UV/vis/near-IR Limb Measurements Onboard The NASA Global Hawk In The Tropical Tropopause Layer (TTL)

Bodo Werner (1)

- 7th Limb Conference and Workshop, Bremen -

Collaborators:

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(2) Jochen Peter Stutz, and Max Spolaor, University of California, Los Angeles, Department of Atmospheric and Oceanic Sciences, UCLA, Los Angeles, USA

7th Atmospheric Limb Conference LIMB-13

This presentation participates in the student award contest

Bodo Werner, 19.6.2013

NASA ATTREX Objectives and DOAS Contribution

NASA ATTREX overarching goals and mini-DOAS contributions

1. **Across TTL transport** due to deep convection, slow large-scale ascent waves, et cetera

2. **Microphysics**

   - Mini-DOAS: Detection of water in the TTL and of ice particles (sub-visible cirrus clouds) and quantification of some of their optical properties

3. **TTL Photochemistry**

   - Mini-DOAS: The oxidation capacity in the TTL by observation of some relevant nitrogen (NOx) and halogen compounds (BrO, and IO)

   - Mini-DOAS: The budget and photo-chemistry of chlorine, bromine and iodine in the TTL and lowermost stratosphere

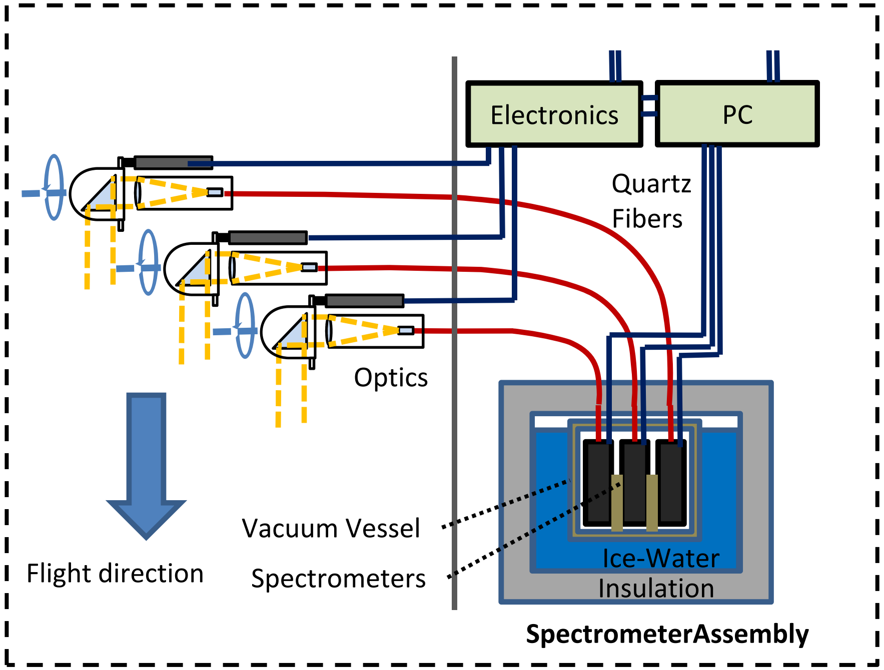
4. **Radiative heating:**

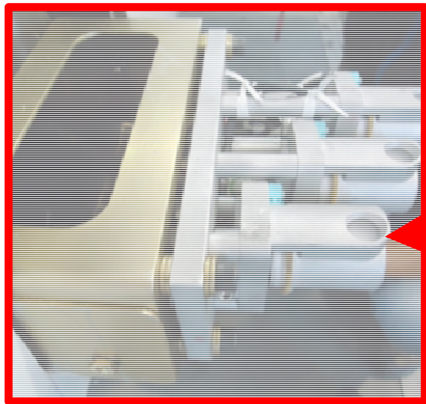
   - Mini-DOAS: Validation of short-wave radiation schemes

Campaigns:

- Test campaign at EAFB (Ca) in Oct/Nov. 2011 with 3 deployments ✓
- 1st scientific campaign at EAFB (Ca) in Jan./Feb. 2013 with 6 deployments ✓
- 2nd scientific campaign at Guam in Jan./Feb. 2014
- 3rd scientific campaign at Darwin in June/July 2014

The GH mini-DOAS Instrument





Telescopes

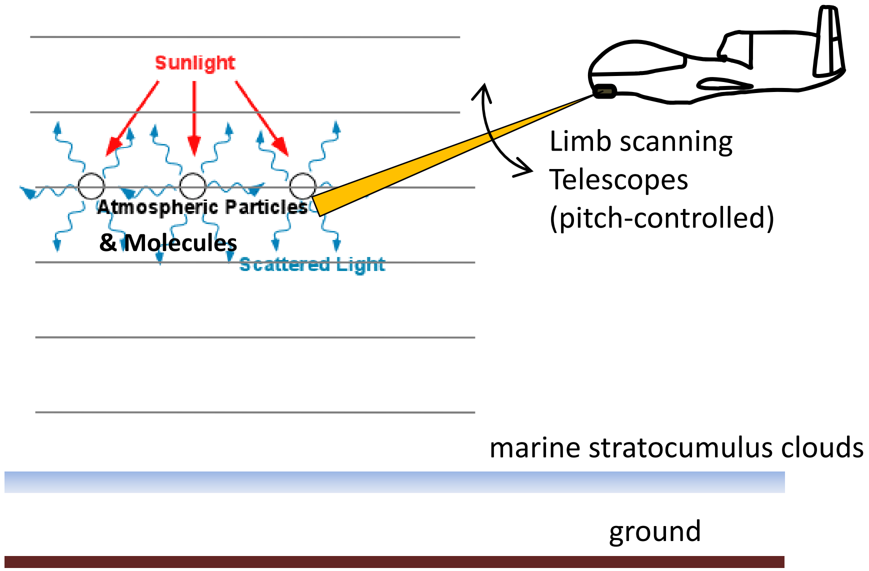
Diffuser for direct solar reference

Spectrometers

Quartz fibers

Telescopes with cover

Major Measurement Features



- Limb viewing geometry
- Pointing into flight direction (-> sensitive to the pitch of the aircraft)
- Telescope elevation angles: +1°, 0°, -0.5°, -1°, -1.5°, -2°, -2.5°, -3°, -4°, -7°, -15°
- During ascents/descents: fixed limb (-0.5°, which yields the highest sensitivy at flight altitude)

Major optical properties and measured species of the GH mini-DOAS instrument

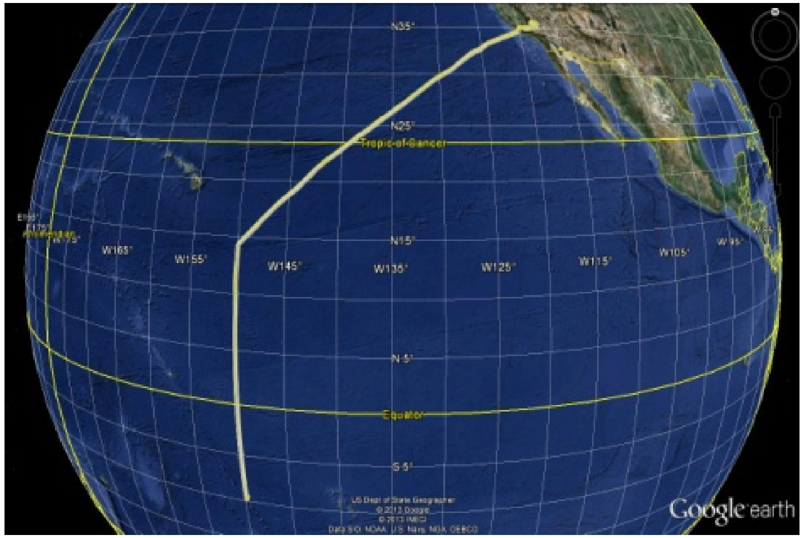
Channel	Wavelengths	Resolution	Vertical FOV	Measured Species
UV	300 - 380 nm	0.8 nm	0.19 °	**BrO, O3, O4 (361nm)**
vis	410 - 530 nm	0.9 nm	0.24 °	**NO2, O3, O4 (477nm)**
near-IR	900 - 1700 nm	20 nm	0.19 °	**H2O (vapor, liquid, ice)**

2013 NASA Dryden Deployment - Flights

Flights DRFC deployment 2013

Date	Duration
Jan 19	6.5 hrs (test flight)
Feb 5-6	24.5 hrs
Feb 9-10	24.3 hrs
Feb 14-15	24.5 hrs
Feb 11-22	24.6 hrs
Feb 26-27	24.4 hrs
Mar 1-2	24.1 hrs

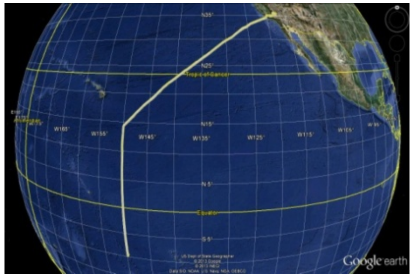
Flight path Feb 9-10

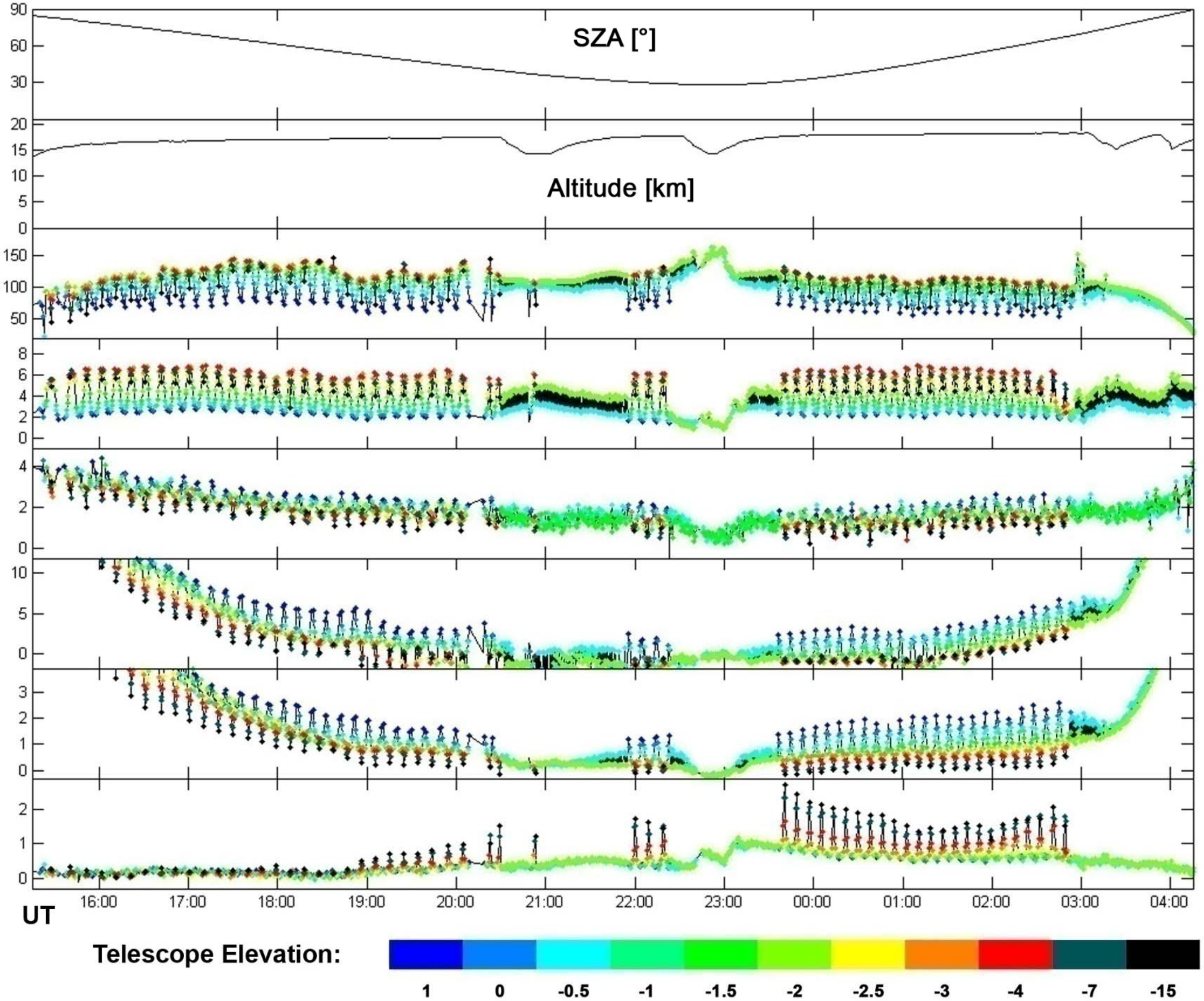


Southernmost point: 10°S

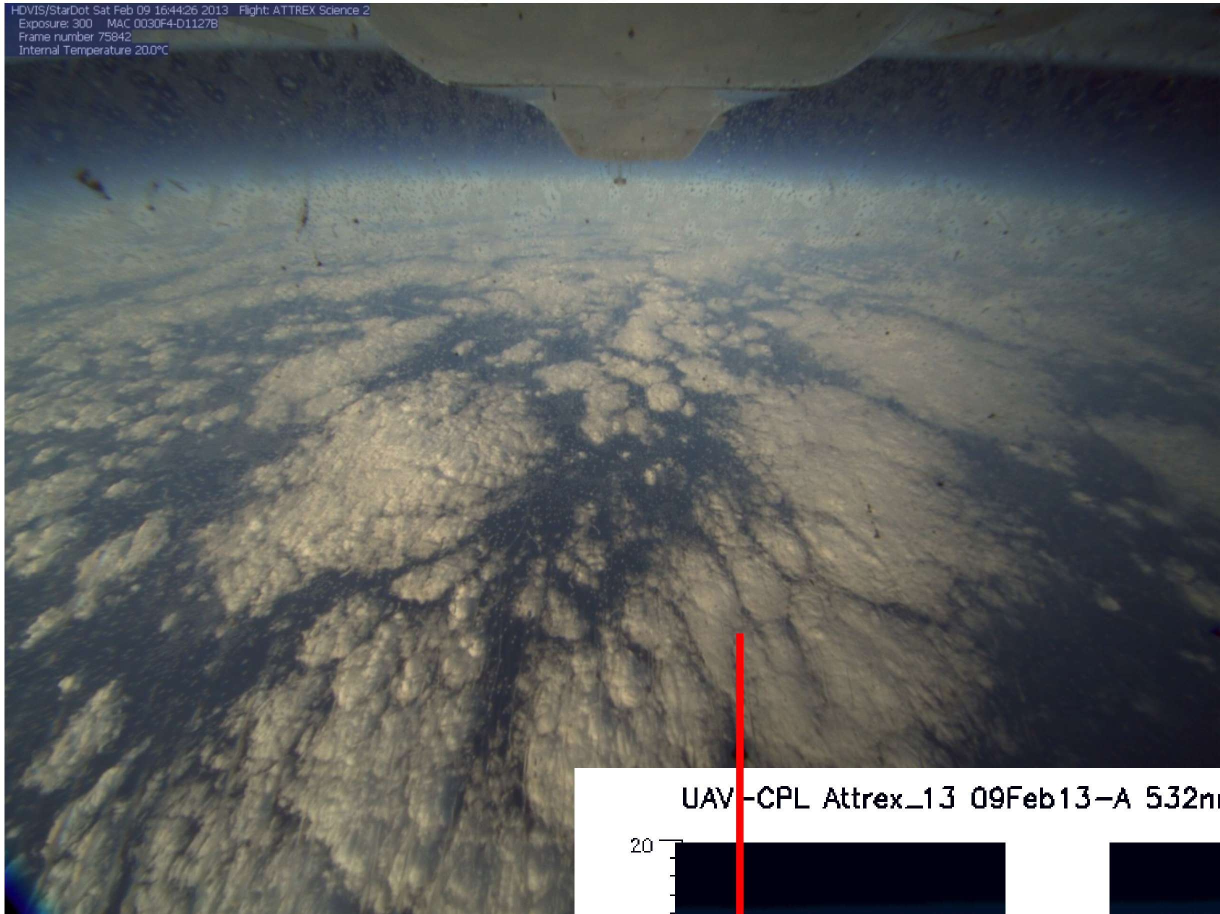
The GH mini-DOAS instrument worked well during all conducted flights
→ 150 hrs of data (from which approx. 80 hrs at sunlight)

Science Flight 2 2013 – (diff.) Slant Column Densities



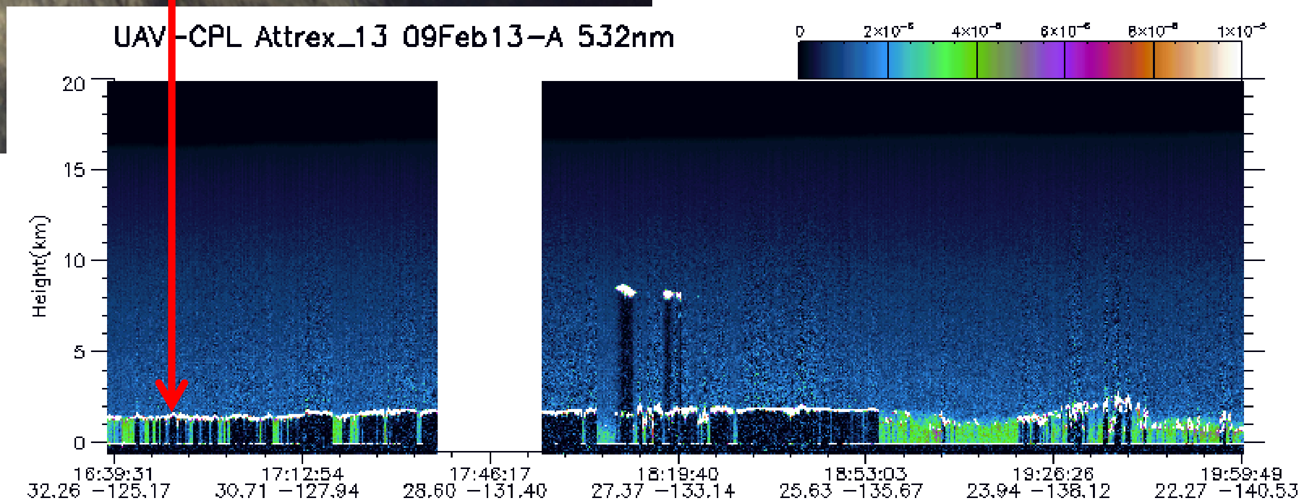


Typical Marine StratoCumulus (MSC) Clouds

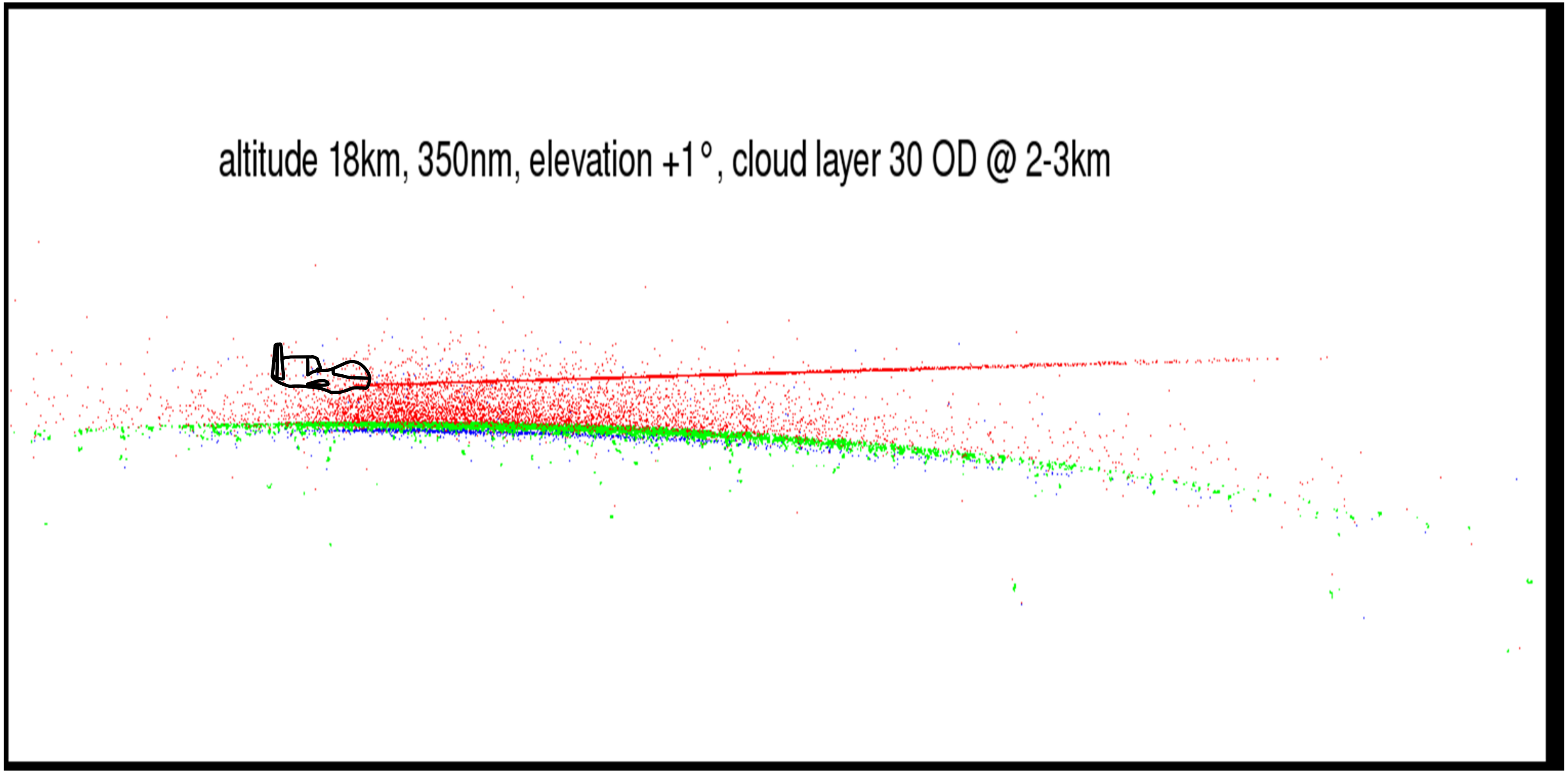


GH belly cam picture

Cloud Physics LIDAR (CPL)



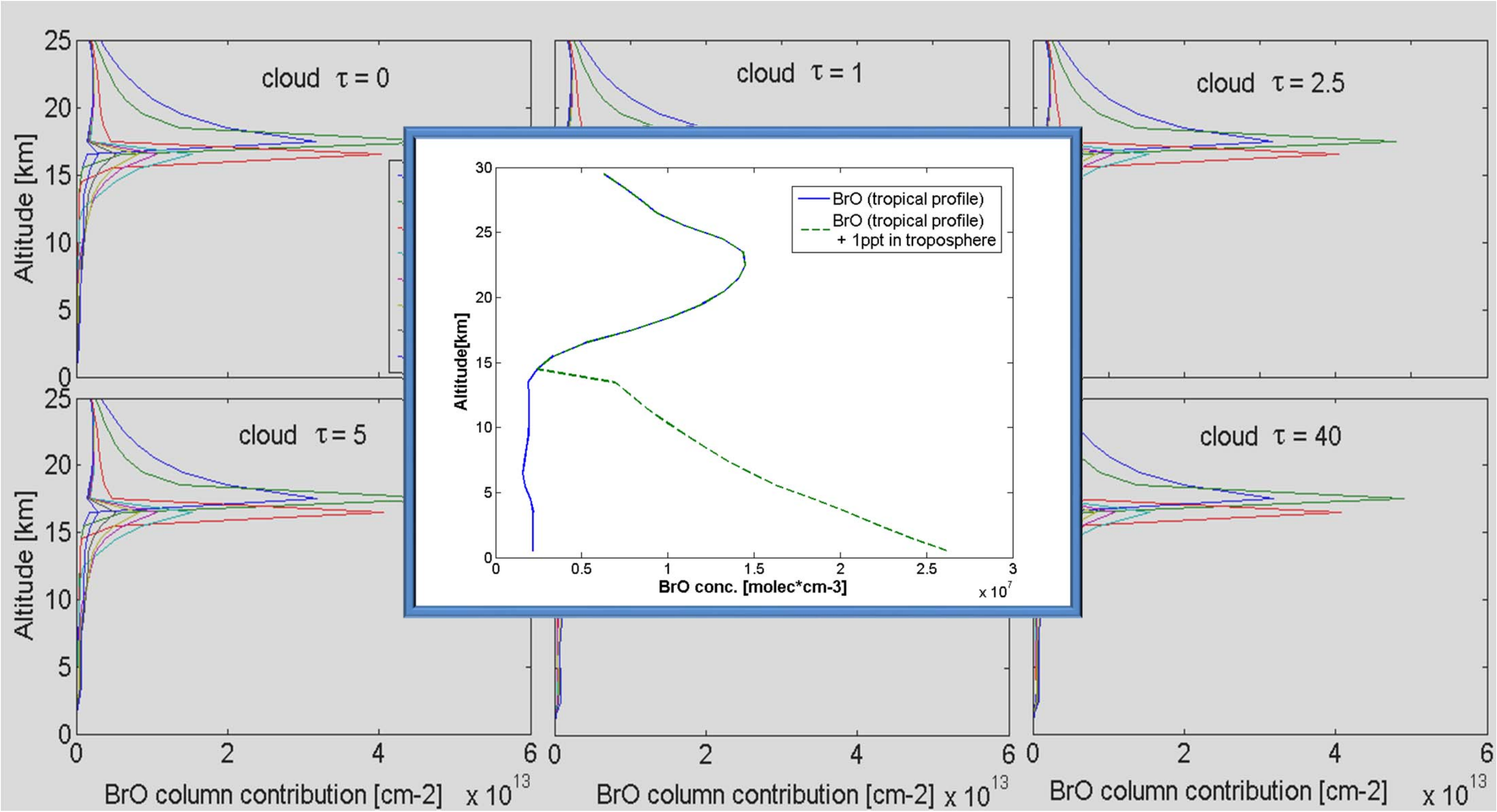
Scattering Events - Visualisation



[Tim Deutschmann, PhD thesis, 2013]

Red: Rayleigh scattering events
Green: Mie scattering events
Blue: Ground reflection

Influence of MSC Clouds on BrO Box Slant Columns



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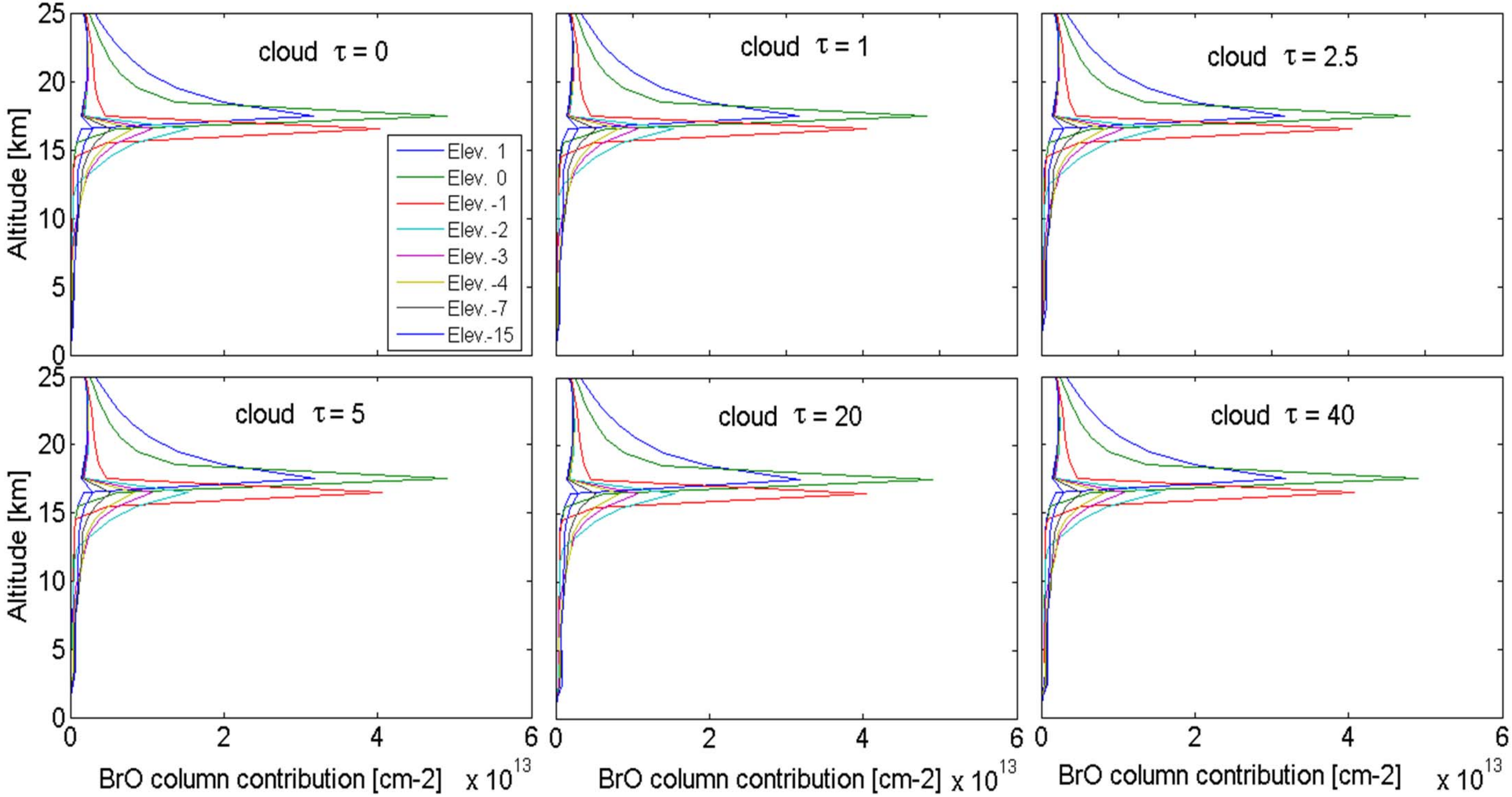
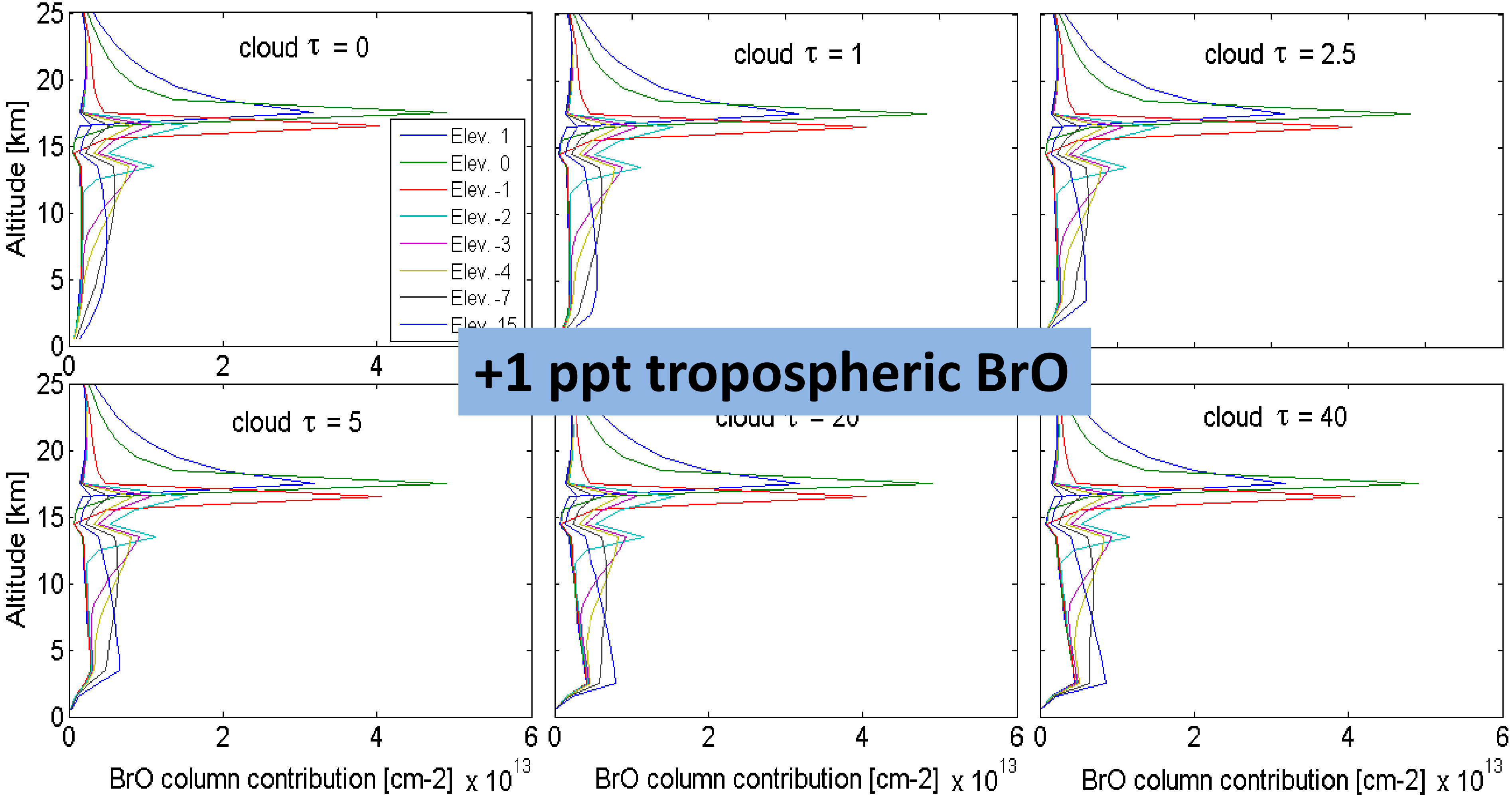
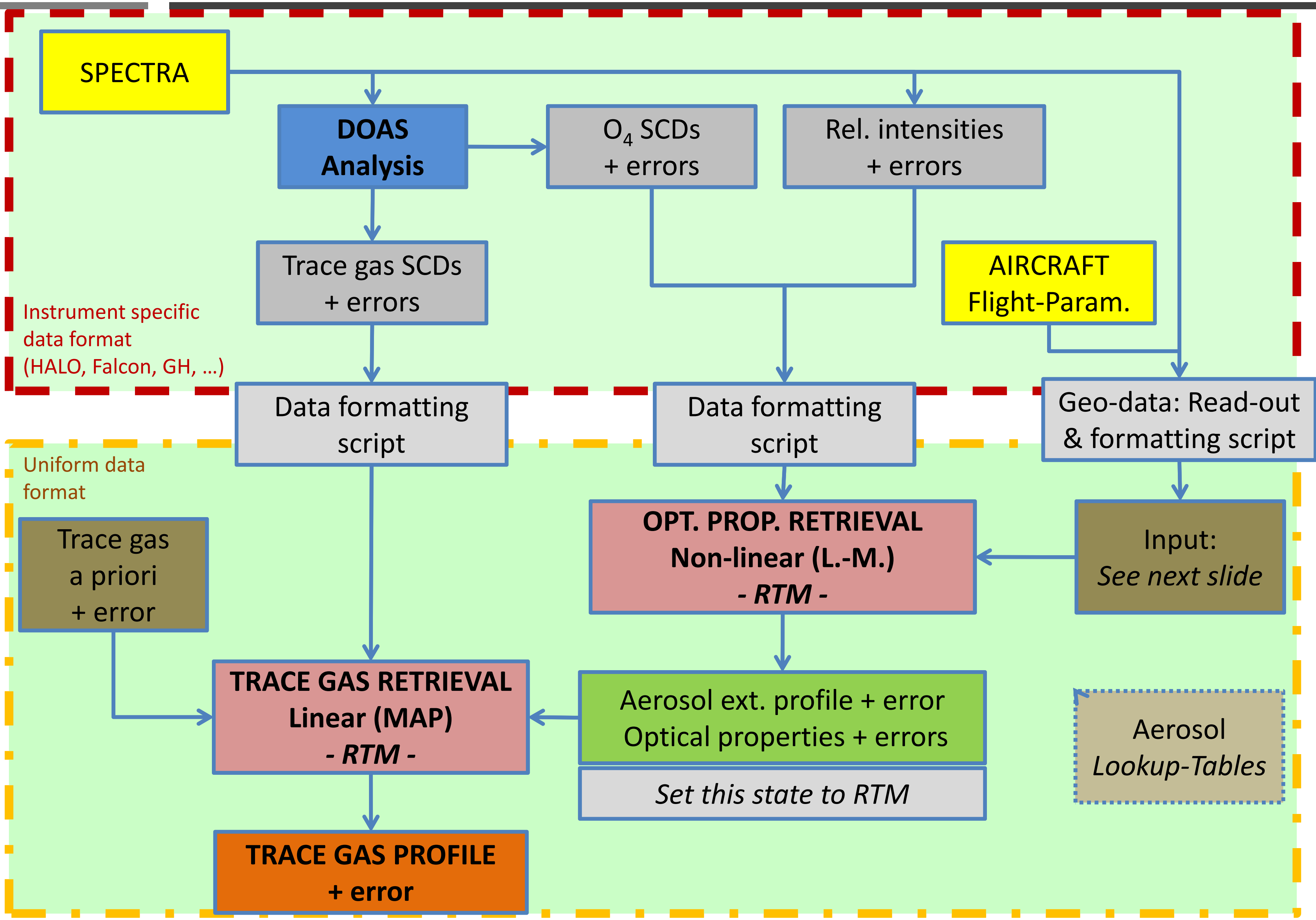


Influence of MSC Clouds on BrO Box Slant Columns



→ The error propagation of the tropospheric cloud retrieval into the BrO retrieval can eventually be significant

Retrieval Flow Chart



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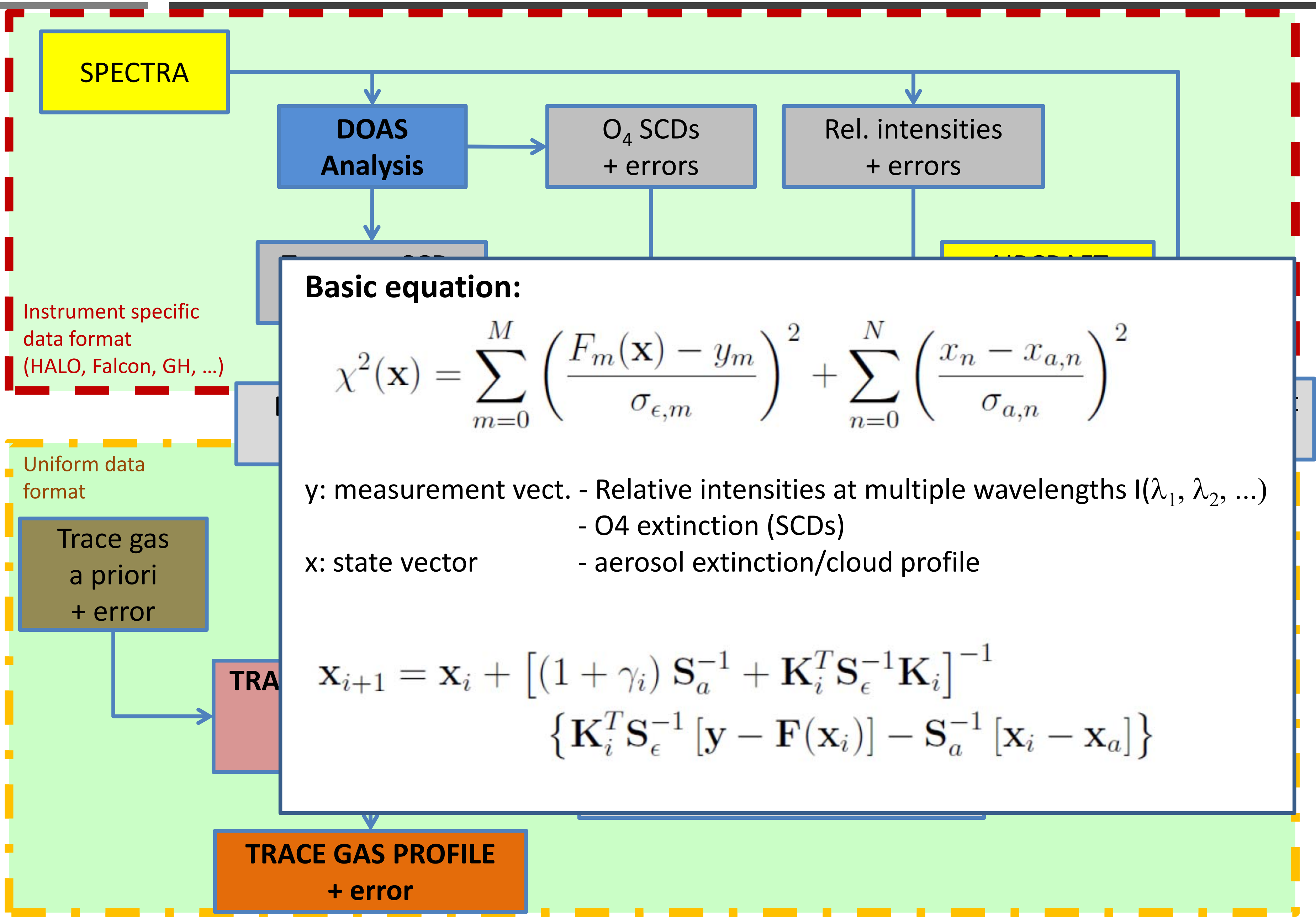


Basic equation:

$$\chi^2(\mathbf{x}) = \sum_{m=0}^{M} \left(\frac{F_m(\mathbf{x}) - y_m}{\sigma_{\epsilon,m}} \right)^2 + \sum_{n=0}^{N} \left(\frac{x_n - x_{a,n}}{\sigma_{a,n}} \right)^2$$

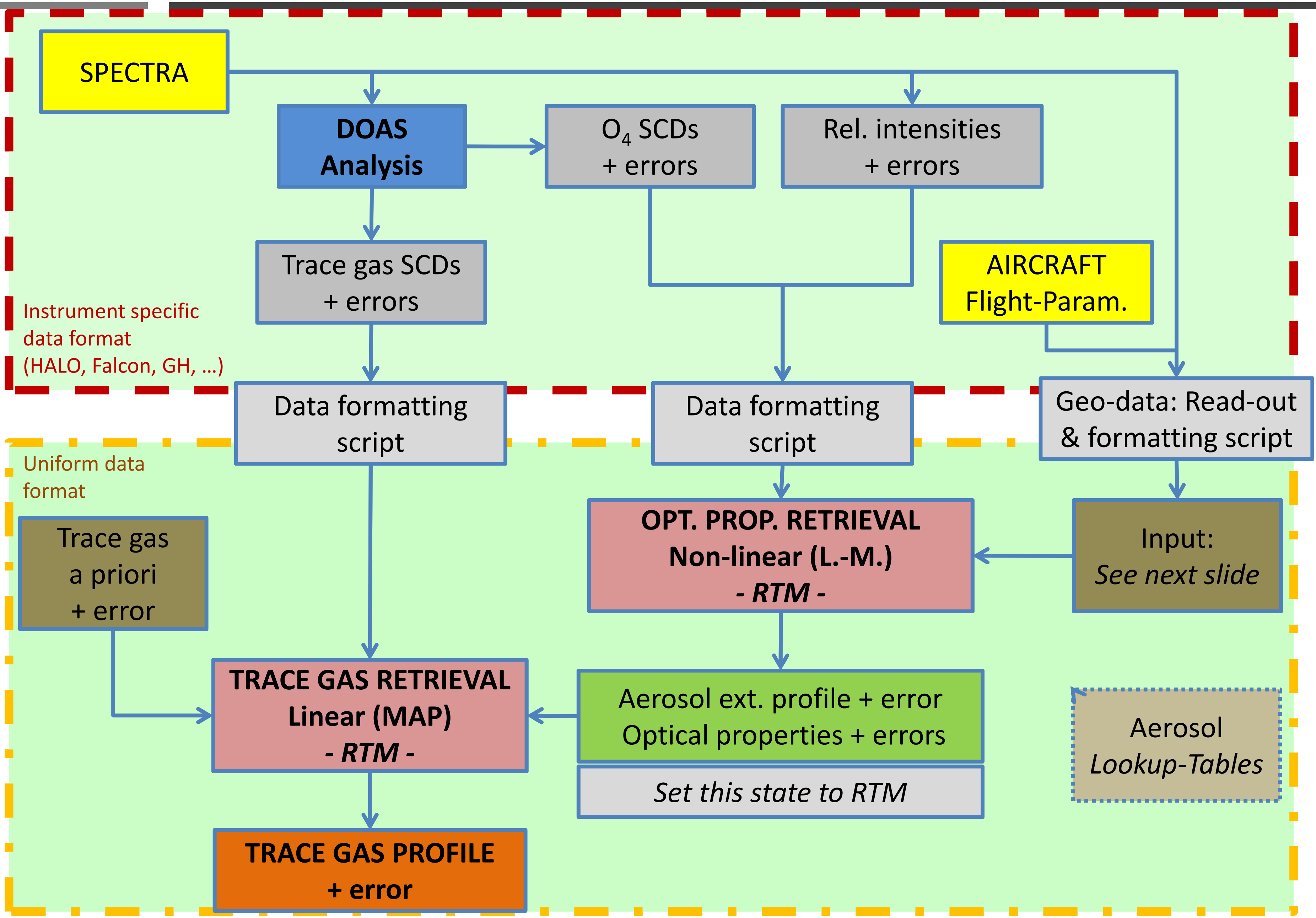
y: measurement vect. - Relative intensities at multiple wavelengths I(λ_1, λ_2, …)

- O4 extinction (SCDs)

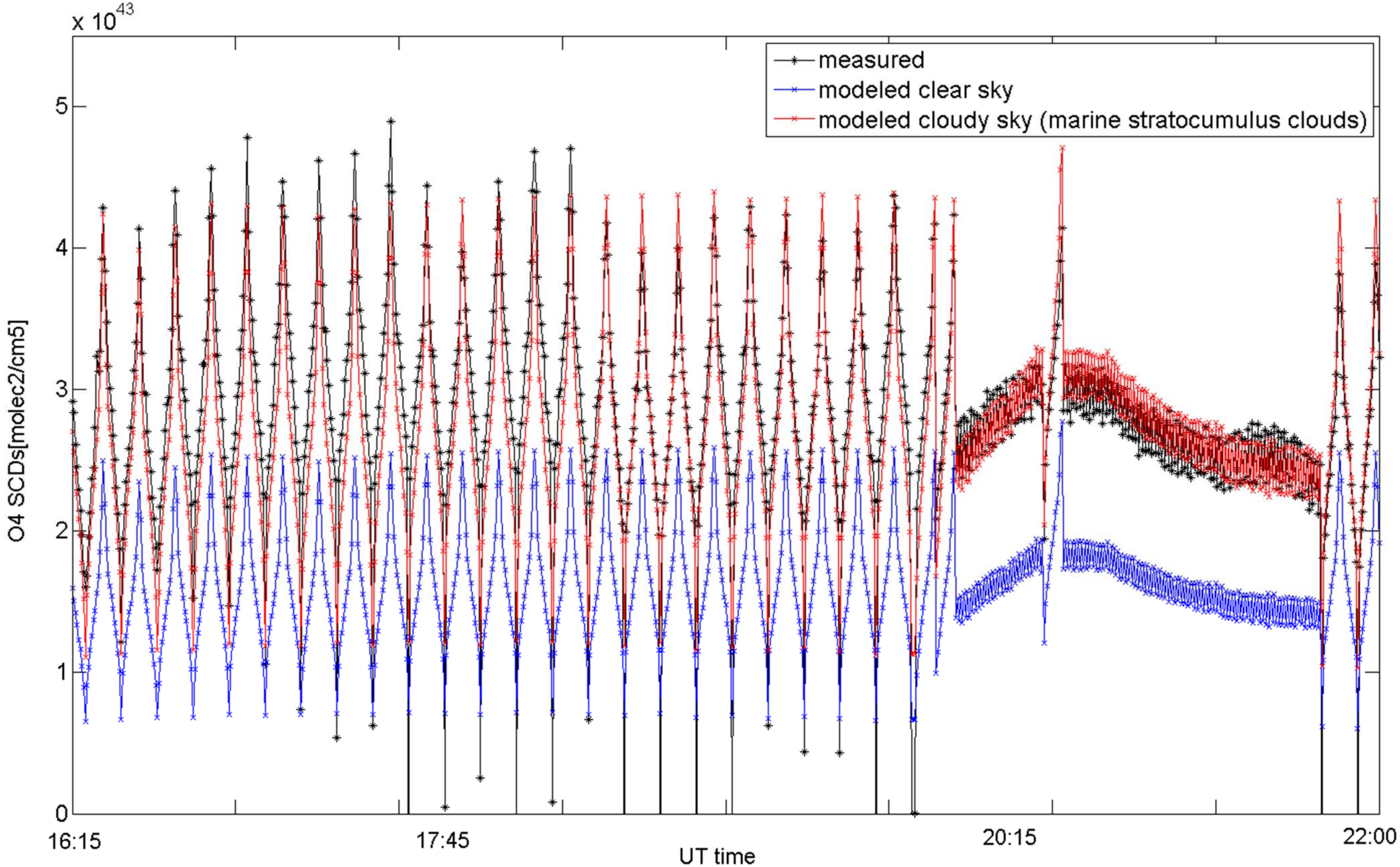
x: state vector - aerosol extinction/cloud profile

$$\mathbf{x}_{i+1} = \mathbf{x}_i + \left[(1+\gamma_i)\, \mathbf{S}_a^{-1} + \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \mathbf{K}_i \right]^{-1} \left\{ \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \left[\mathbf{y} - \mathbf{F}(\mathbf{x}_i) \right] - \mathbf{S}_a^{-1} \left[\mathbf{x}_i - \mathbf{x}_a \right] \right\}$$

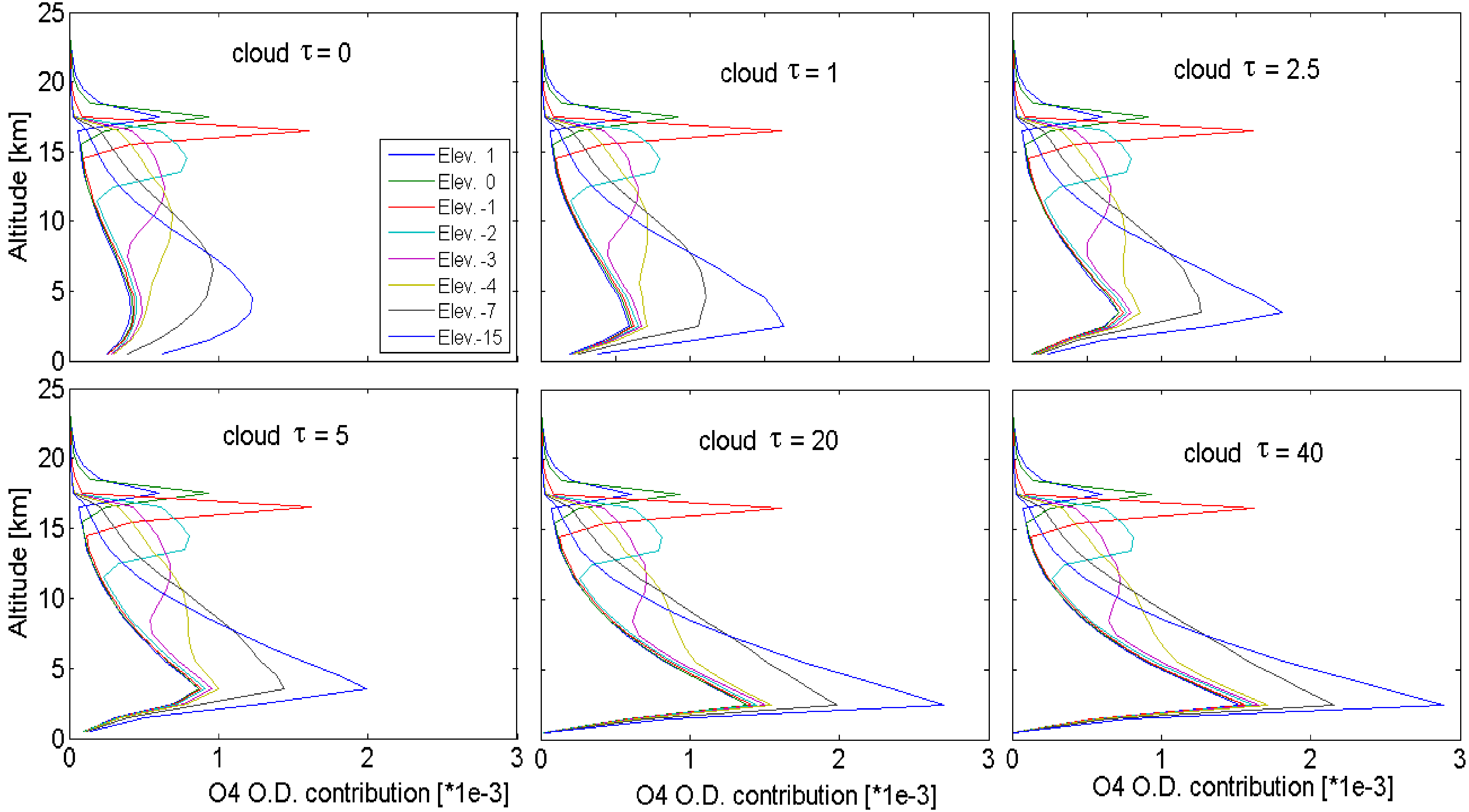
Retrieval Flow Chart



O4 361nm Extinctions – Clear and Cloudy Sky (MSC)

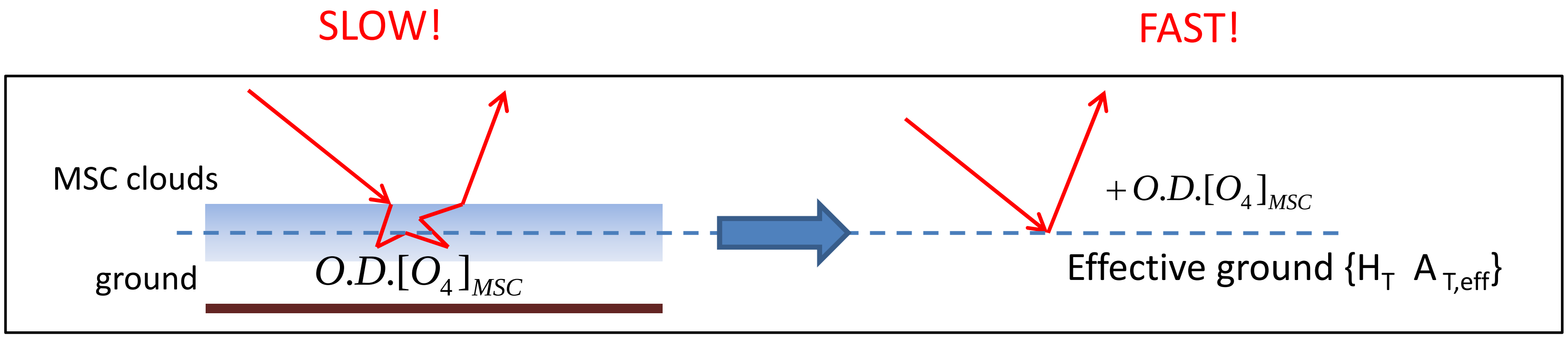


O4 361nm Extinctions, MSC Clouds at 2km



- Long computing time

Effective Model for Low Clouds



$$O.D.[O_4]_{MSC} = k_{eq} \cdot \sigma \cdot [O_2]^2 \cdot \tau \cdot d_{MSC} \cdot l_{Mie}(1-g)$$

→Retrieve effective albedo $A_{T,eff}$ at effective cloud top height H_T

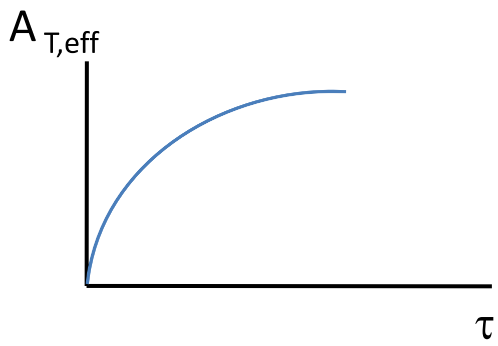
Needed derivatives:

(from RTM)

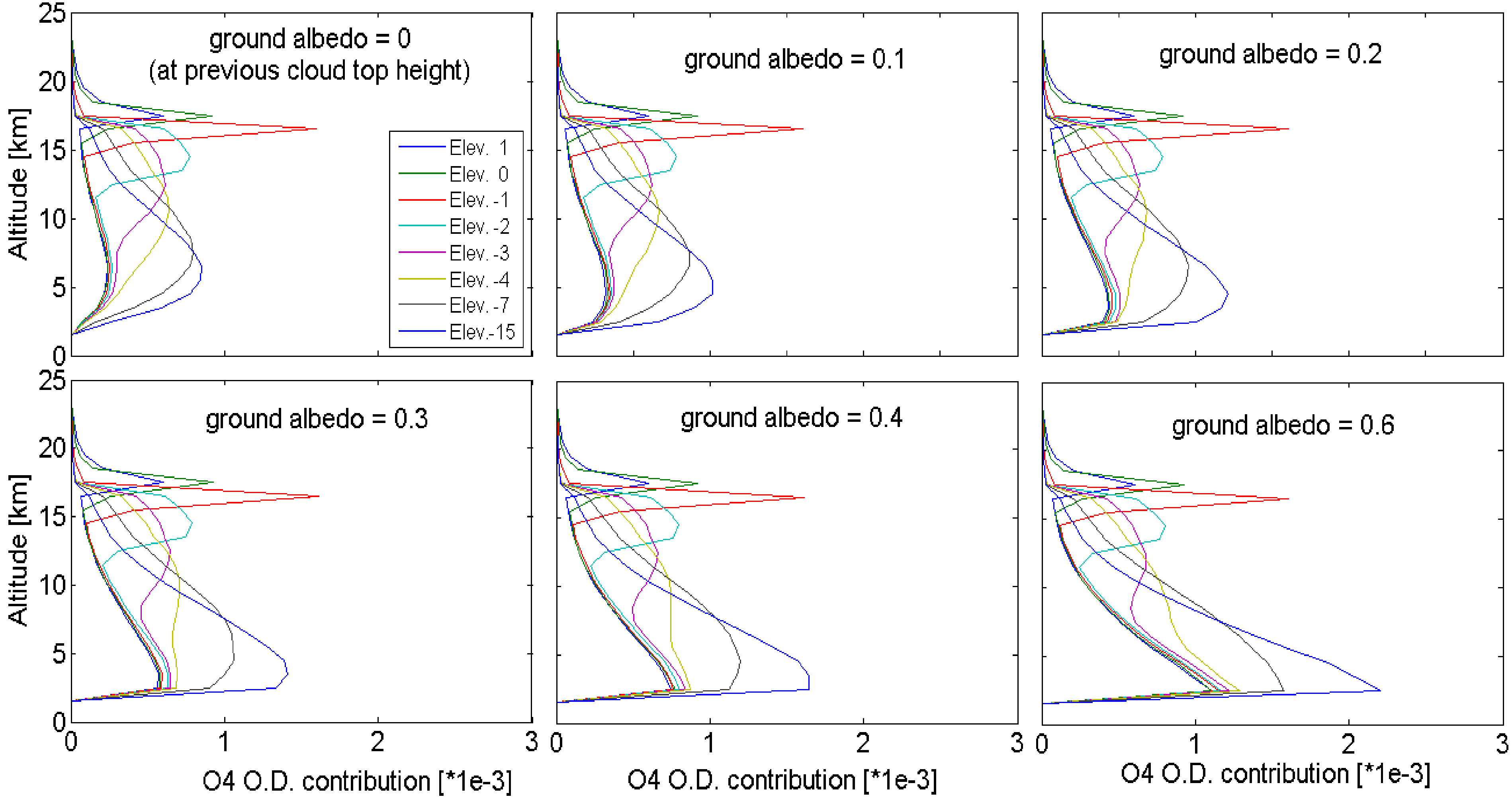
$$\frac{\partial\{O_4, I_{rel}(\lambda_i)\}}{\partial\{A_T, H_T\}_{eff}} = \frac{\partial\{O_4, I_{rel}(\lambda_i)\}}{\partial\tau} \cdot \frac{\partial\tau}{\partial\{A_T, H_T\}_{eff}}$$

derivative

$$\{A_T, H_T\}_{eff}(\tau)\Big|_{\{O_4, I_{rel}(\lambda_i)\}} \rightarrow \tau(\{A_T, H_T\})\Big|_{\{O_4, I_{rel}(\lambda_i)\}}$$



O4 Extinctions, Ground at 2km with Effective Albedo



•Parametrisized differently -> very short computing time

Conclusion & Outlook

1. Long horizontal light paths (AMFs) supports sensitive detection species of extremely low (some ppt) concentrations (e.g., BrO, IO, NO2, CH2O, …) in the UT/LS, TTL
2. Interference of the measurements comes with
   - Aerosol and cloud cover (cirrus) around flight level
   - Cloud cover (m.s.c.) / ground albedo
   - but these effects are minor/major on retrieval of gases with small/high concentration in the lower atmosphere i.e. NO2, BrO, O3, IO,… vs. O4, H2O
3. Major constraints for forward modelled RT are measured O4, rel. intensities (and potentially the Ring effect)

Current / next steps

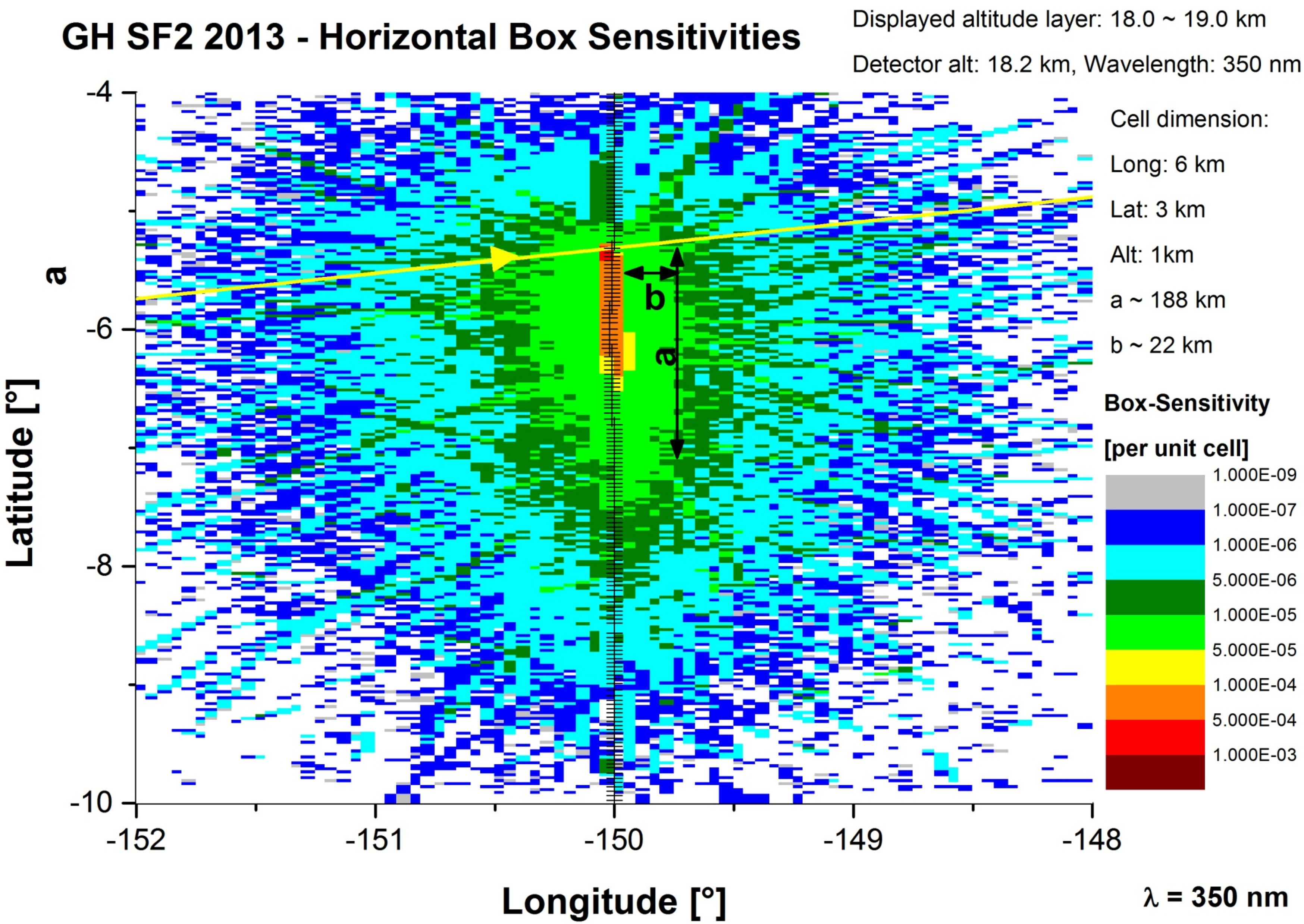
4. Set-up of a suitable forward model
   - Test stability of the cloud retrieval with synthetic scenarios
   - Quantify influence of UT/LS aerosols&clouds
5. Optimal estimation retrieval
6. Validate and compare results at flight altitude with in-situ data (e.g. AWAS)

Thanks for your attention!

Questions and comments are very welcome

Additional slides

Retrieval – Horizontal Sensitivity



Retrieval – Relative Intensities and O4

Basic equation:

$$\chi^2(\mathbf{x}) = \sum_{m=0}^{M} \left(\frac{F_m(\mathbf{x}) - y_m}{\sigma_{\epsilon,m}} \right)^2 + \sum_{n=0}^{N} \left(\frac{x_n - x_{a,n}}{\sigma_{a,n}} \right)^2$$

y: measurement vect. - Relative intensities at multiple wavelengths $I(\lambda_1, \lambda_2, ...)$
- O4 extinction (SCDs)

x: state vector - aerosol extinction profile, SSA

Goal:

Minimize χ^2 which ist the error-weighted difference between measurement and foward model output and the difference between the actual state and the a priori state

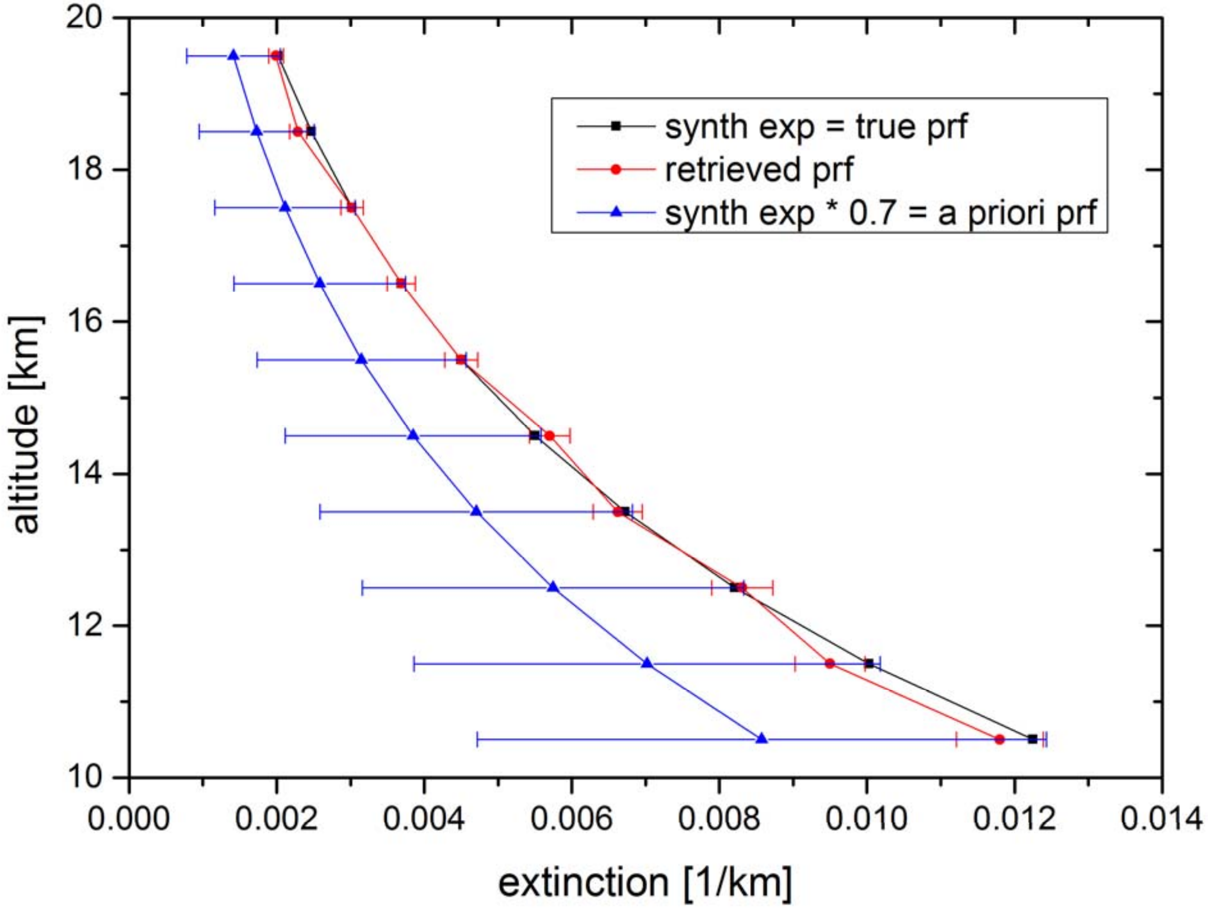
The foward model **F** depends in a non-linear way on **x**

→ χ^2 has to be minimized iteratively (Levenberg-Marquard-Algorithm)

$$\mathbf{x}_{i+1} = \mathbf{x}_i + \left[(1+\gamma_i)\, \mathbf{S}_a^{-1} + \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \mathbf{K}_i \right]^{-1} \left\{ \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \left[\mathbf{y} - \mathbf{F}(\mathbf{x}_i) \right] - \mathbf{S}_a^{-1} \left[\mathbf{x}_i - \mathbf{x}_a \right] \right\}$$

Retrieval – Synthetic Test

Synthetic example run

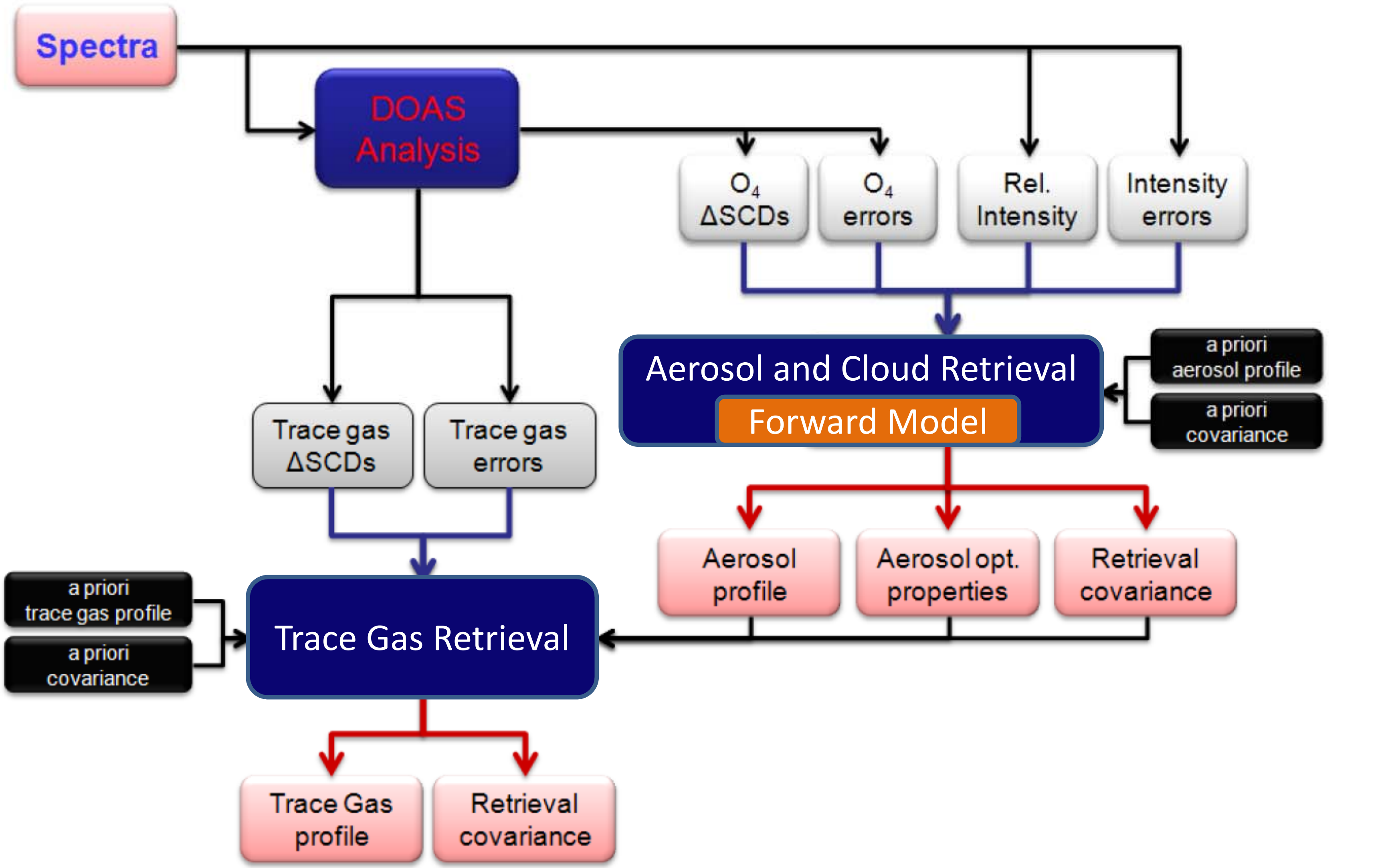


y: relative Intensities at three wavelengths (320, 350, 380nm)

Information gained at different wavelengths are combined with an Angstrom model
→ $\tau(\lambda_1) / \tau(\lambda_2) = (\lambda_1 / \lambda_2)^{-\alpha}$

The retrieved profile agrees well with the true profile
→ The technical implementation and the Jacobians are correct

Retrieval Flow Chart



[Yilmaz, PhD thesis 2012]

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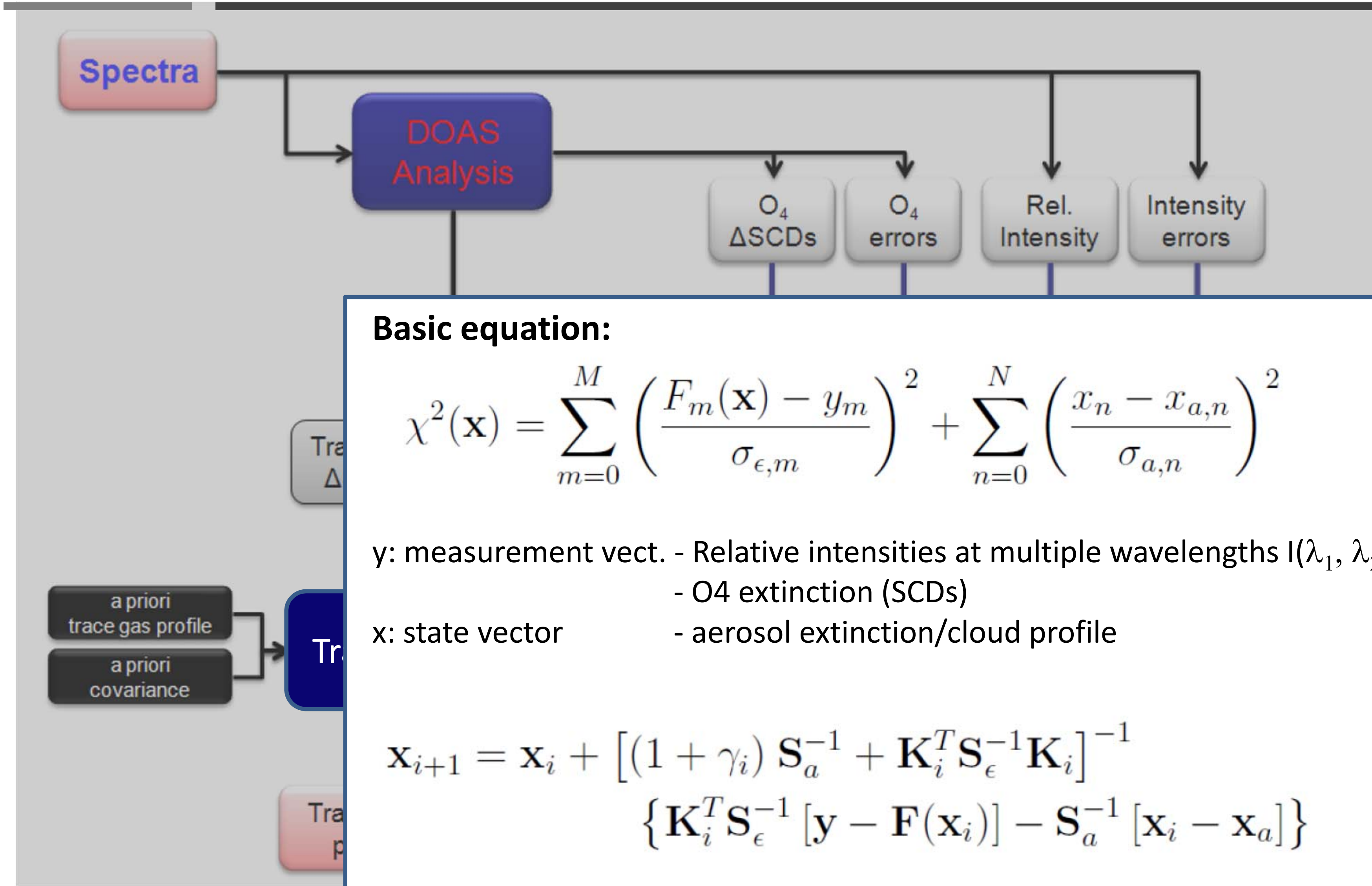

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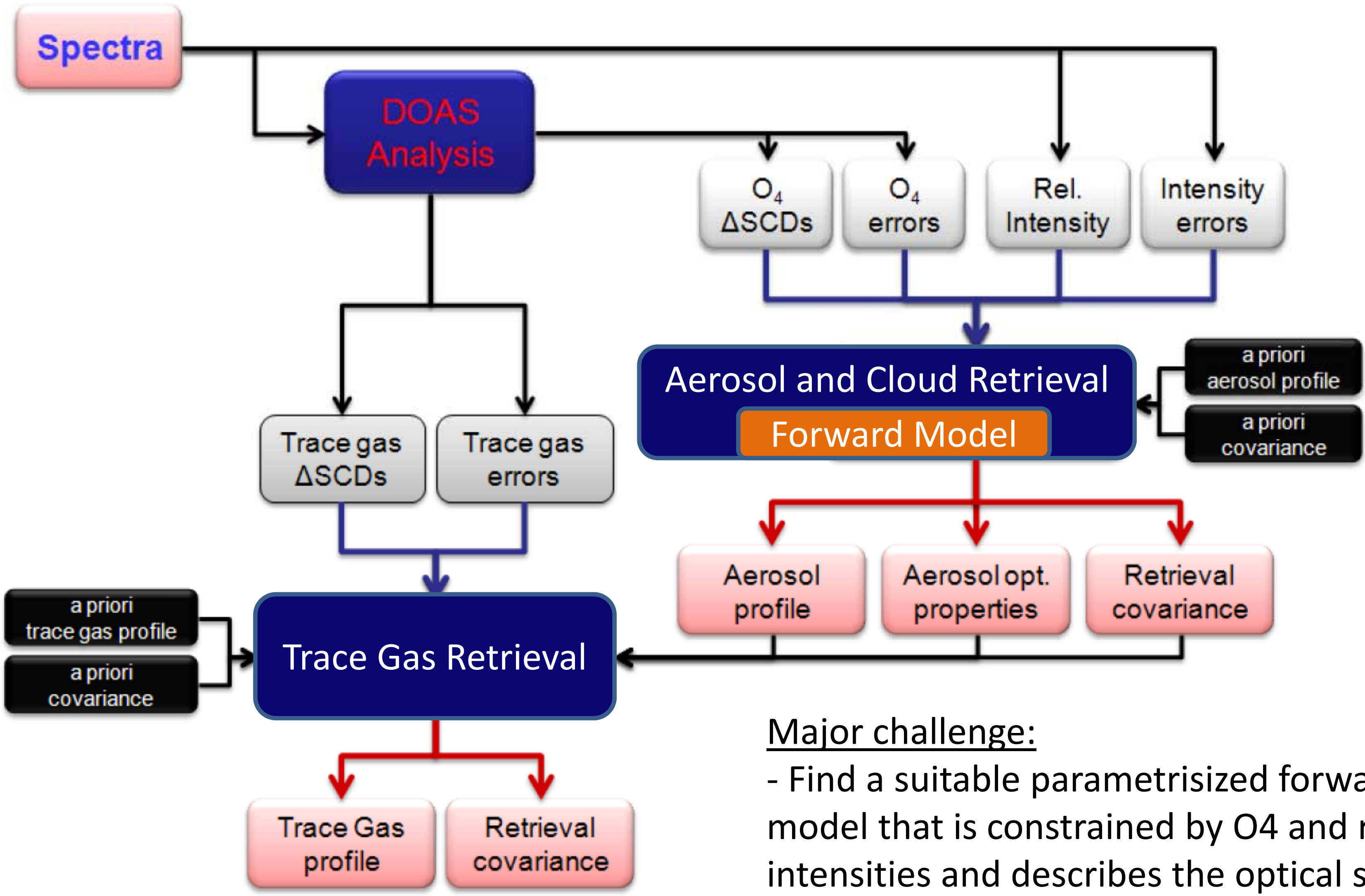

Major challenge:

- Find a suitable parametrisized forward model that is constrained by O4 and relative intensities and describes the optical state of the atmosphere in a sufficient way to invert BrO concentration profiles

[Yilmaz, PhD thesis 2012]