A Novel Modeling Framework to Improve Stratocumulus by Increased Horizontal and Vertical Resolution

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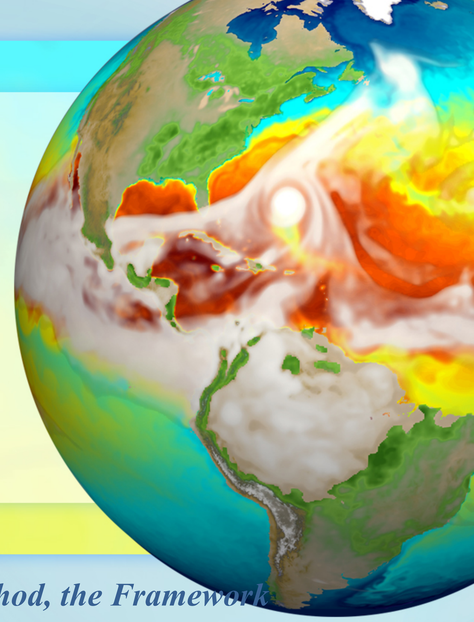
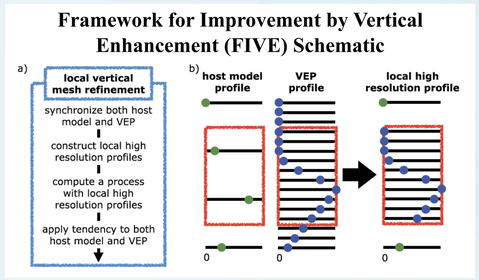


The work arms to investigate the sensitivity of marine stratocumulus to different horizontal and vertical resolutions by using a new computational method, the Framework for Improvement by Vertical Enhancement (FIVE) implemented into the Energy Exascale Earth System Model (E3SM).

1. Introduction

E3SM, like many GCMs, produces too little subtropical marine stratocumulus (Sc), primarily due to coarse vertical resolution which cannot resolve sharp gradients in temperature and moisture that cap these clouds. Lee et al. (2020) demonstrates that increasing vertical resolution in E3SM using the novel modeling framework FIVE significantly improves the representation of marine Sc. However, coastal biases remain. **In this study, we further investigate the sensitivity of offshore and coastal Sc in E3SM through concurrent increases of vertical and horizontal resolutions.**

2. Methodology



- **Experiment design:** (All simulations run for one year)
  - Control run with the original host model vertical resolution (**CNTL**; 72 layers)
  - 7 levels inserted for each E3SM level between 995 mb to 700 mb (**FIVE_OCT**; 212 layers)
  - CNTL and FIVE_OCT vertical layers run with **ne30** (1-degree) and **ne120** (0.25-degree) horizontal mesh

To mitigate computational cost, we **increase E3SM vertical resolution in the lower troposphere via FIVE** for select processes/parameterizations instead of the entire model (Yamaguchi et al., 2017; Lee et al. 2020).

- **FIVE implementation covers**:
  1) The physics schemes:
     - CLUBB (turbulence, shallow conv., macrophysics)
     - MG2 microphysics
     - RRTMG Radiation
  2) Large-scale vertical advection in dynamical core

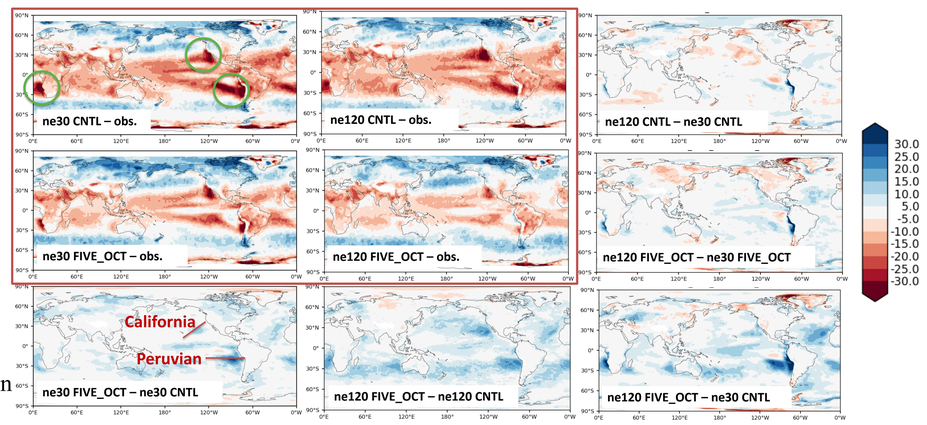
- **Computational costs:**

	ne30 (1-degree)	ne120 (0.25-degree)
CNTL	4.30 SYPD/1024 cores	0.20 SYPD/2048 cores
FIVE_OCT	1.21 SYPD/1024 cores	0.06 SYPD/2048 cores

3. Preliminary Results

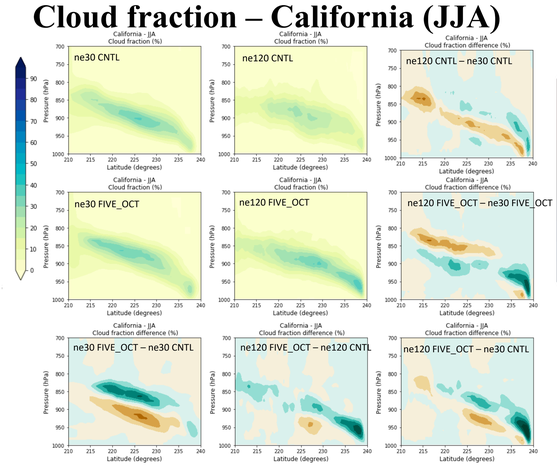
Low level cloud amount comparison (annual mean)

The figures in the red box show the differences of low-level cloud amount between simulations (generated by Cloud Feedback Model Intercomparing Project (CFMIP) Observation Simulator Package (COSP)) and observation (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) lidar data from January 2007 to January 2010).

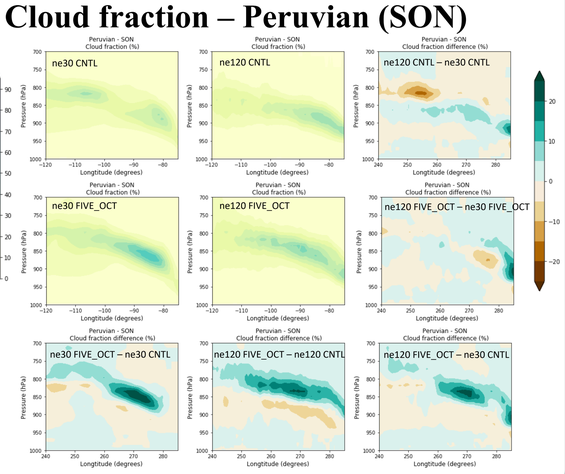


The rest of figures outside the red box are model to model comparison. The red lines indicate the location of cross sections below.

Cloud fraction – California (JJA)



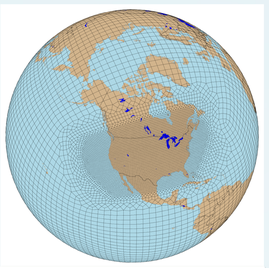
Cloud fraction – Peruvian (SON)



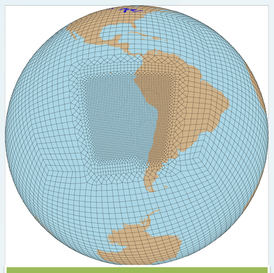
4. Ongoing work - applying FIVE to RRM

A regional refined model (RRM) is designed to simulate a fraction of the globe at high resolution. We are in the process of **developing a new Peruvian RRM** (right panel) domain to determine if Sc improvements can be replicated with such a framework, with FIVE applied. Comparison of size of the new Peruvian RRM grid is shown relative to the pre-existing CONUS RRM.

Computational cost	CONUS
CNTL (72L)	1.74 SYPD/2048 cores
FIVE_OCT (212L)	0.71 SYPD/2048 cores



CONUS domain – 9905 refined elements



New Peruvian domain – 8351 refined elements

5. Summary

- Using FIVE in E3SM we are able to improve the representation of marine Sc with reduced computational cost compared to running the entire E3SM model at high vertical resolution.
- However, we demonstrate that **concurrent increases in vertical and horizontal resolution are key** towards achieving the most significant reduction in Sc biases.
- Offshore Sc is more sensitive to vertical resolution while coastal Sc has better response to higher horizontal resolution due to better resolving terrain induced land-sea flow.
- We are currently working to develop a new Peruvian RRM grid to determine if improvements in Sc can be replicated in the context of a RRM with FIVE.

E3SM Energy Exascale Earth System Model

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Reference:
Yamaguchi, T., G. Feingold, and V.E. Larson (2017), Framework for improvement by vertical enhancement: A simple approach to improve representation of low and high-level clouds in large-scale models, *J. Adv. Model. Earth Syst.*, 9. 627-646, doi: 10.1002/2016MS000815.
Lee, H.-H., P. Bogenschutz, and T. Yamaguchi (submitted), The Implementation of Framework for Improvement by Vertical Enhancement (FIVE) into Energy Exascale Earth System Model (E3SM). *J. Adv. Model. Earth Syst*.

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