CTIPe Model

The Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) model is a global, three-dimensional, time-dependent, non-linear code that is a union of three physical components. The first is a global, non-linear, time-dependent neutral thermosphere code developed by Fuller-Rowell and Rees (1980; 1983). The second is a mid- and high-latitude ionosphere convection model developed by Quegan *et al*. (1982). These first two components were initially coupled self-consistently and are known as the Coupled Thermosphere-Ionosphere Model (CTIM) (Fuller-Rowell, *et al.* 1996). CTIM was further extended by including a third component, a plasmasphere and low latitude ionosphere (Millward et al., 1996), to produce CTIP. Later the electrodynamics was solved self-consistently with the neutral dynamics and plasma components.

The thermospheric code simulates the time-dependent structure of the wind vector, temperature and density of the neutral thermosphere by numerically solving the non-linear, first-principles, equations of momentum, energy and continuity. The global atmosphere is divided into a series of elements in geographic latitude, longitude and pressure. Each grid point rotates with the Earth to define a non-inertial frame of reference in a spherical polar coordinate system. The latitude resolution is 2°, longitude resolution 18°, and each longitude slice sweeps through local time with a one-minute time step. In the vertical direction the atmosphere is divided into 15 levels in logarithm of pressure from a lower boundary of 1 Pa at 80 km altitude.

A time-dependent mean mass equation was incorporated into the model by Fuller-Rowell and Rees (1983). This formalism assumed the upper atmosphere could be approximated by two species, atomic oxygen and the sum of molecular nitrogen and oxygen. Later the major species composition was improved to include solution of the three major species, O, O_2 and N_2, including chemistry, transport and the mutual diffusion between the species. Using a combination of the generalized diffusion equation (Chapman and Cowling, 1970) and the continuity equations, the change in mass mixing ratio of the three species is evaluated self-consistently with the wind and temperature fields. Allowance is made for mutual molecular diffusion, horizontal and vertical advection, turbulent mixing vertically and horizontally, and production and loss mechanisms. The time dependent variables of southward and eastward wind, total energy density, and concentrations of O, O_2 and N_2 are evaluated at each grid point by an explicit time-stepping numerical technique. After each iteration, the vertical wind is derived, together with temperature, density, and heights of pressure surfaces. The parameters can be interpolated to fixed heights for comparison with experimental data.

The equations for the neutral thermosphere are solved self-consistently with a high latitude ionosphere convection model (Quegan et al., 1982). Traditionally, ionosphere models are evaluated in a Lagrangian system, where the evolution of ion density and temperature of parcels of plasma are computed as they are traced along their convection paths. In the high latitude ionosphere model the Lagrangian frame has been modified to be more compatible with the Eulerian frame by implementing a semi-Lagrangian technique (Fuller-Rowell et al., 1987; 1988). Adoption of a rotating frame of reference for the ionosphere implicitly includes the "co-rotation potential".

Transport under the influence of the magnetospheric electric field is explicitly treated, assuming $E \wedge B$ drifts and collisions with the neutral particles. The atomic ions H^+ and O^+, and ion temperature are evaluated over the height range from 100 to 10,000 km, including horizontal transport, vertical diffusion and the ion-ion and ion-neutral chemical processes. Below 400 km the additional contribution from the molecular ion species N_2^+, O_2^+ and NO^+, and the atomic ion N^+ are included.

The model of the Earth's mid- and low-latitude plasmasphere and ionosphere is based on the code of Bailey and Balan (1996). The densities, temperatures, and velocities are calculated for H^+ and O^+ along closed flux-tubes with geometry defined by the tilted dipole approximation to the Earth's magnetic field. The model solves the coupled equations of continuity, momentum, and energy balance along the flux-tubes to yield ion density, field-aligned velocity, and temperature, including the effects of interhemispheric coupling. The plasmasphere component of the CTIPe model also adopts an Eulerian framework in which individual flux-tubes are fixed in space. This represents a modification to the original Bailey code that used the more conventional Lagrangian scheme, where individual flux-tubes are followed as they drift under the influence of the electric field. The Eulerian fixed frame, where cross flux tube plasma transport is accommodated by advection, has been adopted to enable storm-time low latitude electric fields to be used without incurring the problem of flux tubes not returning to their initial position after a full diurnal cycle. To produce a global model of the ionosphere, 1400 individual flux-tubes are computed concurrently and defined by magnetic longitude, i.e., constant along a tube. The L value determines the equatorial crossing height relative to the center of the dipole in units of the Earth's radius. The plasma moves across flux-tubes under the effect of electric fields where the velocity is assumed to be completely decoupled from the field aligned velocities of the ions, which are the result of winds, diffusion, and space-charge electric fields. The mid and low latitude electric fields are computed self-consistently within the model using the code of Richmond and Roble (1987). The temperatures of the two ion species are also solved by the coupled energy balance equations. A reliable and reasonably realistic ionosphere is important for the calculation of neutral winds because of the ion drag process. At high latitudes ion drag acts more as a driver, elsewhere more as a drag on the neutral winds.

The magnetosphere input is based on the statistical models of auroral precipitation and electric fields described by Fuller-Rowell and Evans (1987) and Weimer (1995), respectively. The auroral precipitation is keyed to the hemispheric power index (PI), based on the TIROS/NOAA auroral particle measurements, and has been available since the mid 1970s. The PI index runs from 1 to 10 to cover very quiet to storm levels of geomagnetic activity; the relationship between PI and K_p can be found in Foster et al. (1986). The Weimer electric field model is keyed to the solar wind parameters impinging the Earth’s magnetosphere. The input drivers include the magnitude of the interplanetary magnetic field (IMF) in the y-z plane, together with the velocity of the solar wind.

The (2,2), (2,3), (2,4), (2,5), and (1,1) propagating tidal modes are imposed at 80 km altitude (Fuller-Rowell et al. 1991) with a prescribed amplitude and phase. Ionization rates from the EUV flux are evaluated from the Hinteregger et al. (1981) reference spectra for high and low solar activity based on the Atmospheric Explorer (AE) measurements.