SYMPOSIUM OP'24
ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

MITHO
MULTIPLE THREATS ON OCEAN HEALTH

Generative Models For Spatial-Based Bottom Hypoxia Forecasting In The Black Sea

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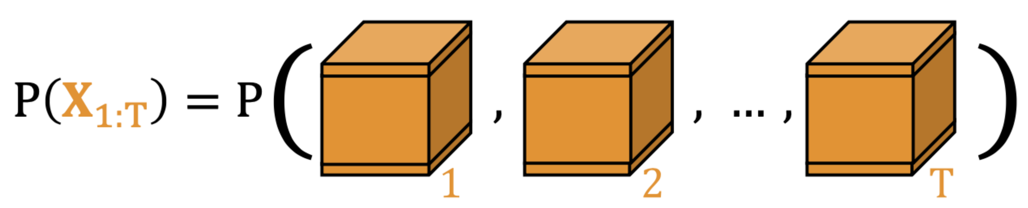
Can we **accurately forecast** ocean oxygen levels by assimilating **Earth observations** ?

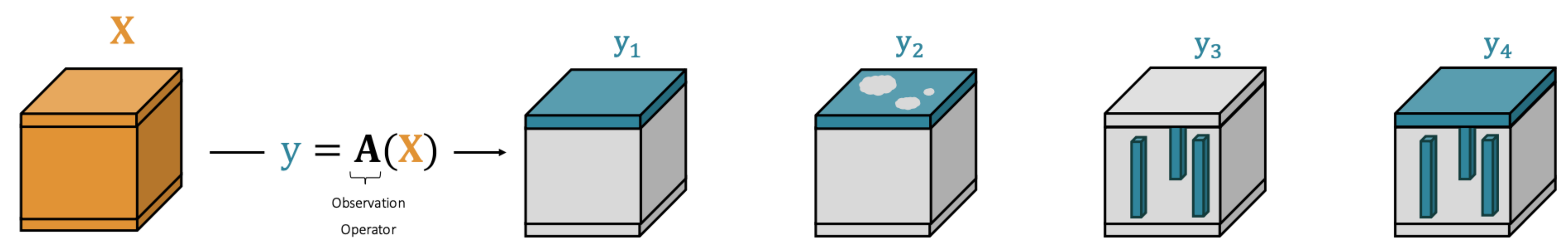
Problem Statement

The Black Sea can exist in different states $\mathbf{X}$, but some are more probable than others. When forecasting, we are interested in generating a trajectory of states $\mathbf{X}_{1:T}$:



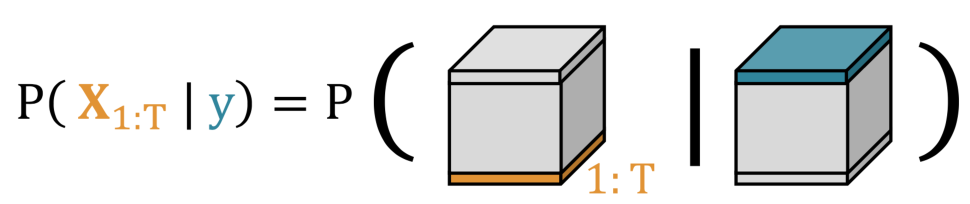
Mathematics. 1: The notation $P(\mathbf{X}_{1:T})$ represents the distribution of all possible trajectories, or state evolutions, of the Black Sea. The orange cube indicates the state of the Black Sea at a specific timestep t. Orange highlights what we want to know.

An observation of the Black Sea, denoted as y, provides partial information about $\mathbf{X}$:



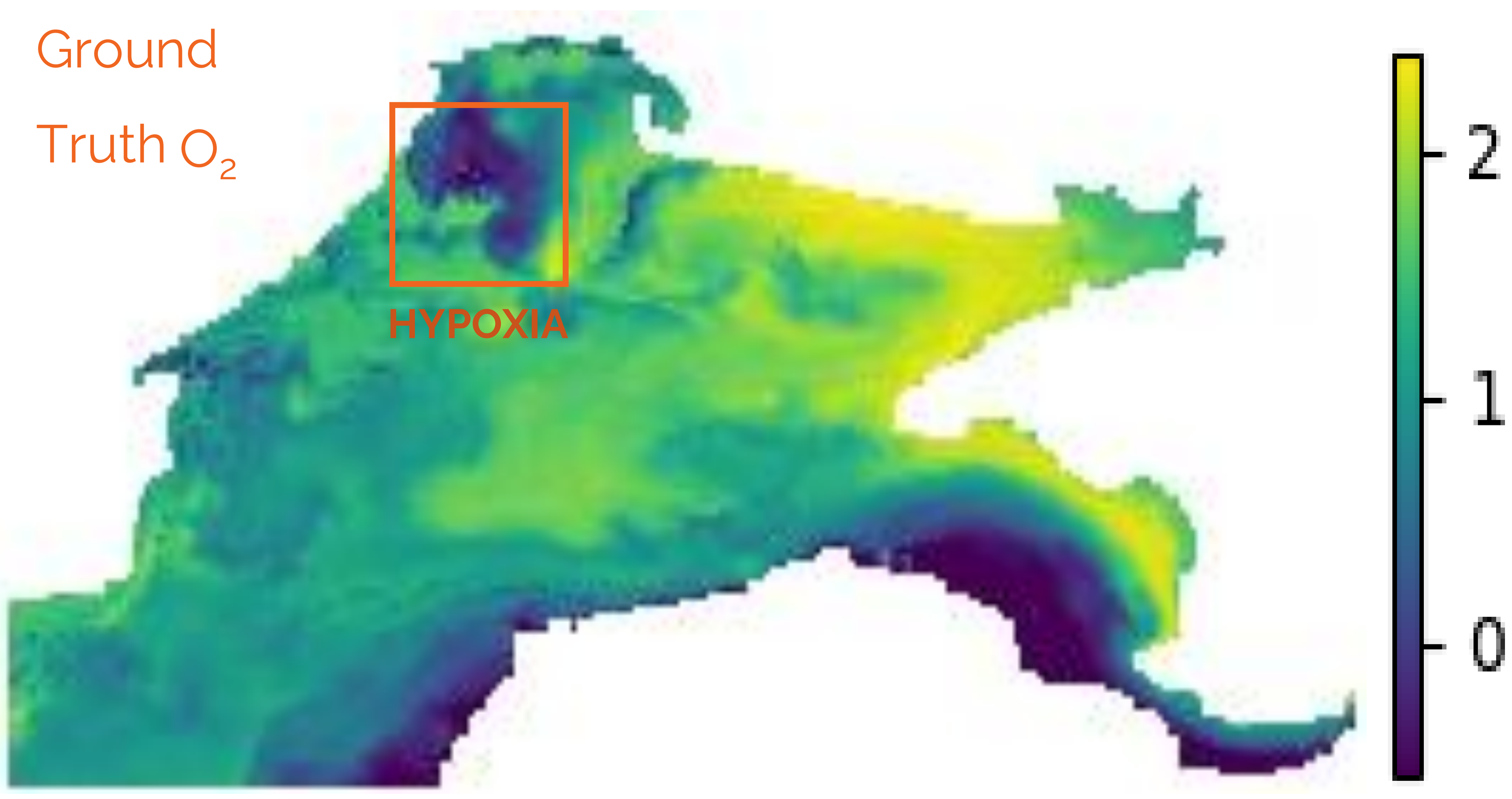
Mathematics 2: Observations y vary widely. Blue indicates that the state has been observed and is known at this position, while grey indicates areas where the state is currently unknown.

Given an observation y, can we estimate the posterior distribution $P(\mathbf{X}_{1:T} \mid y)$ of trajectories $\mathbf{X}_{1:T}$ for the Black Sea continental shelf bottom that align with observations y:



Mathematics 3: Accessing the posterior $P(\mathbf{X}_{1:T} \mid y)$ allows us to sample from this distribution, generating multiple forecasts for probabilistic trajectory forecasting.

Results



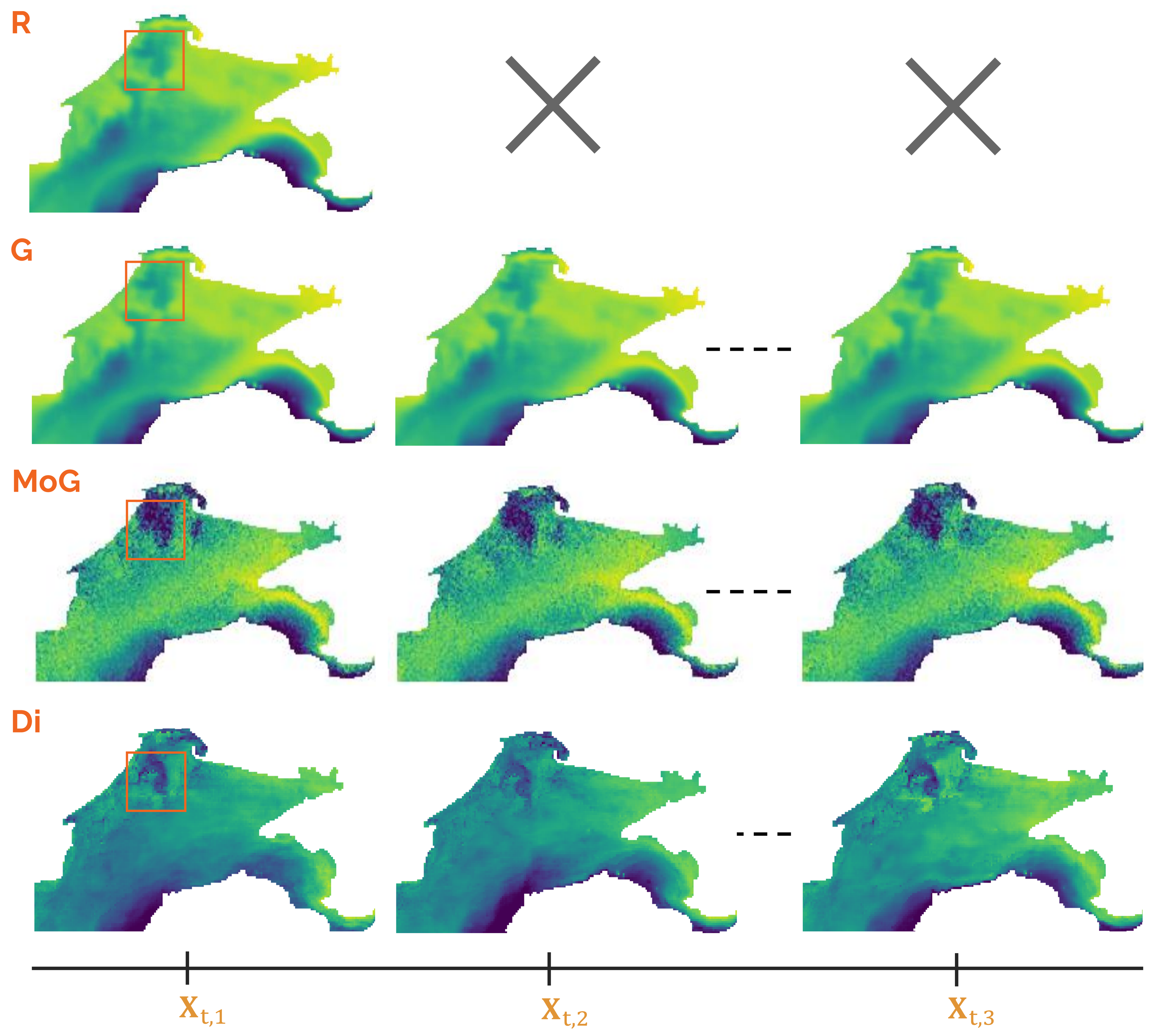
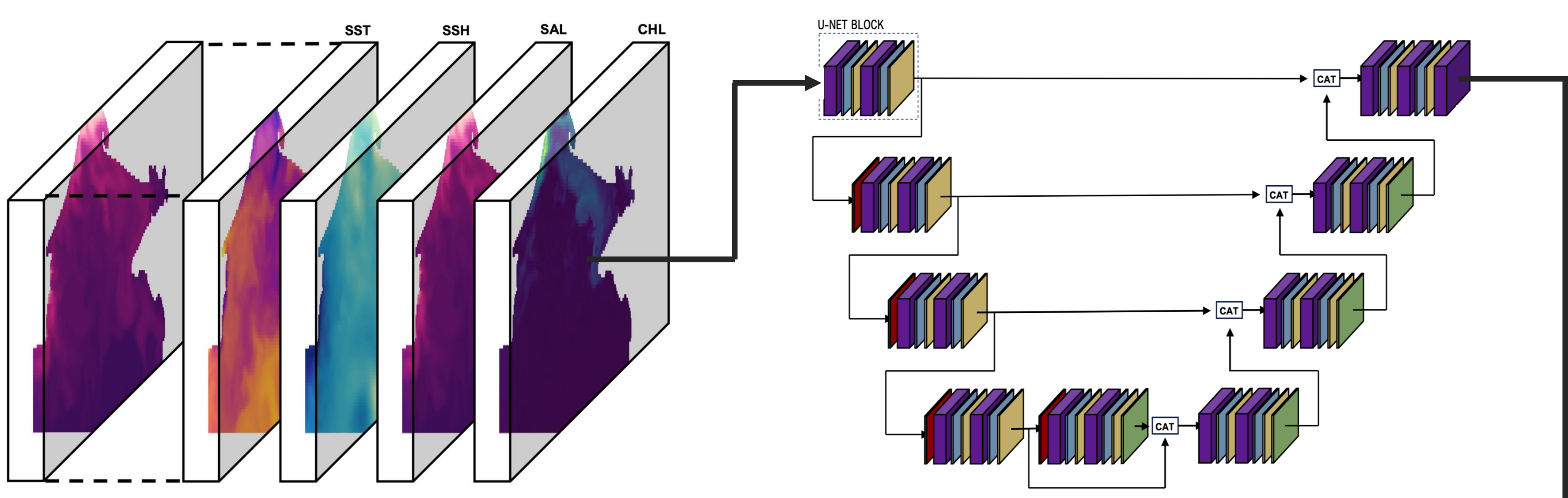


Figure. 2: At the top, we show the ground truth standardized oxygen profile at the bottom of the continental shelf $\mathbf{X}_t$ on August 1st, 2016. A rare event, hypoxia, which typically occurs in summer, is highlighted in the red square. The rows represent different levels of posterior approximation, while each column shows a different oxygen state prediction $\mathbf{X}_{t,1}$, $\mathbf{X}_{t,2}$, ... They are obtained by sampling the posterior (if possible).

Posterior

The posterior distribution can be approximated by a selected distribution with parameters estimated by a Neural Network (with parameters θ), which is trained on Earth surface observations y from the present and/or past:



$\mathcal{N}(\mathbf{X}_{1:T}\,;\mu_\theta(y,t),\sigma^2)$ — **Regression** (R)

$\mathcal{N}\left(\mathbf{X}_{1:T}\,;\mu_\theta(y,t),\sigma^2_\theta(y,t)\right)$ — **Gaussian** (G)

$\sum_{i=1}^{K} \pi_{\theta,i}(y,t)\,\mathcal{N}\left(\mathbf{X}_{1:T}\,;\mu_{\theta,i}(y,t),\sigma^2_{\theta,i}(y,t)\right)$ — **Mixture of Gaussians** (MoG)

$P(\mathbf{X}_{1:T} \mid y\,;\theta)$, — **Diffusion** (Di)

Figure. 1: We observe temperature, salinity, chlorophyll, and sea surface height fields from the Black Sea surface. These observations can be from the current time t, the forecast moment, or a combination of past data. The observations y are then fed into a U-Net Neural Network, where each block is modulated by the forecast start date. Next, the network predicts the parameters of the distribution used to approximate our posterior distribution $P(\mathbf{X}_{1:T} \mid y)$. Finally, depending on the desired approximation level, we may sample trajectories from the posterior.

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