GOMOS error estimation

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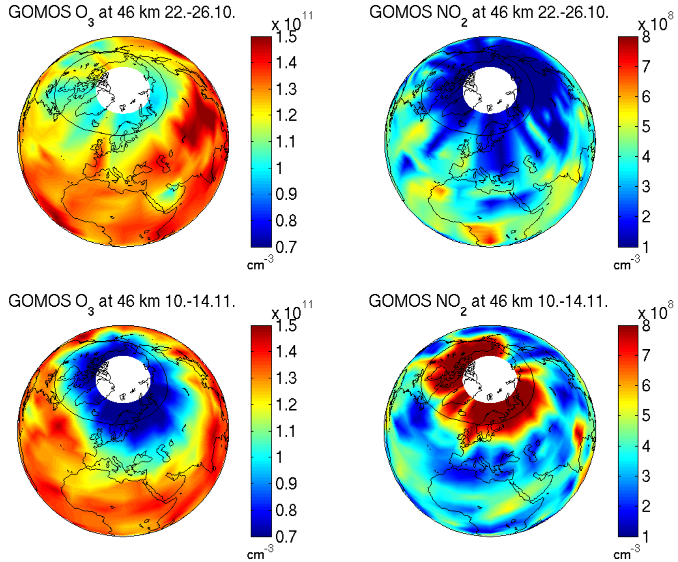
Thanks to E. Kyrölä, V. Sofieva, M. Laine,A. Seppälä, J. Hakkarainen, S. Tukiainen, ….

CEOS Atmospheric Composition Constellation Meeting, ACC-8

18-19 April 2012, Columbia, MD

Envisat/GOMOS

- **Stellar occultation instrument**
- **UV-VIS: 248-690 nm**
  - O_3, NO_2, NO_3, aerosols,
  - Scientific products: OClO, Na, PMC, aurora
- **NIR: 760 nm & 936 nm**
  - O_2, H_2O
- **1 KHz photometers:**
  - High resolution T, turbulence
- **Vertical resolution: 2-4 km**
- **Altitude range 10 – 100 km**



Impact of SPE on atmospheric composition at 46 km.

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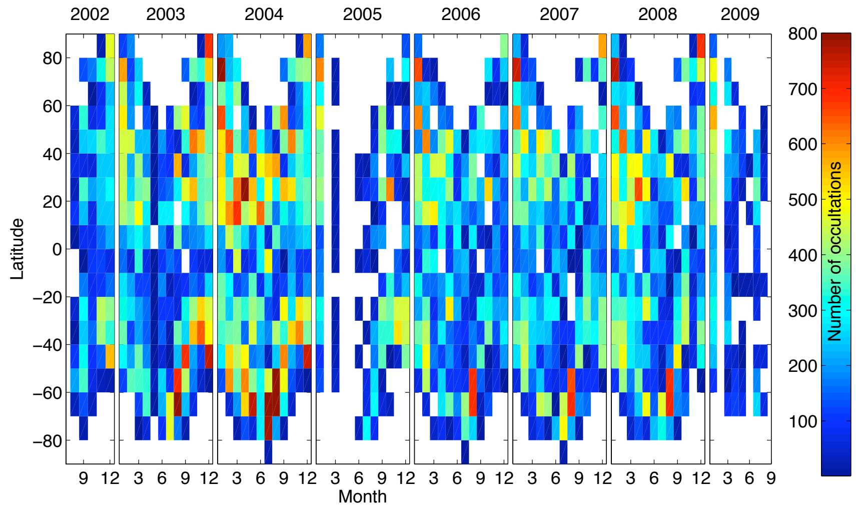
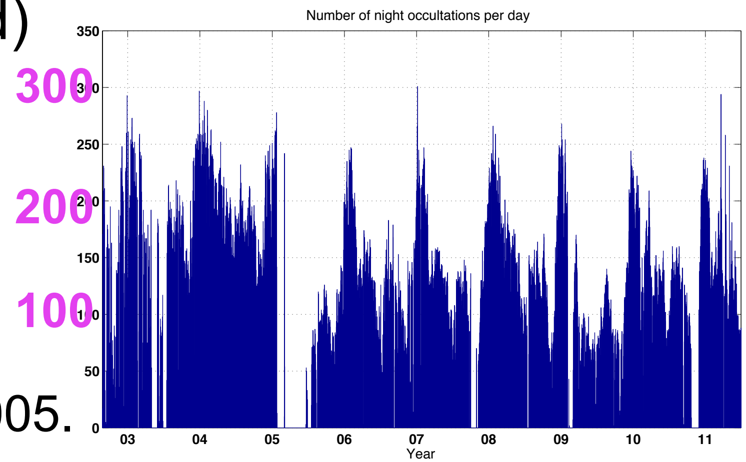
GOMOS data

- **Data availability:**
  - 2002 – 2012
  - **400 000 nighttime profiles**
  - On-going work to improve day time measurements (ESA/SPIN project).
  - Basically from pole to pole during night time (ie. summer pole not measured)
  - Valid altitude range: 15 – 100 km.
  - Instrumental problems:
    - 2003 missing data in May
    - 2005 missing data Jan – Jun
    - Restricted viewing angle since Jun 2005.
    - Since fall 2011 only few measurements/ orbit

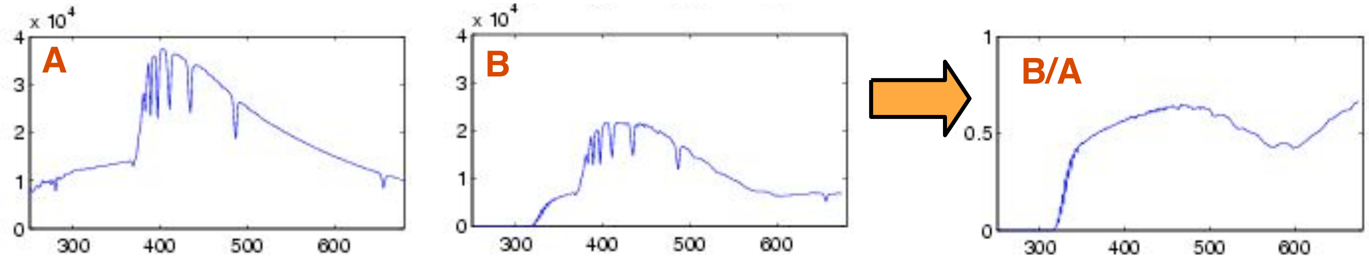


Lat-month coverage of data

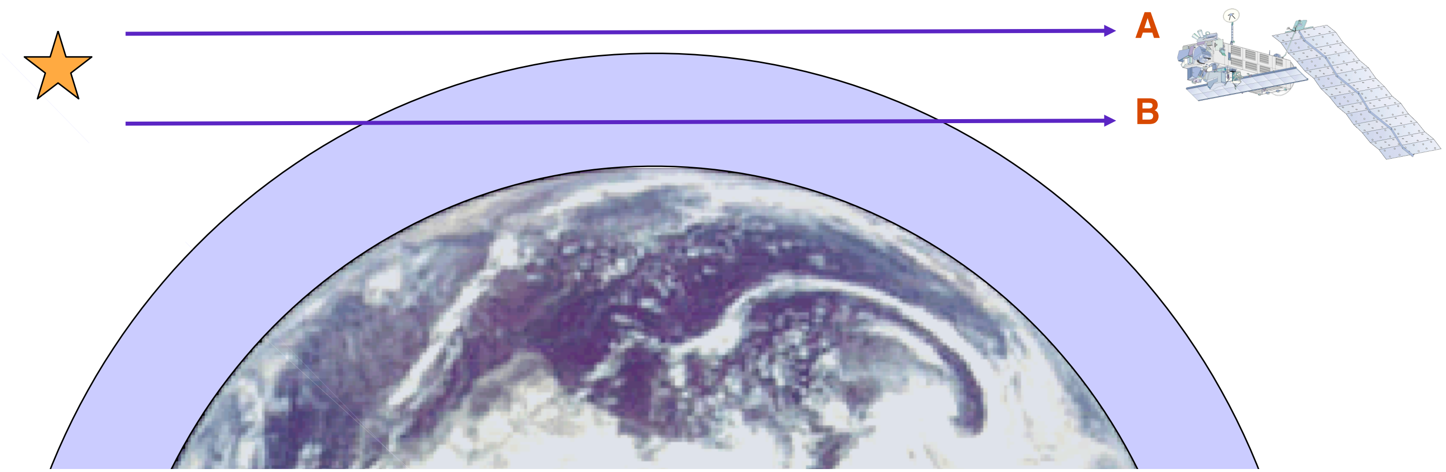


Number of measurements/day

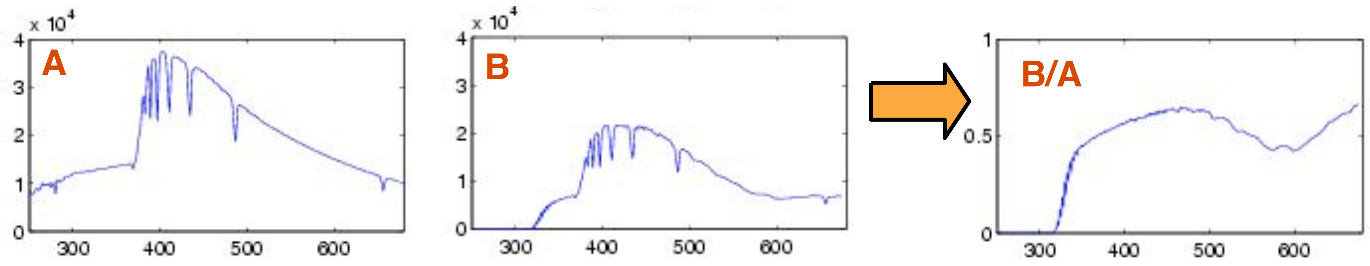
Envisat/GOMOS stellar occultation



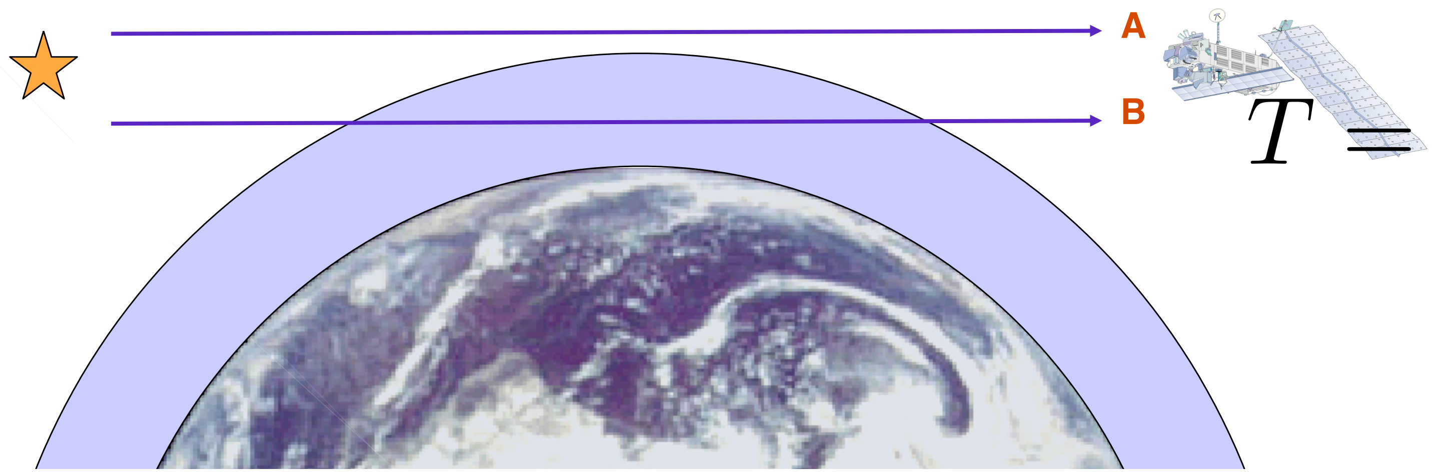
$$T = \frac{I_B}{I_A}$$



Envisat/GOMOS stellar occultation



$$T = \frac{I_B}{I_A}$$



$$T = \frac{I_B - I_{\mathrm{dc}}}{I_A - I_{\mathrm{dc}}}$$

Data retrieval steps:

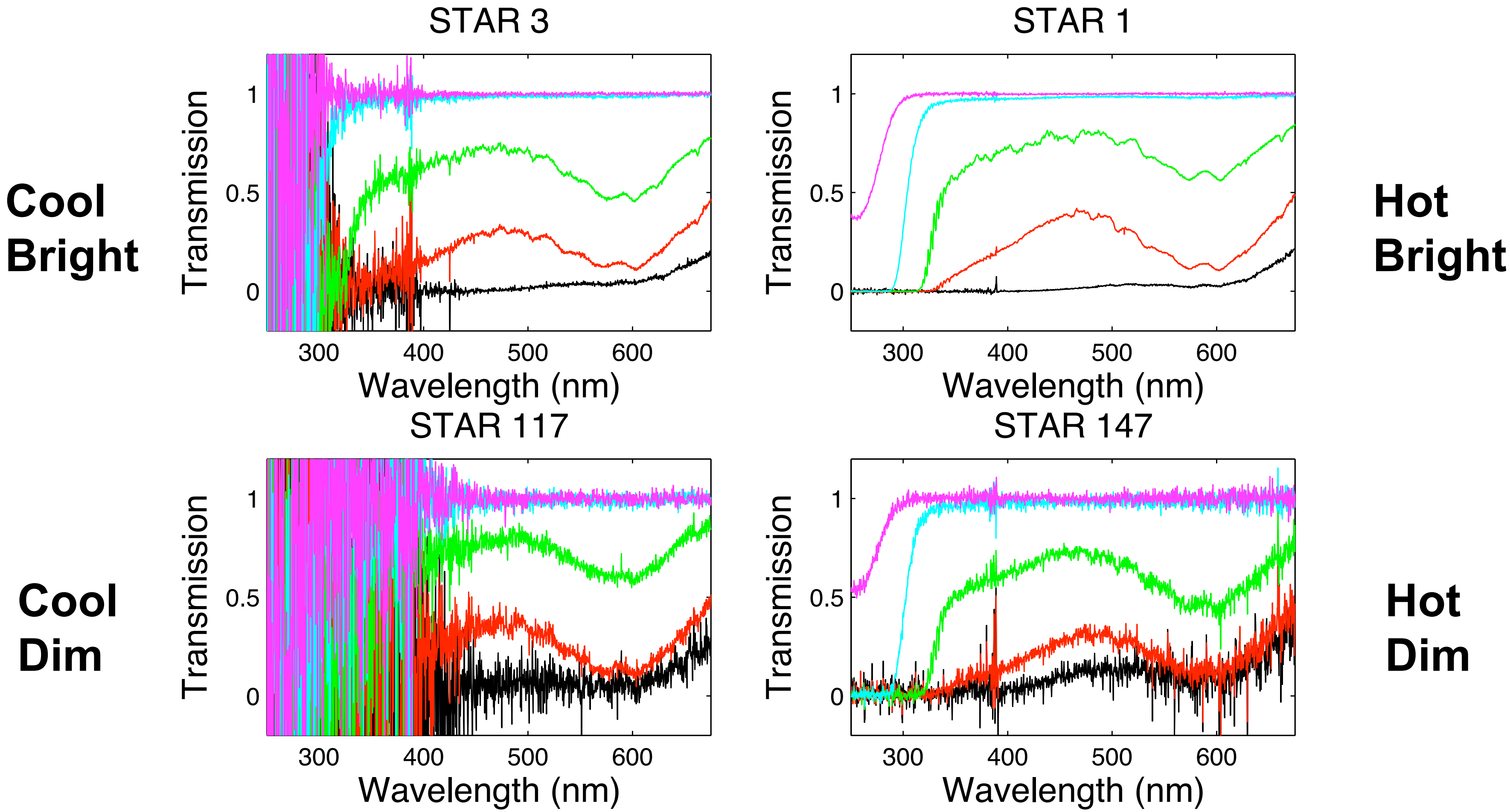
1. **Removal of refractive effects, dilution and scintillation**
2. **Spectral inversion:**
   - Horizontally integrated densities of O_3, NO_2, NO_3, aerosols are fitted simultaneously for each altitude using 250-675 nm
   - Non-linear iterative Levenberg-Marquardt fit.
   - Error propagation provided by the algorithm (based on assuming Gaussian error)
   - Assumptions:
     - Rayleigh and T from ECMWF
     - Simplified aerosol model (wavelength denpendence)
     - Cross sections (Ozone Bogumil et al.)
3. **Vertical inversion:**
   - Vertical density profiles are fitted for each constituent separately
   - Linear matrix retrieval with Tikhonov regularization and standard linear error propagation.
   - Assumption: locally spherically symmetric atmosphere

Error sources

- **Random errors:**
  - Measurement noise
  - Scintillations

- **Systematic errors / model uncertainties:**
  - Aerosol model
  - Cross sections
  - Temperature, Rayleigh, ECMWF

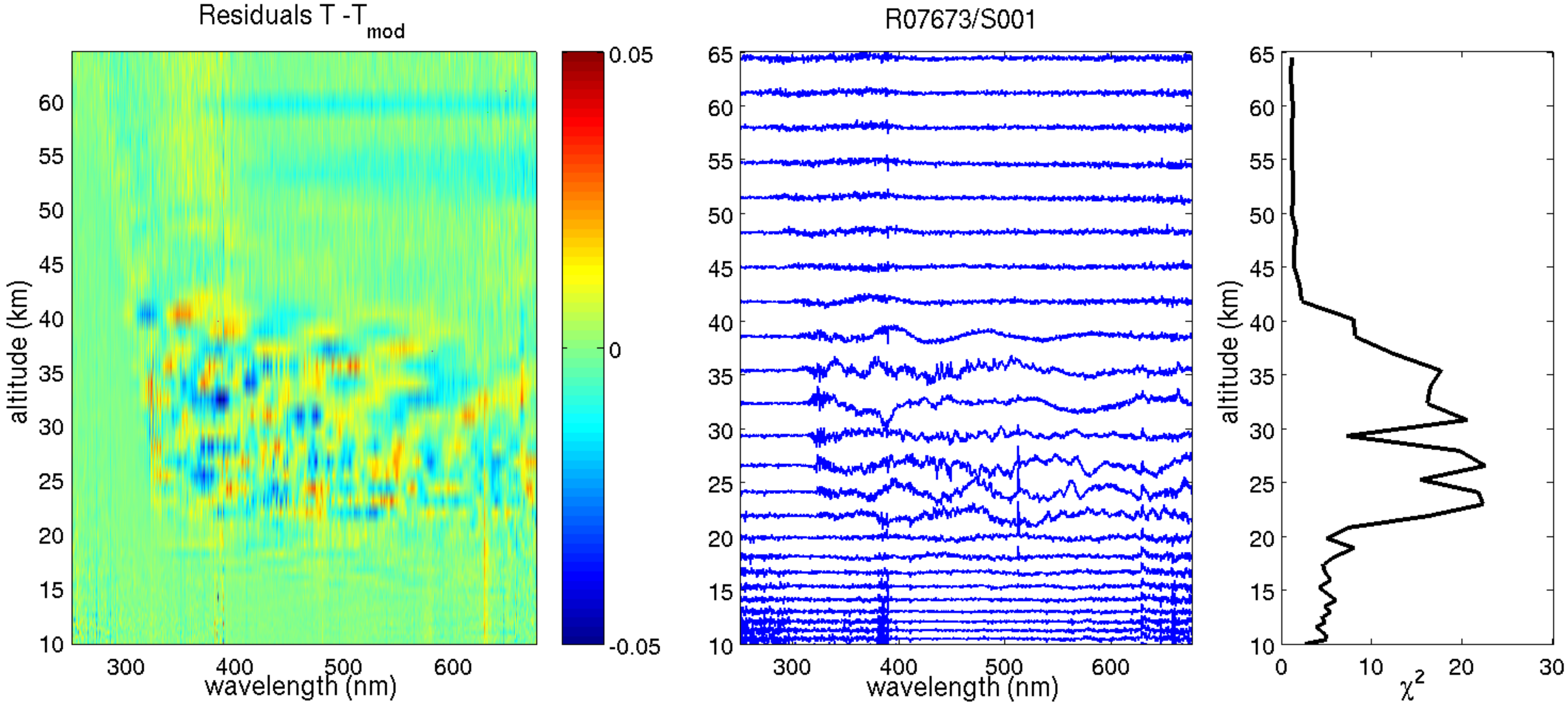
Varying signal to noise ratio



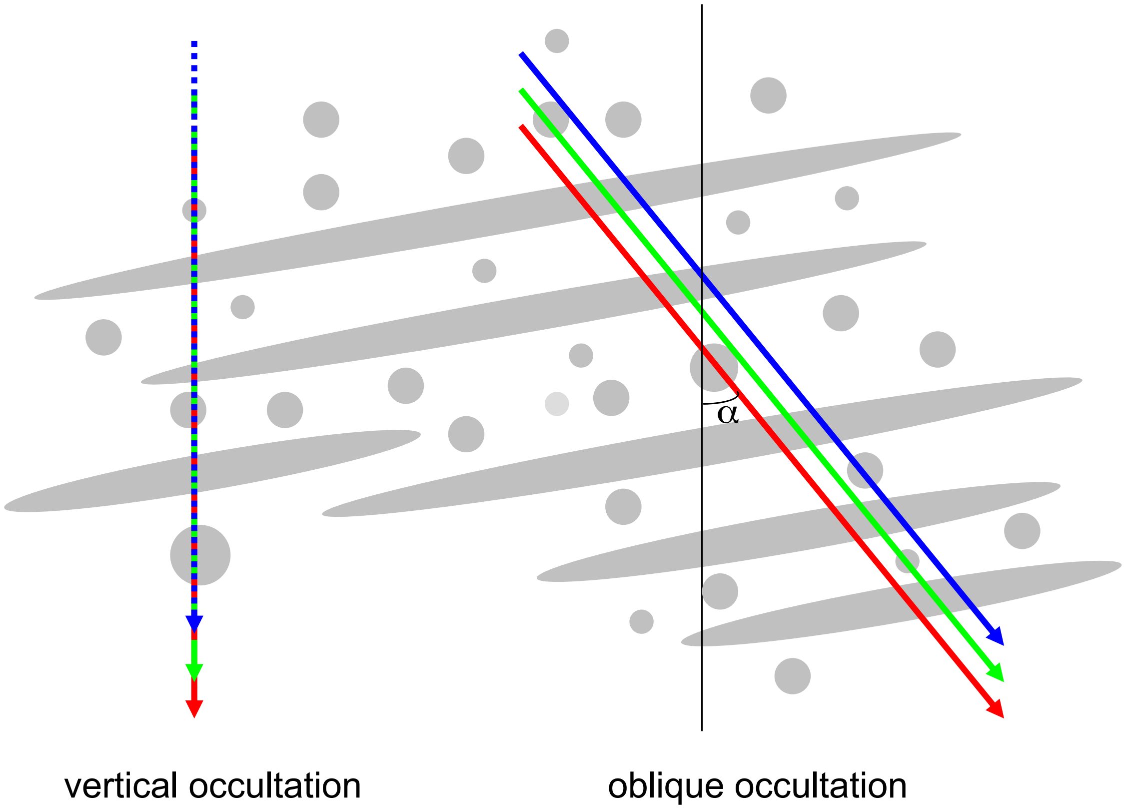
GOMOS transmissions measured using different stars at 10, 20, 30, 50, 70 km.

Scintillations:

Residuals $R(\lambda)=T_a(\lambda) - T_{mod}(\lambda)$ in oblique occultations



Scintillation: the phenomenon



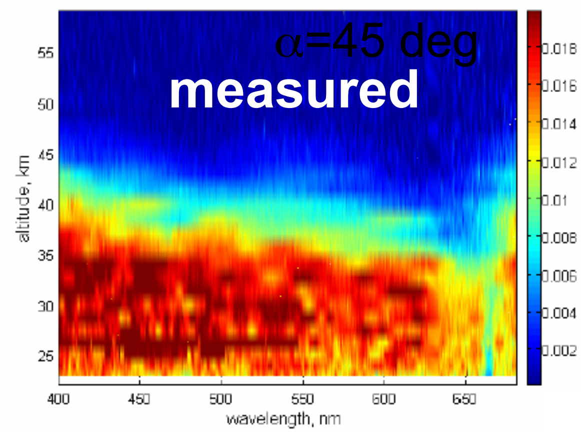
- Different wavelengths see different atmosphere
- Small scale structures are different

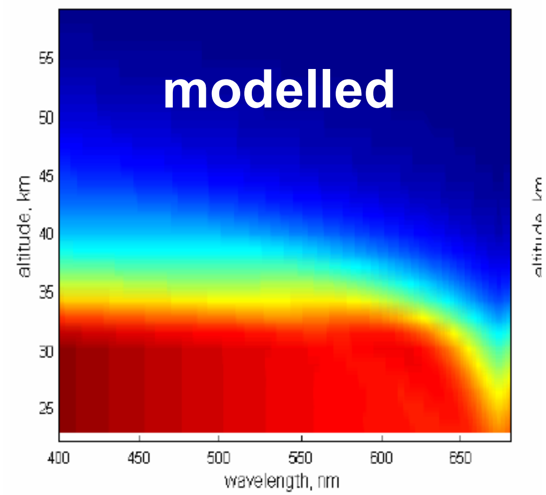
- Scintillation correction applied originally does not remove perturbations caused by this isotropic scintillation

V-6: Parameterization of the correlation function

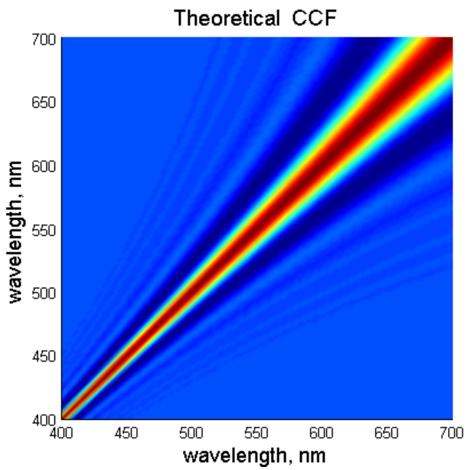
- The scintillation error was parameterized and included as correlated modeling error used in the fit in addition to measurement error

α=45 deg

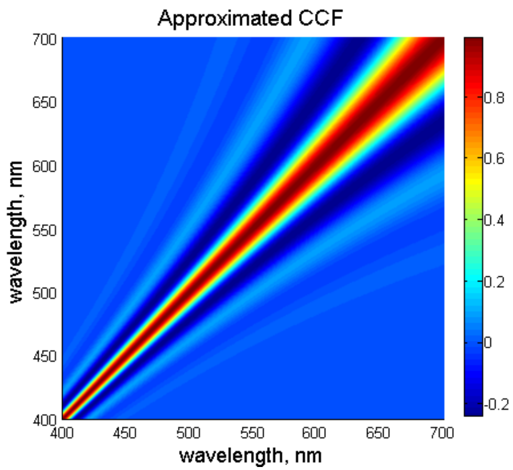




Theoretical correlation



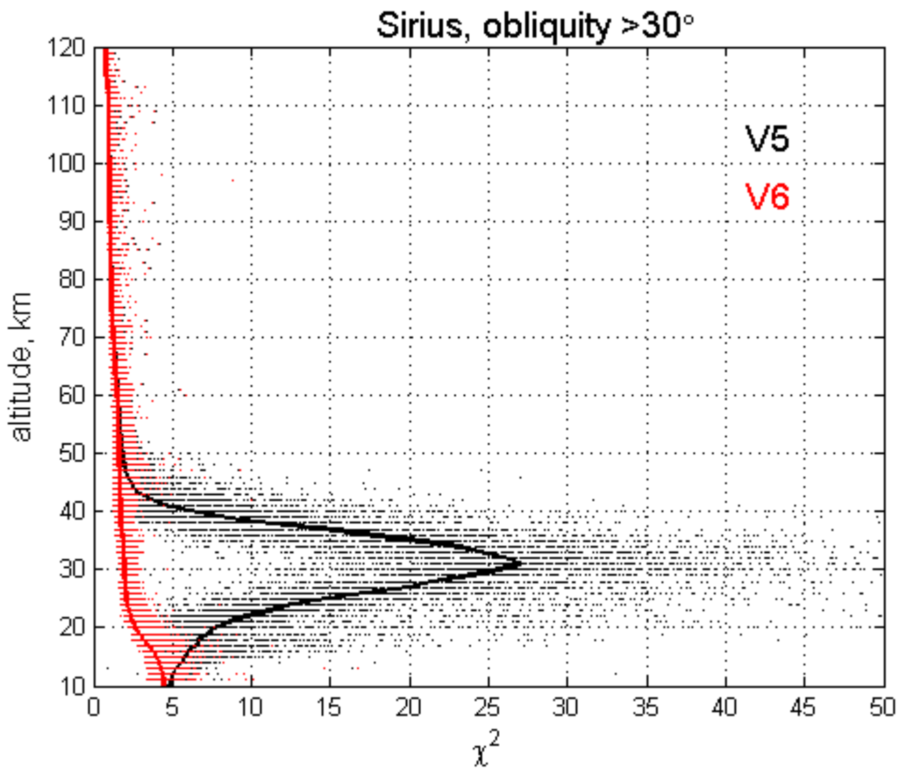
Parametrization



30 km

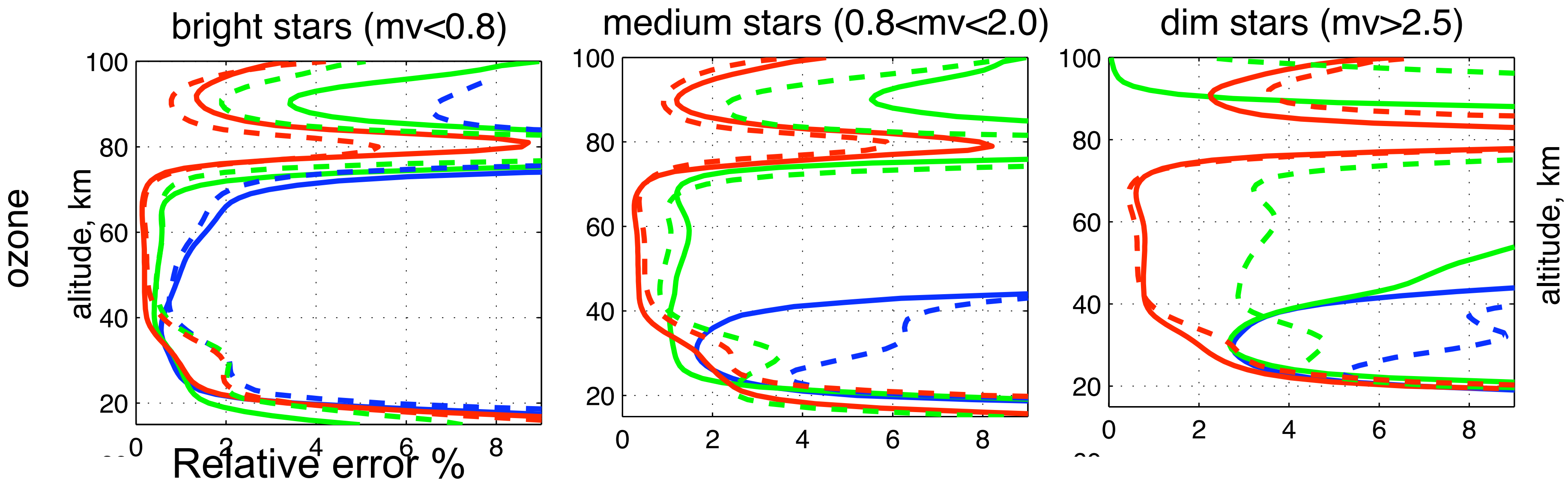
GOMOS version 6 vs version 5· χ^2

- **Improved modeling of modeling error:**
  - Chi2 values close to 1
  - Most significant with bright stars
  - Indication of improved error estimates



- **Release of Version 6 data expected in autumn 2012.**

Random error: error estimates of ozone

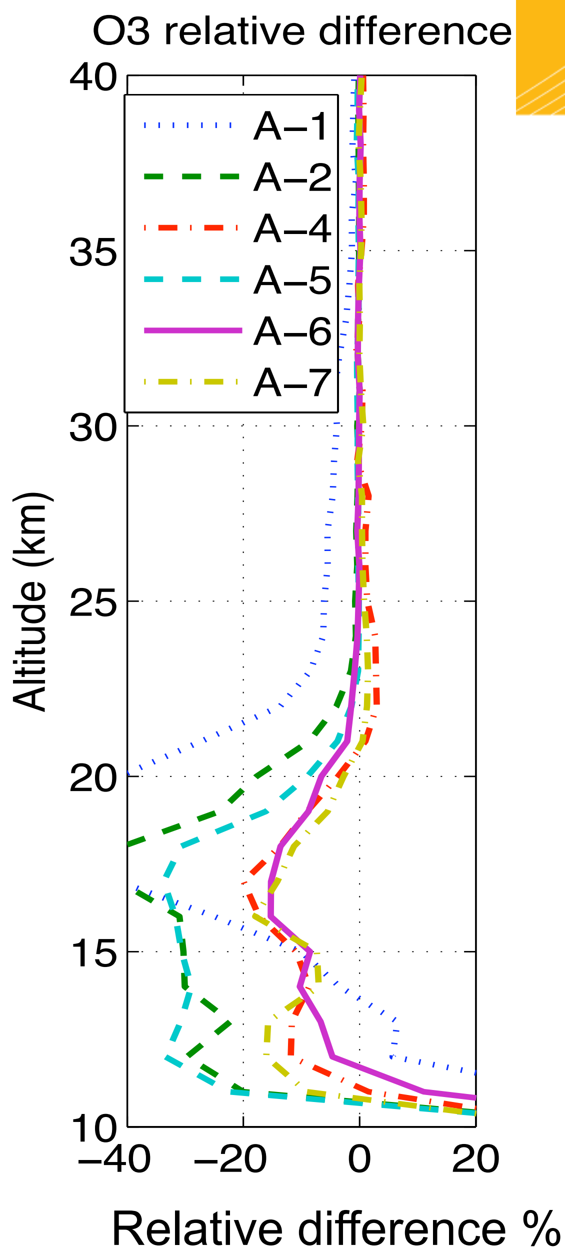


Hot stars
Medium stars
Cool stars

- Ozone:
  - Below 15 km ~10%
  - 0.5-4 % stratosphere
  - 2 - 10 % mesosphere
- NO2: 10 - 20 % in stratosphere
- NO3: 20 - 40 % in stratosphere
- Aerosols: 2 – 10% below 25 km; more above

Systematic errors

- **Aerosols are the main source of systematic errors below 25 km**
  - **Uncertainty in wavelength dependence of the aerosol model causes**
    - **10-20 % uncertainty below 20 km.**

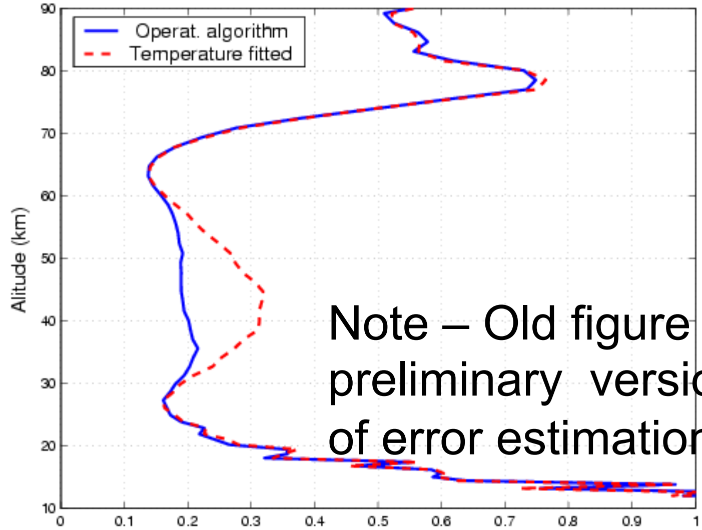


Impact of aerosol model selection

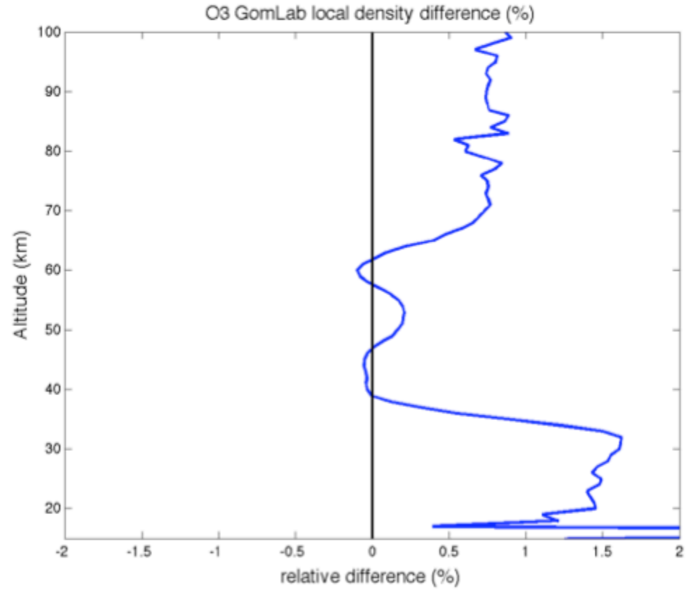
More systematic errors

- **Temperature:**
  < 0.5%
  uncertainty in ozone profile at 40 km.

- **Ozone cross sections:**
  BDM vs Bogumil
  1-1.5%
  uncertainty
  in ozone profiles



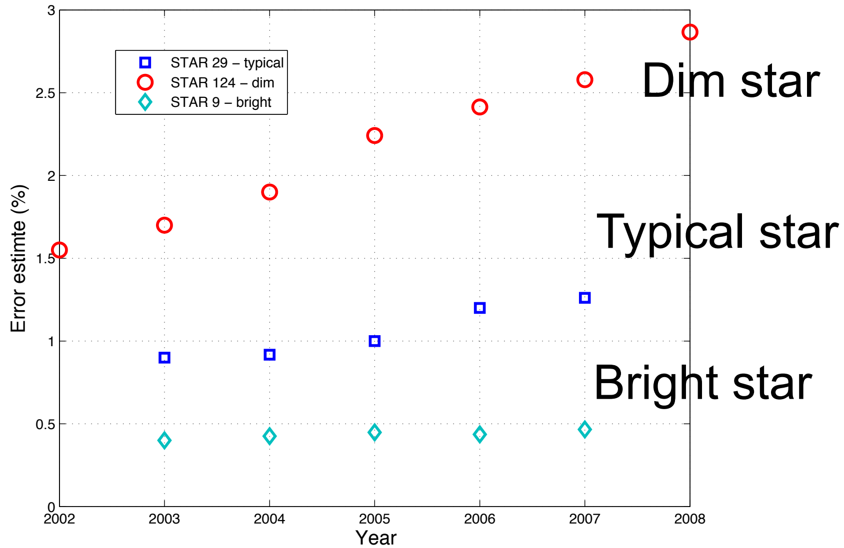
Note – Old figure - preliminary version of error estimation.



Vertical densities

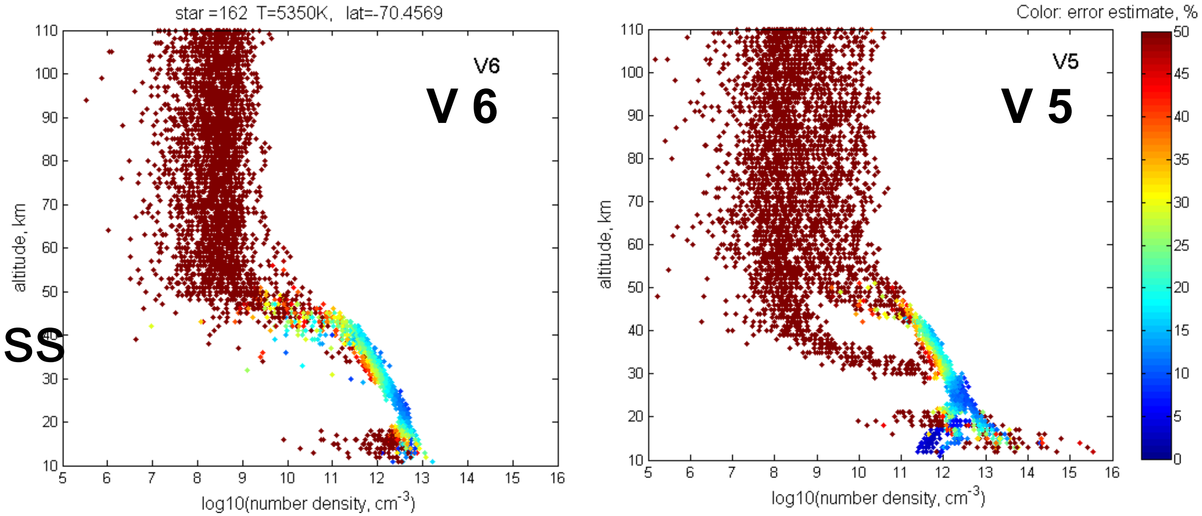
Aging of the instrument

Time evolution of GOMOS error estimates at 40 km.



- Random errors increasing due to aging of the instrument and increasing dark charge in particular in the accuracy of dim/cool stars.

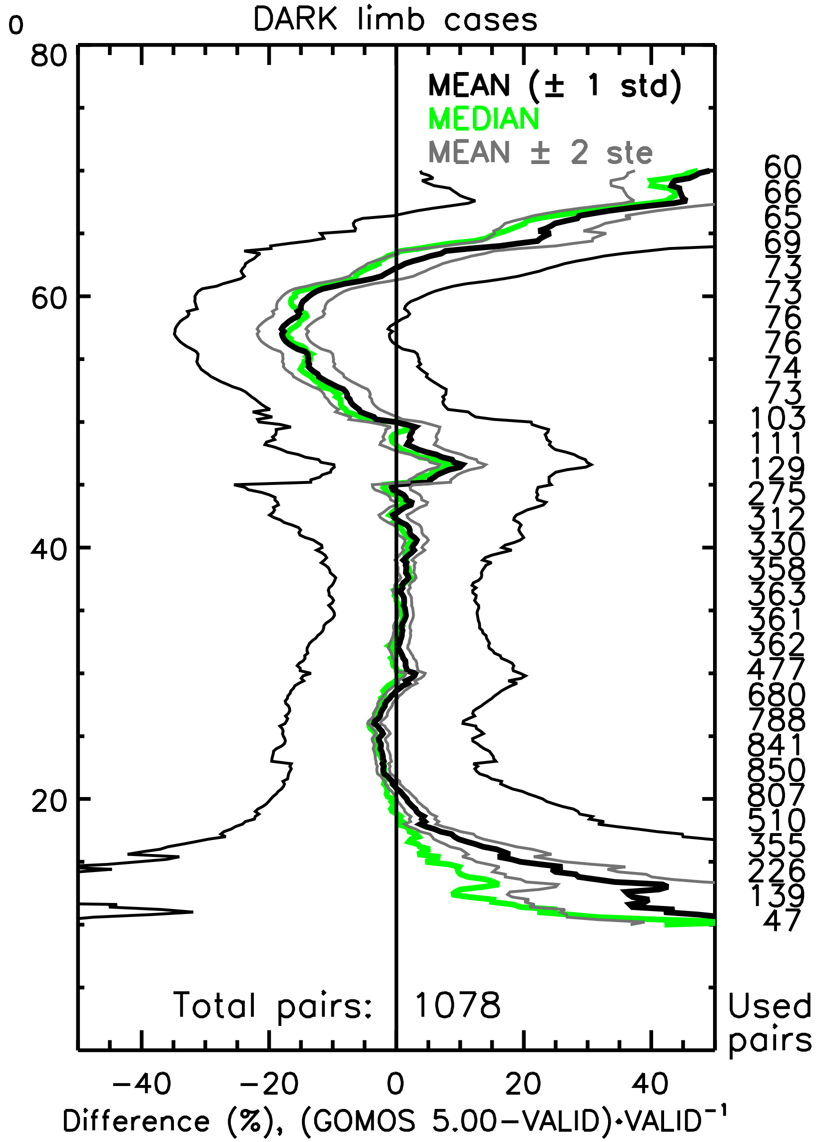
Ozone profiles using star 162



- Expected improvement of 'cool star problem' in new version 6: less outliers and error estimates useful

Validation

- **A. van Gijsel et al compared GOMOS ozone profiles with lidars, soundings and microwave profiles**
- **Good agreement btw 20-40 km: ±2%**
- **At 15-20 km GOMOS larger by 5-20%**



A.Van Gijsel et al. ACP GOMOS special issue 2010

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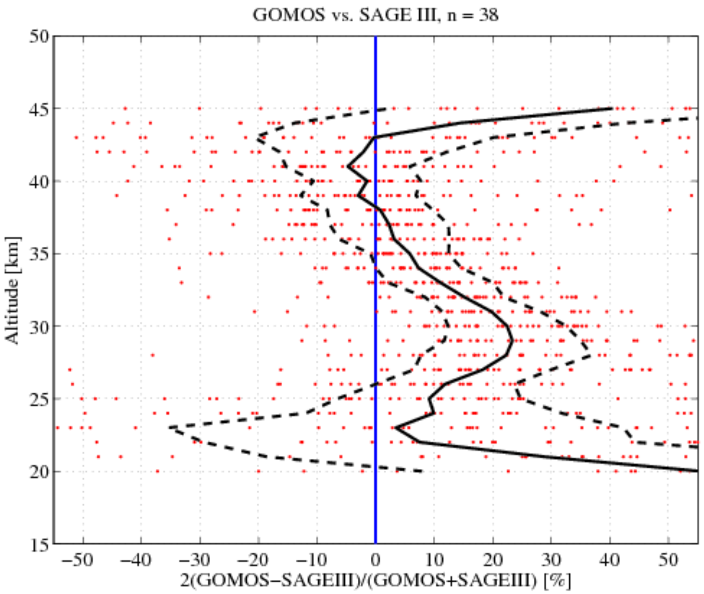
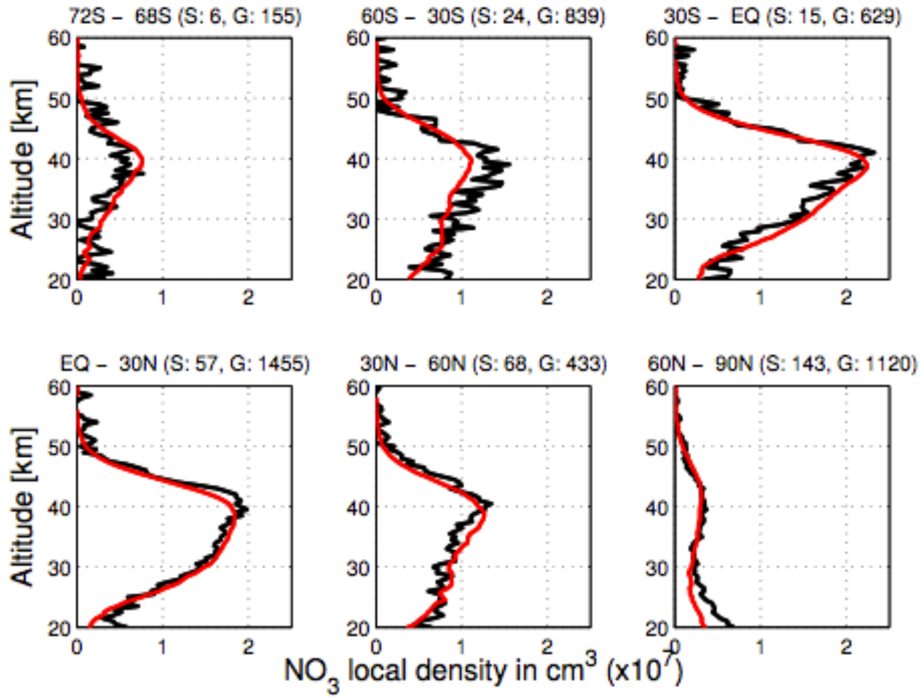
Comparing GOMOS and SAGE III lunar NO_2 and NO_3

- **NO_2: Lat < 2° Lon < 5° and local hour < 2 h**



NO_3: Zonal averages



Hakkarainen et al., ACPD, 2012

GOMOS error estimates - summary

Data characteristics	O_3	NO_2	NO_3	Aerosol extinction
Altitude range range	15–100 km	20–50 (65) km	25–50 km	10–40 km
Resolution	2 km stratosphere 3 km mesosphere	4 km	4 km	4 km
Random errors: Measurement noise and scintillations	10% around 15 km 0.5–4% stratosphere 2–10% mesosphere	10–20% slightly increasing with time	20–40%	30% around 10 km 2–10% at 15–25 km 10–50% 25–40 km
Systematic errors: Aerosol model selection	∼20% below 20 km 1–5% at 20–25 km <1% above 25 km	∼10% at 15–20 km 0–5% at 20–25 km negligible elsewhere	negligible above 25 km	<10% below 35 km 10–50% at 35–40 km
Temperature uncertainty	<0.5% at 30–60 km negligible elsewhere	negligible	negligible	–
Uncertainty in cross sections	∼1%	few per-cents (*)	few per-cents (*)	–
Uncertainty in neutral density	<1% below 20 km negligible elsewhere	negligible	negligible	<5% below 22 km 5–15% at 22–40 km

From Tamminen et al ACP 2010

Summary

- **Envisat/GOMOS measurements from pole to pole 2002-2012**
- **Random errors dominating in stratosphere**
- **In UTLS aerosols main cause for systematic errors**
- **Other error sources have only small effect**
- **Aging of the instrument**
  - Decreasing precision
  - Increasing cool star problem (expected improvement in Version 6)
- **Version 6 data with improved error characterization expected in summer/autumn 2012**
- **On average good agreement with ground based and satellite instruments.**

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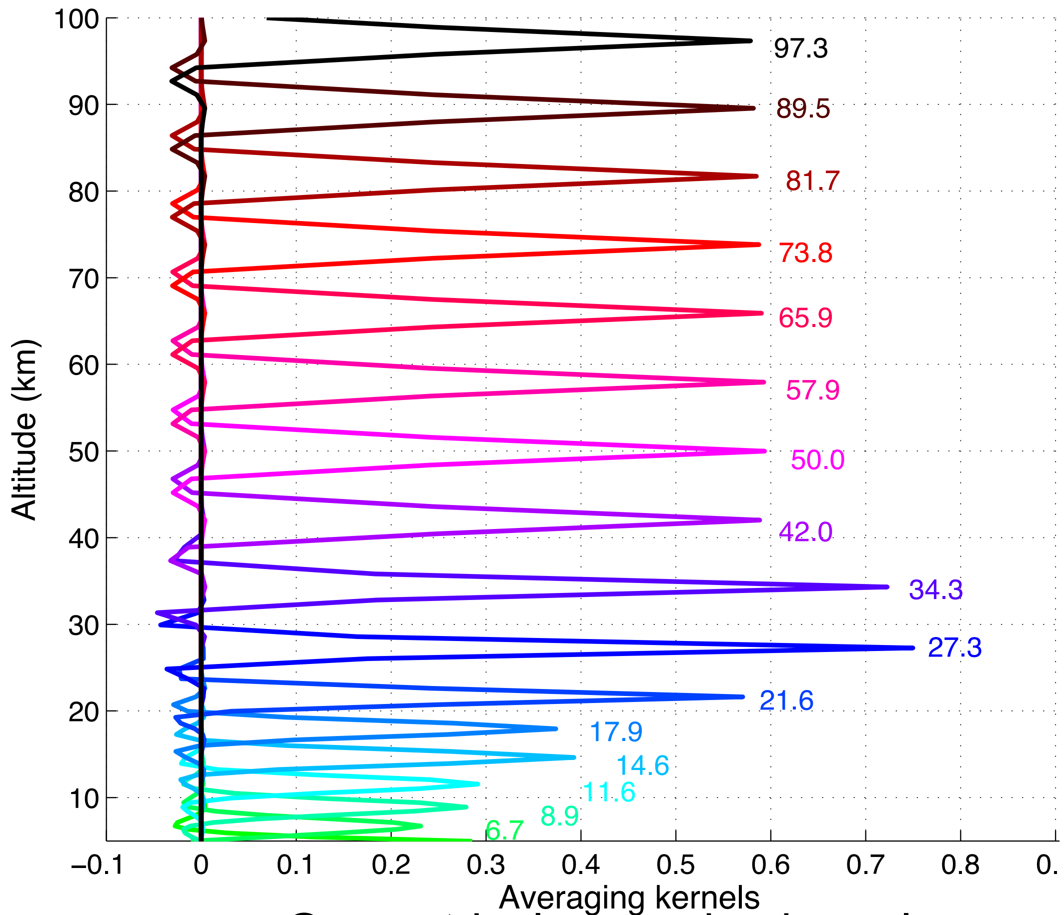
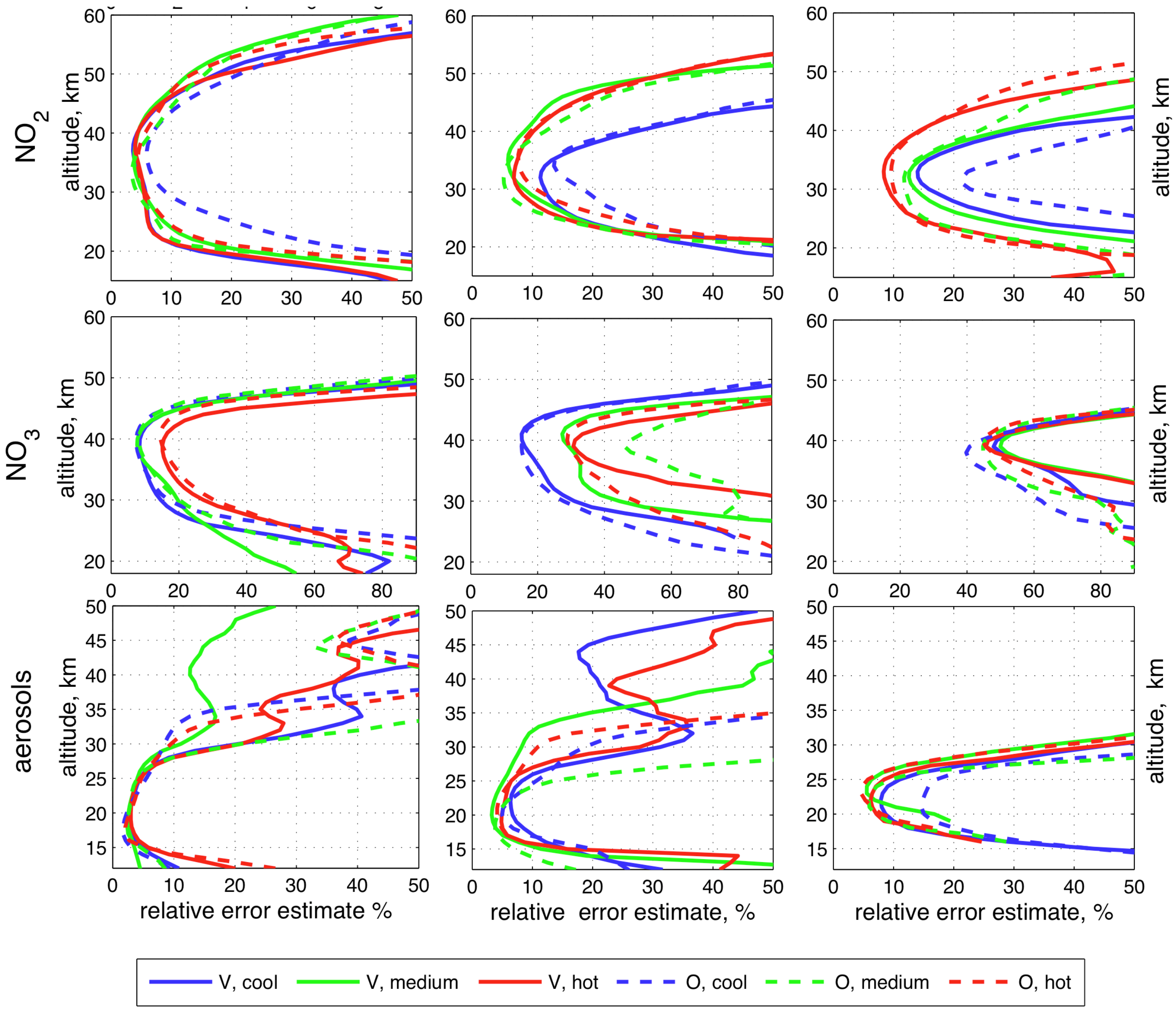
GOMOS resolution

- **Vertical sampling resolution 0.2-1.7 km**
- **Tikhonov regularization applied**
- **Vertical resolution of ozone:**
    - **2 km below 30 km**
    - **3 km above 40 km**



Geometrical averaging kernels

Error estimates of NO2, NO3 and aerosols



Hot stars
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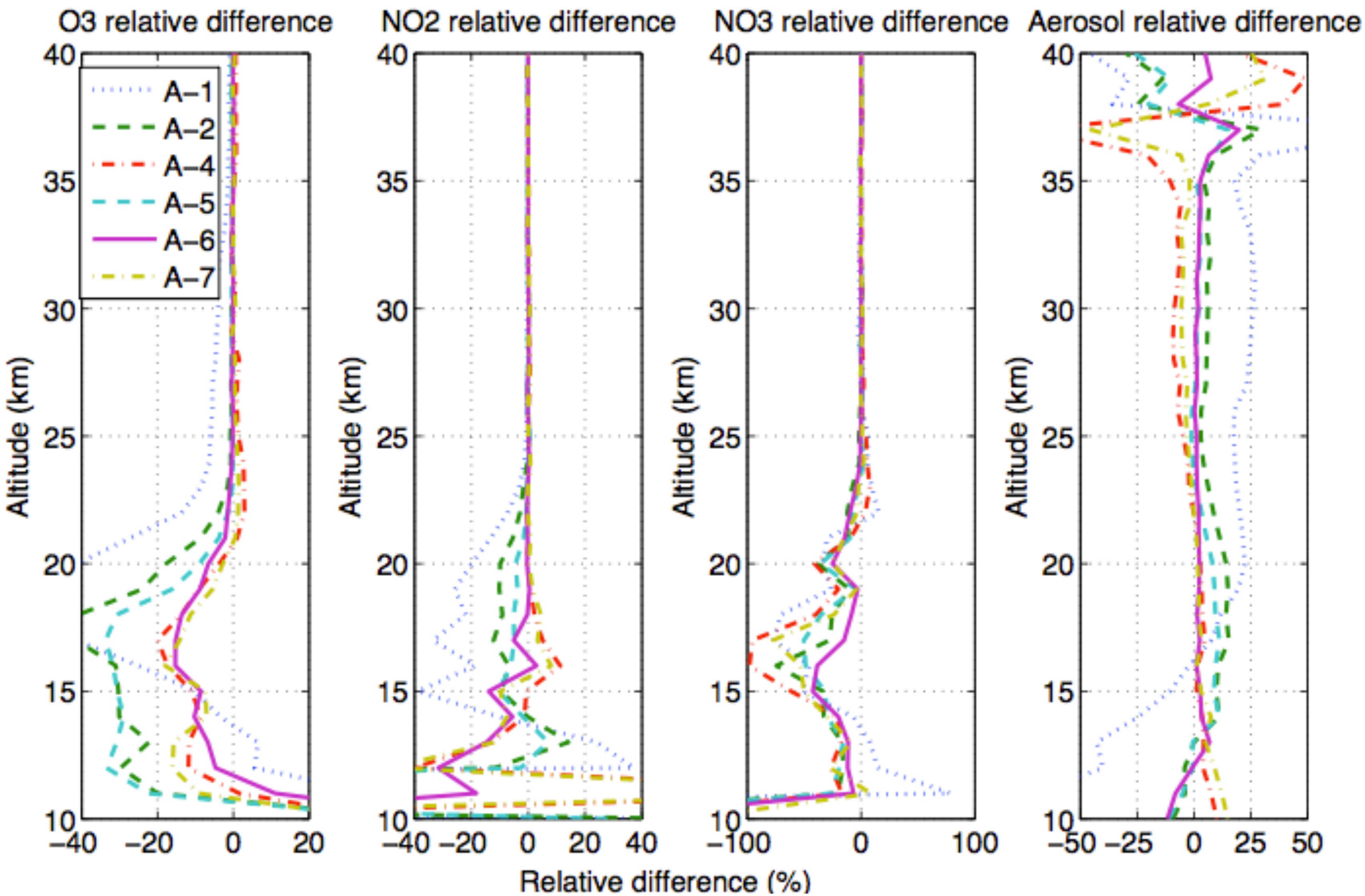
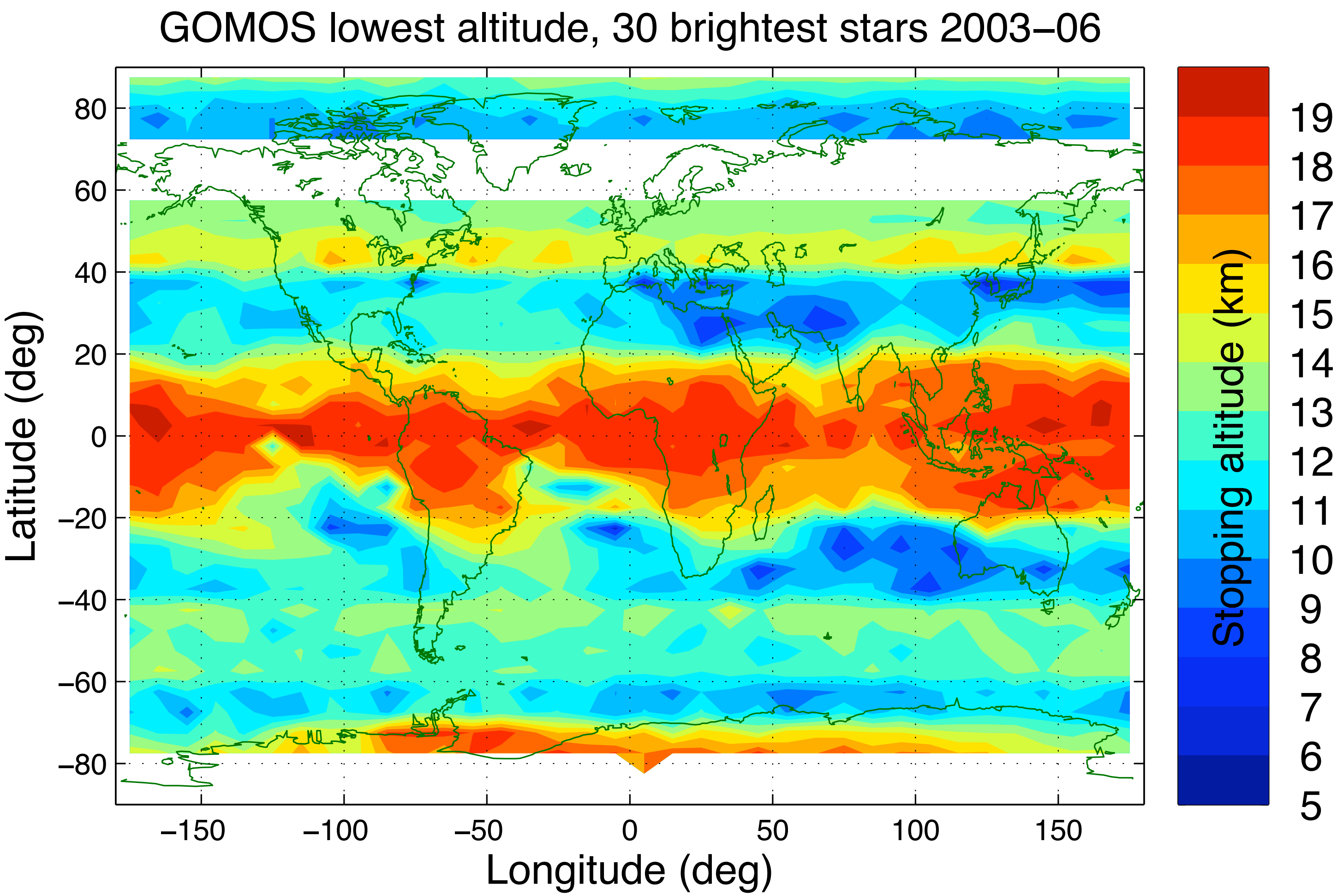
Cool stars


O3 relative difference
NO2 relative difference
NO3 relative difference
Aerosol relative difference
A–1
A–2
A–4
A–5
A–6
A–7
Altitude (km)
Relative difference (%)

Altitude range of measurements



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Latitude/month coverage and stars