Convection and Surface-Atmosphere Interactions

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Atmospheric convection plays important roles in the Earth's water cycle. Through the release of latent heat, convection is a major driver of atmospheric circulations that redistribute heat, moisture, and momentum in the atmospheric column and between the tropics, extratropics and polar regions. Organized convection, particularly when manifested as mesoscale convective systems (MCSs), is often associated with heavy precipitation and strong winds and is thus linked to extreme events worldwide. Through its impacts on radiation, winds, and precipitation, convection can alter surface-atmosphere interactions and processes such as precipitation recycling and ocean mixing. Likewise, land- and ocean-surface conditions can influence the triggering and strength of convective events. Hence convection is a major element of the regional and global water cycle, with important implications for understanding and predicting precipitation and floods on weather time scales, and water cycle changes and cloud-feedbacks on longer time scales.

Changes in atmospheric composition and land-use–land-cover are expected to have impacts on convection, which can modulate the climate system's response and have significant implications for the water cycle. For example, changes in convective storms, such as the intensity, frequency and areal coverage, can influence the characteristics of precipitation and surface-atmosphere interactions, with consequences for the statistics of flooding. As an important driver of large-scale circulation systems, particularly monsoon and Hadley circulations, changes in convection can influence the climates of large populated regions. Our ability to predict how drivers and responses in the Earth system will affect convection is hampered by significant gaps in understanding and modeling convection and its role in surface-atmosphere interactions and large-scale circulation. Advances in observation, modeling, and computing present important opportunities for improving predictive understanding of convection and its regional and global consequences.

Grand Challenge Question: *How do cloud microphysics, atmospheric dynamics, surface fluxes and their multiscale interactions influence the predictability of mesoscale convection and its impact on surface conditions and land-atmosphere interactions from synoptic to interannual time scales?*

Addressing this grand challenge question will require improved capabilities for observing and modeling mesoscale convection and associated cloud, dynamical, and surface processes. Model-data fusion (e.g., ModEx) and modeling experiments that leverage existing BER investments will play a key role in hypothesis-driven modeling and analysis.

Expertise across existing projects within RGMA offers a unique opportunity to advance our understanding of convection and surface-atmosphere interactions by organizing research on the following science questions:

- How do cloud microphysical processes influence the macro-physical properties and lifecycle of mesoscale convection?
- How do the spatial and temporal variability of surface fluxes influence mesoscale convection and its predictability during the warm season?
- How do mesoscale convection and atmospheric circulation interact locally and remotely to limit the predictability of precipitation from synoptic to interannual time scales?
- How does the frequency, intensity, and timing of precipitation from mesoscale convection impact the surface water balance and its influence on surface temperature and runoff?

Description of Challenges and Current Research in RGMA

RGMA has been supporting research on convection with an increasing focus on organized MCSs because of their relatively larger impacts on precipitation and atmospheric circulation compared to isolated convection and the larger challenges for Earth system models to simulate MCSs. RGMA funded research has been investigating the role of the coupled energy and water cycles in the warm season over the Central U.S. to determine why global Earth system and numerical weather prediction models overestimate regional surface temperatures. Through studies such as the CAUSES (Clouds Above the United States and Errors at the Surface), (Morcrette et al. 2018), the ubiquitous warm bias was linked to too much solar radiation at the surface and too little evaporation, both related to the lack of MCSs simulated in models with parameterized cumulus convection.

RGMA has also been supporting research to understand observed and future changes in MCSs. Statistically significant increases in MCS mean and extreme precipitation and MCS lifetime have been identified east of the Rocky Mountains for the past 35 years (Feng et al. 2016). These results motivated the need to understand robust, long-lived MCSs that contribute importantly to extreme precipitation and their past and future changes. Convection permitting simulations suggested a positive feedback between MCSs and atmospheric circulation that enhances the lifetime of MCSs. Studies are investigating the large-scale environments that support the development of robust MCSs over the Central U.S. in the warm season (Song et al. 2019), which aid in understanding model biases and projections of multidecadal changes in MCSs. Ongoing research is also assessing the impacts of wildfires and urbanization on severe convective systems through changes in aerosols and heat fluxes (Chen et al. 2020).

Through RGMA, studies have been evaluating several different approaches for improving the ability of models to represent MCSs. These include convection permitting regional models, non-hydrostatic global variable resolution models with the capability for convection permitting modeling through regional refinement, and global models with superparameterization to capture different aspects of convective systems including MCSs, their interactions with the land surface, and their impacts on surface hydrology. Advances have also been made in developing methods to track MCSs, and metrics and diagnostics to quantify and understand model biases.

Research Gaps and Future Directions

Current research supported by RGMA is making great strides in improving understanding and modeling of convection and surface-atmosphere interactions. To address the grand challenge and science questions identified above, more research highlighted below is needed to bridge major remaining gaps in order to transform our predictive understanding of mesoscale convection and related surface-atmosphere processes:

Short Term (3- 5 years) Research Goals

- Improve the availability and synergistic use of a variety of measurements from field campaigns to in-situ and remote sensing platforms of microphysical processes, latent heating, dynamics, and thermodynamics environment to understand convective microphysics feedbacks on cloud-scale and large-scale dynamics.
- Leverage Atmospheric Radiation Measurement (ARM) and other BER investments in observation (e.g., data from Next Generation Ecosystem Experiments) with data-fusion techniques to improve estimates of surface fluxes of energy and water in order to better constrain observation and modeling of surface-atmosphere interactions and their roles in the development and evolution of mesoscale convective systems over land and ocean through local and non-local processes including feedbacks.
- Improve understanding of the key microphysical, surface, dynamic and thermodynamic processes that influence the development of MCSs during spring and summer and differentiate the predictability of different types of MCSs in the two seasons.

Long Term (10 years) Research Goals

- Develop a modeling hierarchy, including single-column models, limited area models, and multiscale and uniform/variable resolution global models for the atmosphere coupled to land-surface models with simple-to-complex representations of processes to improve understanding of model biases in the simulation of MCSs and land-atmosphere coupling, and to test hypotheses of convection-surface and convection-circulation interactions.

- Improve the characterization of MCSs, including their three-dimensional structure, across a variety of different climate regimes, and hence understanding of the roles of MCSs in the global and regional water and energy cycles.
- Elucidate the roles of different MCS characteristics (e.g., size, intensity, and propagation speed) and land-surface conditions in the development of convective events that are most conducive to extreme precipitation and flooding.
- Develop a better understanding of the major mechanisms that control how MCSs respond to warming and the implications for the global and regional water cycles and hydrologic extremes.

References

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