Western Boundary Currents in a changing climate: Case study of the Agulhas Current

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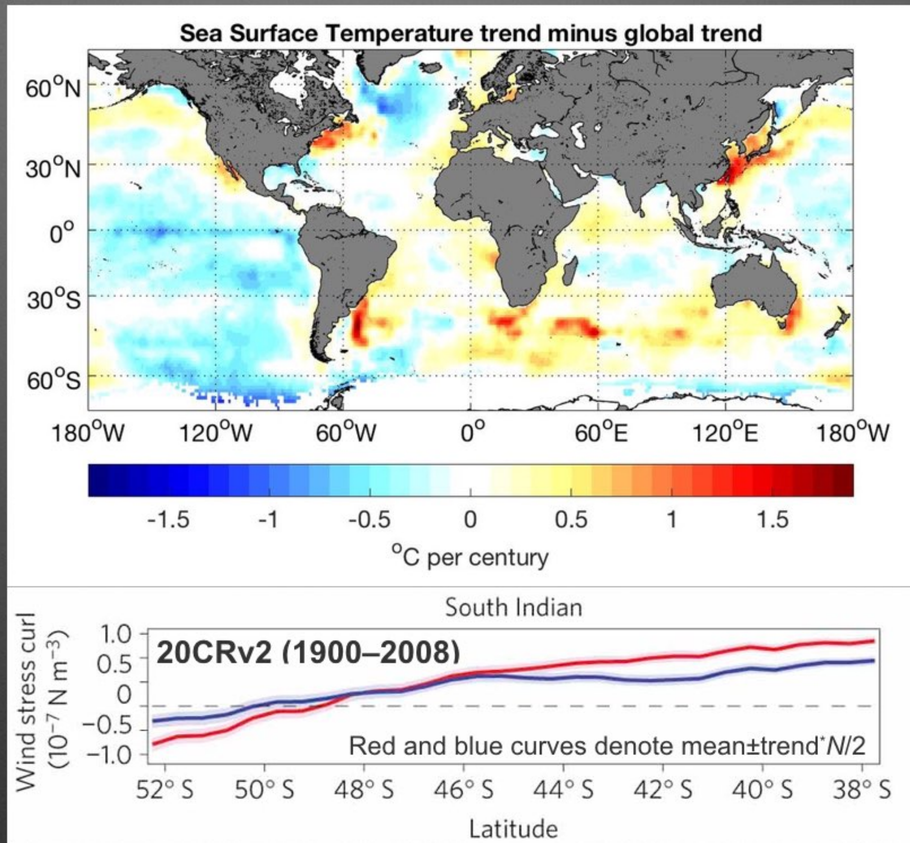
How are we expecting WBCs to change?

- WBCs warming more quickly than other parts of the ocean
- Westerlies and Trades intensifying
- Poleward shift and/or intensification of WBCs (Wu et al, 2012)?



Wu et al, 2012

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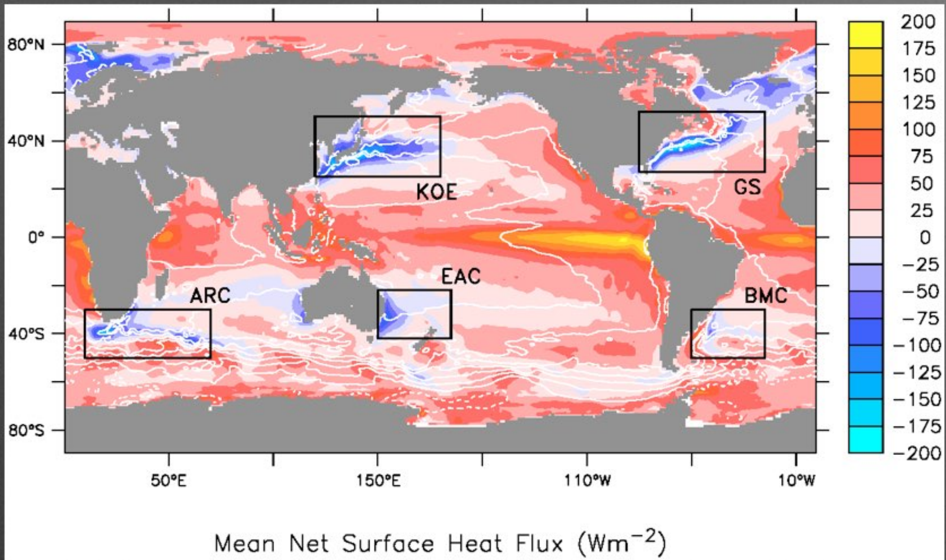
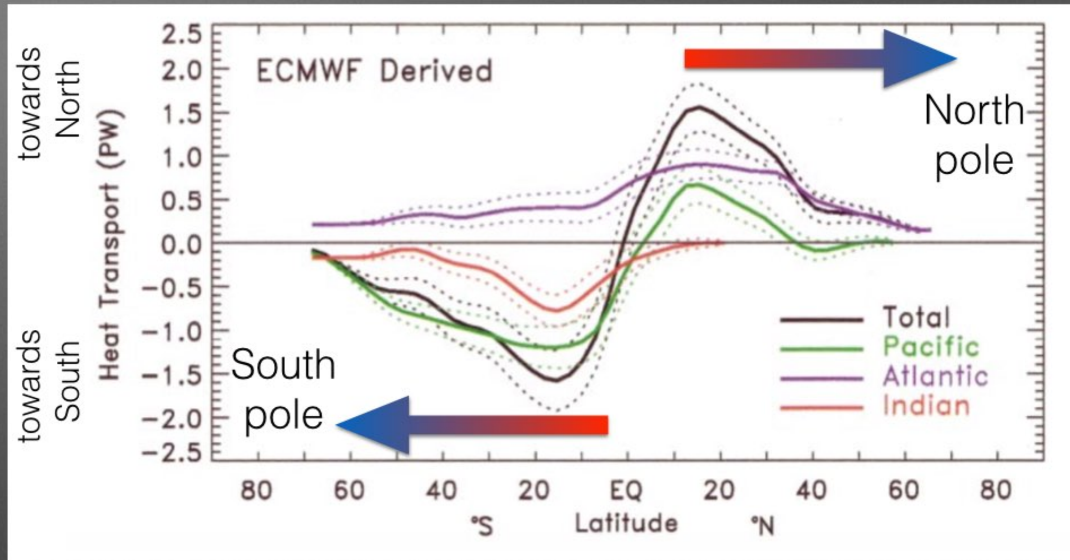
Why is understanding these changes important?





- WBCs support the highest air-sea fluxes in the world, fueling mid-latitude storm tracks. (Lee-Thorp et al, 1998; Rouault et al., 2000; Reason, 2001. Fig courtesy M Cronin)

- WBCs are the major carriers of meridional heat transport in the ocean (Trenberth & Caron, 2001; Bryden and Beal, 2001)

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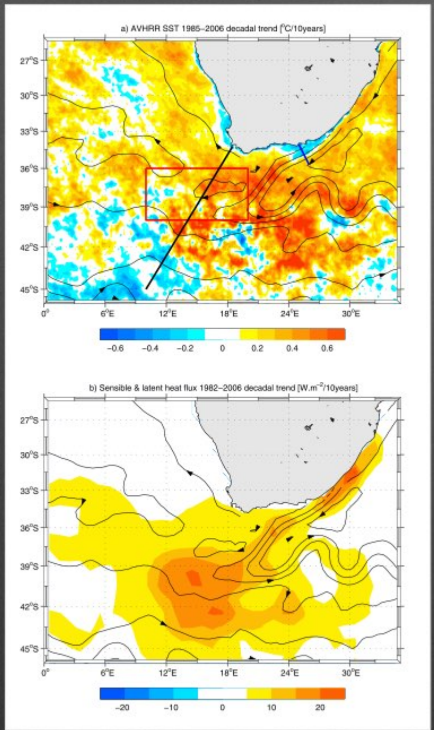
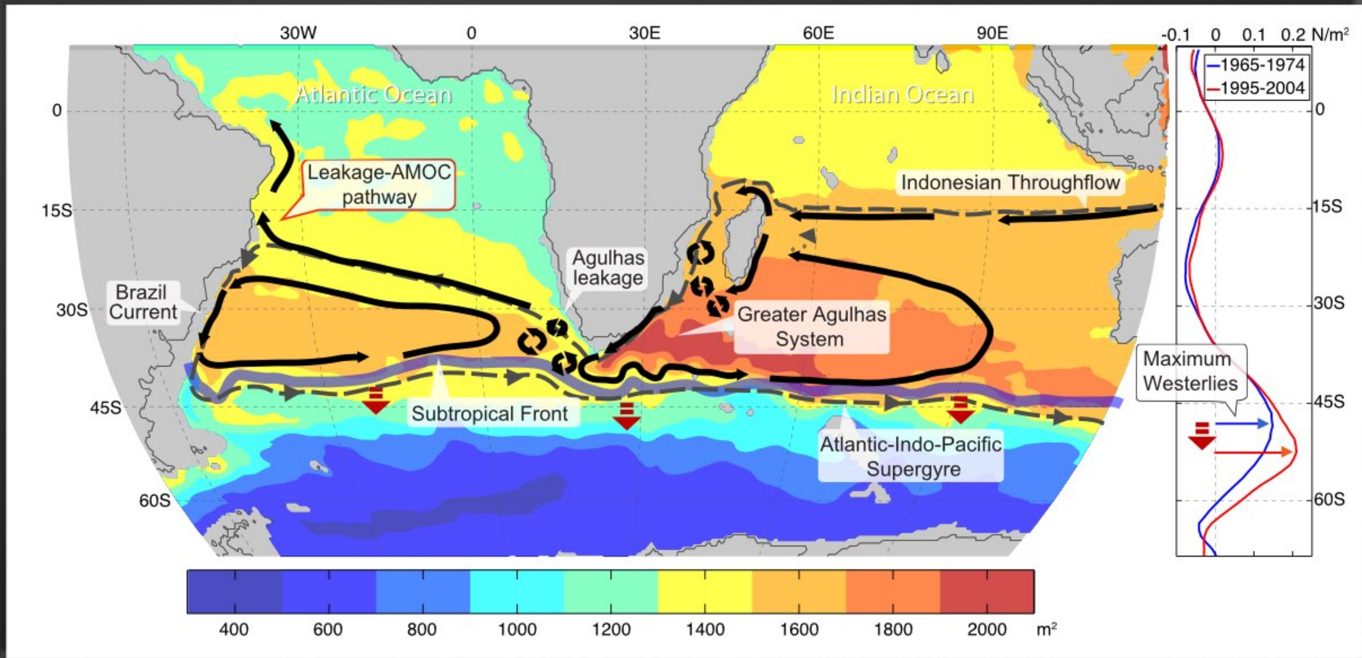
What’s significant about the Agulhas system?



Rouault et al, 2009



- Increase in Agulhas leakage could strengthen Atlantic overturning at a time when ice sheet melting is predicted to weaken it (Weijer et al, 2002; Biastoch et al., 2009; Beal et al., 2011).

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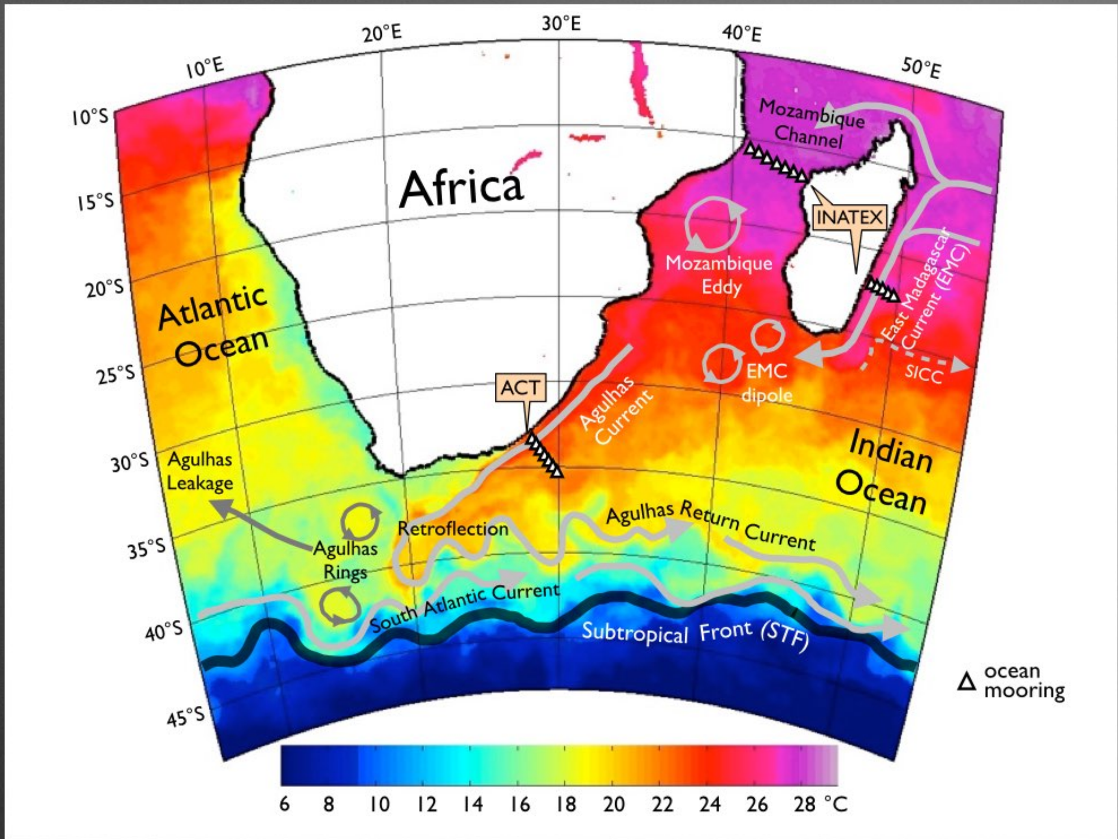
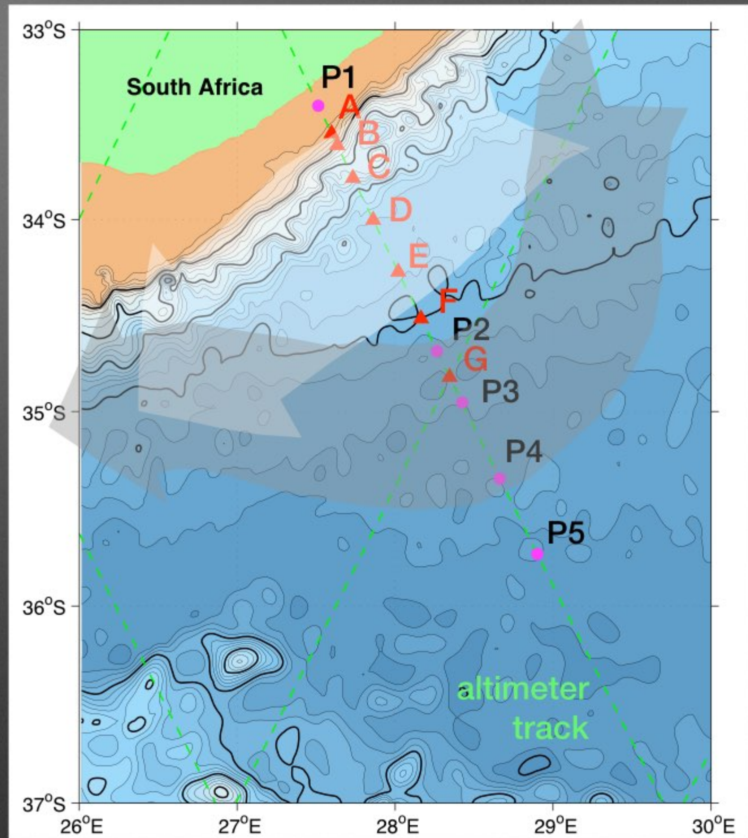
ACT: Agulhas Current Time-series





Beal et al., JPO (2015)

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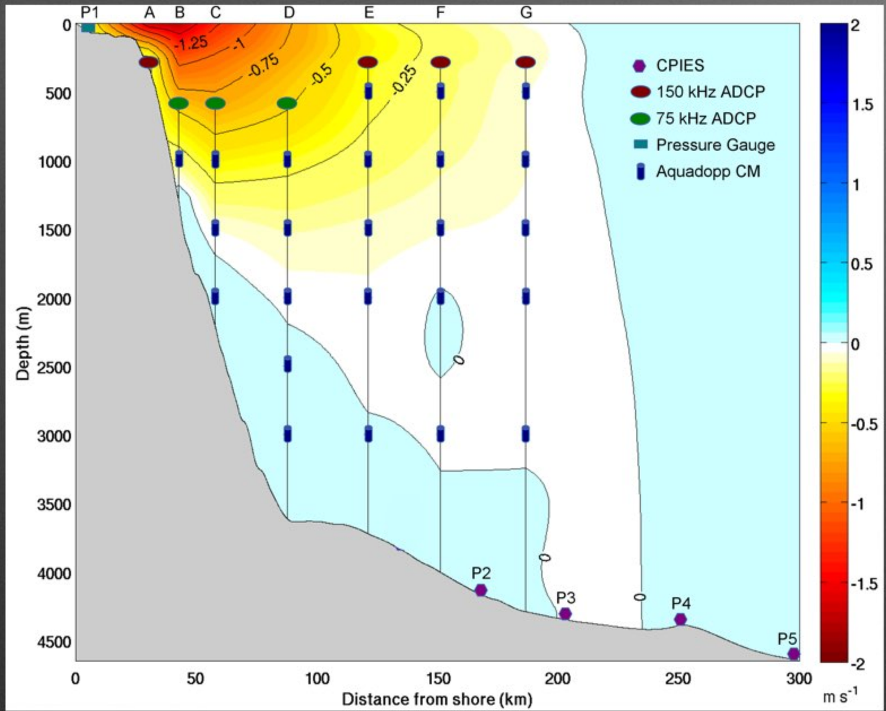
Array Design and Instrumentation

7 full-depth CM moorings, 4 CPIES



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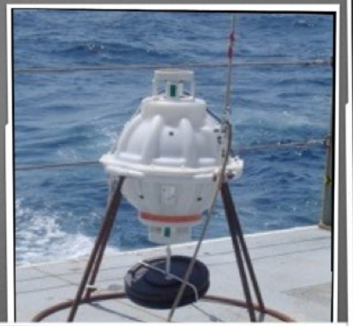

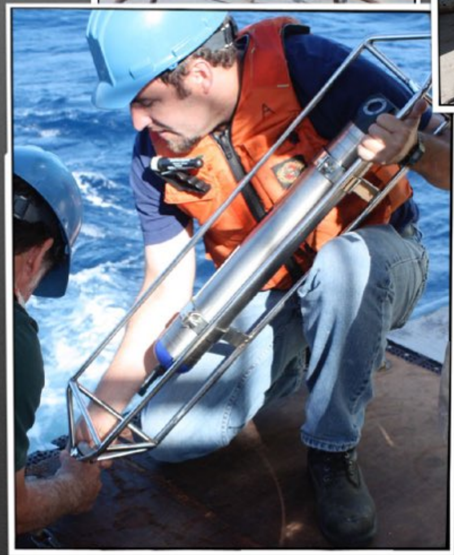

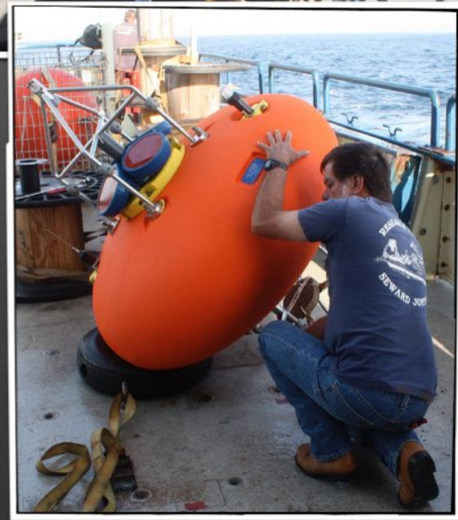

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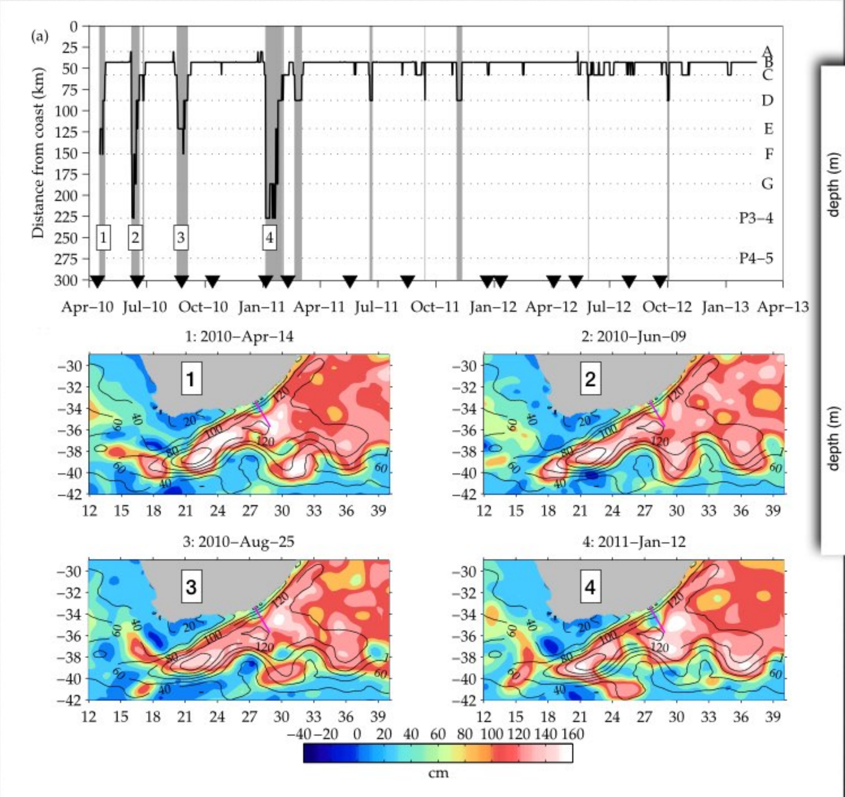
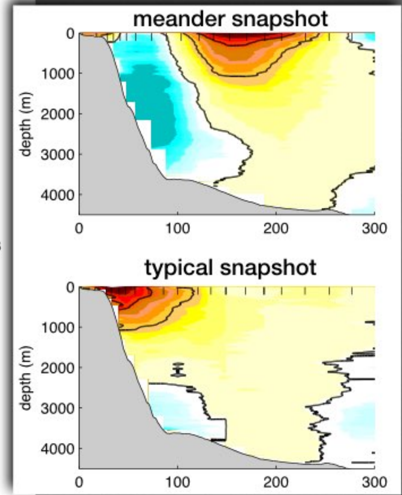
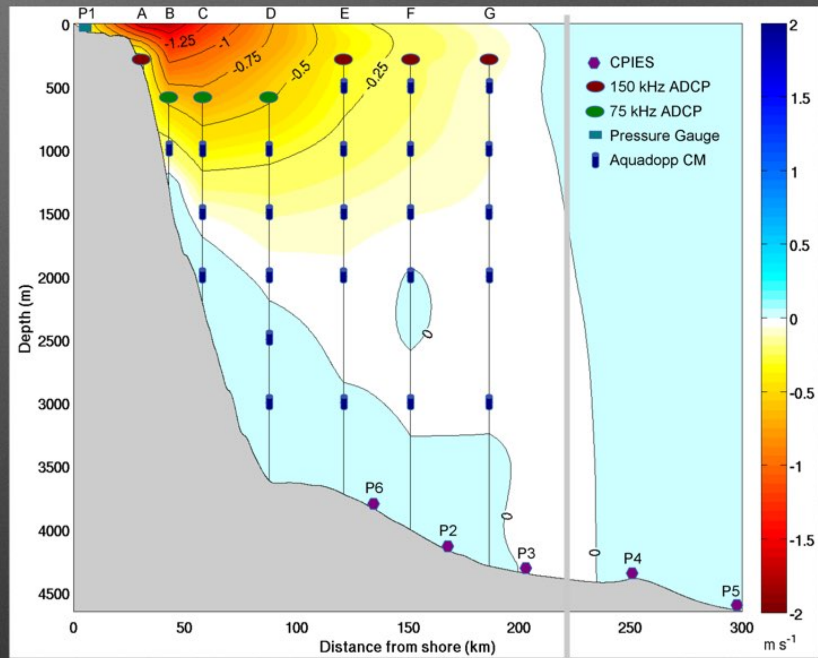
Meandering and mean structure of the Agulhas Current

Four mesoscale meander events and 14 ring-shedding events during ACT





3-yr mean structure of Agulhas Current



Mean width of current = 219 km

…more on meander snapshot see Leber & Beal (2014; 2015)

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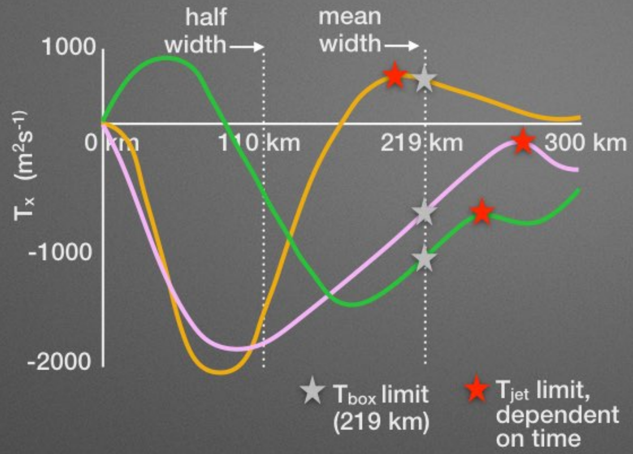
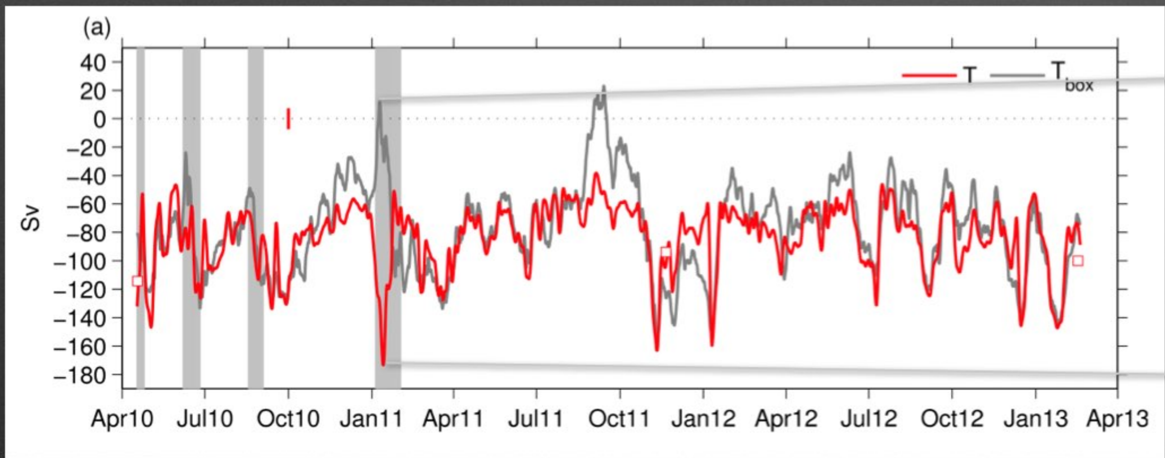
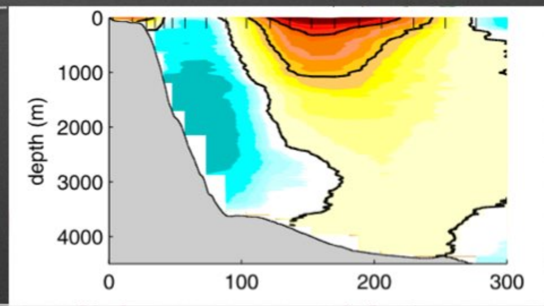
In situ time series of Agulhas Current transport

- T_{box} : Net transport out to mean width ★ of poleward flow (219 km)
- T_{jet} : Poleward transport out to the first maximum ★ of transport-per-unit-distance (T_x), beyond the half width of the jet (110 km).



	T	T_{box}
Mean	-84	-77
Median	-79	-76
standard deviation	24	32
decorrelation time scale	7	17
standard error of the mean	2	4
Estimated error (20-h)	14.8	6
Estimated error (mean)	9.0	0.5





Beal et al., JPO (2015)

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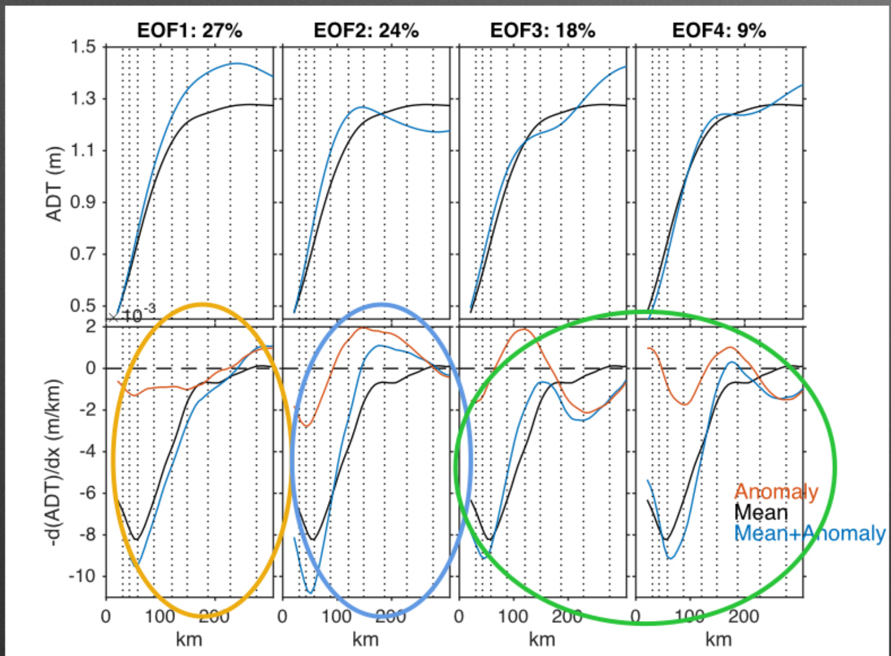
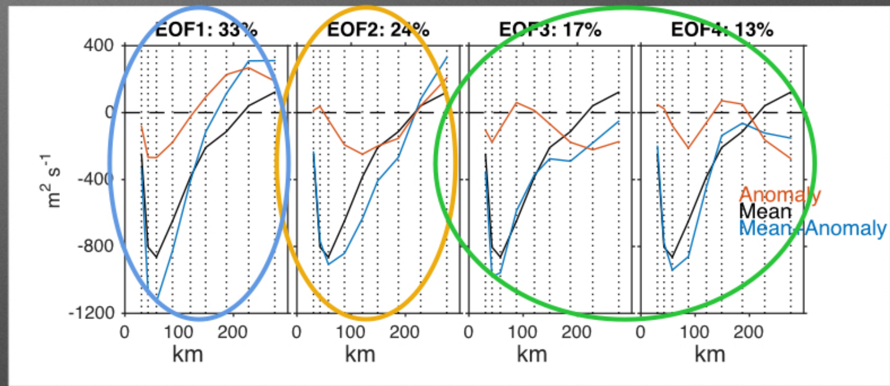
Can we build a proxy?

Combined EOF on sea surface height and sea surface slope, from along-track AVISO ADT (22 yr)



Modes or variance of transport per unit distance ($T_x = \int v\,dz$) from ACT array (3 yr)



- transport mode
- narrowing/broadening of jet
- meandering/eddying of jet
- Variance of sea surface height captures modes of variance of transport (Tx) across the Agulhas Current

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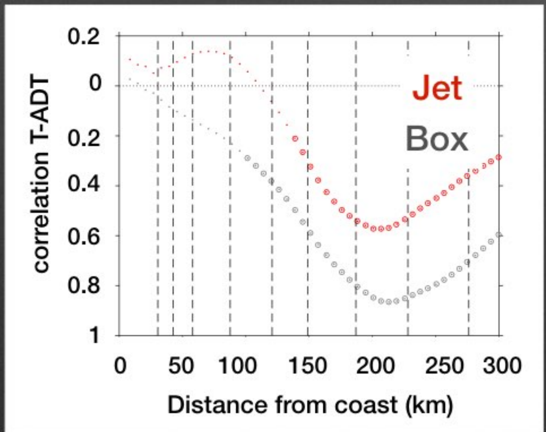
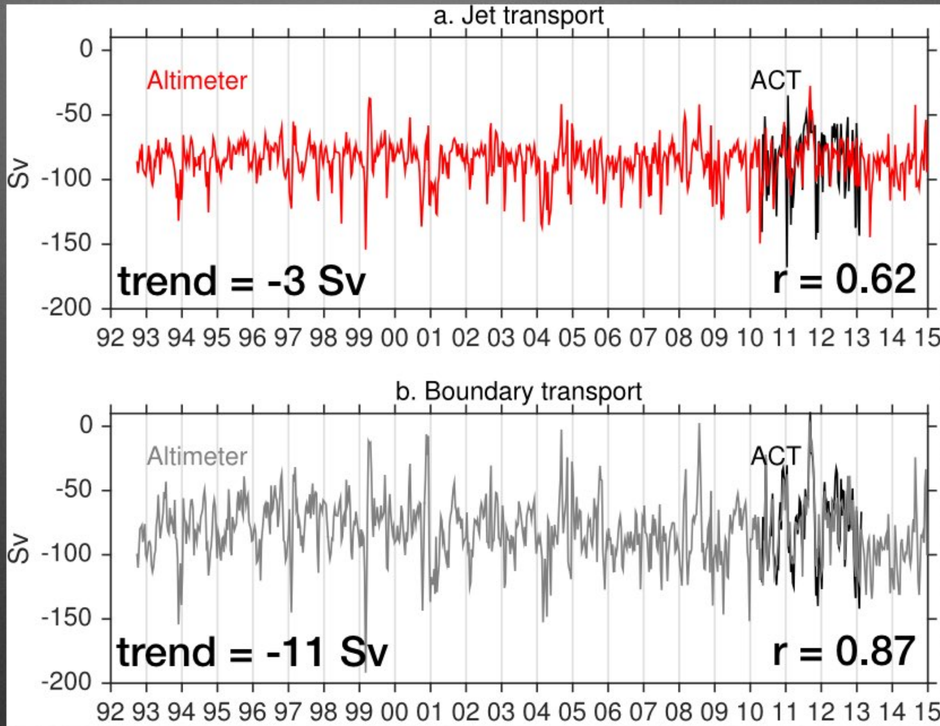
22-year proxy of Agulhas Current transport using multivariate regression between 4 PC time-series of along-track ADT and transports T_{jet} and T_{box}

$$T = \alpha_0 + \sum_{k \in \Omega} \alpha_k A_k(t)$$

Only offshore ADT significantly correlates with transport





These Transport proxies give spurious trends. Need to allow for variance of cross-shore jet structure.

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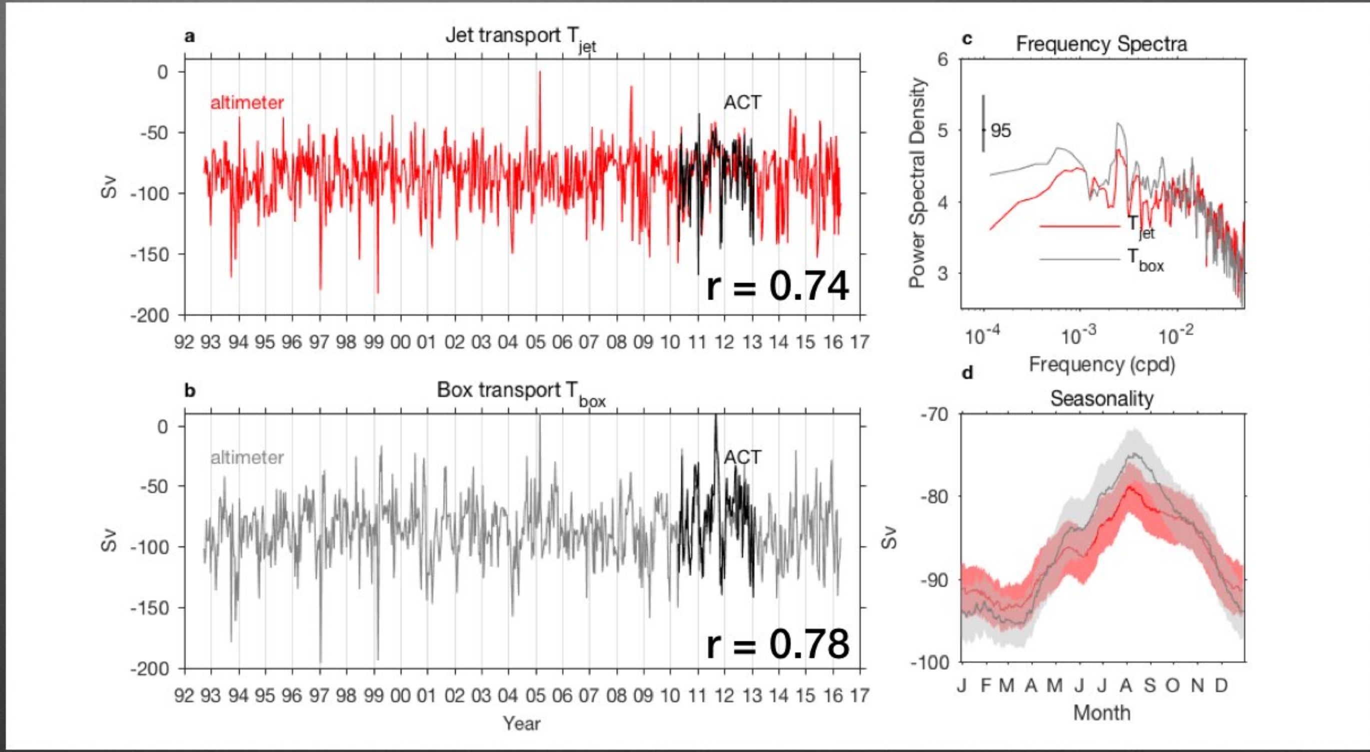
Build proxy based on regression of local sea surface slope at each of 9 moorings

- We regress local sea surface slope against vertically integrated cross-track velocity from each mooring (transport per unit distance, T_x)
- We choose dx such that the correlation between dADT/dx and vertically integrated velocity is a maximum (from 27 km at B to 102 km at G)
- Significant annual cycle. Resulting trends in T_{jet} and T_{box} are +1 Sv and +2.1Sv, not significant.



This is not what we were expecting. How do we know this proxy trend is robust?

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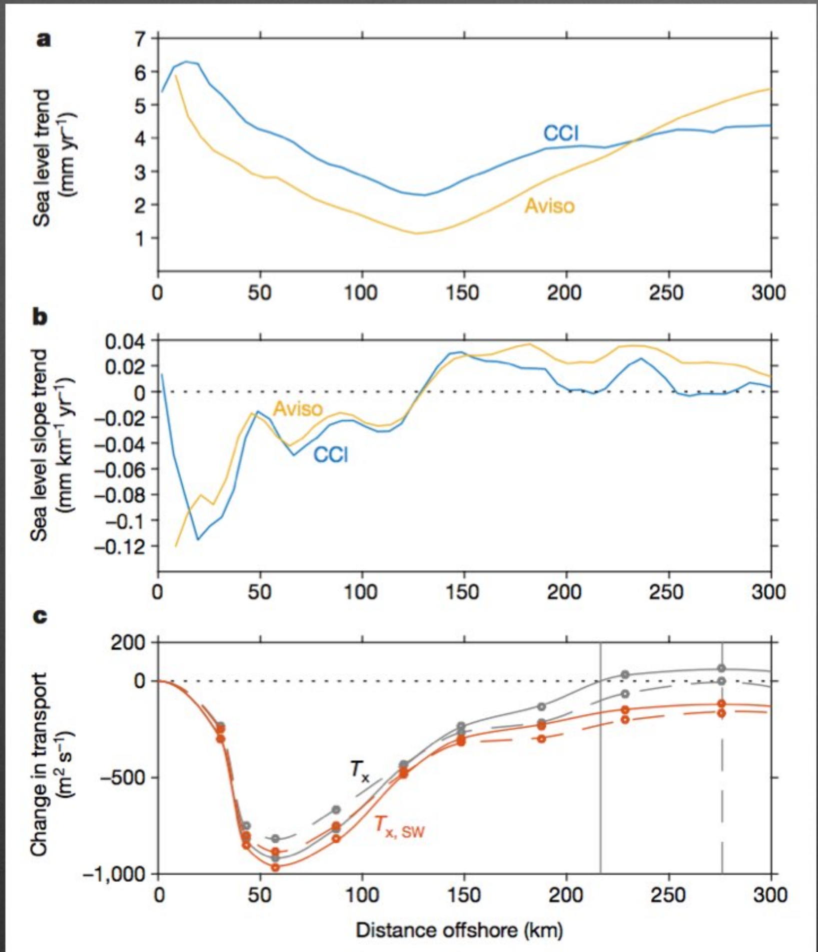

Agulhas Current is weakening AND broadening

- Core of Agulhas jet is weakening over time, while its offshore flank (>130 km) is strengthening, yet the transport is unchanging.
- Fixed integration T_{box} cannot account for a widening of the jet and neither can a proxy based on total transport.

CCI: Ablain et al. (2012)   Beal and Elipot, Nature, 2017

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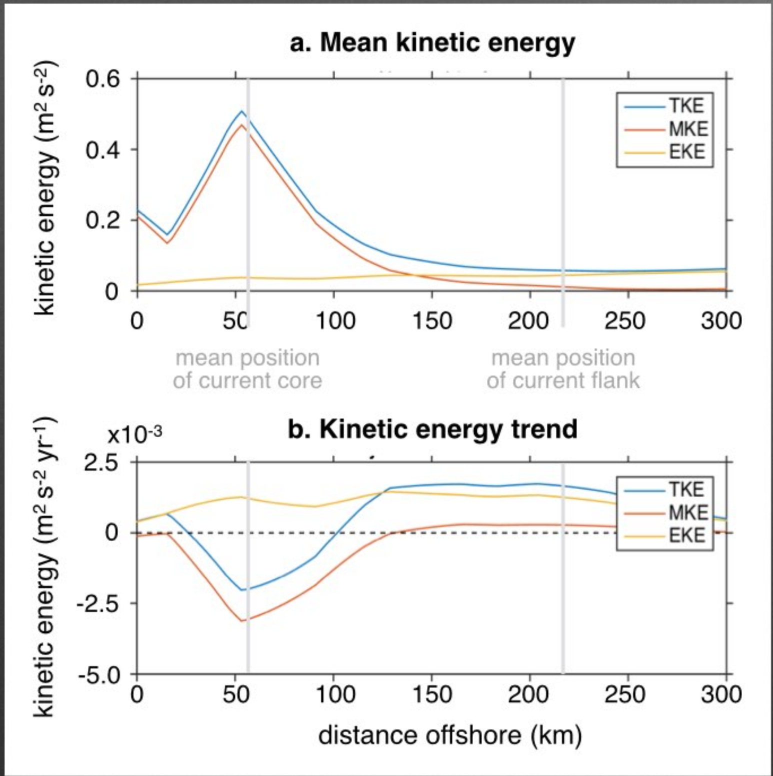
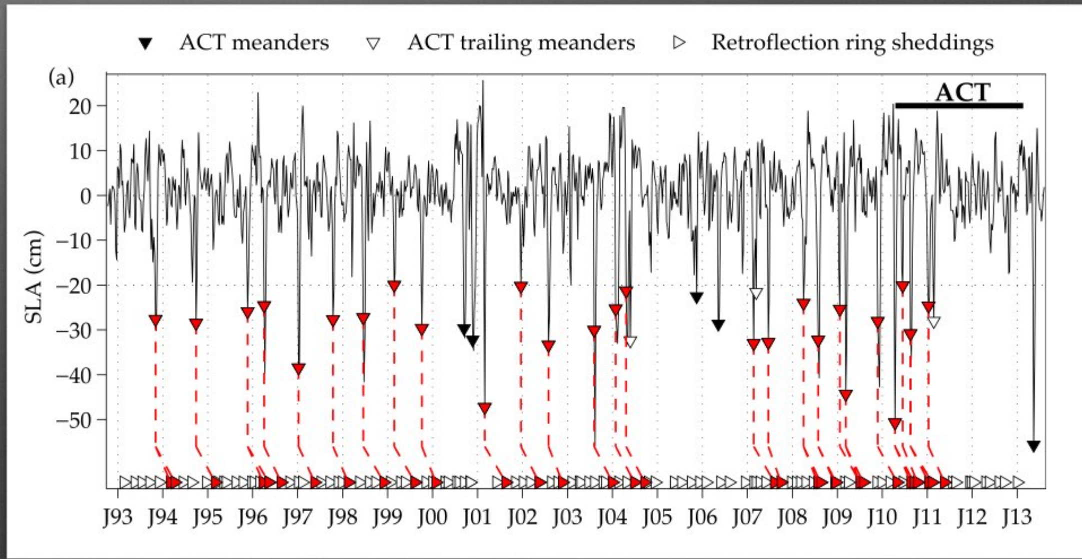
Boundary layer has broadened due to an increase in eddy viscosity, or EKE





...although the trend is a small component of the variability

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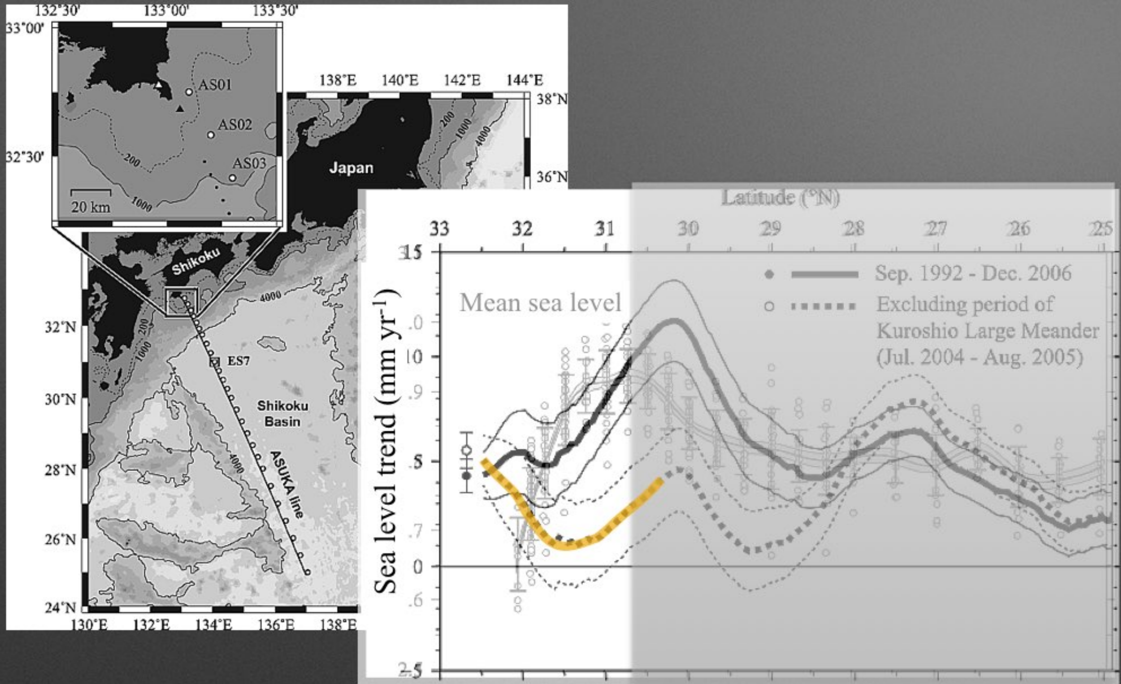
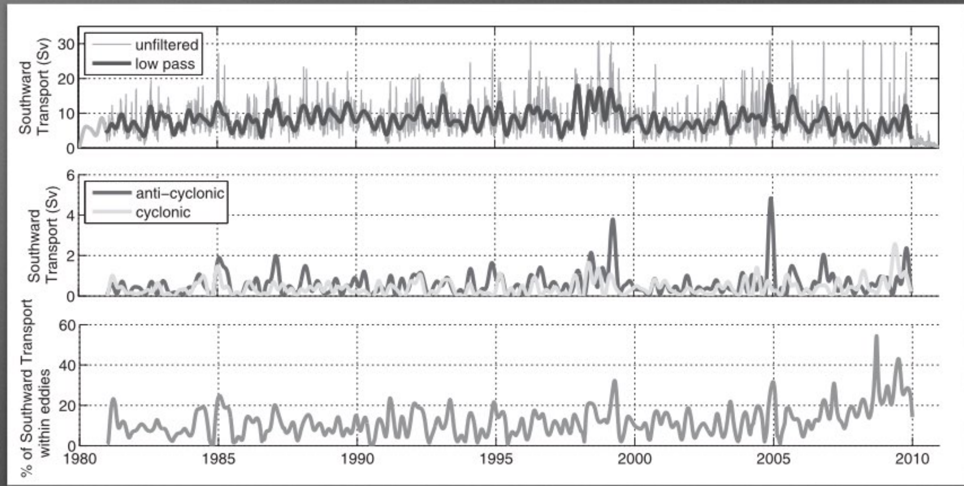
Evidence of increasing EKE in other WBCs



- Similar pattern of sea level trend and increasing EKE in Kuroshio (Uchida & Imawaki, 2008; Yan & Sun, 2015)

Total and eddy transport of East Australia Current



- No trend in EAC transport, but warming (Oliver & Holbrook, 2014) and increasing eddy transport (Cetina-Heredia et al., 2014). Eddying linked with basin-scale wind stress curl (Sloyan & O'Kane, 2015).

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Conclusions

- Important to capture the *whole* jet at all time steps: The *boundary* and *jet* transports have different means and variability, particularly during meander events.
- The 3-yr mean Agulhas *jet* transport is -84 ± 11 Sv at 34 S. This equates with mean Sverdrup transport (60 Sv) + ITF + overturning (another ~25 Sv).
- A 22-year proxy built from a regression between local sea surface slope and *in situ* transport at each mooring allows for changing horizontal structure (although vertical structure still fixed).
- Agulhas transport is strongest in summer and weakest in winter, similar to the Gulf Stream and Kuroshio.
- From the proxy, the Agulhas Current *jet* appears to be weakening and broadening over the last two decades, with little change to its total transport.
- Broadening is associated with increasing EKE, and there is evidence of a similar trend in the Kuroshio and East Australia Currents.

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