GRASP: A versatile algorithm for characterizing the atmosphere

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GRASP: Generalized Retrieval of Aerosol and Surface Properties
Current GRASP activities:

1. Satellite applications:
   - multi-viewing polarimeters: PARASOL
   - polar orbiting imagers: MERIS, AATSR, MISR (?), etc.;
   - geostationary imagers: GOCI/COMS, Sentinel-4, FCI.;
   - space borne lidars: CALIPSO (?)

2. Ground-based and airborne applications:
   - AERONET, lidar, lidar + AERONET;
   - spectral AOD, luna-photometer
Diverse applications of GRASP

- Nephelometer
- Sun-photometer
- Lidar
- AERONET PARASOL

Instrument design

Aerosol $\tau(\lambda, h)$, $\omega_0(\lambda, h), P(\lambda, \theta, h)$

vertical profiles

All modules are fully consistent !!!
General structure of the algorithm

**FORWARD MODEL**
Simulates observations $f(a^p)$ for a given set of parameters $a^p$

**NUMERICAL INVERSION**
Stat. optimized fitting of $f^*$ by $f(a^p)$ under *a priori* constraints

- **Input:** Observations $f^*$
- **Retrieved parameters:**
  - $a^p$ – describes optical properties of aerosol and surface
- **Observation definition:**
  - Viewing geometry, spectral characteristics; coordinates, etc
- **Inversion settings:**
  - description of error $\Delta f^*$; *a priori* constraints

**INDEPENDENT MODULES !!!**

$ap \rightarrow f(a^p) \rightarrow f^*$

$ap \rightarrow f(a^p) \rightarrow f^*$
Forward Model

Vector of retrieved parameters:
- \( a_{aer} \) - aerosol properties
- \( a_{surf} \) - surface properties

Aerosol single scattering
\( \tau(\lambda, h), \omega(\lambda, h), P(\lambda, \Theta, h) \)

Surface reflectance
BRDF, BPDF

Radiative Transfer:
\( F(\lambda, \Theta, \phi) \)

Simulated observations:
In situ, laboratory
PARASOL: the space–borne instrument most suitable for enhanced aerosol/surface characterization

PARASOL daily coverage image, March 3, 2013

**INTEF**

3 March 2013

Version: 02.04  Created: 20130304

**for aerosol:**

- (0.44, 0.49, 0.56, 0.67, 0.865, 1.02 μm) for gas absorption:
- (0.763, 0.765, 0.910 μm)

**POLARIZATION (Q, U):**

- (0.49, 0.67, 0.865 μm)

**Swath:** about 1600 km cross-track

**Global coverage:** every 2 days

**1 pixel spatial resolution:** 5.3km × 6.2km

**Viewing directions:** 16° (80° – 180°)
“independent” POLDER/PARASOL measurements:

GLOBAL: every 2 days  SPATIAL RESOLUTION: 5.3km × 6.2km

VIEWS: \( N_\Theta = 16 \ (80^0 \leq \Theta \leq 180^0) \)

INTENSITY: \( N_\lambda^t = 6 \ (0.44, 0.49, 0.56, 0.67, 0.865, 1.02 \mu m) \)

POLARIZATION: \( N_\lambda^P = 3 \ (0.49, 0.67, 0.865 \mu m) \)

SINGLE OBSERVATION:
\[
(N_\lambda^t + N_\lambda^P) \times N_\Theta = (6 + 3) \times 16 = 144
\]
a lot !!! – as much as AERONET
AERONET retrievals are driven by 31 variables:

- $dV/d\ln r$ - size distribution (22 values)
- $n(\lambda)$ and $k(\lambda)$ - ref. index (4 values)
- $C_{\text{spher}}$ (%) - spherical fraction (1 value)

**Particle Size Distribution:**

$0.05 \, \mu m \leq R (22 \text{ bins}) \leq 15 \, \mu m$

**Complex Refractive Index at**

$\lambda = 0.44; 0.67; 0.87; 1.02 \, \mu m$

**Maritime**

**Smoke**

**Desert Dust**
Aerosol representation in the algorithm:

**Trapezium Approximation**

\[
V_{\text{total}}(r) = \sum_{i=1,...,5} a_i V_i(r)
\]

**Approximation by Log-Normals**

\[
V_{\text{total}}(r) = \sum_{i=1,...,5} a_i V_i(r)
\]

*Log-normal:*

\[
\frac{dV(r)}{d \ln r} = \sum_{i=1,...,N} C_i e^{-\frac{(\ln r - \ln r_i)^2}{2\sigma_i^2}}
\]

- Size distribution is multi-component
- Each component may have same or different \(n(\lambda)\) and \(k(\lambda)\)

Twomey 1977

for **detailed** description of size distribution

for **moderately detailed** description of size distribution

for **bi-modal** size distribution

\(C_i, r_i, \sigma_i\) – retrieved
**Concept of internal mixing of the aerosol components:**

**Host media:** Water + Soluble

*Soluble - Ammonium Nitrate with the properties depending on Relative Humidity (RH)*

**Insoluble Inclusions:**
- Black Carbon
- Iron
- Other insoluble components ("quartz")

**Maxwell Garnett’s Effective Medium Approximation:**

describes the macroscopic properties of a medium based on the properties and the relative fractions of its components

**Schuster et al. 2005, 2009**
AERONET model of aerosol

Dubovik et al., 2006

spherical:

Randomly oriented spheroids:
(Mishchenko et al., 1997)
Mixing of particle shapes

\[ \tau(\lambda) = C \int_{r_{\text{min}}}^{r_{\text{max}}} K_{\tau}^{\text{spherical}}(k; n; r)V(r)dr + (1-C) \int_{r_{\text{min}}}^{r_{\text{max}}} \int_{\varepsilon_{\text{min}}}^{\varepsilon_{\text{max}}} K_{\tau}^{\varepsilon}(k; n; r, \varepsilon)N(\varepsilon)d\varepsilon V(r)dr \]

**ASSUMPTIONS:**
- \(dV/d\ln r\) - volume size distribution is the same for both components;
- **non-spherical** - mixture of randomly oriented polydisperse spheroids;
- aspect ratio distribution \(N(\varepsilon)\) is fixed to the retrieved by Dubovik et al. 2006
Surface Reflectance

**BRDF**
1. **Rahman-Pinty-Verstraete** (RPV) model (Rahman et al., 1993)
   \[ \rho_{sfc}(\theta_1, \varphi_1; \theta_2, \varphi_2) = \rho_0 M_i(k) F_{HG}(\Theta) H(h) \]
2. **Li – Ross** model (MODIS, etc) (Ross, 1981; Li, X., Strahler, 1992)

**BPDF**
1. **Maignan et al., (2009)**
   \[ R_{p}^{\text{surf}}(\theta_s, \theta_v, \varphi_r) = \frac{B \exp(-\tan(\alpha_i)) \exp(-v)}{4(\mu_0 + \mu_i)} F_{\gamma}(\gamma) \] (B - empirical parameter)
2. **Nadal and Bréon, (1999)**
3. **Fresnel facet model for Gaussian surfaces** (Litvinov et al., 2011)

**BRDF + BPDF**
1. **Cox-Munk model** (ocean surface)
2. **Physical models for land surface reflection matrix** (Litvinov et al., 2012)
Single - Pixel Retrieval:

\[ f_j^* - \text {PARASOL data:} \]

- Angular measurements (~15 angles) of
  - Intensity \( (\lambda = 0.49; 0.67; 0.87; 1.02 \mu m) \)
  - Polarization \( (\lambda = 0.49; 0.67; 0.87 \mu m) \)

\[ a_j - \text {Parameters to be retrieved:} \]

- Aerosol properties:
  - size distribution; - real refractive index
  - imaginary refractive index; - particle shape, - height
- Surface properties (over land):
  - BRF parameters; - BPRF parameters

\[ \begin{bmatrix} f_j^* \\ 0_j^* \end{bmatrix} = \begin{pmatrix} F_j & D_j \end{pmatrix} a_j + \begin{pmatrix} \Delta^m_j \\ \Delta^a_j \end{pmatrix} \]

A Priori Constraints limiting derivatives (e.g. Dubovik 2004) of
- for aerosols (e.g. in AERONET, Dubovik and King 2000):
  - aerosol size distribution variability over size range;
  - spectral variability of complex refractive index;
- for surface (e.g. in AERONET/satellite retrievals, Sinuyk et al. 2007):
  - spectral variability of BRF/ PBRF parameters.

Multi-term LSM statistically optimized Solution (Dubovik and King 2000, Dubovik 2004):

\[ a_j = \left( F_j^T W_j^{-1} F_j + \gamma_j \Omega_j \right)^{-1} \left( F_j^T W_j^{-1} f_j^* \right) \]

, where \( \Omega_j = D_j^T D_j; W_j = \frac{1}{\varepsilon_f^2} c_f; \gamma_j = \frac{\varepsilon_f^2}{\varepsilon_a^2} \)
Aerosol/Surface. Difference in angular dependences

Surface contribution dominates, i.e. aerosol retrieval is very challenging

Litvinov et al.
The concept of multi-pixel retrieval

POLDER/PARASOL

Time-variability Constraints

Y-variability Constraints

X-variability Constraints

Multi-days observations

(t_3; x; y)

(t_2; x; y)

(t_1; x; y)
\[ f_1^* = F_1 a + \Delta_1 \]
\[ f_2^* = F_2 a + \Delta_2 \]

Independent !!!

\( a = (F^T C_1^{-1} F_1 + F^T C_2^{-1} F_2 + \ldots)^{-1}(F^T C_1^{-1} f_1^* + F^T C_2^{-1} f_2^* + \ldots) \)

Kalman Filter, “Optimal Estimation” by Rodgers, etc.

\[ a = (F^T C_f^{-1} F + C_a^{-1})^{-1}(F^T C_f^{-1} f^* + C_a^{-1} a^*) \]

Phillips – Tikhonov – Twomey
Constrained Inversion

Multi-Term LSM
(e.g. see Dubovik and King 2000, Dubovik 2004, Dubovik et al. 2011)
Multi-Pixel Retrieval:

\[
\begin{pmatrix}
\begin{bmatrix} f_1^* \\ O_1^* \\ f_2^* \\ O_2^* \\ f_3^* \\ O_3^* \\ \vdots 
\end{bmatrix}
& =
\begin{bmatrix} F_1 & 0 & 0 \\ D_1 & 0 & 0 \\ 0 & F_2 & 0 \\ 0 & D_2 & 0 \\ 0 & 0 & F_3 \\ 0 & 0 & D_3 \\
\end{bmatrix}
\begin{bmatrix} a_1 \\ a_2 \\ a_3 
\end{bmatrix}
+ 
\begin{bmatrix} \Delta_1^q \\ \Delta_1^a \\ \Delta_2^q \\ \Delta_2^a \\ \Delta_3^q \\ \Delta_3^a 
\end{bmatrix}
\end{pmatrix}
\]

**Single-Pixel Data** (PARASOL measurements and physical a priori constraints) are used by the same way as in Single-Pixel retrieval.

**Multi-Pixel a priori constraints** (e.g. Dubovik et al. 2008):
- limited **spatial** variability of each aerosol/surface parameter
- limited **temporal** variability of each aerosol/surface parameter

**NOTE:** degree of variability constraints (smoothness) can be different and adequately chosen for each parameter

---

**Multi-term LSM Multi-Pixel Solution:**

\[
\begin{bmatrix}
\begin{bmatrix} f_1^* \\ O_1^* \\ f_2^* \\ O_2^* \\ f_3^* \\ O_3^* \\ \vdots 
\end{bmatrix}
& =
\begin{bmatrix} F_1 & 0 & 0 \\ D_1 & 0 & 0 \\ 0 & F_2 & 0 \\ 0 & D_2 & 0 \\ 0 & 0 & F_3 \\ 0 & 0 & D_3 \\
\end{bmatrix}
\begin{bmatrix} a_1 \\ a_2 \\ a_3 
\end{bmatrix}
+ 
\begin{bmatrix} \Delta_1^q \\ \Delta_1^a \\ \Delta_2^q \\ \Delta_2^a \\ \Delta_3^q \\ \Delta_3^a 
\end{bmatrix}
\end{pmatrix}
\]

, where

\[\Omega_x = D_x^T D_x; \quad \Omega_y = D_y^T D_y; \quad \Omega_t = D_t^T D_t; \quad \gamma_x = \frac{\varepsilon_f}{\varepsilon_x^2}; \quad \gamma_y = \frac{\varepsilon_f}{\varepsilon_y^2}; \quad \gamma_t = \frac{\varepsilon_f}{\varepsilon_t^2}\]
GRASP objectives:
Accurate, Versatile, Fast and Attractive for users.

- Inversion scheme:
  - search in continues space of solution;
  - optimization as Multi-term LSM;
  - adapted for synergy of observations: multi-pixel retrieval;

- Forward model:
  - applicable to diverse remote sensing observations;
  - very accurate: direct “on-line” computations;

- Software implementation:
  - advance programing: highly parallelized, using GPU;
  - easy accessible: open source aerosol retrieval code;
GRASP – user adapted library of routines

- Original system: Input files (sensor data files)
- Driver concept
Sequential version:
- read settings
  - settings file
- load data
  - sdata file
- GRASP
- organize output
  - output file

Parallelized version (MPI):
- read settings
  - settings file
- load data
  - sdata file
- GRASP
  - GRASP
  - GRASP
  - GRASP
  - GRASP
- organize output
  - output file

GPGPU: https://www.catalysts.cc/
User interface

- Yaml settings files (Standard format)
- Runtime help information
- Documentation
Sub-zones $N_x \times N_y$ are treated independently using "core inversion".

$N_x \times N_y = 100 \times 100$?

$N_t \gg 1$ (for simplicity)

$N_t = 1$? (for simplicity)
GRASP – is too slow?

Acceleration using GPU

Overall Timing Trends

Time[s] per Pixel

Speedup per Pixel

Now: ~ 0.1 sec per pixel, it is not over…
POLDER: LOA-2 (Dubovik) algorithm (BRDF)

Case 1

Case 2

Numerical tests
Retrieved seasonal variability of aerosol AOT

AOT(0.56)
Retrieved seasonal variability of aerosol SSA

SSA(0.56)
Retrieved seasonal variability of surface albedo
Surface Albedo (0.67)
Comparison with other aerosol products

**PARASOL / GRASP**
AOD555 Seasonal Average July-September 2008

**PARASOL / fine mode operational**

**MODIS / Dark Target**
MYD08_M3.051 Aerosol Optical Depth at 550 nm [units of 0.1]

**MODIS / Deep Blue**
MYD08_M3.051 Deep Blue AOD at 550 nm [units of 0.1]
Comparison with modeling and assimilation products

PARASOL / GRASP

(EMWF calculations – courtesy of A. Benedetti)

ECMWF forecast model corrected by 4D-Var assimilation of MODIS Dark Target and AATSR retrievals.
Desert dust inventories produced using satellite data

Ginoux et al. (Rev Geophys. 2012) approach.

TOMS + 10 years of MODIS DB data

TOMS + 1 year of PARASOL/GRASP data
Comparison of NDVI - Normalized Difference Vegetation Index

MODIS
MODIS NDVI. February, 2001

February, 2001

PARASOL/GRASP
January – March, 2008
Comparison of NDVI - Normalized Difference Vegetation Index

MODIS

MODIS NDVI. July, 2001

PARASOL / GRASP

July – September, 2008

July, 2001
GRASP retrieval. Regional maps (1800 x 1800 km). Mongu, SSA 670 nm

Small SSA correspond to biomass burning!
1 year of PARASOL data processed by ICARE were compared with AERONET data at 7 sites:

Saada, DMN_Maine_Soroa, Ilorin, Banizoumbou, Mongu, Agoufou and Beijing
1 year of PARASOL data compared with AERONET over Africa at 6 sites:

Aerosol AOD

AOD(440nm)

\[ K = 0.896 \quad a = 0.83 \quad b = 0.16 \quad \text{RMSE} = 0.193 \]

AOD(870nm)

\[ K = 0.885 \quad a = 0.74 \quad b = 0.11 \quad \text{RMSE} = 0.161 \]
1 year of PARASOL data compared with AERONET over Africa at 6 sites:

**Angstrom Exponent**

AE(675–870nm)

\[
\text{GRASP retrieval} = K \times \text{AERONET} + a \quad \text{with} \quad K = 0.838, \ a = 0.68, \ b = 0.32, \ \text{RMSE} = 0.345
\]

**Aerosol SSA**

SSA(870nm)

\[
\text{GRASP retrieval} = K \times \text{AERONET} + a \quad \text{with} \quad K = 0.783, \ a = 0.64, \ b = 0.36, \ \text{RMSE} = 0.044
\]
In this ICARE processing no “quality flag” was saved, i.e.
It is impossible to screen out poor retrieval

Illustration of “screening” effect:
Banizoumbou, Jan – Feb, 2008

ICARE results
Retrieval with screening

\[ K = 0.896 \quad \alpha = 0.79 \quad b = 0.18 \quad \text{RMSE} = 0.179 \]

\[ K = 0.989 \quad \alpha = 0.93 \quad b = 0.09 \quad \text{RMSE} = 0.079 \]
1 year of PARASOL data compared with AERONET

Ilorin –
complex mixture of dust and biomass burning

Angstrom Exponent

Aerosol SSA

\[ AE(675-870\text{nm}) \]

\[ SSA(870\text{nm}) \]

\[ K=0.832 \quad a=0.90 \quad b=0.23 \quad \text{RMSE}=0.235 \]

\[ K=0.795 \quad a=1.00 \quad b=0.02 \quad \text{RMSE}=0.039 \]
1 year of PARASOL data compared with AERONET

Beijing –
complex mixture of dust and urban pollution over urban surface with complex reflectance

Aerosol AOD

\[
\begin{align*}
K &= 0.921 \quad a &= 0.74 \quad b &= 0.18 \quad \text{RMSE} = 0.259 \\
K &= 0.910 \quad a &= 0.84 \quad b &= 0.09 \quad \text{RMSE} = 0.128
\end{align*}
\]
1 year of PARASOL data compared with AERONET

Ilorin –
complex mixture of dust and biomass burning

**Angstrom Exponent**

\[ \text{AE}(675-870\text{nm}) \]

![Graph](image)

- \( k = 0.832 \)
- \( \alpha = 0.90 \)
- \( b = 0.23 \)
- RMSE = 0.235

**Aerosol SSA**

\[ \text{SSA}(870\text{nm}) \]

![Graph](image)

- \( k = 0.795 \)
- \( \alpha = 1.00 \)
- \( b = 0.02 \)
- RMSE = 0.039
Banizoumbou, January – February, 2008

Aerosol Loading

Imaginary part of ref. ind
(∼ absorption)

AOD(440nm)

\[ K = 0.989 \ a = 0.93 \ b = 0.09 \ RMSE = 0.079 \]

\[ K = 0.795 \ a = 0.76 \ b = 0.00 \ RMSE = 0.001 \]
**Parameters to retrieve:**

**AEROSOL:**
- \(dV(r)/d\ln r\) (16 bins 0.07 to 10 \(\mu m\));
- \(n(\lambda)\)
- \(k(\lambda)\)
- Fraction of spherical particles
- Aerosol height

**SURFACE:**
- BRF (3 parameters for each \(\lambda\))
- BPRF (parameters for each)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MERIS (N_{mes} = 7)</th>
<th>AATSR (N_{mes} = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N_r)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>(N_\lambda)</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>(N_\lambda)</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>(N)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(N)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>32</td>
</tr>
</tbody>
</table>

**TOTAL = 47**

**TOTAL = 32**
HIGH POTENTIAL of Multi-Pixel approach!!!

\[ N_{\text{total}}^{\text{retr}} = N_{\text{par}} N_x N_y N_t \]

9 Multi-pixel constraints

\[ N_{\text{total}}^{\text{data}} \approx (N_{\text{mes}} + N_{\text{smooth}} + N_{\text{retr}}^t + N_{\text{retr}}^x + N_{\text{retr}}^y) N_x N_y N_t \]

7 33 = ((9-3) + (7-1) + (7-2) + (7-1) + (7-1) + (7-1) + (7-1))

MERIS - ?
MERIS : Aerosol + Surface

Numerical tests

Single-Pixel :

\[ \tau(0.44) \]

Multi-Pixel :

\[ \tau(0.44) \]
Numerical tests

Single-Pixel:

Multi-Pixel:

Surface Albedo
A dust cloud evolves over Nigeria

Scene from Jan. 28th to Feb. 2nd, centered over Banizoumbou, Niger.
AOT 675 retrieval from MERIS and PARASOL.
Banizoumbou/Niger
MERIS AOD 440 nm

PARASOL versus AERONET
Banizoumbou, January - February, 2008

\[
y = 0.03233 + 1.025x, \quad R = 0.9822
\]

\[
y = -0.052796 + 0.91589x, \quad R = 0.97614
\]
**Sentinel - 4**

**Wavelength selection:**

*Preselected channels:*

<table>
<thead>
<tr>
<th>Wave.</th>
<th>Purpose</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>323.85</td>
<td>Surface</td>
<td>O₃ contamination</td>
</tr>
<tr>
<td>342.45</td>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>374.00</td>
<td>Atm. Corr.</td>
<td></td>
</tr>
<tr>
<td>399.50</td>
<td>Atm. Corr.</td>
<td></td>
</tr>
<tr>
<td>430.50</td>
<td>Atm. Corr.</td>
<td></td>
</tr>
<tr>
<td>446.70</td>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>456.55</td>
<td>Atm. Corr.</td>
<td>Useful for surface</td>
</tr>
<tr>
<td>751.50</td>
<td>Atm. Corr.</td>
<td>Useful for surface</td>
</tr>
<tr>
<td>756.10</td>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>770.75</td>
<td>Surface</td>
<td>O₂ contamination</td>
</tr>
</tbody>
</table>

Required wavelengths:

- **Surface:** 320, 325, 340, 342, 374, 417, 450, 456, 756
- **Aerosol:** 756
East-Asia aerosol, AOD (440)

**GOCI** - The Geostationary Ocean Color Imager

**COMS** (Communication, Ocean, and Meteorological Satellite)

1800 x 1800 km

temporal diurnal variation of AOD
Beijing 1-10 April, 2013

GOCI + AERONET cloud-screened
Beijing 1-10 April, 2013
GOCI + AERONET cloud-screened

\[ AOD(440\text{nm}) \]

\[ AOD(870\text{nm}) \]

\[ \begin{align*}
K &= 0.906 \\
a &= 0.66 \\
b &= 0.41 \\
RMSE &= 0.263
\end{align*} \]

\[ \begin{align*}
K &= 0.853 \\
a &= 0.93 \\
b &= 0.01 \\
RMSE &= 0.126
\end{align*} \]

Aver. Value = -0.134 St.D. = 0.226 N=138

Aver. Value = 0.020 St.D. = 0.124 N=138
Multi-instrument Remote sensing:

Co-incident:

- CALIPSO (Satellite-based lidar)

Non co-incident:

- CALIPSO
- AERONET

Time-variability Constraints

X-variability Constraints

Multi-days observations

(t_1; x; y)

(t_2; x; y)

(t_3; x; y)
Synergy realized within GRASP for ground-based observations

**GARRLiC/GRASP**
Generalized Aerosol Retrieval from Radiometer and Lidar Combined data

- **Lidar + AERONET**
- **Columnar**
- **fine & coarse**

- $\frac{dV(r)}{d\ln r}$
- $n(\lambda), k(\lambda)$
- $\omega_0(\lambda), P_{ii}(\lambda, \Theta)$

Lopatin et al. 2013
Synergy provides new aerosol characteristics

Profiles of fine and coarse mode concentrations

Profiles of aerosol absorption
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  - optimization as Multi-term LSM;
  - adapted for synergy of observations: multi-pixel retrieval;

- **Forward model:**
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  - easy accessible: open source aerosol retrieval code;
GRASP Status:

Core Algorithm is developed and performs well:

- uses very elaborated aerosol and RT models;
- inversion is based on rigorous statistical optimization;
- performs well in numerical test (Dubovik et al. 2011, Kokhanovsky et al. 2010);
- has a lot of flexibility

Issues and in progress aspects:

- Producing new PARASOL aerosol product;
- too long for satellite data:
  2 sec per pixel...(now → ???)
- open source GRASP code distributed by internet
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