ATMOSPHERIC ANGULAR MOMENTUM FLUCTUATIONS
IN GENERAL CIRCULATION MODELS DURING THE AMIP PERIOD (1979- 1988):
REPORT ON AMIP DIAGNOSTIC SUB-PROJECT NUMBER 15

R. Hide[1,2] (Principal Investigator), J. O. Dickey[1], S. L. Marcus[1], R. D. Rosen[3], and D.A. Salstein[3]

[1]Jet propulsion Laboratory, California Institute of Technology, Pasadena, California 91109
[2]Physics Department (Atmospheric, Oceanic, and Planetary Physics), Oxford University, OX 1 3PU England, UK
[3]Atmospheric and Environmental Research, Inc., Cambridge, Massachusetts 02139

INTRODUCTION

Background and Motivation

The Earth's atmosphere rotates faster than the underlying planet by about 10 ms^{-1} on average. If transferred to the solid Earth, the atmospheric angular momentum (AAM) associated with this super-rotation would reduce the length-of-day (LOD) by about 3x 10-3s (3 ins). Geodetic observations going back several decades reveal more or less irregular LOD fluctuations of up to about 1 ms on interannual, seasonal, and intraseasonal time scales, and detailed studies using modem meteorological and geodetic data have established that these fluctuations are largely of meteorological origin (for reviews see Hide and Dickey, 199 l; Rosen, 1993). Because these fluctuations are readily shown to be intimately related to global energetic processes (Barnes et al., 1983; Hide, 1984; Bell et al., 1991), the ability of a global atmospheric general circulation model to represent AAM variations satisfactorily should be one good test of its trustworthiness. Indeed, large-scale dynamical fluctuations of the atmosphere produce strong and useful signals in AAM and LOD over a wide range of time scales (e.g. Hide et al., 1980; Rosen et al., 1984; Dickey et al., 1991; Salstein et al., 1993; Dickey et al., 1994).

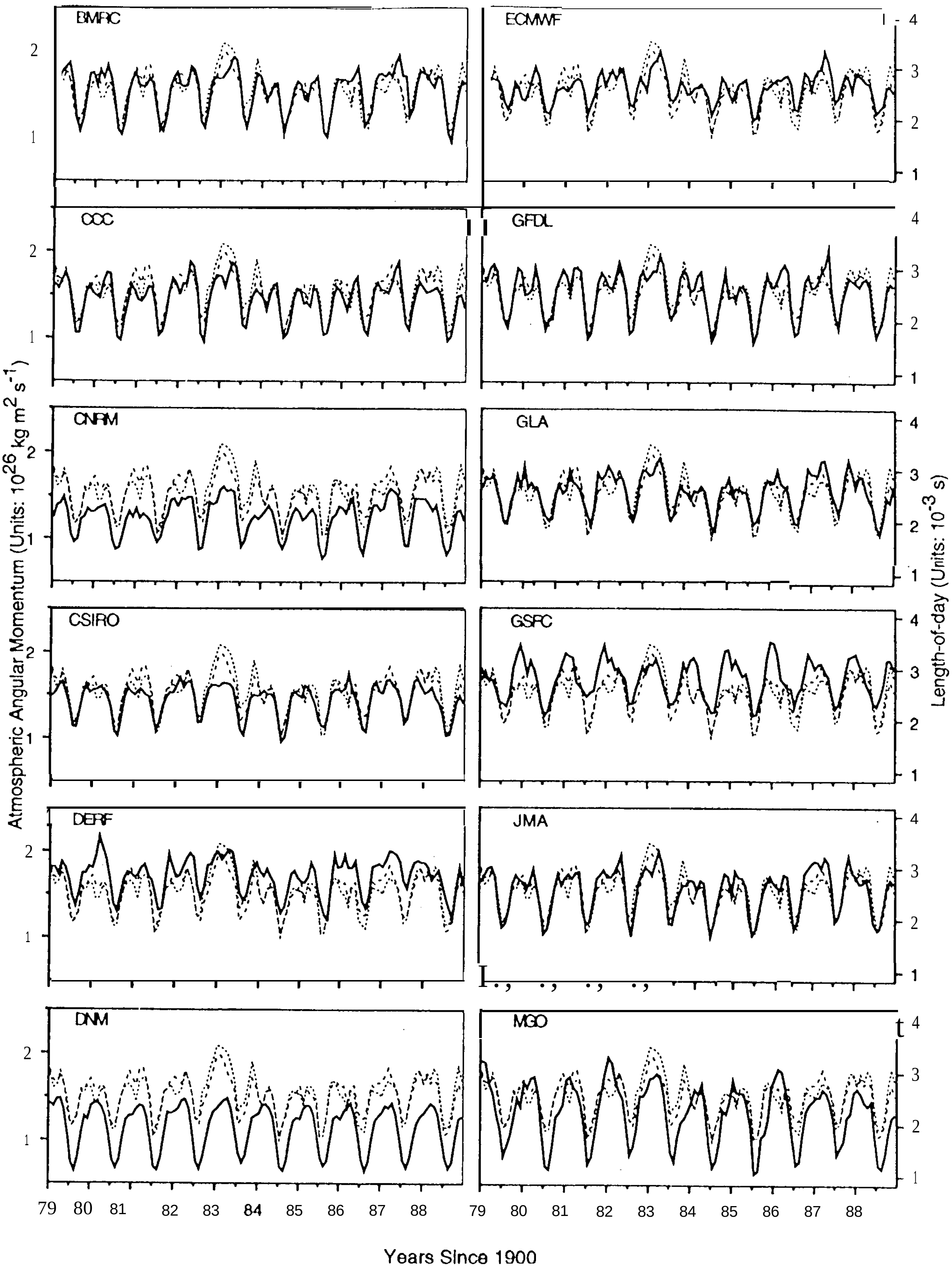
Approach

The most complete series of zonal wind fields generally available for the AMIP decade (1979-88) are those produced operationally by the NMC. These fields were used to create a monthly series of the relative angular momentum (M^w) of the atmosphere about the polar axis by evaluating

$$M^w = 2\pi R^3 g^{-1} \int_{50}^{1000} \int_{-\pi/2}^{\pi/2} [u] \cos^2\phi \, d\phi \, dp$$

where R = 6.3674 x 10^6 m is the mean radius of the solid Earth, g = 9.810 m S^{-2} is the average value of the acceleration due to gravity at the Earth's surface, and [u] is the zonal-mean zonal wind at latitude ϕ and pressure p. Here M^w represents the contribution to AAM from zonal winds in the troposphere and lower stratosphere; smaller contributions from the upper stratosphere (above 50 mb) and from the planetary component of AAM (related to the surface pressure distribution) are neglected in this initial study.

On decadal and longer time scales, the dominant forcing of LOD is due to non-meteorological processes, including angular momentum exchange between the Earth's liquid metallic core and the overlying solid mantle. If these long-term influences are removed by fitting a second-order polynomial to the LOD time series during the AMIP decade, the residual intraseasonal to interannual variations in the geodetic record track the relative angular momentum M^w quite closely. Monthly observed AAM and LOD variations during the AMIP decade are plotted using dashed and dotted lines, respectively, in each frame of Figure 1, for comparison with the M^w series determined from the standard output for the individual AMIP models (solid lines). As of early 1995, monthly mean values of [u] were available from 28 GCMS; all but 5 of the GCMS include pressure levels up to 50 rub, and these 5 models were dropped from further consideration to maintain consistency with the depth of the atmosphere in the NMC observations.


BMRC
ECMWF
CCC
GFDL
CNRM
GLA
CSIRO
GSFC
DERF
JMA
DNM
MGO
Atmospheric Angular Momentum (Units: 10^{26} kg m^2 s^{-1})
Length-of-day (Units: 10^{-3} s)
79 80 81 82 83 84 85 86 87 88
Years Since 1900

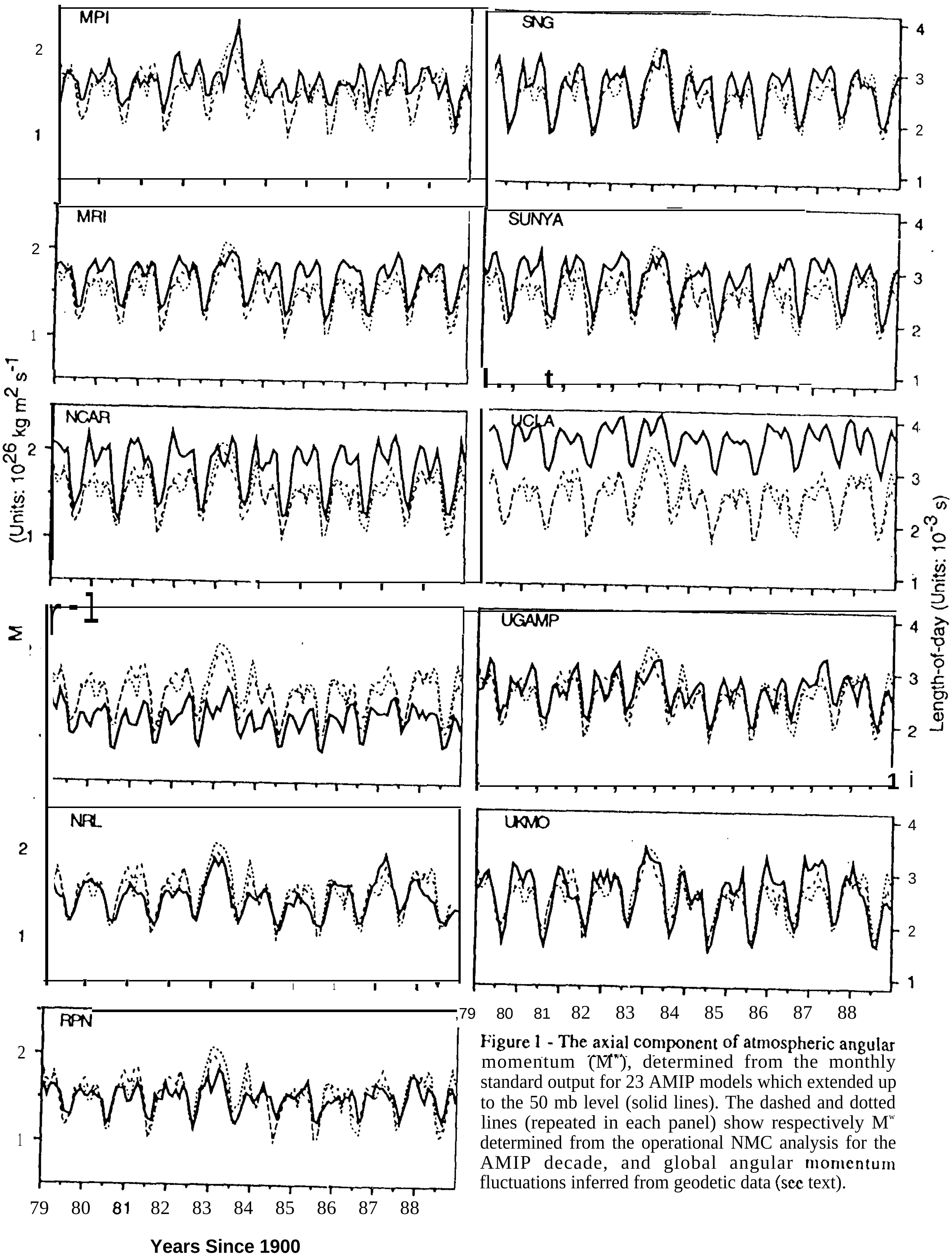


Figure 1 - The axial component of atmospheric angular momentum (M^w), determined from the monthly standard output for 23 AMIP models which extended up to the 50 mb level (solid lines). The dashed and dotted lines (repeated in each panel) show respectively M^w determined from the operational NMC analysis for the AMIP decade, and global angular momentum fluctuations inferred from geodetic data (see text).

RESULTS

Decadal Mean

During the AMIP decade, the mean value of M^w determined from the NMC data was 1.51 $X10^{26} kg\, m^2 s^{-1}$ (the residual LOD, of course, provides no information on the time-mean value of AAM). While many of the models reproduced the observed mean value quite well, some were consistently too high or too low (see Figure 1). Encouragingly, the model median was only some 3.5% larger [ban the observed value, and 10 of the 23 model values lie within 5% of the observed, although 5 of the 23 model values were more than 15% away from the observed (sec. Figure 2).

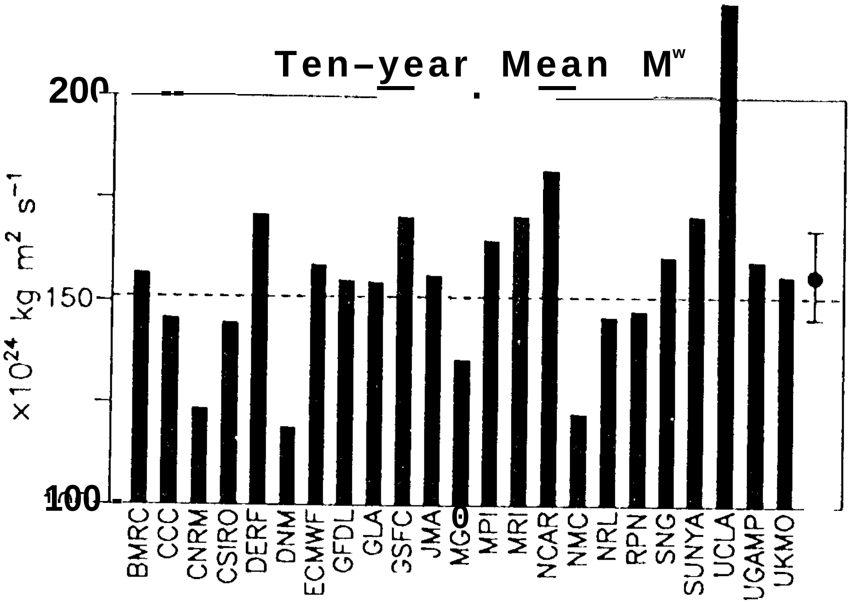


Figure 2 - Mean value of M^w averaged over the whole of the AMIP period (1979-88) for each of the 23 models. At the right are plotted the median and the upper and lower quartiles of the distribution of the 23 determinations. The dashed line indicates the value based on NMC operational analyses of atmospheric observations.

Seasonal Cycle

A striking feature of the global atmospheric circulation is its strong seasonal cycle, evident in the time series displayed in Figure 1. The seasonal cycle in AAM derives from the asymmetry in the land-ocean distributions of the northern and southern hemispheres and the resulting difference in the seasonality of the two hemispheres' subtropical jets (Figure 3).

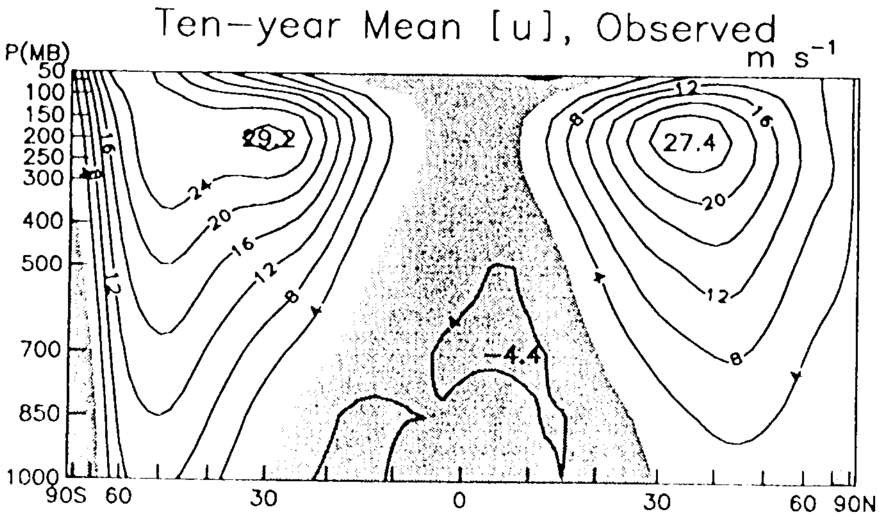


Figure 3 - Meridional cross-section of the average value (with respect to time and longitude) of the observed zonal wind during 1979-88, based on NMC operational analyses of atmospheric observations. Shaded values are negative (easterlies). The worst discrepancies in [he 23 AM I}' models we have investigated are found at upper levels, where they can exceed amplitudes of 12 m/s

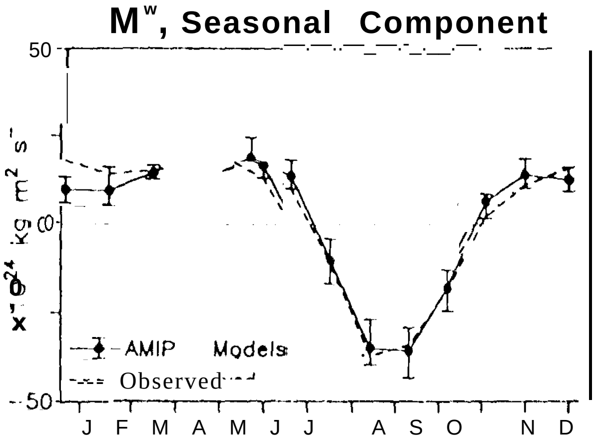


Figure 4- The median among [he 23 model values of the relative angular momentum of the atmosphere between 1000 and 50 mb for each composite calendar month of 1979-88 (solid line), along with (he upper and lower quartiles of the distribution of model values for each composite month, The dashed line indicates the observed composite monthly values, based on NMC operational analyses. The decadal mean of the series for each model and for the observations has been removed prior to generating these results.

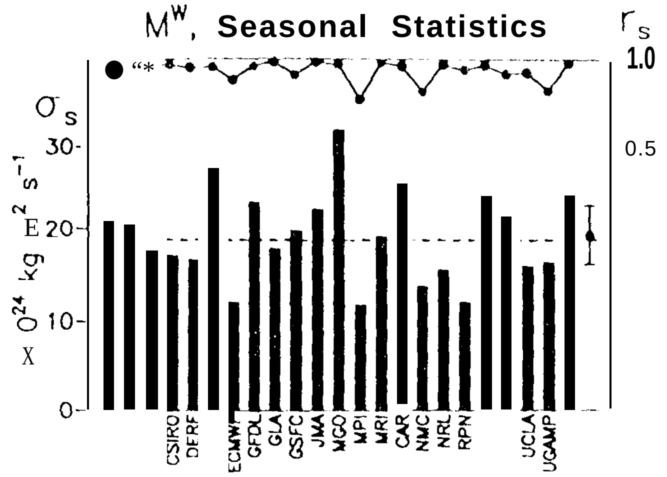


Figure 5 - At bottom, the standard deviation of the twelve composite calendar- month means during 1979-88 of the relative angular momentum of the atmosphere between 1000 and 50 mb for each of 23 models. To the right on [he same scale are plotted the median and the upper and lower quartiles of the distribution of model values, The dashed line indicates the value observed for the same decade based on NMC. operational analyses. At top, the correlation coefficient (scale on right) between each model's series of composite monthly M^W values and the observed series.

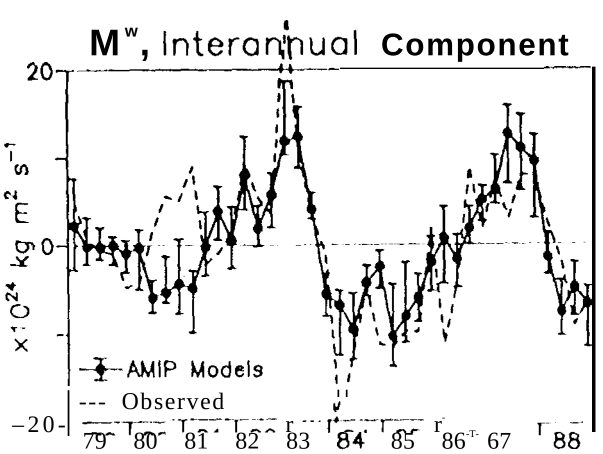


Figure 6 - As in Figure 4, but for the interannual component of the relative angular momentum of the atmosphere between 1000 and 50 rnb formed by averaging monthly values of M^w in each of 40 seasons during 1979-88 and subtracting from this series the decadal mean seasonal cycle.

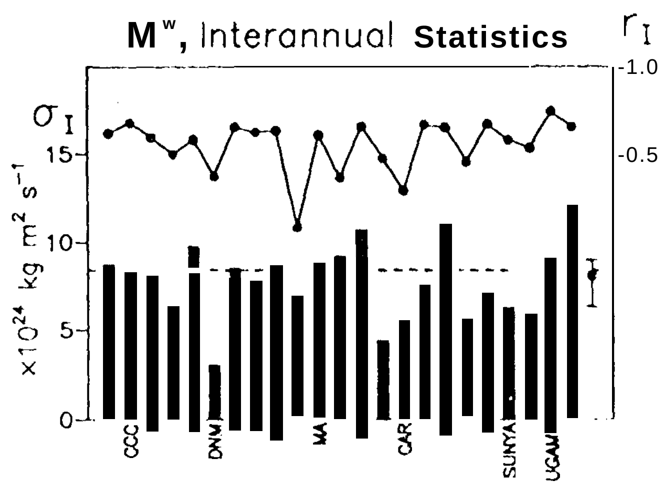


Figure 7 - As in Figure 5, but for the interannual component of the relative angular momentum of the atmosphere between 1000 and 50 mb formed by averaging monthly values of M^w in each of 40 seasons during 1979-88 and subtracting from this series the decadal mean seasonal cycle.

Because [he seasonal cycle represents the largest mode of variability in the AAM time series, it is encouraging to see in Figure 4 that the AMIP models do tend to reproduce the behavior observed in the climatological monthly mean progression of AAM values. Figure 5 displays a measure of the amplitude of the seasonal cycle, namely the standard deviation (es) of the twelve composite calendar-month means of AAM, for each AMIP model and the observed NMC series. There dots not appear to be any relationship between errors in a model's seasonal cycle and its decadal mean bias shown in Figure 2. Also shown in Figure 5 is the correlation coefficient (r_S) between each model's composite monthly M^w values and the observed series. Not surprisingly in light of Figure 4, r_S is generally quite large (median = 0.95).

Interannual Variation

The AMIP decade encompassed two ENSO events, those of 1982-83 and 1986-87. The signature of the two events is apparent in the observed interannual AAM anomaly series in Figure 6 as a sharp peak in early 1983 and a broader, less intense maximum from late 1986 through 1987, On average, the AMIP models reproduce the observed interannual anomaly series fairly well, albeit not so successfully as [hey do the seasonal cycle (Figure 4; note, by the way, the difference in scale between Figures 4 and 6, reflecting the smaller variance present in interannual than seasonal time scales). Figure 7 contains the interannual standard deviation σ_I for each model separately, along with the correlation coefficient r_I between each model's time series of 40 seasonal anomalies and the observed. The median value of σ_I is quite close to the observed, and, as is the case for the seasonat cycle, half of the model σ values lie within about 15% of the observed. No relationship between individual 0_I and σ_S values appears to exist, so that a model's performance on one time scale is generally independent of that on the other. A striking difference between overall model performances on seasonal and interannual time scales is that r_I is notably smaller than r_S. In particular, several models had difficulty simulating the intense AAM maximum, visible in both the observed M^w and LOD series, which characterized the strong ENSO event of 1982-83 (see Figures 1 and 6).

CONCLUSION

In this short summary no more than a few specimens of our findings can be given; further details will be presented in reports now being prepared for publication in the open literature. We trust that these AAM intercomparisons arc of interest to modeling groups as (hey investigate discrepancies in their models. Indeed at least one group has already responded to our findings by implementing model changes.

ACKNOWLEDGMENTS

We wish to thank the staff at PCMDI for their assistance in accessing and interpreting the model output. The work of R. hide, J. Dickey, and S. Marcus is the result of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration (NASA). The efforts of R. Rosen and D. Salstein at AER have been supported by the Climate Dynamics Program of the National Science Foundation under grant ATM-9223164 and the NASA EOS and Lageos II projects under grant NAGW-2615.

REFERENCES

Barnes, R.T.H., R. Hide, A. A. White, and C. A. Wilson, 1983: Atmospheric angular momentum fluctuations, length of day changes and polar motion. Proc. R. Sot. London, A387, 31-73.

Bell, M. J., R. Hide, and G. Sakellarides, 1991: Atmospheric angular momentum forecasts as novel tests of global numerical weather prediction models. Phil. Trans. R. Sot. Lond. A, 334, 55-92.

Dickey, J. O., Ghil, M., and Marcus, S. L., 1991: Extratropical aspects of the 40-50 day oscillation in the length-of-day and atmospheric angular momentum. J. Geophys. Res., 96, 22643-22658.

Dickey, J. O., S. L. Marcus, R. Hide, T. M. Eubanks, and D. H. Boggs, 1994: Angular momentum exchange among the solid Earth, atmosphere, and oceans: A case study of the 1982-83 El Niño event. J. Geophys. Res., 99, 23921-23937.

Hide, R., N. T. Birch, L. V. Morrison, D. J. Shea, and A. A. White, 1980: Atmospheric angular momentum fluctuations and changes in the length of the day. Nature, 286, 114- I 17.

Hide, R., 1984: Rotation of the atmospheres of the Earth and planets. Phil. Trans. R. Soc. Lond. A3 13, 107-121,

Hide, R., and J. O. Dickey, 1991: Earth's variable rotation. Science, 253, 629-637.

Rosen, R. D., 1993: The axial momentum balance of Earth and its fluid envelope. Surveys Geophys., 14, 1-29.

Rosen, R. D., D. A. Salstein, T. M. Eubanks, J. O. Dickey, and J. A. Steppe, 1984: An El Niño signal in atmospheric angular momentum and Earth rotation. Science, 225, 41 1-414.

Salstein, D. A., D M. Kann, A. J. Miller, and R. D. Rosen, 1993: The Sub-Bureau for Atmospheric Angular Momentum of [he international Earth Rotation Service: A meteorological data center with geodetic applications, Bull. Am. Meteorol. Soc., 74, 6"/-80,