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TITLE: High-frequency Variations in Earth Rotation and the Planetary Momentum Budget

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1. Introduction

The major focus of the subject contract was on helping to resolve one of the more notable discrepancies still existing in the axial momentum budget of the solid Earth-atmosphere system, namely the disappearance of coherence between length-of-day (l.o.d.) and atmospheric angular momentum (AAM) at periods shorter than about a fortnight. In several studies analyzing modern geodetic and atmospheric data, strong coherence between time series of l.o.d. and AAM have been found across a broad range of frequencies, but agreement on the high-frequency end of this range remains elusive. The sub-fortnightly time scale in the atmosphere is dominated by so-called synoptic wave activity, which is manifested at the surface by the familiar migratory high and low pressure systems on weather maps. Coherence between separate meteorological analyses of AAM is lower for synoptic time scales than for longer periods, suggesting that the high-frequency demise of coherence between AAM and l.o.d. may be due to errors in the atmospheric data. Uncertainties in l.o.d. measurements at high frequencies also exist, however, and may contribute to the problem. Apart from measurement errors, another plausible explanation for this lack of closure in the solid Earth-atmosphere momentum budget is the presence of a third body, in particular the ocean, in the system.

Recognizing the importance of identifying the source of the high-frequency momentum budget anomaly, the scientific community organized two special measurement campaigns to obtain the best possible determinations of l.o.d. and AAM. An additional goal was to analyze newly developed estimates of the torques that transfer momentum between the atmosphere and its underlying surface to determine whether the ocean might be a reservoir of momentum on short time scales. Under the subject contract, we played an active role in designing the measurement campaigns (Dickey et al. 1994)[1], amassing atmospheric data for the campaign periods (Salstein and Kann 1994)[2], and analyzing results. In sections 2 and 3 below, we report the major findings from each campaign in turn, and in section 4, we summarize our results and offer concluding remarks.

2. SEARCH '92

The SEARCH '92 campaign was conducted from June to September 1992, with a special period of intensive measurements held from 25 July to 8 August. During the intensive period, a rapid increase in both l.o.d. and AAM over a 6-day period was captured by the geodetic and atmospheric data. Salstein and Rosen (1994) isolated the cause of the increase in AAM primarily to zonal wind changes in Southern Hemisphere low latitudes. Examination of the mechanisms responsible for accelerating the atmosphere during this event pointed to "mountain" torques in these latitudes, and

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1 "SEARCH '92 Campaign: An Overview", IERS Tech. Note 16, I-1 to I-22.

2 "Activities of the Sub-bureau for Atmospheric Angular Momentum in Support of SEARCH '92", ibid, II-15 to II-31.

further analysis revealed that pressure differences across the South American Andes in particular, associated with a high-pressure weather system traversing the mountains, could explain the behavior observed in the solid Earth and atmosphere.

Full details of the analysis are presented in Salstein and Rosen (1994), a copy of which is attached. The results of this case study indicate that rapid changes in l.o.d. and AAM do occur virtually simultaneously and are effected by atmospheric pressure differences across topography. To determine whether this result depends on the time of the year, plans were formulated to conduct another measurement campaign, CONT '94, but scheduled instead to run during a northern winter season.

3. CONT '94

The time series of AAM during the bulk of CONT '94, encompassing January-February 1994, was dominated by a low-frequency signal (Fig. 1) of little interest for our present purposes. Superimposed on this signal, however, is a higher frequency fluctuation in AAM, spanning the last ten days or so of January. Isolating regional contributions to this fluctuation across the globe, we find that most of the behavior is due to zonal wind anomalies in northern subtropics.

A comparison of AAM with l.o.d. values during January 1994 (Fig. 2) shows reasonable, albeit far from complete, agreement. Differences between independent reductions of the geodetic measurements are also apparent, suggesting that improvements in these are still desirable. Nonetheless, the atmospheric and geodetic data are consistent in depicting the late-January increase in AAM associated with the high-frequency event in Fig. 1.

As in SEARCH '92, mountain torques appear to dominate the exchange of momentum between the atmosphere and solid Earth during CONT '94, although friction torques (not shown) play more of a role than they did in the earlier campaign. A plot of the atmospheric pressure difference between the periods of rapid increase and decrease in AAM during the late-January event (Fig. 3) highlights contrasts across the Rockies of North America and, therefore, mountain torques in this region.

4. Summary and Concluding Remarks

Discrepancies between AAM and l.o.d. at sub-fortnightly periods have been attributed to either measurement errors in these quantities or the need to incorporate oceanic angular momentum into the planetary budget. Results from the SEARCH '92 and CONT '94 campaigns reported here suggest that when special attention is paid to the quality of the measurements, better agreement between l.o.d. and AAM at high frequencies can be obtained. Moreover, the mechanism most responsible for the high-frequency changes observed in AAM during these campaigns involves a direct coupling to the solid Earth, i.e, the mountain torque, thereby obviating a significant oceanic role.

Our conclusion, therefore, is that the high-frequency loss of coherence between AAM and l.o.d. is due at least in part to observational shortcomings in the routine atmospheric and geodetic series, but shortcomings in the latter can be overcome by the careful analysis of better measurements, as evidenced by the results from SEARCH '92 and CONT '94. The small number of cases captured by these campaigns, however, prompts a caveat to this conclusion: it is possible that the two events chosen here are not typical of the more general high-frequency fluctuation in AAM. Further studies of rapid changes in the angular momentum of the atmosphere and solid Earth are warranted.

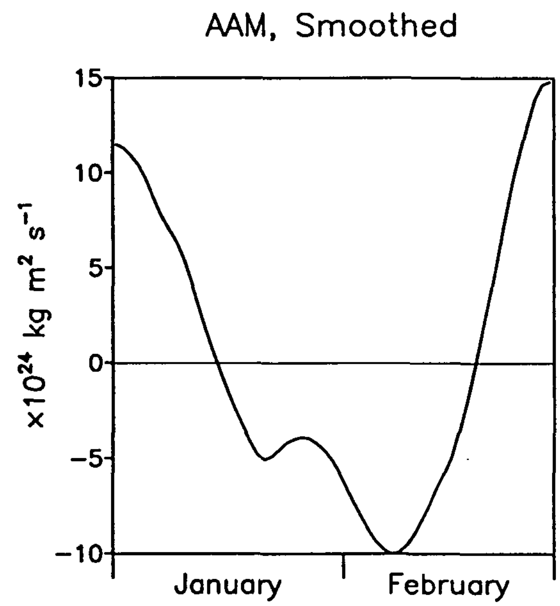

Fig. 1. Smoothed time series of the relative angular momentum of the atmosphere between 1000 and 50 mb during the first two months of 1994, obtained by applying an 11-day running-mean filter to momentum values produced daily by the U.S. National Meteorological Center (NMC). The mean value over the period has also been removed.

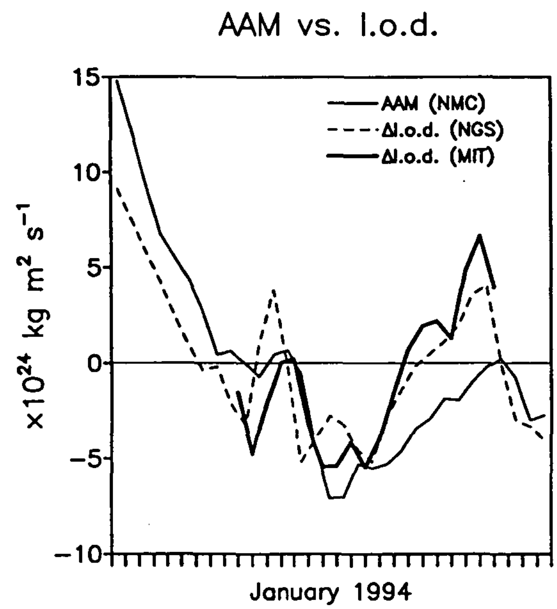

Fig. 2. Daily values of the total effective angular momentum of the atmosphere (i.e., relative plus planetary components, the latter modified by a Love number factor to account for the response of the non-rigid Earth to atmospheric loading) during January 1994 derived from NMC operational weather analyses (thin solid line), along with two determinations of Δ l.o.d. (converted to angular momentum units): one from NGS (dashed line), and another from MIT (heavy solid line) for a portion of the month. A monthly mean has been removed from each series. Note that the correlation (r=0.80) between the AAM and the NGS Δ l.o.d. series over the entire month is statistically significant.

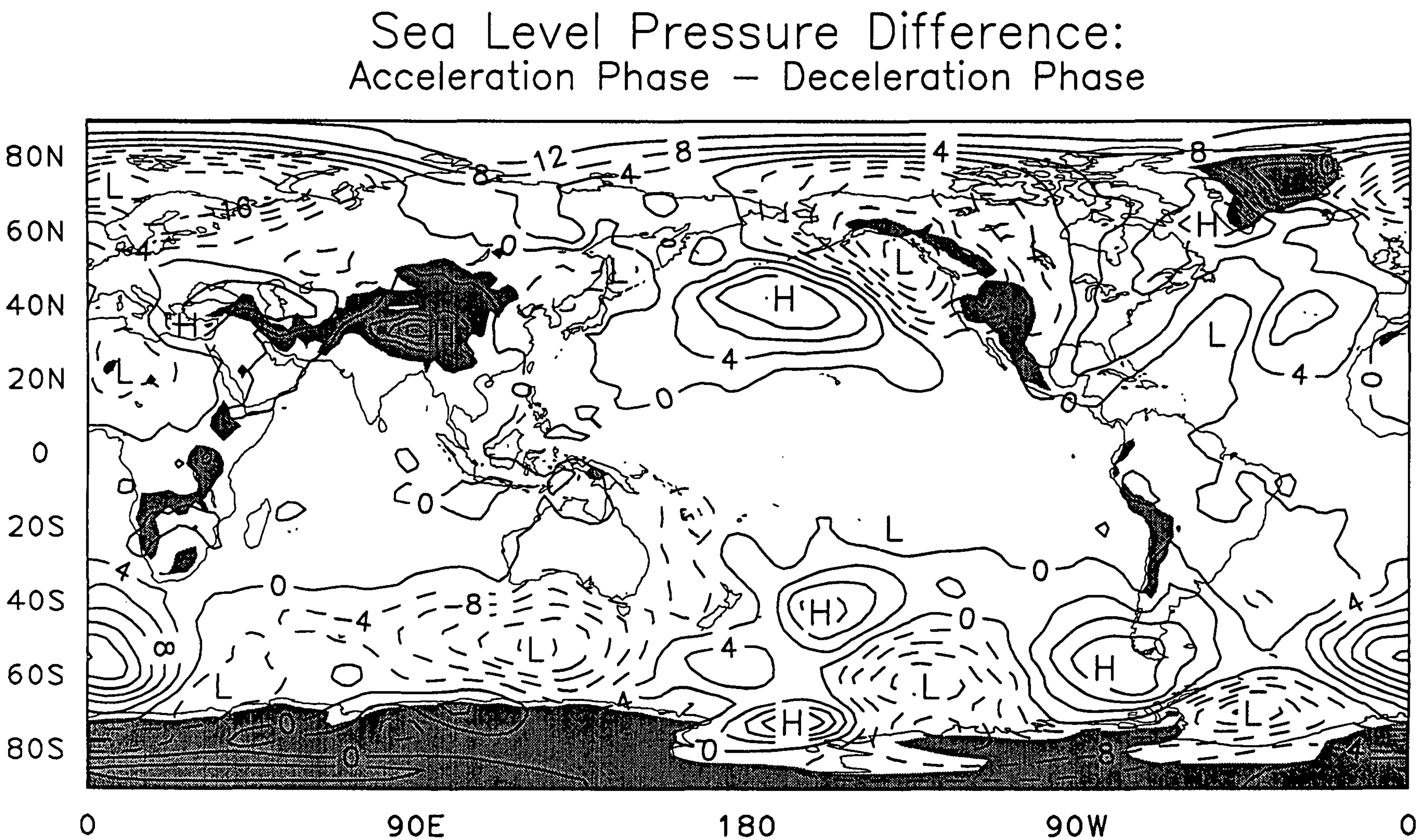

Fig. 3. Difference in atmospheric pressure reduced to sea level between the phase of increasing AAM during the CONT '94 high-frequency event (Jan. 21 to Jan. 28 mean) and the phase of decreasing AAM (Jan. 28 to Feb. 1 mean). Units are mb, and regions greater than 1 km in elevation are shaded.