#EUSpace

Copernicus Foundation Models for a Thinking Earth

EUSPA AI week 2026

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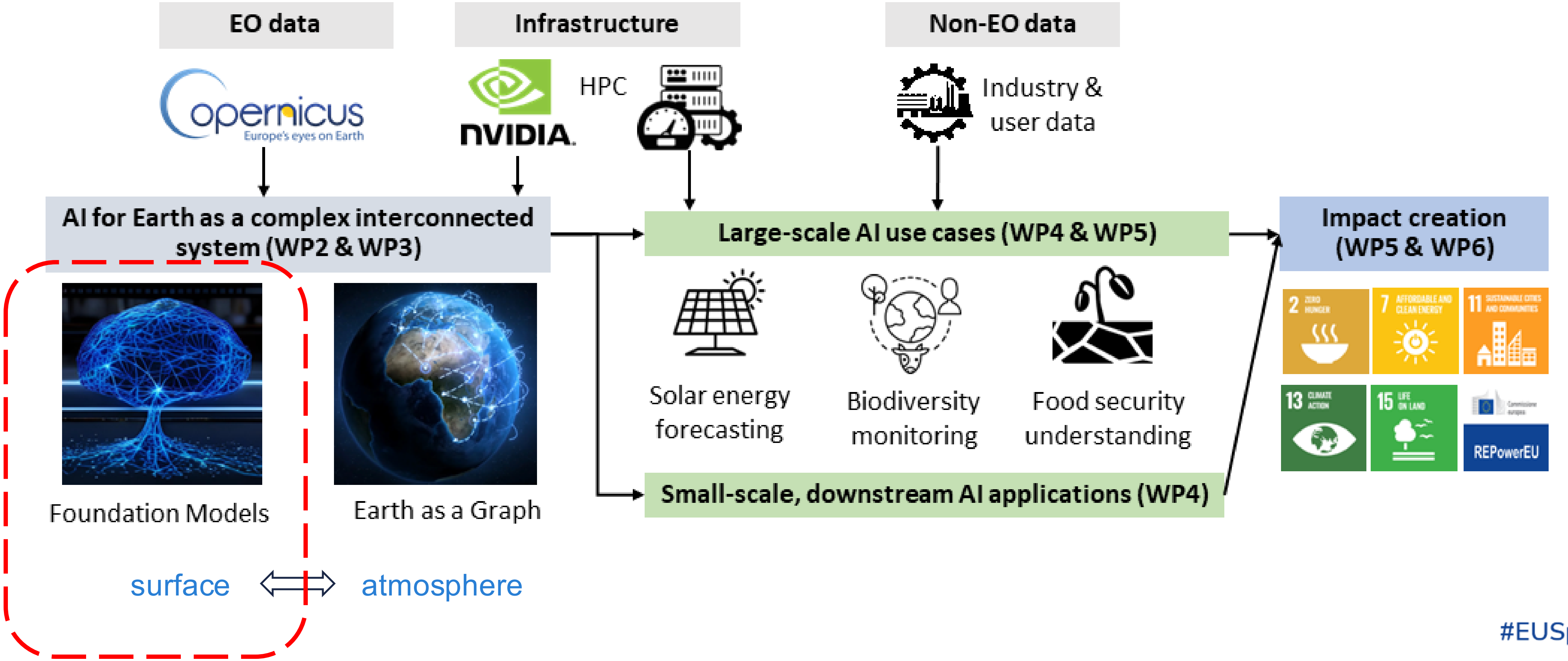
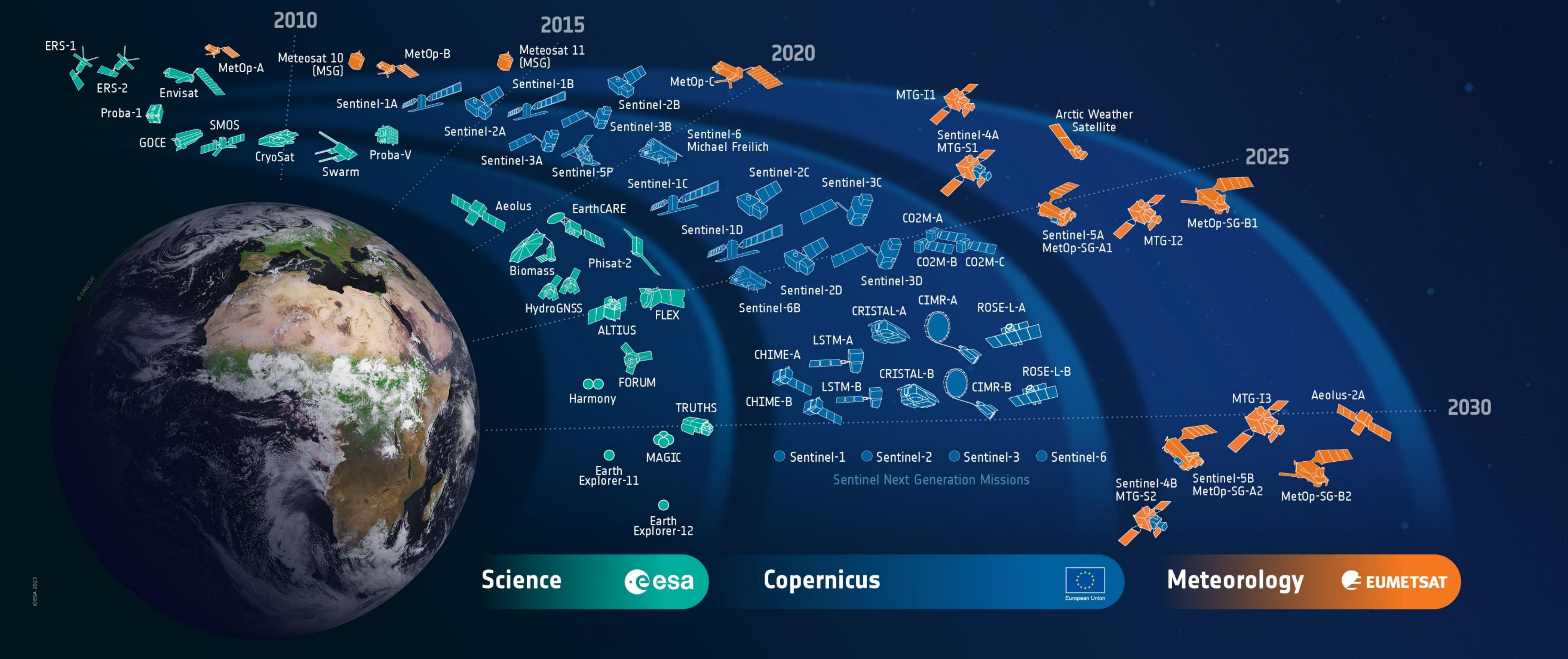
ThinkingEarth

- In ThinkingEarth, we develop generic foundation models for surface and atmospheric applications.

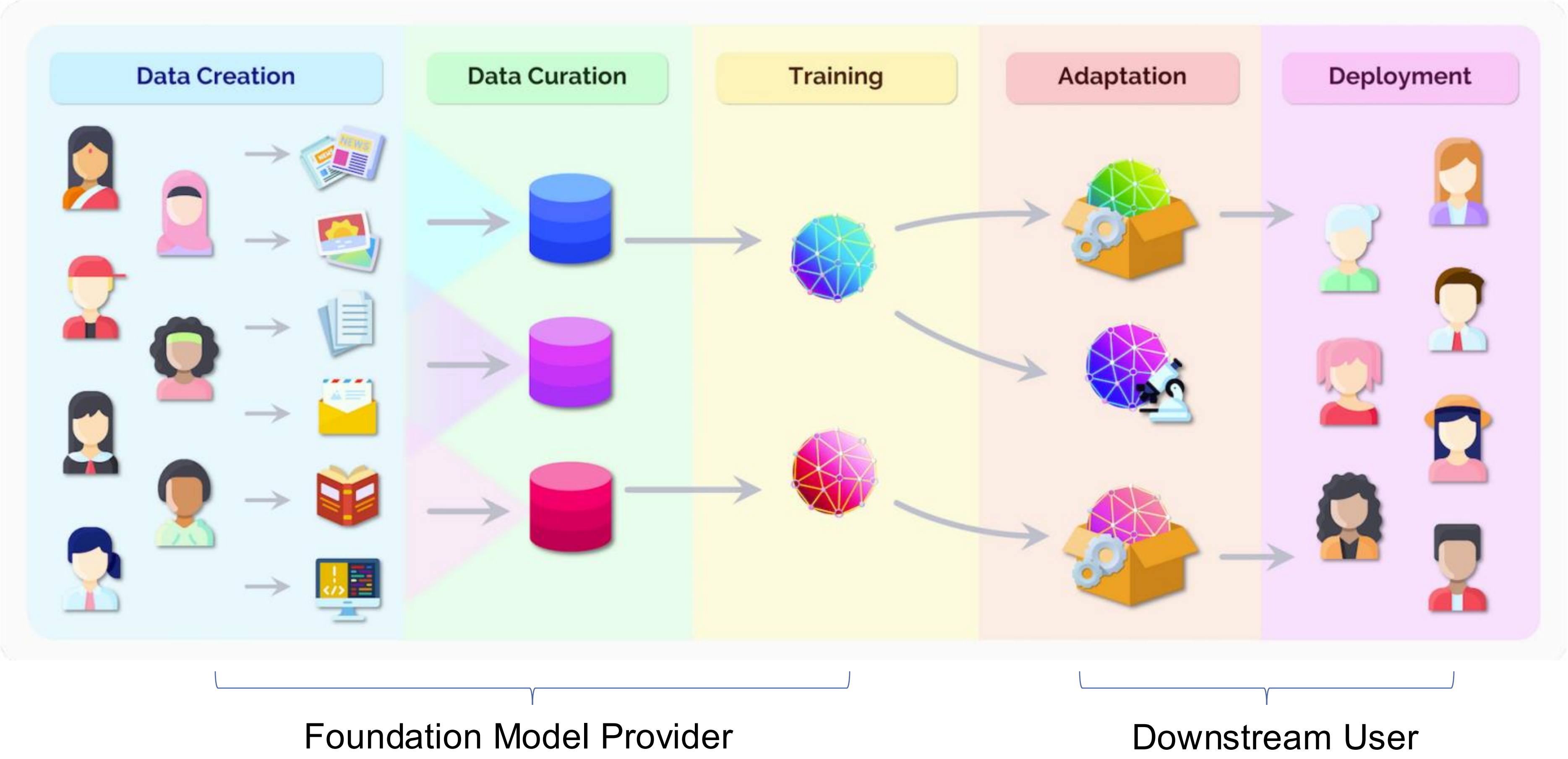


ESA-DEVELOPED EARTH OBSERVATION MISSIONS



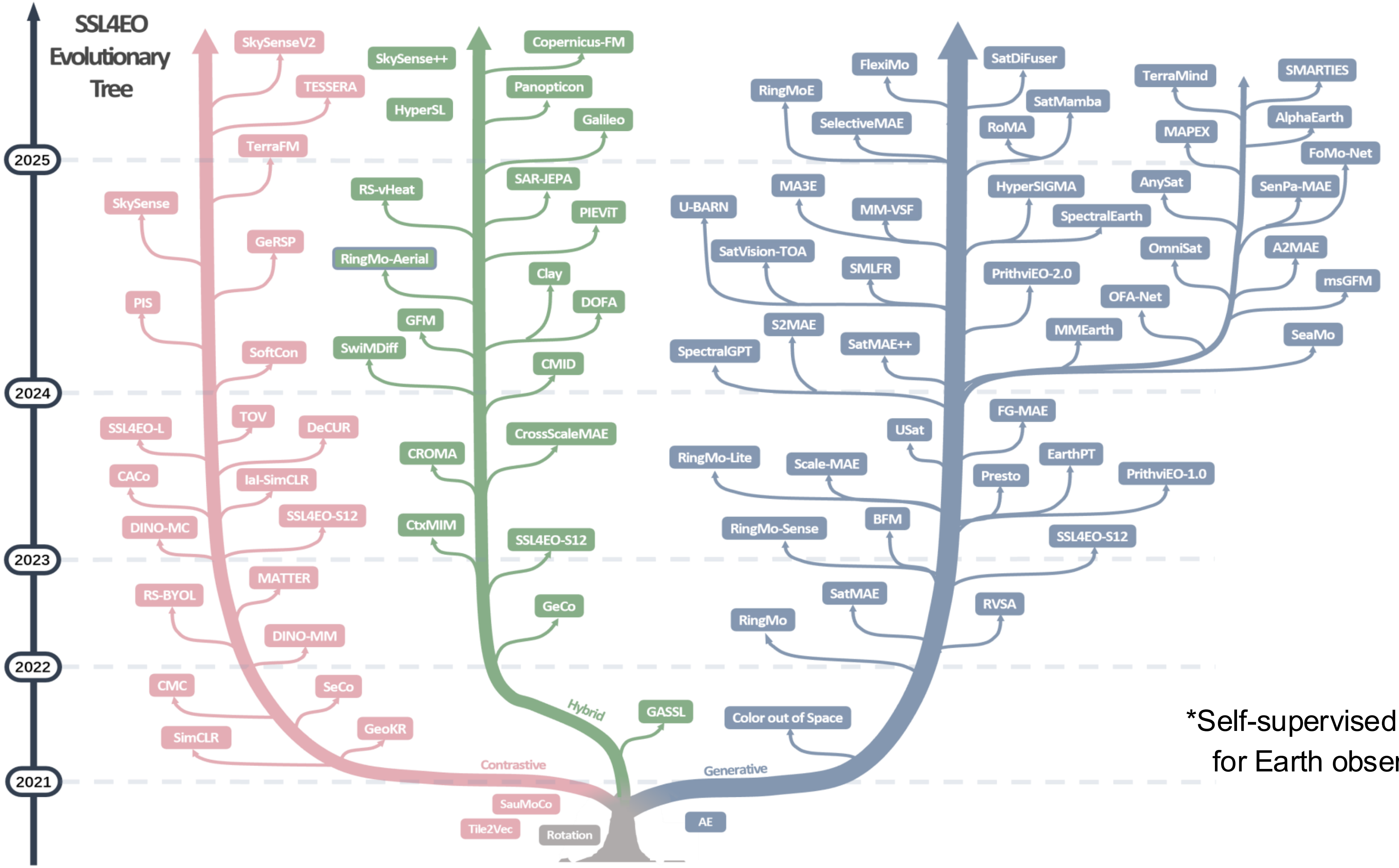
What is a foundation model?

- A model **pretrained** on **broad data** that can be adapted to **various downstream tasks**.



Bommasani, Rishi, et al. "On the opportunities and risks of foundation models." *arXiv* (2021).

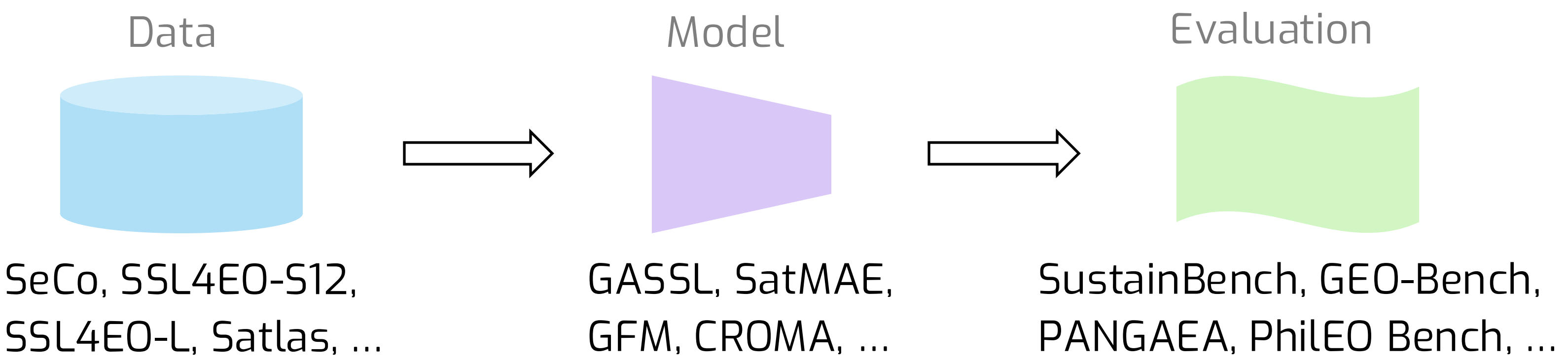
Evolvement of EO foundation models



*Self-supervised learning for Earth observation

Copernicus Foundation Model

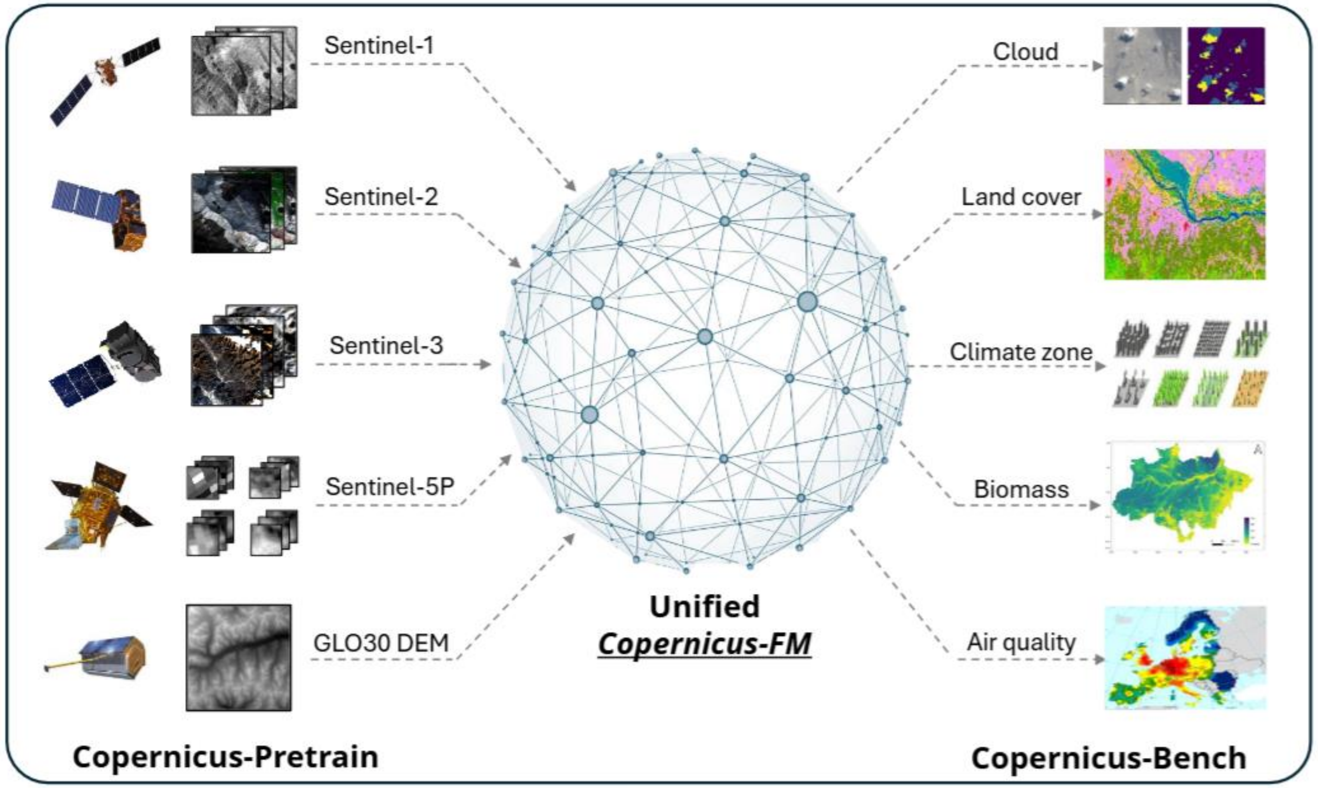
- Existing EO foundation models face limitations:
  - Sensor diversity in pretraining data (RGB, MS, etc.)
  - Encoding flexibility in model architecture (e.g. fixed spectral channels)
  - Evaluation breadth in downstream applications (sensor, task)



→ Copernicus-FM integrates 4 contributions to push forward these dimensions.

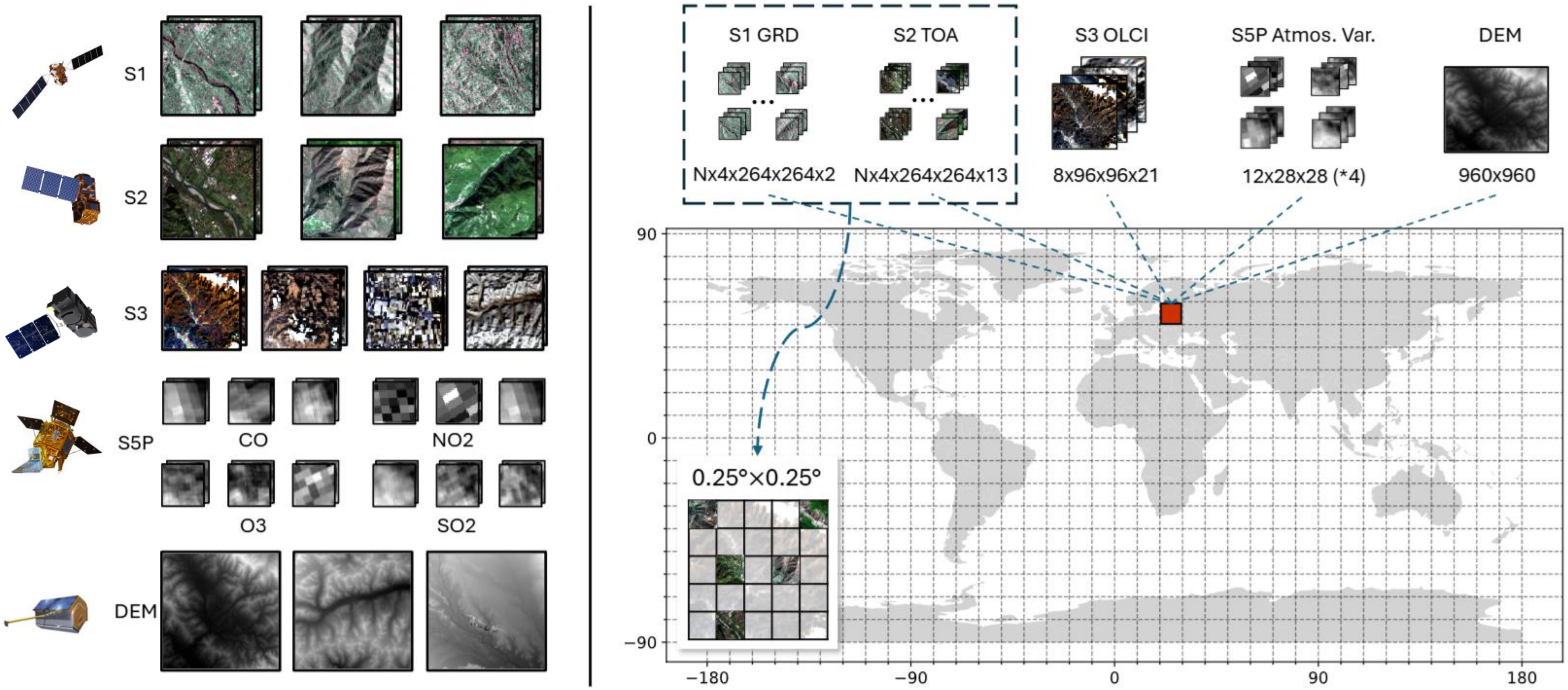
Wang, Yi, et al. “Towards a Unified Copernicus Foundation Model for Earth Vision." *ICCV* (2025).

- **Copernicus-Pretrain**
  - 18.7M images S1-S5P* + DEM
- **Copernicus-FM**
  - Any spectral/non-spectral input
- **Copernicus-Bench**
  - 15 hierarchical downstream tasks
- **Copernicus-Embed**
  - global satellite embeddings



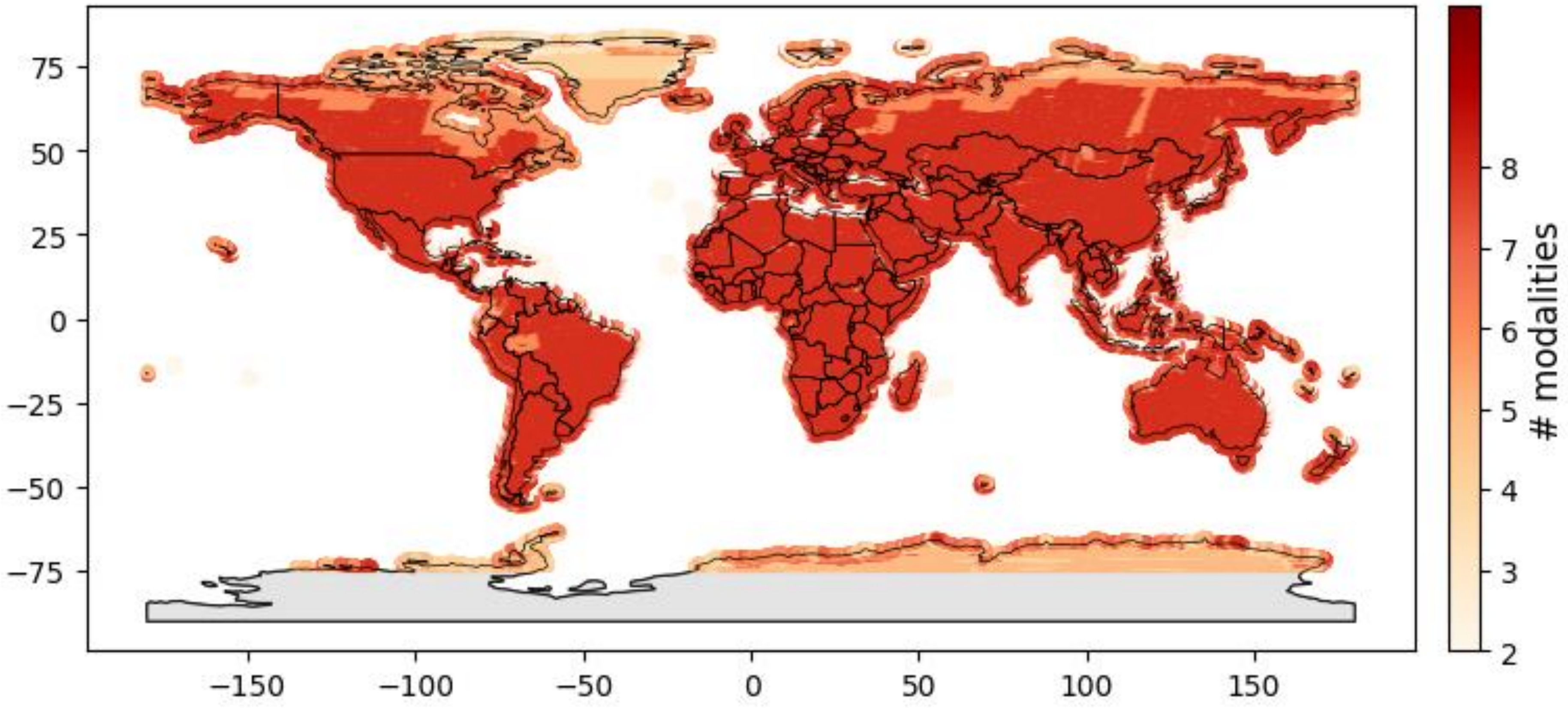
Copernicus-Pretrain

✓ A unified pretraining dataset spanning all major Sentinel missions.



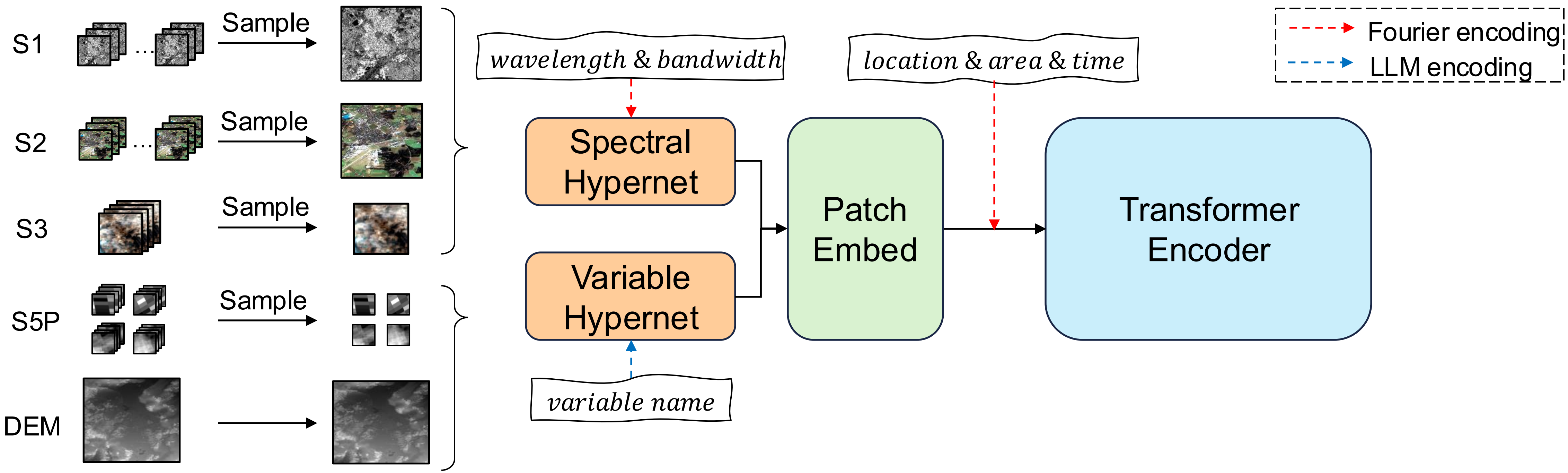
Copernicus-Pretrain

✓ A unified pretraining dataset spanning all land and nearshore ocean.



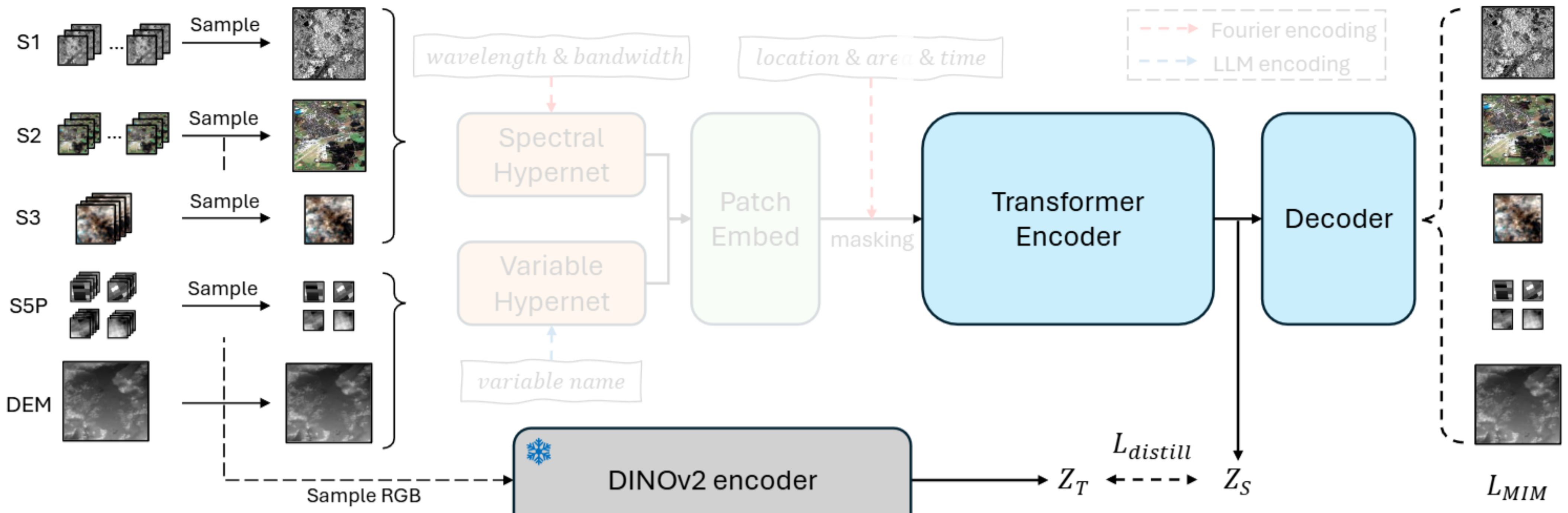
Copernicus-FM

- ✓ A unified foundation model for Earth vision:
  - ✓ Any image sensor → dynamic patch embedding
  - ✓ Metadata support → unified Fourier encoding



Copernicus-FM

- ✓ A unified foundation model for Earth vision:
  - ✓ Masked image modeling (MAE)
  - ✓ Continual distillation of RGB channels (DINOv2)



Copernicus-Bench

✓ A hierarchical benchmark including 15 downstream tasks.

Level	Name	Task	# Images	Image Size	# Classes	Source	License
L1	Cloud-S2	seg	1699/567/551	512×512×13	4	CloudSEN12+ [4]	CC0-1.0
	Cloud-S3	seg	1197/399/399	256×256×21	5	new	CC-BY-4.0
L2	EuroSAT-S1	cls	16200/5400/5400	64×64×2	10	EuroSAT-SAR [65]	CC-BY-4.0
	EuroSAT-S2	cls	16200/5400/5400	64×64×13	10	EuroSAT [30]	MIT
	BigEarthNet-S1	cls	11894/6117/5991	120×120×2	19	BigEarthNet v2.0 [15]	CDLA-Permissive-1.0
	BigEarthNet-S2	cls	11894/6117/5991	120×120×12	19	BigEarthNet v2.0 [15]	CDLA-Permissive-1.0
	LC100Cls-S3	cls	5181/1727/1727*	96×96×21	23	new	CC-BY-4.0
	DFC2020-S1†	seg	3156/986/986	256×256×2	10	DFC2020 [28]	CC-BY-4.0
	DFC2020-S2†	seg	3156/986/986	256×256×13	10	DFC2020 [28]	CC-BY-4.0
	LC100Seg-S3	seg	5181/1727/1727*	96×96×21 (288×288)	23	new	CC-BY-4.0
L3	Flood-S1	cd	3000/1000/1000*	224×224×2	3	Kuro Siwo [9]	MIT
	LCZ-S2†	cls	15000/5000/5000	32×32×10	17	So2Sat LCZ42 [75]	CC-BY-4.0
	Biomass-S3	reg	3000/1000/1000*	96×96×21 (288×288)	1	new	CC-BY-4.0
	AQ-NO2-S5P	reg	1480/493/494*	56×56×1	1	new	CC-BY-4.0
	AQ-O3-S5P	reg	1480/493/494*	56×56×1	1	new	CC-BY-4.0

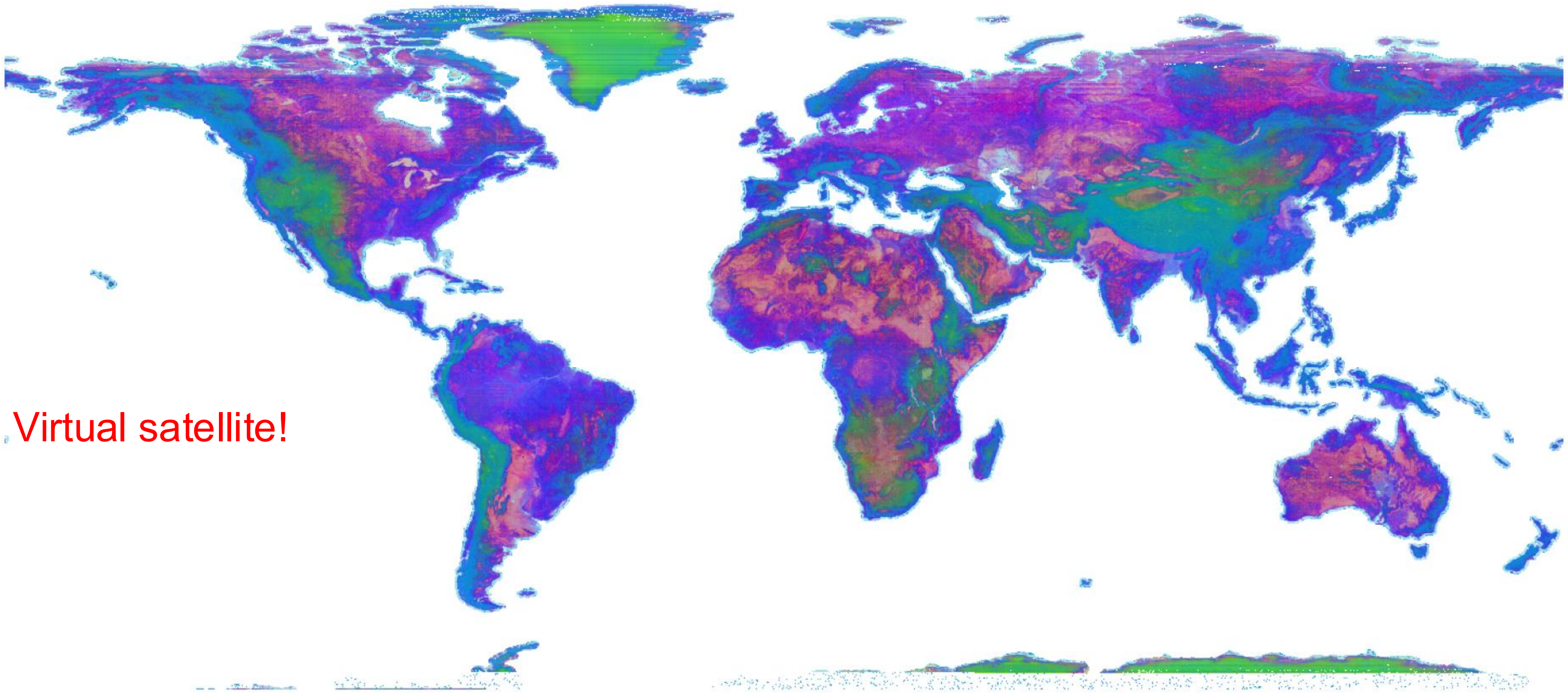
Copernicus-Bench

✓ Benchmark results: comparing Copernicus-FM with SOTA single-/dual-/any-modal FMs.

	Metric	Supervised	Supervised	Random	SoftCon [64]	CROMA [24]	DOFA [69]	Copernicus-FM
Backbone	–	ViT-S/16	ViT-B/16	ViT-B/16	ViT-B/14	ViT-B/8	ViT-B/16	ViT-B/16*
Modality	–	–	–	–	S1/S2	S1+S2	All (spectral)	All
Cloud-S2	mIoU	64.2 ± 0.9	59.4 ± 1.0	60.4 ± 0.2	66.9 ± 0.3	65.0 ± 0.2	65.0 ± 0.2	**66.7** ± **0.1**
Cloud-S3	mIoU	61.7 ± 0.7	**63.0** ± **0.8**	60.9 ± 0.0	–	–	58.2 ± 0.1	62.0 ± 0.7
EuroSAT-S1	OA	81.7 ± 0.7	81.5 ± 0.9	75.4 ± 0.4	83.6 ± 0.1	83.9 ± 0.1	81.7 ± 0.1	**87.2** ± **0.1**
EuroSAT-S2	OA	97.5 ± 0.0	97.6 ± 0.1	92.5 ± 0.1	96.7 ± 0.0	97.0 ± 0.1	97.2 ± 0.1	**97.9** ± **0.1**
BigEarthNet-S1	mAP	71.5 ± 0.4	70.6 ± 0.4	63.8 ± 0.1	**78.7** ± **0.0**	70.8 ± 0.0	70.5 ± 0.0	77.9 ± 0.0
BigEarthNet-S2	mAP	79.5 ± 0.5	80.1 ± 0.1	71.6 ± 0.1	**83.6** ± **0.0**	76.4 ± 0.0	75.5 ± 0.0	79.0 ± 0.0
LC100Cls-S3	mAP	91.3 ± 0.3	91.4 ± 0.5	88.9 ± 0.1	–	–	89.5 ± 0.0	**93.3** ± **0.4**
DFC2020-S1	mIoU	49.9 ± 0.4	50.8 ± 0.5	45.4 ± 0.1	**52.8** ± **0.6**	**52.7** ± **0.1**	49.7 ± 0.1	52.4 ± 0.1
DFC2020-S2	mIoU	65.3 ± 0.6	66.2 ± 0.7	62.3 ± 0.0	64.1 ± 0.3	**66.5** ± **0.0**	61.8 ± 0.1	64.5 ± 0.1
LC100Seg-S3	mIoU	20.1 ± 0.4	19.3 ± 0.5	18.2 ± 0.1	–	–	16.5 ± 0.1	**24.1** ± **0.0**
Flood-S1	mIoU	78.0 ± 0.1	**78.3** ± **0.3**	75.1 ± 0.1	77.2 ± 0.1	77.4 ± 0.1	76.0 ± 0.1	77.7 ± 0.0
LCZ-S2	OA	**86.6** ± **0.7**	85.3 ± 0.8	77.4 ± 0.1	83.6 ± 0.2	84.1 ± 0.0	83.0 ± 0.3	84.4 ± 0.0
Biomass-S3	RMSE ↓	68.1 ± 0.3	68.3 ± 0.4	68.7 ± 0.5	–	–	74.1 ± 0.1	**66.3** ± **0.1**
AQ-NO2-S5P	RMSE ↓	3.4 ± 0.0	3.4 ± 0.0	3.4 ± 0.0	–	–	3.3 ± 0.0	**2.8** ± **0.0**
AQ-O3-S5P	RMSE ↓	1781.3 ± 29.8	1766.8 ± 22.1	1741.6 ± 11.5	–	–	1755.6 ± 19.8	**789.4** ± **2.6**

Copernicus-Embed

- ✓ Grid embeddings at 0.25°x0.25° by fusing all available modalities with Copernicus-FM.

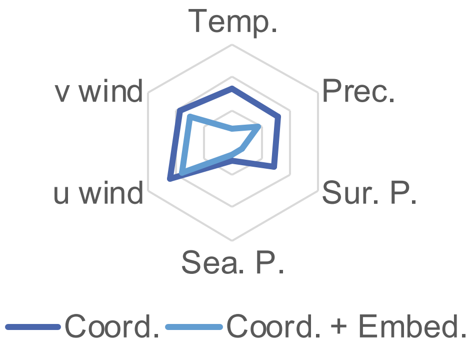


Virtual satellite!

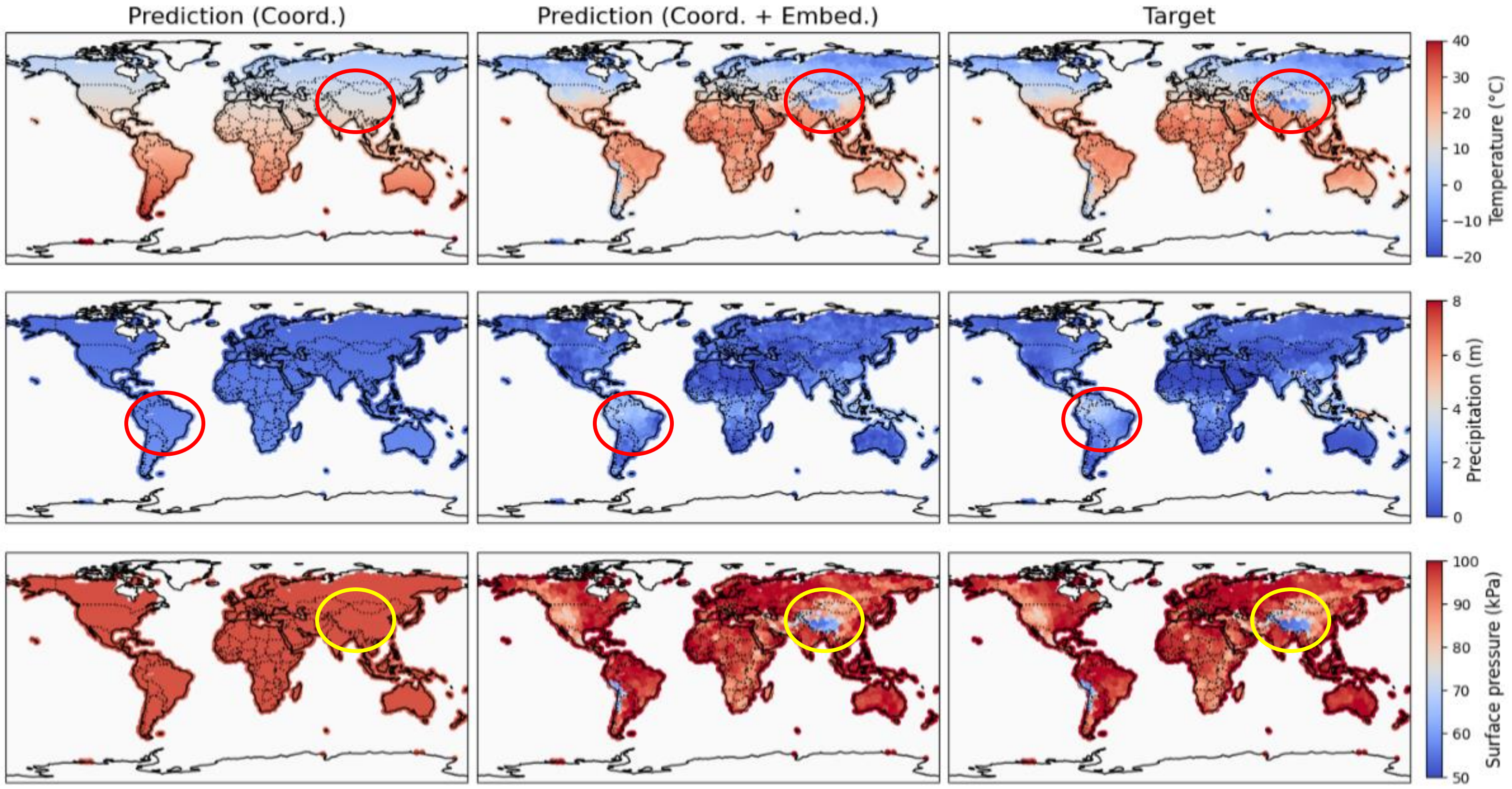
Copernicus-Embed-025deg (PCA visualization)

Copernicus-Embed

✓ Copernicus embeddings help climate studies (10-year mean/std of climate variables).



~46% RMSE drop!



Conclusion & Outlook

✓ We present a series of efforts towards next-gen Earth observation foundation models.
  ✓ Copernicus-Pretrain / Copernicus-FM / Copernicus-Bench / Copernicus-Embed

→ We will extend and make Copernicus-FM more powerful in the next steps.

Copernicus-FM

🌍 In ThinkingEarth, we are also exploring:

- 🌍 Weather / climate foundation models
- 🌍 Causality / Uncertainty / Explainability of large-scale AI models
- 🌍 Operational solutions for solar energy / food security / biodiversity applications

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Linking space to user needs

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