Wind spatial structure underpins ENSO's oceanic warm water volume changes

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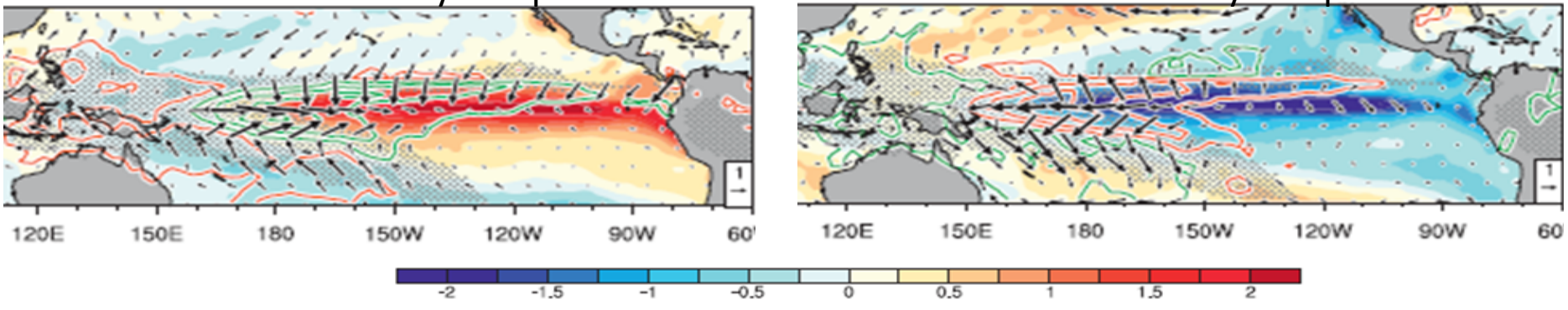
CLEX tropical variability meeting, 6th August 2019

What is ENSO?

El **N**iño-**S**outhern **O**scillation

El Niño SST anomaly composite

La Niña SST anomaly composite



Source: Okumura and Deser, 2010

- Anomalous warming and cooling of east Pacific sea surface temperature (SST, 2-7 year period)

What is ENSO?

- Connected to severe climatic events: droughts, storms, floods, heat waves, bushfires (e.g. Diaz et al. 2001, McPhaden et al. 2006, Sarachik and Cance 2010)

Source: https://www.cdc.gov/features/drought/index.html

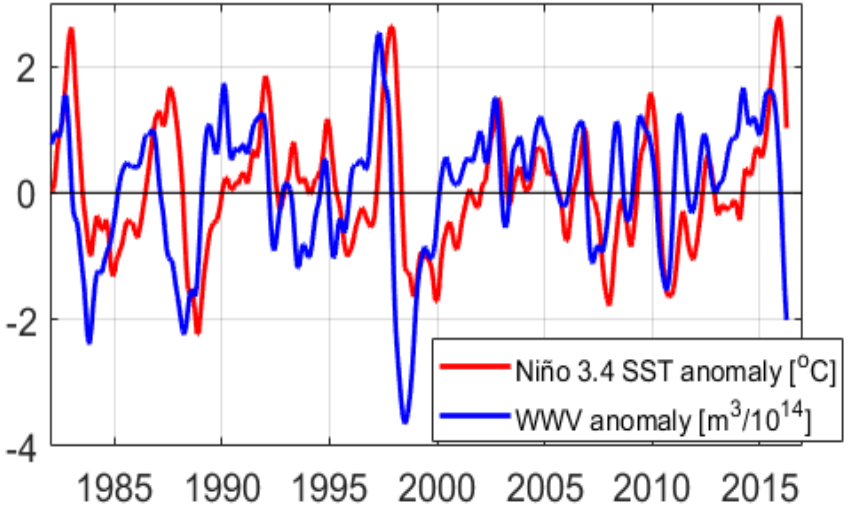
https://gulfnews.com/news/uae/society/expats-shocked-at-flood-damage-and-destruction-back-home-1.2264709

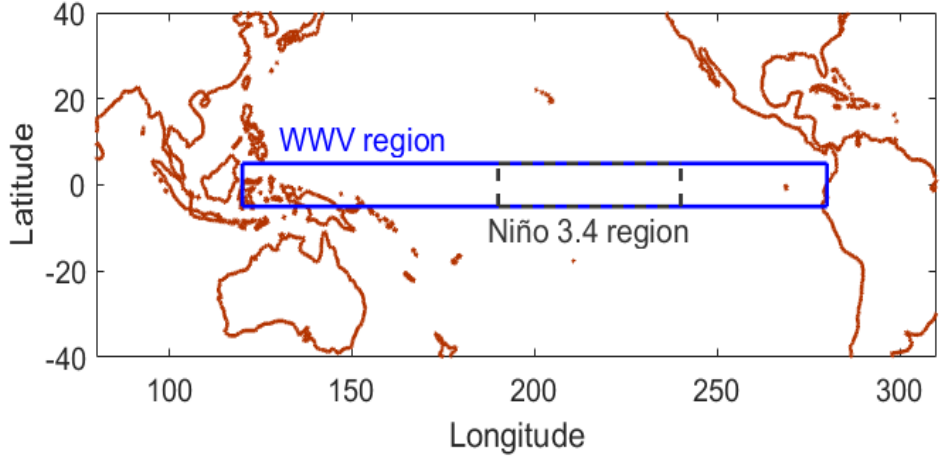
https://www.lecourrieraustralien.com/opinion-australians-are-facing-increasingly-dangerous-bushfire-seasons/?lang=en

! Precise ENSO prediction enables societies to prepare for such climatic events

What is ENSO?

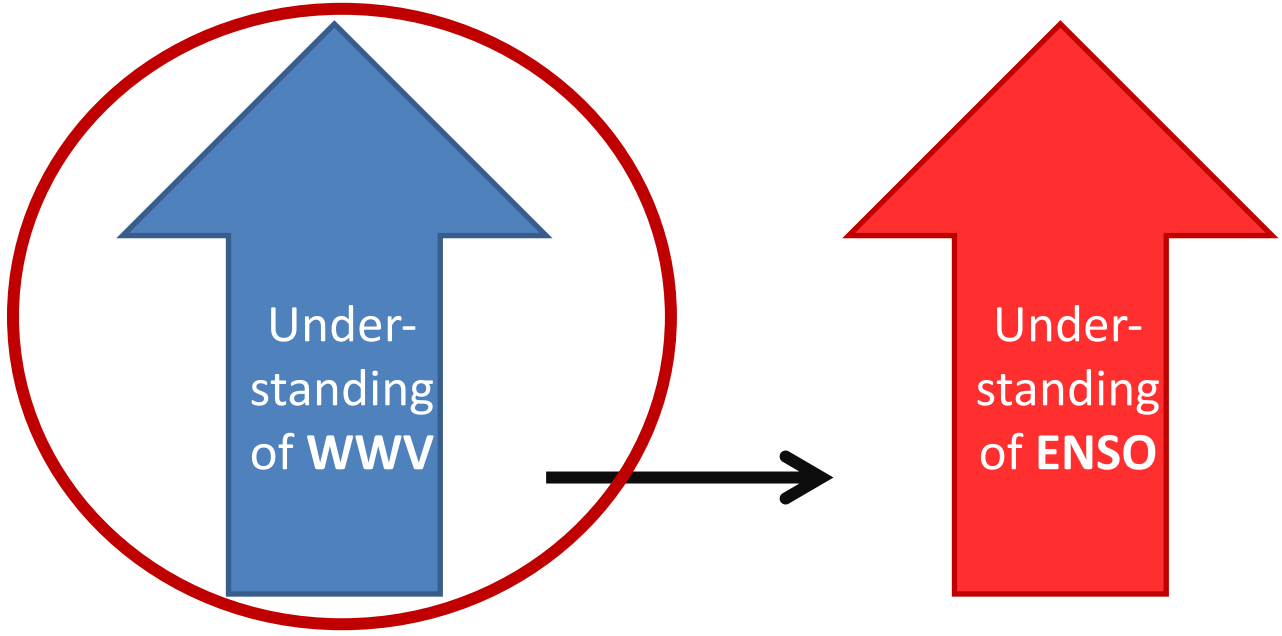
- Warm water volume (WWV) leads ENSO sea surface temperature (SST) (e.g. Wyrtki 1985; Jin 1997; Meinen and McPhaden 2000; McPhaden 2003; McPhaden 2012)





WWV: Volume of equatorial Pacific (120°E-280°E; 5°N-5°S) water above the thermocline

→ WWV is a precursor of ENSO



- Dividing WWV into:

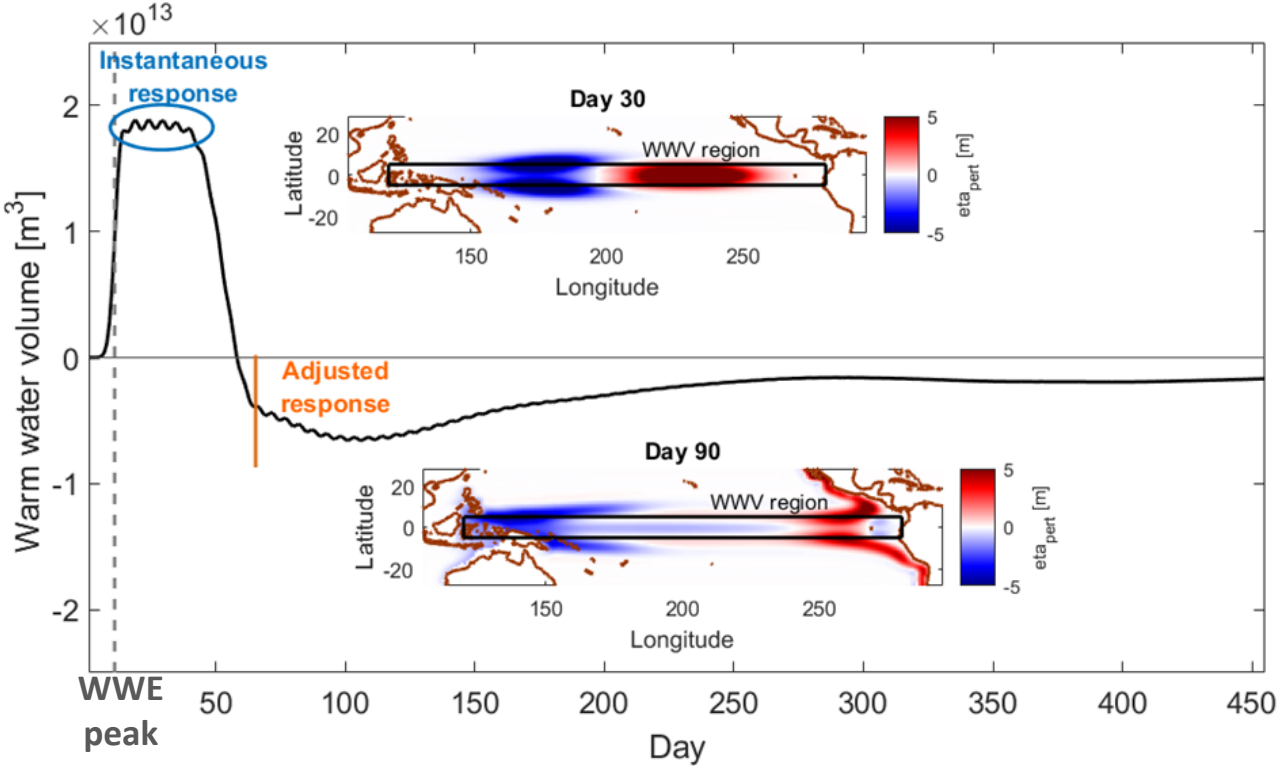
I. Ekman and geostrohpic transports (Meinen and McPhaden 2001; Meinen 2005; Bosc and Delcroix 2008)

II. East and West (Meinen and McPhaden 2000; Izumo et al. 2018; Planton et al. 2018)

III. Instantaneous and adjusted responses (McGregor et al. 2016; Neske and McGregor 2018)

Instantaneous and adjusted WWV responses

1.5 layer shallow water model forced by an equatorial westerly wind event (WWE)



-Instantaneous response obtained during first 2 months after the wind event

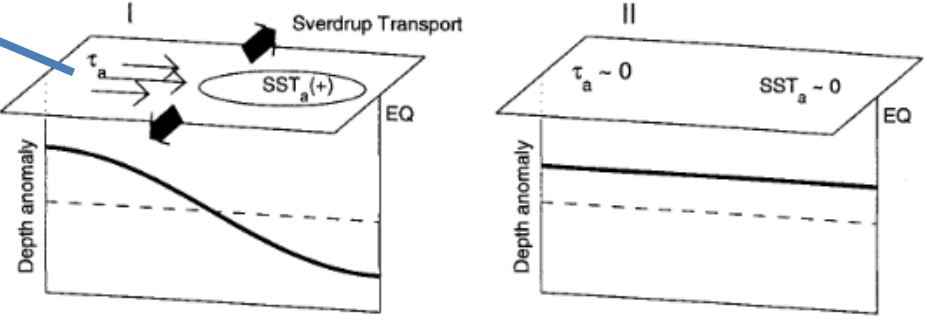
-Adjusted response begins during the 3rd month after the wind event

- Adjusted response plays prominent role in cyclic ENSO theories
  (e.g. Suarez and Schopf 1988; Jin 1997)

Instantaneous and adjusted WWV responses

Equatorial westerlies
→ adjusted WWV discharge

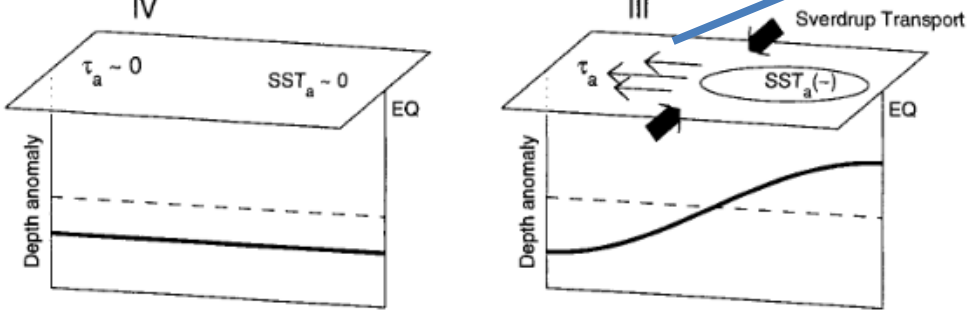
El Niño



- The *recharge-discharge oscillator* (Jin, 1997): considering adjusted response only

La Niña

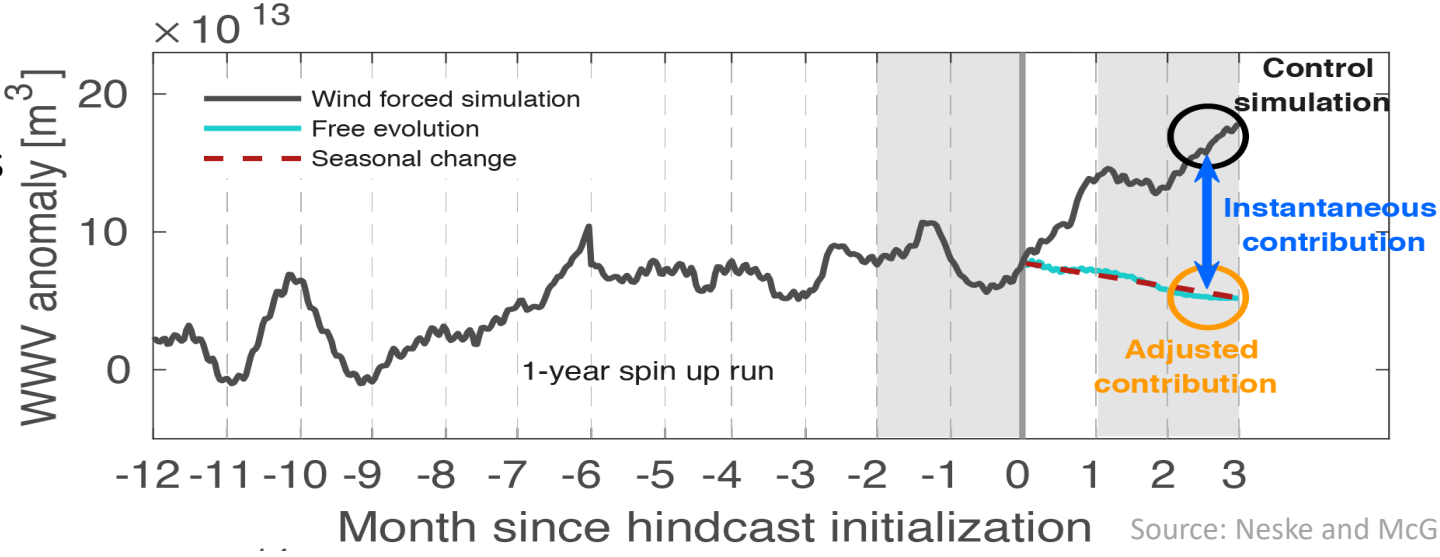
Equatorial easterlies
→ adjusted WWV recharge



Instantaneous and adjusted WWV responses

- 1-year wind forced SWM spin up run (monthly) → free evolution for 3 months

ERA-interim winds
1980-2016

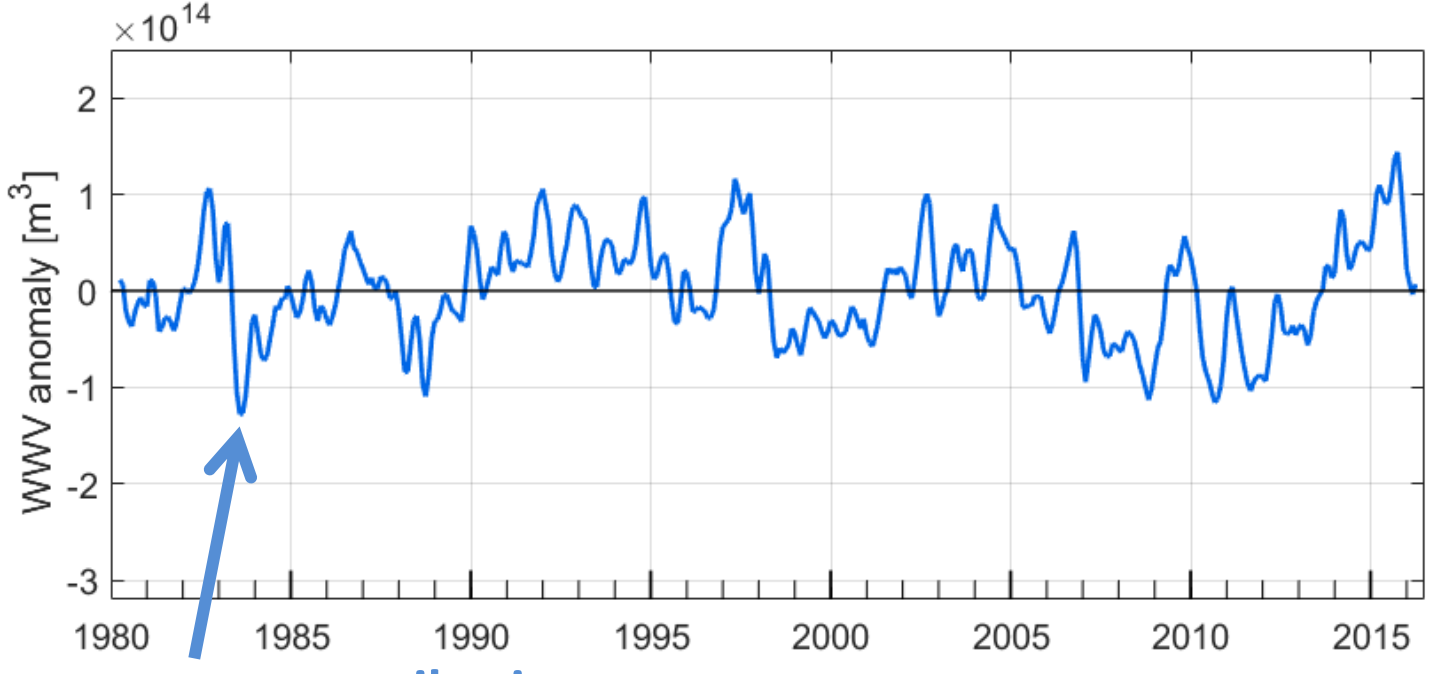


Source: Neske and McGregor 2018

- 3rd month of free evolution defined as **adjusted contribution**
- Difference beween wind forced simulation and adjusted contribution defined as **instantaneous contribution**

Instantaneous and adjusted WWV responses

- Shallow water model results forced by ERA-interim winds (Neske and McGregor, 2018):



Instantaneous contribution

(Due to winds of the preceding 3 months)

Instantaneous and adjusted WWV responses

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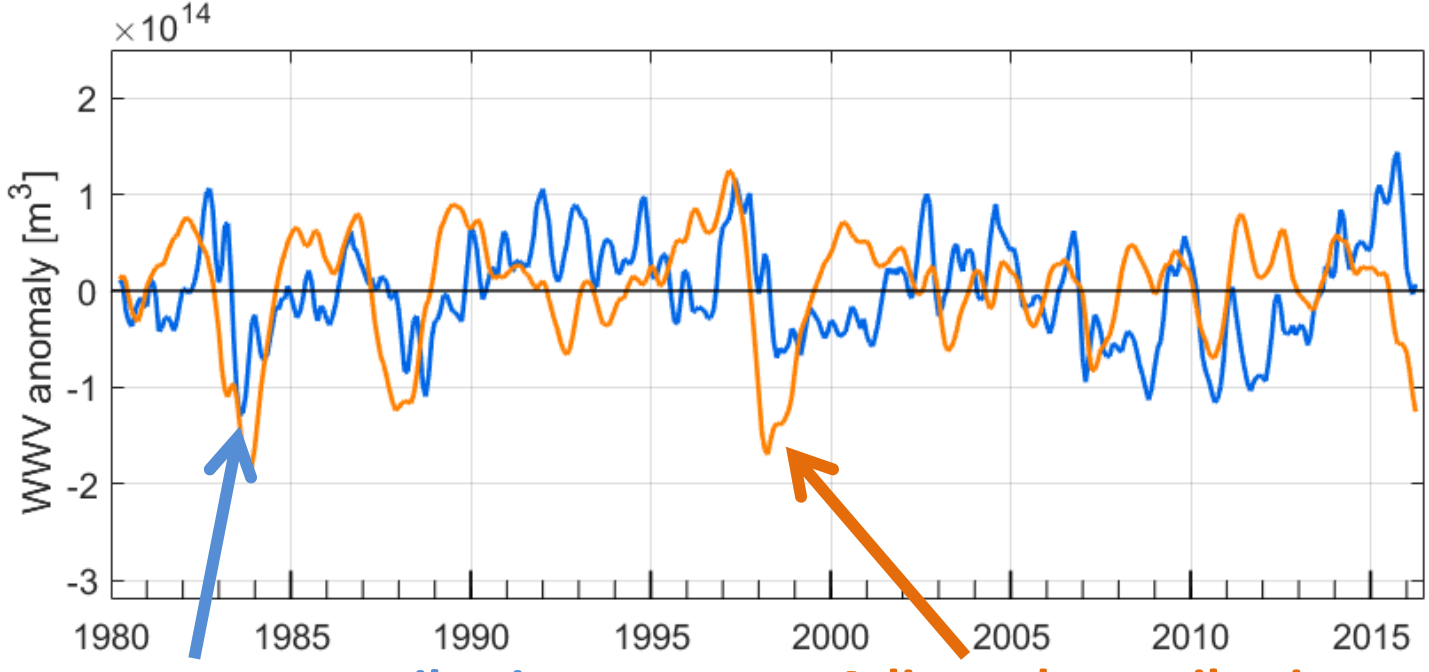

Instantaneous contribution
(Due to winds of the preceding 3 months)

Adjusted contribution
(Due to the winds 3-15 months prior)

Instantaneous and adjusted WWV responses

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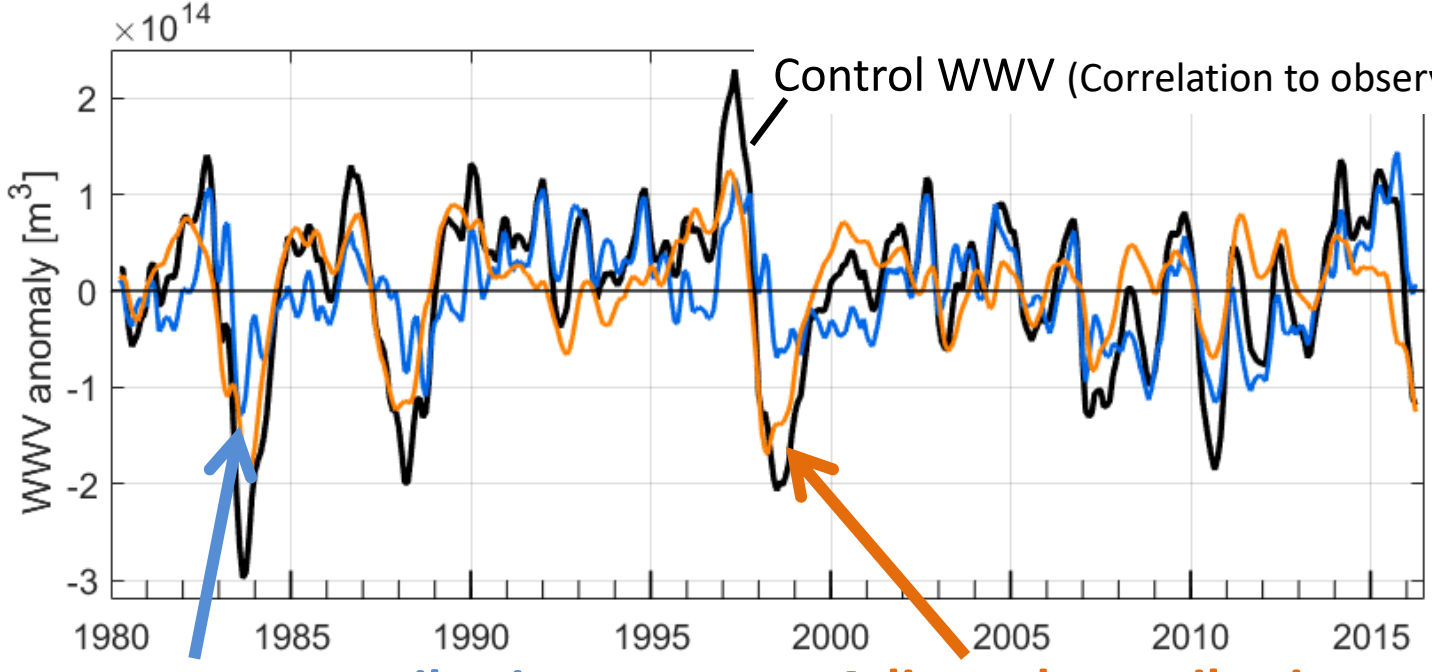

Instantaneous and adjusted WWV responses

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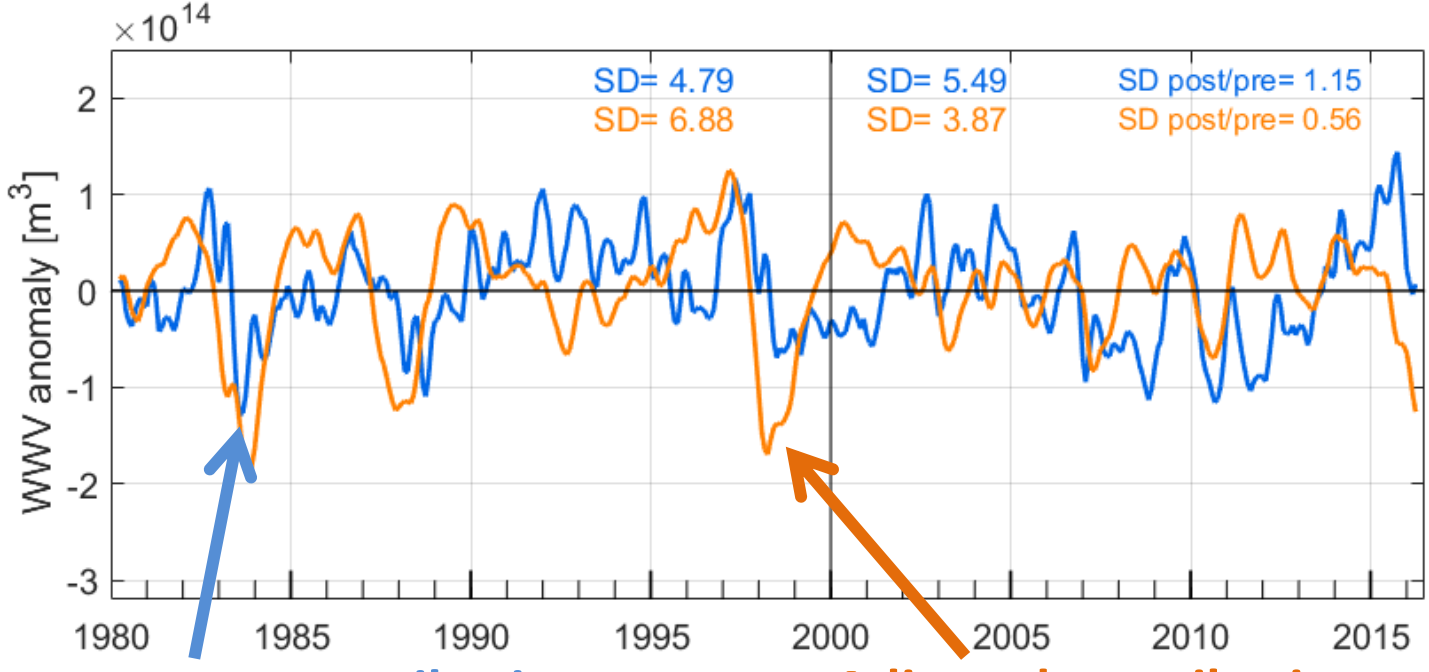
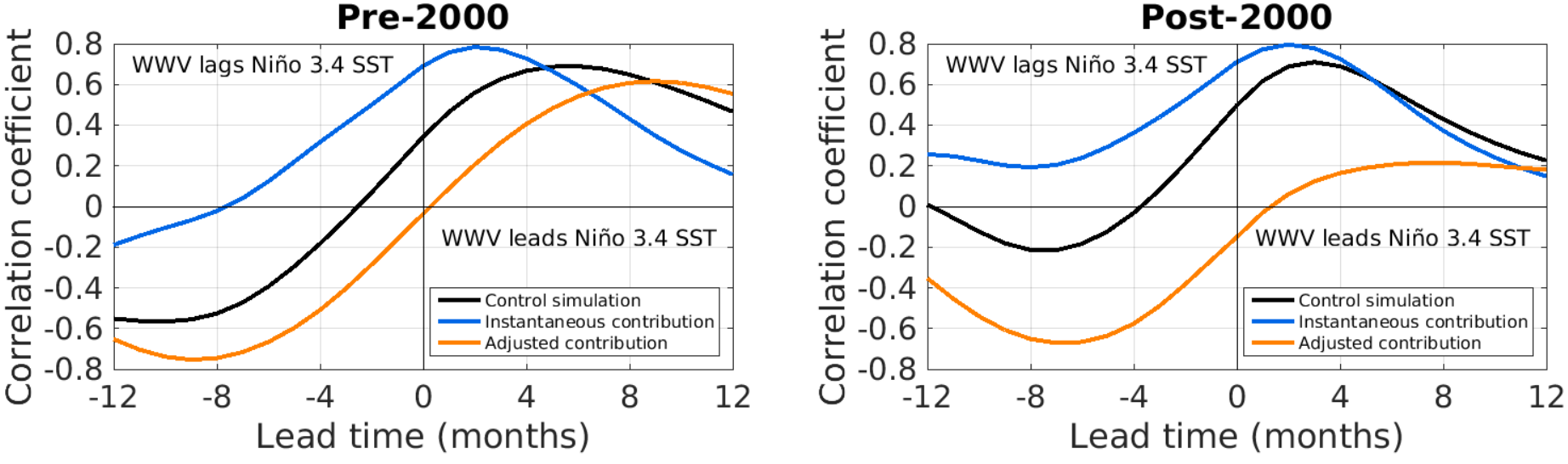


Instantaneous contribution
(Due to winds of the preceding 3 months)

Adjusted contribution
(Due to the winds 3-15 months prior)

Instantaneous and adjusted WWV responses

- ENSO predictability >1 season depends on the adjusted contribution

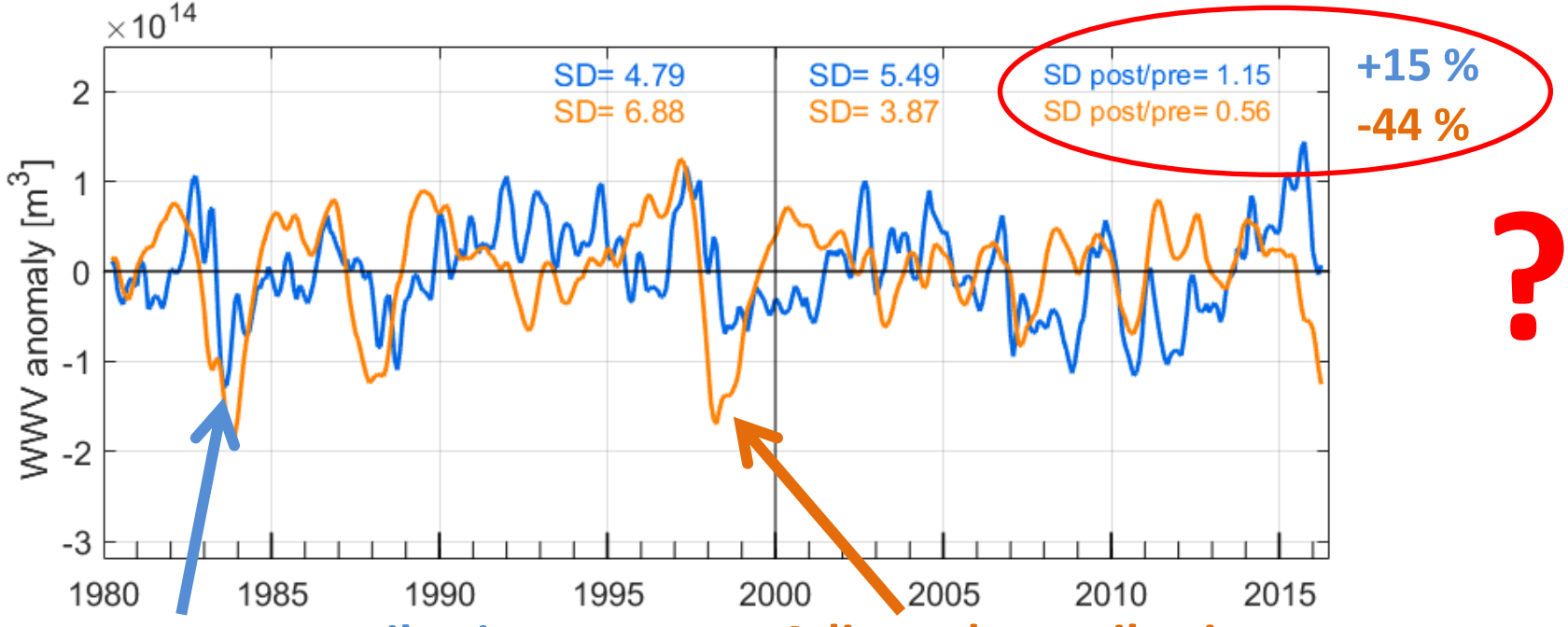


Source: Neske and McGregor 2018

→ Post-2000 control/ENSO SST lead correlation largely reflects the instantaneous/ENSO SST lead correlation

Instantaneous and adjusted WWV responses

- Shallow water model results forced by ERA-interim winds (Neske and McGregor, 2018):



Instantaneous and adjusted WWV responses

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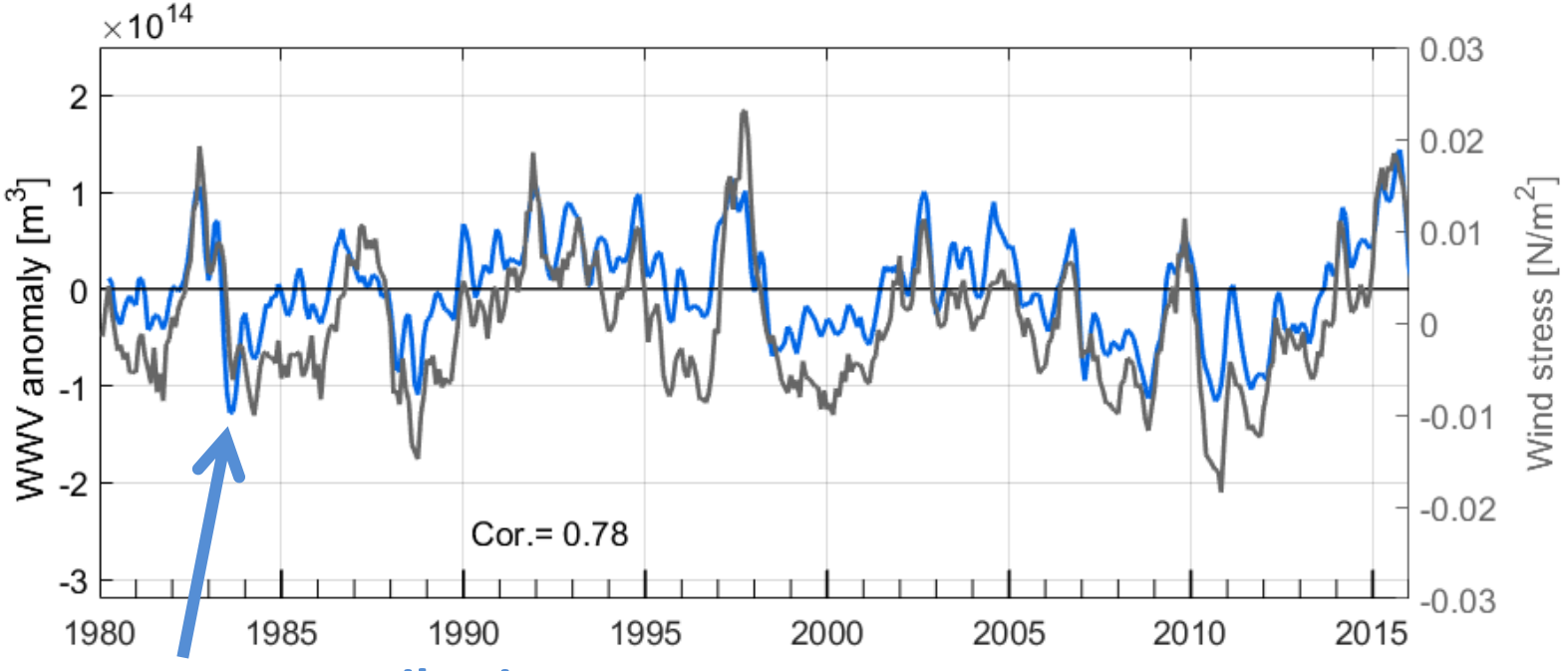


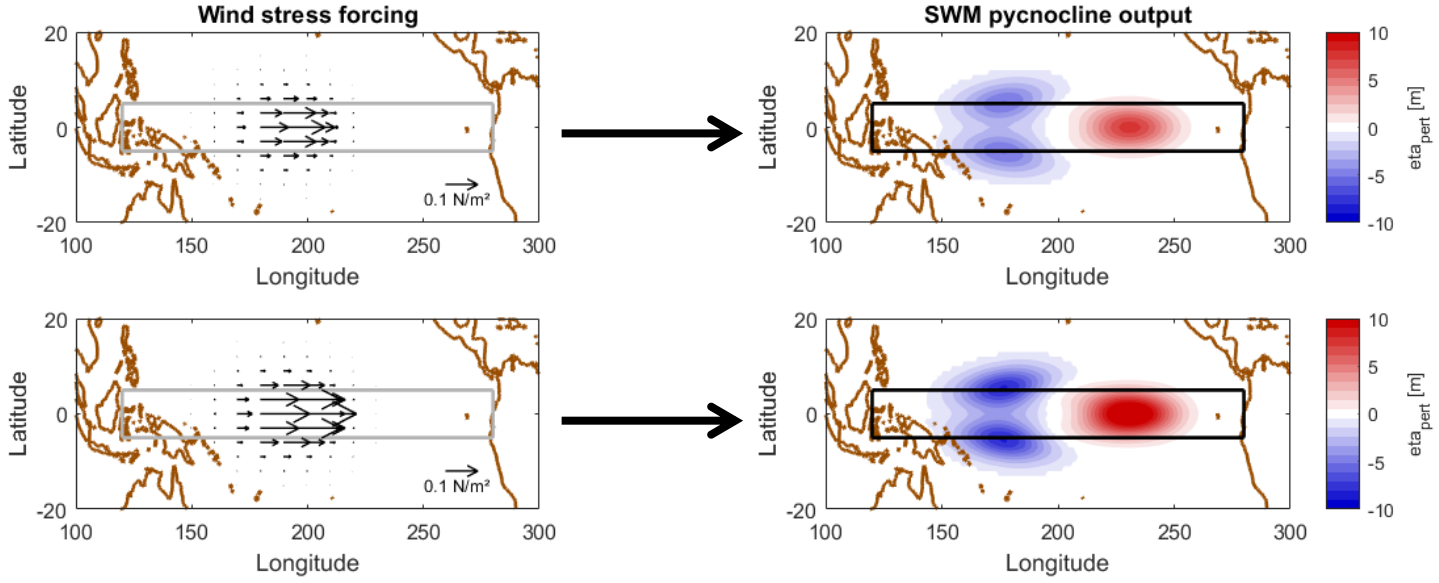
Instantaneous contribution
(Due to winds of the preceding 3 months)

→ Highly consitent with equatorial wind stress

Instantaneous and adjusted WWV responses

- Throughout most literature: increase in instantaneous response → increase in adjusted response:

Wind stress τ_x



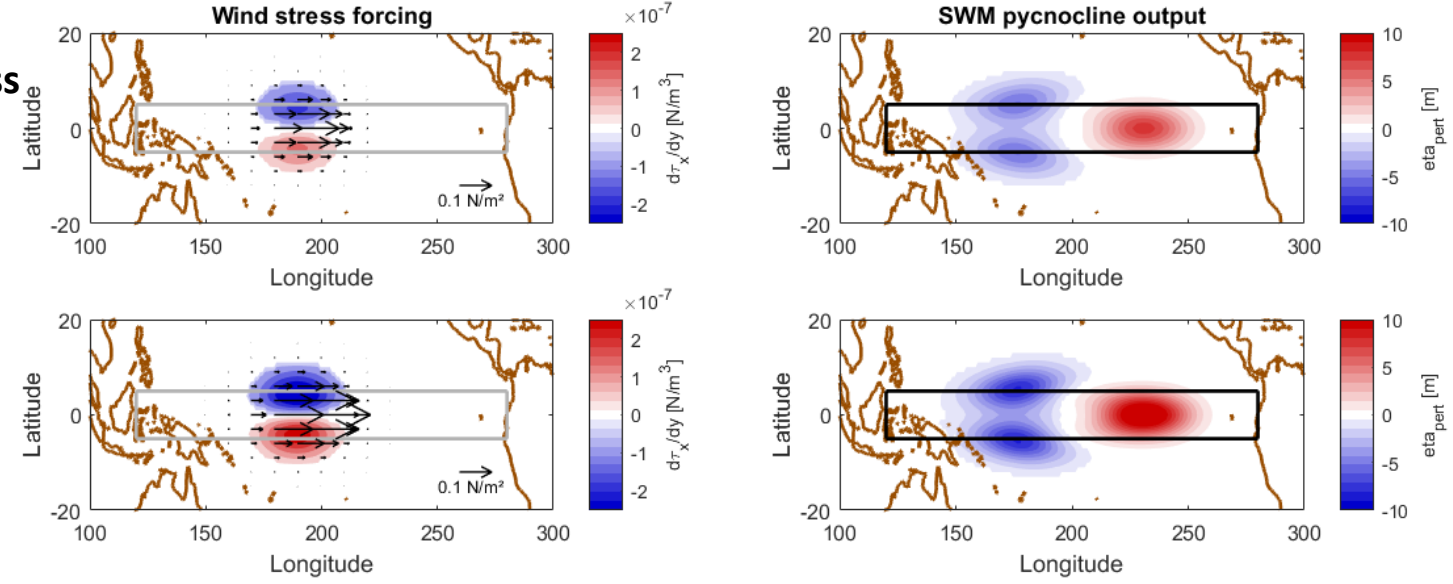
→ It is a good approximation: correlation between equatorial wind stress and Rossby wave signal ~0.75 (Izumo et al. 2018)

Instantaneous and adjusted WWV responses

- Throughout most literature: increase in instantaneous response → increase in adjusted response:

Wind stress curl

$$\frac{\partial \tau_x}{\partial y}$$



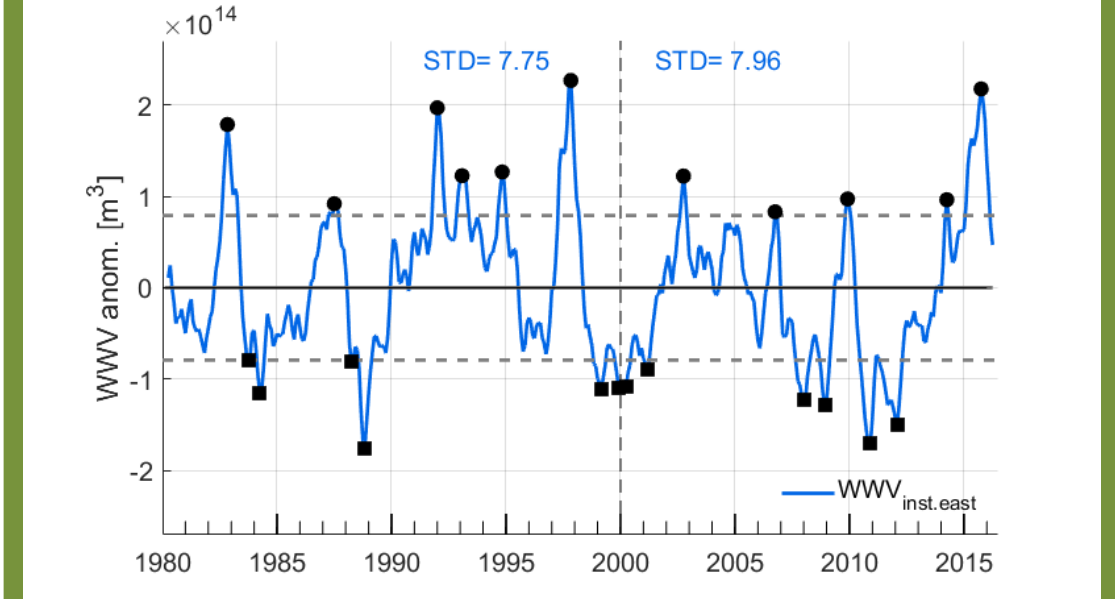
More correctly: Strength and sign of Rossby wave signal depends on the wind stress **curl**

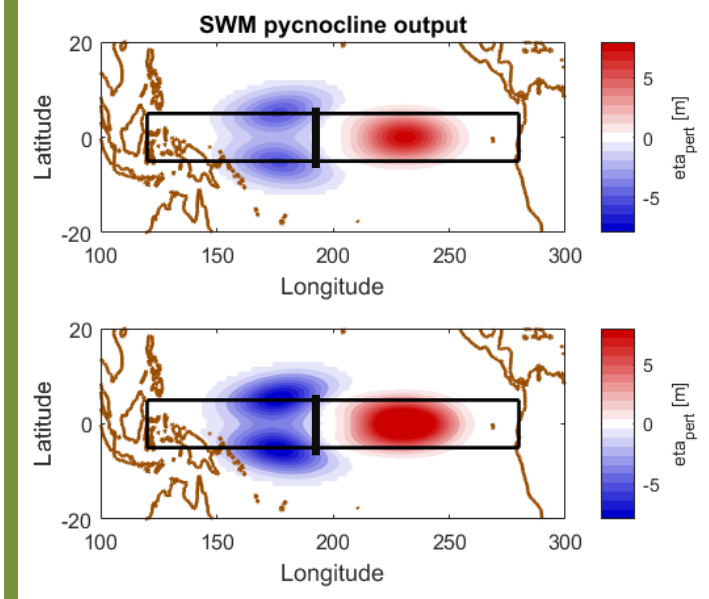
Research question

Are the strongest equatorial wind stresses always followed by strong adjusted contributions?

Identifying strongest equatorial winds

- Instantaneous contribution east of 200°E is chosen





Identifying strongest equatorial winds

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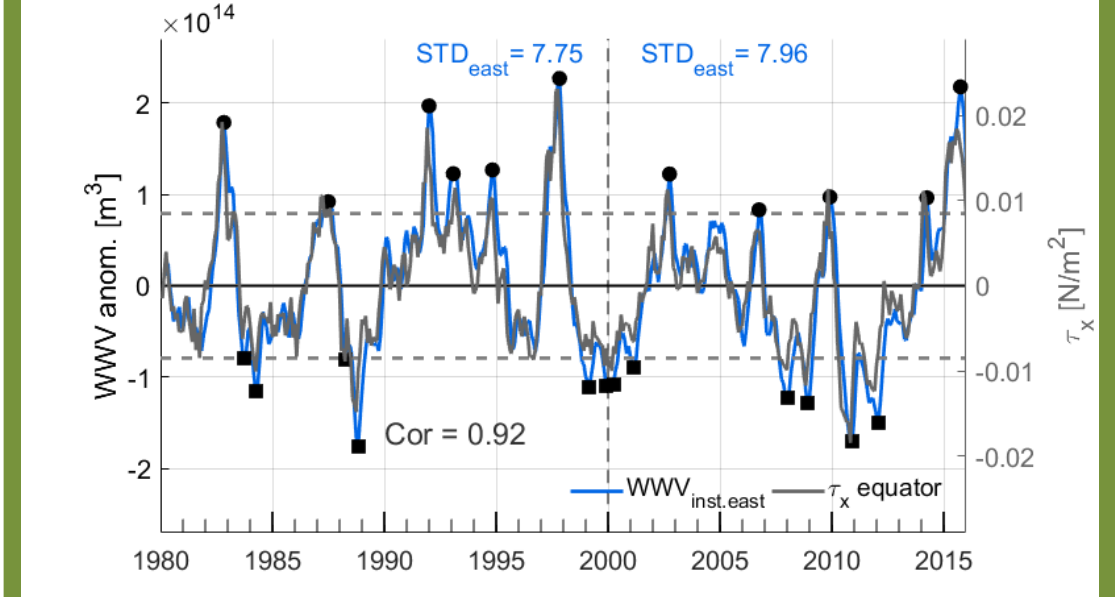
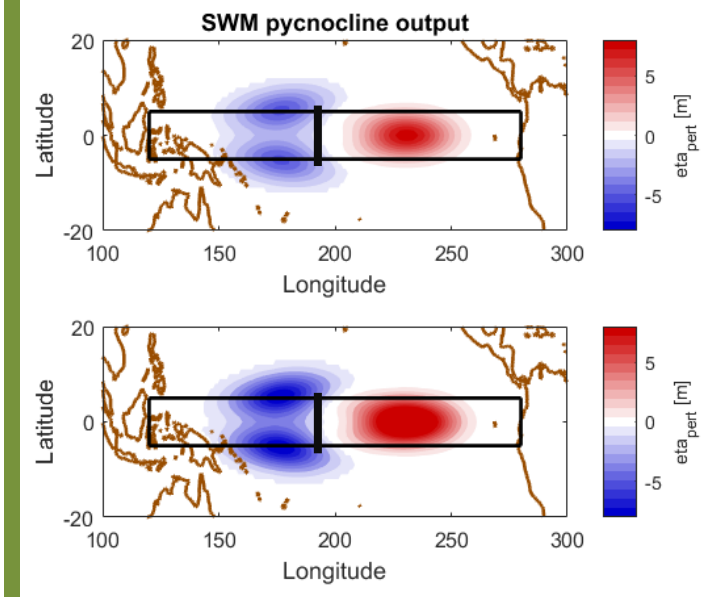
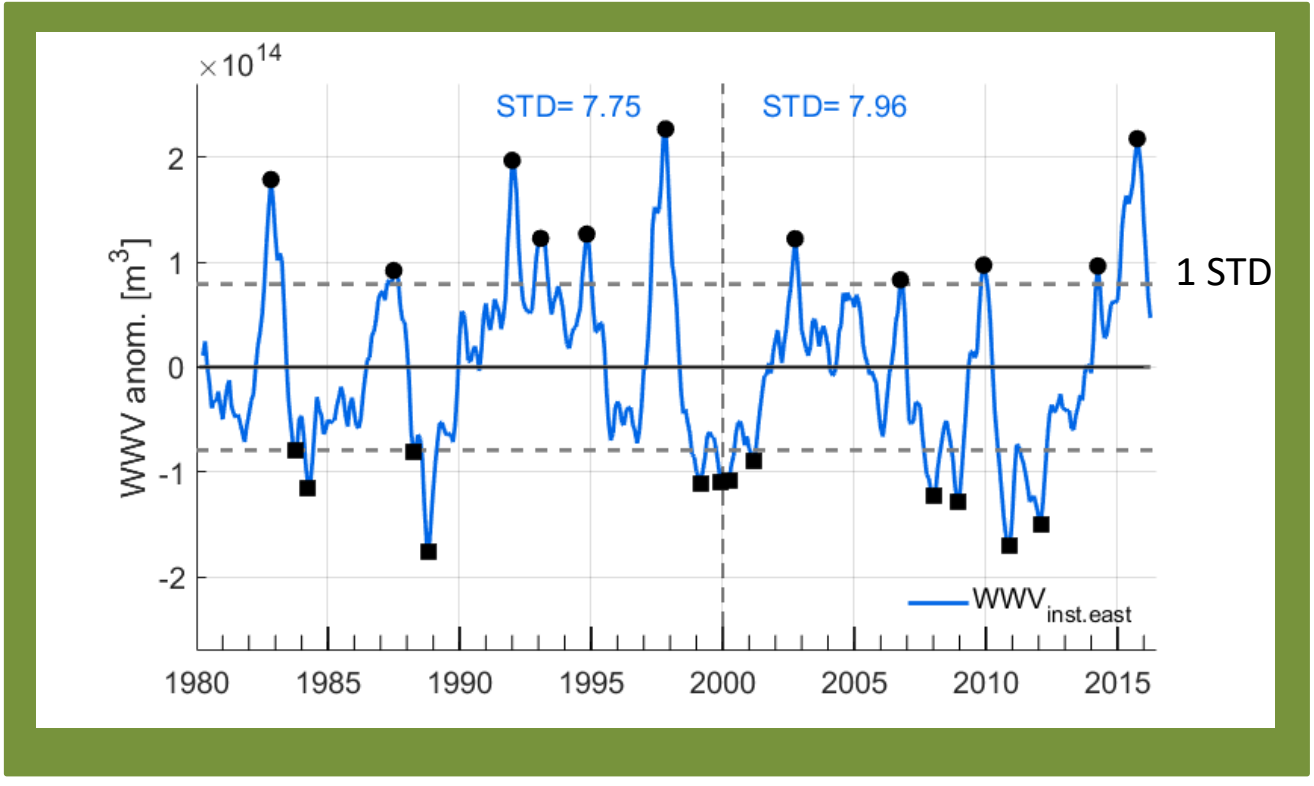




τ_x equator: wind stress averaged over WWV region

→ $WWV_{inst.east}$ due to strongest τ_{xeq}

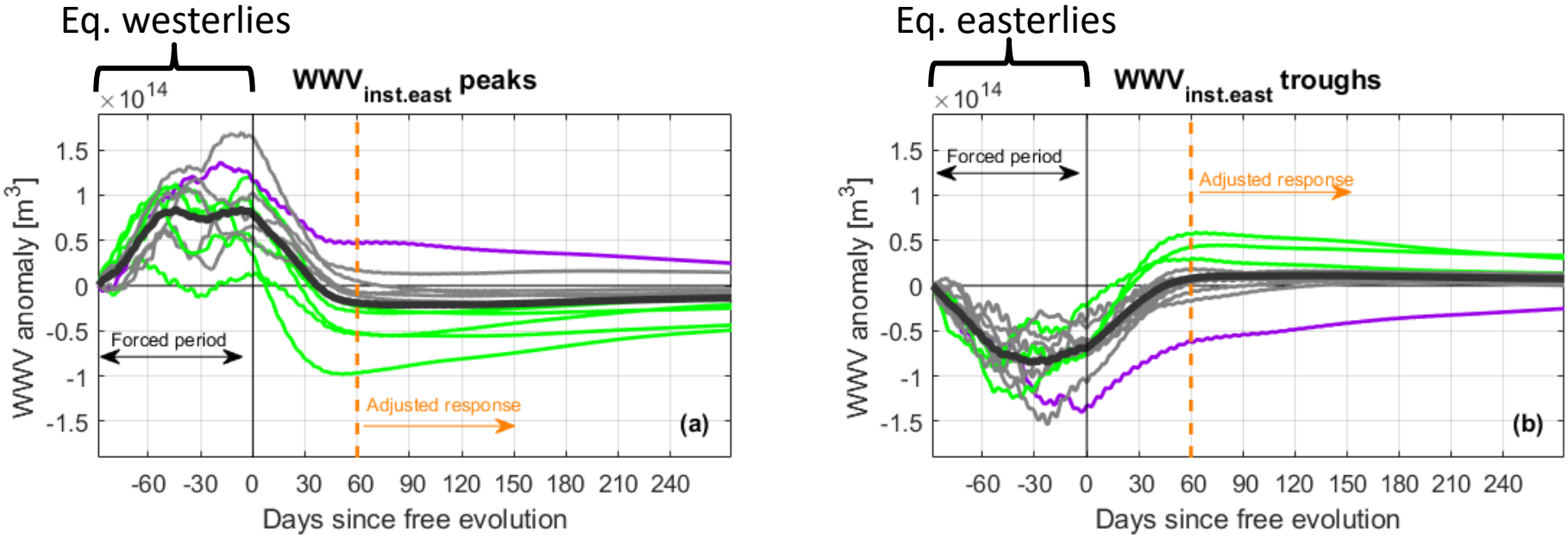
Modeling adj. responses to strongest equatorial winds



- 11 peaks
- 12 troughs

- Forcing the SWM with each 3-month forcing period of the $WWV_{inst.east}$ peaks and troughs → 23 model runs

Modeling adj. responses to strongest equatorial winds



- **Transitioning simulations**:

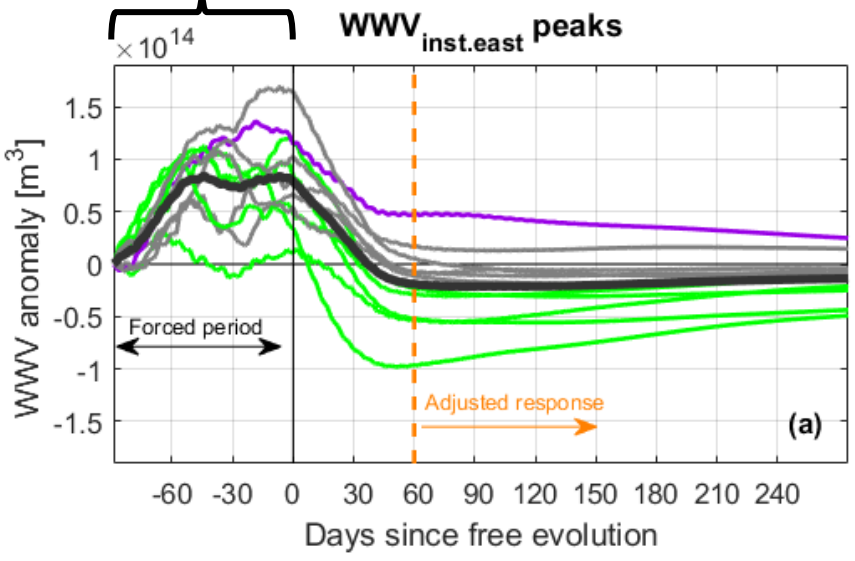
  → adjusted response of opposite sign (expected from theory)

- **Neutral simulations**:

  → no adjusted response (between 0.2 and -0.2 · 10^{14} m³)

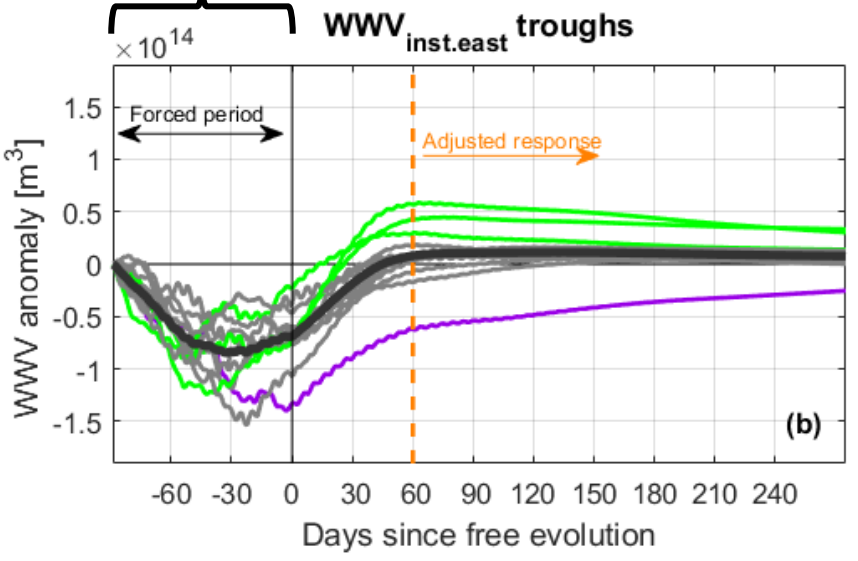
Modeling adj. responses to strongest equatorial winds

Eq. westerlies



5 out of 11…

Eq. easterlies

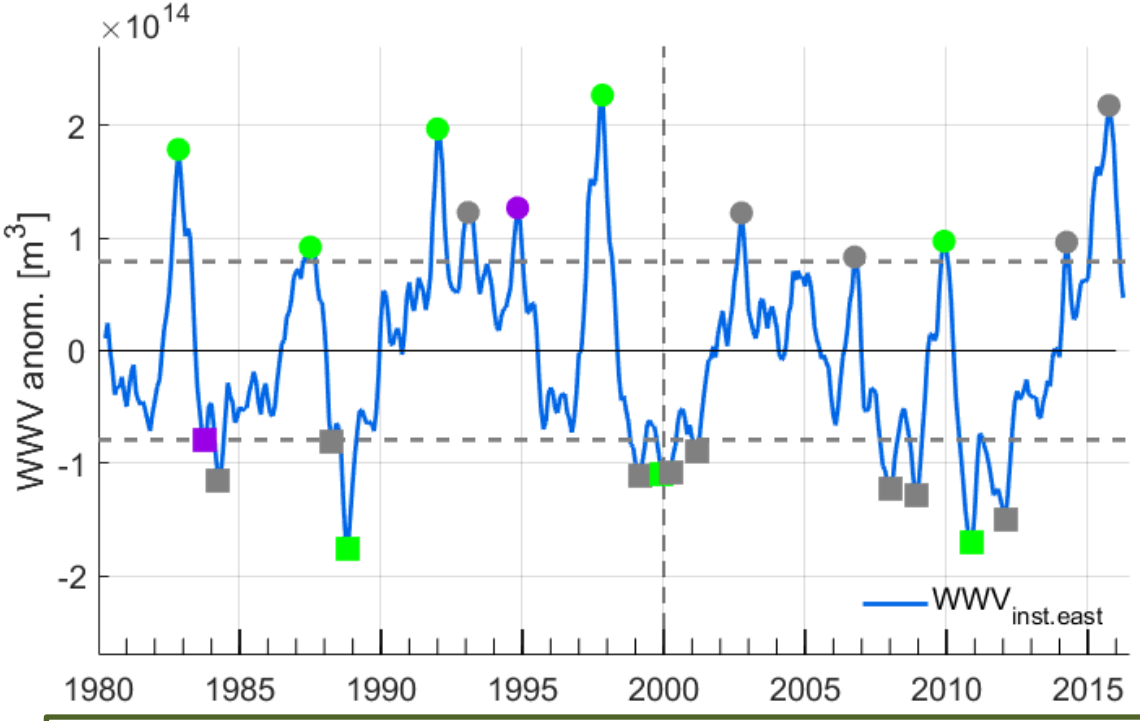


3 out of 12…

…simulations lead to a transitioning adjusted response (consistent with theory)

Modeling adj. responses to strongest equatorial winds

- Pre- to post- 2000 differences:



-Pre-2000: 6/12 simulations are transitioning

-Post-2000: 2/11 simulations are transitioning

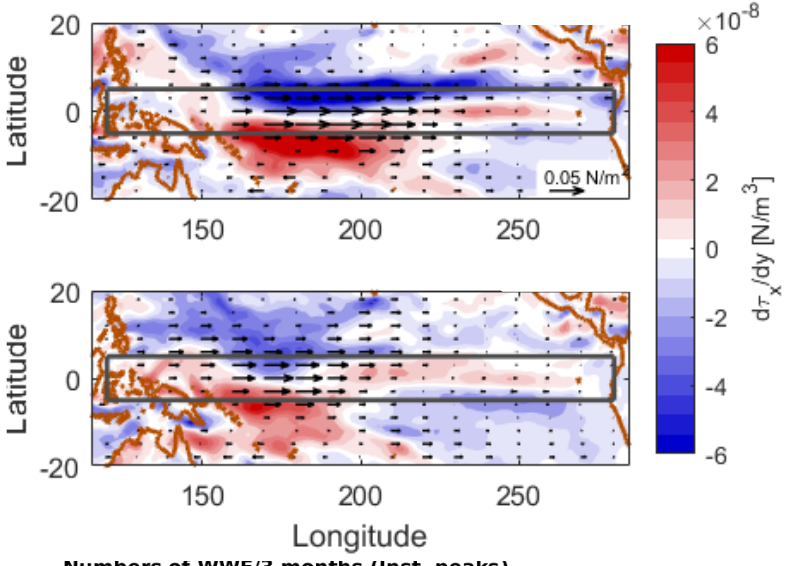
→ Consistent with post-2000 decrease in adjusted contribution (Neske and McGregor, 2018)

Modeling adj. responses to strongest equatorial winds

- Composite $WWV_{inst.east}$ peaks forcing

Transitioning adj. responses

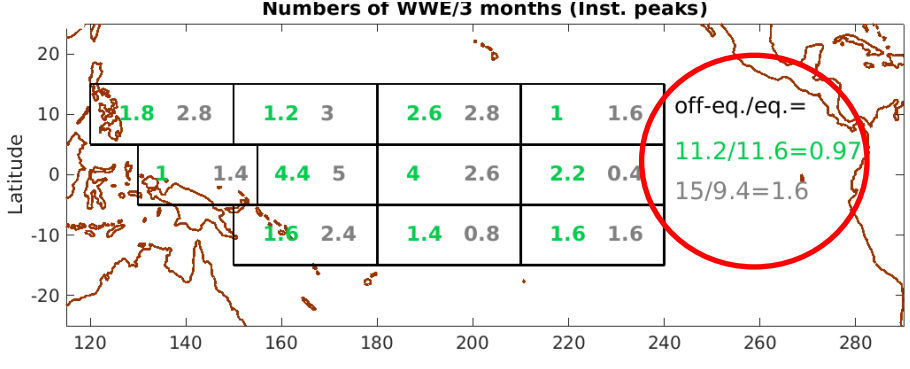
Neutral adj. responses

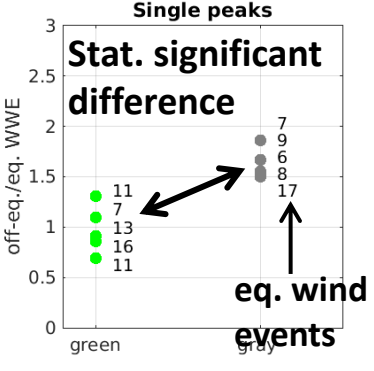


Neutral forcing:
meridionally broader τ_x

↓

weaker $\frac{\partial \tau_x}{\partial y}$ around WWV region





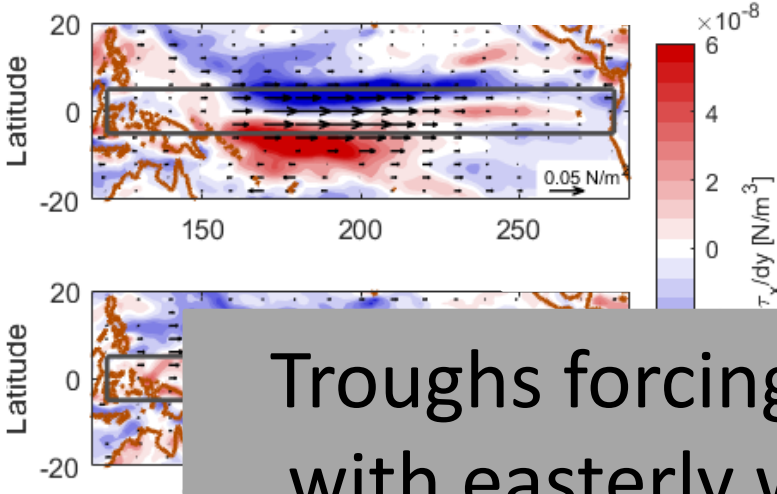
Westerly wind event (WWE):
>2 days with zonal wind stress anomaly averaged over a region exceeds 0.04 N/m²
(following Harrison and Vecchi, 1997)

Modeling adj. responses to strongest equatorial winds

- Composite $WWV_{inst.east}$ peaks forcing

Transitioning adj. responses

Neutral adj. responses

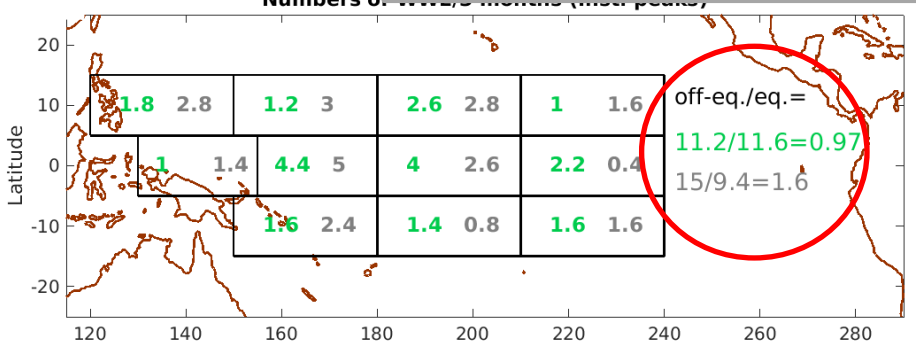


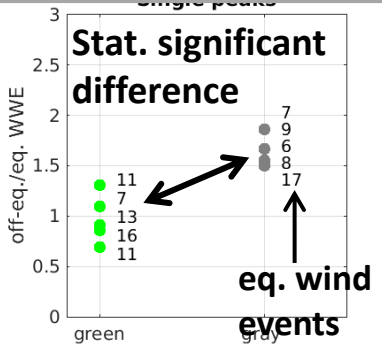
Neutral forcing:
meridionally broader τ_x

↓

round

Troughs forcing similar but with easterly wind events





Westerly wind event (WWE):
>2 days with zonal wind stress anomaly averaged over a region exceeds 0.04 N/m²
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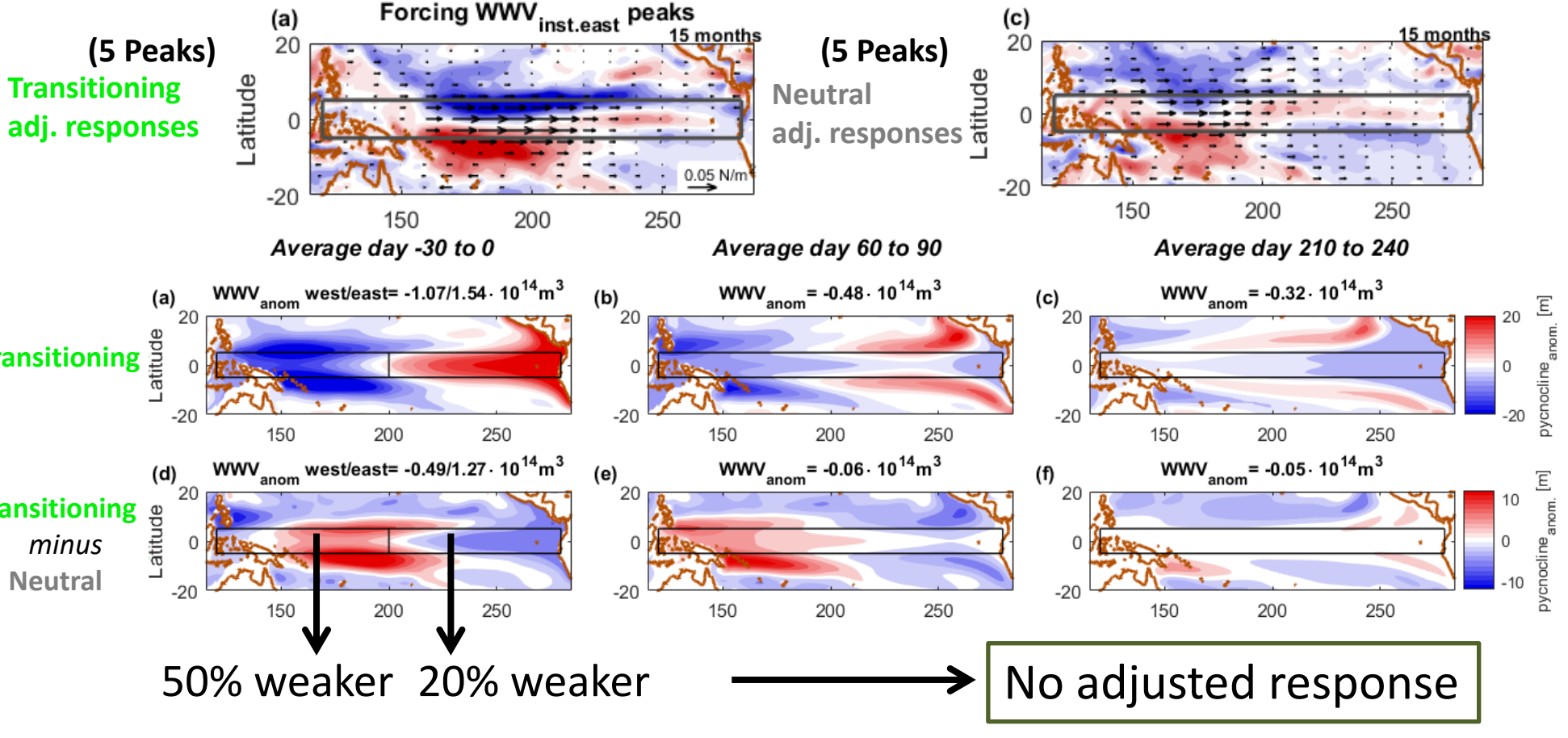
Modeling adj. responses to strongest equatorial winds

- Composite SWM output



Modeling adj. responses to strongest equatorial winds

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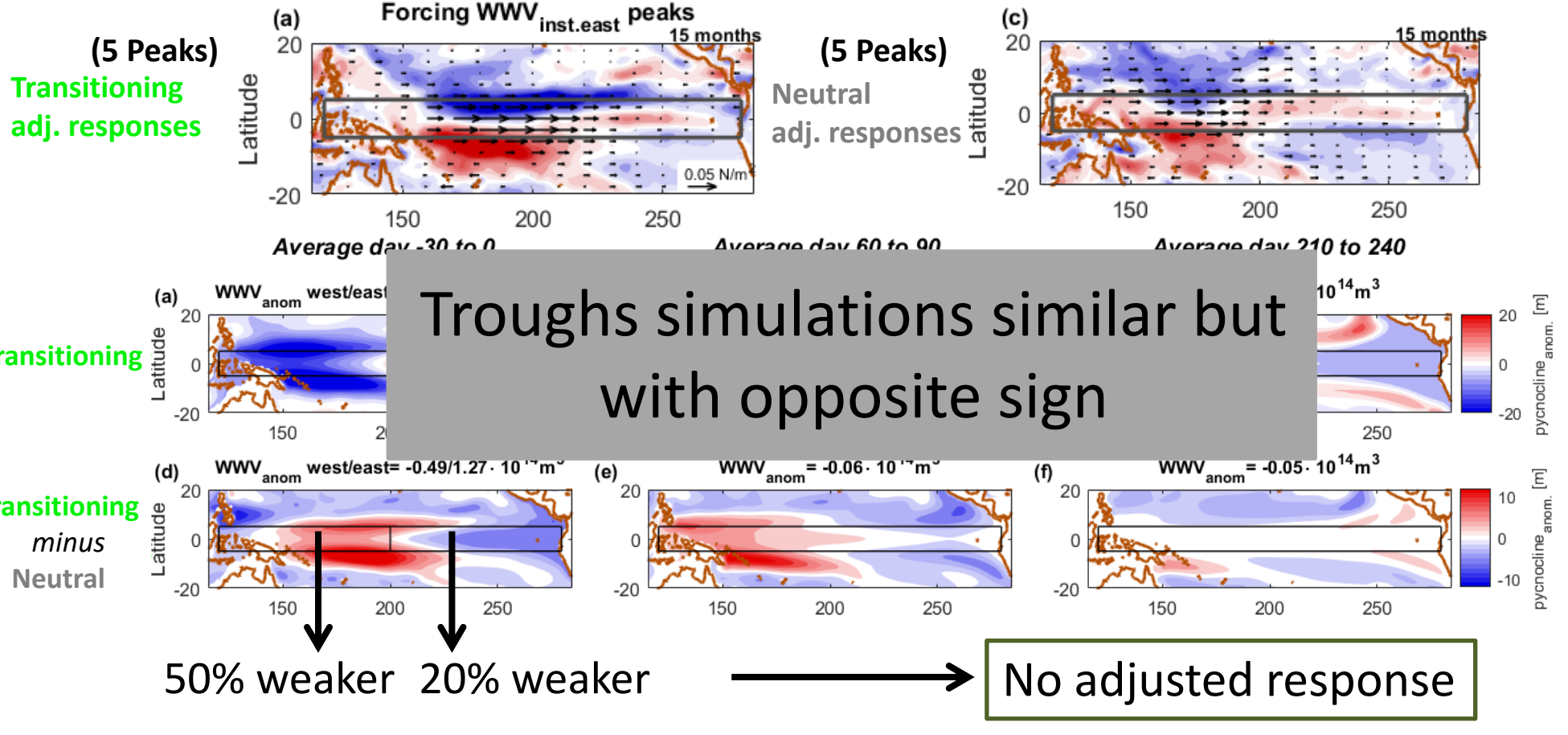
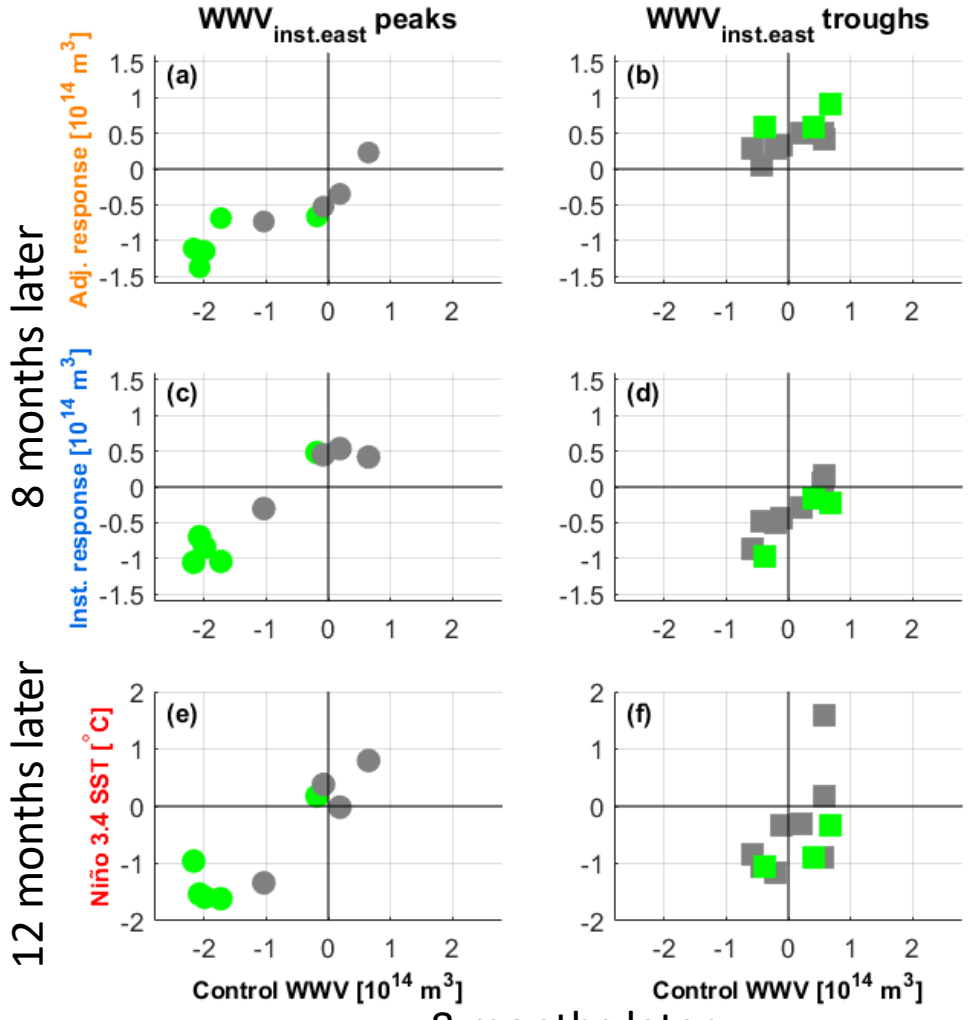


ENSO precursor?

ENSO precursor?



- 4/5 of **transitioning** adjusted responses have a clear negative control WWV 8 months later

→ La Niña conditions 12 months later

- No clear tendency for **neutral** simulations
- No clear tendency for **transitioning** troughs simulations

Conclusions

- 65% of the strongest equatorial winds lead to no adjusted response (neutral simulations) → at odds with traditional models describing ENSO as a self-sustained oscillation (e.g. Suarez and Schopf, 1988; Weisberg and Wang; 1997, Picaut et al., 1997; Jin, 1997)
- Neutral simulations dominate post-2000 period → consistent with post-2000 decline in adjusted WWV (Neske and McGregor 2018)
- **Considering the wind stress curl/co-exsitence of equatorial and off-equatorial winds is crucial for understanding details of ENSO dynamics** (consistent with McGregor et al. 2016)
- Adj. westerly discharges (trans. peaks) are twice as frequently than adj. easterly recharges (trans. troughs)
- Precursor skill is good for adj. westerly discharges (trans. peaks) but poor for adj. easterly recharges (trans. troughs)

  → explain why El Niños are more often followed by La Niñas than the other way around (e.g. Kessler 2002; Larkin and Harrison 2002)

- SWM results are consistent with GFDL-MOM025 simulations

Thank you!

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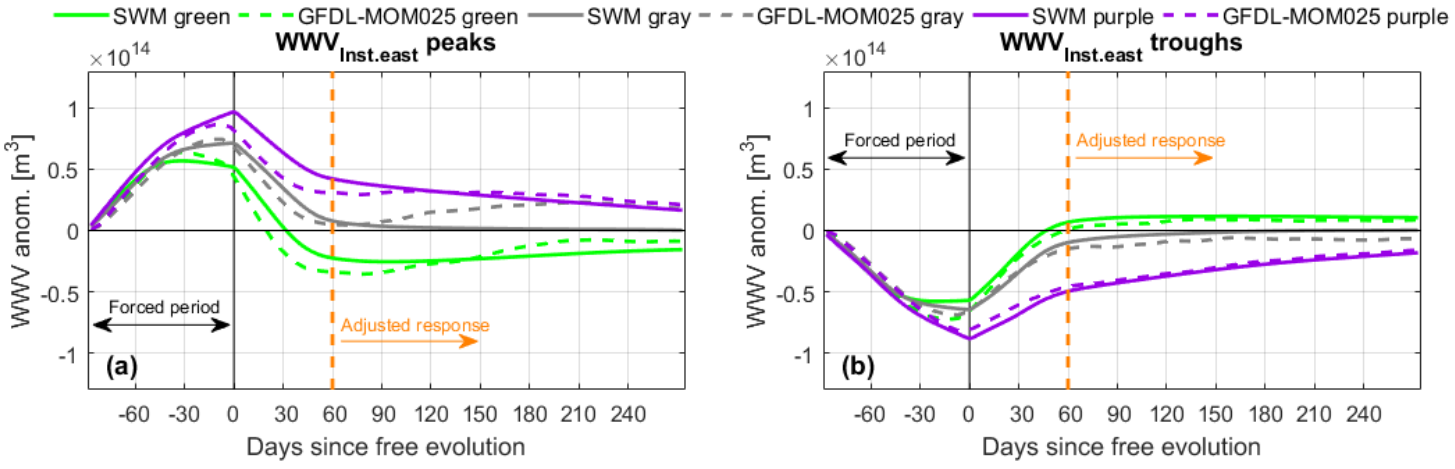
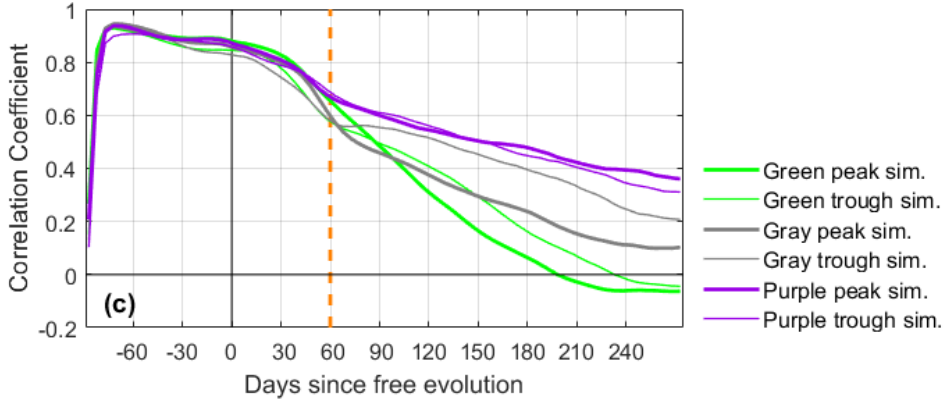
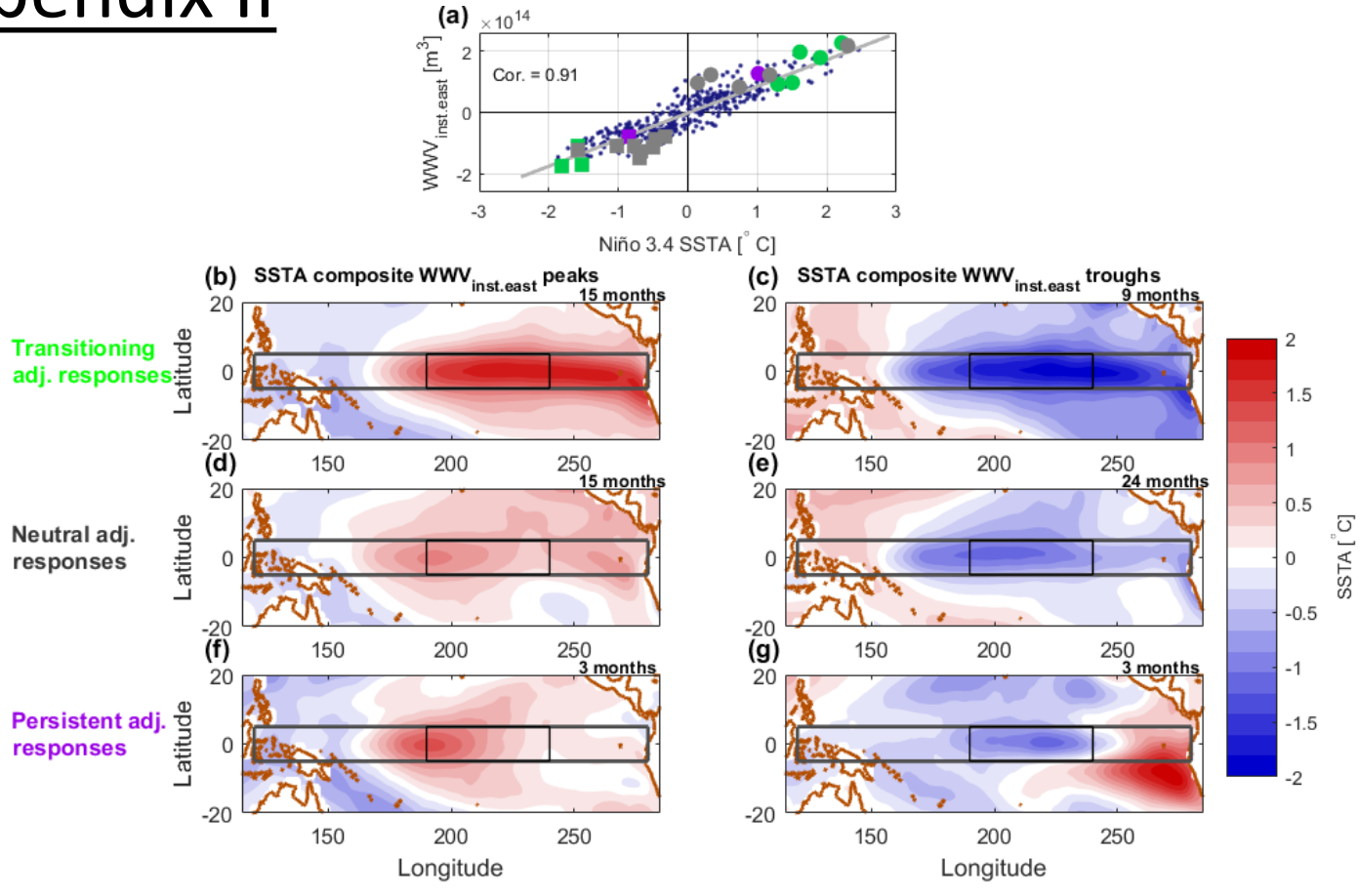
Appendix I


SWM green
GFDL-MOM025 green
SWM gray
GFDL-MOM025 gray
SWM purple
GFDL-MOM025 purple
WWV Inst.east peaks
WWV Inst.east troughs
×10^14
WWV anom. [m^3]
Forced period
Adjusted response
(a)
(b)
Days since free evolution


Correlation Coefficient
(c)
Days since free evolution
Green peak sim.
Green trough sim.
Gray peak sim.
Gray trough sim.
Purple peak sim.
Purple trough sim.

Appendix II


(a)
Cor. = 0.91
Niño 3.4 SSTA [° C]
(b) SSTA composite WWV inst.east peaks
15 months
(c) SSTA composite WWV inst.east troughs
9 months
Transitioning adj. responses
(d)
15 months
(e)
24 months
Neutral adj. responses
(f)
3 months
(g)
3 months
Persistent adj. responses
Latitude
Longitude
SSTA [° C]