Deep transient circulation resulting from the initialization of an ocean ensemble assimilation system

Alicia R. Karspeck
National Center of Atmospheric Research
Boulder, CO

Steve Yeager and
Gokan Danabasoglu

Tim Hoar, Nancy Collins,
Kevin Raeder, and Jeff Anderson

At the National Center for Atmospheric Research, a 48-member ensemble adjustment Kalman filter (EaKf) is being used to assimilate daily subsurface temperature and salinity data into the POP 1°x1° global ocean model. EaKf systems are typically initialized with an ensemble of model states that represent a climatological distribution. Over many cycles of the assimilation system, the ensemble narrows into a distribution that is a function of the internal variability of the system and the observations that are constraining it. A well-equilibrated ensemble should not be strongly influenced by the choice of the initial ensemble. The POP/EaKf system was initialized in model-yr 1998, with the goal of having an equilibrated ensemble of ocean states by model-yr 2000. While the dynamic time-scales of the upper ocean support this choice of "burn-in" time, we show here that the deep ocean can be sensitive to the initial ensemble for about a decade. We illustrate this here with a case-study from the equatorial Atlantic Ocean, where the choice of initial ensemble leads to spurious, transient behavior that impacts large-scale climate variables like the vertically integrated northward heat transport and the meridional overturning circulation.

An unusually large deep counter circulation

A 48-member EaKf has been used to assimilation daily subsurface observations of temperature and salinity into the POP ocean model ("POPDART"). Each member of the ensemble was forced with a unique sample of a CAM4 atmospheric analysis. For comparison, we also used the CAM4 ensembles to force the identical model, with no assimilation ("NoAssim"). Assimilation of data into complex numerical models can sometimes yield surprising results. Here we report on one such phenomena in the northern hemisphere Atlantic basin.

Fig. 1 shows the 4-yr average Atlantic meridional overturning streamfunction (AMOC) with and without assimilation. Data assimilation results in a strong, deep, counter circulation on the northern side of the equator. Fig. 2 shows the northward heat transport in the two experiments averaged over the same period. The higher basinwide mean transport results from the stronger circulation in the upper 1000m. The reduction in heat transport between 0 and 10°N appears to be related to the deep counter circulation.

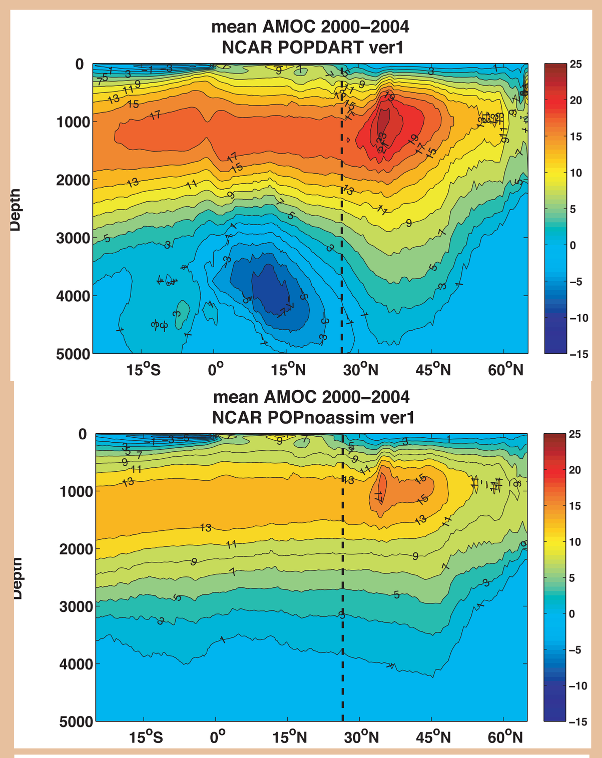

Fig. 1

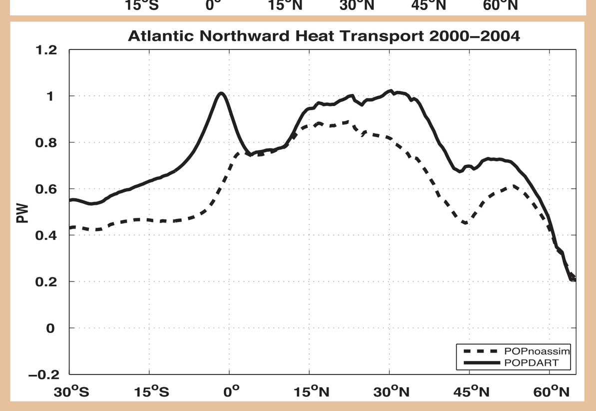

Fig. 2

Transient Northward Flow

Fig 3. shows a closer view of the deep tropical cell. The bottom panel is an 8yr (monthly) time series of the streamfunction at 4000m depth and 12°N. The strength of the counter circulation reduces in time. Fig. 4 shows that the initial increase in magnitude is related to changes in the position of the cell, not its strength. Within approximately a year, it shifts 7° to the north before continuing to decline in strength.

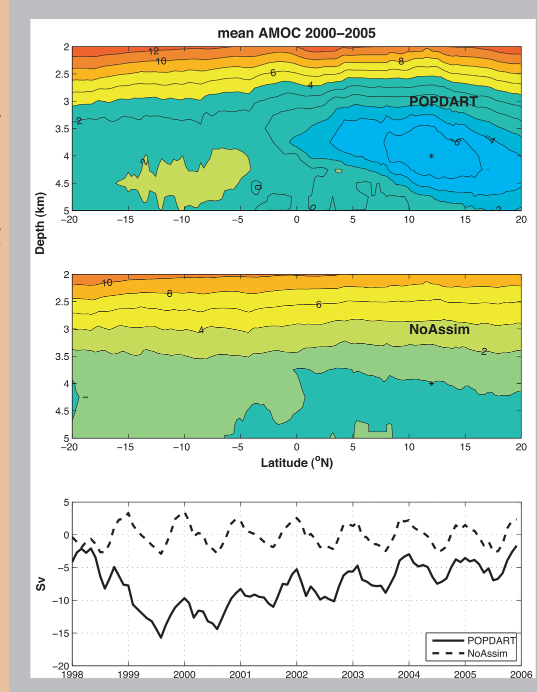

Fig. 3

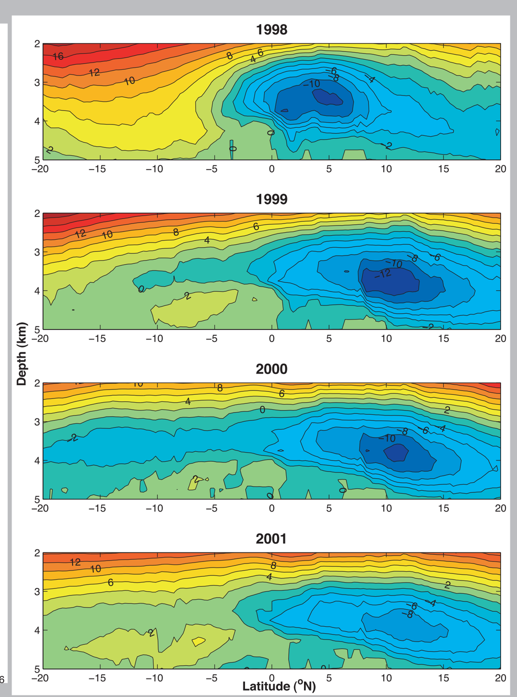

Fig. 4

What is the nature of this deep northward transport?

Fig. 5 shows the temperature and velocity vectors on the densest layers of the deep tropical Atlantic (annual average in the year 2000 of the assimilation). The flow of cold, fresh water appears to originate at the equator and moves northward – following downward through the narrow channel bathymetry between the Mid-Atlantic Ridge and the northeast continental shelf of South America into the abyssal plane. The current has horizontal speeds reaching ~3 cm/s, comparable to those found in the deep western boundary current. There is no equivilent annual averge flow in the NoAssim run.

Fig. 6 shows bathymetric contours of the region. The square shows the region of flow origin and the stars indicate points along the path of the current. Fig. 7 shows the montly time evolution of temperature at the deepest model levels along the starred transect from Jan 1998 to Dec 2005. This shows the cool (and fresh- - not shown) front being set up within the first month of assimilation and traveling the length of the transect. The extra-tropical abyssal plane continues to slowly cool over the 8years of the experiment.

All evidence indicates that the flow is a gravity current induced by high density waters atop the equatorial bathymetric plateau separating the basin north to south. The current is not passively advecting cool waters into the basin, but is driven by buoyancy and steered by bathymetry. The overturning streamfuntion (Fig. 4) shows the transport front that rapidly passes down the slope. Over time, the temperature gradient along the transect diminishes, and the flow subsides.

Where do these dense waters come from?

While there are many subsurface observations in the upper kilometer of the ocean, the ocean below 2000m is not well observed. Particularly, in the Atlantic there were no observations taken below 2000m within 10° of equator from Jan 1998 until July 1999. Yet Fig. 8 (top panels) shows that the temperature betlow 3000m in the box was cooling by over half a degree within the first year of the assimilation. Fig 8 (middle panel) shows additionally that this was due to increments in the data assimilation scheme -- which is to say that it emerged from the data assimilation, not through integration of the model. Strong correlations (on daily time-scales) exist between the temperatures/salinites in the upper kilometer and below 3000m (not shown) that allow surface observations to impact the temperature and salinity at depth. High initial variability at depth enables these increment to be relatively large.

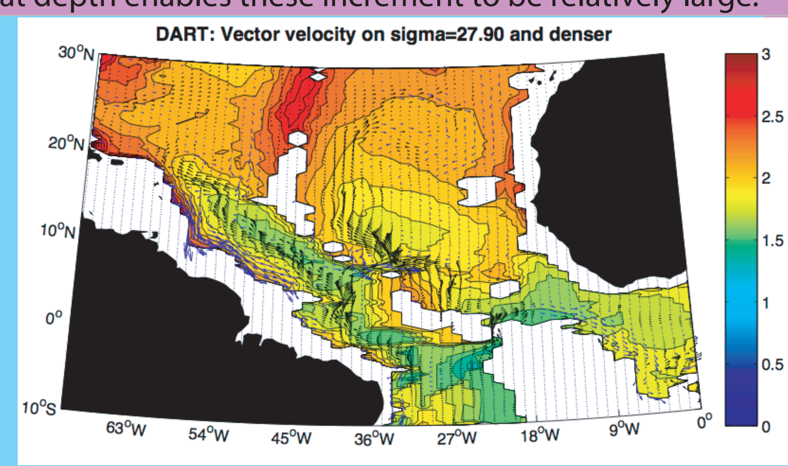

Fig. 5

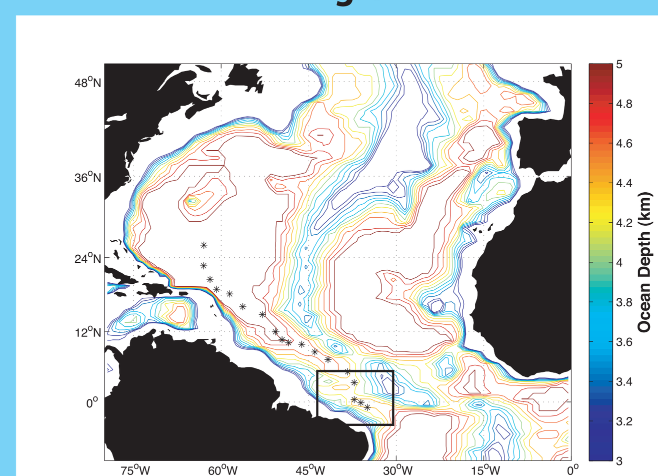

Fig. 6

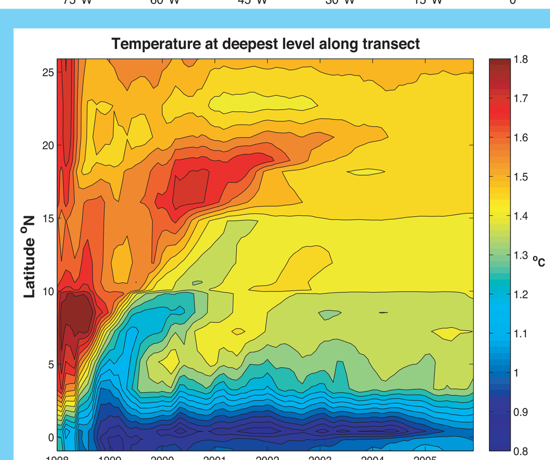

Fig. 7

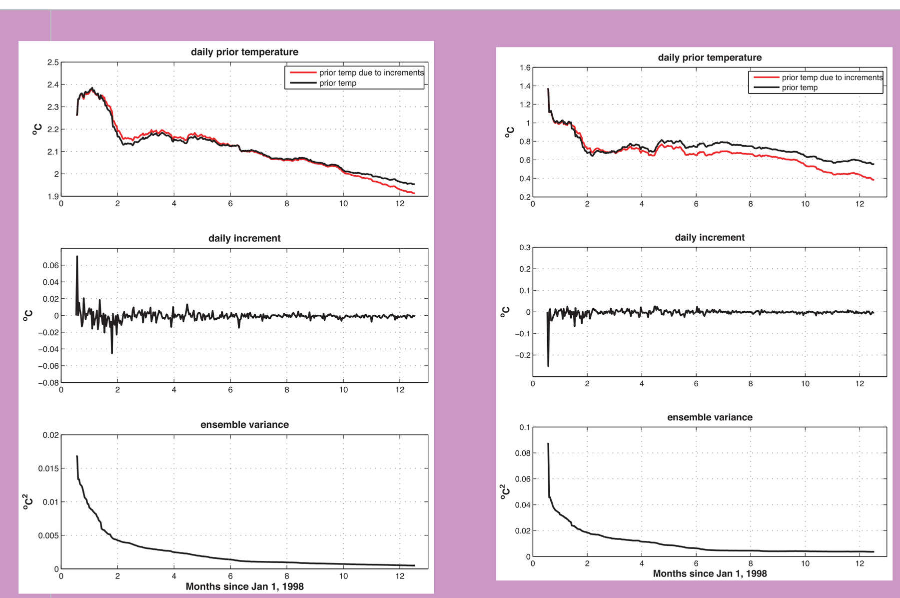

Fig. 8 Daily prior temperature (top panels), increments (middle) and ensemble variance (bottom) west of equatorial mid-Atlantic ridge. Left: average from 3000m to 4000m. Right: average below 4000m

Summary

Because of strong vertical covariance in the equatorial Atlantic, the initial assimilation of upper ocean data leads to the formation cool, fresh (dense) waters at the deep equatorial plateau. A rapidly forming gravity current carries these waters into the abyssal basin of the northern Atlantic, forming the deep counter-circulation in the AMOC streamfunction and impacting the vertically integrated northward heat transport. While transient, these features last long into the life of the assimilation.

The rapid acceleration of the flow is almost certainly a spurious feature caused by the data assimilation system. However, CTD observations of the temperature and salinity in this region that become available in July of 1999 show good agreement with the assimilation temperatures (they are range between .75 and 1°C below 4000m).

The equatorial plateau within the box in Fig. 6 divides the cool, fresh waters of the southern basin (fed by Antarctic Bottom Water -- AABW) from the relatively warm, saline waters of the deep northern hemisphere Atlantic. The connection between these basins is a very narrow, steep channel. This channel normally carries ~2Sv of AABW into the north Atlantic (Rhein et al.,1998). Presumably, the course bathymetry (at least) of this version of POP inhibits this flow, setting up a large north-south density gradient, such that a perturbation of cool water at the equator drives a vigorous downward and northward gravity current.

The introduction of dense waters could be controlled in the EaKf by localizing in the vertical. However, the long-term impact of forming these waters is positive in the sense that it cools the deep Atlantic basin to more realistic temperatures. A very long burn-in time (on the order of a decade) appears to be required for the deep ocean to "forget" its initial ensemble. This is a computationally difficult demand and alternative solutions are being explored.

Please see compansion poster is this session entitled **Ensemble Data Assimilation in CESM/POP and CAM** for a more complete descritpion of the POPDART data assimilation system.