An Advanced Framework for Battlespace Environment Data Assimilation

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Introduction: Battlespace environment data assimilation is a key element of the DoD's strategic plan to ensure information superiority and battlespace dominance in the 21st century. It is used to provide all the necessary initial conditions for making atmospheric/oceanic forecasts and to produce the common operational picture required by the warfighter. This environmental picture is critical for the safety of ships, aircraft, personnel, and other assets, for sea-basing and ship fuel economy, for accurate delivery of precision ordnance, for theatre air and missile defense, for transformational communications, and for homeland security. Battlespace environmental data assimilation is a process that infers the atmospheric/oceanic state through an optimal combination of previous numerical model forecasts, in situ and remotely sensed observations, and theoretical information. The Navy's current operational data assimilation systems are three-dimensional (3D) and provide the warfighter with a snapshot of the battlespace environment at a single point in time, several times a day. To provide the warfighter with a continuous picture of the battlespace environment over the time window of the observations used to generate the initial conditions, a highly advanced and efficient four-dimensional (4D) data assimilation algorithm suitable for both atmospheric and oceanic applications is essential. To meet the warfighter's requirement in the 21st century, scientists at NRL-Monterey have recently developed an advanced framework for battlespace environment data assimilation, called NAVDAS-AR: NRL Atmospheric Variational Data Assimilation System – Accelerated Representer. Here we give a brief description of the current operational system, then describe the NAVDAS-AR framework and its current and future applications.

Current Operational System: The Navy's current operational data assimilation system is based on the observation-space three-dimensional variational (3DVAR) algorithm, NAVDAS: NRL Atmospheric Variational Data Assimilation System. 3DVAR is widely used in intermittent cycling atmospheric/oceanic data assimilation for the analysis of global and synoptic scales around the world. NAVDAS has been quite successful in handling slowly evolving flows and observation platforms that sample heterogeneously in space. Two major assumptions were made in developing NAVDAS and the 3DVAR data assimilation system in general. First, all the observations collected over a 6-hour data assimilation window are assigned to the middle of the time window (Fig. 4(a)) due to the lack of a time dimension in the theoretical formulation of the 3DVAR. Second, the analyzed fields are required to satisfy only simple geophysical relationships with each other due to the fact that a dynamic model is not used to constrain the fields during the minimization step. Also, from an efficiency perspective, the computational cost of NAVDAS is proportional to the square of the number of observations (Fig. 5), which creates an insurmountable barrier in assimilating the huge volume of remotely sensed observations expected to be available in the near future.

NAVDAS-AR Framework: NAVDAS-AR is based on the latest scientific research in estimation theory and computational technologies and provides a flexible framework for a wide variety of applications, including global and mesoscale atmospheric and oceanic data assimilation.[1,2] It consists of three major components: data quality control and pre-processing, four-dimensional variational (4DVAR) data analysis, and post-processing. The centerpiece of NAVDAS-AR is an accurate and efficient observation-space 4D variational minimization algorithm. It is used to produce the best fit to the observations and the numerical model forecasts simultaneously over a 6-hour data assimilation window. Due to the inclusion of the time dimension, NAVDAS-AR is a natural framework for the assimilation of observations that are not made at the standard synoptic observing times, but are taken more frequently in time over the data assimilation window (Fig. 4(b)). Because of the use of the numerical forecast model as a dynamic constraint, NAVDAS-AR is also capable of properly assimilating single-level data such as aircraft winds and temperatures (commercial and military), satellite feature-tracked winds, and sea-surface wind retrievals from satellite instruments such as NRL's WindSat or scatterometers. Moreover, the computational cost for NAVDAS-AR is proportional to the model grid density and is not impacted by the amount of data to be assimilated, a highly desirable benefit for operational efficiency, as shown in Fig. 5.

Concluding Remarks: NAVDAS-AR, a highly advanced framework suitable for 4D battlespace environmental data assimilation, has recently been developed at NRL-Monterey. Like the Navy's current operational data assimilation systems, NAVDAS-AR is theoretically cast in observation-space. It possesses all the advantages that the observation-space algorithm can provide, such as its ability to produce the adjoint of the data assimilation system with minimal effort. But unlike the operational observation-space 3DVAR algorithm, NAVDAS-AR preserves the time information in the observations, uses a dynamical model to constrain the analyzed fields, and does not limit the total number of observations to be assimilated. Because of these advantages, NAVDAS-AR has recently been chosen as the basis for the Navy's next-generation atmospheric and oceanic data assimilation systems.

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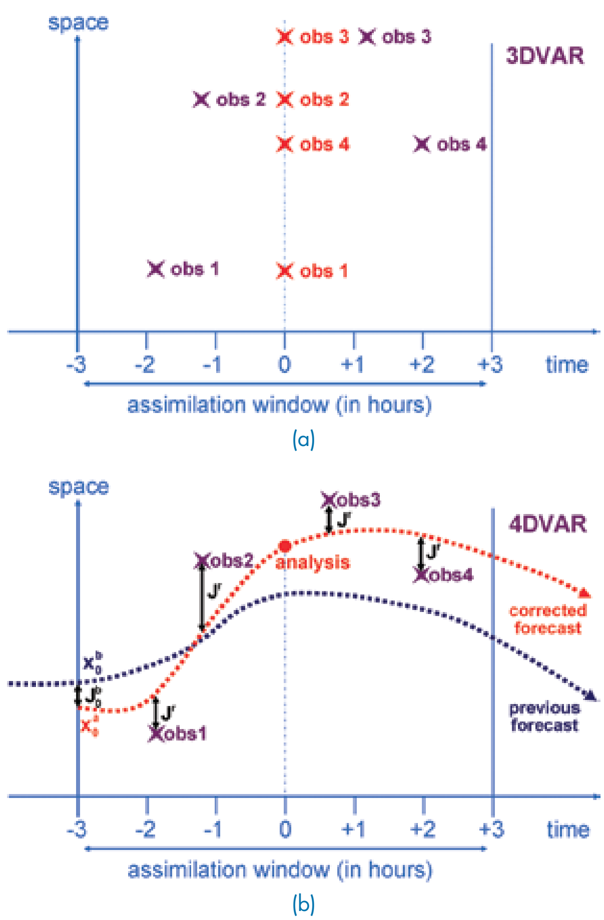

FIGURE 4
A schematic of 3DVAR (a) and 4DVAR (b). The abscissa represents time of the data assimilation. The ordinate indicates the observation locations in three-dimensional space. Four observations (obs 1 – obs 4) are scattered at different temporal and spatial locales over the 6-hour data assimilation time window. (a) In 3DVAR, all observations are assimilated at "0" hour and the results are constrained by simple geophysical relationships. (b) In 4DVAR, all observations are assimilated at the "observed" hours and the dynamical model is used to constrain the results.

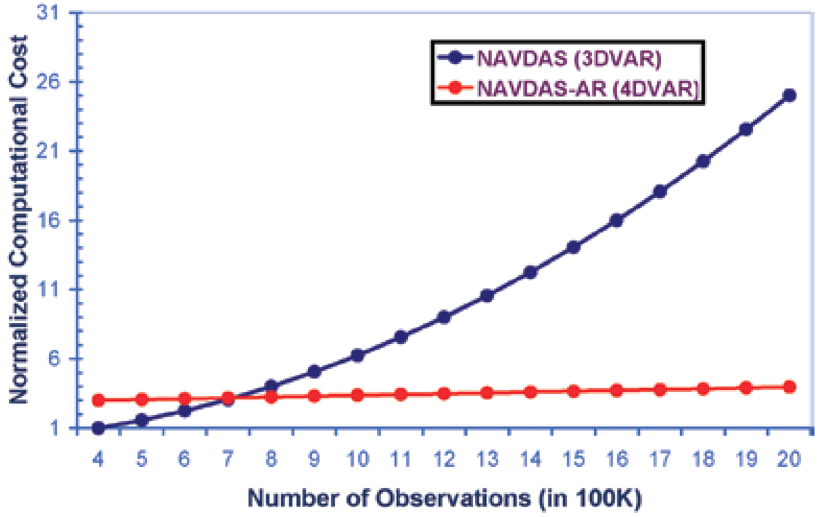

FIGURE 5
The ordinate is the computational cost normalized by the cost of assimilating 400K observations using operational NAVDAS. The abscissa is the number of observations to be assimilated (scaled by 100K). The computational cost of NAVDAS is a quadratic function of number of observations to be assimilated, while the computational cost of NAVDAS-AR increases very little with an increase in the number of observations.