Applications of Deep Leaning to Internal Tide Extraction from Satellite Imaging

Kerryn van Rooyen[1], Han Wang[2], Nicolas Grisouard[1]
[1]University of Toronto, [2]University of Edinburgh

Internal Tides

- Internal Gravity Waves at the tidal frequency
- Occur between fluid layers of different densities due to temperature and salinity gradients
- Essential to global circulation of water, heat, and nutrients

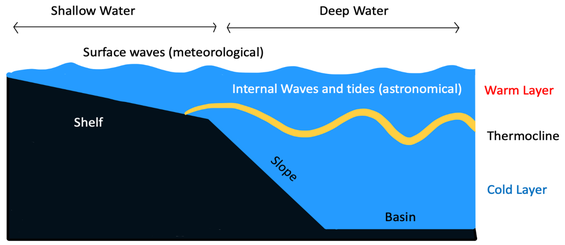


Figure 1: Schematic showing internal waves and tides near an ocean shelf [1] (Redrawn for print clarity)

Data Collection

- Satellite observations of sea surface height (SSH) can allow us to detect IT signals
- Currently collect data in linear swaths
- Extensive time series necessary for analysis

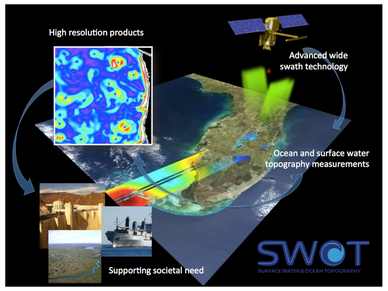


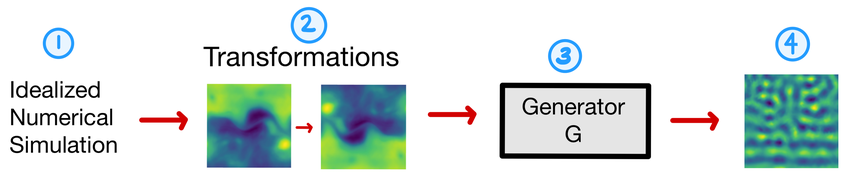
Figure 2: Surface Water and Ocean Topography (SWOT) advanced wide swath technology [2]

The new SWOT mission launching in November 2022
- has increased spatial resolution
- collects data in a dual swath, producing 2D SSH data
- **Turns IT detection into an image to image translation problem.**

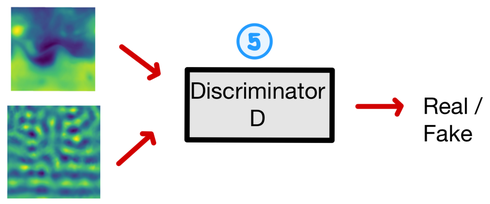
To support model development, we train on snapshots from idealized numerical simulations, where traditional filtering is unsuitable. [3]

Model and Data Processing

Conditional Generative Adversarial Networks (cGANs) have 2 components:
- Generator: creates a new image from the input
- Discriminator: classifies as real (from the dataset) or fake (generated)



1. Simulation produces a 2D SSH field
2. Data is augmented to improve model performance on unseen data (random cropping, flipping, and rotation)
3. Transformed data is passed through G (an encoder decoder network) which makes use of techniques such as dropout and skip connections
4. Generated image predicts the cosine component of the internal tide.
5. Both the reference image and the generated image are fed into the D (fully connected) to be classified as real (in the data set) or fake (generated by G)



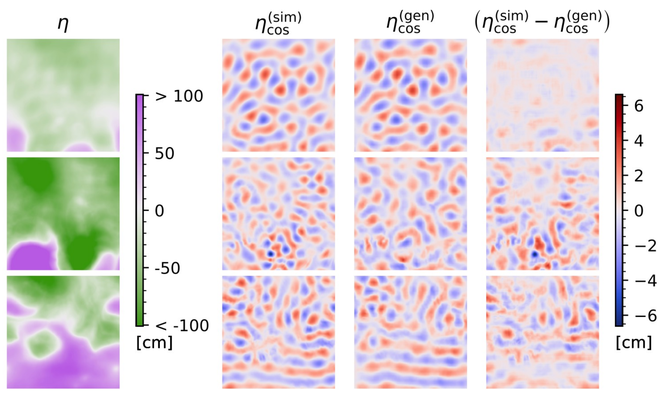


Figure 3: Taken from [3] to illustrate predictions at different turbulence levels.

Row 1 is a low turbulence case, which shows good agreement between the simulated (analytical) and generated (predicted) cosine components. Rows 2 and 3 show less accurate predictions for more turbulent snapshots.

Left to right, columns are: input SSH, true (simulated) SSH, generated (predicted) SSH, difference between columns 2 and 3.

Improvements

Power spectra characterize the energy of turbulent fluids at different scales

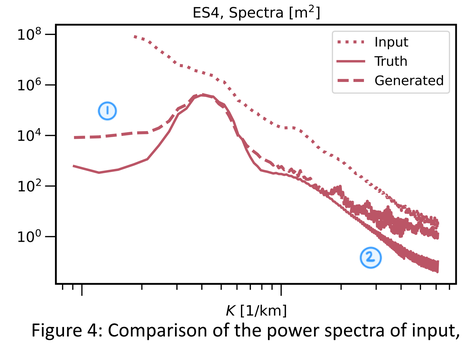


Figure 4: Comparison of the power spectra of input, truth, and generated ITs [3] (Provided by Han Wang)

Figure 4 shows:
1. Too much energy in very low wavenumber flows
   - These turbulent, large scale flows are important for circulation
2. Too much energy in very high wavenumber flows
   - These small scale eddies are important for balancing ecosystems

Future work will feed these spectra into G to improve agreement in wavenumber space.

Key Points

〜 Advanced satellite imaging lends itself to using image translation techniques to detect ITs
〜 Turbulent Flows are more difficult to predict, especially at very high/low wavenumbers
〜 Future work will force better spectral agreement

References

[1] G. Shanmugam, "4. 8 BAROCLINIC CURRENTS (INTERNAL TIDES)," in *Handbook of Petroleum Exploration and Production*, vol. 9, pp. 194–195.
[2] https://swot.jpl.nasa.gov/resources/94/swot-technologies-and-societal-needs/
[3] H. Wang, N. Grisouard, H. Salehipour, A. Nuz, M. Poon, and A. L. Ponte, "A deep learning approach to extract internal tides scattered by geostrophic turbulence," *Geophysical Research Letters*, vol. 49, no. 11, 2022.
[4] P. Isola, J.-Y. Zhu, T. Zhou, and A. A. Efros, "Image-to-Image Translation with Conditional Adversarial Networks," *CoRR*, vol. abs/1611.07004, Aug. 2018.