Pacific Northwest NATIONAL LABORATORY

Understanding Physical Factors Impacting Past and Future Severe Convective Storms in the Central United States

Jiwen Fan

jiwen.fan@pnnl.gov

Acknowledgement:

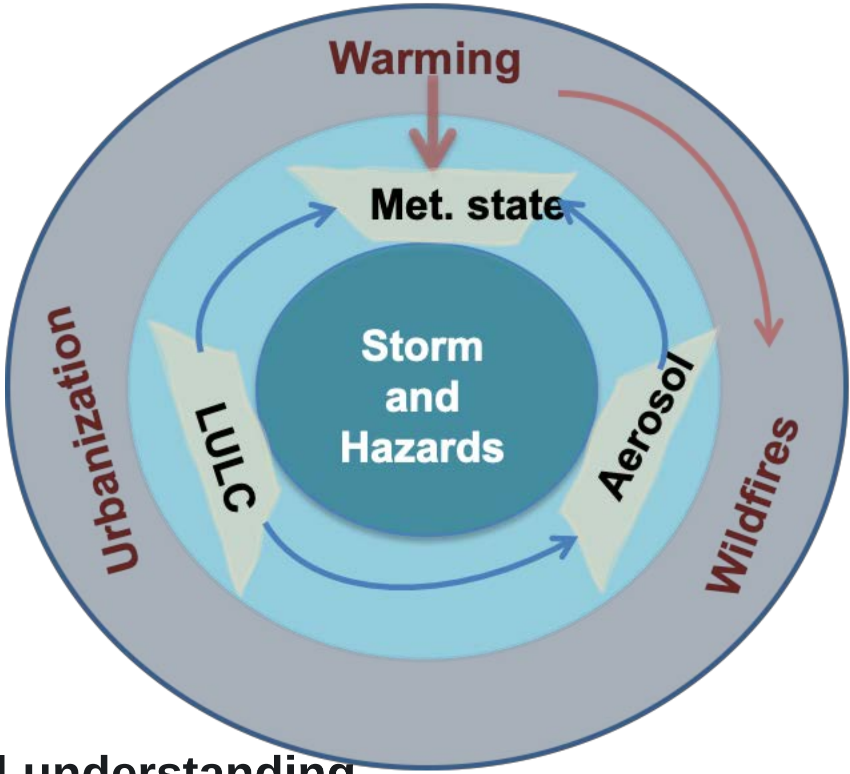
- Collaborators particularly my postdocs: Yuwei Zhang, Jong-Hoon Jeong, Yun Lin, Jingyu Wang
- DOE Early Career Research program

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Background and Motivation

- Robust prediction of severe convective storms (SCSs) and associated hazards (hail, tornado, flash floods, etc) is not possible with the current climate models because of coarse resolutions and poor understanding of physical factors impacting them.
- In the past decades environmental factors such as global temperature, land use and land cover (LULC), and anthropogenic aerosols, were significantly changed and will continue changing in the next a few decades.



Science questions

Q1. What are the significant interactions of storm dynamics with physical factors of anthropogenic warming, urbanization, and wildfires that affect SCS occurrence and intensity?

Q2. What are the joint and respective effects of those factors on SCS characteristics in the present-day and future climate over the Central United States?

Approach

Step 1: Process-level understanding Completed

Conduct WRF/WRF-Chem simulations at cloud-resolving scales and observational analysis to improve our understanding of the key interaction processes and effects.

Step 2: Long-term statistical effects Current focus

Conduct observational analysis and WRF-Chem simulations for 10 warm seasons (6 month per season) at the convection permitting scale over the central U.S. for the present-day and future climate, respectively.

Urbanization impacts on Storms

Objective

- Understand how urban land cover change and anthropogenic aerosols as a result of urbanization jointly and respectively affect storm properties.

Approach

- Conduct WRF-Chem-SBM simulations at 0.5-1 km grid-spacings for two different types of convective storms: **a supercell storm** influenced by Kansas City producing hail, tornado, and strong wind during PECAN campaign and a **sea-breeze induced thunderstorm** occurring near Houston

General findings

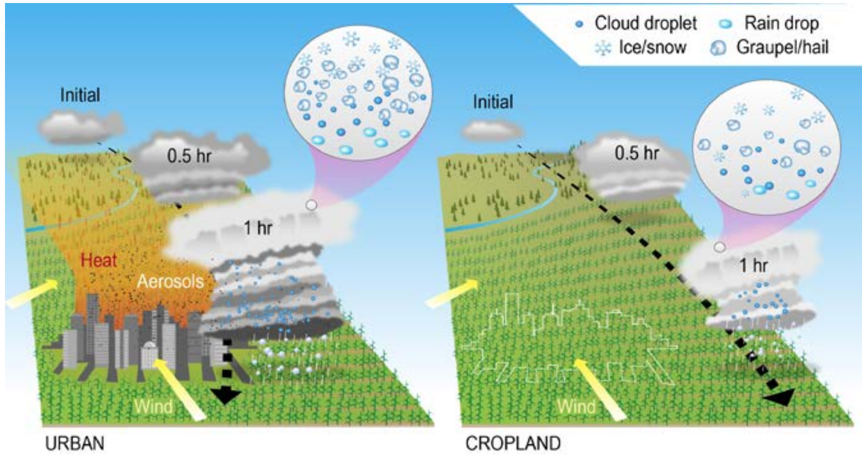
- The joint effect of urban land and anthropogenic aerosols is larger than either of the individual effect, significantly affecting storm dynamics, evolution, precipitation, and hail frequency and size.
- The relative importance of the urban land effect to the aerosol effects strongly depends on storm types and associated environmental conditions, emphasizing resolving storm dynamics is key for accurately simulating their effects.

Fan, J., Zhang, Y., Li, Z., Hu, J., and Rosenfeld, D. (2020). Urbanization-induced land and aerosol impacts on sea breeze circulation and convective precipitation, Atmos. Chem. Phys., https://doi.org/10.5194/acp-2020-411, 2020.

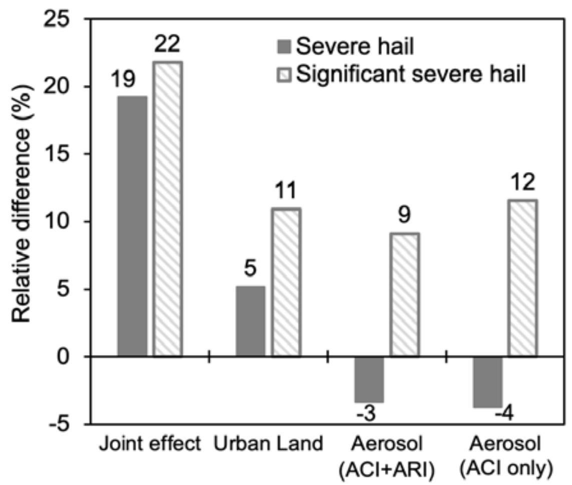
Lin, Yun, Jiwen Fan, Jong-Hoon Jeong, Yuwei Zhang, Cameron R. Homeyer, Jingyu Wang (2020). "Urbanization-induced land and aerosol impacts on storm propagation and hail characteristics." Journal of Atmospheric Science, in revision.

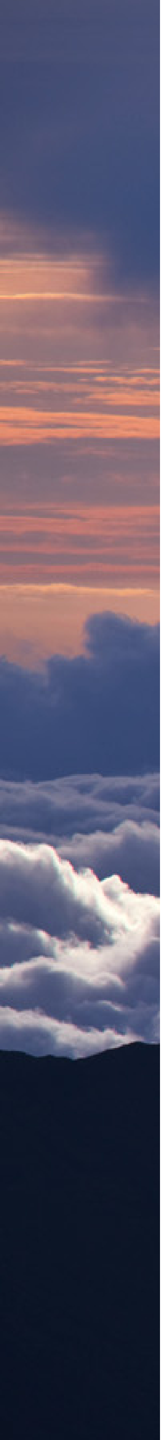
Kansas City supercell

Urban land effect on storm initiation and propagation path



Impacts on hailstones

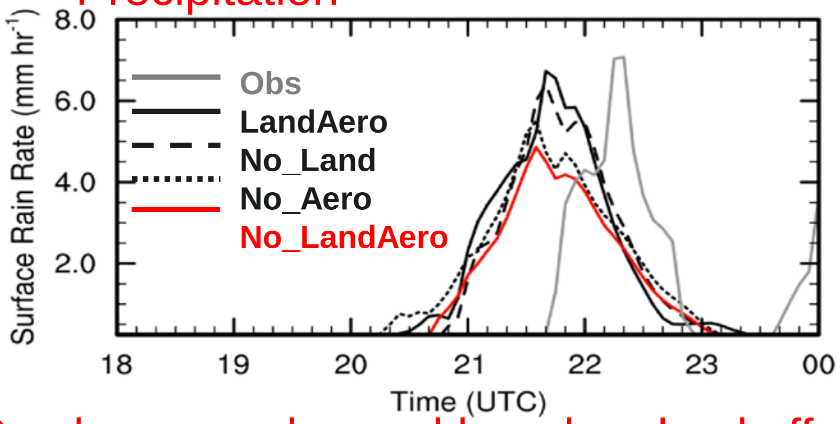




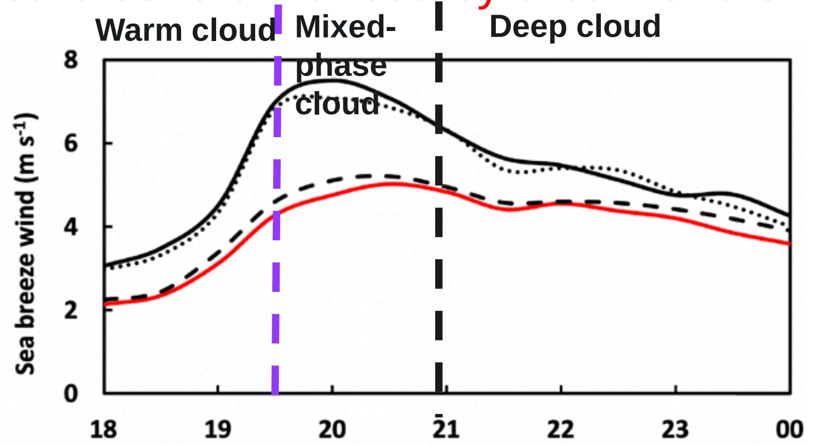
Houston thunderstorm

- The joint effect drastically enhances storm intensity and precipitation, with the anthropogenic aerosol effect more significant than the urban land effect.
- The urban land effect strengthened sea breeze circulation, leading to faster development of the deep storm and earlier rain.

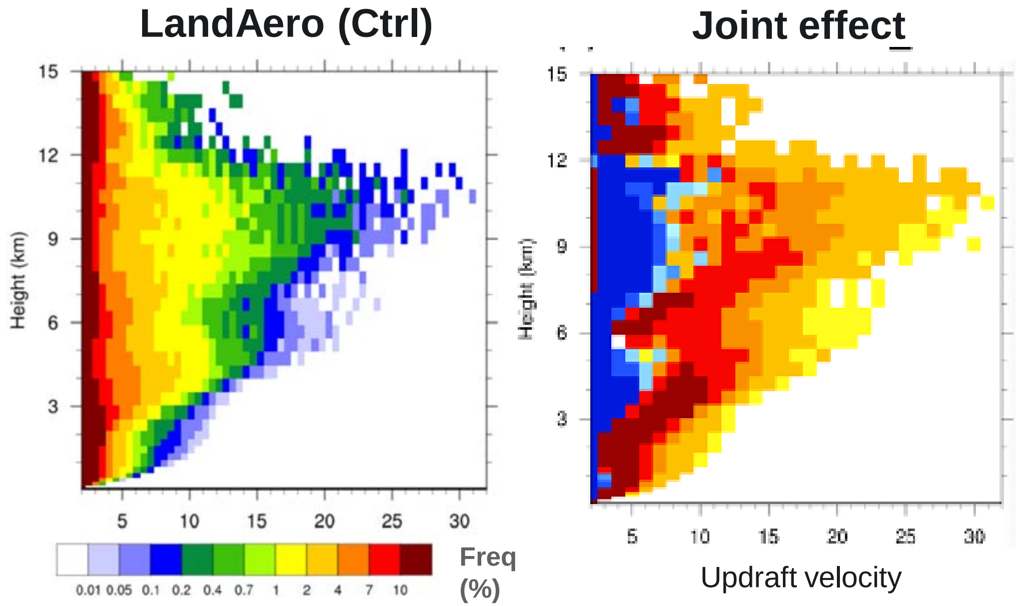
Precipitation

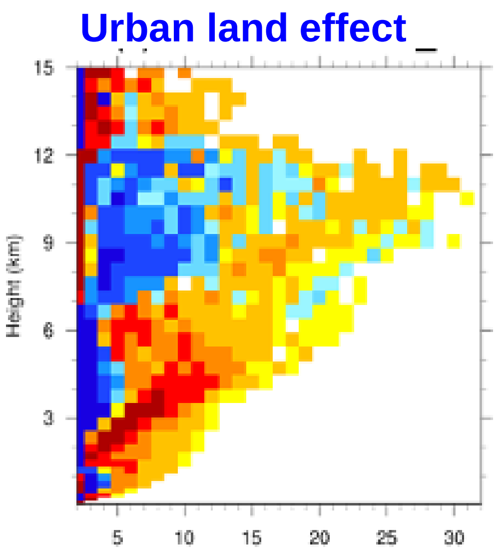


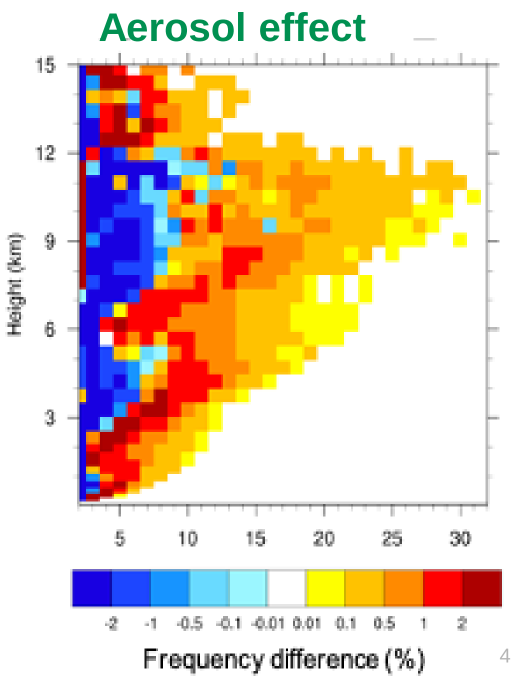
Sea breeze enhanced by urban land effect



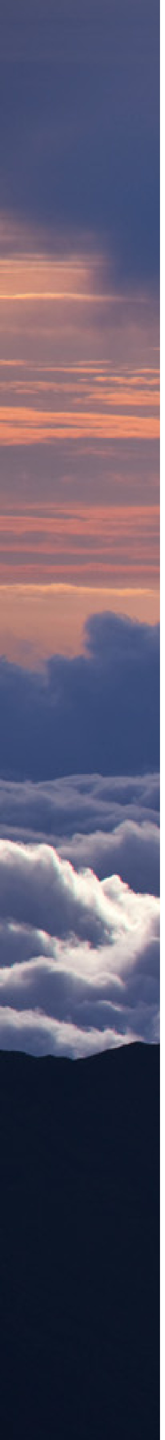
Convective intensity







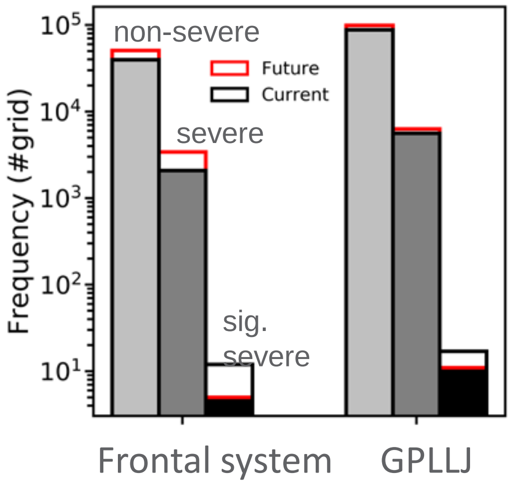
Breakout of Cloud and Aerosols



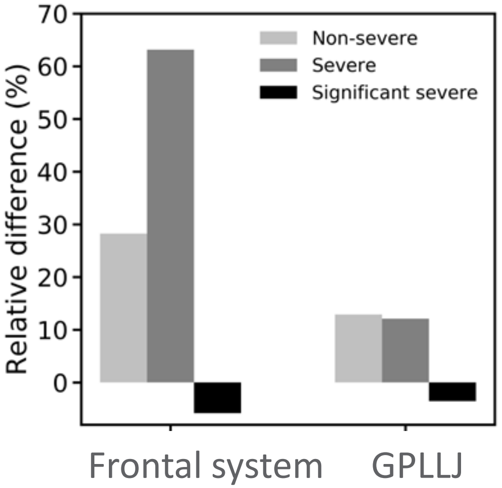
Anthropogenic climate change (ACC) impact on hailstorms

- Selected typical hailstorms in spring over the central US, which are generally under **two major** synoptical scale patterns
- Conduct **1-km WRF** simulations with NSSL. Used RAP to drive the present-day simulations and employed the pseudo-global warming (PGW) approach with the fields from **CMIP5 RCP8.5** simulations to drive the future runs.

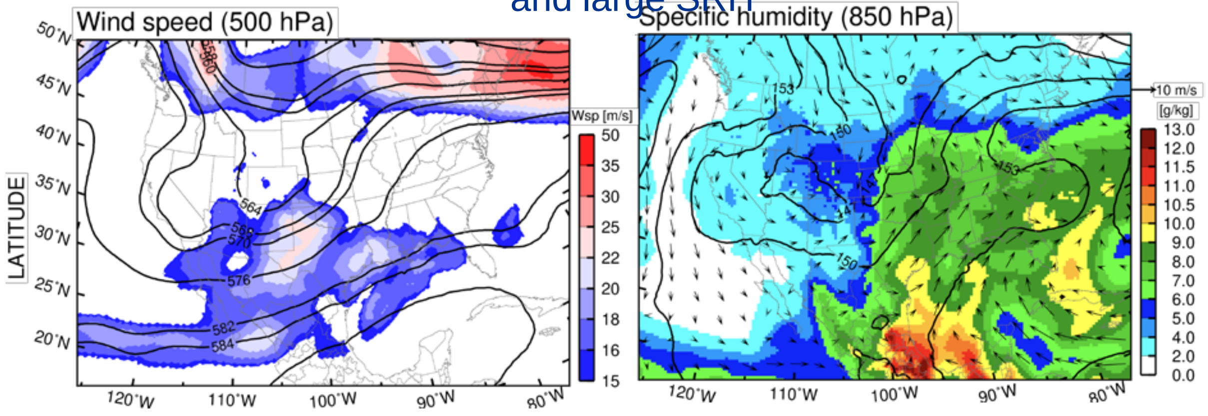
Hail occurrences



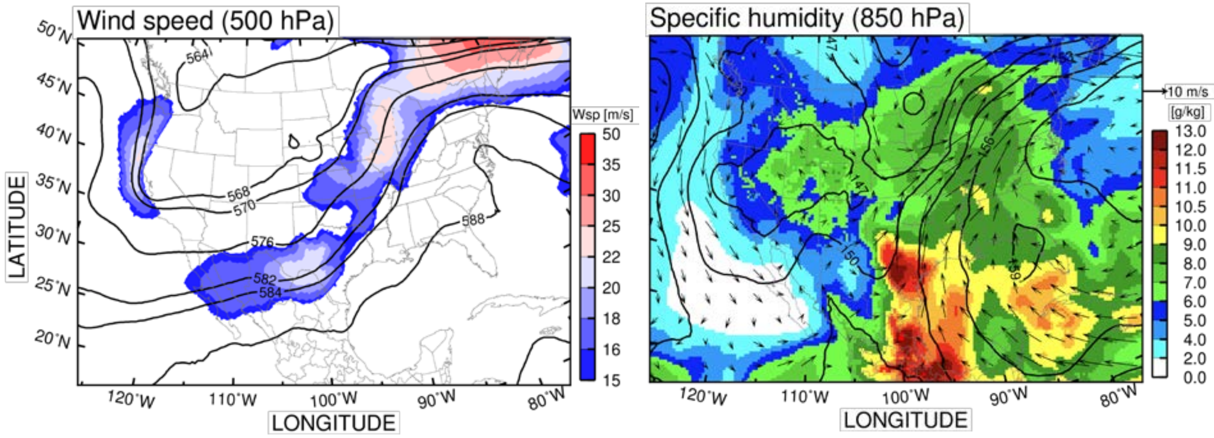
Relative difference



Three frontal systems cold T, low CAPE, strong wind shear, and large SRH



Three Great Plains Low-level Jets (GPLLJ) Warmer T, high CAPE

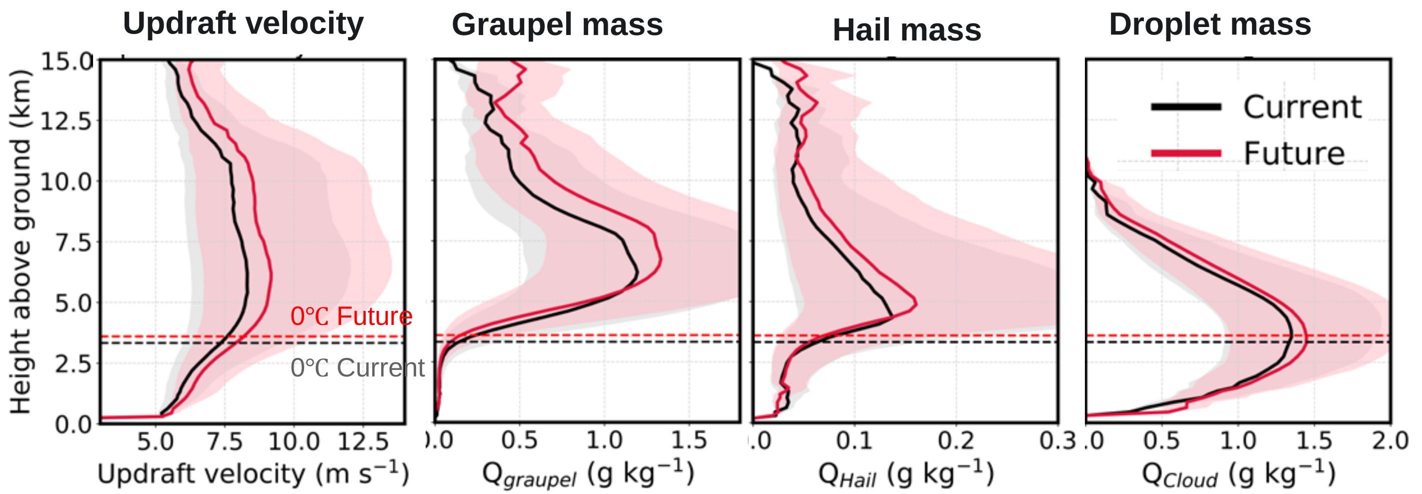


- Frontal systems have over 60% more severe hail (2.5 < diameter < 5.0 cm), whereas for GPLLJ, less than 10%.
- Responses of met. variables to ACC are similar between the two types of storm systems

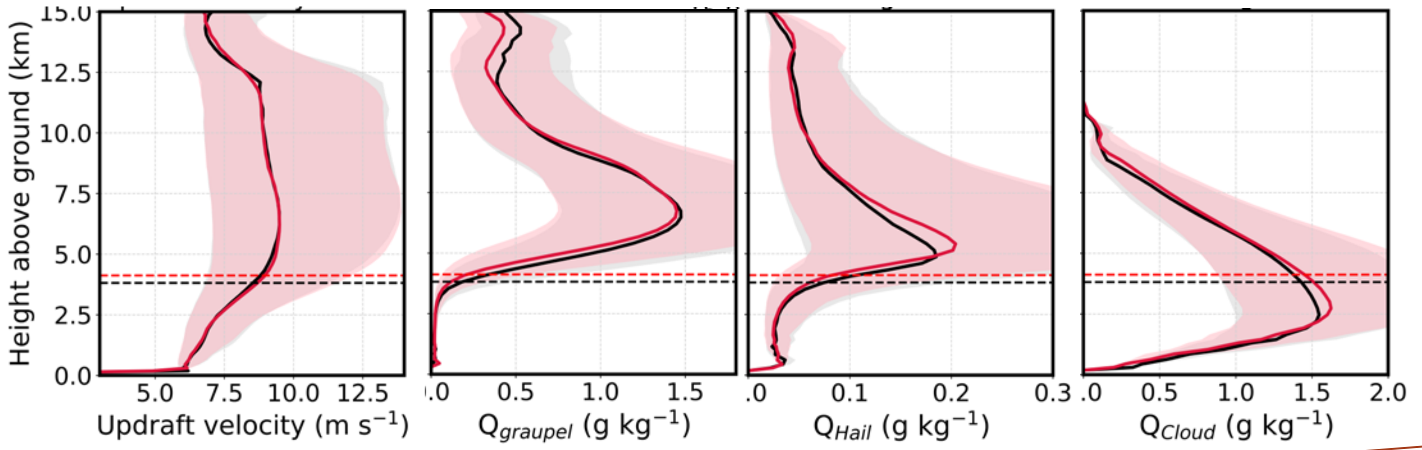
Fan, J., J.-H. Jeong, Y. Zhang, "Contrasting responses of hailstorms to anthropogenic climate change", in preparation

Cloud dynamics and microphysics

Frontal system



GPLLJ



- Frontal systems: updraft intensity is enhanced, more favorable for graupel/hail formation and growth
- GPLLJ: convective intensity is not sensitive to the met. change induced by ACC, probably because the intensity is already too strong in the present-day

- GPLLJ cases have a larger warm cloud layer depth than the fronts and a larger increase of WCLD (90 vs. 320m) by ACC may also contribute to the smaller effect.

Improve understanding the predictability of hailstorms by linking with the synoptical–scale patterns

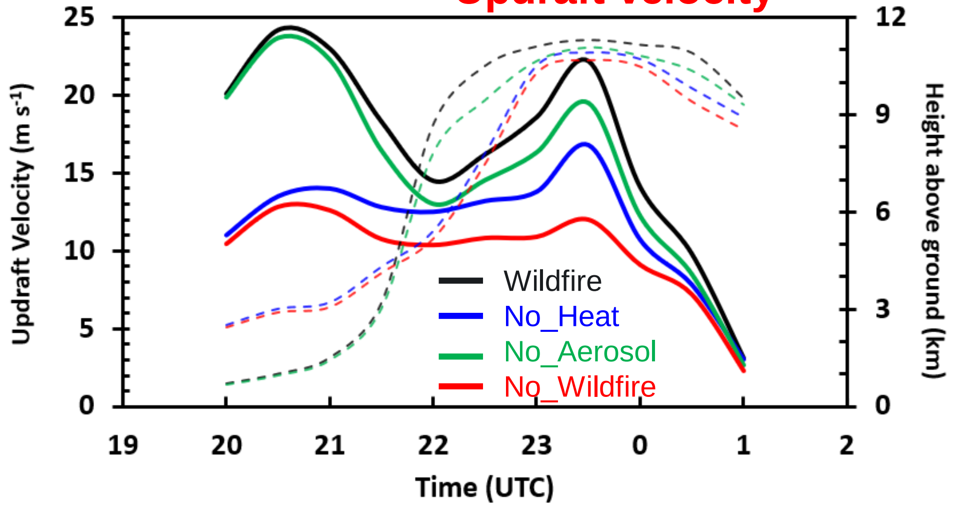
Wildfire Impact on Environmental Thermodynamics and Severe Thunderstorms

Objective

- Build a computationally efficient model capability to forecast wildfire impacts on severe storms (**consider heat impact**)
- Quantify the roles of **wildfire heat and aerosols** in storm severity such as hail and lightning

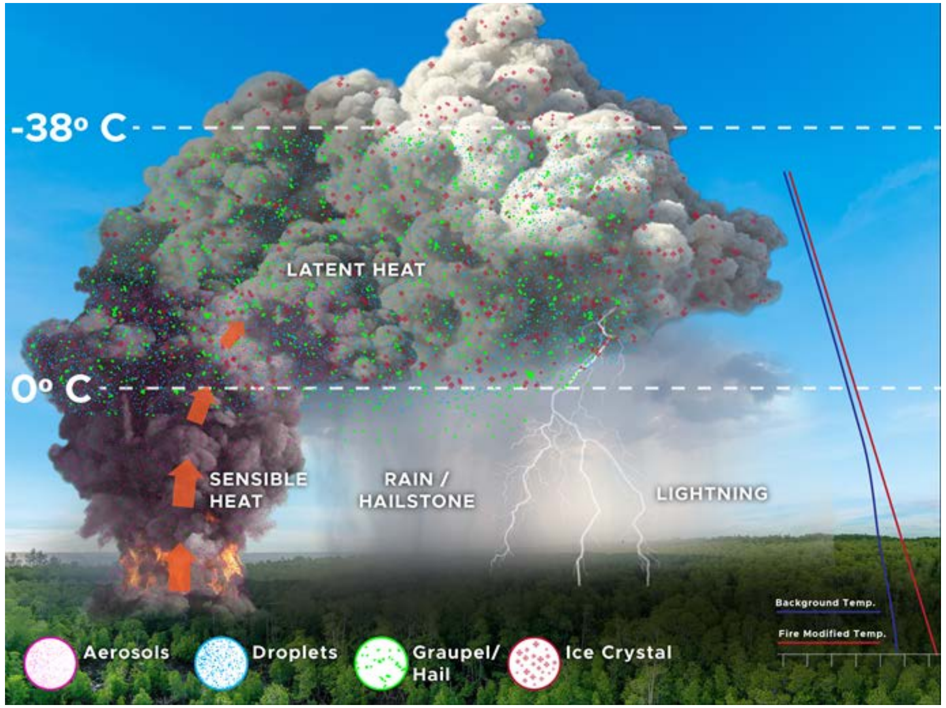
Approach

- Developed the heat flux parameterization and apply it to a real pyrocumulonimbus event that produced hailstones and lightning
- Carried out model sensitivity studies to understand respective heat and aerosol effects



Key points

- Both the heat and aerosol emissions from wildfires invigorate the pyro-convection, enlarge hail size, and enhance lightning
- The heat plays a predominant role in triggering a strong storm but aerosols play a significant role in enhancing storm intensity, hail, and lightning after storm is initiated.



Zhang, Y., Fan, J., Logan, T., Li, Z., and Homeyer, C. R. (2019). Wildfire impact on environmental thermodynamics and severe convective storms. Geophysical Research Letters, 46, https://doi.org/10.1029/2019GL084534

Factors Contributing to Large Hail Annual Variability over the U.S. Great Plains

Objective

- Understand the important factors contributing to the annual and seasonal variability of hailstones in the Central U.S., which improves its prediction

Approach

- Analyzed hail spatial and temporal distribution using reports from the Storm Prediction Center and the newly developed radar retrieved maximum expected size of hail (MESH).
- Composited the large-scale environment data including aerosols to reveal the possible factors contributing to the hail occurrences observed from 2004 to 2016.

Key findings

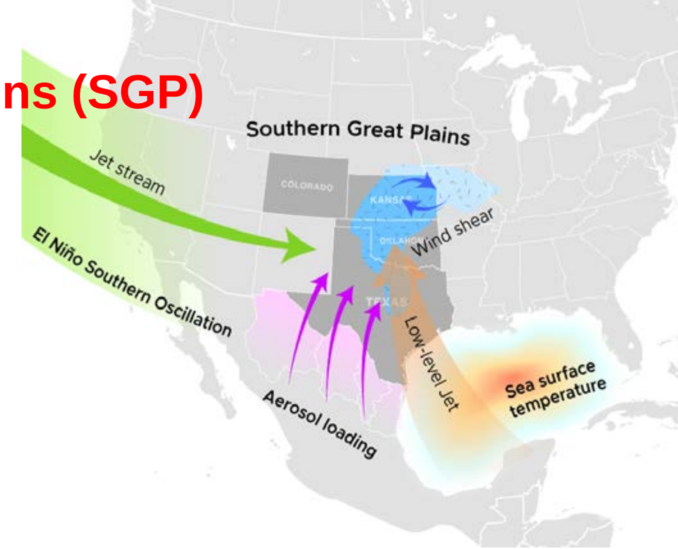
- Severe and significant severe hail occurrences have considerable year-to-year temporal variability in the Great Plains.
- important factors impacting hail interannual variability over the NGP are quite different from those for the SGP, except ENSO.

*Jeong, J.-H., J. Fan, CR Homeyer, and Z Hou. 2020. "Understanding hailstone temporal variability and contributing factors over the United States Southern Great Plains," Journal of Climate, **33**: 3947-3966. DOI: 10.1175/JCLI-D-19-0606.1.*

*Jeong, J-H., J. Fan, CR Homeyer. 2020. "Spatial and temporal trends and variabilities of hailstones in the United States Northern Great Plains and their possible attributions," Journal of Climate, **in revision**.*

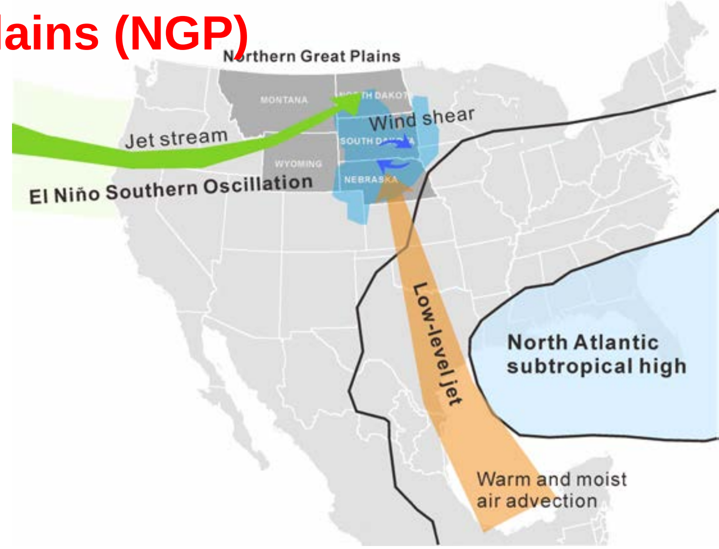
Southern Great Plains (SGP)

- Aerosol loading from Northern Mexico
- SST anomalies over the northern Gulf of Mexico
- ENSO



Northern Great Plains (NGP)

- North Atlantic subtropical high (NASH)
- Low-level jet (LLJ)
- ENSO



Pacific Northwest NATIONAL LABORATORY

Other major studies

- Aerosol impacts on various types of MCSs (Chen et al., 2020, JGR)
- Long-term statistical relationships of hail and tornado with mesoscale convective systems (Wang et al., to be submitted)
- Effect of wildfires in Western U.S. on synoptical-scale processes and severe convective storms over Central U.S. (in preparation)

Breakout of Extremes

Next work

- Long-term WRF-Chem CPM studies for statistical results on the impacts of warming, urbanization, wildfires, etc.
- Employ ML/AI to understand processes/factors affecting the predictability of severe convective storms.

Long-term goal

- Gain robust predictive understanding of SCS through RRM-CPM or global CPM modeling and ML/AI– based data analysis.