The Radar Altimetry Mission: RA-2, MWR, DORIS and LRR

J. Benveniste
Earth-Observation Exploitation Development and Projects Division,
ESA Directorate of Earth and Environment Monitoring from Space,
ESRIN, Frascati, Italy

M. Roca, G. Levrini
Envisat Project Division, ESA Directorate of Earth and Environment Monitoring
from Space, ESTEC, Noordwijk, The Netherlands

P. Vincent
CNES, Toulouse, France

S. Baker
Mullard Space Science Laboratory, University College London, Dorking, UK

O. Zanife
Collecte Localisation Satellites, Toulouse, France

C. Zelli, O. Bombaci
Alenia Aerospazio, Rome, Italy

The Altimetry mission on Envisat will extend the time series of observations started by ERS-1, and the new features of the RA-2 instrument will improve the quality of the measurements in many respects. The new on-board algorithms for tracking the surface, the larger range window and the extra low-resolution mode will all improve data acquisition over the important ice-sheet margins and over most land and wetland surfaces. New, in-situ ionospheric corrections from the dual radar frequency will be a significant improvement on the model-based corrections used on previous missions. The more precise DORIS orbit will improve the precision of all measurements, particularly in near-real time. The near-real-time products will be built with the same algorithms as the offline final precision products (only some auxiliary input data may differ), thus providing near-high-quality geophysical-data-record products within 3 hours of observation to support near-real-time oceanography.

Introduction

The Radar Altimetry mission encompasses four of the ten instruments on-board Envisat. Its main objective is to ensure continuity of the altimetric observations started with the ERS-1 satellite in 1991. The science mission objectives are similar to those of ERS, but the altimeter record will exceed 15 years in length and will permit changes to be examined on inter-annual to decadal time scales in:

- global and regional sea level
- dynamic ocean-circulation patterns
- significant wave height and wind-speed climatology
- ice-sheet elevation and sea-ice thickness.

Another objective is to provide for the enhancement of the ERS ocean and ice missions, in particular, by improving the quality of the measurements and monitoring capabilities for:

- ocean mesoscale, significant wave height and wind speed in near-real-time
- marine geophysics – polar oceans
- ice-sheet margins – sea ice
- lakes, wetlands and river levels
- land
- ionosphere and water vapour.

The Envisat mission is part of a coherent European Earth-Observation Programme ensuring the long-term provision of continuous data sets, which are essential for addressing environmental and climatological issues. The Altimetry mission is therefore a contribution to such international programmes as the International Geosphere – Biosphere Programme and the World Climate Research Programme. Envisat is also directed at the promotion of applications and the commercial use of Earth-observation altimetry data for operational sea-state and ocean-circulation forecasting.

Oceanographic applications

Oceans cover 70% of our planet and play a key role in regulating the global climate. They are the main reservoir for heat, as well as a powerful vehicle in transporting warm water masses poleward. They have the capacity to take in (but also to reject) significant amounts of carbon dioxide, one of the greenhouse gases. They also allow the cost-effective transportation of goods by ship, they are where we can discover new oil fields, and they are the feeding grounds for the fish and other sea-food needed to nourish Earth's ever-growing human population.

The oceanographic mission objectives for Envisat altimetry, based on the results already obtained with ERS, include the monitoring of dynamic topography, mesoscale variability, seasonal and inter-annual variability, mean global and regional sea-level trends, marine geophysics (especially in polar oceans, even covered with sea-ice), and sea state. These objectives are to be met with data products available either in near-real-time (3 hours), in quasi near-real-time (2-3 days), or with the highest precision offline products.

Seasonal and inter-annual variability has an important impact on climate. Planetary waves propagate from months to seasons across basins to adjust the ocean in response to wind forcing. Inter-annual variations in the seasonal or annual cycles have a direct and sometimes dramatic impact on the global climate, as is well illustrated by the El Niño Southern Oscillation (ENSO) (Fig. 1). The data gathered from space serve to develop and tune global ocean and atmosphere models, in order to better understand the ocean-atmosphere interaction and the underlying processes.

The ocean is vast and generates a whole spectrum of signals that one orbiting satellite alone cannot pretend to cover. There are therefore significant advantages to be gained by merging the data from two or more altimetry missions sampling the Earth with different orbital patterns. A good illustration in this respect is the enrichment in spatial resolution of the mesoscale variability field computed with merged data from ERS and Topex-Poseidon (Fig. 2), which have the same orbital configuration as the Envisat and Jason missions.

Ice and sea-ice applications

Polar ice sheets and sea ice play a vital role in the global climate system, due both to their effectiveness in reflecting incoming solar radiation, and their role as a huge store of fresh water. Sea ice acts as a barrier between the ocean and the atmosphere, cutting off exchanges of heat, moisture and momentum. Brine expulsion during seasonal sea-ice formation and intense cooling of the sea surface through polynyas drive the thermohaline circulation of the oceans. This process creates the dense bottom water in the Pacific, Indian and Atlantic Oceans, and is responsible for the poleward transport of heat in the North Atlantic, which ensures mild winters for Western Europe.

This critical component of the climate system is not well represented in current climate models, but is clearly important if accurate predictions

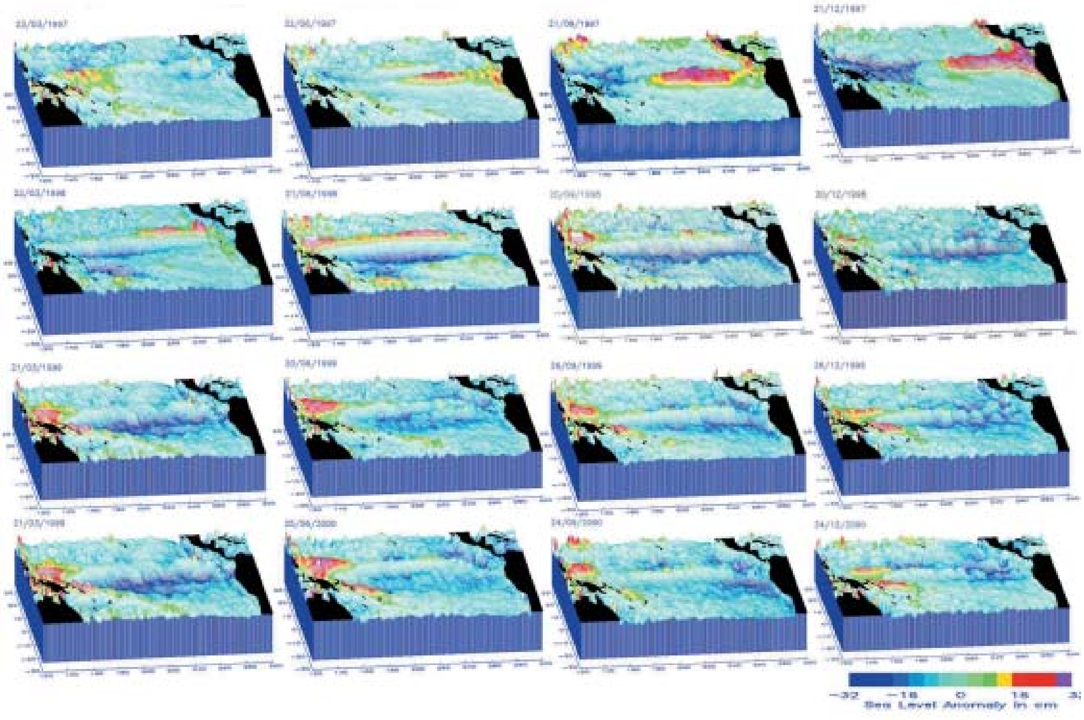

Figure 1. Series of sea-level-anomaly (cm) data for the tropical Pacific Ocean. Each row is for one year (1997 - 2000) with one sea-level-anomaly field sample each season, by column: March, June, September and December. The strong El Niño event of late-1997 followed by a La Niña event is clearly visible. A film of such 3D vignettes helps researchers to visualise the wave propagation involved in such events. Each weekly field can be assimilated into an ocean model (SLA data processed by R. Scharroo, DEOS, NL; graphics processed at ESA/ESRIN)

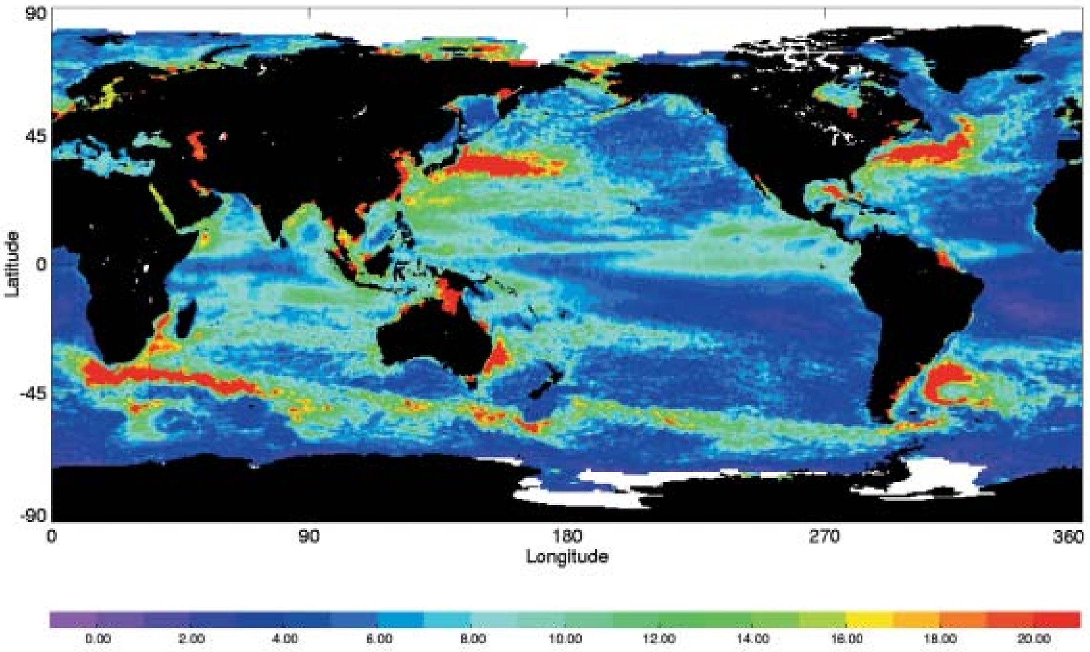

Figure 2. Root-mean-square of sea-level anomaly (in cm) obtained from merged ERS and Topex-Poseidon data from October 1992 to October 1997. Note the high resolution of the map brought by the denser ground-track mesh of ERS (courtesy of P.Y. LeTraon, CLS)

of the consequences of global warming are to be made. Global warming is predicted to be greatest in the Arctic region, and if Arctic sea-ice is lost it could change the circulation pattern of the North Atlantic, resulting in severe winters for Western Europe. Melting of the Greenland and Antarctic ice sheets would contribute to a rise in global sea level.

The vast, remote and inhospitable polar regions can only be monitored effectively through a global remote-sensing system. Polar regions experience between 50 and 90% cloud cover and spend long periods in darkness, which limits optical and thermal-infrared instrument observations. Fortunately, this task is particularly well served by satellite-borne active radar instruments.

Techniques developed using the ERS Radar Altimeters have allowed the monitoring of ice-sheet mass balance and the derivation of sea-ice thickness through the measurement of freeboard. Continuous altimetric measurement of the Antarctic ice sheet since 1992 has revealed for the first time a significant thinning of a West Antarctic glacier (Fig. 3). The Pine Island Glacier has retreated, and has thinned inland by as much as 10 metres. It is important to continue this monitoring with the Envisat RA-2 instrument to establish whether this retreat will accelerate the mass discharge from the West Antarctic ice sheet.

Balance velocities (the depth-averaged velocity required to maintain the ice sheet in a state of balance at a given point for a given surface mass flux) have been estimated over the Antarctic grounded ice sheet using ERS Altimeter data (Fig. 4). These balance velocities depend mainly on the surface slope and are modulated by surface mass balance and ice thickness. Their study contributes to our understanding of ice-sheet dynamics and its response to climatic forcing.

Sea-ice thickness can be sampled using moored or submarine-mounted Upward Looking Sonar (ULS). Moored ULS only samples a fixed location, and submarines tend to sample limited areas for only a few weeks each year. This is not sufficient to deduce full regional and seasonal variations. Freeboard measurement by satellite is the only technique

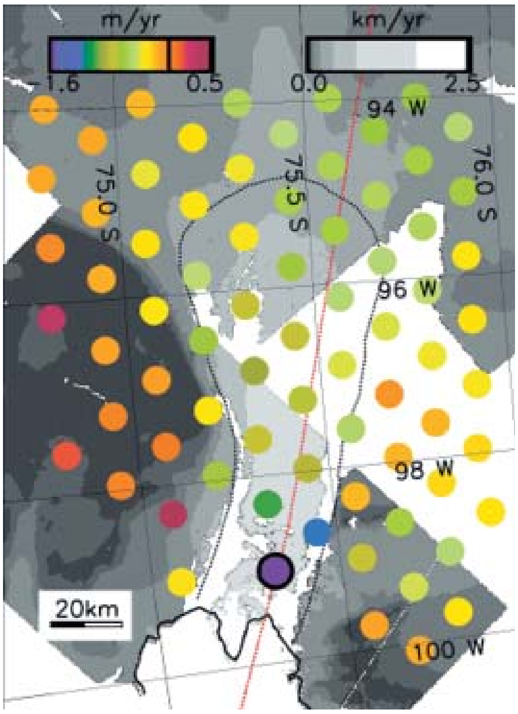

Figure 3. Rate of elevation change of the lower 200 km of the Pine Island Glacier. The coloured dots are located at crossover points and have an area equal to the RA footprint. The grey shading is the velocity field derived from ERS SAR data (courtesy of MSSL/UCL)

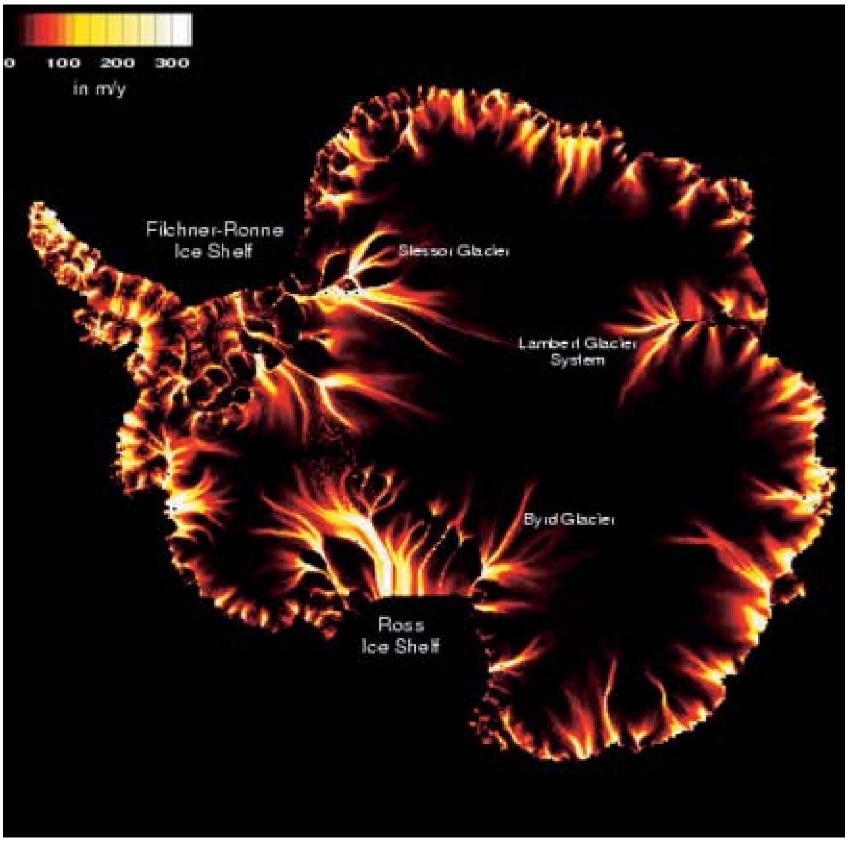

Figure 4. Balance velocities estimated from ERS Altimeter data (courtesy of F. Remy, LEGOS)

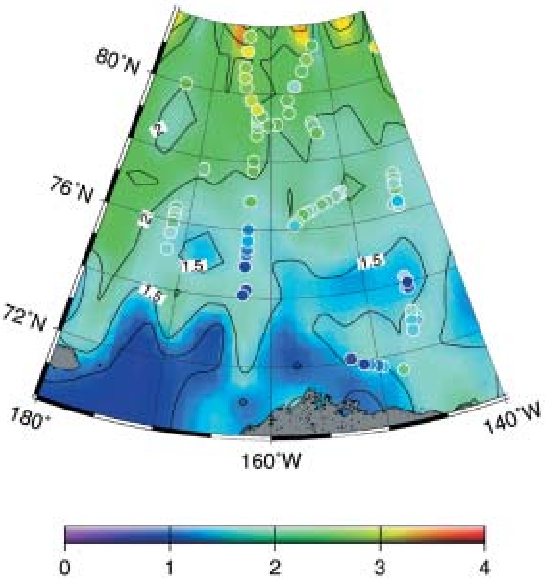

Figure 5. A comparison between RA-derived sea-ice thickness (m) and sparse measurements from ULS on submarines (dots), in October 1996 (courtesy of MSSL/UCL)

that can measure sea-ice thickness on the time and length scales that climate investigation demands. The technique has been developed using ERS Altimeter data, has been verified using the ULS measurements, and will be implemented in Envisat's RA-2 ground processing. Results from ERS suggest that the recently reported thinning of Arctic sea ice may be localised (Fig. 5), and continued monitoring using RA-2 is critical to establish long-term trends.

The Envisat Altimetry mission will both extend and improve the monitoring of the cryosphere in the climatically important polar regions.

Land applications

Over land, the Radar Altimeter echoes have a non-predictable shape, which is why its land-based applications have matured only slowly and painstakingly. One remarkable result from the ERS-1 geodetic phase is the Altimeter Corrected Elevation Model (ACE), which replaces more than 28 % of the most precise global Digital Elevation Model with an Altimeter-derived height dataset and corrects another 17% (Fig. 6). The Envisat Altimeter, even though it will not fly an orbit as dense as the ERS-1 geodetic mission, will improve on this result in terms of accuracy and by including

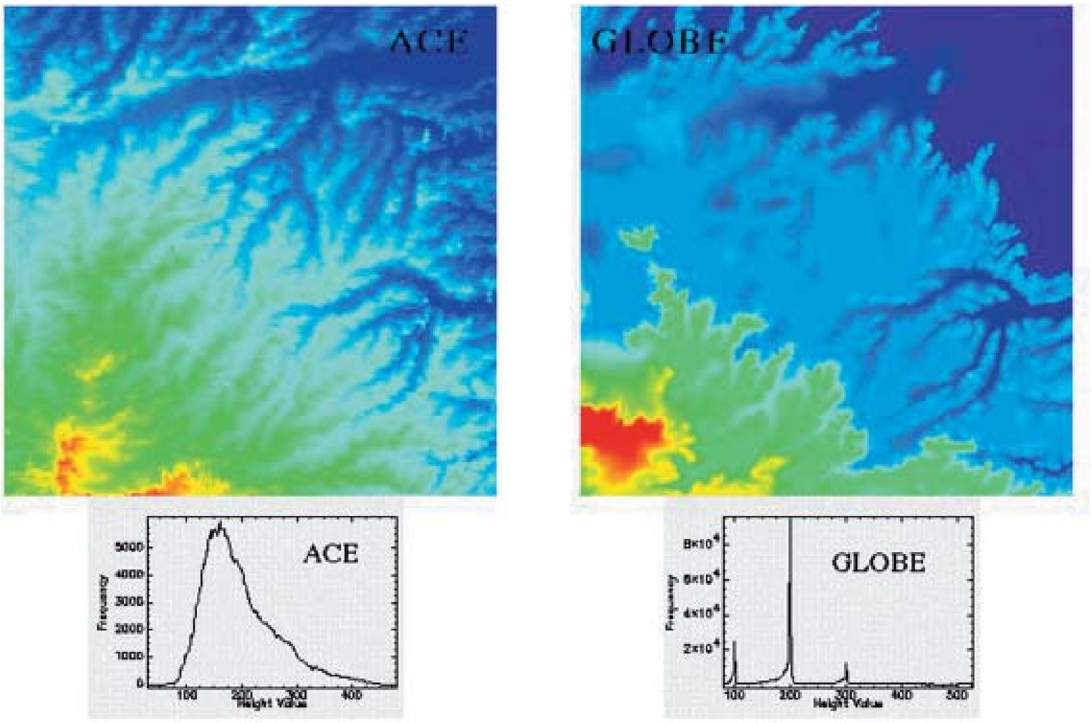

Figure 6. Comparison of the ERS Altimeter-derived map (ACE) of part of the Amazon Basin with the GLOBE map of the same area (73-68 W, 11-6 S). Note the 100 m contours in the GLOBE histogram and the fine (rich histogram) detail in the ACE product (courtesy of Prof. Ph. Berry, De Montfort University, UK)

new areas never before measured. The newly generated ACE product, released at the end of February, forms part of the market-development activity within the ESA Earth-Observation Envelope Programme.

Another land application that has been painstakingly attempted since Seasat is river- and lake-level monitoring. Radar altimetry is a powerful tool for this application as it unifies all river- and lake-level measurements around the world, even for the most remote or inaccessible regions, with a unique gauge. Being able to measure the global river levels, be it only once or twice a month, would be a significant contribution to hydrology.

It has been demonstrated with the ERS Altimeter that echoes from an inland water surface are clearly discernible and convertible to river or lake levels. The inclusion of an Ice mode on ERS-1 and ERS-2 has led to a huge increase in the percentage of the Earth's land surfaces from which valid altimeter echoes have been obtained. This has also resulted in coverage of the majority of the world's river systems, raising the exciting possibility of a 10-year time series of river-height data. The inclusion of a third tracking mode on Envisat should further increase the land hydrology potential of altimetry with even greater river coverage, as well as continuing the hydrology time series. To illustrate the ERS/Envisat contribution, Figure 7 shows part of the Amazon River system, with crossings from the ERS-1 geodetic phase superimposed on an altimeter-derived river map.

Envisat altimetry mission characteristics

Envisat will cover high-latitude ocean, ice-sheet and land-surface areas not covered by the Topex/Poseidon, GFO or Jason missions. The 35-day repeat cycle, on the same ground track as ERS-2, allows for dense cross-track spacing and optimum synergistic combinations with the simultaneously operating Jason/GFO altimetric missions for a wide range of applications. The advantages of this have already been clearly demonstrated by combining current ERS mission data with data from Topex/Poseidon. The orbital characteristics for Envisat are summarised in Table 1.

Table 1. Envisat orbit characteristics

Orbit type:	Sun-synchronous
Ascending node:	22:00 MLST
Inclination:	98.5°
Altitude:	~ 800 km
Orbits per day:	14 11/35
Repeat period:	35 days (501 orbits)
Equatorial ground-track spacing:	~80 km
Ground-track repeat:	±1 km

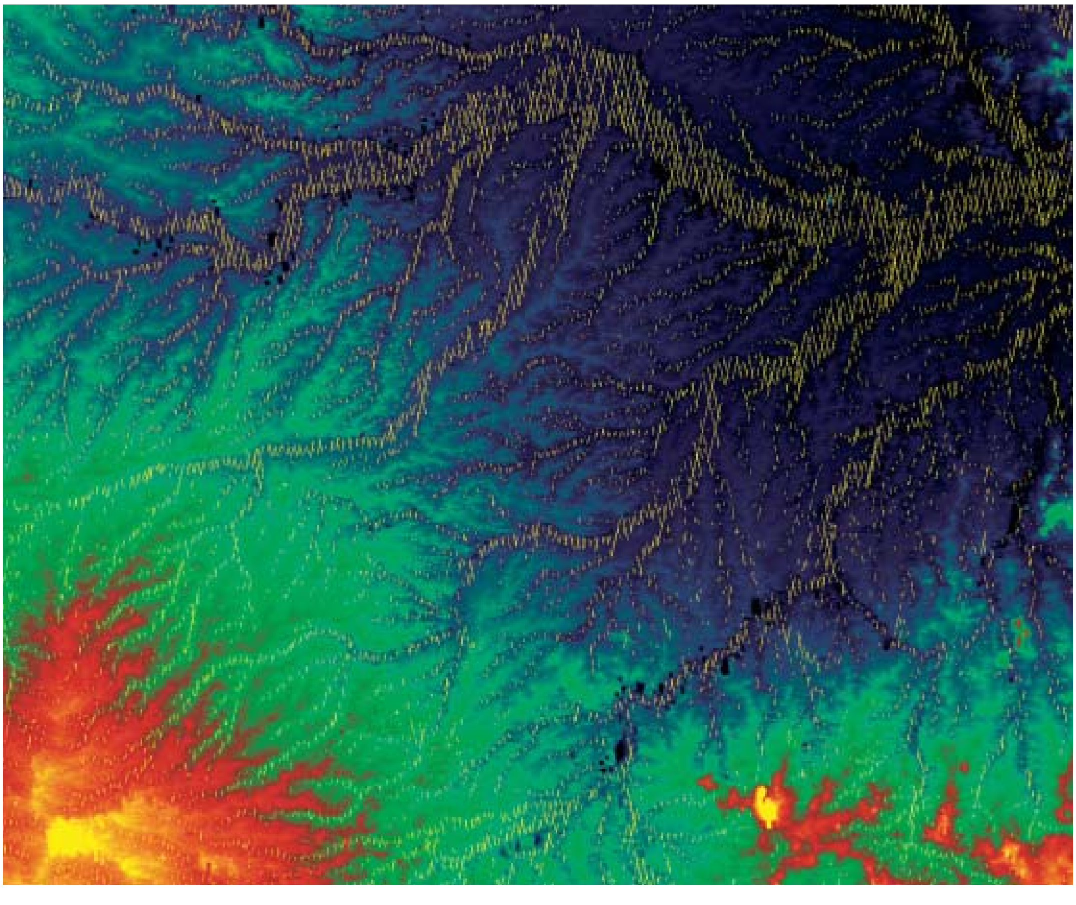

Figure 7. River echoes superimposed on high-resolution ERS-1 Altimeter-derived topography and river network. The plot shows a 11° x 12 ° area of South America containing part of the Amazon Basin (15-4 S, 75-63 W) with the ACE GDEM heights (high: yellow through red; low: green to dark blue) overlaid with ERS-1 Geodetic Mission 'water-type' returns in bright yellow. Note that this part of the ACE GDEM is totally derived from altimetry, which has provided a huge increase in spatial and vertical resolution over previous GDEM models for this region rich in river networks (courtesy of Prof. Ph. Berry, De Montfort University, UK)

The Envisat altimetry payload

The instrument set is composed of:

- RA-2: a multi-resolution, self-adaptive, dual-frequency radar altimeter
- MWR: a dual-frequency nadir-viewing microwave radiometer
- DORIS: a dual-frequency Doppler tracking system for orbit estimation
- LRR: a laser retro-reflector for tracking.

RA-2

Radar Altimeter-2 belongs to a new generation of radar altimeters. One of the major improvements with respect to the ERS RA lies in its second frequency (3.2 GHz, S-band) allowing compensation of the delay due to ionospheric electron density. It is designed for low height noise (pulse repetition frequency of 1795 Hz) and improved wave-height accuracy, with two additional bins on the echo leading edge. Its tracking follows a novel strategy allowing robust on-board collection of accurately quantified radar echoes over all surfaces. Another new feature is the Model Free Tracker, which is robust at handling non-ocean-like echoes, sampled over 128 bins.

RA-2 has three different range resolutions, adapted to different sensing scenarios (ocean, ice sheets, sea ice, wetlands, ice edge and land) and thus to avoiding losing track. Whereas previous altimeters have suffered data dropouts over areas with difficult terrain, RA-2 will be more robust, providing valuable data for applications involving ice edges, land, lakes, wetlands and coastal zones. The switching is controlled autonomously. RA-2 has the ability to preserve a small amount of individual echoes (unaveraged echoes, at 1795 Hz), which are useful for engineering and scientific studies.

Table 2. The three different resolution modes of RA-2

Bandwidth (MHz)	**Resolution (m)**	**Range window (m)**
320	0.5	64
80	2	256
20	8	1024

No geophysical-parameter estimation is performed on-board, where computer resources are limited and fully dedicated to collecting high-quality echoes, and so re-tracking is applied on the ground to create each product, including those delivered in near-real-time. To optimise retrieval for each kind of surface, the waveforms are processed in different complementary manners: four re-trackers – ocean, sea-ice, ice 1, ice 2 – are run in parallel all the time (over all surfaces). Their outputs are delivered in the Geophysical Data Record (GDR) product and in the waveform product (SGDR). Land echoes are so complex, diverse and unpredictable that they cannot be handled by a single re-tracker: the land-applications users will access the waveforms. More details on instrument operation and performance can be found in ESA Bulletin No. 98.

MWR

The Microwave Radiometer's primary mission is determination of the tropospheric-water-vapour path-delay correction for RA-2. Additional applications of MWR data include surface emissivity, ice-sheet dynamics, sea-ice mapping and land-surface temperature, but imaging radiometers are rather used for these applications. The Envisat MWR has the same concept and specification as the two ERS MWRs, but is of a new design. The MWR shares its Instrument Control Unit with DORIS (was ATSR on ERS). It is a dual-frequency, Dicke radiometer (1 kHz switch frequency), with near-nadir viewing using an offset parabola antenna and two feeds (the parabola is fixed, whereas it needed deployment on ERS). Calibration, which is based on a sky-horn (cold load) and an internal hot load, will be performed about twice per minute.

All MWR measurements are to be delivered with the RA-2 products, as so-called RA-2/MWR data products. Further details can be found in ESA Bulletin No. 104.

Table 3. MWR characteristics

Frequency:	23.8 GHz	36.5 GHz
Bandwidth:	400 MHz	400 MHz
Polarisation:	Linear	
Integration time:	150 ms	150 ms
Dynamic range:	3 – 313 K	3 – 313 K
Footprint size:	20.5 km	19.2 km
Footprint centre:	25 km behind	35 km ahead
Sensitivity:	0.6 K	0.6 K
Absolute accuracy:	< 3 K	< 3 K
Data rate:	0.427 kbps	

DORIS

The Doppler Orbitography and Radio-positioning Integrated by Satellite system was developed by CNES (Centre National d'Etudes Spatiales), IGN (Institut Géographique National) and GRGS (Groupe de Recherche en Géodésie Spatiale) to meet scientific and operational user requirements in very precise orbit determination. The basic principle of the DORIS system and its capabilities on Envisat were explained in some detail in ESA Bulletin No. 104.

Designed and optimised to provide high-precision orbit determination and beacon positioning, DORIS was developed in the framework of the Topex/Poseidon (T/P) oceanographic Altimetry mission. Operational since 1990 when the Spot-2 satellite was launched, it is an uplink radio system based on the Doppler principle. It measures the relative velocity between the orbiting satellite and a dense, permanent network of orbit-determination beacons, which form the core of the system and are distributed homogeneously over the Earth. The DORIS permanent network includes 54 beacons hosted by institutes from more than 30 different countries. More than 20 beacons are collocated with other precise positioning systems to allow cross-calibration. The dual-frequency signals at 400 MHz and 2 GHz emitted by the beacons are used by the receivers on-board the various satellites to perform Doppler measurements. Within the network, two master beacons, located in Toulouse (F) and Kourou (Fr. Guiana) are connected to the control centre to allow data uploading to the on-board package, and are also linked to an atomic clock to allow synchronisation of the DORIS system with international reference time.

The DORIS package on-board Envisat includes: a receiver performing Doppler measurements and receiving auxiliary data from the beacons, a bi-frequency omni-directional antenna, an Ultra-Stable Oscillator, and a two-channel receiver with DIODE navigator capability as part of the on-board software. The bi-channel receiver allows two beacons to be tracked simultaneously.

The DORIS Control and Processing Centre, located in Toulouse, is in charge of: beacon network monitoring, on-board package monitoring and programming, science telemetry acquisition and pre-processing, technological archiving, precise orbit determination, and beacon positioning. This Centre is also part of the SSALTO (Orbitography and Altimetry Multi-mission Centre) CNES ground segment. Interfaces between SSALTO and the Envisat Flight Operations Segment and Payload Data Segment have been defined to meet all Envisat mission requirements.

For Envisat, the accuracy of the real-time orbit provided by the DORIS/DIODE onboard software has been specified as 1 m (on three axes). The performance of the DIODE software on Spot-4 and subsequent improvements that have been tested on the ground indicate that this level of accuracy should be reached without difficulty. In fact, various simulations of the radial component of the Envisat orbit indicate that DIODE real-time navigation to the 30 cm level can be achieved using an upgraded version of the software. The Altimeter real-time products will certainly benefit from such a high-quality real-time orbit determination.

The accuracy of the radial component of the offline precise orbit has been specified at the 10 cm level, with the even more challenging figure of 3 cm often quoted as a goal. Experience with Topex/Poseidon and the Spot satellites indicates that the 10 cm target will be reached with no major difficulty, whereas the 3 cm goal is a challenge that the Envisat Precise Orbit Determination (POD) team will actively pursue. The Jason-1 POD group and the other geodetic-mission teams (e.g. CHAMP, GOCE, and GRACE) will help in optimising orbit computation using DORIS and laser tracking measurements.

Within the climate-change research framework, the rate of present-day global sea-level change is a crucial topic, to which DORIS can contribute in several areas, such as: the geodetic reference frame, horizontal and vertical motions of beacons entering the terrestrial reference frame, variations in the geocentre, altimeter calibration using tide gauges, etc. During the Envisat mission, DORIS will also be flying on at least two other satellites, namely Jason-1 and Spot-5. This will ensure the achievement of the required performances in terms of absolute positioning of the DORIS beacons participating in the terrestrial reference frame, leading in turn to an improved final Envisat orbit-error budget. More generally, observation of the ocean is now thought of more and more by oceanographers in terms of a global and ‘integrated’ system. Indeed, there is now a general understanding that space and in-situ techniques are complementary in terms of the characteristics of the observation techniques, sampling, precision and accuracy, and that they must be exploited in a joint way to provide the optimum observing system.

For a few years already, the GPS and DORIS geodetic techniques have been used together with Altimetry and tide gauges to estimate the rate of sea-level change. The continuous enhancement of the DORIS ground network by multiplying the co-location of DORIS beacons with tide gauges is very favourable. Upgraded versions of the DORIS system, for instance through the multiple-channel capability, now offer the possibility to design an efficient integrated 'tide-gauge + GPS + DORIS + altimetry + laser' sea-level system. It is the intention that the Envisat Altimetry mission, including DORIS and LRR for precise positioning, should play a significant role in this global integrated observing system.

LRR

A Laser Retro-Reflector is mounted on the Earth-facing panel of Envisat close to the RA-2 antenna to support satellite ranging for precise orbit determination and RA-2 range measurement calibration. Laser tracking provides the distance between the spacecraft and the station and is assimilated in precise orbit determination. It will be used extensively during the commissioning phase and regularly during the mission to verify the stability of the positioning system.

The LRR is a passive device that will be used as a reflector by ground-based laser ranging stations using high-power pulsed lasers. The operating principle is to measure, on the ground, the round-trip time of laser pulses reflected from the LRR. The 2 kg LRR is composed of corner-cubes designed to reflect the incident laser beam back directly, making the reflected beam parallel to the incident beam within a few arcseconds. The corner-cubes, made of highest-quality fused silica, work in the visible part of the spectrum at two specified wavelengths: 694 and 532 nm. They are mounted symmetrically on a hemispherical housing, with one nadir-looking corner-cube in the centre, surrounded by an angled ring of eight corner-cubes (Fig. 8). This will allow laser ranging with field-of-view angles of 360° in azimuth and 60° in elevation around the satellite nadir.

The LRR was developed by Aerospatiale (F).

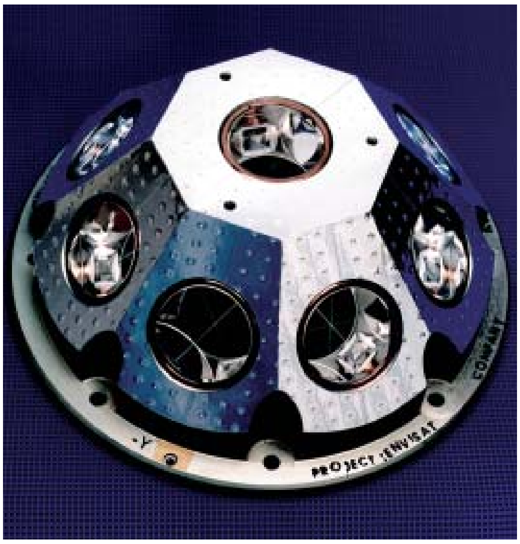

Figure 8. The Envisat Laser Retro-Reflector (courtesy of Aerospatiale)

RA-2/MWR data products

Based on the experience from the ERS missions, significant improvements have been built into this new generation of altimetric products, particularly in terms of the enhanced quality of the near-real-time observations, which will be almost as accurate as the final precise product. The product-specification process has included wide consultation with users of ERS and Topex/Poseidon altimetric data. Further product refinement and state-of-the-art algorithm specification were conducted with the help of three European Expert Support Laboratories (ESLs): Alenia Aerospazio (I), Collecte Localisation Satellites (F) and Mullard Space Science Laboratory (UK).

The algorithm specifications were validated by prototyping within the ESL. Once verified, ESL prototypes became reference processors to produce test data sets designed to validate the ground-segment Instrument-data Processing Facility (IPF). Moreover, the RA-2 and MWR products and algorithms were peer-reviewed by dedicated experts and were the subject of an open review at the Envisat Altimetry Products and Algorithms Review Workshop held at ESRIN in Frascati in June 1999.

The EnviSat RA-2 and MWR Data Products will have – already available in near-real-time – global coverage, the wet tropospheric correction from the microwave radiometer and the ionospheric correction from the two frequencies, as well as many other improvements coming from the novel design of second-generation Radar Altimeter. The comprehensive near-real-time processing runs the same algorithms as for the offline products, with only the availability and quality of the auxiliary data differing.

The suite of products is based on one main Geophysical Data Record (GDR) product. The Envisat general product format is exploited to add sub-structure inside the product to hold additional data such as the averaged waveforms (at 18 Hz), the individual waveforms (at 1800 Hz) and the Microwave Radiometer data set. Thus, the waveform data product (SGDR) is a superset containing the same geophysical data records as the GDR, but with waveform data sets appended. Moreover, these products are global, independent of the sub-satellite terrain and of the Radar Altimeter measurement resolution mode, thus avoiding artificial boundaries between geographical features like land/sea, land/ice or land/lake transitions, and ensuring that ocean, land, ice, lake or wetland data always ends up in the same (unique, global) data product.

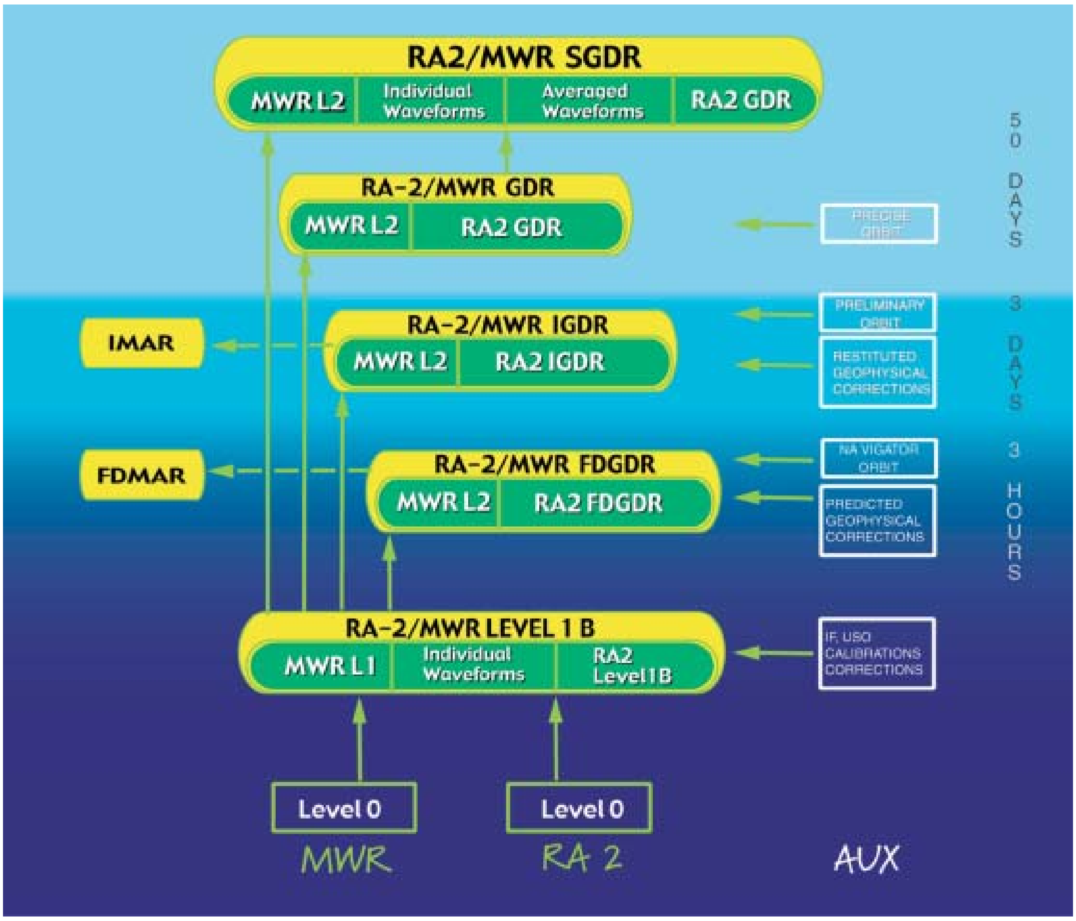

Figure 9. The Radar Altimeter and Microwave Radiometer product tree

The Fast Delivery GDR (FDGDR) product is transmitted in less than three hours, for weather-forecasting, sea-state and real-time ocean-circulation applications. An ocean-related parameter subset of the FDGDR called FDMAR (for Marine Abridged Record) is extracted to reduce the volume of on-line data transfers. FDMAR is converted into the BUFR format commonly used by Meteorological Offices. Less than three days later, the so-called Interim GDR (IGDR) for ocean-circulation monitoring and forecasting applications is delivered, replacing the original meteorological predictions with more precise analyses, and the preliminary orbit with an improved orbit solution. The final GDR and SGDR products containing the most precise instrument calibrations and orbit solutions are delivered after 30 days (not more than 50 days). The schematic in Figure 9 summarises the organisation, the inter-relationships and latency of the product generation. The terminology used to name products is based on the nomenclature traditionally used in altimetry, with the product names stored in the first field of the specific product header.

The Envisat products (identified by their 'Product ID') are categorised into three distinct levels:

- Level 0 (raw): unprocessed data as it comes from the instrument.
- Level 1b (engineering): data converted to engineering units, with instrumental calibration applied (IF filtering, to correct power distortions of echo waveforms, internal range calibrations, corrections for possible drift of reference timing source, no re-tracking); the half-orbit segmented (pole-to pole) product mainly contains: datation (conversion of satellite time to UTC), geo-location, time delay, orbit (<50 cm NRT to ~3 cm offline), sigma-zero, averaged wave-form samples at 18 Hz data rate, individual waveform at full pulse repetition frequency and MWR brightness temperatures.

- Level 2 (geophysical): data converted to geophysical units (with re-tracking); the product mainly contains datation, geo-location, output from re-trackers (range, wind speed, significant wave height, etc.), at 1 Hz plus some 18 Hz parameters (range, orbit). All geophysical products, including the near-real time products, are re-tracked (waveform data are fully processed in the ground processor to extract the geophysical parameters). In order to retrieve the geophysical parameters over all types of surface (ocean, ice, sea-ice, etc.), four specialised re-trackers are continuously run in parallel (over all surfaces):
  - Ocean re-tracker: optimised for ocean surfaces, and based on a modification of the Hayne model

- Ice-1 re-tracker: optimised for general continental ice sheets, it is a model-free re-tracker called the ‘Offset Centre of Gravity Echo Model’; it is used for ERS and will ensure measurement continuity
- Ice-2 re-tracker: optimised for ocean-like echoes from continental ice-sheet interior, it is a Brown-based model re-tracking algorithm
- Sea-Ice re-tracker: optimised for specular returns from sea-ice, it is a threshold re-tracking scheme for peaky waveforms.

The usual necessary geophysical corrections are available in the Level-2 products. The ionospheric correction will come from the dual-frequency altimeter, backed-up by the measu-rements from DORIS and the Bent model. The wet tropospheric correction will come from the on-board microwave radiometer, backed-up by a value computed from ECMWF fields. Users requiring the Altimeter waveforms will find them conveniently stored in the Level-2 SGDR product, along with the co-located geophysical corrections and the outputs of the four re-trackers. In other words, the SGDR holds the GDR data augmented by averaged and individual waveforms. Therefore, users of Envisat Altimetry need not access the Level-1b products.

The Fast Delivery data (FDGDR) will be processed at the receiving stations and delivered in less than 3 hours. The Interim Geophysical Data Record (IGDR) and the final precision Geophysical Data Record (GDR) products will be processed offline at the French Processing and Archiving Centre in Toulouse, the so-called F-PAC, with the same algorithms as the Fast Delivery processor. The SGDR is also built at F-PAC.

Envisat User Services will be a unique interface with the user community to provide the required geophysical data products. They will register the data requests, both Fast Delivery and Offline, and organise the acquisition, processing and product delivery. They will be accessible using a WWW browser via a Unified User Services Interface, which will be identical at all stations and centres. Under the new Envisat Data Policy, users of Earth-observation data for scientific purposes will be granted special Category-1 status. These users are invited to submit a research project proposal at any time via the web site http://projects.esa-ao.org (the new data policy is detailed herein). All other, so-called Category 2, users are invited to contact the commercial distributors.

Sample data covering the whole suite of RA-2/MWR products have been distributed on CD-ROM, including a Java display tool known as ‘Enviview’. Batch (no graphical user interface) read-write software in C, Fortran and IDL, containing all the RA-2/MWR data set structures, is also available on request.

Conclusion

The Envisat Radar Altimeter mission, including its support instruments, MWR, DORIS and LRR, will serve a myriad of mission objectives, covering oceanographic, cryospheric and land applications. The new-generation Radar Altimeter-2 has many new capabilities to enhance the quality of its measurements, including a second frequency and additional echo sampling near the leading edge for more accurate reading of wave heights. It will be able to make previously impossible measurements over very difficult terrain, using three resolution modes and autonomous switching.

The Geophysical Data Record (GDR) products will be built up from four specialised re-trackers running in parallel over all surfaces. They will be global in nature, with no artificial boundaries, and will be common to the waveform product (SGDR). The data coverage will be up to 81.5 deg N and S in a dense ground-track layout (35-day repeat cycle). The Envisat ground system will deliver global near-real-time data in less than 3 hours. These products will already be of near-GDR quality, as they will be built running the same algorithms as the final precise GDRs. They will contain the good-quality orbit produced in real time by the DORIS navigator and the MWR corrections, and will permit accurate real-time monitoring of global oceanographic signals, contributing to such major near-real-time applications as the Global Ocean Data Assimilation Experiment (GODAE).

The full exploitation of RA-2 data demands high-quality absolute calibration at Ku- and S-band for the three instrument parameters, as well as a very accurate cross-calibration with previous altimeter data during overlapping flights. The objective is to provide the user community with a continuous and consistent altimetric time series (see article on calibration and validation elsewhere in this Bulletin).

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