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NCAR Creates Global Thermospheric/Dynamics Model Using CRAY IA, X/MP

Senior scientists Raymond Roble (High Altitude Observatory) and Robert Dickinson (Climate and Global Dynamics Division) and their colleague Cicely Ridley (HAO) have created a numerical model of thermospheric dynamics that is available for use by the university community. Termed the thermospheric general circulation model (TGCM), it has been developed to investigate the response of the thermosphere, 97 to 500 kilometers above the earth's surface, to changes in the highly variable components of the sun's energy output. Roble and colleague Barbara Emery, as well as numerous NCAR visitors and university collaborators, compare the model with data from the NASA Dynamics Explorer satellites, various ground-based radars, and airglow facilities using NCAR's CRAY supercomputers.

Birth of TGCM

In late 1978 Roble, Dickinson and Ridley began development of the thermospheric model, derived from NCAR's general circulation climate model (GCM). Stripping out all the processes that represented the physics of the lower atmosphere (the troposphere), such as those related to mountains, clouds, and radiation, the three NCAR scientists then modified the GCM to incorporate auroral processes, ionospheric interactions, some fast diffusive properties, and chemical reactions that occur in the upper atmosphere.

After simulating the impact of solar ultraviolet radiation and solar wind variability on the circulation, temperature and compositional structure of the thermosphere, the Roble team compared the TGCM model results with data collected from the NASA satellites and ground-based observatories to gain a better understanding of the physical processes taking place in the outer atmosphere. The data sources include satellite systems, ground-based incoherent-scatter radars that probe the upper atmosphere, and radio and optical systems that provide a network capable of measuring wind speeds and temperatures 300 kilometers above the earth.

TGCM Status prior to Arrival of X-MP

Prior to the arrival of the X-MP at NCAR in the fall of 1986, the TGCM was limited in scope by the CRAY-1A's 700,000 word-core memory. Roble, Dickinson and Ridley wanted to put more physics into the model, but they were up against the lack of computer time and core memory. At that time, the TGCM was able to solve for temperature, circulation, and the major atmospheric constituents of molecular and atomic oxygen and molecular nitrogen at every grid point of the model. "We wanted to include additional species, such as nitric oxide (NO), and the excited states of atomic nitrogen and also have the physics represent a global ionosphere that would be interactive with the model," explains Roble.

Present Status of Model since Arrival of X-MP

Since the arrival of the X-MP/48, Roble and his colleagues have increased the complexity of the TGCM, using about 1 million of the 7-million-word memory now available with the larger machine. At present the model requires about 3,000 seconds of CRAY X-MP time per model day. Its three-dimensional grid consists of points at 5 degree intervals on latitude and longitude and 25 layers extending from 97 to 500 kilometers; it calculates in time steps of 150 seconds. The model is now self-consistent, meaning that it calculates many of the physical parameters that were specified previously.

The major external driving forces are the sun's radiative output in the extreme ultraviolet and ultraviolet ranges of the spectrum, and the auroral processes and tides and other disturbances propagating from the lower atmosphere.

Preliminary Results With X-MP's Computing Power

So far, Roble's model has described strong interactions of the thermosphere's neutral gases and variable solar output. It also has been used to study the impact of particles of the solar wind that bombard the earth, causing the aurora borealis. Variability in solar wind properties regulates the intensity of the aurora during geomagnetic storms and, in turn, the thermospheric and ionospheric response.

Roble and his colleagues plan to couple the TGCM with a magnetospheric model that will describe how solar wind energy is transferred into the earth's atmosphere. Eventually, Roble and colleagues hope that the model will realistically describe how solar wind plasma and solar ultraviolet radiation variability will affect the earth's dynamics, radiational, and chemical processes. This, says Roble, will help scientists better understand the propagation of the radio communication signals, satellite drag, and the transport of chemicals produced in the upper atmosphere to the lower atmosphere.

For example, nitric oxide, one chemical produced by processes involved in the aurora borealis, can be transported to the vicinity of the polar night region, where it does not come in contact with sunlight. It then can be transported downward to the stratosphere where it can catalytically react with ozone.

Future Plans for TGCM

"Our future plans for the TGCM require even more computer power than we now have with the X-MP," Roble explains."We would like to extend the model into the mesosphere, so that the range would be from 50 to 500 kilometers. The model then would include a whole number of new chemical species such as ozone, water vapor, carbon dioxide, methane, atomic hydrogen, the hydroxyl radical, hydrogen peroxide, and nitrogen dioxide."

Why Do We Need This Model?

Scientists basically need to understand the processes in near space and how they are affected by solar activity. "We know the properties of the upper atmosphere vary dramatically, but we don't know how deeply they penetrate into the earth's atmosphere," Roble explains.

There are also applied science needs. "The most recent concern is

NASA's interest in launching the Space Telescope. "People were expecting a low-activity solar cycle, but now they think that it may be a high activity cycle," Roble explains. "Scientists need to know the amount of drag on the telescope." The North American Air Defense he adds, needs to know about the drag on satellites in general. "As man's activity in space increases, information from the model would be increasing. We need to make more weather predictions in space."

The model has widespread use by NCAR, university, and government scientists for a broad range of upper-atmospheric problems. For example, the TGCM has been used to:

1) Investigate the mean structure of the thermosphere and its diurnal and seasonal behavior for both solar cycle minimum and maximum conditions.

2) Examine the time-dependent thermospheric circulation, temperature, and compositional response to geomagnetic (auroral) storms and substorms.

3) Investigate the thermospheric impact from upward-propagating tides excited in the lower atmosphere.

4) Investigate the importance of solar in-situ driven winds and tidal winds in maintaining the ionospheric wind dynamo.

5) Investigate specific physical processes, such as the effect of

magnetospheric plasma convection on high latitude thermospheric dynamics, the effect of infrared emissions, and transport of heat and momentum in the thermosphere.

6) Investigate the downward transport of solar induced variability into the lower atmosphere.

7) Investigate the transport of passive helium and argon and chemically active nitric oxide, and atomic nitrogen, and neutral constituents in the thermosphere.

8) Make extensive comparisons of TGCM predictions with measurements made by ground-based incoherent-scatter radars, optical instruments and satellites.

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