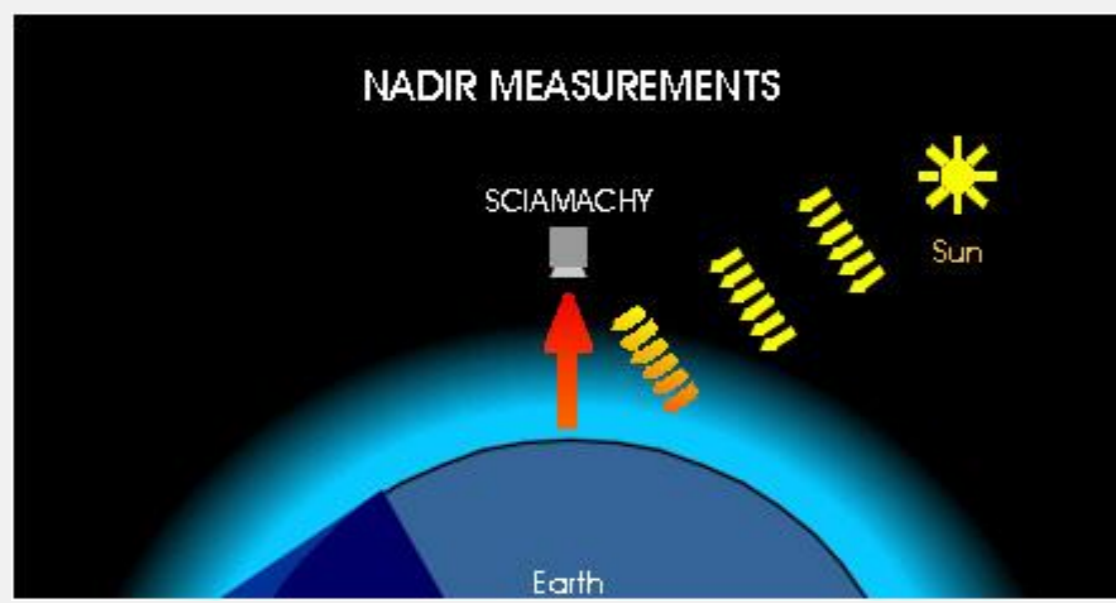
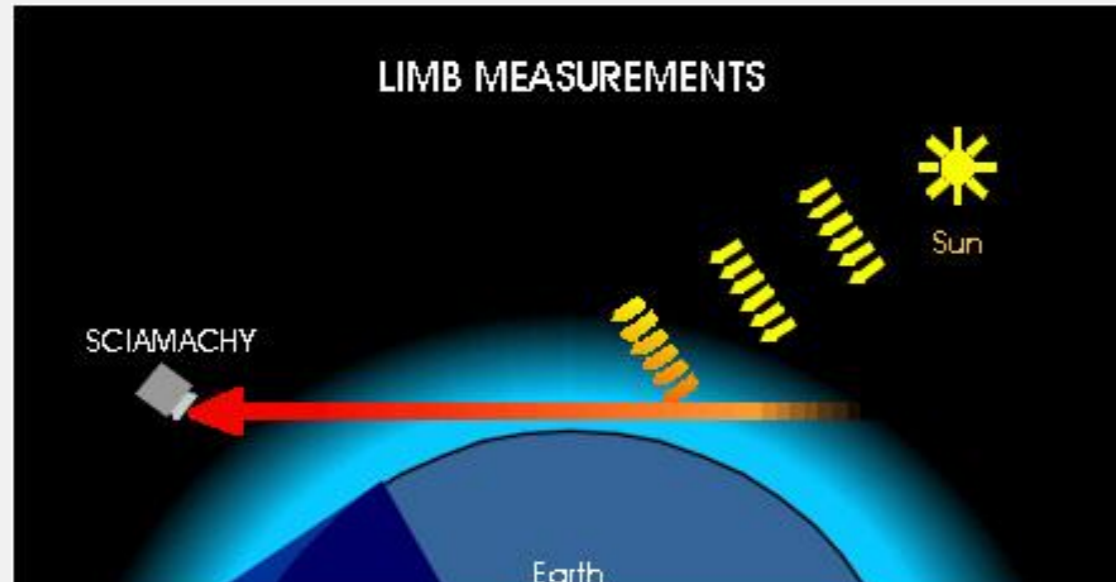


Introduction

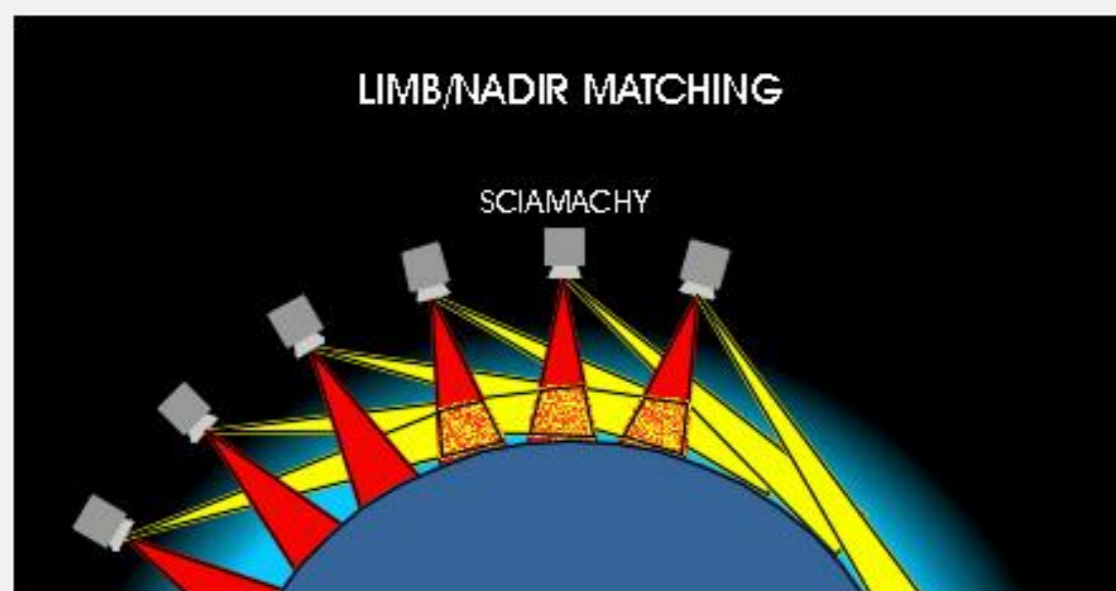
- Spectrometer SCIAMACHY onboard ENVISAT
- Wavelength range: 8 channels ranging from UV/VIS to NIR
- Two main observation geometries:
 - Nadir mode: observing the atmospheric volume directly under the instrument



- Limb mode: the instrument looks at the edge of the atmosphere



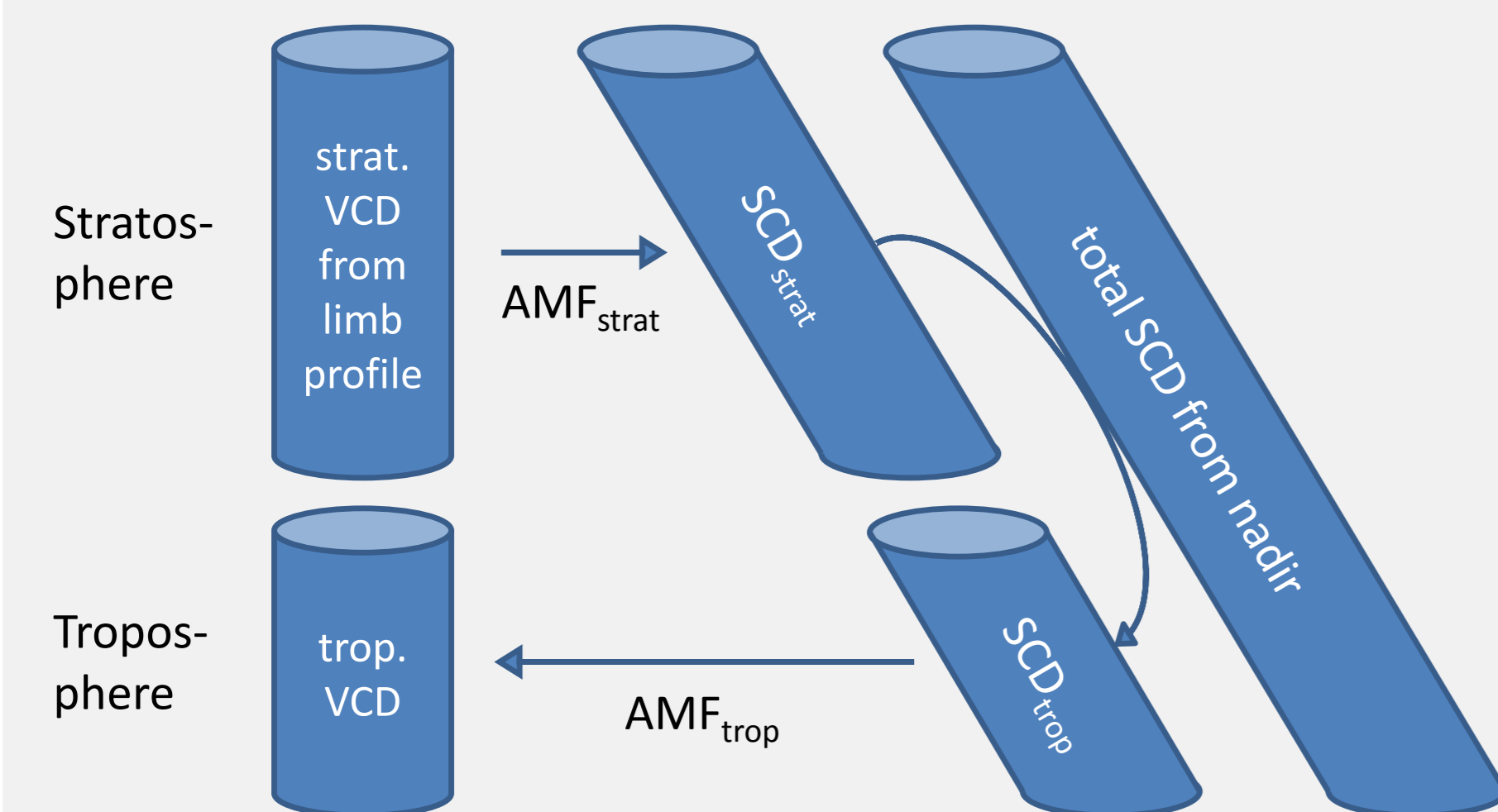
- Limb–nadir matching:
 - the same atmospheric volume is first observed in limb and about 7 minutes later in nadir geometry



- combine these measurements to derive new products
- Operational NO₂ processing:
 - Limb fit window: 420–470 nm
 - Nadir fit window: 427–452 nm

Basic Principle

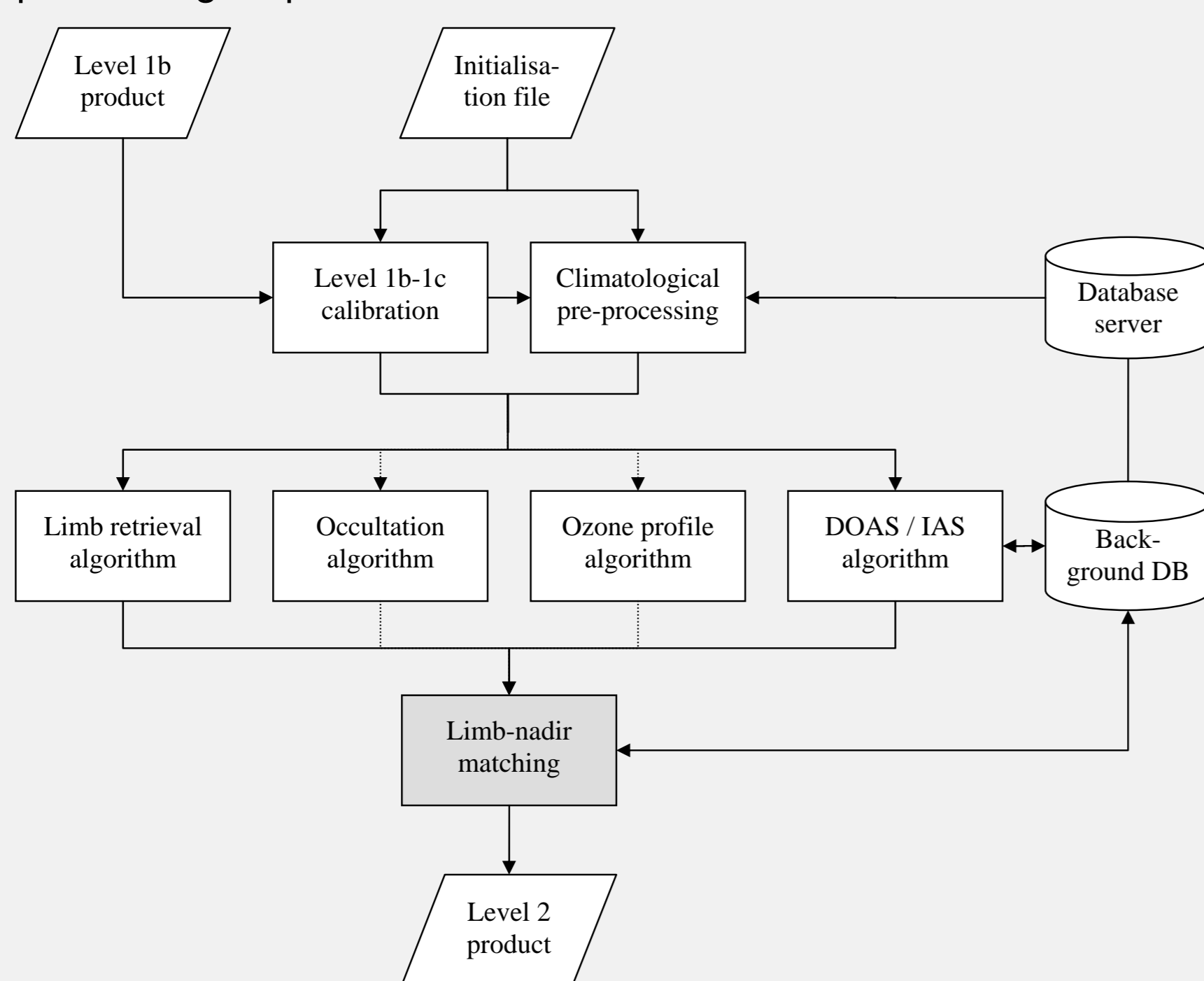
The basic idea of the limb–nadir matching algorithm is to use limb profile data to calculate a stratospheric column, and to subtract this intermediate result from a total column obtained from nadir measurement data.



The above scheme sketches such an approach in a simplified way, which converts vertical column densities (VCD) to slant column densities (SCD) and vice versa by air mass factors (AMF). There are additional processing steps and corrections required to achieve the accuracy of an operational product. We outline them in this presentation, following IUP's reference algorithm [1, 2].

Processor Integration

The limb–nadir matching algorithm needs limb profiles and nadir slant columns of the full orbit as input. Therefore it is implemented as a processing step that starts after the limb and nadir retrievals.



Since the limb–nadir matching does not require any time-critical fitting or radiative transfer calculations, it turned out that the limb–nadir matching algorithm can be implemented as post-processing step that does not need parallel computation.

Algorithm Input/Output

Input

- Limb NO₂
- Nadir NO₂
- Nadir cloud and aerosol
- Limb geolocation
- Nadir geolocation
- State geolocation

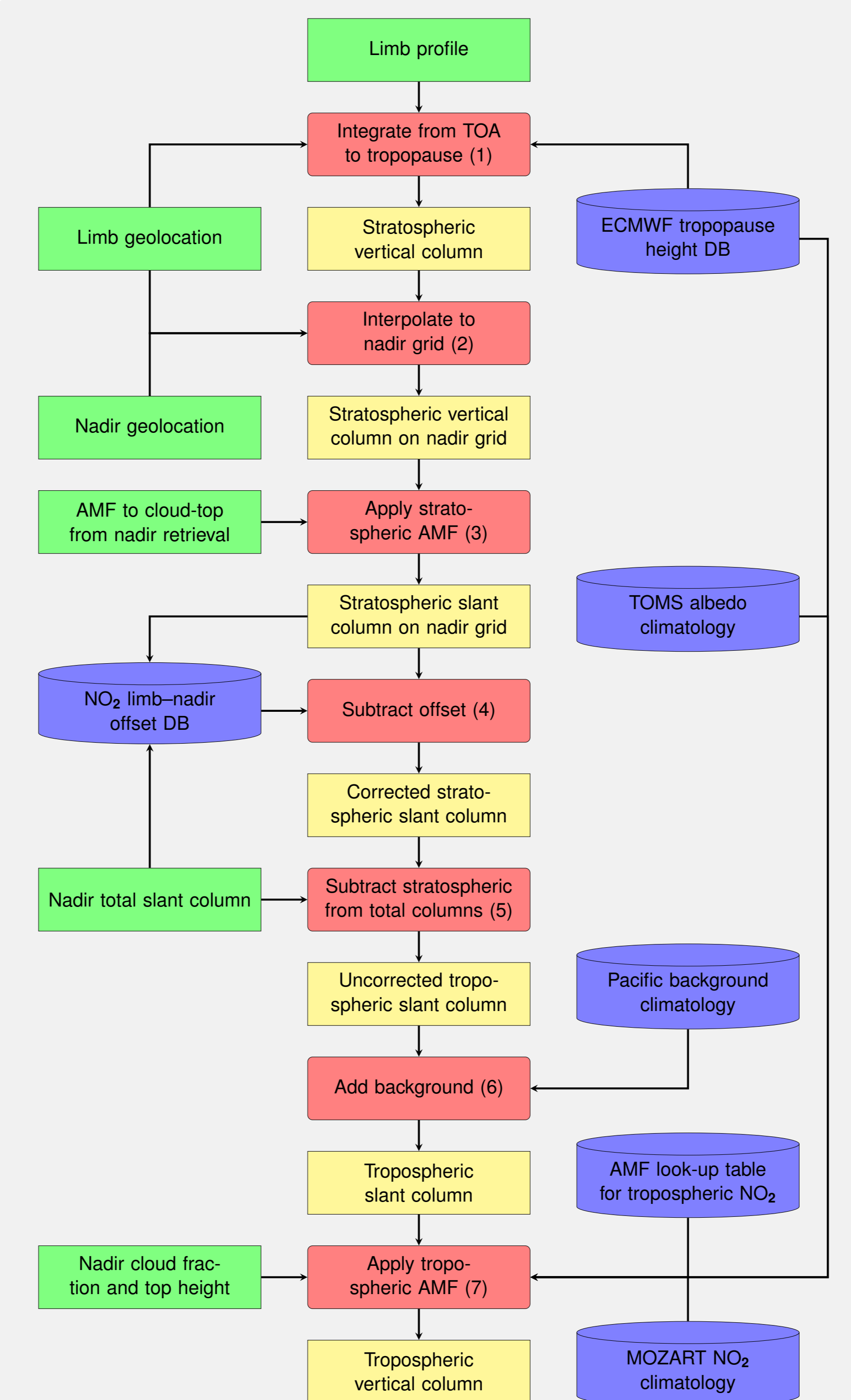
Databases

- ECMWF tropopause height DB
- TOMS albedo climatology
- NO₂ limb–nadir offset DB
- Pacific background climatology
- AMF LUT for tropospheric NO₂
- MOZART NO₂ climatology

Output

- Tropospheric vertical column
- Tropospheric slant column
- Fitting output flag
- Tropospheric AMF to ground
- Tropospheric AMF to cloud top
- Intermediate results

Algorithm Flowchart



Detailed Processing

1. **Integrating limb stratospheric profiles.** Stratospheric slant columns are computed by integration of partial columns from limb profiles.

2. **Interpolating limb stratospheric slant columns to the nadir grid.** As limb profiles are sparse compared to nadir measurements, the limb stratospheric vertical columns need to be interpolated to the positions of the nadir pixels. This is done by associating the limb columns with their four line of sight (LOS) angles, e.g. -25°, -8°, +10°, +27°, and by performing a 2-dimensional interpolation to the nadir geolocations based on their LOS angles and latitudes. Note that only the descending parts of the orbits and forward scans are used.

3. **Applying stratospheric AMF.** AMF_{strat} are computed by the radiative transfer model LIDORT using the climatology of the Halogen Occultation Experiment (HALOE) stratospheric NO₂ profiles. They are applied to convert limb stratospheric vertical columns VC_{strat}^{limb} on the nadir grid into stratospheric slant columns:

$$SC_{strat}^{limb} = VC_{strat}^{limb} \cdot AMF_{strat}$$

4. **Subtracting offset between nadir total slant column and stratospheric slant column on nadir grid.** Experience shows that small but significant offsets exist between the slant columns from limb SC_{strat}^{limb} and nadir slant columns SC_{total}^{nadir} even over clean regions, and that these offsets vary with latitude and season. This is the result of systematic errors in one or both data products. Since the tropospheric column in less polluted regions is very sensitive to the stratospheric correction, these offsets need to be accounted for. In order to do this, a data base of daily difference

$$Offset = SC_{strat}^{limb} (Pacific) - SC_{total}^{nadir} (Pacific)$$

over the Pacific reference sector (180 - 220°E longitude) is computed as a function of latitude (5° bins). This data base is constantly being updated with new values as they become available. In the retrieval, the **Offset** is interpolated to the current latitude and subtracted from the SC_{total}^{limb} , resulting in

$$SC_{strat} = SC_{total}^{limb} - Offset.$$

Detailed Processing (continued)

5. **Subtracting limb stratospheric slant columns from total slant columns.** The tropospheric slant column is computed as the difference between the nadir NO₂ total slant column and the stratospheric slant column:

$$SC_{trop} = SC_{total}^{nadir} - SC_{strat}$$

6. **Adding Pacific background to tropospheric slant column.** Applying the aforementioned offset to the retrieved SC_{trop}^{limb} , it is assumed that there are no significant tropospheric quantities of NO₂ in the reference sector. Therefore SC_{trop} obtained in the previous step must be corrected for the tropospheric NO₂ background levels:

$$SC_{trop}^{corr} = SC_{trop} + SC_{trop}^{model} (month, latitude).$$

Climatological NO₂ data derived from the Oslo chemistry–transport model simulations [3] are used for this purpose as SC_{trop}^{model} .

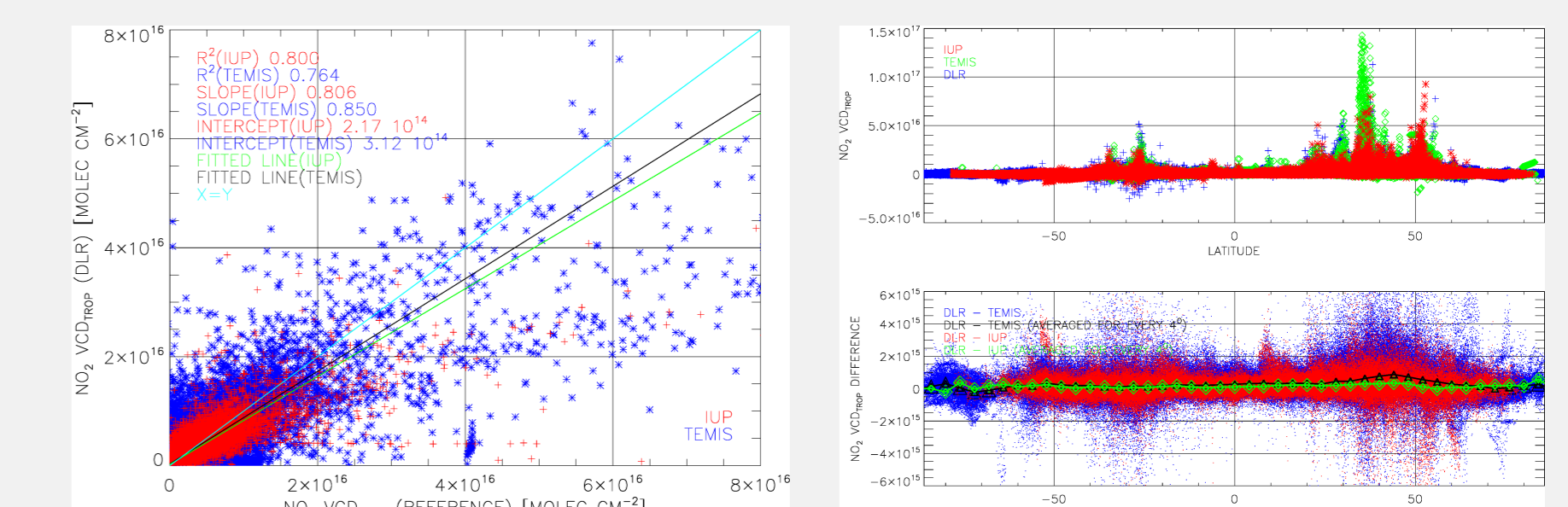
7. **Applying tropospheric AMF.** Tropospheric vertical columns are derived from the tropospheric slant columns by division with the air mass factor

$$VC_{trop} = SC_{trop}^{corr} / AMF_{trop}$$

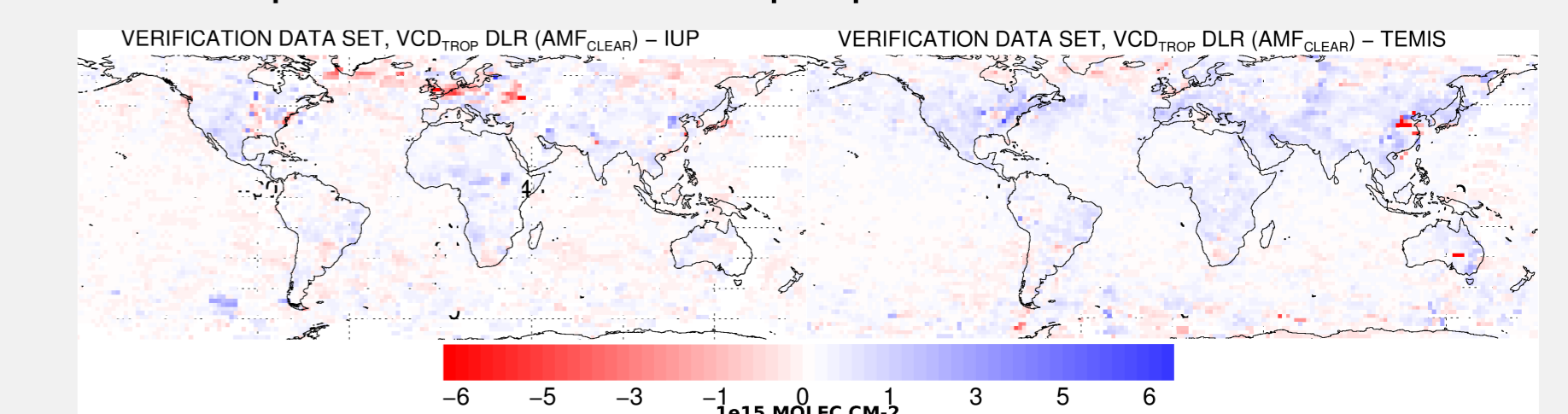
Block AMFs are read from a look-up table used in the operational processing of the GOME-2 data (based on [4]) and depend on five parameters including the viewing geometry. After several interpolation and accumulation operations, taking NO₂ profiles from MOZART climatology into account, AMF_{trop} is calculated from these block AMFs.

Verification Results

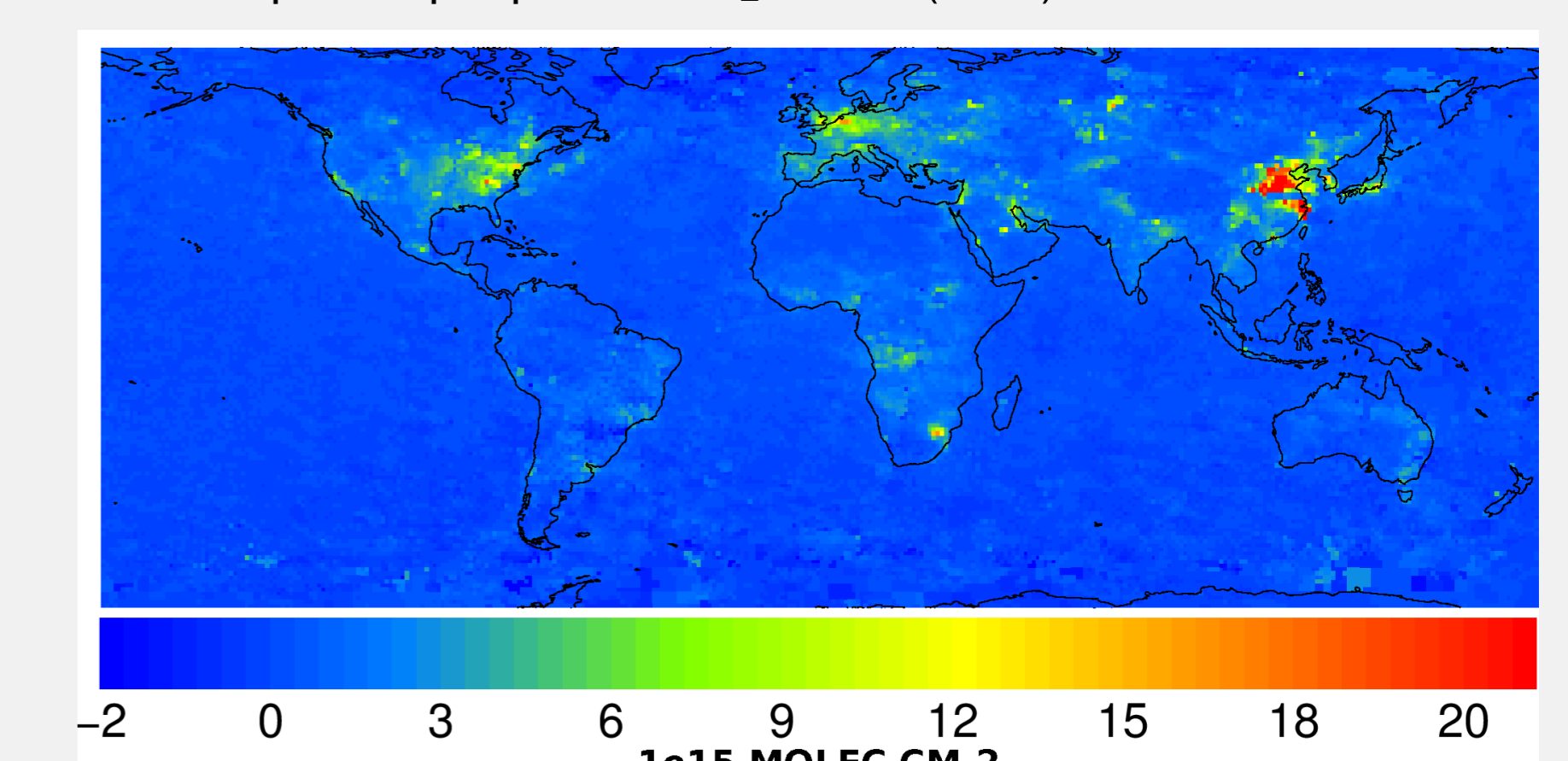
- Verification data set: total of 216 orbits
- Reference data from scientific NO₂ products provided by:
 - IUP (Institute of Environmental Physics, University of Bremen) [1, 2]
 - TEMIS (Tropospheric Emission Monitoring Internet Service) [5]
- Scatterplots of tropospheric NO₂ VCDs



- Global maps of differences in tropospheric NO₂ VCDs



- Global map of tropospheric NO₂ VCDs (DLR)



- Accepted for ESA's operational level 2 processor (version 6) and included in the forthcoming reprocessing campaign

Outlook

- Operational limb–nadir matching is programmed in a generic way
- Suitable for further tropospheric trace gas retrievals (BrO, O₃)

References

- [1] A. Hilboll et al: Retrieval of tropospheric NO₂ columns from SCIAMACHY combining measurements from limb and nadir geometries. *Atmos. Meas. Tech. Discuss.*, **5**, 5043–5105, 2012.
- [2] A. Hilboll et al: Improvements to the retrieval of tropospheric NO₂ from satellite — stratospheric correction using SCIAMACHY limb/nadir matching and comparison to Oslo CTM2 simulations. *Atmos. Meas. Tech.*, **6**, 565–584, 2013.
- [3] O. A. Søvde et al: Evaluation of the chemical transport model Oslo CTM2 with focus on Arctic winter ozone depletion. *J. Geophys. Res.*, **113**, D09304, 2008.
- [4] R. V. Martin et al: An improved retrieval of tropospheric nitrogen dioxide from GOME. *J. Geophys. Res.*, **107**, 4437–4456, 2002.
- [5] K. F. Boersma et al: Error Analysis for Tropospheric NO₂ Retrieval from Space. *J. Geophys. Res.*, **109**, D04311, 2004.

Acknowledgements

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