The Simple Cloud-Resolving E3SM Atmosphere Model (SCREAM)

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SCREAM - Simple Cloud-Resolving E3SM Atmosphere Model

1. Goal is to keep code as simple as possible
    a. You shouldn’t trust results you don’t understand physically…
    b. Simplicity makes clean rewrite (needed for performance) possible
    c. Resolving more makes complex parameterizations less important

2. Not quite cloud-resolving (yet!), but makes for a cool acronym
    a. Target dx = 3 km globally, 128 vertical layers with a top at 40 km

3. SCREAM has access to E3SM’s coupled ocean, land, and sea ice

Why 3km Δx?

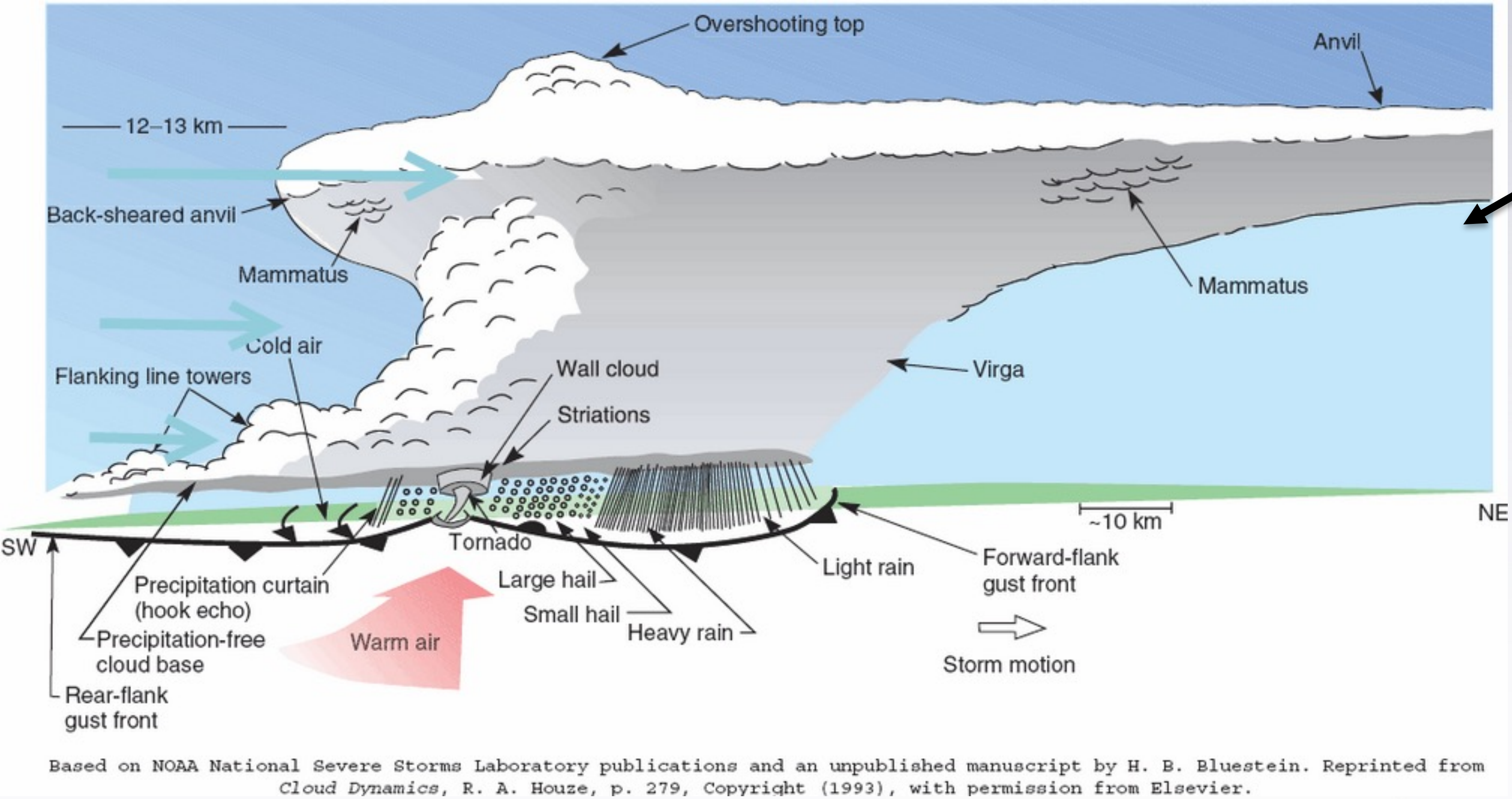


Fig: Schematic of a supercell thunderstorm from Houze' Cloud Dynamics (1993), extracted in color from inthecloudhead.blogspot.com .

- Convection is the major driver of the tropical circulation, is hard to parameterize, is critical for climate sensitivity, and begins to be resolved at 3 km

- Exascale computers require more parallelism than conventional GCMs can provide. Higher resolution provides this!

Thesis: Climate Change Can be Understood from Short Runs

This thesis is critical to SCREAM because high-res requires short timesteps, limiting simulation length

Reasonable because:

- Clouds are the main source of climate uncertainty
- Clouds respond rapidly to forcing change

  ⇒ Cleverly-designed short runs should tell us a lot

- Several clever short tests already exist
  - Climate sensitivity from “Cess” (prescribed SST increase) runs
  - Aerosol sensitivity with nudging to observations

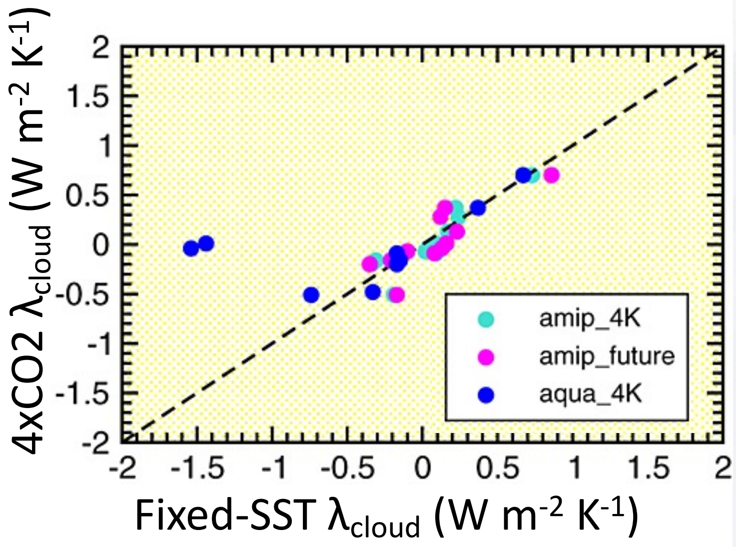


Fig: Cloud feedback from full-complexity (y-axis) versus fixed SST simulations in CMIP5. Adapted from Ringer et al, (2014 GRL).

Joining the Bandwagon…

- Many other groups are also working on global cloud-resolving models
- DYAMOND (https://www.esiwace.eu/-services/dyamond) is an intercomparison of 40 day simulations with dx<5 km globally

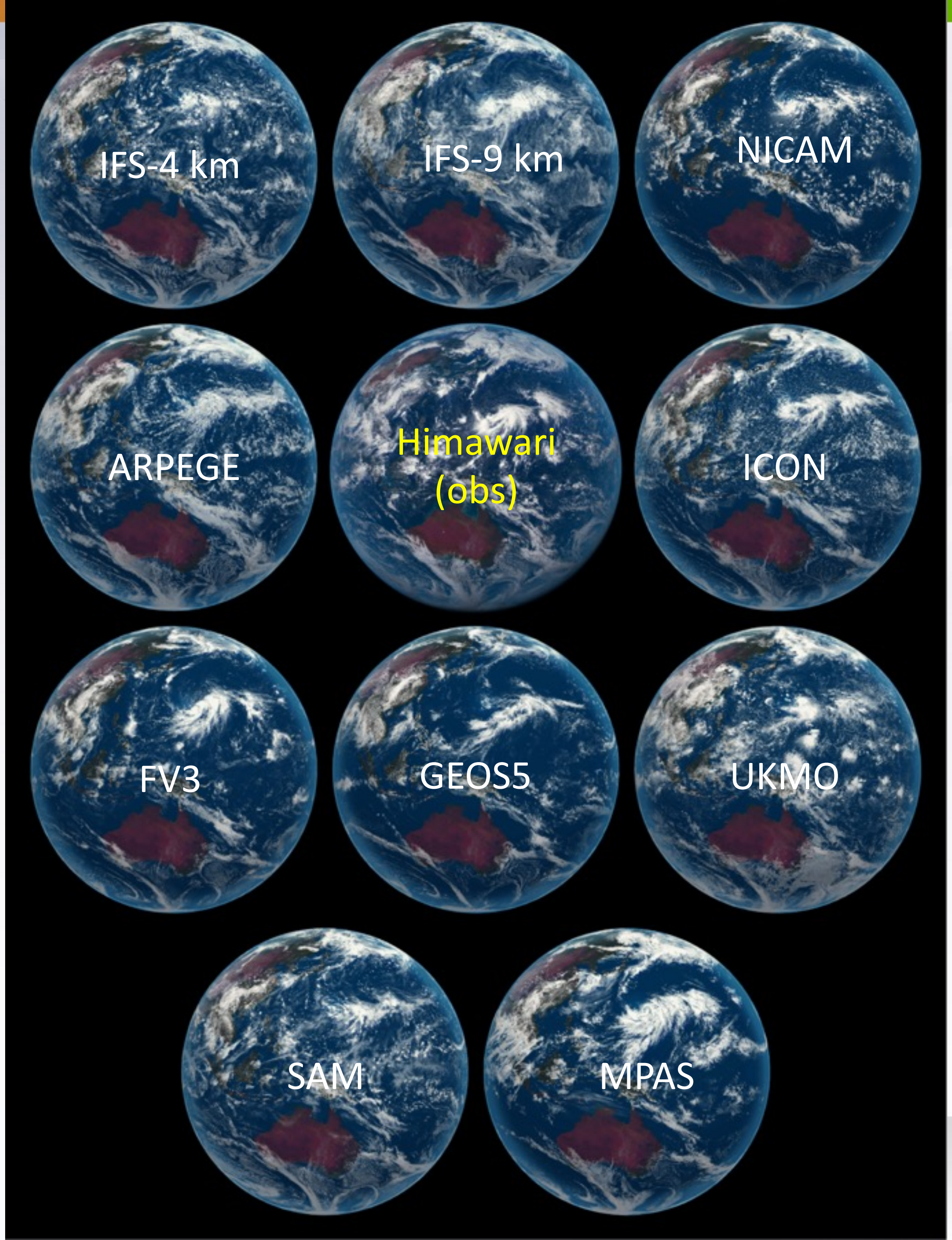
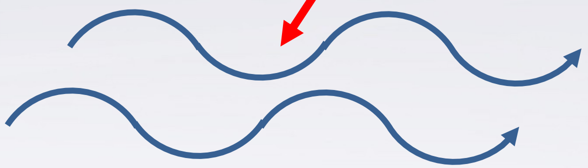


Fig: Snapshot of cloud fields from Aug 4, 2016 from DYAMOND models and Himawari satellite

Overview of Processes

~~parameterized convection~~

Resolved-scale **fluid dynamics** treated by a non-hydrostatic Spectral Element (**SE**) approach



Turbulence and **cloud formation** handled by Simplified Higher-Order Closure (**SHOC)**

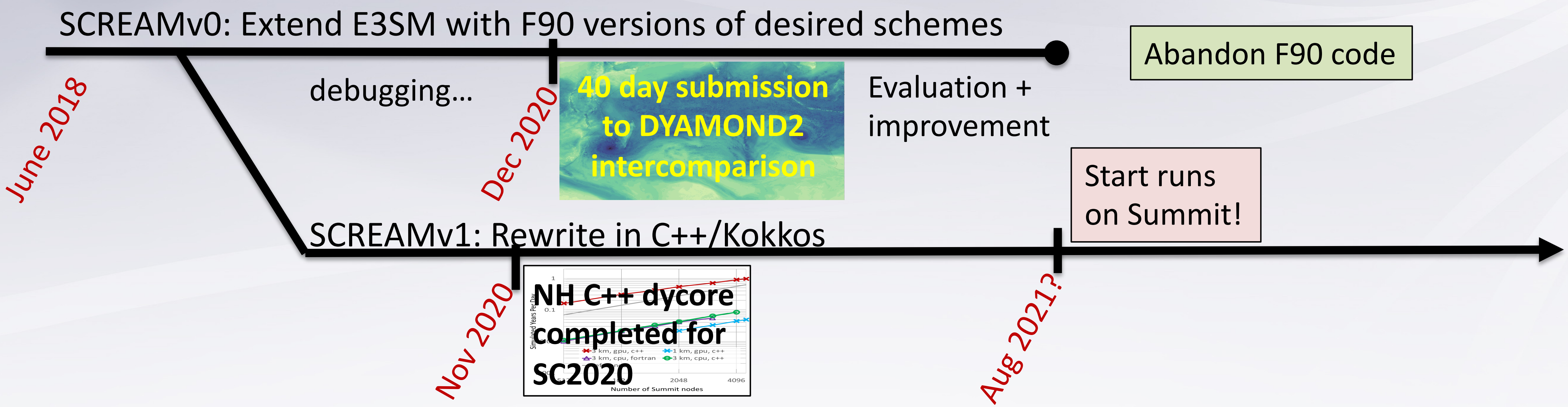
Radiation handled by externally-developed, GPU-ready **RRTMGP** package

Aerosols will be prescribed in initial implementation, but see EAGLES talk

Microphysical processes handled by Predicted Particle Properties **(P3)** scheme

* Using coarser grid for physics parameterizations (PG2) *

The 2-Pronged Plan

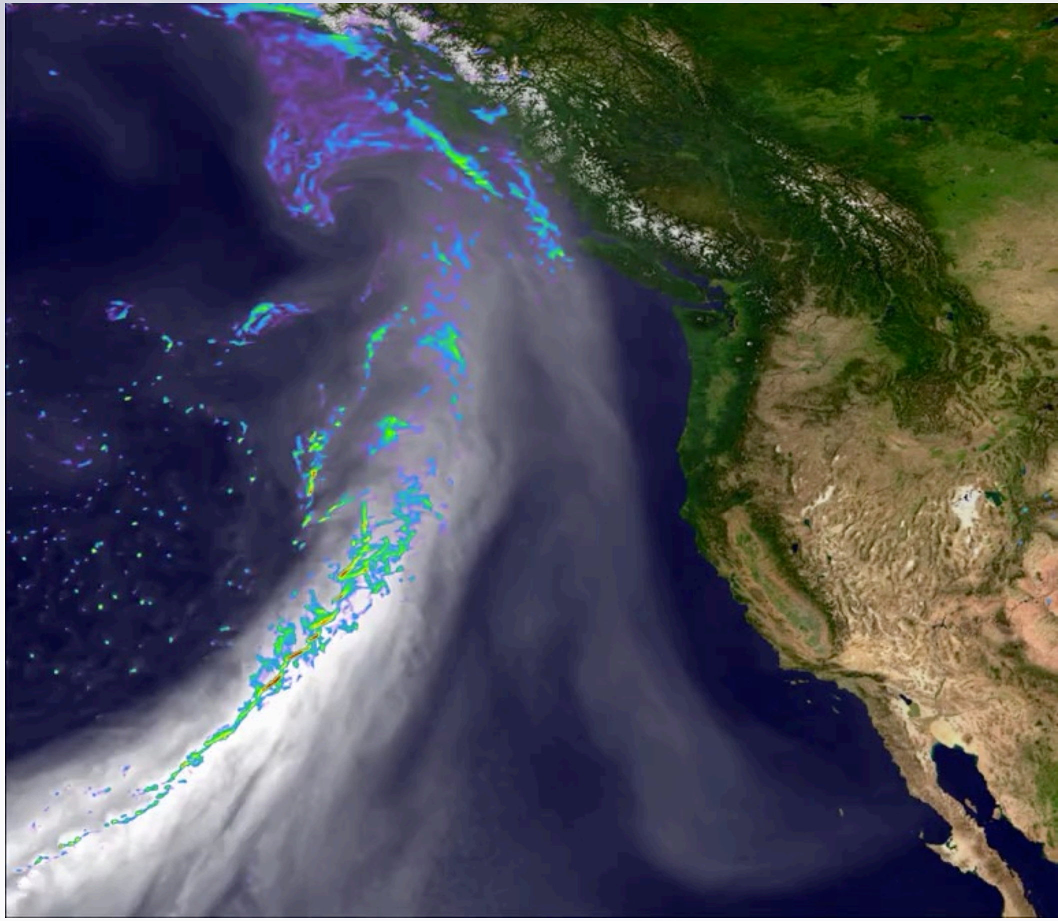


- Major successes so far: C++ dycore paper and DYAMOND2 paper
- Major campaigns right now: improving v0 and finishing v1
- Minor campaign: completing Doubly Periodic version

SCREAMv0 DYAMOND2 Results

- Achieved 4 to 20 sim**days**/wallday on Cori-KNL
  - C++ version should get 0.5 to 1 sim**years**/wallday using all of Summit
- Punchline: great skill with ~no tuning
  - that's what 0.3M core hrs/sim**day** buys you?
- Simulation has several flaws we're correcting now: downside to "early and often" model releases

Citation: Caldwell, Terai, and 28 coauthors, *Convection-Permitting Simulations with the E3SM Global Atmosphere Model*, Submitted to J. Adv. Model. Earth Syst. (2021). https://www.essoar.org/doi/abs/10.1002/essoar.10506530.1

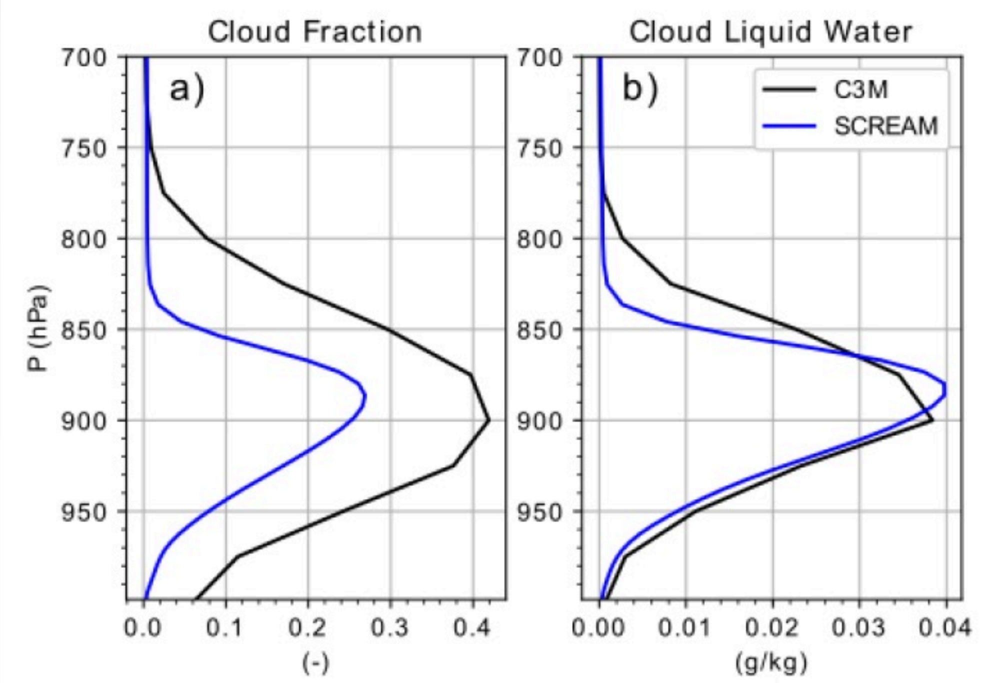


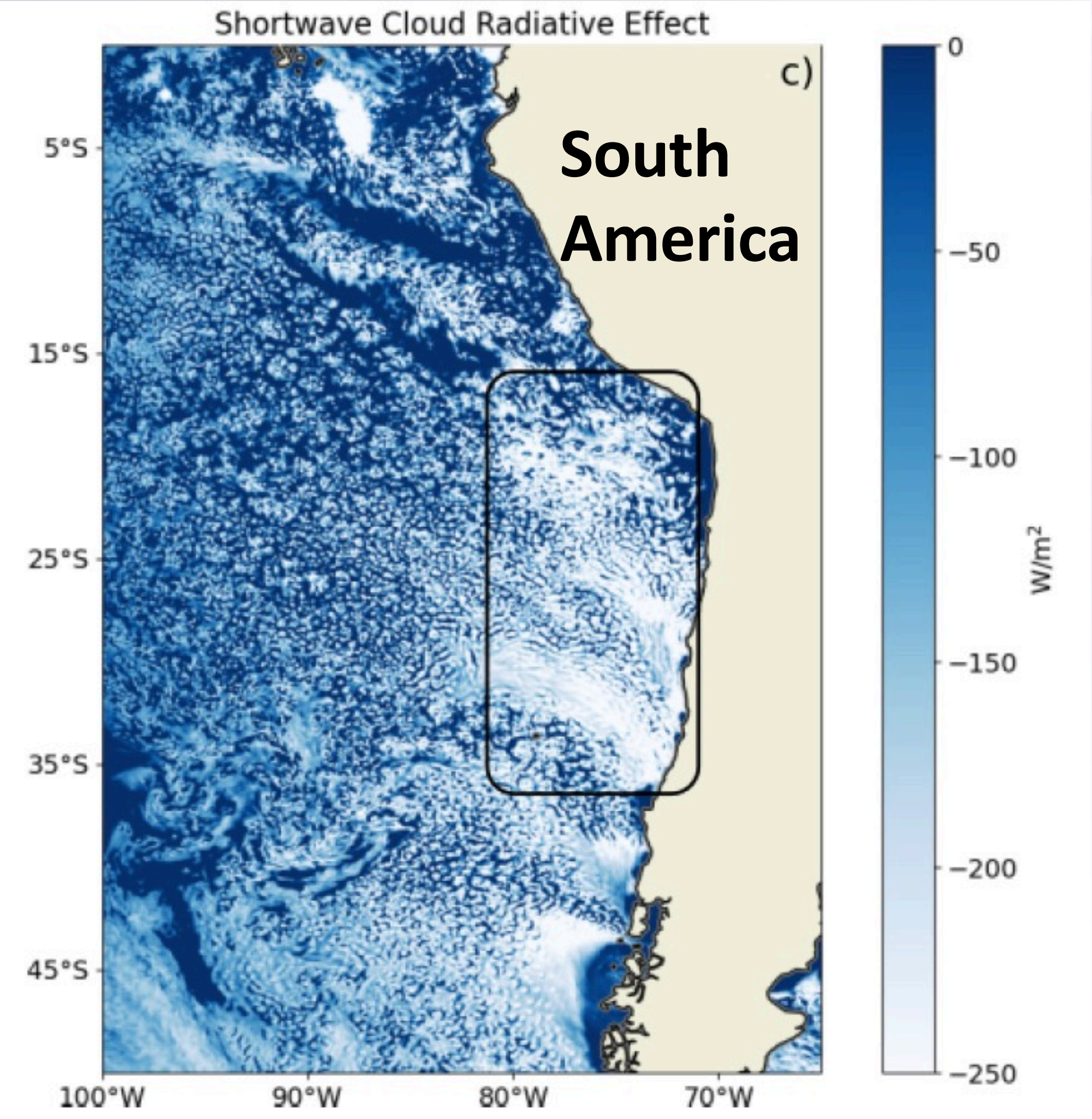
Movie: Precipitation (colors) and integrated water vapor (gray) for an atmospheric river from E3SM's DYAMOND2 simulation. By Paul Ullrich/UC Davis

Stratocumulus

- Unlike most GCMs, SCREAM is able to simulate these radiatively important clouds
  - 50 m PBL resolution, higher-order turbulence closure, and horizontal resolution help(?)

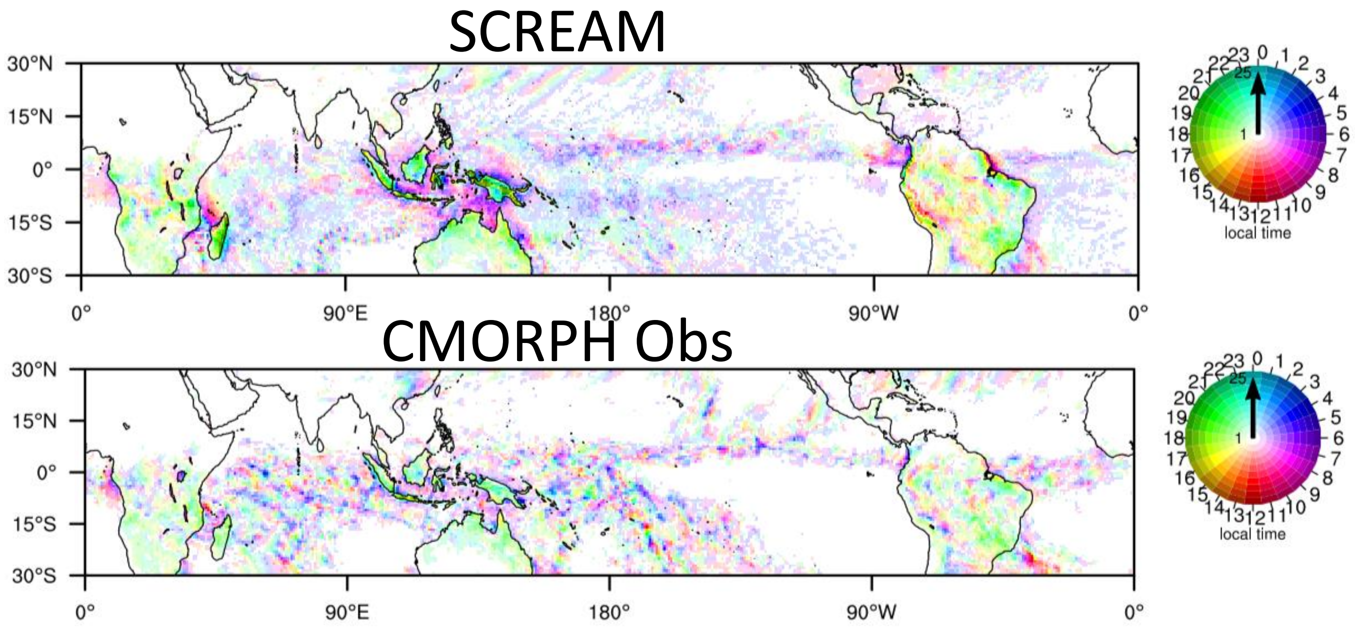
Fig: cloud fraction (a) and mass (b) over the boxed region in panel c, which shows shortwave cloud radiative effect.





Precipitation variability

- Diurnal cycle is excellent
- MJO propagation speed is correct
- Frequency of tropical convection is too high



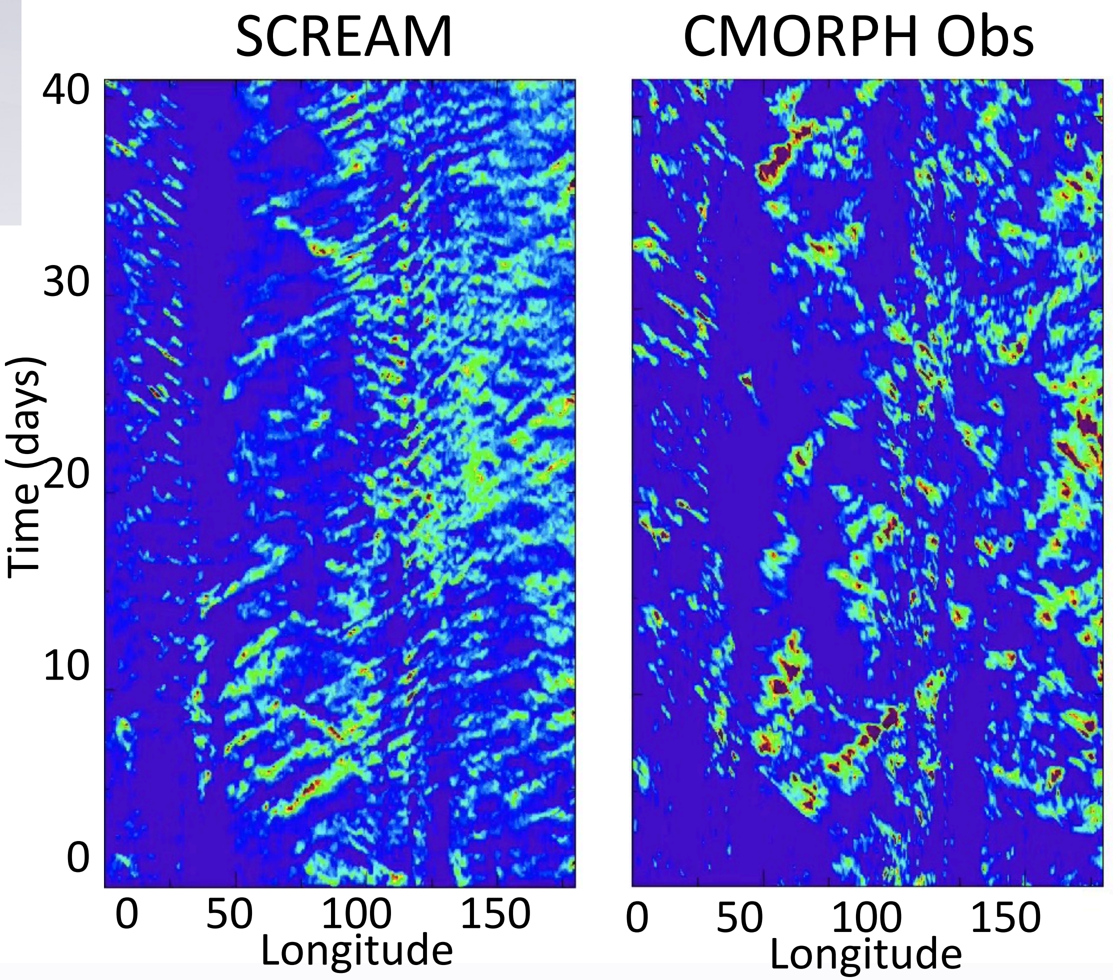


Fig: Left = diurnal cycle of precipitation (peak time in color, amplitude in hue). Right = Hovmoller of precip averaged from 5S to 5N over MJO longitudes (x axis) vs time (y axis). No time filtering was done.

Doubly Periodic SCREAM

- We are creating a doubly-periodic limited-area version of SCREAMv0
  - This is a typical CRM… but with physics and dynamics identical to the full global model!
  - Final testing of F90 version being done now
  - C++ version will take 1 more year

- Regionally-refined, small-planet, and radiative-convective equilibrium modes are also available

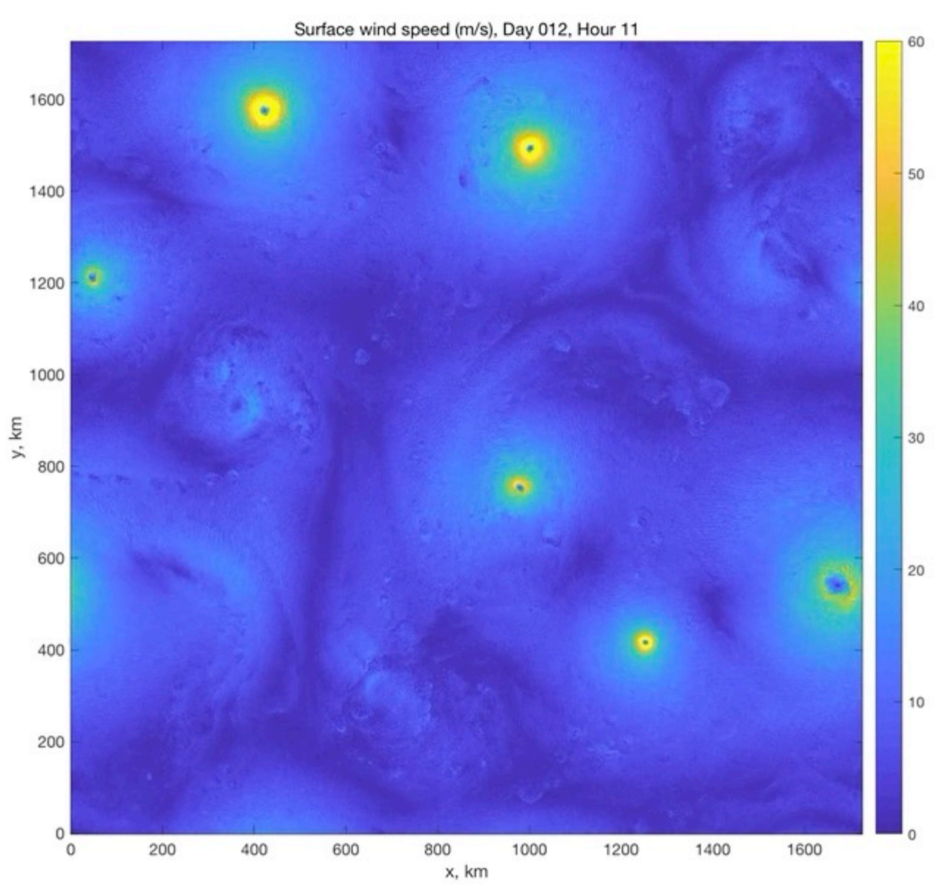


Fig: Doubly-periodic"Hurricane World" simulation from Cronin + Chavez (2019)

Doubly-Periodic Test Cases

- Doubly-periodic mode is an extension of E3SM's single-column capability
  - inherits the cases Peter Bogenschutz + Shaocheng Xie have built (see list)
  - For info, see https://github.com/E3SM-Project/scmlib/wiki/E3SM-Single-Column-Model-Case-Library

Available Cases:

1. AEROSOLINDIRECT
2. ARM95
3. ARM97
4. ARM_shallow
5. ATEX
6. BOMEX
7. DARWIN
8. DYCOMSrf01
9. DYCOMSrf02
10. DYNAMO_amie
11. DYNAMO_northsounding
12. DYNAMO_revelle
13. GATEIII
14. GOAMAZON
15. ISDAC
16. MC3E
17. MPACE
18. MPACEB
19. RACORO
20. RICO
21. SGP
22. SGP_continuous
23. SPARTICUS
24. TOGAII
25. TWP06

Testing, Testing, Testing…

- All C++ functions have unit tests.
  - Most are BFB tests against F90.
  - We also have *property tests* ensuring code matches physical expectations

- Sandia's continuous integration (automatically checking all unit tests + merging to master if they pass + a reviewer approves) speeds up our progress

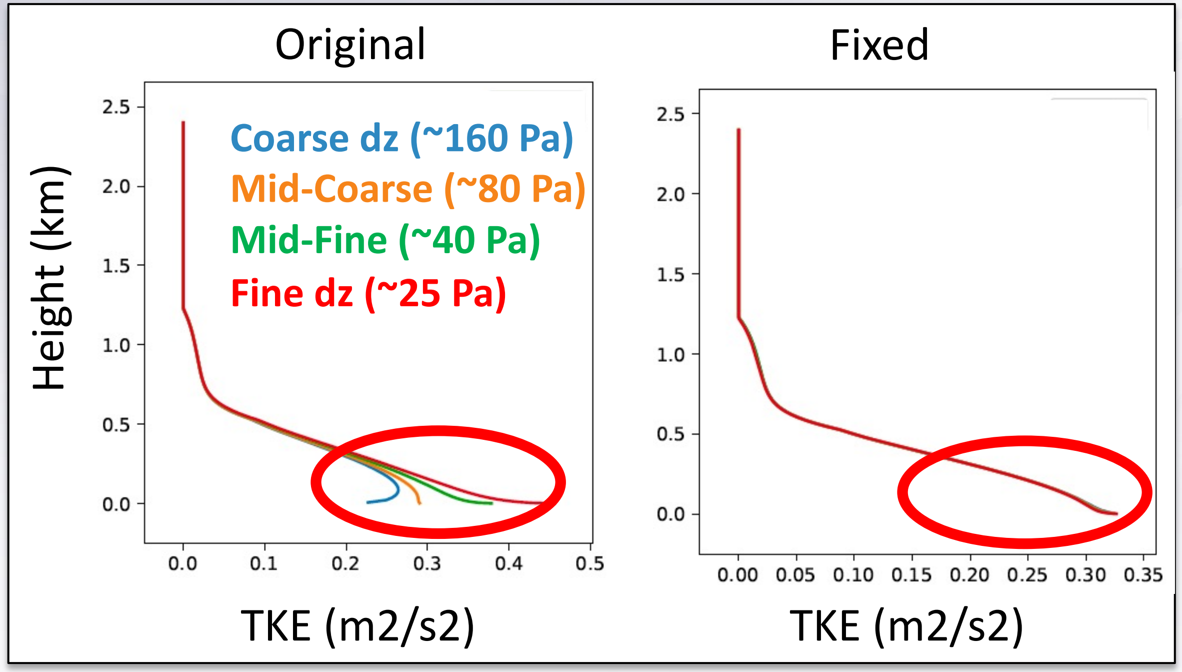


Fig: SHOC standalone simulations running the BOMEX test case (trade wind Cumulus) for 6 hrs with a variety of vertical resolutions

Opportunities for Collaboration

1. SCREAM has *not* been sufficiently evaluated yet
   a. Output for Feb 2020 DYAMOND case is publicly available now (via https://www.esiwace.eu/services/dyamond or on NERSC)
   b. Output for Aug/Sept 2016 DYAMOND case will be available in a few months
2. Doubly-periodic mode is the perfect testbed for developing new parameterizations
3. It is easy to run individual parameterizations in isolation for idealized tests
4. Parameterizations that could use improvement:
   a. fraction of grid cell filled with precipitation (see Xue Zheng et al, MWR 2020)
   b. coupling between SHOC and P3
   c. impact of aliasing deep convection onto 3 km grid

The End

Questions? caldwell19@llnl.gov

Top-of-Atmosphere Radiation

- Not enough clouds over the Southern Ocean
- Stratocumulus regions look great!
  - transition to trade Cu is problematic (not shown)
- Not enough tropical deep convective clouds

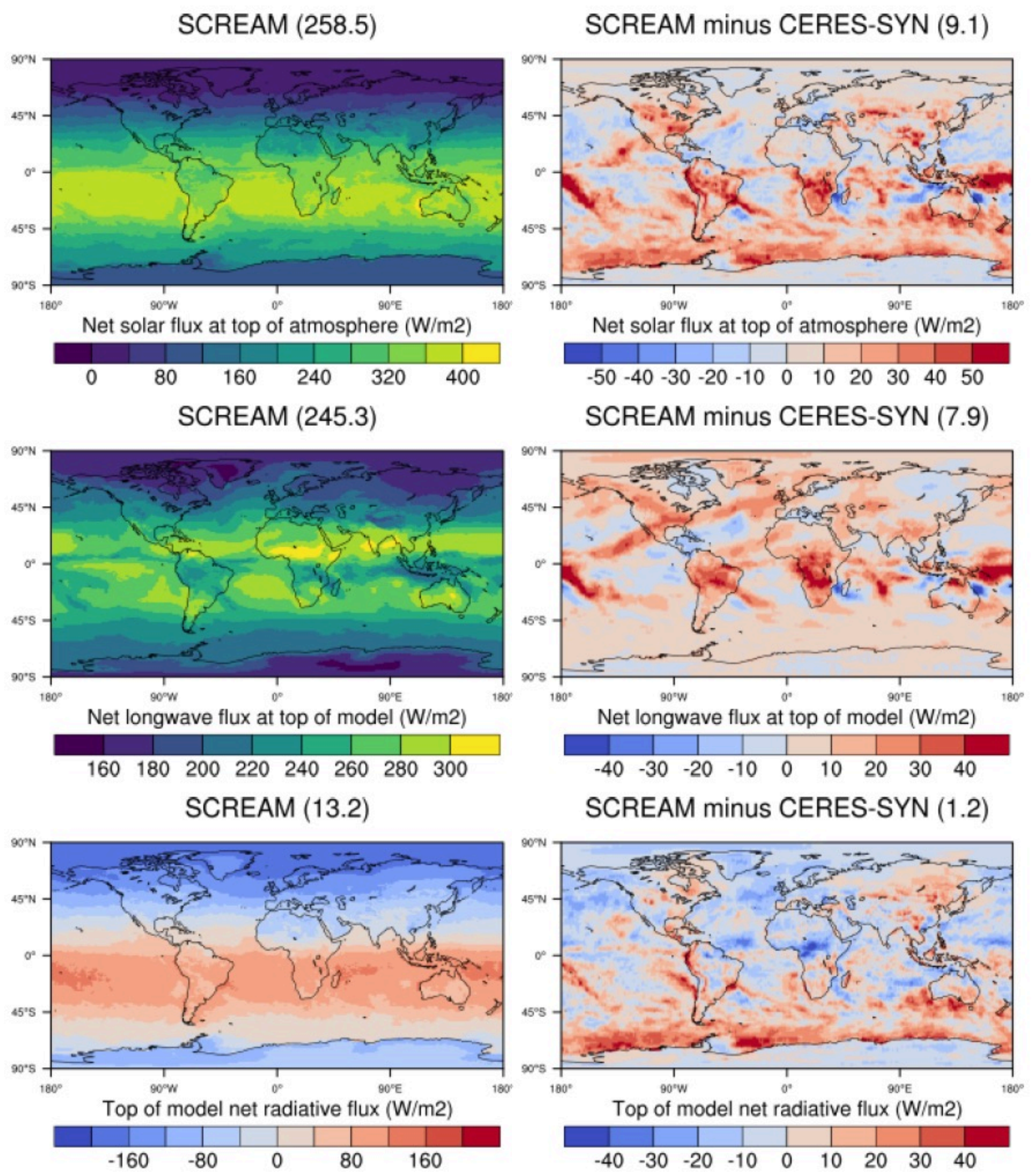


Fig: Top-of-Atmosphere SW (top), LW (middle), and total (bottom) net radiation for last 30 days of DYAMOND2 period. From SCREAM on left and bias relative to CERES-SYN (right)