A new understanding of the relationship between precipitation and temperature via Pressure Change Events and its trend in climate change

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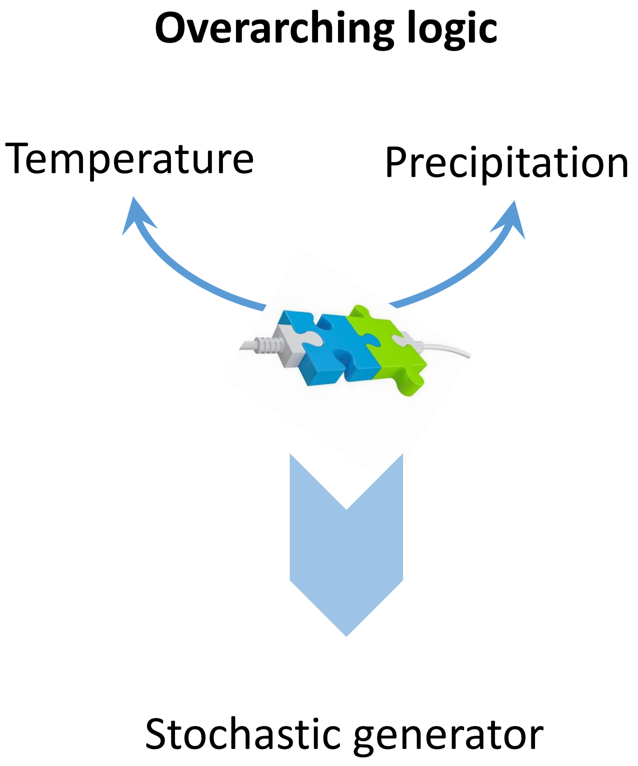
OVERVIEW OF PRESENTATION

Motivation and data

Knowledge-based modelling

- Climate change impact on precipitation
- Review of the atmospheric physics behind precipitation
- Underscored importance of pressure changes in precipitation formation
    - Specifically, in NE US
    - Relationship to the probability, and depth of precipitation
    - Association between precipitation and temperature



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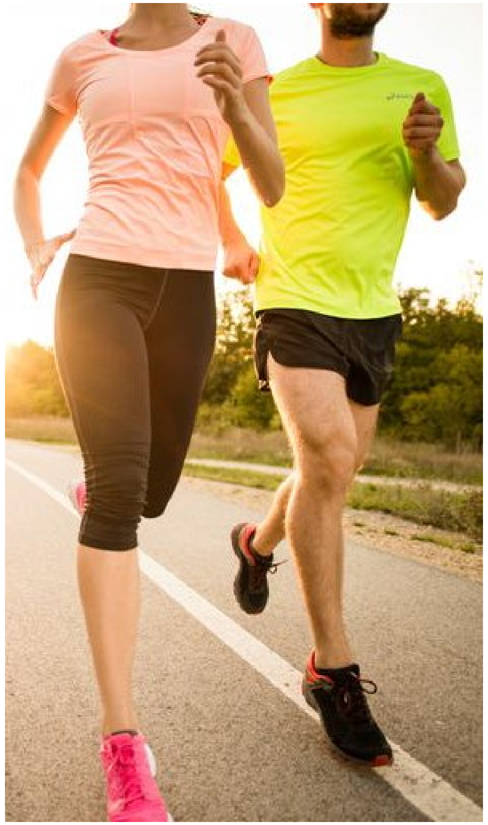
GOAL AND MOTIVATION

- **Develop an approach to include climate change considerations in hydrologic and hydraulic (H&H) models**

- **More specifically, Develop a data-driven stochastic precipitation generator with knowledge basis :**
  - Is physically realistic, e.g. is informed by the actual physical causes of precipitation
  - Utilizes only high confidence GCM outputs (e.g. Temperature)
  - Requires least manual tuning (e.g. parameter calibration)
  - Includes plausible extreme events



DATA AND VALID GEOGRAPHICAL AREA

Data sources

- NCDC airport gages in NYC, Boston, Philadelphia
- > 50 years of hourly precipitation, temperature, sea level pressure from each gage
- Over 1,000,000 rows of data

Data quality

- Gaps (1.04%)
  - Missing data
  - Cumulative period
- Inconsistent time interval

GCM projections:

- Monthly temperature projections for 2035~2099 generated by MIROC model with A2 scenario
- Provided by Dan Bader, Radley Horton

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KNOWLEDGE-BASED MODELLING

Precipitation change is evident. (Solomon, Qin et al. 2007, Trenberth 1988, Trenberth, Dai et al. 2003)

How to quantify?

- Why and how does precipitation change?
- What factors determine its extent?

<u>What is the force that draws moisture from air?</u>

Clausius-Clapeyron (CC) relation

- A warmer atmosphere has a larger saturation water vapor content
- CC relation interpret the interactions between “moisture-holding capacity” of the atmosphere, temperature and pressure
- An increase in the moisture-holding capacity of the atmosphere of approximately 7 % per degree temperature rise

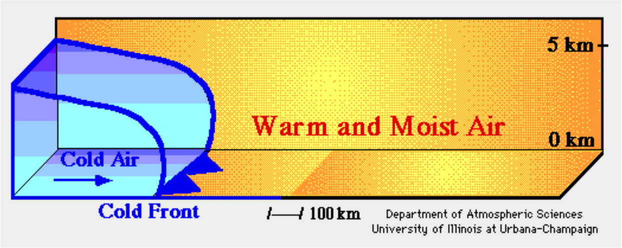
Increase in the moisture-holding capacity ≠ increase in the rain volume

- Extreme showers all water vapor in the air is converted into rain (7% increase rate)

ATMOSPHERIC CAUSES OF PRECIPITATION

Meteorological interpretation

- Moist air rises
- Air moisture saturation
- Moisture condensation
- Growth of the precipitation particles
- Type of air lifting
  - Frontal movement
  - Orographic effect
  - Local convection



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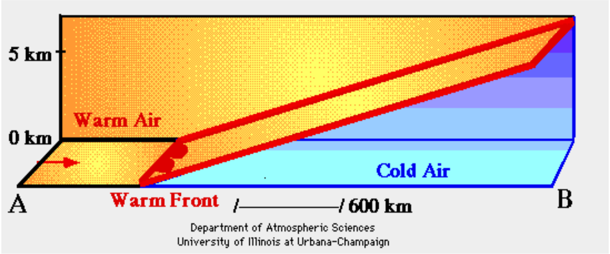

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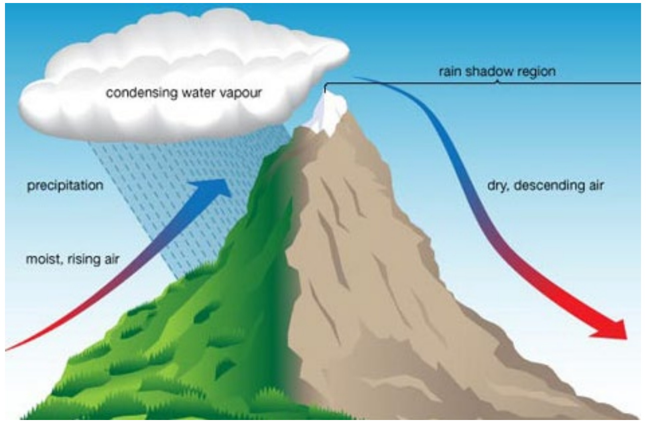
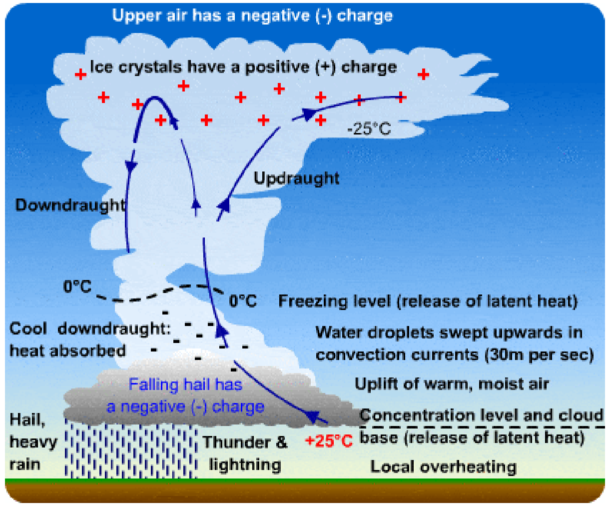


http://peter-mulroy.squarespace.com/how-do-clouds-and-precipitation-form/



https://www.s-cool.co.uk/a-level/geography/weather-conditions/revise-it/atmospheric-moisture-and-precipitation

Hypothesis:

- Air moisture is drawn by ***pressure decrease*** during precipitation formation

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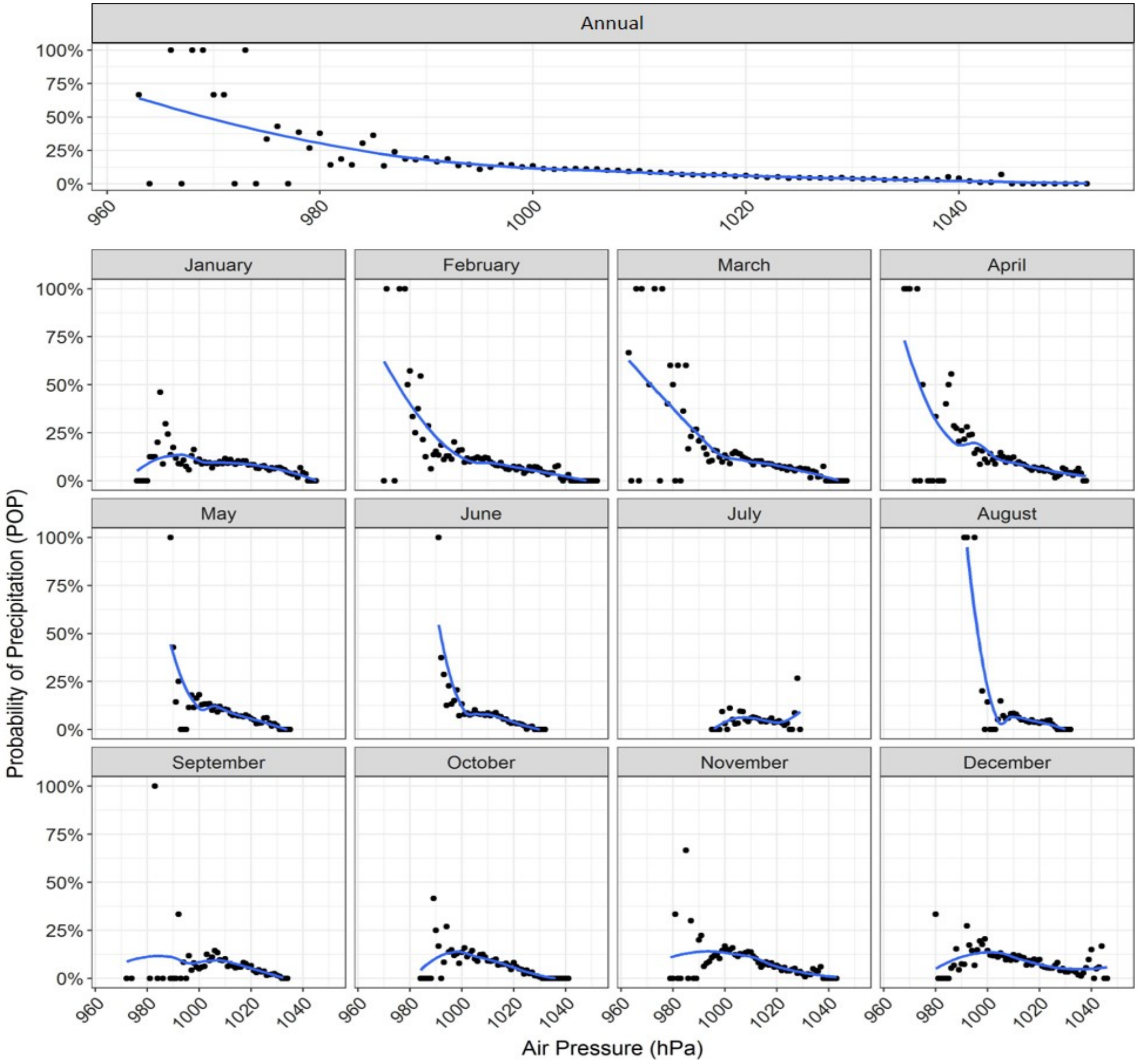
PRESSURE AND PRECIPITATION OCCURRENCE



Investigate on time step

Data from NYC LGA

Similar results in BOS and PHL

Precipitation is more likely to occur under low air pressure.

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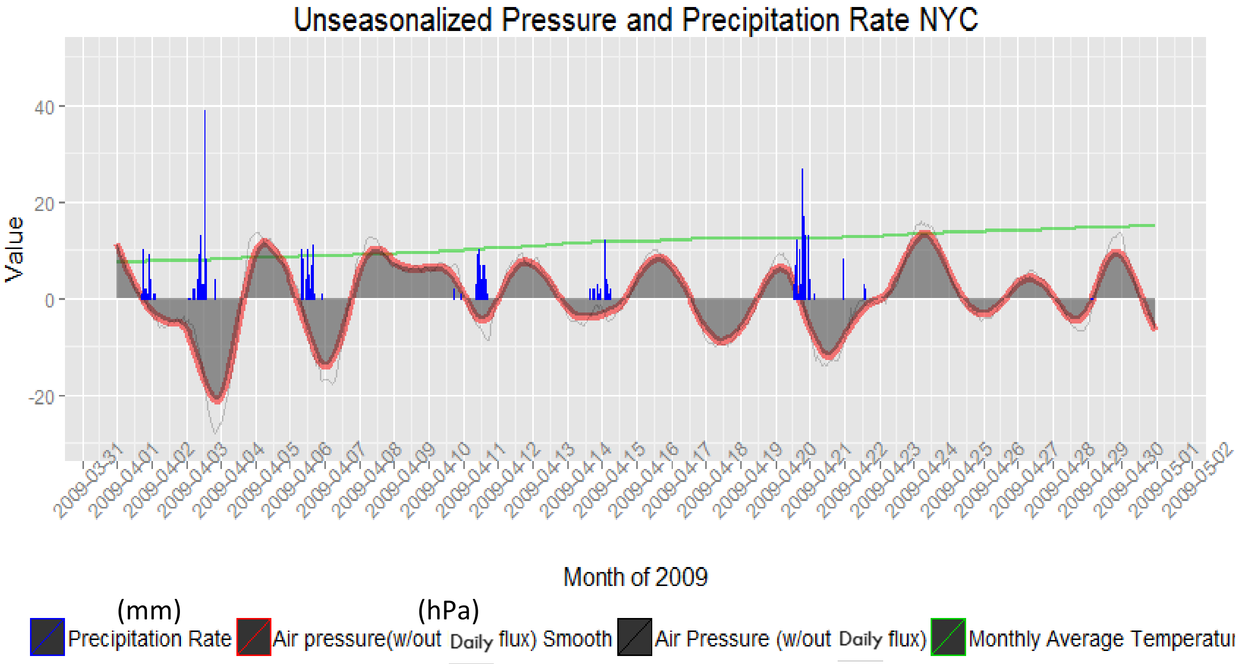
WHAT IS A PRESSURE CHANGE EVENT?

- Computed 24 hour pressure differences as pressure change (no daily fluctuation)
- Two pressure change events (PCEs)
  - Increase pressure change events (InPCEs)
  - Decrease pressure change events (DePCEs)



<u>Precipitation is more associated with DePCEs than InPCEs</u>

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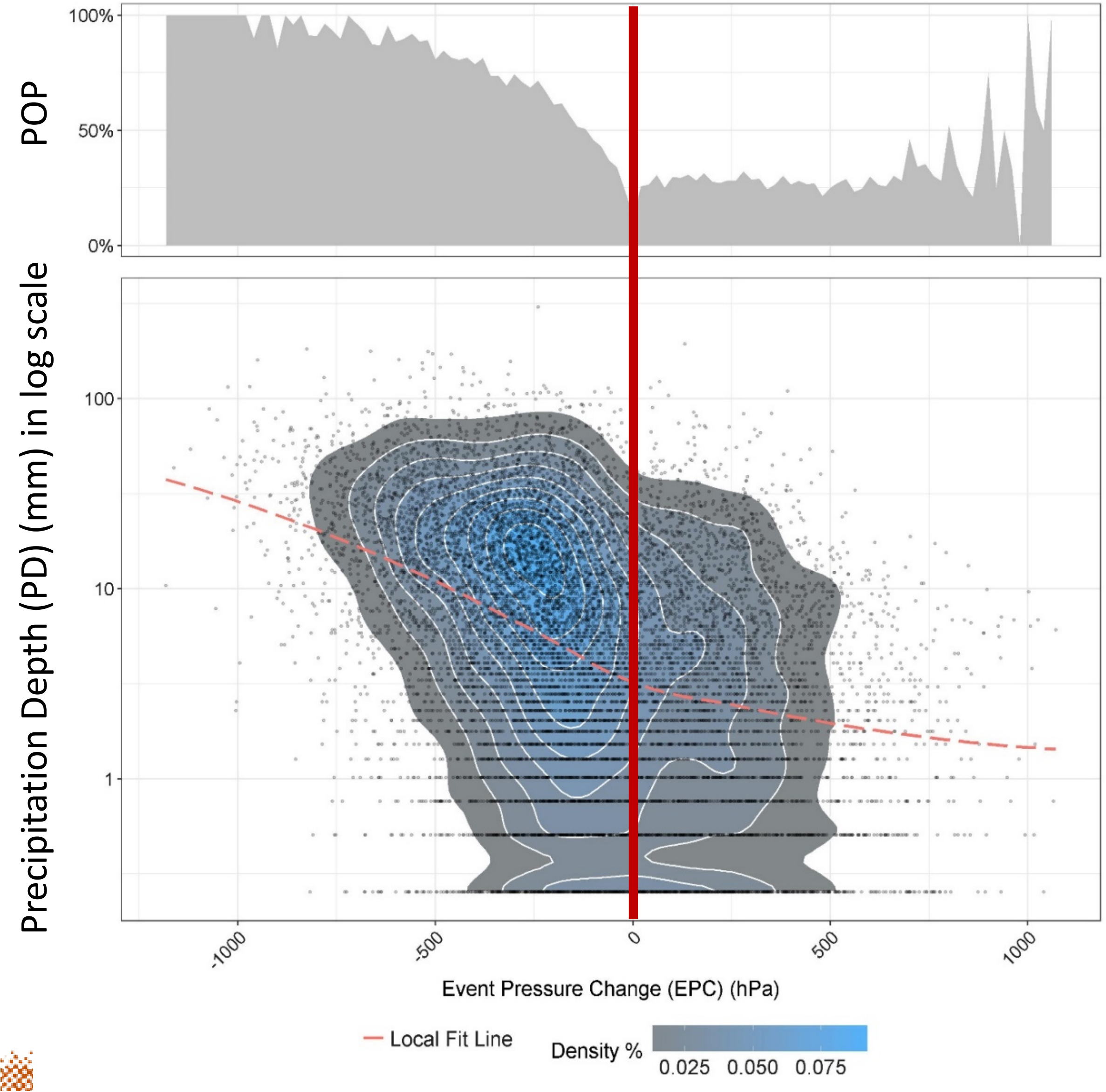
RELATIONSHIP BETWEEN PCE AND PRECIPITATION



InPCE:

- ~ 25% Probability of Precipitation (POP)
- Slight decrease of Precipitation Depth (PD) by EPC

DePCE:

- POP decreases on EPC
- PD decreases on EPC

PCE is a strong determinant of precipitation characteristics

PCE → Precipitation

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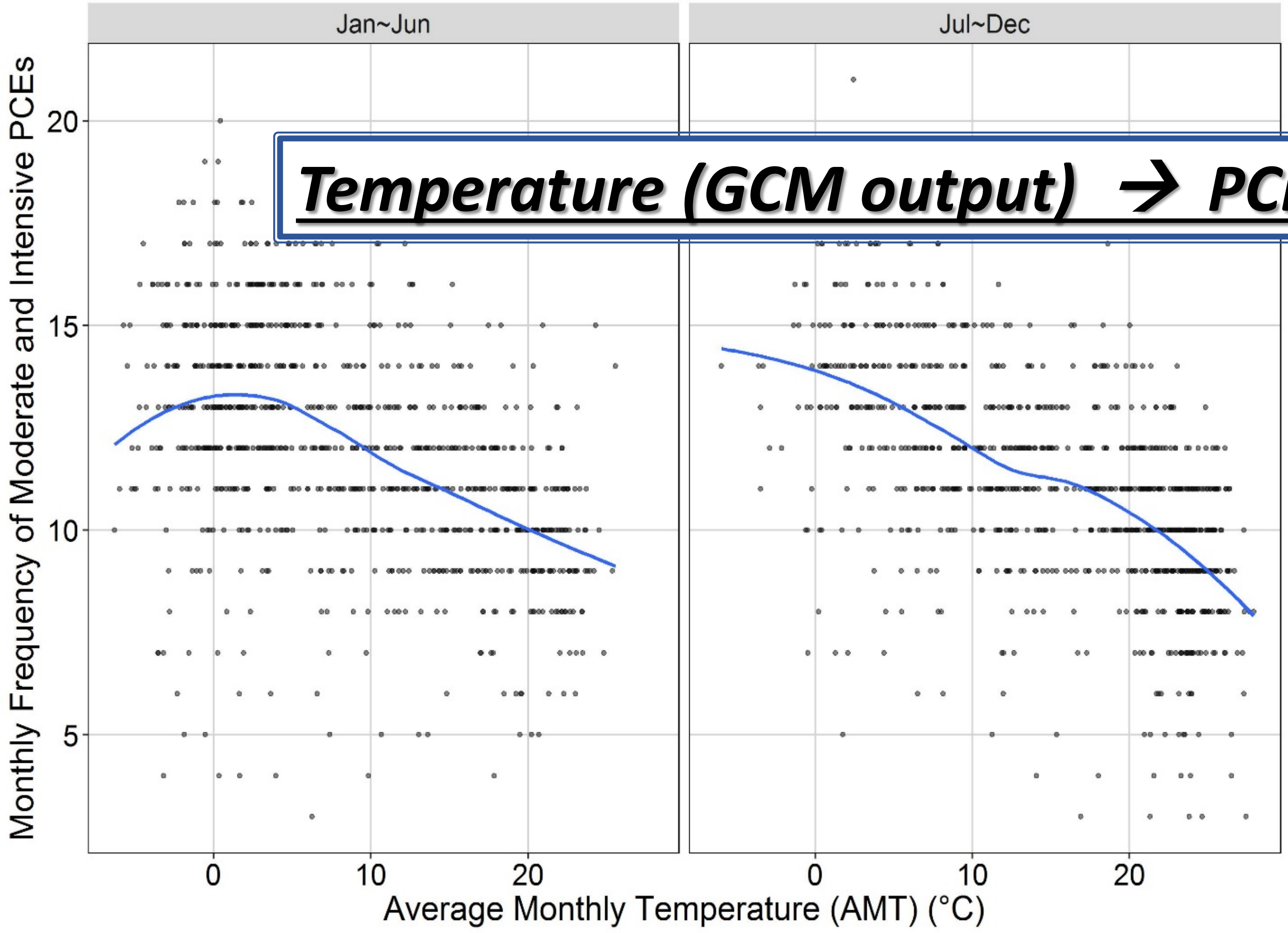
IS PCE AFFECTED BY TEMPERATURE?



EPC > 50 hPa or EPC < -50 hPa

Temperature (GCM output) → PCE → Precipitation

The phase changing temperature of water causes the atmospheric stability.

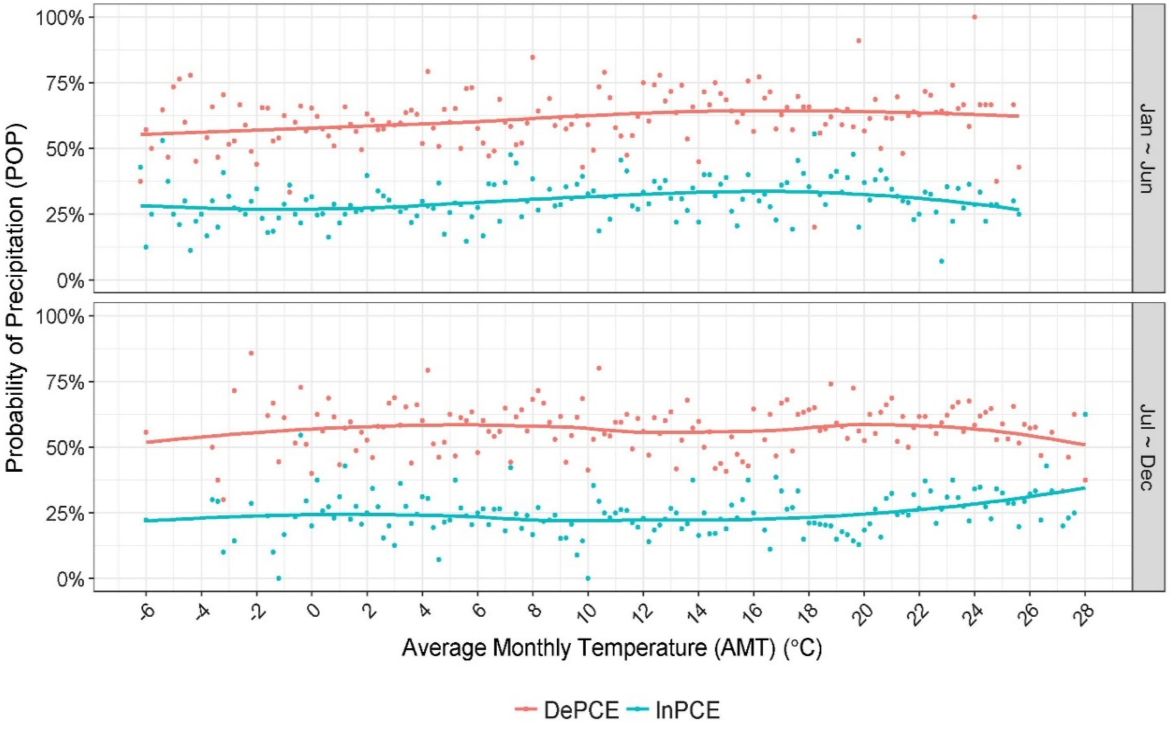
Temperature is a strong determinant of PCE occurrence.

Temperature → PCE

PRECIPITATION AND AVERAGE MONTHLY TEMPERATURE

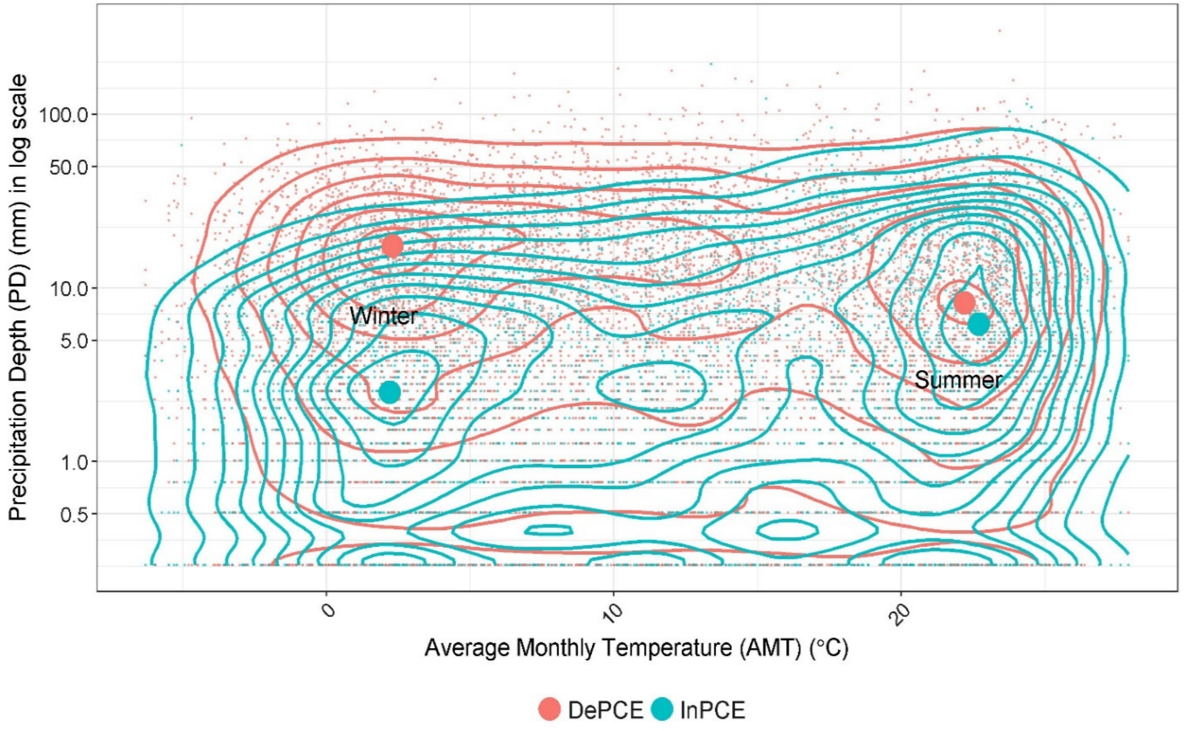
Probability of Precipitation:

DePCE > InPCE (for all temperatures)



Precipitation Depth:

- DePCE > InPCE (greater in winter)



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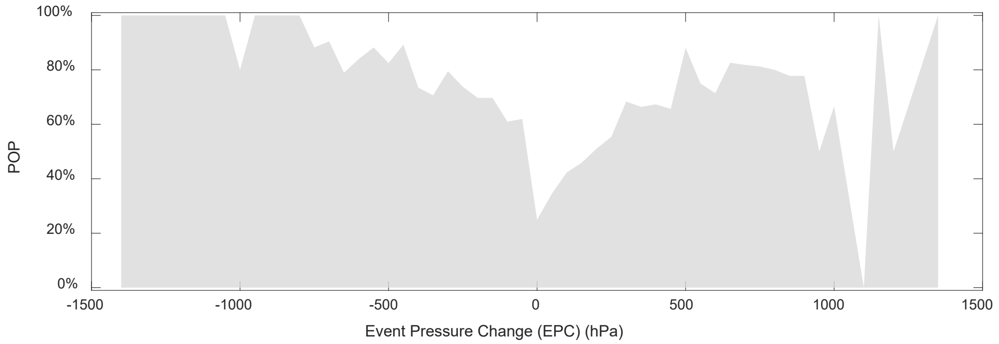
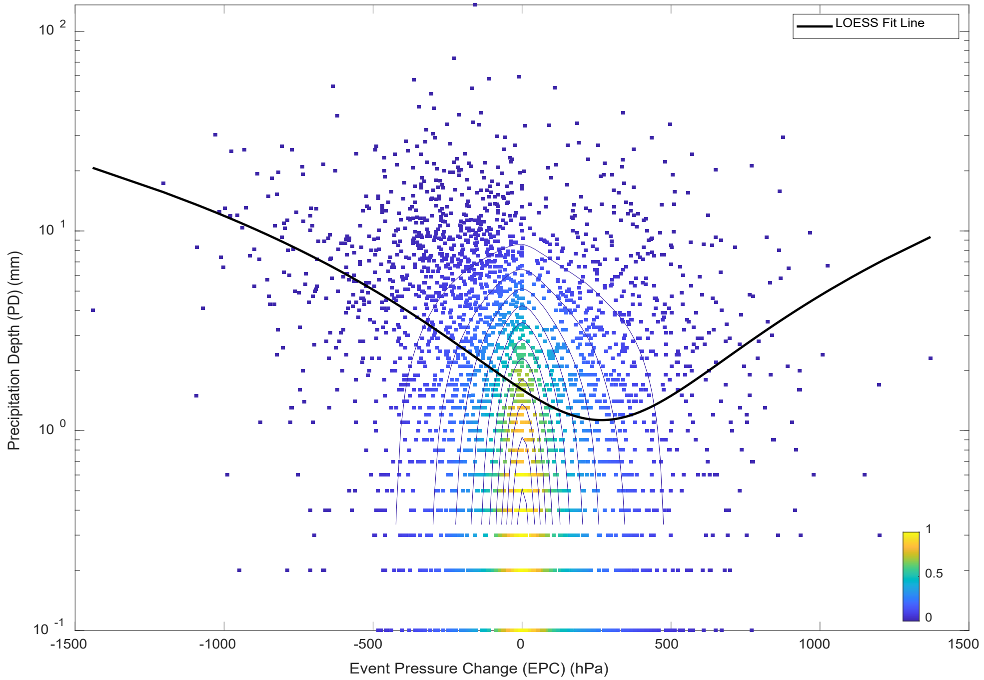
PROOF BY OTHER RESEARCHERS

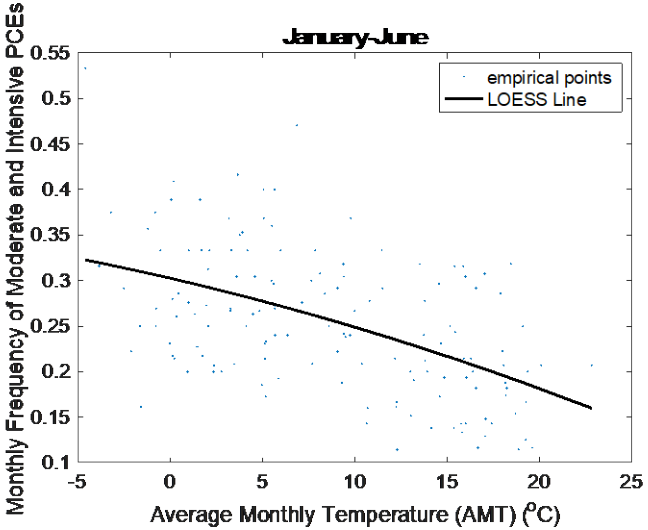


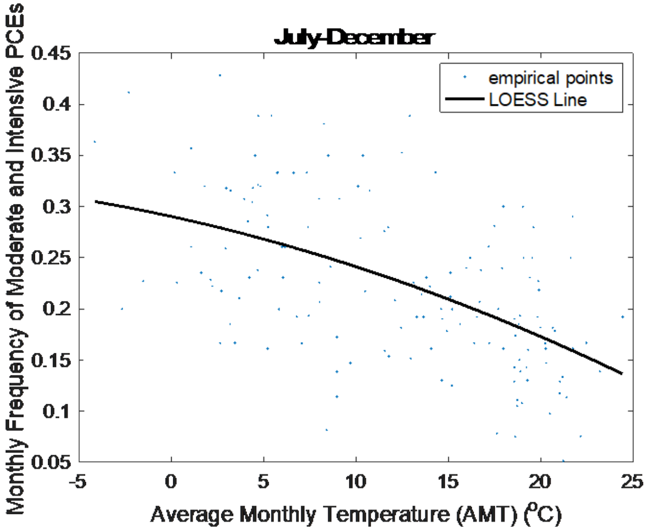


Station information: Berlin Tegel Airport, Germany (13.29°, 52.56°)

Data length: 1995-9-1 to 2020-01-07

Provided by **Mingxi, Shen**, PhD student, Department of Civil Engineering, University of Hong Kong, focusing on urban hydrometeorology and climate modeling at high resolution





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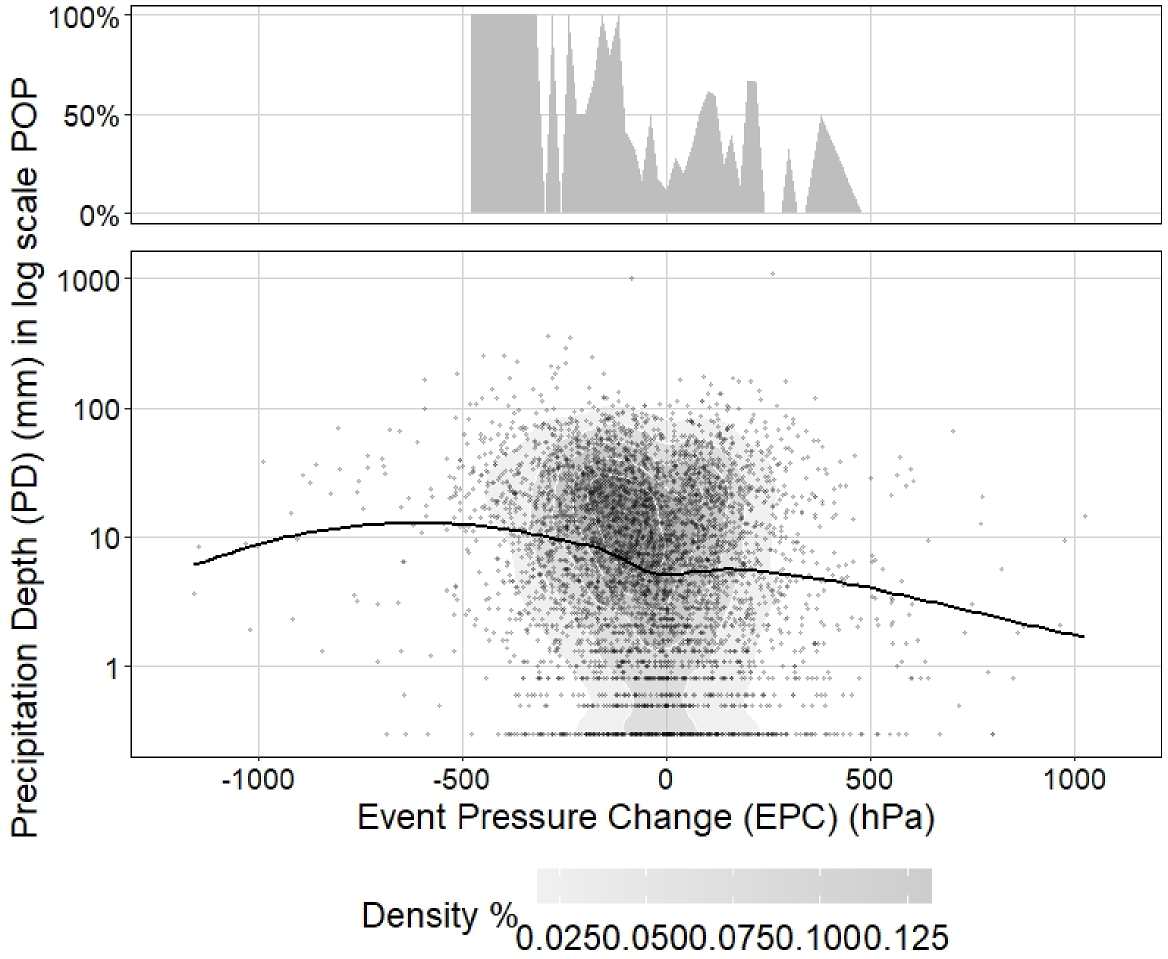
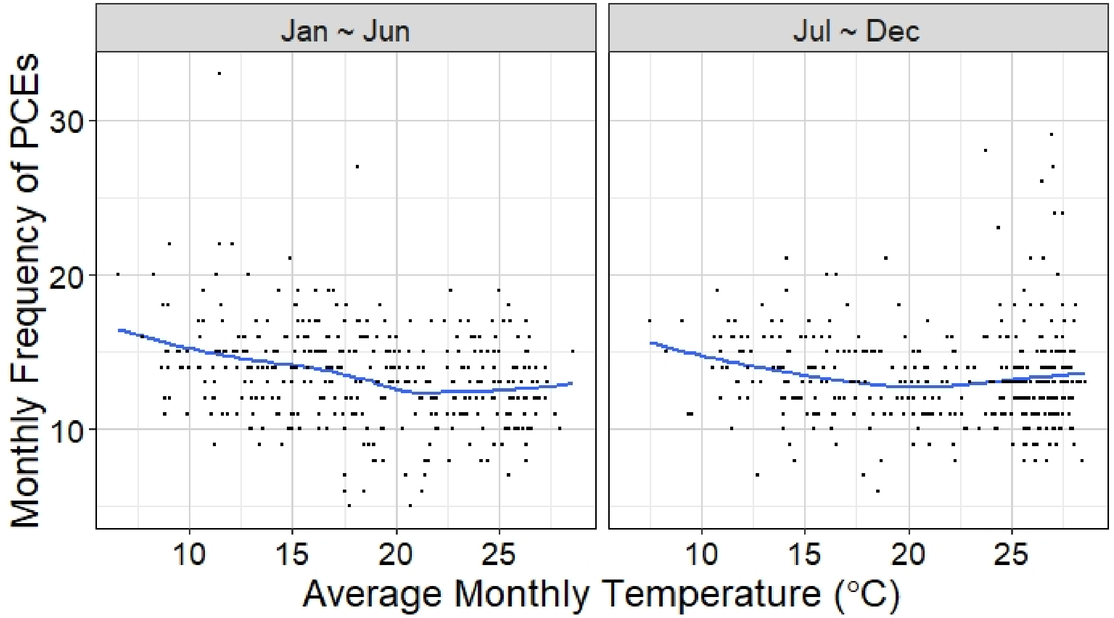
ANALYSIS ON FLORIDA DATA



Station information: Jacksonville International Airport

Data length: 1950-1 to 2020-01

Provided by **Tiantian, Li**, PhD candidate, UF/IFAS Agricultural and Biological Engineering Department



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ARCHITECTURE OF STOCHASTIC MODEL

Temperature (GCM output)

↓

PCE

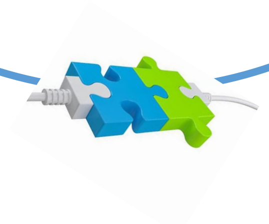
↓

Precipitation

Overarching logic

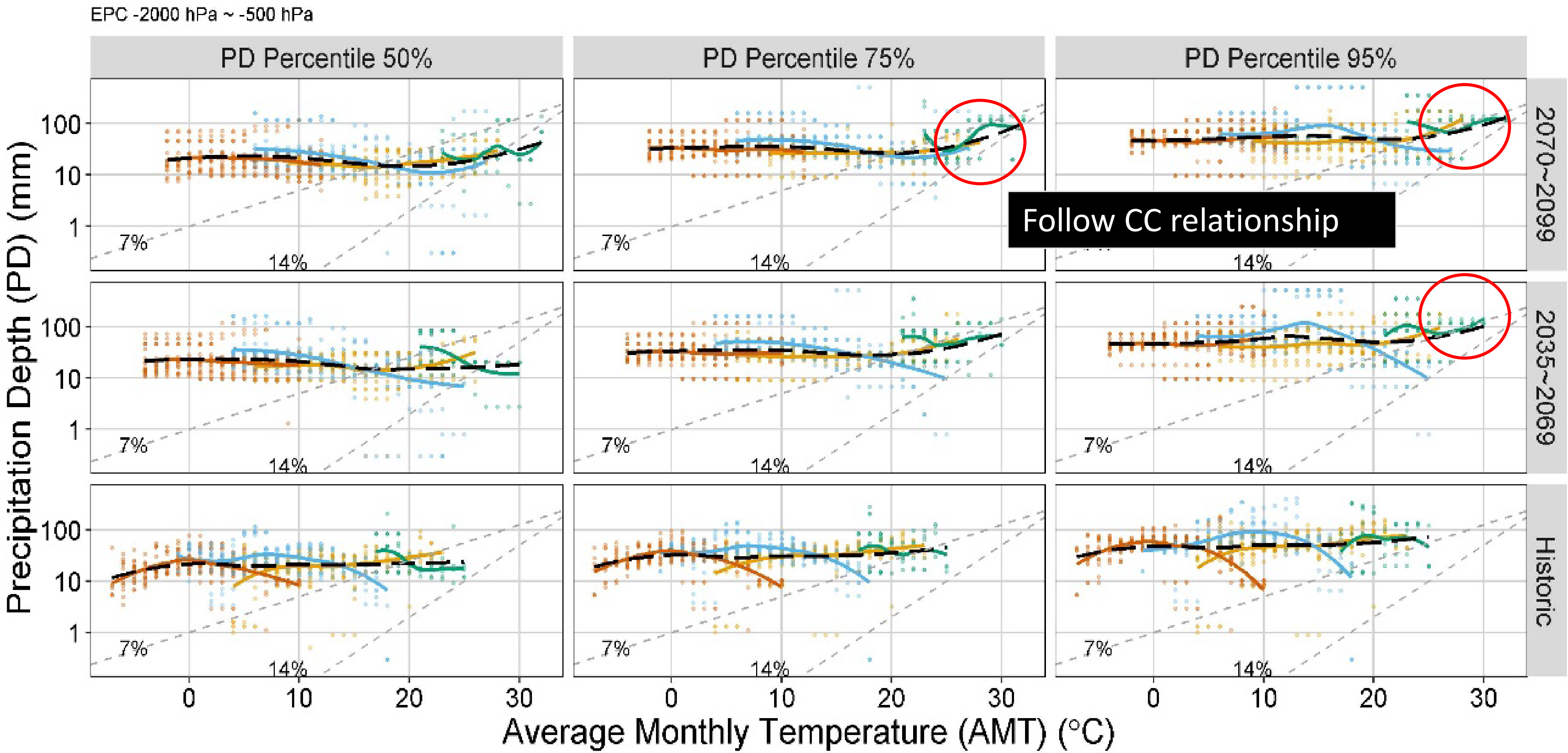
Temperature

Precipitation



Stochastic generator

SAMPLE SUMMARY FROM STOCHASTIC MODEL RESULTS



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SUMMARY AND CONCLUSION

- Precipitation is favored under decreasing pressure.
- Temperature (GCM output) → PCE → Precipitation (proved by other researcher)
- Relationships between subsequent PCEs can be found for pressure change and duration
- Extreme events can be plausibly modeled
- Knowledge based model provides a physical realistic evidence to investigate the impact of climate change on precipitation

RESEARCH SHARE AND QUESTIONS?

Journal papers:

- Yu, Z., Miller, S., Montalto, F., & Lall, U. (2018). The bridge between precipitation and temperature–Pressure Change Events: Modeling future non-stationary precipitation. *Journal of Hydrology*, *562*, 346-357.
- Yu et al. (2020). Using pressure change to stochastically disaggregate non-stationary hourly precipitation series from monthly temperature projections in the northeast of the US (ready for submission)

To replicate this model:

- Data: sub-daily weather data, GCM monthly temperature outputs
- Can provide assistances in generating your climate change precipitation series

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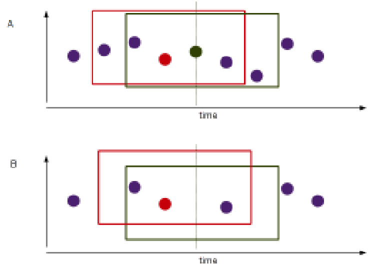
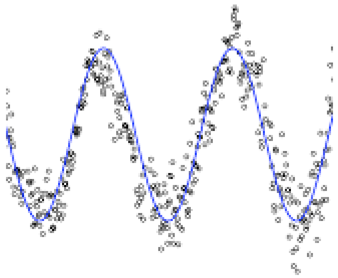
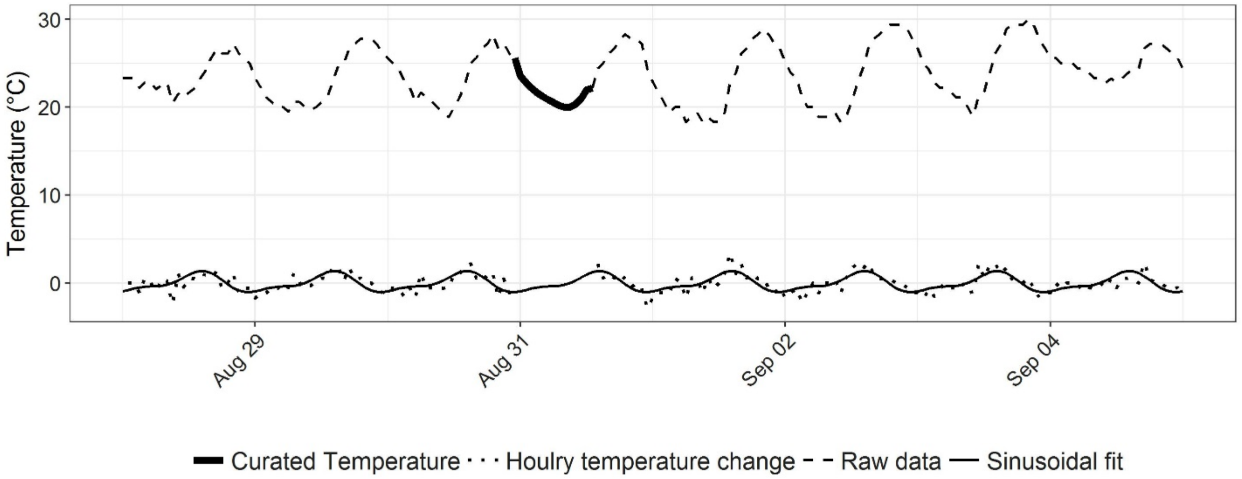
DATA CURATION

<u>Data curation</u>

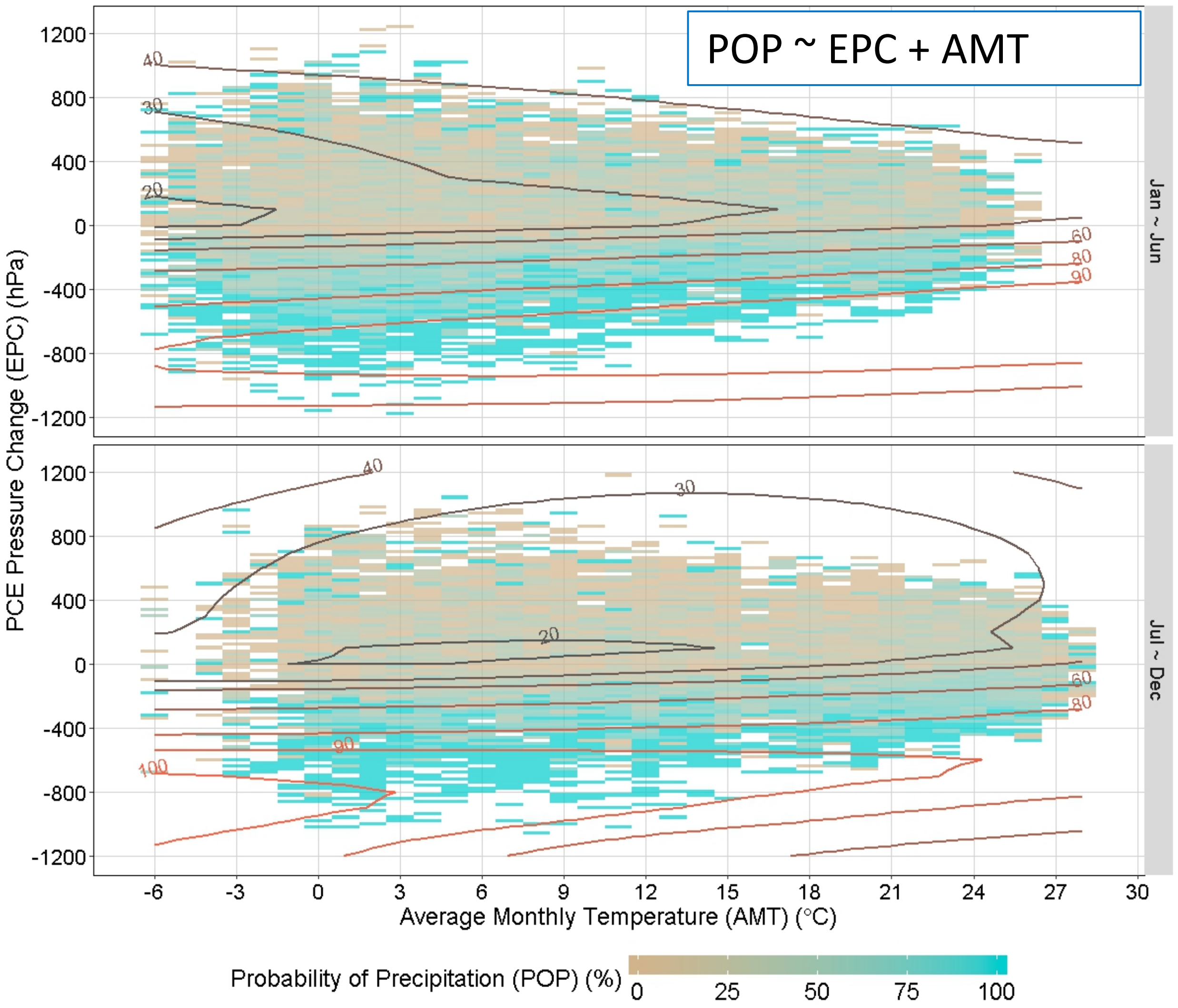
- Regulate time step
- Fill gaps < 6 hr (1.03%) by moving average of 24 hours
- Fill gaps <24 hr (0.01%) by fitting a 2nd harmonic function on close dry hours (all gaps are treated as dry)

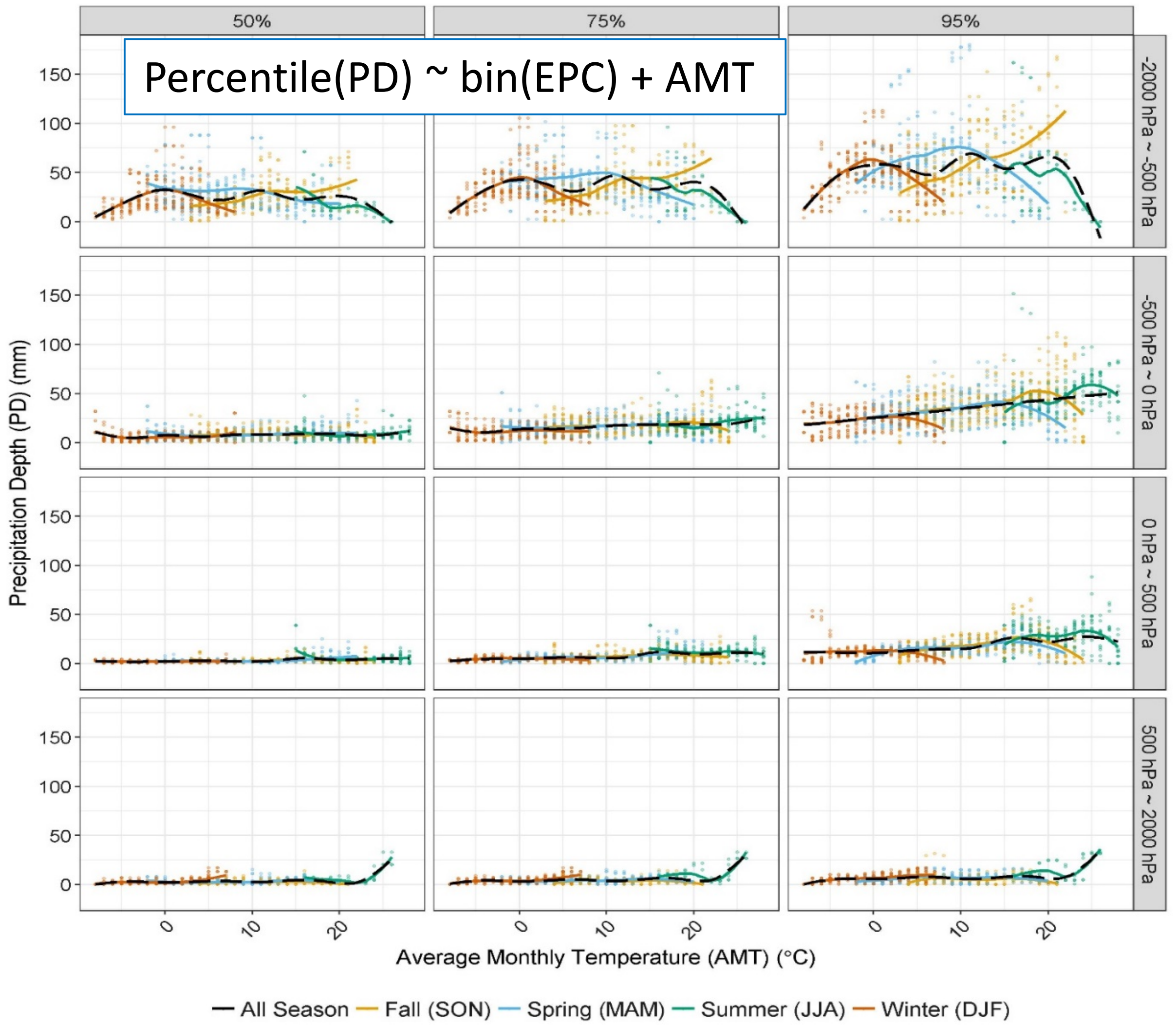






BRIDGING PRECIPITATION AND AMT WITH EPC





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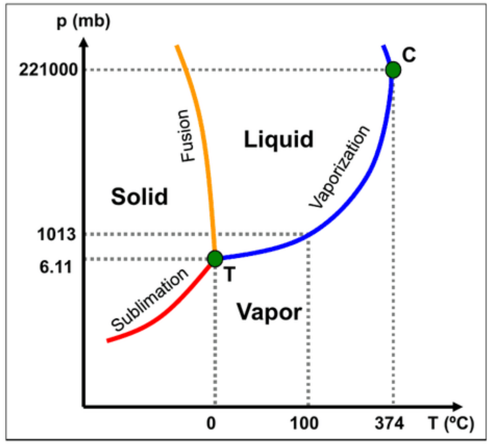

$$\frac{de_s}{dT} = \frac{L_v(T)e_s}{R_v T^2}$$

where:

- e_s is saturation vapor pressure
- T is temperature
- L_v is the specific latent heat of evaporation of water
- R_v is the gas constant of water vapor

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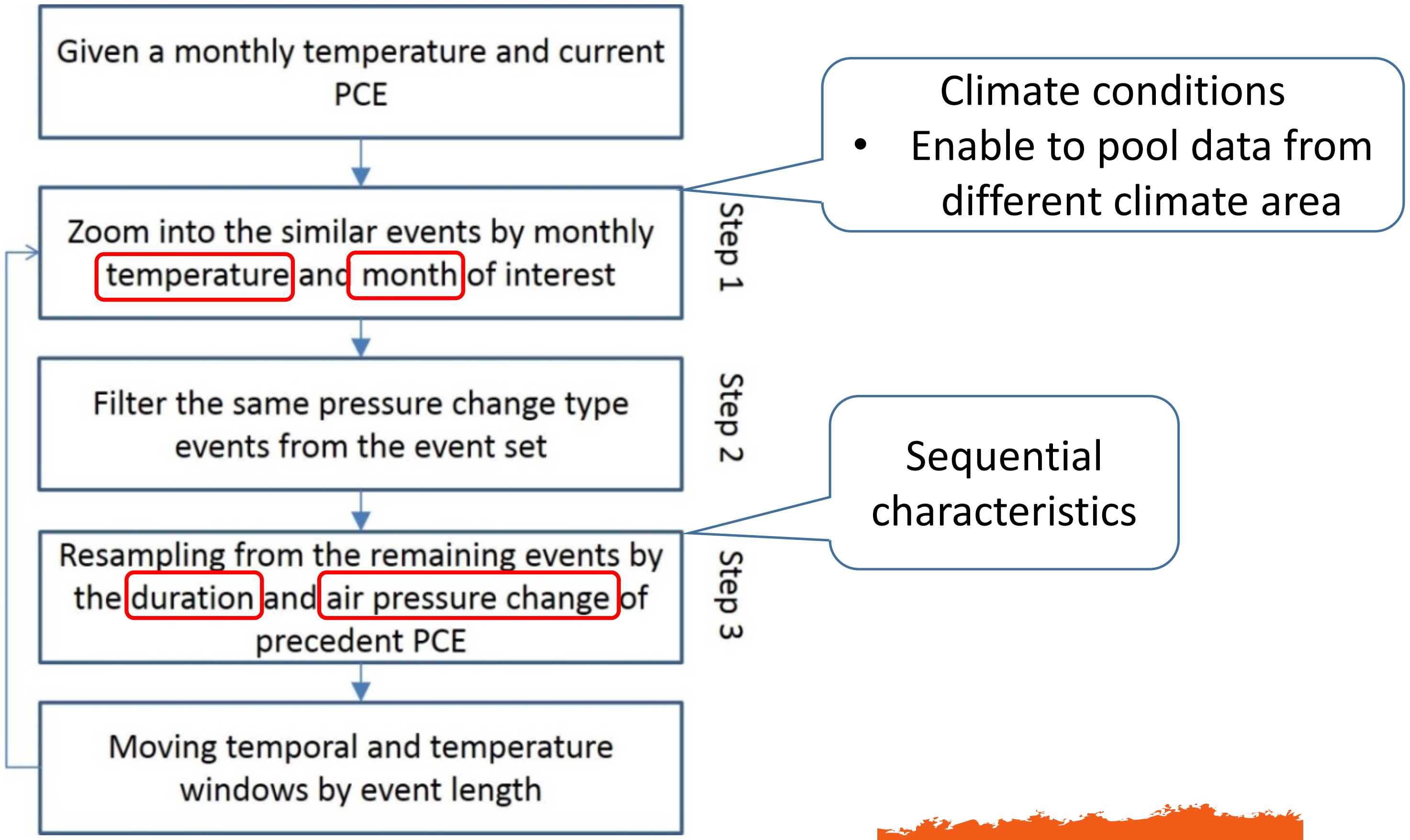
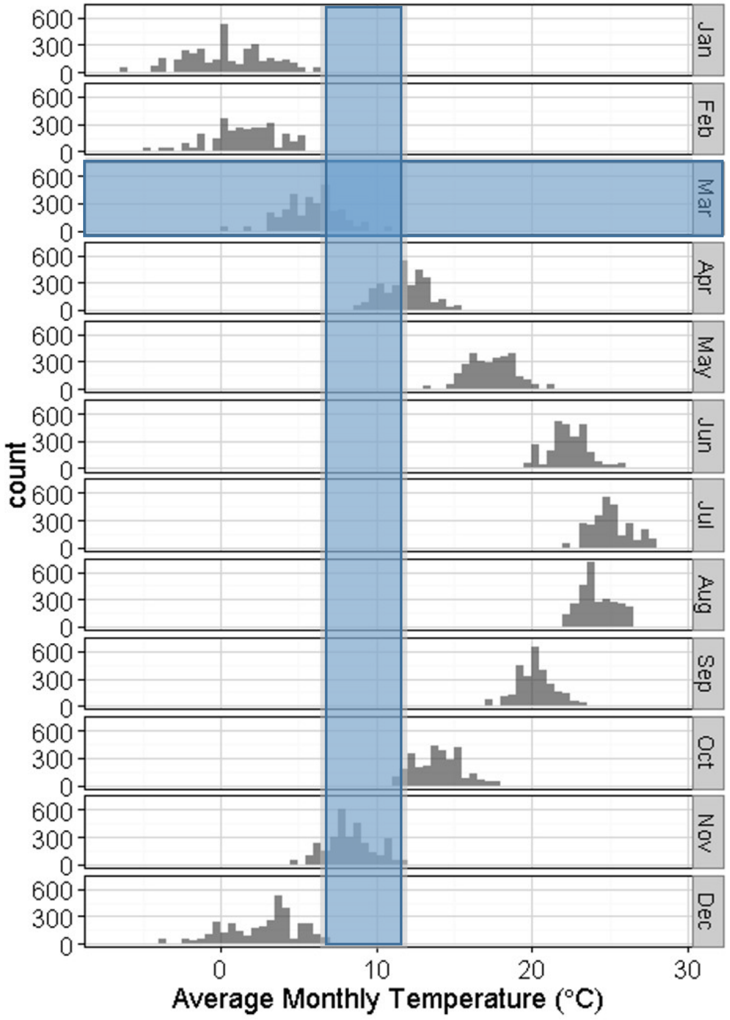
STEPS OF STOCHASTIC MODEL





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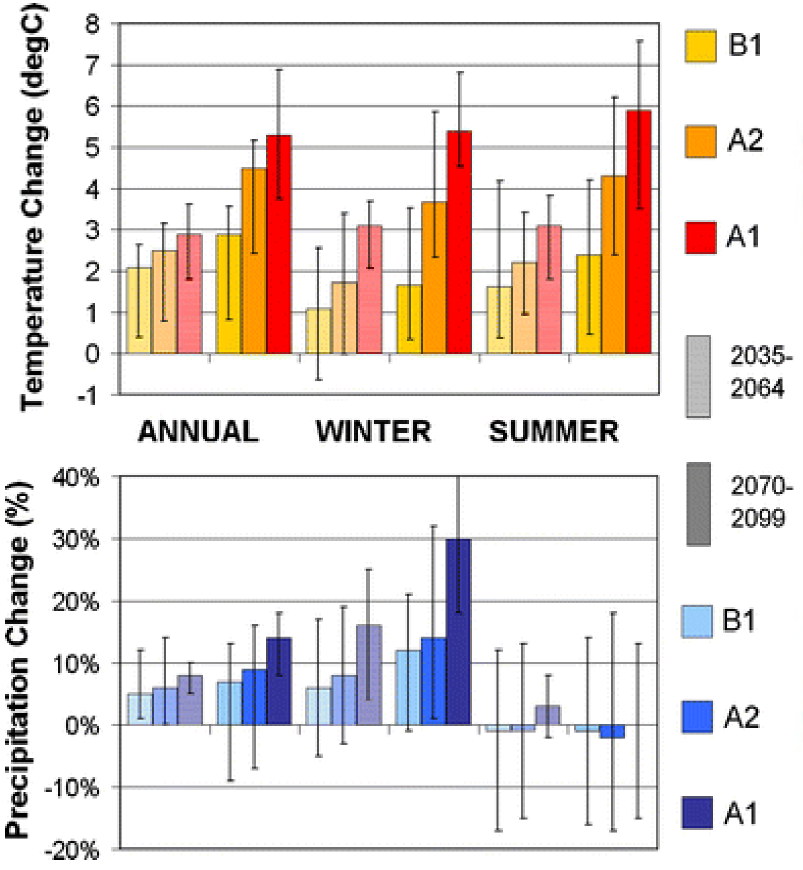
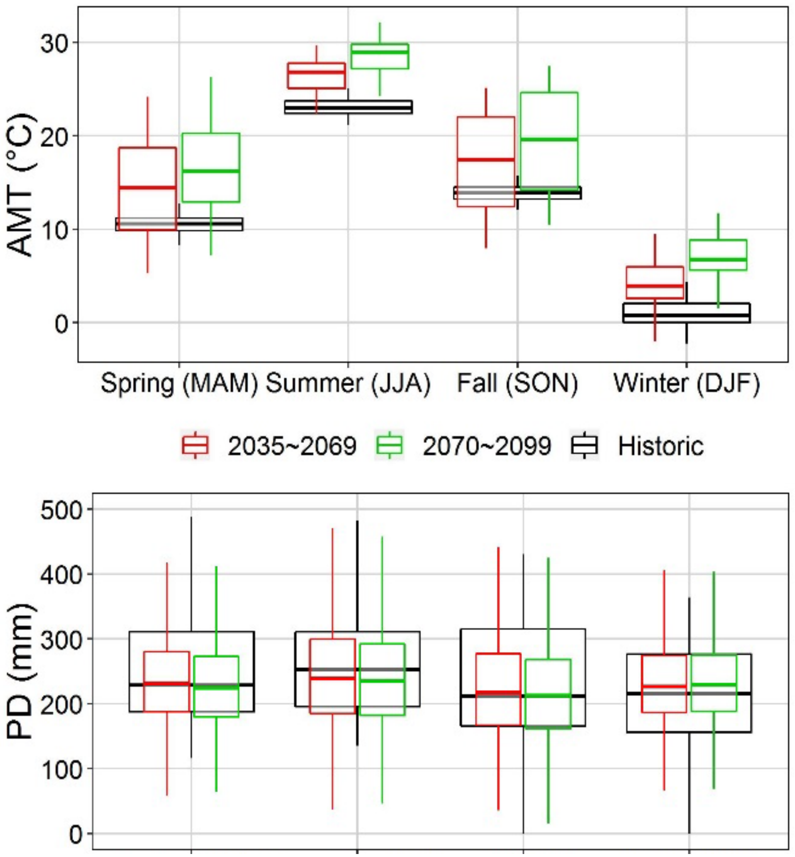
VALIDATION

Pressure change sequences

Chain up associated precipitation records



Hayhoe et al. 2007



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