4. Satellite Validation Principle
Atmospheric Remote Sensing Measurements

• Atmosphere is continuously changing in time and space. => No repeated measurements of the same quantity.

• Radiation field measurements are direct, all other are indirect

• Measurements probe large atmospheric volume => Large averaging and validation by in situ measurements difficult

Courtesy Erkki Kyrola
Atmospheric Satellite Sensors

We launch a satellite sensor for dedicated purposes:

- Meteorology, dynamical tracer, surface UV monitoring;
- Global climatology;
- Montreal and Kyoto Protocol related issues;
- Atmospheric processes: polar chemistry, etc.;
- Tropospheric issues like pollution, biomass burning, oxidizing capacity…;
- Radiative Transfer and Chemical Transport modelling.
Satellite Validation Principles

Ideally,

the observations of atmospheric constituents must not be dependent on:

- the atmospheric temperature;
- the abundance of other species;
- the Sun elevation;
- the presence of clouds;
- the instrument degradation (aging);
- etc…
Satellite Validation Principles

First issue: Remote sensing output is affected by:

- Instrument degradation;
- Calibration uncertainties;
- Errors/assumptions on retrieval model (forward + inverse): radiative transfer codes, spectroscopic databases, atmospheric profile databases, surface albedo, treatment of clouds and aerosols.
Satellite validation principles

Therefore:

- Validation is required to confirm error budgets derived from theoretical and laboratory studies, and identify new error sources.

- Quantitative validation must take into account both satellite and correlative data error sources.
Satellite Validation Principles

Second issue: Remote sensing does not provide a direct measure of the number density, but:

- Earth radiance and solar irradiance measurements
- Horizontal resolution
- Latitude/time sampling
- The [measurement] + [retrieval algorithm] system is characterised by weighting functions determining altitude range, sensitivity, vertical resolution of the retrieved information
Satellite Validation Principles

**Therefore:**

- Validation must characterise the real information content coming from the measurement, including sampling and smoothing aspects, and independency w.r.t. databases and assumptions.

- Satellite and ground-based data give a differently smoothed/sampled/truncated perception of the ozone field.
Satellite Validation Principles

**Third issue**: Atmospheric ozone exhibits

- Spatial structures;
- Temporal variability at a hierarchy of scales;
- Strong correlations with temperature, altitude/pressure, dynamics, etc.
Satellite Validation Principles

Therefore:

- It is not a well mixed, homogeneous, like laboratory sample;
- No linearity;
- Differences in ozone field perception make comparisons and their interpretation difficult.
Satellite Validation Principles

**Conclusion**: Proper validation is highly instrumental driven in:

- Determining if, how and to what extent satellite data can meet the dedicated objectives
- Pointing to defiances in calibration and retrieval algorithms
- Improving data products
Satellite Validation Principles

Validation goes well beyond a simple comparison exercise, in scope and in difficulty; ideally it should combine both qualitative and quantitative correlative studies with information content studies. Scientific/operational purposes must serve as a baseline. A few comparison pairs at a few stations during a limited campaign are by far not sufficient.
GOME GDP 2.7 versus Dobsons (4 years)

However, annual means concluded to an excellent agreement!
T dependence of ozone cross-section

GOME versus Dobsons and Brewers

GOME Ozone VCD versus Northern Dobson stations

GOME Ozone VCD versus Northern Brewer stations

GDP 3.0

GDP 4.0
T dependence of ozone cross-section

TOMS versus Dobsons and Brewers
Solar Zenith Angle dependence

[Solar zenith angle dependence graph with data points and error bars. The graph shows the relationship between GOME v2.0 total ozone and solar zenith angle with respect to SAOZ network observations for the period July - November 1996. There are vertical error bars representing standard deviation (2σ). The graph also includes GDP 1.20 and GDP 2.0, with notes on all latitudes except Antarctica.]
Ozone Profile Validation

Similar problems as with ozone column validation plus:

- Importance of absolute radiometric calibration;
- Polarization aspects (instrument + atmosphere);
- Vertical smoothing issues;
- Retrieved value is a mix of measured information and a priori information (first guess, constraints);
- Geolocation and time mismatches;
- Upper stratosphere: diurnal variation of ozone, …
Collocation

Are we trying to integrate apples and bananas?
What does "collocation" mean?
Error Budget of a Comparison

**Error covariance matrix:**

Five covariance contributions

1. Measurements errors
2. Errors associated with measurement parameters
3. Retrieval parameter errors
4. Vertical smoothing error
5. Horizontal smoothing error (or “collocation” errors)

\[ S = S_M + S_B + S_{SA} + S_{SV} + S_{SH} \]
Error Budget of a Comparison

Dependent on:

– technique,
– constituent,
– atmospheric state (variability, profile shape, temperature, surface …) …
– and intended use!
OZONE Profile Validation
Ozone Profile Validation

Ozone sounding on 27-AUG-1997 10:38:51 (Lat=47.66°; Long=11.51°)

- GOME RAL v20 GD0
- \(O_3\) Sonde Hohenpeißenberg
- Lidar Hohenpeißenberg
- MWR Bern

Altitude [km]

\(O_3\) Number Density [Molec.cm\(^{-2}\)]
Ozone Sondes & Lidar Validation
Ozone LIDAR Validation

![Graph showing Ozone number density against altitude for GOMOS and LIDAR data. The graph includes the mean and median values for the difference between the two measurements. The total number of pairs is 649.]
O3 GOMOS R2 vs LID Mauna Loa JPL (19.5°, -155.6°)

GOMOS

LID

(GOMOS-LID)/LID

Altitude (km)

0 20 40 60

03 04 05 06

O₃ (10¹² mol/cm²)

Relative Difference (%)
O3 GOMOS R2 vs LID Haute Provence CNRS (43.9°, 5.7°)

GOMOS

LID

(GOMOS-LID)/LID

O3 (10^12 mol/cm²)

Relative Difference (%)
O3 GOMOS R2 vs LID Ny-Alesund AWI (78.9°, 11.9°)

(GOMOS-LID)/LID

Altitude (km)

0 20 40 60

04 05 06

O3 (10^12 mol/cm²)

0 2 4 6

Relative Difference (%)
Satellite Validation by Microwave Radiometer SOMARA

- Averaging kernel smoothing has been applied
- Horizontal distance < 800 km from SOMORA in Payerne
- Time difference < 1h between ground and satellite data
- Time intervals of satellites data are quite different
Satellite Validation by Microwave Radiometer

good agreement of all instruments at altitudes < 45 km

SOMORA
MIPAS Ozone Validation

Partial columns (185 - 3 hPa) of O₃ at Lauder

FTIR
MIPAS

PC amount [molec. cm⁻²]

Differences [%]

Jul 02  Oct 02  Jan 03  Apr 03  Jul 03  Oct 03  Jan 04  Apr 04
Temperature Validation
Validation of MIPAS Temperature

Ridolfi et al., ACP (to be submitted)
NO$_2$ Validation

NO$_2$ Diurnal variation
Geophysical Validation of MIPAS NO$_2$

MIPAS OL 4.61 vs. NDACC/UVVIS NO$_2$ column

![Graph showing comparison of MIPAS OL 4.61 and NDACC/UVVIS NO$_2$ column values](image)

Wetzel et al., ACP (to be submitted)
GOME and SCIAMACHY BrO product
GOME & SCIAMACHY BrO Validation

- Ground-based DOAS evaluated at noon for comparison with GOME/SCIAMACHY (daily averages)

- Excellent agreement of GOME and GB DOAS (day-to-day and seasonal variations)

- Good agreement with BIRA-IASB SCIA BrO evaluations
Trend of stratospheric BrO

• Removal of seasonal variation using empirical model
• Long-term variations of stratospheric BrO column controlled by variations in total inorganic bromine (Bry)
• Maximum of bromine load observed in early 2000, consistent with reduction of sources initiated by Montreal Protocol
NDACC FTIR Stations for SCIAMACHY Validation
### NDACC FTIR Stations for SCIAMACHY Validation

<table>
<thead>
<tr>
<th>Station</th>
<th>Lat N</th>
<th>Lon E</th>
<th>Altitude(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ny Alesund</td>
<td>78.91</td>
<td>11.88</td>
<td>20</td>
</tr>
<tr>
<td>Kiruna</td>
<td>67.84</td>
<td>20.41</td>
<td>419</td>
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<tr>
<td>Harestua</td>
<td>60.22</td>
<td>10.75</td>
<td>580</td>
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<tr>
<td>Zugspitze</td>
<td>47.42</td>
<td>10.98</td>
<td>2964</td>
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<tr>
<td>Jungfraujoch</td>
<td>46.55</td>
<td>7.98</td>
<td>3580</td>
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<tr>
<td>Egbert</td>
<td>44.23</td>
<td>−79.78</td>
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<td>Toronto</td>
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<td>Izaña</td>
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<td>Wollongong</td>
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<td>30</td>
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<tr>
<td>Lauder</td>
<td>−45.05</td>
<td>169.68</td>
<td>370</td>
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<tr>
<td>Arrival heights</td>
<td>−77.85</td>
<td>166.78</td>
<td>190</td>
</tr>
</tbody>
</table>
MIPAS HNO$_3$ FTIR Validation
MIPAS HNO₃ Validation

Partial columns (145-15 hPa) of HNO₃ at Jungfraujoch

PC amount [molec. cm⁻²]

- FTIR
- MIPAS < 1000 km
- MIPAS < 400 km
- BASCOE

Differences [%]

Jan 03  Apr 03  Jul 03  Oct 03  Jan 04

MIPAS $\text{N}_2\text{O}$ FTIR Validation
NDACC FTIR Time Series

Trend: significantly positive, in agreement with the surface trend of 
+\((0.25 \pm 0.05) \%/\text{yr}\) reported in IPCC 2003 based on in-situ observations
MIPAS N$_2$O FTIR Validation

Partial columns (182-24 hPa) of N$_2$O at Kiruna

- FTIR
- MIPAS < 1000 km
- MIPAS < 400 km
- BASCOE

PC amount [molec. cm$^{-2}$]

Differences [%]

Date:
- Jan 03
- Apr 03
- Jul 03
- Oct 03
- Jan 04
MIPAS N$_2$O FTIR Validation

[Graph showing N$_2$O at Kiruna with various lines indicating differences and errors between MIPAS and FTIR measurements.]
MIPAS CH$_4$ FTIR Validation
MIPAS CH$_4$ FTIR Validation

Partial columns (224 - 6 hPa) of CH$_4$ at Jungfraujoch

PC amount [molec. cm$^{-2}$]

Differences [%]

Date

Jul 02 Oct 02 Jan 03 Apr 03 Jul 03 Oct 03 Jan 04 Apr 04
MIPAS CH$_4$ FTIR Validation

Partial columns (222-12 hPa) of CH$_4$ at Ny-Alesund

PC amount [molec. cm$^2$]

Date

FTIR
MIPAS

Differences [%]