Coupled model Simulation by Constraining Ocean Fields with Ocean Data thorough the JMA operational ocean data assimilation system

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1. Introduction
Coupled Model Initialization in JMA Current System

- **Atmosphere Obs.**
  - Atmospheric Data Assimilation System (JCDAS)

- **Ocean Obs.**
  - Ocean Data Assimilation System (MOVE/MRI.COM-G)

Initial Values for the Atmosphere and Ocean are prepared by the separate data assimilation systems and are affected by coupled, initial shock.

Ensemble Forecast

- Coupled Model (JMA/MRI-CGCM)
  - Atmosphere Model: TL95L40
  - Ocean Model: 1° × 0.3-1°L50

Seasonal Forecast

- El Nino Forecast
We call this “Quasi-Coupled” assimilation system and here we named the system MOVE-C.
Purpose of the Development

1. Reanalysis for seasonal-to-interannual variation researches.
   - reconstruct the effect of air-sea interactions
   - It does not depend on the atmospheric reanalysis and its errors.
   - To explore how good the climate variations are reconstructed with assimilating ocean data alone.

2. Initial Values and Ensemble members for Seasonal Forecast.
   - Avoid the coupled, initial shock.
   - Generating ensemble members reflecting the growth rate in the coupled system (e.g., Breeding in the assimilation system)

3. Prototype of a truly coupled data Assimilation System
Outline of this Presentation

1. Introduction
2. Global Ocean Data Assimilation System in JMA (MOVE-G)
3. Evaluation of the Ocean Field in MOVE-C
   →Comparison with the free run of the coupled model and the regular ocean reanalysis by MOVE-G
4. Improvement of the Atmospheric Field in MOVE-C
   →Comparison with the coupled free run and the AMIP Run
      • Precipitation in tropics, Tropical Cyclone Generation, Variability of the Monsoon, etc. is improved over AMIP Run
5. Effect of the Air-Sea Interaction
6. Final remarks

* This presentation is based on Fujii et al. 2009, *J. Climate*, 22, 5541-5557
2. Global Ocean Data Assimilation System in JMA (MOVE-G)
**MOVE System (MOVE/MRI.COM)**

**Multivariate Ocean Variational Estimation (MOVE) System**

→ Ocean Data Assimilation System Developed in MRI and JMA.

**MOVE-G**
- Lat. 0.3(Eq) ~ 1 degree
- Lon. 1 degree
- 50 layers

**MOVE-C**
- 0.5 x 0.5 degree
- 54 Layers

**MOVE-NP**
- 0.1 x 0.1 degree, 54 L.

**MOVE-WNP**
- 0.5 x 0.5 degree
- 54 Layers

Past

MRI community

Bias

First-guess

Observation
- Temperature
- Salinity
- Altimetry

Climatology
Analysis scheme in MOVE/MRI.COM (3DVAR)

Analysis Increment is represented by the linear combination of the EOF modes.

\[ x(y) = x_f + S \sum_l w_l U_l \Lambda_l y_l \]

Amplitudes of EOFs

Background Constraint

\[ J = \frac{1}{2} \sum_m \sum_l y_{m,l}^T B_l^{-1} y_{m,l} + \frac{1}{2} \left[ H(x(y)) - x^0 \right]^T R^{-1} \left[ H(x(y)) - x^0 \right] \]

Constraint for T, S observation

Constraint for avoiding density inversion

Constraint for SSH observation

Seek the amplitudes of EOF modes \( y \) minimizing the cost function \( J \).

\[ \rightarrow \text{Analysis increment of } T \text{ and } S \text{ will be correlated.} \]

See. Fujii and Kamachi, JGR, 2003
Example of Coupled T–S EOF modes

EOF modes representing North Pacific Intermediate Water (NPIW)

This mode represents
Low salinity water of NPIW → cold water
Intercomparison (GODAE)

0–100m mean temp.

- WOA01 pot. temp. 0–100 m (°C)
- CORE
- ECCOa
- ECCOd
- ECCOe
- ECMWF
- MOVE
- SODA
- UKDP

0–100m mean Sal.

- WOA01 salinity 0–100 m (PSU)
- CORE
- ECCOa
- ECCOd
- ECCOe
- ECMWF
- MOVE
- SODA
- UKDP

Monthly zonal Mean
3. Evaluation of the Ocean Field in MOVE-C
Simulation Run, Reanalysis, Observation

1. Reanalysis by MOVE-C
   - Reanalysis from 1940 using historical ocean observation data.
   - Ocean Analysis is performed once a month.

2. Regular Ocean Reanalysis by MOVE-G (MOVE-G RA07)

3. AMIP Run
   The atmospheric model same as used in MOVE-C is integrated using daily COBESST data.

4. Free Run of the coupled model used in MOVE-C

5. Regular Atmospheric Reanalysis (JRA-25, etc.)

6. Observation Data (COBESST, CMAP)

* Analysis is performed for the period of JRA25 (1979-2004).
The shading shows the deviation from COBE-SST (Observation)
Variation of the OHC on the equatorial Pacific

MOVE-C Eq. Pac. OHC

MOVE-G Eq. Pac. OHC

OHC: Ocean Heat Content
4. Improvement of the Atmospheric Field in MOVE–C
Monthly Climatology of Precipitation

(a) CMAP

(b) MOVE-C RA

(c) CGCM Run

Free Run
Monthly Climatology of Precipitation
ACC score for the monthly average precipitation

MOVE-C

AMIP-Run

Winter

Spring

Summer

Fall
Difference of SLP and Precipitation (July 1997)

MOVE-C RA

AMIP Run

July 1

July 5

July 9

July 13

July 17

July 21

July 25

July 29
Isobars are gathered and cyclonic winds are developed around the monsoon trough in MOVE-C and JRA25.

But isobars are sparse, and the winds are weak particularly south of the monsoon trough in AMIP Run.
Isobars shows the monsoon trough is not developed in AMIP compared with MOVE-C and JRA25.

The small sheer in AMIP imply the weak walker circulation, which is improved in MOVE-C.

Vertical Sheer of zonal Winds : U(850hPa)-U(200hPa)
Reproducibility of the Asian Monsoon (Jun.-Aug.)

Time Series of DU2 Index

Correlation Coefficients: MOVE 0.81 AMIP 0.60

DU2 Index (Wang and Fan, 1999) represents the strength of the summer monsoon trough. U850hPa(5-15N, 90-130E) — U850hpa(22.5-32.5N, 110-140E).
W-Y Index (Webster and Yang, 1992) represents the strength of the Walker Circulation in summer.

Average anomaly of U850hPa - U200hPa in 0-20N, 40-120E in the summer period.
Regression of 200hPa V potential to NINO3 Index

Lag 0 month

JRA25

Lag 6 month

MOVE-C

AMIP

CHI Lead0 REF

CHI Lead0 MOVE

CHI Lead0 AMIP

CHI Lead6 REF

CHI Lead6 MOVE

CHI Lead6 AMIP

Color scale:

-1.8, -1.4, -1, -0.8, -0.6, -0.2, 0.2, 0.6, 1, 1.4, 1.8
5. Effect of the Air–Sea Interaction
Negative Feedback between SST and Precipitation

- High SST promote convection
- Cool SST suppress convection
- Low SST heat SST

- This negative feedback has a role of adjusting the precipitation (avoiding the continuous rainfall over high SST regions).
- Because of the negative feedback, the variation of precipitation lagged SST about a month.
- This negative feedback does not work in non-coupled atmosphere models (and in the AMIP Run)!!
Time Lag of the precipitation behind SST

Yellow: One month Time Lag
Green: No time Lag
Significance > 99%

MOVE-C: Assimilation interval of IAU → Monthly.
It does not destroy the negative feedback.
AMIP: Overestimate of PRC at E India → Suppress the divergence over the Pacific.

MOVE: Overestimate is removed → The Walker Circulation is improved.
Correlation between SST and PRC in Jun-Aug

AMIP Run: Variation of PRC is controlled by SST.

CMAP-COBESST: The negative feedback mitigates the coupling. The atmosphere rather controls the SST variation.

MOVE-C: The negative correlation on the Philippine Sea is recovered, and the positive correlation in the Indian Ocean is reduced because of the existence of the negative feedback.
Trends in the Indian Ocean

The spurious trends in PRC is removed in MOVE-C.

→ Better than regular atmospheric reanalyses!!
6. Final Remarks
Final Remarks

- We developed the quasi-coupled data assimilation system where ocean observation data is assimilated into the coupled model, JMA/MRI-CGCM.

- Reconstruction of the negative feedback between SST and PRC in the system improves the atmospheric fields (precipitation, monsoon trough, Walker Circulation, TC generation) over AMIP Run.

- The system removes the spurious increasing trend of precipitation over the Indian seen in the regular atmospheric reanalyses.

Showing the potential of the truly coupled data assimilation system

- Improvement of the seasonal forecast skill in JMA by the system update is probably caused by the similar mechanism (the negative feedback between SST and precipitation).
Thank you
Final Remarks

- Atmospheric Data Assimilation System without coupling
  Absence of the negative feedback between SST and precipitation.
  → Degrade the reproducibility in the tropics.
    (Tropical Cyclone, Monsoon, Walker Circulation, etc.)
  If the model is nudged to the observation strongly, errors will appear where no observation exists (e.g., air-sea flux).

- Ocean Data Assimilation System
  The wind stress and the pressure gradient produced by the observed sloping thermocline is not balanced.
  → If the model TS fields are nudged to obs. strongly, the spurious vertical circulation occurs. → Correction of wind stress

- Coupled Data Assimilation System is required for resolving the problems above. → Mitigating shocks and improving the score.
Reproducibility of MOVE-G

North Pacific Intermediate Water (NPIW) Salinity Minimum (165E, 2000/4and9)

Assimilation

Observation

Currents in the mid-depth layer in the North Pacific (Climatology)
Red: Calculated from floats
Black, Gray: MOVE-G
(Gray denotes the absence of the floats data.)
ACC for PRC, SLP, 200hPa zonal Winds

MOVE-C1

AMIP

REF: CMAP, JRA25
Comparison of 0-300m Temp. (OHC)

Shading shows the deviation from WOA05.
Incremental Analysis Updates (IAU)

Past  

Assim. Run  

Forecast Run  

Forecast  

Analysis Routine  

First Guess  

Analysis (T, S)  

Analysis Increment  

Spread to each time step  

Assimilation Run  

* Analysis fields are calculated for T and S alone. Current fields are adjusted through the assimilation.

Future

Climatology

Observation

Inc = Analysis - Forecast  

Time T₀

\[ \frac{dx}{dt} = M(x) + \frac{I_{nc}}{N_{step}} \]  

Time T₁

Analysis

Assimilation Run

Assimilation Run