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Trends in mean and extreme winds over the Southern Ocean from 1980-2020

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Abstract

- Winds important for SO circulation and things
- Trends due to ozone depletion etc
- Evaluate trend, means, extremes

Introduction

Strong near-surface westerly winds are a dominant feature of the midlatitude atmospheric circulation above the Southern Ocean, playing an important role in regional climate, including storm patterns {xx}, precipitation {xx} and temperature {xx}. These winds also drive the Antarctic Circumpolar Current, the largest ocean current and a dominant feature of the local circulation that acts as an important control on the Southern Ocean heat and carbon sink {xx}. In the latter half of the 20th century, the depletion of stratospheric ozone has driven an acceleration and poleward shift of Southern Ocean winds, particularly in the austral summer, with an accompanying shift towards a more positive index of the southern annular mode (SAM), the principal mode of atmospheric variability(Swart & Fyfe, 2012) (xcc=cite Marshall2003?) {xcc-Thompson and Solomon 2002}. As Southern hemisphere ozone levels are projected to recover, this ozone-driven latitudinal shift and intensification may reverse, but may be counteracted by a greenhouse-gas driven trend towards stronger and more southerly winds, year round. (xcc-Bracegirdle)

These changes in the Southern Hemisphere wind regime are likely to have multiple downstream effects on the local and global climate system and have thus attracted substantial research. Past work has observed an overall summertime poleward trend in the position of the wind jet in both reanalyses and earth system models (i.e., the location of the strongest westerly winds), as well as its intensification {Swart and Fyfe 2012, xx-see other waugh citations)}, with substantial longitudinal variation {Goyal 2021, Waugh 2020}. However, differences in representation of these trends exist between reanalysis products, which may translate to differences in ocean properties when comparing global ocean models forced by varying reanalyses {e.g. GCB 2023-xx}, or have implications for energy production (xx). Furthermore, most studies to date have focused on the mean trend in the wind jet and omitted variability and the extreme winds, which are disproportionately important for example in air-sea interaction (xx). Here, we first aim to provide a comprehensive overview of the representation of Southern Ocean winds in a number of the most commonly used reanalysis products over 1980-2020, evaluating a climatology, mean wind speed trends, trends in the position of the wind jet, and trends in extreme winds, as well as the representation of the SAM index (xcc-garettmarshall?), considering a relationship between trends in the SAM index and trends in major wind speed. We then use the UKESM1 model to estimate the contribution of ozone depletion to the observed changes.

Methods

Selection of Reanalyses and their previous in-situ evaluation

Meteorological reanalysis combines satellite and in-situ observations with numerical weather prediction systems to attempt to provide the best estimate of the atmospheric state at any given time. Currently, a large number of global atmospheric reanalysis products are available (see https://reanalyses.org/atmosphere/overview-current-atmospheric-reanalyses for an overview). It is not practically feasible to analyze all of them, so we select an available subset of reanalyses that are commonly used in research: ERA5, NCEP-NCAR1, JRA3Q, and NASA-MERRA2 [xx-Table-products].

Table-products

product	**type**	source	**native temporal resolution**	**native spatial resolution**
NASA-MERRA2	Reanalysis	https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/	hourly	0.5 ° x 0.625 °
ERA5	Reanalysis	https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels	hourly	~0.25 deg

NCEP-NCAR	Reanalysis	https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html	6-hourly	~1.5 deg
JRA3Q	Reanalysis		6-hourly	~1.5 deg
UKESM1	Earth system model	xx - fill in	3-hourly	~0.75 deg

xx-before 1979 not enough satelites
xx-JRA does well ERA does well
xx-we follow Goyal in treating ERA5 as our 'benchmark reanalysis'

The advantage of reanalysis products is typically global spatial coverage and uninterrupted temporal coverage over several decades. However, especially in remote regions, these products are often based on sparse observations and evaluations may be limited. We briefly survey some existing in-situ

Li et al (2013) found that ERA-Interim (predecessor to ERA5) had a low bias against in-situ shipboard observations (0.06 m/s), as compared to 1.37 m/s for NCEP-DOE, predecessor to NCEP-DOE2. (In this study, we initially also analyzed NCEP-DOE2, an update of NCEP-NCAR1, but ultimately excluded it because of anomalously large biases in wind speed and magnitude relative to the other four products – see Supplement xx).

Both Li and Jones find that all reanalysis products underestimate in-situ winds at low-wind (~<4 m/s) conditions and overestimate them at high-wind (~>25 m/s).

Spatiotemporal standardization

When comparing reanalysis products, we must account for their differing spatial and temporal resolution [Table-products]; for example, 10-m wind speed calculated from u and v components at hourly resolution and then averaged to daily resolution is typically higher than wind speed calculated from the same u and v components that have been first averaged to daily resolution. Thus, in order to be able to compare the products, we always first average all u and v components to daily resolution, which is the highest commonly-shared temporal resolution, and then calculate wind speed as:

Wind speed = sqrt(u-component^2 + v-component^2),

even in products where hourly wind speed is available (such as in MERRA-2).

For similar reasons, we then interpolate all three fields (u-component, v-component, and wind speed) to a standard 1°x1° grid using the same cdo package {xcc-cit}. We then use these daily standardized wind products in the intercomparison. We are interested primarily in the mean state and trends of the elevated open-ocean circumpolar winds, and the wind jet is typically found between -48°S and -54°S {xcc-Swart and Fyfe 2012}. Thus, we focus our statistical analyses on the overwater winds in the region 40°S to 60°S, and the forty-year timeperiod (Jan 1, 1980 – Dec 31, 2019). For some analyses, we further subdivide this time period into two halves, where the first half corresponds to a period of heightened ozone influence (xcc).

When reporting seasonal means, we first calculate area-weighted daily mean over-water wind speeds from the 1°x1° gridded product, then calculate the seasonal mean from these daily means. To calculate extreme winds, we calculate the daily weighted 95th percentile of winds from the 1°x1° gridded product, then take the weighted average of all cells above this percentile. For any season in any year, the seasonal extreme winds are then the average of these daily extreme winds.

SAM index

In each reanalysis, we evaluate the SAM index at monthly resolution against the observational SAM index (Marshall 2003). Following Velasquez-Jimenez, we calculate the "natural", or non-normalized, SAM index:

$SAM = P^* 40° S – P^* 65° S$,

where $P * 40° S$ and $* 65° S$ are the zonal MSLP anomalies at 40 and 65° S respectively. We calculate anomalies relative to the time period 1980-2019. In contrast to the more traditional SAM index (xcc-Marshall 2003), the natural sam index is not normalized by dividing by the reference interval standard deviation. It is therefore dimensionless and given in units of hPa. This approach has the advantage of making the trends and magnitude of the index less sensitive to sampling frequency.

Results and Discussion

Evaluation - Trends

Conclusions

Figures and tables

Figures

[1] Fig-spat-clim

Caption: A climatology of 10m wind speed for 1980-2019 for four reanalysis products and UKESM, calculated from daily-averaged winds regridded to a 1x1 degree grid.

Tables:

climatological mean windspeed	climatological extreme windspeed

	ERA5	NCEP -NCAR	MERRA2	NCEP -DOE II	UKESM
full year	9.05	9.00	8.80	10.36	9.36
DJF	8.41	8.37	8.15	9.62	8.74
MAM	9.13	9.11	8.83	10.47	9.48
JJA	9.50	9.42	9.30	10.86	9.71
SON	9.16	9.09	8.91	10.48	9.51

	ERA5	NCEP -NCAR	MERRA2	NCEP -DOE II	U
full year	15.61	15.47	15.26	18.55	
DJF	14.75	14.57	14.29	17.41	
MAM	15.76	15.65	15.34	18.75	
JJA	16.23	16.11	16.04	19.38	
SON	15.68	15.53	15.35	18.63	

climatological mean windspeed trend

climatological extreme windspeed trend

	ERA5	NCEP -NCAR	MERRA2	NCEP -DOE II	UKESM
full year	**0.036**	**0.143**	**0.096**	**0.187**	**0.035**
DJF	**0.059**	**0.166**	**0.116**	**0.200**	**0.059**
MAM	**0.054**	**0.169**	**0.130**	**0.228**	0.007
JJA	0.024	**0.130**	**0.078**	**0.180**	0.017
SON	0.009	**0.109**	**0.060**	**0.141**	**0.055**

	ERA5	NCEP -NCAR	MERRA2	NCEP -DOE II	U
full year	**0.035**	**0.231**	**0.095**	**0.356**	
DJF	**0.040**	**0.266**	**0.097**	**0.388**	
MAM	**0.060**	**0.270**	**0.157**	**0.424**	
JJA	0.028	**0.200**	**0.070**	**0.320**	
SON	0.013	**0.187**	**0.055**	**0.292**	

latitude	**-90:-30**	**-90:-70**	**-70:-50**	**-50:-30**
Full Year				
ERA5	8.02	5.98	8.66	7.72
NCEP-NCAR	7.85	5.29	8.33	7.67
NCEP-DOE	9.12	6.95	9.92	8.72
UKESM	8.27	5.64	8.73	8.12
DJF				
ERA5	7.30	5.20	7.93	7.00
NCEP-NCAR	7.16	4.65	7.67	6.96
NCEP-DOE	8.24	5.68	8.98	7.89
UKESM	7.51	4.46	7.97	7.38

MAM				
ERA5	8.09	6.21	8.96	7.62
NCEP-NCAR	7.98	5.70	8.80	7.57
NCEP-DOE	9.26	7.58	10.40	8.60
UKESM	8.38	6.06	9.12	8.02
JJA				
ERA5	8.60	6.38	8.98	8.48
NCEP-NCAR	8.37	5.52	8.53	8.43
NCEP-DOE	9.81	7.55	10.32	9.60
UKESM	8.83	6.10	8.96	8.90
SON				
ERA5	8.09	6.09	8.76	7.77
NCEP-NCAR	7.86	5.28	8.29	7.72
NCEP-DOE	9.17	6.98	9.95	8.78
UKESM	8.37	5.92	8.86	8.19

MT2-mean: Mean m/s in se