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A 3D Visualization and Analysis Model of the Earth Orbit, Milankovitch Cycles and Insolation.

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Milankovitch theory postulates that periodic variability of Earth's orbital elements is a major climate forcing mechanism. Although controversies remain, ample geologic evidence supports the major role of the Milankovitch cycles in climate, e.g. glacial-interglacial cycles. There are three Milankovitch orbital parameters: orbital eccentricity (main periodicities of $\sim$100,000 and $\sim$400,000 years), precession (quantified as the longitude of perihelion, main periodicities 19,000-24,000 years) and obliquity of the ecliptic (Earth's axial tilt, main periodicity 41,000 years). The combination of these parameters controls the spatio-temporal patterns of incoming solar radiation (insolation) and the timing of the seasons with respect to perihelion, as well as season duration. The complex interplay of the Milankovitch orbital parameters on various time scales makes assessment and visualization of Earth's orbit and insolation variability challenging. It is difficult to appreciate the pivotal importance of Kepler's laws of planetary motion in controlling the effects of Milankovitch cycles on insolation patterns. These factors also make Earth-Sun geometry and Milankovitch theory difficult to teach effectively. Here, an astronomically precise and accurate Earth orbit visualization model is presented. The model offers 3D visualizations of Earth's orbital geometry, Milankovitch parameters and the ensuing insolation forcings. Both research and educational uses are envisioned for the model, which is developed in Matlab® as a user-friendly graphical user interface (GUI). We present the user with a choice between the Berger et al. (1978) and Laskar et al. (2004) astronomical solutions for eccentricity, obliquity and precession. A "demo" mode is also available, which allows the three Milankovitch parameters to be varied independently of each other (and over much larger ranges than the naturally occurring ones), so the user can isolate the effects of each parameter on orbital geometry, the seasons, and insolation. Users select a calendar date and the Earth is placed in its orbit using Kepler's laws; the calendar can be started on either vernal equinox (March 20) or perihelion (Jan. 3). Global insolation is computed as a function of latitude and day of year, using the chosen Milankovitch parameters. 3D surface plots of insolation and insolation anomalies (with respect to J2000) are then produced. Insolation computations use the model's own orbital geometry with no additional *a-priori* input other than the Milankovitch parameter solutions. Insolation computations are successfully validated against Laskar et al. (2004) values. The model outputs other relevant parameters as well, e.g. Earth's radius-vector length, solar declination and day length for the chosen date and latitude. Time-series plots of the Milankovitch parameters and EPICA ice core CO_2 and temperature data can be produced. Envisioned future developments include computational efficiency improvements, more options for insolation plots on user-chosen spatio-temporal scales, and overlaying additional paleoclimatological proxy data.