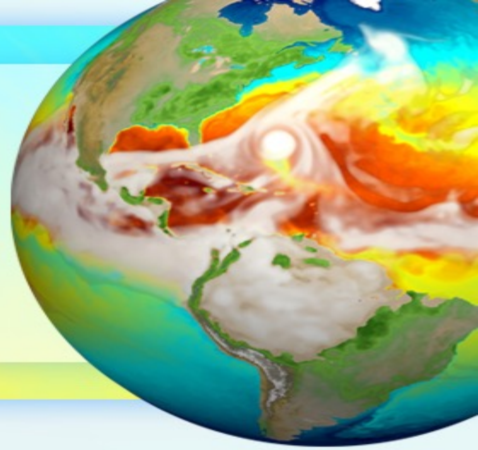
Updates on E3SM Next Generation Development (NGD) - Atmospheric Physics



Shaocheng Xie

Lawrence Livermore National Laboratory

DOE LAB Staff

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

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)

> 35 team members including scientists, postdocs, and students

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-820838

U.S. DEPARTMENT OF ENERGY

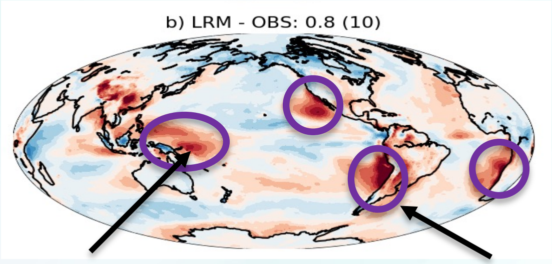
Goals of NGD-Atmospheric Physics

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 and precipitation**: lack of coastal Sc, regional precipitation biases, weak MJO and Kelvin wave, 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 physics for aerosol species (SOA, stratospheric aerosols, nitrate, dust) that are critical to BGC
  - Coupling of atmospheric chemistry, aerosols/dusts to BGC

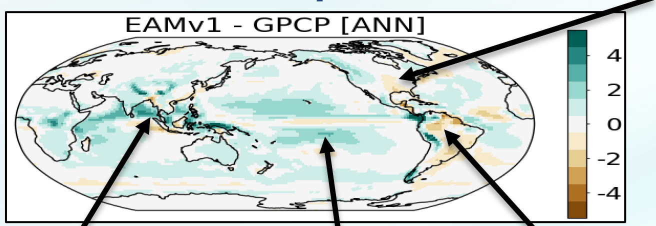
The development will address the combined problems of scientific accuracy, scale-awareness, and computational efficiency

SWCRE Bias



Zhang, Xie et al. (2019)

Annual Precipitation Bias

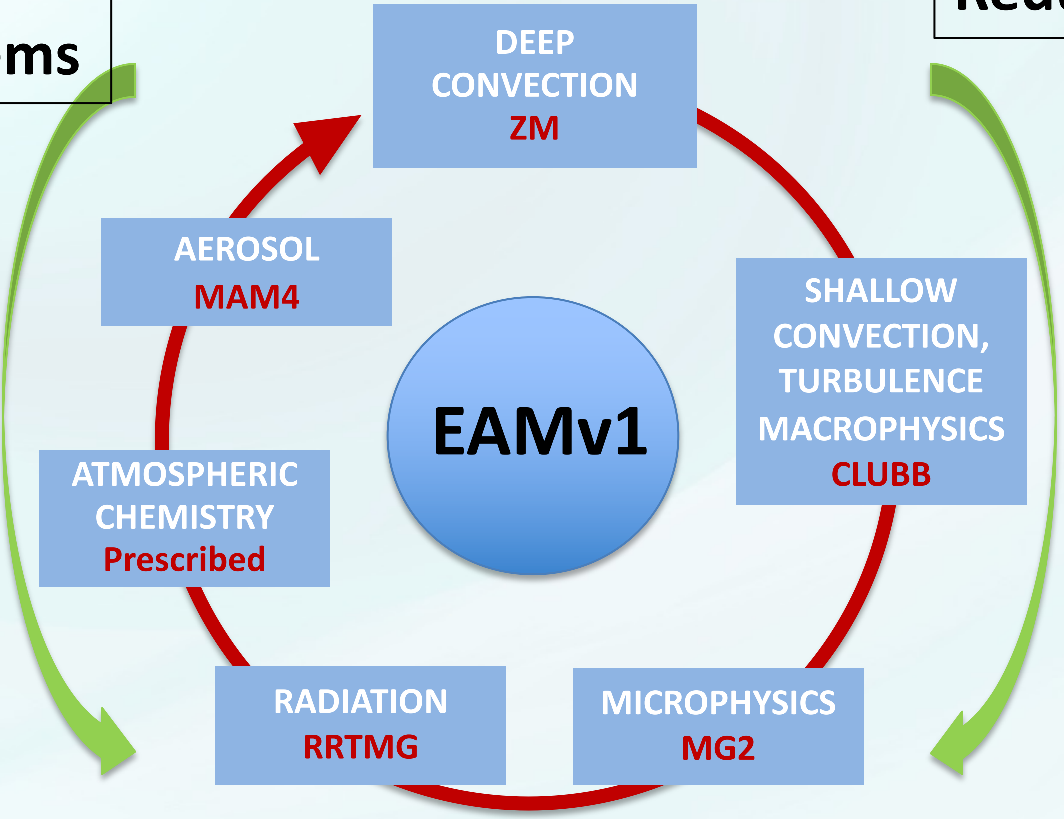


Rasch, Xie et al. (2019)

NGD Atmospheric Physics for E3SM v3

Enhance model capability of coupling across Earth systems

- New aerosol/dust physics
  - Nitrate aerosol
  - SOA
  - Stratospheric sulfate
  - Dust emission & deposition
- UCI Chemistry
- UCI Solar-J and radiative treatment



Reduce outstanding V1 errors

- Efforts to improve deep convection
  - Unified schemes (CLUBB-SILHS, EDMF)
  - ZM Enhancements (trigger, closure, stochasticity, mesoscale heating, cloud microphysics)
  - SHOC+ZM
- Predicted Particles Properties (P3) cloud microphysics

Modeling testbeds and metrics and diagnostics

Model integration, evaluation and tuning

Short-range PPE and CAPT for tuning

Progress Highlights

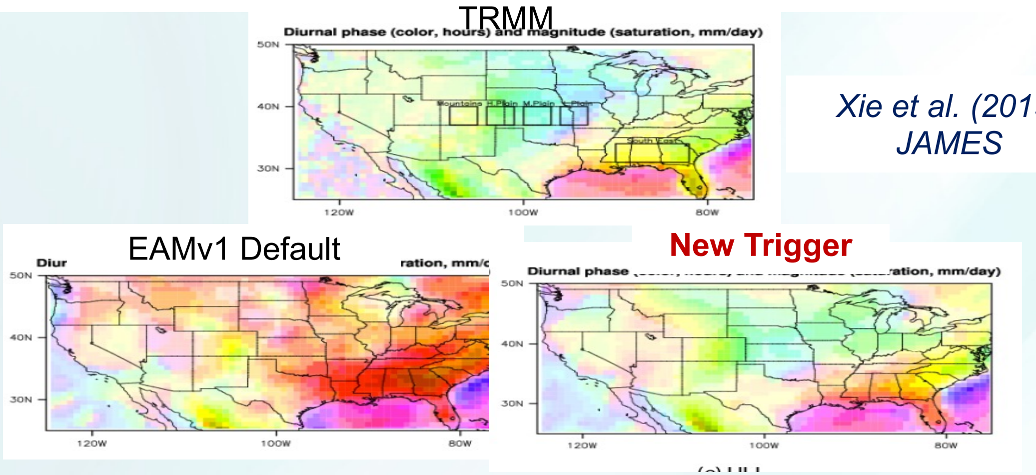
Contributions to E3SM v2

- **Improved convective trigger for better diurnal cycle of precipitation (Led by Shaocheng Xie)**
  - 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 scheme for better QBO (Led by Yaga Richter)**
  - CF: Conversion Factor of ZM heating rate to convective cell heating rate (20 -> 12.5)
  - Efficiency of convective GWs (0.4 -> 0.35)

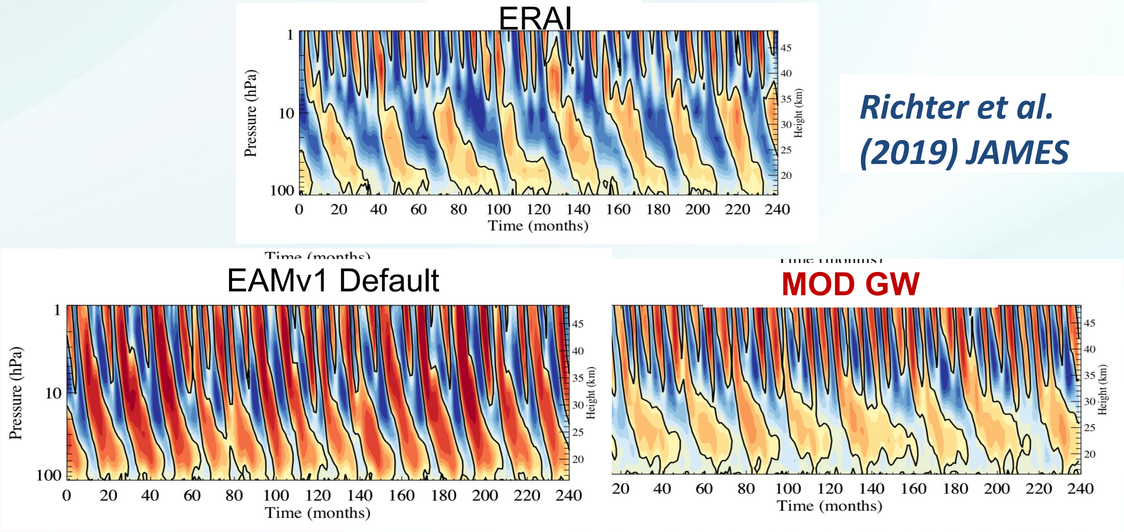
- **Improved dust emission (Led by Yan Feng)**
- **CLUBBv2 (Led by Vince Larson)**

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



Xie et al. (2019) JAMES

QBO



Richter et al. (2019) JAMES

Progress on Convection and Cloud Parameterizations

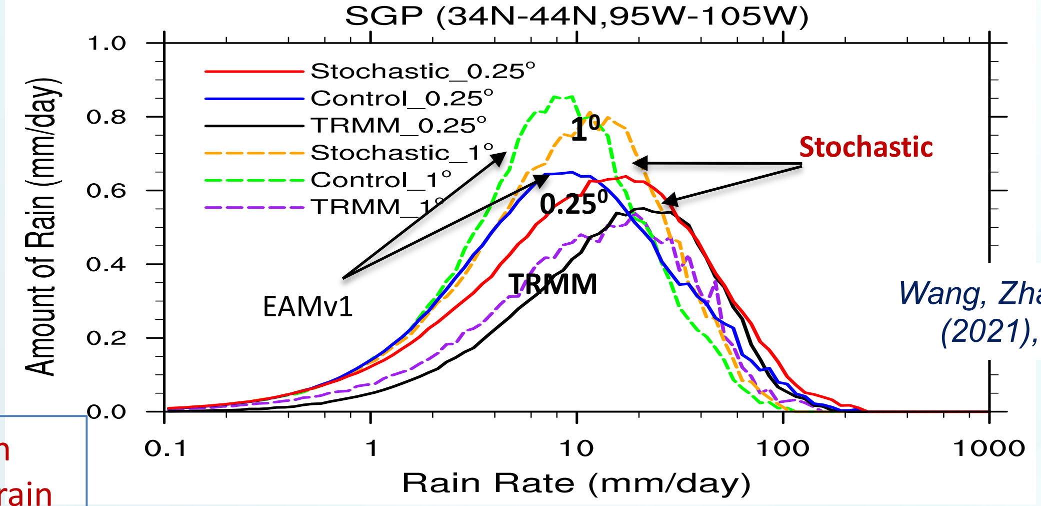
Improving ZM

- **Representing stochasticity of convection in E3SM for better precipitation intensity distribution (Led by Guang Zhang, SCRIPPS)**
  - Implemented the Plant-Craig stochastic convection parameterization and coupled it with ZM

Less light rain
More heavy rain

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

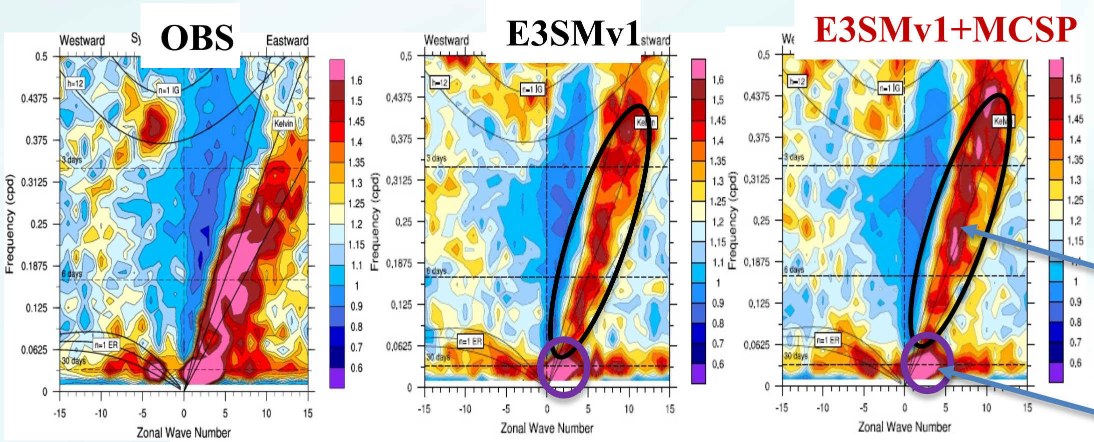
Improved Rainfall amount pdf



Wang, Zhang et al. (2021), GMD

Improved Tropical Waves

Wheeler-Kiladis diagram



Chen, Richter et al. (2021) JAMES

Cloud Microphysics for Convective Clouds

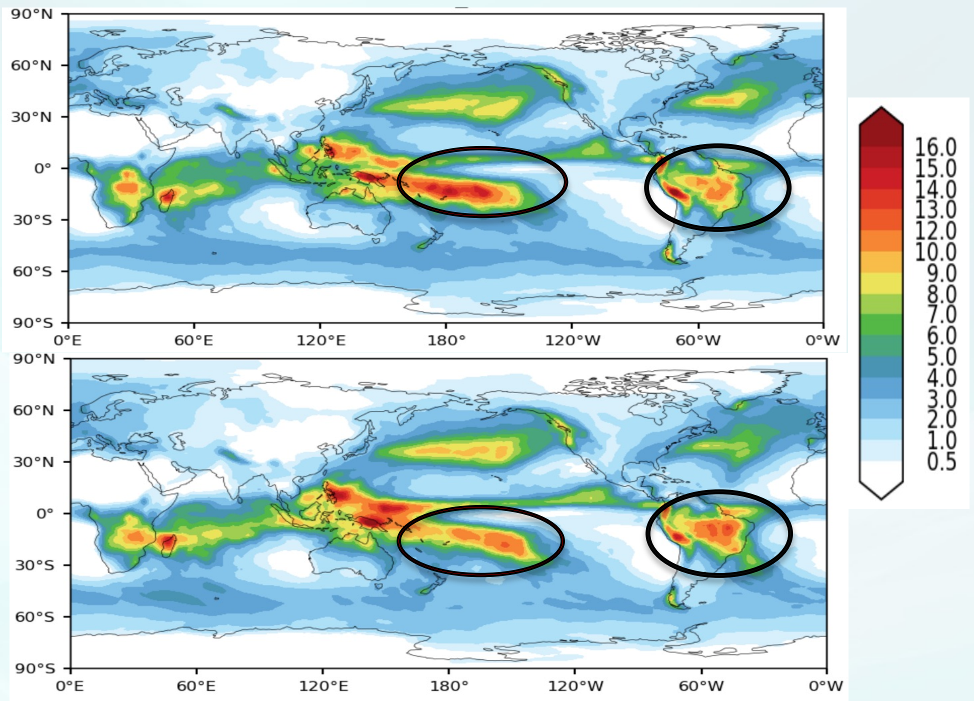
Guang Zhang, Xiaoliang Song
Scripps/UCSD

To improve the representation of convective precipitation and the coupling with large-scale anvil clouds.

5yr- Average DJF Precipitation

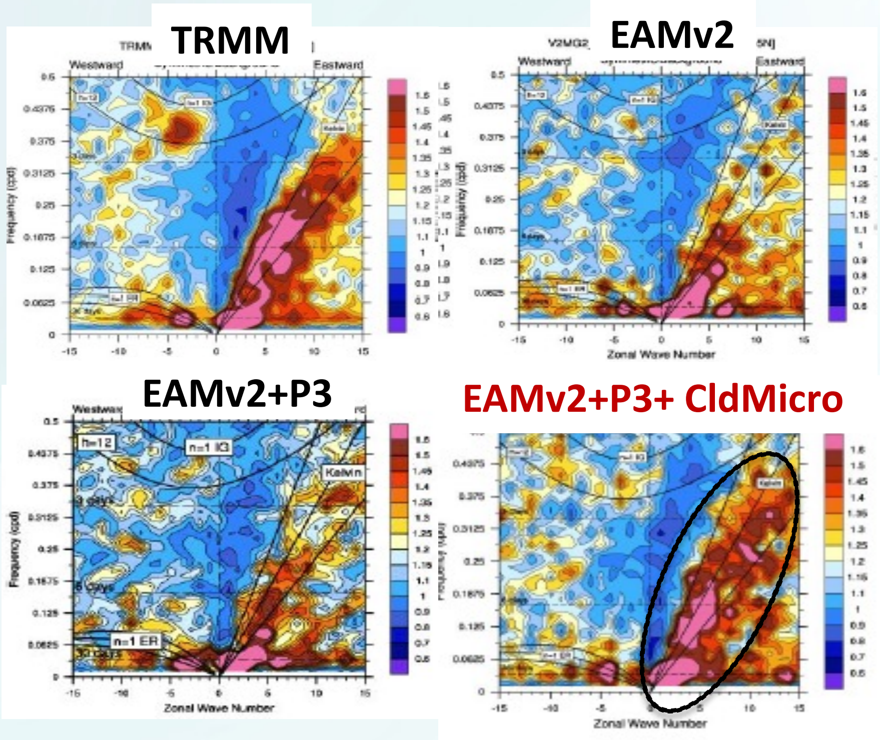
EAMv2+P3

Convective Microphysics



Reduced SPCZ precipitation

Increased precipitation over Amazon



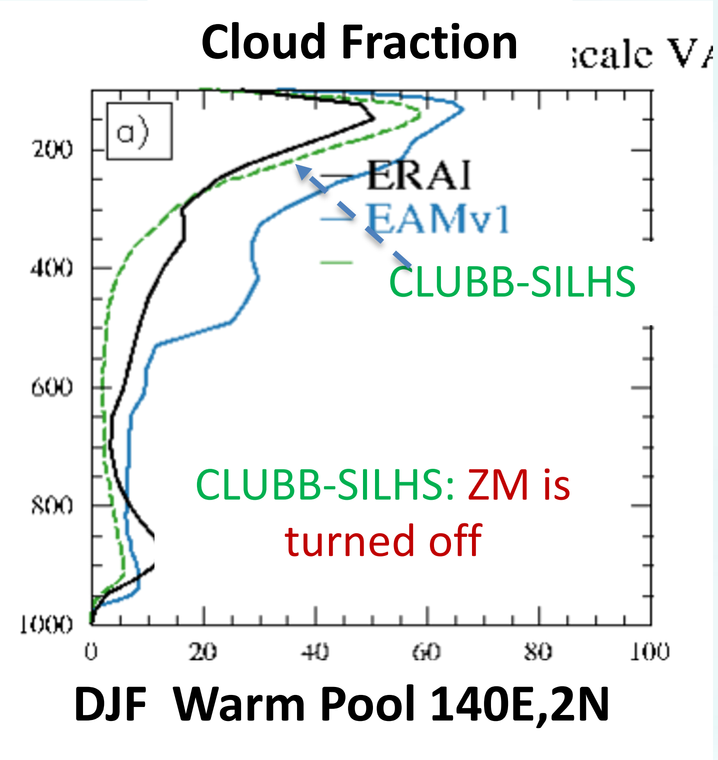
With more sophisticated microphysics for convective clouds, the observed MJO and Kelvin wave have been nicely captured

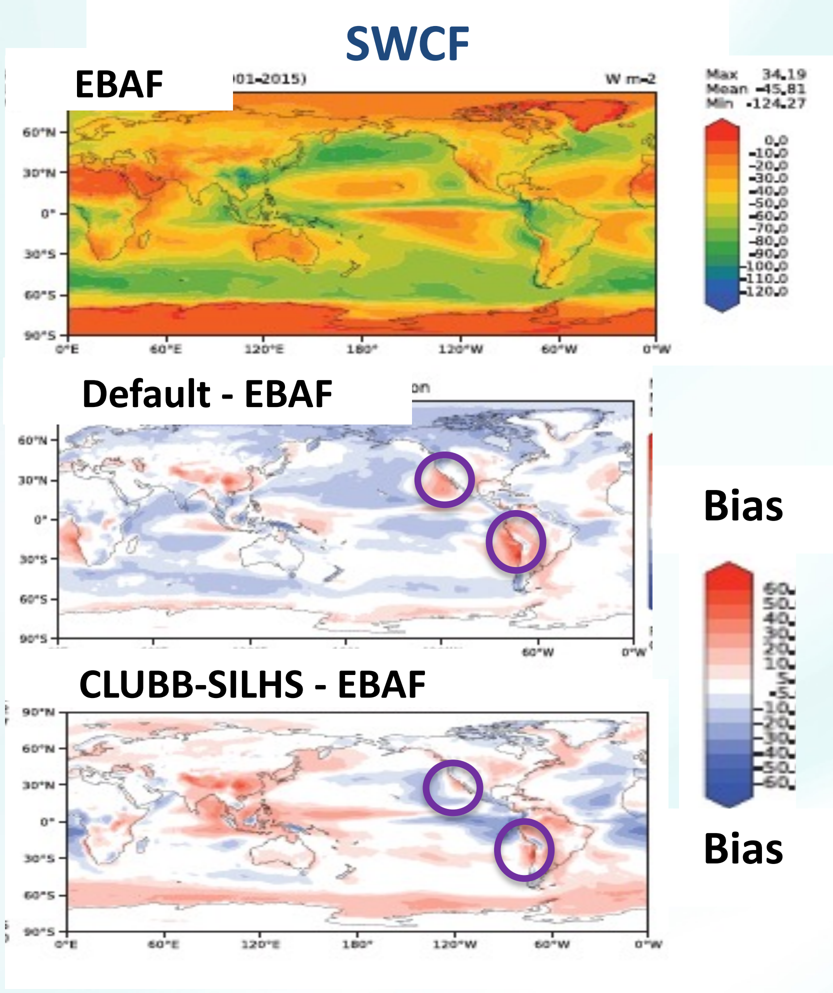
Convection – Make CLUBB for Deep Convection

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 param. 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
- Only one single microphysics and good scale-awareness





Guo, Larson et al. (2021), JAMES

Convection – Unify Turbulence and Shallow/Deep Conv via EDMF

Joao Teixeira, Marcin Kurowski (JPL/UCLA)

Improving the representation of low-level clouds and the planetary boundary layer by the unified stochastic multi-plume Eddy-Diffusivity/Mass-Flux (EDMF) convection parameterization

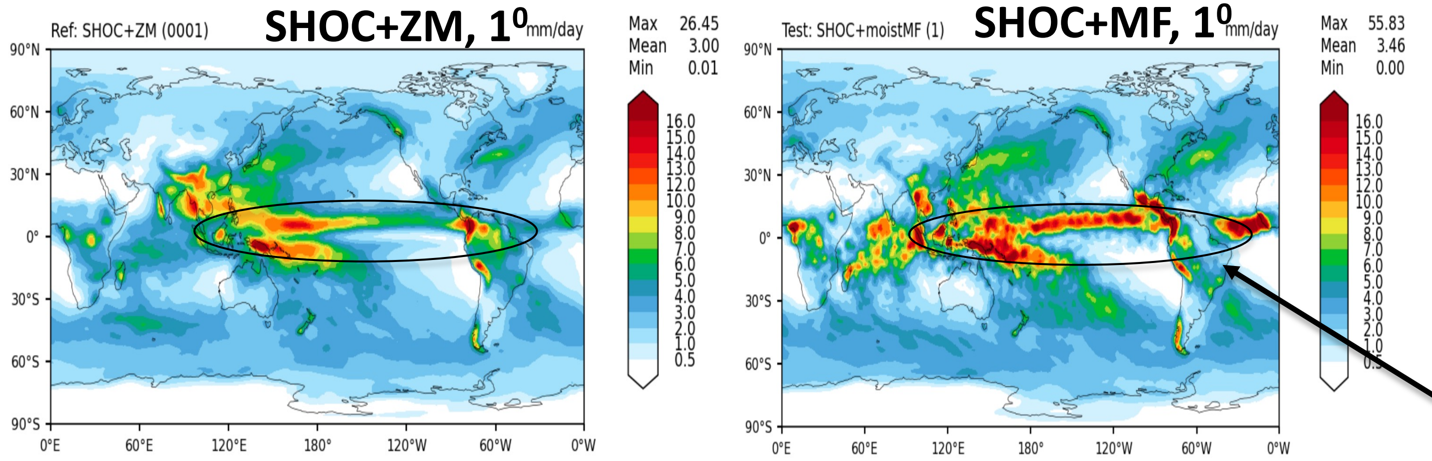


Fig 1. Annual precipitation from (left) SHOC+ZM and (right) SHOC+MF for a 1-year test climate simulation.

SHOC+ZM: SCREAM Physics but with MG2

SHOC+MF: ZM turned-off, coupling SHOC with moist non-precipitating plumes (MF). All precip is from MG2

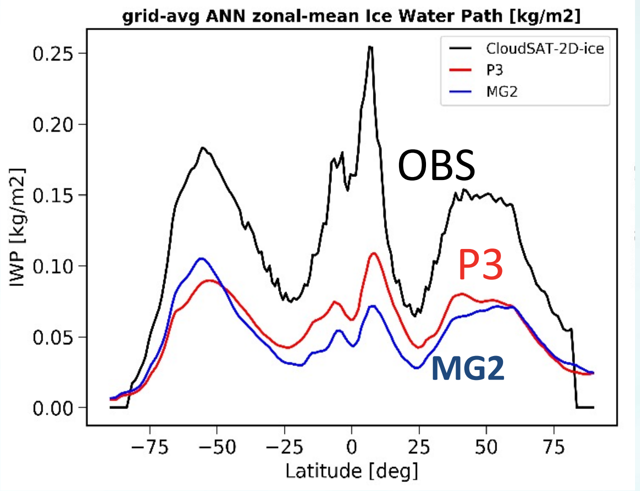
Precipitation is significantly increased, but the double ITCZ is largely removed.

New Cloud Microphysics - Predicted Particles Properties (P3) in EAMv2

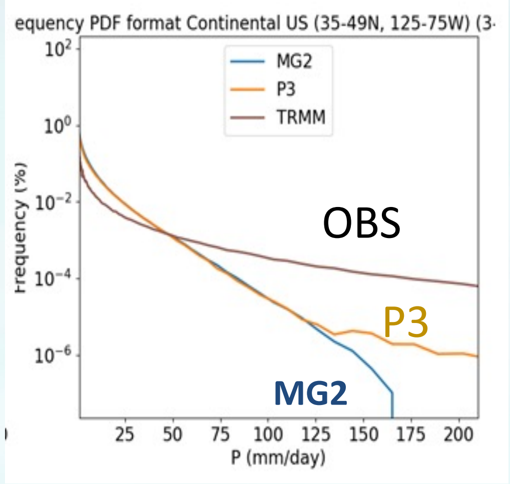
Jiwen Fan, Koby Shpund , Kai Zhang (PNNL)

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

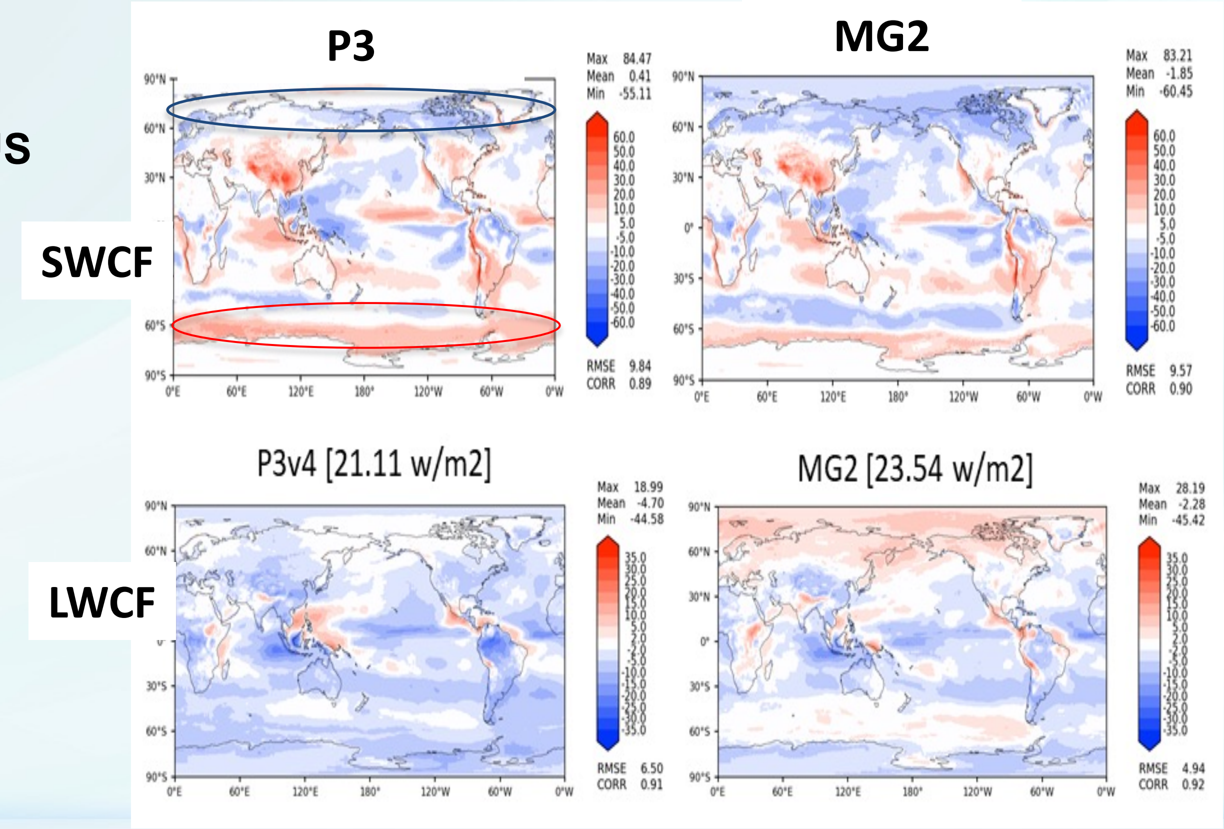
Improved simulation of IWP between (50S-50N)



Higher frequency of heavy precipitation rates over CONUS

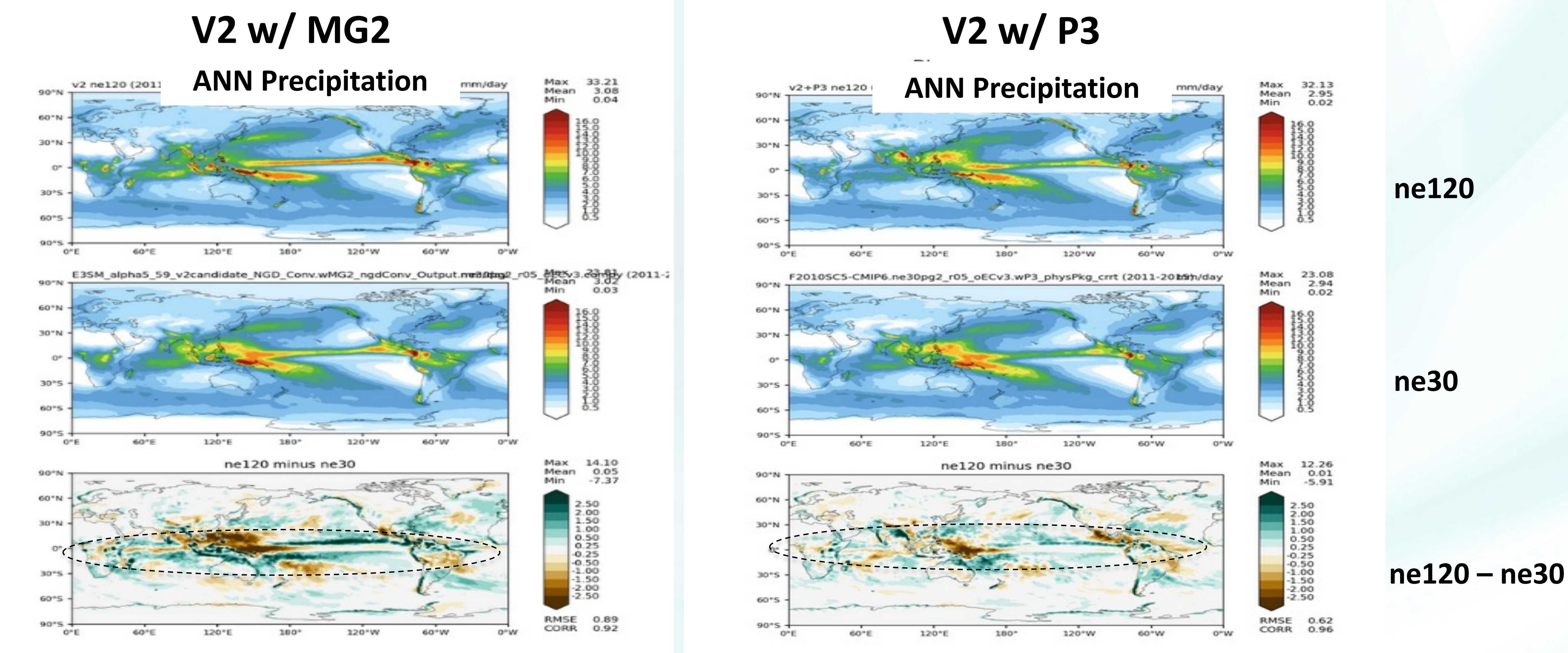


Cloud Radiative Forcing



P3 Makes E3SM More Scale-Aware

Jiwen Fan, Koby Shpund ,
Kai Zhang (PNNL)



The change in annual mean precipitation from ne30 to ne120 is significantly smaller in E3SMv2 with P3 than with MG2.

Progress on Atmospheric Chemistry and Aerosol Physics

Atmospheric Chemistry and Radiation (2021)

Qi Tang, Philip Cameron-smith (LLNL)

Michael Prather, Juno Hsu (UCI)

Ability to project future GHGs (CH_4, N_2O, O_3) based on emission scenarios and climate change by implementing UCI chemistry mechanism with ~30 transported species.

Current Status

- The O3v2 paper was published in GMD
- The 3rd Solar-J paper was published in JAMES
- Created CMIP6 emissions from biogenic sources
- Processed observations for tropospheric column ozone (TCO) and surface CO
- Implemented Linoz v3 on the UCI chemistry branch. Initial results are reasonable.
- Debugged the OpenMP Fast-J issue with help from the E3SM software engineers.
- The decadal test with CMIP6 emissions simulates reasonable tropospheric O_3 and surface CO.

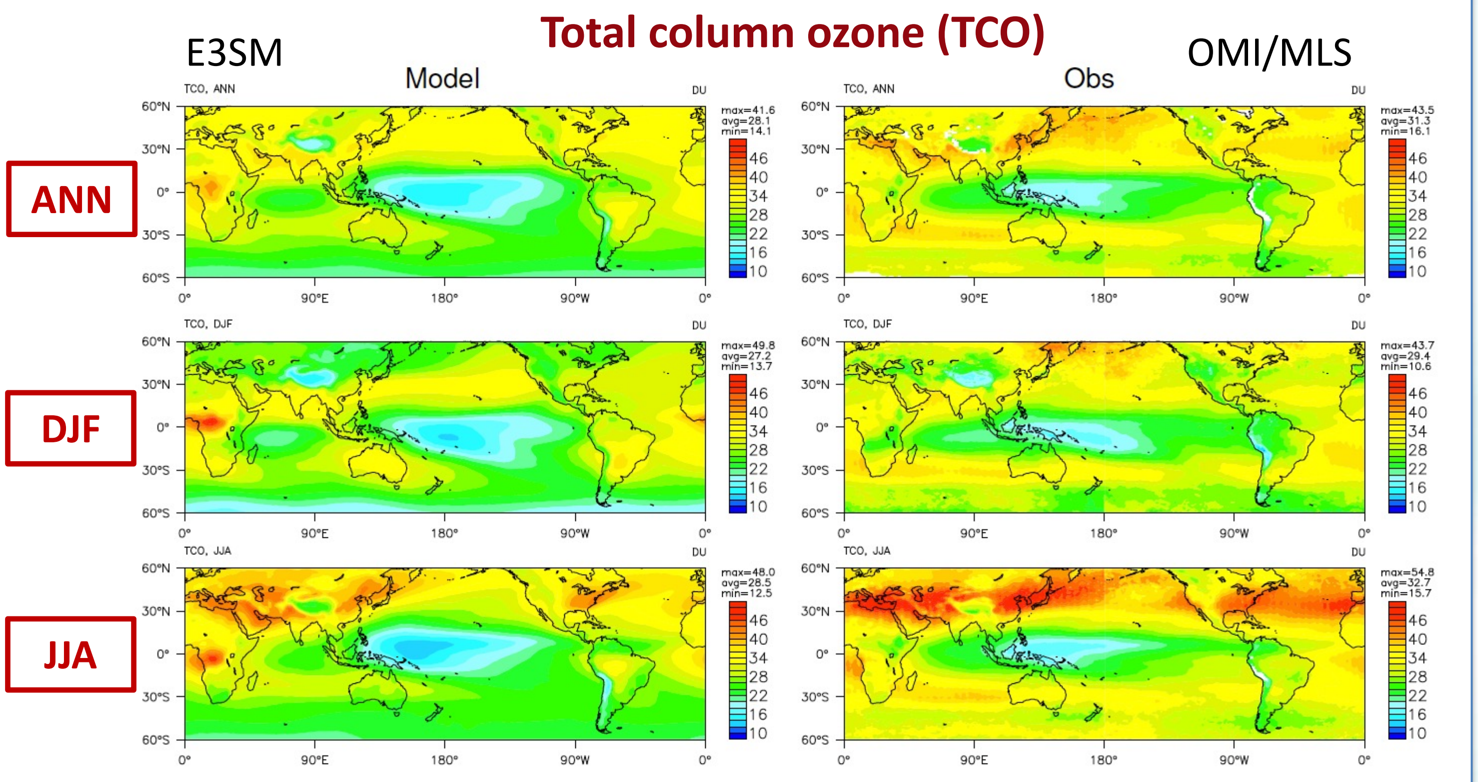


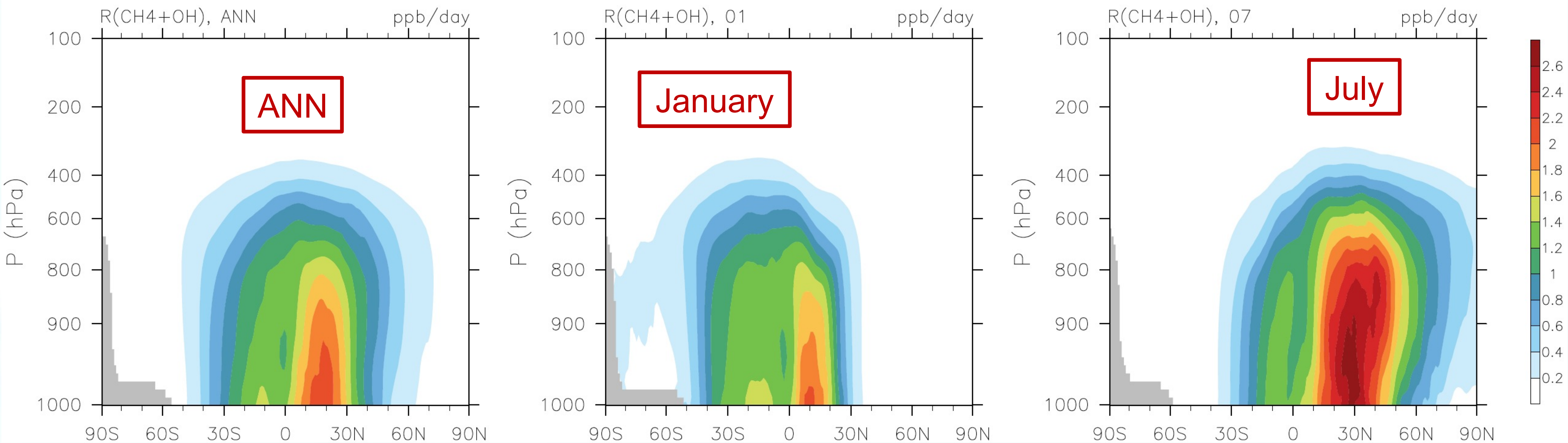
Figure. E3SM chemUCI simulates reasonable TCO vs. satellite obs.

Ready for phase III BGC tests

Qi Tang, Philip Cameron-smith (LLNL)

Michael Prather, Juno Hsu (UCI)

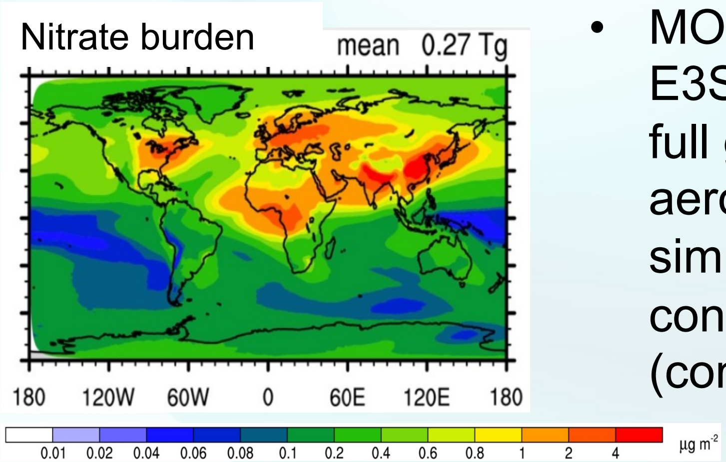
chemUCI + Linoz v3 code (full stratospheric + tropospheric chemistry) is ready in E3SM *before the original plan,* set for BGC experiment tests, such as coupled CH_4-O_3-vegetation simulations.



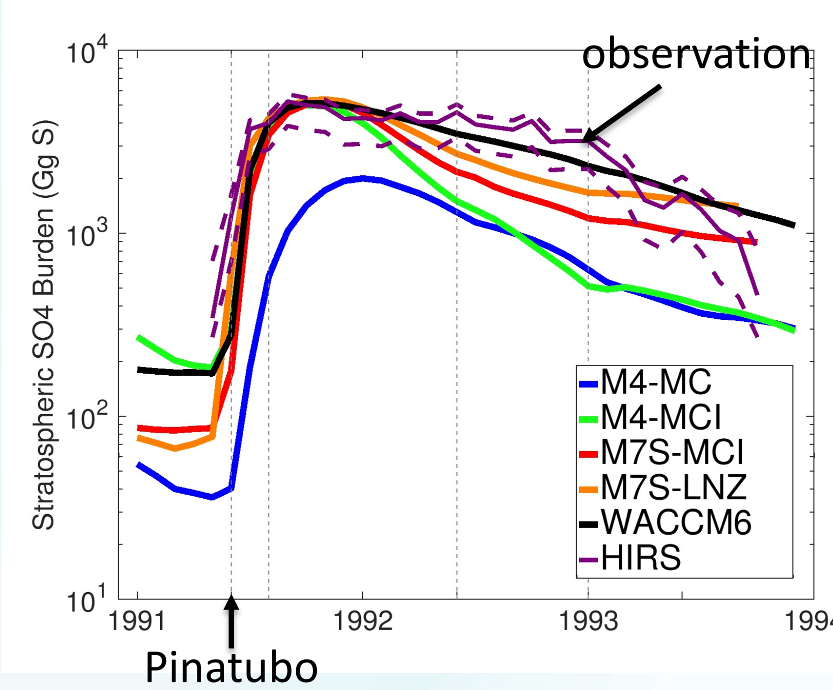
- CH_4 loss rate (ppb/day) ~ OH, key for future coupled BGC-Chem experiment.

New Aerosol Physics

H. Wang, X. Liu, Y. Feng, M. Shrivastava, M. Wu, Z. Ke, Q. Rasool



- MOSAIC has been implemented in E3SMv1/v2, coupled with MAM4 and full gas chemistry, to treat nitrate aerosol, producing reasonable simulation of present-day nitrate concentrations and radiative effects (compared to existing studies).



- Created a common branch for the integration of new aerosol treatments (e.g., nitrate, SOA, stratospheric sulfate) with UCI chemistry
- Completed the implementation of new dust emission scheme and speciation and evaluated the new schemes in E3SMv2
- Began to implement the dust iron dissolution model

- MAM7S has been developed for prognostic stratospheric sulfate, coupled with various chemistry packages, can simulate Pinatubo volcanic sulfate reasonably well.
- MAM7S is being simplified to MAM5 for a better computational efficiency and coupling with UCI chemistry.

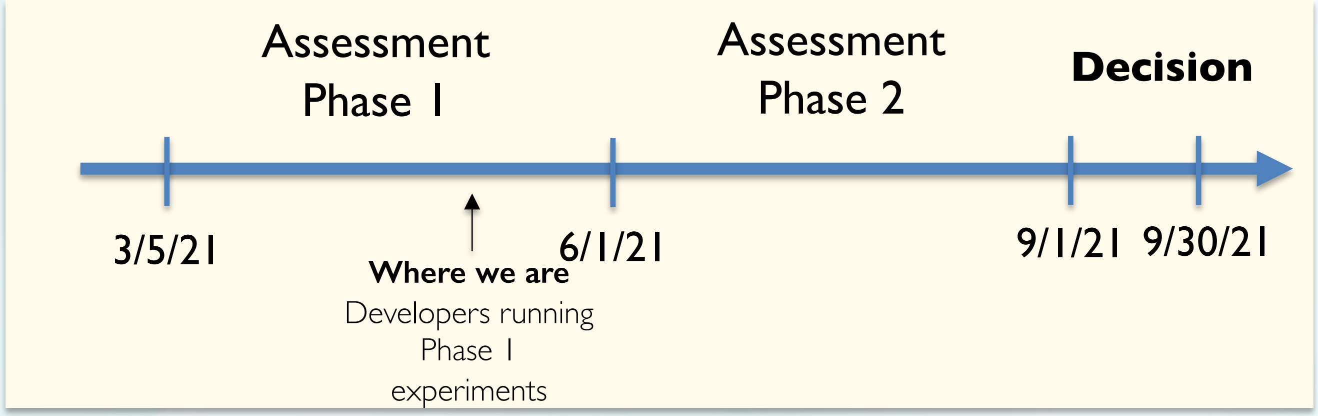
Moving Forward

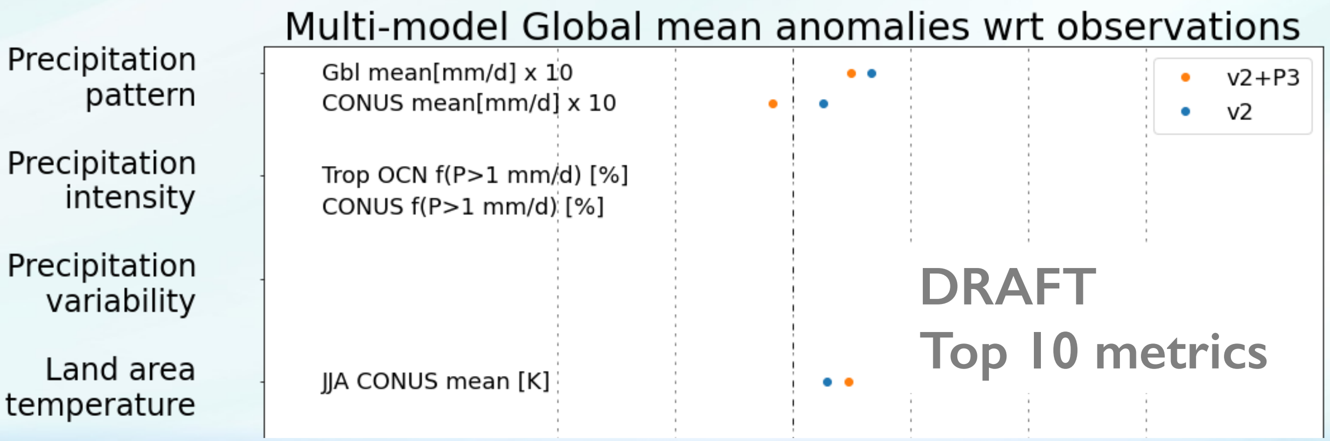
Convection Assessment

Shaocheng Xie & Chris Terai
plus Convection, P3, and
evaluation teams

Joint activity with various team members to evaluate and assess convection schemes when they are run in v2+P3 configuration of E3SM

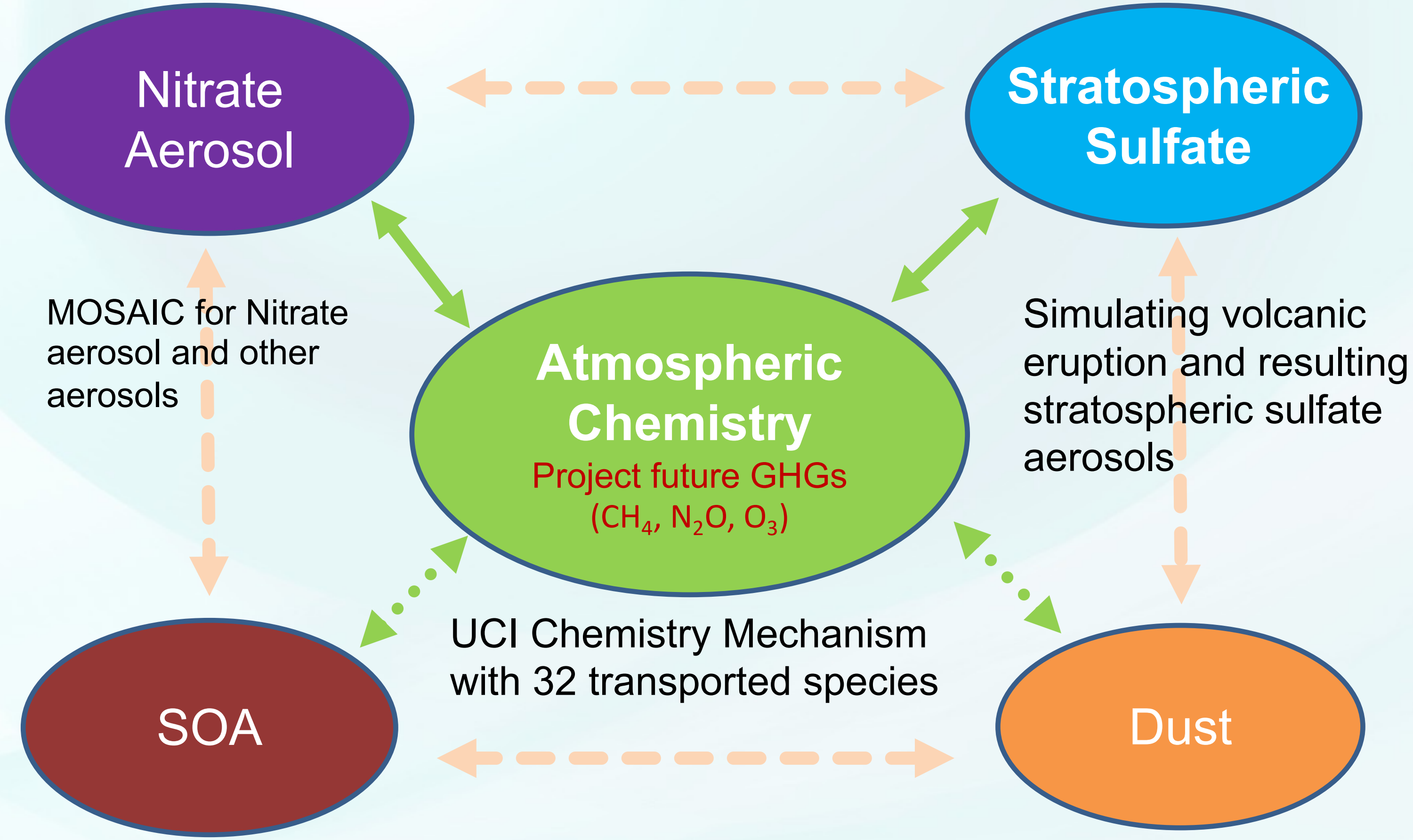
- Code base: V2+P3
- Two Phases
  - Phase I – scale smaller, testing with the new code
  - Phase II – more thorough tests (ne30 & ne120 AMIP, ne30 AMIP+4K,
    ne30 PI aerosol); results used for making a decision.
- Diagnostics: E3SM-Diag, AMWG-Diag, ARM-Diags, tropical variability diagnostics, GPCI cloud transect, precipitation PDF, monsoon diagnostic.
- Top 10 metrics based on v3 science questions and v1 biases are broadly set
  - Summary diagnostic being developed (right)





Coupling of Chemistry-Aerosol-BGC

Aerosol & Chemistry Teams



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

Implement new emission and dry deposition schemes; couple to BGC

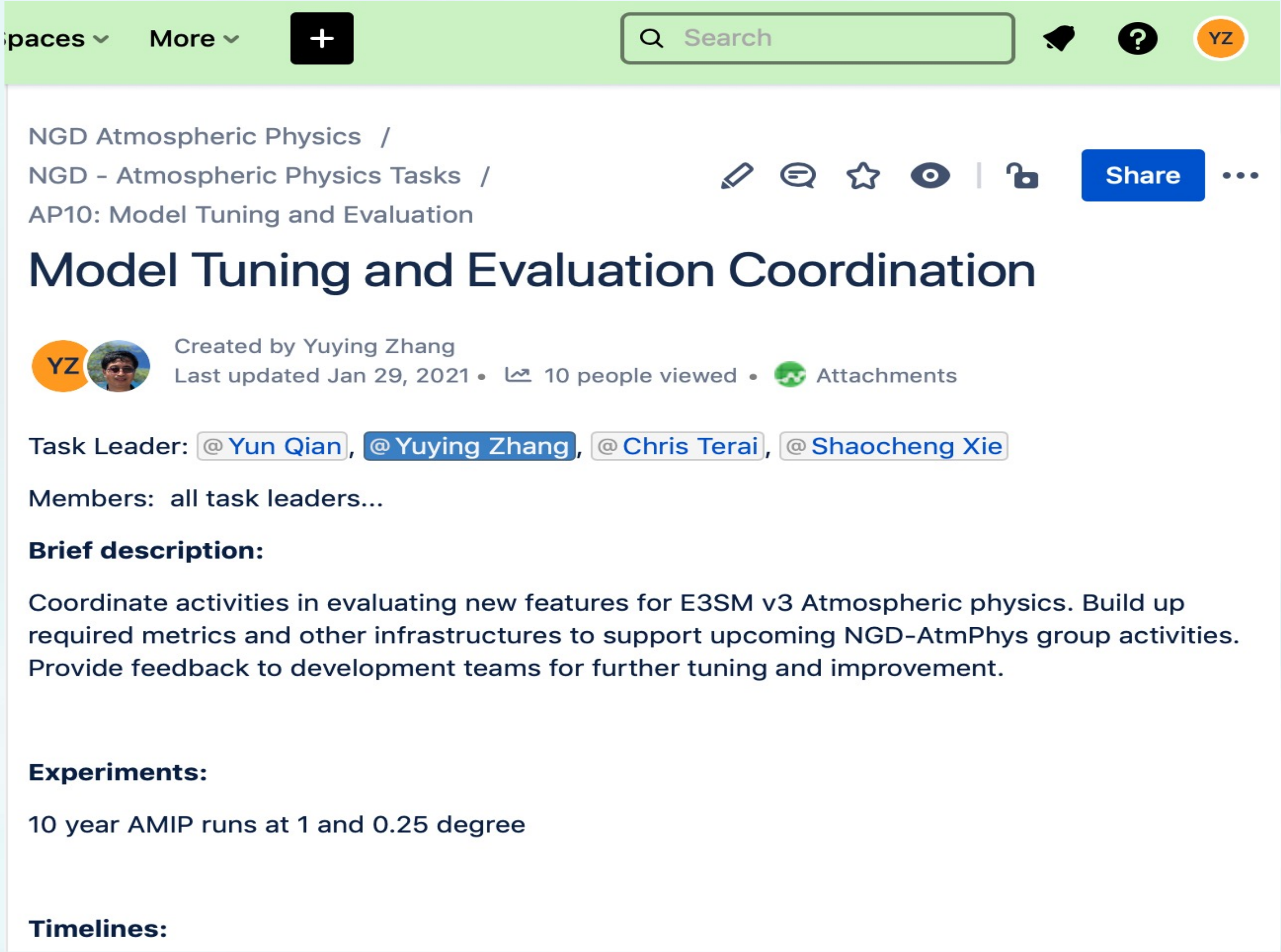
Chemistry is a central piece

- Heterogeneous reactions, additional emissions required by aerosol simulations.
- Interface for BGC interactive methane simulations
- Coupling of chemistry–BGC and chemistry-aerosols

Model Integration, Tuning and Evaluation

Evaluation Team: Yun Qian, Yuying Zhang, Chris Terai, ……

- Define standardized experiments for testing all new features
- Collect/store simulation output and metrics/diagnostics accessible for entire NGD project
- Define top metrics unique for evaluating specific new features
- Perform short-term PPE and CAPT hindcasts for model tuning and evaluation as needed
- Support model tuning and integration


paces More Search YZ

NGD Atmospheric Physics / NGD – Atmospheric Physics Tasks / AP10: Model Tuning and Evaluation

Share

Model Tuning and Evaluation Coordination

Created by Yuying Zhang
Last updated Jan 29, 2021 • 10 people viewed • Attachments

Task Leader: @Yun Qian, @Yuying Zhang, @Chris Terai, @Shaocheng Xie

Members: all task leaders...

Brief description:

Coordinate activities in evaluating new features for E3SM v3 Atmospheric physics. Build up required metrics and other infrastructures to support upcoming NGD-AtmPhys group activities. Provide feedback to development teams for further tuning and improvement.

Experiments:

10 year AMIP runs at 1 and 0.25 degree

Timelines:

Summary

- ➢ The NGD-Atmospheric Physics Project created in E3SM to address model biases and enhance model capability
  - Target V3 with 100 km – 12.5 km, but new features could be further integrated into v4 for its various science applications
  - 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 the end of 2022