# Decadal changes in the Antarctic sea ice response to the changing ENSO in the last four decades

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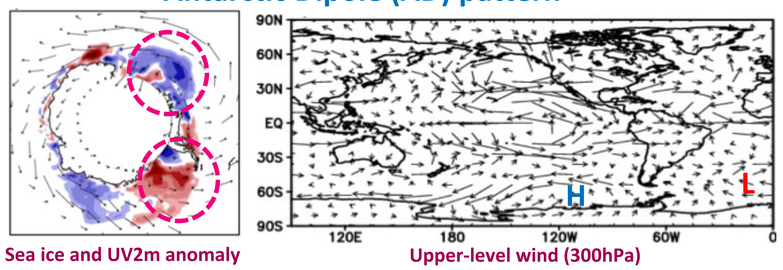
## Antarctic Dipole (AD) pattern




Sea ice and UV2m anomaly

Upper-level wind (300hPa)

## Abstract

The Antarctic Dipole (AD) structure, resulting from the Pacific South American pattern triggered by the El Niño-Southern Oscillation (ENSO), leads to a reduction in sea ice over the Ross and Amundsen Sea in the Pacific sector and an increase over the Weddell Sea in the Atlantic sector during El Niño, with the opposite occurring during La Niña. In the initial two decades of the 21st century, there is a notable weakening of the AD pattern compared to the late 20th century. This research provides evidence that the weakened AD pattern and the associated sea ice response are connected to a higher frequency of weaker and central Pacific type ENSO events, on average, in the early 21st century as opposed to the late 20th century.

## Data and Method

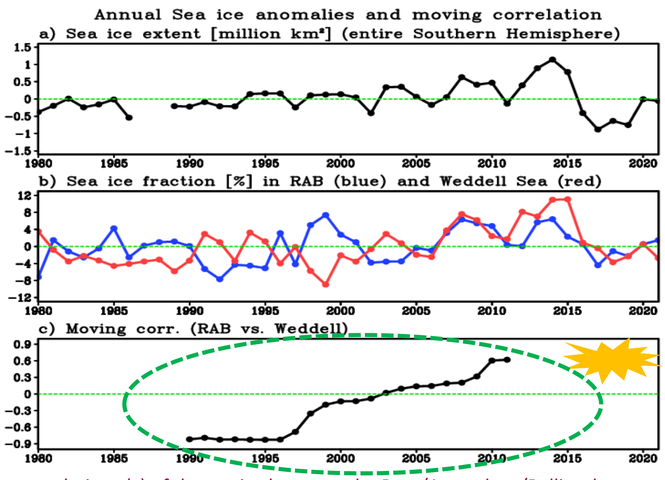
### A. Data

- SST: The Merged Hadley NOAA/OI SST,
- Sea ice extent: National Snow and Ice Data Center (NSIDC)
- Sea ice fraction: Modern-Era Retrospective analysis for Research and Applications (MERRA-2)
- Atmospheric variables from MERRA-2: Upper-tropospheric wind, temperature, and geopotential height (300hPa), vertical wind at each pressure level (1000 to 100hPa), sea level pressure, and 2-meter wind.

### B. Primary Methods

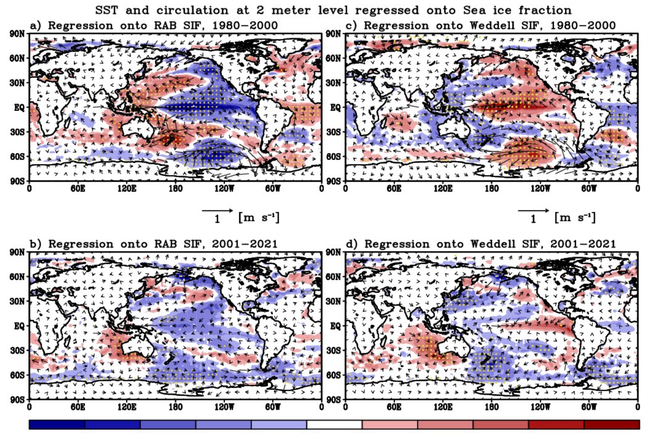
- Time-lagged moving correlations
- Time-lagged regressions of sea ice, SST, wind, geopotential height, Hadley/Ferrell cell, Wave activity flux onto the mature phase of El Niño
- Wave activity flux (WAF) is calculated to assess how large-scale waves propagate spatially toward Antarctica in response to the ENSO.
- Rossby wave source is calculated to distinctly pinpoint the origin of the wave.

## Decadal change in the Antarctic Dipole (AD)



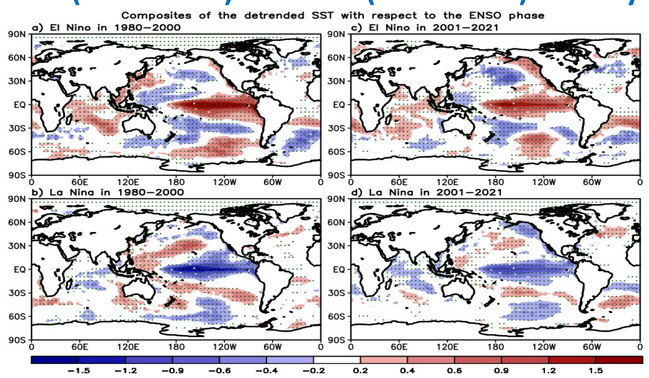

Moving correlations (c) of the sea ice between the Ross/Amundsen/Bellingshausen and Weddell Sea, applying 21-year sliding window, exhibits a significant change in correlation when comparing the 20th century (with a negative corr.) to the 21st century (positive correlation)!

## Decadal change in remote connection between SST and Antarctic sea ice




Opposing (same) SST anomalies are seen over Ross/Amundsen/Bellingshausen and Weddell during the 20th (21st) century, reflecting a robust (diminished) AD structure. The SST pattern in the tropical Pacific resembles the distribution associated with ENSO. This ENSO-related distribution is evidently prevalent in the 20th century, but considerably weaker in the 21st century period.

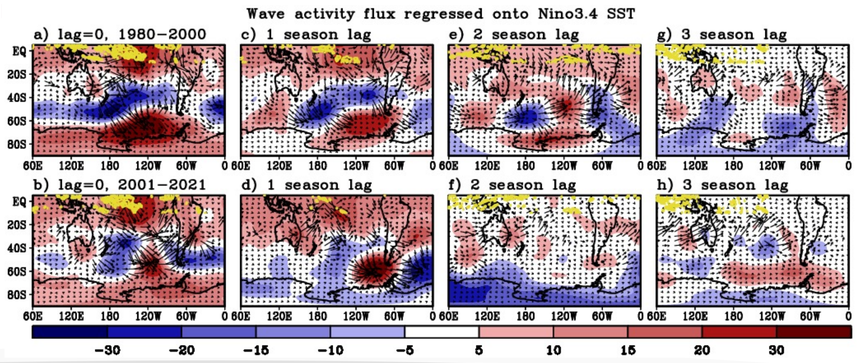
## Difference in the type and intensity of ENSO between the 20th (1980-2000) and 21st (2001-2021) century



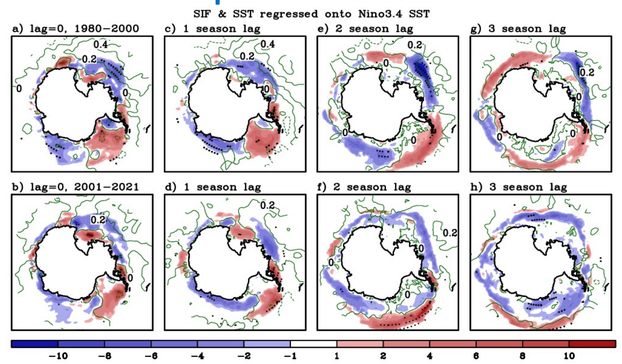

The amplitude of anomaly in the tropical Pacific (ENSO occurrence region) is clearly larger for the late 20th century (~34% larger for El Niño and ~53% larger for La Niña). In the 20th century period, the SST anomaly distribution extends prominently to the eastern equatorial Pacific, resembling the EP type ENSO pattern. Conversely, the maximum amplitude of the SST anomaly in the 21st century period is found in the central equatorial Pacific.

## Large-scale wave activity associated with ENSO

Wave activity flux (vector), 300hPa height (shaded), and Rossby wave source (contours).
A prevailing northwest-southeast aligned Rossby wave train is prominent at lags of 0 and 1 season during the 20th century (a and c), followed by wave flux vectors aligned more zonally at a lag of 2 seasons (e), while the wave train is notably insignificant at that lag in the 21st century (f). Rossby wave source patterns exhibit clearly that the tropical Pacific is a wave source more dominantly at lags of 0 and 1 season.

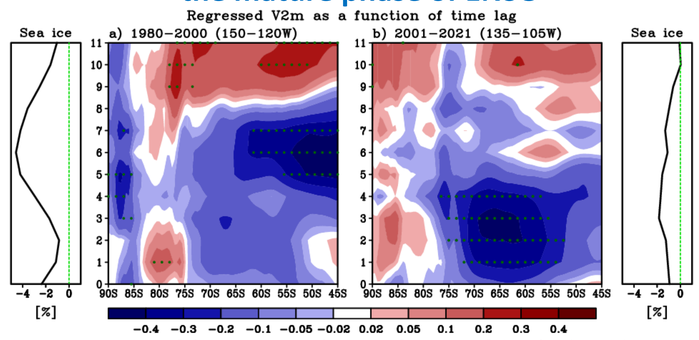



## Lagged response of the SST and sea ice to the mature phase of ENSO




The regressed anomaly over the Ross-Amundsen-Bellingshausen (RAB) Sea reaches the maximum at 2 season lag in the late 20th century, while the amplitude gets weak at the same lag in the early 21st century. AD structure persists through the 3-season lag in the 20th century, while the weakening of the AD pattern is seen with negative sign of anomalies over both the RAB and Weddell Sea starting at the 2-season lag in the 21st century.

## Lagged response of the near-surface meridional flow to the mature phase of ENSO




Lat.-time cross-section of the V2m anomalies, as a function of time lag (y-axis), regressed onto the DJF Niño3.4 SST. Line curves: Regressed sea ice fraction anomaly over the RAB Sea area as a function of time lag from 0 to 11 month.
During the late 20th century (left), the prevailing negative anomaly (poleward northly flow) is most pronounced at lags of 5-7 months, resulting in the greatest reduction in sea ice in response to El Niño. In the early 21st century (right), the most robust poleward flow is seen at lags of 0-4 months, aligning with the highest sea ice reduction at those lags, followed by significant weakening of the poleward flow afterwards.

### For more details, please refer to

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