ACTIVITIES OF THE SUB-BUREAU FOR ATMOSPHERIC ANGULAR MOMENTUM IN SUPPORT OF SEARCH'92

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ABSTRACT. This article describes the role that the Sub-bureau for Atmospheric Angular Momentum (SBAAM) of the International Earth Rotation Service (IERS) played during the special SEARCH'92 (Study of Earth-Atmosphere Rapid Changes) campaign. During this period, atmospheric angular momentum values and related parameters from all four participating meteorological centers were received and archived by the SBAAM. Also, values of components of the torques linking the atmosphere and its underlying surface were received from one of the centers. These data sets are most useful for studying the high-frequency dynamic interactions which were the focus of the SEARCH'92 campaign.

1. Introduction

During portions of the SEARCH'92 campaign, held during the three-month period 21 June-22 September 1992, the Sub-bureau for Atmospheric Angular Momentum received very high frequency atmospheric angular momentum data, at 6-hourly resolution, from three meteorological centers, the U.S. National Meteorological Center (NMC), the Japan Meteorological Agency (JMA), and the European Centre for Medium Range Weather Forecasts (ECMWF). Data from the fourth participating center, the United Kingdom Meteorological Office, was received at 12-hourly resolution. The atmospheric angular momentum parameters, which are related to Earth rotation, were made available to a network of international scientists, as well as to the IERS. In addition, personnel at the U.S. NMC have been producing values of the components of torques between the atmosphere and solid Earth, which are derived from the weather forecasting and analysis models.

2. SBAAM Parameters

Effective atmospheric angular momentum (EAAM) functions were developed by Bames et al. (1983), who related atmospheric motions and mass distribution to Earth rotation and polar motion, and their use in an operational setting has been discussed by Salstein et al. (1993). The first two functions, \( X_1 \) and \( X_2 \), are the equatorial components and are associated with the excitation of polar motion. The axial component, \( X_3 \), is involved with changes in the length of day. The functions can be

\[ IERS(1994) \text{ Technical Note No 16.} \]
further partitioned into contributions by wind and pressure. The calculation of wind contributions involves the computation of integrals over the depth of the atmosphere, which varies in the global models. Therefore, wind contributions to 100 hPa, as well as to the top of the model, were specified so that values from the various centers could more accurately be compared. Changes in the mass distribution, and hence the moment of inertia, of the atmosphere, are closely related to its two-dimensional surface pressure field. The pressure-related components from the centers can be compared without regard to the vertical construction of the model. A key issue is the extent to which an equilibrium response of the ocean modifies the changes in the pressure distribution felt by the solid Earth. At certain time scales, this inverted barometer (IB) response acts to reduce the equivalent angular momentum fluctuations of the atmosphere. Because the IB exists to at least a certain extent, calculations with a global IB correction are performed in parallel to the regular pressure terms. These excitation parameters are given at very high resolution for much of the SEARCH'92 period.

Other meteorological parameters are included in the Sub-Bureau files. Zonal mean zonal wind, from which the $X_3$ term can be calculated, and zonal mean temperatures, whose gradients are related to overall zonal winds, are SBAAM analysis fields. Routine specification of the mass distribution of the atmosphere, expressed in low-order spherical harmonic expansions, is important in the study of various problems in geodynamics and geodesy, including the effects of mass redistribution on satellite orbits. These coefficients are also SBAAM fields.

The analysis file at high resolution is calculated either six-hourly (00, 06, 12, and 18 UTC) or twelve hourly (00 hr and 12 hr UTC), as specified, and consists of the following set of parameters:

1) hemisphere values of $X_1$, $X_2$, and $X_3$, for wind to top of model, wind to 100 hPa, and pressure, and pressure + inverted barometer (6 hourly)
2) zonal mean zonal winds (m/s) at 5 degree latitude intervals at 12 mandatory pressure levels (1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 and 50 hPa) (12 hourly)
3) zonal mean temperatures (K) at the same grid as the zonal mean zonal winds (12 hourly)
4) mean surface pressure (hPa) over the globe (6 hourly); and
5) low-order coefficients of surface pressure, including spherical harmonics in full triangular truncation to degree 4 and zonal harmonics to degree 20 (6 hourly).

In addition, forecasts of the EAAM functions are part of the normal SBAAM products. These are made at 12-hour lead times out to 10 days or to the limit of the model if less than 10 days. The 12-hour interval was selected so that models with different start times could be validated at the same time. The EAAM functions $X_1$, $X_2$, and $X_3$, are globally integrated for wind to top of model, for wind to 100 hPa, for pressure, and for pressure + inverted barometer.

3. Results for the SEARCH'92 Period

Figs. 1a-1c show the excitation quantities for the three-month SEARCH'92 period from NMC, ECMWF, and JMA, the centers which have provided very high resolution analysis data. Some points to note are as follows. The winds terms are to the top level of the center, noted in the figures, and so vary from the different centers. Values are given at the highest temporal resolution possible.
Earth rotation excitation


Winds (to 50 hPa)

\[ \chi_1 \]

\[ \chi_2 \]

\[ \chi_3 \]

Pressure

\[ \begin{array}{c}
\text{Pressure (inverted barometer)} \\
\end{array} \]

\[ \begin{array}{c}
\text{Pressure (I.B.)} \\
\end{array} \]

Figure 1a. Values of the global effective atmospheric angular momentum functions \( \chi_1, \chi_2, \) and \( \chi_3 \) for wind, pressure, and pressure (inverted barometer) from the NMC analysis system for the whole period of SEARCH'92 (21 June-22 September 1992), given four times per day, as available. Units are non-dimensional multiplied by 10\(^{-7}\). Vertical dashed lines denote the intensive period of the campaign.
Earth rotation excitation

(21 June – 22 Sept. 1992) (ECMWF)

Figure 1b. Same as Figure 1a, but for the ECMWF system.
Earth rotation excitation


Winds (to 10 hPa)

Pressure

Pressure (l.B.)

Figure 1c. Same as Figure 1a, but for the JMA system.
In order to best observe the diurnal variations, data from the two week intensive period, 25 July-8 August are given in Fig. 2 for the three centers. The sub-diurnal variability present in the $X_1$ and $X_2$-wind terms are likely due to the tidal response of the atmosphere to thermal forcing; such types of variations have been discussed by Hsu and Hoskins (1989). Six-hourly data are necessary to resolve these parameters, and so the SEARCH'92 period was the first in which we examined such fluctuations in both these equatorial wind parameters. The amplitude of the tidal response appears greater in the ECMWF fields than in the NMC fields, probably due to the higher level over which the former center calculated its wind values. Values for 06 and 18 UTC from the JMA, in particular, provided a weaker amplitude of this tidal signature during these synoptic times than the other centers. These hours are ones when fewer meteorological observations are taken.

The different mean values of the pressure-related excitation terms are likely due to the differences in topography of the three models. Each of the models uses its own representation of the surface topography, which relates to the overall surface pressure, and mass, of the atmosphere, and hence the pressure-based excitation ($X''P$) terms.

Values of the low-order coefficients of a spherical harmonic representation of the surface pressure, truncated to degree 4, based on the NMC system, are given in Figure 3a and b for the intensive period of SEARCH'92. The two portions of the figure contain the real and imaginary coefficients, respectively.

4. Earth-Atmosphere Torques during the SEARCH'92 Period

The atmosphere exchanges its momentum with the underlying surface by means of two separate processes involving forces applied at the atmosphere's underlying boundary whose moment arm is the distance from the Earth's surface to its axis. These two torques arise from (i) a normal pressure gradient force against the Earth's topography, usually called a mountain torque, and (ii) a tangential stress against the underlying surface, either ocean or solid land, which is termed a friction torque. Global values of these two torques have been computed from the U.S. National Meteorological Center's analysis-forecast system every 6 hours for the SEARCH'92 period and kindly supplied by G.H. White. The procedure used to calculate these values is described by White (1991).

In Fig. 4 the global values of the 6-hourly mountain and friction torques, as well as their diurnal average is given. Also shown is the sum of the two terms on a daily averaged basis and changes in the axial angular momentum of the atmosphere. This daily agreement is good, but not perfect; whereas momentum is derived from a combination of observations and values forecast by the meteorological prediction model in data sparse areas, the torque terms are related also to physical parameterizations and other approximations in the forecast portion of the NMC model. On a 6-hourly basis, however, the two terms agree less, raising the difficulty of defining the momentum variation at these extremely short time scales. One item to note is that friction torque tends to be less variable than mountain torque, over these short periods.
Earth rotation excitation


$\chi_1$

$\chi_2$

$\chi_3$

Winds (to 50 hPa)

Pressure

Pressure (I.B.)

Figure 2a. Same as Figure 1a, but for the intensive period of SEARCH'92 (25 July-8 August 1992).
Earth rotation excitation


Figure 2b. Same as Figure 2a, but for the ECMWF system.
Earth rotation excitation


Figure 2c. Same as Figure 2a, but for the JMA system.
Surface Pressure, Spherical Harmonic Coefficients

Figure 3a. Values of real coefficients of a triangular truncation (to degree 4) of a spherical harmonic expansion of the 6-hourly NMC surface pressure field. Units are hPa. The value of $a_0^0$, when divided by $2^{1/2}$, yields the global mean pressure.
Surface Pressure, Spherical Harmonic Coefficients

Figure 3b. Same as Figure 3a, but for imaginary coefficients. The zonal terms are equivalent to zero and are not given.
Figure 4a. (Top). Values of both mountain torque and friction torque, given every 6 hours, for the NMC analysis-forecast system. (Courtesy G.H. White of NMC). The daily means are given by the dashed lines. (Below) A comparison of the sum of the daily mean mountain and friction torque with the time derivative of axial angular momentum, proportional to the sum of the $\chi_3$ wind and $\chi_3$ pressure terms.
Torques and angular momentum (M) changes

Mountain Torque

Friction Torque

\[ \frac{dM}{dt} \]

Total Torque

Figure 4b. Same as Figure 4a, but restricted to the intensive period of SEARCH'92.
5. Relevant Bibliography

A discussion of the support for SEARCH'92 by the SBAAM was presented by Salstein et al. (1992) [Abstract in Appendix A] highlighting the intensive period. Further analysis of the local mechanisms responsible for rapid changes in atmospheric angular momentum, and hence in length of day, was presented by Salstein and Rosen (1993 and 1994). [Abstracts in Appendices B and C]. The particularly important regions for the intensive period were isolated to the low latitude southern hemisphere, where weather systems moving across the spine of the high Andes mountains of South America played a special role in accelerating the atmosphere during one phase (31 July-5 August) of a 1-2 week wave during this period.

6. References


Appendix A

Abstract from the Fall Meeting of the American Geophysical Union, 1992

Activities of the IERS Sub-bureau for Atmospheric Angular Momentum in support of SEARCH'92

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During summer 1992, excitation functions for Earth orientation were received at the SBAAM from our four participating meteorological centers, the U.S. National Meteorological Center, the United Kingdom Meteorological Office, the Japan Meteorological Agency, and the European Centre for Medium-Range Weather Forecasts. These functions, which measure the role of the atmosphere in changing the length of day and polar motion, are based on global integrals of winds and surface pressures and are now being reported at either a 6- or 12-hourly frequency, depending on the center. The higher frequency data now available reveal a strong diurnal signal in the polar motion-related wind term, in particular. The ability to capture this signature, which has been attributed to atmospheric tides, suggests that useful information is provided by the meteorological analyses at all four synoptic hours, despite the smaller number of observations available at some of these hours.

The interfacial torques that are responsible for the transfer of axial angular momentum across the atmosphere's lower boundary have begun to be computed from the operational analysis-forecast system at NMC. These values, computed on a 6-hourly basis, consist of the so-called friction and mountain torques, which are caused, respectively, by tangential stress forces over land or ocean, and normal pressure gradient forces against topography. Although the stress torque is the less variable of the two over a season, it appears to contain a relatively large diurnal signal. As a check on the accuracy of the calculations, the sum of the two torques is found to closely match the independently computed time derivative of global atmospheric angular momentum for this system.
Appendix B

Abstract from the Spring Meeting of the American Geophysical Union, 1993

Momentum variability and dynamic Earth-atmosphere interactions during SEARCH'92

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A special campaign to study Earth's rapid rotational variations and related atmospheric momentum variability was held in June-September 1992. As part of this effort, high temporal resolution angular momentum data from a number of meteorological data centers, especially during a two-week intensive period, were collected. The global axial component of atmospheric angular momentum during part of the SEARCH'92 period was observed to undergo oscillations on about a 10-day time scale, superimposed on a longer seasonal signal. Analysis in zonal belts indicates the importance of low and middle southern latitudes in contributing to the variance in these global signals. Further examination based on models and analyses of the U.S. National Meteorological Center reveals the relative importance of the two agents of dynamic momentum transfer, the frictional stress torque and the pressure-gradient mountain torque. In particular, the South American Andes region appears to have had special significance in producing a rapid transfer of momentum from Earth to atmosphere during the intensive period.
Appendix C


Topographic forcing of the atmosphere and a rapid change in the length of day

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**ABSTRACT:** During June-September 1992, a special campaign was held to measure rapid changes in Earth's rotation rate and to relate these to variations in the atmosphere's angular momentum, due principally to changes in zonal winds. A strong rise in both length of day and atmospheric momentum during a particular six-day subperiod is documented. For the first time, such a high-frequency perturbation is identified with a regional coupling mechanism. Mountain torques within the southern tropics appear to account for most of the rapid momentum transfer between the solid Earth and atmosphere, with those across the South American sector dominating.