AI-based spatial and temporal correlation structure analysis of the Earth's albedo using CERES EBAF data

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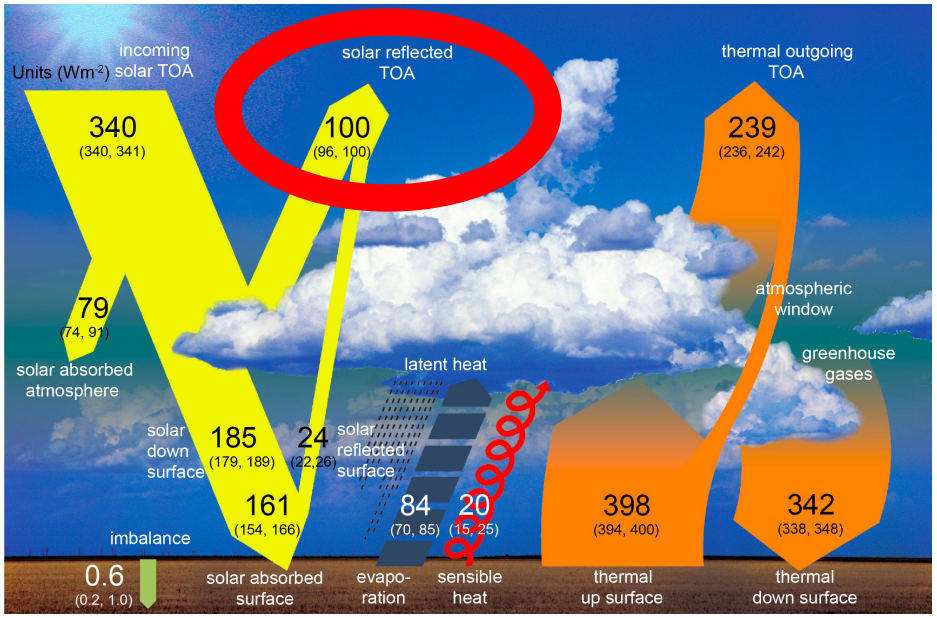
1. Lawrence Berkeley National Laboratory
2. Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder
3. NOAA Chemical Sciences Laboratory
4. Laboratory for Atmospheric and Space Physics
5. NASA JPL
6. UC-Santa Cruz

Scientific Motivation

- A predictive understanding of the Earth's TOA radiation budget is central to climate modeling construction and performance. The scientific understanding of how atmospheric and land features interact to stabilize planetary albedo on interannual time-scales is not mature.

- Can measurements and models be used to advance the understanding of TOA albedo stability and symmetry phenomena?

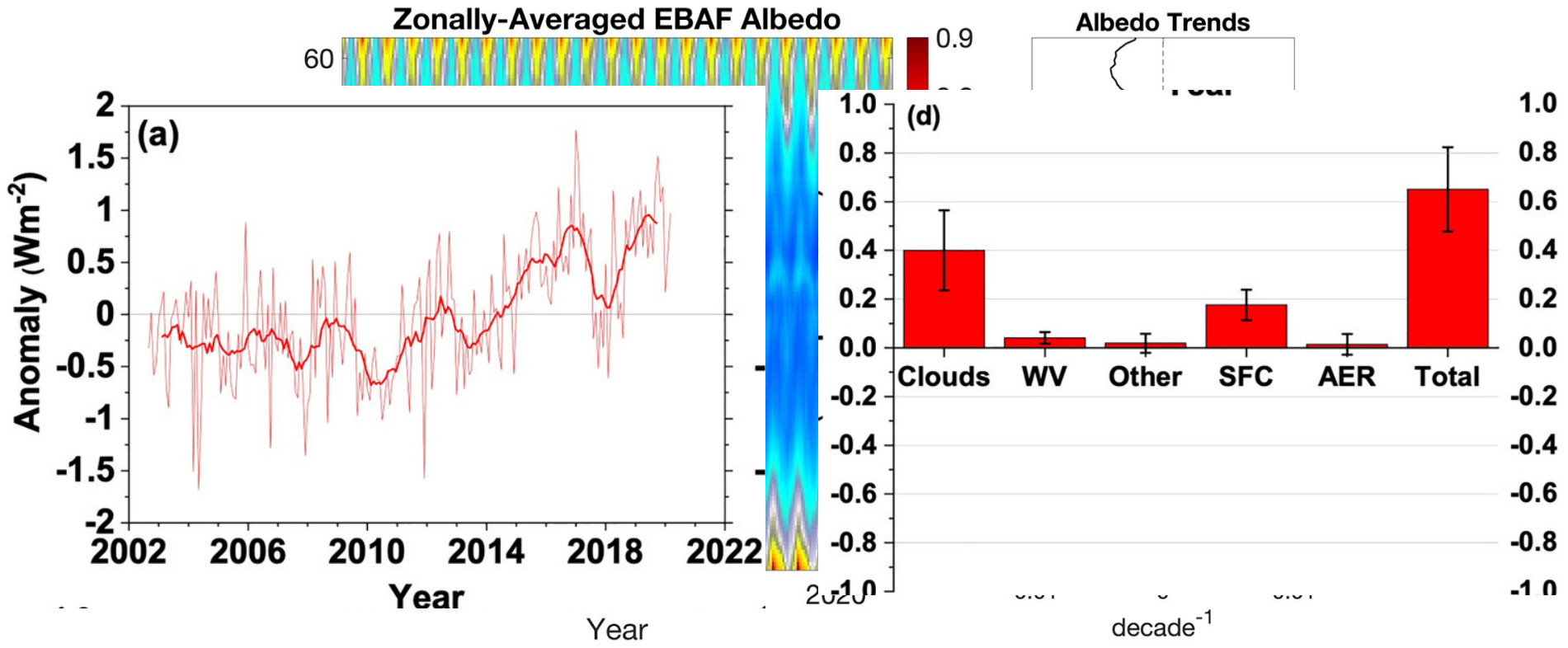


IPCC AR5, 2013

Why Now?

- TOA albedo has been (more—or-less … less so recently) stable and highly symmetric over the observational record.

- Should either of those change, the Libera science team needs be prepared not just to notify the community of such a change, but also to explain the cause(s) for such changes and, more importantly, predict future albedo. Also, it's a lot easier to prepare now than later

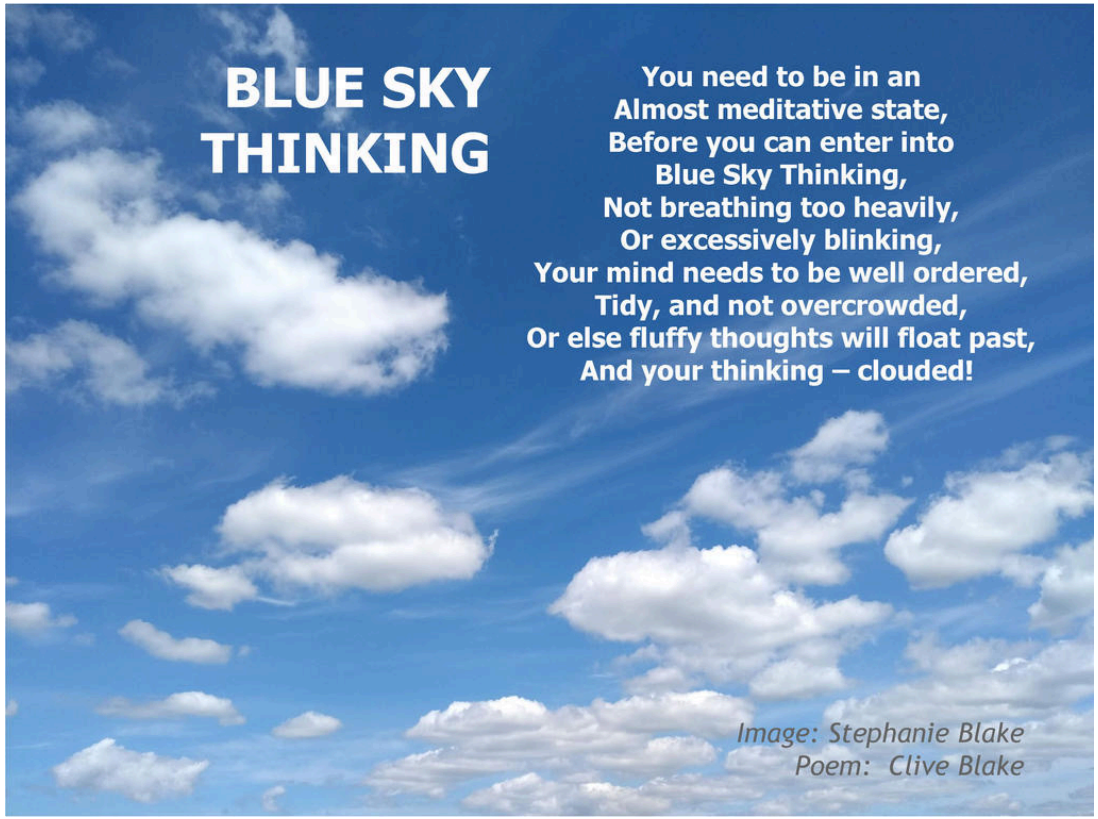


Loeb et al, JGR 2021; Feldman, Gristey, Hakuba, Hellinger, Kahn Submitted

Why Now?

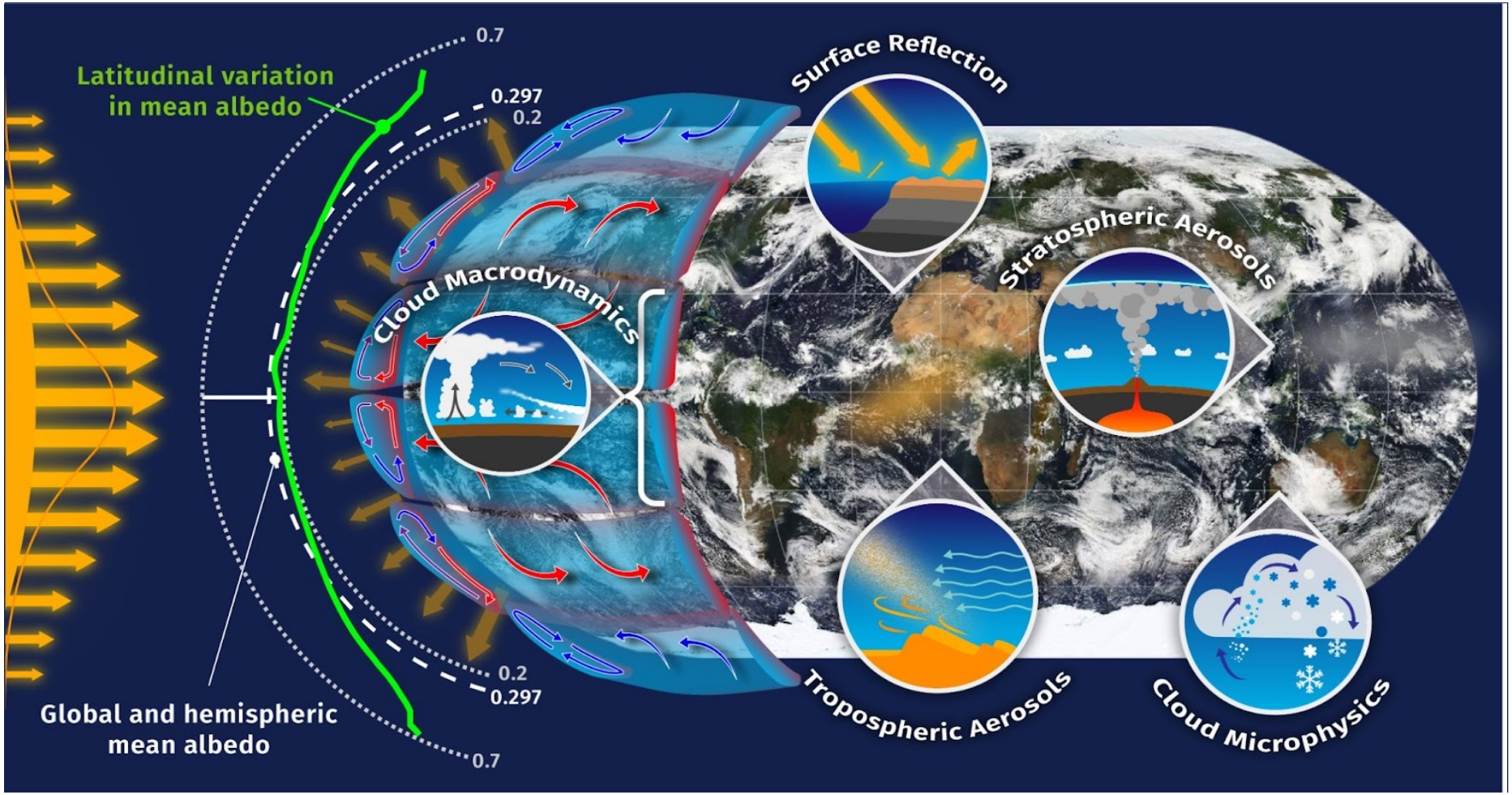
- It is easier to do “blue-sky thinking” before we are focusing on the new, cool things we see with Libera data.

- We can be prepared to explain the Libera observations beyond just reporting out the numbers.



The Wide Range of Spatial and Temporal Scales

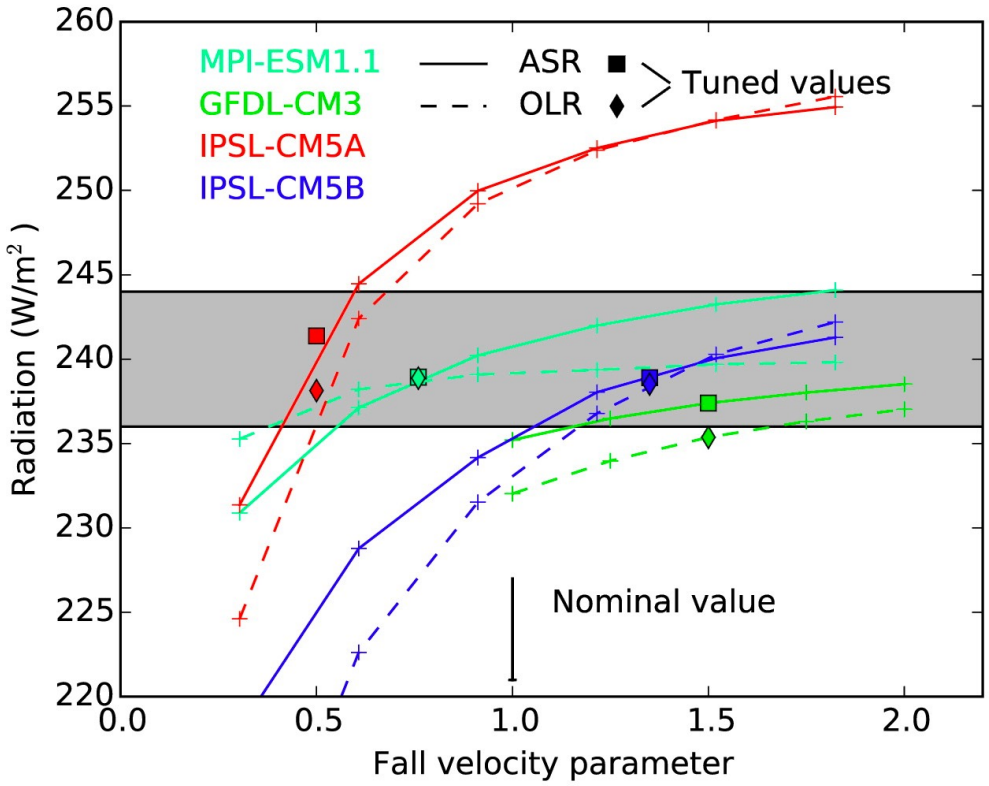
- TOA albedo is the result of processes across a very large range of temporal and spatial scales.
- Diagnostic approaches will not resolve all scales. So there is a fraught path between reductive phenomenology and predictive understanding … theory is required.



Feldman, Gristey, Hakuba, Hellinger, Kahn Submitted

Climate Model Albedo Projections Disagree

- Tuning climate models to achieve historical, observed TOA albedo has consequences for albedo projections.
- The change in TOA shortwave radiation budget is several W/m2 at end of century depending on model used.



Mauritsen et al, JAMES, 2012

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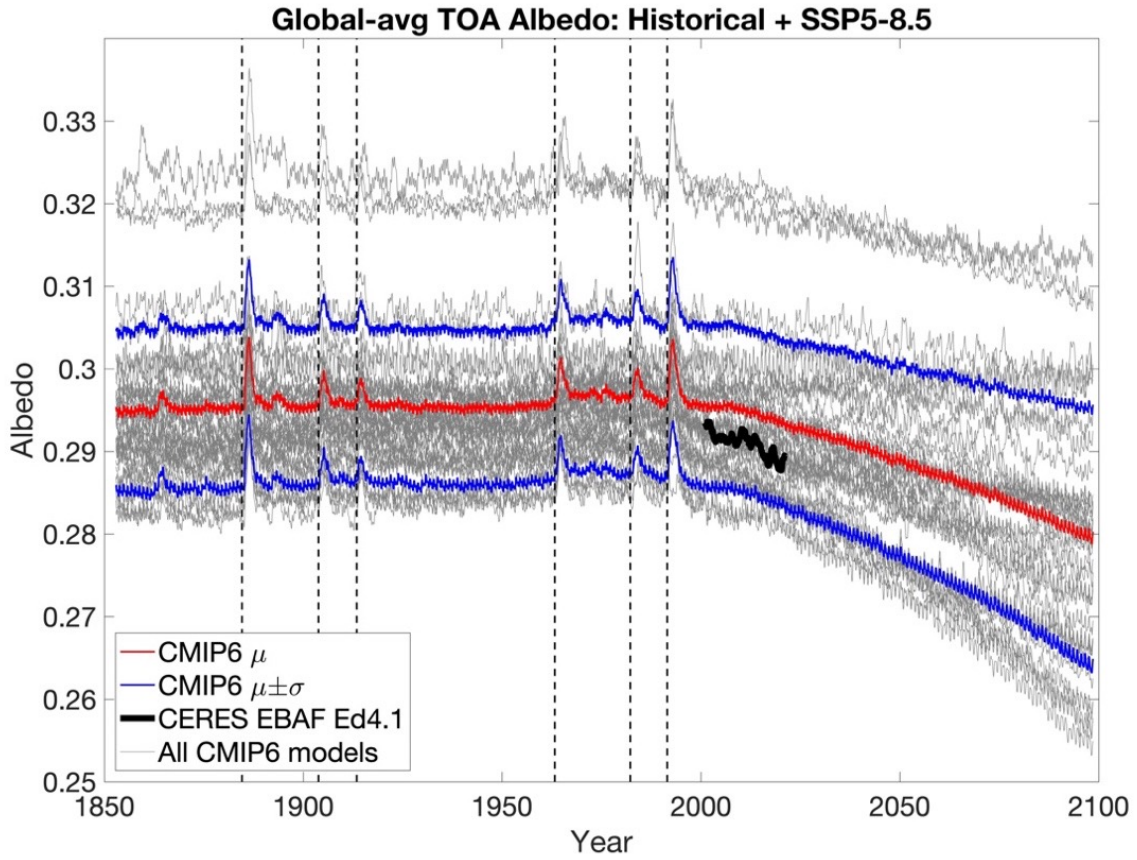

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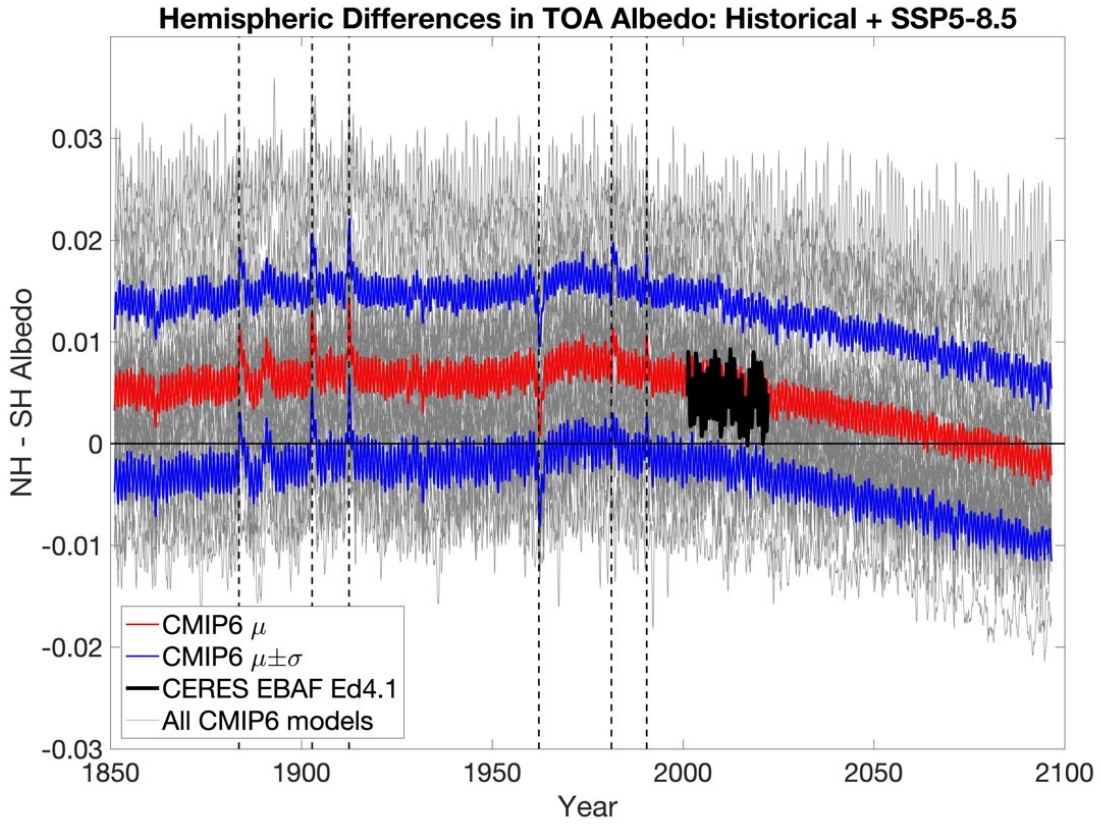

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A Possible Role for AI in Understanding Albedo

- AI methods may be able to assist the testing of hypotheses related to Earth's albedo.
- They are well-suited to capture both the obvious and subtle teleconnections that likely exist (Voigt et al, 2013; 2014) and produce data-driven insights.
- Let's explore what that could look like.

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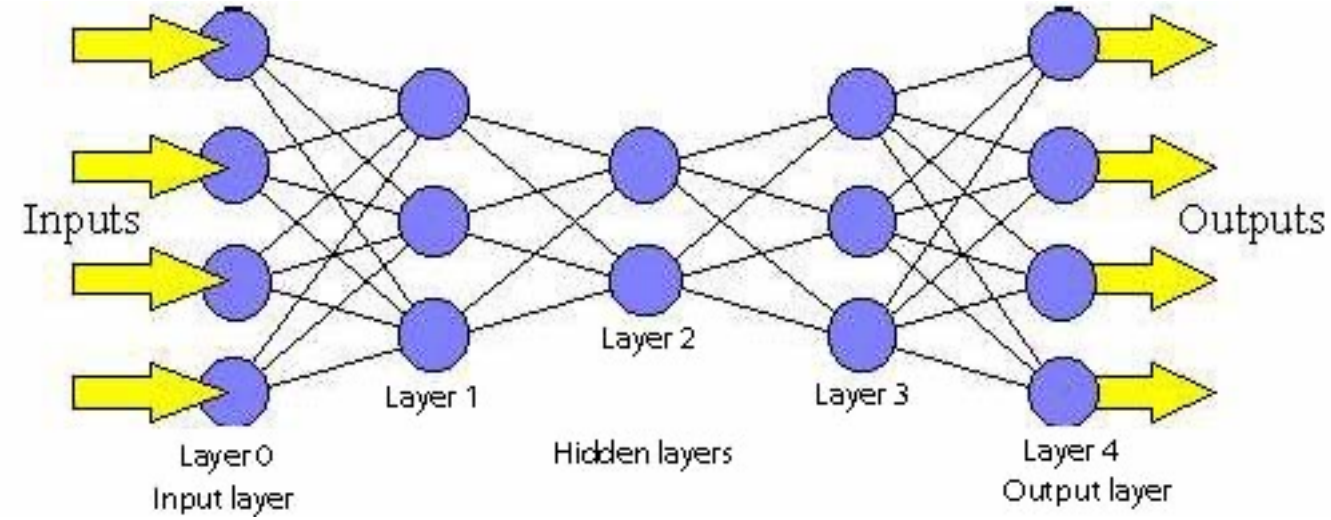
Feed-Forward Neural Network for Albedo Prediction

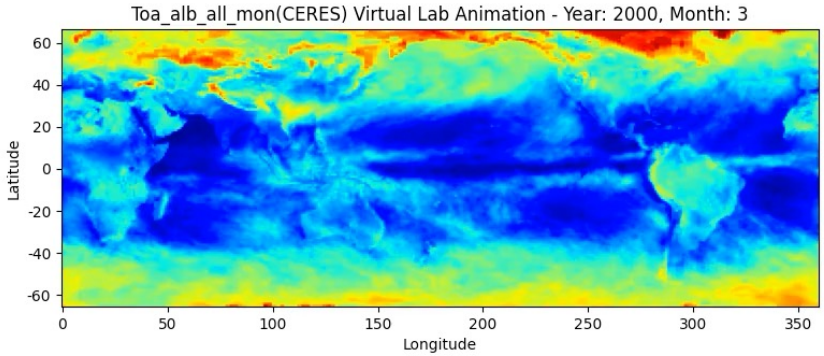
- The observed TOA albedo phenomena could be the result many resolved and unresolved Earth system teleconnections.

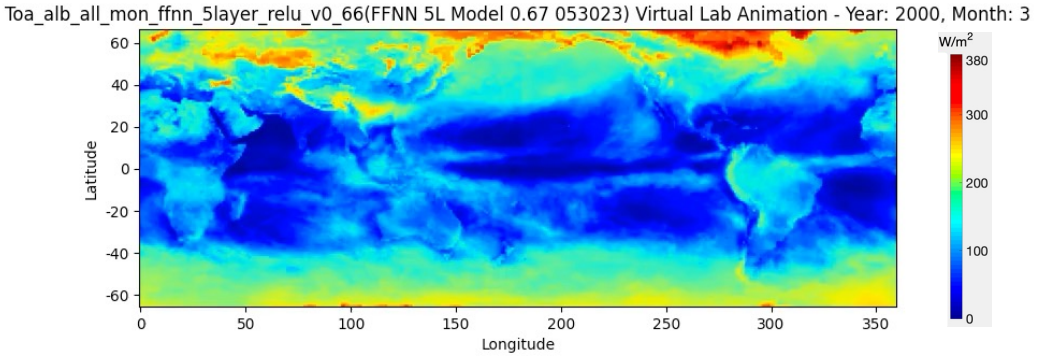
- A data model which learns the sensitivities of the sum-total of the teleconnections that impact albedo is needed. That is what we are developing under a feed-forward neural network architectural framework.

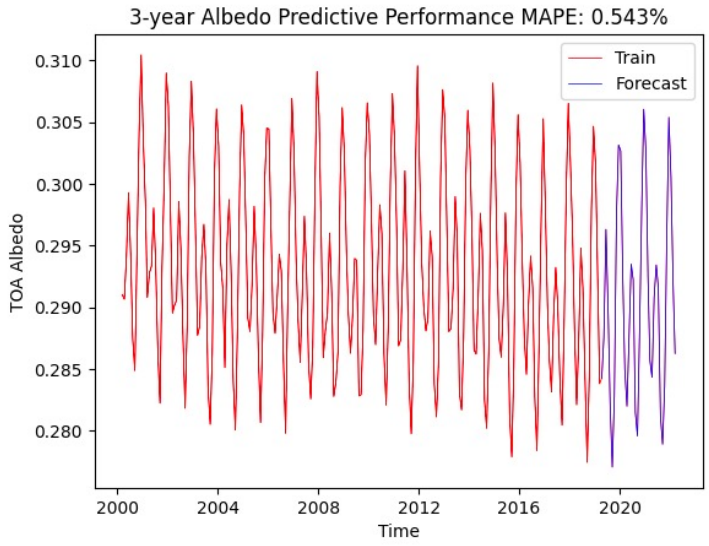


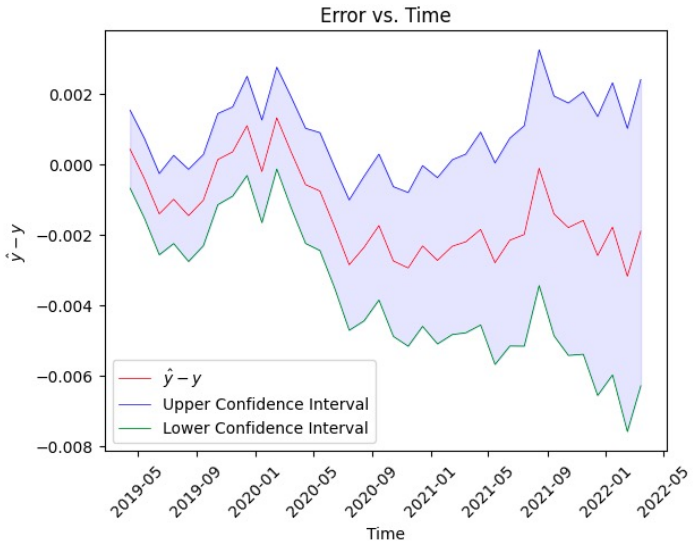
AI Can Emulate Albedo Spatial Patterns

- The spatial and temporal variability in albedo are easily emulated by both deep and shallow FFNNs. Translation: FFNN's can quickly learn how to emulate the relevant radiative transfer.



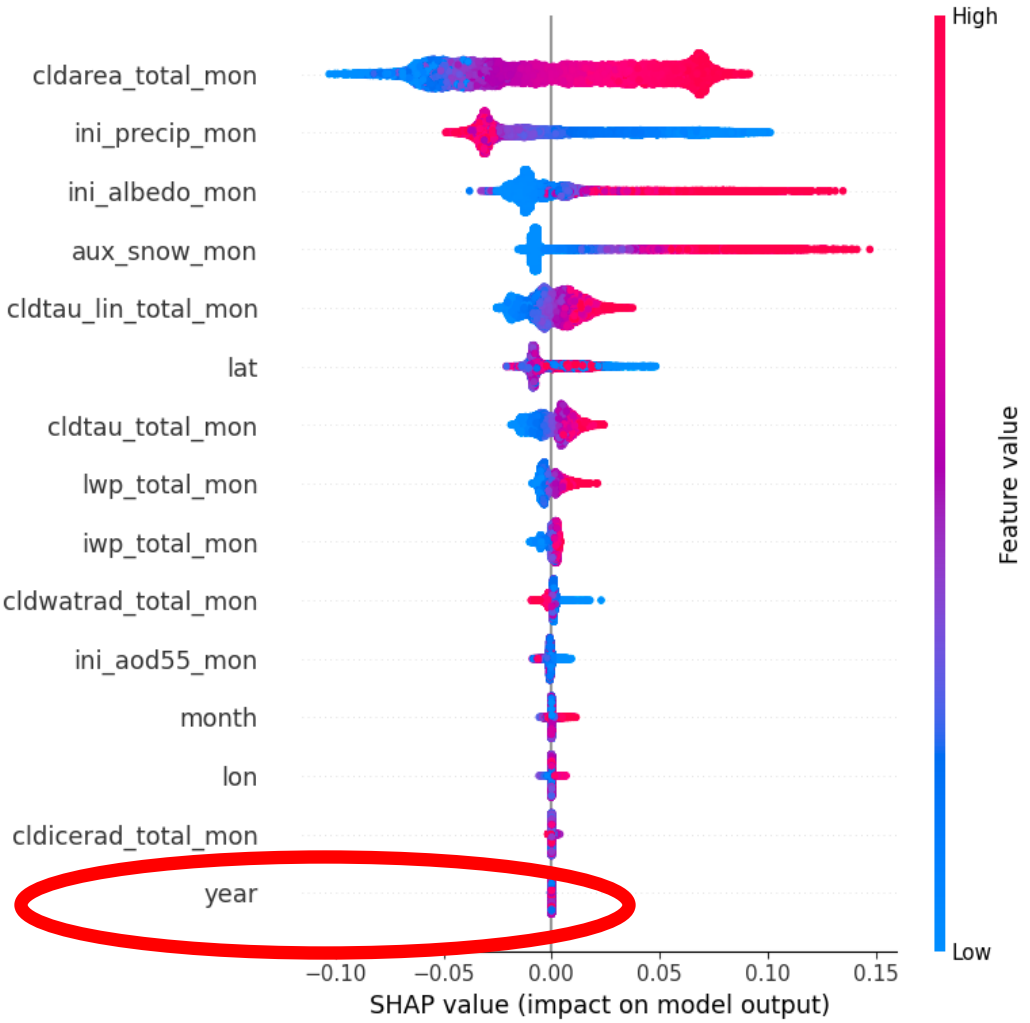




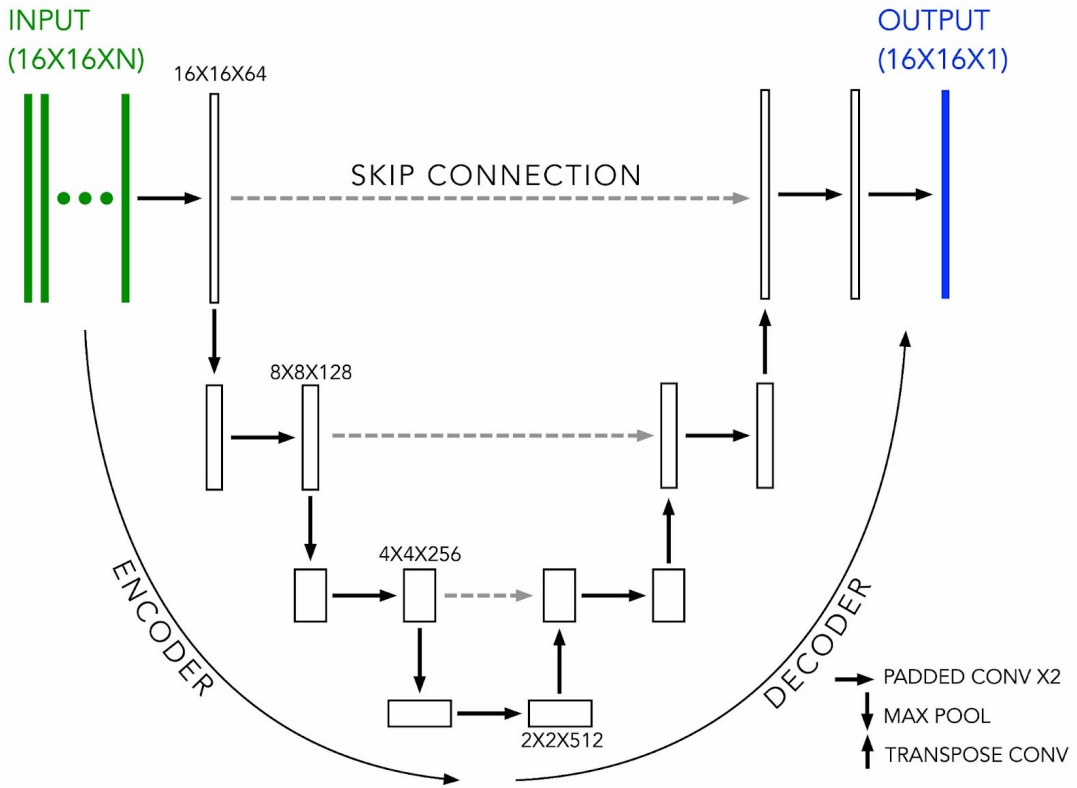


AI Reveals Feature Importance and Stationarity

- Shapley Additive Parameters (SHAP) analysis produces a rank-ordered list of how the surface and atmosphere are impacting albedo over time.
- SHAP is widely-utilized in eXplainable AI workflows.
- The analysis produces some recognizable results and provides new insights too.
  - Clouds are very important for albedo.
  - The contributions of clouds, aerosols, and surface reflection to TOA albedo have not changed since 2000. I.e., the processes relevant to albedo have been stationary.

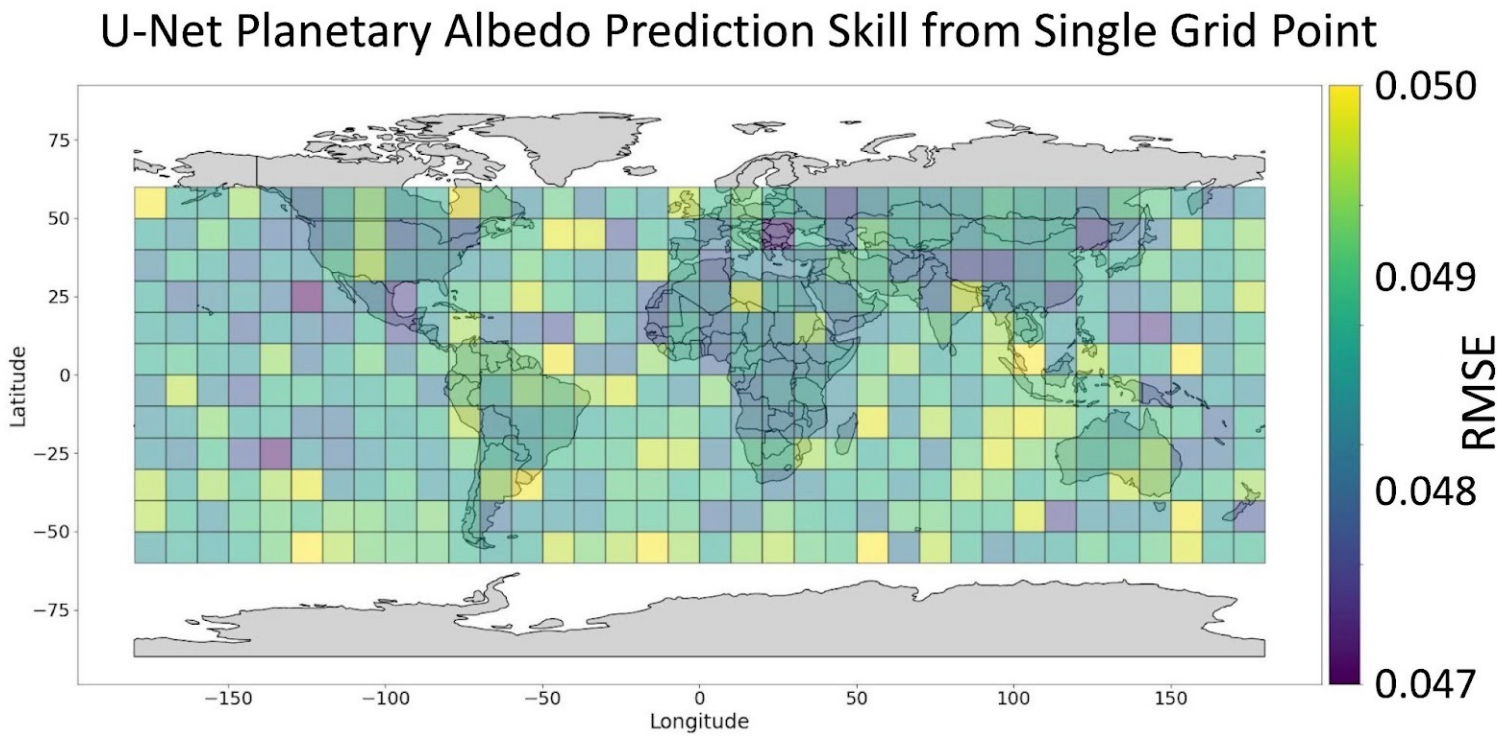


Teleconnection Analysis with U-Nets



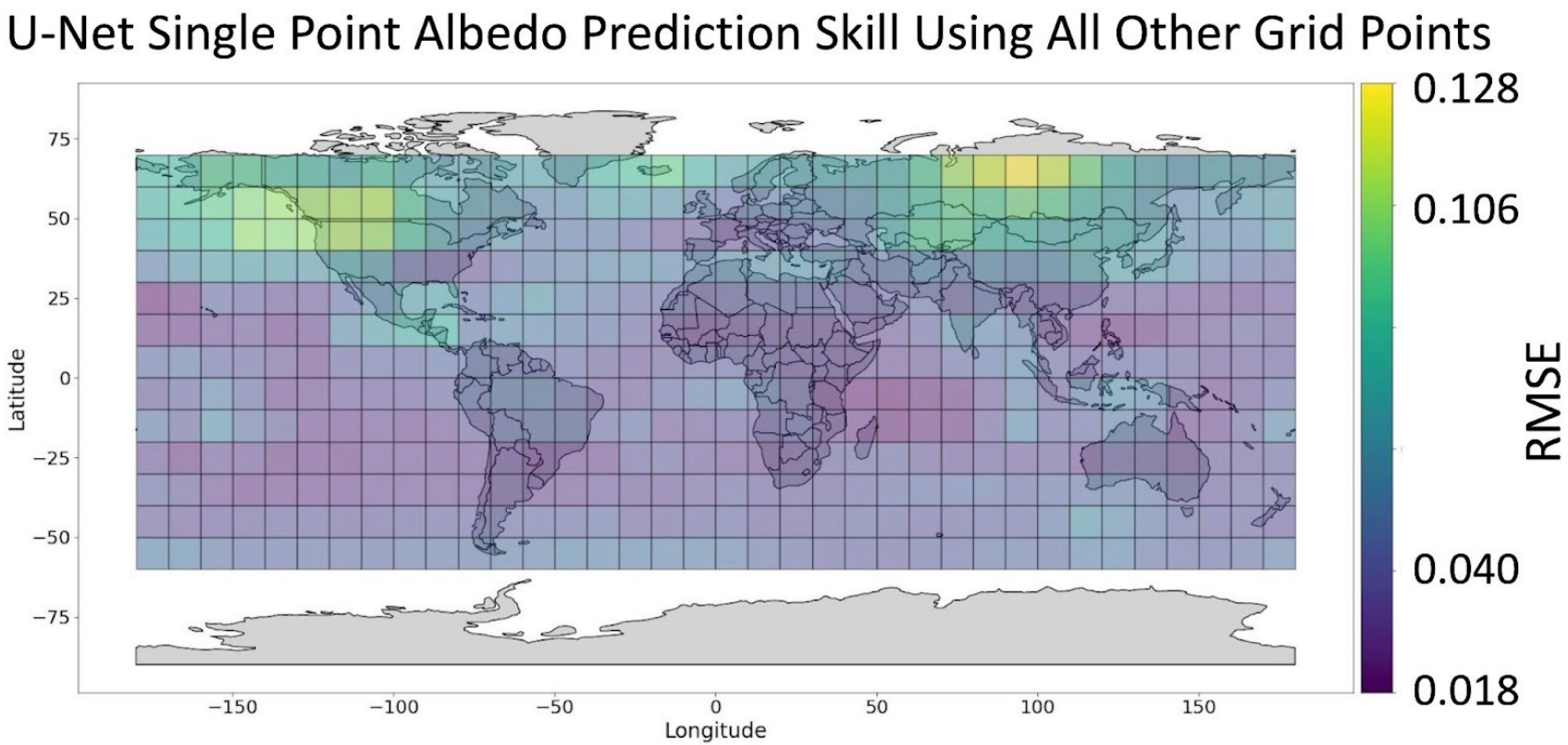
- Other AI methods are very powerful in identifying obvious and subtle correlations (teleconnections).
- U-Nets are convolutional neural networks which are well-positioned to ***extract feature information from spatial information***.
- We can uncover how different locations on Earth work together to create albedo phenomena.

Teleconnection Analysis with U-Nets



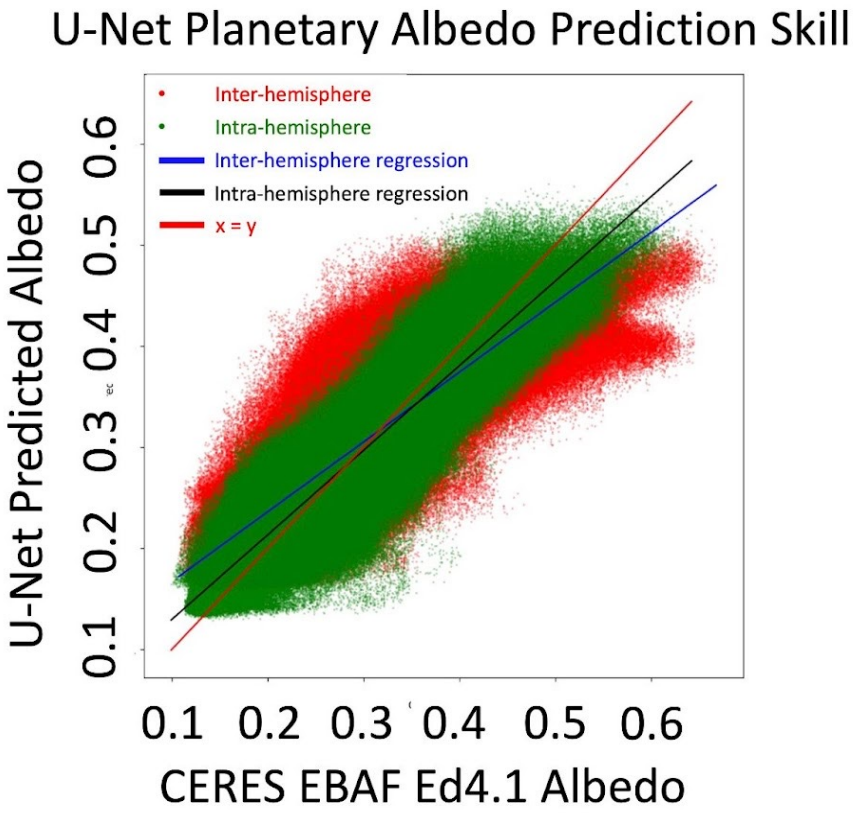
- The U-Net importance maps shows how well we can use the time-history of atmospheric and surface information in one region to predict the current albedo value. This shows regions are most important for controlling albedo.
- The result? There really isn't a location on Earth that is more important than others for controlling albedo.

Teleconnection Analysis with U-Nets



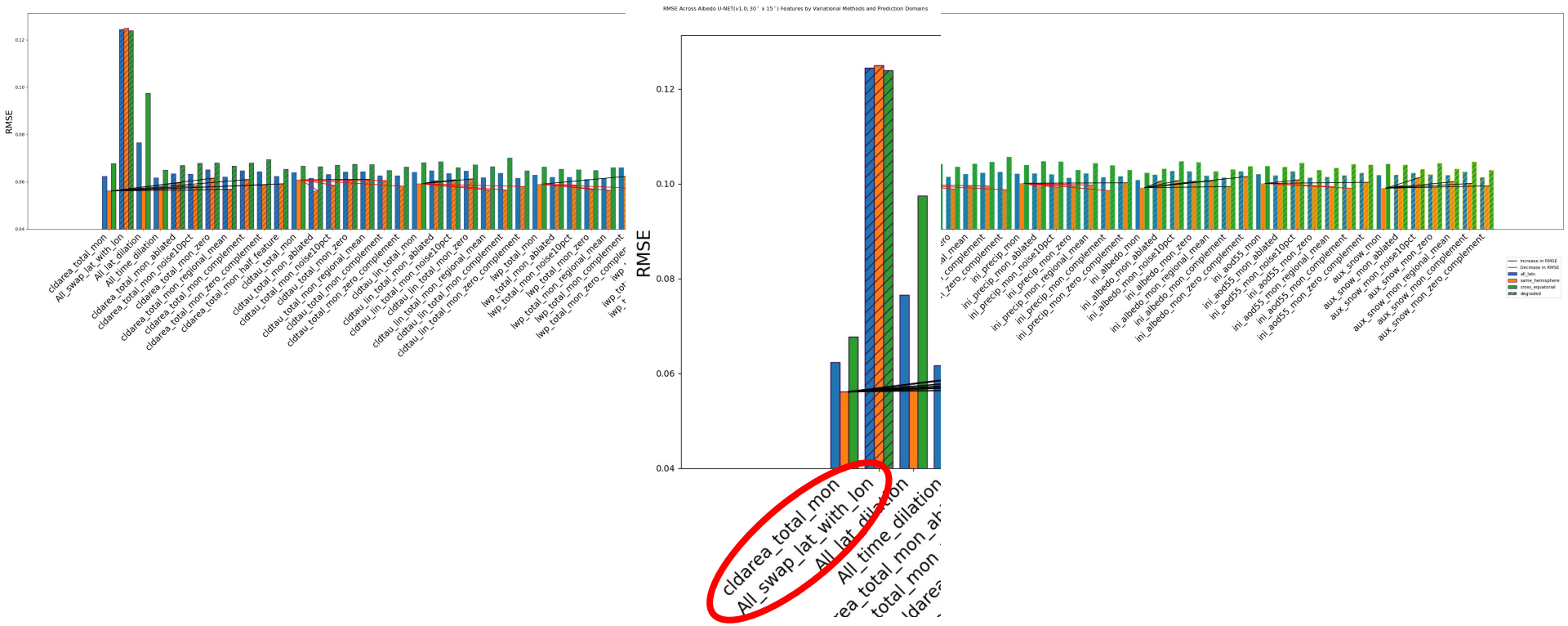
- We can also flip that around: how well can we predict the time-varying albedo in one location with the time history of atmospheric and surface conditions around the Earth?
- The result? Outside of possible some northern hemisphere areas, most of the Earth's albedo is constrained by the albedo fields elsewhere.

Teleconnection Analysis with U-Nets



- Also, we can break down how well a U-Net performs when given the time-history of atmospheric and surface conditions in one hemisphere and asked to predict albedo in the other hemisphere.
- Also, albedo in one hemisphere has slightly less control on albedo in the other hemisphere

Ablation Analysis: All about the Latitude



- Ablation is a process to take away variables and see when model breaks down.
- The ablation analysis shows that the U-Net model determines that **only latitude** matters for predicting teleconnections.
- What does that mean? That only meridionally-varying processes matter for albedo teleconnections. This is no

Some Thoughts on AI Assistance for Albedo Science

- Why are we using AI to understand albedo?
- Because we need to probe the phenomena across the range of spatial and temporal scales that have been measured, and basic data methods have not yet produced a deeper understanding of those phenomena.
- Advanced data methods can easily identify obvious, subtle, actual, and spurious correlations. They can be a powerful tool in the science toolbox, if used appropriately.
- There are many, many more data methods other than a U-Net that can be used.
- These methods only assist, and are no substitute, or may not even be a large part of albedo science.

Summary

- The scientific community has a limited predictive understanding planetary albedo stability and symmetry, but needs to develop one/some for the Anthropocene.

Acknowledgements

- Thanks to the NASA CERES Science Team and LLNL for giving me time today!
- Thanks to NASA Libera for supporting my work (NASA Contract 80LARC20D0006).
- Thanks to NASA HEC Resources for supporting AI model development.
- Thanks to Berkeley AI Research (BAIR) for hosting Sam and Doug.

- Questions? Let's follow up! drfeldman@lbl.gov