MEOM/IGE Group

Implicit Neural Representations for Sea Surface Height Interpolation (a.k.a. Modern Optimal Interpolation)

MeLODy Project*

J. Emmanuel Johnson

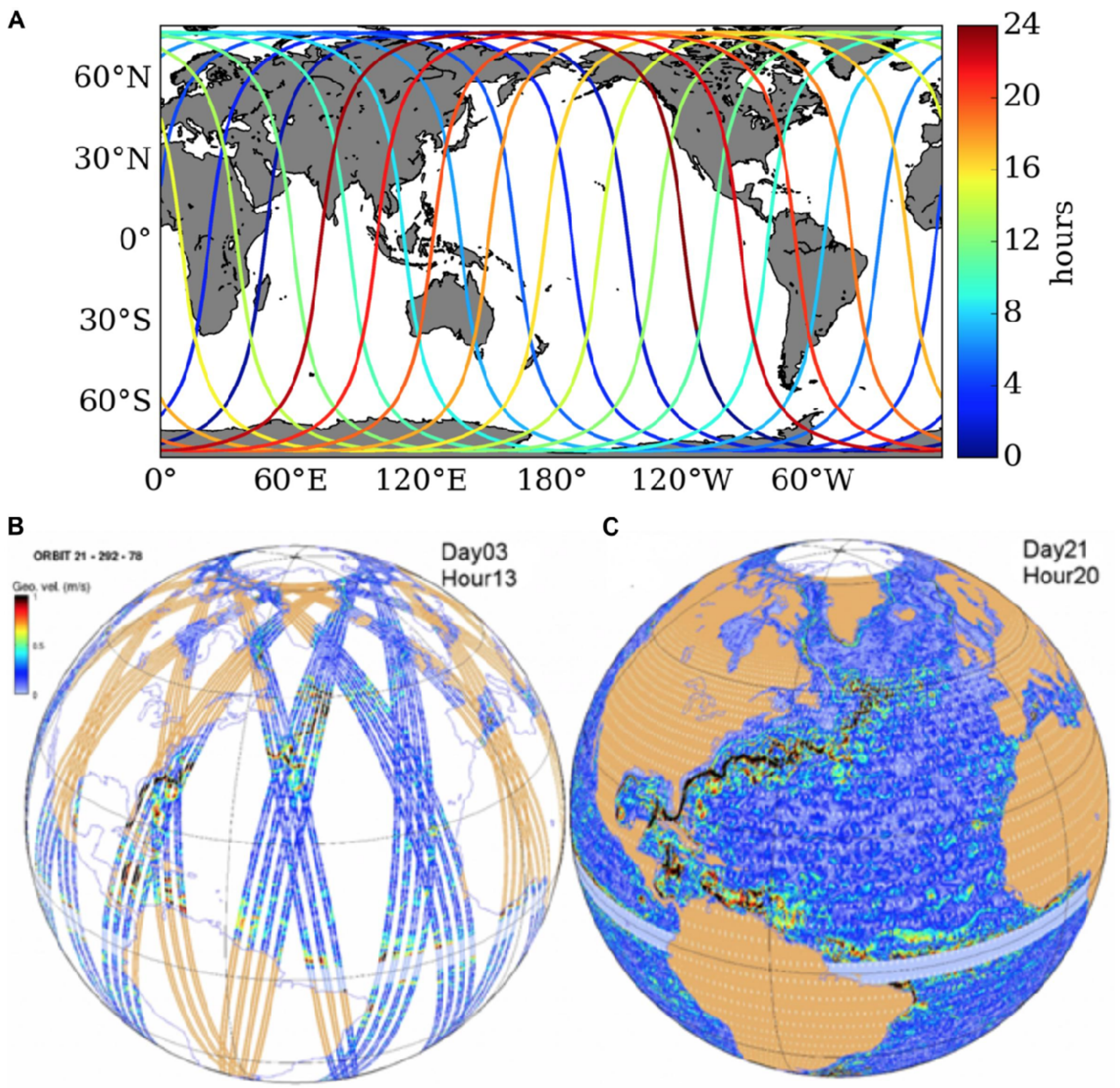
Collaborators:
Redouane Lgeusat, Julien LeSommer, Ronan Fablet, Quentin Febvre, Emmanuel Cosme, Jean-Michel Brankart, Pierre Brasseur*

IGE

cnrs

Motivation

SWOT Mission (2022+)

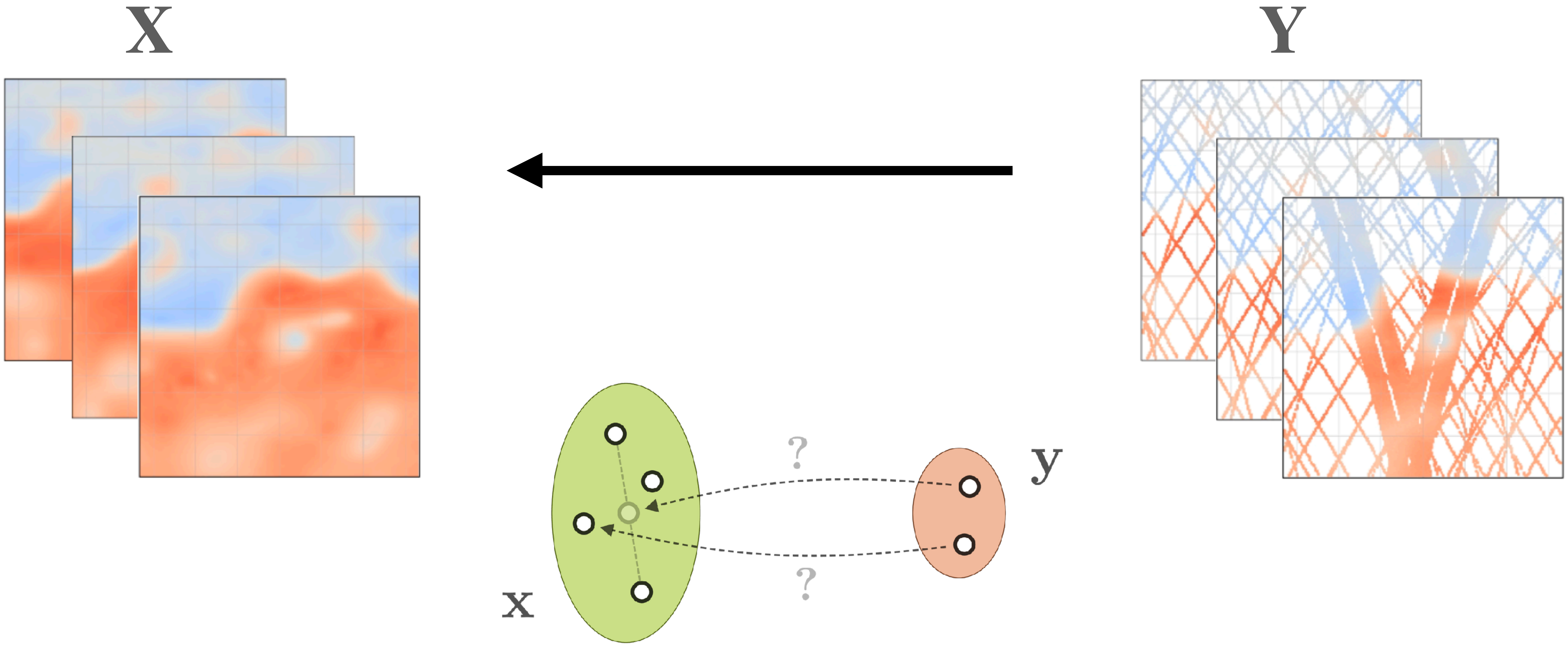


- Sea Surface Height (SSH)
- **Gateway to the Ocean State**
- Physical Processes
- Bio-Geochemical Processes

A new influx of data with a multitude of applications!

https://www.frontiersin.org/files/Articles/433647/fmars-06-00232-HTML/image_m/fmars-06-00232-g005.jpg

Problem Statement



Can we interpolate the missing observations?

Table of Contents

In Practice

Coordinate

$$\mathbf{X} \in \mathbb{R}^{N \times D_\phi}$$

$D_\phi = [\text{Latitude, Longitude}, \ldots]$

$N =$ [★ ★ ★ ★ ★ ★ ★]

- Scalability
- Easy to Compute
- Expressive
- Take Advantage of Sparsity

In some operational settings, coordinate-based inputs are used in practice!

A technique for objective analysis and design of oceanographic experiments applied to MODE-73 - Bretherton et. al. - 1975

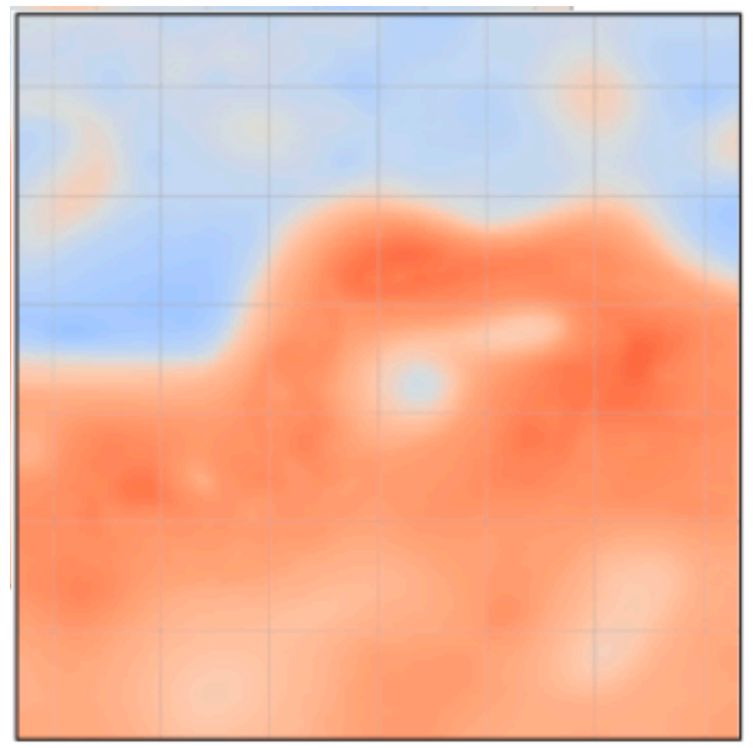
A numerically efficient data analysis method with error map generation - Rixen et al - 2000

Coordinates

Training

$$\mathbf{y}_{obs} = f_{\boldsymbol{\theta}}\left(\mathbf{X}_{\phi}\right) + \epsilon$$

Evaluation

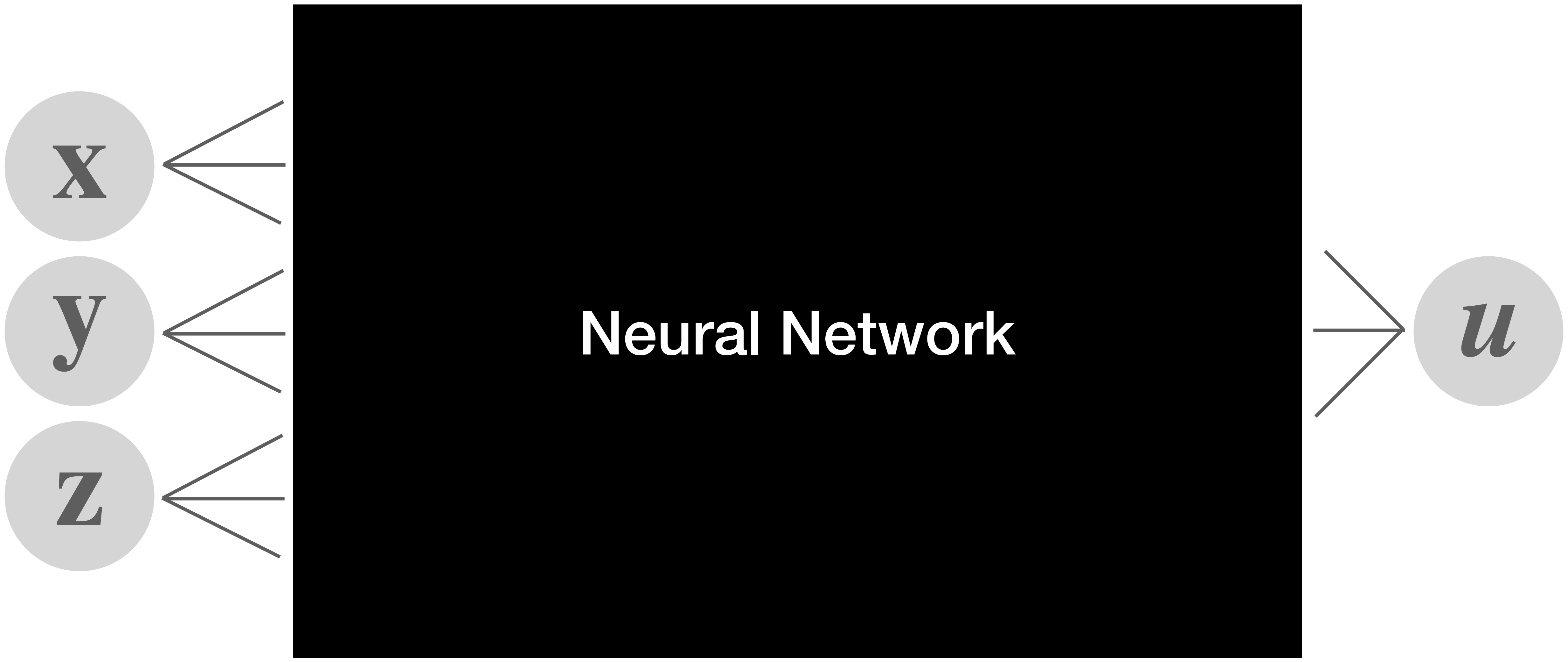


$$\mathbf{y}^{*} = f_{\boldsymbol{\theta}}\left(\mathbf{X}_{\phi}^{*}\right) + \epsilon$$

$$p(\boldsymbol{\theta} \,|\, \mathbf{X}_{\phi}, \mathbf{y}_{obs}) \propto p(\mathbf{y}_{obs} \,|\, \mathbf{X}_{\phi}, \boldsymbol{\theta}) \; p(\boldsymbol{\theta})$$

What are the best parameters of our model which best fits the observations?

Implicit Neural Representations



Optimal Interpolation with a different Model…

Problem

Neural Networks have problems with high frequency signals…!

Example: Interpolating an Image

https://wandb.ai/wandb/nerf-jax/reports/Implementing-NeRF-in-JAX--VmlldzoxODA2NDk2?galleryTag=jax

Problem

Neural Networks have problems with high frequency signals…!

Solutions

Basis Function Transformations

Sinusoidal Activation Functions

Fourier Features Mapping

Basis Transformation

Basis Function

$$\phi(\mathbf{x}) = \begin{bmatrix} \sin\left(2\pi\boldsymbol{\Omega}\mathbf{x}\right) \\ \cos\left(2\pi\boldsymbol{\Omega}\mathbf{x}\right) \end{bmatrix} \qquad \boldsymbol{\Omega} \sim \mathcal{N}(\mathbf{0}, \gamma^2 \boldsymbol{I})$$

Fourier Features Let Networks Learn High Frequency Functions in Low Dimensional Domains - Tancik et. al. - NeurIPS 2020

$$\phi(\mathbf{x}) = \begin{bmatrix} \sin(2\pi\Omega\mathbf{x}) \\ \cos(2\pi\Omega\mathbf{x}) \end{bmatrix}$$

Fourier Features Mapping

Basis Transformation

$$f_\theta(\phi(\mathbf{x})) := \mathrm{NN}_\theta \circ \phi(\mathbf{x})$$

Standard NN

RFF Transformation

Transform using Fourier Features, then use any Neural Network…

Fourier Features Let Networks Learn High Frequency Functions in Low Dimensional Domains - Tancik et. al. - NeurIPS 2020

Example: Interpolating an Image

Revisited

Fourier Features Let Networks Learn High Frequency Functions in Low Dimensional Domains - Tancik et. al. - NeurIPS 2020

Problem

Neural Networks have problems with high frequency signals…!

Solutions

Basis Function Transformations

Sinusoidal Activation Functions

Sinusoidal Layer

Frequency Parameter

$$\phi(\mathbf{x}) = \sin\left(\omega_0(\mathbf{w}\,\mathbf{x} + \mathbf{b})\right)$$

Sine function

Linear Layer

Implicit Neural Representations with Periodic Activation Functions - Sitzmann et. al. - NeurIPS 2020

$$\phi_\ell(\mathbf{x}) = \sin\left(\omega_0(\mathbf{w}\,\mathbf{x} + \mathbf{b})\right)$$

SIREN Model

Sine Layer

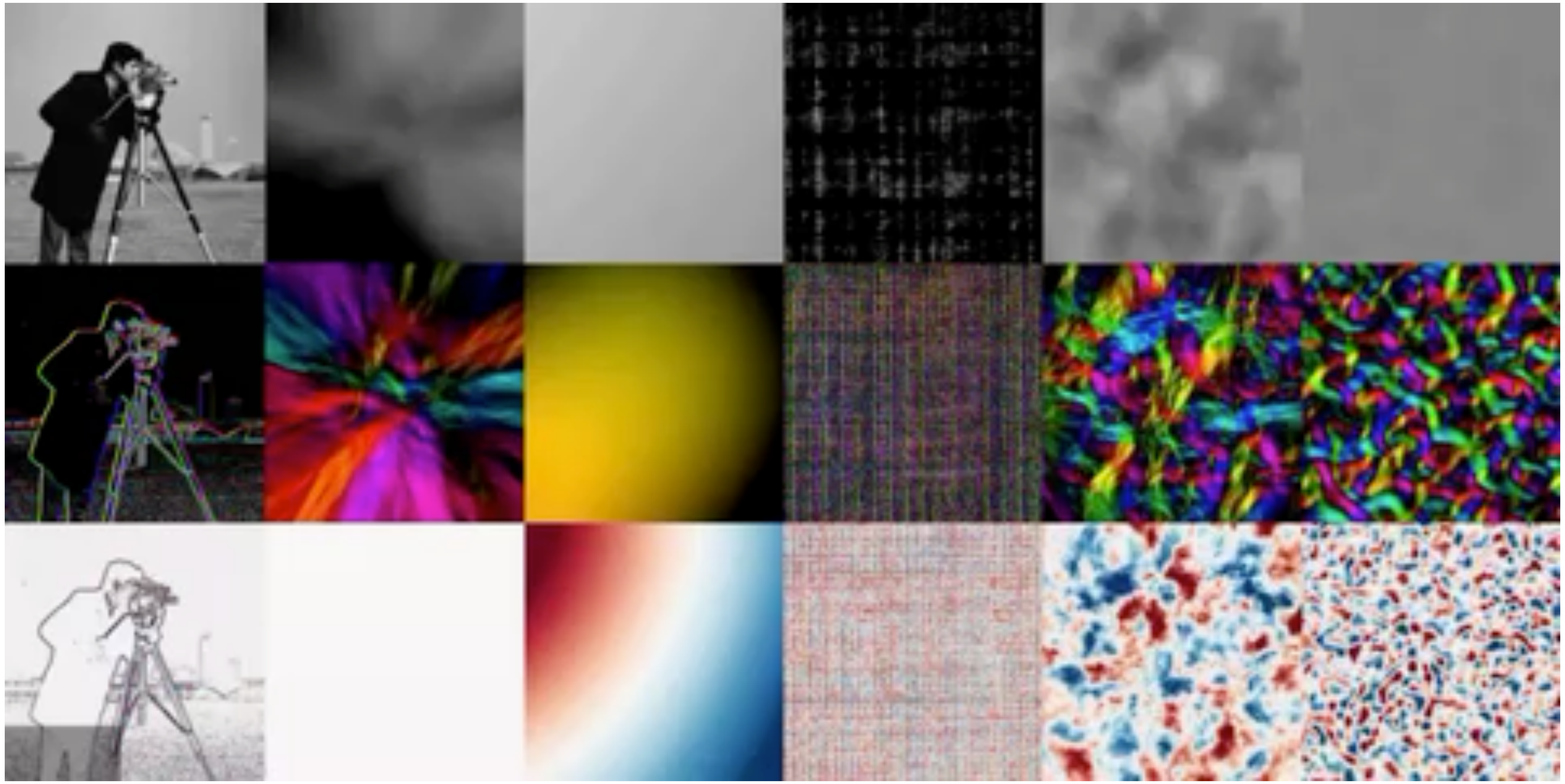
$$f(\mathbf{x}) = \mathbf{w}\left(\phi_L \circ \phi_{L-1} \circ \ldots \circ \phi_1\right)(\mathbf{x}) + \mathbf{b}$$

Linear Layer

Fourier-Inspired (Deep) Basis Function

Implicit Neural Representations with Periodic Activation Functions - Sitzmann et. al. - NeurIPS 2020

Result - Better Gradient Representation

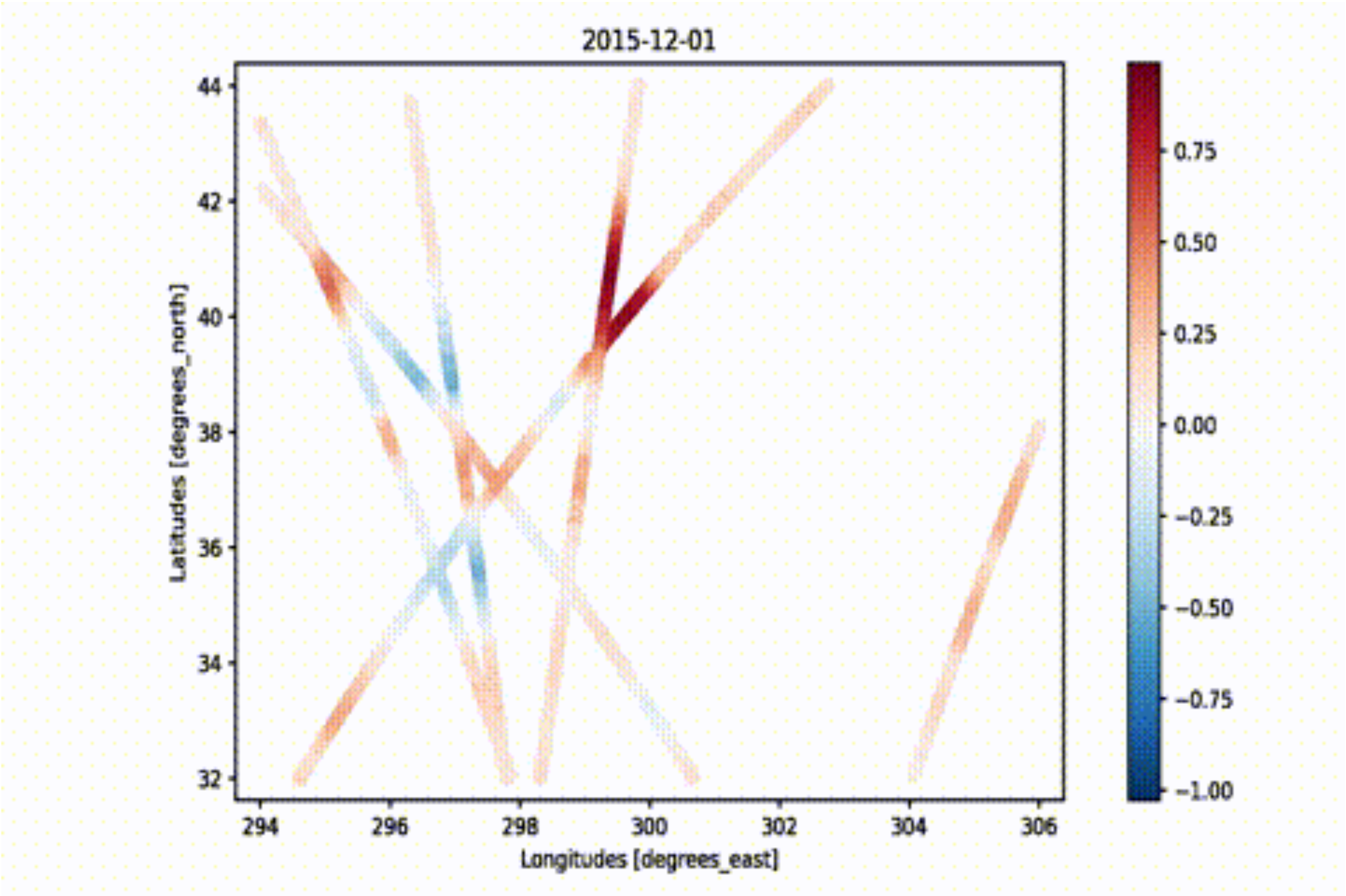


Implicit Neural Representations with Periodic Activation Functions - Sitzmann et. al. - NeurIPS 2020

Preliminary Results

How does this work on oceanographic-like datasets?

Data Challenge 2021a



- Gulf Stream
- 7 Altimetry Sources
    - 1 Left out for validation

DOI 10.5281/zenodo.5511905

SSH Mapping Data Challenge 2021a

This repository contains codes and sample notebooks for downloading and processing the SSH mapping data challenge.

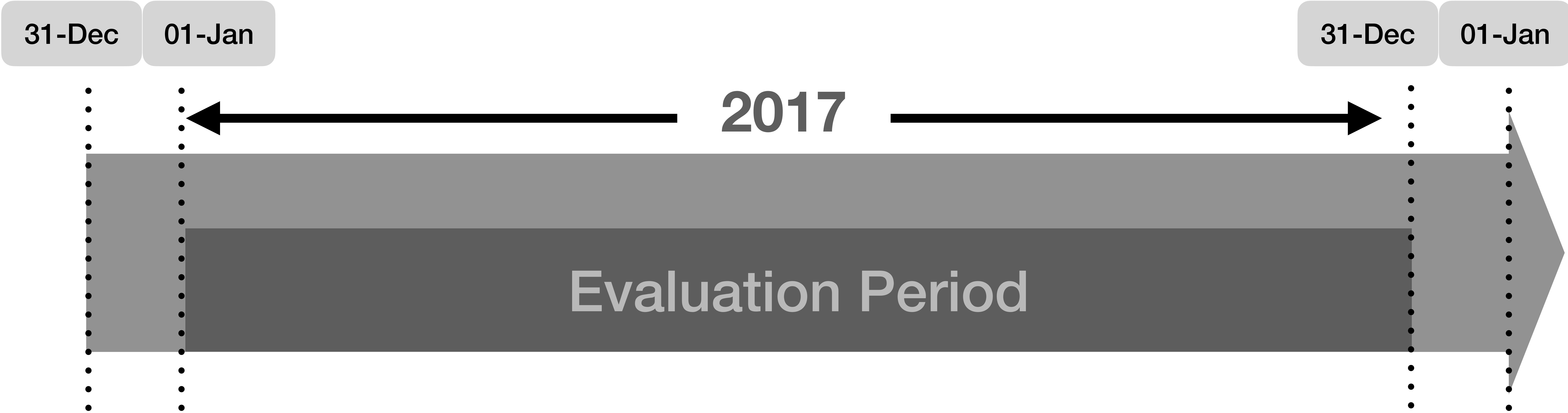
The quickstart can be run online by clicking here:

Motivation

The goal is to investigate how to best reconstruct sequences of Sea Surface Height (SSH) maps from partial satellite altimetry observations. This data challenge follows an *Observation System Experiment* framework: Satellite observations are from real sea surface height data from altimeter. The practical goal of the challenge is to investigate the best mapping method according to scores described below and in Jupyter notebooks.

https://github.com/ocean-data-challenges/2021a_SSH_mapping_OSE

Evaluation Period

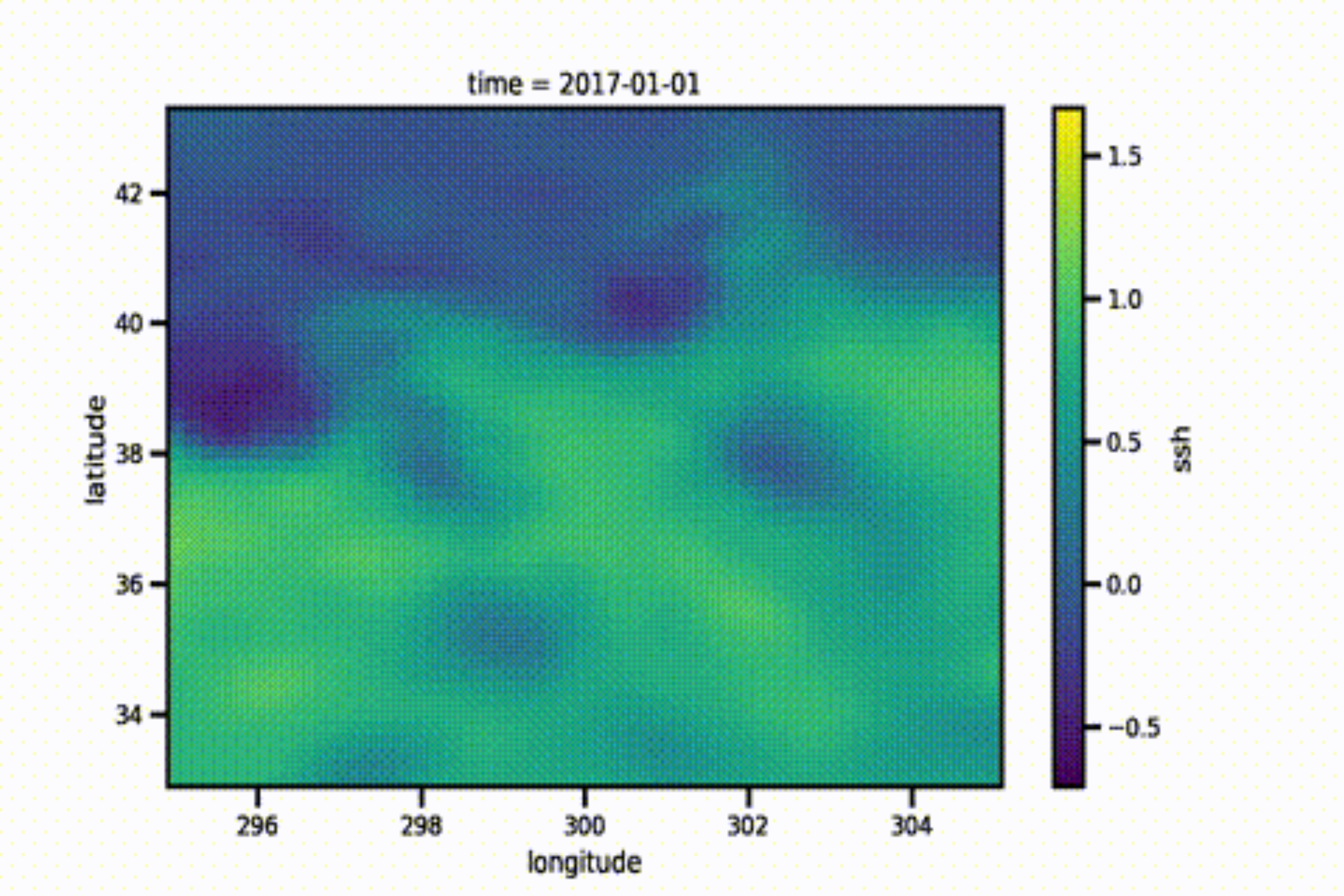


1.6 Million Data Points

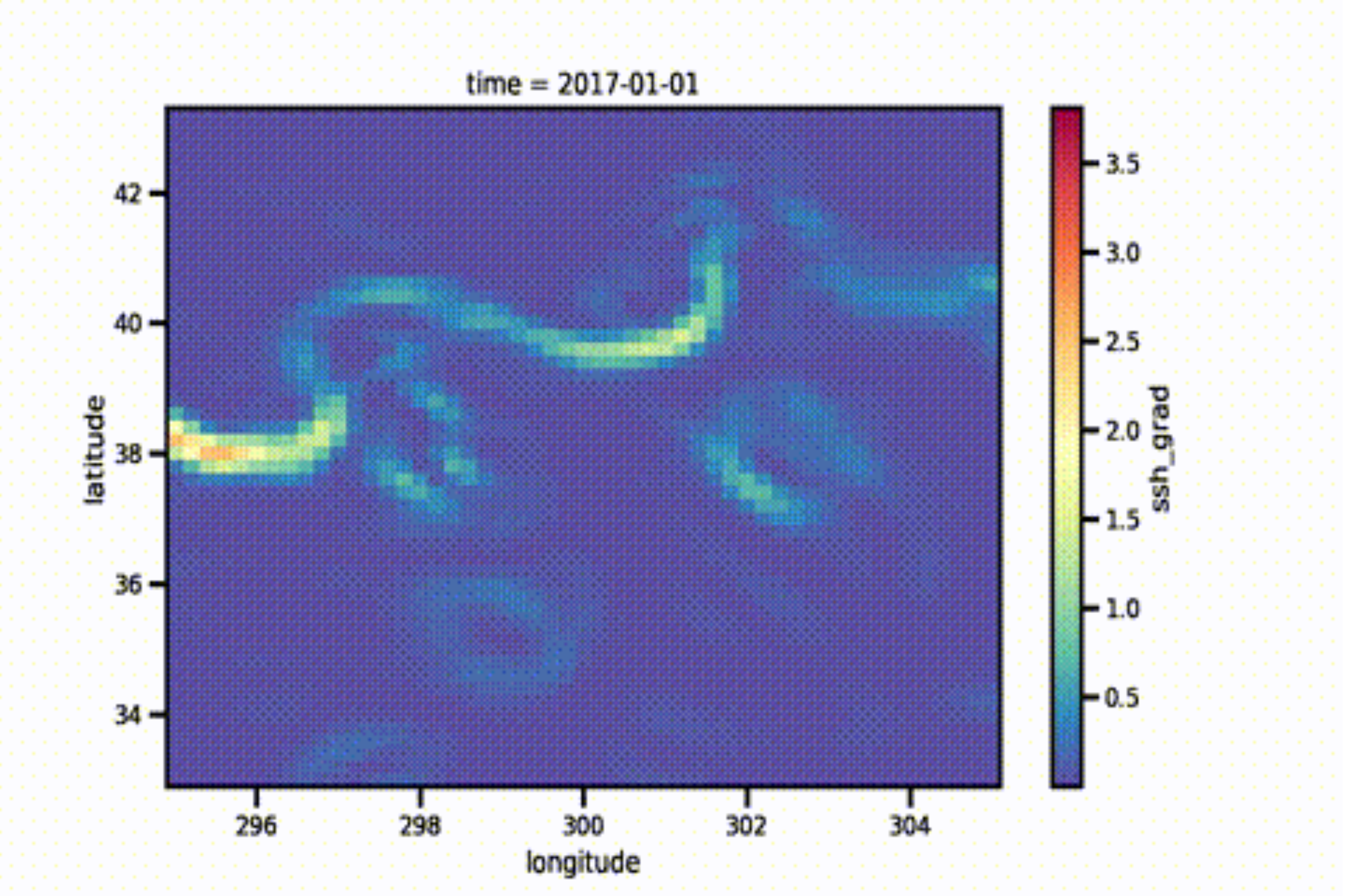
https://github.com/ocean-data-challenges/2021a_SSH_mapping_OSE

Results

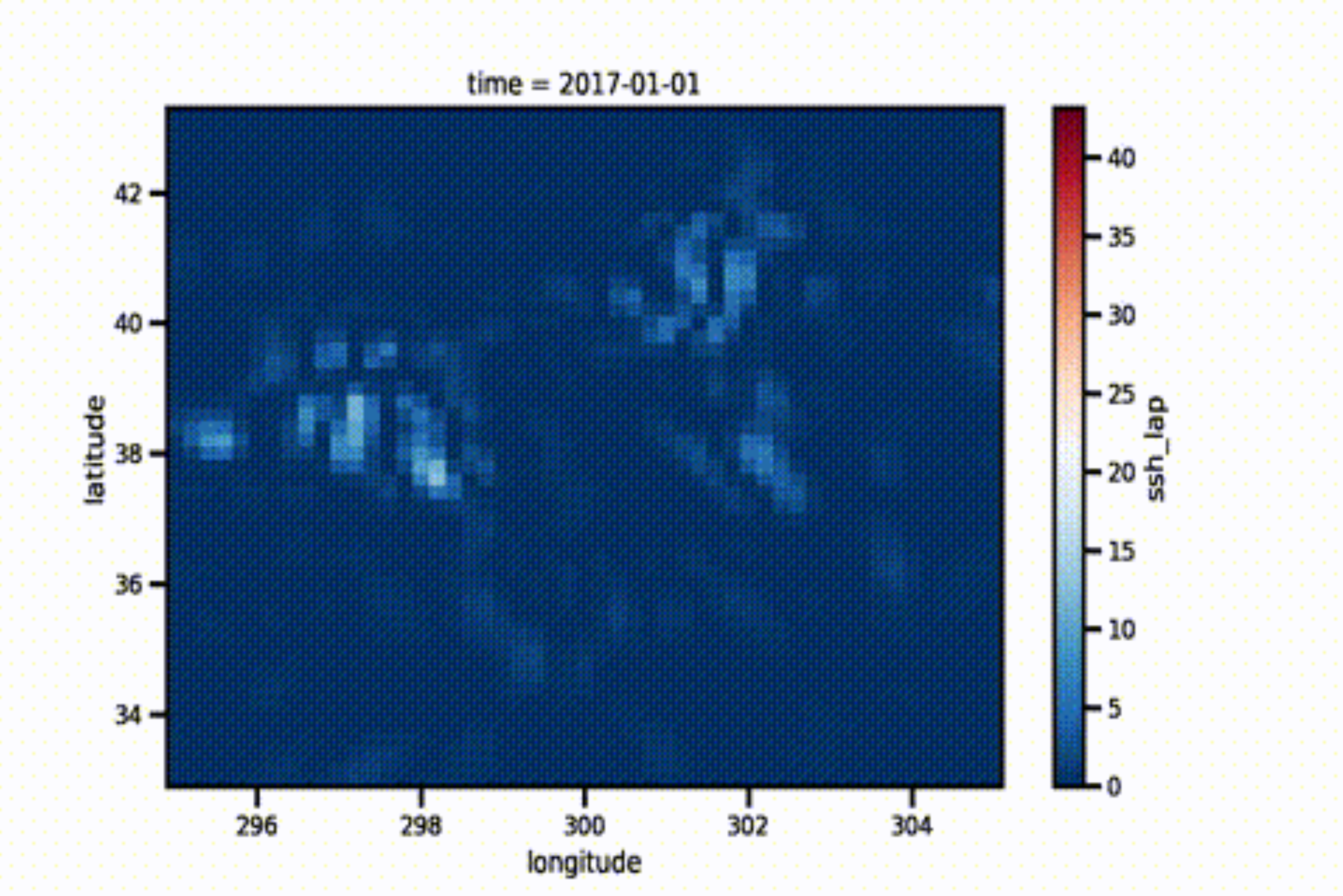
Visual Maps



Predictions



Gradient (Norm)



Laplacian (Norm)

No crazy looking structures…

Poor Laplacian…

Results

Metrics

Algorithm	Normalised RMSE (Mean)	Normalised RMSE (Standard Dev)	Resolved Spatial Resolution (km)
Optimal Interpolation	0.85	0.09	140
Optimal Interpolation (Production - DUACS)	0.88	0.07	152
SIREN (Ours)	**0.88**	**0.08**	**146**

All metrics are comparable.

Results

Inference Times - (~1 million data points)

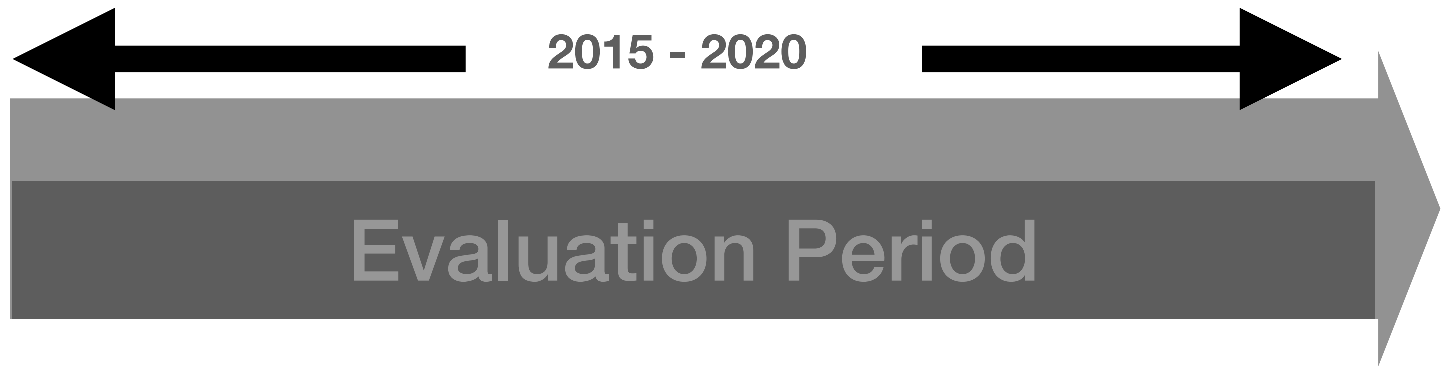
Algorithm	CPU (10 cores)	GPU	Multi-GPU
Optimal Interpolation	1 hour	— —	— —
Optimal Interpolation (Production - DUACS)	— —	— —	— —
SIREN (Ours)	**30 secs**	**5 secs**	— —

Predictions are fast…really fast.

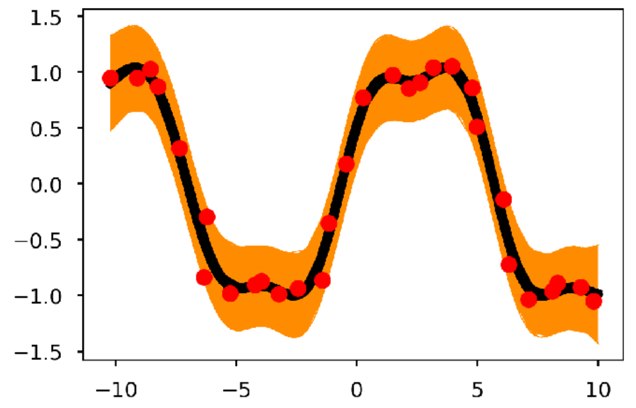
The Next Steps

Wish List

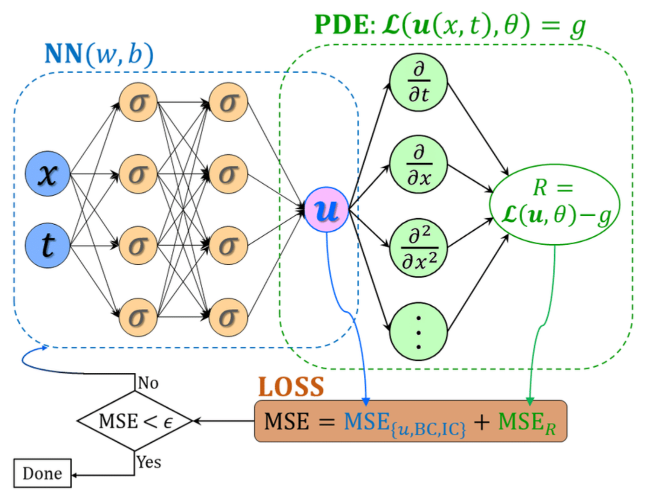
My Potential Contributions



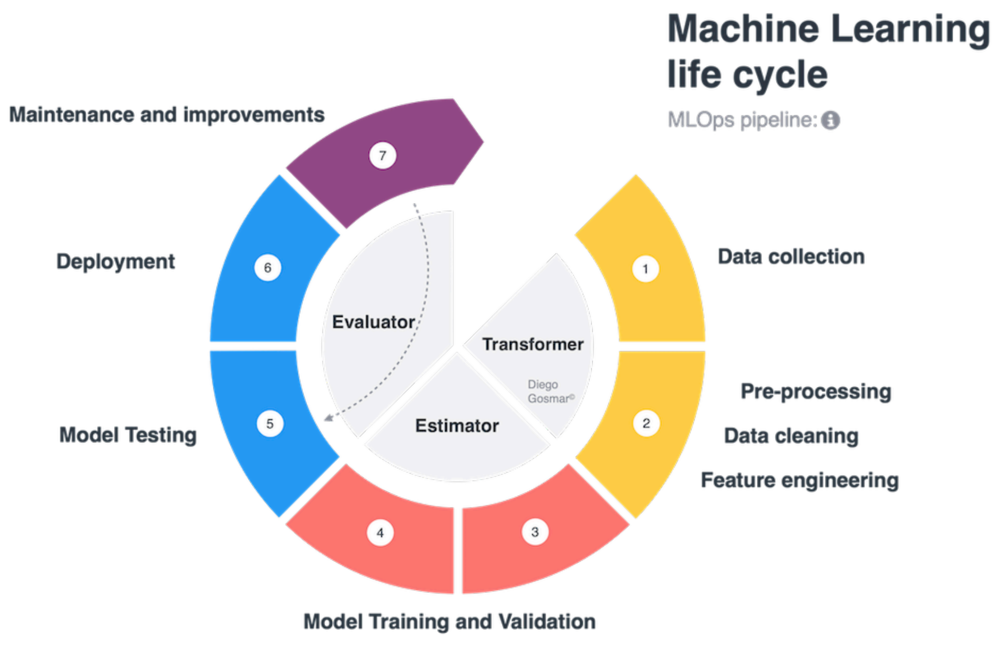
- Data (Easy)



- Pragmatic Bayesian (Medium)



- Physics Informed Loss Function (Hard)



- MLops + Reproducibility (**Easy**)

Thank You

Any Questions?

github.com/jejjohnson

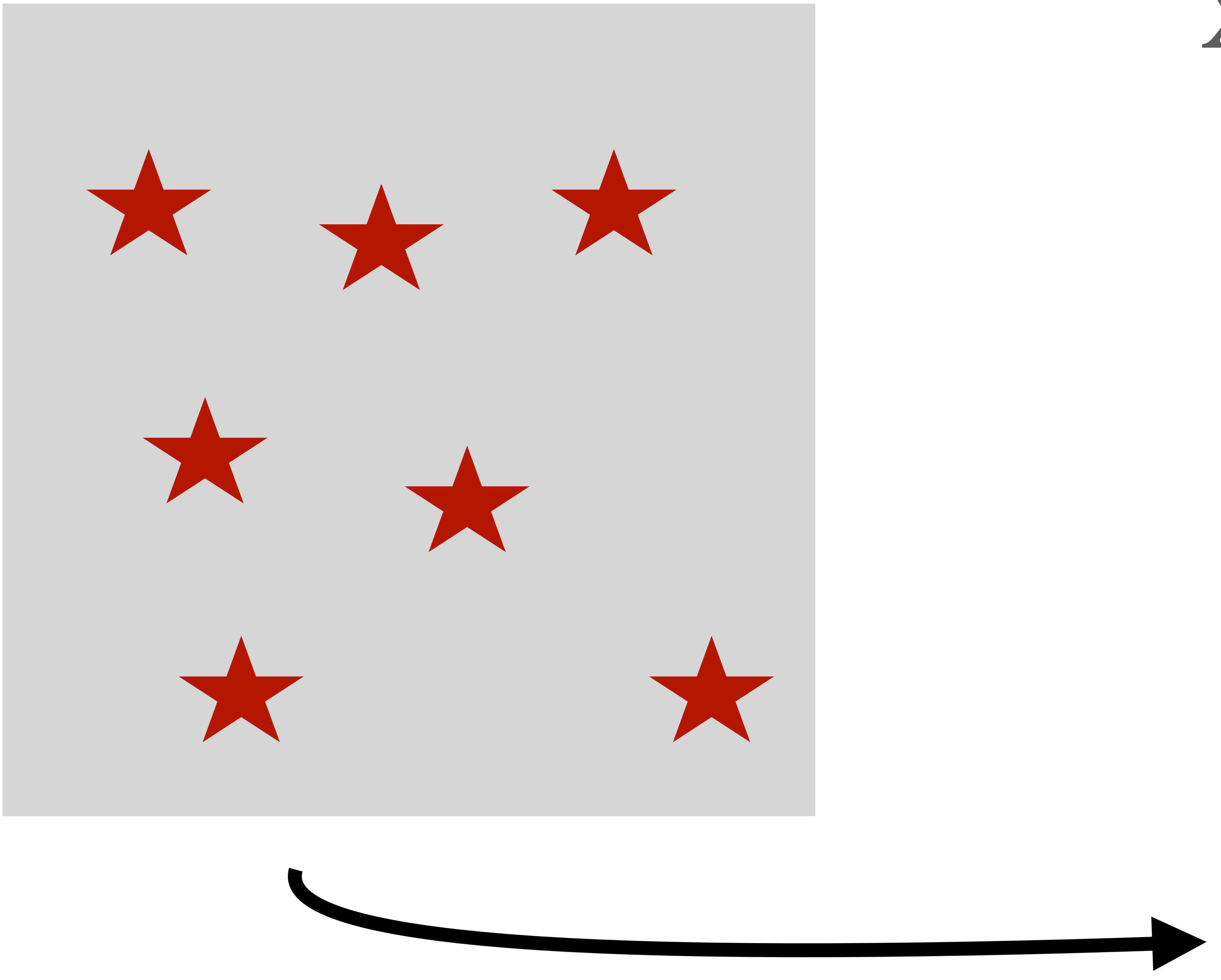
johnsonj@univ-grenoble-alpes.fr

@jejjohnson

Coordinate Representation

$$\mathbf{x} \in \mathbb{R}^{D_\phi}$$

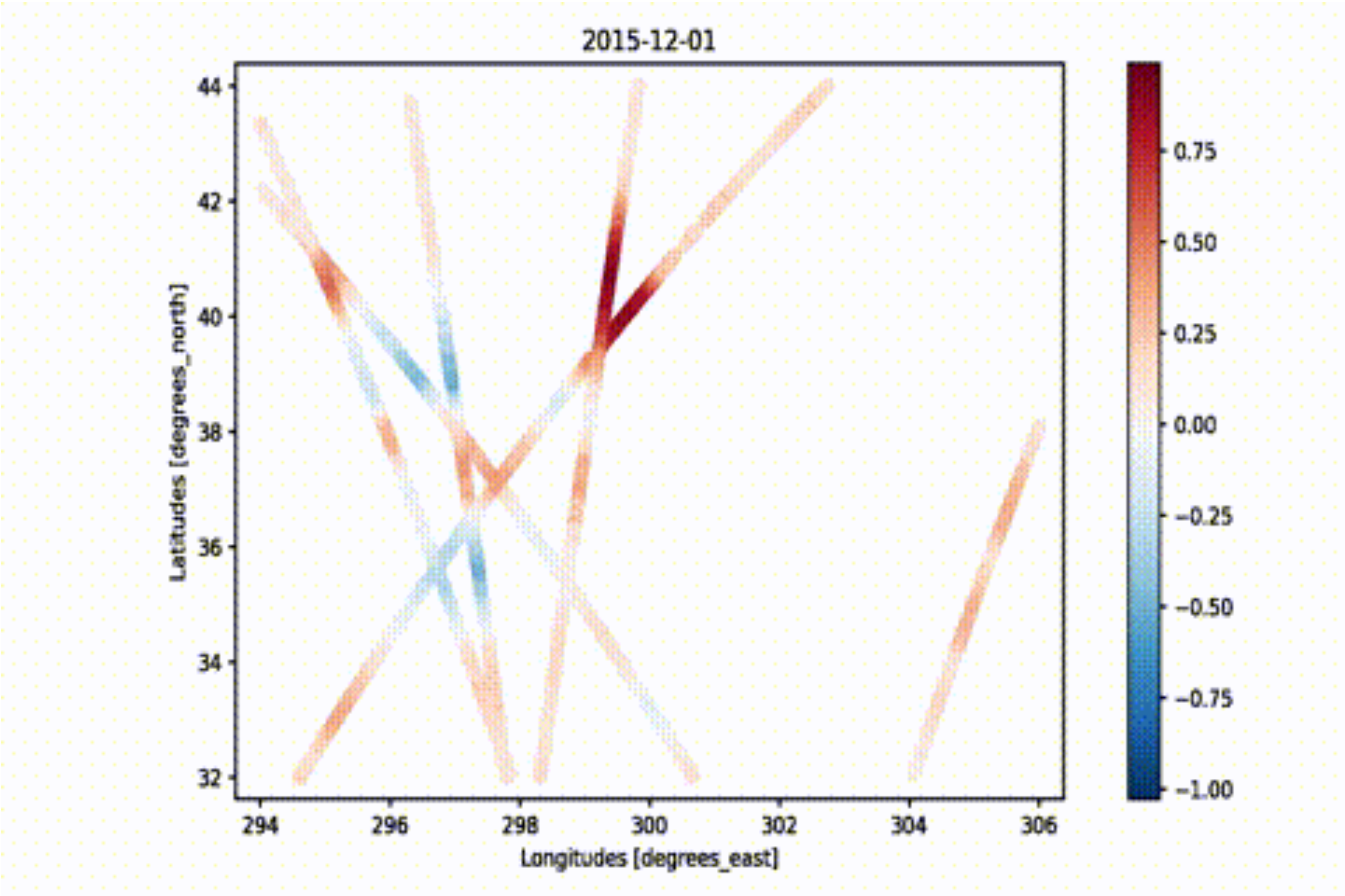
Coordinate



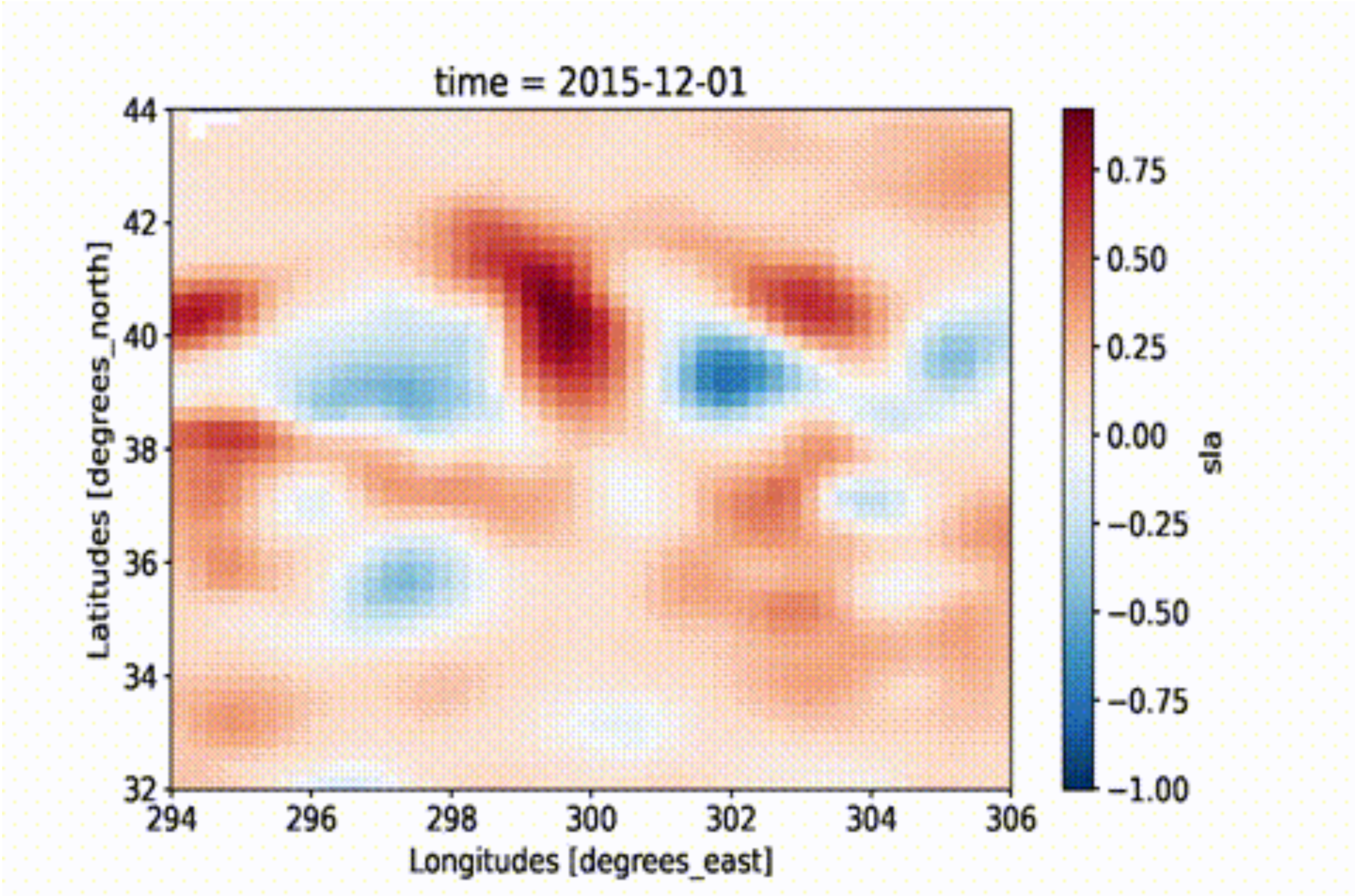
$$D_\phi = [\text{Latitude, Longitude}, \ldots]$$

$$N = [\star \; \star \; \star \; \star \; \star \; \star \; \star]$$

Baseline



Observations



Optimal Interpolation (Production)