

Aerosol forecasting and assimilation at ECMWF: overview and data requirements

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Acknowledgements:
Jean-Jacques Morcrette, Carole Peubey, Olaf Stiller, and
Richard Engelen

Outline

- General introduction of the European Global Monitoring for Environment and Security (GMES) initiative
- Brief technical overview of the MACC aerosol analysis/forecasting system
- Near-real time aerosol forecasts and dust warning system
- Recent developments
- Verification (presented by Luke Jones)
- Future developments and open questions

GMES Atmosphere Component Service

- Part of Europe's Global Monitoring for Environment and Security initiative
 - development of operational space-based observation
 - strengthening of complementary in-situ observing systems
 - development and operation of services, based on core integrated assimilation and forecasting
 - three environmental services for Land, Ocean and Atmosphere



- A 32-partner EC project called GEMS (Global and regional Earth-system Monitoring using Satellite and in-situ data)
 - developed systems for the core GMES atmospheric service
 - May 2005-May 2009, status completed

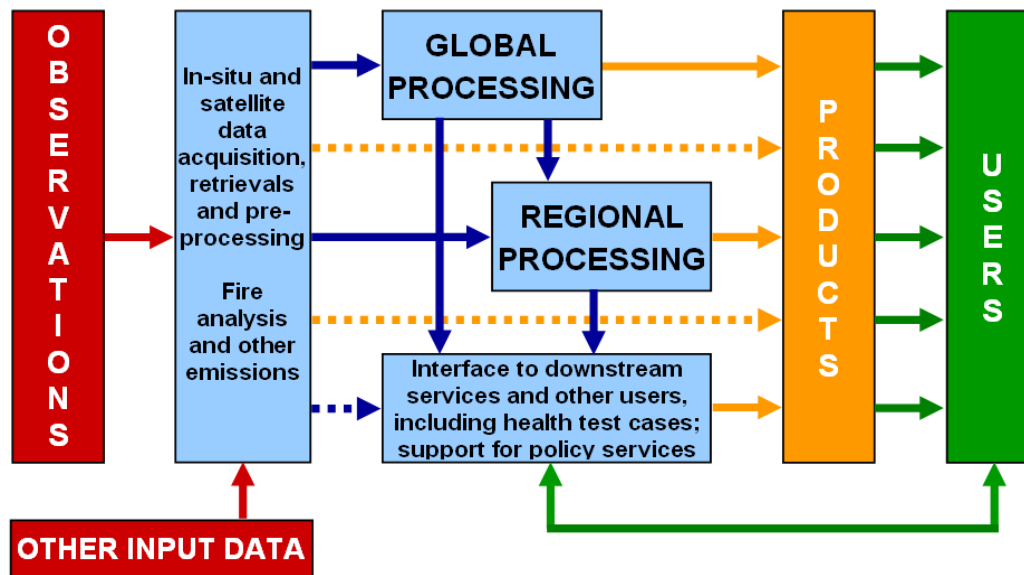


- A 48-partner EC-funded project called MACC:
 - provides pilot GMES Atmosphere Component Service
 - succeeds earlier projects GEMS and PROMOTE
 - coordinated by ECMWF
 - started in June 2009, scheduled to end October 2011



MACC – Monitoring Atmospheric Composition and Climate

- Integrates space-based and in-situ observations of atmospheric composition with state-of-the art atmospheric modelling
- Provides monitoring and forecasting services
- Helps Europe to respond to climate change and poor air quality



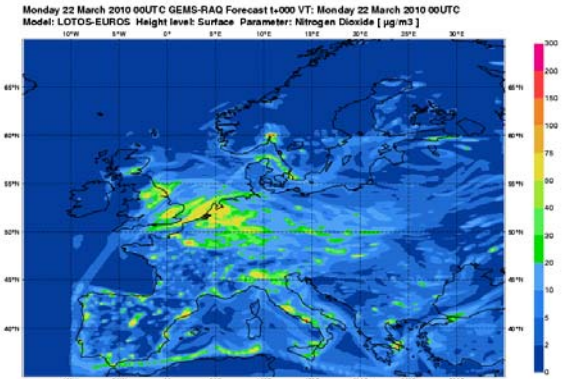
<http://www.gmes-atmosphere.eu>

MACC Daily Service Provision

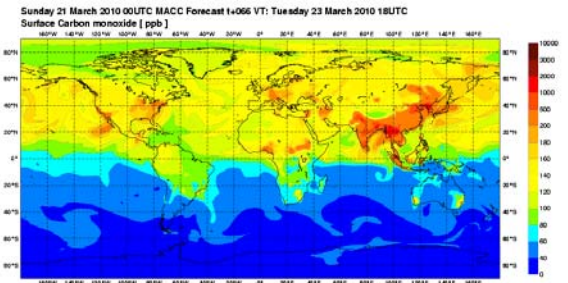
<http://www.gmes-atmosphere.eu>

The screenshot shows the MACC website interface. At the top, it says 'Monitoring atmospheric composition & climate'. The main navigation bar includes: HOME, NEWS, ABOUT THE PROJECT, SERVICES, DATA PRODUCTS, DOCUMENTS, EVENTS, CONTACT US. Below this, there are sections for 'Home', 'Services by theme' (European Air Quality, Global Atmospheric Composition, Climate, UV and Solar Energy), and 'Services by user' (Health, Environment, Science Community, Citizen, Meteorology). A footer note states: 'MACC is a Collaborative Project (2009-2011) funded by the European Community under the 7th Framework Programme. It is coordinated by the European Centre for Medium-Range Weather Forecasts and operated by a 45-member consortium.'

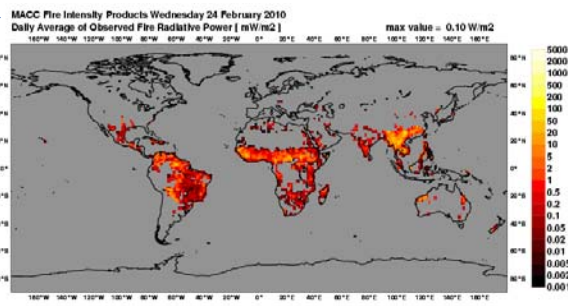
Air quality



Global
Pollution



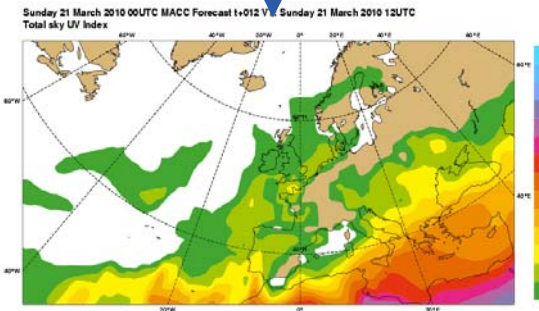
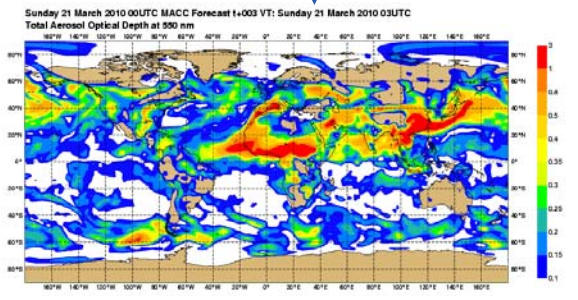
Biomass
burning



Aerosol



UV index

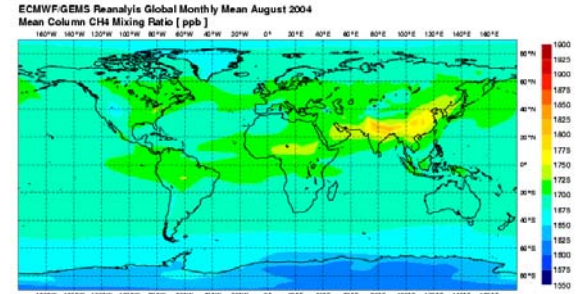


MACC Service Provision

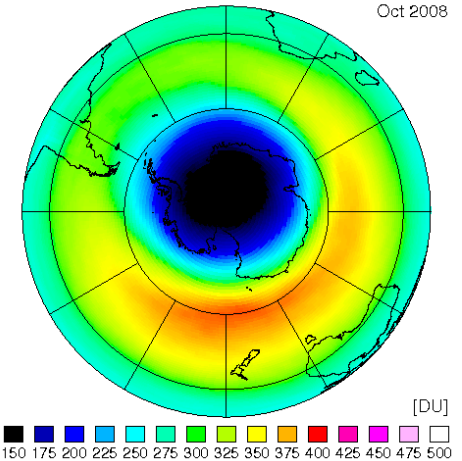
<http://www.gmes-atmosphere.eu>

The screenshot shows the MACC website interface. At the top, it says "Monitoring atmospheric composition & climate" and includes logos for "macc" and "Gmes". A search bar is present. Below the header is a navigation menu with items like HOME, NEWS, ABOUT THE PROJECT, SERVICES, DATA PRODUCTS, DOCUMENTS, EVENTS, and CONTACT US. The main content area is divided into sections: "Home" with a brief description of MACC, "Services by theme" with icons for European Air Quality, Global Atmospheric Composition, Climate, and UV and Solar Energy, and "Services by user" with icons for Health, Environment, Science Community, Citizen, and Meteorology. At the bottom, there is a footer with logos of participating countries and a note about the project's funding by the European Commission.

Reanalysis



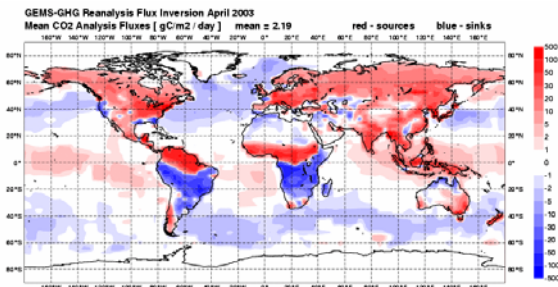
Multi Sensor Reanalysis Monthly mean total ozone Oct 2008



Ozone records



Flux Inversions





MACC Users

- **Advisory programs** (i.e. WMO Sand and Dust Storm Warning Advisory and Assessment System, <http://www.bsc.es/sds-was/>
In the future, Volcanic Ash Advisory Centres)
- **Regional air quality modellers** for boundary and initial conditions (EPA, European centres, JRC, Serbian Meteorological Service)
- **Field campaigns** (POLARCAT, HIPPO, upcoming SAMBBA)
- **Retrieval groups** (University of Leeds, University of Reading)
- **Solar irradiance forecast groups** for renewable energy and plant ecology applications (Geomodel)
- **National Weather Services** for UV warnings (DWD)

The ECMWF aerosol model

12 additional aerosol-related prognostic variables:

- * 3 bins of sea-salt (0.03 – 0.5 – 0.9 – 20 μm)
- * 3 bins of dust (0.03 – 0.55 – 0.9 – 20 μm)
- * Black carbon (hydrophilic and –phobic)
- * Organic carbon (hydrophilic and –phobic)
- * $\text{SO}_2 \rightarrow \text{SO}_4$

Sources, horizontal and vertical advection by dynamics, vertical advection by vertical diffusion and convection, dry deposition, sedimentation, wet deposition by large-scale and convective precipitation, hygroscopicity (SS, OM, BC, SU)

- * Forward modelling: Morcrette et al., 2009, JGR
- * Analysis including [assimilation of MODIS tau550](#): Benedetti et al., 2009, JGR

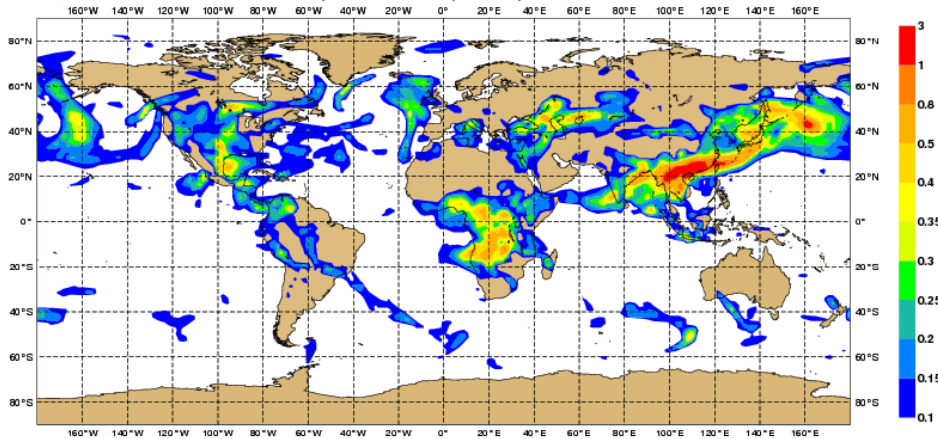
4D-var assimilation system for aerosols

- The control variable is formulated in terms of the **total aerosol mixing ratio**
- Background error statistics have been computed using the NMC method
- Assimilated observations: **MODIS** Aerosol Optical Depths (AODs) at 550 nm over land and ocean. Observation errors are prescribed as a percentage of the observed optical depth value (now changed to fixed values as a result of investigation into observations bias using the variational approach).
- Validation datasets: optical depths from the AErosol Robotic NETwork (AERONET) and lidar backscattering from CALIPSO

Near-real time forecasts of atmospheric aerosol

Anthropogenic aerosols

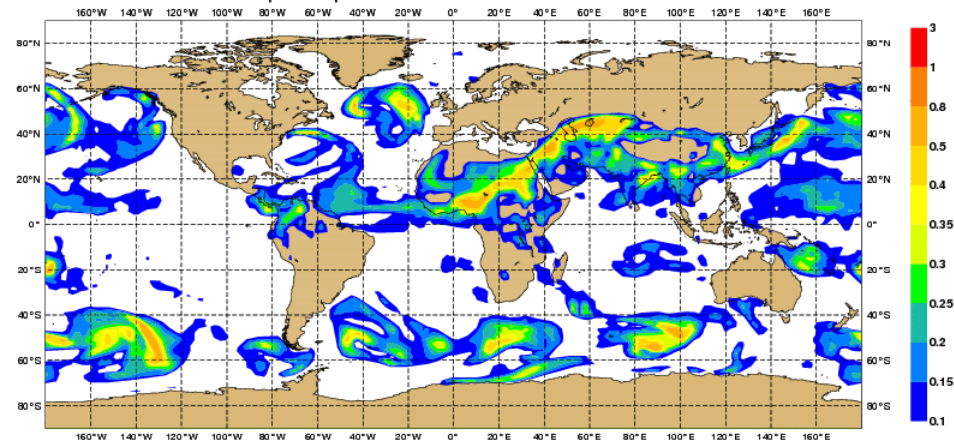
Tuesday 16 March 2010 00UTC MACC Forecast t+003 VT: Tuesday 16 March 2010 03UTC
Organic Matter, Black Carbon and Sulphate Aerosols Optical Depth at 550 nm



- Global forecasts at ~125 km Resolution will increase to 80 km in the near future.
- Forecasts are run one day behind actual date. The effective forecast length is 3 days.
- Soon, near-real time configuration will become real time.

Natural aerosols

Tuesday 16 March 2010 00UTC MACC Forecast t+003 VT: Tuesday 16 March 2010 03UTC
Sea-salt and Dust Aerosols Optical Depth at 550 nm



The same system developed for the multi-year reanalysis is used for the near-real time forecasts. The aerosol forecasts with assimilation of MODIS data have been running daily since **July 2008**.

Dust warning system

Huge sandstorm covers Beijing, turns sky orange

AP Associated Press

Buzz up! 76 votes | Send | Share | Print



Reuters – Tourists wearing face masks stand amid a sandstorm on Tiananmen Square in Beijing March 20, 2010. REUTERS/Grace ...



By CARA ANNA, Associated Press Writer – Sat Mar 20, 12:38 pm ET

BEIJING – Tons of sand turned Beijing's sky orange as the strongest sandstorm this year hit northern China, a gritty reminder that the country's expanding deserts have led to a sharp increase in the storms.

The sky glowed Saturday and a thin dusting of sand covered Beijing, causing workers and tourists to muffle their faces in vast Tiananmen Square. The city's weather bureau gave air quality a rare hazardous ranking.

Air quality is "very bad for the health," China's national weather bureau warned. It said people should cover their mouths when outside and keep doors and windows closed.

China's expanding deserts now cover one-third of the country because of overgrazing, deforestation, urban sprawl and drought. The shifting sands have led to a sharp increase in sandstorms — the grit from which can travel as far as the western United States.

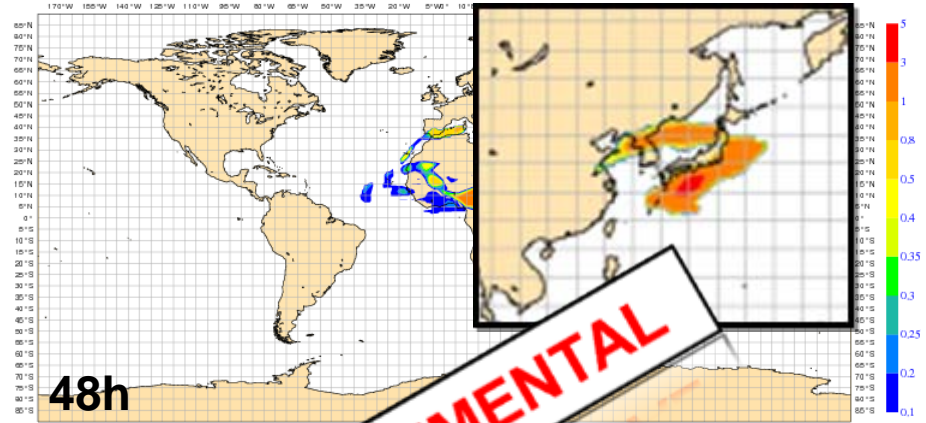
The Chinese Academy of Sciences has estimated that the number of sandstorms has jumped six-fold in the past 50 years to two dozen a year.



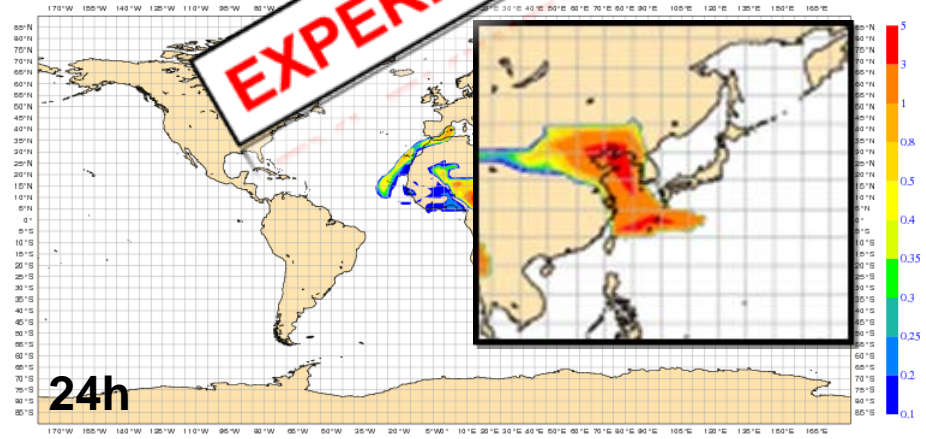
Beijing's Tiananmen Square was shrouded in orange dust

Dust Index

Thursday 18 March 2010 00UTC ECMWF Forecast t+48 VT: Saturday 20 March 2010 00UTC Surface: **



Thursday 18 March 2010 00UTC ECMWF Forecast t+24 VT: Friday 19 March 2010 00UTC Surface: **



EXPERIMENTAL

$$\text{Index} = \text{absolute}(\text{forecast AOD} - \text{mean AOD}) / (\text{std. dev. AOD}) * (\text{forecast AOD})$$

Standard deviation and mean AOD are calculated for every month of the years 2008 and 2009 which are used as reference.

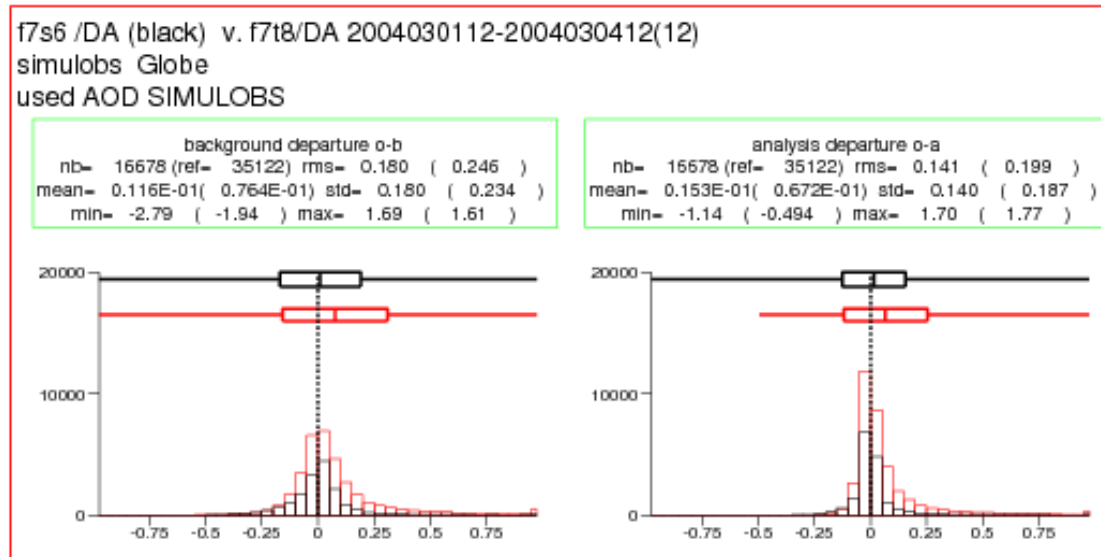
Recent developments

- **Model improvements** contributed greatly to improving the analysis
- **Modifications in observation errors** also contributed to a better analysis. In general, specification of observation errors proved to be **FUNDAMENTAL**.
- Aerosol assimilation system has proven **flexible** in regards to the **inclusion of** AOD observations at 550nm from **different sensors** (AATSR, SEVIRI, ground-based AERONET observations).
- Assimilation of AOD from sensors other than MODIS has emphasized **the need for a bias correction**. This has been recently implemented using the same approach which is adopted for radiance and ozone data (variational bias estimation). Work on bias correction has shown weaknesses in the error assumptions both on background and observations.
- **Dual control variable** is being put in place to benefit from assimilation of fine-mode AOD and other size-related aerosol observations
- **Lidar assimilation** is being developed in the context of the project QuARL (1D-Var to be extended to full 4D-Var system in the next years).

Assimilation of SEVIRI optical depths:

Importance of the observation errors and quality control

observation errors fixed at 30% (red) of the AOD vs errors provided with retrieved AOD (black)

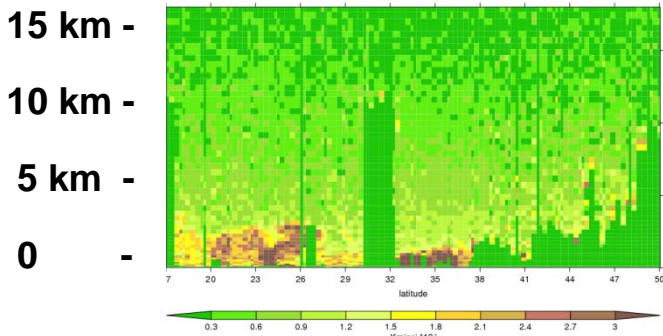


→ more desirable first-guess and analysis departure distributions with the retrieval errors: smaller bias and more Gaussian shape compared to using the errors of 30 %.

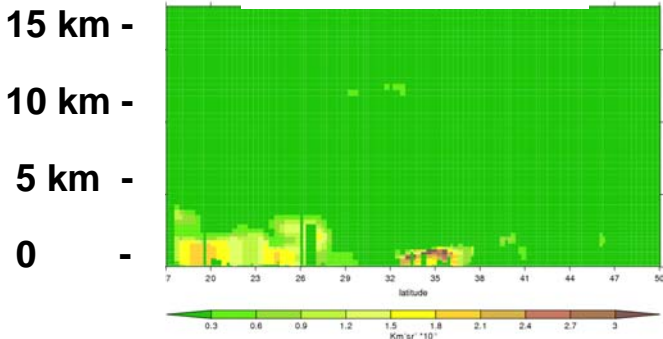
→ the number of assimilated data in the retrieval error case is half that of the 30% error case but of better quality

1D-Var experiments with CALIPSO data

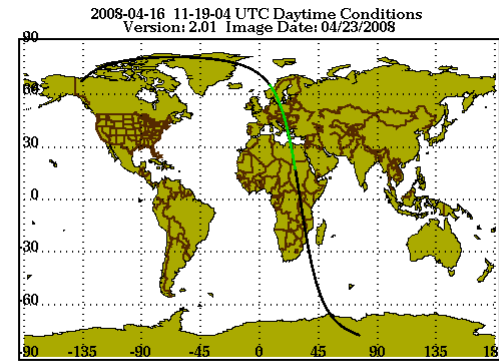
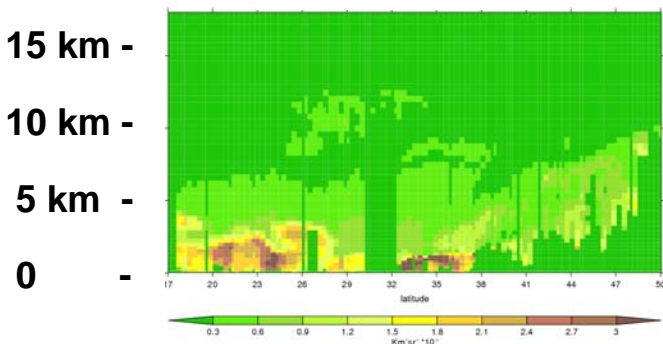
Observed lidar backscatter



Model first guess



Model analysis



- Optical properties derived using Mie theory for the 11 aerosol species
- CALIPSO backscatter data at 532 nm pre-processed with cloud screening using level 2, 5 km cloud top height product (no data used below highest cloud top)
- Observed lidar backscatter averaged to model grid box
- Observation error set to 25% of observation value (acceptable for feasibility study)
- First guess of aerosol backscatter of good enough quality to allow assimilation

Data requirements for assimilation/monitoring

General:

- Near-real time availability (3-5 hours), easy access and data format
- Level 2 products have to come with error specification at a pixel level
- Good cloud screening
- Direct observations with good calibration

Short term:

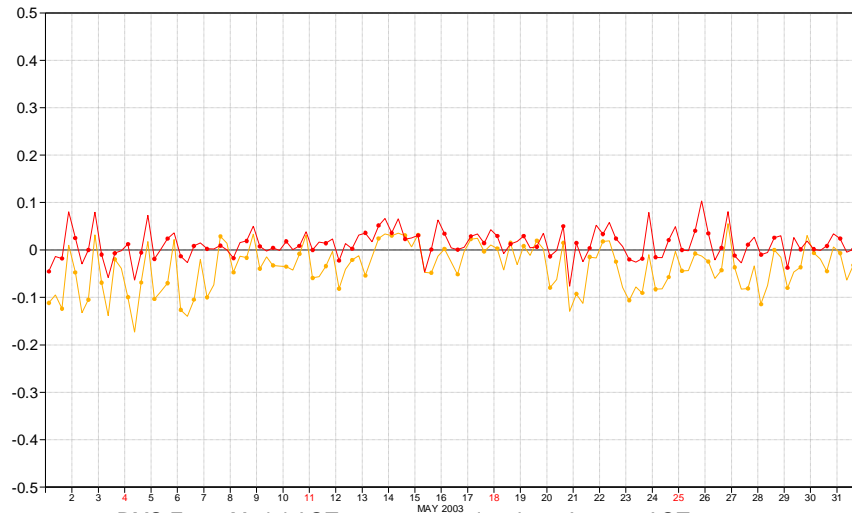
- Invest on available sensors/algorithms (i.e. SEVIRI and AATSR) and make data operationally available
- Push for aerosol data from ongoing or planned non- aerosol missions (VIIRS on NPP, Sentinel-3, GCOM-C, ...)
- Liaise with aerosol forecasting centres as for standard meteorological parameters

Long term:

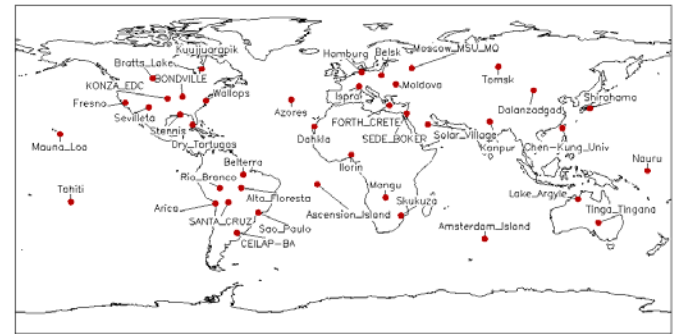
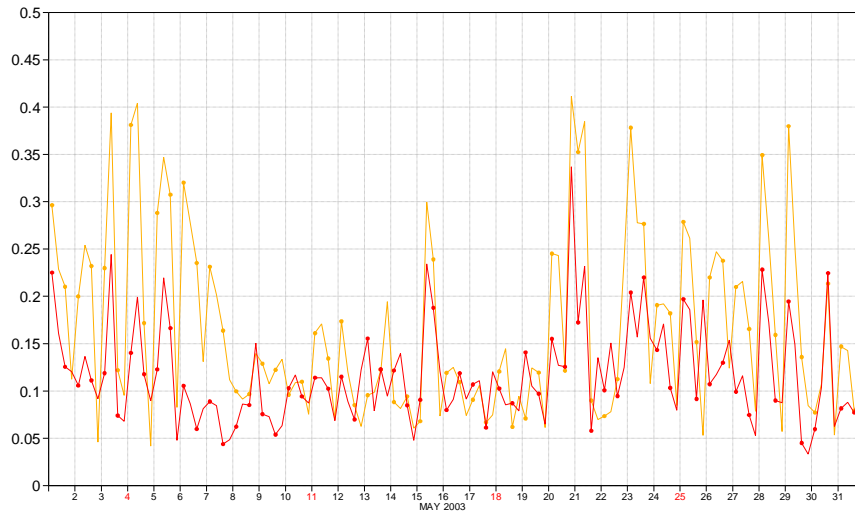
- Plan future mission keeping also aerosol forecasting applications in mind (i.e. level 1 lidar data from Earthcare in NRT)
- Plan aerosol-missions that have an operational character

Global comparisons with AERONET (May 2003)

FC-OBS Bias. Model AOT at 550nm against L2.0 Aeronet AOT at 500nm.
Meaned over 41 sites globally. Period=1-31 May 2003. FC start hrs=00,12Z.



RMS Error. Model AOT at 550nm against L2.0 Aeronet AOT at 500nm.
Meaned over 41 sites globally. Period=1-31 May 2003. FC start hrs=00,12Z.



Analysis (red) shows lower bias and lower RMS wrt AERONET optical depths than free-running model (dark yellow)

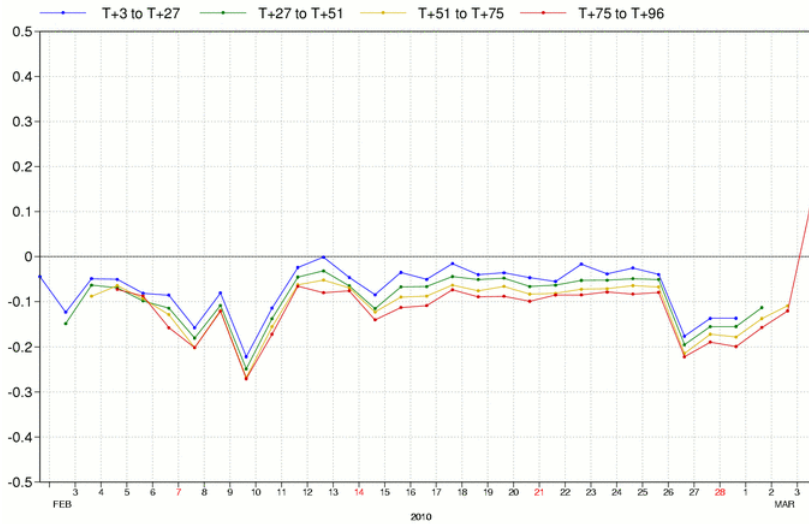
Average bias (over 41 stations):
0.012 (ASSIM) vs -0.036 (FCST)

RMS:
0.117 (ASSIM) vs 0.164 (FCST)

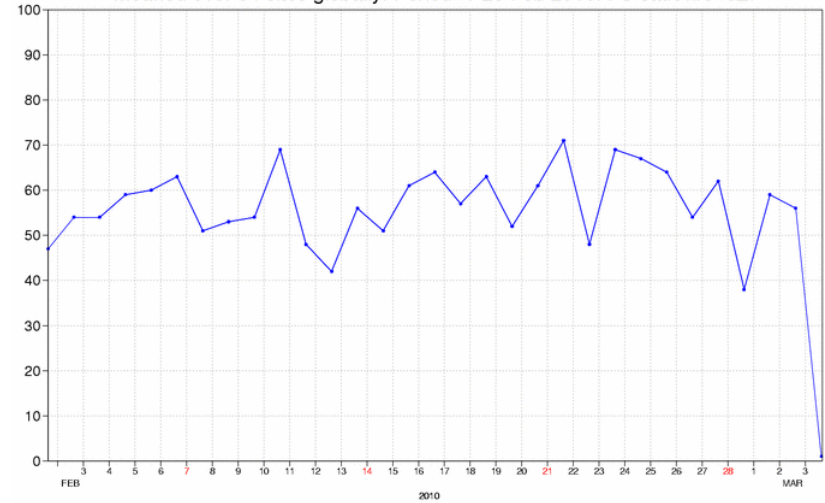
— Analysis
— Free-running forecast

Forecast range verification (24h means, Feb 2010)

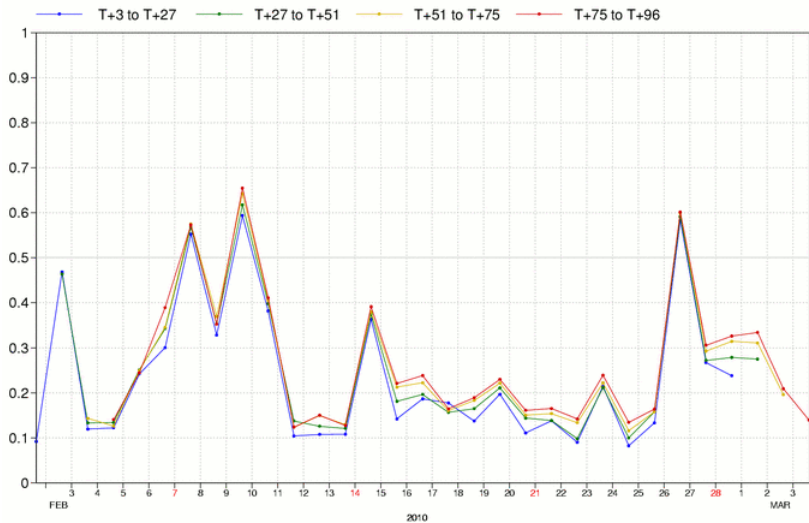
FC-OBS Bias. Model (f93i) AOT at 550nm against L1.5 Aeronet AOT at 500nm.
 Meaned over 64 sites globally. Period=1-28 Feb 2010. FC start hrs=0Z.



Sample size. Model (f93i) AOT at 550nm against L1.5 Aeronet AOT at 500nm.
 Meaned over 64 sites globally. Period=1-28 Feb 2010. FC start hrs=0Z.



RMS Error. Model (f93i) AOT at 550nm against L1.5 Aeronet AOT at 500nm.
 Meaned over 64 sites globally. Period=1-28 Feb 2010. FC start hrs=0Z.



- Bias increases with forecast range

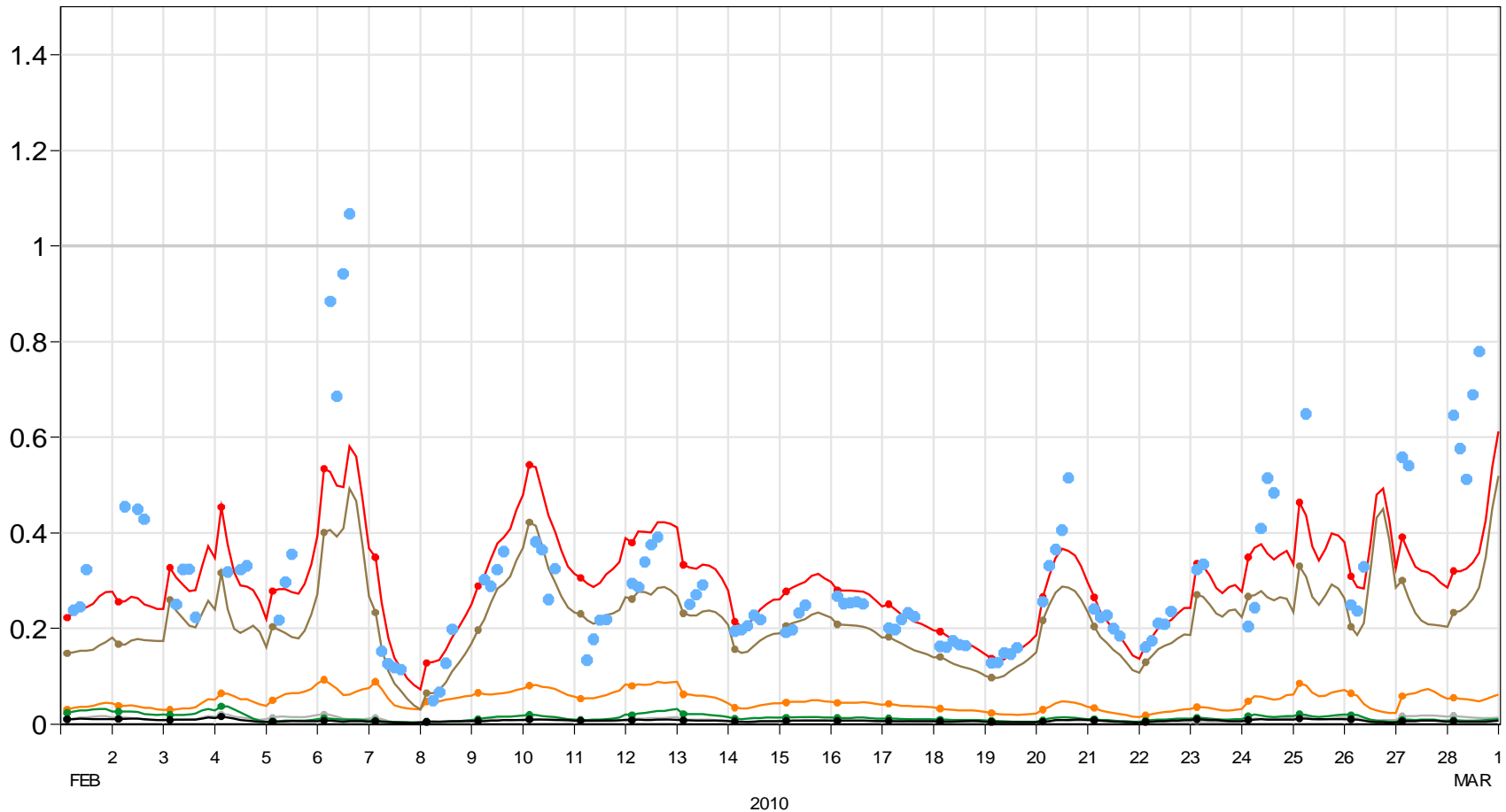
- Less noticeable on the RMS

— Day 1 — Day 3
— Day 2 — Day 4

AERONET site comparisons (February 2010)

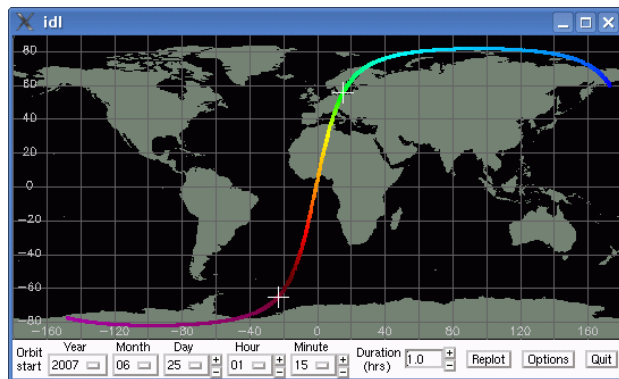
Comparison of model (f93i) and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Solar_Village (24.91°N, 46.4°E). Model: 00UT, 1-28 Feb 2010, T+3 to T+24.

Aeronet AOT MODIS AOT Total FC AOT Sulphate Sea Salt Dust Organic Matter Black Carbon

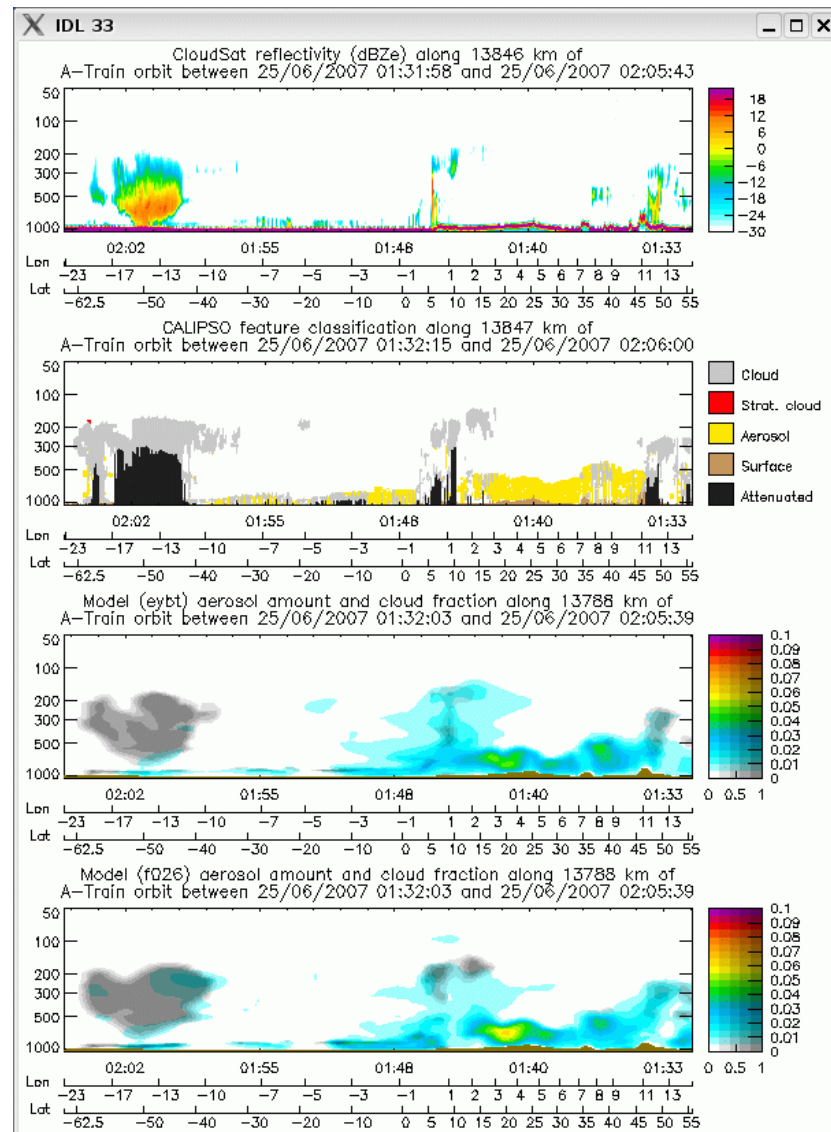


- **Dust-dominated site (Solar Village) show good agreement between the analysis and AERONET despite the lack of MODIS data over this type of sites**

Aerosol & cloud profile validation with A-Train data

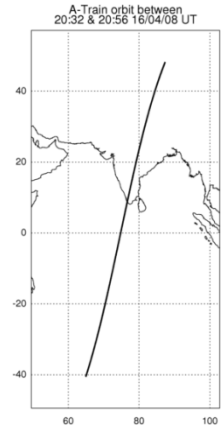


- **General good agreement in the vertical but no major differences with or without assimilation**
- **For some convective situations, too much aerosol is present in the upper troposphere in the model and analysis (likely to depend on interaction between convection/vertical diffusion and aerosol transport)**
- **Assimilation of optical depth obs do not constrain the vertical profile (only operate a total aerosol mass adjustment)**

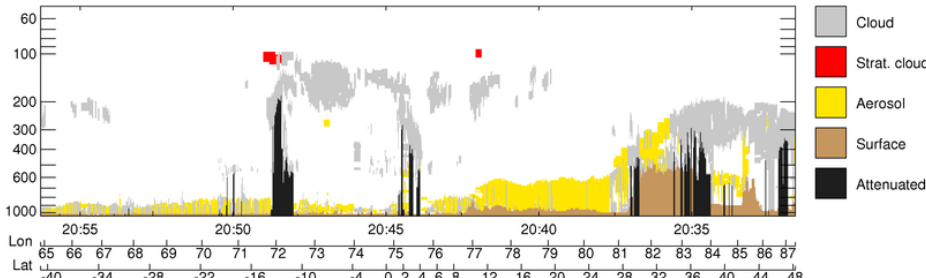


Simulated Aerosol Backscatter

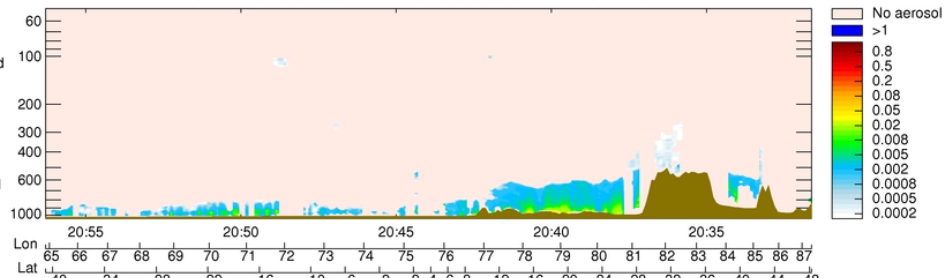
- Allows direct numerical comparison between CALIPSO & model



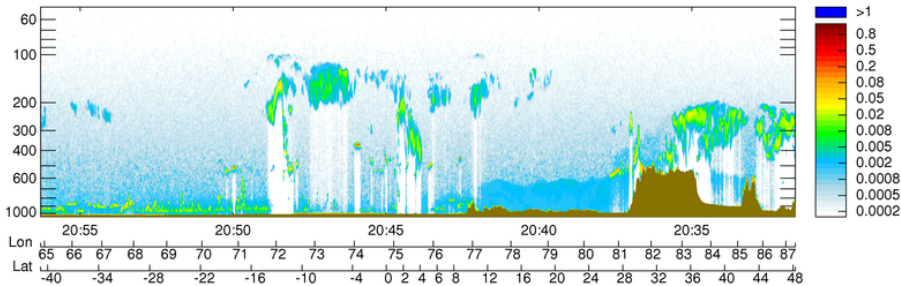
CALIPSO feature classification along 10150 km of A-Train orbit between 20:31:36 & 20:56:17 16/04/08 UT



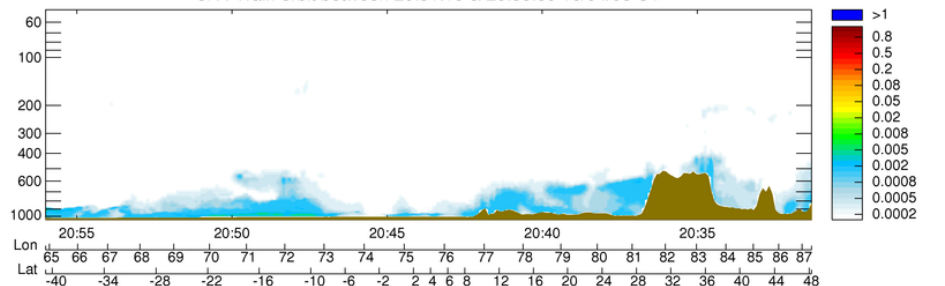
CALIPSO Aerosol Backscatter Coefficient ($\text{sr}^{-1}\text{km}^{-1}$) at 532 nm along 10150 km of A-Train orbit between 20:31:36 & 20:56:17 16/04/08 UT



CALIPSO Total Attenuated Backscatter ($\text{sr}^{-1}\text{km}^{-1}$) at 532 nm along 10150 km of A-Train orbit between 20:31:36 & 20:56:17 16/04/08 UT



Model (fb2u) Simulated Total Attenuated Backscatter ($\text{sr}^{-1}\text{km}^{-1}$) at 532 nm along 10149 km of A-Train orbit between 20:31:19 & 20:56:00 16/04/08 UT



Data requirements for verification

General:

- Good data quality
- Easy access and data format
- NRT access for immediate evaluation (1 day)

Short term:

- Collaborate with aerosol forecasting centres in defining data requirements (data providers)
- Develop common verification measures (forecasting centres)
- Use existing expertise from the operational and research communities

Long term:

- Invest in and promote AERONET-type activities and ground-based lidar networks
- Development of new products that can be used for validation (R&D community)

Summary and future plans

- The assimilation of MODIS aerosol optical depths has proven **successful** in providing initialisation for aerosol forecasts with the GEMS/MACC ECMWF model. Thanks to NASA/NESDIS for providing **MODIS data in real time** (typical latency is 1-2 hours).
- Verification activities have benefitted from provision of **near real-time AERONET data** (typical data latency is 1 day, thanks to NASA/GSFC) and are now expanding to use other observations (i.e. CALIPSO data).
- Inclusion of Aerosol Optical Depth data from different passive sensors (SEVIRI, AATSR) is promising and will provide a way forward in developing and maintaining the aerosol forecasting services
- A new, more complete aerosol model is being implemented and will be tested in assimilation. Model aerosols will eventually **interact with radiation** and cloud microphysics (at the moment they are assumed to be passive tracers)
- Work will continue on the assimilation of aerosol retrievals/observations from **passive and active sensors** (aerosol radiances, lidar backscattering)