# Cloud albedo's hemispheric asymmetry: why is the Southern Ocean cloudier?

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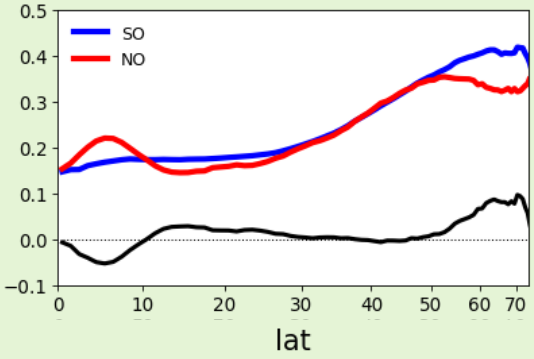
# 1. Introduction

- *Earth's albedo nearly symmetric*
- *NH's excess of landmass implies more reflection*

- ***SH must have more clouds to compensate***

- Stevens and Schwartz (2012)
- Voigt et al (2013)
- Stephens et al (2015)
- Datseris and Stevens (2021)




Time-zonal mean of cloud albedo over ocean:

- The integrated tropics (0°: ±30°) are approx. symmetric.
- SO is significantly cloudier poleward of 50°.

Objective: Identify **cloud controlling factors (CCFs)** that can explain or at least predict the hemispheric cloud albedo asymmetry over the high-latitude oceans.

# 2. Data and Methodology

## a) Cloud Albedo function

$$C = f\frac{a\tau}{2 + a\tau}$$

- Datseris and Stevens (2021)

Intrinsic property of clouds and not a measure of reflected solar radiation

- $\tau$ ***cloud optical thickness***
- $f$ ***cloud cover fraction***

## b) Data

- 15 years (2003-2017)
- MODIS Level-3
- ERA-Interim

- Timescale: 1day
- Resolution: 1°x1°
- latitude band: 50°:65°
- ocean only

- Assessment of 6 CCFs:

  SST, $\omega_{500}$, EIS,

  MCAO, $\Delta T_{sfc}$, $V_{sfc}$

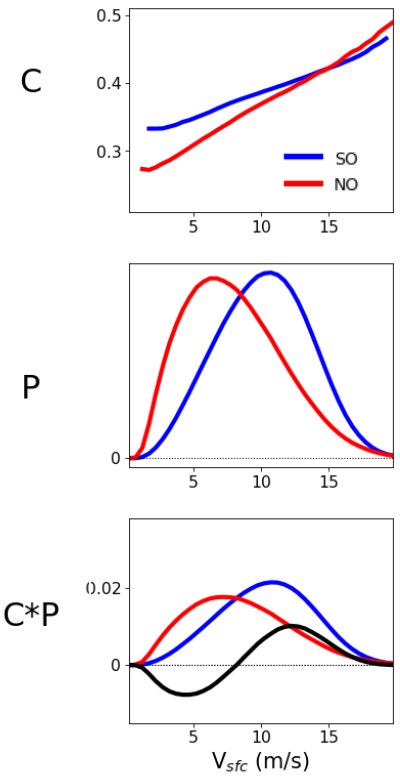
EIS= Estimated Inversion Strength

MCAO=Marine Cold Air Outbreak index

# 3. Cloud Controlling Factor approach

**EXAMPLE:**

Cloud albedo as a function of $V_{sfc}$ only (1D)




**1-** bin-averaging of the cloud albedo function C, and computation of frequency P over the range of one (or more) CCFs

**2-** albedo A expressed as the sum over all bins, of the product between C and P

$$A = \sum_{i=1}^{N} C_i\ (\phi) P_i\ (\phi)$$

**RATIONALE:**

If CCFs are hemispherically symmetric (invariance of ***C*** sensitivity to CCFs) then the asymmetry **Δ*C*** can be attributed to differences in frequencies ***P*** of these predictors.

**3-** Hemispheric asymmetry is decomposed in two terms: average of cloud albedo functions x difference in frequencies, and vice versa.

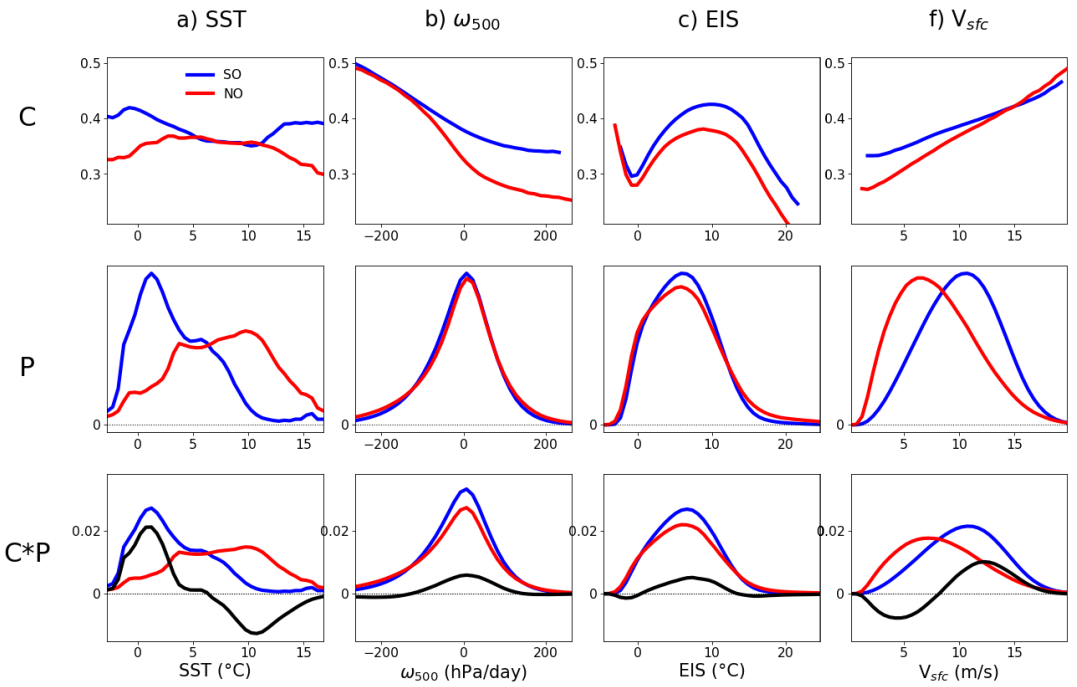
$$\Delta A = \sum_{i=1}^{N} C_i^{SO} P_i^{SO} - C_i^{NO} P_i^{NO} = \sum_{i=1}^{N} \underbrace{\frac{C_i^{SO} + C_i^{NO}}{2}\left(P_i^{SO} - P_i^{NO}\right)}_{\Delta A_a} + \underbrace{\frac{P_i^{SO} + P_i^{NO}}{2}\left(C_i^{SO} - C_i^{NO}\right)}_{\Delta A_b}$$

$$\Delta A = \Delta A_a + \Delta A_b$$

$$1 = a + b$$

**ASYMMETRY SKILL:**

By computing "$a$", each CCF can be assessed in terms of how much of the asymmetry $\Delta A$ it can predict.




$V_{sfc}$ is the most skilful predictor of the hemispheric asymmetry

| | SST | $\omega_{500}$ | EIS | $V_{sfc}$ |
|---|---|---|---|---|
| $a$ | 0.22 | -0.05 | 0.15 | 0.50 |

**$V_{sfc}$ is a good predictor of the cloud albedo asymmetry !**

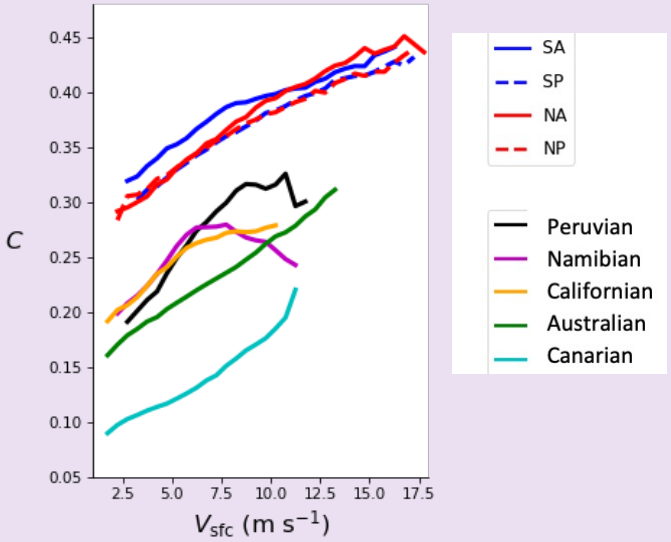
**Is $V_{sfc}$ simply a good predictor of cloudiness? Or is it a genuine CCF? If so, how?**

Theoretically & numerically

Dynamics explained in Nuijens and Stevens (2012) using LES, and also bulk theory arguments (although for the subtropical trade region). Stronger winds generate more oceanic cloud albedo.

Empirically

Robust behavior found with observations in all midlatitude, stratocumulus and shallow cumulus oceanic regions (below, Mieslinger et al 2019)




Averages over oceanic 10°x10° boxes as used in Klein and Hartmann (1993) and Wood and Bretherton (2006)

# 4. Summary

1. Novel methodology using Cloud Controlling Factor framework applied to the study of the causes of the hemispheric cloud albedo asymmetry over oceans ($\Delta A$).
2. Although $\omega_{500}$ largely controls cloud albedo, it cannot explain the observed hemispheric asymmetry.
3. $V_{sfc}$ predicts and explains cloudiness, and also its N-S asymmetry
4. Method in 2D: SST and $V_{sfc}$ combined explain 91% of the asymmetry (not shown).
5. The asymmetry is due mostly to low-level clouds (not shown)
6. The asymmetry is smallest in winter (not shown)

# 5. Questions?

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study to be submitted to Journal of Climate…
Blanco et al (2022)

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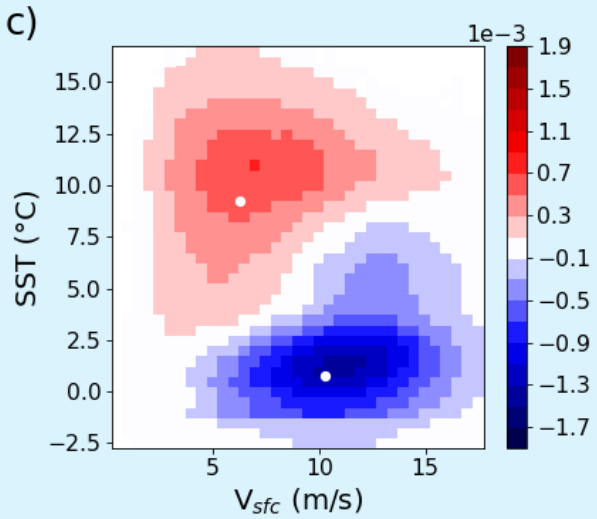
# *** 2D method: SST & $V_{sfc}$

$$\Delta A = \sum_{i,j=1}^{N,M} C_{ij}^{SO} P_{ij}^{SO} - C_{ij}^{NO} P_{ij}^{NO}$$




Southern ocean is cloudier because it's windier and colder

**ASYMMETRY SKILL:**

$\alpha$=0.91

… greater than the added values for Vsfc (0.50) and SST (0.22) in the 1D case

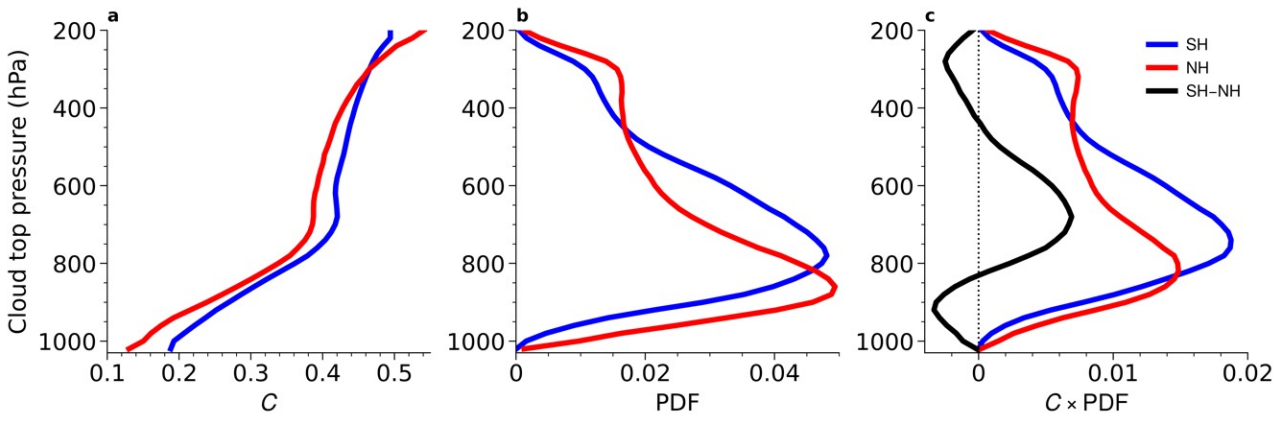
However, Vsfc and SST are not two independent CCFs. The pair is correlated:

- Large-scale meridional temperature gradient determines baroclinicity, cyclone activity, and wind strength.
- The wind-driven Antarctic Circumpolar Current generates coastal upwelling (via equatorward Ekman transport) feeding back on cold SSTs

# *** Albedo asymmetry and low clouds

ISCCP: low clouds defined as ctp > 680 hPa

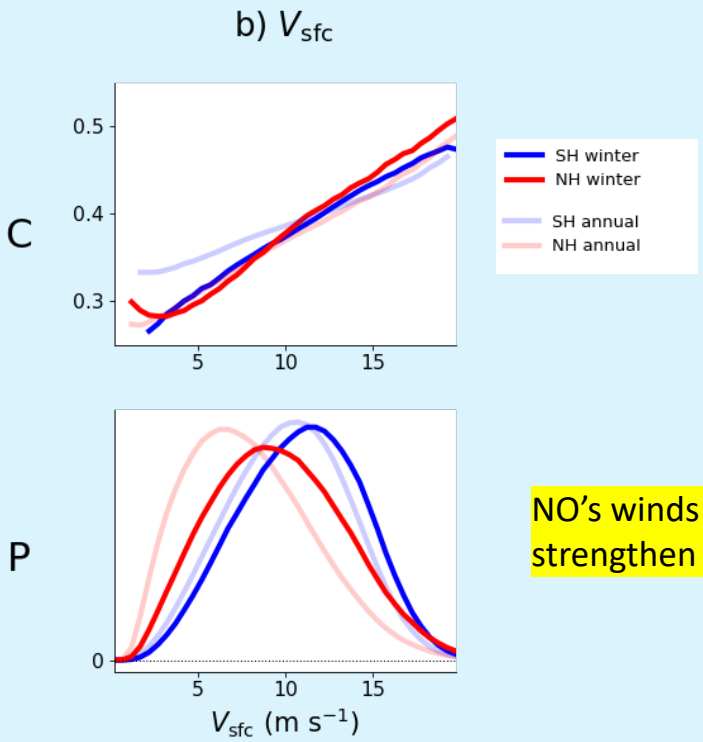
Cloud top pressure (MODIS), treated formally as a CCF




positive contributions to hemispheric albedo asymmetry peak at ctp ~ 700 hPa

# *** Seasonality

Despite the simplicity of the method (1-D),
it is very useful in terms of interpretations of seasonal variations.




The integrated asymmetry over oceans in 50°: 65°

$\Delta C = 0.044$ year-round

$\Delta C = 0.022$ **winter**

NO's winds significantly strengthen in winter

The Southern Ocean is always windy and cold, but there is a strong seasonality for the NH