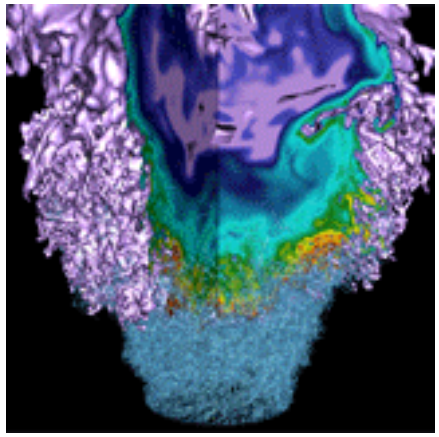
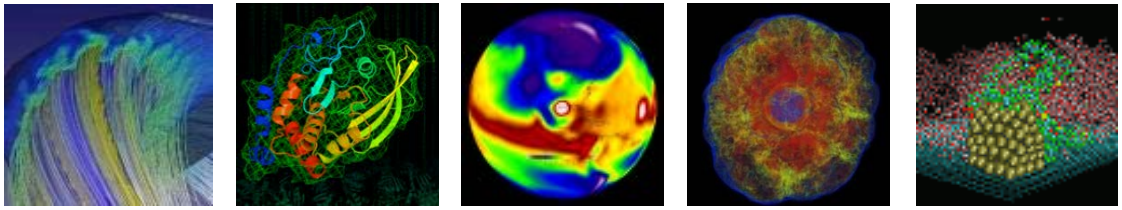
Deep Learning recognizes weather and climate patterns



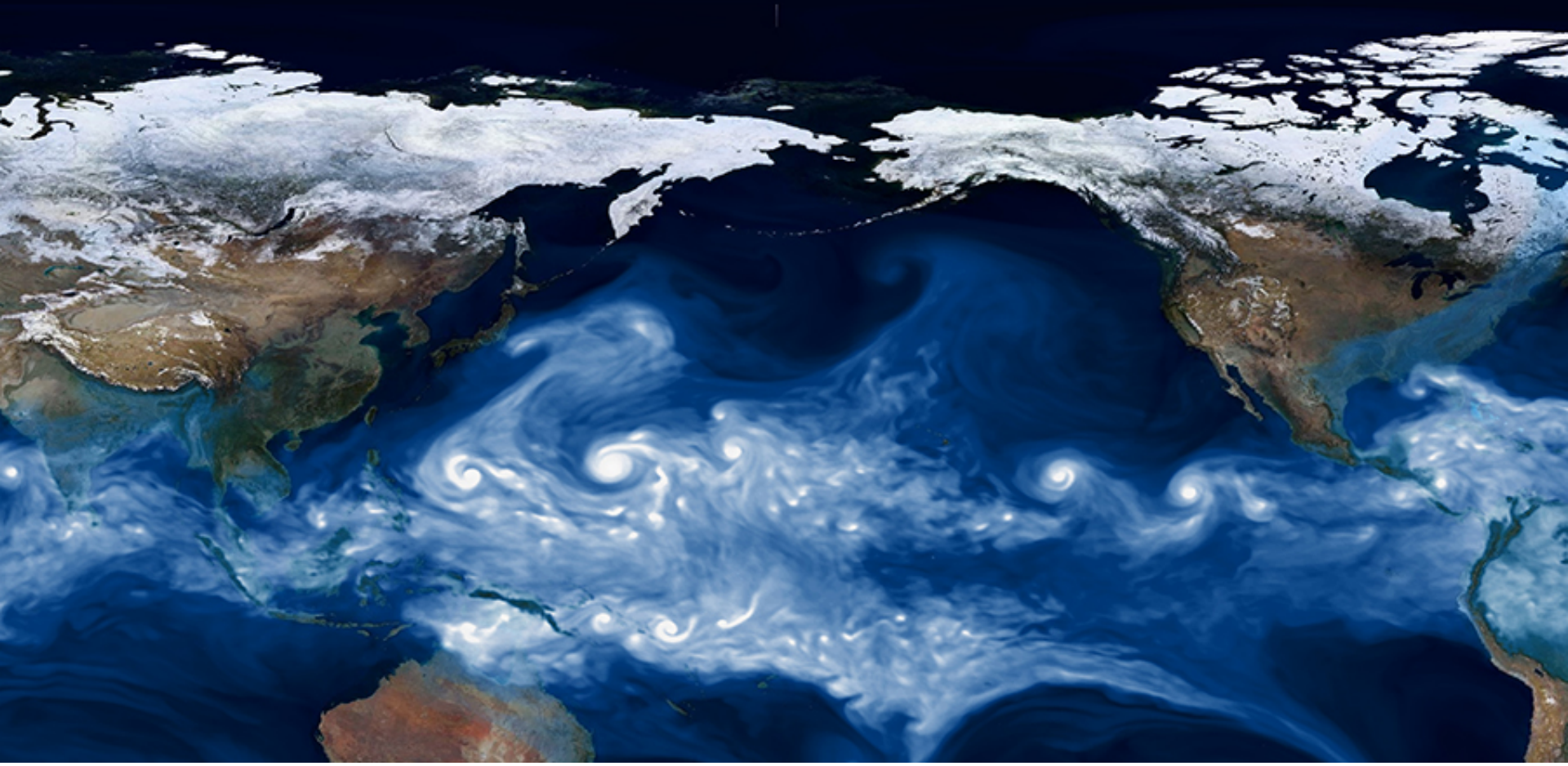


Karthik Kashinath, Prabhat, Mayur Mudigonda, Kevin Yang, Ankur Mahesh, Travis O'Brien, Michael Wehner, Bill Collins

Lawrence Berkeley National Laboratory

Collaborators: Benjamin Toms, Yunjie Liu, Evan Racah, Soo Kyung Kim, Samira Kahou, Christopher Beckham, Chris Pal, Tegan Maharaj, Jim Biard, Kenneth Kunkel, Dean Williams

Characterizing Extreme Weather in a Changing Climate



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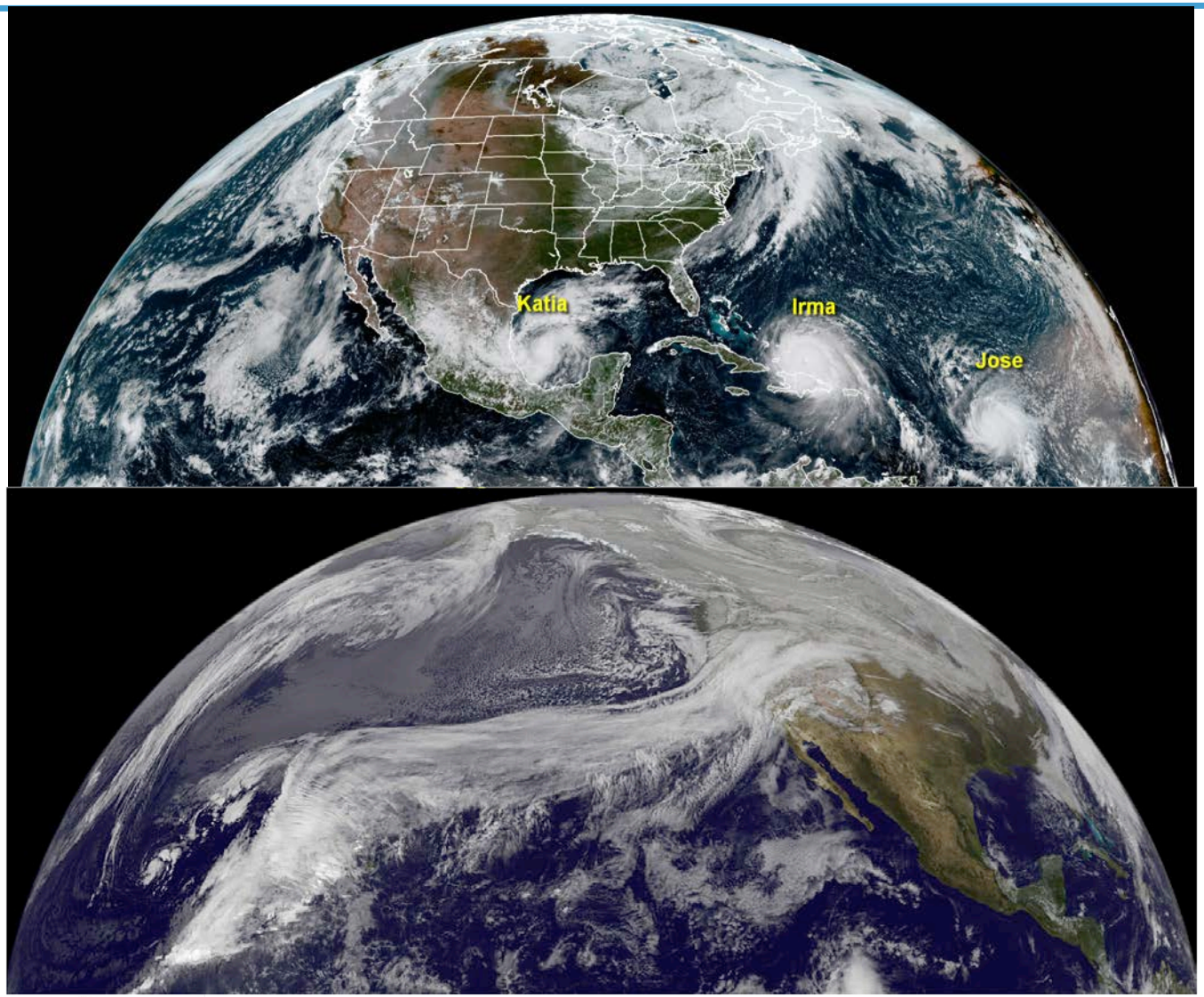
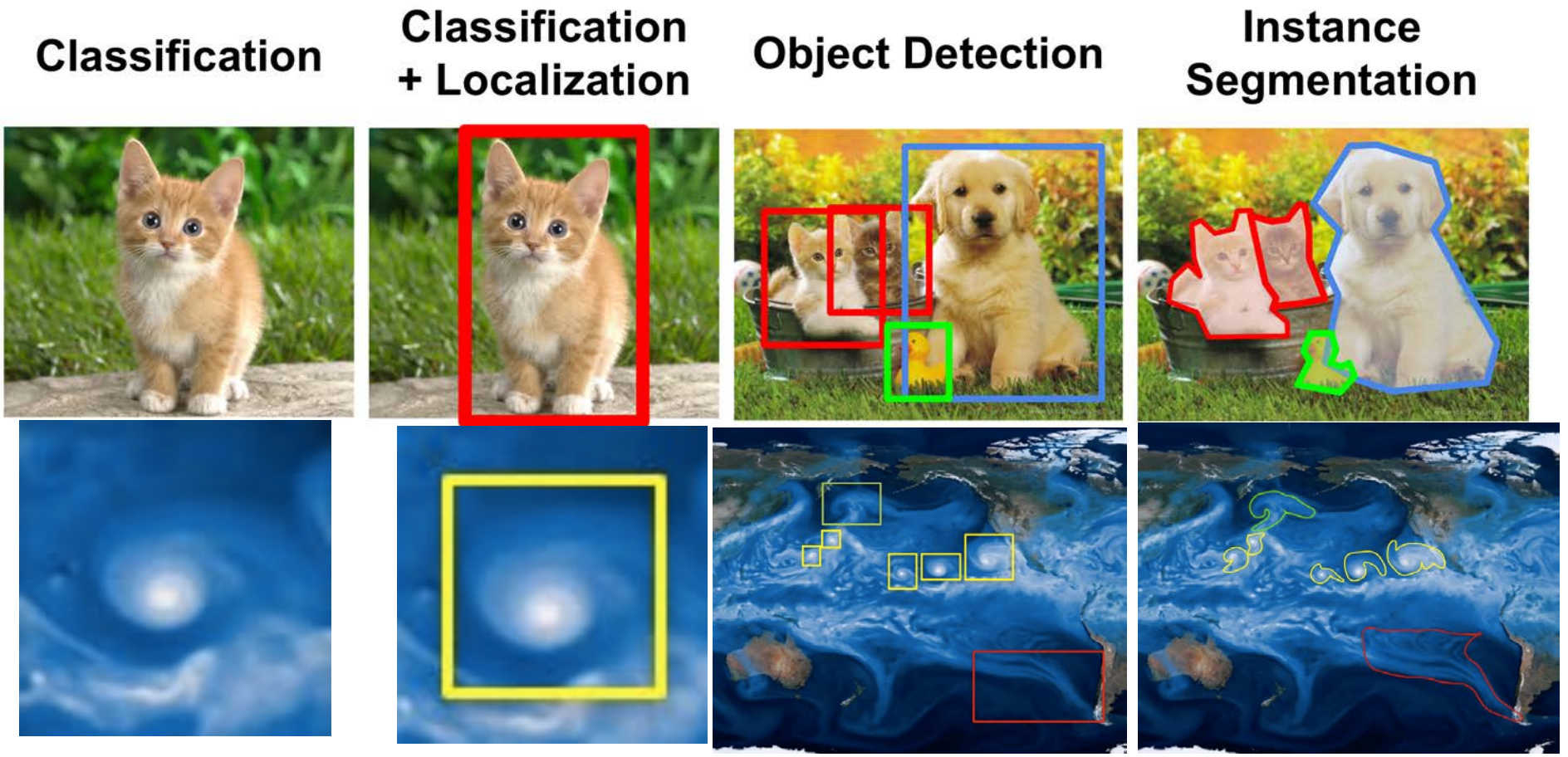
Characterizing Extreme Weather in a Changing Climate



Outline

- Deep Learning for classification, localization and pixel-wise segmentation of Tropical Cyclones, Atmospheric Rivers & Weather Fronts
- Deep Learning for detecting the MJO
- ClimateNet: a community-sourced expert-labeled dataset for training a unified DL model
- Challenges and Opportunities

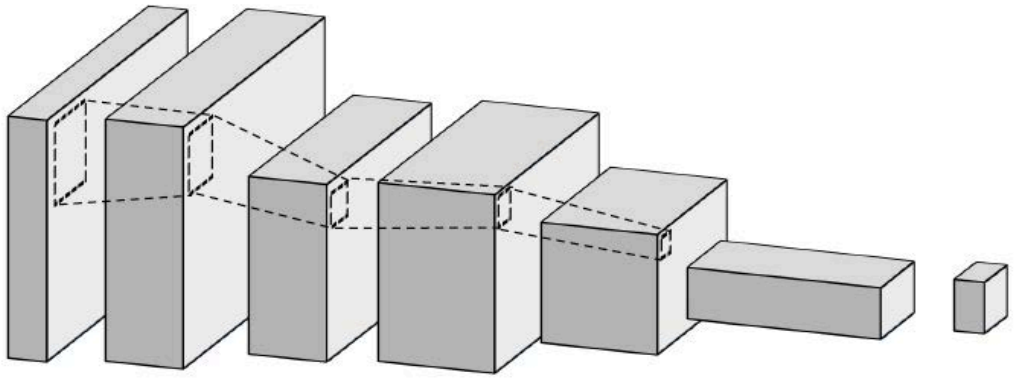
Computer Vision <> Climate Science



Key Differences: Multi-variate; Different & multiple spatio-temporal scales; Double precision floating point; Underlying statistics are different.

Supervised Classification Accuracy (NIPS 16)

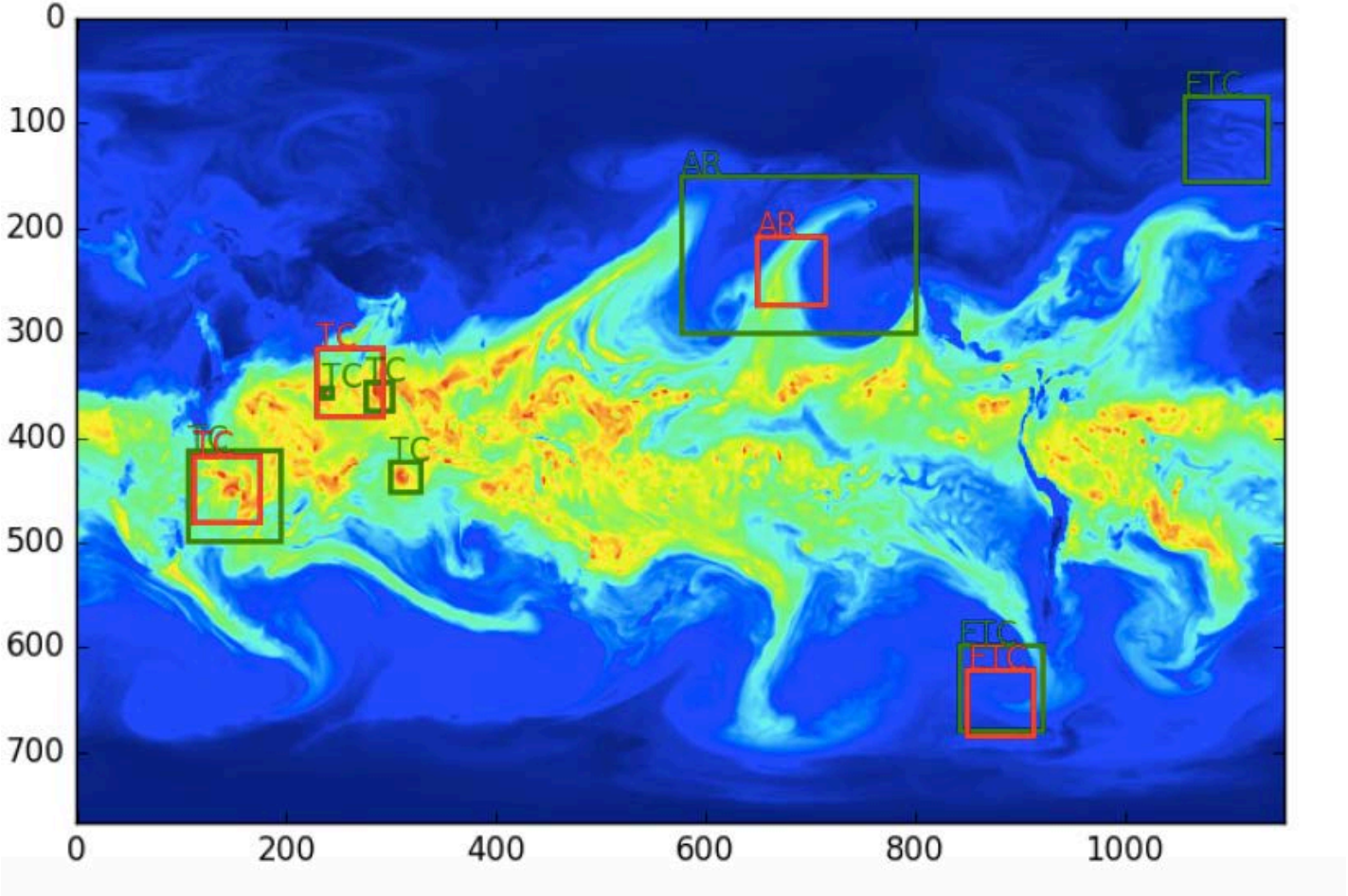
	Logistic Regression	K-Nearest Neighbor	Support Vector Machine	Random Forest	ConvNet
	Test	Test	Test	Test	Test
Tropical Cyclone	95.9	97.9	95.9	**99.4**	**99.1**
Atmospheric Rivers	82.7	81.7	83.0	88.4	**90.0**
Weather Fronts	89.8	76.45	**90.2**	87.5	**89.4**



Semi-Supervised Detection

- **Objectives:**
  - Create unified architecture for all weather patterns
  - Predict bounding box location for each weather pattern
  - Work with few/no labels for several weather patterns
  - **Discover new (hitherto unlabeled) patterns**

Classification + Detection (NIPS17)

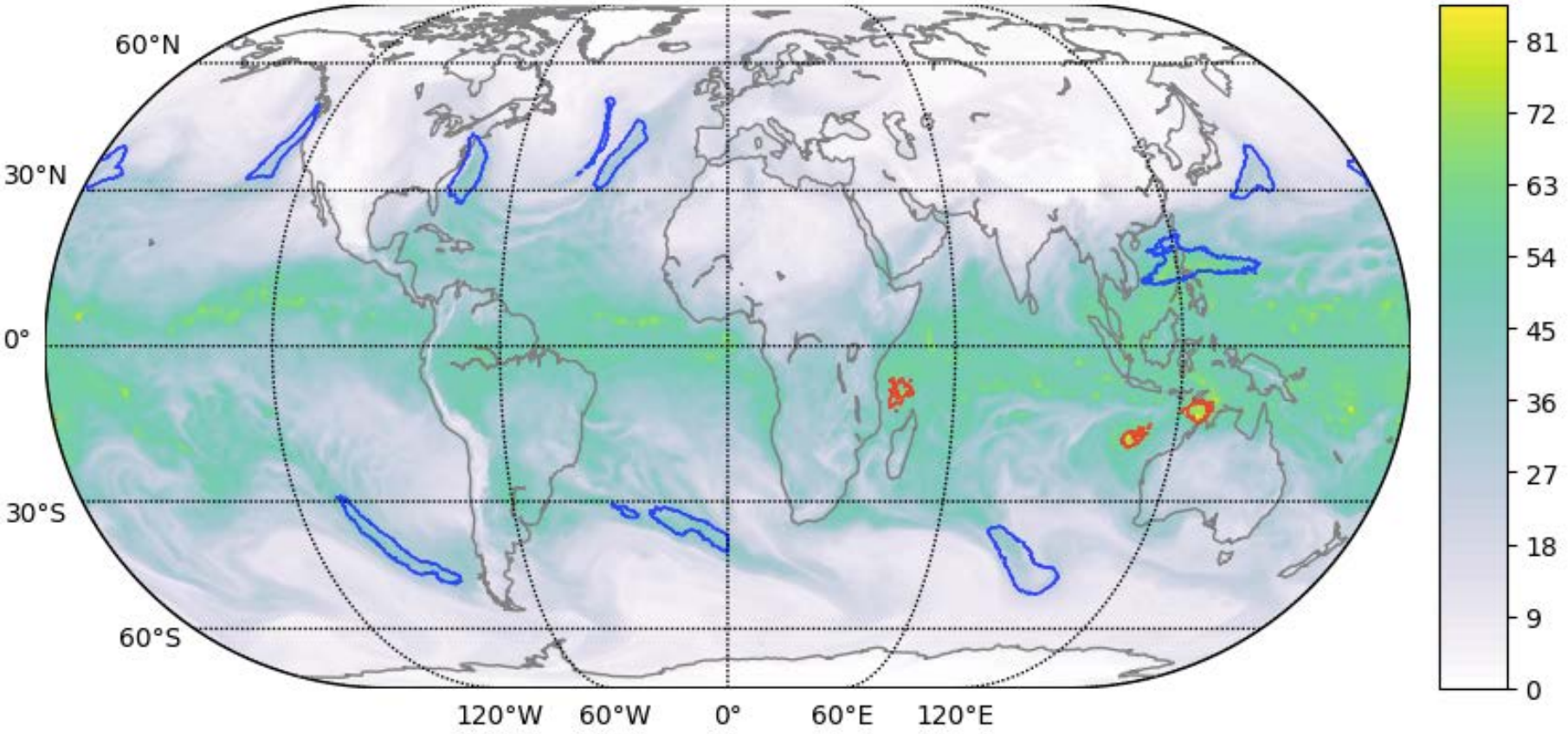


Ground Truth
Prediction

Contributors: Evan Racah, Chris Pal, Chris Beckham, Samira Kahou, Tegan Maharaj. *MILA*

Pixel-wise Segmentation: SC'18

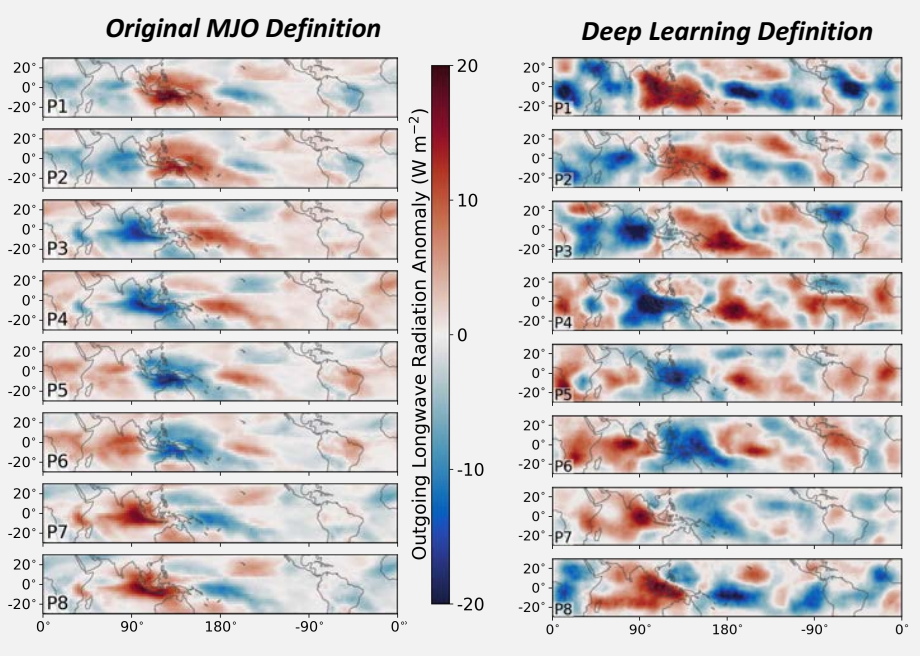
Gordon Bell Prize Winner! DL @ 1EF



Contributors: Thorsten Kurth, Sean Treichler, Joshua Romero, Mayur Mudigonda, Nathan Luehr, Everett Phillips, Ankur Mahesh, Michael Matheson, Jack Deslippe, Massimiliano Fatica, Michael Houston. *NERSC, NVIDIA, UC Berkeley, OLCF*

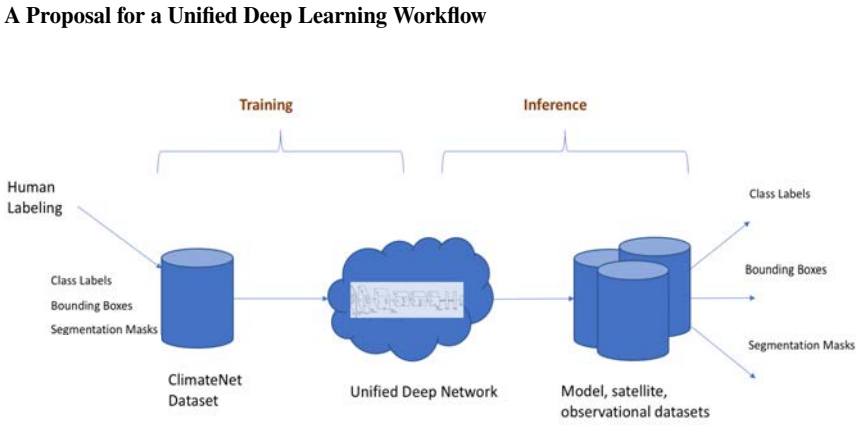
Deep Learning for the MJO

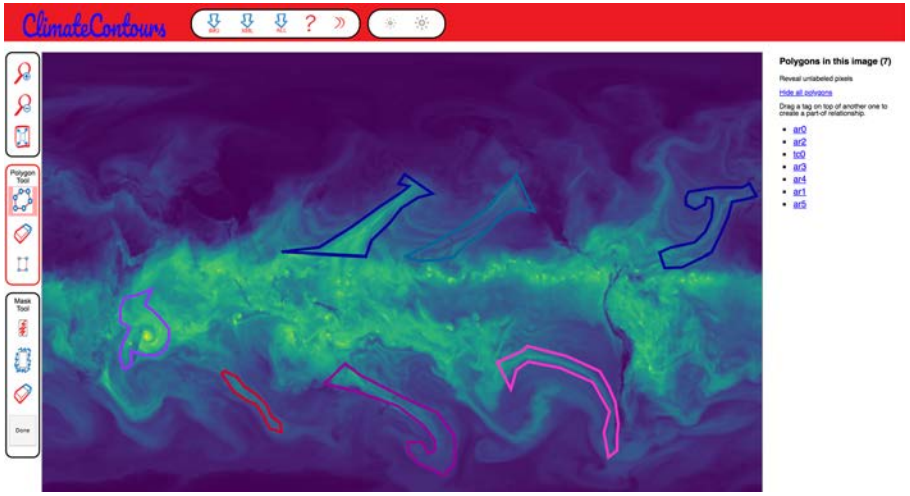
- DL can correctly classify the phase of the MJO
- DL can independently infer which variables are most important for the classification
- DL can learn the spatial structure of the MJO
- https://arxiv.org/abs/1902.04621 (*Deep Learning for Scientific Inference from Geophysical Data: The Madden-Julian Oscillation as a Test Case*)



ClimateNet: a community-sourced labeled dataset (ICML 2019)

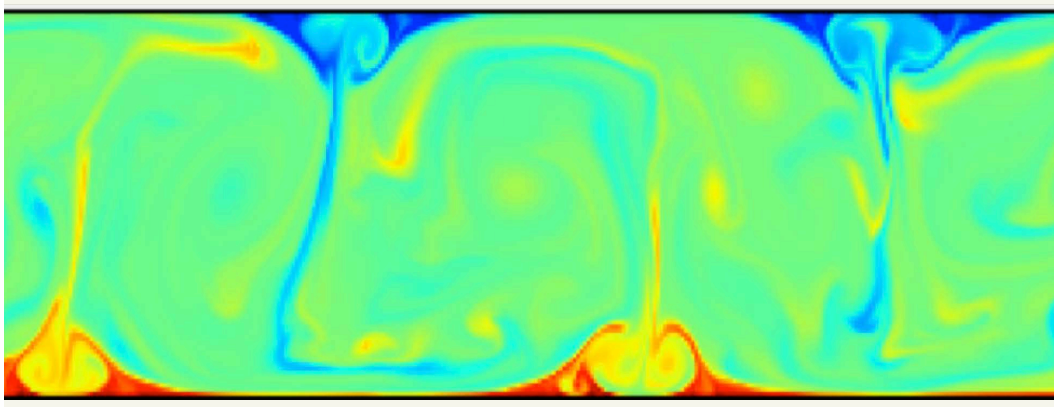
- Pattern recognition using DL works best (so far) in the supervised mode
- Reliable labeled data is sparse in climate science
- Heuristics for pattern detection in climate science fraught with discrepancies and uncertainties
- Ultimately we want to *avoid* heuristics ("feature engineering")
- https://www.nersc.gov/research-and-development/data-analytics/big-data-center/climatenet

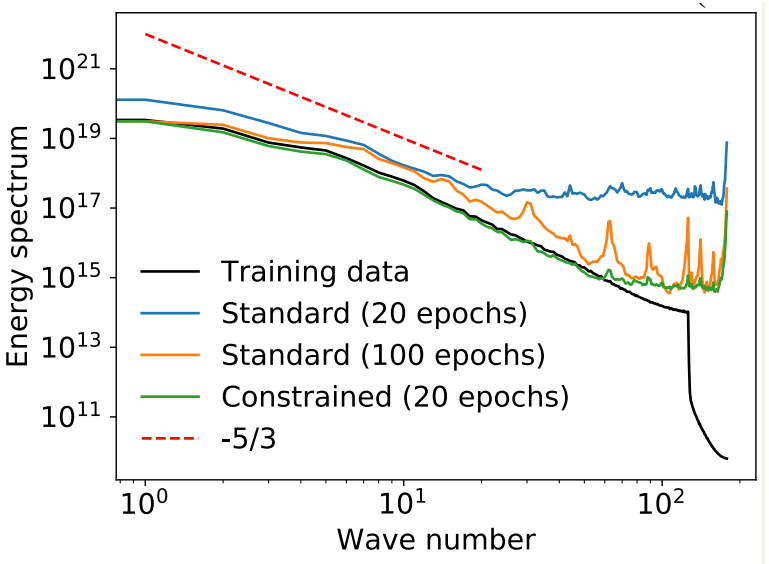




Physics-informed Deep Learning

- Reliable and robust DL models for science need to obey the laws of nature
- A systematic framework for physics-informed approaches in ML and DL is needed
- We've made a first step in this direction with PI-GANs for atmospheric flows





[1] J.-L. Wu, K. Kashinath, A. Albert, D. Chirila, Prabhat and H. Xiao, "Enforcing Statistical Constraints in Generative Adversarial Networks for Modeling Chaotic Dynamical Systems", Submitted, available at arXiv:1905.06841, 2019.

[2] Y. Zeng, J.-L. Wu, K. Kashinath, A. Albert, Prabhat and H. Xiao, "Physics-informed Generative Learning to Emulate PDE-Governed Systems by Incorporating Conservation Laws", in preparation, 2019.

Short-Term Challenges

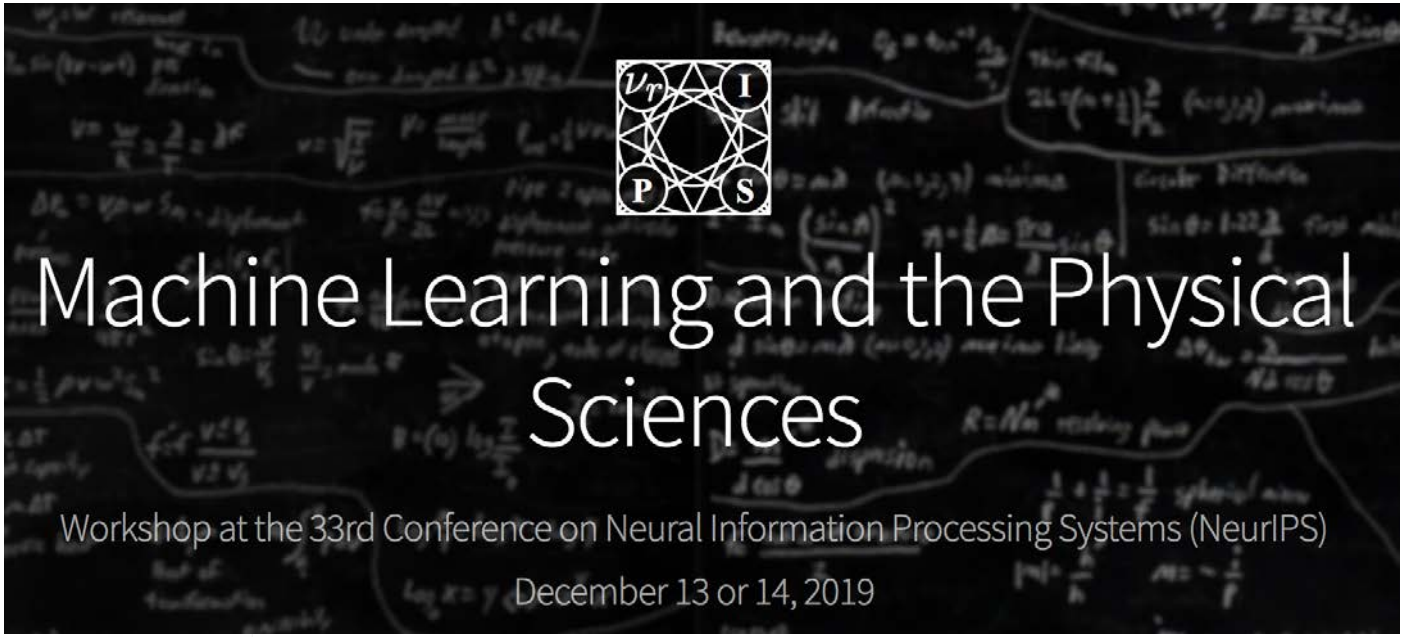
- **Complex Data**
  - 2D/3D/4D, multi-channel, dense/sparse
  - Multi-scale, Spatial and Temporal coherence
- **Hyper-Parameter Optimization**
  - Tuning #layers, #filters, learning rates is a black art
- **Performance and Scaling**
  - Current networks take days to train on O(10) GB datasets, we have O(100) TB datasets on hand
- **Scarcity of reliable, high-quality Labeled Data**
  - Communities need to self-organize and run labeling campaigns

Long-Term Challenges

- **Theory**
  - Limits of supervised, unsupervised, semi-supervised learning
  - GANs are promising, but unstable and hard to train
- **Interpretability and Explainability**
  - Need to visualize representations
  - Incorporate domain science principles (physical constraints, conservation laws, etc.)
- **Uncertainty Quantification**
- **Formal protocol for applying Deep Learning**
  - Applied Math has developed methodology for solving PDEs over decades, no analog in DL

IN033: Incorporating physics and domain knowledge to improve interpretability, explainability, reliability and generalization on Machine Learning Models

AGU Tutorial on Machine Learning and Deep Learning for the environmental and geosciences



Questions?

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