Inter-annual predictability of net primary productivity (NPP) in the central equatorial Pacific

Why is NPP longer predictable than SST?

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NPP is longer predictable than SST in the central equatorial Pacific

Correlation of yearly means in the central equatorial Pacific (CEP, 170°W-120°W, 5°S-5°N)

Net primary productivity (NPP)

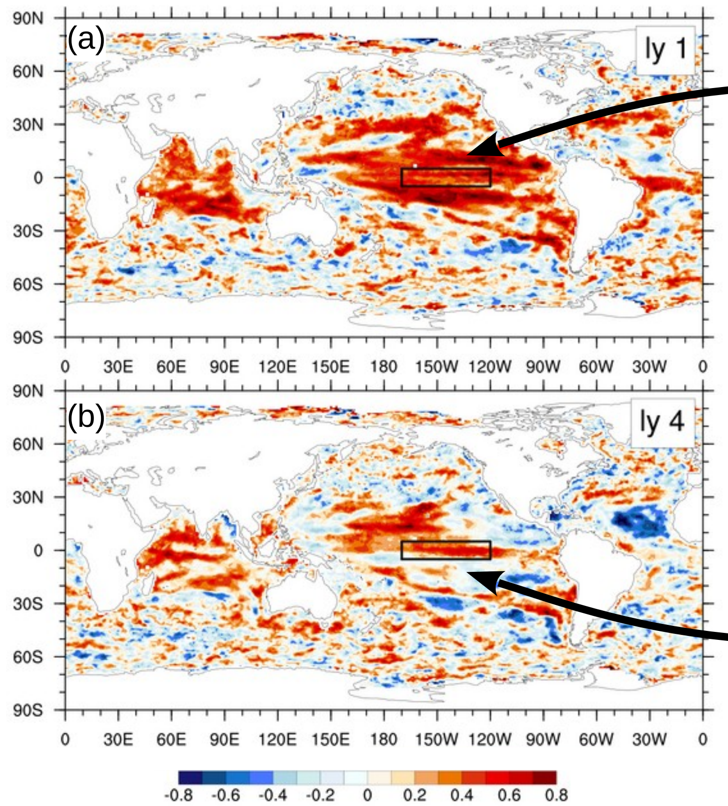


Fig.1 Correlation of 1998-2014 simulated NPP for (a) lead year 1 and (b) lead year 4 with VGPM data (Behrenfeld & Falkowski 1997) derived from SeaWiFS/MODIS satellite missions retrieved via http://science.oregonstate.edu/ocean.productivity/index.php). Black box indicates CEP.

NPP predictable
in lead year 1

**NPP still predictable
in lead year 4**

SST predictable
in lead year 1

**SST hardly predictable
in lead year 4**

Sea surface temperature (SST)

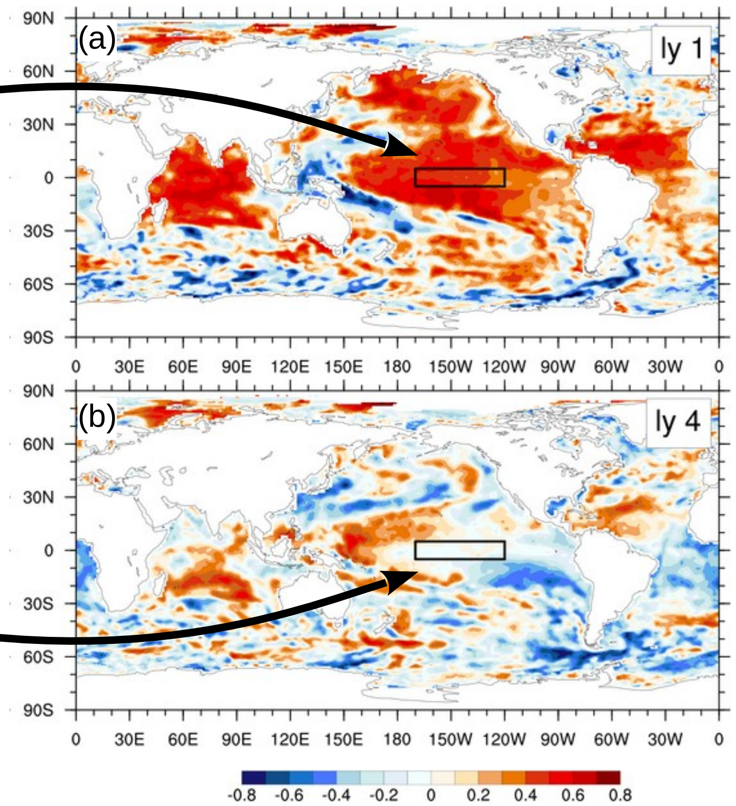


Fig.2 Correlation of 1998-2014 simulated SST for (a) lead year 1 and (b) lead year 4 with HadISST (Rayner et al. 2003). Black box indicates CEP.

Max Planck Institute Earth system model MPI-ESM-LR (*Giorgetta et al. 2013*):
10 year hindcasts (*Brune et al. 2018*), 8 member ensemble mean, yearly initialized by

- oceanic global EnKF assimilation of EN4 profiles (*Good et al. 2013*),
- atmospheric nudging to ERA40/ERAInterim (*Uppala et al. 2005, Dee et al. 2011*).

Nutrient and productivity diagnosis with HAMOCC (*Ilyina et al. 2013*)

NPP predictions in CEP benefit from initialization

Correlation of yearly means in the central equatorial Pacific (CEP): **NPP better predictable than SST in lead years 2 to 6**
What **process** could be responsible for **NPP multi-year memory**?

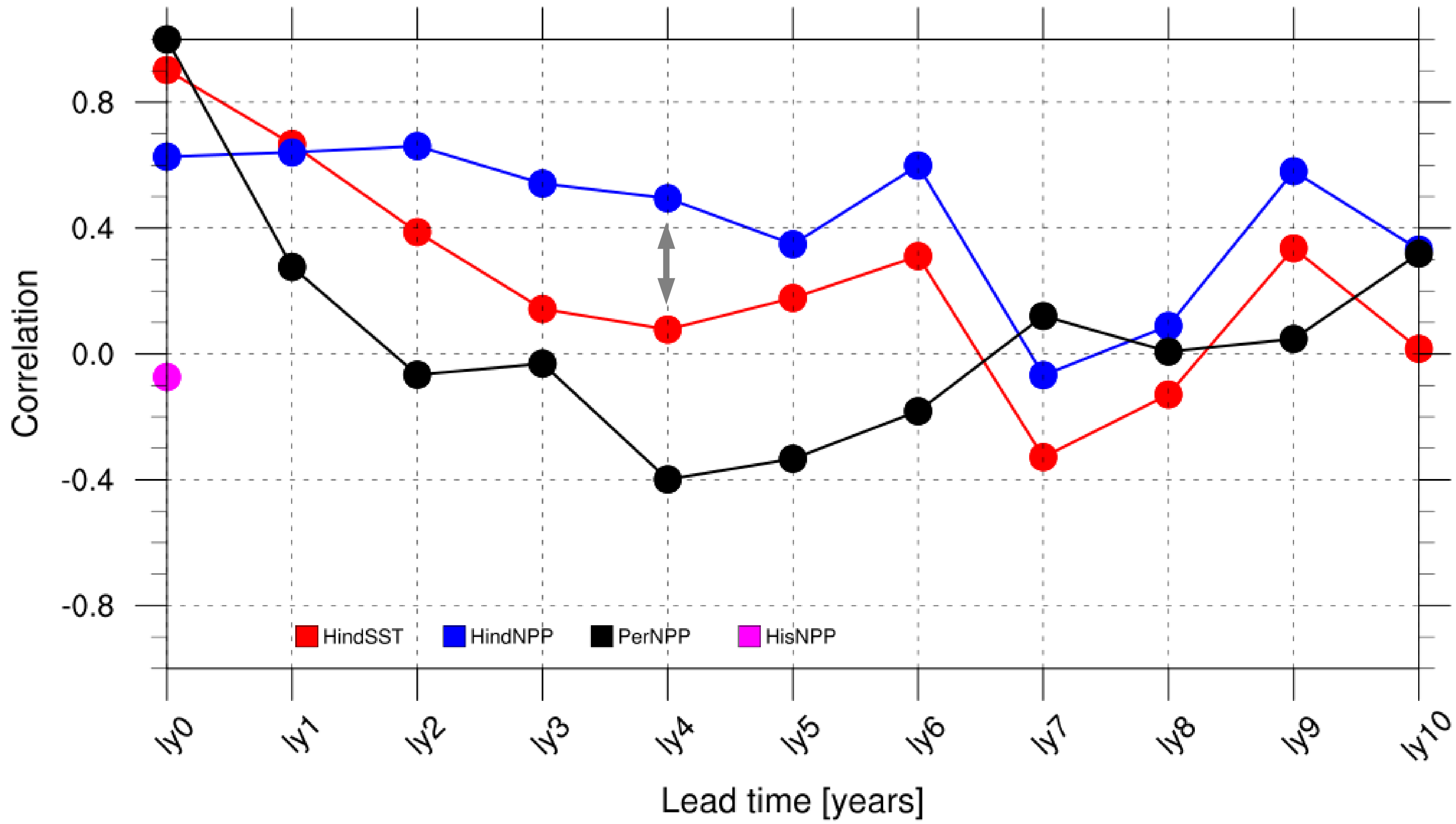


*Fig.3 Correlation of 1998-2014 simulated yearly mean central equatorial Pacific mean **NPP (blue)** and **SST (red)** for lead years 0 (assimilation) to 10 with VGPM data derived from SeaWiFS/MODIS satellite missions and HadISST. Persistent NPP (black) and NPP from an uninitialized prediction (purple) are plotted for reference.*

What process could be responsible for NPP multi-year memory?

A candidate: properly initialized oceanic **off-equatorial Rossby waves** with multi-year travel times across the Pacific *(Killworth et al. 2004).*

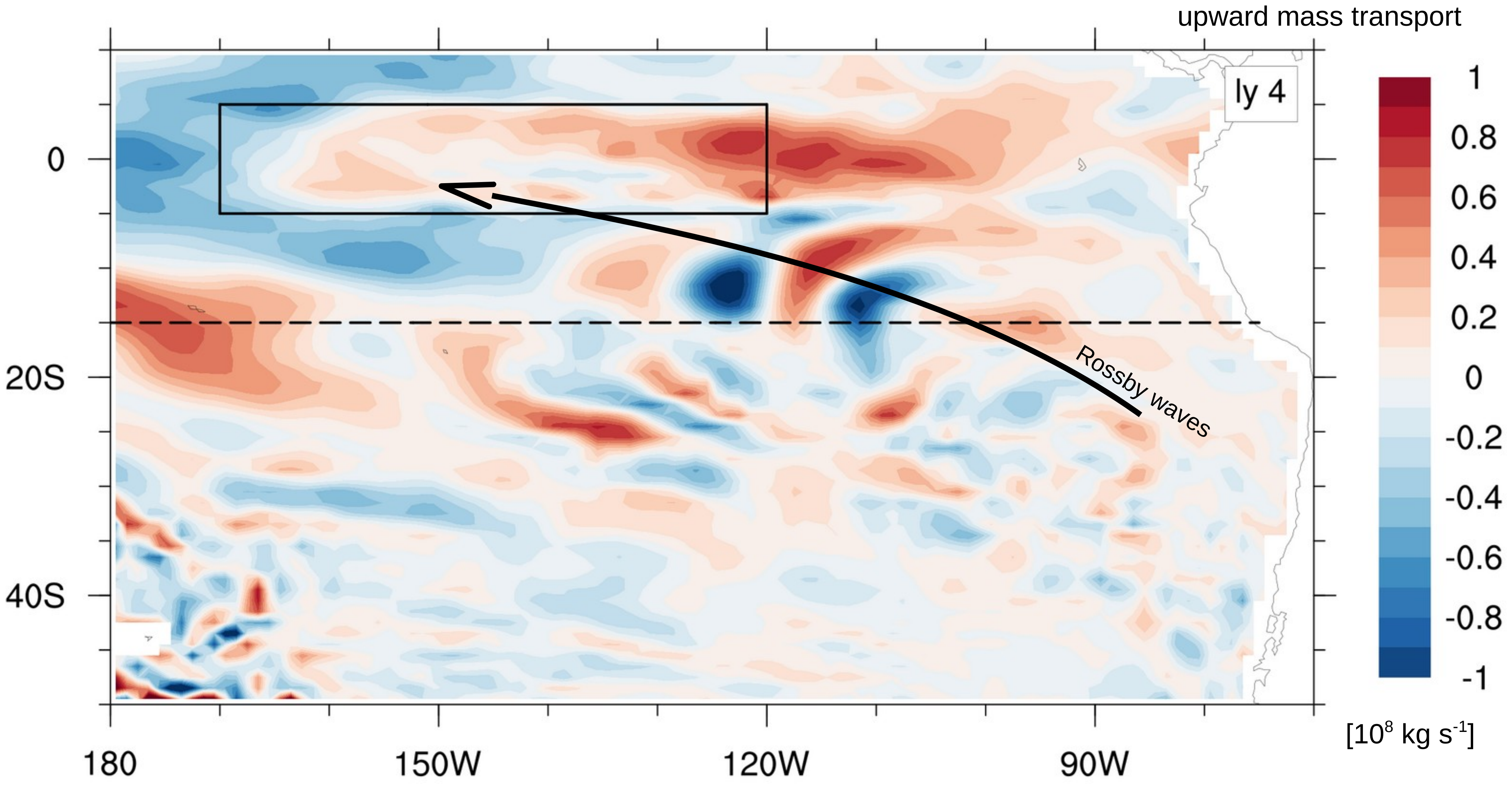


Fig.4 June 2004 snapshot of lead year 4 anomaly of upward ocean mass transport at 200m depth. A ***Rossby wave train (arrow)*** *travels from off-shore South America in the direction of the central equatorial Pacific (CEP, box indicated). Dashed line indicates 15°S.*

What process could be responsible for NPP multi-year memory?

Off-equatorial Rossby waves **modulate the nutricline** and thermocline on inter-annual time scales.
Nutricline and thermocline are elevated in the positive phase of the Rossby wave, and lowered in the negative phase.

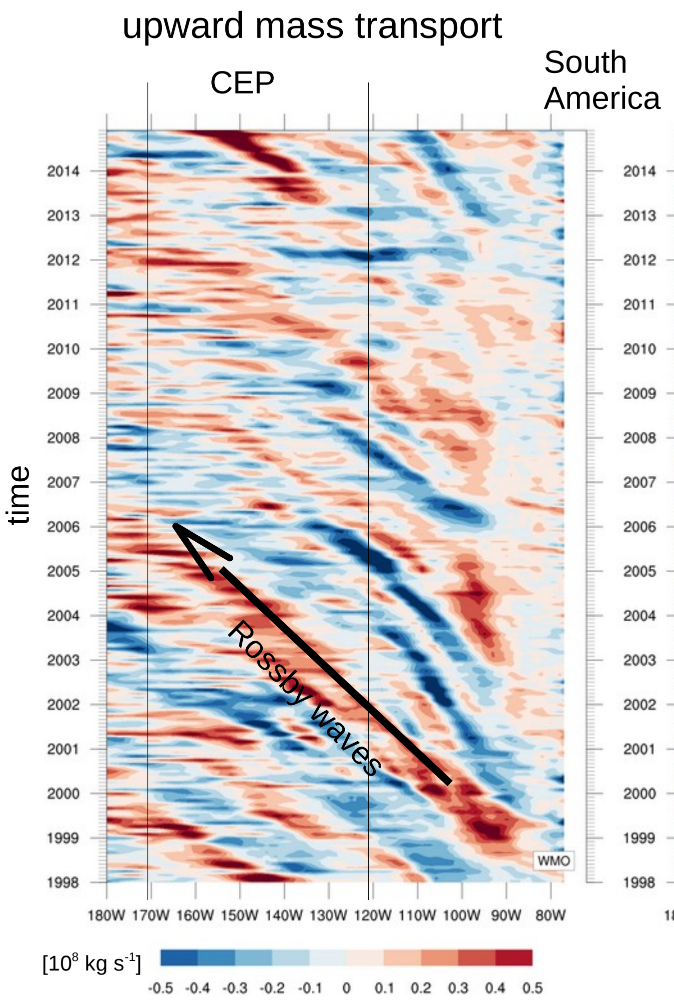


*Fig.5 1998-2014 Hovmöller plot of anomaly of **upward ocean mass transport** at 200m depth at 15°S, concatenated lead years 4.*

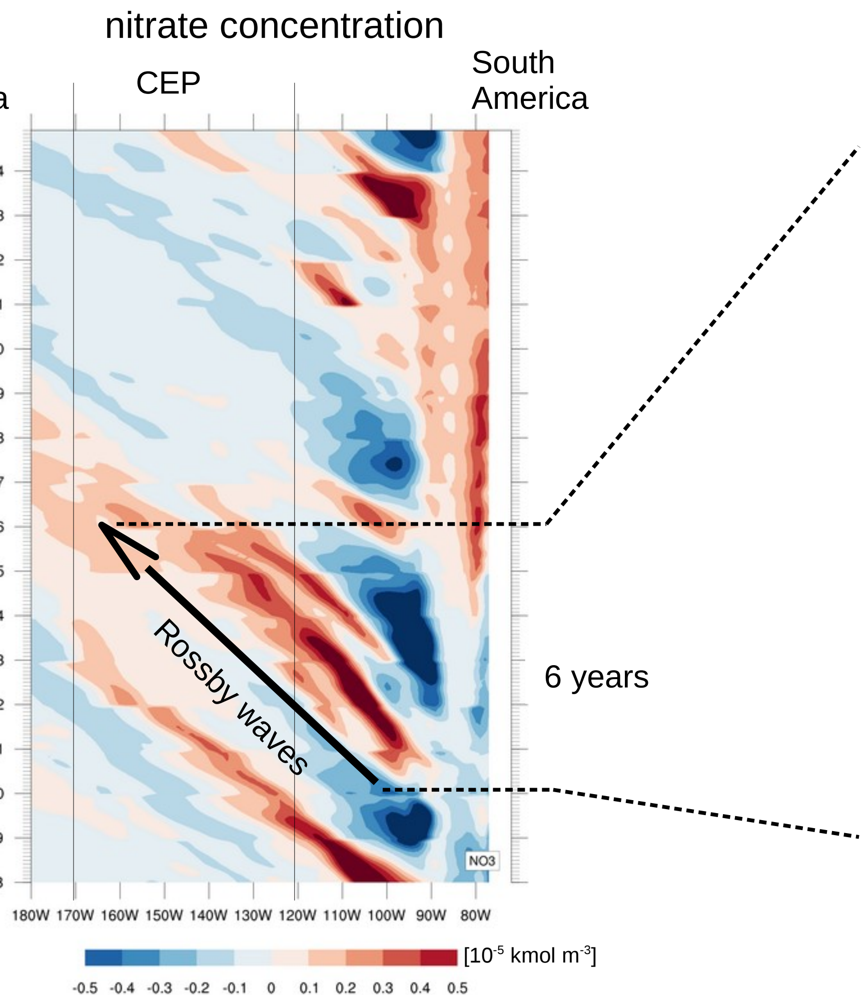


*Fig.6 1998-2014 Hovmöller plot of anomaly of **nitrate concentration** at 200m depth at 15°S, concatenated lead years 4.*

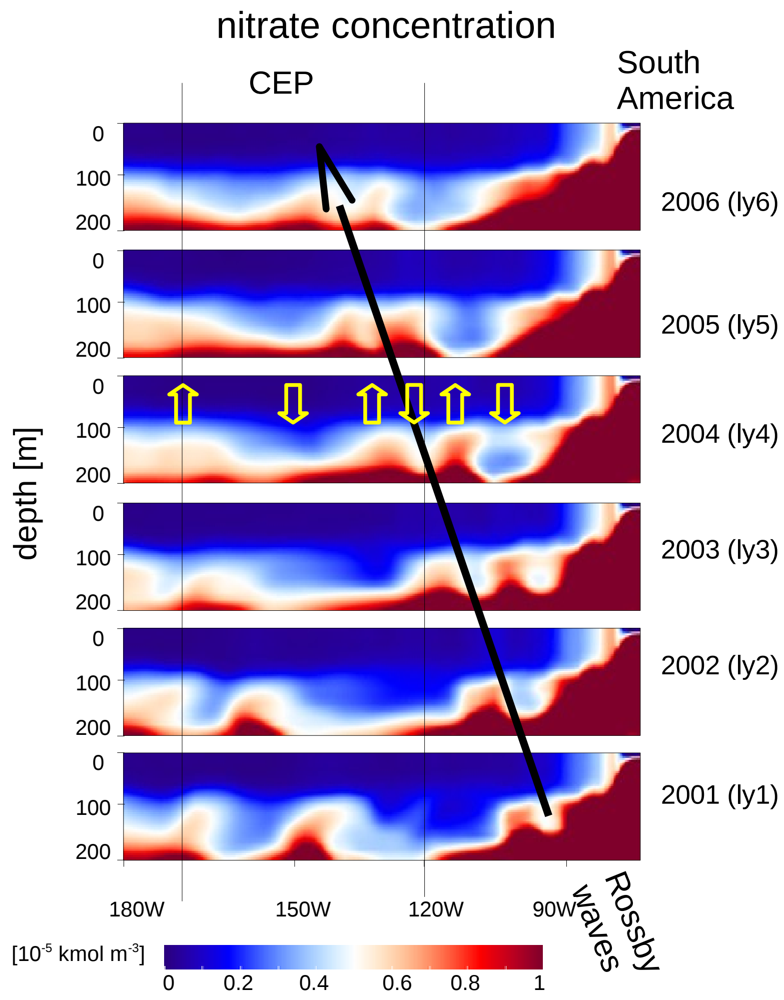


*Fig.7 2001-2006 June **nitrate concentration along** 15°S, ensemble mean hindcast started January 1st, 2001, **modulation of nutricline due to Rossby waves** (yellow arrows) illustrated for 2004.*

Seasonal upwelling transfers nutrients to surface productive layer

In a positive phase of the Rossby wave, seasonal upwelling **replenishes nutrients and cools** the water in the surface layer more than in the negative phase. **Primary productivity changes with the nutrients** while **surface temperature quickly adjusts** to atmospheric temperatures.

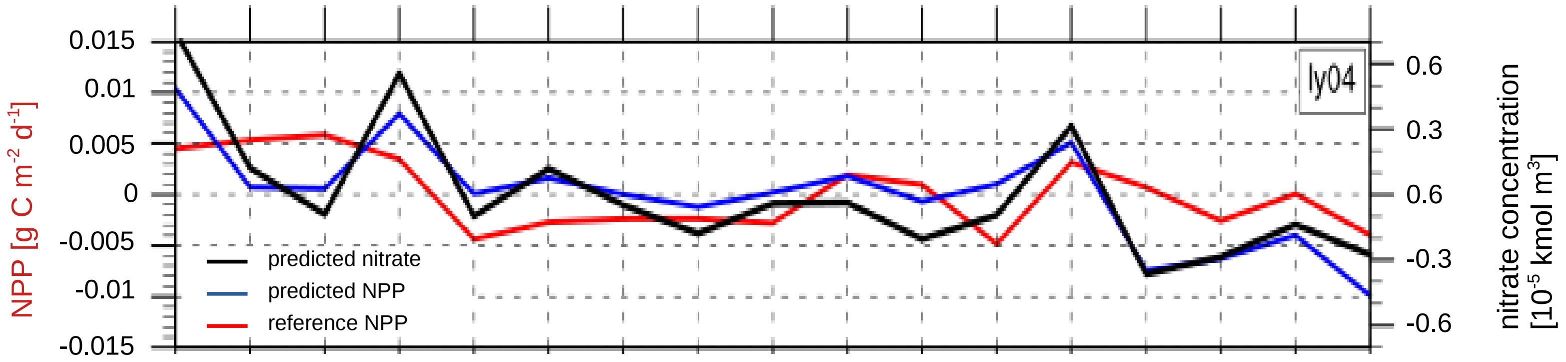


Fig.8 1998-2014 yearly mean anomaly of predicted nitrate concentration (black, 0-100m mean) and predicted NPP (blue), concatenated lead years 4, and reference NPP from SeaWiFS/MODIS (red) in the CEP.

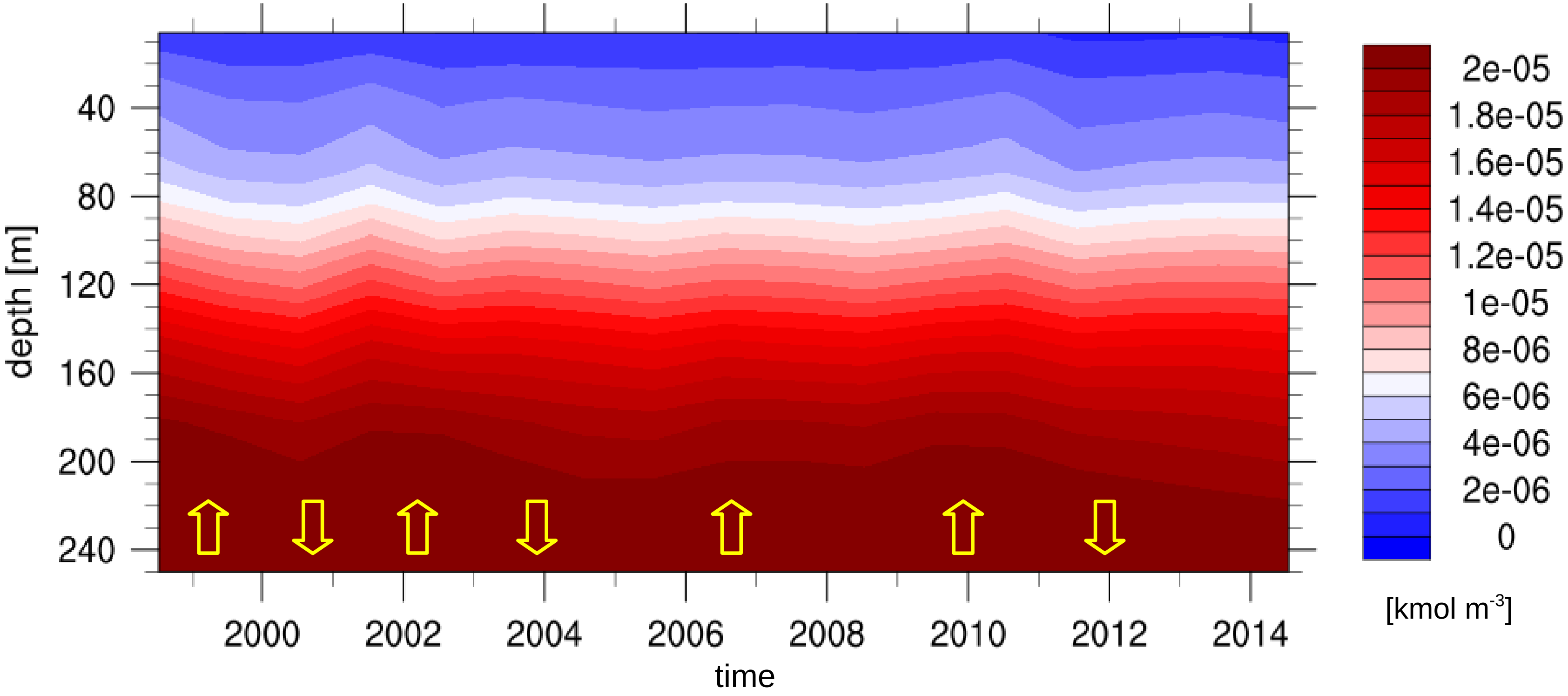
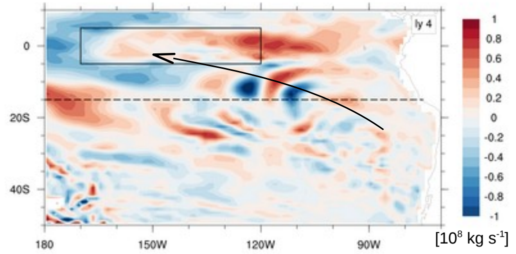


Fig.9 1998-2014 predicted yearly mean nitrate concentration in the CEP above 250m, concatenated lead years 4, modulation of nutricline due to Rossby waves indicated by yellow arrows.

NPP in CEP is longer predictable than SST due to Rossby waves

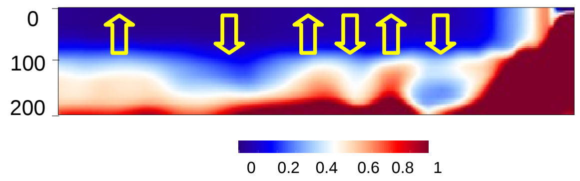
Proper initialization of off-equatorial Rossby waves with multi-year travel times

MPI-ESM with oceanic EnKF assimilation + atmospheric nudging (Brune et al. 2018)



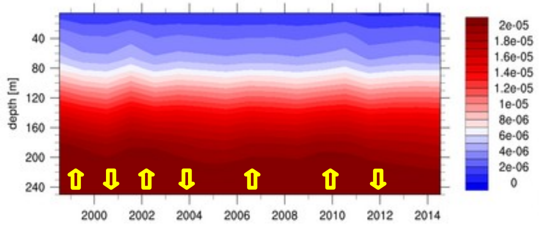
Rossby waves modulate on inter-annual time scales:

- **nutricline** (shallower in positive phase),
- **thermocline** (shallower in positive phase).



In the positive phase of a Rossby wave, the seasonal equatorial upwelling supplies to the surface layers (vice versa in a negative phase):

- **nutrient rich waters** from deeper layers, and
- **cool water** from deeper layers.



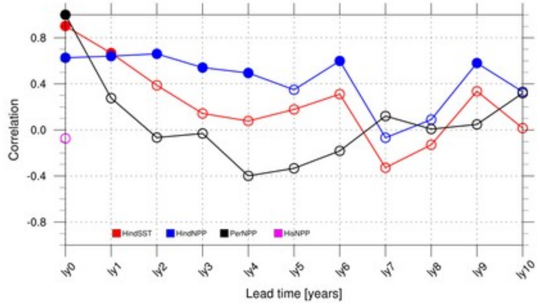
Surface layer interacts with atmosphere on subseasonal time scales.

Nutrients
independent of atmosphere

Net primary productivity depends on nutrient signal → **NPP predictable**

Temperature
quickly adjusts to atmosphere

Sea surface temperature (SST) signal destroyed by unpredictable atmosphere → **SST not predictable**



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The inter-annual signal of properly initialized off-equatorial Rossby waves is conserved for nutrients and primary productivity but not for surface temperature.

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