Indian Ocean impact on ENSO evolution 2014-2016 in a set of seasonal forecasting experiments

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Background and Motivation

Mayer et al. 2018 findings:

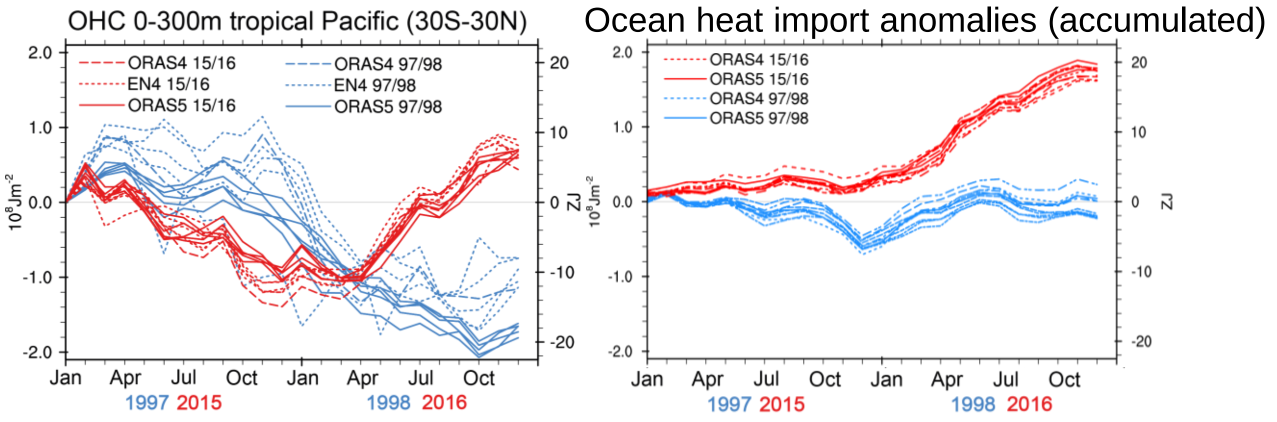
1. Tropical Pacific was warmer end of 2016 than before the 2015/16 El Nino – in stark contrast to cooling associated with earlier El Ninos

2. Weak Indonesian Throughflow (ITF) was a main contributor to this anomalous behaviour:

3. This anomalous behaviour was attributed to the high Indian Ocean sea level anomaly, associated with accumulation of ocean heat content.

See also: *Mayer, Michael, Magdalena Alonso Balmaseda, and Leopold Haimberger 2018: "Unprecedented 2015/16 Indo-Pacific heat transfer speeds up Tropical Pacific heat recharge." GRL, 45(7), 3274-3284*

1)



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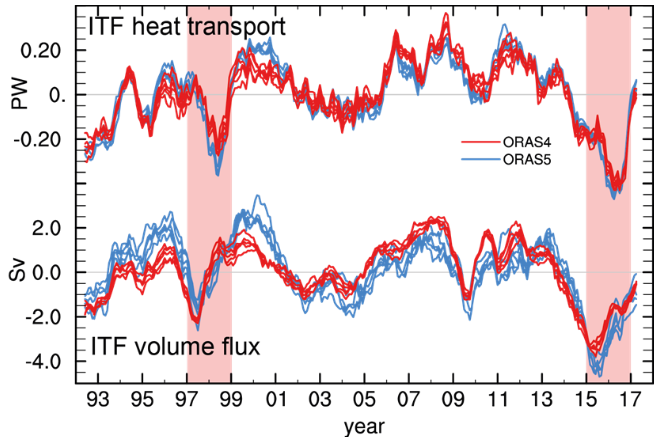

ORAS4 and ORAS5 are ECMWF's ocean analysis systems
EN4 is an objective ocean analysis by the UK MetOffice

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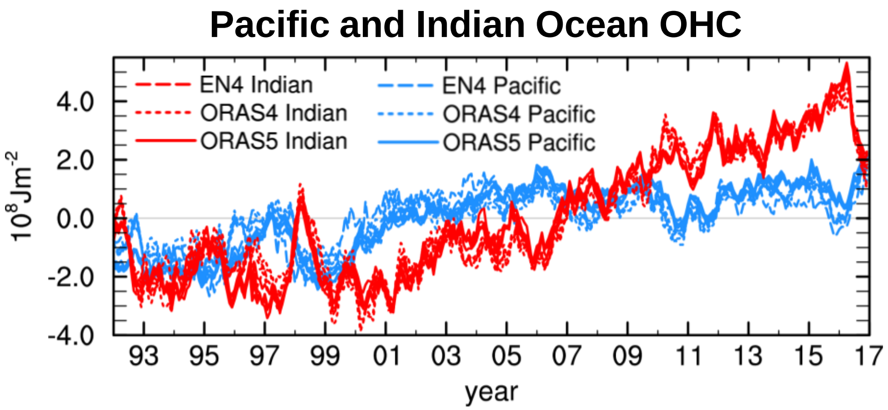

Follow up questions addressed in this presentation

- How much did the state of the Indian Ocean contribute to the 2014-16 ENSO evolution?
- What was the role of the atmospheric versus the oceanic bridge?
- How strong is the relationship between changes in tropical Pacific OHC and ENSO?

- Methodology: 24-month seasonal forecast experiments with altered ocean initial conditions.

Experiments

- 2-year-long SEAS5*-like experiments, 50 members each
- **Batch_14: Feb 2014 start date**
- 1) **REF_14**: ICs as in SEAS5 for Feb 2014
- 2) **IndO_97**: as ref14, but Indian Ocean ICs taken from Feb 1997
- 3) **AllO_97**: all ocean ICs taken from Feb 1997
- 4) **IndO_97sfc**: as ref14, but Indian Ocean ICs in upper 50m taken from Feb 1997
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- 1) **REF_97**: ICs as in SEAS5
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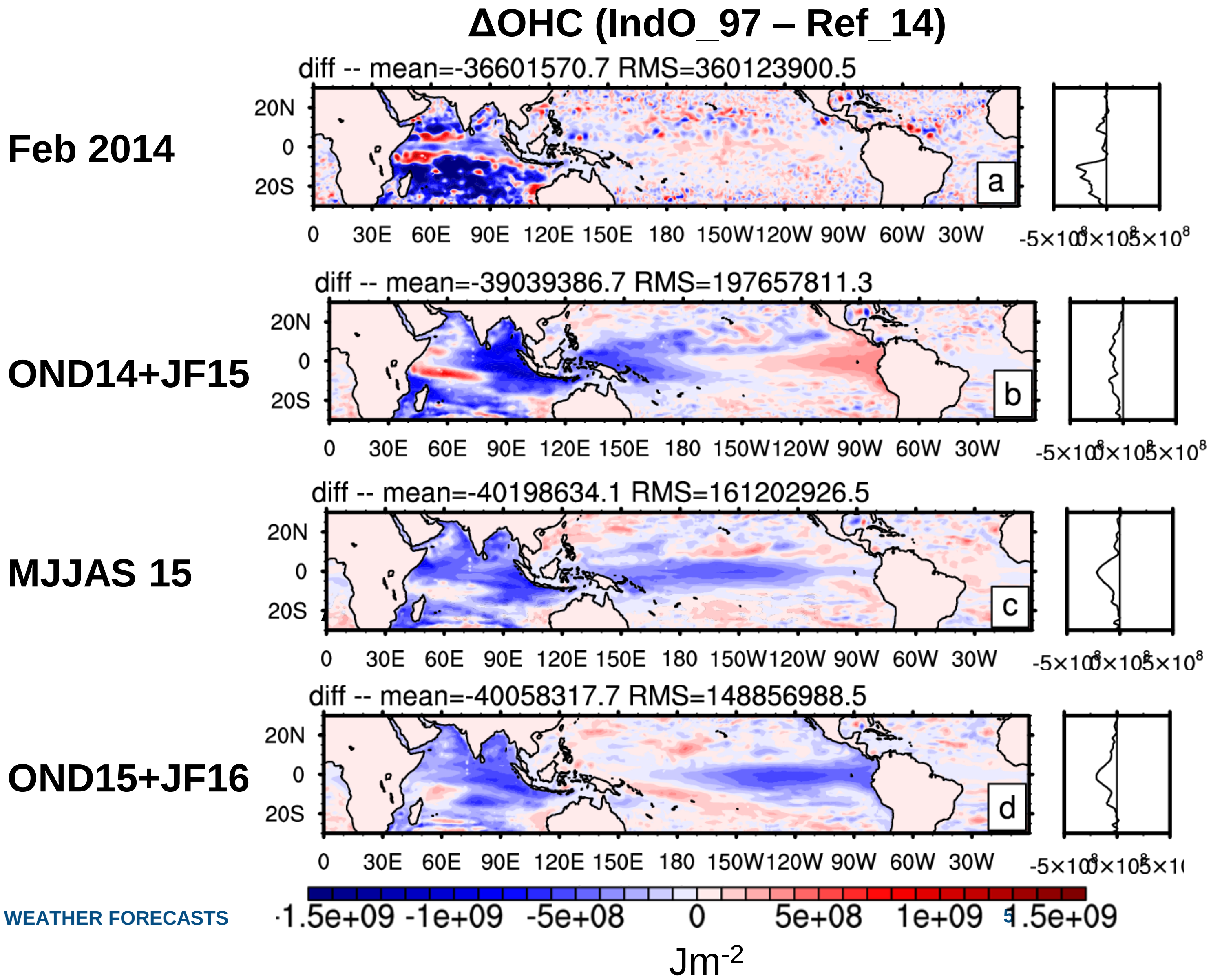
- 3) **AllO_14**: ocean ICs as in SEAS5 for Feb 2014

**SEAS5 is the seasonal forecasting system currently operational at ECMWF; see Johnson, Stephanie J., et al. "SEAS5: the new ECMWF seasonal forecast system." Geoscientific Model Development 12.3 (2019).*

Impact of Indian Ocean Initial Conditions:

Ocean Heat Content Differences (ΔOHC) IndO_97 minus REF_14 at different forecast lead times

- Initial negative difference in the Indian Ocean (1997 is colder than 2014)
- Negative differences from the Indian Ocean spread eastward with time, penetrating the Pacific
- Towards the end of the forecasts, there is sizeable cooling of the tropical Pacific in IndO_97 compared to REF_14

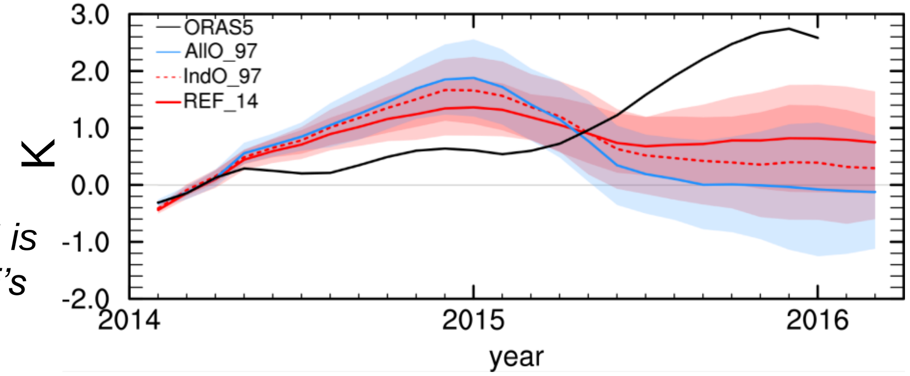


Perturbing the Indian Ocean – impact on Nino 3.4 and Pacific heat budget

- **IndO_97** has stronger ENSO variability and substantial Pacific ocean heat loss relative to **REF_14**

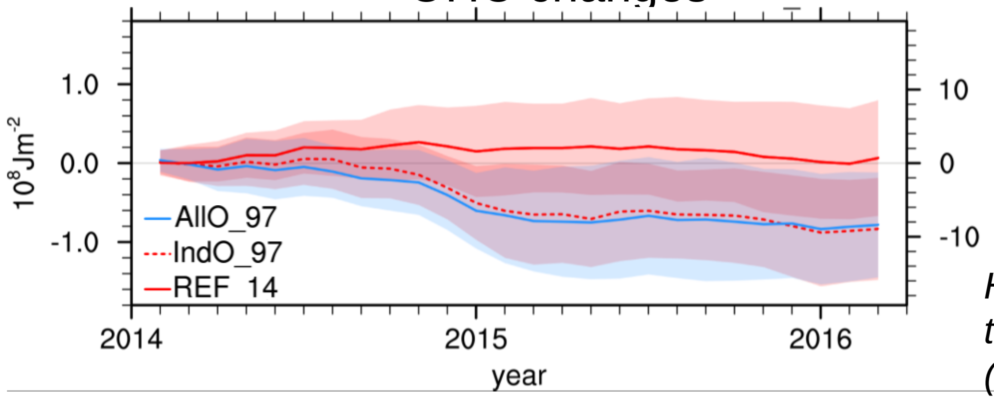
- Interesting note: **REF_14** produces warm conditions in year 1**,** but no cooling in year 2. So the forecast with 2014 Indian Ocean is confident about non-occurrence of a La Nina event in year 2 (2015/16)

Nino 3.4



**ORAS5 is ECMWF's ocean analysis system*

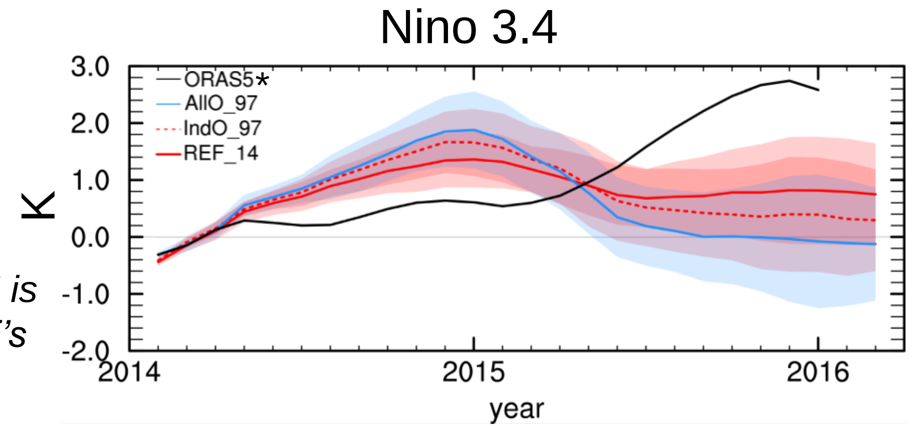
OHC changes



Heat budget terms are tropical (30N-30S) Pacific area-averages

Perturbing the Indian Ocean – impact on Nino 3.4 and Pacific heat budget

- **IndO_97** has stronger ENSO variability and substantial Pacific ocean heat loss relative to **REF_14**
- OHC evolution in **IndO_97** is similar to **AllO_97**. What explains the differences in OHC evolution?
- 2-yearly surface heat loss similar for all experiments, but ocean heat convergence is quite different and can explain different OHC trajectories



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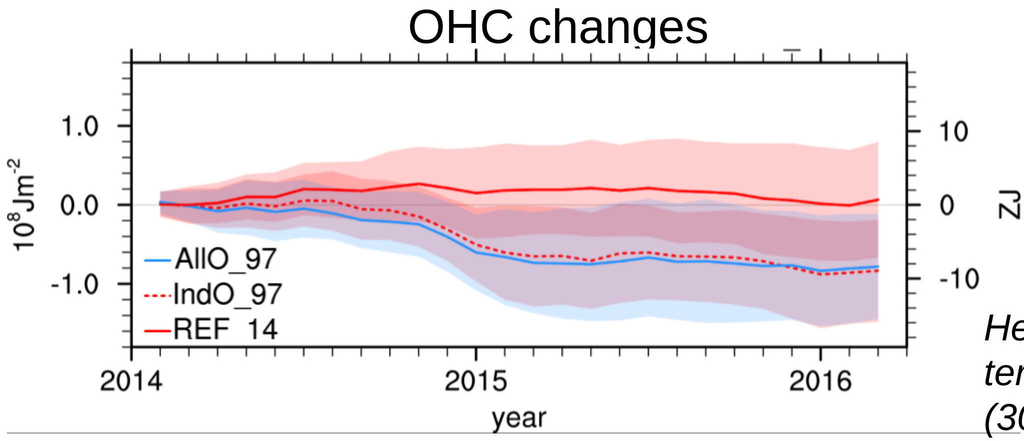

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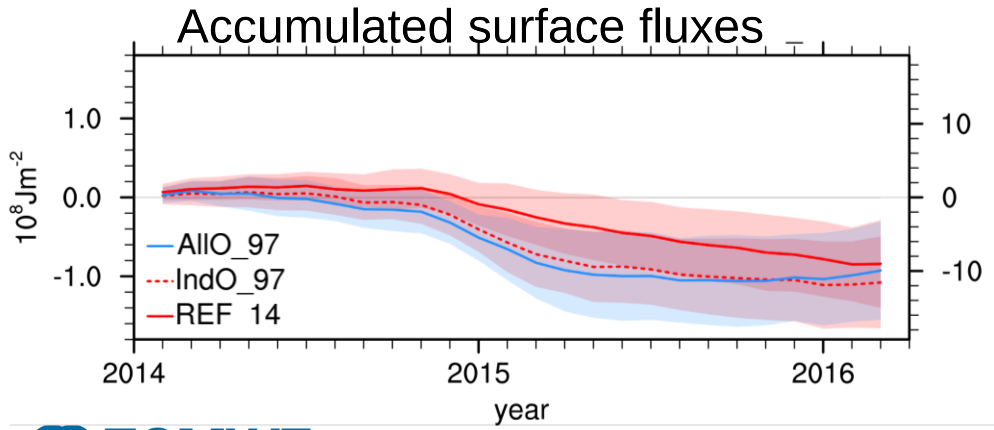
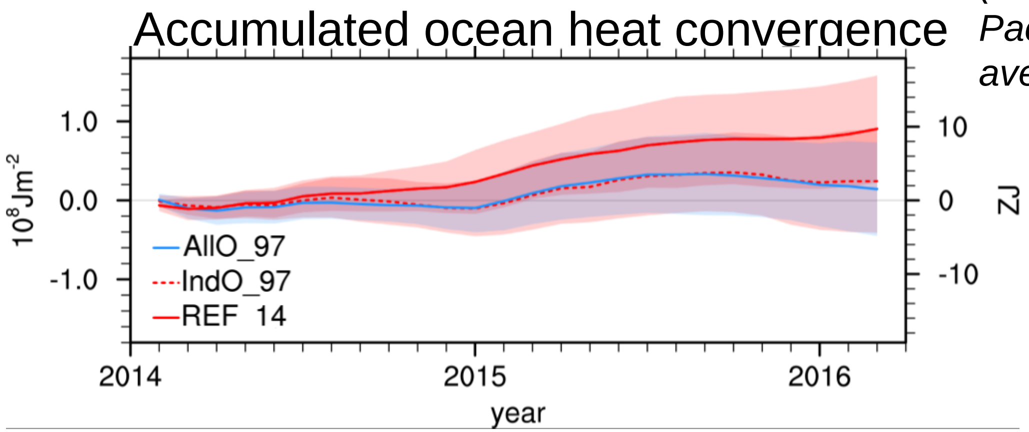




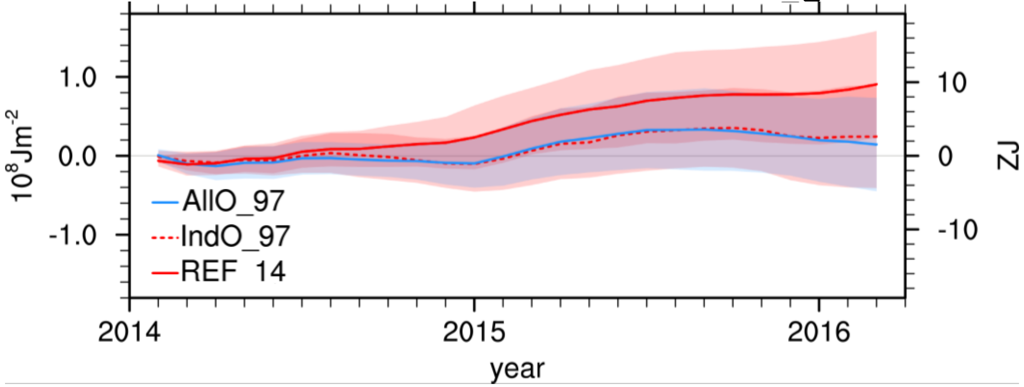
Perturbing the Indian Ocean – impact on Pacific heat budget

- What drives changes in ocean heat convergence?

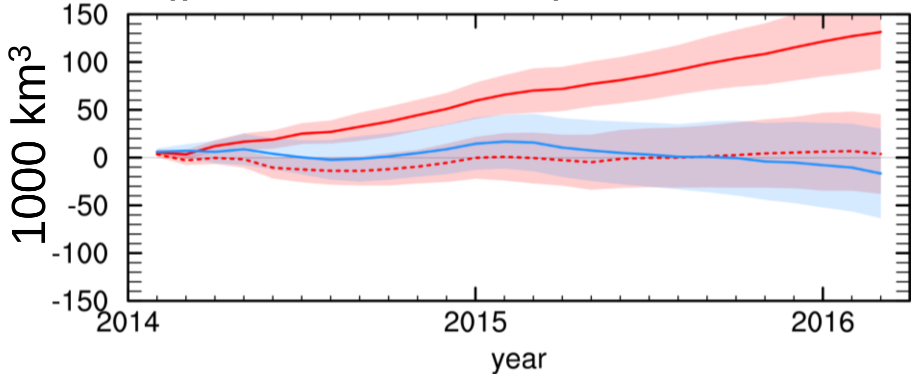
- **REF_14** has a much reduced ITF volume flux compared to IndO_97 (on average by 2.3Sv) → This confirms the hypothesis that it was the warm Indian Ocean that forced the strong reduction of the ITF transports observed in 2015-16

- ITF exports warm West Pacific water to the Indian Ocean → A reduction of ITF transports means weaker heat export and thus anomalous warming of the tropical Pacific. This can be seen in the OHC loss of **IndO_97** relative to **REF_14** (see slide before)

Accumulated ocean heat convergence

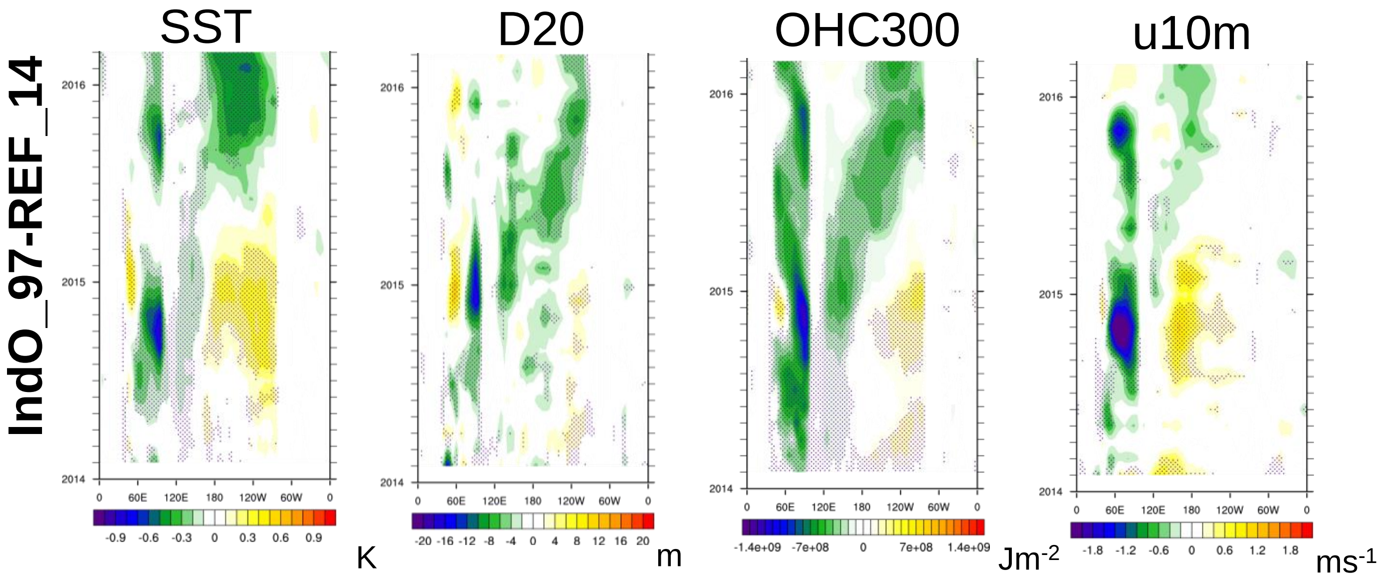


Accumulated ITF volume flux (positive eastward)



Spatial evolution differences

- The longitude-time hovmoeller diagrams below show differences between **IndO_97** and **REF_14** along the equator
- We see more westerly winds in Western Pacific during lead month 1-2 → This triggers positive SST differences in the Pacific
- In year 1, IndO_97 develops a positive Indian Ocean Dipole (IOD) event and warmer Pacific SSTs than **REF_14**. The IOD triggers eastward-propagating subsurface signals
- A negative OHC anomaly propagates eastward from end of year 1 onward



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Sensitivity experiments – modify only upper 50m Indian Ocean

- Comparison of **IndO_97sfc** with **IndO_97** shows that

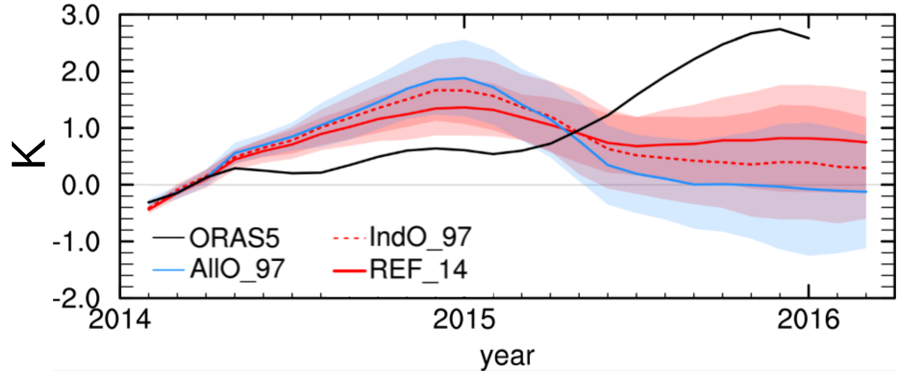
→ SSTs in year1 are similar to **IndO_97** and SSTs in year 2 lie between **REF_14** and **IndO_97**

→ 2-yearly OHC loss **in IndO_97sfc** is much weaker than in **IndO_97**

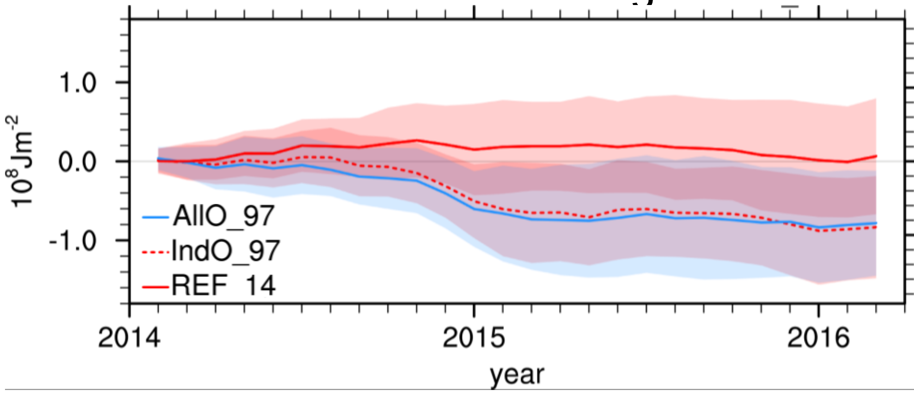
- **IndO_scramble** is very similar to **IndO_97** and **AllO_97**: suggests that Indian Ocean in 2014 was highly anomalous

Main experiments

Nino 3.4



OHC changes



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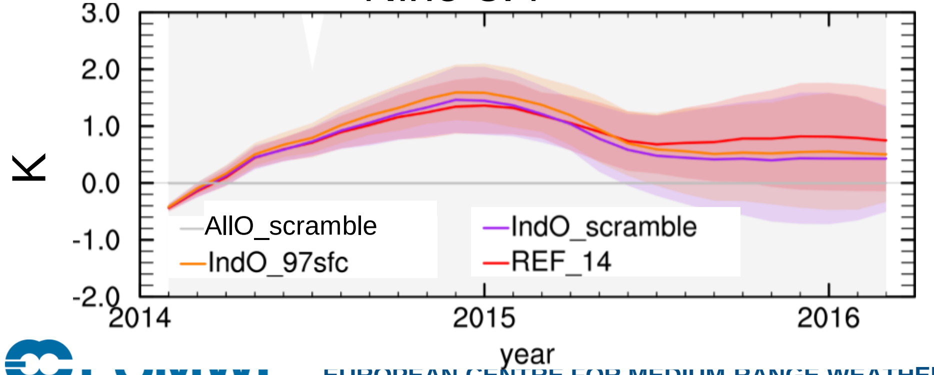
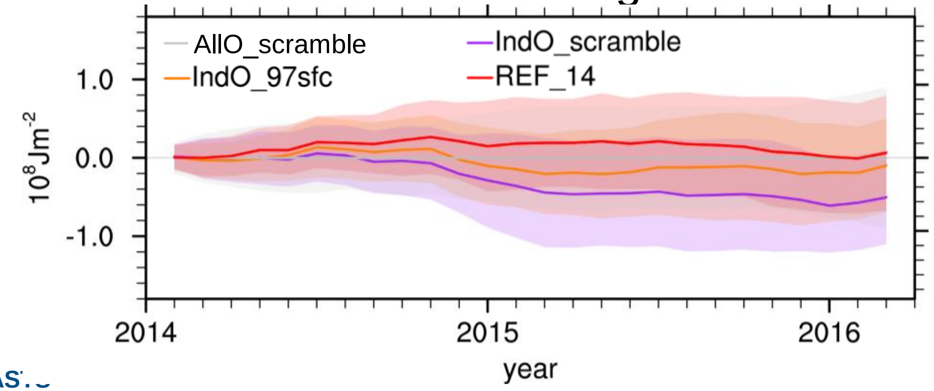
sensitivity experiment

Nino 3.4



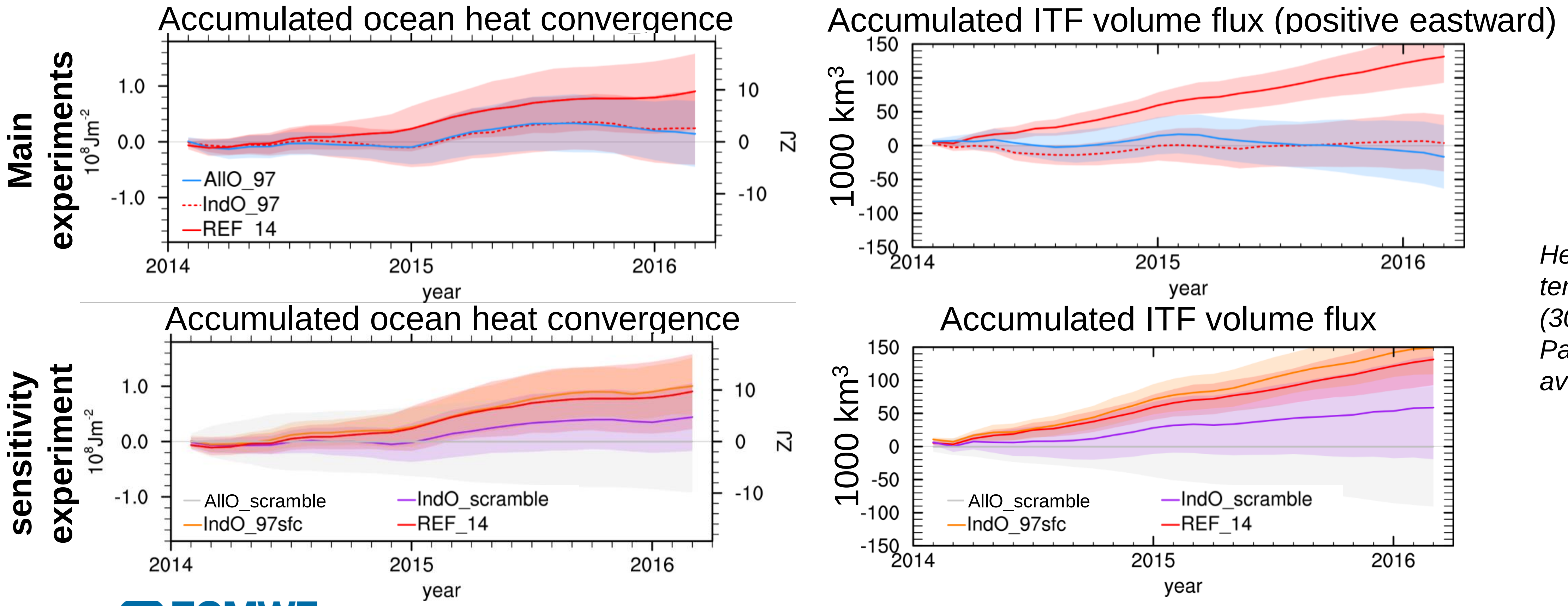
OHC changes



Sensitivity experiments – modify only upper 50m Indian Ocean

- Ocean heat convergence and ITF volume flux are very similar in **Ind_97sfc** and **REF_14**

→ This shows that changing only the upper 50m of the Indian Ocean is not sufficient to change the ITF. It is the warm Indian Ocean *sub*-surface that drives the ITF reduction in 2014-16



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Conclusions

- "Sluggish" ENSO behaviour in 2014 was likely related to anomalously warm Indian Ocean. It acted to retain atmospheric convection over the Maritime continent and it acted to weaken the ITF (which acted to retain warm waters in the Pacific not only in 2014, but also in 2015/16)
- When changing Indian Ocean ICs to 1997 in 2014 re-forecasts (IndO_97), ENSO evolution becomes more similar to 1997 evolution than 2014 evolution
  - Year 1: changes related to atmospheric bridge
  - Year 2: At least sub-surface changes are related to oceanic bridge (stronger ITF → cooler Pacific), which also affects SSTs and reduces likelihood of El Nino in year 2

  → Indian Ocean surface and sub-surface ICs play a critical role for ENSO prediction
- Differences in 2-yearly Pacific OHC evolution is mainly governed by ocean heat transports
  - Year 1 and year 2 changes in surface fluxes compensate each other, yielding ~0 difference over two years
  - Ocean heat transport anomalies crucially depend on Indian Ocean state and persist for two years

→There is a paper in preparation that includes more diagnostics and discussion!
(*Mayer and Balmaseda 2020, to be submitted)*