Mid Term Review, Eumetsat, 9 August 2007

‘The added value of satellite observations of aerosol optical depth for operational air quality forecasts”

Synthetic AOD observations
Richard Siddans, RAL
Overview

• Input data
• Instrument definitions
• Retrieval simulation method
• Treatment of errors
• Example results
• Special cases
  – Broken cloud
  – Cirrus
• Status
Input data

• Model aerosol fields delivered
  – 0.5 hour time sampling
  – Two periods
    • 15 July – 15 August 2003
    • 15 Feb - 15 March 2003
  – Two regions
    • Europe at 0.125 x 0.25° latitude/longitude grid.
    • Paris at 0.027 x 0.04°
• MVIRI data is used to define a cloud mask at full MVIRI resolution (2.5km sub-satellite point)
  – (based on vis channel reflectances)
Method

- **Instruments:**
  - imager with 2.5 km spatial resolution at sub-sat point
  - A-band spectrometer with 1cm\(^{-1}\) spectral and 6km spatial resolution.
- The same throughput (as in “O\(_2\) A-band” study) is assumed for both instruments.
- For European domain, model resolution < sensor spatial resolution:
  - 1 retrieval simulated per model box assuming that all cloud free radiances are averaged.
- For Paris domain, model resolution > sensor resolution
  - Field is averaged to sensor resolution and values reported on a sub-sampled spatial grid.
- Only scenes with solar zenith angle < 80° considered.
**O₂ A-band**

- O₂ A-band contains optically thick molecular absorption lines
  - Effective scattering altitude of photons (viewed in nadir) varies with wavelength
  - O₂ mixing ratio known therefore measurements can be used to infer scattering profile.

- Amount of information depends critically on spectral resolution but also on random and systematic instrumental and forward model errors
**Retrieval set-up**

- For both instruments…
- Retrieve 5 layer AODs 0-0.025, 0.025-0.5, 0.5-1.5, 1.5-3.5, 3.5-5.5 km.
- In addition, surface albedo is retrieved in each grid box.
- To constrain problem, we assume
  - A priori covariance of profile (derived from model fields)
  - A priori knowledge on surface albedo of 0.01
- For imager this limits AOD accuracy
  - *a priori* value = 0.01 and 0.3 for sea and land, resp.
- Bottom 3 layers co-added in output so final layers are
  - 0-1.5, 1.5-3.5, 3.5-5.5 km
- Perfect knowledge of aerosol type (*sing.scat.alb.*, *phase fn*) is assumed
Profile covariance

- *a priori* profile = mean model AODs.
- covariance calculated over the whole month and all grid boxes of the model layer-AODs.
  - Strong vertical correlation constrains retrieval
  - For imager covariance is scaled by large factor to avoid bias towards a priori seen in previous study.
Linear retrievals

- All retrievals performed linearly
  \[ x_{\text{ret}} = x_{\text{apr}} + A(x_{\text{true}} - x_{\text{apr}}) \]
- Averaging kernels, A are calculated for
  - albedos of 0.01 and 0.3
  - 10° intervals of solar zenith, LOS zenith & rel. azimuth
- A is interpolated to the actual viewing geometry
- Errors are estimated using interpolated covariances for
  - measurement noise
  - temperature profile error assuming ECMWF+IASI
- A random error which is consistent with noise + temperature error covariance is added to retrieved profile
- Error due to imperfect surface reflectance knowledge modelled using MODIS data
- AODs + covariance delivered to TNO
Simulating errors in surface reflectance

- MODIS albedo product given every 16 days
- Have taken data for August/Sept 2004
- Assume true case is linear interpolation in time between the 3 fields covering 1 month while retrieval assumes albedo = mean of 3 fields spanning the month
- Error due to difference between retrieval assumption and true obtained by "linear mapping" ($\Delta x = G \Delta y$)
Example retrievals

• Results for 11 August (no temperature error)
Example retrievals

• Results for 11 August (with temperature error)
Dependence of estimated errors on time of day
Dependence of estimated errors on time of day

- Imager errors dominated by uncertainty on surface reflectance
- Leads to strong time dependence in errors
  - Light path through aerosol shorter at noon than sun-rise/sun-set
  - Phase function smaller (except direct back-scatter)
  - Surface contribution larger
    - NB cos solar zenith for lambertian + shadows
- A-band sounder errors dominated by Temperature errors (effect on modelling line-shape), which is time-of-day independent
Smoke/Pollen event
4-9 am 9 May 2006

Further consideration of specified surface reflectance error

- Eumetsat (Wagner, Govaerts) state-of-art retrieval scheme for SEVIRI recovers BRDF + aerosol together
- In doing so, uses RPV surface model:

\[
\tilde{\rho}_{sfc}(z_0, \Omega_0 \rightarrow \Omega; \rho_c, \Theta, k) = M_I(\theta_0, \theta; k) F_{HG}(g; \Theta_{HG}) H(\rho_c; G)
\]

- Typical minimum estimated error for the other derived parameters are:
  - \( \rho_0 : 0.01 \)
  - \( k : 0.05 \)
  - \( \Theta_{HG} : 0.05 \)

(Govaerts pri.comm.)
Dependence of estimated errors on time of day

Desert

Dark vegetated

Lambertian
Broken cloud case

- To demonstrate more clearly the potential benefit of high spatial resolution attainable by the imager, the winter period over Paris is simulated with a "broken" cloud field.

- This is defined by:
  - start with basic MVIRI cloud mask
  - 3 days with broken cloud during the period selected
  - "holes" in cloud cover from the broken cloud days are added to the basic mask
  - 15-24 Feb: add holes from 16 Feb
  - 25 Feb - 6 March: add holes from 3 March
  - 7 March-15 March: add holes from 12 March
Broken cloud cases
16 Feb, 3 March, 12 March
Cirrus case

- Additional error which would affect imager retrieval more than A-band is unmodelled high cloud which is not flagged prior to the retrieval
  - Imager would place erroneous AOD in boundary layer
  - A-band would place erroneous AOD at high altitude and so not contaminate boundary AOD.
- Planned to simulate effect of undiagnosed cirrus as follows
  - Cirrus location defined by taking cloud mask for 2 hours before nominal time (cirrus in advance of low cloud)
  - Assume cirrus has AOD 0.02
  - Linearly map effect onto retrievals
  - Ultimately this case was not simulated.
- Higher priority to focus on existing cases
Summary

- Main errors for imager are due to uncertainty in modelling surface reflectance
  – leads to strong diurnal variation in estimated errors
- Main error for sounder is uncertainty in temperature profile (+ instrument noise).
- Main benefits of sounder may be quality of aerosol product throughout the day, in addition to height resolved capability...
## Derived requirements

<table>
<thead>
<tr>
<th>Error</th>
<th>0.1000</th>
<th>0.5000</th>
<th>1.000</th>
<th>5.00</th>
<th>10.0</th>
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<tbody>
<tr>
<td><strong>Resolution / cm⁻¹</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Signal:Noise</strong></td>
<td>0.0122</td>
<td>0.0211</td>
<td>0.0295</td>
<td>0.125</td>
<td>0.251</td>
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<tr>
<td>Geo:case</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
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<tr>
<td><strong>Worst case</strong></td>
<td>206 (596)</td>
<td>797 (1330)</td>
<td>1570 (1880)</td>
<td>14800 (4180)</td>
<td>41600 (5850)</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>0.00434</td>
<td>0.00459</td>
<td>0.00763</td>
<td>0.0274</td>
<td>0.0498</td>
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<tr>
<td><strong>Worst case</strong></td>
<td>89.5 (729)</td>
<td>211 (1630)</td>
<td>498 (2300)</td>
<td>3960 (5120)</td>
<td>10100 (7160)</td>
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<tr>
<td><strong>Temperature</strong></td>
<td>0.00279</td>
<td>0.00296</td>
<td>0.00277</td>
<td>0.00279</td>
<td>0.00465</td>
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<tr>
<td>ECMWF+IASI</td>
<td>AMa 7.11</td>
<td>AMa 7.11</td>
<td>LMa 7.10</td>
<td>LMa 7.10</td>
<td>AJa 7.12</td>
</tr>
<tr>
<td><strong>Best case</strong></td>
<td>12.7</td>
<td>11.9</td>
<td>14.9</td>
<td>12.7</td>
<td>7.60</td>
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<td><strong>Wav.cal.error</strong></td>
<td>19.2</td>
<td>10.6</td>
<td>12.3</td>
<td>7.33</td>
<td>23.4</td>
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<tr>
<td>1 cm⁻¹</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
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<tr>
<td><strong>Worst case</strong></td>
<td>0.00184</td>
<td>0.00334</td>
<td>0.00288</td>
<td>0.00482</td>
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<tr>
<td><strong>Wav.cal.error</strong></td>
<td>5.33</td>
<td>2.97</td>
<td>1.94</td>
<td>1.88</td>
<td>4.95</td>
</tr>
<tr>
<td>1 cm⁻¹</td>
<td>AJa 7.15</td>
<td>AJa 7.15</td>
<td>AJa 7.15</td>
<td>AJa 7.15</td>
<td>AJa 7.15</td>
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<tr>
<td><strong>Best case</strong></td>
<td>0.00663</td>
<td>0.0119</td>
<td>0.0182</td>
<td>0.0188</td>
<td>0.00714</td>
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<tr>
<td><strong>ILS width</strong></td>
<td>1.25</td>
<td>2.09</td>
<td>3.61</td>
<td>117</td>
<td>33.0</td>
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<td>fractional</td>
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<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
<td>Alm 7.15</td>
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<tr>
<td><strong>Worst case</strong></td>
<td>0.0282</td>
<td>0.0169</td>
<td>0.00411</td>
<td>3.01 × 10⁻⁴</td>
<td>0.00107</td>
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<tr>
<td><strong>ILS width</strong></td>
<td>0.352</td>
<td>0.903</td>
<td>1.14</td>
<td>38.5</td>
<td>7.30</td>
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<tr>
<td><strong>Best case</strong></td>
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<td>0.0392</td>
<td>0.0311</td>
<td>9.18 × 10⁻⁴</td>
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<td><strong>Offset</strong></td>
<td>0.110</td>
<td>0.0966</td>
<td>0.235</td>
<td>0.560</td>
<td>1.53</td>
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<tr>
<td>10⁻⁶ W/cm²/cm⁻¹/σr</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
</tr>
<tr>
<td><strong>Worst case</strong></td>
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<td>0.366</td>
<td>0.151</td>
<td>0.0631</td>
<td>0.0231</td>
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<td><strong>Offset</strong></td>
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<td>0.00573</td>
<td>0.0262</td>
<td>0.0385</td>
<td>0.405</td>
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<tr>
<td>10⁻⁶ W/cm²/cm⁻¹/σr</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
<td>AJa 7.12</td>
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<tr>
<td><strong>Best case</strong></td>
<td>1.63</td>
<td>6.17</td>
<td>1.35</td>
<td>0.919</td>
<td>0.0873</td>
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