

work for the hydrology of ice caps, these eruptions have enabled us to examine the complicated interplay and feedback responses between water pressure and buoyancy, ice cap response, heat transfer rates, and hydrology. The studies showed that meltwater generation is voluminous in sub-glacial eruptions, almost irrespective of glacier thickness. This demonstrates the need for more research on heat transfer mechanisms in sub-glacial eruptions.

Volcano-Snow/Ice Interactions on Stratovolcanoes

Lavas that encounter mountain valley glaciers produce meltwater by thermal erosion of cavities, tunnels, and trenches in the ice, which, in turn, confine the lavas that flow in them. These are poorly known aspects of volcano-ice interaction, although good examples of the resulting landforms are found on stratovolcanoes in the Cascade Range. The features can be used to yield information on phases of glaciation that would otherwise be impossible to interpret. Sub-surface ice interaction is also postulated to have occurred on the flanks of some Martian stratovolcanoes. For example, the interaction probably played a critical role in the formation of some fluvial landforms and valleys. The catastrophic release of groundwater on Mars indicated by studies of those landforms may have been

triggered by the accumulation of magmatic gases or may be associated with increased hydraulic pressures in hydrothermal systems. Impermeable permafrost or ground-ice layers may have trapped dissolved magmatic gases in ground-water. Modeling suggests that hydrothermal activity associated with magmatic intrusions penetrates the ice layers and releases the gases.

Palagonite Alteration of Volcanic Glasses and Martian Exobiology

Remarkable evidence for microbial alteration of basaltic glass was presented. It was demonstrated how the microbes preferentially ingest the volcanic glass, and apparently avoid large crystals. Palagonite alteration commonly proceeds in two distinctively different ways—soil formation processes and hydrothermal alteration—although it seems to proceed much faster in hydrothermal systems. Spectral identification of the palagonite can also be used as an indicator of Martian geochemical history. Because volcanic heat sources may generate long-lasting hydrothermal systems, they potentially provide hospitable subsurface environments for the evolution of life on Mars. Thus, the exploration for extant life on Mars may be predicted by the discovery of hydrothermal areas identified by the spectral characteristics of palagonite-rich Martian regolith.

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A thematic volume will appear as a special publication of the Geological Society, London. For information, visit <http://www.flag.wr.usgs.gov/USGSFlag/Land/IcelandMeeting>.

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SECTION NEWS

ATMOSPHERIC SCIENCES



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High-Frequency Geophysical Fluid Modeling Necessary to Understand Earth Rotation Variability

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Improvements in diurnal atmospheric and oceanic modeling are needed to calculate excitations of high-frequency Earth orientation parameters. The study of Earth rotation variability is useful not only for practical application involving areas of astronomy, satellite

geodesy, and spatial navigation, but also for obtaining constraints on parameters of Earth's internal structure. Modeling Earth rotation requires an interdisciplinary approach, involving subjects as diverse as magneto-hydrodynamics, oceanography, atmospheric science, and celestial mechanics. When studying Earth rotation, we are dealing with its non-constant rate and the position of the rotation axis, observed both from an inertial reference frame and from a frame rotating with the Earth.

The orientation of Earth in space is determined using very precise geodetic techniques such as Very Long Baseline Interferometry (VLBI). Most of the Earth's motions are generated by gravitational interaction between Earth and the Sun, Moon, and planets, causing torques acting on Earth. Earth, as a non-uniform and non-rigid body, responds to these torques in a complex way. A "transfer function" for each frequency can be defined as the ratio between the amplitude of the observed Earth's orientation variation and what would be expected theoretically for a rigid Earth. The transfer function can also be computed using realistic Earth models. The comparison between the observed and modeled transfer functions can, in turn, be used to constrain models of Earth's interior.

Fluctuations of mass and motion in the superficial fluid layers—the atmosphere, ocean, and fresh water reservoirs—also

produce variations of Earth's orientation [Dehant *et al.*, 1997]. The variations due to the effect of these superficial fluids are large enough to be detected, given the present level of observation accuracy. For this reason, the International Earth Rotation Service (IERS) created the Global Geophysical Fluids Center (GGFC); see Chao *et al.* [2000] for more details. As those fluids have only negligible gravitational interaction with the Sun, Moon, and planets, there is no linear relationship between external gravitational forcing and the fluids' effect on Earth's rotation. The fluid effects have to be removed before the transfer function for the non-rigid Earth is computed. The nutation of Earth is a long-period motion of the Earth rotation axes in the inertial reference frame, and it is forced mainly by gravitational torques. Because nutation is a diurnal signal in the Earth reference frame, its strength and phase are influenced by the diurnally varying atmosphere.

To derive information about the non-rigid Earth parameters with similar precision as that of the observations, the influences of the atmosphere and ocean must be removed carefully. The atmospheric effects on Earth's orientation parameters are computed classically from the angular momentum of the fluid layer. Such an approach is based on the consideration that the total angular momentum of the Earth-atmosphere-ocean system is invariant. To any angular momentum change in the superficial fluid layer there is a corresponding opposite change in the solid Earth's angular momentum. The evolution of the fluid angular momentum should therefore provide all the information needed to determine the temporal evolution of solid Earth angular

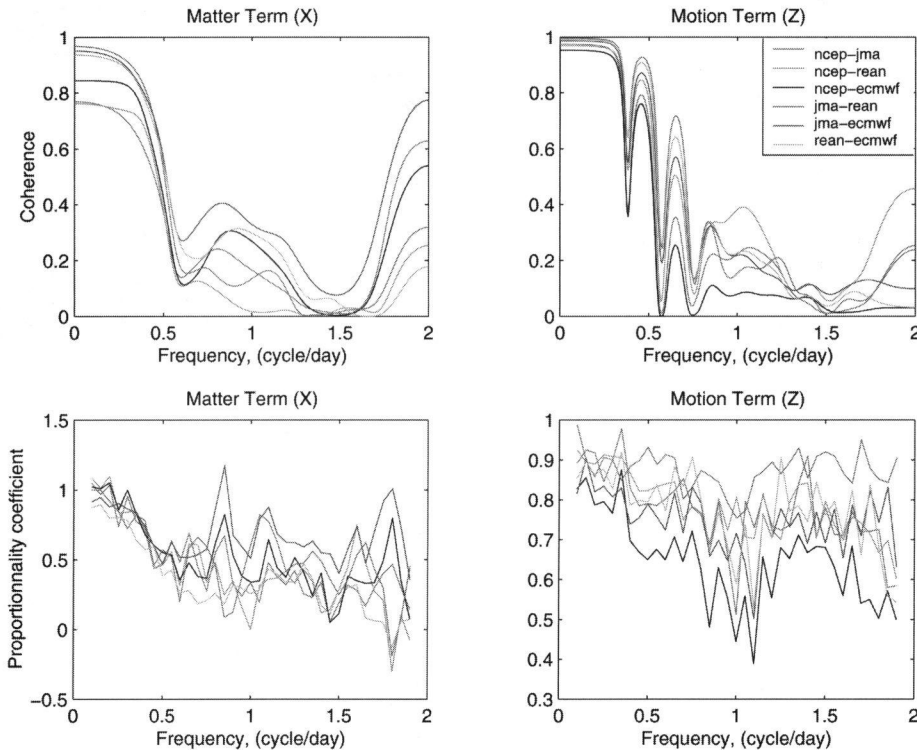


Fig. 1. Coherency and proportionality coefficients are shown between pairs of atmospheric series of equatorial angular momentum terms as a function of frequency. Original color image appears at the back of this volume.

momentum, and hence its rotation. Angular momentum series are calculated from the data assimilation systems of the world's major weather centers. The atmospheric models used are built to study short-geographical-scale atmospheric dynamics, while atmospheric angular momentum (AAM) is a larger-scale integrated parameter; but on longer lead times, nonlinearities between large and small spatial scales produce an interaction, and so capturing long scales are just as or even more important for users of such models, for example, for successful weather forecasting. Larger scales are also central to climate models, which may have lower spatial resolution. The basic observations of the atmosphere are not typically taken on the shortest time scales; the radiosonde network is mostly 12 hours, and 6 hours at just some stations.

Satellite-based information is temporally more continuous, but the frequency of data from polar-orbiting-type platforms depends upon orbit precession, sensor swath width, and latitude. Geosynchronous satellites take more continuous observations, but they are higher and provide lower resolution. Sensor information must also be interpreted for level information. So, given the limited observations, models are needed to fill in the gaps. Models describing the atmosphere well on sub-diurnal and diurnal time scales will be most successful for determining nutation and subdiurnal length-of-day and polar motion. The full description of weather events, moreover, can depend in part on the phase of the diurnal atmospheric or oceanic tides. Comparisons of pairs of such angular momentum series are given in Figure 1 from analyses of the following organizations: the European Centre for Medium-Range Weather Forecasts (ECMWF), the Japan

Meteorological Agency (JMA), the National Centers for Environmental Prediction (NCEP), and the National Center for Atmospheric Research (NCEP-NCAR Reanalysis Series) [Salstein *et al.*, 1993]. The figure shows the coherency and the proportionality coefficient between those series as a function of frequency. The proportionality coefficient is computed for each frequency band by dividing the covariance between the two series by the variance in one of them. These coherencies and coefficients are shown for the equatorial components and involve both the matter and motion terms that contribute to angular momentum parameters.

Figure 1 shows large differences between results from different analyses in the angular momentum matter term arising at all frequencies above 0.5 cycles per day. The uncertainties implied by these high-frequency differences between models are above the observational precision, the precision needed to determine forcing for high-frequency Earth Orientation Parameter variation, and the precision needed to constrain an Earth model. In particular, these uncertainties greatly hamper calculation of the atmospheric term needed for modeling Earth's nutation. The modeling and the observation of those motions now have a precision of about 20 micro-arcsecond (μ as), though the expected effect of the atmosphere is larger, on the order of one-tenth of a milli-arcsecond. Accounting for the atmospheric effect on Earth's nutation is thus an essential step to model it accurately. More generally, correction for the atmospheric and oceanic effect is a prerequisite for precise modeling of all the Earth rotation terms, but such correction is currently impossible for the diurnally dependent motions: nutation, diurnal, and subdiurnal length-of-day, and polar motion variations. For example, both the amplitudes and phases for the annual (in the space reference frame) terms of the atmospherically excited nutations, shown in Table 1, disagree considerably from one model to the other.

Although we have presented current results for atmospheric analyses here, similar information about the oceans is needed as well for the most accurate models of nutation. Thus, the necessity of having nutation corrections that are at least one order of magnitude better than the submilliarcsecond-level requires atmospheric and

Table 1. Effect of the atmosphere on the nutation for the annual frequency (in the space reference frame). This motion is excited by diurnal variation in the atmosphere. The magnitude is in micro-arcseconds, and the phase is given (in degrees) with respect to the astronomical forcing potential at that frequency.

	Prograde annual frequency		Retrograde annual frequency	
	Amplitude (μ as)	Phase (degree)	Amplitude (μ as)	Phase (degree)
NCEP-NCAR reanalysis	82.3	83	56.3	157
JMA	61.8	154	75	178
NCEP	109.4	122	159.4	-74
ECMWF	42.9	131	245.1	158

oceanic corrections to a comparable level of precision. We therefore urge scientists who analyze and model the atmosphere and ocean to calculate pressure and winds/currents, the parameters needed for computations of angular momentum, with better accuracies on times scales as short as the diurnal and subdiurnal, for the purpose of Earth orientation parameters studies.

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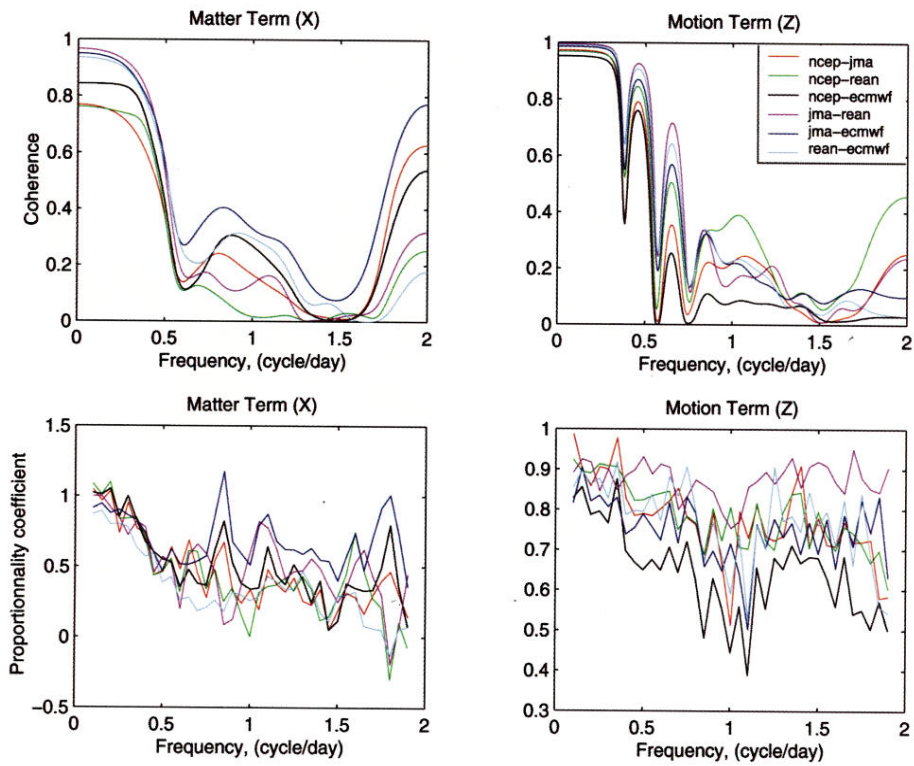


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