Effects of Water Vapor Continuum Absorption on Tropical Atmosphere Destabilization

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Introduction

The stability of the sea surface temperature (SST) in the tropical western pacific has been an issue of considerable interest. Various mechanisms have been proposed to explain this stability including the egulation of solar radiation by cirrus clouds (Ramanathan and Collins 1991). The feedback between SST and cloud cover in the cirrus regulation scheme is an enhanced column absorption of infrared (IR) radiation that is observed to occur above 300 K. Hallberg and Inamdar (1993) indicate that this enhanced IR convergence is best explained by the redistribution of water vapor due to deep convection. In regions of deep convection, water vapor mixing ratios may be significantly increased in the middle troposphere. This redistribution moves the effective emission-to-space level to higher altitudes and lower temperatures thus reducing the top of atmosphere outgoing IR flux and increasing the column convergence of IR radiation. The association of water vapor redistribution in the vertical column and enhanced IR flux convergence suggests another possible feedback mechanism connecting SST with cloud cover related to the nature of IR absorption by water vapor.

The absorption of IR radiation by water vapor exhibits a unique character in the tropics because of the high column concentrations found there (4-6 g/cm) and the nature of absorption in the window region. In the 8-12 micron window region, absorption is dominated by the water vapor continuum. Continuum absorption is unusual because it exhibits an $[H_2O]$ dependence. At mid-latitudes where water vapor column concentrations are typically less than 4 g/cm, the window region is nearly transparent. However, in the tropical western pacific, where the water vapor column generally exceeds 4 g/cm, absorption in this region becomes important. Because continuum absorption is particularly sensitive to the water vapor concentration, it is primarily a factor near the tropical sea surface where water vapor mixing ratios can exceed 20 g/m. As absorption increases in the window region with high water vapor concentrations, the ability of the tropical boundary layer to cool via IR emission is diminished. At the same time, cooling from the region immediately above the boundary layer is enhanced. Depending on the details of the atmosphere's thermodynamic structure, this change in the vertical IR heating rate profile may destabilize the region above the boundary layer thus acting as a trigger for convection.

Calculations

To study the hypothesis that the IR cooling profile can destabilize the tropical atmosphere, clear sky radiative transfer calculations were performed on a series of soundings from TOGA-COARE (the Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Response Experiment) using a two-stream model (Toon et al. 1989) with a modified treatment of the water vapor continuum (Clough et al. 1989). Soundings were used from the ship R/V Kexue at the southern tip of the Intensive Flux Array (IFA) from the week of January 11-17, 1993. GMS-4 IR satellite images indicate that much of the IFA was free of deep convection from January 11 until January 16. On January 16, large-scale, deep convection was present throughout the IFA.

Simulated soundings were obtained by shifting the temperature of the actual profile by 5 K at all vertical levels. The water vapor concentration was changed so that the relative humidity at a given altitude would be the same for all three levels. For the coolest and driest sounding, the cooling maximum is at the surface and decreases monotonically with height. For the observed sounding, the cooling maximum is still at the surface, but a secondary local maximum has developed at 2 km. For the warmest and wettest sounding, the cooling maximum has shifted to 2 km.

Discussion

The IR cooling rate profile is very sensitive to the vertical profile of water vapor. To obtain the elevated cooling rate maximum, it is necessary to have high relative humidities at levels of approximately 1-3 km. Study of soundings from TOGA-COARE indicate that this layer is often dry with relative humidities below 50 but moistening occurs periodically. For the week of January 11-17, 1993, moistening of this layer progressed throughout the week in advance of a significant outbreak of deep convection.

Given that cooling rate profiles with maxima at altitudes above the boundary layer occur, destabilization and the resulting convection and cloud cover resulting from these profiles may be partially responsible for maintaining the SST in the tropical western pacific. These calculations indicate that as the water vapor column is increased in step with the SST, the tendency of the IR cooling rate profile to destabilize the profile increases. To assess the real impact of this effect on the tropical atmosphere, the next step in this study is to study IR cooling rates in the context of a radiative-convective model.

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