Toward a COPERNICUS service for ground displacements from PS/INSAR Sentinel-1 data. Example from a pilot project in South West France

Philippe Durand, Mioara Mandea, Juliette Lambin, Frédéric Adragna (CNES)
Fifame Koudogbo (CLS), Daniel Raucoules (BRGM), Michel Diament (IPGP-Form@Ter)
OUTLINE

» Copernicus services and background

» A EU-Ground Motion Service for Copernicus ?

» French analyse and initiative

» Pilot project in SW France
FULL, FREE AND OPEN ACCESS TO DATA

- ATMOSPHERE MONITORING
- MARINE ENVIRONMENT MONITORING
- LAND MONITORING
- CLIMATE CHANGE
- EMERGENCY MANAGEMENT
- SECURITY

Copernicus
Europe's eyes on Earth
Components & Competences

Coordinators:

Partners:

Industries
National Space Agencies
Private companies
Eumetsat

Overall Programme Coordination

Space Component

Services Component

In-situ data are supporting the Space and Services Components
ESA PS Journal

Meeting 2015 Collaborative GS WS #10 & #11
The ‘Sentinel-1 European WW Persistent Scatterers (PS)’, with an overarching objective to prepare and maintain a European datasets and database of World Wide Persistent Scatters (PS) for public usage.

ESA dedicated technical note including a proposal for the PS Journal scope and implementation approach.

Recommendation: preparing a presentation to the Copernicus User forum addressing how the Journal could support the generation of value-added products and services as well as research activities in public/private sector.
Under in the impulse of BGR (German Geological Survey),

3 meetings at a European level, including 13 Copernicus participating states, were held in Nov 2016, March and July 2017.

The objective of these meetings was to **discuss and consolidate user needs and to scope key specifications for a European Ground Motion Service (EU-GMS)**. (France representatives : CNES, IPGP, BRGM, CLS)

**A white paper** was proposed to the stakeholders in summer 2017 :

> following slides are exposing the main content of a proposed EU-GMS
What is EU-GMS?

EU-GMS is a service that aims at providing consistent, regular, standardized, harmonized and reliable information regarding natural and anthropogenic ground motion phenomena over Europe and across national borders, with millimeter accuracy.

Main objective:

Measure ground displacements, including landslides and subsidence, as well as deformation of infrastructure.

Derive Ground motion from time series analyses of Copernicus Sentinel-1 data using PS (Persistent Scatterers) and DS (Distributed Scatterers) radar interferometry approach.

Complement GNSS and other in-situ observations.

Provide tools for visualization, interactive data exploration and user uptake elements for further ground investigations.
A Pan-European Service

Processing at a European scale is efficient, providing a uniform product for large and small countries.

Pan-European service is needed to reach:

- public users
- commercial downstream service providers,

Several Copernicus Participating States have already or are in the process of implementing national ground motion services.

All these services will both benefit from and complement the EU-GMS.

EU-GMS can provide the opportunity to uniform and standardize national service components.
Target Applications

- Natural and man-induced geohazard assessment
- Geodesy
- Land management, urban and rural planning
- Climate services
- Infrastructure development and management
- Mining and other natural resources extraction
- Dam and groundwater monitoring
- Insurance topics and mitigations
- Structural and civil engineering
- The property market
- Railway and road management
Targeted users

Direct Users of EU-GMS:

- Geological and geodetic surveys
- Public authorities at European, national, regional and municipal levels
- Academia

Downstream Services Users:

- Road, railway and mining administrations
- Regulators and planners
- Citizens of Copernicus participating states
- Industry
- Academia
Service definition 1/3

EU-GMS provide ground motion time-series information with **full spatial and temporal resolution** based on interferometric analysis of Sentinel-1 time-series.

**Area covered**
Copernicus participating states.

**Frequency of product updates**
Updated every 12 months.

Updates should be generated incrementally, i.e. by processing newly acquired images rather than the whole data inventory from scratch.

Data processed and archived in epochs of e.g. 5 years in order to monitor the temporal evolution of deformation patterns.

**Spatial resolution**
The InSAR processing of time series in EU-GMS shall be based on using the Sentinel-1 IW mode **SLC products at 5x20 meter resolution**.

Expected scatterer density:
- **thousands points per km²** for urban areas
- **hundreds points per km²** for non-urban areas

**Full spatial resolution not degraded** or down sampled
Service definition 2/3

Temporal resolution
Ascending + Descending every six days.

Methodology
From these data, ground motion can be derived using InSAR time series analyses. There are many different InSAR processing concepts, and common to all is an end product consisting of a set of ground motion time series valid for specific points or pixels, with a corresponding quality measure.

In order to provide a seamless and consistent EU-wide ground motion base map, the processing method in the **EU-GMS will be standardized using state-of-the-art algorithms.**

The final products and intermediate auxiliary data will be made available, so that local deformation phenomena can be processed with special user or specific algorithms.
Service definition 3/3 – Main products

(Level 1 Single Look Complex data : input data only)

Level 2a – an intermediate product
Basic displacement information provided in the satellite line-of-sight (LOS), projected to ground geometry and quality measures per measurement point. Community best practices and state-of-the art algorithms shall be used in data processing and analysis.

Level 2b
Level 2a products integrated into a standardized reference frame using external information such as GNSS network measurements and mosaicked. For products integration and mosaicking, best geodetic practices will use EUREF network for georeferencing.

Level 3
East-West and Up-Down deformation rates produced by combining Level 2 data stemming from ascending and descending orbits. Granularity of level 3 product, i.e. maximum granularity, sampling grid size, depends on the area of interest, and the deformation signal.
Identified Links to services and other initiatives in Europe

Copernicus Land Monitoring Service: http://land.copernicus.eu

Copernicus Emergency Management Service (EMS): http://emergency.copernicus.eu

Copernicus Climate Change Service (C3S): http://climate.copernicus.eu

OneGeology: http://www.onegeology.org/

European Plate Observing System (EPOS): https://www.epos-ip.org/

European Soil Data Centre (ESDAC): http://esdac.jrc.ec.europa.eu/

Reference frame Subcommission for Europe (EUREF): http://www.euref.eu
Foreseen schedule for EU-GMS

2017/18  Preparation Phase
technical definition of product content, format, quality indicators, metadata, etc.; service implementation concept; preparation of the tender; setting up validation group.

2018 Tender for initial production/operation

2019 Initial Production Phase

2020 production, service setup, delivery of products, first validation activities

2020+ Tender for Routine Operations Phase: regular updates and validation activities

Need for a EC approval
French analyse and initiative

Governemental Institutions

**BRGM** (French Geological Survey)expertises in InSAR and PS at European level
(TerraFirma, PSIC4, Pangeo…)
**CNES** (French Space Agency) expertises and InSAR promoter (DIAPASON…)
…also InSAR & POLinSAR activities in **CEA, ONERA**

Private compagnies

**CLS/TRE-ALTAMIRA** with well known expertise
1999 Altamira spin off creation
2010-2015 Altamira and TRE integrate CLS group

Scientific Community

Research laboratories (from CNRS, ENS, IPGP, IRD, Universities …) are very active in the use and
development of InSAR and PS new methods of analysis supported by national fundings (from ANR,
CNES,…) as european ones (such ESA). They are federated in the **ForM@Ter** data and services pole
that also represents the French scientific community in the dedicated EPOS Thematic Core Service
and various National Research infrastructure for acquiring complementarity in situ data.
Past projects based on extended PSI
where BRGM (French Geological Survey) contributed

- **Terrafirma** (EU funded)
  BRGM role: *validate the relevance of the output from PSI processing as a geological and engineering product, to identify causes for the observed ground motion and produce hazard related products of use to end-users*

- **PSIC-4** (ESA funded)
  BRGM role: Persistent Scatterer Interferometry Codes Cross-Comparison And Certification - validation and cross comparison with ground truth.

- **Pangeo** (EU funded)
  BRGM role: provide information coupling the stability of the ground on which we live to Geological information already held by the National Geological Survey

**Exemple: Combination with ancillary data (e. g. geology) / interpretation:**

Possible ancillary data from BRGM:
- Hazard maps
- Ground motion database (BD MVT)
- Ground cavities database (BD Cavités)
- Geological maps
- Hydrogeological informations

Image: PSI results on clay shrink-swell hazard map (Toulouse area). Source (pangeo/brgm/altamira)
What products - National or European products? (1/2)

- Precise displacement data can provide “sensitive information” which should be managed with care.

- InSAR data would be published on the web with no interpretation; make them accessible to the general public can be misleading.

- Displacement data and velocity maps are not risk maps, however, they can cause concern and cause “false alarms” within uninformed public.

- Precise displacement maps can provide conclusive data to Public Administration and Governmental agencies about whether or not some local or national regulations are followed (e.g. maximum subsidence rates over O&G reservoirs or coastal areas, illegal water pumping, etc.).
What products - National or European products? (2/2)

- High-Resolution (HR) displacement data over a whole country should be managed by individual member states.
- There are, however, InSAR services which have a broader (transnational) scope and for which a European service could be envisaged (e.g. subsidence along coastal areas all over Europe or the generation of water vapor maps from InSAR data).
- Copernicus products should not kill the InSAR market. Free downloadable HR InSAR can be a threat for any commercial applications (+ potentially misleading if not interpreted), medium resolution data can create awareness and foster the adoption of the technology.
- New Copernicus products must be “in phase” with other UE/ESA initiatives EPOS/GTEP/etc. and their end-users have to be defined/identified in detail.
Step-by-step approach

To come up with a national InSAR service, we recommend a step-by-step approach to carefully evaluate all aspects of the project.

- **Proof Of Concept** – an area of about 20,000 km\(^2\) has been selected. On this area, all products/deliverables foreseen for the national service will be generated and evaluated with potential users.

- Creation of the so called «baseline» - all data acquired by Sentinel-1A/B over France are processed, geocoded and the geo-database is created. The processing chain is tuned for a national service and the web-based platform is optimized for quick and reliable queries and early warning.

- Start of the **monitoring service** on a national scale – here the key parameter, impacting also on the cost of service, is the frequency of update of the information.
The pilot project focussed on a 2 year duration of Sentinel1 IW SLC data.

More than 50 images acquired in each mode have been processed to provide deformation data over the area of interest.
**Pilot project – The possible applications**

- Various themes that can be addressed within the pilot area to serve as a demonstrator.
- The results will make it possible to evaluate the interest of the information provided and the possible upgrade of the service at national or European level.
Pilot Project – The results
Ascending
LOS 20m
Descending
LOS  20m
East-West Component 40m
Vertical Component 40m
Pilot Project – Focus result
City of DAX: a unique experience

» a community that finances itself long term HR InSAR studies

- The 2010 study, based on ASAR (2003-2010) data, allowed the InSAR potential to be demonstrated. Antea's interpretation of the source of the subsidence measured on the Sablar district was decisive.

- The 2013 study made it possible to validate the contribution of this solution by considerably densifying the number of measurement points with the use of High Resolution. A Corner Reflector network was installed.

- The 2016 study was dedicated to the analyse of ground motion over the whole Dax agglomeration using 2012-2015 HR data stack.
Pilot project  – The Sablar district in DAX

Despite the short duration of the analysed period, the generalised subsidence on Sablar is visible with IW S1 data.
Not define as EU-GMS product – The SAR image analysis
Climate change (floods)
Not define as EU-GMS product: Atmospheric Phase Screen for each pass
**Conclusions**

» **Sentinel-1** data can play a **key role** in fostering the adoption of InSAR data.

» InSAR results should be treated with **care**. They provide **sensitive**, though extremely useful, **information**.

» Individual **member states** should look after the data of their **own territory**, taking into account also local and national regulations to tune the service accordingly.

» There are **information layers** based on InSAR data which could be considered of **«European interest»** (e.g. motion along coastal areas). In this case, we recommend an international management.

» CNES is well aware of the potential of the InSAR technology and the Copernicus program, and has already planned a set of activities aiming at a **national service** based on Sentinel-1 data.

» Key features for any national service are: **data usability, reliability, regular update** as well as a **training program** for all potential users.

» The **planned service** is **nationally** based for the reasons above mentioned and is **viewed as a brick** (element) for the building of a EU-GMS service in the Copernicus framework
B/U SLIDES
Main potential applications/limitations in France for a 100mx100m gridded product: BRGM feedback

- **Urban vertical motions** (phenomena size > few hundreds of m): different origins (workings, fluid extraction, cavities, salt/gypsum dissolution, urban landsliding)

- **Gas storage/Geothermal exploitation.** The 6 days repeat cycle will allow full injection/extraction cycles monitoring. The expected size of deformation is appropriate for 100x100m cell product. In certain cases new/future regulation could require InSAR monitoring.

- **Post-Mining** (there are no more active mines in France). The monitoring is focused on the evolution of areas of past underground mining. The product can be useful (except for sudden or very localized ground motion).

- **Coastal management.** Increase of coastal vulnerability due to combination of sea level rise and land motion. In certain cases, the 6 days repeat cycle would allow successful PSI processing on short periods. In other cases, best targets are the coastal urbanizations. BRGM is developing services on climate changes (i.e. ERANET ERA4CS). Such applications could integrate the PSI product.

- **Landslides.** In France, 100m grid resolution is a major limitation to landsliding monitoring as most of threatening slides are smaller than that. The 6 days repeat cycle is interesting for targeted rates, from cm/yr to dm/yr. This is the application for which ascending+descending processing is essential as there is an important horizontal component of the displacement.

- **Clay Shrink-Swell hazard.** The 100m grid could be a limitation as there is strong local motion variability.
## Projet Pilote – précisions

<table>
<thead>
<tr>
<th>Mesures</th>
<th>Direction de la mesure</th>
<th>Résolution spatiale</th>
<th>Ecart-type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitesse moyenne de déplacement</td>
<td>LOS</td>
<td>20 m</td>
<td>± 1 mm/an</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td>40 m</td>
<td>± 3-4 mm/an</td>
</tr>
<tr>
<td></td>
<td>Est-Ouest</td>
<td>40 m</td>
<td>± 6-7 mm/an</td>
</tr>
<tr>
<td>Mesure individuelle de déplacement</td>
<td>LOS</td>
<td>20 m</td>
<td>± 5 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Localisation du point de mesure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position Nord</td>
</tr>
<tr>
<td>Position Est</td>
</tr>
<tr>
<td>Hauteur ellipsoïdale</td>
</tr>
</tbody>
</table>

Précisions théoriques à 1 km du point de référence
Valeurs obtenues à partir de l’analyse d’un jeu de 55 images S1 acquises sur une période de 24 mois.
France
Espagne