SeasFire

Earth System Deep Learning towards a Global Digital Twin of Wildfires

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Funded by

Vision - A digital twin of wildfires

Monitoring

- Detection, nowcasting

Causality

- Effect of the human activities, climate change

Anticipation

- Extreme Events
- Interannual variability

Simulation (What-if scenarios)

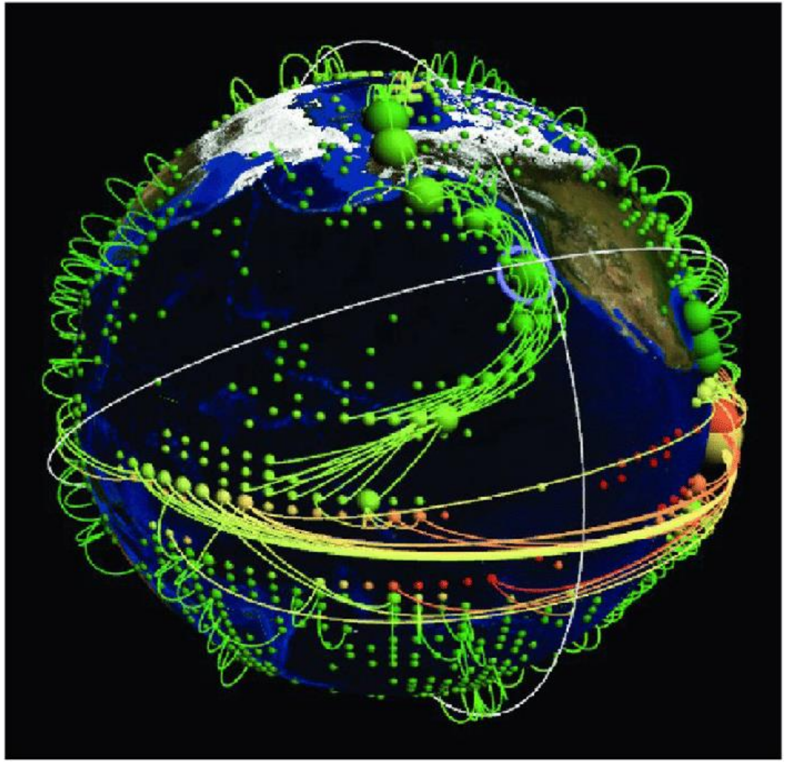
- Assessing the impact of land use changes
- Assessment of wildfire practices, policies

Impact Quantification

- Interaction with other twins
- Ecosystem damage and recovery


A digital twin of wildfires imagined by Stable Diffusion

Earth is a complex interconnected system



Fan, Jingfang, et al. "Statistical physics approaches to the complex Earth system." *Physics reports* 896 (2021): 1-84.

Teleconnections are long-range spatio-temporal connections in the earth system. “Arctic oscillation anomalies linked to extreme wildfires in Siberia” Kim et al. (2020)

Memory effects refer to the temporal dynamics of earth system variables. Vegetation drought response after previous year drought.

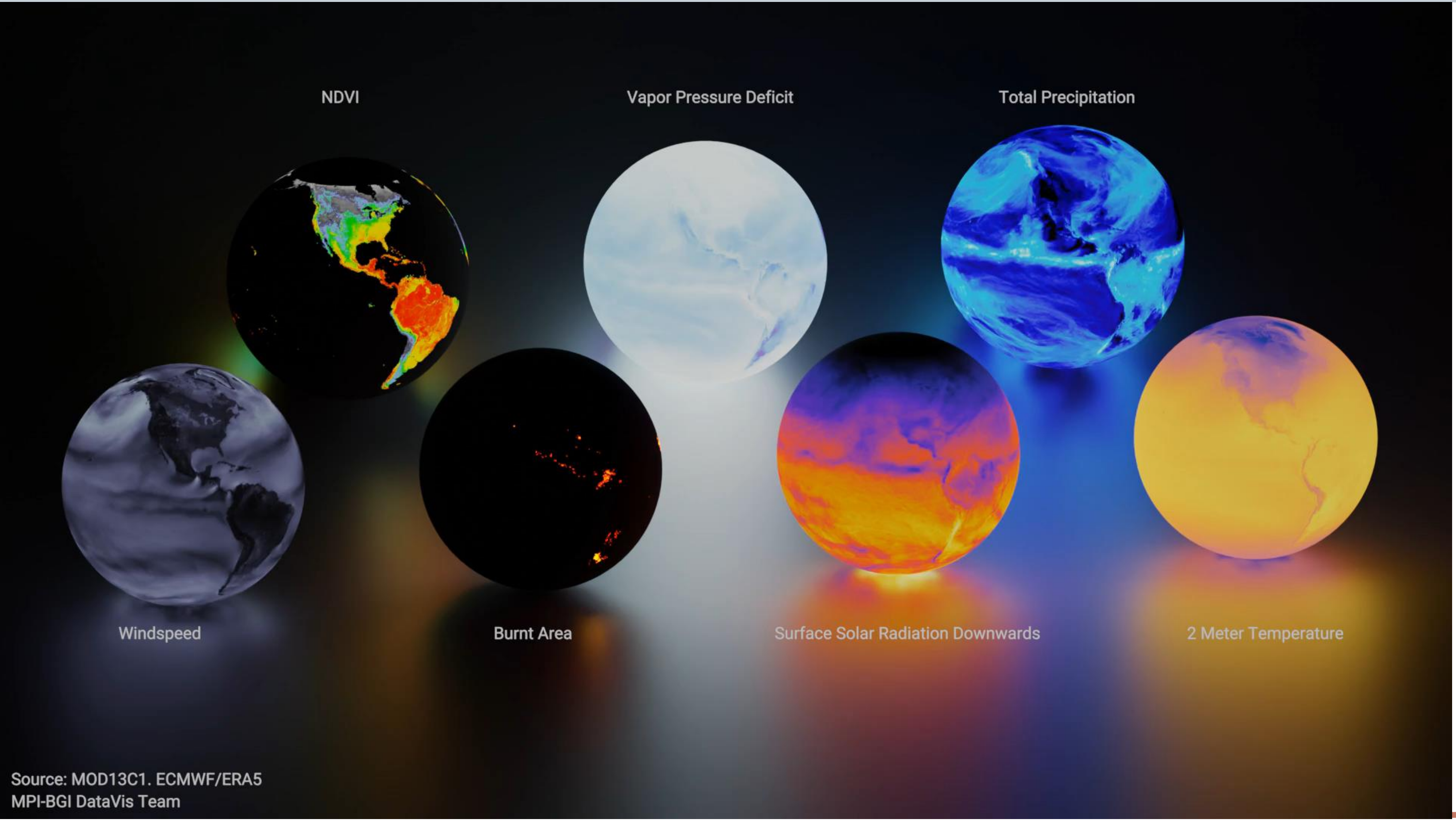
Why Deep Learning?

(a) Non-Linear Interactions: Hard to capture relationships on seasonal and sub-seasonal scales.

(b) ML works well with large-scale datasets

(c) Modern ML methods like Transformers and Graph Neural Networks learn from non-local variable interactions

SeasFire DataCube as a test-bed for wildfire twinning



Resolution: 8dx0.25°x0.25°

(Sub-seasonal to Seasonal)

Extent: Global, 2001 - 2020

Fire drivers
Meteorology (ERA5)
Satellite Observations (MODIS) - NDVI, LST
Oceanic Indices (NOAA)
Population Density
Land Cover (ESA CCI)

Fire products
Burned Areas
(GFED, FireCCI, GWIS)
Fire Emissions (GFAS)

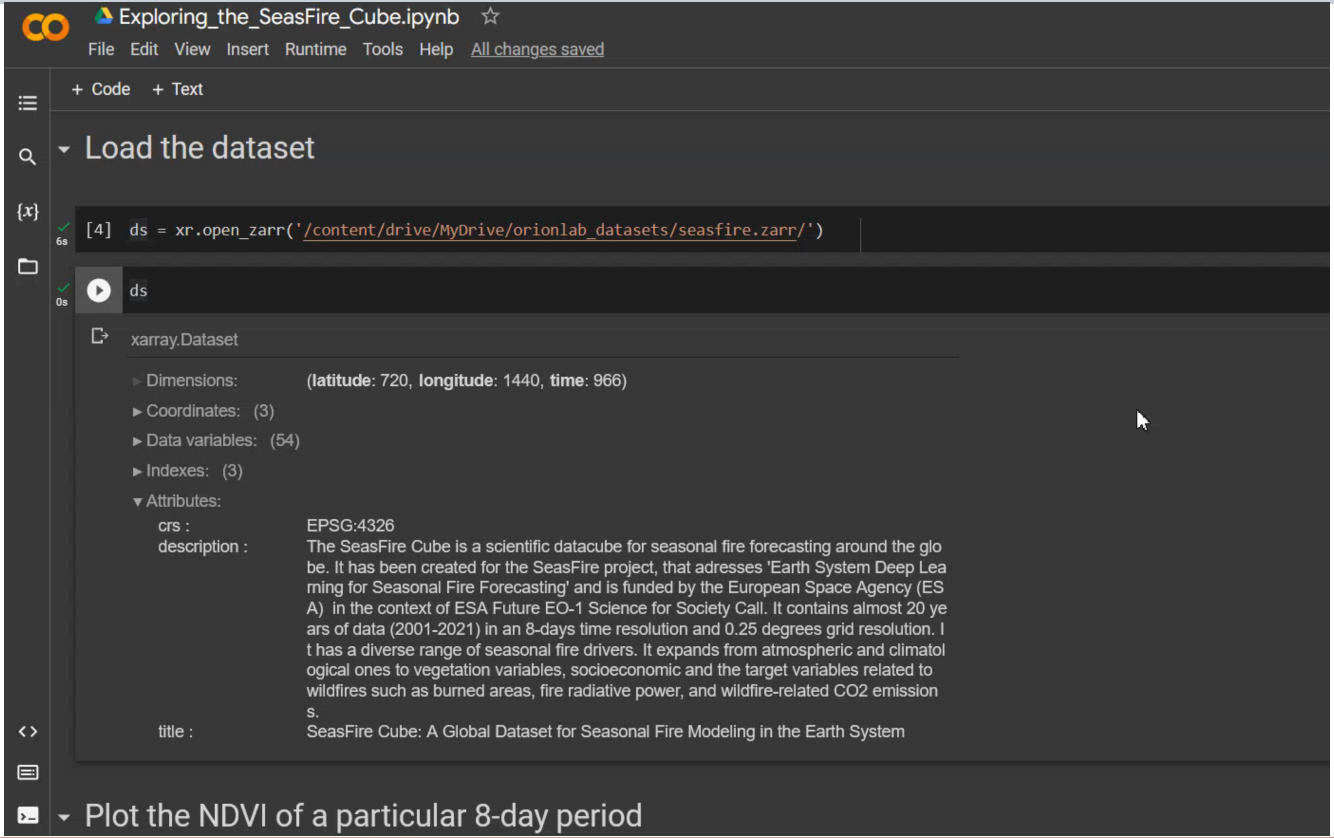
Datacube Demonstration

Cloud-optimized zarr dataset

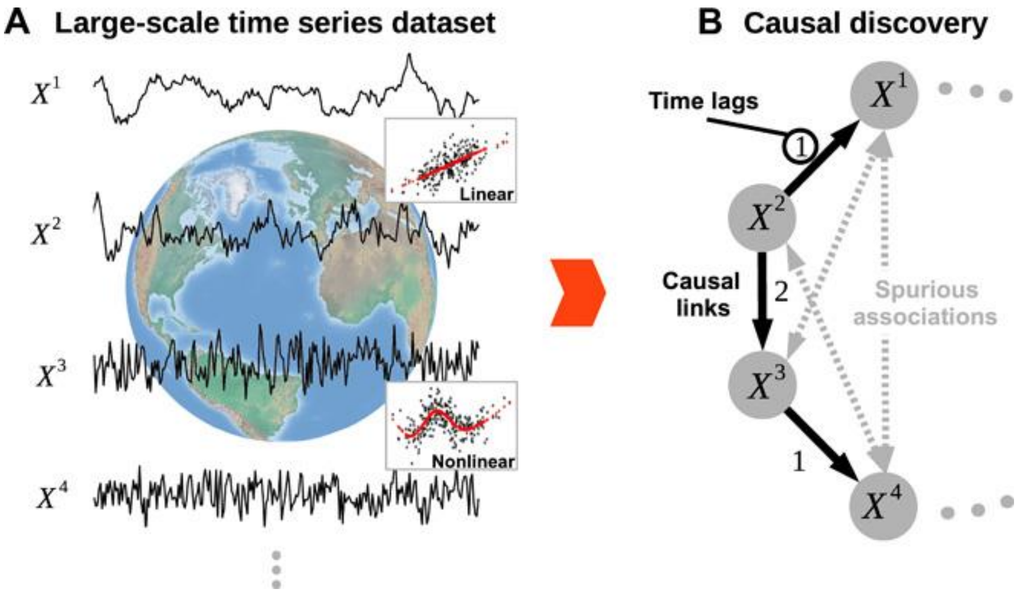
Rapid analytics without downloading the dataset

Can associate fire drivers to wildfires around the world

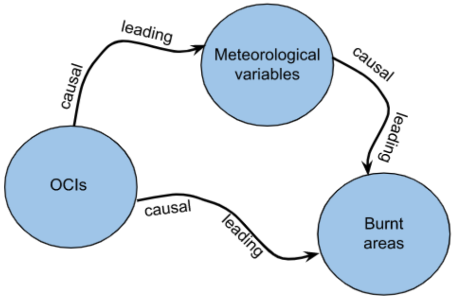
Zarr

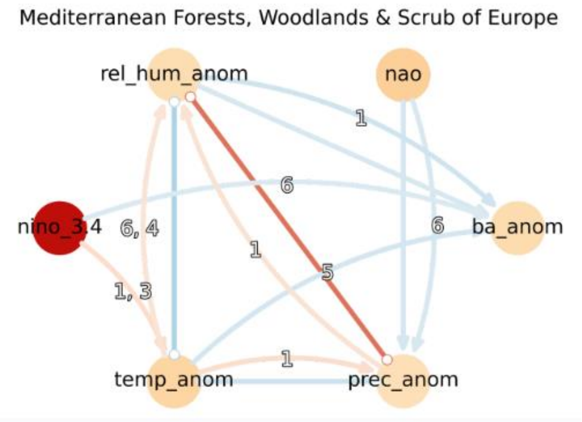


Causal Analysis



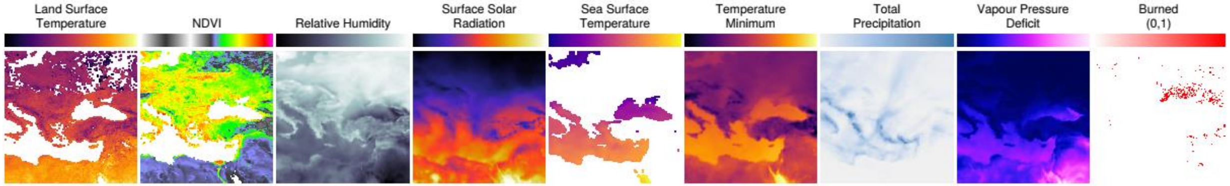
Runge, Jakob, et al. "Detecting and quantifying causal associations in large nonlinear time series datasets." *Science advances* 5.11 (2019): eaau4996.

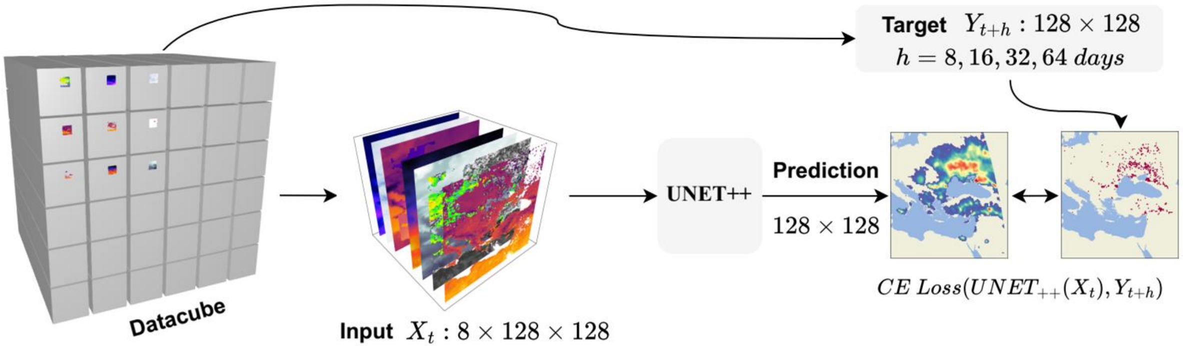




Burned Area Forecasting

- **Input**: 8 fire driver variables at time ***t***.
  Stacked 128x128 patches
- **Target**: Presence of burned area at time ***t+h***
  (h=8, 16, 32, 64 days)
- A separate **UNET++** model is trained for each ***h***
- **Data split temporally:**
  Training (2001 to 2017)
  Validation (2018)
  Testing (2019)



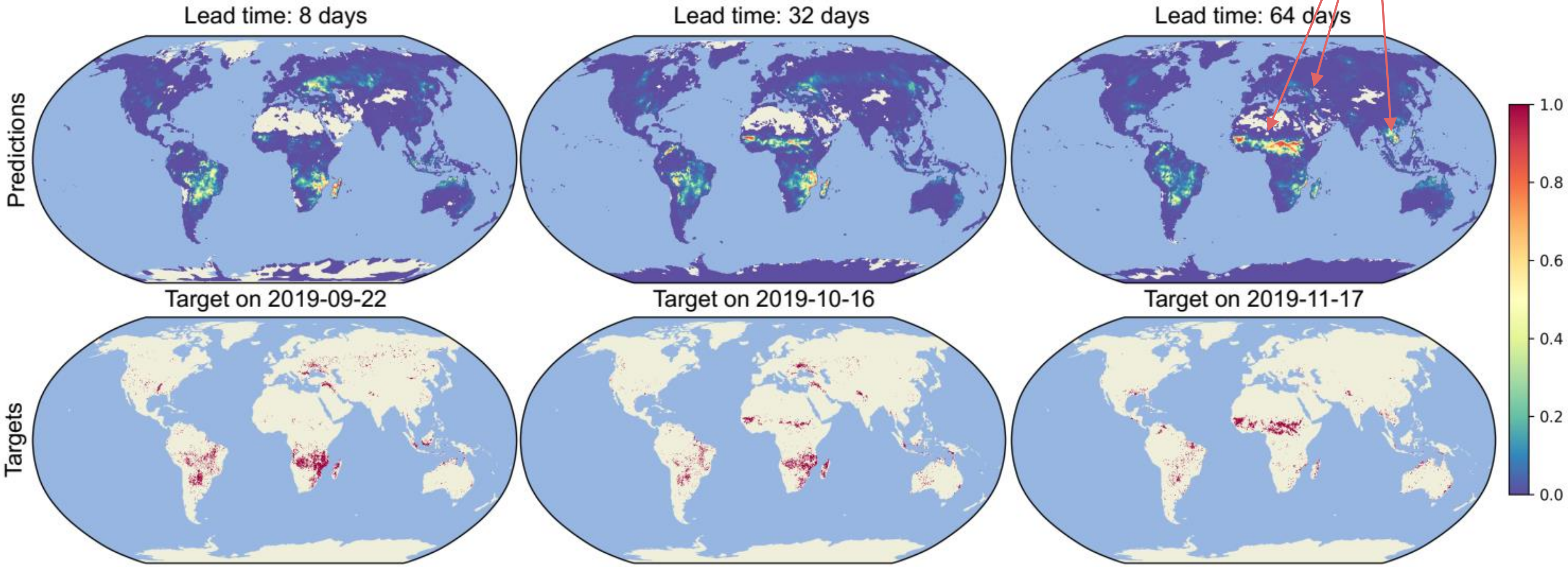


Presented in NeurIPS 2022 Workshop on Tackling Climate Change with AI
https://www.climatechange.ai/papers/neurips2022/52

Global Prediction Maps

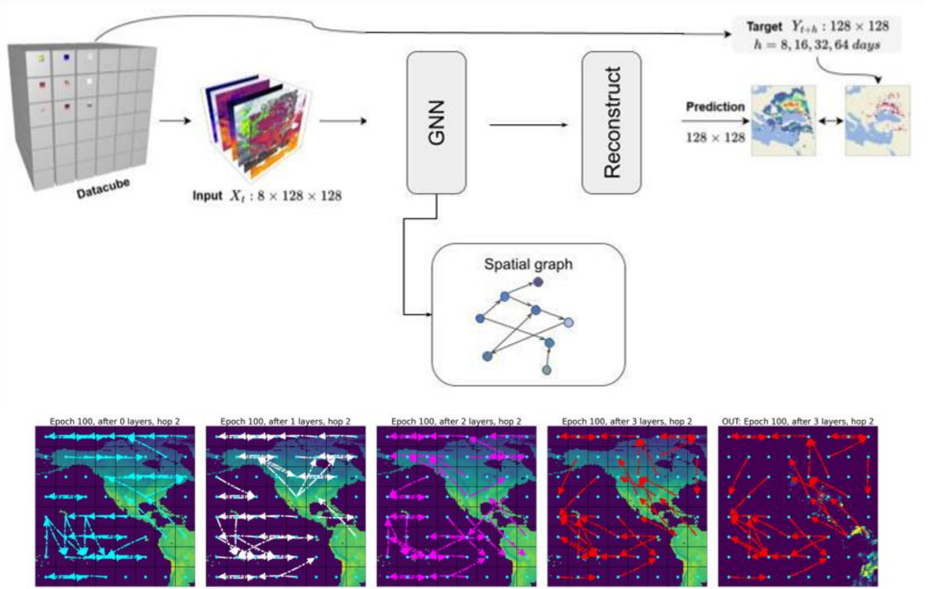
Captured change of fire activity in eastern Europe and south-east Asia, shift from the southern to the northern African savanna.

- Main patterns shifts are captured
- Predictive skill better than the mean seasonal cycle
- Sub-second global inference



Earth System DL: Leveraging non-local interactions

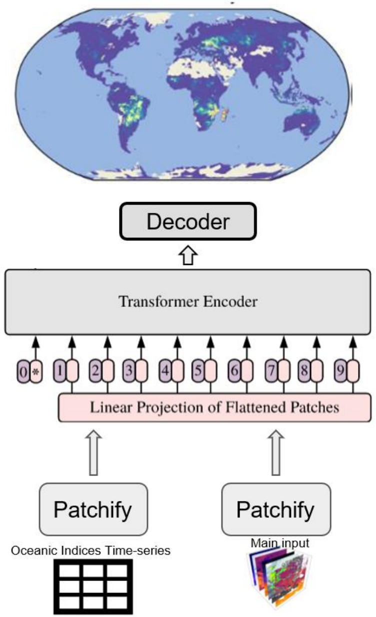
Graph Neural Networks



Learned edges of GNN hints into model's inner workings

Y. Wang, Y. Sun, Z. Liu, S. E. Sarma, M. M. Bronstein, and J. M. Solomon, 'Dynamic Graph CNN for Learning on Point Clouds'. (2019).

Transformer models



Better performance when adding info from oceanic indices.

Dosovitskiy, Alexey, et al. "An image is worth 16x16 words: Transformers for image recognition at scale." (2020).

Main Takeaways

- SeasFire cube can serve as a test bed for digital twin models of wildfires (for sub-seasonal to seasonal scales)
- Deep Learning can increase our ability to forecast and simulate wildfires
- Modeling the earth as a system can enhance our understanding of large-scale processes

Links

SeasFire Project: https://seasfire.hua.gr
Preprint: https://arxiv.org/abs/2211.00534
SeasFire Cube: https://zenodo.org/record/7108392
Tutorials: https://github.com/SeasFire/seasfire-datacube