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Atmospheric and
Environmental Research, Inc.

Earth Rotation and Coupling to Changes in Atmospheric Angular Momentum

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The subject contract came into force on November 19, 1997 and, with amendments, continued for three years, through November 19, 2000. The research supported under the contract dealt primarily with: (a) the mechanisms responsible for the exchange of angular momentum between the solid Earth and atmosphere; (b) the quality of the data sets used to estimate atmospheric angular momentum; and (c) the ability of these data and of global climate models to detect low-frequency signals in the momentum and, hence, circulation of the atmosphere. Three scientific papers reporting on the results of this research were produced during the course of the contract, two of which have already been published. In the next section, we provide an overview of these results, further details being available from the cited publications.

Scientific Accomplishments

Although in some respects the study of Earth's global momentum balance has become a mature subject, much remains uncertain about the torque mechanisms involved in the transfer of momentum among different Earth system components. Moreover, the rapid pace at which new data assimilation systems and global climate models are being introduced provides new opportunities to reassess and expand previous momentum budget estimates. We considered both aspects of this subject during the last three years, and we highlight our findings below.

Torques responsible for Earth rotation changes

Early in the project, we obtained newly created time series of surface friction and mountain torques based on the reanalysis product of the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR). To demonstrate the utility and to test the quality of the torque series, we chose to relate behavior in these torques to the most prominent signal in length-of-day (LOD) during the modern era, namely the peak in LOD associated with the intense 1982-83 El Nino event.

In Ponte and Rosen (1999), we report that anomalies in atmospheric angular momentum (AAM) are mostly positive from mid-1982 onward, but they notably double in amplitude over a 2-week period in early 1983. Analysis of the torque series reveals that this sharp increase in AAM is mostly related to anomalies in the mountain torque, primarily associated with American and Eurasian orography. After reaching its peak value in January, AAM anomalies decay slowly to near-normal values over the next three months, with anomalies in the friction torque, especially over the subtropical North Pacific, playing a dominant role in this downturn.

We returned to the NCEP-NCAR torque estimates near the end of the project to examine the relative roles of torques over land and over the ocean in changing AAM (and LOD) on time scales from days to years. Using 40 years of NCEP-NCAR reanalysis AAM and torque data, Ponte and Rosen (2000) confirm the good balance between AAM tendency and torques at periods < 6 months found by others. At longer periods, it appears that torque errors, rather than uncertainties in AAM, are the likely reason for a poorer balance. Land torques are the most important source of AAM variability at intraseasonal and shorter periods (Fig. 1). Ocean torques assume an equally important role in the AAM balance at periods > 3 months, implying a three-way angular momentum exchange among atmosphere, oceans, and solid Earth at these time scales. For the observed land and ocean torque amplitudes and phase relationship, the small time lags introduced by an ocean that rapidly transfers momentum between the atmosphere and solid Earth cannot explain the observed, small phase lead of LOD relative to AAM. Other sources of angular momentum variability, such as that due perhaps to core-mantle coupling, are, thus, likely involved.

Data quality and AAM signals in observations and models

During the course of the project, data became available from three independent reanalysis projects: NCEP-NCAR, European Centre for Medium-range Forecasts (ERA-15), and the NASA Data Assimilation Office. From these products, we produced time series of daily values of AAM of varying length, but providing an overlap of 15 years among the

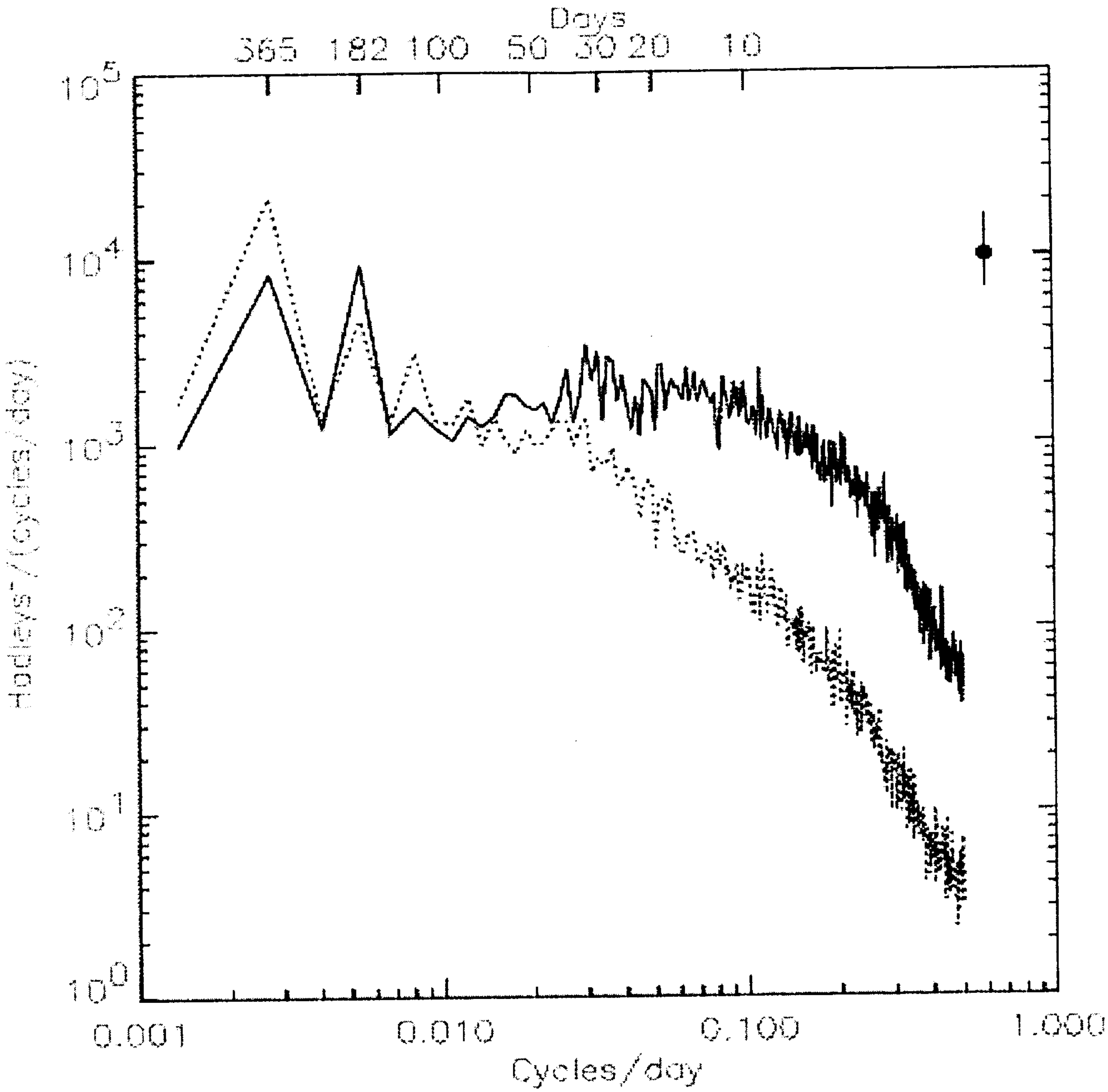

Figure 1. Power spectra of land torque (solid line) and ocean torque (dotted line), based on 40 years (1957-96) of NCEP-NCAR reanalysis data. Spectral estimates are based on frequency averaging over 20 adjacent bands, and a 95% confidence bar for the spectral estimates is also shown.

different records. This overlap allowed us to compare reanalysis AAM values from the different centers, thereby yielding estimates of the uncertainties still present in AAM data sets. An example is shown in Fig. 2, depicting a loss of coherence between the NCEP-NCAR and NASA DAO series at the highest frequencies resolved, mirroring disagreements long present among operational series. Errors in stratospheric estimates of angular momentum at seasonal and longer time scales also appear to remain in the reanalysis products.

Over much of the temporal domain, however, the coherence among AAM series is very high, offering a measure of confidence when searching the atmospheric data for sources of AAM anomalies that give rise to particular signals in LOD. One such example occurred in the mass component of AAM during a five-week period in the middle of 1992, when a remarkable increase in AAM was detected by a number of different atmospheric analyses. Even after accounting for "inverted barometer" effects, this signal in the mass term explains much of the behavior then in the residual in the LOD-AAM wind term. As the project ended, work was underway to determine the source of the signal in the atmospheric mass field. In general, we believe that more research into the behavior of the mass term, and its role in accounting for subseasonal LOD signals, is warranted.

Independent of data quality issues, the constraint posed by the availability of only five decades of reanalysis values of AAM limits studies of climate change signals in the coupled Earth-atmosphere dynamical system. In Rosen and Salstein (2000), therefore, we turned to lengthy output from a simulation of the climate of the 20th century to examine low-frequency behavior in AAM. Reanalysis output since 1948 was used to compare with the model results for their period of overlap, and a significant correlation between the two AAM series lent credibility to the interpretation of the full model series. Rosen and Salstein find evidence in the model for a notable increase in the interannual variability of AAM since around 1970, but this recent high level of variability may not be significantly greater than that during 1900-1920. This result is strongly dependent on the character of the sea surface temperature field used in an experiment, because low-frequency signals in AAM are closely linked to those in the El Nino/Southern Oscillation. Large differences

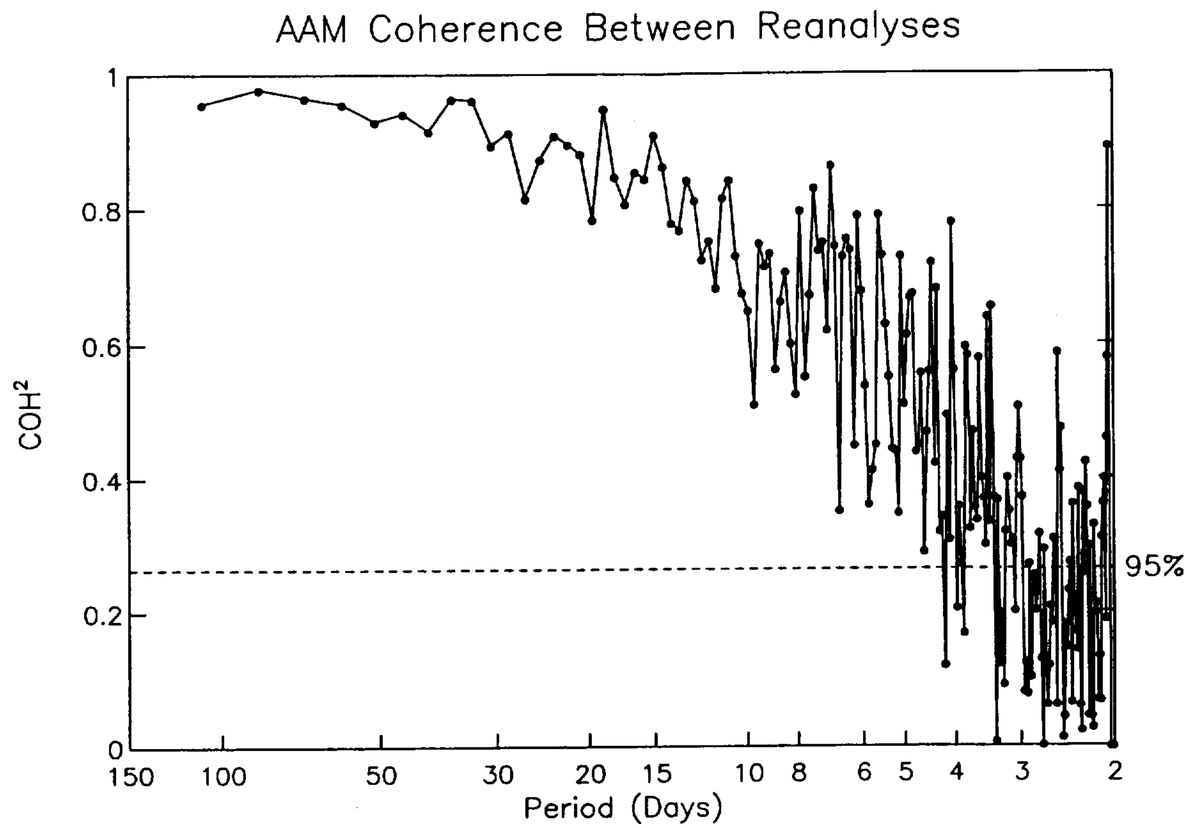

Figure 2. Coherence-squared between AAM values from NCEP/NCAR and NASA DAO reanalyses during their overlap period (1979-1993), and the estimated 95% level of significance.

exist, however, among SST estimates in the tropical Pacific for the early part of the century.

Our interest in data quality issues reemerged as the project drew to a close, with the introduction by NOAA/NCEP of a new, high resolution operational forecast/analysis system in January 2000. Wind fields used to calculate AAM are now archived on a 1x1 degree horizontal grid (instead of the 2.5 degree resolution of the NCEP-NCAR reanalysis) and at more pressure levels than before. It will be important to assess whether this finer resolution results in smaller residuals in the LOD-AAM budget than currently achieved. Concluding the project by taking initial steps in this assessment brought our efforts full circle and was fitting recognition of the ongoing nature of progress in our field.

Presentations and Publications

The results described above formed the basis for a half-dozen or so presentations at seminars and/or conferences during the course of the project, details of which may be found in our bimonthly and annual reports. In addition, three formal publications acknowledging support from the subject contract were produced. Their complete citations follow:

Ponte, R.M., and R.D. Rosen, 1999: Torques responsible for evolution of atmospheric angular momentum during the 1982-83 El Niño. *J. Atmos. Sci.*, **56,** 3457-3462.

Rosen, R.D., and D.A. Salstein, 2000: Multidecadal signals in the interannual variability of atmospheric angular momentum. *Clim. Dyn.*, **16,** 693-700.

Ponte, R.M., and R.D. Rosen, 2000: Atmospheric torques on land and ocean and implications for Earth's angular momentum budget. *J. Geophys. Res.*, submitted.

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The research supported under the contract dealt primarily with: (a) the mechanisms responsible for the exchange of angular momentum between the solid Earth and atmosphere; (b) the quality of the data sets used to estimate atmospheric angular momentum; and (c) the ability of these data and of global climate models to detect low-frequency signals in the momentum and, hence, circulation of the atmosphere. Three scientific papers reporting on the results of this research were produced during the course of the contract. These papers identified the particular torques responsible for the peak in atmospheric angular momentum and length-of-day during the 1982-83 El Nino event, and, more generally, the relative roles of torques over land and ocean in explaining the broad spectrum of variability in the length-of-day. In addition, a tendency for interannual variability in atmospheric angular momentum to increase during the last several decades of the 20th century was found in both observations and a global climate model experiment.

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