Artificial Intelligence/Machine Learning
Pre-Summit Intensive Read-Ahead

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What We Know and (Generally) Agree On

- We must organize the community to effectively leverage available investments, find synergies. and collaborate. Other relevant efforts include:
    - Europe's Destination Earth project (DestinE) is organizing the community to address many of the same issues as our project, though at 2-4 km not 1 km.
    - Private sector and operational center AI-based NWP models already are notably successful, can handle extremes, and can cheaply generate ensemble members.
    - An operational center has recently demonstrated that a fully AI-based model is possible (i.e., bypassing data assimilation).
    - An operational center is running daily simulations at 1-km and decade-long simulations at 1 km (not fully coupled ESM) and seeing benefits (e.g., extremes).
    - An operational center and the commercial sector are keeping a dynamical core of a physics-based model intact and replacing physical parametrizations with ML.
- Placing stakeholder needs front and center is important and we need to direct our innovations toward addressing those needs in addition to pursuing scientific questions.
- Researchers are practitioners as well. When building a code for a computational system, ease of use is an important consideration.
- Running physics-based models at km-scale necessitates observations at similar scale (e.g., initial state, validation). From an ethics and equity perspective, it's important to think about where we lack observations. AI can help with "optimal" sensor placement.
- AI does not hold great promise for improving the efficiency of parameterizations. More potential lies in improving their accuracy (e.g., low clouds and radiative feedbacks).
- Replacing the dynamical core with AI does not appear to offer most benefit currently.

Views Between the AI and km-Scale Communities

- There is evidence of the need for global km-scale resolution to capture extremes in physics-based models. AI-based models are not built to extrapolate, but there is growing evidence that current (not km-scale) AI-based models can skillfully predict extremes.
- The extent to which uncertainty would be reduced with km-scale resolution in ESMs or carried over to AI is not clear, given that other sub-grid scale processes (e.g., cloud microphysics) are a large source of uncertainty and would still not be explicitly resolved.

- Physics-informed frameworks within AI models are recognized as extremely important but as of now, data-driven ("physics-free") weather prediction models are top performers, at times exceeding the skill of traditional physics-based models.
- Users care about local scales, but physics-based models do not necessarily need to be run at that resolution. Alternatively, one can envision the following scenarios:
  - A finer-resolution regional AI-based model that is nested within a coarser resolution global (AI-based or physics-based) model.
  - Neural operators to seamlessly downscale without km scale data (although its availability would likely improve performance).

Opportunities and Open Research Questions on AI and km-Scale Modeling

- To what extent do physics-based scale dependencies also apply in fully AI-based models?
- What horizontal resolution is required for practical forecast value in NWP, which likely depends on how the information is to be used (e.g., by stakeholders)?
- The extent to which AI-based spatial downscaling could explicitly generate thunderstorms needs to be explored and developed. As such, what applications need km-scale prognostic forward modeling instead of spatial downscaling?
- AI-based models can generate large ensembles cheaply, though the "optimal" number depends upon the problem and remains an open question.
- Can AI-based models capture the fastest growing modes in ensembles?
- Do AI-based and physics-based models have different predictability?
- Empirical evidence of the need for physics-informed AI frameworks is needed.
- Why can some AI-based models extrapolate to extremes? We don't fully know the extent to which AI can extrapolate and these experiments should be a focus in the near term.
- **Opportunity:** AI to enable more efficient calibration for existing parameterizations.
- **Opportunity:** Pairing AI-based ensembles with ensemble assimilation systems.
- **Opportunity:** AI to allow interactivity and exploration of km-scale simulations and while interpolating between different emissions scenarios and modes of variability.

Potential Issues on the Horizon

- Rapid advances in AI/ML mean that concrete decisions regarding approaches to be taken are difficult because they might be superseded (e.g., as with AI in NWP).
- Confusion can arise when timescales of interest are not clearly outlined (e.g., S2S, S2D, and climate projections). Timescale(s) of relevance for tasks should be established.
- Careful consideration needs to be given to model validation and factors that are needed to gain trust, which may require re-thinking what validation means in the context of a km-scale model and the needs this modeling effort aims to fill.
- Global km-scale simulations would serve as an essential resource for training AI, but data storage and access to the broader community is an important consideration.