A DYNAMICAL MECHANISM THROUGH WHICH VARIATIONS IN SOLAR ULTRAVIOLET RADIATION CAN INFLUENCE TROPOSPHERIC CLIMATE*

J. R. BATES
Irish Meteorological Service, Dublin

Abstract. Variations in solar UV radiation can lead to changes in the mean temperature and wind distributions in the stratosphere and, through modification of the ozone photochemistry, to changes in the damping rate of temperature perturbations about the mean. Such changes can influence the stratospheric propagation characteristics of planetary waves generated in the troposphere, leading to changes in the steady state interference pattern of these waves at all levels. In particular, the poleward heat transfer by the planetary waves in the troposphere can be strongly modified, thus providing a mechanism whereby solar cycle variations in ultraviolet radiation can influence climate.

The dynamics of the mechanism are presented in a simple form and the literature on the subject is reviewed.

1. Introduction

The solar radiation absorbed by the earth-atmosphere system has a strong latitudinal gradient, whereas the compensating infrared radiation emitted to space is much more uniformly distributed. Consequently, there is a radiative energy surplus at low latitudes (roughly equatorward of 38° in the annual mean) and a radiative energy deficit at high latitudes. The function of the atmospheric circulation is to transfer energy polewards to effect an overall energy balance at all latitudes.

The poleward transfer of energy across middle latitudes is accomplished by two distinct modes of atmospheric motion: the transient cyclone scale waves (zonal wave numbers greater than 5) which arise from hydrodynamic instabilities in the mean westerly current, and the quasi-stationary planetary waves (zonal wavenumbers 1–4) which are generated by thermal and topographic asymmetries of the Earth’s surface. In the northern hemisphere in winter, the task of poleward energy transport is roughly equally divided between these two modes.

A notable difference between the cyclone and planetary scales of motion in winter is that the cyclone scales are confined to the troposphere whereas the planetary scales extend into the stratosphere and beyond. It turns out that the governing equation for the vertical propagation of planetary waves is formally similar to the equation for the propagation of electromagnetic radiation. As in the case of electromagnetic radiation, variations in the index of refraction can lead to partial or total reflections and the steady state which is set up can be sensitive to the distribution of refractive index far from the source. In the case of planetary waves, the effective index of refraction depends on the wind strength, the static stability and the damping rate of temperature perturbations. In the stratosphere,

all three of these quantities can change in response to variations in solar UV radiation in the range 190–320 nm. Observational studies (e.g. Schwentek, 1971; Zerofos and Mantis, 1977; Angell and Korshover, 1978; Quiroz, 1979; Nastrom and Belmont, 1980) have provided evidence of significant variations in stratospheric temperatures and winds associated with the solar cycle. Blake and Lindzen (1973) have shown theoretically how solar UV variations can influence the thermal damping rate through a process known as the photochemical acceleration. By modifying the planetary wave index of refraction in the stratosphere, such variations can influence the pattern of standing planetary waves in the troposphere and, in particular, can modify the meridional heat transporting properties of the waves. A mechanism thus exists whereby variations in solar UV radiation can subtly exert an influence on the central dynamics of the atmospheric circulation.

2. The Mechanism in Its Simplest Form

In this section the essential dynamics of the mechanism in its simplest form will be described. This will provide a basis for discussing the literature on the subject in the next section.

The governing equations of atmospheric motion are

\[
\frac{d\mathbf{V}}{dt} = -\frac{1}{\rho} \nabla p - 2\Omega \times \mathbf{V} + \mathbf{g},
\]

(1)

\[
\nabla \cdot (\rho \mathbf{V}) = -\frac{\partial p}{\partial t},
\]

(2)

\[
c_v \frac{dT}{dt} + p \frac{d}{dt} \left(\frac{1}{\rho}\right) = \dot{Q},
\]

(3)

\[
p = R\rho T,
\]

(4)

where

\[
\frac{d}{dt} = \frac{\partial}{\partial t} + \mathbf{V} \cdot \nabla,
\]

\[
\mathbf{V} = u\mathbf{i} + v\mathbf{j} + w\mathbf{k}.
\]

In the above, \(\mathbf{V}\) is the velocity, \(p\) is pressure, \(\rho\) is density, \(T\) is temperature, \(\dot{Q}\) is the diabatic heating rate per unit mass, \(t\) is time, \(\Omega\) is the Earth's rotation, \(c_v\) is the specific heat of air at constant volume, \(R\) is the gas constant, and \((\mathbf{i}, \mathbf{j}, \mathbf{k})\) are unit vectors in the eastward, northward, and vertical directions. The apparent gravitational acceleration \(\mathbf{g}\) is the actual gravity modified by the inclusion of the small centrifugal force:

\[
\mathbf{g} = \nabla[\phi + \frac{1}{2}(\Omega \times \mathbf{r})^2] = -g\mathbf{k},
\]

(5)

where \(\phi\) is the gravitational potential.