Incremental Low-Rank Dynamic Mode Decomposition Model for Efficient Dynamic Forecast Dissemination and Onboard Forecasting

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For many unmanned autonomous platforms at sea, providing environmental situational awareness in the form of ocean forecasts and acoustic data is key to evaluate their current mission status and to plan the next leg of their missions. However, due to critical operational constraints such as memory, computing power, communication-bandwidth, etc., these platforms often rely on transmission of ocean forecasts from numerical models that are run on remote centers such as but not limited to the Hybrid Coordinate Ocean Model (HYCOM) provided by the Fleet Numerical Methodology and Oceanography Center (FNMOC) or the data-assimilative MIT-MSEAS ocean simulations. However, these forecasts provided by the remote centers are not only expensive to transmit to communication-disadvantaged platforms, but may also have significant lapse in time between transmission due to its mission profiles such as operating in contested waters. In this work, we aim to directly address these two issues by: i) utilizing a compression technique to enable efficient transmission of ocean forecast and acoustic data to communication-disadvantaged users and ii) to use these compressed forecasts to build a reduced-order model (ROM) that can be used to provide onboard forecasts in between the significant lapse in between transmissions with remote centers.

We introduce the incremental, low-rank Dynamic Mode Decomposition (iLRDMD) algorithm [4] as the solution to the above. This algorithm gains significant reduction in bandwidth requirement in disseminating forecasts computed in remote centers by compressing the full-dimensional forecasts using the truncated Proper Orthogonal Decomposition (POD) basis, therefore operating in the truncated POD coefficients space [4]. The POD basis can be computed from historical forecasts on the remote centers and be pre-loaded on to the communication-disadvantaged platforms prior to the mission. Then these coefficients are used to incrementally update the onboard Dynamic Mode Decomposition (DMD) reduced-order model [1] which are then used to provide onboard ROM-based forecasts [4]. The incremental updates to the DMD model are done to address the decay of predictive accuracy of classic DMD methods previously identified in [2]. Finally, when the underlying dynamics significantly change over a longer period of time, the truncated POD basis which the forecasts are compressed onto, are updated via rank-1 updates [3] on the remote centers and transmitted to the platforms.

In this work, we build upon our previous tests of the iLRDMD algorithm on a univariate 2D flow behind a cylinder test case [4] and further demonstrate the iLRDMD algorithm on multivariate 3D real ocean applications. The multivariate variables include 3D fields of velocity, temperature, salinity, and acoustic variables and are from real ocean applications from MIT-MSEAS reanalysis of the 42-day forecast in the Middle Atlantic Bight region and the FNMOC’s HYCOM forecasts of the North Atlantic and Western Pacific domains shown in Figures 1 and 2. Building the DMD model using the multivariate, 3D ocean physics, acoustic and atmospheric variables enables us to provide joint reduction of all the components of the forecasts relevant to its operations and inherently couples ocean physics and acoustics.

Furthermore, we introduce the multi-resolution iLRDMD algorithm that is either based on relevant physical regions and or dynamics. This will help improve the predictive accuracy of the onboard ROM for the dynamics that are of interest. For example, for some missions, the global ocean forecasts may be accurate at specific scales or in specific regions, but not at all scales or regions. In such situations, it is beneficial to eliminate the scales (e.g. small) in the forecasts that are not accurate when building the onboard ROM. The multi-resolution iLRDMD algorithm is demonstrated on the same multivariate 3D real ocean applications outlined previously.

Fig. 1: Sea Surface Temperature of the HYCOM North Atlantic domain on Jan. 09, 2020 06:00:00