Wave height from satellite altimetry and its comparison with ECMWF product

Seungbum KIM and P.David Cotton*

Satellite Technology Research Center, Korea Advanced Institute of Science and Technology, 373-1 Kusung, Yusung, Taejeon, S. Korea 305-701

* Satellite Observing Systems, UK

Tel: +82-42-869-8626. Fax: +82-42-861-0064. E-mail: sbkim@krsc.kaist.ac.kr

***Abstract*:** Monitoring of wave height is important primarily to reduce storm risks at sea and along the coast. Wave heights in recent years have increased 50% for the last 40 years, thus requiring intensive monitoring. Satellite altimetry offers a powerful tool for regular and extensive monitoring of the wave height. We extracted significant wave height (SWH) using several altimeter missions from 1987-1995 over the Northwest Pacific and compared with ECMWF reanalysis (ERA) products. For large wave heights > 2.5 m, the ERA wave heights are smaller than the altimetric ones, while for small wave heights the ERA wave heights are larger. Comparison in SWH between altimetric derivations and ERA model products shows the discrepancy of $0.46 - 0.21 \times$ SWH (m).

***Keyword*:** Significant wave height, altimetry, ECMWF, TOPEX/Poseidon, Geosat

1. Introduction

Monitoring of wave height is important primarily to reduce storm risks at sea and along the coast. Wave heights in recent years have increased 50% for the last 40 years. The intensified wind forcing is the most likely cause of this change. The intensification would be associated with the rise in the energy in the Earth atmospheric and oceanic system, resulting from the global warming. This suggests the link between the changes in the global wave height and climate change, thus requiring intensive monitoring of the wave height.

Routine monitoring of wave heights has traditionally been made using marine buoys. More recently satellite altimetry began to offer a powerful tool for regular and extensive monitoring of the wave height. The fist altimetry mission that proved the efficacy of altimetric wave monitoring is the Geosat since 1987. Also extensive wave data are available from dedicated wave models. Wave models are of special interest to the climate modeling because waves are important coupling parameter between ocean and atmosphere (Sterl and Bonekamp 2000). For example, currently ERA-40 (40-year European Center for Medium-Range Forecast ReAnalysis model) employs the strategy of coupling between a wave model and the conventional ECMWF atmosphere-ocean model. Since the altimetric monitoring and model simulation of wave heights are indirect measurements, their validation and performance assessment are essential.

Validation should be performed with respect to in situ measurements such as from buoys, and numerous studies of this kind are available in the Pacific, the Atlantic and around Japan. However the availability of *in situ* data are limited. Therefore intercomparison between extensive data sets such as altimetric observations and model results would provide useful data set.

The intercomparison of wave height between ERA and altimetric observations is crucial also for the validation of ERA products. For validation of the ERA15 products (15-year reanalysis), it is necessary to use *independent* data which were not used during the ECMWF data assimilation. The independent truth data that cover the area and the ERA period are significant wave heights (SWH) derived from altimeter measurements[1].

In this paper, we compare SWHs from altimeter observations and ERA15 data and analyze the comparison results.

2. Data and Method

ERA15 products (Gibson *et al.* 1997) are generated based on the ECMWF atmospheric general circulation forecast model. The 'analysis' procedure combines model forecasts with observations to provide optimum estimates for the model output. A scheme called 're-analysis' is required because a forecast-analysis system is continually undergoing changes. A time series of operational analysis fields is likely to lack consistency due to changes in the analysis procedure. Thus a retrospective re-analysis is applied to the observational record in order to create a consistent description of the atmosphere. For the ERA, such a re-analysis is applied to the 15-year period from January 1979 until February 1994. The ERA and the Operational Analysis data are given every 6-hours interval from January 1979 onwards.

The wave heights from the ERA wind are generated by the WAve Model (WAM, Komen 1994), which is driven by the ERA wind (this wave height is denoted as ERA_WAM wave height, hereafter). The ERA_WAM wave heights are available globally on a monthly 1.5° by 1.5° grid. Since input wind speed is found to be the critical parameter in the wave model, the ERA_WAM wave height is considered to be a good representation of the ERA wind speed.

The altimetric wave heights are a combination of measurements by Geosat, European Remote-Sensing satellite (ERS)-1, and TOPEX/Poseidon. The principle behind the altimetric measurement of wave heights is that the shape of the altimeter return echo depends on the sea state or wave height. The altimetric wave heights are available globally on a 2° by 2° grid in monthly averages from April 1985 up to 1995.

The area of interest is the entire Northwest Pacific. The time span runs from January 1987 to December 1993 excluding a gap in the altimeter data, from October 1989 until March 1992.

[1] Unlike for ERA15, ERS altimeter SWHs are assimilated into ERA40 products. Geosat and TOPEX/Poseidon data are still independent of the ERA40.

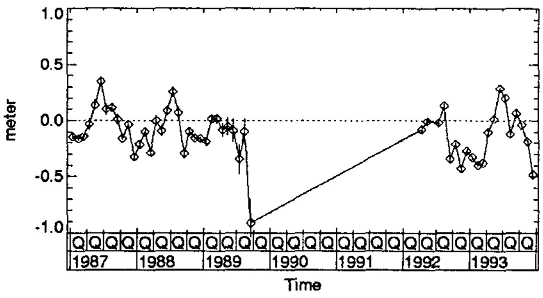

Fig. 1. The time series of SWH comparison: ERA_WAM SWH minus altimetric derivations in m. *Q* denotes the quarter of a year. There is a data gap between 3rd quarter of 1989 and 1st quarter of 1992.

3. Results

The time series of the intercomparison in SWHs between ERA15 and altimeter solutions is presented in Fig. 1. There is a consistent feature that ERA SWHs are greater in summer and smaller in winter. Presented in the form of a scatter plot, Fig. 2, we now can find that for large wave heights > 2.5 m, the ERA_WAM wave heights are smaller than the altimetric ones, while for small wave heights the ERA_WAM wave heights are larger.

We attribute the above discrepancy to the fact that for high winds the ERA_WAM system underestimates wave heights, because the ERA vector wind misses the peak winds due to the spatial and temporal resolutions of the ERA model. This argument is confirmed by the comparison of ECMWF and NASA scatterometer vector winds: ECMWF underestimates the wind on a spatial scale less than 300 km.

For low winds, one of the reasons for the greater ERA_WAM wave heights may be that shipboard wind measurements tend to overestimate 10-m winds. Since shipboard wind measurements are assimilated into ERA, the effect would lead to greater ERA wind speed.

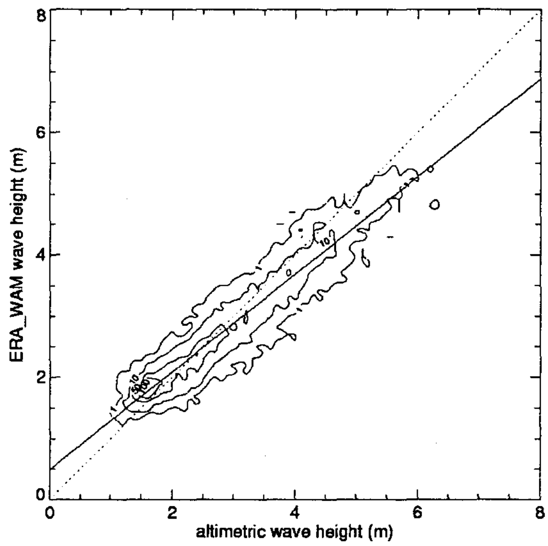

Fig. 2. Scatter plot of the comparison in Fig. 1. The solid line is a linear regression line and the dotted line is the one-to-one line. The contours represent the number of points.

For a quantitative presentation of the intercomparison, it is useful to employ the concepts of systematic and random errors. From Fig. 2, systematic error in the ERA_WAM wave height is the difference between the regression line and the altimetric wave height, and is given as:

$$0.48 - 0.21 \times (\text{altimetric SWH}) \text{ (in m)}$$

Random error in the ERA_WAM wave height is the scatter about the regression line, that is, the widths of the contours in the figure. The widths are uniform with respect to the abscissa values. This means that the magnitude of random error is independent of the magnitude of the signal, altimeter wave height. Thus the random error should be treated as an absolute value. The distribution of the scatter about the regression line has a Gaussian shape with a constant standard deviation of 0.23 m.

4. Summary and Future

We extracted significant wave height (SWH) using several altimeter missions from 1987-1995 over the Northwest Pacific. Comparison in SWH between altimetric derivations and ECMWF reanalysis model products shows that: for large wave heights > 2.5 m, the ERA wave heights are smaller than the altimetric ones, while for small wave heights the ERA wave heights are larger. These discrepancies are attributed to the underestimation of the ERA model and the overestimation of buoy in situ data assimilated into ERA model.

The systematic and random errors in ERA wave product may be used to define errors in the wind speed using the equation: (Janssen and Komen 1984):

$$SWH = \frac{\beta}{g} |(u10, v10)|^2,$$

where β is the dimensionless growth rate of a wave (0.22 for a fully developed sea), g the gravitational acceleration and ($u10$, $v10$) are u- and v- winds at 10-m height.

Acknowledgements

A. Sterl in the Royal Dutch Meteorological Institute, The Netherlands, is thanked for kind provision of the ERA_WAM data and fruitful comments on the comparison results. The Korean Ministry of Science and Technology (MOST) is acknowledged for supporting this research through a grant "Development of a mobile terminal for a data collection system and its utilization".

References

Gibson, J.K., P. Kallberg, S. Uppala, A. Hernandez, A. Nomura and E. Serrano, 1997: *ECMWF re-analysis project report series: 1. ERA descriptions*, ECMWF, , 72pp..

Janssen, P.A.E.M. and G.J. Komen, 1984: An operational coupled hybrid wave model, *J. Geophys. Res.*, **89**, 3635-3654.

Komen, G.J., Dynamics and modelling of ocean waves. , pp. 532, Cambridge Univ. Press, Cambridge, 1994.

Sterl, A. and H. Bonekamp, 2000: Comparison of wind stress from ERA and from WAM, *Proceedings of Second WCRP International Conference on Reanalysis*, WMO, Reading, U.K., 149-152.

October 31, 2002, Thursday

Eton Hall - Technical Session

TH-AT-1

Atmosphere(1)

Chairperson : Byung-Ju Sohn

TH-AT-2

Atmosphere(2)

Chairperson : H. Fukushima

TH-DP-1

Data Processing(1)

Chairperson : Jae-Hong Yom