



Embed2Scale

Forest Disturbance Monitoring with Geospatial Foundation Models

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Abstract



Forest Disturbance Monitoring

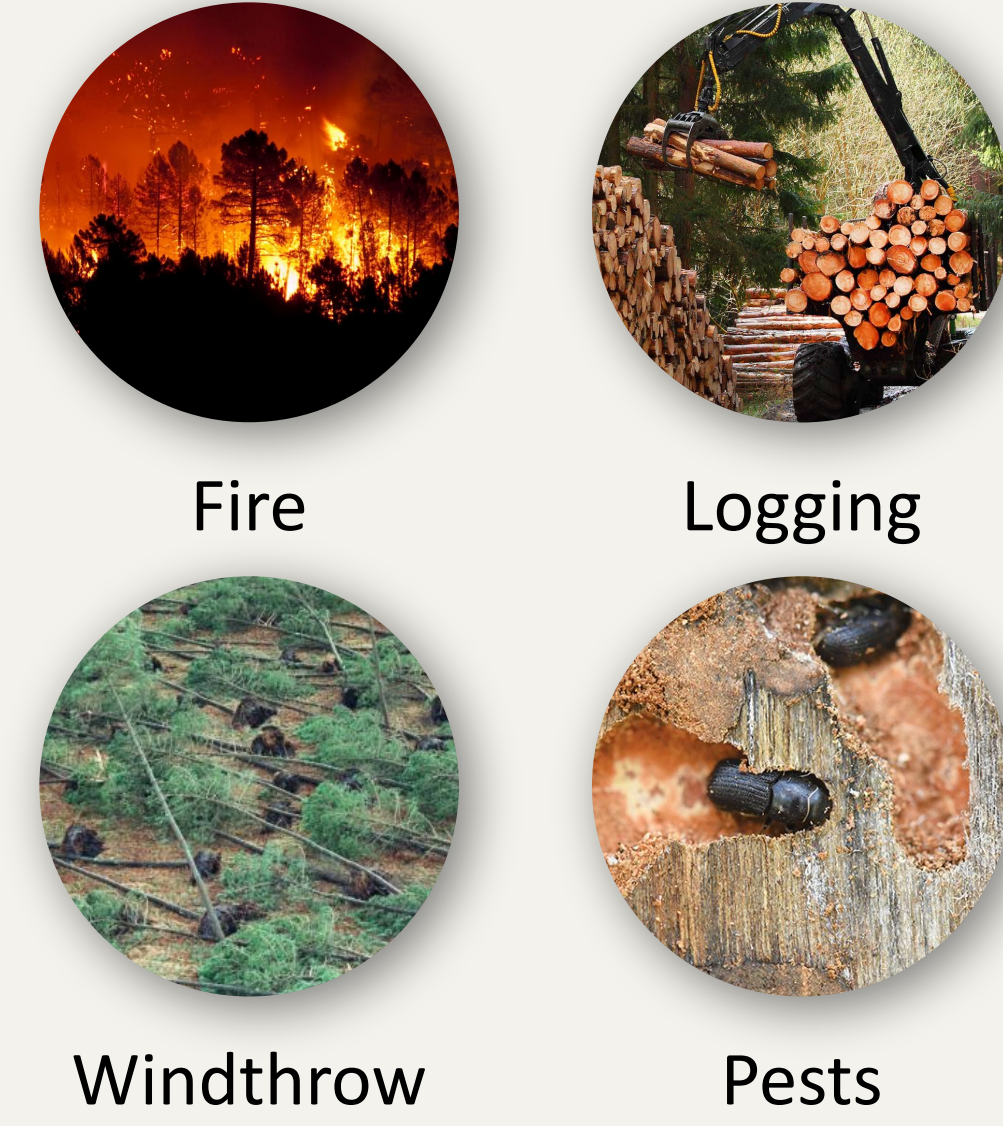
In-situ observation accurate but not scalable - need for **EO-based monitoring**

Various event speeds, requiring **daily to monthly monitoring**

Diverse **agents** affecting **tree cover** and **land use** and potentially **correlating**

Require **timely event detection** and **agent attribution**

Regional patterns requiring tailored models for local forest practitioners



Fire

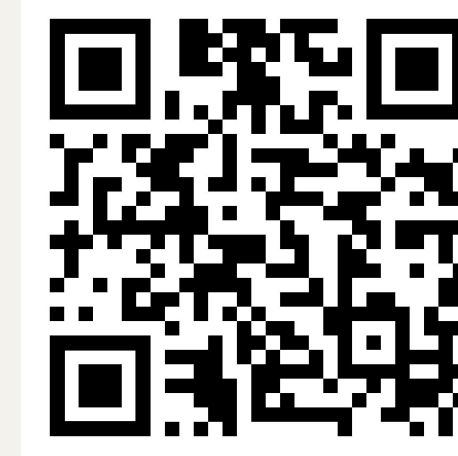
Logging

Windthrow

Pests

	Existing works	Desiderata
Latency	Yearly, few near real-time	Near real-time
Output	Detection XOR attribution	Detection AND attribution
Modality	Cloud-free optical XOR SAR	Optical AND SAR
Model	Heuristics, no spatial context, non-DL	Spatio-temporal DL
Tuning	Region-specific	Tunable to small regional datasets
Reference	Few 1x1 Landsat pixels, no agents	DL-friendly benchmark
Inference	GEE-aided, no DL at scale	Open DL-based system

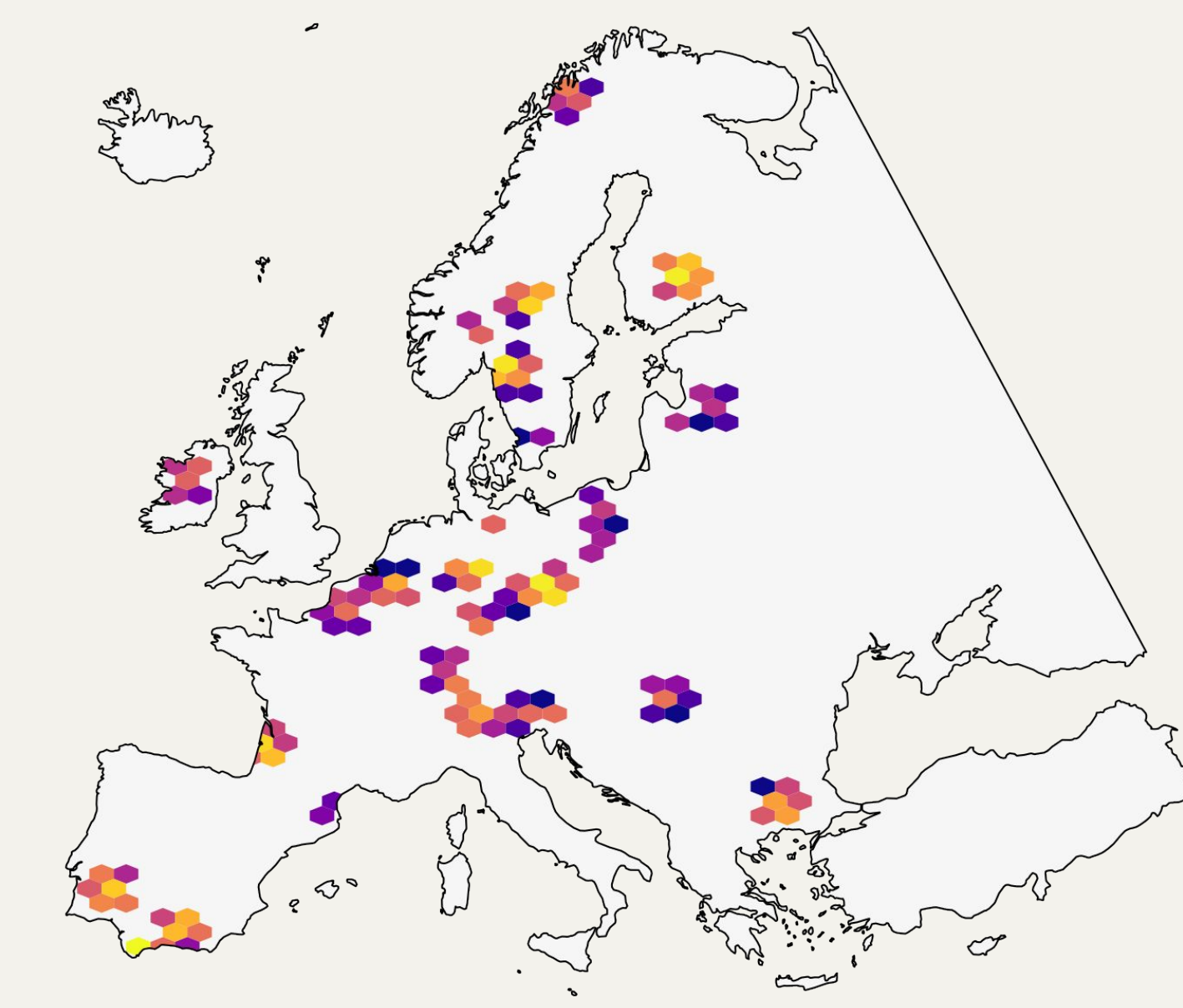
Benchmark Dataset



DISFOR
Viehweger et al., 2026

- 3,777 sample locations in **Europe**
- 2015-2024**
- +2k event / +5k segment annotations

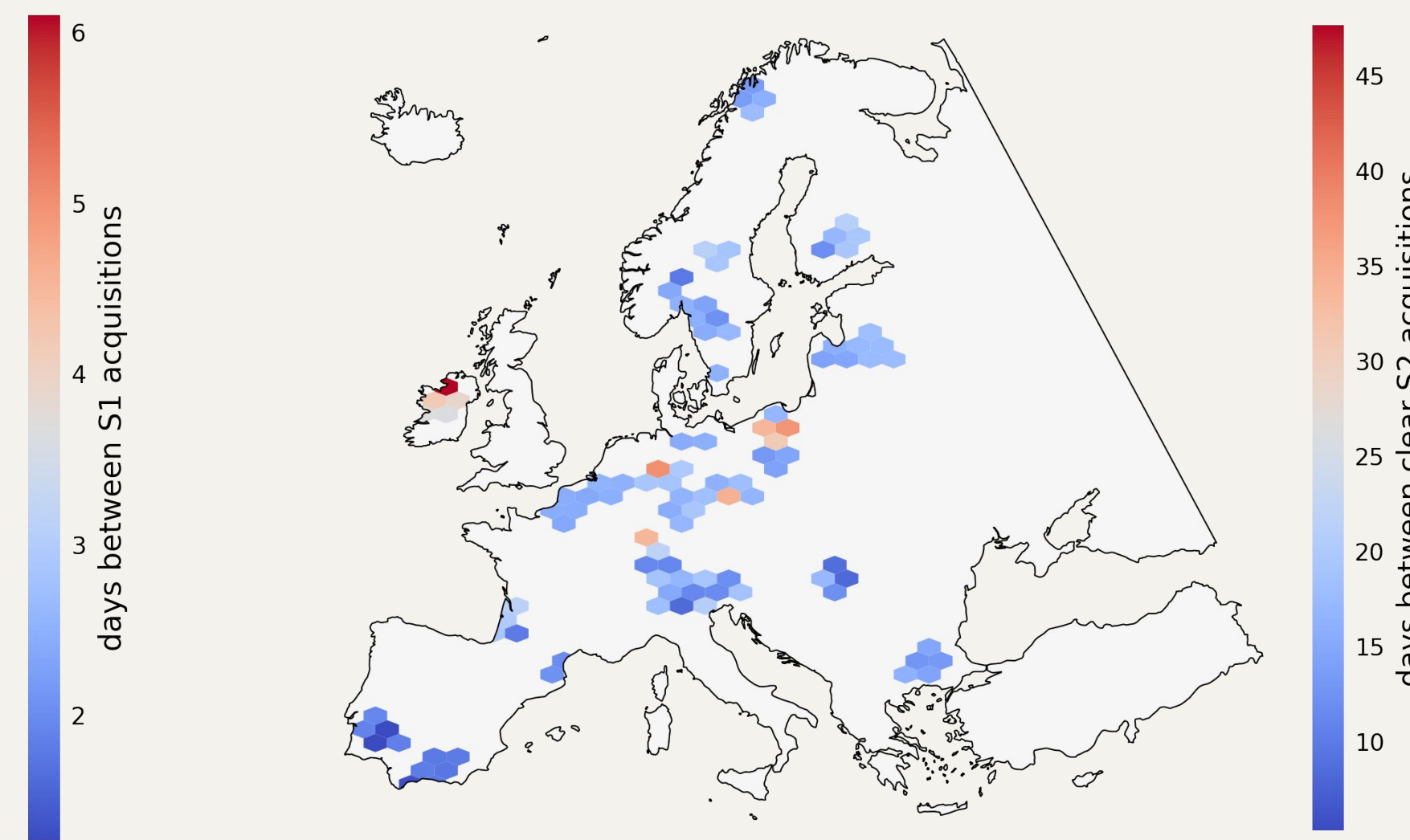
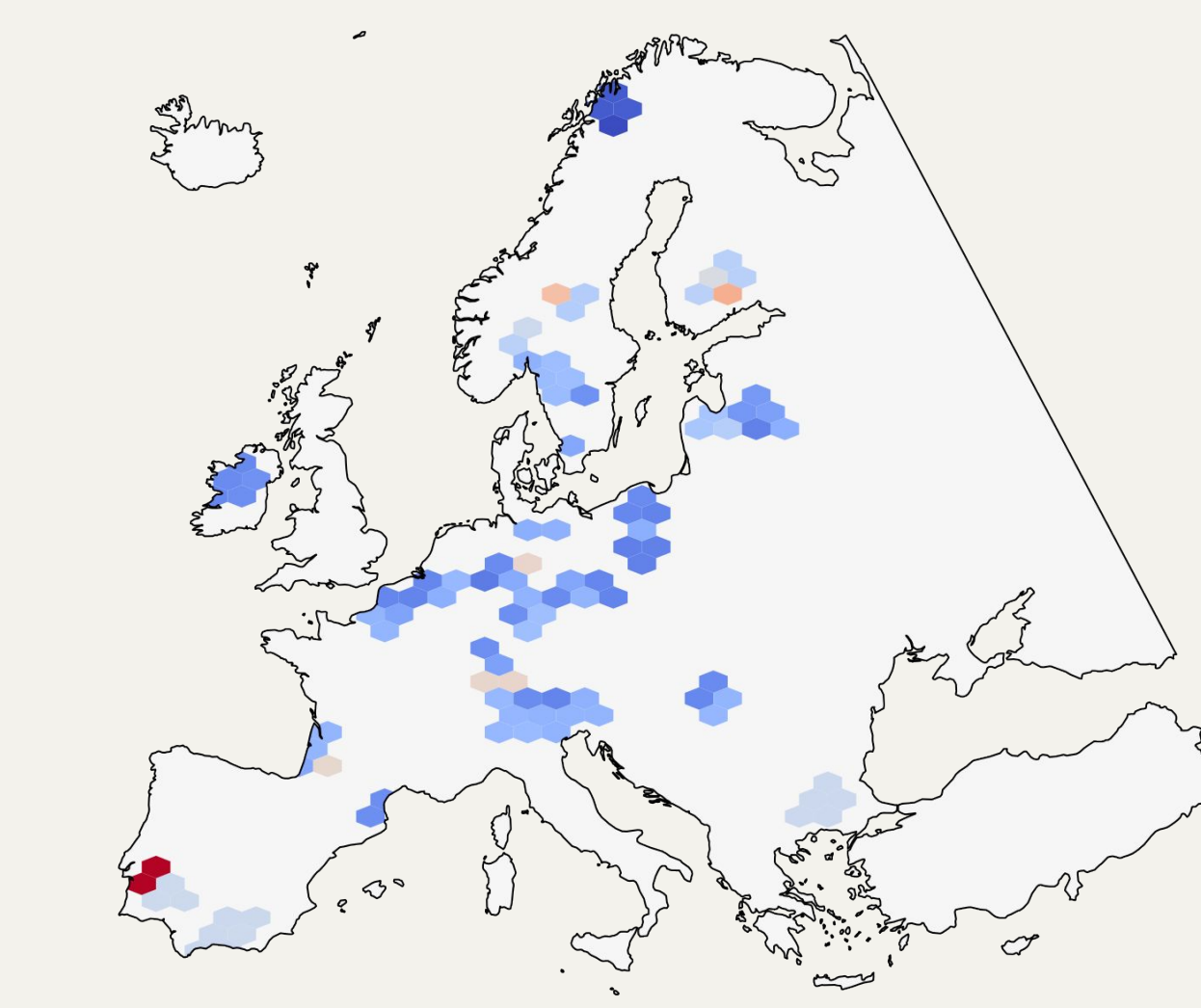
- 512x512** pixel patches
- 5M Sentinel-1** GRD patches
- 800k Sentinel-2** L2A cloud-free patches
- 2TB** storage



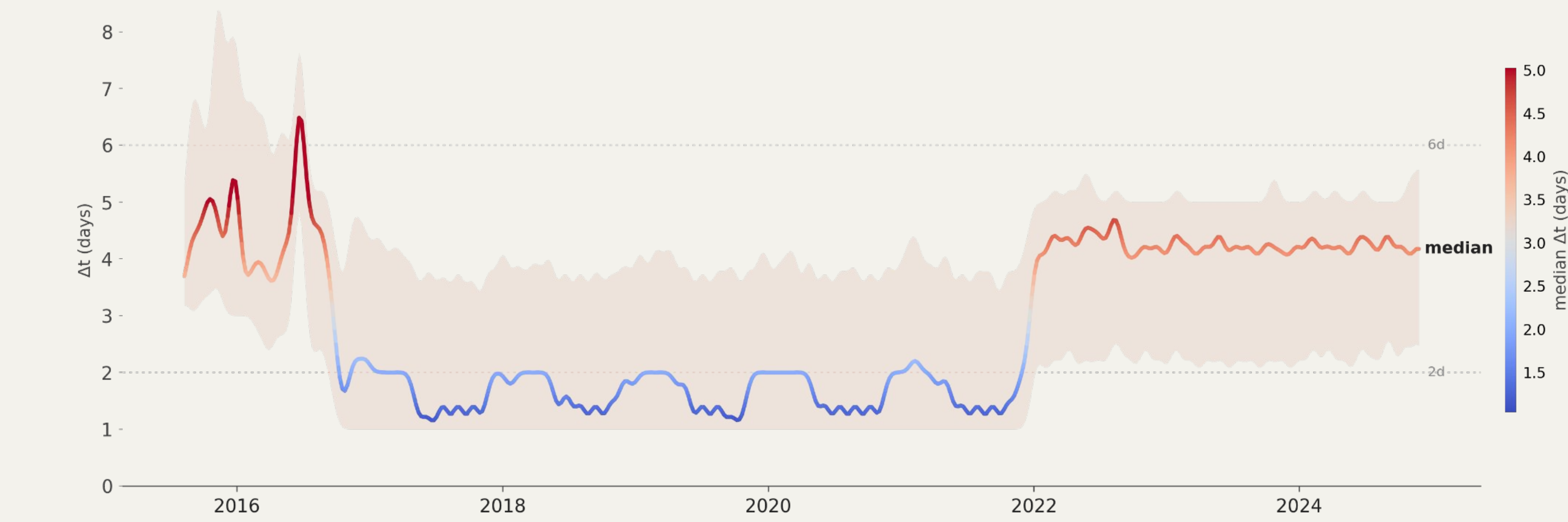
Sample density



Fine-grained disturbance annotation



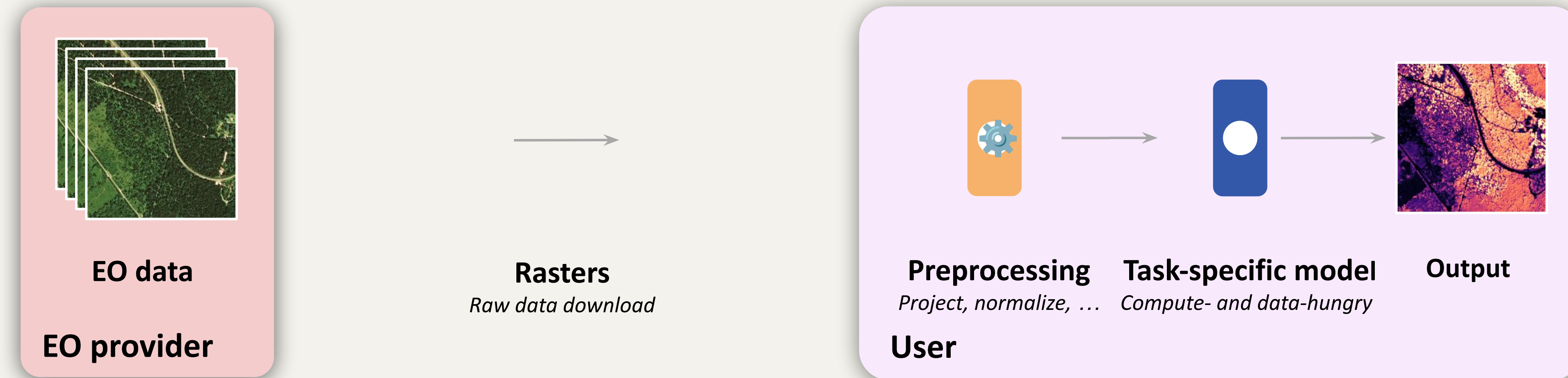
Sentinel-1/2 (left/right) median revisit period across space



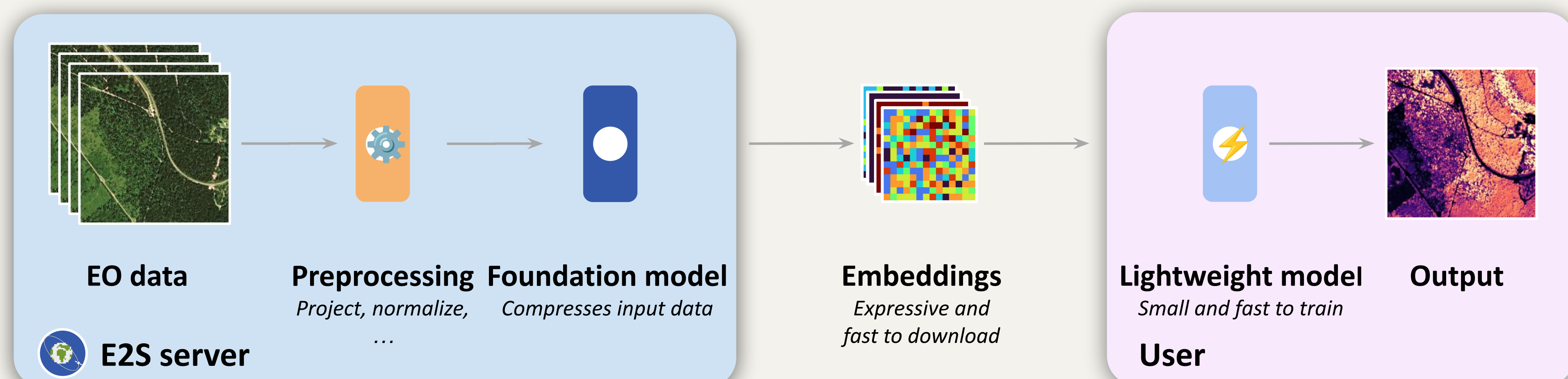
Sentinel-1/2 (top/bottom) median revisit period across time

Earth Observation Analysis Workflows

Standard

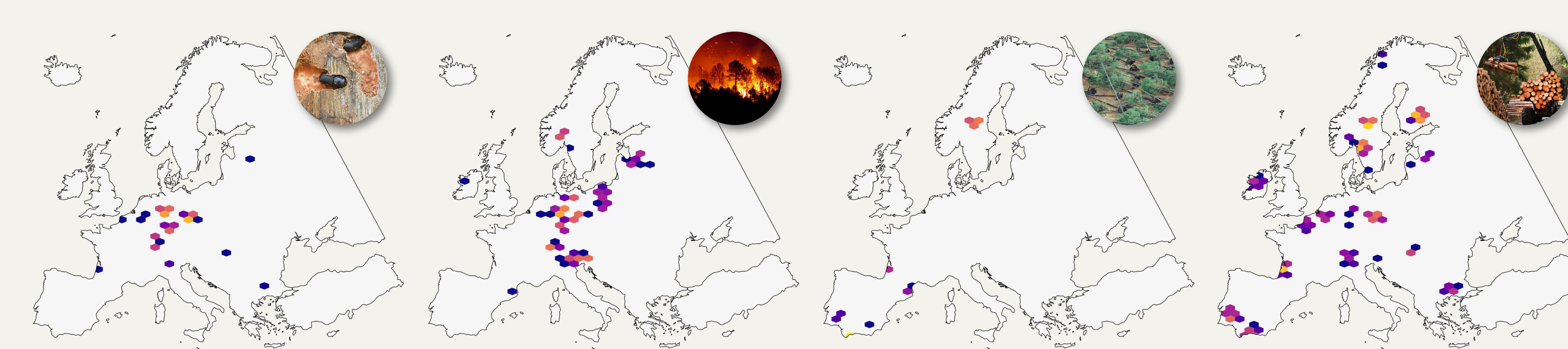


Embedding-based

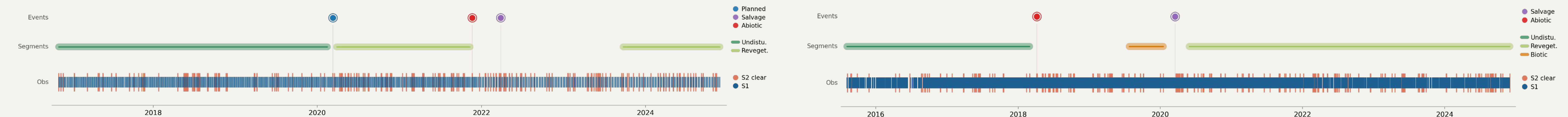


Lowering **expertise** and **hardware barriers** for using **Earth Observation (EO)** data and using **"AI"** for EO

- AlphaEarth / TESSERA**: Open, EU-based pipeline for on-demand, non-aggregated, compressed embeddings
- Unmet GFM expectations**: Low-data, low-compute, low-expertise applications
- Distributing GFM embeddings**: Raster projection, spatial/temporal resolution, modality



Agent disturbance densities



Example sample time series

Future Work

Metrics definition

- Early detection
- Hierarchical agent attribution
- Uncertainty estimation
- Temporal refinement

Benchmarking

- Prior forest disturbance models
- Deep learning baseline from scratch
- Geospatial foundation model embeddings
- Embedding products

Inference

- Alert system deployment
- Inference at scale
- Rigorous product assessment