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Liquid cloud testbed simulations using a novel large eddy simulation capability

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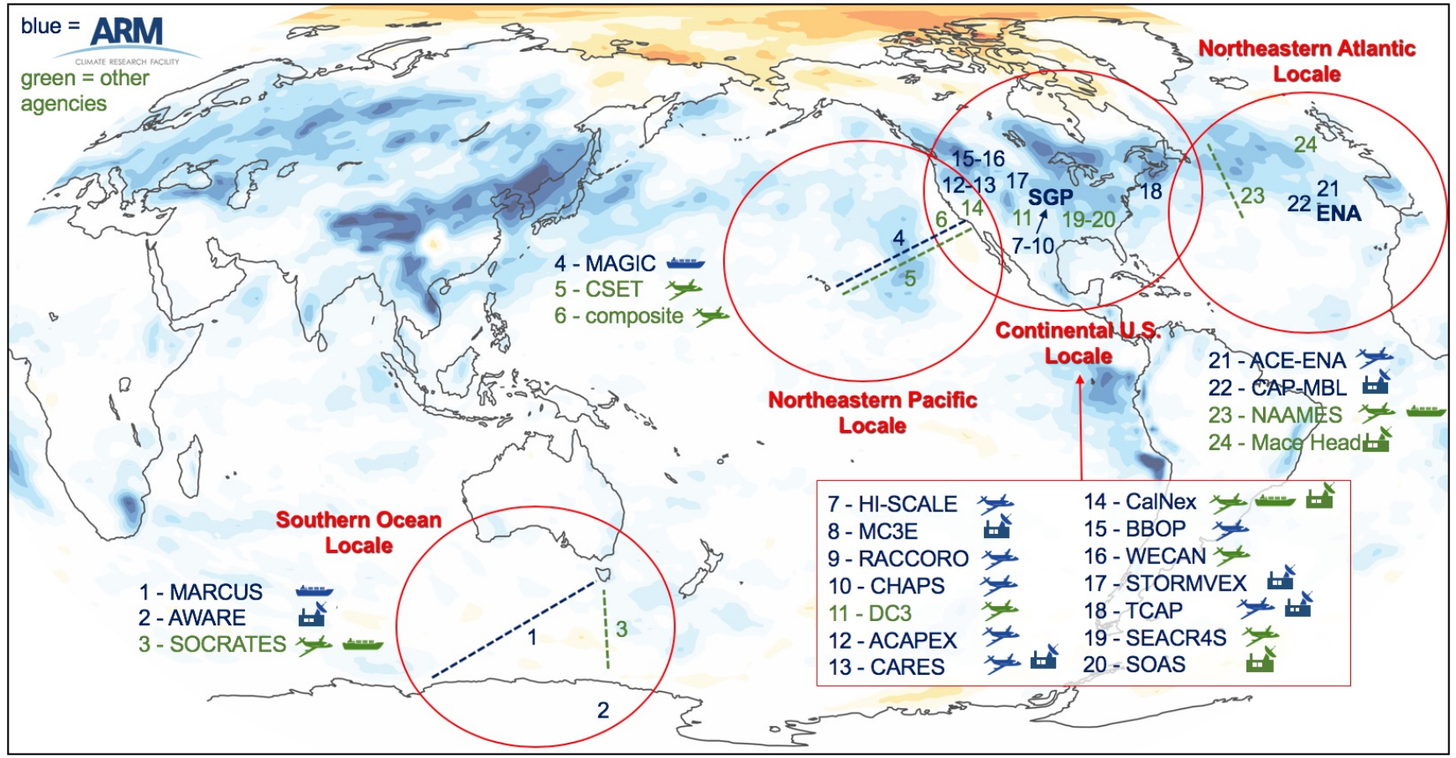
EAGLES liquid cloud testbeds

What?

- A suite of observations and simulations compiled for four focus regions that cover a wide range of liquid cloud and aerosol conditions

Why?

- To facilitate development, testing, and evaluation of new aerosol and microphysics parameterizations developed under EAGLES



This map identifies the four liquid cloud testbed focus regions: Continental U.S., Northeastern Atlantic, Northeastern Pacific, and Southern Ocean, as well as measurement sources associated with each.

Testbed LES case studies

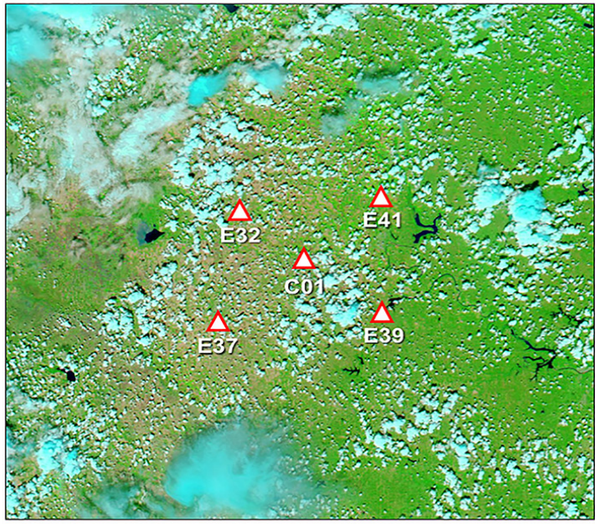
We define detailed case studies which can leverage field campaign measurements, especially aircraft in situ data, to drive and evaluate large eddy simulations (LES)

Holistic Interactions of Shallow Clouds, Aerosols and Land Ecosystems (HI-SCALE; Fast et al., 2019a)

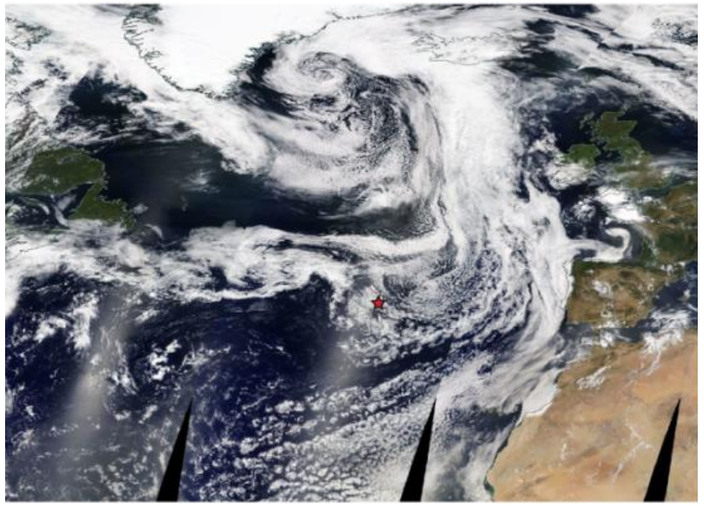
- 30 Aug. 2016: Shallow convective clouds over the U.S. Southern Great Plains
- Also used as a LASSO scenario (Gustafson et al., 2020)

Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA)

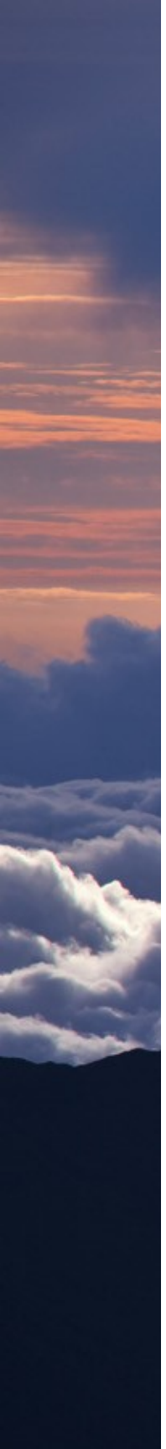
- 18 July 2017: Summertime, drizzling single-layer stratocumulus cloud topping a well-mixed boundary layer
- 19 Jan. 2018: Wintertime, drizzling single-layer stratocumulus cloud topping a decoupled boundary layer
- 25 Jan. 2018: Wintertime, drizzling single-layer stratocumulus cloud deck topping a well-mixed boundary layer



MODIS AQUA image over SGP at ~1350 CST on 30 Aug 2016 showing the observed cloud distribution. Reproduced from Fast et al. (2019b)



MODIS real color image of the ENA region on 18 July 2017. The red star marks the ARM ENA site. Reproduced from Zhang et al. (2020)



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PINACLES: a novel LES capability

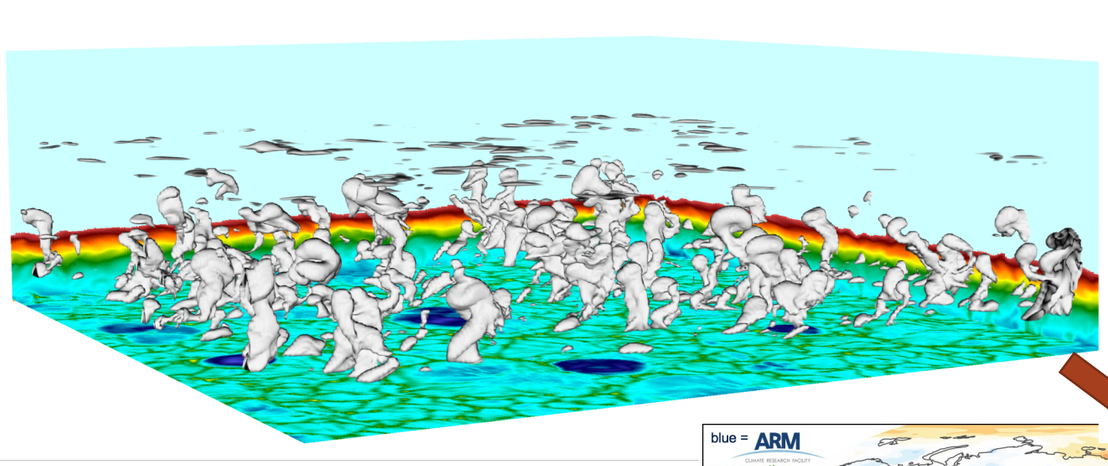
Our ultimate goal is to produce high-resolution, relatively large domain LES of testbed cases using sophisticated spectral bin microphysics (SBM) to **capture a range of scales of interactions between turbulence, aerosol, and clouds**

- Such simulations are computationally intensive. We estimate >1 million core-hours per run with WRF-LES.

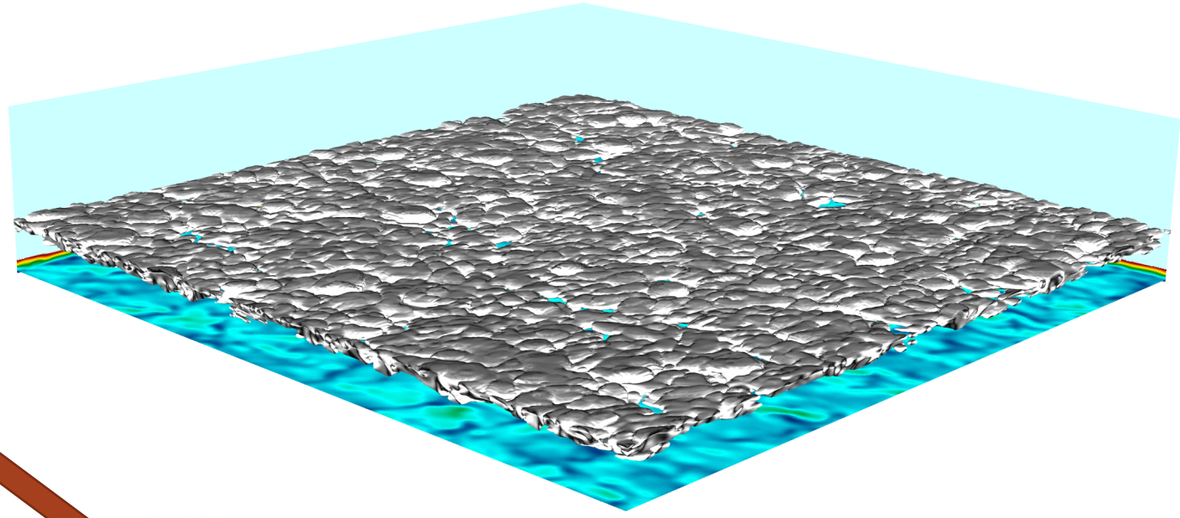
A novel LES capability **Predicting INteractions of Aerosol and Clouds in Large Eddy Simulations (PINACLES)** is being developed to enable this (and other modeling goals) of the EAGLES project

- The governing equation set and software design of PINACLES enable roughly an order-of-magnitude higher throughput than obtained using WRF-LES.
- PINACLES can efficiently adopt microphysics (and other physics) packages from WRF.
- PINACLES can be driven with large-scale forcing data similarly to WRF-FASTER (Endo et al., 2015) and is coupled to RRTMG for radiative flux calculations.

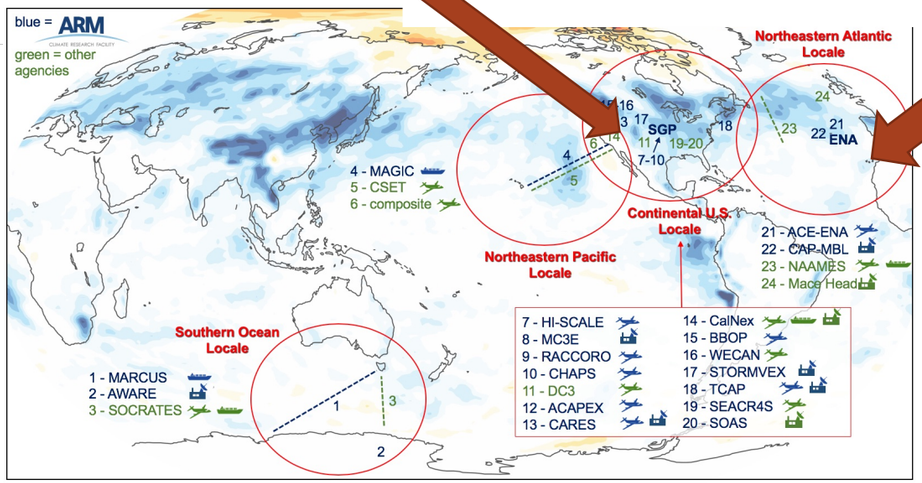
Testbed simulations using PINACLES



HI-SCALE 30 Aug. 2016



ACE-ENA 18 July 2017



Testbed case simulations using PINACLES are ongoing. To assess our model configurations (resolution, domain size, large-scale forcing specifications) efficiently prior to coupling with spectral bin microphysics, we are performing an initial set of simulations using the simpler Kessler and P3 microphysics schemes.

Observational validation of PINACLES

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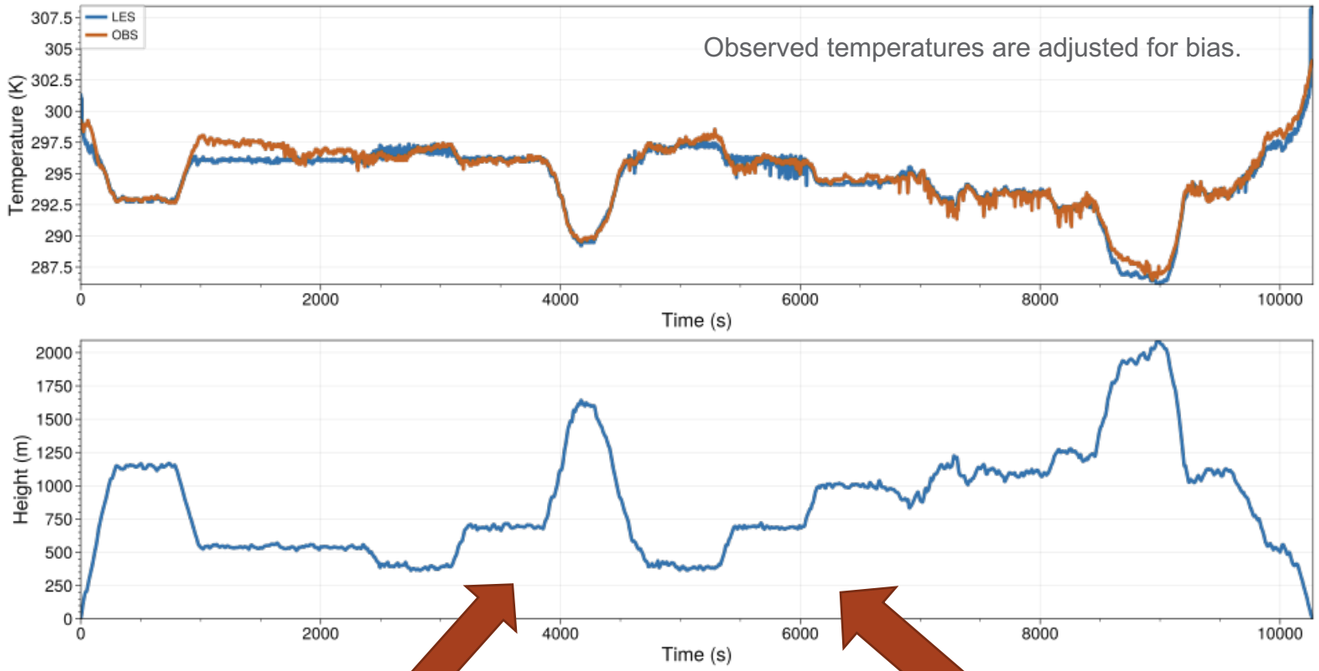
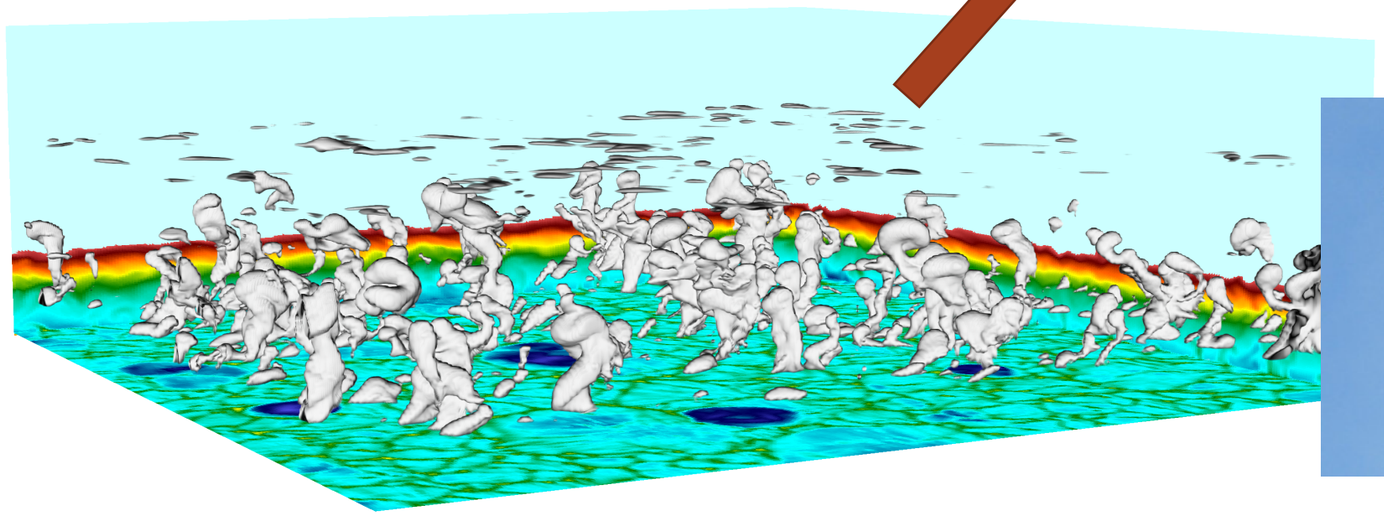
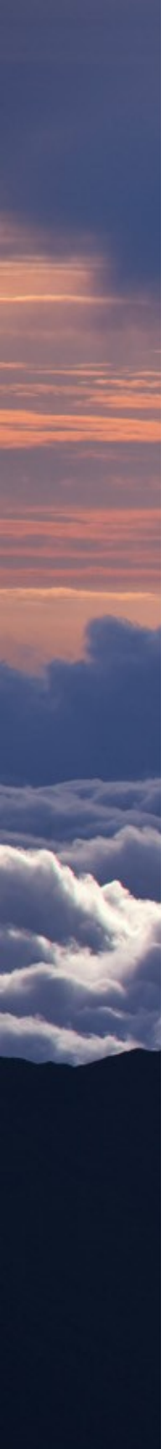
The flexible software design of PINACLES enables us to tailor outputs to best align with available observations for validation.

- Example: at-runtime aircraft simulator

Validation of testbed cases simulated with PINACLES is a crucial step in establishing confidence in parameterizations developed by applying machine learning to LES training data.







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Next Steps

- Continue observationally based validation of our existing testbeds cases from HI-SCALE and ACE-ENA
- Simulate these cases using spectral bin microphysics and realistic aerosol distributions.
- Expand the methodology to the Northeastern Pacific and Southern Ocean testbeds sites
- Share validated testbeds LES data across the EAGLES team to drive parameterization development via machine learning and other techniques

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References

- Endo, S., Fridlind, A. M., Lin, W., Vogelmann, A. M., Toto, T., Ackerman, A. S., McFarquhar, G. M., Jackson, R. C., Jonsson, H. H., and Liu, Y. (2015), RACORO continental boundary layer cloud investigations: 2. Large-eddy simulations of cumulus clouds and evaluation with in situ and ground-based observations. *J. Geophys. Res. Atmos.*, 120, 5993– 6014, https://doi.org/10.1002/2014JD022525.
- Fast, J. D., and Coauthors (2019a), Overview of the HI-SCALE Field Campaign: A New Perspective on Shallow Convective Clouds. *Bull. Amer. Meteor. Soc.*, **100**, 821–840, https://doi.org/10.1175/BAMS-D-18-0030.1.
- Fast, J. D., Berg, L. K., Feng, Z., Mei, F., Newsom, R., Sakaguchi, K., and Xiao, H. (2019b), The Impact of Variable Land-Atmosphere Coupling on Convective Cloud Populations Observed During the 2016 HI-SCALE Field Campaign, *J. Adv. Model. Earth Syst.*, 11, 2629– 2654, https://doi.org/10.1029/2019MS001727.
- Gustafson, W. I., and Coauthors (2020): The Large-Eddy Simulation (LES) Atmospheric Radiation Measurement (ARM) Symbiotic Simulation and Observation (LASSO) Activity for Continental Shallow Convection. *Bull. Amer. Meteor. Soc.*,**101**, E462–E479, https://doi.org/10.1175/BAMS-D-19-0065.1.
- Zhang, Z., Song, Q., Mechem, D., Larson, V., Wang, J., Liu, Y., Witte, M., Dong, X., and Wu, P.: Vertical Dependence of Horizontal Variation of Cloud Microphysics: Observations from the ACE-ENA field campaign and implications for warm rain simulation in climate models, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-788, in review, 2020.