in size (a few square kilometers), there is evidence that thermogenic gas hydrates may be widespread on the Gulf continental slope. Anderson *et al.* (*10*) recently reported oil-stained sediments containing large amounts of gas over a 20-km^2 area of the upper slope. Some of the sediment gases they collected contained large amounts of isobutane but little *n*-butane, suggesting that hydrates were originally present in these cores. Our report expands the area where oil, and probably hydrates, occur intermittently in surface sediments to ~250 km^2. The migration of thermogenic gas and oil to the surface in this area occurs along faults and fractures created by salt tectonics in the area. Since these processes are pervasive over large areas of the Gulf Coast, hydrates associated with thermogenic hydrocarbon seepage may be common along the continental slope.

Little seismic evidence for gas hydrates in the Gulf of Mexico has been reported. BSR's have not been reported for the northern Gulf of Mexico, although they have been reported along the Mexican Ridge systems (*2*). Sidner *et al.* (*11*) observed anomalous seismic features described as chaotic facies (gas-charged sediments). The gas hydrates sampled in this study were associated with chaotic facies or gas "wipeout" zones. Sections reported as chaotic facies may in reality be the top of a sediment section containing disseminated gas hydrates (*12*).

The discovery of thermogenic hydrates associated with oil-stained cores in the Green Canyon area of the Gulf of Mexico will necessitate more detailed chemical, geological, and biological studies of the area. The extent and distribution of hydrates, their seismic signature, and their possible association with active oil and gas seepage are only a few of the areas of interest suggested by this discovery. Many complicating processes in these cores need further study, such as (i) the response of the microbial ecosystem to seeping oil and gas and dissolving salt; (ii) the effect of the microbial processes on isotopic fractionation in the oil, methane, and carbon dioxide, and (iii) geochemistry associated with carbonate formation from degradation of the seeping oil. Because of the apparent widespread occurrence of oil in slope sediments from natural seepage, questions are also raised as to our ability to differentiate between natural seepage and petroleum pollution in the Gulf of Mexico and to determine baseline levels. The effect of solid hydrates and oil-stained sediments on the benthic ecology of an area is unknown. Gas hydrates may also represent a recoverable resource if they exist in significant quantities in the subsurface.

J. M. BROOKS
M. C. KENNICUTT II
R. R. FAY
T. J. MCDONALD
Department of Oceanography, Texas A&M University, College Station 77843
ROGER SASSEN
Getty Oil Company Research Center, Houston, Texas 77042

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$$\delta^{13}C = \frac{(^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{std}}{(^{13}C/^{12}C)_{std}} \times 1000$$

The δD value is reported relative to standard mean ocean water.
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An El Niño Signal in Atmospheric Angular Momentum and Earth Rotation

Abstract. *Anomalously high values of atmospheric angular momentum and length of day were observed in late January 1983. This signal in the time series of these two coupled quantities appears to have been a consequence of the equatorial Pacific Ocean warming event of 1982–1983.*

Interest in the angular momentum budget of the earth-atmosphere system has been sparked in recent years by the availability of routine global analyses of atmospheric wind fields and improved astronomical measurements of the rotation of the earth. Studies (*1–3*) have demonstrated that, on time scales of about a year and less, changes in the angular momentum of the atmosphere are strongly coupled to changes in the rotation rate of the solid earth, that is, to changes in the length of day (ΔLOD). We show here that, starting in late January

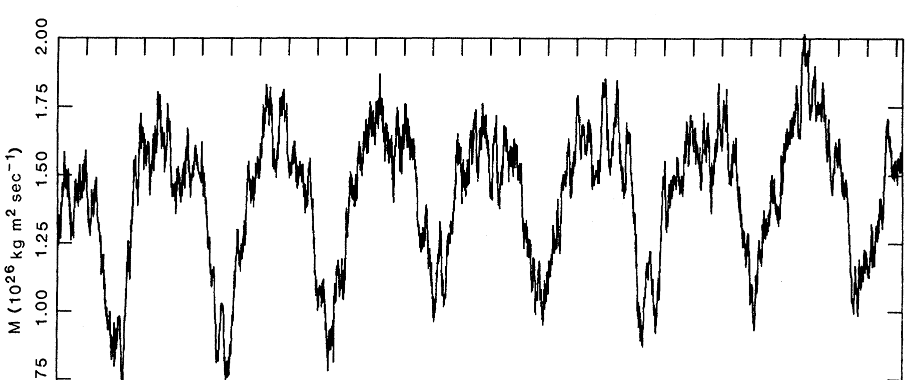

Fig. 1. Twice-daily values of the angular momentum of the atmosphere above the globe between 1000 and 100 mbar for the period 1 January 1976 to 31 December 1983. Time is marked along the abscissa in units of days.

1983, when the El Niño Pacific warming event of 1982–1983 was near its peak (*4*), major anomalies in the wind fields resulted in record values for atmospheric angular momentum and concomitant anomalies in ΔLOD.

A time series of the angular momentum (M) of the atmosphere about the polar axis, relative to an earth-fixed frame, is presented in Fig. 1 for the period from 1 January 1976 through 31 December 1983. The quantity M is given by

$$M = \frac{2\pi a^3}{g}\int_{1000\ \text{mbar}}^{100\ \text{mbar}}\int_{\pi/2}^{-\pi/2} [u] \cos^2\phi \; d\phi dp$$

where a is the mean radius of the earth, g is the acceleration due to gravity, ϕ is latitude, p is pressure, u is the eastward component of the wind, and the brackets denote a zonal average around a complete circle of latitude. Values of $[u]$ were derived from the twice-daily final analyses produced by the U.S. National Meteorological Center. These analyses were performed on a global grid with points spaced every 2.5° in both latitude and longitude and at each of 12 pressure levels in the vertical. The general nature of the temporal behavior of M has been discussed (*1, 5*); for example, the large seasonal cycle has been shown to result from an asymmetry in the winds between the Northern Hemisphere and the Southern Hemisphere. We wish to focus here on the remarkable feature (Fig. 1) in late January 1983 when M reached a peak about 8 percent larger than any other value (*6*). The existence of this peak is confirmed by independent meteorological analyses produced by the European Centre for Medium Range Weather Forecasts (*7*).

We have isolated the latitude zones most responsible for this M anomaly by using our $[u]$ series to compute the angular momentum (m_b) in each of 22 equal-area belts over the globe. In Fig. 2a we have plotted for the 4-month period beginning on 1 December 1982 daily values of m_b at the midpoint of each belt (*8*). By late January, the area around the equator covered by easterly momentum was at a minimum and a strong westerly momentum maximum was developing in the subtropics of the Northern Hemisphere. To contrast the winter of 1982–1983 with earlier ones, we computed mean values of m_b for each latitude belt and date during four previous winters and subtracted these values from those in Fig. 2a. The resulting difference plot in Fig. 2b demonstrates that the record M values in late January 1983 were due to the anomalies that existed in the tropics and subtropics. Indeed, strong positive anomalies between roughly 5° and 30°N persisted into late March.

The anomalous zonal winds in the Northern Hemisphere tropics and subtropics that began in January 1983 were but one manifestation of what in many respects appears to be among the strongest El Niño events of the past century (*4, 9*). This event, like those preceding it, involved a complex set of interactions between the ocean and the atmosphere throughout the equatorial Pacific that took many months to evolve (*10*). Moreover, the perturbations to this region's sea-surface and atmospheric temperature fields affected the circulation of the atmosphere in areas far removed from the equatorial Pacific. Recent model experiments (*11*) demonstrate that a sea-surface temperature anomaly in the equatorial Pacific can lead to a strengthened Northern Hemisphere subtropical jet over most longitudes. Indeed, the westerly wind anomaly displayed in Fig. 2 for zonal mean conditions appears to have resulted not only from record winds over the Pacific but also from contributions above the Gulf of Mexico, the equatorial Atlantic, and southern Asia (*4, 12*). Of course, some of these anomalies may represent in part some other manifestations of the interannual variability of the climate system. In any case, the Northern Hemisphere subtropical jet was generally observed to be several degrees latitude south of normal (hence at larger values of cos ϕ), and this winter saw new high values for the troposphere's zonal kinetic energy (*4*) in addition to the record values of M reported here.

On the basis of the work previously

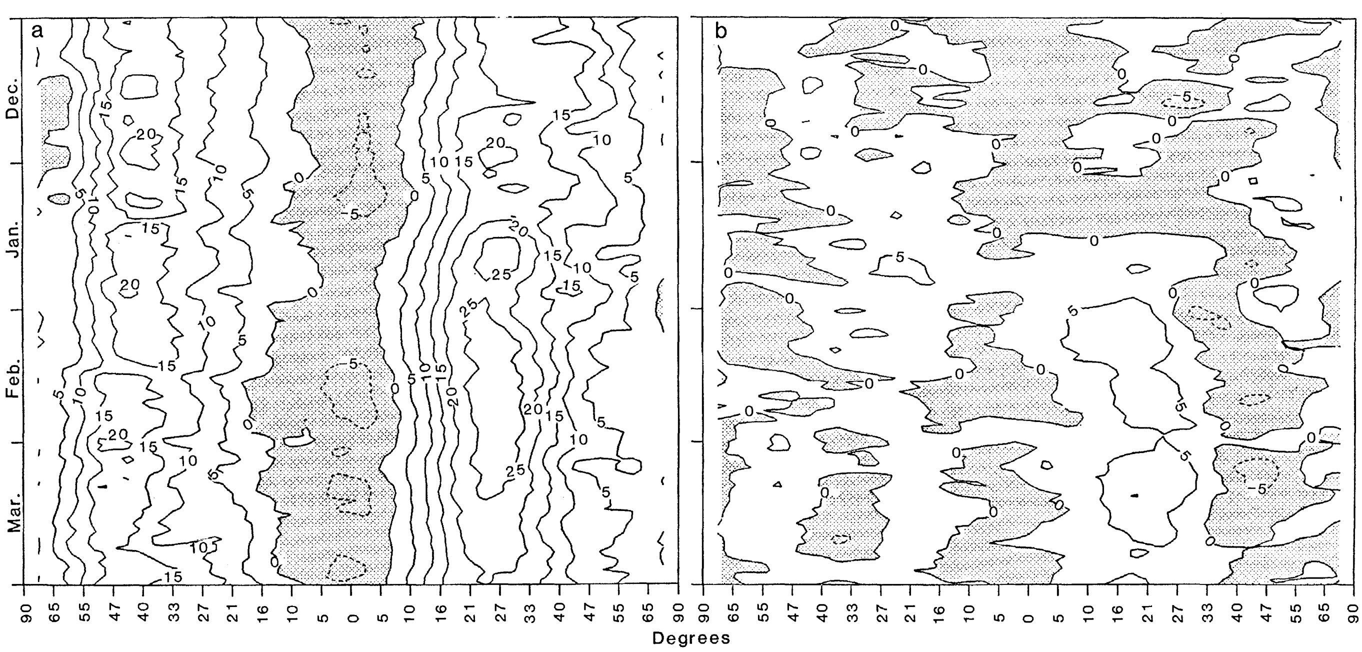

Fig. 2. (a) The angular momentum ($\times 10^{24}$ kg m^2 sec^{-1}) in each of 22 equal-area belts over the globe on a daily basis for December 1982 through March 1983. Contours are plotted every 5×10^{24} kg m^2 sec^{-1}, and negative values (corresponding to easterly momentum) are dashed. The latitudinal boundaries of the belts are indicated along the abscissa, and time runs down along the ordinate. (b) The difference between the belt angular momentum values for the winter of 1982–1983 given in (a) and the average of the belt angular momentum values for the four winters beginning in December 1976. Contours are plotted every 5×10^{24} kg m^2 sec^{-1}. Positive values indicate that a larger value existed during the El Niño winter than in the longer-term mean. Negative values are shaded.

cited, we would expect the record values for M in early 1983 to be reflected in time series of ΔLOD (*13*), and indeed this is the case. Figure 3a shows values of ΔLOD derived by applying a Kalman filter to 5-day averages of UT1 provided by the Bureau International de l'Heure (BIH) (*14, 15*). The Kalman filter used here incorporates a statistical model of the unpredictable high-frequency variations in the earth's rotation to determine an optimally smoothed estimate of ΔLOD (*16*). The secular trend in the curve in Fig. 3a cannot be associated with exchanges of momentum between the earth and the atmosphere but instead most likely involves the interaction between the core and mantle (*17*). To remove the low-frequency component, we have used a 365-day moving average. The resulting detrended series is given in Fig. 3b. The root-mean-square scatter, prior to 1983, of these data about the average seasonal cycle in late January is 0.21 msec; the anomaly in 1983 is 3.5 times this value and is clearly evident. Moreover, the ΔLOD data place this anomaly within a longer historical record than our atmospheric data. The detrended series in Fig. 3b shows it to be the most extreme positive anomaly since the start of our record in 1970. Finally, the amplitude and phase of the 1983 anomaly in ΔLOD agree well with those in M, as demonstrated in Fig. 4 where the two series are juxtaposed for the period since July 1981. Similar agreement between the two quantities is also evident when independent earth rotation data are used (*18*).

Although we have established that an unusually large amount of momentum was transferred from the earth to the atmosphere in early 1983, we have yet to identify the dynamical process, that is, the torque, that accomplished this exchange. Unfortunately, evaluating the torques linking the earth and the atmosphere is quite difficult (*19*). Computing the surface friction torque involves assumptions about the surface drag coefficient and boundary layer dynamics. Computing the torque associated with pressure stresses at the surface, the so-called "mountain" torque, requires an adequate topography field along with analyses of surface pressure gradients across the topography. Nevertheless, some calculations of these torques (*20*) indicate that it is generally the mountain torque that causes short-term exchanges of momentum between the earth and the atmosphere. We have not calculated these torques here but, in light of this earlier work, we can speculate about their behavior during January 1983. Closely associated with an El Niño event is the massive rearrangement of atmospheric mass within the tropical Pacific, a phenomenon that is generally measured by the difference in atmospheric surface pressure between Tahiti and Darwin, Australia. This difference, known as the Southern Oscillation Index (SOI), reached a record low value in January 1983 in conjunction with extraordinarily high pressure at Darwin and low pressure at Tahiti (*4, 21*). The higher-than-normal pressure to the east of the Asian topography and lower-than-

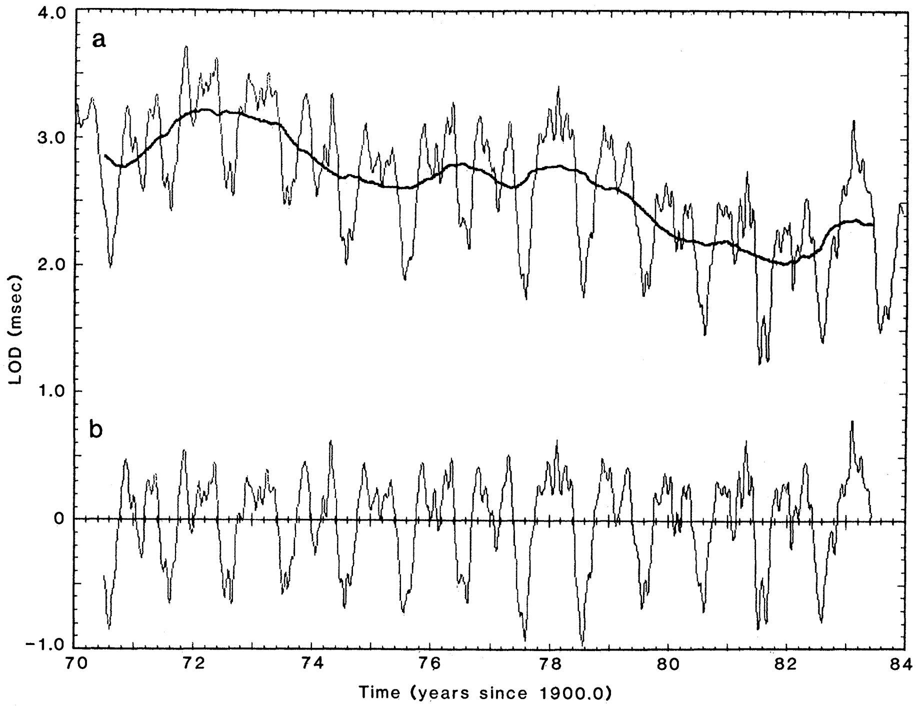

Fig. 3. (a) Changes in LOD from a base state of 86400 seconds, as determined from BIH astronomic data for the period from January 1970 to November 1983. All tidal terms with amplitudes greater than 0.01 msec of UT1 and periods of 18.6 years or less have been removed. The heavy curve is a 365-day moving average of this time series. (b) Difference between the original series and its moving average.

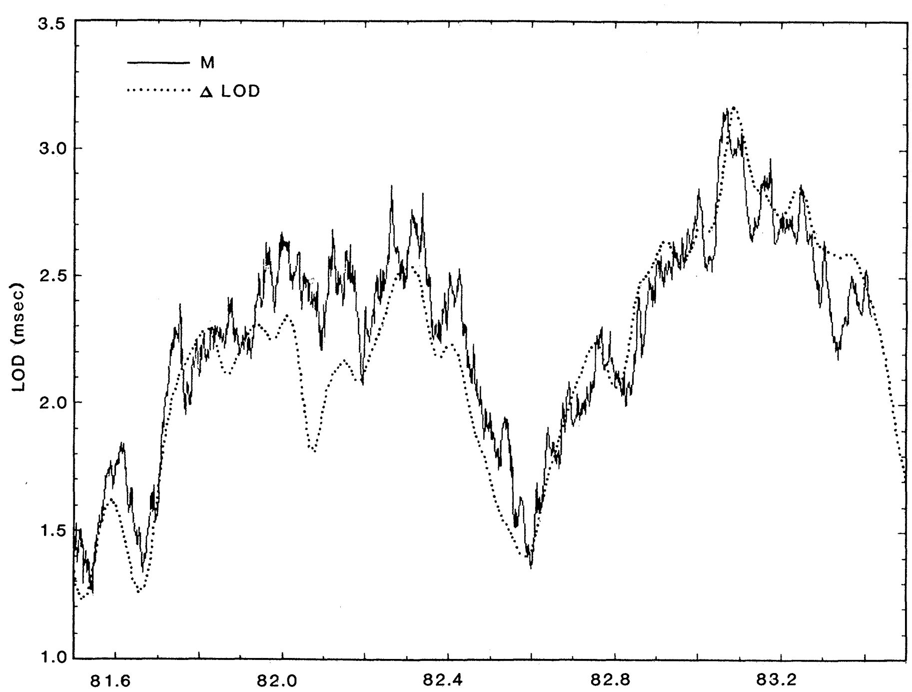

Fig. 4. Changes in LOD as inferred from the values of M in Fig. 1 (solid line) and as determined from the BIH data in Fig. 3a (dotted line) since July 1981. The mean difference between the two quantities has been subtracted from the M curve.

normal pressure to the west of the American topography should impart a "mountain" torque that would decelerate the solid earth while accelerating the atmosphere. This hypothesis, at least, is consistent with the sign of the anomalies we have detected in the momenta of the solid earth and the atmosphere around January 1983. Actual calculations are needed to verify whether the amplitude of this mountain torque is sufficient to account for the size of the anomalies.

The equatorial Pacific warming episode of 1982–1983 had widespread biological, economical, and physical impacts (*9*, *22*). Its effect on the atmosphere appears to have been especially profound and will be the subject of much further research. The results reported here suggest that, through its link with the atmosphere, this oceanic event even had a detectable influence on the motion of the solid earth.

RICHARD D. ROSEN
DAVID A. SALSTEIN
Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge, Massachusetts 02139
T. MARSHALL EUBANKS
JEAN O. DICKEY
J. ALAN STEPPE
Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91109

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14. The BIH values of UT1 prior to 1978 are taken from its annual reports and are based solely on astrometric data, whereas after 1978 data from other techniques are combined as well. The BIH values for 1978 through 1981 are from a rereduction of data in its annual reports, for 1982 from the annual report, and for 1983 from the raw averages in its Circular D.
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Analysis of Obsidian from Moho Cay, Belize: New Evidence on Classic Maya Trade Routes

Abstract. *Trace element analysis of obsidian artifacts from Moho Cay, Belize, reveals that the obsidian derives primarily from the El Chayal outcrop in highland Guatemala and not from the Ixtepeque source. This is contrary to the widely accepted obsidian trade route model for Classic Maya civilization and suggests that Classic Maya obsidian trade was a more complex economic phenomenon than has been recognized.*

More than a decade ago Hammond proposed a trade model to explain the distribution of obsidian artifacts at Classic Maya centers in the lowlands (*1*). Trace element analysis by x-ray fluorescence (XRF) and neutron activation (NAA) revealed a heavy reliance on two primary sources of obsidian—at El Chayal and Ixtepeque—during the Classic Period (A.D. 250 to 900). Both are located in the volcanic highlands of Guatemala, which is a considerable distance from the lowland Maya centers of obsidian use in Guatemala, Belize, and Mexico (Fig. 1). From analyses of obsidians from 23 lowland Maya sites, Hammond proposed that the movement of the valued volcanic stone most likely followed trade routes along major river valleys: (i) from El Chayal to the Maya interior lowlands by the Usamacinta and Sarstoon basins and (ii) from Ixtepeque, down the Motagua River to the Caribbean, and thence up the Belize-Mexico Yucatán coast.

The distribution of obsidian from the two sources appeared to be largely complementary, overlapping at or near Tikal in the central Maya lowlands. This suggested to Hammond that the two highland sources were being exploited contemporaneously during the Classic Period and that there was a level of competition between them for the lowland Maya market.

The validity of the two-pronged trade route has been questioned as the sources of more samples of obsidian have been identified. Some samples from the western lowland site of Seibal, for example, proved to have been derived from El Chayal, as predicted by the trade model, but others were from Ixtepeque and two other sources (*2*). Johnson raised additional queries after determining the sources of samples from Palenque and surrounding sites (*3*). As was the case at Seibal, most of the obsidian was derived from El Chayal, but there were specimens from Ixtepeque, San Martin Jilotepeque, Pachuca, and possibly Zaragosa. The distribution of obsidian in the western Maya lowlands did not convincingly support the trade model.

Some sources of Guatemalan obsidian appear to have been used more heavily at different times (*4*), indicating that obsidian from Classic Period deposits should be selected to analyze Classic Period obsidian trade routes. Hammond refined his model with data on obsidian from several sites located in southern Belize (*5*). The Classic Maya center of Lubaantun, for example, located but 25 km from the coast on several waterways, had no Ixtepeque obsidian at all (*6*). Islands off the southern coast of Belize received Ixtepeque obsidian, as predicted by the original model, but also El Chayal obsidian.

In reexamining the trade model, Hammond (*5*) suggested that during the Classic Period there were several transshipment points on a coastal Yucatán trade route between such major ports as Cozumel and Nito: there were "way stations where large trading canoes would put in