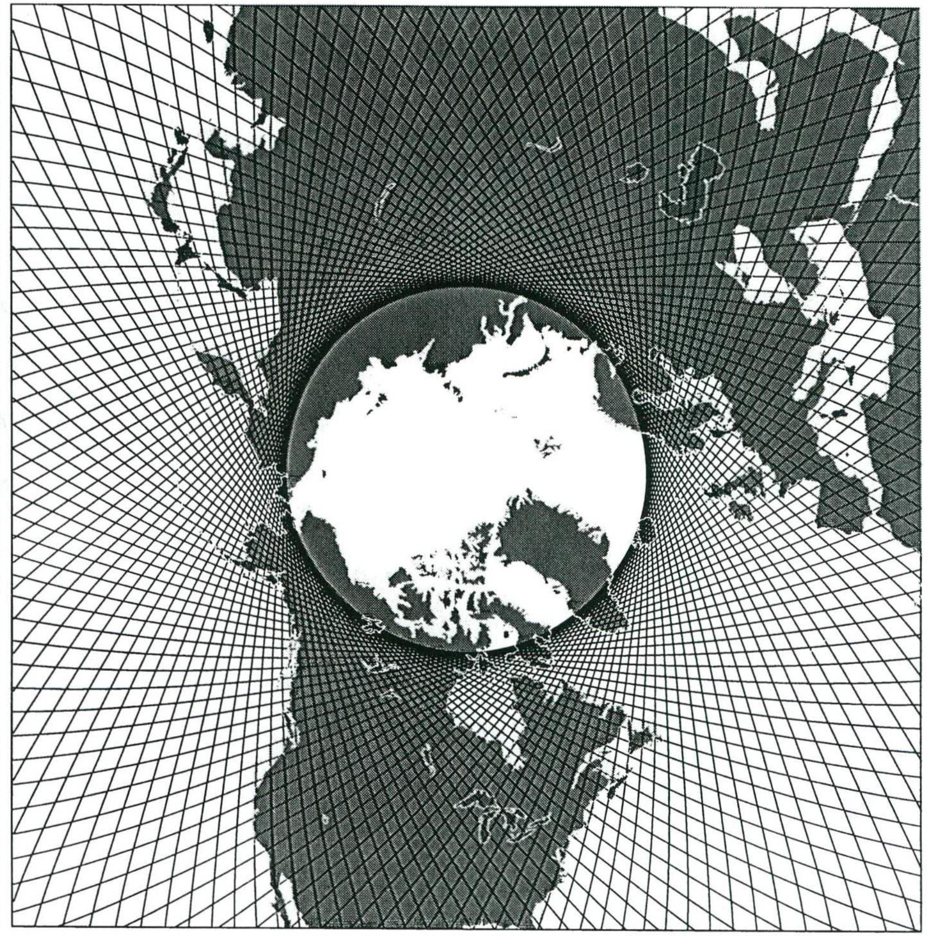
Spatial data coverage

Examples of altimeter data coverage; TOPEX/POSEIDON in its 10-day repeat orbit and ERS-2 in its 35-day repeat orbit. Note the (extreme) difference in spatial resolution.

Northern Hemisphere

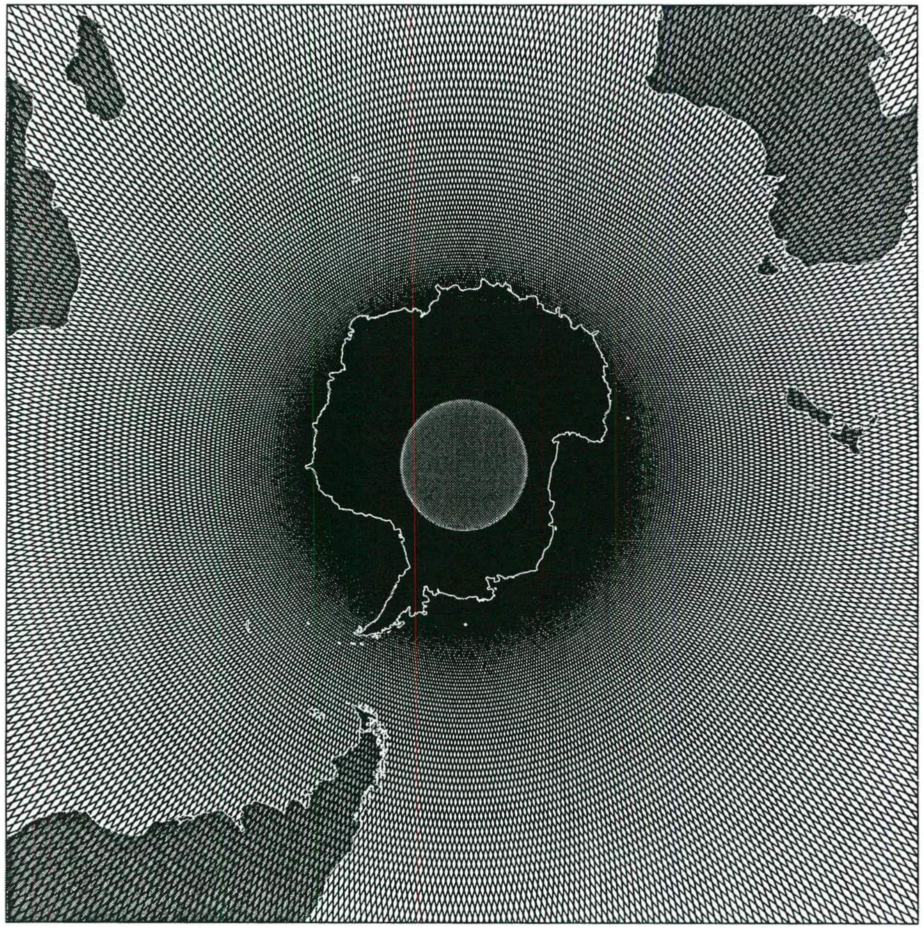


Altimeter coverage of the ERS-2 satellite (35-day repeat orbit)

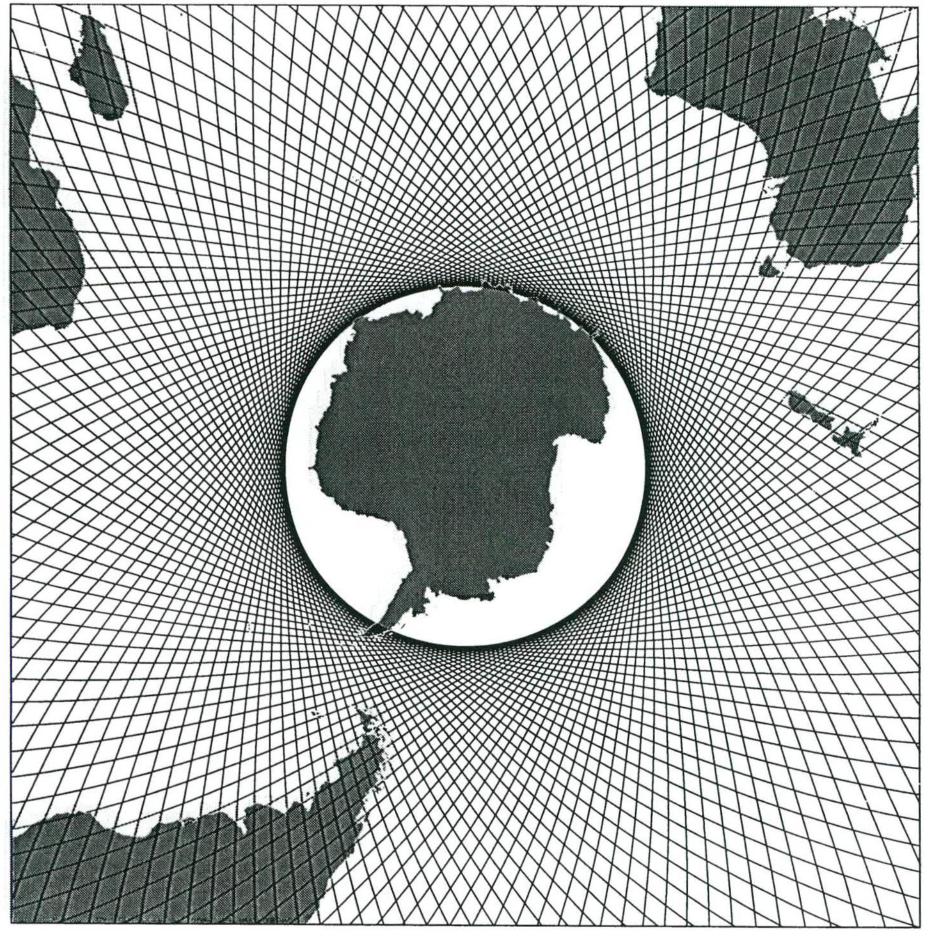


Altimeter coverage of the TOPEX satellite (10-day repeat orbit)

Southern Hemisphere



Altimeter coverage of the ERS-2 satellite (35-day repeat orbit)



Altimeter coverage of the TOPEX satellite (10-day repeat orbit)

The User Support Programme 1996-2005 (USP-2) is implemented under the responsibility of the Netherlands Remote Sensing Board (BCRS) and the Space Research Organization of The Netherlands (SRON).

The objectives of the USP-2 are: to support Dutch users of information from future European earth observation systems in the development of applications for operational and scientific use; to develop the required national infrastructure and to support users in developing countries with applications for the purpose of sustainable development, in connection with activities carried out by ESA and EUMETSAT.

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