Annual Progress Report

Objective Assessment of ACE Dual-frequency Doppler Radar Instrument Requirements for Extra-Tropical Precipitation Measurement

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1. Project Statement

This project seeks to establish quantitative criteria for mapping requirements for the Aerosol-Cloud-Ecosystems (ACE) dual-frequency Doppler radar onto the set of ACE scientific objectives related to understanding the factors that govern the global characteristics of precipitation-producing clouds. This study applies a combination of sensitivity studies and objective information content metrics to establish robust criteria for defining ACE radar requirements based on the required accuracy of extra-tropical and high latitude precipitation retrievals and associated latent heating estimates.

2. First year accomplishments

The first year of research focused on several fronts: 1) completing the cloud resolving model simulations (CRM) needed to build the database of hydrometeor profiles, 2) updating the QuickBeam radar simulator to provide dual-frequency Doppler capabilities with updated snow particle scattering properties, 3) assessing the quality of latent heating rates retrieved from W-band reflectivity profiles via a Bayesian algorithm, and 4) initial testing of radar detection threshold constraints applied to snow observations. Progress was achieved in each of these areas and is summarized below.

2. a CRM simulations for database generation

Three targeted simulations for higher-latitude precipitation were completed using the Colorado State University - Regional Atmospheric Modeling System (RAMS, Saleeby and van den

Heever, 2013). These targeted simulations encompassed widespread synoptic snowfall, lake-effect snowfall, and snow transitioning to rain at a shallow melting level. In addition, a simulation was completed for an event recognized as one of the GCPEx "golden days", the event consisting of synoptic snow associated with a midlatitude cyclone followed by lake effect snow.

Further, these targeted simulations have been supplemented with simulations obtained via cooperative work with Prof. Sue van den Heever's cloud process research group at Colorado State University. The simulations, provided by Steve Saleeby, include winter orographic snowfall from the Colorado Front Range, convective precipitation from a mesoscale convective system over Oklahoma, and a simulation of shallow stratocumulus associated with the Atlantic Tradewind Experiment (ATEX).

C3VP Synoptic

This simulation represents a synoptic event with moderate snowfall observed on 22 January 2007 during the Canadian CloudSat CALIPSO Validation Project (C3VP) in southeastern Ontario. A prior simulation was updated to use the most current version of the Regional Atmospheric Modeling System (RAMS), which incorporates significant enhancements to microphysical parameterizations and enables output in the HDF5 format. As part of the update, the simulation was initiated with a starting time 2.5 days earlier than the prior simulation in order to capture a period of lake effect snow which preceeded the synoptic event. The updated simulation has been evaluated and is in reasonable agreement with upper air and surface observations.

GCPEx "golden case" Synoptic + Lake Effect

This simulation captures a southeastern Ontario synoptic snowfall event associated with a low pressure system followed by lake effect snowfall as the near-surface flow shifted to be northwesterly and picked up moisture from Georgian Bay. For the combined synoptic and lake effect periods, measured snowfall amounts at the main GCPEx ground site were 20.4 mm snow water equivalent (SWE), with rates as high as 5 mm liquid equivalent per hour (Hudak et al., 2012). For the simulation, maximum snowfall accumulations on the grid collocated with the GCPEx ground site reached almost 13 mm, while maximum precipitation rates reached 5 mm liquid equivalent per hour, consistent with the observed rates.

GCPEx Lake Effect and LPVEx Light Rain

The GCPEx lake effect case was recently completed and is being evaluated. The LPVEx light rain case will be completed in year 2.

2.b Radar simulator

A version of the QuickBeam radar simulator (Haynes et al., 2007) tailored to work with RAMS model output was obtained from Dr. Wes Berg of Colorado State University, and a number of improvements were made to facilitate using enhanced scattering properties and calculating Doppler moments. The particular modifications were to:

- replace code specific to the Intel Fortran compiler with standards-compliant language to allow use with open-source compilers,
- add routines required to read parameters for and calculate particle fallspeeds,
- modify the radar forward model to include fallspeed inputs and Doppler moment outputs,
- begin modifications to the Mie data table code to allow the use of discrete dipole approximation (DDA) scattering properties at multiple wavelengths,
- and converted the original binary output to standard HDF5 output.

DDA modeling of Ka-band scattering properties was also completed for a range of particle shapes designed to emulate pristine and aggregate snow particles. These particle shapes are used in the CloudSat 2C-SNOW-PROFILE product (Wood et al., 2013), along with previously-calculated W-band scattering properties, to retrieve snowfall rates from CloudSat Cloud Profiling Radar observations. Work currently in progess with QuickBeam includes enabling it to use these Ka- and W-band DDA scattering properties and completing the Doppler moment calculations code.

When significant precipitation is present, multiple scattering can significantly influence radar reflectivity observations. QuickBeam is a single-scattering code, unable to simulate the effects of multiple scattering. We've initiated a discussion with Simone Tanelli of the NASA Jet Propulsion Laboratory on evaluating our QuickBeam results against a multiple scattering Doppler radar simulator (part of the NASA Earth Observing System Simulator Suite , NEOS[3]) for select cases to evaluate the impact of QuickBeam's single scattering assumption.

2.c Latent heating rate retrieval

Assessing the impacts of radar characteristics on estimates of latent heating is a critical aspect of the research. Toward this end, an algorithm has been developed for retrieving latent heating and other cloud properties from features of radar reflectivity profiles. When applied to simulated radar observations from the cloud resolving model dataset, the retrieval algorithm will provide insight into the changes in information content and latent heating rate accuracy that occur with changes in the assumed radar configuration.

The algorithm is built using a Bayesian framework following Kummerow and Giglio (1994). Characteristics of the input reflectivity profile are ingested into the algorithm, including cloud top height, precipitation top height, maximum reflectivity, and path integrated reflectivity. The algorithm then provides a retrieved vertical latent heating profile, rain rate, and liquid water path with associated uncertainties. The relationship between the reflectivity profile characteristics and the algorithm outputs is defined in a database of cloud resolving model profiles and related simulated W-band reflectivity observations.

Initial results have shown that the accuracy and certainty of the algorithm is dependent upon properties of the input reflectivity profile, namely instrument spatial resolutions and sensitivity. Information content metrics are being used to quantitatively assess the impact of these properties on the retrieval. Database profiles of reflectivity and respective latent heating are downscaled to represent decreased instrument resolutions. Instrument sensitivity effects are implemented by altering the error estimate associated with an observation when calculating the posterior probabilities.

At present the algorithm uses a database of warm rain simulations from RAMS. Simulations were initialized from Atlantic Tradewind Experiment (ATEX) data and use a 100 x 100 x 4 km domain with 250 m horizontal and 100 m vertical resolutions (Stevens et al., 2001) as well as two moment microphysics. The database uses multiple simulations with SST varying from 293 K to 303 K and CCN concentrations varying from 100 per cc to 800 per cc. Sea surface temperature provides a proxy for local thermodynamic stability which, when coupled with varied CCN concentrations, provides simulations of a range of precipitation types and captures variability associated with the real atmosphere (van den Heever et al., 2006). Synthetic W-band reflectivities are related to the RAMS latent heating profiles using QuickBeam (Haynes et al., 2007).

2.d Simple radar detection threshold constraints

Examining the tradeoff between radar operating parameters, spatial resolution, sensitivity and detection is a key component of the investigation. When completed, the cloud resolving model database will allow us to assess how the sensitivity of various anticipated radar configurations influences detection of precipitation and resultant impacts on estimates of accumulation.

In the interim, existing recently-developed retrieval products provide some capability to make similar analyses. The CloudSat 2C-SNOW-PROFILE product estimates instantaneous snowfall rates for W-band radar observations from the CloudSat Cloud Profiling Radar. By applying appropriate thresholds to simulate the effects of reduced radar sensitivity, the effects of sensitivity on detection and accumulation of snowfall can be estimated.

Such an analysis was completed for the CloudSat record from July, 2006 to April, 2011 (CloudSat epochs 01 through 04). By gridding the CloudSat snowfall estimates (a 2x2 degree lat/lon grid was used), treating each CloudSat pass through a gridbox as a spatial sample, and treating the mean of each spatial sample as a sample of the time series of precipitation rates occurring within the grid box, accumulations could be estimated. Under cold conditions, the 2C-SNOW-PROFILE algorithm performs snowfall retrievals when the near-surface reflectivity, adjusted for attenuation, exceeds -15 dBZe. In the analysis, the radar was assumed to have a minimum detectable signal (MDS) of -10, -5, 0, 5, or 10 dBZe. Retrieved snowfall rates were set to zero when the near-surface reflectivity fell below the MDS.

Preliminary results show that the effects of reduced sensitivity can be substantial, particularly in regions dominated by light snow such as Antarctica. At 0 dBZe MDS, the globally-averaged accumulation is biased low by almost 10% compared to the 2C-SNOW-PROFILE standard product, but accumulations in East Antarctica are underestimated by 70% to 90%. The results underline the importance of adequate radar sensitivity, particularly for the study of higher latitude regions thought to be strongly sensitive to climate change.

3. Work plan for year 2

Work for year 2 will focus on the formal information content analyses required to construct the ACE radar trade space. Specific activities will include:

- A light rain case will be simulated and added to the CRM database. This particular case coincided with the LPVEx field experiment and will be evaluated against available in situ and remote sensing observations. The setup for the simulation is done and will proceed as computer resources are available.
- As noted above, QuickBeam will have the Ka- and W-band scattering properties added along with the ability to simulate Doppler spectra features.
- QuickBeam will be applied to the CRM database to simulate profiles of Ka- and W-band reflectivities, along with Doppler properties. Using a range of instrument performance specifications appropriate for the ACE radar, simple detection threshold constraints will be applied and Shannon information content diagnostics will be determined, then used to relate expected retrieval performance to instrument performance specifications.
- Continuing support for RADEX planning and execution as needed.
- The PI will serve as Mission Scientist representing ACE objectives in the upcoming IPHEx field campaign.
- Further develop the latent heating retrieval to extend applicability globally. RAMS simulations of higher-latitude mixed phase precipitation regimes, such as extratropical cyclones and mesoscale convective systems will be added to the database to extend the algorithm's coverage. Ka-band reflectivities and Doppler velocity measurements will be included in the algorithm inputs. This will support testing of ACE instrument configurations and the assessment of information content metrics which will be used to determined the instrument accuracies and resolutions that provide required retrieval performance.

4. References

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