Simulating Deep Convection Using Translating Large-Eddy Simulations for 20 May 2019 MC3E Case

William I. Gustafson Jr.[1], Raj K. Rai[1], Jiwen Fan[1], Zhe Feng[1], Scott E. Giangrande[2], Joseph C. Hardin[1], Die Wang[2]
[1]Pacific Northwest National Laboratory, [2]Brookhaven National Laboratory

Pacific Northwest NATIONAL LABORATORY

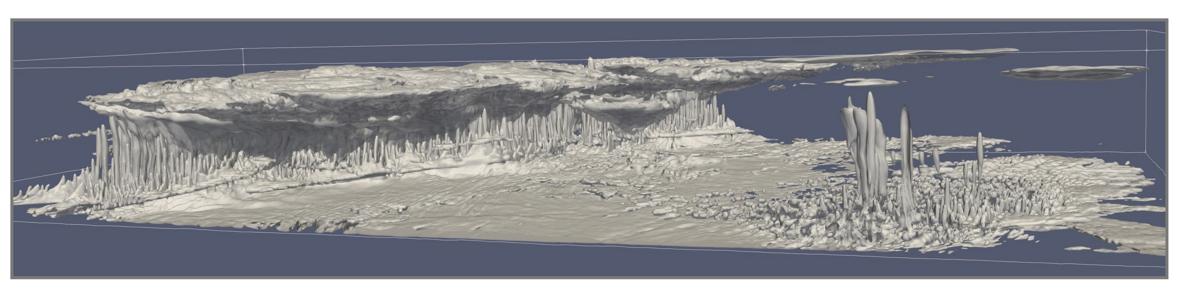
What is a translating LES?

Traditionally, large-eddy simulation (LES) uses doubly periodic lateral boundary conditions. One assumes a scale separation between the small, turbulent motions within the LES domain and the large-scale synoptic forcing that modifies the environment.

For large convective systems, such as a mesoscale convective system (MCS), one cannot assume this scale separation and domains need to be too large to contain the full lifecycle of an MCS.

Translating LES avoids these difficulties by using nested LES domains with time-dependent lateral boundary conditions combined with having the domain move with the convective event. This enables cost-permissive domain sizes that capture a sufficient portion of the storm lifecycle.

Translating LES differs from Lagrangian LES techniques where the boundaries are still doubly periodic.

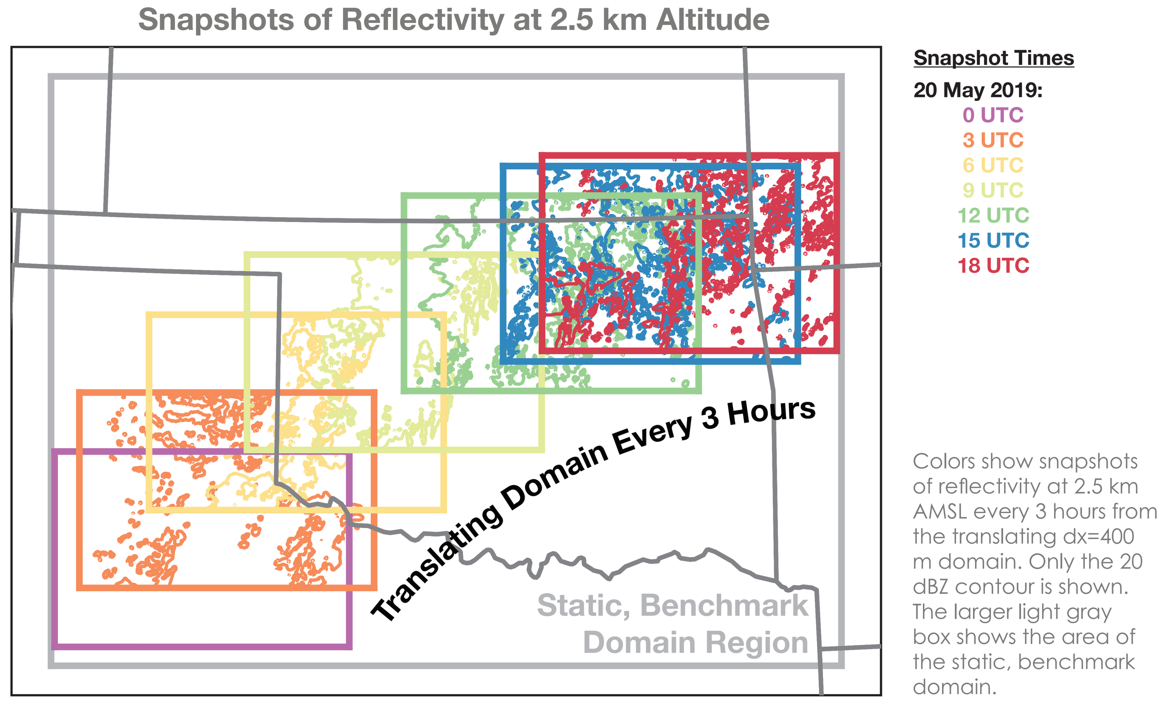


Cloud water and ice isosurface of the storm within the static, benchmark dx=400 km domain. The view is about 800 km across.

Track of the Translating Domain

Our proof-of-concept translating setup uses a dx=1.2 km mother domain to drive a translating domain with dx=400 m. This semi-LES resolution permits a comparison with a large static dx=400 m domain that serves as a benchmark for evaluating the behavior of the smaller translating domain.

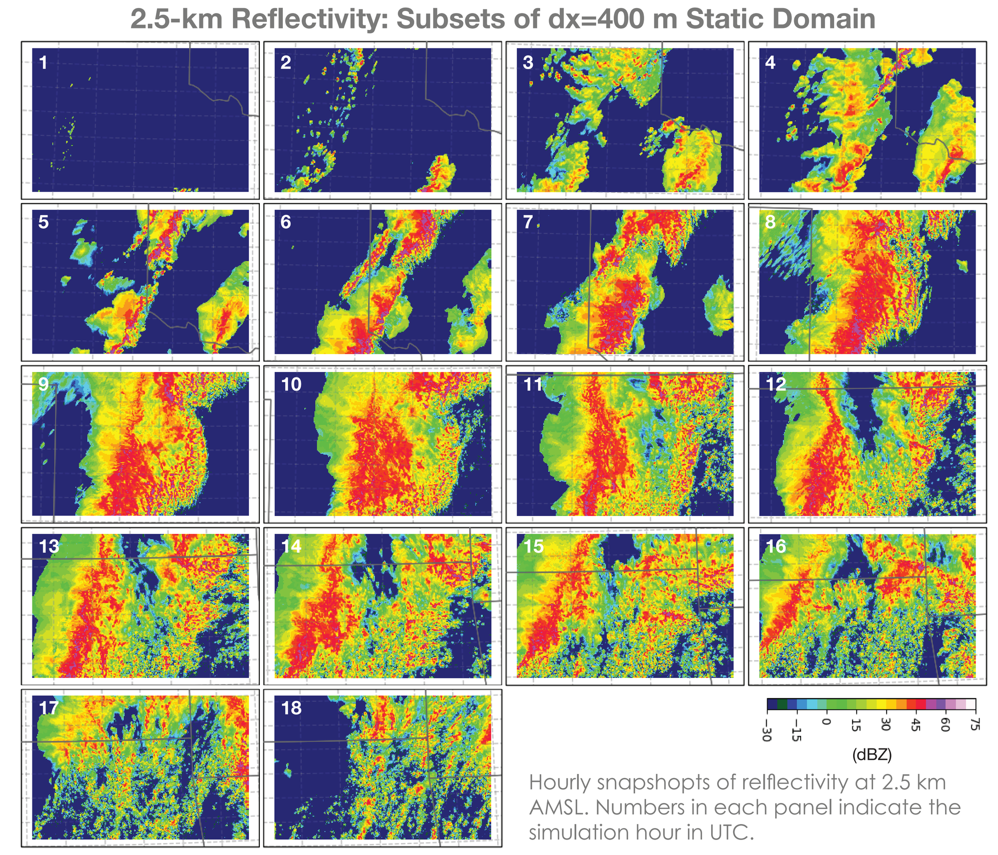
Snapshots of Reflectivity at 2.5 km Altitude



Colors show snapshots of reflectivity at 2.5 km AMSL every 3 hours from the translating dx=400 m domain. Only the 20 dBZ contour is shown. The larger light gray box shows the area of the static, benchmark domain.

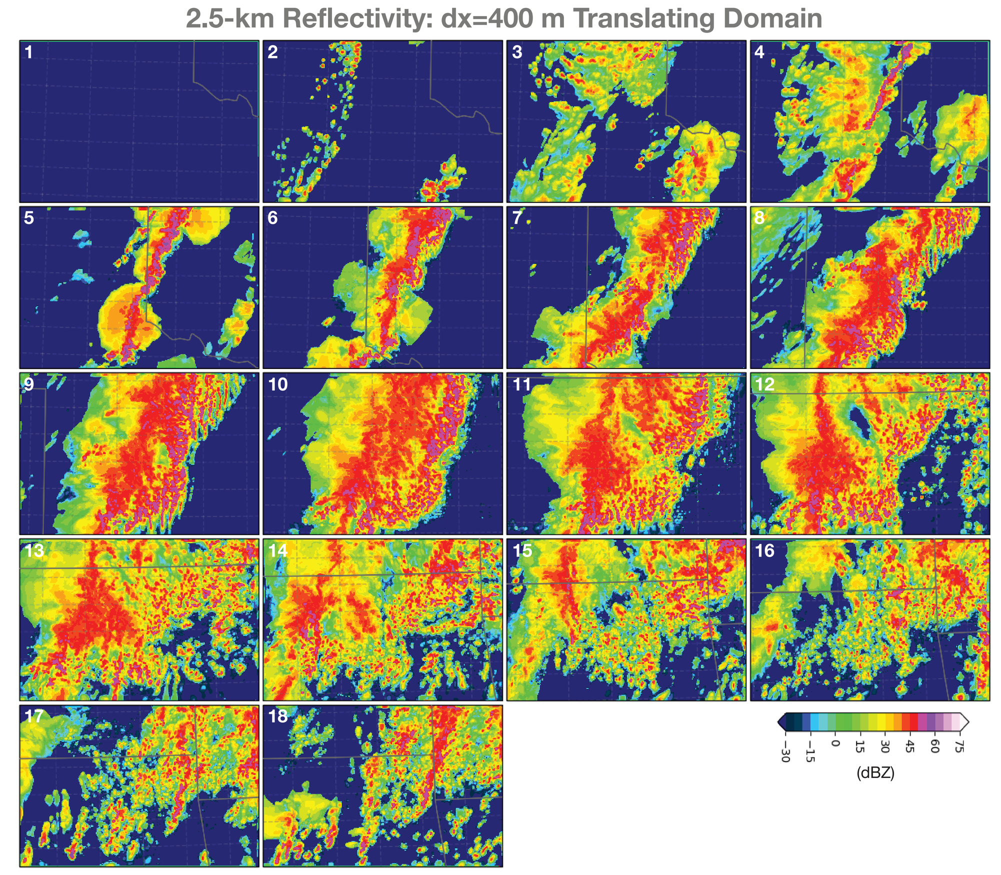
The translating domain is small enough that we could afford a dx=240 m simulation for more detailed process studies.

2.5-km Reflectivity: Subsets of dx=400 m Static Domain

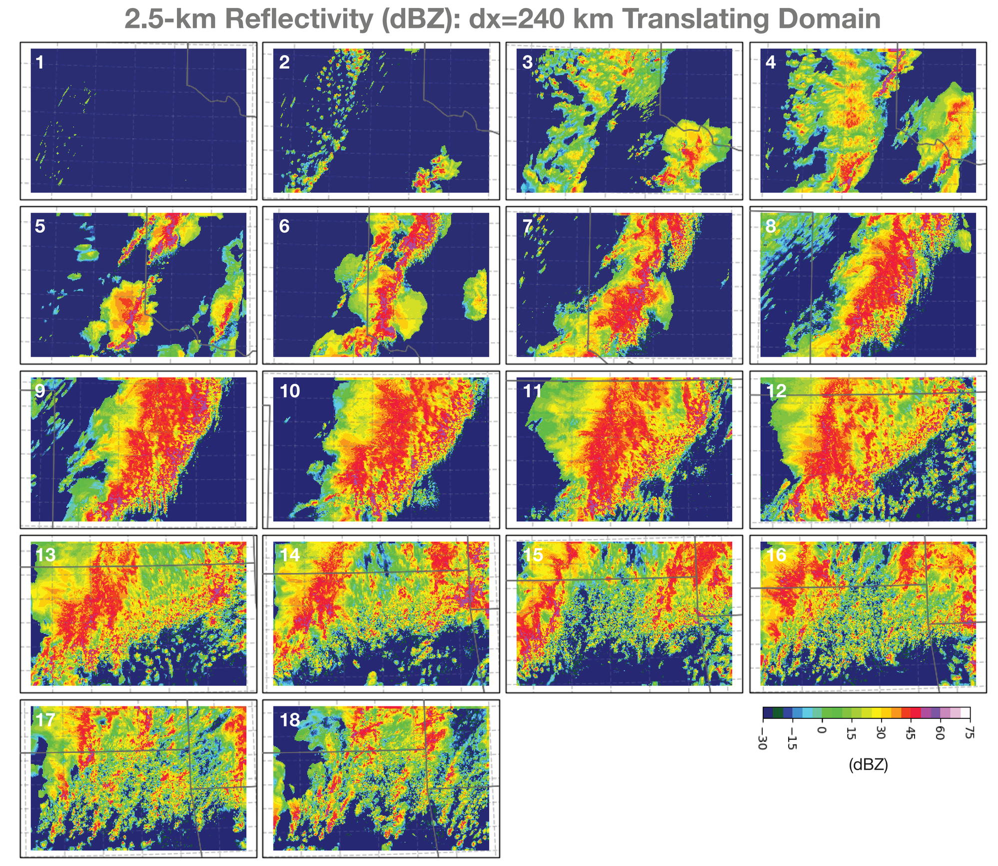


Hourly snapshots of reflectivity at 2.5 km AMSL. Numbers in each panel indicate the simulation hour in UTC.

2.5-km Reflectivity: dx=400 m Translating Domain



2.5-km Reflectivity (dBZ): dx=240 km Translating Domain

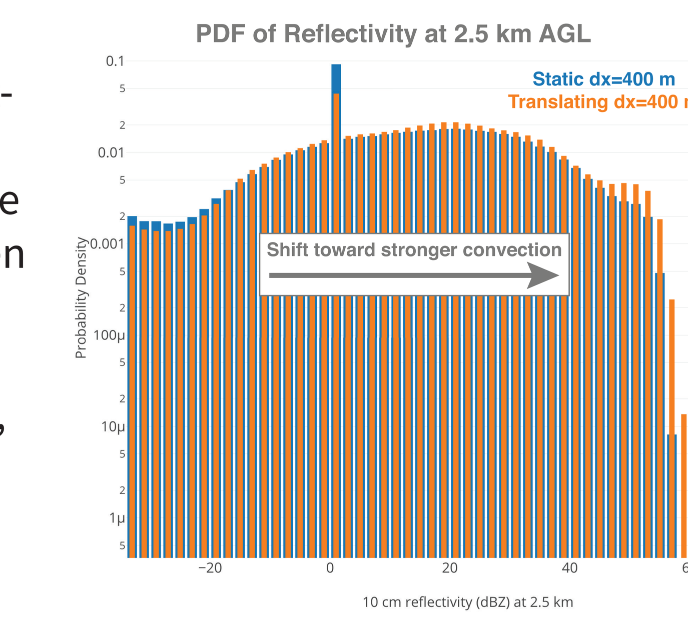


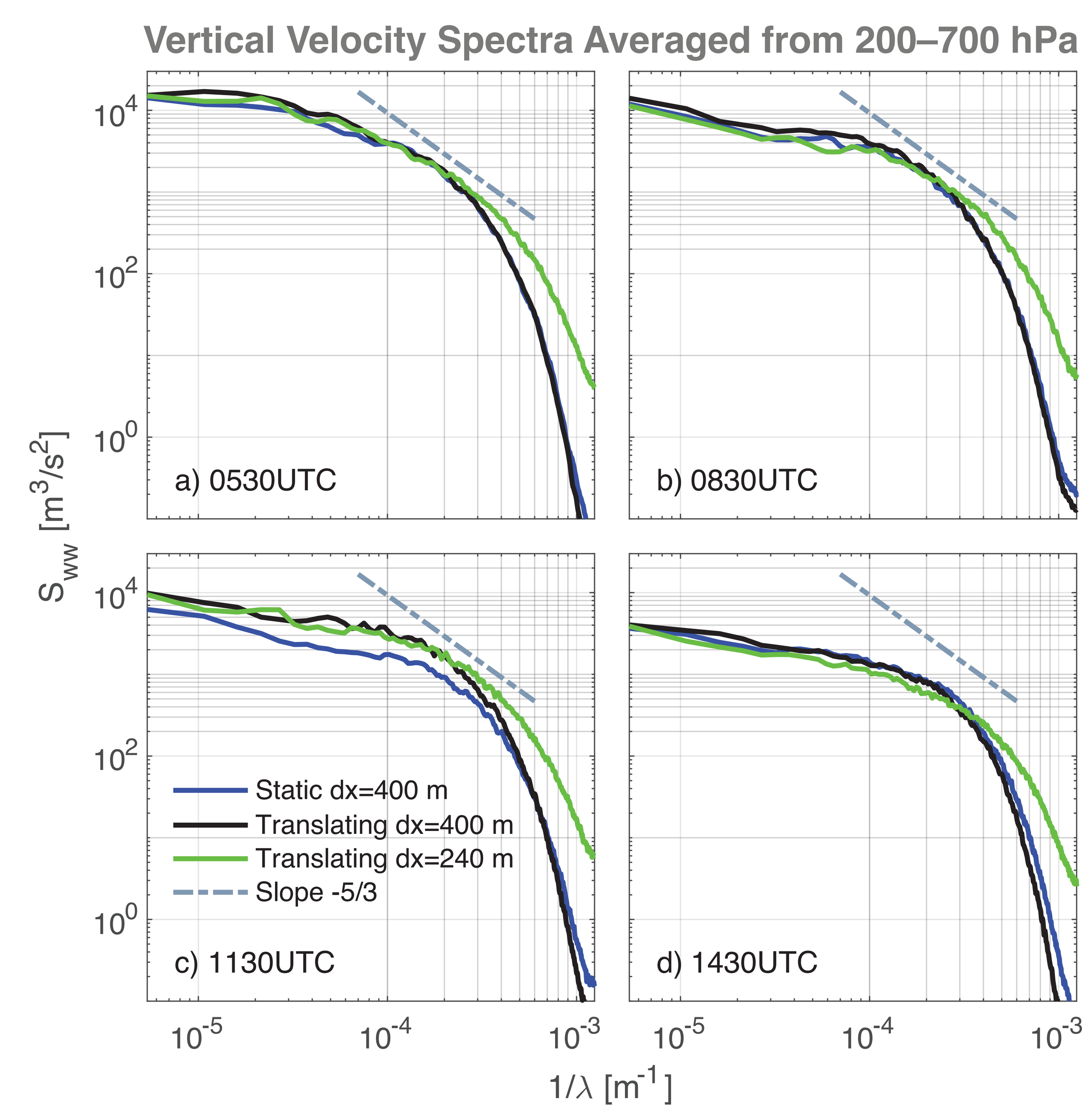
Convective Behavior

The translating domain captures the large-scale cloud structures similarly to the static domain, but there are differences.

- The leading line convection during the spin-up times decays more quickly in the translating domain (hour 6).
- The orientation of the main convective line sometimes differs (e.g., more north-south in the static domain at hour 8).

The smaller translating domain produces slightly coarser and stronger convective cells than the benchmark domain even though the 400 m grid spacings match. (see snapshot hours >9, PDF, and tails of spectra).



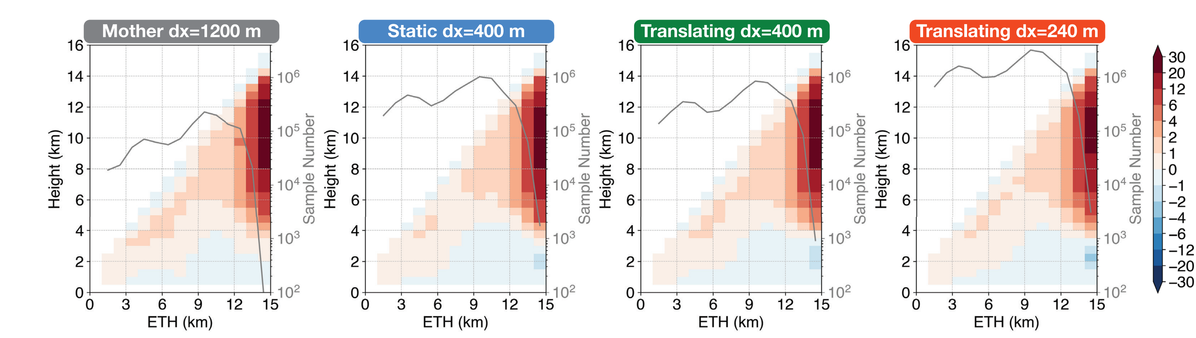


The translating domains are mostly free of numerical artifacts (the N-S stripes in hour 9 may be numeric, but this is unclear).

As expected, the convective features look more realistic in the dx=240 m simulation compared to dx=400 m.

Updraft & Downraft Behavior

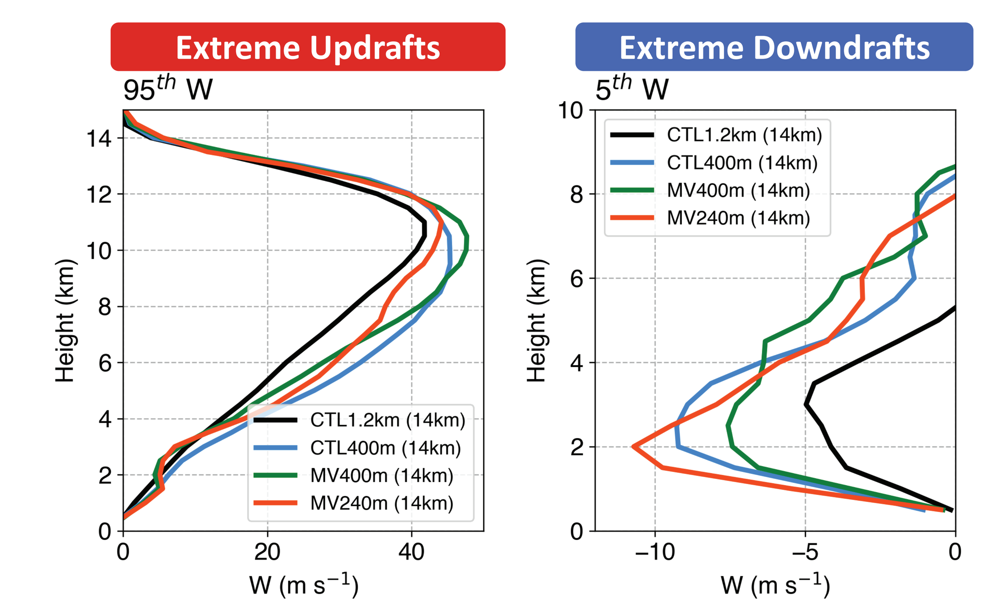
The translating domain reproduces mean updraft/downdraft statistics across different depths of convective cells vs. the static domain.



Binned mean vertical velocity (w, m s⁻¹) by cloud echo-top height (ETH, km) and height above ground level (km). W is sampled from 3–18 UTC.

For the deepest convectivce cells:

- Dx=1200 m has weaker extreme updrafts followed by dx=240 m. Dx=400 m has the strongest updrafts.
- Dx=240 m has stronger and shallower extreme downdrafts.



We are exploring a fair comparison with multi-Doppler retrievals for evaluation vs. observations.

Conclusions

1. Using transient domains is a powerful tool to avoid the computational cost of capturing large portions of convective system lifecycles.
2. Transient domains produce almost the same storm structure as static domains and thus can be used for understanding storm dynamics within the scales afforded by the domain.
3. It is unclear whether the fine-scale differences between the static and transient domains with the same grid spacings are due to domain size differences or to the transient domain movement.
4. This test is for a single storm day and more work needs to be done to understand the robustness of these conclusions.

U.S. DEPARTMENT OF ENERGY   CMDV Mesoscale Convective Systems

For more information, contact William.Gustafson@pnnl.gov.
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