GASS Diurnal Cycle of Precipitation (DCP) Project

Shaocheng Xie

Lawrence Livermore National Laboratory

Co-Chairs: Hsia-Yen Ma (LLNL), Peter Bechtold (ECMWF), David Neelin (UCLA)

SCM Lead: Shuaiqi Tang (LLNL, now at PNNL)

GCM lead: Cheng Tao (LLNL)

http://portal.nersc.gov/project/capt/diurnal/

Lawrence Livermore National Laboratory

LLNL-PRES-841502

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Goals & Research Themes

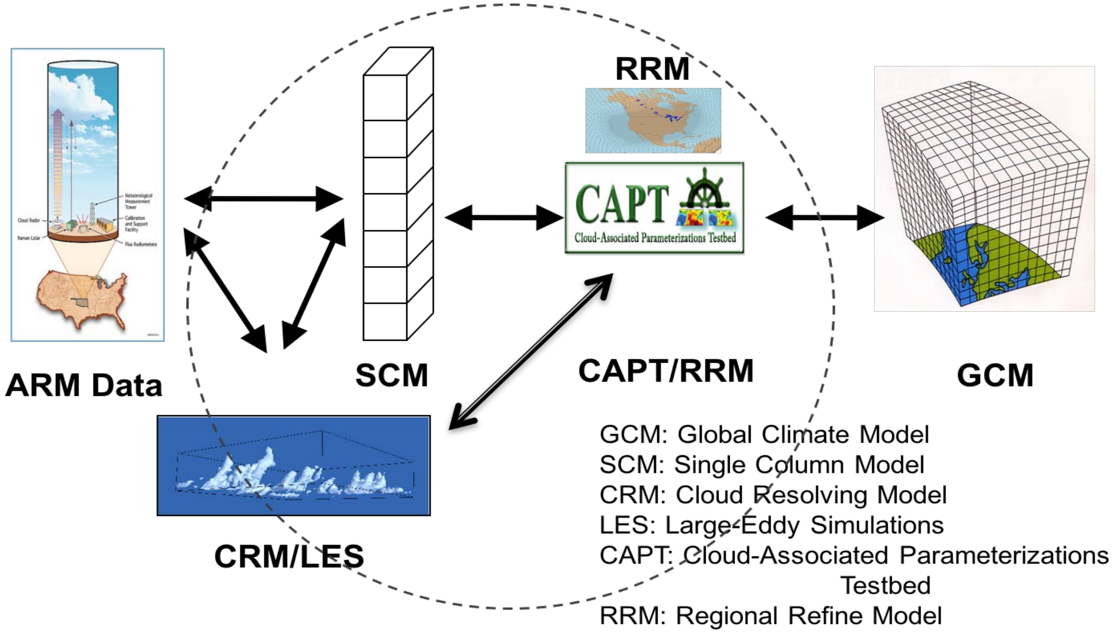
Identify model deficiencies and/or missing physics to gain insights for further improving model capability in simulating diurnal precipitation

- **Nocturnal convection over land**
  - *What is the role of convective memory (advection), elevated convection initiation, nighttime low-level jet, radiative cooling from cloud tops?*
- **Diurnal cycle of convection over ocean**:
  - *What is the role of the "direct radiation–convection interaction" (or lapse-rate) mechanism on diurnal cycle of convection over ocean?*
  - *What is the role of the "dynamic cloudy–clear differential radiation" mechanism?*
- **Convection transition**
  - *What controls the transition from shallow to deep convection? Free tropospheric humidity or boundary layer inhomogeneity?*
- **Interaction between convection and water vapor**
  - *Which processes are most essential and how can these be improved in weather and climate models?*

Approach

- **A hierarchy modeling approach**
  - *SCMs, CRMs, LESs, Regional Models, Convection Permitting models, and GCMs*
  - *Provides a direct link to field data (e.g., ARM)*
- **Case studies vs. statistical studies**
  - *Major field campaigns*
  - *Multi-year simulations*
- **Short-range hindcasts vs. climate simulations**
  - *The Transpose-AMIP or CAPT approach with models initialized with NWP analysis*
  - *Free AMIP type of runs*
- **Observational studies & modeling tests**

A hierarchy of process models is the key to bridge the scale-gap



5

Model, Data, Experiments

- 11 SCMs (E3SM, E3SM-Trigger, E3SM-SILHS, SCAM5/6, SAM0-UNICON, SKIM, CMC, SMCPCP, ICON, TaiESM)
  - Driven by the ARM long-term continuous variational analysis forcing data (Xie et al. 2004)
    - SGP: 12 warm seasons (May – Aug) (2004-2015);
    - MAO: two full years (2014-2015) (GoAmazon2014/15)

- 9 GCMs/2RGCMs (CAM6-CTL, CAM6-Trig, CMCGEM, ECMWF-IFS, E3SMv2, E3SMv2-CAPETrig, MPAS, TaiESM1, UMGA7, UMGA8, NUIST-WRF)
  - 8-year AMIP runs:
    - full convection-environment interaction
    - circulation could be different from OBS
  - Multi-year 5-day Initialized hindcasts covering MC3E, PECAN, and GoAmazon:
    - full convection-environment interaction
    - circulation is close to OBS (due to initialization)

4

- Need participants and leads for CRM/LES studies

Status

- **SCM component of the project is done**. Results are documented in Tang et al. (2021), QJ, https://doi.org/10.1002/qj.4222.
- Actively working on GCM simulations. Expect a draft done in the next few months.
- Need more participations and leads for CRM/LES studies.
  - LLNL can provide necessary technical and data support
  - Need to identify science questions and connections to the SCM/GCM parts of the project
- Need more follow-up studies by individual groups with the data collected.

http://portal.nersc.gov/project/capt/diurnal/

What have we learned from SCM tests?

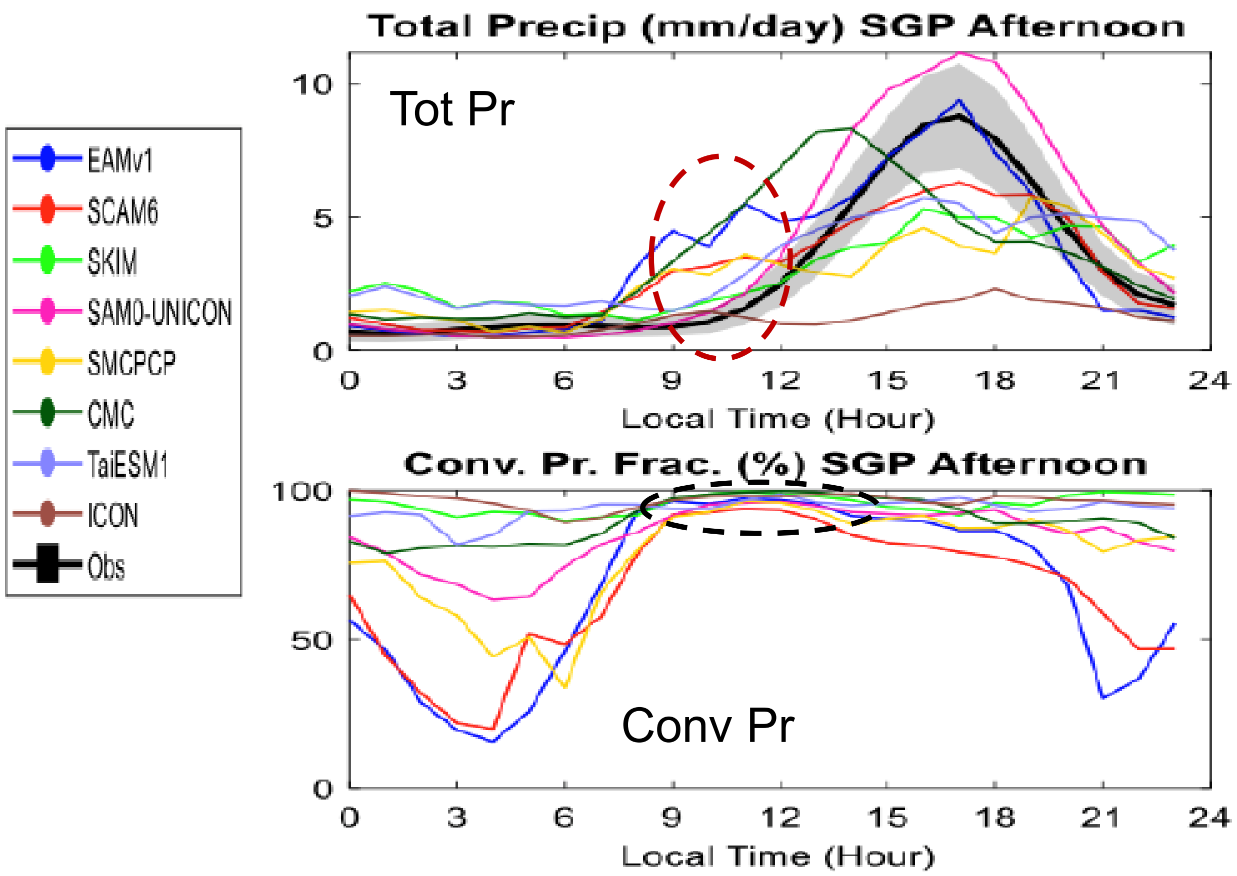
- Afternoon convection: surface driven
- Nocturnal convection: Propagation of MCS and elevated convection

Afternoon Precipitation

Surface-driven deep convection

- Peak Pr > 1mm/day
- Peak hours*: 1pm (11am) – 8pm
- Peak Pr > 1.5 Pr outside Peak Hrs

SGP



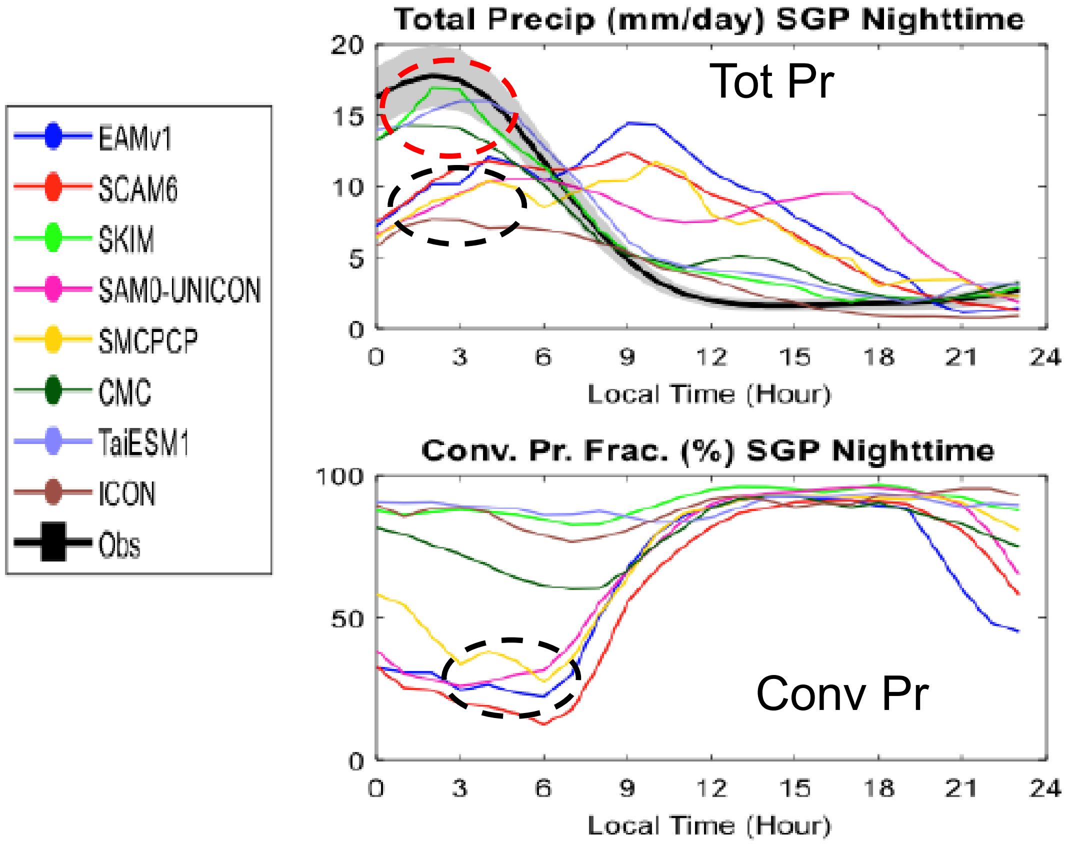
- **All the models trigger convection too early**
  - Simulated precipitation peak time is more spread at MAO than at SGP
- **Convective precipitation dominant**

Nocturnal Precipitation

Propagation of MCSs and elevated convection

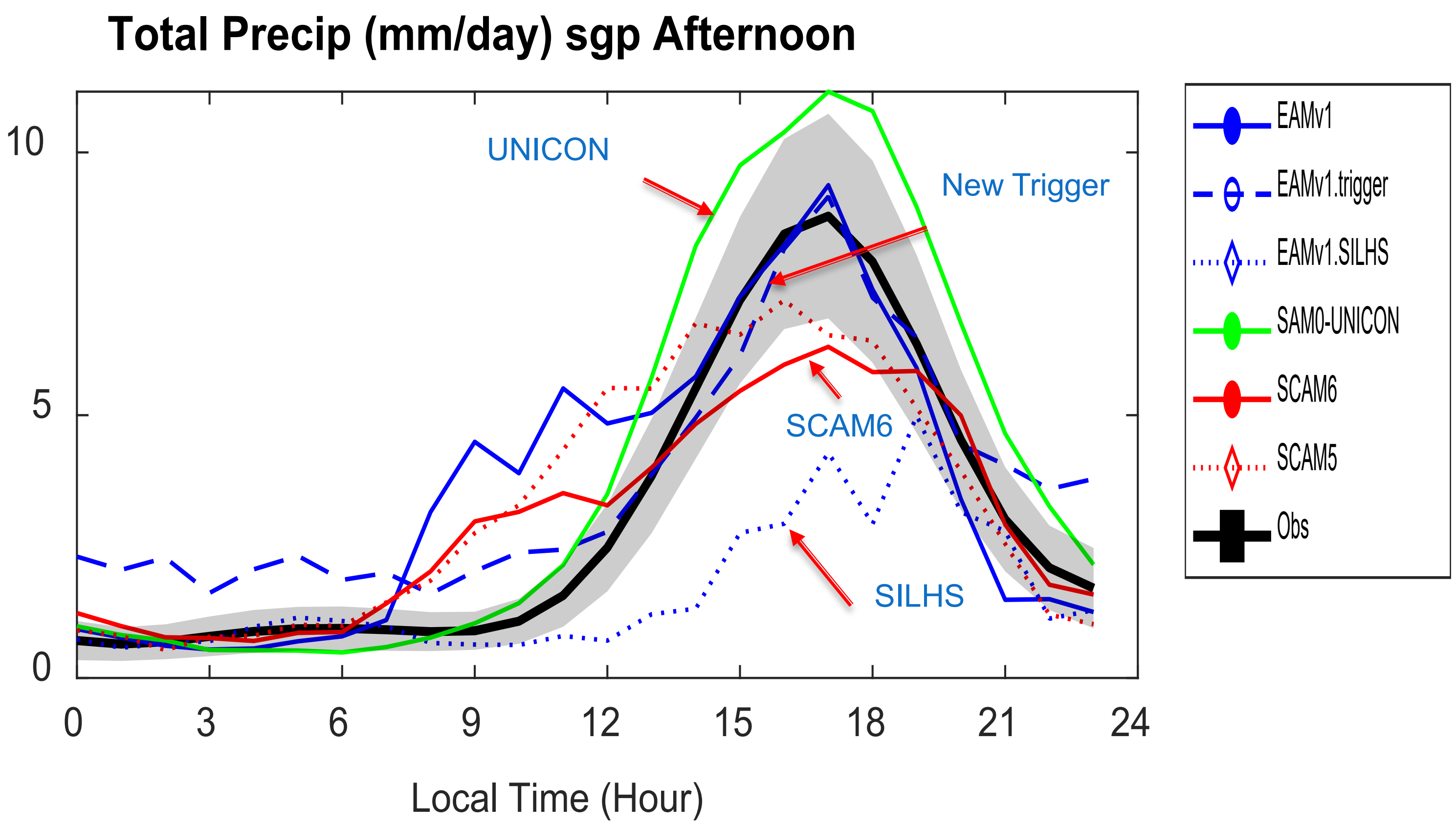
- Peak Pr > 1mm/day
- Peak hours: 00Z – 07Z

SGP



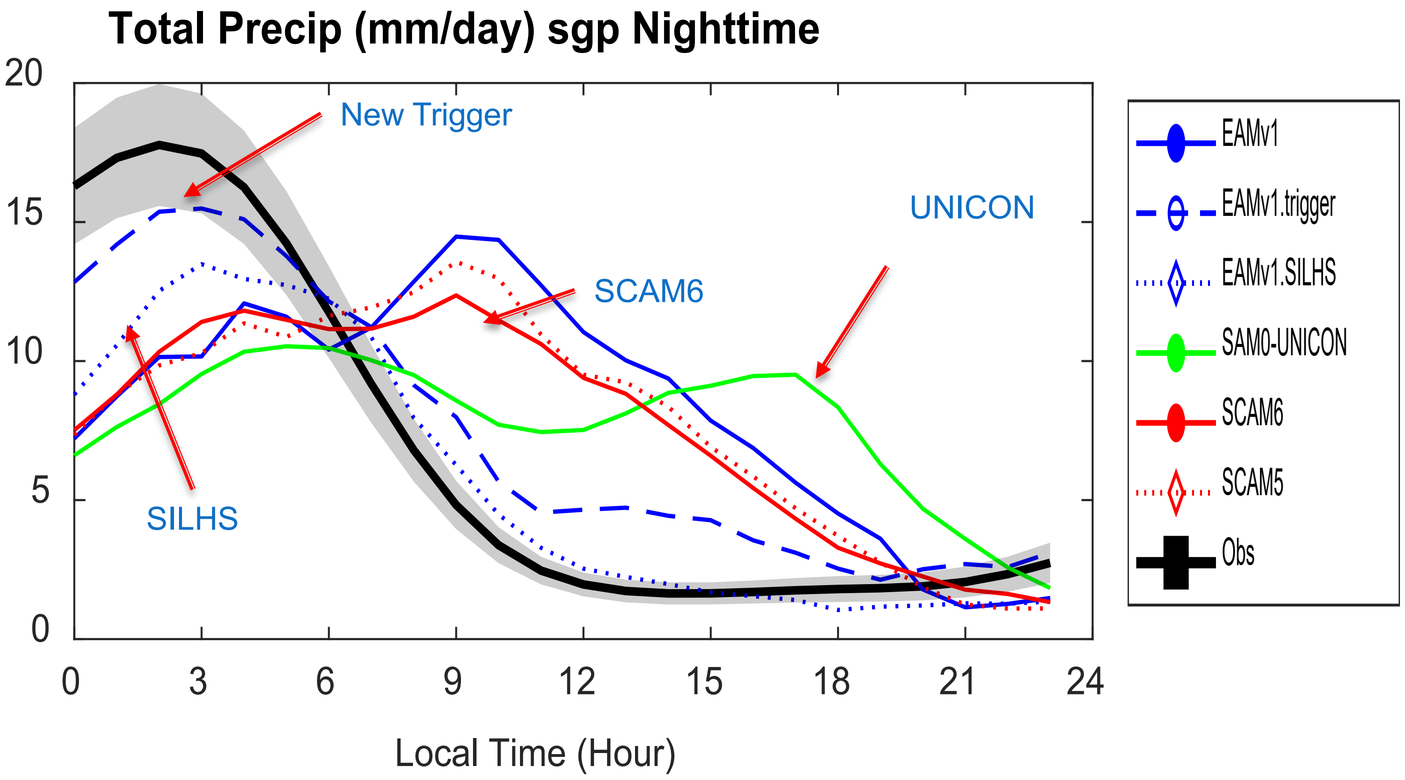
- **SCMs separated into two groups:**
  - **G1: SKIM, CMC, TaiESM1, ICON (well captured)**
  - **G2: EANv1, SCAM6, SAM0-UNICON, SMCPCP**
- **The nocturnal peak from G2 models largely contributed by large-scale precipitation 🡐 controlled by the specified forcing data**
- **All G1 models consider mid-level convection while G2 models do not.**

Impact of convective trigger and unified schemes on afternoon precip



- The dynamical constraint used in dCAPE-ULL ➔ lead to a delayed peak for afternoon precip.
- Unified Sh and Deep Conv (UNICON and SILHS) delayed the convection onset time of afternoon events for both SGP & MAO – ***a better transition from shallow to deep convection during the day?***
- CLUBB also leads to a delayed precip peak, but it does not delay the convection onset time.

Impact of convective trigger and unified schemes on nighttime precip



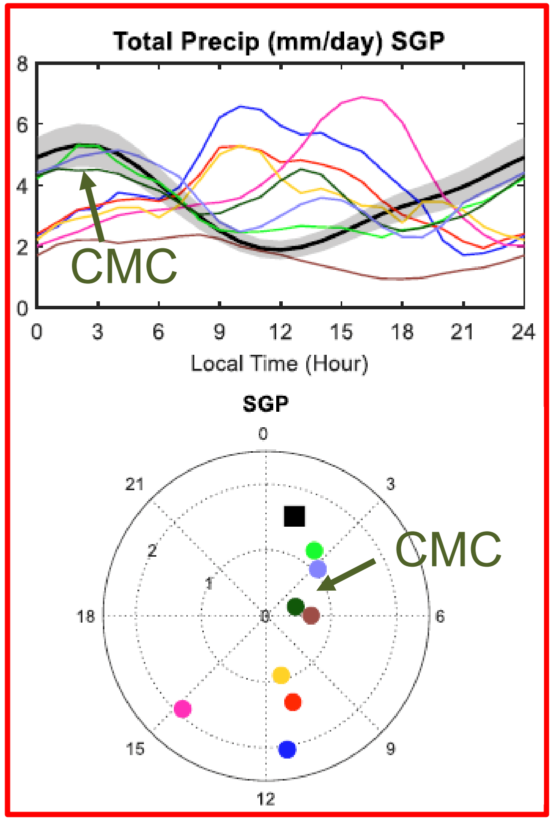
- The unrestricted air parcel launch level method used in dCAPE-ULL to capture mid-level convection ➔ lead to a well captured nocturnal peak for nighttime precip.
- SILHS also well captured the nocturnal peak likely because it does not need specification of parcel launching level.
- UNICON unable to capture the nocturnal peak due to the lack of treatment of mid-level convection.
- CLUBB won't help for the nocturnal peak.

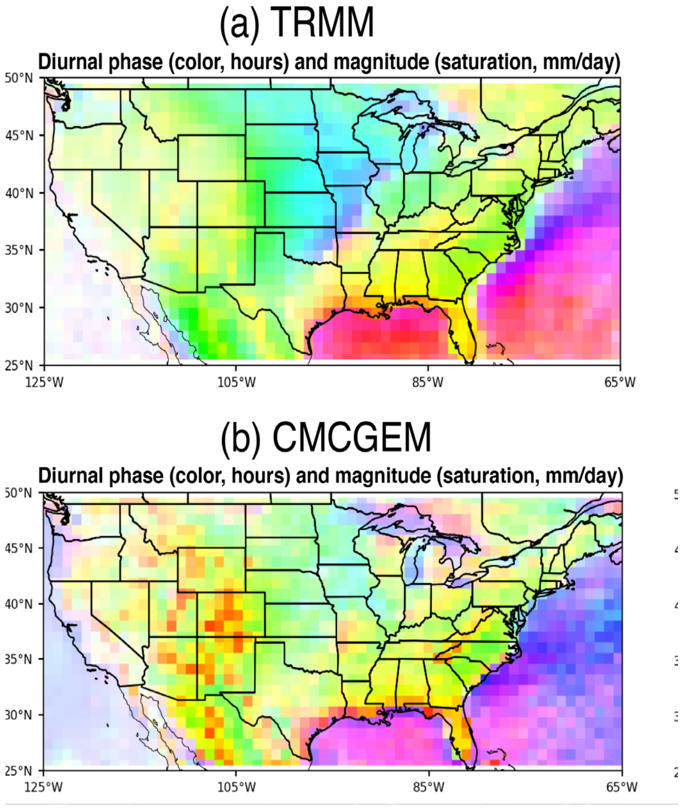
Connections to GCMs

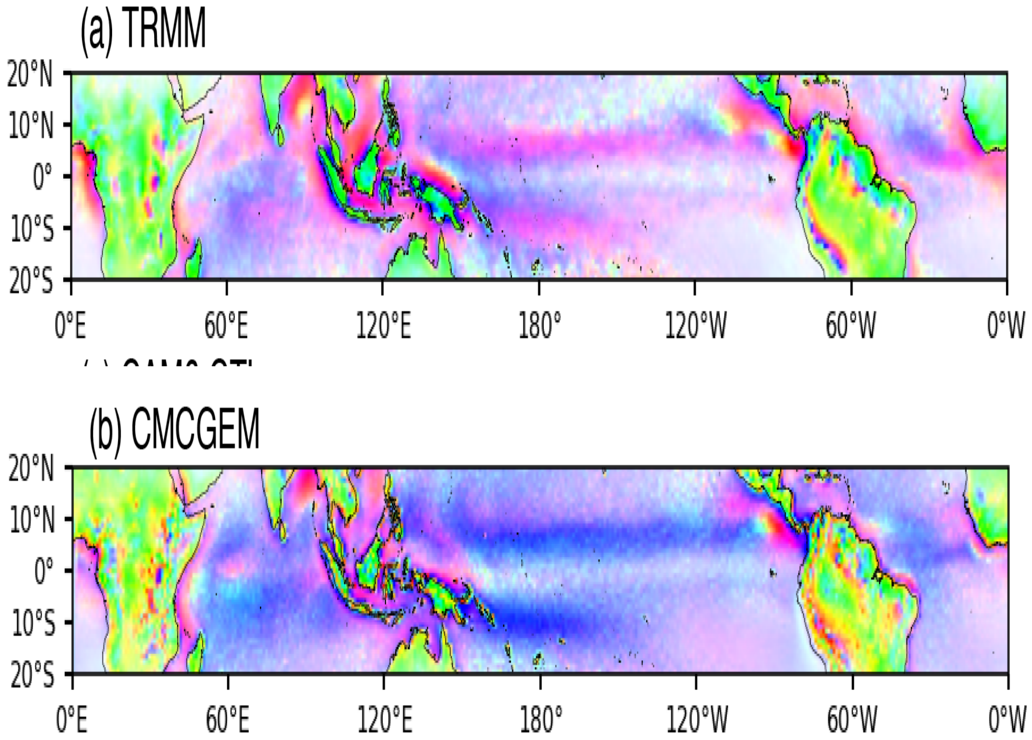
11

CMCGEM – SCM vs GCM

SCM







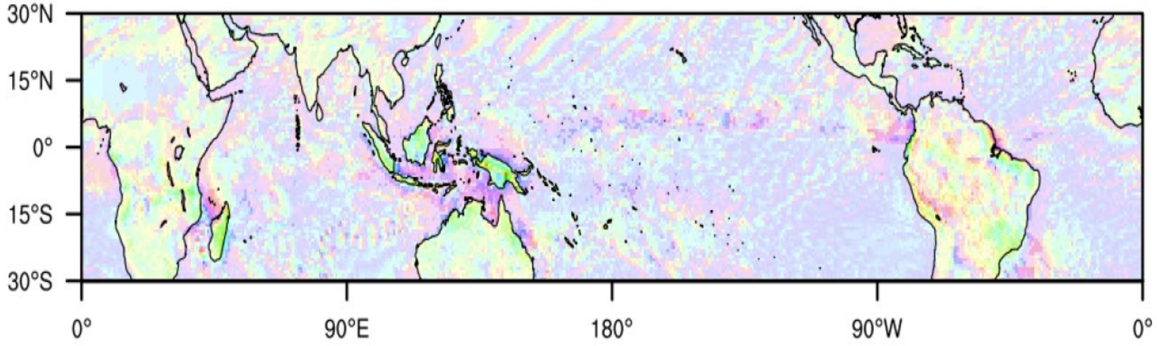
- The nocturnal peak is also well captured by both SCM and GCM runs, likely due to its consideration of mid-level convection

Sensitivity to Model Resolutions

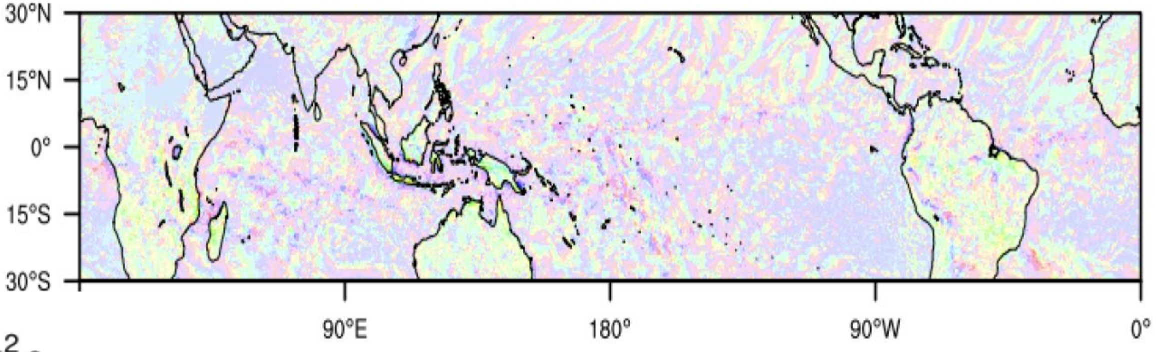
13

DOE Storm-Resolving Model (E3SM – SCREAM) Participate in DYAMOND

TRMM



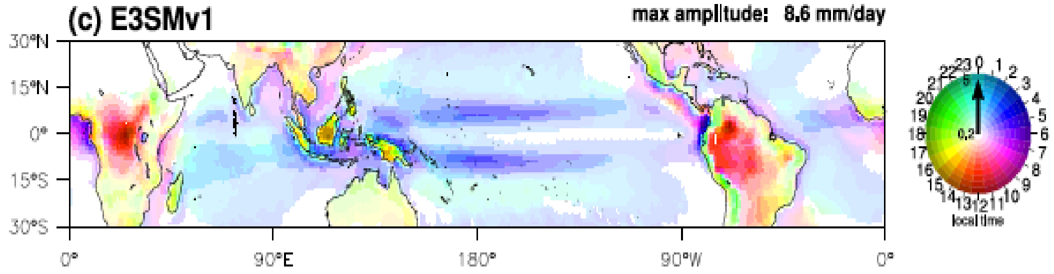
SCREAM



Caldwell et al. (2022) JAMES

The DOE **Energy Exascale Earth System Model (E3SM)** with 3km resolution

- The diurnal cycle is captured surprisingly well!



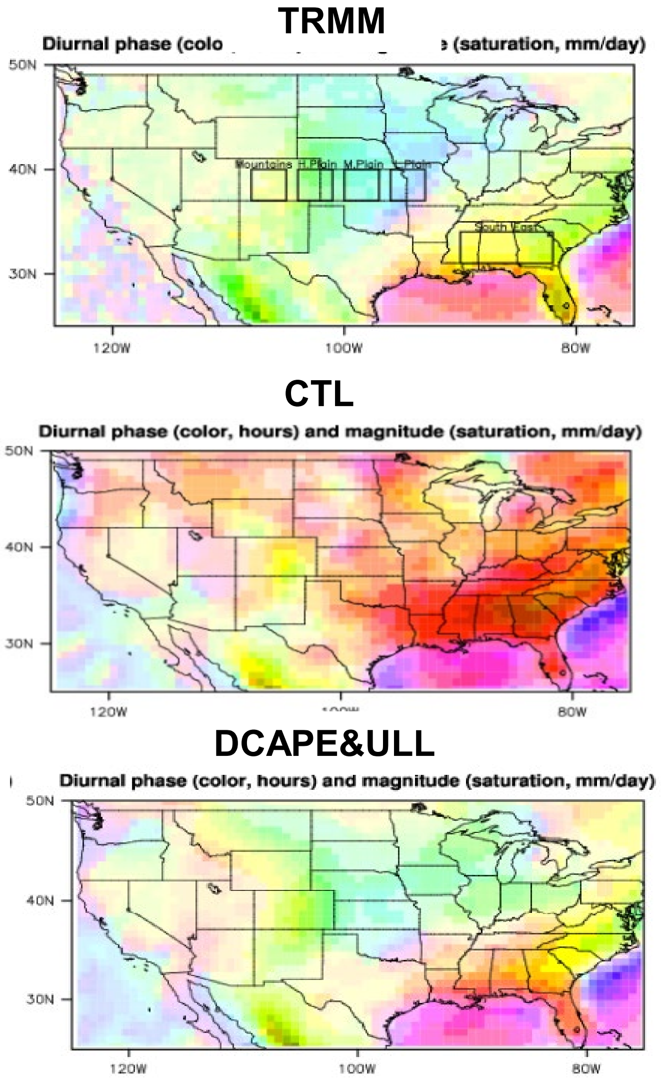
Summary

- The errors in model simulated DCP ~ deficiencies in its deep convection parameterizations.
- For afternoon precip: need additional constraints in triggering and/or unified convection schemes.
    - Unified schemes better capture ShCu to DeepCu, but not necessarily for nocturnal precip, which is often related to elevated convection associated with the passage of MCS.
- The key to capture the nocturnal peak is to allow elevated convection to be captured ~ Including a mid-level convection scheme or launching air parcel above PBL
- Models start to show better skill in capturing DCP only when model resolution is increased to the storm-resolving scale.
- *Connection between SCMs and GCMs needs to be better established. Physically improved schemes usually lead to better simulations seen in both modeling frameworks.*
- *Cold pool physics and convection memory should be also important for the diurnal cycle of precipitation, but they are not tested and examined in the current study*

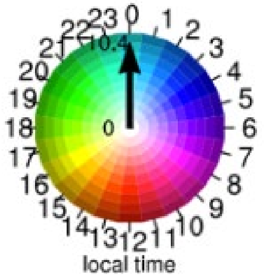
Thank you

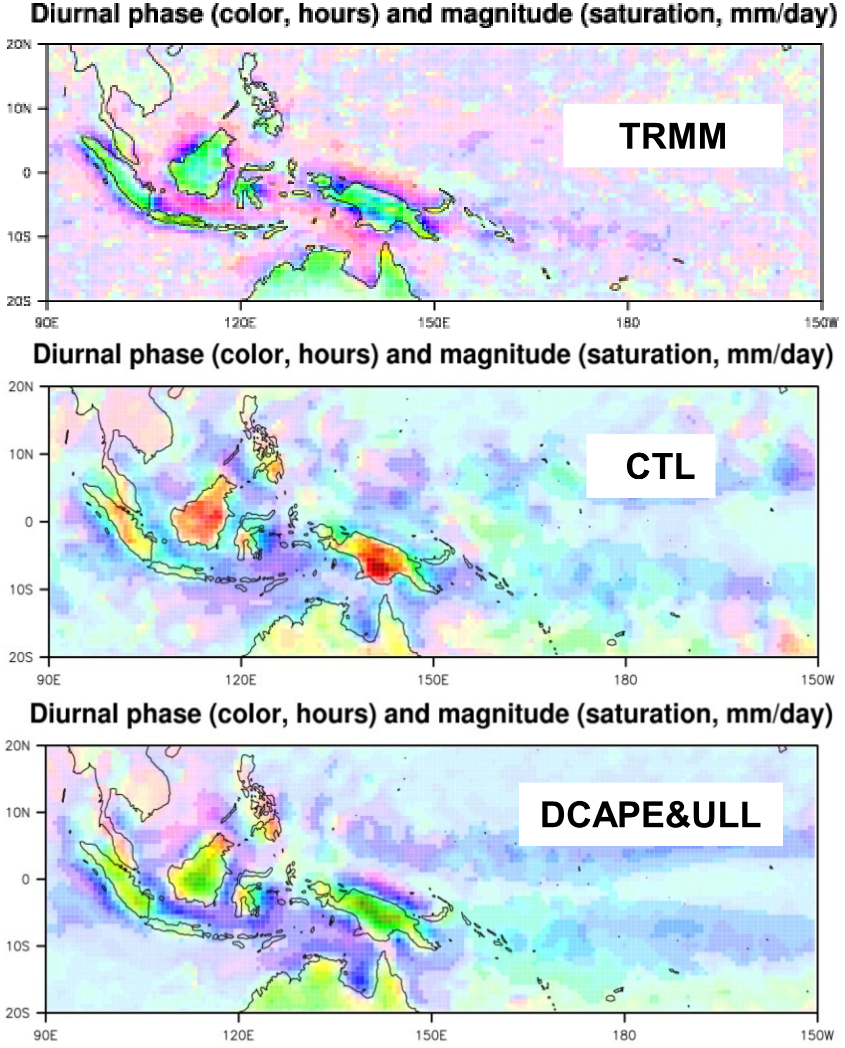
E3SMv1 with the dCAPE&ULL trigger

Xie et al. (2019) JAMES

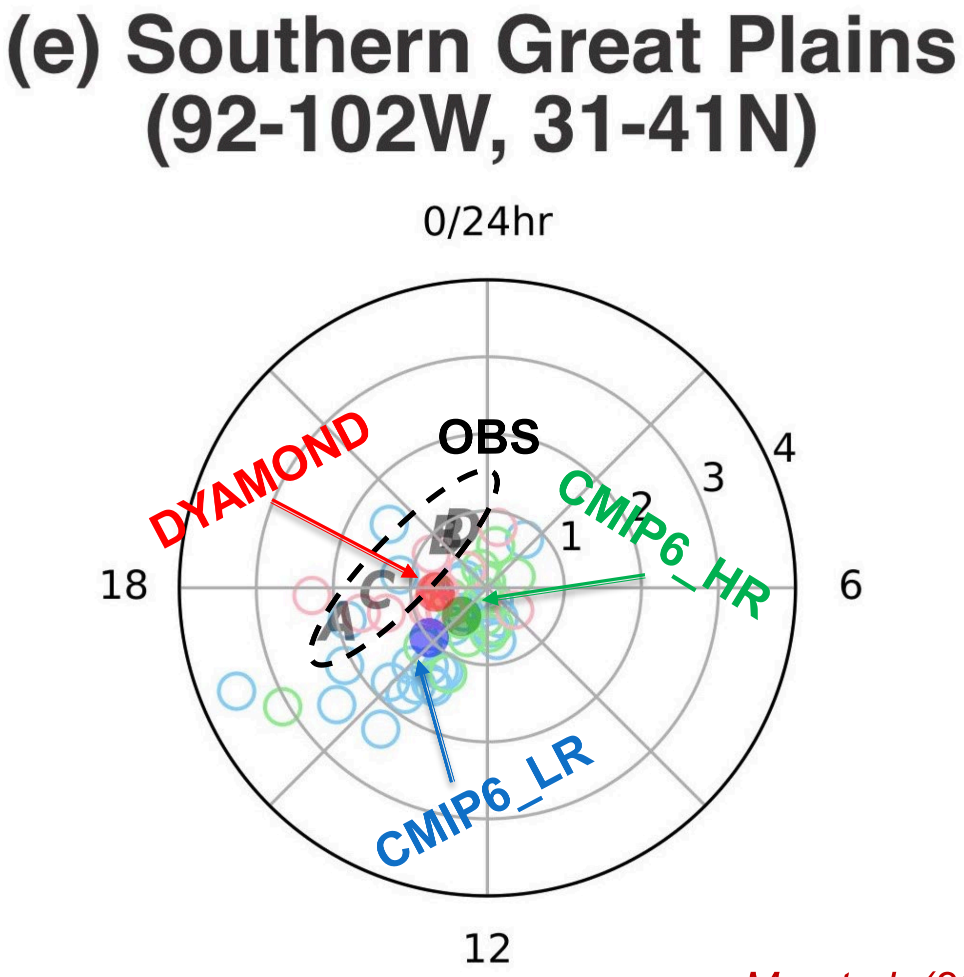


– **dCAPE** reduces the “too frequent, too weak” problem
– **ULL** is the key to capture nocturnal elevated convection
– A substantial improvement in the phase of the diurnal cycle
– The improvement is seen globally

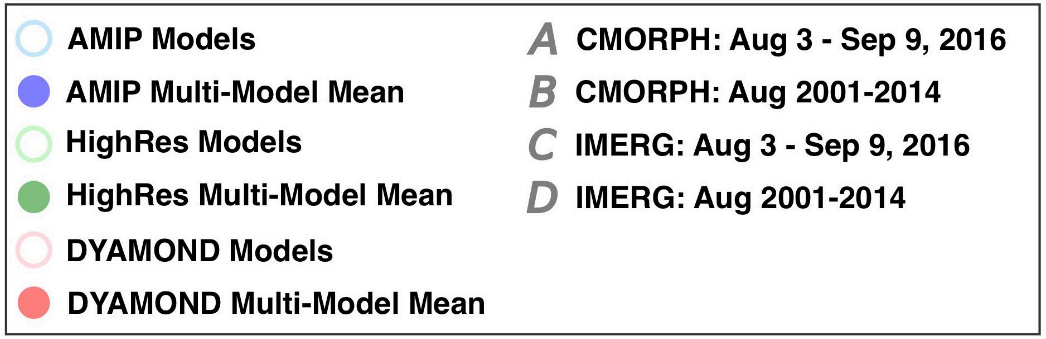




DYAMOND Models vs. AMIP LowRes Models vs AMIP HighRes Models

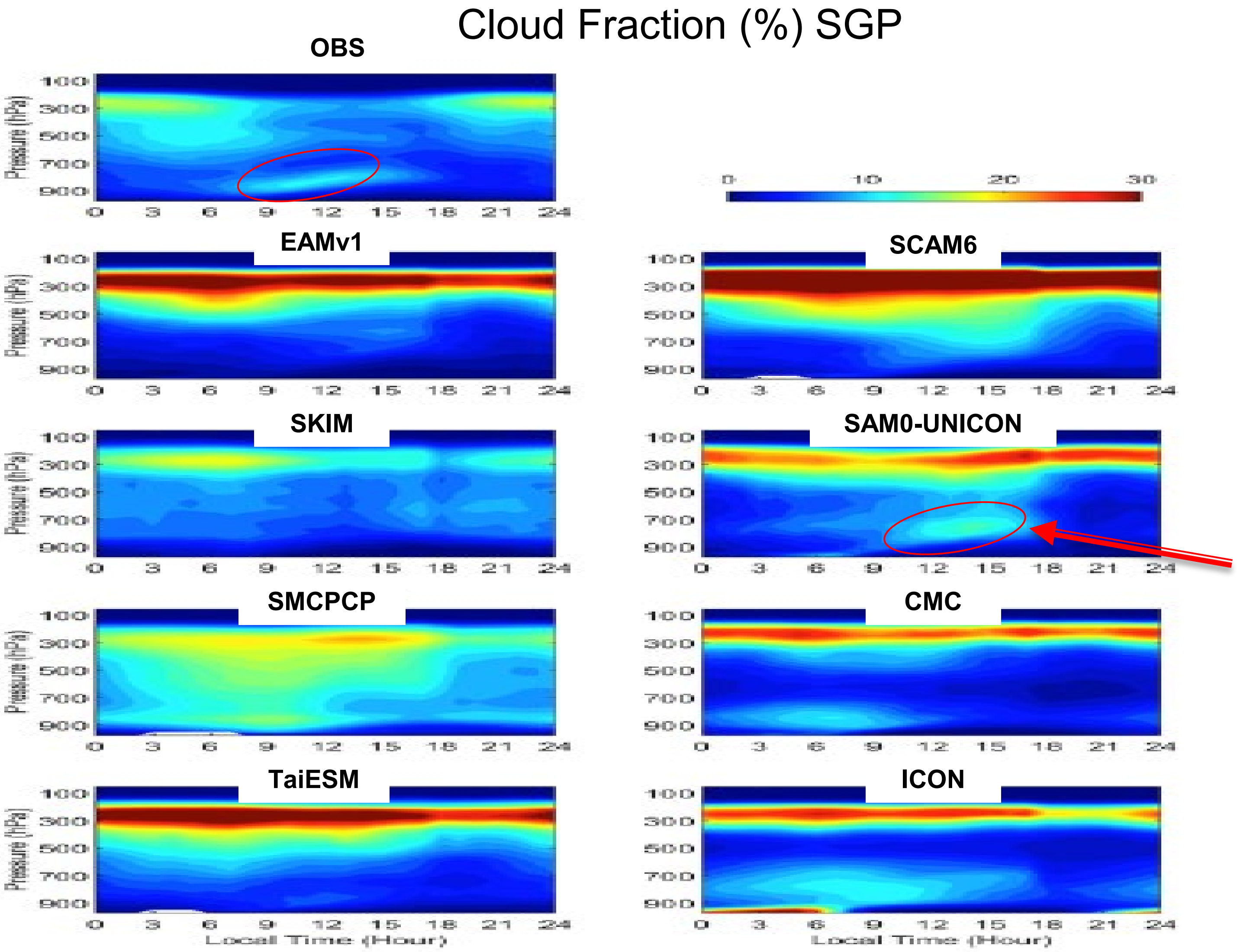


- DYAMOND: 9 models (dx ~ 4 km), a single 40-day simulation started from 1 August 2016 (boreal summer experiment phase)
- CMIP6/HighRes: 14 models (dx ≤ 50 km), 2001-2014 (only August), highresSSTpresent
- CMIP6/AMIP: 28 models (dx ≥ 100 km), 2001-2014 (only August)
- Observations: 2 satellite datasets: CMORPH, IMERG



Ma et al. (2022) GRL

Transition from Shallow to Deep Convection



UNICON well captures the rising of low clouds