Convection and Surface-Atmosphere Interactions

Notes, Comments, and Suggestions from Breakout Session

Data and analysis talks:

1. Zhe Feng: Development of a Global High-resolution Mesoscale Convective System Tracking Database

MCS's account for > 50% of tropical rainfall, have an impact on circulation due to latent heating.
A hi-res global MCS dataset is lacking.
They develop a new algorithm to track MCS from obs
Input data: cloud top IR temperature + precip from IMERG.
10 km, 1 hourly resolution for a 20-year period.
Includes location, time, lifetime, size.
Has been validated using ground-based radar -- successfully captures number and timing over US and China.
MCS are most common over WP, Central Africa, Amazon in the tropics, but also the South America and East Asia in midlats.
MCS > 60% in WP, BoB, EPac, E Atl
MCS > 70% over Central Africa & South America

2. Nana Liu: Global Mesoscale Convective System Latent Heating Characteristics from GPM and IMERG Retrievals

Convective & stratiform regions affect the latent heating due to MCS
Significant model errors come from latent heating effects of parameeterizations of cumulus convection.
Uses Zhe Feng's dataset + SPH Product + FLEXTRKR
When systems in diff datasets overlap >30% they are considered a single system. The datasets are integrated this way.
Characteristics:
Tropical MCS are more convective, less area
Mid & hi lats → more top-heavy, stratiform profiles than tropics but lower latent heating.
Future steps -- model validation, variability of LH in MJO phases, use 4D latent heating distribution to predict MJO.

3. Robert Junod: Toward an improved estimate of climate sensitivity and its application to key climate Metrics – surface air temperature datasets

Nighttime marine air temp dataset serve as a complement to near-surface temp over land that is physically consistent.
Only NMAT dataset existed before, important for multiple groups to independently develop them.
ICOADS → Air temp height adjustment to 10 m using varying lapse rate method (esp for shipd after 1970 for which info was available), ww2 warm bias correction (and others from differing observing methods, esp from ships).

Virtually identical to Hadley center's dataset with differences b/w trends within 95% CI. Diff in trends are a little larger after 1979 but still broad agreement spatially.
Future steps - also developing a max temp dataset over land

4. Fengfei Song: The propagating environments for the initiation of summertime MCSs over the U.S. Great Plains and the role of middle tropospheric perturbation
Though large-scale env is unfavorable, smaller scale env is able to initiate summertime MCS over CONUS.
Composites of the conditions show consistent conditions when calculated based on convection centered rather than fixed-grid -- trough to the east and ridge to the west.
Hovmoellers show common eastward-propagating features in all 4 types of MCS environments.
Only < 5% of MCS types 1-3 are initiated by MP but for type 4, this fraction is 10%. MP-initiated give more precip.
Future - track short-wave troughs by using reanalyses and quantify their role in MCS initiated, use ML methods to detect MCS initiation in hi res model simulations.

5. Huancui Hu: Different rainfall characteristics in MCS and non-MCS events lead to different hydroclimate impacts and roles in land-atmosphere interactions
~ 50% of warm season rainfall is not associated with MCS but rainfall is about 7 times less intense than MCS-generated rainfall
Use flextrak to separate rainfall into MCS and non-MCS rainfall and use water tracer in models to track their transit over land.
MCS contributes more to runoff b/c higher intensity exceeds amount of rainfall the soil is able to hold. Non-MCS contributes more to evapotranspiration.
Earlier-season MCS rainfall has an impact on July rainfall by introducing a moisture gradient over soil.
Nighttime MCS rain occurs over wetter soil, strongly coupled with earlier-season MCS rainfall that can wet soils with longer timescales.
Future: Tracer-enabled coupled WRF simulations to understand processes. Long term, ML to better quantify movement of water through land.

6. Binod Pokharel: Diagnosing the August 2020 Midwest Derecho
Was this associated with MP (Mid trop perturbation) and are there trends in MPs over the midwest?
This event destroyed ~ 50% of crops in Iowa.
Hail damage, high winds, tornadoes were reported up to 2 days ahead of the event in neighboring states.
MP was less frequent over Iowa.
There was divergence over Iowa in the upper troposphere during the week before.
August -- increasing trend in MPs in Iowa. Not in July. Smaller trend in June.
Future = improve predictions of extreme events in climate models. What are important conditions that lead to these event?

7. Nandini Ramesh: The Globally Coherent Pattern of Autumn Monsoon Precipitation

There are tropical regions on multiple continents where the peak rainfall occurs in autumn, accounting for more than 50% of annual rainfall. These are typically narrow strips along eastern coastlines. A simple model of orographic rainfall accounting for only stable upslope flow significantly underestimates rainfall amount and predicts timing of annual rainfall peak incorrectly. Rainfall also doesn't peak when ITCZ is directly overhead. A moisture budget shows convergence is the dominant term. Upward motion at all vertical levels occurs in autumn, suggesting deep convection. A relative SST metric is able to capture the timing of rainfall correctly, showing that local SST as well as large-scale conditions over the tropics set the conditions for convection in autumn in these regions.
Future: Variability on intraseasonal to interannual timescales. Evaluation of CMIP6 model representation of this, esp in HiResMIP.

8. Robinson Negron-Juarez: The Association Between Extreme Rainfall Events and Forest Dynamics in the Amazon
Wind events that uproot trees are the main cause of tree mortality in the Amazon.
Preferentially east-west winds cause this
Consistent with the MCS propagation direction
Using 90th percentile on rainfall (6 mm/hour), extreme rainfall events accounted for >50% of tree mortality events.
Using Edy2 model - used wood density data to assess species based on residence times.
MCS spatial pattern is able to explain spatial pattern of ecosystem variability
Extreme rain & MCS spatial pattern are v similar.

Data and analysis discussion:

Radar data -- now that we have Doppler radar, we are able to distinguish different forms of precipitation over CONUS
Satellite data has quite large uncertainty in precipitation estimates and especially doesn't clearly distinguish between stratiform and convective rain. Radar data is an important ground truth with which to compare satellite-based estimates.
Impacts of convection can be both precip and winds - in the Amazon the winds are the main feature responsible for impacts, and downdrafts are a possible culprit but not well-observed. Field work on this could be a cross-cutting project with the ecosystem group. Important to base dataset development on the needs of communities based on impacts -- many datasets will need joint/multivariate distributions to be useful e.g., wind speed and precip.

Environment for convection:
This is key to many of the types of convection discussed in our session. E.g. the Derecho needed northwesterly flow and MPs.
One direction to explore the relationship between convection and the environment -- developing indices parallel to TC community's GPI which is useful for connecting to large-scale climate conditions and climate modes such as MJO or ENSO.
Important to consider the feedback of the convection on to the large-scale conditions as well.

Important to consider the role of stochasticity and natural variability in examining relationships between storm environments and convection development.
There may be unknown but important processes missed from traditional “storm ingredient based analysis” techniques (observed storm and compared environments). Given similar types of observed environments, how often do storms occur and why? How can we develop better tools to identify different types of storm environments to better understand other factors (e.g. land-atmos feedback) that also play important roles in organizing convection? How can ML techniques help?

Surface-land interactions:
Do tree root depths correlate with soil moisture percolation depths that can be connected to the typical rainfall patterns from a region?

Studies interested in MCS need specialized field data from specific locations where these events occur (e.g., the western Amazon, where field studies have not had as much coverage).

Model development, sensitivity, and evaluation talks:

9. Bryce Harrop: Conservation of dry air, water, and energy in CAM and its impact on tropical rainfall

CAM assumes that dry air + water vapor mass is fixed during the physics parameterizations, which requires an adjustment be made after water vapor is lost to conserve dry air mass. This adjustment process exposes an inconsistency in CAM’s energy budget where water is allowed to have sensible energy only in its vapor phase. In other words, when water vapor condenses the sensible energy of that water is no longer kept track of by the model. This inconsistency results in a large energy tendency that is spatially coherent with water vapor tendencies in the atmosphere.
They ran an experiment where the energy was “returned” to the dry air and uncondensed water vapor. This results in significant increase in mean rainfall and rainfall variability. So the hydrological cycle is quite sensitive to the treatment of water in the energy budget.
An example of a more realistic portrayal was given using a rigorous treatment of the surface enthalpy flux of water that includes terms frequently neglected by earth system models. The missing terms are spatially similar to the energy error from the adjustment, suggesting the hydrologic cycle will be sensitive to these missing terms.

10. Koichi Sakaguchi: Resolution-Sensitivity of the Hydrological Cycle over North America in the CAM-MPAS Variable-Resolution Framework

GF scheme improves precipitation diurnal cycle phase compared to ZM during summer in Central U.S., but biases are still apparent compared to observations
GF increases convective precipitation with finer grid spacing, opposite to ZM
GF captures significantly more MCS rainfall over US than ZM but not the maximum in the northern midwest

The JJA mean heating profiles do not change much with resolution with both schemes, but cloud ice profiles are sensitive to resolution, especially with GF, implying potential impact on tracking MCSs because OLR is used for tracking
In the next 3-10 years, dynamical downscaling experiments will be done by the combination of high-res global model (~30km grid) and convection-permitting limited area models (a few km grid spacing), and/or VR models with refinement down to convection permitting resolutions.

- This combination is about X 20 or more expensive than the current combination (~1° grid GCM + ~20km RCM)
- The 3D turbulent flows at scales below ~10km is more difficult to understand; less simplified underlying dynamic/thermodynamic equations -> need to analyze more terms in more equations for process understanding. And the flow behaves more randomly, so to detect a signal we are interested, especially with non-uniform boundary conditions, we will need ensemble simulations (Yano et al., 2018; Emmanuel 2020).
- The increasing computational cost and more complex workflow call for even more organized collaborations among RGMA projects and more stable and sustainable computing resources

11. Rebecca Barthelmie: WRF Modelling of Deep Convection and Hail
Hail from severe convective storms causes blade leading-edge erosion on wind turbines, costing billions of dollars. As wind farms in the SGP increase and the turbines get larger, this becomes a bigger problem.
Estimate the KE transfer from the hail and rain to the turbine blade. Hail transmits > 500 times more KE than rain.
Hail typically occurs at wind speeds where turbines are operating so this has a large impact.
Is WRF able to model the conditions that lead to hail?
WRF is skillful for most sites tested in TX.
Tested both high-hail and low-hail events
Running at 1.3 km resolution - important for processes that have impacts on wind farms.
Research needs - need to use ensemble simulations, and validate with obs

12. Stefan Rahimi: A framework for dynamical downscaling of CMIP6 simulations in the western US
Sub 10-km resolution is highly in demand
Use WRF v4
Testing: validate over the western US
Downscaled ERA5 onto grids
How to select GCMs?

- Need to have sufficient consistent data that satisfy WRF requirements
- Historical biases in temperature

Results are being set up to be accessible, user-friendly
Daily avg variables, hourly variables for some - up to 2100
There are biases but these vary depending on region considered

13. Hongchen Qin: Summertime convection and surface climate over the Central U.S. in a regional convection-permitting simulation
Soil moisture errors might lead to underestimate of evaporation from surface
MCS is well-captured by the hi res simulations (4 km, 65 levels)
Warm bias over kansas and nebraska in both simulations with Morrison and Thompson microphysics, Thompson has larger biases in evap frac and precip
Non-MCS precip is associated with large warm bias in diurnal cycle of T2m
T2m bias are consistent across the diurnal cycle
T2m bias is largest in non-MCS precipitation, larger than non-MCS w/o precipitation and MCS precipitation periods

14. Hsi-Yen Ma: Evaluation of precipitation characteristics in global convection permitting models
Evaluation of DYAMOND project - an intercomparison between the convection-permitting models (CPMs)
Each modelling group performed 1 40-day hindcast
DYAMOND models simulate the PDF of rainfall over the tropics better than CMIP6, esp for intense precip, which CMIP6 underestimates.
Summertime propagation of convection from Rockies to Great Plains. Rain usually starts in the afternoon. Captured well by CPMs, as is nocturnal propagation of convecting systems. There are still biases in the precip, however.
Future - study processes with aim of guiding GCM development

15. Zhe Feng: Evaluation of mesoscale convective systems in climate simulations: methodological development and results from MPAS-CAM over the U.S.
Aim: to evaluate MCS-like features in GCMs to compare with obs
Adapted a tracking algorithm used on obs to climate models.
Downscales the radar obs of MCS to GCM resolution to identify the features associated with MCS at these scales.
MCS frequency is underestimated in simulations (in central CONUS)
Used SOMs associated with the MCSs in obs. GCMs are able to simulate these but not with enough frequency. Biases come mainly from low-level moisture and the meridional wind field.
Future: looking at this globally, and combining with process-oriented metrics to evaluate models.

16. Samson Hagos: A relationship between the vertical structure of convection and tropical precipitation climatology in CMIP6 simulations

Excess precip over trop oceans and dry bias over trop land in last few generations of CMIP. Does this relate to convective processes?
Representation of P - PW relationship. Intense precip is controlled by moisture convergence, results in intense precip over evaporative regions off the equator
Vertical structure is key to getting this right. Therefore cloud structure and associated precip is important to represent correctly.

17. Melissa Bukovsky: SSP-based land use change scenarios: a critical uncertainty in future regional climate change projections
CORDEX WRF simulations as baseline (doesn't include land use change)
SSP3 - dominated by change in crops
SSP5 - change in urban land use
Warming due to urban land use change alone is comparable to that from GHG forcing alone
Crop expansion leads to cooling
Precip & convection intensify over east coast urban areas, but are suppressed in surrounding areas
Future land use do matter to local climate change
Warmer in urban area
Crop change decreases surface temperature
Convection, intensity and precipitation in urban area is enhanced
Future: higher resolution for LUC, different model configurations, sensitivity of simulation to how LUC is represented.

Jiwen Fan: Urbanization effect on convective intensity and hazardous effects and climate change on hailstorms
Key results:
The joint effects of urban land and anthropogenic aerosols on precipitation, intensity, and severe hails are larger than either of the individual effects, as well as the sum of the both effects on hails. Both effects need to be considered in order to reasonably simulate the observed storm. The joint effects and the relative importance of urban land and aerosol effect strongly depend on storm types and associated environmental conditions, emphasizing resolving storm dynamics is key for accurately simulating their effects. These are from two studies Fan et al. (2020, ACP) and Lin et al. (2020, JAS, in review).
About anthropogenic climate change (ACC) on hailstorms, we find that the contrasting responses of the two major types of hailstorms in the Central US. Frontal system-associated hailstorms are sensitive to ACC with 60% increase in severe hails while Great Plains jet systems are not, mainly because convective intensity of the frontal systemes is enhanced by the increased CAPE, favorable for hail and graupel formation and growth.
Future work: Study how future ACC and urbanization impact extreme precipitation and hail using CPM (WRF-Chem) in the near future. Over the long term, use E3SM RRM and SCREAM.

Model development, sensitivity, and evaluation discussion:

Cloud microphysics (1 or 2 moment schemes) play important role in simulation of precipitation
Excessive size sorting could cause large heavy rain
Without coupling with aerosols could cause overestimating light precipitation
Most GCPMs do not have interactive aerosols, may be contributing to the bias

Voice the need for a dedicated supercomputer for RGMA activities?
Global CPM models are much more chaotic compared to parameterized models (mean), we need ensembles of simulations
Articulate sciences need for GCPM type of simulations

Land use change is prescribed in current WRF implementation, no gradual “evolution”
Changes in convection is largest over urban areas. Precipitation is more intense and lasts longer over urban areas. But simulations are only 25km grid spacing, unclear how it would behave in higher resolution.

Future warming shifts critical PW to the left and favor tropical convection ultimately

Large suite of physics options in WRF makes it difficult to choose optimize physics that produce smaller biases in climate simulations

How much do we understand various factors that control summer MCS? This is also a challenge for models of various complexity to simulate MCS.

Output MSE components in global models to better diagnose the water vapor budget.