A Model of Saturn's Seasonal Stratosphere at the Time of the Voyager Encounters

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ABSTRACT

Seasonal variability of temperature within Saturn's stratosphere for all latitudes has been modeled, and results are presented for January 1981, a time which is representative of the Voyager I (November 1980) and Voyager II (August 1981) encounters with Saturn.

1. Introduction

We have previously explained observed north-south asymmetries in thermal radiation from Jupiter in terms of stratospheric seasonal effects (Caldwell *et al.*, 1979). Furthermore, recent observational evidence also indicates that seasonal processes occur within Saturn's stratosphere (Tokunaga *et al.*, 1978, 1979). A modeling endeavor by Cess and Caldwell (1979), restricted solely to the polar and equatorial stratospheres, is consistent with these observations. In view of the forthcoming encounters of Voyagers I and II, which will provide additional information on the latitudinal variation of stratospheric temperature, we have extended our existing polar-equatorial climate model to encompass all latitudes of Saturn.

The results presented are temperature-latitude profiles for several pressure levels within the Saturnian stratosphere. These results are for January 1981 and should be directly comparable with the IRIS observations of the Saturn Voyager encounters in November 1980 and August 1981. [For an indication of the capability of these instruments, see Fig. 4 of Hanel *et al.* (1979).] From such a comparison, we expect to be able to assess the validity of the assumptions inherent in our model, and thereby gain insight to the processes which influence the stratosphere of Saturn.

2. The model

The polar-equatorial time-dependent stratospheric model developed by Cess and Caldwell (1979) was extended for use at intermediate latitudes. The model is strictly radiative, and no attempt was made to incorporate dynamical processes. The extension of the Cess-Caldwell model to intermediate latitudes requires modifications involving solar absorption within the stratosphere. Such absorption is by near-infrared bands of CH_4 and C_2H_6 as well as by some unidentified UV absorber commonly referred to as an aerosol or "axel dust."

The effect of the absorbed sunlight on the model is clearly a function of the assumed abundances of these minor constituents of the Saturnian atmosphere. We followed the same compositional assumptions used by Tokunaga and Cess (1977). They employed a $[CH_4]/[H_2]$ mixing ratio of 7×10^{-4}, which then required that the aerosol absorb 20% of the Saturn solar constant in order to produce a model that agrees with infrared spectrophotometry near 20 μm. If the $[CH_4]/[H_2]$ mixing ratio is increased to 2×10^{-3}, then the required aerosol absorption is reduced to 16%. Tokunaga and Cess (1977) also discuss the minor effect of varying the C_2H_6 mixing ratio within plausible limits. The model is insensitive to the assumed He mixing ratio.

Considering first solar absorption by CH_4 and

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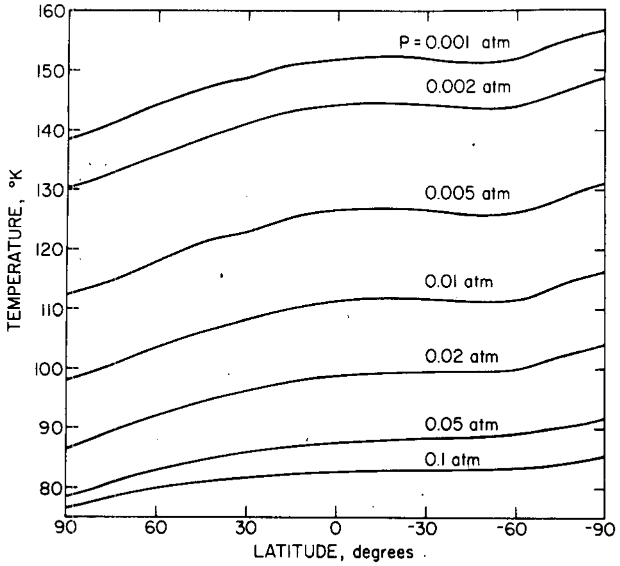

FIG. 1. Stratospheric temperature-latitude calculations for January 1981, at the time when the Voyager spacecrafts encounter Saturn.

C_2H_6, we will, as did Cess and Caldwell (1979), simply express the seasonal absorption in terms of the global annual definition of Cess and Chen (1975) [their Eq. (7)], which we will designate as K_j(C-C), with the subscript j referring to individual CH_4 and C_2H_6 absorption bands. The corresponding latitudinal time-dependent quantity, $K_j(\theta,t)$, where θ is latitude and t is time, is then incorporated within the Cess-Caldwell seasonal model [their Eq. (9)]. Employing the same procedure as in their polar-equatorial formulation, it readily follows from diurnal averaging that

$$K_j(\theta,t) = 3\epsilon(t)Q(\theta,\delta)K_j(\text{C-C}),$$

where $\epsilon = (d/\bar{d})^2$, with d the Saturn-sun distance and $\bar{d}$ its annual mean value, while

$$Q(\theta,\delta) = (1/2\pi)\int_{-\tau_0}^{\tau_0} \mu^{1/2}d\tau.$$

Here $\tau = \Omega t$, where Ω is the rotational velocity of the planet, while τ_0 is the half-day length (rad) and $\mu = \cos$ (solar zenith angle). Expressions for τ_0 and μ, in terms of θ, τ and solar declination angle δ, are given by Sellers (1965, p. 15).

A second modification of the Cess-Caldwell model pertains to solar absorption by the aerosol. They have assumed the aerosol layer to be optically thin, and from their discussion the only time-dependent quantity which affects aerosol absorption is the fractional length of daytime, $\zeta(t)$, within their Eq. (11). For present purposes $\zeta(t) = 1/(\pi\tau_0)$.

Finally, we have included the latitudinally and temporally variable effects of absorption, but not scattering, of sunlight by the rings of Saturn, according to the formulation of Brinkman and McGregor (1979).

This completes the model modification within Eq. (9) of Cess and Caldwell (1979). The polar day/night cases were handled separately employing methods described by Sellers (1965). The gravitational acceleration was computed as a function of latitude using the Saturn parameters of Allen (1973). The polar and equatorial values are 1330 and 891 cm s^{-2}, respectively. All other input parameters remain unchanged from the Cess-Caldwell model.

3. Results and discussion

The seasonal stratospheric model simulates the entire Saturnian seasonal cycle (30 earth years). Fig. 1 illustrates, for the time of the Voyager encounters, stratospheric temperature as a function of latitude for several pressure levels. The model indicates no significant stratospheric changes between the times of the two Voyager encounters.

The time depicted by Fig. 1, January 1981, is just a few earth months past Saturn's Southern Hemisphere autumnal equinox. The strong latitudinal asymmetry shown in Fig. 1, with high-latitude regions in the Southern Hemisphere being considerably warmer than comparable regions in the Northern Hemisphere, is a consequence of the model stratosphere exhibiting a 90° phase lag with the insolation cycle, as discussed by Cess and Caldwell (1979). A slight depression occurs in the temperature profiles from roughly −30 to −60° latitude; this is be-

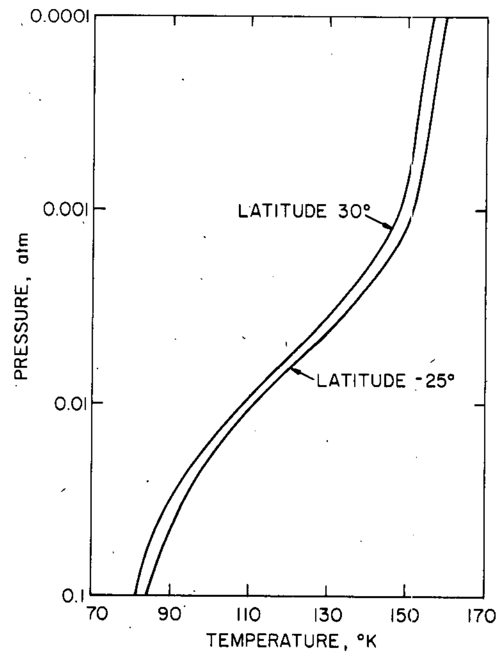

FIG. 2. Predicted temperature-pressure profiles for the ingress (+30°) and egress (−25°) latitudes to be probed by the Voyager II Radio Science experiment.

tween the region of maximum insolation at the subsolar point and the region of the onset of the polar day, both of which occur a quarter-cycle earlier.

Fig. 2 shows the temperature-pressure profiles for two specific latitudes, +30° and −25°, which correspond to the planned points at which the Radio Science experiment aboard Voyager II will produce occultation observations which will be inverted to corresponding models analogous, and we expect similar to, those of Fig. 2.

The model should constitute a first approximation to the Saturnian stratospheric seasonal temperature at the time of the Voyager encounters. The weakest part of the model is the uncertainty in the radiative properties of the aerosol absorber and its Saturnographic distribution. We have assumed the aerosol to be uniformly distributed with latitude and with altitude. Of the two assumptions, the one concerning latitudinal aerosol homogeneity is probably the more critical. Hord *et al.* (1979) have demonstrated possible latitudinal variability in aerosol concentration for Jupiter using the Voyager II photopolarimeter, and a similar phenomenon might occur on Saturn. As Tokunaga and Cess (1977) have emphasized, the influence of an aerosol in the Saturnian stratosphere is certain and cannot be ignored in thermal calculations.

In summary, our model excludes both latitudinal variability of the aerosol and stratospheric dynamical influences. If such effects are important, we hope they will be revealed through departures of the model calculations from the forthcoming Voyager observations.

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