REEXAMINATION OF THE STATE OF THE ART OF CLOUD MODELING SHOWS REAL IMPROVEMENTS

BY ANDREAS MUHLBAUER, WOJCIECH W. GRABOWSKI, SZYMON P. MALINOWSKI, THOMAS P. ACKERMAN, GEORGE H. BRYAN, ZACHARY J. LEBO, JASON A. MILBRANDT, HUGH MORRISON, MIKHAIL OVCHINNIKOV, SARAH TESSENDORF, JULIE M. THÉRIAULT, AND GREG THOMPSON

For nearly 30 years, International Cloud Modeling Workshops have been held traditionally every 4 years and typically during the week before the International Conference on Clouds and Precipitation (ICCP). That is exactly when the Eighth International Cloud Modeling Workshop[1] took place in summer 2012, this time in Poland.[2]

Rooted in the weather modification program of the World Meteorological Organization (WMO), the core objectives of the International Cloud Modeling Workshops have been focused on the numerical modeling of clouds, cloud microphysical representations, and the interactions between cloud microphysics and cloud dynamics. In particular, the goal of the workshops is to provide insight into the pertinent problems of current state-of-the-art cloud modeling and identify key deficiencies in the microphysical

EIGHTH INTERNATIONAL CLOUD MODELING WORKSHOP

WHAT: Fifty-six scientists from 14 different countries and four continents carried on a nearly three-decade history of International Cloud Modeling Workshops that traditionally utilizes observationally derived case studies to provide a framework for model comparisons.

WHEN: 23–27 July 2012

WHERE: Warsaw, Poland

AFFILIATIONS: MUHLBAUER AND ACKERMAN—University of Washington, Seattle, Washington; GRABOWSKI, BRYAN, LEBO, MORRISON, TESSENDORF, AND THOMPSON—National Center for Atmospheric Research, Boulder, Colorado; MALINOWSKI—Faculty of Physics, University of Warsaw, Warsaw, Poland; MILBRANDT—Atmospheric Numerical Prediction Research, Environment Canada, Montreal, Quebec, Canada; OVCHINNIKOV—Pacific Northwest National Laboratory, Richland, Washington; THÉRIAULT—Université du Québec à Montréal, Montreal, Quebec, Canada

CORRESPONDING AUTHOR: Andreas Muhlbauer, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, P.O. Box 355672, Seattle, WA 98195-5672

E-mail: andreasm@atmos.washington.edu

DOI:10.1175/BAMS-D-12-00188.1

In final form 15 November 2012

[1] The eighth workshop, hosted by the Institute of Geophysics at the University of Warsaw, was organized by Szymon Malinowski and his local team of students and cochaired by Wojciech Grabowski (NCAR MMM) and Andreas Muhlbauer (University of Washington).

[2] Previous International Cloud Modeling Workshops took place in Irsee, Germany (1985); Toulouse, France (1988); Toronto, Canada (1992); Clermont-Ferrand, France (1996); Glenwood Springs, Colorado (2000); Hamburg, Germany (2004); and Cozumel, Mexico (2008).

representation of clouds in numerical models and cloud parameterizations. In recent years, the workshop has increasingly shifted the focus toward modeling interactions between aerosols and clouds and provided case studies to investigate the effects of aerosols on clouds and precipitation as well as the impact of cloud and precipitation processes on aerosols.

More than 50 participants of the Eighth International Cloud Modeling Workshop contributed to discussions and oral and poster presentations as well as the workshop's plenary and breakout sessions. Several scientists contributed to the workshop by setting up five observationally based case studies covering a wide range of cloud types—namely, marine stratocumulus, midlatitude squall lines, midlatitude cirrus clouds, Arctic stratus, and wintertime orographic clouds and precipitation. Interested readers are encouraged to visit the workshop website (at www.atmos.washington.edu/~andreasm/workshop2012/) and browse through the list of case studies. The web page also provides a detailed list of participants and the workshop agenda.

In addition to contributed oral and poster presentations, parallel breakout sessions focused on presentations and discussions of the individual cases. Short summaries of and science highlights from each of the cases are presented below.

CASE 1: CCN PROCESSING BY DRIZZLING MARINE STRATOCUMULUS. This case of drizzling marine stratocumulus in the subtropical southeast Pacific is designed to investigate the accuracy and efficiency of various numerical approaches in simulating the processing of cloud condensation nuclei (CCN) by precipitating clouds. The case leaders are Wojciech Grabowski [National Center for Atmospheric Research (NCAR) Mesoscale and Microscale Meteorology (MMM)] and Zachary Lebo [NCAR Advanced Study Program (ASP)].

The case is motivated by the observed dramatic microphysical contrasts between adjacent areas of stratocumulus clouds with open and closed cellular characteristics and is based on aircraft observations from the Variability of the American Monsoon Systems (VAMOS) Ocean–Cloud–Atmosphere–Land Study (VOCALS) Regional Experiment (REx) research flight (RF) 6 that took place on 25 October 2008. The processing of CCN is assumed to play an important role in the transition from closed to open cellular convection and the development of "ultra-clean layers," which are regions of highly depleted aerosol concentrations. The major objective of this case is to provide numerical standards and benchmarks for assessing the performance of simplified methods such as double-moment bulk microphysics schemes with a prognostic treatment of aerosols.

A simplified two-dimensional (2D) kinematic model framework with prescribed dynamics is used to investigate the impacts of drizzle formation on aerosols in the absence of dynamical feedbacks. In the future, a 3D dynamic model setup will be used to investigate interactions among aerosols, clouds, and drizzle in the presence of dynamical feedbacks.

The results of numerous numerical techniques, including traditional 1D bin microphysics, 2D bin microphysics, Lagrangian microphysics, the superdroplet method, and bulk model representations using the kinematic modeling framework were presented at the meeting. All models explicitly treat aerosol processing and the removal of aerosols by activation and subsequent scavenging due to cloud droplet collisions and coalescence.

A preliminary comparison of model results suggests that aerosol processing is key to qualitatively reproducing the depletion of aerosols and the development of ultra-clean layers with exceptionally low aerosol concentrations that were frequently observed within pockets of open cells during VOCALS REx. Models with microphysical parameterizations that lack the ability to treat aerosol processing are unable to generate ultra-clean layers near cloud top. However, the aerosol depletion rates are crucially dependent on the technical approach used for treating aerosol processing, and thus far little agreement has been reached among various models and numerical techniques.

CASE 2: MIDLATITUDE SQUALL LINE. The midlatitude squall line case is based on a large mesoscale convective system that occurred on 20 June 2007 in Oklahoma and Kansas. The storm resulted from three separate convective systems that formed during the afternoon and merged together later that evening. The case leaders are Hugh Morrison, George Bryan, Sarah Tessendorf, and Greg Thompson (all from NCAR).

The goal of this case is to compare model simulations of the squall line and investigate interactions between microphysics, cold pool intensity, and low-level environmental wind shear. Previous studies have shown that these factors can strongly affect surface precipitation, storm structure, dynamics, and propagation. The squall line was well observed by a combination of dual-polarization radar, video disdrometers, and Mesonet surface meteorological observations. Semi-idealized setups are provided for 2D and 3D dynamic models. Model sensitivity tests vary the low-level environmental wind shear and rain evaporation rate (which strongly affects cold pool properties) to investigate interactions between the cold pool and environmental wind shear.

Preliminary analysis of the modeling results indicates a wide spread of outcomes from different models, as well as from the same model but with different microphysics schemes. Several models had difficulty initiating squall lines for certain settings of wind shear and rain evaporation rate. For models that did initiate and maintain squall lines, simulations with stronger cold pool circulation, relative to the environmental wind shear, tended to produce more extensive trailing stratiform regions. However, there was considerable spread among models in terms of peak updraft velocities and surface precipitation. Future work will focus on a more detailed comparison of model results with observations and analysis of simulated cold pool–wind shear interactions.

CASE 3: MIDLATITUDE CIRRUS. The case of a synoptically driven cirrus cloud field occurred on 1 April 2010 over the Atmospheric Radiation Measurement Program (ARM) Southern Great Plains (SGP) site in Oklahoma. The cirrus was sampled in situ by aircraft during the Small Particles in Cirrus (SPARTICUS) field campaign RF 45. Additionally, observations are available from the ground-based millimeter wavelength cloud radar (MMCR) at the ARM SGP site and from active and passive remote sensors aboard the A-Train satellites, particularly the Moderate Resolution Imaging Spectroradiometer (MODIS), *CloudSat*, and Clouds and the Earth's Radiant Energy System (CERES). The case leaders are Andreas Muhlbauer and Thomas Ackerman (University of Washington).

The core objectives of the case are to compare the simulated microphysical, macrophysical, and radiative properties of midlatitude cirrus clouds among models and with observations. The goal is to identify deficiencies in current ice microphysical parameterizations that lead to a misrepresentation of cirrus cloud properties in numerical models such as homogeneous and heterogeneous ice nucleation, ice particle growth, and ice fall speeds. Two- and three-dimensional model setups based on observations and analysis data are available for this case.

Preliminary analysis of the modeling results suggests that models have difficulty in predicting the observed ice number concentrations and representing the vertical structure of the cirrus. Ice number concentrations are overestimated in the homogeneous freezing regime and at cold temperatures but underestimated in the warmer temperature regime, where ice is initiated by heterogeneous ice nucleation mechanisms. The modeling results also indicate deficiencies in correctly representing the observed vertical profiles of ice water content and radar reflectivity, and show an underestimation of the ice water path in the mesoscale cirrus cloud field.

CASE 4: MIXED-PHASE ARCTIC CLOUDS. This case is based on a single-layer mixed-phase stratiform Arctic cloud observed on 26 April 2008 during RF 31 of the Indirect and Semi-Direct Aerosol Campaign (ISDAC). The case leader is Mikhail Ovchinnikov (Pacific Northwest National Laboratory).

The major objectives of this case are to better understand the interactions among microphysics, dynamics, and radiation in a single-layer mixed-phase Arctic stratus deck and to compare the ability of models to simulate the observed phase partitioning between liquid and ice. One of the goals is to assess factors controlling the stability of shallow mixed-phase Arctic cloud layers and examine the sensitivity of the simulated cloud parameters to ice particle properties such as ice number concentration, growth rates, and ice fall speeds. A semi-idealized setup with prescribed ice particle properties and constrained ice number concentrations is available for 3D dynamic models.

A preliminary analysis of the results shows that all models are able to qualitatively reproduce the observed mixed-phase cloud, although different models achieve a quasi-steady state at different ice concentrations. It is found that using uniform treatments for ice crystal growth and sedimentation across all the models reduces but does not eliminate the intermodel spread in liquid water path, ice water path, and precipitation. Further analysis of the turbulent motions in the simulated mixed layer suggests that the remaining intermodel variability is likely due to differences in the representation of dynamics rather than microphysics.

CASE 5: OROGRAPHICALLY ENHANCED SNOWSTORM. This case is based on a wintertime orographic precipitation event that took place on 14 February 2010 during the Vancouver 2010 Winter Olympic Games in the Whistler area of western Canada. The case leaders are Jason Milbrandt (Environment Canada) and Julie Thériault (Université du Québec à Montréal).

Previous studies of this case hypothesized that diabatic cooling induced by the melting of snow played an important role for the low-level weather conditions. Strong correlation between the onset of the flow reversal and a rapid cooling associated with melting was observed. The objectives of this case are to investigate the effects of diabatic cooling on the precipitation phase transition and the mesoscale flow in complex terrain and the sensitivity to details in the parameterization of melting snow. Idealized 1D kinematic and 2D dynamic model configurations based on observations are provided. In both setups, bulk and bin microphysics schemes are used. The 1D kinematic model with a prescribed snowfield allows for studying the effects of melting snow on the temperature profile and precipitation phase transition. In the 2D dynamic model setup, the impact of diabatic cooling on the valley flow direction can be examined. In the future, a real-case 3D configuration will be set up to study other factors such as orographic flow blocking and the impact of the surrounding mountains on the change of the valley flow direction.

Preliminary results show that the change of the direction of the valley flow is caused by—or at least enhanced by—diabatic cooling from melting, which can be achieved even with very low precipitation rates. Overall, this case study highlights the sensitivity of orographic precipitation, precipitation phase transitions, and low-level flows to the parameterization of melting snow.

GENERAL CONCLUSIONS. The International Cloud Modeling Workshop brought together scientists from around the world to discuss cutting-edge research problems in the field of cloud modeling, especially those pertaining to the prediction of high-impact weather and the response of clouds and cloud systems to environmental changes such as aerosol loadings and global warming. Presentations and discussions during the workshop provided insight into the current status of cloud modeling and allowed participants to understand current research interests of the international cloud modeling community. General conclusions from the workshop are as follows:

1) For most cloud modeling applications, simple microphysical parameterizations with fixed CCN are being replaced with more detailed schemes, and there is a clear trend toward more sophisticated and interactive cloud microphysical schemes with the capability of aerosol processing.
2) Advances in the representation of ice properties, ice initiation, and crystal growth in cloud microphysical parameterizations have led to improved simulations of the properties of mixed-phase and cold clouds, but uncertainties remain, especially with respect to the prediction of ice number concentrations and the effects of aerosol particles on ice formation.
3) Regional climate models are approaching the cloud-permitting and cloud-resolving scale; this will open the way for new regional climate change applications and links to hydrology.

Research on the individual case studies and model comparisons is continuing following the workshop and the scientific outcomes will be summarized in forthcoming publications.

ACKNOWLEDGMENTS. Workshop organizers gratefully acknowledge financial support from WMO, which allowed the participation of several students, and funds as well as local support received from the following institutions: the Ministry of Science and Higher Education of the Republic of Poland, the Faculty of Physics of the University of Warsaw, and Pro Physica. The authors thank Roy Rasmussen for his comments on the manuscript.