Wind-driven Response of the Northern Indian Ocean to Climate Extremes

Tommy G. Jensen

International Pacific Research Center

CLIVAR Indian Ocean Workshop

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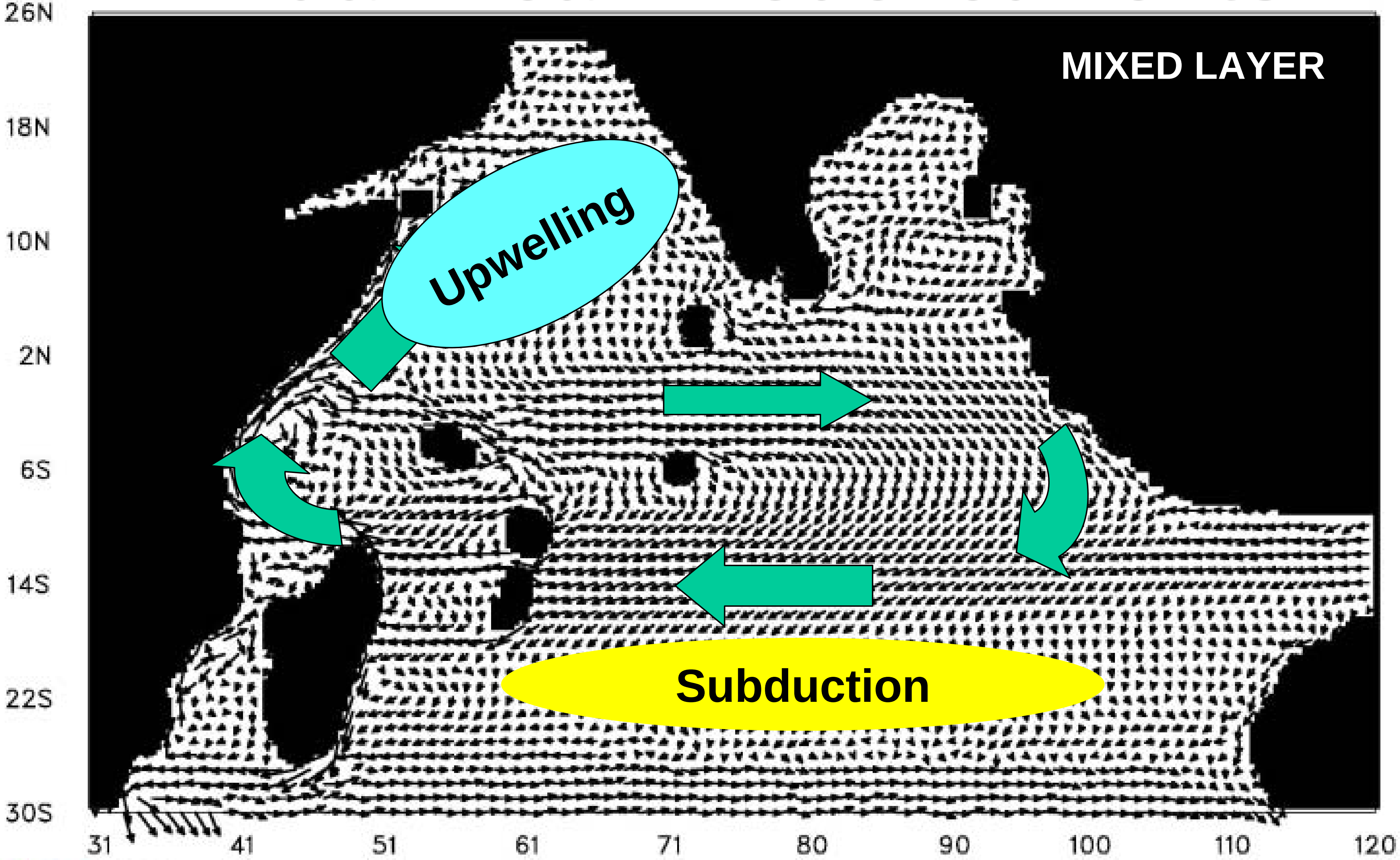
Motivation

- Pathways of water masses in the Indian Ocean are part of a cyclonic cross-equatorial cell with shallow overturning (McCreary et. al, 1993; Miyama et al., 2003; Jensen, 2003)
- Recent research on climatological exchanges between the Arabian Sea and the Bay of Bengal Jensen (GRL, 2001); Jensen (DSR, 2001)
- How are the circulation cell and the exchanges affected by events like El Nino, La Nino and the Indian Ocean dipole ?

Annual mean model currents



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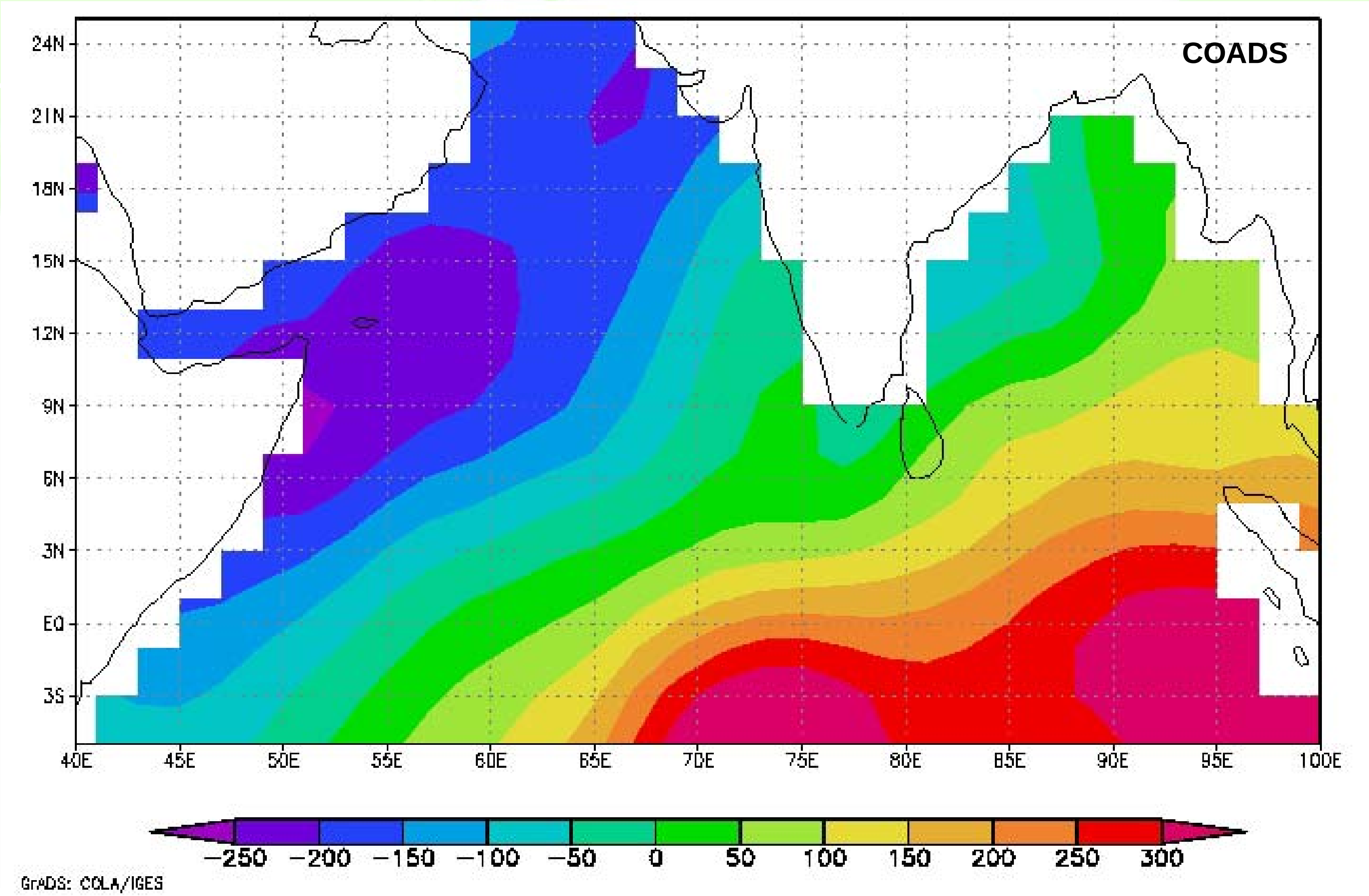
Annual Mean P - E



4.5 Layer Model Configuration

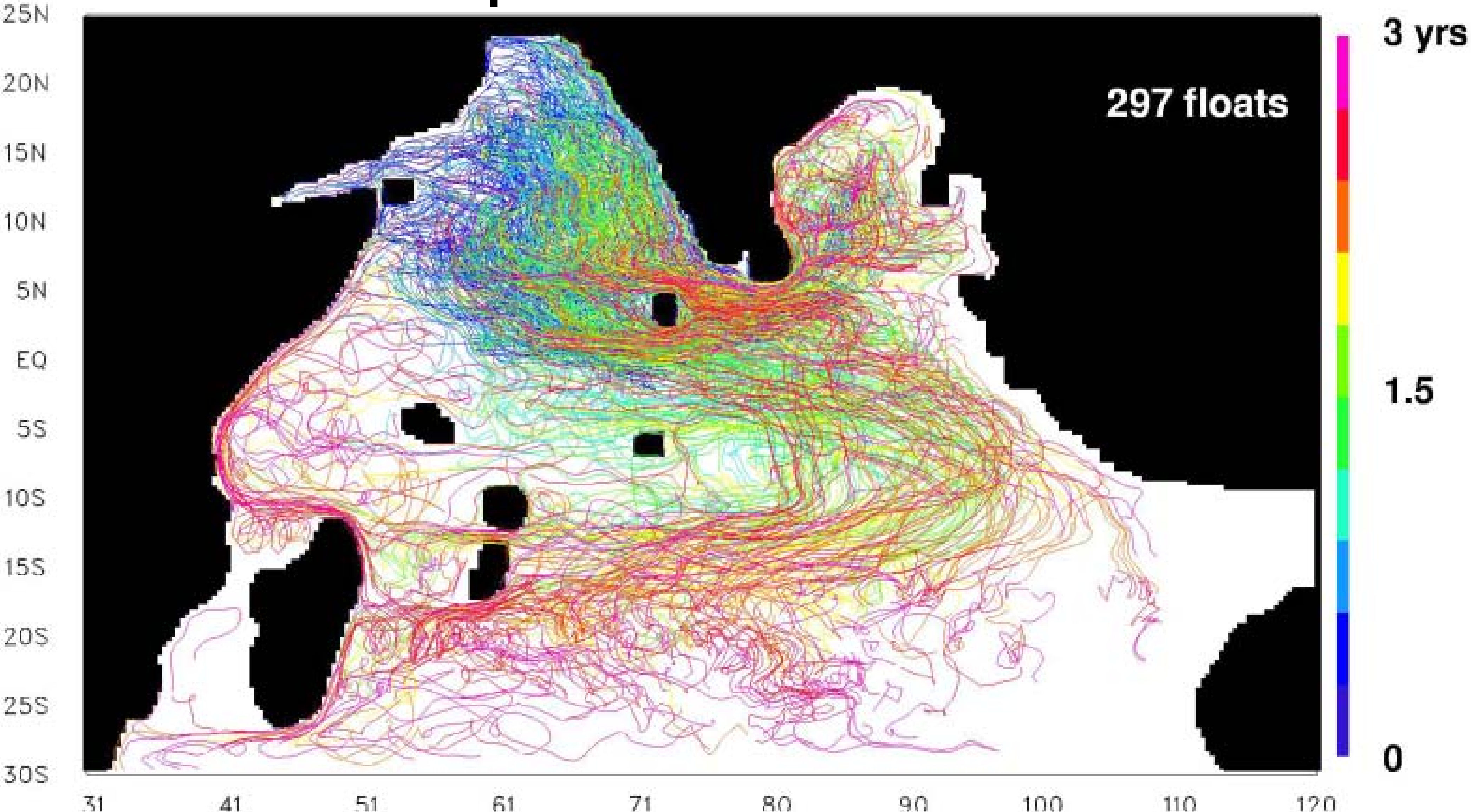
- **Area:** 30^{o}E - 120^{o}E ; 30^{o}S - 25^{o}N
- **Grid:** $1/3^{o}$ x $1/3^{o}$
- **Layers:** 80 m, 120 m, 250 m, 600 m
- **Variables: U, V, H, T, S, AS and BB tracers**
- **Generalized bulk mixed layer model**
- **Smagorinsky eddy viscosity**

Lagrangian Floats

- Based on model velocity every 3 days
- Linear interpolation in time
- Bi-linear interpolation to float position
- Initial float position on grid point
- Forward or backward trajectories
- Float position updated every 12 hours

Mixed layer

Floats exported from the Arabian Sea



iprc
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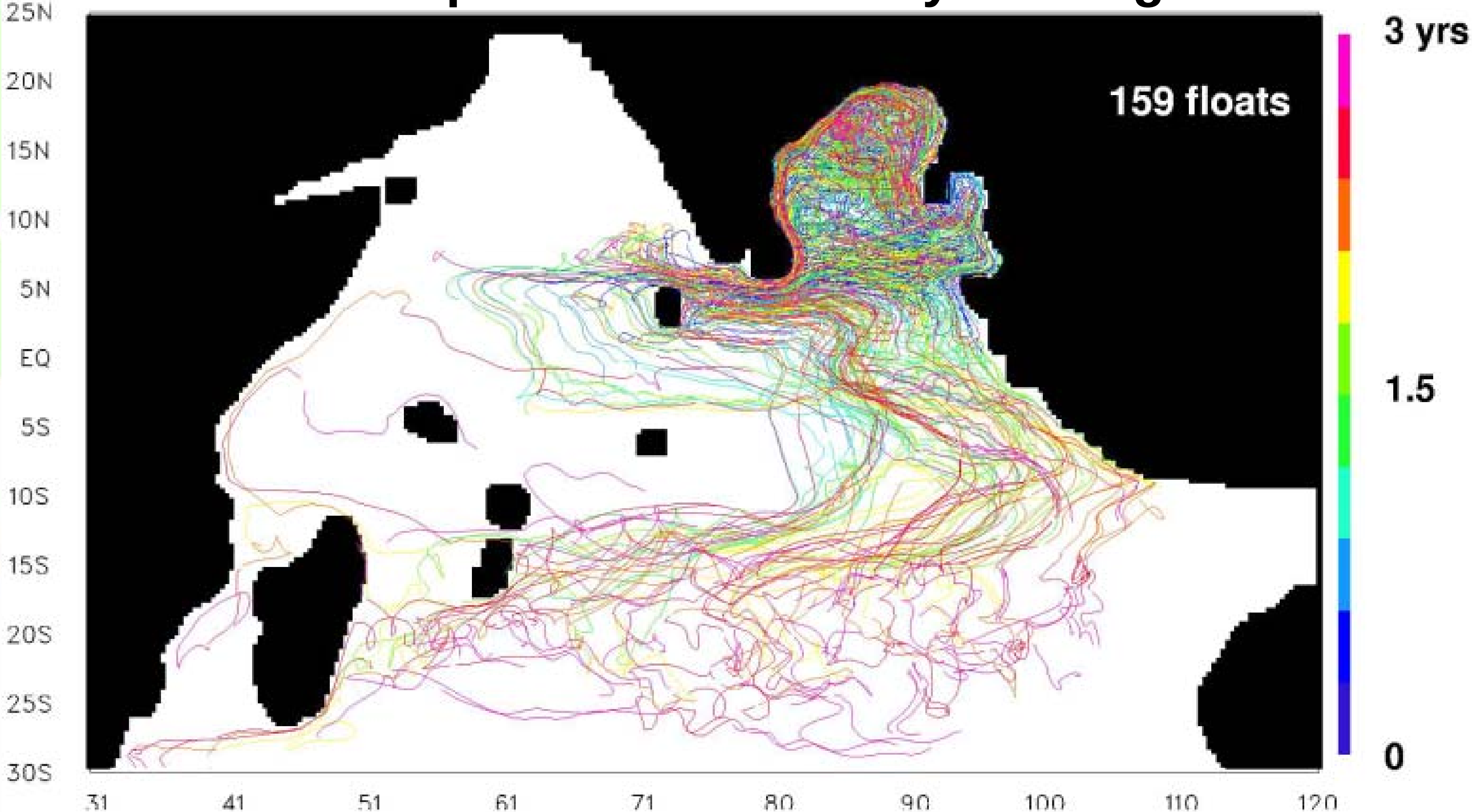
Mixed layer

Floats exported from the Bay of Bengal



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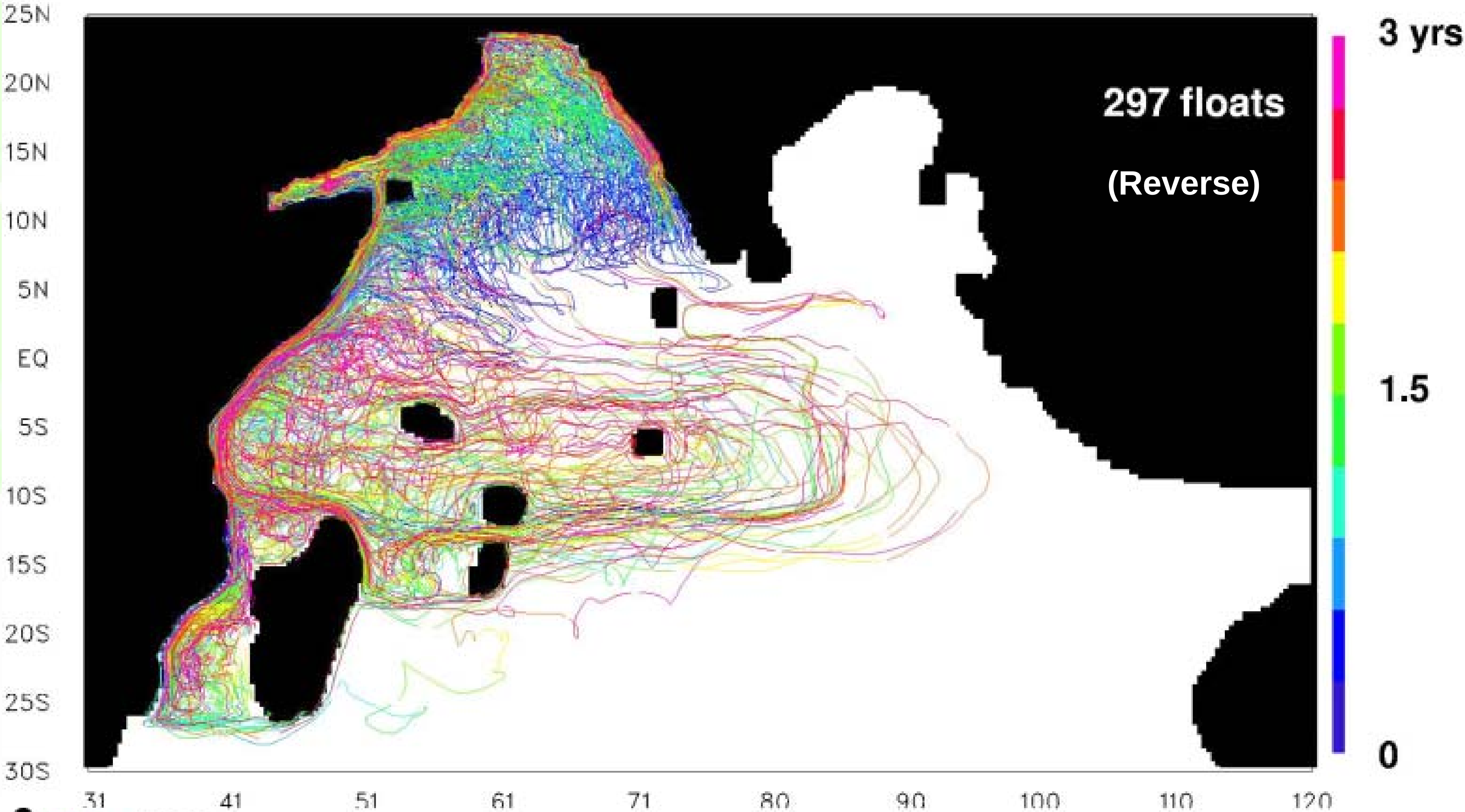
Mixed layer floats

Cross-Equatorial Gyre



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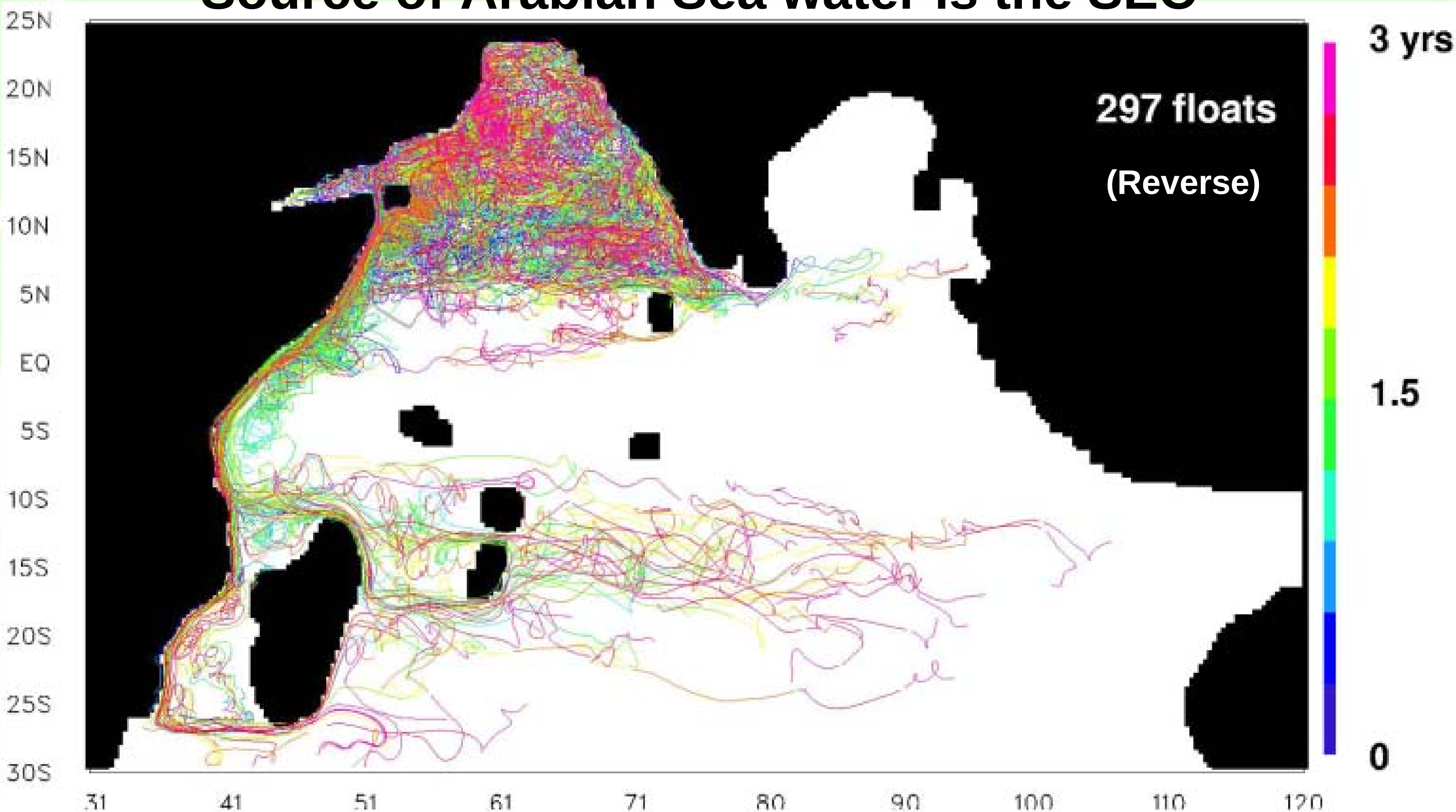
Subsurface floats

Source of Arabian Sea water is the SEC



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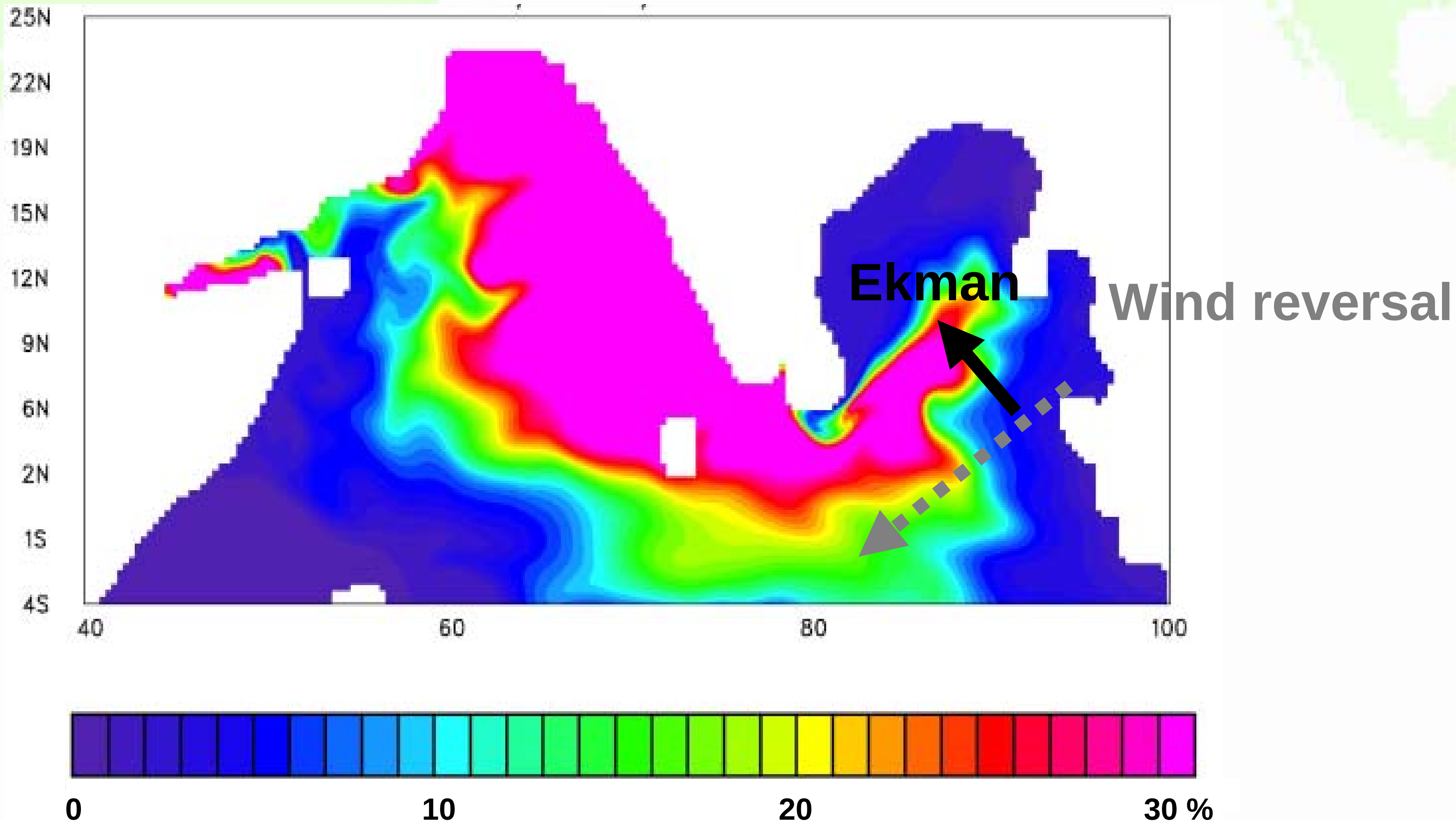
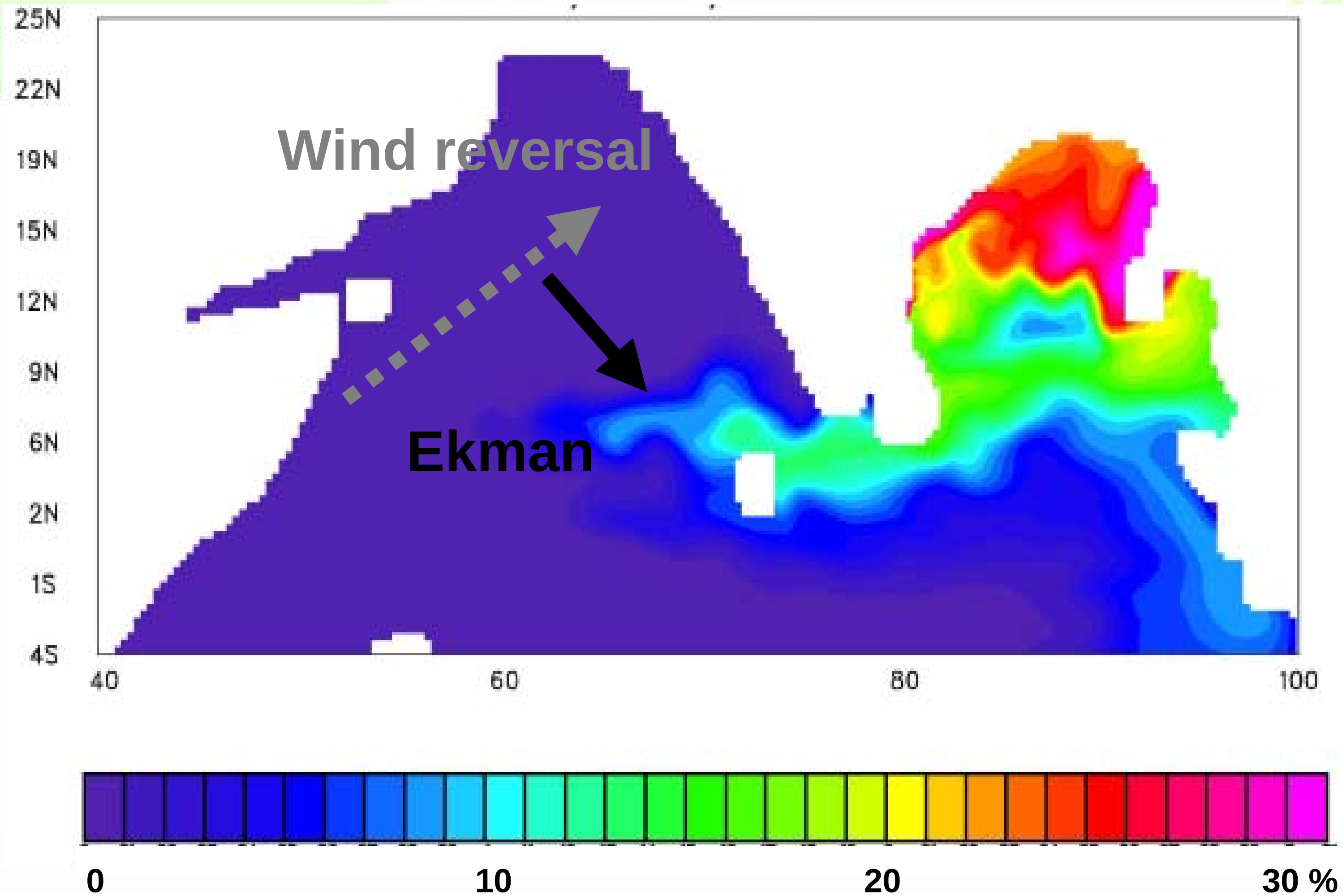
Pathways in the Indian Ocean

Arabian Sea tracer after SW monsoon



Pathways in the Indian Ocean

Bay of Bengal tracer after NE monsoon



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- **How are the circulation cell and the exchanges affected by events like El Nino, La Nino and the Indian Ocean dipole ?**

Forcing

- Wind stress: monthly climatologies:

  FSU 1970-99
  ECMWF, H-R, QuickScat

- FSU composites: El Nino, La Nina, IO-dipole
- T and S: relaxation to WOA94 SST and SSS
- T and S along southern and eastern boundary
- ITF: 10 Sv

Salinity Transport

Flux of *high salinity* in layer j :

$$Q_{high} = V_j \, \Delta S \, \Theta(\Delta S)$$

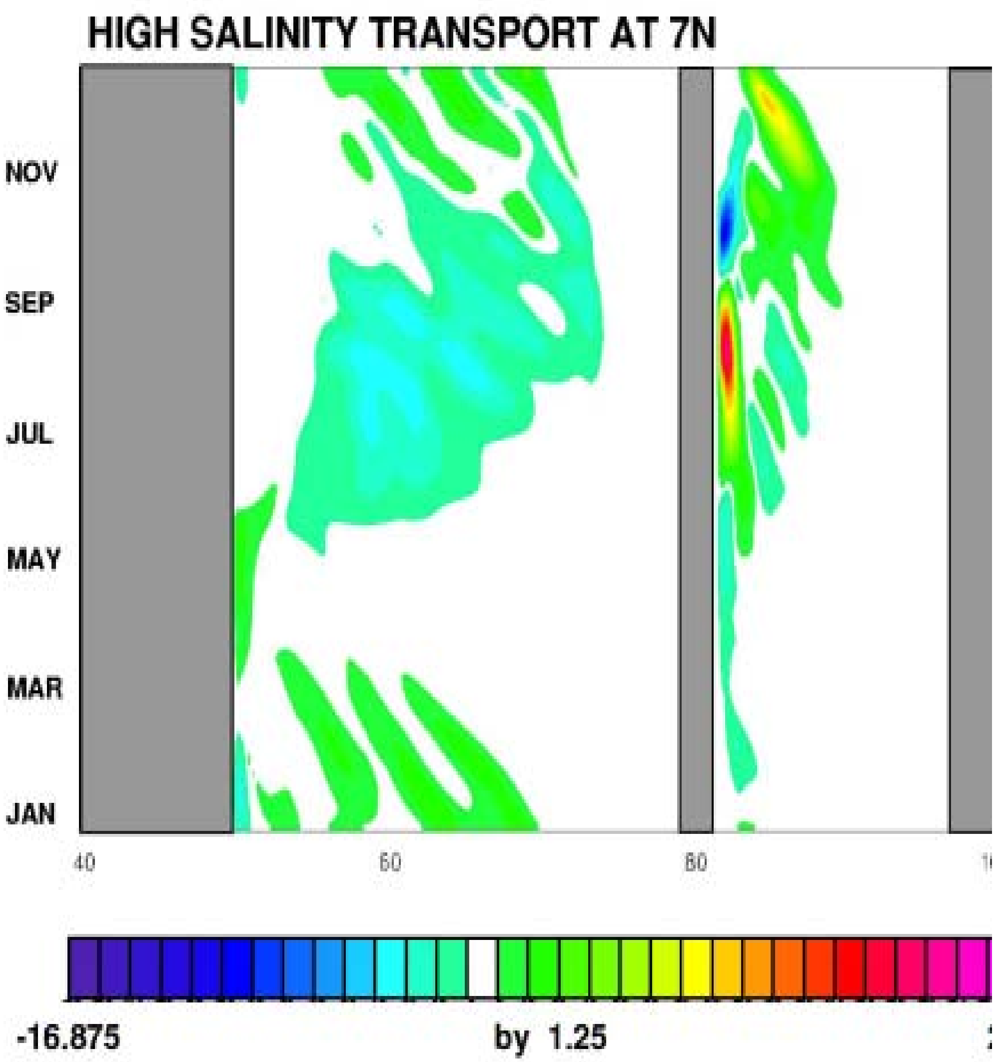
and flux of *low salinity*

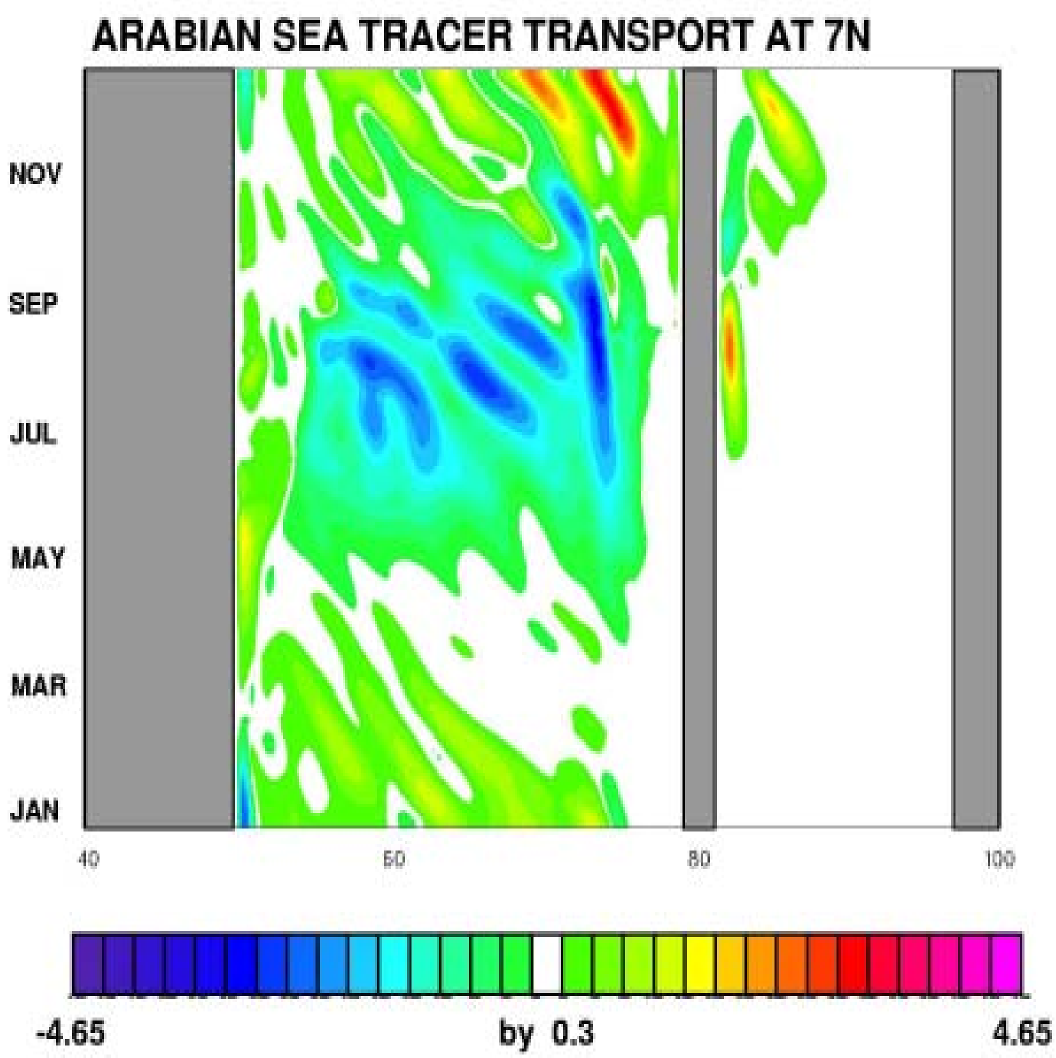
$$Q_{low} = -V_j \, \Delta S \, \Theta(-\Delta S)$$

where $$\Delta S = \left(S_j - S_j^{\phi t} \right)$$

and $S^{\phi t}$ **is the section average salinity**

FSU 1970-99 wind stress





mixed layer transport

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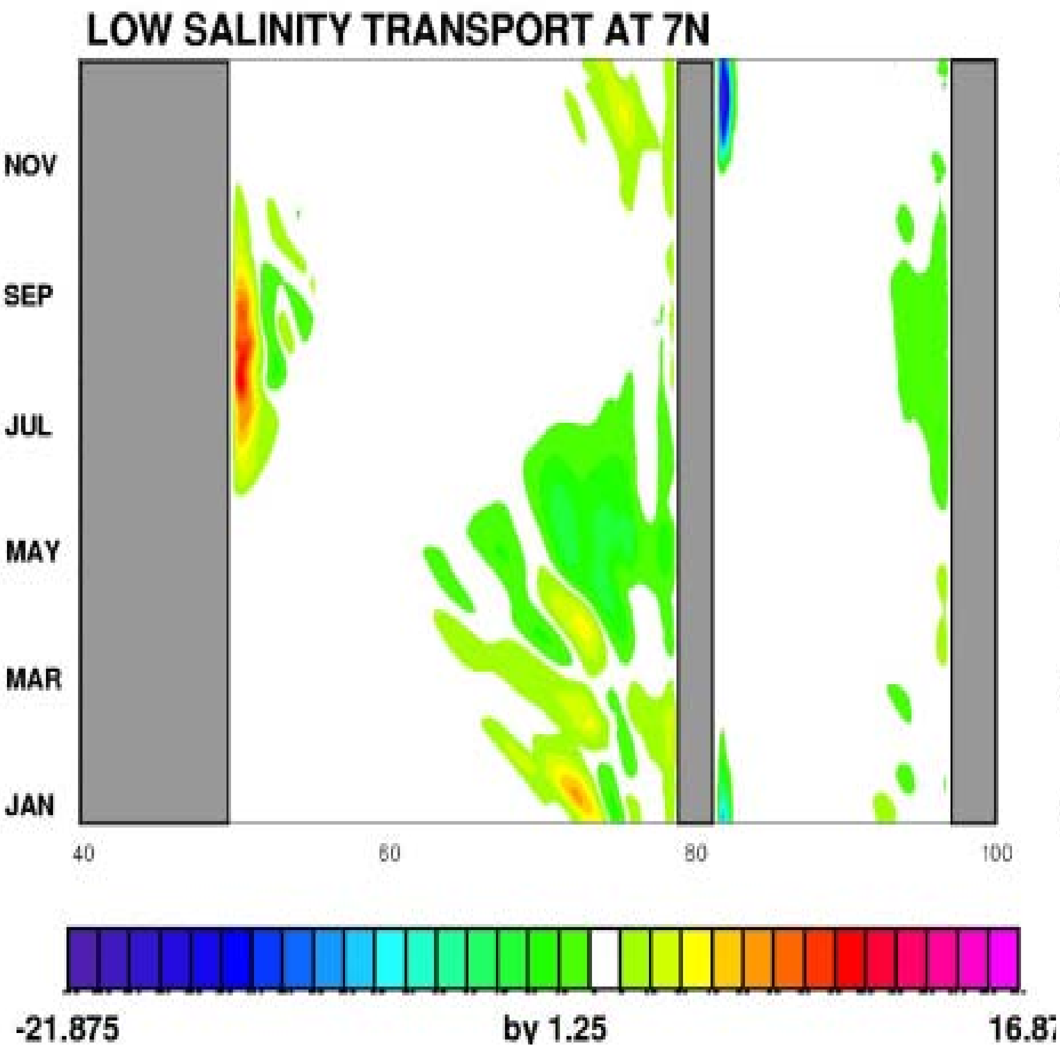
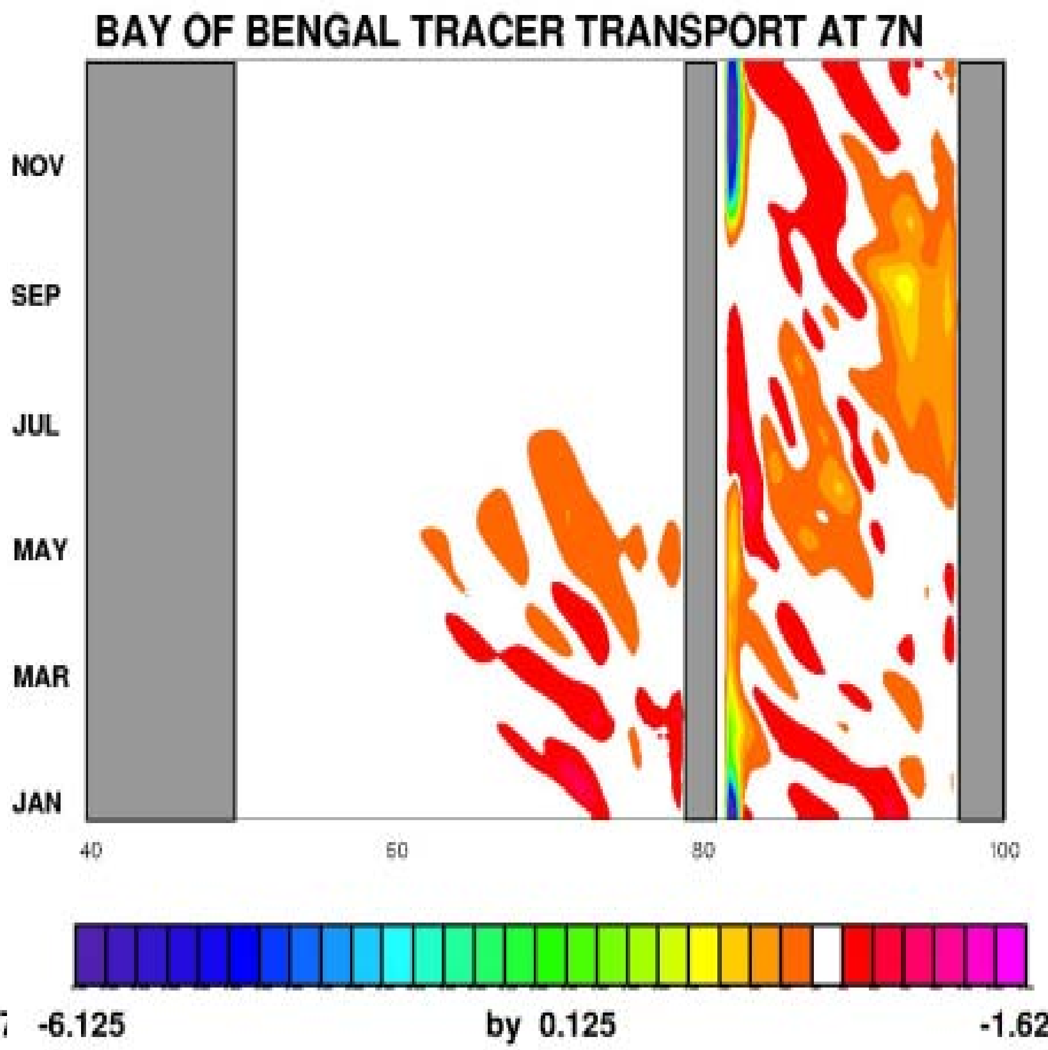
FSU 1970-99 wind stress





mixed layer transport

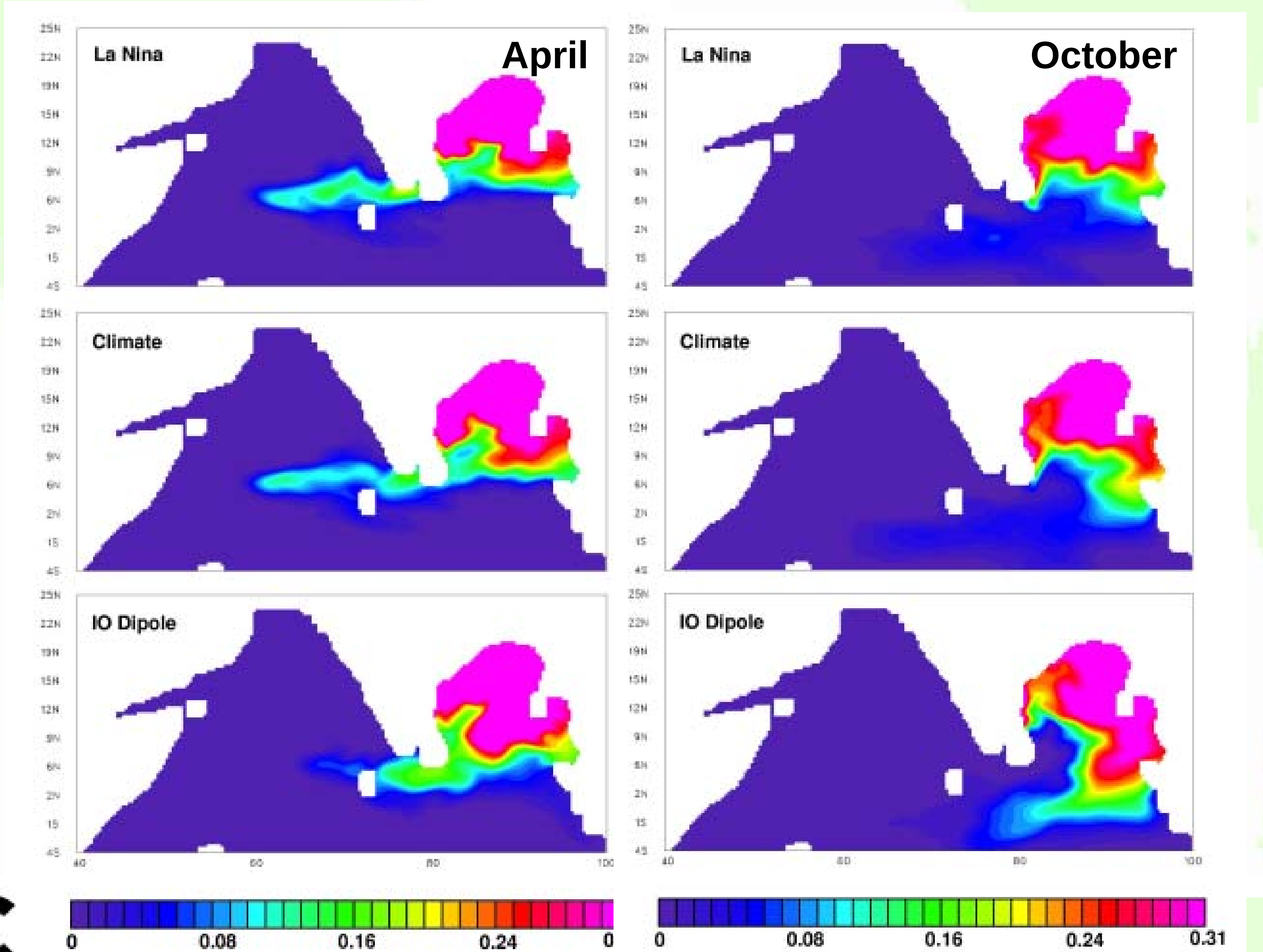
Extreme climate events

- Do El Nino, La Nina or the IO dipole affect the exchanges between the Arabian Sea and the Bay of Bengal ?

Composite winds

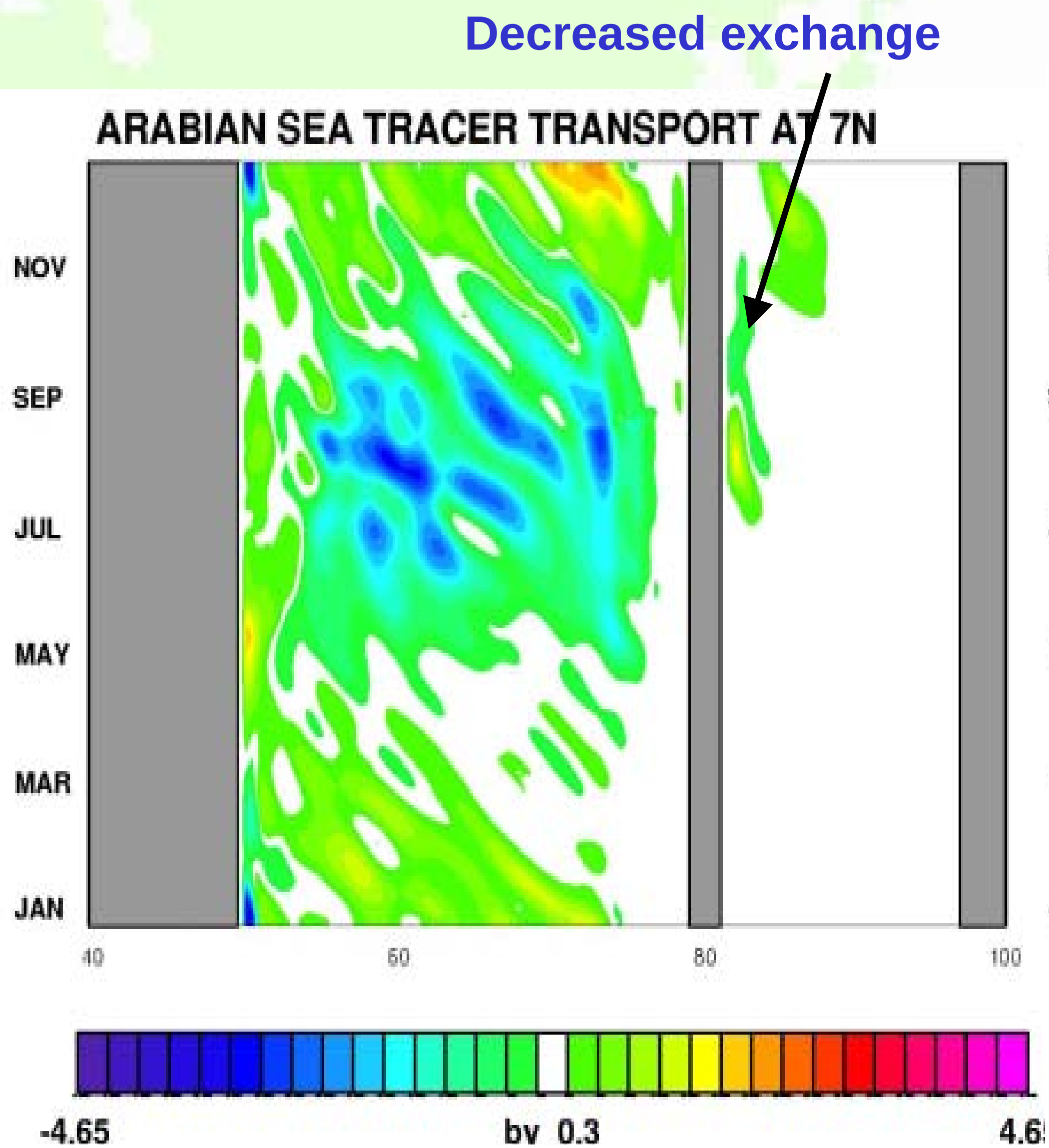
- FSU wind 1970-1999
- El Nino: 1972, 76, 82, 86, 87, 91, 97
- La Nina: 1970, 71, 73, 75, 88, 98
- IO dipole: 1972, 82, 94, 97

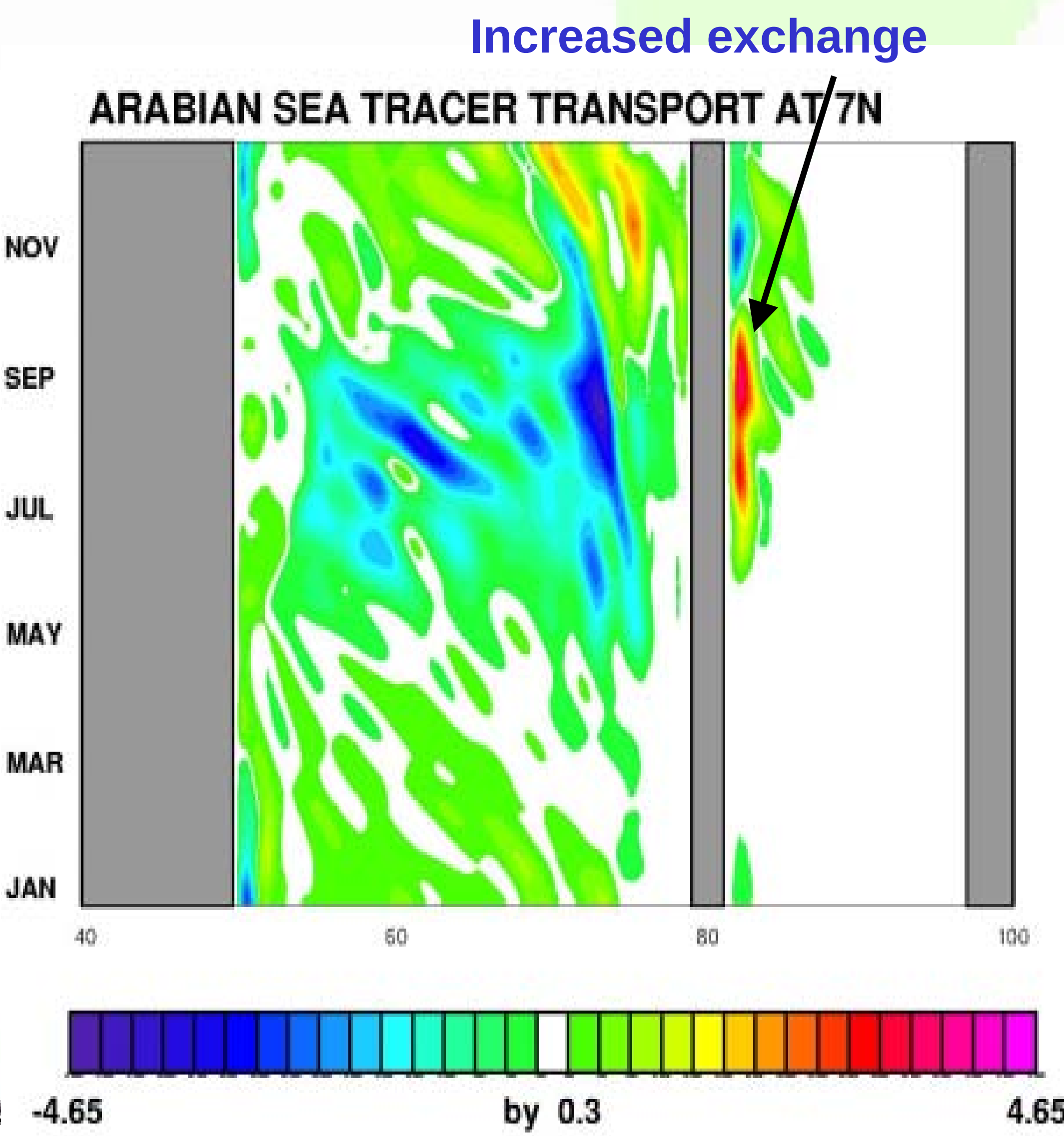
Bay of Bengal tracer



La Nina

IO dipole





mixed layer transport

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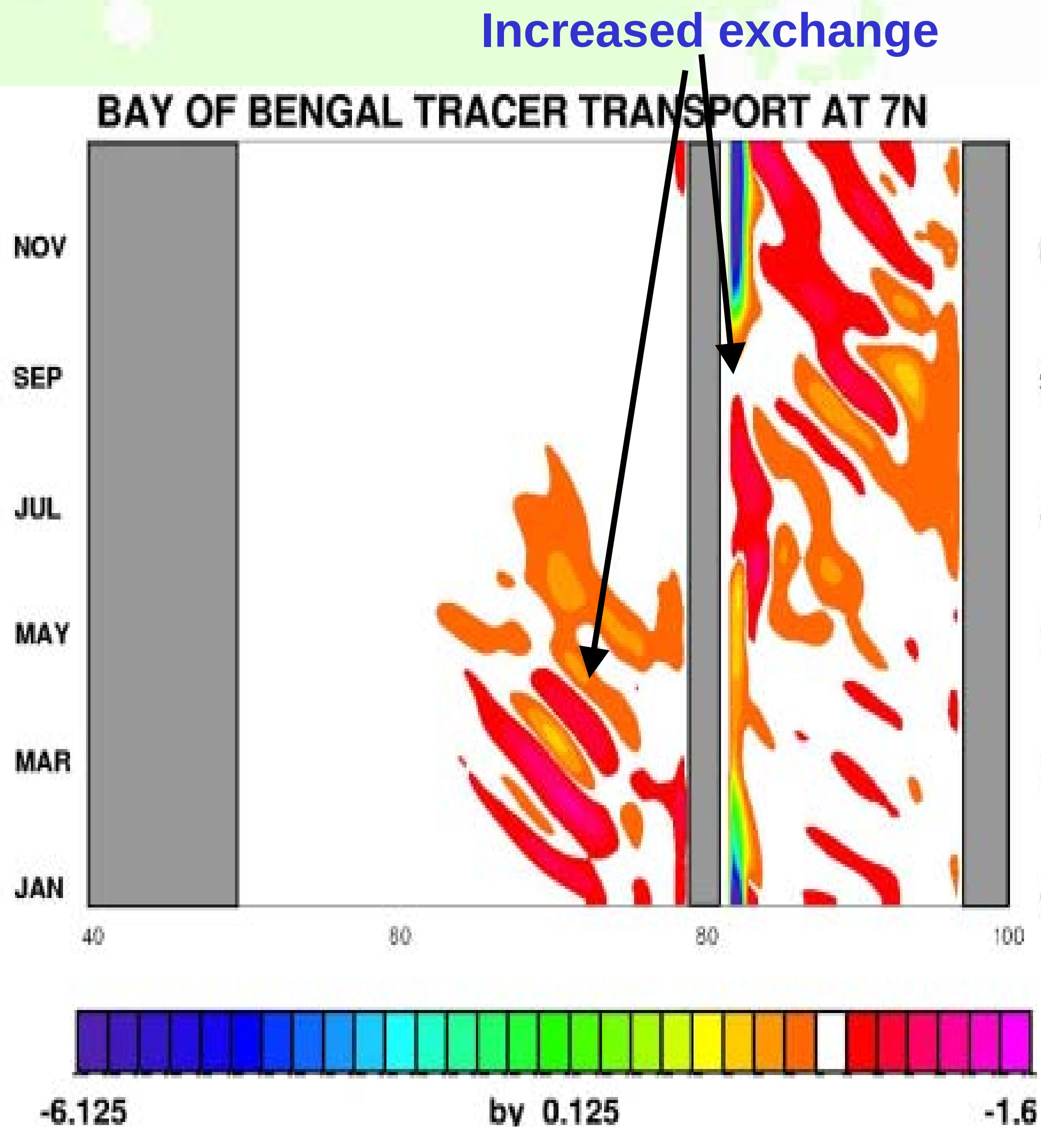

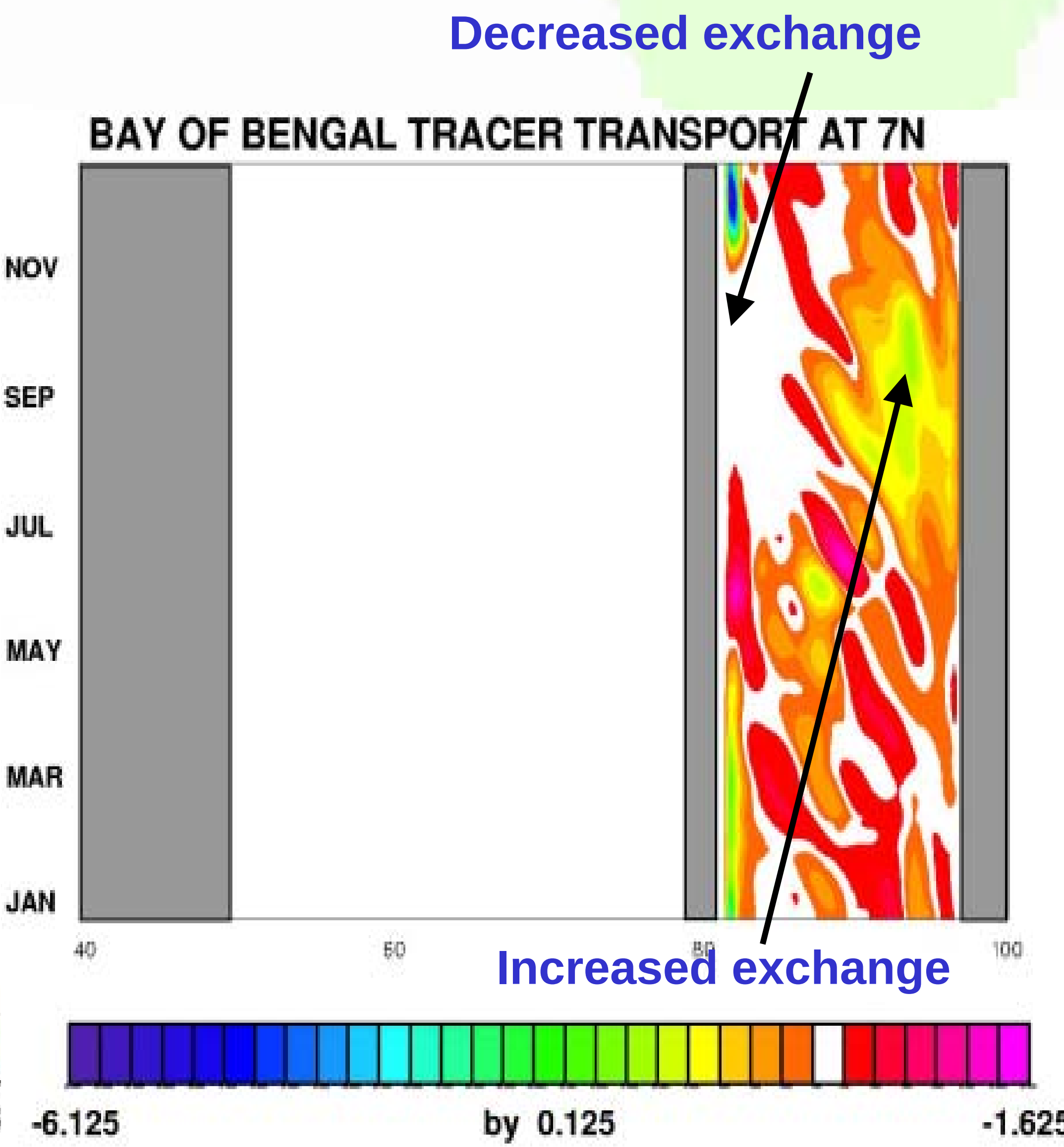

mixed layer transport

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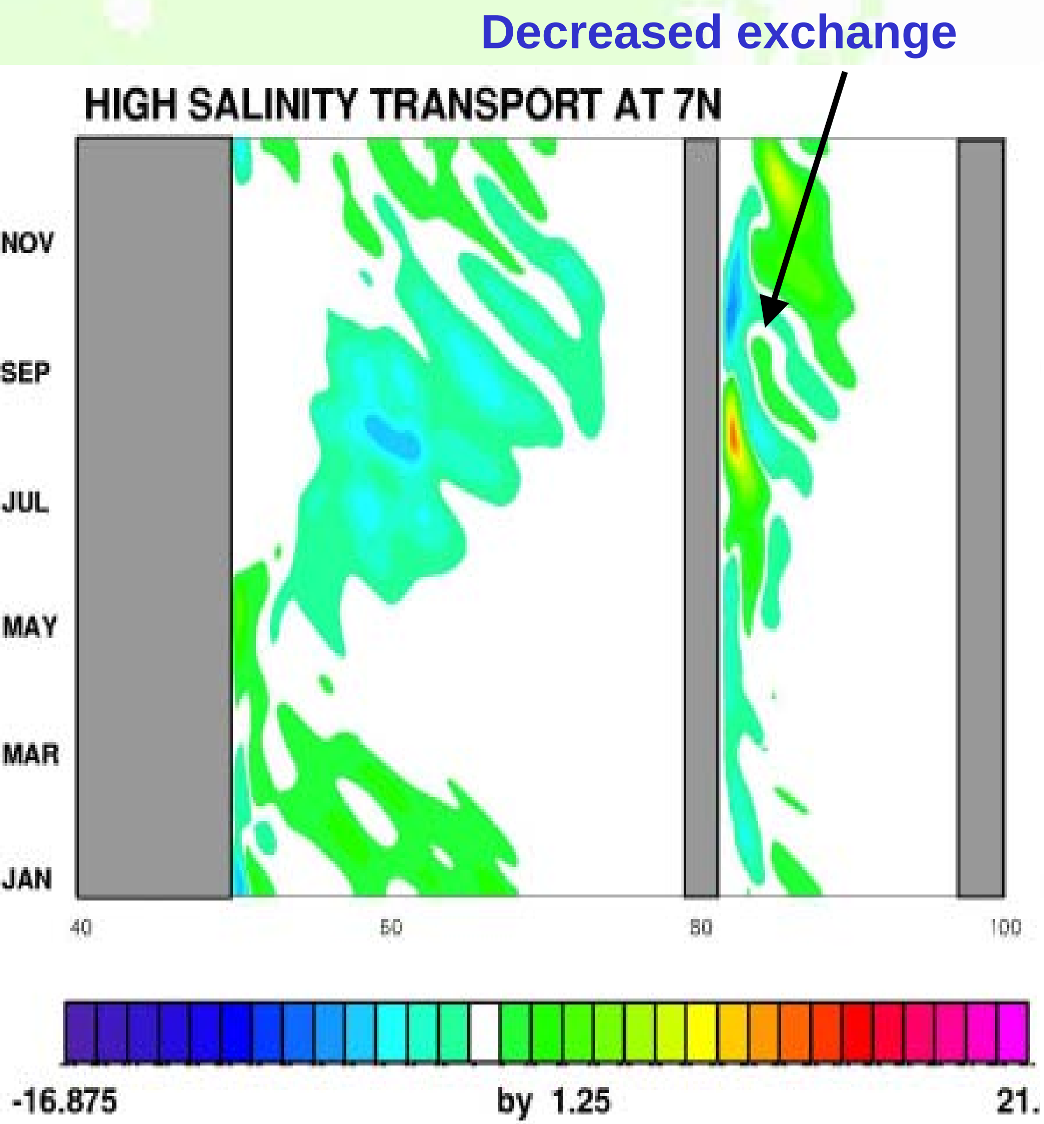
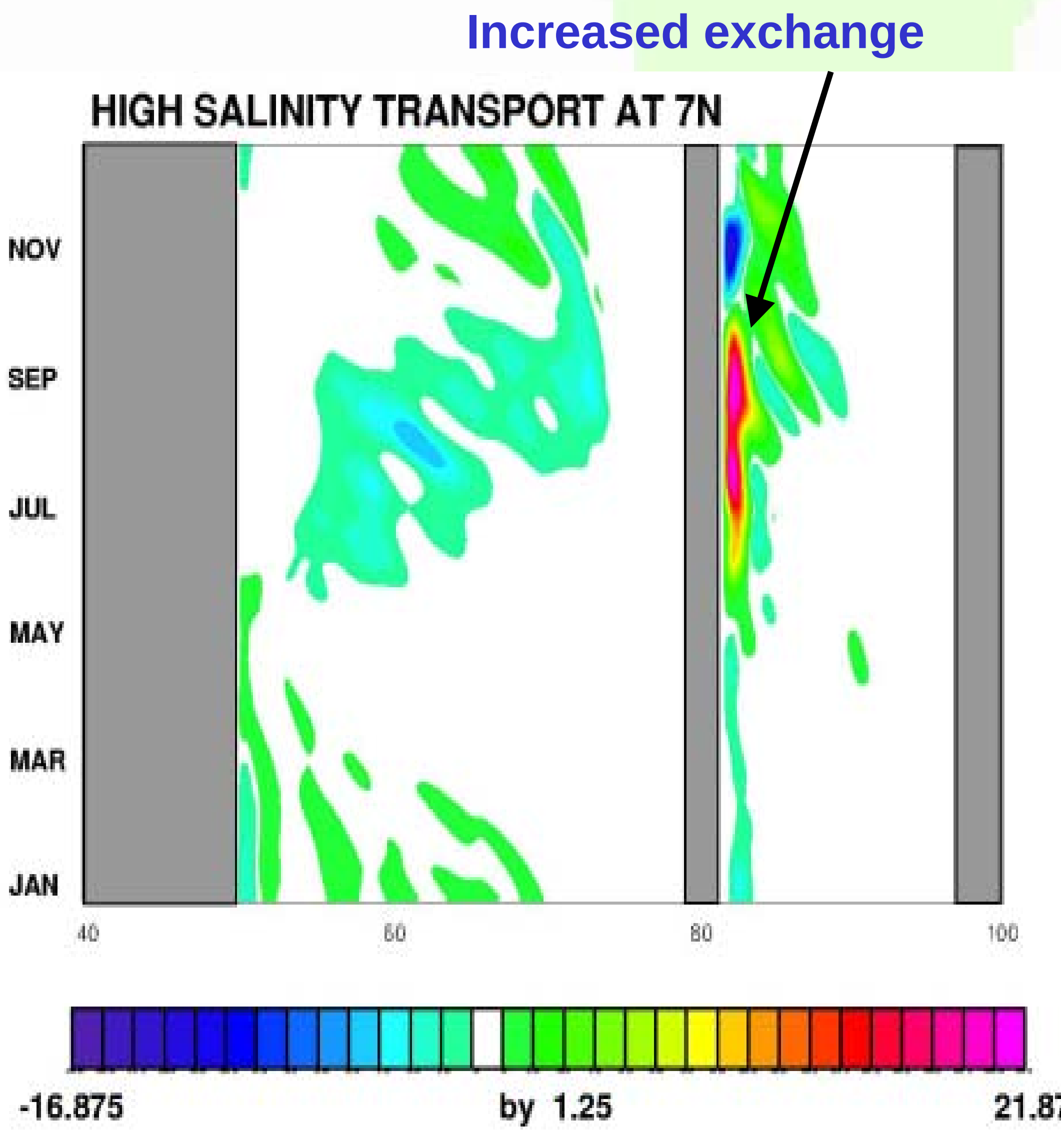
La Nina

IO dipole



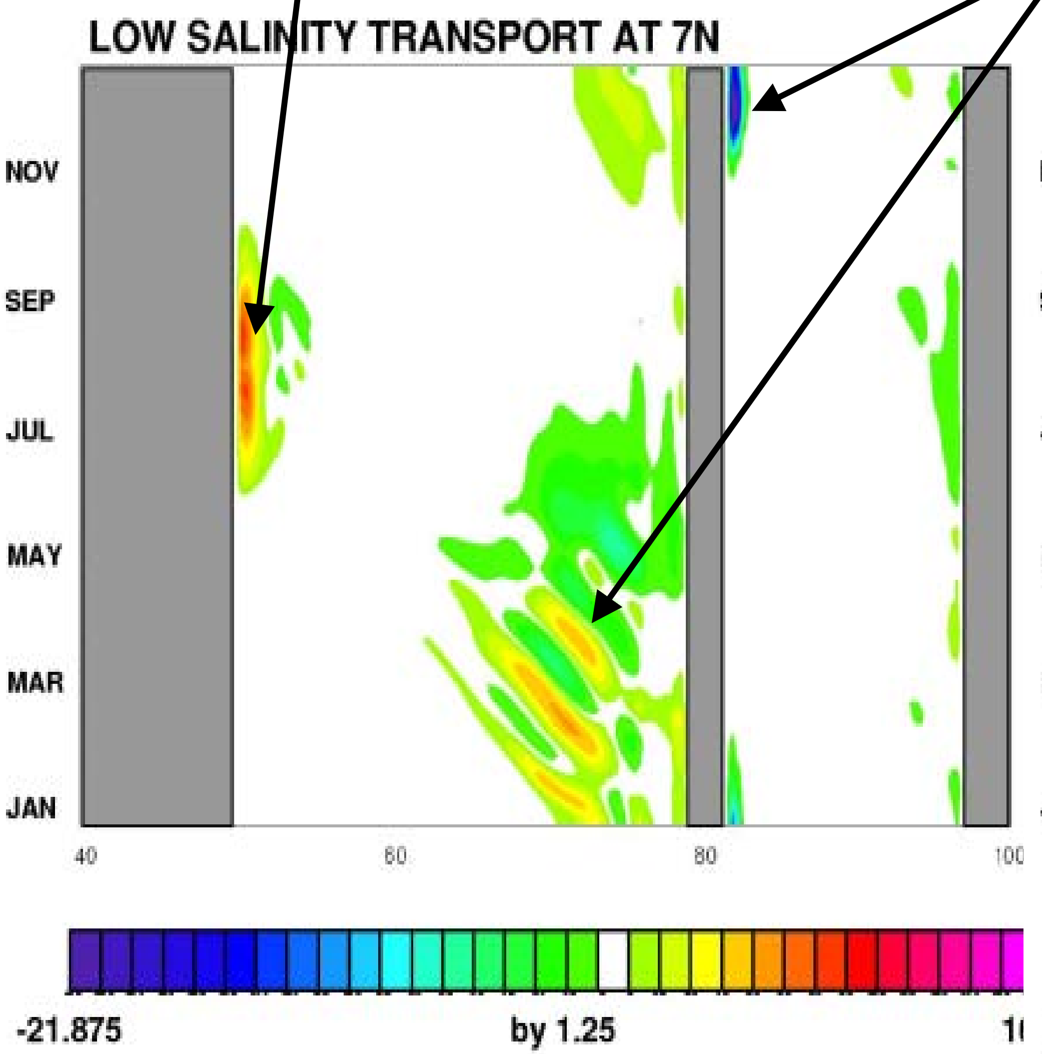


mixed layer transport

La Nina

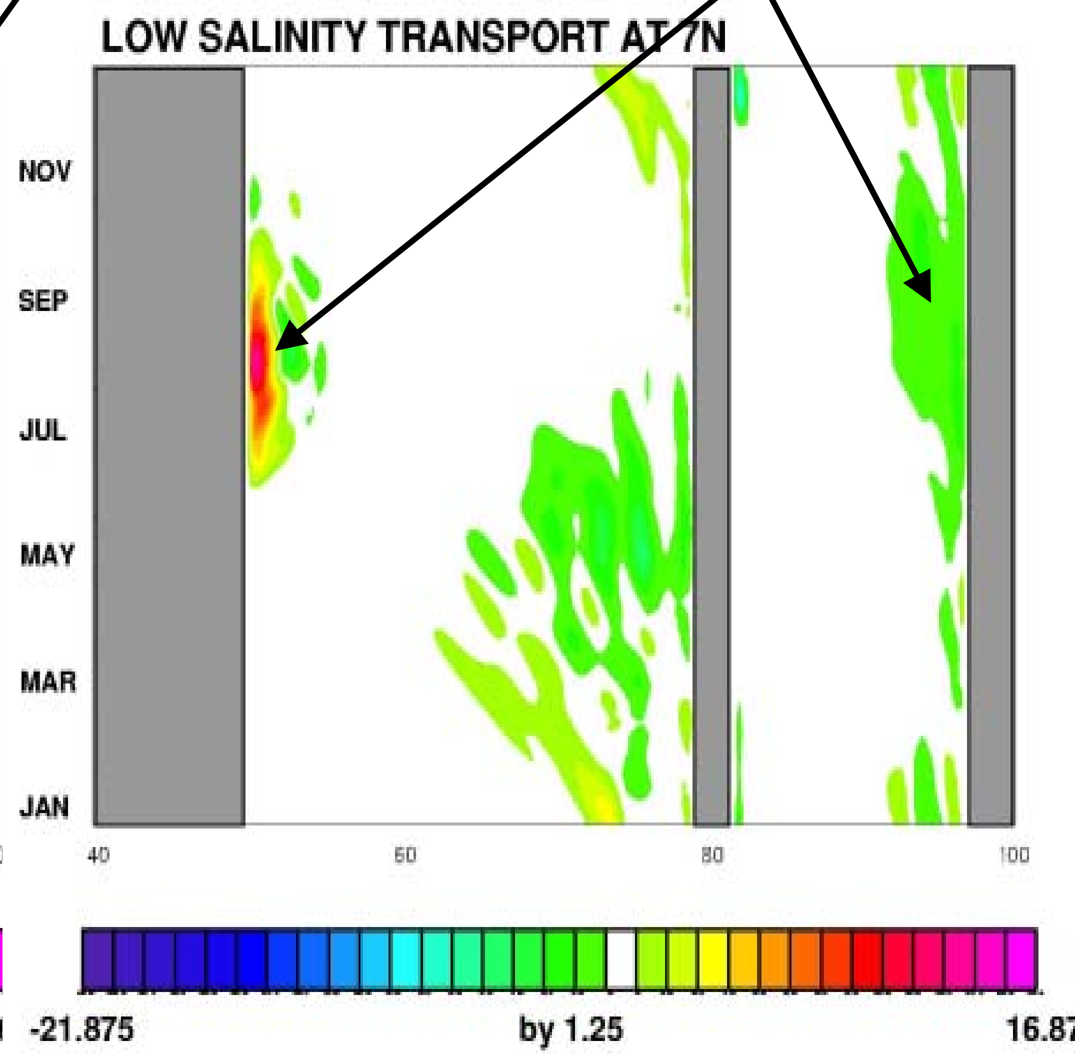
Decreased exchange

Increased exchanges



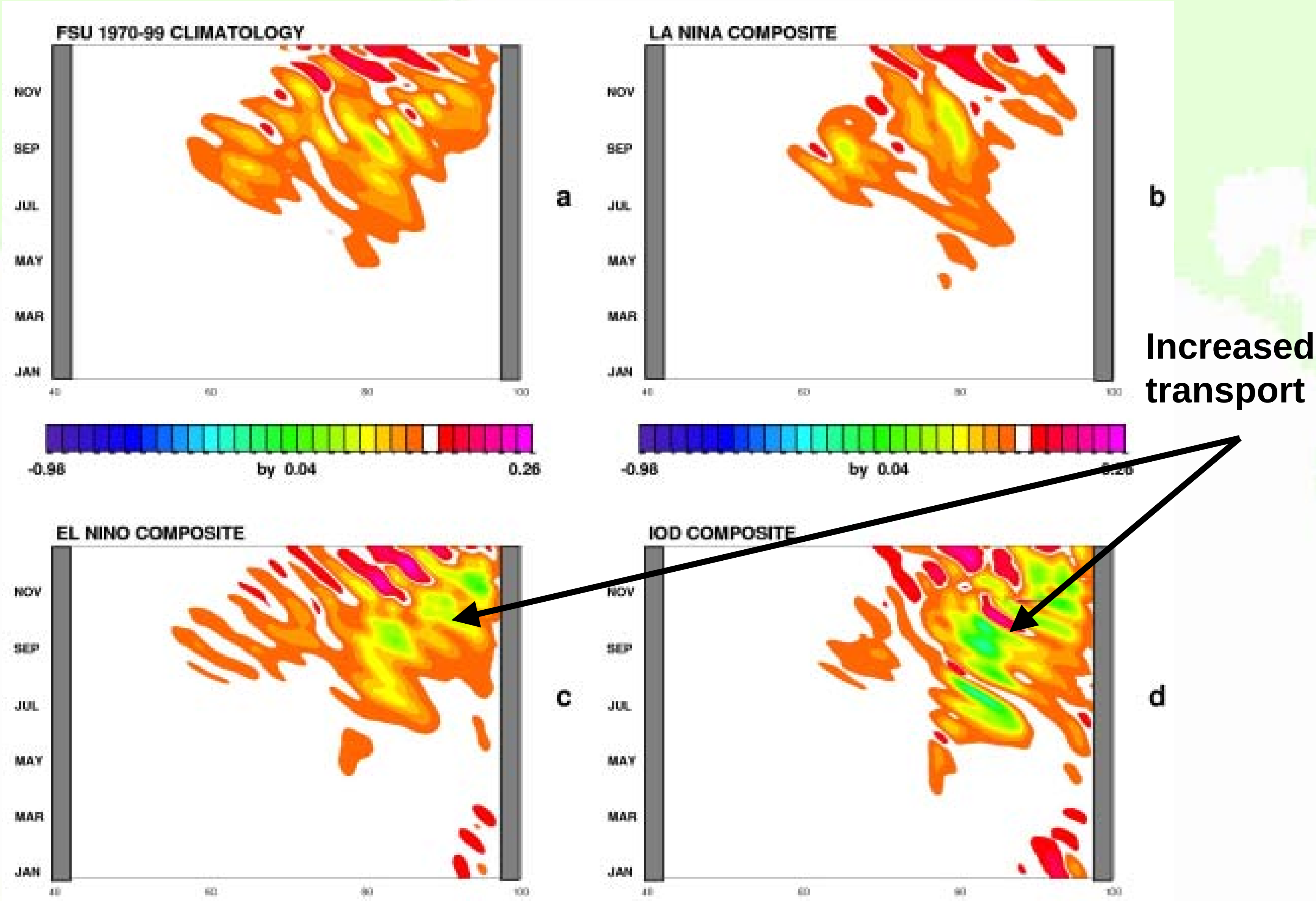
IO dipole

Increased exchanges

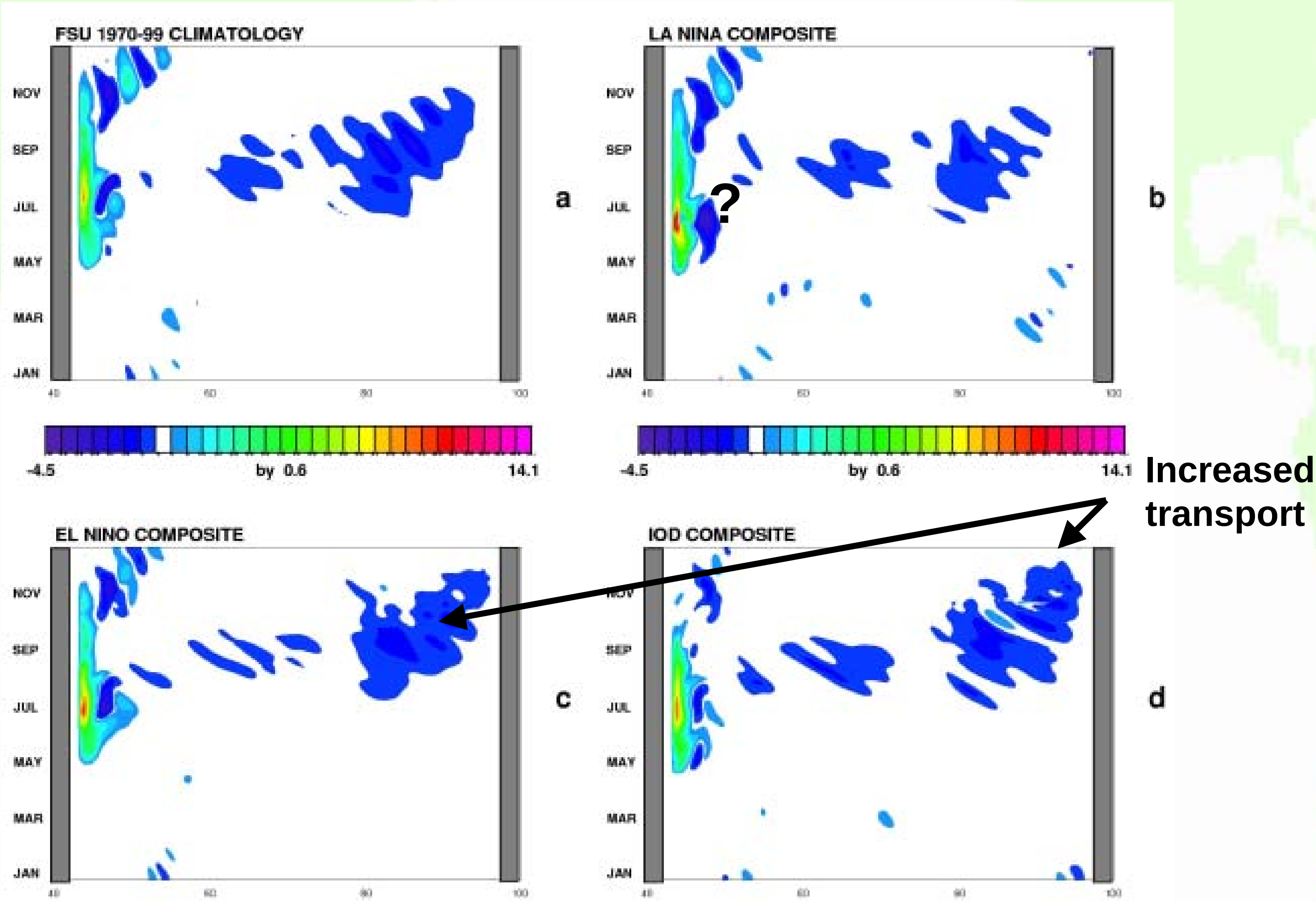


mixed layer transport

Cross-Eq BB tracer transport



Cross Eq Low Salinity Transport



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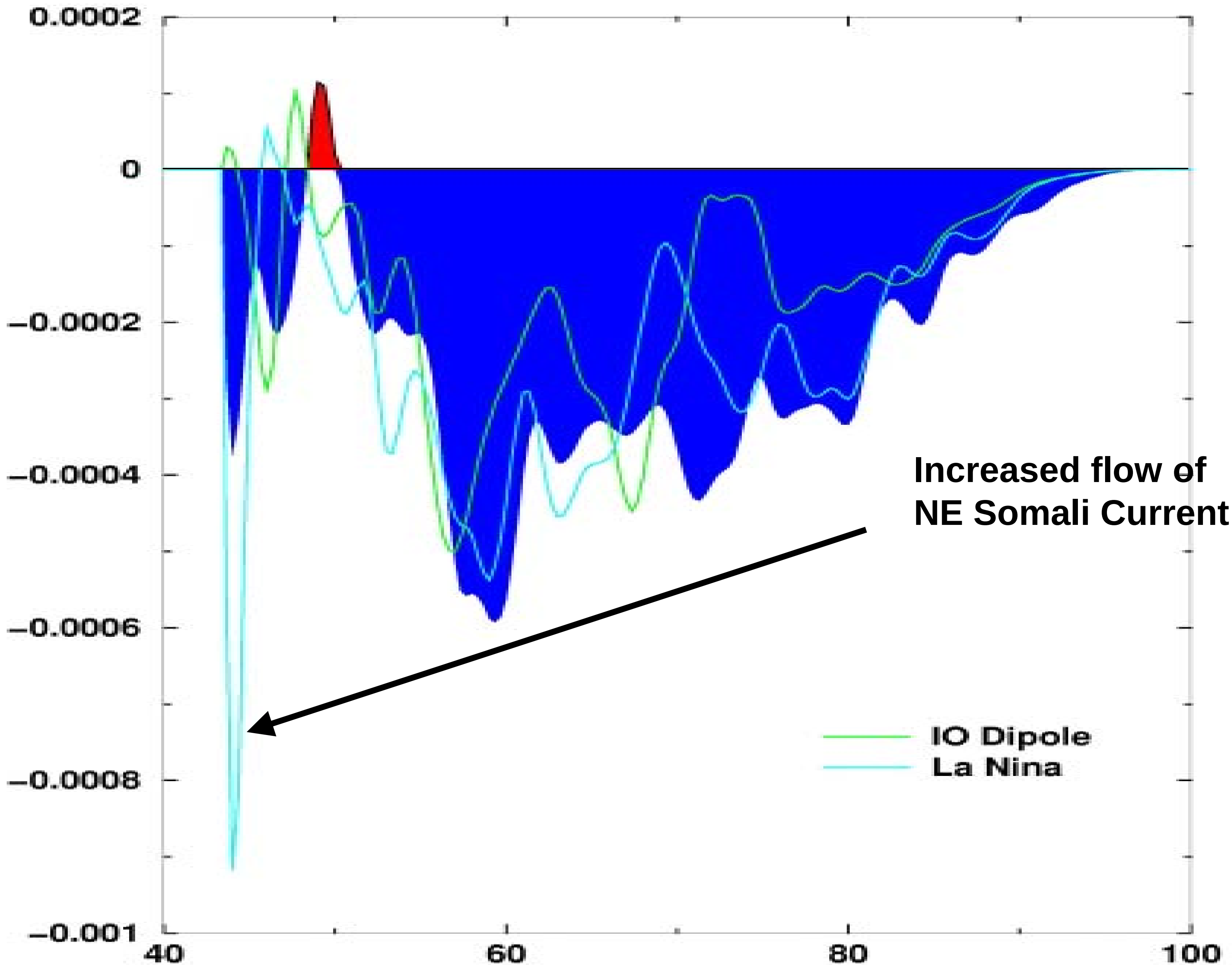
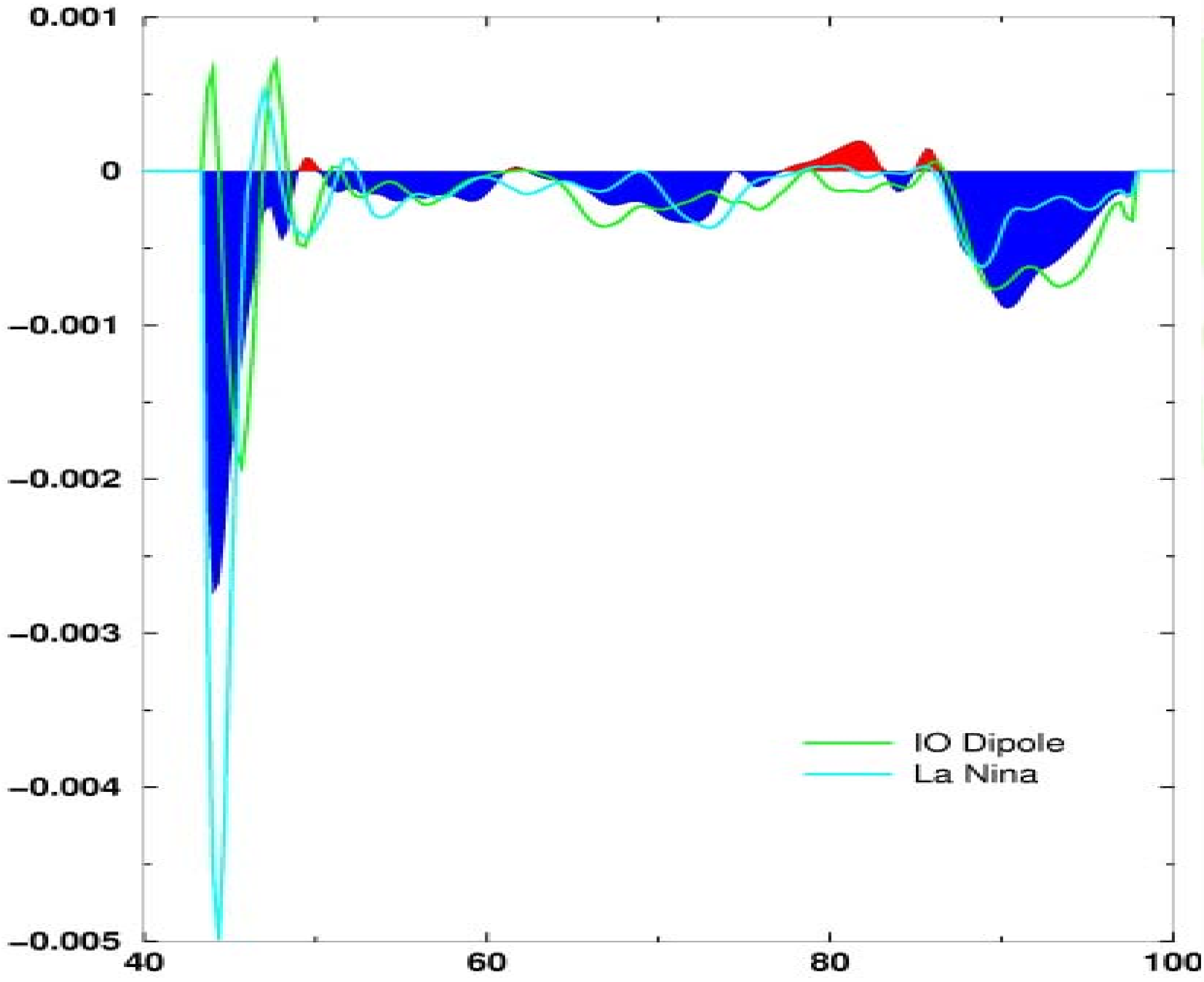
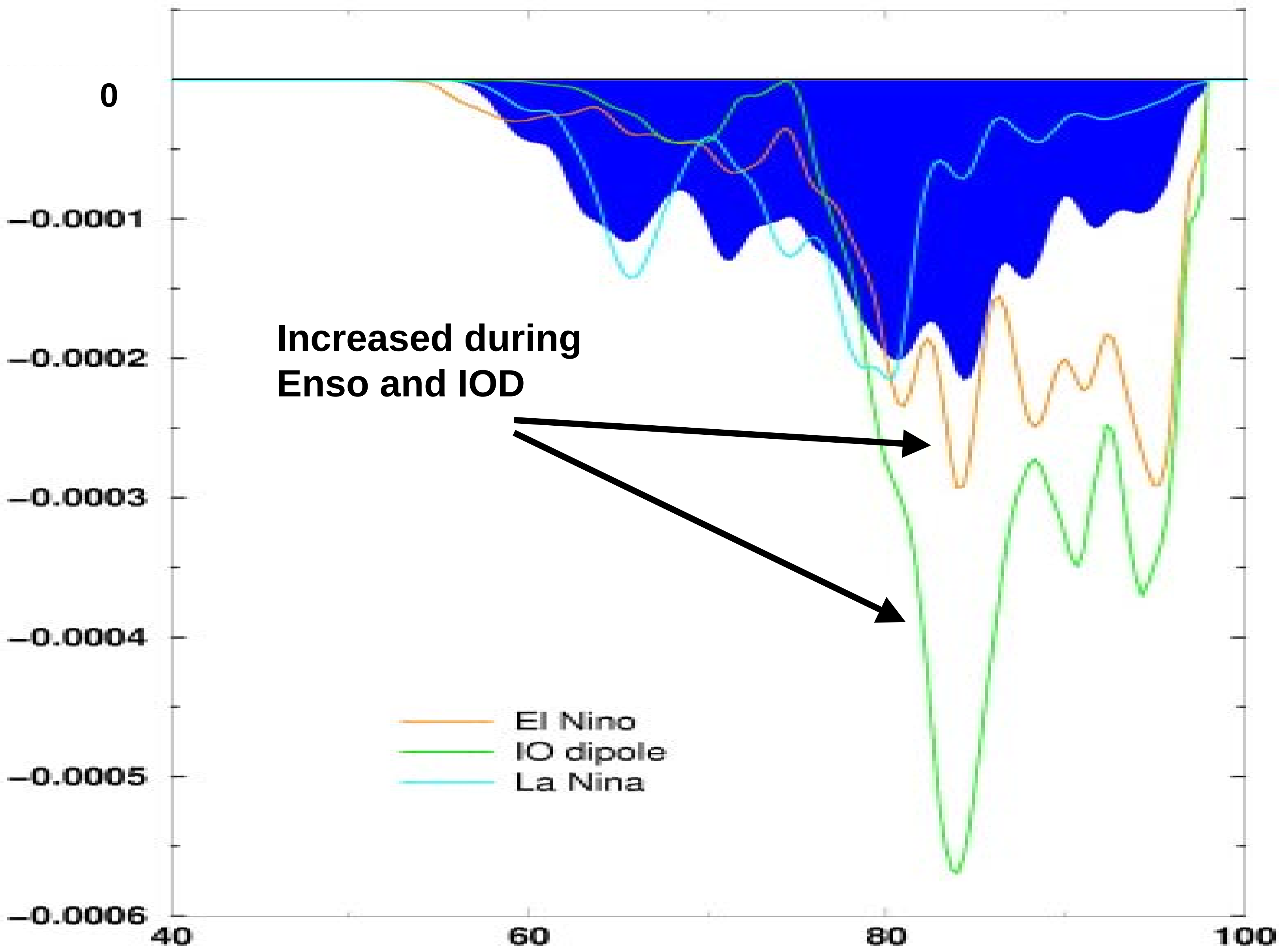
Annual mean AS tracer along Eq



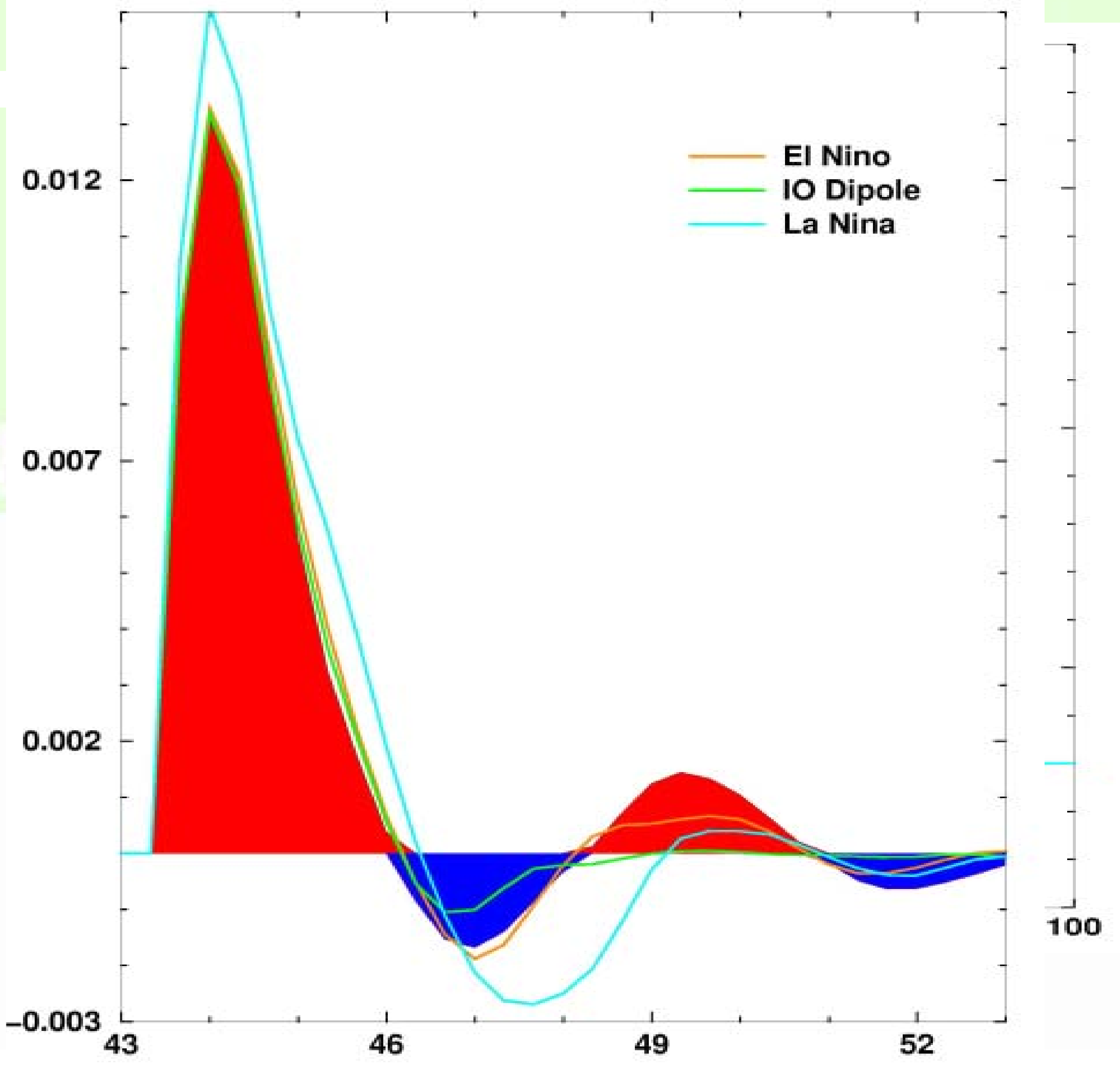
Annual mean HS water along Eq



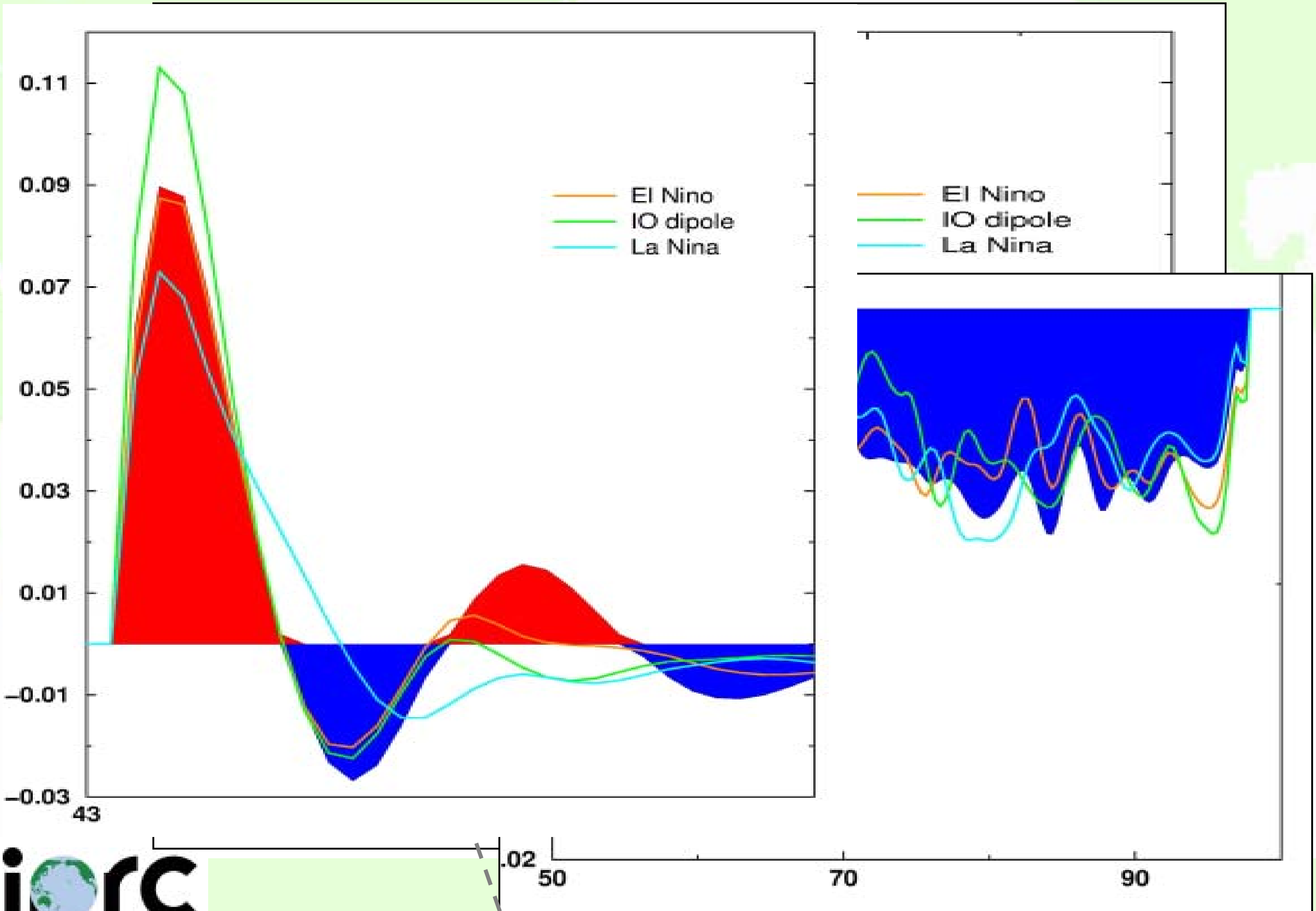
Annual mean BB tracer along Eq



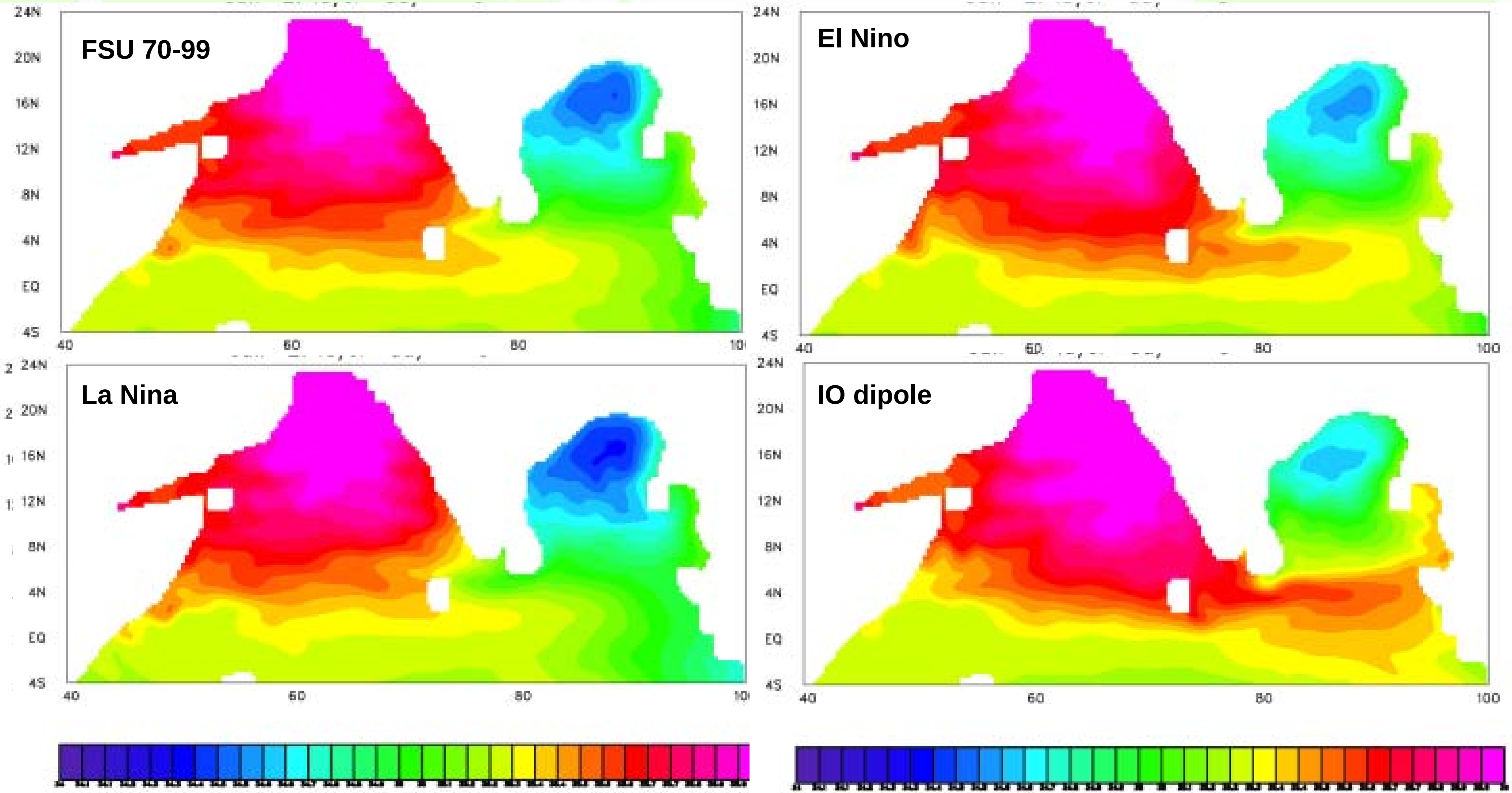
Annual mean LS water along Eq



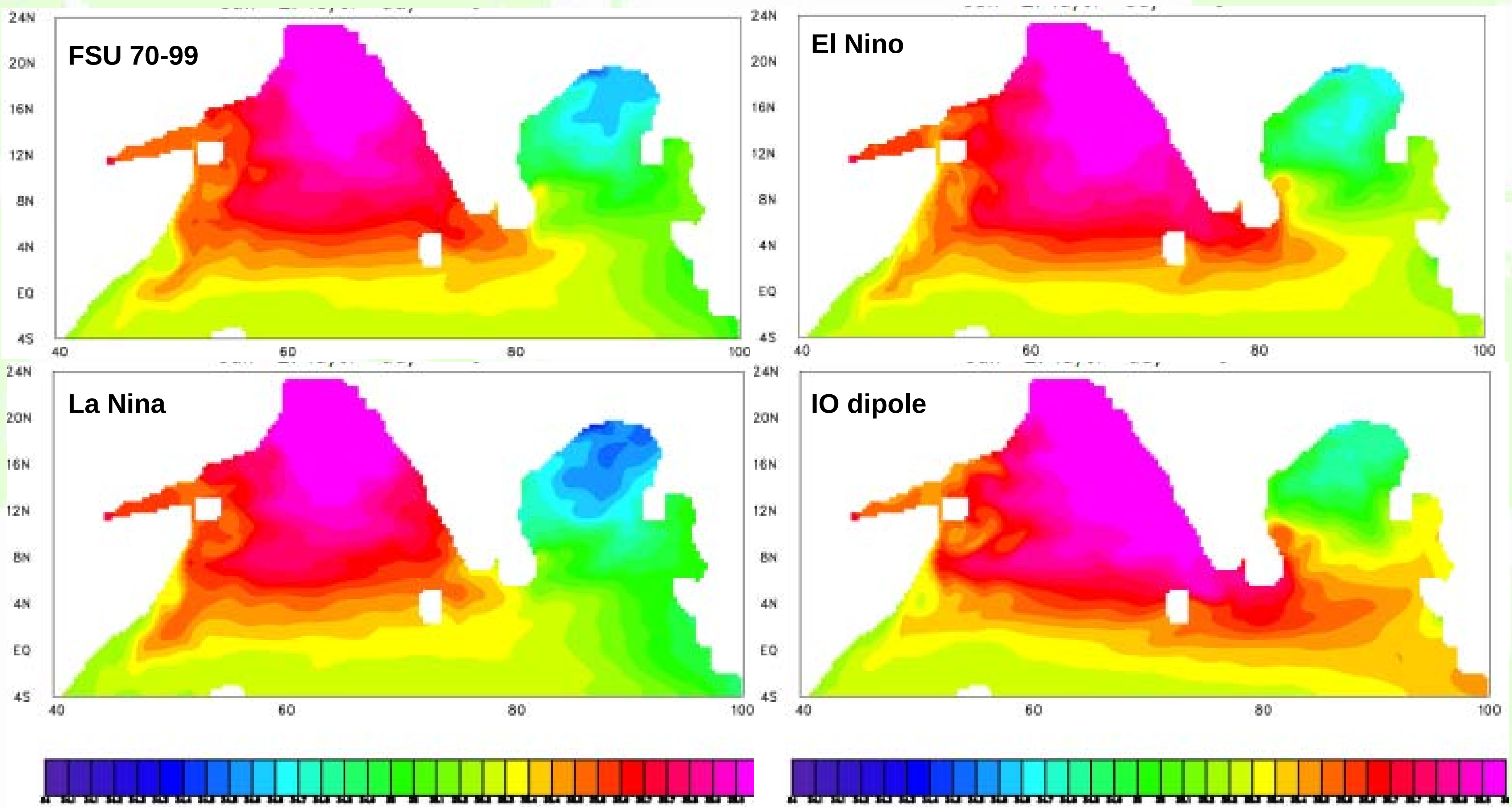
Cross-equatorial volume transport



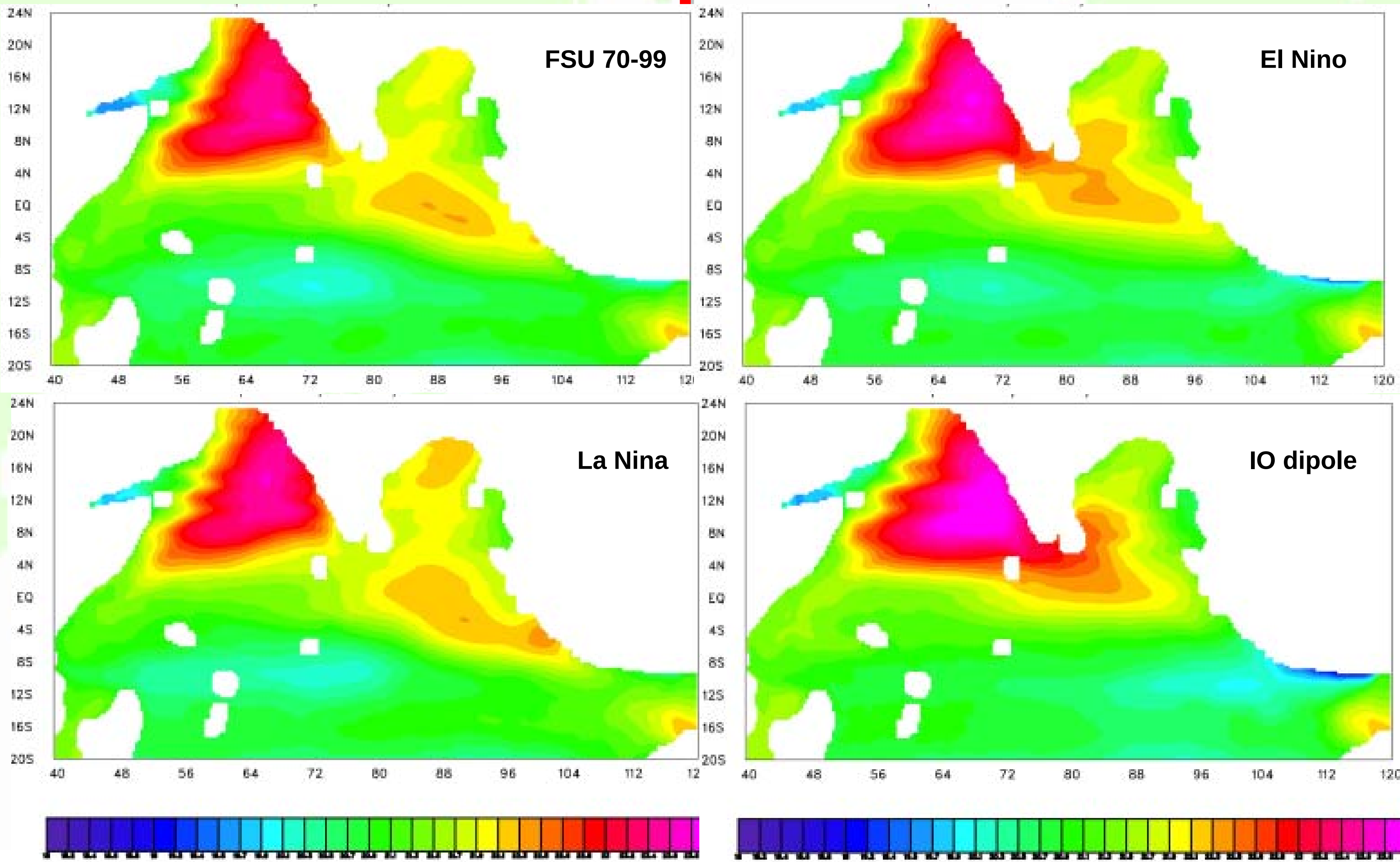
Salinity below ML in March



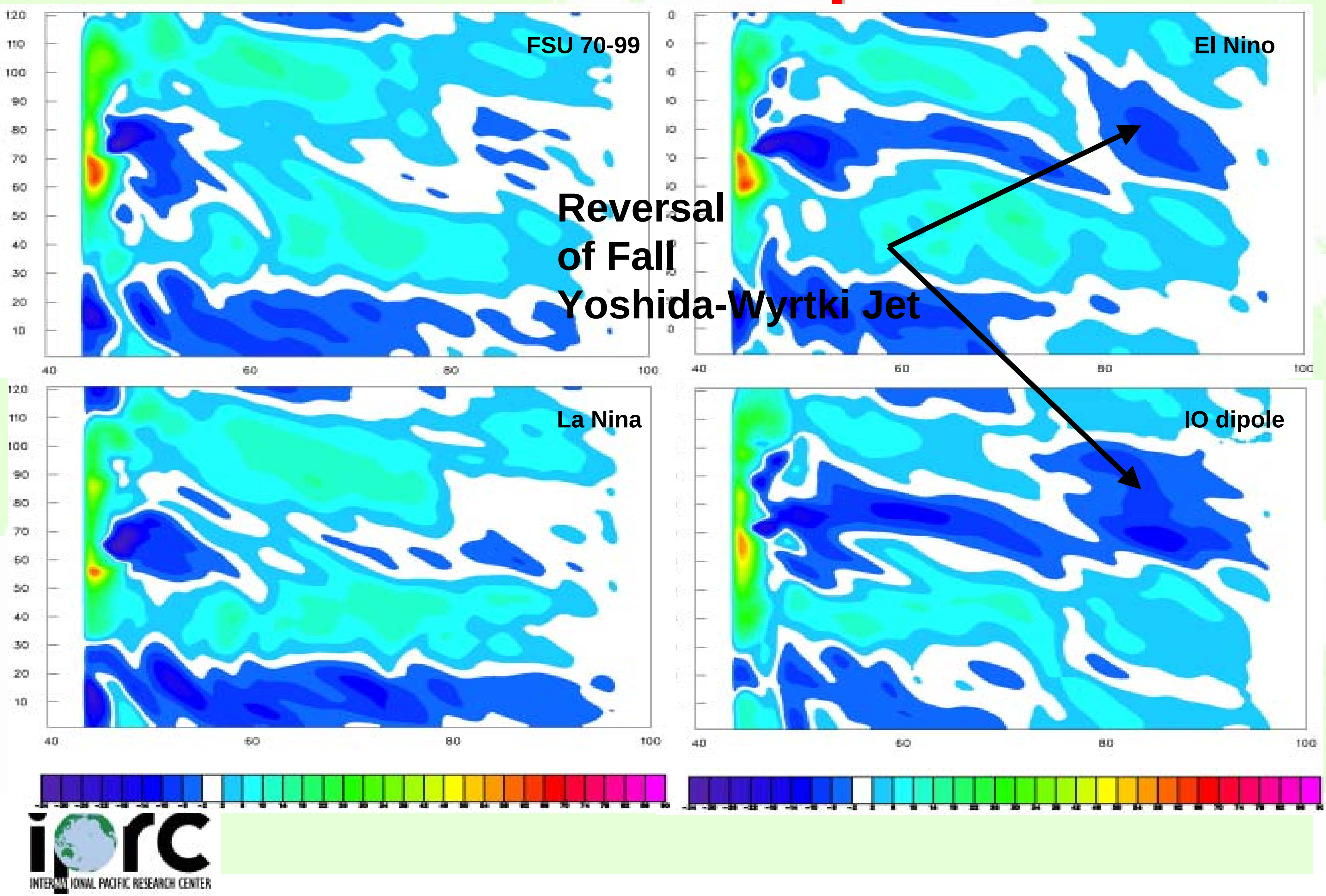
Salinity below ML in September



Annual mean temperature below ML



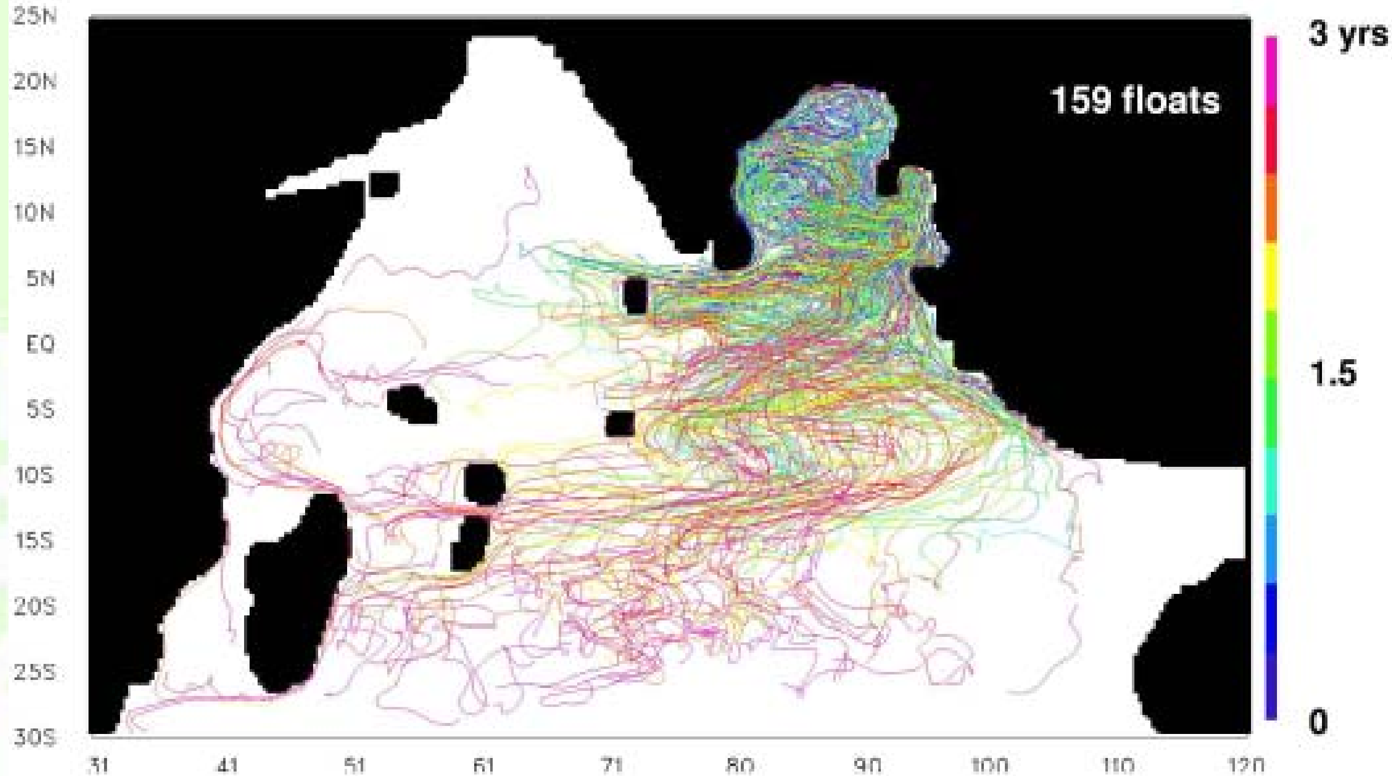
Zonal volume transport in ML



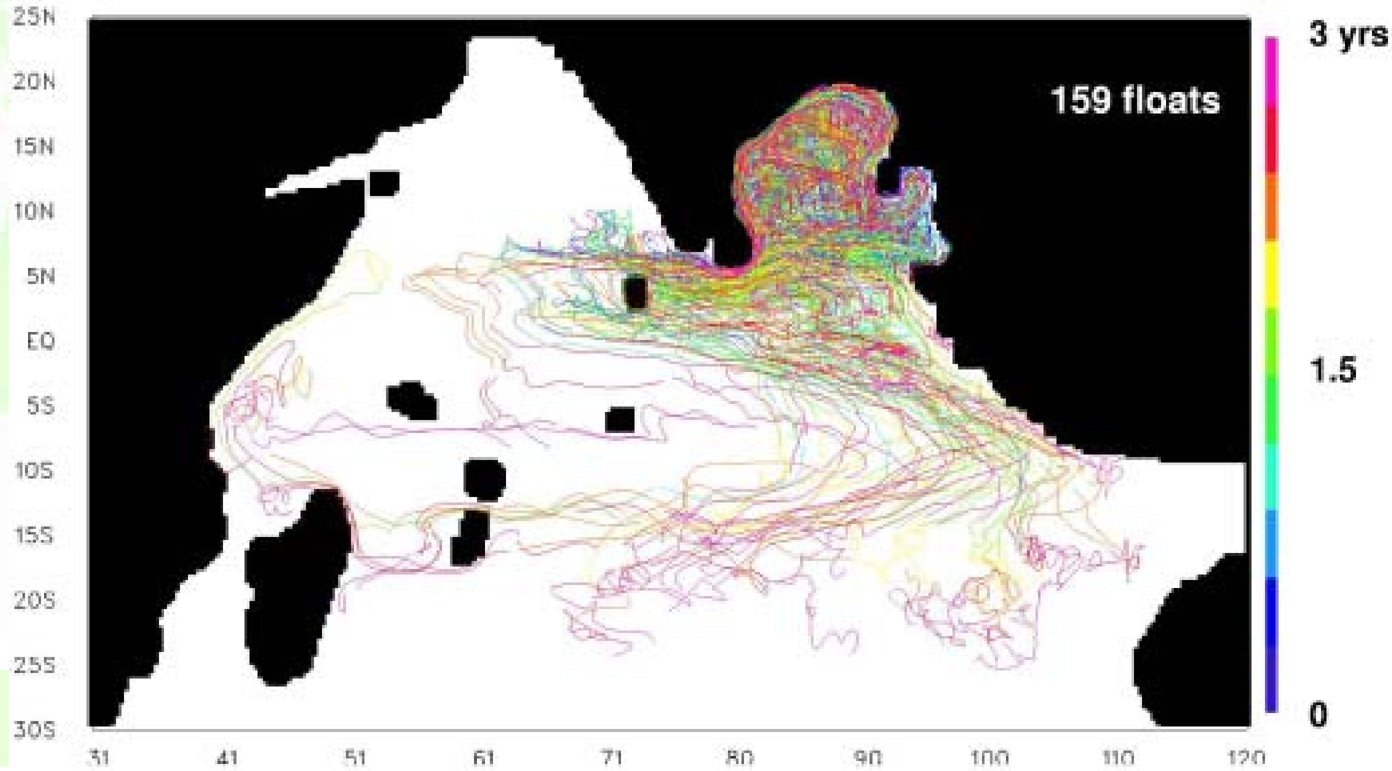
Extreme Pathways

- What if the extreme event lasted 3 years ?
- \- or equivalently we look at special groups of floats where the start positions of group 2 are the final positions of floats from group 1 after one year etc

IO Dipole



Mixed layer floats exported from the Bay of Bengal



La Nina

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Conclusions

- Cross-equatorial transport of low-salinity water is part of a clockwise gyre
- El Nino and IOD events strengthen this circulation. La Nina weakens it:
- Transport from the Arabian Sea to the Bay of Bengal is enhanced during El Nino and IO events
- Transport from Bay of Bengal towards Arabian Sea is further inhibited during El Nino and IOD events
- Transport of southern low-salinity water to the Arabian Sea via the Somali Current is increased during El Nino and IOD events