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NASA NA65-6549
NCAR #1996-153

Interaction of the Climate System and the Solid Earth: Analysis of Observations and Models

Final Report

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December 2001

Under SENH funding we have carried out a number of diverse analyses of interactions of the climate system (atmosphere, ocean, land surface hydrology) with the solid Earth. While the original work plan emphasized analysis of excitation of variations in Earth rotation, with a lesser emphasis on time variable gravity, opportunities that developed during the proposal period in connection with preparations for the GRACE mission led us to a more balanced effort between these two topics. The results of our research are outlined in several topical sections below.

I. Oceanic Excitation of Variations in Earth Rotation

Using a global, non-eddy resolving, ocean general circulation model we computed the oceanic contribution to excitation of variations in Earth rotation (polar motion and length of day) on time scales from daily to decadal. A series of simulations for the period 1985 to 1996 were carried out using various combinations of wind stress, atmospheric pressure loading and buoyancy forcing to elucidate the oceanic processes contributing to the net excitation. In contrast to the case of axial angular momentum (length of day), the ocean makes a significant contribution to the excitation of polar motion across a range of time scales. The ocean contribution is largest in the x-component, particularly on intraseasonal (15 to 90 days) and seasonal (90 to 365 days) time scales. The correlation of the geodetically inferred x-component excitation with the combined ocean plus atmosphere excitation is nearly double that with the atmospheric excitation alone. The excitation resulting from the dynamic ocean response to atmospheric pressure loading (deviation from the static inverted barometer response) exceeds that of wind forcing at the shortest time scales (less than 15 days). In contrast, there is little direct contribution from buoyancy forcing. Simulations with an unstratified version of the ocean model (basically a shallow water model) yield virtually identical excitation time series as the stratified general circulation model. This points to the dominant importance of mid-latitude barotropic dynamics in determining the oceanic contribution to the net excitation. These result suggested that further improvements in ocean model simulated excitation time series would come from improvements in the quality of the wind stress forcing and the representation of the bottom topography in the model: factors that largely determine the barotropic response of the model. Our model development efforts included the later. These results were presented at the 1997 IUGG in Melbourne, and at the 1997 Fall AGU meeting in San Francisco.

II. Short Period Atmosphere-Ocean Excitation of Variations in Earth Rotation

Following on work carried out prior to the proposal period we examined the role of non-tidal atmospheric and oceanic dynamics in excitation of variations in Earth rotation on periods from semidiurnal to several days. Standard atmospheric analysis products provide, at best, 4 analyses per day and thus do not provide adequate resolution of the shortest of these periods. As a proxy we have used high frequency output (20 minute intervals) from runs of an atmospheric general circulation model. Our analyses thus far have focused on the excitation due to variations in atmospheric mass. At these periods, the inverse barometer approximation is not a good representation of the ocean response, so we have combined the atmospheric model results with output from the same ocean model used above, except that it is forced with the same 20 minute interval atmospheric pressure loading. The striking result of this analysis is that the dynamic response of the ocean to variations in the atmospheric pressure load leads to a greater excitation than that resulting from the atmospheric mass load itself. Portions of this work were presented at he 1998 EGS meeting in Nice, and are described in reference [3].

III. Analysis of Coupled Climate System Simulation

In collaboration with John Wahr and Michael Celaya of the University of Colorado, we examined simulations with the NCAR Climate System model with an emphasis on longer period (annual to decadal) excitation of variations in Earth rotation. In particular we found that the combined atmosphere and ocean excitation provide sufficient power to excite the Chandler wobble. The model is less successful in explaining the Markowitz wobble. While the climate system model does produce an excitation with the correct polarization, the period and amplitude are each about 1/2 of the observed values. This work was published in reference [2].

A number of integrations with the NCAR CSM with transient forcing for the 20th and 21st centuries were carried out to examine issues of climate variability and sensitivity. The emphasis of our analyses related to this proposal sas concerned with the model estimates of global sea level rise. The NCAR model is generally exhibiting a lower sensitivity to anthropogenic forcing than other extant coupled models, with our sea-level rise estimates in the range of 0.15 to 0.2 mm/year for the late 20th century. These results were submitted to and included in the most recent IPCC report.

IV. Observing System Simulation Studies for GRACE Mission Design

In addition to our studies related to Earth rotation, we collaborated with John Wahr and Mery Molenaar of the University of Colorado in examining the time-space spectral characteristics of ocean bottom pressure as part of the mission design studies for GRACE. Ocean bottom pressure from the same model simulations described under topic I, above, were combined with estimates of land water storage and atmospheric mass to generate time-evolving synthetic geoids. These were then sampled using various scenarios to determine the resolving power and aliasing characteristics of the GRACE mission. These results are described in reference [1]. Additional studies to examine the utility of GRACE bottom pressure estimates in computing deep ocean currents and ocean heat storage were also conducted using synthetic data sets produced with our ocean models. These studies are described in references [6] and [7].

We also examined, in more detail, the dynamics of ocean bottom pressure variability, and the ability of ocean models to capture this signal. While the model simulations of the high variability in ocean bottom pressure in the Southern Ocean seem quite robust with respect to resolution, dissipation parameterizations, etc., there are several notable regions (Brazil-Malvinas confluence, Gulf Stream) where the model simulations appear to be fairly sensitive. These results were presented at the meeting on Ocean Bottom Pressure at the Royal Society of London in April 1999.

As an outgrowth of this work, it became apparent that high frequency barotropic variability was also present in sea surface height at an amplitude measurable by Topex/Poseidon class altimeters. This variability is predominantly at periods less than 10 days and hence is aliased by the altimeter 10 day sampling. A pilot study in providing "corrections" for high frequency barotropic ocean dynamics using model simulated sea level was carried out with encouraging results. This study was published in reference [4].

V. Oceanic Response to Atmospheric Pressure Loading

Using a global, non-eddy resolving, ocean general circulation model we computed the oceanic response to atmospheric pressure loading for both barotropic and baroclinic configurations of the model. This was the first time, to our knowledge, that such a study has been carried out with a baroclinic OGCM. The results indicate that the dynamic response, i.e., that part not explained by the inverse barometer approximation is dominantly barotropic, geographically inhomogeneous, and strongly controlled by topography. The enhancement of baroclinic kinetic energy over that of an experiment driven with wind stress alone is quite modest, suggesting that previous studies using shallow water models have captured the bulk of the dynamic response. The baroclinic model is required however to unravel the contributions of wind stress, static and dynamic response to pressure loading in observed sea level variability, however. The low latitude response to wind stress is strongly baroclinic, making barotropic, shallow water model simulations ineffective in interpreting the observed response, through regression analysis, for example. This work has been submitted to the Journal of Geophysical Research (reference 5).

REFERENCES

[1] Wahr, J., M. Molenaar and F.O. Bryan, 1998: Time-variability of the Earth's gravity field: Hydrological and oceanic effects and their possible detection using GRACE. J. Geophys. Res. 103, 30,205-30,229.

[2] Celaya, M., J. Wahr, and F.O. Bryan, 1999: Climate driven polar motion. J. Geophys. Res. 104, 12,813-12,829

[3] Madden, R.A. and F.O. Bryan, 1999: Effects of the daily march of atmospheric pressure on the matter terms of the atmosphere-ocean angular momentum. (unpublished manuscript).

[4] Tierney, C., J. Wahr, F. Bryan, and V. Zlotnicki, 2000: Short-period oceanic circulation: Implications for satellite altimetry. Geophys. Res. Lett. 27, 1255-1258.

[5] Bryan, F.O., D. Wang and W.R. Holland, 2001: Response of a global ocean general circulation model to atmospheric pressure loading. J. Geophys. Res. , (submitted).

[6] Wahr, J.M., S.R. Jayne, and F.O. Bryan, 2001: A method of inferring deep ocean currents from satellite measurements of time variable gravity. J. Geophys. Res. , (submitted).

[7] Jayne, S.R., J. M. Wahr and F. O. Bryan, 2001: Observing ocean heat content using satellite gravity and altimetry. J. Geophys. Res., (in preparation).