Vertically propagating waves below the Indian equatorial undercurrent

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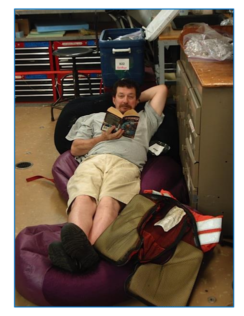


In memory of our shipmate Ray Kreth

1. Outline

- Fluctuating equatorial currents at 80E suggest two distinct wave patterns below the EUC. [4]
- Theory allows us to identify the wave types via their meridional structure. [5,6]
- Results from a zonal transect reveal limits to this simple picture. [7]
- Undaunted, we compute vertical fluxes of momentum and energy for the Rossby mode to assess their importance in large scale momentum and energy balances. [8,9]

2. Summary of results

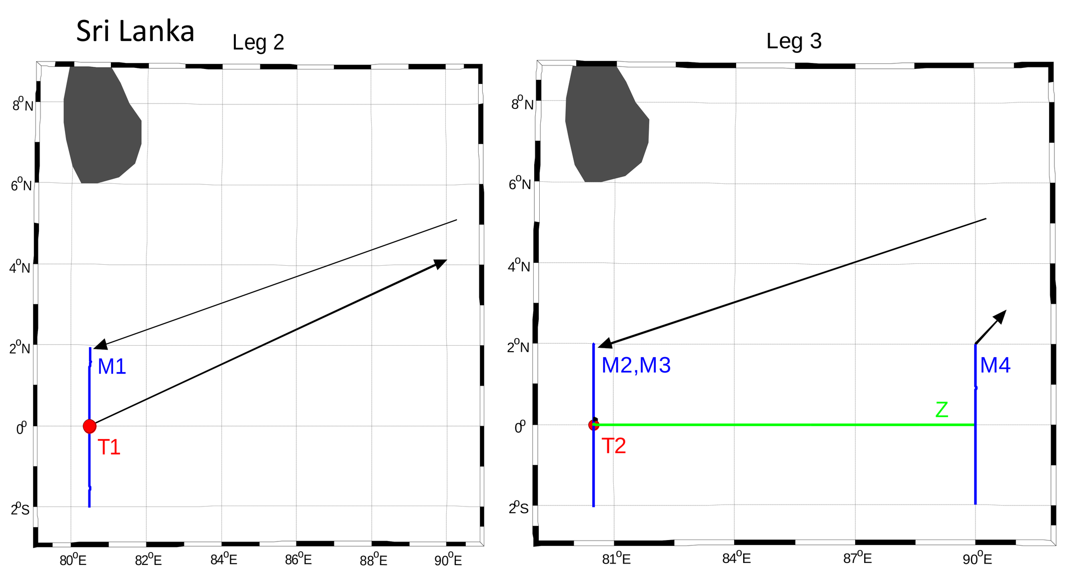
Fluctuations are interpreted as two independent wave types:

- **Rossby waves** with
  - meridional mode 1
  - period >120 days
  - zonal wavelength 50°
  - Too deep to be wind-driven.
  - Could be generated by reflection of Kelvin waves from the Sumatra coast.
  - Vertical fluxes of momentum and kinetic energy would deplete the EUC in 1-3yrs.
  - The momentum flux is similar to that carried by turbulence.
- **Yanai waves** with
  - period = 20 days
  - zonal wavelength = 17°

3. Measurements

As part of the DYNAMO IOP, R/V Revelle

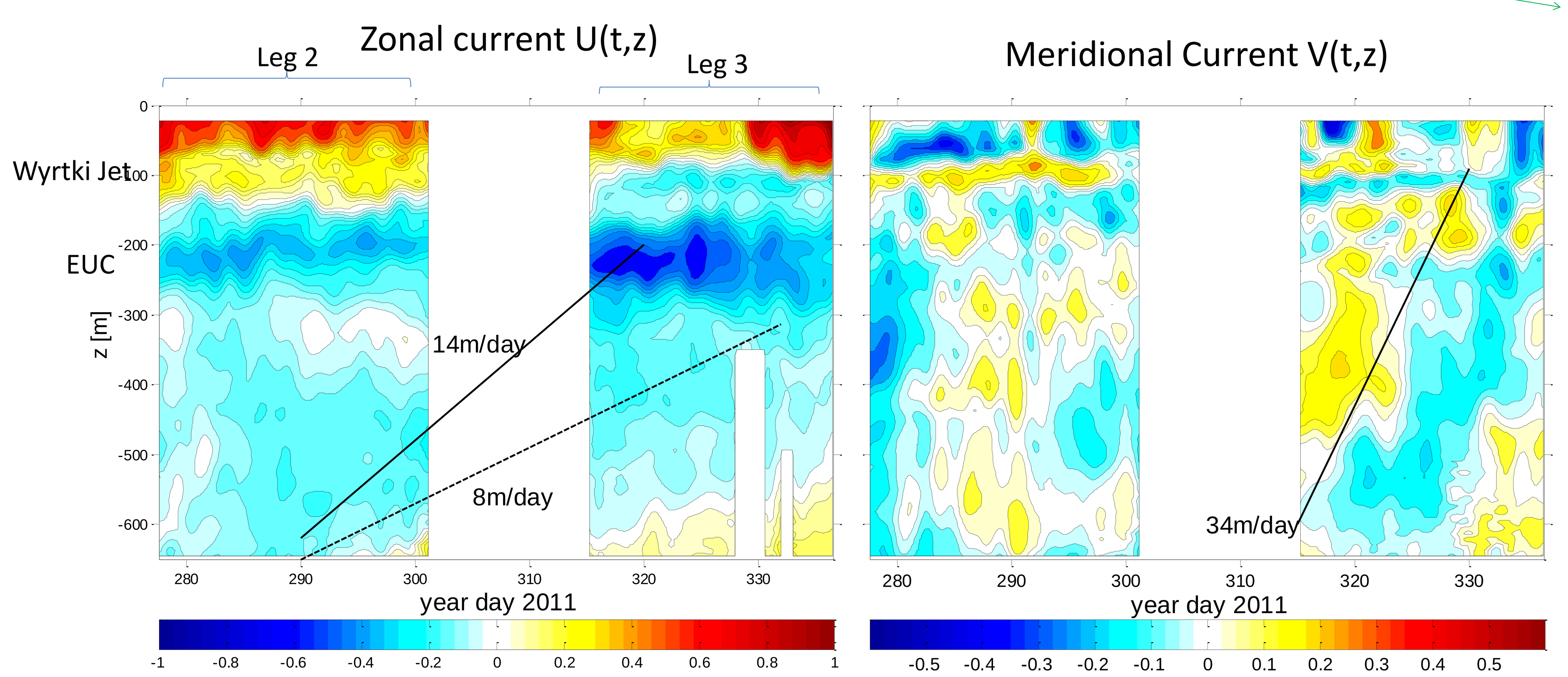
- held station at 80.5E, 0N, for two intervals of ~3 weeks, marked T1, T2 below.
- Executed 4 meridional transects between 2N and 2S (M1-M4) and 1 zonal transect at 0N from 80.5E to 90E (Z).



Measurements used in the present study:

- 75kHz shipboard ADCP
- CTD casts
- Chameleon microstructure probe
- Thermistor at 300m depth on nearby RAMA mooring.

4. Wave signals in zonal and meridional currents



U(t,z) shows rising phase below EUC $\Rightarrow$ downgoing wave

- amplitude $u_0 = 0.15\pm0.05 m/s$
- vertical phase velocity $c_z = 11\pm3 m/day$
- period τ > 120days; we'll ASSUME 6 months

V(t,z) shows rising phase at similar amplitude, but different velocity and period:

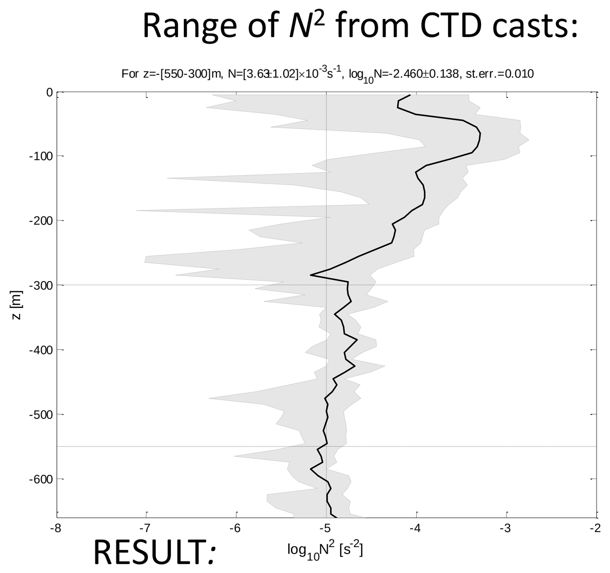
- $c_z \sim 34\pm3 m/day$,
- $\tau = 20\pm2 days$

5. Wave identification via the meridional trapping scale L_{eq}

Linear theory for uniform N: $L_{eq}=\sqrt{\frac{N c_z}{\omega \beta}}$

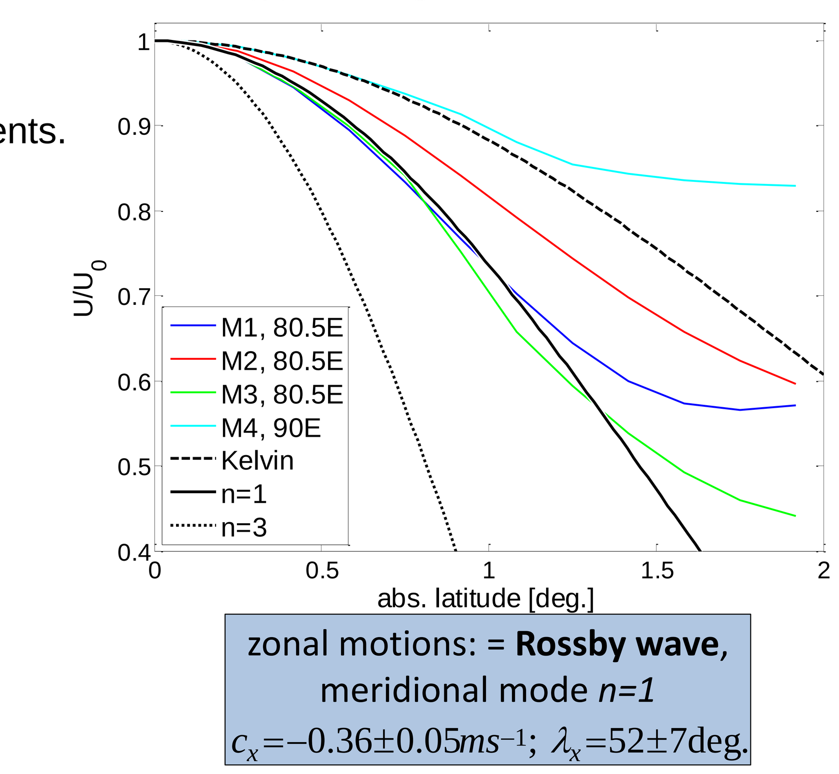
Have $\omega=2\pi/\tau$ and c_z from measured currents.
Have $\beta=2.28\times10^{-11} m^{-1}s^{-1}$.
Need N.

Range of N^2 from CTD casts:



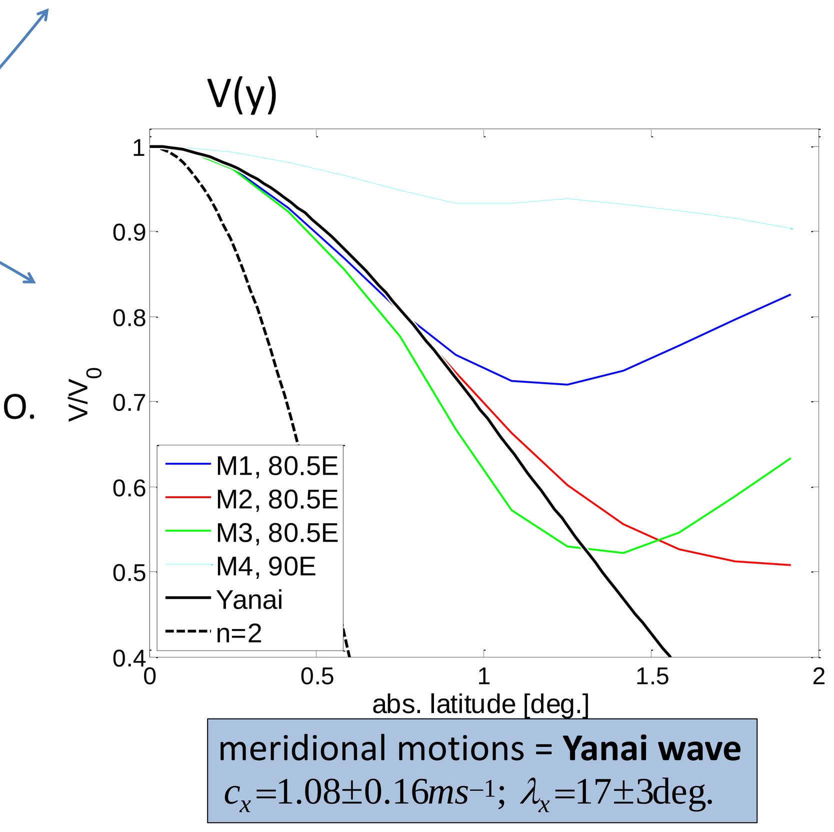
RESULT:
$N^2 = 10^{-5} s^{-2}$ for -550m < z < 300m.
$\Rightarrow$Zonal: $L_{eq}=2.00\pm0.07$deg.
Meridional: $L_{eq}=1.15\pm0.07$deg.

U(y), averaged 300-550m



zonal motions: = **Rossby wave**, meridional mode *n=1*
$c_x=-0.36\pm0.05 ms^{-1}$; $\lambda_x=52\pm7$deg.

V(y)



meridional motions = **Yanai wave**
$c_x=1.08\pm0.16 ms^{-1}$; $\lambda_x=17\pm3$deg.

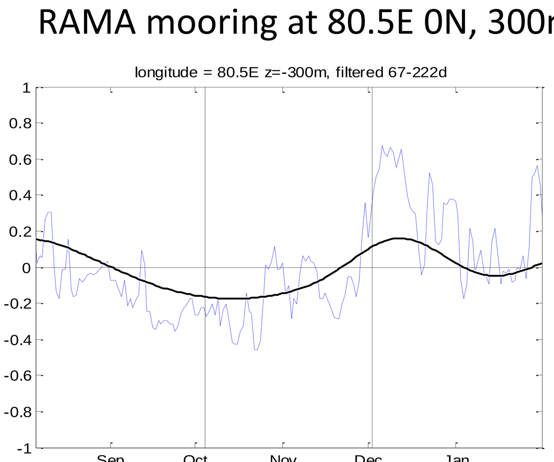
Note: M4 = transect at 90E after November windburst/MJO. No Rossy or Yanai signature.

6. Consistency check #1: Energy partitioning in zonal waves

$$\frac{KE}{PE}=\frac{u_0^2 N^2}{b_0^2},$$

where u_0= velocity amplitude, $b_0=\alpha g T_0$= buoyancy amplitude.
Have u_0, N, need b_0.

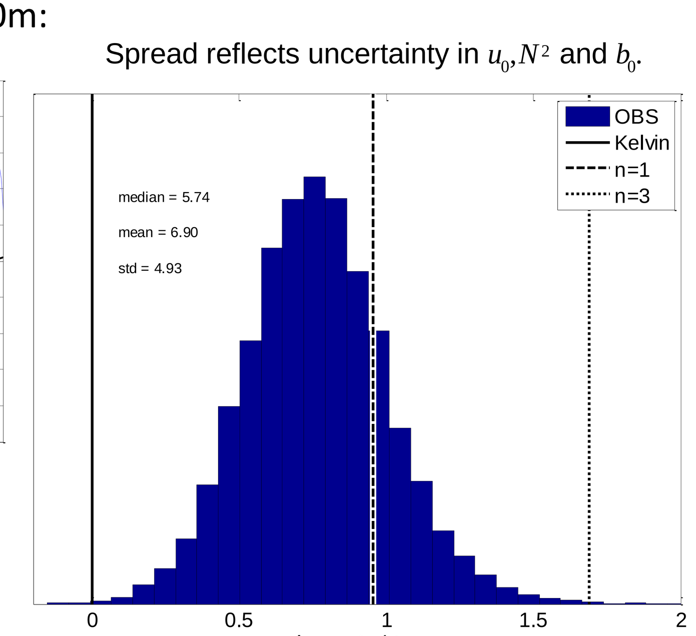
Temperature from RAMA mooring at 80.5E 0N, 300m:



$T_0=0.12\pm0.05K$
$\Rightarrow b_0=(2.2\pm1.0)\times10^{-4} ms^{-2}$

Phase consistent with westward propagation.

Spread reflects uncertainty in u_0, N^2 and b_0.



Consistent with n=1 Rossby wave.

7. Consistency check #2: Ray paths in a zonal transect, 0N, 80.5-90E

Rossby waves in U(x,z):

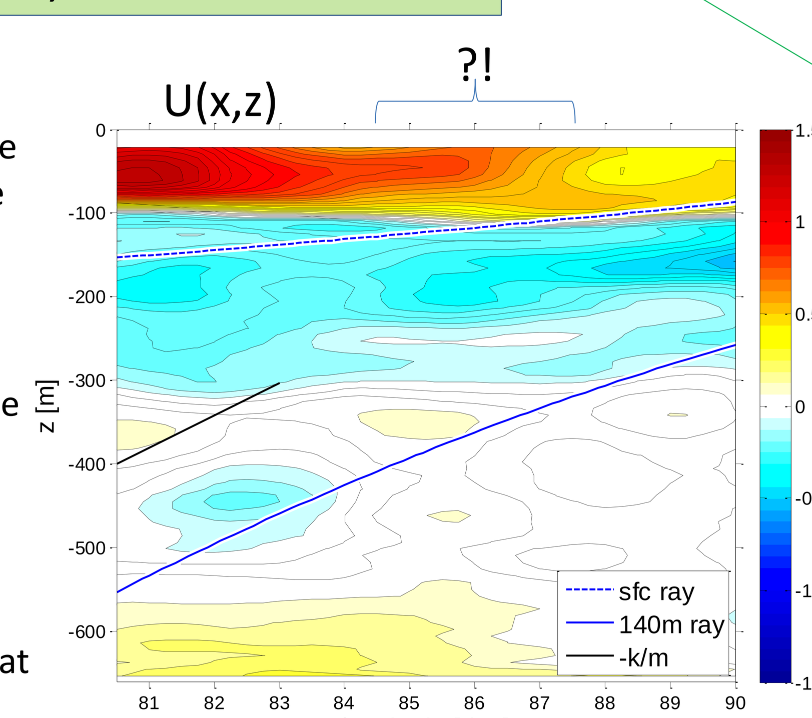
There are hints of the theoretical phase tilt $-k/m$ (black line) directly below the EUC.

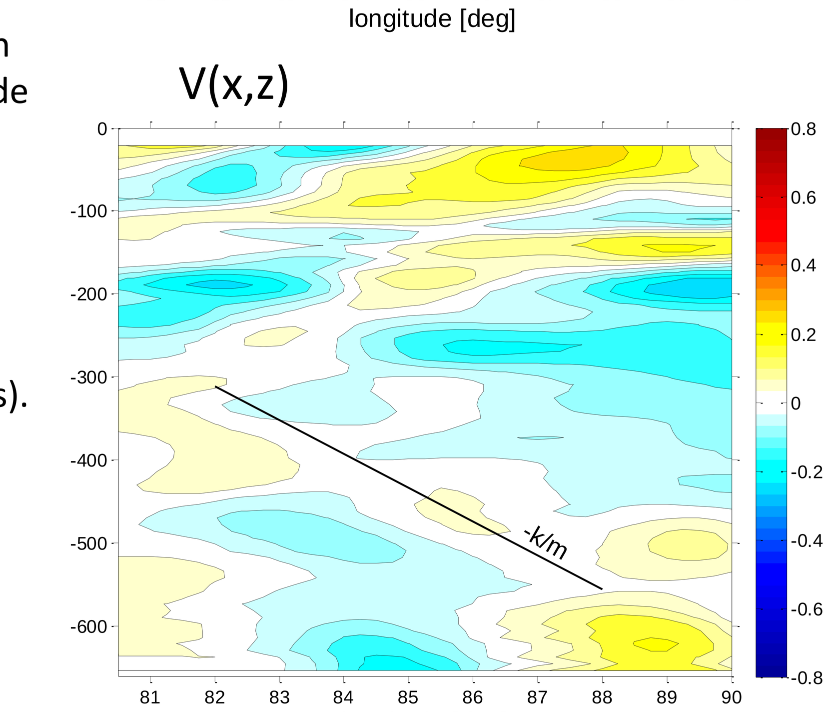
This is deeper than the depth of maximum penetration for surface generated waves (dashed curve), so the observed waves cannot be forced directly at the surface.

Could the waves originate at the EUC core? The maximum depth for a ray originating at the Sumatra coast (97E) at 140m depth (blue curve) descends to 550m at 80.5E, the approximate depth of the observed waves at that longitude (section 4).

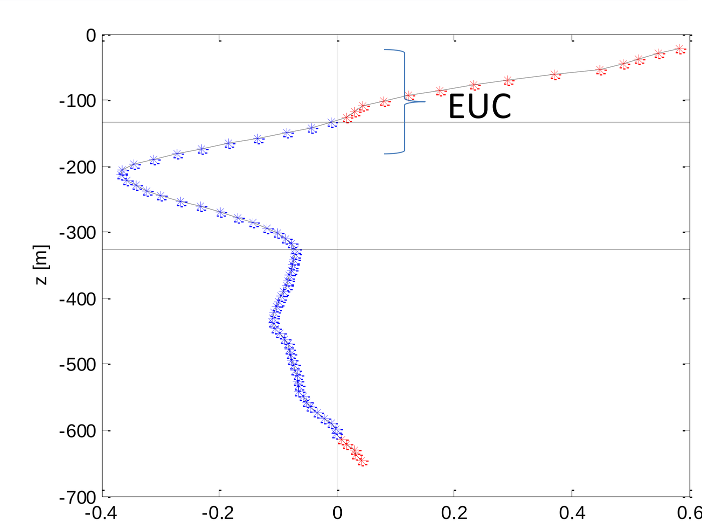
Absence of waves deeper than this could therefore be a shadowing effect from the Sumatra coast. This is consistent with lack of meridional trapping at 90E (section 5, cyan curves).

Yanai waves in V(x,z):
Theoretical phase tilt is visible below 300m.





8. Depletion of the EUC

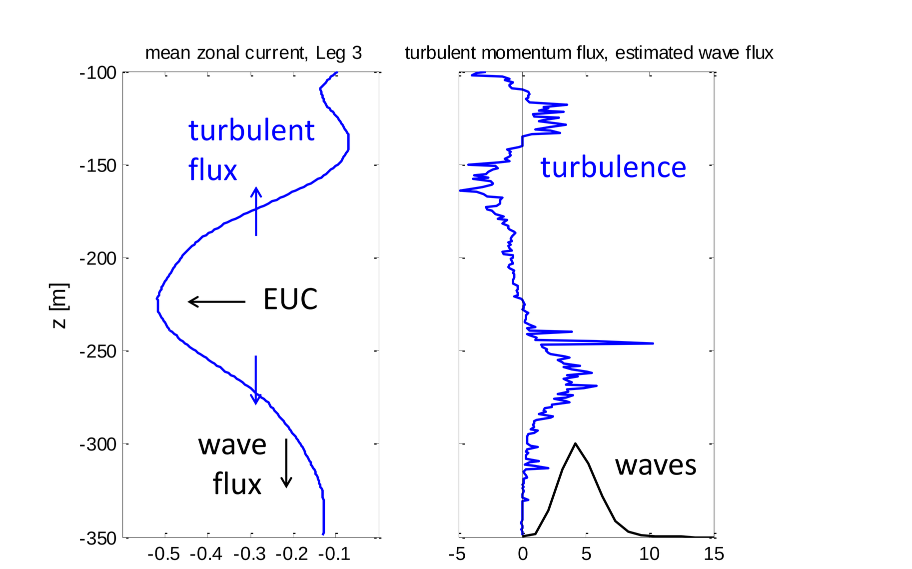


$$\int U=\int_{-320m}^{-130m} U dz=-40.7 m^2/s;\ \int KE=\int_{-320m}^{-130m}\tfrac{1}{2}U^2 dz=5.46 m^3/s^2$$

Wave momentum flux $\overline{u'w'}=4\times10^7 m^2s^{-2}$
Decay time $-\int U / \overline{u'w'}=3.3$yrs.
Wave energy flux $\rho_0^{-1}\overline{p'w'}=-1.6\times10^7 m^3s^{-3}$.
Decay time $-\rho_0\int KE / \overline{p'w'}=1.3$yrs.

Acting over the full 6-month period, these waves would remove 15% of momentum and 40% of energy.

9. Momentum fluxes from the EUC: comparison with turbulence



The EUC is maintained by a balance between

- westward zonal pressure gradient
- eastward accelerations due to wave radiation and turbulence

In this balance, wave radiation is comparable to turbulence.

10. Questions

- Did the Rossby wave propagate to the western IO and generate a new MJO? (e.g. Webber et al. 2011 QJRMS)
- What causes sudden disappearances of the Wyrtki Jet? (section 4, day 315; section 7, 86E)
- Do the waves correlate with satellite observations?
- ...?