Thermal Structure and Aerosols on Giant Planets

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Introduction: Thermal structure and aerosols are but two facets of atmospheric science open to investigation on the giant planets. Except for the Galileo Probe at Jupiter our only measurements are from remote sensing. This abstract will summarize what we have learned from measurements, how these are used with models, what we still do not know and what may be fruitful avenues of investigation in the future.

Observations and Models: Thermal structure and aerosols are related both in terms of information content of the observations and in terms of physical and chemical processes in the atmosphere. Aerosols contribute to atmospheric opacity and radiative energy budget. To fully understand how aerosols influence what we see and to implement accurate retrievals or to calculate heating rates where aerosol opacity is significant it is necessary to know the vertical structure of aerosol opacity, the particle scattering phase function and single-scattering albedo as functions of wavelength, space and time. In practice we have been able to measure some of these properties over limited ranges in spatial and time dimensions. Similarly, our ability to measure atmospheric temperature is limited in space and time.

A wide variety of observations have contributed. Spacecraft observations from the Pioneer, Voyager, Galileo and Cassini thermal radiometers/spectrometers and Hubble and ground-based images, radiometers and spectrometers in recent times have shown details at the scale of zonal jets, including the evolution of hot spots on Jupiter and polar warm vortices on Jupiter, Saturn and Neptune. Observations at centimeter wavelengths show significant brightness temperature changes in the Uranus troposphere. Cassini observations at UV and near-IR wavelengths sensitive to aerosols and at thermal wavelengths reveal longitudinal wave structure in the upper troposphere. Ground-based observations of Jupiter over a multi-year time span revealed a stratospheric quasi-quadrennial temperature oscillation at low latitudes.

Both Jupiter and Saturn have distinct UV-absorbing polar stratospheric haze. On Jupiter this haze extends to lower latitude in the northern hemisphere relative to the southern hemisphere. Ultraviolet and methane-band images which reveal haze morphology and a circumpolar wave structure provided the first evidence of a polar vortex on Jupiter. The origin of this haze is most likely due to auroral energy deposition which is also hemispherically asymmetric on Jupiter. Optical properties suggest that individual particles are aggregates of hydrocarbon monomers whose radii are quite small (~0.05 micro-meter). At lower latitudes the stratospheric haze is probably dominated by photochemical formation of hydrazine on Jupiter and diphosphine on Saturn. Uranus and Neptune also have stratospheric hazes and these are almost certainly hydrocarbons.

Stratospheric haze absorbs sunlight and contributes to the radiative energy budget of the stratosphere. If the stratosphere were in radiative equilibrium we would expect to see a strong equator-to-pole temperature gradient but this is not the case for the outer planet atmospheres. Departure from radiative equilibrium can be used to diagnose what is called the mean meridonal residual circulation. Long-term studies of the transport of aerosols from the comet Shoemaker-Levy 9 impact on Jupiter in 1994 showed that horizontal eddy diffusion rather than the residual mean meridional circulation dominates horizontal transport at high latitude.

The Future: Many observations of temperatures and aerosols on the giant planets are not understood. These are becoming apparent only after years of observation. Images of Saturn from the Hubble Space Telescope and from the Pioneer, Voyager and Cassini spacecraft reveal a remarkable variety of haze optical depth and albedo variations both seasonal and non-seasonal. It has been almost one Saturnian year since the Voyager flybys and the temperature variations observed from the ground and by Cassini are not as expected from a seasonal model based on Voyager observations. Adaptive-optic observations of Uranus and Neptune at near-infrared wavelengths and images at thermal infrared and centimeter wavelengths reveal temporal changes of temperature, cloud and haze structures not seen during the Voyager epoch. These topics are of current research interest.