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The Role of the Tropical Indian Ocean and Polar Stratosphere for the Sharp Decline of Antarctic Sea-Ice in 2016

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Wang, G., Hendon, H.H., Arblaster, J.M., Lim, E.P., Abhik, S. and van Rensch, P., 2019. Compounding tropical and stratospheric forcing of the record low Antarctic sea-ice in 2016. *Nature communications*, *10*(1), p.13.

Lim, E.P. and Hendon, H.H., 2017. Causes and predictability of the negative Indian Ocean Dipole and its impact on La Niña during 2016. Scientific reports, 7(1), p.12619.

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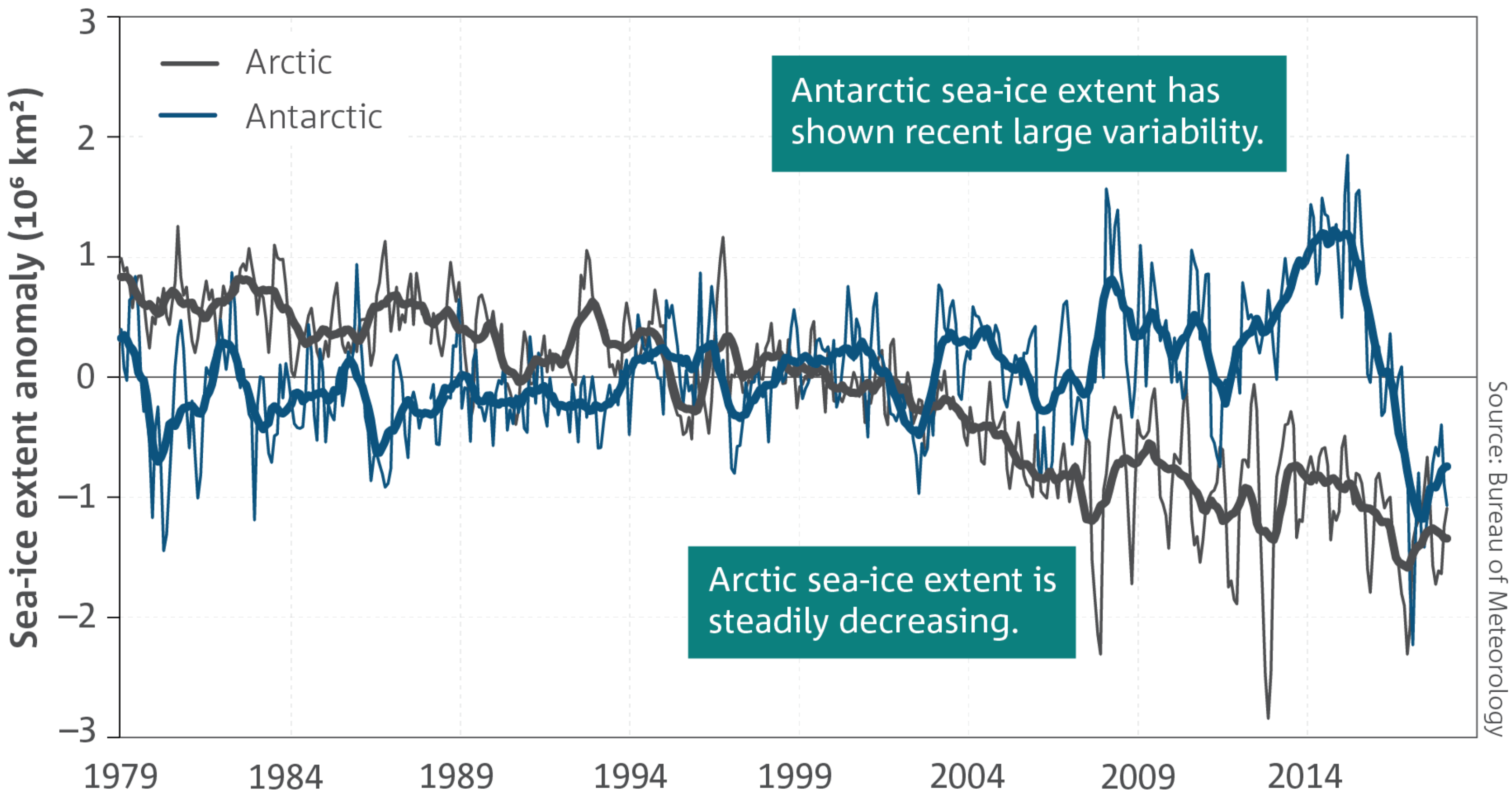
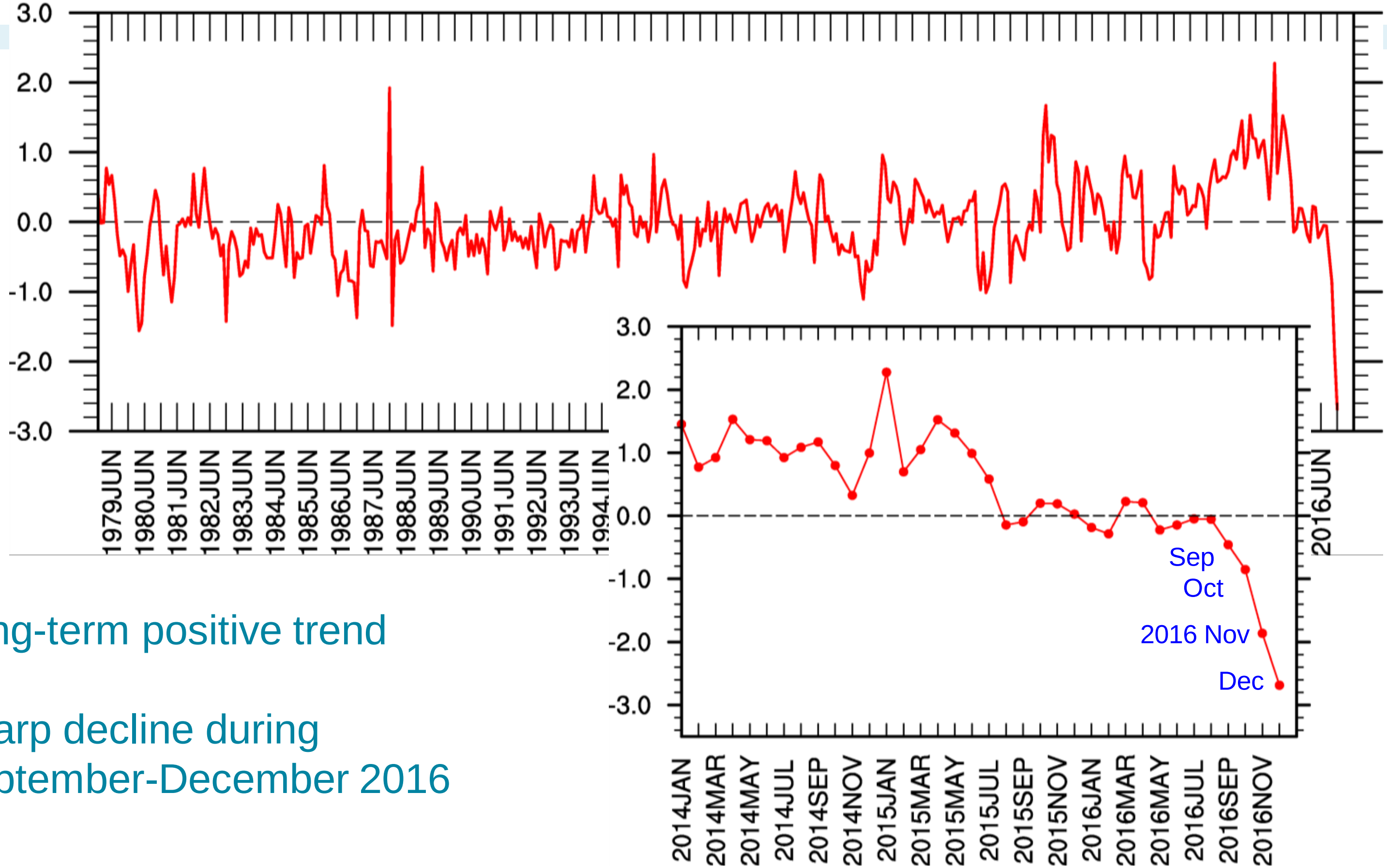
A climate change conundrum:

Artic sea ice has been steadily decreasing but Antarctic sea ice had been slightly increasing up through 2016



Monthly Antarctic Sea-Ice Extent 1979-2016



- Long-term positive trend
- Sharp decline during September-December 2016

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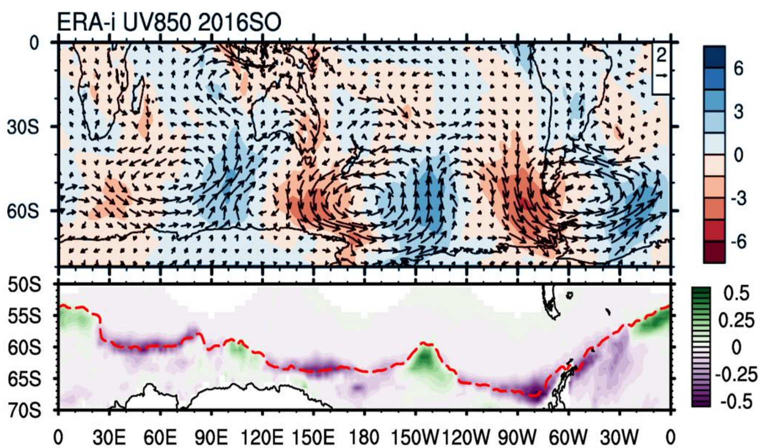
Anomalous atmospheric circulation in the Antarctic region has been implicated for the sharp decline

(Turner et al. 2017; Stuecker et al 2017)

Circulation and Sea-Ice Concentration

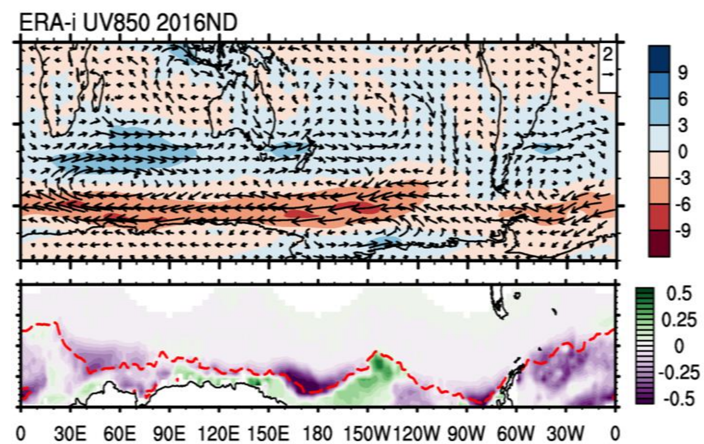
Sep-Oct 2016



IndianO WPO RossS BAS WS

High latitude wave 3 pattern

Nov-Dec 2016



IndianO WPO RossS BAS WS

Annular (low SAM) pattern

What promoted these atmospheric circulation anomalies?

Tropical conditions Sep-Oct 2016

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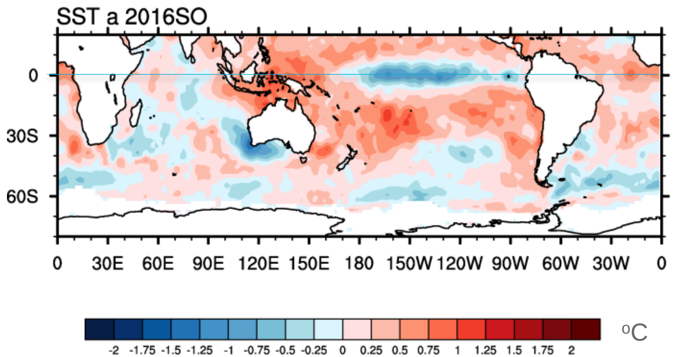
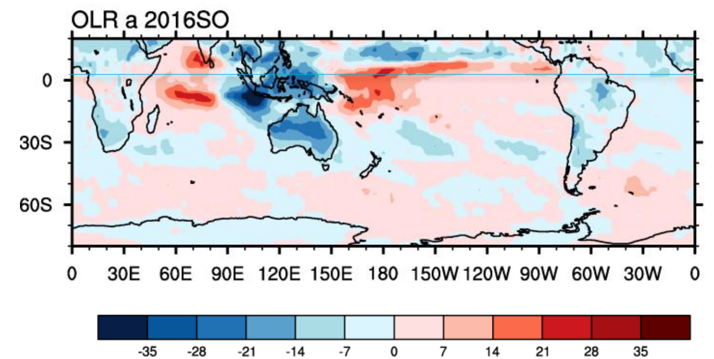
SST

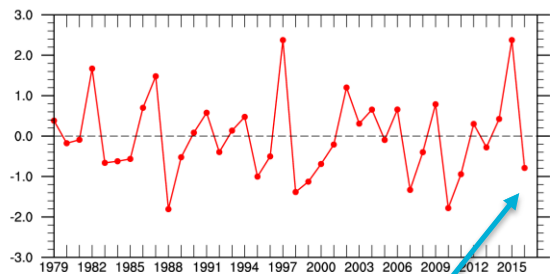


OLR



Record strong convective dipole

Nino34

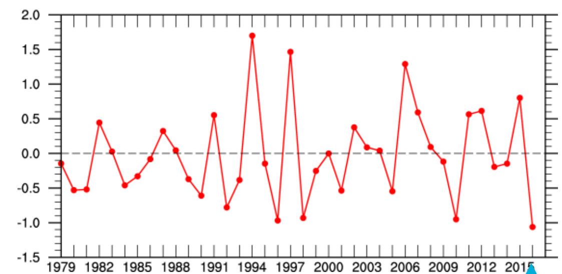


1979

2016

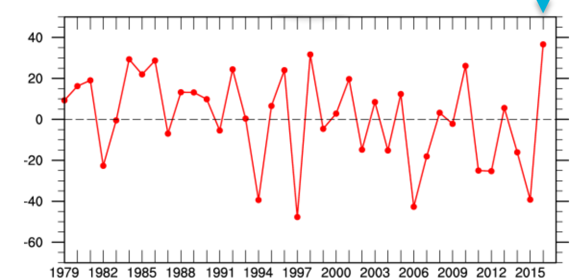
Weak La Nina

DMI



Record negative IOD

OLR DMI



Rossby Wave Source and Wave Activity Flux
Sep-Oct 2016
Convective anomaly in Indian Ocean and far western Pacific appears to be source Rossby wave train

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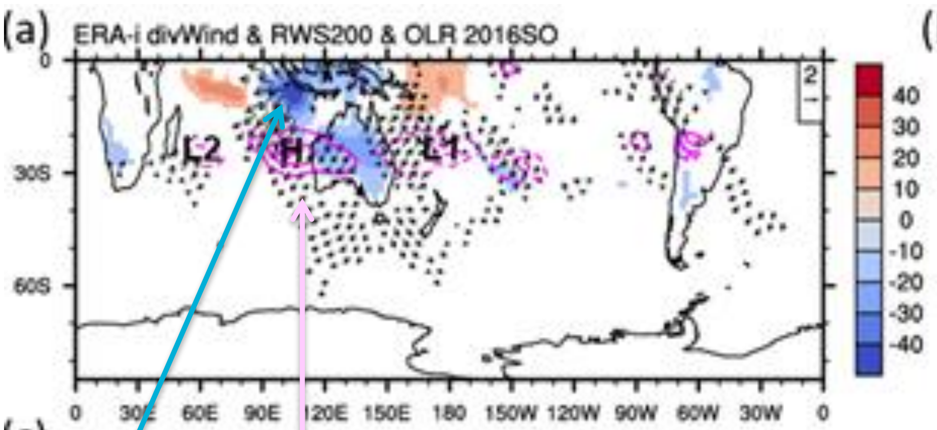

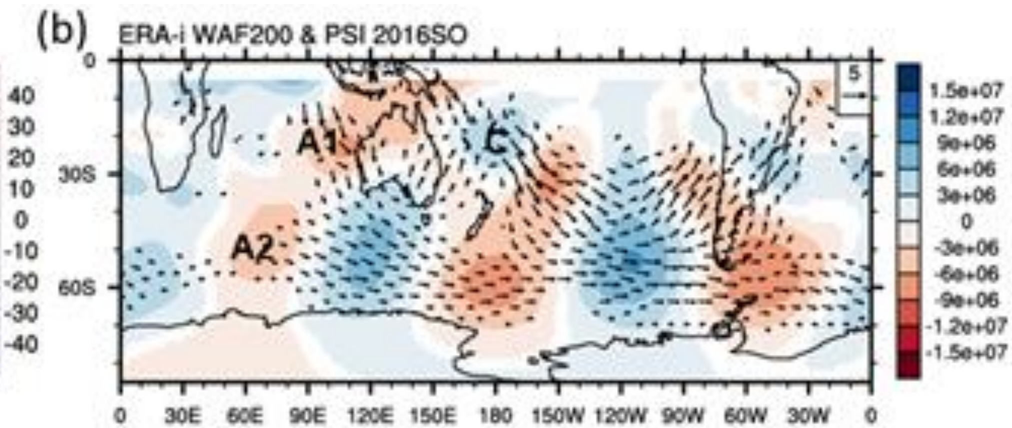

Shading = OLR

Vectors = divergent wind at 200 hPa

Pink contours = Rossby wave source due to advection of mean absolute vorticity by anomalous divergent flow

=***V***d' dot grad (mean abs vort)

Shading = Streamfunction

Vectors = Rossby wave activity flux

Parallel to Rossby wave group velocity

Divergence: wave source

Convergence: wave sink

Observed behaviour in Sep-Oct 2016 consistent with historical relationship with IOD/ENSO 1979-2015

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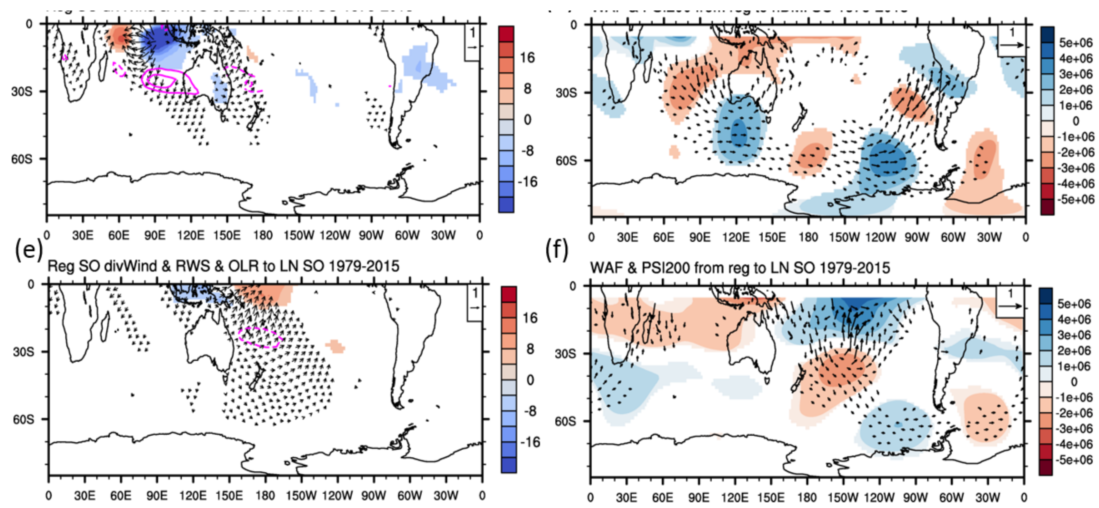
Multiple Linear regression 1979-2015 using DMI and Nino34 as predictors.

OLR, RWS, Div wind **Psi200, Wave activity flux**

DMI

Nino34



Observed behaviour in Sep-Oct 2016 consistent with historical relationship with IOD/ENSO 1979-2015

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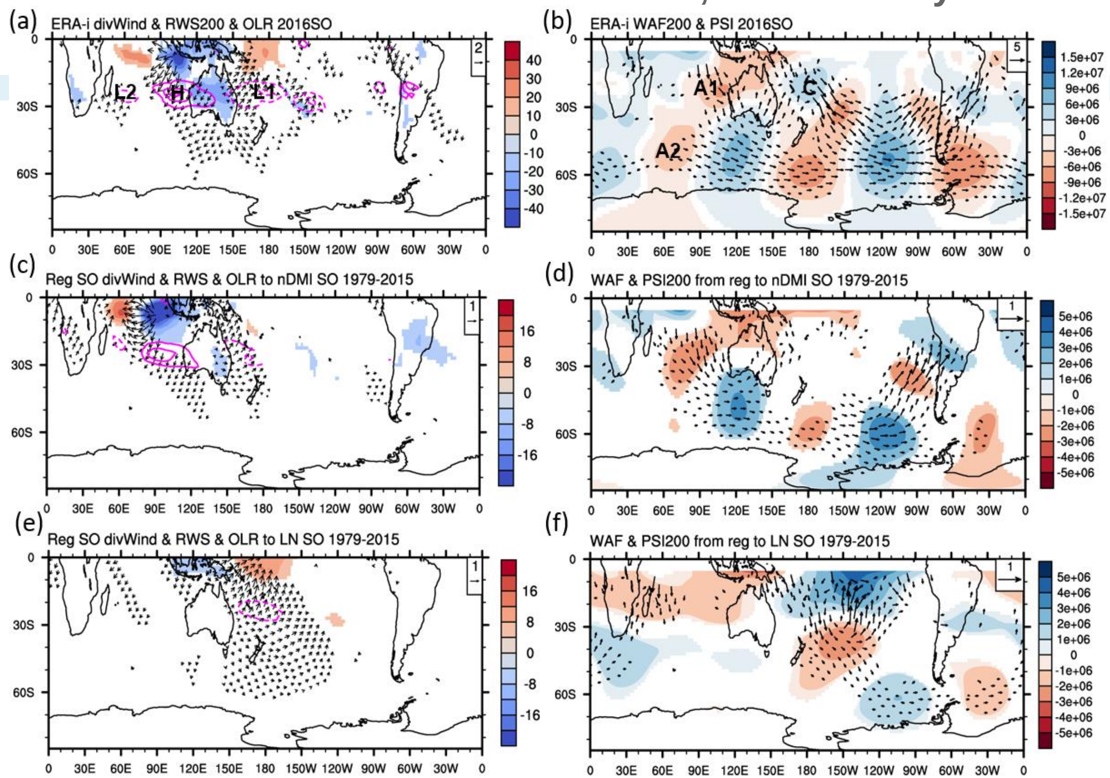
OLR, RWS, Div wind **Psi200, Wave activity flux**

Obs 2016

DMI

Display scaled by DMI 2016

Nino34
Display scaled by Nino34 2016



Neg IOD was primary source of wave 3 pattern, boosted by La Nina in SA sector

Wave 3 pattern understood from Rossby wave theory (e.g. Hoskins and Ambrizzi)

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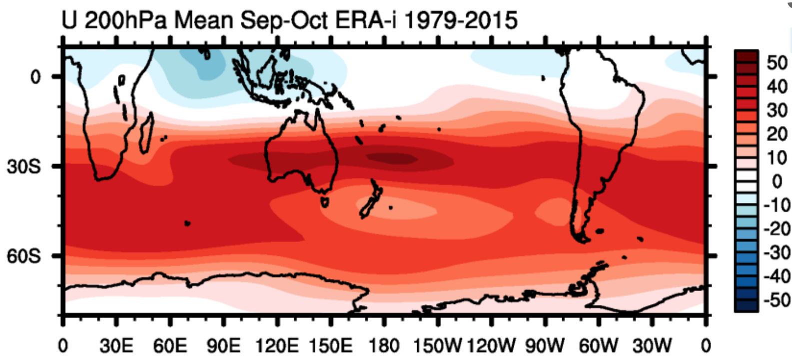
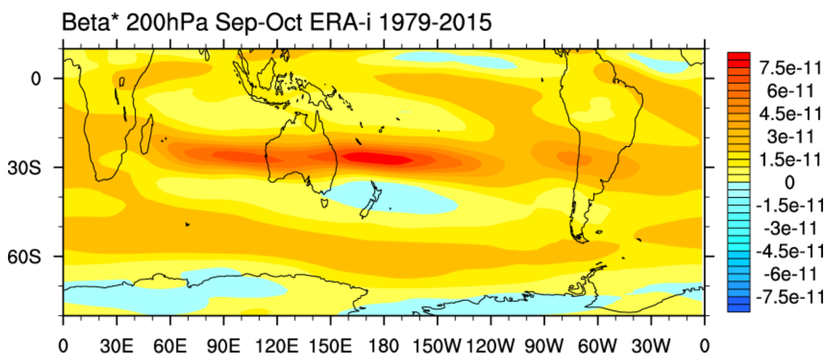
Wave train refracted into high latitude wave guide

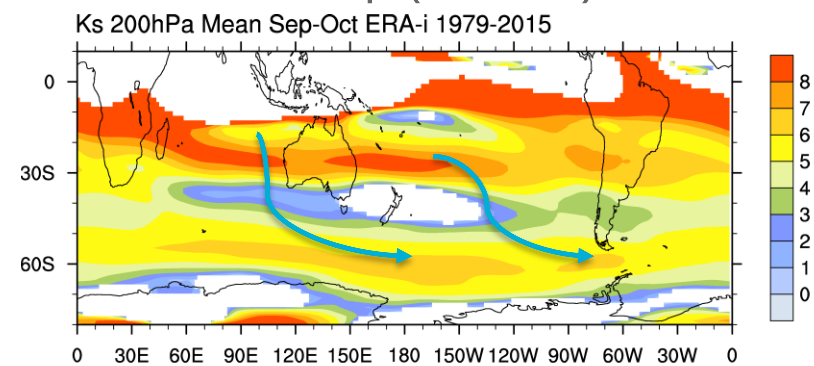
U200

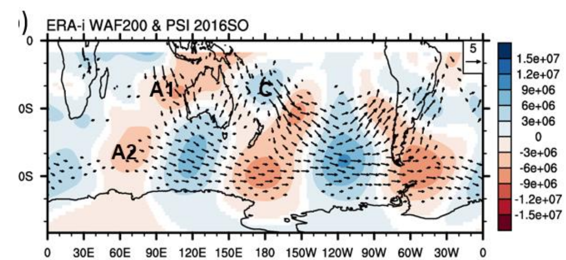


Beta*



Ks=sqrt(B*/ubar)

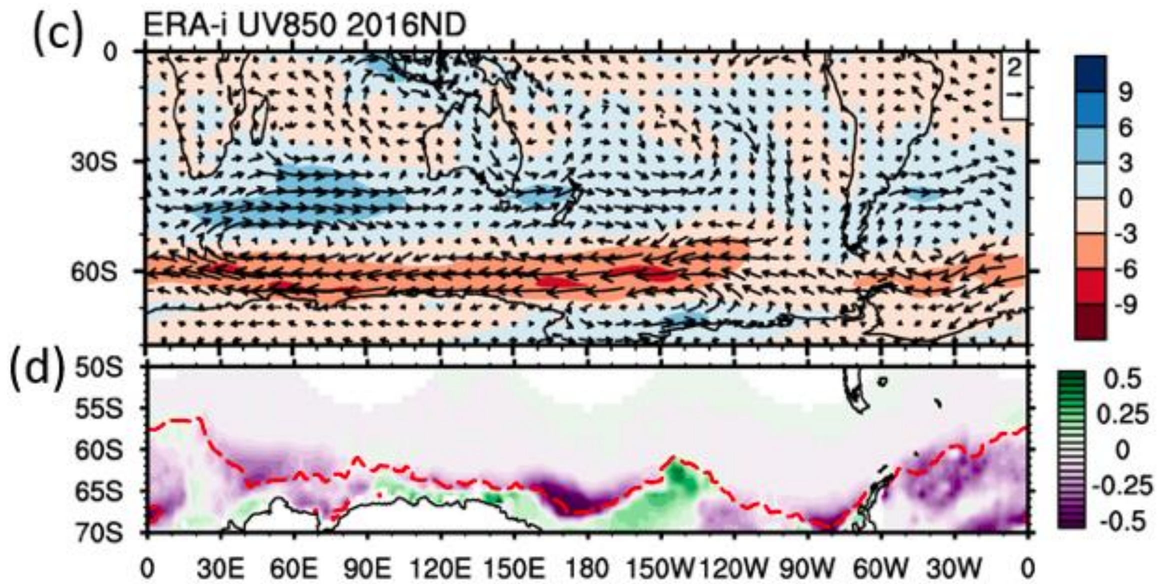




November-December 2016 Circulation: Low SAM rapidly developed and continued to promote sea ice decline

Easterly wind anomalies (low SAM) >Southward (warm) Ekman transport

Sea ice concentration anomalies



High SAM is usually observed during La Niña. Why did a strong low SAM rapidly develop during Nov-Sep 2016?

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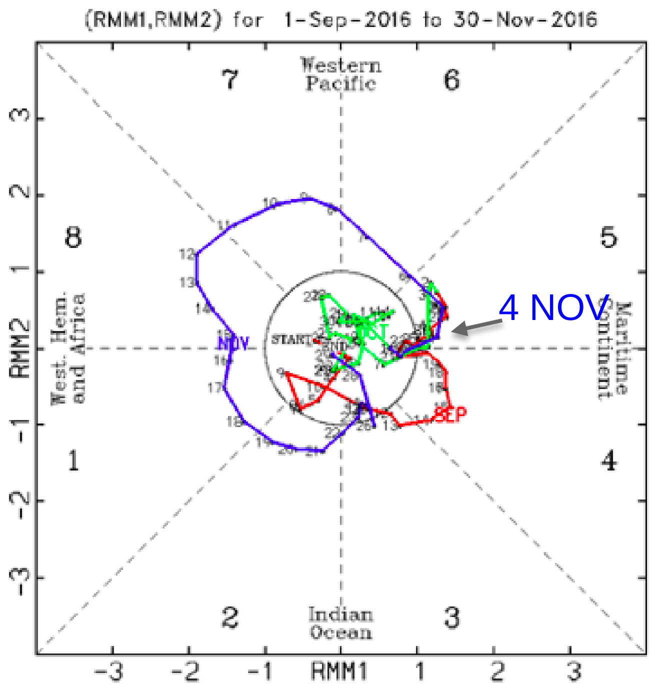
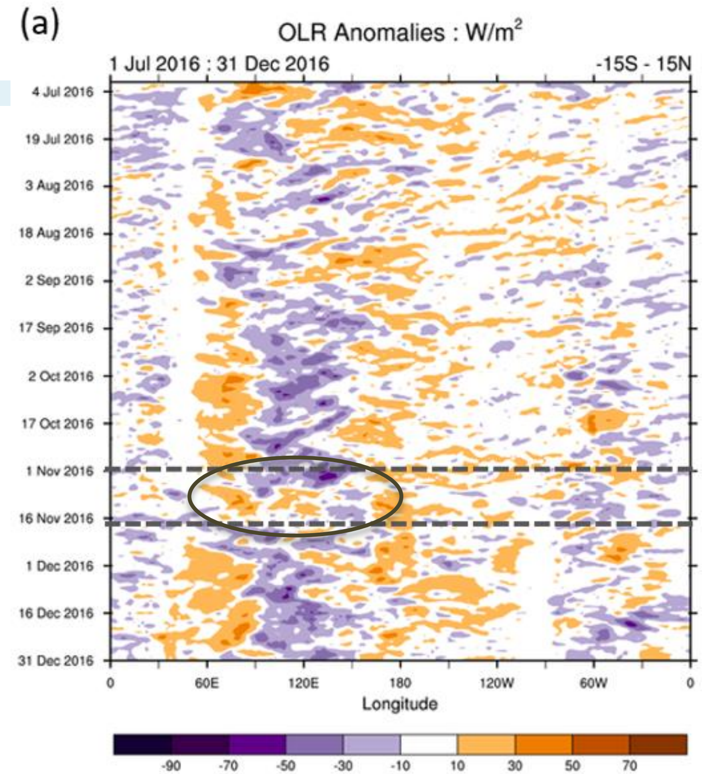
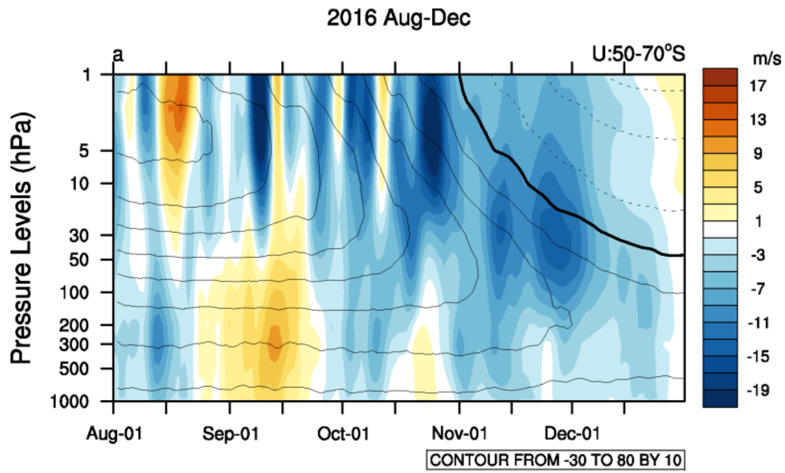
Impact of MJO event during November 2016



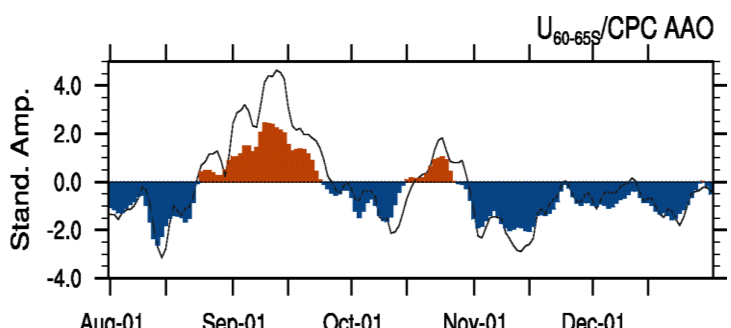


MJO acted to shut down the convection in east IO in early Nov that was providing the Rossby wave source during Sep-Oct.

Also experienced a strong early breakdown (weakening) of the polar stratospheric vortex that first emerged in upper stratosphere in Oct that then coupled downward through Dec



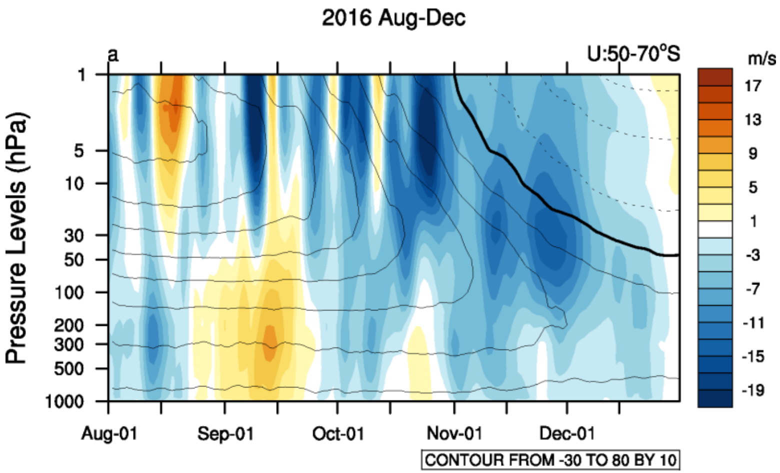
Polar Cap Zonal mean zonal winds   50-70S

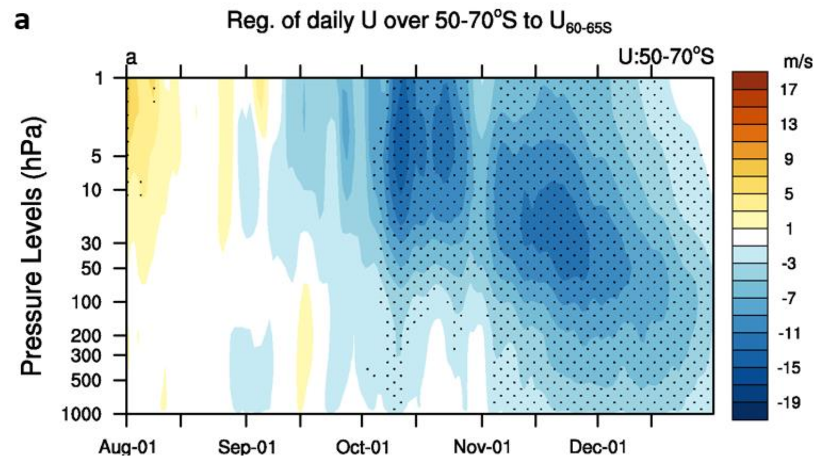


Daily SAM index

Historical relationship 1979-2015 : regression of polar cap zonal winds onto Nov-Dec surface zonal wind: downward coupling is a prominent feature of circumpolar winds in late spring-summer

Observed 2016





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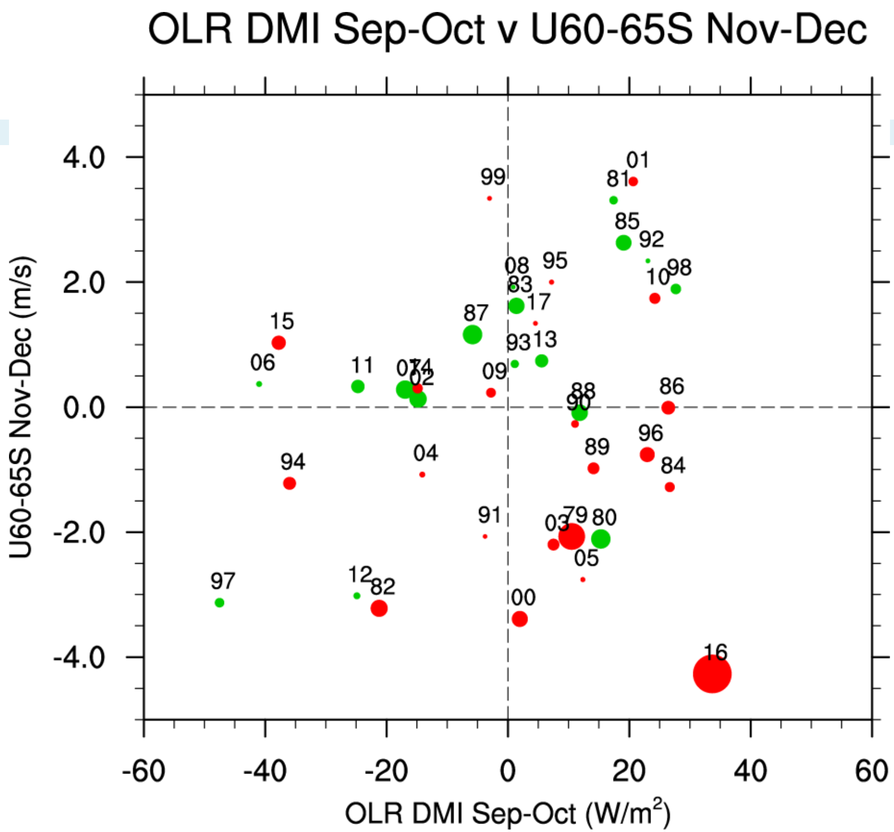
Circumpolar westerlies



OLR Dipole Sep-Oct

Dot proportional to sea ice drop (red) or increase (green)

Sea ice decline 2016 was result of unprecedented negative IOD followed record negative SAM:

Just bad luck?

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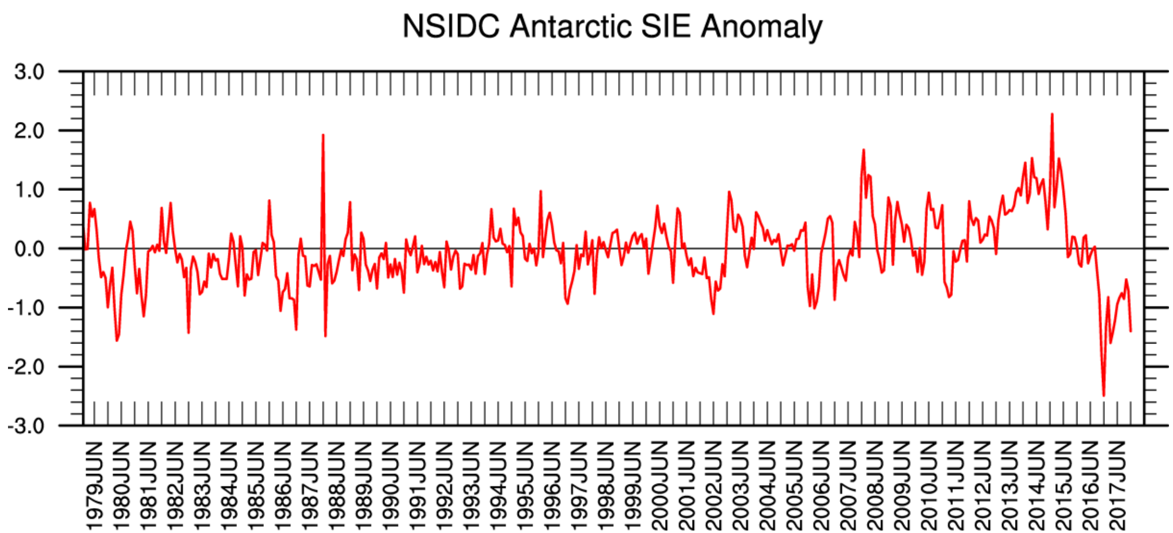
Partial recovery in 2017 suggests that internally generated variability (IOD and polar vortex weakening) played a primary role in the 2016 decline: but doesn't preclude a role for global warming



Causes and predictability of the record strong negative Indian Ocean dipole 2016

Eun-Pa Lim & Harry H. Hendon

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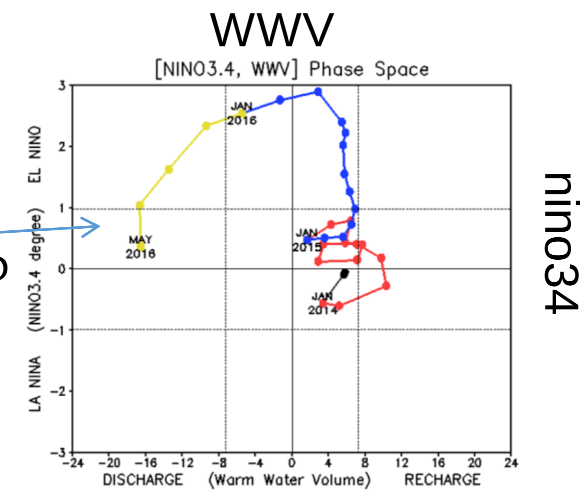
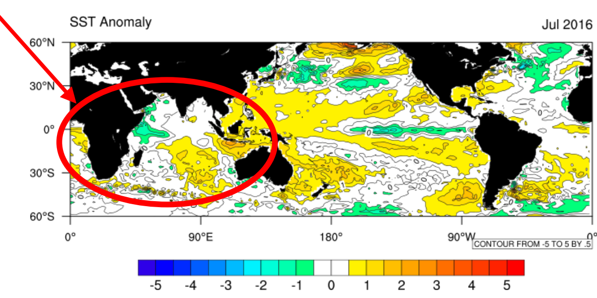
Was there a role for ongoing warming in the Indian Ocean?

Background

- Strong La Nina was expected in mid-2016
  - Strong discharge of the heat in the tropical Pacific subsurface in the 1st quarter of 2016 from massive El Nino 15/16
  - Early development of strong –ve IOD by July
- But La Nina of 2016 ended up to be a weak event



(taken from BoM seasonal outlook meeting materials; E. Miles)

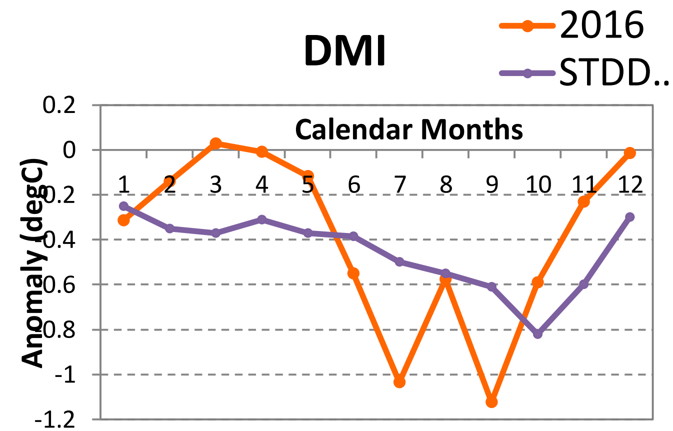


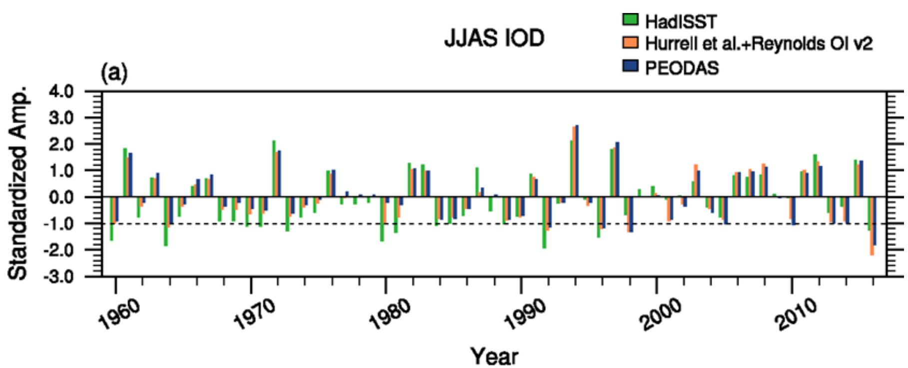
Aim of the study:

Causes and predictability of record strong negative IOD 2016

Negative IOD in June – Sep 2016

- Typically IOD peaks in Sep-Nov
- Negative IOD of 2016 developed from May, **peaked in July and Sep** & decayed rapidly in November
- **Strongest negative IOD June-Sep** since 1960



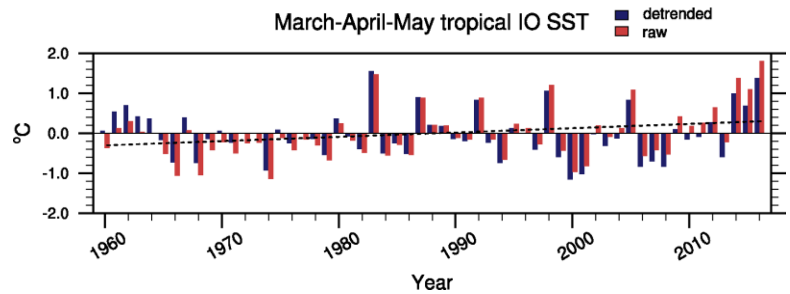


Preconditions of negative IOD in June-Sep 2016

Record high SSTs in the tropical IO in March-May 2016

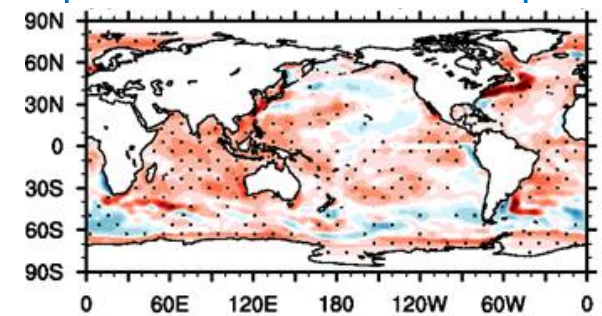
→Basin-wide warming and downwelling Rossby wave forced by strong El Nino 2015-16

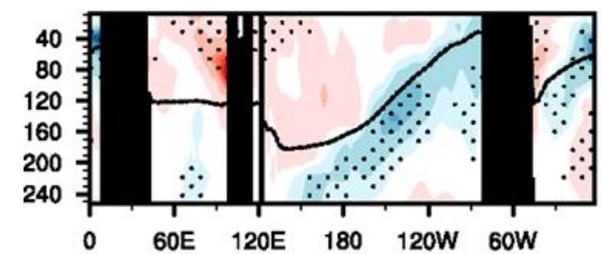
→But also significant contribution from long-term warming trend



Late boreal spring IO temperature trend pattern is **similar to negative IOD pattern**

Temperature trend over 1960-2014 in April/May





Conduct coupled model seasonal prediction experiments to elucidate the role of warming trend and other mechanisms for promoting the record strong negative IOD

Coupled model seasonal forecast sensitivity experiments

POAMA: an atmosphere-ocean **coupled system, run operationally in BoM** for sub-seasonal to seasonal climate outlook:

- Atmospheric model: **B**ureau's **A**tmospheric **M**odel v3 (~250km x 250km x 17 vertical levels)
- Ocean model: **A**ustralian **C**ommunity **O**cean **M**odel **2** (200km x 50-150 km x 25 vertical levels)

Initialisation:

- Observed atmosphere, land and ocean initial conditions generated from BoM's data assimilation systems - **ALI** (Hudson et al. 2010 Clim. Dyn.) and **PEODAS** (Yin et al. 2011 Mon. Wea. Rev.)
- Skill has been assessed using 33 member ensemble hindcasts for 1980-2014
- **POAMA is competitive with other international models** in predicting ENSO and IOD (e.g. Barnston et al. 2012, Shi et al. 2012) → gives us confidence to use POAMA to understand the dynamics of the IOD and La Nina of 2016

POAMA forecast sensitivity experiments

- 7 experiments: a CTRL forecast, 5 forecast sensitivity exps, and a climatological exp
- Each experiment consists of 11 member ensemble forecasts
- In all experiments, forecasts were **initialised on 21st April 2016** and **verified for May to November 2016**
- In the 7 experiments, **atmosphere** & **land** were initialised with **observed conditions of 21st April 2016**
- **Ocean** was **initialised with 7 different configurations** (various combinations of observed conditions of **21st April of 2016 plus 21st April climatology 1980-2010**

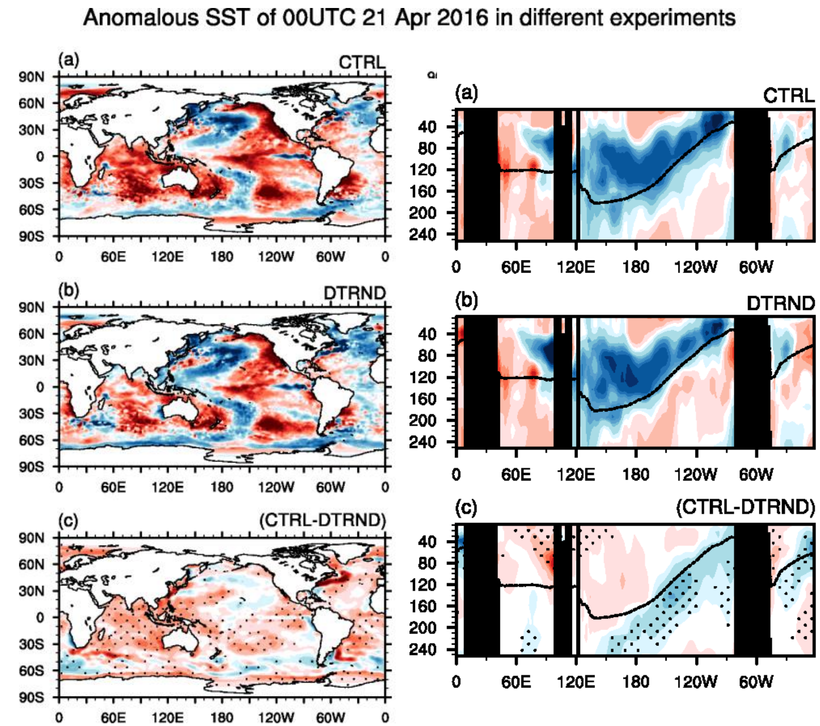
Design of experiments – different ocean initial conditions

CTRL: Observed conditions of 21 Apr 2016 (i.e. Bureau's real-time fcsts)

DTRND Exp: Observed conditions but temperature and salinity trends over 1960-2014 removed

Trend on 21 Apr 1960-2014

- SST trend: significant warming over most of the Indian and the western Pacific sea surface
- Eq. subsurface temperature trend:
  * deepening of the thermocline in the eastern IO
  * shallowing of the thermocline in the eastern Pacific and eastern Atlantic subsurface



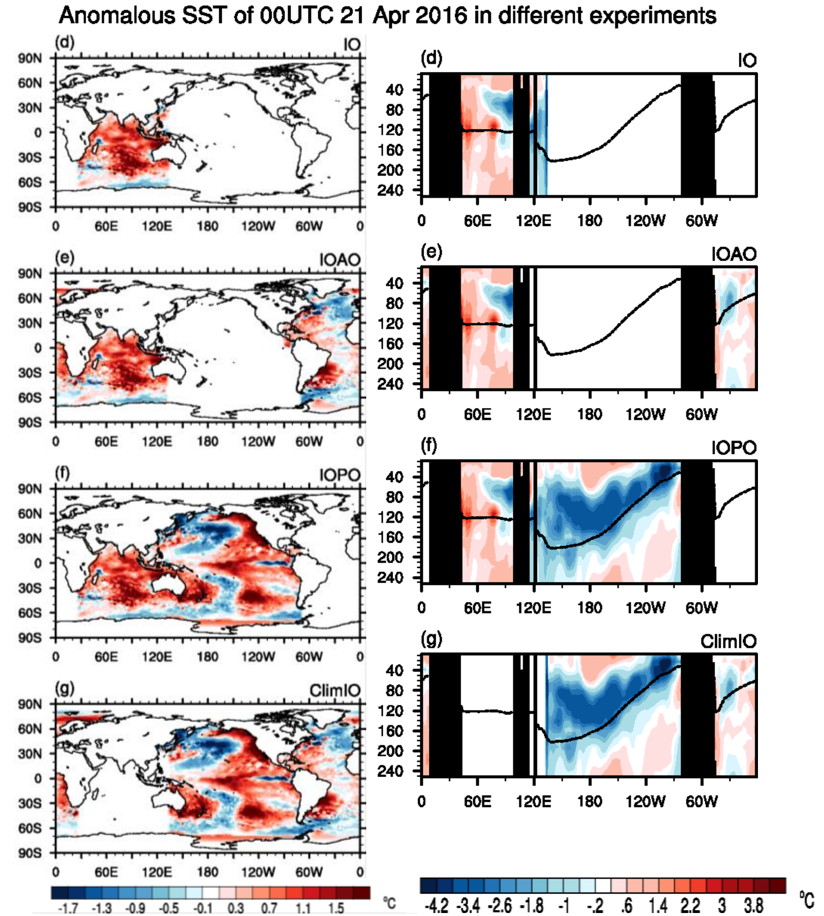
Design of experiments – different ocean initial conditions

IO Exp: observed conditions in the Indian Ocean & climatological conditions elsewhere

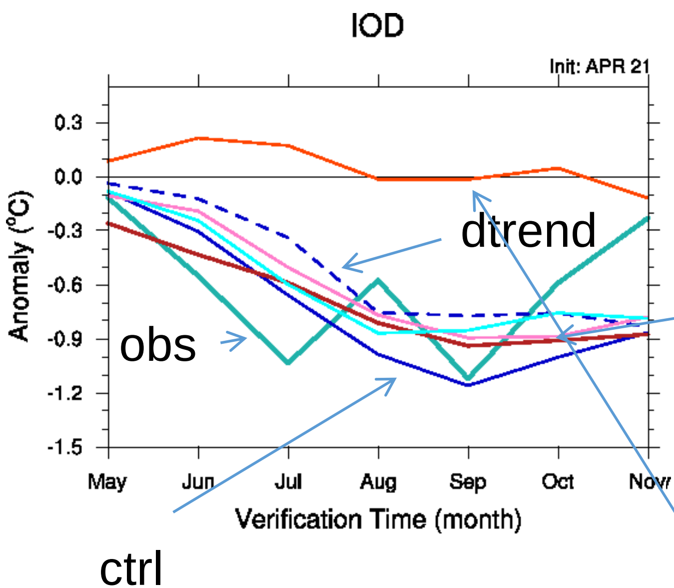
IOAO Exp: observed conditions in the Indian Ocean and Atlantic Ocean

IOPO Exp: observed conditions in the Indian Ocean and Pacific Ocean

ClimIO Exp: climatological conditions in the Indian Ocean & observed conditions elsewhere



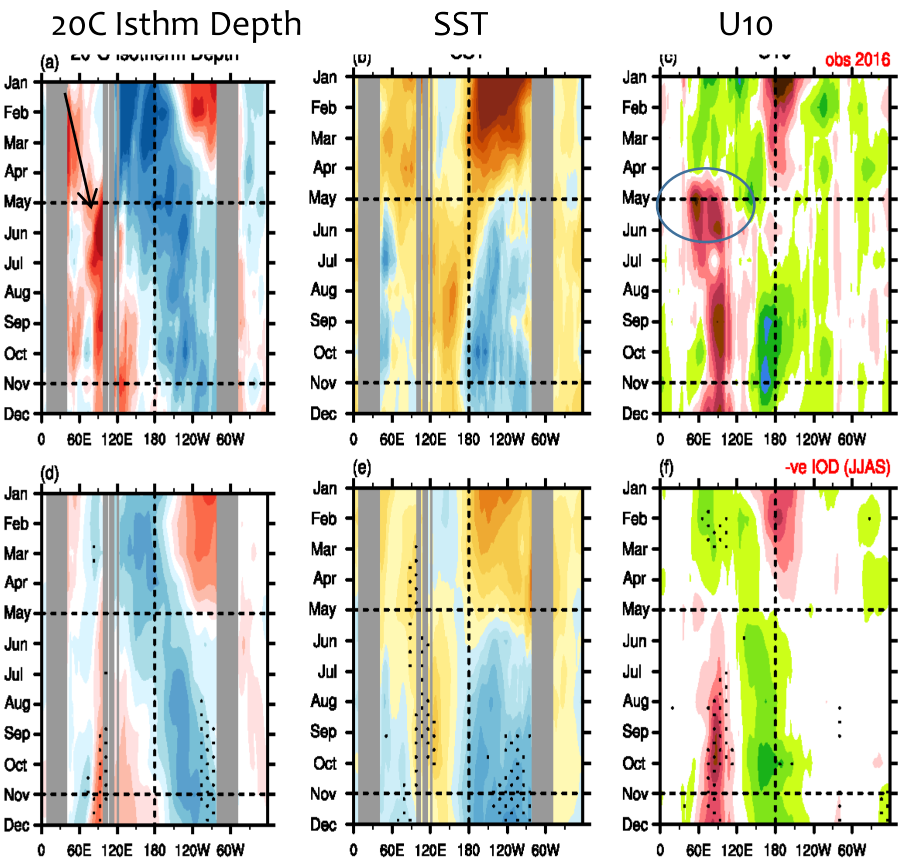
Negative IOD of 2016



- POAMA **CTRL** exp **skilfully predicts** the –ve IOD of 2016
- The –ve IOD-like **long-term ocean T trend +vely contributed** to the strength of the 2016 –ve IOD
- Using **observed ocean initial conditions** only over the **Indian Ocean** was **good enough** to generate strong –ve IOD
- Adding observed **Atlantic Ocean** or **Pacific Ocean** information **didn't** make any difference
- **Climo Indian Ocean** initial conditions, **-ve IOD** was **not predicted** at all

→ Strong Jun-Sep –ve IOD of 2016 was primarily driven by the Indian Ocean conditions with moderate contribution from trend

Causes of the negative IOD 2016



2016

Outstanding features of –ve IOD 2016

- Ocean subsurface wave dynamics

  : Eq downwelling Kelvin wave emanating from west boundary in Feb resulting from 2015-16 El Nino

- Air-sea feedback

  initiated with westerly wind bursts over central IO in May

Composite of five strongest Jun to Sep –ve IOD 1992,1996, 1998, 2005, 2010

No signature of preceding downwelling K-wave and much weaker westerly wind burst in

Summary of IOD Experiments

Lim & Hendon (2017)
Sci. Rep, 7, 12619

- Strong negative IOD was skilfully predicted by POAMA CTRL experiment initialised in late April 2016; predictability provided by antecedent conditions in Indian Ocean
  - Downwelling oceanic Kelvin wave (leftover from 2015-16 El Nino)
- Negative IOD-like long-term temperature trend contributed to the extraordinary strength of this negative IOD

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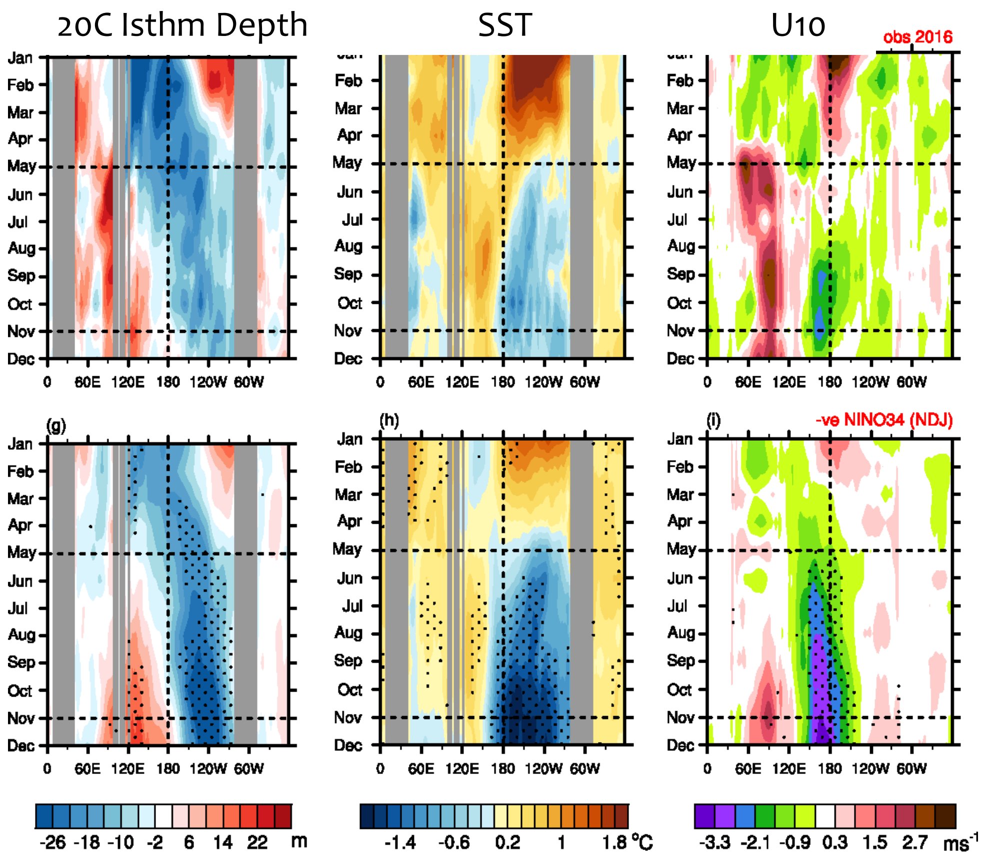
Overall Summary

- The sharp decline in Antarctic sea-ice extent in Sep-Oct 2016 promoted by record negative Indian Ocean Dipole (IOD) event
  - Emphasizes the important role that tropical Indian Ocean plays for global climate
- Random occurrence of polar stratospheric warming in late Oct then maintained the ice decline in Nov-Dec by promoting low SAM
  - General conclusion is that dramatic sea ice decline was a result of internal ocean-atmosphere variability
- However a possible role of climate change is suggested via promotion of the strong negative IOD by ongoing warming of the Indian Ocean
  - Our results suggest that strong negative IOD events maybe more likely in the future.

Causes of weak La Nina of 2016



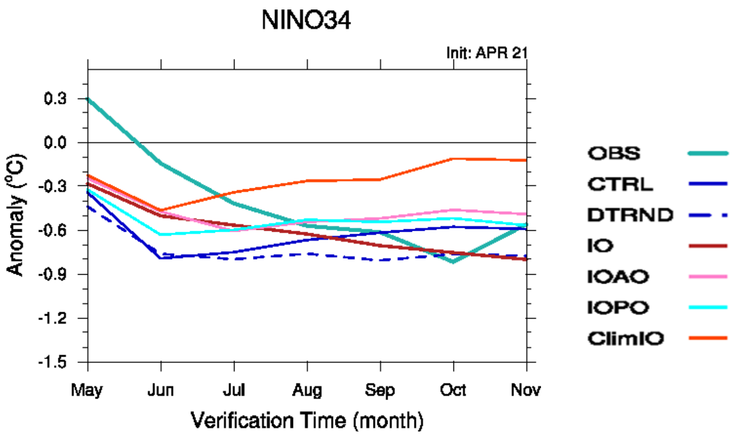
2016

Composite of
four strongest La Nina
1988, 1998, 2007, 2010

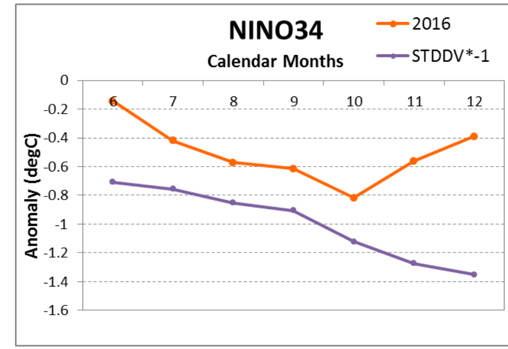
Outstanding features of La Nina 2016

- Extraordinary long-tail of El Nino especially over the dateline
- Much delayed air-sea coupling for La Nina
- **Forecasts** initialised **with the warming over the dateline** produced **weaker La Nina** than those without the warming

La Nina of 2016



The cold condition over the NINO34 region was weak in the 2^{nd} half of 2016



- In CTRL exp, POAMA over-predicted La Nina development initially but predicted it better from August onwards
- Cooling trend in the eastern Pacific subsurface caused a weaker La Nina, but the difference between CTRL and DTRND is not statistically significant (< 90%c.l.)
- La Nina was better predicted with observed initial conditions used only over the Indian Ocean
- Adding realistic **Pacific Ocean** or Atlantic Ocean information **weakened the strength of La Nina** forecast
- **Without** realistic Indian Ocean initial conditions, La Nina was not predicted

→ **Indian Ocean played a key role in driving this La Nina of 2016**