Report of the

Second SARAL/AltiKa Science Workshop

Organised by ISRO and CNES

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In a few words…

The 2nd SARAL/AltiKa Science Workshop was held in Ahmedabad (India), on March 15-17, 2011.

The primary objectives of the meeting were to:

- gather the Principal Investigators / Co-Investigators community selected in Spring 2010 together with the CNES and ISRO Project Teams
- review the progress of science research and especially new insights expected from AltiKa (first Ka-band altimeter) particularities
- consolidate and disseminate the CALVAL Plan

The meeting was hosted by ISRO/SAC (Indian Space Research Organization / Space Applications Center) in its Bopal Campus premises (here). The 1st Workshop was held at the same place on April 22-23, 2009.

The meeting was open to the Principal Investigators / Co-Investigators community and gathered about 70 participants: 39 from India (+ participation of ISRO/SAC employees), 23 from France, 2 from USA, 2 from Greece, 1 from Australia and 1 from Portugal, whereas only Indian and French delegates participated to the previous meeting (full list at the end of this document).

A dedicated web page has been created on the Aviso web site to manage the venue of the participants and to publish the presentations of the meeting: http://www.aviso.oceanobs.com/es/courses/sci-teams/altika-science-team/2011-altika-science-workshop/index.html

Note that ISRO has taken over the distribution to all participants of a set of materials including on a CD-ROM, the latest version of the **Science Plan** and **CALVAL Plan documents** as well as a draft version of the **AltiKa Product Handbook**.

Note also that the **3rd Joint Science Working Group** was held in parallel on Wednesday 16 March 2011 morning.

Dr J.S. Parihar, Deputy Director, SAC, welcomed the participants, outlining the enlargement of the audience to international delegates.

In their opening remarks, **Dr R.R. Navalgund**, Director SAC, **Mr A.S. Kiran Kumar**, Associate Director SAC (Ahmedabad, India) and **Dr J. Verron**, (LEGI, France) Science PI SARAL/AltiKa, recalled the main progress on the SARAL/AltiKa Project since the first meeting held two years ago, and in particular the joint ISRO / CNES selection process of Principal and Co-Investigators conducted in spring 2010. The need for a quick launch of the SARAL/AltiKa mission, especially to take over the aging ENVISAT satellite, was also pointed out, Dr J. Verron recalling the following recommendation from the 2010 OSTST: "*The OSTST recognizes that the SARAL/Altika mission will be an essential component of the altimetry constellation from 2011 onwards, re-occupying the long-term ERS and ENVISAT ground track. SARAL/Altika will also provide the first demonstration of Ka-band altimeter capabilities for fine resolution along-track applications, including for coastal and inland water applications, which will be further developed for the future SWOT mission. The OSTST recommends that all efforts be made to launch SARAL/AltiKa as soon as possible in 2011.*"

After an overview of the SARAL/AltiKa Project, the meeting was organized around 7 oral sessions and 1 poster session, covering all the measurement capabilities of the sensor and the induced applications:

- General presentations
- Instrument Performances
- CAL/VAL
- Climate and Mesoscale Variability
- Coastal Altimetry and Sea Surface Bias
- Data Assimilation and Operational Oceanography
- Ice and Inland Waters

The presentations can be found on the AltiKa web page on Aviso and short summaries of the presentations are given in the paragraphs below

Before the concluding session, **V. Rosmorduc** (CLS) made an extensive presentation of the BRAT (Basic Radar Altimetry Toolbox) software, especially useful for newcomers to altimetry, with a wide range of application examples over ocean, ice and inland water surfaces.

The **concluding session** was leaded by **Dr J. Verron**, Science PI SARAL/AltiKa, who thanked ISRO and the organization for this excellent venue and atmosphere. He underlined the high scientific level of talks, and noticed that the various science objectives of SARAL/AltiKa were covered by the presentations. He also pointed out a lot of shared interests between Indian and non-Indian scientists, together with an impressive extent of the Indian activities, based on a clearly growing expertise. He also stressed that more coherency is seen within the project that is clearly moving forward (publication of CalVal and Science Plan documents, Data Handbook). Such a meeting also represents a great opportunity to know each other, and to share expertise on data. Some issues are also evoked: request for simulated data, exploitation of the specificities of the SARAL/AltiKa instrument (better performance over coastal areas, hydro and ice) with dedicated products (like PISTACH). He also suggested to improve interactions the PIs and Co-Is community and the national and international visibility: sharing of publications, training via a Summer School in 2013. He finally summarized the recommendations from the scientists, saying they are waiting for SARAL/AltiKa data but also that they are confident the mission will be a success.

The most recently updated tentative date for the launch of the SARAL/AltiKa mission is April 2012 on PSLV#20 rocket.

The third SARAL/AltiKa Science Workshop is expected to be held a few month after the launch (end of 2012 ?), with a important focus on CAL/VAL issues.

Summaries of the presentations

Project Overview

The first presentation of the meeting has been given by **P. Sengenes** (CNES, Toulouse, France), SARAL/AltiKa Project Manager at CNES. After an overview of the SARAL Program, the AltiKa and ARGOS-3 missions, the SARAL system and the accommodation of the payloads on the plateform, they presented the CNES Progress Status of the Payload Integrated Module (PIM), with illustrations of the PIM during the recent various successful tests. CNES/THALES Qualification Review is planned to be held on April/May '11 and the PIM is expected to be ready for shipping to India at the end of 2nd Quarter of 2011.

J. Noubel (CNES, Toulouse, France) then presented the main components of the SARAL Ground Segment. Notably, the final versions of processing chains are ready for installation in EUMETSAT and ISRO/SAC and ISRO/NRSC facilities for the Long Term Routine tests and System Operational Qualification. Completion of Ground Segment Overall Validation (GSOV) & Mission System tests is a forthcoming activity. Science data policy as well as users services contacts were also detailed.

Finally, a general outreach movie on SARAL was presented.

D.V.A. Raghavamurthy (ISRO) also gave an overview of the SARAL Project for ISRO side, detailing the respective contributions of the Indian en French space agencies, as well as the accommodation of the satellite in the PSLV envelop.

Session I: General Presentations

J. Lambin (CNES, Toulouse, France) presented the CNES involvement in Ocean Sciences which are one of the major interests of CNES Earth observation programs, supporting (and supported by) a strong scientific community through dedicated research funding. CNES is also supporting several larger scope projects and initiatives (e.g. Mercator-Ocean, Boussole, Senetosa calibration sites, bio-Argo …) and also brings strong support to R&D (Instrument, mission concepts, data processing…). In terms of satellites missions, the heavy weight is on physical ocean observation with altimetry missions (Jason-1/2/3/CS, SARAL/AltiKa, SWOT, Sentinel-3, Hy-2A) but also wind/waves (CFOSAT), salinity (SMOS), ocean color (PARASOL, S3, OCAPI). In that context, AltiKa/SARAL mission is strongly awaited by all !

RajKumar (ISRO/SAC, Ahmedabad, India) presented the mission of ISRO Ocean Programme: generation of high quality satellite observations (ocean color with SSC-OCM, LISS; surface winds with OSCAT; SST with MSMR, VHRR; sea ice with MSMR, OSCAT; sea sevel, waves and geoid with altimeter; waves, winds and oil spill with SAR) and its effective utilisation for the benefit of society and scientific community in terms of physical, biological and geological oceanography for coastal and open oceans. Various examples of applications were shown and recent developments in ocean modeling and forecasts were pointed out.

V. Rosmorduc (CLS, Toulouse, France) presented the Outreach ("reaching out of the project team") activities of the AVISO project (http://www.aviso.oceanobs.com). The objective is to be the focal point of the altimetry community and the mission is to disseminate data, products, information and tools adapted to users of altimetry, for educational to expert research purposes. An overview of the content of the AVISO web pages and data base was illustrated with several examples.

Session II: Instrument Performances

N. Steunou (CNES, Toulouse, France) first described the AltiKa instrument composed of a single frequency Ka-band altimeter with an enhanced bandwidth and a dual-frequency radiometer (23.8 GHz +/- 200 MHz & 37 GHz +/- 500 MHz). With respect to existing conventional altimeter, the AltiKa altimeter will undergo reduced ionosphere effects, have a better vertical resolution, an improved spatial resolution but will be more sensitive to atmospheric water content. Concerning pre-flight altimeter performances, recent tests at instrument and PIM levels with the almost completed flight model have shown that system requirements on geophysical parameters are met with margin with a very stable behaviour. Look up tables (from simulations) have been generated from tests results.

After an overview of the AltiKa Radiometer parameters design**, R. Rodriguez Suquet** (CNES, Toulouse, France) presented the radiometer architecture and internal calibration system. As for the altimeter, results of the radiometer performances tests (in terms of sensitivity and absolute accuracy) at instrument level were presented together with performance tests in AIT (Assembly, Integration, Test). All radiometer instrument performances have been reached. These results prove a very good instrument stability on the overall tests. After instrument calibration, the updated radiometric model has been implemented in ground processing segment to retrieve the Brightness Temperature. The AIT test results contribute successfully to the validation of the Payload Instrument Module (PIM). Further AIT tests are being performed to achieve a complete validation.

E. Obligis (CLS, Toulouse, France) presented the AltiKa/MWR End-to-End Simulator developed to support ground processing, error budget and in-flight activities. This simulator comprises 1) a scene generator that uses ECMWF analysis and other geophysical parameters as input together with a radiative transfer model 2) an antenna simulator that performs the convolution of TB map by the antenna pattern (with spill over contamination) 3) a receiver that computes the temperatures of the thermistor, convert them and finally writes the telemetry file 4) a ground processing prototype that processes L1.0, L1.B and L2 products. The processor is currently used to assess the pre-flight performances. It will be used during the commissioning phase to survey the main instrumental parameters (stability of the physical temperatures, gain...) and to test the in-flight calibration of the radiometer. It could be used during the mission lifetime to support investigation in case of problems (impact) and to support the definition and implementation of any new algorithm to improve the final product.

Session III: CAL/VAL

F. Mercier (CNES/CLS, Toulouse, France) presented a status and overview of SARAL/AltiKa Joint CALVAL Plan which objectives are the validation of the data quality and the certification of the actual performance of SARAL/AltiKa data with respect to the error budget specifications and goals, with particular attention given over coastal and inland water areas, over polar oceans and ice surfaces, as well as under rainy/cloudy conditions. Intensive verification and calibration during the Verification Phase (9-10 months since beginning of cycle 1) and routine CALVAL activities later on will be conducted by the 2 partners CNES & ISRO project teams and the selected international SARAL/AltiKa Science Team PIs (64 members) and Co-Is. The presentation mainly presents the CALVAL Plan document disseminated to the participants on a CD-ROM.

After the presentation of the Indian organizations participating to the SARAL/AltiKa CALVAL activities, **A.K. Shukla** (ISRO/SAC, Ahmedabad, India) presented the in situ and other geophysical datasets required to perform the calibration of the payload and the validation of the products. A particular focus is given to the calibration of altimeter using tide gauge network, with illustration of the tide gauge locations in Indian coastal region and a selection of potential calibration sites along Indian coastline and also over some reservoirs/lakes. Bangaram site is envisaged as an absolute calibration site, while Kavaratti site, already well equipped for OCEANSAT-II calibration could be useful for validation of the radiometer. These CALVAL activities are also seen as opportunities for international collaboration.

P. Bonnefond (OCA, Grasse, France) presented a review of the CALVAL activities in Corsica at Senetosa (mainly for T/P, J1 and J2) calibration site (established in 1998), which survey area has been recently enlarged to Ajaccio (for EnviSat) area (equipped with tide gage, GPS buoy, IGS GPS receiver, Doris, FTLRS). Calibration results for Envisat from tide gages and GPS buoys were shown, with a particular focus on the wet tropo correction with comparison between MWR, model and GPS-derived wet tropo delays. Absolute biases of the altimeters are computed and they allow deriving relative bias that should be compatible with global analysis. Radiometer monitoring using GPS appears very performing to monitor bias and drift.

P. Mehra (NIO, Goa, India) presented the NIO's network of real-time sea-level reporting and surface meteolorogical systems made of 7 stations along the west coasts of India, and 5 on the east coasts (including islands). These sites are equipped with pressure and/or radar sea-level gages and the monitoring and analysis of the differences between these 2 systems was illustrated for Verem (Goa) and Mandpam (Tamilnadu) sites. Finally, comparison of NIO radar gauge at Karwar and Kavaratti with Jason SLA data along track 181 are presented in terms of daily-mean sea level and residuals (before and after 10-day running average) with standard deviation between gages and Jason SLA measurements ranging from 5 to 10 cm.

S. Mertikas (GGEL, TUC, Crete, Greece) presented the greek absolute satellite calibration activities at Gavdos, small island south of Crete, located on the crossover of 2 Jason tracks and below track 571 of Envisat (and AltiKa), starting by illustrations of in situ facilities (GPS and Doris antenna, tide gages, transponder, meteo station ..) on both Gavdos and Crete islands. The principle of operation is then explained with details on the geophysical correction models and description of track legs selected to avoid land contamination for the computation of the absolute bias for Jason-2. Specific field sea-surfaces campaigns activities during the Jason-1/ Jason-2 tandem phase are described (GPS buoys and in situ kinematic surveys below the tracks) as well as on-going work based on the use of a transponder for the altimeter calibration.

J.F. Crétaux (CNES/LEGOS, Toulouse, France) presented principles and advantages of lakes for absolute calibration of radar altimeters mainly based on the example of lake Issykkul (FOAM project): waves, EM bias, tides and Inverse barometer effects generally negligible; in situ facilities easy to install, useful for assessment of tracking/retracking algorithms. Wet and dry tropo delays are an important issue but dedicated computations using meteo models give discrepancies with in situ measurements within 1 cm. Estimations of the absolute and relative biases of Jason-1 and Jason-2 during the tandem phase are shown are compared with good agreement to results from other CALVAL studies over both ocean and inland water areas. Future work will deal with seiches effect and lakes tides, tropo corrections and should be extended to other lakes.

Suchandra A. Bhowmick (ISRO/SAC, Ahmedabad, India) presented the activities on the validation of SARAL/AltiKa geophysical products to be undertaken at ISRO/SAC. Methodology is based on the analyses of Envisat data to validate direct measurements (Range, SSH) as well as retrieved parameters (SWH, wind speed). Preparation of in situ tide gage (ex: Doodson filtering) and SSH satellite data are illustrated, together with their comparison. Intercomparison of Envisat and Jason-1 SLA are also shown. After removing of data out of range, SWH and wind speed data from Envisat are compared on a statistical basis with in situ buoy data (NDBC, TRITON RAMA and TAO), estimations from high resolution models (WAM, NCEP) and other satellite observations (Jason-1, Jason-2, EnviSat).

For **G. Jacobs** (US Navy/Stennis Space Center, MS, USA,), latency and accuracy of altimeter measurements are critical factors for synoptic ocean weather prediction, an application that requires the daily monitoring of altimeter performances and time evolving EM-bias corrections, since SSH is assimilated in an HYCOM model together with SST and in situ measurements. An overview of the so-called “post-GDR” processing is given (application of corrections, along-track interpolation, removing of GOT02 tide, quality/control check, orbit error correction), with illustration on Jason-1 interleaved data. A focus on the EM-bias correction is given since this reveals some sensor uncertainties. A time-varying EM-bias correction has been implemented that updates automatically daily. Testing with the TOPEX data shows the effect of drift in the significant wave height (SWH) and the change in GDR processing algorithms for EnviSat. A complete integration of SARAL/AltiKa into the system is planned and results will be provided to the community and updated daily during CALVAL and operational phases.

Y Faugère (CLS, Toulouse, France) presented the CNES/SALP plans for the global data quality assessment of the SARAL/AltiKa altimetric system (over oceans). These are based on the long-lasting expertise on Topex/Poseidon, Jason-1, Jason-2, ERS1&2, and Envisat altimeters are especially useful at the beginning of the altimeter mission to detect potential anomalies and correcting them as soon as possible. Three categories of validation diagnostics are described (global internal analyses, global multi-mission comparisons and global altimetry and in situ data comparisons) and the objectives of some diagnostics are illustrated based on in-flight altimeters monitoring examples: data availability, validity of measurements, physical content quality of product parameters, estimation of the system performances, better knowledge of the sea-level physical content, information for users and production centers. Dedicated diagnostics could take into account the specificities of SARAL/AltiKa, such as the Ka-band.

Session IV: Climate and mesoscale variability

TN Shyni (NPOL, Kochi, India) studied the seasonal and inter-annual variability of the Arabian Coastal Current (ACC) in the North-western Arabian Sea. The geostrophic currents are estimated using weekly maps of SSHA from Aviso while the wind stress is derived from QuickScat daily wind maps. A mean monthly climatology of geostrophic currents in the NW Arabian Sea was computed: a northward current (max speed 35-40 cm/s in june) is observed from March to August, together with clockwise eddies while a southward current (max speed 30-38 cm/s) is observed from October to February, together with anti-clockwise eddies. ACC exhibits inter-annual variability in terms of current strength, northward & southward turning and location and dimension of eddies. FFT analysis indicates annual, semi-annual,100 day, and 1200 day oscillations in SSHA field which contain sufficient energy.

In the first part of her talk, **A. Nunes** (Univ. Porto, Portugal) presented the AtlantiKa project that aims at the characterization of the eastern subtropical Atlantic, with emphasis on the Azores (AzC) and St. Helena currents (StHC) and their associated fronts using satellite altimetry, sea surface temperature and GOCE

data. These 2 currents have similarities (horizontal structure, intensity, meridional width, location, origin in the western boundary currents and interaction with north and south atlantic currents) but also differences (zonal extension, proximity of other currents) that SARAL/AltiKa data will help to investigate, notably via the computation of objectively analyzed SLA grids. In the second part, is presented a GNSS-derived Path Delay (GPD) method for computing an improved wet tropo correction in coastal zones. It is based on the objective analysis of GNSS-derived + NWM + valid MWR tropospheric fields and has been developed for existing altimeters. The formal error in coastal zone is estimated within 1-2 cm, although improvement of the methodology is expected. This method is applicable globally, and to any mission.

H.S. Chaudhari (IITM, Pune, India) presented an evaluation of coupled free runs of Coupled Forecast System (CFS) over India using reanalysis and altimeter data. After a description of the model used (NCEP CFS based on Atmospheric GFS and GFLD MOM-3), the mean state and ISO in CFS and observations is analysed: ISO Variance in the model is reasonably well simulated, however, its strength is almost double in the model. Implementation of altimeter data such as SSH and Ocean currents (OSCAR) and reanalysis data have played an mportant role in identifying model biases. Satellite dataset will enhance the current understanding of coupled processes and it will provide a pathways to improve the existing coupled climate model.

F. Durand (IRD/LEGOS, Toulouse, France) presented the AltiGlidEx project accepted within the AltiKa Pis selection process. After a description of the area of interest (south western Pacific, and more particularly the area between New-Caledonia and Vanuatu islands) that exhibits complex geophysical characteristics but also high climatic relevance, the objectives of the project were shown: to implement a synergy between AlitKa and 3 in situ observing systems (gliders, mooring and XBT/CTD sections) to monitor the whole spectrum of the boundary current. Results from these systems, detailed during the presentation, and already in action below Envisat/AltiKa ground tracks indicate a strong (~10Sv) and highly variable western boundary current. The delay before AltiKa launch together with the change in Envisat orbit strongly impact the planning of in situ campaigns.

D. Griffin's presentation (CSIRO, Hobart, Australia) deals with extreme ocean eddies off SE Australia during the 2010-2011 La Nina. The description of the main oceanographic characteristics of that part of the Tasman sea is followed the observation (in terms of geostrophic speed, SST and altimetric SLA) of a strong cyclonic warm-core eddy that reached its maximum on mid-January 2011. Similar observations some days before indicates that eddy has its origin in an odd situation with apparently very high coastal sea level but with no nearshore current anomaly. More generally this raises the issue of the management of extreme values: these are often errors but genuine extreme values are rare, and pose a challenge to automatic quality control. However a correct processing of these extreme values is essential for operational oceanography to become a reality.

R. Sharma (ISRO/SAC, Ahmedabad, India) presented her mesoscale studies in the Indian Ocean, starting with a comparative description of eddies in the Arabian Sea / Somali area (warm core, 400-500km, southwest monsoon season) and Bay of Bengal (50-200 km, slow propagation, present through out the year). The eddy detection algorithm based on the analysis of along-track SLA is presented together with detection results for Jason-2, Envisat (and merged). Eddies persisting for more than 2 weeks would be detected by even 2 altimeters while moving towards lower period (10 days), would require 3-altimeters. Then, focus is given to the Bay of Bengal, with a census of eddies via the analysis of the merged SLA products: eddy trajectories, lifetime and propagation speed are compared for year 2000 and 2001. Finally, the synergy of scatterometer and altimeter in deriving ocean currents (AltiKa and OSCAT) is presented, with the following motivations: to use Oceansat-2 scatterometer wind data, to assess the regional validity of the global algorithm (NOAA-OSCAR) and to study the surface current sensitivity to Ekman, geostrophic and thermal. First simulations spot on the need to assimilate altimeter data (Altika especially).

P. Prandi (CLS, Toulouse, France) presented the most recent synthesis regarding the monitoring of the Mean Sea Level, from past historical observations from tide gages (+0.8mm/yr before 1925, +2.0mm/yr between 1925 and 1985 and +3.2 mm/yr from 1985) to present-day sea level rise from satellite altimetry (+3.3 +/- 0.6 mm/yr, based on T/P, J1 and J2). All components of the sea level budget (land ice, ice sheets, glaciers, thermal expansion) have a positive contribution the sea level rise at the exception of the land water (more inland water storage) contribution. As assessed by CAL/VAM activities, uncertainties in satellite altimetry measurements are low enough for climate studies and therefore the estimated global trend is reliable. With the possible end of Envisat and Jason-1, SARAL/Altika will provide complementary data to Jason-2 allowing to keep track of mean sea level rise. At regional scales, altimetry MSL error budget is higher due to geographically correlated errors and the Artic MSL is an issue (sea ice loss, ice sheet melting). Altimetric data over this area, only sampled by ERS-1&2 and Envisat up to 82°N suffer from increased error sources (geophysical corrections, seasonnaly covered by sea-ice) and a regional reprocessing of the data is needed to get more reliable estimates for the Artic regional sea level variability.

M.K. Dash (IIT, Kharagpur, India) analysed the mesoscale surface oceanographic features with horizontal scales of ~100 km as a proxy to subsurface fields such as planetary Rossby waves. The detection of Rossby waves in the ocean is much more difficult because of their tiny sea surface signature (height variations of the order of 10cm or less), slow propagation speed (of the order of 10cm/s) and long wavelength (hundreds to thousand km). Aviso SSHA gridded products were analysed in the Bay of Bengal for two contrasting monsoon seasons i.e. 2002 and 2003 (March-October), and the Rossby velocity has been calculated at each 0.5° latitudinal interval from 5°N to 16°N. Several techniques to measure the Rossby wave speed were presented: Hovmöller diagram + Fourier Transform and more suitable, the Radon Transform. The Rossby wave speed derived in the Bay of Bengal matches with that of the global value derived by Hill et al., 2000. During a bad monsoon condition i.e. 2002 the phase speed shows five clusters having less Rossby wave speed compared to the normal years. The gradient in the Rossby wave speed is less during this period. In year 2003 (normal Monsoon year), the phase speed of Rossby wave shows three clusters.

The presentation given by **C.M. Kishtawal** (ISRO/SAC, Ahmedabad, India) investigates the correlation pattern between the Indian Summer Monsoon Rainfall (ISMR) variability and Sea Level Anomalies (SLA) since SLA could be a more robust and stable parameter compared to SST for prediction of monsoon rainfall. The study is based on weekly merged SLA (T/P, J1, ERS-1&2), Reynold's OI SST and IMD observation for rainfall, for 1993-2010 period. Grid-wise correlation between these parameters are computed and maximum-covariance analysis is performed. Pre-Monsoon SLA shows potentially usable predictive patterns for Indian summer rainfall. Highest correlations occur over the horse-shoe region surrounding Nino-4 area. Substantial correlations occur near IOD region, but not exactly at the same location. MAY month SLA only within the monsoon region explains 64% variability of Indian monsoon. The differential patterns display higher explained variance. SLA-ISMR correlation patterns appear more robust, and physically meaningful than SST based patterns.

Session V: Coastal Altimetry and Sea Surface Bias

J. Verron (LEGI, Grenoble, France) presented an OSSE (Observing System Simulation Experiment) using SARAL/AltiKa SSH and in situ TS profiles applied to the North Mediterranean Current (NMC) in the Gulf of Lions. Over coastal areas, operational oceanography systems suffer from few developments, although coastal processes have smaller and faster scales, with complex forcings. Ka-band altimetry on SARAL/AltiKa is expected to bring more numerous and precise measurements near the coasts. The objectives of the study are to set up a data assimilation system in a coastal region based on the SEEK filter, to explore the

capabilities of (simulated) SARAL/AltiKa data and in-situ data and to assess the impact of the assimilation of those data on the simulation of coastal physical processes. The area of interest and the methodology were then presented, as well as the diagnostics. Results shown indicate that the NMC is poorly represented in the model free runs in terms of surface velocity and spatial features. Clear improvement is noticed when AltiKa data are assimilated. Further sensitivity studies have to be conducted to find the best complement to altimetry.

RajKumar (ISRO/SAC, Ahmedabad, India) presented an analysis of coastal altimeter products and corrections based on Jason-2 "PISTACH" coastal products and radiosonde data over the Indian Ocean for the period July 2008-January 2011. Measurements very close to the coasts show high erroneous values of SWH, especially for OCE3 algorithm, but with normal behavior (peak in June-July) when monthly averaged over Bay of Bengal and Arabian Sea. Regarding the wind speed, the Weibull probability distribution function peaks for lower values in costal zones wrt offshore areas. Then, 3 different wet tropo delays (AMR, ECMWF, composite correction) are compared to radiosonde measurement in several places (Port Blair, Mombay, Vishakhapatnam).

Via a comparison of several altimetry products, **Y.K. Somayajulu** (NIO, Goa, India) presented a study on the seasonal pattern of altimeter along-track sea level anomalies off the Indian Coasts. Land contamination of the instruments footprints, high frequency ocean response to tidal and atmospheric loading and badly know MSL near the coast make the computation of SLA difficult. Using Lowess/Loess filter to remove noise in coastal altimetry data, biais between various products (RADS, CTOH and Aviso for Jason-1; RADS, Aviso and PISTACH for Jason-2) were estimated along 4 tracks on each of the eastern and western coasts of India. No clear tendency is evidenced in the results for the moment, but the methodology is still under development and will be adapted to Envisat and AltiKa.

F. Birol (LEGOS, Toulouse, France) presented the activities of the CTOH (Centre de Topographie des Océans et de l'Hydrosphère) on the regional processing of altimetry data. Based on its global data base of altimeter products and geophysical corrections, the CTOH has developed the X-TRACK post-processing coastal tool that is able to re-compute 1-Hz or high-resolution along-track sea level anomalies on a regional basis. An example on the northern Indian Ocean shows a substantial improvement in both the quantity and the accuracy of the retrieved data. More particularly, high resolution sea-level observations are required for the study of coastal and near-shore processes but smart filtering has to be applied. This expertise will be used for the analysis of AltiKa performances during CAL/VAL activities and AltiKa data will be added in the COTH data base and products, with the aim of analysis and characterize the sea level variability (mesoscale and sub-mesoscale) observed in the coastal regions.

L. Testut (LEGOS, Toulouse, France) presented a collaborative work between LEGOS and NIO on the tidal modeling of the Arabian Sea with T-UGO model (2D barotropic model without assimilation, using finite element for the discretization of the mesh, and base on the non-linear shallow water equations. It is forced at the boundary with FES 2004 and uses the ETOPO2 modifier bathymetry. Then, the meshes of FES2004 and TUGO were shown and compared, together with the comparison of M2 wave for both model. Validation against tide gages indicate a clear improvement for TUGO wrt FES2004 for both M2 (28cm rms against 38 cm) and K1 (8cm rms against 15cm). These results can still be improved via sensitivity tests against bathymetry, bottom friction and boundary conditions. The extension of the study area to the whole Northern Indian Ocean is envisaged.

The first part of **R.K. Nayak**'s presentation (ISRO/NRSC, Hyderabad, India) deals with the development of a high-resolution tidal model for the coastal ocean around India. The Gulf of Khambhat (north-west coast) and surrounding region is the test area for that coastal tidal model based on Princeton Ocean Model (POM) using modified ETOPO-2 bathy, T&S from Levitus and tidal height based on FES99 global tide simulator, variable horizontal grid size (from 7km to 1.5km), 16 vertical layers, external barotropic mode time step of 6 sec and internal baroclinic mode time step is of 1 minute. It is shown that FES99, POM and observations have similar amplitudes and that FES04 under estimates amplitudes at the upstream ends. Amplitude and Phases of 8 major tidal constituents in the Gulf can thus be used for altimeter data correction. The 2nd part of the presentation focuses on the comparative analysis of SSH anomalies from altimetry and Steric Height Anomalies (STHA) from SODA (Simple Ocean Data Assimilation) T- S profiles. It appears that SSH trend in the south tropical Indian ocean is mostly governed by steric contribution while the variability of SSH trend in the north tropical Indian ocean could be explained partially by the variability in steric height on all time scales.

K.V.S.R. Prasad (Andhra Univ., Visakhapatnam, India) studied the possibility of using altimetry data products together in situ observation to estimate coastal erosion. The coastline is mainly affected and modified by tides, waves and surges which are not easily accessible to land based or satellite remote sensing. Although present altimeters are not designed for near shore applications, some efforts are on-going on the processing of coastal data. With improvement of the spatial and temporal resolution, AltiKa is conceived for a better observation of coastal areas. The presentation focuses on the comparison of SWH data from different sources. A home-run wave model (based ECMWF/NCMRWF global wind data) is calibrated with altimetry derived SWH and in situ buoy observations. The study of the Laila cyclone (May 2010) in Bay of Bengal and Monsoon seasons shows discrepancies between ECMWF and altimeter SWH values. Data gaps in altimetry products near the coasts remain important even if the open ocean estimates are fairly good as they catch the seasonal signal of SW Monsoon and increase of wind speed during JAL cyclone during Dec 2010.

J.M. Lefevre (Meteo-France, Toulouse, France) presented the work undertaken at Météo-France for wind and sea-state forecasts issues. Meteo-France is running operational Global (ARPEGE/IFS) and Regional (ALADIN, AROME) Numerical Weather and Wave Prediction models. Since very weak in situ validation over seas and oceans is available, Météo-France intends to validate AROME (MesoScale) winds and wave height from wave model/AROME using AltiKa (and others altimeters). Noticeable improvements are expected in coastal zones since it is shown that assimilation of satellite data (SAR, altimeters) has already enhanced off-shore sea-state analysis and predictions during the past 15 years, therefore providing more accurate boundary conditions to coastal wave models. More generally, coastal prediction is still poor compared to offshore predictions, and work has to be done on data assimilation schemes and coastal data collection.

R.M. Gairola (ISRO/SAC, Ahmedabad, India) presented a sensitivity study on the wind dependence of specular microwave sea scatter and slope distribution, with objectives of developing a model for the estimation of the nadir radar backscatter and studying the wind dependent foam and whitecap coverage for climate applications. It is recalled that the reflectivity at sea-surface is altered by the layered media formed by foam and breaking waves, simulated results showing that the reflectivity declines rapidly with increasing roughness and thickness of foams at the C, Ku and Ka frequencies with different magnitudes. The proposed model provides better agreement with TOPEX and Jason-2 retrieved wind speed. The wind and wave dependent foam and whitecap coverage could be attempted for mentioned climate applications.This theoretical basis could be tested as a model function for retrieval of wind speed as well as flagging and quantifying rainfall from AltiKa.

Session VI: Data Assimilation and Operational Oceanography

S. Basu (ISRO/SAC, Ahmedabad, India) presented several examples of assimilation of satellite altimeter data in ocean circulation models. The first illustrated assimilation scheme is the assimilation of SLA in MOM-3, with the Cooper and Haines displacement scheme that conserves water property. Adjustments are done with vertical displacement of model water column, so that the pressure at the ocean floor should not change. Experiments are done with MOM3.0, fluxes from NCEP reanalysis, winds from QuickSCAT (2004), and weekly merged SLA from AVISO. Simulated SST is then compared to AMSR-AVHRR data, showing good performances. In the second example, SLA and SST are assimilated in IO-POM (Princeton Ocean Model, sigma-coordinate free surface primitive equation model, 0.5°x°.5° resolution and 26 sigma levels over the Indian Ocean). Assimilation experiments were conducted for year 2008 with daily merged SLA, SST (AVHRR+AMSR) and a combination of both; the model was forced by daily QuickSCAT winds and NCEP fluxes. Forecast were run without assimilation while assimilation was used for nowcast. Good results were obtained when compared to RAMA buoy SST and OSCAR currents.

M. Doron (LEGI, Grenoble, France) presented the issue of data assimilation in 3D ocean coupled physical-biogeochemical models where phytoplankton appear as the link between inorganic and organic matter. However, there is a non-linear dependence between key-variables that also exhibit a non-Gaussian behavior, meaning that linearized methods, like the Kalman filter are far from optimal. The work thus focuses on the state and parameter estimation using nonlinear extensions of the Kalman filter. The development of the anamorphosis (done locally and independently for each variable in order to deal with non-Gaussian distribution and non-linear response of the model, that can be different depending on the geographical situation) is explained. The parameter estimation step is also detailed, with consideration of various ecological provinces and using MonteCarlo experiment, checking with a twin experiment that the non-linear analysis is more efficient that the classical linear one. Finally, the implementation of the SEEK filter is described and its positive impact is seen of the state estimation of blooms (observed) and nitrates (non observed variable). This methodology has to be tested over longer time scales and could be transferred to assimilation of altimetry data.

S. Dwidedi (DAOS, Allahabad, India) showed how understanding the dynamics and variability of Colored Dissolved Organic Matter is important since it is an important reservoir of organic carbon and contributes to light absorption. The remote and autonomous CDOM observations can provide indicators of change in the balance of ocean biogeochemistry. A physical and biogeochemical upper ocean state estimation is presented, in which the in-situ hydrography and biogeochemical tracer (CDOM and SF6) measurements, and remotely-sensed SLA, SST and surface CDOM measurements are used to constrain a high-resolution ocean circulation model with realistic physics, around the Southern Ocean Gas Exchange Experiment (SO GasEX) region using 4D variational data assimilation technique. New modules for modeling CDOM photo-bleaching and surface transport of SF6 are developed and coupled with MITgcm. The assimilated fields are the best estimates in the locale of cruise, and are several times better than the initial guess solution before assimilation. The space-time variability in mixed-layer depth is consistent with the GasEx observations, and is correlated with sea-level height anomalies, sea-surface temperature, and air temperature, during the assimilation window. The mixed layer entrainment time scale and effect of photobleaching are also quantified in an effort to better understand spatio-temporal variability of GasEx CDOM.

In his presentation, **Y. Faugere** (CLS, Toulouse, France) started with an in depth overview of the SSALTO/DUACS (Developing Use of Altimetry for Climate Studies) system, that is based on a NRT component to provide operational applications with homogeneous high quality multi-missions altimeter data and on a Delayed Time (DT) component for state of the art altimeter climate data record. The various processing steps have been detailed and illustrated: more information on the Aviso web site ! Then, some illustrations of the use of the Duacs products are given: data assimilation in MERCATOR, ocean variability studies and monitoring (Mean Sea Leve, El Niño), model validation (mesoscale). With some ageing satellites

(Jason-1, Envisat, ERS-2) and other not yet adapted or integrated (Crysosat), AltiKa appears crucial to ensure the continuity of the multi-mission altimetry products quality and downstream applications: mesoscale in NRT, Polar areas. Additionally, new characteristics of AltiKa altimeter (smaller footprint and thus coastal data, higher resolution) will enhance resolution of DUACS products and help the development of new regional products.

S. Giraud St Albin (CLS, Toulouse, France) presented the latest developments at CLS and Mercator Ocean on a global ocean forecasting system at 1/12°, mainly to predict mesoscale activities. The core components of this forecasting system were first described: the ocean code is NEMO (1.09) coupled with LIM2 sea ice model, on a global 1/12° ORCA-type grid; the data assimilation scheme is based on a multivariate SEEK filter, with adaptative scheme for the background error variance, and incremental analysis update; the assimilated datasets are SLA from SSALTO/DUACS, MDT (Rio, 2010), daily SST from NCEP and insitu profiles from CORIOLIS. The forecasting production system has just passed its readiness review in early march 2011, with a distribution system to be completed in end of April 2011. The calibration phase was based on hindcast robustness verification (April 2009 --> July 2010) and gave interesting results on mesoscale activities in the southern hemisphere: jet, eddies and storm tracks in the Antarctic Circumpolar Current, with an underestimation of 40% of the currents at 45°S. SARAL/AltiKa is expected to ensure product quality continuity (Envisat gap filler) and to improve the data assimilation performances.

As shown by **P.V. Nagamani** (ISRO/NRSC, Hyderabad, India), Tropical cyclone heat potential (TCHP) is an important parameter influencing the tropical cyclone intensity. The best approach for computing TCHP is to use in-situ measurements. However, there are limitations with the in-situ data collected over the ocean regions in terms of spatial and temporal observations. Hence, there is a need for satellite altimeter based observations for studying the ocean thermal structure for oceanographic applications. Sea surface height anomalies (SSHAs) obtainable from altimeter observations have the potential to estimate this parameter but need validation. Satellite derived TCHP values are compared with in-situ measurements during 1993-2009. The available sea truth measurements collected in the north Indian Ocean using Conductivity Temperature Depth profiler (CTD), Expendable CTD profiler (XCTD), Bathy Thermograph (BT), Expendable BT (XBT) and Argo floats are used to estimate in-situ derived TCHP values in this study. Satellite derived and the in-situ measured TCHP values are well correlated over north Indian Ocean. Since altimeter derived SSHA are not accurate closer to the coast, with normal processing, the estimations have improved by removing the coastal observations the r2 value has improved from 0.65 to 0.67 for north Indian Ocean, 0.74 to 0.77 for Arabian Sea and 0.55 to 0.56 for Bay of Bengal regions.

Session VII: Ice and Inland Waters

F. Mercier (CLS, Toulouse, France) presented 2 applications of the analysis of spurious altimeter waveforms. After an illustration based on the developments undertaken within the PISTACH (Prototype Innovant de Système de Traitement pour les Applications Côtières et l'Hydrologie) regarding the classification of the waveforms, with examples on the Amazon Basin and the Issykkul Lake. Then, the waveforms polluted by the presence of a floating reflector over the ocean are described and their mapping clearly indicates coherent structures such as shipping routes (reflection over boats) and icebergs. An operational service, based on Jason-1, Jason-2 and Envisat data has been set for world around sailing races, since a SAR-only based solution is very expensive. The detections are then shown over the South Atlantic Ocean for the period August 2009 – march 2010. Detections in early 2011 also show a large distribution of icebergs in a 10°C sea water. In the second part, waveforms observed over fresh water frozen lakes (Northern Canada) are interpreted as complex waveforms resulting from the superimposition of a reflection at the air/snow (or air/ice) interface and at the water/ice interface, meaning that the signal

penetrates through the ice and that such waveforms can give a direct access to the monitoring of the ice thickness. With reduced penetration in Ka-band, AltiKa waveforms could validate this hypothesis.

S.R. Oza (ISRO/SAC, Ahmedabad, India) presented investigations on the inter-annual variations of polar Ice surface characteristics, starting by reviewing the various techniques and sensors already used (MSMR, QuickSCAT) for the monitoring of sea-ice extent and concentration. Interannual fluctuations of the sea-ice characteristics have been evidenced, and the condition in which sea-ice is formed is important because it determines the roughness of the surface, to which the radar is sensitive. Focus is then given on the use altimeter waveforms characteristics, and especially the peakiness, since sea-ice waveforms are generally more peaky than open-ocean ones. The analysis of Jason-2 PISTACH data show a possible correlation between peakiness and ice concentration/compactness. The usefulness of the radiometer brightness temperatures is also illustrated and all theses observation allow the seasonal, inter-annual and long term monitoring of sea-ice and ice sheet/shelves surface characteristics and elevation change.

T. Flament (LEGOS, Toulouse, France) presented an overview of the use of radar altimetry over ice sheets, with the advantage of almost 20-years of record but with the drawback of a badly quantified penetration through snow. These observations are used for the identification of ice flow feature, as input for meteo and ice-sheet models and for the contribution of ice sheets volume change to the global water cycle. The trends in height changes are first shown over the Antarctic for the period 2002- 2009 and then with a focus over some glaciers, and especially the Pine Island Glacier that is thinning very fast. A better accuracy of the altimetric measurement is now necessary to refine height and volume change estimates and the real challenge is now to separate the contribution of the surface (roughness, density) and the volume (grain size, internal stratification) to the radar echo. New insights are expected from the Ka band radar onboard SARAL/AltiKa (especially due to the lesser penetration of the signal into the snow).

Within the framework of the AltiKamala project, **S. Calmant** (IRD/LEGOS, Toulouse, France) presented a collaborative work on the inter-comparison of altimetry (Envisat and AltiKa when launched) over rivers at sites monitored locally, with the example of the Amazon river. The altimetry quality assessment over rivers must includes retracking and data selection algorithms considerations. The choice of a calibration site results from an analysis of data acquisition capabilities. Then altimeter measurements are compared in terms of time series of water height vs gauge series for an external validation, and at crossovers over river beds for an internal validation. GPS surveys along selected tracks are also required to identify local fine undulations of the river water surface. This methodology is illustrated at a dedicated site that is equipped at Iracema near the crossing of Envisat/AltiKa tracks 063 and 478. Comparison with GPS cruises is also illustrated, as well as an investigation on the loss of data due to strong rains.

On behalf of **J.S. Silva** (U.E.A, Manaus, Brazil), S. Calmant (IRD/LEGOS, Toulouse, France) presented several configurations of satellite altimetry river cross-sections analysis, based on examples in the Amazon Basin. In the first case, the slope of the river can be estimated by the difference between the altimetry time series at 2 different river cross sections. In the second example where the satellite track is aligned with the river, its longitudinal slope is directly extracted from the altimeter time series along the cross section. The following examples illustrate the variations of the river bed, as seen by the altimeter, between the low and high water stages. During high water stage, the reflecting surface is flat all along the cross section. During intermediate and low water stages, reflection over emerged rivers banks, and islets allow the mapping of these structures. It is also shown that the reflections can occur over very narrow (20 m wide) rivers. This characteristics is used over flood plains to identify the various water channels during laws water stages even if the measurements suffer from off-nadir effects.

Conclusions of the meeting

The community being now open to international PIs teams (whereas it was previously restricted to Indian and French teams), ISRO kindly asked some these “new” participants (G. Jacobs and D. Richman) to expose their interest in the SARAL/AltiKa Mission.

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