Effects of Aerosol Concentration on Arctic Cloud Albedo from Ground-Based Observations

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Background & Motivation

- Arctic temperatures are warming nearly 3x faster than the global average [1]
- Clouds strongly influence the Arctic surface energy budget by:
  - Reflecting incoming sunlight
  - Trapping outgoing heat
- Climate change is expected to increase wildfire activity, releasing more aerosols into the atmosphere [2]
- Wildfire aerosols may modify cloud properties making clouds more reflective[2]
- Arctic cloud albedo has increased over the past two decades, but the cause is still uncertain

Terms to know:

Cloud Albedo: A measurement on how reflective a cloud is.

Aerosols: Tiny particles in our atmosphere.

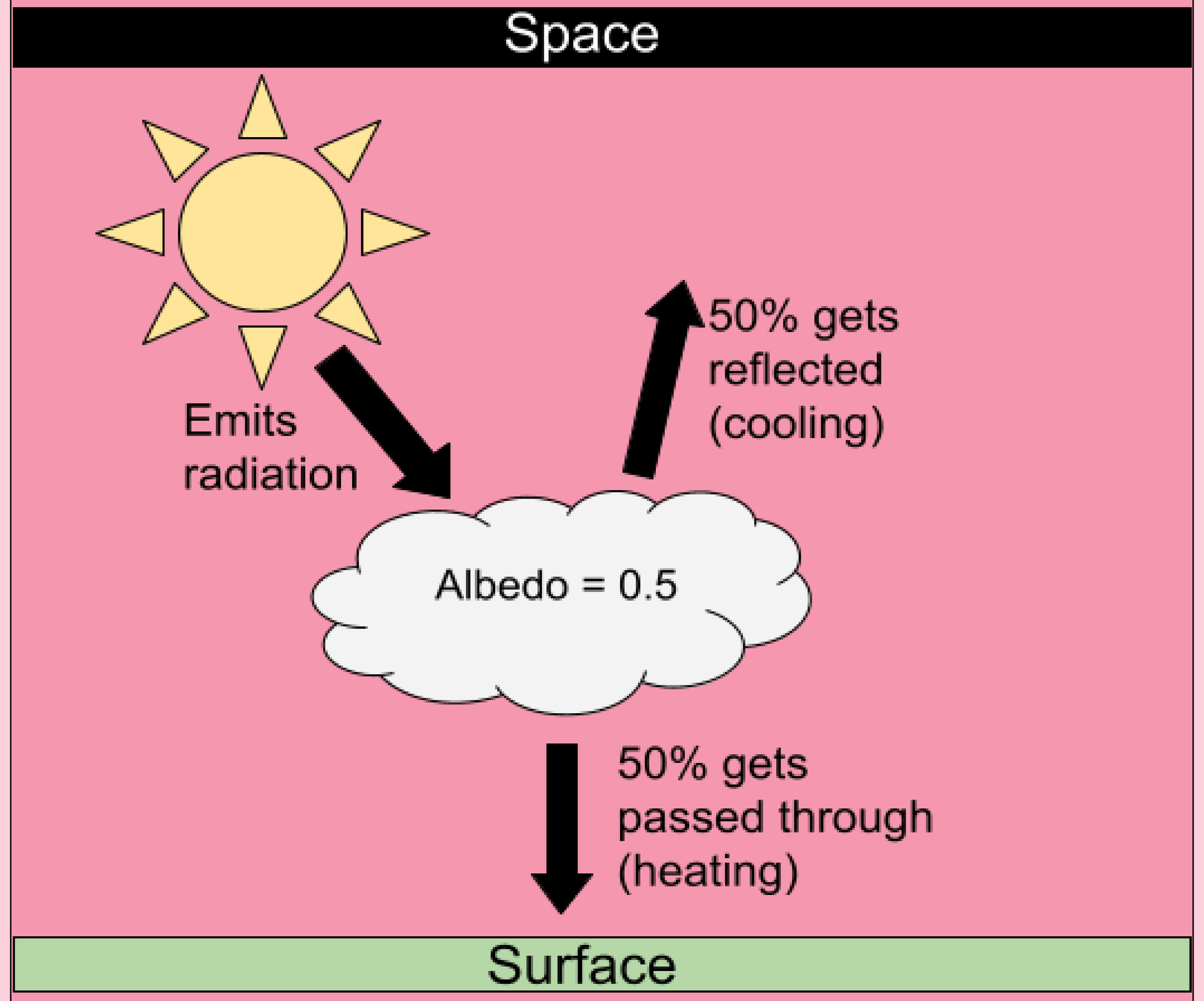


Figure 1. Conceptual diagram of cloud albedo, showing how clouds reflect incoming solar radiation back to space.

Question

How do aerosol number concentrations affect cloud albedo during the Arctic summer?

Methods

- Ground-based observations collected in the North Slope of Alaska:
  - Aerosol concentration
  - Cloud properties (specifically cloud albedo)
- Data analysis in Python to evaluate the relationship between aerosol concentration and cloud albedo.

Aerosol Concentration Data:

- Collected by NOAA
- Measurements span from 1976-2025
- Measured at surface using butanol-based particle counters[3]

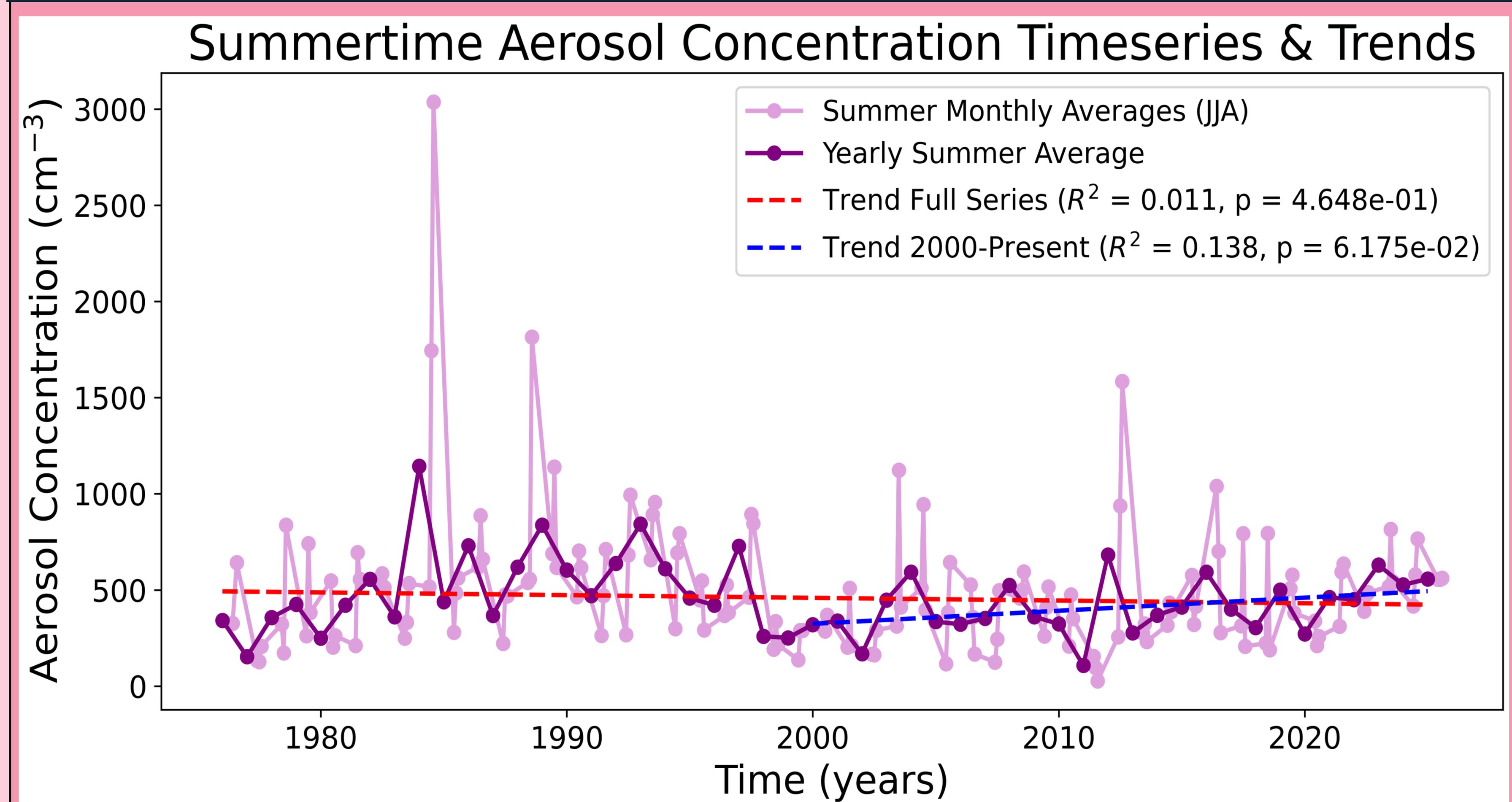
Cloud Property Data:

- Collected by ARM
- Observations span from 2000-2023
- Surface shortwave radiation measured using surface radiometers[4]
- SW CRE = All Sky – Clear Sky SW DW

Cloud Albedo = -SW CRE / Clear Sky SW DW

SW = Shortwave
DW = Downwelling
CRE = Cloud Radiative Effect

Results



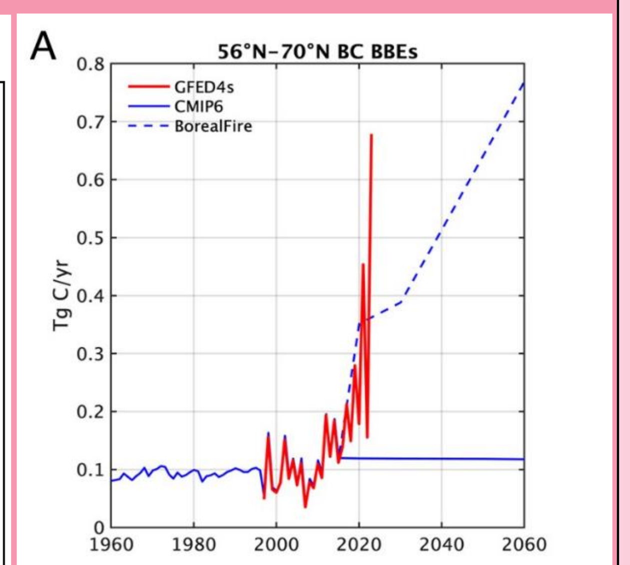


Figure 2. Summertime (June, July, and August) aerosol concentrations measured on the North Slope of Alaska from 1976-2025. Monthly summer averages (light purple) and yearly summer averages (dark purple) are shown with linear trend lines for the full dataset (red) and from 2000-2025 (blue). Aerosol concentrations remained relatively stable over the full dataset but showed a moderate increase over the past two decades.

Figure 3. Observations (red line) show an increase in boreal wildfire emissions, increasing aerosol optical depth. Adapted from Blanchard-Wrigglesworth et al. (2025) [2].

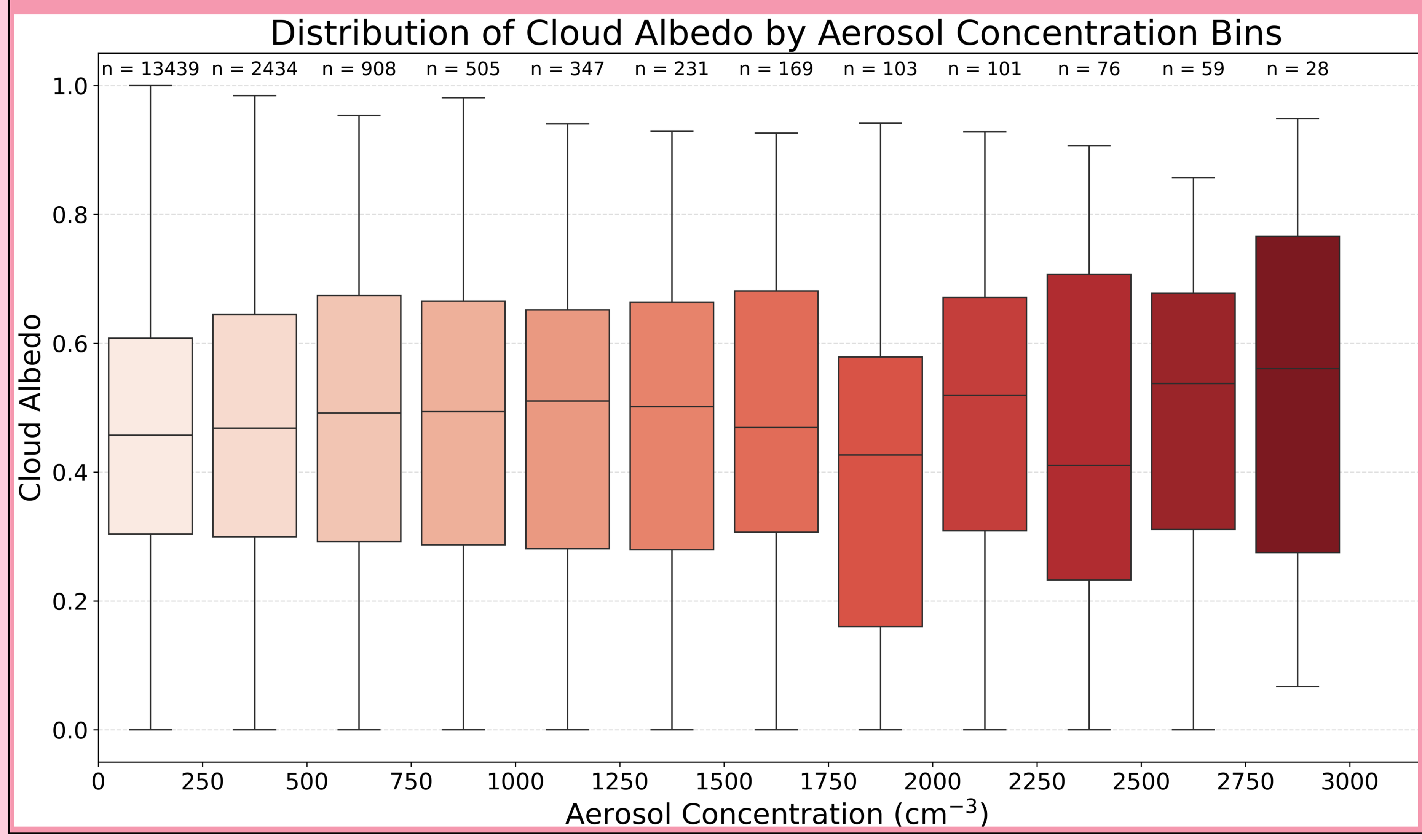


Figure 4. Distribution of cloud albedo by aerosol concentration bin. Cloud albedo generally increases with aerosol concentration, but the overlap between boxplots indicates that the relationship is weak.

Discussion and Conclusion

- Aerosol concentration remained consistent over the full 50 years (red trend-line), while the more recent years show a slight increase (blue trend-line; Figure 2)
- Cloud albedo increased slightly as aerosol concentration increased, but there was substantial overlap between the boxplots, suggesting they have a weak relationship with one another (Figure 4)

Overall, aerosol concentration appears to weakly influence cloud albedo, but the relationship is likely affected by other atmospheric factors. Understanding these aerosol-cloud interactions can help improve Arctic climate models and our understanding of Arctic climate change.

Future Work:

- Identify periods with expected wildfire smoke transport using atmospheric circulation and focus the analysis on those cases
- Compare long-term aerosol trends across multiple Arctic observation sites to determine whether similar patterns occur throughout the Arctic
- Focus on cases where clouds are coupled (interacting with one another) with the surface aerosol layer

Acknowledgements and References

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