Pacific Northwest NATIONAL LABORATORY

WACCEM
WATER CYCLE AND CLIMATE EXTREMES MODELING

Water Cycle and Climate Extremes Modeling (WACCEM) SFA: Progress and Update

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U.S. DEPARTMENT OF ENERGY BATTELLE

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WACCEM's vision and overarching science questions

To advance robust predictive understanding of water cycle processes and hydrologic extremes and their changes in a warming climate

- How do **large-scale circulation** features modulate regional mean and extreme precipitation, and how will they change in the future?
- What processes control **mesoscale convection** and associated warm season regional mean and extreme precipitation and how will they change in the future?
- What are the **multiscale interactions between atmospheric circulation features and water cycle processes**, and how do they influence regional precipitation?

Research elements for phase 3 (FY24–26)

Enhancing predictive understanding of water cycle and climate extremes from local to global scales

RE1. Large-Scale Circulation

- **1A.** Midlatitude stationary waves and extremes
- **1B.** Tropical circulation and intraseasonal variability

RE2. Mesoscale Convection

- **2A.** Mesoscale convective organization over tropical ocean
- **2B.** Extreme mesoscale convective systems over land

RE3. Surface-Atmosphere Interactions

- **3A.** Local and remote land-atmosphere interactions
- **3B.** Land-atmosphere-ocean interactions

Extreme events: heatwaves, storms and extreme precipitation, floods, droughts

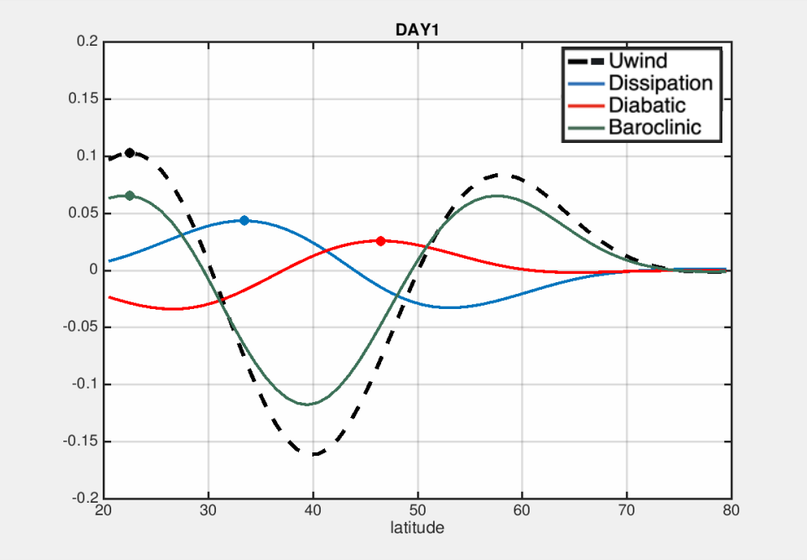
RE1: Cloud radiative effect (CRE) on atmospheric circulations and extreme events

Seven experimental designs to disrupt CRE have been implemented in E3SMv2

Experiment name	Experiment type	SSTs prescribed	Flag settings (i, ii, iii, iv)	Years used
Control	Control	Present day, +4 K	FFFF	2–11
Clouds off	Complete radiation denial	Present day, +4 K	TTTT	2–11
Clouds-off LW	Complete radiation denial	Present day, +4 K	TFTF	2–11
Clouds-off ATM	Complete radiation denial	Present day, +4 K	TTFF	2–11
Surface locking	Complete radiation denial	Present day, +4 K	TTFF	2–11
Cloud locking	CRE–circulation decorrelation	Present day, +4 K, mix-and-match	FFFF	2–11
Prescribed RadHt	CRE–circulation decorrelation	Present day, +4 K, mix-and-match	FFFF	2–11
Prescribed CRE	CRE–circulation decorrelation	Present day, +4 K, mix-and-match	FFFF	2–11

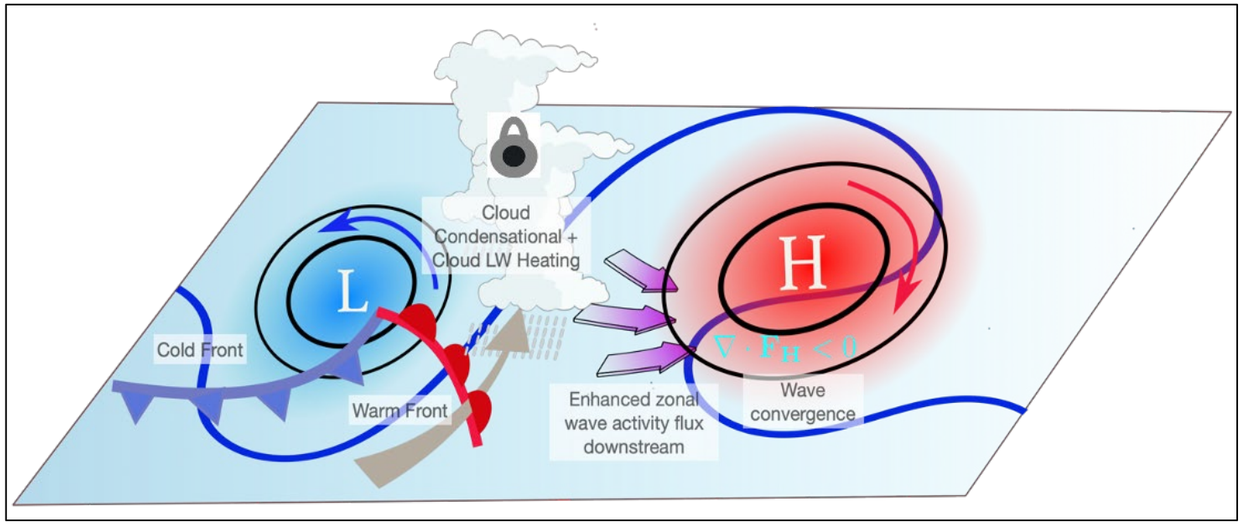
(Harrop et al. 2024 GMD)

Southern Annular Mode (SAM) becomes more predictable when CRE is disabled



(Lu et al. 2024 JGRA; Modes of Variability and Teleconnections, Trends Breakout Session)

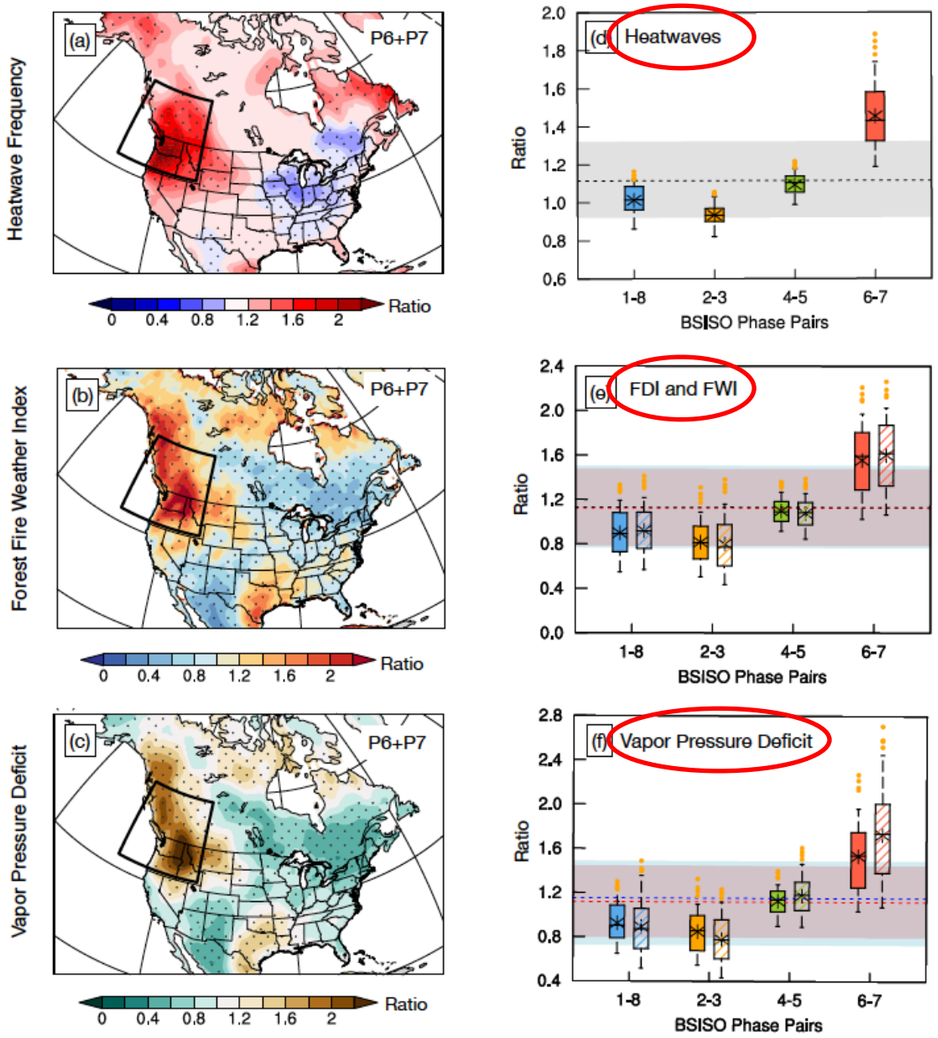
CRE increases the formation of atmospheric blocking over the Euro-Atlantic sector



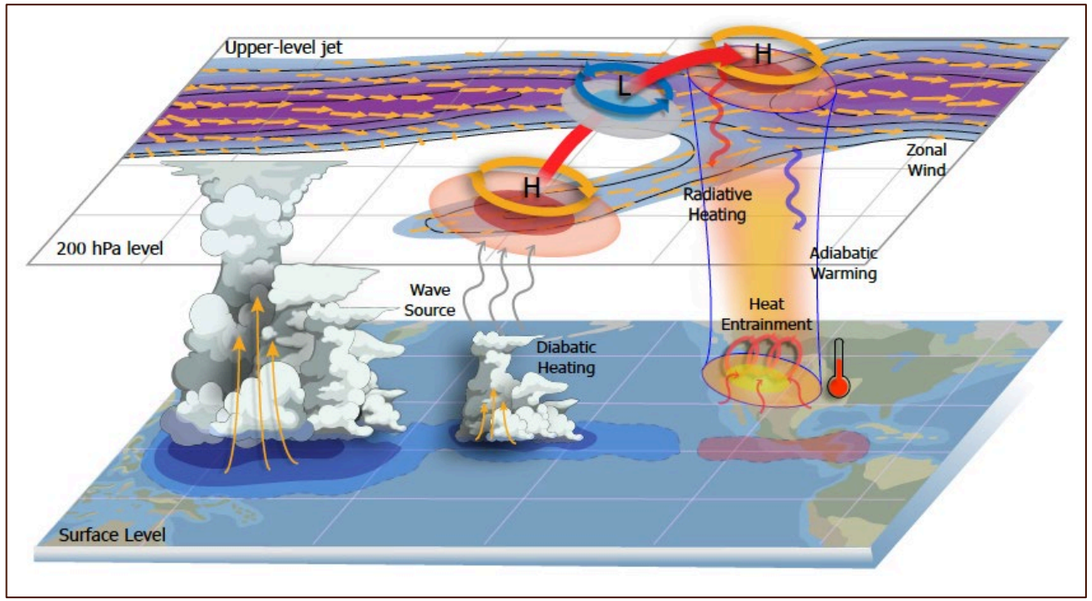
(Lubis et al. in prep)

RE1: Enhanced PNW heat extremes and wildfire risks induced by Boreal Summer Intraseasonal Oscillation (BSISO)

Heat extremes and fire weather occurrence in PNW enhanced by 50-120% during BSISO phases 6 & 7



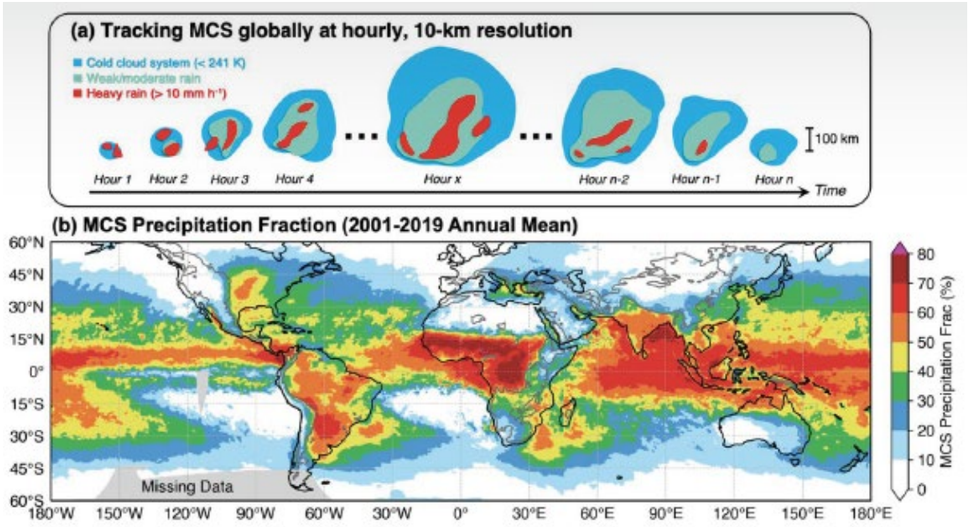
Enhanced diabatic heating over tropical central-to-eastern North Pacific during BSISO phases 6 & 7 generates wave train traveling downstream towards North America



(Lubis et al. in review)

RE2: Mesoscale convective systems tracking tools, datasets, metrics, and intercomparison

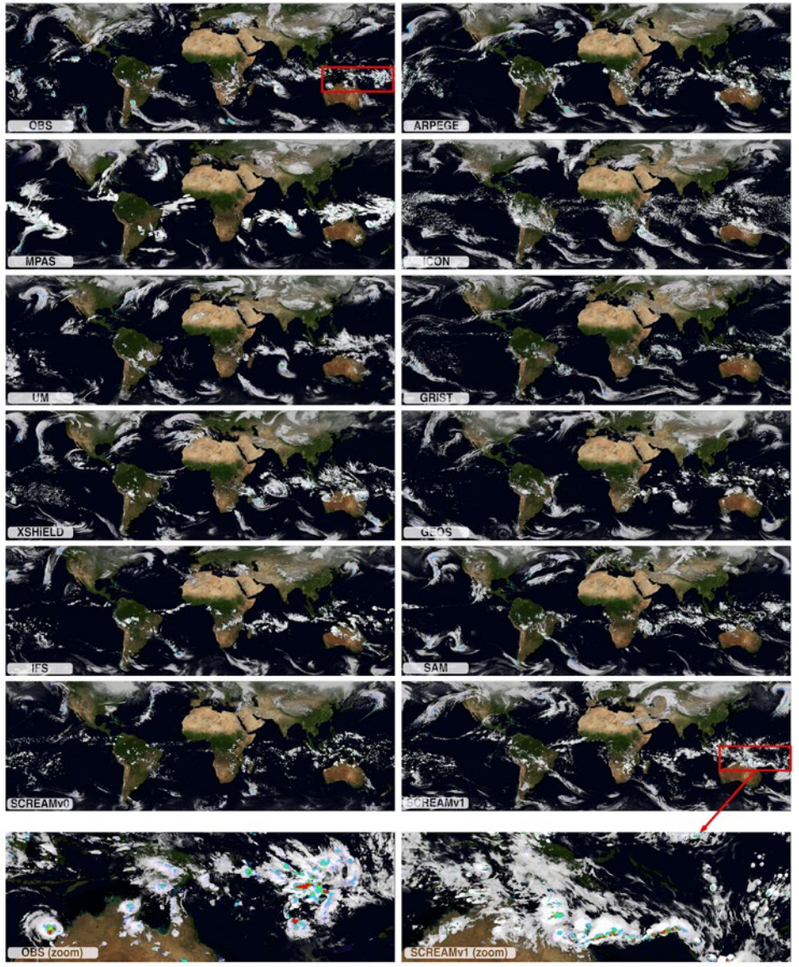
Global and US MCS tracking data based on pyFLEXTRKR



Global MCS tracking data is being used by >40 research groups worldwide

(Feng et al. 2018 JAMES; Li et al. 2021 ESSD; Feng et al. 2023 GMD)

MCSMIP compares >8 MCS feature trackers applied to DYAMOND simulations

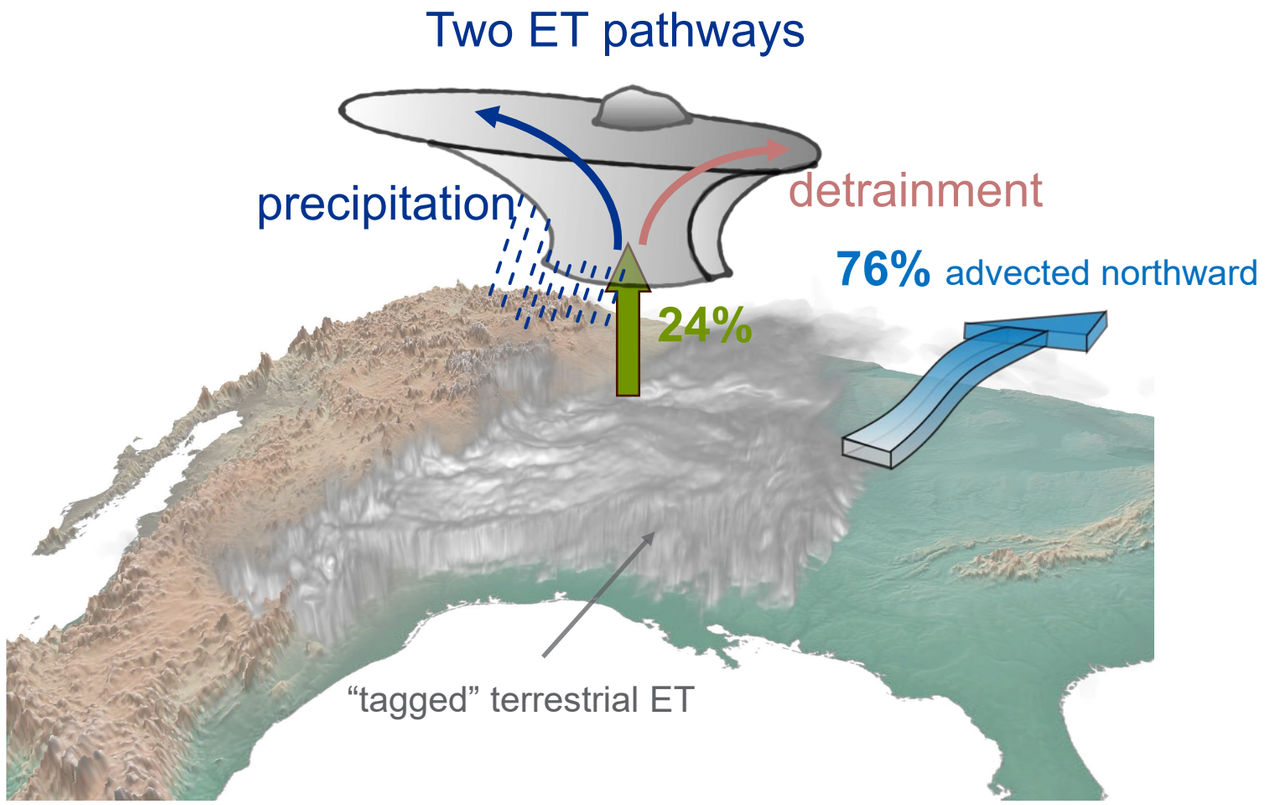


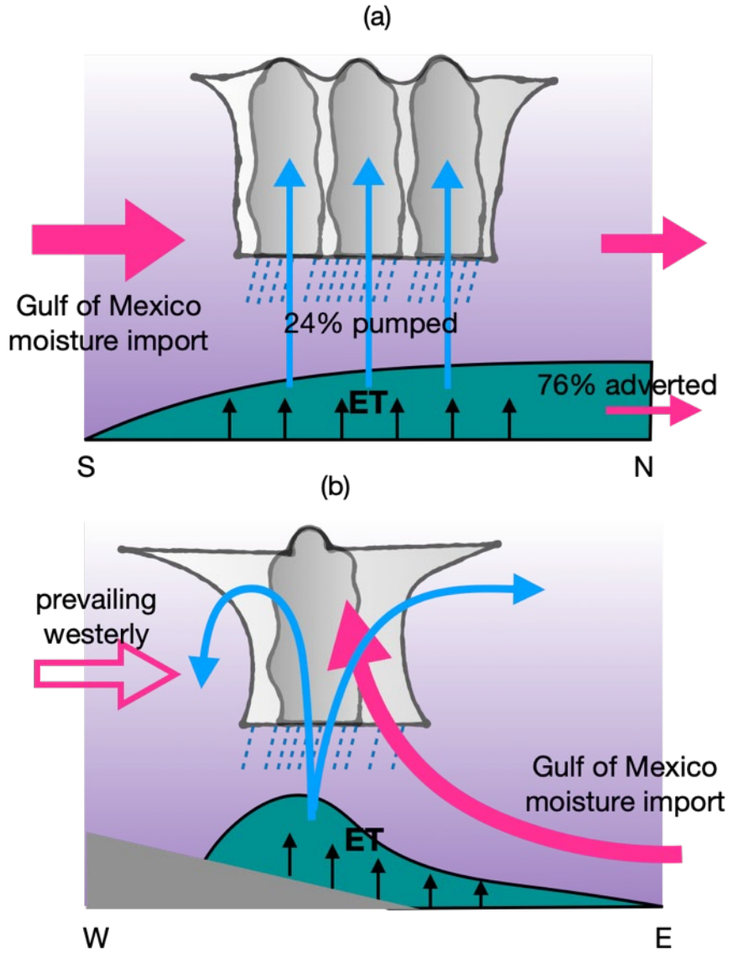
(Feng et al. in prep; Water Cycle and Hydroclimate Breakout Session)

RE2: Understanding moisture recycling associated with MCS

Numerical tracers provide insights on role of MCS in soil moisture-precipitation feedback

Developed land-atmosphere coupled tracers in WT-WRF; developing WT-E3SM focusing on ELM

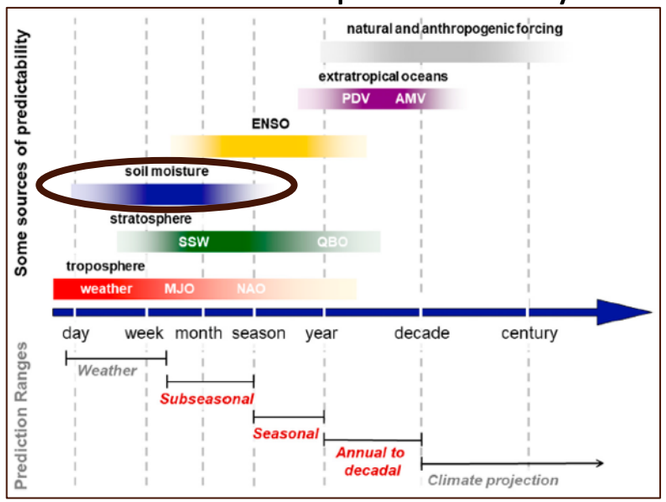




(Hu et al. 2024 JHM)

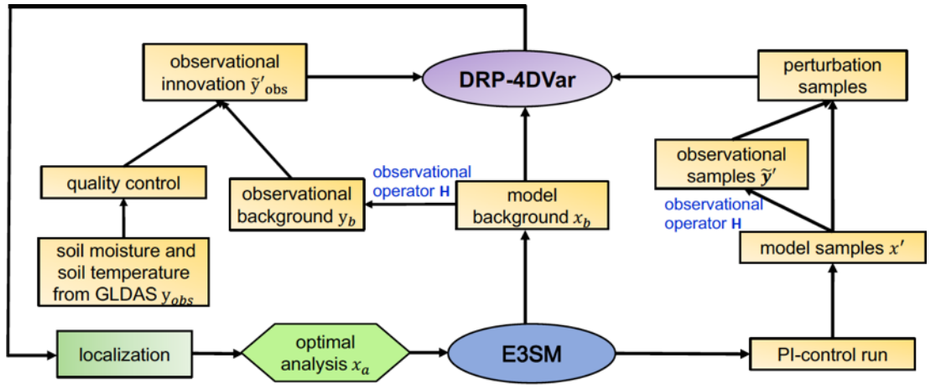
RE3: A weakly coupled land data assimilation system for understanding Earth system predictability

Sources of predictability



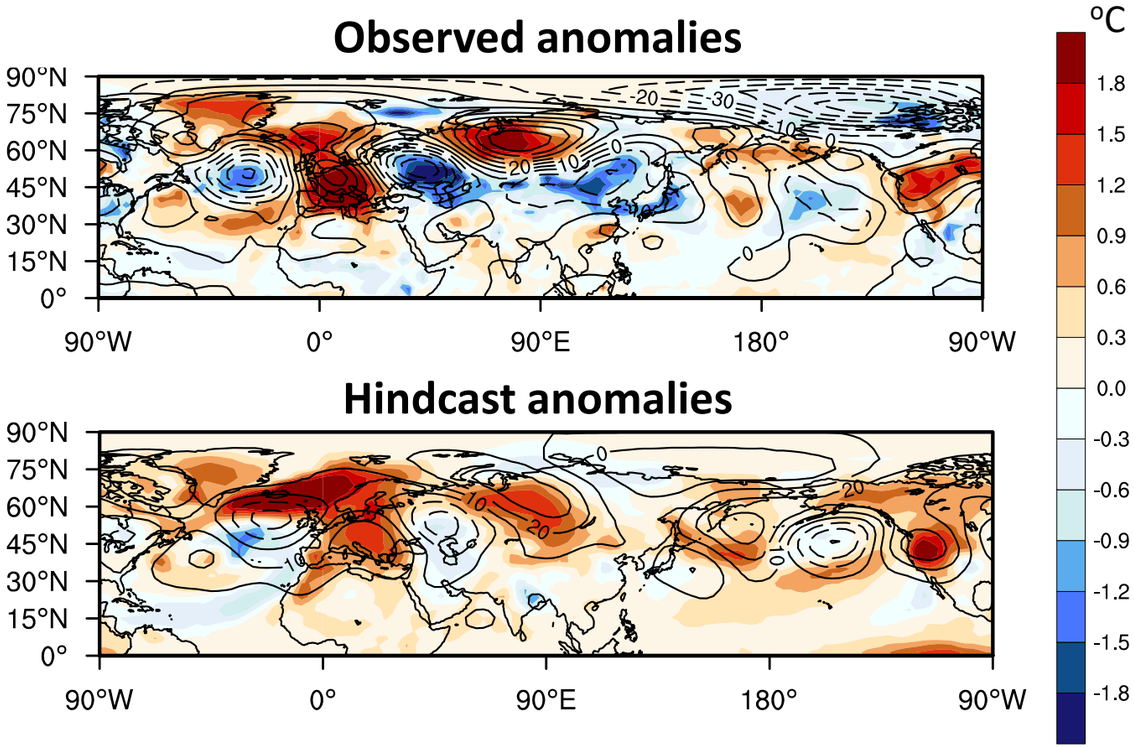
(Merryfield et al. 2020 BAMS)

A land data assimilation system implemented in E3SM for coupled modeling experiments



(Shi et al. 2024 GMD)

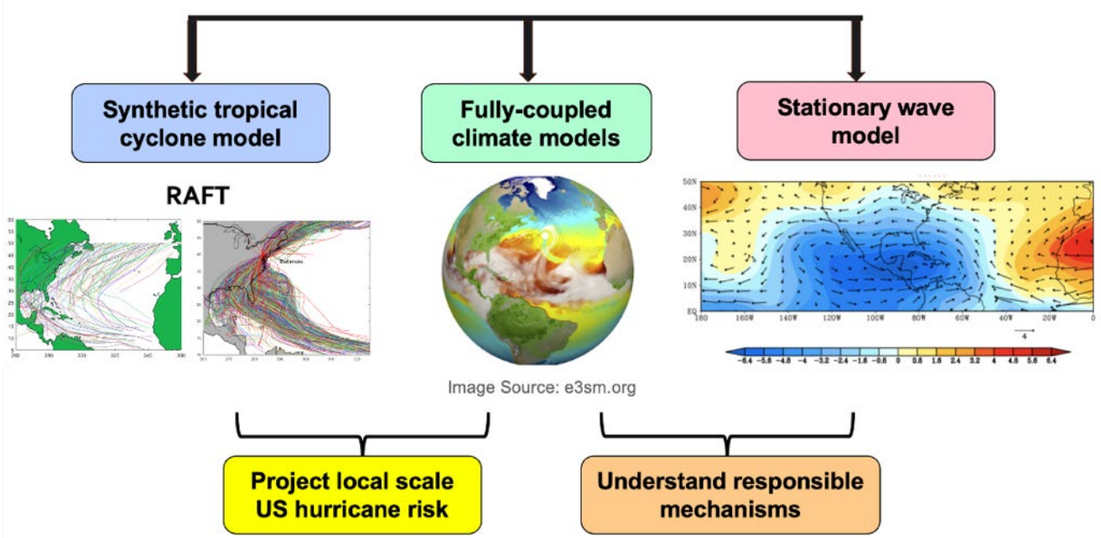
The 2003 European heat wave can be predicted two years in advance by incorporating observed soil moisture and temperature information in E3SM

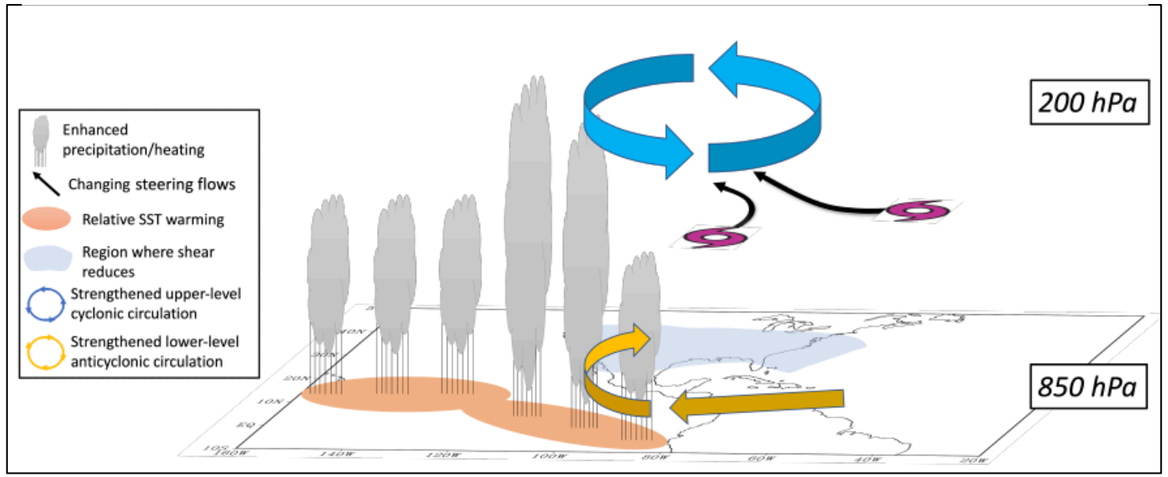


(Shi et al. in review; Extremes Breakout Session)

RE3: A global increase in near-shore tropical cyclone intensification

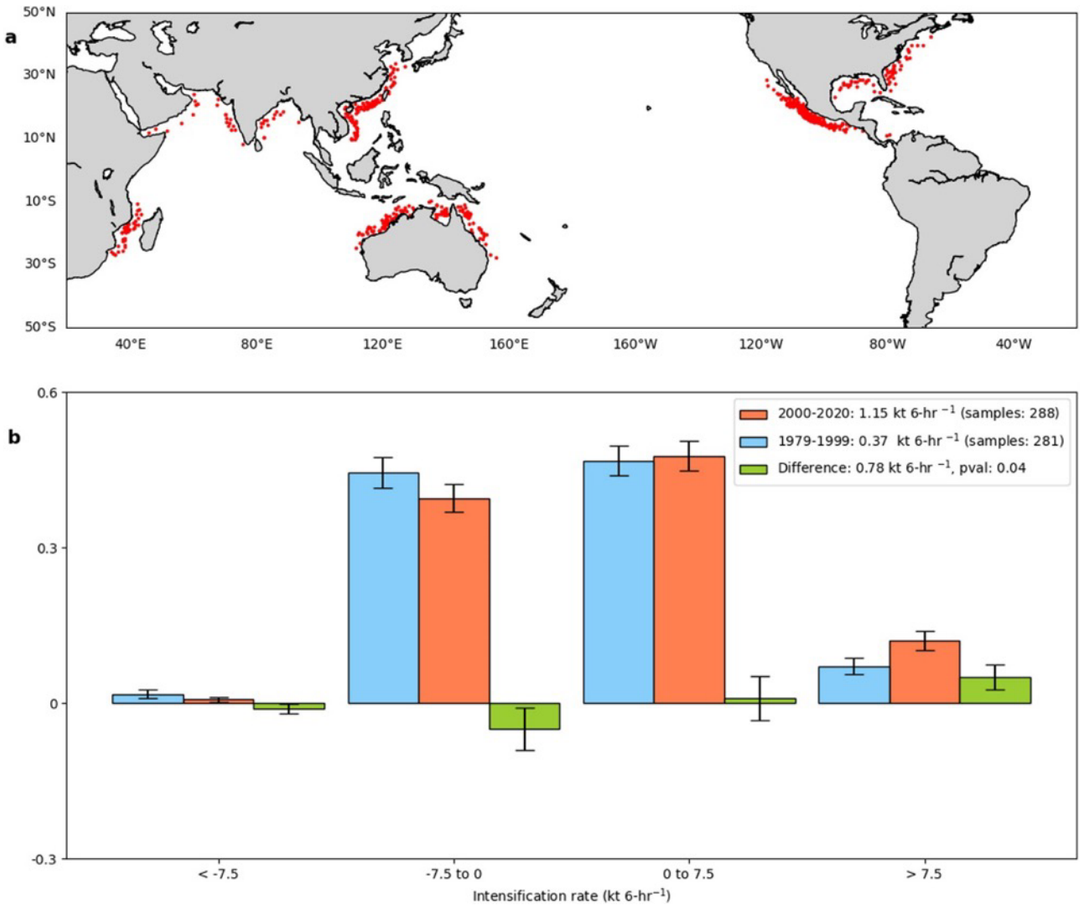
Increased US coastal hurricane risk with warming





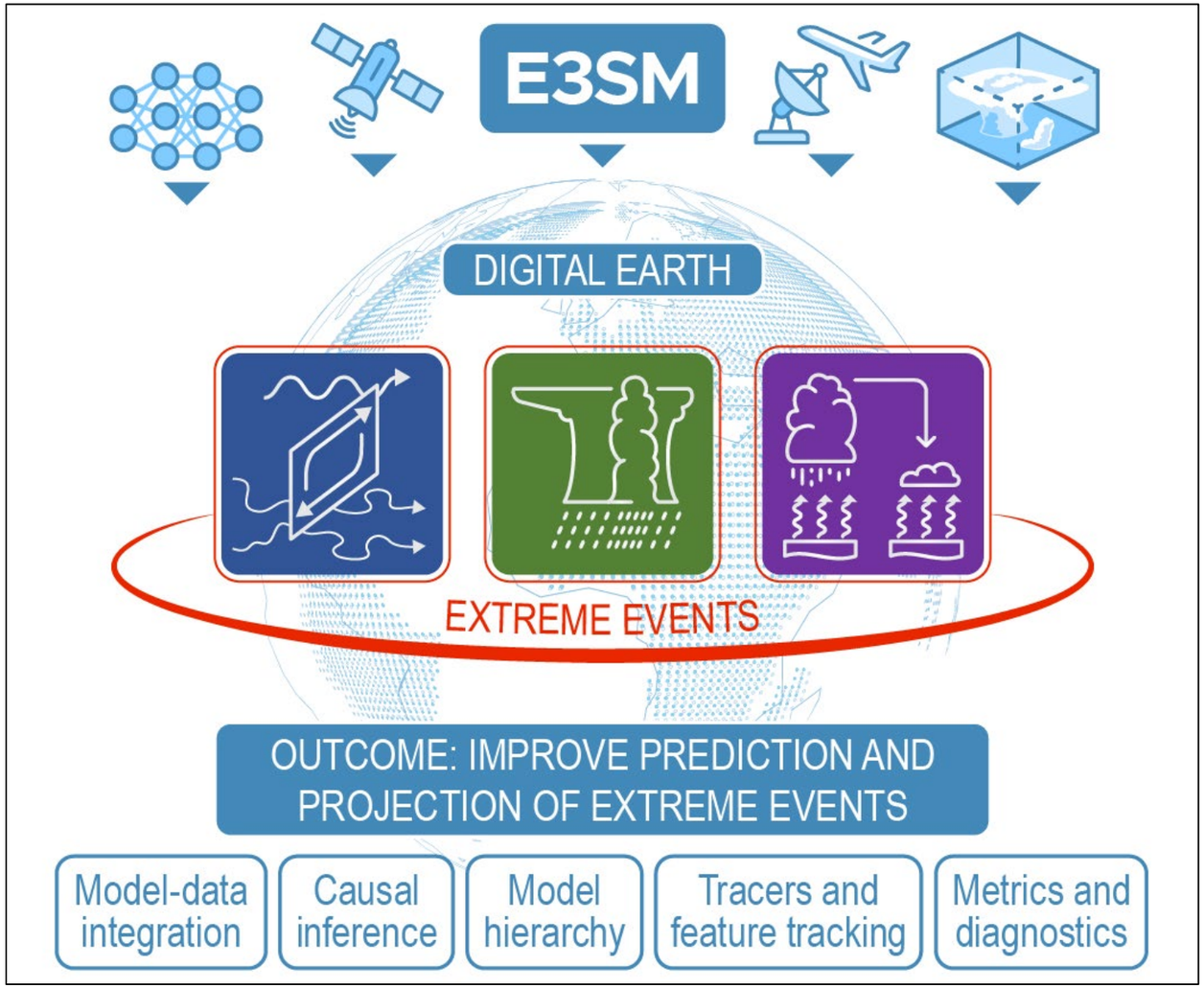
(Balaguru et al. 2023 Sci. Adv.)

Nearshore TC intensification rates have increased globally by about 3 knots per 24 hours over 1979-2020



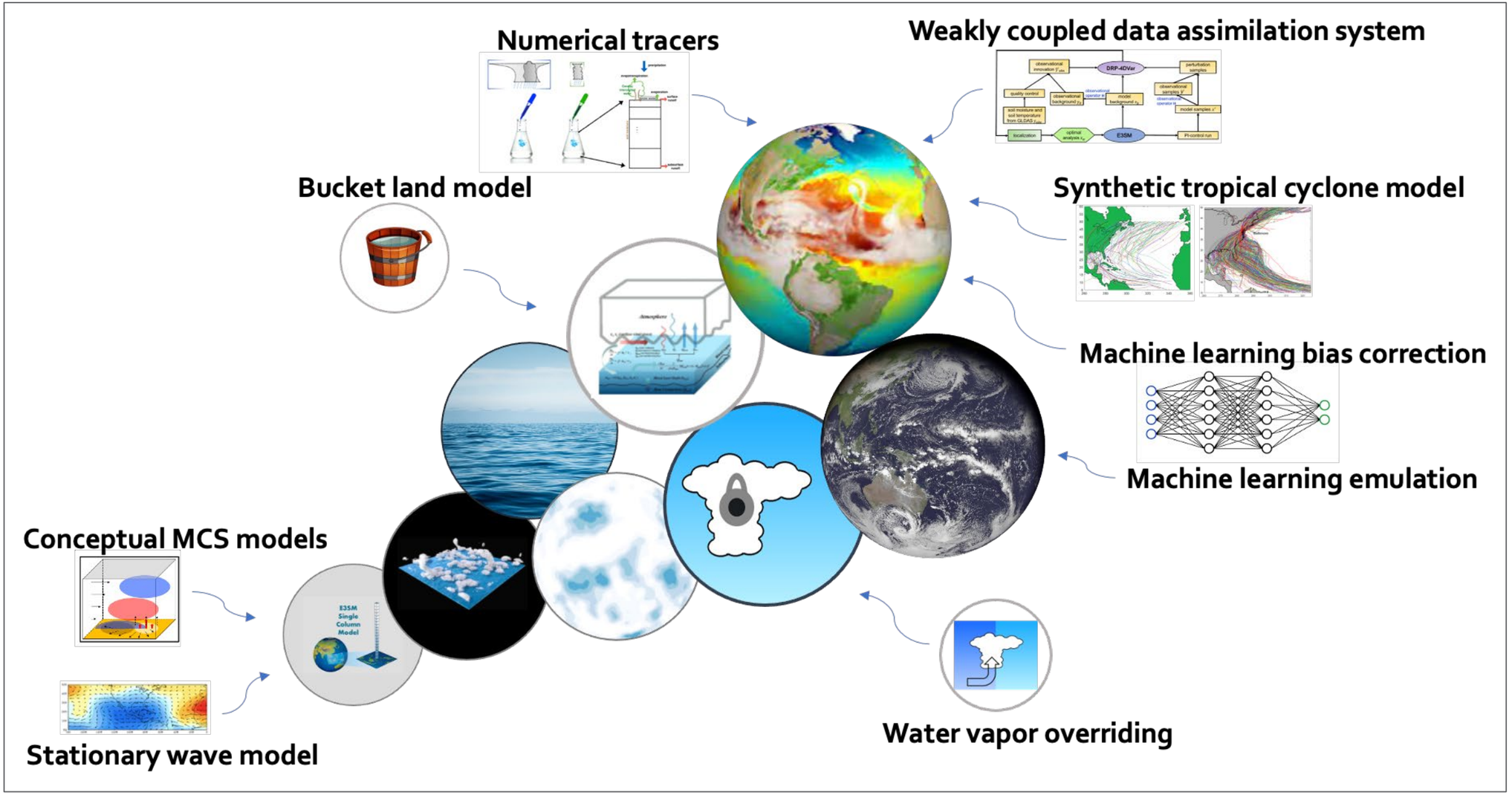
(Balaguru et al. 2024 EF)

WACCEM enhances E3SM as a “digital Earth” for scientific discovery



- Leveraging E3SM’s capabilities, WACCEM aims to enhance E3SM as a “digital Earth” for scientific discovery by the broad atmospheric science and climate research community
- To support this goal, **a model hierarchy and other capabilities are needed to better connect modeling with theories and observations**
- WACCEM’s goal is complementary to E3SM’s actionable science goal

A model hierarchy based on E3SM



Novel data, models, and experiments from phase 3

Data

- Co-located MCS tracks, characteristics, and large-scale environments
- Soil moisture characteristics connected to different storm types
- WRF-EnKF regional reanalysis of MCS at 4 km

Model

- Weakly coupled land/ocean data assimilation in E3SM using DRP-4DVar
- Water tracers in WT-WRF and WT-E3SM
- A E3SM model hierarchy including different levels of complexity
- AI/ML: Koopman operator, neural network, XAI, PGM, causal inference

Experiment

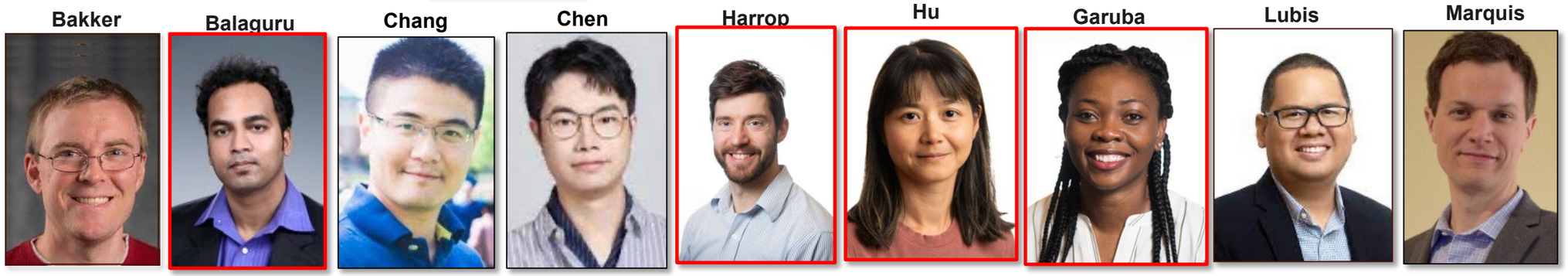
- A library of CPM/LES simulations of MCS (PINACLES, EAMxx, CM1)
- Hierarchical model experiments on midlatitude QSW and BSISO
- A large ensemble of initialized E3SM RRM S2S hindcasts, LESFMIP, LS4P, IRRMIP
- An ensemble of month-long EAMxx simulations of co-occurring extreme events

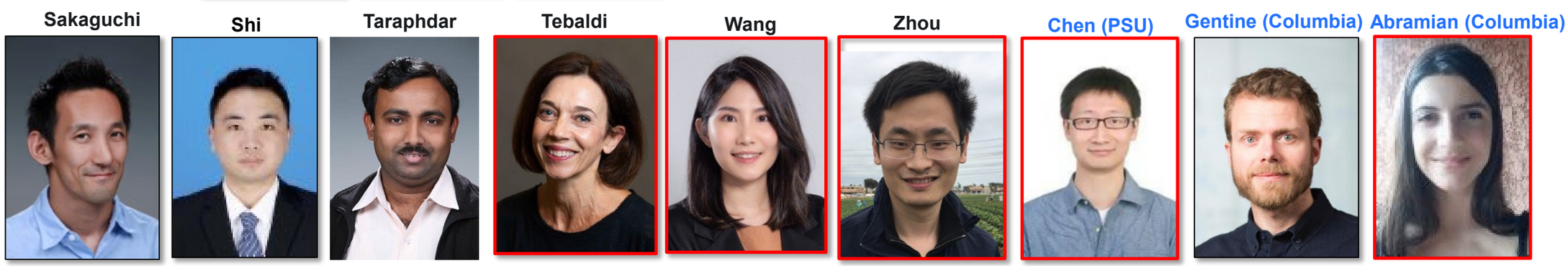
Synthesis

- Synthesis papers (e.g., MCS tracking methods and data)
- Review papers (e.g., review of monsoon seasonal cycle changes)

WACCEM team


Leung (PI)
Lu (RE1)
Feng (RE2)
Hagos (RE3)


Bakker
Balaguru
Chang
Chen
Harrop
Hu
Garuba
Lubis
Marquis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Thank you