A DAOS Perspective

Andy Moore

- **Summary of WWRP Report on "Coupled Data Assimilation for Integrated Earth System Analysis and Prediction," Penny *et al.* (2017)**
- **Following the International workshop on Coupled Data Assimilation ,Météo France, Toulouse, October 2016.**

Initialization Approaches for Coupled Models

- **Uncoupled DA:** *models components initialized from separate DA analyses*
- **Flavors of coupled DA (CDA):**

Weakly Coupled Data Assimilation (WCDA) - DA applied to each individual component separately.

- advantage is that it is straightforward
- disadvantage is that observations of one component may not strongly constrain or influence other components directly (this happens only during the forecast stage)
- quasi-WCDA also used (DA only in some sub-components)

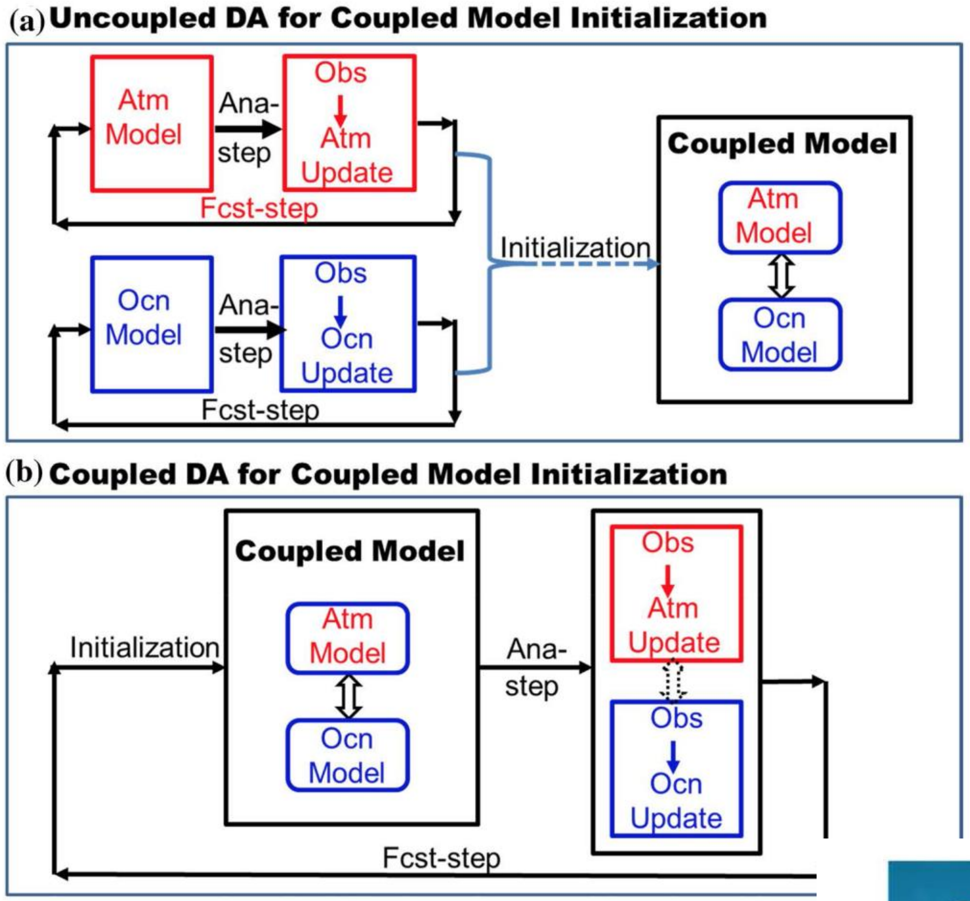
Strongly Coupled Data Assimilation (SCDA) - DA coupled Earth system model as a whole.

- advantage is that observations of each component can directly influence each component during the DA stage
- a major challenge is that cross-covariance information is needed which is poorly known and/or understood. Covariances are critical:

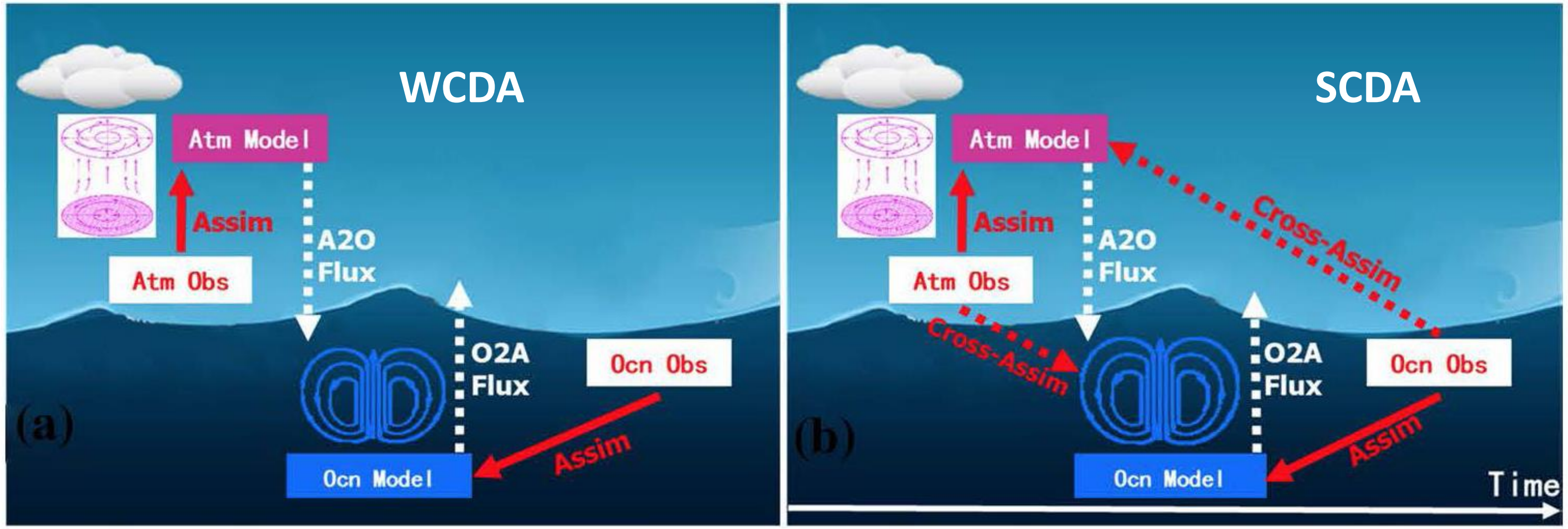
$$\boldsymbol{x}_a - \boldsymbol{x}_b = \boldsymbol{B}\boldsymbol{H}^T(\boldsymbol{H}\boldsymbol{B}\boldsymbol{H}^T + \boldsymbol{R})^{-1}\left(\boldsymbol{y} - H(\boldsymbol{x}_b)\right)$$ *Linear analysis equation*

- quasi-SCDA also used (DA only in some sub-components)

- **Based on the flavor used, exchange of information between model components is either direct via covariance information, or indirect via flux interactions.**



Zhang *et al.* (2020)



Some challenges:

- coupled covariances are difficult to estimate
- disparate space- and time-scales of the state of the different earth system components
- current methods of DA may not be appropriate (i.e. some form of hybrid ensemble-based approach will probably be most effective, and multi-scale DA will very likely be necessary)
- coupled models are large and complex -> CDA computationally challenging
- model error and bias is a major issue (could perhaps be ameliorated by simultaneous *parameter* estimation during CDA)
- balancing and elimination of initialization shocks that potentially degrade forecasts

Some benefits:

- CDA has been shown to increase forecast skill on a range of timescales, although at the short-range, skill is hampered by coupled initialization shocks.
- Forecasts can benefit from strong interactions between coupled components: examples include TC forecasting (i.e. cold ocean wakes and ocean restratification); tropical instabilities waves (TIWS) in the ocean; sea-ice and ocean.
- CDA could potentially make better use of existing data streams observations (e.g. assimilation of SST via radiative transfer in ABL and OBL; assimilation total integrated column measurements as constraints on A-O system).

CDA methodologies:

- Hybrid approaches will perhaps work best
- Multi-scale approaches will probably be essential
- Non-Gaussian behavior should be expected (e.g. sea-ice, atmos chemistry, ocean biogeochemistry, etc)
- Non-linear DA -> emerging
- Stochastic physics to account for model errors
- New approaches? So far the field has progressed primarily from a "bottom-up" approach based on existing DA systems for individual components. A "top-down" approach considering the SCDA problem as a whole may be more beneficial. This could be a good candidate for Machine Learning (ML) (*e.g. for developing coupled covariance models; model error covariances; emulators for subcomponents such as BLs).* The WMO S2S WG has a data base of coupled model forecasts that could possibly be used as “training” data.

- **Currently there is lack of consensus on best approaches and best practices**
- **Infrastructure projects such as OOPS*/JEDI** (tools and forward operators) are probably a smart way forward but are not readily accessible to everyone without significant effort.**

* Object Oriented Prediction System (OOPS)

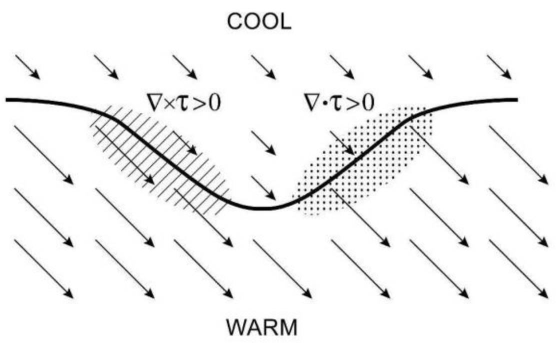
** Joint Effort for Data Assimilation Integration (JEDI)

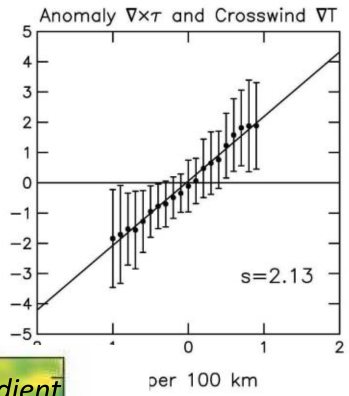
Operational/research center approaches circa 2017:

- **ECMWF** - quasi-SCDA (3D-Var, 4D-Var)
- **NOAA-NCEP** - SCDA (3D-Var, EnVar?)
- **JMA/MRI** - WCDA (3D_Var, 4D-Var)
- **JMASTEC** - SCDA (4D-Var)
- **BOM** - WCDA (EnOI)
- **UKMO** - WCDA (?)
- **NASA/GMAO** - WCDA
- **NRL** - WCDA (hybrid 4D-Var, 3D-Var), SCDA (4D-Var?)
- **NCAR** - WCDA and SCDA (EnKF, DART)
- **ECCC** - WCDA (4DEnVar, OI, 3D-Var)
- **GFDL** - ensemble CDA

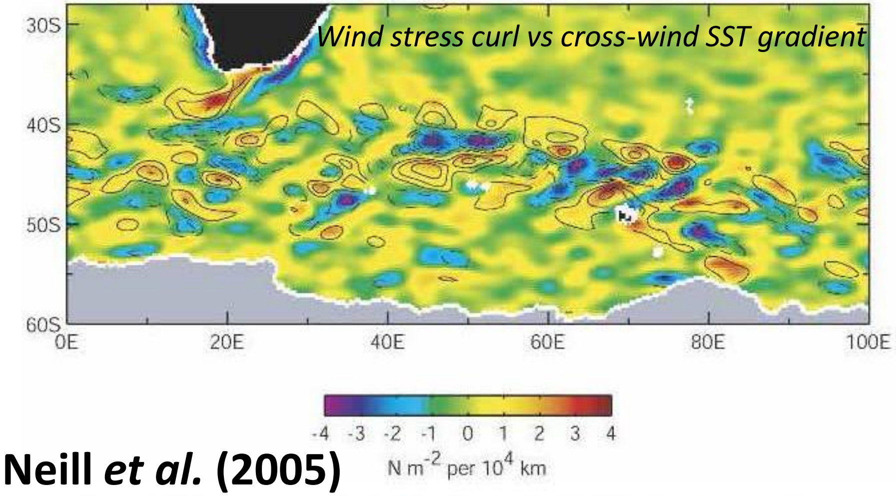
An example as a reminder about the importance of air-sea coupling at the ocean mesoscale, and the need for multi-scale DA approaches…

Chelton *et al.* (2007) – CA Current

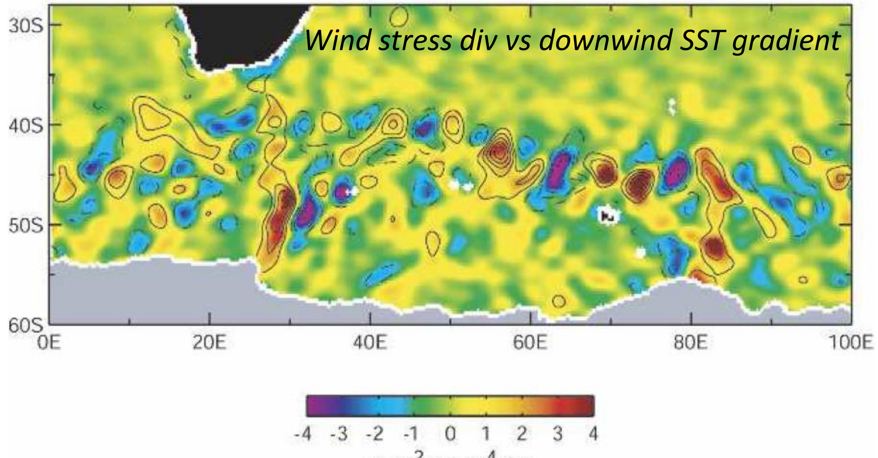




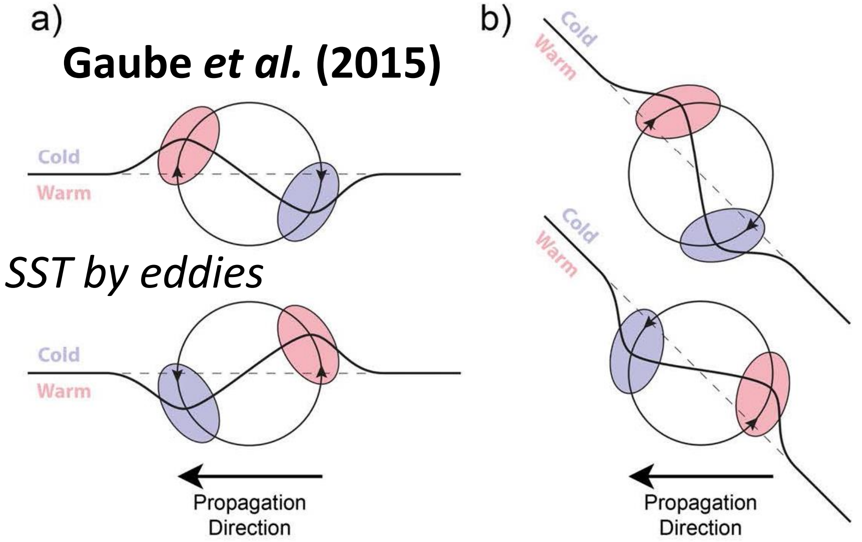
From observations



O'Neill *et al.* (2005)



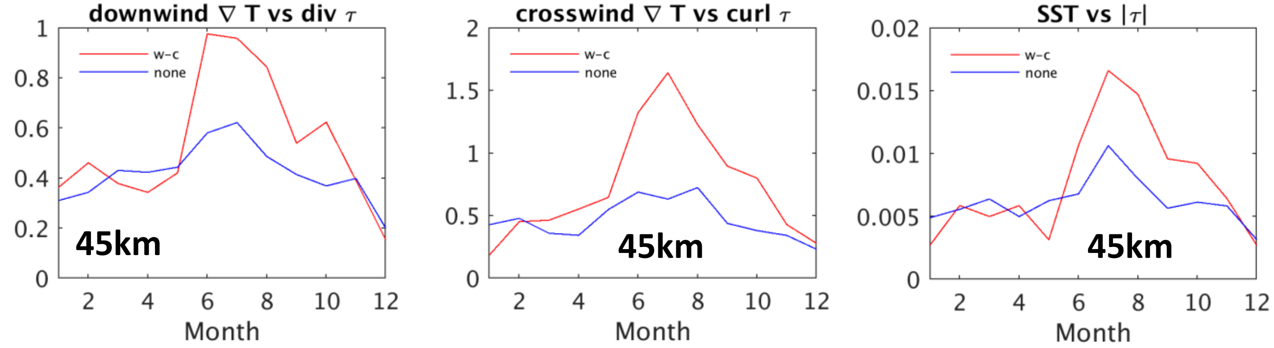
Gaube *et al.* (2015)



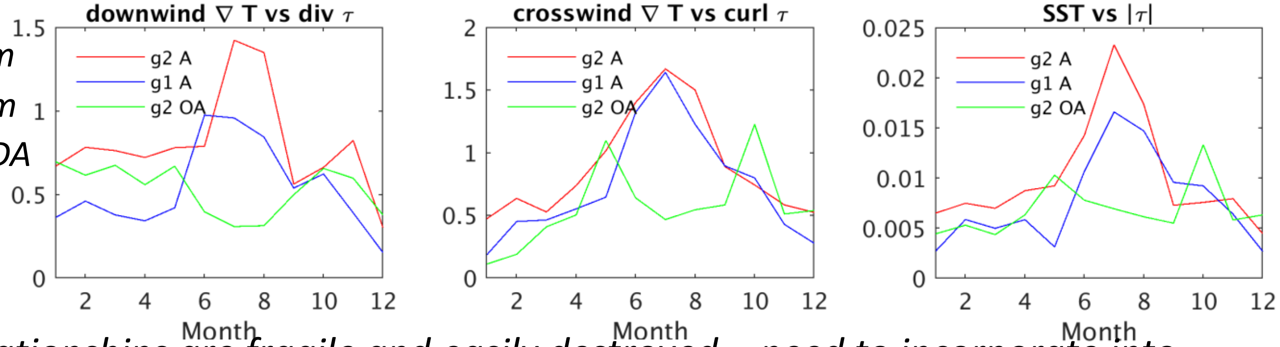
Self-advection of SST by eddies

<u>*COAMPS-ROMS CA Current – coupling coefficients*</u>

U-u
U



45km
15km
OA DA



These relationships are fragile and easily destroyed – need to incorporate into background covariance matrix

Ideas:

- **The OceanPredict Data Assimilation Task Team (DA-TT) has a current membership that represents many of the national centers and several research groups engaged in CDA. This might be a good platform for galvanizing community engagement in some kind of joint activity in line with the current plans of each center -> a joint DAOS/WGNE/OMDP/OceanPredict DA-TT activity.**
- **The Toulouse workshop was almost 5 years ago – an update on progress made since then would be very timely.**
- **Are the current issues and challenges the same as reported on the WWRP white paper?**
- **Joint ECMWF/OceanPredict Workshop on Ocean DA: CDA is a theme also -> a working group could focus on this topic**