

Polar Mesospheric Clouds and Solar Effects – An Update

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2002 SORCE Science Working Group Meeting Agenda

Thursday, July 18

9:55 – 10:20 a.m. Contributed Talk – Matthew DeLand, Science Systems and Applications, Inc.
SBUV Observations of PMCs Over Two Solar Cycles.

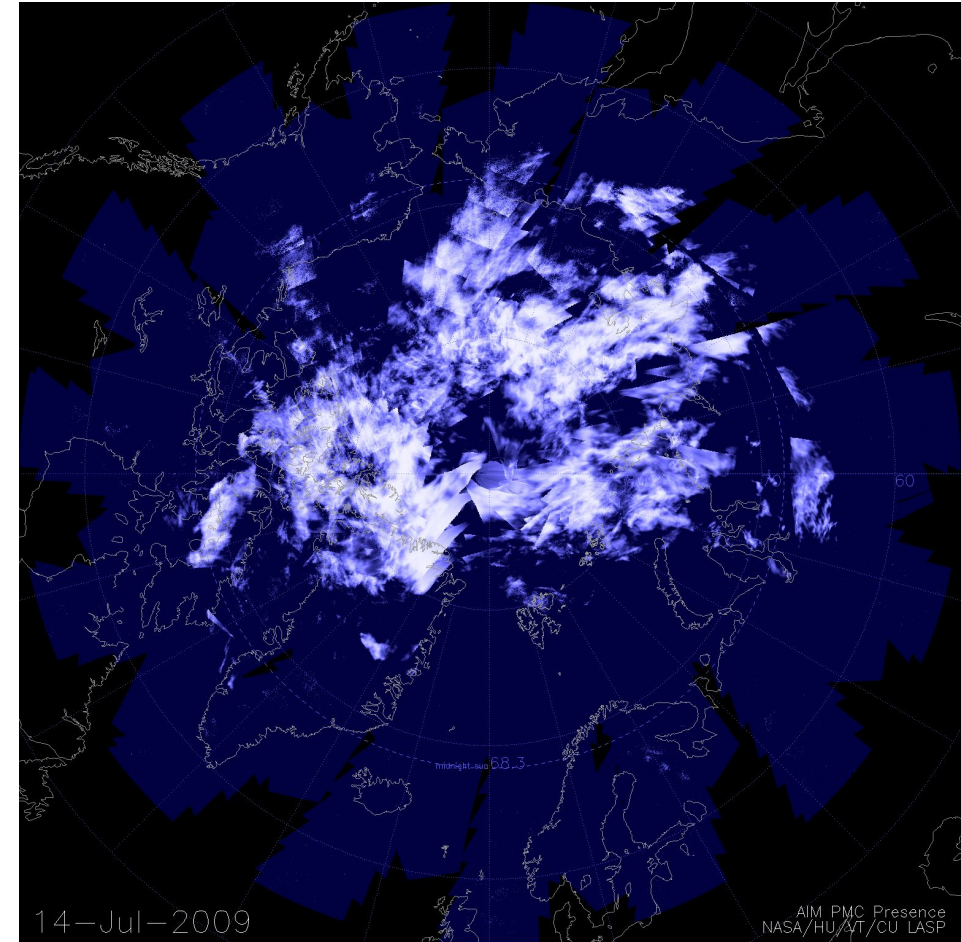
Introduction

- What are polar mesospheric clouds (PMCs)?
 - Also known as **noctilucent** (“night-shining”) **clouds**, since naked-eye observations occur after sunset or before sunrise.
 - Only exist at very high altitude (80-85 km).
 - Only observed in summer with very cold temperatures (< 150 K).
 - Mostly seen at high latitudes ($> 50^\circ$).
 - Large horizontal extent (hundreds of km), small vertical thickness (1-3 km) □ optical depth is $\sim 10^{-4}$ or less.
 - Composed of water ice crystals (size ~ 20 -60 nm).
- First ground-based observations reported in 1880s. Most sightings made from Northern Europe between 50° - 63° latitude.
- First satellite observations in 1969 showed greater latitudinal extent, presence in both hemispheres.
- PMC formation and brightness are “exquisitely” sensitive to mesospheric temperature and water vapor content.

PMCs from Ground and Space



15 July 2009: **Noctilucent clouds** over Nebraska [44°N] (*courtesy Mike Hollingshead*)



14 July 2009: “Daily daisy” of **polar mesospheric clouds (PMCs)** observed by CIPS (*courtesy AIM Science Team*)

Observations: Visual

- Interpretation of noctilucent clouds (NLCs) as mesospheric ice clouds implies sensitivity to solar irradiance input through mesopause temperature, water vapor dissociation. Expect anti-correlation between NLC occurrence frequency and solar flux.
- ***Vestine* [1934]**: Noted that seasons with more frequent NLC observations (*e.g.* 1887, 1899, 1911, 1932) coincided with sunspot minima, but did not draw physical connection.

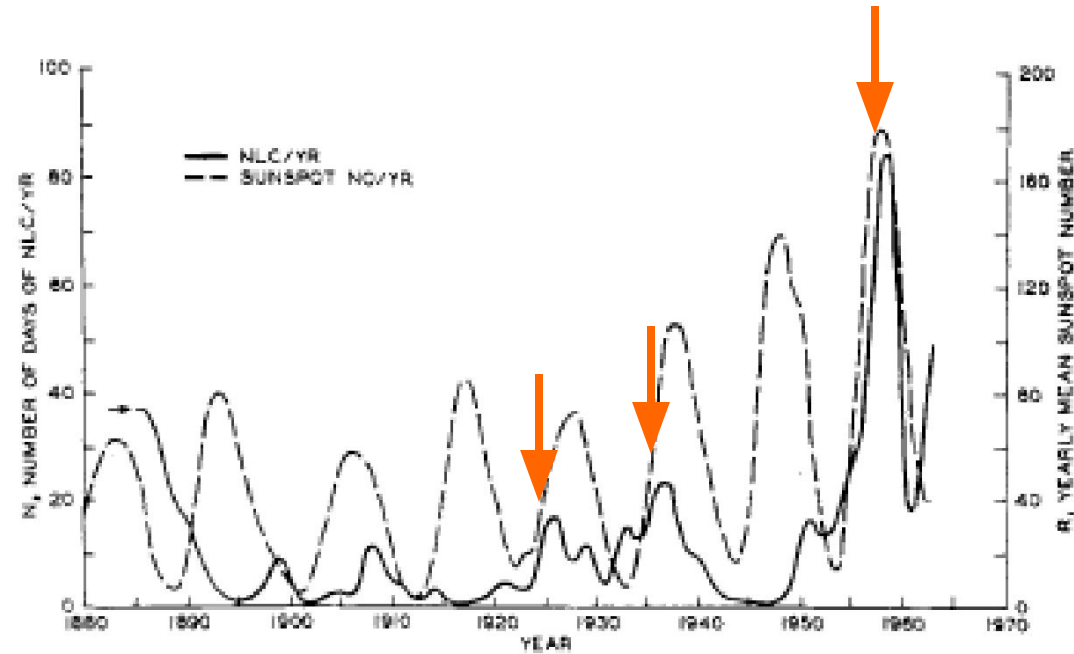


Fig. 40. Yearly variation of reported NLC activity compared with solar activity.

Fogle and Haurwitz [1966]: “Thus the comparison of the variation of the number of reported NLC sightings per year with the sunspot cycle at this time cannot lead to a reliable conclusion as to whether there is a dependence of NLC activity on solar activity.”

“An extended series of NLC observations over a few sunspot cycles by the existing large network of observers should provide the necessary data to settle this question, however.”

Gadsden [1982]: “There does not seem to be a marked anticorrelation between noctilucent cloud occurrence and level of sunspot activity.”

Gadsden [1985]: Focus on Northwest Europe data for 1966-1982 (*excludes 1958 peak*). Finds anti-correlation between NLC displays and May-August sunspot numbers. Best result ($r = -0.67$) for 2-year lag.

Gadsden [1990]: Similar results to 1985 paper. Solar cycle amplitude in NLC occurrence approximately factor of 2 (± 10 nights/year).

Gadsden [1998]: Reconfirmed result with extended NLC record. Best period found to be 10.4 years (*sine wave*), with approximate 2-year lag vs. 10.7 cm flux.

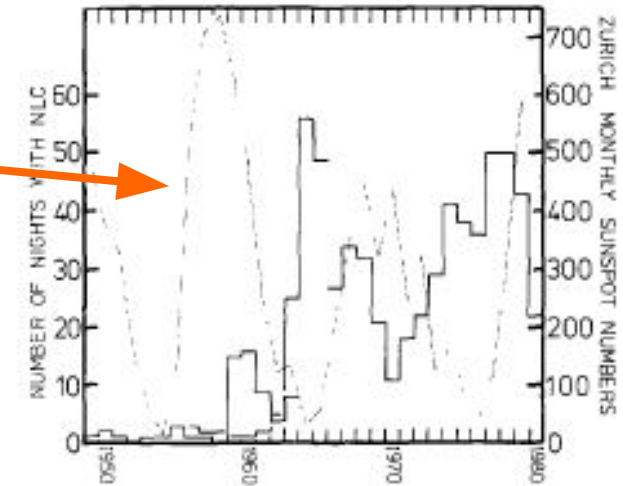


Fig. 8. The variation in number of nights with noctilucent clouds from year to year. The 1949–1963 data are from Paton (1964), the 1956–1965 data from Fogle (1966), and 1966–1980 (North European) data have been summed by Simmons (1982). The thin line shows the summer sums (May + June + July + August) of the Zurich monthly mean sunspot numbers.

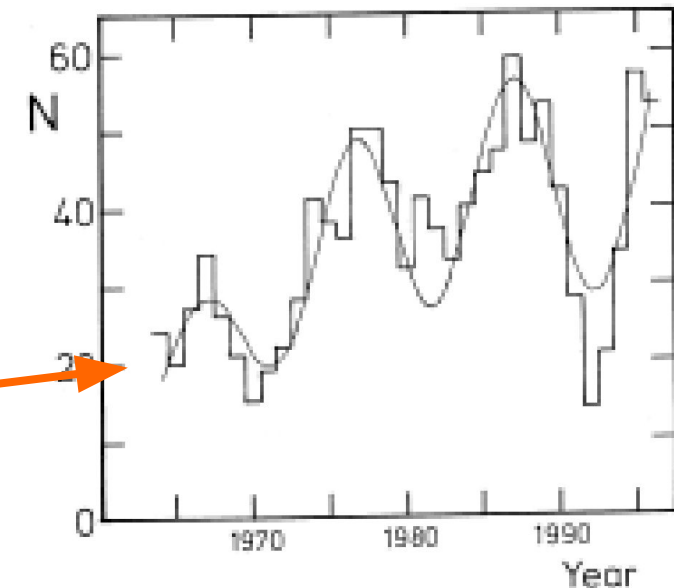


Fig. 1. The year-to-year variation in the number of nights, N , on which noctilucent clouds were reported.

von Zahn and Berger [2006]:

- Review of previous results
- Observed that NLC observation range (55° - 65° N) is limited to lower latitudes of polar region (□ increased sensitivity?)
- Noted inconsistency regarding NLC behavior [*top*] and solar flux [*bottom*] during 1950s compared with other time periods

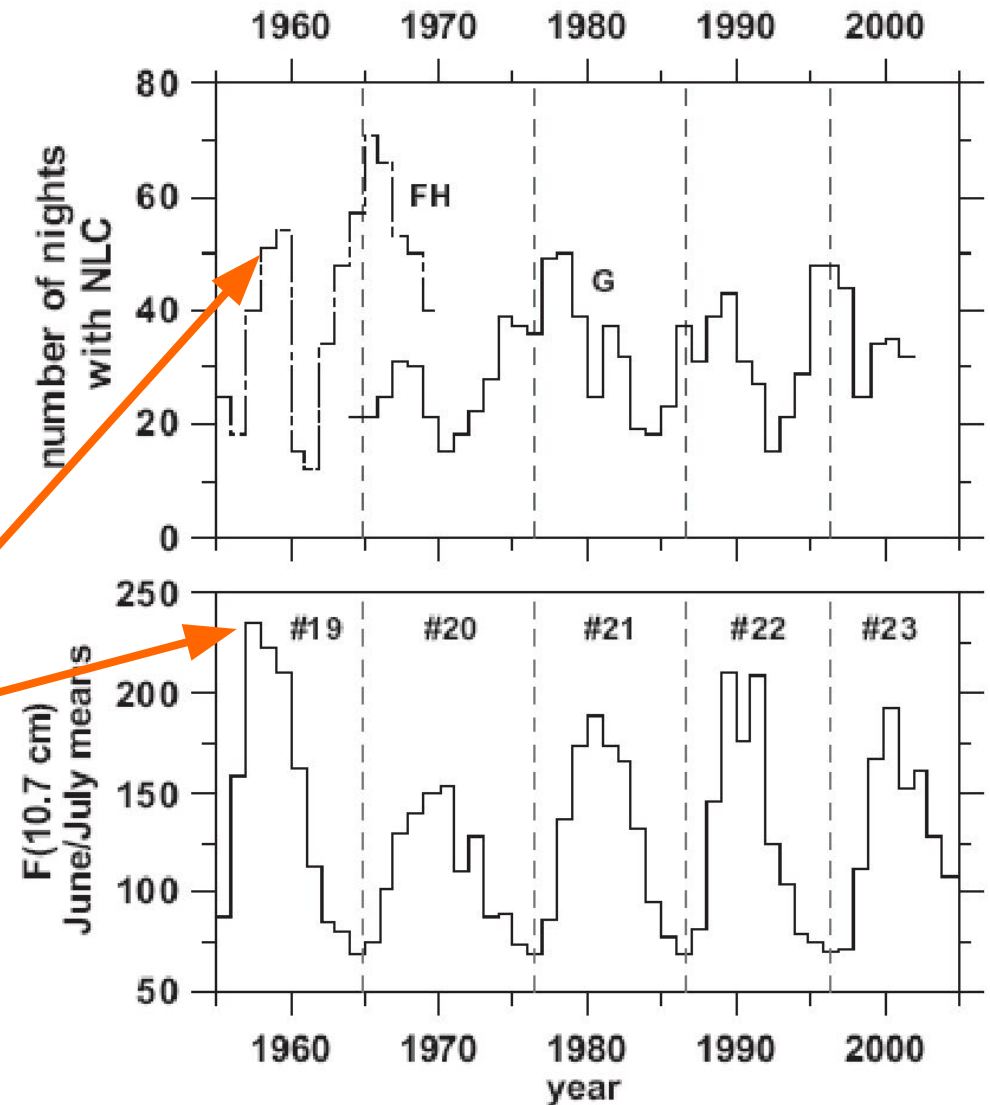


Figure 1: The variations of NLC occurrence rate (upper panel) and summer values of the solar F10.7 cm index (lower panel) since 1955. FH = FOGLE and HAURWITZ (1974); G = GADSDEN (2002). For more details, see text.

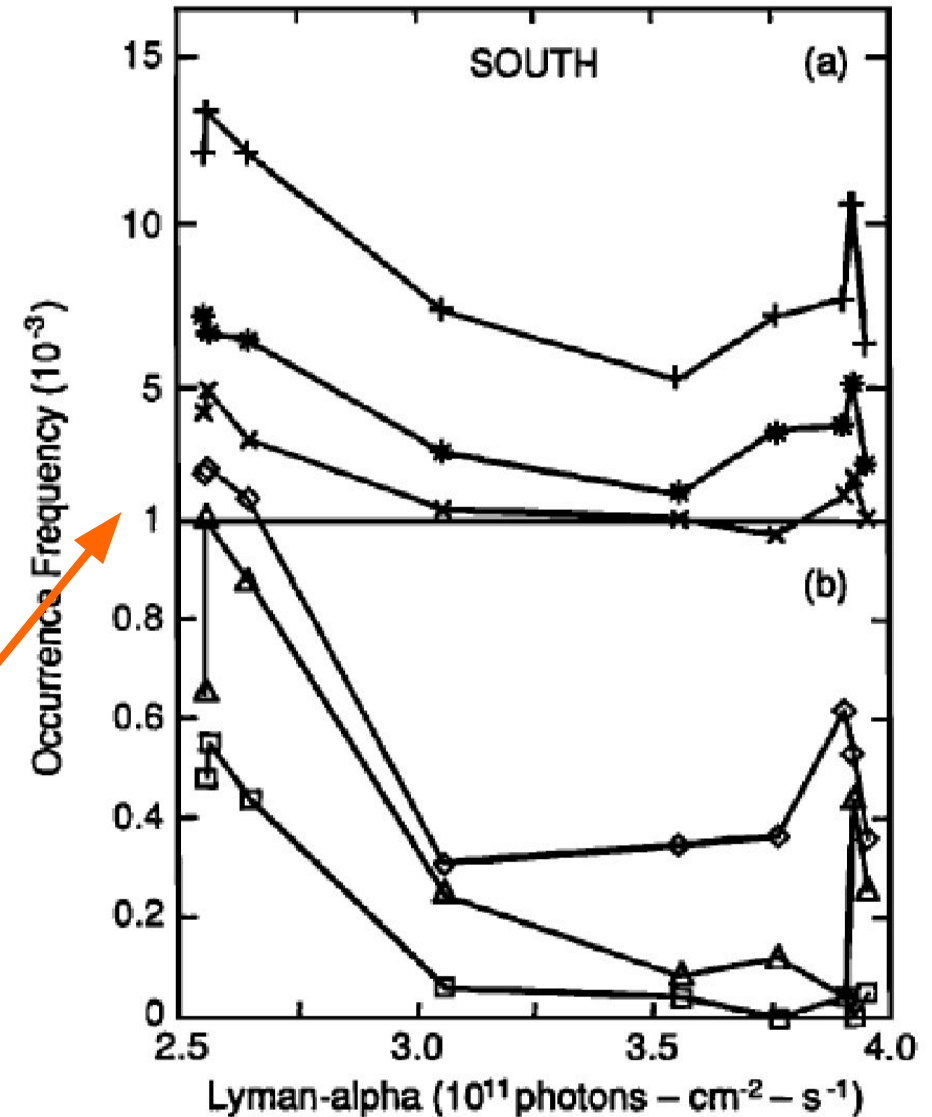
Observations: Satellite

Thomas and Olivero [1989]:

- No long-term trend in SME data (1981-1985).
- No way to separate solar cycle, trend signals with short data set and timing of measurements.

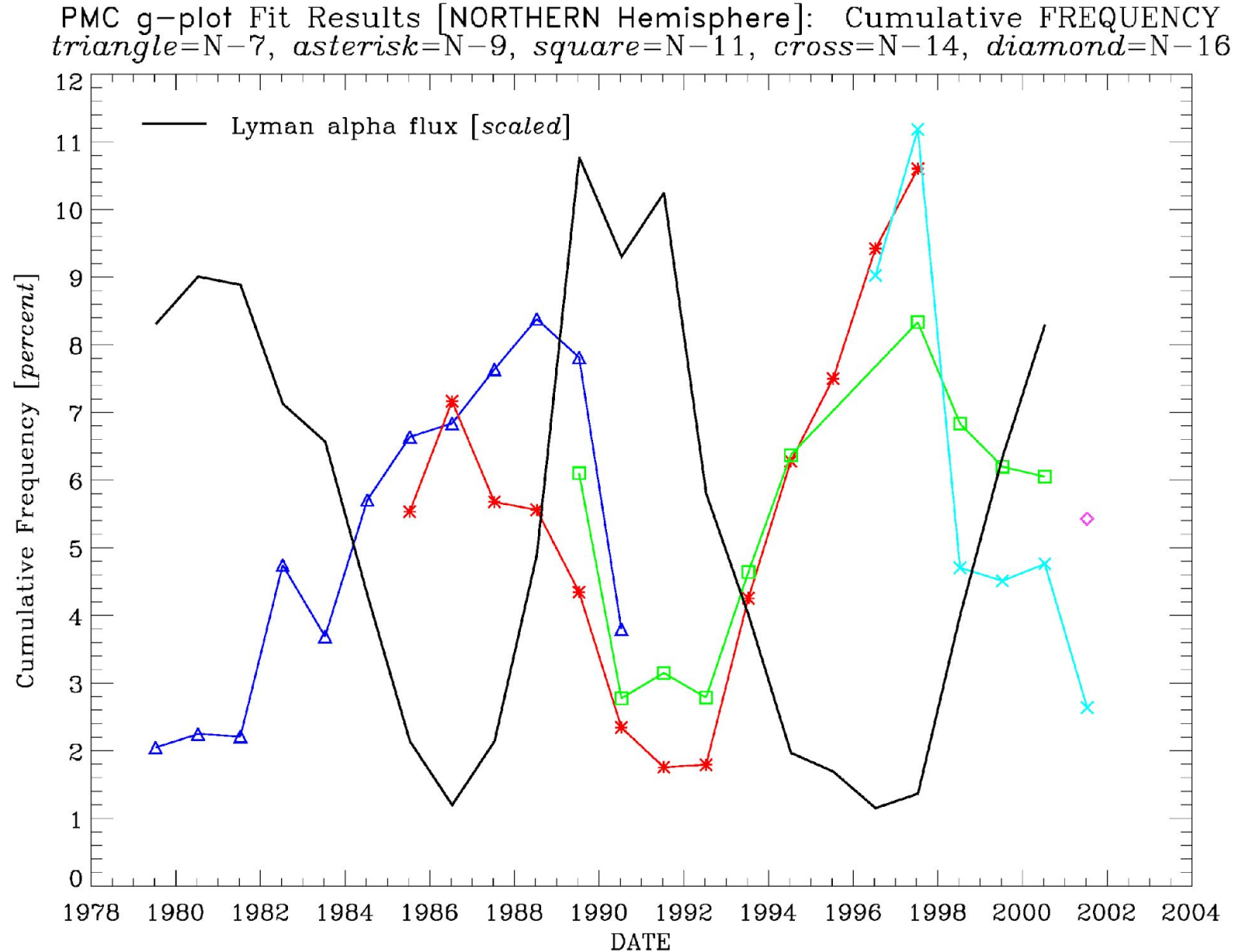
Thomas et al. [1991]:

- Nimbus-7 SBUV shows anti-correlation between frequency and Lyman alpha.
- SH data (1978-1986) show $2x$ variation for faintest clouds (PMCs), $\sim 10x$ variation for brightest clouds.



DeLand et al. [2003]:

- Use data from multiple SBUV and SBUV/2 instruments for 1978-2002 (2+ *solar cycles*).
- Combined data show anti-correlation vs. Lyman alpha for frequency and g-distribution slope, lag = 0-1 year.
- Hemispheric average frequency varies by 4-5x (no normalization between instruments).



Hervig and Siskind [2006]:

- Long data set from HALOE (1992-2004) with simultaneous atmospheric data.
- 80 km, 67.5° lat. temperature: Positive correlation with Lyman alpha, ~4-5 K amplitude, no lag.
- 80 km, 67.5° lat. water vapor: Anti-correlation with Lyman alpha, 25% amplitude for cycle, < 1 year lag (not sharp).
- PMC extinction: Anti-correlation with Lyman alpha, 23% amplitude for cycle, < 1 year lag.

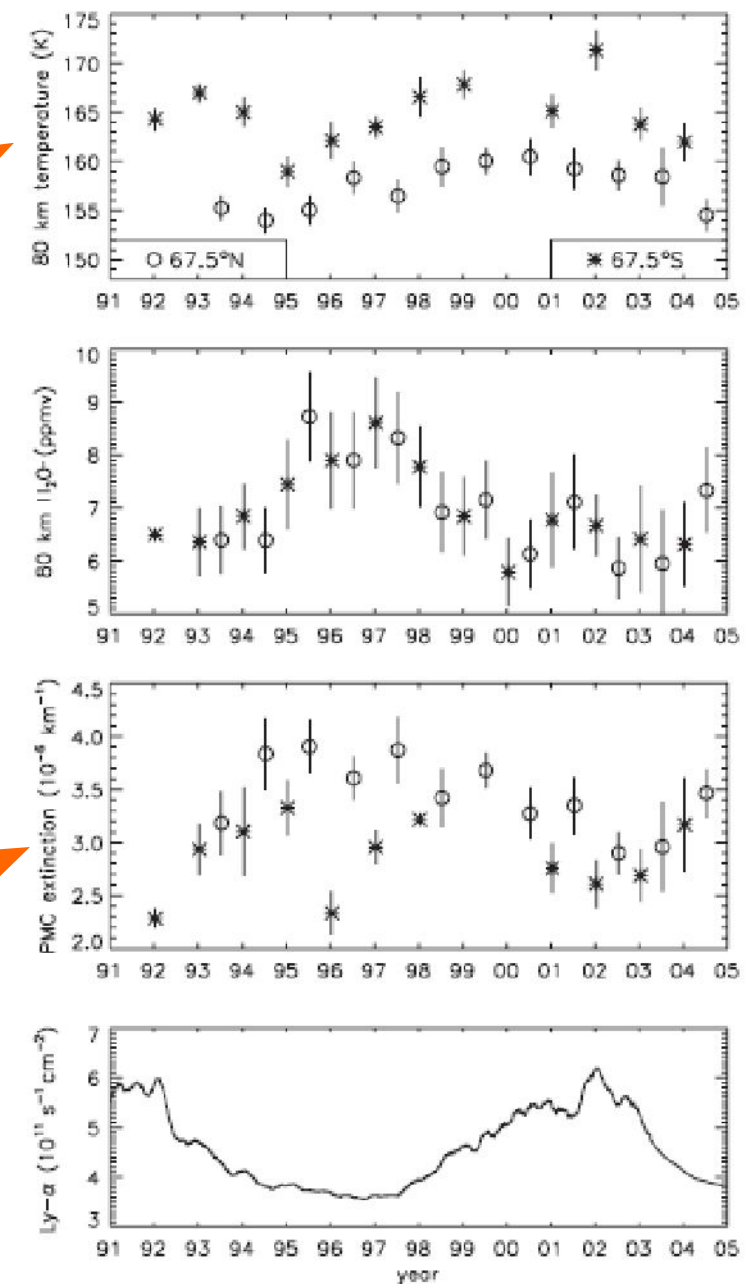
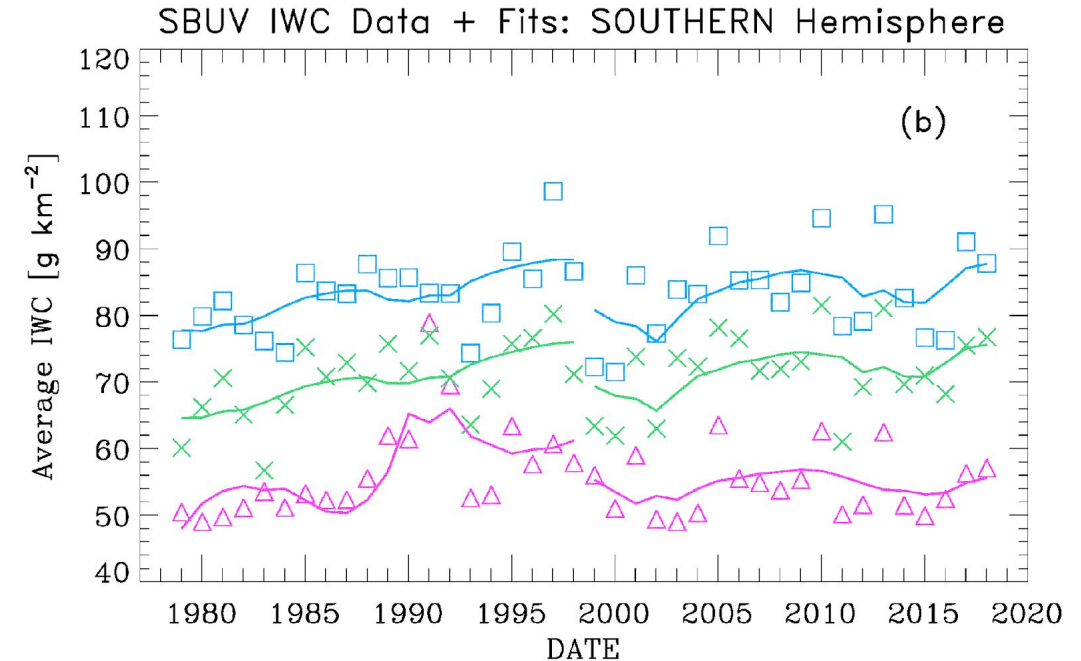
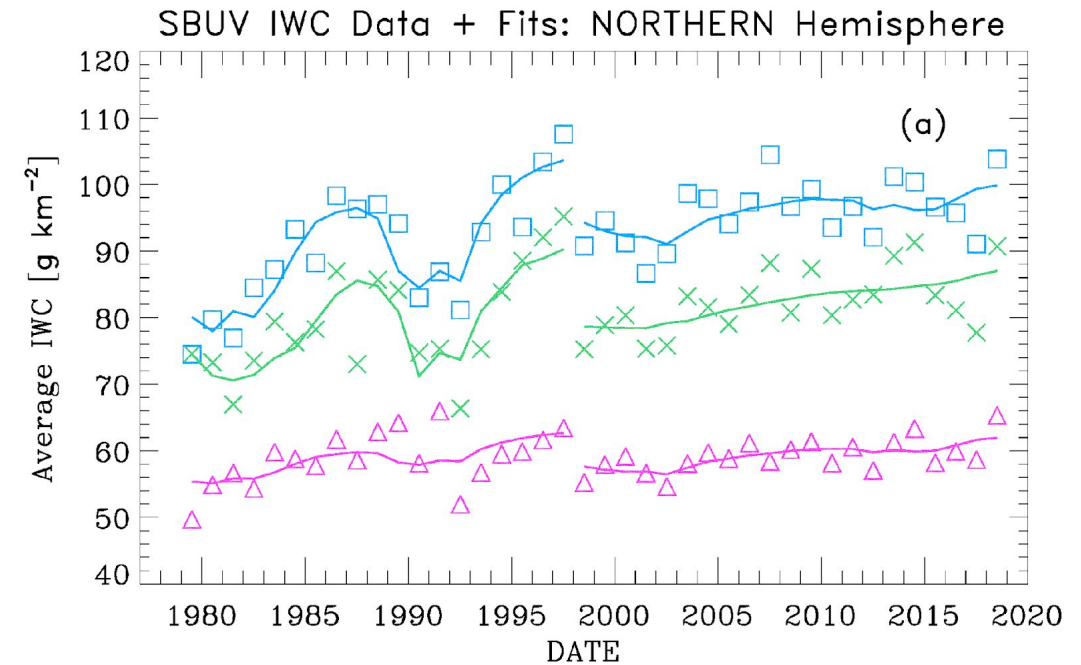


Fig. 3. Time series of 80km temperature, 80km H₂O, and peak 3.40μm PMC extinction. The data points are for 20 days from solstice taken from seasonal fits to HALOE measurements at 65–70°N and 65–70°S for each year (see Fig. 2). Solar Ly-α flux data from the SOLAR2000 model. Error bars represent the standard deviations of the means.

DeLand and Thomas [2019]:

- Merge data from multiple SBUV instruments for each season
- Calculate ice water content (IWC) to adjust brightness for different measurement conditions
- Introduce break point in trend analysis that corresponds with turnaround in stratospheric ozone time series (proxy for mesospheric temperature?)
- NH solar correlation is $r \approx -0.8$ during 1979-1997, $r \approx -0.4$ during 1998-2018
- SH solar correlation is $r \approx -0.4$ during both periods



Observations: Lidar

Fiedler et al. [2017]:

Lidar measurements at ALOMAR (69° N) for 1997-2017.

- Results shown for occurrence frequency [top left], cloud altitude [top right], brightness [bottom]
- Also classified by intensity [colors]
- No significant solar correlation if 1997 data (first season) are excluded
- Possible dependence on longitude? Local time? (□ planetary waves, tides)

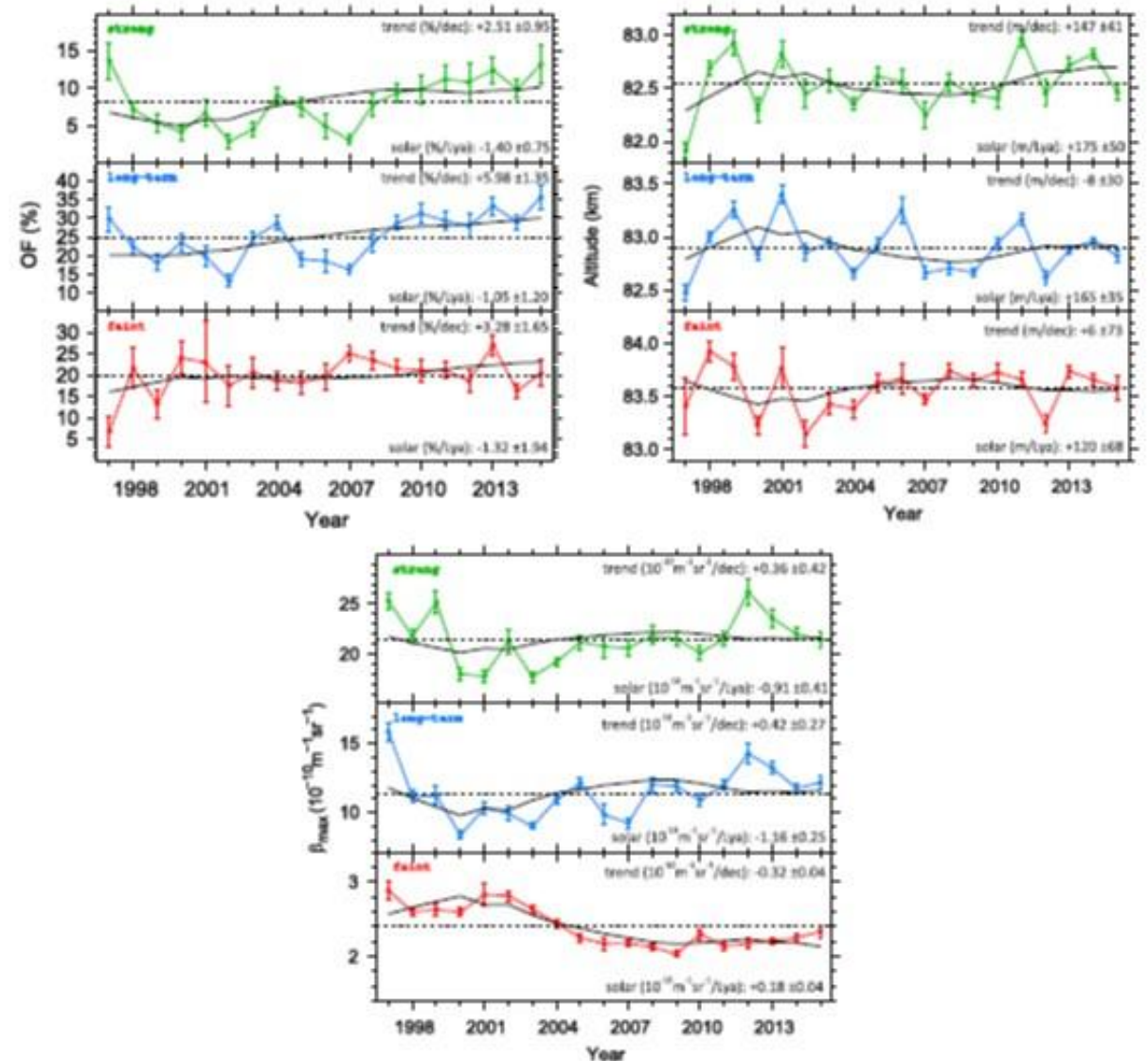


Fig. 4. Seasonal mean NLC occurrence frequency (top left), altitude (top right) and brightness (bottom) for each cloud class. Vertical bars indicate confidence limits for occurrence frequency at 95% level and errors of the mean for altitude and brightness. Solid lines result from MLR fits allowing for a linear trend and solar forcing via Lyman- α . Fit terms are indicated in the panels and summarized in Table 2.

Model Results (Solar Cycle)

- Many studies have looked at solar cycle variations in mesospheric environmental parameters (temperature, water vapor, vertical winds).

- ***Garcia [1989]:***

- 2-D model
- $>2x$ Lyman alpha variation produced 35-40% change in H_2O mixing ratio at 80 km through photodissociation
- Interpreted as support for water vapor control of PMCs

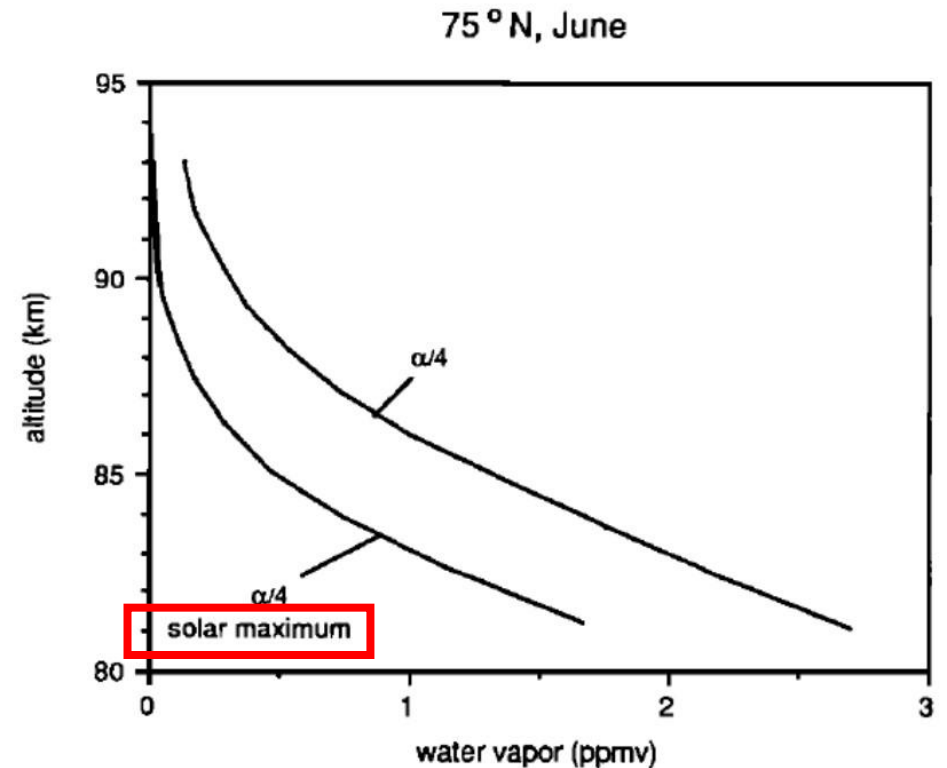


Fig. 11. Vertical profile of water vapor (ppmv) for the case with α reduced by a factor of 4, and for the same case with ultraviolet fluxes typical of solar maximum conditions.

Lubken et al. [2009]:

- Improved 3-D model (LIMA) with ECMWF “nudging” up to 35-45 km
- Explicit ice particle microphysics calculation with 40,000,000 condensation nuclei
- Yearly PMC variations in brightness and frequency are anti-correlated with Lyman alpha over 1961-2008 ($r \approx -0.4$)

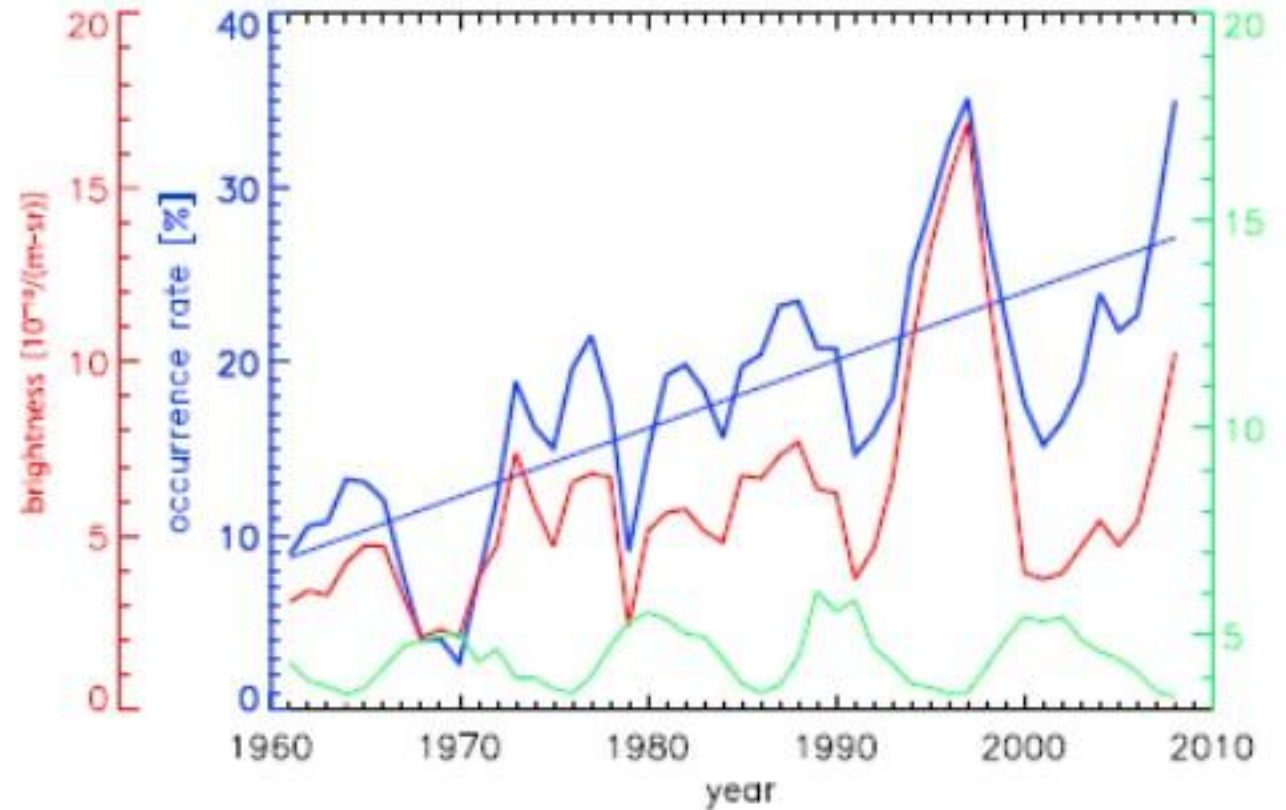
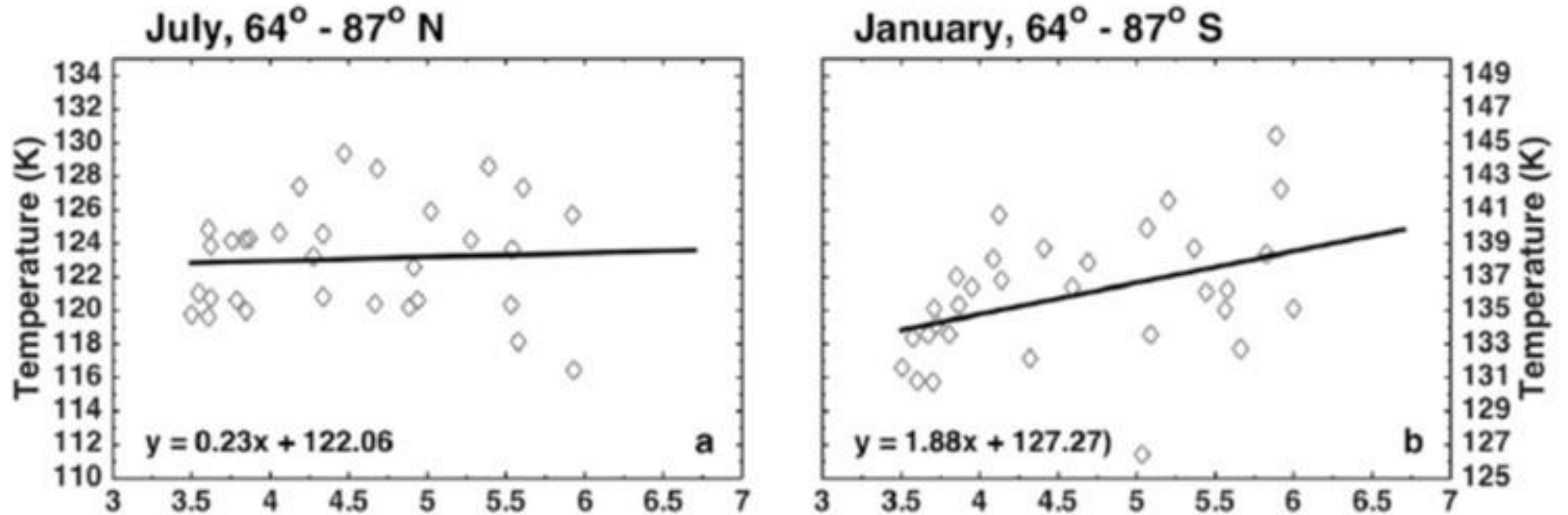


Figure 7. Time series of NLC brightness (red) and occurrence rates (blue) from LIMA/ice at 69°N. The data have been smoothed by running mean over 2 years. The solar cycle variation of Ly- α radiation is also shown (green line, right axis in 10^{11} photons/(cm² s⁻¹)).

Mesopause temperature vs. Lyman alpha flux



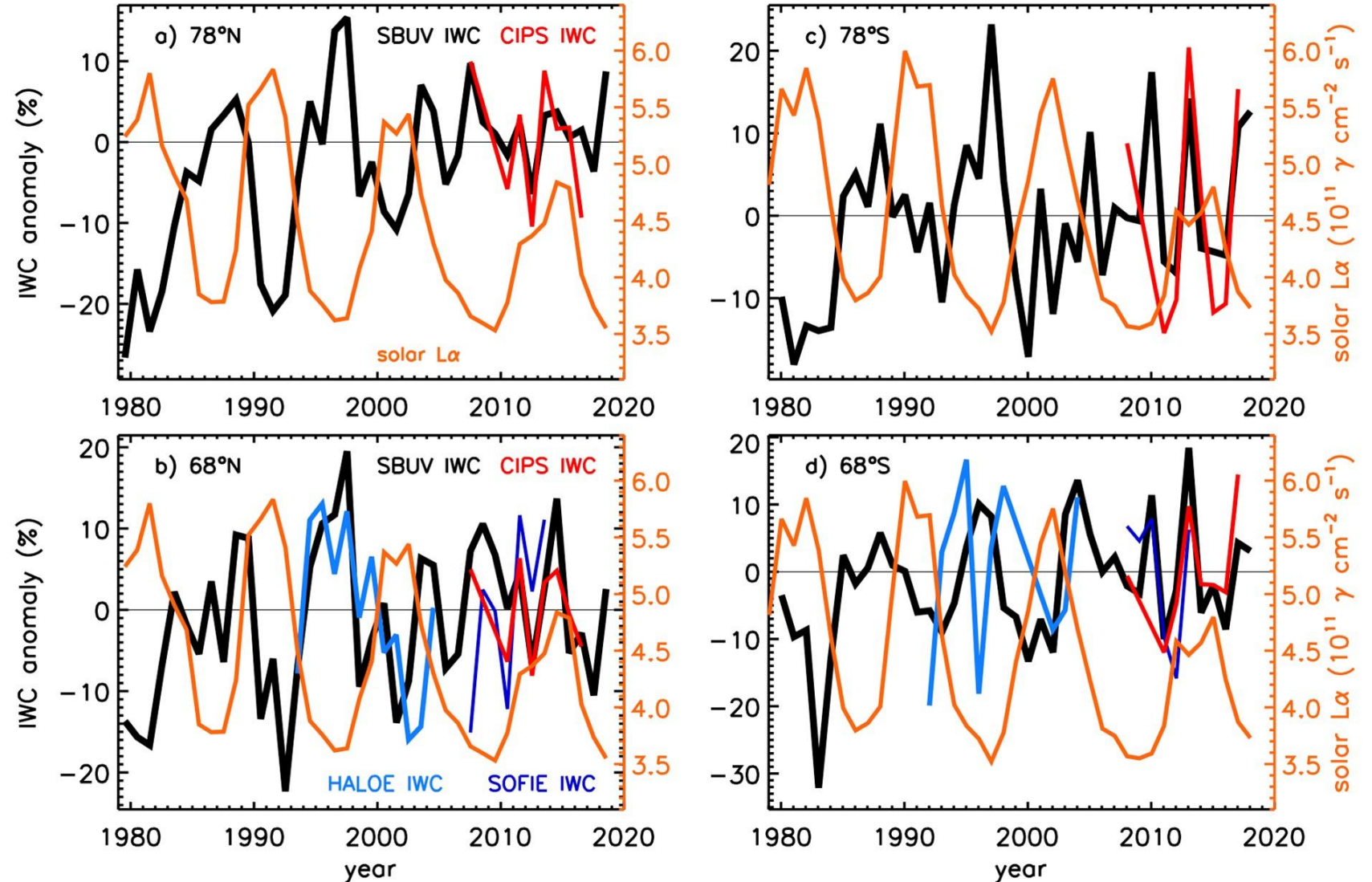
Karlsson and Kuilman [2018]:

- Use CMAM30 model to examine residual circulation response
- Increased solar flux affects temperature gradients, winter zonal flow
- Increased gravity wave breaking in summer polar mesosphere gives adiabatic cooling
- Result is small mesopause temperature response to solar activity

Recent Analysis

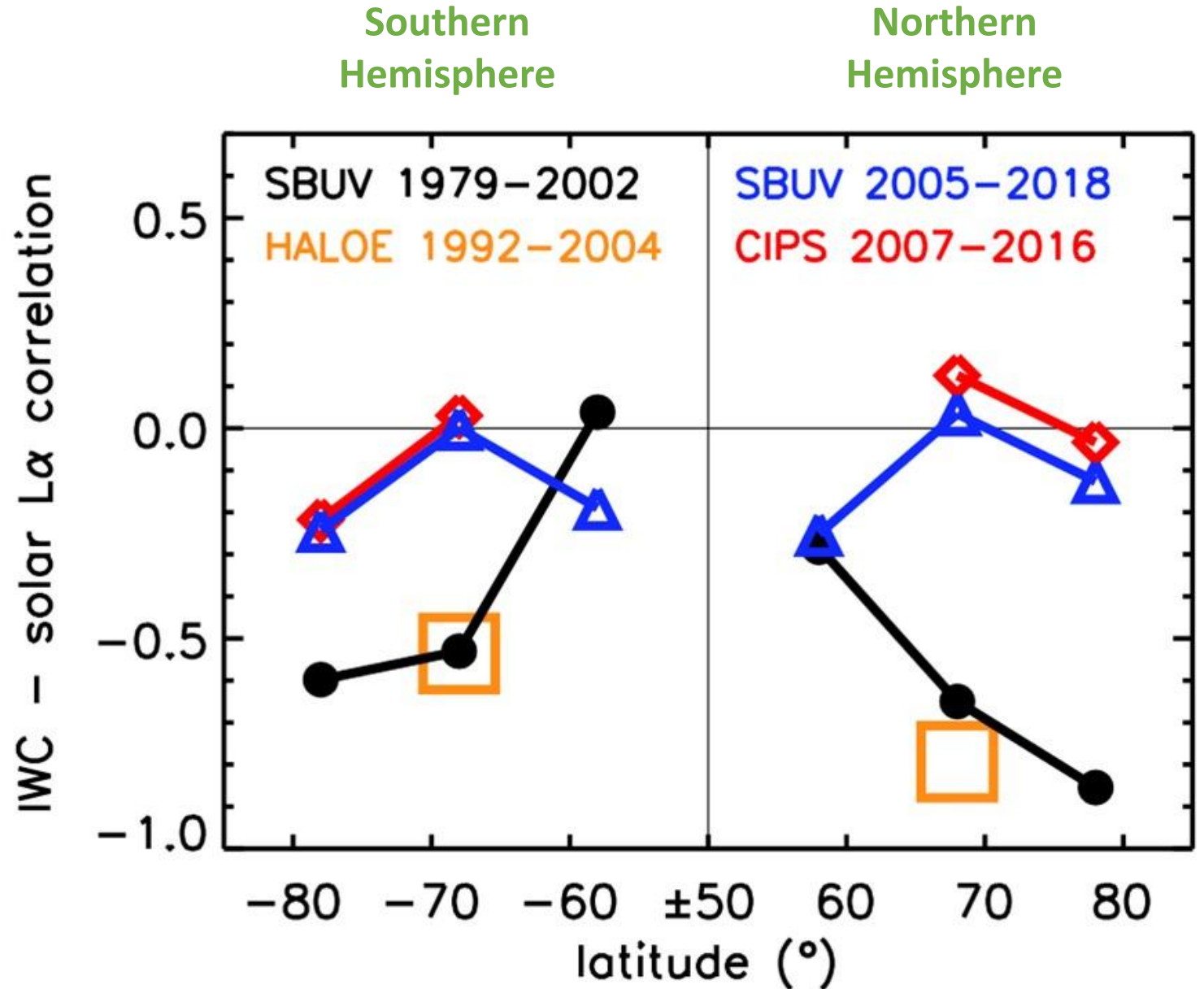
Hervig et al. [2019]:

- Examine additional data sets for PMC behavior (CIPS and SOFIE instruments on AIM satellite)
- Calculate IWC variations as anomalies from long-term mean to adjust for sampling differences and deseasonalize data



Hervig et al. [2019]:

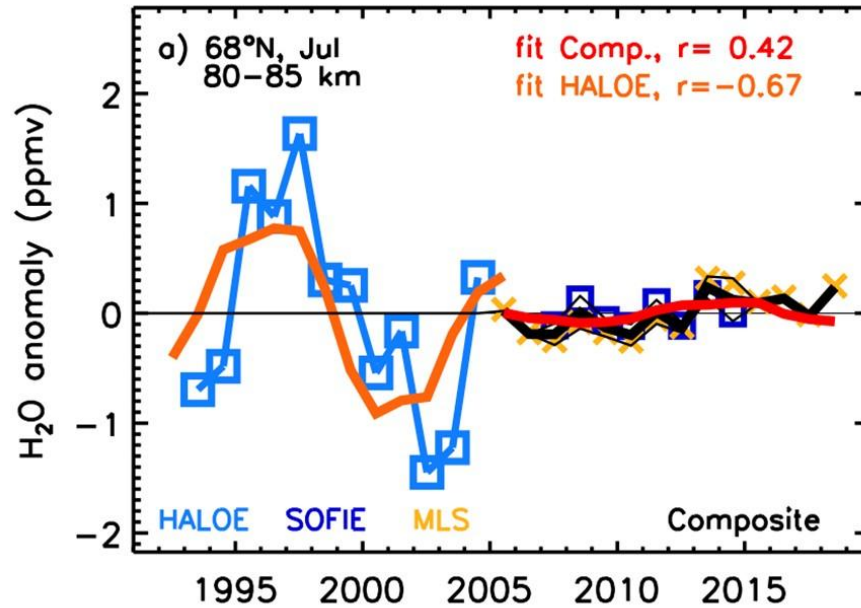
- Correlation coefficients between IWC and Lyman alpha using data from previous slide (with SBUV separated into two sections)
- Note poor correlation using post-2005 data (*blue, red*) in both hemispheres



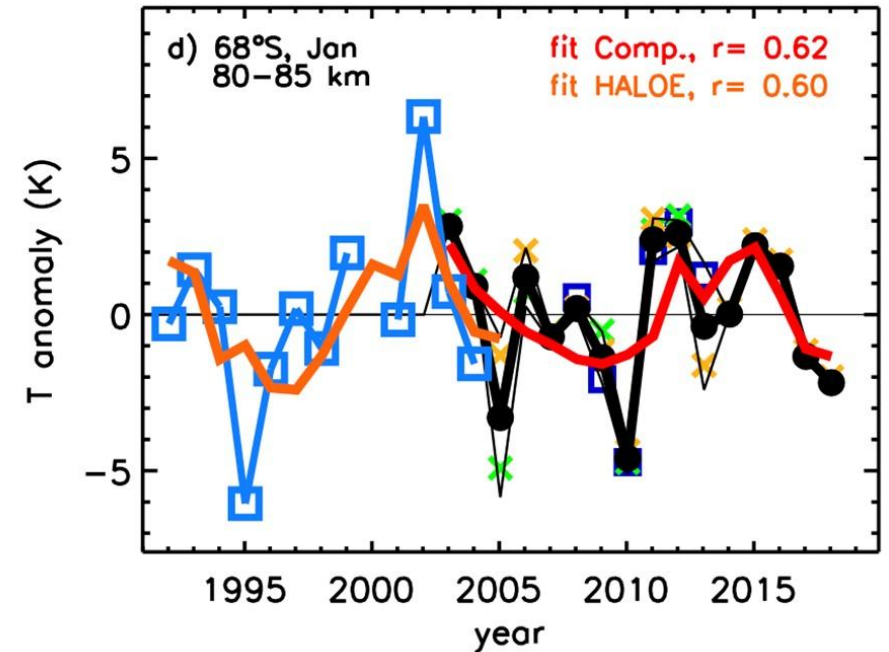
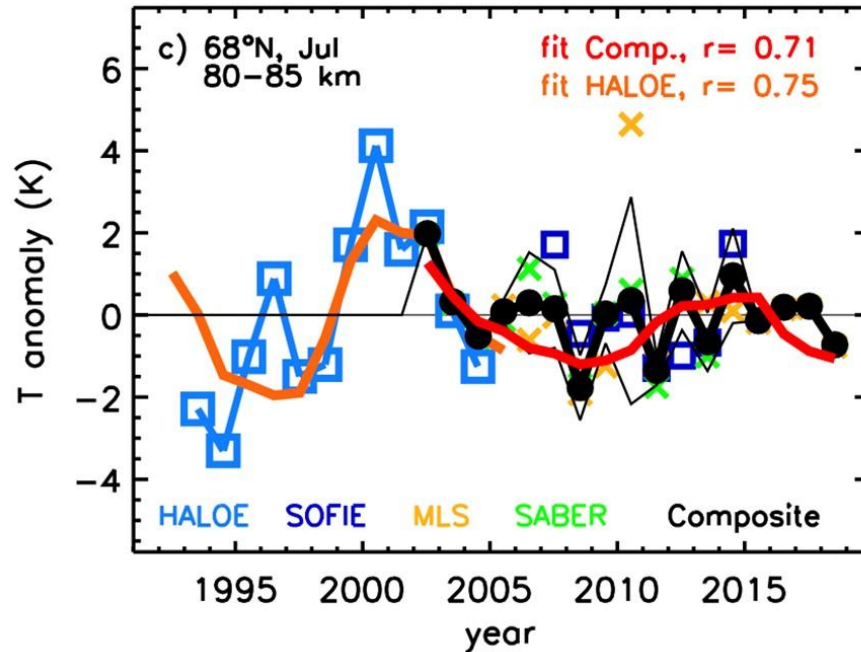
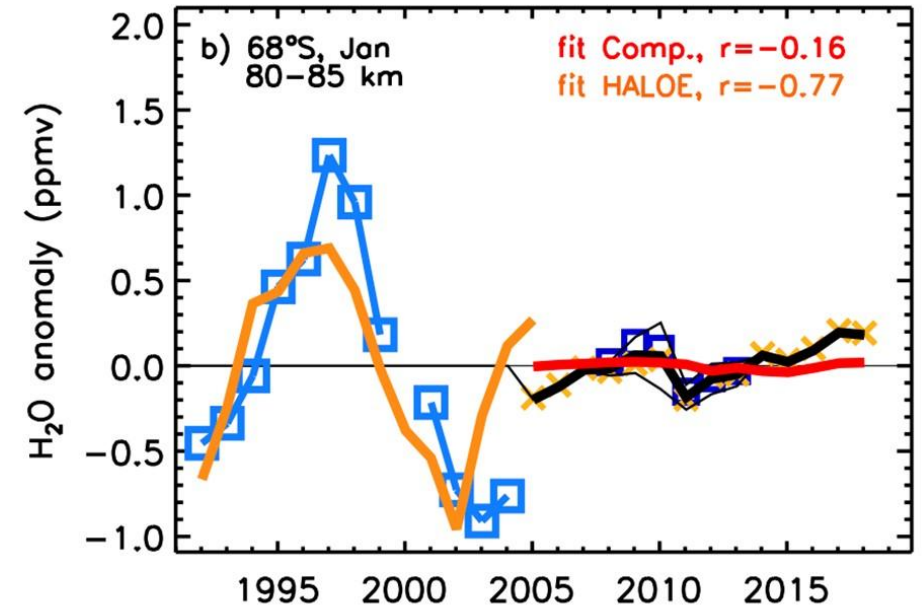
Hervig et al. [2019]:

- Compare to anomalies for water vapor [*top*], temperature [*bottom*]
- H₂O signal disappears from 2005 onward
- Sensitivity of IWC to ΔT is 3-4x larger than response to ΔH_2O (SOFIE results)

68°N, July

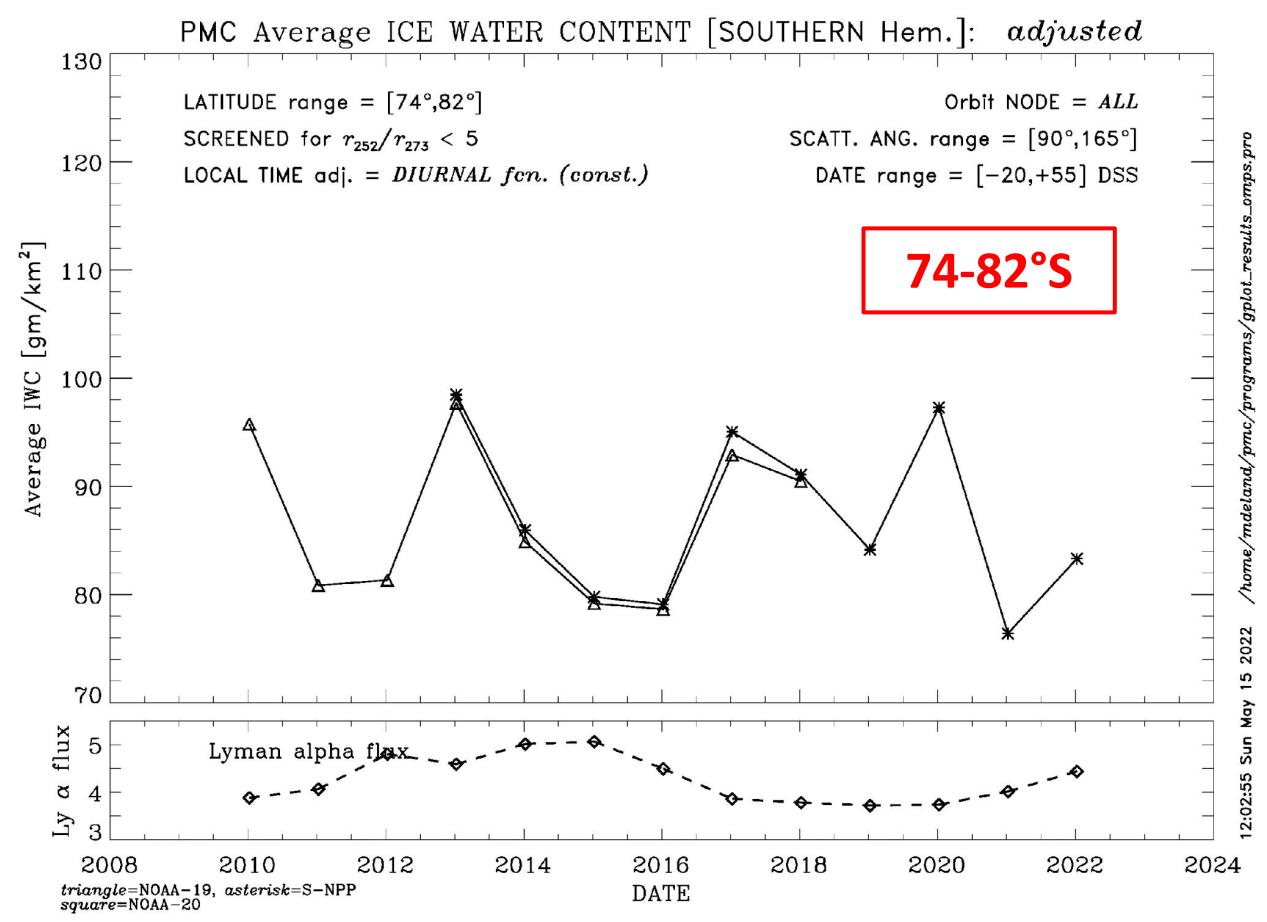
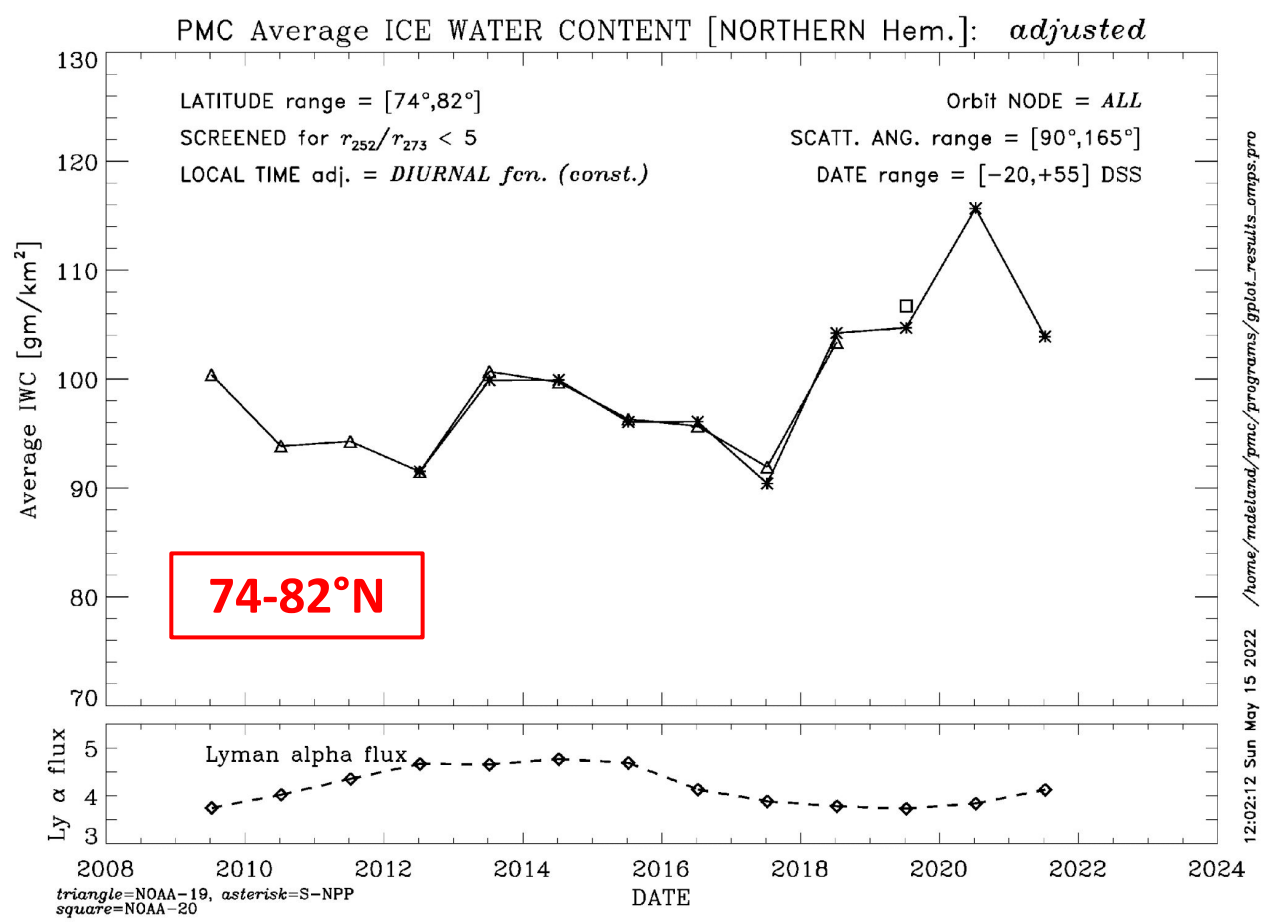


68°S, January



NOAA-19 SBUV/2 and Suomi NPP OMPS NP IWC data:

- Updated through most recent season (SH 2021-2022)
- NH IWC values follow Lyman alpha during 2013-2017, then rise during solar minimum
- SH IWC values jump in 2017, but have significant interannual variability



Summary

- PMCs are very sensitive to local environment in mesosphere (temperature, water vapor), which responds to solar activity
- Visual observations in 20th century showed possible solar cycle relationship, but data quality is inconsistent
- Satellite measurements show clear anti-correlation between PMCs and solar activity during ~1978-2000, but very little correlation since 2000
- Models suggest no solar signal in T and H₂O at polar summer mesopause
- *Were previous results showing a correlation amplified by volcanic eruptions (El Chichon, Mt. Pinatubo) near solar maxima?*

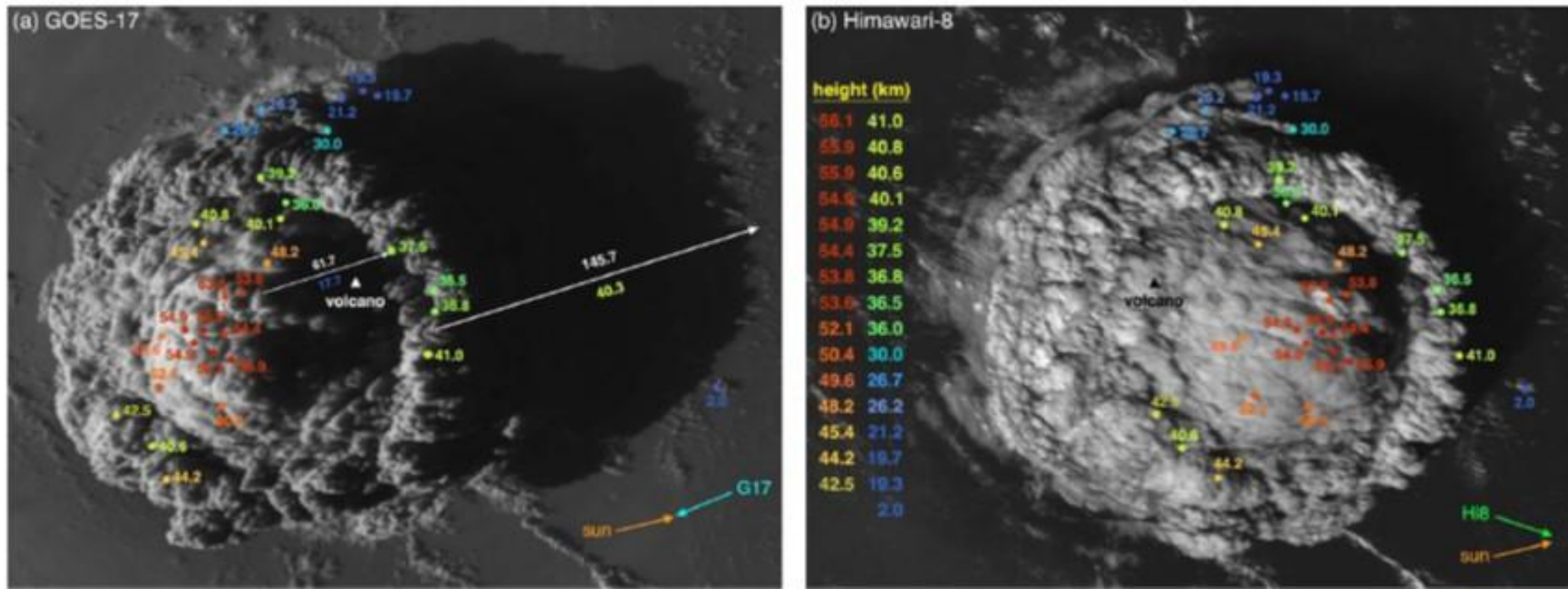


Figure 1. Image of the plume on 15 January 2022 at 04:30Z from (a) GOES-17 and (b) Himawari-8. Colored dots mark manual stereo height estimates (in km), and the white/black triangles show the volcano's location. The white arrows in panel (a) depict the shadow of a plume edge feature and a dome feature, with the shadow length and the derived height given above/below the arrow. Arrows in the lower right of each panel indicate the sun-to-pixel and satellite-to-pixel azimuths.

[Carr et al. \[2022\], *Geophys. Res. Lett.*, 49, e2022GL098131](#)

Hunga Tonga-Hunga Ha-apai eruption (15 January 2022):

- Plume height reached ~55 km!
- Water vapor injection into stratosphere ~10% of global budget [*P. Newman, priv. comm.*]
- Occurred on rising phase of solar cycle
- *Possible long-term effects on PMC behavior?*