DART Perspectives on Infrastructure Challenges of High Resolution and Coupled Data Assimilation

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Data Assimilation Research Testbed

- Ensemble Kalman Filter

- Research
  - Dozens of model and observation interfaces
  - Good parallel performance on many machines (not tuned like operational)
  - Education via tutorials

- Software Engineering Focus
  - Standardized, small interface to any sized model
  - Flexibility; choice of model, any relevant observations, filter
  - Tools which make EnKF work well with large models, ‘small’ ensembles.
  - Make DA accessible to non-DA experts
CESM + DART:
NCAR’s current framework for
global assimilation applications

CESM+DART

- Community Earth System Model (multi-component earth system model designed for climate studies)
- Ensembles of CESM run in any supported configuration (i.e. coupled-model, high-resolution, etc) can interface with the DART system.

Relevant to this workshop → there is active work at NCAR on resolving challenges associated with

- coupled ocean-atmosphere assimilation
- high resolution 1/10° global ocean assimilation (eddy resolving)
Challenges associated with CESM global assimilation (and large-state space models in general)

1) **Data motion**
   - within DART (internal)
   - Between CESM and DART
   - Between DART and the file system (DA diagnostics)

2) **Memory and Parallelism**
   - How best to distribute the state and ensemble information?

3) **Model Design:**
   - The CESM architecture was not designed with ensemble DA in mind

4) **System Robustness:**
   - more processors leads to more machine failures.

5) **Storage and access:**
   - huge output data sets.

Resources and funding are needed to address these challenges
Status of coupled assimilation with CESM+DART

- Multi-component assimilation (global ocean/atmosphere at nominal 1° resolution) has been operable for 2+ years.
  - Quality of reanalysis is very promising, however
  - Infrastructure work is needed to make the system viable (faster and more parallelizable)

- Cross-component assimilation is on the horizon
  Open questions:
  - how to localize across components?
  - Is there a detectable benefit in analysis quality over multi-component coupled assimilation

- To date, this work has largely been accomplished with non-base funds:
  - NSF EASM
  - NSF+DOE supercomputing
  - Funding beyond 2016 unclear

- Recent allocation of NCAR base funds towards making CESM interact more efficiently with DART

Significantly more software engineering is needed to adapt large, complex state vectors in DART to existing computing environments.
Assimilating with the 1/10° ocean model: challenges associated with large state vector*

- State vector (T,U,...) size
  - > largest 32 bit integer: convert integers to 64 bit
  - = 17 Gb (2/3 of a Yellowstone node)

- New “RMA” capabilities allow each state vector to be distributed across multiple nodes, but requires:
  - internode communication for many observation forward operators
  - book-keeping of which node has which parts of the state vector

- On the horizon: distribute static memory across nodes

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Assimilating with the 1/10° ocean model: challenges associated with large state vector

About the new “RMA” version of DART:

- Eliminates the need to hold the entire state on any one processor, making it possible to assimilate to models with otherwise prohibitively large state-spaces.
- Forward observation operators can use state variables that are distributed in memory essentially randomly.
  - The state is distributed across all processors.
  - Using MPI one-sided communication a task can get the state elements it needs from any other process. This happens asynchronously.
  - Asynchronously is the key point – you don’t have to calculate which processors need what from where and when they need it.

**Diagram:**

- Processor has needed data
- ‘window’
- Other processors need data
Assimilating with the 1/10° ocean model: challenges associated with intensive I/O

- 30 members -> 516 Gb of state vectors read and written each assimilation.
- 4 Gb/s for read + movement to where it’s needed.
- I/O is a significant fraction of the assimilation time, and it doesn’t scale well.

![Time vs. # PEs graph]

Legend:
- **Blue**: Read
- **Green**: Assimilate
- **Red**: Write
- **Cyan**: Total

**Time (s)** over **# PEs** from 2048 to 8192
Assimilating with the 1/10° ocean model: challenges associated with intensive I/O

*Potential* accelerations given current I/O limitations

- Read in only subset of state values which will be effected by assimilation.
- POP2: Run ensembles with a 1° model to constrain the planetary scales and use a stationary ensemble OI to constrain the mesoscale variability.
Rethinking how CESM generates ensembles and how CESM interfaces with DART

New ideas and research horizons

- Make CESM more parallel
- Make CESM more resilient to machine failures
- Create a true ensemble coupled model (?)
  - Separate model members are replaced by a new dimension (“member”) in each state variable. A given computation would be performed for all members at the same time. That would move larger chunks of data fewer times.
- Compute forward operators within the model, rather than afterwards in the DA.
- Pass state between model and DA via memory, rather than files.
Summary and Conclusions

- For ‘high’ resolution, significant software infrastructure development in CESM and DART is needed to use even currently available computing resources effectively.

- The trends of increasing processor count, decreasing shared memory/node, and increasing data set sizes will require ongoing software infrastructure development.

- Large model development in CESM+DART benefits greatly from true software engineers, rather than (talented) DA scientists.