Satellite measurements of nitric monoxide (NO) in the mesosphere and lower thermosphere

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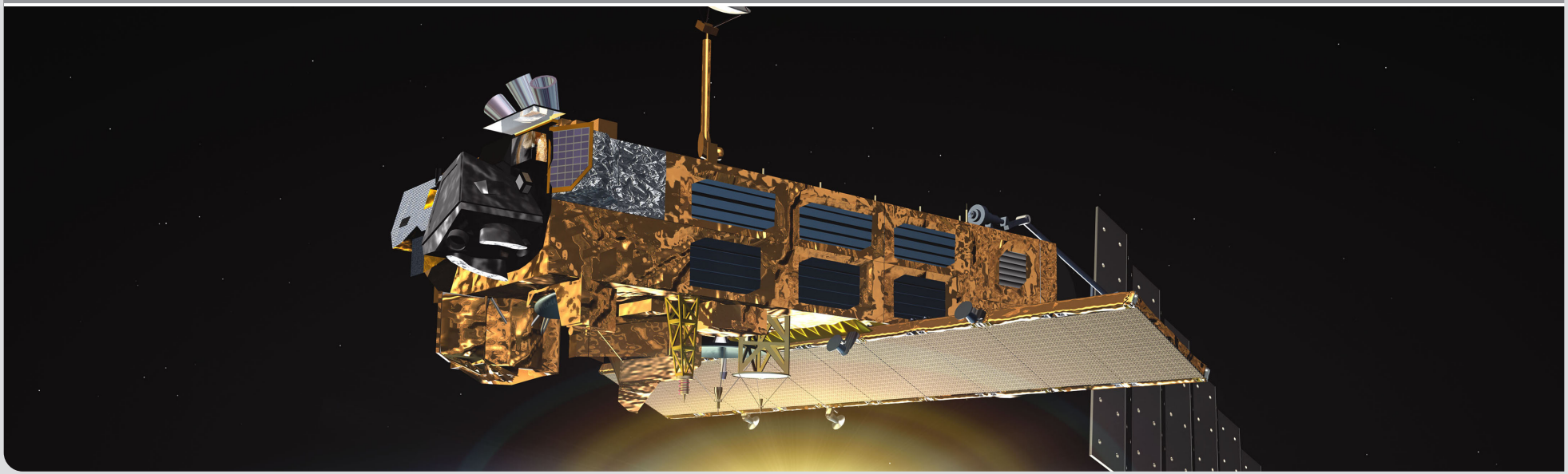


Solar variability and climate

- Climate variability (natural and anthropogenic)
- Solar activity: solar cycle, solar storms, CMEs
- Geomagnetic activity: aurora, SPEs

- Solar activity impact on Earth's atmosphere and climate

- Solar particle forcing in climate models

- Solar particles and X-rays:
  NO in mesosphere and lower thermosphere (MLT, 50–150 km)
- Satellite NO measurements in MLT
  - Envisat (ESA mission): MIPAS, SCIAMACHY
  - Odin (ESA third party mission): SMR
  - SCISAT-1 (ESA third party mission): ACE-FTS

Solar influences on the atmosphere

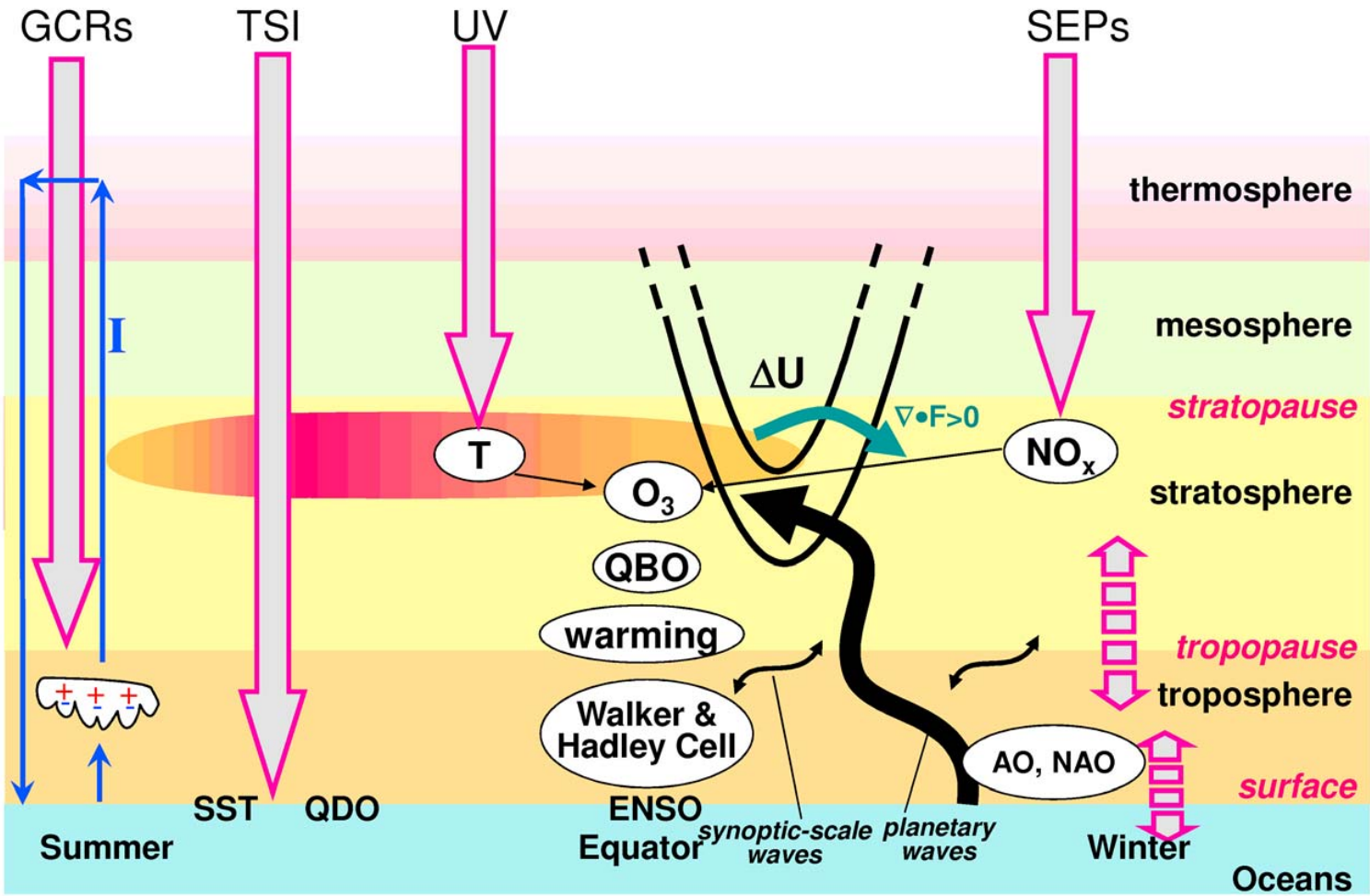
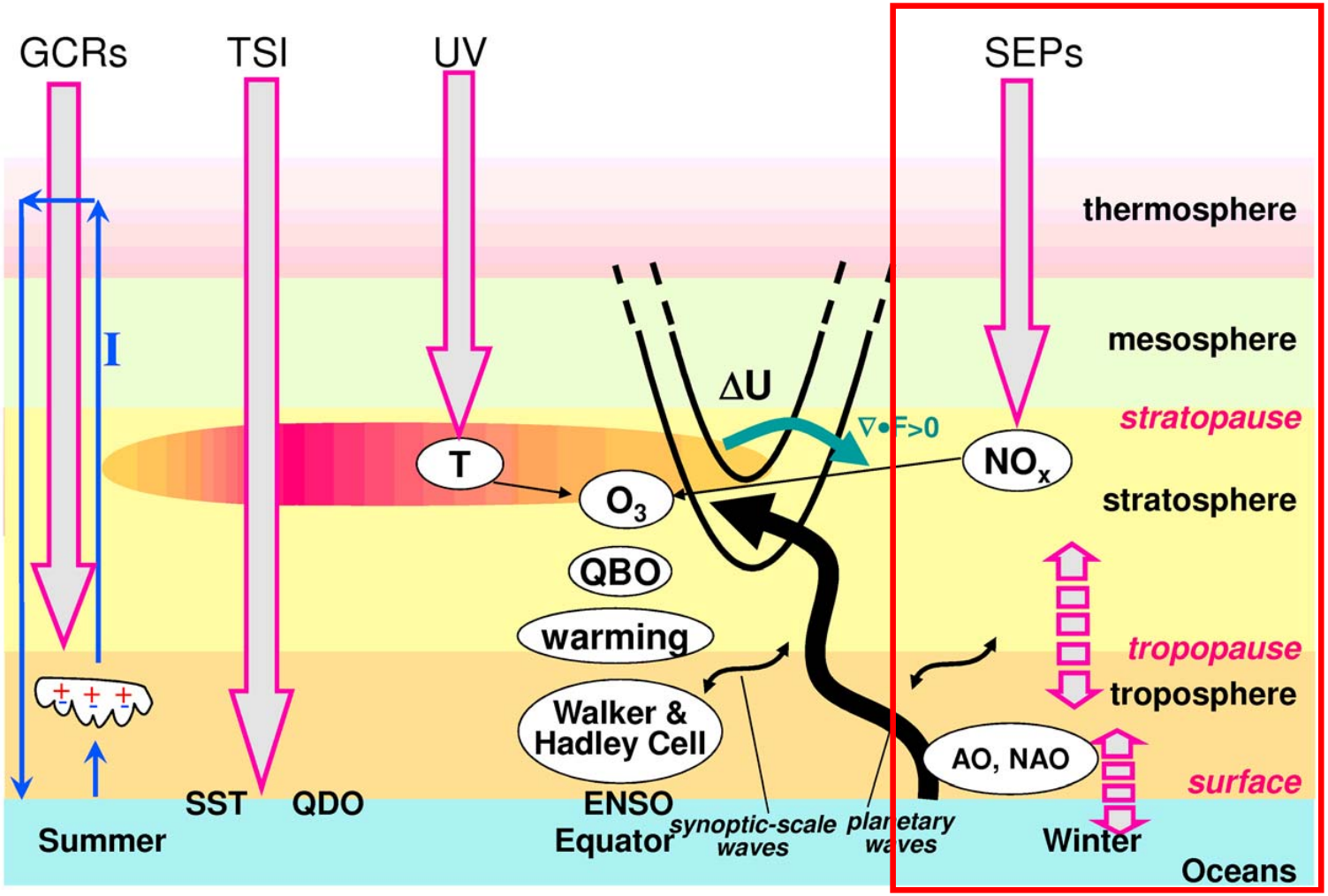


Figure: Gray *et al.*, 2010

Solar influences on the atmosphere



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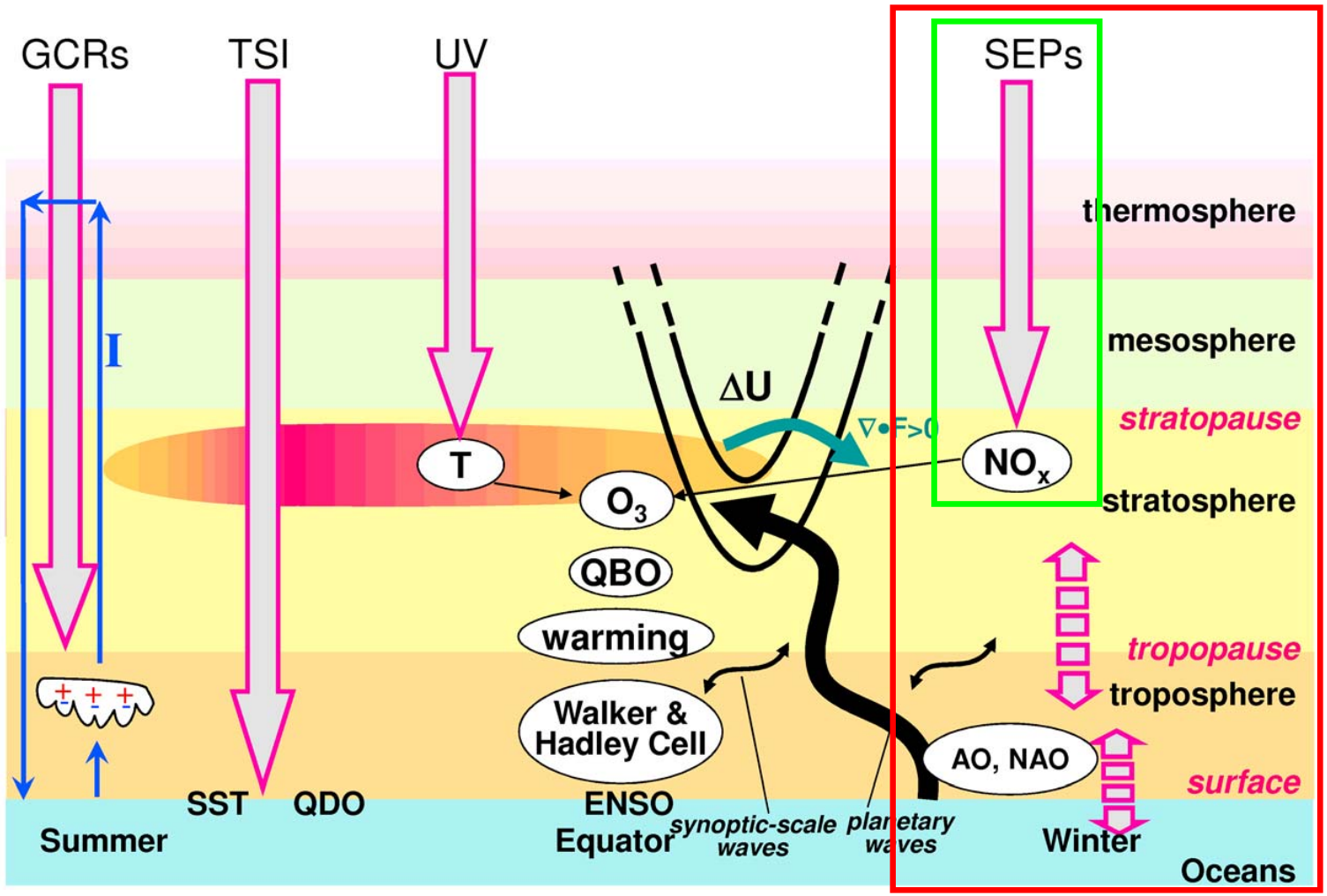

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Mesospheric–Thermospheric NO

- by-product of N_2 (strong bond) dissociation:
  - main reactions: $N^* + O_2$, $NO + h\nu$
  - energy source: auroral and fast secondary electrons, soft solar X-rays
- coupling to the atmosphere below (polar winter, SSW)

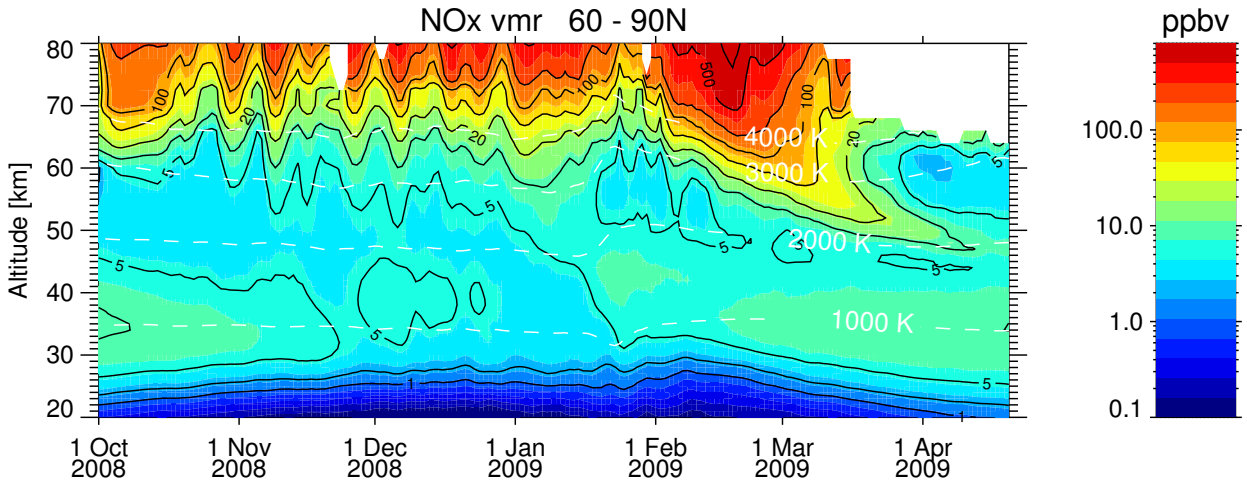

Figure: NOx descent 2008/2009, data courtesy of the MIPAS collaboration.

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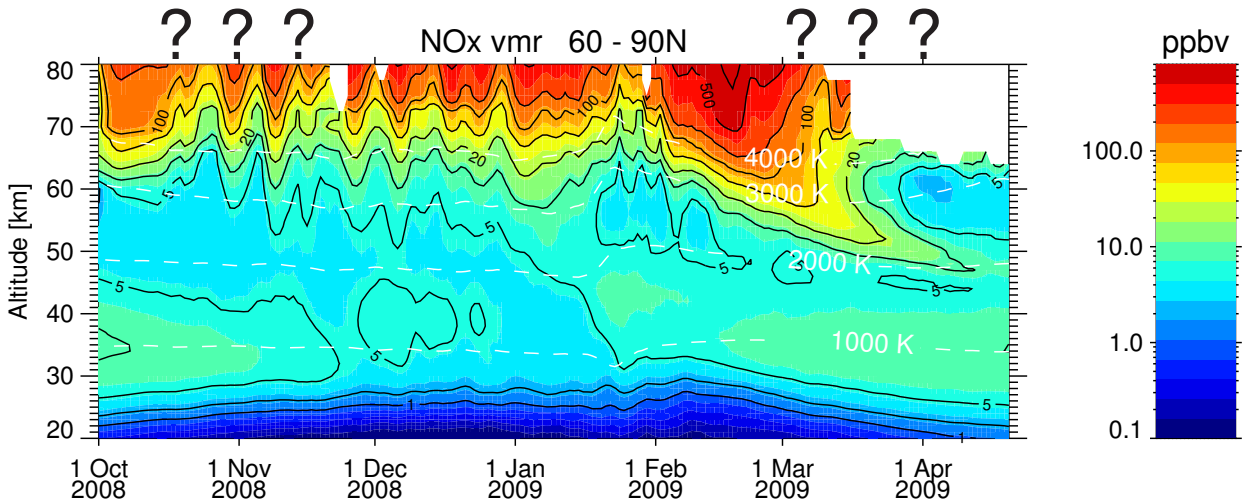

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Satellite NO MLT measurements

Daily zonal mean data

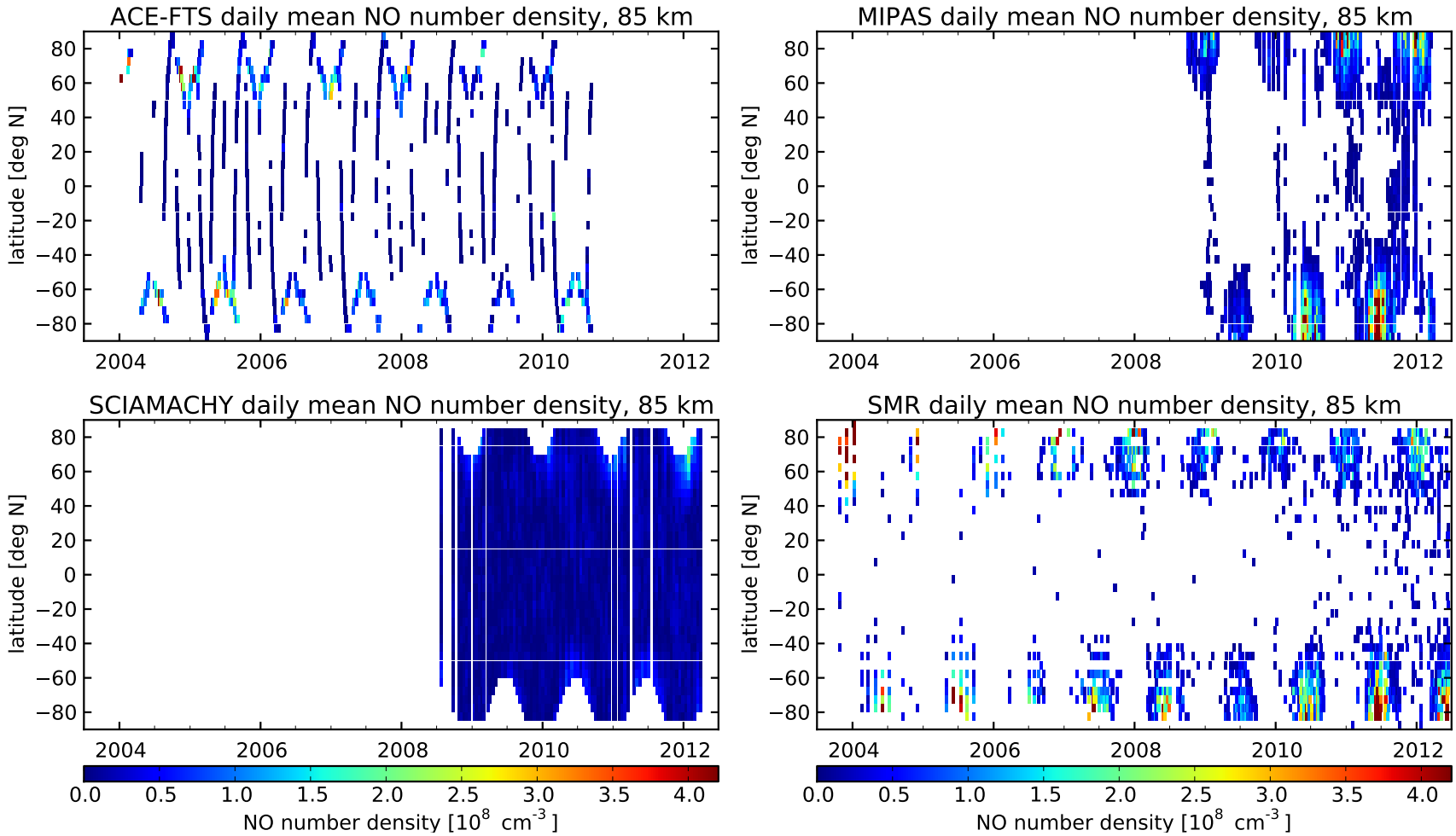
- scans in the MLT region (50 km to 150 km)
- ACE-FTS: IR, solar occultation, 1941 days 2004–2010
- MIPAS: IR, limb sounding,
  upper atmosphere (UA) mode, 199 days 2005–2012
- SCIAMACHY: UV, limb sounding,
  MLT mode, 78 days 2008–2012 (only daytime data)
- SMR: radio, limb sounding, 301 days 2003–present

Analysis

- time series at selected altitudes and latitudes
- multi-linear regression analysis
- superposed epoch analysis

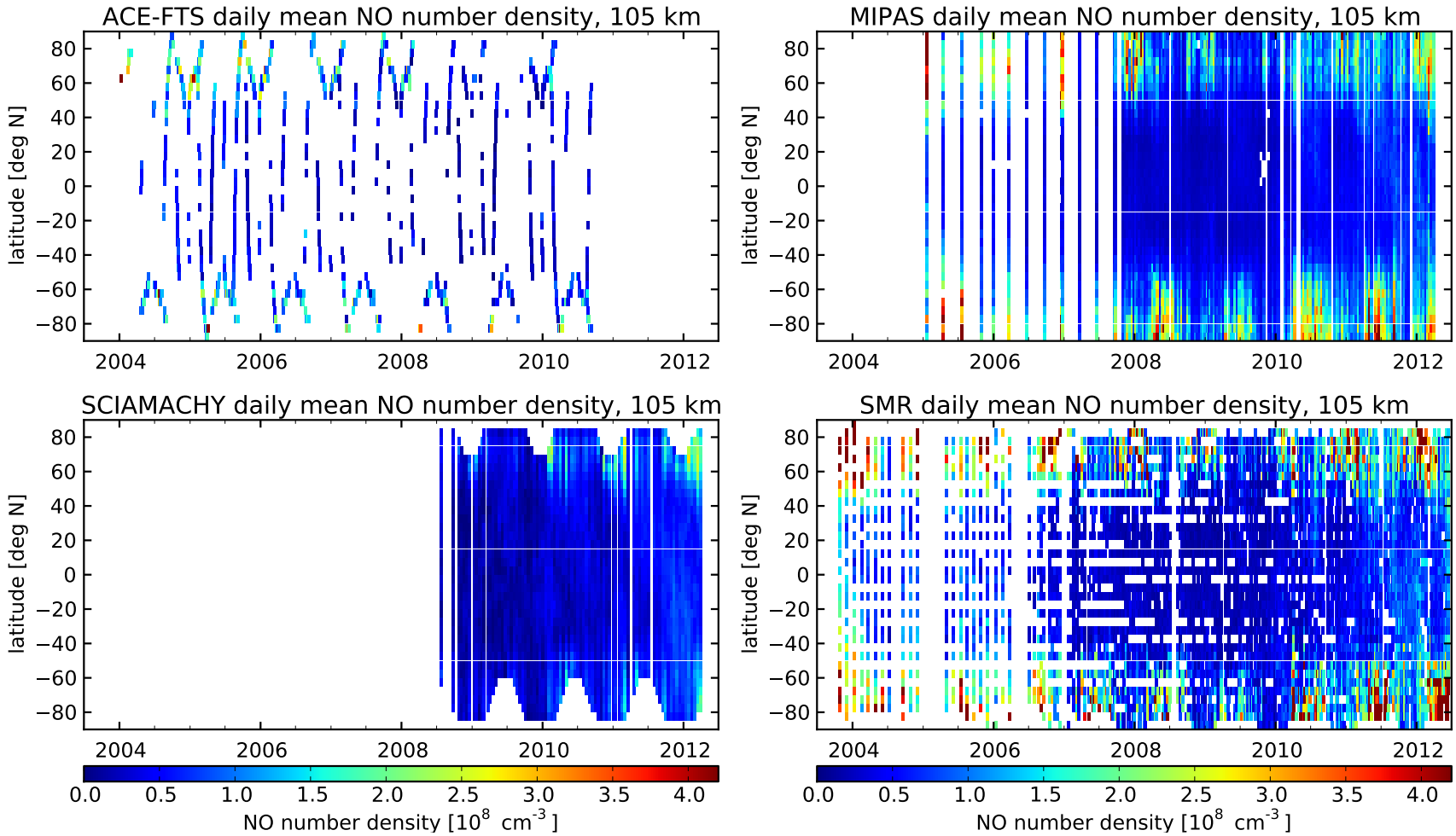
Time series

Morphological overview at 85 km



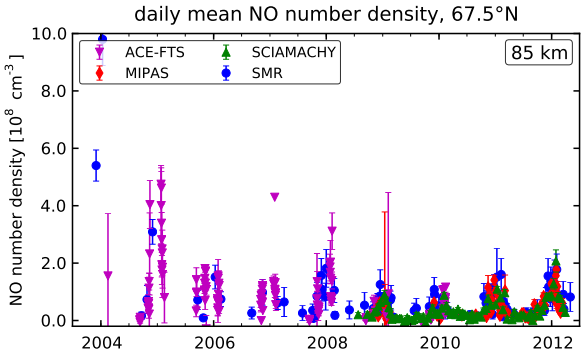
Time series

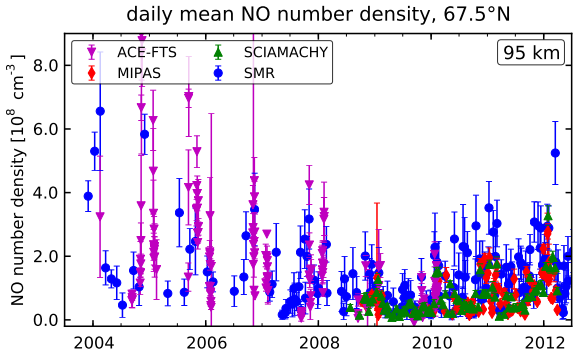
Morphological overview at 105 km

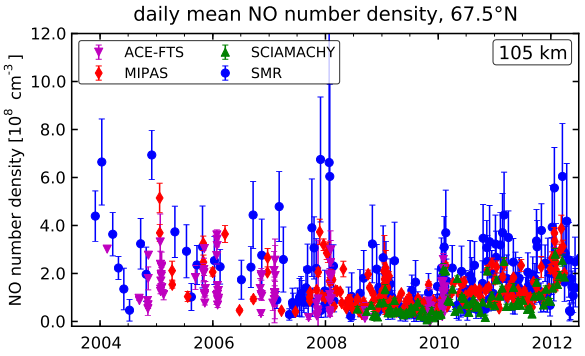


High latitudes

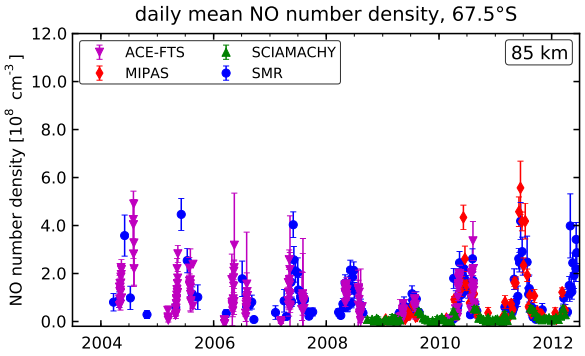
Northern polar region (67.5°N)

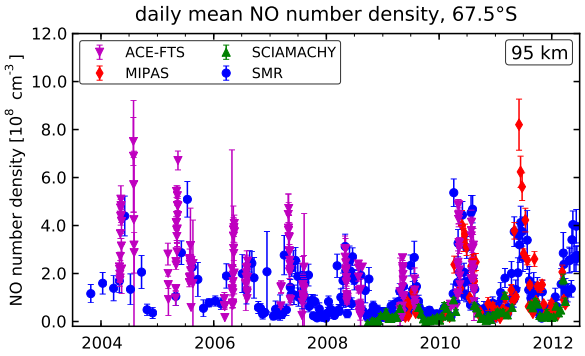


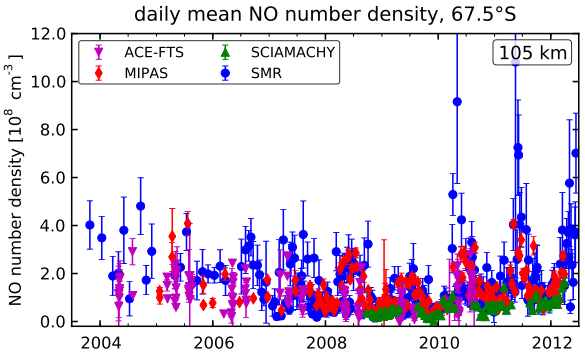




Southern polar region (67.5°S)







Multi-linear regression

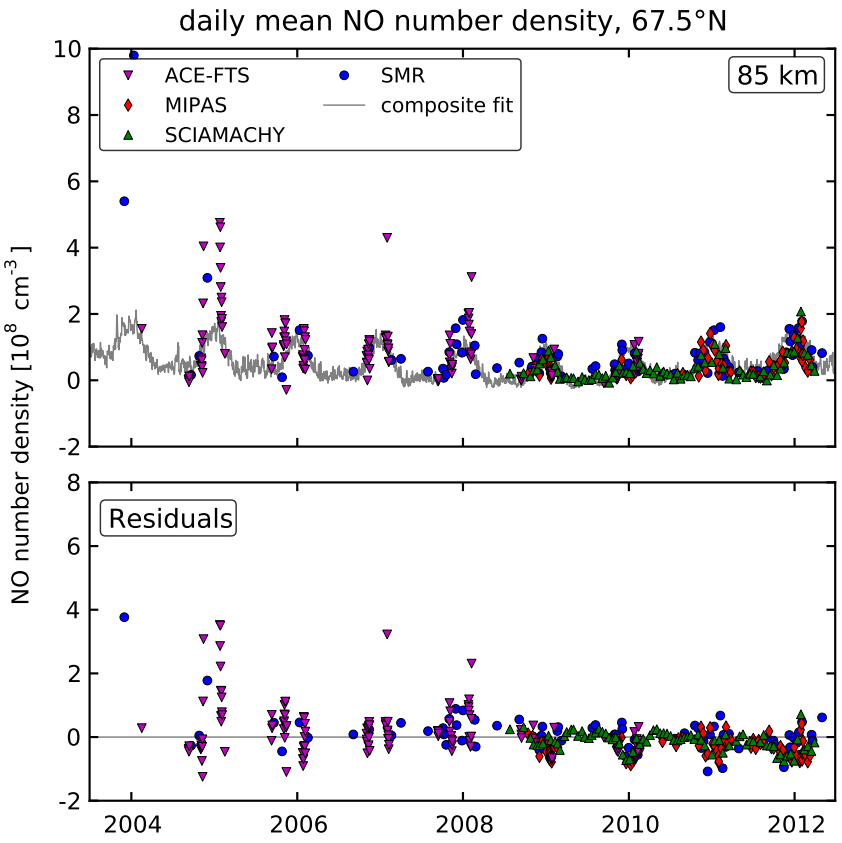
regression model

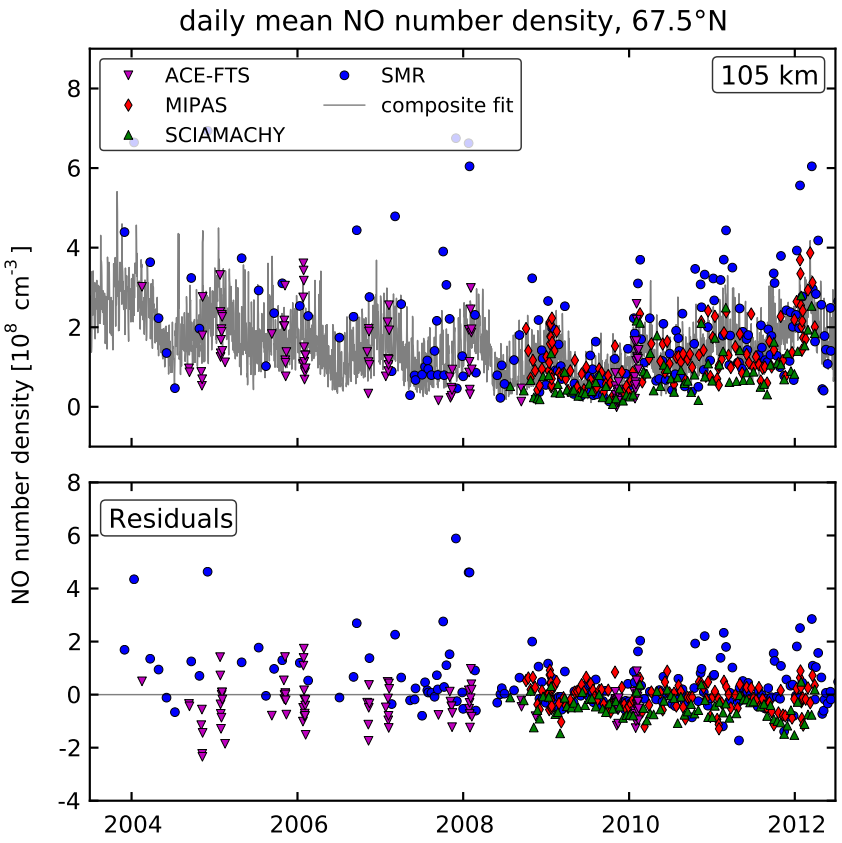
- annual and semi-annual harmonics
- linear in Lyman-α and Kp
- offset

$$\varrho_{\mathrm{NO}}^{\mathrm{model}}(\phi, z, t) = a(\phi, z) + b(\phi, z) \cdot \mathrm{Ly}\alpha(t) + c(\phi, z) \cdot \mathrm{Kp}(t) + \sum_{n=1}^{2} \left[d_n(\phi, z) \cos(n\omega t) + e_n(\phi, z) \sin(n\omega t) \right]$$

Multi-linear regression fit results

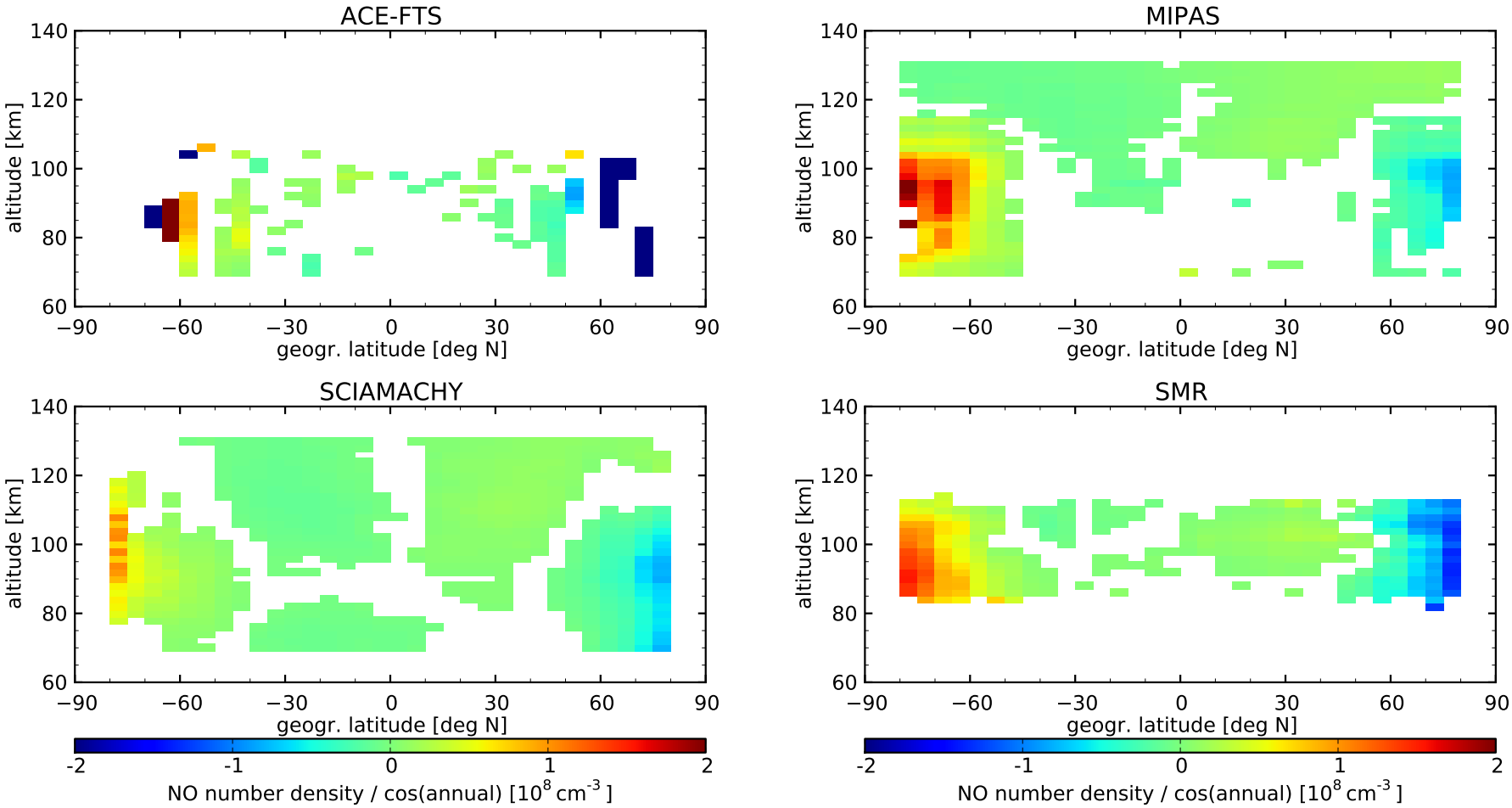
Northern polar region (67.5°N)





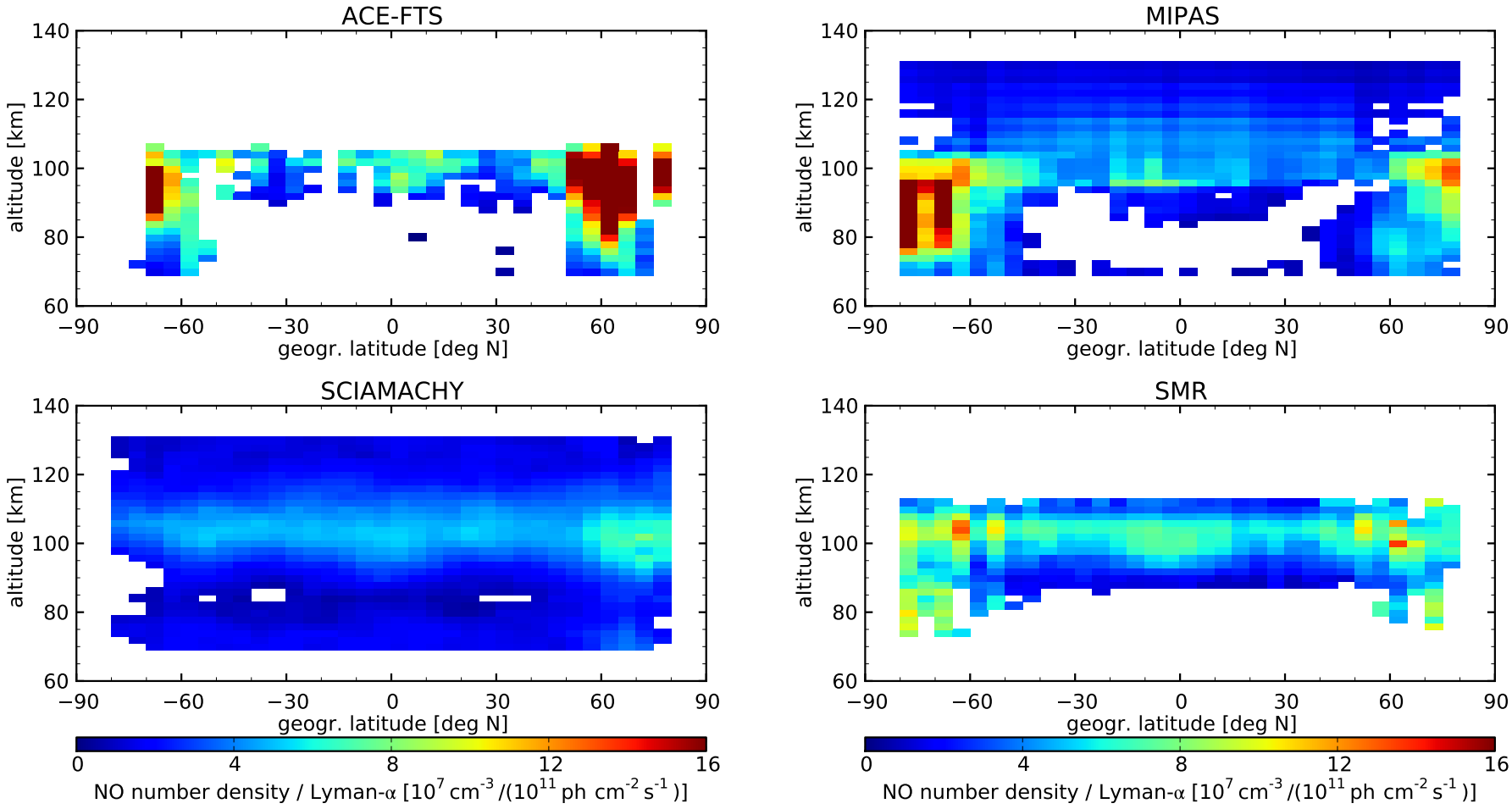
Multi-linear regression coefficients

Annual cycle (cosine part)



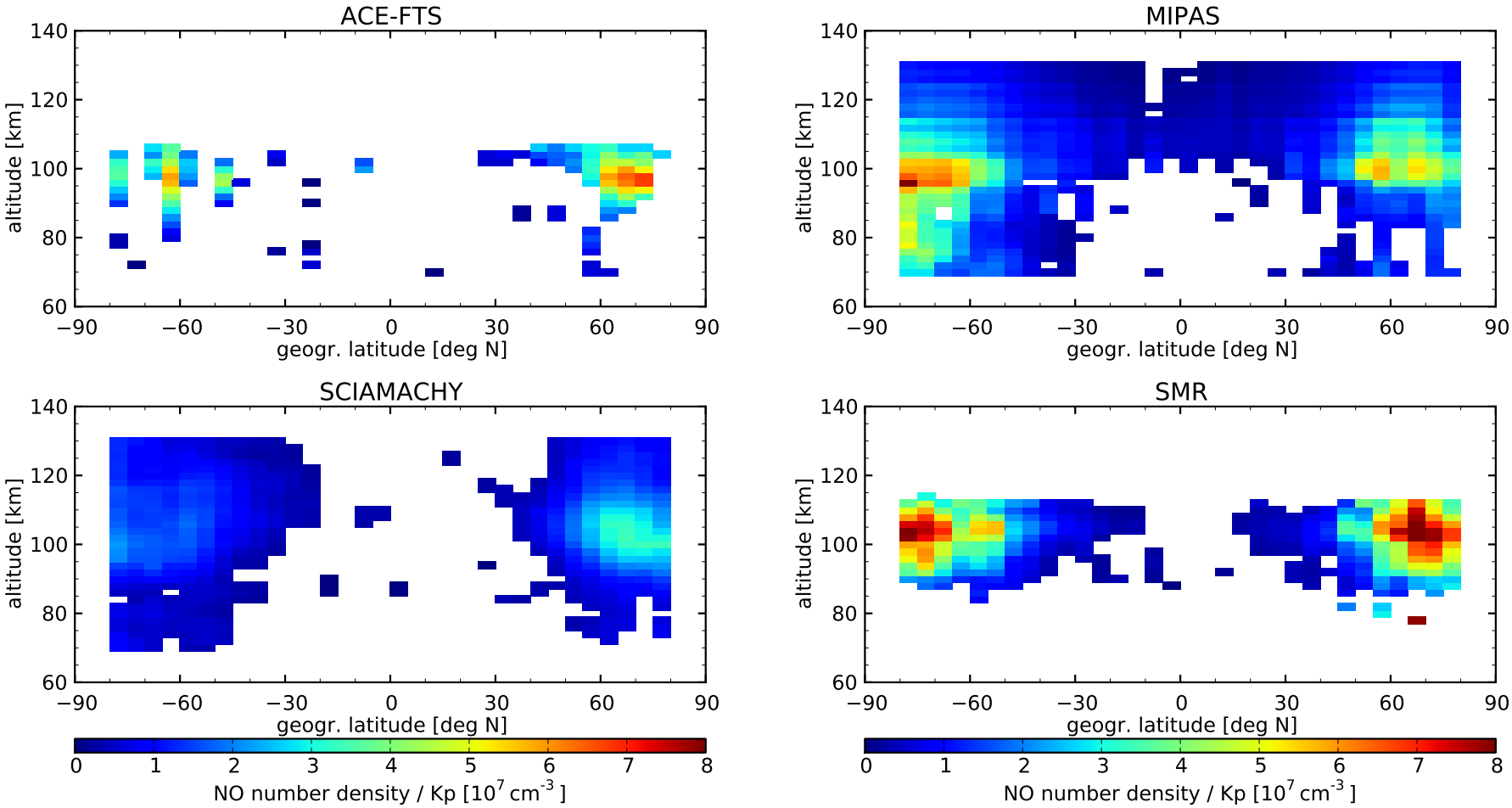
Multi-linear regression coefficients

Lyman-α



Multi-linear regression coefficients

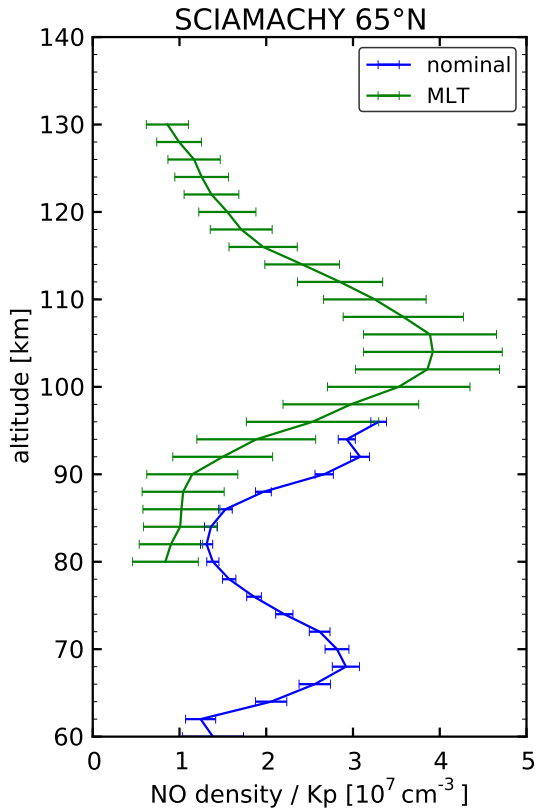
Kp



Kp vertical profile

Polar region regression coefficients

- solar (particle) influence
- NO number density / Kp
- simple model for NO in MLT
- 1-D chemistry model
  $\Rightarrow$ ionisation rates



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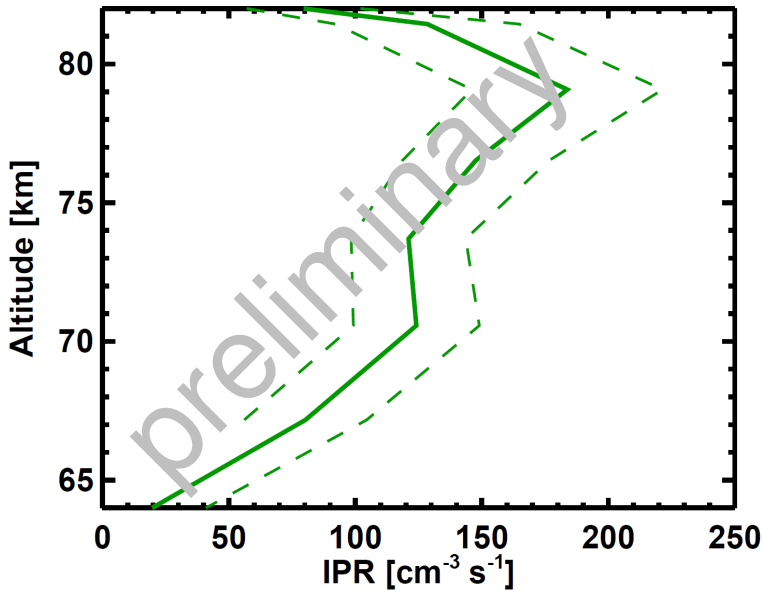

Figure: 2002–2003, $0.5 < \Delta Kp < 1.5$

Conclusions

- MLT NO important proxy for solar activity
- best suited: UV and IR limb sounders
  (daily global coverage possible)
- consistent MLT NO measurements:
  ACE-FTS, MIPAS, SCIAMACHY, SMR
- MIPAS and SCIAMACHY lost in April 2012

Other instruments

- OSIRIS: only from 85 km to 100 km
- SABER: only above 100 km
- SOFIE: solar occultation (limited global coverage)

Outlook

- refine statistical analysis methods
- reliable solar forcing parameters for (chemistry) climate models
- **future missions?**