# Impact of the solar 11-year and 27-day cycles on mesopause temperatures

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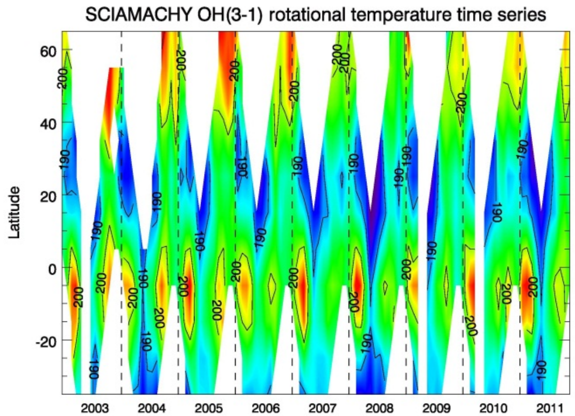


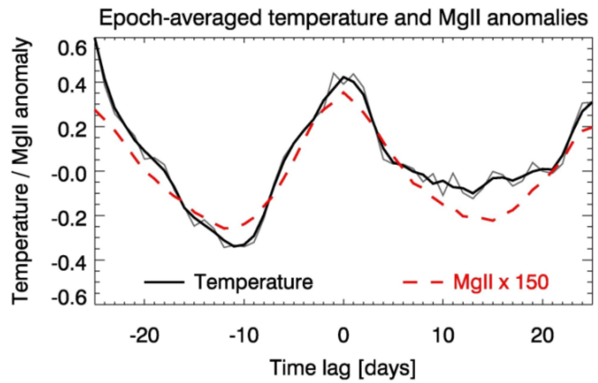


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*7th limb conference, Bremen, 2013*

# Why care about solar-cycle effects on middle atmosphere?

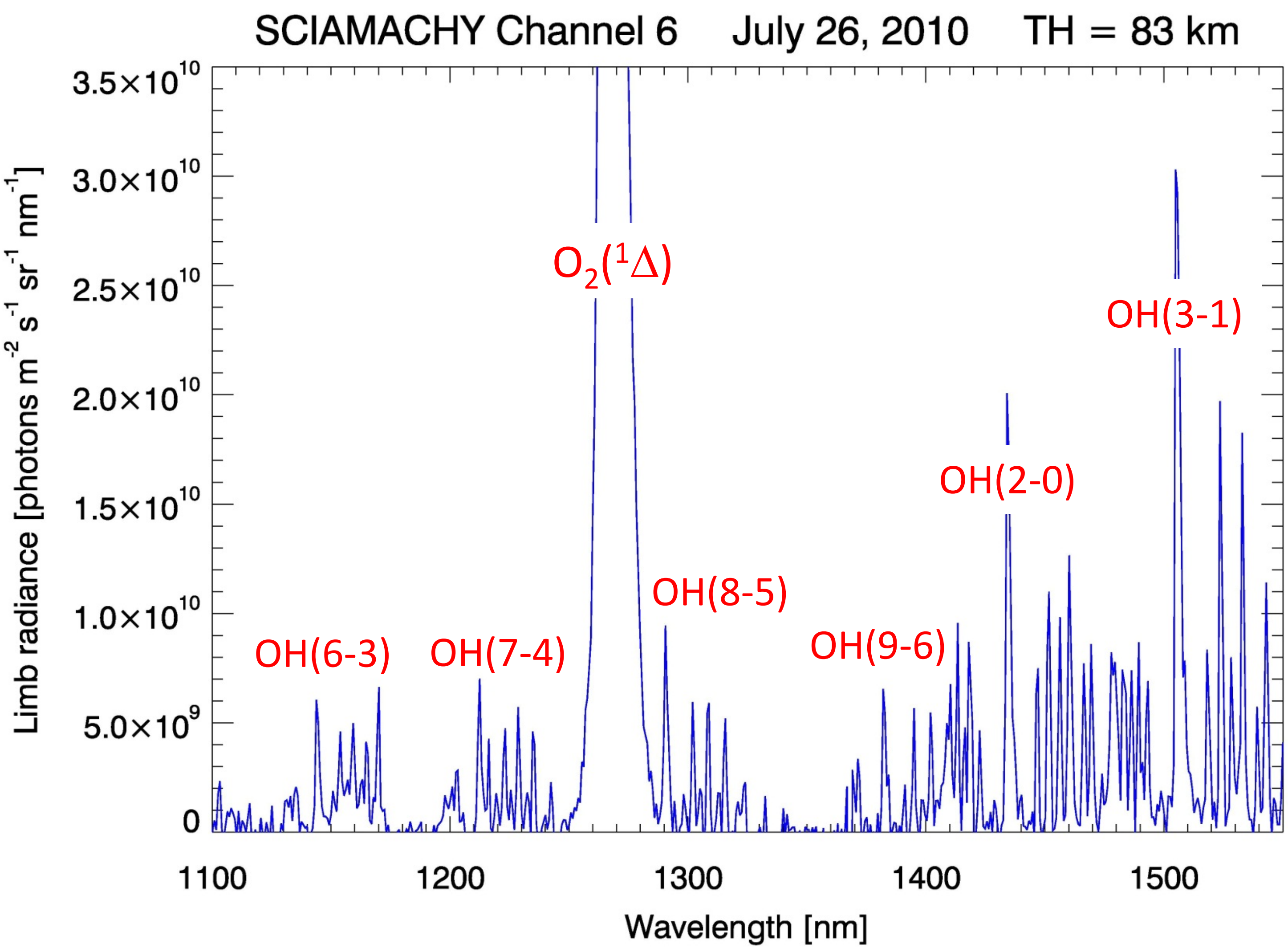
- To improve understanding of middle atmosphere system
- Understanding middle atmospheric climate change requires full understanding of all sources of variability, in particular caused by solar cycle effects

Challenges:

- Measurements of 11-year solar cycle signatures are challenging, because they require long and high quality time series

⟶ Investigation of solar 27-day effects in atmospheric parameters may allow constraining 11-year solar cycle effects if sensitivities are similar for both solar cycles

# Night-time emission spectrum at 83 km tangent height



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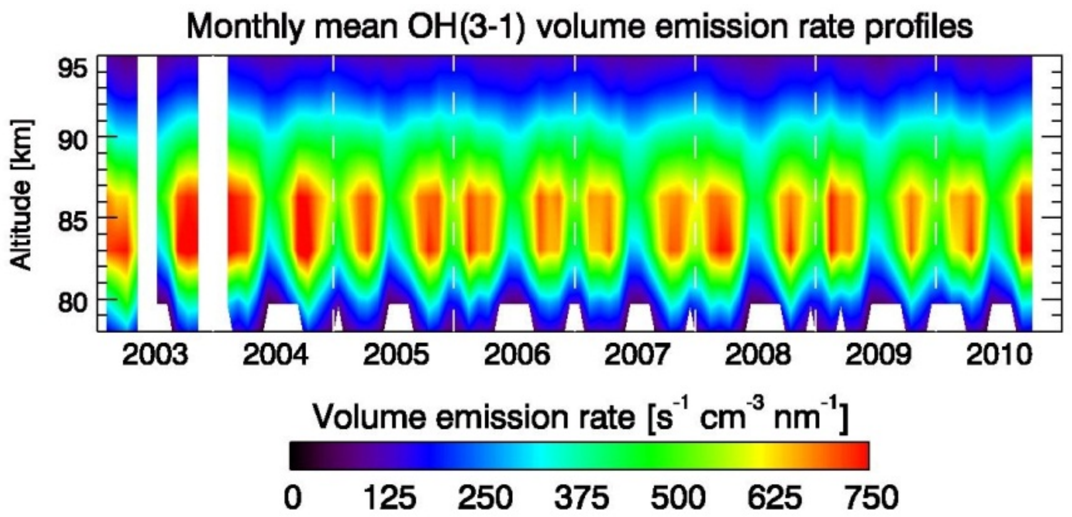
# $OH^*$ Meinel-Emissions

- $OH^*$ is formed and excited near the mesopause through:

$$H + O_3 \longrightarrow OH^*(\nu' \leq 9) + O_2 + 3.3\ eV$$

→ **Airglow emission in ≈ 87 km with 8 – 10 km thickness**




*von Savigny et al.*, (2013)

# $OH^*$ rotational temperature retrieval using OH(3-1) band

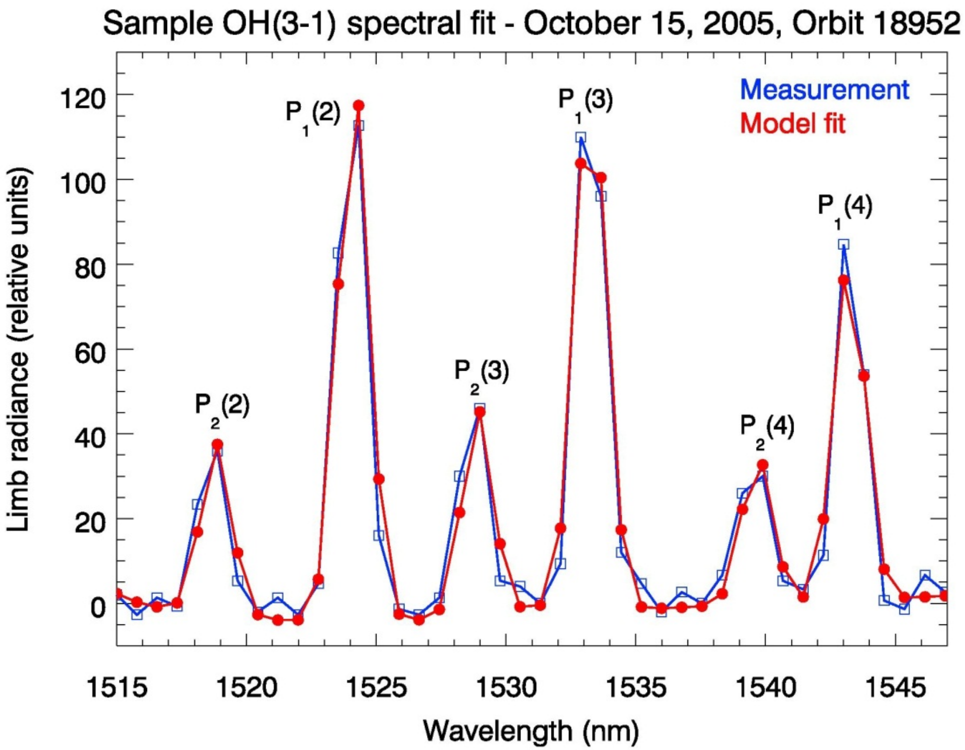
OH spectrum model:

- Energy levels from Coxon & Foster [1982]
- Line strength factors from Kovacs [1969]

Iterative retrieval approach:

(1) linear fit with 2nd order polynomial

(2) non-linear fit (Levenberg-Marquard) driving OH model, including $\lambda$-shift



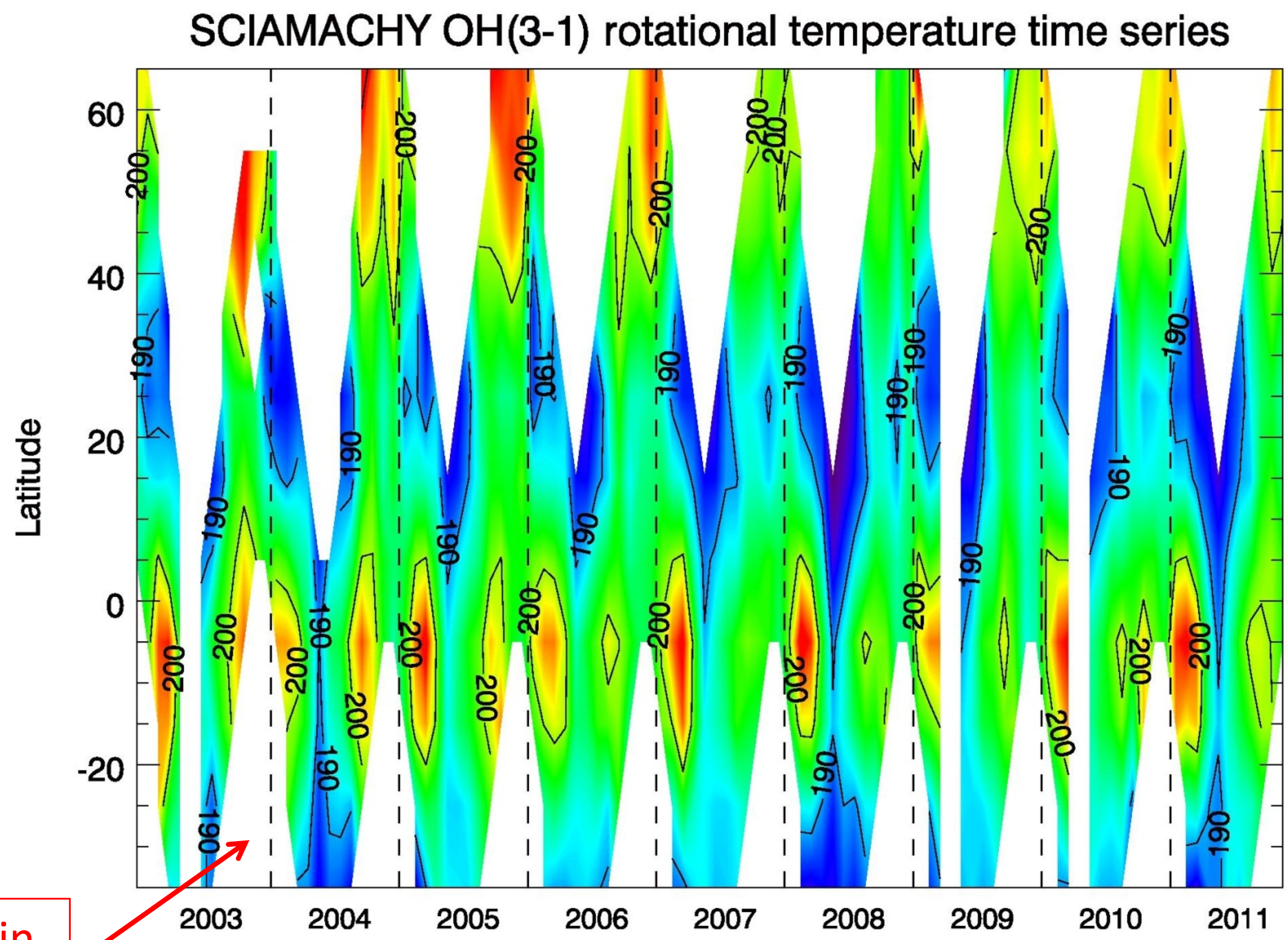

Impact of different Einstein coefficients used:

*Kovacs* [1969], *Mies* [1974], *Goldman et al*. [1998]

$T_{Kovacs} - T_{Mies} = 1.1$ K and $T_{Kovacs} - T_{Goldman} = 3.2$ K

*von Savigny et al*., GRL (2004)

# Geographical coverage of night-time limb observations




Gaps in coverage



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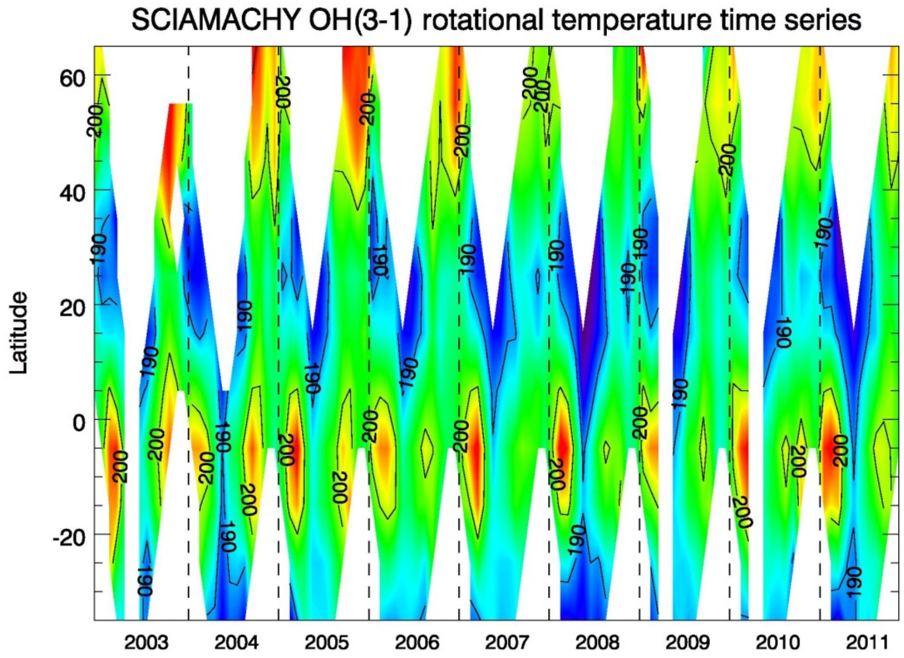
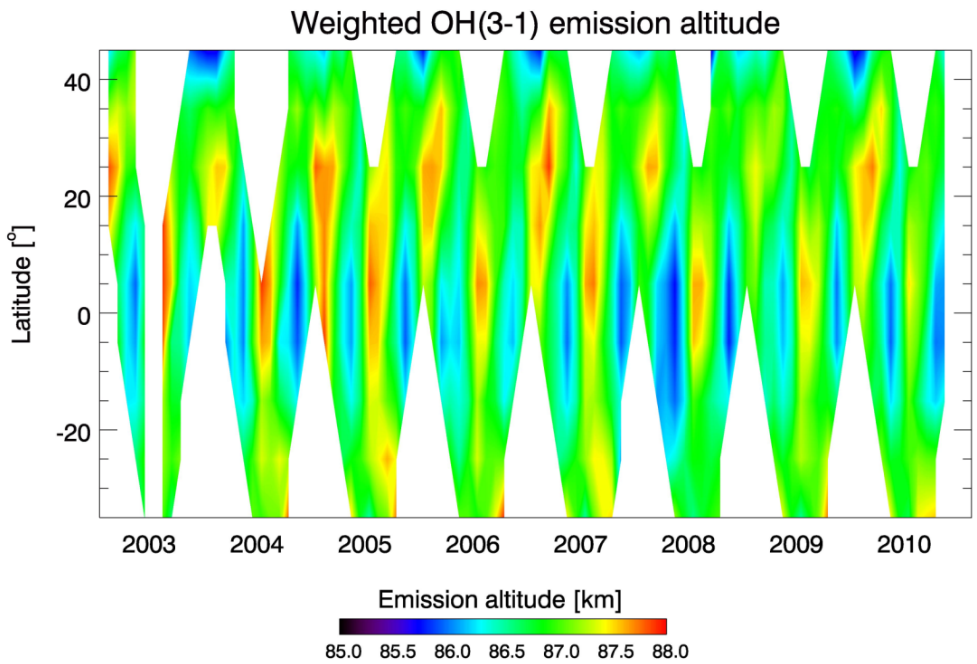
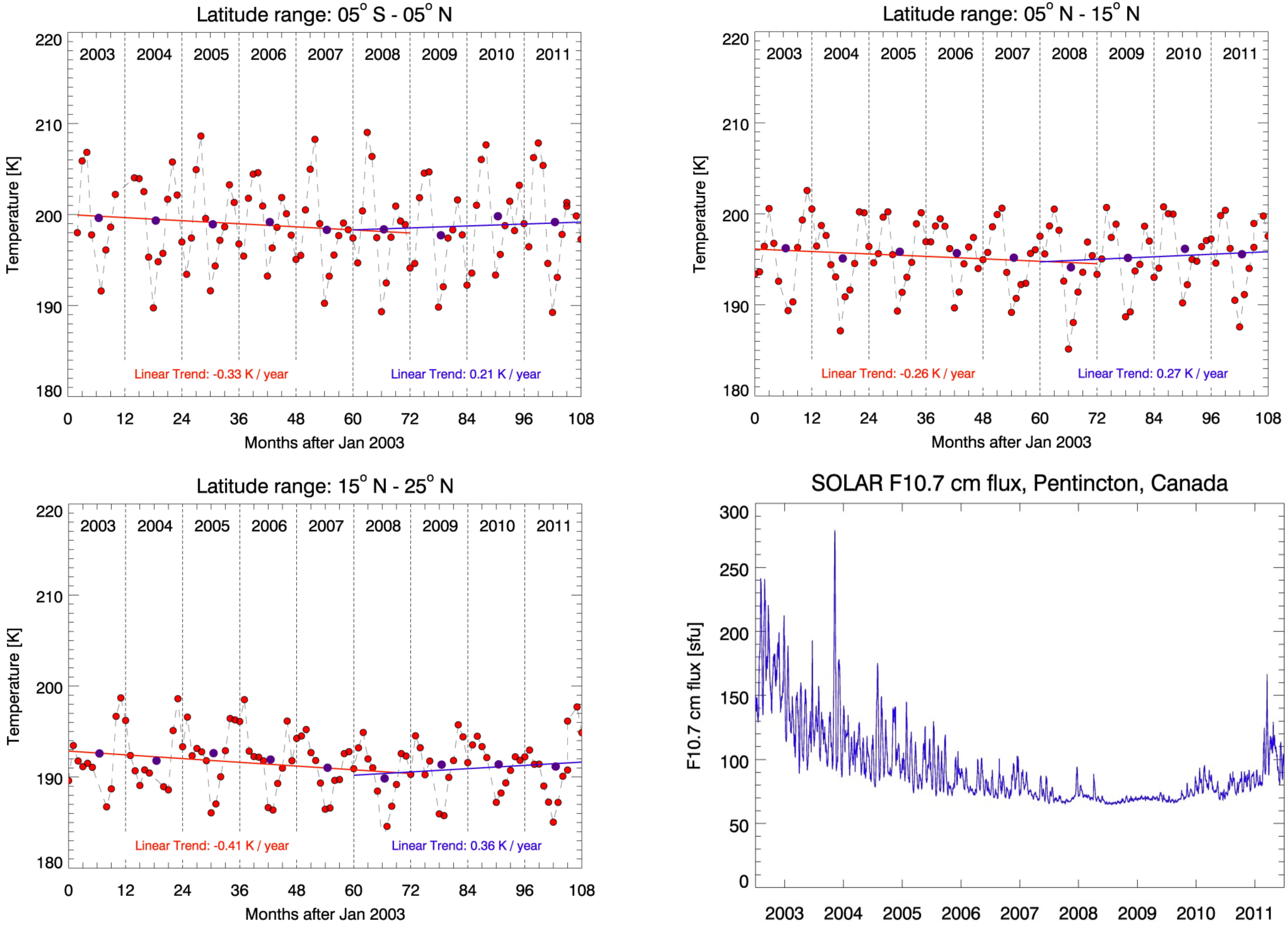
# Temperature and mean OH(3-1) emission altitude



# Solar cycle effects on OH rotational temperatures (mesopause) measured with SCIAMACHY

# SCIAMACHY OH(3-1) temperature time series



# Temperature sensitivity to solar activity

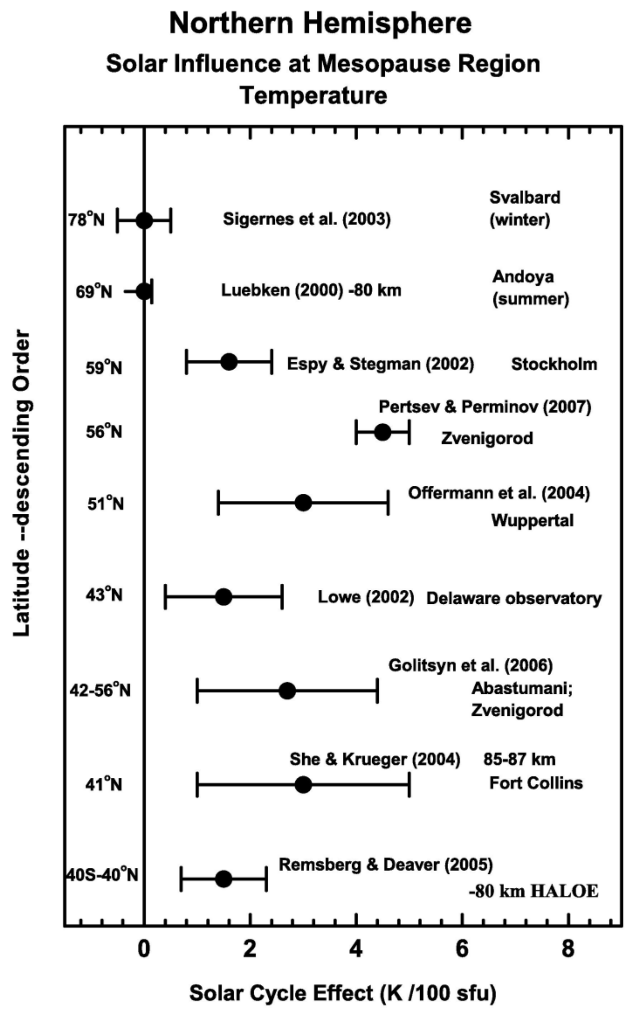
- Let's assume that there is no long-term temperature change apart from the 11-year solar cycle variation

- Sensitivity values differ slightly for different latitude bands and range from

  0.9 – 3.3 K / 100 sfu (± 2 K / 100 sfu)

- Good agreement with majority of published values

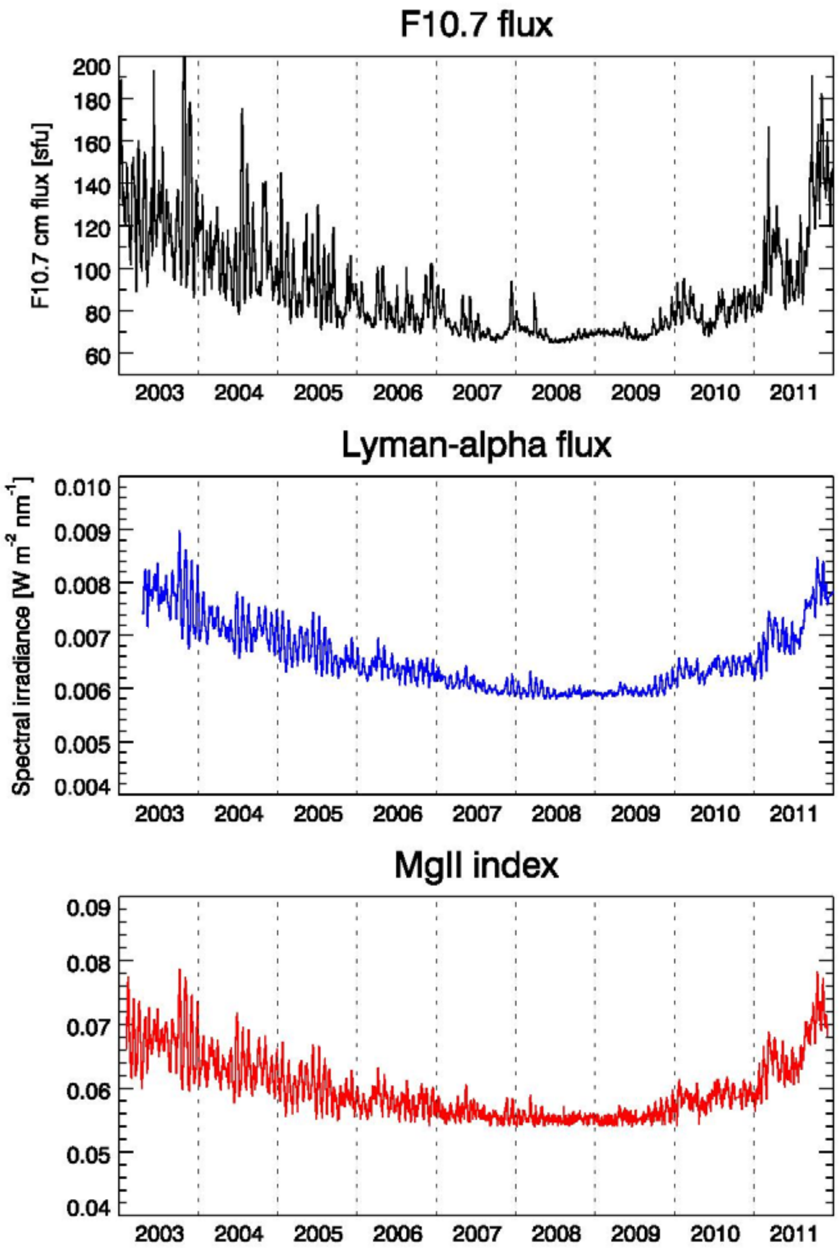
- **<u>But:</u>** Time series not long enough for robust separation of solar cycle signature and long-term trend




*Beig et al.* (2008)

# Relationship of 11-year and 27-day solar cycle

Pentincton F10.7 cm flux data




SORCE Interactive Data Access

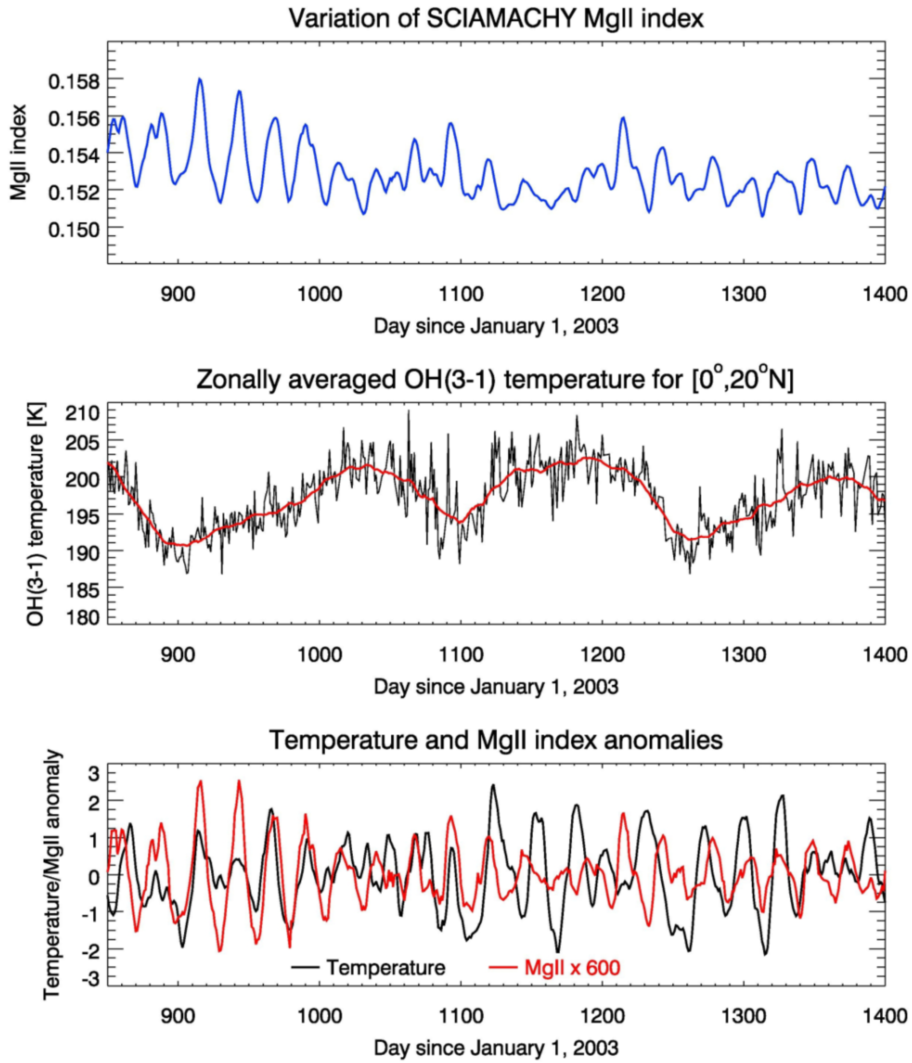
# Solar 27-day signature in OH(3-1) rotational temperatures

# Temperature & MgII-index anomalies

MgII index

Red Line:
35-day running mean

Anomaly = time series – running mean

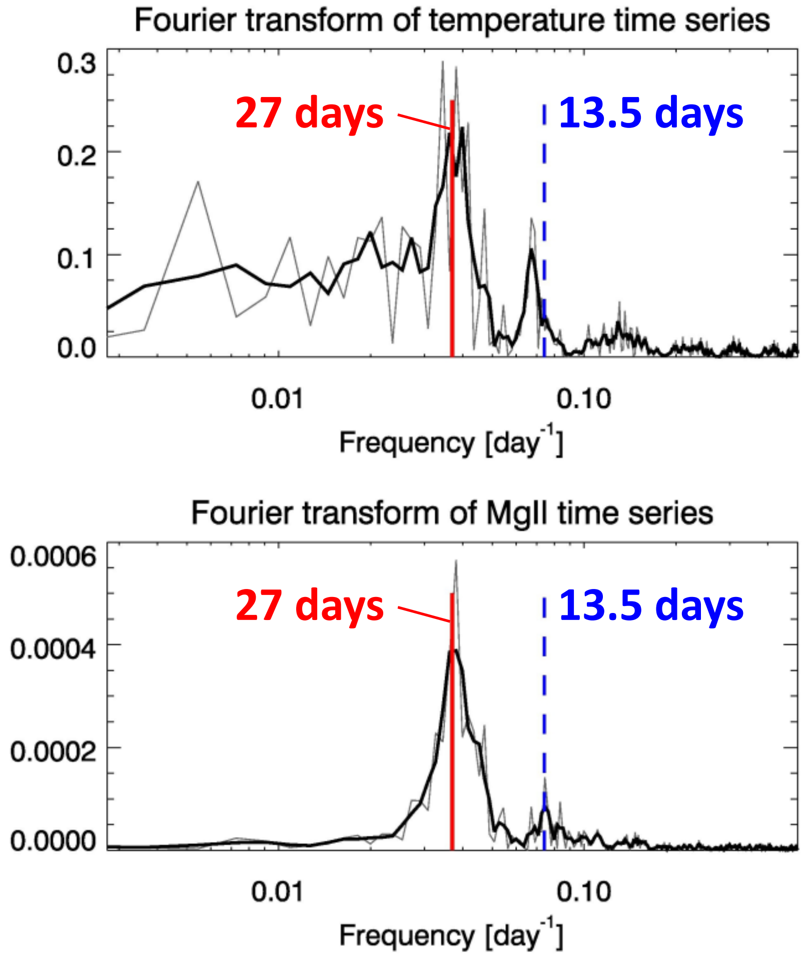



*von Savigny et al.*, GRL (2012)

# Fourier Transform of MgII index and OH temperature

Temperature FFT

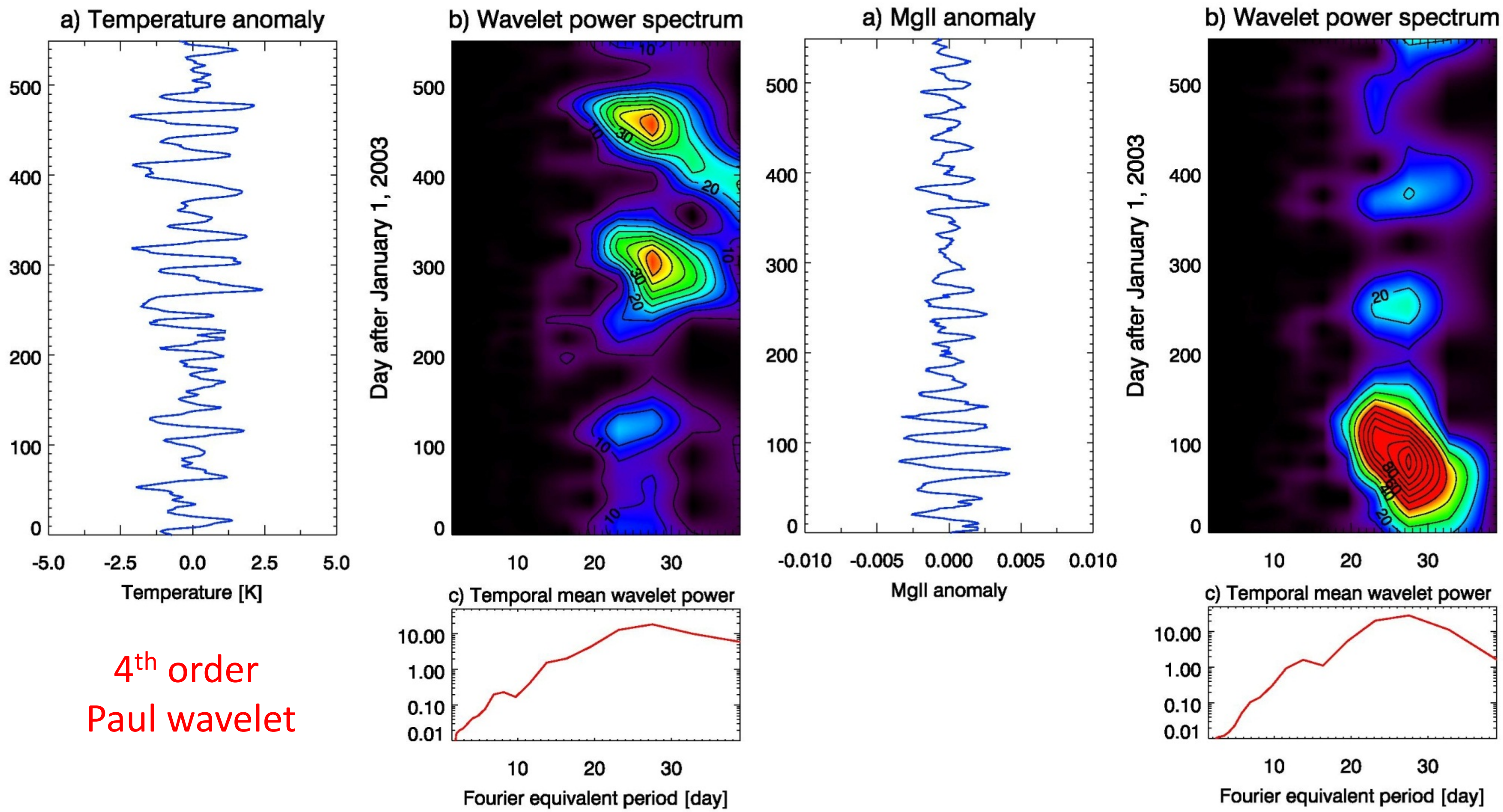
MgII index FFT




→ Use wavelet transform and superposed epoch analysis

*von Savigny et al.*, GRL (2012)

# Temporal correspondence of 27-day signatures in mesopause temperature and MgII index

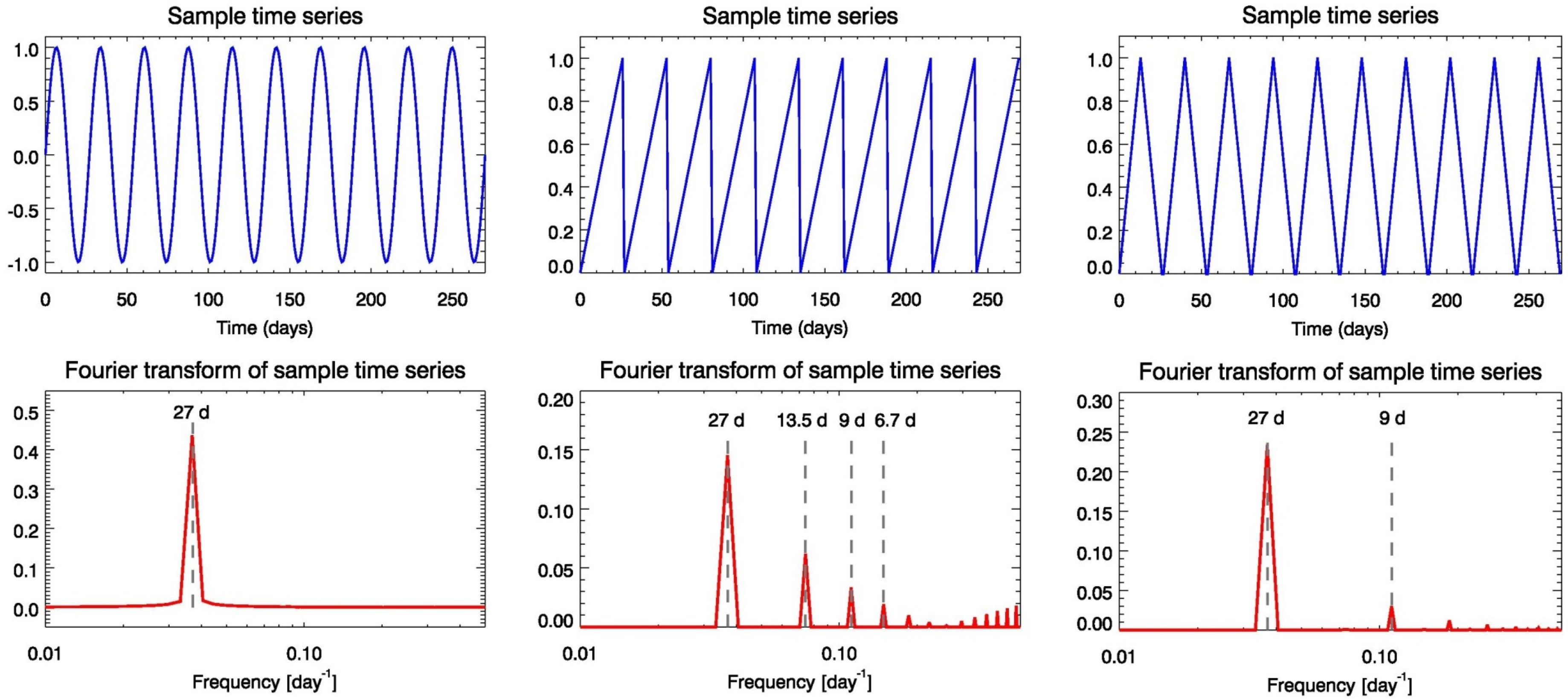



4th order
Paul wavelet

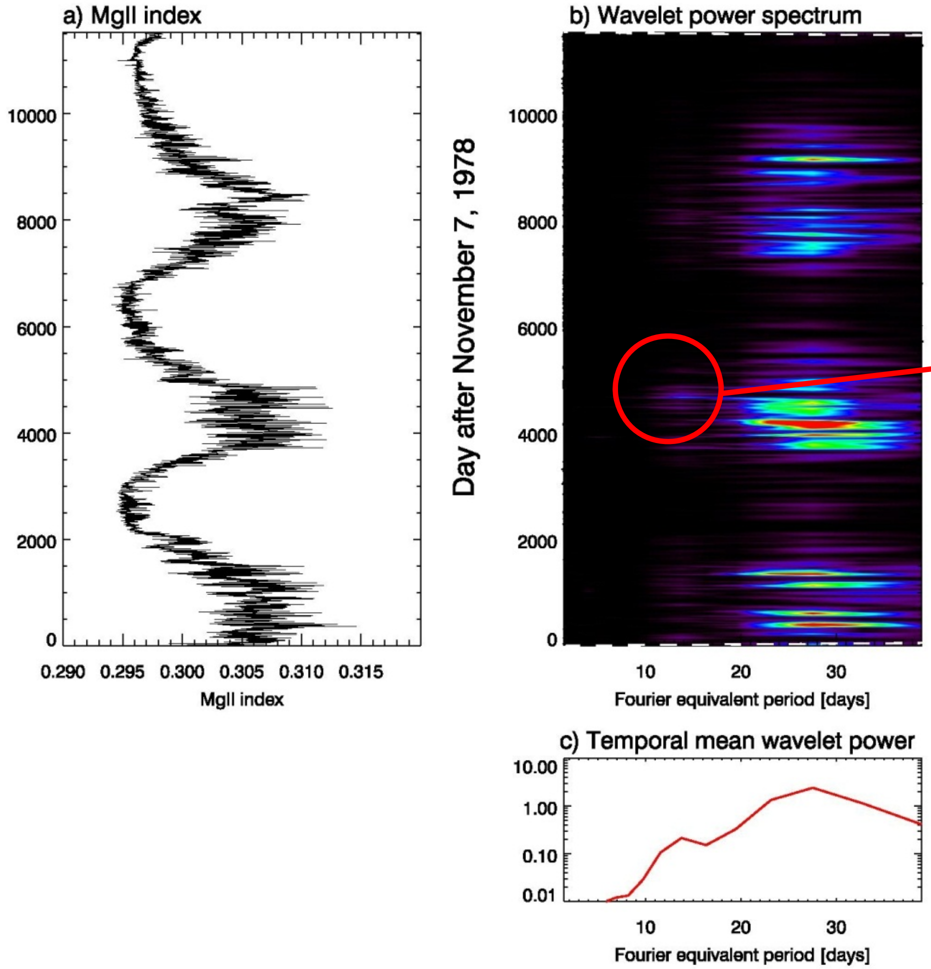
→ No obvious temporal correspondence of 27-day signatures in temperature and MgII index

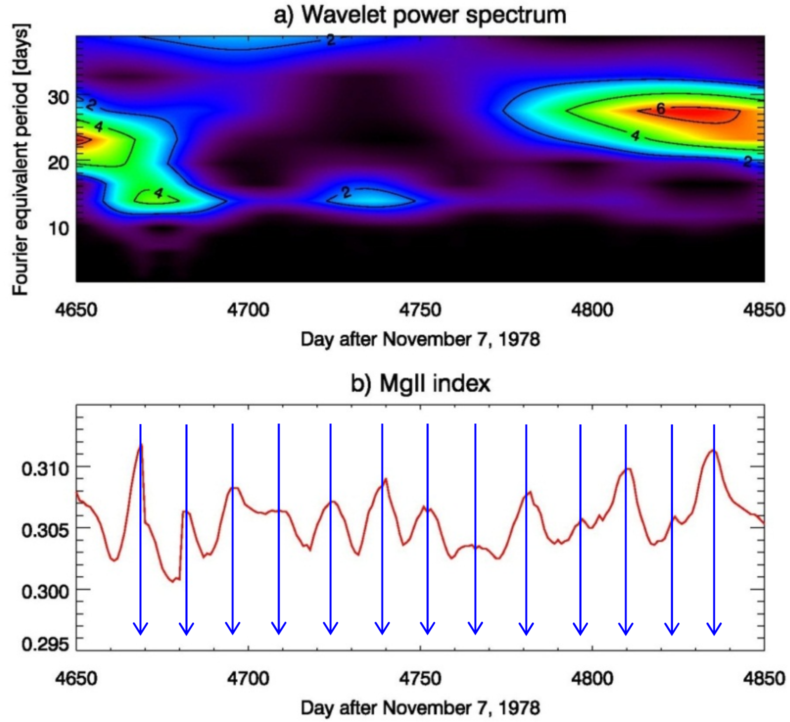
# Is the 13-day signature in temperature and MgII index real?

## Or is it just caused by harmonics?



# Quasi-13-day signature in MgII index time series

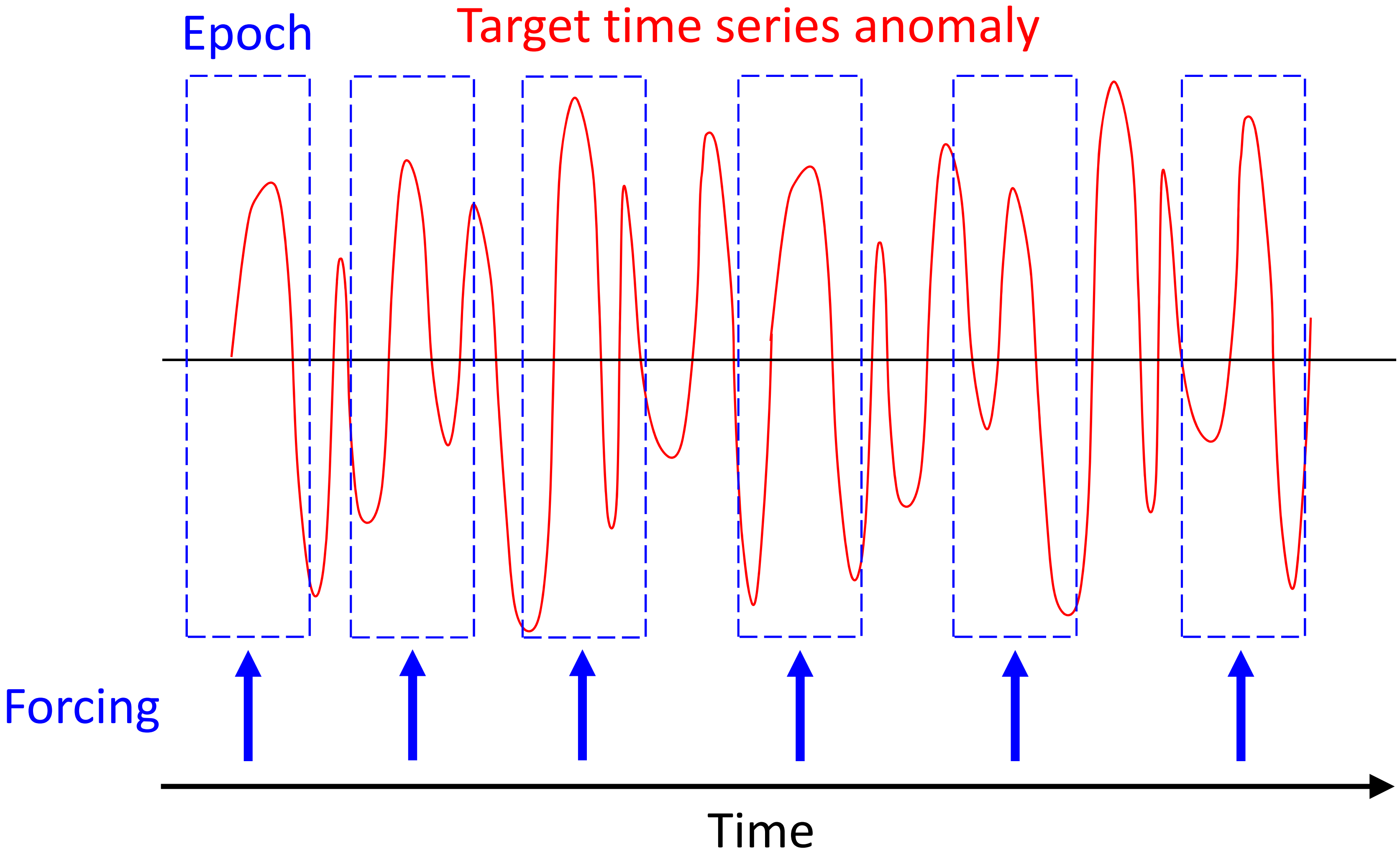



→ MgII index time series exhibits real quasi-13-day signatures

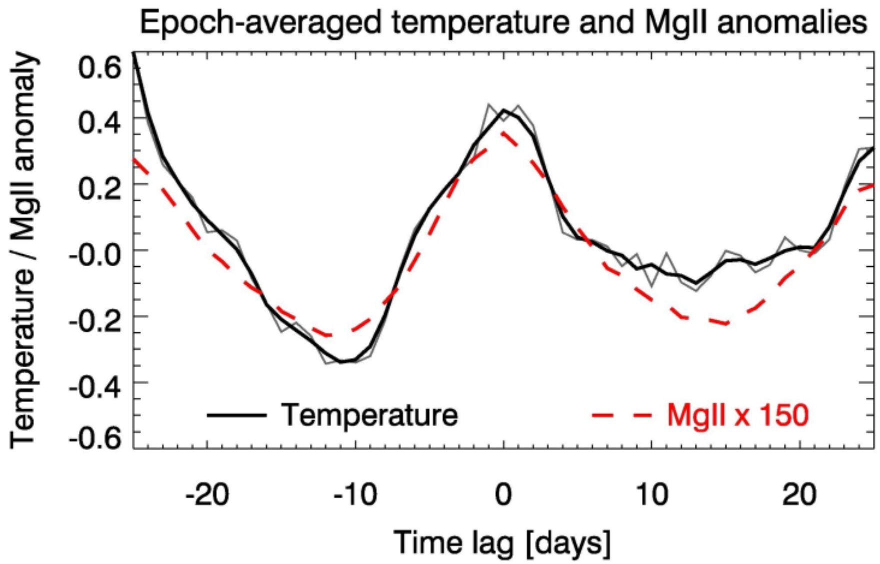
Comined SBUV/GOME/SCIAMACHY MgII index time series

# Superposed Epoch Analysis (SEA)



# Superposed Epoch Analysis

## Epoch-averaged anomalies




- Temperature sensitivity for 27-day cycle:

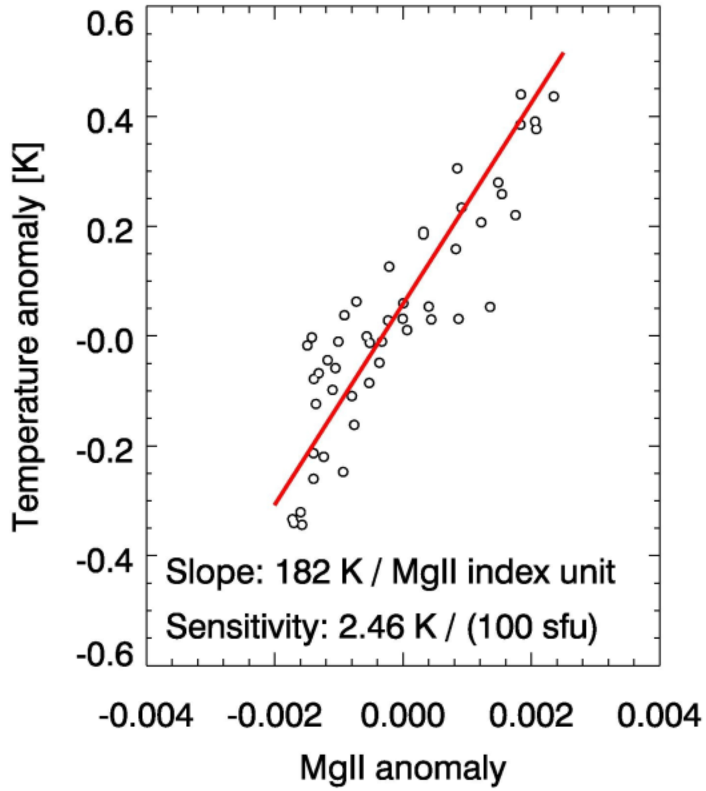
  **2.46 ± 0.93 K / (100 sfu)**

- Sensitivity for 11-year cycle:

  **≈ 1 – 4 K / (100 sfu)**

- Time lag between temperature and MgII-index a few days at most

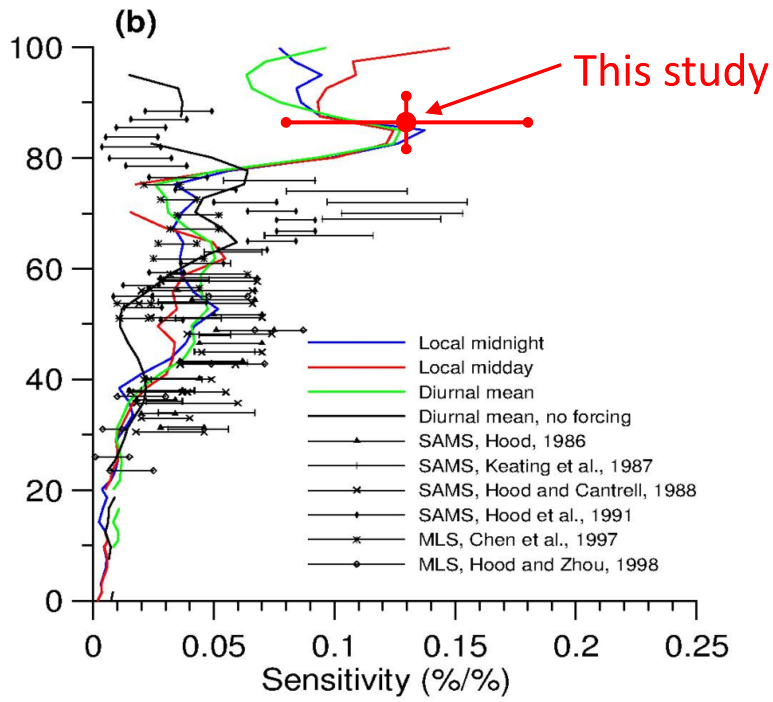
## Temperature sensitivity




*von Savigny et al.*, GRL (2012)

# Comparison with previous results

- Conversion of sensitivity to % change in temperature per % change in solar irradiance at 205 nm



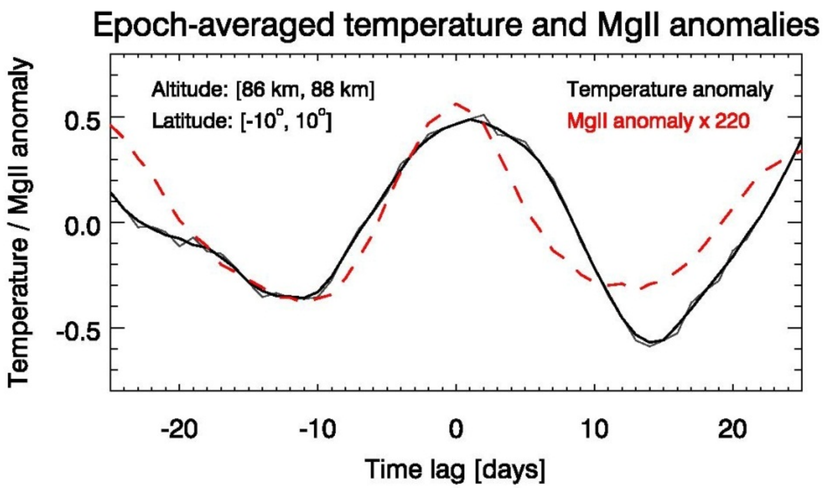

*Gruzdev et al.*, ACP *(2009)*

- SCIAMACHY results in good agreement with HAMMONIA simulations (*Gruzdev et al.*, 2009), but systematically larger than SAMS results (*Hood et al.*, 1991)

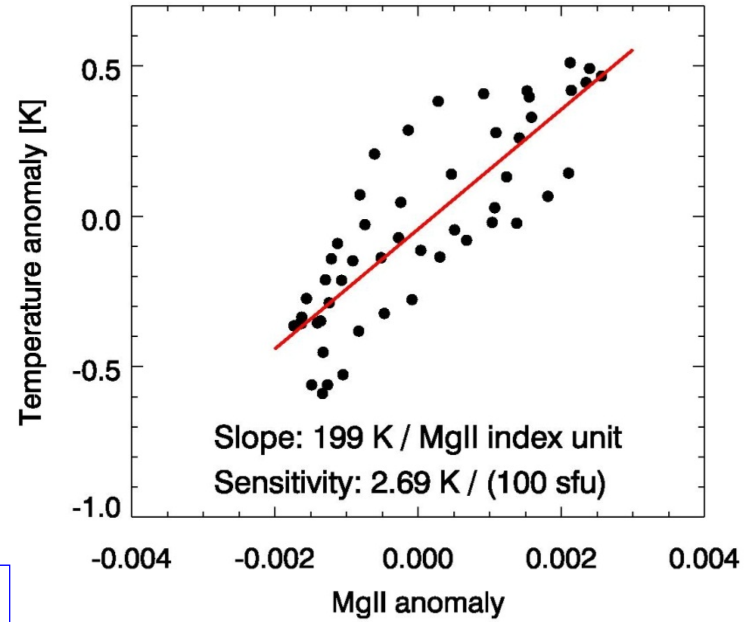
# Superposed Epoch Analysis of MLS temperature data

- Microwave Limb Sounder (Aura) nighttime mesopause temperature measurements used

## Epoch-averaged anomalies




## Temperature sensitivity




- Temperature sensitivity for 27-day cycle:

  ≈ **2.7 / (100 sfu)**

- Consistent with SCIAMACHY result

# Mechanisms for solar-driven temperature effects

- Solar irradiance changes will directly affect amount of energy deposited in mesosphere
- Solar-driven photochemical composition changes (of, e.g., $O_3$) may affect diabatic solar heating
- Changes in chemical heating by exothermic reactions, e.g.:

$$\mathrm{H} + \mathrm{O}_3 \longrightarrow \mathrm{OH}^* \, (\nu' \leq 9) + \mathrm{O}_2 + 3.3 \text{ eV}$$

  can affect temperature
- Solar-induced dynamical changes may lead to altered adiabatic heating/cooling rates

But: individual contributions of these processes to the actual solar-driven temperature change not well understood

# Summary

- SCIAMACHY yields temperature sensitivities w.r.t. 11-year solar cycle of 1 – 3 K / (100 sfu) in very good agreement with previous studies (if pssible long-term trend is neglected)

- SCIAMACHY data set shows evidence for solar-driven 27-day signature in OH temperatures with time lags of a few days at most

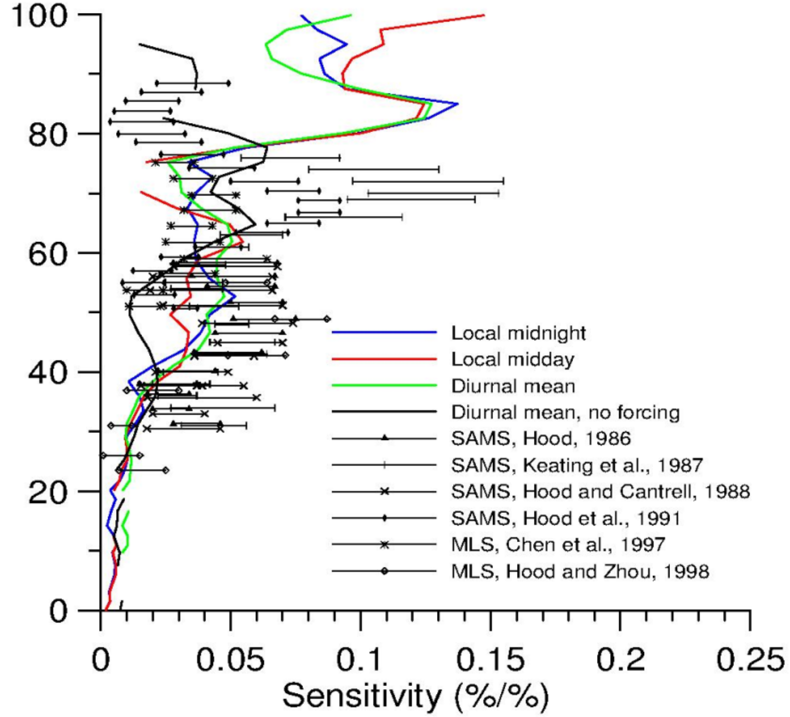
- Temperature sensitivities w.r.t 11-year and 27-day cycles have similar values

- Results confirmed by analysis of MLS/Aura mesopause temperatures

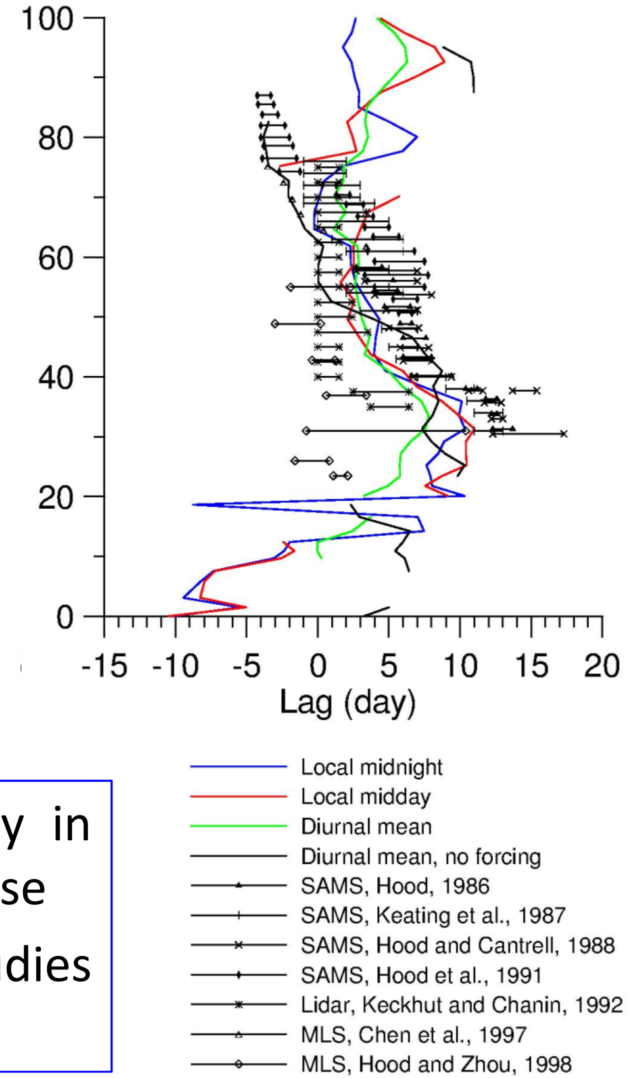

Thank you for your attention

# 27-day signature middle atmospheric temperature

## Sensitivity (to flux at 205 nm)




## Time lag

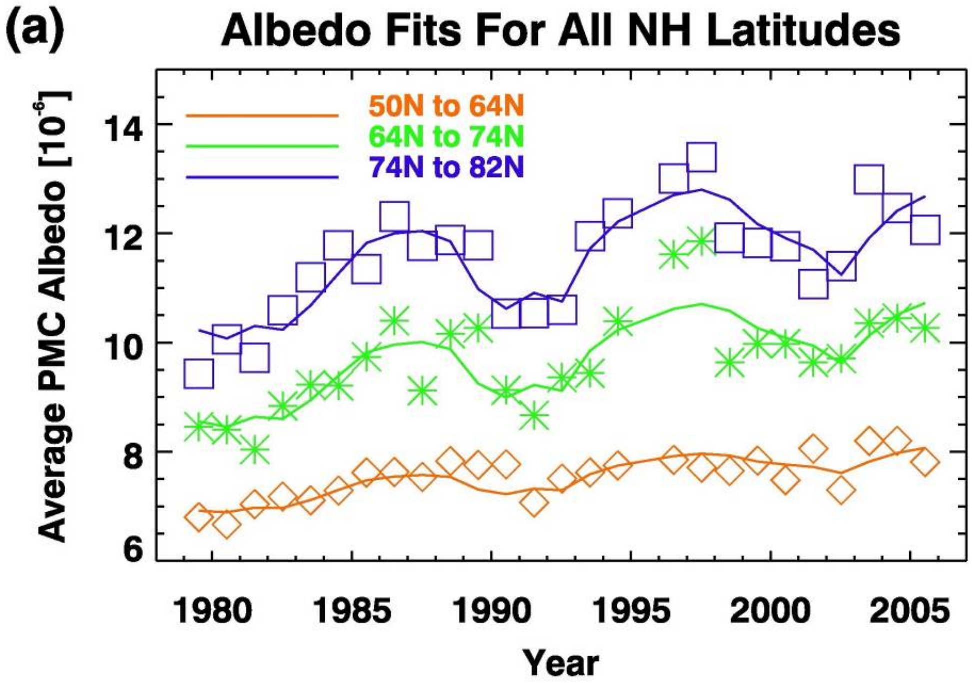



*Gruzdev et al.,* ACP *(2009)*

- Modelled and measured sensitivity in good agreement except at mesopause
- Time lags in observational studies scatter significantly

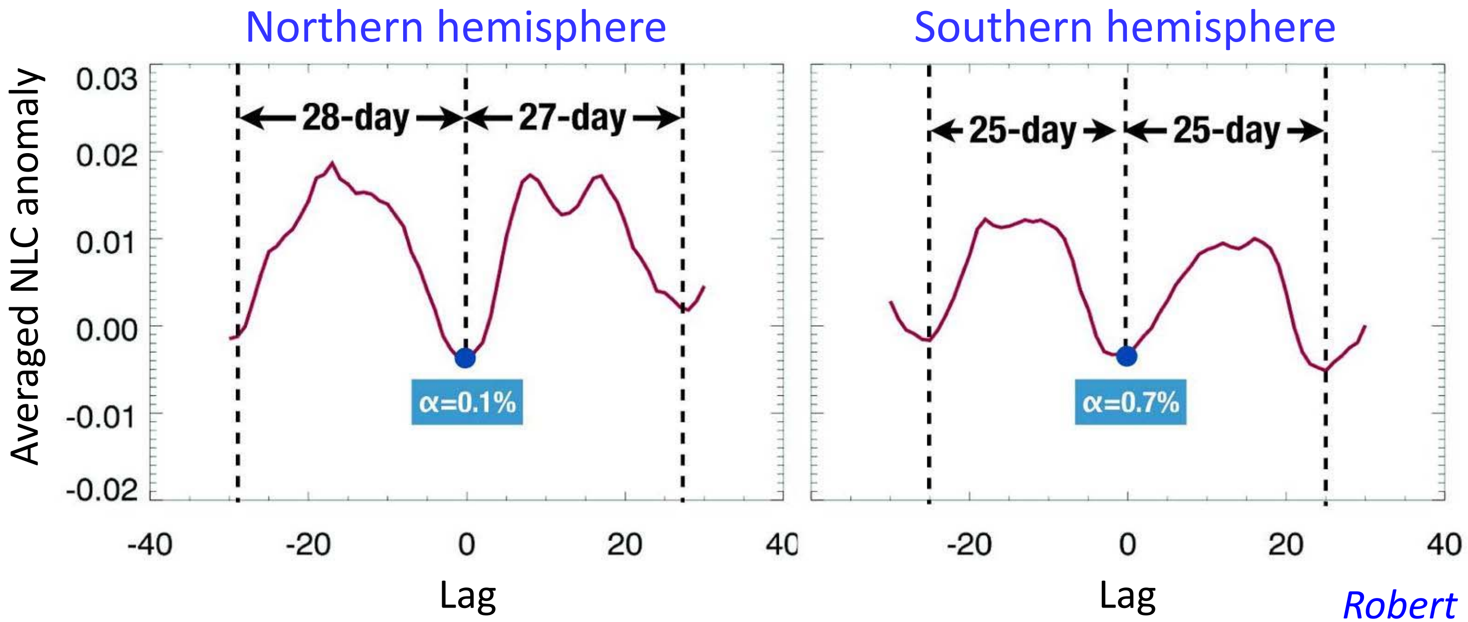
# Solar cycle signatures in noctilucent clouds

# 11-year solar cycle signature in NLCs/PMCs




*DeLand et al.*, JGR (2007)

# Superposed epoch analysis of SBUV NLC albedo




*Robert et al.* (2010)

- Comparison of Sensitivity in terms of 11-year and 27-day solar cycles: (11-year sensitivity taken from *DeLand et al.* [2007])

**Table 1.2** Sensitivity of the SBUV albedo to the 27-day and 11-year solar variation. Values of the sensitivities of the 11-year solar cycle were taken from (*DeLand et al.*, 2003) for corresponding latitudes. Sensitivity unit: $10^{-6}\ sr^{-1}/(10^{11}\ photons\ cm^{-2}\ s^{-1})$.

| Hemisphere | 27-day | 11-year |
|---|---|---|
| North | -0.61 ± 0.11 | -0.71 ± 0.02 |
| South | -0.46 ± 0.12 | -0.41 ± 0.02 |

*von Savigny* et al. (2012)

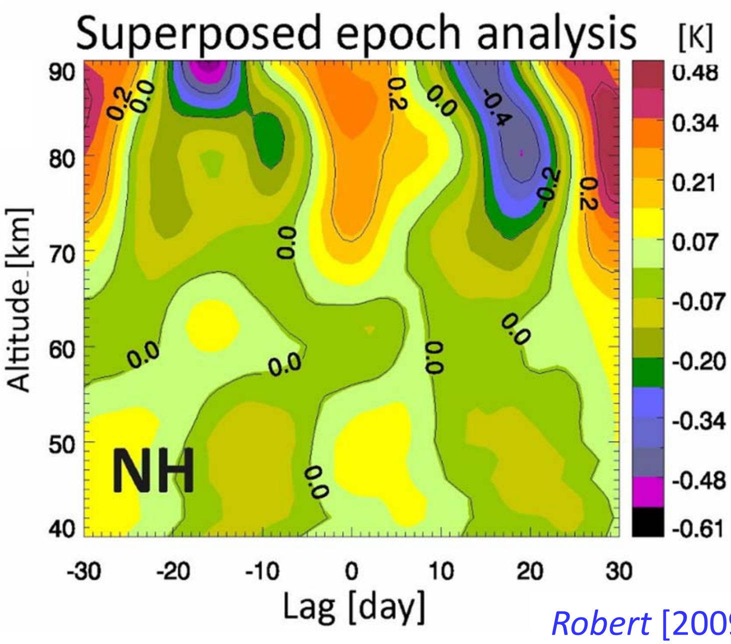
Unit:

$10^{-6}$ /($10^{11}$ $\gamma$ $s^{-1}$ $cm^{-2}$)

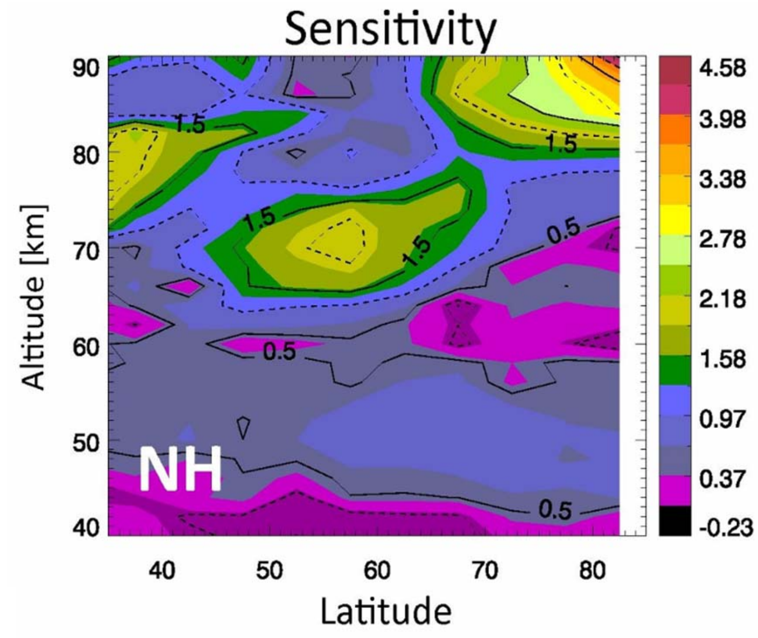
→ Sensitivities for 11-year and 27-day solar cycle agree within uncertainties

# Superposed epoch analysis of MLS/Aura temperature profiles

Latitudes:
60°– 80°N




*Robert* [2009]




- 27-day signature also present in middle atmospheric temperature profiles measured with MLS/Aura
- Reason for 27-day signatures in temperature not fully established

  But: Sensitivity maximum near polar summer mesopause may suggests dynamical mechanism