# Development of a Convolutional Neural Network to Predict Orographic Precipitation Gradients of the Western CONUS

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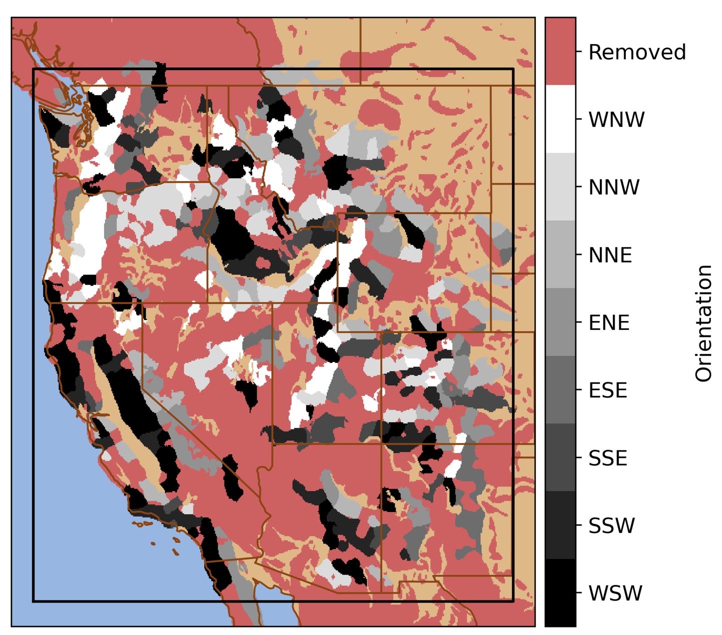
## Motivation

- Cool-season precipitation in the Western contiguous United States (CONUS) impacts water resources, recreation, and public safety.
- Can a convolutional neural network (CNN) for the Northern Rockies region be expanded to predict orographic precipitation gradients (OPGs) for the entire Western CONUS?
- Can custom loss functions based on correlation or absolute difference in OPGs be utilized to improve the prediction of facets with less available training data?

## Data and Background

### Datasets Used[1]

- Global Historical Climatology Network – Daily: 1979–2018
- Global 30 Arc-Second Elevation (GTOP30); drawn to 4-km grid-spacing




205 facets; facets removed if length of record < 20% or number of station < 3

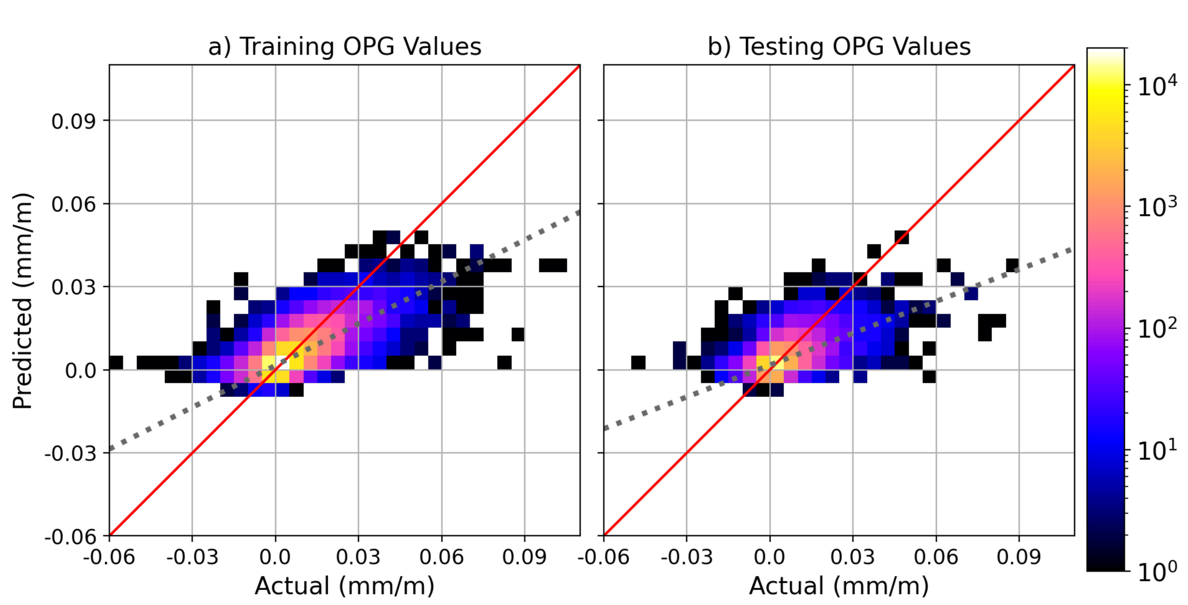
### Input Dataset[2]

ECMWF ERA5 at 0.5° Grid-Spacing

| Variables | Levels |
|---|---|
| E/W Winds | 700 hPa |
| N/S Winds | 700 hPa |
| Specific Humidity | 700 hPa |
| Temperature | 700 hPa |
| Geopotential Height | 500 hPa |
| Integrated Vapor Transport | All Levels |

### Northern Rockies CNN[3]

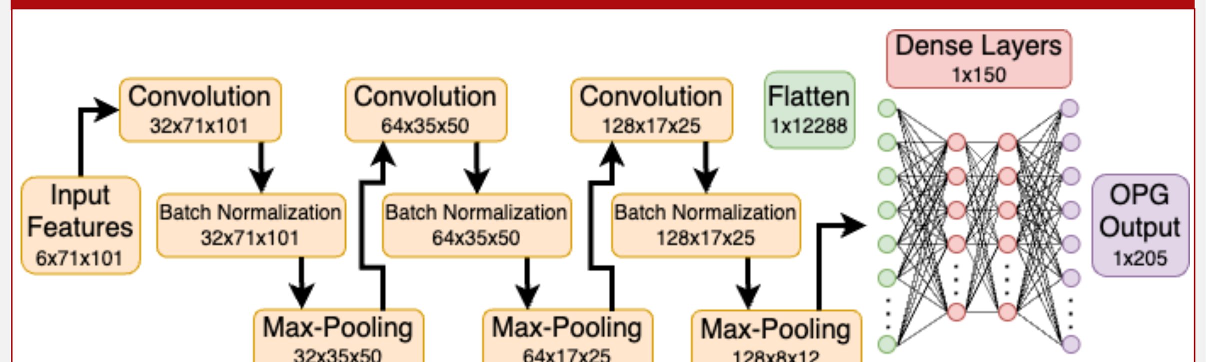
- Original CNN focused on the test case of the Northern Rockies region.
- Included surface variables that were removed for the Western CONUS model.




**Training**
$r^2 = 0.53$
MAE = 2.6 mm $km^{-1}$

**Testing**
$r^2 = 0.34$
MAE = 2.9 mm $km^{-1}$

## CNN Architecture

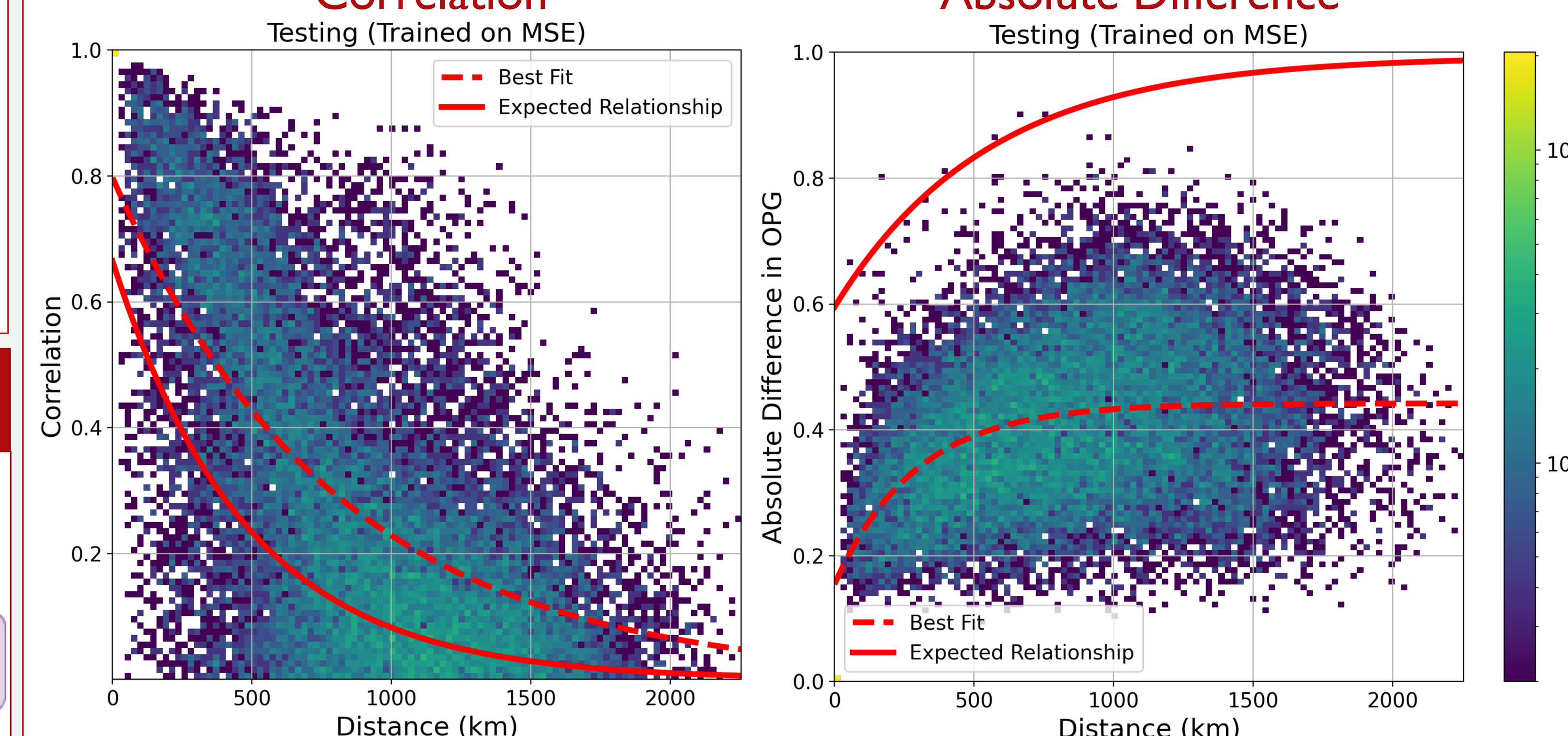



### Hyperparameter Tuning

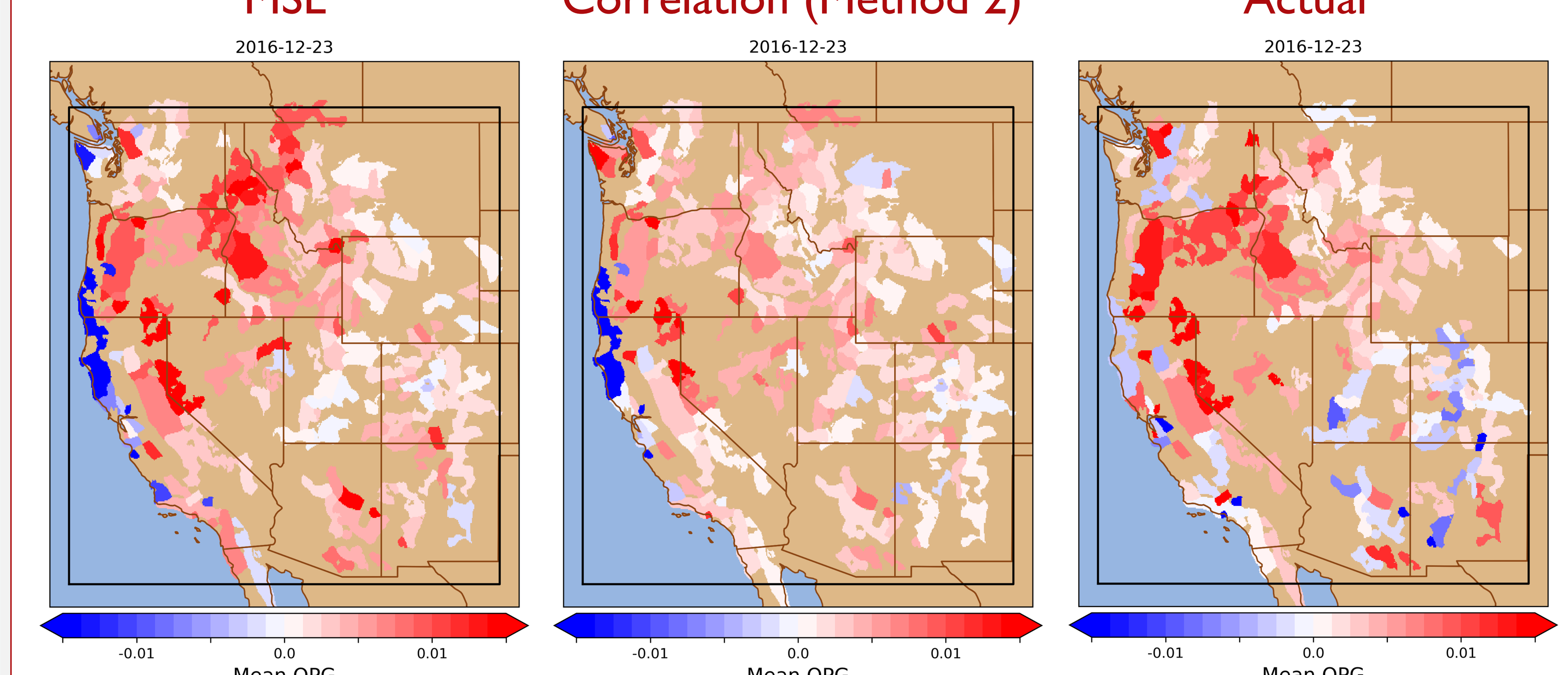
- Automates the process of finding the optimal values for various parameters that control the learning process for the CNN
- Improves model performance

| Hyperparameter | Options | Chosen value |
|---|---|---|
| Optimizer | Adam, SGD, RMSProp | Adam |
| Learning rate | 0.01, 0.001, 0.0001 | 0.0001 |
| NN width | 10 – 150, step = 10 | 150 |
| Kernel size | 2, 3, 4, 5 | 5 |

## Custom Loss Functions




Expected relationship is based on the correlation/absolute difference of facets with a length of record >= 75%




Depicts a test case from December 23, 2016

### 2 Methods

1. Train the model 3 times
   1. Mean squared error (MSE)
   2. Custom loss
   3. MSE again
2. Train the model once with a combined loss function (MSE and custom)

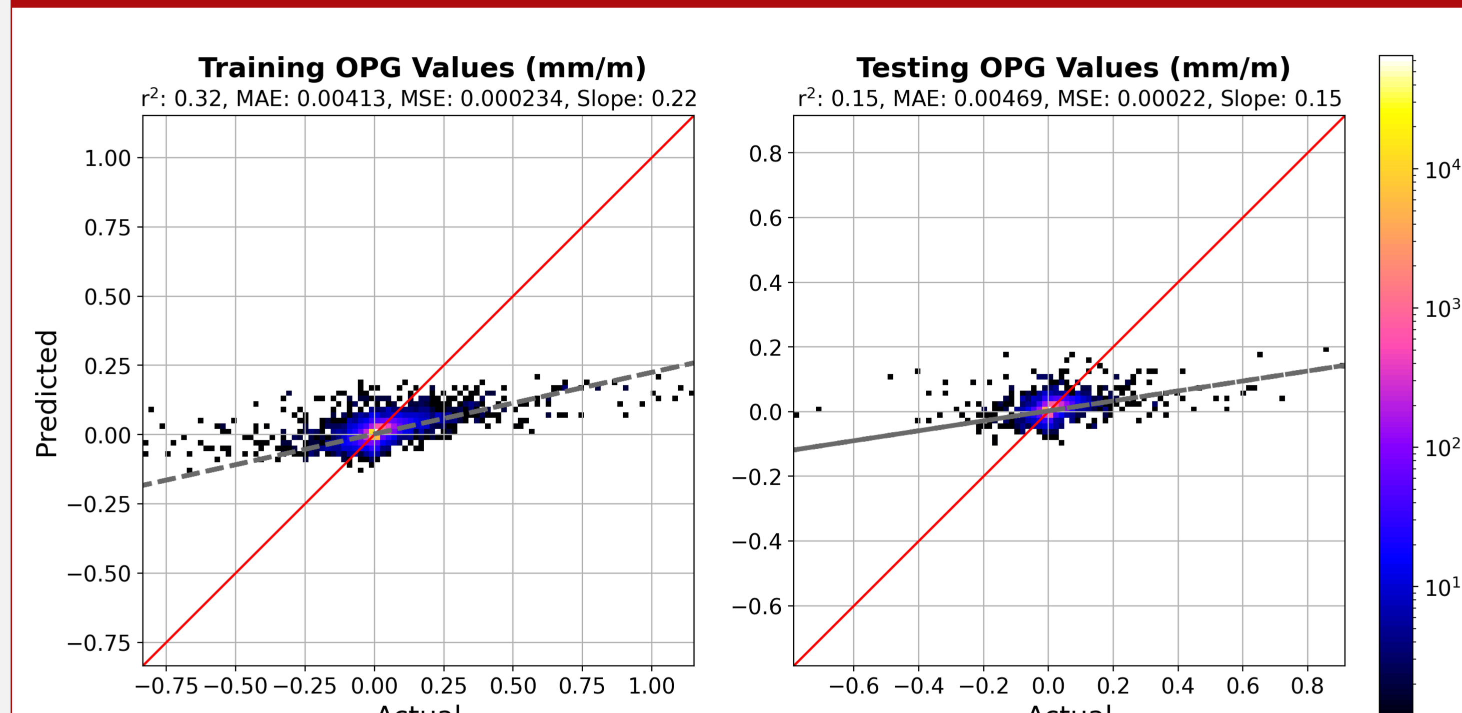
### Result

- Both methods decreased OPG prediction accuracy
- However, the custom loss was minimized (correlation decreased, absolute difference increased)

### Summary

- **Goal:** utilize correlation or difference between nearby facets to improve prediction of facets with less data available
- Surprisingly, model predicts **too much correlation**
- Penalizing the model for having too much correlation just creates random heterogeneity that **decreases OPG prediction accuracy**

## OPG Prediction




- High OPGs are significantly underpredicted
- Low OPGs are significantly overpredicted
- Extremes are not predicted

## Conclusions and Future Work

- The model struggled to generalize a region as large as the entire Western CONUS (high MSE, low $r^2$ values); subregions performed the same or better than entire Western CONUS
- Custom loss functions are ineffective to improve OPG prediction but are effective to minimize loss (decrease correlation, increase absolute difference)
- Future work could include implementing a moving window CNN which will predict OPGs at one facet at a time with one CNN

## References & Acknowledgments

1. Bohne, L., C. Strong, and W. J. Steenburgh, 2020: Climatology of orographic precipitation gradients in the contiguous western United States. *J. Hydrometeor.*, 21, 1723–1740.
2. Hersbach, H., and Coauthors, 2023a: ERA5 hourly data on pressure levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), accessed 18 January 2023.
3. Wolvin, S., C. Strong, S. Brewer, W. J. Steenburgh, A. Warner: Evaluation of a Convolutional Neural Network to Predict Wintertime Orographic Precipitation Gradients of the CONUS Northern Rockies, Unpublished Manuscript.

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