Predictability of the 2020 Strong Vortex in the Antarctic Stratosphere and the Role of Ozone

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JGR Atmospheres

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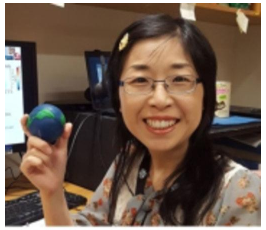
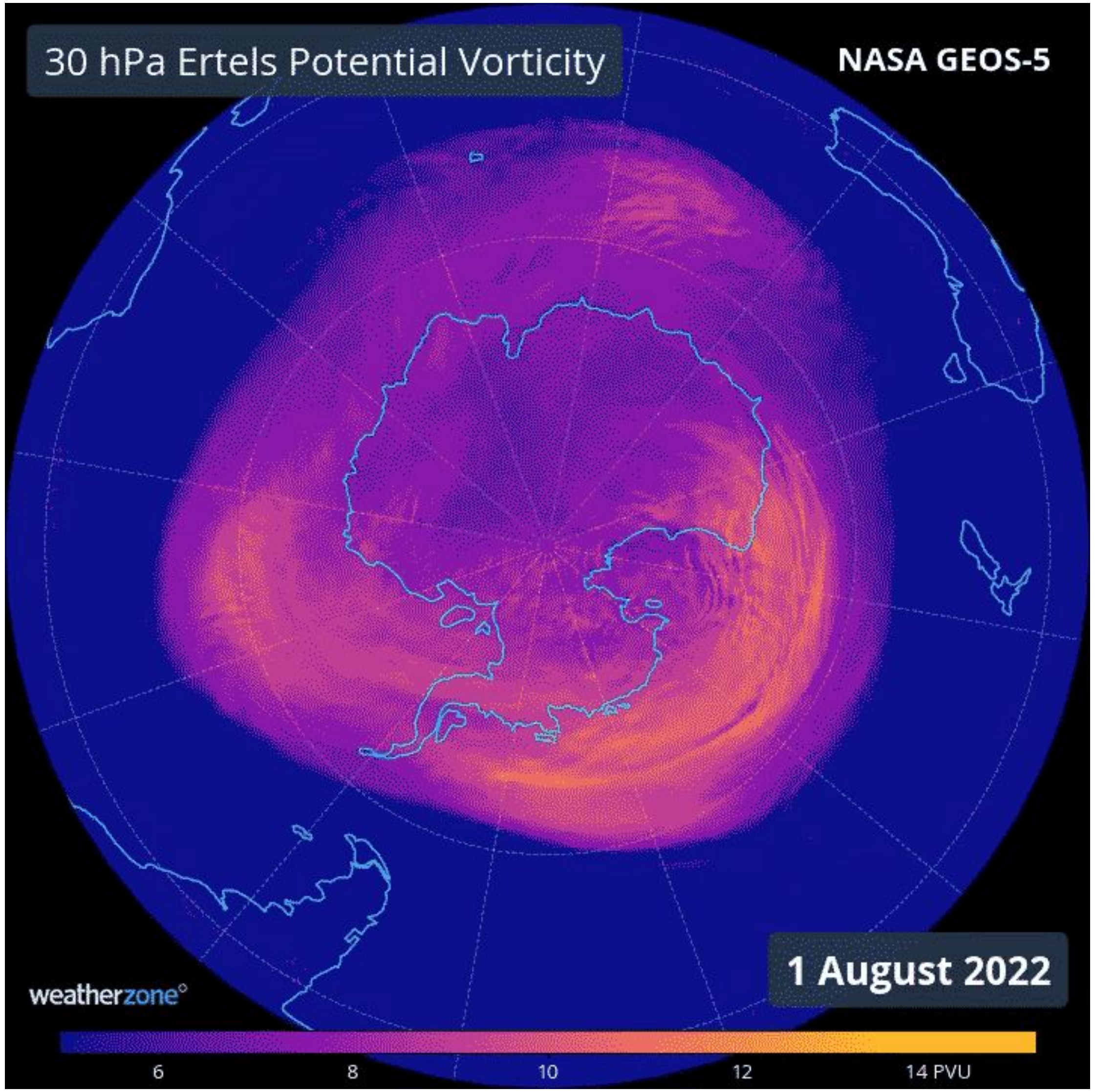


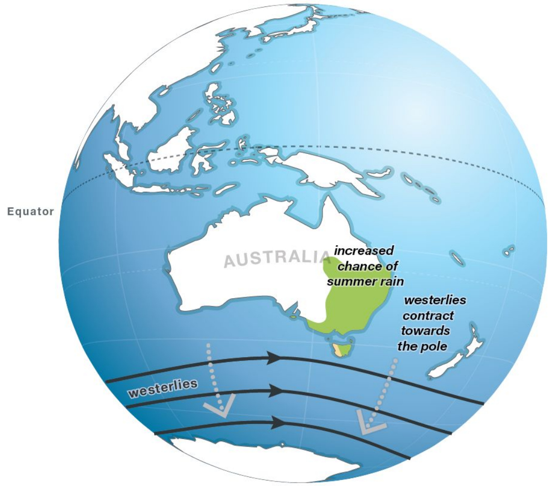
Eun-Pa Lim

NSF NCAR U.S. DEPARTMENT OF ENERGY Office of Science catalyst SAI Securing Antarcti Environ Future An Australian Research Council Special Rese

The movement of the winds encircling Antarctica can impact SH climate

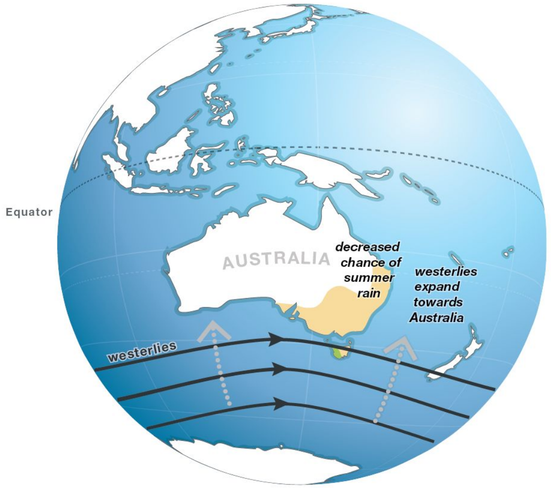


ABC News Online



Southern Annular Mode (SAM): **Positive phase (summer)**

Winds move south and strengthen

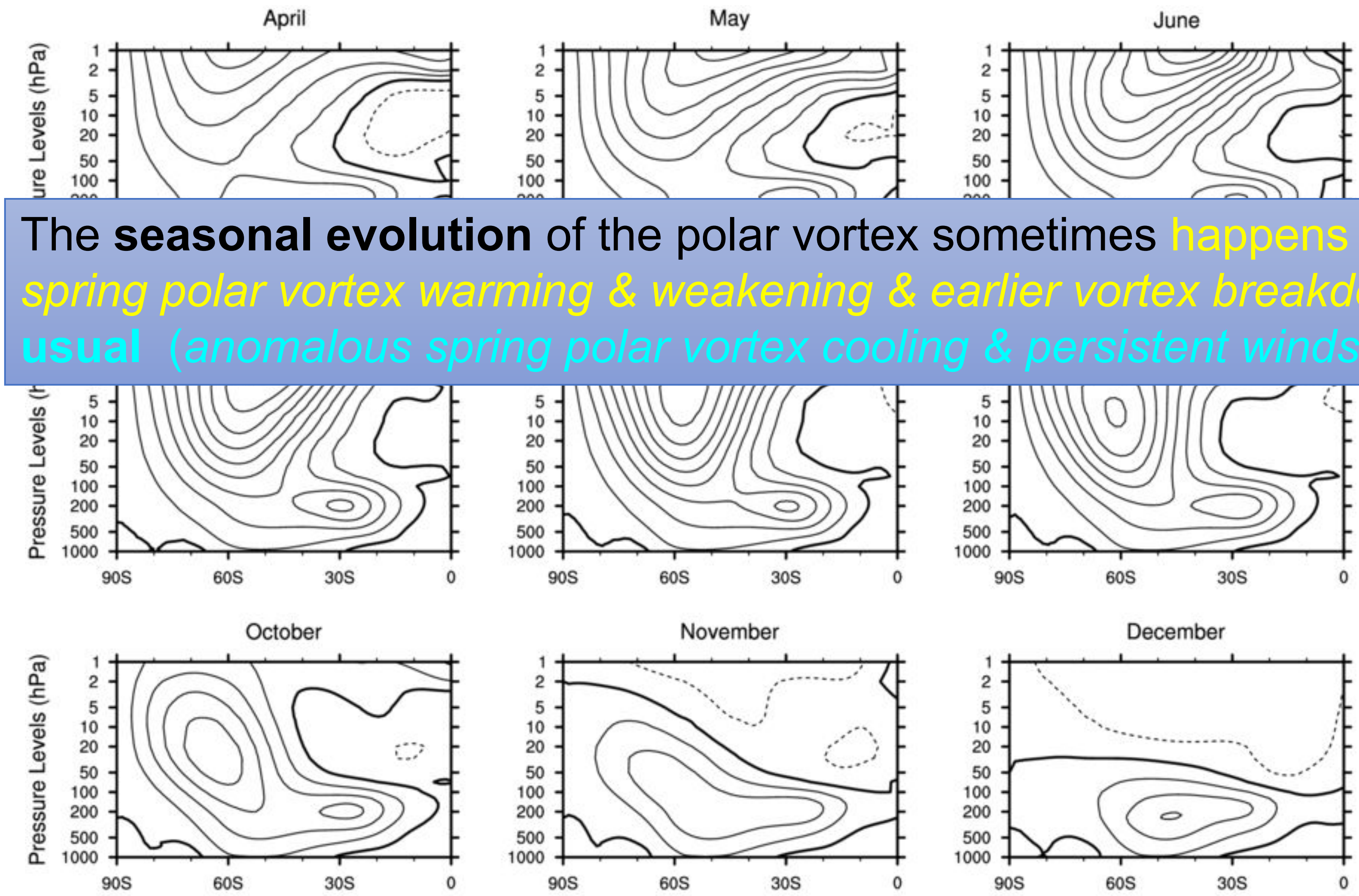


Southern Annular Mode (SAM): **Negative phase (summer)**

Winds move north and weaken

Life cycle of the SH stratospheric jet (polar vortex)

Climatological zonal-mean zonal winds [U]



SH stratospheric westerly jet starts developing in autumn and peaks in winter in the latitude band of 40-50°S at the stratopause (~ 1 hPa; 50km)

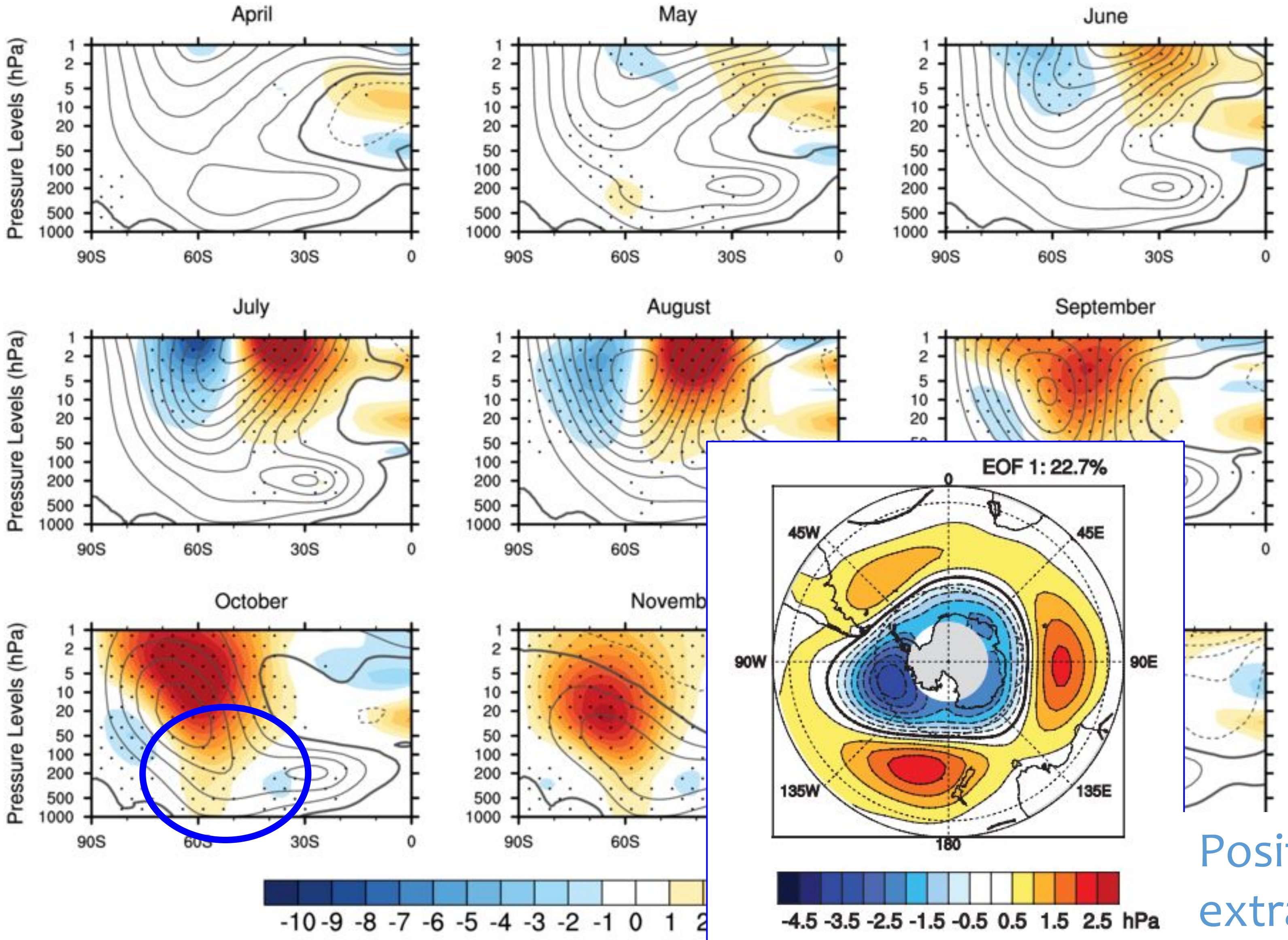
The **seasonal evolution** of the polar vortex sometimes happens **faster than normal** (*anomalous spring polar vortex warming & weakening & earlier vortex breakdown*) & at other times **slower than usual** (*anomalous spring polar vortex cooling & persistent winds & delayed vortex breakdown*)

disturbed by large-scale atmospheric waves propagating vertically from the lower stratosphere/upper troposphere
□ further **weakens and warms the vortex, causing it to contract towards the pole and move downward**

The stratospheric polar vortex completely **breaks down in the upper to mid-stratosphere by late Nov to early Dec**

Typical dynamical evolution of unusually strong spring polar vortices

Slower evolution of the polar vortex



An equatorward shift of the winter stratospheric jet

The meridional dipole anomalies of the jet move poleward and downward with time, leading to a stronger and colder polar vortex in spring

The spring vortex anomalies move further downward □ **a poleward shift of the tropospheric jet (i.e., positive SAM)** in mid-spring and

Positive SAM – leading mode of the SH extratropical circulation variability

Antarctic polar vortex weakening □ Australian heat, dry and fire danger extremes

nature geoscience
ARTICLES
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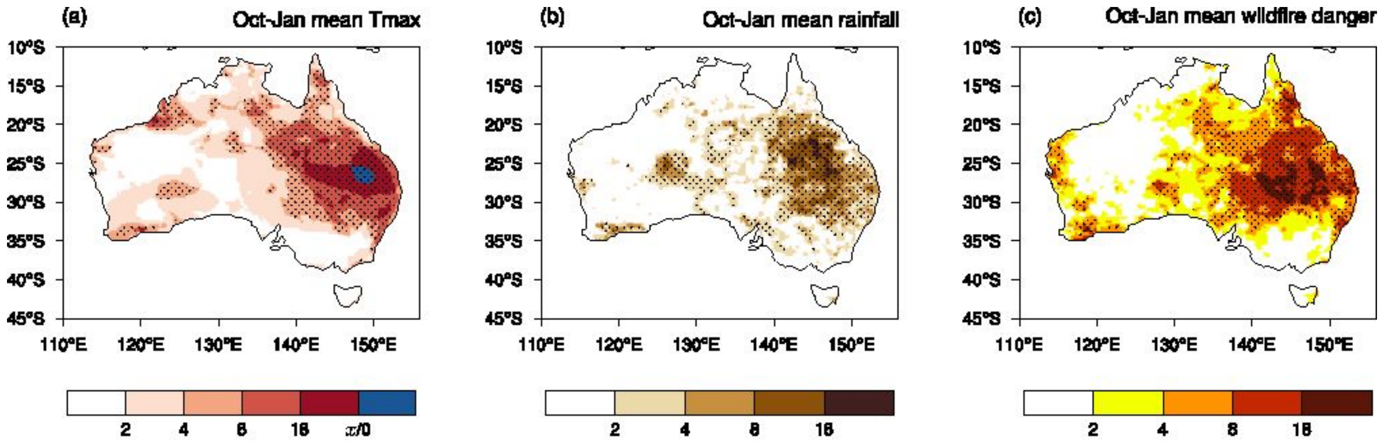
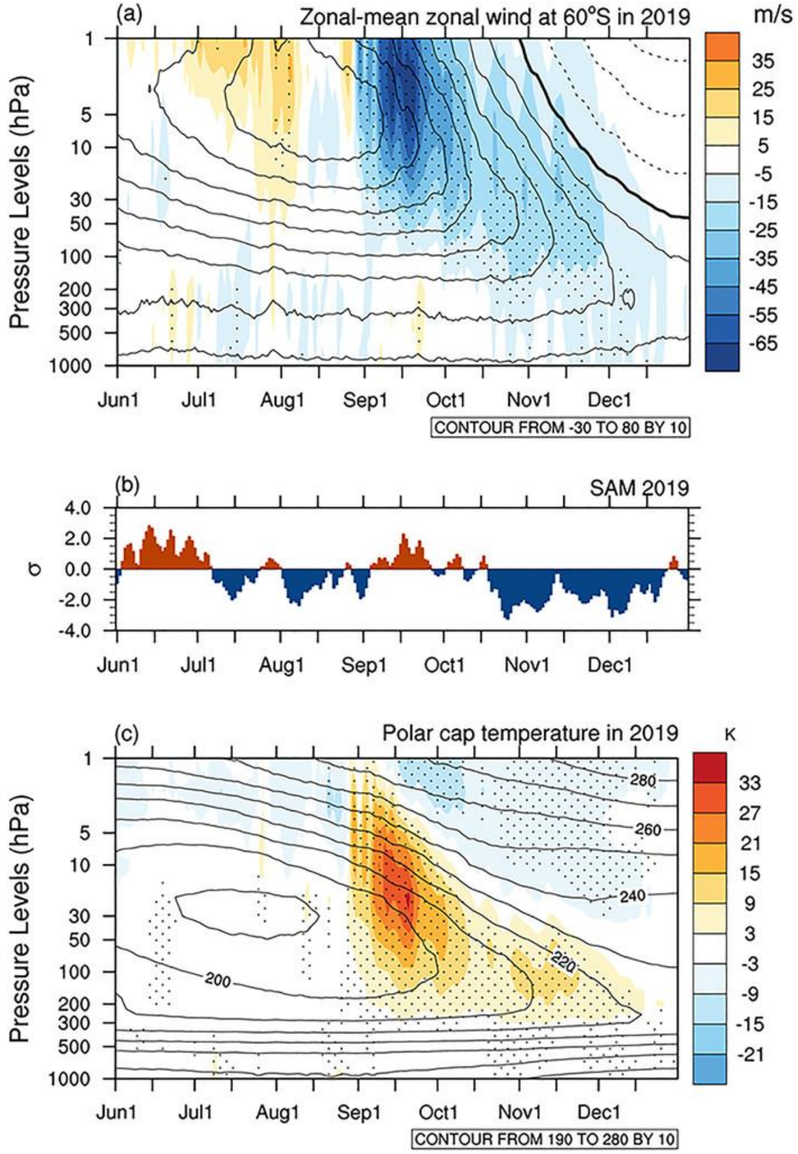
Australian hot and dry extremes induced by weakenings of the stratospheric polar vortex

Eun-Pa Lim[1]*, Harry H. Hendon[1], Ghyslaine Boschat[2,3], Debra Hudson[1], David W. J. Thompson[4], Andrew J. Dowdy[1] and Julie M. Arblaster[2,3,5]



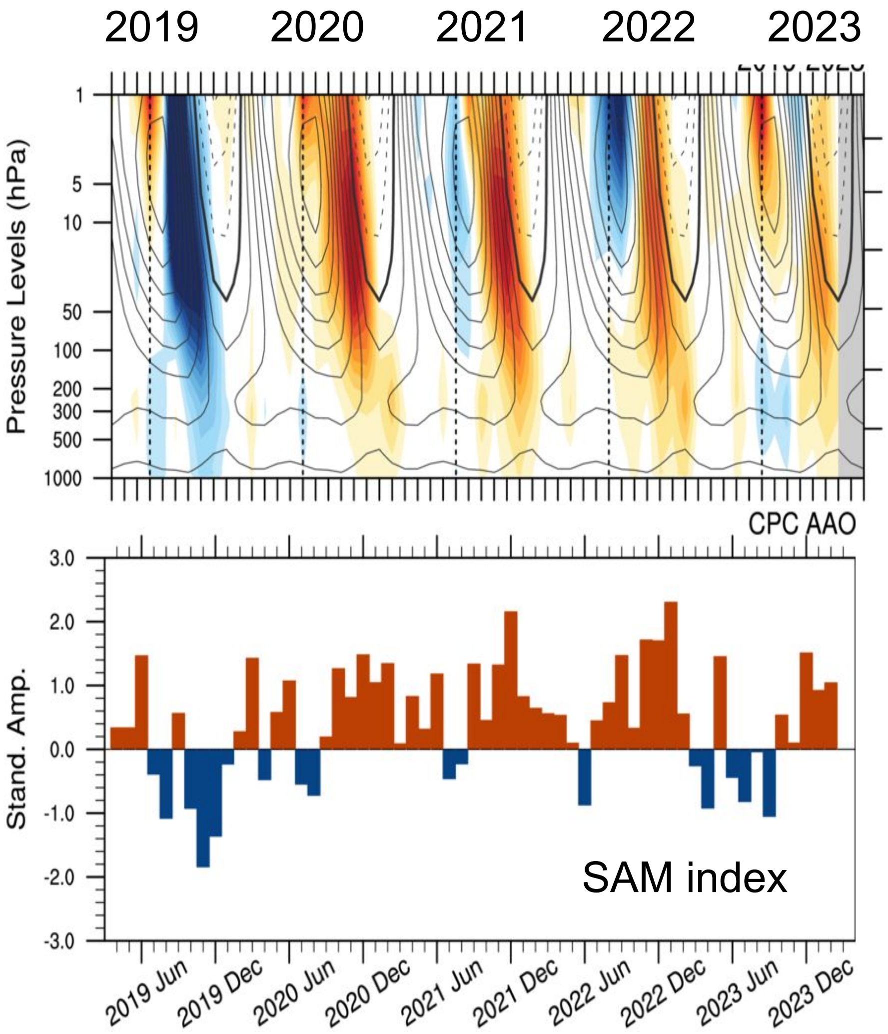
A sudden polar vortex weakening in 2019 =>



Lim et al 2021

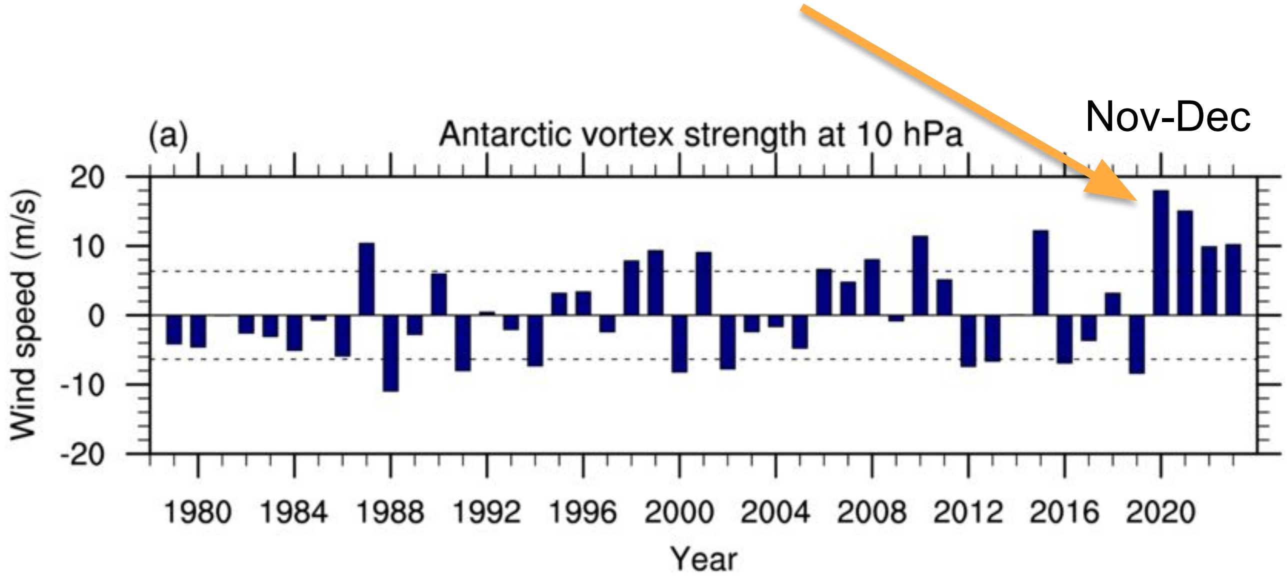
Recent extreme variability of the SH polar vortex

Zonal mean westerly anomalies at 60S (JRA-55)

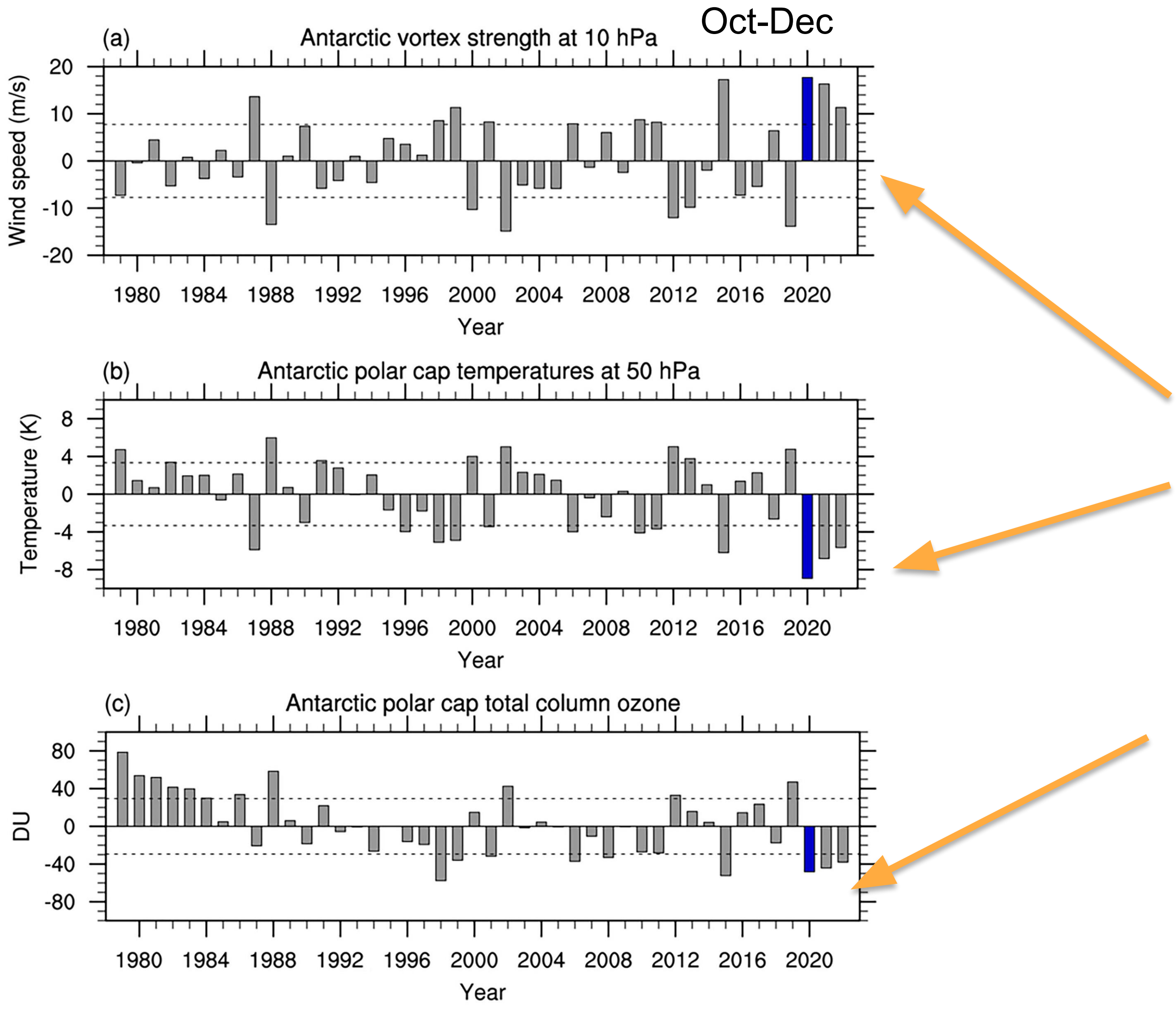


After the extreme stratospheric vortex weakening and warming event in 2019, the Antarctic stratosphere experienced four consecutive strong vortex events in austral late spring seasons

The 2020 vortex in late spring was **the strongest** on record in the last 45 years



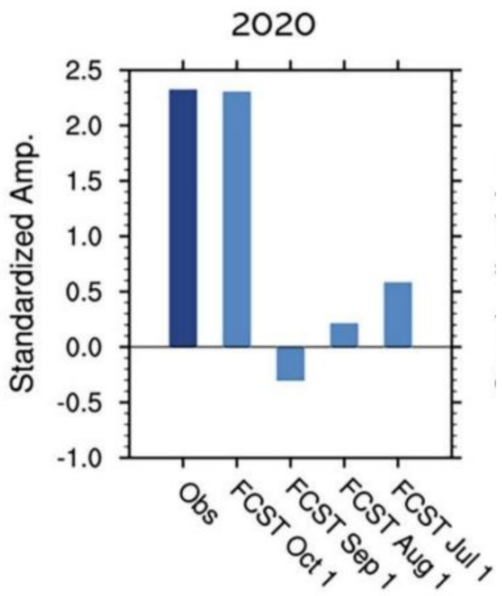
The 2020 Antarctic polar vortex event



For Oct-Dec the 2020 vortex in late spring was the **strongest** and **coldest** on record in the last 45 years and had significant **ozone depletion** over Antarctica

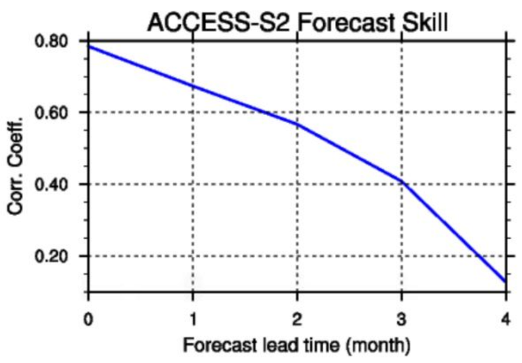
Lim et al JGR 2024

ACCESS-S1 forecast of the mean SH stratospheric polar vortex

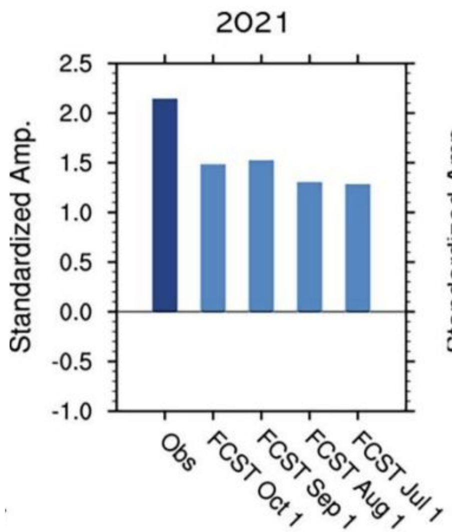


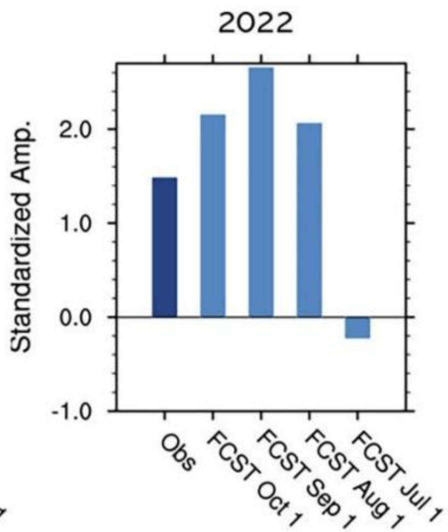
The extraordinary circulation pattern of September 2020 was not well predicted by the Australian Bureau of Meteorology's coupled ocean-atmosphere seasonal forecast system (ACCESS-S1)

The polar vortex was not predicted even at 1 month lead time



Oct-Dec mean stratospheric vortex forecast skill





In contrast with the 2021 and 2022 polar vortex strengthening cases which were well predicted as much as three months in advance

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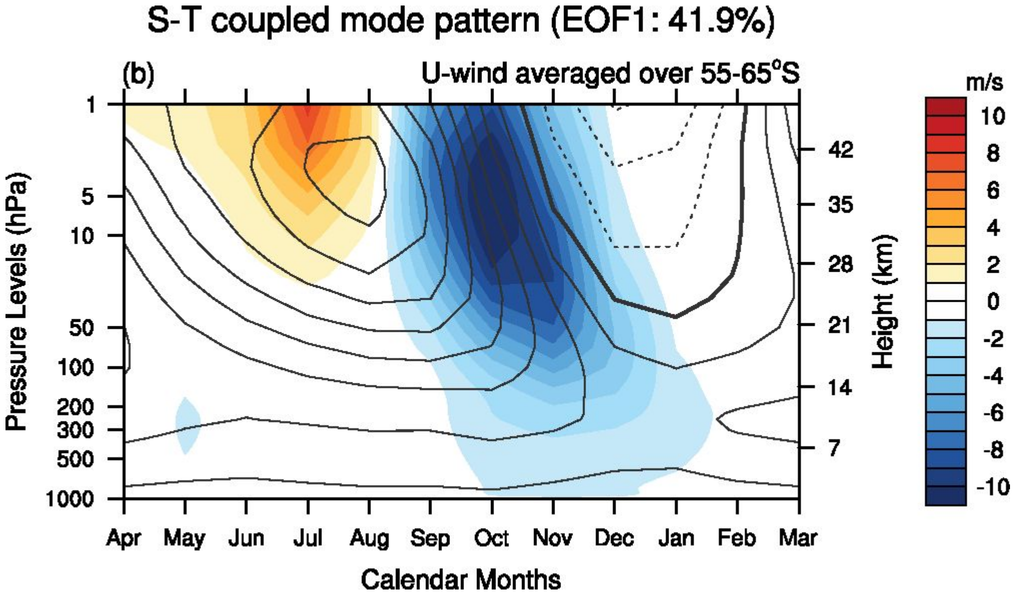
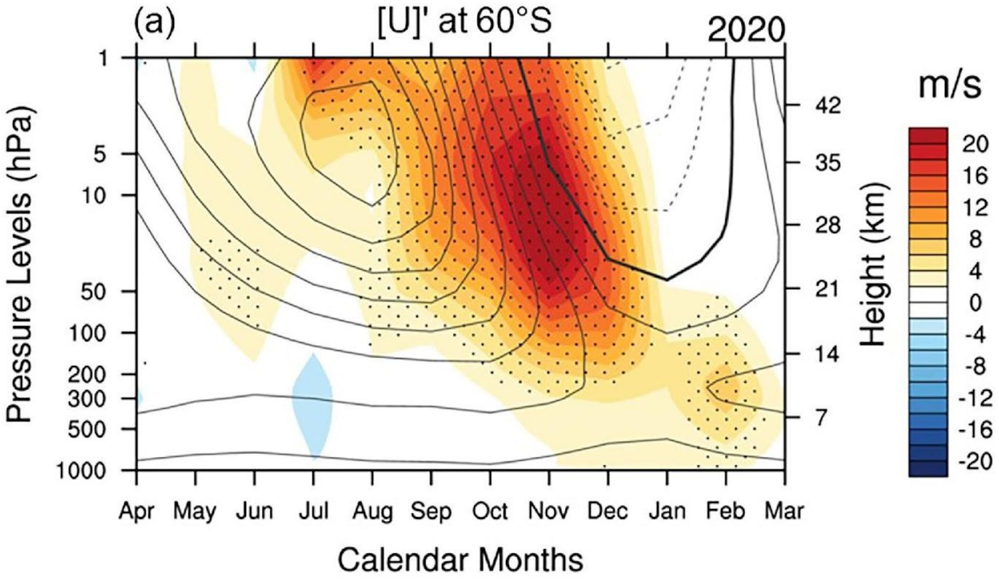
The 2020 Antarctic polar vortex event



Canonical vortex weakening/strengthening has maximum wind anomalies in upper stratosphere in October & downward propagation of the signal through Oct-Jan



In 2020 the vortex did not follow this canonical pattern. The upper stratospheric winds remained remarkably persistent through October before coupling down to the surface

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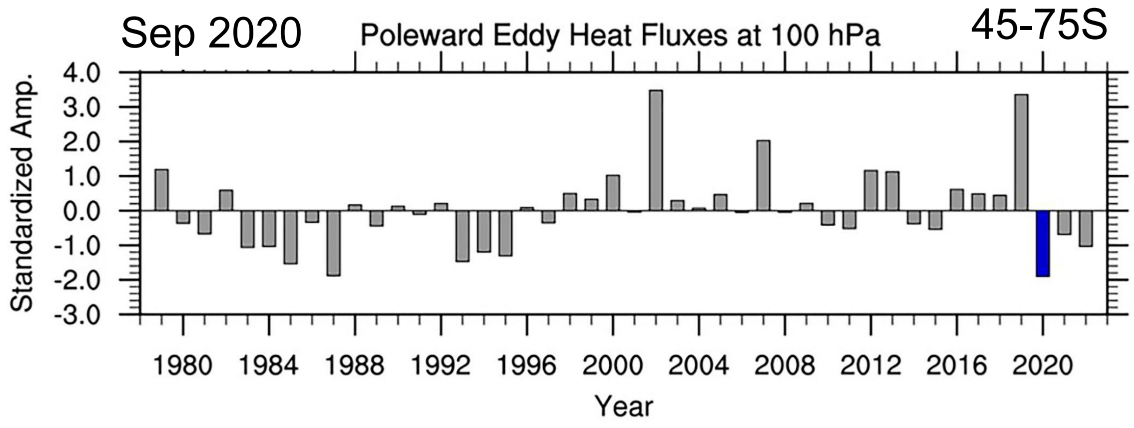
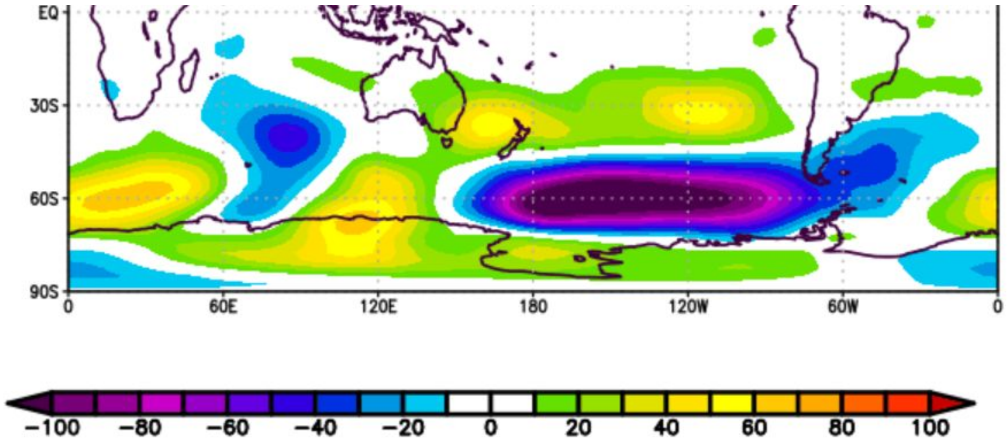
The 2020 Antarctic polar vortex event



The reduction of upward propagating wave activity in September 2020 was on par with the previous record set in 1987

700 hPa geopotential height anomaly in September 2020



An anomalous tropospheric circulation pattern that persisted in September 2020, reduced the upward propagating wave activity, therefore leaving the vortex undisturbed and staying strong

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ACCESS–S2: Bureau of Meteorology's ocean-atmosphere coupled dynamical subseasonal to seasonal forecast system

Atmospheric model
Global Atmosphere 6.0 (GA6): The Unified Model version 8.6 (UM; Williams *et al.* 2015; Walters *et al.* 2017)
Horizontal resolution: N216 (~60 km in the mid-latitudes)
Vertical resolution: 85 levels
Land surface model
Global Land 6.0 (GL6): Joint UK Land Environment Simulator (JULES; Best *et al.* 2011; Walters *et al.* 2017) with four soil levels
Ocean model
Global Ocean 5.0 (GO5): Nucleus for European Modelling of the Ocean version 3.4 (NEMO ORCA25; Madec *et al.* 2013; Megann *et al.* 2014)
Horizontal resolution: 0.25°
Vertical resolution: 75 levels. Level thicknesses range from 1 m near the surface to ~200 m near the bottom (6000-m depth)
Sea Ice model
Global Sea Ice 6.0: Los Alamos Sea ice model version 3.1 (CICE; Hunke and Lipscomb 2010; Rae *et al.* 2015)
Coupler
Ocean Atmosphere Sea Ice Soil coupler version 3.0 (OASIS3, Valcke 2013)

Data assimilation and initial conditions

ACCESS-S1	**ACCESS-S2**
• Met Office FOAM 3D-Var data assimilation scheme (Blockley *et al.* 2014) • FOAM provides ocean and sea-ice initial conditions • Atmospheric initial conditions from pre-existing analysis: ERA-Interim (Dee *et al.* 2011) or the Bureau's 4D-Var analysis (Bureau of Meteorology 2019*a*) • Climatological soil moisture initialisation	• The Bureau's weakly coupled ensemble optimum interpolation data assimilation scheme (described in this paper) • This system produces ocean, sea-ice and land surface initial conditions • Atmospheric initial conditions from pre-existing analysis: ERA-Interim (Dee *et al.* 2011) or the Bureau's 4D-Var analysis (Bureau of Meteorology 2019*a*) • Dynamic soil moisture initialisation influenced by atmospheric 4D-Var

Wedd et al 2022

ACCESS-S2 experiments for understanding the 2020 SH polar vortex

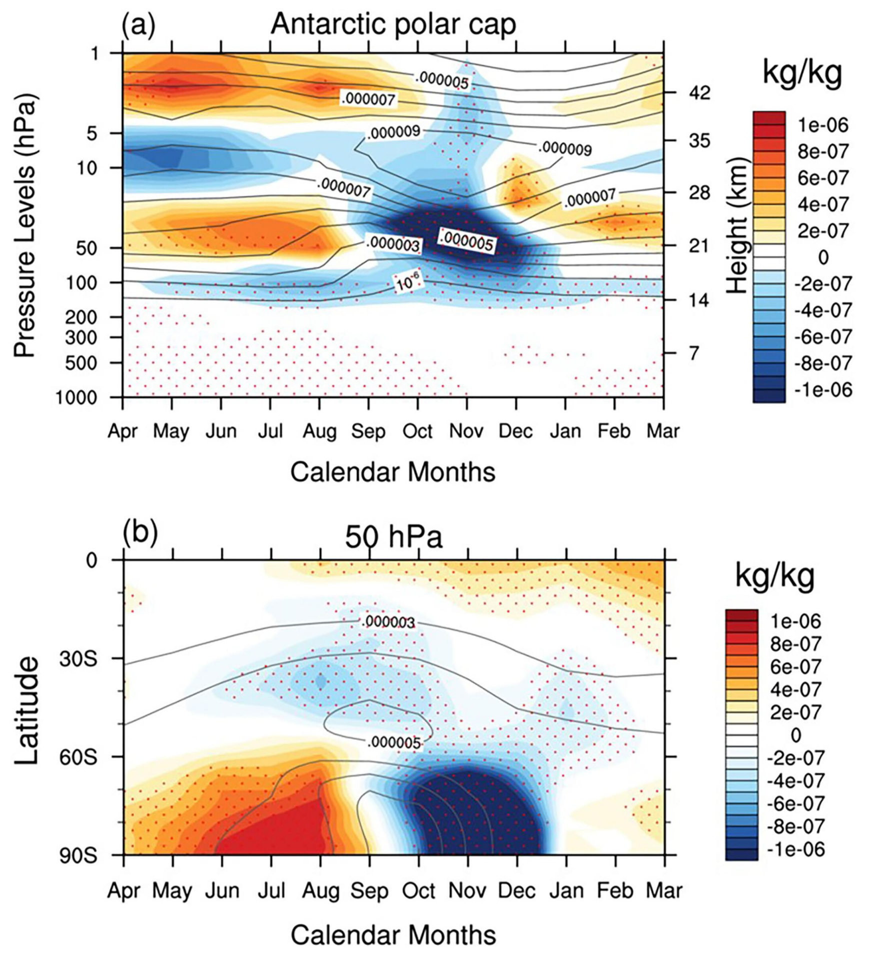
Control experiments

3-member ensemble hindcasts for 1981–2018 to compute the forecast climatological mean and standard deviation and 33-member ensemble forecasts for 2020 using monthly *climatological* zonal-mean ozone averaged over 1994–2005 (Cionni et al., 2011).

Ozone experiments

33-member ensemble forecasts for 2020 using the prescribed *2020 observed* monthly zonal-mean ozone anomalies from ERA5 added onto the Cionni et al. (2011)'s monthly ozone climatology

Ozone anomalies in 2020



All experiments were initialized on 1 September 2020

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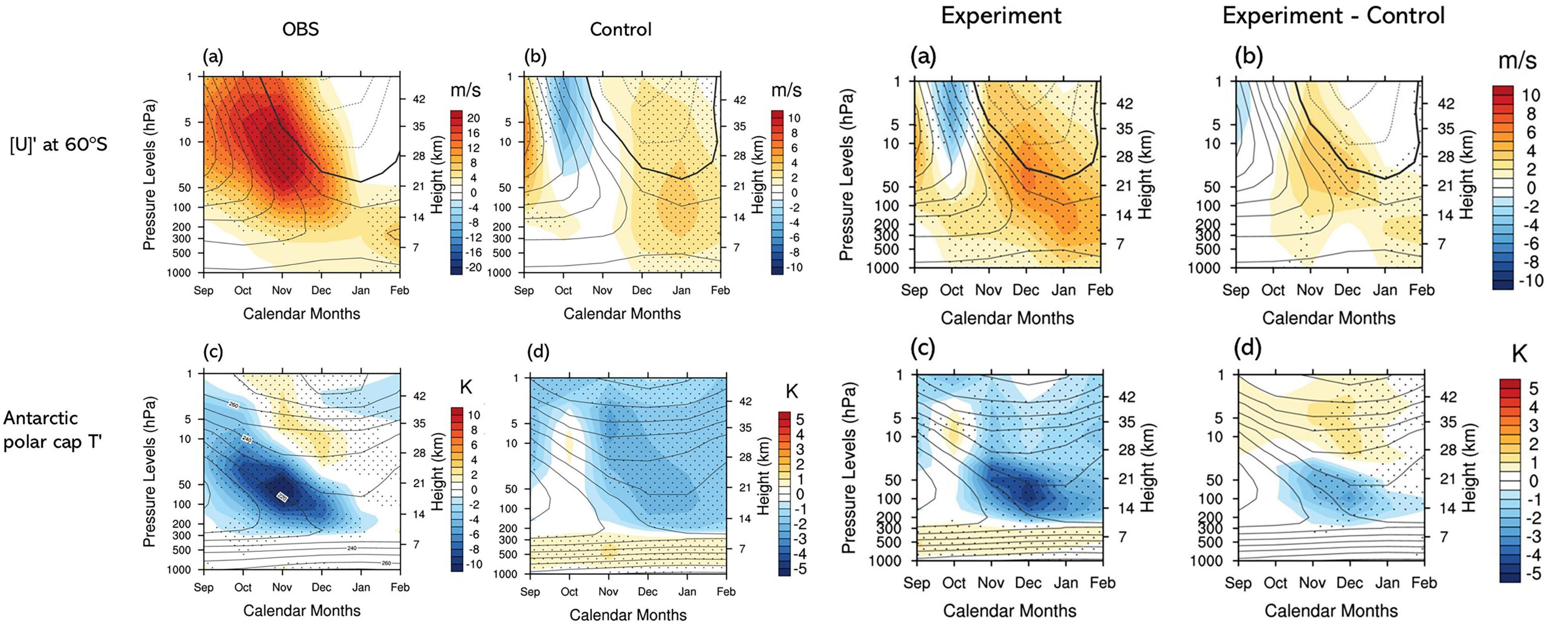
ACCESS-S2 experiments for understanding the 2020 SH polar vortex



Including realistic ozone in ACCESS-S2 experiments improves the simulation of the 2020 SH polar vortex

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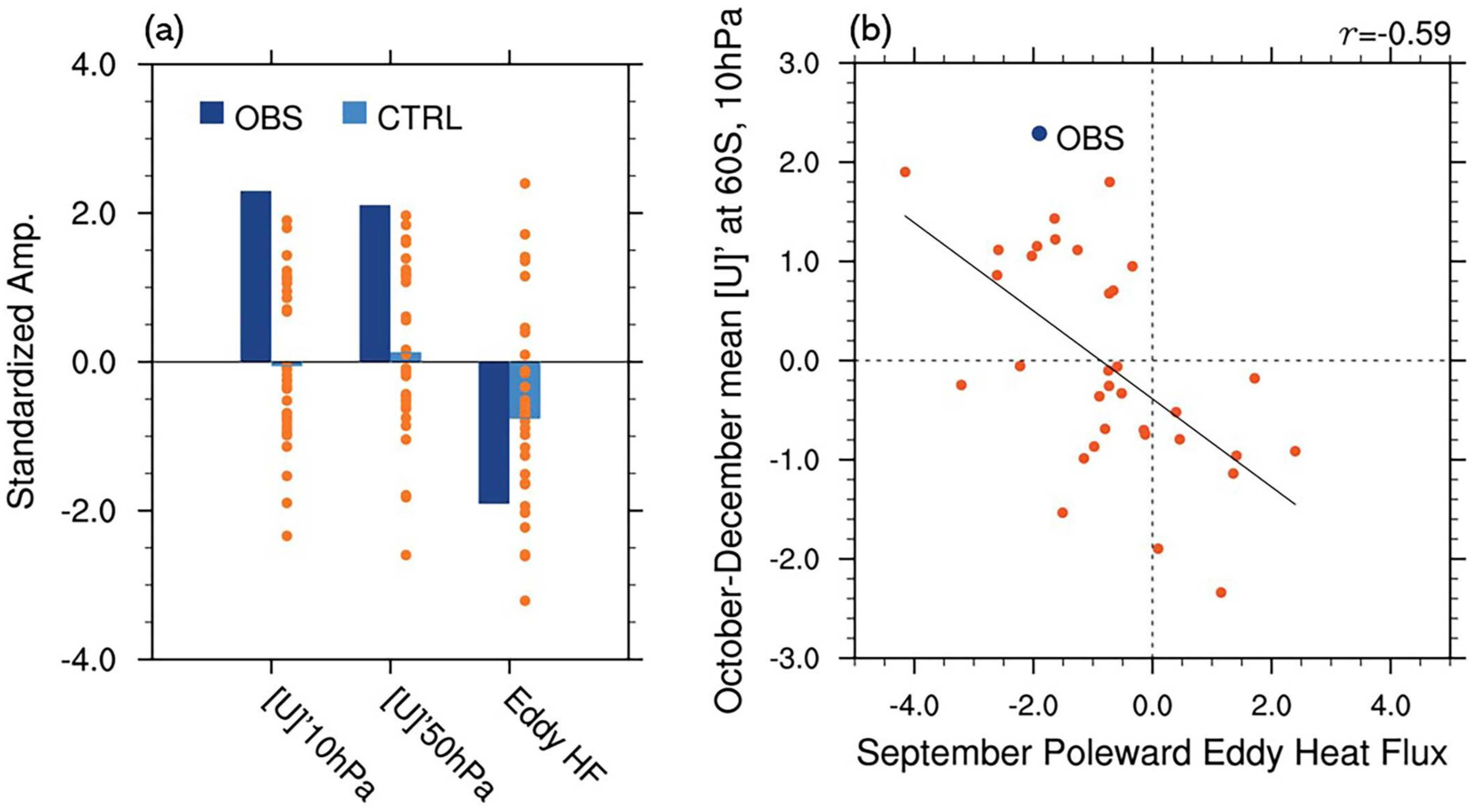

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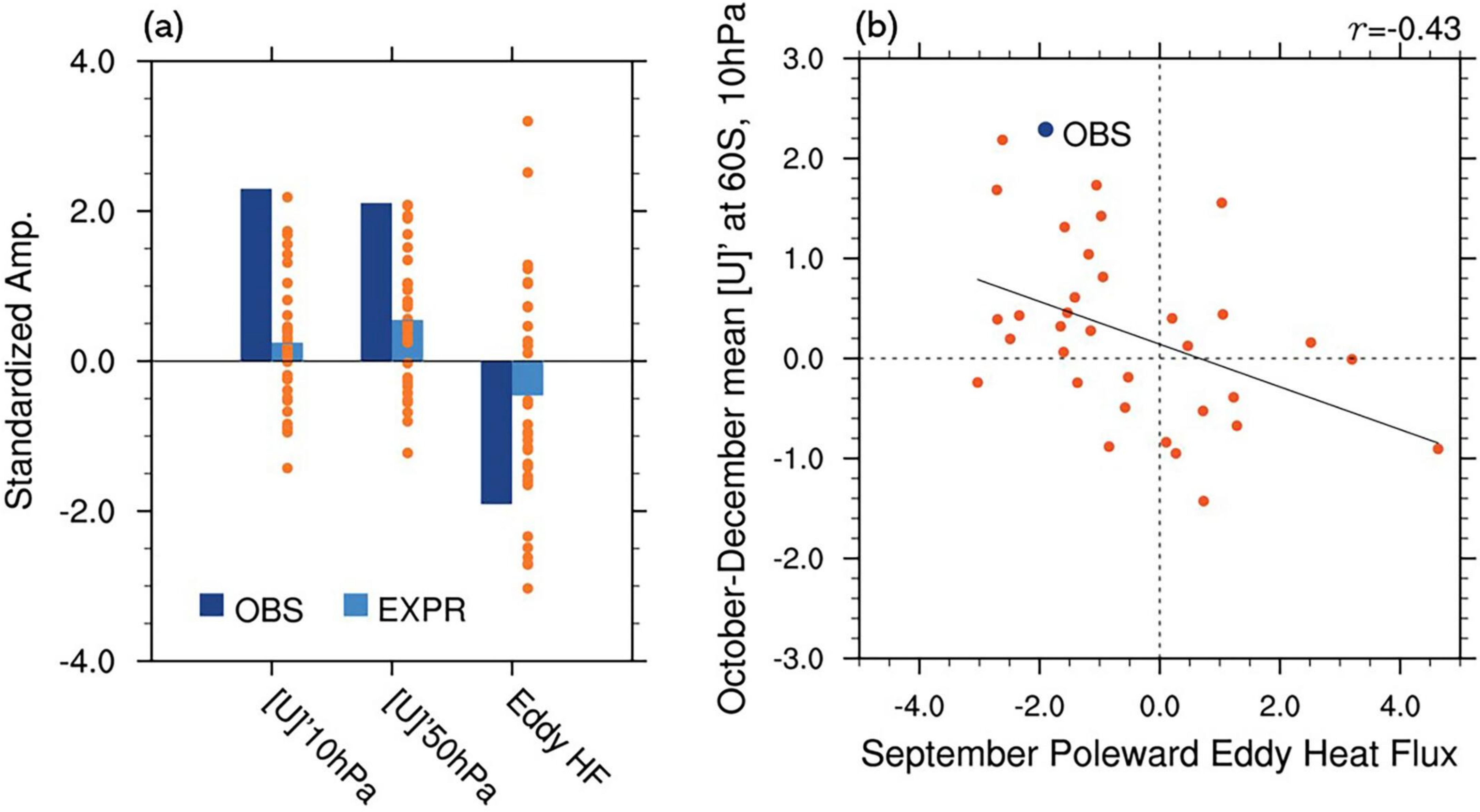

Oct-Dec 2020

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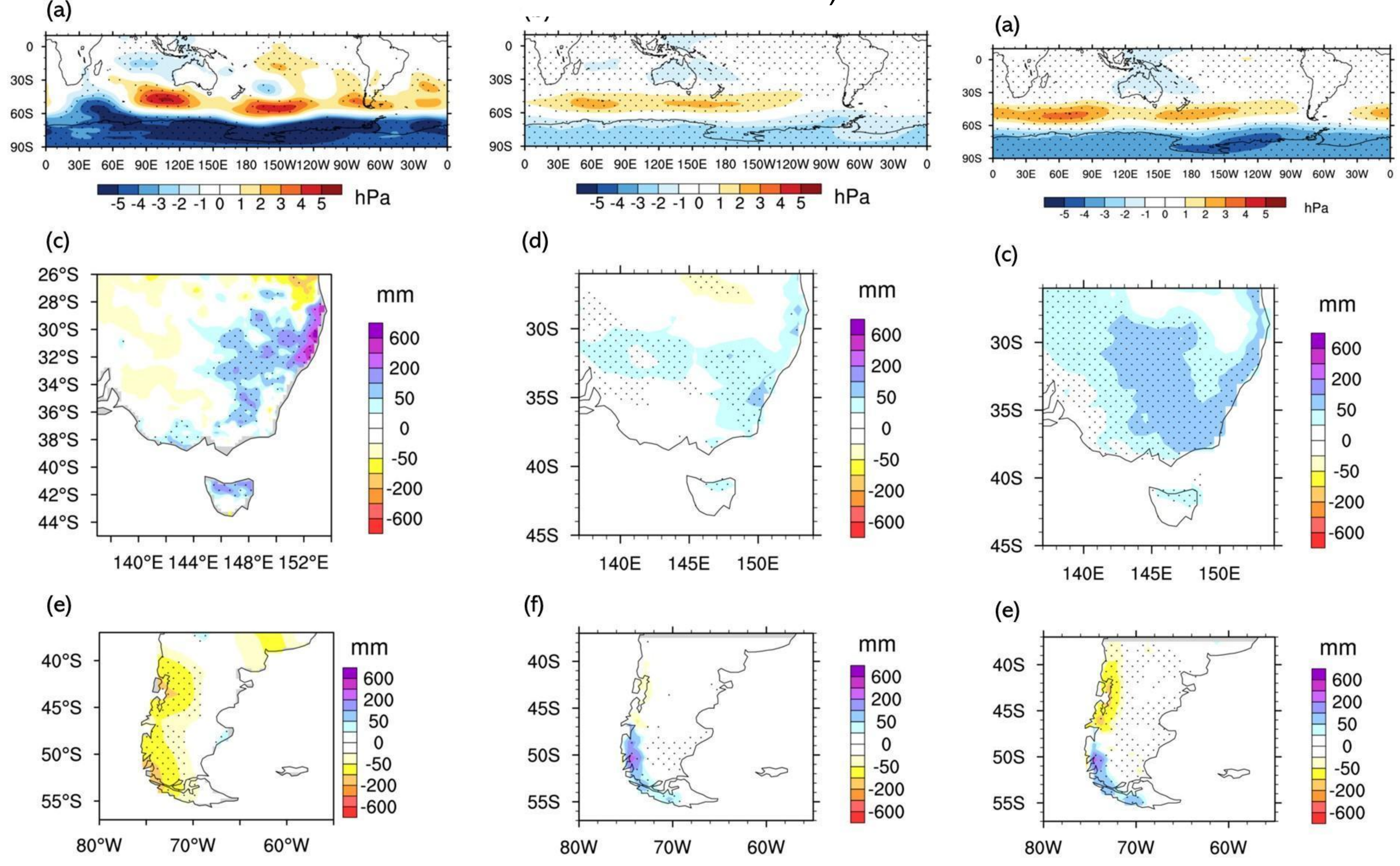
Observed anomalies | Forecast (with climatological ozone concentrations) | Forecast including realistic ozone concentrations



ACCESS-S2 predictions of December-February of 2020-2021 with one month lead time

Using the observed 2020 spring ozone in ACCESS-S2 experiments had ~10-20% improvement in forecasting the strong polar vortex at lead-time of one month & significant improvements in forecasting subsequent positive SAM & increased summer rainfall over the eastern part of SEA at lead time 3 months.

Scope for further improvements in the forecast skill for the SH climate by improving the ozone representation and its feedback in a forecast system

Lim et al JGR 2024

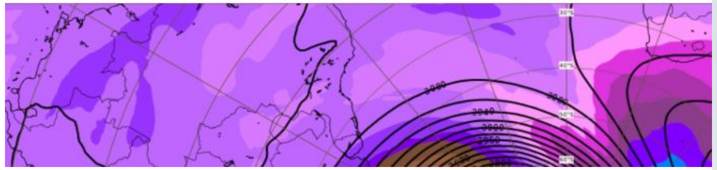
Winter stratospheric warming in July-August 2024

Sudden stratospheric warming event underway – here's what it means for Australian weather

SHARE

Ensemble mean for 10 hPa temperature and geopotential

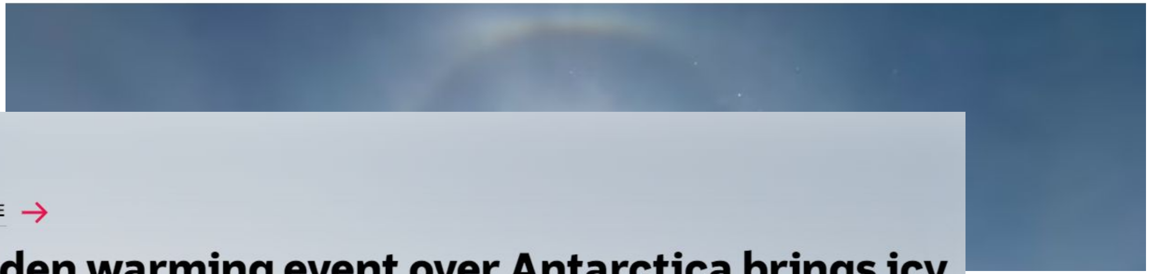
Base time: Thu 11 Jul 2024 12 UTC Valid time: Sun 14 Jul 2024 03 UTC (+63h) Area : South Pole

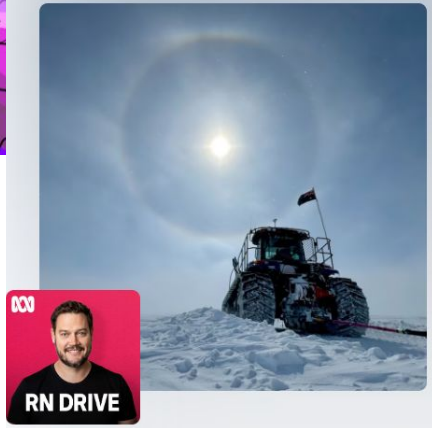


Record 50C temperature increase over Antarctica to shift Australia's weather patterns

By ABC meteorologist Tom Saunders

Posted Sat 27 Jul 2024 at 6:33am, updated Sat 27 Jul 2024 at 7:12am





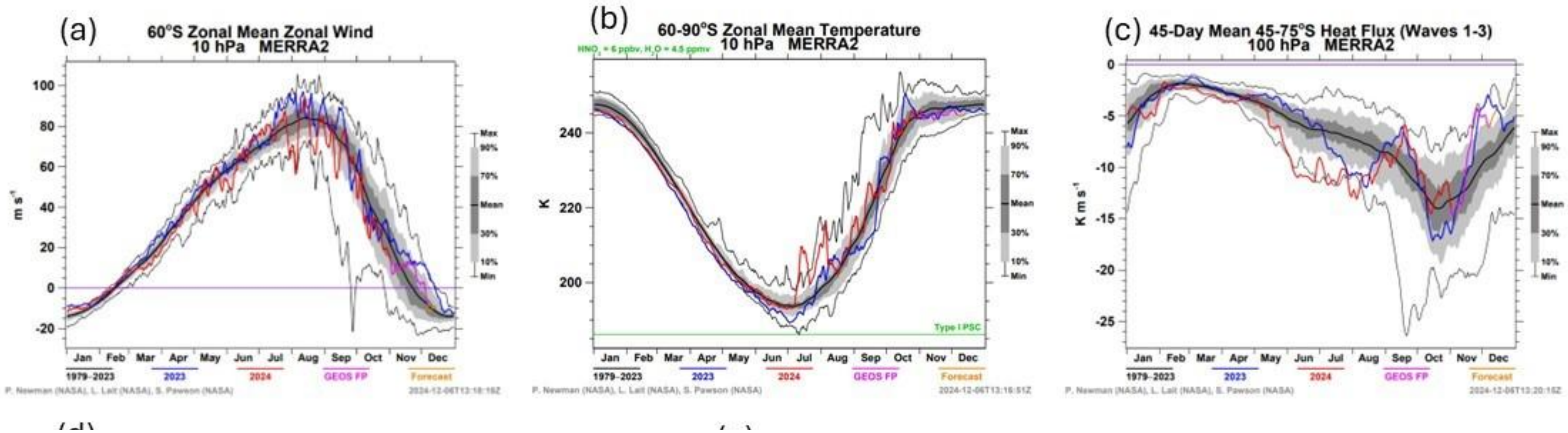
RN DRIVE →

Sudden warming event over Antarctica brings icy weather to Australia

Broadcast Mon 29 Jul 2024 at 5:20pm

Play 7 m

Winter stratospheric warming in July-August 2024



Sudden stratospheric warming events frequently occur in the NH in winter

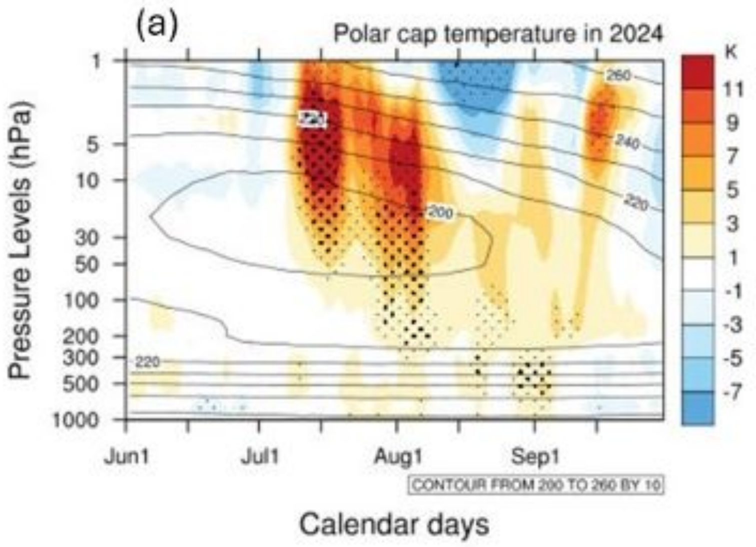
They are very rare in the SH because

- planetary-scale wave activities that erode the vortex are weak in the SH – i.e. ocean hemisphere
- the stratospheric vortex is strong likely because of the presence of Antarctica & the weak planetary-scale wave forcing

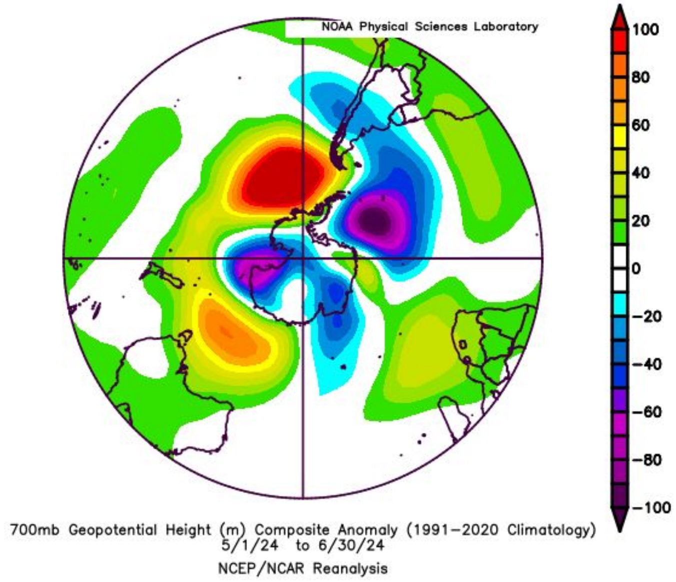
Winter stratospheric warming in July-August 2024

The winter stratospheric warming event was caused by the persistent lower tropospheric circulation anomaly pattern, characterised by primary high-pressure anomalies over the Bellingshausen and Amundsen Seas and secondary high-pressure anomalies south of Australia in May and June 2024

- unprecedentedly active upward wave propagation
- eroded the stratospheric vortex, causing the vortex to substantially shrink towards the pole, and warmed the Southern Ocean & the Antarctic coastal region

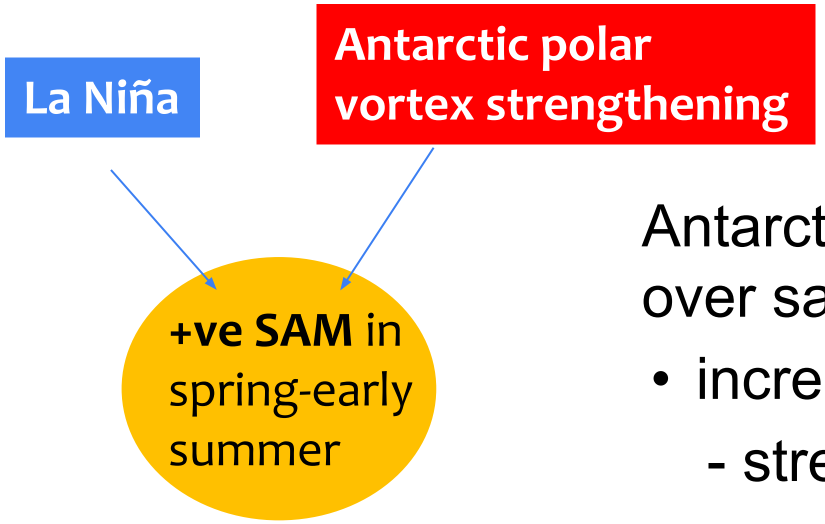


May-June mean height anomalies at 700 hPa



Lim et al (in preparation)

Sources of SH subseasonal to seasonal predictability



-ve SAM (+ve SAM) can be promoted by eastern Pacific El Niño (La Niña) in late spring – early summer

Antarctic polar vortex variation and ENSO are not strongly related over satellite era. ENSO can …

- increase the predictability of SAM
  - strengthening of vortex + La Nina □ +ve SAM (e.g. 1998, 1999)
  - weakening of vortex + El Nino □ -ve SAM (e.g. 1982)
- decrease the predictability of SAM
  - strengthening of vortex + El Nino (e.g. 2015)
  - weakening of the vortex + La Nina (e.g. 2016)

- Two sources of predictability of SAM and associated surface climate in late spring to early summer
- Both ENSO and Antarctic polar vortex behaviour need to be well monitored and predicted for skilful forecasts of SAM & SH warm season climate

Summary

- Dynamical seasonal evolution of the polar vortex from winter to early summer is an important source of long-lead predictability of SH climate anomalies
- Antarctic stratospheric polar vortex variability has been exceptionally large over the last 5 years, directly impacting the surface SAM and associated SH climate anomalies in spring and summer
- Case study of the 2020 super vortex - Antarctic ozone is another important source of predictability of the SH surface climate anomalies => improving the realistic ozone representation in seasonal forecast systems can improve the forecast skill for the SH climate anomalies
- Antarctic upper stratosphere experienced extraordinary warming in July and August 2024 with the early July warming being the greatest on record for that time of year
- Surface negative SAM was extraordinarily strong and persistent, making a record for early August – finding the mechanistic linkage with the stratospheric warming event needs further investigation