1. INTRODUCTION

This report tries to synthesize the scope, requirements and uses of the Globaerosol project. The Globaerosol project focus on the requirements for atmospheric modelling and public health. Along the present project the best possible aerosol products based on the selected sensors and aerosol retrieval methods will be created. Aerosol optical depth, Ångström coefficient and aerosol composition directly from the satellite measurements and the vertical PM composition after the assimilation of the aerosol data in a CTM model.

2. AEROSOLS

Aerosol particles in the atmosphere arise from natural sources such as wind-borne dust, sea-spray and emission of biogenic volatile organic compounds. They are also arisen from a range of anthropogenic activities, in particular the combustion of fossil fuels. Emitted directly as particles, which is known as primary aerosol, or formed in the atmosphere by conversion, which use to be photochemical, of gaseous precursors, known as secondary aerosol, atmospheric particles range in size from a few nanometres (nm) to tens of micrometers (μm).

Aerosol particles are denominated in number of ways. An aerosol is a gas in which solid particles or droplets are suspended. Hence aerosol refers to both the gas phase and the particles (and droplets). The consideration of both phases is important because many of the relevant components are semi-volatile and exchange mass between the gas phase and the particle phase. In the atmospheric aerosol, the compounds include water, nitrate and a range of organic compounds.

Particulate Matter is another way of referring to these particles. For one reason or the other, the climate effects community tends to use aerosol particles, whereas the health effects community prefers to use particle matter or PM.

PM\textsubscript{x} means the mass of particles with an aerodynamic diameter lower than x μm.

Aerosols are a fundamental component of the Earth's atmospheric chemistry and radiative balance. Their importance in atmospheric radiative transfer means that the lack of accurate information on their distribution is a major limitation for weather forecasting. Aerosol distribution is also essential information in the study of the Earth's climate and biogeochemical cycles, for climate change assessment, and for the atmospheric correction of satellite remote sensing data. Particulate matter is also of major concern for public health. Although much of the anthropogenic component arises in industrial regions, it is often advected across national boundaries and affects remote and otherwise pristine environments. Information on the concentrations of particulates, the emission sources, transport and sinks are required by public agencies responsible for monitoring environmental hazards to human health, and in the formulation of policy on local and transboundary pollution.
Aerosols have a direct radiative impact by reflecting solar radiation back to space, which leads to cooling. Aerosols also control the radiative properties of clouds and their ability to produce precipitation.

2.1. AEROSOL AND HEALTH

Epidemiological studies show that an increase in PM10 mass concentration by 10μm-3 results in an increase of 0.5 – 1.5% in premature total mortality in case of short term/episodic exposure and increase up to 5% in premature total mortality in case of long term/life long exposure (Wilson and Spengler 1996). There are also some studies that relate PM10 with respiratory responses and PM2.5 is associated with cardiovascular diseases (Wyzga, 2002). Information on the concentrations of particulates, the emission sources, transport and sinks are required by public agencies responsible for monitoring environmental hazards to human health. The detection and tracking of desert dust events towards populated areas can be usefully exploited in linking those events to threshold exceeding of PM concentrations measured at surface. So it is clearly linked the levels of PM concentration to healthy problems.

2.2. AEROSOL AND MODELLING

Numerical models describing aerosol particle emissions and production, transport, transformation and removal have become accepted tools to extrapolate monitoring data (Council directive 96/62/EC on ambient air quality). They are used in source apportionment studies and aerosol precursor emissions. The calculation of e.g. PM10 levels or radiative forcing must necessarily be based on a description of the emissions of the individual chemical species and how they transform and mix in the atmosphere. Models with this capability are becoming available (Hass et al. 2002) but need testing and validation against fundamental data such as aerosol particle size distribution and chemical composition.

3. GLOBAEROSOL

The Globaerosol project has been initiated to improve current atmospheric models and the monitoring of pollution levels over Europe through the provision of more complete aerosol climatology than is currently available. For the coverage to be truly global, and considering the sources of information currently available, the aerosol data will be derived from EO satellite sensors. In particular, the ATSR-2, ATTSR and MERIS data managed by ESA and SEVIRI managed by EUMETSAT.

The determination of aerosol properties from satellite measurements is a difficult problem. To make measurements of mid-lower tropospheric aerosol one is limited to nadir or near-nadir viewing geometries (clouds and the optical thickness of the atmosphere itself preclude limb viewing as a method of measuring the lower atmosphere). In the nadir geometry the signal is generally dominated by radiation reflected from the surface (particularly at visible wavelengths), with the aerosol signal being a small perturbation. This combined with the limited number of channels available on satellite radiometers to be used to produce the GlobAEROSOL product means that several assumptions have to be made a priori about the aerosol in order for any information to be retrieved.

These limitations mean that reliable PM concentrations are unlikely to be derivable from satellite measurements without good knowledge of the aerosol size distribution.
Although radiometer measurements are sensitive to composition, the information content of the measurements is not high enough to allow this to be distinguished from aerosol concentration and particle size distribution. Sensitivity to the vertical profile of aerosol, particularly at sub kilometre scales, is low.

3.1. PROJECT DESCRIPTION

The project is divided in two phases. Phase I is devoted to analysing user requirements and developing a system that generates global aerosol products to meet those requirements. Phase II will then centre on the extraction of the required aerosol data set, the quality of this set and possible applications of a Globaerosol service to satisfy the user community.

The project covers the following activities:
1. Development of a satellite data processing system to generate a standard reference multi-year global aerosol product (GAP) over land and water.
3. Validation of the GAP using independent ground-based measurements.
4. Intercomparison of the GAP with other satellite-based aerosol data sets.

Produced data from:
2. Envisat AATSR (2002-2005)

3.2. PROJECT USERS

Globaerosol users can be found among the following institutions:

- ECMWF European Centre for Medium Range Weather Forecasts
- CNRM Météo-France
- MPI Max Planck Institute for Meteorology, Hamburg
- EMEP European Monitoring and Evaluation Programme
- VMM Flemish Environment Agency
- North Rhine Westfalia State Office for Environment
- HME Hellenic Ministry for Environment
- ARPA Regional Agency for the Protection of the Environment, Lombardia, Italy
- DLR Deutsches Zentrum für Luft- und Raumfahrt.
- INM Spanish Meteorological Institute.

User requirements that have been expressed belong to 2 applications:
1. Aerosol optical properties and radiative impact on climate

For this application the expected benefit is an improved accuracy of the atmosphere modelling and climate prediction, in particular in the perspective of a global warming. Computer simulations of climate change show a great sensitivity to aerosols with some uncertainties on its amplitude. The aerosol concentration levels may be increased in the future due to human activities as well as climate change feed back. This will require global accurate aerosol monitoring over the next decade. We need to build a comprehensive data set of the present geographical distribution, to assess the accuracy of this data set.
2. Particulate Matter (PM) at the surface for air quality monitoring and potential health problems. Particulate matter depends on aerosol size distribution and type. Links have been established between PM levels and health problems in the respiratory system of the human body. Standard levels of air quality are being established for PM levels. Global observation will help to extend the studies based on local measurements, to analyse the relationships between PM and health risks, to monitor and predict PM level for air quality forecasting.

The requirements expressed by the 7 identified users can be divided in 2 categories:

- Atmospheric modelling, 2 users: ECMWF, MPI, DLR
  - They require aerosol optical properties: aerosol optical thickness (AOT) and its spectral dependence expressed by the Angstrom coefficient. Aerosol absorption and vertical distribution, clear sky radiances are also mentioned.
  - Required accuracy on aerosol optical depth: 0.1 in the visible 10-100 km
  - Daily to weekly
  - Global

- Air quality monitoring, 5 users: ARPA, Athens, EMEP, NRW, VMM.
  - They require particulate matter concentrations: PM10, PM2.5 and PM1, as far as possible in the surface layer, with some speciation.
  - Required accuracy on PM: 25-50% 5-100km with some focus at 250 m resolution over industrial hot spots hourly to annual, with some statistics Europe

- Only the ECMWF, DLR (ENVISOLAR) and INM users require NRT.
- The nominal requirement for the aerosol products spatial resolution is 10kmx10km, users have expressed they preference for higher resolution products: 1Km x 1km for polar orbiters sensors and up to 3kms for stationary satellite sensors.

According to the requirements the steps to be followed by the GAP product is:

i. Derive the AOT and Angstrom coefficient from the space sensors radiances,

ii. Relate an aerosol type to the Angstrom coefficient

iii. Relate AOT and type to columnar PM as input to a Circulation Transport Model) CTM

iv. Get the surface PM as output of the CTM

Climate modelling requirements are met after step ii. Air quality requirement after step iv.

3.3. PROJECT PARTICIPANTS

Globaerosol is composed by GMV in Spain, RAL (Rutherford Appleton Laboratory) & Oxford University in UK.
Oxford and RAL have developed an algorithm called ORAC: The Oxford-RAL Retrieval of Aerosol and Cloud algorithm has been developed with funding from EUMETSAT the EU and NERC. The code is being used by the NERC project GRAPE and the EU project PARTS to examine global cloud and aerosol properties. The results from the cloud component of the code have been extensively tested and have been well validated with ground based and Earth Observation data.
GMV has developed the system that integrates ORAC and process the remote information coming from the 4 different satellites. This system can operate in two different modes, automatic and manual.

### 3.3.1. ORAC

As it has been stated, ORAC algorithm has been developed by RAL and Oxford University.

It also can be split into:

- **SEVIRI ORAC (RAL):** input SEVIRI 1.5 bsq images.
- **AATSR & ATSR2 ORAL (Oxford University):** input level 1B products.

Both are based on processing its input images. While the SEVIRI one process for every segment and then for every channel the AATSR and ATSR-2 just establish a loop over all the channels. To understand how the algorithm works, it basically read the input image or product, converts radiance to reflectance, and for the first channel only:

1. Outputs solar geometry, solar zenith angle, solar azimuth angle
2. Outputs lat and longitude of each observation

The Channels used are: 1,3,4 and 5 for SEVIRI, ??? For AATSR and ??? For ATSR-2

Five different aerosol models have been set: Urban, Maritime, Continental, Desert Dust, Biomass. The algorithm finally implements an fit process (iterative to get the best fit). The outputs are five different products (in HDF) formats, each one for each of the different models, containing AOD, Julian date, angles information (solar azimuth, sun azimuth, solar zenith), errors (variances of the estimation), iterations, cost function. The algorithm needs a set of auxiliary data:

- ECMWF snow flag information
- ECMWF u and v winds
- Seviri ‘CLMK’ Cloud mask data
- Aerosol Look-up tables
- MODIS Albedo

### 3.3.2. PROCESSING SYSTEM

The processing system is developed to integrate the ORAC algorithm into a chain that starts from satellite data to get the best estimation when computing the AOD for the five different aerosol models (Urban, Maritime, Continental, Desert Dust, Biomass). This system can be split in two different parts.

1. It first calls ORAC that will read the input products and will generate the best fit of the AOD from the radiances (stored into HDF file) for the each of the aerosol models.
2. From the HDF file it will generate the final product with more information:
   a. Geolocation parameters: Latitude, Longitude and Altitude.
   b. AOD at 550nm and 870nm
   c. Ångström coefficient
   d. Error of the AOD at both 550nm and 870nm and Julian date for every ground pixel
   e. Speciation, according to the five different models: MARITIME, URBAN, BIOMASS, CONTINENTAL and DESERT DUST.

The outputs of the processing system are NetCDF products than can be groped into three different groups:
• Individual-sensor Orbit-based Aerosol Products (IOAP). These files contain all the output of the individual sensor retrievals, with coverage corresponding to that of the original level 1 (radiance) data from the sensor. These files contain the results for all of the five aerosol types, plus an indication of the “best” type, i.e., a flag indicating which aerosol retrieval is considered most representative of the scene, based on quality control criteria.

• Individual-sensor Global Aerosol Products (IGAP). One IGAP is produced per day for each sensor. The IGAPs contain records for all Globaerosol grid boxes (filled with null-records were no retrieval is available for a given box). In all cases the IGAPs contain estimates of aerosol optical depth (AOD) at 0.55 and 0.865 μm and the Angstrøm coefficient.

• Merged Global Aerosol Products (MGAP). One MGAP is produced per day, which combines the results from all available sensors into a single map in the same format as the IGAPs, valid for the same specific time of day.

All those products are written in a sinusoidal grid, with a spatial resolution of 10 km. The speciation is computed as estimation. It will be done using an algorithm, that will apply some filters for every measurement such as: satisfactory cost function value at solution, satisfactory cloud fraction, satisfactory estimated errors from the retrieval scheme, level of contamination by sun-glint. The algorithm will later apply a merging algorithm to generate the IGAPs and the MGAPs where the best type (which means the best aerosol estimation for a given grid point) will be used to “merge” different measurements (coming from the same sensor IGAPs, or from three sensors MGAPs). A single merged product will be produced per day, which corresponds to the Envisat observing time.

3.4. VALIDATION

Validation of three sensors has been performed and all the validations have been performed following Intercomparison with Aeronet Data (AErosol RObotic NETwork, program is an inclusive federation of ground-based remote sensing aerosol networks established by Aeronet and PHOTONS and greatly expanded by AEROCAN and other agency, institute, and university partners). The period validated was covering from 27th August 2004 to 30th September 2004.

The intention is to overcome the inherent difficulty of comparing point measurements from the ground with spatially averaged satellite data, both taken at slightly different
times, by assuming the spatial and temporal variability of the two datasets is correlated (though winds).
The validation was due using 44 available AERONET Stations for the period to be validated. This sub-set of Aeronet stations was selected with long record of measurements to sample aerosol variability as well as possible geographically & temporally. Files were created from each daily 10km GAP in which “co-located” satellite and selected ground-based data is associated. An statistical analysis was perform on the sets of co-located measurements (time series of statistics produced).

### 3.4.1. MERIS VALIDATION

Only the specific physical aerosol parameters contained in the GAPs are validated. The validation will be by comparison to estimates of the same parameter from AERONET ground Stations at the same temporal and spatial resolution and sampling as the GAP. The parameters to be validated are:

- Aerosol optical thickness (AOT), at wavelengths, 550 and 865 nm.
- The angstrom coefficient,
- Aerosol Index, obtained from: \( AI = \lambda^*\tau_{0.865} \)

Those parameters are compared against the following AERONET parameters:

- Angstrom coefficient is estimated from the slope of the linear regression of \( \ln(\tau_{\lambda}) \) versus \( \ln(\lambda) \) using 500, and 870nm AOT estimates.
- AOT at 550 nm is derived from AOT500nm (when available) or AOT865 nm (iotherwise) and Amstrong coefficient (500_865nm)
- Aerosol Index is calculated from AI = AOT_870 * AE

The extraction Of Co-Incident Measurements was taking into account the following criterias:

- Pixels are selected within a region on ±20 km from each station (from a 10km resolution grid).
- All aeronet measurements for the given ground station are extracted with time ±DT of the satellite overpass. The baseline for DT is 30 minutes (which given a typical aerosol transport speed of 50km/hour is consistent with the 50km spatial distance sampled from the GlobAerosol GAP if DP is 2). An aeronet measurement both before and after should be available.

Since MERIS sensor uses different algorithms for land or sea pixels in the calculation of aerosol related products, this classification is used. Land or sea pixels are selected using the landsea mask from MERIS GAP product. Pixels are then filtered using MERIS GAP product flags.

- Land pixels are filtered using a DDV (Dark Dense Vegetation) flag.
- Sea pixels are filtered using different flag masks [R.D.1]:
  - PCD19: Uncertain aerosol type and optical thickness or cloud optical thickness
  - PCD1_13: Uncertain normalized surface reflectance
  - CASE2_S: Turbid (sediment dominated Case 2) water
  - SUSPECT: Suspect pixel
3.4.2. AATSR & SEVIRI VALIDATION

As for MERIS only the specific physical aerosol parameters contained in the GAPs are validated. The validation will be by comparison to estimates of the same parameter from AERONET ground Stations at the same temporal and spatial resolution and sampling as the GAP. The parameters to be validated are:

- Aerosol optical thickness (AOT), at wavelengths, 550 and 865 nm.
- The angstrom coefficient

The validation procedure was perform selecting a sub-set of Aeronet stations, following the characteristics:

- with long record of measurements
- to sample aerosol variability as well as possible geographically & temporally

Files were created from each daily 10km GAP in which “co-located” satellite and selected ground-based data is associated, also some statistical analysis was perform on the sets of co-located measurements and finally time series of statistics produced.

For SEVIRI a separate file is produced for each time-step. Validation is performed using the data in the coincidence files, filtered to select specific sub-sets:

- Co-location fiter
- Classification/aerosol type filter
- Viewing geometry especially solar zenith angle
- Estimated retrieval errors are small
- Station lies within a particular geographical region
- Station represents a particular surface type
- dark land, desert, sea, ice etc
- Retrieved surface reflectance is within a specific range
3.5. CONCLUSIONS

1. GlobAerosol will deliver a 10-year aerosol dataset based on ATSR-2, AATSR, MERIS and SEVIRI.
2. Products from the individual sensors for a 5-week test period have been produced and validated.
3. Work on the merging scheme is close to completion.
4. Data for the test period and a report describing its validation will be made available in mid June to all interested users & we welcome feedback.
5. There will be a workshop [Mid July-Beginning September]
6. Please contact us if you are interested in receiving the test products.

Processing of the complete 10-year period is set to follow the user consultation exercise and should be completed by early 2008.

3.6. REFERENCES

A European Aerosol Phenomenology- Joint Research Centre, European Comisión
GlobAerosol Merging ATBD Algorithm, Richard Siddans, Caroline Poulsen