Report as of FY2007 for 2006WY33B: "Precipitation Measurement and Growth Mechanisms in Orographic Wyoming Snowstorms"

Publications

Project 2006WY33B has resulted in no reported publications as of FY2007.

Report Follows

Abstract

Much of Wyoming's water supply originates as winter snow, mainly over the state's numerous mountain ranges. Snowrate and snow accumulation measurements are complicated by strong winds. A consequence is that springtime runoff estimates have limited accuracy and this uncertainty impacts our ability to assess the efficacy of water management practices. This work, sponsored by WWDC and the USGS has two related objectives: (a) to advance techniques for measuring regional snowrates based on a newly developed hotplate snowrate sensor and operational weather radar data; and (b) to conduct airborne investigations with a view toward advancing understanding of atmospheric processes leading to snow generated in clouds forming over the Wyoming high country. Such research is fundamental to snow measurement and to its augmentation by artificial means (i.e., cloud seeding).

The first objective was addressed using data acquired at a surface site 25 km northwest of Cheyenne, WY; data was collected in winter orographic snowstorms between January and March 2006. The study recognizes the advantages of using radar to monitor region-wide snowfall amounts, but also recognizes the need for robust parameterizations which relate snowrate (S) to what a radar measures (backscattered microwave energy or Z). This work focused on the development of a Z-to-S parameterization for the National Weather Service radar operated in Cheyenne, WY. Since temperature can influence both Z and S, a surface temperature-dependent, and a cloud temperature-dependent, Z-S parameterization were developed.

The airborne studies were performed using the University of Wyoming King Air equipped with a millimeter-wavelength radar, the Wyoming Cloud Radar (WCR; acronyms are defined in the Appendix). The WCR was used to measure snow above and below the aircraft as well as the associated air motion fields. Funding from WWDC/USGS supported seven additional flight hours, supplementing an allotment of 23 flight hours procured with support from NASA. We acquired data by conducting flight transects across the Laramie Range and Snowy Range; the data set is now being used to investigate how cloud depth, horizontal and vertical wind speed, thermal stability and properties of the aerosol ingested by winter orographic storms influence snow formation. The surface and the airborne investigations, plus the ongoing data analyses, are being conducted in close coordination with the State of Wyoming Weather Modification Program.

To date, one MS student has graduated with support from the WWDC/USGS project (Jonathon Wolfe); a second MS student is currently supported (Bujidmaa Borkhuu). In addition, two related awards, from NASA and DEPSECoR, are being used to support two students who are conducting analyses of the WWDC/USGS data set as part of their MS thesis research.

Year- 1 Progress Report -

We conducted both airborne- and ground-based studies in Year-1. The former benefited from work previously planned by the University of Wyoming Department of Atmospheric Science through a grant from NASA (acronyms are defined in the Appendix). In total we flew 13 missions in January and February 2006; six of these were conducted on the same day as missions flown by the Weather Modification Inc. (WMI) aircraft. Flight operations are summarized in Table 1. In addition, surface measurements of snowrate were made in coordination with the Cheyenne, WY National Weather Service Weather Surveillance Radar (WSR) between January and March 2006.

In year-1 our overarching objective was to conduct airborne and surface measurements with a view toward our broader objectives of studying how cloud depth, horizontal and vertical wind speed, atmospheric stability and properties of the aerosol ingested by winter orographic storms influence snow formation. A further objective was to derive a reflectivity-to-snowrate relationship using data collected near Cheyenne. As we discuss below, the Year-1 objectives were met. We now look forward to continuing support from WWDC/USGS, so we can continue our data analysis, to assist graduate students as they complete their theses, and to report findings in peer-reviewed journals.

Table 1 - Wyoming King Air Flights Sponsored by NASA and WWDD/USGS

Date, YYYYMMDD	HHMMSS to HHMMSS, UTC	Duration, hr	WMI Flight?
20060210	1919-2131	2.3	
20060209	2152-0019	2.6	Yes
20060205	1321-1600	3.1	
20060202	1854-2207	3.3	Yes
20060131	1310-1630	3.4	Yes
20060127	2358-0302	3.2	Yes
20060127	2133-2300	1.5	
20060126	1902-2215	3.4	Yes
20060124	2025-2123	1.1	
20060118	1957-2258	3.1	Yes
20060113	2109-2214	1.2	
20060110	2224-2328	1.1	
20060110	2108-2244	0.7	

Year-1 Findings –

Measurements made with the Wyoming King Air and its Wyoming Cloud Radar (WCR) during January and February 2006 provide us with unprecedented views of the structure of winter orographic clouds, the motion fields embedded within them and the interplay among the spatial distribution of the snow, velocities and the underlying terrain. Four specific avenues of investigation were pursued:

1) A variety of cloud and precipitation structures were observed in orographic clouds that formed over the Snowy and Sierra Madre ranges. An important finding obtained from the WCR vertical-plane measurements of reflectivity and Doppler velocity is that turbulent motions are evident through a substantial depth of the cloud section. These motions are evident even when the atmospheric stability is relatively large. Vertical velocities associated with this turbulence, and with the cumulus convection that was observed on a few of the study days, are typically larger than the orographically-forced ascent rate. We believe that the turbulent and convective motion fields are key to understanding snow particle growth and snowfall rates. Quantification of the importance the turbulent and convective motions, compared to the orographically-driven ascent, is an area of investigation for Professor Bart Geerts and MS student Heather McIntyre. Heather is supported by our NASA grant.

2) Laboratory characterizations of a hotplate snowrate sensor (YES Inc.), and field studies of the reflectivity (Z) versus snowrate (S) relationship for the Cheyenne Wyoming WSR, were conducted by Jon Wolfe. Jon's analyses of these data reveal a temperature dependence in the Z/S relationship. This result is compelling for two reasons: 1) It squares well with previous results showing that crystal concentration in Wyoming wintertime orographic clouds are related inversely to temperature, and 2) the derived Z/S relationship should improve the accuracy of snowrate estimates derived from WSR measurements of radar reflectivity. Jon was supported by the WWDC/USGS grant during 2006 and graduated with a MS in Atmospheric Science in May 2007. A new MS-level student, Bujidmaa Borkhuu, is now supported by our WWDC/USGS grant.

3) Aerosol particle measurements made upwind and downwind of the Snowy Range show evidence for particle removal during transport through the orographic clouds probed by the King Air. How this removal is related to the cloud macroscopic structure, e.g. cloud depth, and to snowrate, is a MS research topic for Binod Pokharel. Binod is supported by an award from DEPSCoR.

4) Two proposals have been submitted and awarded in the past year; neither could have been written without the King Air and WCR data collected over the Snowy Range in Jan-Feb 2006, in a project partly funded by our Year 1 WWDC-USGS grant. Firstly, our colleague Gabor Vali investigated the production of ice crystals originating from processes other than nucleation. His analysis of the King Air and WCR data reveals that ice crystals can enter orographic clouds from a source at the terrain/atmosphere interface. This crystal source process is not yet characterized but testable hypotheses were articulated in a proposal submitted by Vali to NSF. Vali's NSF proposal was successful and his initiative is expected to have important implications for cloud seeding efficacy in Wyoming.

Secondly, co-PI Bart Geerts submitted a proposal to the WWDC/USGS to use the WCR and King Air particle probes to describe the signature of cloud seeding in orographic snowstorms in Wyoming. That research is directly relevant to the 5-year Cloud Seeding Pilot Program awarded to NCAR/RAL, and involves close collaboration with the PI of that program, Dan Breed at NCAR/RAL. Our understanding of the efficacy of cloud seeding has been plagued by lack of direct observations of physical processes; rather, the approach has been statistical, and the causality of the relationship between seeding and snowfall has remained veiled in a black box. The purpose of this successful proposal is to observe changes in ice crystal shape within volumes of the atmosphere treated with ice nucleating AgI aerosol. The AgI plumes will be tracked by the WCR as long as possible, possibly until they reach the ground. If successful, this initiative would be the most physically explicit test of cloud seeding efficacy ever conducted.

Plans for Year-2 -

In our WWDC/USGS proposal we proposed two activities for Year-2: 1) Intercomparison of two hotplate sensors at the NCAR Marshall Field Site in Colorado, and 2) Intercomparison of hotplate versus SNOTEL snowrate measurements made in the Snowy Range. We now propose to change the first of these activities; however, the approach now proposed will not depart from our Year-2 objective of improving the accuracy of surface snowrate measurements.

During Year-2 we plan to focus our efforts on measurements of snowrate made at the Glacier Lakes Ecosystem Experimental Site (GLEES) located near the summit of the Snowy Range. Specifically, we plan to make intercomparisons of five nearly collocated snowrate systems: 1) a hotplate located above the forest canopy on the 30 m AMERIFLUX tower, 2) a SNOTEL system (site number 367), 3) a NADP gauge system (site number WY95), 4) a NADP sample bucket system, and 5) a Vaisala VRG precipitation gauge. All of these sensors will be positioned within a circle of radius 2 km.

The activities now proposed have developed from our growing confidence in measurements of snowrate made with our hotplate sensor, particularly our understanding of its performance in strong wind conditions. Another factor influencing the modification of our research is an analysis of snowrate measurements made at the GLEES site. The latter is shown in Figure 1 where we present data from the two NADP precipitation measurement systems at GLEES (gauge and sample bucket, see previous paragraph), stratified by time of year. Week-averaged precipitation measurements from the months June/July/August and December/January/February are shown in the left- and right-hand panels, respectively. It is evident that precipitation measured with the gauge and sample bucket are in reasonable agreement during the summer months.   However, during the winter months very different values are reported by these two measurement systems.   We attribute the wintertime disparity to blowing snow captured by the gauge, but not by the sample bucket, and to loss of collected precipitation (stored in the sample bucket) that occurs during windy precipitation events.   Given the degree of the mismatch during winter, about a factor of seven, and that GLEES is located in a region targeted by the cloud seeding planned for winter 2006/2007 and future years, we feel justified in focusing our Year-2 research at the GLEES site. As discussed above, we will not conduct the proposed Marshall Site intercomparisons in 2006/2007 (Year-2).

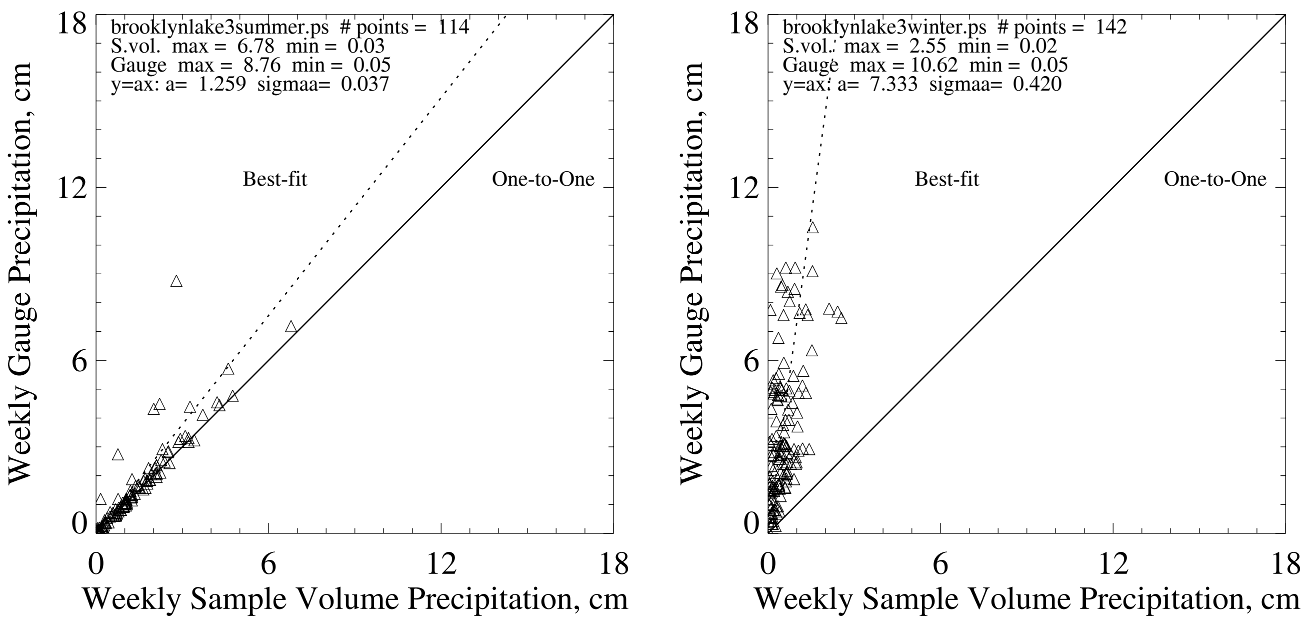

Figure 1 – Weekly precipitation from two sensors operated at the Brooklyn Lake National Atmospheric Deposition Program site. The two NADP sensors are referred to as “gauge” and “sample volume.”   Twenty years of data is analyzed (1985 to 2005).   Weekly samples collected in June/July/August (left-hand panel) and into December/January/February (right-hand panel) were selected for this presentation.   Precipitation was detected in 114 weeks out of 261 (June/July/August; left-hand panel) and in 142 weeks out of 261 (December/January/February; right-hand panel).

Specific Objective for Year-2-

1) From the above- and below-canopy measurements of precipitation rate we intend to investigate if snow falling into the forest canopy can be distinguished from blowing snow generated within the canopy. Preliminary results from our Year-2 field season, including temperature, wind speed, precipitation rate, relative humidity, barometric pressure and wind direction, can be viewed in the directory http://www-das.uwyo.edu/~jsnider/snow/preliminary/. These data were acquired using the hotplate and a Vaisala WXT510 surface observing station operated on the AMERIFLUX tower at GLEES.

2) We are also plan to analyze two-way comparisons of the five snowrate measurements planned for GLEES in 2006/2007.   One strategy will be to stratify these comparisons by wind speed and time since the beginning of a snow event.

3) From these analyses we should be able to advise on the relative merits of the five snowrate measurement systems, to specify conditions that they can be relied on, and to also specify conditions when the data quality is suspect.

4) We will also continue our analysis of data collected by the WCR, King Air and WSR during 2006. The first step in this direction is the successful completion of Wolfe's MS thesis work in May 2007. On going is the thesis work of three more MS students who are either supported by the WWDC/USGS award (Borkhuu) or are analyzing data collected with support from WWDC/USGS (Pokharel and McIntire). Theses and peer-reviewed publications are forthcoming.

Student Involvement

Wolfe, J.P., Radar-estimated Upslope Snowfall Rates in Southeastern Wyoming, MS thesis, Dept. of Atmospheric Science, University of Wyoming, May 2007

Casey, G., A comparison of observed vs. predicted snowfall amounts over the mountains of Southeastern Wyoming in Jan-Feb 2006. An undergraduate research term paper, Dept. of Atmospheric Science, University of Wyoming, 2006

Presentations with Abstracts

Pokharel, B., J.R.Snider and D.Leon, Freshly-formed Aerosol Particles: Connections to Precipitation, accepted for presentation at the 17th International Conference Nucleation and Atmospheric Aerosols, Galway, Ireland, August, 2007

Geerts, B., Detailed vertical structure of orographic precipitation development in cold clouds. Oral presentation at the 16th Conf. on Mountain Meteorology, American Meteorological Society, Santa Fe, NM, 28 Aug-1 Sept. 2006

Presentations without Abstracts

Snider,J.R., Precipitation Measurement and Growth Mechanisms in Orographic Wyoming Snowstorms, Wyoming Weather Modification Technical Advisory Board, January 18, 2007

Snider,J.R. (for B.Geerts), Detecting the Signature of Cloud Seeding with the Wyoming Cloud Radar, Wyoming Weather Modification Technical Advisory Board, January 18, 2007

McIntyre, H., NASA06 observations of orographic precipitation types over the Snowy Range under different stability and flow regimes, UW-NCAR RAL workshop in Boulder, CO, September 6, 2006

Snider, J.R., Aerosol scavenging in winter orographic clouds, presented at the Wyoming-NCAR RAL workshop in Boulder, CO, September 6, 2006

Wolfe, J., Temperature dependence of the Z-S relationship for upslope snowfall, presented at the Wyoming-NCAR RAL workshop in Boulder, CO, September 6, 2006

Appendix –

AgI – Silver Iodide
DEPSCoR – Defense Experimental Program to Stimulate Competitive Research
NADP – National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/)
NASA – National Aeronautic and Space Administration
NCAR – National Center for Atmospheric Research (http://www.ncar.ucar.edu/)
NSF – National Science Foundation
SNOTEL – SNOpack TELemetry (http://www.wcc.nrcs.usda.gov/snotel/)
NWS – National Weather Service (http://www.crh.noaa.gov/cys/)
WCR – Wyoming Cloud Radar (http://www-das.uwyo.edu/wcr/)
WMI – Weather Modification, Inc. (http://www.weathermod.com/index.php)
WSR – Weather Surveillance Radar (http://weather.noaa.gov/radar/radinfo/radinfo.html)