Evaluating model mixing using observational turbulence estimates in the tropical Pacific cold tongue

Deepak Cherian, Anna-Lena Deppenmeier,
Gustavo Marques, Frank Bryan (NCAR)
Dan Whitt (NASA Ames)
Jim Moum (Oregon State University)

Turbulence at the equator: marginal stability (Ri ~ 0.25)

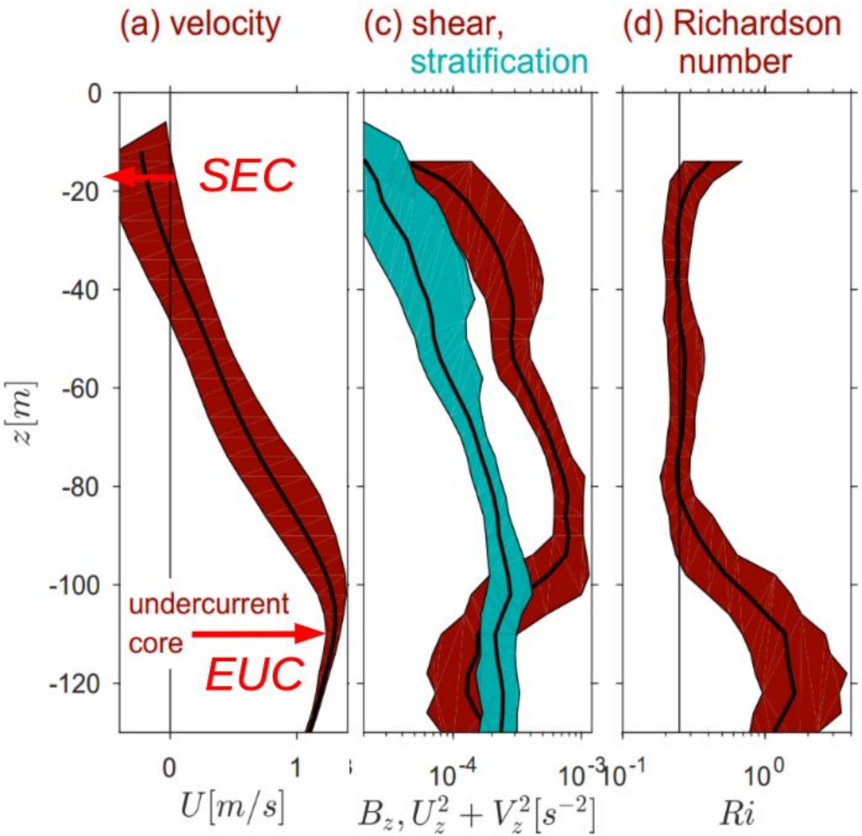
Smyth & Moum (2013)

Smyth et al (2019)

Ri = $N^2/(\text{shear}^2)$

Forcing reduces Ri

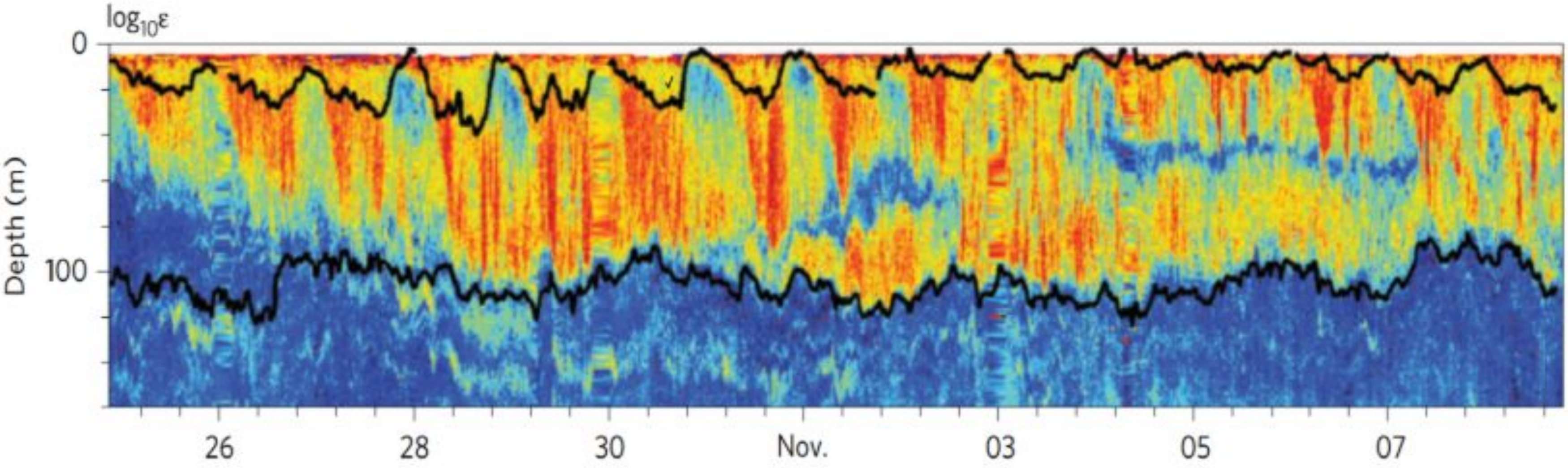
Turbulence increases Ri



Turbulence at the equator: the deep cycle

Diurnal cycle of turbulence **below** the mixed layer, **above** the EUC

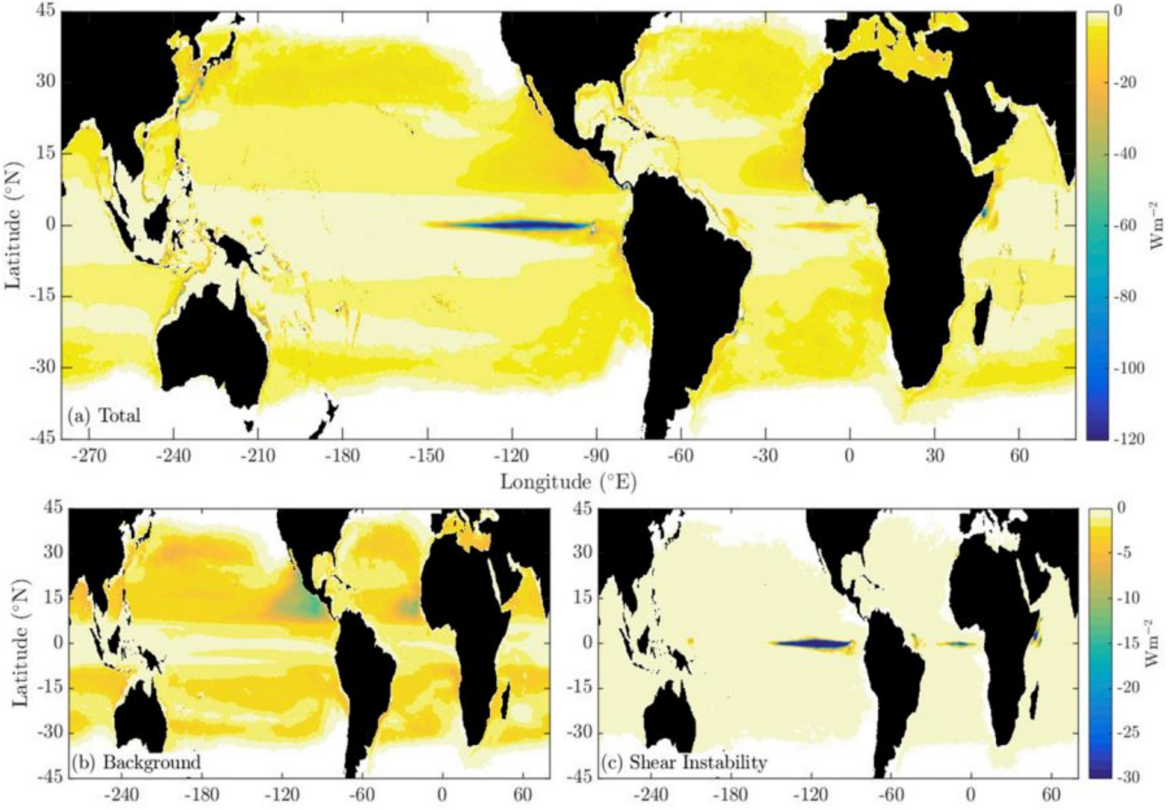
Obs from Moum et al 2009.



Why measure turbulence at the equator?

Diathermal heat transport through 21.5°C in an ocean model

Holmes et al (2019)



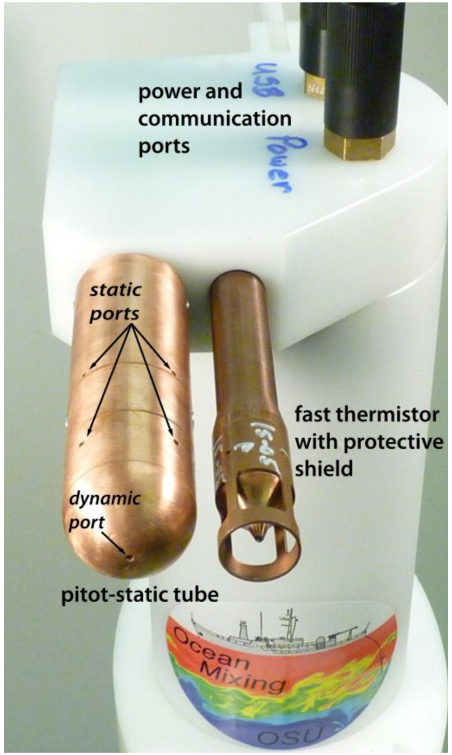
χpods: moored mixing meters

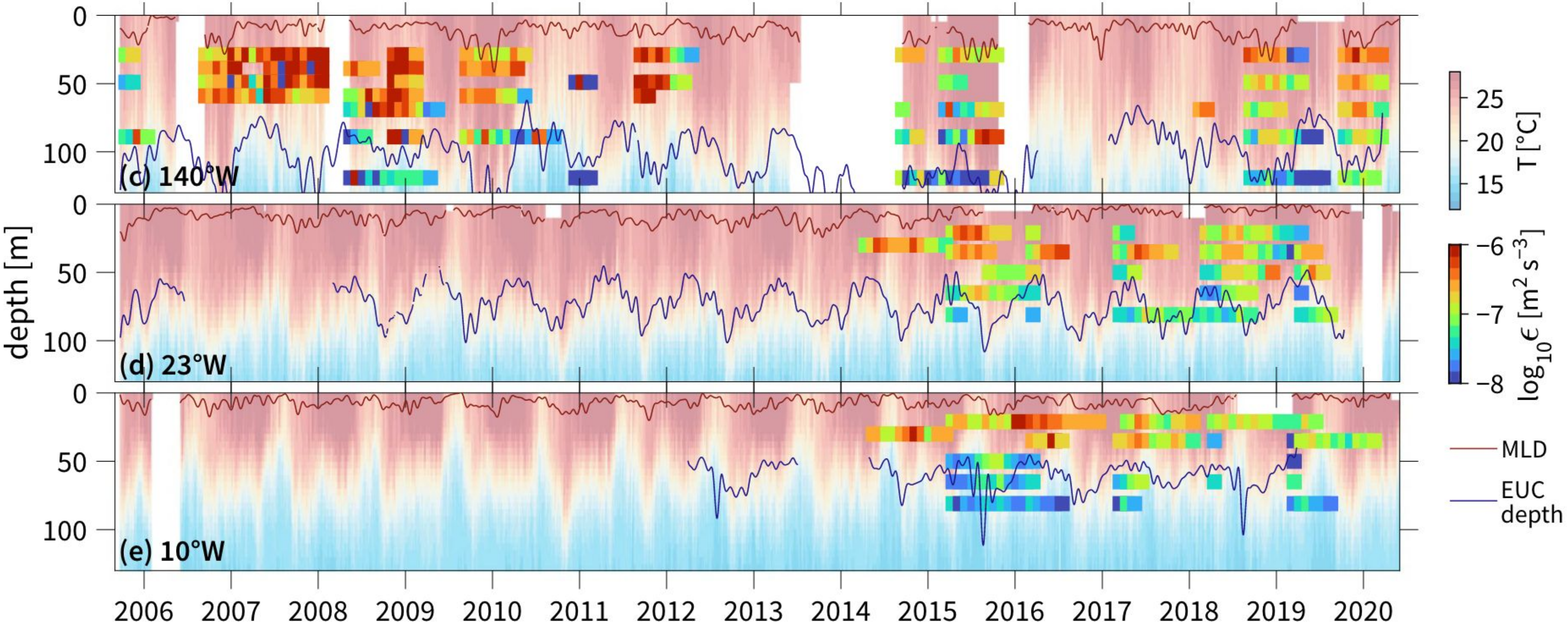
(Moum & Nash, 2009)
Deployed on equatorial mooring arrays
TAO: **140W** (since 2005), 125W, 110W
PIRATA: 23W, 10W

χ = dissipation rate of temp variance.
ε = dissipation rate of velocity variance

Turb Diffusivity $K = (\chi/2)/T_z^2$
Turb Viscosity $\nu = \varepsilon/U_z^2$

Heat flux = $\rho\, C_p\, K\, T_z$

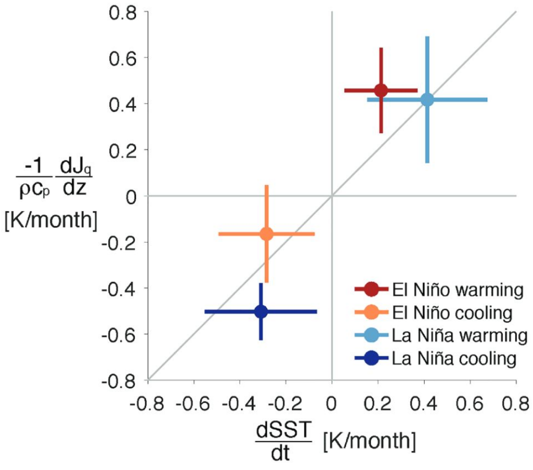


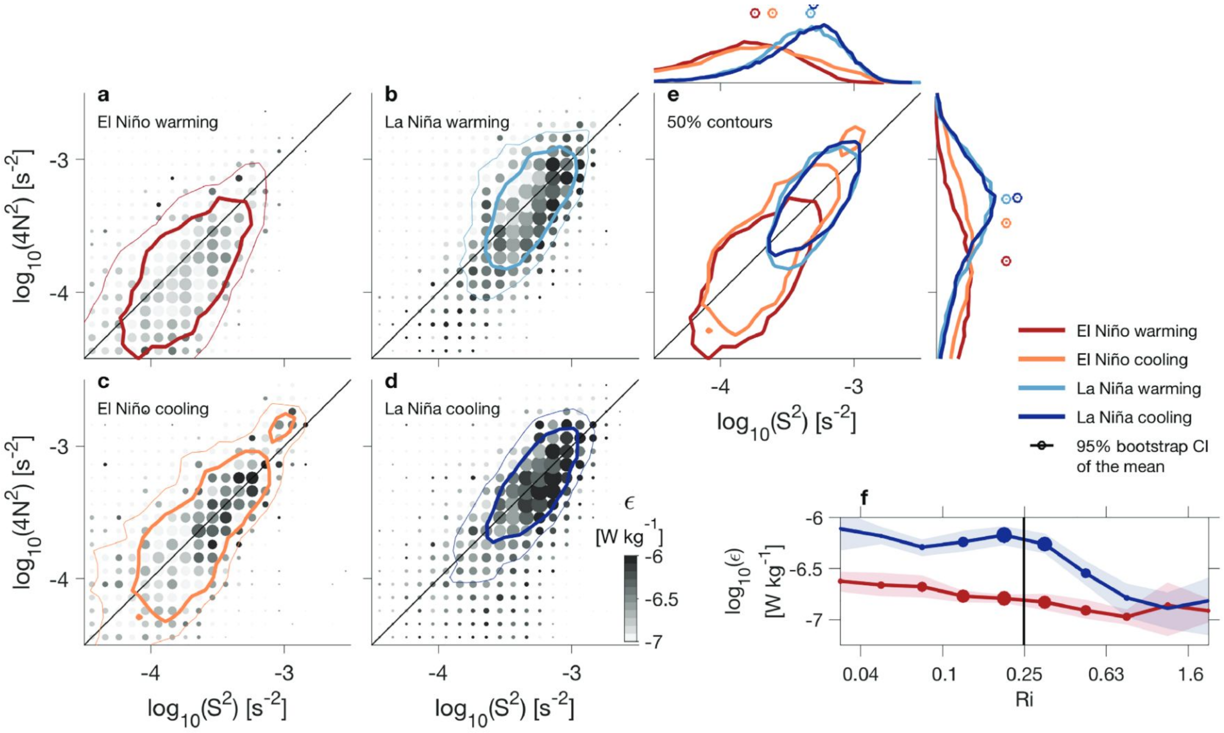


(c) 140°W
(d) 23°W
(e) 10°W
depth [m]
0
50
100
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
T [°C]
25
20
15
$\log_{10}\epsilon$ [$m^2 s^{-3}$]
−6
−7
−8
MLD
EUC depth

Warner & Moum (2019)

The ocean’s microstructure is meaningfully organized in macroscale patterns,





Hypothesis

Climate models must represent these macroscale patterns of microscale turbulence with fidelity.

Do they?

Large & Gent (1999) : clean and direct comparisons

The comparison of a 1D mixing model with LES or DNS is

- **clean,** because the forcing is the same, and
- **direct**, because the evaluation compares turbulence quantities

The performance of a mixing scheme in global and regional model simulations is commonly tested by comparing the simulated mean state to an observed mean state after a long integration.
This comparison is

- **not clean**, because of errors in forcing fields, compensating errors, etc.
- **not direct**, since mean state properties are not a direct output of the mixing scheme.

This talk : **not clean but direct**

Simulations

- **Baseline:** CESM, MOM6, 2/3°, z*, 65 vertical levels; KPP
- JRA55 first cycle.
- Default KPP parameters
- Virtual moorings:
    - Save output every hour (every tracer time step) along TAO mooring longitudes (140W etc)
        - State vars,
        - Turbulence vars,
        - Heat budget terms

Changes

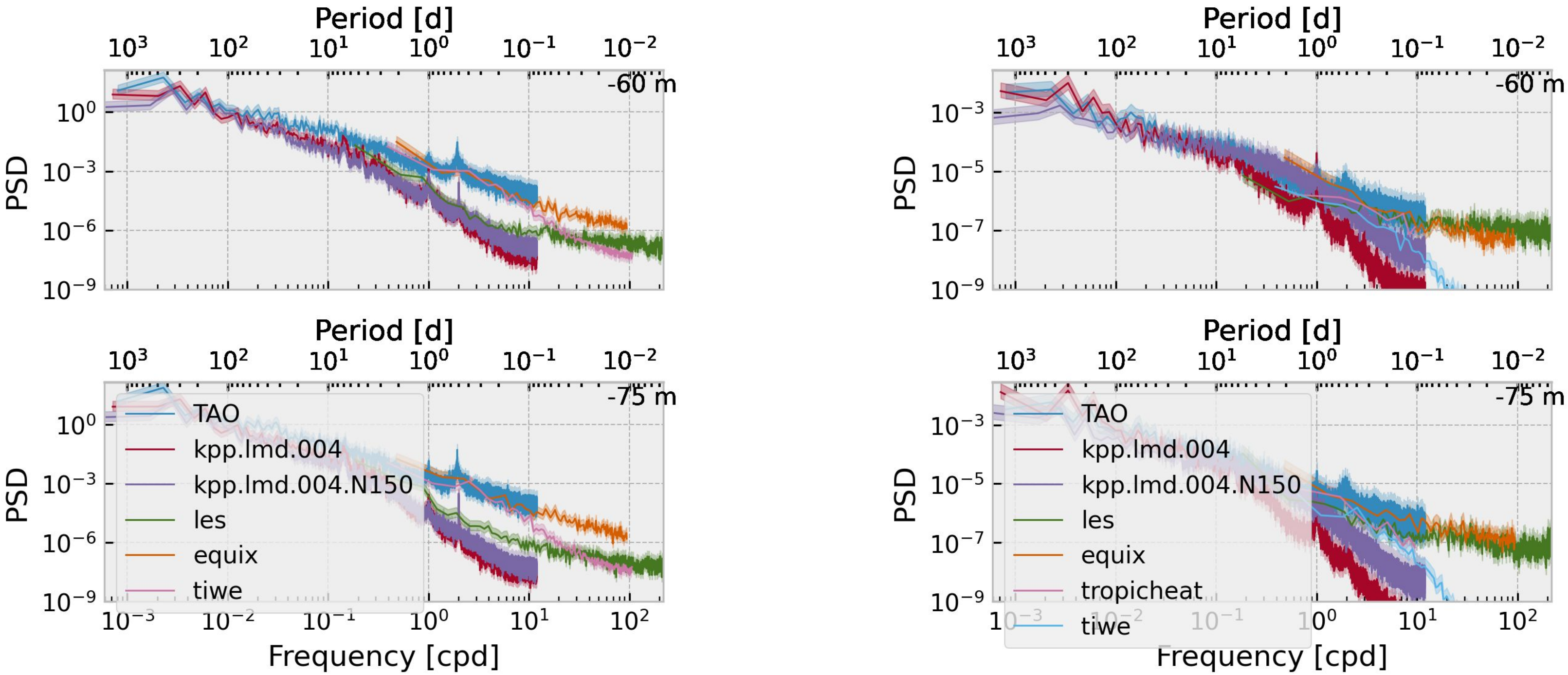
- **kpp.lmd.004** Modified KPP parameters
  - Tuned by Whitt's natural intelligence + Whitt et al, 2022 LES.
    - Lower max viscosity: numax=2.5e-3 m2/s, (vs 5e-3)
    - Reduce boundary layer depth: Rib=0.2, (vs 0.3)
    - Shear mixing turns on at higher shear: Ri0=0.5 (vs 0.7)

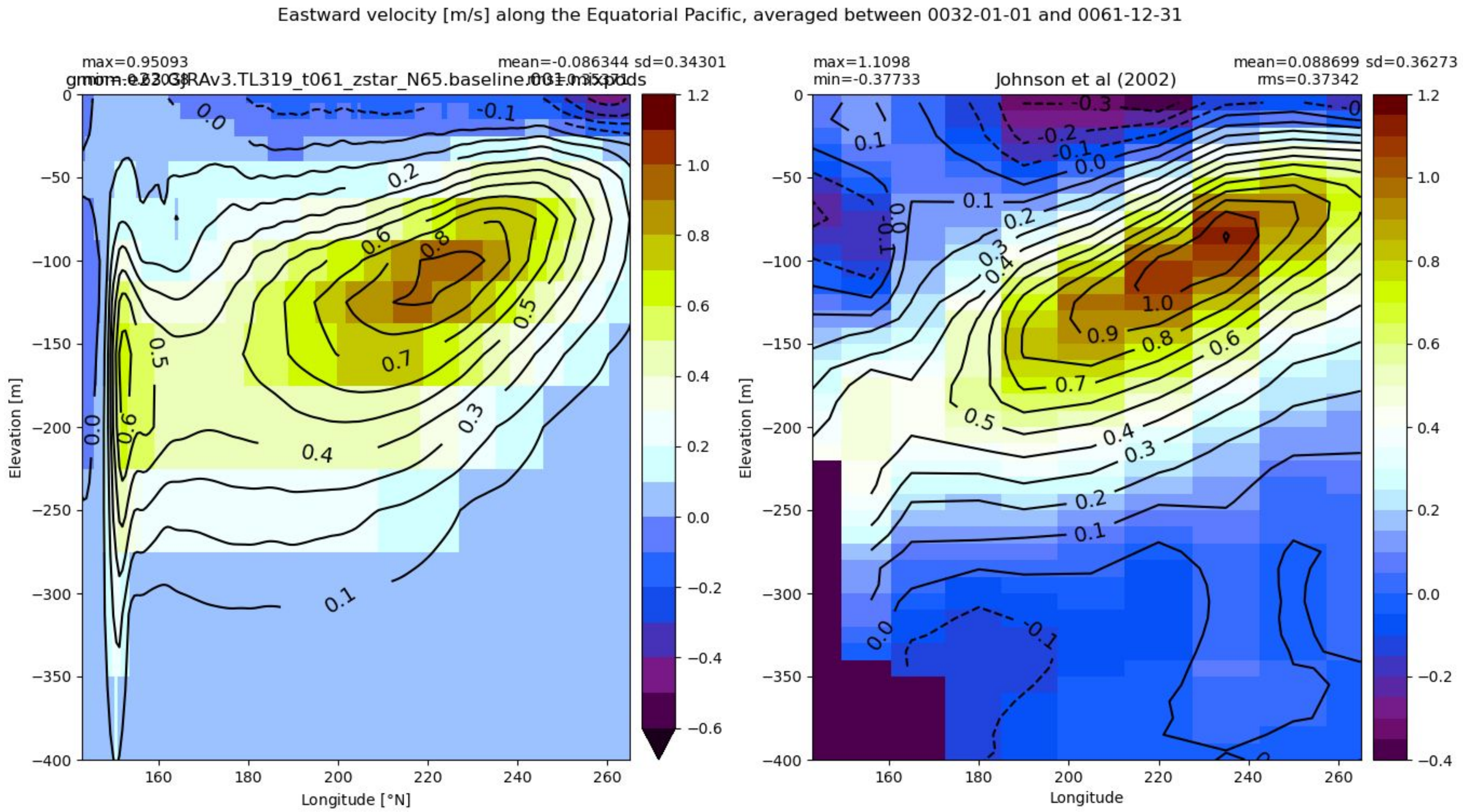
- branch off baseline in 1992
    - (TAO ADCP velocity measurements start in 1996)

- **kpp.lmd.004.N150** Modified KPP + 150 vertical levels (2.5m top 250m)

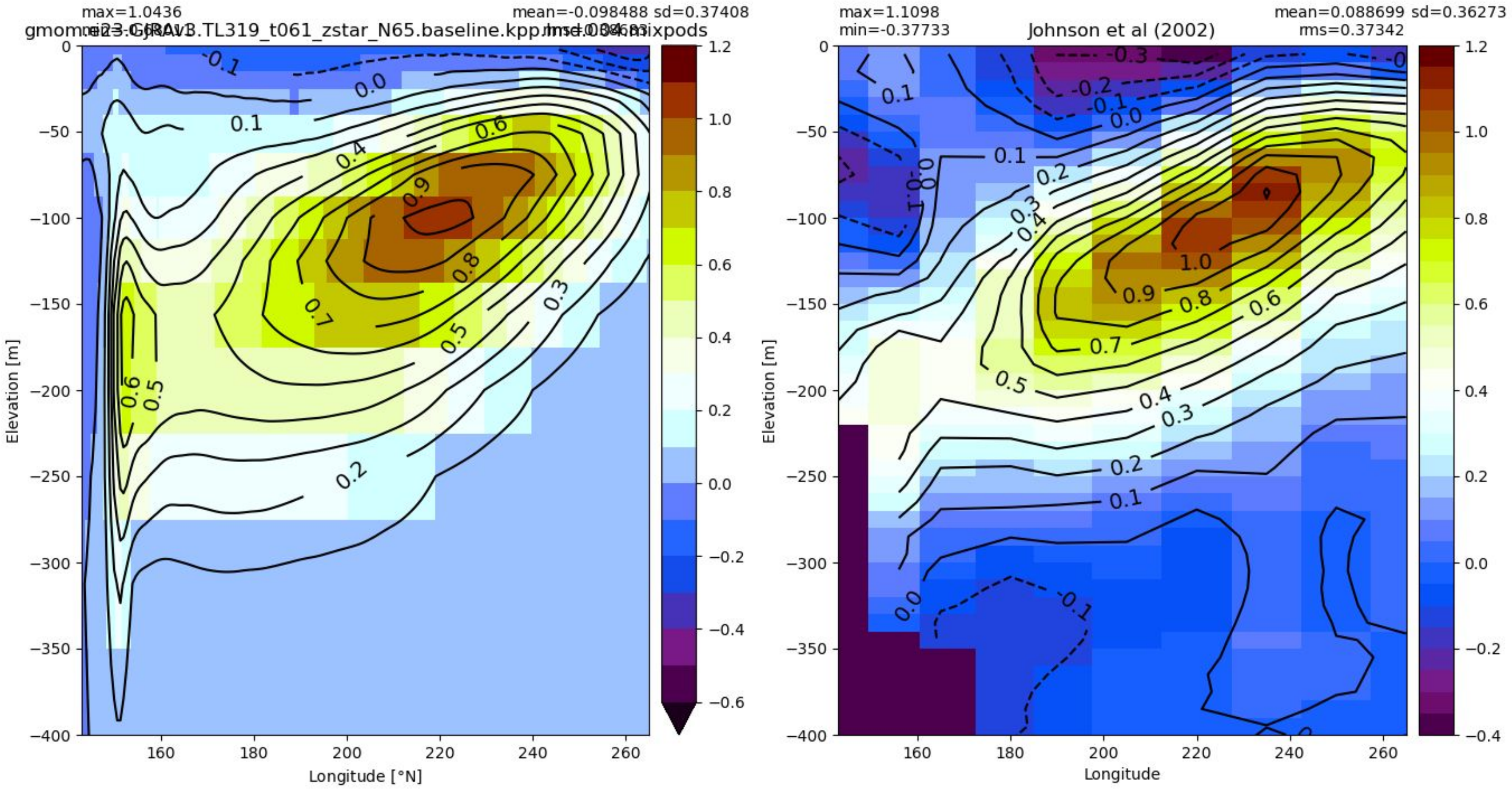
Switch

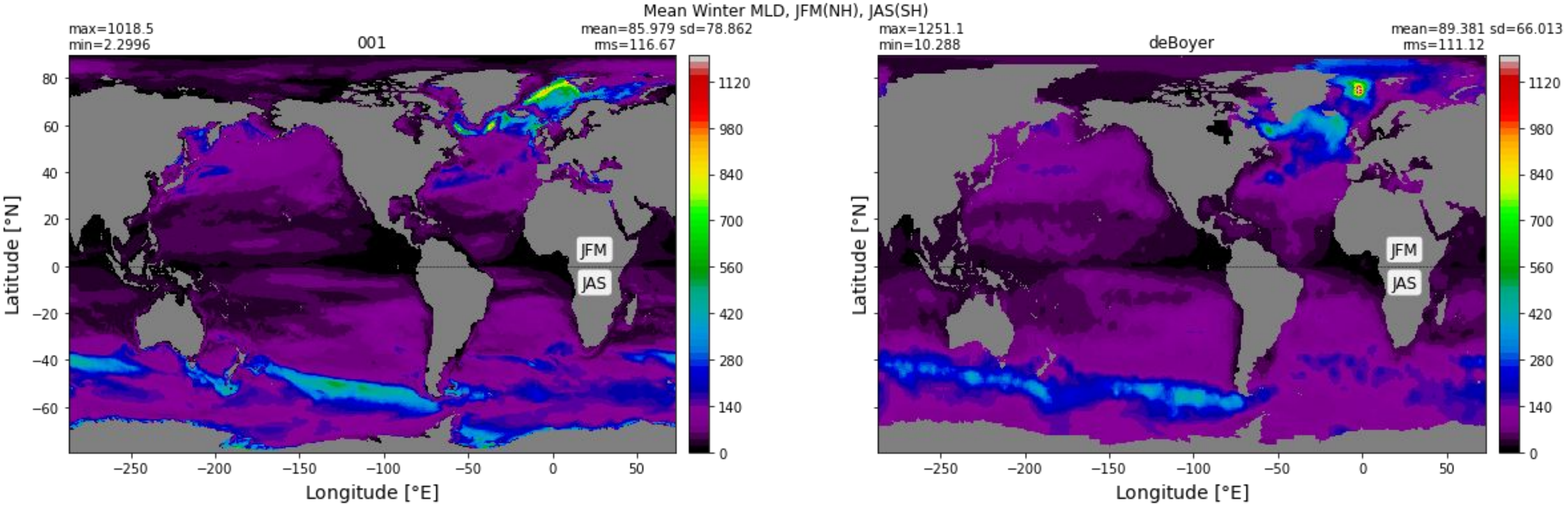
Bonus Confusions: Frequency spectra of shear, velocity

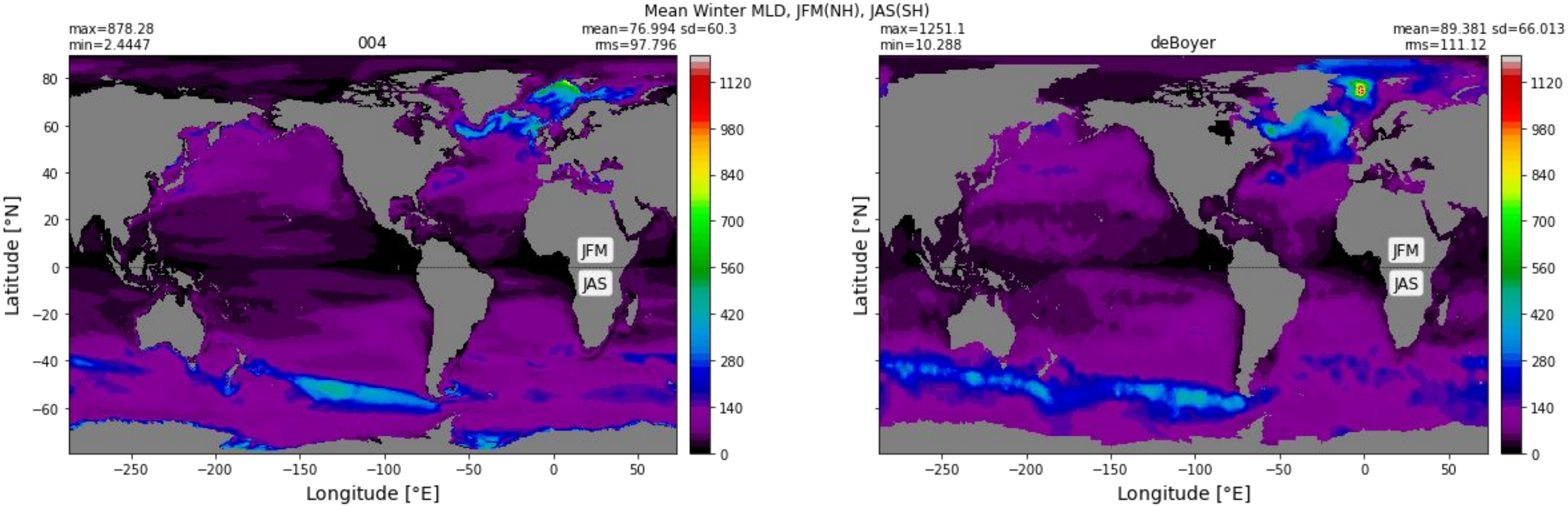


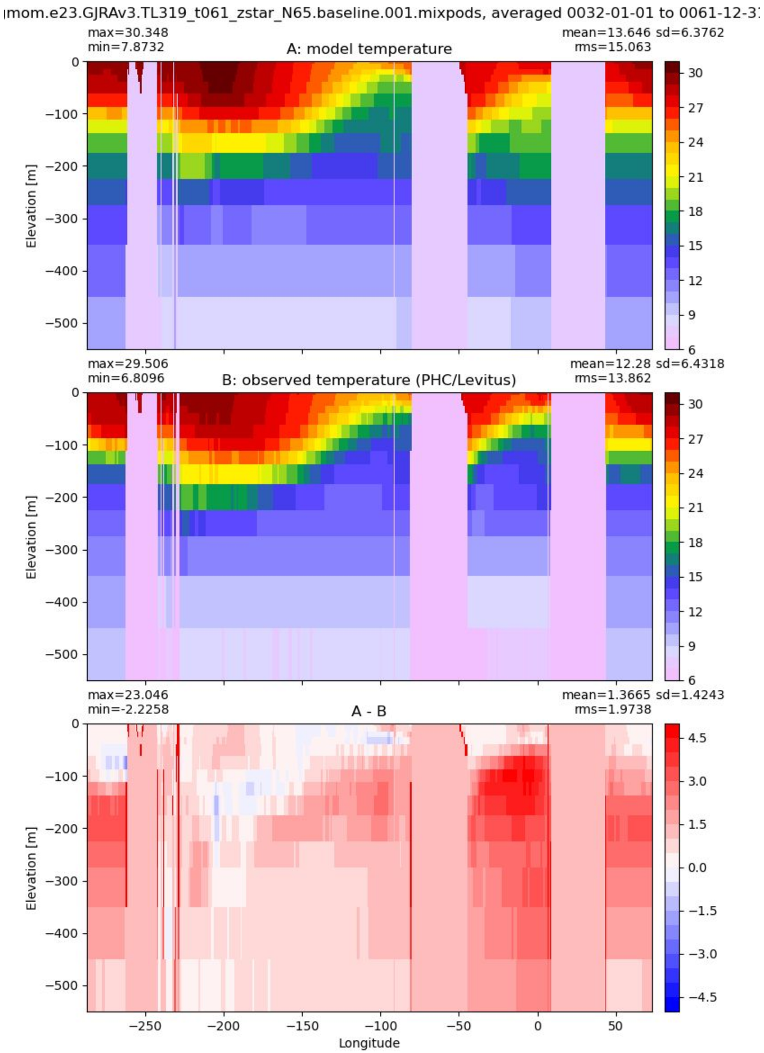

Eastward velocity [m/s] along the Equatorial Pacific, averaged between 0032-01-01 and 0061-12-31
max=0.95093
mean=-0.086344 sd=0.34301
gmom.e23.GJRAv3.TL319_t061_zstar_N65.baseline.001.mixpods
Elevation [m]
Longitude [°N]
max=1.1098
min=-0.37733
mean=0.088699 sd=0.36273
rms=0.37342
Johnson et al (2002)
Elevation [m]
Longitude

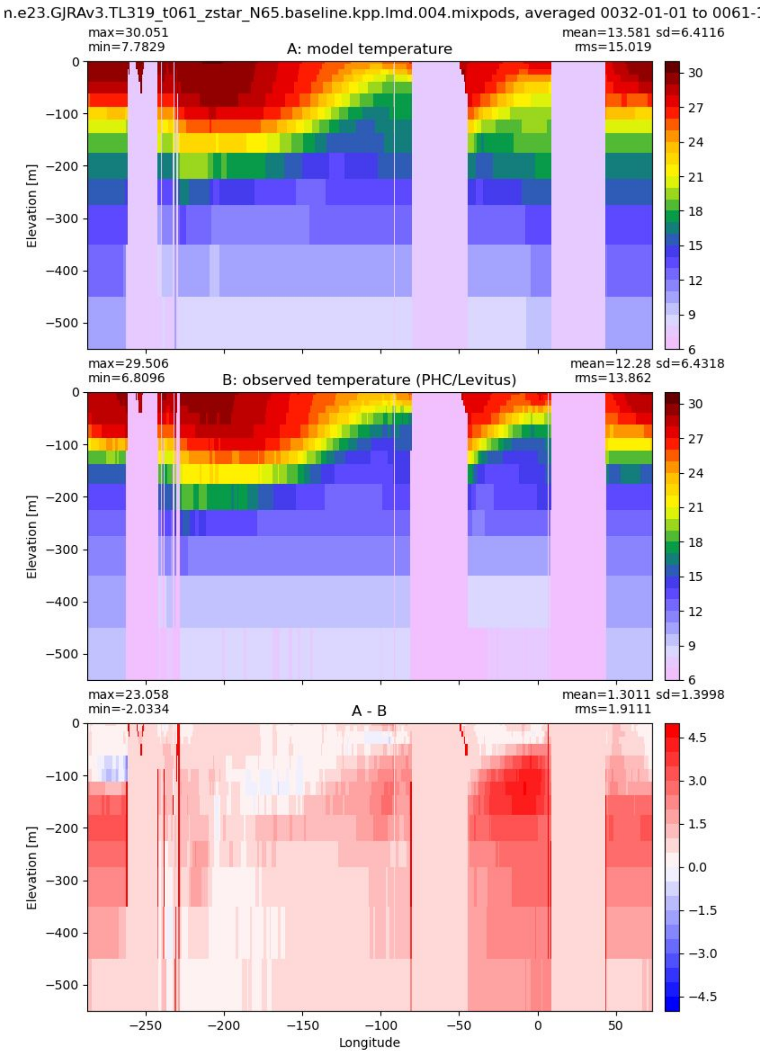
Eastward velocity [m/s] along the Equatorial Pacific, averaged between 0032-01-01 and 0061-12-31




Mean Winter MLD, JFM(NH), JAS(SH)
max=1018.5
min=2.2996
001
mean=85.979 sd=78.862
rms=116.67
max=1251.1
min=10.288
deBoyer
mean=89.381 sd=66.013
rms=111.12
JFM
JAS
Latitude [°N]
Longitude [°E]
0
140
280
420
560
700
840
980
1120


Mean Winter MLD, JFM(NH), JAS(SH)
max=878.28
min=2.4447
004
mean=76.994 sd=60.3
rms=97.796
max=1251.1
min=10.288
deBoyer
mean=89.381 sd=66.013
rms=111.12
JFM
JAS
Latitude [°N]
Longitude [°E]

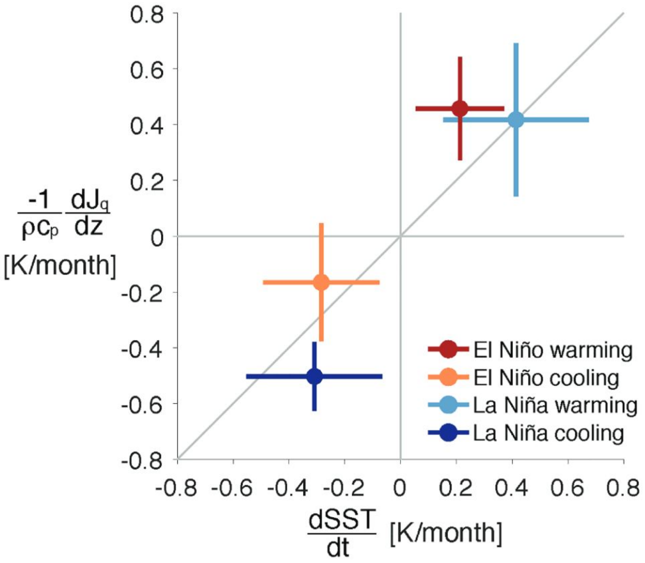

mom.e23.GJRAv3.TL319_t061_zstar_N65.baseline.001.mixpods, averaged 0032-01-01 to 0061-12-31
max=30.348
min=7.8732
A: model temperature
mean=13.646 sd=6.3762
rms=15.063
max=29.506
min=6.8096
B: observed temperature (PHC/Levitus)
mean=12.28 sd=6.4318
rms=13.862
max=23.046
min=-2.2258
A - B
mean=1.3665 sd=1.4243
rms=1.9738
Elevation [m]
Longitude

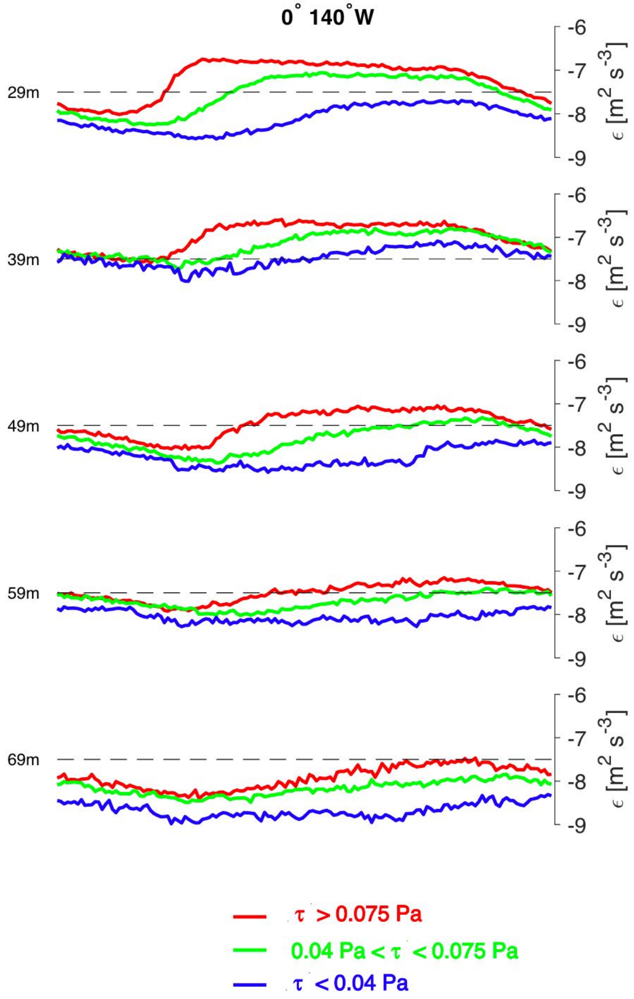


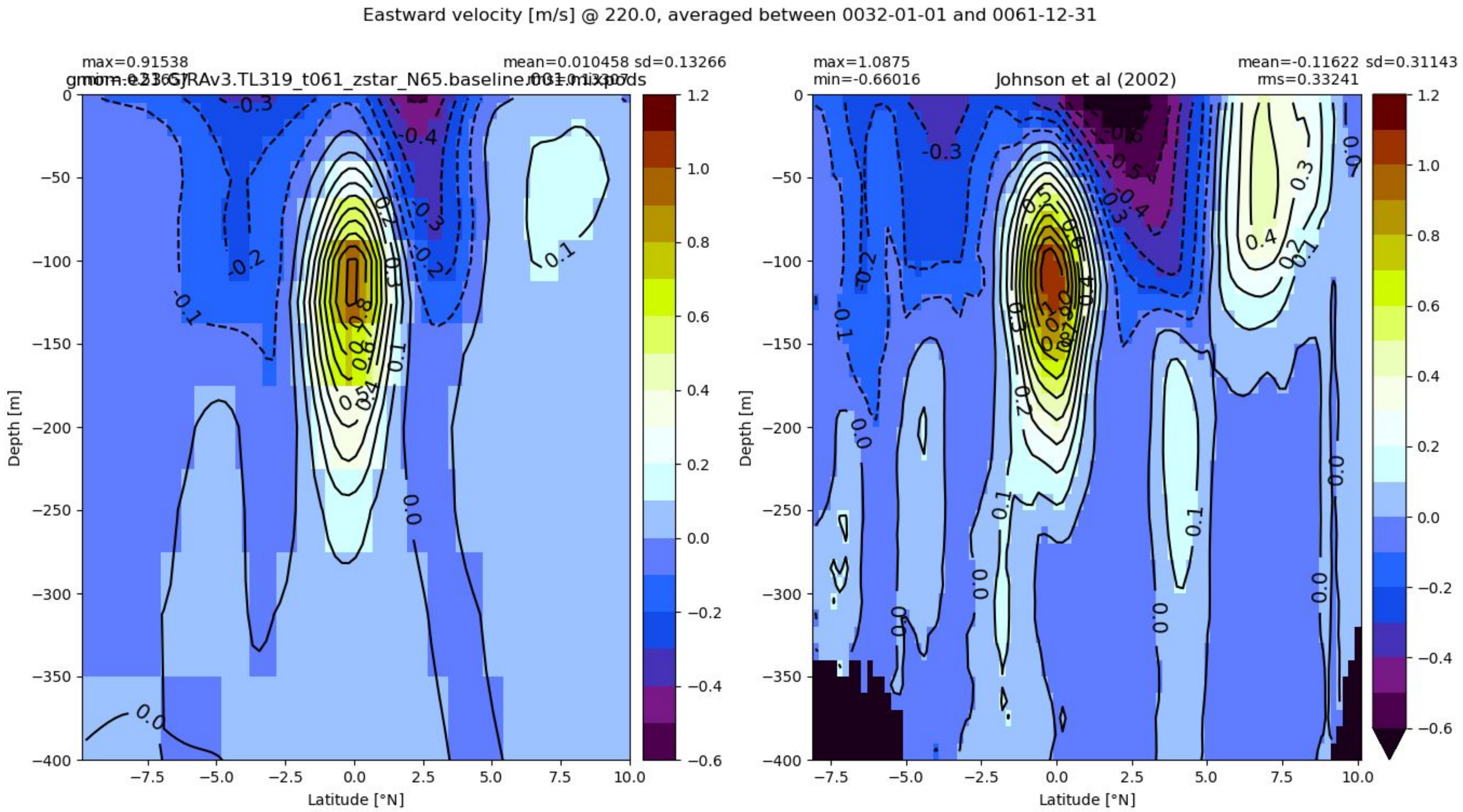
n.e23.GJRAv3.TL319_t061_zstar_N65.baseline.kpp.lmd.004.mixpods, averaged 0032-01-01 to 0061-
max=30.051
min=7.7829
A: model temperature
mean=13.581 sd=6.4116
rms=15.019
max=29.506
min=6.8096
B: observed temperature (PHC/Levitus)
mean=12.28 sd=6.4318
rms=13.862
max=23.058
min=-2.0334
A - B
mean=1.3011 sd=1.3998
rms=1.9111
Elevation [m]
Longitude

Next

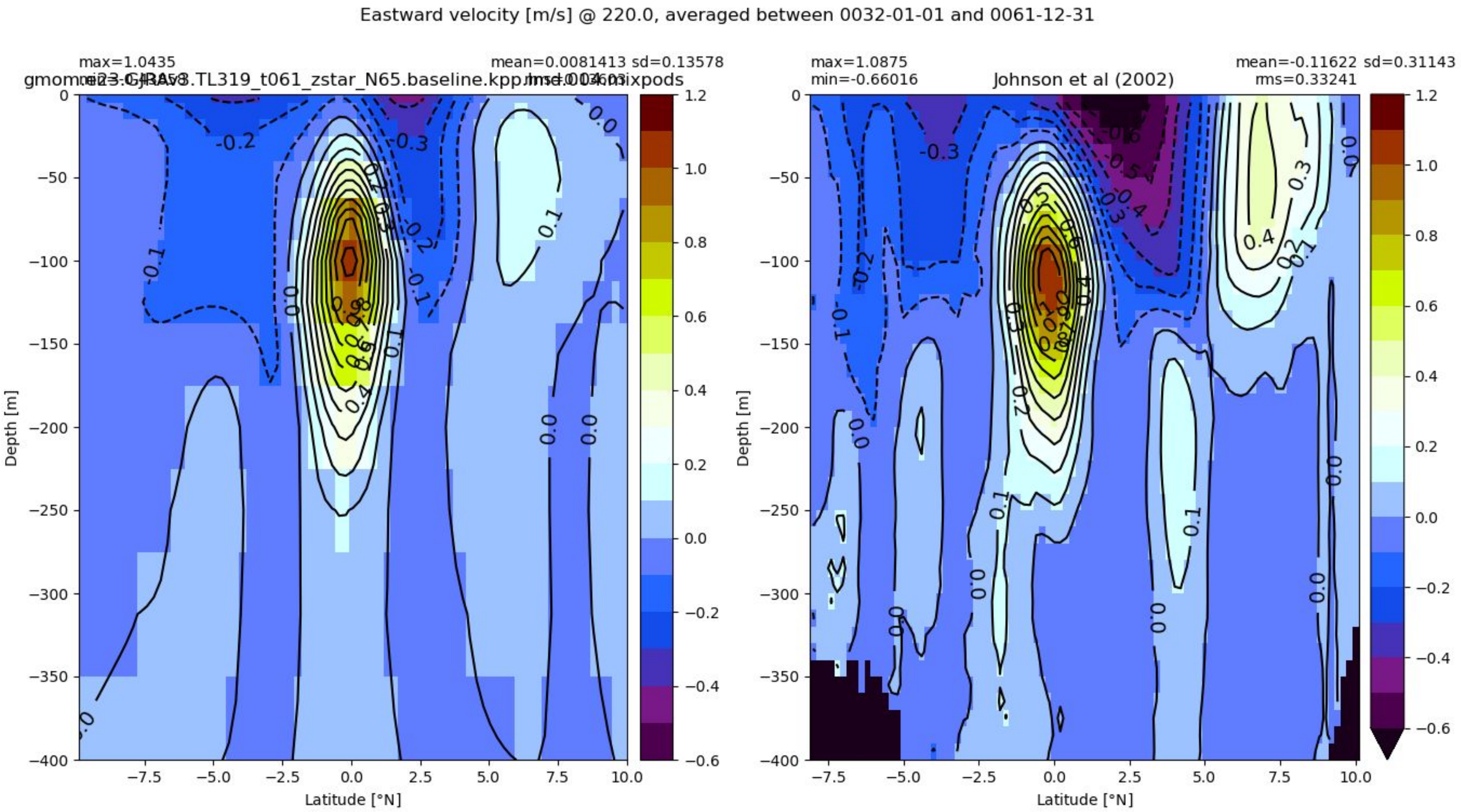
- Atlantic (PIRATA; 23W, 10W)
- (Moum et al 2022, JPO)
- More diagnostics

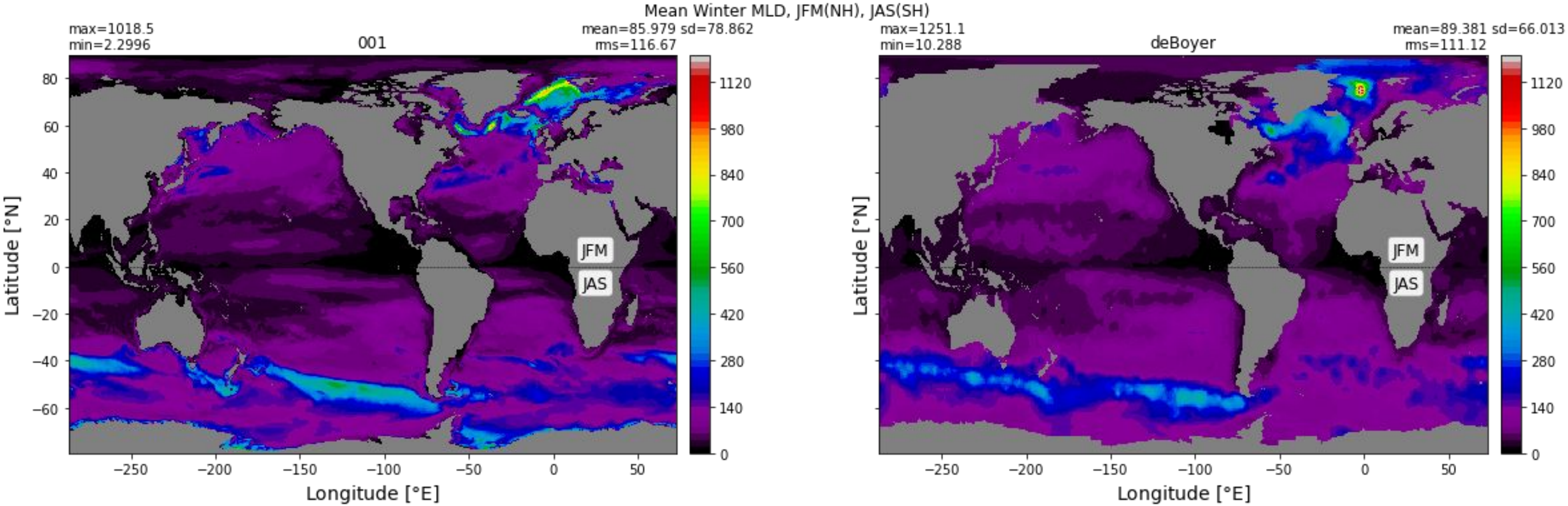


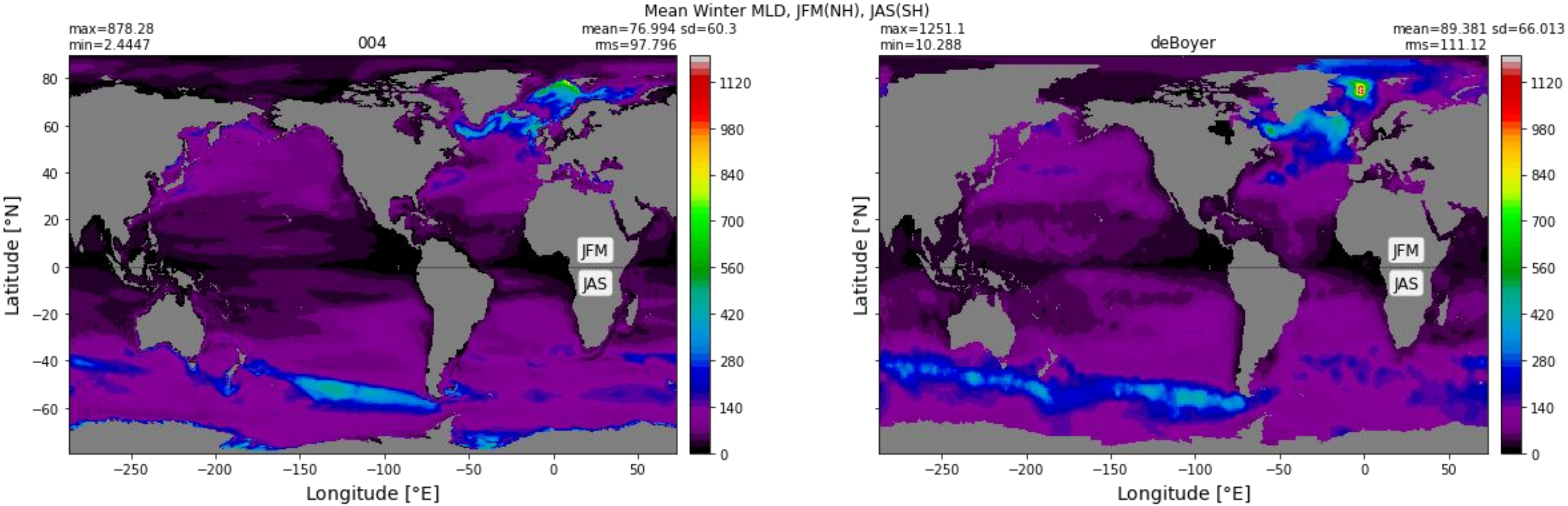




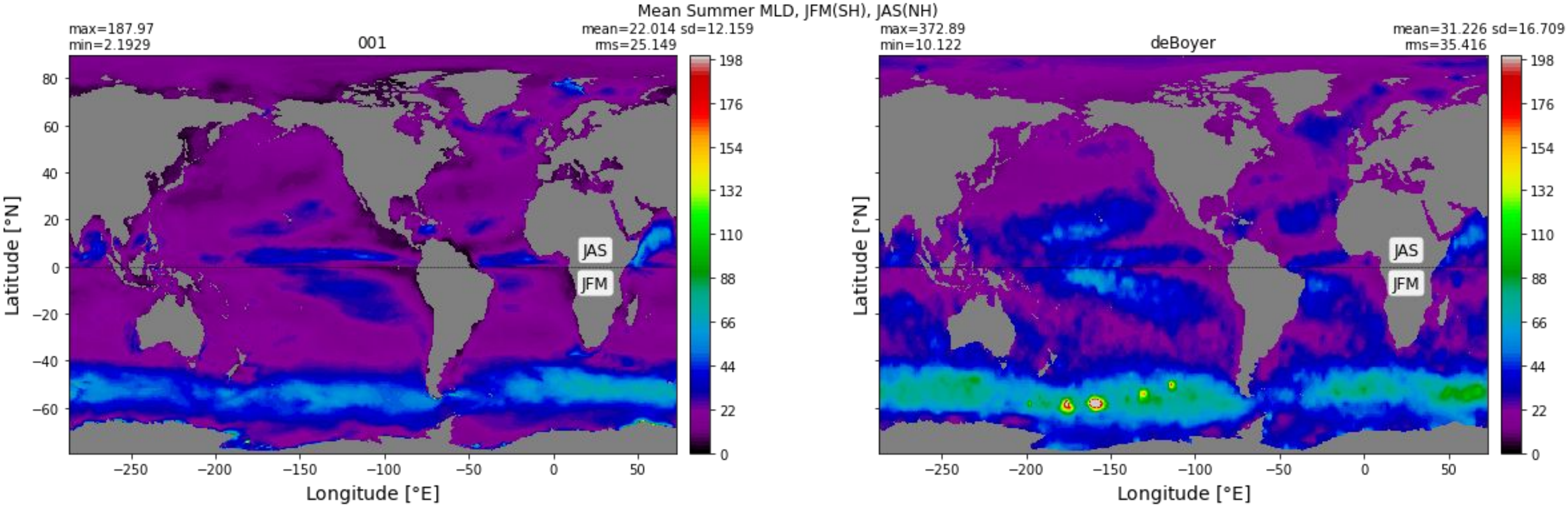
Eastward velocity [m/s] @ 220.0, averaged between 0032-01-01 and 0061-12-31
max=0.91538
mean=0.010458 sd=0.13266
gmom.e23.GJRAv3.TL319_t061_zstar_N65.baseline.001.mixpods
Depth [m]
Latitude [°N]
max=1.0875
min=-0.66016
Johnson et al (2002)
mean=-0.11622 sd=0.31143
rms=0.33241


Eastward velocity [m/s] @ 220.0, averaged between 0032-01-01 and 0061-12-31
max=1.0435
mean=0.0081413 sd=0.13578
Depth [m]
Latitude [°N]
max=1.0875
min=-0.66016
Johnson et al (2002)
mean=-0.11622 sd=0.31143
rms=0.33241
Depth [m]
Latitude [°N]

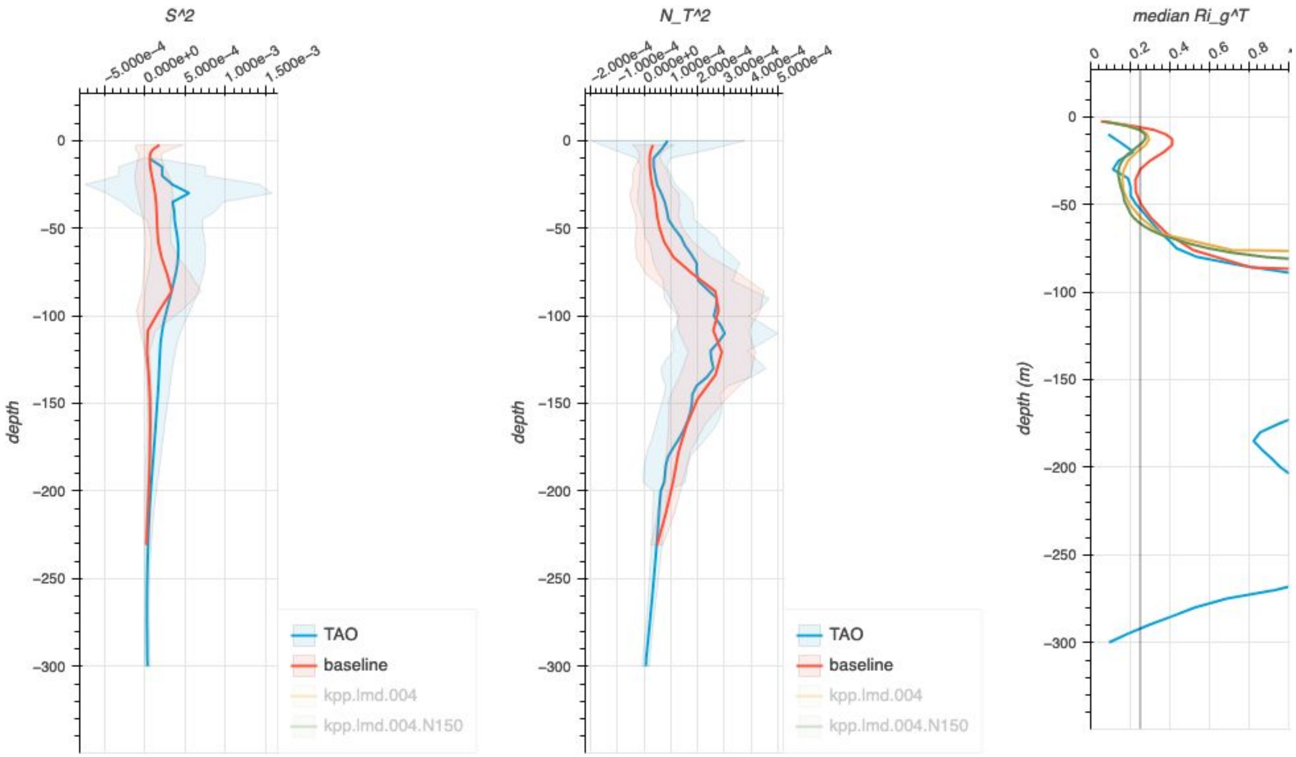

Mean Winter MLD, JFM(NH), JAS(SH)
max=1018.5
min=2.2996
001
mean=85.979 sd=78.862
rms=116.67
max=1251.1
min=10.288
deBoyer
mean=89.381 sd=66.013
rms=111.12
JFM
JAS
Latitude [°N]
Longitude [°E]
80
60
40
20
0
−20
−40
−60
−250
−200
−150
−100
−50
0
50
1120
980
840
700
560
420
280
140
0



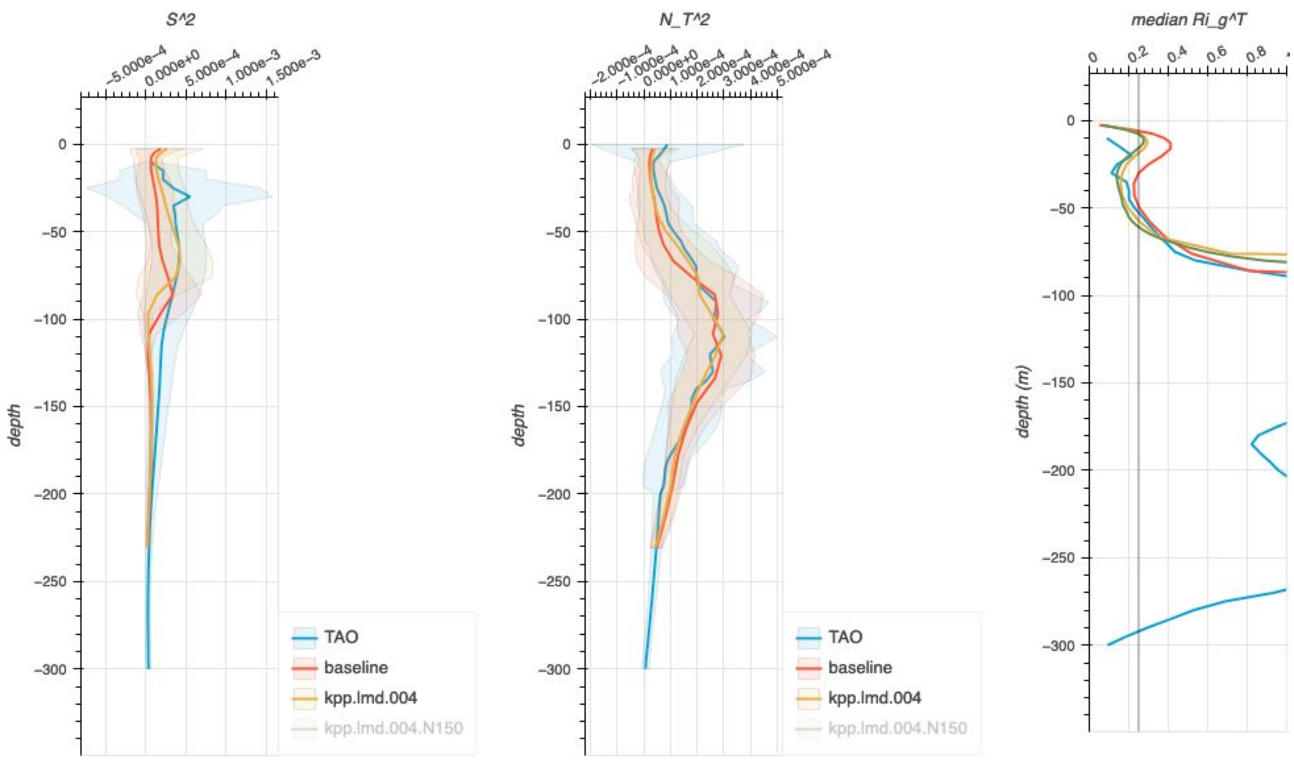
Mean Winter MLD, JFM(NH), JAS(SH)
max=878.28
min=2.4447
004
mean=76.994 sd=60.3
rms=97.796
max=1251.1
min=10.288
deBoyer
mean=89.381 sd=66.013
rms=111.12
JFM
JAS
Latitude [°N]
Longitude [°E]


Mean Summer MLD, JFM(SH), JAS(NH)
max=187.97
min=2.1929
001
mean=22.014 sd=12.159
rms=25.149
max=372.89
min=10.122
deBoyer
mean=31.226 sd=16.709
rms=35.416
Latitude [°N]
Longitude [°E]
JAS
JFM
0
22
44
66
88
110
132
154
176
198
80
60
40
20
0
−20
−40
−60
−250
−200
−150
−100
−50
0
50

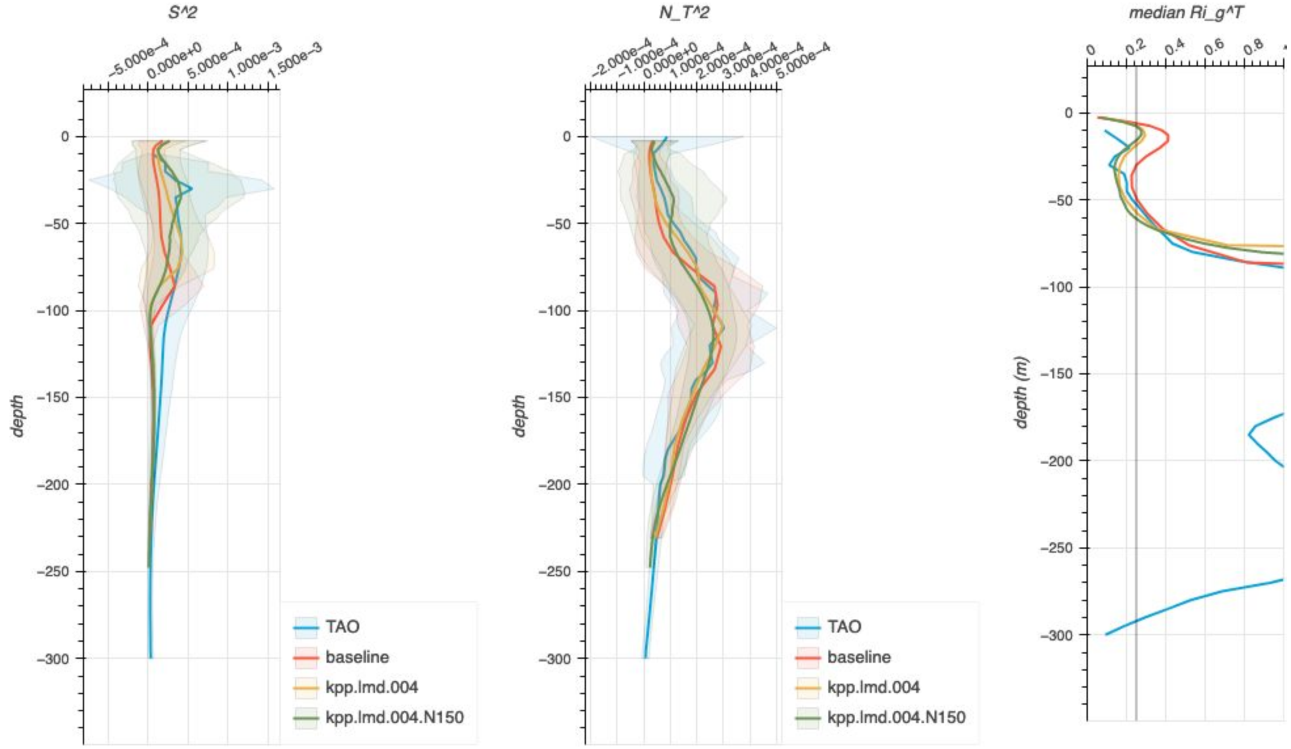
Mean state


S^2
-5.000e-4
0.000e+0
5.000e-4
1.000e-3
1.500e-3
depth
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150
N_T^2
-2.000e-4
-1.000e-4
0.000e+0
1.000e-4
2.000e-4
3.000e-4
4.000e-4
5.000e-4
depth
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150
median Ri_g^T
0
0.2
0.4
0.6
0.8
depth (m)

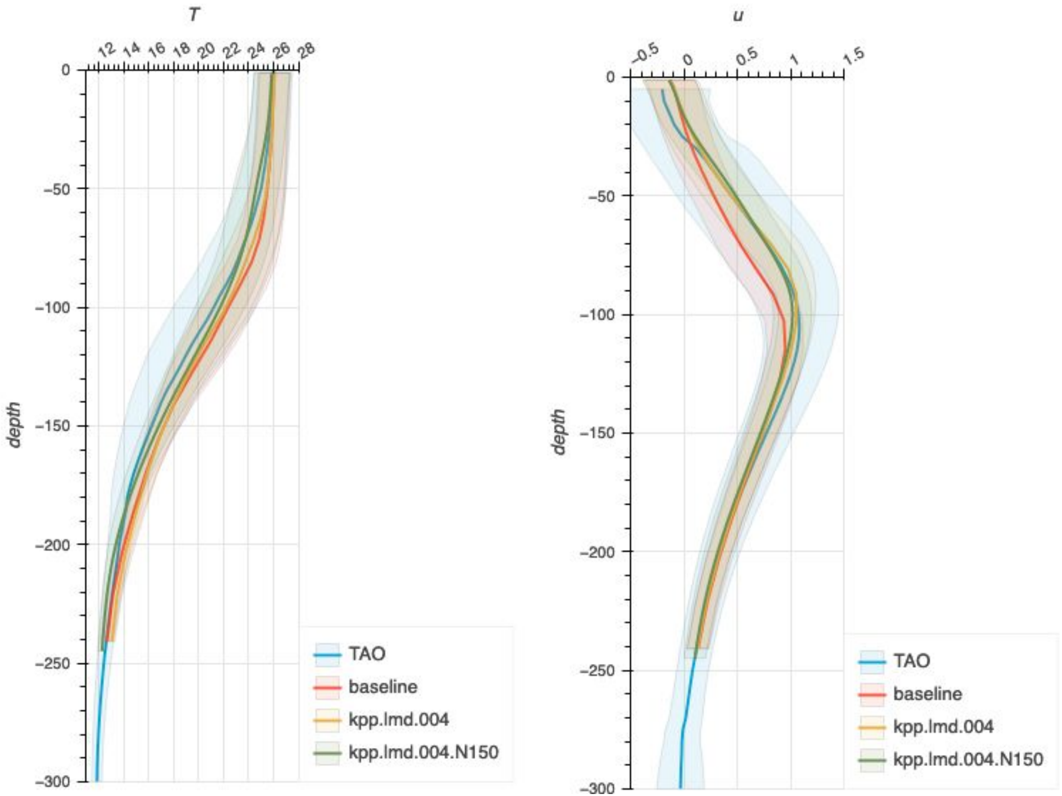
Mean state


S^2
-5.000e-4
0.000e+0
5.000e-4
1.000e-3
1.500e-3
depth
0
-50
-100
-150
-200
-250
-300
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150
N_T^2
-2.000e-4
-1.000e-4
0.000e+0
1.000e-4
2.000e-4
3.000e-4
4.000e-4
5.000e-4
depth
0
-50
-100
-150
-200
-250
-300
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150
median Ri_g^T
0
0.2
0.4
0.6
0.8
depth (m)
0
-50
-100
-150
-200
-250
-300

Mean state


S^2
N_T^2
median Ri_g^T
depth
depth
depth (m)
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150

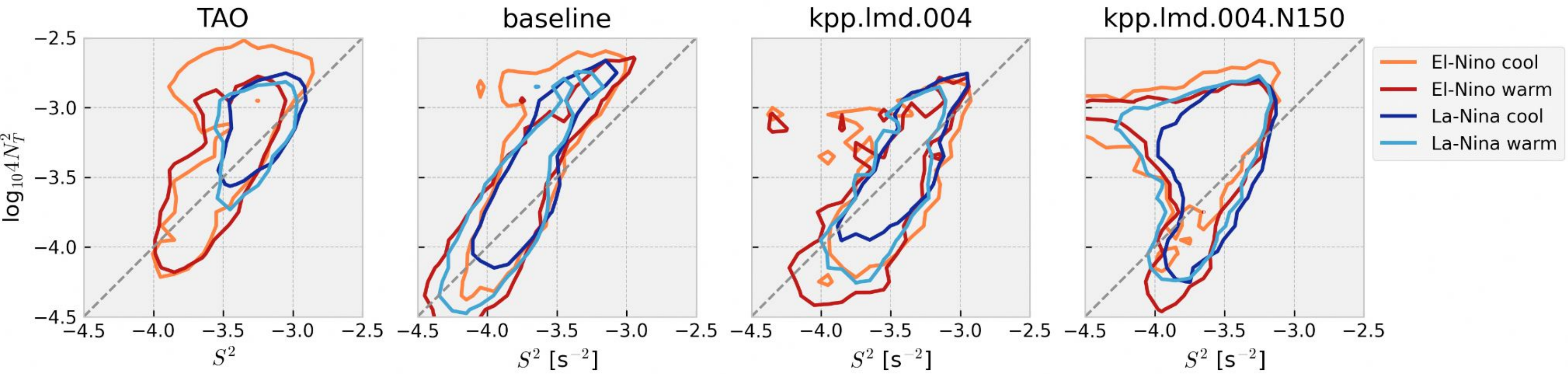
Mean state


T
12
14
16
18
20
22
24
26
28
0
−50
−100
−150
−200
−250
−300
depth
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150
u
−0.5
0
0.5
1
1.5
0
−50
−100
−150
−200
−250
−300
depth
TAO
baseline
kpp.lmd.004
kpp.lmd.004.N150

Marginal Stability Diagram: S2-4N2

Contours enclose 50% of data; El-Nino dT/dt phases

- S^2-4N^2 in between 70m and surface (obs limitation + crude EUC filter)
- Use N^2 with T only (obs limitation)
- Use daily averaged u,v,T instead of hourly (model spectrum is deficient)
- Haven’t matched vertical resolution (shear spectra drop off at 30m wavenumber)



Turbulence Histograms: still too much dissipation