Diversity of Surface Easterly Wind Speed and Thermocline Depth Along the Equator in El Niño and La Niña Events During 1997 to 2016

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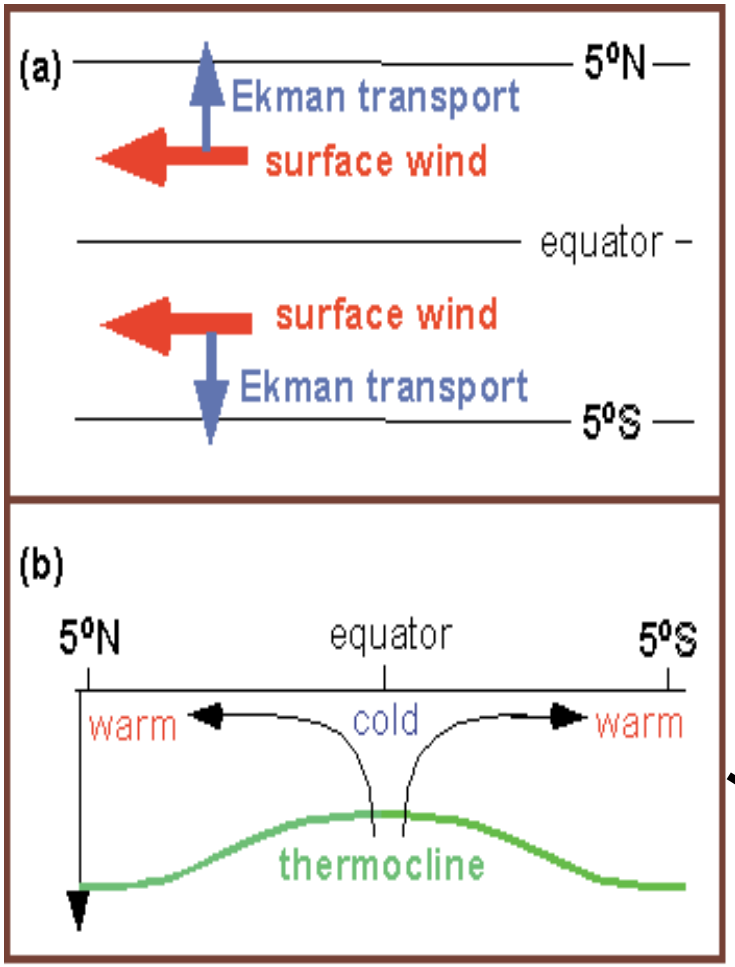
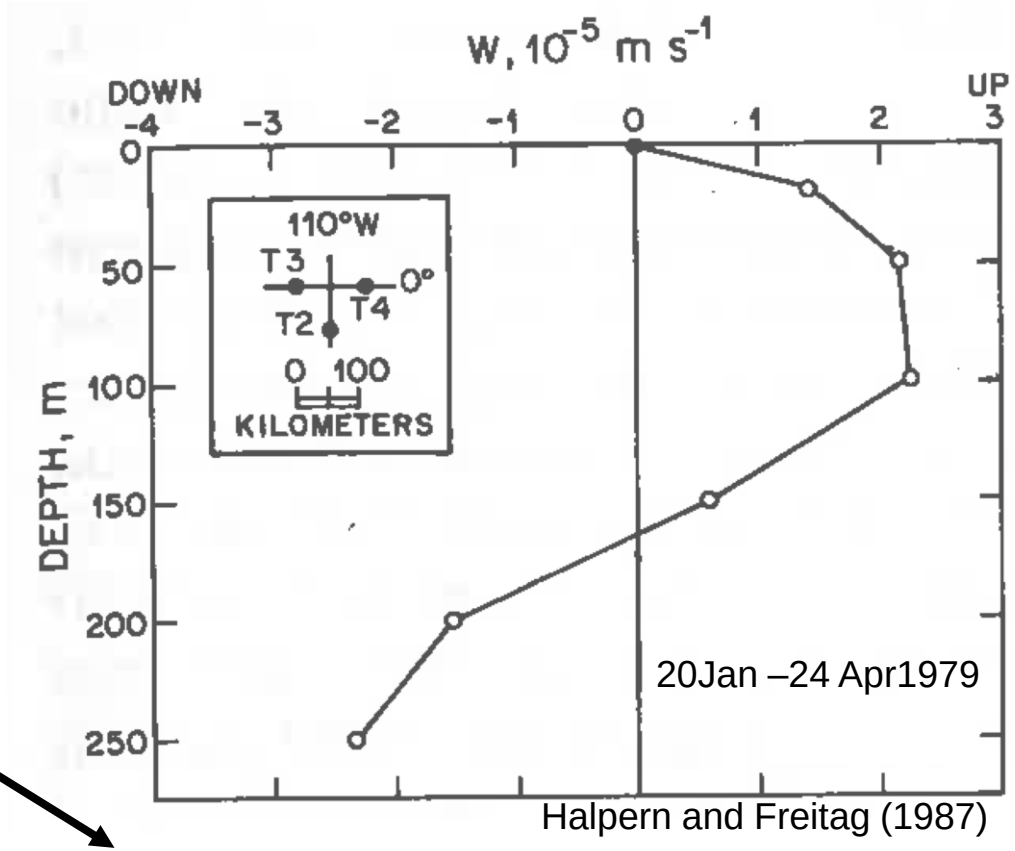
Hypothesis:

Thermocline depth at the equator is correlated with strength of zonal wind speed through wind-driven upwelling



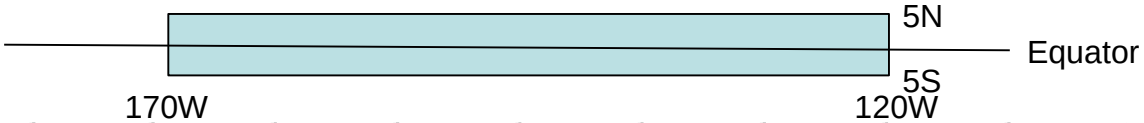
Geerts and Linacre (1998) http://www-das.uwyo.edu/~geerts/cwx/notes/chap11/equat_upwel.html



Halpern and Freitag (1987)

- **Westward wind speed would raise thermocline**
- **Eastward wind speed would deepen thermocline**

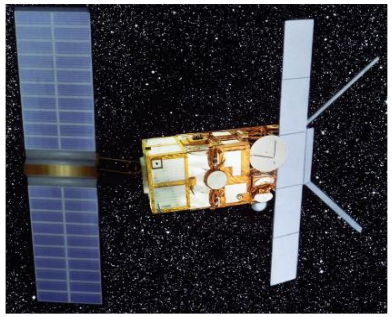
El Niño, La Niña and Normal Intervals



Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	
1997	-0.5	-0.4	-0.2	0.1	0.6	1.0	1.4	1.7	2.0	2.2	2.3	2.3	Super El Niño 1
1998	2.1	1.8	1.4	1.0	0.5	-0.1	-0.7	-1.0	-1.2	-1.2	-1.3	-1.4	
1999	-1.4	-1.2	-1.0	-0.9	-0.9	-1.0	-1.0	-1.0	-1.1	-1.2	-1.4	-1.6	La Niña 1
2000	-1.6	-1.4	-1.1	-0.9	-0.7	-0.7	-0.6	-0.5	-0.6	-0.7	-0.8	-0.8	
2001	-0.7	-0.6	-0.5	-0.3	-0.2	-0.1	0	-0.1	-0.1	-0.2	-0.3	-0.3	
2002	-0.2	-0.1	0.1	0.2	0.4	0.7	0.8	0.9	1.0	1.2	1.3	1.1	El Nino 1
2003	0.9	0.6	0.4	0	-0.2	-0.1	0.1	0.2	0.3	0.4	0.4	0.4	
2004	0.3	0.2	0.1	0.1	0.2	0.3	0.5	0.7	0.7	0.7	0.7	0.7	
2005	0.6	0.6	0.5	0.5	0.4	0.2	0.1	0	0	-0.1	-0.4	-0.7	El Niño 2
2006	-0.7	-0.6	-0.4	-0.2	0.0	0.1	0.2	0.3	0.5	0.8	0.9	1.0	El Niño 3
2007	0.7	0.3	0	-0.1	-0.2	-0.2	-0.3	-0.6	-0.8	-1.1	-1.2	-1.3	La Nina 2
2008	-1.4	-1.3	-1.1	-0.9	-0.7	-0.5	-0.3	-0.2	-0.2	-0.3	-0.5	-0.7	
2009	-0.8	-0.7	-0.4	-0.1	0.2	0.4	0.5	0.6	0.7	1.0	1.2	1.3	El Niño 4
2010	1.3	1.1	0.8	0.5	0	-0.4	-0.8	-1.1	-1.3	-1.4	-1.3	-1.4	La Niña 3
2011	-1.3	-1.1	-0.8	-0.6	-0.3	-0.2	-0.3	-0.5	-0.7	-0.9	-0.9	-0.8	La Niña 4
2012	-0.7	-0.6	-0.5	-0.4	-0.3	-0.1	0.1	0.3	0.4	0.4	0.2	-0.2	
2013	-0.4	-0.5	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	
2014	-0.5	-0.6	-0.4	-0.2	0	0	0	0	0.2	0.4	0.6	0.6	
2015	0.5	0.4	0.5	0.7	0.9	1.0	1.2	1.5	1.8	2.1	2.2	2.3	Super El Niño 2
2016	2.2	1.9	1.5	1.1	0.7	0.1	-0.3	-0.6	-0.8	-0.8	-0.8		

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

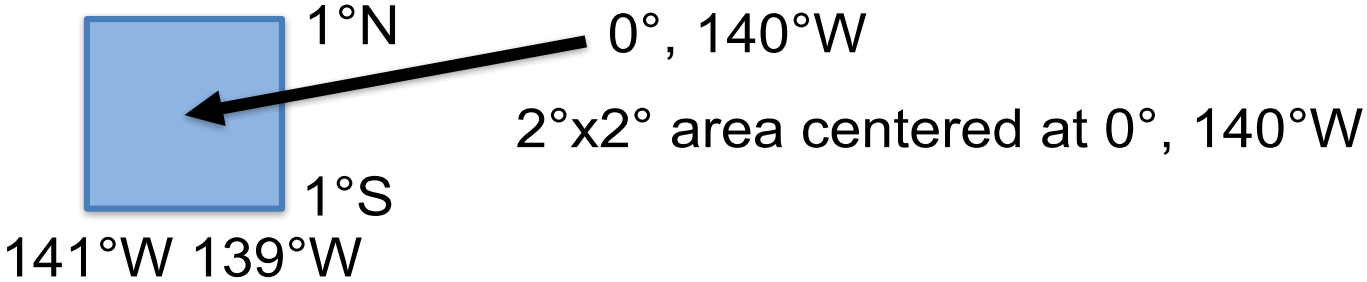
Data Acquisition (1)
Satellite Measurements



AMI-SCAT
on ERS-2

SeaWinds
on QuikSCAT

ASCAT-A
on MetOp-A



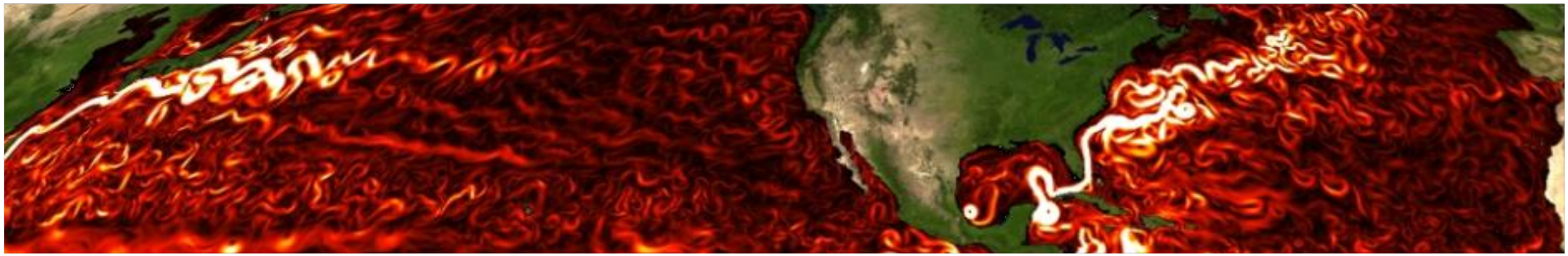
Data Acquisition (2)

ECCO: Estimating the Circulation and Climate of the Ocean

$$
\begin{aligned}
\frac{D\vec{\mathbf{v}}_h}{Dt} + f\hat{\mathbf{k}} \times \vec{\mathbf{v}}_h + \frac{1}{\rho_c}\nabla_z p &= \vec{\mathcal{F}} \\
\epsilon_{nh}\frac{Dw}{Dt} + \frac{g\rho}{\rho_c} + \frac{1}{\rho_c}\frac{\partial p}{\partial z} &= \epsilon_{nh}\mathcal{F}_w \\
\nabla_z \cdot \vec{\mathbf{v}}_h + \frac{\partial w}{\partial z} &= 0 \\
\rho &= \rho(\theta, S) \\
\frac{D\theta}{Dt} &= \mathcal{Q}_\theta \\
\frac{DS}{Dt} &= \mathcal{Q}_s
\end{aligned}
$$

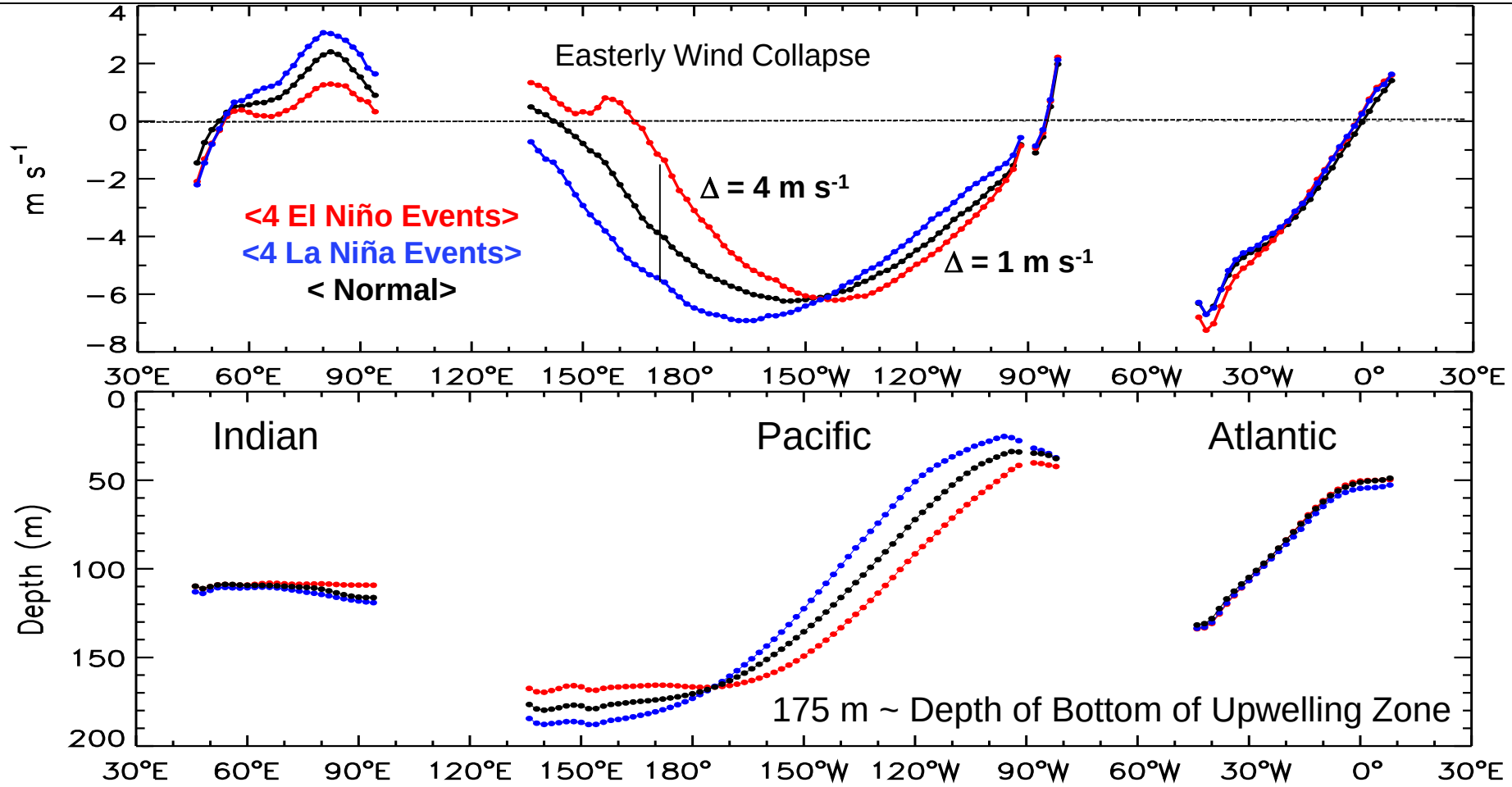
+

- Bathymetry
- Mean dynamic topography
- Ocean surface topography
- Bottom pressure
- Sea surface temperature
- Sea surface salinity
- Vertical profiles of T and S
- Horizontal velocity
- Climatological T and S
- Sea ice cover
- Wind stress
- Air-sea flux estimates



An Example: 5-m Depth Ocean Speed in Mid-Latitude Pacific and Atlantic

Zonal Wind Speed Along Equator
Thermocline (20°C Isotherm) Depth Along Equator



Indian: **YES** Stronger eastward wind correlated with deeper thermocline

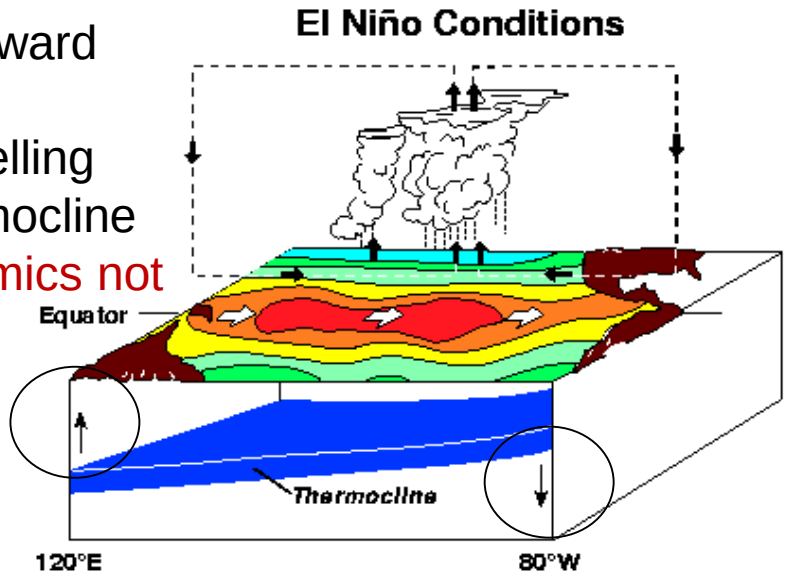
West Pacific: **No** Stronger westward wind not correlated with shallower therm.

East Pacific: **No** Stronger westward wind not correlated with shallower therm.

Atlantic: **YES** Equal wind strength correlated with equal thermocline depth

Observed Correlations and Conventional Wisdom (Typical El Niño and La Niña)

West Pacific
- Weaker westward wind
- Weaker upwelling
- Deeper thermocline
- Ekman dynamics not dominant



Atlantic and Indian
- Ekman dynamics applicable

East Pacific
- Stronger westward wind
- Stronger upwelling
- Shallower thermocline depth
- Ekman dynamics not dominant

West Pacific
- Stronger westward wind
- Stronger upwelling
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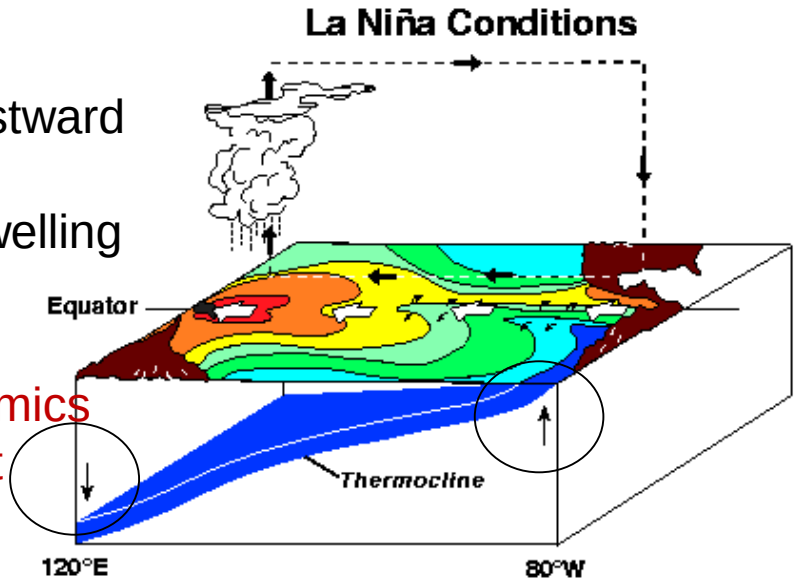

East Pacific
- Weaker westward wind
- Weaker upwelling
- Deeper thermocline depth
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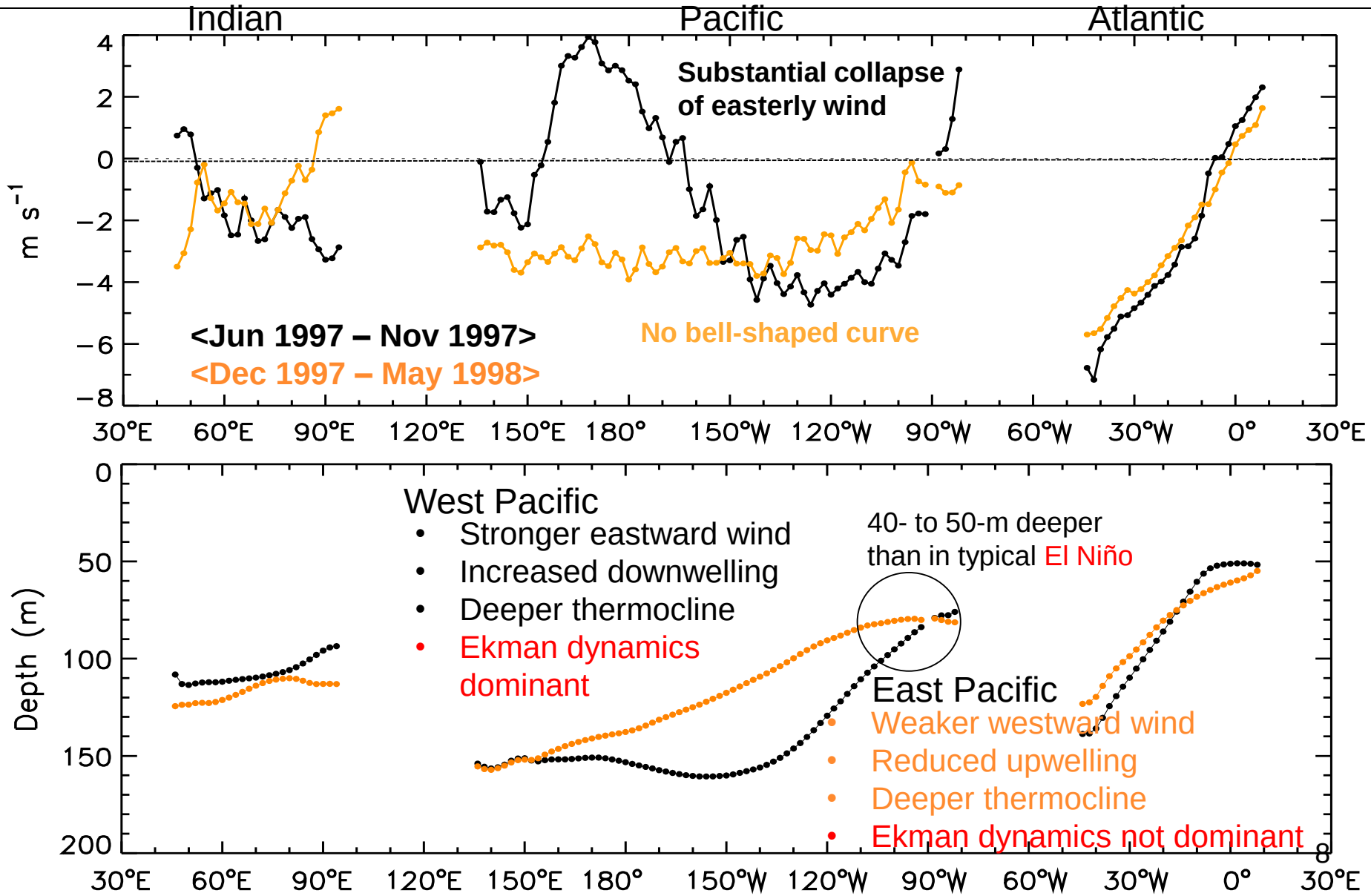
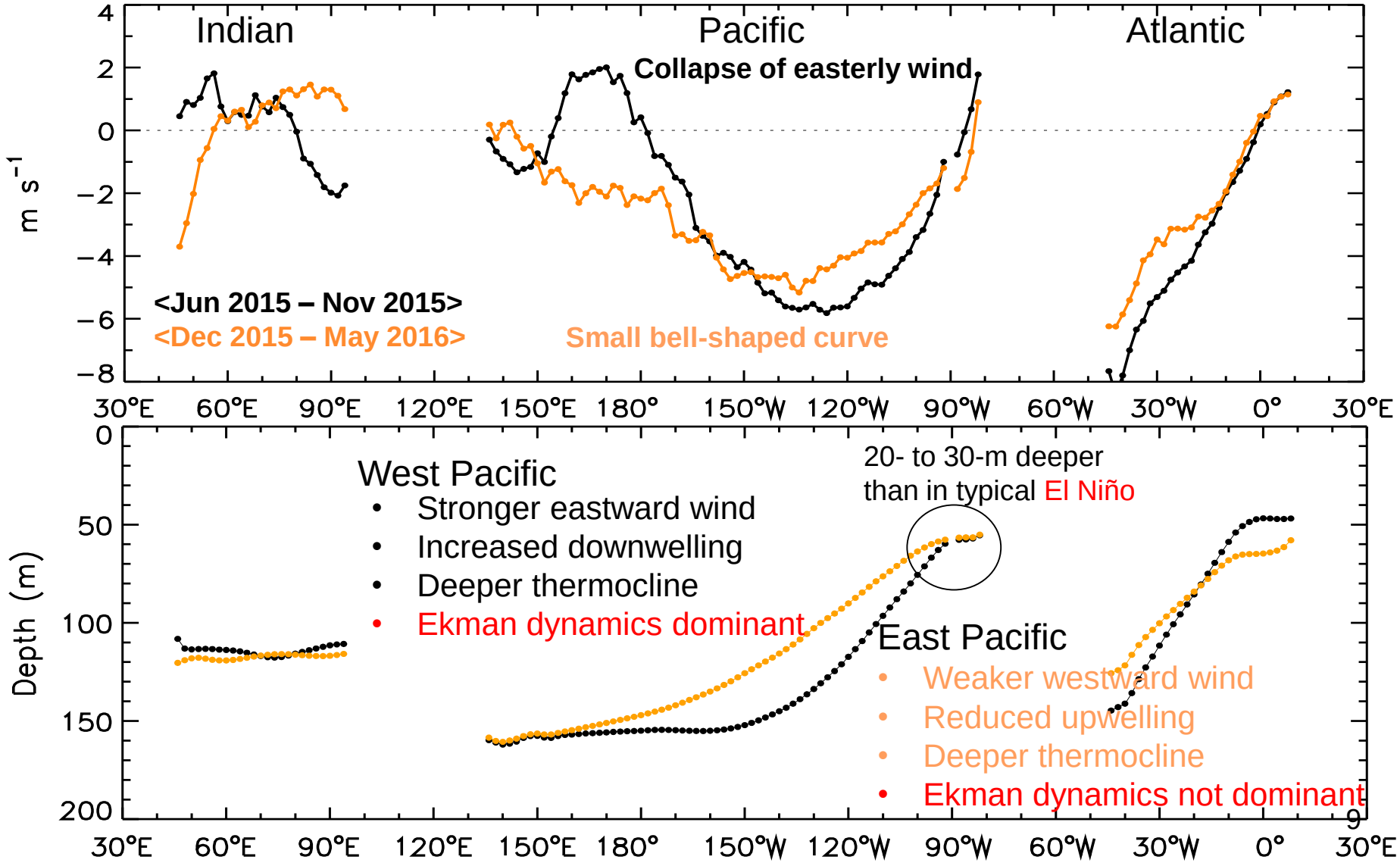
http://www.pmel.noaa.gov/tao/elnino/nino_normal.html (based on 1982-1983 Super El Niño)

Zonal Wind Speed and Thermocline Depth 1997-1998 Super El Niño



Zonal Wind Speed and Thermocline Depth 2015-2016 Super El Niño



Summary

- Hypothesis
  - At the equator, thermocline depth and strength of zonal wind speed are correlated through wind-driven upwelling
- Results
  - Typical El Niño and La Niña Event
    - Indian – correlation was positive
    - West Pacific – correlation was negative
    - East Pacific – correlation was negative
    - Atlantic – correlation was positive
  - Super El Niño Event
    - Indian Ocean – correlation was negative
    - West Pacific – correlation was positive
    - East Pacific – correlation was negative

Thank You