CHALLENGES FOR CLOUD MODELING IN THE CONTEXT OF AEROSOL–CLOUD–PRECIPITATION INTERACTIONS

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NINTH INTERNATIONAL CLOUD MODELING WORKSHOP

What:	More than 40 experts on cloud modeling convened to discuss key advances in the representation of clouds in numerical models and future efforts to further improve the predictability of clouds and precipitation.
When:	22–26 July 2016
Where:	Met Office, Exeter, United Kingdom

The International Cloud Modeling Workshop (CMW) has been a longstanding tradition in the cloud microphysics modeling community and is typically held the week prior to the International Conference on Clouds and Precipitation (ICCP). For the Ninth CMW, more than 40 participants from 10 countries convened at the Met Office in Exeter, United Kingdom.

The workshop included four detailed case studies (described in more detail below) rooted in recent field campaigns. The overarching objectives of these cases were to utilize new observations to better understand intermodel differences and model deficiencies, explore new modeling techniques, and gain physical insight into the behavior of clouds. As was the case at the Eighth CMW, there was a general theme of understanding the role of aerosol impacts in the context of cloud–precipitation interactions. However, an additional objective was the focal point of several cases at the most recent workshop: microphysical–dynamical interactions. Many of the cases focused less on idealized small-domain simulations (as was the general focus of previous workshops) and more on large-scale nested configurations examining effects at various scales.

The CMW provides a forum for detailed discussion within the community on current issues, and this was further emphasized at the Ninth CMW. The workshop was framed around the four cases described below in which all participants were encouraged to participate in discussion. There were also several plenary talks discussing novel modeling techniques and advancements in cloud modeling. The interaction among the

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participants resulted in a sometimes lively discussion, several key outcomes, and a clear direction for further advancing the state of the science. More details on the workshop can be found online (at http://icmw2016.weebly.com).

A brief summary of the motivation, setup, and preliminary conclusions are provided below.

CASE 1: A MODEL INTERCOMPARISON. This intercomparison study was based on a linear mesoscale convective system that occurred on 20 May 2011 during the Midlatitude Continental Convective Clouds Experiment (MC3E). This is a well-documented case that has received considerable attention in recent research. The case leaders were Jiwen Fan [Pacific Northwest National Laboratory (PNNL)], Hugh Morrison [National Center for Atmospheric Research (NCAR) Mesoscale and Microscale Meteorology (MMM) Laboratory], and Adam Varble (University of Utah).

The case was motivated by the need for a detailed comparison of microphysics schemes that are used in numerical models to simulate aerosol–cloud–precipitation interactions in deep convective clouds. Previous studies have indicated a large spread in deep convective cloud simulations using different microphysics schemes, although isolating the processes responsible for these differences is difficult because of the use of different dynamical models and other complications. There is also uncertainty in the processes most relevant to the effects of aerosol on deep convective clouds, some of which is caused by differences in microphysics parameterizations, while additional uncertainty may be related to differences in the dynamical model used to investigate these interactions. The purpose of this intercomparison study is to examine the major differences produced by different microphysical schemes and to identify the dominant factors responsible for these differences.

To realize this goal, a unified approach with the same dynamical core [i.e., the Weather Research and Forecasting (WRF) Model] was used with various microphysics schemes. The initial comparison stage was focused on key processes leading to differences in simulated convective system characteristics. The second stage of the project will investigate feedbacks between the microphysics and dynamics using the “piggybacking” approach, in which all of the microphysics schemes are driven by the same dynamical fields to isolate the separate effects of microphysical and dynamical changes on convective system properties. The third stage will quantify the responses of different microphysics schemes to increased aerosol concentrations and identify causes for different responses based on the understandings gained from the first two stages.

Real-case WRF simulations were performed with a nested domain configuration in which outer domains provide boundary conditions for inner domains. The U.S. National Centers for Environmental Prediction Final Operational Global Analysis (NCEP FNL) was used for initial conditions. In the innermost domain, simulations were carried out using eight different microphysics schemes, including one-moment, two-moment, and bin approaches. The initial conclusions were that 1) the simulations generally underpredicted surface precipitation and overpredicted convective updraft speed and reflectivity compared to observations and 2) the spread in updraft speed was jointly determined by differences in low-level vertical perturbation pressure gradients and buoyancy, which resulted from differences in the parameterization of ice properties and processes. Work planned on this case for the next 4 years will focus on stratiform precipitation biases, feedbacks between microphysics and dynamics, and the sensitivity of the simulated aerosol–cloud–precipitation interactions to the representation of microphysical processes.

CASE 2: COPE CONVECTIVE SQUALL LINES. This case focused on squall lines observed during the Convective Precipitation Experiment (COPE) conducted over the southwest of England during the summer of 2013. The focus of the CMW case was the 3 August 2013 event, which closely resembled the conditions conducive to flash flooding events in the area, although the observed precipitation was much lower, presumably related to lower cloud tops and mobile convergence lines. The case leaders were Annette Miltenberger and Phil Rosenberg (University of Leeds) and Adrian Hill (Met Office).

Motivation for this case arose from the resulting economic losses and societal impacts caused by flash floods (e.g., Boulder, Colorado, in 2013 and Boscastle, United Kingdom, in 2004). Convective systems are significant contributors to these heavy precipitation events. However, the processes resulting in high precipitation intensities are not well understood, particularly the importance of warm rain processes in midlatitudes and the role of secondary ice multiplication. The observations collected during COPE provided a unique dataset to explore the representation of these processes in convective clouds and the effects on convective cloud life cycle.

Convection-resolving simulations over the COPE domain formed the bases of the case. Simulations were run with different background aerosol conditions and different settings for the microphysics schemes. Similar to case 1, a nested configuration was used to capture large-scale features that are often overlooked in idealized modeling studies. However, unlike case 1, in which a single model and dynamical core drove the different microphysics schemes, participants contributed simulations using their own choice of model. The focus of the analysis was on the sensitivity of the precipitation formation and cloud glaciation to various microphysical parameters and aerosol concentrations.

The initial results demonstrated that the various models predicted the location of the convective line well compared to radar observations. However, the simulated precipitation rates and reflectivity values varied among the different models, with no clear dependence on the use of bin versus bulk microphysics. It was found that subkilometer horizontal resolutions were required to represent the observed convective cells. While domainwide statistics, such as the average precipitation rate, seemed to converge for subkilometer resolution, horizontal cell structures in most models did not converge with increasing resolution. Furthermore, the sensitivity to the Hallet–Mossop process (determined by running simulations both with and without the process turned on) appeared to be model dependent. For example, the Thompson microphysics used in the WRF Model exhibited little or no sensitivity to the Hallet–Mossop process, while a configuration of the Unified Model (UM) that uses the Cloud AeroSol Interactions Microphysics (CASIM) scheme exhibited a much larger sensitivity. Further investigations will be carried out to elucidate the causes for these intermodel differences.

CASE 3: SILVER IODIDE SEEDING OF WINTERTIME OROGRAPHIC CLOUDS.

This case was focused on comparing model simulations of wintertime orographic clouds with recent observations from state-of-the-art remote sensing instrumentation during the AgI Seeding Cloud Impact Investigation (ASCII) over southern Wyoming. As its name suggests, ASCII took place with the intention to determine the potential impact of silver iodide (AgI) seeding on precipitation amount and distribution. These precipitation facets are critical in the western United States mountains, where snowpack is a major source of freshwater. The case leaders were Lulin Xue [NCAR Research Applications Laboratory (RAL)] and Istvan Geresdi (University of Pécs).

The objectives of ASCII, which were extended to the CMW case, were to understand how ground-based glaciogenic seeding using AgI impacts wintertime orographic clouds over southern Wyoming. The case leveraged the wealth of data collected from the University of Wyoming King Air (UWKA) during the field campaign to validate the model simulations. The 13 February 2012 case formed the basis of the modeling efforts to investigate the dynamic, thermodynamic, and microphysical processes in the observed orographic clouds in a turbulent and weakly convective environment.

The initial simulations relied heavily on a semi-idealized setup with a simple bell-shaped mountain to mimic topography in the domain. This idealization provided early insight into the behavior of the schemes, but as with the other cases, future efforts will focus on real-case simulations that encompass a larger domain and the actual topography of the study location. Simulations were conducted using both bin and bulk microphysics schemes.

The preliminary conclusions were as follows: 1) Simulations with different grid spacing suggested that a coarse grid (900-m horizontal spacing) was insufficient for resolving turbulent eddies associated with orographic clouds and precipitation; higher resolution was needed. 2) Convective cells tended to organize in a linear structure when using bulk microphysics, while the bin simulations produced nonlinear convection. 3) The cloud phase partitioning and precipitation spatial distribution were sensitive to both the microphysics scheme and cloud condensation nuclei concentration. 4) The AgI seeding simulated using bin microphysics had no effect on the cloud dynamics, resulting in a slight increase in precipitation on the upwind side of the hill, which was almost completely compensated for by a reduction on the leeward side.

CASE 4: VOCALS AEROSOL–CLOUD–PRECIPITATION INTERACTIONS.

The final case study followed from the previous cases on aerosol processing by drizzling stratocumulus from the Eighth CMW and the Global Atmospheric System Studies (GASS) Kinematic Driver-Aerosol (KiD-A) intercomparison. These previous studies were predominantly focused on using kinematic tools for assessing microphysical behaviors. In the current case, fully coupled 3D simulations of drizzling stratocumulus were developed, and aerosol processing was predicted using various microphysical modeling techniques. The case leaders were Adrian Hill (Met Office) and Zachary Lebo (University of Wyoming).

Recent modeling developments have resulted in numerous microphysics schemes capable of representing aerosol processing in clouds. The purpose of this case was to investigate the accuracy and efficiency of these approaches in the context of drizzling stratocumulus. The motivation arose from the observed differences between aerosol characteristics in closed and open cells over the subtropical eastern Pacific. These cells have dramatically different cloud characteristics, and aerosol processing at the boundary has been argued to play an important role (and perhaps even control) the transition from open- to closed-cell circulations. The overarching goal was to obtain a benchmark from the available state-of-the-art modeling frameworks.

The case focused on 3D idealized simulations with relatively small grid spacings and based on observations of drizzling stratocumulus collected during the Variability of the American Monsoon Systems (VAMOS) Ocean–Cloud–Atmosphere–Land Study (VOCALS) field campaign; however, results of 1D and 2D kinematic simulations were also presented. Unlike the first three cases, which relied on more traditional bin and bulk microphysics schemes, this case levied two additional microphysical representations—namely, Lagrangian microphysics (sometimes referred to as the superdroplet method) and 2D bin (which predicts both droplet mass and solute mass in cloud and precipitation hydrometeors). One of the overarching issues with the intercomparison was determining a suitable initialization and spinup for all models. For example, some models require time to evolve wet aerosol particles into cloud droplets (typically the more detailed models), while others can instantaneously condense all excess water vapor prescribed in the sounding (typically the bulk schemes).

The initial findings highlighted a large spread in simulated precipitation rates among the models. The detailed models (e.g., traditional bin, 2D bin, and Lagrangian schemes) exhibited the largest spread, with the less detailed bulk frameworks somewhere in between. However, even with these large differences, when examining the results in terms of aerosol susceptibility (or, the relative change in the precipitation rate of a relative change in the aerosol number concentration), the detailed models provided a very narrow range of values, while the bulk models exhibited large spread. Furthermore, the intermodel differences varied based on the background conditions (e.g., aerosol loading and/or vertical velocity). Future efforts will focus on pinpointing the reasons for the large intermodel spread.

GENERAL CONCLUSIONS. Innovative research problems formed the basis of the International Cloud Modeling Workshop, which brought together participants from around the world. The cases had a general theme of assessing sensitivities of cloud properties to various microphysical parameters and processes and of understanding the impacts of varying environmental and aerosol conditions on cloud characteristics. Moreover, the presentations and discussions focused on novel modeling concepts, many of which were developed after the previous modeling workshop, and outlining areas of improvement and defining future endeavors. Based on the numerous presentations and extensive discussion in the plenary sessions, the following main conclusions were drawn:

1) The cloud modeling community is moving away from solely focusing on only detailed microphysical studies with idealized frameworks and toward augmenting these with a more systemwide focus by examining the coupling between microphysics and dynamics.
2) To advance the parameterization of ice-phase microphysics (in bulk and bin schemes), the modeling community should further explore the paradigm of free ice-phase categories.[1]
3) The large spread in current "detailed" schemes is problematic and presents a challenge for those hoping to constrain simple numerical approaches or define a benchmark.
4) Resolution and microphysics are inherently linked; moving toward higher resolution is still a primary goal of the community to better resolve detailed microphysical structures. Kilometer-scale models are still not sufficient to resolve necessary details, and effort should be put forth to improve the linkage between grid-scale cloud microphysics and subgrid-scale variability.
5) There is a need to better integrate advances in modeling techniques and detailed case studies with observational campaigns, which will help constrain numerical models; the effort to include observations is strong, yet incorporating more observationalists in the workshop cases would be beneficial to the community and should be emphasized in future workshops.

Efforts are continuing for the individual cases following the workshop; scientific outcomes and future directions will be presented in upcoming publications.

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[1] Here, "free ice-phase categories" is used to describe microphysics schemes that do *not* rely on predefined ice categories (cloud ice, snow, graupel, hail, etc.) and their characteristics (e.g., the density). These schemes have prognostic equations for ice crystal properties, allowing the ice characteristics to freely evolve with time.

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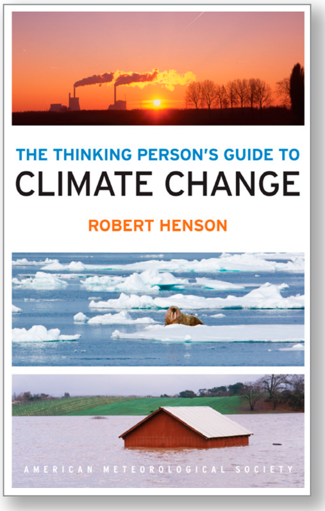

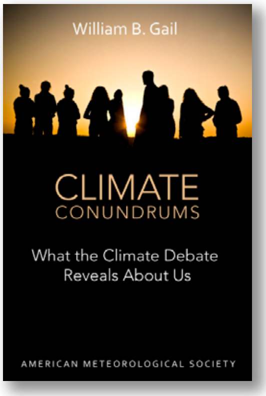

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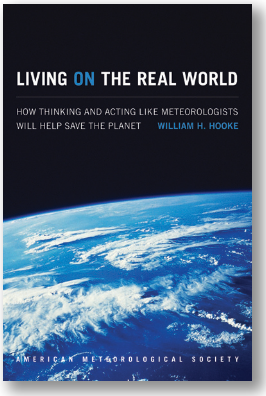

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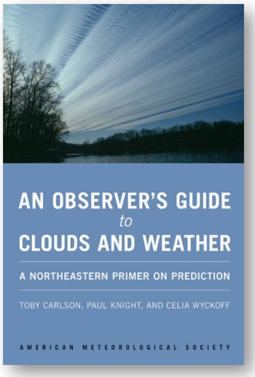

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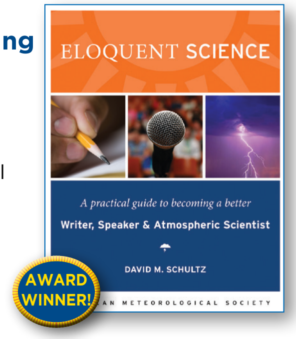

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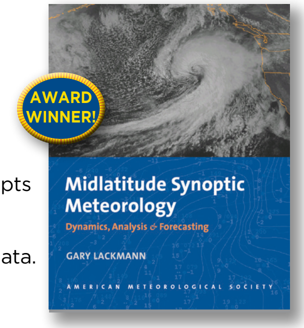

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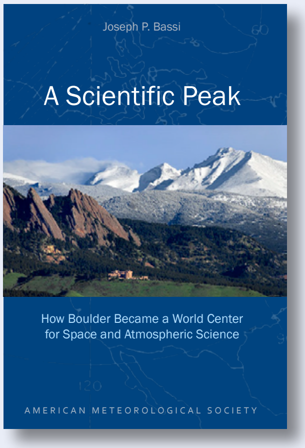

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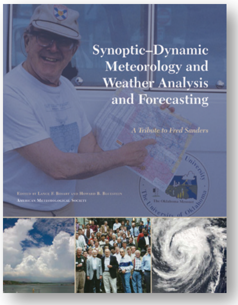

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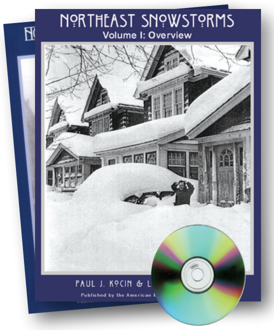

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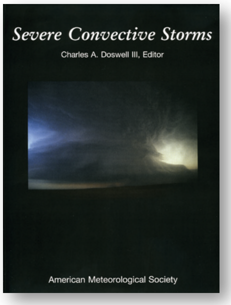

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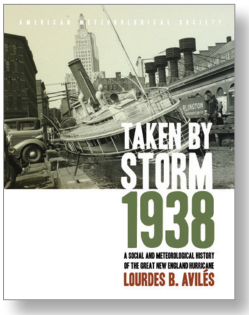

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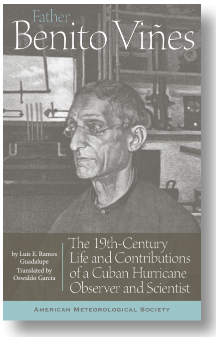

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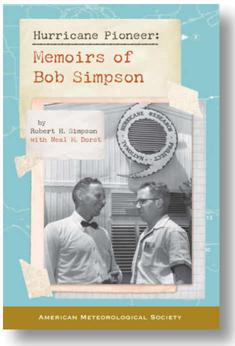

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