Comparing Aircraft Observations of Snowfall to Forecasts Using Single or Two Moment Bulk Water Microphysics Schemes

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High resolution weather forecast models with explicit prediction of hydrometeor type, size distribution, and fall speed may be useful in the development of precipitation retrievals, by providing representative characteristics of frozen hydrometeors. Several single or double-moment microphysics schemes are currently available within the Weather Research and Forecasting (WRF) model, allowing for the prediction of up to three ice species. Each scheme incorporates different assumptions regarding the characteristics of their ice classes, particularly in terms of size distribution, density, and fall speed. In addition to the prediction of hydrometeor content, these schemes must accurately represent the vertical profile of water vapor to account for possible attenuation, along with the size distribution, density, and shape characteristics of ice crystals that are relevant to microwave scattering.

An evaluation of a particular scheme requires the availability of field campaign measurements. The Canadian CloudSat/CALIPSO Validation Project (C3VP) obtained measurements of ice crystal shapes, size distributions, fall speeds, and precipitation during several intensive observation periods. In this study, C3VP observations obtained during the 22 January 2007 synoptic-scale snowfall event are compared against WRF model output, based upon forecasts using four single-moment and two double-moment schemes available as of version 3.1. Schemes are compared against aircraft observations by examining differences in size distribution, density, and content. In addition to direct measurements from aircraft probes, simulated precipitation can also be converted to equivalent, remotely sensed characteristics through the use of the NASA Goddard Satellite Data Simulator Unit. Outputs from high resolution forecasts are compared against radar and satellite observations emphasizing differences in assumed crystal shape and size distribution characteristics.
Comparing Aircraft Observations of Snowfall to Forecasts Using Single or Two-Moment Bulk Water Microphysics Schemes

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Abstract

The snowfall event was simulated with the WRF model, version 3.1.1, using six different single- or double-moment microphysics schemes. Forecasts use a topographically nested grid configuration (5-3.1 km) with forcing provided by GPS analyses, and other parameters retrieved within 50 km. Aircraft data were separated into two vertical profiles: a descending spiral near the radar site, and a second vertical profile. Measured particle sizes and quantities were used to estimate moments and use distribution characteristic to compare model assumptions. As the 0600 UTC model output period was selected because observed precipitation rates were nearly steady, the radar indicated wide coverage of moderate precipitation, and each forecast produced a reasonable depiction of precipitation intensity and coverage during this period. WRF model vertical profiles were extracted within 50 km of the King City radar and compared to compare model conditions along the aircraft spiral and aircraft aerosol profile data.

Introduction

High-resolution forecast models are developing double-moment microphysics schemes to simulate the evolution and precipitation of various hydrometeors. Model output can be used to generate representative cloud and precipitation products for use within satellite simulations, assisting in the development of precipitation and cloud property retrievals.

This document includes the development of Canadian CloudSat/CALIPSO/PSD Validation Project (CVP) used to evaluate assumptions from single- and double-moment models within the available in the Weather Research and Forecasting (WRF) Model as of version 3.1.1. CVP intensive observation periods included observations from dual-polarimetric radar, the CloudSat radar, aircraft, and surface instrumentation.

Results here are presented from observations acquired during a widespread, synoptic-scale snowfall event on 21 January 2007 (Figure 1).

Figure 1. Observations available during the CVP intensive observation period on 21 January 2007, overlaid upon horizontally polarized radar reflectivity at 0.8 km, acquired from the dual-polarimetric, C-band radar at King City, Oregon.

Methodology

Snowfall event was simulated with the WRF model, version 3.1.1, using six different single- or double-moment microphysics schemes. Forecasts use a topographically nested grid configuration (5-3.1 km) with forcing provided by GPS analyses, and other parameters retrieved within 50 km. Aircraft data were separated into two vertical profiles: a descending spiral near the radar site, and a second vertical profile. Measured particle sizes and quantities were used to estimate moments and use distribution characteristic to compare model assumptions. As the 0600 UTC model output period was selected because observed precipitation rates were nearly steady, the radar indicated wide coverage of moderate precipitation, and each forecast produced a reasonable depiction of precipitation intensity and coverage during this period. WRF model vertical profiles were extracted within 50 km of the King City radar and compared to compare model conditions along the aircraft spiral and aircraft aerosol profile data.

Snow Characteristics in Selected Microphysics Schemes

- Snowfall event
- High-resolution forecast models
- Double-moment microphysics schemes
- WRF model, version 3.1.1
- Six different single- or double-moment microphysics schemes
- Forecasts used a topographically nested grid configuration (5-3.1 km)
- Forcing provided by GPS analyses
- Other parameters retrieved within 50 km
- Aircraft data separated into two vertical profiles
- Descending spiral near the radar site
- Second vertical profile
- Measured particle sizes and quantities used to estimate moments
- Use distribution characteristic to compare model assumptions
- Selected for observed precipitation rates nearly steady, wide coverage of moderate precipitation
- Each forecast produced a reasonable depiction of precipitation intensity and coverage during this period
- WRF model vertical profiles extracted within 50 km of the King City radar
- Compared model conditions along the aircraft spiral and aircraft aerosol profile data

Hydrometeor Profiles

- Ice water content retrieved onboard the aircraft via a counterflow virtual impactor (CIV; Tepley et al. 1999). Although liquid water measurements were also available, no appreciable liquid water content was reported (Figure 2).
- Conditional mean profiles of hydrometeor content were produced from WRF model profiles within 50 km of the King City radar.

- All schemes generally reproduced the aircraft vertical profiles of ice water content, although some place greater emphasis on small cloud ice crystals.

- The dominance of the snow category is supported by CIVP and radar observations of ice crystals and aggregates throughout the vertical column.

Size Distribution Parameters

- Aircraft measurements included imaging probes with crystal imagery used to construct particle size distributions (PSDs) binned by maximum diameter.
- Although the Thompson scheme uses a very specific PSD, remaining schemes use a generalized gamma distribution (3), with dispersion factor set to zero, resulting in an exponential size distribution.

- Exponential size distributions were fit to each of the five second aircraft PSDs with parameters estimated if the resulting best-fit distribution was well fit to observations (Figure 4). Figure 5. Comparison of various PSD moments estimated from aircraft data versus mean moments acquired from model simulated profiles.

Terminal Velocities

- Terminal velocity and diameter relationships combine with WRF simulated mass content to determine precipitation against scene assumptions.

- Surface observations of fall speeds were used to compare with the Hydrometeor Velocity and Shape Detector (HVSDD, Bitner et al. 2006) at the CARE site, northwest of the King City radar.

- HVSDD data were binned by particle maximum dimension, then combined in a joint histogram by size and fall speed increments of 5 cr.1.

- Observations and fits limited to particles 2 mm or greater.

A power-law fit was acquired for CIVP observations and compared to simulated fundamental functions using each scheme (Figure 6).

Implications for Simulating Remote Sensors

- Satellite simulators have been developed, generating forcing for remote sensors from high resolution forecast model output (Mahrt et al. 2006).
- Model simulated profiles of hydrometeor content and remotely sensed quantities may facilitate the development of satellite-based retrievals.
- One challenge in this process is the representation of varying by complex ice crystal shapes.
- Molthan et al. 2012 simulated CloudSat 94 GHz radar reflectivity, from various non-spherical shapes and demonstrated a better fit than Mie spheres.

- To avoid mismatched assumptions, the mass-diameter relationship within the forecast model should match the characteristics of simulated crystals, such as those described by Liu (2008) and alternatives in Bhattacharjee (2008).
- Mass-diameter relationship and model assumption models are compared in Figure 7a. The asymmetry parameters of two Liu 2008 crystal types are compared in Figure 7b for a variety of frequencies within the Liu 2010 database.

Figure 7. a) Mass-diameter relationships from selected forecast model assumptions versus Liu 2008 dendrites and vector plates. b) Comparison of the asymmetry parameter for Liu 2008 crystal habits at a variety of frequencies.

Future Work

- Use aircraft PSFs and other CIVP data sets to evaluate the simulation of satellite products for this event.
- Select a single- or double-moment scheme and incorporate flexibility in mass-diameter relationships to provide for a match to crystal database entries.
- Verify that the WRF simulated microphysics, PSDs, and crystal database entries produce reasonable and realistic snow quantities and attempt to use model profiles toward the retrieval of cloud properties.

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A complete list of references is available upon request.