SUMMARY AND RECOMMENDATIONS FROM THE "20 YEARS OF PROGRESS IN RADAR ALTIMETRY" SYMPOSIUM

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ABSTRACT

This paper summarises the main results, conclusions and recommendations of the "20 Years of Progress in Radar Altimetry" Symposium organised by the European Space Agency (ESA), in collaboration with the French Space Agency (CNES) (Fig. 1). The Symposium is a sequel to the one held in Venice in March 2006 to celebrate fifteen years of progress in radar altimetry. Nearly 600 scientists, engineers and managers returned to Venice in September 2012 from 32 countries worldwide, submitting papers with more than 1000 authors and co-authors. The closing plenary session was the opportunity to have a community discussion focused on the future of altimetry and the future observational requirements, the risks and challenges. A "Manifesto" was drawn-up and discussed by the participants. This paper presents the "Manifesto", highlights the main results presented in the sessions, summarises the discussions and provides guidance for future mission design, research activities and sustainable operational Radar Altimetry data exploitation.

Figure 1. The "20 Years of Progress in Radar Altimetry" Symposium was held in Venice from 24 to 29 September 2012. Within the framework of this Symposium, three related events were scheduled over 6 days: the Ocean Surface Topography Science Team Meeting, the International DORIS Service Workshop and the 4th Argo Science Workshop.

1. THE RADAR ALTIMETRY MANIFESTO

Venice (I), 26 September 2012 - We, the radar altimetry community, are proud to celebrate the astounding successes of 20 years of radar altimetry from space. This saga started in the early 1980's, thanks to the efforts of a small group of visionary scientists and the leadership of a few space agency program managers.

Radar altimetry from space started in the context of the World Ocean Circulation Experiment. Since its inception, the altimetry community has expanded in size and scope from a few handful of ocean scientists and a couple of countries to a worldwide concerted effort involving both R&D and operational space agencies from Europe, USA, China and India, benefiting from the expertise of several hundreds of scientists and engineers, serving the needs of thousands of data users, and covering a variety of disciplines, from large-scale to mesoscale oceanography, through to coastal studies, ice sheets and ice cap survey, marine geodesy, hydrology and limnology. One crucial achievement of radar altimetry has been the 20 year record of sea level rise and its geographic pattern and variability, a key climate indicator of global warming, made possible by the incredible accuracy of the combined technique of sea surface height measurement and precise orbit determination. The iconic image of sea level variations since 1992, showing a steady increase of 3.2 mm/yr, twice as much as the average rate over the 20th century, is the symbol of the success of radar altimetry. More recently synthetic aperture radar altimetry has provided the first ever image of the rapidly vanishing Arctic sea ice cover (extent and thickness) and of the fast melting Greenland ice sheets.

Radar altimetry is a key component of the *Global Earth Observation System of Systems* (GEOSS), and over the last 20 years has provided the principal global data source enabling the development of operational oceanography. Radar altimetry contributes to a large number of societal needs, from climate monitoring to

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weather forecasting, with subsequent applications in a range of activities of socioeconomic importance, including agriculture, health, energy, water, maritime safety, etc. These twenty years of success cannot mask the fact that this complex system is fragile and at risk: today we are just one satellite-failure away from a gap in the twenty year record. Such a situation should be considered seriously, in view of the dramatic and costly impact that sea level rise and associated extreme events will have on many coastal areas of the planet and their inhabitants.

We, the radar altimetry community gathered in Venice on 26 September 2012, wish to express our collective will to work at ensuring the continuity of the historical climate data record and preparing the next generation of missions, which will continue the success and expansion of radar altimetry.

The purpose of this Manifesto is to express the following recommendations that are respectively addressed to the relevant scientific community, to space agencies and to intergovernmental entities, national governments and the European Union.

We commit ourselves to:

- Working to reduce the present uncertainties affecting the global mean sea level trend and its interannual and regional variability

- Pursuing altimeter constellation time series over a longer time period with concurrent Argo observations so as to understand the mesoscale dynamics and the vertical structure of eddies

- Developing altimetry products of use by a large fraction of the inland water community

- Developing a ‘seamless’ product over the different surfaces (open and coastal ocean, hydrosphere, cryosphere)

- Extending coastal and mesoscale studies to include data from other altimetry missions (HY-2, CryoSat, SARAL/AltiKa)

- Including discussions on data quality and algorithms in scientific workshops and in a combined OSTST format for mission intercomparison.

- Participating in public outreach and information to decision and policy makers highlighting the societal importance of radar altimetry

We encourage all space agencies, whether R&D or operational, to:

- Maintain the continuity of the climate record, by ensuring an uninterrupted reference mission time series of global, high-accuracy altimeter data.

- Plan a ‘tandem phase’ for all new missions, to accurately link successive altimeter time series

- Maintain the international scientific framework of the OSTST and expand it to new partners

- Strengthen the relationships between agencies, which has led to the successful merging of individual mission data sets

- Continue and improve the work done on the 20 year data record

- Maintain a long-term archive of raw and processed data, and ensure regular reprocessing

- Establish a program aimed at extending the sea level record to high latitudes and coastal zones, and including all available and future missions (HY-2, CryoSat, SARAL, Sentinel-3, etc.)

- Include the coastal sea level and the inland water needs in future observational requirements

- Ensure production and dissemination of altimetry products for use by the inland water community, including non-remote sensing scientists

- Ensure production and dissemination of a ‘seamless’ product over the different surfaces (open and coastal ocean, hydrosphere, cryosphere)

- Devote a substantial effort to cross-calibration and extensive validation of altimetric satellite mission products quality all along the operational lifetime, as a key element of their success.

- Share expertise between R&D agencies and operational agencies

- Sustain and strengthen the funding necessary to accomplish the scientific research and development to extract maximum knowledge from all missions, whether research or operational

- Distribute currently generated value-added science products on a free and open basis.

- Ensure the continued training of the new generation of altimetric scientists

We urge the intergovernmental bodies, individual governments and the European Union to:

 Ensure the necessary continuity between past (LRM) and future (SAR) altimetry series, so as to take advantage of technological advances while preserving the integrity of the long term record.

 Secure the funding necessary to pursue the invaluable time series of radar altimetry data, having in mind that the costs involved are but a fraction of the damages that could be avoided and the benefits that will be harvested with the knowledge and information gathered by these missions.

2. SESSION SUMMARIES

2.1. Building the 20-Year Altimetric Record

Co-chairs: Pascal Bonnefond, Remko Scharroo, Nicolas Picot, Shailen Desai, Pierre Féménias, Bruce Haines and Frank Lemoine

In the overall summary of the session we wanted to point out:

- ***The "success story" of altimetry lies on the synergy of the different agencies, the scientific community (e.g. SWT/OSTST and QWG) and missions objectives and we all have learned a lot from cross comparing all the datasets (including in situ) and notably from the Formation Flight Phases that permits to cancel some common uncertainties and then to focus on coherence of the whole measurement system: same scenario have to be used in the future (e.g. Jason-3/Jason-CS) to insure the continuity. From that, reprocessing efforts have and will permit to increase the accuracy and the consistency of the 20-year altimetry record and preserve not only the datasets but also the knowledge. The lessons learned will pave the next 20-year but with the incoming new technologies (e.g. SAR) strong efforts have to be made to insure the continuity from past to future but also insure and widen the international cooperation (e.g. US/Europe).***
- ***To be usable by a large scientific community this 20-year altimetry record have to be "simplified" but insuring the consistency and accuracy. DUACS system, NOAA CDR and ESA CCI for global record as well as SALP (CNES) or RADS (NOAA) at the individual mission level are very important steps in that direction and should be continued and amplified. However, improvements on either modeling or processing are not frozen and then efforts have to be made to move towards more flexible information systems.***

*The **Building the 20-Year Altimetric Record** session was divided into different themes:*

An overview of the past and present mission series and the importance of the reprocessing

This session started with an historical overview of the early stages of altimetry, followed by several talks on the importance and status of the reprocessing effort made by the different agencies. For example, the REAPER project concerns the reprocessing of ERS-1&2 to achieve standards close to Envisat GDR-C standards. On-line delivery is expected by the end of 2012. Geosat and GFO reprocessing is also underway. The first stage of this project concerned the data recovery from tapes and was achieved with a very good percentage of recovery (99.2%). With this reprocessing crossover statistics for both Geosat and GFO now have an rms of 6-9 cm. GFO had limited waveform data for hydrology but due to the increasing need it has been decided to include these data in the final data set. The T/P reprocessing issue was also discussed. In order to bring TOPEX data up to the standard of more recent altimeter data and to correct for waveform features and PTR changes the TOPEX data are being retracked, and numerous corrections and parameters will be updated to Jason-like GDR-C/D standards, including the SSB correction.

Benefits of the multi mission/agency approach

Agencies on both side of the Atlantic (SALP for CNES and RADS for NOAA) are now providing users with consistent data sets for the numerous past and current altimetry missions. While SALP project mainly focused on operational activities with homogenous standard datasets (I/O/GDRs), RADS offers a more flexible database with different options for the altimetry recipe. In their conclusions, they both agree with the current paradigm that a fixed GDR product is very important for stability but this freezes the data releases even when shortcomings are known; there are also many different data formats and contents. Then there is a need for an additional more flexible and more regularly updates GDR-like products. CNES has engaged a study on this subject. The importance role of the SWT/OSTST was also recalled, from which innovative ideas often become standards (e.g. HF dynamics). One of the key factors for the success in altimetry is the multi-disciplinary approach; this has been achieved over the last 20 years and should pave the way for the future 20 or more years. It was also noted that Formation Flight Phases (e.g. T/P - Jason-1 first six months) are very important for cross-calibration, and that we continue to learn more from these phases: the same scenario needs to be used in the future (e.g. Jason-3/Jason-CS) to ensure the continuity. However, continuous monitoring during the nominal mission (multi mission crossovers, in situ comparisons, ...) is also important for long term monitoring (drift, ...).

Review of 20 years of research on some of the most important ingredients in the altimetry recipe.

With 20 years of improvements in Precise Orbit Determination, we now have orbit precision better than 1cm for Jason-2. This is the results of mainly reference frame improvements (e.g. ITRF05/ITRF08), stable performances of the tracking systems (e.g. GPS GRACE-based antenna phase maps to improve current and past GPS measurements) and various modeling improvements (time varying gravity field being the most important). However, radiometer issues remain the largest source of uncertainty in Global MSL. A brief history of the radiometers and their errors were presented, and showed that the past 20 year efforts permit us to achieve a better long-term stability, reduce Geographically Correlated Errors, and provide enhanced measurements toward the coast. A review of the different retracking schemes was also presented, which are extremely dependent on the application needs but also on the mission design: there is for the moment no consensus on one "universal" retracker. SAR mode is also opening a door but need to be carefully analyzed (notably with regards to Sea State Bias). Indeed, although there has been much progress made on SSB, mainly from adding ocean wave statistical parameters from independent wave model (3 to 4 parameters), however this should be made carefully because any trend in the wave model can be transferred to SLA trend. AltiKa and Cryosat will also help further delimit the frequency/mode dependency of SSB. Finally, the differences between historical LRM measurements, the new present (SAR) and future measurements (Ka- band) were discussed. The availability of individual SAR echoes is of large benefit for coastal and hydrology applications, limiting the land contamination. Moreover, SAR processing is highly flexible. However, many issues remain for SAR: mispointing impacts, low SWH states dependency and how to insure continuity between LRM and SAR.

How to calibrate and validate such a 20-year altimetry record?

A historical overview was given, of the absolute calibration history with details on the different calibration sites that have been and are involved in the different altimetry missions. This history was paved of important errors identified through the synergy of the SWT/OSTST community and where the in situ calibration sites have played a key role. The importance of a well distributed "network" of in situ calibration sites was noted, to be able to mitigate the Geographically Correlated Errors and also to provide new insights on coastal altimetry & the connection to open ocean. The important role of tide gauges in the altimeter CalVal was also addressed. One very important finding was the early discovery of the T/P spurious drift due to an error in the USO algorithm thanks to the tide gauges network comparison. Recent improvements of such a method are mainly due to the use of land motion estimates at the tide gauge locations and to the global reference frame improvements. Such a method is very important to reduce the error bar in our estimates of the global sea level rise rate.

How to provide data for the wider scientific community and not only altimetry specialists?

Different projects are providing long term climate records for scientific analyses. The NOAA Sea Level Climate Data Record project is one of these. A review was made of the current state of knowledge of the altimeter record, estimates of the relative biases between missions, and an inventory of known inconsistencies among missions. With an overall improvement of the 20-yr data record and the tide gauge calibration method (see Mitchum et al.), the T/P+Jason missions show a stability of -0.15 ±0.4 mm/yr. There was also a report on the European (ESA) counterpart of such a Climate Data Record, where sea level is one of the key components. The first phase of the ESA CCI was presented, whose main objective is to involve the Climate Research community which is the main user of the Sea Level ECV in order to improve the understanding of their needs and thus to ensure a perfect consistency between the need and the future development and improvement of the altimeter processing system. One other key objective is to develop, test and select the best algorithms in order to produce high quality sea level products for climate applications. Finally, the history of the CNES AVISO/DUACS project was made, from its early beginning in 1997 to the most recent improvements. Today, the DUACS system responds to various needs including the provision of NRT altimetry products for monitoring and forecasting centers. Concerning the delayed time product, the DUACS system regularly produces a complete reprocessing of the whole dataset which is very useful for the scientific community. All of the altimeter missions from all Space Agencies from 1992 onwards have been successively integrated in the system as soon as the data have been made available and assessed: including T/P, ERS-1&2, GFO, Envisat, Jason-1, Jason-2 and recently Cryosat-2.

2.2. Oceanography - Wave and Wind

Co-chairs: Nicolas Picot and Frank Lemoine

Building a 20-Year altimetry record concerns not only Sea Surface Height but also wind and wave fields**.** A historical overview was given on the assimilation of altimetric significant wave height (SWH) data into the ECMWF global wave forecasting system. Concerning the altimeter wind speed, it is not used in data assimilation at ECMWF since its impact would be small compared to that of scatterometers, which have a wide swath. Instead, altimeter wind speed is used for monitoring the model performance and for the validation of new model developments. The use of altimeter wind and wave data during the past two decades was summarized and their impact assessed. Météo-France studies also showed that the satellite altimetry data record is essential for global validation and wave model forecasts improvement at global scale but also crucial for regional model where no in situ data are available.

2.3. Oceanography – Large Scale

Co-chairs: Sarah Gille, Jens Schröter, Bo Qiu

20 years of satellite altimetry has provided a wealth of long term observations of large-scale ocean processes, allowing us to better understand the oceanic response to the changing atmospheric forcing, on seasonal, internannual and longer time scales. The presentations and discussion in the large-scale sessions showed the diversity of the studies that are now being performed with this long time series. We find great success in using altimetry to describe and evaluate oceanic and related climatic processes.
In the first session, regional sea level trends were examined in the western tropical Pacific. Results based on satellite altimeter data suggest that regional sea level rise is linked to southward migration of the North Pacific Current and North Pacific Countercurrent, which in turn were linked to a strengthening in the Walker circulation. In another study, the Pacific Decadal Oscillation, which has historically been defined from sea surface temperature, is more robust when defined using sea surface height. Lagged regressions of ocean currents and a simple dynamical model were used to explore the underlying dynamics. The variability of the Gulf Stream was also discussed, based on an analysis comparing repeat in situ observations from the Oleander line with altimeter observations. The data indicate both a seasonal cycle in the position of the North Wall of the Gulf Stream and also coherence between Gulf Stream displacements and changes in the NAO. The variability of the Atlantic climate across a wide range of scales was also addressed, looking at ocean-atmosphere coupling and the impact on the meridional circulation during the last 20 years. Strong links between sea surface height and ocean heat content revealed how the North Atlantic couples with atmospheric variability and in particular with atmospheric blocking events. Finally, satellite data allow us to distinguish between Central Pacific and Eastern Pacific El Niño events, using a clustering technique to distinguish events. A recharge/discharge oscillator framework implied distinctly different patterns, with weak discharge in Central Pacific events and strong discharge in Eastern Pacific events.
In the second session, the relationship between the changing atmospheric forcing and the large-scale ocean response was further evaluated. Meridional heat transport (MHT) anomalies in the Atlantic Ocean have been inferred from satellite and in-situ observations in a coherent way. Increases in MHT are accompanied by increases of heat loss through surface fluxes in the subtropical gyre. An intensification of MHT anomalies toward the south and a correlation of MHT with the Antarctic Oscillation suggest a southern source for the coherent MHT anomalies. North Atlantic subpolar gyre variability has been extensively studied using satellite Altimetry and the repeat hydrographic section, OVIDE. The magnitudes and time scales of the MOC variability in 1993-2011 have been evaluated using a MOC index built upon altimetry and Argo, and validated with the hydrographic sections. The MOC index shows a decline of 2 Sv in the MOC intensity between 1993 and 2010**.**The relation between the Pacific Decadal Oscillation and basin-scale ocean variations was also considered. An index of the PDO based on altimetric SSH is a more robust indicator of the PDO state than the SST index in the North Pacific. In the Indonesian Throughflow (ITF) region, proxy techniques have also been established to link a 3-year time series of in-situ transport estimates from the INSTANT campaign, to the 20-year time series of altimeter data. The resulting 20-year time series shows strong interannual ITF variability that is related to Indo-Pacific climate variations driven by distinctive processes associated with both ENSO and the Indian Ocean Dipole. Large-scale interannual variability was also studied in the Southern Ocean from sea level and bottom pressure sensors, in the Mediterranean Sea from altimetry and surface drifters and in the Beaufort Gyre from altimetry.

2.4. Oceanography – Tides, Internal Tides and High Frequency Processes

Co-chairs: Richard Ray & Ole Andersen

Tides play a fundamental role in the ocean circulation. Tidal currents interact with other ocean currents, and are particularly strong in coastal and estuarine regions. Tidal mixing and energy dissipation are one of the key unknown factors which impact strongly on the thermohaline 3D circulation in the ocean, and thus on the ocean's response to a change in climate. Our increased knowledge in tides over the last 20 years has been largely driven by the excellent global coverage of open ocean tides by satellite altimetry, and specifically the T/P-Jason series on a non sun-synchronous orbit, which is adapted to observing the full tidal spectrum. The accuracy of tidal models has greatly improved during the last 20 years. Still, significant errors still remain mainly in shelf seas and in polar regions.

A new global tidal model FES2012 was presented, which takes advantage of longer altimeter time series, improved modelling and data assimilation techniques, and more accurate ocean bathymetry. Special efforts have been dedicated to the determination of accurate tidal currents and to address the major non-linear tides issue. The effect of tides on the Earth's rotation was also presented. In terms of regional tidal modelling, the recent improvements in the coastal altimeter data processing now enable us to retrieve better-quality sea surface heights in shallow waters. So regional high resolution tidal models are needed to more properly correct the altimeter data. Regional tidal models were presented with increased model accuracy and an extended prediction spectrum, in particular for coastal non-linear constituents. Improved digital bathymetry, higher model grid resolutions and 20-year long assimilated altimetry time series are some of the numerous improvements that benefited the regional tidal atlases construction during the last years. A large number of scientific and offshore engineering applications depend on these atlases, as well as their contributions to the coastal altimeter data accuracy.

The 20 year time series of T/P-Jason observations has also revealed extensive regions with active internal ocean tides. The stationarity of the internal tides generated in a global eddy-resolving ocean circulation model was explored using 5 years of model output. The simulated internal tide is first compared with estimates obtained from altimetric sea-surface heights. Both the model and observations show strong generation of internal tides at a limited number of "hot spot" regions with propagation of beams of energy for thousands of kilometres away from the sources. The simulated internal tide is found to be largely stationary over the hot spot regions. A combination of numerical modelling, satellite altimetry, and observations of polar motion were used to determine the Mf ocean tide and to place constraints on certain global properties, such as angular momentum. Polar motion provides the only constraints on Mf tidal currents. A model of the Mf ocean tide was then used to remove the effects of the ocean from estimates of fortnightly variations in length-of-day.

Finally, although satellite altimetry does not have the necessary temporal resolution to monitor high-frequency events such as storm surges, there are enough observations in the 20 year record to capture certain events. Satellite altimetry has been used to observe the cross-shelf features of a storm surge, providing important information for analysing the surge characteristics and for validating and improving storm surge models.

2.5. Oceanography – Mesoscale

Co-chairs: Bo Qui, David Griffin, Frank Shillington and Somayajulu Yenamandra

The 20-year time series of T/P-Jason and ERS-Envisat data, as well as the DUACS multi-mission data sets, have provided an unprecedented insight into mesoscale ocean structures, and allowed us to observe both long-lived and rapid adjustment processes. Many of these observed mesoscale structures were unexpected, leading to a wealth of new theoretical and modelling studies to help elucidate their physics.

The first session highlighted a number of new results from these new observations of ocean mesoscale processes. The dynamics of "striations", quasi-zonal jet-like features seen on maps of multi-year mean geostrophic velocity, were analysed in the framework of beta-plumes, which are ocean circulations generated by localized sources of vorticity. These striations appear linked to the instability of meridional flow, and new eddies are generated not only in the beta-plume vorticity source but also along the jets west from the source area. Another study presented new ways to retrieve the upper ocean mesoscale and submesoscale dynamics, in the first 500m below the surface, using both fine resolution satellite altimetry and sea surface temperature as well as existing in-situ data such as those from Argo floats. The vertical projection is made using surface quasi-geostrophy theory, but can also include the effects of surface fluxes which modify the mixed layer dynamics. Surface cross-stream eddy diffusion has also been estimated from satellite altimetry fields in the Southern Ocean, by monitoring dispersion of particles advected numerically with observed satellite altimetry velocity fields. The mean-flow and topography shape the global structure of Southern Ocean mixing by reducing diffusion in the core the Antarctic Circumpolar Current and by increasing mixing on its northern flank along the stagnation bands, themselves partly controlled by topography, and in the wake of obstacles.

A few presentations also investigated the energy at different spatial scales in the ocean, revealed by spatial wavenumber spectra. Along-track altimetric wavenumber spectra were compared to ocean model spectra, with and without tides, and surface current spectra. Different studies show that the resolution of the models and the resolution/noise of the SSH impact the spectra. Altimetry responding to deeper ocean variations can also have a different surface response to measurements made in the surface mixed layer. This subject is still an active field of debate. The session finished with an overview of the Rossby waves detected from 20 years of altimetry, and a review of the past, present and future developments in Rossby wave theory to help explain the observations.

The presentations in the second session showed a variety of mesoscale results from the Norwegian Sea, the western Pacific Ocean, the southwestern Indian, the Southern Ocean and the global ocean. Lively discussion between the large (150 +) audience and the speakers ensued. Twenty year altimetry records in the Norwegian Sea showed a cyclonic wavelike motion with phase speeds of 2-4 km/day and a wavelength of about 500 km. This was determined by the use of complex EOF (CEOF) analysis. The dispersion relation suggests that these are baroclinic, topographic waves. In another study, high resolution SST and ocean colour sensor data at submesoscale complement and correct ocean mesoscale velocity fields that emerge from altimetry. This study addressed the feasibility of assimilating tracer fields at submesoscale into ocean models. This is a great example of the synergy between different remote sensing data.

Decadal changes in mesoscale energy along the Pacific Counter Current (STCC) and variations of vertical geostrophic shear between the eastward flowing STCC and westward (subsurface) flowing North Equatorial Current in the western Pacific Ocean between eddy rich and eddy weak years were compared. Model studies also revealed enhanced baroclinic instability from the larger vertical velocity shear. This was related to the western Pacific Index. In a separate study, a synthesis of altimeter data with concurrent current meter measurements from moorings deployed for 14 months and a number of vertical temperature sections (using CTD and XBTs) in the region south of Madagascar enabled an estimation of the depth integrated deep transport in an eddy. Finally, time series of the 20 year global mean altimeter derived eddy kinetic energy (EKE), showed both seasonal and interannual variability, ENSO related signals and other global modes. Correlation with a number of climate variables with the area weighted mean EKE were largely insignificant at the global scale, although on the regional scale, these correlations were significant, and revealed interesting areas of higher variability in the major ocean basins.

2.6. Oceanography – Coastal Altimetry

Co-chairs: Paolo Cipollini and Florence Birol

The oral and poster session clearly demonstrated that coastal altimetry has become a very lively domain of research and application, with promising results, especially when the synergies with other in situ measurements and modelling are exploited. The availability of reprocessed data is closing the loop between developers and users and things look even better for the future in virtue of the new techniques (SAR Altimetry, Ka-band altimetry) that have better performance at the coast. It is recommended that research on coastal retrackers (for which there is not consensus on a universal solution) and optimized corrections should continue to be supported. But at the same time the existing products should be upgraded and their dissemination to and uptake by the users encouraged.

The first two talks in the session dealt with product development studies in coastal altimetry. Firstly, the motivations behind the development of the experimental CNES / PISTACH product for Jason-2 were presented. This is a Level-2 product for coastal altimetry and hydrology, originally envisaged for one year of data, which has been continuously extended until the present. The project included a user/need product definition phase that lead to the definition of the requirements of the coastal ocean products. The implementation was completed in 2009 but the product started to be disseminated in November 2008 at the 2nd Coastal Altimetry Workshop in Pisa. It is global, in NetCDF, free and fully documented, with 700+ registered users. Examples of hydrological applications were also shown based on the ICE3 retracker. For coastal applications, PISTACH is now also providing Level 3 data over a small number of sites. A number of upgrades are foreseen for 2013-2015, including processing updates (with updated tides and reference surfaces – other evolutions are under discussion), and a new dissemination tool in collaboration with CTOH. Discussions are also on-going on how to extend PISTACH: CNES are now proposing to reprocess Jason-2 and Jason-1, plus all Cryosat-2, and produce a global Level 3 product.

There is also a parallel study funded by ESA for the development of coastal altimetry for Envisat, called COASTALT. This has been an incubator of ideas and techniques and has led to the specification of products, the implementation of a prototype processor, the design of novel correction concepts (like the GPD wet tropospheric correction, see below), and finally the release of demonstration products over a number of pilot tracks around Europe. The recommendations stemming from COASTALT for the future development of the field were also presented. R&D is continuing on ESA side with the eSurge Project devoted to integration of Earth Observation data in storm surge studies, that has a significant coastal altimetry component.

Examples of the expected applications from coastal altimetry were also presented, including the problem of resolving the coastal mesoscale using 2D altimetry maps in the North Western Mediterranean Sea. A number of datasets are used, including High Resolution (HR) regional maps recomputed from along-track altimetry with an adapted OI (optimal interpolation) method. The Lagrangian approach allowed the characterization of the influence of mean currents and optimal interpolation. In combination with climatologies, it is possible to attempt a reconstruction of sub-surface currents that compare well with the drifters; applications include the forecasting of the distribution of *Pelagia noctiluca* jellyfish. This was an excellent example of how the value of coastal altimetry

increases dramatically when it is used in combination with additional information.
Another application concerned the monitoring of the Leeuwin Current along the West coast of Australia. The oceanographic conditions in the area were described, and the coastal pathway through which the annual Rossby wave coming from the Pacific propagates and drives the current – this propagation is very clear in a Hovmöller diagram. There is a clear signal in the Gulf of Carpentaria that is also captured by GRACE, and a distinct seasonal warming on the NW Australia Shelf. The characterization of this entire process has improved enormously with the advent of altimetry, and it is clear that standard altimetry does resolve the annual cycle in the coastal region but to go any further we now need improved coastal altimetry data.
Another question was the pressing issue of how we choose which retracker to use in the coastal zone. The solution proposed is use HF radar coastal currents to inform that decision. Their demonstration area is the California Current. CODAR current are averaged on 3-day to approximate to geostrophy, and used alongside a mean current to create Synthetic Height fields. These are compared to the Jason-2 PISTACH data to see which retracker of those available within PISTACH best captures the currents. Closer to shore, this comparison can be made by using 20Hz data and 2-km CODAR. Including SAR data is also useful. In some instances there was a really excellent match, however the best retracker depend on the specific case.
Finally, an intercomparison of algorithms for wet path delay in the coastal regions was made. This is a field where great progress has been made in various years, with different solutions proposed (Mixed Pixel Algorithm, Land Proportion Algorithm, GPD or GNSS-derived Path Delay), and these were compared with model (ECMWF) correction, MWR-based correction and the Composite correction currently used in AVISO products. The comparison calls for a harmonization of the corrections available through COASTALT and PISTACH (and all altimeter missions in general). However the improvements of the new corrections with respect to the composite one are apparent. All of the radiometer-based corrections are still better than using the ECMWF/ERA model. A GPD type of approach is now being developed for CryoSat-2, which has no onboard radiometer.
15 posters in the poster session dealt with several aspects of coastal altimetry, from the generation of new improved coastal and regional products and their validation against tide gauges to a range of applications including coastal currents and upwelling, coastally trapped waves, storm surges (and other extreme events), seasonal cycle monitoring, inland waters. Some dealt with retracking issues and waveform analysis to detect specific coastal targets, or on the synergy with other in situ measurements (such as GPS) and models.

2.7. Oceanography - Mean Sea Level Trends

Co-chairs: Steve Nerem & Anny Cazenave

This session gave an overview of our current understanding of sea level change based on the satellite altimeter record, the satellite gravity record, the tide gauge record and other in situ measurements and ocean models. The rate of sea level rise was 50% higher during the 1990s compared to the 2000s, which has been widely attributed to ENSO (El Niño–Southern Oscillation) variability, but a broader interpretation of this result is lacking. One important fact we have learned from these observations is that the 20-year altimeter record occurs during a remarkably unusual time in the 100+ year sea level record. As a result, we must ask ourselves how this affects our interpretation of the altimeter record – are the changes we are observing short term or long term? Sorting out the natural and anthropogenic climate signals is a continuing challenge as we move into the future and look for answers to the many questions that remain. Today is also an appropriate time to pause and ask if we have the measurements we need to answer these questions, or if new measurements are needed? Several new satellite measurement systems are planned – how will they enhance our understanding of sea level change?
The session presentations covered sea level reconstructions techniques at global and regional scales, and analyses of the causes of the observed sea level rise. One approach uses statistical EOF analyses to combine long tide gauge records of limited spatial coverage and 2-D sea level patterns based on the shorter altimetry dataset or on ocean model runs. A number of different reconstruction techniques are compared including the ensemble mean reconstructed time series. These techniques allow us to estimate sea level variability over the 1950-2010 period, globally and regionally, and highlight how the dominant modes of variability evolve over time. EOF reconstruction techniques can also be used to create indices computed solely from sea level measurements for monitoring signals such as the eastern-Pacific ENSO, central-Pacific ENSO and the Pacific Decadal Oscillation. It was shown that significant improvement can also be made in the first half of the 20th century by including sea surface temperature measurements in the reconstruction.
Some of the causes of the MSL rise have also been clarified: that thermal expansion simulated by AOGCMs has been underestimated owing to omission of volcanic forcing in their control states; the rate of glacier mass loss was fairly constant throughout the century, probably because of the compensating effects of the warming climate and the loss of ablation area; and that the Greenland ice sheet could have made a positive contribution throughout the entire century due to ice discharge.

2.8. The Marine Geodesy, Geoid, Bathymetry and Mean Sea Surface session

Co-chairs: Marie-Hélène Rio and Walter Smith

Marine geodesy has greatly beneficiated over the last 20 years of the advanced in altimetry. Furthermore, the Geoid, the Mean Sea Surface and the Mean Dynamic Topography are three key reference surfaces for altimetry. A dedicated session was organized in the framework of the 20 years of altimetry symposium for scientists to present the state of the art in computing these important reference surfaces. A number of important improvements and exciting perspectives have emerged from this session.

Marine Geodesy

Marine geodesy at high wavenumber requires altimetry. Gravimetry at satellite altitude (CHAMP, GRACE, GOCE) has a spatial resolution limited to the order of orbital altitude, whereas altimeters measure sea level and hence the gravity field at sea level directly. Over the last 20 years there has been much effort to understand and improve the signal-to-noise ratio in altimeter measurements, and to find the best blend between altimetric gravity and space gravimetry mission data.

A launch failure at Arianespace in 1994 allowed the ERS-1 geodetic phase F to continue to completion, and this may have prompted the U.S. Navy to release all the Geosat geodetic mission data in 1995. These data sets were the backbone of marine geodesy until the launch of Cryosat2 in 2010, the move of EnviSat to a new orbit, and now in May 2012 the move of Jason-1 to a geodetic orbit.

With these new sources of data the accuracy of marine gravity fields is now approaching 2 mGal and may reach 1 mGal if the Jason-1 geodetic orbit can continue to completion. This is expected to reveal many previously unknown seamounts and other features. The MSS and Geoid models should consequently improve as well.

Mean Sea Surface (MSS)/Geoid

The strong improvement of the Mean Sea Surface over the past 20 years has been shown. RMS of MSS minus altimeter Mean Profiles has dropped from 1.33 cm (1998) to 0.80 cm (2011). This 30% improvement is due to the longer altimeter data time series and improved altimeter corrections. The main large scale difference between the most recent MSS models (DTU10 and CNES-CLS11) is due to the different time period covered (1993-1999 versus 1993-2010). Once this is removed, the main error source is due to residual ocean variability and Sea Ice coverage issues at high latitudes.

Significant improvements are expected with the inclusion of new missions in the MSS computation (CRYOSAT-2, Sentinel-3, Jason-CS, HY2A) or retracked data (ERS-1 GM (SSH>1 Hz)

In the Arctic ocean, a region of growing interest where, due to ice coverage, and altimeter satellite orbit inclination, altimeter data are scarce, and more noisy, significant impact of laser altimetry (IceSat) has been shown for the retrieval of the ocean MSS. However this implies interpolation of the altimeter SSH between ocean leads. The short IceSat mission time period is also an issue since temporal variability needs to be corrected. An Arctic MDT has been derived. Using a satellite-only GOCE based geoid reduces the error compared to the use of the EGM08 combined geoid. Also a new geoid over Arctic including in-situ gravity data to improve the GOCE geoid based resolution has been computed and is available.

Mean Dynamic Topography (MDT)

GOCE geoid brings significant improvements over GRACE for MDT computation at 100km scale. However, geoid error at that resolution is about 5 cm, still above the mission objectives.

The estimate of MDT error is a crucial issue (for assimilation of altimeter data into models for instance). Heuristic approaches are interesting and needed since the formal errors on geoid and MSS may be in some cases underestimated.

Since oceanographers are mainly interested in sea slope (geostrophic currents) rather than sea height, it could be worth investing the direct use of the geoid gradients from GOCE rather than geoid heights in order to avoid the issue of the higher – and for the moment unresolved-noise level in the GOCE Z-Z gradiometer data.

To get rid of the errors inherent to the use of mean reference surface (MSS, MDT) for oceanographic application, an along-track approach may be used (computing SSH-Geoid) along track. This is an interesting approach for the Arctic Ocean where the MSS and therefore the MDT suffer from a lot of uncertainties. Preliminary results have been shown for the global ocean, that still need to be validated.

2.9. Oceanography - Integrated Systems

Co-Chairs: P-Y. Le Traon, J. Lillibridge, Dean Roemmich, Gilles Larnicol, Eric Dombrowsky and Pierre De Mey

The overall conclusion of the session is that there are many interdisciplinary areas of study that can benefit from the inclusion of altimetry in an integrated approach, and we have only begun to see the potential benefits and future possibilities from this work. In addition, for operational purposes, the along track altimeter data observing system is the keystone observing system on which services rely on, and that the availability and sustainability of a virtual altimeter constellation are crucial matters in this context. The poster session for the entire "Integrated Systems" theme contained 31 presentations, illustrating the large interest the altimetry community shares in operational oceanography.

This first session on oceanographic integrated systems, applications, forecasts and assimilation was comprised of a very diverse set of 7 oral presentations. The subject matter spanned physical, biological, and geochemical aspects of oceanography, from sub-mesoscale to global scale monitoring. The important role of traditional pulse-limited altimetry, as well as prospects for the new Delay-Doppler/SAR altimeters, was illustrated through a variety of applications. The theme of an integrated ocean observing system, including altimetry in conjunction with other satellite measurements such as scatterormeter winds, plus in situ measurements such as Argo and model assimilation, was very evident over the course of the session. The synergy of different satellite measurements was illustrated by new findings on eddy dynamics, and the coupling of physics and biology via the joint analysis of altimeter and ocean colour data. One new practical application to highlight was the modeling of tuna fisheries management using a combined bio-physical model plus predator-prey and pelagic fish behavior parameterization. Another was the use of Lyapanov coefficients as a new technique to better predict frontal advection in sub-mesoscale features in support of in situ campaigns.

The second session continued on the evaluation of large-scale ocean changes using synergistic observations and models, including re-analysis products. The changes to upper ocean heat content due to the correction to the XBT bias were presented with a discussion on the impact for the global energy balance. The extent to which ocean models, which include re-analysis or data syntheses, are accurate enough to monitor sea level trends was also discussed, with both global and regional analyses. The scientific value of reanalysis products was also illustrated in a wide range of areas such as climate, mesoscale processes, mixed layer processes, sea ice, etc. Finally, the role of the intrinsic, chaotic ocean variability versus the forced variability was also addressed. Modelling studies show that intrinsic variances, which are negligible in climate ocean models, may exceed their atmospherically-forced counterparts in eddying regions and leave a large imprint on several climate-relevant variables, including regional sea level.

The third session covered global data assimilation systems, starting with an overview of GODAE OceanView, the international program put together in 2009 after the end of the Global Ocean Data Assimilation Experiment (GODAE). This program, working on a 5-year cycle, gathers some of the scientific forces of the 11 participating countries, to address scientific questions about ocean modeling and data assimilation in an operational context. It addresses also new fields of operational oceanography (e.g.: coastal, marine ecosystem and high resolution coupling with the atmosphere) through the work of task teams. One of his conclusions is that altimeter observations are the major observational input to their services and finds benefit from that use. Another presentation addressed the impact of altimeter data on the accuracy of the forecast of the ocean state, with a focus on results obtained using the BLUElink system which has 1/10° horizontal resolution around Australia. Using OSSEs, it was shown that the quality of the ocean fields estimated depends strongly on the number of altimeter used, especially when one wants to resolve mesoscale features. There is almost no skill for the mesoscale when no altimeter data are assimilated, even if SST and In situ T/S profiles are assimilated, and a large improvement was obtained when using up to 3 altimeters simultaneously.

The UK Met Office has decided to implement a 3D-VAR assimilation scheme in their global ocean forecasting system. The current implementation of their 3D-VAR scheme provides state-of-the-art products whose quality is similar to the one of their production-mode implementation, which indicates that they are almost successful with respect to their goal of replacing the assimilation kernel without degrading the results. Mercator Océan has also made recent upgrades to their operational systems. They have worked on new releases of the systems which show large improvements of the quality of the products when comparing to observations, despite some problems they encountered at some interim stages with unrealistic slow drift which are now resolved (new release planned for spring 2013).

A final presentation was made on the MyOcean project, which is conducted in the context of the Global Monitoring for Environment and Security (GMES) European marine initiative. MyOcean delivers ocean products derived from observation processing systems (the Thematic Assembly Centers, TACs) and forecasting systems based on assimilative models (the Monitoring and Forecasting Centers, MFCs). The services cover the global ocean with enhanced capacity on the European seas. The plans for the near future (e.g. after the end of the MyOcean 2 project, April 2014) are to implement a fully operational service for the marine sector, with the aim to deliver core services based on free and open access to ocean analysis and forecast and reanalysis products in the GMES context, and to have these services sustained on the long term.

2.10. Hydrology and Land Processes

Co-chairs: Frédérique Seyler, Stephane Calmant, Doug Alsdorf, Paul Bates, Peter Bauer-Gottwein and Jean-François Crétaux

Even though the achievements are more recent than in Oceanography, major efforts have been spent on exploiting radar altimetry to monitor surface water storage and runoff through the unification with modeling and in-situ data. This is reflected by the 55 presentations shown in the Hydrology and Land

Processes session, 19 of which found a time slot for an oral delivery.
The major difficulty in bringing Altimetry to inland water is the development of techniques to analyse the waveform content and extract the water level out of the spurious power returned by surrounding reflective target. A new generation of retrackers have been developed in the past five years such as adaptive retracking, taking into account statistical inhomogeneity of the reflecting surface adjusted to the geographic area. Another reported approach is to use an a priori estimate of surface height to then focus on the appropriate peak from multi-peak waveforms, but it seems from the comparison shown that no decisive improvement is made by this method for the difficult cases, and there is definitively a need for further research in this area.
Concerning applications, several topics were addressed from frozen lakes and their snow cover, to surface water level, flood monitoring, discharge and assimilation into models. To discriminate between thick/thin ice/snow cover and seasonality of snow cover both active and passive microwave data are used. Altimetry over frozen lakes can give reasonable estimates of water surface elevation, but not in all circumstances. In addition, it was shown how the use of GRACE data can complement the estimations from altimetry in these difficult conditions and confirm the evidence of lake level changes. Many reports focused on the error estimate, which is essential information for further use of the data such as for assimilating into catchment models. For assimilation into models, the obvious best approach is to use all the altimetric data available in a multi-satellite context to produce maps of surface water level. A data assimilation scheme for the Amazon and the Zambezi using the EnKF demonstrated significant improvements of the models' predictive capability; the key issues remain the quantification of model errors and the effect of large reservoirs.
Reservoir storage is an important parameter both for water management and climate studies. The addition of an optical or radar imager provides the measurement of the reservoir area and volume variation are produced when combined with altimetric level data.
Inundation estimates from gravity and optical satellites, combined with altimetry products are becoming sufficiently mature to consider their use in near real time flood forecasting systems. Proof of concept studies have been conducted for several rivers world wide, predominately in arid areas. An approach to produce high-resolution flood extent maps was shown, that led to a discussion focused on the utility of this dataset to inform the planning process for SWOT.
Discharge is a key parameter to derive from altimetry. A successful approach to produce pseudo-rating curves for the Amazon system was reported. Discharge is the main objective of SWOT, at much finer scales than accessible today with classical altimetry. Meanwhile there are some great expectations from SAR altimetry over rivers and small lakes but the topic is too recent to provide mature results at this time. Nevertheless some early attempts were reported, showing the promising capabilities of the new generation of altimeters, which will fly on future missions (Sentinel-3, Jason-CS).
Radar Altimetry has also proven its ability to supply accurate data, after careful retracking adapted to land targets, for global digital elevation models. The "Altimetry Corrected Elevations", version 2, GDEM was presented and compared to other global DEMs. Radar Altimetry is used to further correct existing GDEMS with known anomalies or artefacts or void areas. ACE2 is built using the best available data, e.g. from SRTM, proposing a warping of these data to exploit the high resolution of the interferometer and enhance the vertical accuracy of the altimeter. A by-product between ACE2 and STRM is the height of the trees, particularly in the tropical regions (the nadir-looking altimeter measures the ground level).
The attempt to derive soil moisture from radar altimetry was also reported. The results are good but only on the rather arid regions. The estimates were compared to SAR, Scatterometer and SMOS soil moisture products in view of assessing the consistency and their complementarity.
All presentations highlighted the usefulness of radar altimetry data for hydrological applications for a range of case studies with a wide geographical scope. A focus area of this session and a high potential area for future research is the merging of models and radar altimetry in data assimilation approaches. All papers used radar altimetry data from virtual stations based on repeat-orbit missions. Long-term continuation of virtual station time series is thus a priority for the hydrological user community. On the other hand some effort will have to be spent on exploiting data from long repeat mission such as CryoSat and missions launched on a new ground track such as Sentinel-3.

2.11. Cryosphere

Co-chairs: Katharine Giles, Ron Kwok, Frédérique Remy and Andrew Shepherd

The Cryosphere is a key player in global climate and radar altimetry is a major supplier of data over these hostile regions. Both ice sheet mass balance and sea-ice thickness were in the limelight at the Cryosphere session. The session opened with a review of the new vision of the Cryosphere thanks to 20 years of altimetry. The features observed are showcased with the Pine Island Glacier that has been monitored for two decades in term of acceleration, thinning and grounding line retreat. Limitations of the data were discussed focusing on the temporally variable penetration into the snow pack and the difference in backscatter coefficient between ascending and descending tracks at cross-overs. This is not fully understood but there are different methods proposed for correcting for this. The comparision with a Laser Altimeter (IceSat) may shed light as the radar and laser measure different reflectors but both try to resolve the same quantity dh/dt. Agreement between IceSat and ERS are good but agreement between IceSat and Envisat poor. Remains the need to understand the reasons for this disagreement. The Envisat data compared with IceSat was not included in the Ice Sheet Mass Balance Inter-Comparison Exercise (IMBIE), whose aims to reconcile the differences between 1) Altimetry 2) Gravimetric methods and 3) in-put/out-put (interferometry) methods to estimate volume loss from the ice sheets. The differences between the methods lead to a range of estimates of the contribution to sea level rise between -2 mm/yr to +1.9 mm/yr, based on several tens of papers in the literature. Improvement to the intercomparisons included using consistent spatial and temporal domains across all studies and earlier PGR models were rejected in favour of newer ones, which resulted in changing the estimates of mass change from the gravity data. The result is a better agreement of the different techniques. Remaining open issues include the radar penetration, the altimeter antenna polarisation and the proper use of the backscatter coefficient. A dedicated experiment should be designed to solve this problem. Keith Raney suggested always using circular polarization to avoid this problem. It was also recommended that both radar and laser altimetry should be operating at the same time to help address these uncertainties.

Sea-ice thickness and ice volume from CryoSat-2 were reported as the lowest level ever recorded, much beyond what all models had predicted. A peak low occurred in 2012 after the recent 2007 record. This time ice thickness has dropped drastically as well, not just ice extent. The accuracy of the Cryosat data was confirmed by the in-situ data (low frequency electro-magnetic readings and ice draft moorings). PIOMAS seasonal volume also correlates very well with Cryosat-2 data. Extensive work was also done with Envisat to classify sea ice and ice sheet snow facies. The detection of sea-ice corrupted sea surface height data within quality control processing is important for oceanography applications, but also provides the sea-ice type for cryosphere studies. Knowledge of the partition between first year ice and multi year ice zones provides another view of the on-going transformation of the Arctic's ice cover. A method was developed using both altimeter frequencies and passive microwave data on the same platform, exhibiting good performances for sea-ice contaminated data detection for oceanographic applications and good potential of altimetry for use within a sea-ice monitoring system to supply sea-ice extent. With very long time series, a climate signal can be extracted, which means exploiting SARALAltiKa and Sentinel-3 data to pursue the time series.

Icebergs were also scrutinised with a 20-year database of Small Icebergs. The interest for icebergs and their possible impact on southern ocean circulation and biology has increased during the recent years. While large icebergs (>6km) are tracked routinely and monitored using scatterometer data, smaller icebergs (less than a few km) are still largely unknown as they are difficult to detect operationally using conventional satellite data. Icebergs may account for a significant part of the freshwater flux in the southern ocean and they have been shown to transport nutriments (in particular labile iron) that could have a significant impact on ocean primary productivity. They are also a great source of concern for ocean-goers. A target emerging from the sea such as an iceberg, a ship or a lighthouse is detectable in the noise part of the altimeter waveforms, and aligns as a parabola in a series of waveforms. Probability, size and ice volume maps are drawn monthly.

Editors' note: At the time of editing these reports, a special thought goes to the memory of Seymour Laxon and Katharine Giles, to their families and to their colleagues at CPOM. Their contribution to Science and their participation at the 20 Years of Progress in Radar Altimetry Symposium will never be forgotten.

2.12. Outreach

Co-chairs: Vinca Rosmorduc & Margaret Srinivasan

Twenty years of availability of ocean altimeter and complementary data sets has provided a rich environment for the development of a broad-spectrum of educational and public outreach opportunities, activities and products. It has also allowed for a multitude of operational uses of the data sets, supporting many direct and indirect benefits to society, and reinforcing the value of the resources that are in place to keep these important missions operating.

The focus of the Outreach session in the 20 Years of Progress in Radar Altimetry symposium was primarily on accessibility of the datasets by operational users and user access to data products and services. Another important focus of the session was outreach to general audiences in order to educate and inform about these important missions. Our Outreach efforts center on ocean literacy, on understanding the influence of the ocean on climate change, and the responsible stewardship of this vital natural resource.

Speakers in the Outreach session included both scientists and outreach professionals. The session was enriched with the presentation of a review of "Altimetry" on the web and a 20-year review of the approach to communication and collaboration towards Education, Outreach, and Societal Benefits of Ocean Altimetry Missions. Specialised web sites were displayed focusing on currents and sea level, e.g., the

Australian 'OceanCurrent' Website, an Outreach activity of the Integrated Marine Observing System, and a sea level education program from Colorado. Services were also in the limelight with a ten-year review on downstream oceanographic services based on altimetry but also other relevant EO data. The session was introduced recalling the Basic Radar Altimetry Toolbox developed by ESA and CNES to support all levels of users, from teachers and scholars to students and all newcomers to radar altimetry as well as the GOCE User Toolbox for merging Gravity data and Altimetry. There were ten posters of wide interest to be discovered in these proceedings, including a novel topic on the synergy of multimedia contents, interactive features and social network tools.

The highlight in terms of outreach and education was the report in the closing plenary session by French scholars on Argonautica, an educational project using Jason data, involving two high schools. Beyond their excellent oral report in a foreign language in front of 500+ people, their feedback underlined the recognition of the immense opportunity to mix-in and discuss with engineers and scientists, and the motivation it generated.

Outreach efforts during these 20 years has facilitated the relevance of ocean altimetry protocols, techniques and data to the attention of many potential users, including end-users, as well as to the general public and students. These efforts should be continued in the future and strengthened, in particular developing a closer collaboration with all involved agencies and institutions would serve to better promote the science and societal benefits of the missions.

We applaud 20 years of successful cooperation and collaborations beginning with the launch of TOPEX/ Poseidon, and continuing through the extended Jason-series missions. Among partnering organizations, NASA, CNES, NOAA, and Eumetsat, as well as by ESA, we look forward to continued successful endeavors and collaborative efforts with new spacecrafts in the coming decade, to continue the wide variety of outreach and educational activities focusing on ocean literacy, stewardship, science, and the societally beneficial applications that are possible with these important altimetry missions.

Recommendations

There is a heightened interest by the general public concerning climate issues. We feel that more effort can be made in making altimetry more visible in this framework. Some successes were demonstrated by ESA with a press release about the Venice Symposium and the release of a new global and regional mean sea level Essential Climate Variable product.

We feel that the altimetry community members can make a significant difference in their local communities by organizing training sessions and/or classes and presentations. The mission outreach teams are willing and available to facilitate these interactions. The development of international collaborations between students is another area that we continue to work on developing via shared resources and communications. The 2013 '7th Continent Expedition' is an excellent example of this, where students in France and in San Diego will track and study this French expedition to the great Pacific Ocean plastic island.

2.13. The Future of Altimetry

Co-chairs: Sophie Coutin-Faye, Peter Wilczynski, Jean-Louis Fellous and Albert Fischer

The Future of Altimetry session gave an outlook of the newly launched and planned missions which include HY-2, SARAL/AltiKa, Jason-3, Sentinel-3, Jason-CS' heritage of CryoSat-2, and SWOT. SWOT is altogether a different approach to altimetry offering very high-resolution 2D maps. On Jason-CS, the new capability of simultaneous measurements in the low resolution mode and in the SAR mode, called interleaved mode, will be a further revolution in altimeter technology beyond the SAR technique used on CryoSat and Sentinel-3 and was highly acclaimed by the community for maintaining the record of sea level essential climate variable at it its highest accuracy. The Future of Altimetry session continued in the shape of two Plenary Round-Table Discussions on future observational requirements and on current and future altimetry missions. It was the opportunity to look ahead and gather the altimetry community's recommendations. These are summarised in the "Radar Altimetry Manifesto", in section 2.

3. ACKNOWLEDGEMENTS

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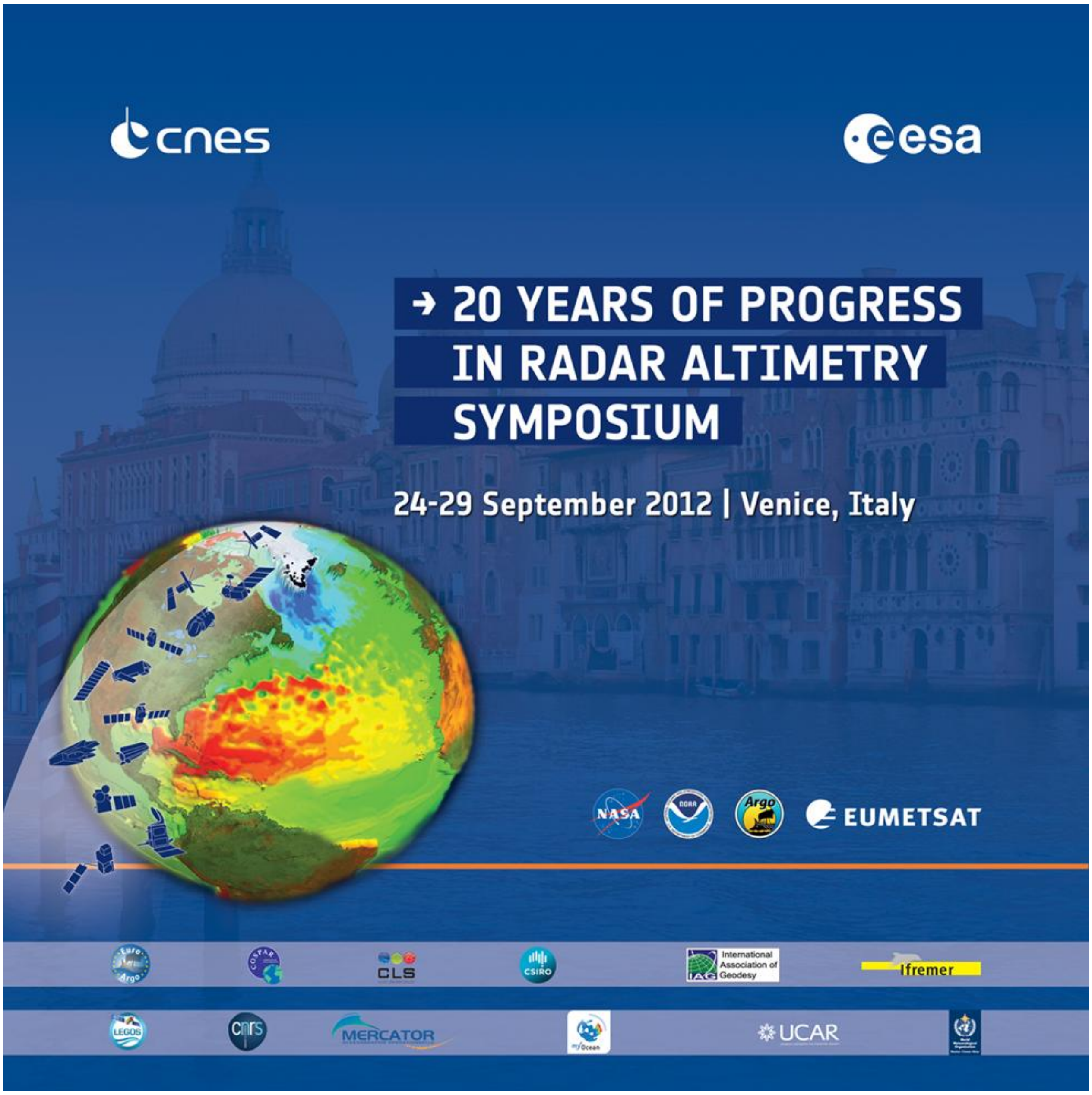
Figure 2. The audience in Sala Perla during the opening plenary session of the 20 Years of Progress in Radar Altimetry Symposium.



The Co-Chairs of the Symposium, on behalf of all the participants, would like to extend their grateful thanks to the sponsors of the Symposium whose contributions, alongside the effort from ESA and CNES, made this event possible.

The Symposium abstract book can be downloaded from http://www.altimetry2012.org.

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