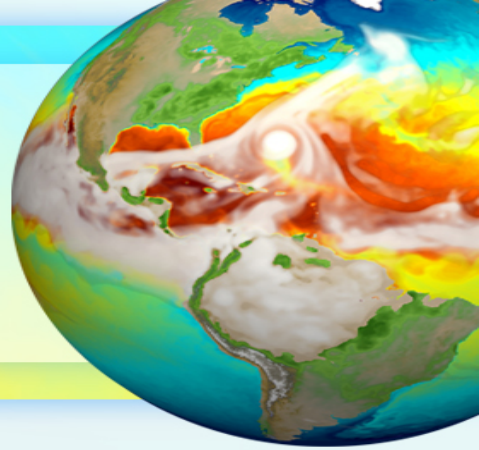
E3SM Next Generation Development (NGD) - Atmospheric Physics



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Lawrence Livermore National Laboratory

DOE LAB Staff

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BNL: Wuyin Lin

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Xiaohong Liu (UW)

Michael Prather (UCI)

Jadwiga (Yaga) Richter (NCAR)

Joao Teixeira (JPL/UCLA)

Guang Zhang (SCRIPPS/UCSD)

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-816007

U.S. DEPARTMENT OF ENERGY

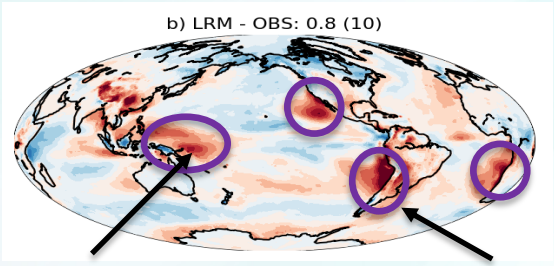
Goals of NGD-Atmospheric Physics

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

- **Continue to reduce outstanding biases in E3SMv1 for a more accurate physical model**
  - Biases in cloud and precipitation
  - 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

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

SWCRE Bias

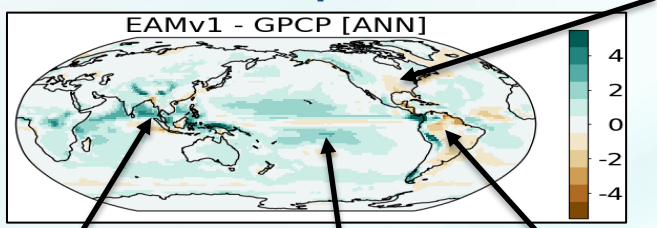


Lack of clouds over TWP

Lack of coastal Sc

Zhang, Xie et al. (2019)

Annual Precipitation Bias



Warm and dry central US

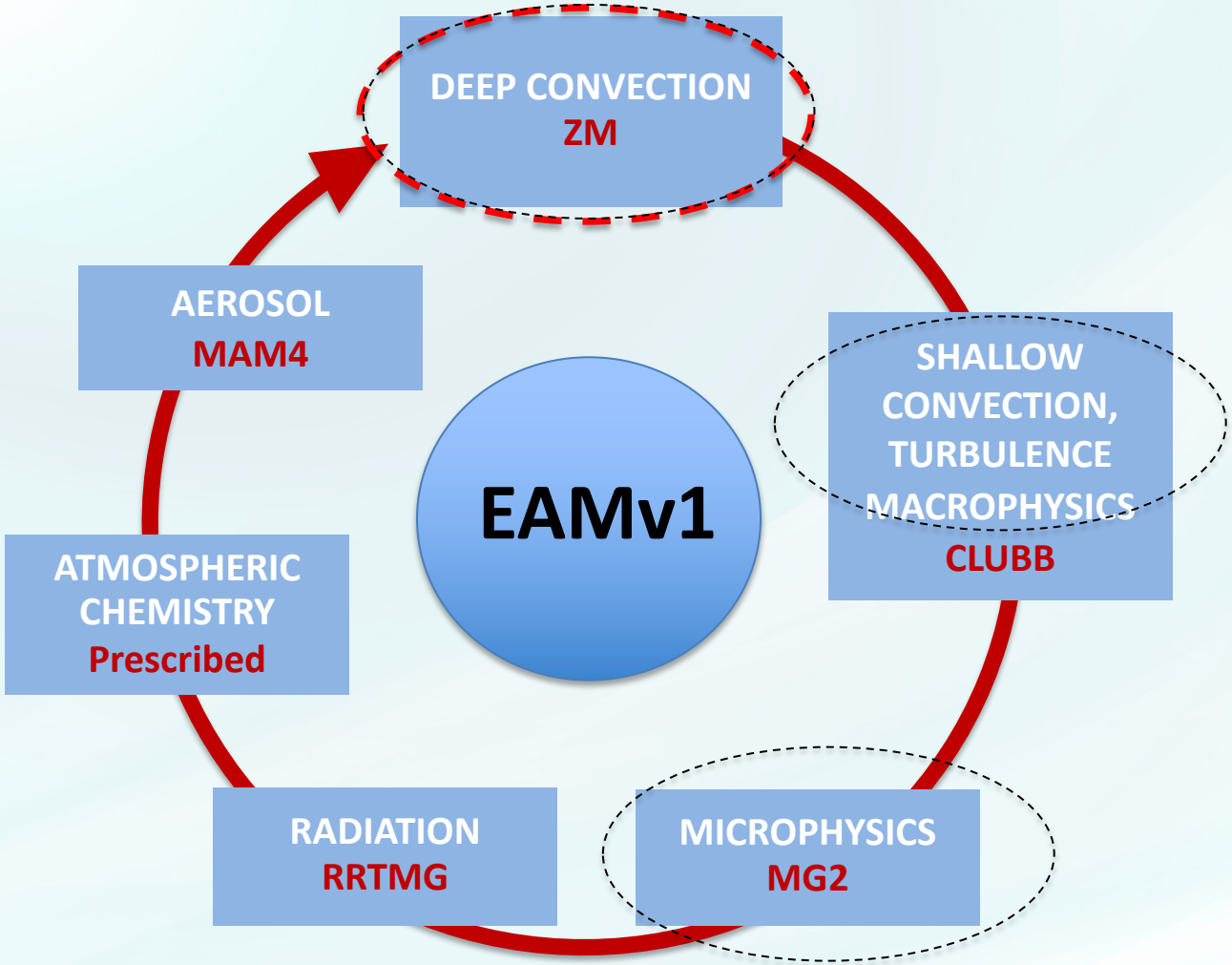
Excessive precip over Tropical IO & warm pool

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: trigger, stochasticity, mesoscale effect, scale-awareness,

Vince Larson (UWM)

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

Joao Teixeira (JPL/UCLA)

A Simplified Higher-Order Closure (SHOC)

Chris Terai (LLNL)

A single code base for future E3SM

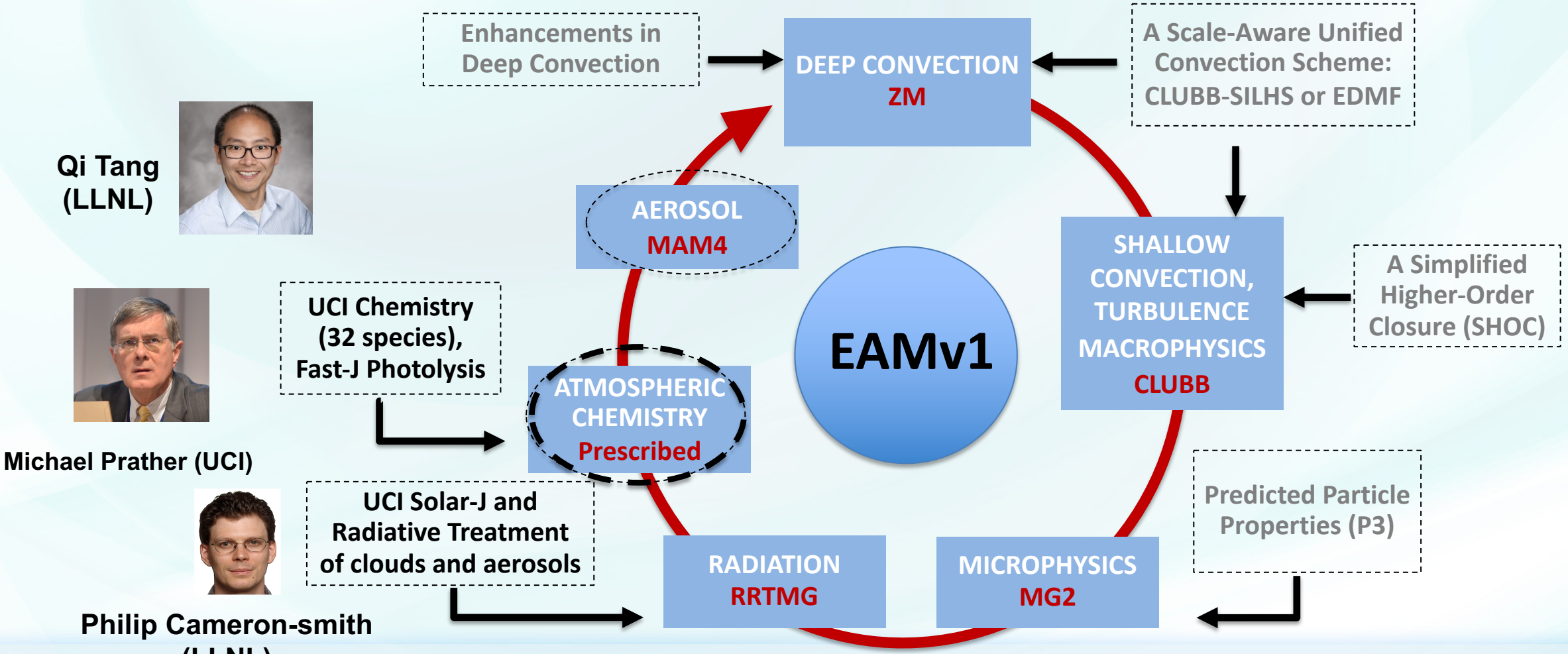
Predicted Particle Properties (P3)

Jiwen Fan (PNNL)

Improve ice clouds and aerosol-cloud interaction

NGD-Atmospheric Physics for E3SM v3

Improving model capability for coupling across the Earth system



E3SM Energy Exascale Earth System Model

U.S. DEPARTMENT OF ENERGY

New Aerosol / Dust Physics

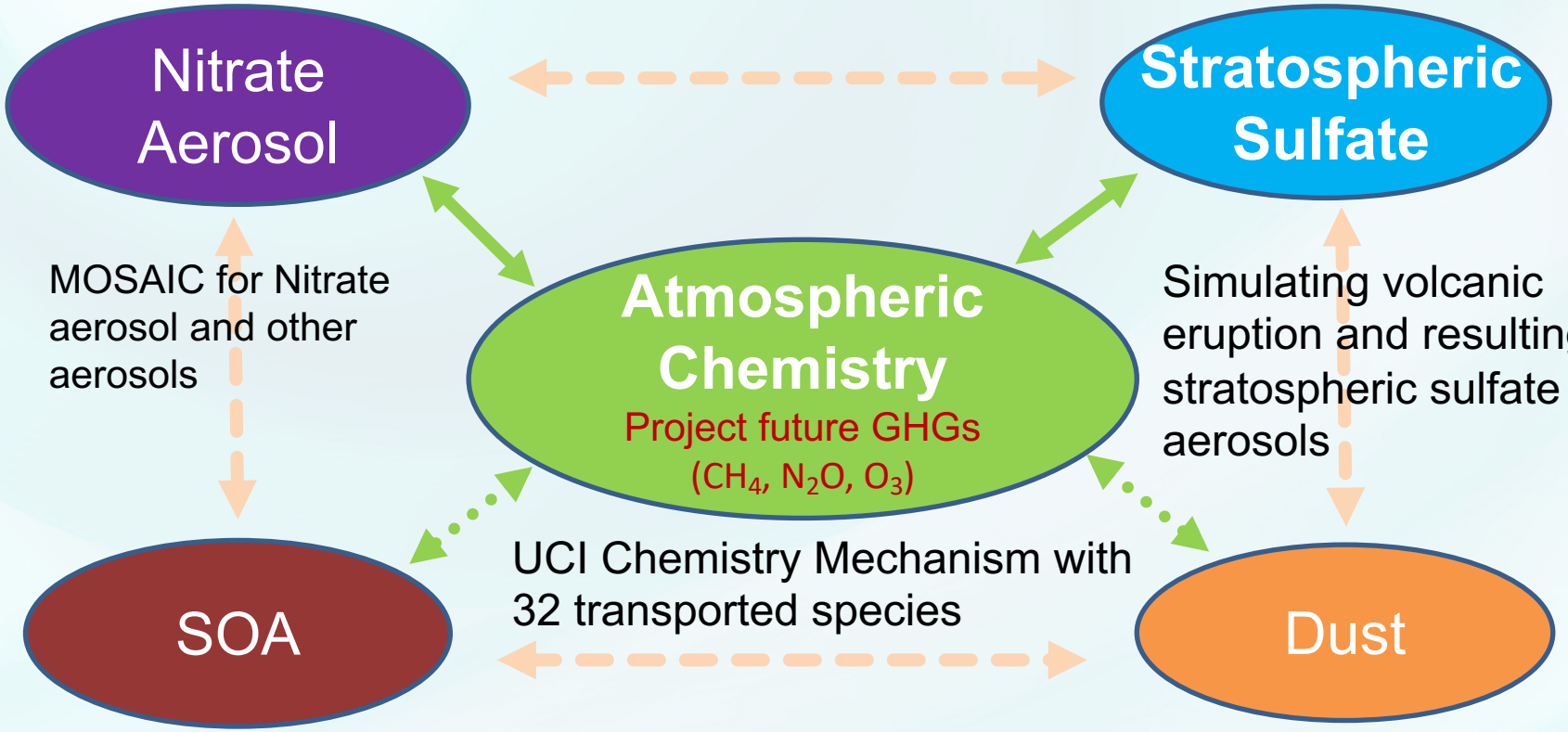
Hailong Wang
(PNNL)

Hailong Wang
(PNNL)

Xiaohong Liu,
(TAMU)

Manish
Shrivastava
(PNNL)

Yan Feng
(ANL)



Explicit treatment of SOA formation and coupling with atmos. Chem. and land/energy use

Implement new emission and dry deposition schemes; couple to BGC

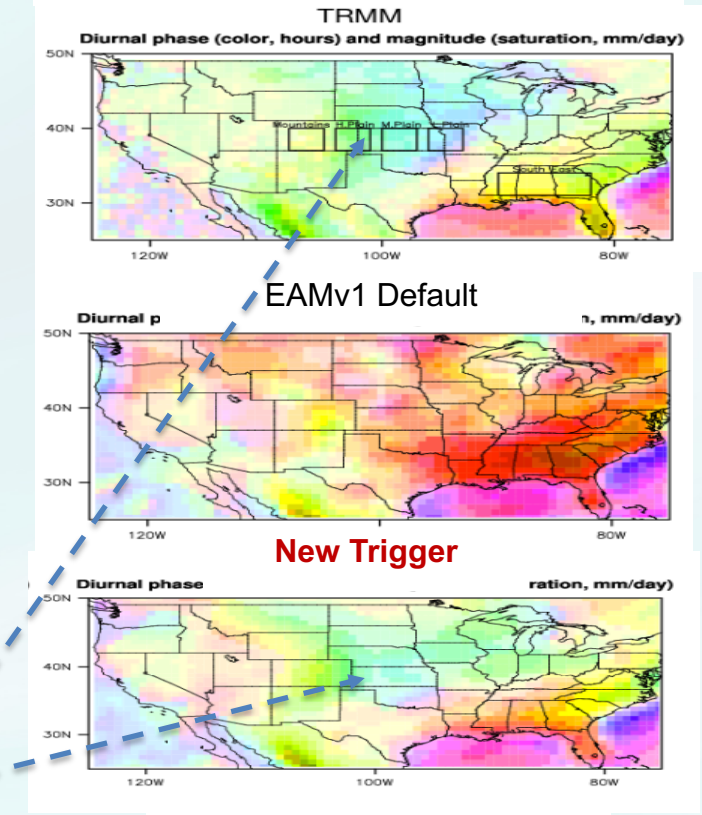
Progress Highlights

Contributions to E3SM v2

- **Improved convective trigger for better diurnal cycle of precipitation**
  - dCAPE&ULL: Better coupling of convection with its environment and capable to capture mid-level convection
  - Improved diurnal cycle of precipitation
- **Re-tuned convective gravity wave (GW) parameterization for better QBO**
  - CF: Conversion Factor of ZM heating rate to convective cell heating rate (20 -> 12.5)
  - Efficiency of convective GWs (0.4 -> 0.35)
- **Improved dust emission**
- **CLUBBv2 – improved computational efficiency**

Improved Diurnal Cycle of Precipitation

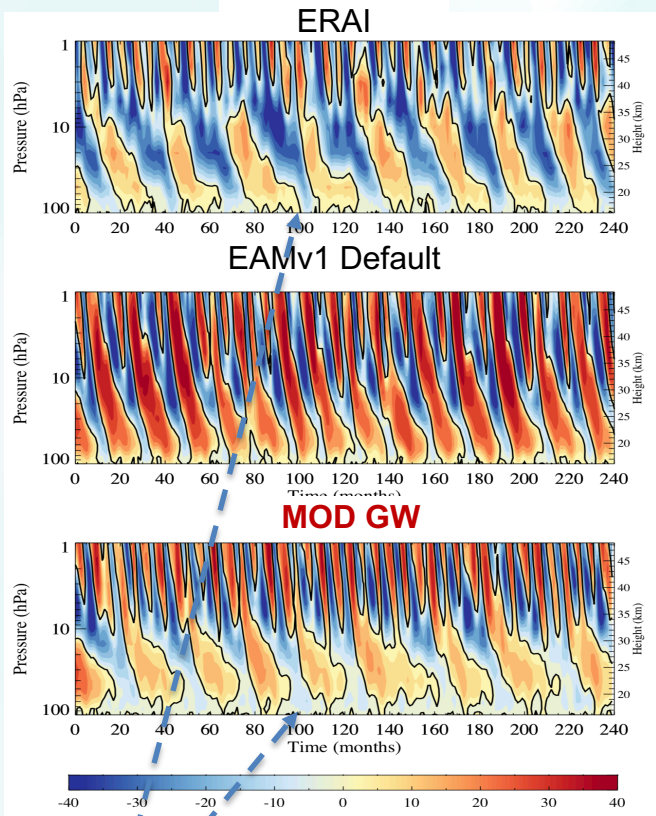
Diurnal Phase (color) and Amplitude (saturation) at CONUS



Xie et al. (2019) JAMES

The nocturnal peak is well captured in central US

Improved Quasi-Bennial Oscillation (QBO)



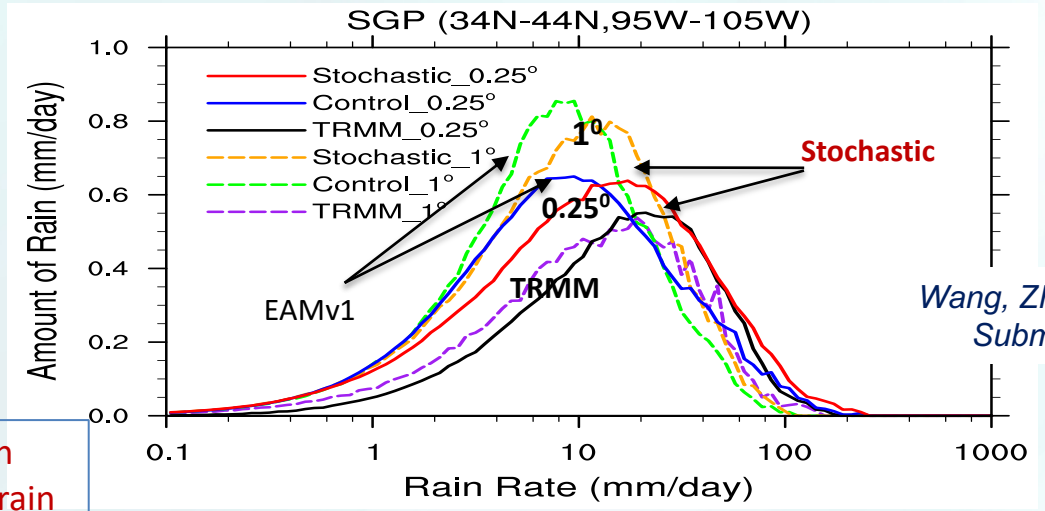
Richter et al. (2019) JAMES

QBO is more realistic

Improving Deep Convection

- **Representing stochasticity of convection in E3SM for better precipitation intensity distribution**
  - Implemented the Plant-Craig stochastic convection parameterization and coupled it with ZM

Improved Rainfall amount pdf



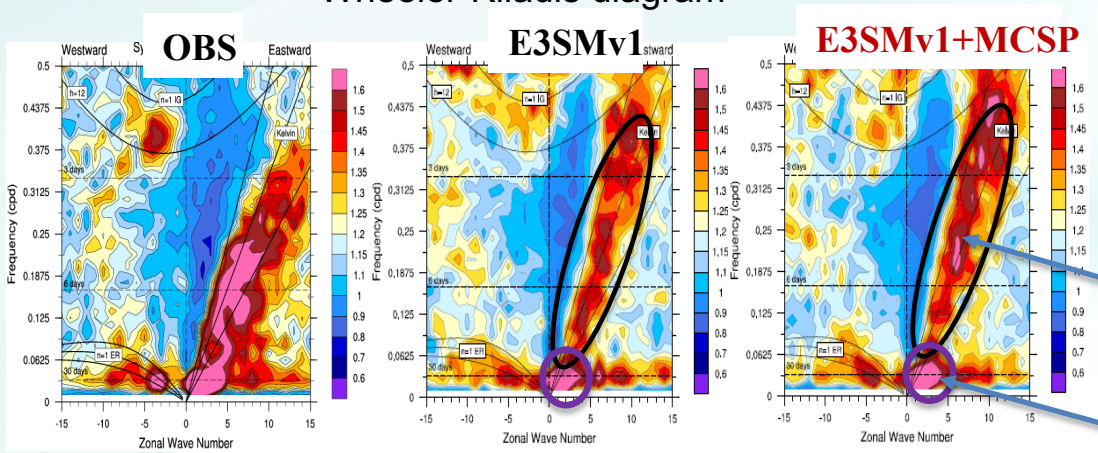
Wang, Zhang et al. (2020) Submitted to GMD

Less light rain
More heavy rain

- **Representing mesoscale effect on convection in E3SM for better capturing tropical waves**
  - Implemented the Multiscale Coherent Structures Parameterization (MCSP, Moncreff 2019) for mesoscale effect on convection
  - Added mesoscale heating on top of ZM heating

Improved Tropical Waves

Wheeler-Kiladis diagram



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

stronger Kelvin wave

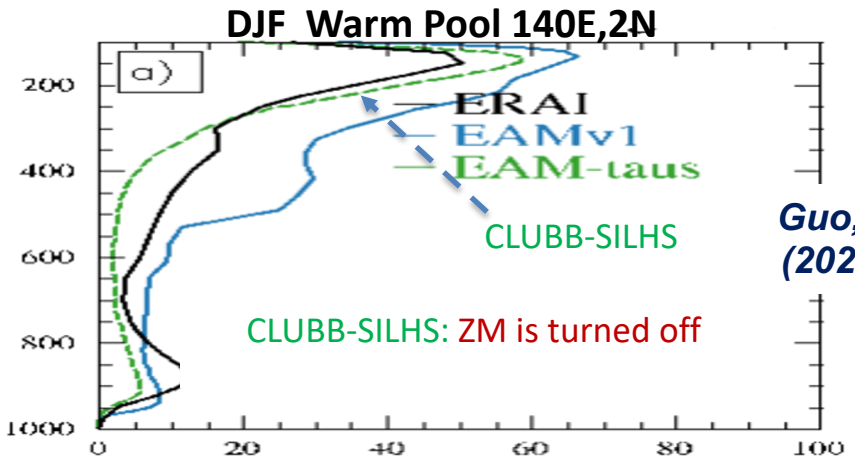
Better MJO

Towards A Unified Scheme

A unified scheme for turbulence, shallow, and deep convection

- **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
  - Computational expensive

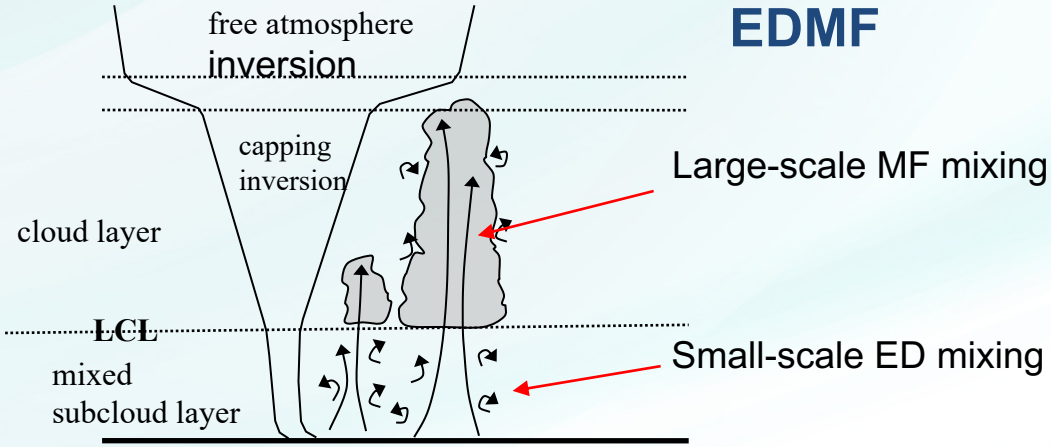
SILHS makes convection go deep



Guo, Larson et al. (2020), submitted

- **A Multi-plume Eddy-Diffusivity/Mass-Flux (EDMF)**
  - **ED for turbulent mixing and MF for convection**
  - **Computational inexpensive**

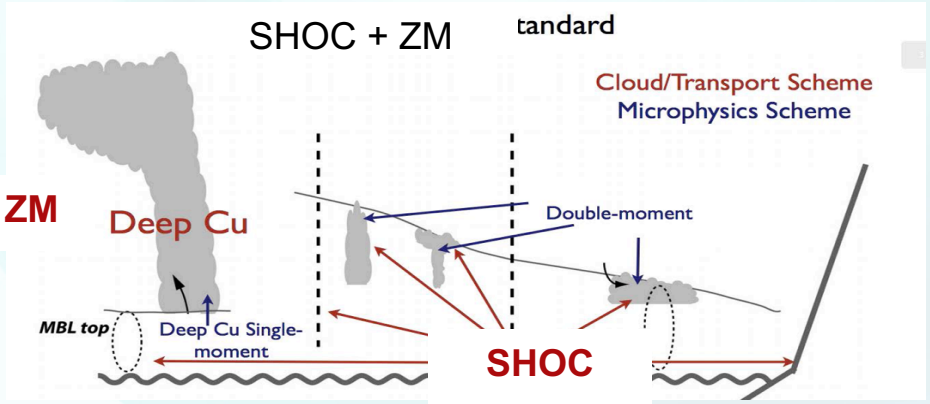
EDMF



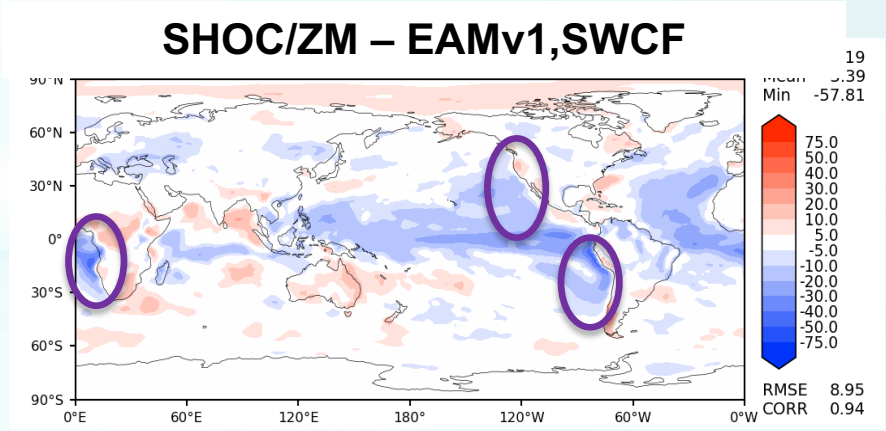
Bimodal joint pdf of w and qt

Coordinating with SCREAM

- **Coupling SHOC with ZM**



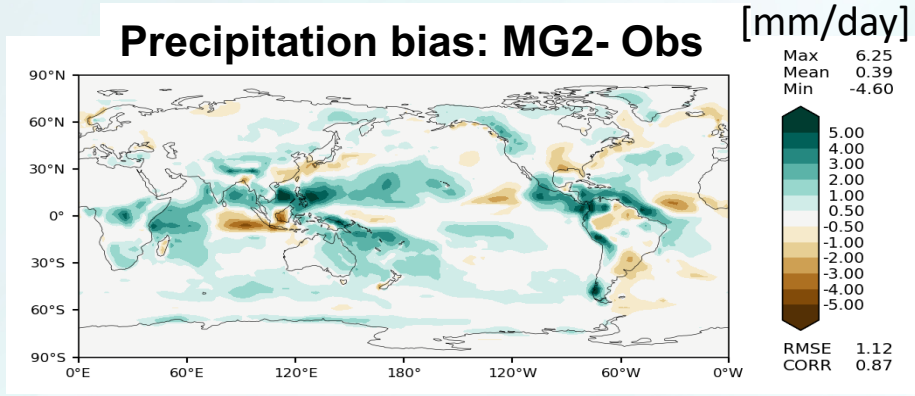
Courtesy of Peter Bogenschutz

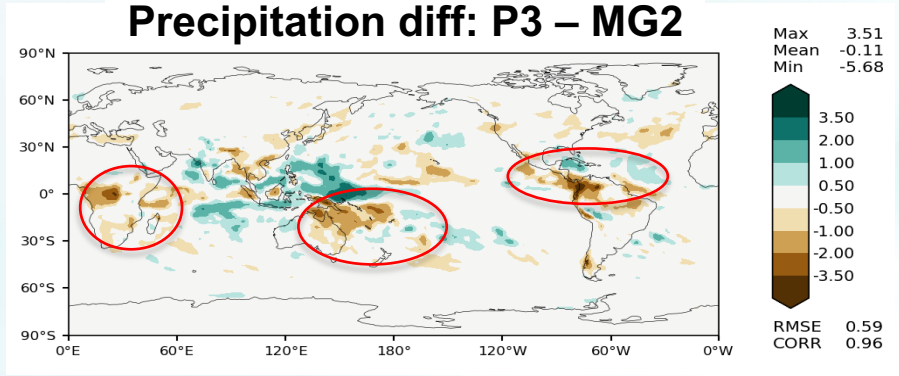


Better Sc

- **Predicted Particles Properties (P3) for Cloud Microphysics**

Reduced Precip Biases





Reduced Precip Error

UCI Chemistry is in E3SM

- 32 transported species, critical for projecting future GHGs (CH4, N2O, O3)
- Ready to be coupled with aerosols and BGC.

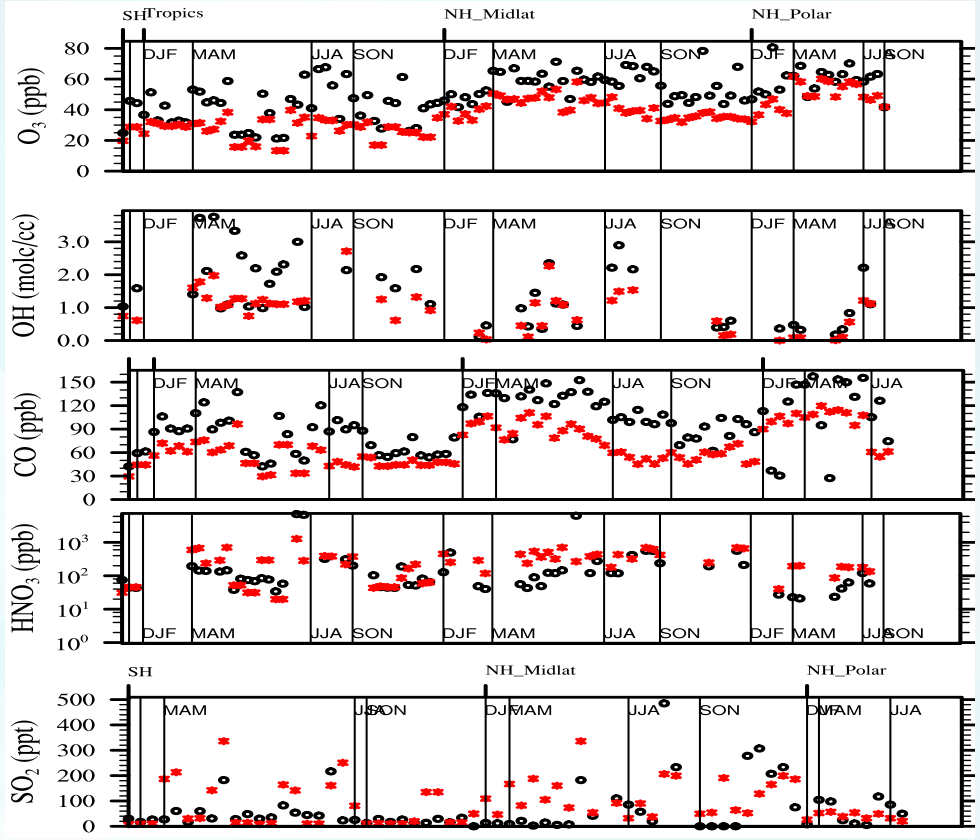
O_3

OH

CO

HNO_3

SO_2



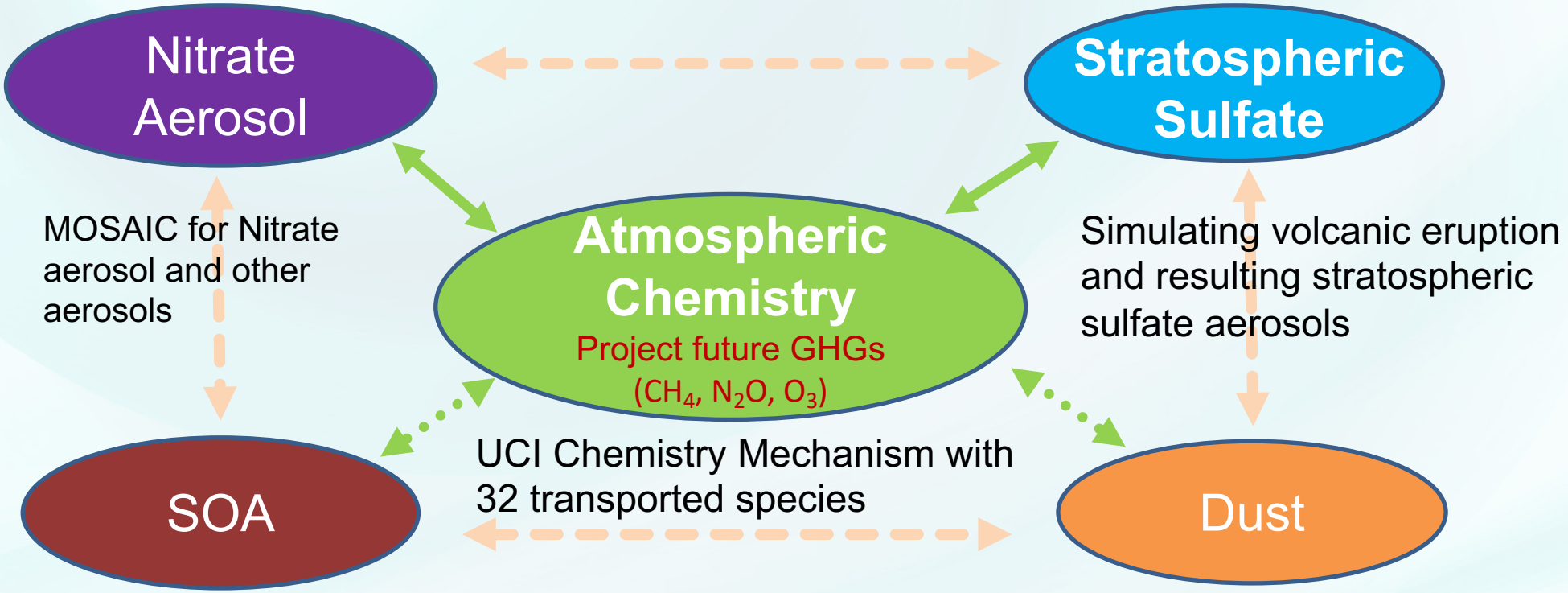
2-7 km

E3SM vs Aircraft

(historical missions)

Initial 15-year tests show acceptable spatio-temporal variability for key tracers.

New Aerosol Physics are coupling with Atmospheric Chemistry and BGC

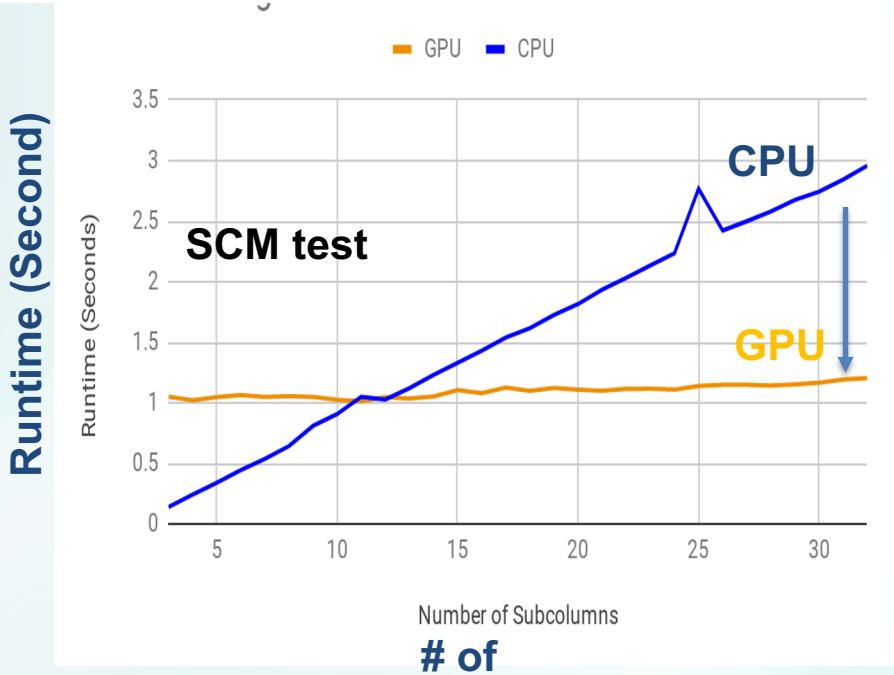


Moving Forward

- Integration of all new developments in E3SM v2
  - Selection of a suitable convection scheme for V3 by July 2021
    - A comprehensive assessment of 4 candidate convection schemes is under planning and will start early next year
- Coupling aerosols, chemistry, and BGCs and make sure our developments meet BGC V3 science needs
- Porting new atmospheric physics to the new atmospheric driver that the SCREAM team is developing for a single V3 code base on CPU-based machines
- Porting new atmospheric physics to GPUs
  - CLUBB-SILHS

*SCREAM is working on porting SHOC, P3, ZM to GPUs

CLUBB-SILHS Scaling on GPU vs CPU



As the # of subcolumn increases, the runtime is significantly reduced on GPU

Collaborations across DOE labs and Universities

DOE Labs

LLNL: Convection, Chemistry, model integration, model evaluation and diagnosis

PNNL: Aerosols and cloud microphysics

ANL: Dust Emission

BNL: Climate integration, tuning, etc.

University Collaborators funded by ESMD

Vince Larson (UWM) – CLUBB-SILHS

Xiaohong Liu (UW) – Stratospheric Sulfate

Michael Prather (UCI) – Chemistry & Radiation

Jadwiga (Yaga) Richter (NCAR) - MCSP

Joao Teixeira (JPL/UCLA) - EDMF

Guang Zhang (SCRIPPS/UCSD) - ZM

Collaborations within E3SM

Water Cycle/Cryo: clouds, convection, precipitation

BGC: coupling across the Earth system

Infrastructure: new diagnostics (QBO, precip PDF and diurnal cycle, etc.)

Performance: CPU/GPU performance

NGD-SCREAM: SHOC, P3, new atmospheric driver

NGD-Software/Algorithm: Chemistry solver

Collaborations with other DOE projects

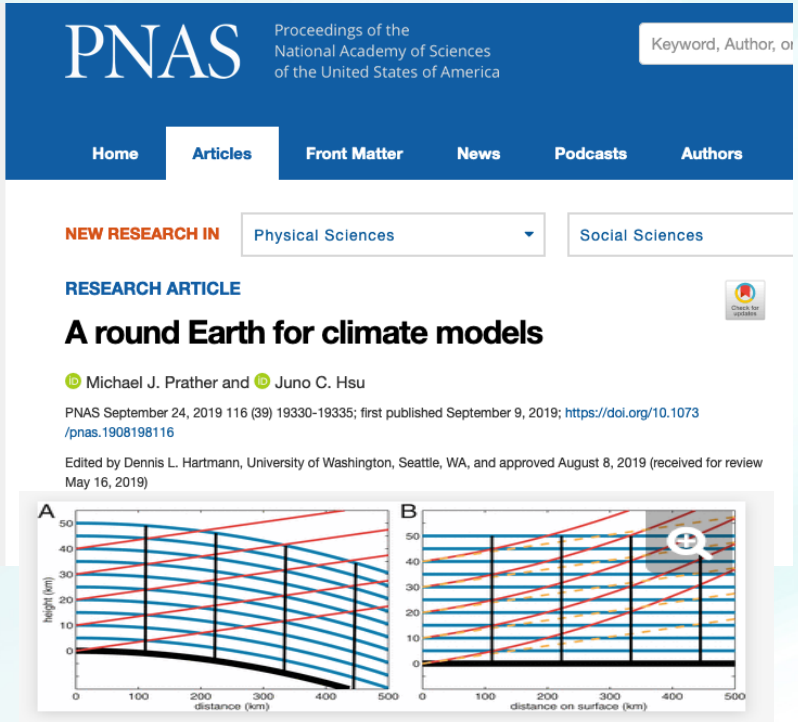
LLNL CMDV-RRM, CAPT, ASR, ARM projects

PNNL SFA on MCS

Will reach out to EAGLES on aerosols for v4

Publications

- ~35 papers either published or submitted since 2018 with >20 papers led by NGD-atmosphere team members
- FY2020 metric reports (Q1 – Q4) on MCSs
- 4 E3SM all-hands webinar presentations
- 1 E3SM newsline story



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
  - Ready by 2022