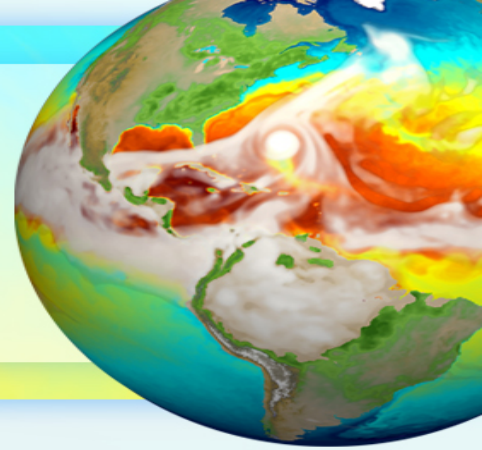
E3SM Next Generation Development (NGD) - Atmospheric Physics



Shaocheng Xie

Lawrence Livermore National Laboratory

DOE LAB Staff

LLNL: Shaocheng Xie, Chris Teri, Qi Tang, Philip Cameron-Smith, Yuying Zhang, Chris Golaz

PNNL: Hailong Wang, Jiwen Fan, Manish Shrivastava, Yun Qian, Kai Zhang, Mingxuan Wu, Sijia Lou, Kobby Shpund

ANL: Yan Feng

BNL: Wuyin Lin

Collaborators

Vince Larson (UWM)

Xiaohong Liu (UW)

Michael Prather (UCI)

Jadwiga (Yaga) Richter (NCAR)

Joao Teixeira (JPL/UCLA)

Guang Zhang (SCRIPPS/UCSD)

Xianglei Huang (U. Michigan)

E3SM Energy Exascale Earth System Model

Work from LLNL is performed under the auspices of the US DOE by LLNL under Contract DE-AC52-07NA27344. LLNL-PRES- 815147

U.S. DEPARTMENT OF ENERGY

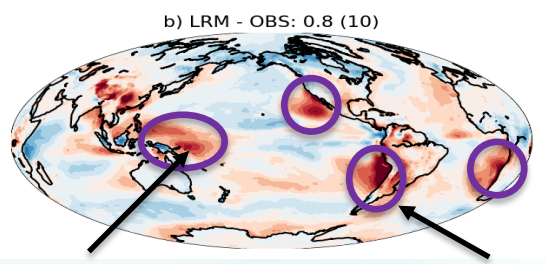
Goals of NGD-Atmospheric Physics

Develop an improved suite of atmospheric physics suitable for various science applications using low-resolution E3SM (12km – 100km)

- **Reduce outstanding biases in E3SMv1**
  - **Biases in clouds**: lack of coastal Sc, mixed-phase clouds, etc.
  - **Biases in precip**: regional biases (wet biases over tropics, dry biases over Amazon, double ITCZ …); rains "too frequent, too weak", too weak MJO and Kelvin waves, wrong diurnal cycle.
  - **Too strong aerosol indirect forcing**
  - Poor scale-awareness
- **Enhance the model's capability for coupling across the Earth system (**chemistry, aerosols, dust, greenhouse gases …)
  - Lack of interactive atmospheric chemistry
  - Missing a few important aerosol species (SOA, stratospheric aerosols, nitrate, dust) that are critical to BGC
  - Coupling of atmospheric chemistry, aerosols/dusts to BGC

The development will address the combined problems of scientific accuracy, scale-awareness, and computational efficiency

SWCRE Bias

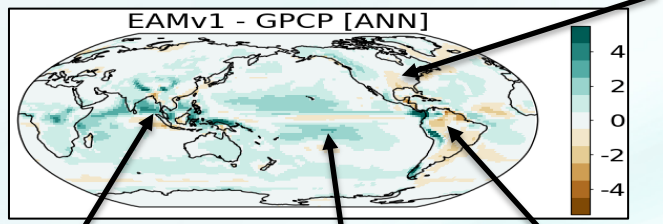


Lack of clouds over TWP

Lack of coastal Sc

Zhang, Xie et al. (2019)

Annual Precipitation Bias



Warm and dry central US

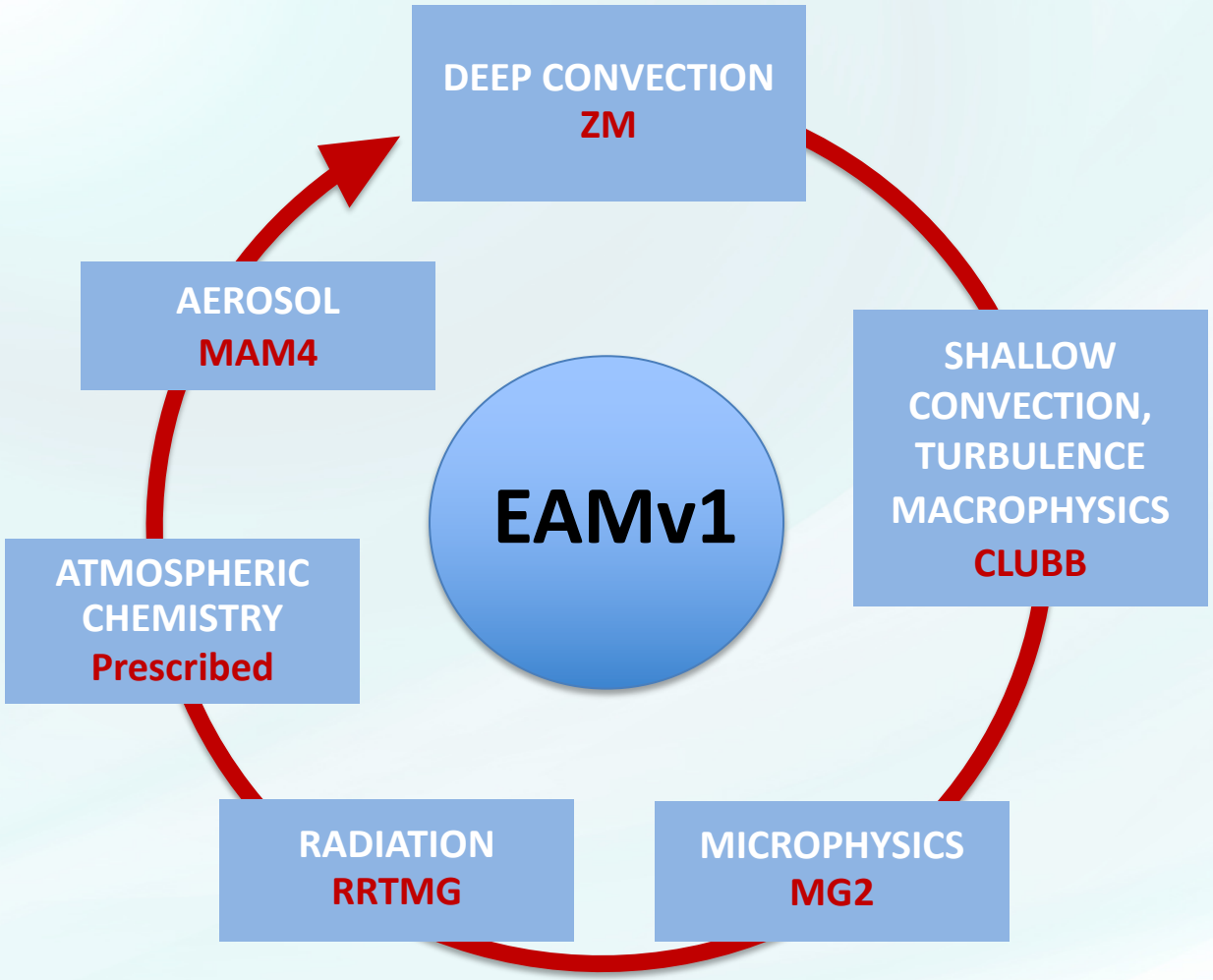
Excessive precip over Tropical IO & warm pool

Double ITCZ

Dry Amazon

Rasch, Xie et al. (2019)

Atmospheric Physics in E3SM v1



NGD-Atmospheric Physics for E3SM v3

Improving cloud and convection to reduce model biases

Guang Zhang (UCSD)

Yaga Richter (NCAR)

Enhancements in Deep Convection

DEEP CONVECTION
ZM

A Scale-Aware Unified Convection Scheme:
CLUBB-SILHS or EDMF

Vince Larson (UWM)

Joao Teixeira (JPL/UCLA)

New Aerosol/dust

AEROSOL
MAM4

SHALLOW CONVECTION, TURBULENCE MACROPHYSICS
CLUBB

A Simplified Higher-Order Closure (SHOC)

Chris Terai (LLNL)

EAMv1

UCI Chemistry (32 species), Fast-J Photolysis

ATMOSPHERIC CHEMISTRY
Prescribed

Jiwen Fan (PNNL)

Predicted Particle Properties (P3)

UCI Solar-J and Radiative Treatment of clouds and aerosols

RADIATION
RRTMG

MICROPHYSICS
MG2

NGD-Atmospheric Physics for E3SM v3

Improving model capability for coupling across the Earth system

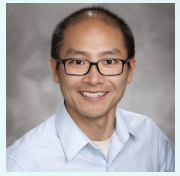
Hailong Wang (PNNL)

Enhancements in Deep Convection

DEEP CONVECTION
ZM

A Scale-Aware Unified Convection Scheme: CLUBB-SILHS or EDMF

New Aerosol/dust



Qi Tang (LLNL)

AEROSOL
MAM4

UCI Chemistry (32 species), Fast-J Photolysis

Philip Cameron-smith (LLNL)

ATMOSPHERIC CHEMISTRY
Prescribed

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SHALLOW CONVECTION, TURBULENCE MACROPHYSICS
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A Simplified Higher-Order Closure (SHOC)

Michael Prather (UCI)

UCI Solar-J and Radiative Treatment of clouds and aerosols

RADIATION
RRTMG

MICROPHYSICS
MG2

Predicted Particle Properties (P3)

Progress Highlights

- More details refer to

Plenary talks scheduled on Day 2

- **Guang Zhang**: Valuation of the Effects of Stochastic Convection Scheme in E3SMv1
- **Joao Teixeira**: A new unified boundary layer and convection parameterization in the E3SM model: The multi-plume Eddy-Diffusivity/Mass-Flux (EDMF) approach
- **Jack Chen**: Effects of organized mesoscale heating on the MJO and precipitation in E3SMv1

Oral talk at the NGD-atmosphere breakout session (Day 4)

- **Chris Terai**: Evaluating the climate of coupling SHOC with ZM
- **Qi Tang and Hailong Wang**: update on atmospheric chemistry and aerosols

Posters

- **Vince Larson**: Parameterization of deep convection in E3SM with higher-order closure
- **Jiwen Fan**: Impact of P3 on the Simulations of MCSs Using E3SM RRM Framework
- …

Convection – Improved the Phase of Diurnal Precipitation

Shaocheng Xie, Wuyin Lin, Guang Zhang

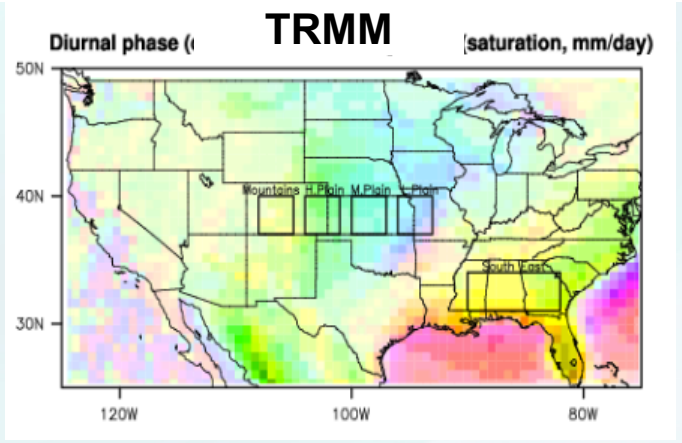
Improved features for ZM

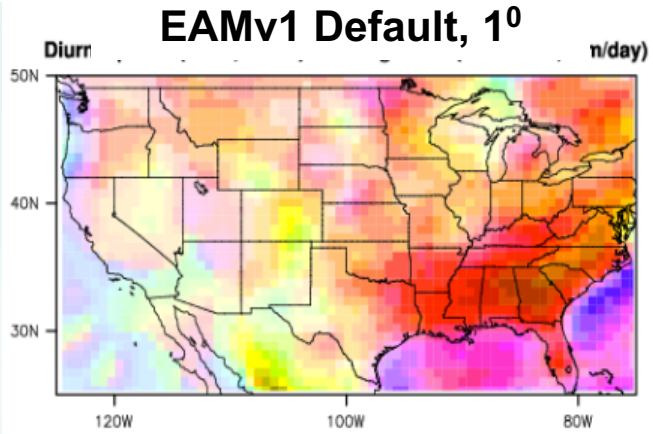
- **A new convective trigger** (dCAPE&ULL, Xie et al. 2019) to improve diurnal cycle precipitation
  - A dynamic constraint (dCAPE) on convection onset to suppress day-time convection and an unrestricted parcel launch level (ULL) to detect moist instability above BL for nocturnal precipitation

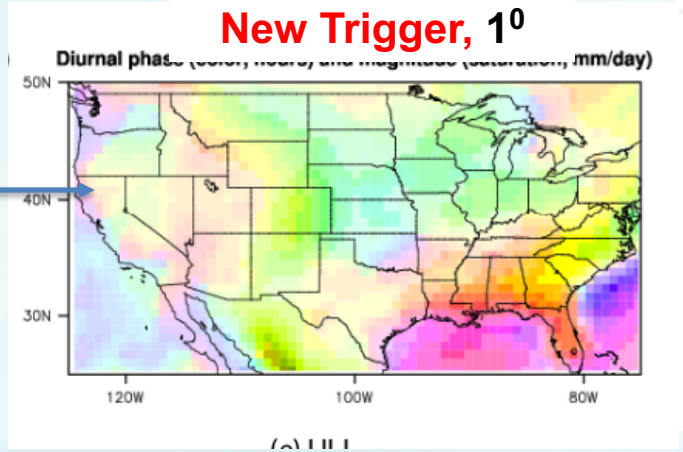
Phase: substantially improved
Amplitude: still largely underestimated

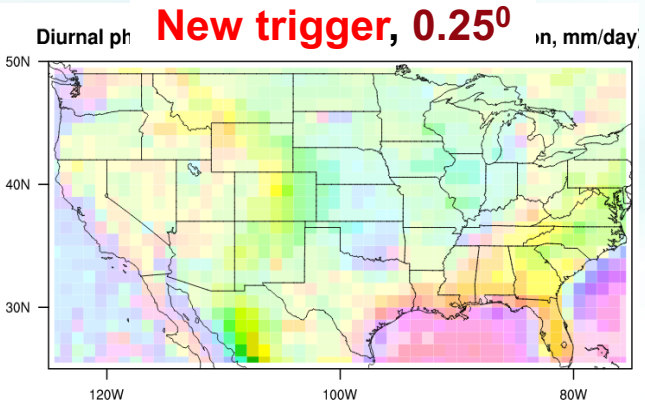
Xie et al. (2019) JAMES

Diurnal Phase (color) and Amplitude (saturation) at CONUS









Convection – Improved Precipitation Distribution

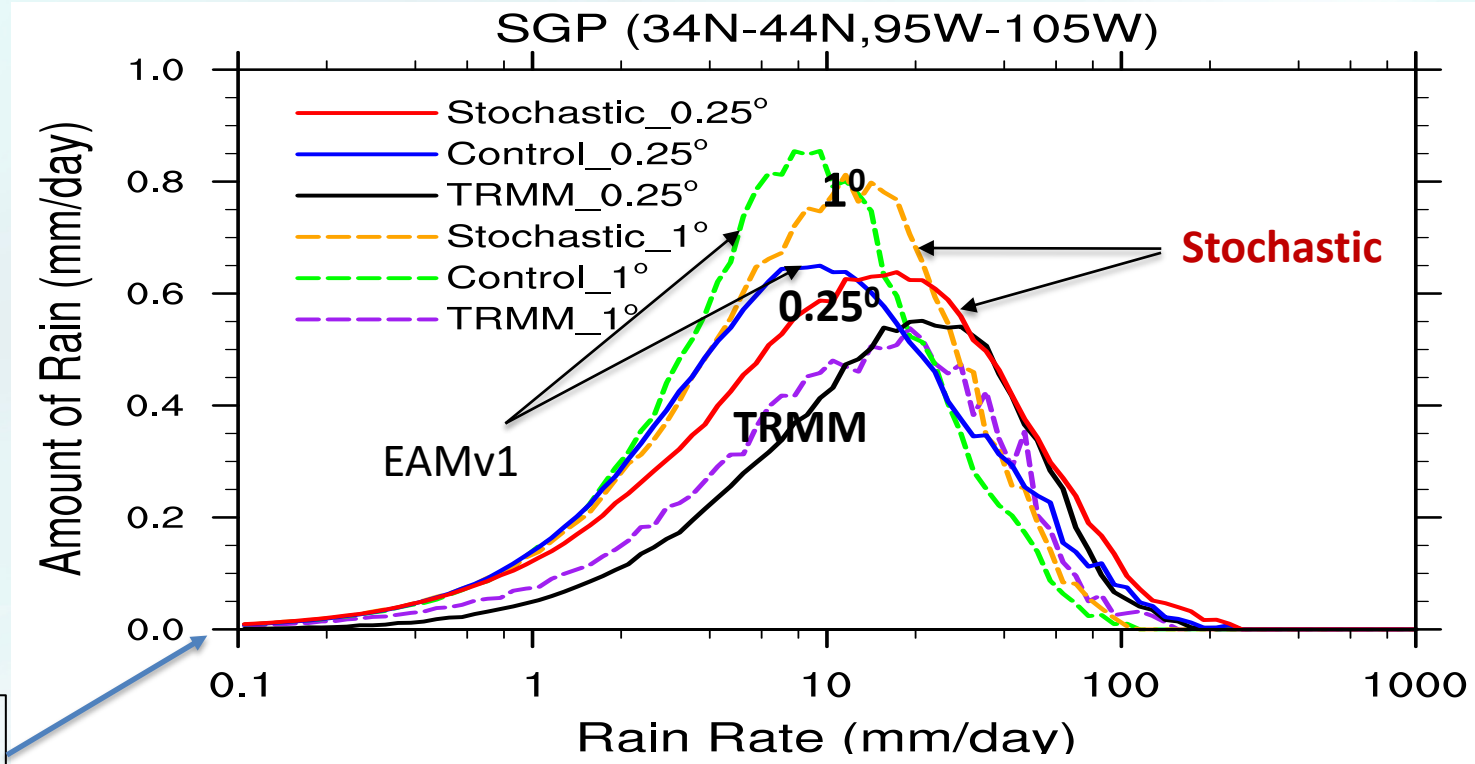
Guang Zhang (UCSD), Xu Wang, Yong Wang, Xiaoliang Song

Improved features for ZM

- **A stochastic convection scheme** is incorporated into ZM to improve precipitation distribution (Wang et al. 2020)
- Cloud microphysics for convective clouds following Song&Zhang (2011)
- Improved scale-awareness

Decreases light rain and increases heavy rain

Rainfall amount pdf at Great Plains



Wang, Zhang et al. (2020) Submitted to GMD

Guang Zhang: Valuation of the Effects of Stochastic Convection Scheme in E3SMv1 **D2S3**

Convection – Improved Tropical Waves

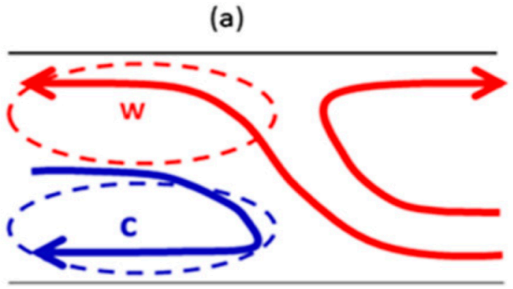
NCAR: Yaga Richter, Jack Chen, Mitch Moncreff, Changhai Liu

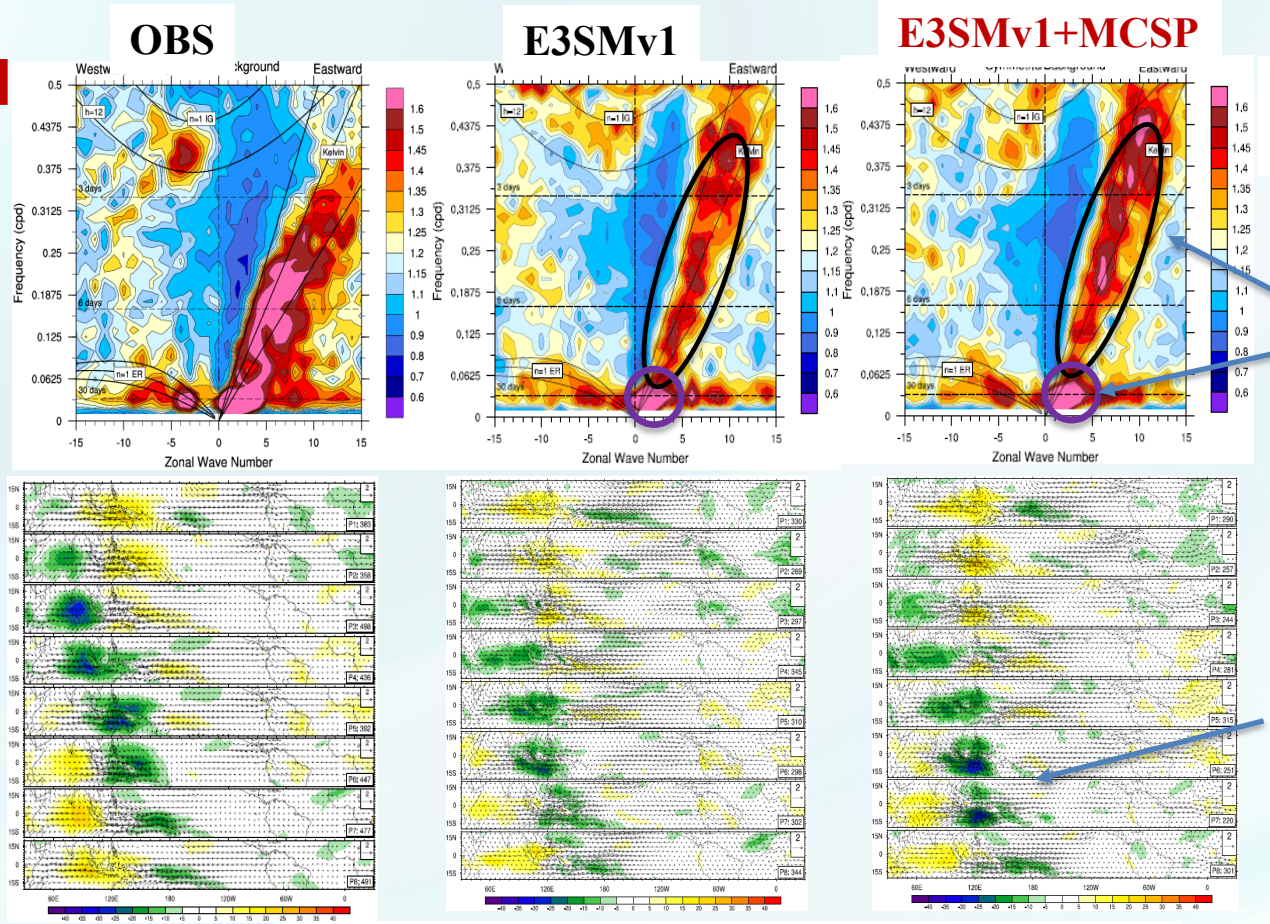
Improved features for ZM

- **The Multiscale Coherent Structures Parameterization** (**MCSP,** Moncreff 2019) for mesoscale effect on convection

Added Mesoscale Heating Profile on Top of ZM Heating:

$$Q_m = Q_{ZMDT}\ \frac{\pi}{2}\left(\frac{P_{Qtop} - 400}{300}\right)$$





Wheeler-Kiladis diagram

Stronger Kelvin wave and MJO

Stronger signal and better eastward propagation

Chen, Richter et al. (2020) To be submitted

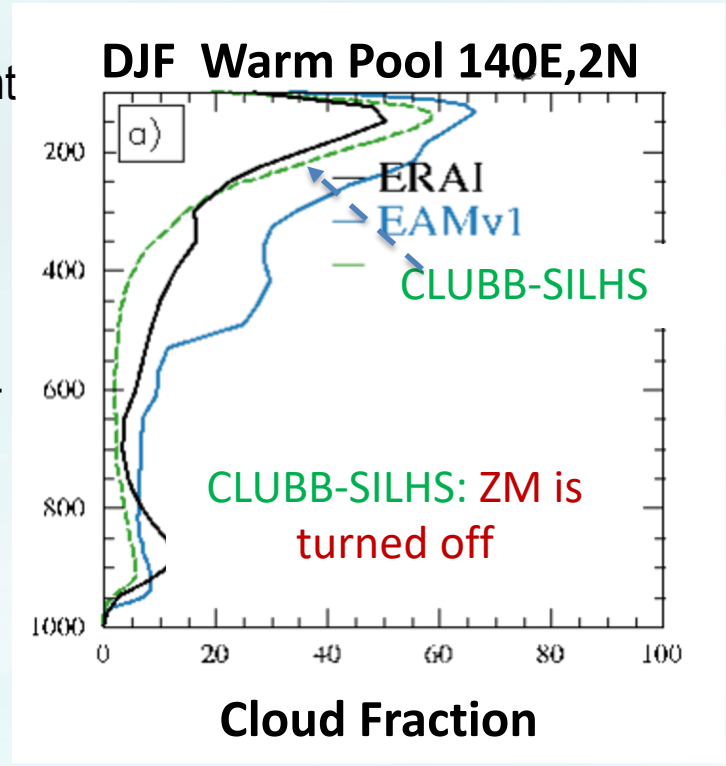
Jack Chen: Effects of organized mesoscale heating on the MJO and precipitation in E3SMv1. **D2S3**

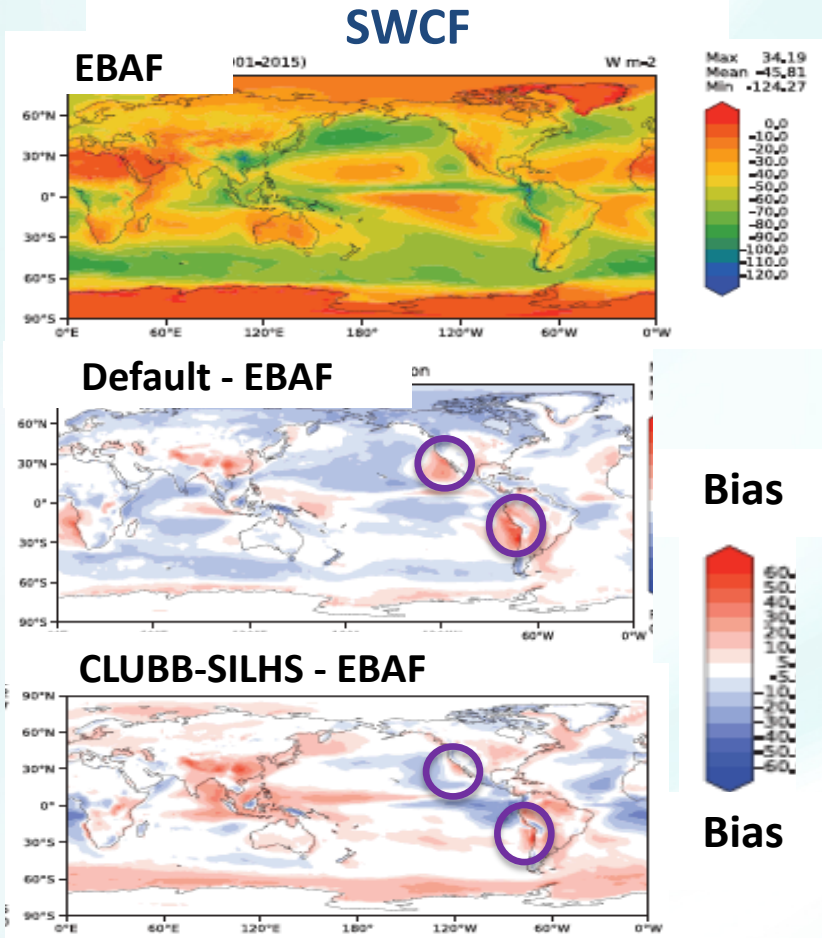
Convection – Make CLUBB for Deep Convection

Vince Larson (UWM)

CLUBB-SILHS to unify all types of clouds. Use ***the Subgrid Importance Latin Hypercube Sampler (SILHS)*** to sample the subgrid PDFs predicted by CLUBB and allows the microphysics to respond to subgrid variability in clouds

- Parameterizing non-gradient terms e.g. turbulent advection & buoyancy to make convection go deep
- Using a multi-time-scale parameterization for CLUBB's turbulent damping time scale to improve the distribution of shallow Cu and near-coast Sc.
  - In the stable layers, damping fluxes more to preserve Sc
  - In the stable layers, damping variances less to permit partial cloudiness
- Good scale-awareness





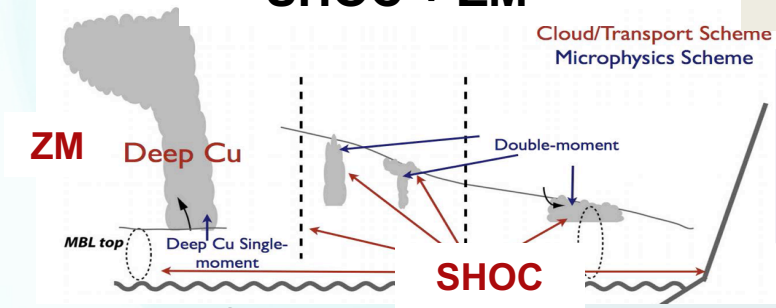
Guo, Larson et al. (2020), submitted

Vince Larson: Parameterization of deep convection in E3SM with higher-order closure (**Poster)**

Turn-on Deep Conv in SCREAM for Its Low-res Applications

Collaboration with the SCREAM team

SHOC + ZM

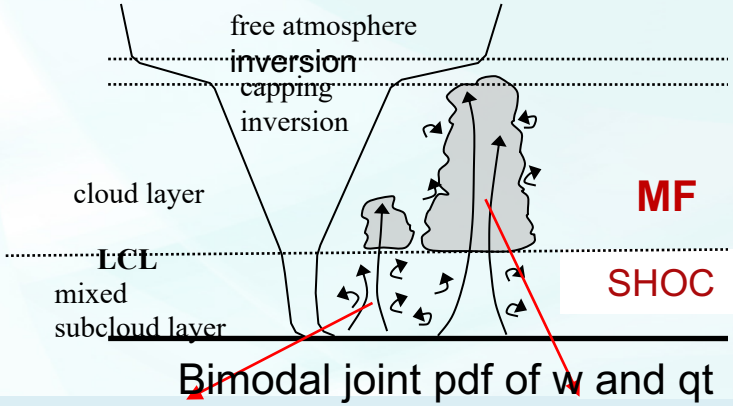


Courtesy of Peter Bogenschutz

Chris Terai (LLNL)

Oral Talk: Evaluating the climate of coupling SHOC with ZM. **Day 4, NGD-atm breakout**

SHOC + EDMF



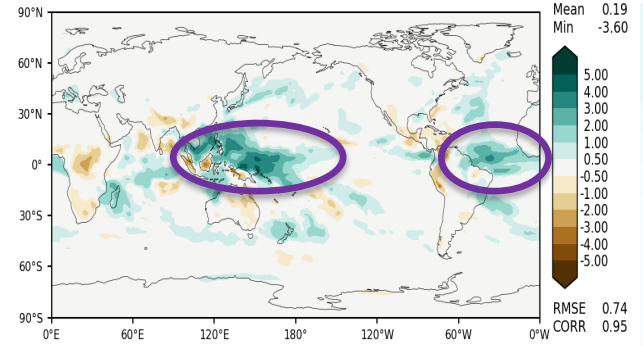
Bimodal joint pdf of w and qt

Small-scale ED mixing Large-scale MF mixing

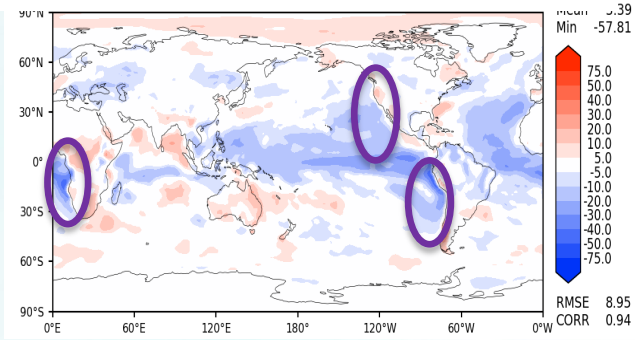
Joao Teixeira (JPL/UCLA)

Plenary talk on a multi-plume eddy-diffusivity/mass-flux (EDMF) parameterization in E3SM. **D2S3**

SHOC/ZM – EAMv1, Precip



SHOC/ZM – EAMv1,SWCF



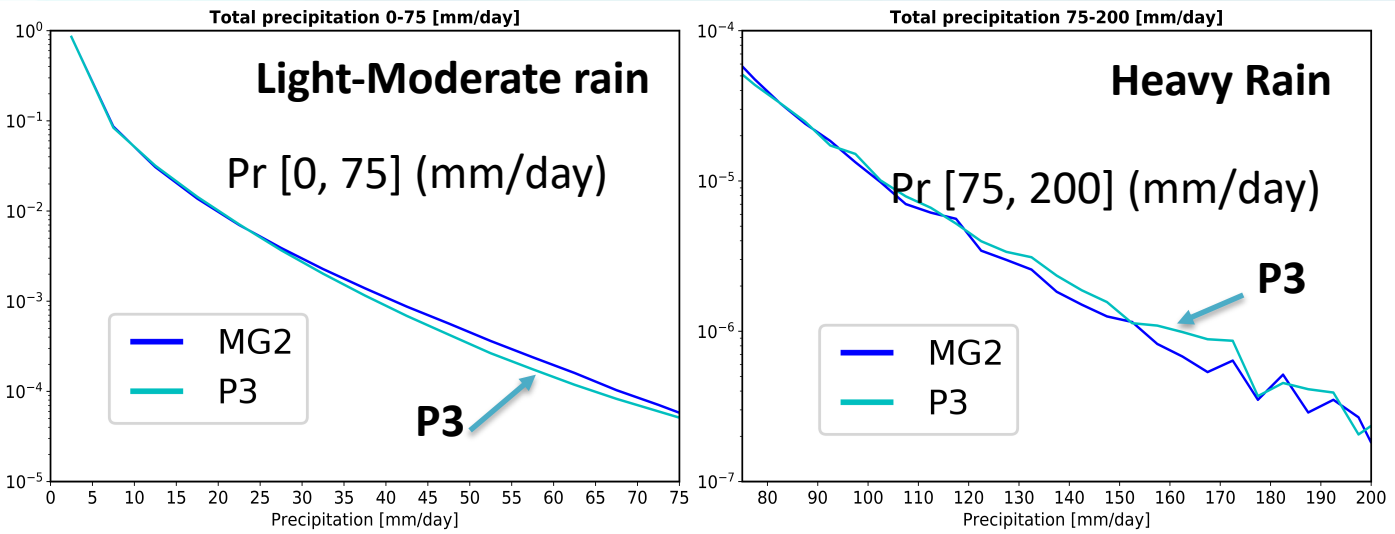
Too much precip in the tropics and better Sc

Cloud Microphysics - Predicted Particles Properties (P3)

Jiwen Fan, Jacob Shpund, Kai Zhang,
+ the SCREAM Team

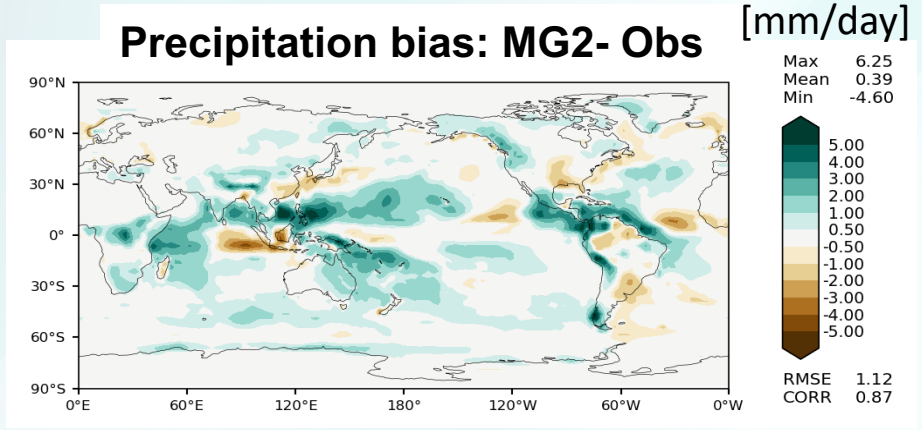
Allows for improved representations of ice particle evolution and inclusion of rimed particles, with expectation of improving precipitation rates and cloud properties.

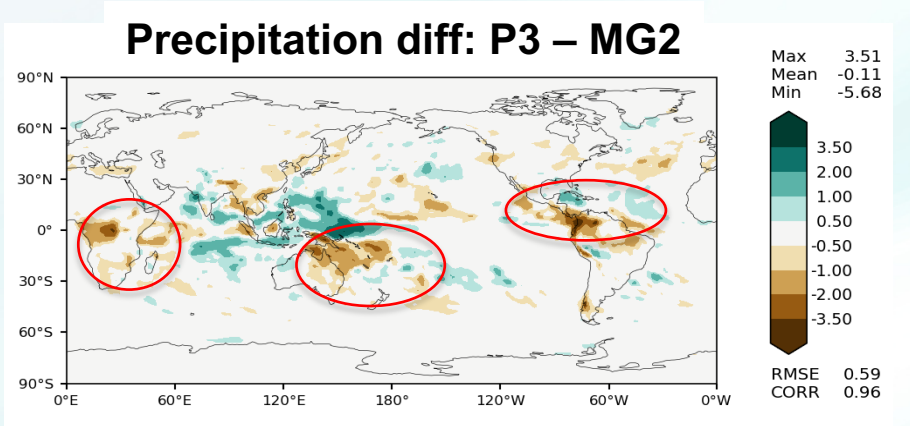
Improved Precipitation PDF



With P3, the model predicts higher frequencies of large precipitation rates (> 120 mm/day) and lower frequencies of moderate precipitation (30-70 mm/day) compared with MG2

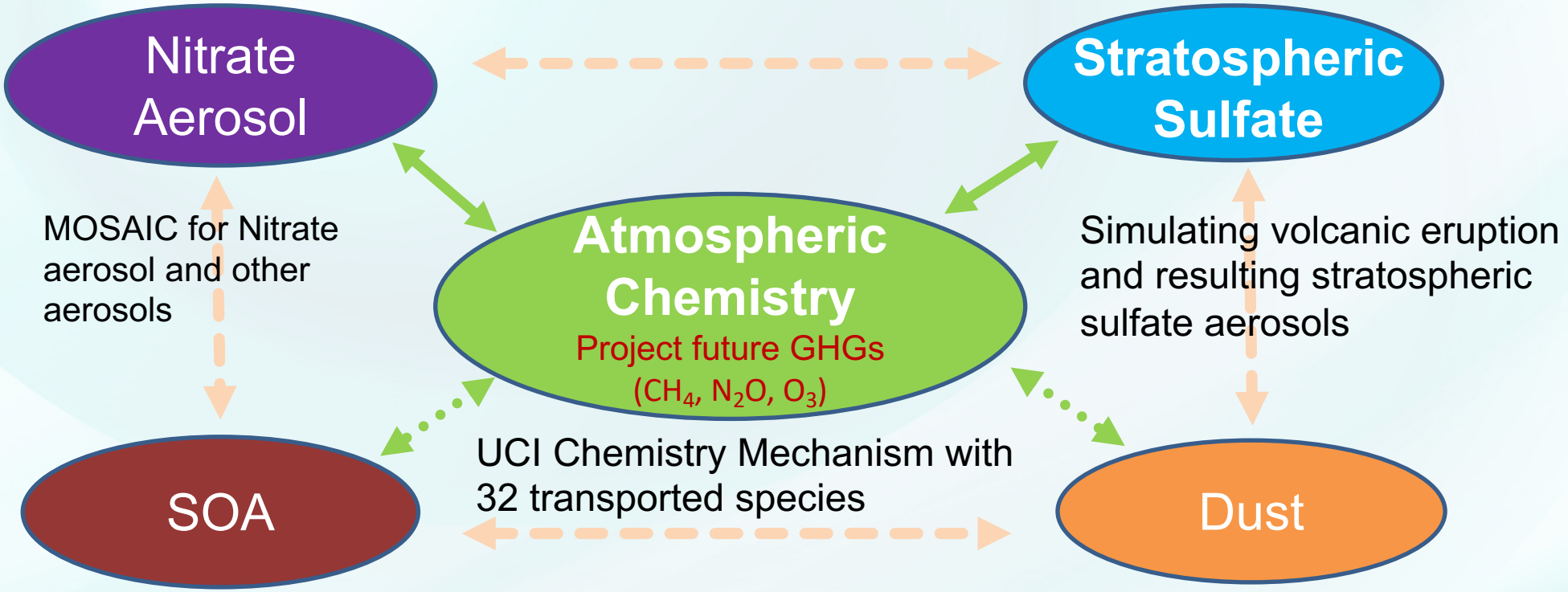
Reduced Precip Biases





New Aerosol Physics & Atmospheric Chemistry

Hailong Wang, Qi Tang, Michael Prather, Philip Cameron-Smith, Xiaohong Liu, Yan Feng, Manish Shrivastave



Qi Tang/Hailong Wang's talk at the NGD-atmosphere breakout session on Day 4

Summary

- The NGD-Atmospheric Physics Project created in E3SM to address model biases and enhance model capability
  - Target V3, 100 km – 12.5 km,
  - Improve scale-awareness, unification, clouds, aerosol physics, and atmospheric chemistry
  - Capability for chemical coupling across the system (Gas-phase chemistry, aerosols, GH gases)
    - Capability for coupling of aerosols/dusts to chemistry, BGC, and Land/energy use
- Close collaboration with ESMD funded research on model developments
  - Several new parameterizations are being implemented into E3SM
- Developments on track
  - Reduced errors in clouds and precipitation in both mean states and variability
  - New aerosols and interactive chemistry in E3SM
  - To be ready by 2022