TECHNIQUES AND BENEFITS OF SATELLITE DATA IN WIND AND WAVE MODELS

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CONTENTS

FOREWORD

This report documents techniques and benefits of satellite data in wind and wave models. It provides an overview of available satellite wind and wave data and their possible usage based on the questionnaire prepared by the Expert Team on Wind Waves and Storm Surges (ETWS) to collect information on Members' use of wind and wave satellite data, in particular, regarding type of sensor used, satellite name, real time use, product name, data format, provider, areas of concern, purpose of use, quality control and status of the data use. The compilation of the questionnaires' replies contributes to disseminate information about satellite data, to motivate more interest in satellite data and to provide some guidance for future satellite sensors.

A brief description of various satellite instruments that provide ocean wind and wave data is presented in Section 2. These satellite instruments produce a precious and extensive source of data, generally with global coverage. This has a significant importance for atmospheric and wave models, as they can combine these types of data with other data sources, using assimilation techniques to produce the best estimate of the atmosphere and the oceans states. Such data can also be used for climate and various model verification studies. Section 3 summarizes all purposes of use satellite data, and Section 4 lists several concluding remarks.

1. INTRODUCTION

A questionnaire to collect information on the use of wind and wave satellite data was proposed by the Expert Team on Wind Waves and Storm Surges (ETWS) and sent by WMO secretariat to all member countries on August 13, 2004. The questionnaire (see Appendix A) was organized to collect information such as: type of sensor used, satellite name, real time use, product name, data format, provider, areas of concern, purpose of use, quality control and status of the data use. Replies from 43 countries were registered by the end of 2004. The replies were checked and analyzed. Some results of this analysis are provided in Appendix B. About 45 % of the countries use satellite surface wind and wave data for oceanic and marine activities. The compilation of the replies should serve to disseminate information about satellite data, to provoke more interest in satellite data and to provide some guidance for future satellite sensors.

This report provides an overview of available satellite wind and wave data and their possible usage. Section 2 presents a brief description of various satellite instruments that provide ocean wind and wave data. Satellite instruments produce an invaluable and extensive source of data, generally with global coverage. This has a significant importance for atmospheric and wave models as they can blend these types of data with other data sources using assimilation techniques to produce the best estimate of the state of the atmosphere and the oceans. Such data can also be used for climate and various model verification studies. All those uses of satellite data are summarized in Section 3. Finally, several concluding remarks are listed in Section 4.

2. DESCRIPTION OF SENSORS

2.1 Radar Altimeters (RA)

RA is a nadir-looking active microwave device that measures, with high accuracy, the time delay, the power and the shape of the reflected radar pulses for the determination of the satellite height with respect to ground surface and the surface characteristics. The shape and the intensity of the reflected radar pulses contain information on the characteristics of the surface that caused the reflection. Operating over oceans, the shape of the echo is used to determine the significant wave height (SWH) while the power intensity is translated into surface wind speed through its relation to the sea-surface roughness.

SWH is determined along the satellite track by the half-power slope of the radar pulse waveform. The pulse duration is about 3 ns. The measurement is made over an area corresponding to the radar footprint. The footprint diameter depends on the SWH itself and can vary from 2 to 8 km over the 1-23 m range of SWH. The geophysical parameters are provided every second and are obtained by averaging the 20-Hz measurements made by altimeter. Because the pulse repetition rate varies from typically 1000-4000 pulses per second, typically 50-200 waveforms are averaged in order to get one measurement every 50 ms. Information about the noise of these 20-Hz measurements is also provided and can be used for quality control.

RA is a main component of the payload of different satellites like Seasat, Geosat, ERS-1/2, TOPEX/Poseidon, GFO, ENVISAT and Jason. For operational models, the data need to be available in near-real time (NRT) (i.e. within a few hours or less). ERS-1, ERS-2, ENVISAT and Jason provide fast delivery products in NRT. Figure 1 shows the SWH from RA instruments onboard Jason and ENVISAT during a typical 6-hour time window.

The standard accuracy specifications state that the accuracy of the RA SWH is typically better than 0.5 m or 10% while the wind speed accuracy is 1.5-2 m/s (for wind speed between 0 and 20 m/s). However, Janssen et al. (2006) found that for ERS-2, the 20-Hz RA SWH is accurate within ~7%. They also found that ENVISAT RA SWH is slightly more accurate.

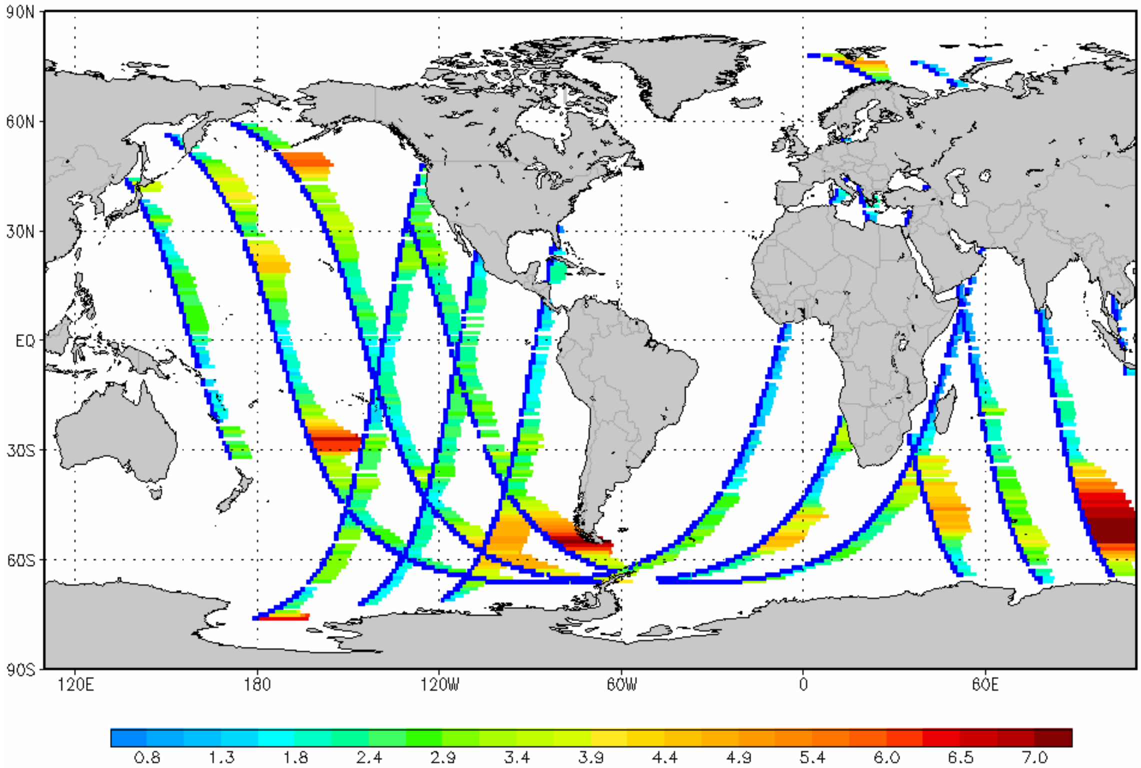

Figure 1: SWH data from Jason and ENVISAT along tracks during a 6-hour period plotted as coloured bar diagrams along the ground tracks.

2.2 Synthetic and Real Aperture Radar (SAR/RAR)

The SAR antenna consists of a coherent, active array of radar transmitter/receiver elements that operate usually at C-Band. The long axis of the SAR antenna is aligned in the direction of the satellite track (azimuth direction). It images a strip of ground at an angle to one side of the satellite (range direction). The SAR produces two-dimensional representation of the surface reflectivity. Usually the SAR instrument operates in different modes. Wave mode is the one with interest to wave modeling. In this mode, SAR senses the changes in the backscatter from the ocean surface, mainly due to the action of long ocean waves (swell). As a result, it produces small images in the order of ~5 km x ~5 km at a given spacing of few hundred kilometers. Those small images are processed to produce what is known as SAR spectra. The SAR spectra are then inverted into ocean wave spectra. This inversion process is not straightforward (see Hasselmann et al., 1996). Furthermore, SAR images can also be processed to extract surface wind fields as demonstrated by Horstmann et al. (2003).

SAR is currently the only satellite-borne instrument that is able to provide spectral representation of the sea state. However, the image of the ocean surface seen by a satellite-borne SAR may be very different from reality because of the motion at the ocean surface. This induces, by Doppler effect, a distortion of the image in the azimuth direction. Only wave components with wavelengths exceeding 150-300 m (depending on the conditions) can be sensed by SAR in the azimuth direction. Effectively this effect imposes a wavelength limit below which the SAR spectrum cannot be trusted. This limit is called the azimuthal cut-off wavelength. In practice, it means that the waves that are locally generated by the wind (the so-called wind sea) are not properly imaged. However, the accuracy of the SAR for waves longer than 200-300 m is satisfactory for some offshore industry applications (c.f. Mastenbroek and de Valk, 1998). In the range direction, the SAR wavelength limit is reduced to the SAR resolution, which is around 100 m.

The inversion of a SAR spectrum into a full ocean wave spectrum requires a priori knowledge of the wind sea to overcome the above-mentioned limitations. External data are thus necessary. It may be provided for instance by a model first-guess (Hasselmann et al., 1996, Schulz-Stellenfleth et al. 2005) or by using collocated scatterometer wind data (Mastenbroek and de Valk, 1998). It is difficult, however, to estimate the impact of an error in the estimation of the wind sea on the quality of the restored spectrum. Another possibility for using SAR data is to extract from the signal only some partial information (Johnsen et al. 2002). A different alternative is to only recover integrated parameters, such as wave height and mean wave periods, without retrieving the wave spectrum, as proposed by Schulz-Stellenfleth et al. (2006).

SAR is available onboard several satellites like Seasat, ERS-1, ERS-2 and ENVISAT. The latter three are able to provide SAR spectra in NRT. ENVISAT has an advanced SAR (ASAR) instrument with several improvements over its predecessors.

In order to remove most of the problems, mainly due to the synthetic-aperture concept, an alternative to the SAR was first proposed by Jackson et al (1985). The Real Aperture Radar, RAR, is now the subject of the SWIMSAT project (Hauser et al., 2001) for the measurement of the wave spectrum. The radar points to the surface at small incidence angle (less or about 10°) and uses a scanning beam in the azimuth direction. The instrument can generate a complete wave spectrum for an area of approximately 50 x 70 km if the sea state is homogeneous within this area. The along-track variability can be estimated by the nadir antenna, which gives the SWH along the satellite track. In any case, the instrument provides spectral information in each footprint of about 18 km of diameter.

2.3 Scatterometer

Scatterometer is an oblique-viewing active microwave radar (usually operating in either C-band or Ku Band) which accurately measures the power of the transmitted signal and its backscatter in order to calculate the normalised radar cross section of the ocean surface. The radar cross section depends on the surface roughness, the incidence angle (which is the angle between the radar beam and the vertical at the illuminated cell) and the azimuth angle (which is the horizontal angle between the wind and the antenna of the radar). Therefore, for given incidence and azimuth angles, the backscatter can be related to the wind speed. The geophysical function used for this inversion usually produces several wind speed solutions. The proper solution is quite often selected with the aid of Numerical Weather prediction (NWP) models (Hersbach, 2003).

Scatterometers provide wind speed measurements typically in the 2-28 m/s range with a typical resolution of 25-50 km over a swath of 500-1000 km. According to specifications, the typical accuracy of the scatterometer is 2 m/s. However, a triple collocation of ERS scatterometer measurements with buoy and ECMWF model values shows that the standard deviation of error for wind speed is less than 1.0 m/s and for wind direction is about 15° (see Abdalla and Hersbach, 2006). ERS-1, ERS-2 and QuikSCAT are among the few satellites equipped with a scatterometer instrument. About 45% of the countries from questionnaires are using satellite wind information from scatterometers.

2.4 Special Sensor Microwave/Imager (SMM/I)

SMM/I is a passive multi-frequencies microwave sensor consisting of seven separate radars providing measurements of brightness temperature at 19, 37 and 85 GHz with vertical and horizontal polarizations and 22 GHz with vertical polarization only. Surface wind speed is among the geophysical parameters retrieved from the 7 brightness temperature values. The microwave energy emitted from the ocean surface is related to the ocean surface roughness, which in turn, is influenced by the surface wind stress (see Wentz, 1997). The surface roughness is transformed into wind speed assuming that the boundary layer over the ocean is neutrally stable.

Observations are made over a swath of 1400 km width. Complete global coverage is achieved every 2-3 days (except for two small regions centered at the North and South poles). The spatial resolution ranges from 15 to 55 km. The typical accuracy of SMM/I wind speed is 2 m/s for the range 3-25 m/s. However, Wentz (1997) found that for a spatial resolution of 50 km, the wind speed root mean square retrieval accuracy is 0.9 m/s.

3. PURPOSE OF USE

3.1 Data Assimilation

Today, several operational numerical weather prediction (NWP) centres around the world run wave forecasting models that routinely assimilate satellite RA SWH data (Abdalla et al., 2004; Skandrani et al., 2004 and Greenslade 2001) and SAR directional wave spectra (Abdalla et al., 2003, 2004 and 2006). Wave data assimilation is not as advanced compared to what has been done in the area of atmospheric prediction models. Two main reasons can explain this situation. Firstly, contrary to weather forecasts, the wave forecast is strongly constrained by wind forcing. The evolution of the atmospheric conditions is mainly controlled by the atmospheric initial state, whereas the initial wave field loses its influence after a relatively short time ranging from a few hours to a few days depending mainly on the basin size, the sea-state conditions and on the atmospheric dynamic time scale. In theory, a perfect wave model driven by perfect wind fields would produce perfect wave fields after a certain time, whatever the initial state might have been. However, this is not the case for the atmospheric model for which unstable behaviour makes it very sensitive to its initial conditions. The second reason for the late introduction of wave data assimilation is that before the advent of the satellites, little reliable data were available for assimilation. Due to their sparseness, the assimilation of in-situ wave data has positive impact on local applications only (for example in the North Sea, Voorrips et al.). At one stage, the majority of in-situ sea-state data was estimated in a rather subjective way, based on human visual observations. This leads to a great uncertainty in the data, and renders them unsuitable for the purposes of numerical forecasts. However, such data are of unquestionable interest for the control and monitoring of NWP models.

The advent of satellite data encouraged NWP centres to study the possibility of including data assimilation schemes in their operational wave forecast suites. For wave analysis, the wind fields are provided from the analyses of the atmospheric models. Satellite wave data are assimilated to improve the initial sea-state used for wave forecast. Verified against in-situ wave measurements, the benefit of altimeter SWH data assimilation can be clearly seen in Figure 2. This impact is a result of the fact that the current wave models are far from being perfect. Moreover, the assimilation impact depends on the geographical region as suggested by Figure 3.

Data assimilation has a positive impact on wave forecast as can be seen in Figure 4. For that specific example, the impact lasts more than five days in terms of systematic error (bias) and less than three days for random error (root mean square error). The degree of improvement in the wave forecast achieved by assimilating wave data depends on the wave model itself, the accuracy of the forecast wind fields, the sea-state conditions and the assimilation procedure used.

The assimilation methods which were first developed were obviously the simplest and the least expensive in terms of computer resources. Several techniques are conceivable and can be classified into two categories: the sequential methods and the multi-time level methods. The assimilation techniques most commonly used for operational applications are based on the instantaneous sequential methods like Optimum Interpolation (OI) (e.g. Lionello et al., 1992) and successive corrections (e.g. Thomas, 1988). Such methods are very attractive due to their low computational cost. However, the corrections are done at a local scale, and at one time level. Furthermore, some constraints exist regarding the assimilation time step and the inability of directly identifying past model winds. Usually the assimilation of wave data is done in terms of a limited number of integrated parameters like SWH. This parameter is the wave data type most commonly available from satellite (from RA). The resulting analysis increment after applying the assimilation technique is then translated into corresponding distribution in the spectral domain (i.e. over all wave components with different frequency and directions). To do so, few assumptions are needed (Lionello et al. 1992, Greenslade 2001). Some of these assumptions, however, may not always be valid.

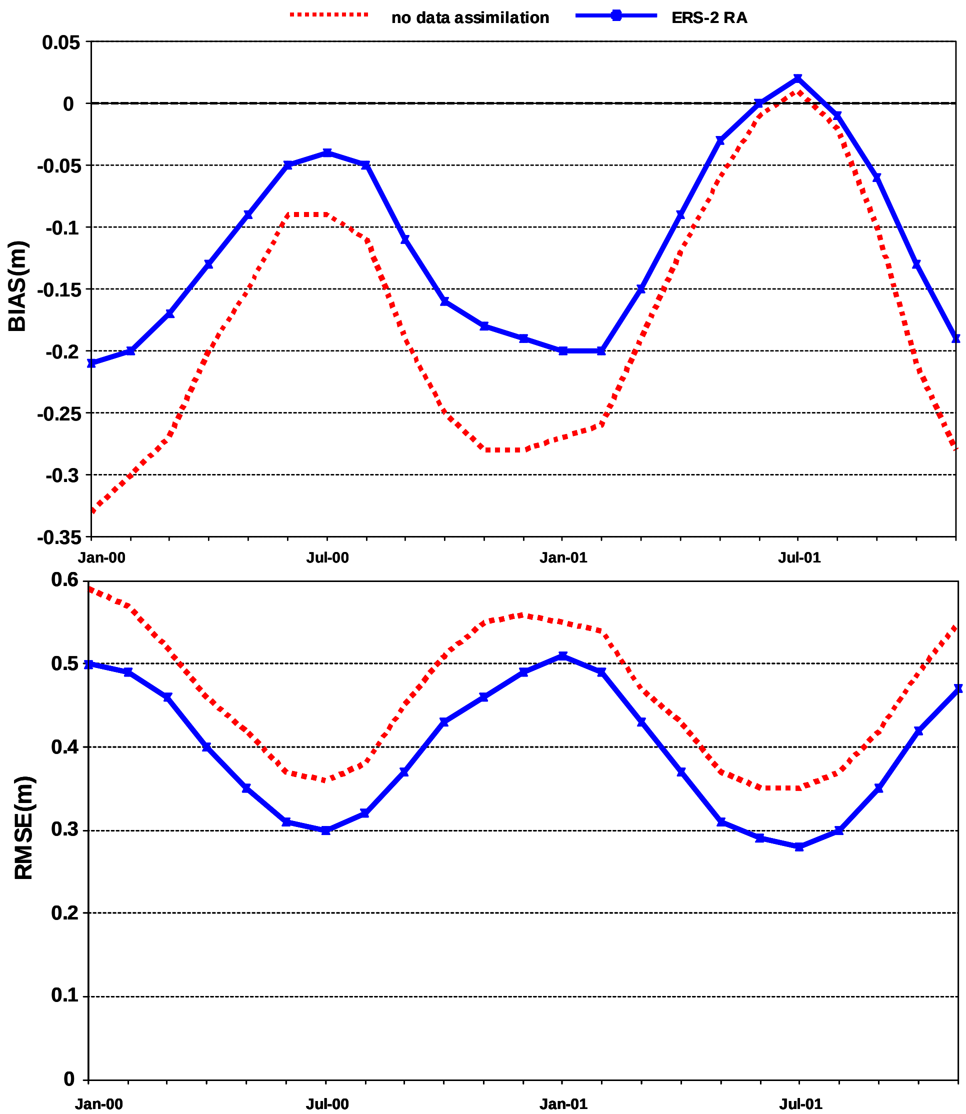

Figure 2: Impact of ERS-2 RA SWH data assimilation on ECMWF wave height analysis with respect to in-situ SWH observations for the whole years of 2000 and 2001 (see Abdalla et al., 2004) in terms of bias (model - observations) and root mean square error (RMSE).

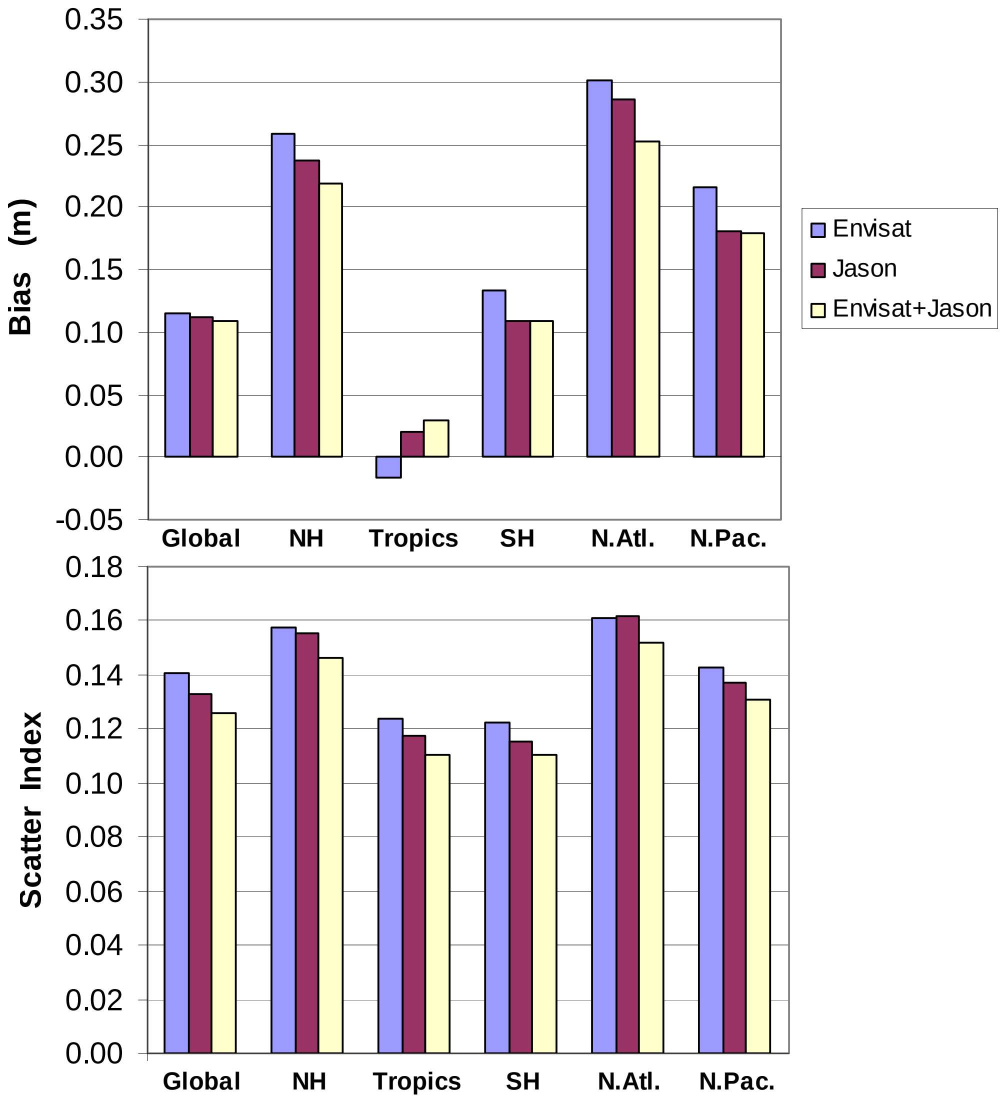

Figure 3: Impact of ENVISAT and Jason RA SWH assimilation on bias and scatter index for ECMWF wave model first guess against ENVISAT RA SWH for the period from 25 October to 12 November 2003 (see Abdalla et al., 2005).

Methods based on the Kalman Filter (KF) are multi-level in time. Furthermore, they are also able to provide error statistics on the model variables. The KF propagates a forecast error covariance matrix (FECM), which gives further information on the state of model. The problem of implementing these techniques arises from the dimension of the FECM, which then has implications on the required number of model integrations. Some simplifications are required to reduce the cost of such methods (Voorrips, 1998).

Advanced methods based on variational schemes have been developed as well. Such methods are based on the minimization of a cost function and often use the adjoint technique in order to compute the gradient of the cost function. Multi-level time variational techniques take into account the history of the observations under the constraint of the wave model dynamics. However the high cost of these methods has slowed down the speed of their development in the field of wave forecasting, although they are now widely used in the field of operational atmospheric forecasting. Some simplifications are always needed for operational implementations. For instance, a simplification of the tangent linear model as well as a reduction of its resolution allows a significant reduction of its cost. It is indeed necessary to carry out between 10 and 100 integrations of the adjoint of the linear tangent model to converge towards the optimum trajectory. This is tractable for operational purpose if a lower resolution is used for the model run in the minimization procedure. When applied to a wave model, such method can also estimate corrections to the wind forcing (Hersbach 1998). Moreover, the impacts of the observations are better propagated in space than with the OI scheme. Furthermore, variational schemes require fewer assumptions compared to OI schemes. The perfect model assumption is however needed for those models. The method is computationally expensive and its performance depends on the approximate Linear Tangent Model (LTM) used. A comparison study with an OI based method has been done by Voorrips and de Valk (1997). No advantage was found for the variational method probably because of a poorly calibrated LTM and poor error statistics.

An alternative to the technique of the adjoint is based on the Green functions and was proposed by Komen et al. (1994) and Bauer at al. (1996). Although it is much less expensive than the previous method, it relies on the use of rather strong assumptions. Green functions may be used to approximate the response of a spectrum to a disturbance in the forcing wind field. Contrary to four-dimensional (4-D) variational methods, this method minimizes a cost function, which takes into account observations at a single time only (Voorrips et al., 1998). However, these variational methods rely on the assumption of a perfect model as mentioned earlier. Moreover, they do not give an accurate estimate of the error on the restored trajectory or on the model forcing variables, like the wind vector.

Today most weather centres with wave modeling capabilities are only assimilating RA SWH data or are working towards doing so in the future. Assimilation procedures based on the OI or successive corrections techniques are usually used for that. The OI technique was first implemented for the WAM model at the European Centre for Medium-Range Weather Forecasts (ECMWF) in 1993, based on the work of Lionello et al. (1992). About the same time, the successive corrections technique, which is based on the work of Thomas (1988), was introduced at the United Kingdom Met Office (UKMO).

As previously mentioned, those low-cost assimilation techniques suffer several limitations that mainly follow from the distribution of SWH analysis increments over the whole wave spectrum. This involves several strong assumptions related to the distribution. So, progress in operational wave forecasting should come from the use of wave spectral information, which is also particularly important in coastal wave studies. The design of harbour protection, the layout of harbour entrance channels, coastal protection measures such as beach-fill or artificial dikes all depend critically on correct directional information. Additionally, spectral information is also very important for oil platform management and ship routing.

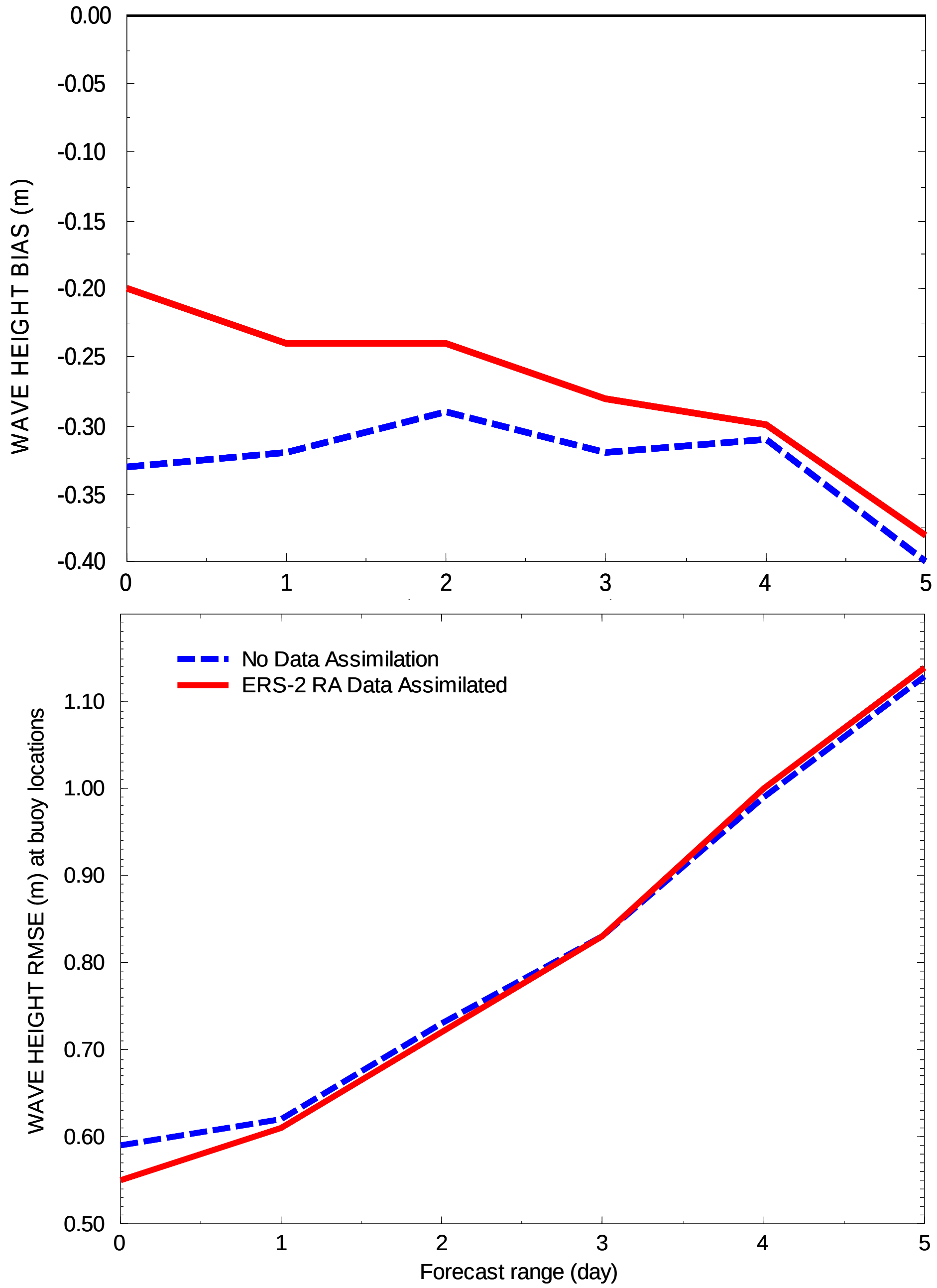

Figure 4: Impact of ERS-2 RA assimilation on bias and RMSE of SWH forecasts verified against the in-situ observations during January 1999 (see Abdalla et al., 2004)

SAR provides a unique opportunity for supplying some spectral information with global coverage. So far, however, very few centres assimilate SAR spectra for operational forecasts. ECMWF is the first to do so (Abdalla et al., 2003, 2004 and 2006), and few others are working towards that goal. Figure 5 shows the impact of ERS-2 SAR assimilation with and without RA on one-dimensional wave spectra compared to buoy measurements. In general, the assimilation procedure is based on an OI technique that is carried out on integrated parameters of wave systems identified by a partitioning technique proposed by Gerling (1991). This scheme was developed by Hasselmann et al. (1997). Other works were devoted to the contribution of assimilation of SAR data in the North Atlantic (Breivik et al. 1996) and at global scale (Aouf et al., 2005). In Breivik et al. (1996) the assimilation scheme used was based on a modification of the successive correction method but the impact of the assimilation was found not to be significant when compared with buoy measurements. Possible explanation is the absence of the long swell in the limited domain of the study. Aouf et al. (2005) incorporated the Voorrips (1997) assimilation method in a WAM model version to assimilate 2-D SAR spectra.

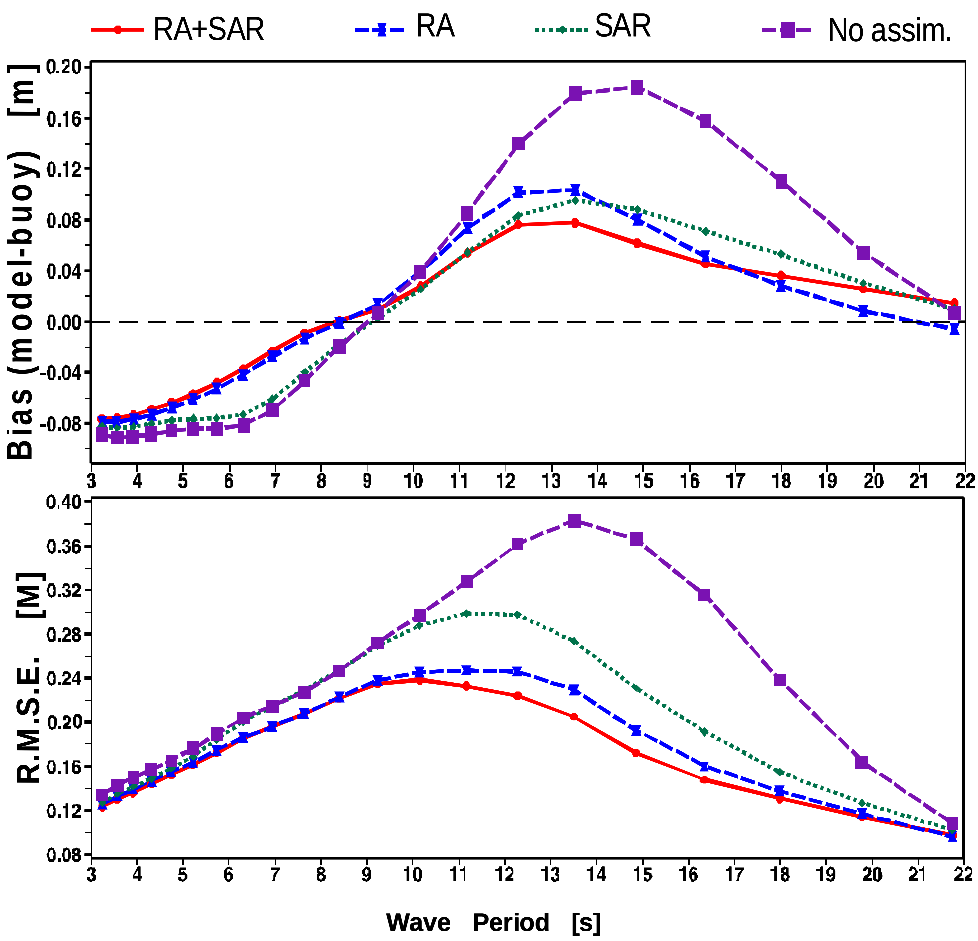

Figure 5: Impact of various assimilation set-ups (ERS-2 RA and SAR) on bias and RMSE of one-dimensional wave spectrum verified against the *in-situ* observations for 1-29 May 2001 (see Abdalla et al., 2004).

3.2 Climatology

Long-term climatological data over the sea are very important for several reasons, ranging from scientific knowledge to crucial applications such as marine safety and planning, design and construction of coastal and marine structures. Untill the late 1980's, the only source of data required for such statistics was the collection of in-situ observations (visual or buoy) with severe limitations. The launch of ERS-1, ERS-2 and Topex-Poseidon followed by ENVISAT and Jason offered an unprecedented continuous flow of wind and wave measurements. At the same time the improvements in computer resources and numerical modeling led to a continuous synoptic description of the oceanic wind and wave characteristics.

However, numerical models often fail in describing accurately strong events, especially in areas where strong spatial gradients exist, due to a complicated geometry of the basin, as in the case of the Mediterranean or other mountainous basin. Satellite measurements are very useful to correct such model biases. A combined satellite and model data set can be used to derive a global wind and wave atlas (Caires et al., 2005, http://www.knmi.nl/waveatlas) or a regional wind and wave atlas for the Mediterranean Sea (MEDATLAS; Stefanakos et al., 2004; see Figure 6).

Figure 6: Cover of the MEDATLAS electronic Wind and Wave Atlas.

3.3 Model Validation and Real-Time Monitoring

Wind and wave measurements from buoys are usually accepted as the ground truth for any validation exercise. Those buoys, however, are mainly located in coastal areas of the Northern Hemisphere, as can be seen in Figure 7. Therefore any validation and verification done against them will not be globally representative. One of the strengths of the satellite wind and wave data is their global coverage with uniform distribution over the oceans. This makes them very useful to locate wave model errors in order to improve the physical and numerical aspects of wave models. In some areas, satellite measurements are the sole source of data for model validation. For instance, the systematic difference between model and altimeter data for an area north of French

Polynesia in the South Pacific (Figure 8) indicated that global model did not properly treat the impact of small islands on wave propagation. A scheme for the treatment of unresolved bathymetry has since then been successfully introduced in operational models (Tolman 2003, Bidlot et al., 2005).

On the other hand, it is also important to mention that the well-tuned wave models that are using high quality winds can be used to verify satellite data. Extensive global and regional model-satellite wind and wave validations were carried out. For example, Abdalla (2005) and Abdalla and Hersbach (2006) made extensive global verification of ENVISAT and ERS, in respective order, wind and wave products against ECMWF models and available wave buoys. Figure 9 shows an example of such verifications. Another example is the work of Ardhuin et al. (2006) who used the offshore wind and wave data from Jason and ERS-2 to validate several numerical weather prediction models and wave prediction model over the Mediterranean Sea.

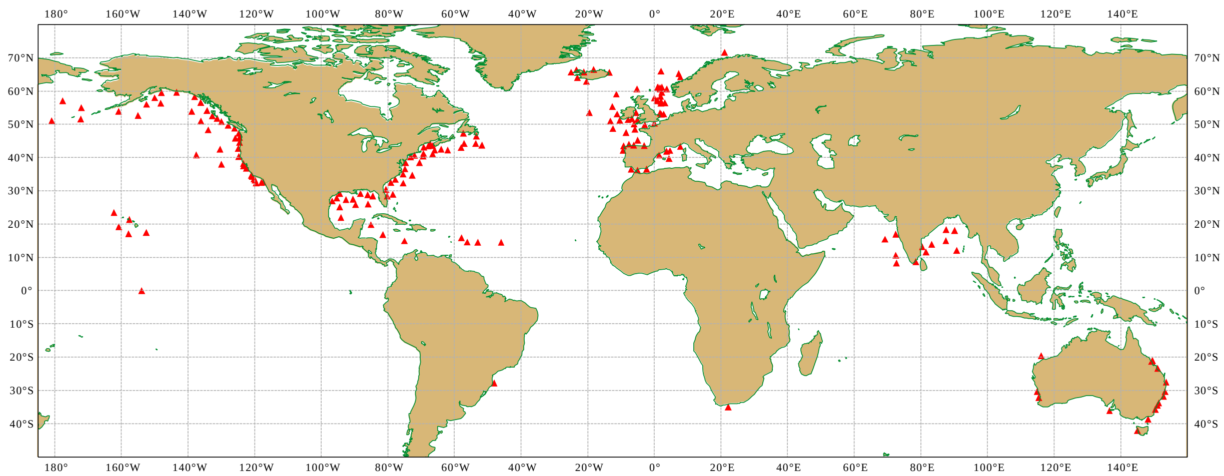

Figure 7: Fixed locations (red symbols) for ocean wave data regularly available on GTS in 2005 that can be used for global wave model validation.

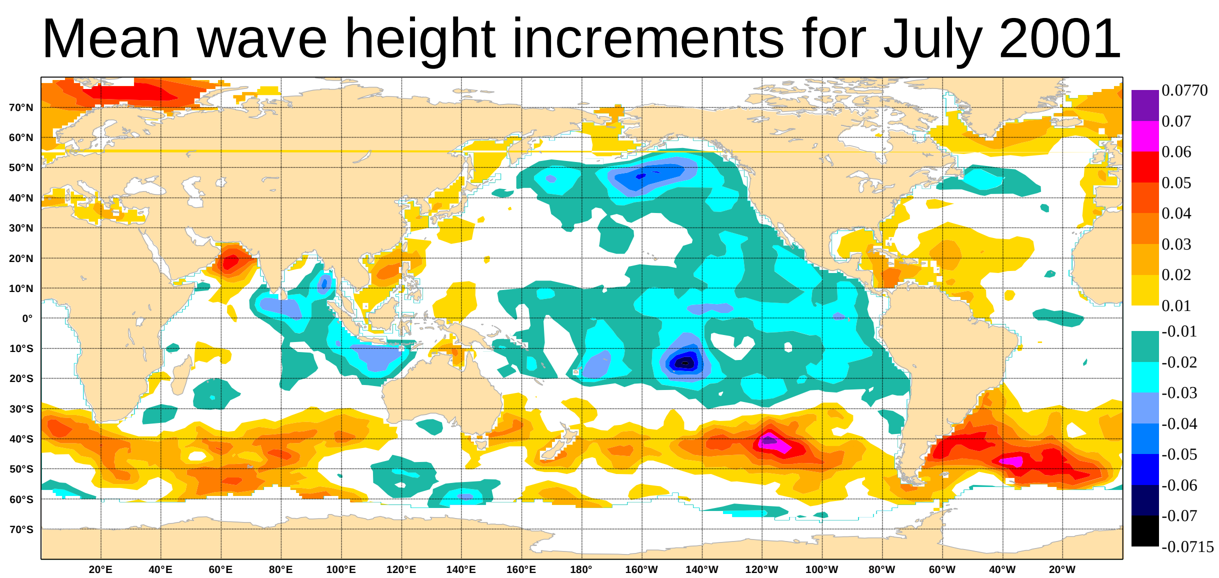

Figure 8: Mean wave height analysis increments (analysis - first guess) for July 2001 in the ECMWF model. ERS-2 RA data were used.

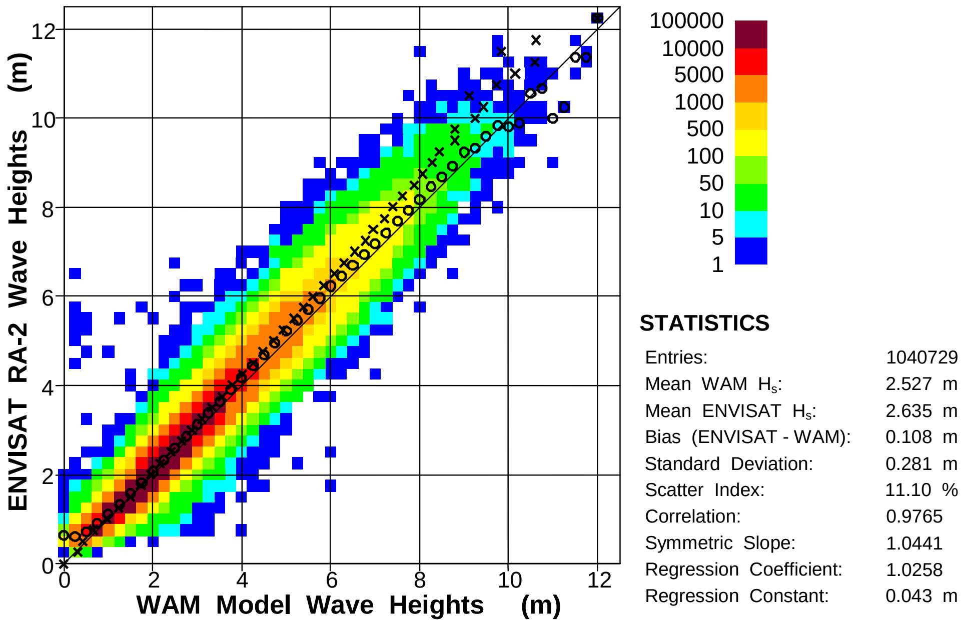

Figure 9: Global comparison between ENVISAT altimeter SWH and ECMWF wave model first guess for the period from 1 June 2005 to 1 June 2006.

4. CONCLUDING REMARKS

A summary of the available satellite wind and wave data and the characteristics of each type were presented. The usefulness of such data for data assimilation, model validation and climate computations was briefly demonstrated as well. Some of this type of data can be easily obtained in near real time (NRT) through the GTS (e.g. Jason, Quikscat, ERS-2) or can be made available in NRT on request from ESA (for ENVISAT). Irrespective of this fact, a questionnaire prepared by ETWS and distributed to the WMO member states revealed that about 55% (based on the number of replies) of the member states do not make use of the satellite wind and wave data. A first positive impact of the distribution of this questionnaire was to provoke some interest for such data among those countries.

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Annex I

JCOMM ETWS QUESTIONNAIRE

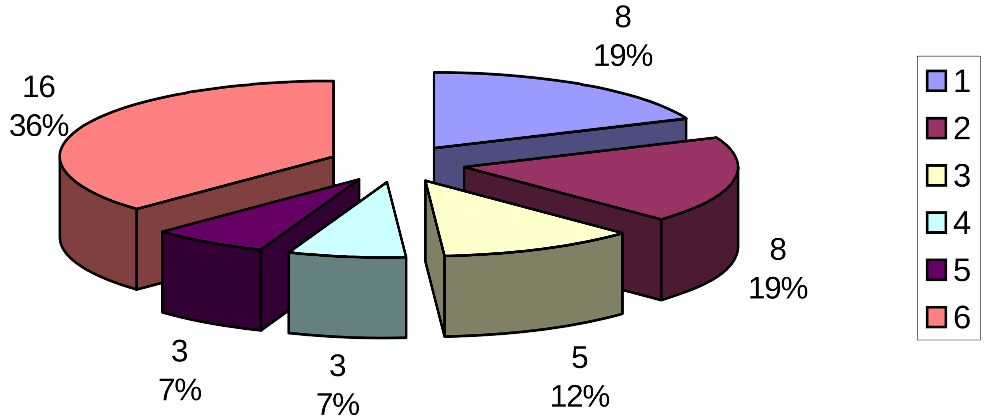
Identification
Member state/territory : Name of contact : Mailing address : Telephone : Fax : E-mail :
Does your service use **satellite** data for ocean surface wind wave related activities ? **If yes, please complete the column below for each type of data you use.**

	Data Type					
	Example for 2D.Wave Spectra	2D Wave Spectra	Significant Wave Height	Wind speed	Mean wave period	other
Do you use the data (Y or N)	Y					
Sensor : a. ASAR b. Altimeter c. Scatterometer d. Radiometer e. Other (please specify)	a					
Satellite name : a. JASON b. GFO c. ENVISAT d. ERS2 e.TOPEX/Poseidon f. Other (please specify)	c					
Availability : a. Real-time / fast delivery b. Off-line / delayed mode	a					
Product Name : a. Fdmar (ENVISAT), please specify in level 1 or 2 for ASAR b. OSDR (Jason) c. FDP (ERS2) d. other (please specify)	a. ASA_WVW_2P					
Data Format : a. BUFR b. Other	a.					
Provider a. GTS b. Space Agency c. Other (please specify)	a					
Area : a. Global b. Regional (please specify)	a.	.				

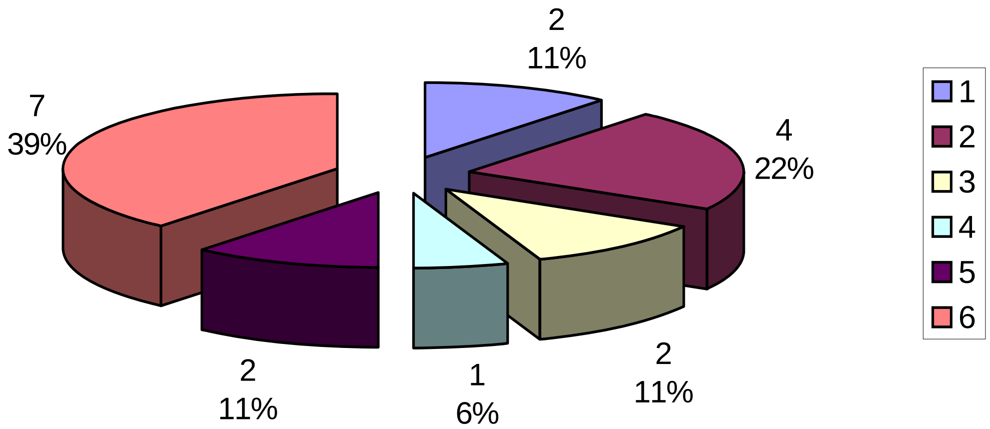
Annex II

Compilation of the questionnaire replies according to the six WMO Regional Associations: (1) Africa, (2) Asia, (3) South America, (4) North America, Central America and the Caribbean, (5) South-West Pacific and (6) Europe. The number of WMO member states of each Regional Association (coloured slices represent Regional Associations 1 to 6) and their percentage with respect to the total number of positive replies are displayed.

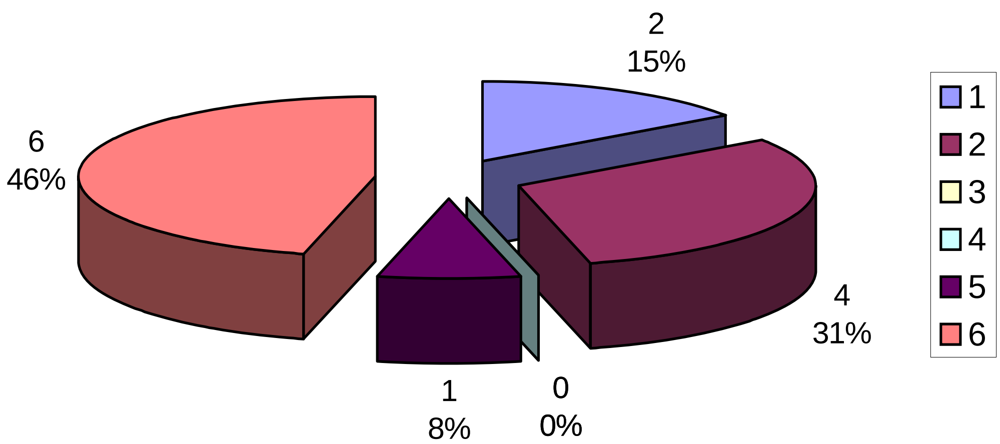
1. Origin (WMO region) of received questionnaire replies



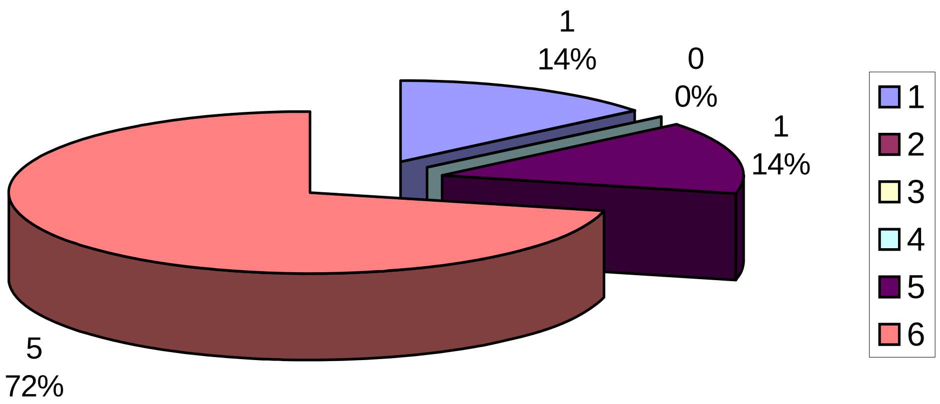
2. Origin of countries that use wind and wave satellite data



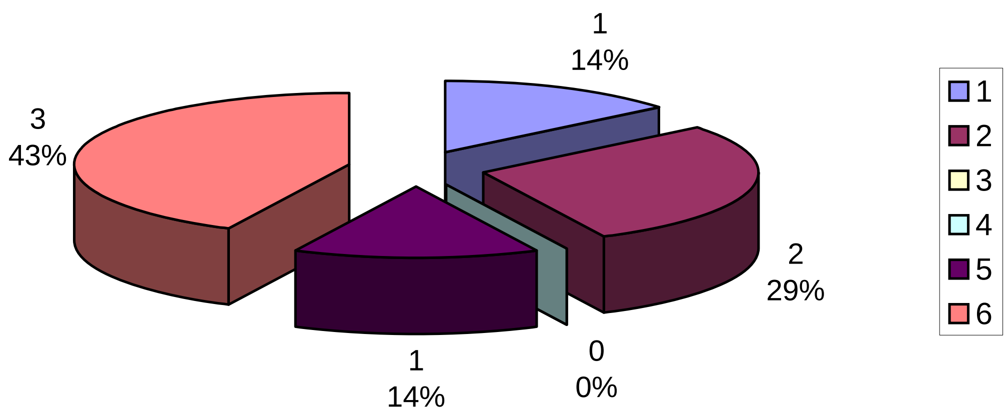
3. Origin of countries that use satellite wave data



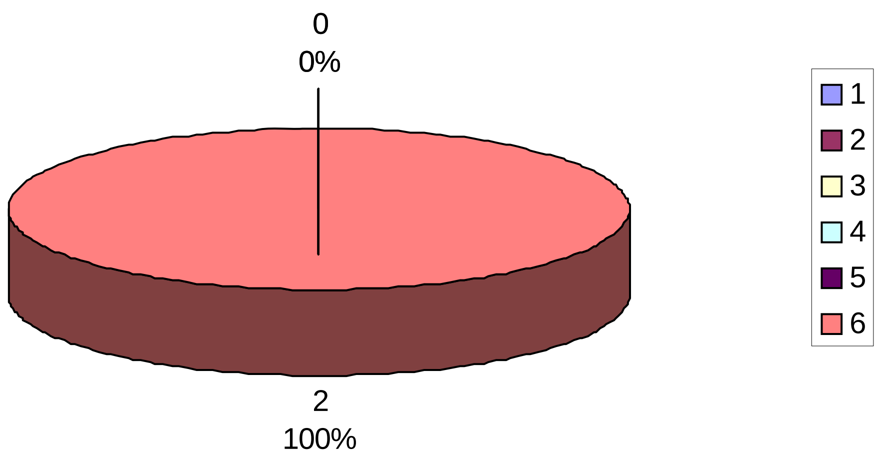
4. Origin of countries that use near real time wave data



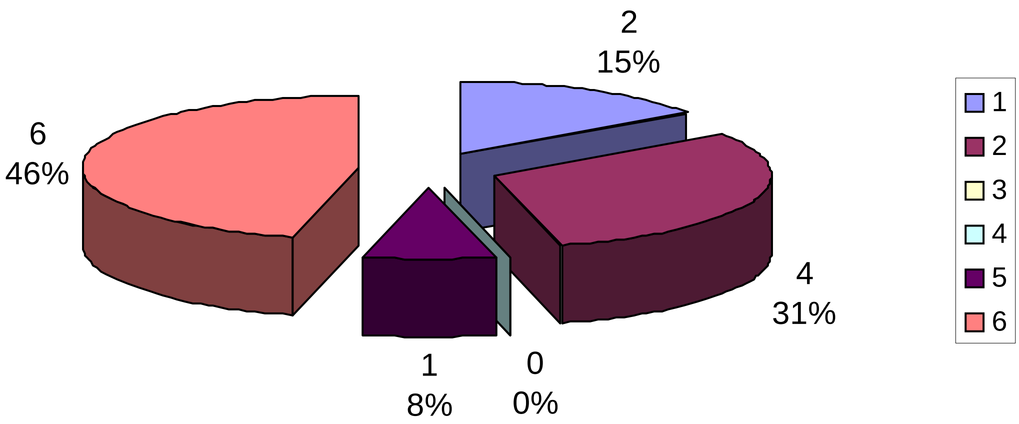
5. Origin of countries performing satellite wave data assimilation



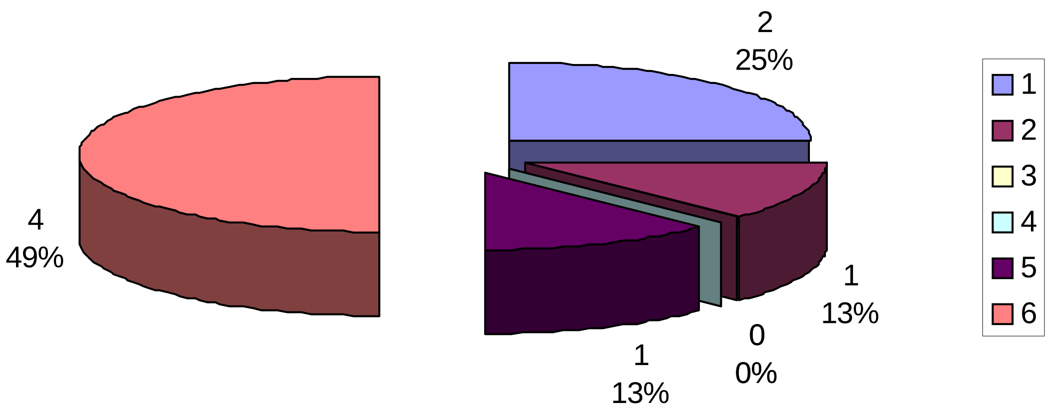
6. Origin of countries that use satellite wave spectra



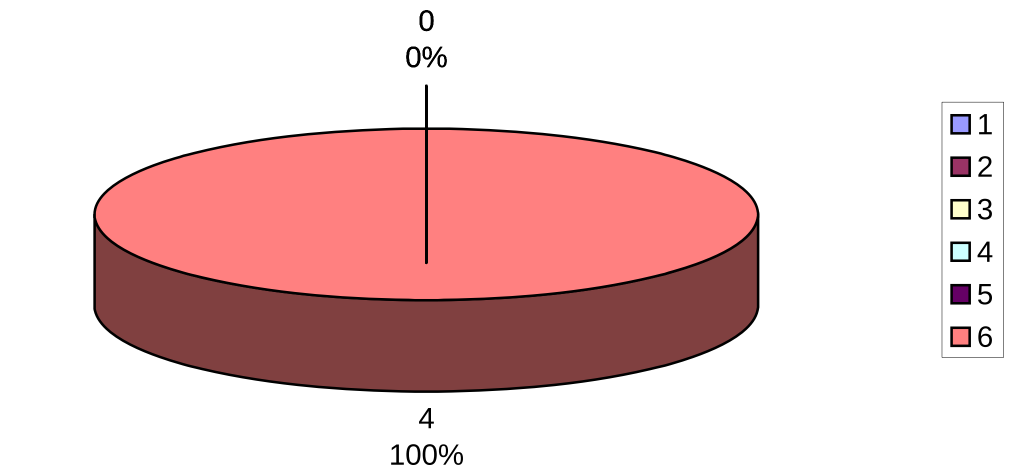
7. Origin of countries that use altimeter wave data



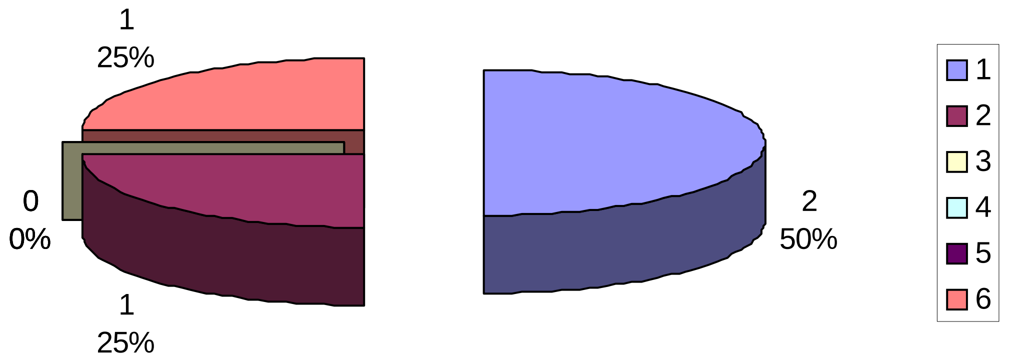
8. Origin of countries that use Jason wave data



9. Origin of countries that use Envisat wave data



10. Origin of countries that use satellite wave data for climatology



Annex III

ACRONYMS AND OTHER ABBREVIATIONS AND SYMBOLS

ASAR	Advanced Synthetic Aperture Radar
ECMWF	European Centre for Medium-range Weather Forecast
ENVISAT	Environment Satellite
ERS	European Remote Sensing Satellite
ETWS	Expert Team on Wind Waves and Storm Surge
FECM	Forecast Error Covariance Matrix
GFO	GeoSat Follow-On satellite
GTS	Global Telecommunication System
JASON	Mission to TOPEX/Poseidon
KF	Kalman Filter
LTM	Linear Tangent Model
MEDATLAS	Wind and Wave Atlas of the Mediterranean Sea
NRT	Near-Real Time
NWP	Numerical Weather Prediction
OI	Optimum Interpolation
RA	Radar Altimeters
RAR	Real Aperture Radar
RMSE	Root Mean Square Error
QuickSCAT	NASA/JPL mission launched in 1999 to study remote sensing of ocean winds with the SeaWinds scatterometer
SAR	Synthetic Aperture Radar
SHW	Significant Wave Height
SMM/I	Special Sensor Microwave/Imager
SWIMSAT	A proposal for a satellite borne Wave Measuring Radar
TOPEX/Poseidon	Joint US-French orbital mission, launched in 1992 to track changes in sea-level height with radar altimeters
UKMO	United Kingdom Met Office
WAM	Wave Model
WMO	World Meteorological Organization

Annex IV

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