THE AXIAL MOMENTUM BALANCE OF EARTH
AND ITS FLUID ENVELOPE

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(Received 26 March 1992; in revised form 2 June 1992)

Abstract. The emergence of greatly improved data sets over the past decade has heightened awareness of the close relationship between changes in the axial component of the angular momentum of the atmosphere and that of the solid Earth, the latter being reflected in small, though detectable, changes in the planet's rate of rotation. Changes in the large-scale wind field, and hence in atmospheric angular momentum, on intraseasonal through interannual time scales can be associated with a number of identifiable meteorological phenomena, whose further study has been given new impetus by the discovery of their signals in Earth's rotation. Future advances in the subject are apt to occur in connection with new data sets that will help address questions remaining about rapid changes in Earth rotation and the torques responsible for the momentum changes. Also in the coming decade, both new data and modeling approaches should help clarify the role of the oceanic portion of Earth's fluid envelope in the planetary momentum balance.

1. Introduction

The past decade has seen remarkable advances in the study of Earth's variable rate of rotation and the role of Earth's fluid envelope in contributing to this variability. This progress was achieved because of independent breakthroughs in the geodetic and atmospheric measurements of the relevant geophysical parameters. It is now accepted that changes in the axial component of the atmosphere's angular momentum (AAM) explain most, if not all, of the nontidal changes in the length-of-day (Δl.o.d.) over a broad range of time scales up to the decadal. The pursuit of this result has encompassed a wide spectrum of research, including studies of tropospheric and stratospheric wind fields, the El Niño/Southern Oscillation (ENSO) phenomenon, and tropical 40–50 day wind oscillations.

Meteorologists' interest in the subject of Earth's rotation dates back to Starr (1948). Although primarily concerned with explaining how the atmosphere's jet streams are maintained against dissipation, Starr noted in passing that "there is no reason to expect that the partition of angular momentum [between the solid Earth and the atmosphere] should remain constant when seasonal and other short time-intervals are considered." Munk and Miller (1950) then pointed out that seasonal changes in l.o.d. had indeed been detected and demonstrated that these could be explained by changes in AAM. The ensuing decades saw a number of studies aimed at better quantifying the relationship between AAM and Δl.o.d. (see reviews by Munk and Macdonald, 1960; Lambeck, 1980), and although considerable progress was made, results were limited by the quality of the data.

sets at hand. On the meteorological side, the data generally available were constrained to monthly mean values of wind collected at an irregularly spaced network of upper-air radiosonde stations, located mainly over the land in the Northern Hemisphere. Hence, prior to the 1980s, studies relating AAM and Δl.o.d. dealt mostly with seasonal time scales and involved large uncertainties because of the under-representation of observations over the oceans and the Southern Hemisphere.

The breakthrough in atmospheric measurements that changed this state of affairs is one of the legacies of the Global Weather Experiment (GWE) of 1978–1979, during which an unprecedented array of observing systems was used to monitor the atmosphere. In preparation for this Experiment, operational weather centers in a number of countries began to develop new data analysis systems that could assimilate observations not only from the traditional network of radiosonde stations but also from satellites, aircraft, and other platforms. With the promise of more global coverage made by these newer observing systems, data analysis systems could also be designed to encompass the entire horizontal extent of the atmosphere. Thus, in September 1974 the first operational global data analysis system was introduced by the U.S. National Meteorological Center (NMC) thereby enabling AAM to be evaluated not only with global data but also at a high temporal resolution. Up to twice-daily values of the fields needed to evaluate AAM have been archived by NMC in a convenient form beginning January 1, 1976.

The first comparison between values of AAM produced by an operational weather center and values of Δl.o.d. was made by Hide et al. (1980), using analyses from NMC and the United Kingdom Meteorological Office (UKMO) for four months of special observing periods during the GWE. A formal framework that takes advantage of the new meteorological data sets to relate changes in the atmosphere’s three-dimensional angular momentum vector to changes in l.o.d. and polar motion was developed by Barnes et al. (1983). Rosen and Salstein (1983) used six years of NMC analyses to perform an in-depth study of fluctuations in AAM on both seasonal and nonseasonal time scales, and they identified the regions of the global atmosphere that contribute most importantly to these fluctuations.

By fortunate coincidence, the dramatic improvement in the meteorological data sets has been matched by major advances in the geodetic data used to determine changes in Earth rotation. Thus the classical method for measuring such changes, based on observing the transit times of stars at a network of astronomical observatories, has been supplanted by a number of space-based techniques. These include very long baseline interferometry (VLBI) and laser ranging to either the moon (Dickey et al., 1985) or to artificial satellites (Degnan, 1985; Tapley et al., 1985). Advances in VLBI now permit Δl.o.d. to be determined to high accuracy on a daily basis (Robertson et al., 1985; Robertson, 1991), and plans to develop this capability further are being pursued. Another development in space-based geod-