Data Assimilation in Geosciences

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Data Assimilation - Outlook

Data Assimilation best combines model and observations and brings synergy.

An on-going rapid expansion from *Weather Science (NWP)* into *Climate Science/Geophysics* in general:

- Oceanography
- Climate Prediction
- Climate Assessment
- Hydrology
- Geology
- Climatology
- Detection & Attribution
- ... and many more beyond geosciences ...
Problem Statement

- The problem is in principle solved using a probabilistic framework.
- The quantity of interest are the probability density functions, PDF.
- The PDFs are evolved in time and updated at analysis times using Bayes’s rules.
DA methods in geoscience: David vs Goliath

- Climate models have huge dimension: \( \geq 10^9 \) variables
- Environmental observations constitute a massive dataset: \( \geq 10^7 \) daily obs
- Climate phenomena are intrinsically nonlinear and chaotic
- Nonlinear observation

**EnKF**
NERSC world-class milestone
Evensen, 1994

**Present ...**
DA for geosciences
The role of NERSC

Evensen, Bertino, Sakov, Counillon, Raanes, Xie, Lisæter, Carrassi and many other...

- Worldwide leadership in the theory of ensemble DA methods
  - Stochastic and square-root formulations
  - Parameter estimation
  - Anamorphosis for non-Gaussian variables

- Parallel operational development
  - Real-time DA for ocean and sea-ice (TOPAZ)
  - Ocean and sea-ice reanalysis (1990-present)
  - Climate predictions (NorESM)
Nowadays challenges for geophysical DA

*Where are we going?*

- Coupled Data Assimilation
- Fully Bayesian method (nonlinear and non-Gaussian)
- Lagrangian Data Assimilation
- Computationally efficient DA – *Big Data*
Coupled Data Assimilation

- Improve the forecast of **coupled phenomena** (hurricanes, coastal weather, ENSO, MJO)
- Use **Earth System Simulators** as the unified modeling instrument across all timescales from days to decades
- Better exploit the **new generation of Earth observations** (Argo, SMOS ...)
- Produce **coupled reanalysis**

Key Scientific Issue

- **Presence of multiple scale of motions**
- **Information propagation** across model compartment
- Difficult to **compute cross-covariance**

- NERSC pioneer in the coupled DA for ocean and sea-ice (*Lisæter et al. 2003*)
- NERSC **DA group** is conducting basic research on coupled DA and applied-oriented investigation in collaboration with the *Climate Dynamics and Prediction* group.

NERSC

Ocean and atmosphere interactions during normal conditions

Convective loop

Equator

Thermocline

NASA

120°E

80°W

30 YEARS IN SCIENCE

1986 - 2016
Efficient Bayesian Data Assimilation

- EnKF/4DVar fails in highly nonlinear/non-Gaussian situations
- Nonlinear Bayesian **Particle Filter** are required.

**Key Scientific Issue**

- **Curse of Dimensionality**
- **Big Data Problem** \((\text{model/obs } 10^9/10^7)\)
- Not **computational power alone**

- **NERSC DA group** is actively studying advanced formulations of Particle Filter and EnKF to deal with nonlinearity
- The main idea is to study PF which incorporates model dynamic's features in its design (see Raanes and Grudzien poster)
Lagrangian Data Assimilation
DA for the Sea Ice

Assimilation of data instruments or for model grid that are not stationary is known as **Lagrangian DA**

- Mesh varies in time
- **Remeshing** procedures which does not conserve the total number of elements
- New formulation of DA methods are required
- A collaboration between **DA and Sea-Ice modeling groups** is studying extensions of the EnKF for time-evolving and remeshed grid (see Matthias Rabatel poster)

Credit: P. Rampal