Ακραία Συμβάντα σε Ροές Ρευστών και Κύματα

Θεμιστοκλής Σαψής

Καθηγητής Μηχανολογίας και Ωκεάνιας Μηχανικής
Massachusetts Institute of Technology

Extreme events and why ML?

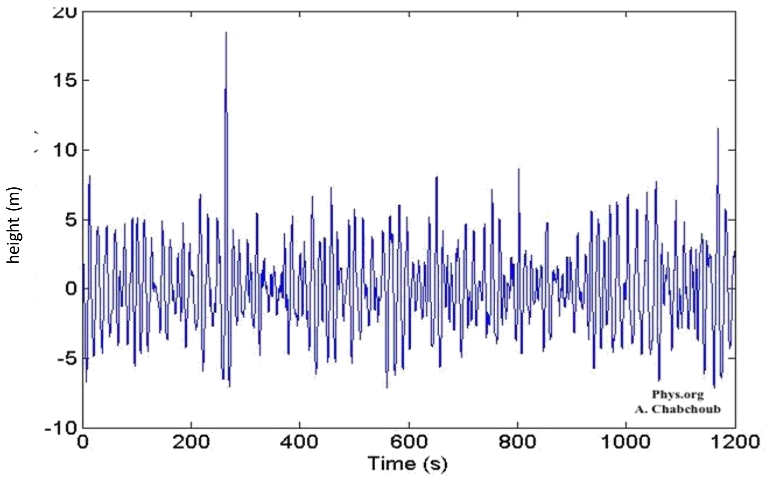
Examples and general characteristics

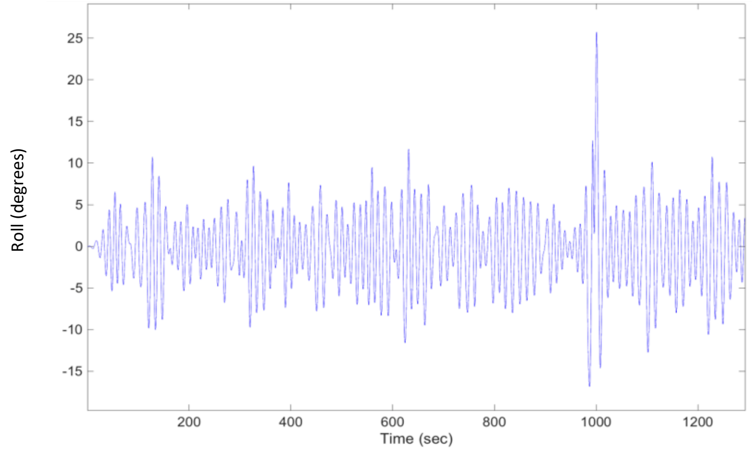
- Limited predictability
- Intrinsic uncertainty
- Complex dynamics
- High dimensionality
- Rare events
- Extreme impact

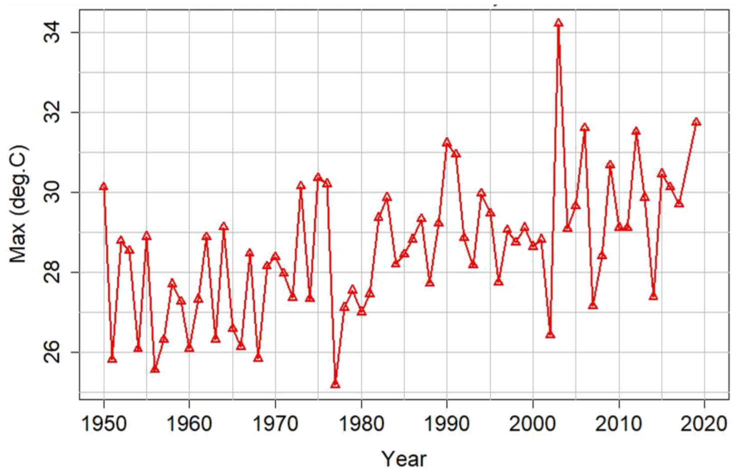
Challenges

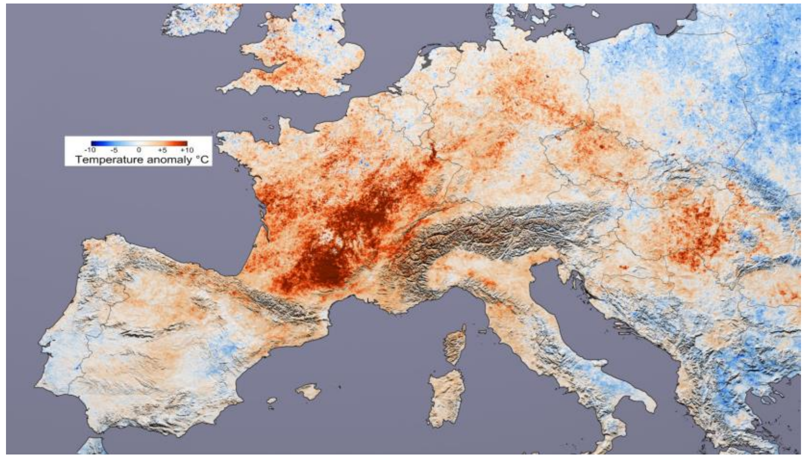
Not enough data

Not enough <u>useful</u> data









Challenges in Modeling and Design of Offshore Facilities and Structures

- Design of <u>economical</u> floating or submerged structures that can survive <u>harsh open sea storms</u>
- Modeling of severe offshore sea environments: nonlinear waves, strong current, winds, …
- Modeling of nonlinear sea loads and sea-keeping responses of ocean structures in storms
- Optimal sensor placement for structural health monitoring
- Characterize operational envelope
- Need to reduce computational time

aquaculture structures

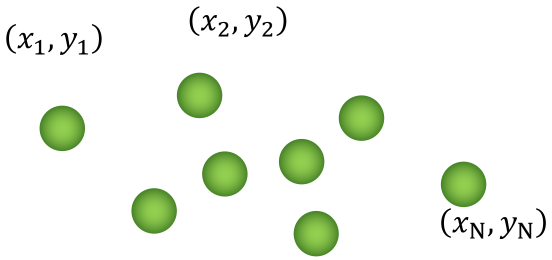
offshore platforms

Cargo ship in extreme waves

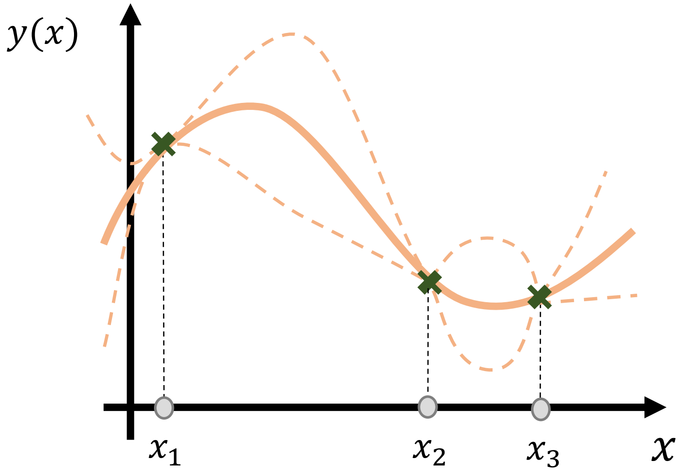
Fatigue characterization

Active learning

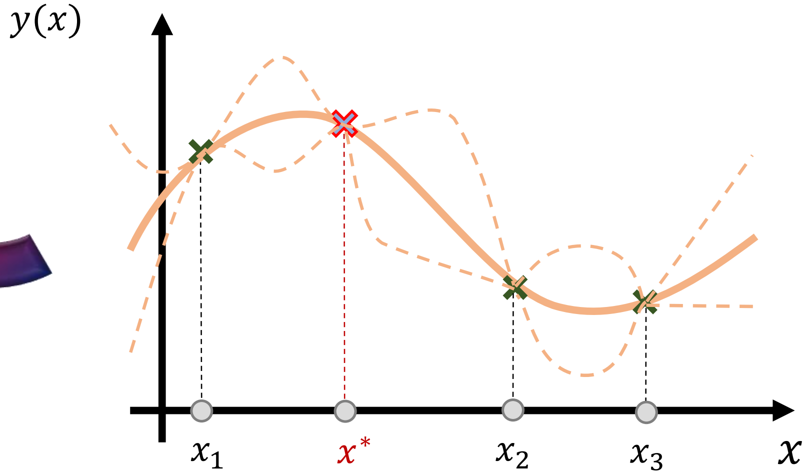
Initial data



Probabilistic regression



Selection of new input



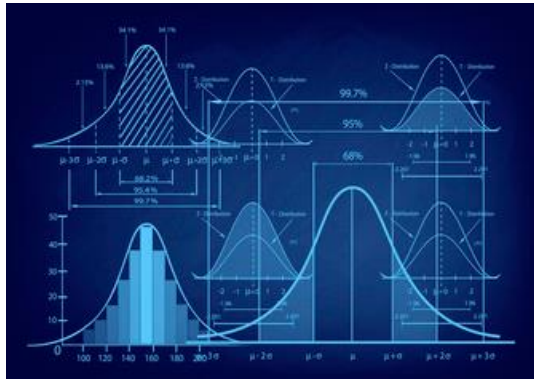
$$\min_{x^*} \alpha(x^*)$$

New experiment

$$x_{N+1} = x^*$$
$$y_{N+1} = F(x^*)$$

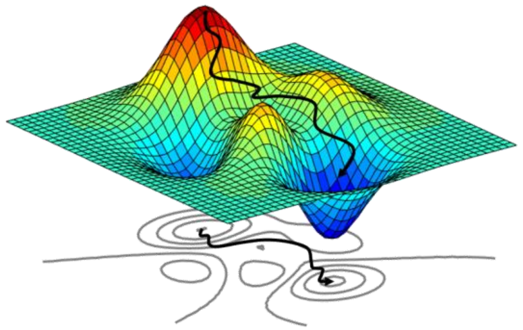
Uncertainty Quantification

$p_y(y)$



Optimization

$$\min_x y\,(x)$$

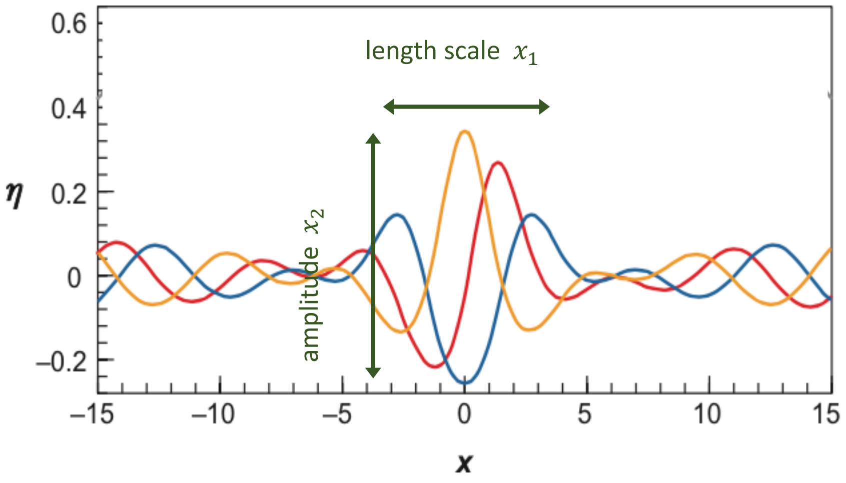


Extreme events quantification with very few experiments/simulations

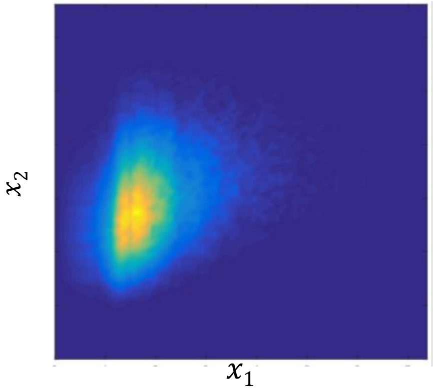
JONSWAP spectral density

$$S(f) = \frac{\alpha g^2}{(2\pi)^4 f^5}\exp\left[-\frac{5}{4}\left(\frac{f_p}{f}\right)^2\right]\cdot\gamma^{\exp\left[\frac{-(f-f_p)^2}{2\delta^2 f_p^2}\right]}$$

2D parametrization of waves

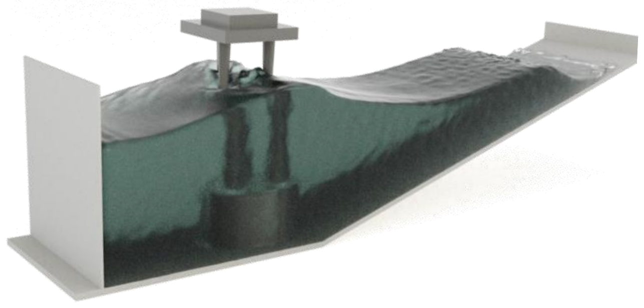


Probability density function of wave parameters



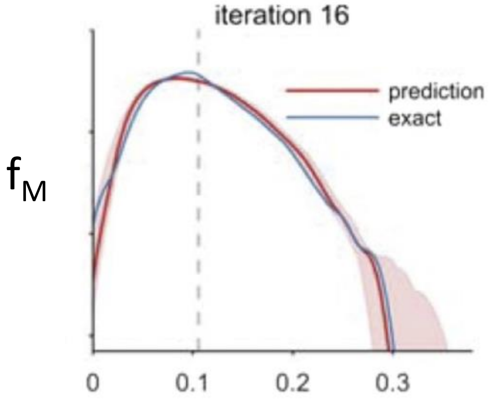
Mohamad & Sapsis, PNAS, 2018

CFD experiment



Output pdf acquisition function

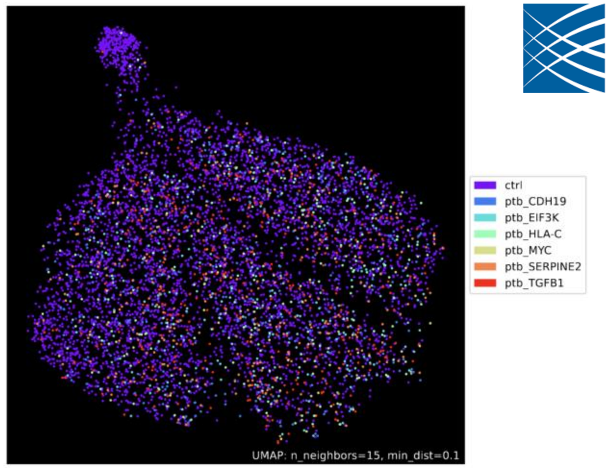
$$\min_{x^*}\int\left|\log p_{\bar{y}_N+\sigma_N}(s;x^*) - \log p_{\bar{y}_N}(s)\right|ds$$



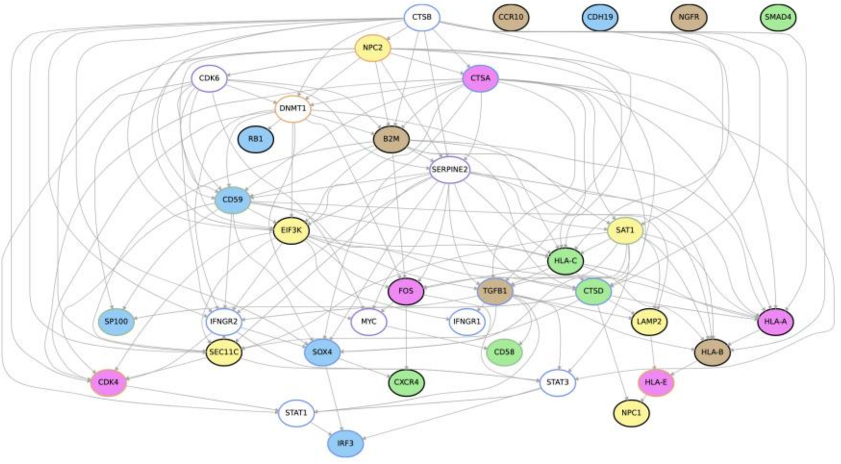
pdf of structural moments with 16 simulations

Optimal Experimental Design (Active learning) in other areas

Optimally induce cell state change in human cells

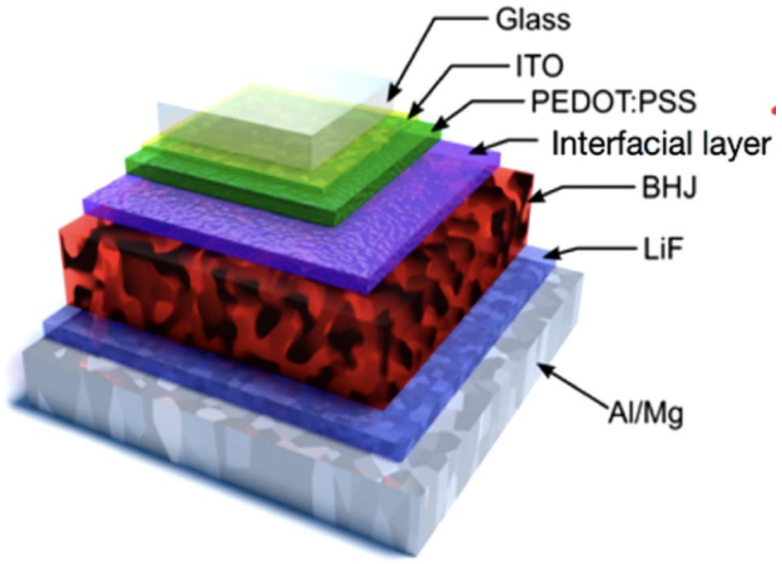


An optimally designed set of experiments leads to the discovery of a causal network for cellular reprogramming.

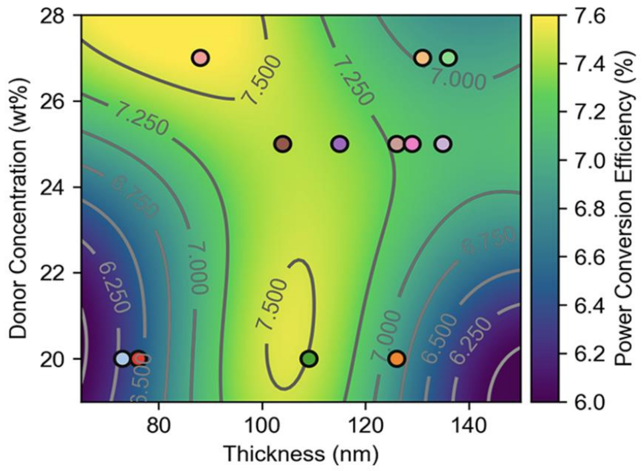


Zhang et al., ArXiv, 2022

Optimal experimental design for material and devices

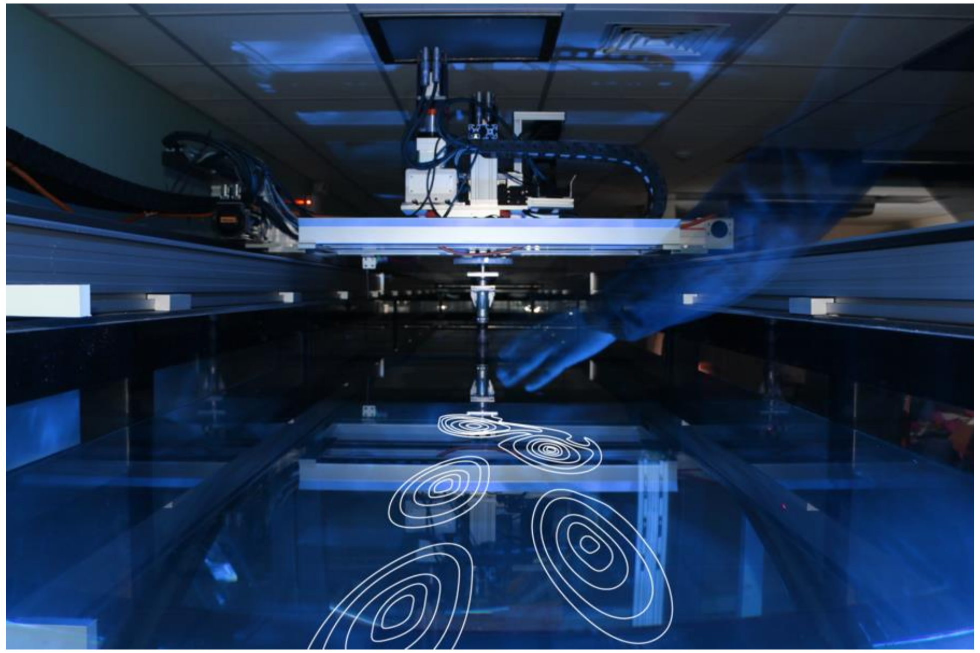


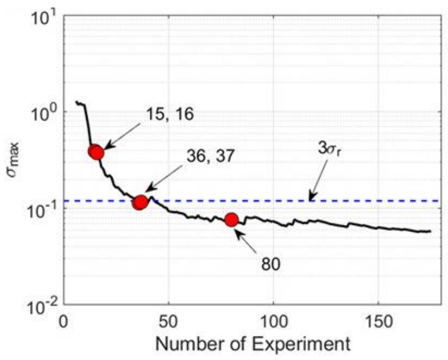
Optimization of organic PV

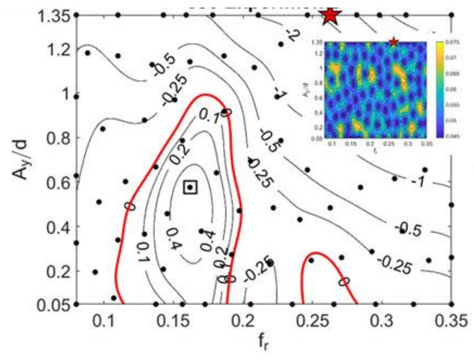


Cao et al., ACS Nano, 2019

Intelligent towing tank

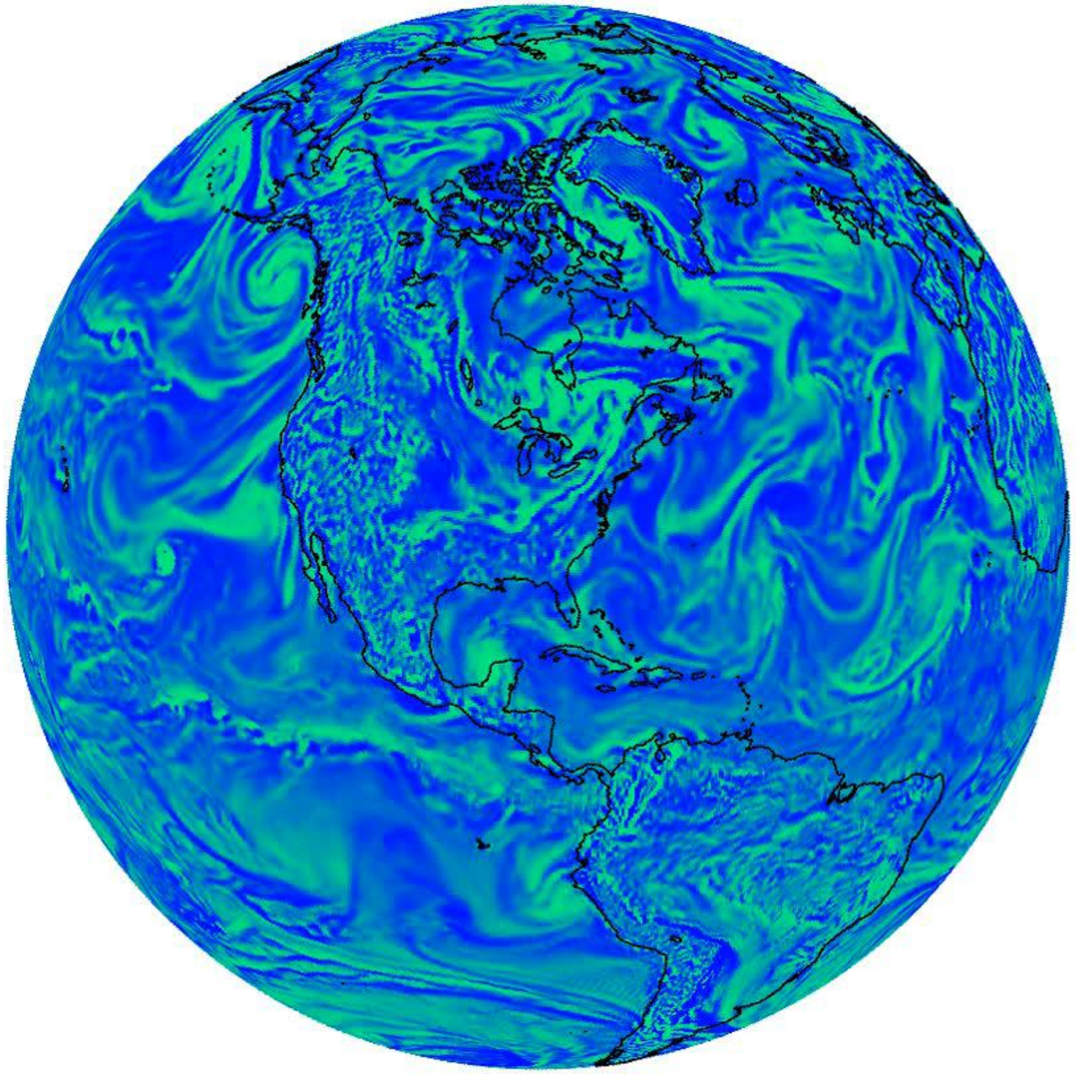






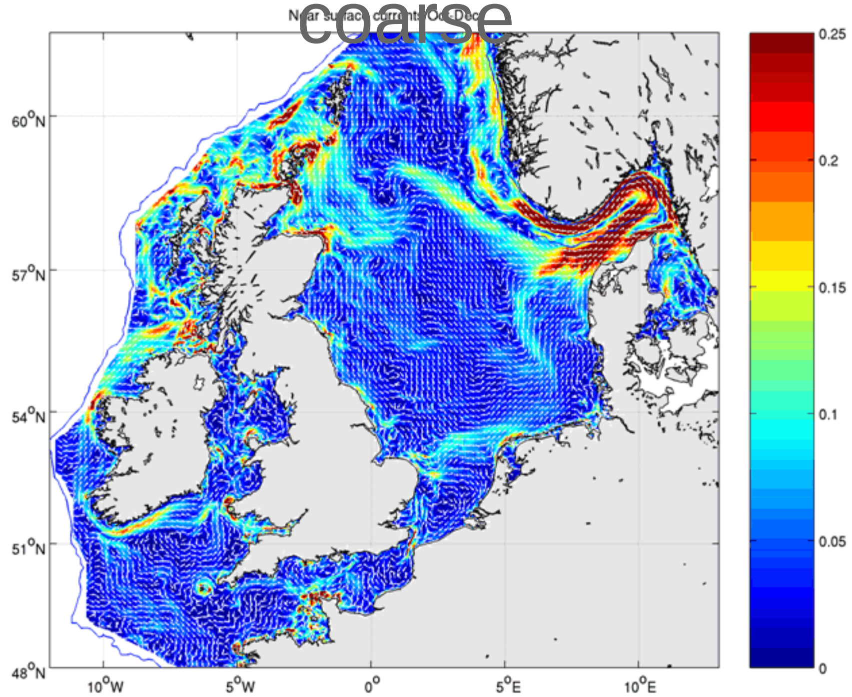
Fan et al., Science Robotics, 2019

Monitoring & Prediction of Nonlinear Geophysical Systems



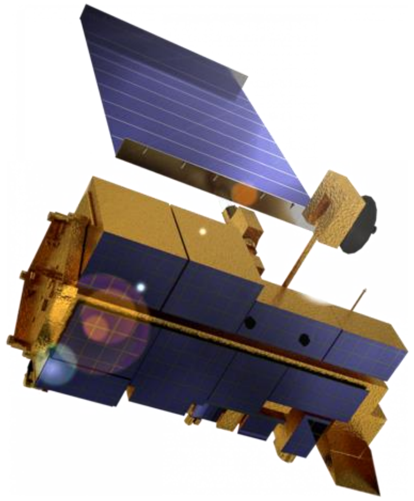
inherently multi-scale and uncertain

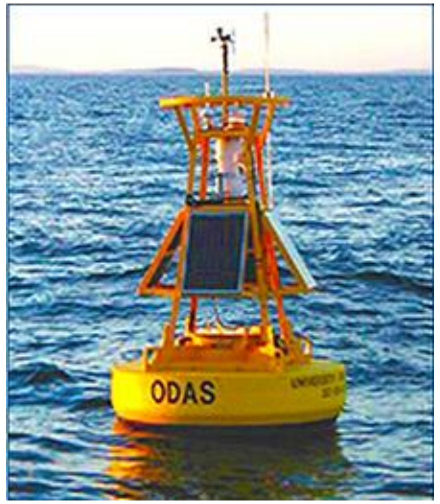
real time measurements are coarse



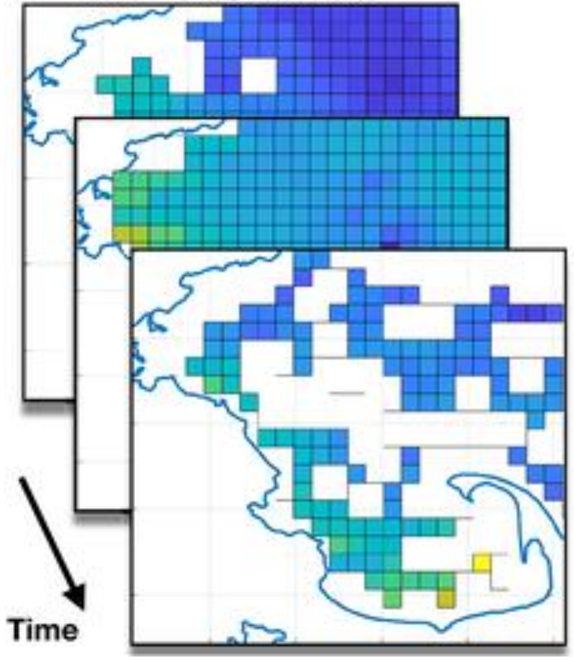
simulations are expensive

A multi-fidelity framework for ocean acidification

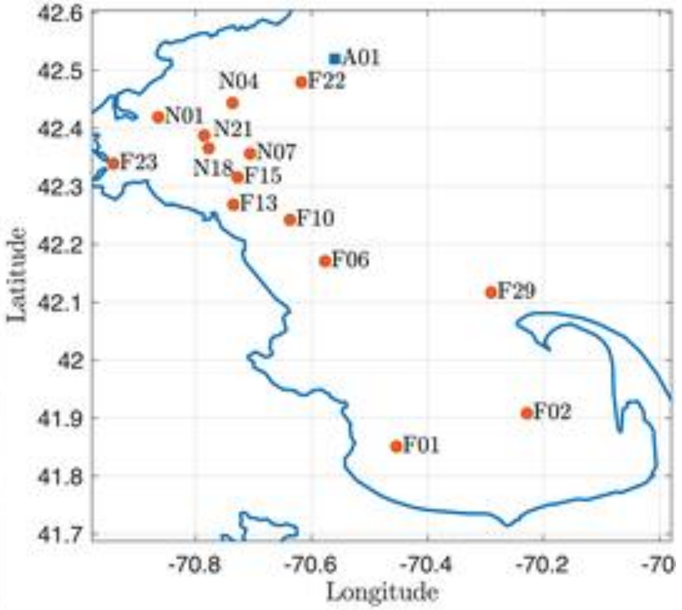




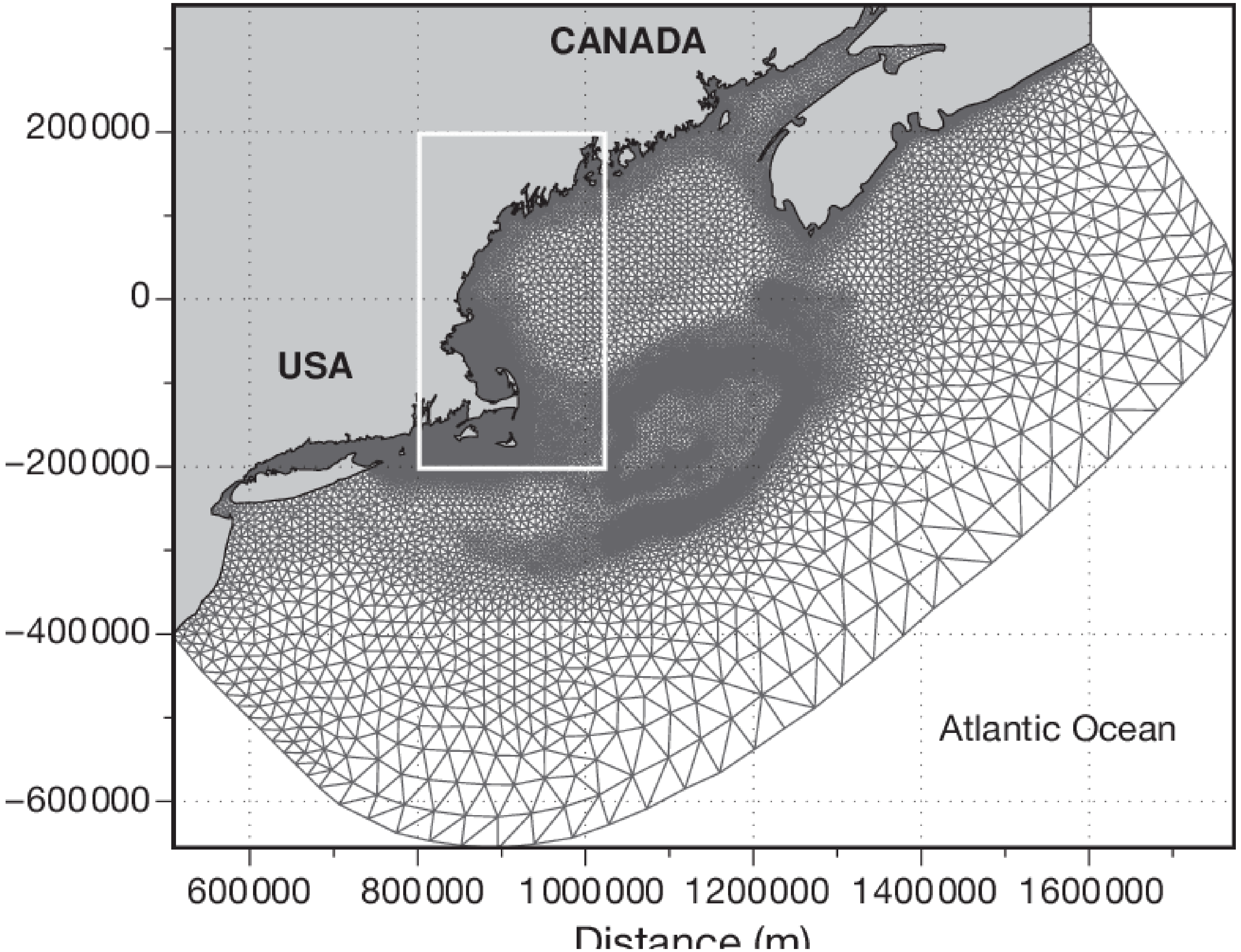
Low Fidelity: *Satellite*



High Fidelity: *MWRA In-situ Measurements*

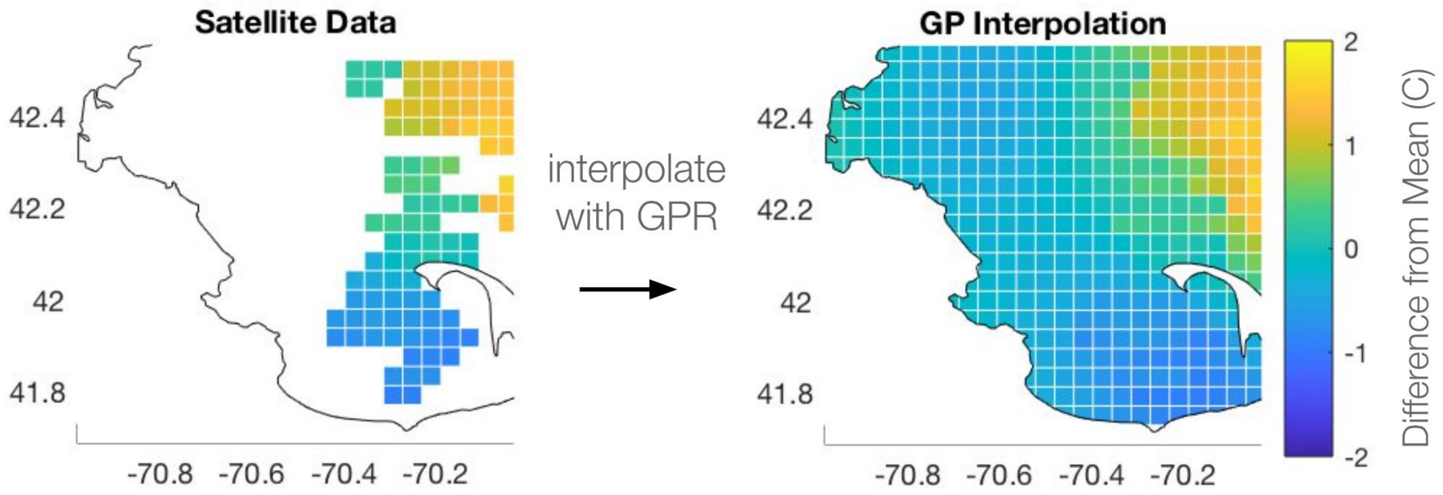


Finite-Volume Coastal Model (FVCOM)



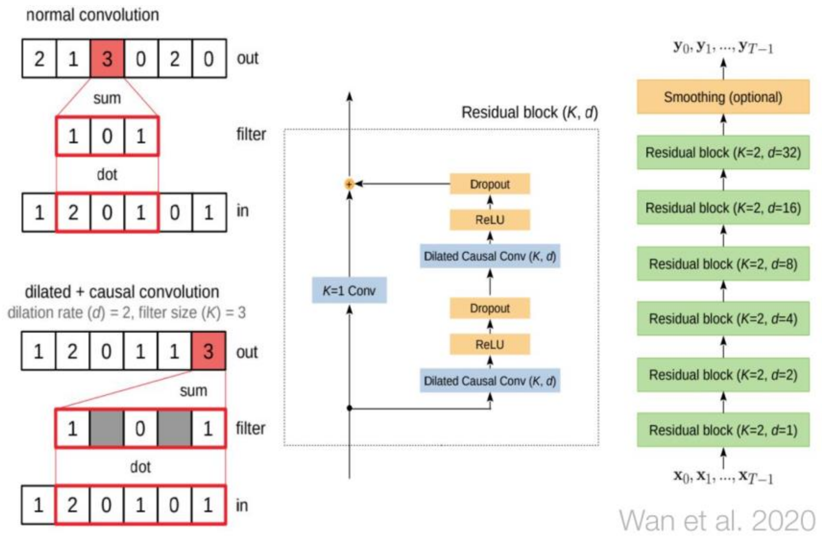
Real time estimation of 3D temperature field in Massachusetts Bay

Extrapolation of satellite data using GPR and merging with buoy data using MF-GP

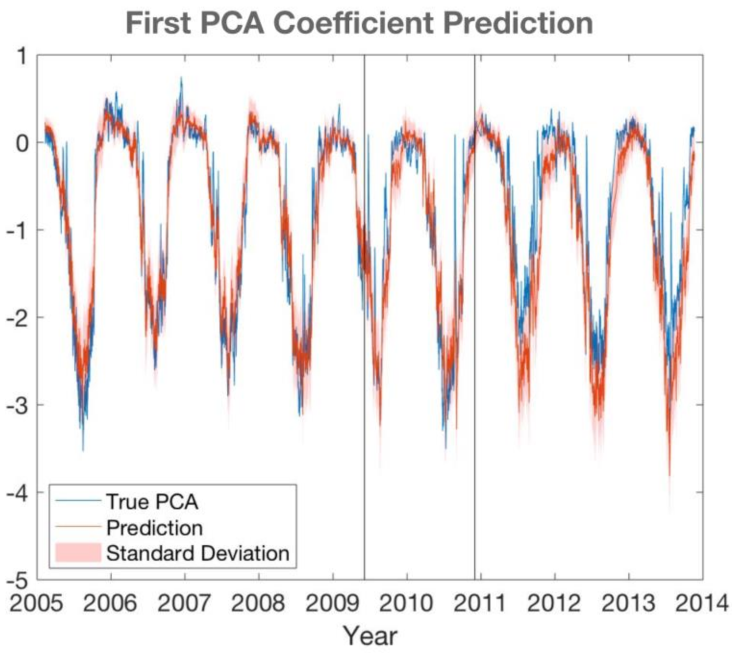


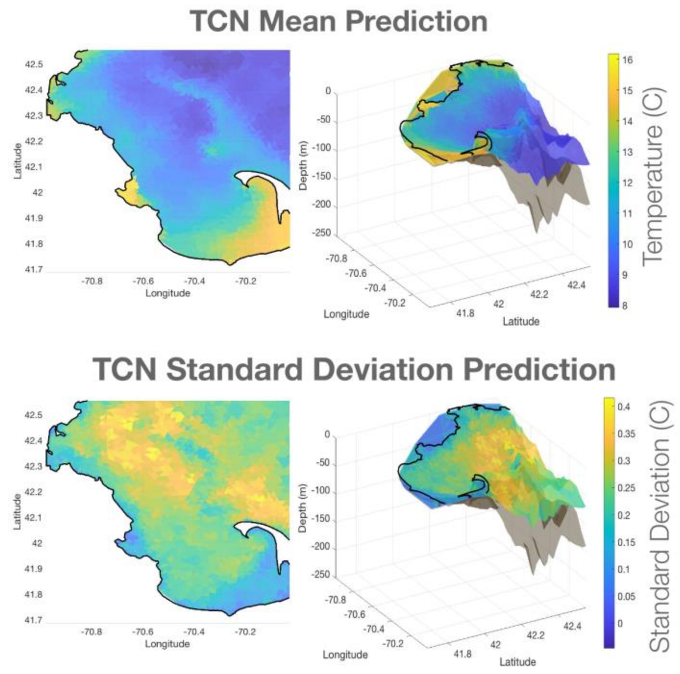
Prediction of vertical PCA coefficients using nonlocal TCN

Temporal Convolutional Network (TCN)



Wan et al. 2020





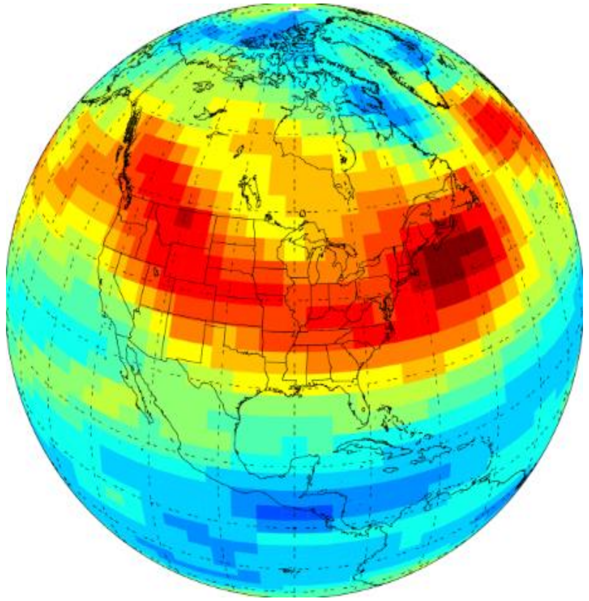
Real-time estimation of 3D temperature and its uncertainty

Champenois and Sapsis, 2022, ArXiv

Creating extreme event catalogues from coarse GCM

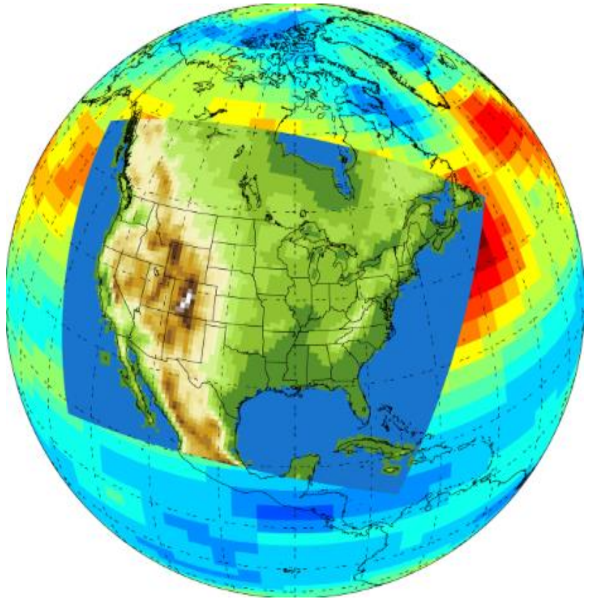
- → Weather – climate disasters cost: $152B (NOAA)
- → Critical for policy makers and insurance industry
- → Quantifying probability of extremes is expensive
- → Global circulation models in 100km resolution (not very accurate) cost $2m for 100k yrs catalogues
- → Industry needs resolutions closer to 2-3km
- → Cost increases faster than 1/res^3
- → AI to represent smaller scale dynamics

Coarse GCM



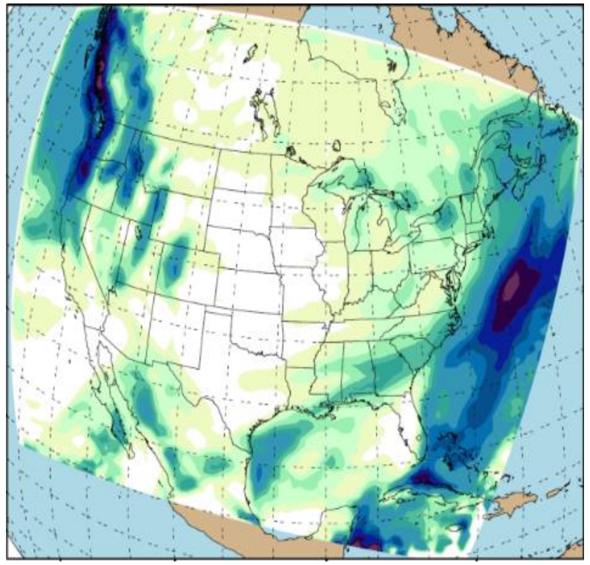
(available for thousands of years)

State-of-the-Art reanalysis



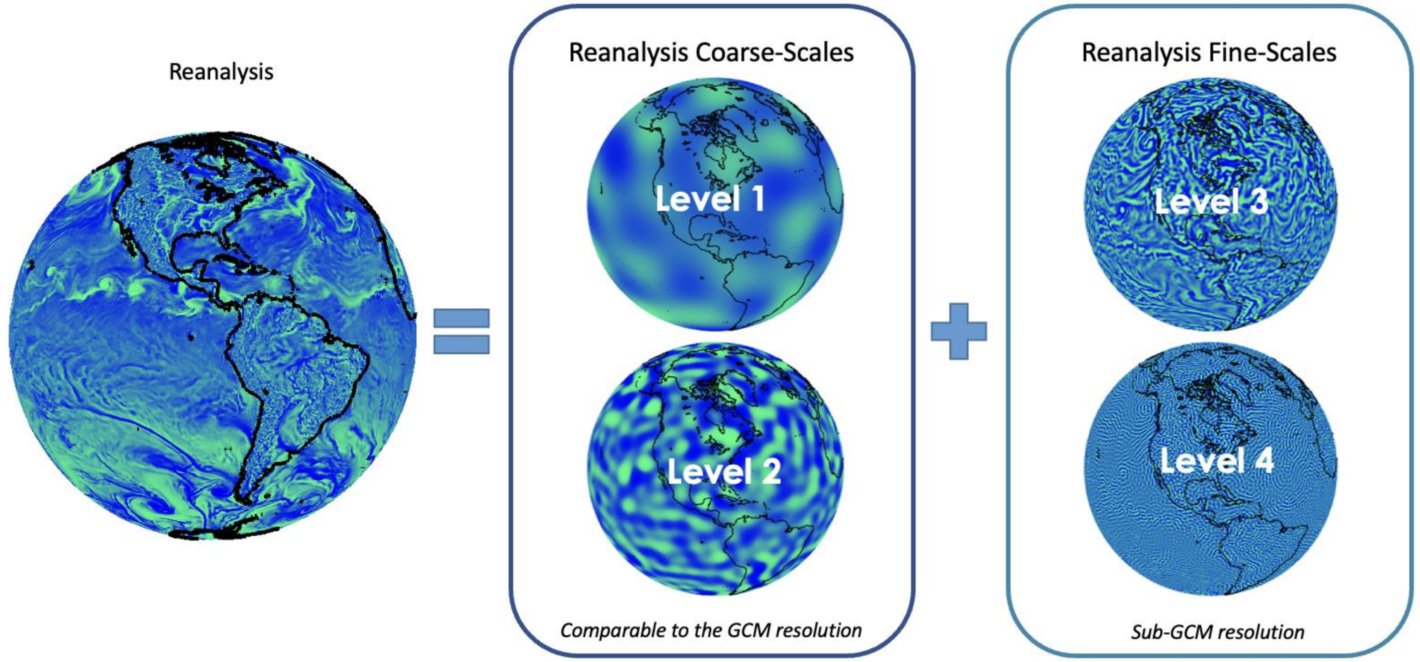
(available for 40-50 years)

Statistical Downscaling to High-Resolution Product

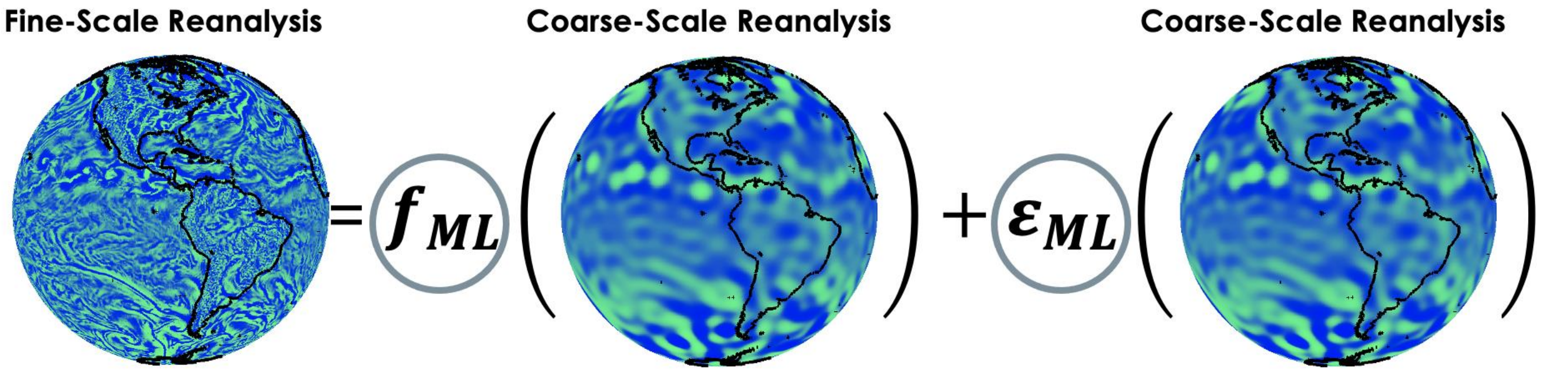


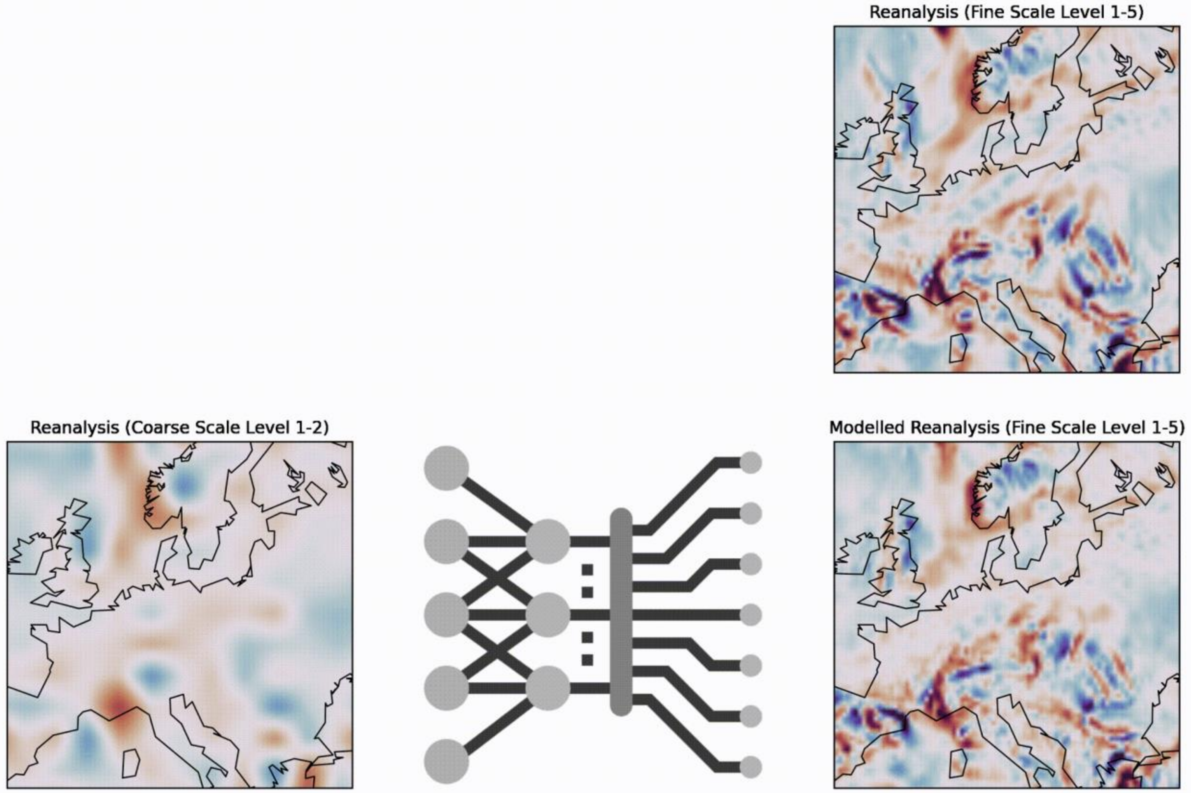
AI for increasing resolution in coarse scale climate models

Wavelet decomposition into multiple scales



Use ML to Parameterize Fine Scales as Functions of Coarse Scales





Thank you!