Effects of Ocean Initial Perturbation to ENSO Prediction in a Coupled Model
Outline

- A Coupled Model
  Model configurations

- Hindcasts of NINO3.4 (1981-2010)
  Issue in seasonal dependence of prediction

- Effects of ocean initial perturbations to ENSO prediction
  Improvement of seasonal dependence issue
Low Resolution version of CFSv2 (CFSv2L)

*a fast and seamless version* of National Center for Environmental Prediction (NCEP) Climate Forecasting System version 2, CFSv2

**Objective:**

- To enhance capability and applicability from *seasonal* to *decadal* climate simulation and prediction
Characteristics:

- Resolutions

<table>
<thead>
<tr>
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<th>CFSv2</th>
<th>CFSv2L</th>
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<tbody>
<tr>
<td>Ocean-H</td>
<td>0.5 x 0.5</td>
<td>1.0 x 1.0</td>
</tr>
<tr>
<td></td>
<td>(0.25 x 0.25)</td>
<td>(0.33 x 0.33)</td>
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<tr>
<td>Ocean-V</td>
<td>40-levels</td>
<td>40-levels</td>
</tr>
<tr>
<td>Atmos-H</td>
<td>T126</td>
<td>T62</td>
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<tr>
<td>Atmos-V</td>
<td>L64</td>
<td>L64</td>
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- CPU time of ocean for 5 days integration with 160 npes
  
  CFSv2 : 209 sec  
  CFSv2L : 25 sec  

- Enable to employ larger ensemble members

- Enable to research **wide-range investigation** for optimal physics and parameterization to employ its production version of seasonal prediction
### Characteristics:

- **Ocean mixing schemes**

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<tr>
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<th>CFSv2</th>
<th>CFSv2L</th>
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<tbody>
<tr>
<td>Lateral mixing</td>
<td>Laplacian (ksmag=2.5)</td>
<td>Laplacian (ksmag=1.5)</td>
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<tr>
<td></td>
<td>NCAR enhancement (equatorial)</td>
<td>No enhancement</td>
</tr>
<tr>
<td>Vertical mixing</td>
<td>KPP</td>
<td>KPP</td>
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<td></td>
<td>Bryan-Lewis mixing</td>
<td>Barotropic coastal tidal mixing</td>
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Ensemble Hindcast Experiments for 30 years (1981-2010)

- **Ocean and Atmos initial conditions:**
  Initial months: 01, 04, 07, and 10
  CFSR data in the first day of month
  by interpolation (bi-linear) with box-car smoothed (5 points).

- **Ensemble:** 9 members,
  perturbed by only ocean IC's of one day lagged
  CFSR data

- **Forecast:** 12 months

- **SST verification:** OISSTv2
Hindcast for NINO3.4 index, IC: 01 (Obs)
Hindcast for NINO3.4 index, IC: 04 (Obs)
Hindcast for NINO3.4 index, IC: 07 (Obs)
Hindcast for NINO3.4 index, IC: 10 (Obs)
Model Climatology in 12 Month Hindcast

SST in NINO3.4 region
30 year hindcast (ensemble average)

IC: 01
IC: 04
Model Climatology in 12 Month Hindcast

SST in NINO3.4 region
30 year hindcast (ensemble average)

Effects of ATOVS since 1999, (Kumar et al., 2012, Xue et al., 2011, Wang et al., 2011)
Seasonal Correlation Skill of NINO3.4

Correlation of seasonal NINO3.4 index (1981–2010)

(NINO3.4 index from one climatology and two climatology)
Seasonal Correlation Skill of NINO3.4

Correlation of seasonal NINO3.4 index (1981–2010)

(NINO3.4 index from one climatology and two climatology)

Spring prediction barrier
Hindcasts of 04,07 IC’s are comparable to CFSv2, but ones of 01,10 IC’s have SPB issues.
CFSv2L Correlation Skill (IC:04)


CFSv2 Correlation SST
Initial month: Mar 1982–2009
CFSv2L Correlation Skill (IC:07)


CFSv2 Correlation SST
Initial month: Jun 1982–2009
CFSv2L Correlation Skill (IC: 01)


Initial month: Dec 1982–2009
Forecast for 2015
(CFSv2L, NMME, Obs)

NINO3.4 SST forecast, IC=01

NINO3.4 SST forecast, IC=04

NINO3.4 SST forecast, IC=07

NINO3.4 SST forecast, IC=10

Blue:NMME, Green:OBS, Red:CFSv2L
(line:81ens, dashed:9ens of atmos perturb, dotted:9ens of ocean perturb)
Concluding Remarks

- Hindcasts for NINO3.4 index from April and July initial conditions are comparable with CFSv2 results.

- Hindcasts for NINO3.4 index from January and October initial conditions have the spring prediction barrier issue.
Effects of Ocean Initial Perturbation to ENSO Prediction in a Coupled Model
Argo float density in 6x6 grid (September 2015)

(In TPAC, the density is about 100%, which means 4 floats per 36 grids of 1x1)

from argo.jcommops.org
Objectives

• **Ocean Initial condition** is generated from state-art data assimilation system (eg. CFSR, GODAS), but the **small scale structures are smoothed and damped** because of limits of ocean observation, which can induce **initial errors** in the coupled model prediction.

• Can ocean initial errors from the smoothed small scale structures in sub-surface layer affect to ENSO prediction skill in a coupled model?
Configurations

• Model: CFSv2L

• Experiments: three runs from different IC’s

  - NOSM: no smoothing for CFSR ocean IC (only interpolation)
  - 5PSM: 5 point box-car smoothing for CFSR ocean IC
  - 9PSM: 9 point box-car smoothing for CFSR ocean IC

• Hindcasts: for 30 years of 1981-2010 from January and October IC’s
  with 9 ensemble member (one day lagging ocean IC of CFSR)

• Under the assumption that the ocean initial condition of NOSM is the perfect one, the comparison of 5PSM (9PSM) with NOSM can show the errors due to the initial problems of 5PSM(9PSM).
Initial Temperature Error in 1997-01 1st

(a) (5PSM-NOSM)

(b) (9PSM-NOSM)

[shade: differences, line is of 5PSM(9PSM)]

at sea surface

at 150 m depth
Initial Temperature Error in 1997-01 1st along the Equator

(a) (5PSM-NOSM)
(b) (9PSM-NOSM)

e-folding scale of response function for 5(9) point box-car low pass filter, is about 126km (228km)
Initial errors fast disappear

In western TPAC thermocline the error develops

Error at thermocline develops and propagates to the east

Cold error follows warm error in western region

Cold SST error

\( \sigma_\theta = 25 \)
Temperature Errors (5PSM-NOSM), IC:1997-01, Ens Ave.

Cold SST error

Eastward propagation

$\sigma_\theta = 25$

Error propagates to the east along thermoclines

$\sigma_\theta = 25$
Initial error fast dissipates

Eastward propagates

O(10000) km length scale
Evolution of T and U errors on 25$\sigma_0$ surface along Eq. (Ens#5 and Ens Ave. from IC: 1997-01)

Equatorial Kelvin waves

Mode3: 0.92 m/s
Mode2: 1.53 m/s
Mode1: 2.56 m/s

from the mean condition of NOSM (180W-120W, 5S-5N)
Temperature Errors between surface and thermocline along Eq. Ens ave, IC: Jan 01, (shade: SST, line: T on 25σθ)
SST Errors and along Eq. Ens ave, IC: Jan 01, (shade: SST, line: T on 25σθ)

Warm error at thermocline Induces warm SST error

Cold error at thermocline Induces cold SST error

Even T errors occur in the thermocline, there is almost no SST error
Variances (1981-2010) for SST and SST Error (5PSM and NOSM)

IC: January 01

(a) IC: January (1981-2010)

(b) IC: October (1981-2010)

IC: October 01

(c) IC: January (1981-2010)

(d) IC: October (1981-2010)

SST variance

SST Error variance
In boreal spring, minimum SST variance

In eastern TPAC, SST error variance occurs after boreal spring

SST variance

SST Error variance
Correlation Skill (1981–2010), IC: Jan 1st

SPB issue is Improving in NOSM

Only impact occurs in eastern TPAC

5PSM
9PSM
NOSM
Correlation Skill (1981–2010), IC: Oct 1st

NINO 1+2

NINO 3

NINO 3.4

NINO 4

5PSM NOSM

after boreal spring ENSO prediction skill in eastern TPAC is affected by ocean Initial errors.
Skill Spread vs. Mean Skill

Over-confidence in 5PSM (9PSM)

Even small sample size, large Ens spread occurs after boreal spring.
Total Buoyancy Flux and Variance of MLD Differences

IC: January 01

IC: October 01

(Shade:NOSM, Line:5PSM)
minimums buoyancy flux in boreal spring

after boreal spring, MLD error occurs

no MLD errors before boreal spring

small in eastern large in western

large in eastern small in western
More accurate ocean initial states can improve the boreal spring prediction barrier in the eastern tropical Pacific.

Concluding Remarks

The seasonal dependence of ENSO prediction in eastern TPAC would be associated with the surface buoyancy fluxes in the tropical Pacific.

- The sub-surface ocean initial errors in the western TPAC develop and propagates to the east in the form of the first mode of equatorial Kelvin wave with the length scale of $O(10000\text{km})$.

- The ocean resolution of CFSv2L is sufficient to resolve not only the main ocean dynamics of ENSO but also initial error evolution in the TPAC.
Seasonal RMSE of NINO3.4

RMSE of seasonal NINO3.4 index (1981–2010)

(NINO3.4 index from one climatology and two climatology)
NINO3.4 SST forecast, IC=01

Blue: NMME ave, Green: NMME ens, Red: CFSv2L