Super-Resolution of GOES-16 ABI Bands with a Convolutional Neural Network

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Cooperative Institute for Research in the Atmosphere (CIRA)

ABI Band-13 (10.3 µm)

Native Resolution (2-km)

Super-Resolved (0.5-km)

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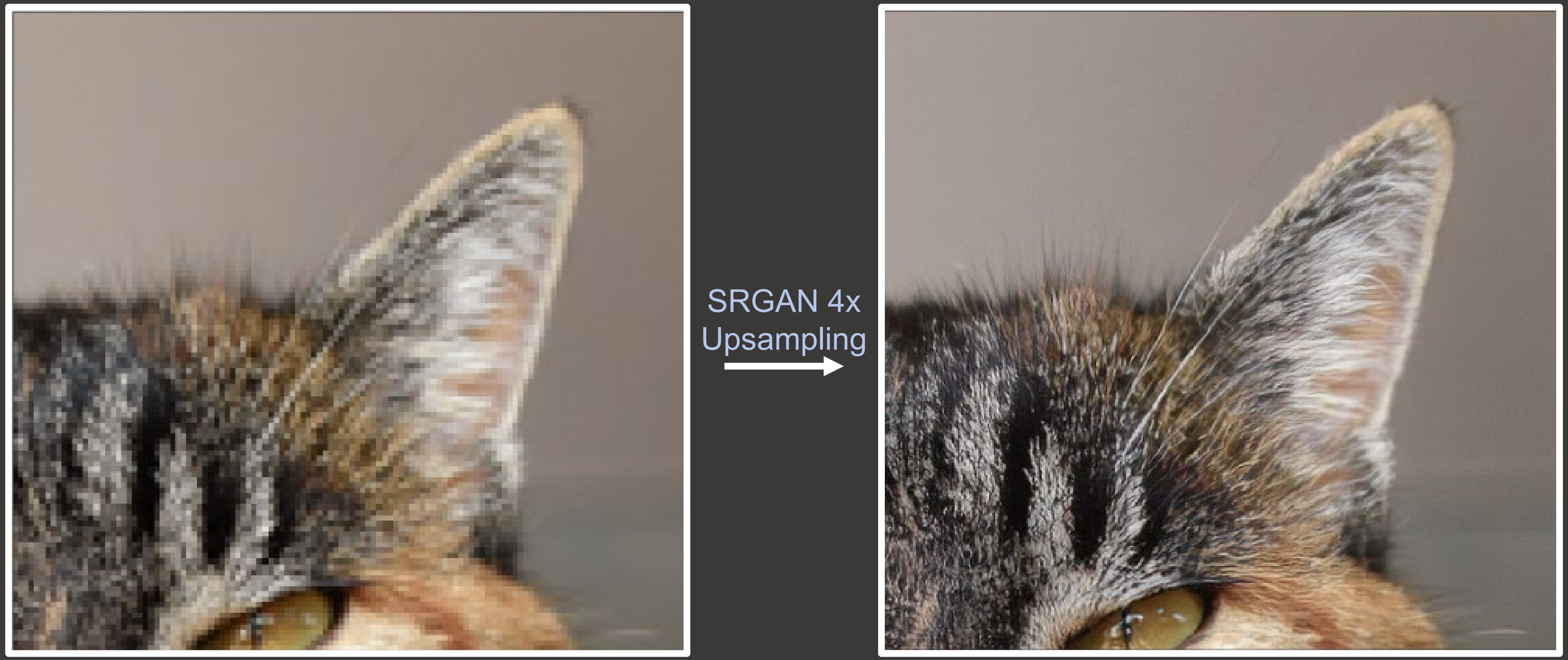
Super-resolution

- General term for increasing the resolution of an image or imaging system
- Most of the recent approaches use neural networks
- Not a new problem, and many non-AI based methods exist (Lukosz 1966)



Martin Krasser; https://github.com/krasserm

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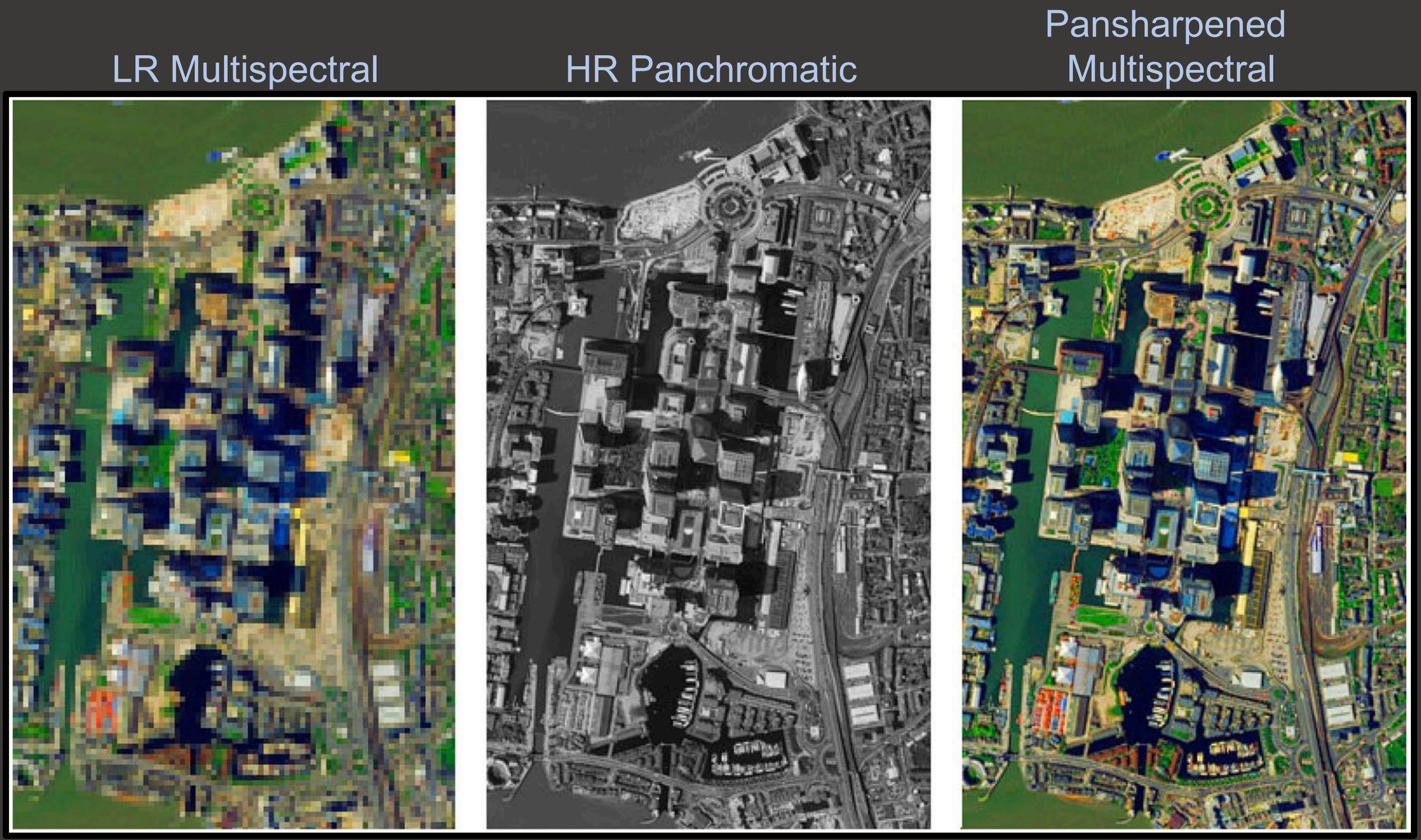
W. Lukosz, "Optical Systems with Resolving Powers Exceeding the Classical Limit*," J. Opt. Soc. Am. 56, 1463-1471 (1966)

Pan-sharpening

- Using high-spatial-resolution panchromatic bands to “increase” the spatial resolution of other bands
- Panchromatic band typically has a wide spectral response function that overlaps lower resolution bands
- Could be considered a special case of super-resolution



Kaur et al. 2021; A Comprehensive Study on Computational Pansharpening Techniques for Remote Sensing Images

Motivating Questions

- Can we use information from 0.5-km Band-2 to make reasonable 0.5-km imagery from the other ABI channels?

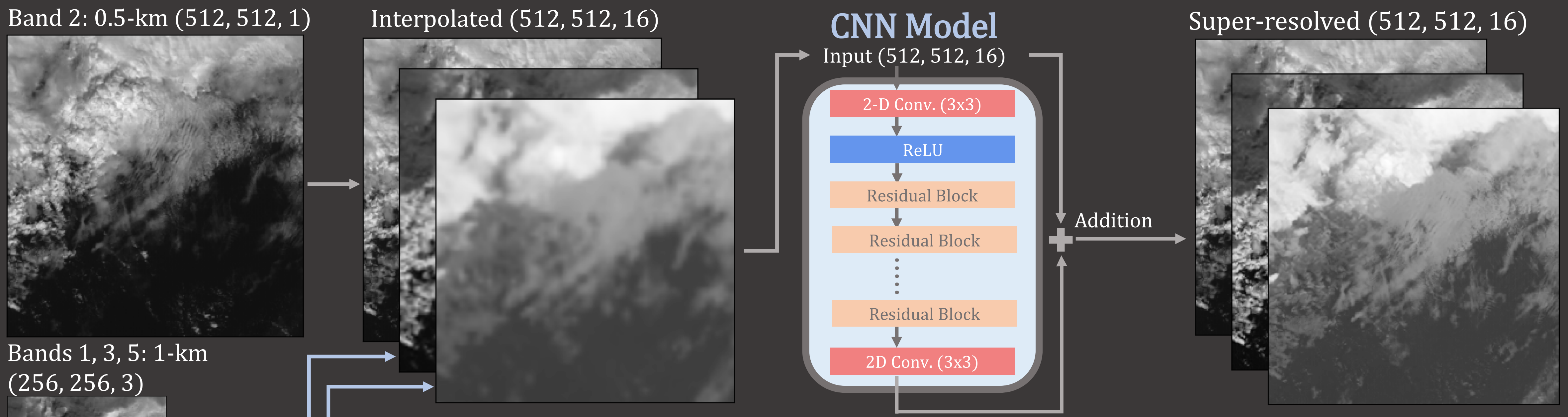
- How accurately can we do this?
  - Spectral relationships
  - Spatial structure

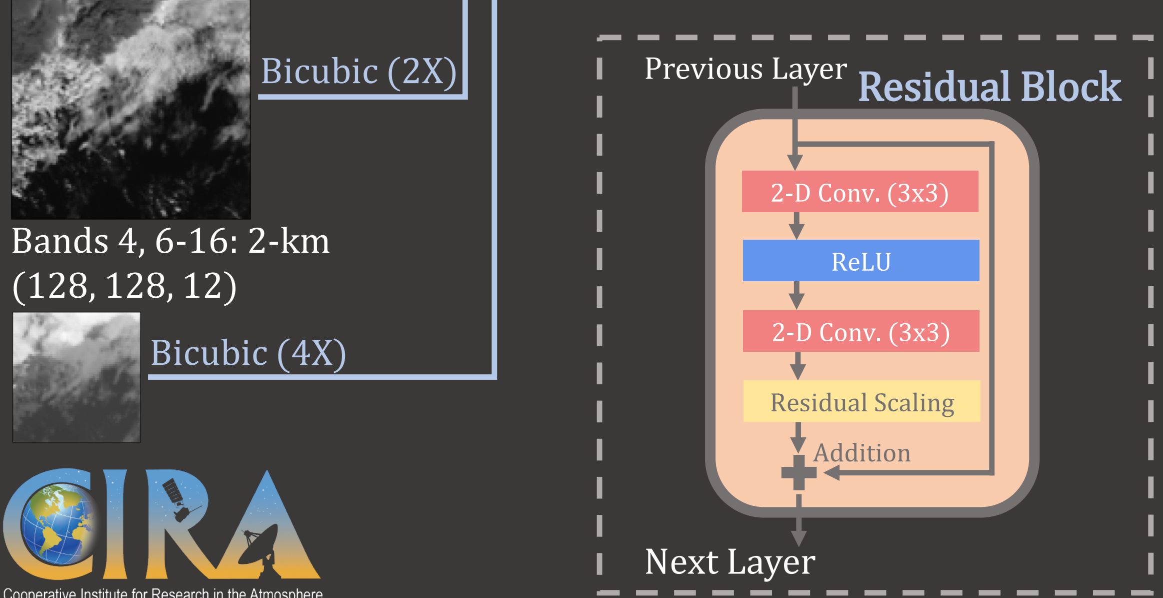
- **How do we even evaluate 0.5-km imagery in the first place?**

ABI

Band Number	Central Wavelength (µm)	Nadir Spatial Resolution (km)
1	0.47	1.0
2	0.64	0.5
3	0.86	1.0
4	1.37	2.0
5	1.6	1.0
6	2.2	2.0
7	3.9	2.0
8	6.2	2.0
9	6.9	2.0
10	7.3	2.0
11	8.4	2.0
12	9.6	2.0
13	10.3	2.0
14	11.2	2.0
15	12.3	2.0
16	13.3	2.0

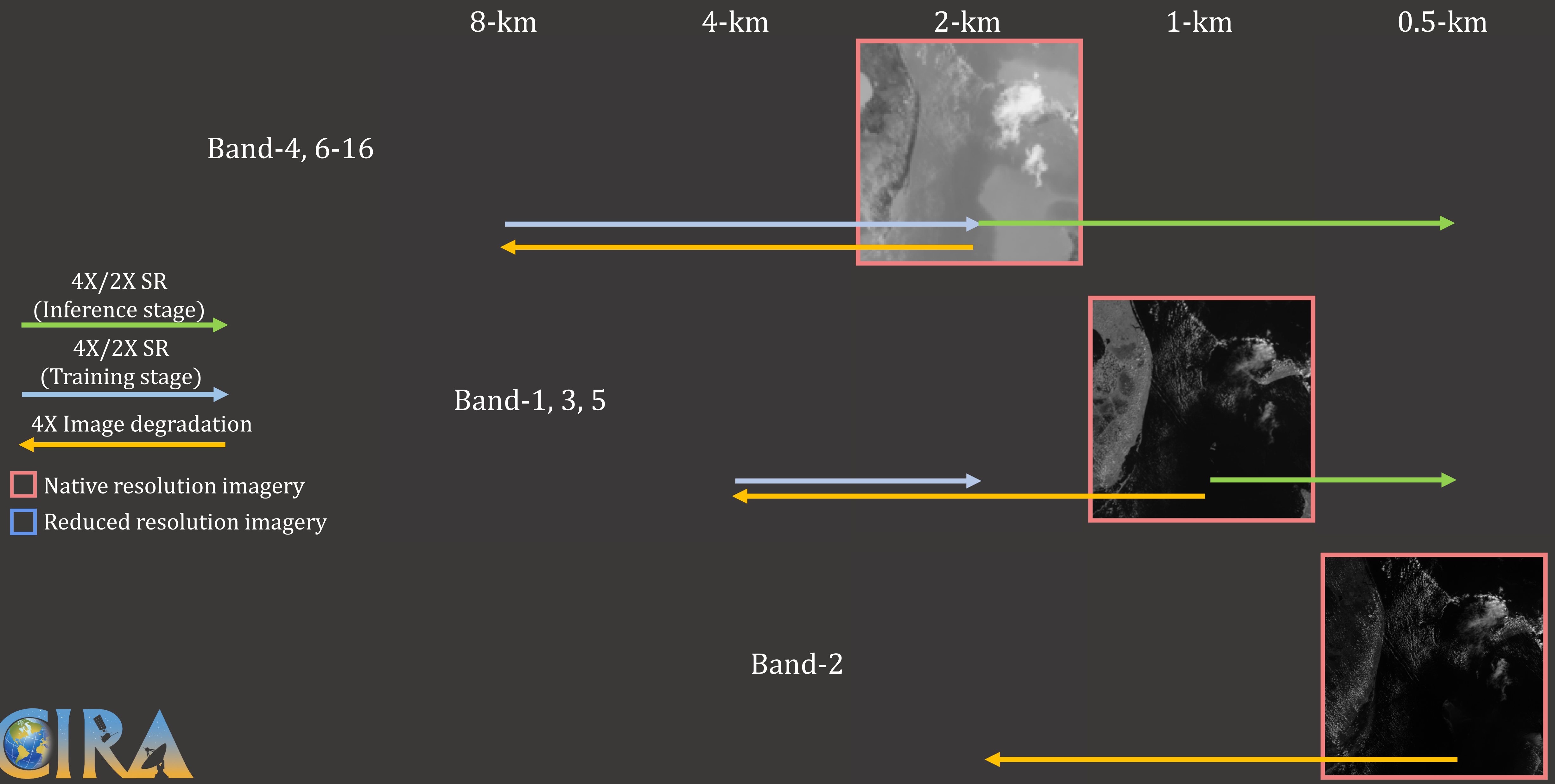
The Model





- Small receptive field
- Residual scaling (instead of batch normalization)
- Fully Convolutional (no dependence on image size)
- <60 seconds to process a full-disk image

Synthetic Low-Resolution Training Data



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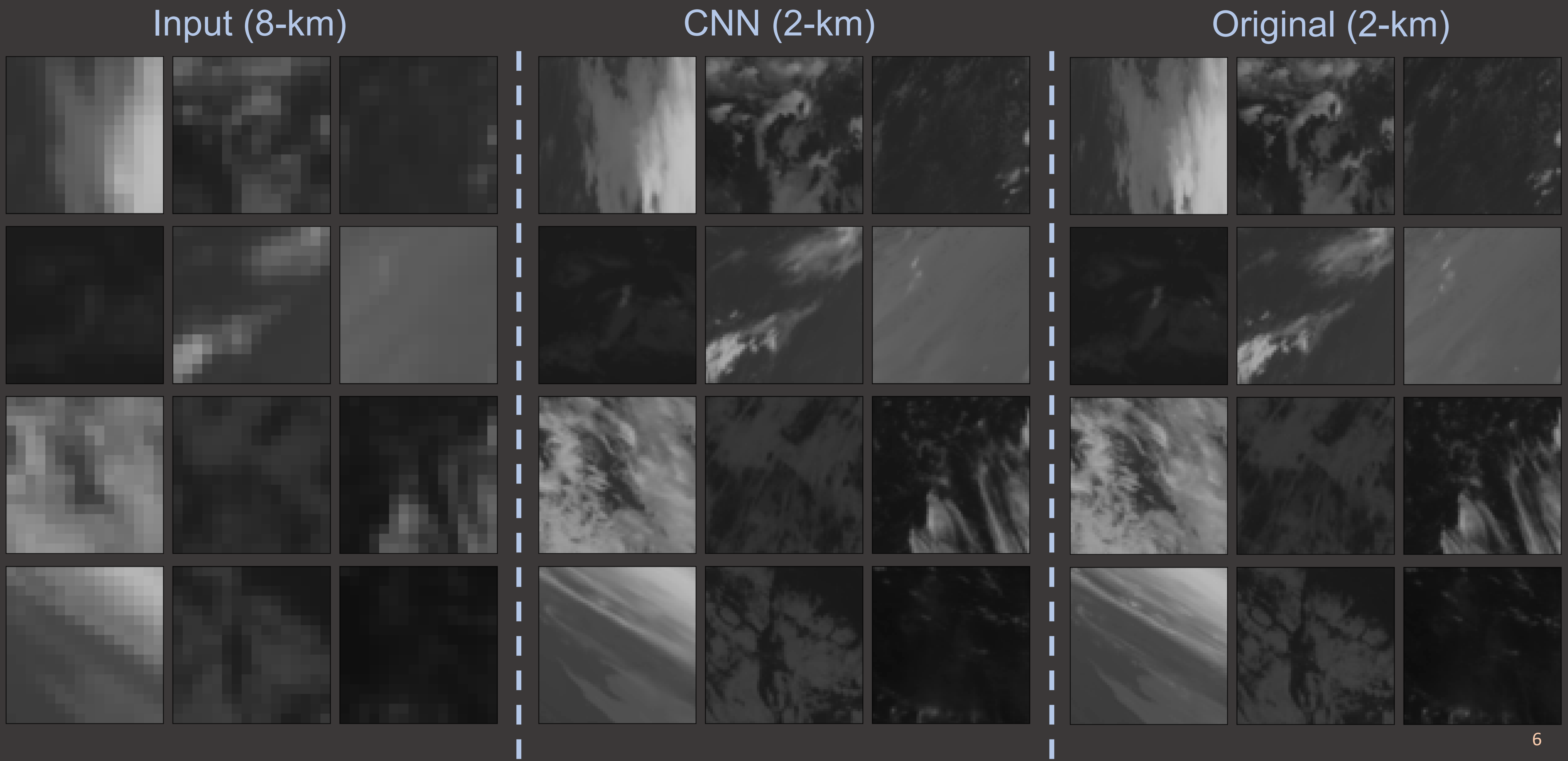
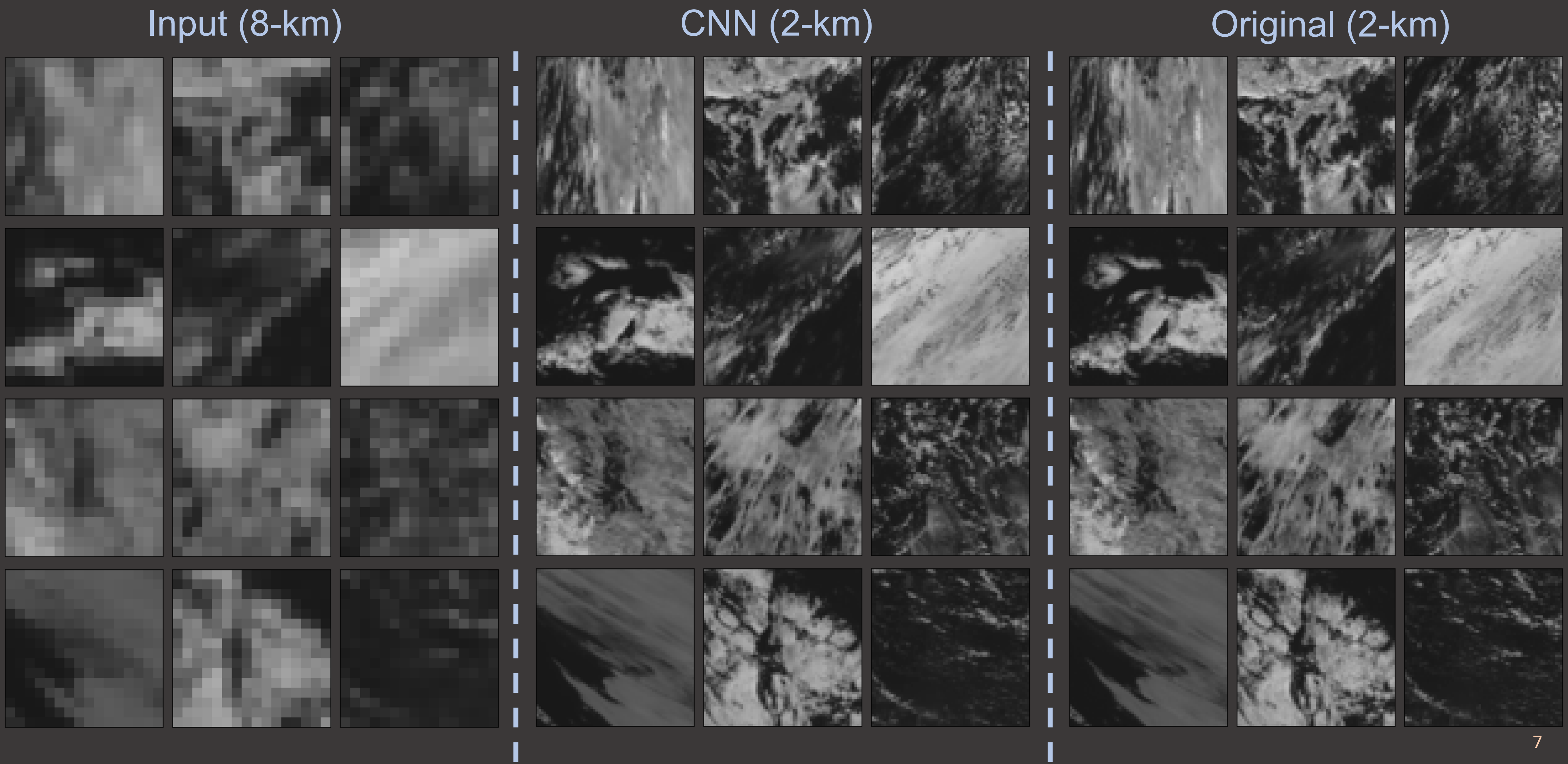
Reduced Resolution Examples (Band-13, 10.3 µm)



Reduced Resolution Examples (Band-6, 2.2 μm)



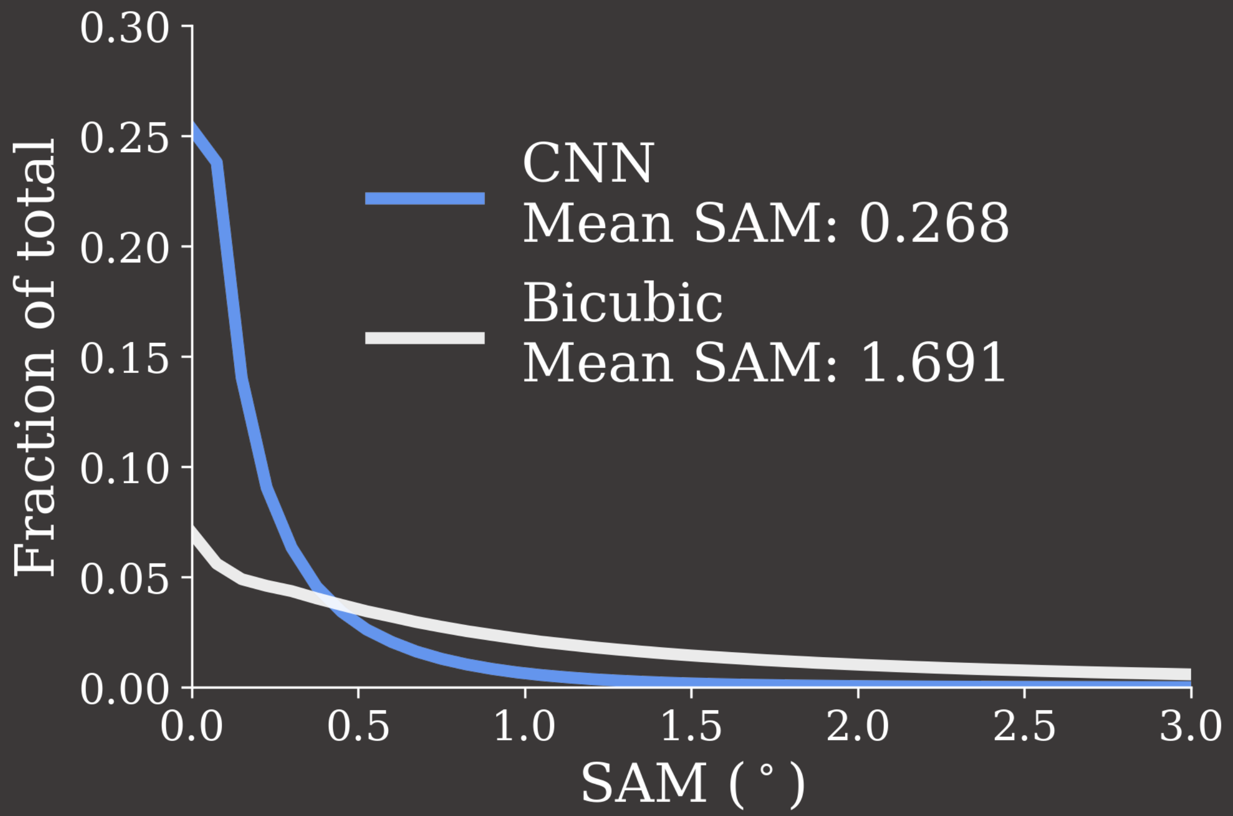
Reduced Resolution Comparison (RMSE)

- 2X (4-km to 2-km) super-resolution easier than 4X (8-km to 2-km)
- VIS/NIR channels typically better than IR
- The more shared information with the highest resolution band there is, the easier super-resolution will be

Band	CNN RMSE	Bicubic RMSE	Ratio (CNN / Bicubic)
0.47 μm	0.45	7.75	**0.06**
0.64 μm	---	---	**---**
0.86 μm	0.48	4.75	**0.10**
1.37 μm	0.18	0.51	**0.35**
1.60 μm	0.13	0.86	**0.16**
2.20 μm	0.072	0.404	**0.18**
3.90 μm	0.012	0.034	**0.35**
6.20 μm	0.016	0.032	**0.49**
6.90 μm	0.043	0.099	**0.43**
7.30 μm	0.083	0.217	**0.39**
8.40 μm	0.41	1.46	**0.28**
9.60 μm	0.27	0.96	**0.27**
10.3 μm	0.60	2.17	**0.27**
11.2 μm	0.66	2.37	**0.28**
12.3 μm	0.68	2.30	**0.29**
13.3 μm	0.49	1.51	**0.32**

Spectral Distortion

- Spectral Angle Mapper (SAM)
- SAM describes the angle between estimated and reference spectra
- Similar to Cosine Similarity (CS)
- Results imply that CNN has fewer issues with unrepresentative spectra.



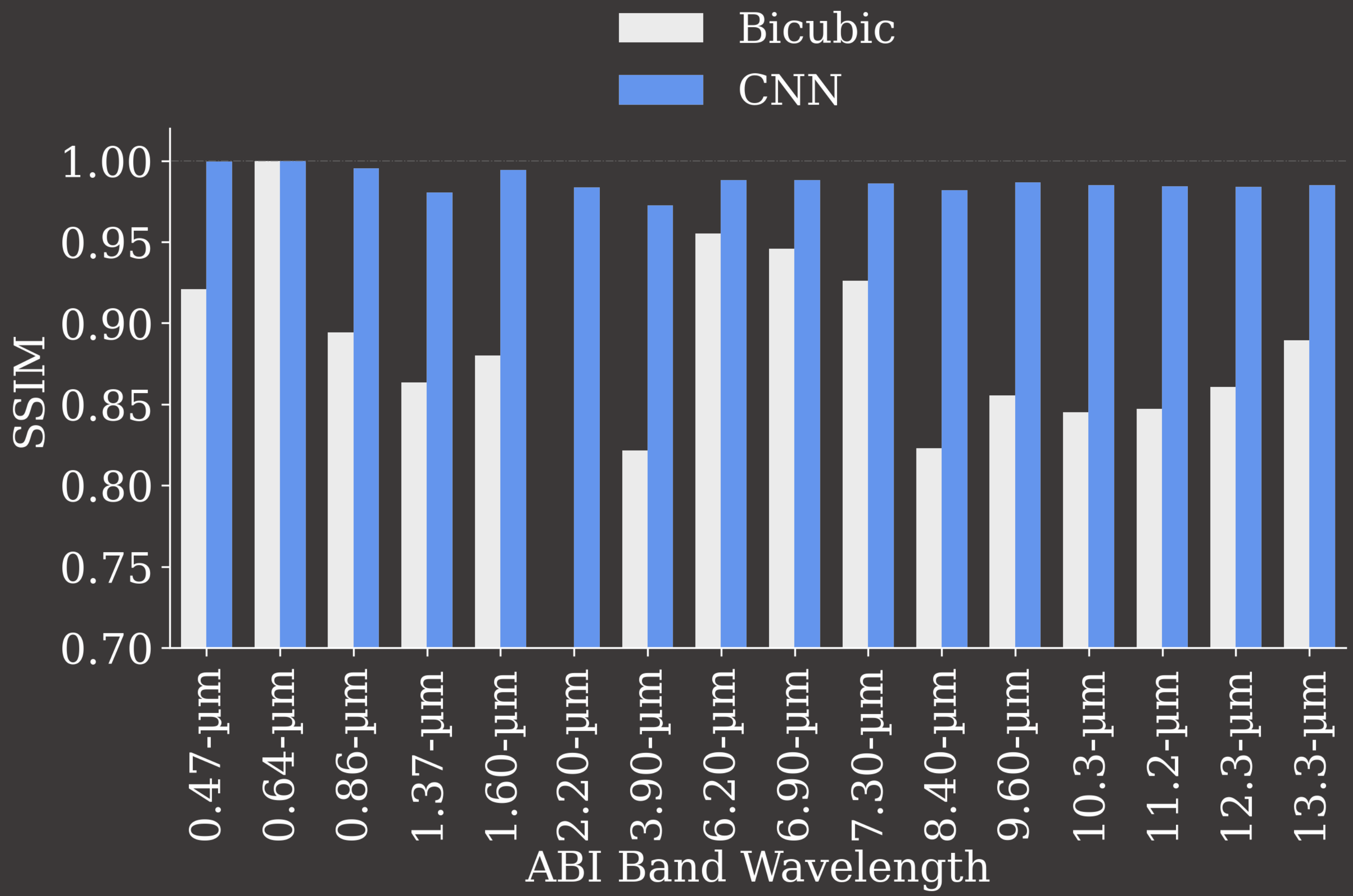
$$CS = \frac{\sum_{i=1}^{16} \hat{y}_i y_i}{\sum_{i=1}^{16} \hat{y}_i \sum_{i=1}^{16} y_i} \qquad SAM = \cos^{-1}(CS)$$

Structural Similarity Index Measure (SSIM)

- SSIM index is calculated on a sliding window throughout the image

$$SSIM = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

- c_1 and c_2 are small constants, exact value determined by dynamic range
- Max=1, Min=-1. Larger is better
- CNN has more accurate spatial structure – adds value for every channel over bicubic interpolation



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Evaluation at 0.5-km (Band-6, 2.2 μm)

Native (2.0 km) | Bicubic (0.5 km) | CNN (0.5 km)

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Evaluation at 0.5-km (Band-13, 10.3 µm)

Native (2.0 km) | Bicubic (0.5 km) | CNN (0.5 km)

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Evaluation at 0.5-km (Band-5, 1.6 μm)

Native (1.0 km) | Bicubic (0.5 km) | CNN (0.5 km)

Comparisons with Landsat 8/9

- Landsat native resolution is 30-m to 100-m
- Needs to be done at the GOES-16 sub-satellite point
- 191 Landsat 8/9 tiles collocated with super-resolved ABI imagery
- Around 25 million individual collocated observations

300 km Radius

OLI/TIRS Bands	Wavelength Range [µm]	Sensor	Spatial Resolution [m]
Band-1	0.435 - 0.451	OLI	30
Band-2	0.452 - 0.512	OLI	30
Band-3	0.533 - 0.590	OLI	30
Band-4	0.636 - 0.673	OLI	30
Band-5	0.851 - 0.879	OLI	30
Band-6	1.566 - 1.651	OLI	30
Band-7	2.107 - 2.294	OLI	30
Band-8	0.503 - 0.676	OLI	15
Band-9	1.363 - 1.384	OLI	30
Band-10	10.60 - 11.19	TIRS	100
Band-11	11.50 - 12.51	TIRS	100

Landsat 8/9 Bands

Challenges when comparing to Landsat

1. Landsat has some similar channels, but spectral response is different
2. Time difference of 2-5 minutes between ABI and Landsat Images

Select collocations based on matching spatial patterns in ABI Band-2 and Landsat Band-4

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Band-11	11.50 - 12.51	TIRS	100

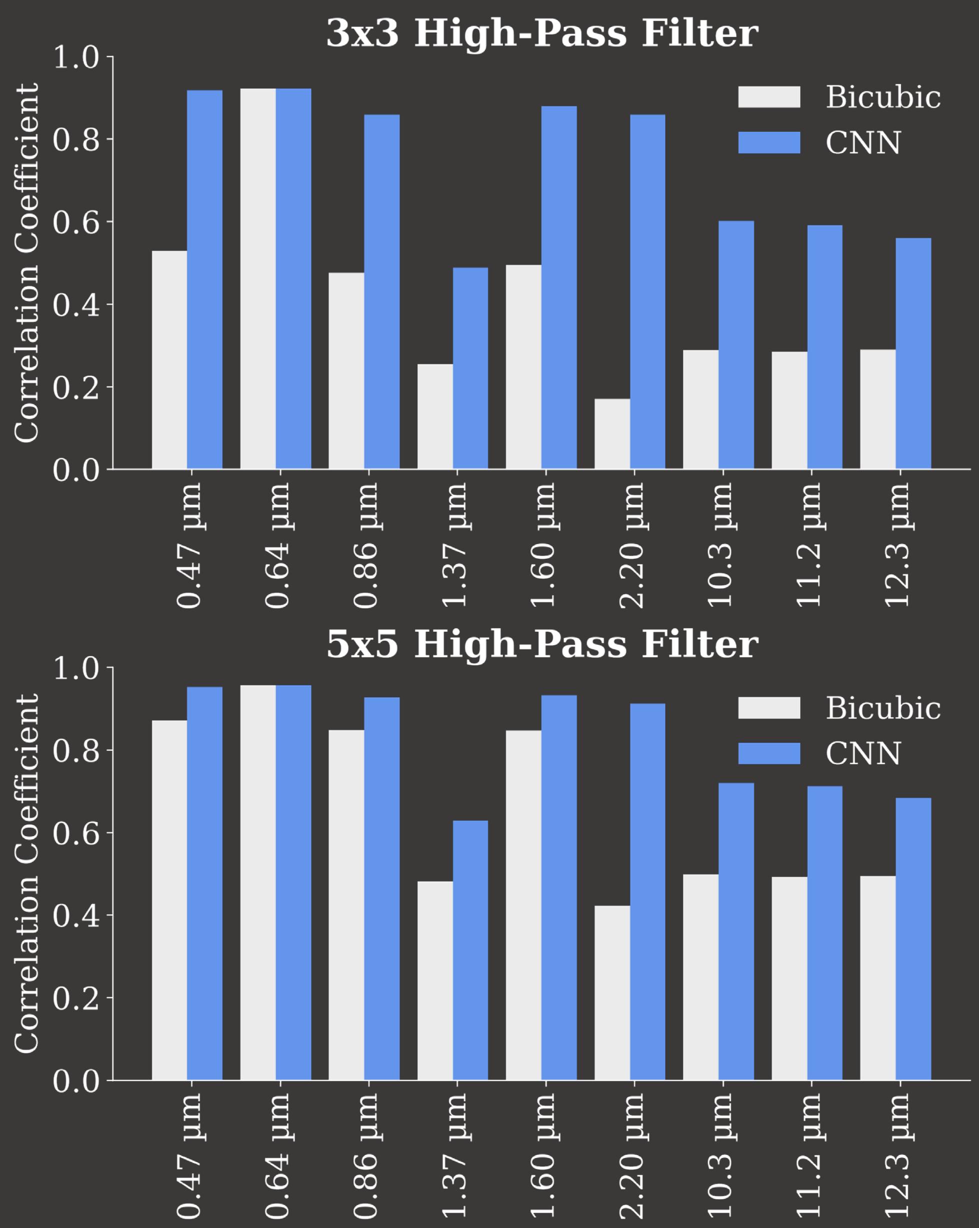
Landsat 8/9 Bands

Selected Landsat collocations

- Heavily biased towards stationary surface features, and low-level clouds

- Comparison based on correlations of high-pass filtered imagery (using a 3x3, and 5x5 filter)

- CNN better estimates high-frequency detail when compared to Landsat



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Takeaways

1. We can super-resolve all 1-km and 2-km channels to 0.5-km on ABI
2. CNN adds value according to all metrics used at reduced-resolution
3. Full-resolution evaluation confirms CNN inserts realistic texture
4. Easily extensible to other satellite imagers
5. Preprint coming very soon

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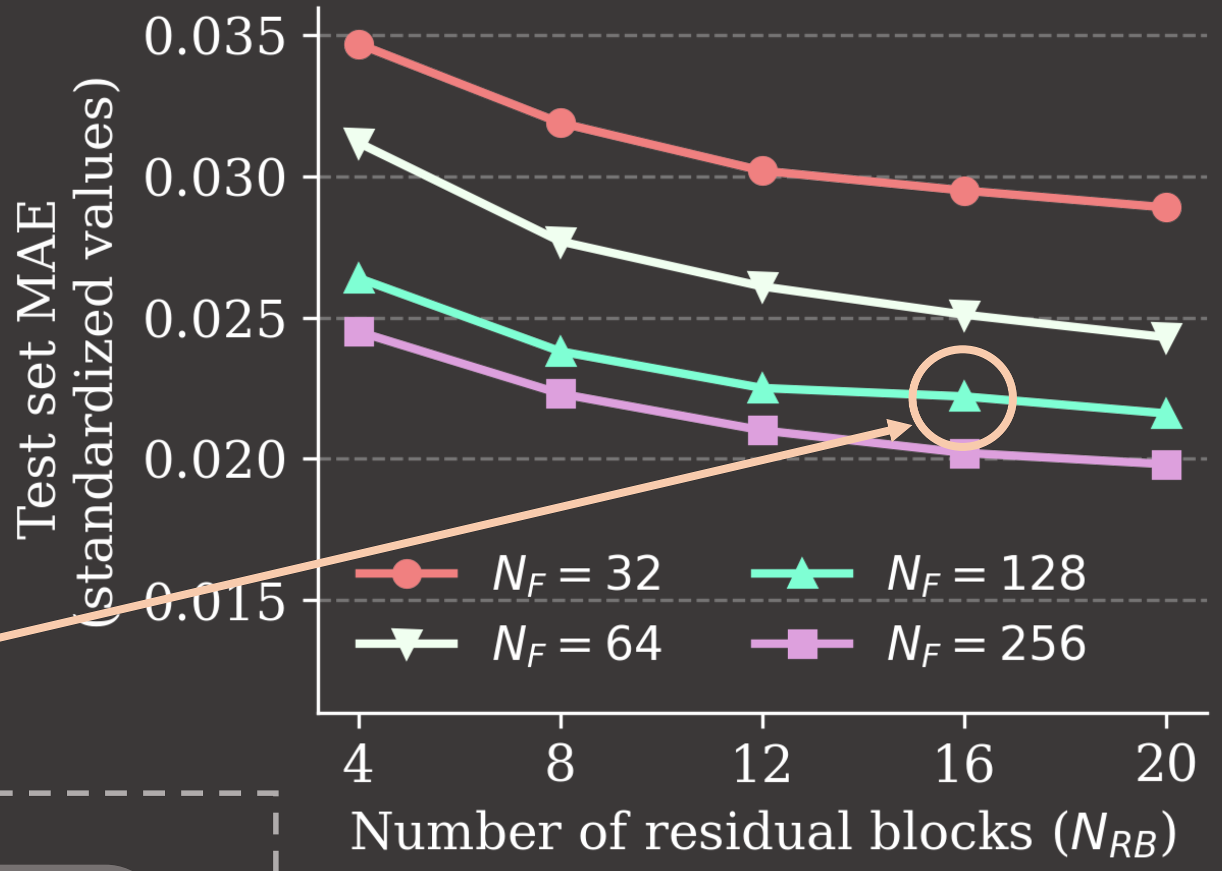
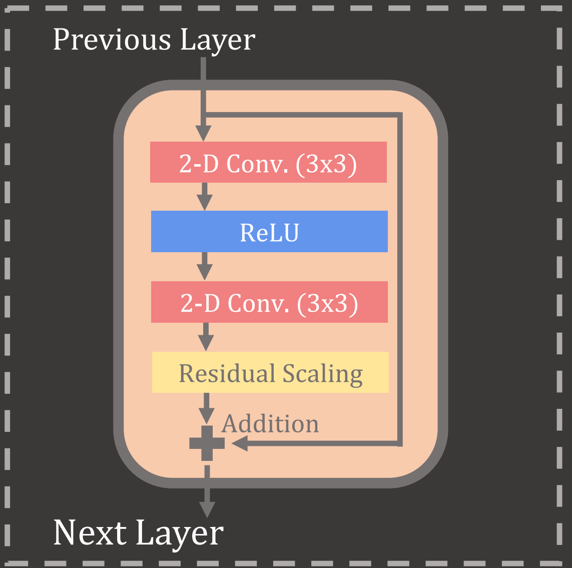
Evaluation at 0.5-km (Band-3, 0.86 μm)

Native (1.0 km) | Bicubic (0.5 km) | CNN (0.5 km)

Hyperparameters

- Two main hyperparameters
  - N_F = Filters per convolutional layer
  - N_{RB} = *Residual blocks*
- Further increases could give better performance, but diminishing returns
- We use N_F = 128, N_{RB} = 12





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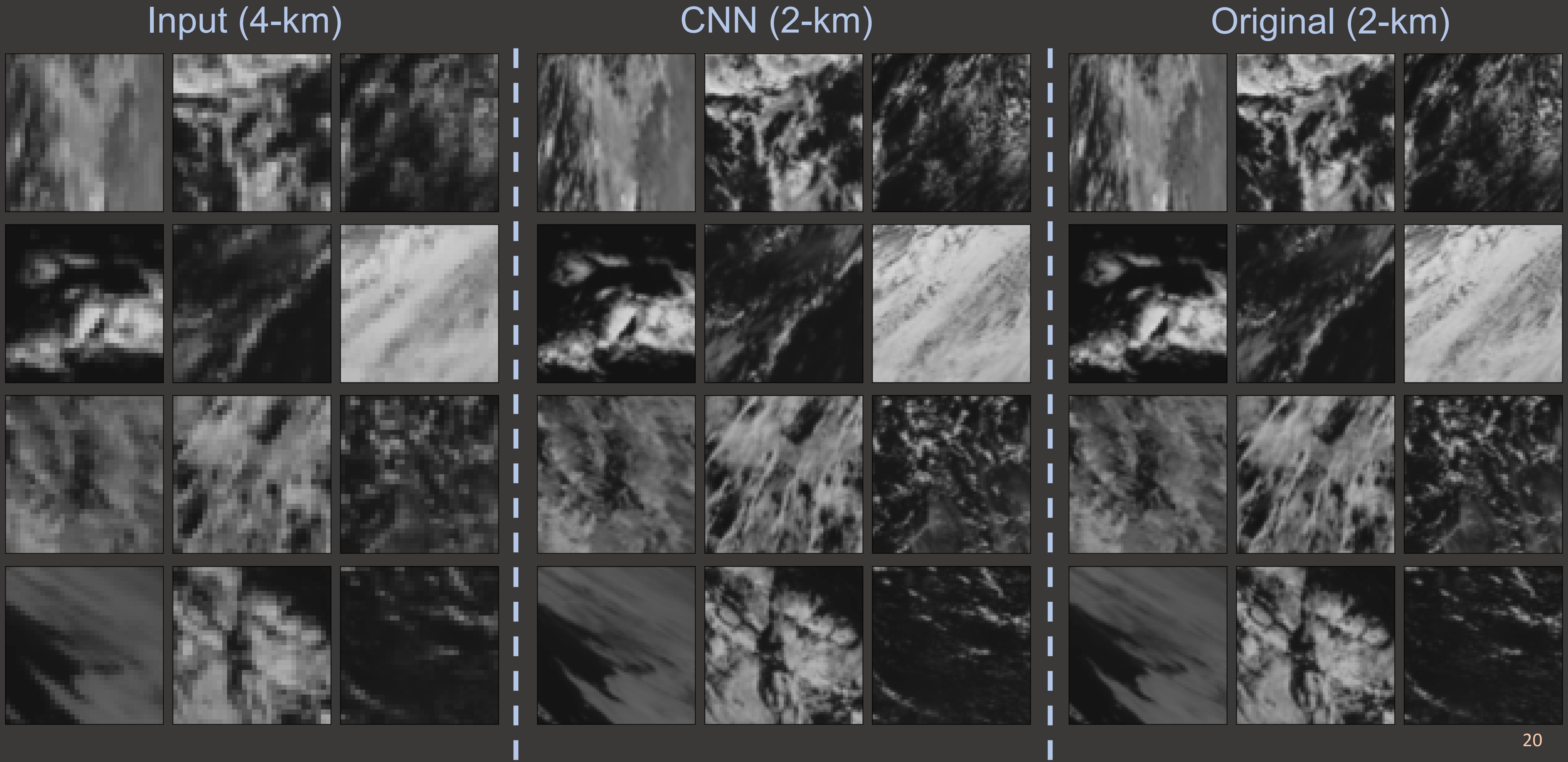
Reduced Resolution Examples (Band-5, 1.6 μm)

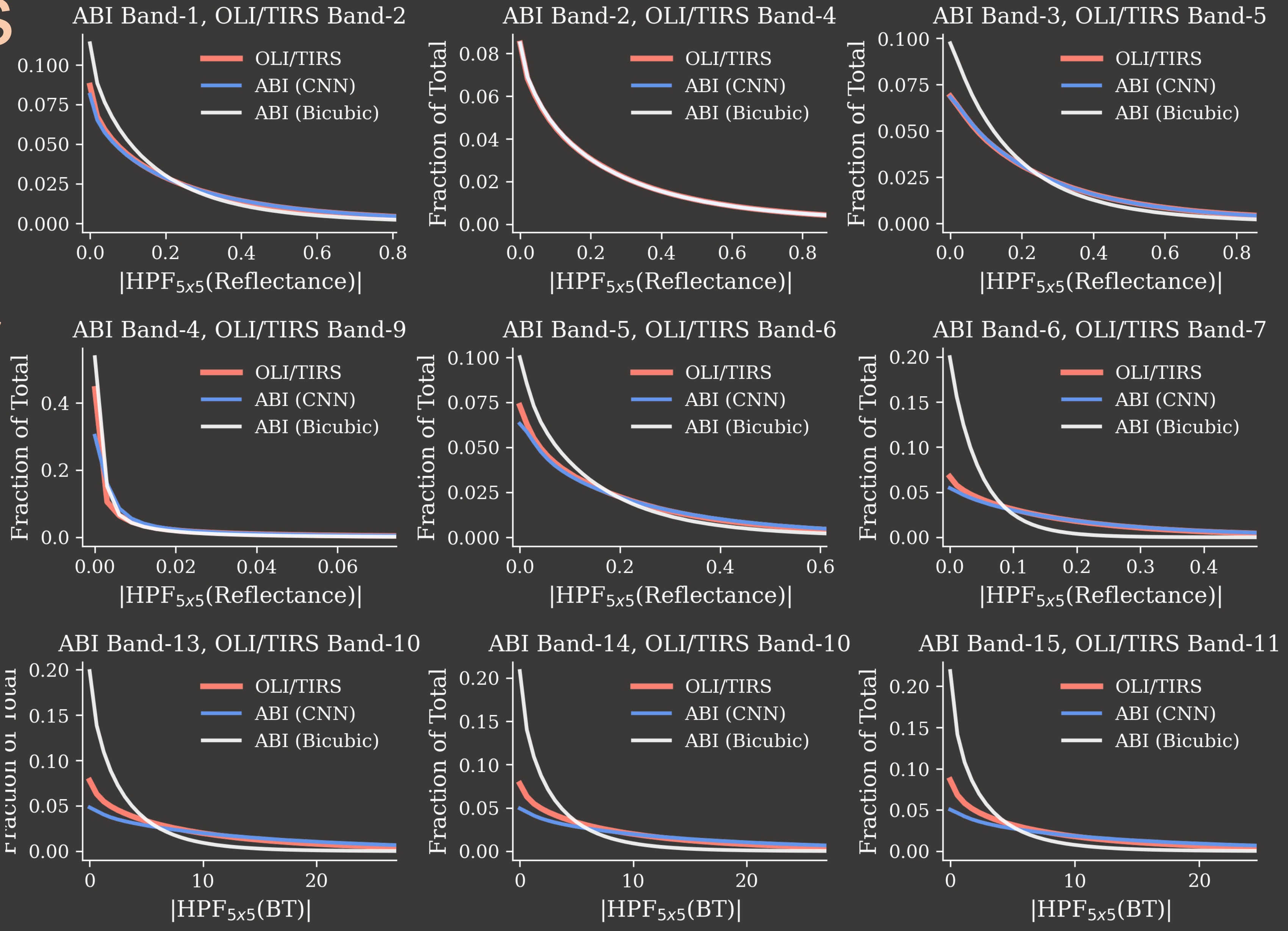


All Collocations

- Compare histograms of high-pass filtered imagery

- CNN output has a more similar distribution of gradients, but over-sharpens infrared channels

- Confirmed quantitatively by Wasserstein distance



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9	6.9	2.0
10	7.3	2.0
11	8.4	2.0
12	9.6	2.0
13	10.3	2.0
14	11.2	2.0
15	12.3	2.0
16	13.3	2.0

VIIRS

Band number	Central Wavelength (μm)	Nadir Spatial Resolution (km)
I-1	0.640	0.375
I-2	0.865	0.375
I-3	1.61	0.375
I-4	3.74	0.375
I-5	11.45	0.375
M-1	0.412	0.75
M-2	0.445	0.75
M-3	0.488	0.75
M-4	0.555	0.75
M-5	0.672	0.75
M-6	0.746	0.75
M-7	0.865	0.75
M-8	1.24	0.75
M-9	1.38	0.75
M-10	1.61	0.75
M-11	2.25	0.75
M-12	3.70	0.75
M-13	4.05	0.75
M-14	8.55	0.75
M-15	10.76	0.75
M-16	12.01	0.75

GXI

(requirements)

Central Wavelength (μm)	Nadir Spatial Resolution (km)
0.47	0.5
0.64	0.25*
0.865	0.5
0.91	1.0
1.378	2.0
1.61	1.0
2.25	1.0
3.9	1.0
5.15	1.0
6.185	2.0
6.95	1.0**
7.34	2.0
8.50	2.0
9.61	2.0
10.35	1.0**
11.20	2.0
12.30	2.0
13.30	2.0