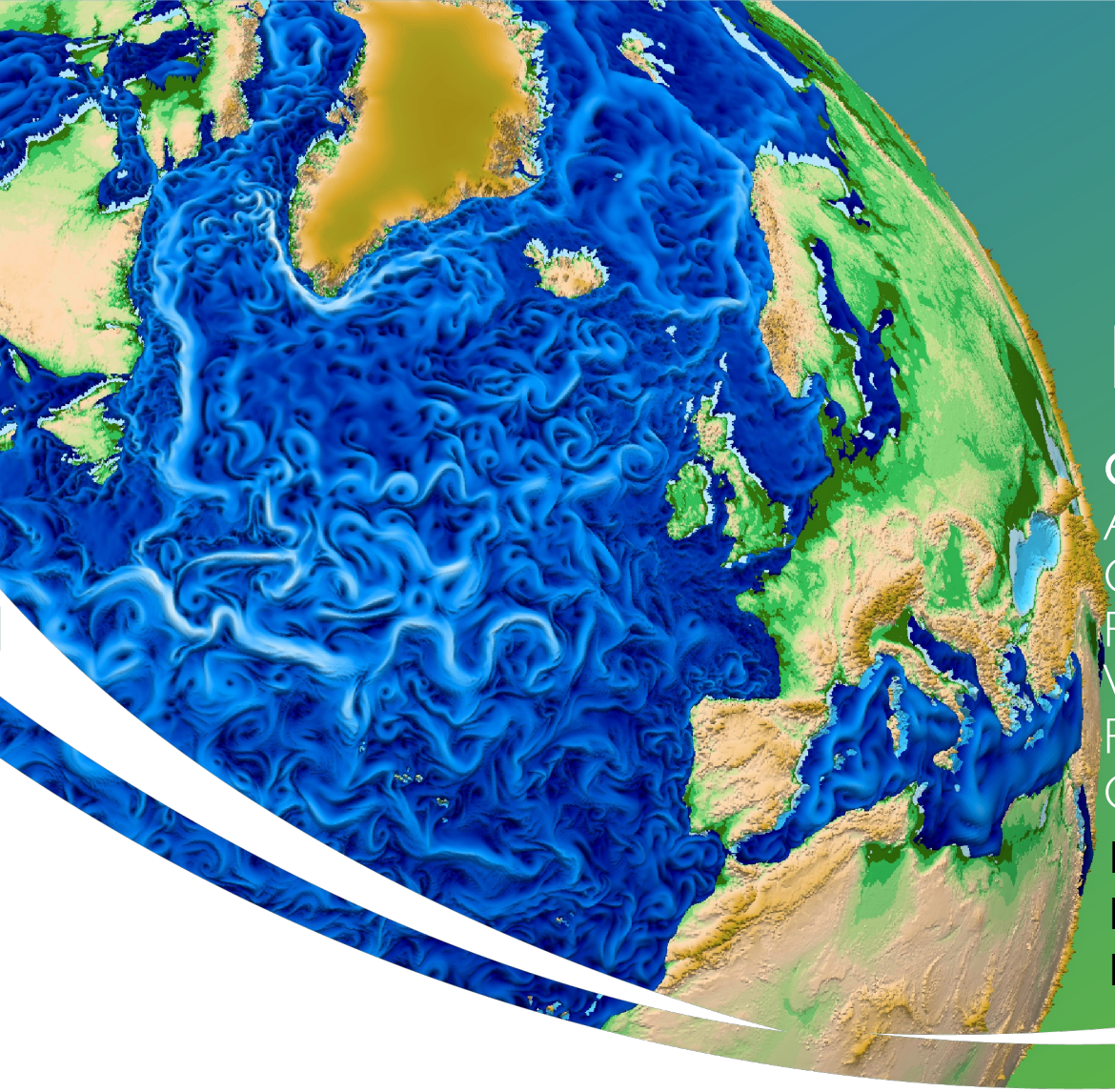


Representation of clouds and precipitation in the Simple Cloud Resolving E3SM Atmosphere Model

Christopher Terai, Peter Caldwell, Hassan Beydoun, Aaron Donahue, Andy Salinger, Luca Bertagna, Peter Bogenschutz, Andrew Bradley, Chris Eldred, Jim Foucar, Chris Golaz, Oksana Guba, Ben Hillman, Rob Jacob, Jeff Johnson, Noel Keen, Jayesh Krishna, Wuyin Lin, Weiran Liu, Balwinder Singh, Andrew Steyer, Mark Taylor, Paul Ullrich, Danqing Wu, Xingqiu Yuan, Charlie Zender

ICCP-GSRA / 2nd EarthCARE Modeling workshop
March 28, 2023

U.S. DEPARTMENT OF ENERGY

E3SM Energy Exascale Earth System Model

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 IM Release Number LLNL-PRES-846440

What is SCREAM?

Simple Cloud-Resolving E3SM Atmosphere Model

- Global atmosphere model with dx=3.25 km, 128 vertical layers with top at 40km
- Components:
  - Non-hydrostatic Spectral Element (SE) dycore
  - Simplified Higher-Order Closure (SHOC)
  - Predicted Particle Properties (P3)
  - RRTMGP
  - Prescribed aerosols (for now)
  - **No deep convection**

Vision:

- GSRM to run on DOE's new Exascale machines
  - V0: Written in F90 (contribution to DYAMOND2 – Caldwell et al. 2021)
  - V1: Written in C++ & Kokkos
- Couples with E3SM's land, ocean, and sea ice models for coupled simulations (future plans)

Recent News: GPU Version is Operational!

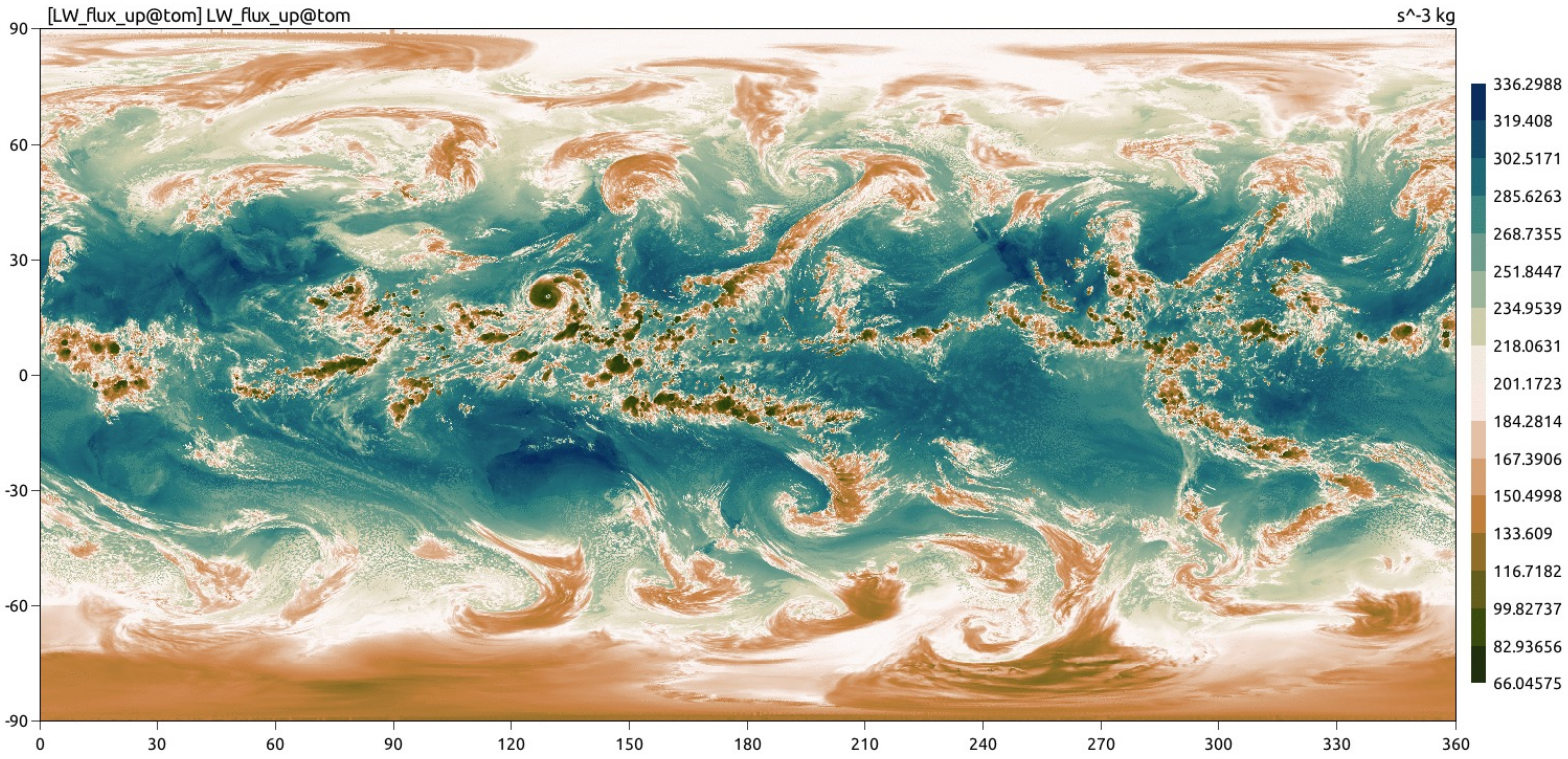


Fig: Outgoing longwave radiation (in W/m^2) from Oct 1, 2013 initialized 40 day simulation with ne1024pg2 grid (dx=3.25 km)

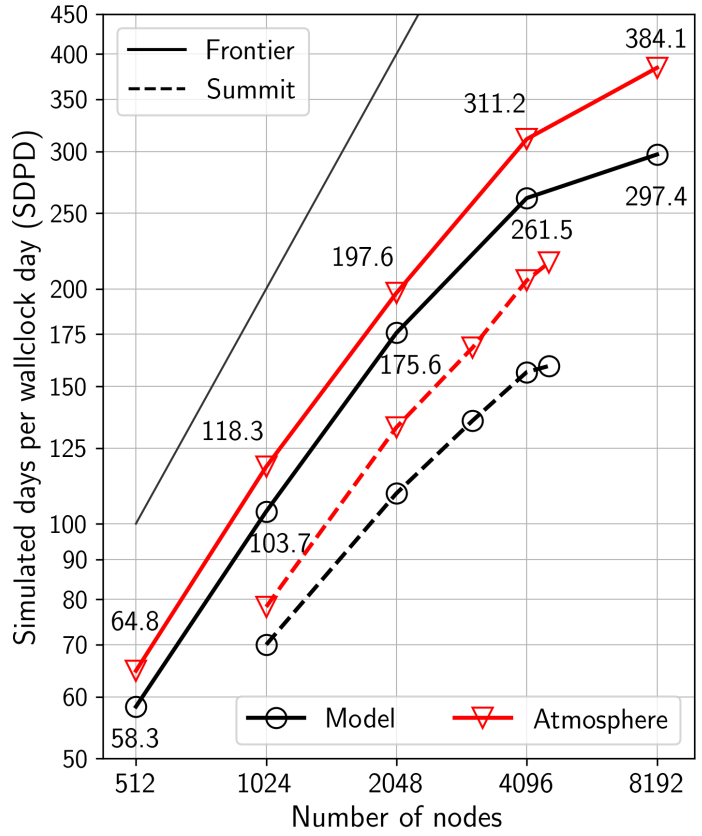


Fig: Model performance on Summit and Frontier at ne1024pg2 (3.25 km). Atmosphere model reached 1SYPD on OLCF's Frontier machine.

Precipitation and clouds in SCREAM

Four 40-day simulations across four seasons (*Donahue et al in prep*)

- January and August simulations follow DYAMOND2 and DYAMOND1 protocol
- Ran April 2013 and October 2013 simulations

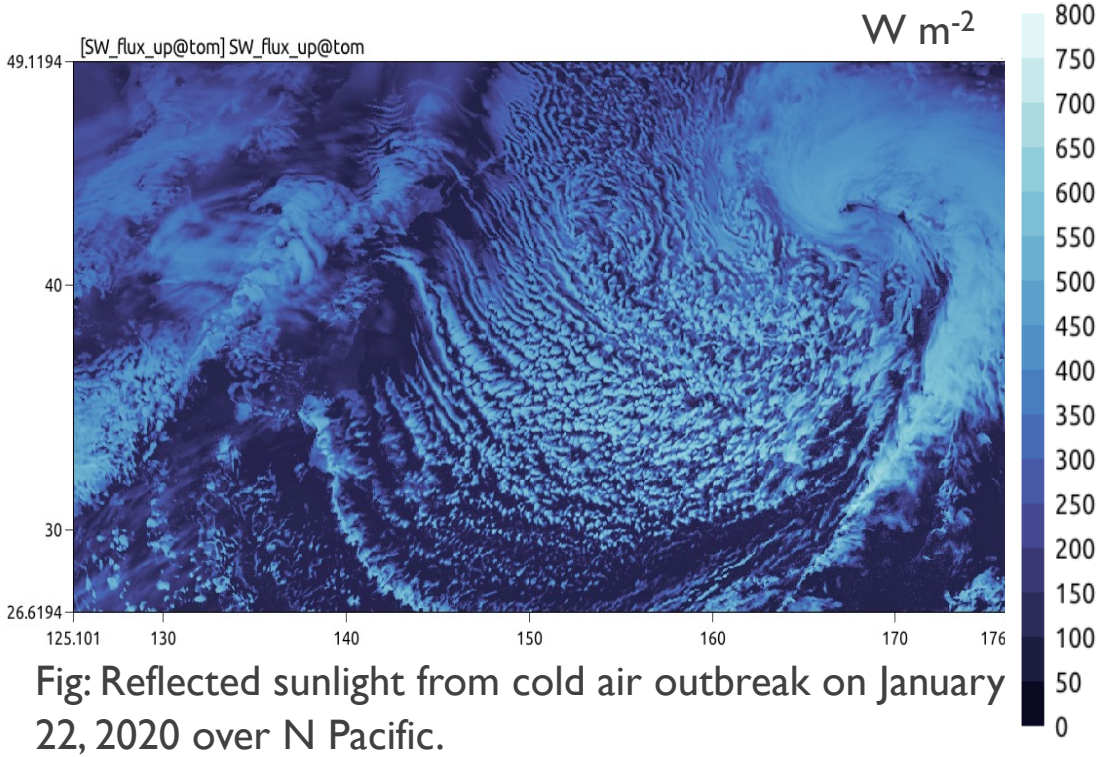


Fig: Reflected sunlight from cold air outbreak on January 22, 2020 over N Pacific.

Some highlights:

- Well-resolved storm systems and cloud mesoscale structures
- Better diurnal cycle and intensity of precipitation compared to traditional GCMs
- Well-balanced global-average TOA radiation due to compensating biases

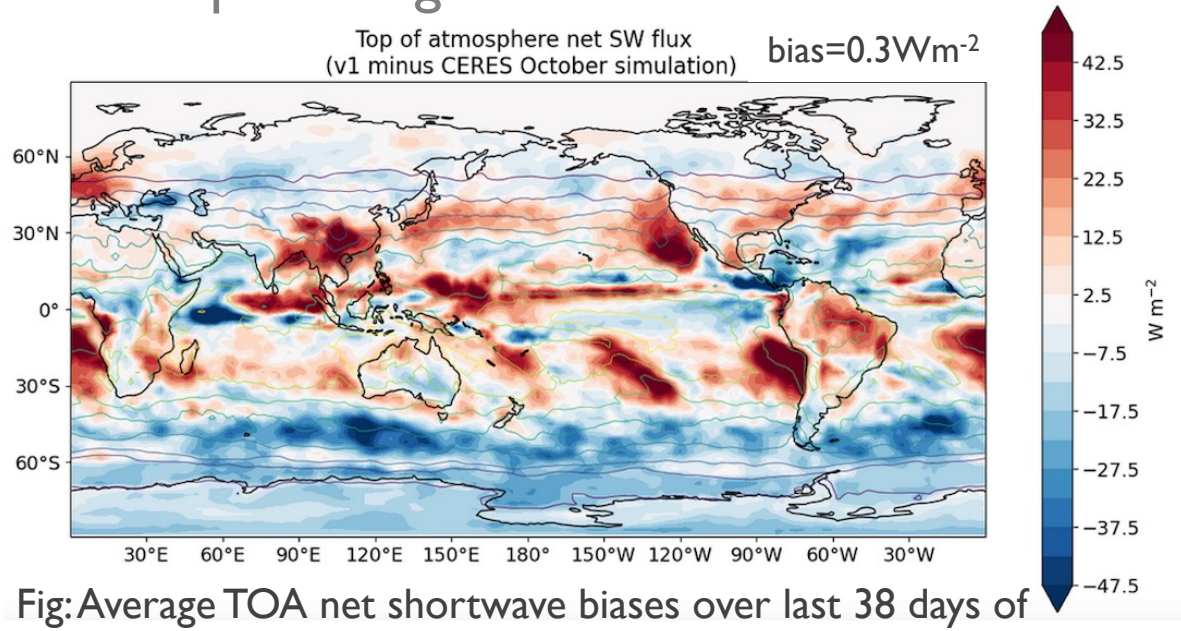


Fig: Average TOA net shortwave biases over last 38 days of simulation initialized on Oct 1, 2013

Precipitation and cloud biases in SCREAM

More things to work on:

- Missing mid-level clouds
- Small, unaggregated "popcorn" convection in tropics

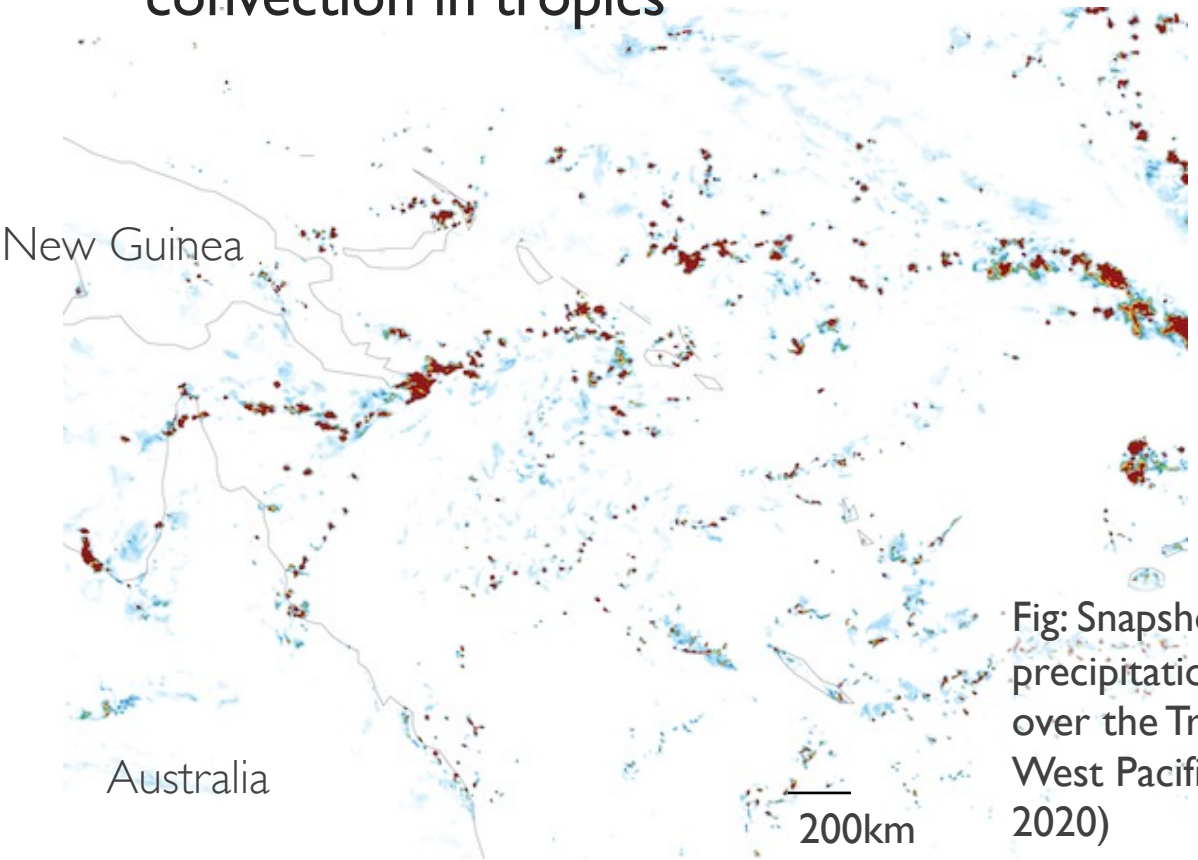


Fig: Snapshot of precipitation rate over the Tropical West Pacific (Jan 22, 2020)

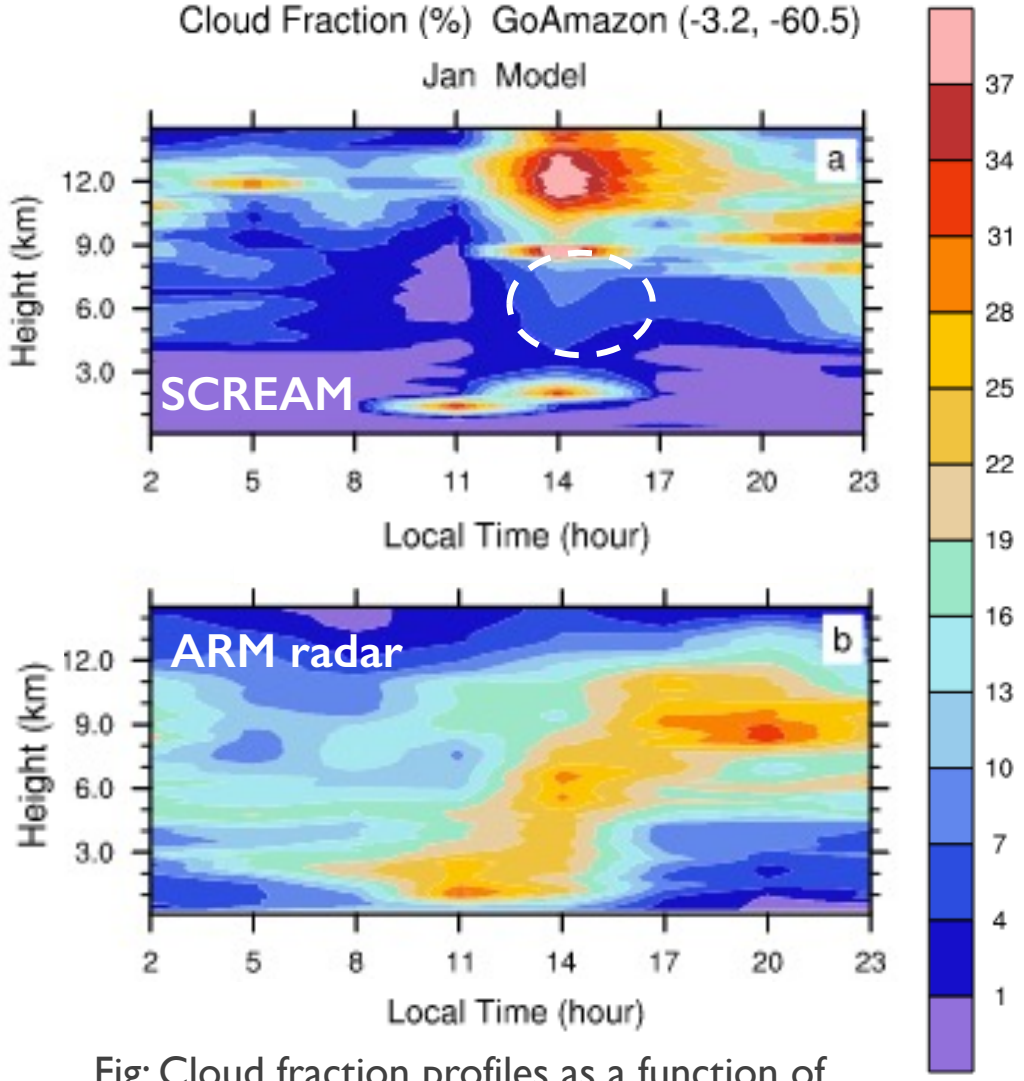


Fig: Cloud fraction profiles as a function of local time in SCREAMv1 (top) and ARM (bottom) for Jan 2013 sim.

Popcorn clouds & precipitation in SCREAM

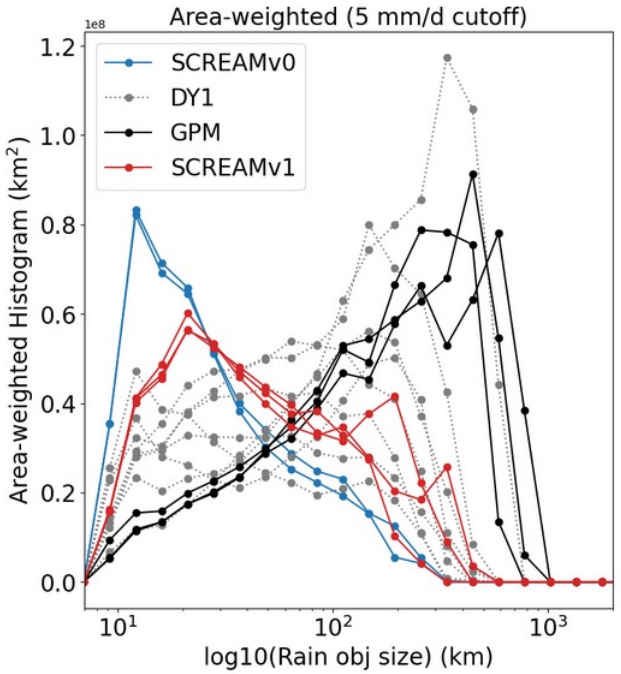
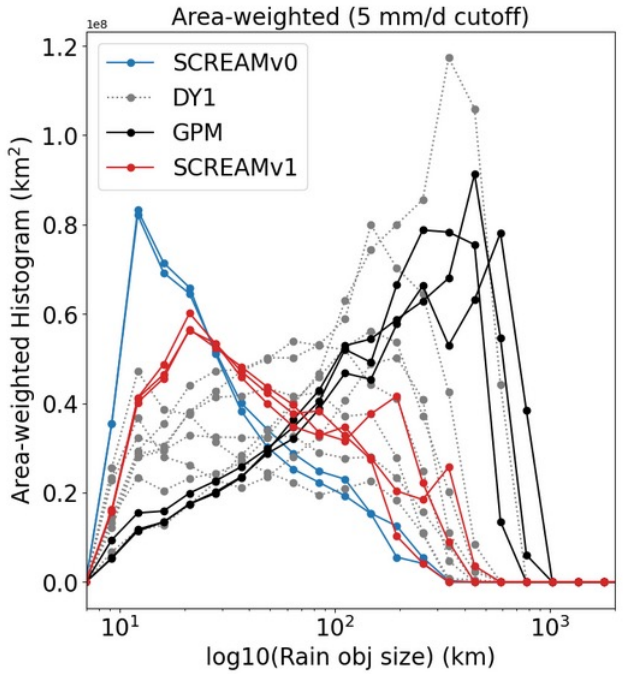


Fig: Area contribution of convective events as a function of their size (x axis). Note SCREAMv0 (F90) from DYAMOND2 (winter), SCREAMv1 (C++) is from and Oct 2013, and other lines are from DYAMOND1 (summer) model runs.

SCREAMv1 has less popcorn than our DYAMOND2 contribution (v0)

- Due partially to removing subgrid rain enhancement
- Popcorn is still a problem
- Potentially impacting our tropical variability

Popcorn clouds & precipitation in SCREAM



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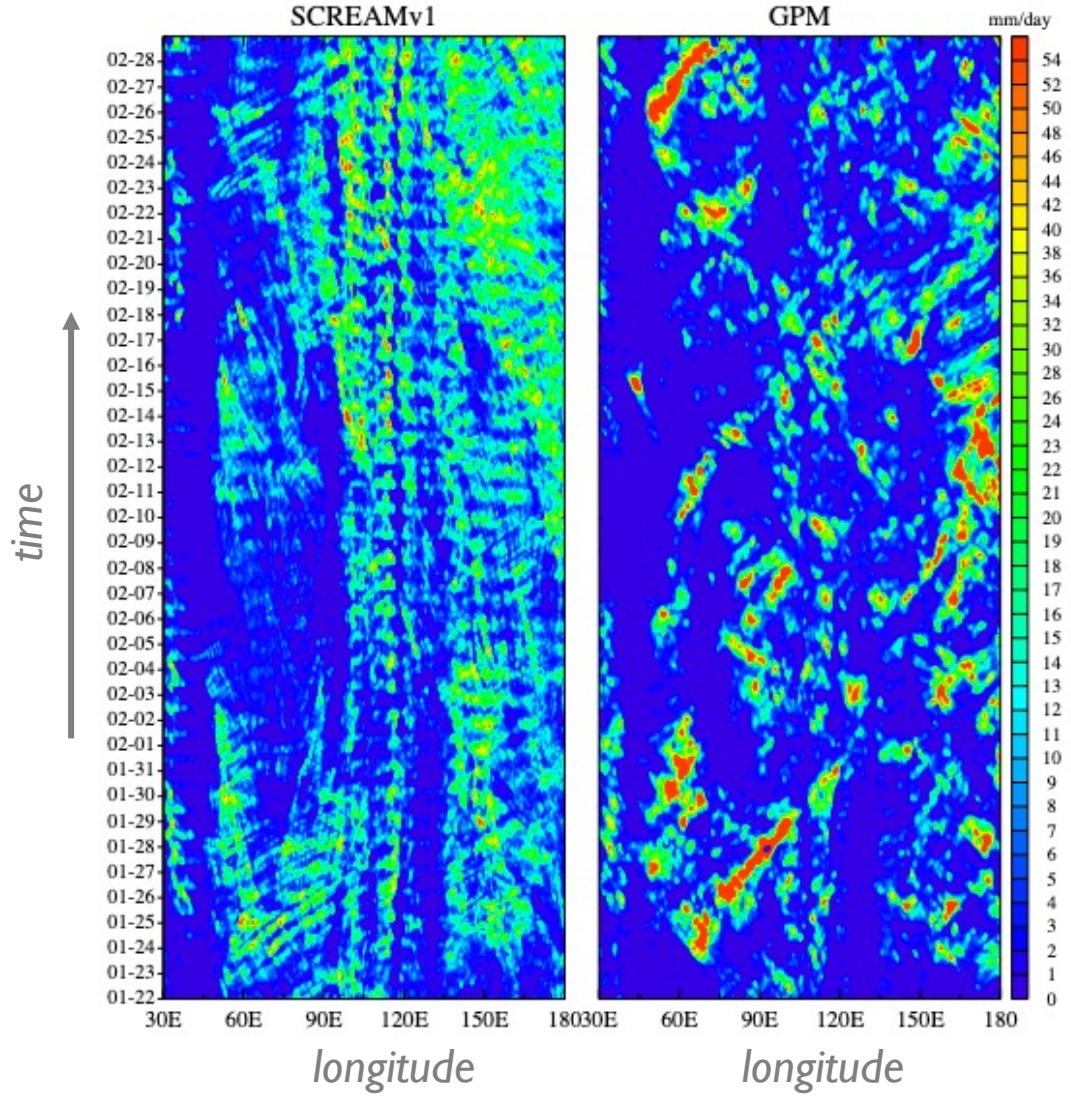
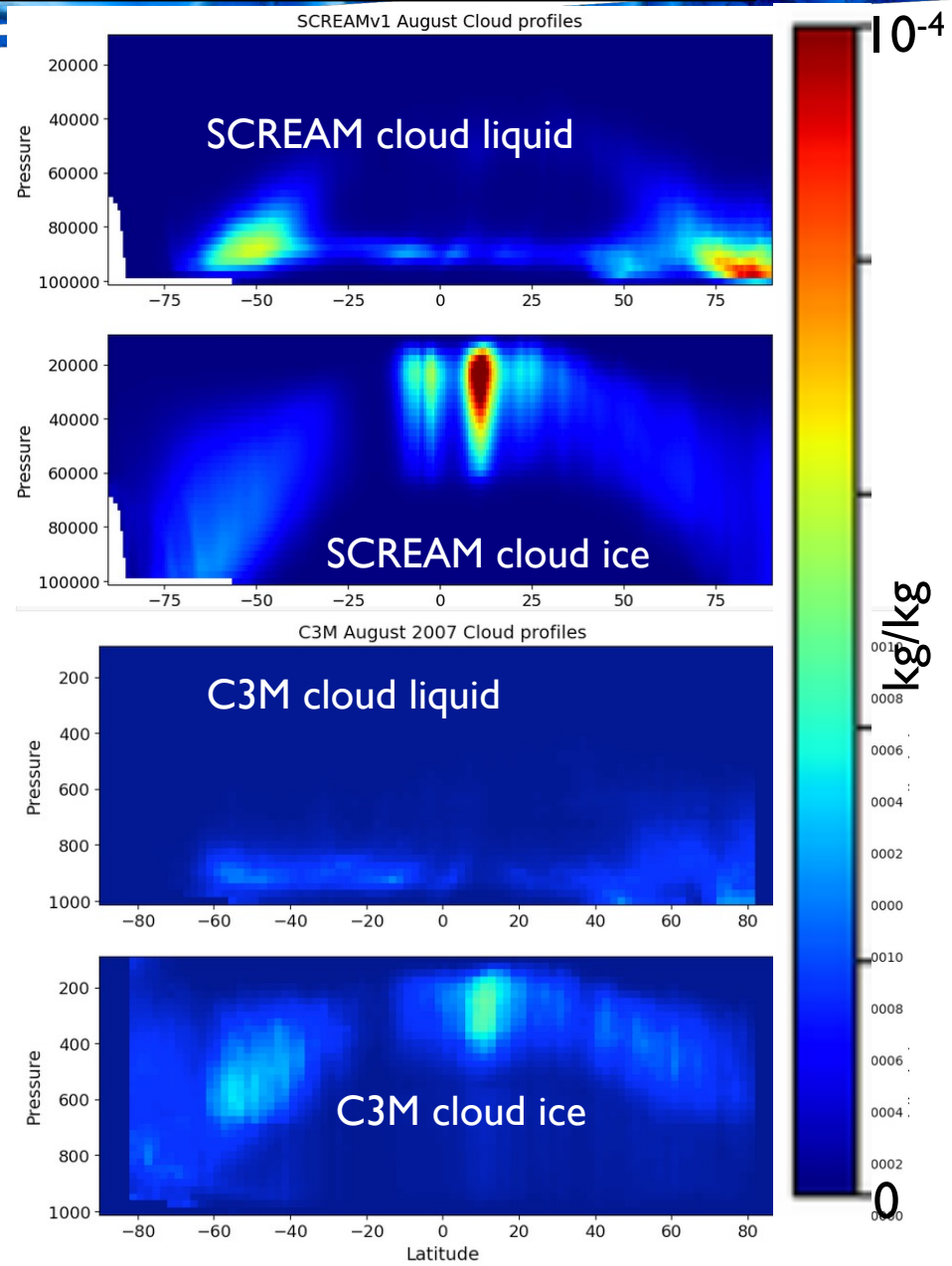


Fig: 3 hourly mean precipitation rate averaged over 5S to 5N during the DYAMOND2 period

What does the resolution of GSRMs afford us?

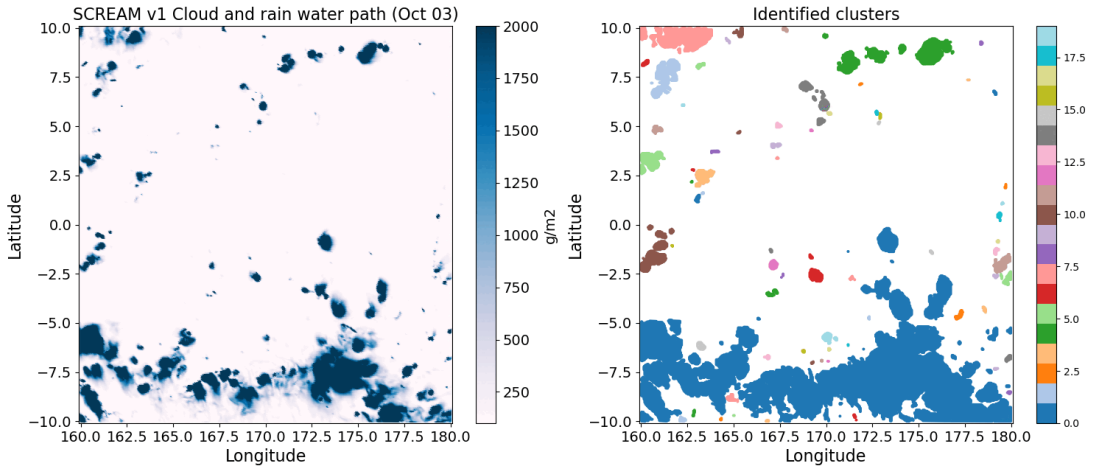
- For cloud evaluation, we can compare time-spatial average cloud profiles with satellite retrievals like we do with GCMs

Fig: Pressure-latitude cross-section of cloud liquid (top row) and ice (2nd row) in SCREAM, compared with C3M retrievals (3rd and 4th row)



- We can also dig deeper with evaluation with 15-min snapshots of 2D fields, 3-hourly snapshots of 3D fields

Fig: Vertical integrated cloud and rain water over Tropical West Pacific (left) and separate clouds tracked over time



Tracking clouds (storms) in GSRMs

- Placing cloud profiles in context of cloud evolution allows us to better match obs with models and understand processes

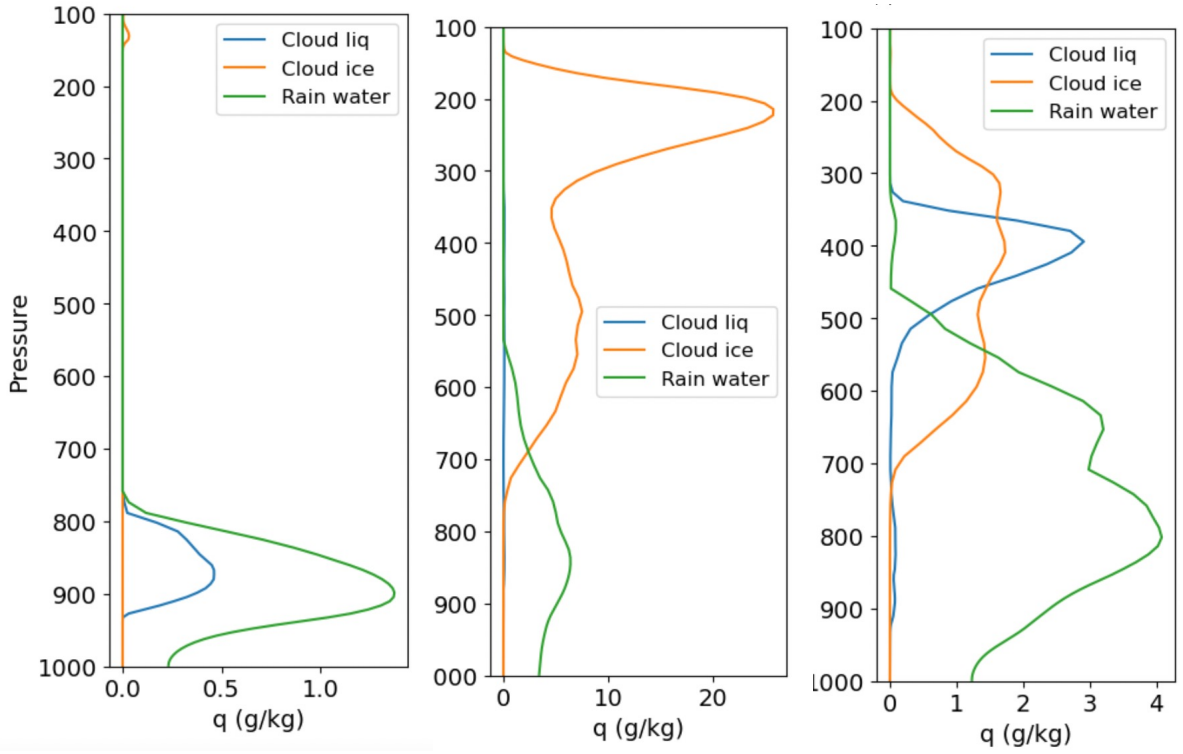


Fig: Cloud profiles from three 3D snapshots of the tracked cloud

Tracking clouds (storms) in GSRMs

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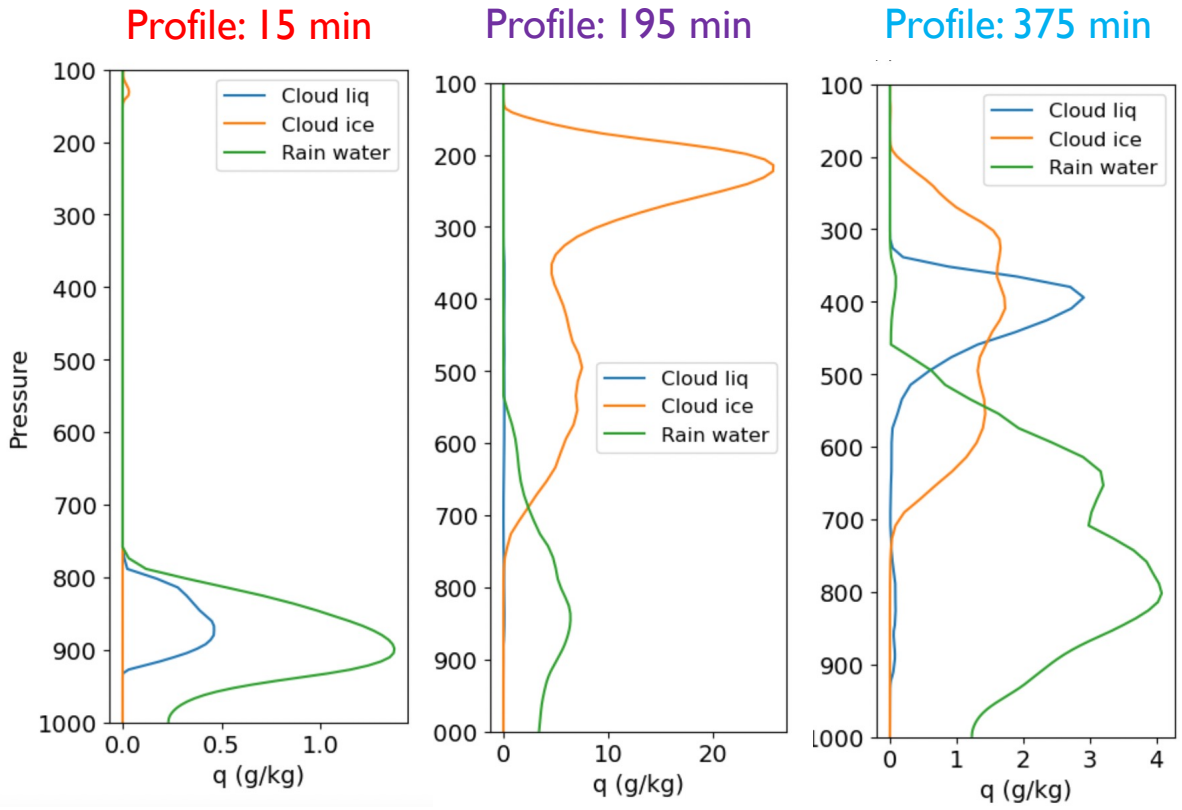

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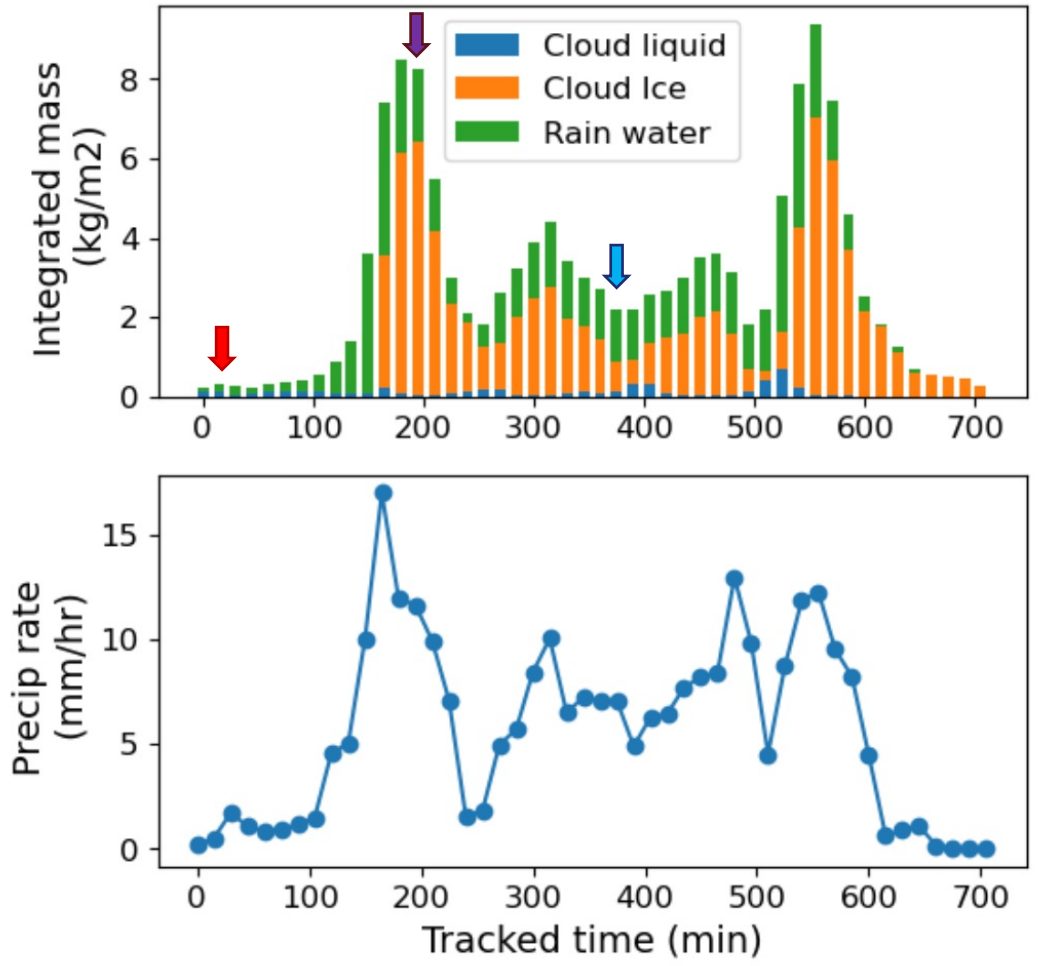


Fig: Temporal evolution of cloud and rain water over the cloud lifetime and associated precipitation rate

SCREAM simulation plans and constraints

- With our computer allocation, we can run ~10 simulated years with one year's allocation
- Planning 1 year present-day and 1 year +4K SST simulations to obtain cloud feedbacks (Cess simulations)
- Since we cannot gather large statistics of large-scale fields → more reliance on process understanding

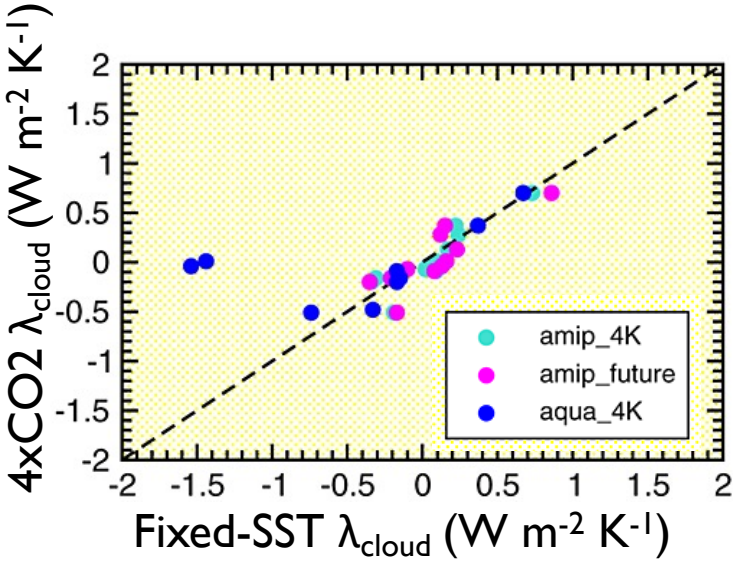


Fig: Cloud feedback from full-complexity (y-axis) versus fixed SST simulations in CMIP5. Adapted from Ringer et al, (2014 GRL).

Tools for evaluating SCREAM

- Doubly-periodic, forced simulations (DPSCREAM)
- Regional refined model

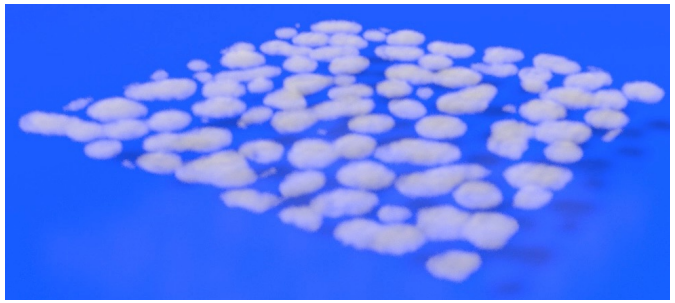
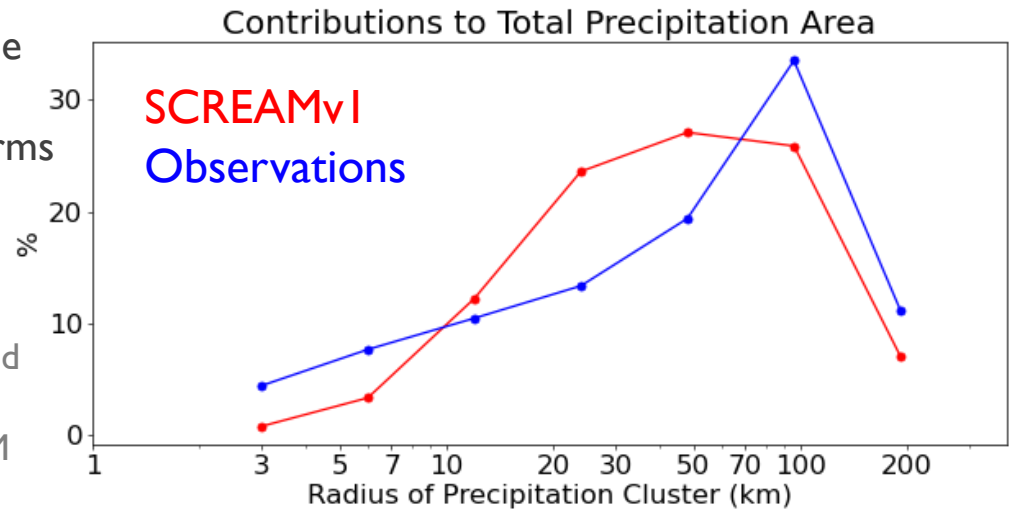


Fig: Clouds from a DPSCREAM simulation for RICO case

- Collaborating with newly formed THREAD team to evaluate SCREAM with ground-based ARM observations

Fig: PDF of precipitation clusters identified over the GoAmazon region shows SCREAM has smaller storms



Courtesy of J. Tian and Y. Zhang. Work supported by DOE Early Career project and ASR THREAD project using DOE ARM GoAmazon SIPAM scanning radar data.

Summary and EarthCARE connections

- SCREAMv1 is positioned to run multiple years now with year-long Cess experiments planned
- Lots of room for improvement on how clouds and precipitation are represented in the model
- GSRM's resolution allows us to identify individual clouds that go into temporally & spatially averaged fields → better use cloud observations for evaluation/hypothesis testing

- How best should simulation output and satellite cloud retrievals be compared?
- What workflow or online diagnostics will enable process understanding without overwhelming output?

Questions? terai1@llnl.gov, Peter Caldwell – caldwell19@llnl.gov