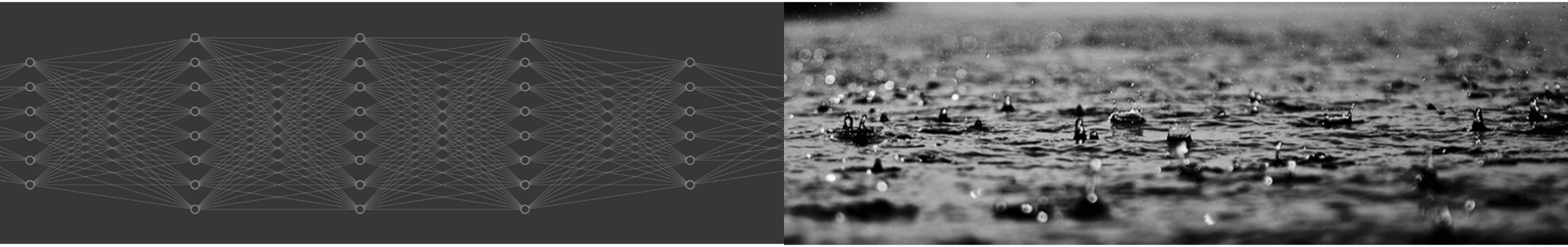
# Machine Learning for the Geosciences




## Maria J. Molina

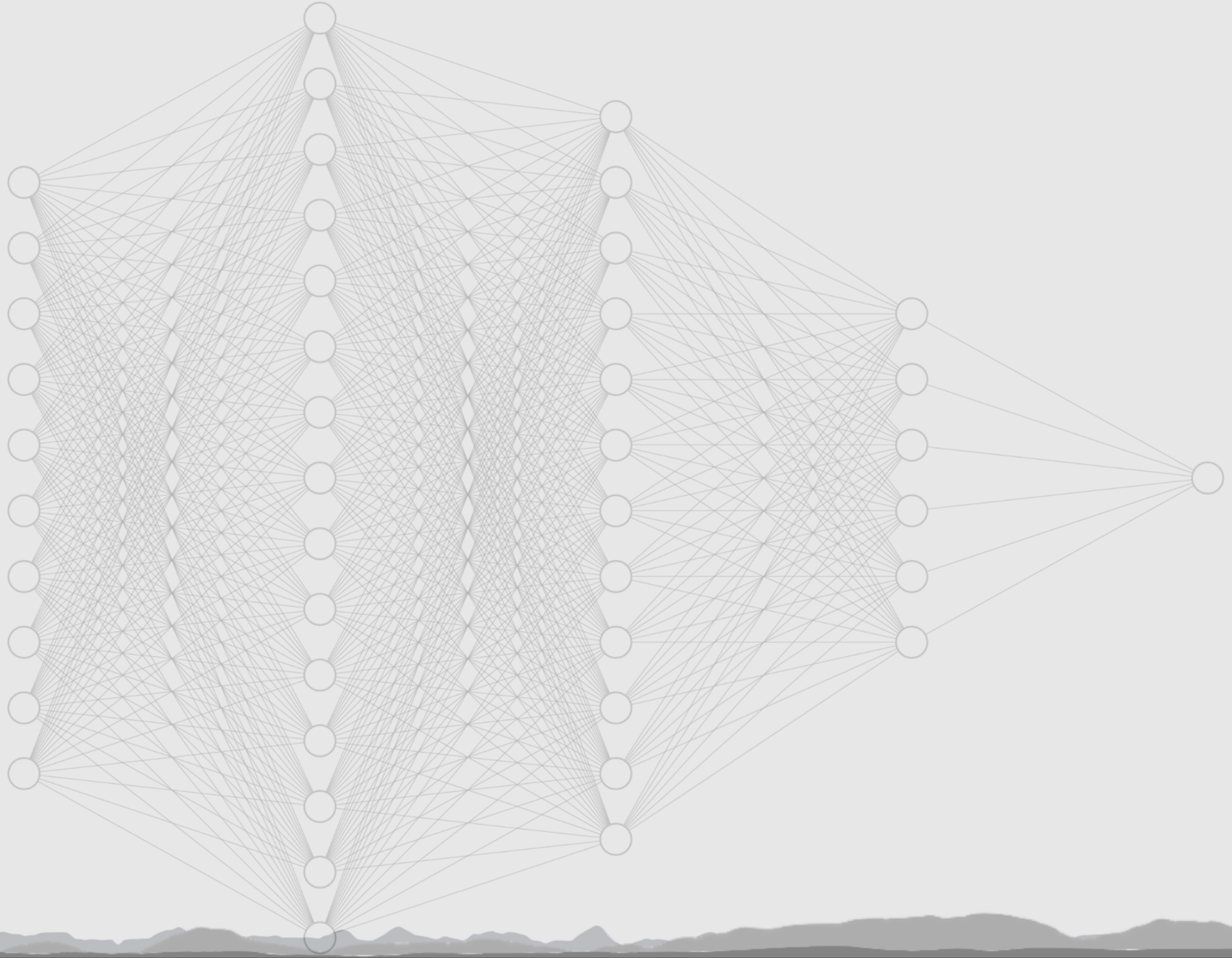
National Center for Atmospheric Research, Boulder, Colorado

Pronouns: She/her; Email: molina@ucar.edu


NCAR U.S. DEPARTMENT OF ENERGY | Office of Science NSF catalyst


WALL-E


Star Wars



**1959**, ML defined

**1986**,

Backpropagation

**Since 1990s**,

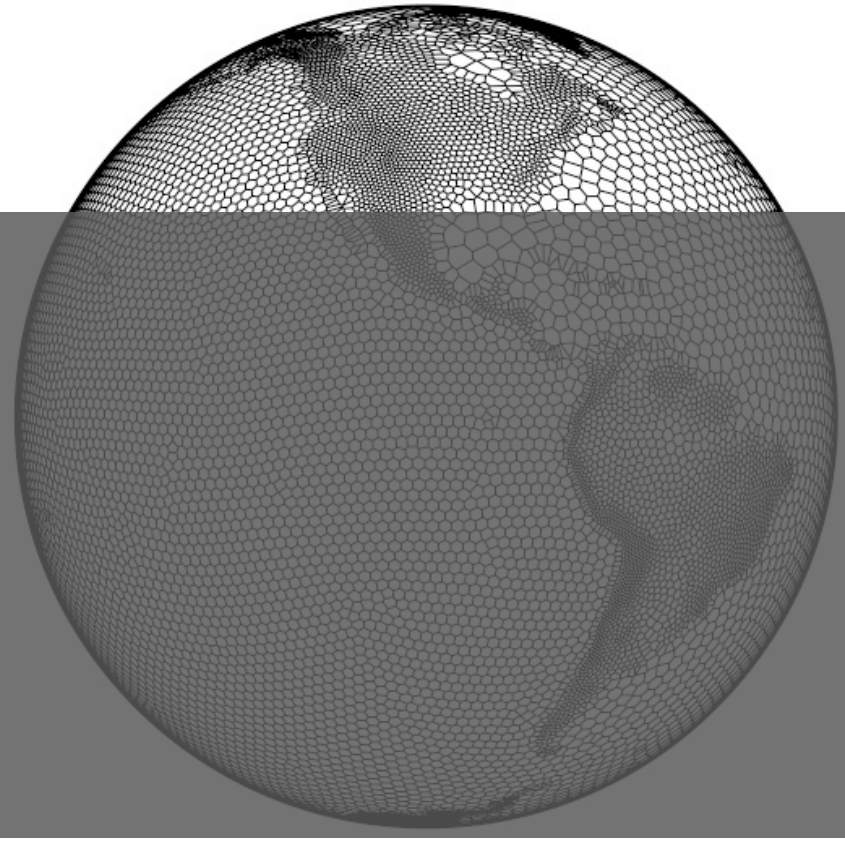
GPUs

ImageNet

DL advances

ML for Earth system modeling should incorporate:

- Physics and Domain Knowledge
- Robustness
- Interpretable ML and Explainable AI



# Where does machine learning fit in Earth system modeling?

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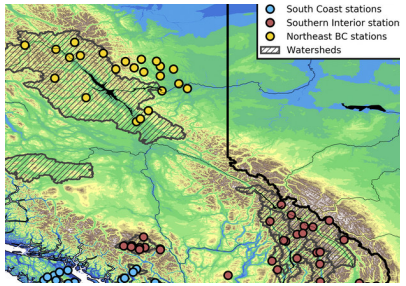
**Input**
Observations
Initialization

**Run Model**
Parameterizations
HPC Costs

**Output**
S2S Predictions
Feature Detection

Sha, Y., Gagne, D.J., West, G. and Stull, R., 2021. **Deep-learning-based precipitation observation quality control.** Journal of Atmospheric and Oceanic Technology.



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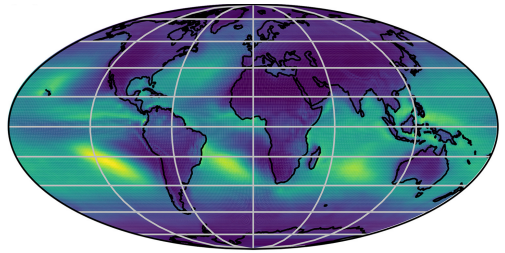
Gettelman, A., Gagne, D.J., Chen, C.C., Christensen, M.W., Lebo, Z.J., Morrison, H. and Gantos, G., 2021. **Machine learning the warm rain process.** Journal of Advances in Modeling Earth Systems.



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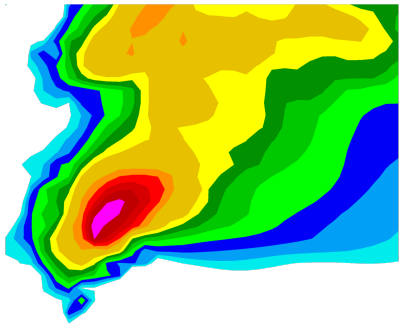


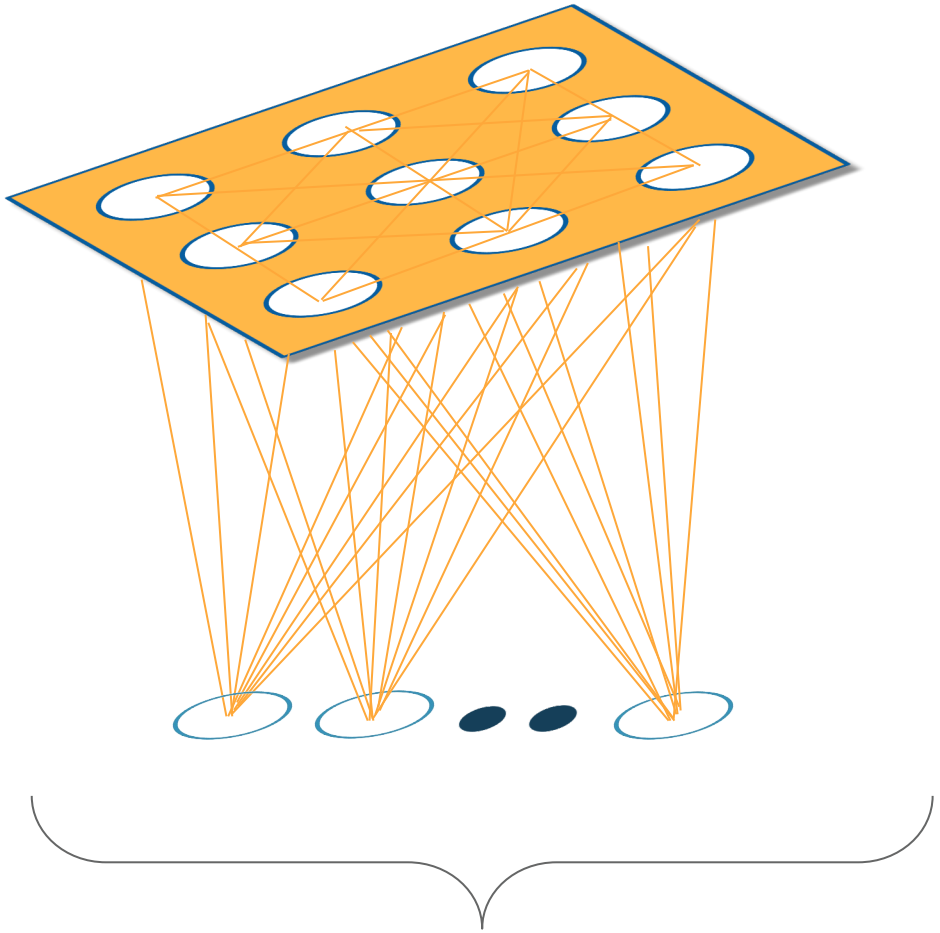
Molina, M.J., Gagne, D.J., Prein, A.F., 2021. **A benchmark to test generalization capabilities of deep learning methods to classify severe convective storms in a changing climate.** Earth and Space Science.

# Three Applications of ML for Earth system modeling:

1. **Characterization** of atmospheric, synoptic-scale patterns preceding Antarctic polynya development.

2. **Classification** of potentially severe thunderstorms from high-resolution numerical model output.

3. **Prediction** of subseasonal (2 weeks or more) prediction errors of temperature generated by a coupled climate model.



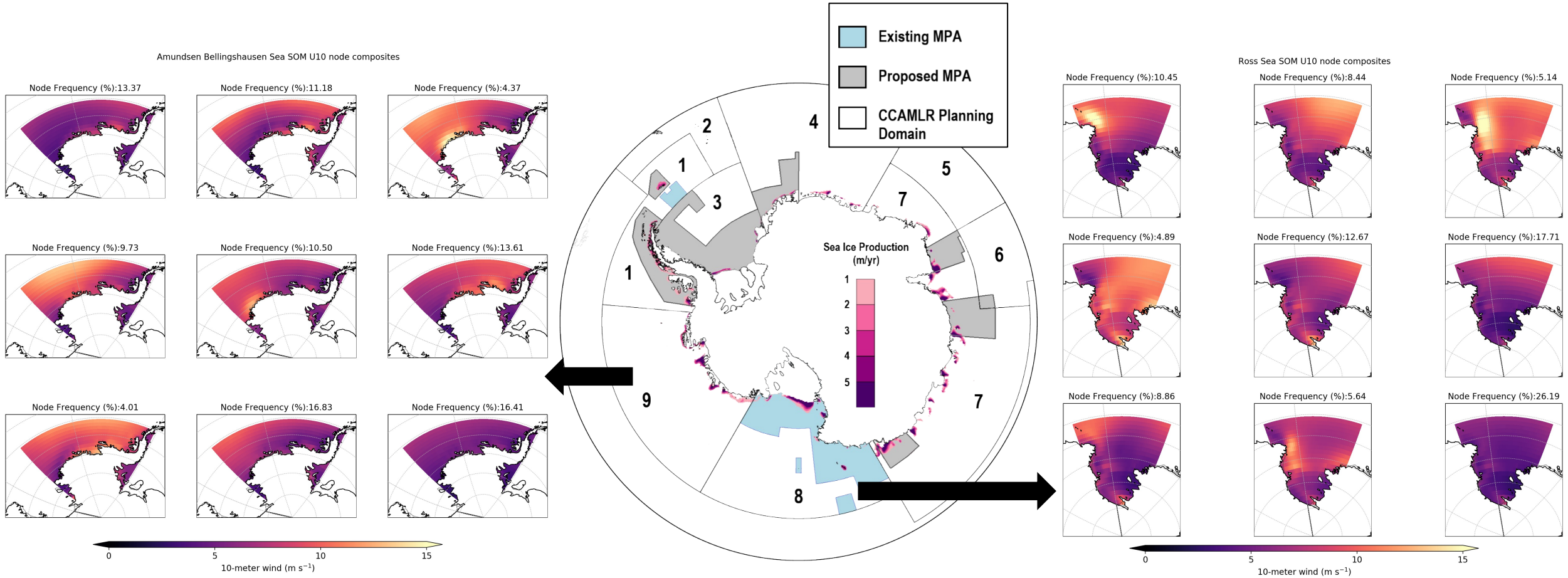
Input vector

Unsupervised learning can be used to group synoptic-scale patterns without the need for labels (Sheridan and Lee 2011).

Kohonen (2013)

# Antarctic Marine Protected Areas (MPAs)

Alice DuVivier, Maria J. Molina, and Marika Holland (in prep.)



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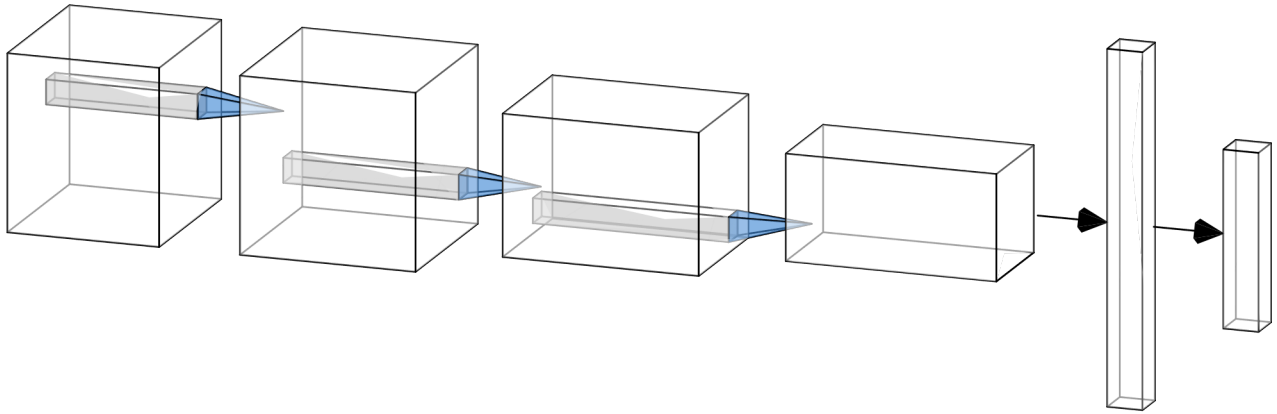
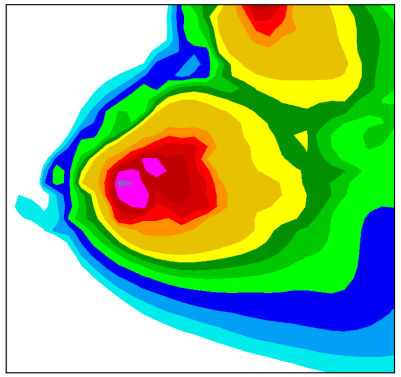
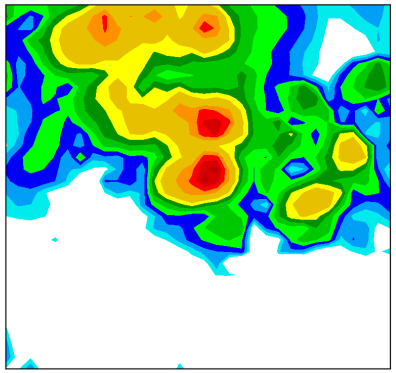
# Convolutional Neural Network (ConvNet)





Strongly Rotating

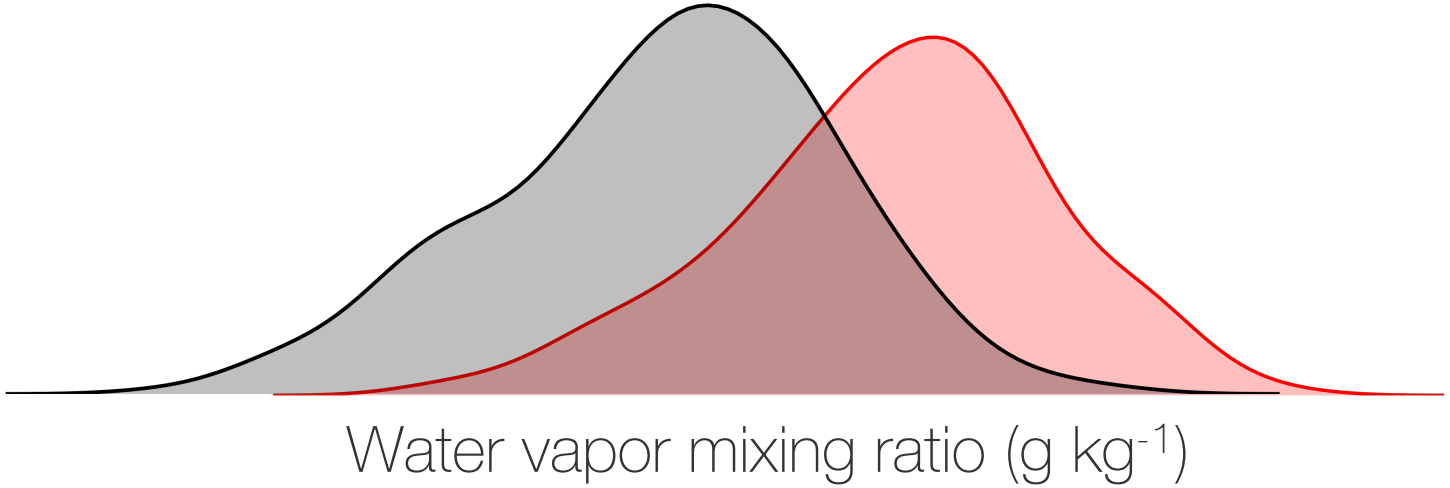
( ≥ 75 $m^2 s^{-2}$ )



Non-strongly Rotating

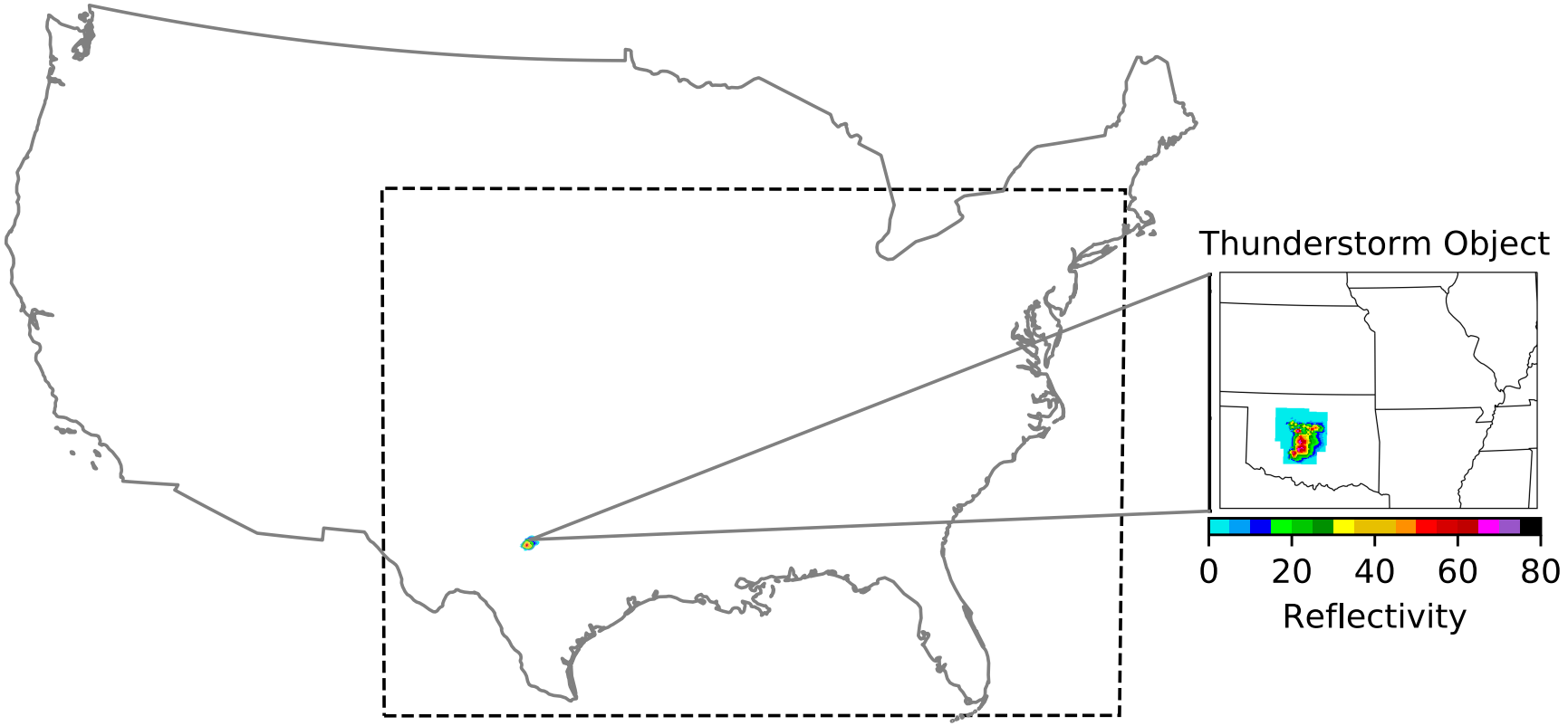
( < 75 $m^2 s^{-2}$ )

# The climate is changing…

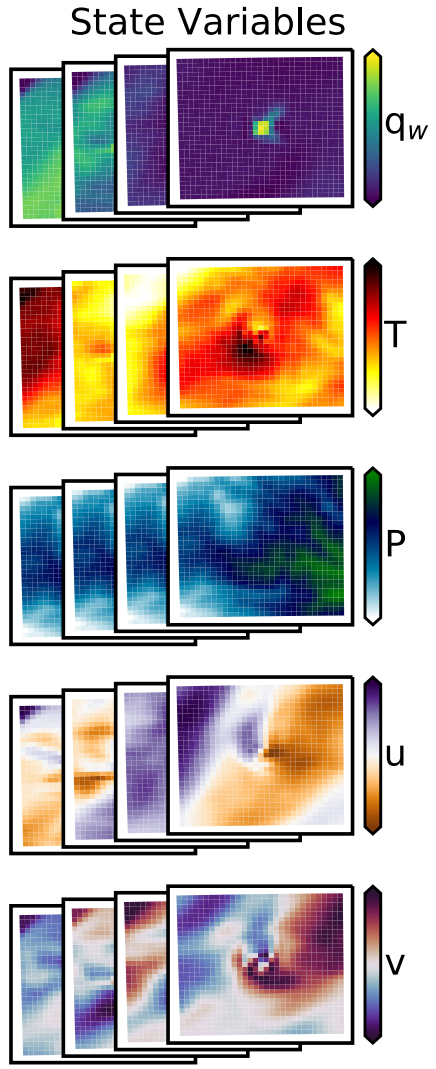


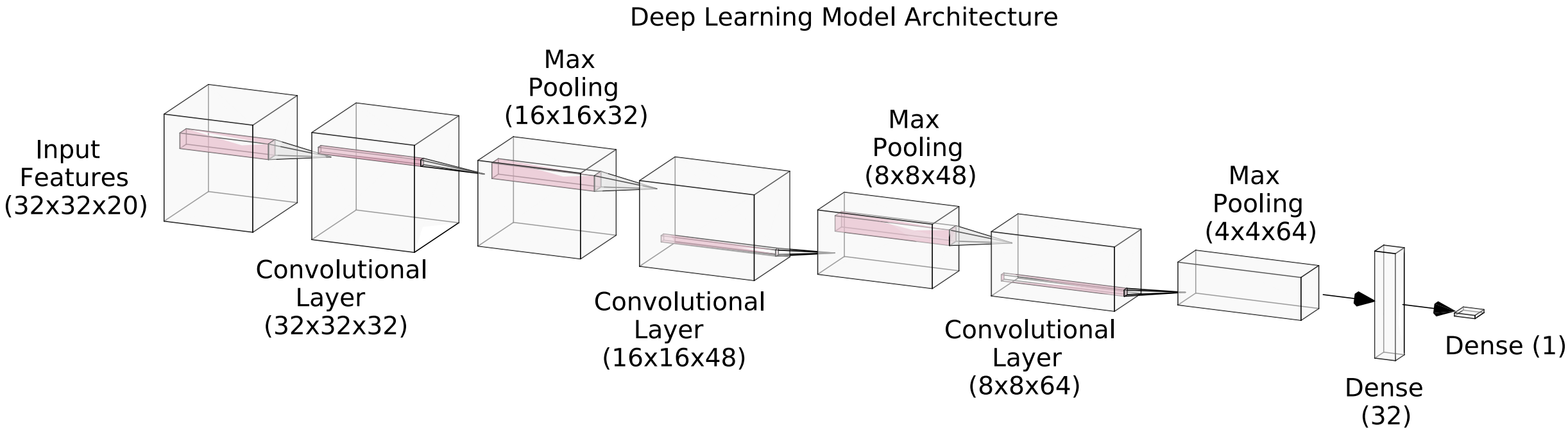

How will the ConvNet perform well when evaluated with **outlier** storms?

# Study Domain for Extraction of Thunderstorm Objects and Corresponding State Variables





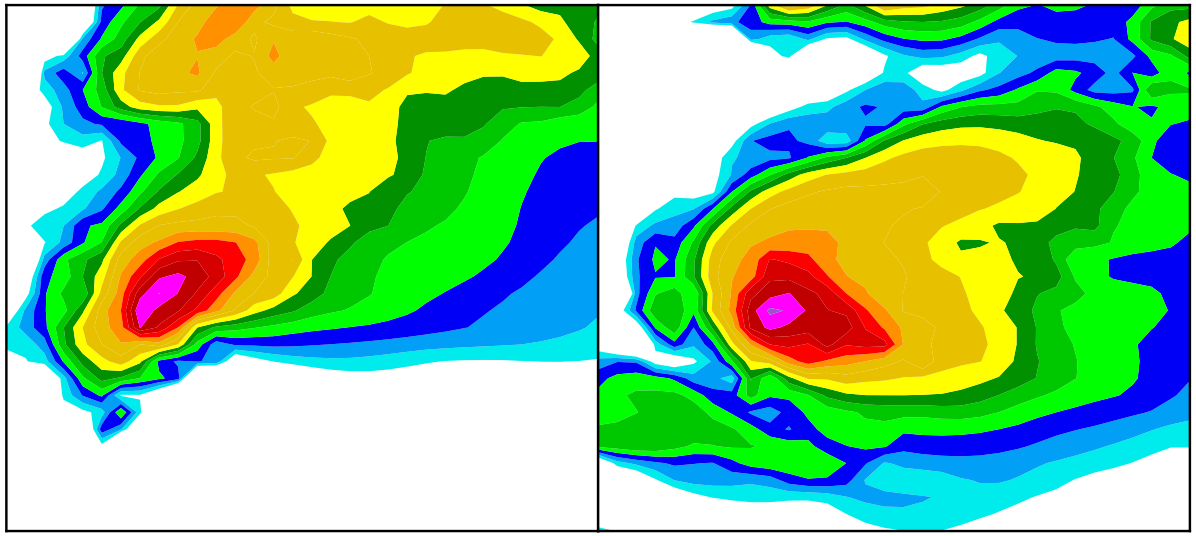






Visualization: LeNail, 2019: NN-SVG.

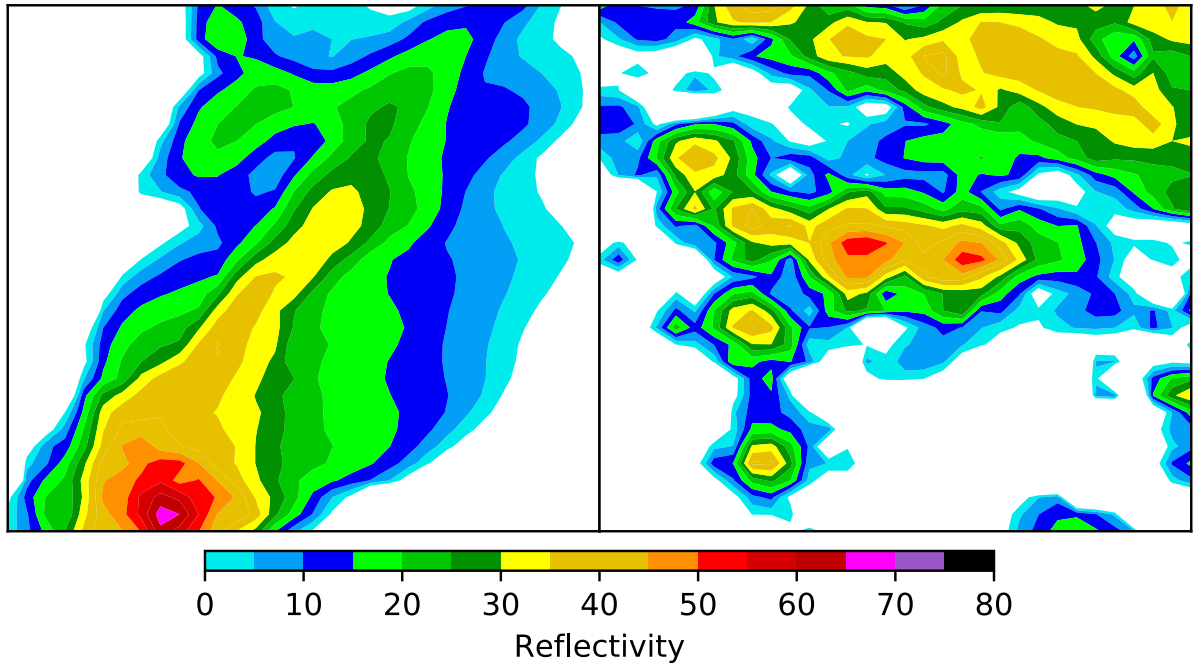
Hit

False Alarm



Miss

True Negative



**What are the physical reasons for the model's performance?**





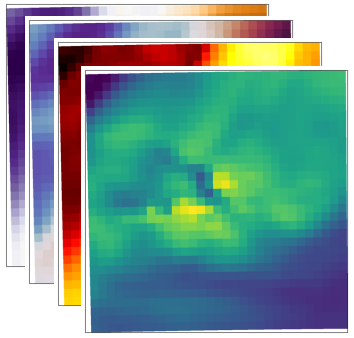
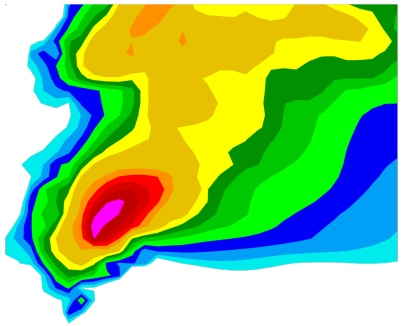
Molina et al. 2021

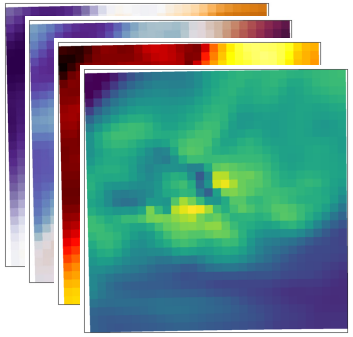
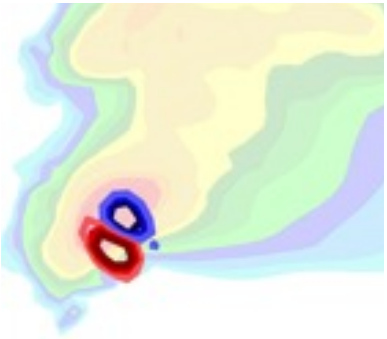
Saliency maps highlight areas that contribute to the ConvNet's prediction (Simonyan et al., 2013).

$$f(x) = y$$

$$\nabla_x f(x) = S$$

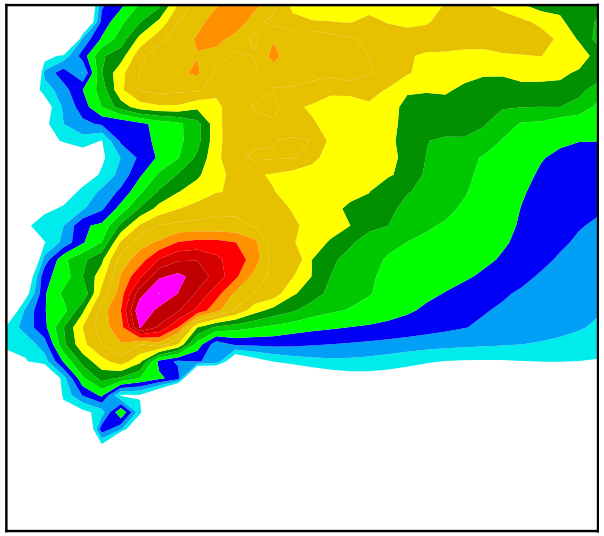
$f$ = CNN
$x$ = Input variables
$y$ = Model prediction
$S$ = Saliency maps

$f($  $) =$ 

$\nabla_x f($  $) =$ 

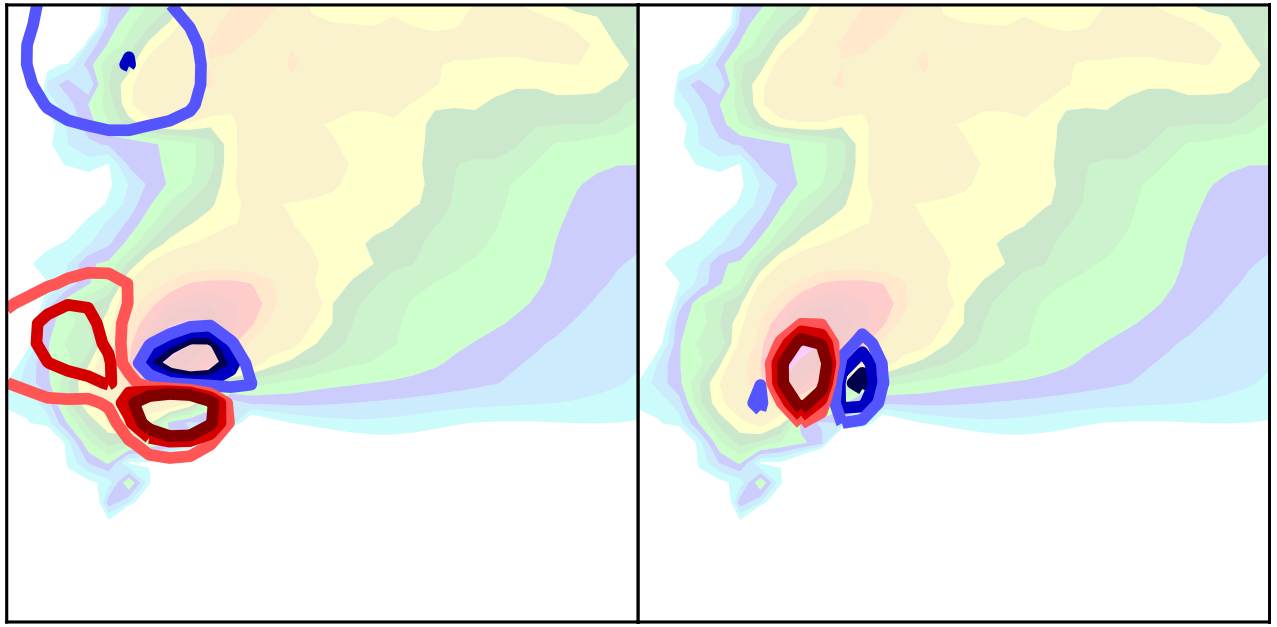
Simonyan, K., Vedaldi, A., & Zisserman, A. (2013). Deep inside convolutional networks: Visualising image classification models and saliency maps.

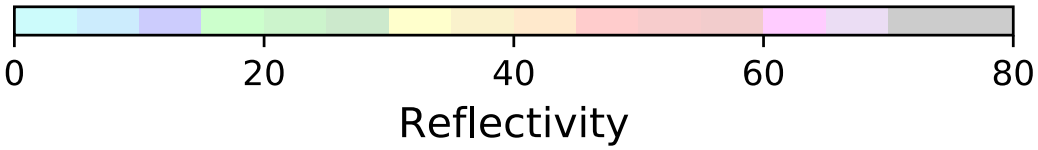
# Correct Classification

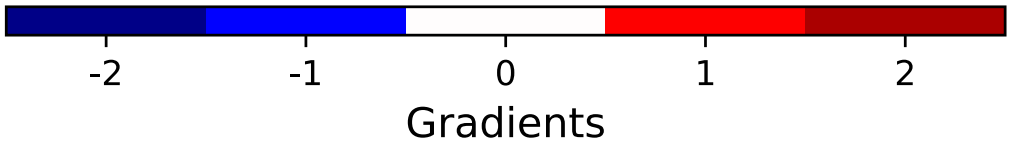


U-wind (3 km)

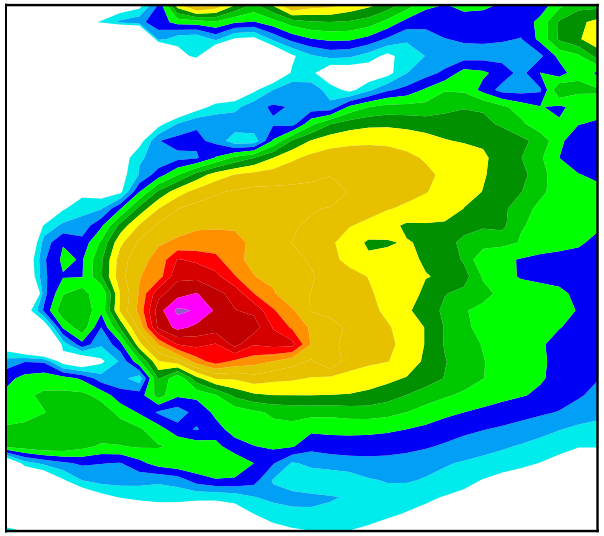
V-wind (3 km)





False Alarm



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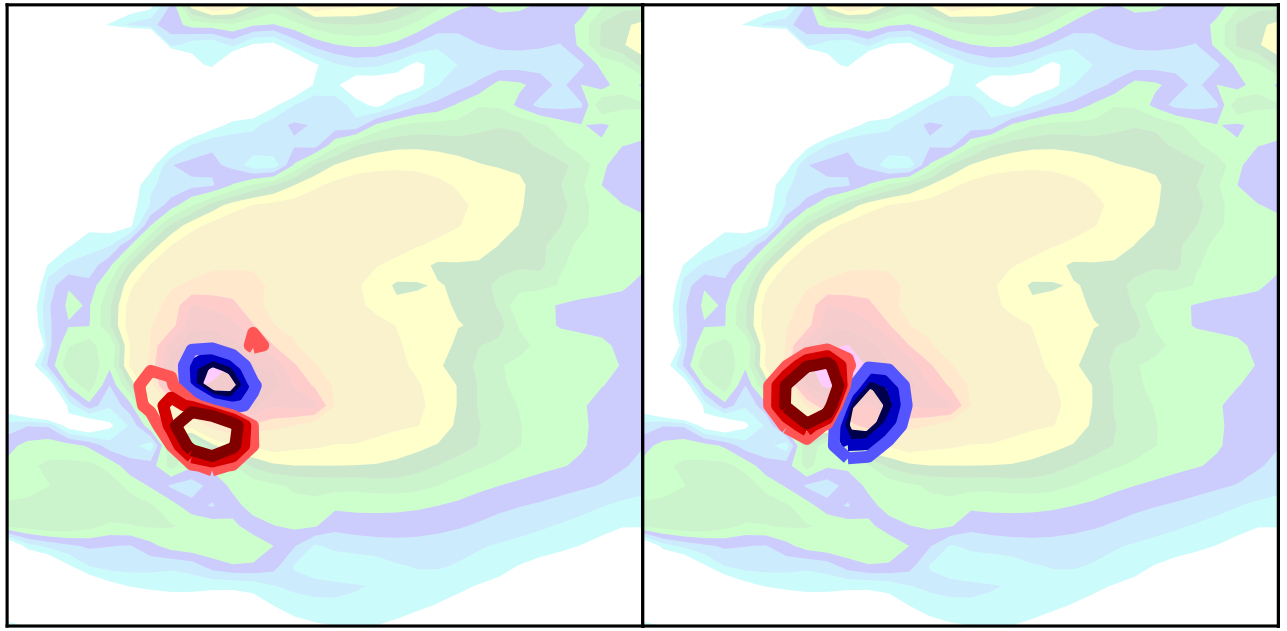
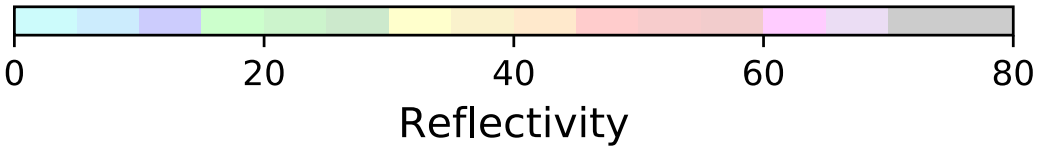
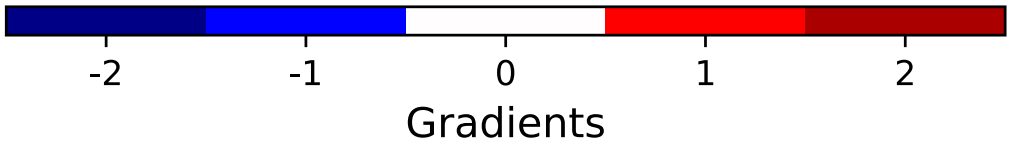
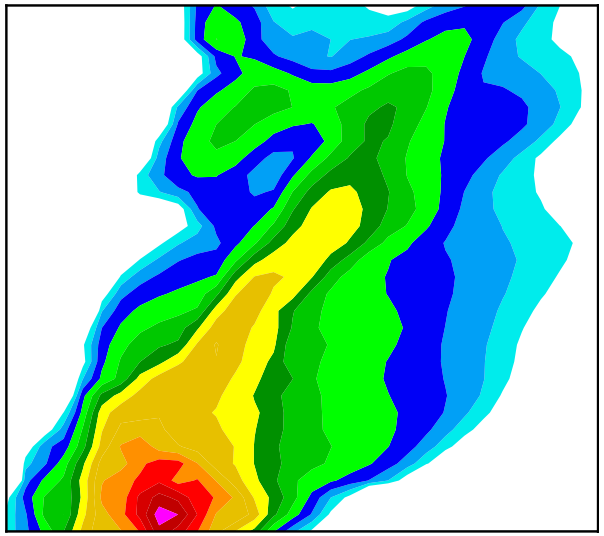




Miss



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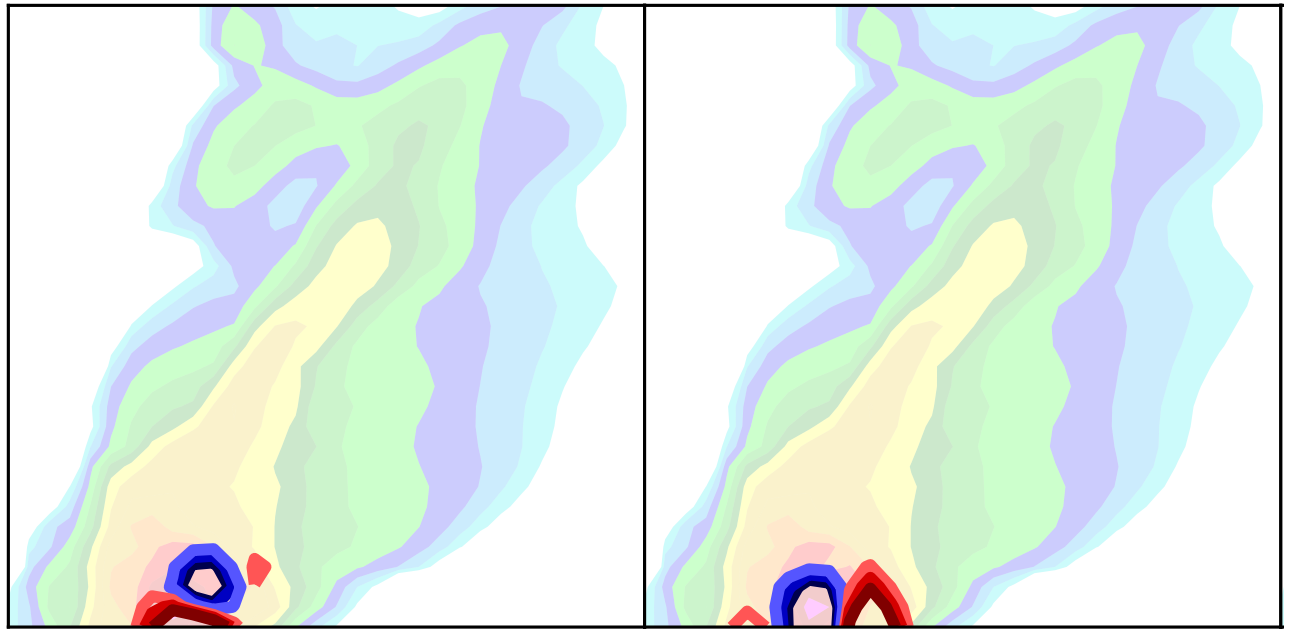

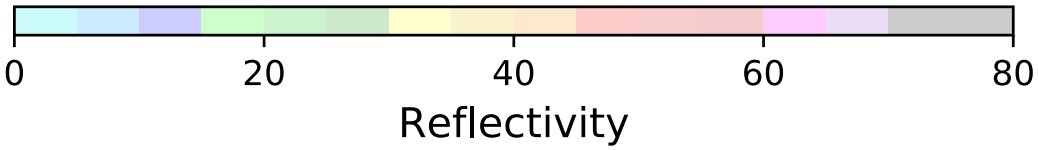


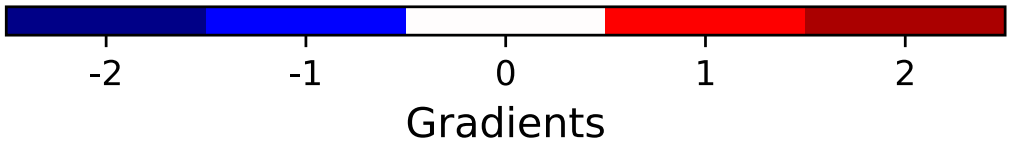

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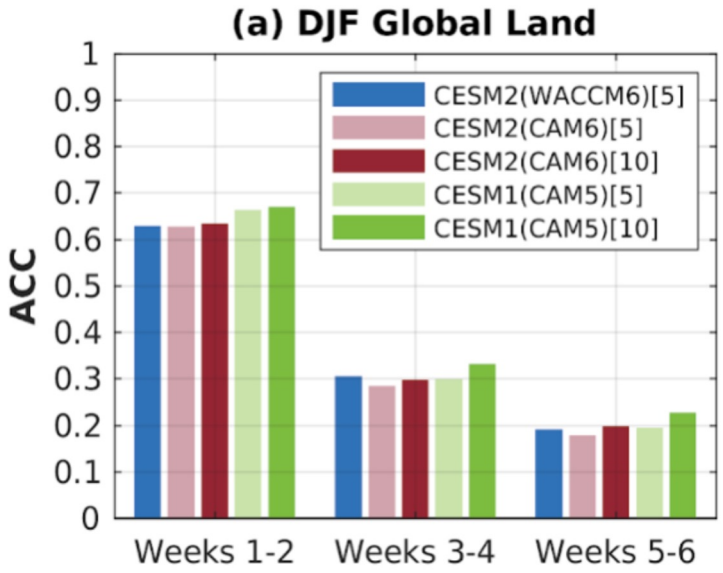
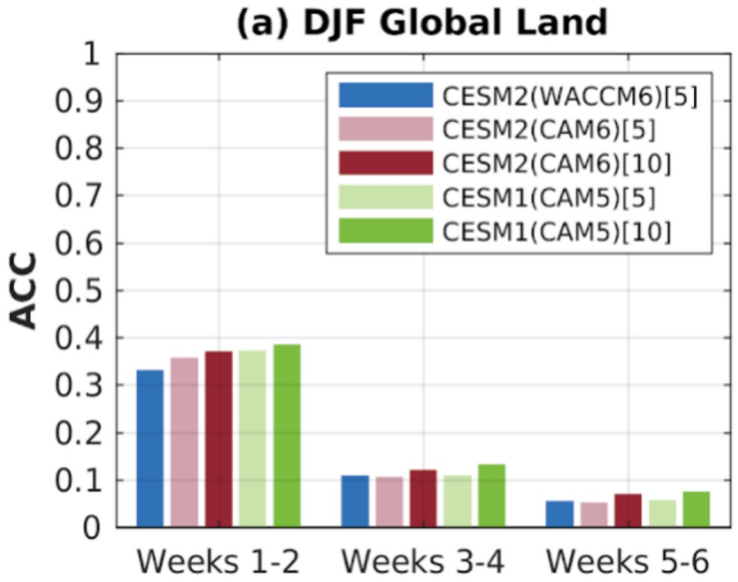
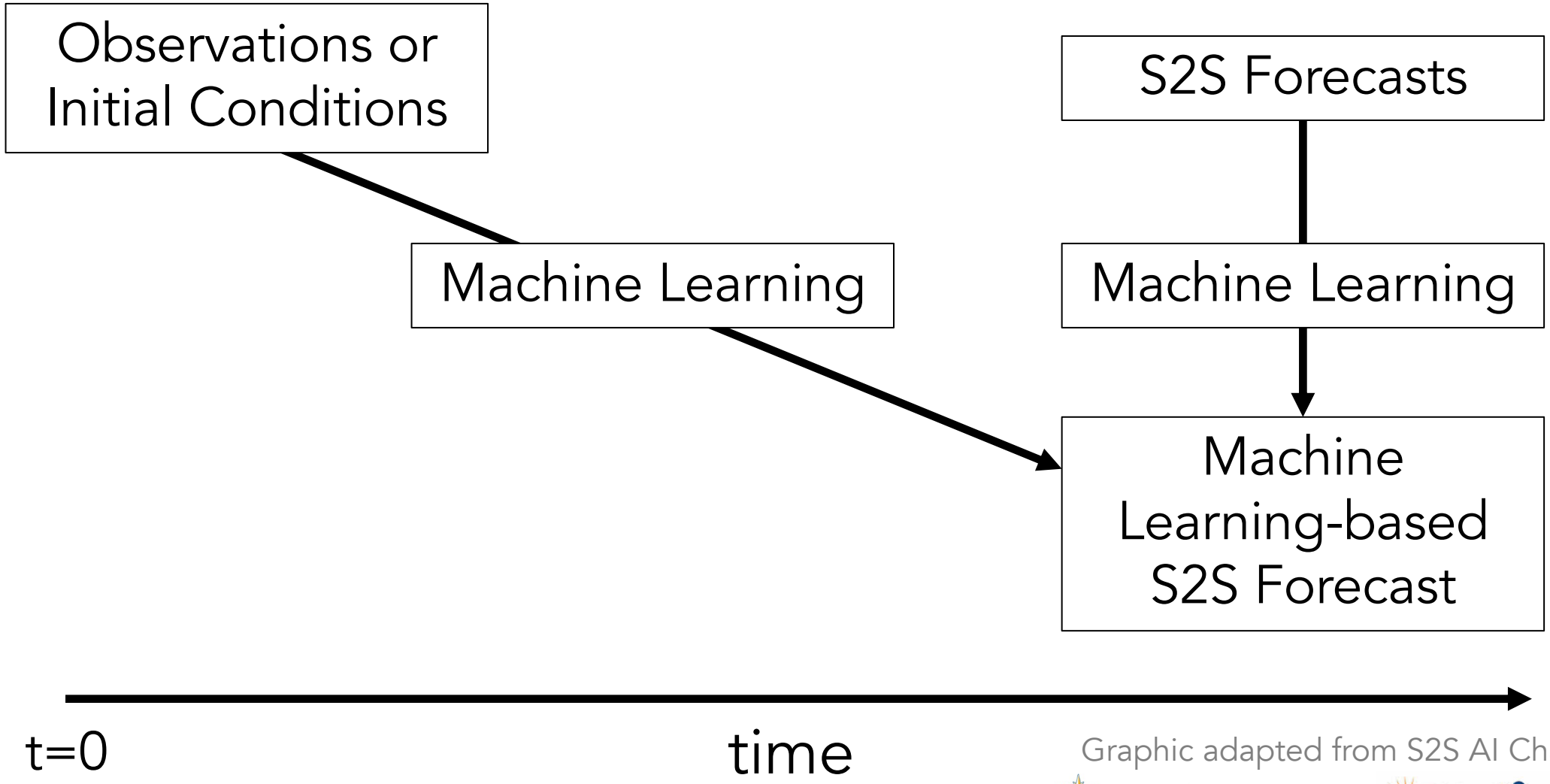
# Temperature skill

# Precipitation skill



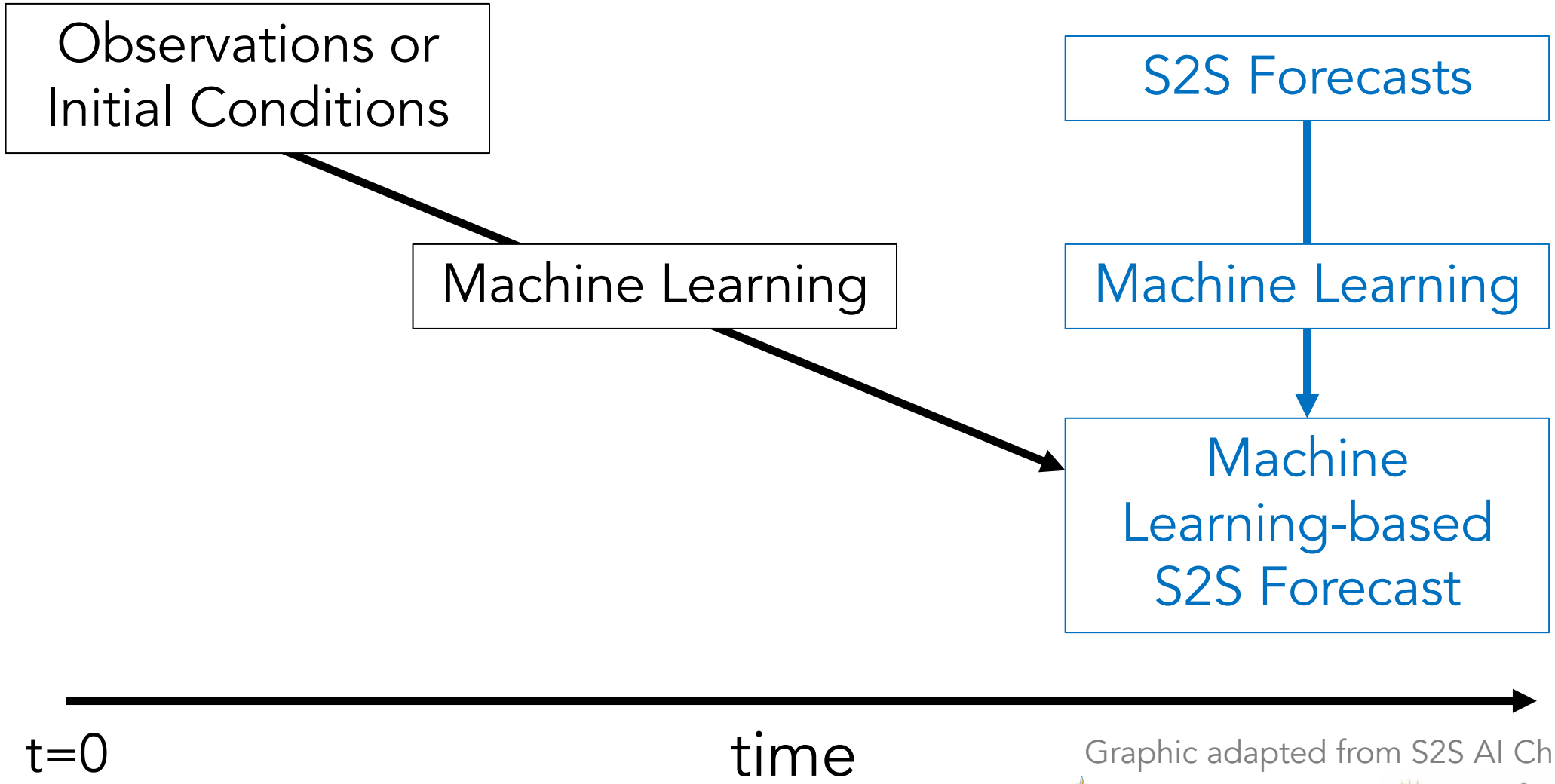




(Richter et al. 2022; under review)




Graphic adapted from S2S AI Challenge 2021

(Pegion et al. 2019, Merryfield et al. 2020, Barnes et al. 2020, Meehl et al. 2021)

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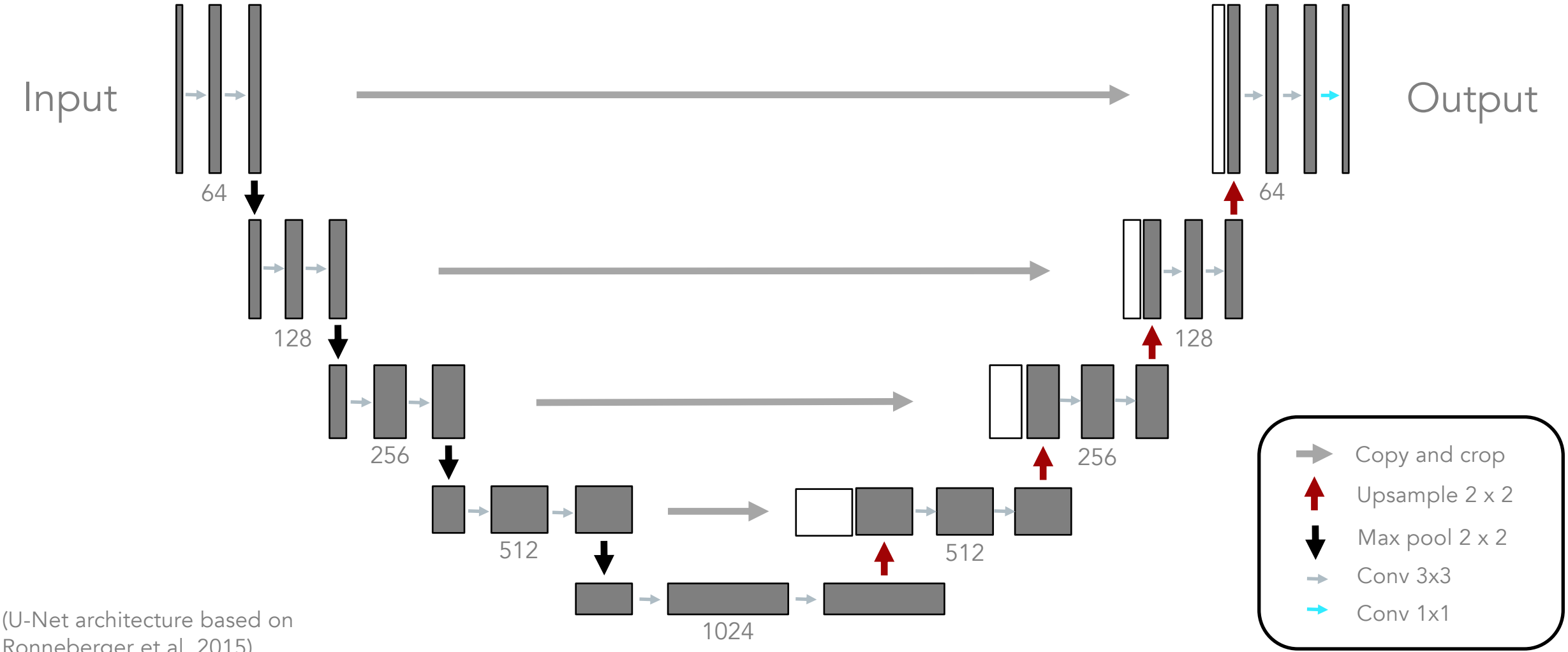
# U-Net Architecture (training and validation: 1999-2015)




(U-Net architecture based on Ronneberger et al. 2015)



Molina et al. (in prep.)

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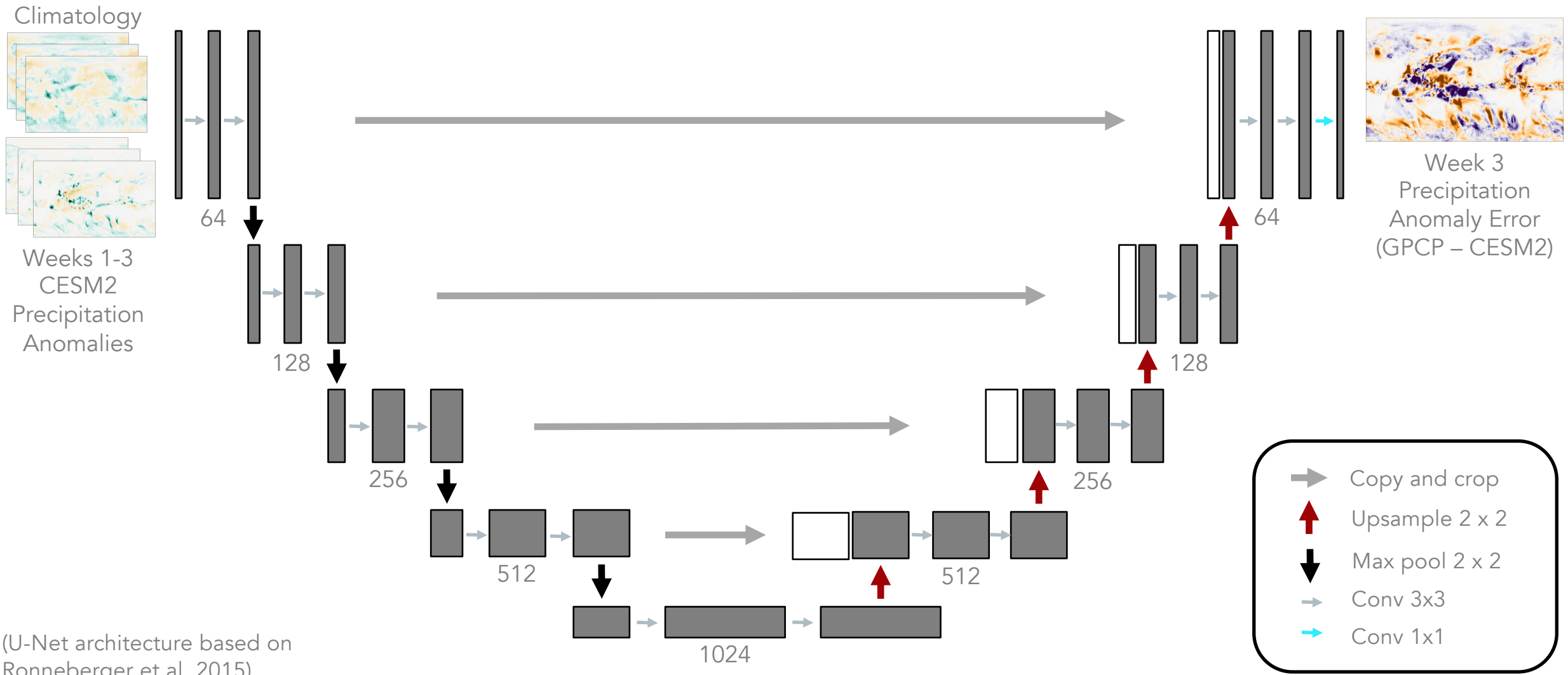
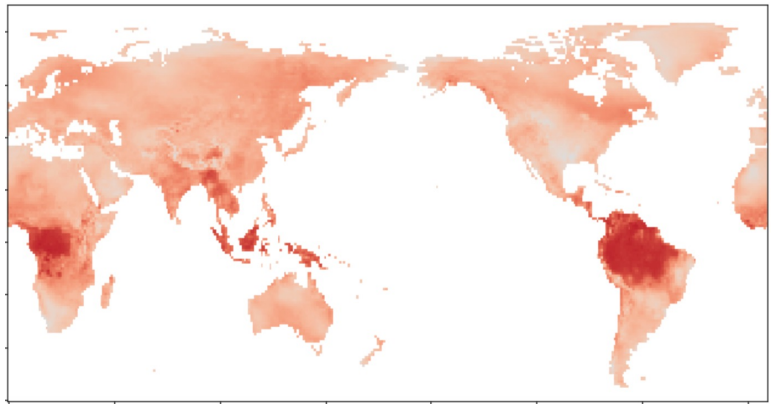


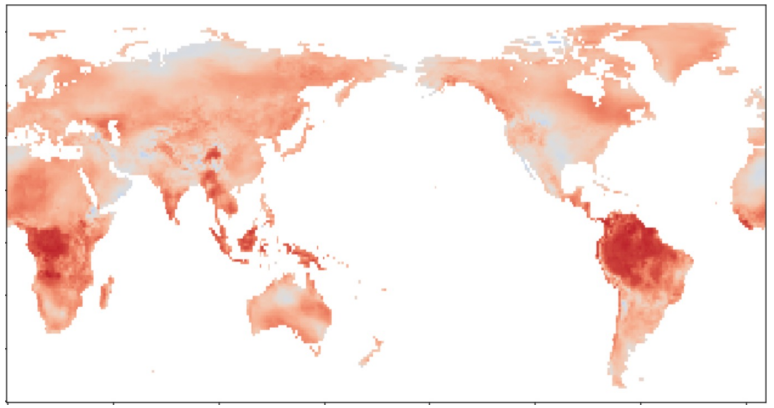

(U-Net architecture based on Ronneberger et al. 2015)

# Skill of Week 3 Temperature Error Prediction (2016-2019)

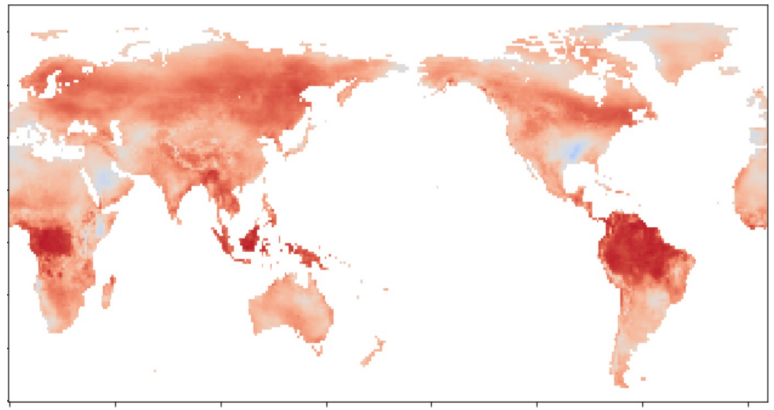
All Seasons (0.41)



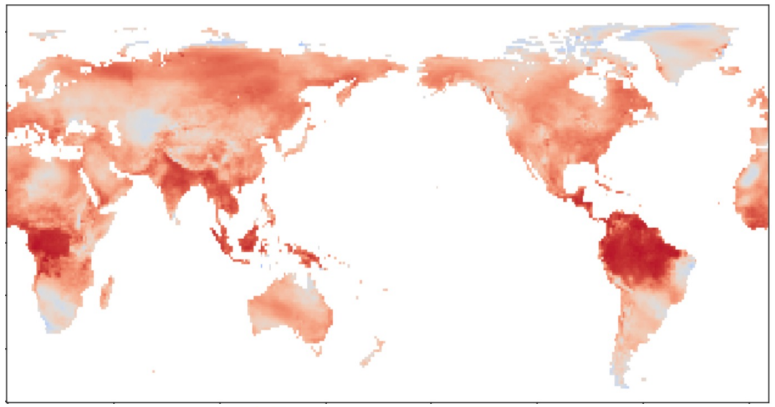
DJF (0.39)



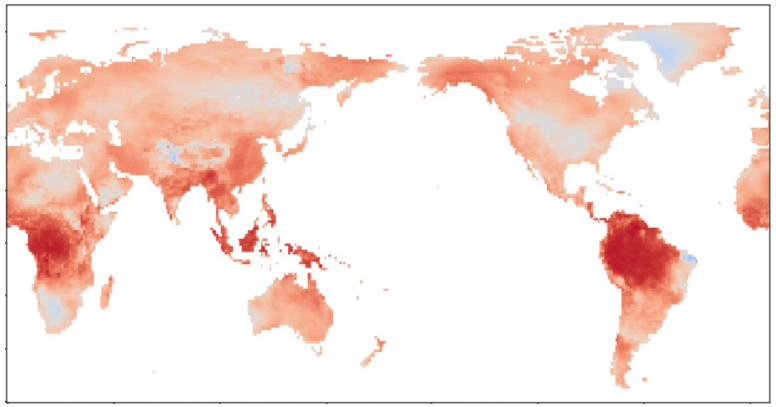
MAM (0.44)

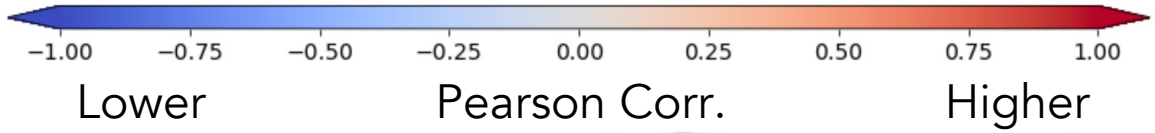


JJA (0.44)



SON (0.40)



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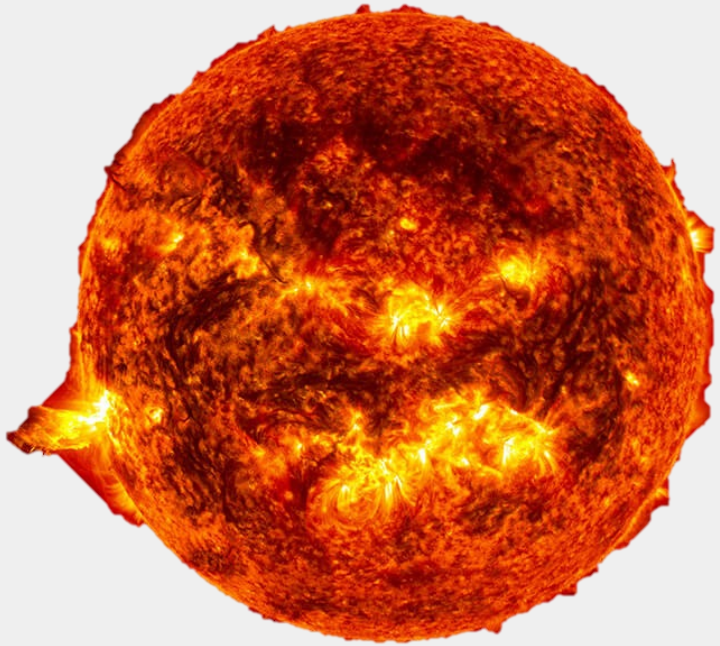
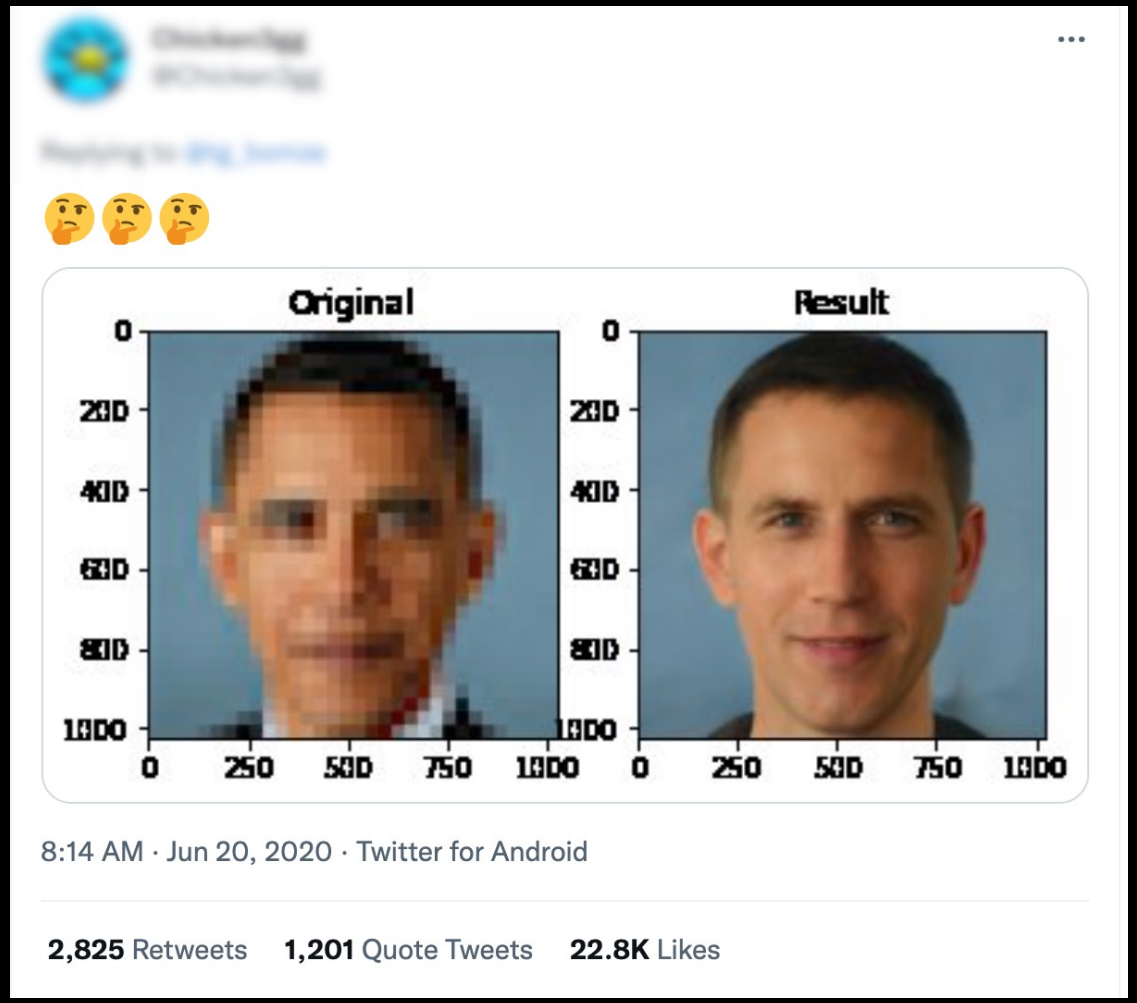
Molina et al. (in prep.)



Credit: NASA/SDO

# Opportunities for Cross-Discipline Collaboration?

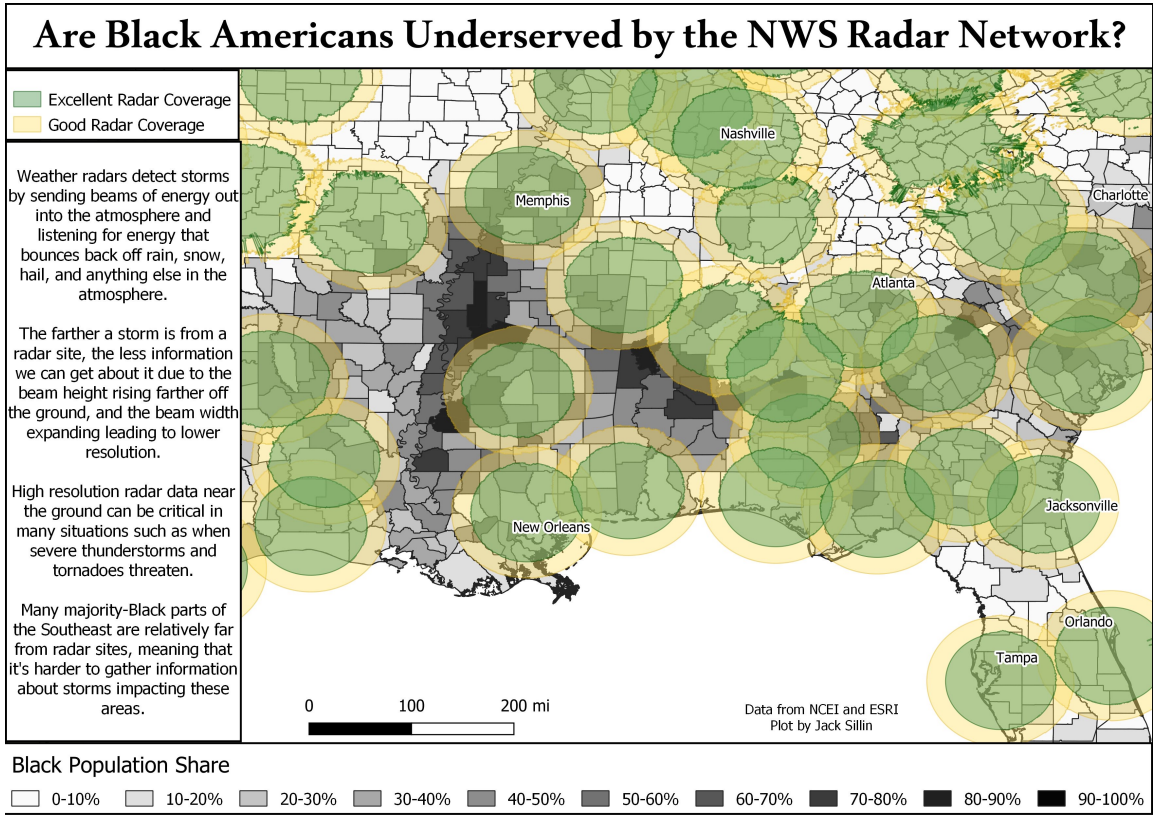
molina@ucar.edu




Face-Depixelizer
https://github.com/tg-bomze/Face-Depixelizer

# Ethics in AI

# Ethics in AI for Weather and Climate




Funded NCAR Innovator Program grant led by Dr. Amy Yeboah (Howard University; 2021-23).

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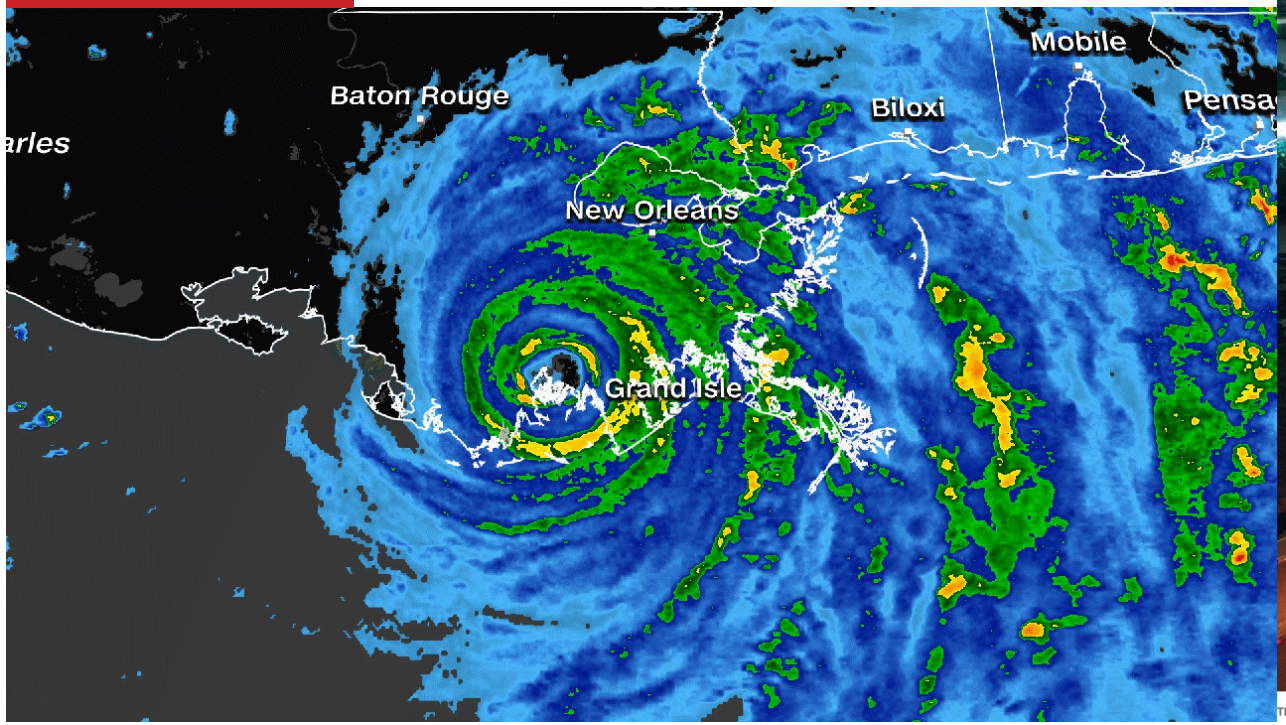
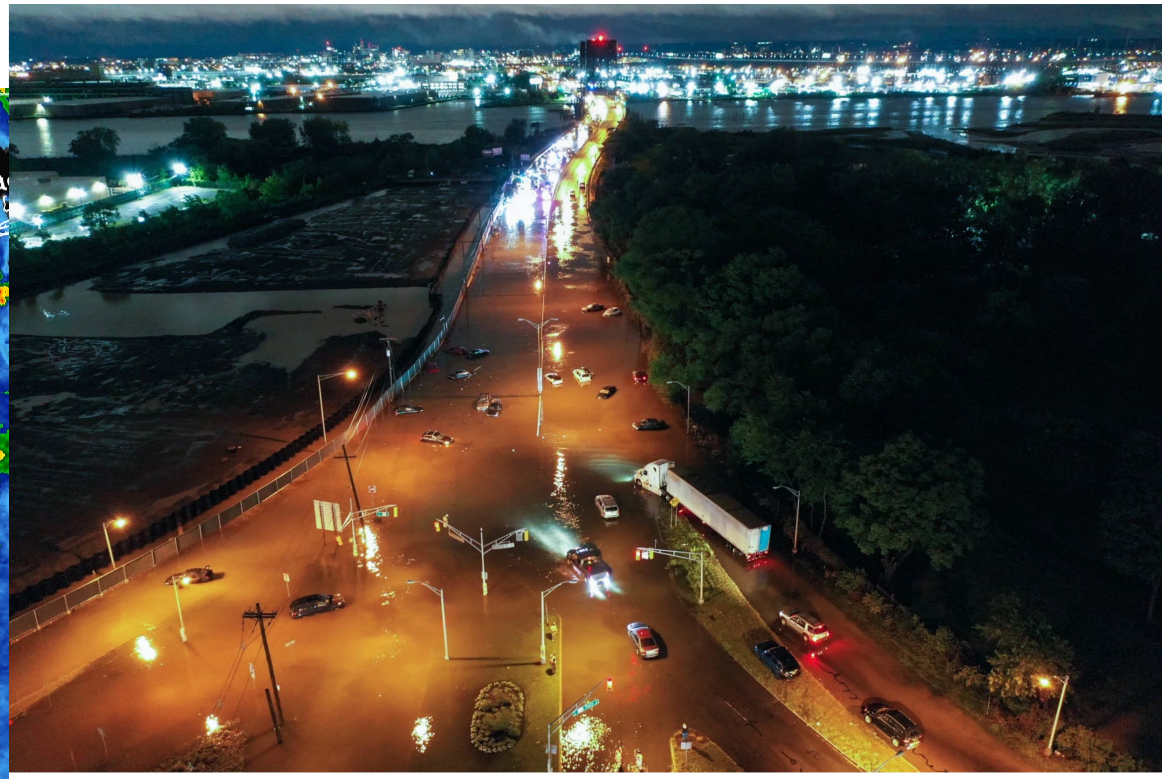
# NYPD rescues more than 800 passengers from city's subways, chief says

From CNN's Mark Morales



**Thursday., Sept. 2:** Highway 440 flooded in Jersey City of New Jersey as hundreds of cars stuck in water as Hurricane Ida left behind flash floods east coast.

*Tayfun Coskun/Anadolu Agency via Getty Images*

## Ida remained a Category 4 hurricane for about 6 hours after landfall