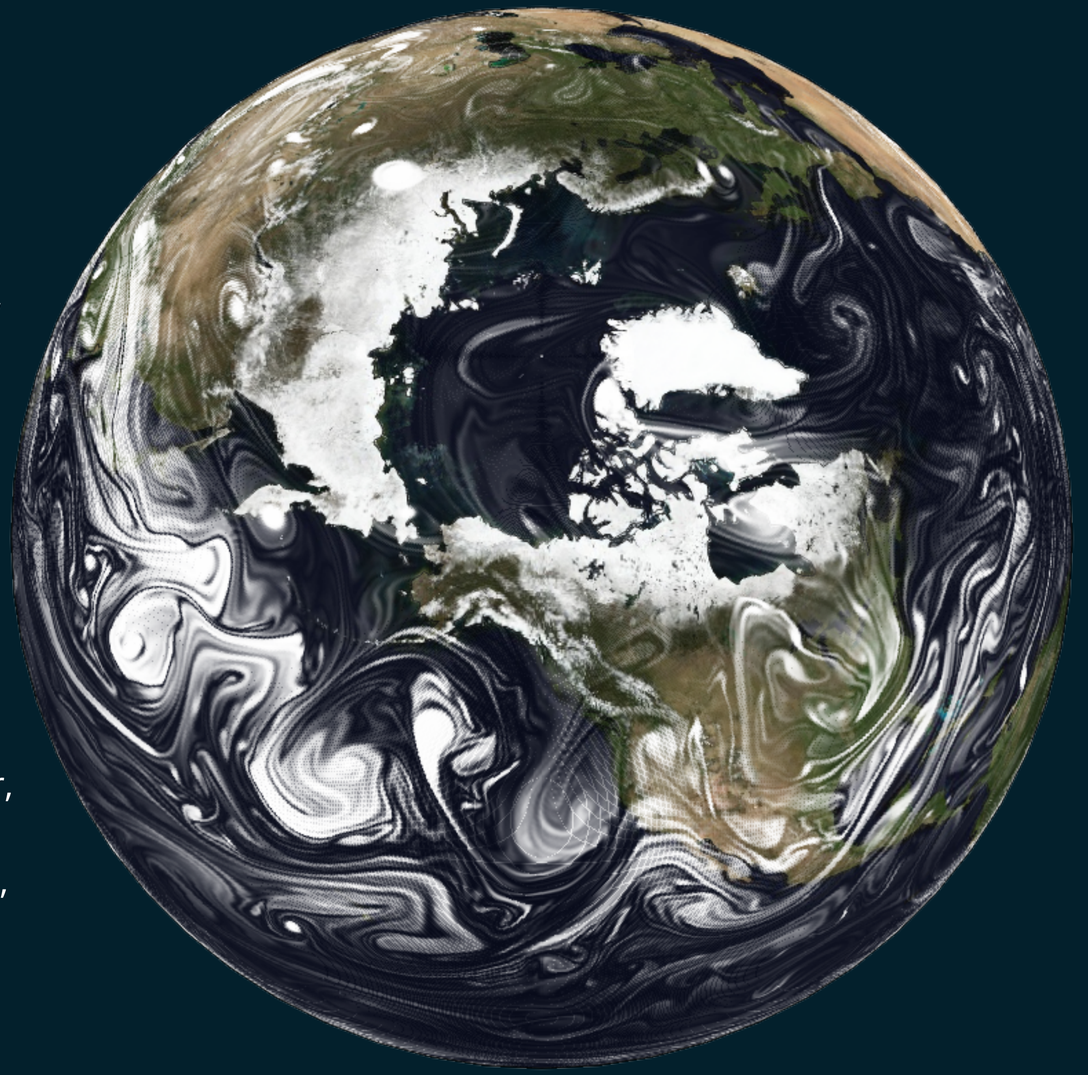
SpeedyWeather.jl:

How to build an atmospheric model towards extensibility and interactivity for machine learning-based climate science



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Maximilian Gelbrecht, Daisuke Hotta, Justin Willmert, Simone Silvestri, Greg Wagner, Alistair White, Sam Hatfield, Tom Kimpson, Navid Constantinou, Yu-Kun Qian, Nathanael Wong, Pietro Monticone, David Meyer, Valentin Churavy, Mosè Giordano, Chris Hill

[1]University of Oxford

Simulations vs Satellite

Uncertainties in *dynamics* reduce with higher resolution

Uncertainties in *physics* often dominate weather forecasts

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Dynamics ⟷ (micro) physics
     Laws ⟷ heuristics
  Certain ⟷ uncertain
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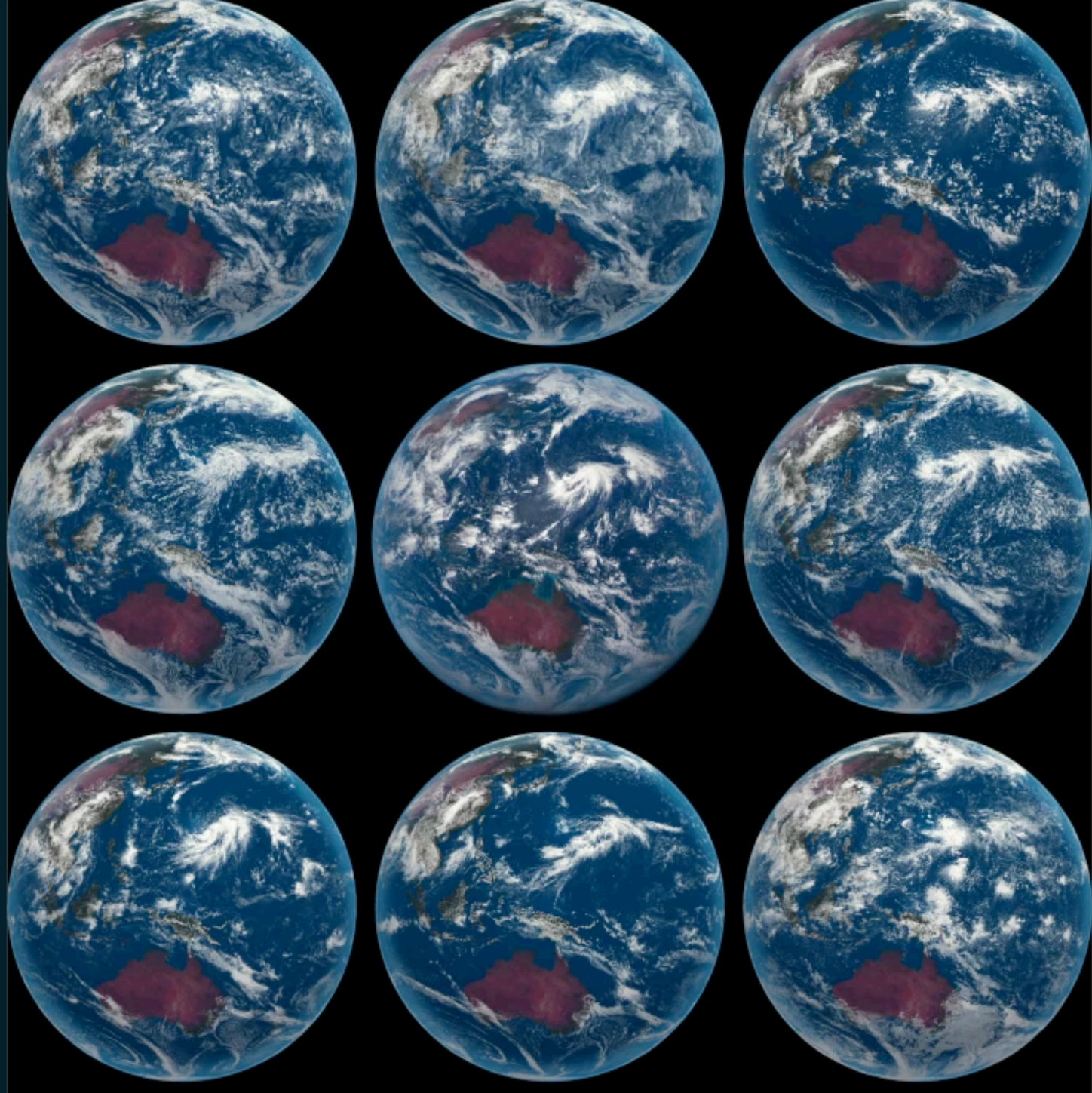
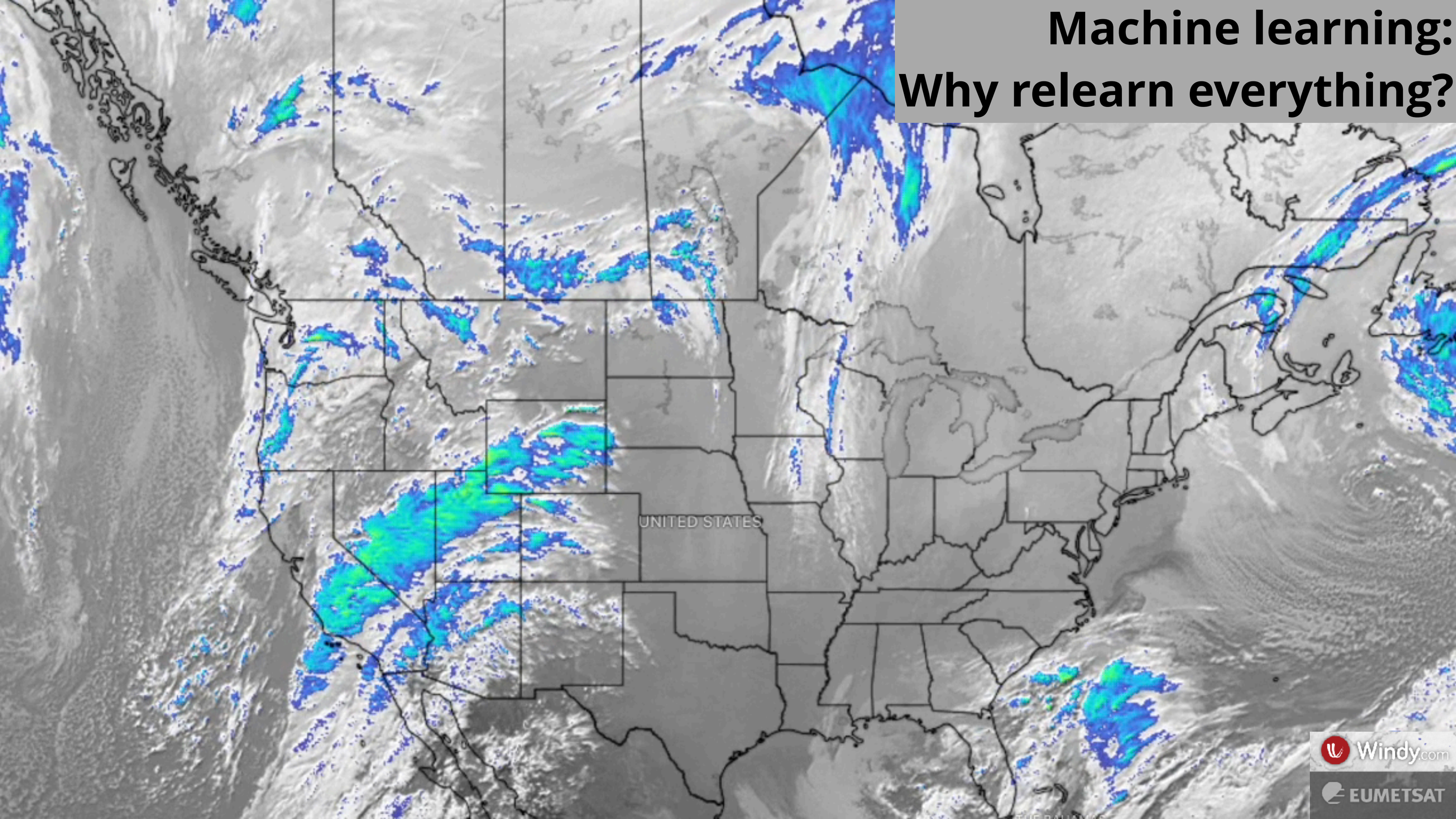
How can we constraint models better to data?

Stevens et al., 2019




Machine learning:
Why relearn everything?
UNITED STATES
Windy.com
EUMETSAT

GraphCast

Pure machine learning weather forecast model

GraphNN with encoder - processor - decoder architecture

6h time steps

No physical laws, not generalizable (?) nor explainable (?)

Lam et al., 2023

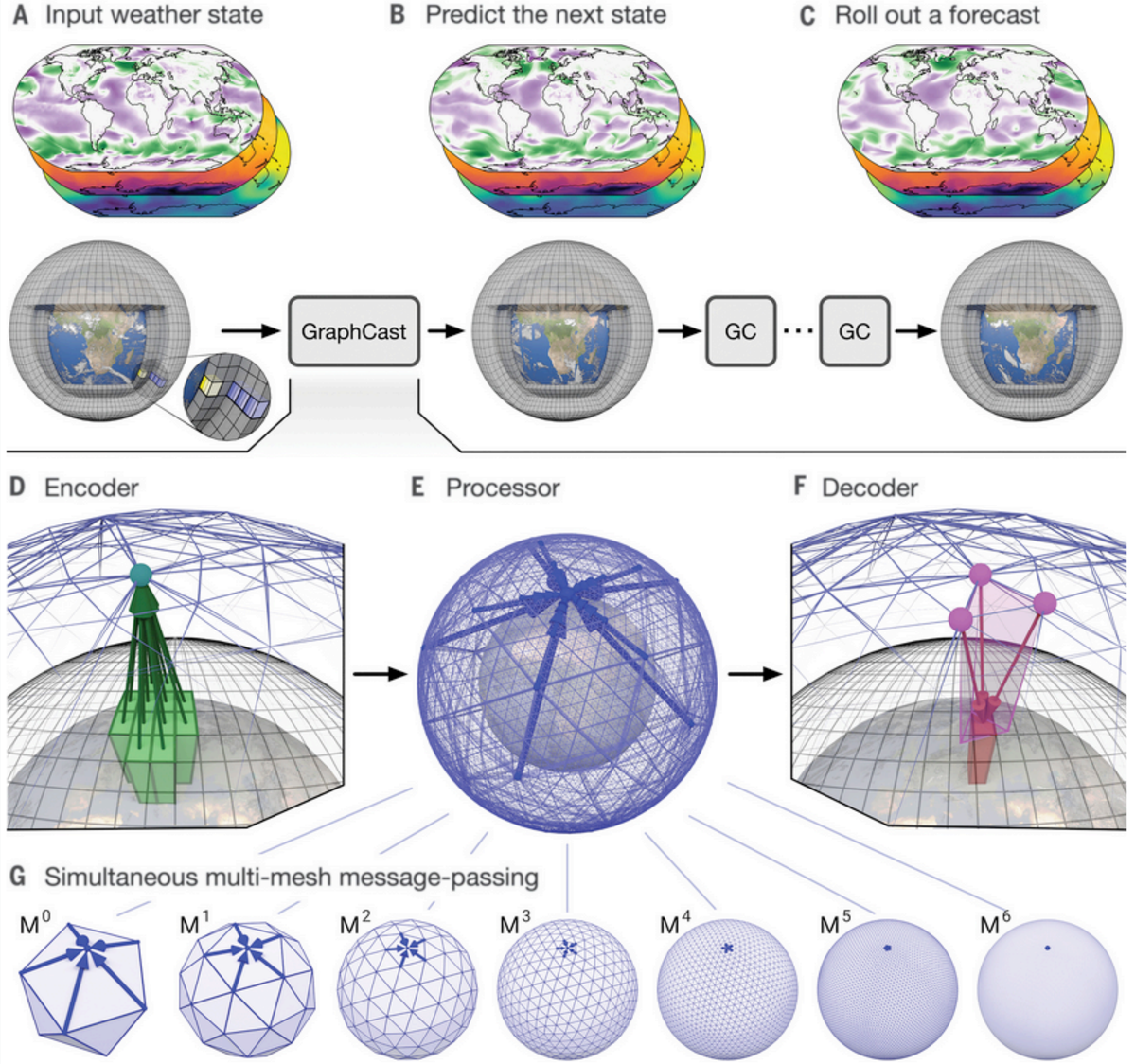
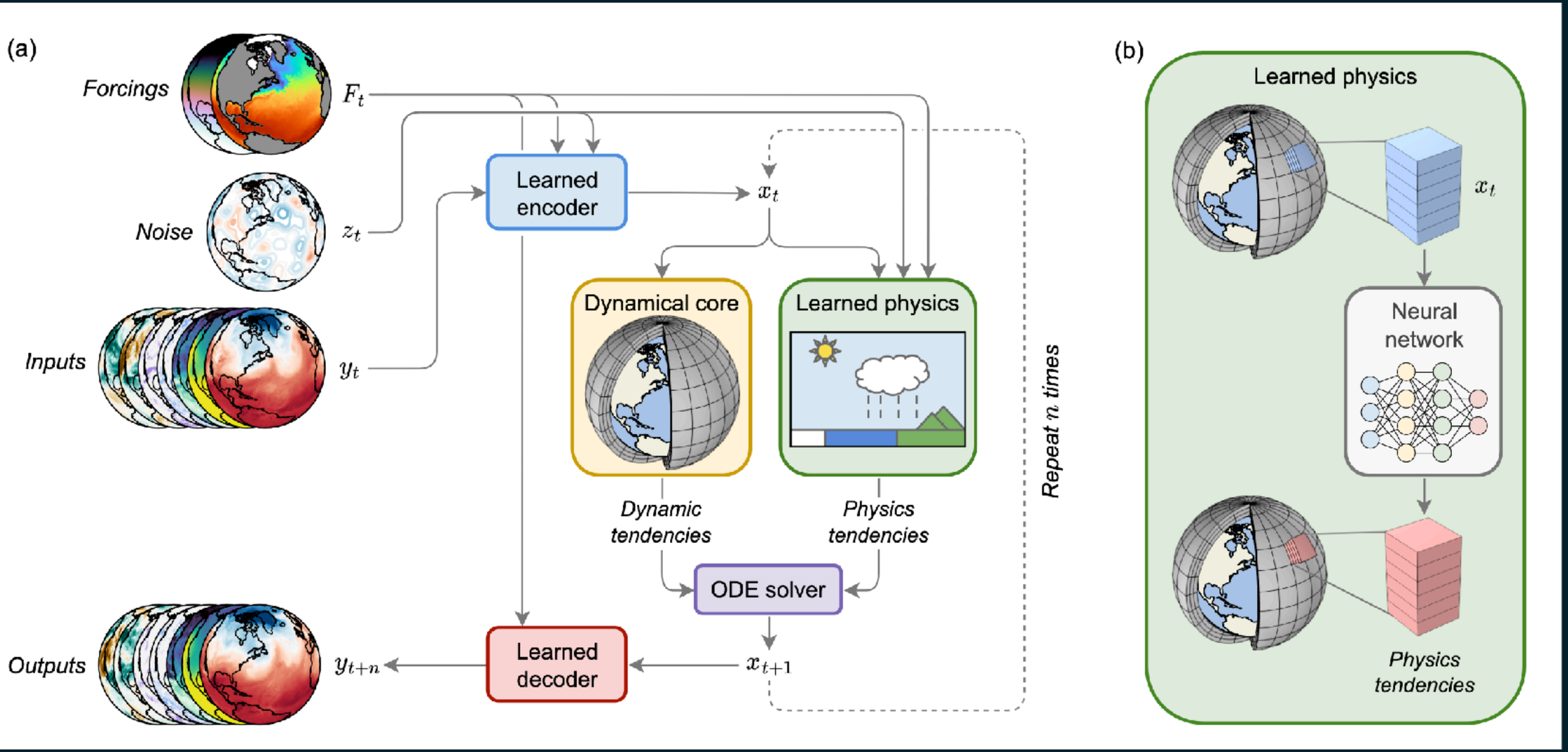


Fig. 1. Model schematic.

(**A**) The input weather state(s) are defined on a 0.25° latitude-longitude grid comprising a total of 721 × 1440 = 1,038,240 points. Yellow layers in the close-up pop-out window represent the five surface variables, and blue layers represent the six atmospheric variables that are repeated at 37 pressure levels (5 + 6 × 37 = 227 variables per point in total), resulting in a state representation of 235,680,480 values. (**B**) GraphCast predicts the next state of the weather on the grid. (**C**) A forecast is made by iteratively applying GraphCast (GC) to each previous predicted state, to produce a sequence of states that represent the weather at successive lead times. (**D**) The encoder component of the GraphCast architecture maps local regions of the input (green boxes) into nodes of the multimesh graph representation (green, upward arrows that terminate in the green-blue node). (**E**) The processor component updates each multimesh node using learned message-passing (heavy blue arrows that terminate at a node). (**F**) The decoder component maps the processed multimesh features (purple nodes) back onto the grid representation (red, downward arrows that terminate at a red box). (**G**) The multimesh is derived from icosahedral meshes of increasing resolution, from the base mesh (M^0, 12 nodes) to the finest resolution (M^6, 40,962 nodes), which has uniform resolution across the globe. It contains the set of nodes

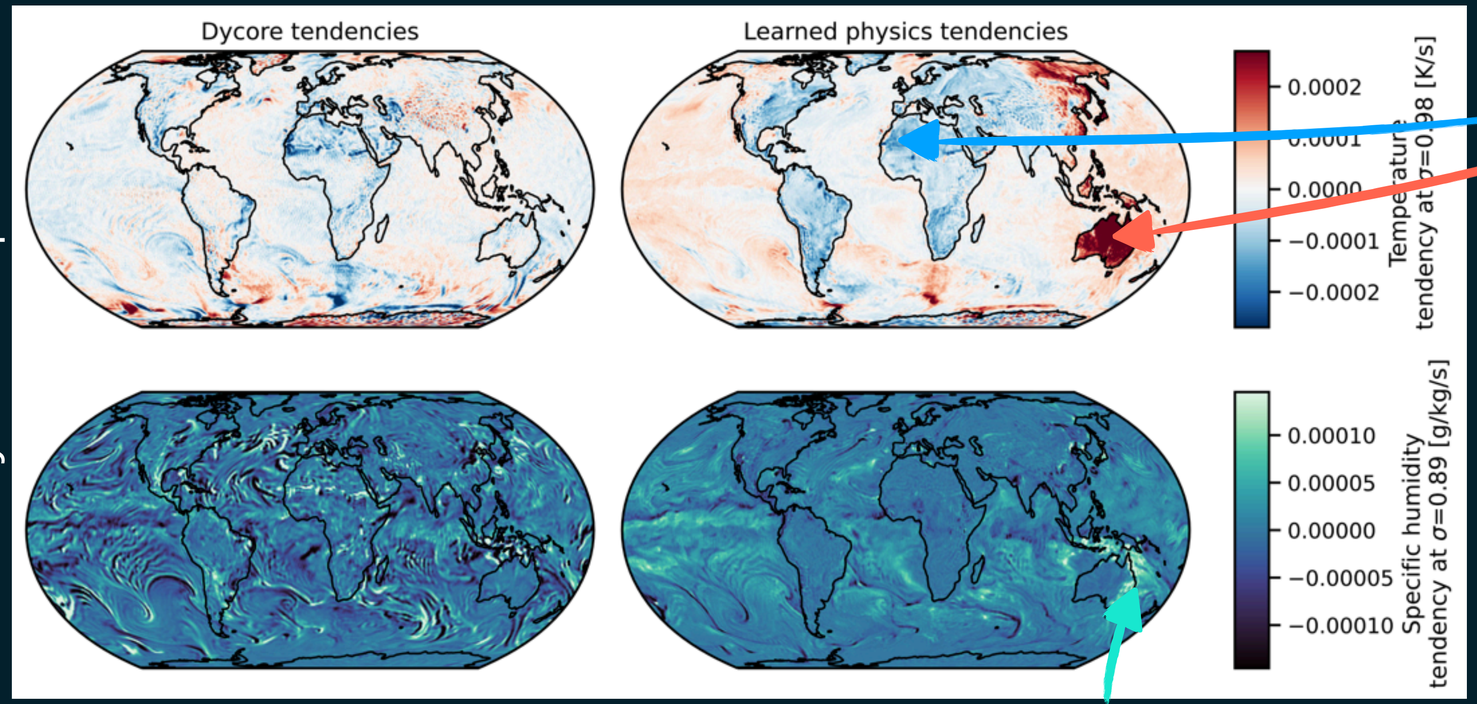
Neural General Circulation Models



Kochkov et al., 2023

- Differentiable model (dynamics + physics) based on Python+JAX
- More explainable than pure ML

Physics discovery and generalisation

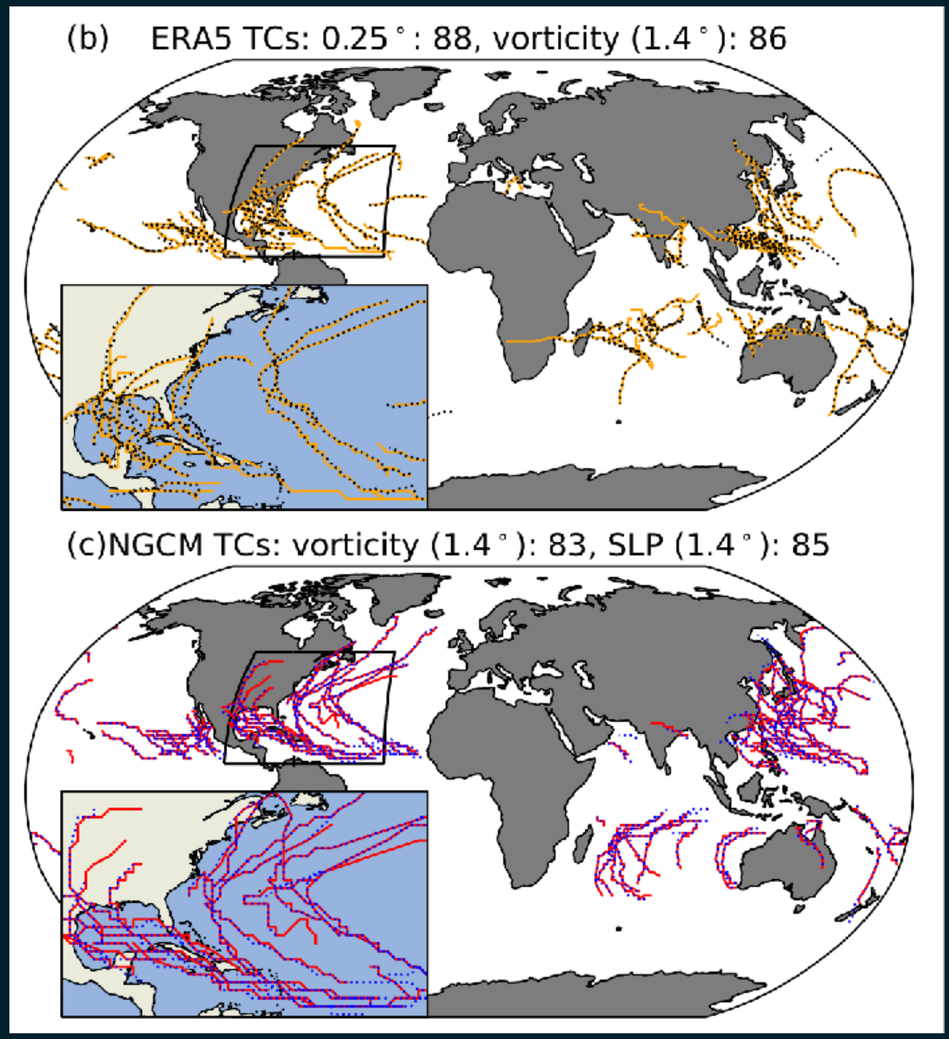


Kochkov et al., 2024

Radiative surface cooling (night) and heating (day)

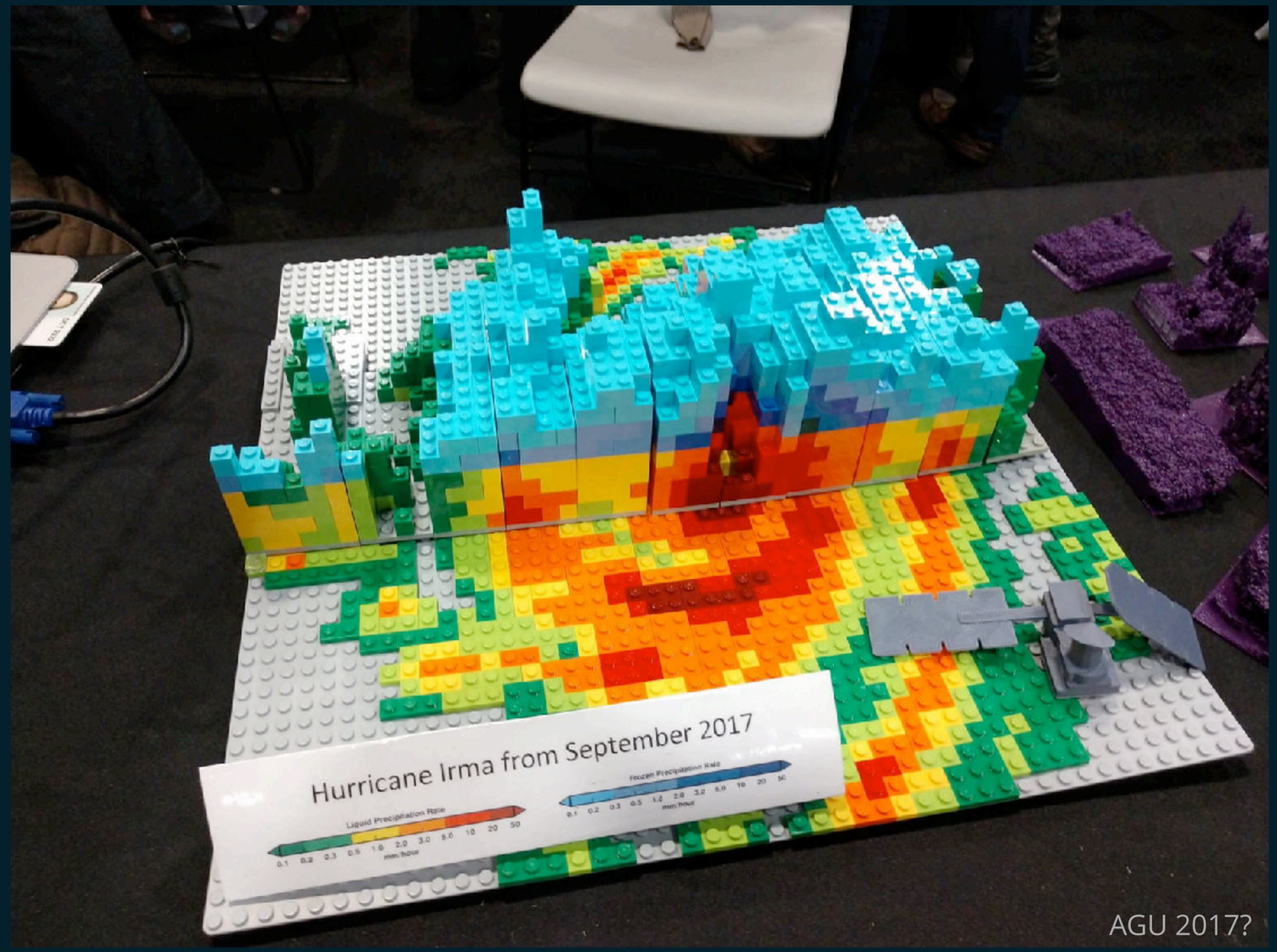
Daytime evaporation + convection over tropical oceans

Tropical cyclone statistics well simulated



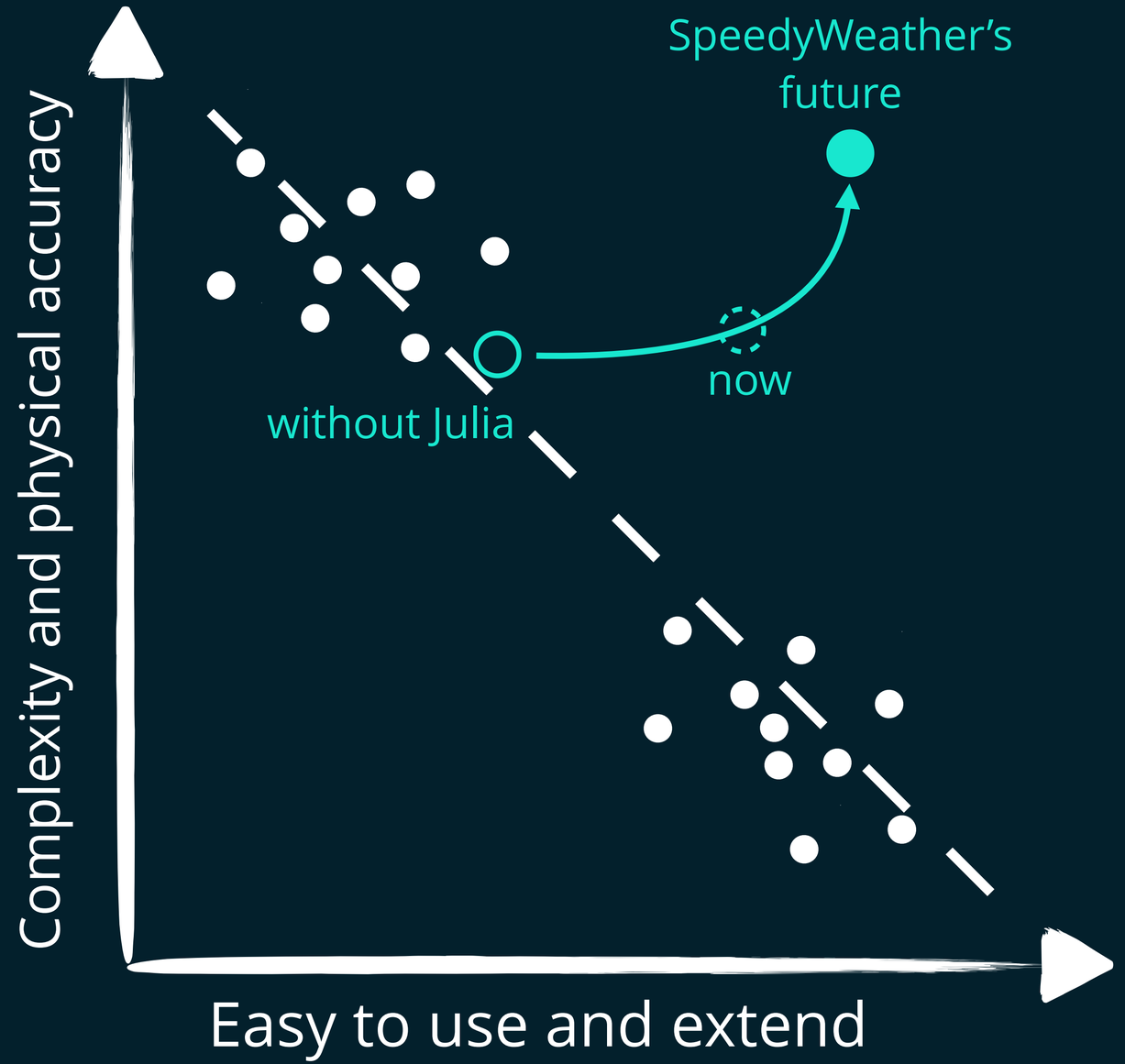
Trained on weather but skilful for climate

What do we want climate models to be?

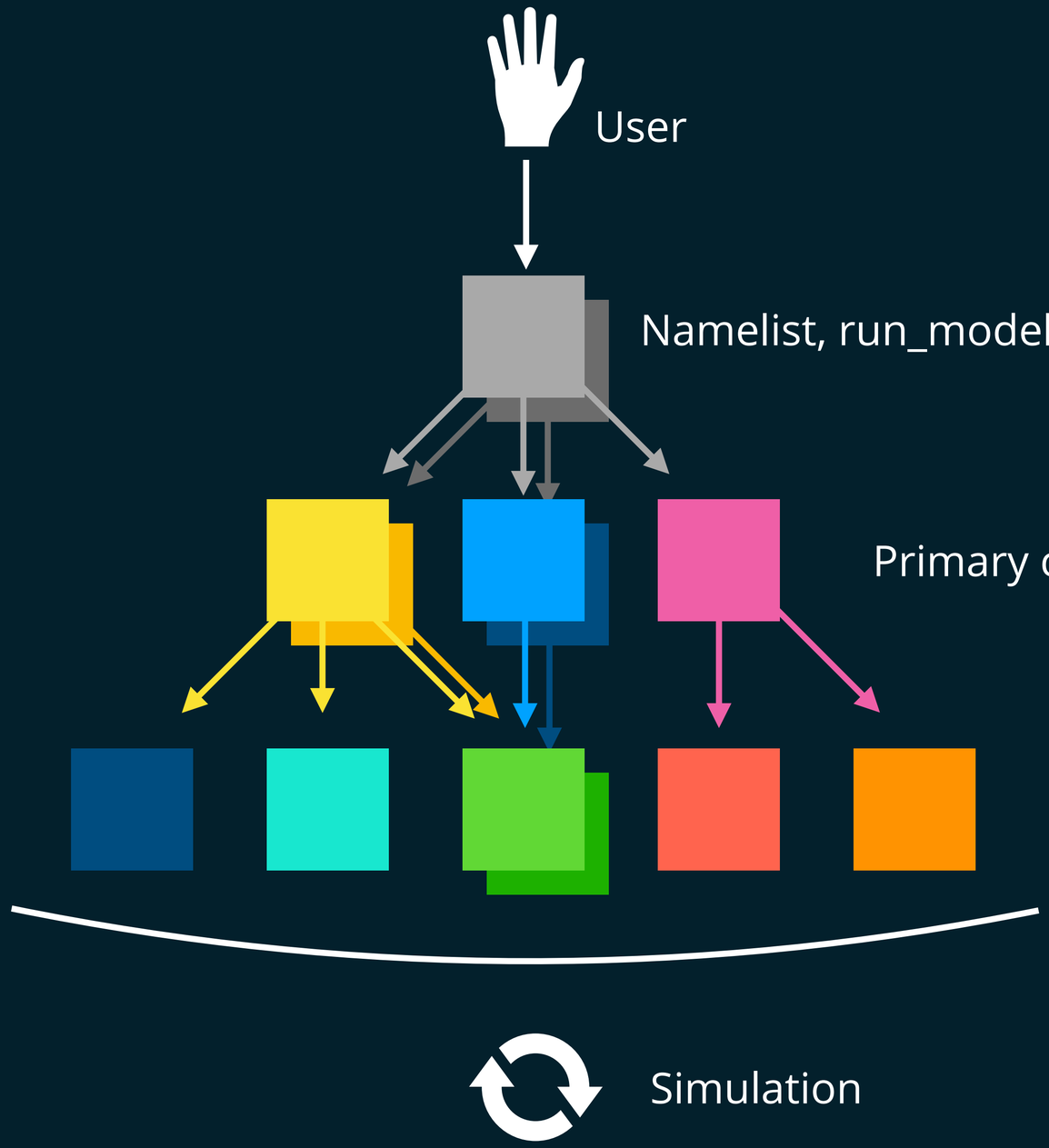


AGU 2017?

Two language-problem of weather and climate models

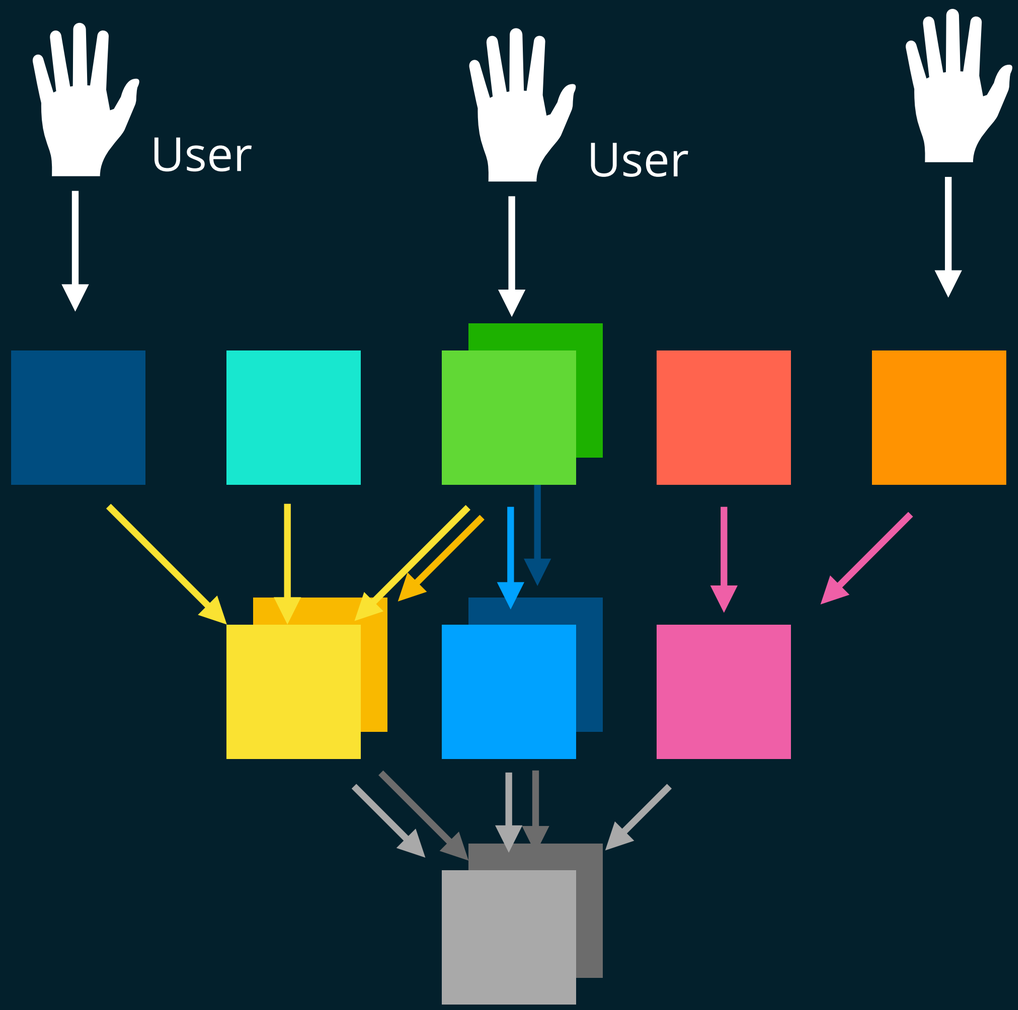


Monolithic interface?



Modularity, extendability, composability very hard!

Model constructor interface



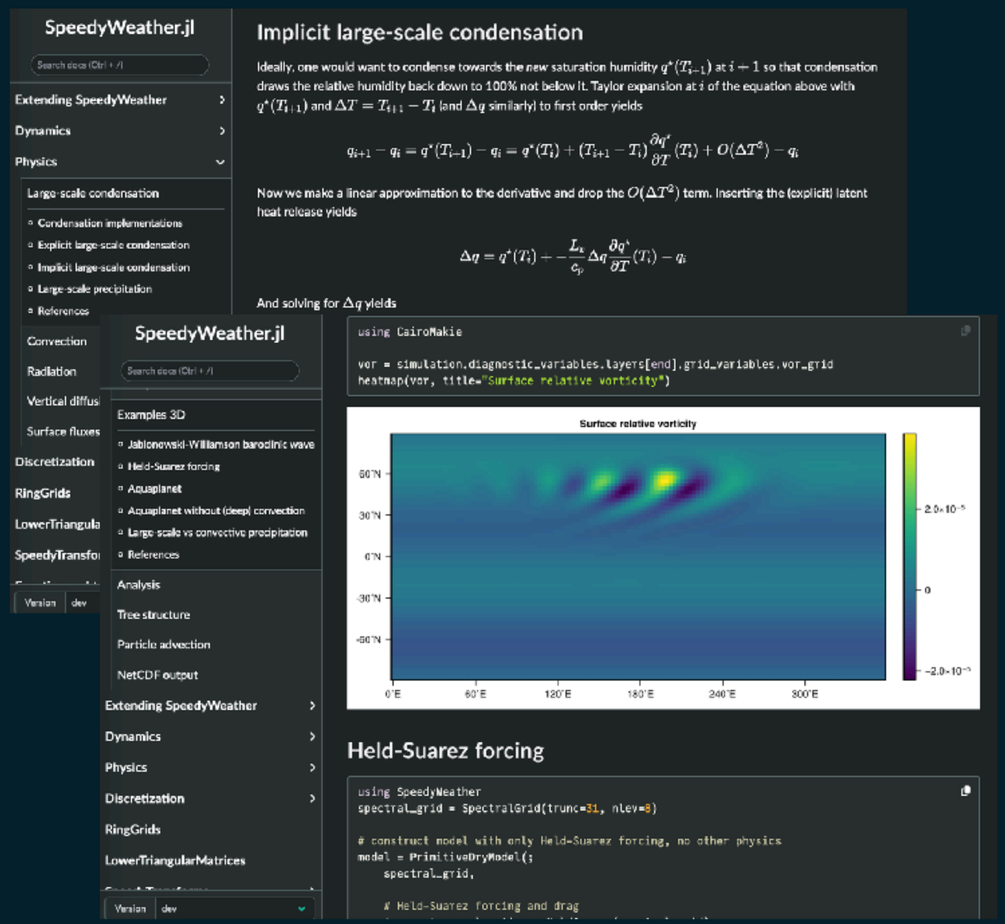
Model components

Internals

Model

Simulation

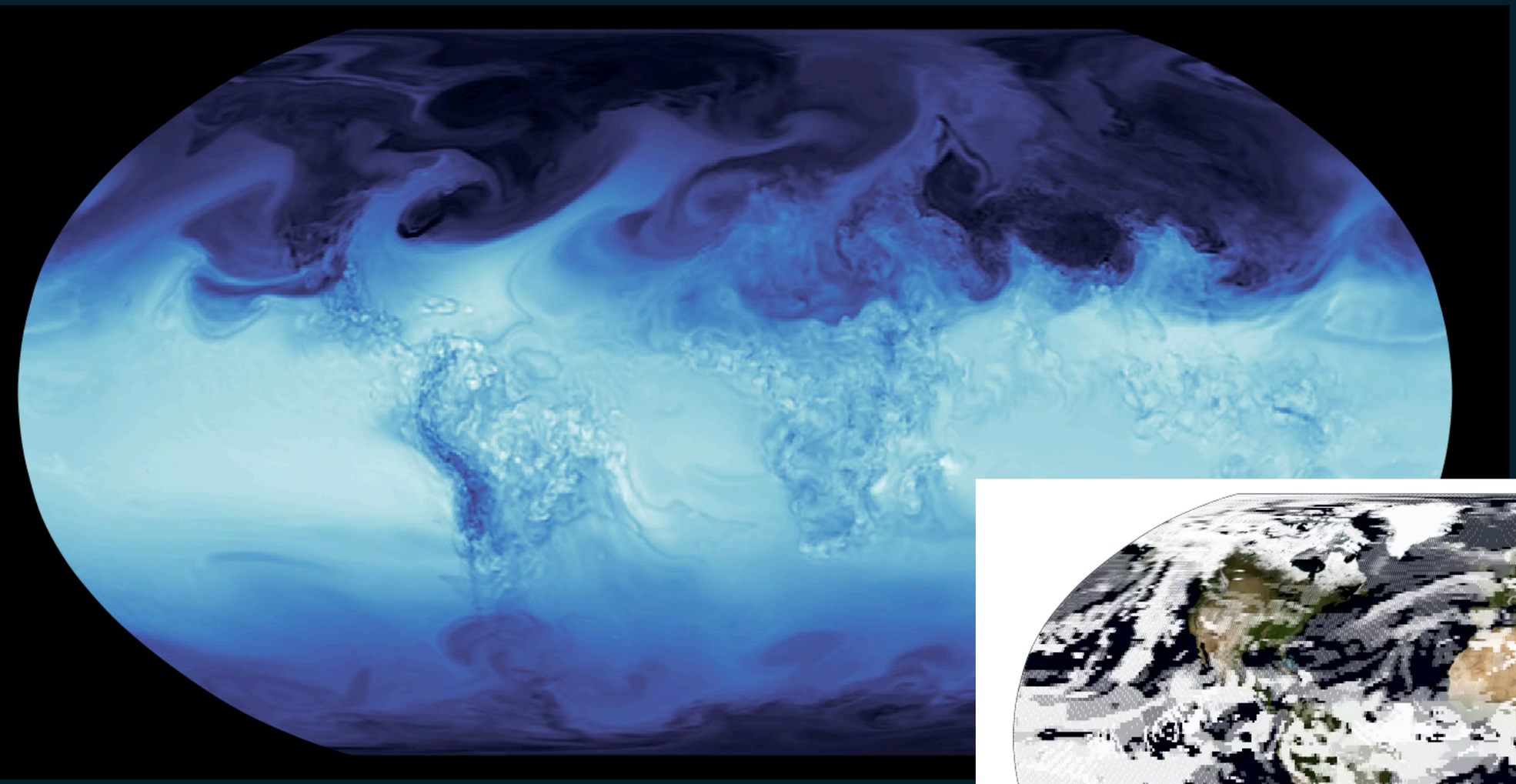
SpeedyWeather.jl v0.10: Where are we?



Extensive documentation, with examples
+ “textbook” on global atmospheric modelling

JOSS paper is out!

Higher resolution examples



Humidity at 40km resolution

Cloud cover