Satellite Remote Sensing of Cirrus: An Overview

Patrick Minnis

Atmospheric Sciences Division
NASA Langley Research Center
Hampton, Virginia 23692
757-864-5671
email: p.minnis@larc.nasa.gov

1. Introduction

The determination of cirrus properties over relatively large spatial and temporal scales will, in most instances, require the use of satellite data. Global coverage, at resolutions as high as several meters are attainable with Landsat, while temporal coverage at 1-min intervals is now available with the latest Geostationary Operational Environmental Satellite (GOES) imagers. Cirrus can be analyzed via interpretation of the radiation that they reflect or emit over a wide range of the electromagnetic spectrum. Many of these spectra and high-resolution satellite data can be used to understand certain aspects of cirrus clouds in particular situations. Production of a global climatology of cirrus clouds, however, requires compromises in spatial, temporal, and spectral coverage. This paper summarizes the state of the art and the potential for future passive remote sensing systems for both understanding cirrus formation and acquiring sufficient statistics to constrain and refine weather and climate models.

2. Cirrus properties

Many different aspects of cirrus can theoretically be determined from passive sensing systems. A limited number of quantities are presently the focus of most efforts to quantify cirrus clouds. These include the areal coverage, top and base altitude, top and base temperatures, optical depth, effective particle size and shape, vertical ice water path, size and shape of the cloud cells and their spacing. In many situations, accurate values for all of these parameters should be sufficient to describe a cirrus cloud and its potential to interact with the environment. They determine how much water must be frozen to form the cloud, the volume of space it should occupy, and how it will affect the radiation fields. As we learn more about cirrus, however, more detailed quantities such as the vertical and horizontal distribution of the ice crystals within the cloud may be required to obtain an accurate description of cirrus. Ideally, each parameter should be evaluated at all times of day over all areas, but the spectral, temporal, and spatial sampling characteristics of current and future satellites are limited.

3. Current techniques

A limited climatology of thin cirrus clouds was developed by Prabhakara et al. (1988) using a split-window technique similar to that described by Inoue (1985) and studied by Parol et al. (1991). This approach works both day and night but suffers from some ambiguities because of the necessity for solving particle size, temperature, and optical depth from two channels. Rossow and Lacis (1990) have developed a global climatology of clouds including cirrus. Their 3-hourly products are based on a bispectral visible-infrared method that assumes a fixed particle size with a fractal shape for the cirrus cloud. Thus, cirrus optical depth and altitude are retrieved during the day, but cirrus information at night is limited only to the height of optically thick clouds. Minnis et al. (1995b) also derive cirrus clouds from GOES on a half-hourly basis in a similar fashion but over a domain limited to the central U.S. and with a hexagonal ice crystal model (Minnis et al., 1993). Wylie et al. (1994) are continuously monitoring cirrus clouds on a global basis using a CO2-slicing technique to determine cloud height and effective emissivity. While the method provides global coverage, it, like other techniques, is weak over the poles and does not produce any microphysical properties. Extremely thin, subvisible cirrus clouds undetectable by current nadir-viewing instruments are also monitored with solar-occultation sensors (e.g., Wang et al, 1998; Rinsland et al., 1998) but the spatial sampling is extremely constrained. Thus, a long time period must be sampled for meaningful statistics. Techniques for deriving cirrus particle size have been developed for interpretation of 0.65, 0.87, 3.7, 10.8, and 12 μm radiances (e.g., Ou et al., 1993; Minnis et al., 1995a; Giraud et al., 1997). Some large datasets have been analyzed to produce the first climatologies of cirrus particle size and optical depth (e.g., Han et al., 1996; Minnis et al., 1997). These techniques are limited to daytime and also have difficulty over the poles. Techniques that are useful for all times of day are multispectral infrared methods that are applicable only to semi-transparent cirrus. They can provide some better data on cirrus than single-channel methods but are extremely sensitive to water vapor loading (Liou et al., 1990) or require accurate surface emissivity data (Strabala et al., 1994; Smith, Jr. et al., 1997). Cloud base and thickness are currently only estimated with a few crude techniques (e.g., Smith, Jr. et al., 1993). New methods are needed to address these parameters.

A wide variety of new sensors are currently being flown on new research satellites such as the Visible Infrared Scanner (VIRS) on the Tropical Rainfall Monitoring Mission satellite and the Along Track Scanning Radiometer (ATSR) on ERS-2. The Clouds and Earth's Radiant Energy System project is using the VIRS 0.65, 1.6, 3.7, 10.8, and 12 μm data to derive all of the cirrus properties except for cirrus in multilevel cases (Minnis et al., 1995a). The 1.6 μm channel is being used in a method similar to that proposed by Masuda and Takashima (1990) for the new sensor on the NOAA-15. Baran et al. (1997) use the 1.6-μm channel on the ATSR and its multi-angle views to discern cloud particle size and an estimate of shape.

4. Future methods

One of the biggest limitations to current techniques is the frequent occurrence of multilevel clouds. Several techniques have been developed, but none are sufficiently mature for general application. Baum et al. (1994) used HIRS CO2-slicing to determine the altitude of the upper-level cirrus and then used multispectral infrared data to derive the cloud properties. This approach may eventually be applied to the upcoming MODIS instrument on the EOS satellites. It is somewhat similar to the method of Jin and Rossow (1997). Another approach that will be applicable only over oceans is the combination of microwave for liquid water cloud temperature and infrared for the upper-level cloud temperature (Lin et al., 1998). The wide range of MODIS channels will also enhance the application of other algorithms such as that used by CERES because of improved spatial resolution. Thin cirrus clouds will be better detected during the daytime with the 1.38-μm channel (e.g., Gao et al., 1993). Other spectra have been considered for cirrus retrievals but have not yet been measured with spaceborne instruments, although proposals for such instrumentation are in the works. Cloud-top height estimates may be improved with oxygen A absorption band radiances (e.g., Fischer and Grassl, 1991). Selected spectra in the microwave (Evans and Stephens, 1995) and in the submillimeter (Evans et al., 1998) ranges show considerable promise for better 24-hour measurements of water path and large particle sizes in ice clouds. These spectra are also insensitive to liquid water so that the signal from the cirrus clouds can be isolated. Infrared interferometers may also yield new insight into cirrus microphysics (Smith et al., 1993). Thus, future monitoring systems may carry a wide array of instruments that can be used synergistically to provide a more complete quantification of cirrus clouds for climate and weather model verfication and, possibly, initialization.

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