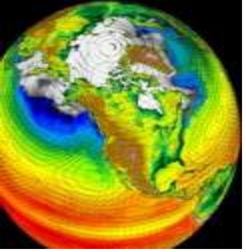
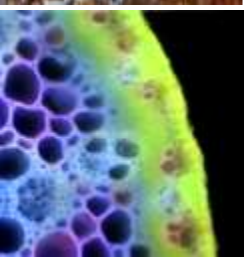
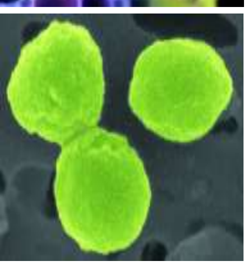


Workshop on the Initialization of High-Resolution Earth System Models: Report to BERAC

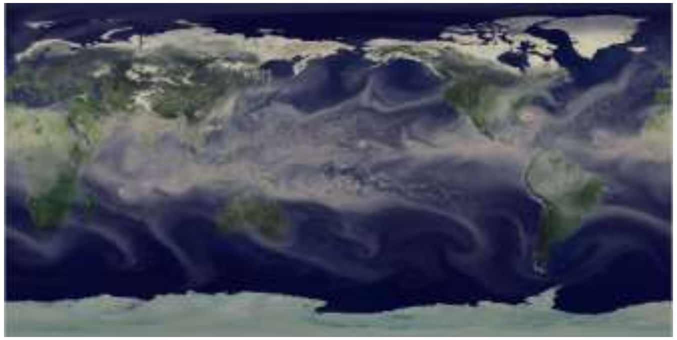
October 18, 2018
Dorothy Koch
Earth and Environmental Systems Modeling (EESM)

Workshop chairs:
Todd Ringler (Los Alamos National Laboratory)
Steve Penny (University of MD, College Park)

Sponsored by BER's EESM and NOAA's Climate Program Office

High Resolution Model Initialization workshop: Motivations

The Problem: How can we initialize or “spin-up” high resolution Earth system models such as E3SM?



Traditional approach: Lower resolution Earth system models perform *very long* “spin-up” simulations to allow the system to equilibrate and come to approximate equilibrium.

Computational constraints: However, with high-resolution models like E3SM, these lengthy control simulations are too expensive.
Even with DOE computers!
Without the spin-up, the model output will not look very much like the real world.

DOE E3SM aims:
for seasonal to decadal predictability in order to inform energy needs such as:

- water availability;
- extremes – storms, droughts, fires, heat;
- sea-level change and coastal impacts

E3SM
Energy Exascale Earth System Model

Initialization workshop: interests and approach

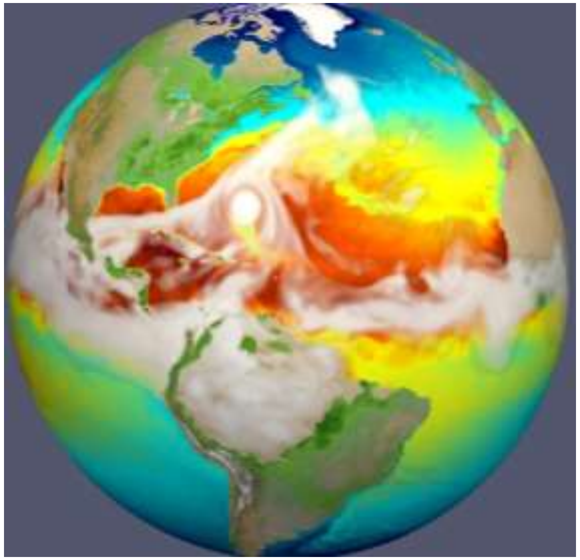
DOE interests: Bring DOE skills in math/algorithms (e.g. in SciDAC program) to help advance the coupled earth system model initialization challenge.

First we need to better understand the initialization challenge and listen to community expertise.

NOAA interests: Develop Unified Forecast System
Advance toward coupled data assimilation and initialization strategy

Approach: As a first step, explore whether *better data assimilation (DA) methods* would be path forward.

- The **weather community** has deep experience with DA particularly for the atmosphere, with focus on days-to-weeks
- Many in the **climate or earth system model community** also work with DA.
- **Both communities** are starting to work with Coupled Data Assimilation (CDA), where both the atmosphere and the ocean (and other components) assimilate observations. CDA is very challenging…



Workshop logistics

The workshop assembled international experts from both the weather and earth system communities for discussion on state-of-science for model initialization, with focus largely on Coupled Data Assimilation (CDA)

- Venue: Rockville Hilton, April 9-10, 2018.
- Participants: 41 International experts from -- DOE, NOAA-GFDL, NCEP, CIRES, NASA-GMAO, NCAR, Navy, ECMWF, Qingdao, NERSC (Norway), and many university experts
- Seven sessions: each comprised of 2 to 3 topically related presentations followed by 20 to 30 minutes of facilitated discussion:
  - Session 1: Small-ensemble, high-resolution initialization (The problem)
  - Session 2: Coupled data assimilation roadmaps (Current ESM approaches)
  - Session 3: initialization of eddying ocean configurations (e.g. using new Argo data)
  - Session 4: Data assimilation methods (Research directions)
  - Session 5: Data assimilation for shorter time-scale prediction
  - Session 6: Possible solutions to the DA Input/Output barriers (important at high-resolution)
  - Session 7: Operational centers and data assimilation (Opportunities to build community-led collaborations, e.g. JEDI)

ESM initialization: the traditional approach

Earth System Models (ESM's) standard practice to initialize:

1. **A long pre-industrial control simulation** in order to get the entire system into "natural" equilibrium with natural forcings (solar, volcanoes, natural greenhouse gases and aerosols)

- 1000 years (typically takes a few poor starts until it works)

2. **Historical transient simulation,** e.g. 1850-present to be sure model captures the real-world changes

- 200 years (x 5 ensembles) = 1000 years

3. **Future simulation present to e.g. 2100 to study the future,** given possible changes in drivers

- 100 years (x 5 ensembles x 2 scenarios) = 1000 years

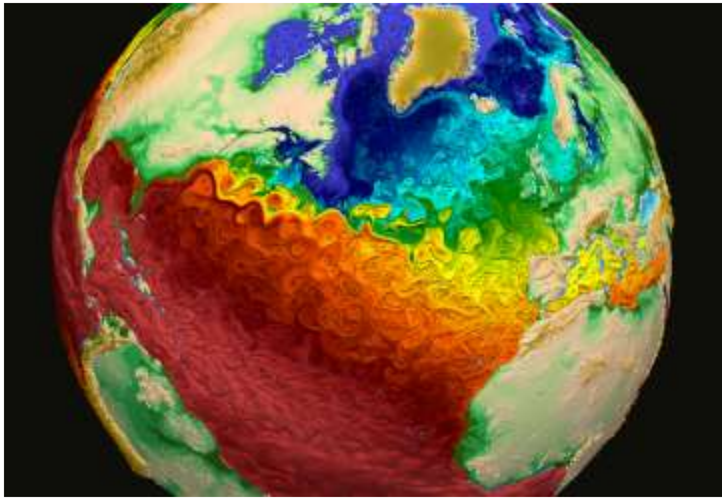
Pre-industrial simulation is at least 1/3 of the cost!

For very high-resolution simulations, we can only afford short simulations, so initialize in e.g. 1950:

1. 1950 control (1000 years)
2. 60 year historical transient (1950-2010)
3. 60 year projection (2010-2070)

- Initialization is prohibitively expensive!

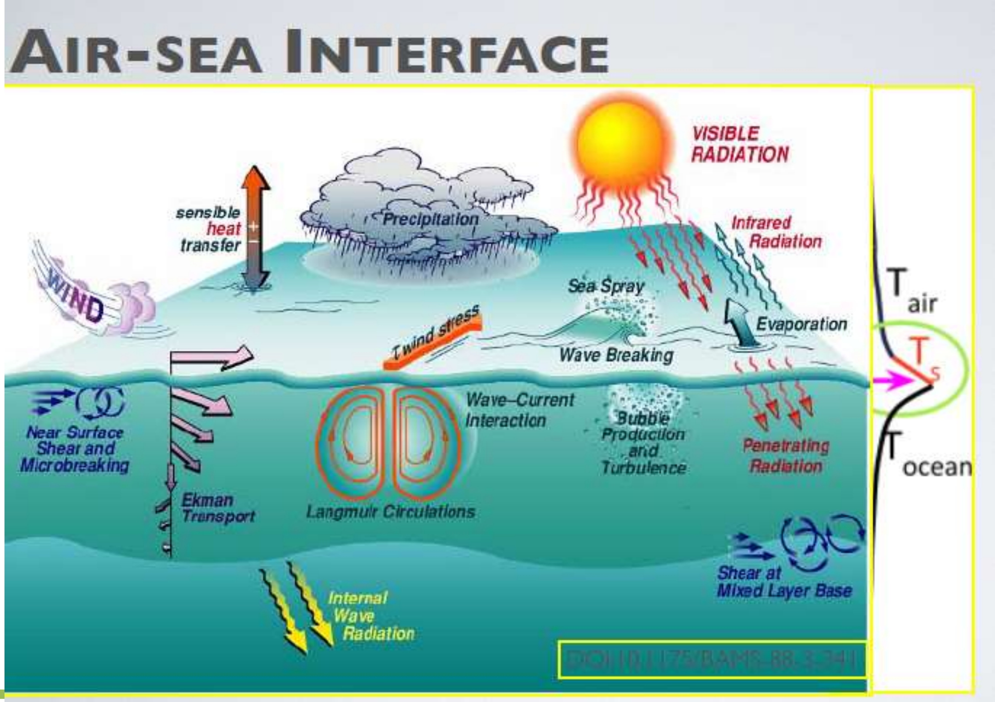
Can we initialize using (e.g. 1950s) observations and with minimal spinup??



ESM initialization using data assimilation – the challenges

- Numerical Weather Prediction (NWP) uses data assimilation routinely, however
  - Earth system models (ESM's) must work with a complex coupled system (more than atmosphere)
  - The longer timescales of interest (decades instead of days) means an initialized ESM will drift away from observations fairly quickly
- Observations are needed for the most inertial systems that affect long-term changes (e.g. ocean):
  - Before about 2005, lack on real-time ocean observations of sufficient space-time extent precluded routine, real-time ocean DA. Now we have Argo float data.

- Nature of climate-system research:
  - Focus of community has been toward the forced response -- having an equilibrated, biased model initial condition that is drift-free has been more important than an accurate initial condition.

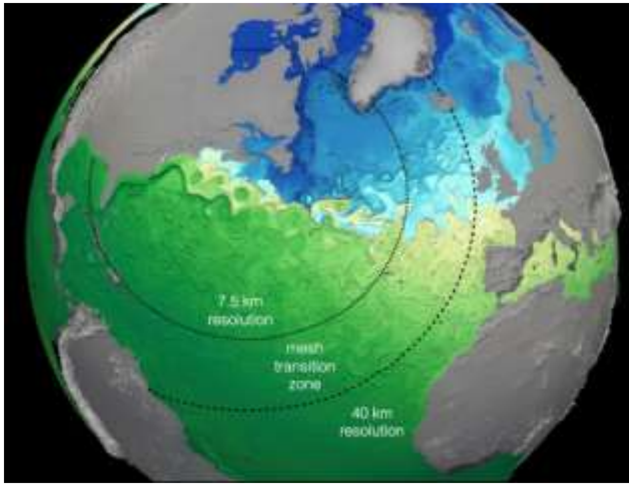


Earth system (ESM) - Numerical Weather (NWP) interactions

- As the ESM community gains interests in seasonal timescales and model initialization and NWP community gains interests in subseasonal to seasonal timescales, there is increasing reason for these communities to collaborate.
  - E.g. UK-Met office uses same code for weather and climate
  - E.g. CLIVAR meeting last month convened “S2S” and “S2D” communities together at NCAR (but primarily in different sessions)

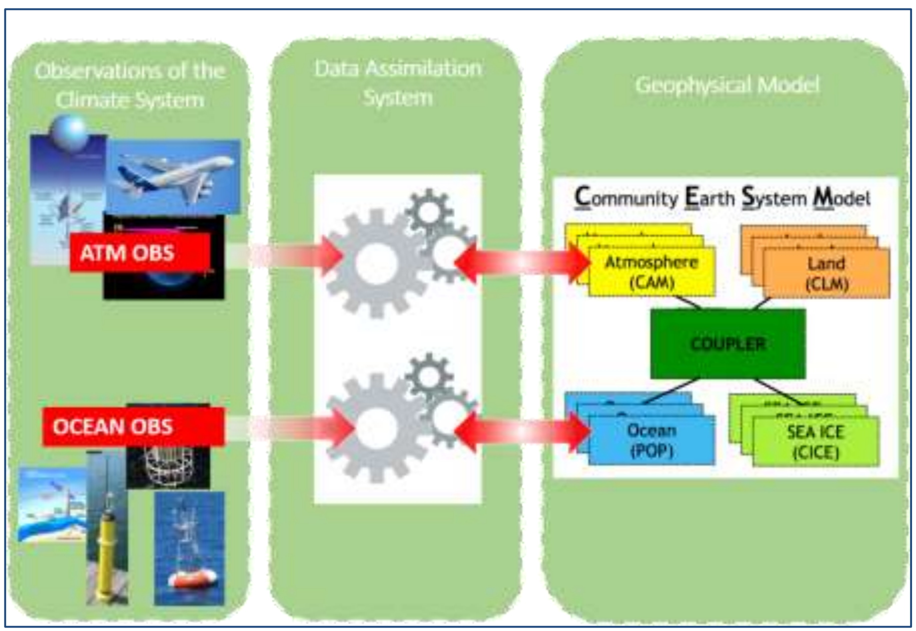
- NWP centers begin to include ocean and land components in order to improve long-range forecasts

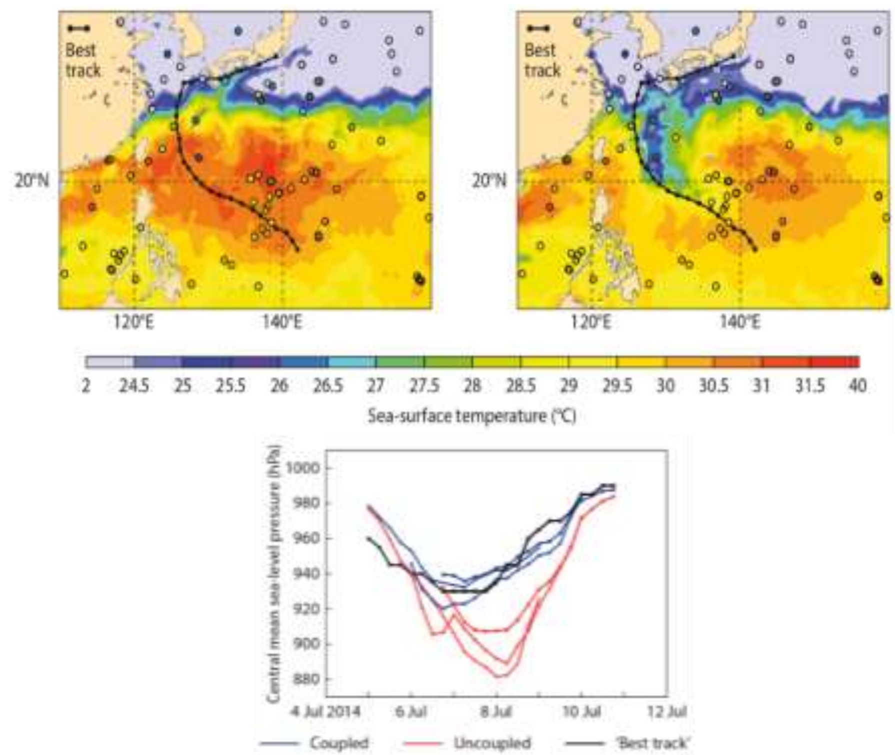
- ESM’s begin to work with initialization, in order to better predict, as well as to better identify model errors



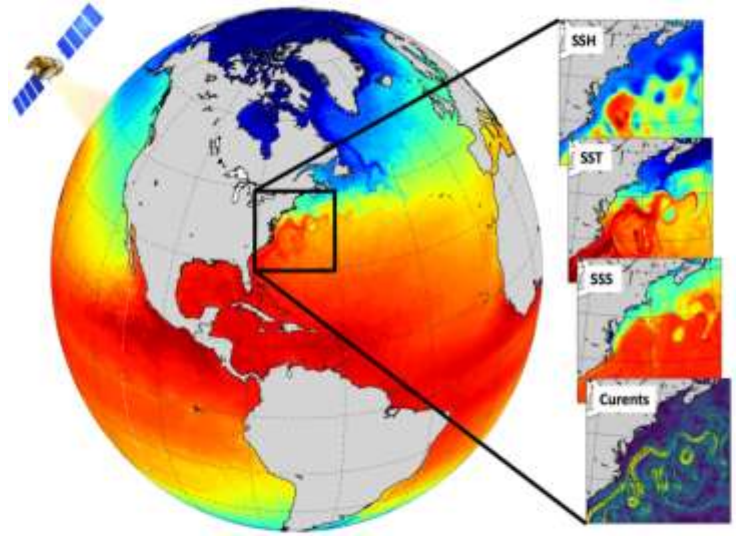
Research challenge: #1 Coupled vs uncoupled initialization

- Single component (e.g. atmosphere) initialization is simplest. Some ESM's demonstrate reasonable skill by initializing only the ocean.
- However it is increasingly clear that using and initializing the coupled system can improve the prediction. Two methods:
    - Weakly coupled initialization – each component is initialized separately, then combined (easier). However the coupling produces a "shock".
    - Strongly coupled initialization – much more challenging, but an active area of research. Best done with data at the interface between components – not much of this data is available

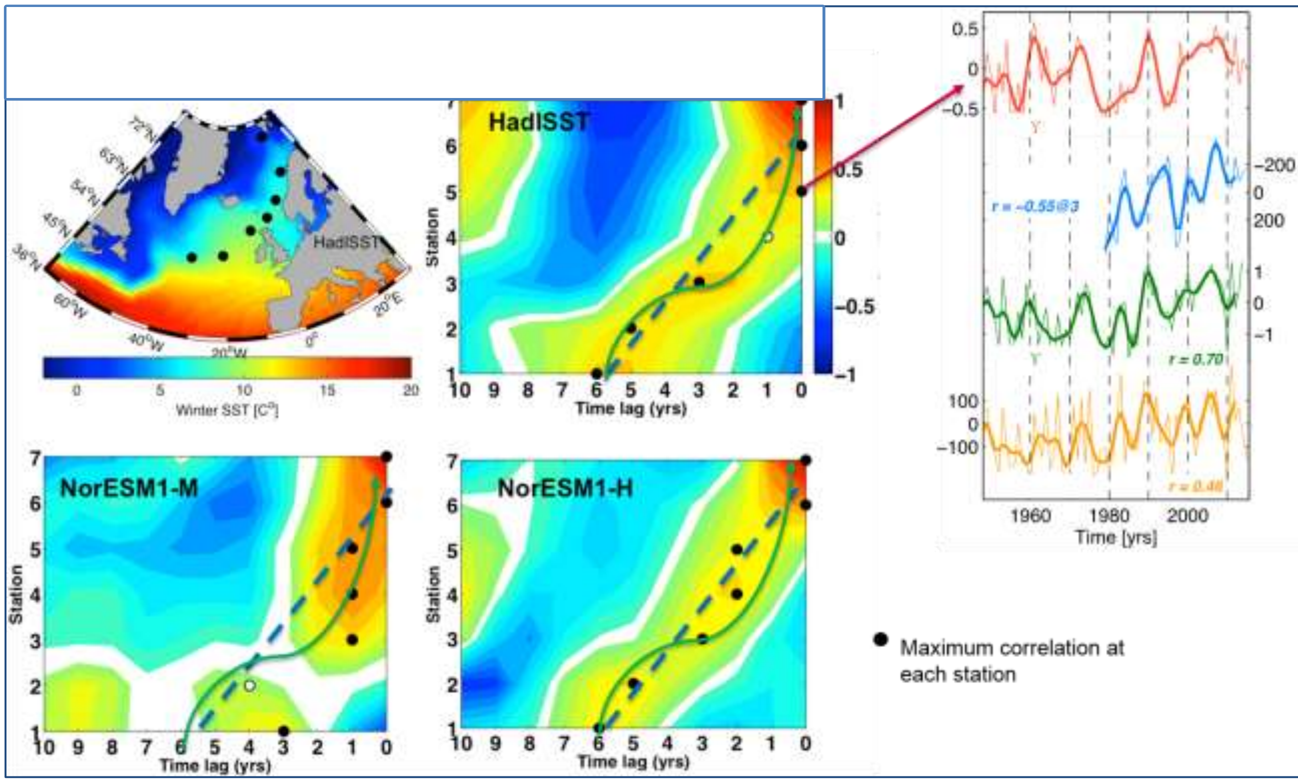




Research challenge: #2
Resolution requirements



- Working with higher-resolution (e.g. ocean) improves forecast skill
- How to initialize high-resolution systems is challenging and may depend upon timescale of interest:
  - Initializing individual eddies - may mismatch the model tendencies
  - Initializing eddy-characteristic may be more effective

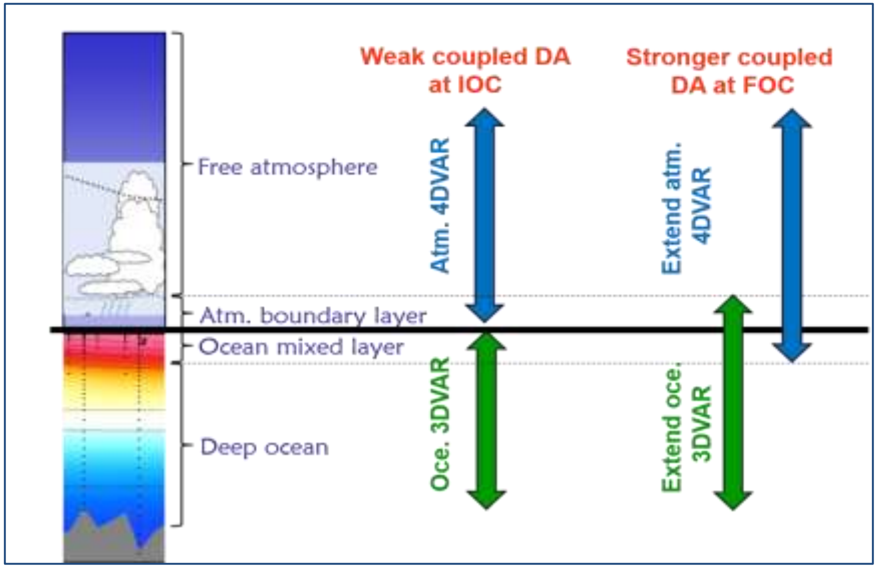


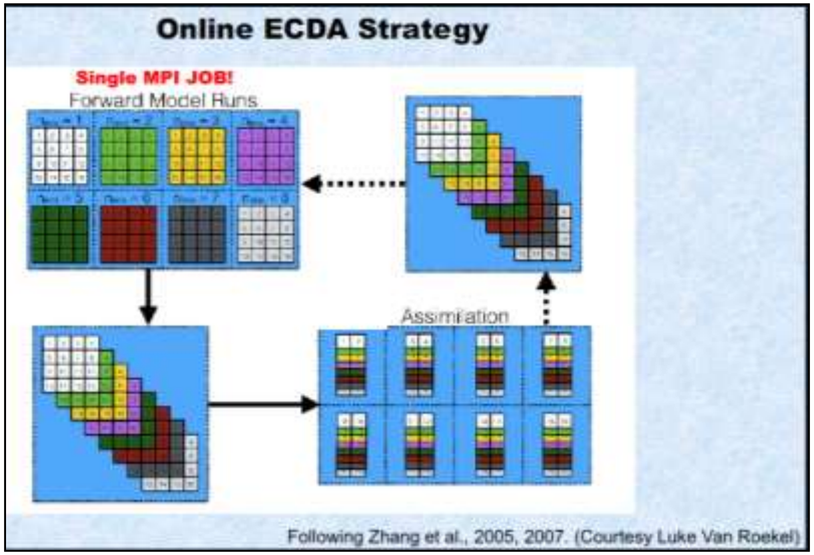
Research challenge: #3 Data Assimilation Methodologies

Various approaches, each with its own challenges, including:

- Ensemble Kalman Filter (EnKF)
  - Requires statistics from large ensemble for robust prediction – expensive
- Hybrid between EnKF and EnOI
  - Use statistics from long control run together with fewer ensemble members
- 3D-Var (spatial) or 4D-Var (includes temporal)
  - Statistical approach using variational methods to harmonize observations and model

How do these compare in terms of cost, skill, complexity?



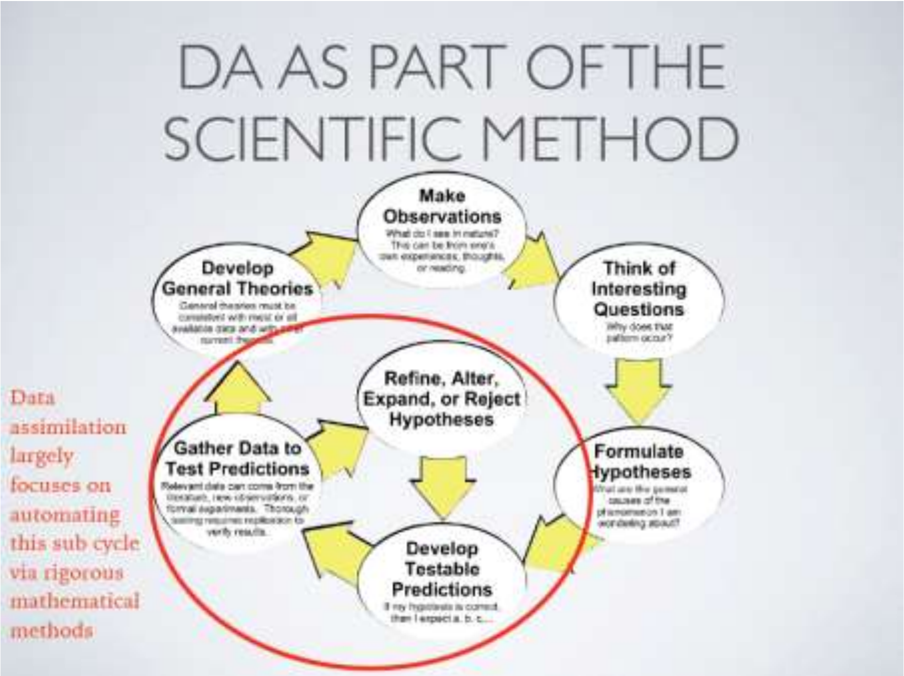


Research challenge: #4 Using DA to improve ESMs

Initialize the model, let it run freely, then see where the model has biases and where it drifts

- BER's Cloud-Associated Parameterization Testbed (CAPT) is an example where this has been quite effective

- How far can this take us in terms of correcting for the most fatal of model-data mis-matches, toward decadal predictability?



Workshop conclusions & next steps

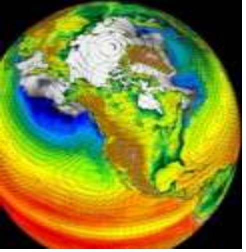
Conclusions

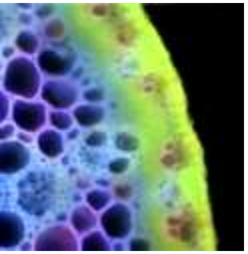
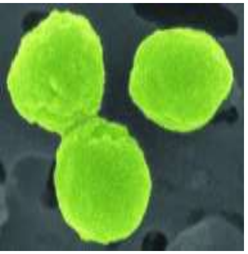
1. Routine use of Coupled Data Assimilation (CDA) with ESMs is a natural progression of the ESM research activity and maturity.
2. As ESMs adopt assimilation methods they look more like weather models. As weather models are adding more dynamical components (ocean, sea-ice, etc.) they are looking more like ESMs. CDA is both an area of intersection and a vehicle for knowledge transfer between these two communities.
3. CDA is a promising -- yet still risky -- approach to initialization of high-resolution ESMs
4. CDA offers more to the ESM community than a tool for state estimation -- including study of model drift, remedying biases, and Climate-Observing System Simulation Experiments (COSSE).

Possible next steps

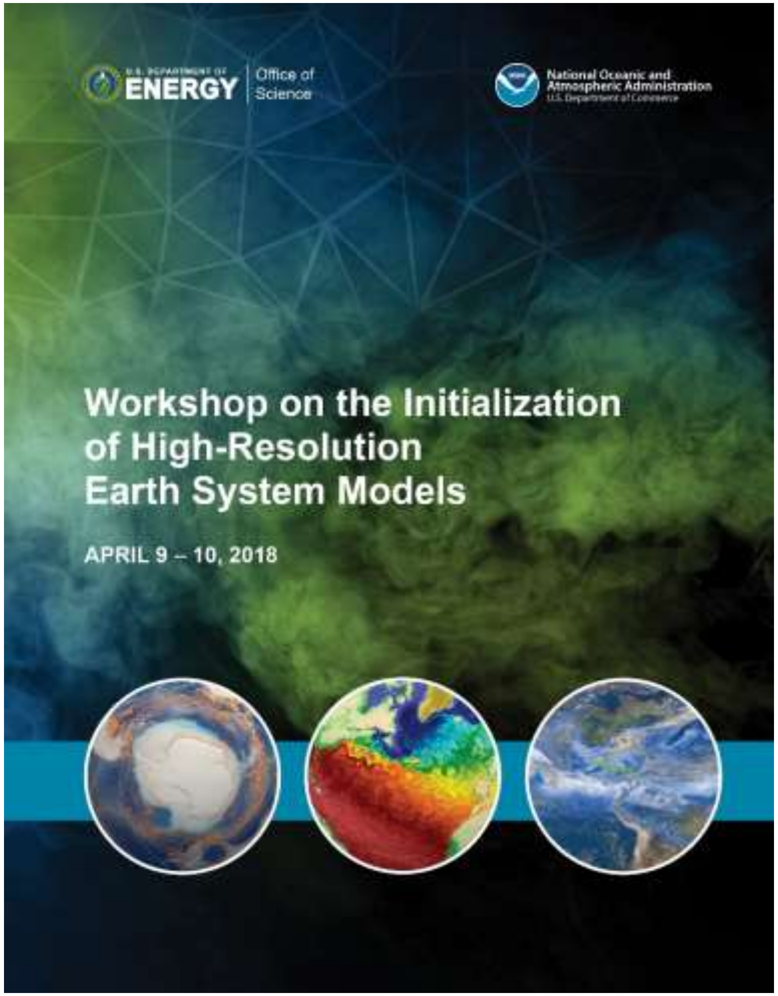
1. Research into how tightly (or how coherently) different model components should be assimilated.
2. Support organization and development of community common frameworks, to compare and test DA methods
3. Pursue use of CDA to study model drift, bias remedy, and COSSEs.

***EESM-ASCR-SciDAC continues to consider how to better leverage applied mathematical methods to initialize/optimize E3SM*



Thank you!



Dorothy Koch
Dorothy.Koch@science.doe.gov