Air Parcel Trajectory Analysis to Identify the Effects of Low Cloud Formation on High-Latitude Cold Air Outbreaks in Warm Climates

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November 22, 2022

Abstract

In the present-day climate, cold air outbreaks occur when marine air intrudes over high-latitude continental interiors and radiatively cools, producing an abrupt drop in surface air temperature to as low as -40 C. But during the Eocene warm climate period, 55 million years ago, the presence of frost-intolerant species even at high latitudes in the Northern Hemisphere indicates that cold air outbreaks were suppressed. In projected future climate scenarios, relatively high surface temperatures at high latitudes are predicted as part of polar amplification. The lapse rate “feedback”, corresponding to enhanced warming of the lower troposphere, was found to be a major contributor [1]. The suppression of cold air in the Eocene is not well reproduced in global climate models (GCM) and the lapse rate feedback that contributes to polar amplification is still not well understood. Recent work hypothesized that the formation of low clouds as moist air flows from a warm ocean to a cold continental surface could suppress cold air outbreaks in warmer climates. Cronin and Tziperman, 2015, took a one-dimensional Lagrangian column model approach to track cloud formation and surface temperature as an air column migrates from a warm ocean surface to a cold continent [2]. Hu et al, 2018, followed up with an Eulerian analysis of GCM output over a range of cold and warm climates, looking at regional cloudiness, continental interior temperatures, and cold air extremes [3]. But neither approach is complete. The Lagrangian column model does not take into account mixing with surrounding air masses, while the Eulerian analysis does not explicitly follow the formation of clouds and their radiative impact as an air mass moves. In this work, we combine the two perspectives by studying cold air outbreaks in a variety of warm and cold climate scenarios using model output from the Community Atmosphere Model. After identifying cold air outbreaks, we backtrack trajectories for the air parcels that make up the entire cold air column. We then analyze the formation of clouds and the radiative budget to study the effects of clouds along each trajectory. Pithan, F. & Mauritsen, T. (2014). Nat Geo, 7, 181-184. Cronin, T. W. & Tziperman, E. (2015). PNAS, 112(37), 11490-11495. Hu, Z., Cronin, T. W. & Tziperman, E. (2018). JCLI, 31(23), 9625-9640.

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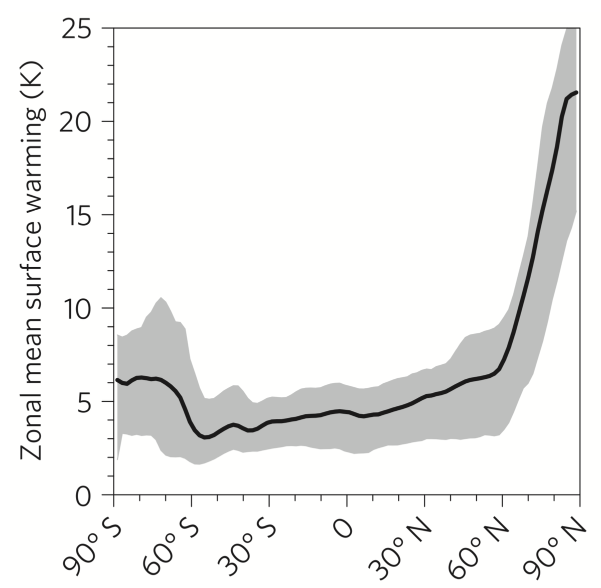
Poster # 1269

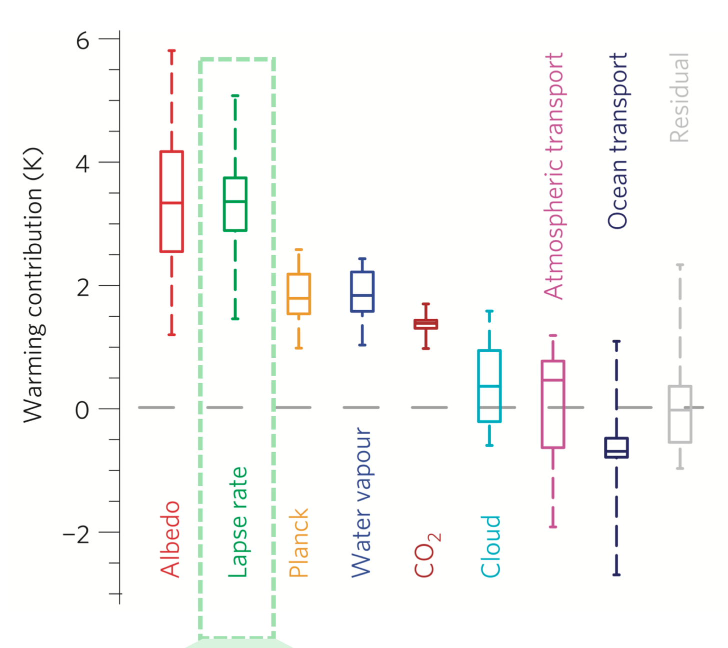
Arctic Amplification is already underway and projected to increase but not fully understood

Figures: Pithan & Mauritsen 2014



Zonal mean surface temperature change over the CMIP5 4xCO_2 experiment

Contributions to Arctic warming in CMIP5

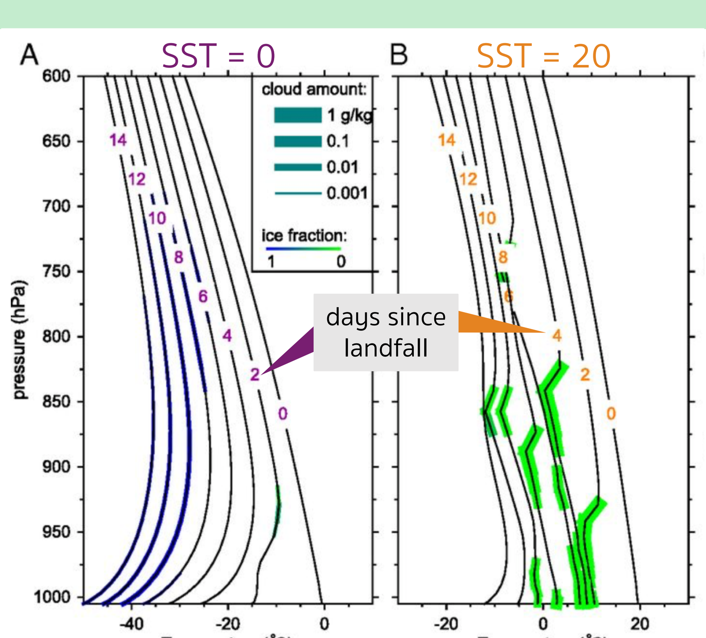


Lapse Rate Feedback: warming is surface-amplified in Arctic

- major contributor to Arctic amplification, on par with ice-albedo
- no comprehensive explanation yet

Previous Work indicates low clouds may suppress cold air formation over Arctic continents

Figures: Cronin et al 2015
Hu et al 2018

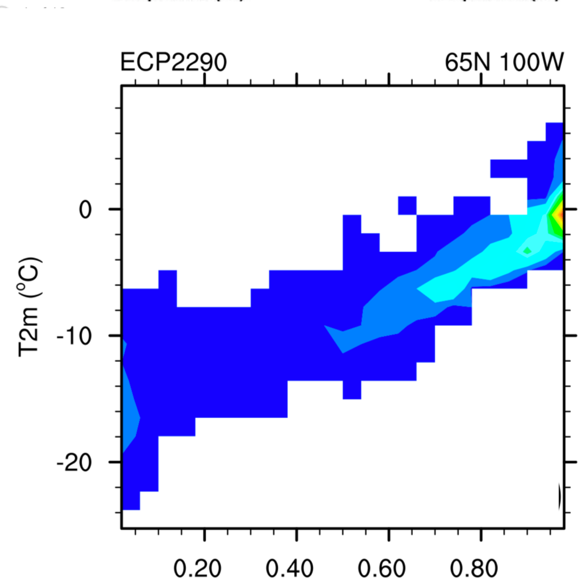


Lagrangian column model

SST=0 (left):
air mass cools rapidly over land

SST=20 (right):
low clouds (green bars) suppress cooling

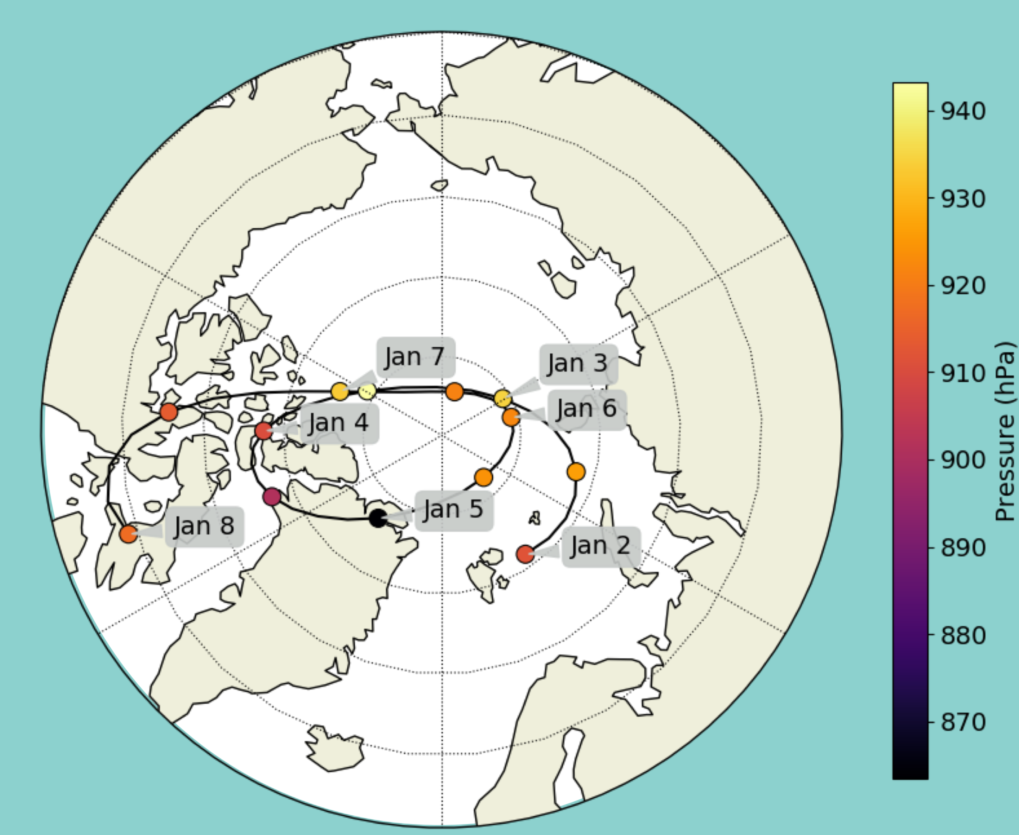
Limitation: no air mass mixing



Eulerian GCM

in warmer climates (left, EPC8.5 in year 2281-2300), 2-meter temperature and low cloud fraction are correlated

Limitation: no causation, only correlation



Air parcel backtracking is proposed to determine the effects of a warmer ocean on **low cloud formation** and **cold air suppression** over land during the Arctic winter.

MODEL warmer climates

Community Atmosphere Model (CAM4), coupled to land and sea ice

Four climate scenarios based on CMIP5 projections for comparison:

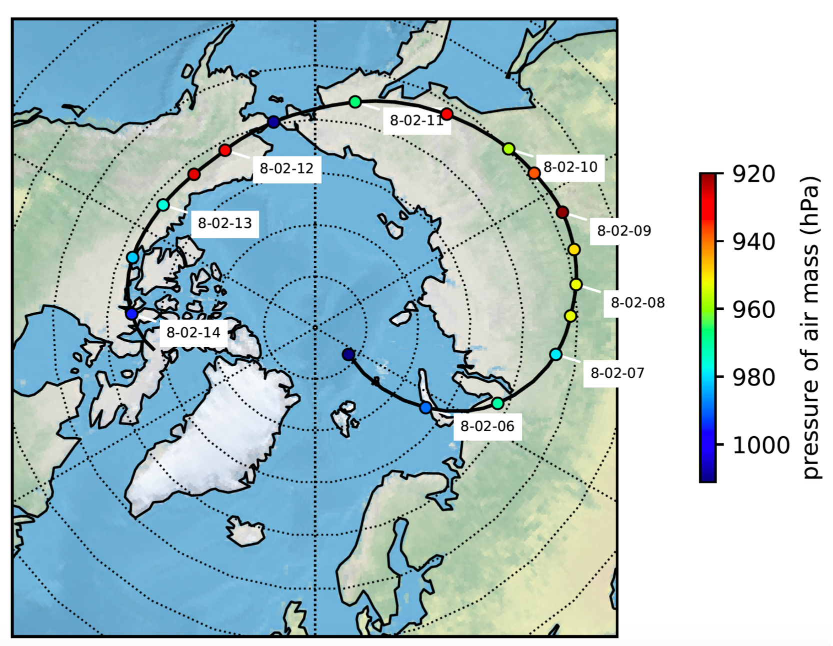
- Pre-industrial
- RCP8.5 2081-2100
- ECP8.5 2281-2300
- ECP8.5 with no sea ice, minimum SST=20

IDENTIFY cold air events

Compare 3-hourly surface temperatures to DJF climatology and identify the 20 coldest events over the model run period (~10 years)

BACKTRACK corresponding air parcels

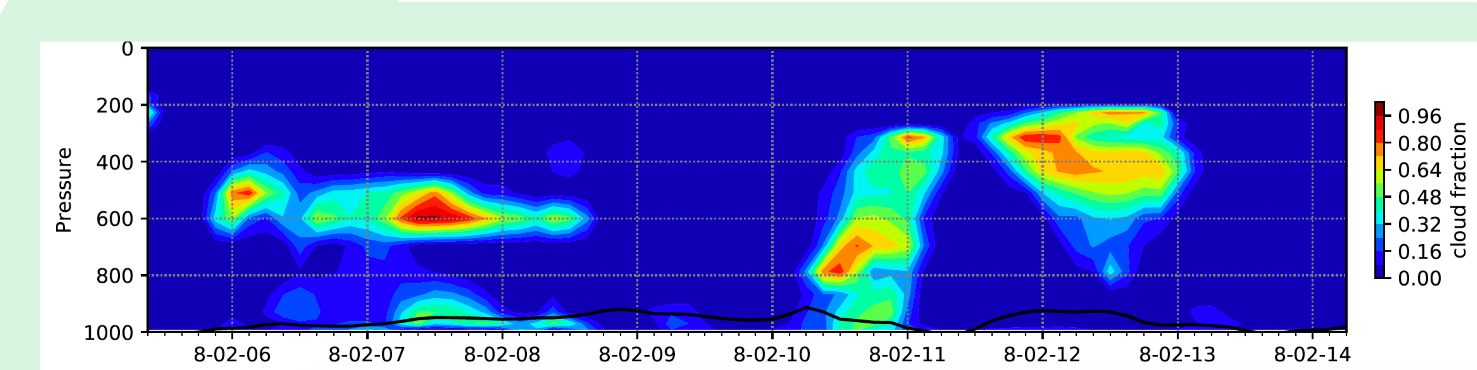
Using NOAA's HYSPLIT trajectory software, trace corresponding air columns back in time



ANALYZE cloudiness and radiative forcing

Create time series for air column along trajectory of:

- surface temperature
- downward longwave radiation at surface
- anomaly temperature from climatology
- cloud radiative forcing
- cloud fraction



References

Pithan, F. et al. Arctic amplification dominated by temperature feedbacks in contemporary climate models. *Nature Geoscience* **7**, 181–184 (2014).

Cronin, T. W. et al. Low clouds suppress Arctic air formation and amplify high-latitude continental winter warming. *Proceedings of the National Academy of Sciences* **112**, 11490–11495 (Sept. 2015).

Hu, Z. et al. Suppression of Cold Weather Events over High-Latitude Continents in Warm Climates. *Journal of Climate* **31**, 9625–9640 (Oct. 2018).