The Canadian CloudSat Validation Project

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1 Introduction

The CloudSat satellite mission, a joint venture by NASA and the Canadian Space Agency, has deployed a nadir-pointing, W-band cloud-profiling radar on a near-polar orbiting, sun synchronous platform. This represents an important step toward: (1) providing information required to clarify the processes that interrelate clouds and climate; and (2) investigating the utility of space-based W-band radars to observe and quantify cloud and precipitation. An overview of the mission is given in Stephens et al. (2002).

CloudSat was launched from Vandenberg Air Force Base in California on April 28, 2006 along with a sister satellite, CALIPSO, that has a lidar onboard (Winkler et al., 2003). After launch, a validation project to investigate the applicability of the satellite data and their products to the northern climate will take place in Canada. Hudak et al. (2004), using ground-based radar data collected in northern Canada, suggested that the sensitivity of the CloudSat radar should be adequate for most purposes. That is, most clouds should be above the detection limit of the radar and attenuation by clouds with high moisture content should be of little concern. However, biases in retrieved cloud properties related to both multi-layer systems with high ice content and mixed phase clouds were suggested.

The goals of this validation project are to provide independent validation of CloudSat data products and verification of the physical basis of the underlying algorithms. This will complement validations planned elsewhere that are focused on warm-season, convective-cloud systems.

2 Data from the A-train

As part of the so-called A-train constellation of satellites, CloudSat and CALIPSO will fly in formation with EOS AQUA satellite (Stephens et al., 2002). This will allow for the combined use of data from the three satellites in a synergistic manner. Data products from the CloudSat data processing center will make use of not only the cloud profiling radar data from CloudSat but also data from the dual-channel cloud-aerosol lidar onboard CALIPSO and MODIS and CERES onboard AQUA. Supplementary data based on ECMWF model analysis is also part of the data package.

Standard data products include both macrophysical and microphysical cloud properties. Macrophysical properties include cloud occurrence, cloud base and top altitudes, cloud thickness, and precipitation occurrence. Microphysical properties include vertical profiles of optical depth, cloud liquid and ice water contents, and radiative fluxes and heating rates (Stephens et al, 2002). Other experimental products dealing with precipitation type, precipitation amount, and cloud phase will also be considered for validation studies.

3 Validation Activities

The Canadian CloudSat validation experiment will begin in the winter 2006/07 and focus on cold-season stratiform cloud systems. There are two aspects of the mission that require consideration. First, being a nadir-viewing instrument, the cloud-profiling radar has a beamwidth of just ~1.4 km. Second, the orbital parameters of the A-train are such that orbits repeat every 233 orbits, or 16 days. This combination of a narrow data-swath and the long time interval between satellite revisits to a locale must be taken into account in devising a validation strategy. One aspect is the acquisition of long term ground measurements. These are required to provide independent ground-truth of the cloud properties. These data will be used to develop cloud statistics, define climate regimes, understand error structure in sampling the stratiform cloud systems, and assess the CloudSat radar sub-pixel variability and sensitivity. The second aspect is to conduct aircraft measurements underflying the satellite

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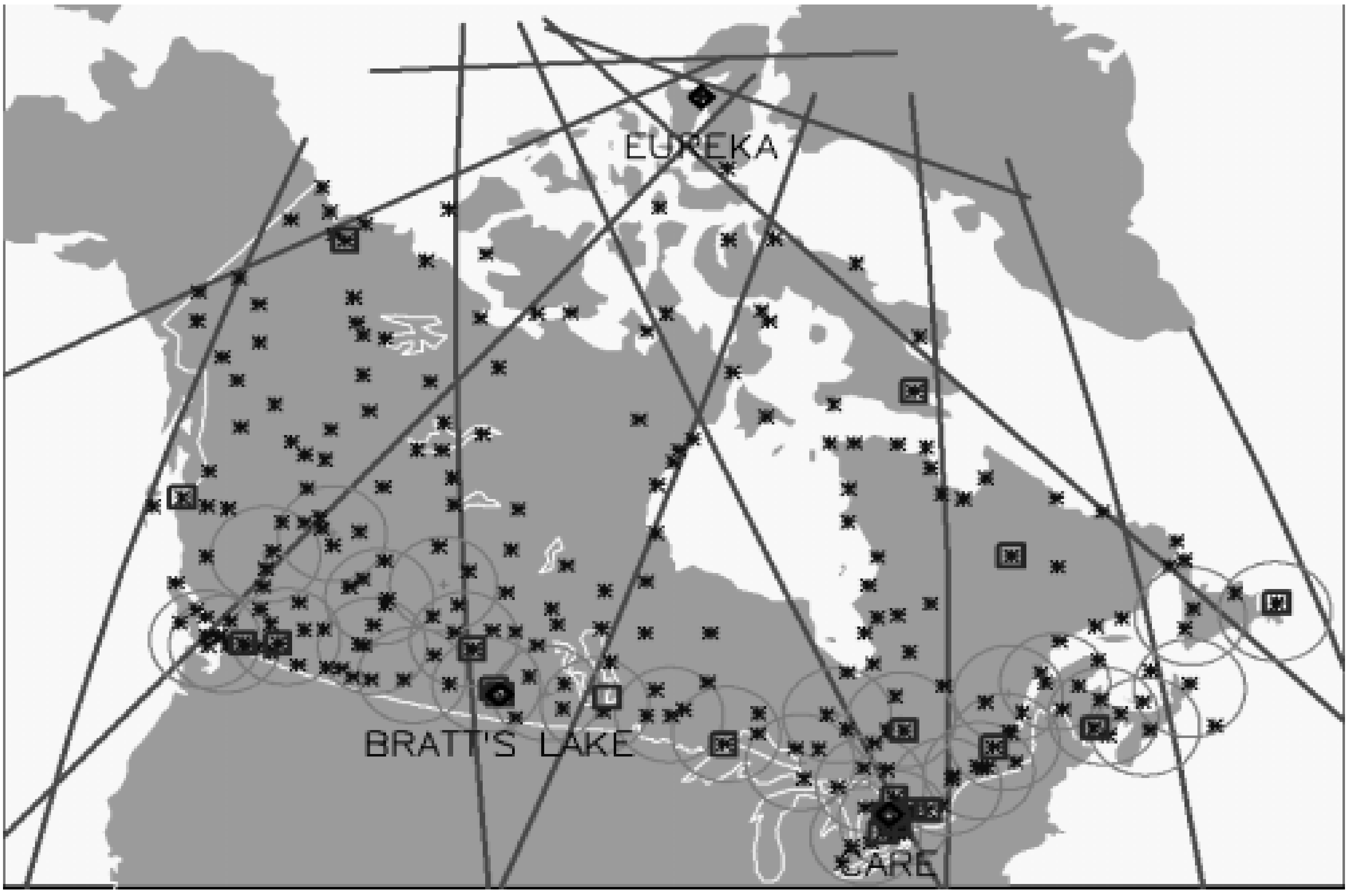

Fig. 1. The Canadian surface observation network and CloudSat ground tracks for a typical A-train day. Enhanced measurement sites are shown as diamonds; POSS sites are located as squares; Cloud and precipitation observation stations are indicated by asterisks. 256km range rings corresponding to the National Radar Project network are shown.

tracks in targeted field campaigns. These measurements will provide crucial in situ sampling of cloud properties. From this, assumptions associated with satellite inversion algorithms can be checked and an assessment of the whole retrieval process can be carried out.

3.1 Network Measurements

The Environment Canada (EC) weather observing network will be used as a source of ground-truth data. An overview of this network is given in Fig. 1. It includes hourly observations of clouds and weather and the network of 31 C-band Doppler radars. In addition, some of the observing sites have a Precipitation Occurrence Sensor System (POSS) from which additional information on precipitation characteristics can be deduced (Sheppard and Joe, 2000). Also contained in Fig. 1 is a depiction of the number of passes of the A-train over Canada in a typical day. The sparseness of the coverage highlights the need for an extensive observing network to validate the cloud macrophysical data products.

3.2 Enhanced Measurement Sites

In order to provide a more complete record of cloud and precipitation information, two enhanced measurement sites (Fig. 1) will be maintained. These two sites involve cloud radar and lidar observations from the ground that match the satellite measurements. The first is in the Great Lakes region of Canada at the Centre for Atmospheric Research Experiments (CARE). Table 1 provides a summary of the in-situ and remote sensing instruments at CARE (more details at http://c3vp.org/data/EMS/EMS_care.html). The second locale is in the high Arctic on Ellesmere Island. The Polar Environment Atmospheric Research Laboratory (PEARL) was recently opened in Eureka as part of the Canadian Network for the Detection of Atmospheric Change (CANDAC; see http://www.candac.ca/index.html) and the US Studies of Environmental Arctic Change (SEARCH; see http://www.arcus.org/SEARCH/index.php) programs. Eureka, at 80°N, is close to the northern extent of the A-train orbit and as a result has many more opportunities for validation – about 10 times more overpasses than at mid-latitudes. At PEARL, there is a cloud radar provided by NOAA (Moran et al., 1998) and a high-resolution spectral lidar provided by the U. of Wisconsin (Eloranta et al., 2005) as part of SEARCH.

3.3 Aircraft Campaign

During the first winter (2006/07) of the CloudSat mission, an aircraft campaign will be mounted in the vicinity of CARE. The National Research Council of Canada (NRC) Convair-580 research aircraft, containing a suite of in-situ and remote sensing sensors, will fly missions along CloudSat's ground-

Table 1. Instrumentation at CARE.

Sensor /system	Measurement
2-wavelength polarized lidar	Cloud detection, cloud phase, aerosols
NASA/JPL W-band radar	Cloud phase, particle type, precipitation rate
McGill X-band radar	Cloud detection, particle type
Ceilometer	Geometric cloud profile
POSS	Precipitation occurrence, rate, and type, DSD
Precipitation gauges (Hot Plate, Geonor)	Precipitation rate, snow depth
Rawinsonde system	Pressure, temperature and RH profile
915MHz Wind Profiler with RASS	Wind profile, turbulence
McGill video disdrometers	Precip fall velocity and shape
Profiling radiometer	Liquid water path
Meteorological station	10m tower w/ pressure, temperature, RH and winds
Visibility meter	Visibility
Sunphotometer	Radiation
Sky Imager	Cloud opacity
Ground precipitation photography	Precipitation characteristic
Broadband radiometers	Radiation
Penn State dual-radiometer package	Cloud optical depth

track and over the CARE site. Table 2 gives an overview of aircraft instrumentation.

In order to maximize resources and sample as wide an array of winter cloud conditions as possible, aircraft observations will occur during every other 16-day cycle of the A-train orbit. These Intensive Observation Periods (IOPs), will span the time period from the beginning of November, 2006 to the end of February, 2007. Figure 2 depicts the operations setup. The possible satellite tracks that can be reached by the aircraft are shown in Fig. 3. During each IOP, there will be 6 targeted flights. Suitable cloud conditions and the proximity to the CARE site will be used to determine the actual cases that will be flown. In all, about 100 h of flying is envisioned.

Table 2. Instrumentation on the NRC Convair-580 aircraft.

Remote sensing
NRC W- and X-band radar
EC Ka-band radar
EC dual polarization Lidar
Microphysics probes
LWC: King, Nevzorov
TWC: Nevzorov, SEA, DMT CVI (0.005-0.05 gm-3)
Water vapour: LICOR
Ice detection: Rosemount, Vibrameter, TAMDAR
CSU IN counter
TSI 7610 CN counter (CN>0.014 um)
Cloud spectrometers
PCASP-100X spectrometer (0.1-3 um)
FSSP-100X (2-32 um, 5-95 um)
PMS 2D2-C (25-800 um)
PMS 2DCgrey (15-960 um)
PMS 2DP (200-6400 um)
SPEC 2DS (10-1280 um)
SPEC HVPS (200-25000 um)
DRI T-probe/cloudscope
DMT CIP probe (15-960 um)

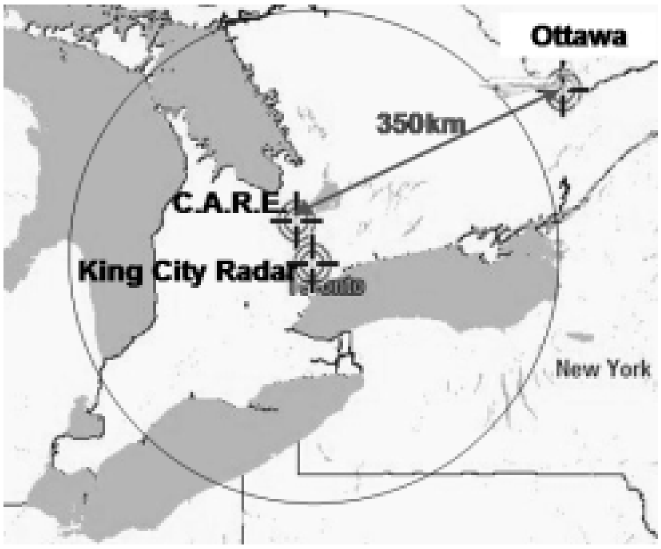

Fig. 2. Great Lakes aircraft campaign area.

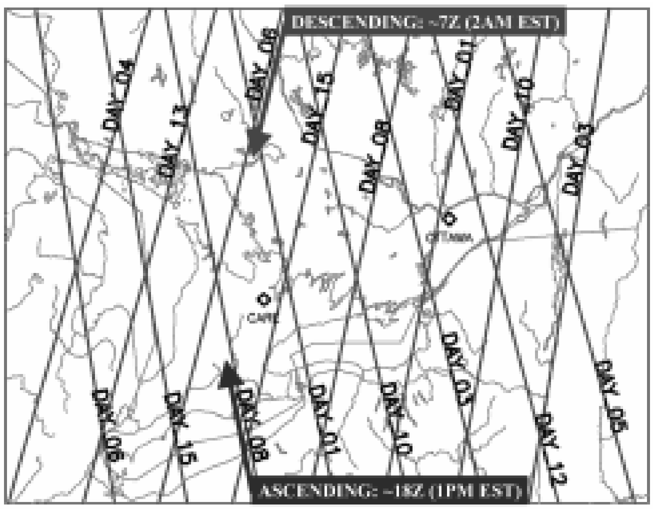

Fig. 3. Great Lakes CloudSat overpasses within the A-train 16-day cycle. Adjacent passes are approximately 120 km apart.

4 Use of the Radiation Simulator

A novel aspect of the project is the use of an enhanced version of ESA's EarthCARE satellite simulator (see http://www.esa.int/esaLP/LPearthcare.html). The plan is that the simulator will help facilitate planning and data analyses activities. During the first phase of the project, the simulator was enhanced to accurately simulate CloudSat and CALIPSO instruments as well as ground- and aircraft-based lidars and radars.

An example of simulated CloudSat and CALIPSO measurements, and their ground-based equivalents, is shown in Fig.4. This idealized situation contains a stratocumulus layer with an overlying cirrus cloud, and boundary-layer aerosol. It can be seen (Fig. 4c) that due to CloudSat's limited sensitivity the stratocumulus (liquid phase) layer is not detected even though it is optically thick enough to completely attenuate the lidar signal (Fig. 4e). It can also be seen that the physically thick portion of cirrus cloud is optically thick enough to completely attenuate the lidar signal. However, this portion of cirrus is easily detected by CloudSat. These types of results demonstrate the essential need to combine data from both CloudSat and CALIPSO for cloud detection and cloud property determination.

The enhanced EarthCARE simulator can also be used to calculate irradiances and radiances at the top-of-atmosphere and surface and is fully capable to treating complex realistic cloud scenes. For more information see http://c3vp.org/ECARE/ECARE_sim.html.

5 Summary

A comprehensive validation exercise is planned for CloudSat data products as they apply to cold season stratiform cloud systems. It includes a Canada-wide observation network, maintenance of long-term enhanced measurement sites, and a targeted aircraft campaign. The goal is to quantify both random and bias errors inherent in cloud property and precipitation characteristic retrieval methods. Application of the algorithms to synthetic data will be an important component of the analysis.

Acknowledgements: Major funding for the field project is being provided by the Canadian Space Agency, the Canadian Foundation for Climate and Atmospheric Sciences, the Canadian Foundation for Innovation, NASA, and the DoD Center for Geosciences/Atmospheric Research at Colorado State University.

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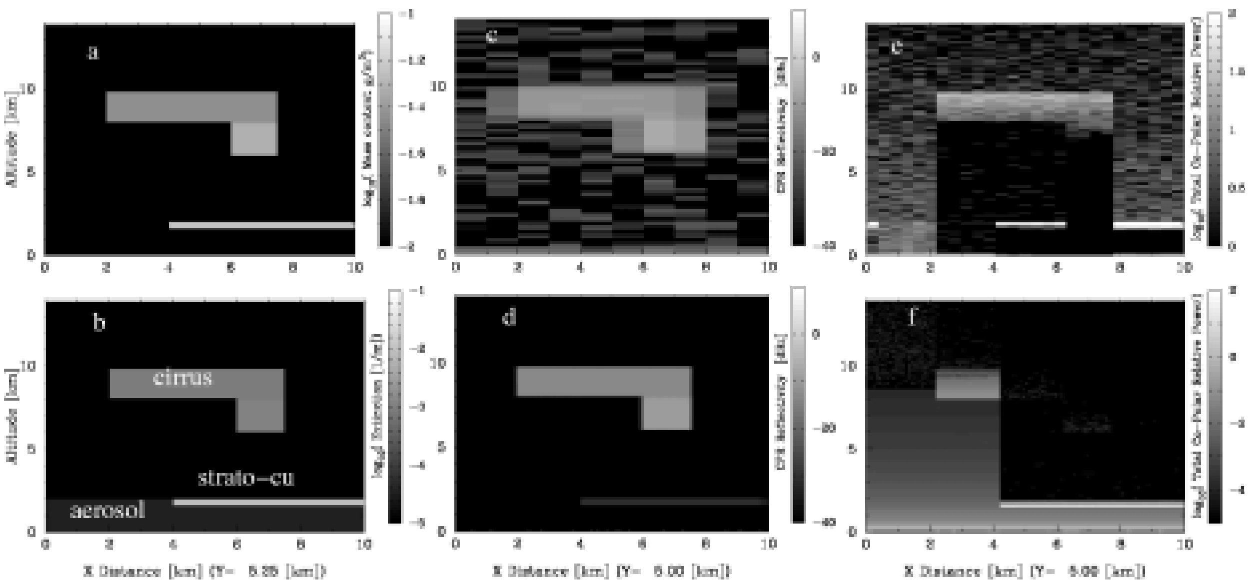

Fig. 4: Example of an idealized cloud field and corresponding simulated measurements: a) condensed mass content; b) extinction coefficient; c) CloudSat radar reflectivity; d) ground-based radar reflectivity; e) CALIPSO lidar signals; and f) surface lidar measurements.