ENSO-related energy budget perturbations in CMIP models

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1. Introduction

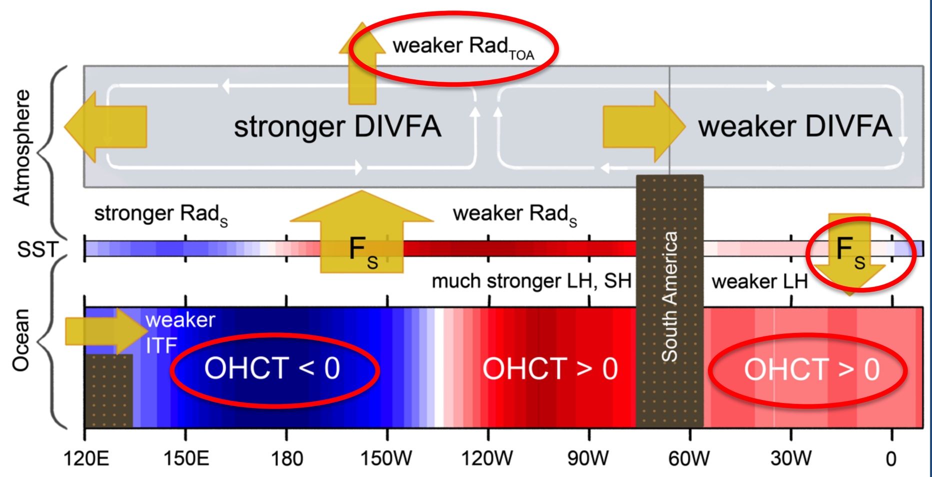
Mayer et al. (2014) found strong ENSO-related anomalous energy exchanges between Atlantic and Pacific, employing atmospheric and oceanic reanalyses (see schematic below). This behavior should be reproduced by state-of-the-art climate models. The variability of the vertically integrated tropical atmospheric and ocean energy budgets in association with ENSO is evaluated, employing historical (ca 1850-2005) runs from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and 3 (CMIP3) archive.
The energy budget equations for atmosphere and ocean read as follows:

$$F_S = -AET - DIVFA + RAD_{TOA},$$

$$F_S = OHCT + DIVFO,$$

where F_S is net surface energy flux, AET atmospheric energy tendency, DIVFA divergence of horizontal atmospheric energy transports, Rad_{TOA} net radiation at top-of-the-atmosphere, OHCT ocean heat content tendency, and DIVFO divergence of horizontal oceanic heat transport. Based on these basic equations, this study investigates the following basic aspects of ENSO-related energy exchanges in the coupled atmosphere-ocean energy budget:

- **Relationship of SST and OHC variability in the equatorial Pacific**
- **Rad_{TOA} variability in the tropical Pacific**
- **OHC dis-/recharge in the tropical Pacific**
- **Teleconnections to tropical Atlantic**

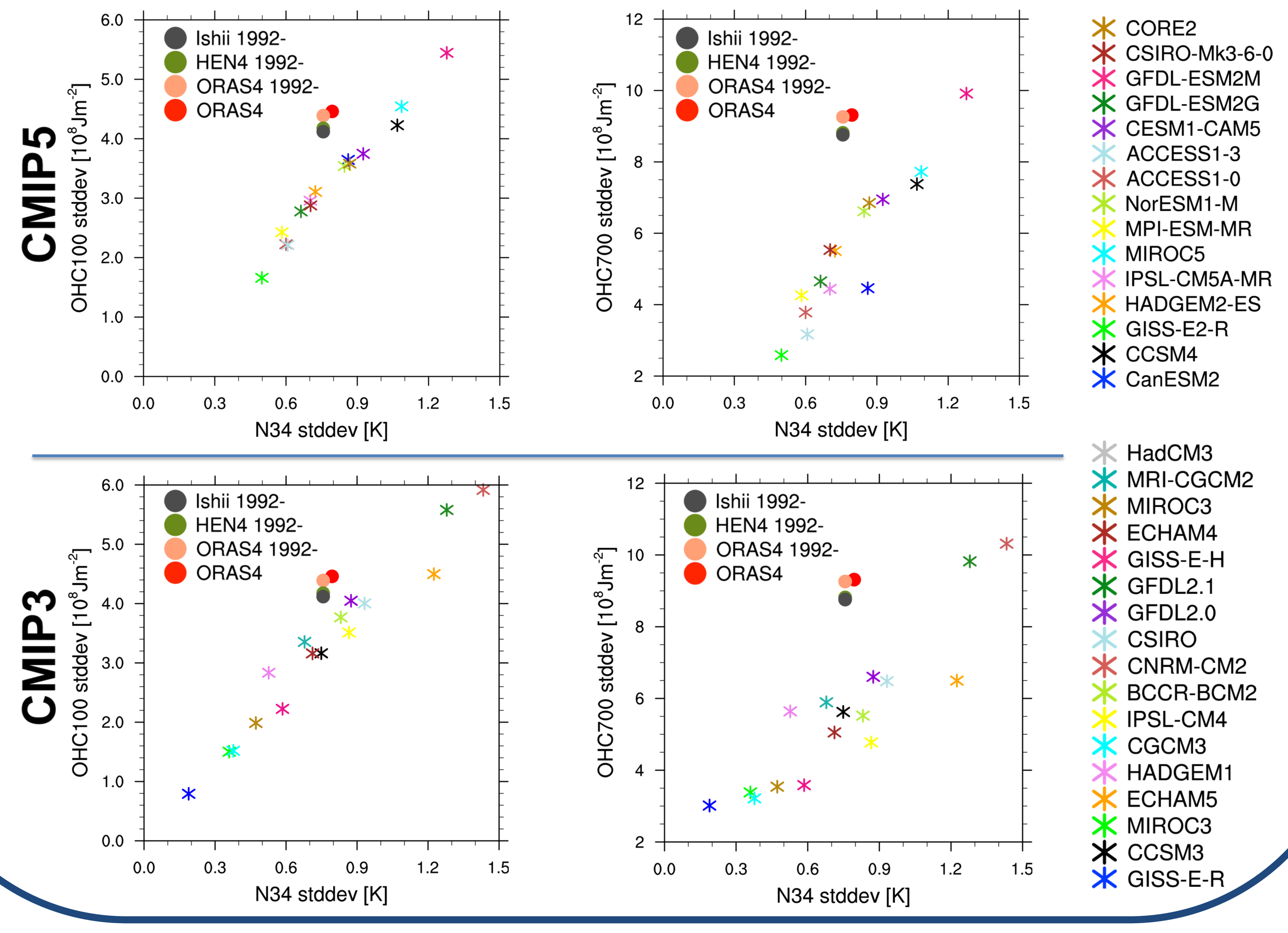


On the right: Schematic of anomalous energy flows during ENSO; processes studied here are marked

Employed Datasets:
- CMIP5 models: 14 historical coupled runs, 1 CORE2 run (CCSM4)
- CMIP3 models: 17 historical coupled runs
- Atmospheric reanalyses: European Re-Analysis Interim (ERA-I), Modern Era Retrospective-analysis for Research and Applications (MERRA)
- Ocean datasets: Ocean Reanalysis System 4 (ORAS4), Hadley EN4 (HEN4), ocean temperature data from Ishii et al (2009) (See end of poster for references)

2. Variability of SST and OHC

- Clear linear relationship between Nino 3.4 index (N34) and OHC standard deviations (averaged over N34 region) across all CMIP models
- All CMIP models exhibit too low OHC variability compared to their respective N34 variability
- No significant progress in OHC variability from CMIP3 to CMIP5
- The CORE2 run is aligned with coupled runs → correct wind forcing does not improve results!



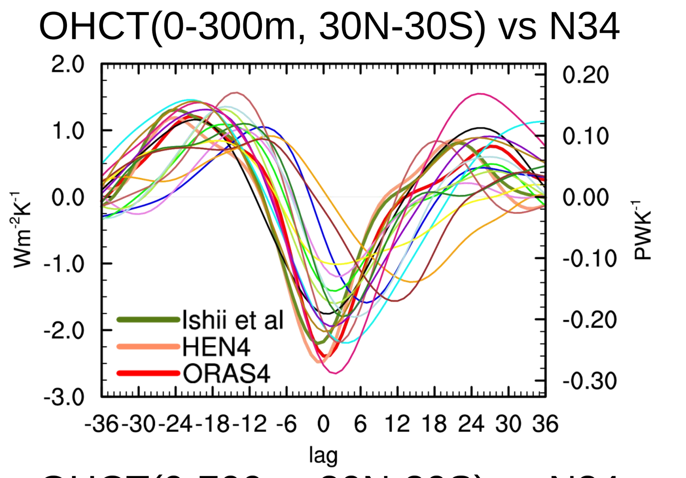
3. Energy budget in the tropical Pacific

3a) Tropical Pacific Ocean (30N-30S)

- Modeled response of OHCT (0-300m) too weak in most models and also out of phase in some models
- Modeled OHCT response (0-700m) vanishes in some models and is too weak in all considered models
- CORE2 run is generally closer to reanalyses than coupled runs

Full tropical Pacific 30N-30S

OHCT(0-300m, 30N-30S) vs N34

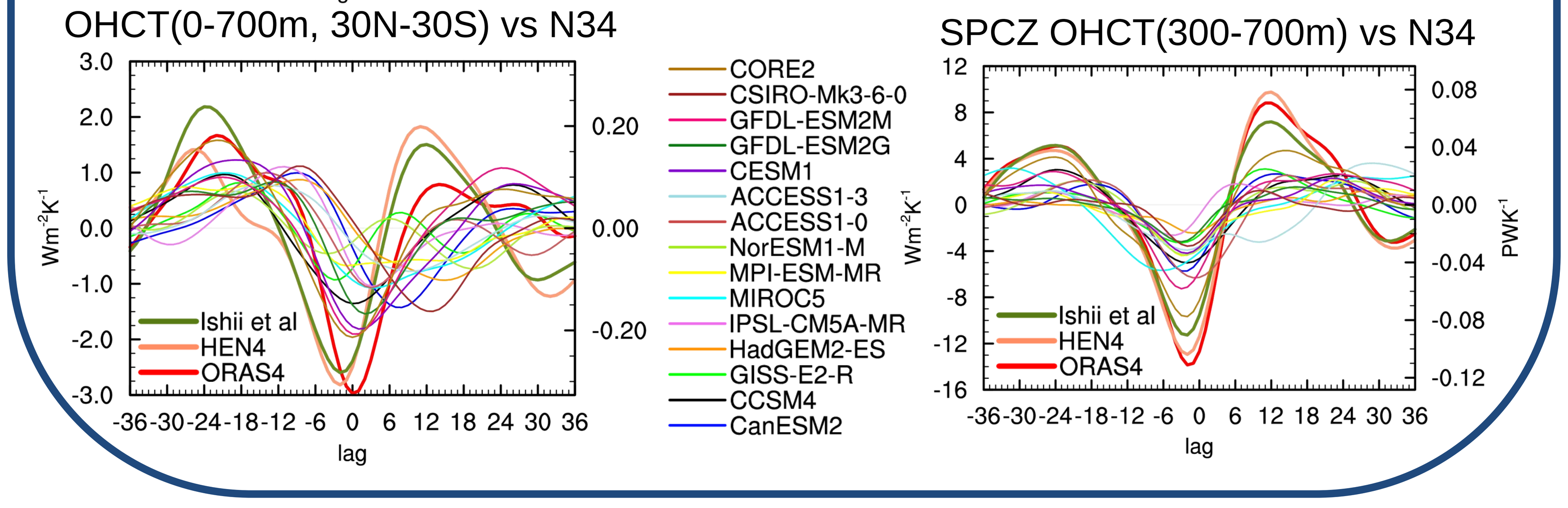


OHCT(0-700m, 30N-30S) vs N34

Focus on OHCT in SPCZ region

- Strong ENSO-related Ekman pumping
- OHCT variability in models too weak, especially in deeper layers
- Clear relationship between strength of wind stress curl (w_e) and OHCT response to ENSO
- This bias appears to be related to generally too weak Bjerkness feedback in the models

SPCZ OHCT(300-700m) vs N34



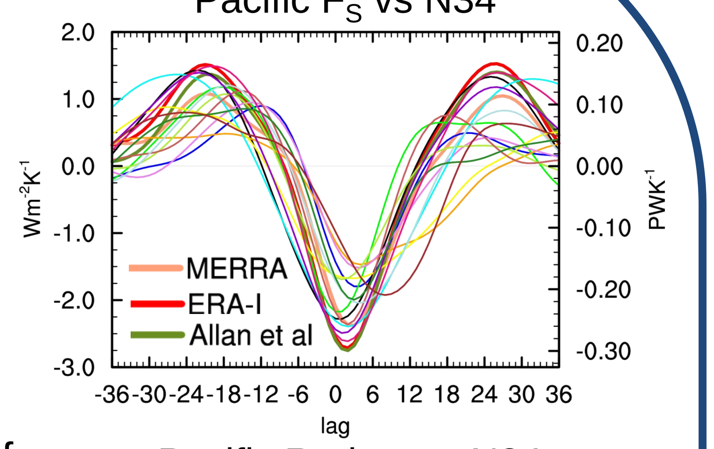
3b) Tropical Pacific: Atmosphere

- Modeled relation of Rad_{TOA} in the tropical Pacific to ENSO is very different from observations.
- Atmospheric transports are in reasonable agreement with reanalyses, as Rad_{TOA} errors mainly project on F_S

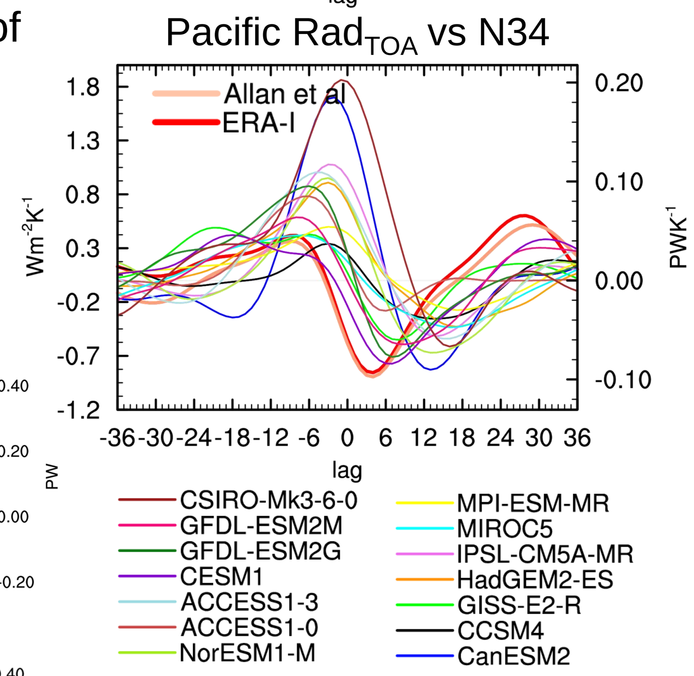
Focus on Rad_{TOA} in eastern equatorial Pacific (10N-10S, east of 155W)

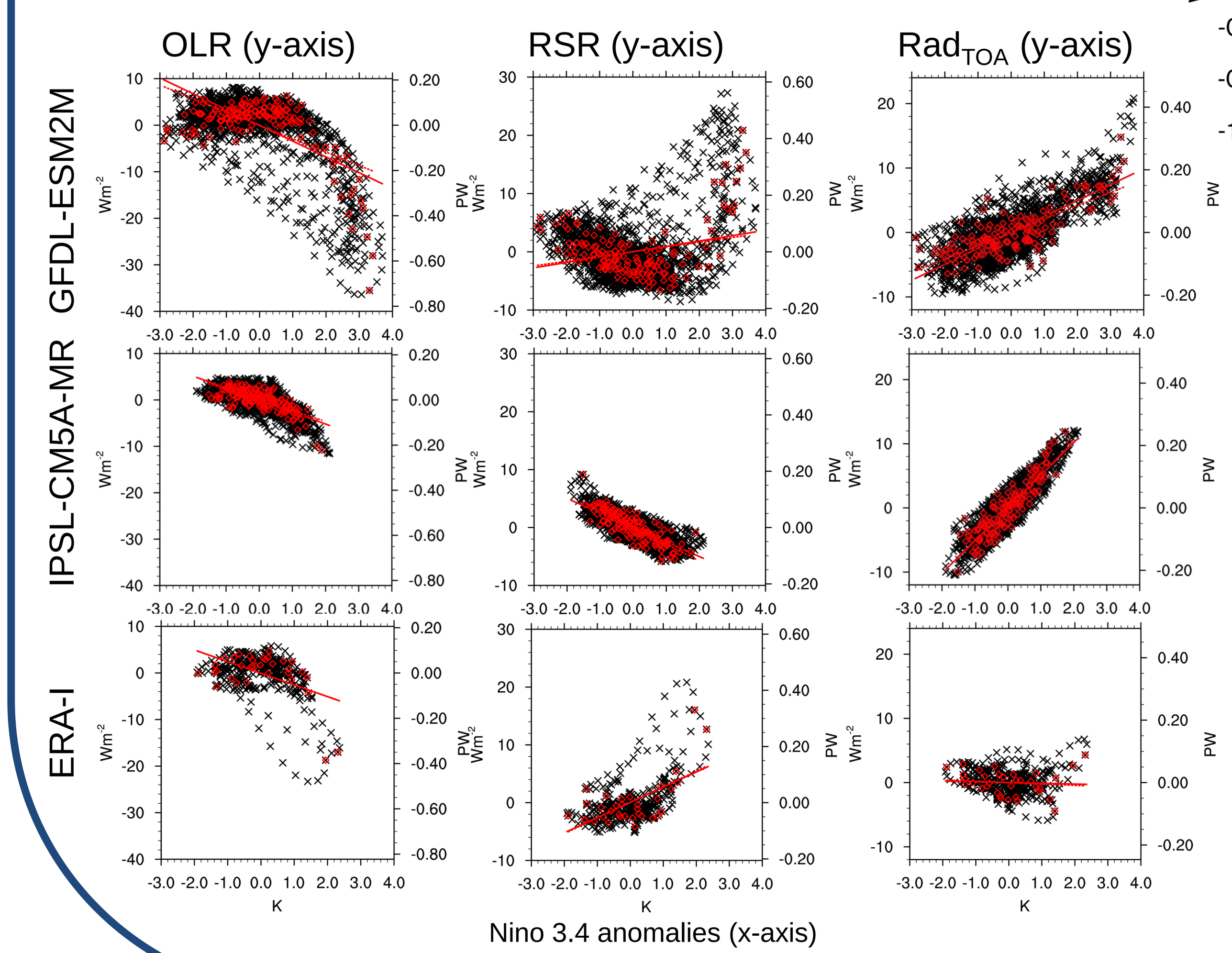
- Decomposition of Rad_{TOA} into SW and LW components reveals strong non-linearities of the radiative ENSO response.
- A strong dependence of the radiative response on the model mean convective activity is found.

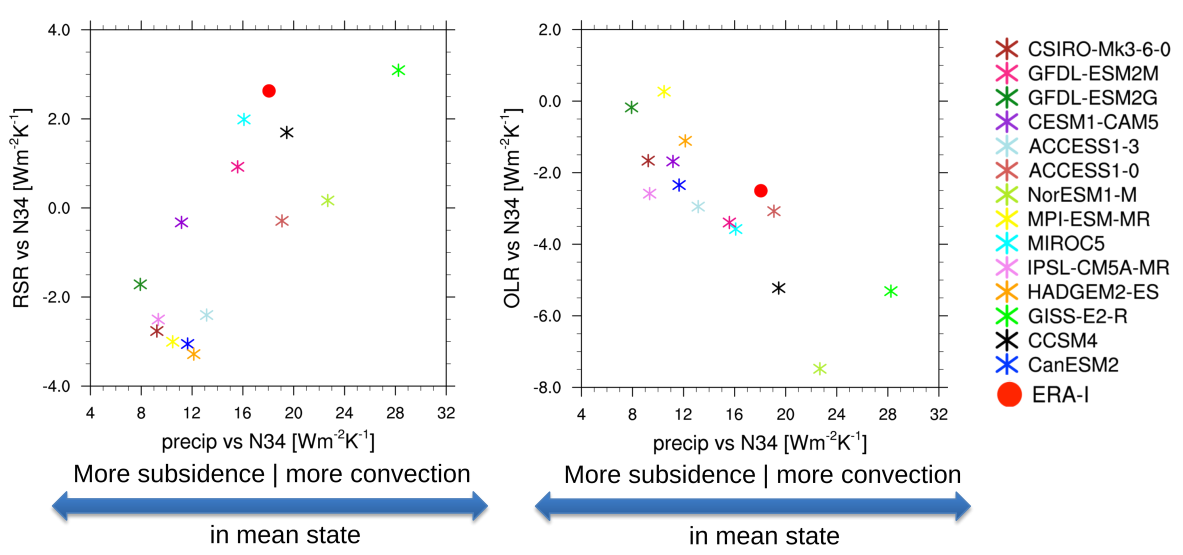
Pacific F_S vs N34



Pacific Rad_{TOA} vs N34







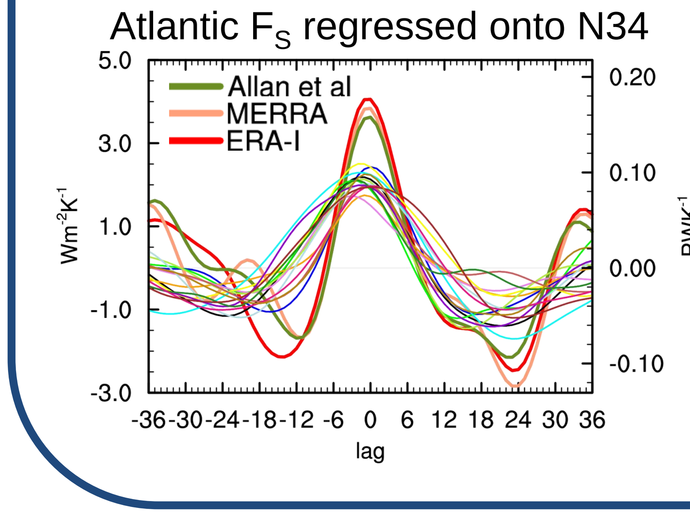
5. Conclusions

- OHC sensitivity to SST is too low – too weak Bjerkness feedback alone cannot explain this
- CMIP5 models show major biases in the simulation of energy budget variability in association with ENSO
- OHC dis-/re-charge in the tropical Pacific is too weak or even completely missing in the models – reasons are biased wind variability patterns, but also imperfect ocean models (e.g. CORE2)
- Pacific Rad_{TOA} response to ENSO is seriously biased in many models due to biased mean convective activity in equator region
- ENSO-related Pacific-Atlantic energy exchange is significantly underestimated by CMIP models

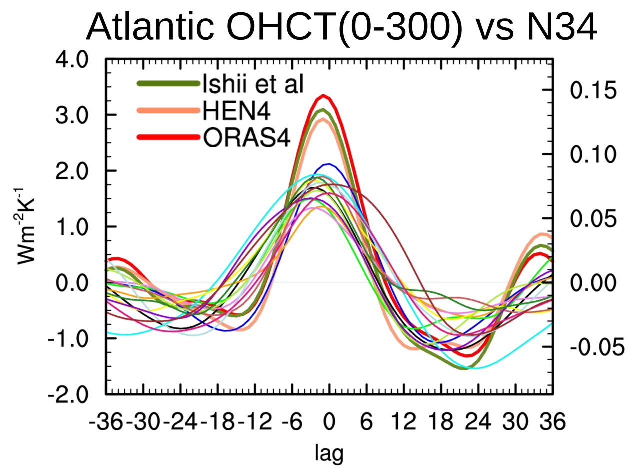
4. Teleconnections to tropical Atlantic (30N-30S)

- Strengthening/Weakening of F_S during El Niño (La Niña) clearly underestimated in all models
- OHC changes associated with ENSO are mainly governed by F_S (Mayer et al 2014) and consequently underestimated in all models

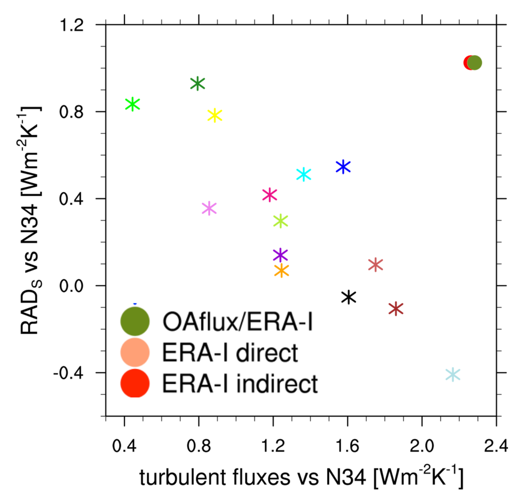
Atlantic F_S regressed onto N34



Atlantic OHCT(0-300) vs N34



- The well-known Atlantic trade wind variations associated with ENSO is missed by about 50% of the models (not shown), contributing to a too weak evaporation response



- Turbulent flux and net surface radiation (Rad_S) responses are inversely proportional and much too weak in the models (figure to the left), indicating biases in precip and cloud response to ENSO

Above: Regression of net surface radiation (Rad_S) onto N34 (y-axis) versus regression of turbulent fluxes (tropical Atlantic average) onto N34 (x-axis)

Acknowledgments
We acknowledge the CMIP3 and CMIP5 modeling groups and the ESG data distribution center.

References
Allan, R.P., et al 2014: *GRL*, **51**, 5588-5597.
Balmaseda, M.A., et al 2013: *QJRMS*, **139**, 1121-1161.
Dee, D., et al 2011: *QJRMS*, **137**, 553-597.
Good, S., et al 2013: *JGR: Oceans*, **118**, 6704-6716.
Ishii, M., and M. Kimoto, 2009: *J. Oceanogr.*,**65** ,287-299.
Mayer, M., et al 2014: *J. Climate*, **27**, 6393–6403.
Rienecker, M.M., et al 2011: *J. Climate*, **24**, 3624-3648.