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The structure and dynamics of Titan's middle atmosphere and troposphere

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Abstract

Titan, after Venus, is the second example in the solar system of an atmosphere with a global cyclostrophic circulation. The origin and maintenance of these superrotating atmospheres is not well understood, but Titan has a strong seasonal modulation in the middle atmosphere, and the seasonal changes in the winds may offer clues. The pole in winter and early spring is characterized by temperatures 20-30 K cooler at 100-170 km than those at low latitudes, and strong circumpolar winds as high as 190 m s^{-1} at 200-250 km. At these levels the polar region is characterized by enhanced concentrations of several organic gases, and also detectable condensates. All this suggests that the polar vortex provides a mixing barrier between winter polar and lower-latitude air masses, analogous to the polar ozone holes on Earth. Because the concentrations of organic gases increase with altitude in the middle atmosphere, the observed enhancements suggest subsidence over the winter pole. Consistent with this are the observed temperatures ~200 K at the winter-polar stratopause (280 km), making it the warmest part of the atmosphere. The warm stratopause likely results from adiabatic heating associated with the subsidence. Recent observations in late northern winter and early spring indicate that the warm anomaly at the winter-polar stratopause is weakening.

In contrast to the middle atmosphere, latitude contrasts in tropospheric temperatures are muted. During the northern winter season, they were ~5 K at the tropopause and 3 K or less near the surface, being coldest at high northern latitudes. This is understandable in terms of the long radiative relaxation times in the troposphere, compared to times that are much shorter than a season in the upper stratosphere and higher. Curiously, the transition between the small meridional contrast (and presumably seasonal variations) in temperatures observed in the troposphere and the large variations observed at higher altitudes occurs abruptly above 80 km. Here the temperatures in the lower stratosphere, generally increasing with altitude, exhibit a sudden drop with increasing altitude at high northern latitudes, producing the contrast between low and high northern winter latitudes in the upper stratosphere described above. While the radiative relaxation time associated with infrared gaseous coolants decreases with altitude in the stratosphere, the abrupt transition suggests the presence of an optically thick condensate at thermal-infrared wavelengths.

Near the surface, temperature lapse rates are adiabatic over the lowest 2 km, with the suggestion of a nocturnal stable inversion over the lowest 200 m in radio-occultation soundings near the morning terminator. At mid and high latitudes in both winter and summer hemispheres, the profiles are more statically stable (i.e., subadiabatic). This is most pronounced in the winter hemisphere.