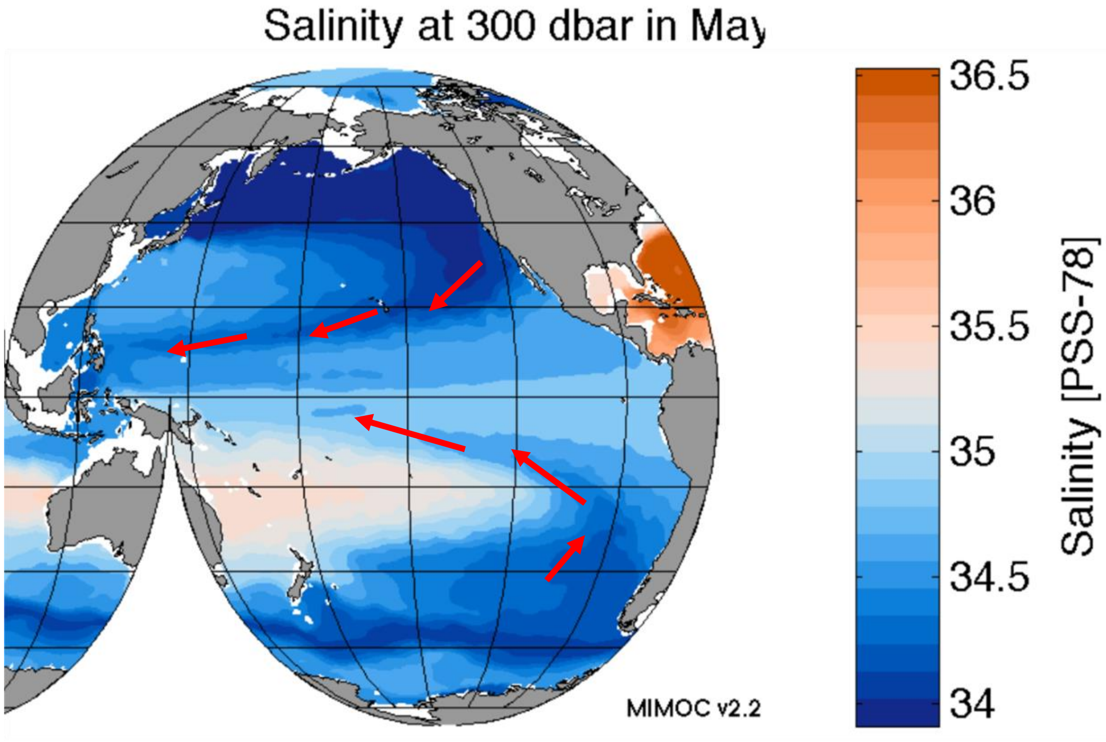
A first look at modified-forcing experiments to investigate drivers of interannual variability in subtropical-to-tropical pathways

Cora Hersh, Jake Gebbie, Susan Wijffels
MIT-WHOI Joint Program
2024 ECCO meeting

Mean water properties persist from subduction in subtropics to upwelling regions in the tropics

- Luyten, Pedlosky, and Stommel 1983



Interannual anomalies of these water mass properties

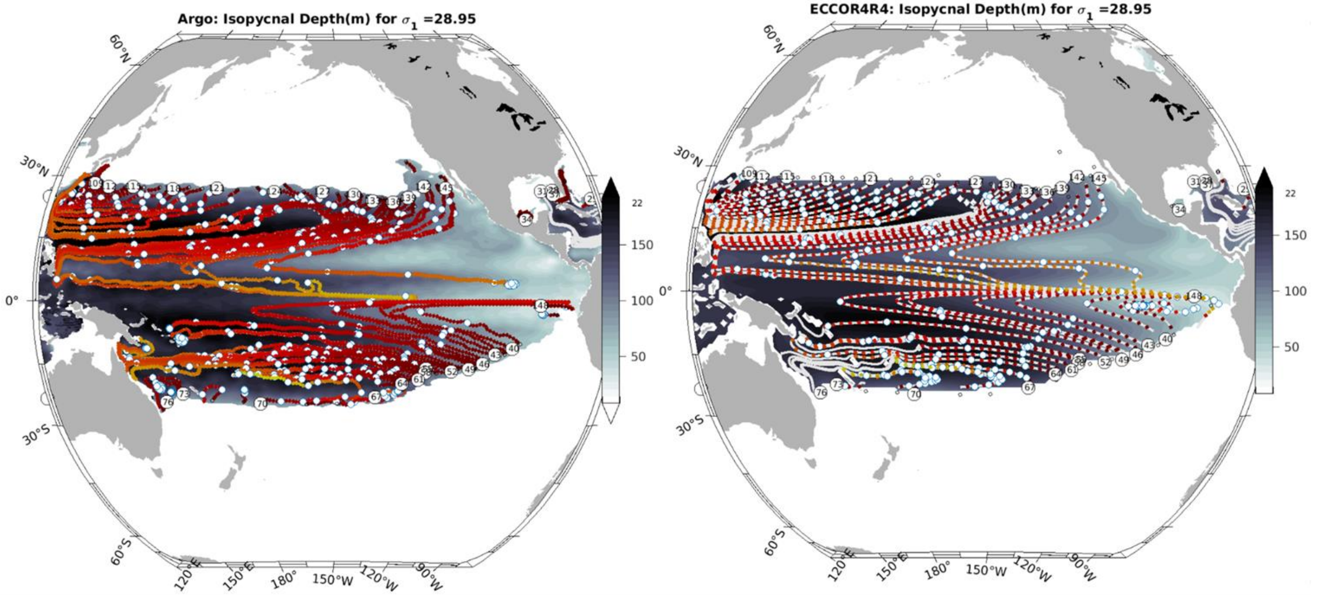
Our previous work:

- Interannual water mass anomalies (PV, spice) are common in all subtropical ocean basins
- Propagation in tunnel regions is well-described by the mean advective speed
- Anomalies can be tracked for up to 10,000 km downstream of the outcrop

Remaining questions:

- What are the surface forcing mechanisms responsible for their formation?
- Do these anomalies have the potential to re-emerge in the tropics or western boundary currents, thereby impacting air-sea fluxes and providing a new mode of climate predictability?

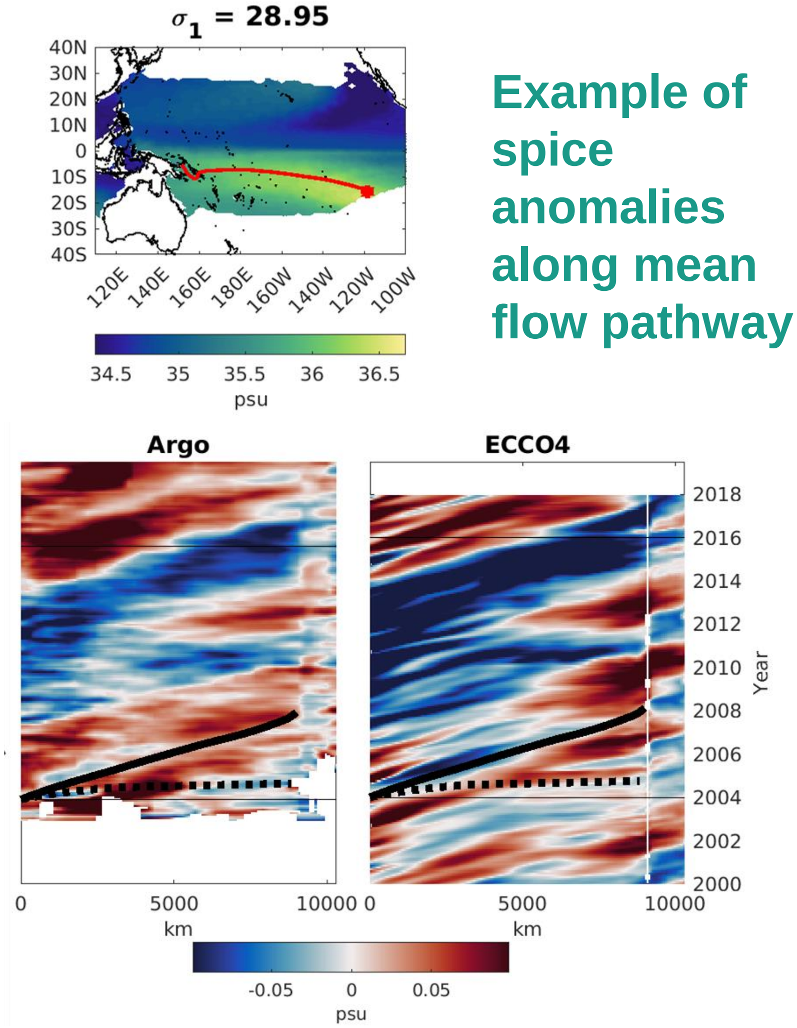
Argo/ECCO comparison



- Survey of characteristics and longevity of interannual water mass anomalies along mean flow pathways in all subtropical oceans in both Argo and ECCOV4R4
- Analyzed anomalies on isopycnal surfaces (potential density referenced to 1000 dbar)

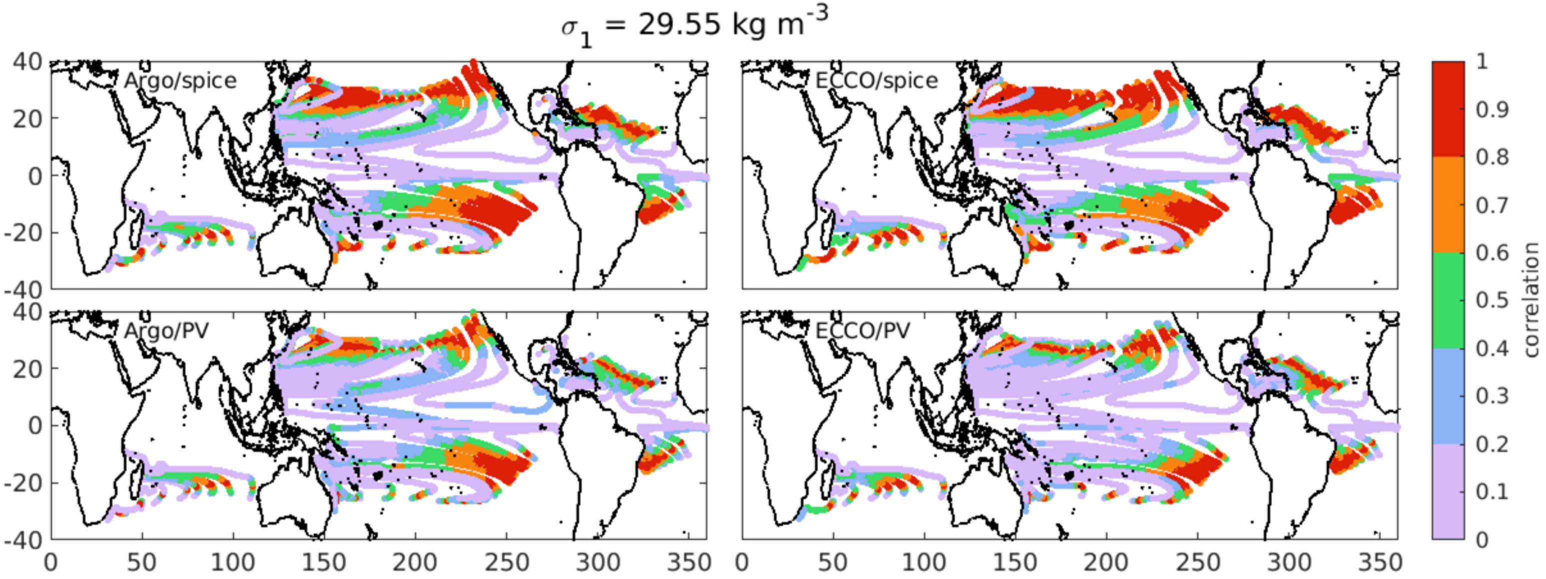
Argo/ECCO comparison

- Spice: salinity on density
- PV: $1/\rho_{ref} * f *$ DRHODR
- Long-lived spice and PV anomalies are common in all subtropical basins
- Propagate at mean advective speed
- **Results are encouraging for use of ECCO as a tool to study this variability**



Example of spice anomalies along mean flow pathway

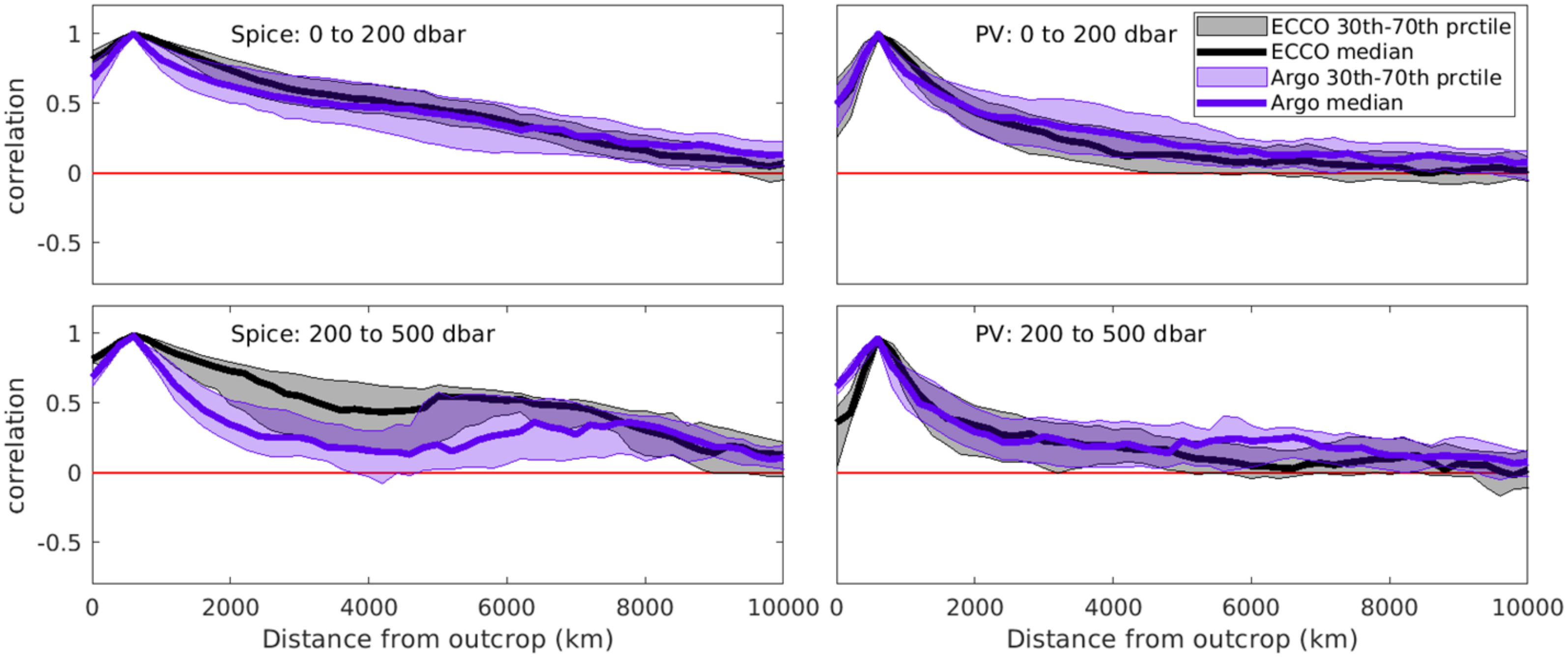
Downstream lagged correlation



We calculated correlation coefficients between a timeseries at the beginning of a streamline (near outcrop) and each timeseries further downstream

Subtropical ventilation windows are clearly visible

Agreement in anomaly coherence dissipation rates downstream of subduction windows

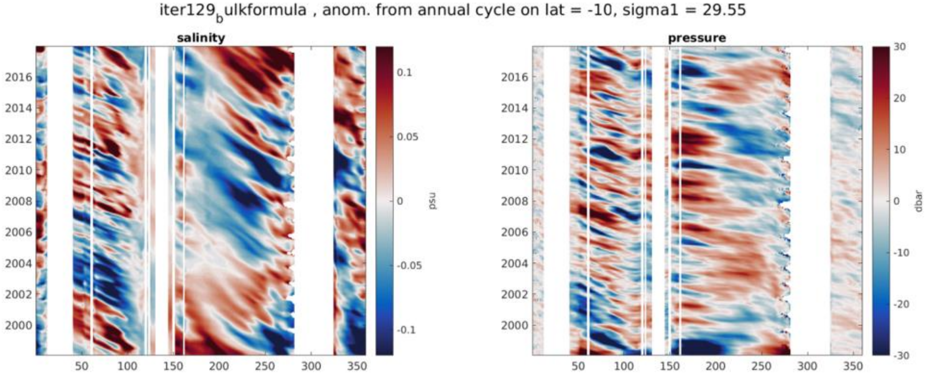


Note that max. median correlation falls after zero on the x axis because correlation coefficients are calculated from a point typically a few hundred km from the beginning of each streamline to avoid capturing seasonal variability in outcrop position

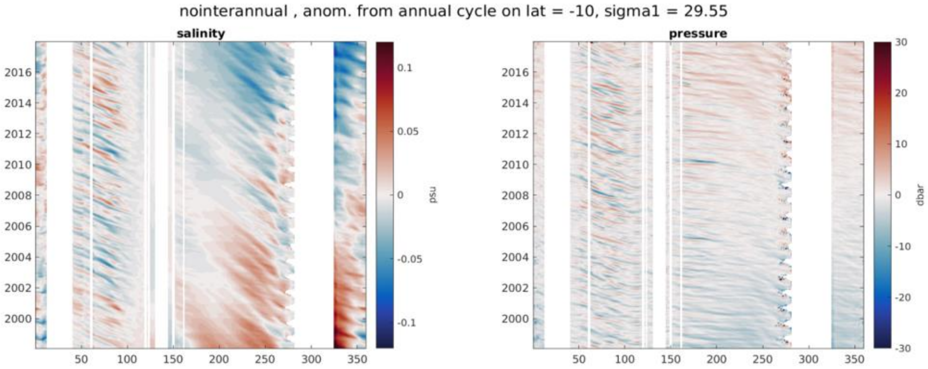
Modified-forcing experiments

- Hypothesis: the interannual band of the surface forcing variability is the major driver of interannual subsurface water mass anomalies (as opposed to e.g. red-shifting of synoptic variability)
- To test this, we re-run flux-forced MITgcm, removing the interannual variability from all surface forcing variables (wind stress, heat fluxes, salt fluxes, etc.)
- Further experiments test the impact of interannual forcing
  - Over specific ocean basins (e.g. the North Pacific)
  - Separate wind from buoyancy forcing

Interannual variability at the surface drives interannual ocean response



ECCOV4R4

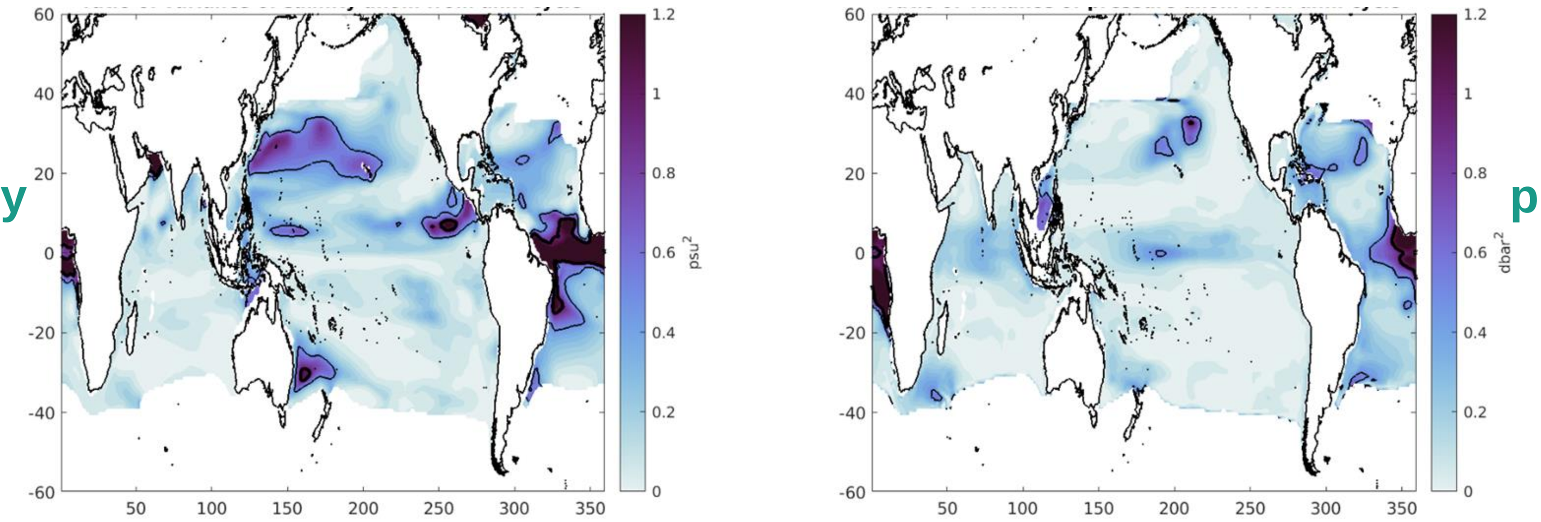


Interannual forcing variability removed

Interannual variability at the surface drives interannual ocean response

$$\frac{\text{Variance in experiment with no interannual forcing}}{\text{Variance in ECCOV4R4}}$$

salinity

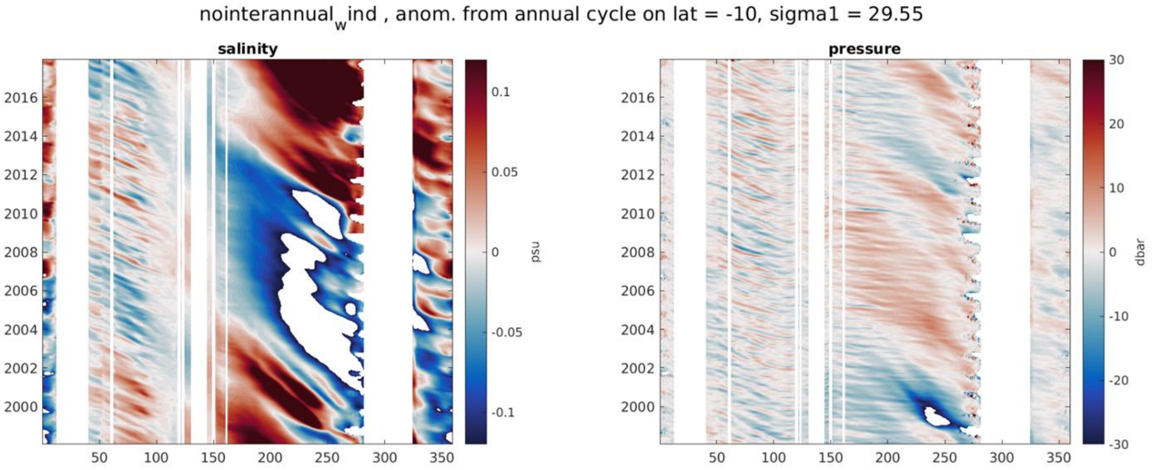


pressure

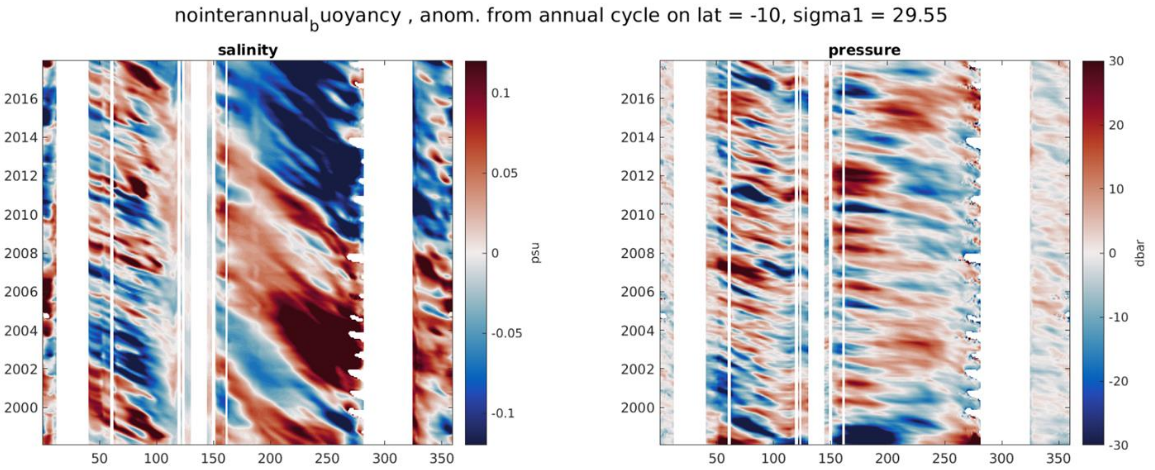
sigma1 = 30.6 kg/m^3

Compensating wind and buoyancy-driven spice anomalies

Interannual wind removed —>



Interannual buoyancy removed —>



Compensating sea level anomalies:
Piecuch and Ponte, GRL 2012
Piecuch and Ponte, JPO 2012

Summary

- We are interested in the ability of the subtropical-to-tropical “tunnels” to transmit interannual water mass signals and to potentially re-emerge at the sea surface far downstream of an outcrop
- ECCOV4R4 is able to capture this variability as compared to Argo, and is thus an appropriate tool for investigating the tunnel mechanism
- We are running a suite of modified-forcing experiments in the flux-forced ECCOV4R4 configured MITgcm to understand the drivers of the variability
- Preliminary results confirm initial hypotheses and show many interesting avenues of further study

Questions?

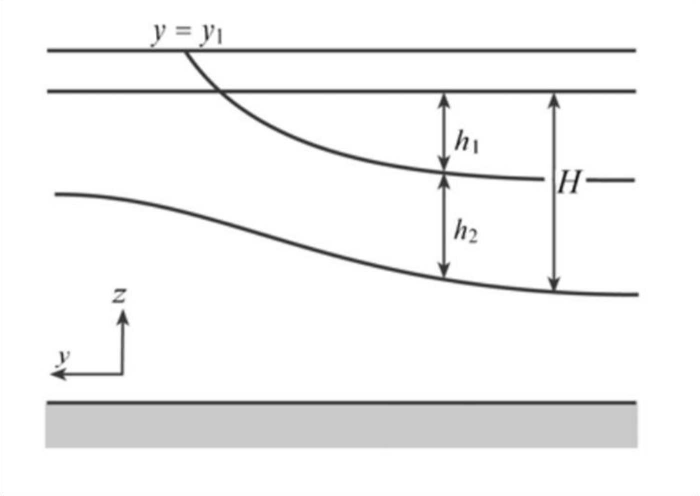
This work supported by:

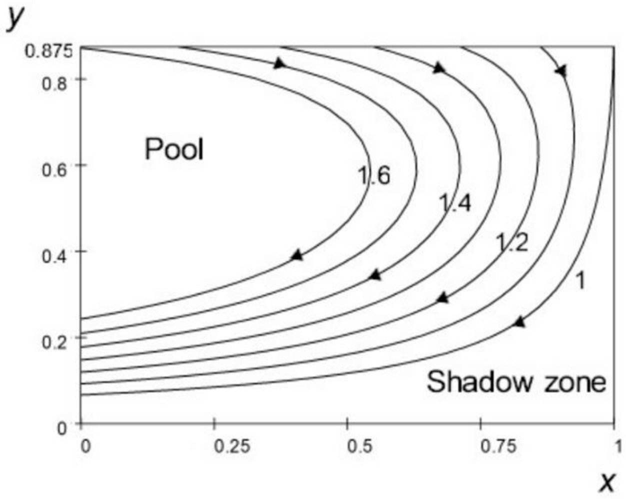
MIT·WHOI
JOINT PROGRAM IN OCEANOGRAPHY/APPLIED OCEAN SCIENCE & ENGINEERING

NASA

NSF

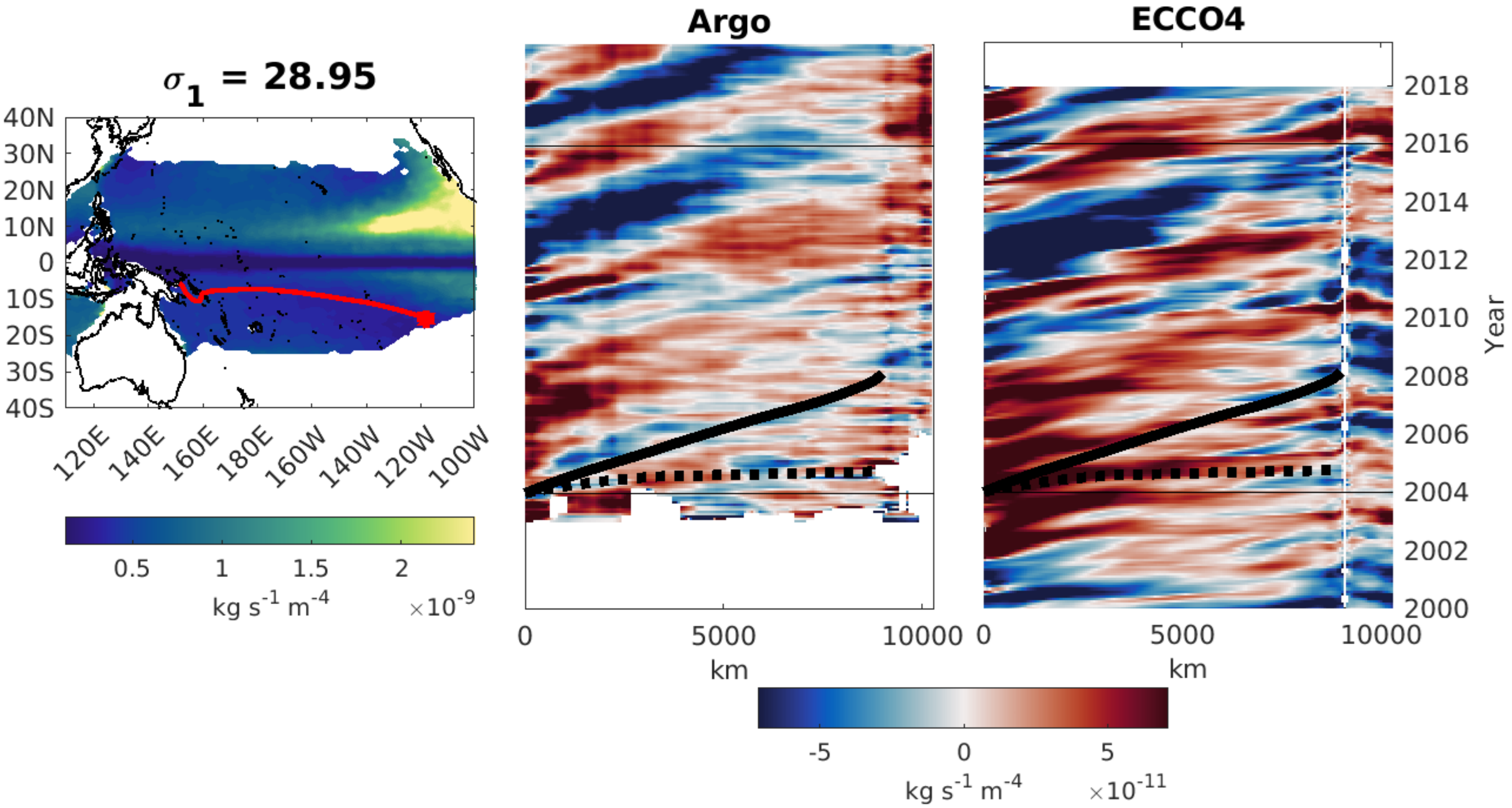
Background: Ocean subduction and thermocline ventilation in subtropical gyres



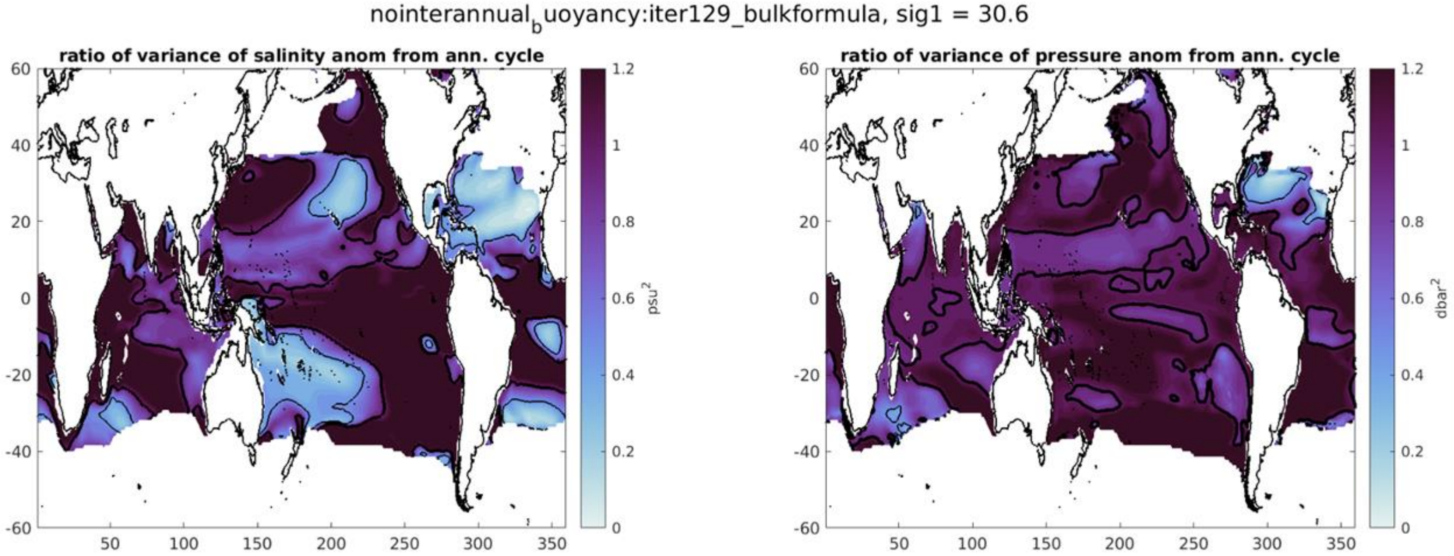


Water mass properties are set at the surface and conserved along subducting streamlines

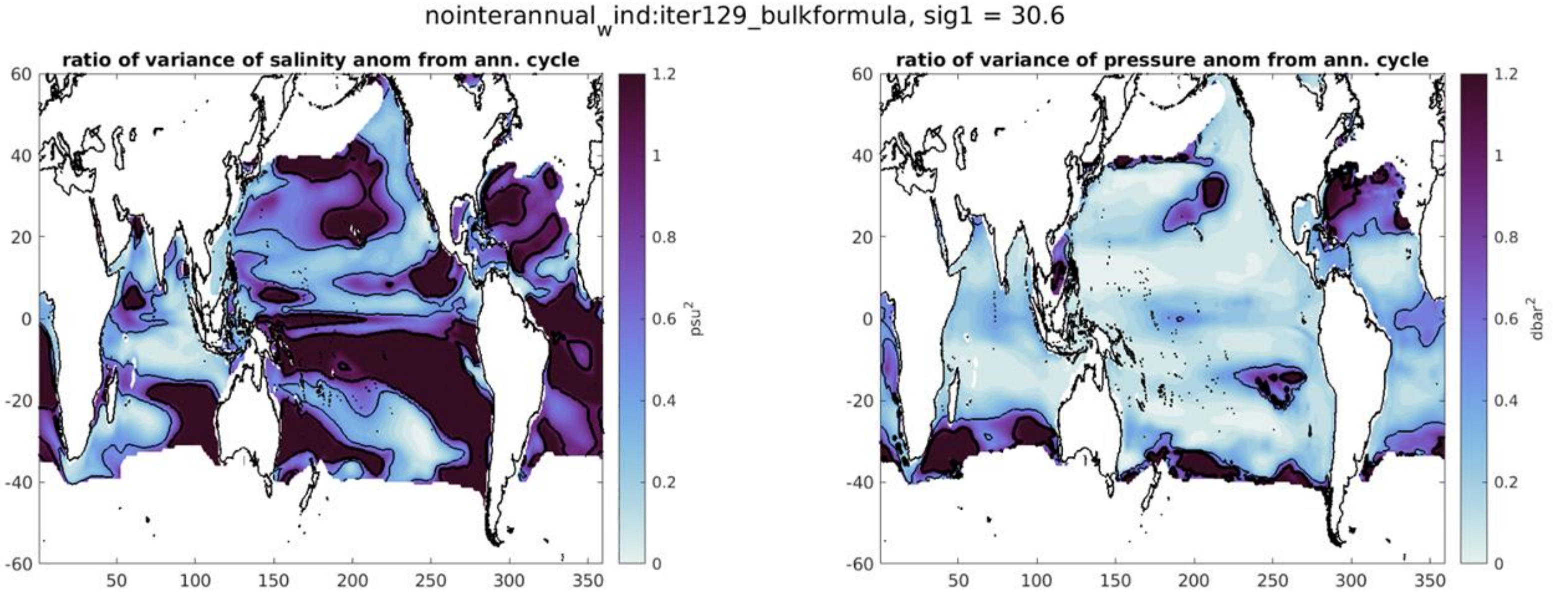
John Marshall, schematics adapted from Luyten, Pedlosky, and Stommel 1983


σ_1 = 28.95
40N
30N
20N
10N
0
10S
20S
30S
40S
120E
140E
160E
180E
160W
140W
120W
100W
0.5
1
1.5
2
kg s^{-1} m^{-4}
×10^{-9}
Argo
ECCO4
0
5000
10000
km
0
5000
10000
km
2018
2016
2014
2012
2010
2008
2006
2004
2002
2000
Year
-5
0
5
kg s^{-1} m^{-4}
×10^{-11}

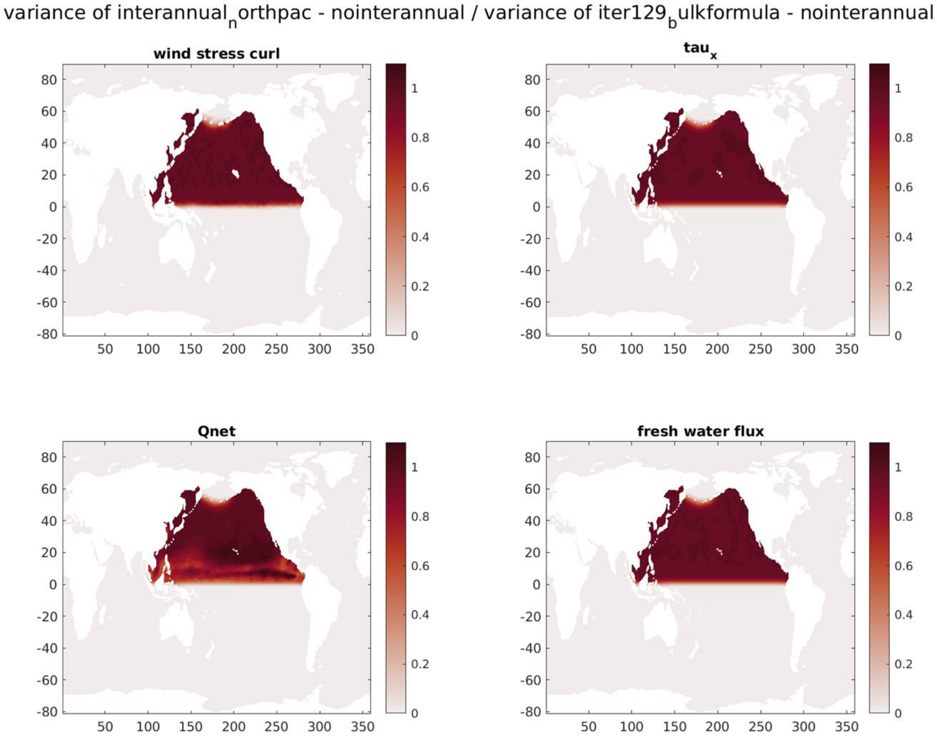
Interannual variability of buoyancy forcing removed everywhere



Interannual variability of wind forcing removed everywhere



Retrieve mask by subtracting runs from each other

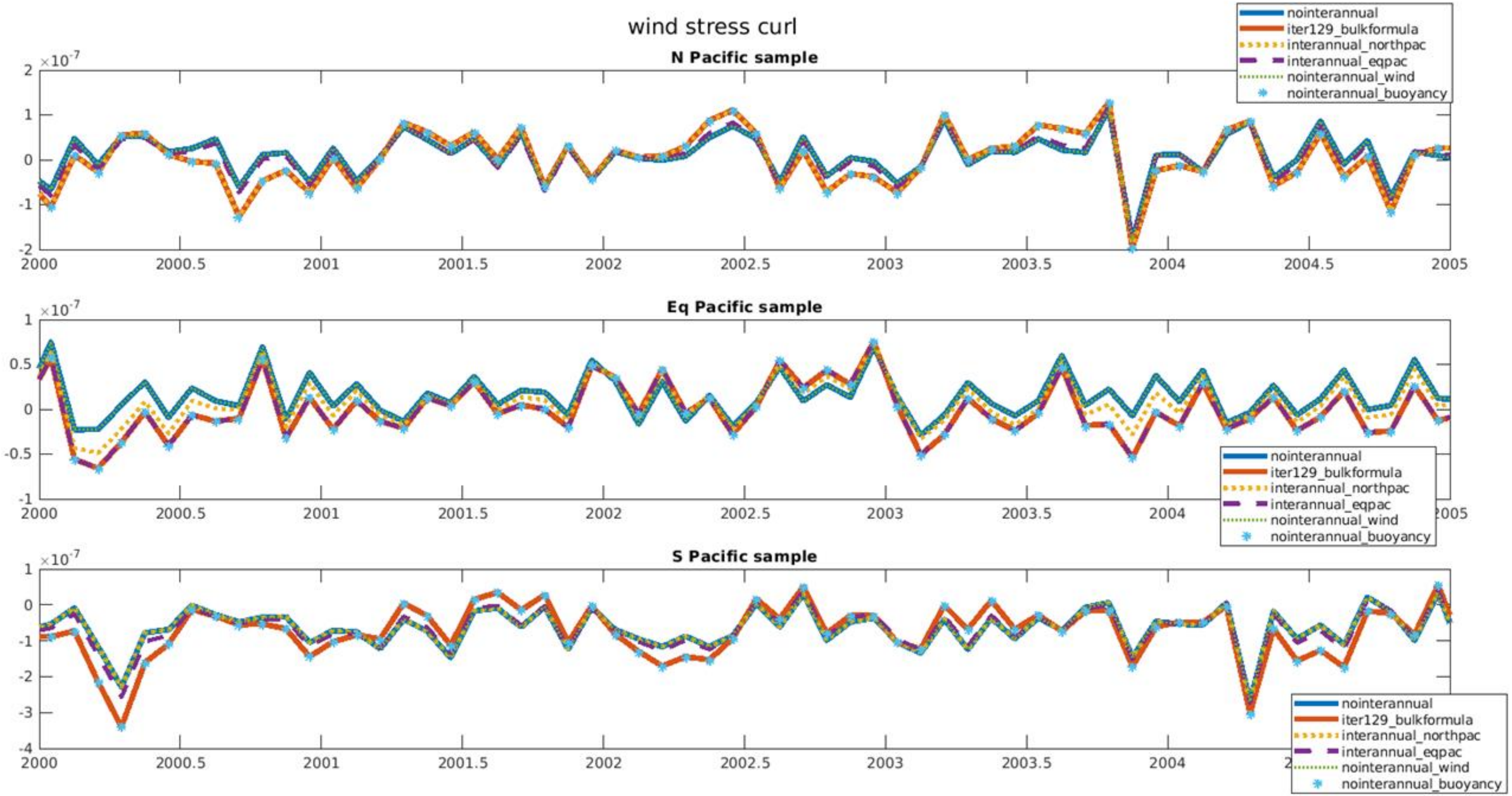

variance of interannual$_{n}$orthpac - nointerannual / variance of iter129$_{b}$ulkformula - nointerannual

wind stress curl

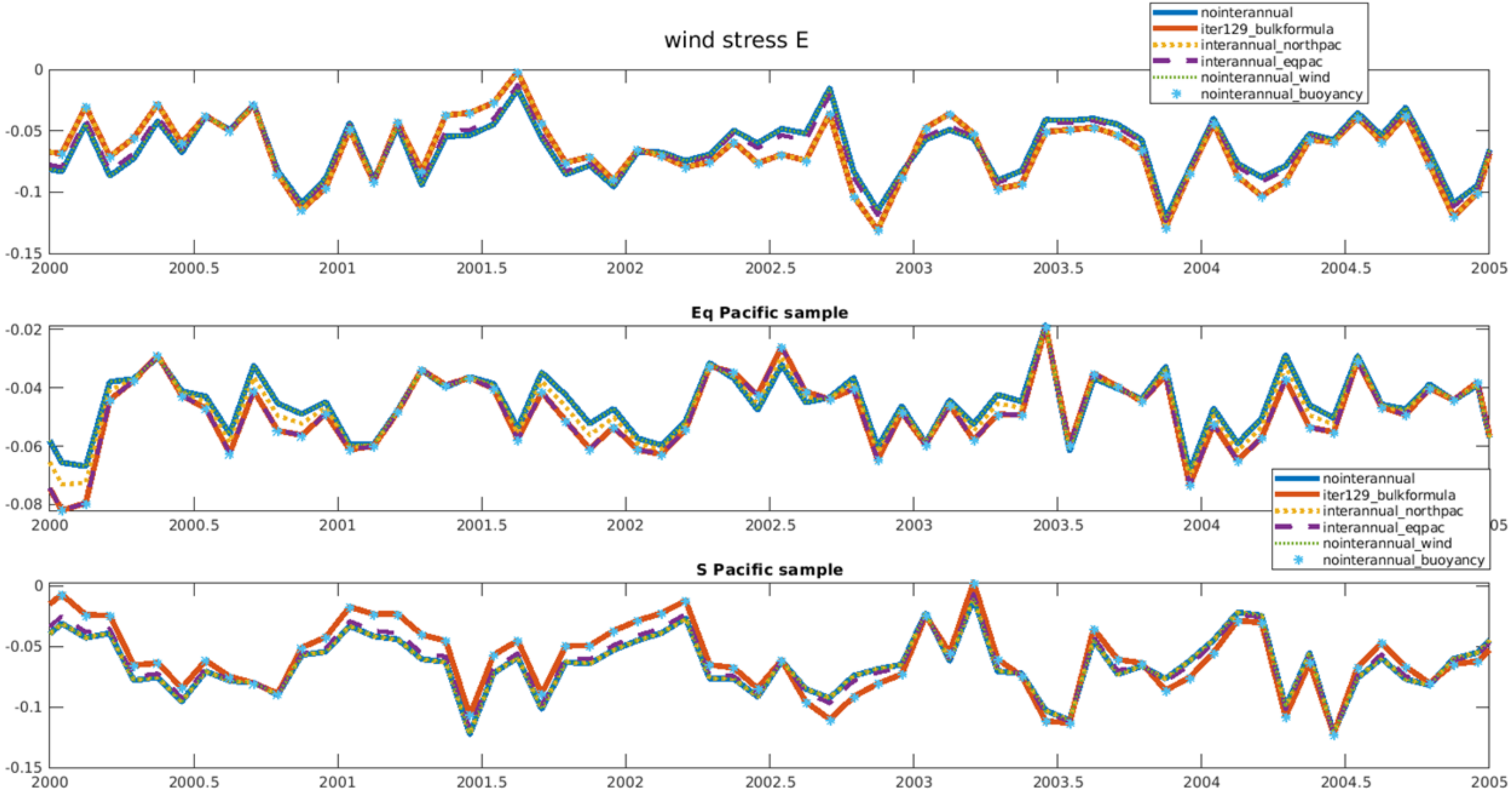
tau$_{x}$

Qnet

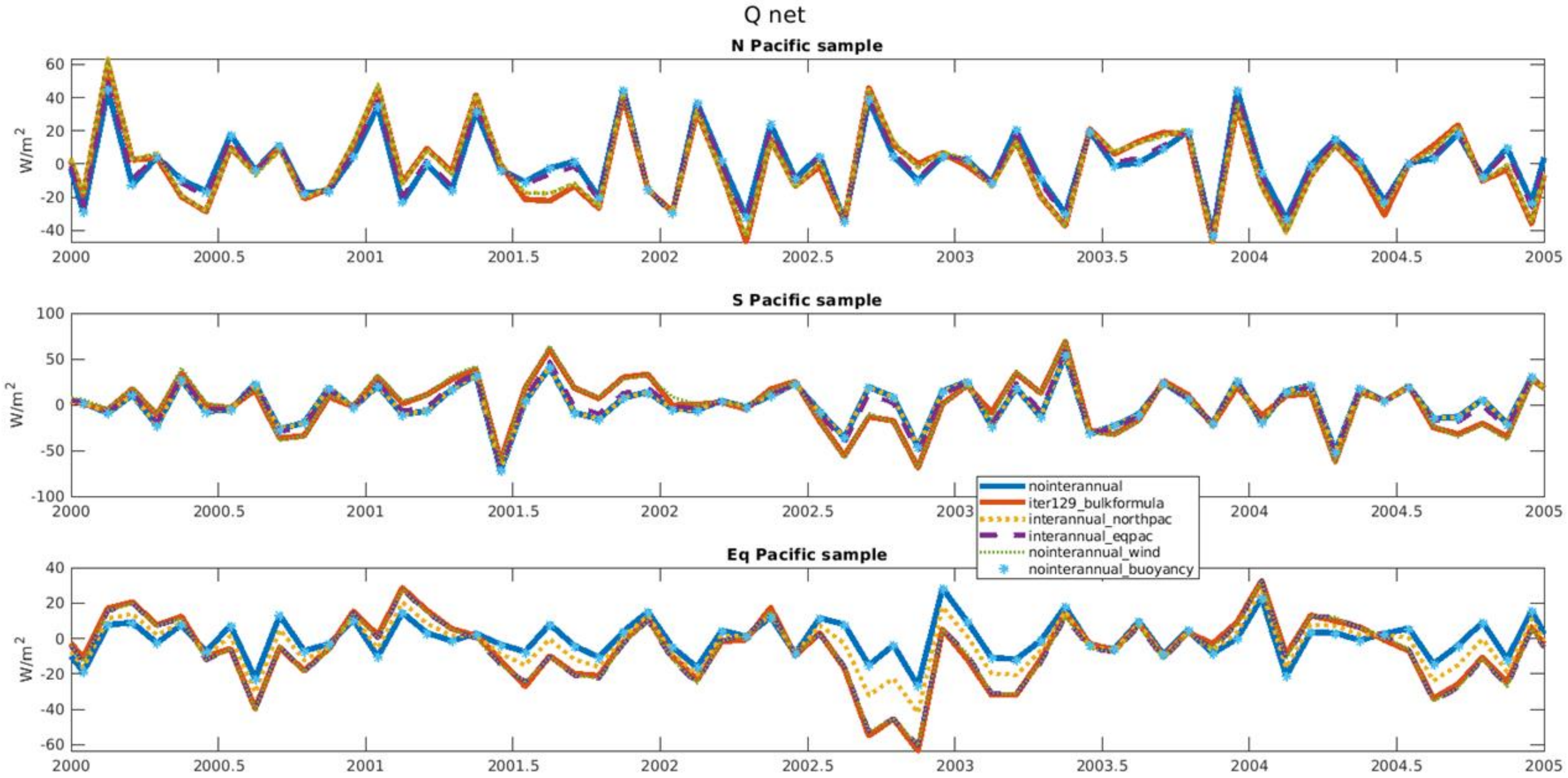
fresh water flux



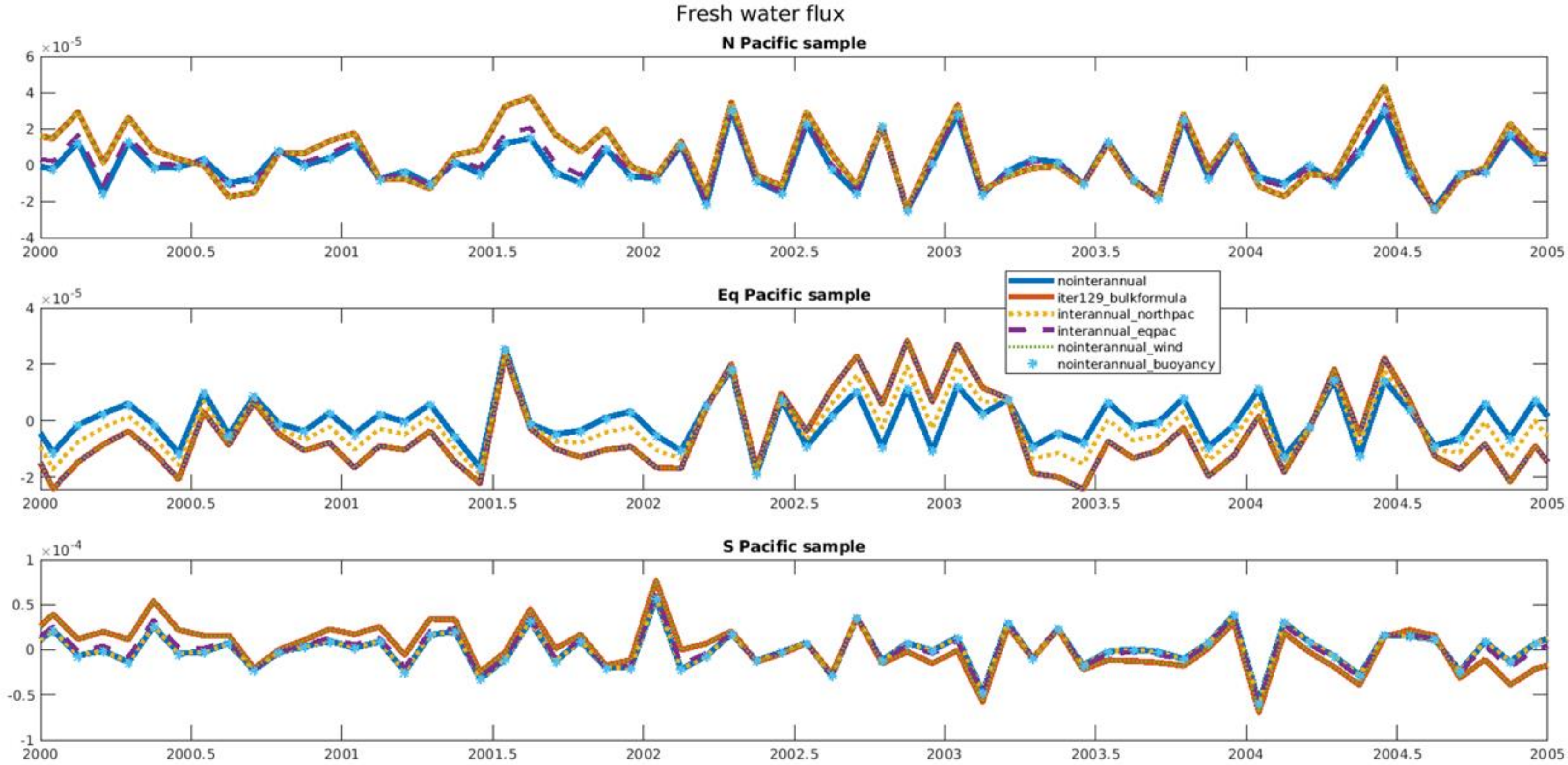
Full variability shown



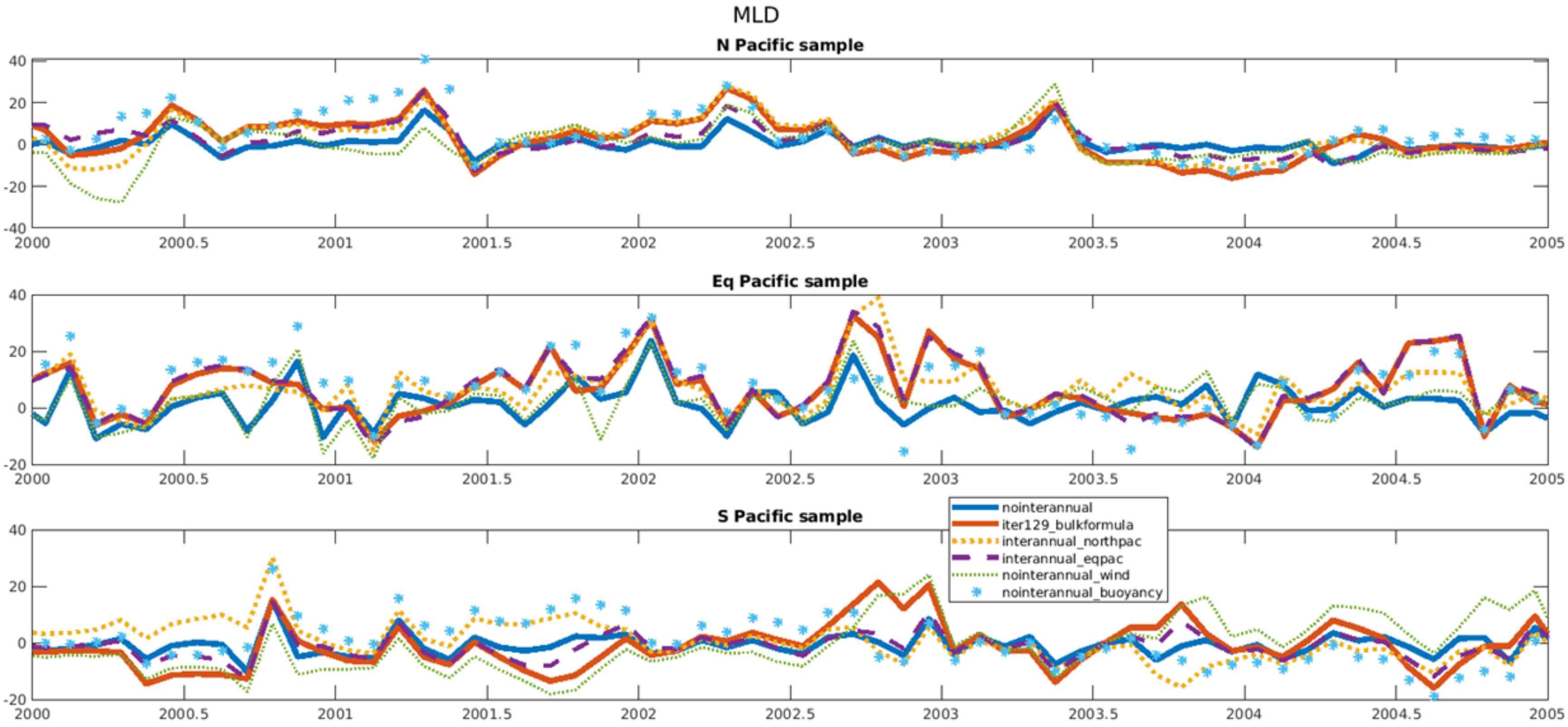
Full variability shown



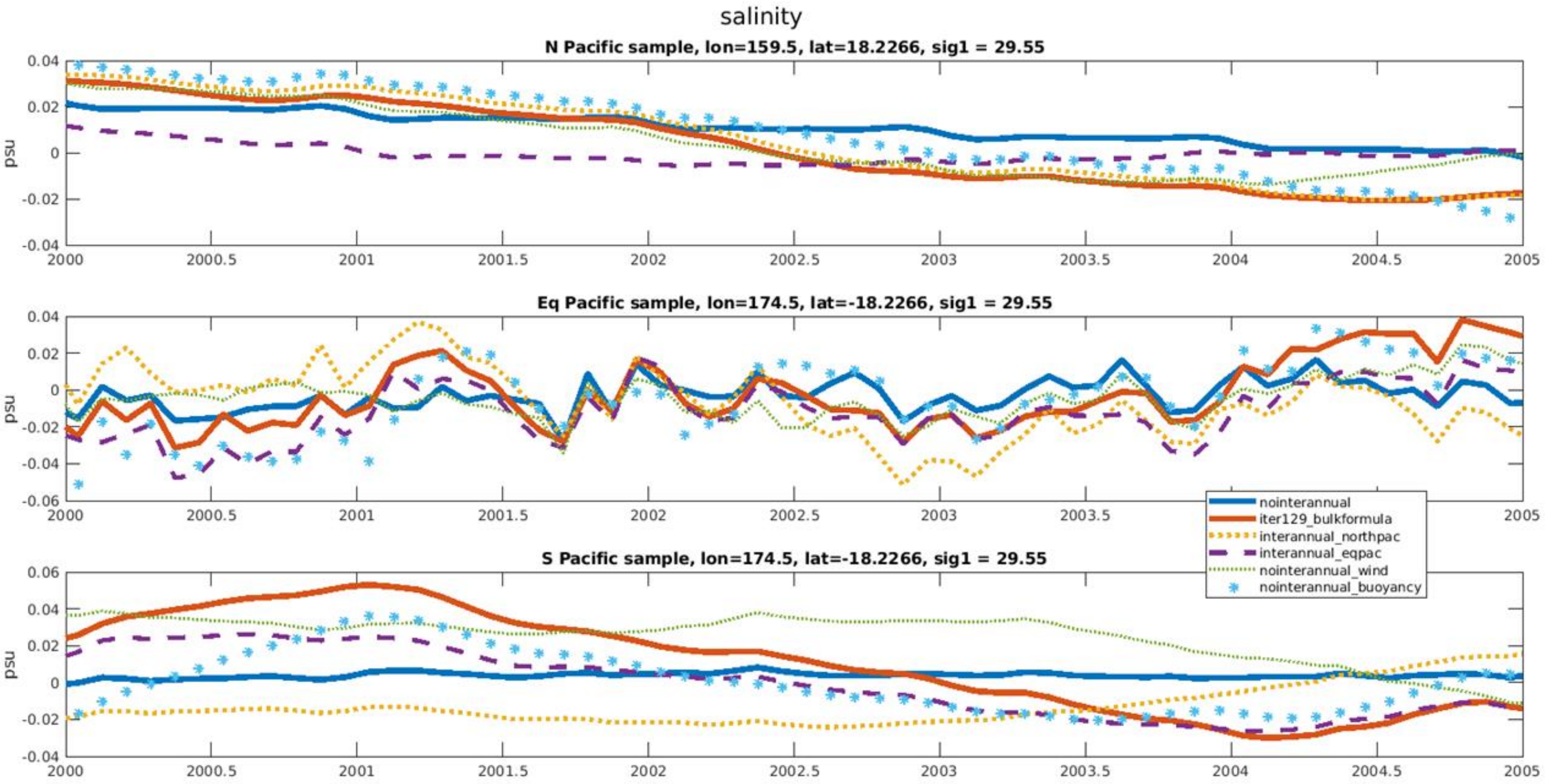
Seasonal cycle removed



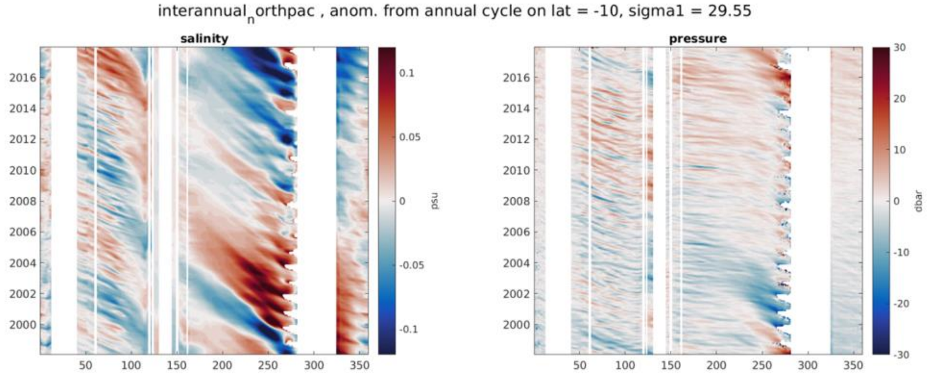
Seasonal cycle removed



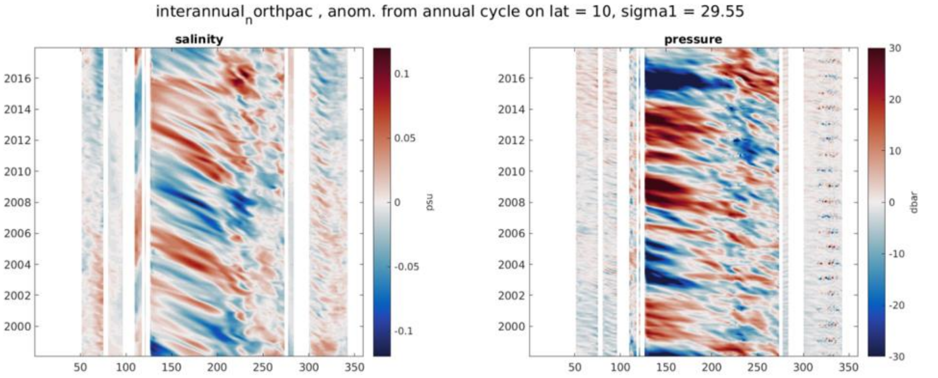
Seasonal cycle removed


salinity
N Pacific sample, lon=159.5, lat=18.2266, sig1 = 29.55
Eq Pacific sample, lon=174.5, lat=-18.2266, sig1 = 29.55
S Pacific sample, lon=174.5, lat=-18.2266, sig1 = 29.55
psu
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
2000
2000.5
2001
2001.5
2002
2002.5
2003
2003.5
2004
2004.5
2005
nointerannual
iter129_bulkformula
interannual_northpac
interannual_eqpac
nointerannual_wind
nointerannual_buoyancy

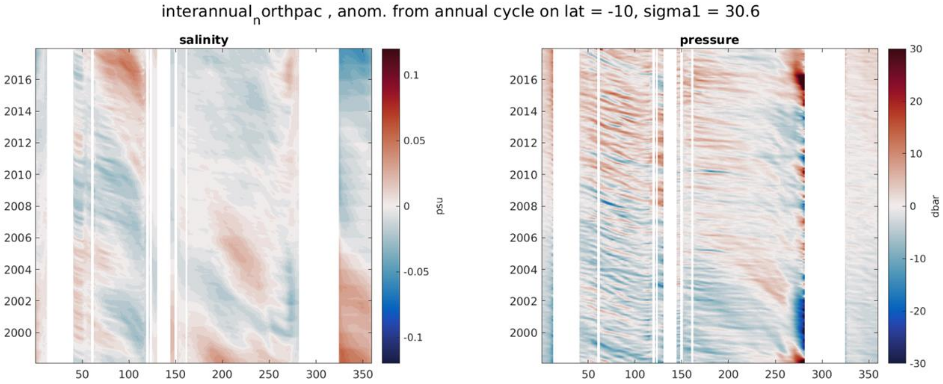
interannual_northpac



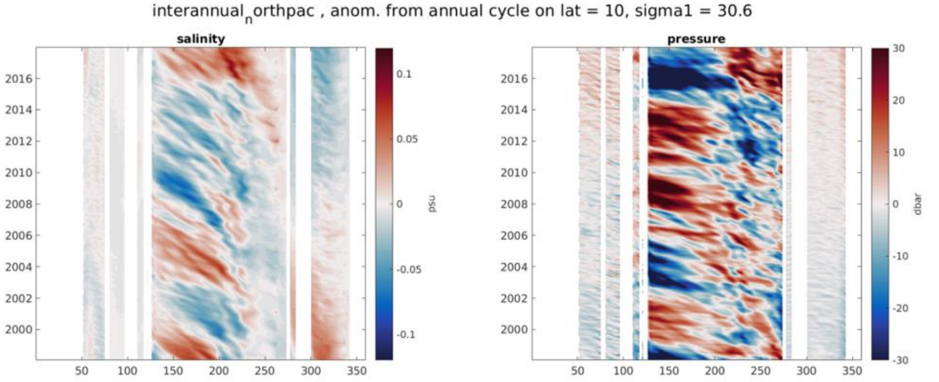
interannual$_{n}$orthpac , anom. from annual cycle on lat = -10, sigma1 = 29.55



interannual$_{n}$orthpac , anom. from annual cycle on lat = 10, sigma1 = 29.55



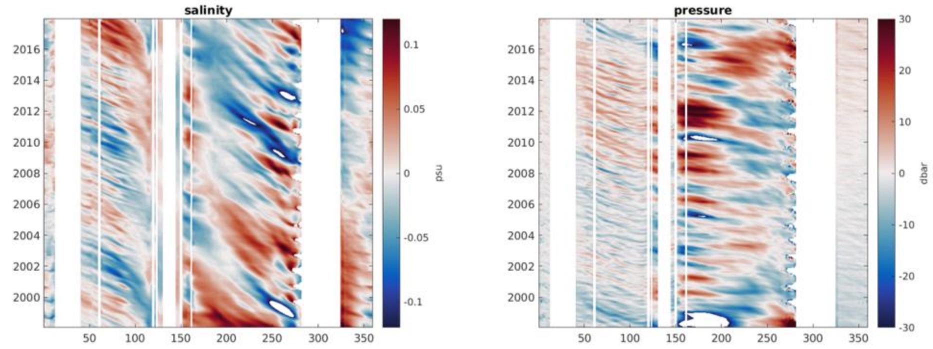
interannual$_{n}$orthpac , anom. from annual cycle on lat = -10, sigma1 = 30.6



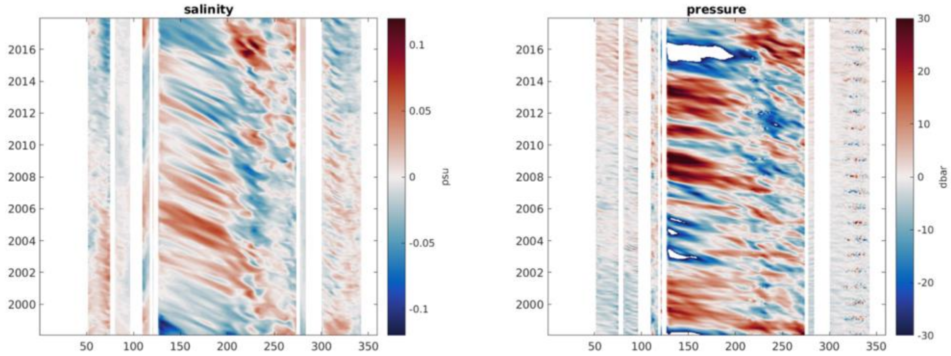
interannual$_{n}$orthpac , anom. from annual cycle on lat = 10, sigma1 = 30.6

interannual_eqpac

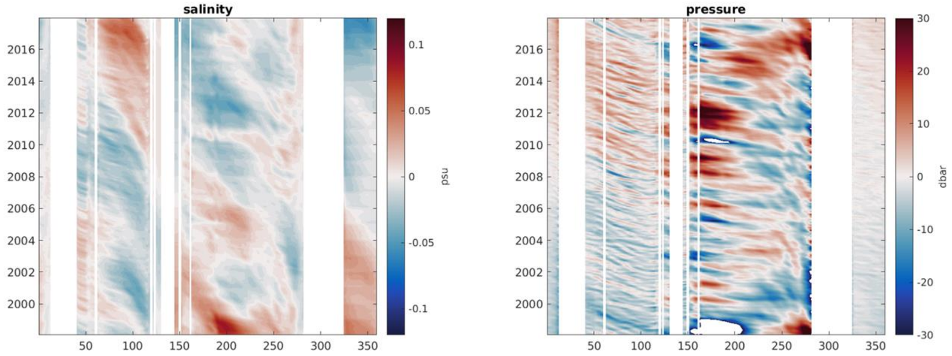
interannual$_e$qpac , anom. from annual cycle on lat = -10, sigma1 = 29.55



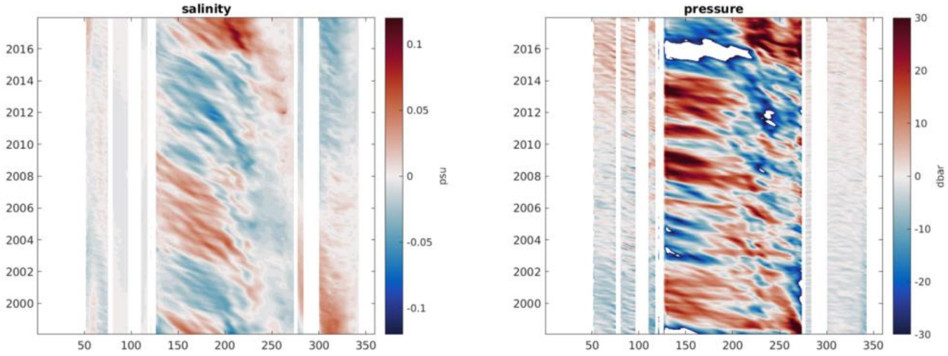
interannual$_e$qpac , anom. from annual cycle on lat = 10, sigma1 = 29.55



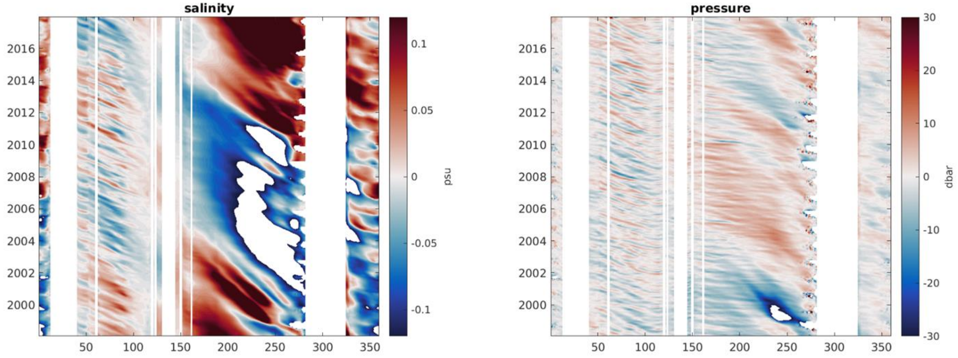
interannual$_e$qpac , anom. from annual cycle on lat = -10, sigma1 = 30.6



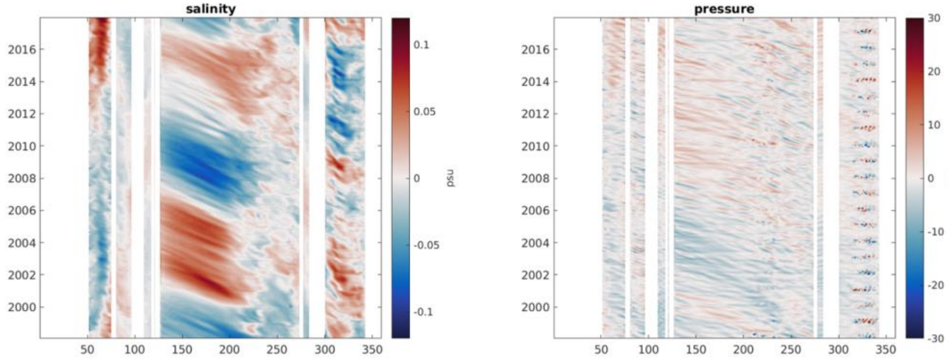
interannual$_e$qpac , anom. from annual cycle on lat = 10, sigma1 = 30.6



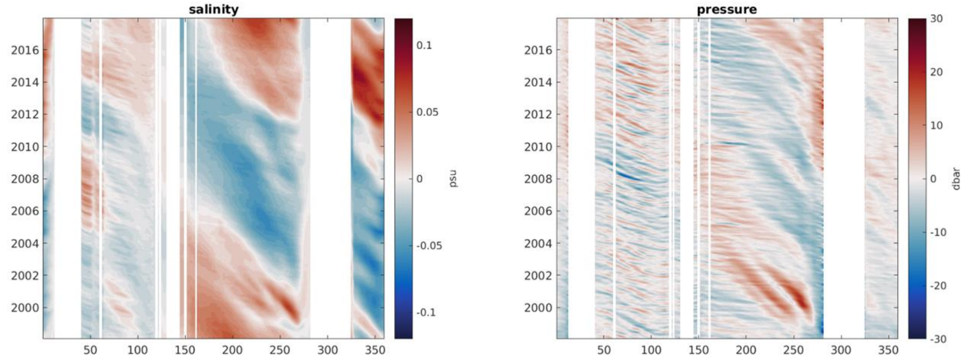
nointerannual_wind



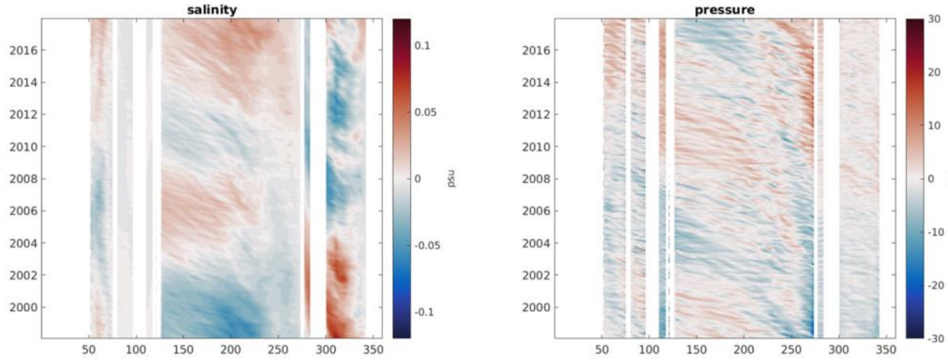
nointerannual$_w$ind , anom. from annual cycle on lat = -10, sigma1 = 29.55



nointerannual$_w$ind , anom. from annual cycle on lat = 10, sigma1 = 29.55



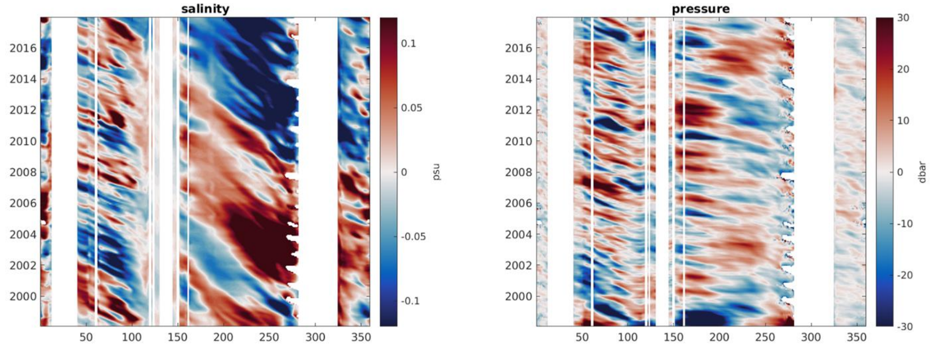
nointerannual$_w$ind , anom. from annual cycle on lat = -10, sigma1 = 30.6



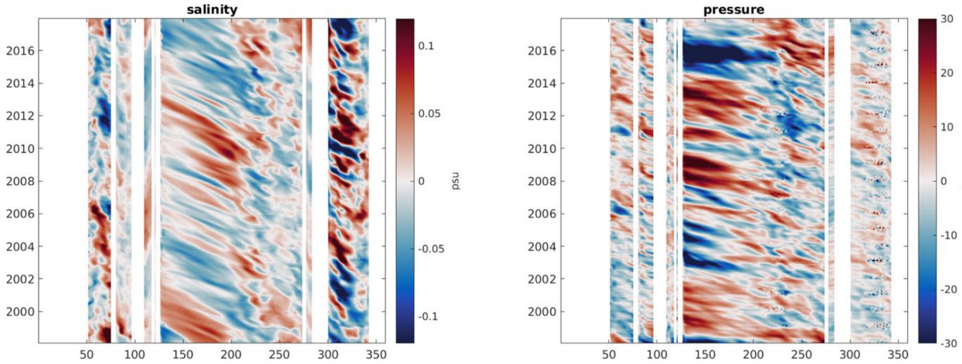
nointerannual$_w$ind , anom. from annual cycle on lat = 10, sigma1 = 30.6

nointerannual_buoyancy

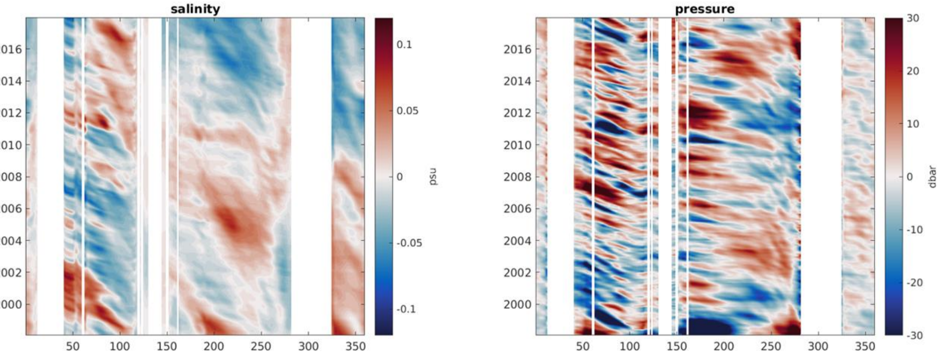
nointerannual$_b$uoyancy , anom. from annual cycle on lat = -10, sigma1 = 29.55



nointerannual$_b$uoyancy , anom. from annual cycle on lat = 10, sigma1 = 29.55



nointerannual$_b$uoyancy , anom. from annual cycle on lat = -10, sigma1 = 30.6



nointerannual$_b$uoyancy , anom. from annual cycle on lat = 10, sigma1 = 30.6