Light Precipitation Validation Experiment (LPVEx)

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Executive Summary

Rationale

Accurate satellite-based estimates of rainfall are critical for characterizing and monitoring the global energy and water cycle yet comparisons of rainfall products from CloudSat, Aqua, and the Tropical Rainfall Measuring Mission (TRMM) highlight significant disagreement regarding the amount of rain that falls at latitudes poleward of 30 degrees. Ground-based measurements demonstrate that a significant fraction of the rainfall at these latitudes comes in the form of light rainfall from systems with shallow freezing levels that pose a significant challenge to most satellite precipitation sensors. Ongoing development of new or improved algorithms for detecting and quantifying high latitude rainfall, however, suffers from a general lack of dedicated ground-validation datasets in these environments.

Scientific Objectives

The Light Precipitation Evaluation Experiment (LPVEx) planned for the Gulf of Finland in September and October, 2010 will seek to address this shortcoming by collecting microphysical properties, associated remote sensing observations, and coordinated model simulations of high latitude precipitation systems to drive the evaluation and development of precipitation algorithms for current and future satellite platforms. Specifically, LPVEx seeks to characterize the ability of CloudSat, the Global Precipitation Measurement mission (GPM) Dual-frequency Precipitation Radar (DPR), and existing/planned passive microwave (PMW) sensors such as the GPM microwave imager (GMI) to detect light rain and evaluate their estimates of rainfall intensity in high latitude, shallow freezing level environments. Through the collection of additional microphysical and environmental parameters, the campaign will also seek to better understand the process of light rainfall formation and augment the currently limited database of light rainfall microphysical properties that form the critical assumptions at the root of satellite retrieval algorithms. Specific science questions include: identify source of spread in current satellite estimates of rainfall- minimum detectable rain rates, phase discrimination, physical assumptions in algorithms, spatial variability,

- What are the minimum rainrates that can be detected by current satellite precipitation sensors in environments with shallow freezing levels (lower than 2 km)? How will rainfall detection be improved by proposed future platforms?
- How well can these 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 inhomogeneity on random errors in retrieved rainfall rate?
- Collectively, are the above inter-sensor differences large enough to explain the wide spread in current satellite estimates of high-latitude rainfall?

Methodology

Assessing both 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. LPVEx will, therefore, consist of coordinated aircraft flights within an extensive network of ground-based observations that includes three dual-polarization, C-band, Doppler radars, a network of surface weather and sounding stations, several micro-rain radars, and surface rainfall and drop size distribution (DSD) measurements from a large number of raingauges and disdrometers. The core analysis strategy for the experiment is based on an "algorithm-simulator" approach where well-calibrated, multi-frequency, polarimetric radar observations are used to extend in situ measurements of the vertical/spatial distributions of temperature, humidity, aerosol concentrations, cloud water concentration, rain drop size spectra, particle phase, and surface rainfall intensity to full three-dimensional volume depictions of rainfall scenes. When combined with appropriate satellite simulators, these 3D volumes can be used to characterize the detection characteristics and evaluate algorithm performance for all current rainfall platforms including PMW imagers and sounders and the CloudSat CPR and assist in the development of the next generation of satellite rainfall retrieval algorithms for GPM GMI and DPR instruments. In this way, the combination of C-band radar reflectivity measurements and coincident in situ and ground-based microphysics measurements can be used to isolate the effects of a wide variety of algorithm assumptions including the assumed drop size distribution, relative amounts of cloud and rain water, mixed-phase and ice scattering properties, and vertical and horizontal variations in the cloud and rain field. CloudSat's precipitation algorithms will also be evaluated using measurements of reflectivity from the airborne equivalent to the Cloud Profiling Radar (CPR). These observations will be used as input to CloudSat's precipitation algorithms allowing the physical models relating cloud and precipitation microphysics to reflectivity, attenuation, and multiple-scattering to be tested and providing direct evaluation of algorithm performance against measured in situ microphysical information.

International Collaboration and Experiment Coordination

LPVEx is a collaborative effort between CloudSat, the GPM Ground Validation (GV) program, the Finnish Meteorological Institute (FMI), Environment Canada (EC), the United Kingdom National Environmental Research Council, Vaisala Inc., and the University of Helsinki (UH). CloudSat will lead the overall coordination of the field campaign including the planning, execution, and subsequent analysis and archival of results. CloudSat will support a majority of the proposed aircraft operations, including transit to/from Helsinki, crew costs, instrument installation and operation, a minimum of 25 science flight hours, pre-flight planning, in-flight coordination of airborne and ground-based assets with the meteorology of interest, and leading post-flight data analyses of collected data. It has been determined that the optimal platform for LPVEx is the University of Wyoming King Air (UWKA) aircraft since it is the only platform that offers multi-beam W-band radar allowing microphysics and reflectivity observations to be collected simultaneously. Given its compact size, the UWKA is also well-suited to making rapid in-flight adjustments to flight plans to target areas of interest. Upon completion of field operations, CloudSat will oversee all subsequent data analysis ensuring that quality-controlled versions of all data products are archived in a timely fashion. CloudSat will also coordinate with the appropriate algorithm development teams to conduct comprehensive evaluation of satellite rainfall estimates and maximize the benefits of the collected data for improving future products.

GPM will oversee the installation and operation of numerous additional ground assets including rain gauges and disdrometers to augment and extend the volumetric use of existing in situ rainfall sensors on the ground. In addition, GPM will support an additional 15 flight hours allowing the experiment to be extended for two additional weeks in October 2010. Under a sub-project entitled "Microphysical Characterization of Light Precipitation – Multi-sensor Observations and Modeling (MILIP)" funded by the Academy of Finland (decision pending), FMI and other Finland-based collaborators will be responsible for the operation and data collection from 3 polarimetric, C-band, Doppler radars, the operation of in situ instrumentation at relevant Helsinki Testbed (HTB) sites, and the launch of soundings to support flight operations. In addition, FMI and UH will provide local forecast support in flight planning briefings and contribute aerosol probes to augment cloud/precipitation microphysics probes aboard the aircraft.

Expected Outcomes

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 for improving the underlying assumptions in satellite rainfall algorithms and to 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 highly relevant to, and drive the synergisms between the CloudSat and GPM programs.

1. Introduction

1.1 Scientific Motivation

Establishing closure of the hydrologic cycle is fundamental to our understanding of the global climate system and the way it responds to both natural and anthropogenic forcings. To achieve the precision required to meet this challenge requires accurate assessment of the spatial distribution of precipitation and its variability on timescales ranging from tens of days (intraseasonal) to several years (interannual/decadal). While significant progress has been made in satellite-based precipitation measurement, large differences remain in precipitation estimates from active and passive sensors at latitudes poleward of 30 degrees. Mixed-phase shallow freezing level (SFL) systems that dominate precipitation at these latitudes pose a significant challenge to both active and passive sensors since the shallow depth of liquid water results in both weak emission signature at typical PMW frequencies and is often obscured by ground clutter that contaminates active measurements near the surface. Given that light rainfall at these latitudes constitutes a significant fraction of the fresh water available for human consumption and agriculture, there is a need to better understand the uncertainty charactersitics of satellite rainfall estimates in these environments and improve algorithm performance in the future. Yet despite their importance for human activity, detailed descriptions of the microphysical properties of these systems/regimes are under-represented in the available ground-validation archives. The Light Precipitation Validation Experiment (LPVEx) will address these issues by making detailed in situ observations of cloud and precipitation microphysics in coordination with a ground-based Polarimetric C-band Doppler radar network, three heavily instrumented ground sites and the RV Aranda to: (a) evaluate the rainfall detection characteristics of current and future spaceborne instrumentation for detecting light rainfall in high latitude, shallow freezing level environments, (b) document the macro- and microphysical properties this rainfall with detailed ground and airborne observations of Baltic late-summer light rainfall events, (c) couple observations of melting layer physics to the underlying rain water path, (d) establish the implications of variability in these characteristics for the accuracy in satellite-based rainfall intensity estimates at high latitudes, (e) explore methods for improving these estimates using future satellite instrumentation and focused cloud-resolving model experiments, and (f) extend these analyses to mixed-phase, wet snow events that occur in early fall. It is anticipated that the data collected during LPVEx will provide an invaluable resource for resolving discrepancies in current satellite rainfall estimates and furthering precipitation algorithm development in a regime that current sensors have the most difficulty in identifying. The eventual outcome of this effort will be to help improve our understanding of the precipitation processes in high-latitude environments and their importance in the context of the global hydrological cycle.

1.2 Background

In recent years the capability to quantify precipitation from space has been greatly enhanced with the addition of several new measurement capabilities from low-Earth orbit, most notably from passive microwave (PMW) sensors such as the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), Earth Observing System (EOS) Advanced Microwave Scanning Radiometer (AMSR-E) onboard Aqua, the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I), Windsat onboard the Coriolis satellite, and the SSM/I-Sounder (SSMI/S) onboard DMSP F-16. These sensors, commonly refered to as imagers, estimate the vertical hydrometeor profile using top-of-atmosphere (TOA) based on observed upwelling brightness temperatures (T_B) at 6, 10, 19, 37, and 85 GHz. As pointed out by many studies (Evans et al, 1995; Bauer, 2001) this relationship is not unique owing to variations in the vertical distribution of precipitation characteristics (mass content, DSD, melting layer properties, etc.), the amount of cloud water present, dielectric properties of the melting level, and horizontal variability in the large PMW field of view (FOV). These properties can be statistically constrained to some extent with *a priori* information but introduce uncertainty in retrieved rainfall rates. Furthermore, uncertainty in the specification of surface emissivity over land or the reduced emission from liquid droplets in SFL environments reduce signal to noise increasing errors in these environments.

PMW sounders, such as the National Oceanic and Atmospheric Administration (NOAA) Advanced Microwave Sounding Unit (AMSU-B), offer an alternative for estimating surface rainfall based on higher frequency measurements ranging from 150 to 183 GHz. Sounders have the advantage of being less sensitive to uncertainties in prescribed surface emissivity and offer smaller FOVs but also suffer from enhanced sensitivity to ill-defined scattering properties of ice aloft and reduced sensitivity to rain water itself.

This growing network of PMW sensors has recently been augmented with two new active platforms, the TRMM Precipitation Radar (PR) (Kummerow et al, 1998) and CloudSat's Cloud Profiling Radar (CPR) (Stephens et al, 2008) that provide unprecedented information concerning the vertical distribution of hydrometeors in the atmosphere. PR observations provide direct observations of backscatter from raindrops throughout the atmospheric column that can be converted to rainrate given appropriate drop size distribution (DSD) assumptions. However the fact that observed reflectivities depend on the sixth moment of drop size can lead to potentially large uncertainties in retrieved rainrates. In addition, with a minimum detectable signal of 17 dBZ, the PR cannot detect very light rainfall, especially from systems that do not completely fill its 5 km FOV. The CPR, on the other hand, exhibits excellent sensitivity to both drizzle and light rainfall. Strong attenuation at the 94 GHz frequency of the CPR, however, places special importance on the inferred path-integrated attenuation (PIA). Thus uncertainties in the relative contributions of cloud water, rainfall, and the associated profile of rain DSD to PIA and in the estimated clear-sky surface return can introduce corresponding uncertainty in retrieved rainfall rates. Furthermore, in more intense precipitation, attenuation can become so large as to completely overwhelm the reflectivity signal and multiple scattering effects, that are difficult to model in retrieval algorithms, can become significant. Finally, all active spaceborne sensors suffer from an inability to detect hydrometeors in the lowest kilometer of the atmosphere due to contamination from the surface return. This results in the need to extrapolate rainrates retrieved at 1 km or higher down to the surface, a particularly important concern in SFL environments.

Clearly each of the state-of-the art precipitation sensors has characteristic strengths and weaknesses. This can lead to significant discrepancies in rainfall accumulations from such products (Berg et al, 2006, 2008) and it is not surprising that these uncertainties are especially pronounced at high latitudes (Haynes et al, 2009 and Ellis et al, 2009). These results suggest that, despite recent advances in sensor technology, there remain several key areas of space-based precipitation retrieval that are not well understood and their impacts are especially acute at higher latitudes. For PMW sensors, retrievals of the light precipitation that is common at these latitudes (i.e., less than 2-3 mm hr^{-1}) over ocean, the majority of the signal is contained in the lower frequency channels where the on-Earth resolutions are the coarsest leading to the largest beam-filling/heterogeneity errors. Also, due to the fundamental path-integrated nature of a passive measurement, the already weak emission signature of shallow precipitation systems is further complicated by the need to discriminate precipitating and non-precipitating cloud. This leads to uncertainty in both the up-front screening of a rain/no-rain pixel(s) and the retrieved intensity. While CloudSat exhibits a much smaller FOV than these low frequency PMW channels, the discrimination of cloud and rain water is also a significant source of uncertainty in CPR rainfall retrievals. In addition, attenuation from the melting layer represents a significant source of uncertainty in rainfall retrievals rain/no-rain discrimination can be very sensitive to uncertainties in the prescribed clear-sky surface return and estimated freezing level height. Light rainfall also presents a problem to spaceborne precipitation radar technology. For example, the lightest precipitation detectable by the TRMM PR is ~0.7 mm h^{-1} (more or less independent of surface type), assuming a Z-R relationship appropriate to tropical precipitation and that the entire 4 km footprint of the PR is filled with rain (Iguchi et al., 2000). The DPR will extend this limit down to 0.2 mm h^{-1}, however, in addition to sensitivity issues, ground clutter still poses a significant problem from both the DPR and CPR viewpoints at higher latitudes, obscuring much of the liquid precipitation between the SFL and the surface.

A significant fraction of the global population resides at latitudes where a significant fraction of the fresh water originates from light precipitation that falls in SFL environments. This point is illustrated in Fig. 1, which presents the fractions of zonally averaged precipitation accumulation that falls in the form of liquid precipitation lighter than 1 mm h^{-1} and snowfall derived from the Comprehensive Ocean-Atmosphere Data Set (COADS) ship-borne meteorological observations between 1958 and 1991. This dataset provides evidence that as much as 50 % of mid-latitude precipitation and 80 % of that which falls poleward of 60° derives from precipitation events with intensities less than 2 mm h^{-1} (eg. Kidd, 2005). There is, therefore, a great motivation for improving light precipitation retrieval algorithms and resolving discrepancies between products from different sensors. Regrettably, for light precipitation over the global oceans there is scant and incomplete validation data from which to quantify how much of the rain distribution we are effectively capturing. Kidd (2005) found substantial differences in the spectrum of daily rainfall totals from various satellite algorithms, ground-based radar, and numerical weather prediction models, and found the largest discrepancies for the light-to-medium rain totals (less than 2 mm h^{-1}). Since the majority of precipitation at high latitudes is associated with spatially incoherent, shallow cloud layers producing light but persistent rainfall, detection limitations of current sensors may lead to a substantial underestimate of the rainfall and its contribution to the associated water cycle. It is, therefore, important to both characterize the abilities of current satellite precipitation sensors to detect and estimate the intensity of light precipitation events and an accurate characterization of the microphysical properties of such events upon which to base development of new algorithms for future sensors such as the DPR and GMI that will fly on the GPM core satellite.

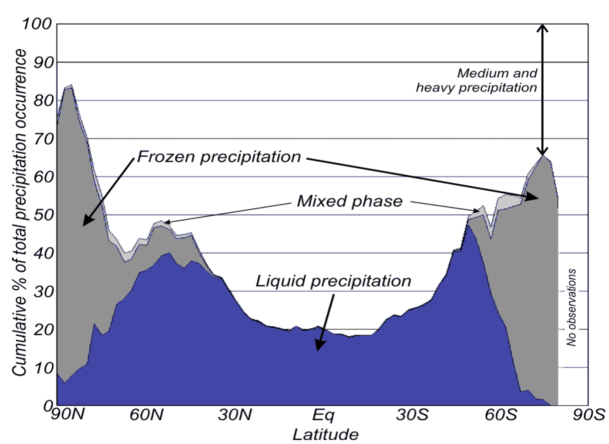

Fig. 1 Zonally averaged fraction of precipitation from 1958-1991 falling in the form of light rainfall (less than 1 mm h^{-1}) and snowfall (adapted from the analysis of COADS ship-borne meteorological observations summarized in the EGPM Report for Mission Selection, ESA SP-1279(5).

1.3 Helsinki Rainfall Climatology

The primary objectives of LPVEx are to obtain coordinated high quality in situ and remote sensing observations of SFL rainfall events in a northern latitude maritime climate. Such systems are prevalent in the Gulf of Finland in early fall. Table 1 presents a 20-year climatology of precipitation frequency in Helsinki and further reporting days when precipitation intensities exceeded 1 mm h^{-1} and observations of snowfall. Helsinki receives measurable precipitation on approximately 50% of days in September with 11 of the 16 days receiving more than 1 mm of precipitation. Furthermore, as evidenced by the reflectivity histograms shown in Figure 2, freezing levels are quite shallow, hovering near the 1 km level. A deployment to the Gulf of Finland from mid-September through mid-October therefore provides an ideal opportunity to observe several rain events with freezing levels ranging from 500 m to 2 km.

DAYS WITH PRECIPITATION												
limit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0,1 mm/day	23	19	16	14	11	13	14	15	16	18	21	23
1 mm/day	10	8	8	7	6	8	8	11	11	11	12	12
DAYS WITH SNOWFALL												
Any rate	23	20	16	9	1	0	0	0	0	3	13	22

Table 1. 20-year climatology of precipitation occurrence in Helsinki, Finland. The upper row indicates the number of days in the given month where a precipitation rate of 0.1 mm d-1 was recorded. The second row shows equivalent statistics for intensities in excess of 1 mm d-1. The average number of days each month with snowfall at any intensity is reported in the bottom row.

In addition, there are large discrepancies in rainfall estimates from co-located CloudSat and AMSR-E observations in the region. Figure 3 compares frequencies of occurrence of rainfall derived from these two platforms as a function of season from December 2006 through November 2007. Large discrepancies in the frequency of light rainfall (0-1 mm h^{-1}) are evident in both summer and fall. While it may ultimately be interesting to also understand the source of the discrepancies in summer-time precipitation estimates that may be linked to FOV-related biases, LPVEx will focus on the problem of understanding the source of differences in the shallower freezing level environments that occur in the fall for which fewer high-quality data sets currently exist. The Helsinki area has the added benefit of routine meteorological observations collected at the Finnish Meteorological Institute's (FMI) Helsinki Testbed (HTB) that provide ideal existing infrastructure upon which enhanced observing sites can be built. These measurements can be leveraged at no additional cost to the project to provide meteorological context for the results.

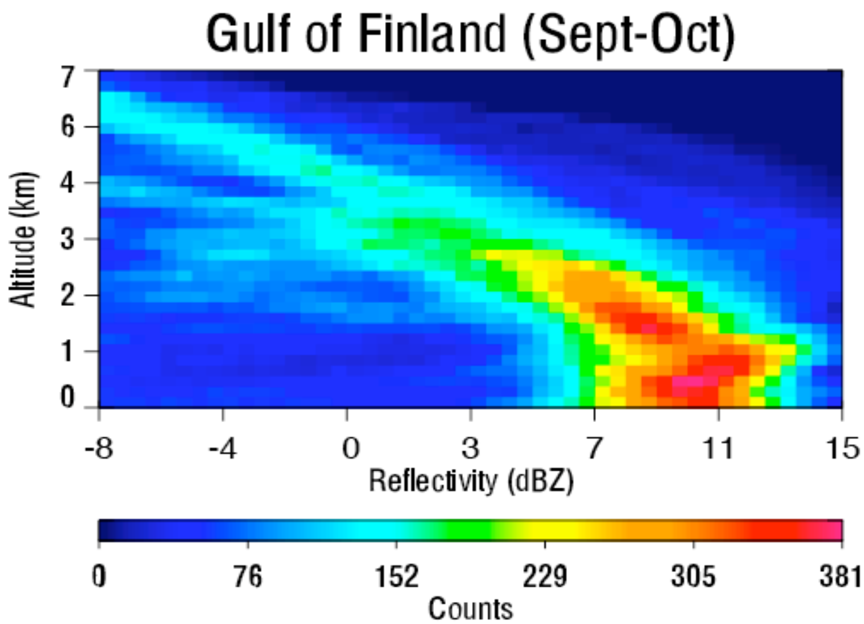

Fig. 2 Reflectivity-altitude histogram of CloudSat CPR observations in the Gulf of Finland during September and October 2007. Reflectivities in excess of 0 dBZ are indicative of precipitation. The peak at ~1 km likely corresponds to the transition from ice to liquid water indicative of the melting layer.

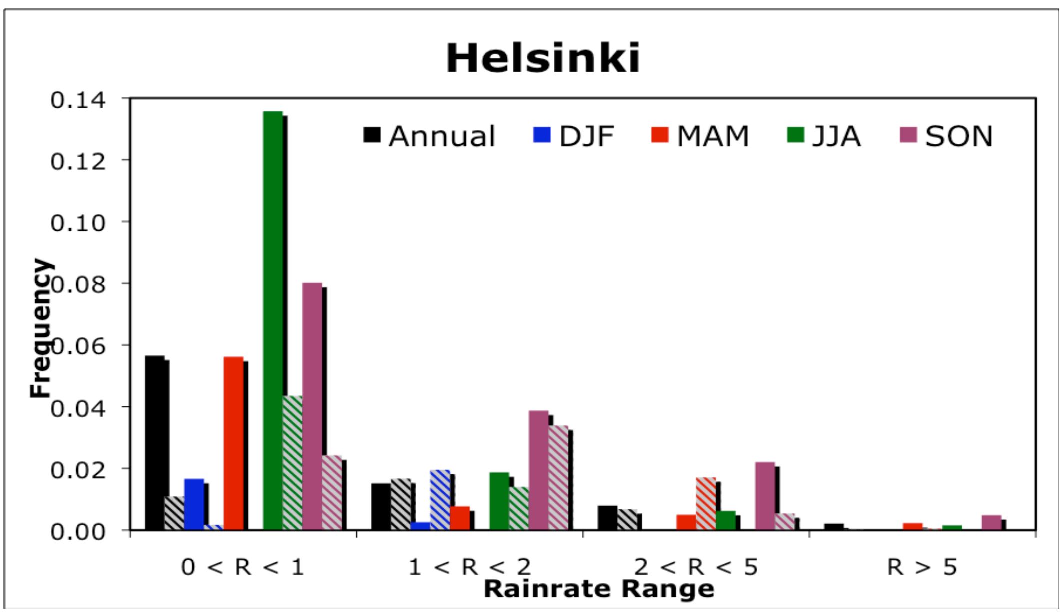

Fig. 3 Zonally averaged fraction of precipitation from 1958-1991 falling in the form of light rainfall (less than 1 mm h^{-1}) and snowfall (adapted from the analysis of COADS shipborne meteorological observations summarized in the EGPM Report for Mission Selection, ESA SP-1279(5).

2. Science Goals

The overarching goal of LPVEx is to characterize the ability of the CloudSat CPR, GPM DPR, and PMW imagers and sounders to detect light precipitation and evaluate their estimates of rainfall intensity in high-latitude environments with SFLs. In addition, LPVEx seeks to provide the rainfall algorithm development community with a database of well-calibrated measurements of the microphysical properties of high-latitude precipitation events and their associated PMW and radar signatures for future algorithm development.

2.1 CloudSat Algorithm Evaluation and Improvement

2.1.1 Detection

With a minimum detectable signal of -30 dBZ, CloudSat is, in principle, capable of detecting even the lightest drizzle. Current algorithms for detecting rainfall from CloudSat employ a hybrid approach that uses both path-integrated attenuation (PIA) and near-surface reflectivity to identify pixels containing precipitation. However, identifying rainfall with CloudSat requires that the ratio of rain and cloud water, reflectivity thresholds for drizzle occurrence, and the relationship between surface backscatter cross-section and wind speed to be assumed. Furthermore, a melting-layer model based on profiles of temperature and humidity from European Center for Medium Range Weather Forecast (ECMWF) analyses is used to discriminate rain, mixed-phase precipitation, and snow at the surface. LPVEx will provide important constraints on these assumptions by answering the following questions:

- What is the probability of rainfall at the surface as s function of W-band PIA?
- How does the relationship between clear-sky surface backscatter cross-section and surface wind speed change in the vicinity of precipitation?
- What is the probability of rainfall at the surface as a function of attenuation-corrected W-band reflectivity at 720m, the lowest CloudSat range bin for which ground clutter can be sufficiently removed?
- How do melting layer thickness and ice/liquid fraction vary as a function of local temperature and humidity profiles? And how well do temperature and humidity profiles from Numerical Weather Prediction (NWP) models constrain the melting layer allowing rain and snow to be discriminated at the surface?

2.1.2 Intensity Estimation

CloudSat rainfall intensity estimates are very sensitive to the assumed attenuation from all hydrometeors in the column, the presence of multiple-scattering and, to a lesser extent, the assumed raindrop size distribution. Specific questions include:

- What is the vertical profile of rainfall in the lowest 720 m "ground clutter" region? How do evaporation and collision/coalescence processes in this region modify the assumed shape of the rainfall profile?
- How much does cloud water below the freezing level and super-cooled water above it impact PIA?
- How much additional attenuation does the melting layer contribute?
- What is the range of observed DSD in high latitude SFL precipitation systems? What are the implications for modeling reflectivity and attenuation at W-band?
- At what rainrates do second and higher order multiple-scattering effects become important? How well can we model these with current techniques?

2.2 GPM Radiometer Algorithm Evaluation and Improvement

2.2.1 Detection

Due to their larger FOVs and strong reliance on emission from raindrops, our ability to detect rainfall using microwave imagers depends strongly on the spatial homogeneity of the rain system and the height of the freezing level. Sounders, on the other hand, provide somewhat higher spatial resolution but rely heavily on the ice scattering aloft as a proxy for surface rainfall. LPVEx will seek to quantify the ability of both imagers and sounders for detecting rainfall in shallow-freezing level environments by addressing the following:

- What are the typical correlation-scales of SFL rainfall systems and how does observed sub-pixel variability impact the detection capability of PMW imagers?
- Do these systems exhibit a strong relationship between ice scattering aloft and the presence of rainfall near the surface?
- How does SFL melting layer thickness impact the ice scattering signature and detection of the underlying liquid water content?
- Can robust relationships be established that relate rainfall probabilities to observed high and low frequency T_B signatures or as a function of retrieved parameters such as LWP and IWP?

2.2.2 Intensity Estimation

Retrieving rainfall intensity from PMW sensors further requires accurate specification of the vertical profile of cloud and liquid hydrometeors in the column, modeling the emission and scattering characteristics of the melting layer and ice aloft, and assumptions regarding the homogeneity of the rain field. LPVEx will provide information regarding each of these assumptions in the context of SFL rain systems at high latitudes:

- What is the typical vertical structure of high latitude rainfall systems in SFL environments?
- What are the emission and scattering properties of melting ice particles in the freezing level? Ice scattering aloft?
- What are the contributions of cloud water below the freezing level and super-cooled water above it to observed T_Bs over the range of sounder and imager frequencies?
- How does spatial inhomogeneity in rain intensity and freezing level height associated with frontal rainfall events impact rainfall rates from microwave imagers and sounders?
- How does the character of these precipitation systems, and, therefore, the factors that influence PMW rainfall retrievals, depend on the surrounding environment (and regime variability)?

2.3 GPM DPR Performance Characterization

The dual-frequency GPM DPR represents a significant technological advance over the TRMM PR providing, for the first time, wavelength diversity on an active satellite precipitation platform. The most important benefit of having wavelength diversity for rainfall retrievals is the significantly improved DSD information provided by differential attenuation in the measurements at each frequency. With a minimum detectable signal of 10 dBZ, the Ka-band channel also provides slightly more sensitivity than the TRMM PR. LPVEx will provide insights into to the rainfall detection characteristics of the DPR and establish uncertainty estimates in DPR rain intensity retrievals in challenging high latitude, SFL environments:

- What are the anticipated minimum detectable rainrates for the DPR given the additional sensitivity afforded by the lower MDS of the Ka-band? Can we verify our ability to measure the GPM-required lower detection threshold of 0.2 mm h^{-1} in these SFL environments?

- How does ground-clutter affect our ability to detect systems with very SFLs?
- How much improvement in DSD and rainfall accuracy can be realized by adding the Ka-band observations in high latitude/SFL environments?
- Is there enough attenuation in these shallow precipitation columns to be of significant benefit to retrievals?
- Can we quantify "typical" fractions of cloud and rainwater relative to testing their impact(s) on precipitation retrievals?

2.4 Process Studies

Analysis of high quality in situ microphysical property datasets along with associated surface precipitation measurements and temperature, humidity, and aerosol information for context will contribute to our understanding of the processes that goven the development of precipitation in high-latitude, shallow-freezing level environments. Moreover, the analysis will produce SFL microphysical databases that provide a framework from which to conduct basic instrument simulator studies for algorithm testing. Specific process questions that will be addressed include:

- What are the precipitation efficiencies of high latitude SFL systems defined in terms of the ratio of condensed water in the form of cloud liquid, raindrops, cloud ice, and precipitating ice and their relationship to surface rainfall rate?
- How does the horizontal and vertical structure of the particle (rain, mixed phase, snow) size distribution vary within the SFL environment?
- How do environmental parameters such as horizontal and vertical temperature gradients, wind shear, and ambient aerosol concentrations influence the aforementioned microphysical characteristics of these systems?

3. Experiment Strategy

These goals will be addressed through a combination of targeted observations of critical algorithm assumptions, simulation of multi-wavelength satellite observations, and synthetic retrievals based on regional cloud resolving model (CRM) simulations. The overall observing strategy centers on using surface instrumentation in conjunction with stacked aircraft flight legs at varying altitudes to provide the most complete sampling of in-cloud and surface microphysical properties possible within a region in the observational envelope provided by the C-band radar network. These observations will, in turn, be used to calibrate polarimetric C-band radar hydrometeor identification and retrieval algorithms by supplying DSD information needed to establish Z-, K_{DP}-, Z_{DR}-R relationships that can be applied over the full radar volume and also used to produce synthetic DPR reflectivites at Ka and Ku-bands. Additional assets at various other ground sites will then be used to evaluate the applicability of these relationships across the full radar volume providing a measure of the auto-correlation scale length of the assumed hydrometeor scattering properties for each rainfall event. The resulting 3D volumes will be combined with to create build a database of scenes for evaluating and developing satellite rainfall retrieval algorithms. This "algorithm laboratory" can be used to test the fundamental capabilities of current and proposed sensors for retrieving rainfall in SFL environments, quantifying the impacts of assumptions in current algorithm formulations, and exploring new retrieval techniques.

3.1 Measurement Strategy

The experiment will consist of coordinated flights within a domain covered by the three Finnish C-band radars located within 30 km of the coastal city of Helsinki (Fig. 4). Cloud and rain microphysical properties and W-band radar reflectivities in the upward, downward, and sideways pointing configurations will be measured along stacked ~100 km transects over the Gulf of Finland and adjacent land area. Where possible, flight legs will be aligned along an RHI scan axis of one of the C-band radars that intersects one of the heavily instrumented ground sites to provide a direct connection between in situ microphysics observations, surface rainfall intensities and DSDs, and multi-frequency radar observations. CloudSat's precipitation algorithms will also be assessed by adapting current level-2 algorithms to W-band reflectivity observations from the aircraft. The results will be evaluated against in situ and C-band-derived surface rainfall rates and uncertainties will be related to discrepancies between assumed cloud water content, clear-sky surface cross-section, raindrop DSD, etc. and those observed using in situ instrumentation. GPM DPR wavelengths will be produced via simulation of measured DSDs constrained by C-band reflectivities and multi-parameter variables. As there is no current airborne high altitude radiometer platform available for coincident LPVEx flights, a small number of in situ aircraft missions will also be coordinated with overpasses of NOAA satellites for direct validation of high frequency passive microwave precipitation estimates from the AMSU-B/MHS instruments. In such cases, cloud radar and in situ observations from a direct satellite underflight at the time of overpass will be supplemented with in situ sampling at multiple altitudes within a 20 km box around the satellite ground track to assess rainfall detection capabilities and relate errors to inhomogeneity within the satellite field of view and algorithm assumptions concerning the vertical distributions of ice and liquid hydrometeors.

3.2 Extrapolation to Other Wavelengths

In situ microphysics information measured both in the air and at the surface using a combination of 2D Video and Parsivel disdrometers combined with micro rain radars (MRRs) will also be used to constrain polarimetric radar microphysical property retrievals to expand the more limited in situ sampling to the full radar sampling volumes for synthetic testing of other satellite rainfall algorithms. Coincident scanning via the University of Bonn Advanced Microwave Radiometer for Rain Identification (ADMIRARI) radiometer/MRR platform will provide coincident information on cloud water contents. This approach involves careful reconstruction of the full 3D volume of cloud and precipitation hydrometeors in both liquid and ice phases using all available in situ observations and state-of-the-art polarimetric radar hydrometeor identification and retrieval algorithms. Synthetic data will be created using two different approaches. The first approach is a direct frequency mapping method (Chandrasekar et al 2006). The method uses scattering simulations to calculate mapping functions that relate radar reflectivity observations at one frequency to reflectivity values at another frequency. This approach can be further constrained by utilizing dual-polarization and multi frequency observations. The second approach is based on radar microphysical retrievals. Dual-polarization radar observations will be used to retrieve precipitation microphysical properties, i.e DSD parameters. The retrieved values will be used to calculate observations at different frequencies. Ground and aircraft based observations will be used to validate proposed algorithms.

This information will be augmented with associated temperature, humidity, and surface wind speed information from regional analyses and used as input to satellite simulators that model appropriate satellite geometry and antenna patterns to generate PMW T_Bs covering the range of frequencies from 6 - 183 GHz and Ka- and Ku-band radar reflectivities. These observations can, in turn, be used as input to rainfall retrieval algorithms of varying complexity to study both the detection characteristics and retrieval uncertainties of current and proposed satellite precipitation sensors. This approach allows all relevant algorithm assumptions to be varied over appropriate ranges observed during LPVEx to assess the impact of individual assumptions on retrieval performance.

3.3 Satellite Simulator/Cloud Resolving Modeling

To augment the observations and provide additional test cases for synthetic algorithm development, a number of modeling activities are also planned. Cloud resolving model simulations of shallow freezing-level precipitation events using both the GSFC-Weather Research and Forecasting (WRF) and CSU-Regional Atmospheric Modeling System (RAMS) models will be performed, initialized with regional atmospheric soundings from the FMI forecast model.

Provided reasonable agreement can be obtained through statistical evaluation against in situ and radar observations, analysis of these model runs may also provide additional insights into precipitation processes in an environment that is not widely studied. Application of simulators for all relevant satellite precipitation sensors to output from these simulations will then allow a database of rain scenes appropriate to shallow-freezing level environments to be constructed. Since such scenes are generally lacking in current PMW rainfall retrieval algorithms that tend to be tropics-centric, these simulations will provide a valuable tool for tailoring current rainfall retrievals for application at higher latitudes.

4. Ground Observing Network

4.1 Helsinki Testbed

Vaisala and the Finnish Meteorological Institute (FMI) have established a mesoscale weather testbed in the greater Helsinki area (Dabberdt et al, 2005). The Helsinki testbed (HTB) is open and comprehensive platform for research and development by companies, universities and research institutes worldwide. Fig. 4 provides an overview of the Helsinki Testbed observation area. Green balloons depict locations of FMI automated weather stations while circles show locations of Vaisala WXT sensors. The Helsinki Tesbed data is archived by FMI and is available from the FMI web-service http://testbed.fmi.fi. In addition to these surface observations, a sounding will be launched from the Harmaja Island site prior to each flight and LPVEx will also benefit from twice-daily soundings at Tallinn, St. Petersburg, and Joikoinen that will provide broader meteorological context for the measurements acquired during the experiment.

Radar Sites

4.2.1 Dual-Polarized C-band Doppler radars

Three C-band weather radars located within the HTB (indicated by the red pointers in Fig. 1) will be leveraged extensively during LPVEx. The University of Helsinki group operates two weather radars, Kumpula and Kerava radars, while a third is operated by FMI. LPVEx will benefit from complete control of the scanning strategies of two radars for the duration of the experiment that will enable special RHI scans to be conducted along flight legs and/or satellite ground tracks where appropriate. The third radar will carry out operational volume scans. Special scans are already being made with the Kumpula and Kerava radars at the time of CloudSat overpasses. Figure 5 shows an example of a snowfall scene observed by both CloudSat and the Kerava C-band radar on March 10, 2009. Data collected by all three radars are routinely archived at UH and additional visualization tools may be developed in collaboration with the radar group at Colorado State University to enhance capabilities for LPVEx.

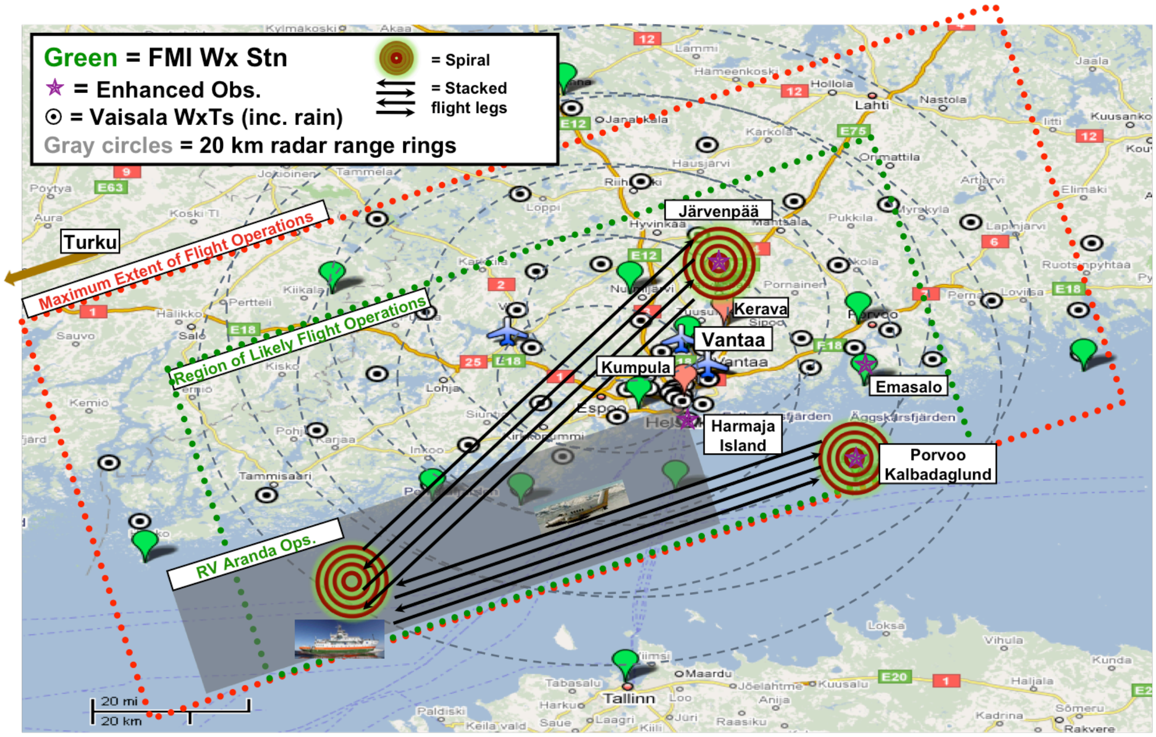

Fig. 4 Experiment layout overlaid on the locations of the HTB instrumentation. Green markers indicate the locations of FMI automated weather stations. Vaisala Weather Transmitters are indicated by the dotted-circles. Dashed circles represent 20 km range rings for the Kumpula and Kerava radars discussed in Section 4.2 while the dotted boxes represent the regions of likely and possible aircraft operations, respectively (discussed in Section 5).

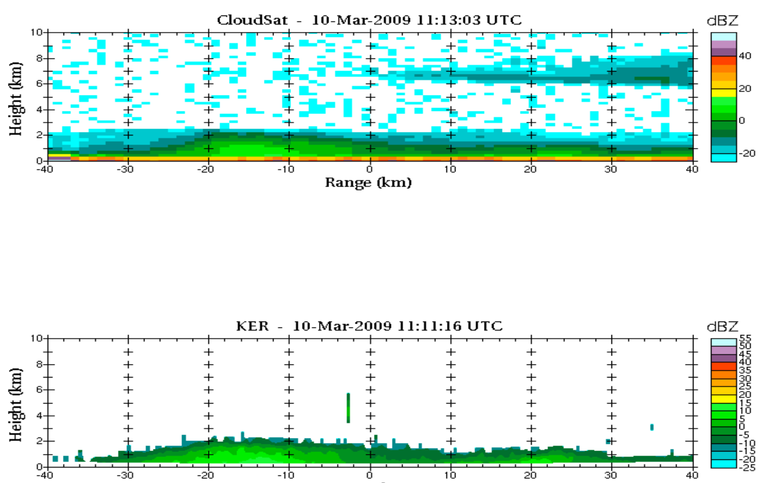

Fig. 5 CloudSat W-band and Kerava C-band radar observations of a snowfall scene in the Gulf of Finland on March 10, 2009. The Kerava observations in the lower panel were extracted along the CloudSat ground track from 3D volume scans since CloudSat does not directly fly over the Kerava radar site.

4.2.2 Järvenpää C-band Doppler Radar

The Järvenpää C-band Doppler radar is operated in vertically pointing mode for retrieval of the column DSD using Doppler power spectra. One DSD site (Sec. 4.3) will be collocated with this platform to retrieve the column DSD. The resultant DSD retrieval will serve as a constraint for the C-band dual-polarimetric radars sampling over the site.

4.2.3 Micro-Rain Radars (MRR) and Disdrometers

A total of five MRR K-band vertically pointing radars (Peters et al., 2002), three 3rd generation compact 2D Video disdrometers (Schönhuber et al., 2008), and six-eight Parsivel disdrometers (Löffler-Mang and Joss, 2000) will be available for LPVEx. At least three of the MRRs will be collocated with pairs of each disdrometer type to facilitate column particle size/concentration measurements to be made at three DSD sites (Sec. 4.3). The MRRs combined with surface disdrometer and POSS data (Sec. 4.2.4) will operate continuously through the experiment and be used to extend the measurement of the surface DSD in light rain and mixed-phase conditions to the column. When the rainfall is heavy enough (i.e., there is sufficient differential scattering behavior between H/V polarizations), data from these measurements will also act to "truth" the C-band polarimetric radar DSD estimates for extension to a broader area. At least one MRR will be installed on the RV Aranda with a collocated disdrometer for measurements to be made further from the coast over the Baltic Sea.

4.2.4 Precipitation Occurrence Sensor Systems (POSS)

Three POSS X-band bistatic DSD radars (Sheppard et al., 1990; Sheppard and Joe, 2008) will be located at each of three surface DSD sites and also operate continuously. The POSS instruments provide a DSD estimate in a small volume located just above the instrument height. They will be used with the surface disdrometers to evaluate DSD uncertainty/heterogeneity and combined with the MRR information to create column DSDs.

4.3 Enhanced Observation Sites

The performance of satellite retrieval algorithms is known to vary significantly between land, coastal, and oceanic backgrounds. In addition to the HTB network, the GPM project will establish three enhanced surface observing sites for LPVEx, representing both coastal and inland conditions. While it is not technically feasible to carry out the same level of observations at a truly oceanic site, these enhanced observation sites will be supplemented with some basic weather and precipitation observations at an oceanic site in the Gulf of Finland.

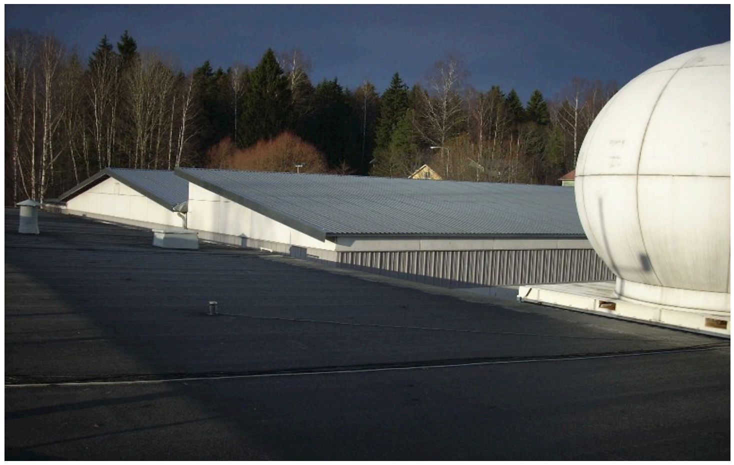

Fig. 6. Inland Järvenpää instrument site

4.3.1 Inland Site at Järvenpää

The inland site will be located at Järvenpää next to the University of Helsinki vertically pointing C-band radar (see Fig. 6). The site exists on a large relatively flat roof and is currently equipped with Joss-Waldvogel disdrometer, Cambel SR50 snow depth sensor, rain gauge, and Vaisala WXT520 weather transmitter. FMI and University of Helsinki will also install Vaisala Ceilometer CL31 for the experiment. These observational capabilities will be augmented by deploying an MRR, a 2D-video disdrometer, a Parsivel disdrometer, and a Duke University snow water equivalent sensor.

4.3.2 Coastal Site at Emäsalo

A similar combination of instruments will be deployed to Emasalo point, a coastal site 20 km east of Helsinki. The ADMIRARI radiometer will be primarily based at this site also but may be operated at Järvenpää or Harmaja pending transportation logistics.

4.3.3 Island Site at Harmaja

Pending approval by the Finnish Military, an intermediate coastal/oceanic site will be established on an island site located on Harmaja Island about 3 km south of mainland Helsinki. Disdrometers, an MRR, and rain gauges will be deployed on the roof of the Pilot facility.

Figure 7. Coastal site at Emäsalo

4.4 RV Aranda

During the experiment, one Parsivel disdrometer and one MRR will be placed on RV Aranda. LPVEx will utilize planned operations. On September 20-25, 2010 it will be carrying out drifting measurements in the Gulf of Finland between Cities of Porvoo and Hanko. This provides an excellent opportunity for carrying out precipitation measurements in maritime environment. For the remainder of the experiment, the ship will be located in a much wider area and the measurements will be used on a target of opportunity basis.

5. Aircraft Observations

During LPVEx, in situ microphysical information in both liquid and ice phases and associated W-band radar reflectivities will be acquired from an airborne platform flying coordinated legs above these ground assets. Given their experience in deploying aircrafts in similar experiments in the past the Department of Atmospheric Science at the University of Wyoming (UW) will lead the aircraft operations during LPVEx and provide technical support in the field. UW has instrumented and operated a series of research aircraft during the past 40 years beginning in the 1960s with a C-45 Twin-Beech, then upgraded to a Queen Air in 1971, and finally to the present Raytheon Beech King Air 200T (N2UW, or UWKA) acquired in 1977. This long-term activity has centered on a core group of scientists, engineers, pilots, and technicians and has flourished because the group is dedicated to the proposition that airborne research using state-of-the-art aircraft, data systems, and instruments is a worthy and stimulating intellectual activity. For the last 21 years, the UWKA has been partially supported through a cooperative agreement between UW and the National Science Foundation (NSF) with additional support for specific projects through other federal agencies including NASA, DoD, and DOE. Over a 21 year period UWKA has flown an average of 211 research hours per year, with 143 funded through NSF and all others funded through other sources.

The UWKA is ideally suited studies within the lower troposphere. Its practical ceiling is 28 kft. It is highly maneuverable, flies relatively slowly, and is certified to fly into known icing conditions. Instrument suites include basic state parameters such as temperature and humidity, a full range of cloud physics probes, flux sensing probes, aerosol and trace gas chemistry, and remote sensors that include a W-band cloud radar and a compact elastic lidar. For any given research project a typical configuration will, however, involve only a subset of these atmospheric science measurements. For LPVEx, a suite of microphysics probes will be deployed to measure hydrometeor size distributions from micron-sized cloud particles through millimeter-sized precipitation droplets an the ambient aerosol size distribution. Radar reflectivity and Doppler velocity above and below the aircraft will also be measured as well as Lidar returned power and depolarization ratio.

Considering all projects flown that the UWKA has participated in, approximately 70% have focused on cloud physics. The remaining 30% include studies of boundary layer processes (air surface exchange, aerosol studies, and/or trace gas studies) and atmospheric dynamics/turbulence. Since 2004, the UWKA has flown more than 300 research hours over the ocean investigating pollution transport over the eastern Pacific, physics of coastal stratus and strato-cu, and dynamics and physics of tropical cumuli. An additional 75 hours during that period have been flown over the Great Lakes investigating physics associated with the development of lake-effect snowstorms. LPVEx will leverage the expertise gained in these deployments to determine flight strategies that optimize in situ sampling and remote sensing in light precipitation regimes over the Gulf of Finland while maximizing sampling above ground assets.

5.1 Wyoming Cloud Radar

The Wyoming Cloud Radar (WCR) is a 95 GHz, dual-channel, Doppler radar designed for airborne use. The UW King Air installation of the WCR uses three antennas – one that can look either upward or horizontally (to the right of the aircraft) plus two downward-looking antennas (one pointing at nadir, the second slanted ~30° forward of nadir along the aircraft centerline). These antennas operate simultaneously, sampling a vertical-plane extending above and below the aircraft with a 250 m gap centered on the aircraft flight level. In addition, the use of two downward-looking antennas allows horizontal and vertical velocity components in a vertical plane below the aircraft to be retrieved. The up/side antenna can transmit and receive horizontal and vertical polarizations, while the downward-looking antennas use only a single polarization. The minimum detectible signal for the WCR is < -25 dBZ at 1 km range. Relevant WCR specifications for LPVEx are summarized in Table 2.

The proximity of the WCR observations to in situ measurements made onboard the King Air will facilitate the use of the radar measurements to provide context for the in situ cloud- and precipitation-particle measurements (that are typically limited by sample volumes on the order of 1 L s^{-1}) during LPVEx. Standard WCR data products that will be archived during LPVEx include radar reflectivity (noise removed, range correction applied), Doppler velocity (corrected for platform motion) and beam orientation (in Earth-relative coordinates) for each beam. These products will be provided in NetCDF format.

WCR for LPVex		
System Characteristics		
Configuration	3-beams: up/side (switchable) down down-slant	
Frequency	94.92 GHz	
Wavelength	3.16 mm	
Beamwidth	0.7° (up/side) 0.5° (down) 0.6° (down-slant)	
Minimum detectible signal	< -25 dBZ (@ 1km)	
Pulse-Length	250 ns (37.5m – typical)	
Unambiguous Velocity Width	31.6 m s^{-1} (maximum)	
Standard Data Products (Supplied in NetCDF format)	Units	
Reflectivity	$mm^6\,m^{-1}$	Noise subtracted, Range correction applied, No attenuation correction
Noise power (mean and standard deviation)	$mm^6\,m^{-1}$	Expressed as reflectivity equivalent at 1 km
Doppler Velocity (mean)	m s^{-1}	Platform motion correction applied
Beam Orientation		Direction cosines for each

beam in ground-relative coordinates

Table 2 Wyoming Cloud Radar (WCR) specifications for deployment during LPVEx and associated standard data products.

5.2 Cloud Microphysics And Aerosol Properties

To provide the microphysics observations central to the LPVEx objectives, the UWKA will also be outfitted with probes capable of spanning the full range of particle sizes in both liquid and ice phases. Cloud droplet spectra will be collected using Particle Measuring Systems (PMS) Forward Scattering Spectrometer Probe (FSSP) and Cloud Droplet Probe (CDP) that measure cloud droplets concentrations from 1 to 31 μm and 2 to 50 μm, respectively. PMS two-dimensional cloud (2DC) and precipitation (2DP) probes will be used to measure the distribution of drizzle and precipitation droplets over ranges from 25-6500 μm and 100-9000 μm, respectively. These probes also supply information regarding the size distribution of large ice particles while the 15 μm version of the Clouds, Aerosol and Precipitation Spectrometer (CAPS) Cloud Imaging Probe (CIP) will sample smaller ice particles. Liquid water content measurements will be obtained using a combination of Droplet Measurement Technology (DMT) model LWC-100 and Gerber PVM-100A probes while a Nevzorov probe supplied by EC will provide measurements to constrain ice and total water content. A Rosemount 871FA icing detector will supply an additional indication of the presence of super-cooled liquid. The linear response of the Rosemount detector to LWC when temperatures are lower than 4°C without sensitivity to ice particles makes the instrument an ideal choice for detecting the presence of super-cooled water (Cober et al. 2001). Finally limited information concerning aerosol size distribution from 0.2-3 μm and cloud condensation nuclei (CCN) concentrations will be provided by the DMT Passive Cavity Aerosol Spectrometer Probe (PCASP-100X) and University of Wyoming CCN Counter (CCNC-100A) probes, respectively.

5.3 Flight Plans

During LPVEx, the UWKA will be based in Turku, Finland approximately 150 km to the west of Helsinki. A majority of the flight operations during LPVEx will be confined to the ~100x150 km box defined by the green box in Figure 4 to maximize data collection along RHI scan planes of the Kumpula and Kerava C-band radars. One or more flights may, however, sample the broader region indicated by the red box, as dictated by the location of interesting weather, especially on days when AMSU-B is underflown. At the request of the Finnish Aviation Authority, flight operations will be restricted to a selection of one or more pre-determined flight plans that will be agreed upon several months in advance of the experiment. This selection of flight plans will cover all desired modes of aircraft sampling and will be chosen to maximize flexibility to adapt to given weather conditions and avoid potential air traffic restrictions. The following options will be available:

- ferry from Turku Airport to either the inland observing site at Järvenpää (indicated by a ✯) or a point in the Gulf of Finland in the western portion of the sampling area taking aerosol and or microphysics measurements while in transit;
- optional spiral descents between 12000 ft and 1000 ft over Harmaja, Emasalo, and Järvenpää to calibrate aircraft and ground microphysical observations in the "sweet spot" of the 2 C-band weather radars;
- stacked ~60 km flight legs along radials from the Kumpula and Kerava radars. Those along Kerava radials will cover three headings to the north of the radar allowing for potential air traffic restrictions from Vantaa Airport. Those from Kumpula will cover

three headings to the south providing sampling over the Gulf of Finland. In each case two distinct sets of altitude options will be available spanning four heights that will be chosen depending on the vertical characteristics of the precipitation being sampled (i.e. cloud top, cloud base, freezing level height);

- similar stacked legs over the Gulf of Finland in an approximately east-west direction designed to sample above both the RV Aranda and the lighthouse observing site. Multiple options will be available to avoid potential conflicts due to military operations in the area.

A typical day of operations will consist of one set of east-west flight legs over the Gulf of Finland, spirals over one or two of the heavily instrumented ground sites, and one set of radial flight legs coordinated with RHI scans from one of the C-band radars. The specific options chosen will depend on weather conditions and must be approved by the local aviation authority prior to takeoff. No flight legs will cross into either Estonian or Russian airspace. Finally, where possible, available flight paths will be further coordinated with additional ground instrumentation such as raingauges and disdrometers in the Helsinki Testbed observing network. In the event a NOAA-16 satellite overpass is targeted, the flight plan will be chosen to maximize stacked flight legs within the satellite swath.

5.4 Coordination

There will be two bases of operation for LPVEx. The central forecasting and data processing site will be located at the University of Helsinki/Finnish Meteorological Institute in Helsinki. This site will provide a majority of the ground operations for the experiment including local meteorological support, ground-based instrument support, and C-band radar control. A second, smaller office will be set up in Turku to support aircraft operations, aircraft instrumentation, and house flight scientists and the UWKA crew. These two sites will be closely coordinated through daily telephone briefings and online data exchange. The typical flight planning schedule will begin with a general afternoon briefing to review the previous day's flight operations (if any) and make an initial decision regarding flights the following day based on local forecast support. Initial flight tracks and radar scanning strategies will be chosen and necessary preparations made in Turku for a flight the following day. The next morning a second briefing will be held a minimum of 3-4 hours prior to the proposed start of flight operations and a final decision on whether or not to fly will be made based on current weather conditions and BALTic RADar (BALTRAD) network observations. A final flight plan will then be constructed including desired flight tracks and approximate times that will be submitted to local air traffic control for approval. Once approved, the flight will proceed according to the proposed schedule with minimal deviations. Aircraft-ground communications will be conducted between the in-flight scientist and a chief ground scientist via VHF radio to coordinate radar scans according to the aircraft location, etc. A post-flight briefing will be conducted after each flight to document all aspects of the flight including the weather sampled, the flight patterns executed, and the status of all ground-based and aircraft observations, especially noting any anomalies. This information and quick-look images from the WCR and C-band radars will be made available through the LPVEx website within 24 hours of each flight (see Appendix A).

6. Modeling Support

Modeling activities are an important component of LPVEx both for placing findings into a broader meteorological context and to improve our understanding of the relevant microphysical processes for rainfall development in high latitude, SFL environments. Toward these ends, LPVEx will leverage large-scale temperature, humidity, winds, and precipitation forecasts from the FMI HIRLAM and AROME models both during the experiment for flight planning purposes and for subsequent analysis of the results. In addition, these datasets will be used to initialize finer-scale CRM simulations of several events sampled during the experiment to (a) test the ability of these models to represent this type of precipitation system and (b) provide a deeper understanding of the underlying dynamic, thermodynamic, and microphysical processes. LPVEx will leverage simulations from both the GSFC-WRF and CSU-RAMS models for these purposes to provide model diversity necessary to study the impacts of different microphysics schemes on the results.

7. Ancillary Satellite Datasets

To augment ground-based and aircraft observations collected during LPVEx, routine subsets of several satellite products will be made over the Gulf of Finland and surrounding areas. Several co-located products from the A-Train will be collected including reflectivity, cloud property profiles, rainfall and snowfall estimates from CloudSat, the Moderate Resolution Imaging Spectroradiometer (MODIS) cloud and aerosol products, the Advanced Microwave Scanning Radiometer-E (AMSR-E) brightness temperatures, cloud liquid water content, rainfall, sea surface temperature, and precipitable water products, and longwave and shortwave radiative fluxes from the Clouds and Earth's Radiant Energy System (CERES) instrument. In addition, the AMSU-B and MHS brightness temperatures, and precipitation products will be collected from all NOAA-16, 17, 18, and 19 overpasses of the region. These data will be made available through the LPVEx website to provide additional context for the local measurements acquired during the experiment.

8. Summary

The LPVEx will be conducted over the Gulf of Finland and Helsinki region from mid September to late October 2010. The experiment is designed to identify the source of variability (spread) in current satellite estimates of rainfall occurring in low-altitude melting layer environments. LPVEx will address topics related to satellite algorithm validation including assessment of minimum detectable rain rates, discrimination of rain and falling snow, microphysical assumptions in the algorithms, spatial heterogeneity of precipitation and its relationship to the aforementioned topics.

To address the above objectives a cross-validated 3-D characterization of precipitation processes in the light rain, low melting-level environment of the Helsinki region will be created. Accordingly, three locations along the Gulf of Finland in the Baltic Sea (Emäsalo, Harmaja, Järvenpää) will be heavily instrumented with collocated disdrometers, rain gauges, precipitation occurrence sensor systems, and micro rain radars. In addition, one site will host the ADMIRARI scanning radiometer and another site (Järvenpää) will host a vertically-pointing C-band Doppler radar. One research vessel (R/V Aranda) will also be instrumented with a disdrometer and MRR to make measurements of precipitation over the Baltic Sea. All of the instrumented sites will be sampled by a network of three C-band dual-polarimetric radars, and the University of Wyoming King Air microphysics aircraft. The King Air will carry a full suite of microphysics probes and a dual-polarimetric W-band cloud radar.

Collectively the measurements will be coordinated to provide a data base of precipitation type and size distribution from the ground through the depth of the cloud, including the melting layer. These observations will be quality assured and prepared for use in forward radiative transfer models designed to simulate radiometer frequencies spanning the 10 – 183 GHz range, and radar reflectivities at W (CloudSat) and Ka-Ku bands (GPM DPR). The LPVEx data set will provide the means to conduct sensitivity studies to assess cold-latitude light-rainfall regime microphysical impacts on the fidelity of satellite retrieval algorithms.

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Appendix A: Data Access

All data collected during LPVEx as well as ancillary satellite, NWP, and CRM datasets will be accessible through the experiment website at http://lpvex.atmos.colostate.edu/lpvex. This website will provide a running log of all precipitation events sampled during the experiment and provide tools for searching and downloading the corresponding ground, aircraft, ship, and satellite datasets. Many of the LPVEx datasets will be collected and archived centrally at Colorado State University and will be directly accessible through the LPVEx website. The site will also serve as a portal to larger or more complex datasets that may be stored elsewhere. Every effort will be made to ensure that individual instrument PIs provide quality controlled datasets to the central archive within one year of their collection. All data will be made freely available to the science community but instrument PIs retain the right to appear as co-author on any publications that make use of them.

NASA policies maintain an open data policy for datasets collected using NASA instruments and/or instruments funded under NASA contracts. These datasets will be made publicly available on the GPM Ground Validation web-site to (or links to relevant datasets) once the data have been quality controlled (typically within 6-months of the end of the experiment). Note that this policy only applies to NASA supported datasets.

Appendix B: Instruments and Contacts

Instrument	Qty	Purpose	Provider	Comments
GROUND				**Järvenpää (land), Emäsalo (peninsula)**
C-band Dual Pol. Radar (scanning)	3	4-D Precipitation and Ka-Ku simulation (microphysics)	UH/Vaisala/FMI Kumpula/Kerava (Dmitri) Vantaa (Jarkko)	HTB; multi-doppler kinematics also possible
C-band Doppler (vertically pointing)	1	Precip. Profiling (DSD and melting layer)	UH (Dmitri)	HTB; spectra measured
UHF Wind Profiler	1	Precip. Profiling (DSD and melting layer)	Vaisala (HTB?)	Uncertain about location and availability HTB (Spectra possible?)
2DVD	1-2	DSD/Radar Calibration	GPM	3rd Gen. 2DVD ; at least 1, potentially 2
Parsivel Disdrometers	6-10	DSD/precip. Rate	GPM	At least 6
Joss-Waldvogel	1	DSD/precip. rate	UH	
Ka-band Radar	?	DSD/Precip/Cloud	?	NEED TO IDENTIFY
Snow LWE probes	5	SWE/rate on/at ground	GPM (Duke U.)	PI Ana Barros
ADMIRARI Radiometer/MRR	1	Combined cloud and rainwater retrievals	U. Bonn(?)/U. Leicester	PI A. Battaglia
MRR	?	DSD profiling, precip rate, melting layer	U. Birmingham	C. Kidd PI
Vaisala WXT 520	>10	Precip rate at ground	FMI	HTB
Weighing gauges	6	Precip rate	FMI	HTB
Automatic Sounding System	1	T/P/RH profiles	Vaisala	Located at Vaisala HQ
Transportable sounding station Vaisala MARWIN MW12	1	T/P/RH profiles	UH	Expendables Vaisala
Twice-daily Soundings	3	T/P/RH profiles at Tallinn, St. Petersburg, and Jokioinen	University of Wyoming webpage http://weather.uwyo.edu/upper air/sounding.html	Otherwise data should be available from FMI
POSS	2?		Environment Canada?	Hudak?
SMEAR Aerosol/flux Tower	1	T/RH/CO2, sensible heat, wind, radiation, aerosol size distribution/compositio n	University of Helsinki	
Ceilometers	6	Cloud base height	FMI	
Aircraft				**40 flight hours**
UW King Air				
FSSP	1	Cloud water/ice	CloudSat/GPM	
DMT and King Hot wire	2	Cloud liquid water	CloudSat/GPM	
Gerber	1	Liquid water	CloudSat/GPM	
2DC	1	Particle size distribution and type	CloudSat/GPM	Cloud-small precip

		(0.1 – 0.8 mm)		
2DP	1	Particle size distribution (0.2 -6.4 mm)	CloudSat/GPM	Small-precip to large precip
CIP	2	Cloud particle imager (0.15-1.5 mm)	Environment Canada/Andy H.	15 micron version
CDP	1	Cloud droplet spectra (2 – 50 m)	CloudSat/GPM	
Nevzorov	1	Liquid and Total water content	Environment Canada	
PCASP-100X	1	Aerosol size distribution (0.2-3 um)	Wyoming	Space permitting
UWYO CCNC-100A	1	CCN concentration	Wyoming	Space permitting
W-band Cloud Radar	1	Cloud profiling		
Ship				
FIMR RV Aranda	**1**		**FMI**	20-25.9.2010
Weather Mast (T, RH, P, Winds)	1	Surface WX		
Vaisala Digicora Sounding System	1	Atmospheric Sounding		Expendables Vaisala
ADCP/CTD etc. (oceanic)	1	Ocean		Will also request skin temperature
Parsivel	1	DSD/precip. rate		Mount on mast
MRR	1	DSD/precip. rate/melting layer		Mount on deck
Satellite			**CloudSat**	**To be archived for HTB area throughout experiment**
CloudSat	1	W-band reflectivity, Cloud geometric profile, LWC/IWC profile, precipitation type/rate		CloudSat Data Processing Center?
MODIS	1	IR TBs, visible TBs, cloud mask, LWP, IWP, effective radius		CloudSat Data Processing Center?
AMSR-E	1	Polarized TBs (6.9-89 GHz), SST, CWV, LWP, rain rate		CloudSat Data Processing Center?
AMSU-B	1	TBs (89-183 GHz), rain/snow incidence, rain rate		CloudSat Data Processing Center?
Model Analysis			**FMI/GPM/CloudSat**	
FMI Regional	1	FMI Regional	FMI	Distributed Atmosphere
CRM/SSM	1	GSFC WRF	GPM	GSFC Group/SSM
CRM	1	CSU-RAMS	CloudSat	CloudSat