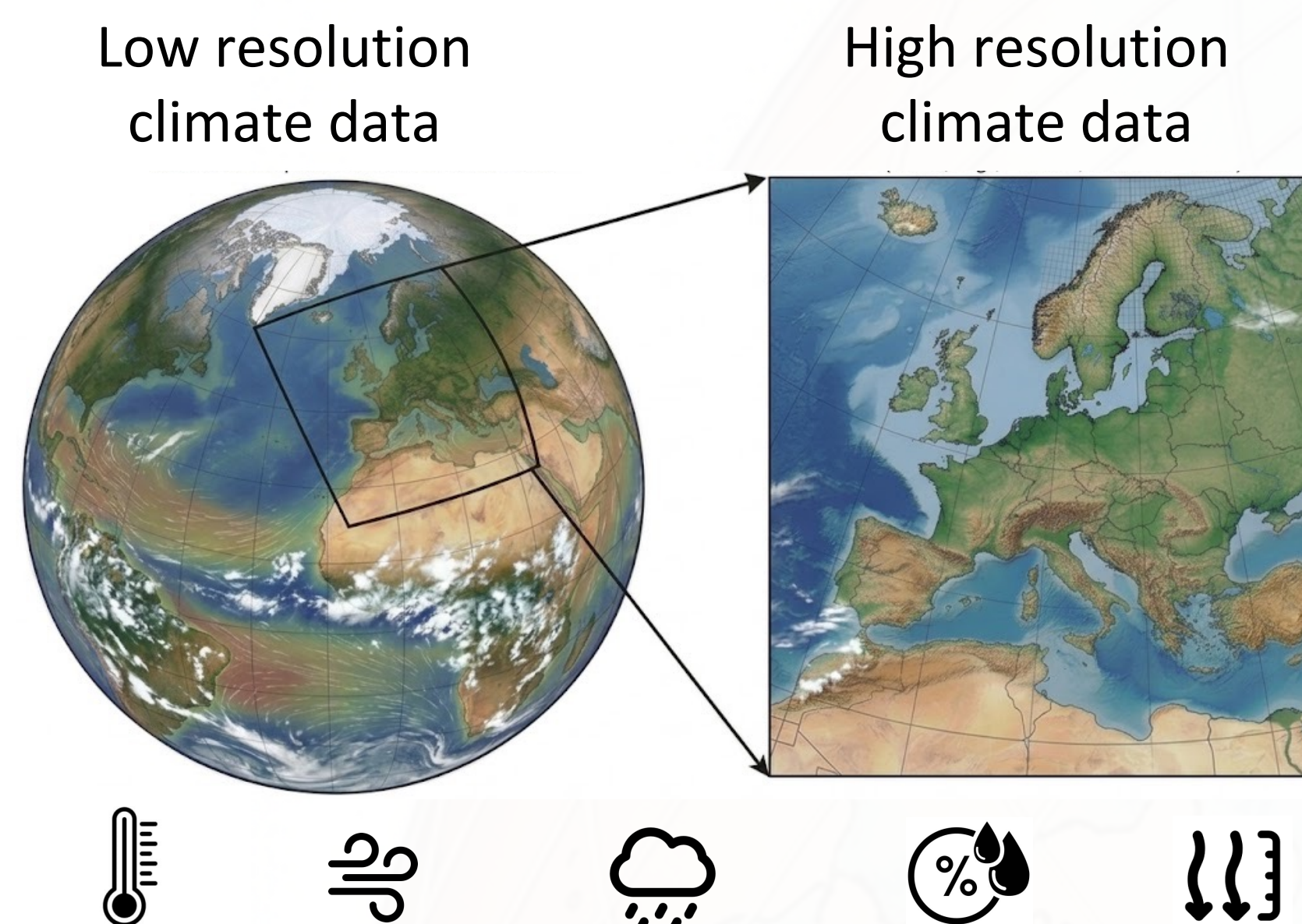


Frequency Bias in Climate Downscaling

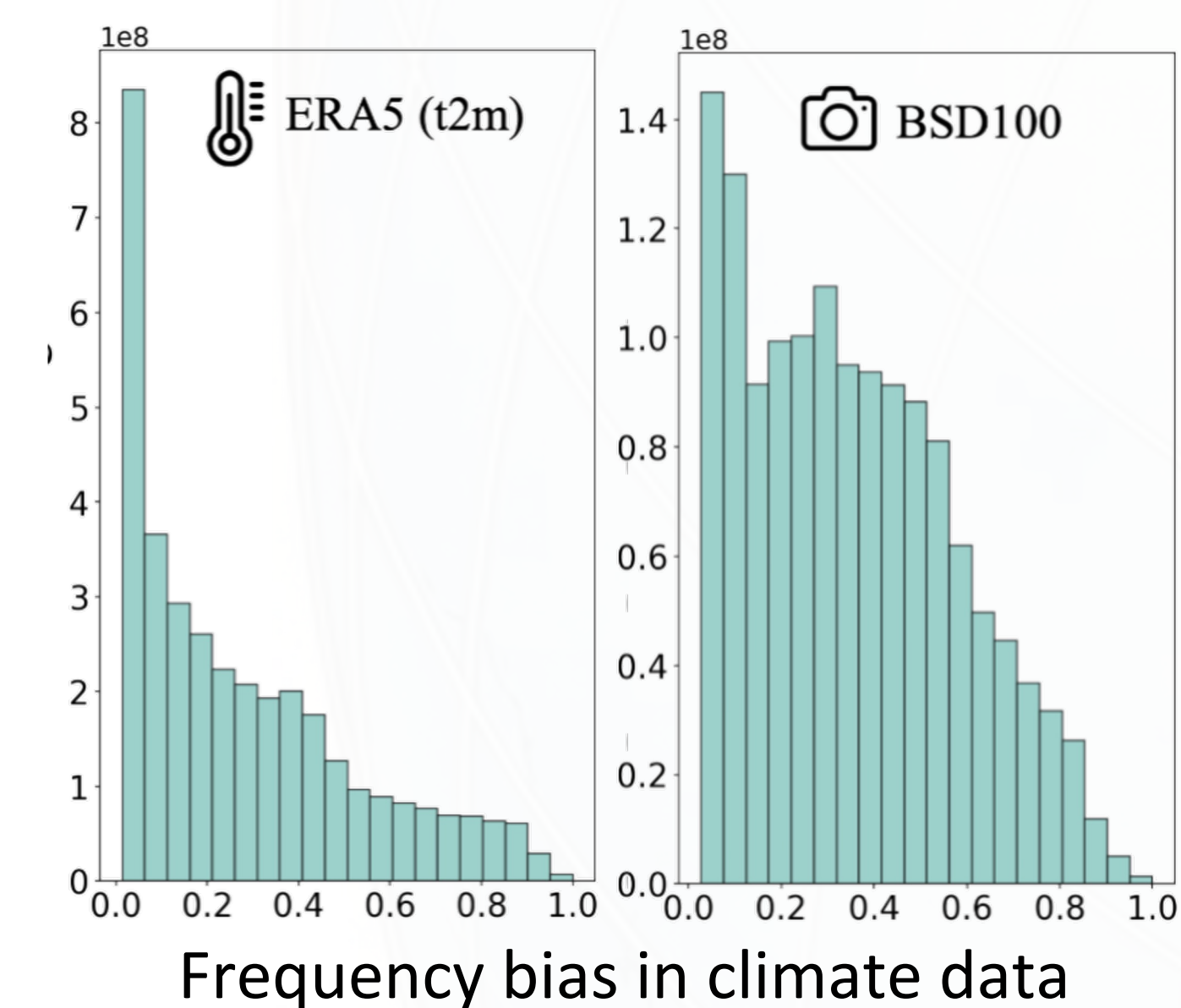
➤ **Climate downscaling:** improve the resolution of climate data



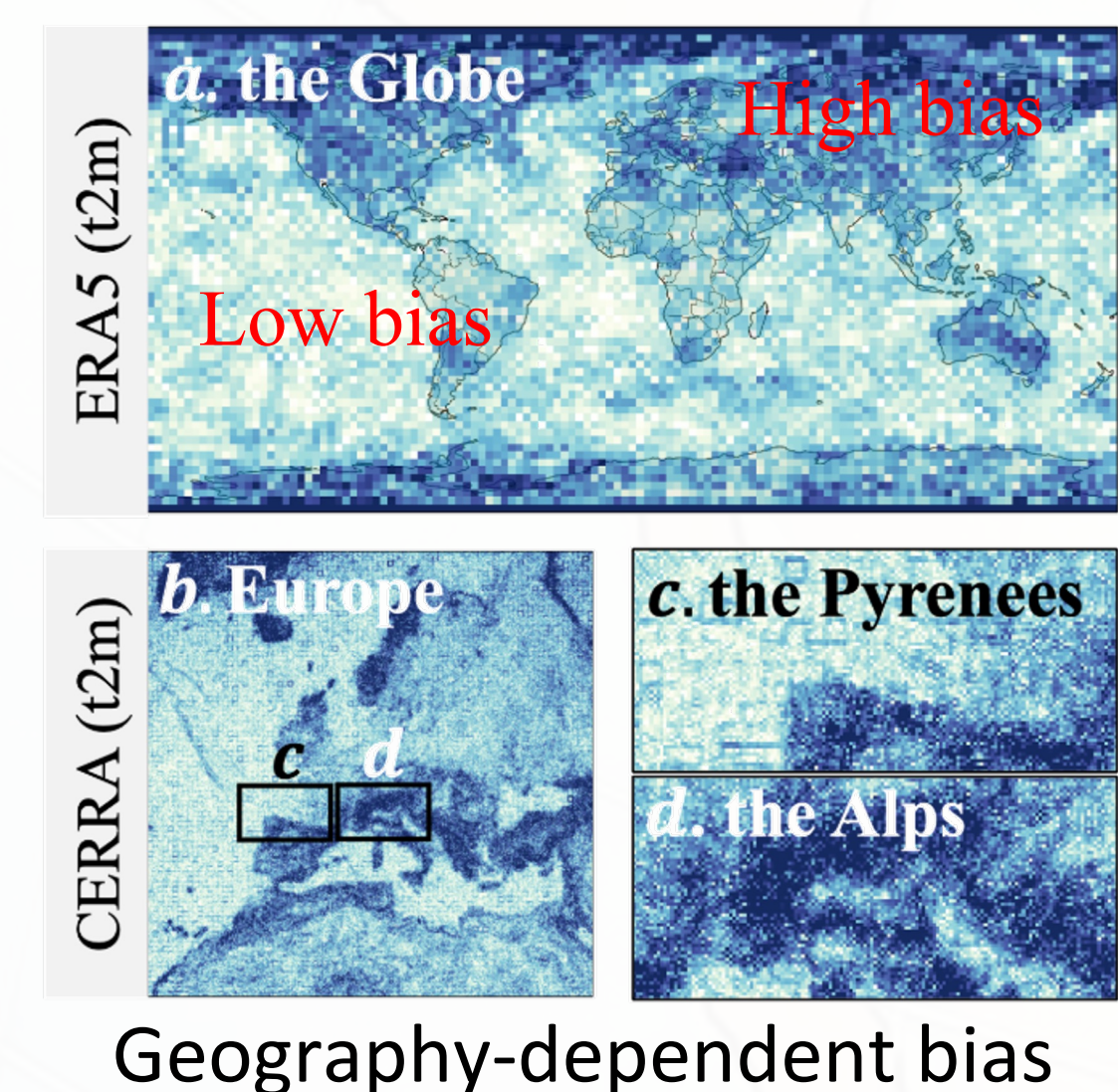
- **Dynamical downscaling**
 - 😊 Physics-driven model
 - 😞 Vulnerable to bias
 - 😞 Low efficiency
- **Statistical downscaling**
 - 😊 Data-driven model
 - 😊 High efficiency
 - 😞 Low interpretability

➤ **Climate SR shows geography-dependent frequency bias**

- **Low-frequency aggregation:** compared to natural images (BSD100), climate data is dominated by low-frequency components, biasing DNNs toward large-scale patterns
- **Geography-dependent bias:** plains and oceans are mostly smooth; mountains, coastlines, and polar regions contain richer high-frequency variability



Laplacian Energy Map of Prediction Bias



How to Mitigate Frequency Bias?

GeoFAR learns **frequency-aware** and **geography-informed** representations for climate SR, reconstructing geography-dependent climate data at high resolution. **GeoFAR** is model-agnostic, supports both **deterministic** and **generative** baselines



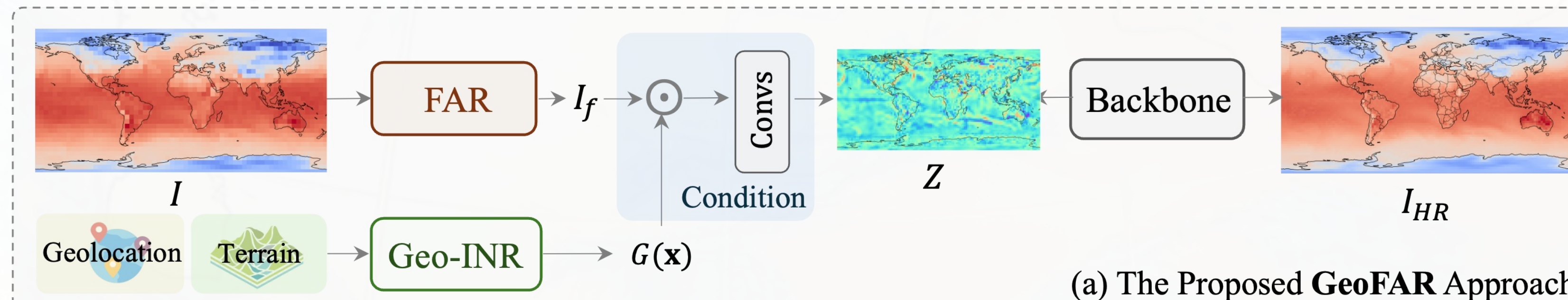
GeoFAR Method

➤ **FAR: Frequency-aware Representation**

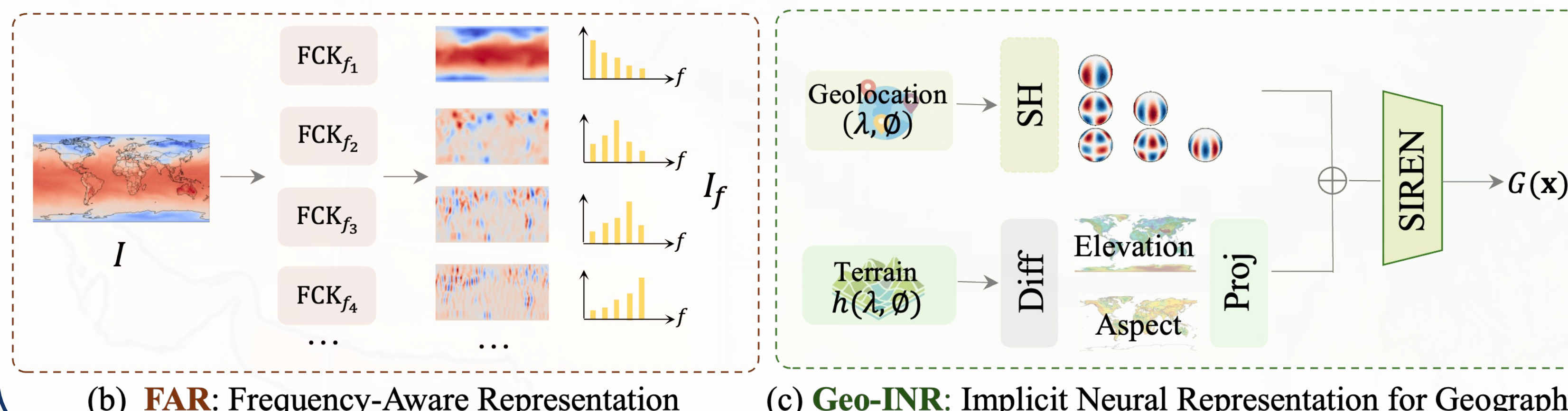
FAR separates frequency-aware patterns into different channels with DCT kernels

➤ **Geo-INR: Geography-informed Implicit Neural Representations**

Geo-INR projects location and elevation meta info as geographical embeddings



(a) The Proposed **GeoFAR** Approach



(b) **FAR**: Frequency-Aware Representation

(c) **Geo-INR**: Implicit Neural Representation for Geography

Experimental Results

➤ **Consistent gains across resolutions, SR ratios, variables**

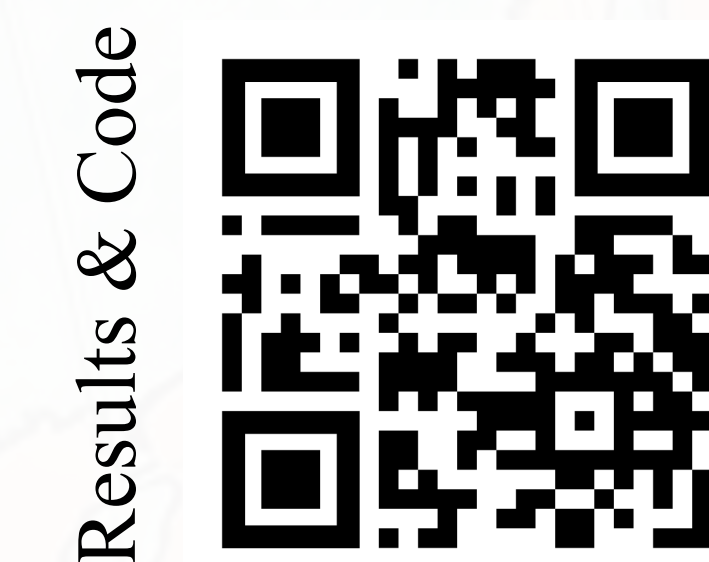
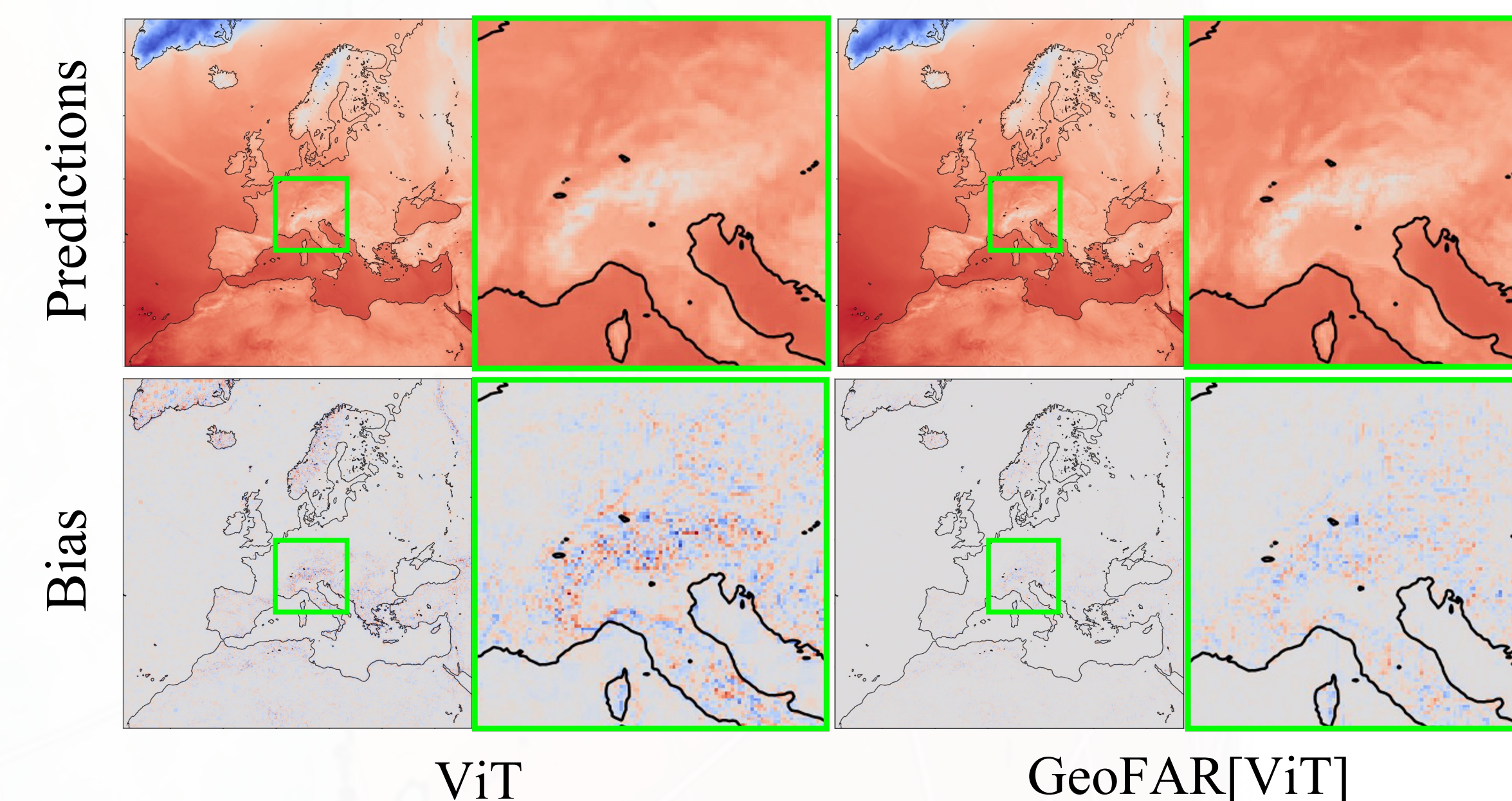
Downscale T2m (K) across resolutions				Downscale CERRA across ratios		
Method	ERA5	PRISM	CERRA	Method	×4	×8
ViT	1.121	2.163	0.380	DeepSD	0.388	0.579
GeoFAR[ViT]	1.099	1.745	0.191	ViT	0.458	0.564
U-Net	1.103	1.501	0.272	U-Net	0.326	0.482
GeoFAR[U-Net]	1.076	1.468	0.180	GeoFAR[U]	0.235	0.393
SRGAN	1.149	1.718	0.245	SRGAN	0.375	0.594
GeoFAR[SRGAN]	1.137	1.561	0.192	GeoFAR[S]	0.253	0.434

Jointly downscale multiple variables on CERRA (22km to 11km)

Method	T2m (K)	10u (ms ⁻¹)	10v (ms ⁻¹)	Rh2m (%)	Sp (hPa)
ViT	0.457	0.341	0.355	1.799	0.278
GeoFAR[ViT]	0.262	0.184	0.186	1.215	0.048

*We report RMSE in the tables above, more baselines can be found in the paper

➤ **Significant improvements in regions of complex terrain**



➤ **Climate SR toolbox**

- ✓ Data processing tools
- ✓ Implementation of over 15 methods (with both generative and deterministic) for climate SR
- ✓ Training and evaluation pipelines