The NASA CloudSat/GPM Light Precipitation Validation Experiment (LPVEx)

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Introduction

Ground-based measurements of cool-season precipitation at mid and high latitudes (e.g., above 45°N/S) suggest that a significant fraction of the total precipitation volume falls in the form of light rain, i.e., at rates less than or equal to a few mm h^{-1}. These cool-season light rainfall events often originate in situations of a low-altitude (e.g., lower than 2 km) melting level and pose a significant challenge to the fidelity of all satellite-based precipitation measurements, especially those relying on the use of multi-frequency passive microwave (PMW) radiometers. As a result, significant disagreements exist between satellite estimates of rainfall accumulation poleward of 45°. Ongoing efforts to develop, improve, and ultimately evaluate physically-based algorithms designed to detect and accurately quantify high latitude rainfall, however, suffer from a general lack of detailed, observationally-based ground-validation datasets. These datasets serve as a physically-consistent framework from which to test and refine algorithm assumptions, and as a means to build the library of algorithm retrieval databases in higher latitude cold-season light precipitation regimes. These databases are especially relevant to NASA's CloudSat and Global Precipitation Measurement (GPM) ground validation programs that are collecting high-latitude precipitation measurements in meteorological systems associated with frequent cool-season light precipitation events.

In an effort to improve the inventory of cool-season high-latitude light precipitation databases and advance the physical process assumptions made in satellite-based precipitation retrieval algorithm development, the CloudSat and GPM mission ground validation programs collaborated with the Finnish Meteorological Institute (FMI), the University of Helsinki (UH), and Environment Canada (EC) to conduct the Light Precipitation Validation Experiment (LPVEx). The LPVEx field campaign was designed to make detailed measurements of cool-season light precipitation by leveraging existing infrastructure in the Helsinki Precipitation Testbed. LPVEx was conducted during the months of September-October, 2010 and featured coordinated ground and airborne remote-sensing components designed to observe and quantify the precipitation physics associated with light rain in low-altitude melting layer environments over the Gulf of Finland and neighboring land mass surrounding Helsinki, Finland.

Science Objectives

The LPVEX effort was designed around two overarching science objectives:

- Characterize the ability of CloudSat, GPM, and passive microwave radiometers in general to detect and accurately estimate rainfall intensity at high latitudes;

- Provide a new database with requisite ice and liquid water content, size distribution, and precipitation information to test and verify critical assumptions being made in current and developing (e.g., GPM) space-based precipitation retrieval algorithms.

In association with the aforementioned science objectives a set of specific science questions to be addressed using the field campaign data include:

- What are the minimum rain rates that can be detected by current satellite precipitation sensors in environments with freezing levels lower than 2 km? How will rainfall detection be improved by future platforms such as GPM?

- How well can existing and how well will new satellite sensors discriminate rain from falling snow?

- Are the microphysical assumptions, such as raindrop size distribution, cloud water contents, and properties of the melting layer and precipitating ice aloft, currently employed in global satellite precipitation algorithms representative of high-latitude precipitation in a statistical sense?

- What is the impact of variability in these microphysical assumptions and those related to vertical structure and spatial heterogeneity on random errors in retrieved rainfall rate?

- Collectively, are the above inter-sensor differences large enough to explain observed disagreements in current satellite estimates of high-latitude rainfall?

Methodology

Assessing the accuracy of rainfall products and quantifying uncertainties due to specific algorithm components requires a combination of in-situ measurements of profiles of cloud and precipitation microphysics and associated surface rainfall observations. Therefore the LPVEx observational and instrumentation strategy consisted of coordinated airborne microphysical sampling conducted within an extensive network of ground-based observations focused on measurement of hydrometeor bulk water contents, precipitation rates, and drop size distributions (DSD). A complete list of the ground and aircraft sensors deployed during the experiment is presented in Tables 1 and 2, respectively. These instruments were deployed at three surface sites representative of island, coastal, and inland regimes while two disdrometer instruments (ODM-470 and Parsivel) and a Micro Rain Radar (MRR) were deployed aboard the FMI Research Vessel Aranda during two weeks of cruises in the Gulf of Finland to provide an oceanic counterpart to the ground sites.

Table 1: LPVEX Ground Sensors
- 3 2D Video, 7 Parsivel, 1 Joss-Waldvogel disdrometers
- 10+ rain gauges
- ADvanced MIcrowave RAdiometer for Rain Identification (ADMIRARI) /Micro Rain Radar (MRR)
- 3 C-band dual-polarimetric radars (fully adaptable scanning geometry)
- 1 Vertically-pointing C-band Doppler radar
- 2 Precipitation Occurrence Sensing Systems (POSS)
- UHF Wind Profiler
- 5 Micro Rain Radars (MRR)
- UH Station for Measuring Ecosystem-Atmosphere Relation (SMEAR) aerosol/flux tower
- 6 Ceilometers

Table 2: LPVEX Airborne (U. Wyoming King Air)
- W-band cloud radar (multiple beams)
- Water content: Droplet Measurement Technologies DMT probe, Gerber, Nevzorov probes
- Microphysics: 2D-P, Cloud Imaging Probe (IP), Cloud Droplet Probe (CDP), Forward-Scattering Spectrometer Probe (FSSP) and 2D-C particle imaging probes
- Aerosol: Passive Cavity Aerosol Spectrometer Probe (PCASP-100X)

- Ancillary RH, T, altitude, wind speed observations

The core sampling strategy for the experiment was designed around the collection of well-calibrated, multi-frequency, polarimetric radar observations to export ground-based and airborne point measurements of the vertical/spatial distributions of hydrometeor phase and shape characteristics, rain drop size spectra, and surface rainfall intensity to the larger 3D volumes characteristic of satellite fields of view. When combined with temperature, humidity, wind, aerosol concentration, and cloud water profile information from the W-band Wyoming Cloud Radar (WCR) aboard the aircraft, these observations will provide a full three-dimensional volume depiction of rainfall scenes and their associated meteorology. When combined with appropriate satellite simulators, these 3D volumes can be used to differentiate the detection characteristics and evaluate algorithm performance for all current rainfall platforms including PMW imagers and sounders and the CloudSat Cloud Profiling Radar (CPR) and assist in the development of the next generation of satellite rainfall retrieval algorithms for the GPM Microwave Imager (GMI) and Dual-frequency Precipitation Radar (DPR).

Operations on any given day of the experiment typically involved an early morning weather briefing given by FMI forecasters, followed by an aircraft briefing to make final go/no-go decisions and to determine track positions for the day's sampling. The targets for sampling were preferably widespread stratiform rain or snow systems though data were also collected to study the backscatter cross-section of the ocean surface on clear days. For days having aircraft missions, Finnish air traffic control typically provided a 4-5 hour operations window from approximately 0630-1130 UTC in which 3.5-hour missions were conducted using the University of Wyoming King Air that was based in Turku. During airborne sampling the radars operated in a combination of narrow sector volume scans and repeating Range-Height Indicator (RHI) scans to provide combined horizontal coverage over the sampling volume and high-resolution vertical sampling of the column. Surface instrumentation operated continuously during the campaign while the aircraft conducted coincident stacked legs and spiral ascents or descents over the ground sites (when possible) within coverage of the polarimetric radars.

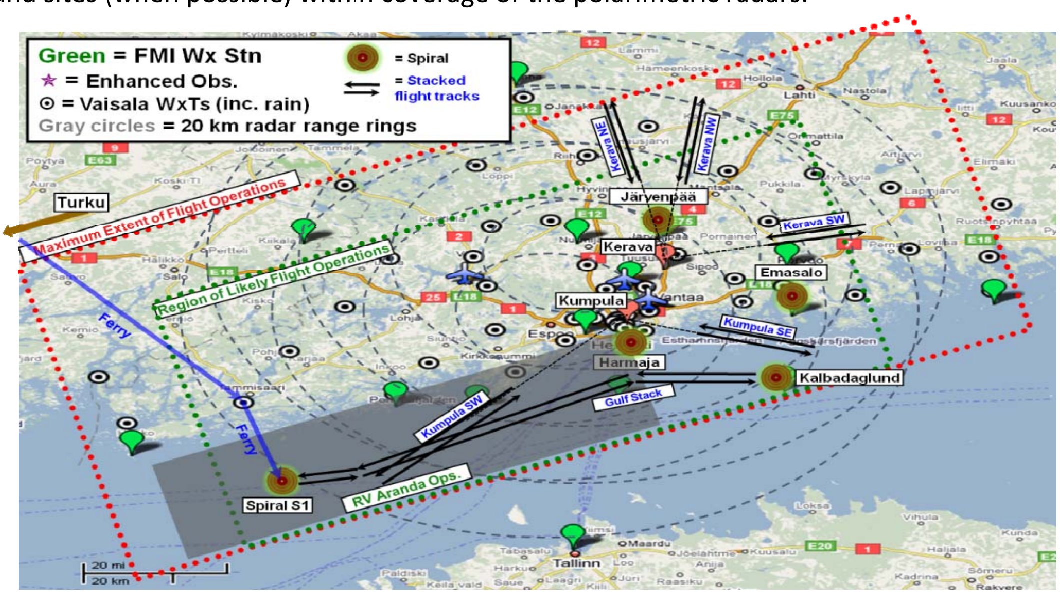

Figure 1. Observing strategy during LPVEx. Predetermined positions of stacked flight track legs executed during the campaign are indicated in black vectors. Filled circles indicate position of spiral ascent and descent aircraft tracks over intensive instrumentation sites. C-band dual-polarimetric radars were located at Kumpala and Kerava, with an additional operational radar located at Vantaa.

Preliminary Results

Observed DSDs and rainfall rates during the LPVEx intensive observations period (IOP) inferred from the Joss-Waldvogel disdrometer at the inland Järvenpää site ~20 km north of Helsinki are shown in Figure 2. Also depicted are the times of the 15 research flights that were conducted during the experiment. By design, the observations straddled the transition from the deeper 3 km freezing levels characteristic of late summer precipitation to much shallower freezing levels (~1 km) and even light snowfall toward the end of the experiment. Both isolated convective and wide-spread stratiform rainfall were sampled during the experiment and the observations spanned a wide spectrum of rainfall intensities from light drizzle to rain rates exceeding 10 mm h^{-1}. Drier conditions during the middle of the experiment were used to conduct four additional research flights in non-precipitating clouds and cloud-free conditions to provide additional datasets for evaluating W-band cloud retrievals and to examine the response of ocean backscatter to wind speed at a range of view angles.

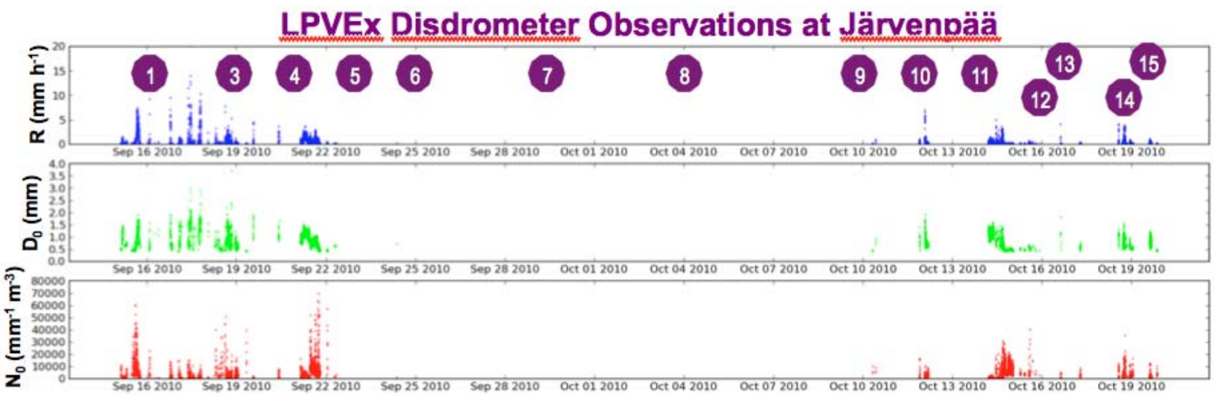

Figure 2. Surface rainfall observations at the Järvenpää site during LPVEx. Numbered circles represent the fifteen research flights conducted during the experiment. Size distribution parameters, D_0 and N_0, are presented in the middle and lower panels, respectively.

Examples from several of the datasets collected during LPVEx are presented in Figure 3, illustrating the overall observing strategy that was adopted for the experiment. In particular, the widespread light rainfall event from October 20, 2010 is representative of the type of precipitation targeted by LPVEx. The freezing level was approximately 1 km and observed rainfall rates at the surface ranged from light drizzle to about 5 mm h^{-1} during the 3.5 hour research flight (RF15). The lower left panel of Figure 3 shows Kumpula C-band radar reflectivity observations which illustrate the widespread nature of the precipitation around the Helsinki area at 0920 Z. Near this time the King Air conducted a spiral descent from 10,000 to 1,000 feet at a rate of 500 feet per minute (fpm) within the coverage of repeated RHIand small-sector volume scans from the Kumpula and Kerava radars, respectively. Cross-sections of the Kumpula radar reflectivity, copolar correlation coefficient, ρ_{HV}, and differential reflectivity, Z_{dr}, are shown with corresponding cross-section taken from the WCR radar in the upper left and center panels of Fig.3 respectively. Simultaneous reflectivity observations from the 24 GHz MRR and ADMIRARI radiometer based at Emasalo are also presented in the lower middle portion of Fig. 3, and provide constraints on cloud base and freezing level height as well as column-integrated liquid water. Collectively this combination of bulk multi-frequency and dual-polarimetric radar remote sensing observations can be related to detailed ice, liquid, and melting-layer microphysics information provided by the imaging probes aboard the height-profiling aircraft as well as surface rainfall and rain DSD information from disdrometers located on the ground at Emasalo. When combined with ancillary observations of temperature, humidity, and surface wind speed, these data collectively allow the observed multi-wavelength radar and radiometric signatures to be related to both the vertical structure of cloud and precipitation microphysics in the atmospheric column and the rainfall intensity at the surface, providing the essential building blocks for developing and testing both active and passive satellite rainfall retrievals.

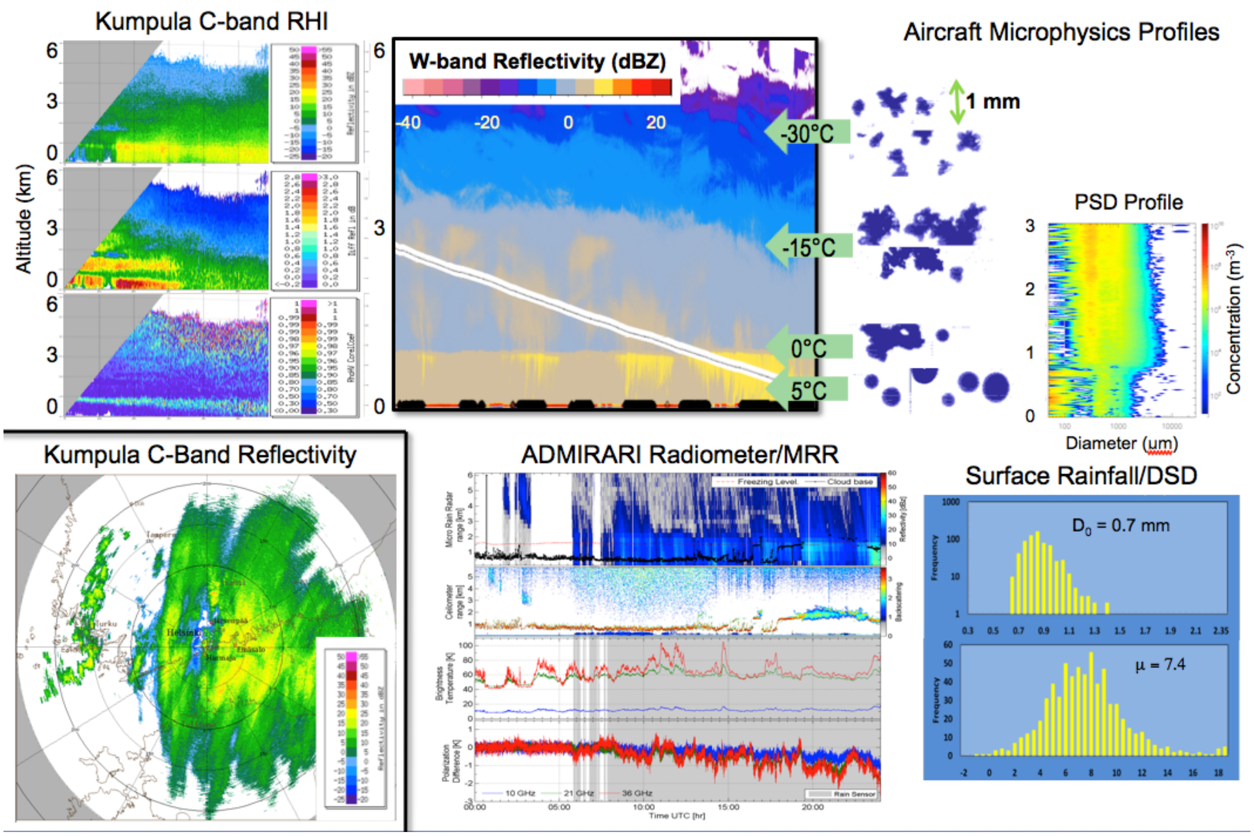

Figure 3. LPVEx observations collected at the Emasalo coastal site on October 20, 2010.

Expected Outcomes

The LPVEx IOP has provided coordinated sampling of cloud and precipitation microphysics profiles, a diverse set of multi-wavelength radar and ground-based radiometer measurements, and surface rainfall/DSD observations in the under-sampled high latitude/cool-season environment. Given the paucity of observations linking microphysics, thermodynamics, and precipitation in shallow freezing level environments, it is anticipated that LPVEx will fill a valuable data gap for rainfall algorithm evaluation and development outside the tropics. LPVEx will provide:

- Quantitative assessment of the detection characteristics of a variety of satellite-based rainfall sensors including current PMW imagers and sounders, the CloudSat CPR, and GPM's GMI and DPR in shallow freezing level environments.

- A robust assessment of the uncertainties in rainfall intensity estimates from these sensors.

- An archive of high quality microphysics and rainfall intensity measurements in high-latitude precipitation systems to improve the underlying assumptions in satellite rainfall algorithms and facilitate the development of algorithms for future sensors.

- An overall better understanding of high-latitude precipitation processes and their implications for satellite remote sensing.

These project objectives and light rain-centric outcomes are necessary to ultimately reconcile differences in current satellite rainfall products at high-latitudes to meet mutual goals of the CloudSat and GPM programs.

More information about the LPVEx campaign and associated datasets can be obtained through the CloudSat LPVEx website at http://lpvex.atmos.colostate.edu. DSD and rain rate observations and associated documentation from the surface sites are also available through the GPM Ground Validation Data Portal (http://gpm.nsstc.nasa.gov/lpvex/index.html).