Analysis of Polar Stratospheric Clouds from Advanced Very-High-Resolution Radiometer Measurements

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Polar stratospheric clouds (PSCs) play an important role in stratospheric ozone destruction under cold polar conditions. The current PSC measurement record comes from a variety of in situ measurements, lidar observations, and limb-viewing satellite data. Although these measurements offer many advantages, including good vertical resolution and the ability to characterize a variety of physical and optical PSC properties, they offer little information concerning PSC spatial and temporal distributions.

The advanced very high resolution radiometer (AVHRR) is a 5-channel nadir-viewing cross-track scanning radiometer. A series of AVHRR sensors onboard the TIROS-N/NOAA polar-orbiting satellites have been collecting data over both polar regions of the Earth since 1979. The horizontal resolution of AVHRR depends on view angle and ranges from 1.1 kilometer (km) at nadir to ~6 km at the steepest view angles. AVHRR is an operational weather sensor and was not designed specifically for PSC detection; however, because the AVHRR archive provides excellent spatial and temporal coverage of the polar regions, the use of AVHRR data for detecting PSCs has been investigated with the goal of producing a long-term, high-resolution PSC climatology.

PSCs form during the polar winter and early spring, when little or no sunlight is present. Prior to this study, conventional wisdom held that PSCs could not be detected in AVHRR imagery because they are too optically thin and there is insufficient thermal contrast between PSCs and the cold polar surfaces. This is true for Type I (nitric acid trihydrate or liquid ternary aerosol) PSCs. However, using the two AVHRR thermal infrared channels, channel 4 (10.3–11.3 micrometer (μm)) and channel 5 (11.5–12.5 μm), project personnel have developed methods to discriminate ice PSCs from other clouds using a combination of channel 5 brightness temperatures and the brightness temperature difference (BTD) between channels 4 and 5.

It was found that the optically thickest ice PSCs can be detected in AVHRR by color contouring channel 5 brightness temperatures. Ice PSCs form at or below ~188 kelvin (K). However, these clouds are not opaque and will transmit upwelling radiation, making the cloud top temperature appear warmer from a nadir view. Because surface and tropospheric temperatures are typically warmer than 195 K in most polar regions, pixels with AVHRR channel 5 brightness temperatures at or below 195 K can be classified as ice PSCs. Although this approach is relatively straightforward, only a small percentage of PSCs can be detected using this method.

Most ice PSCs are optically thin and can be easily confused with tropospheric cirrus clouds using only AVHRR channel 5 brightness temperatures. In this study a radiative transfer model using AVHRR channel 4–5 BTDs to discriminate optically thin PSCs from underlying cirrus has been developed. A suitable range of effective radii and volume densities were chosen to represent both cirrus and ice PSCs. Signals were then simulated using ice refractive indices for a range of PSC and cirrus cloud temperatures and background brightness temperatures. AVHRR pixels are categorized as ice PSCs when the BTD is greater than the maximum cirrus BTD. AVHRR pixels are categorized as probable ice PSCs when the BTD is greater than the average cirrus BTD.

Thresholds provided by the radiative transfer model have been incorporated into a classification algorithm for mapping PSCs. This algorithm inputs surface and tropospheric temperature estimates and employs look-up tables for cirrus average and maximum BTD values for various underlying conditions. To start, each pixel with AVHRR channel 5 brightness temperature at or below 195 K is classified as ice PSC. Then, if each pixel does not meet this criterion, the channel 4–5 BTD for it is checked against modeled cirrus average and maximum BTDs, given the pixel's underlying surface and tropospheric temperatures, and classified accordingly. After PSCs are identified in AVHRR imagery, it is possible to estimate the PSC optical depth, effective radius, temperature, and ice water path. Maps of these PSC characteristics can then be produced.

Work is ongoing to validate the model results with Polar Ozone and Aerosol Measurement (POAM) II and III ice PSC data and lidar PSC data. Future plans include applying the model to moderate resolution imaging spectroradiometer (MODIS) data. This recently launched satellite instrument offers measurements in 36 spectral channels, 16 of them in the thermal infrared range. It is anticipated that the greater number of channels, narrower bandwidths, and greatly improved calibration of MODIS will permit the development of a more robust ice PSC detection algorithm and better estimates of ice PSC cloud properties.

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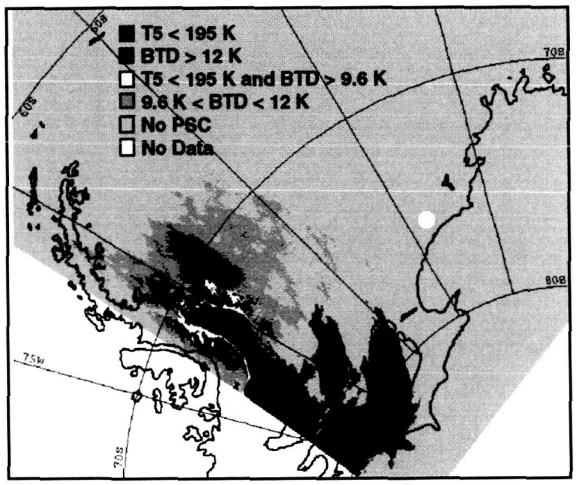

Fig. 1. Ice PSCs identified in the 18:35 Coordinated Universal Time (UTC) AVHRR imagery on July 21, 1992, in West Antarctica. A radiative transfer model was used to calculate AVHRR channel 4–5 BTDs for a range of cirrus and ice PSC conditions. A classification algorithm was then used to map the PSCs. Each pixel with AVHRR channel 5 brightness temperature (T5) at or below 195 K was classified as ice PSC (dark blue). Failing this criteria, a pixel was classified as ice PSC if the channel 4–5 BTD was greater than the modeled maximum cirrus BTD based on the underlying surface and tropospheric temperature (red) of the pixel. Finally, a pixel was classified as probable ice PSC if the channel 4–5 BTD was greater than the modeled average cirrus BTD (cyan). A small amount of pixels were both colder than 195 K and had AVHRR channel 4–5 BTDs greater than the modeled average cirrus BTD (yellow). Pixels that were not identified as PSC represent tropospheric cloud, sea ice, or snow and ice land surfaces (gray). No AVHRR data were available for some regions (white). The location of the nearest radiosonde station is noted (yellow dot).