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# MOTrainer: Distributed Measurement Operator Trainer for Data Assimilation Applications

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## Summary

Data assimilation (DA) is an essential procedure in Earth and environmental sciences, enabling physical model states to be constrained using observational data. (Albergel et al., 2018; Carrassi et al., 2018; Evensen, 2009; Reichle, 2008)

In the DA process, observations are integrated into the physical model through the application of a Measurement Operator (MO) – a connection model mapping physical model states to observations. Researchers have observed that employing a Machine-Learning (ML) model as a surrogate MO can bypass the limitations associated with using an overly simplified MO. (B. A. Forman & Xue, 2017; B. Forman & Reichle, 2014; Xue & Forman, 2015)

## Statement of Need

A surrogate MO, trained as a ML model, is generally considered valid within a specific spatio-temporal range. (Reichle, 2008; Shan et al., 2022; Zhou et al., 2008) When dealing with a large spatio-temporal scale, multiple mapping processes may exist, prompting consideration for training separate MOs for distinct spatial and/or temporal partitions of the dataset. As the number of partitions increases, a challenge arises in distributing these training tasks effectively among the partitions.

To address this challenge, we developed a novel approach for distributed training of MOs. We present the open Python library `MOTrainer`, which to the best of our knowledge, is the first Python library catering to researchers requiring training independent MOs across extensive spatio-temporal coverage in a distributed manner. `MOTrainer` leverages Xarray's (Hoyer & Joseph, 2017) support for multi-dimensional datasets to accommodate spatio-temporal features of input/output data of the training tasks. It provides user-friendly functionalities implemented with the Dask (Rocklin, 2015) library, facilitating the partitioning of large spatio-temporal data for independent model training tasks. Additionally, it streamlines the train-test data split based on customized spatio-temporal coordinates. The Jackknife method (Efron, 1982) is implemented as an external Cross-Validation method for Deep Neural Network (DNN) training, with support for Dask parallelization. This feature enables the scaling of training tasks across various computational infrastructures.

`MOTrainer` has been employed in a study of vegetation water dynamics (Shan et al., 2022), where it facilitated the mapping of Land-Scape Model states to satellite radar observations.

## Tutorial

The `MOTrainer` package includes comprehensive usage examples, as well as tutorials for:

1. Converting input data to Xarray Dataset format: Example 1 and Example 2;

2. Training tasks on simpler ML models using `sklearn` and `daskml`: Example Notebook;
3. Training tasks on Deep Neural Networks (DNN) using TensorFlow: Example Notebook.

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