The AURORA Project and potential links with TEMPO and GEMS

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May 31° - June 1°, 2017
AURORA
in a nutshell

EU Framework Program: HORIZON 2020

Research Area: Leadership in Enabling and Industrial Technologies (LEIT)
Sub-program: Space

Call: H2020-Earth Observation-2015
Topic: EO-2-2015 Stimulating wider research use of Copernicus Sentinel Data

Project Title: Advanced Ultraviolet Radiation and Ozone Retrieval for Applications
Project Duration: 36 months (February 1°, 2016 – January 31°, 2019)
AURORA website: http://www.aurora-copernicus.eu/
The AURORA Consortium

Institute for Applied Physics «Nello Carrara» (IFAC-CNR), Italy

Belgian Institute for Space Aeronomy (BIRA-IASB), Belgium

European Center for Medium Range Weather Forecast (ECMWF), UK

Finnish Meteorological Institute (FMI, Finland)

Royal Netherlands Meteorological Institute (KNMI), Netherlands

Datacraft, Netherlands

Epsilon, Greece

Flyby, Italy

Science&Technology (S&T), Netherlands
Copernicus is the European Union Programme for Earth Observation implemented by the European Commission in partnership with the European Space Agency.

Copernicus aims to provide space and non-space Earth Observation data and accurate and reliable information for operational applications.
«Sentinel» missions
Six families of «Sentinel» space mission Form the space component of Copernicus.

**SENTINEL-1**
Mission providing all weather, day and night radar imagery for land and ocean services

**SENTINEL-2**
Mission providing high resolution optical imagery for land services

**SENTINEL-3**
Mission providing high accuracy optical, radar and altimetry data for marine and land services

**SENTINEL-4**
Geostationary mission for atmospheric monitoring

**SENTINEL-5**
Low Earth Orbit for atmospheric monitoring

**SENTINEL-6**
Radar altimeter for observation of the topography of the global ocean
**GEOstationary (GEO)**
- Hourly revisit time over Europe
- Mainly air quality
- Diurnal cycle of tropospheric composition
  ➔ **Sentinel-4**

**Low Earth Orbit (LEO)**
- Daily revisit time **global coverage**
- Climate, air quality, ozone & UV
- Tropospheric & stratospheric composition
  ➔ **Sentinel-5**
  ➔ **Sentinel-5 Precursor**
<table>
<thead>
<tr>
<th>Mission</th>
<th>Instrument</th>
<th>Utilization of data for</th>
<th>Imager</th>
<th>Infrared sounder</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sentinel-4</strong></td>
<td>UVN spectrometer (1)</td>
<td>FCI (2)</td>
<td>IRS (1)</td>
<td>LI</td>
</tr>
<tr>
<td><strong>Sentinel-5</strong></td>
<td>UVNS spectrometer (3)</td>
<td>VII (3)</td>
<td>IAS (3)</td>
<td>3MI</td>
</tr>
<tr>
<td><strong>Sentinel-5 Precursor</strong></td>
<td>UVNS spectrometer TROPOMI (4)</td>
<td>VIIRS (5)</td>
<td>CRIS (5,*)</td>
<td>ON</td>
</tr>
</tbody>
</table>

(1) on MTG sounder (GEO)
(2) on MTG imager (GEO)
(3) on MetOp-SG (LEO)
(4) on dedicated platform (LEO)
(5) on SNPP/JPSS (LEO)
(*) synergy on higher data level

UVN = Ultraviolet + Visible + Near Water Vapor 
FCI = Flexible Combined Imager 
IRS = Infrared Sounder 
LI = Lightning Imager 

UVNS = UVN + Short wave infrared
VII = Visible/Infrared Imager (Meteosat-8)
IAS = Infrared Atmospheric Sounder
3MI = Multi-viewing, -channel, -polarization

MTG = Meteosat Third Generation
**AURORA: Objectives of the project**

**SCIENCE**
- to investigate the **potential of data fusion and assimilation** to convey complementary information of the atmospheric Sentinels measurements into unique geophysical products
- to focus the **exploitation of the synergy** between simultaneous and independent measurements of the same target on *tropospheric O3* and *UV surface radiation*

**TECHNOLOGY**
- to **reduce the complexity** of managing the high volume of Copernicus S-4 and S-5 data and increase its quality
- to develop a **prototype data processing system** and demonstrate its capability to work with **simulated data** as close as possible to the operational environment.

**APPLICATION**
- To develop **two operational downstream services** (innovative mobile App for UV dosimetry and tropospheric ozone monitoring application for prediction of air quality)
INDIVIDUAL OZONE PRODUCTS FROM LEO AND GEO SENTINELS (UV, VIS AND TIR BANDS)

DATA COMBINATION FUSION AND ASSIMILATION

UNIQUE GEOPHYSICAL PRODUCTS FOR OZONE TROPOSPHERIC OZONE/ UV SURFACE RADIATION

DATA PLATFORM WEB-GIS PORTAL – VISUALIZATION TOOLS

PRE-MARKET APPLICATIONS DISSEMINATION

AURORA
The overall concept
Atmospheric Scenario and Data Simulation

**Atmospheric scenarios**  ➔ definition of the state of the atmosphere for forward calculation and generation of S4 and S5 synthetic measurements (ECMWF).

Atmospheric scenario (4 months of data) are generated from the **MERRA 2** re-analysis, provided by GMAO at NASA Goddard Space Flight Center.

**Sentinel-4 and Sentinel-5 data simulation**

- LEO and GEO UV L2 products for Ozone and associated VCMs and AKMs (FMI, with contributions from KNMI).
- LEO and GEO VIS L1 and L2 data for Ozone and associated VCMs and AKMs (BIRA-IASB, with contributions from KNMI).
- LEO and GEO TIR L2 products for Ozone and associated VCMs and AKMs (IFAC-CNR).
Simultaneous retrieval and data fusion

When two or more instruments sound the same portion of atmosphere and observe the same species, either in different spectral regions or with different observation geometries, two strategies are applicable to obtain the best estimate of the vertical profile

• **SIMULTANEOUS RETRIEVAL**
  to use all the observations acquired by the different instruments as input of a retrieval algorithm that has one unknown profile.
  - It provides the best estimate because it takes into account all the available information and rigorously handle non linear effects;
  - it is of difficult implementation because it requires a forward model that can simulate all the observations (made in different geometries and spectral regions) and the retrieval algorithm has to deal with a large amount of data.

• **DATA FUSION**
  to use a posteriori an algorithm that combines into a single estimate the profiles retrieved from the observations acquired by the different instruments.
  - the implementation is simpler, but usually it is not expected to have the same performance as the simultaneous retrieval, because the fusion method can cause a loss of information.
The Complete Data Fusion method

The AURORA system is adopting a novel data fusion method, the **Complete Data Fusion**, developed by Ceccherini et al. (2016) that:

- Takes into account the CM and te AKM of the profiles to be fused
- Provides results equivalent to those of the simultaneous retrieval (in linear approximation)
- Uses standard retrieval products and has very simple implementation requirements

**Reference**


(also available at the AURORA web site: http://www.aurora-copernicus.eu/data-fusion/)
The Complete Data Fusion method

Having N independent, simultaneous retrievals \((i=1, 2, ..., N)\) that provide independent estimates of the atmospheric species profiles (on a common vertical grid) and characterized by the CMs \(S_i\) and the AKMs \(A_i\):

\[
S_i \equiv \begin{pmatrix} \sigma_i \\ \sigma_i^T \end{pmatrix} = \left( K_i^T S_{yi}^{-1} K_i + S_{ai}^{-1} \right)^{-1} K_i^T S_{yi}^{-1} K_i \left( K_i^T S_{yi}^{-1} K_i + S_{ai}^{-1} \right)^{-1}
\]

\[
A_i \equiv \frac{\partial \hat{X}_i}{\partial x_{\text{true}}} = \left( K_i^T S_{yi}^{-1} K_i + S_{ai}^{-1} \right)^{-1} K_i^T S_{yi}^{-1} K_i
\]

- \(\sigma_i\): errors on
- \(S_{yi}\): CMs of the observations
- \(K_i\): Jacobians of the forward models
- \(S_{ai}\): CMs of the a priori profiles
- \(x_{\text{true}}\): true profile
The Complete Data Fusion method

The fused profile is given by:

\[
\mathbf{x}_f = \left( \sum_{i=1}^{N} \mathbf{A}_i^T \mathbf{S}_i^{-1} \mathbf{A}_i + \mathbf{S}_a^{-1} \right)^{-1} \left( \sum_{i=1}^{N} \mathbf{A}_i^T \mathbf{S}_i^{-1} \mathbf{a}_i + \mathbf{S}_a^{-1} \mathbf{x}_a \right)
\]

\( \mathbf{x}_a \): a priori
\( \mathbf{S}_a \): a priori covariance

The corresponding error covariance matrix is:

\[
\mathbf{S}_f = \left( \sum_{i=1}^{N} \mathbf{A}_i^T \mathbf{S}_i^{-1} \mathbf{A}_i + \mathbf{S}_a^{-1} \right)^{-1} \sum_{i=1}^{N} \mathbf{A}_i^T \mathbf{S}_i^{-1} \mathbf{A}_i \left( \sum_{i=1}^{N} \mathbf{A}_i^T \mathbf{S}_i^{-1} \mathbf{A}_i + \mathbf{S}_a^{-1} \right)^{-1}
\]

The corresponding averaging kernel matrix is:

\[
\mathbf{A}_f = \left( \sum_{i=1}^{N} \mathbf{A}_i^T \mathbf{S}_i^{-1} \mathbf{A}_i + \mathbf{S}_a^{-1} \right)^{-1} \sum_{i=1}^{N} \mathbf{A}_i^T \mathbf{S}_i^{-1} \mathbf{A}_i
\]
The complete data fusion method has been applied to a simulated TIR, VIS and UV Sentinel 4 dataset (1 month, 23881 pixels, same space-time locations) as a first step for the exploitation of the synergy between ozone measurements covering a wide range of spectral regions.

**Average total errors**

For each pressure level the error synergy factor (SF) is defined as:

\[
SF_{err} = \frac{\text{Min}_{1=1,...,N} \sigma_{i,tot}}{\sigma_{f,tot}}
\]

SF >1 synergy among sources of information

\(\sigma_{i,tot} = \text{total error of the } i\text{-th profile to be fused}\)

\(\sigma_{f,tot} = \text{total error of the fused profile}\)

**Average of the diagonal elements of the AKMs**

**Average error SF**

**Average number of degrees of freedom (DOF)**

<table>
<thead>
<tr>
<th>Spectral range</th>
<th>TIR</th>
<th>UV</th>
<th>FUS (TIR+VIS+UV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of DOF</td>
<td>4.9</td>
<td>3.4</td>
<td>5.8</td>
</tr>
</tbody>
</table>
State-of-the-art Data Assimilation Systems (DASs) will be used to combine the LEO and GEO fused profiles, and contrasted with the assimilation of standard retrievals.

Two DASs are available to AURORA:
- ECMWF Integrated Forecasting System (IFS)
- KNMI Chemical Transport Model DAS (TM5)

Output
Ozone vertical profile ➔ Tropospheric Ozone
   UV Surface Radiation

Assimilation of fused products versus assimilation of standard products
AURORA
Data Processing Chain
AURORA Technological Infrastructure

From an operational point of view, the data processing is executed in the AURORA infrastructure framework using a cloud-based architecture.
Validation

Validation Chain

- Translation of user requirements and of data/service specifications into validation requirements; conception of the Product Validation Plan (PVP).
- Performance assessment of retrieval/fusion/assimilation procedures and their resulting ozone and UV data products and associated uncertainties.
- Performance assessment of the full data processing chain and QA/validation of the final ozone and UV products using ground-based reference observations.

Applications

AURORA aims to develop two operational downstream services using innovative mobile App for UV dosimetry and tropospheric ozone monitoring application for major cities and regional prediction of air quality reaching a pre-market version at the end of the project.

Pre-market service on Urban Pollution Monitoring

Personal UV dosimetry

http://www.happysun.it/
International links

Strong links with a significant number of European and non-European projects.

- Link with **GEOSS** (Global Earth Observation System of Systems) and **CEOS** (Committee on Earth Observation Satellites)
- Link with **Ozone CCI** (Climate Change Initiative)
- Link with FP7 **smeSPIRE**
- Link with **TEMPO** and **GEMS**
- Link with **CAMS** (Copernicus Atmosphere Monitoring Service)
Possible cooperation with TEMPO and GEMS

First priority for AURORA:
comparative evaluation of the assimilation of Sentinel-4 and Sentinel 5 fused products versus assimilation of S-4, S-5 and TEMPO and GEMS data.

This might also be used as a first test case for the data exchange between AURORA and TEMPO and GEMS.

Additional cases can be considered at a later stage, based on the outcomes of the above mentioned evaluation.

Application of the AURORA prototype data processor to synergistic exploitation of GEO data from TEMPO (or GEMS) and LEO data from Sentinel-5 (or Sentinel-5p).
Proposed approach
(preliminarily agreed by AURORA scientific coord. and data assimilation teams)

To run the following sets of experiments:

- **Set A (use only Sentinel simulated data)**
  1. Exp1A: Control (assimilates standard retrievals from Sentinel simulated data on top of a baseline set of $O_3$ data)
  2. Exp2A: Fusion (assimilates fused products on top of a baseline set of $O_3$ data)
  3. Exp3A: Baseline (only assimilates the baseline set of $O_3$ data)

- **Set B (uses also GEMS & TEMPO data)**
  1. Exp1B: Control (assimilates standard retrievals from Sentinel/GEMS/TEMPO simulated data on top of a baseline set of $O_3$ data)
  2. Exp2B: Fusion (assimilates fused products from Sentinels/GEMS/TEMPO on top of a baseline set of $O_3$ data)
Thank you for your attention!

AURORA – Advanced Ultraviolet Radiation and Ozone Retrieval for Applications.

AURORA web-site: http://www.aurora-copernicus.eu/