



## **GAMBLE - OFFSHORE OPERATORS' WORKSHOP May 19<sup>th</sup> 2003**

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### **Future Priorities for Satellite Provision of Sea State and Ocean Current Data – 2005 and beyond**

#### **Draft Report and Discussion Document**

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WWW addresses are provided for readers to download the complete presentations summarised in this report.

## 1. Introduction

[http://www.altimetric.net/docs/GAMBLE\\_OWS\\_agenda.pdf](http://www.altimetric.net/docs/GAMBLE_OWS_agenda.pdf)

[http://www.altimetric.net/docs/GAMBLE\\_OWS\\_intro.pdf](http://www.altimetric.net/docs/GAMBLE_OWS_intro.pdf)

### *GAMBLE*

The EC funded "GAMBLE" network has brought together European experts to consider future developments in satellite altimetry. The aims of GAMBLE are to coordinate developments so that the best use is made of data from altimeter missions that are already approved, and to make recommendations for the optimisation of forthcoming altimeter missions (orbits, tracking, orbit maintenance, payload specifications, scheduling) to best satisfy user needs.

### *GAMBLE Operators' Workshop Aims*

Offshore operators are working to specifications that become more challenging year by year. These specifications can relate to operational activities, e.g. the need to operate within precise sea state limits, or for advance knowledge of "weather windows", or they can form part of the design procedure (operational planning or vessel and structure design).

It is a priority of GAMBLE to consider input from offshore operators, so that the requirements for future satellite altimeter missions are driven as much by the needs of offshore operators (taking into account commercial, safety or environmental considerations) as they are by the needs of the scientific community. Thus an operators' workshop was convened to allow operators to communicate their priorities, and to initiate a dialogue between GAMBLE partners and offshore operators to find the best way in which these requirements can be satisfied.

### *This Document*

This document is intended to:

- Report on the GAMBLE operators workshop
- Initiate a discussion between offshore operators and GAMBLE partners to identify and prioritise requirements for metocean products that can be derived from satellite altimeter measurements

*Section 2* provides an overview of satellite altimeter missions that are now flying, and of plans for the next 10 years or so.

*Section 3* gives a summary of the types of data products (derived from satellite altimeter data) available now, and of likely developments in the medium term.

*Section 4* includes contributions from OGP members and the service industry – covering present and future needs and applications for altimeter derived data products.

*Section 5* summarises issues that arose from the meeting discussion. This discussion remains open and we invite all readers to contribute through the email discussion list ([gamble-operators@deos.tudelft.nl](mailto:gamble-operators@deos.tudelft.nl)).

**2. Overview of Altimeter Missions – 2003-2010 and beyond**  
**(Y. Menard, CNES, FR)**

[http://www.altimetric.net/docs/GAMBLE\\_OWS\\_missions.pdf](http://www.altimetric.net/docs/GAMBLE_OWS_missions.pdf)

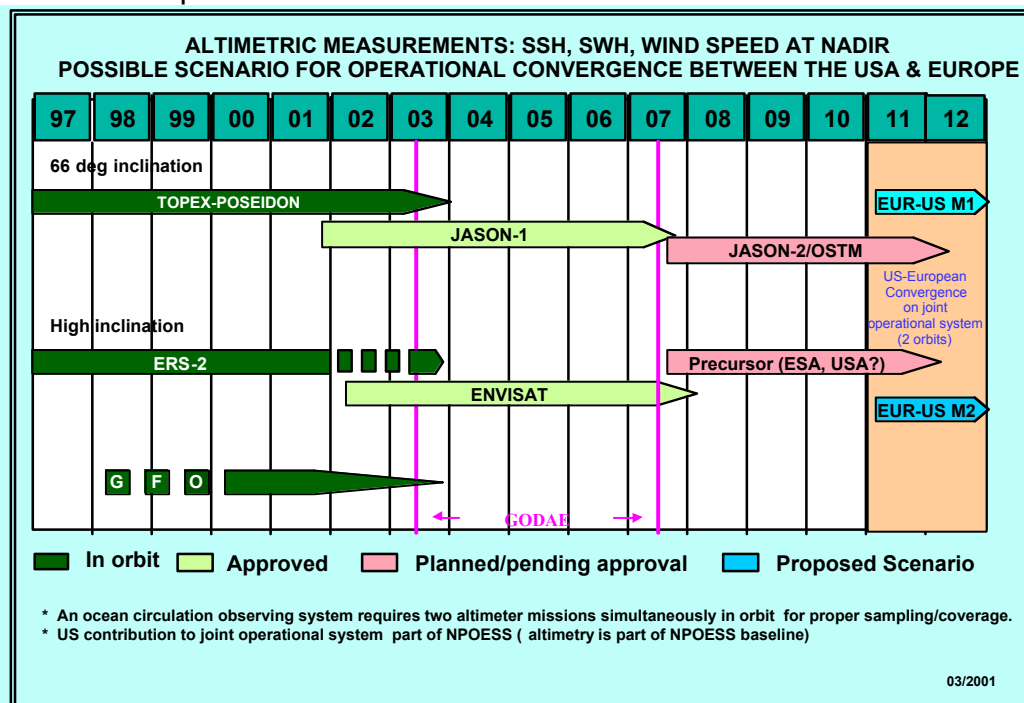
The first satellite altimeter (Geos 3) was launched in 1975. Satellite altimeter measurements have now been continuously available since 1991, through ERS1, TOPEX/Poseidon, ERS2, Geosat Follow-On, Jason, and ENVISAT. Measurements from these instruments have revolutionised our knowledge of the ocean, through studies in sea level, ocean circulation and climate variability.

There are presently 5 satellite altimeters flying and providing sea surface height, wave height and ocean wind speed data. These data have allowed further significant advances in our understanding of ocean processes.

The next mission planned is Jason-2 in 2007 (jointly supported by NOAA, CNES, EUMETSAT and NASA), which is expected to fly a “conventional” nadir altimeter and an experimental wide swath altimeter which will provide sea surface height measurements across a 100 km swath on either side of the nadir ground track. However, no missions are planned as “follow-ons” to GFO or ENVISAT, until the first US “NPOESS” altimeter, due in 2011 (see below). Thus we have a potential situation in 2007-2011 which would interrupt the 2 satellite coverage required to carry out global scale ocean climate monitoring.

A number of proposals for additional missions are at varying stages of preparation. They include, from Europe:

- SWIMSAT – A wave measuring satellite radar which would provide direction and wavelength information.
- AltiKa – Ka band altimeter on a micro-satellite platform.
- GANDER – A constellation of wave-measuring altimeters on micro-satellite platforms.



Satellite altimeter missions – operational, planned and proposed 1997-2012

### 3. Altimeter derived data products and expected future developments

This section provides an overview of operational altimeter derived products that are currently available, and on likely developments in the short-medium term. The products presented are representative of a wider range of products available from a number of different agencies.

Data products derived from satellite altimeters include:

#### *“Direct” Measurements*

##### Real Time (< 3 hours)

- Significant wave height (and wave period, experimental parameter)
- Wind speed
- Sea surface height and derived parameters (with initial, ~10cm class, orbit)
  - Sea level anomaly
  - Surface geostrophic currents
  - Eddy kinetic energy
- Sea ice edge

##### Near Real Time ( ~days) – can include combination of data from 2-3 satellites

- Wave height (wave period), and wind speed
- Sea surface height and derived parameters (3 cm class orbit)
  - Sea level anomaly
  - Surface geostrophic currents
  - Eddy kinetic energy
- Sea ice edge

##### Offline (~ weeks / months)

- Wave height (period) and wind speed climatologies
- Sea surface height and derived parameters and derived parameters (2 cm class orbit orbit)
  - Sea level Anomaly
  - Surface geostrophic currents
  - Eddy kinetic energy
- Various experimental parameters:
  - Rain climatologies
  - Sea ice thickness
  - Air sea gas transfer velocities

#### *“Indirect” Products (through assimilation into models)*

##### Real Time (< 3 hours)

- Wave forecasts and analyses (including directional spectra)

##### Near Real Time ( ~ days)

- Surface (and sub surface) currents.
- Ocean structure (temperature, salinity,...)

##### Offline (~ weeks / months)

- Global and regional ocean circulation analyses
- Sea level variability,
- Analyses / predicted developments of climate phenomena (e.g. El Niño / La Niña), etc.
- Wave climatologies (directional spectra) – coastal and offshore

### 3.1 Ocean Currents (F. Lefèvre, CLS, France )

[http://www.altimetrie.net/docs/GAMBLE\\_OWS\\_Lefevre.pdf](http://www.altimetrie.net/docs/GAMBLE_OWS_Lefevre.pdf)

CLS combine and process near real time altimeter products from Jason, Geosat Follow On and ERS2 to generate maps of "Sea level Anomalies" - variations in sea level from a long term mean sea level. Products are produced twice weekly with a delay of 48 hours, and are interpolated onto a global 1/3° grid . Hindcast products are also produced, with a 2 months delay. These hindcast products are more accurate because they are able to use more precise satellite orbit information. The products include 7 day averages of Sea Level Anomaly, derived surface geostrophic currents and maps of eddy kinetic energy. The movement of individual eddies can be followed.

Most mapping errors are a consequence of high frequency variability in time and space that cannot be picked up by the present satellite coverage.

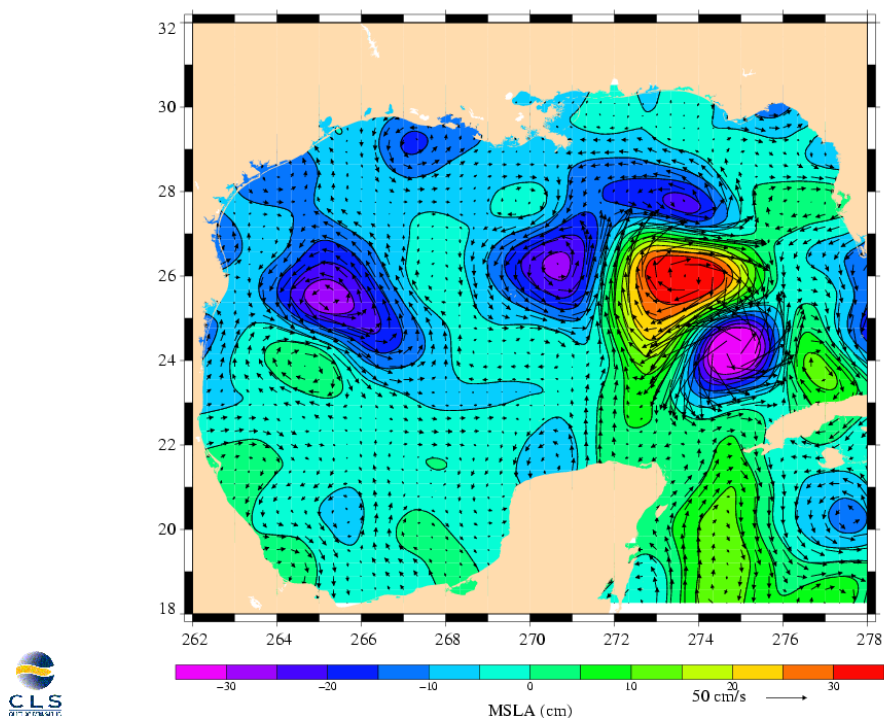
A number of projects are ongoing (e.g. with Shell and FugroGeos) to investigate ways to continue to develop operational services.

An operational service for fisheries being developed by CLS, called CATSAT (<http://www.catsat.com>), which provides access to sea-level, ocean circulation models, sea surface temperature, ocean colour and met-ocean products.

Also see the CLS website at

([http://www.cls.fr/html/oceano/general/savoir/donnees\\_en.html](http://www.cls.fr/html/oceano/general/savoir/donnees_en.html))

Mean Sea Level Anomalies and Geostrophic Velocities from DUACS (TP+ERS+GFO)  
26-Feb-2003 (CNES day 19414)



Example of DUACS 7 day SLA and Geostrophic Velocity for Gulf Of Mexico, 26 Feb 2003.

### 3.2 Operational Products from Mercator (V. Toumazou, MERCATOR, FR )

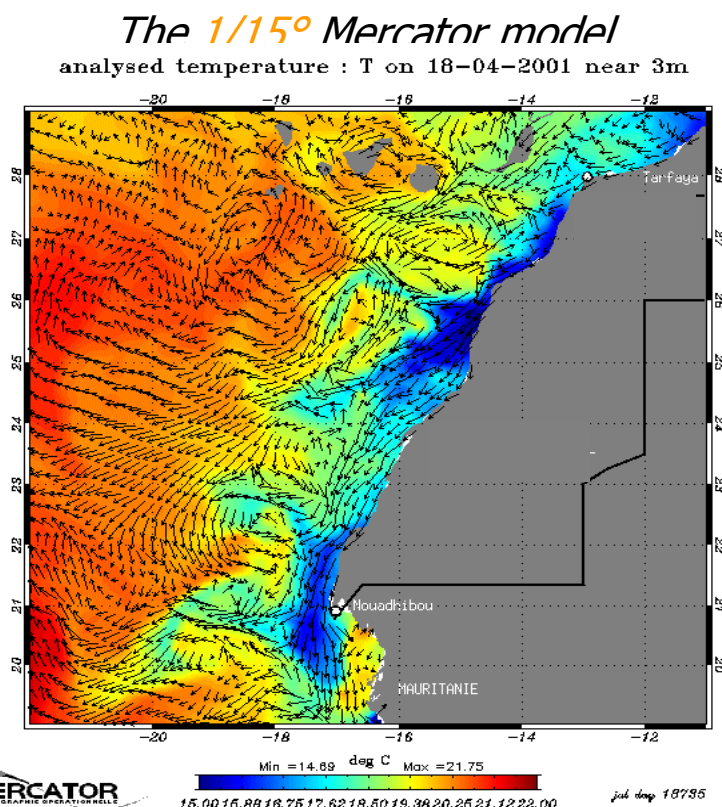
[http://www.altimetrie.net/docs/GAMBLE\\_OWS\\_mercator.pdf](http://www.altimetrie.net/docs/GAMBLE_OWS_mercator.pdf)

Mercator is a 4-D ocean nowcast and prediction system, a product of cooperation between a number of French agencies. It is based upon a series of operational ocean circulation models, which assimilate satellite and in-situ data, and provide analysis and forecasts of ocean parameters at different levels throughout the water column.

Early demonstrations have shown the ability of the system to provide realistic representations of fields associated with coastal upwelling, eddies, meddies and the loop current in the Gulf of Mexico.

By the summer of 2003 global products will be available, weekly, at a 1/3° resolution, by June 2003 products will be available for the Atlantic at 1/6° resolution and for the Mediterranean at 1/8° resolution. Each weekly set of information provides forecasts up to 2 weeks in advance. Parameters include temperature, velocities and salinity, throughout the water column.

Website at <http://www.mercator-ocean.fr>.



Example  
1/15°



of Mercator  
model

output showing upwelling off the North-West African Coast, temperature at 3m depth and surface currents. For 18 April 2001.

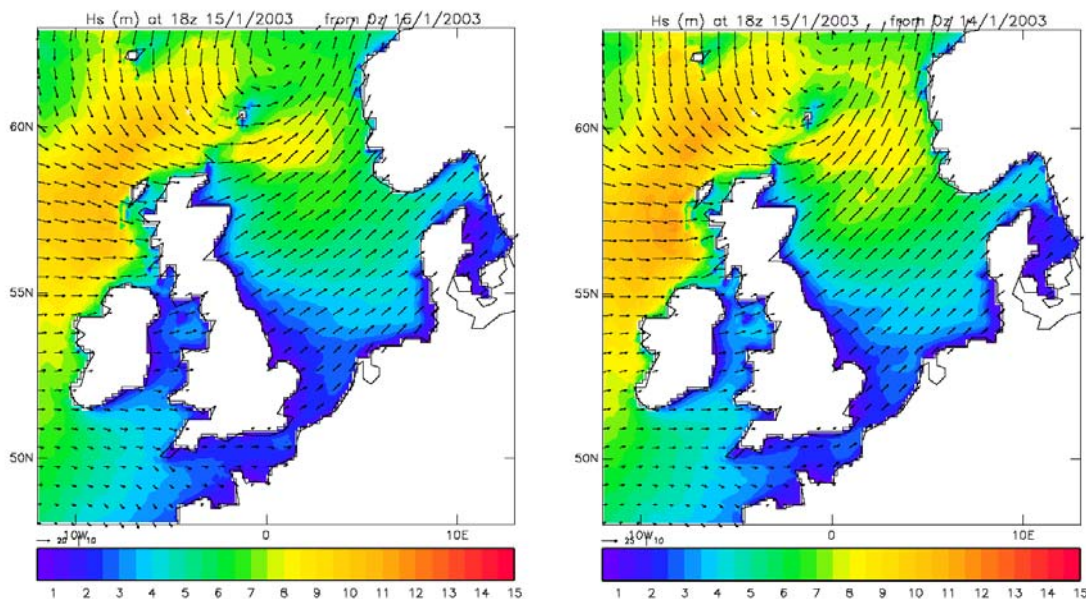
### 3.3 Wave Modelling at the UK Meteorological Office (J. Gunson, UKMO, UK)

[http://www.altimetric.net/docs/GAMBLE\\_OWS\\_ukmo.pdf](http://www.altimetric.net/docs/GAMBLE_OWS_ukmo.pdf)

The UK Meteorological Office routinely runs a number of ocean models to provide forecasts for a wide range of clients. These include the coupled ocean atmosphere model, FOAM (Forecast Ocean Atmosphere Model), the shelf seas model, and global and regional wave models.

The UKMO runs an operational second generation wave model, at three scales: Global (  $5/6^\circ$  long x  $5/9^\circ$  lat 60km grid at mid-latitudes); European ( $0.4^\circ$  long x  $0.25^\circ$  lat – 35 km); and UK ( $1/6^\circ$  - 12km). The latter includes wave current interactions. Products are available twice daily with forecasts to 5 days. Parameters include integrated parameters (e.g.  $H_s$  and  $T_p$ ) and 1-D and 2-D spectra (the latter at specified grid-points on request). Altimeter data (ERS-2) are assimilated into the model.

Future developments include investigations into the development of diagnostics for conditions favourable for the occurrence of rogue waves and further assessments on how assimilation of satellite radar measurements can improve model predictions. In addition, one of the biggest problems is believed to be the accurate modelling of the propagation of swell, which may have relatively low amplitude but long period. Altimeter data may be able to improve models significantly in this respect.



*Hindcast (left panel) and forecast (Right Panel) of a severe wave event to the NW of Scotland on 15 Jan 2003).*

### 3.4 Multiple altimeter sampling – Case study of the 15/01/03 Schiehallion event. (D Cotton, SOS, UK)

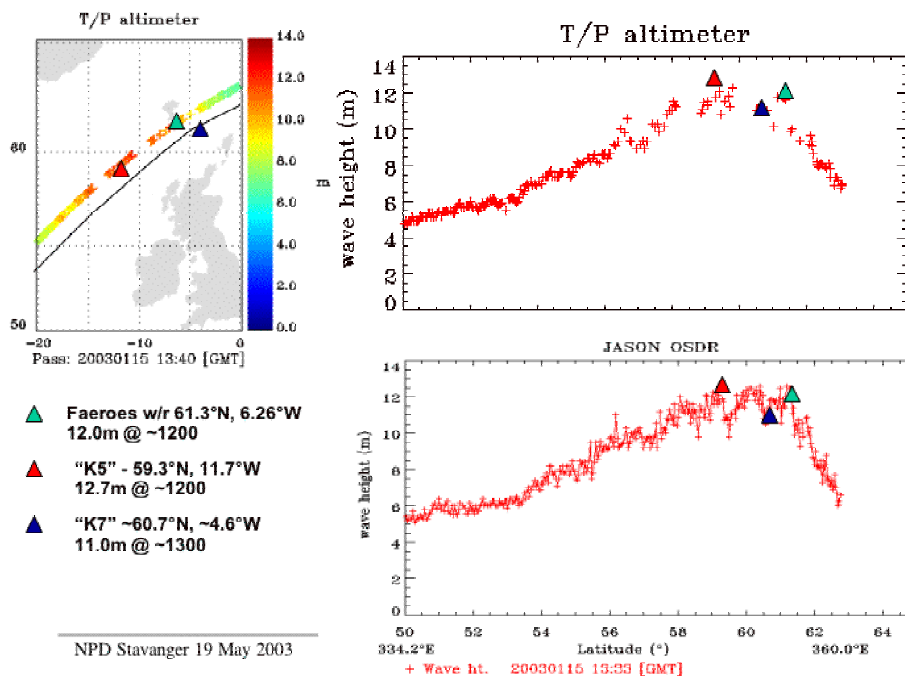
[http://www.altimetry.net/docs/GAMBLE\\_OWS\\_sampling.pdf](http://www.altimetry.net/docs/GAMBLE_OWS_sampling.pdf)

On January 15<sup>th</sup> 2003 a storm accompanied by particularly high waves passed to the North of Scotland, close to the BP Schiehallion and Foinaven fields. At one point the significant wave heights were predicted to be 17m, close to that of the 100 year return value. Buoys in the region measured sig. wave hts of 12-14.8 m.

Jason, Topex, ERS2 and ENVISAT passed over the storm. The maximum altimeter measured significant wave heights were 12m (Jason and Topex) and 16m (ENVISAT and ERS2). ENVISAT and ERS-2 measured conditions earlier in the day, and closer to the peak of the storm. The altimeter measurements were seen to be consistent with available in-situ data.

A number of issues were highlighted:

- Severe events are difficult to model, they change quickly in space & time.
- Jason, Envisat and ERS2 data are available in real time (1-3 hours). Could these data have been used to support operational decisions?
- What is the best way to use of such data: assimilation into models to improve accuracy; or validation of independent model forecasts?
- Even if there were a perfect description 100-200 km “upwind” and 1 hour in advance - how accurately can models predict subsequent development?
- How much warning is required of such events to enable defensive actions?
- Emphasises the need for real time data for operational decision support (ideally <1 hour).
- This event provided confirmation that the altimeter & buoy measurements of significant wave height agree well up to  $H_s = 12+m$ .



*Satellite altimeter measured significant wave heights (Topex and Jason) NW of Scotland during severe conditions on 15 January 2003.*

### **3.5 Summary of Expected Developments in Altimeter Derived Data Products**

#### **Sea Surface Topography / Ocean Currents**

- Improved ocean current products are becoming available.
- Interpolated and gridded sea level anomalies and surface current fields. Available as 5-7 day averages, at resolutions of up to  $1/3^\circ$ .
- Forecasts and analyses of surface and subsurface currents are available from coupled ocean circulation models. Resolutions range from  $1/3^\circ$  (global) to  $1/8^\circ$  or better in regional models.

#### **Ocean Waves**

- Forecasts and analyses (hindcasts) are available from global and regional wave models which routinely assimilate satellite altimeter data. Resolutions range from 60km (global) to 12km (regional)
- Research is ongoing, aiming to provide improved representation of swell and identification of conditions favourable for "rogue waves".
- A case study shows that in-situ and satellite altimeter data are consistent for significant wave heights to 12m.
- Severe events are difficult to predict.

#### **4. User Priorities for ocean current and sea state data over the next decade.**

In this section we include contributions from OGP members and representatives of the offshore service industry, outlining present requirements and expected developments.

##### **4.1 Operational Oceanographic Needs for the Offshore Oil and Gas Industry.**

[http://www.altimetric.net/docs/GAMBLE\\_OWS\\_OGPreqs\\_20021.pdf](http://www.altimetric.net/docs/GAMBLE_OWS_OGPreqs_20021.pdf)

A recent overview of user requirements from the perspective of the OGP community was given in an article by Chris Shaw and Colin Grant in a paper published in the GOOS products and service bulletin (full paper available at the location given above).

The authors summarised requirements in terms of: Statutory requirements, operations support, short term forecasts, design and operational planning, and lifetime performance monitoring.

They indicated that the most important parameter for offshore operations was wave height followed by wave period, wind speed and ocean currents. Other metocean parameters required are water elevation, air and sea temperature, visibility, cloud height and sea ice.

It was noted that new techniques and equipment were required for deep water operations which were more vulnerable to long period swell and ocean currents. New models have been developed which couple rig response models to wave model output, to provide forecasts of rig "heave". At the time that the article was written (Spring 2001) it was believed that the ocean current products then available were not yet sufficiently mature to be able to provide the same level of added value as wave products.

## 4.2 Offshore renewable energy, and other sectors of interest (Mark Calverly Fugro-Geos UK).

[http://www.altimetric.net/docs/GAMBLE\\_OWS\\_Fgeos.pdf](http://www.altimetric.net/docs/GAMBLE_OWS_Fgeos.pdf)

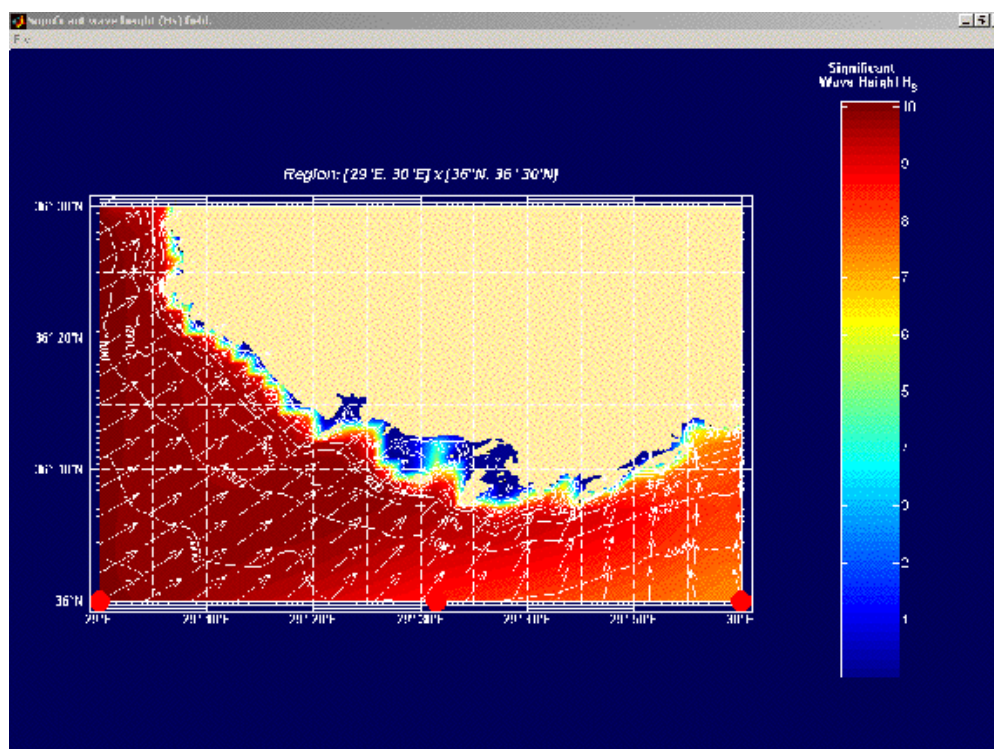
The offshore renewables market is expected to grow significantly in the coming years (a predicted tenfold increase between 2010 and 2020). The largest potential wind power resource in Europe lies in the coastal waters around the UK.

Because of the necessity to connect offshore generators to a land based distribution network, most of these installations will be developed in shallow water and close to the coast. Thus there is anticipated to be limited direct use of altimeter data, which may be best applied to validate shallow water models, and/or to provide (deepwater) boundary conditions for these models. These data can be used: to establish the level of potential wind or wave resources; to inform the design process; to support operational decision making (during installation or maintenance).

For assessing coastal wave climate Fugro-Geos use a package which runs a shallow water wave model (SWAN) over a high resolution local bathymetry, using climatology from the global ECMWF wavemodel as boundary conditions.

Anticipated that developments include the addition of new statistical modules for wind and wave energy assessments, including resource assessments, extreme analysis and influence of climate change on the resource.

New wind models are being considered both for coastal wind transformations and for predictions at various exposure levels.



*Example of coastal wave climatology off the SW coast of Turkey.*

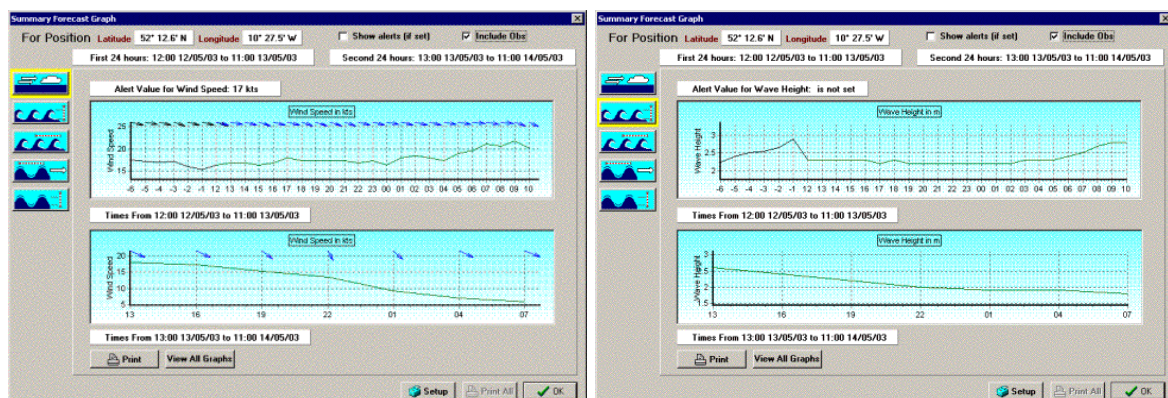
### 4.3 Observations, short term forecasts and technology for increased user confidence - Mark White. Nowcasting International.

[http://www.altimetrie.net/docs/GAMBLE\\_OWS\\_Nowcasting.pdf](http://www.altimetrie.net/docs/GAMBLE_OWS_Nowcasting.pdf)

Nowcasting International are a private Irish company who act as brokers of weather information. Their speciality lies in the communication and presentation of met-ocean information in a form more accessible to offshore users. They argue that whilst improvements in models and measurements in recent years have led to higher resolution forecasts with better accuracy, the presentation and delivery of data to users has been slower to evolve. Data should be formatted and systems established so that a specific set of required information is easily transmitted under the control of the customer.

At the moment such services that are available direct to the offshore user tend to be limited to "conventional" met-ocean data (winds, waves) – they could be broadened to include surface and sub-surface currents, sea surface temperature.

In addition more use could be made through intelligent comparisons of observations (in-situ or satellite) made close by the area of interest, with a view to establishing a confidence level in the model forecasts.



*Examples of Nowcasting output – time series of predicted wind speeds and wave heights.*

## 5. Discussion, identification of priorities.

[http://www.altimetry.net/docs/GAMBLE\\_OWS\\_discussion.pdf](http://www.altimetry.net/docs/GAMBLE_OWS_discussion.pdf)

The presentations from data providers gave an overview of the types of products now available, and of developments expected in the near future. Presentations from users and service providers anticipated future requirements. Participants were asked to consider the following points:

What are the most important parameters in each category?

- Waves
- Winds
- Currents (surface, sub surface)

What are the priorities for improved provision?

- Improved spatial and temporal resolution?
- Improved precision?
- Improved accuracy / reliability?
- Better coverage close to coasts?
- More easily accessible information?

What is the best route to achieve these improvements?

- Better models – improved assimilation techniques.
- New satellite technology
- Higher density satellite sampling

What are the priorities for new research?

“Rogue” waves, improved predictions of swell, improved predictions of severe events,...

A general discussion highlighted some issues:

### *Ocean Currents*

- Although wave heights continued to be the “most important” parameter for planning, design and operations, the biggest uncertainties lay in gaining accurate knowledge of ocean currents. Participants were aware of the potential of satellite altimeter data to improve our knowledge of ocean currents, and some had made use of sites such as those maintained by the University of Colorado. However, there was still felt to be a deficiency in the quality and amount of ocean current information that was available.
- It had been observed that currents derived from altimetry often seemed to be lower than those directly observed offshore. Could this be a resolution problem, or something more fundamental?
- Daily to weekly surface current charts were regarded as providing sufficiently temporal resolution – spatial resolution was seen as a bigger problem.

### *Ocean Waves*

- Improved spatial and temporal resolution in waves is also important.
- Wave period measurements are important even at low wave heights. Long, low swells can create problems. Areas of particular interest in this respect are West Africa and North East Asia (specifically Sakhalin)
- Wave direction is important for design as well as for operational use.
- A particular problem at higher latitudes is the sudden development of polar lows. These can generate severe wave conditions which models are unable to predict accurately. More satellite measurements at latitudes poleward of 60° could help to make a significant improvement.

### **Recommendations**

- It was suggested that the OGP community test out the data sets offered by MERCATOR and CLS (web site addresses are given in section 3).
- It was suggested that OGP might wish to identify a region of particular common interest and the GAMBLE team could look into the possibility of establishing a web-site providing central access to a range of sources of relevant information.

### **Further Contributions**

We are grateful to all participants for their contributions to the workshop. We would now value further contributions from the user community, to assist us in identifying the areas in which improvements to altimeter derived data products would be most useful.

In particular we would welcome comments on:

1. Which improvements/developments to altimeter data provision have the highest priority for your operations:
  - a. Now
  - b. in 5-10 years time

Please identify which parameters are of greatest interest, and indicate necessary accuracy, resolution.

2. Can you identify relevant areas of research of particular interest? (e.g. rogue waves, development of reliability indices for predictions,...)
3. It may be possible to set-up a trial web-site, providing access/links to satellite derived information for a geographical area of mutual interest. If such a proposal would be of interest, could you suggest possible areas and indicate which geophysical parameters would be required?

We would like to initiate a time-limited discussion on these issues via email. A mailing list "gamble-operators" has been set up on the GAMBLE website (<http://www.altimetrie.net>) . If you wish to participate in the discussion please subscribe by clicking on the "Mailing lists" link or go directly to <http://www.altimetrie.net/maillinglists.shtml>.

If you do not wish to join the email list, but have comments to make, please email to [gamble-operators@deos.tudelft.nl](mailto:gamble-operators@deos.tudelft.nl)

**Finally**

Many thanks to all contributors. We will be circulating these notes to a wider audience and encourage all of you to pass them to colleagues. Please continue to discuss these issues amongst yourselves, and pass on comments to us.

**Acknowledgements:**

Many thanks to Chris Shaw, (Chair OGP MetOcean Committee), the local organisers at NPD, and to the OGP MetOcean Committee – all of whom provided essential and appreciated support to allow the GAMBLE workshop to take place within the JIP week.

## Appendix 1

### Glossary of Terms and Acronyms

<b>AltiKa</b>	A proposed Ka band altimeter on a microsatellite.
<b>CLS</b>	Collecte Localisation Satellites.
<b>CNES</b>	Centre National D' Etudes Spatiales.
<b>DUACS</b>	"Developing Use of Altimetry for Climate Studies", a near real time multi-mission altimeter data processing system.
<b>EC</b>	European Commission
<b>ECMWF</b>	European Centre for Medium Range Weather Forecasting.
<b>ERS-1, ERS-2, ENVISAT</b>	ESA remote sensing satellites, all carrying altimeters.
<b>EUMETSAT</b>	European organisation for the exploitation of meteorological satellites.
<b>FOAM</b>	Foecasting Ocean Atmosphere Model (UK)
<b>GANDER</b>	A proposed a constellation of wave measuring altimeters on micro-satellites.
<b>Geosat, Geosat Follow-On (GFO)</b>	US Navy satellite altimeter missions.
<b>GOOS</b>	Global Ocean Observing System.
<b>Hs</b>	Significant Wave Height
<b>OGP</b>	International Association of Oil and Gas Producers
<b>JIP</b>	OGP MetOcean committee Joint Industry Project
<b>NASA</b>	(US) National Aeronautics and Space Administration
<b>NOAA</b>	(US) National Oceanographic and Atmospheric Administration
<b>NPOESS</b>	(US) National Polar Orbiting Operational Environmental Satellite System – A series of earth observing satellites.
<b>SOS</b>	Satellite Observing Systems (UK)
<b>SWAN</b>	Shallow Water Wave Model
<b>SWIMSAT</b>	A proposed a wave measuring satellite radar.
<b>TOPEX/Poseidon, Jason</b>	US/French satellite altimeter missions.
<b>Tp</b>	Peak wave period
<b>UKMO</b>	United Kingdom Meteorological Office

**Appendix 2****Attendees at GAMBLE Offshore Operators' workshop  
NPD Stavanger Monday 19<sup>th</sup> May 2003***OGP*

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*Invited by GAMBLE*

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Mark White	Nowcasting Intl	mark.white@nowcasting.ie

## Appendix 3 Other Gamble Documentation of Interest

### *Documentation Web Page*

<http://www.altimetry.net/documents/shtml>

### *Reports on New Altimeter concepts*

Alcatel report: Radar state of the art and new concepts for GAMBLE

[http://www.altimetry.net/docs/alcatel\\_altconcepts.pdf](http://www.altimetry.net/docs/alcatel_altconcepts.pdf)

ALTIKA: A micro-satellite Ka-band altimetry mission

<http://www.altimetry.net/documents/altika.pdf>

WITTEX: A multi-satellite delay doppler radar altimeter proposal

<http://www.altimetry.net/documents/wittex.pdf>

WSOA: The measurement capabilities of wide-swath ocean altimeters

<http://www.altimetry.net/documents/wsoa.pdf>

High-resolution ocean topography from GPS reflections

<http://www.altimetry.net/documents/gps.pdf>

SWIMSAT – A wave measuring satellite radar

[http://www.altimetry.net/documents/GAMBLE\\_kickoff\\_swimsat.pdf](http://www.altimetry.net/documents/GAMBLE_kickoff_swimsat.pdf)

GANDER – A proposal for a constellation of wave measuring micro-satellites

[http://www.altimetry.net/documents/GAMBLE\\_delft\\_cotton\\_gander.pdf](http://www.altimetry.net/documents/GAMBLE_delft_cotton_gander.pdf)

### *GAMBLE “Theme” Reports*

Theme 1 Final Report: Sea height error budgets, feature detectibility:

[http://www.altimetry.net/documents/GAMBLE\\_finalreport\\_theme1.pdf](http://www.altimetry.net/documents/GAMBLE_finalreport_theme1.pdf)

Supplementary Theme 1 Report: The contribution of the TOPEX/Poseidon - Jason 1 tandem mission to meso-scale variability studies

[http://www.altimetry.net/documents/tandem\\_report\\_gamble.pdf](http://www.altimetry.net/documents/tandem_report_gamble.pdf)

Theme 2 Final Report: Sea state error budgets, feature detectibility:

[http://www.altimetry.net/documents/GAMBLE\\_finalreport\\_theme2\\_030126.pdf](http://www.altimetry.net/documents/GAMBLE_finalreport_theme2_030126.pdf)

Theme 3 Final Report: Orbit determination and satellite tracking:

[http://www.altimetry.net/documents/GAMBLE\\_finalreport\\_theme3.pdf](http://www.altimetry.net/documents/GAMBLE_finalreport_theme3.pdf)