The origin and pathway of Nino3 water estimated using products of the ECCO Data Assimilation System

I. Fukumori, T. Lee, D. Menemenlis, L.-L. Fu, and the ECCO Group
Jet Propulsion Laboratory, California Institute of Technology
Consortium for Estimating the Circulation and Climate of the Ocean (ECCO/JPL-MIT-SIO)

ABSTRACT

The origin and pathway of water occupying the surface layer of the eastern Equatorial Pacific (“Nino3”) are investigated using circulation estimates of the ECCO Data Assimilation System (“ECCO-2”). The water mass is traced by a passive tracer and its adjoint that describe where the water goes and where the water came from, respectively. 35% more originate from the southern hemisphere than the north, 90% of the water originating from the subtropics pass the western boundary current. Intra-seasonal variability significantly alters the pathway by stirring the water masses.

Introduction

Subtropical-tropical exchange has been identified as a possible mechanism underlying prolonged El Niño conditions in the early 1990s and other interdecadal fluctuations of the tropical Pacific Ocean [2]. In this scenario, anomalous water subducted in the subtropics is advected over a decade to low latitudes changing the equatorial thermal structure and thereby affecting sea surface temperature and consequently El Niño. The nature of this exchange has been a subject of many investigations. Here, we examine this problem focusing on the origin and pathway of the water mass occupying the surface layer within Nino3 (150°W–90°W, 5°S–5°N), a region central to El Niño. The water mass is traced over time using a passive tracer and its adjoint using circulation estimates of the ECCO-2 ocean data assimilation system [1].

ECCO-2 Assimilation System [1]

A prototype, routine, global-ocean, data assimilation system has been established so as to monitor ocean circulation and to better understand processes underlying the seasonal-to-interannual changes. The system, “ECCO-2”, is a product of the consortium, “Estimating the Circulation and Climate of the Ocean” (ECCO, http://www.ecco-group.org), and employs a general circulation model (MTGcm) in a near-global domain (78°S–78°N) with high resolution (1° x 1°) in the tropics, 46 levels with 10m-resolution near the surface, total grid-size=326244-46,420). The GM is isentropic mixing scheme and the KPP mixed-layer formulation are employed. The model is forced by NCEP reanalysis products (time-mean replaced with those of COADS) with relaxed salinity at the surface to reduce interface observed values. Satellite sea height and in-situ hydrographic data are assimilated using a hybrid of methods (Table 1). ECCO-2 products are regularly updated (e.g., Fig. 1) and are available via the Live Access Server at http://www.ecco-group.org/ecco.

Table 1: ECCO-2 Assimilation System

<table>
<thead>
<tr>
<th>Control</th>
<th>Data Assimilated</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF</td>
<td>mixing coefficients, initial TS, forcing</td>
<td>1993-2000</td>
</tr>
<tr>
<td>PNT/PS</td>
<td>time-averaging, forcing (wind and heat flux)</td>
<td>1993-2001</td>
</tr>
<tr>
<td>Adj/PS</td>
<td>TOPEX/Posidon, Levitus</td>
<td>1993-2001</td>
</tr>
</tbody>
</table>

The hierarchy of data assimilation, including assimilation of different elements of the model uncertainties in a computationally efficient manner (GF: Green’s function, PNT/PS: partitioned NEMO and smoothed).

Passive Tracer and its Adjoint

A passive tracer can be utilized to track the circulation of a body of water: dB/dt = V . ∇V + V ∇V (1)

By using the same numerical algorithm, velocity field, and mixing tensor that operate on temperature and salinity, the tracer operates on temperature and salinity. The adjoint of the tracer describes where the water goes. The adjoint of the tracer is derived by describing the water mass trajectory distribution and the tracer field at a particular location. In particular, the evolution of the tracer describes where the water came from. The adjoint of the tracer describes where the water came from. This can be related to circulation by integrating the trajectory field along the water mass trajectory distribution and the tracer field at a particular location. In particular, the evolution of the tracer describes where the water came from. The adjoint of the tracer describes where the water came from. The adjoint of the tracer describes where the water came from. The adjoint of the tracer describes where the water came from. The adjoint of the tracer describes where the water came from. The adjoint of the tracer describes where the water came from.

Discussion

Most of the Nino3 water originates to the west of the eastern-equatorial Pacific and away from the Equator along distinct pathways (Fig. 2). These routes include the low-latitude western boundary current and the interior pathways of the southern and southern hemispheres (A, B, C, D). A coastal pathway west of Nino3 is also evident along Central and North America (E). The circulation in the interior and LSWC is largely confined within the thermocline (Fig. 4), whereas the coastal pathway mostly resides in the surface layers. In each hemisphere, the LSWC carry 70-90% of the meridional transport (Table 2). The coastal transport in the northern hemisphere is relatively small. On average, nearly 30% of the Nino3 water originates from the northern hemisphere rather than the northern hemisphere. Mean transit times (mode) between the subtropics and Nino3 is about 10 years (Fig. 5). Approximately 15% of the Nino3 water is found in the surface mixed-layer 10-years prior to nearly equal amount in the eastern basin of each hemisphere (Fig. 5). The subtropical water in the northern hemisphere is slightly less dense and extends further westward than found in the southern hemisphere. The intra-seasonal variability plays a significant role in stirring the water mass, resulting in a much larger interannual transport than the pathway inferred from either seasonally averaged or time-mean circulation (Fig 6).

The adjoint tracer elucidates the “slaving” of the thermocline associated with the 97-98 El Niño (Fig. 7). In particular, the western end of the water mass coincides with the movement of the 28°C isotherm [3].

The forward passive tracer (Fig. 8) illustrates where Nino3 water goes after reaching Nino3. The water circulates westward away from the equator in the upper ocean to the subtropics, above the subtropical-pathway identified by the adjoint tracer (Fig. 4).

Conclusion

Subtropical-tropical mass exchange is investigated using a passive tracer and its adjoint based on circulation estimates of an ocean data assimilation system. In the absence of sources and sinks, the evolution of passive tracer describes where the water goes. In comparison, evolution of the adjoint tracer can be identified as describing where the water came from. The tracers reflect effects of both advection and mixing. Nearly 80% of the subtropical water mass reaching Nino3 travels via the low latitude western boundary currents. The remaining 20% directly reaches the tropics by the interior pathway. Mean transit times are approximately 10-years. Intra-seasonal variability of the tropical ocean significantly alters the mean pathway that reaches Nino3. In particular, influences made by seasonal and/or time-mean circulation significantly underestimates the magnitude of the interior pathways.

References

Fig 1: Zonal Velocity and Sea Level Anomalies along Ω

The regular routine updates of ECCO-2 (left) provide near real-time analyses of the complete state of the ocean that complement observations (e.g., TAO on right).

Fig 2: Testing Passive Tracer (a, b) and Its Adjoint (c, d)

The origin of water in Nino3 (top 10m) on 31 Dec 2000 is examined using a passive tracer (left) and adjoint (right), respectively integrated by the ECCO-2 circulation estimates. The passive tracer is released on 1 Jan 2000 in the thermocline in the eastern-equatorial Pacific (150°E-160°W, 5°S–5°N). The adjoint tracer is initialized in Nino3 on 31 Dec 2000. Both tracers are interval to unity on arbitrary tracer unit, ATL. Figure shows zonal sections (a, c) and depth-integrated plain views (b, d) for the respective results after 1-year integration. Both results show that 25% of the Nino3 water originated from the eastern equatorial thermocline 1-year prior.

Fig 3: Column Velocity and Sea Level Anomalies along Ω

The regular routine updates of ECCO-2 (left) provide near real-time analyses of the complete state of the ocean that complement observations (e.g., TAO on right).

Fig 4: Vertical Sections of Adjoint Tracer (ATU/m3)

Contours are potential density (C.I.=1 kg/m3; thick curve is 26.56 kg/m3).

Fig 5: Mode Transit Time of Column Integrated Adjoint Tracer (years) (left) and Adjoint Tracer within the Mixed Layer at Year-10 (ATU/m2) (right)

Contours are potential density (C.I.=1 kg/m3; thick curve is 26.56 kg/m3).

Fig 6: Column Integrated Nino3 Adjoint Tracer (ATU/m2) at Year-5.

Fig 7: Zonal Section (a) (ATU/m4) and Column Integrated Nino3 Adjoint Tracer (ATU/m3) 1-year Prior Starting from 31 Dec 1997. Contours are potential density (C.I.=1 kg/m3; thick curve is 26.56 kg/m3).

Fig 8: Column Integrated Passove Tracer (ATU/m2) and Meridional Section (ATU/m3)

Fig 9: Column Integrated Nino3 Adjoint Tracer (ATU/m2)