The tropics are losing 1,080 square kilometers a year to the temperate zone thanks to the Earth’s constantly changing obliquity.

By David P. Rubincam, B. Fong Chao, and Bruce G. Bills
In the past year the Earth completed one revolution around the Sun, the Moon went through its phases 13 times, and the tropic of Cancer moved another 14.7 meters south.

That's right. The tropic of Cancer — the latitude at which the Sun is overhead at the June solstice — is moving toward the equator. Likewise the tropic of Capricorn, where the Sun stands at the December solstice, moved 14.7 meters northward. The tropics are shrinking.

Close to 1,080 square kilometers move from the tropics into the temperate zones each year. Only 330 square kilometers of the territory is dry land; still, this is equivalent to losing the state of Rhode Island every eight years. Africa, the only continent both tropics pass through, gives up the most real estate at the rate of 110 square kilometers annually — a region two-thirds the size of Washington, D.C.

The reason that the tropics (the region between the tropics of Cancer and Capricorn) are shrinking is that the obliquity of the Earth, the angle between the plane of the equator and the plane of Earth's orbit, is getting progressively smaller by about 47.5 arcseconds per century. The change in the obliquity may not be as familiar as, say, the precession of the Earth's axis, but it is just as real. Both are consequences of Newtonian dynamics. Hence the obliquity is not staying at its present value of 23° 26' but is slowly decreasing, a change caused by the interplay of torques on the Earth and perturbations of its orbit by the planets.

Gravitational torques from the Sun and Moon on the Earth's equatorial bulge make our planet's axis precess about the orbital plane with a period of 26,000 years. At the same time, the pull of gravity by the other planets causes the Earth's orbital plane itself to precess (relative to distant galaxies) in a period of 71,000 years. Taken together, these two motions cause the obliquity to oscillate with a period of roughly 41,000 years.

Unlike precession of the Earth's axis, which sweeps through a huge arc of sky, the obliquity deviates from its average value of 23.3° by a modest ±1.3° or so. The angle peaked 9,500 years ago at 24.2° and just happens to be passing near the average value today. And the rate of decrease is now nearly at its fastest pace. At more than 14 meters per year, the tropics of Cancer and Capricorn are moving at breakneck speed compared to other Earth motions such as plate tectonics. The major plates of the Earth's crust move at most 13 centimeters per year relative to each other.

The obliquity change is also much larger than polar wander. The Earth as a whole is reorienting itself in such a way that Washington, D.C., is moving northward — toward the rotation axis. The reason for this shift isn't clear, but it is probably a result of the last ice age. The weight of ice depressed much of the arctic and subarctic regions of the Earth, particularly northern Canada. Most of the ice has now melted and much of the depression has rebounded. The Earth may be trying to
maximize its moment of inertia by moving the remaining void up to the North Pole. Regardless of the reason, this wholesale adjustment of the Earth proceeds at a mere 10 cm per year.

The gallop of the obliquity compared to other motions wreaks havoc on monuments marking the positions of the tropics of Cancer and Capricorn. While slower than a snail, each tropic still creeps equatorward at 4 cm per day. In 10 years each will have moved the length of 1½ football fields.

Taiwan holds one example of the problem this motion causes. In 1908 the island's Japanese colonial government erected a concrete monument inscribed with the latitude 23° 27' 45.1", to mark where the tropic of Cancer crossed a newly completed railroad. Since then the Taiwanese government has made the area a park and decreasing until it reaches a minimum of 22.6° some 10,200 years from now, when it will start to increase.

These periodic changes affect the Earth's climate. Indeed, the variation of the obliquity is one of the so-called Milankovitch climate cycles, and the 41,000-year period has been observed in oxygen isotope data, which serve as proxy to climate records. The obliquity is the most easily understood of these cycles: when the obliquity is low, the polar regions stay cooler, thus making the sun's light more powerful and the resulting melting of the ice sheets more extensive. When the obliquity is high, the Arctic and Antarctic get more sunshine and solar heating melts the ice and snow. Thus ice ages come and go.

The other two Milankovitch cycles are the precession index (with periods of 19,000 and 23,000 years) and the eccentricity of the Earth's orbit (100,000 and 400,000 years), are less well understood but are also important for the ice ages. The precession index measures how close aphelion (the point in the Earth's orbit farthest from the Sun) is to the solstice. When the Earth is far from the Sun and the weather is cool, snow remains on the ground at high northern latitudes through that hemisphere's summer. The snow accumulates year by year and ultimately builds into an ice sheet. (Currently, however, aphelion occurs in July.)

The climatic effect from the eccentricity of the Earth's orbit is that the other hand, is truly baffling. While the average amount of sunlight received on Earth each year does depend on the eccentricity, the dependence is so weak that it is hard to see how it can affect the climate. Many mechanisms have been proposed to explain the eccentricity's importance, but none appears entirely satisfactory, even though this effect has been the most significant driver of the ice ages for the last 700,000 years.

The Earth is not the only planet to suffer obliquity oscillations. Pluto's obliquity changes by ±15° over a three-million-year cycle, according to Anthony Dobrovolskis at NASA's Ames Research Center and Alan Harris at the Jet Propulsion Laboratory. And thanks to the work of JPL's William Ward and subsequent investigators, we know that Mars undergoes tremendous obliquity swings, perhaps even larger than Pluto's, and on the much shorter time scale of 100,000 years. Recently Jihad Touma and Jack Wisdom at MIT and Jacques Laskar and Philippe Robutel in France have shown that the swings are chaotic, becoming unpredictable over time. These enormous changes doubtless have implications for climate on both planets.

In addition to the 41,000-year oscillations, Earth's obliquity undergoes a long-term progressive increase. Tidal friction tilts the Earth farther and farther askew on the billion-year time scale. And lately we at NASA's Goddard Space Flight Center have identified a new mechanism, climate friction, which was named in analogy with tidal friction. This effect can possibly increase the obliquity on the 400-million-year time scale, depending upon the length and severity of the ice ages and the internal properties of the Earth. Unlike tidal friction, a topic two centuries old, climate friction is such a new field that we can't yet determine its importance for changing our planet's tilt. Only time will tell.

David Rubincam, B. Fong Chao, and Bruce Bills are physicists at NASA's Goddard Space Flight Center. They thank David D. Rowlands for help in the preparation of this article.

The temperate regions gain a total of 1,550 square kilometers per year at the expense of the Arctic, Antarctic, and the tropics.

This tropic of Cancer monument on Taiwan, shown soon after it was erected in 1908, resides more than a kilometer away from the tropic's current boundary.