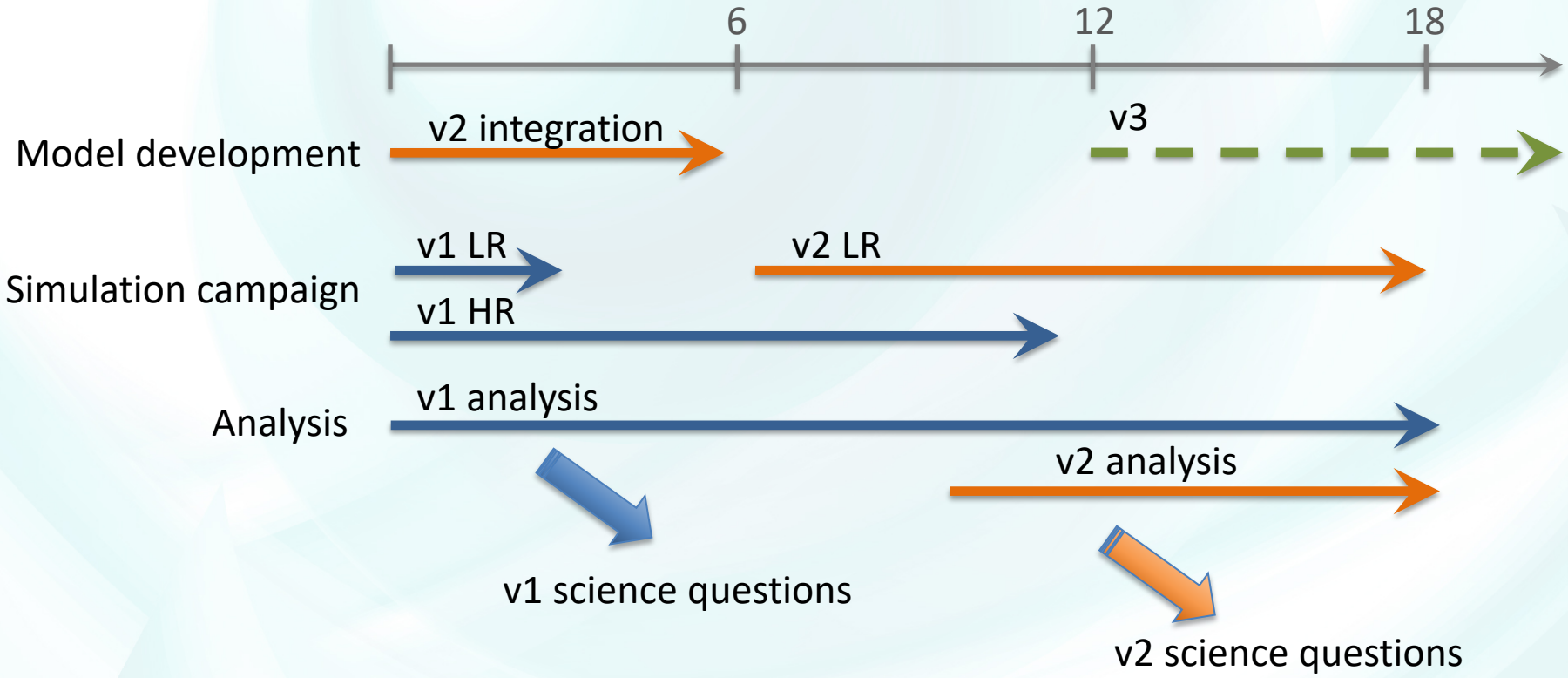
E3SM Water Cycle

Overview

Chris Golaz, Luke Van Roekel
and the entire Water Cycle group

Work at LLNL was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-PRES-797188

E3SM Water Cycle: next ~18 months



v1 Simulation Campaign

Table 1. *Water cycle simulations for v1.*

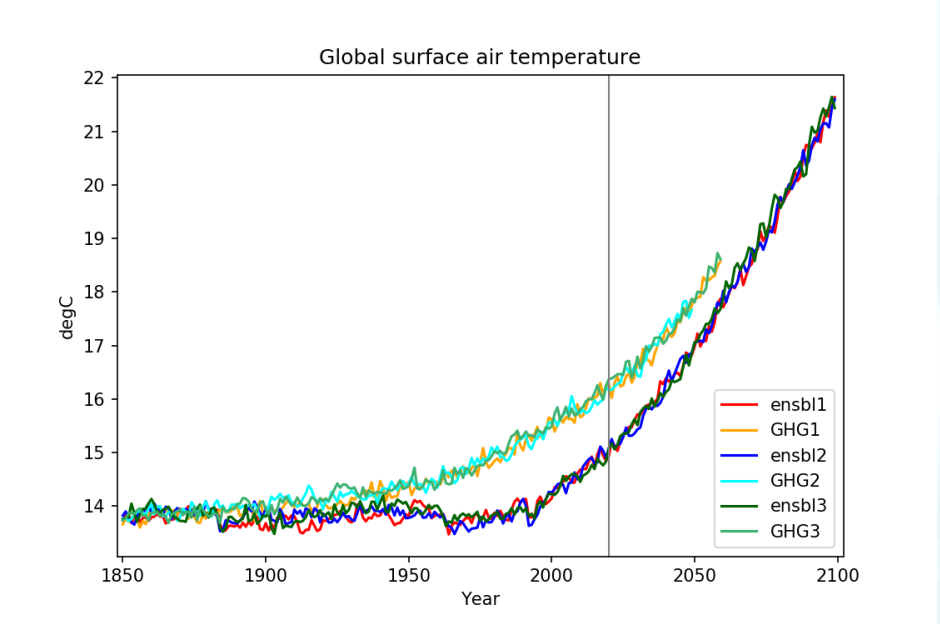
Simulation	Duration	Resolution	Notes
Pre-industrial (1850) control	500 years	LR	DECK
Historical transient (1850-2014)	165 years per ensemble member	LR	DECK - minimum of 3, ideally 5 ensemble members.
Abrupt 4xCO2	150 years	LR	DECK
1%/yr CO2 increase	150 years	LR	DECK
AMIP (1970-2014)	45 years	LR	DECK - possibility of starting earlier (1870) and performing multiple ensemble members
1950 control	50 years	LR, HR	HighResMIP like
1950-2050 (all forcings)	100 years	LR, HR	HighResMIP like - 3 ensemble members
1950-2050 (GHG-only)	100 years	LR, HR	HighResMIP like - 3 ensemble members
AMIP (2000-2010)	10 years	⅛ degree, global	Atmosphere-only global high-resolution simulation
AMIP (2000-2010)	10 years	⅛ degree, RRM	Atmosphere-only high-resolution simulation over North America using RRM

Source: E3SM Phase 2, 2018

v1 LR Simulation Campaign

- ✓ Extend the 5 historical runs from 2015 to 2100 (complete)
- ➢ Extend the 3 historical GHG-only runs from 2015 to 2100 (80% done)

- Running on NERSC Cori-KNL
- ~3 SYPD using 125 nodes (8,500 cores), charged 82,000 NERSC hours/SY
- Compare to 10 SYPD on Edison, 3x slower on Cori-KNL
- Took 3 months instead of 3 weeks (including delay from CA fires – PG&E power outage)



Qi Tang

v1 HR Simulation Campaign

- Currently extending **1950 control** simulation.
- **unc06** — slightly modified output
  - Running for 100 years (?)
  - Currently have 20+ years simulated.
  - 0.80 SYPD and run 9 months with a single 24-hour job (825 nodes)
- **unc03** — large amount of output
  - Running for 20 years (?)
  - Currently have 12+ years simulated.
  - 0.75 SYPD and can run 8 months with a single 24-hour job (825 nodes)
- **Good news**
  - Theta queue has been agreeable to our jobs.
  - The improvements with PIO2 were significant for the unc03 (high IO) run as we can now run with 825 nodes and use more job wallclock time.
  - I'm testing layouts with 1600 nodes and see timing that are 33% faster. Perhaps after unc03 reaches 20 years, we can switch to that for unc06?

Noel Keen

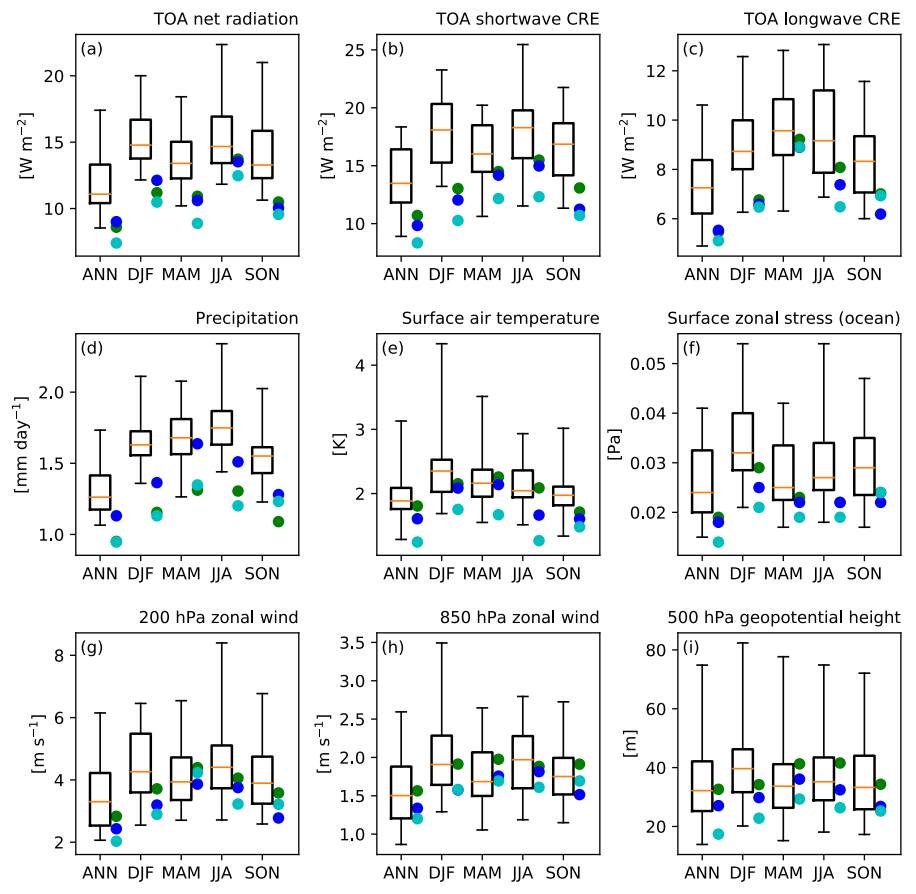
v1 Analysis Campaign

- Primary v1 science question -- How do improved process representations contribute to higher fidelity projections of the water cycle?
- v1 Analysis falls under a few main sub-questions
  - Does the model behave as we expect?
  - Do we understand E3SM responses?
  - What are the key physical processes for the water cycle / water availability?
  - How are extremes modified by resolution of additional physical processes?
- Analyses are currently focused on the first two questions.
- We would be glad to have more people sign up for analysis!

Current Papers

- Golaz et al. 2019 – Standard resolution overview – published.
- Caldwell et al. 2019 – High resolution overview – accepted!
- Monsoon analysis in NGMS framework – Harrop et al 2019 – accepted!
- An overview of the U.S. Water Cycle in E3SM – Harrop and Maltrud
- Tropical Cyclones in E3SM – Balaguru et al.
- Analysis of stratospheric ozone, temperature, etc… – Cameron-Smith
- Sea ice satellite emulator and intercomparison – Roberts
- Evaluation of SAM, NAO, AO (two papers) – Lee
- Examination of aerosol impact in E3SM – Zhang
- Influence of GM in the subpolar gyre and Labrador sea – Conlon
- Mechanisms of the surface freshwater bias in E3SM – Veneziani

E3SMv1 HR is a very good model



- HR bias is generally better than LR and CMIP5
  - Due to some combo of higher resolution, tuning, and short spin up…
- More on this tomorrow

Research question: what is impact of short spin up on model bias in high-res simulations

Fig: Uncentered spatial RMSE for HR and LRtunedHR 1950 ctrl, LRv1 CMIP6 historical, and 45 CMIP5 historical runs as box (=25-75%) and whiskers (=envelope of data). [Caldwell et al. 2019]

Simulation of Tropical Cyclones in E3SMv1

Karthik Balaguru, et al

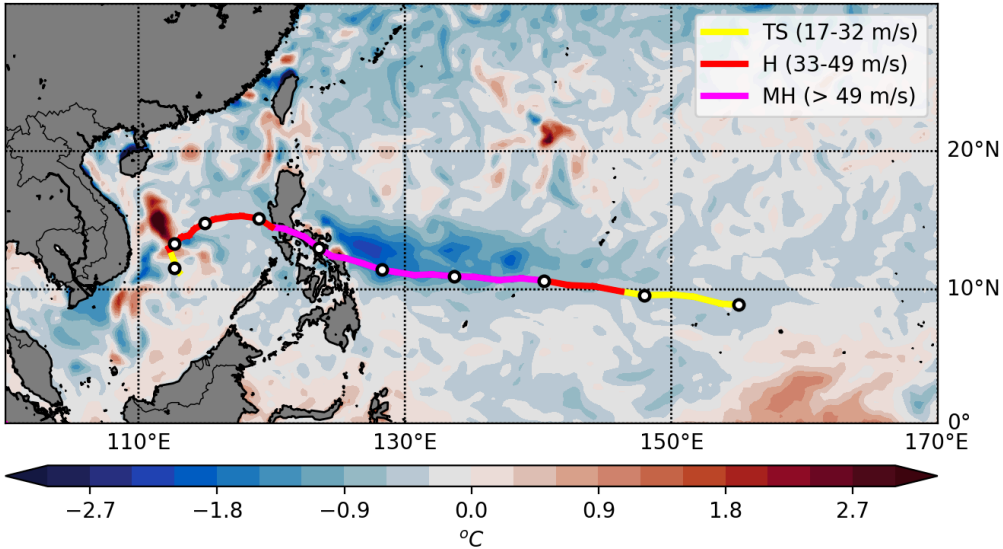


Figure: The track and SST cooling of the strongest TC in the high-resolution E3SM. The TC is near Category 5. The strongest cooling occurs to the right of the track with a maximum of about 3°C.

See Karthik's poster for more details

Simulation of Tropical Cyclones (TCs) in the high-resolution coupled E3SM is much improved compared to the low-resolution version.

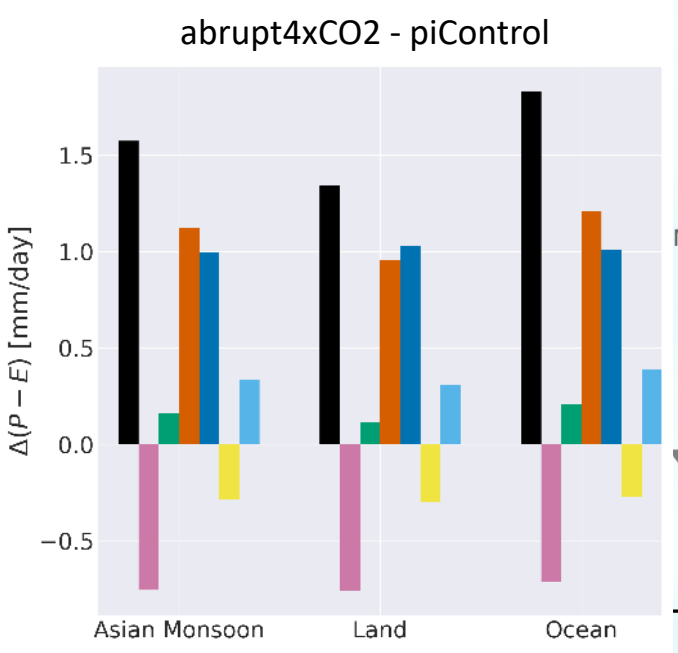
Notable improvements are found in the global TC frequency, TC lifetime maximum intensities and the relative distribution of TCs among the different basins.

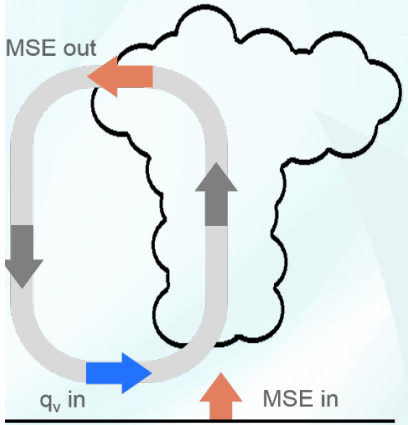
TC-Ocean interaction in the high-resolution E3SM is very realistic. The model is able to well simulate the impact of TCs on the ocean, and the ocean's feedback onto the storms.

A New Perspective on the Asian Summer Monsoon

Bryce Harrop et al.

- Used the link between the flow of energy and moisture in the atmosphere (a relationship termed the **normalized gross moist stability** [NGMS]) to fingerprint the physical processes responsible for the increased rainfall with warming predicted by the model
- The new diagnostic approach confirmed established responses and uncovered the role of NGMS on monsoon rainfall sensitivity to warming
- Atmospheric moisture loading is a key component to changes in NGMS with warming



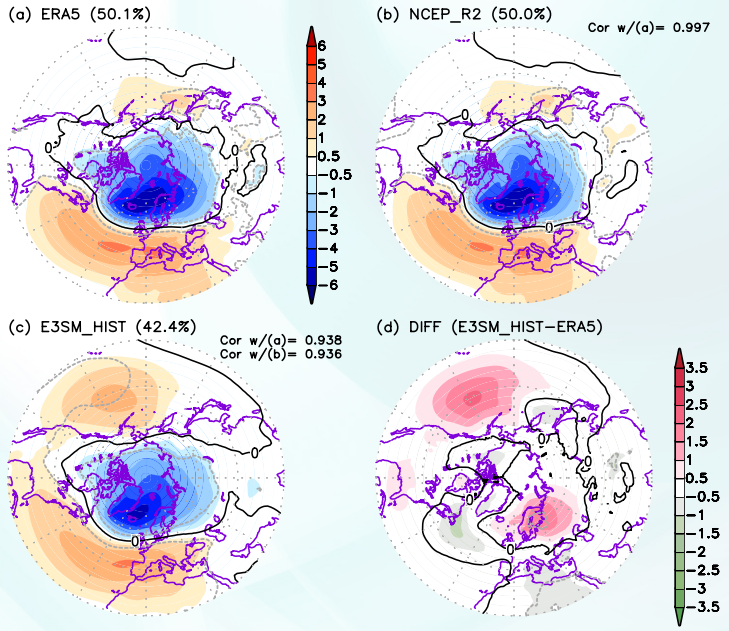


P-E
Clear sky radiation
Cloud Radiative Heating
Nonlinear Interactions
Surface fluxes
NGMS
Storage

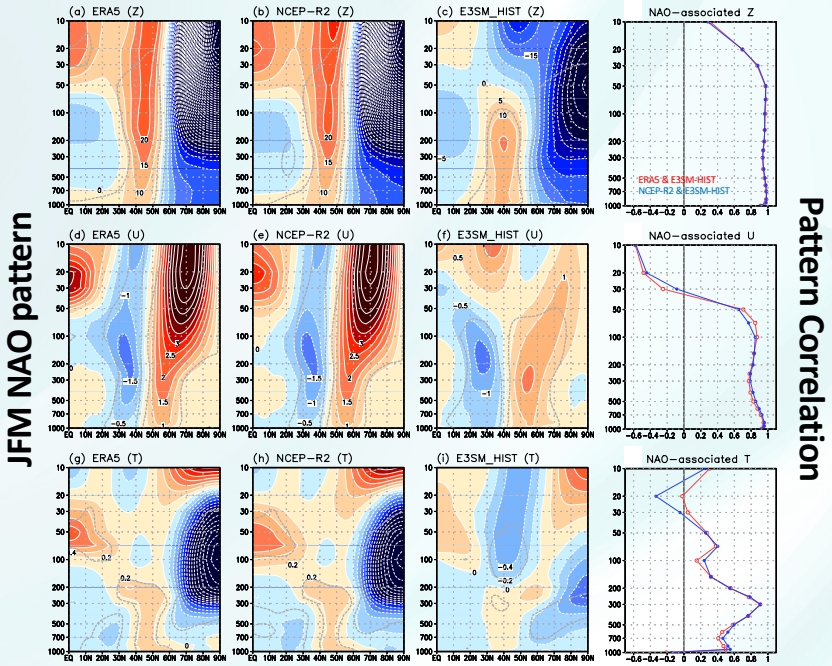
See Bryce's poster for more information

NAO analysis in E3SMv1 – Doo Young Lee et al.

➢ JFM SLPAs regressed on JFM NAO index



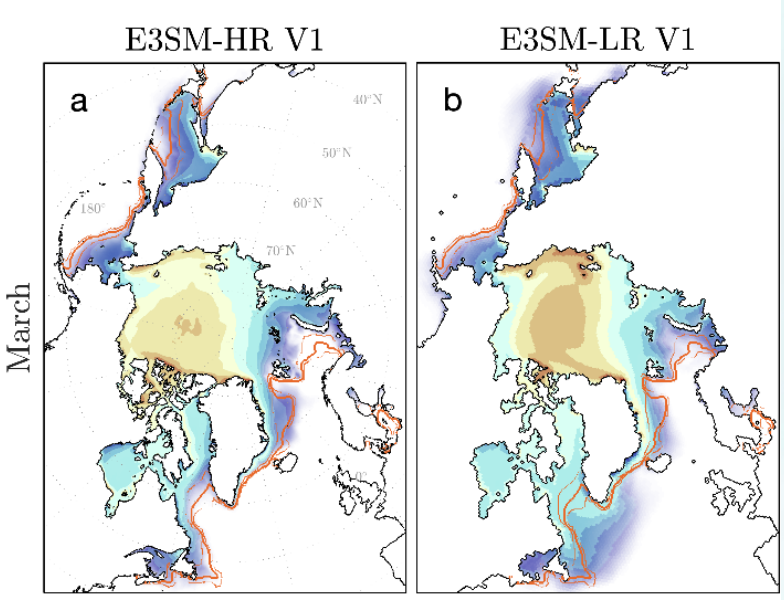
➢ JFM NAO-associated zonal-mean vertical structure



E3SMv1

- Simulates an excessively strong (weak) Pacific and northern Europe (Atlantic and southern Europe) NAO response
- Has difficulties in simulating NAO associated variability in the stratosphere

Labrador Sea Ice Bias: What's causing it, and how do we fix it?
L. Conlon, et al.



We've been examining effects of:

- Resolution
- Gent McWilliams mesoscale eddy parameterization

On:

- Mixed layer depth
- Meridional Heat Transport
- Subpolar gyre
- Stratification
- Transport into the Labrador Sea

as a way to understand (and potentially fix) Labrador Sea biases

More details tomorrow.

Surface salinity fresh bias in low-res E3SMv1 possible ocean remedies

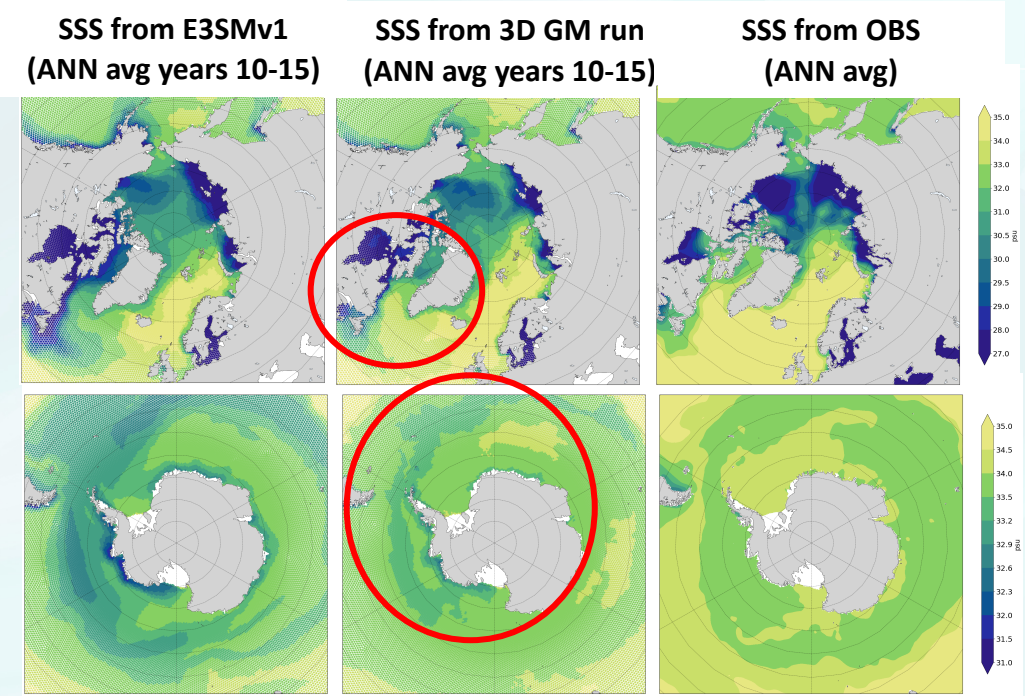
Milena Veneziani et al.

Considered many possibilities:

- Vertical resolution (60 vs. 80 layer)
    - HR coupled uses 80 layer, with much smaller bias
- Ice initial condition too large
- KPP shortcomings
    - Can tune bias away, but values are likely not appropriate.
- Implement 3D varying GM bolus kappa.

Other possibilities

- Redi mixing
- Ocean freezing temperature function of T&S

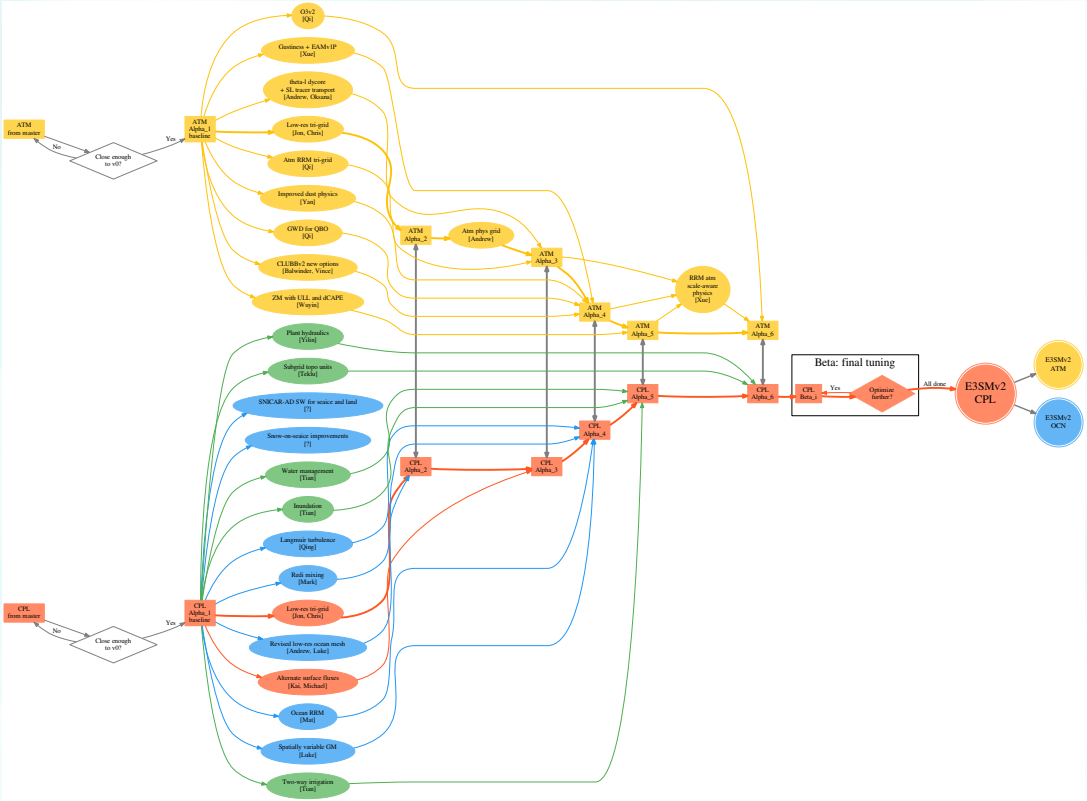


Analysis Metrics

- High priority for the near term
- <u>Water availability</u>
  - Defined as difference between precipitation and evapotranspiration over land.
  - Direct relevance to water resources management and energy production and use.
  - Possible Analyses
    - Spatial distribution of changes in water budget
    - PDF of basin mean precipitation, evapotranspiration and runoff at daily/monthly timescales.
    - Seasonal to decadal variability
- <u>Sea Surface Temperature</u>
  - Biases in SST variability influence model skill of extremes forecasts and cloud distributions.
  - Possible analyses
    - Spatial patterns of SST associated with different climate modes
    - Seasonal to decadal variability

v2 Integration

From here…



… to there.

New features targeted for integration in v2

Grids

- Tri-grid configuration (atmosphere; ocean + sea-ice; land + river) [J. Wolfe]
- North America RRM [M. Maltrud, Q. Tang, E. Roesler, J. Wolfe and many others]

Atmosphere

- theta-l dynamical core with semi-Lagrangian tracer transport [O. Guba, A. Bradley]
- Physics grid [A. Bradley]
- O3v2 [Q. Tang + UC Irvine]
- Improved physics retuning, including gustiness [work from P.-L. Ma; X. Zheng]
- Improved dust physics [Y. Feng]
- Retuning of GWD for improved QBO [from NGD Atmosphere; Y. Richer. J. Chen]
- ZM with modified trigger and closure (ULL, dCAPE) [NGD Atmosphere; S. Xie, W. Lin]
- New options in CLUBBv2 [K. Zhang, B. Singh, V. Larson]
- Revised surface flux formulation [K. Zhang, M. Brunke, J. Eyre]

New features targeted for integration in v2 (cont'd)

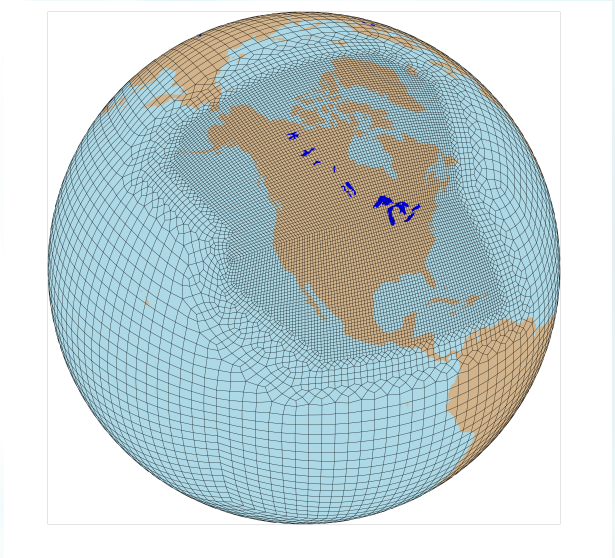
Ocean and sea-ice

- Spatially variable Gent McWilliams bolus diffusivity [L. Van Roekel]
- Reformulation of Redi isopycnal mixing [M. Petersen]
- Langmuir Turbulence induced vertical mixing [Q. Li]
- Theoretical wave drift model [Q. Li]
- Improvements to snow on sea ice [N. Jeffery]

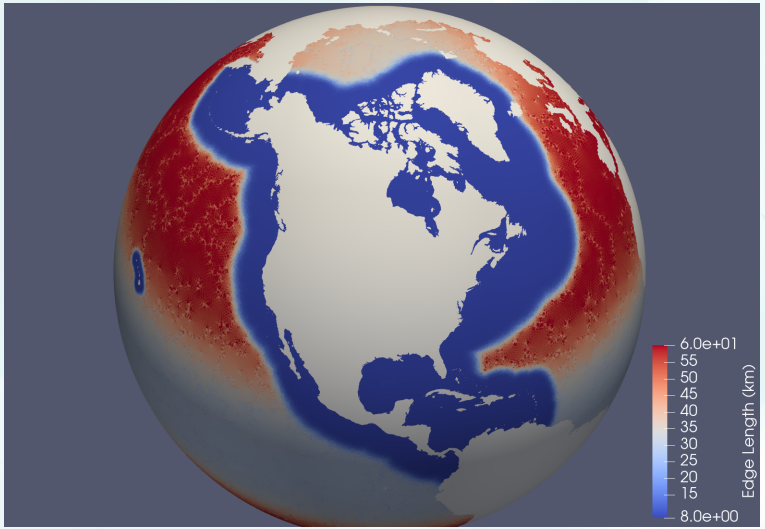
Land and river

- Plant hydraulics [Y. Fang]
- Subgrid topographic units [T. Tesfa]
- Two-way irrigation; water management [T. Zhou]
- Inundation [T. Zhou]

New Atmosphere and Ocean Seaice RRM grids



- Resolution ~25 km in refined region, ~110 km outside.
- 14,454 elements compared to
- 5,400 in low-res (2.7x)
- 86,400 in high-res (1/6 x)



- Resolution increased to 8 km in refined region. EC60to30 outside.
- 763,923 cells, 60 vertical layers, compared to
  - 235,160 cells, 60 layers LR (5x)
  - 3,693,225 cells, 80 layers in high res (1/5x)
- Will try a 12 km high resolution region to reduce cost.

Stuff you didn’t know you needed to know…

(because model development is not predictable)

Super-linear land IO slow-down at 1/8 deg

Jon Wolfe was testing tri-grid with land and river model on 1/8 deg grid. Writing of ELM restart files suddenly took forever…

Update ELM routines to speed up restart write #3163

New issue

Merged jqyin merged 6 commits into `master` from `jonbob/clm/restart-write-fix` on Sep 13

Conversation 23 | Commits 6 | Checks 0 | Files changed 2 | +77 −29

jonbob commented on Aug 28 • edited — Contributor

This PR adds a couple of new routines to help speed up the restart write process. It brings in:

- a function GetGlobalIndexArray that adds capability to get global indices on an array instead of a single point;
- a new routine for only defining the subGrid restart, subgridRest_define_only, which is identical to subgridRest_write_only but does not gather data.
  Previously the restart write process called the same subroutine twice, once to define the variables and once to output them, but was unnecessarily gathering all the data for both steps. This PR also replaces calls to GetGlobalIndex on single points inside loops with calls to GetGlobalIndexArray.

The time for high-res (r0125) restart file output dropped from ~2000s to ~55s using these changes.

[BFB]

36x speedup!!!

jonbob added 2 commits on Aug 28

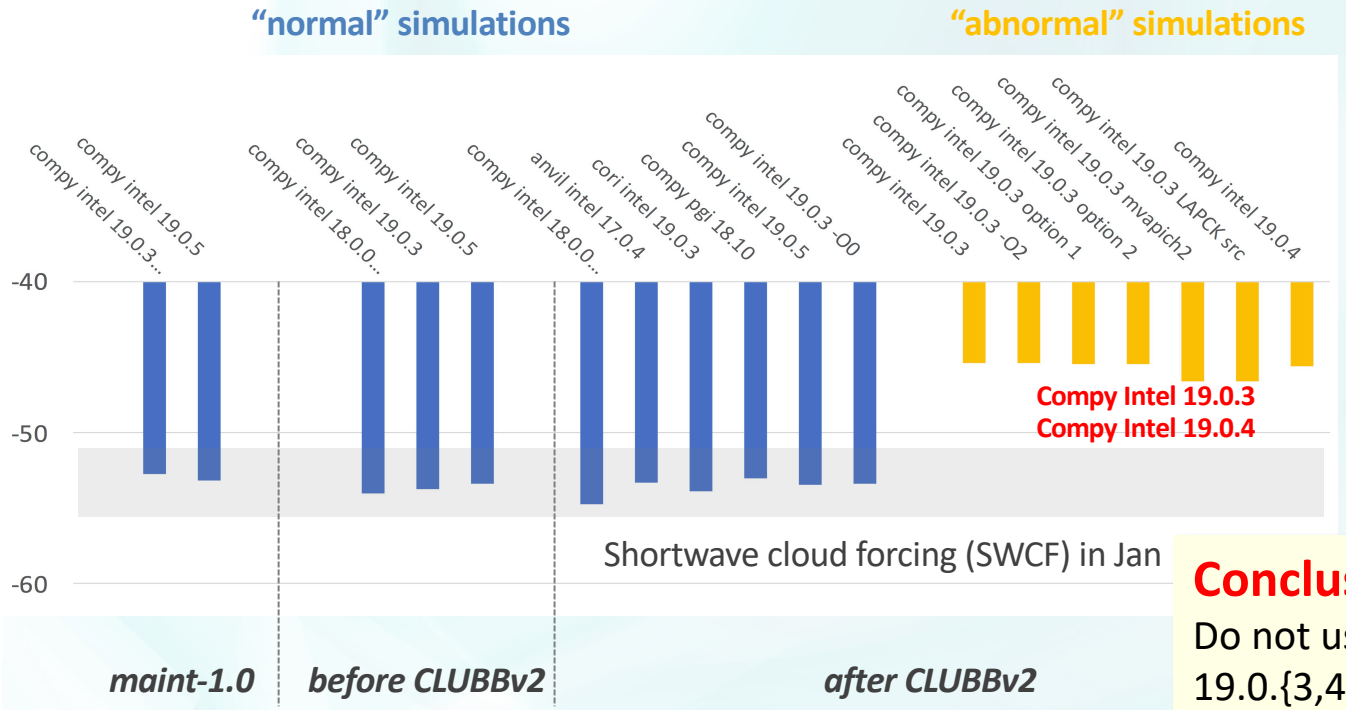
Reviewers
- rljacob ✓
- amametjanov ✓
- bishtgautam ✓

Assignees
- jqyin

Labels
- BFB
- Land

Projects
None yet

CLUBBv2 and Intel compiler



- After CLUBBv2 was merged to master, the model behaves differently on Compy using the (previously-) default compiler.
- Other machines didn't exhibit this problem.
- After significant efforts, we updated the default compiler (19.0.5), the model is back to normal!!!

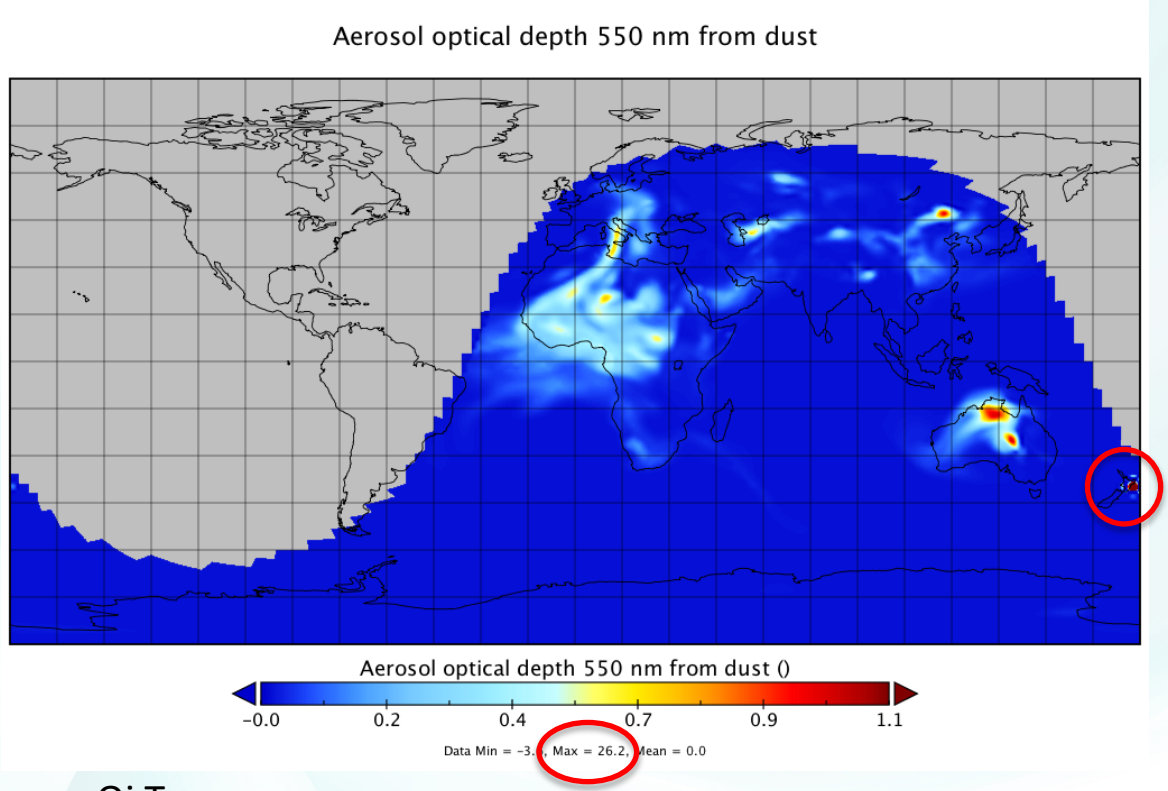
Conclusion

Do not use CLUBBv2 with Intel 19.0.{3,4} compiler on Intel Skylake

And yes, you needed to know that!!!

Source: Kai Zhang

New Zealand dust hot spot with North American RRM



Source: Qi Tang

To be resolved…

Dave's favorite topic:

- mapping files
- domain files.

Or maybe a bug the the aerosol physics?

More on E3SM Water Cycle

- This afternoon (1:45 – 3:30): **breakout**
  - Resolution Sensitivity of the simulation of teleconnections to extremes (Salil Mahajan)
  - Scale-awareness of ZM Convection Scheme (Guang Zhang)
  - Snow-on-SeaIce (Nicole Jeffery)
  - More v2 updates and discussion
- Tomorrow (11:00 – 11:30): **plenary talks**
  - Overview of the E3SMv1 High-Resolution 1950 Control Run (Peter Caldwell)
  - The influence of the Gent McWilliams bolus velocity on North Atlantic circulation, stratification, and sea ice (LeAnn Conlon)
- Tomorrow **evening breakout** (7:30 – 8:30pm): Water Availability Metric and U.S. Water Cycle evaluation paper
- **Poster sessions** today and tomorrow (5:00 - 6:00pm)

Questions?