The NCAR Coupled Model
Data Assimilation System
(CESM-DART)


National Center for Atmospheric Research (NCAR), USA
Need for Coupled Data Assimilation

- Data assimilation schemes for atmosphere and ocean are mature but independent, i.e., separate re-analyses

Why Coupled DA?

- Better and more-balanced ocean-atmosphere states
- Better use of near-surface observational data
- Better representation of coupled phenomena
- Reduce initialization shocks in S-I to decadal predictions
Multi-Component Coupled Data Assimilation (MuC)

- Coupler exchanges fluxes and other necessary information between component models
- Assimilation of conventional (surface, aircraft, etc.) observations
Initial Performance Check – Observation Space Diagnostics

- Ensemble analysis provides an estimate of analysis and forecast uncertainty
  - (Top Panel) evolution of prior and posterior RMS error
  - (Bottom Panels) profile of time-averaged prior and posterior RMS error, total spread and bias relative to the actual radiosonde temp. observations
**Multi-Component Coupled Data Assimilation (MuC)**

- Coupler exchanges fluxes and other necessary information between component models
- Assimilation of conventional (surface, aircraft, etc.) observations
No-Assimilation Coupled Model Run (CESM Free Run)

- Coupler exchanges fluxes and other necessary information between component models
- Assimilation of conventional (surface, aircraft, etc.) observations
Experiment Configurations

- What are the impacts on model biases due to assimilation of observations in multiple CESM components?
- What are the impacts on the modes of tropical intraseasonal variability, for e.g., MJO?
Reduction in SST Biases

2004 Annual Mean SST

- MuC (minus) Hurrell SST
- Ocean–C (minus) Hurrell SST
- Atmos–C (minus) Hurrell SST
- CESM Free Run (minus) Hurrell SST
Impact of DA

Trop. Eastern Pacific Example

- SST, thermocline adjustment with time
- MuC reduces SST bias, has lower RMSE
Ocean Surface Layer Thermodynamic Response

Trop. Indian Ocean
JJAS 2004

SST Difference

Latent Heat Flux Anomalies

Precipitation Difference

Results

WWOSC 2014

CESM-DART CDA

MuC (minus) CESM Free Run

SST (deg C)

MuC (minus) CESM Free Run

Total Precipitation Rate (*1e-7 m/s)

W/m^2

Longitude (degrees)
MJO State during Boreal Summer 2004

Assimilation in coupled model
- impacts atmospheric forcing (westerly wind-bursts)
- impacts air-sea coupling (SST–convection relationship)
→ improves simulation of the MJO state
MJO Forecasting Skill

- After 1 year of assimilation, a 3-week prediction is started
- Caveat: only one event

- MuC retains the MJO signal for ~5-6 days
- Drift towards model climatology after a week
- Hindcast experiments ongoing
Impact of DA in a single-component vs. MuC

Jan 11, 2004

MuC CDA
Atmos-C CDA
Ocean-C CDA

Jun 2004
Sep 2004

Jan 31, 2005

3-week prediction

Boreal Summer 2004
Impact of DA in a single-component vs. MuC

Atmos-C Experiment

- Comparable to MuC in terms of estimating atmospheric states
- Small reduction in SST bias and/or biases in other oceanic states

Ocean-C Experiment

- Comparable to MuC in terms of estimating oceanic states
- Poor job in simulating MJO or reducing biases in atmospheric states
Summary (1)

- Implementation of CESM-DART
  - multi-component coupled model framework -- test-bed for transitioning to cross-component coupled model scheme

- What are the impacts due to assimilation of observations in multiple-components in CESM?
  - reductions in model biases, improvements in model fidelity and forecasting skill

- What are the impacts on the modes of tropical intraseasonal variability, for e.g., MJO?
  - MuC improves the simulation of MJO state in terms of the amplitude (larger), seasonality (stronger), phase speed (faster)
Summary (2)

What are the differences due to assimilation of observations in a single-component vs. multiple-components?

- Single component assimilation limits the ‘full’ impact of observations across the air-sea interface, even though forecast step may be coupled.
- Ocean-C (Atmos-C) provide limited improvement in atmospheric (oceanic) states.

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<th>Atmosphere</th>
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<td>(baseline)</td>
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Ongoing/Future Activities

- **(ongoing)** Explore impact on model biases for other CESM components – land, sea-ice...
- **(ongoing)** Investigate MJO mechanisms – role of moisture, modifications in horizontal and vertical structure
- **(ongoing)** Start MuC experiment from 1960 and run decadal predictions as initial conditions become available
- **(future)** Enable CESM’s Biogeochemical Elemental Cycle Model
- **(future)** Transition towards a Cross-component Coupled Model DA system
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QUESTIONS?

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Community Earth System Model (CESM) Components

- All active components (B COMPSET)
- Horizontal Res: Nominal ~1°
- Vertical Discretization:
  - CAM – 30 levels (~2 hPa)
  - POP – 60 levels with 10 m resolution in the upper 200 m, gradually expanding to 250 m resolution below 3000 m depth

CESM Components – High Level Diagram  The coupler is in the middle and communicates with all other components (adapted from - https://summerofhpc.prace-ri.eu)
A generic ensemble filter system like DART needs:

- A way to make model forecasts
- A way to compute forward operators, $h$
- Observations, observations, observations...

(http://www.image.ucar.edu/DAReS/DART)
Known Model Biases in CESM

**SST**

- **b40_20th_1d_b08c5cn_139jp (yrs 1981-2000)**
  - Sea surface temperature
  - mean: 20.11
  - Min = -0.27 Max = 29.38

- **HadiSST (climatology)**
  - Sea surface temperature
  - mean: 20.31
  - Min = 0.10 Max = 29.60

- **b40_20th_1d_b08c5cn_139jp - HadiSST (climatology)**
  - mean: -0.20
  - rmse: 0.97
  - Min = -5.32 Max = 8.54

**Surface Stress**

- **b40_20th_1d_b08c5cn_139jp (yrs 1981-2000)**
  - Surface stress
  - mean: 0.07

- **NCEP**
  - Surface stress
  - mean: 0.06

- **b40_20th_1d_b08c5cn_139jp - NCEP**
  - Surface stress
  - mean: 0.00
  - Min = -0.14 Max = 0.07
Atmos-Component Coupled Data Assimilation (Atmos-C)

- Coupler exchanges fluxes and other necessary information between component models
- CESM B-compset: several other models (e.g. sea/land-ice) that are active
Ocean-Component Coupled Data Assimilation (Ocean-C)

- Coupler exchanges fluxes and other necessary information between component models
- CESM B-compset: several other models (e.g. sea/land-ice) that are active
SST Time-series

- MuC and Ocean-C do best in matching two independent SST datasets
- Atmos-C has a positive SST bias
- Limited adjustments to the western boundary currents – $f$(length of assimilation time)
Biases in Convective Activity

Profile at 110E
JJA 2004 Average

Vertical Pressure Velocity

CESM Free Run
Ocean–C
MuC
Atmos–C

(3A)
Biases in Sea Ice Concentration

September 2004

MuC (minus) HadISST

Ocean-C (minus) HadISST

Atmos-C (minus) HadISST

CESM Free Run (minus) HadISST
Madden-Julian Oscillation

Key Features

- Dominant mode of intraseasonal variability in the Tropics
- 30-60 day period
- Eastward propagation of large scale convective precipitation anomalies over the Indian Ocean and western Pacific
- Wide ranging impacts on the patterns of tropical and extratropical precipitation, atmospheric circulation, and surface temperature

Weak MJO Signal in CESM? (Hung et al. 2013, J. Climate)

**Boreal Winter**
Lag autocorrelation of the 30-70 day precipitation anomaly averaged between 5°N-5°S – observations show a coherent eastward-propagating signal at 7 ms⁻¹
MJO State during Boreal Summer 2004

MuC

Ocean-C

Atmos-C

CESM Free Run