

SATELLITE-BASED PM TEST CASE

Requirements Report

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1. INTRODUCTION

1.1 DOCUMENT SCOPE

The scope of this document is to describe the combined satellite data and core-downstream processing chain employed within Satellite-based particulate matter test case of the MACC project [RD1] and then set operational and scientific requirements on the basis of the implemented processing chain.

The document is a deliverable planned in the frame of O-INT_2 work package of O-INTERFACE sub-project of MACC project (grant agreement no. 218793).

1.2 DOCUMENT STRUCTURE

In the following paragraph the relevant context in which the service is inserted is introduced. Section 2 presents the main features of the satellite-based PM downstream test-case over Northern Italy geographical domain.

Section 3 is related to the requirements inferred from the implementation of the test-case. The list of acronyms and references are reported in Section 4.

1.3 CONTEXT

In the frame of MACC O-INTERFACE sub-project different core-intermediate and core-downstream processing chains have been tested.

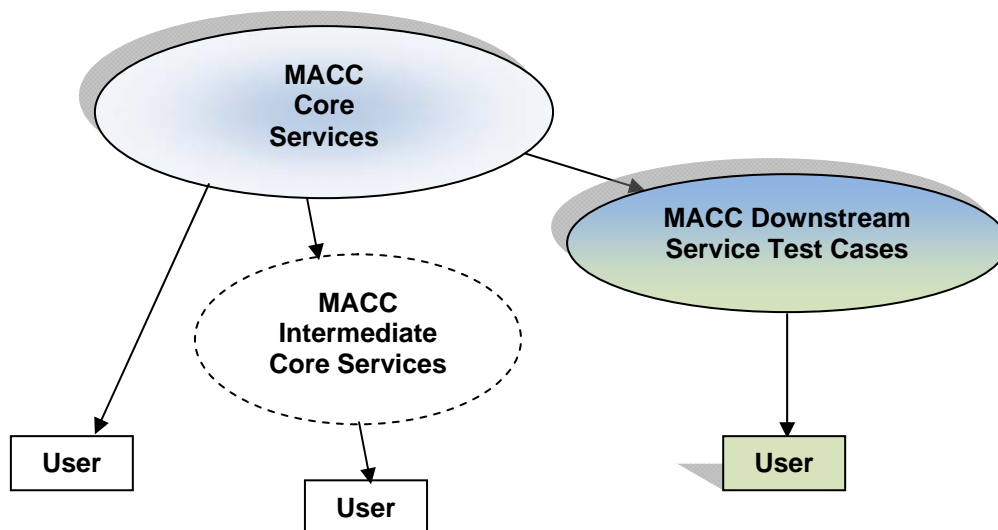


Figure 1. MACC project services relationships: Core-Downstream-Userlinks

Figure 1 highlights the relationships between MACC core services and “Users”. In particular, the MODIS(Terra/Aqua)-based Particulate Matter (PM) demonstration service over Northern Italy, has been implemented and managed by CGS, taking advantage of the heritage of PROMOTE air quality service.

The potential of monitoring PM concentrations by combining direct satellite observations with European meteorological and air quality data has been explored within this downstream service linked to upstream input data and core-service input.

Thus, this test-case turned out to provide an example of a downstream service linked to upstream (satellite) input data and core-service (ECMWF meteo and air quality) input.

It should be also mentioned that, in the frame of MACC, two Environmental agencies based in Northern Italy, namely ARPA Lombardia and ARPA Piemonte, have signed a Service Level Agreement with CGS highlighting their interest for this innovative monitoring tool.

2. SATELLITE-BASED PM PROCESSING CHAIN

2.1 INTRODUCTION

The Satellite-based Particulate Matter Test Case has demonstrated the possibilities for using satellite aerosol observations - i.e. MODIS - and meteorological initial and boundary conditions from MACC core service to provide an estimates of the near-surface particulate matter PM_{2.5} concentration. The data fusion algorithm underlying this processing chain is based on the experience developed in PROMOTE-ESA (2005-2009) and QUITSAT-ASI (2006-2009) projects.

In particular, the output provided to the ARPA users – as agreed in the SLAs – consisted in daily maps of concentration of PM_{2.5} at the spatial resolution of 10x10 km² over the Northern Italy domain for the whole period from 2005 to 2009.

Input data are represented by satellite aerosol data as retrieved by NASA in terms of Aerosol Optical Depth (AOD) from MODIS /Terra and Aqua observations [RD6]. The temporal corresponding meteorological characterization of the domain is also in input, defined by hourly fields of mixing layer height and relative humidity at the ground as simulated by MM5 on the basis of ECMWF analysis. Furthermore, gravimetric samplings of PM_{2.5} concentration at selected sites within the domain are employed to determine the AOD to PM projection coefficients and, subsequently, to compare and validate the test-case performances.

From the dynamic point of view, the software for the Satellite-based PM is characterized by two operational stages:

- *Calibration*, and
- *Estimation*

The first stage – *Calibration* – is aimed at the determination of monthly maps of calibration coefficients over the domain of interest, allowing the following stage – *Estimation* – to generate the final products in terms of daily maps of PM_{2.5} concentration at the ground in correspondance with MODIS observations. It should be pointed out that the *Calibration* stage is an off-line stage. Once the monthly calibration coefficients have been determined, the processing chain is composed only by the functions involved in the *Estimation* stage.

The Satellite-based PM software is now operative at the CGS premises in CNR Bologna and is thus able to provide daily maps of PM_{2.5} concentration [$\mu\text{g m}^{-3}$] over Northern Italy at the spatial resolution of 10x10 km² taking advantage of the synergy of aerosol satellite observations, meteorological simulations and PM samplings at the ground.

2.2 MAIN SOFTWARE FEATURES

As introduced above, the Satellite-based PM processing fuses EO MODIS data, from both Terra and Aqua platforms, meteorological simulations and ground-based data in order to provide final users with daily maps of PM_{2.5} concentration at the ground over the domain of interest.

A careful description of the architectural and component-level design together with the external interfaces and data has been detailed in the [RD9] SW configuration report.

It can be useful summarize here the main features of the satellite-based PM processing chain.

In particular, input data consist in

- ECMWF 3D analysis,
- MODIS level 2 aerosol data (MOD04, MYD04) , and
- PM_{2.5} samplings.

Final products are represented by

- daily maps of PM_{2.5} concentration

In Table 1 these data are summarized together with the Data ID, Content, Classification and Provider.

Table 1 – Input and output data for Satellite based PM processing.

Data ID	Content	Data Classification	Provider
Meteo_An	ECMWF 3D analysis	Input data	ECMWF
MOD_L2	MODIS level 2 aerosol data	Input data	NASA
PM25	PM _{2.5} samplings	Input data	ARPA and dedicated field campaigns
PMsat	PM _{2.5} maps	Final products	CGS

Thus, Satellite-based PM processing SW is able to procure data from :

- ECMWF core service for meteorological analysis fields [Meteo_An] by means of a dedicated FTP service
- NASA Data Base MODAPS for MODIS Level2 aerosol data [MOD_L2], by means of a dedicated FTP service, and
- PM_{2.5} Data Base for PM_{2.5} concentration measured at the ground [PM_{2.5}] provided by ARPA and from dedicated field campaign in the Po valley collected in the frame of QUITSAT project.

Moreover, a SatPM User interface allow users to look for data products and actually download data via a dedicated ftp site. Users' access to the Satellite Based PM and to its final products is regulated by the SLA agreed between CGS and each ARPAs.

The Satellite-based PM test-case is represented in Figure 2 in which the following four processing functions can be clearly recognized:

- meteo simulations,
- meteo post-processing,
- AOP extraction & geo-filtering, and
- Sat_PM processing.

A brief description of these functions is given in Table 2.

Blue arrows in the sketch show the data flux from the Archive to the functions which transform input data into internal data structures (light blue boxes) ending to final product [MODIS-based PM_{2.5} concentration over NI] .

Archive - grey dotted box - is employed for data storage and contains all the input data needed for the processing.

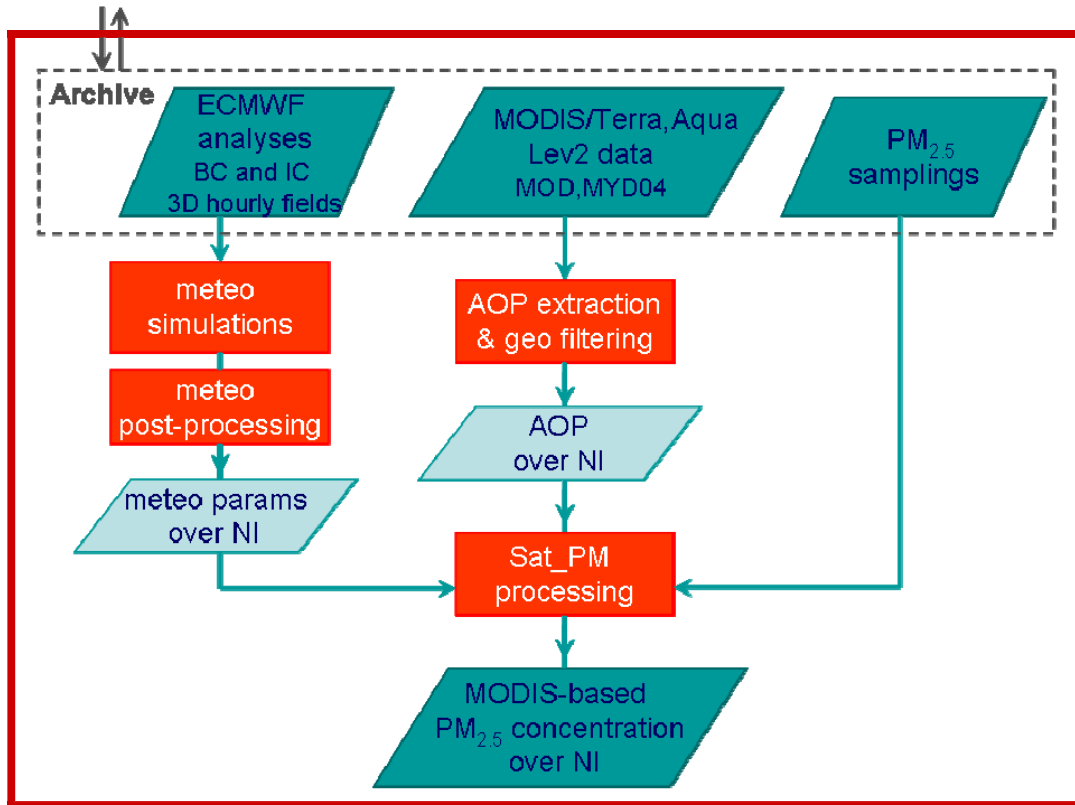


Figure 2. Schematic representation of the Satellite-based PM processing chain.

Table 2 – Functions composing the Satellite Based PM processing

Function	Description
Meteo simulations	Meteorological model (MM5) simulating hourly meteorological fields over the Northern Italy domain.
Meteo post-processing	This function extracts from the standard MM5 output the key parameters needed from the Sat_PM processing and convert them into a proper format [meteo params over NI]
AOP extraction & geo-filtering	This function has MODIS level 2 data in output [MOD_L2] and single out over the Northern Italy domain aerosol optical properties such as aerosol optical depth and optical depth ratio small, as internal data structure [AOP over NI].
Sat_PM processing	This function produces maps of PM _{2.5} concentration at the ground on the basis of the following input data <ul style="list-style-type: none"> aerosol optical properties from MODIS [AOP over NI], estimates of mixing layer height and relative humidity at the ground from MM5 [meteo params over NI], PM_{2.5} samplings data.

2.3 OUTPUT EXAMPLES

In Figure 3(a,b,c) are reported some results of the MODIS-based processing chain as presented also in [RD8].

Figure 1a presents the average map over the whole investigated period (2004-2008) showing that the area located north of the Apennines is characterized by the presence of higher values of PM_{2.5} concentrations with respect to the southern Apennines area. The winter mean from October 2006 to March 2007 shown in Figure 1b highlights significantly high concentration values, which are typical of the winter season. Figure 1c shows the 2007 summer map obtained as the average from April to September 2007, confirming that the Po valley is highly polluted also in the summer season.

From users interactions and comparison with CTM outputs, satellite-based PM_{2.5} estimates in the NorthernItaly domain turned out to be sufficiently robust to make realistic analysis, focusing on monthly and seasonal averages, and a reliable independent comparison for regional CTM models.

In the frame of PASODOBLE EC-FP7 project (2010-2013) the CGS satellite-based PM downstream service will also enable the processing of PM₁₀ concentration at the surface. It should be highlighted here that within this service is aimed towards a compliance monitoring of the PM concentration at the surface following the EU directive on Air Quality.

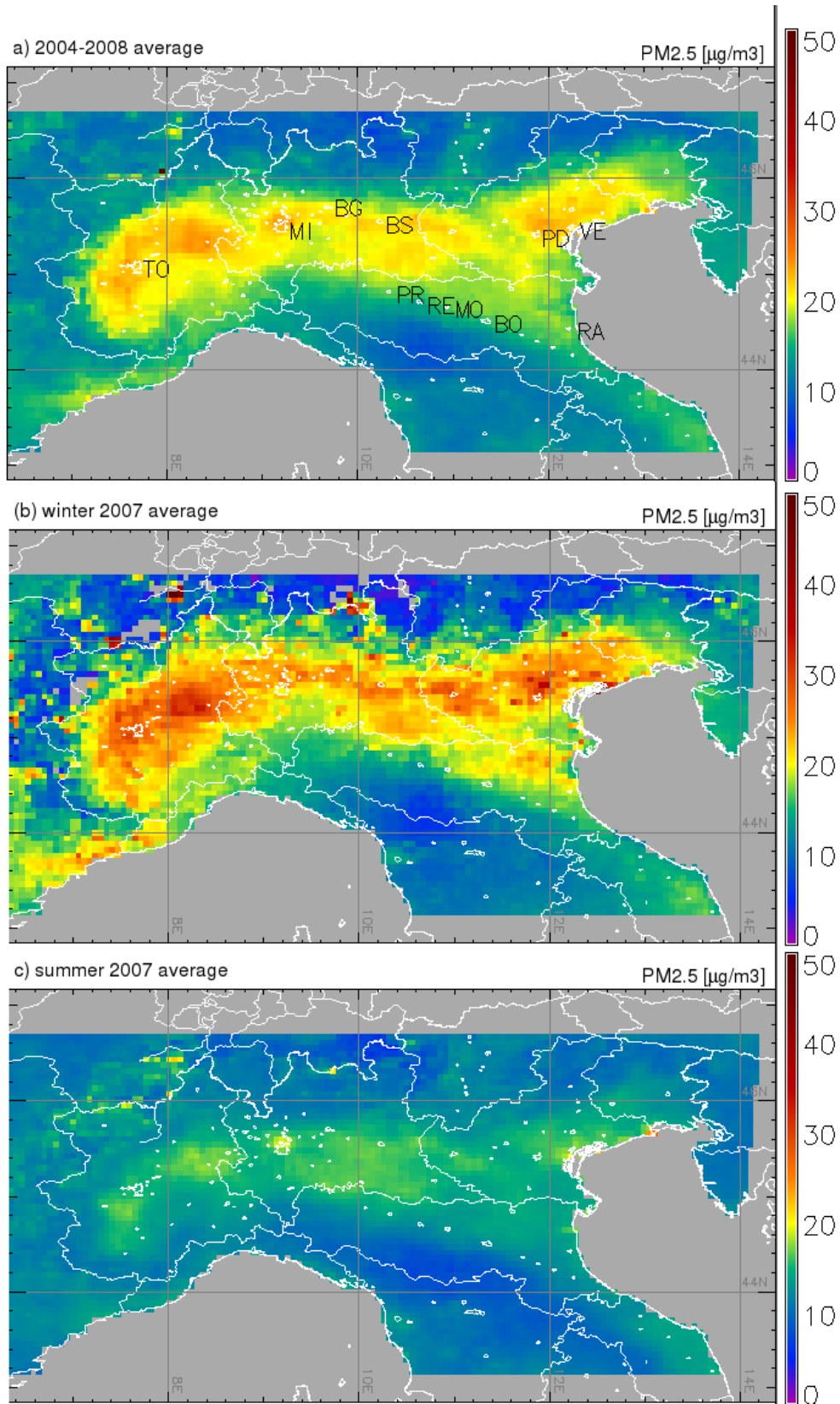


Figure 3. MODIS-based PM_{2.5} average maps over Northern Italy. a) Average values over 2004- 2008 period; b) Winter 2007; c) Summer 2007.

3. REQUIREMENTS ANALYSIS

A requirements analysis for the satellite-based PM test-case has been carried out on the basis of the software implementation and the data products processing relative to the whole period from 2004 to 2008 over the Northern Italy domain.

Concerning software implementation the main issues are represented by input data availability, in terms of meteorological fields characterizing the domain, aerosol satellite data and PM concentration in-situ samplings. On the other hand, about data processing and final products availability, no requirements arise concerning real time or near real time products availability. Actually, also on the basis on the interaction with ARPA users, historical records reconstruction turned out to be more important for environmental agencies institutional duties mainly relating to the analysis and evaluation of the spatial distribution of PM concentrations and averaged behaviours like seasonal, monthly and typical weekly averages.

Being PM_{2.5} objective of the last EC Directive regulations [RD5], the number of PM samplings at the ground will no more represent a critical constraint. The availability of several sampling sites spreaded in the area of interest will allow a more reliable determination of the monthly AOD to PM calibration coefficients.

Meteorological fields characterizing the geographical domain, in particular mixing layer height and relative humidity at the ground, represent a minor critical issue provided that archived ECMWF analysis are available. The meteo fields analysis procured through a dedicated ftp service (one of the needed external interfaces) are employed as boundary and initial conditions for the MM5 processing which takes place within the satellite-based PM processing chain to simulate hourly meteorological fields over the Northern Italy domain.

Aerosol satellite data can be regarded as a critical issue.

In this regards, MODIS life time is foreseen until 2012. Both Sentinel-4 and Sentinel-5 will be devoted to atmospheric composition monitoring. In particular, Sentinel-5 payload is expected to provide measurements of minor gases and columnar aerosol abundance. The Sentinel-4 payload will be embarked on the two Meteosat Third Generation–Sounder(MTG-S) satellites in geostationary orbit (planned to launch in 2017 and 2024). The Sentinel-5 payload will be carried on the post-EUMETSAT Polar System (EPS) spacecraft series (planned to launch starting in 2019). According to this concept, a Sentinel-5 precursor mission is planned to launch in 2013/2014.

Also data from NASA/NOAA satellite sensors on board NPOESS (National Polar-orbiting Operational Environmental Satellite System) could be profitably exploited for retrieving aerosol optical properties. being this mission seen as continuity to EOS-AM (Terra) and EOS-PM (Aqua) observations.

Within this Satellite System, VIIRS (Visible/Infrared Imager/Radiometer Suite), post-MODIS satellite sensor, will collect visible and infrared radiometric data (0.412-12.013 μm) providing data for the ocean, land, aerosol, and cloud research and operational users.

The NPP (NPOESS Preparatory Project) mission has the responsibility for measurements transitions from existing Earth-observing missions such as Aqua, Terra and Aura, to NPOESS. It will provide atmospheric and sea surface temperatures, humidity sounding, land and ocean biological productivity, and cloud and aerosol properties. The first NPP has been launched at the end of October 2011 and VIIRS acquired its first measurements by the end of November 2011. These measurements will help extend the record from earlier sensors like MODIS, which is a key issue for ensuring a continuity also in the satellite-based PM concentration monitoring.

It can be also mentioned here that in the frame of PASODOBLE EC-FP7 project (2010-2013) the CGS satellite-based PM downstream service will provide continuity to the estimation of PM_{2.5} concentration at the surface and will also enable the processing of PM₁₀. It should be highlighted that

within this service is aimed towards a compliance monitoring of the PM concentration at the surface following the EU directive on Air Quality.

Concerning the continuity of this test-case in the PASODOBLE downstream service, improvements in the processing and mainly in the core algorithm for estimating PM_{2.5} are planned. In particular, information on the PM vertical distribution at lower atmospheric levels can be achieved from chemical transport models (CTM), and thus a further function can be inserted in the processing chain making use of these CTM data for rescaling aerosol optical depth within lower atmospheric layers. In this view a link with MACC-II core service CTM ensemble products is envisaged and fostered and can be regarded as a desirable requirements in order to establish a further link between core and downstream services.

4. LIST OF ACRONYMS AND REFERENCES

4.1 ACRONYMS

AOD	Aerosol Optical Depth
AOP	Aerosol Optical Properties
ARPA	Regional Agency for Environmental Protection
ASI	Italian Space Agency
CGS	Compagnia Generale per lo Spazio SpA
CTM	Chemical Transport Model
DB	Data Base
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EO	Earth Observation
EOS	Earth Observing System
EPS	EUMETSAT Polar System
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FTP	File Transfer Protocol
GEMS	Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data
GIS	geographic information system
GMES	Global Monitoring for Environment and Security
GSE	GMES Service Element
HDF	Hierarchical Data Format
HW	hardware
MACC	Monitoring Atmospheric Composition and Climate.
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat second generation
MTG	Meteosat third generation
NASA	National Aeronautics and Space Administration
NI	Norther Italy domain
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
PM	Particulate Matter
PROMOTE	PROtocol MO尼Toring for the GMES Service Element: Atmosphere
QUITSAT	QUalità dell'aria mediante l'Integrazione di misure a Terra, da terra da SATellite e di modellistica chimica multifase e di Trasporto -
SLA	Service Level Agreement
SW	software
VIIRS	Visible/Infrared Imager/Radiometer Suite

4.2 REFERENCES

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