# Attention-Based Scattering Network for Satellite Imagery

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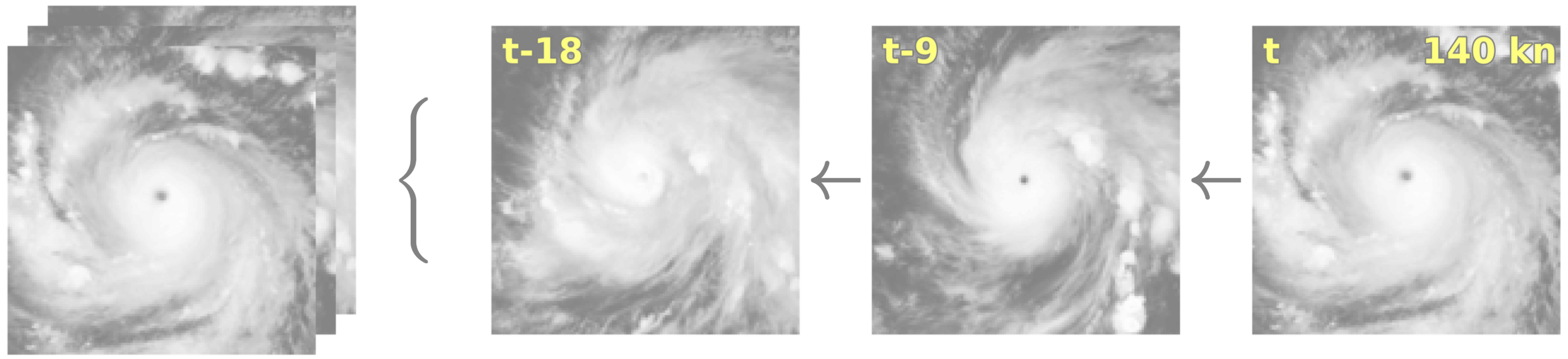


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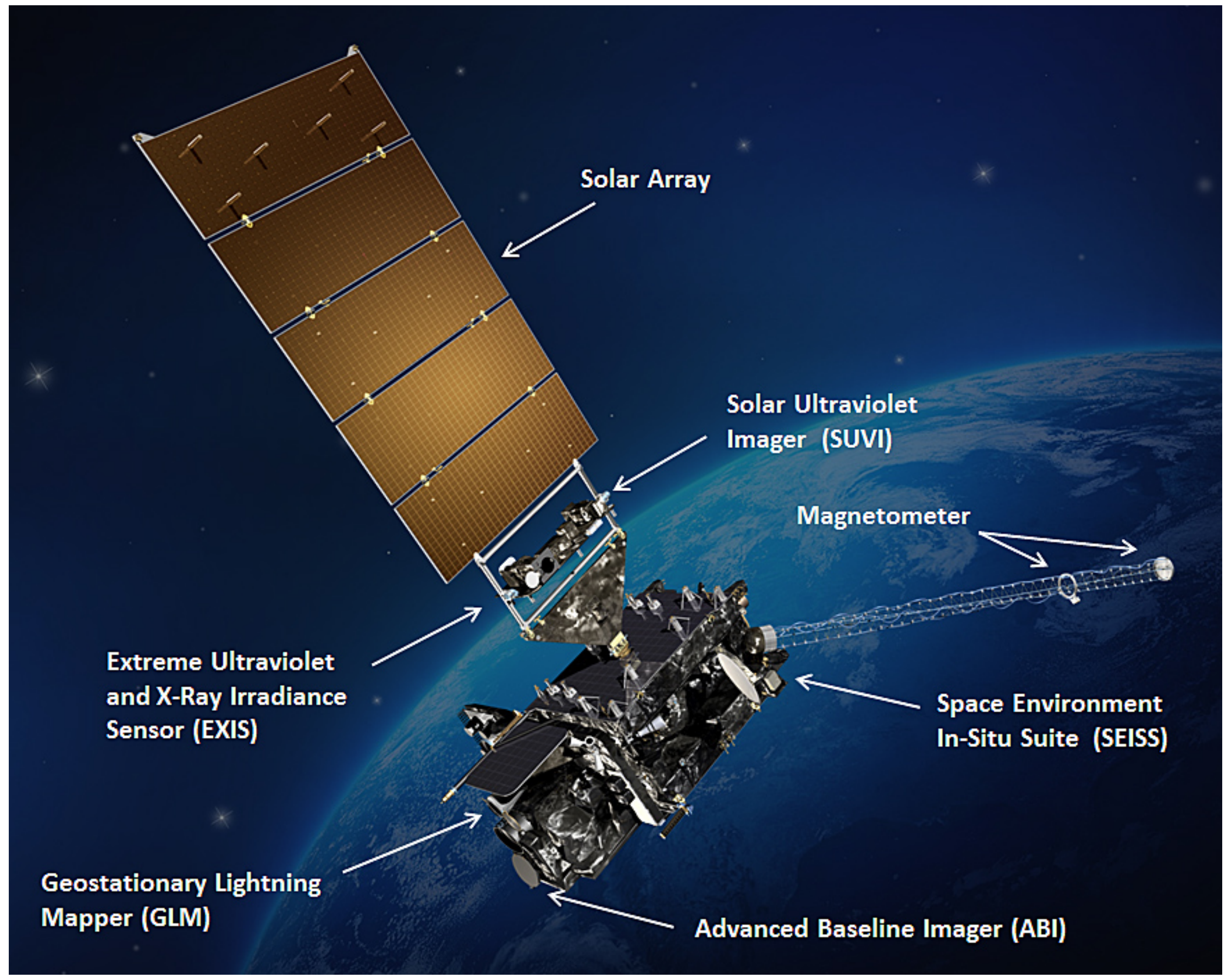
# Introduction

- **Multi-channel satellite imagery**, from stacked spectral bands or spatiotemporal data, have meaningful representations for various atmospheric properties
- Effectively combining these channels to create a **performant** and **trustworthy** model is important to forecasters and modeling experts

- Satellite-based applications + machine learning problems:
  - Deep neural networks **lack inherent interpretability**
  - Often limited by the **quantity of available labeled data**

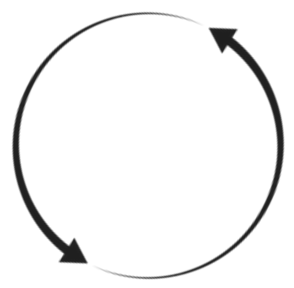



NOAA/NASA GOES-R Satellite

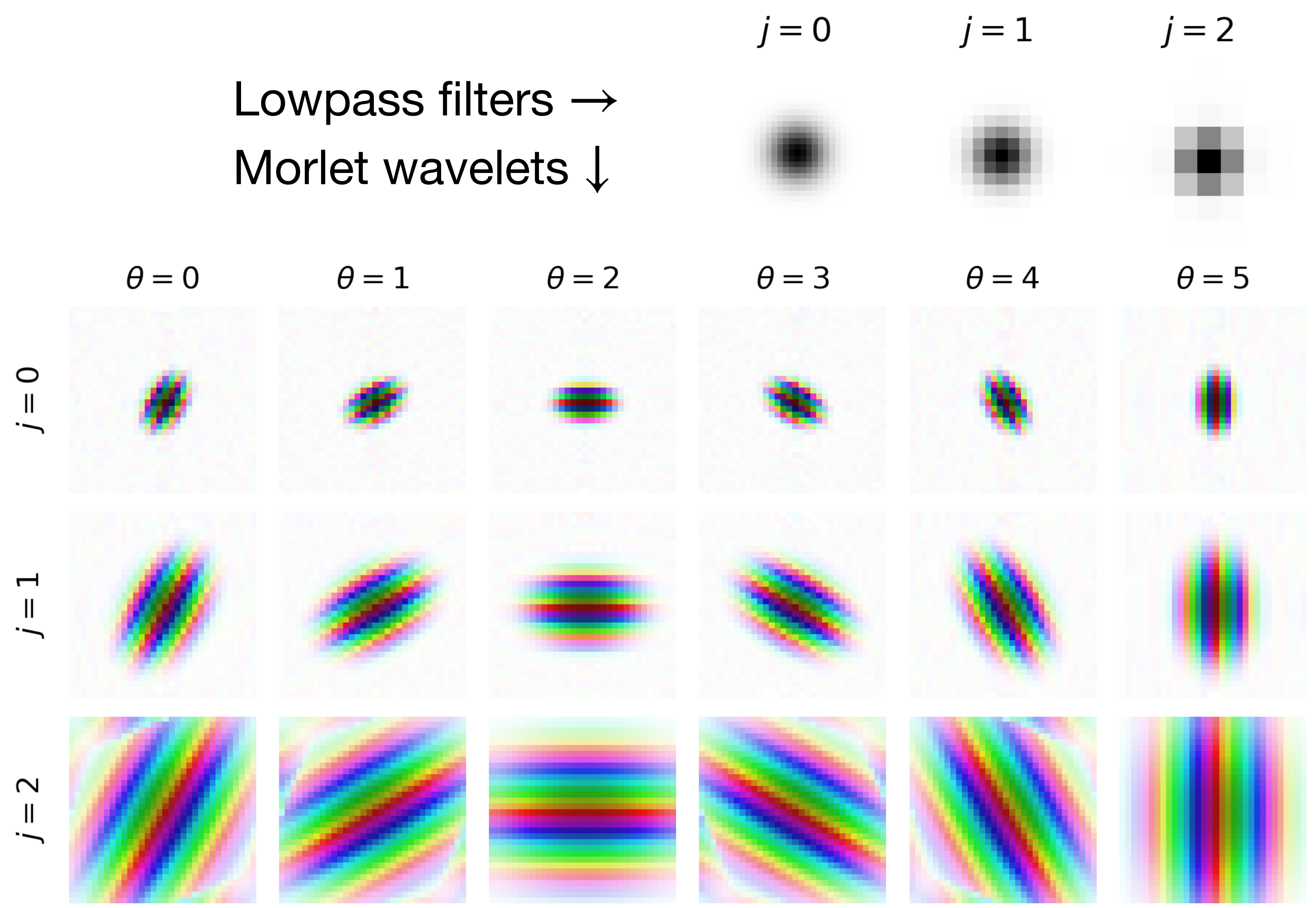
# Scattering Transform

- Introduced by Stéphane Mallat (2012)
  - Strong geometric invariants (translation, rotation, scaling)
  - Robust to noise and stable to deformations

- Defined as a convolutional neural network
  - Wavelet transform (convolution)
  - Lowpass filter (average pooling)
  - Complex modulus (non-linearity)

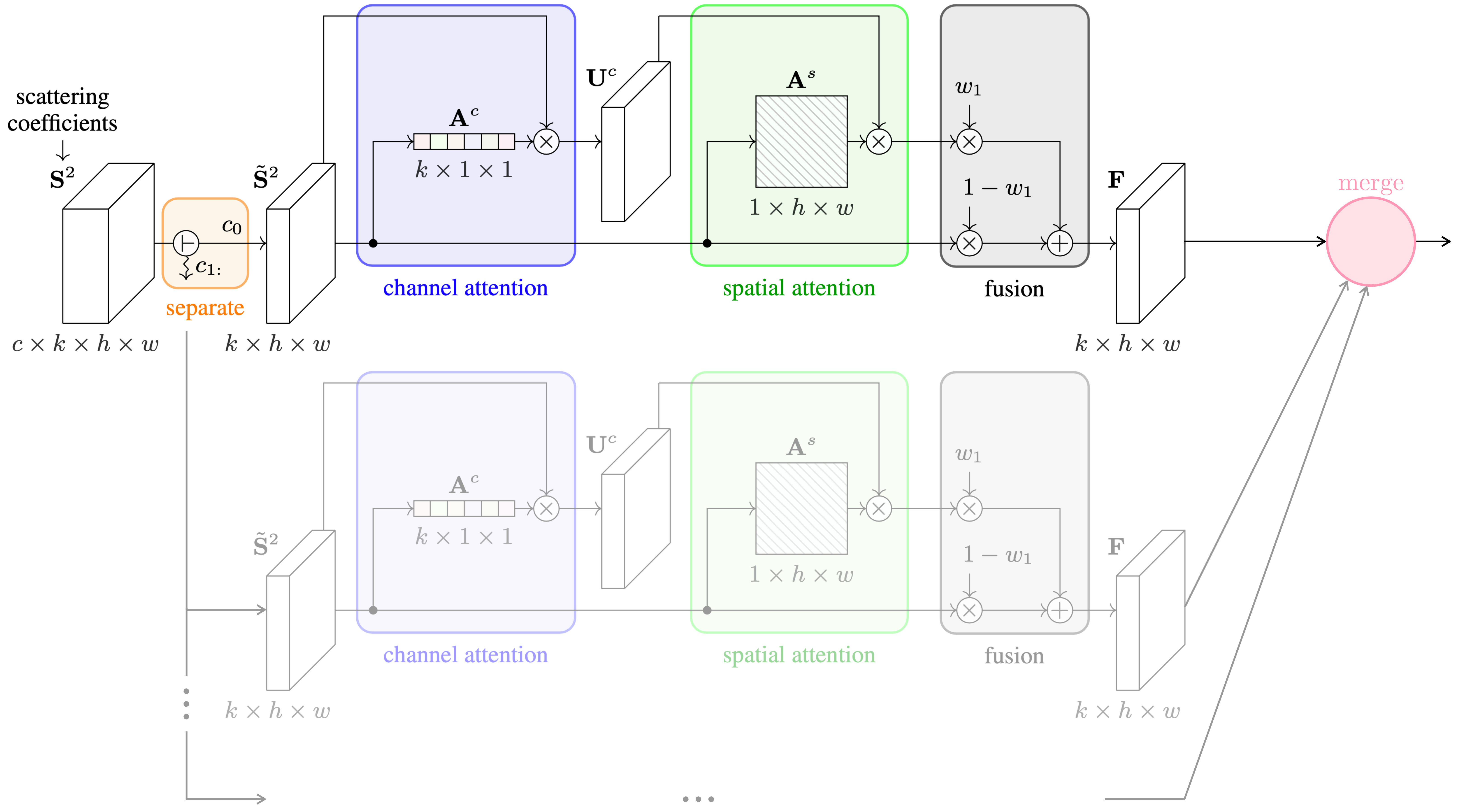


- Largely **underexplored in weather and climate** applications
- **Main contribution:** first approach applying local attention to individual scattering coefficients



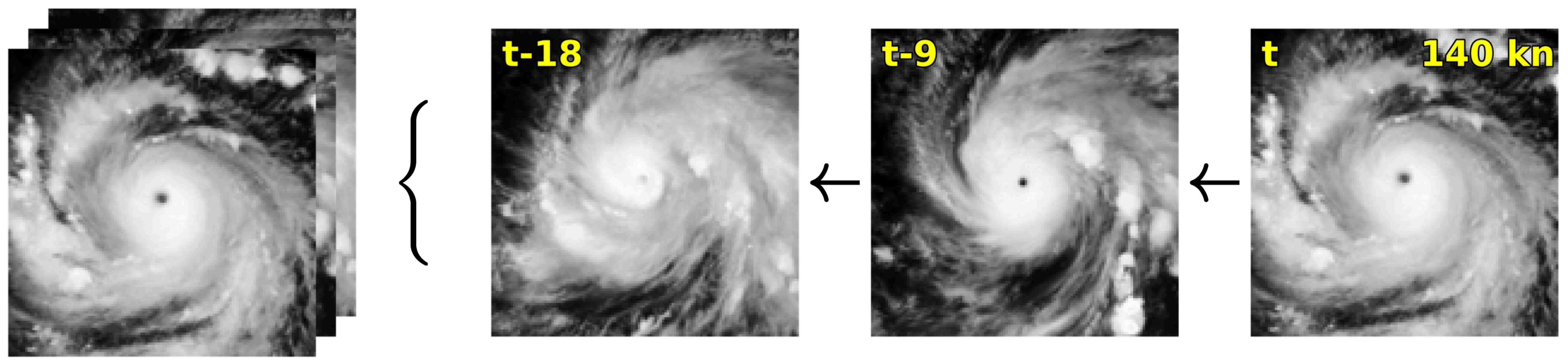
# Network Architecture

1. Scattering Transform
2. Channel Separation
3. Channel Independent Attention Modules
4. Feature Merging

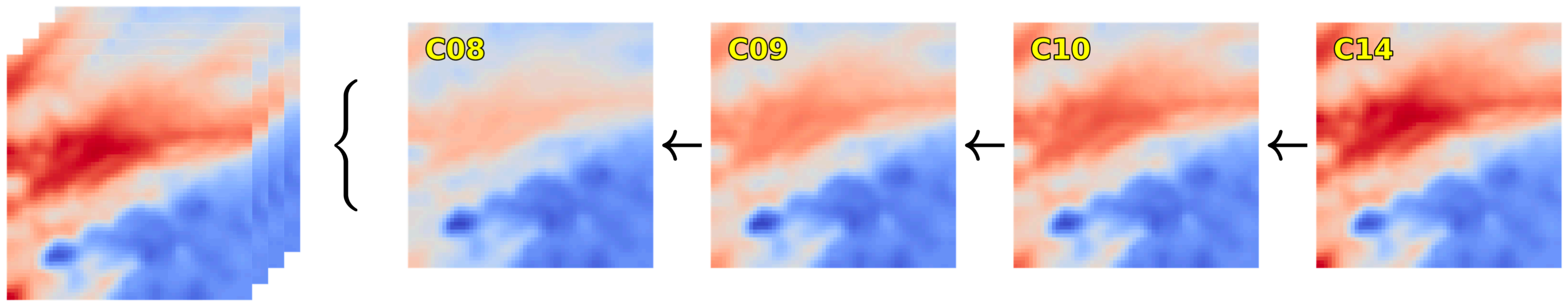


# Experimental Datasets

- **Estimating Tropical Cyclone Intensity**
  - Single-band infrared imagery (10.3 μm) from **GOES-16 ABI** - 600 storms from 2000-2019
  - Leverage temporal relationships of previous timesteps up to the point of prediction (regression)




- **Short Range Lightning Prediction**
  - Water vapor bands (6.2, 6.9, 7.3, & 11.2 μm) from **GOES-16 ABI** and lightning counts from **GLM**
  - Target flash counts, lagged by one hour, are converted to binary labels (classification)



# Results

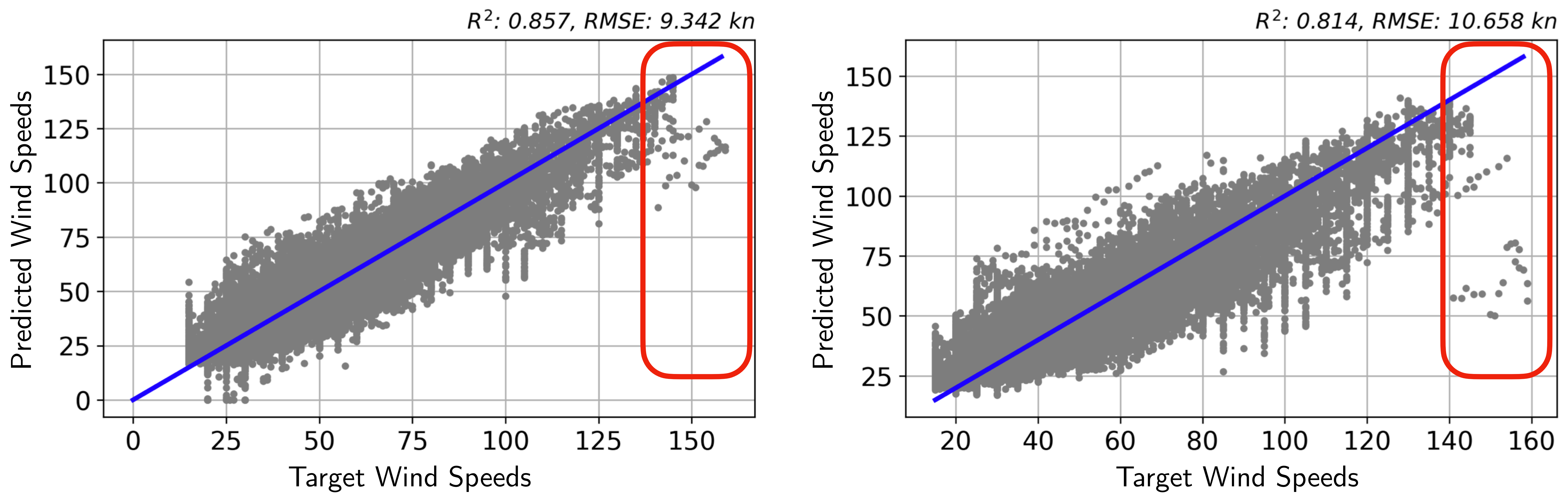
- Multiple trials with a reduced number of training samples
  - Great advantages primarily for **small sample sizes**,
  - While there are diminishing returns for very large sample sizes
- **Better generalization** than common state-of-the-art methods
  - Fewer trainable parameters than a linear model

**Table 1:** Experimental results using $n$ training samples and $p$ parameters.

| $n \downarrow \; p \rightarrow$ | Scattering (51.8K) | ResNet18 (11.2M) | MobileNetV3 (1.5M) | Conv. (268.2K) |
|---|---|---|---|---|
| TC Intensity, rmse ($R^2$) | | | | |
| 1000 | **15.83 (0.59)** | 16.47 (0.56) | 56.85 (-4.28) | 17.51 (0.50) |
| 5000 | **12.01 (0.76)** | 14.30 (0.67) | 55.18 (-3.97) | 13.34 (0.71) |
| 10000 | **10.98 (0.80)** | 11.85 (0.77) | 21.13 (0.27) | 13.81 (0.69) |
| 30000 | **10.35 (0.83)** | 10.74 (0.81) | 13.07 (0.72) | 11.68 (0.78) |
| 47904 | **9.34 (0.86)** | 10.66 (0.81) | 11.90 (0.77) | 11.67 (0.78) |
| Lightning Occurrence, acc. (F1) | | | | |
| 1000 | **86.04 (0.85)** | 73.68 (0.74) | 62.46 (0.39) | 78.27 (0.74) |
| 5000 | **88.01 (0.87)** | 87.59 (0.87) | 68.82 (0.55) | 82.35 (0.82) |
| 10000 | **88.87 (0.88)** | 86.33 (0.85) | 81.46 (0.83) | 84.37 (0.84) |
| 50000 | **89.58 (0.89)** | 89.20 (0.88) | 87.49 (0.87) | 87.99 (0.87) |
| 212604 | 90.46 (0.90) | **90.51 (0.90)** | 86.87 (0.88) | 89.57 (0.89) |

# Estimating Tropical Cyclone Intensity

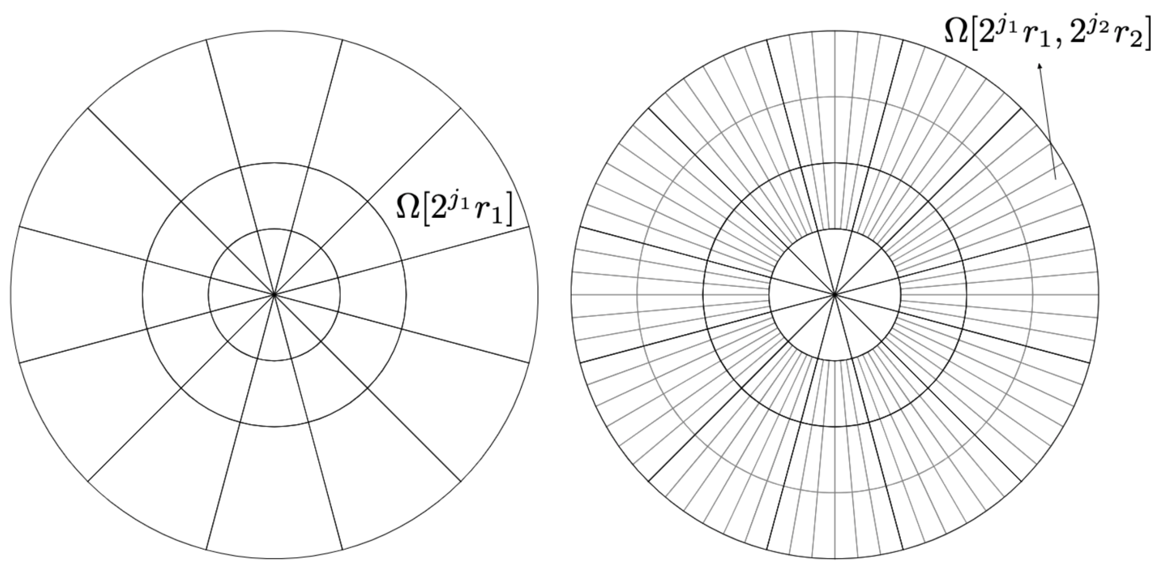
- Lowest errors observed with the **highest intensity samples** (where ResNet18 performs worst)
- Target wind speeds >140 kn
  - Scattering Net RMSE = **27.231 kn**
  - ResNet18 RMSE = **51.630 kn**



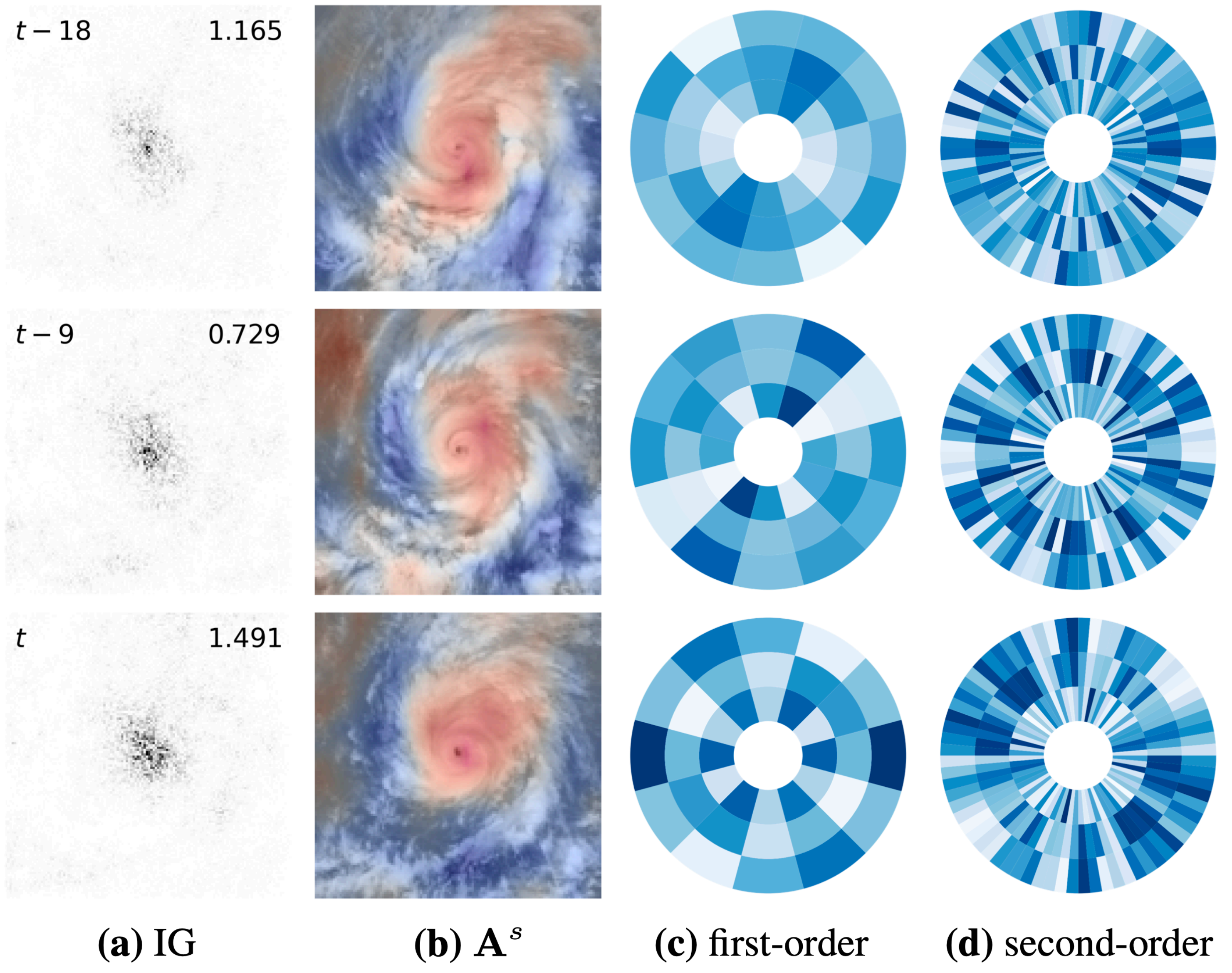

**(a)** Scattering Network **(b)** ResNet18

# Network Interpretations

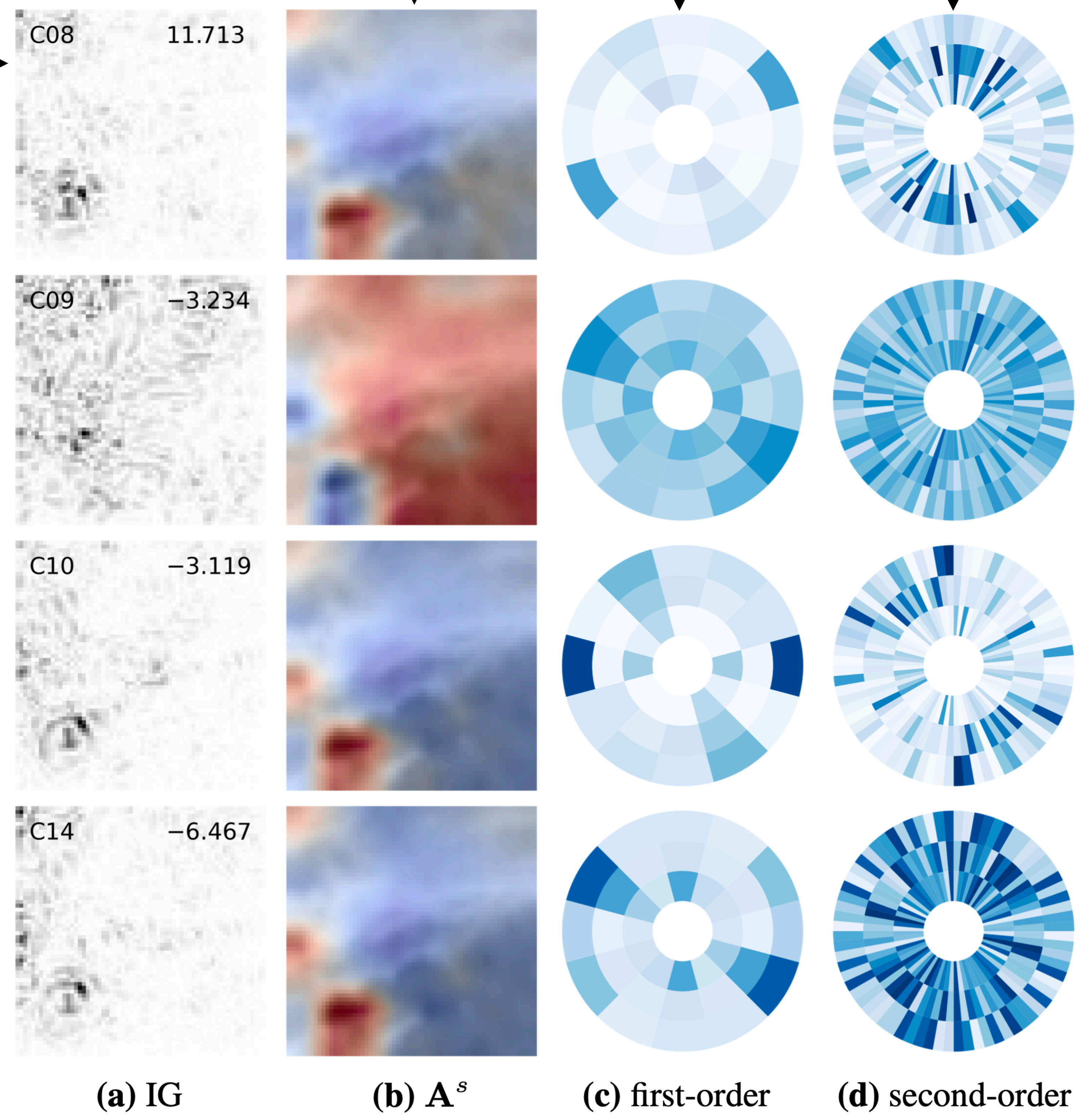
- **Spatial attention features**
  - Feature maps superimposed for individual input channels
- **Scattering coefficient attention features**
  - Scalar weights of first- and second-order coefficients
- **Gradient based methods**
  - Demonstration of differentiable post hoc explainability methods




Bruna, J., & Mallat, S. (2013).
*Invariant scattering convolution networks.*




Tropical Cyclones




Lightning Prediction

# Thank you!

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