Possible Applications of Deep Neural Networks in Climate and Weather

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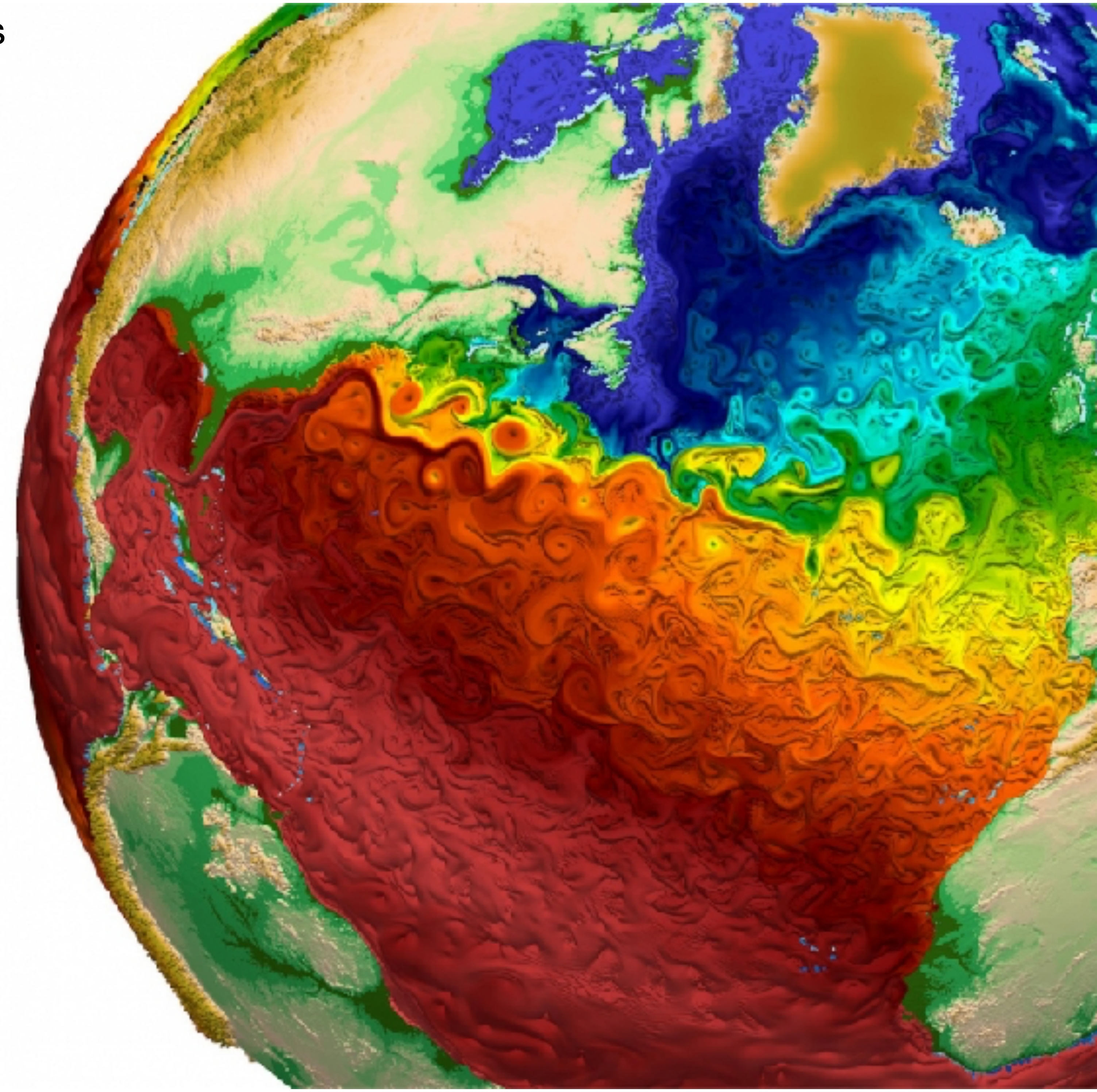
Quick overview of climate and weather models

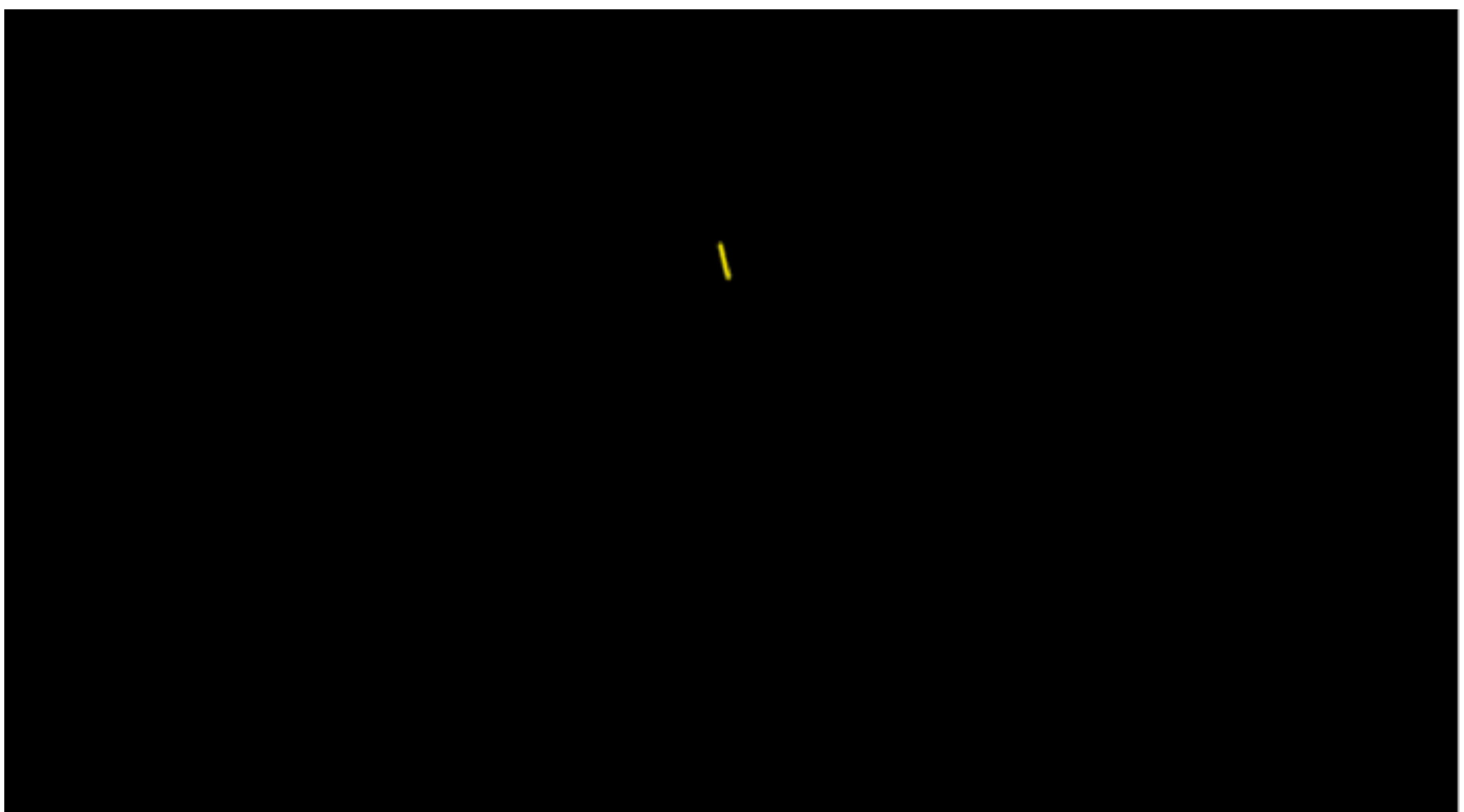
- Weather models use current conditions to try to simulate what the weather will be like for the next 7-10 days
- Climate models estimate what average climate conditions will be like over the next several decades, centuries, or millennia
- Weather models are run at high resolutions, for local regions, for short periods of time.
- Climate models are run at lower resolution, for the entire globe, for very long periods of time
- Both solve fluid dynamics equations to model the motion of the ocean, atmosphere, ice, etc.
- Both have to use approximations for things that are too small to model (ice-crystals, trubulence, etc.)

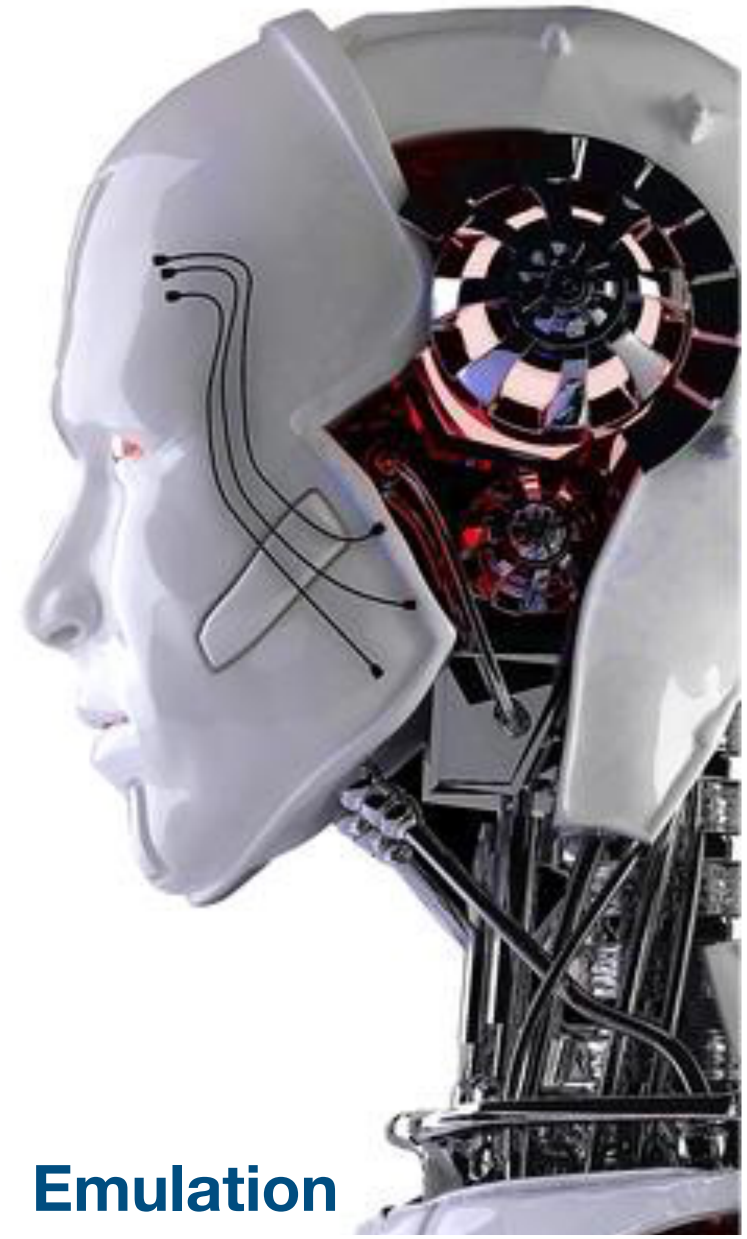


Quick overview of climate and weather models

- It is impossible to get an *exact* forecast for either problem, because geophysical fluid systems are chaotic. (sensitive to initial conditions)
- Small uncertainties in our measurements of the initial conditions grow exponentially larger over time. That’s why we can’t predict the weather months in advance
- Can predict averaged quantities and statistics over much longer time periods. (climate)
- An ensemble of weather forecasts is used to predict which outcomes are mostly likely
- An ensemble of climate models is used to estimate the uncertainty in the projections

Lorenz Attractor: Sensitivity to initial conditions





Accelerate Weather and Climate Models Through Process Emulation

Improve model performance by replacing expensive calculations with neural-network emulations of those calculations

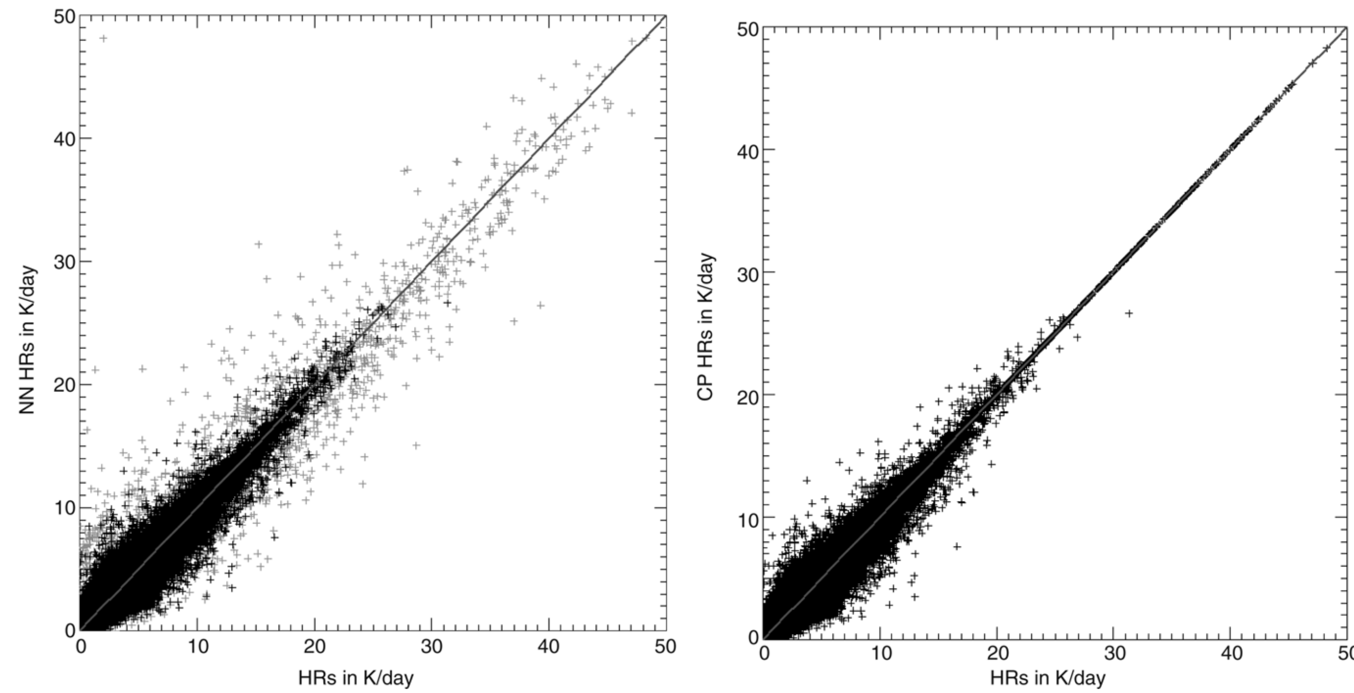
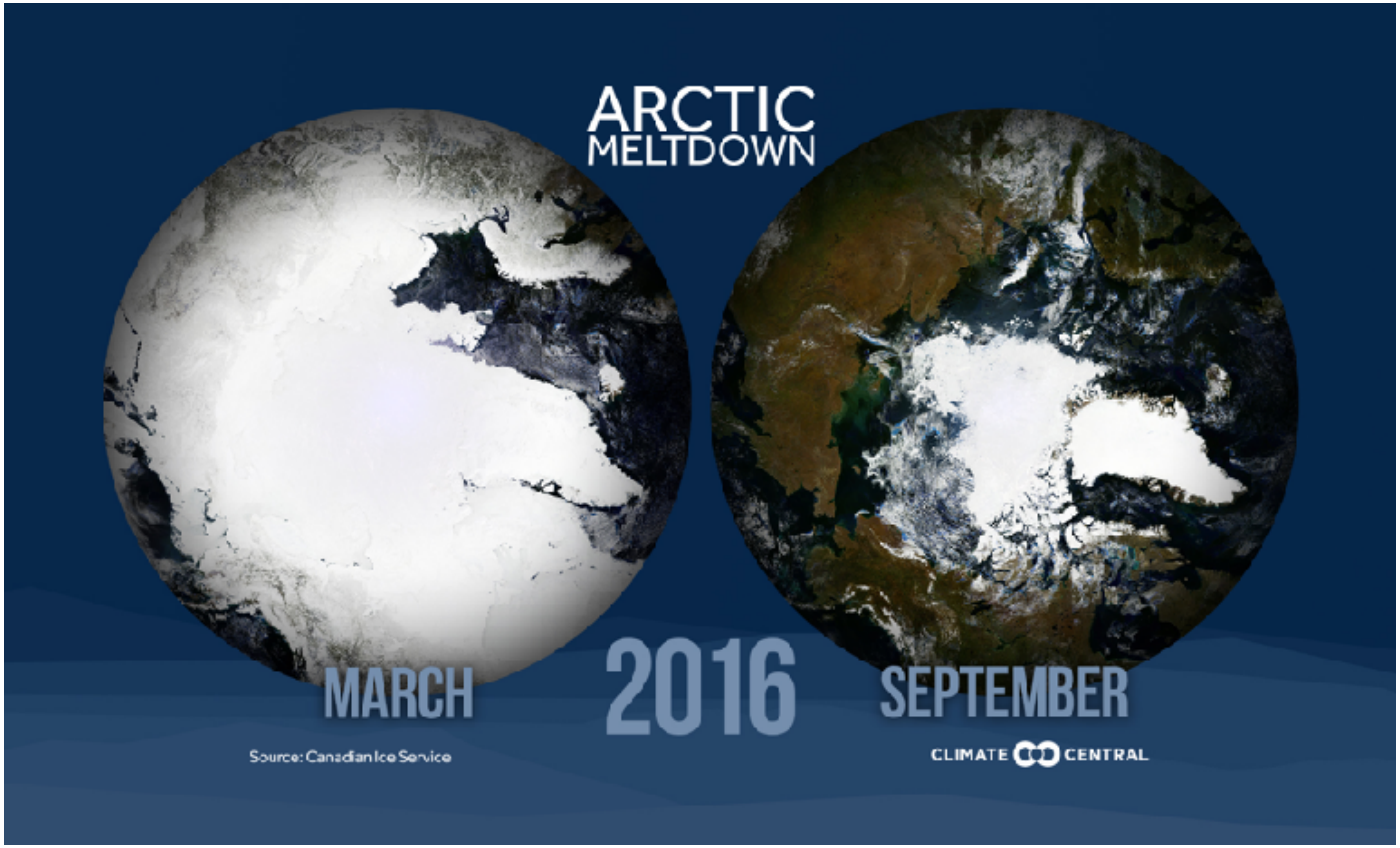


Figure 5: Quantifying emulation accuracy: An ideal deterministic emulation would give the same output as the routine it replaces, forming a straight line on a plot such as this one. Here, the heating rate produced by a NN emulation of short wave radiation in [40] is plotted as a function of the heating rate of the original model. Emulation accuracy is compared without quality control (left) and with quality control (right). (Image credit: [40])

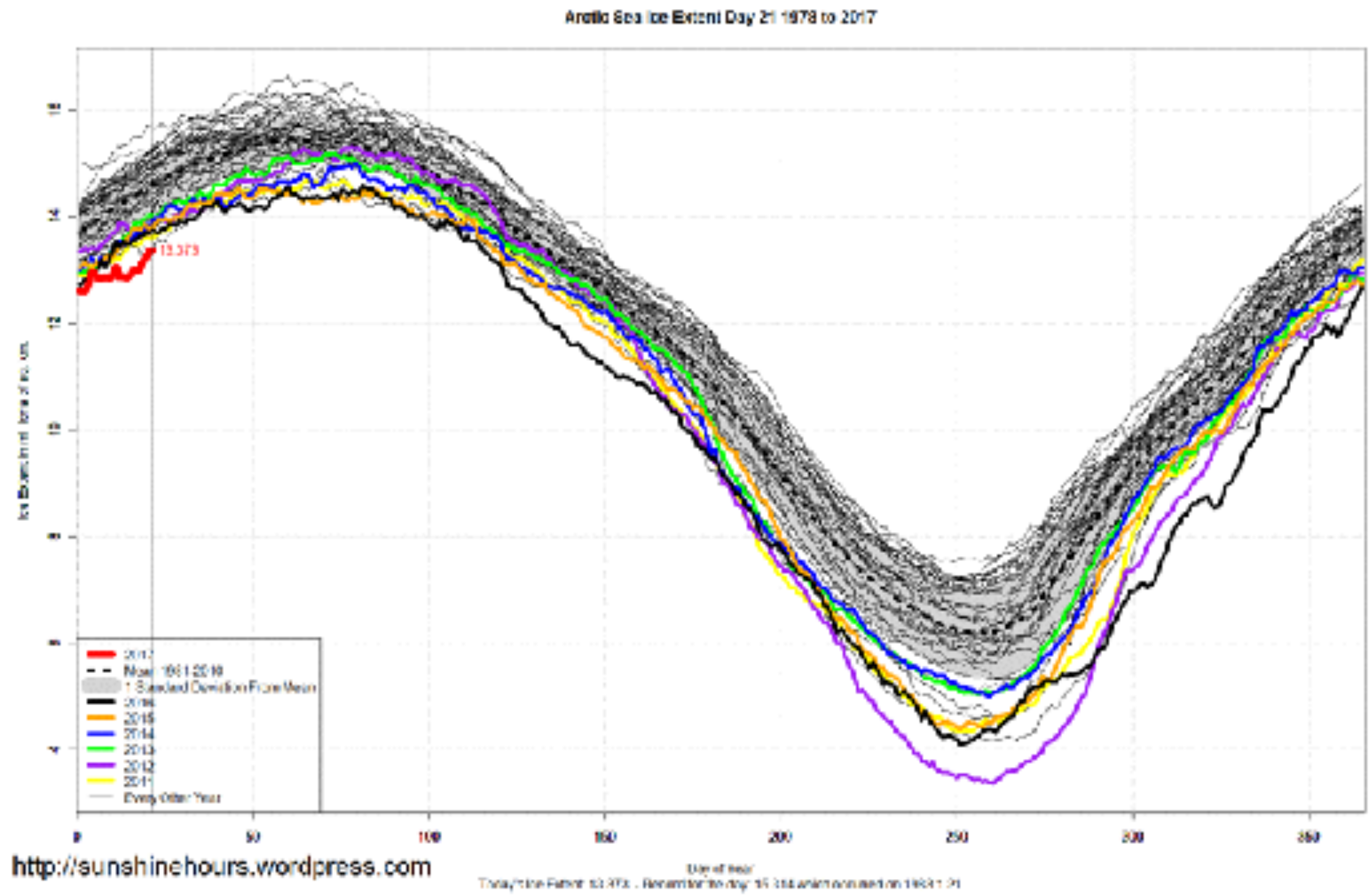
- NN emulation can be used to speed up very expense calculations
- Replace the original function with a neural network that gives the same answers.
- Its like a lookup table of pre-computed values, but generalizes to new inputs.
- Has been used to achieve speedups of 250x in climate simulations
- Increased speed enables higher resolution, more ensemble members, longer runs
- Need to quantify how well the emulation reproduces the original function
- Sometimes a second network is trained to detect anomalous output from the emulator

- Data source: RRTMG or Dynamics model output generated by colleagues at ORNL
- Inputs X: climate variables in a column (Temperature, wind speeds, moisture, pressure, etc)
- Outputs Y: Amount of heat gained/lost at at each point in the column



Forecast Next Year's Arctic Ice Cover

Use early season conditions to determine ice coverage in September.
Figure out whether the Arctic will be passable to ships this year.

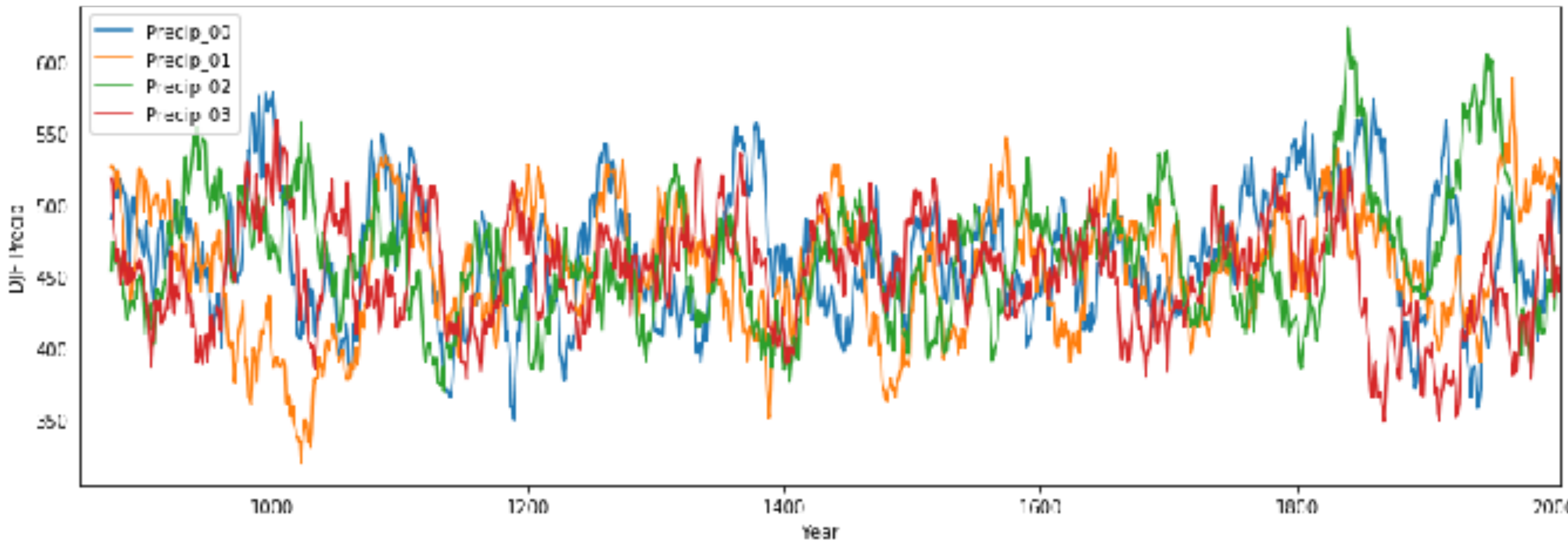


- Each year, the Arctic sea ice peaks in March and reaches a minimum in September
- It is very hard to forecast in the spring how much ice will be left in the fall
- Sea-Ice Outlook website collects predictions in May for Sept of that same year.
- https://www.arcus.org/sipn/sea-ice-outlook
- So far the predictions have not been very skillful.
- Measure success relative to the persistence model (using last year's September value)
- More challenging: Predict where the ice will be in the arctic
  - Will the arctic be passable to ships next year?

- **Data source: NCAR's CESM large ensemble data from Earth System Model Grid**
- **https://www.earthsystemgrid.org/dataset/ucar.cgd.ccsm4.CESM_CAM5_BGC_LE.html**
- Inputs X: current ice concentration, ice thickness, sea-surface temperature, surface winds, precipitation
- Outputs Y: total sea-ice extent in September; sea-ice thickness field

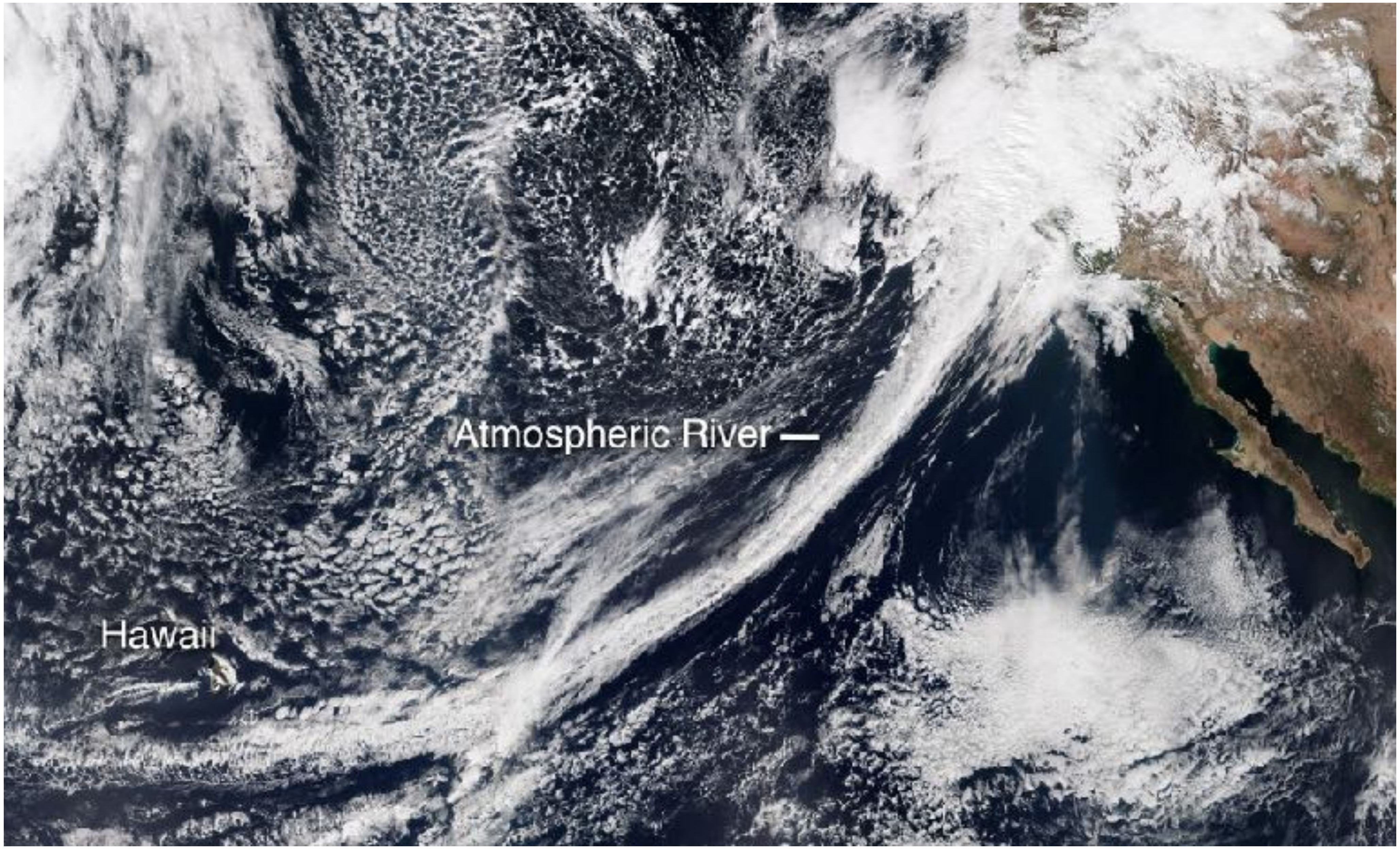
Predict California’s Next Drought or Flood

Use fall conditions to predict whether total winter rainfall will be above or below normal



- California has been experiencing large oscillations in its climate recently.
- Most of the rainfall in CA is delivered by a few large storms in the winter
- Planners need to know wether to empty the reservoirs to avoid flooding, or to keep them full to avoid drought.
- Q: can you predict how much rain CA will get by looking at early season conditions?
- This problem was given as a 1 day hackathon challenge at this year’s climate informatics conference at NCAR
- Competition to see who can make the best predictions

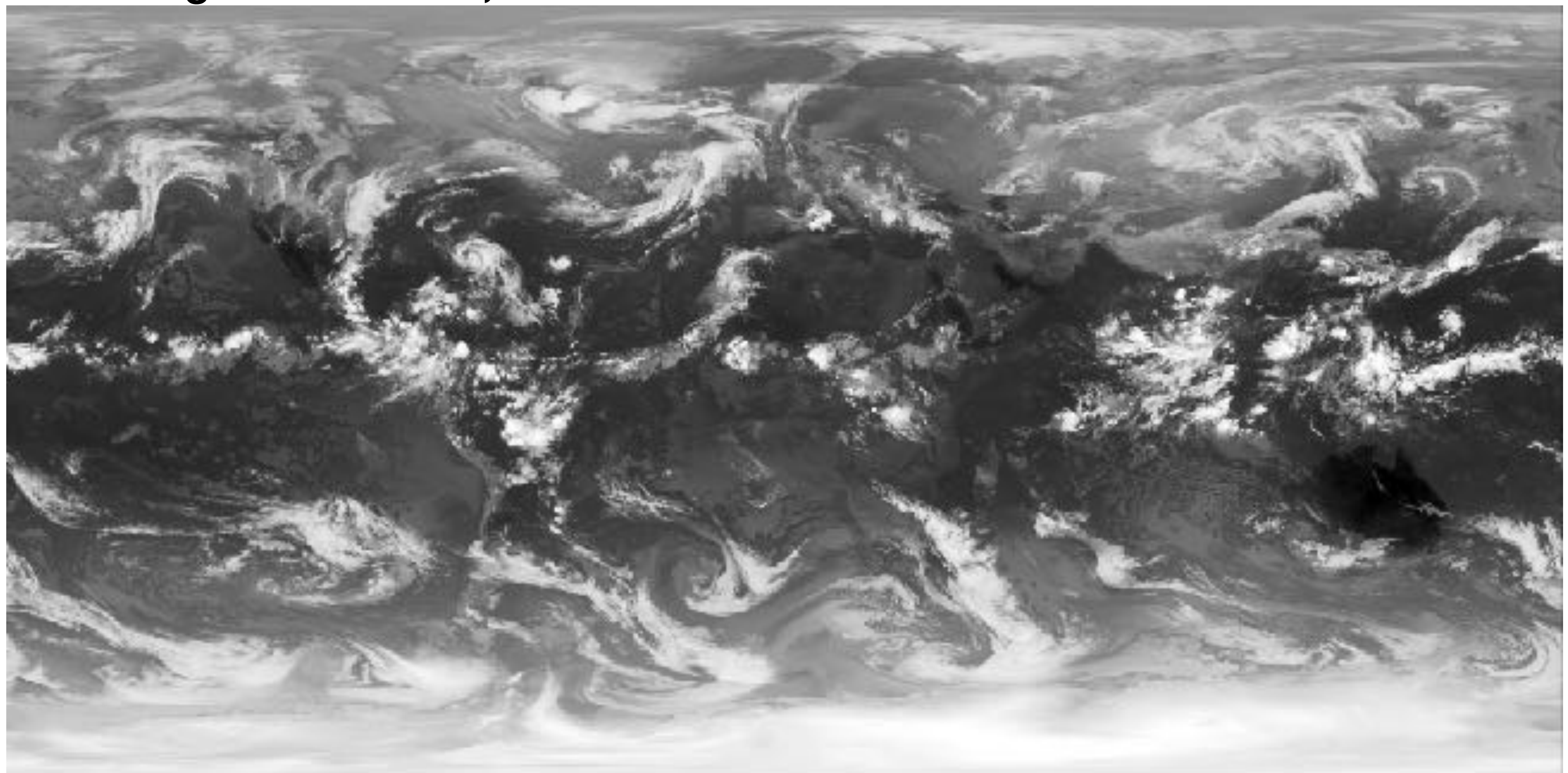
- **Data: NCAR Last Millennium Ensemble Climate Model data**
- https://github.com/ramp-kits/california_rainfall/blob/master/california_rainfall_starting_kit.ipynb
- Input X: November climate fields (T, p, u, v, moisture)
- Output Y: classification as a high rain or low rain year



Detect Extreme Weather In Satellite Imagery

Automatically process satellite images to locate extreme events such as hurricanes, atmospheric rivers, storm fronts, and extra-tropical cyclones

Infrared global satellite, oct 10 2017

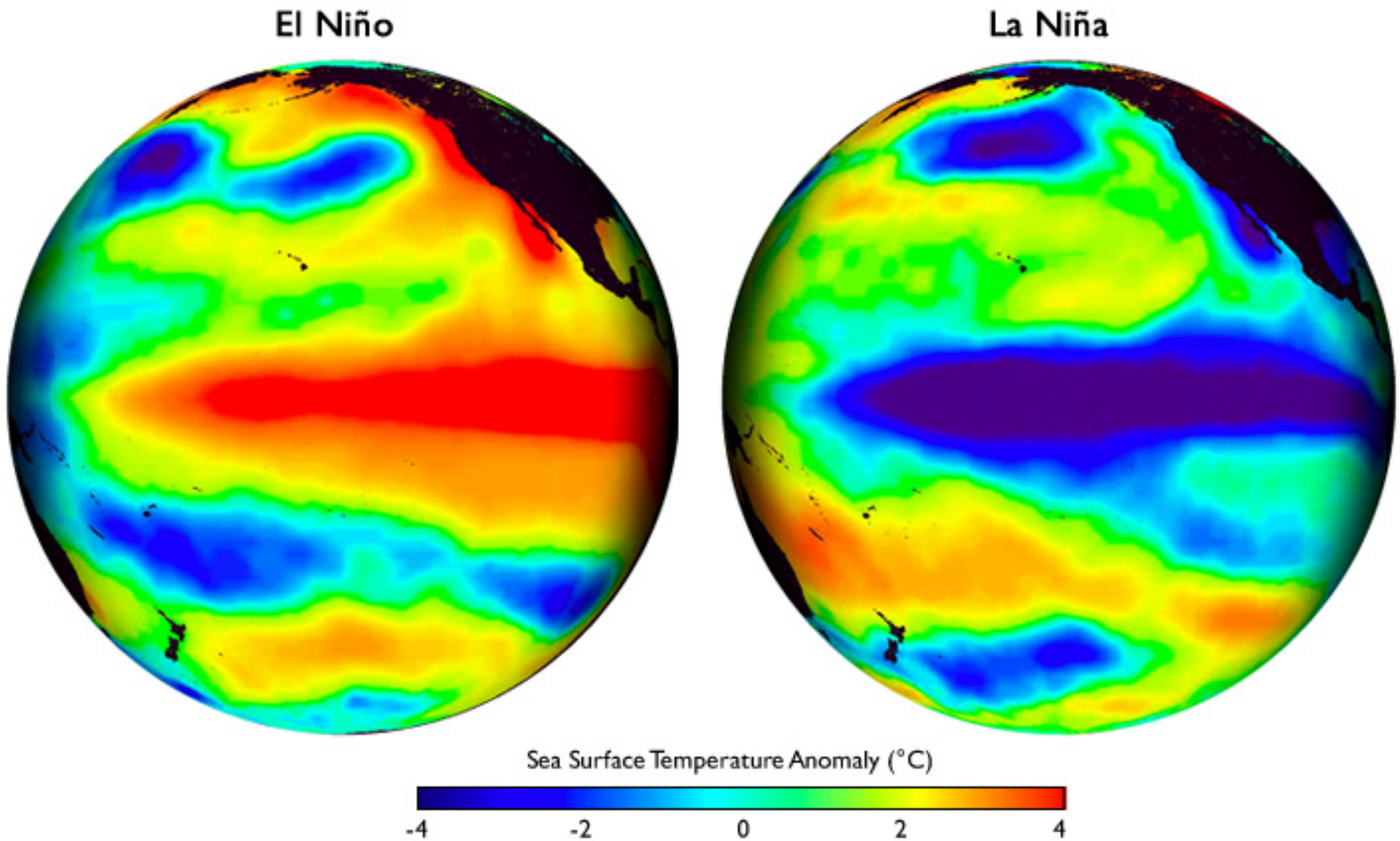


https://www.nnvl.noaa.gov/view/globaldata.html

- Large amounts of data produced by satellites each year
- Most of it goes un-analyzed, since it takes many man-hours to examine it
- NN image analysis can be used to automatically detect important features/anomolies
- Easiest targets are hurricanes: classify them, detect their position and extent
- Somewhat harder: locate atmospheric rivers, extra-tropical cyclones, and storm fronts.

- **Data source: satellite images from NOAA**
- Input X: radar or visible images
- Output Y: locations and number of extreme events

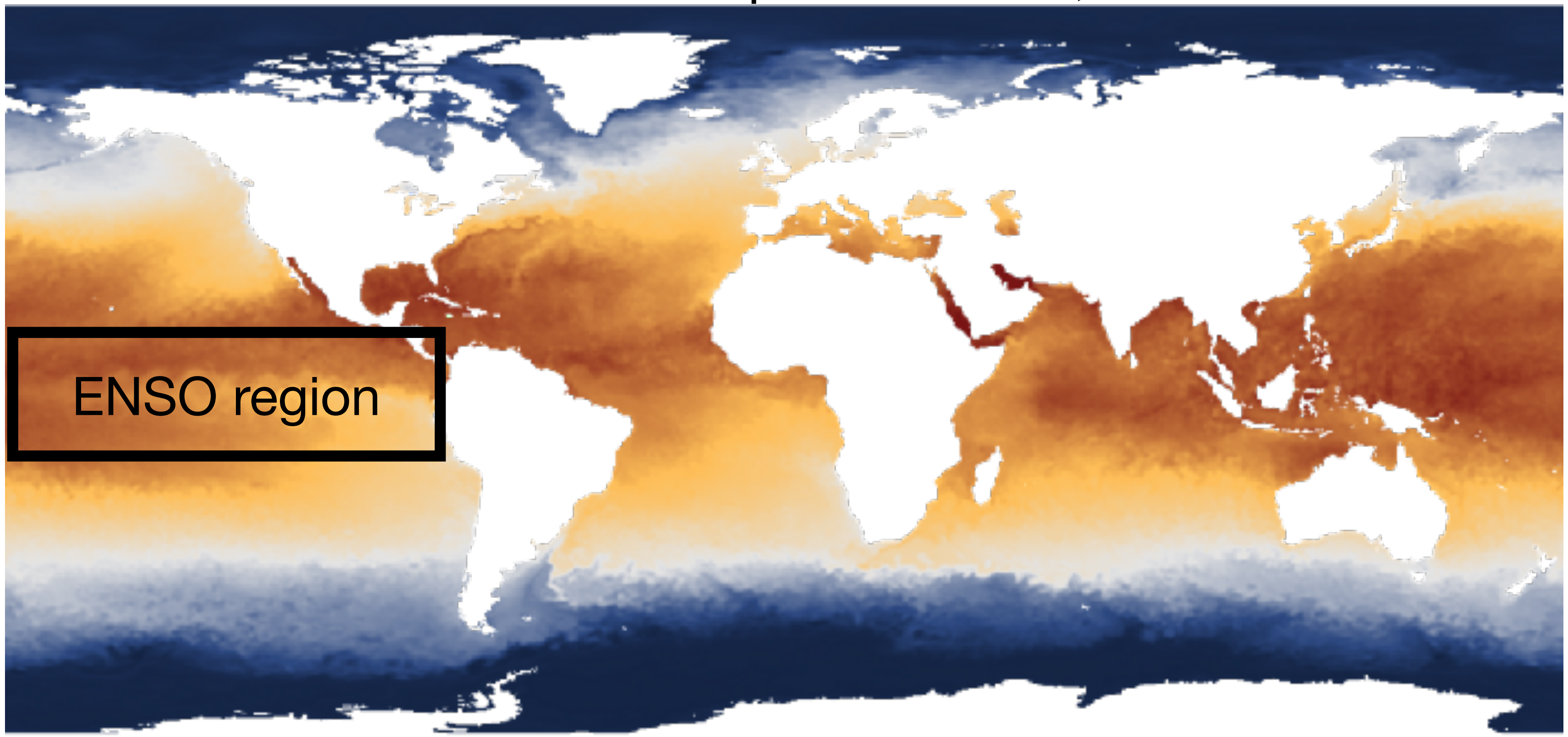
https://www.kaggle.com/uciml/el-nino-dataset



Forecast Next Year's ENSO Oscillation (El Niño / La Niña)

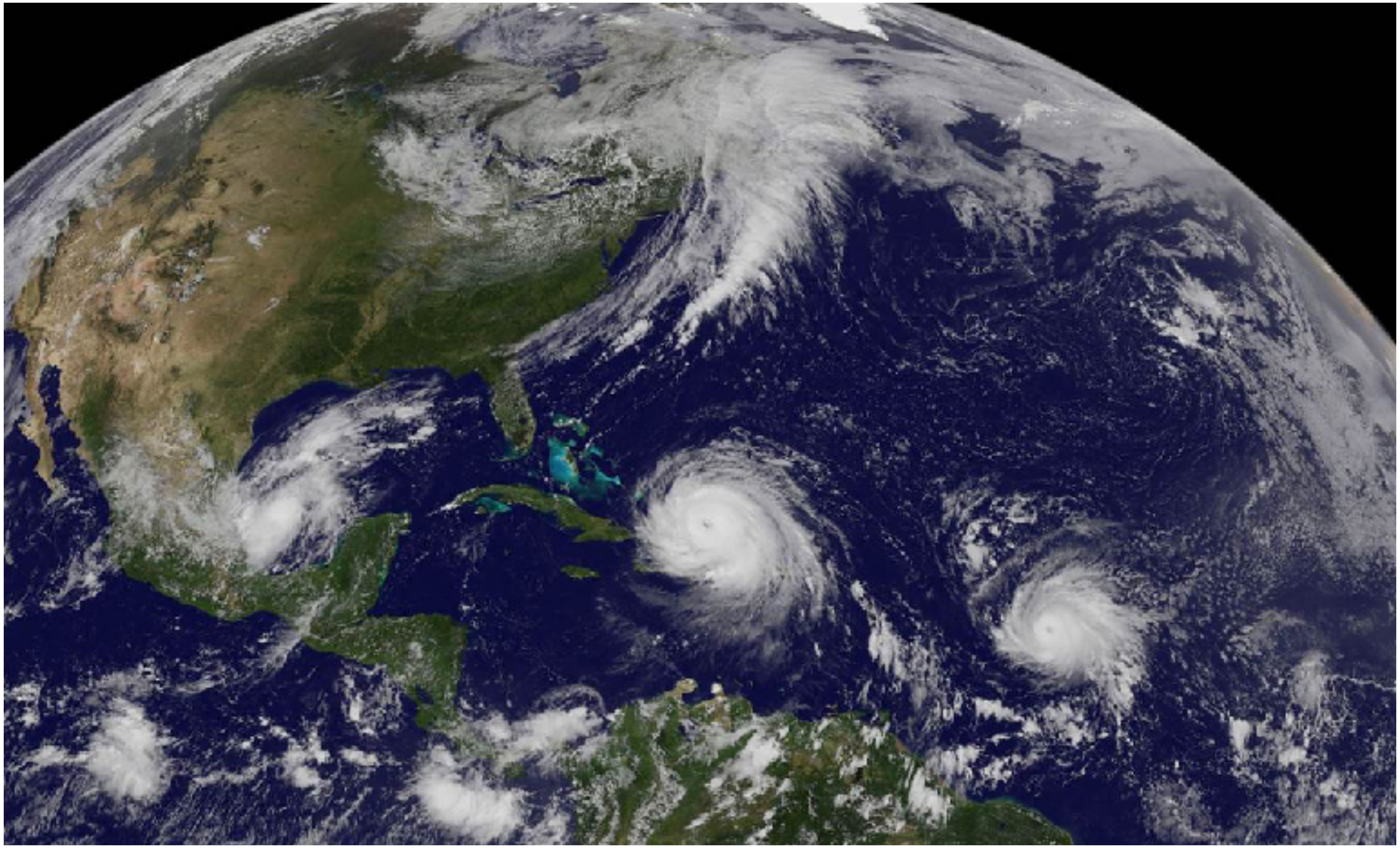
Determine as far in advance as possible whether next year's oscillation will be in a hot or cold phase, with important impacts to global weather

Sea surface temperatures Oct, 2017



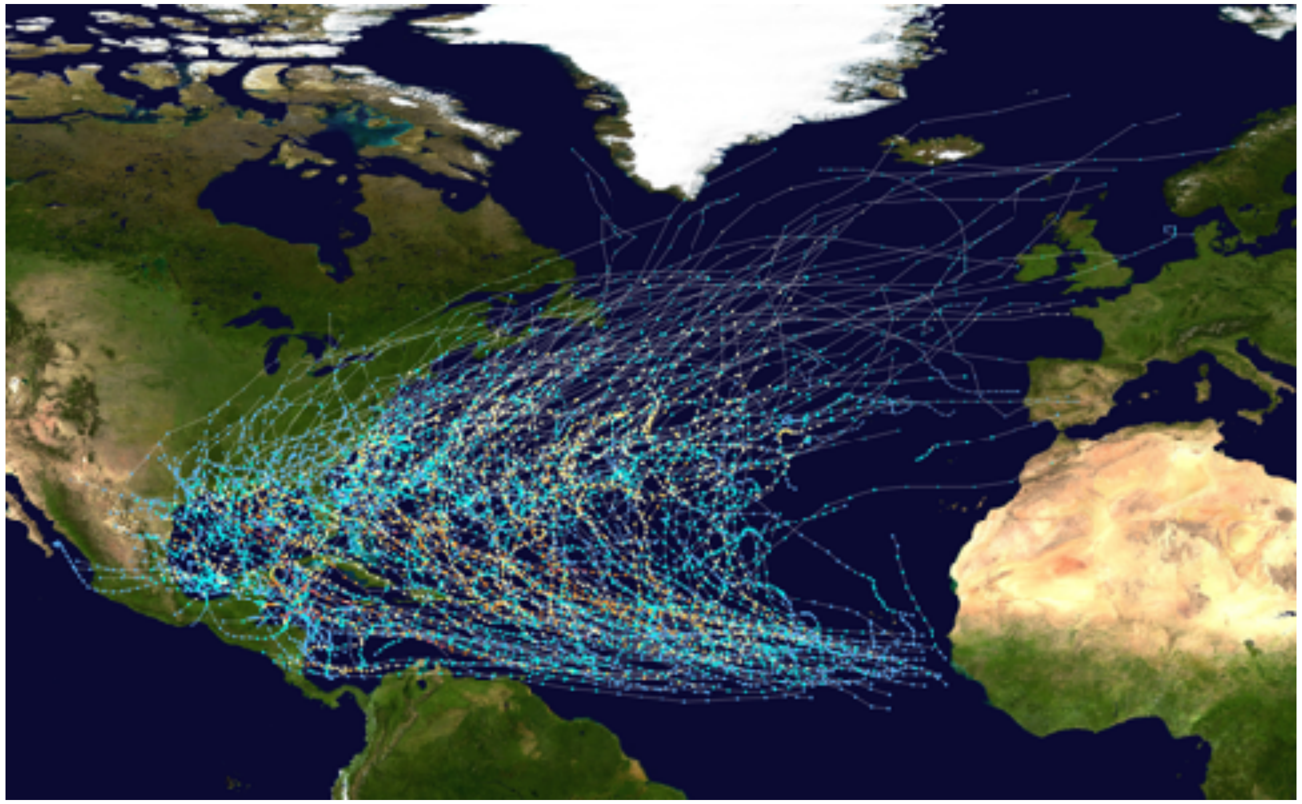
- Each year, the Earth's has a seasonal oscillation: winter, spring, summer, fall
- Second largest oscillation is ENSO: the El Niño Southern Oscillation
- Pattern of winds and sea-surface temperatures over the tropical easter Pacific
- Surface temps can be neutral, hot (El Nino), or cold (La Nina)
- Has a large impact on global weather.
- Each phase lasts typically 6-18 months, but it is very difficult to predict.
- Try to predict the El Nino phase each year using either climate model data, or satellite observations

- Data source: CESM large ensemble data, or satellite images
- Input X: climate data from the previous year
- Output Y: oscillation category: hot, neutral, or cold



Predict The Next Hurricane Season

Use the current climate state to predict how many hurricanes we will have and their intensities



- Each season weather forecasters attempt to predict the hurricane season
- How many hurricanes will there be?
- How strong will they be?
- What tracks will the hurricanes take?
- The skill of these forecasts is very low
- Try to predict these numbers by looking at early season satellite data

- https://www.esrl.noaa.gov/psd/data/timeseries/monthly/Hurricane/

- Data source: Satellite and NOAA data
- Input X: sea-surface temperatures, El Nino phase, winds, etc
- Output Y: number of hurricanes, strength of hurricanes

- Some other ideas
- Downscaling (super-resolution): use coarse climate model data to try to infer higher resolutions versions.
- method: auto-encoders, semantic hashing. Use latent vector to find climate states most similar to current state, to forecast (hurricanes, ENSO, rapid ice loss etc.)
- Other Kaggle datasets related to tornados, hailstorms, etc. Search for the keywords climate or weather