EVALUATING ERA WIND STRESS IN THE WEST EQUATORIAL PACIFIC, USING AN INVERSE OCEAN MODELLING TECHNIQUE

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The aim of this study is to compare the ERA wind stress with observations during the TOGA COARE experiment, and with an ocean model adjusted wind stress. The latter is determined by an inverse ocean modelling technique.

1. INTRODUCTION

The RV *Moana Wave* has participated in the TOGA COARE program and surface flux measurements (Fairall et al, 1996) are made near the equator in the western Pacific during three legs: November 11, 1992 to December 3, 1992, December 17, 1992 to January 11, 1993 and January 28, 1993 to February 16, 1993. These measurements are not assimilated in the ERA15 (Gibson et al., 1997) and therefore an independent measure.

A four dimensional data assimilation (4DVAR) scheme has been developed to assimilate TAO buoy and XBT temperure data in the ECMWF global version of the HOPE OGCM (Stockdale et al.,1998). The main goal of the 4DVAR scheme is to provide accurate ocean analyses for the Tropical Pacific, which are essential for the prediction of the large scale and low frequent variations in the coupled atmosphere ocean system. An additional result of this 4DVAR scheme is the adjusted surface forcing. It can be considered as a flux product in its own right (see e.g. the work of Yu and O'Brien, 1995). The HOPE model will optimally represent the subsurface observational data when forced with the best-guess flux forcing resulting from the assimilation. Therefore, the best-guess forcing form a alternative flux estimate, which contains future information of the upper ocean. Of course, the value of this flux estimate strongly depends on ocean model errors and the efficacy of the 4DVAR scheme.

First, we compare the original ERA wind stresses with those measured by the RV *Moana Wave*. Next, we apply the 4DVAR method to assimilate TAO buoy data and Tropical Pacific XBT data between 10°S and 10°N in the HOPE OGCM for the time period of the TOGA COARE experiment. In the equatorial wave guide of the Pacific, the HOPE model is sensitive to short term (weekly) variation in the forcing (Oldenborgh et al., 1998). Therefore, assimilation periods of several weeks are sufficient to have an impact. Finally, the ocean model adjusted (best-guess) wind stress is added to the comparison. The 4DVAR method is controlling 2-weekly averaged fluxes, so only wind stress variations with a oscillation period of more than a week can be adjusted.

2. ERA VS. TOGA COARE WIND STRESS

Weekly averaged ERA wind stress defined at the 4 nearest HOPE model grid points (2.8°resolution) are interpolated on the 3 legs. The results are shown in Figure 1. In general, TOGA COARE and original ERA wind stress are in good agreement. The differences in weekly averaged meridional wind stress are small, except maybe for the third leg. However, the differences in zonal wind stress are larger. In the first leg, ERA has missed an outbreak of strong winds, while in the second leg it has exaggerated a weekly period of strong winds. As a consequence, the averaged ERA zonal wind stresses are too weak during the first and too strong during the second leg.

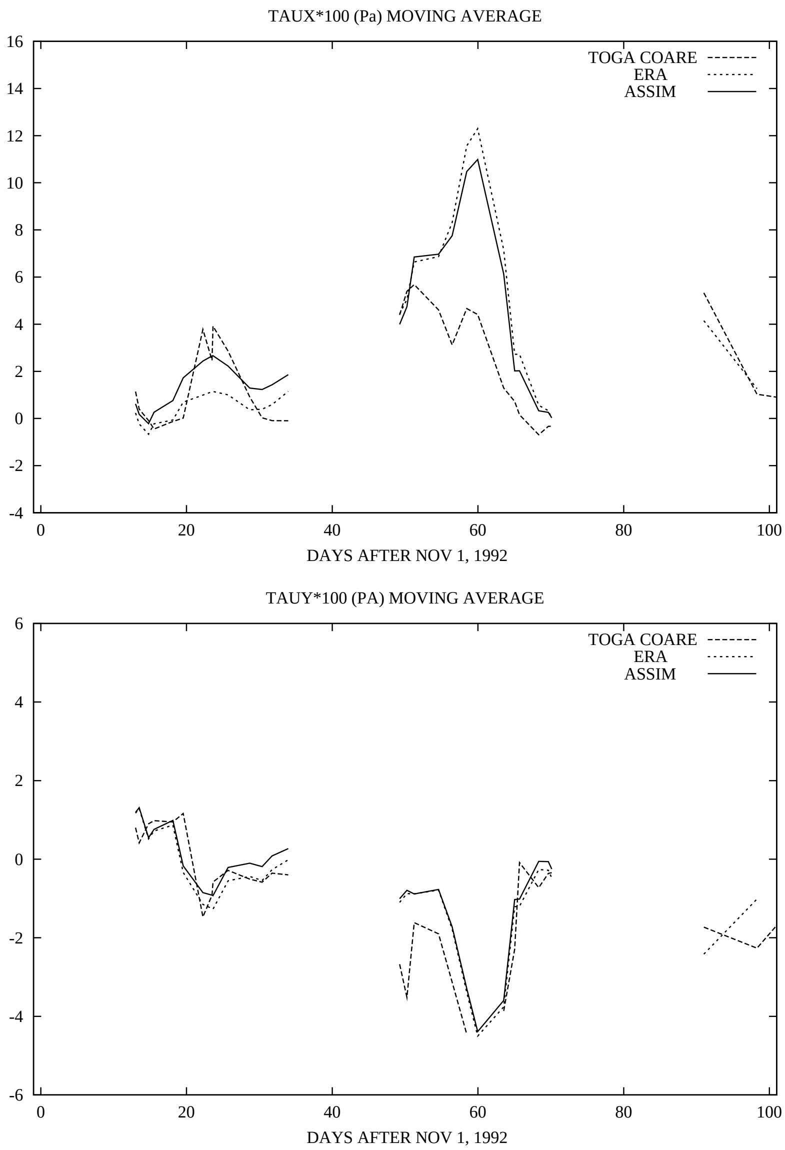

Figure 1: Wind stress at the ship location during the three legs of the RV *Moana Wave* in the TOGA COARE experiment. The dashed, dotted and solid line are the observed, ERA and best-guess wind stress, respectively. A moving (weekly) average is applied to all the plots.

3. VARIATIONAL DATA ASSIMILATION

The 4DVAR data assimilation method for the HOPE OGCM attempts to minimize a penalty function J, made up from a background term for the wind stress and an observational term.

$$J(\mathbf{c}) = \mathbf{c}^T \mathbf{B}^{-1} \mathbf{c} + (\mathbf{H}\mathbf{x}(\mathbf{c}, \mathrm{x}_0) - \mathbf{z})^T \mathbf{E}^{-1} (\mathbf{H}\mathbf{x}(\mathbf{c}, \mathrm{x}_0) - \mathbf{z}) \tag{1}$$

The wind stress forcing is determined as the sum of a first-guess wind stress and a linear interpolation (in time) of 2 two-weekly wind stress corrections. The control vector $\mathbf{c}$ is the time sequence of these two-weekly wind stress corrections for an assimilation time window of 8 weeks. Vector $\mathbf{x}$ contains the HOPE model state and the observation operator $\mathbf{H}$ projects the HOPE potential temperature output onto temperature observations during the assimilation time window ($\mathbf{z}$).

The following assumptions are made with respect to the error covariances. Firstly, The TAO and XBT temperature measurements are assumed to be (spatially and temporally) un-

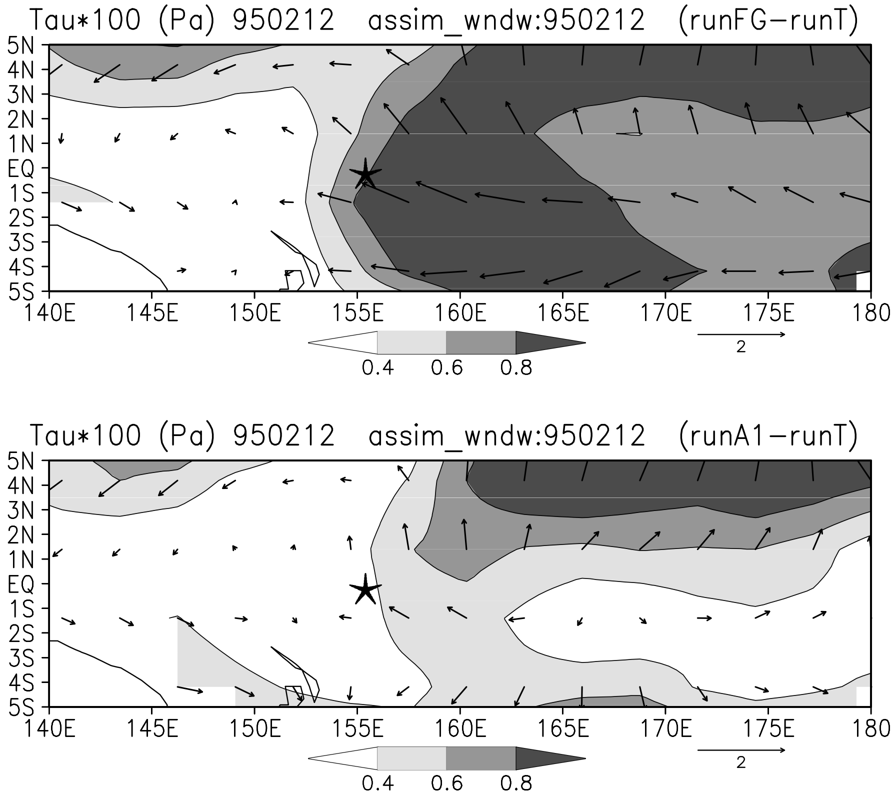

Figure 2: Wind stress analysis of an identical twin experiment with pseudo-observations, see (Bonekamp et al., 1999). a) A priori defined wind stress difference, and b) wind stress differences after data assimilation. Both plots are weighted averages in time for a two-weekly period. The stars mark the location of the RV *Moana Wave* measurements.

correlated. therefore, **E** is an diagonal matrix of variances equal to 1.0 K^2. Secondly, the two weekly forcing correction are assumed be uncorrelated in time. The diagonal elements of **B** are set to 20% of the standard deviation of two-weekly differences in two-weekly averaged ERA wind stress. The off-diagonal elements of **B** (spatial error covariances) are scaled with the decorrelation length of these differences, which is in the order of 18°(6 HOPE forcing grid points).

To obtain ocean analyses every two weeks, the assimilation window is shifted 14 days forward time. The flux corrections over the 3 overlapping fortnights are reused. Thus, two-weekly periods are optimized several times in consequtive assimilation periods.

The efficacy of the 4DVAR scheme in the Tropical Pacific has been tested in a series of identical twin experiments (Bonekamp et al., 1999). These experiments are done for wind stress of ECMWF's operational analyses. Pseudo-observations are defined at the actual TAO buoy and XBT measurements to remove model errors from the analyses. In one identical twin experiment perturbations are added to the first-guess wind stress forcing. Figure 2. shows this perturbation and the remaining perturbation after data assimilation. In conclusion, the best-guess forcing is close to the (defined) true forcing in equatorial regions, including the ship legs of the RV *Moana Wave*. Other experiments (also with real observations) show that wind stress updates are consistent with the reduction of the subsurface temperature misfits.

4. BEST-GUESS WIND STRESS

To obtain the best-guess wind stress, TAO buoy data and Tropical Pacific XBT data between 10°S and 10°N are assimilated in the HOPE model for the time period of the TOGA COARE experiment. The wind stress field between 35°S and 35°N is used as control variable. ERA wind stress is taken as the first-guess forcing. Two assimilation runs (run 1 and 2) are made starting at the initial states at November 1, 1992 and December 1, 1992, respectively. The first ship leg (November 11, 1992 to December 3, 1992) is covered by run 1 with only a few shifts of the assimilation window. The second (December 17, 1992 to January 11, 1993) is covered by run 2. The initial states are taken from the Optimal Interpolation analyses of the ECMWF's seasonal forecast group. The third leg is only covered by the tail of the shifted assimilation windows and therefore not considered in detail.

Weakly averaged best-guess wind stress are represented by the solid line in Figure 1. For the first leg, the best-guess is stronger than the orginal ERA wind stress. TAO buoys and XBT's eastward of the measurements have sensed the Kelvin wave activity triggered by the strong observed peak missed out by ERA. The 4DVAR method has propagated this information to an wind stress increase backward in time. As a result, the best-guess is a better representation of the observed wind during the first leg than ERA. For the second leg the argument is the same, However, here the sensed upper ocean temperatures are translated to an slight decrease in wind stress. Both assimilations runs do not spoil the orginal good fit of ERA and TOGA COARE for meridional wind stress.

5. CONCLUSION

A discrepancy between ERA and TOGA COARE wind stress is identified. On average, the ERA zonal wind stress is too weak for the first leg of the RV *Moana Wave* (Nov. 11, 1992 to Dec. 3, 1992) and too strong for the second leg (Dec. 17, 1992 to Jan. 11, 1993).

A 4DVAR data assimilation method that adjust the ocean surface forcing has been implemented for the HOPE OGCM. In the equatorial Pacific, a large reduction in wind stress misfit can be achieved, with an assimilation time window of 8 weeks.

Assimilating the TAO and XBT upper ocean observations reduces the discrepancy between ERA and observed wind stress. Therefore, Wind stress adjusted by the 4DVAR scheme seems to be more realistic than the orginal ERA wind stress for TOGA COARE region and period.

REFERENCES

Bonekamp, H, G.J. van Oldenborgh, G. Burgers, 4D VAR data assimilation with the HOPE OGCM: Adjusting fluxes over the tropical Pacific Ocean. Proceedings of the 3rd WMO Initernational Symposium on Assimilation of Observations in Meteorology and Oceanogrpahy, 7-11 June 199, Quebec City, Canada, 1999.

Fairall, C.W., E.F. Bradley, D.P. Rogers, J.B. Edson, G.S. Young 1996a, Bulk parameterization of air-sea fluxes for TOGA COARE, *J.Geophys. Res.*, **C101**, 3747-3764,1996.

Gibson, R., P. Kållberg, S. Uppala, A. Nomura, A. Hernandez, E. Serrano (1997), ERA description, ECMWF Re-Analysis Project Report Series **1**, ECMWF, Reading, UK.

Oldenborgh van G.J., G. Burgers, S. Venzke, C. Eckert, and R. Giering, Tracking down the ENSO delayed oscillator with an adjoint OGCM, *Mon. Weath. Rev.*, accepted, 1999.

Stockdale T.N., A.J. Busalachi, and D.E. Harrison, Ocean modeling for ENSO. *J.Geophys. Res.*, **C103**, 14325-14355, 1998.

Yu L. and J.J. O' Brien, Variational data assimilation for determining the seasonal net surface heat flux using a tropical pacific ocean model. *J. Phys. Oceanogr.*, **25** 2319-2343, 1995.