The retrieval of atomic oxygen profiles in the MLT region on the basis of SCIAMACHY airglow observations

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SCIAMACHY

ENVISAT CARING FOR THE EARTH

Strengths of the retrieval

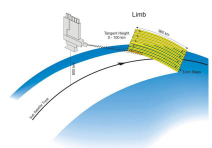
- Optimization of the constrained least-squares method by total least squares regularization
- Retrieval of the atomic oxygen concentration profiles according to transition models
- Response of the mesopause airglow to solar activity cycles

Optimization of the Constrained Least Squares Solution

SCIAMACHY = SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY

Properties:

- UV/Vis/NIR grating spectrograph: Spectral sensitivity: 0.2 – 1.5 nm
- Limb Emission geometry:
  - Airglow emissions along the Line Of Sight are measured



Limb-Measurements:

- Height range: 0 – 92 km (at night: 73 – 150 km)
- Vertical resolution: 3.3 km
- Vertical field: 2.8 km
- Duration of one measurement: app. 60 s

Model-Interpolation:

- Height range: 80 – 130 km
- Altitude grid resolution: 1.0 km

Model assumptions

- Horizontal homogeneity of the atmosphere layers
- Constant height of the satellite
- WSG-84 model of the Earth
- Latitude variability of the Lines Of Sight distances
- Self-absorption of green line is negligible

Inverse Problem

- Inverse solution of a linear system is intrinsically ill-conditioned

$$m \approx Wv$$

- Assume inconsistencies of the solution for **v**olume emission rate:
  - integrated emission rates due to noise in the spectro**m**eter
  - Line Of Sight **W**eighting Matrix's noise due to dynamics

Constrained least-squares solution

- Apply constraints to make the retrieval more stable
- Minimize the differences between adjacent values of **v**

$$\left(W^T W\right)v + \gamma H v = W^T m$$

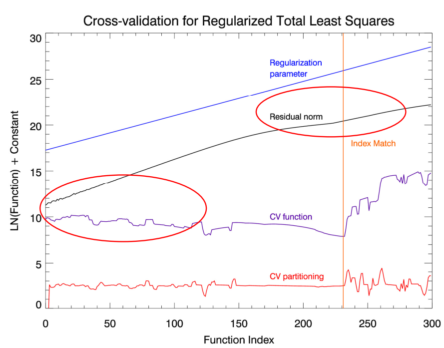
Adapted Cross-validation method for RTLS

- Adjust the strength of the constraint continuously with help of the regularization parameter
- Consider Tikhonov formulation of the Regularized Total Least Squares (RTLS) method to be used in case of a noisy **W** matrix
- Choose the regularization parameter (RP) for RTLS automatically
  - Find global minimum of the overall CV function
  - Reject too small RP due to the random noise realization
  - Look for the left steepest slope

$$CV = \sum_{i=1}^{N} \frac{\left\| W_i v_{-i} - m_i \right\|^2}{\left\| v_{-i} \right\|^2 + 1},$$

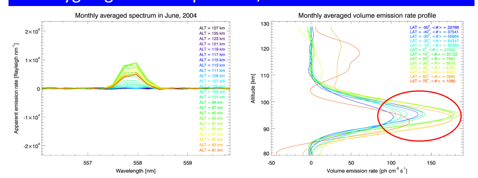
Sima D.M., van Huffel S., Golub G.H. (2004)

$$v_{-i} \text{ from } \left(W_{-i}^T W_{-i} + \gamma H^T H\right) v = W_{-i}^T m_{-i}$$

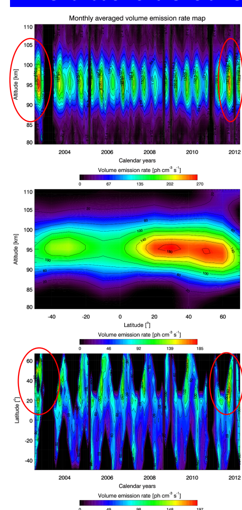


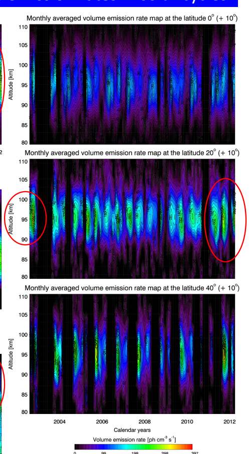
- Note relative minimum and randomness of the Residual Norm
- The position of the left steepest slope is characteristic as well as RN

Oxygen green line spectrum, Volume emission rates



Time variation of the volume emission rates in solar cycles



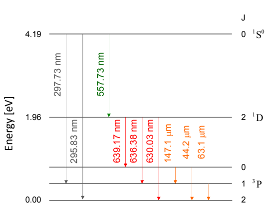


- The data set from South Atlantic Anomaly was excluded: 110 W – 40 E, 50 S – 10 N
- The altitude of EnviSat was mentioned

Behaviour of the atomic oxygen 557.7 nm emission in the solar cycle inferred from volume emission rates

Production of metastable oxygen by Barth and Hildebrandt

Structure of the metastable levels and the transition wavelengths



Production of metastable $O(^1S_2)$

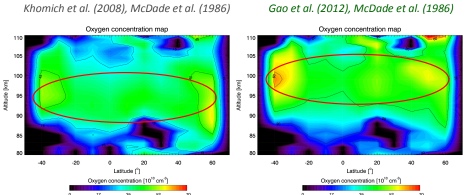
$$O + O + M \rightarrow O_2^* + M \quad \alpha_{O_2}$$
$$O_2^* + N_2 \rightarrow O_2 + N_2 \quad \beta_{N_2}^*$$
$$O_2^* + O_2 \rightarrow O_2 + O_2 \quad \beta_{O_2}^*$$
$$O_2^* + O \rightarrow O_2 + O \quad \beta_O^*$$
$$O_2^* + O \rightarrow O_2 + O(^1S_0) \quad \alpha_O$$
$$O_2^* \rightarrow O_2 + h\nu \quad A^*$$
$$O(^1S_0) \rightarrow O(^1D_2) + h\nu(557.7(nm)) \quad A_{557.7}$$
$$O(^1S_0) \rightarrow O(^3P_1) + h\nu(297.2(nm)) \quad A_{297.2}$$
$$O(^1S_0) + O_2 \rightarrow O + O \quad \beta_{O_2}$$
$$O(^1S_0) + O \rightarrow O + O \quad \beta_O$$

Consider following probable transitions (use MSIS-E-90 model and volume emission rates):

- $^1S{-}^3P\ (J:0-2)$, $^1S{-}^3P\ (J:0-1)$, $^1S{-}^1D\ (J:0-2)$ *Khomich et al. (2008), McDade et al. (1986)*
- $^1S{-}^1D\ (J:0-2)$ *Gao et al. (2012), McDade et al. (1986)*

Oxygen concentration for different transition models

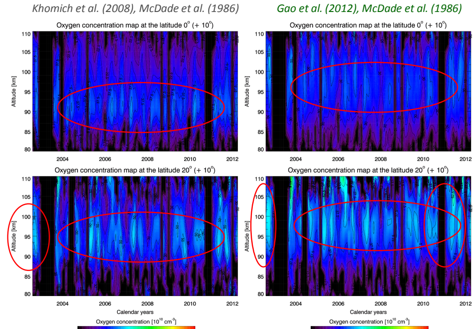
Khomich et al. (2008), McDade et al. (1986) — *Gao et al. (2012), McDade et al. (1986)*



- Oxygen peak is located at lower altitudes in the model of Khomich et al.
- Low oxygen concentration at middle latitudes correlates well with emission rates in the model of the most probable transition by 557.7 nm, Gao et al.

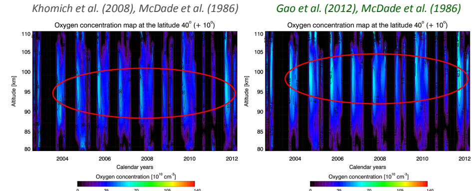
Time variation of oxygen concentration, low latitudes

Khomich et al. (2008), McDade et al. (1986) — *Gao et al. (2012), McDade et al. (1986)*



Time variation of oxygen concentration, middle latitudes

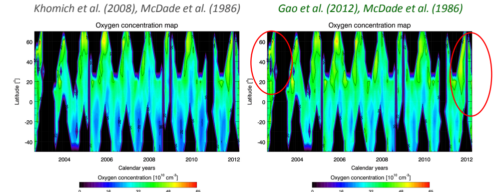
Khomich et al. (2008), McDade et al. (1986) — *Gao et al. (2012), McDade et al. (1986)*



- Variation of oxygen concentration with altitude at low and middle latitudes is high according to the model of Khomich et al.
- This variability corresponds indirectly to the variability of the ozone production correlation with the 27 day solar cycle shown by Kubin et al.

Time variation of oxygen concentration in solar cycles

Khomich et al. (2008), McDade et al. (1986) — *Gao et al. (2012), McDade et al. (1986)*



Conclusions

- Volume emission rates are higher at high latitudes
- The characteristic 11 year solar cycle is evident on the emission rates map, with the maximum of emission rates at the altitude of 95 km
- Atomic oxygen production correlates well with the 11 year solar cycle at low and high latitudes
- The model of Khomich et al. including transitions in UV range correlates with the solar cycles better than the model of Gao et al. of the airglow green line
- Further investigations will focus on quantification of solar impact on atomic oxygen

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Acknowledgments

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