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"Concrete" Testimony to Milankovitch Cycle in Earth's Changing Obliquity

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The present-day obliquity of the ecliptic of the Earth is ε = 23°26' 22" and is decreasing by about 0".5 a year. This article reports a "concrete" terrestrial testimony to this time variation, which plays a major part in the Milankovitch cycles.

The obliquity is the angle between the equatorial plane, which is determined by Earth's rotation, and the ecliptic plane, defined as Earth's orbital plane around the Sun. It gives rise to the seasons; the two parallels of latitude ε, the Tropic of Cancer in the Northern Hemisphere and the Tropic of Capricorn in the Southern Hemisphere, mark the limits of highest latitudes that the subsolar point reaches at solstices each year.

From celestial mechanics theory, it has long been recognized that ε, rather than staying constant, varies slowly with time as a result of external gravitational influences: The Moon and Sun's tidal torques on Earth's ellipticity give rise to the familiar 26,000-year astronomical precession, while the gravitational pull of other planets, primarily Jupiter and Venus, slowly perturbs the orientation of the ecliptic plane in space. The combined effect observed by Earth dwellers is an ~41,000-year oscillation in the obliquity. With peak-to-peak amplitude typically reaching 2°, this oscillation is one of the three Milankovitch cycles that ultimately affects our long-term climatic system and has been identified as the pacemaker of ice ages. The present-day ε happens to be close to the mean value, and we are in the middle of a downswing at the rate $d\varepsilon/dt$ of -46".85 per century (Figure 1) [e.g., *Lieske*, 1970]. In terms of real distance on the Earth's surface, one should see a slow equatorward shift of the tropics by 14.4 m a year—well over 1 km in a century!

This is exactly what has happened on Taiwan, an island 400 km in length that straddles the Tropic of Cancer in the western Pacific. In 1908, to commemorate the completion of the north-south-running island railroad, the colonial Japanese government built a monument beside the railroad on the contemporary Tropic of Cancer. The monument is in Jia-Yi County. Figure 2 shows a rare historical photograph of the monument, with the clear inscription of the latitude N 23°27' 4".51 written in Chinese, which is in remarkable agreement with modern theory.

The Japanese and later the Republic of China governments of Taiwan maintained the tradition of building generations of monuments to commemorate the location of the Tropic of Cancer, mostly of concrete, as old monuments fell victim to typhoons, earthquakes, and exposure to the elements. The newer monuments are conveniently situated near the original site and still bear the old latitude inscription. The general site is now a small dedicated park, with Monuments #4 and #5 standing side by side; but, unable to acquire more land, the park administration faces a dilemma. The true latitude of the Tropic has by now moved southward by as much as 1.27 km (see Figure 1)! Worse still, the Tropic will continue to move south for another 90 km before it swings back some 9300 years later! There are many monuments and landmarks

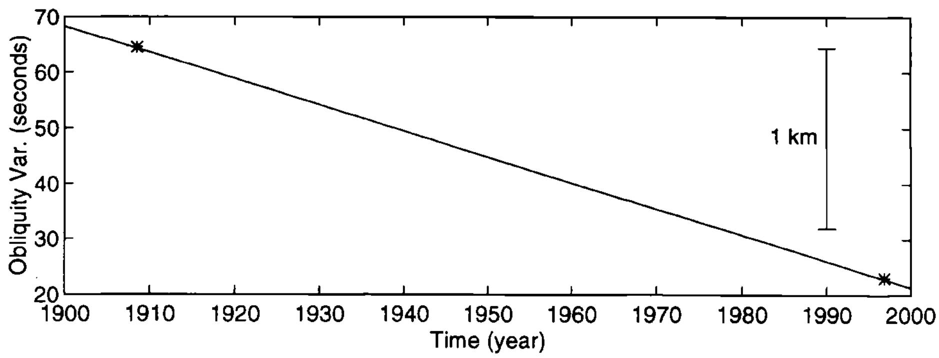

Fig. 1. The theoretically predicted variation of the obliquity of the ecliptic in this century, given as the angle in seconds in excess of 23° 26'. The two asterisks indicate the values of the original Jia-Yi Monument and of the present day.

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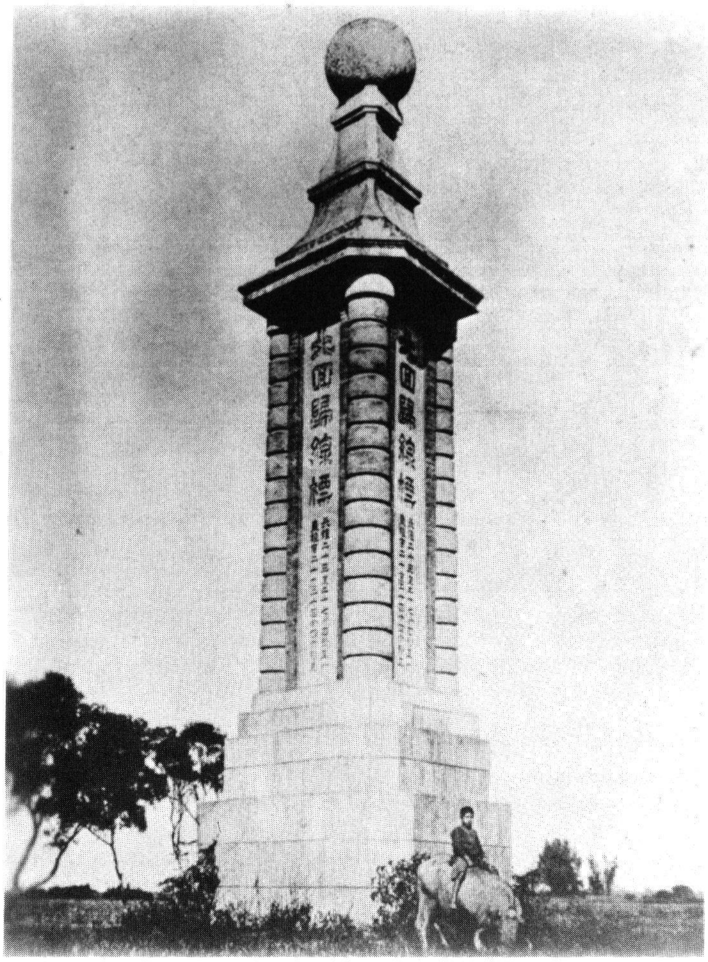

Fig. 2. A rare historical photograph of the original Jia-Yi Monument erected in 1908 (courtesy of J. R. Chen). The Chinese inscription reads "Northern Line of Return Landmark: North Latitude 23 degrees 27 minutes 4 seconds 51; East Longitude 120 degrees 24 minutes 46 seconds 5." The "Line of Return" is the Chinese designation of the tropic lines, referring to the turning point of the Sun's angle during the course of a year.

throughout the world that mark the two Tropics. Over time, they all face the same dilemma as those in Taiwan.

By the same token, the Arctic Circle and the Antarctic Circle, defined as the latitude 90°-ε North or South, are currently moving poleward at the same rate. The world's temperate zone is expanding at the expense of the tropical and Arctic zones at the rate of some 1500 km^2 per year! This is the Milankovitch cycle happening right before our eyes.

It should be mentioned that historical observations of the Sun's angle at solstices, especially those by ancient Chinese records, and more recent astrometric measurements of the Sun and planets, have been analyzed for $d\varepsilon/dt$ for years. The results essentially agree with the theoretical prediction within 1% [e.g., *Lieske*, 1970; *Wittmann*, 1979]. Although small, the discrepancies are believed to be of geophysical significance.

Finally, it is interesting to compare this large motion with the much smaller but perhaps better known phenomenon of the polar drift. The polar drift refers to the slow drift of Earth's mean rotation pole, which has been systematically monitored since 1900. Believed to be caused by large geophysical mass redistributions such as postglacial rebound, a total of only ~10 m of polar drift has been observed in the direction of ~80°W, corresponding to a maximum drift of ~0".3 per century in the apparent latitude along that meridian. This rate is 2 orders of magnitude smaller than the rate of obliquity variation discussed here.

Acknowledgments

I thank J. R. Chen of the Jia-Yi Astronomical Society in Taiwan, Republic of China, who supplied Figure 2 and the historical accounts reported here. The story was earlier reported by Taiwanese news media in 1988 on the occasion of the 80th anniversary of the Jia-Yi Tropic of Cancer Monument. I also thank Bruce Bills, David Rubincam, and Hanshu Liu for helpful suggestions and discussions.

References

Lieske, J. M., On the secular change of the obliquity of the ecliptic, *Astron. Astrophys.*, *5*, 90, 1970.

Wittman, A., The obliquity of the ecliptic, *Astron. Astrophys.*, *73*, 129, 1979.

Scientists Unite to Improve Models Coupling Atmosphere and Hydrology

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It was right down to business at a workshop organized by the Global Energy and Water-cycle Experiment Continental-scale International Project (GCIP) in Silver Spring, Md., from May 9 to 10, 1996. More than 40 atmospheric and hydrological scientists from government and academia met to review past progress and guide scientific priorities within NOAA's and NASA's research programs into coupled hydrologic-atmospheric modeling.

Given GCIP's dual goals of improving weather and climate prediction for North America at timescales up to interannual, and of providing hydrological interpretation of these predictions, the workshop focused on research that addresses three questions: To what extent is meteorological prediction at daily to seasonal timescales sensitive to hydrologic-atmospheric coupling processes? To what extent can meteorological predictions be hydrologically interpreted? And how can models of relevant hydrologic-atmospheric coupling processes be improved to enhance meteorological and hydrological prediction?

When reviewing current understanding, the workshop participants discovered ample evidence that meteorological predictions are sensitive to hydrologic-atmospheric coupling processes, but resolved that their interrelationship needs to be better quantified and, in particular, that the coupling processes most important to improved prediction at the seasonal to interannual timescales need to be identified. On the other hand, it became clear that there is little understanding of how best to hydrologically interpret seasonal-to-interannual predictions at present. Indeed, there is currently a failure in communication between the atmospheric and hydrological communities on this issue that needs to be addressed.

Regarding individual coupling processes, participants considered that although the description of large-scale precipitation processes in meteorological models is now reasonable, the parameterization of mesoscale precipitation processes—particularly the parameterization of warm season convective precipitation—remains poor, while even the measurement of frozen precipitation remains problematic. The workshop also affirmed that the modeling of soil moisture processes has improved, but participants recognized that past progress in this field was greatly limited by the shortage of appropriate measurements. Fortunately, upcoming initiatives in GCIP and elsewhere promise improved availability within the next few years.