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Proceedings of the Symposium on  
15 years of Progress in  
Radar Altimetry

13-18 March 2006  
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*Organisers:*

*European Space Agency*

*Centre National d'Etudes Spatiales*



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## Preface

Fifteen years after the launch of ERS-1 and TOPEX/Poseidon, the European Space Agency, in collaboration with the French Space Agency, CNES, has organised an exceptional Symposium on "15 Years of Progress in Radar Altimetry" in Venice Lido, Italy, from 13 to 18 March 2006. Within the framework of this Symposium, three related events were scheduled: the Ocean Surface Topography Science Team Meeting, the International DORIS Service Workshop and the Argo Workshop.

After many years of development and data exploitation, radar altimetry is at the turn of an epoch. Radar altimetry is going operational for oceanography and entering a new generation with higher resolution and higher precision radar altimeters. The Symposium is about looking back at the progress made since the launch of ESA's ERS-1, back in 1991, and Topex/Poseidon in 1992, followed by ERS-2 in 1995, Geosat Follow-On in 1998, Jason-1 in 2001 and ENVISAT in 2002. The Symposium drew together six scientific communities: Oceanography, Marine Meteorology, Land Hydrology, Cryosphere, Geodesy and Geophysics.

Three different scientific communities, geodesy, geophysics, and oceanography, learned to work closely together on common goals over many decades, developing new technologies with much improved accuracies. The cryosphere community benefited from all the technological and data processing progress made for oceanographers when adapting these techniques to monitoring the ice caps and sea-ice. More recently, it became clear that exploiting radar altimetry to monitor inland water levels was feasible, even if quite complex, and the accuracy over these difficult targets is improving rapidly. Many countries, especially those in Europe and the USA - countries with different cultures and ambitions - learned to work closely together on common goals. By 1992, the progress and results laid a very strong foundation for the future of satellite altimetry and the Jason, Envisat, and Geosat Follow-On missions were decided. The accuracy of global geodetic measurements increased from a few hundred meters at the beginning of the satellite era to a few centimeters during the last fifteen years. As a result, we know much more about the Earth, ocean dynamics and the cryosphere than we would have known without altimetry, and we have laid the foundations for fully operational 3-D oceanography. Satellite altimetry has expanded from conferences attended by a handful of scientists to this Symposium attended by around 500 scientists submitting papers with more than 1200 authors and co-authors.

The "15 Years of Progress in Radar Altimetry" Symposium covered all the themes mentioned above and full papers are collected in these proceedings. In particular, a summary of the recommendations gathered during the plenary session on the future of altimetry and the panel discussion brings guidance on the requirements for future radar altimetry missions. The main message is the need for continuity of a multi-mission radar altimetric system making the best use of new technology arising for a new generation of instruments in support of both science and GMES.

One remarkable expression was the appreciation of the richness and the usefulness of such an exceptional Symposium stimulating a precious exercise of analyzing the past difficulties and the progress made so far. A noteworthy recommendation calls for holding a sequel to this Symposium in five years, hopefully joining-up with the famous Venetian meeting held every ten years since 1980, called "Oceans from Space".

In closing we would like to recognize the contribution of the partner agencies, institutions and organizations supporting the development of altimetry, in particular NASA, NOAA, EUMETSAT, IAG, IAPSO, INSU, IRD, IFREMER, EMS and IOC. As well, we express our gratitude to the Scientific Committee members, the Chairs and the Keynote Speakers, and to the contributors and the participants who made this Symposium a success. *Bonne lecture!*

*Jérôme Benveniste (ESA) and Yves Ménard (CNES)*  
*Organising Committee Chairs*  
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Chairs: A. Cazenave and C.K. Shum

### AN ASSESSMENT OF IPCC 20TH CENTURY CLIMATE SIMULATIONS USING THE 15-YEAR SEA LEVEL RECORD FROM ALTIMETRY

*E. Leuliette, S. Nerem & T. Jakub*

### GLOBAL AND REGIONAL SEA LEVEL CHANGE FROM MULTI-SATELLITE ALTIMETER DATA

*R. Scharroo & L. Miller*

SATELLITE MEASUREMENTS OF SEA LEVEL CHANGE: WHERE HAVE WE BEEN AND WHERE ARE WE GOING

*R.S. Nerem, D. P. Chambers, E.W. Leuliette, G.T. Mitchum & A. Cazenave*

APPLICATION OF OCEAN REANALYSIS TO THE PROBLEM OF GLOBAL SEA LEVEL RISE

*J.A. Carton, S.A. Grodsky & B.S. Giese*

UNDERSTANDING MEASURED SEA LEVEL RISE BY DATA ASSIMILATION

*M. Wenzel & J. Schröter*

REGIONAL LONG-TERM SEA LEVEL AND SEA SURFACE TEMPERATURE CHARACTERISTICS FROM SATELLITE OBSERVATIONS

*O.B. Andersen, P. Knudsen & B. Beckley*

MODELING THE SEA LEVEL VARIABILITY IN THE LAST DECADES

*L. Fenoglio-Marc & M. Becker*

## **THE 15-YEAR ALTIMETRIC RECORD - OTHER and RETRACKING**

Chair: A. Brenner

### **SESSION SUMMARY**

OSCAR: LOOKING AT CONTINENTAL SURFACES WITH RADAR ALTIMETRY

*B. Legrésy, F. Papa, F. Blarel, J.-F. Créteaux, F. Birol, A. Cazenave, K. Dominh, F. Frappart, S. Calmant, M.-C. Gennero, A. Kouraev & F. Rémy*

THE NATIONAL OCEANOGRAPHY CENTRE, SOUTHAMPTON RETRACKING SCHEME

*J. Gómez-Enri, C. Gommenginger, P. Villares, P. Challenor, M. Srokosz, J. Benveniste & M. Drinkwater*

ESTIMATION OF THE SEA STATE BIAS EFFECT ON THE ALTIMETRIC MEASUREMENTS USING A PARAMETRIC MODEL

*A. Rami, M. Khelif, S. Kahlouche & T. Denoukri*

## Session 6

### THE INTEGRATED APPROACH

#### SESSION SUMMARY

#### THE INTEGRATED APPROACH - SYSTEMS

Chairs: J. Gould & D. Roemmich

SYNERGY BETWEEN OCEAN OBSERVATIONS AND NUMERICAL SIMULATIONS: CLIPPER HERITAGE AND DRAKKAR PERSPECTIVES

*T. Penduff, B. Barnier, A.-M. Treguier & P.-Y. Le Traon*

OCEAN MODEL ANALYSIS AND PREDICTION SYSTEM (OCEANMAPS): OPERATIONAL OCEAN FORECASTING BASED ON NEAR REAL-TIME SATELLITE ALTIMETRY AND ARGO

*G.B. Brassington*

THE GLOBAL OBSERVED OCEAN PRODUCTS OF THE FRENCH MERCATOR PROJECT

*G. Larnicol, S. Guinehut, M.-H. Rio, M. Drévillon, Y. Faugere & G. Nicolas*

#### THE INTEGRATED APPROACH - DEMONSTRATIONS

Chairs: P. Knudsen & P.-Y. Letraon

MID-DEPTH CIRCULATION OF THE WORLD OCEAN: A FIRST LOOK AT THE ARGO ARRAY

*J.K. Willis & L.-L. Fu*

ALTIMETRY, SEA SURFACE TEMPERATURE AND OCEAN COLOUR UNVEIL THE EFFECTS OF PLANETARY WAVES ON PHYTOPLANKTON

*P. Cipollini*

MEAN SURFACE CIRCULATION OF THE GLOBAL OCEAN INFERRED FROM SATELLITE ALTIMETER AND DRIFTER DATA

*N.A. Maximenko & P.P. Niiler*

COMBINING ALTIMETRIC AND ALL OTHER DATA WITH A GENERAL CIRCULATION MODEL

*P. Heimbach, R.M. Ponte, C. Evangelinos, G. Forget, M. Mazlo, D. Menemenlis, S. Vinogradov & C. Wunsch*

CHLOROPHYLL BLOOM IN THE WESTERN EQUATORIAL PACIFIC DURING THE 1998 EL NIÑO / LA NIÑA TRANSITION: THE ROLE OF KIRIBATI ISLANDS AS SEEN FROM SATELLITE, IN-SITU DATA, AND A HIGH-RESOLUTION SIMULATION

*M. Messié, M.-H. Radenac & J. Lefèvre*

SEA SURFACE SALINITY FROM A SIMPLIFIED OCEAN MIXED LAYER MODEL USING GLOBAL ALTIMETER DATA

*S. Michel, B. Chapron, J. Tournadre & N. Reul*

UNDERSTANDING OF THE EAST (JAPAN) SEA CIRCULATION BY USING ALTIMETER, ARGO AND SST

*Y.Jae Ro, E. Kim & Y. Hoon Youn*

GLOBAL SURFACE CURRENTS AND HEAT TRANSPORT: A NEW PRODUCT FOR INVESTIGATING OCEAN DYNAMICS

*J. Sudre & R. Morrow*

CONTROL OF A FREE-SURFACE BAROTROPIC MODEL OF THE BAY OF BISCAY BY ASSIMILATION OF SEALEVEL DATA IN PRESENCE OF ATMOSPHERIC FORCINGS.

*J. Lamouroux, P. De Mey, F. Lyard & E. Jeansou*

15 YEARS OF OCEANOGRAPHY IN THE AZORES; FROM OCEANOGRAPHIC CRUISES TO AN INTEGRATED APPROACH.

*M.F. Juliano, M. Alves, A. Simões, J. Rodeia*

ESTIMATING OCEAN MIDDLE-DEPTH VELOCITIES FROM ARGO FLOATS: ERROR ESTIMATION AND APPLICATION TO PACIFIC

*J. Xie, J. Zhu & C. Yan*

## **THE INTEGRATED APPROACH - DIAGNOSTICS**

Chairs: N. Ferris & D. Anderson

USING ALTIMETER MEASUREMENTS FOR QUANTITATIVE ASSESSMENT OF HIGH RESOLUTION OCEAN MODELS

*L. Thompson & K.A. Kelly*

OCEAN SURFACE CURRENT MONITORING FROM SPACE: METHODOLOGY AND PROGRESS

*F. Bonjean, G. Lagerloef, E. Johnson, J. Gunn, L. Miller, R. Legeckis, G. Mitchum, N. Soreide & M. Bourassa*

THE MERCATOR 1992-2002 PSY1V2 REANALYSIS FOR TROPICAL AND NORTH ATLANTIC

*E. Greiner, Benkiran & Pergaud*

EXTRAPOLATING OCEANIC SIGNALS FROM SURFACE DATA TO DEEPER LAYERS: APPLICATION TO DIFFERENT DATASETS

*B. Buongiorno Nardelli, O. Cavalieri, R. Santoleri & M.-H. Rio*

EXPLORATION OF MODEL'S ERRORS IN TERMS OF SEA SURFACE HEIGHT AND TEMPERATURE IN A 1/4° MODEL OF THE NORTH ATLANTIC

*N. Ayoub, M. Lucas, P. De Mey & G. Valladeau*

ON AN ADAPTIVE FILTER BASED ON FORECAST ERRORS MODELLING FOR DATA ASSIMILATION AND ITS COMPARISON WITH OPTIMAL INTERPOLATION METHOD

*H.S. Hoang, R. Baraille, O. Talagrand & P. De Mey*



## Session 7

### NEW APPLICATIONS

Chair: O.-Z. Zanife

#### SESSION SUMMARY

THE DISTRIBUTION OF BIGEYE TUNA, *THUNNUS OBESUS*, AND THREE-DIMENSIONAL THERMAL STRUCTURE ESTIMATED FROM SATELLITE ALTIMETER

*A. Takano & H. Yamazaki*

OCEANOGRAPHY AND YACHT RACING – A HANDFUL OF COMPETITORS, MILLIONS OF SPECTATORS

*D. Griffin, G. Cresswell, K. Badock, M. Cahill, C. Rathbone & P. Turner*

A ROLE FOR ALTIMETER RADARS IN GAS EXCHANGE STUDIES

*N.M. Frew, D.M. Glover & S.J. McCue*

RAIN ALTIMETRY – PAST, PRESENT AND FUTURE

*G.D. Quartly*

APPLICATION OF SATELLITE ALTIMETRY FOR FISHERIES RESEARCH

*A. Sirota, S. Lebedev, S. Burykin, E. Timokhin & P. Chernyshkov*

NEW SCIENTIFIC APPLICATIONS FOR OCEAN, COASTAL, LAND AND ICE REMOTE SENSING WITH ENVISAT RADAR ALTIMETER INDIVIDUAL ECHOES

*C. Gommenginger, P. Challenor, J. Gomez-Enri, G. Quartly, M. Srokosz, P. Berry, J. Garlick, D. Cotton, D. Carter, C. Rogers, S. Haynes, I. LeDuc, M. Pilar Milagro & J. Benveniste*

ENVISAT RADAR ALTIMETER INDIVIDUAL ECHOES

*O.-Z. Zanifé, M. Roca, F. Remy, B. Legresy, B. Chapron, S. Laxon, M.-P. Milagro Perez & J. Benveniste*

### OUTREACH

Chairs: V. Rosmorduc & M. Srinivasan

#### SESSION SUMMARY

(NEARLY) FIFTEEN YEARS OF ALTIMETRY OUTREACH AT CNES AND NASA/JPL

*V. Rosmorduc, A. Richardson & M. Srinivasan*

SOCIETAL BENEFITS OF OCEAN ALTIMETRY DATA

*M. Srinivasan*

SATELLITE ALTIMETRY OUTREACH DURING HURRICANE RITA: LESSONS LEARNED

*R.R. Leben, G.H. Born & M. Srinivasan*

AFRICAN CAPACITY BUILDING IN SATELLITE ALTIMETRY WITH THE UNESCO-BILKO PROGRAMME

*V. Byfield, D. Kirugara, Y.C. Robertson, D.J. McNeill & N. O'Reilley*

OUTREACH AT THE COOPERATIVE INSTITUTE FOR OCEANOGRAPHIC SATELLITE STUDIES

*A. Vandehey, P.T. Strub & M. Phipps*

## DATA SERVICES

Chairs: E. Schrama & Ph. Escudier

### THE CASH PROJECT

*F. Seyler et al.*

### AVISO ALTIMETRY PRODUCTS: SELECT YOUR CHOICE!

*V. Rosmorduc, N. Picot & O. Lauret*

### BASIC RADAR ALTIMETRY TOOLBOX AND RADAR ALTIMETRY TUTORIAL: A NEW SET OF TOOLS FOR ALL ALTIMETRY USERS

*V. Rosmorduc, J. Benveniste, N. Picot, J. Dorandeu, D. Earith, O. Lauret, S. Niemeijer, P. Poilbarbe & P. Sicard*

### JUST-IN-TIME ALTIMETRY: INTERNATIONAL COLLABORATION IN PROVISION OF ALTIMETRY DATASETS.

*H.M. Snaith, R. Scharroo & M. Naeije*

### A REMOTE SENSING OCEAN PORTAL FOR GMES OCEAN

*F. Blanc & Partners of the Mersea Project*

### CTOH : CENTRE FOR TOPOGRAPHIC STUDIES OF THE OCEANS AND HYDROSPHERE

*R. Morrow, Y. Ménard, F. Birol, S. Daillet-Rochette, J. Sudre, F. Blarel & M. Faillot*

### MERCATOR OCEAN FORECASTING PRODUCTS: FITTING INTO THE USERS NEEDS

*S. Baudel & V. Toumazou*

### THE ROLE OF RADS IN BUILDING THE 15-YEAR ALTIMETER RECORD

*M. Naeije, E. Schrama, E. Doornbos & R. Scharroo*

### STEPS TOWARDS AN OPERATIONAL SERVICE USING NEAR REAL-TIME ALTIMETER DATA

*E.R. Ash*

## Session 8

### THE FUTURE OF ALTIMETRY

#### SESSION SUMMARY and RECOMMENDATIONS

#### THE FUTURE OF ALTIMETRY - PART 1

Chairs: H. Bonekamp & E. Lindtrom

FUTURE REQUIREMENTS FOR SATELLITE ALTIMETRY: RECOMMENDATIONS FROM THE GAMBLE PROJECT FOR FUTURE MISSIONS AND RESEARCH PROGRAMMES

*P.D. Cotton & Y. Menard*

ALTIKA: A MICRO-SATELLITE KA-BAND ALTIMETRY MISSION

*J. Verron, N. Steunou & the AltiKa mission group*

THE ROADMAP FOR A GMES OPERATIONAL OCEANOGRAPHY MISSION

*M. Drinkwater, H. Rebhan, P.-Y. Le Traon, D. Cotton, J. Johannessen, G. Ruffini, P. Bahurel, M. Bell, B. Chapron, N. Pinardi, I. Robinson, L. Santoleri & D. Stammer*

EUMETSAT AND OPERATIONAL OCEANOGRAPHY

*H. Bonekamp, F. Parisot & D. Klaes*

IS THERE A FUTURE ROLE FOR ALTIMETERS CARRIED ON MICRO PLATFORMS FOR THE EARLY WARNING OF SURFACE HAZARDS?

*T.D. Allan & D.J.T Carter*

25 YEARS OF ALTIMETER DEVELOPMENTS AT ALCATEL ALENIA SPACE

*L. Phalippou, E. Caubet, L. Rey, P. Calvary, D. Murat, J. Richard, G. Angino, E. Thouvenot, G. Carayon, N. Steunou, C. Mavrocordatos & P. Escudier*

PERFORMANCES STUDY OF INTEROMETRIC RADAR ALTIMETERS: FROM THE INSTRUMENT TO THE GLOBAL MISSION DEFINITION "15 YEARS OF PROGRESS IN RADAR ALTIMETRY"

*V. Enjolras, P. Vincent, J.-C. Souyris, E. Rodriguez, L. Phalippou & A. Cazenave*

ITC AND WATER: THE PROPOSED WATER ELEVATION RECOVERY SATELLITE MISSION

*R.J.J. Dost, B.H.P. Maathuis & Z. Su*

CONTRIBUTION OF WIDE SWATH ALTIMETRIC CROSS TRACK MEASUREMENTS IN THE NORTH SEA: IMPACT OF THE SATELLITE ROLL ERRORS

*M. Le Hénaff, P. De Mey, B. Mourre, P.-Y. Le Traon & F. Lyard*

## **CLOSING KEYNOTE PRESENTATIONS**

### **THE FUTURE OF ALTIMETRY - PART 2**

Chairs: J.-L. Fellous & S. Wilson

MAPPING SEAFLOOR TECTONICS FROM SATELLITE ALTIMETRY: REQUIREMENTS FOR A FUTURE MISSION

*D.T. Sandwell, W.H.F. Smith & S. Gille*

ALTIMETRY AND THE INTEGRATED OCEAN OBSERVING SYSTEM

*P.-Y. Le Traon*

TOWARDS MAPPING THE OCEAN SURFACE TOPOGRAPHY AT 1 KM RESOLUTION

*L.-L. Fu & E. Rodriguez*

## **ADDITIONAL MATERIAL**

LIST OF PARTICIPANTS

CONFERENCE PHOTOS