

**COMITÉ ESPAÑOL DE GÉODÉSIE ET GÉOPHYSIQUE
SPANISH COMMITTEE OF GEODESY AND GEOPHYSICS**

NATIONAL REPORT ON GEODESY OF SPAIN

**FOR
2015 - 2018**

IUGG XXVII GENERAL ASSEMBLY

PREFACE

This report outlines some Spanish activities in Geodesy for the period 2015 to 2018. It has been prepared for submission to the International Association of Geodesy (IAG) on the occasion of the XXVII General Assembly of the International Union of Geodesy and Geophysics in Montreal, Canada, July 7 to July 17, 2019. It is issued on behalf of the Spanish Committee of Geodesy and Geophysics.

In the report the main activities in Geodesy developed in Spain in the period 2015-2018 by different Institutions are presented. These Institutions in alphabetic order are.

1. Cartographic Institute of Valencia. Consejería de Vivienda, Obras Públicas y Vertebración del Territorio. VALENCIA
2. Cluster of Geodesy Research Attached to the Applied Mathematics Department of the EPS. University Of Alicante. ALICANTE
3. Department of Applied Geodesy. Aranzadi Society Of Sciences, SAN SEBASTIÁN
4. Department of Astronomy and Geodesy, Facultad de Ciencias Matemáticas Universidad Complutense, MADRID.
5. Geosciences Institute (Instituto de Geociencias) Consejo Superior de Investigaciones Científicas-Universidad Complutense de Madrid, CSIC-UCM. MADRID
6. Institut Cartogràfic i Geològic de Catalunya. BARCELONA
7. Microgeodesia Jaén Research Group. Universidad de Jaén, JAEN
8. National Geographic Institute (Instituto Geográfico Nacional). Ministerio de Fomento. MADRID.
9. Royal Institute and Observatory of the Navy. (Real Instituto y Observatorio de la Armada). San Fernando, CÁDIZ.

The information provided by the Institutions has been incorporate in the Report, and due to the quantity and diversity of works done some of these have been resumed, giving for each Institution a list of the activities followed by the list of papers published in the period.

Madrid, June 2019

**Miguel J. Sevilla
(IAG Spanish National Correspondent)**

1. CARTOGRAPHIC INSTITUTE OF VALENCIA

**Consejería de Vivienda, Obras Públicas y Vertebración del Territorio
Generalitat Valenciana
carrer de la Democràcia 77, 46018 –VALENCIA (SPAIN)
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a) Areas of Research

1. New approaches of global augmentation services by means of Precise Point Positioning

Precise Point Positioning (PPP) has revolutionized Global Navigation Satellite Systems (GNSS) processing. This computation method achieves precise positioning with a single receiver and undifferenced observations. Its conceptual basis consists of solving the position with pseudo-range and carrier-phase GNSS measurements, with the application of external clock and orbit satellite corrections, previously estimated signal biases and atmospheric products computed in the International GNSS Service or Analysis Centers.

The Cartographic Institute of Valencia (ICV) have done different researchs in order to analyse the performance of PPP for different applications, specifically in the real-time case study. Different analyses were done in order to show how multi-constellation and multi-frequency approaches for external products reduces loss of convergence and outliers in the real-time PPP solutions. Combined products latency have been improved by means of own combination products. The impact of ambiguity resolution in PPP with the phase bias application is also demonstrated in different studies. New standardization products in the present and future stages of the development of models are being analyse actually for real-time.

2. Maintenance of the GNSS Reference Station Network of Valencia (ERVA Network)

The Cartographic Institute of Valencia is responsible for the maintenance and management of the products and services generated by the GNSS Reference Station Network of Valencia (ERVA Network). This network provides coverage of GPS / GNSS data in the Valencian Community, (east area of Spain), and provides real-time and RINEX data. In order to contribute to the definition of the reference frame and global products, the network also provides data to the EUREF network and the EUREF densification network, to the E-GVAP project and it recently has joined the EPOS implementation stage.

For this reason, in recent years, a deep upgrade of the network receivers has been developed and new receivers are being gradually incorporated with multi-constellation tracking. Also, ERVA network densification has been developed based on the demand.

-Renewal of GNSS stations

After 10 years of setting up some receivers, these are the updates:

-2015: Deni station was replaced with a receiver with GPS + GLONASS + GALILEO tracking

-2016: Renewal of the EUREF station BORR (Borriana-Castellón) with a receiver with GPS + GLONASS + GALILEO + BEIDOU.

-2016: Expansion of the network of permanent stations with the new station in ARAS (ARAS de los OLMOS -Valencia) with a receiver with GPS + GLONASS + GALILEO + BEIDOU tracking, in the Astronomical Observatory of the Valencian University with cooperation of the Mediterranean Center for Environmental Studies (CEAM).

-Substitution of BERG station (Bergantes -Morella-Castelló).

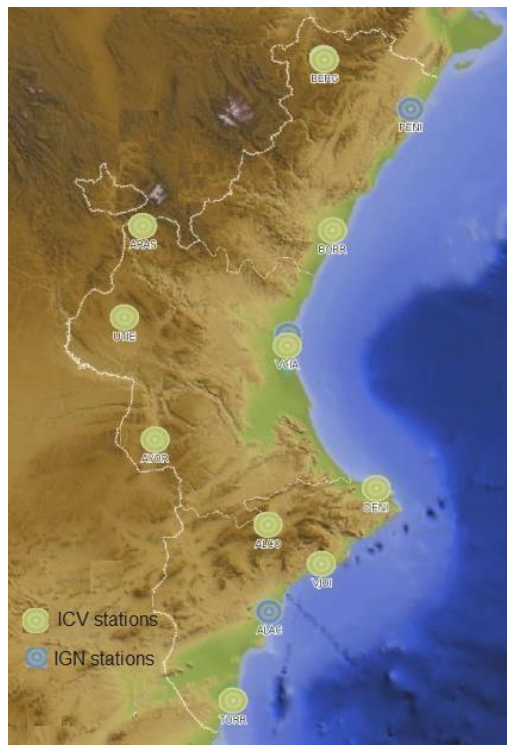
-2017: Renewal equipment for ALCO station (Alcoy-Alicante) with a receiver with GPS + GLONASS + GALILEO + BEIDOU.

-2017: Renewal of the station UTIE (Utiel-Valencia) with a multi-constellation receiver also.

-2017: Densification of the network of reference stations with the study and installation of the new permanent station VJOI (la Vila Joiosa -Alacant) that began to give data in 2018 with a receiver with GPS + GLONASS + GALILEO + BEIDOU.



Installations of the Astronomic Observatory of the Valencian University with the reference station of Aras de los Olmos (CEAM-ICV) .



ICV GNSS Stations

-Adoption and quality control of the new combined coordinate results of the working group of the Geodetic System Commission of the Consejo Superior Geográfico thanks to the work of the members of the group (ARA DAC analysis center, IGC-CAT DAC analysis center, IGN analysis center and ITACYL computations).

-The Cartographic Institute of Valencia did an active collaboration as a member of the working group for real time services and the website design for all reference stations in Spain, in the Geodetic System Commission of the Consejo Superior Geográfico. An important task of the group has been the development of REDGAE webpage and the homogenization of the names of the mountpoints for real-time services in the whole country.

-Complete renovation of GNSS network software

After some years of the last renewal, ICV has updated its positioning infrastructure completely in the control-center with regard to the servers and software that generate RINEX products and real-time corrections. As a novelty, new multi-constellation real-time services of simple station and network solution have been created in RTCM3 -MSM5 format and also with GPS, GALILEO and GLONASS.

The Cartographic Institute of Valencia began to publish RINEX 3.0x files with multi-constellation observations during this period, by means of implementation of new routines.

3.BIG DATA analyses and market segment data mining with GNSS data in real time

The objective of this study has been to analyze the potential of Big Data for the calculation of the statistics of the GNSS network, the performance and the analysis of Geo-spatial data markets and sectors for decision making. In order to achieve this purpose, other data apart from GNSS, are necessary in order to analyse the results and the performance.

Real time data and registers of the GNSS reference station of Valencia provide a suitable scenario for the application of Big Data techniques. Decision making or assessing alternative solutions about the densification of the network are important questions. Also, the use of real time GNSS in rural - areas with precision agriculture help to know how new technologies are improving economy based on agriculture in these area, this question is important regarding the depopulation that suffers the west area of Valencia. Other sectors like infrastructures, logistics and research have been always increasing its performance with the use of GNSS public service.

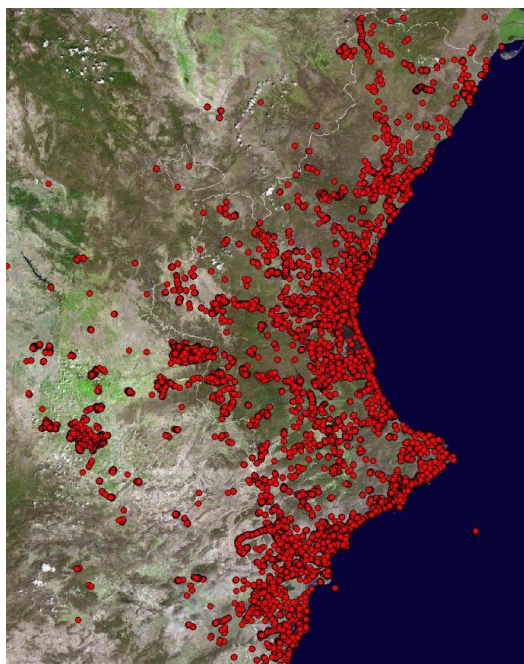
The large amount of information generated in geo-spatial techniques and in particular in the network of reference stations of Valencia (ERVA) makes the Big Data approach very useful. For this approach, Volume, Variety and Speed are three important characteristics:

-Volume of considerable information: for example, only in September 2018 more than 150,000 connections were generated, which had to be debugged and analyzed.

-Variety of the registers because several parameters are stored: satellite tracking, quality of the solution, time-span, PDOP, ionospheric quality, in several formats like XML, MDB, MSQ or NMEA-GGA STREAMS.

-High speed: the generation of the data and statistics in real time.

Combination with other data sources, like demography, kind of land cover or land use, type of crop lands, infrastructures and industrial areas, was successfully done using non-relational database systems. The performance of the real-time service is also being analysed with the combination of the real-time solution reports with error data sources Machine Learning and Artificial Intelligence algorithms.



Connections detected to the real-time service of the GNSS Network of Valencia in three years

4. Passive Fourth order geodetic network

New campaigns for the maintenance and upgrade of the Fourth Order geodetic network have been carried out, its survey monuments were reviewed, and their stability, coordinates, status, access and place names in co-official languages have been verified. In the description of the access of the geodetic markers, the name of the roads and place names have been updated when necessary as well as the graphical description access.

The geodetic markers revised throughout the period corresponds to a surface that covers 100000 Hectares in 2016, 240000 Hectares in 2017 and 250000 Hectares between 2018-2019, updating more than 380 geodetic markers. The corresponding description of the updated signals of the network is available in internet.

b) Scientific Program

PH. D. THESIS

Ph D. Student: Raquel Maria Capilla Romá

Title: Aportación al estudio de la capacidad de los modelos conceptuales en posicionamiento absoluto preciso, Precise Point Positioning, para tiempo real a través del análisis del rendimiento de productos y prototipos en un escenario multi-constelación GNSS

Director: Jose Luis Berné Valero

Date: July 2015

Qualification: Sobresaliente Cum-Laude

MSC. AND GRADE DISSERTATIONS (Co-direction):

Student: Sandra Coba Dart

Title: Implementación y utilización de herramientas de código abierto y software libre para GNSS

Date: September 2015

Qualification: Sobresaliente

Student: Antonio Hermosilla Rodrigo

Title: Simulación de escenarios y casos de estudio de la técnica GNSS Precise Point Positioning (PPP) en tiempo real y post-proceso. Cálculo y análisis mediante programación en lenguaje Python.

Date: December 2014

Qualification: Sobresaliente

Currently PH D. Students with co-director in Cartographic Institute of Valencia:

Student: Mutaz Qafesheh

Title: Establishment of an early warning protocol for deformation monitoring using Real-Time Precise Point Positioning technique

Meetings attended

-EUREF 2016 Symposium- SAN SEBASTIAN. May 25 th-27 th, 2016

Master and GRADE lecturer in December 2016, May 2017 and May 2018: The staff of the Cartographic Institute of Valencia participated in the degree of Geomatics of the Polytechnic University of Valencia and in the Master's Degree in Geomatics Engineering and Geoinformation with presentations about geodetic networks and GNSS scientific and current applications such as deformation control, tropospheric analyses and performance of applications with Precise Point Positioning technique. The sessions also focused on the services of the Valencian Community.

c) Publications

Capilla R. Avances y Aplicaciones en los sistemas GPS/GNSS. Georeferenciando el territorio con los servicios y datos públicos de la Comunitat Valenciana. Actas de las Jornadas de Los Sistemas GPS/GNSS en la geo-referenciación del territorio. Casos actuales y avanzados de uso. 2016 Alicante (Spain). March 2016.

Capilla, R., Berné, J.L, Martín, A., Rodrigo, R. (2016): Simulation case study of deformations and landslides using real-time GNSS precise point positioning technique. *Geomatics, Natural Hazards and Risk* 7:6 , 1856-1873. Taylor & Francis.

DOI: <http://dx.doi.org/10.1080/19475705.2015.1137243> ISSN Print: 1947-5705; online: 1947-5713.

Capilla, R., Berné, J.L, Hermosilla A. (2017) : Impact of multi-constellation products and ambiguity resolution in Precise Point Positioning for real-time measurements.

Measurement Journal of the International Measurement Confederation 100, 183-193. Elsevier <http://dx.doi.org/10.1016/j.measurement.2016.12.047>

ISSN: 0263-2241

Martín A., Anquela A.B, Capilla R., Dimas A. Bigdata and GIS analysis tools applied to real-time user connections to the GNSS reference stations network of Valencia. Proceedings of the 6th International Colloquium on Scientific and Fundamental Aspects of GNSS /Galileo. Valencia Spain. October 2017

Capilla R.Martín A.Berné, J.L. Multi-constellation products and ambiguity resolution in real-time Precise Point Positioning with GPS+GALILEO. Proceedings of the 6th International Colloquium on Scientific and Fundamental Aspects of GNSS /Galileo. Valencia Spain. October 2017

Capilla, R., Berné, J.L. (2018): Evaluation of the ongoing development of GALILEO satellite precise orbits and clocks. In press.

(The information of this Institution has been remitted by R.Capilla)

2. CLUSTER OF GEODESY RESEARCH

ATTACHED TO THE APPLIED MATHEMATICS DEPARTMENT OF THE EPS, UNIVERSITY OF ALICANTE (SPAIN)

<https://www.ua.es/es/index.html>

<https://web.ua.es/en/wgterv>

Presentation

The Cluster of Geodesy (CG) of the University of Alicante (UA) has its origin in the Space Geodesy Laboratory established in 2000 under an agreement NASA-UA on scientific cooperation on Space Geodesy, in force till 2010. From the perspective of the internal organization of the UA, The CG is currently composed of two research groups (RG) that are:

- Space Geodesy and Space Dynamics, that since 2018 runs the
 - UAVAC (UA VLBI Analysis Centre), an Associated AC of the IVS
- Satellite Geodesy for Earth observation and climatic change

Structure

- ***RG on Space Geodesy and Space Dynamics (SGSD)***

Head: José M. Ferrándiz (jm.ferrandiz@ua.es)

Staff Members: Alberto Escapa (on leave in the University of León, Spain)

Juan F. Navarro

M. Carmen Martínez Belda

Collaborators: Juan Getino (University of Valladolid, Spain)

Santiago Belda (University of Valencia, Spain, since 2018)

Tomás Baenas (CUD, MDE-UPCT, Murcia, Spain, since 2018)

- ***RG on Satellite Geodesy for Earth observation and climatic change (SG)***

Head: M. Isabel Vigo (vigo@ua.es)

Staff Members: David García- García

Juan A. Martínez

Mario Trottini

Collaborators: José M. Sánchez-Reales (Independent consultant, Spain)

Ben F. Chao (Academia Sinica, Taiwan)

The **SGSD** operates the **UAVAC (UA VLBI Analysis Centre)**, an Associated Analysis Centre of the IVS since July 2018. UAVAC administrative primary contact is the CG head J.M. Ferrándiz.

Overview

The main research activity of the SGSD RG lies in the Global Geodesy field and specifically focuses on the Earth's rotation, covering both theory and analysis of observations, mainly VLBI. All its staff members and external collaborators are serving the IAG and the IAU (International Astronomical Union) with different responsibility levels, at least as members of the IAU/IAG Joint Working Group on Theory of Earth rotation and validation chaired by the RG Head.

The VLBI unit, currently named UAVAC, has been operating along the whole term in close cooperation with the GFZ Department 1, Geodesy, and its VLBI group, headed by H. Schuh and R. Heinkelmann, respectively. The UAVAC main analysis interests focus on:

- Analysis of the Celestial Pole Offsets (CPO) and improvement of precession - nutation (P-N) models - including FCN modeling, determination of nutation amplitudes and precession polynomials.
- Testing and evaluation of new P-N models or corrections to the existing ones.
- Development and testing of prediction procedures for CPO, polar motion and UT1.
- Consistency issues arising from different sources (reference frames, processing strategies of data, ancillary geophysical models, etc.)
- Interplays among results derived from 24h or intensive session-wise and global solutions

The main research activity of the SG RG focus in space geodesy with experience in this field at regional and global scales, working on Sea Level, Mass Transport, Geoid Determination and Ocean Circulation, Positioning using different geodetic techniques which include Satellite Laser Ranging (SLR), GPS, Satellite Altimetry, Tide Gauges, and Satellite Gravity (GOCE and GRACE).

Activities and publications during the period 2015-2019

Services to the IAG:

The Head and members of the SGSD RG have been performing various services to the IAG and several of its components (namely Commission 3, GGOS, IVS and IERS) along this period.

A.- *The head, JM Ferrándiz, has served the IAG as:*

1. IAG Fellow, appointed at the 2015 IAG General Assembly.

He is the second Fellow from Spain. The associated responsibilities appear on the Bylaws.

2. Chair of the IAU/IAG Joint Working Group on Theory of Earth rotation and Validation (IAU/IAG JWG TERV or JWG 3.1 within IAG), 2015-2019.

This JWG was established with the purpose of promoting the development of theories of Earth rotation fully consistent and in agreement with observations, useful for providing predictions of the Earth orientation parameters (EOP) with the accuracy required to meet the needs of the near future as recommended by GGOS. The accuracy and stability goals are very stringent, since the benchmarks set by the JWG are 30 mas and 3 ma/y in terms of geocentric angles; those figures arise from the requirements to the Terrestrial Reference Frames (TRF) necessary for monitoring the sea level rise and adopting the policies suitable to act against global change and minimize its prejudicial effects.

JWG 3.1 continues the IAU/IAG JWG on Theory of Earth rotation (ThER), that operated in 2013-2015 and was the first IAG WG that addressed the whole set of five Earth orientation parameters (EOP). Former IUGG WGs joint with IAU were solely dedicated to the precession-nutation pair of EOP. However, the highly demanding accuracy and consistency targets require to consider all the EOP at once, since there are reciprocal influences among them. Because of that the JWG has a complex structure, with a Vice-chair who is R. Gross since its beginning and consists of three sub-working groups (SWG), each with a chair-person. The JWG website is hosted by the UA at <https://web.ua.es/en/wgterv>.

Coordination among the SWGs and with other IAG components (in particular GGOS and IERS) is helped by the existence of common members (including correspondents) affiliated to the JWG and e.g. to the IERS Earth Orientation Centre, Rapid Service / Prediction Centre, Conventions Centre, and Central Bureau, the IERS Analysis Coordinator and the GGOS Scientific Panel, Bureau of Products and Standards, and Committee on Essential Geodetic variables. Coordination with IAU is also guaranteed by a majority of JWG members in the Organizing Committee of IAU Commission A2, Rotation of the Earth.

3. *Member at-large of the Steering Committee of the Commission 3, Geodesy and Geodynamics, 2015-2019.*

This term the Com. 3 Steering Committee has 12 members, including President and Vice-President. Their responsibilities are the ones established in the IAG Bylaws.

4. *Member of the GGOS Science Panel, since 2017*

The GGOS Science Panel is an independent and multidisciplinary advisory board with 14 members that provides scientific support and guidance to the GGOS Executive Committee (EC) and Coordinating Board (CB) as requested by them and is invited to attend the CB meetings. Further details are available e.g. at <http://176.28.21.212/en/about/science-panel/>

5. *Ex-officio advisor of the IAG Bureau of Products and Standards (BPS), since 2018*

The BPS supports GGOS in its key goal to obtain consistent products describing the geometry, rotation and gravity field of the Earth. Its mission is of remarkable relevance because even small inconsistencies may cause systematic errors that degrade the accuracy of solutions and prevent the achievement of the GGOS accuracy and stability goals.

6. *Ex-officio member of the Committee on Essential Geodetic Variables (EGV), since 2018*

EGV are the geodetic equivalent to the well-established Essential Climate Variables or Essential Oceanic Variables. Let us remark that some of the main indicators of the climatic change, sea level rise being a prominent example, are indeed determined by the geodetic community but disseminated to the public opinion by other scientific communities or the media.

7. *Head and Administrative Contact of the IVS Associated Analysis Centre UAVAC, since July 2018*

This is the first Spanish unit of analysis of geodetic VLBI data approved as IVS Associated Analysis Centre (AAC), whose main interests focus on Earth rotation as described at the Overview paragraph.

It has a long-term cooperation with the IVS AAC at GFZ, Potsdam, attached to Department 1.

It is also open and willing to cooperate with other Spanish institutions or teams interested in analysing geodetic VLBI data, either by doing joint research or training graduate students.

8. *Editor-in chief of the Chapter on Earth rotation (“transformation between celestial and terrestrial references frames”) of the IERS Conventions 2022, since 2018.*

Ferrándiz was appointed in December 2018 after an open international call closed on May 2018.

The impact of the change of the Conventions will be huge, since the IERS Conventions are the main international standard for processing satellite and space geodesy data. Currently the official release is the IERS Conventions (2010), although the IERS Conventions Centre Co-directors would like to have a first draft of the new conventions ready in 2021.

The responsibilities of the chapter editors-in-chief include:

- a) Determining which new developments to incorporate and which portions of past versions should be deleted,
- b) Coordinating with Chapter Experts and Assistant Chapter Experts to create an advance outline,
- c) Evaluating Chapter Expert contributions,
- d) Resolving possible disputes between Chapter Experts,
- e) Coordinating with the Software Editor as required to ensure software and Conventions are self-consistent, and
- f) Provide a very short chapter summary suitable for inclusion in the overall Introduction

B.- *The services of other members of the RG on Space Geodesy and Space Dynamics are:*

9. ***A. Escapa and J. Getino are the Chair and Vice-chair of the SWG1, Precession and nutation, of the JWG 3.1 (IAU/IAG JWG TERV), in the term 2015-2019.***

Though the word sub-working group could not suggest it and thus be misleading, these services entail a major responsibility.

Let us recall that the scope of this SWG1 includes the full scopes of two previous working groups (WG):

- the former IUGG/IAU JWG on Nutation of the non-rigid Earth, whose successful activity led to the endorsement by the IAU and IUGG of the current IAU2000 nutation model, and
- the IAU WG on Precession and the ecliptic that got approved the IAU2006 precession model.

10. ***J. Navarro, S. Belda and T. Baenas are affiliated to the JWG 3.1 (IAU/IAG JWG TERV) of Commission 3, in the term 2015-2019.***

According to the JWG 3.1 end-of-term report, the external collaborator Belda is member of the SWG3, Numerical solutions and validation, chaired by R. Heinkelmann – inaugurated in January 2019 as the new IERS Analysis Coordinator and member of the GGOS BPS. Navarro is correspondent of the same SWG3, and Baenas correspondent of the SWG1. The involvement of the UA SGSD RG with the activities of the SWG2, Polar motion and UT1, led by A. Brezinski, is got through the JWG and SWG1 chairs, established to satisfy the coordination requirements. Notice that the affiliation within our partner union IUA may be different, since IAU do not limit the number of members but distinguish between (full) and associated members according only to the status of their membership to IAU.

Organization of meetings:

The SGSD head, JM Ferrándiz, has organized splinter meetings (SM) of the JWG and special sessions at several international conferences of particular relevance for its activity, open to all the interested attendees. He has also co-convoked sessions on Earth rotation, or including it, at large meetings or served in scientific organizing committees (SOC), as well as others RG members. Among the first kind of events, the following meetings took place so far:

- ***Open SM of the JWG TERV at the EGU General Assembly 2016***. Vienna, April 20, 2016 (SMP14, <http://meetingorganizer.copernicus.org/EGU2016/session/22333>).

- ***Session 8 (Convener and SOC member) at GAGER 2016*** (Geodesy, Astronomy and Geophysics In Earth Rotation - A Joint IAU / IAG / IERS Symposium), entitled: Open meeting on “Current situation, progress, and challenges of the theory of Earth rotation from the JWG TERV perspective”. Reports of progress of all the SWGs were presented in this session, and afterwards there was a long and very fruitful discussion whose minutes are available at: <https://web.ua.es/es/wgterv/jwg-terv-meetings/open-meeting-at-gager2016.html>

- ***Open SM of the JWG TERV at EGU General Assembly 2017***. Vienna, April 24, 2017 (SMP85, <http://meetingorganizer.copernicus.org/EGU2017/session/26247>).

- ***“Journées 2017, des Systèmes de Référence et de la Rotation Terrestre”, co-organized by the University of Alicante and the Paris Observatory, and chaired by Ferrándiz and Bizouard***. 25-27 September, Alicante, Spain. (<https://web.ua.es/journees2017/index.html>).

The organization of this meeting was of particular relevance for the Earth rotation researchers of Spain and all around the world since it allowed the recovery of the successful series of *Journées “Systèmes de Référence spatio-temporels”*, supported by the IAG and IAU for many years. The series was initiated in 1988 at the Paris Observatory, which always organized or co-organized those meetings, and its concluding edition held in 2014, after the retirement of its Chair for about 20 editions, N. Capitaine. The original Journées never took place in Spain, although a member of our staff, A. Escapa, served in the Organizing Committee in the last editions (2013 and 2014).

The “Journées” were intended since their beginning as a forum of advanced discussion devoted to the study of the space-time celestial and terrestrial reference systems and their evolution with time, and this with emphasis on the rotation of the Earth. The sub-title of the renewed 2017 edition was ***“Furthering our knowledge of Earth Rotation”*** and it addressed the challenges brought to Earth rotation by the accuracy requirements of GGOS, with a scope ranging from concepts and theoretical solutions to observational techniques and data analysis. It was co-chaired by Ferrándiz and Bizouard, already chair of the IERS Earth Orientation Centre at that time, and Mme. Capitaine was appointed the honorary chair of the new Journées.

The UA CG was heavily involved in the organization, Escapa being again a member of the SOC and with Baenas, Belda, Martínez, Martínez-Belda, Navarro and Vigo of the Local Organizing Committee.

A clear sign of the success of this long time waited re-edition lies in the participation of the Vice-President of the IAG, Zuheir Altamimi and the President of IAU Commission A2 at that time, Richard Gross, who delivered speeches at the Opening act and invited talks.

- ***Open SM of the JWG TERV at the EGU General Assembly 2018***. Vienna, April 11, 2018 (SMP40, <https://meetingorganizer.copernicus.org/EGU2018/session/29605>)

- *Session 4, “Earth rotation and reference frames”, (as Co-convenor) of the ISGG 2018* (International Symposium on Geodesy and Geodynamics) co-sponsored by the IAG, Kunming, China, July 30 – August 2).

- *Business Meeting of the JWG TERV at the XXX IAU General Assembly*, Vienna, on August 28, 2018.

The next events displayed on the list are related to IAG through their main convenor (R. Gross) and all the three co-convenors (including Ferrándiz):

- *Session G24 “Earth and Planetary Rotation: Improving Theories, Models and Observations” at the AGU FM (American Geophysical Union Fall Meeting) 2015*, December 15-16 (<https://agu.confex.com/agu/fm15/meetingapp.cgi/Session/8434>)

- *Session G11A “Earth and Planetary Rotation: From Core to Crust” at the AGU FM 2017*, December 11 (<https://agu.confex.com/agu/fm17/meetingapp.cgi/Session/22871>)

Finally, at the European Geosciences Union (EGU) General Assemblies of 2016, 2017, and 2018 we have an indirect participation in the organization of the Earth rotation sessions, attached to the Geodesy Program Group, since no SGSD member was among the convenors, but research related to the JWG activity was cited explicitly on the session description (see e.g. the IERS messages at https://datacenter.iers.org/data/2/message_284.txt, https://datacenter.iers.org/data/2/message_315.txt, https://datacenter.iers.org/data/2/message_343.txt).

However, in the last EGU edition there was no JWG SM but Escapa was co-convenor of:

- *Session G3.1 “Earth Rotation: Theoretical aspects, observation of temporal variations and physical interpretation” at the EGU 2019 General Assembly*, April 10, 2019, (<https://meetingorganizer.copernicus.org/EGU2019/session/30375>).

Figure 1 JOURNÉES 2017



Main outcomes of the research on Earth rotation:

This research has been carried out by the SGSD RG in the framework of the IAU/IAG JWG TERV and in close cooperation with colleagues from GFZ and our external collaborators. Our main contributions are the following:

1. We have shown that the amplitudes of the main nutation terms have to be updated after almost 20 years of use. This is particularly important for the 21 frequencies used to fit the nutation theory IAU2000, at a time in which the amplitude formal errors were not better than $5 \mu\text{as}$ (Herring et al 2002). Currently the number of separable frequencies has increased drastically up to several tens, and the uncertainties of the fitted amplitudes reduced to about 2-3 μas . Belda et al 2017 fit a set of 79 amplitudes from a global VLBI solution derived from 2990 sessions ranging from 1990 to 2010 (the last year used for the ICRF2 realization) and found that the differences between the conventional amplitudes of IAU2000 and the currently determined ones, at individual frequencies, can reach some tens of μas , as shown in the table. Besides, the WRMS (weighted root mean square) of the residuals decreases by 15 μas when the corrections displayed in the table 1 are applied.
2. We proved that, though required by IAU Resolution B1 endorsing P03 (Capitaine et al 2003) as the new precession theory IAU2006, the latter is not fully dynamically consistent with IAU2000 (MHB2000 by Mathews et al, 2002), and consistency requires applying certain corrections to the nutation part, as already pointed by Capitaine et al (2005). The set of corrections already recommended in the IERS Conventions (2010) have been found incomplete, but full consistency can be achieved by applying to IAU2000 series a recently determined set of small corrections that include several so-called Poisson or secular-mixed terms, whose amplitudes are factorized by the time (Escapa et al 2017, Escapa and Capitaine 2018). While these effects are small, they are systematic, not random, and should therefore be included in an improved theory according to the discussions inside the JWG, but preferably along with other updating for the final users' convenience.
3. The precession model has been re-assessed, and a set of minor contributions to the longitude rate has been improved, particularly two corresponding, respectively, to the mathematical second order solution component and to the anelasticity effects – the latter named simply as “non-linear” by Mathews et al (2002). Besides, those findings imply that the value of the Earth's dynamical ellipticity, H_d , must be adjusted since the observed precession rate is of course unchanged. The H_d variation is of some ppm and the resulting corrections to nutations, or “indirect” effects, are non-negligible since they reach more than 50 μas for certain terms (Ferrándiz et al 2017, Baenas et al 2019).
4. As for nutation theory, it has been found that the lunisolar and planetary blocks that compose the IAU2000 series are inconsistent each other (Ferrandiz et al 2018). That is because the MHB2000 transfer function was not applied to the amplitudes of the planetary direct and indirect terms (Herring et al 2002), which were taken without change from an early version of the rigid theory REN2000 since the expected variation was assumed to be negligible. It is not the case nowadays, since the magnitude of this effect reaches near 20 μas in single amplitudes, a value much larger than the joint contribution of hundreds of planetary terms, and the joint effect can be above the GGOS threshold. Those facts are illustrated in table 2 (a simplification of the original table published on A&A 618, A69, 2018) and figure 1.
5. The free core nutation (FCN) is a main component of the residuals and is considered as unpredictable, in the sense of being excited by angular momentum variations resulting from geophysical processes. Belda et al (2016) derived a new accurate empirical model by using a sliding window approach with high temporal resolution (1-day forward steps). We took advantage of it to predict FCN and from them the CPO, allowing accuracy gains of up to nearly a 40% along a year time span with respect to the performance of the conventional predictions reported at the IERS 2016 Annual Report. That result deserved publication in Scientific Reports (Belda et al 2018).

6. Also, in relation with the EOP prediction we have worked in the prediction of polar motion or LOD. The investigated methods may work better for short- or long-term predictions, be based only on past data, or make use of geophysical excitation functions to various extents - Modiri et al (2018), Shuch et al (2018) or Modiri et al (2019).
7. Our analysis of VLBI data (using the software VLBI@GFZ) have confirmed the hypothesis that different realizations of TRF or data processing strategies can give rise to not negligible differences in the EOP determination at the GGOS level of accuracy (Heinkelmann et al 2015 & 2018, Belda et al 2017).

Table 1

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Table 3
Main Corrections to the IAU2000A Nutation Amplitudes

Period (days)	CPO	Median		Range		Median Error		
		As	Ac	As	Ac	As	Ac	
		6798.383	dX	-6.7	63.7	2.0	10.4	2.9
		dY	20.8	-63.0	4.3	6.3	2.9	3.7
3399.192	dX	-7.1	5.6	2.1	1.0	3.0	2.8	
		dY	-6.3	-11.4	4.6	2.6	3.0	2.8
1615.748	dX	-1.4	-6.8	3.4	1.7	2.7	2.8	
		dY	4.0	-8.7	3.5	2.9	2.7	2.8
1305.479	dX	0.1	5.6	1.5	1.4	2.8	2.8	
		dY	7.2	12.2	1.6	1.1	2.8	2.8
1095.175	dX	2.7	-15.1	3.0	0.6	2.7	2.8	
		dY	9.3	2.1	2.5	1.8	2.7	2.8
182.621	dX	10.6	-12.7	4.3	5.5	2.7	2.8	
		dY	24.6	10.2	1.6	2.9	2.7	2.8
169.002	dX	8.6	0.4	3.3	2.3	2.7	2.7	
		dY	4.2	4.6	5.0	2.5	2.7	2.7
29.531	dX	4.0	-0.3	4.2	2.7	2.8	2.8	
		dY	6.4	8.7	4.2	1.8	2.8	2.8
27.555	dX	-3.5	-16.4	3.0	3.6	2.7	2.7	
		dY	10.3	-5.9	6.1	4.7	2.7	2.7
27.093	dX	3.2	-6.0	3.0	2.0	2.7	2.7	
		dY	3.9	11.9	3.4	1.9	2.7	2.7
26.985	dX	-3.1	4.3	1.9	3.3	2.8	2.8	
		dY	1.9	-9.9	4.2	5.4	2.8	2.8
25.325	dX	-2.1	-2.9	3.2	1.6	2.7	2.8	
		dY	8.3	-0.4	2.9	2.8	2.7	2.8
13.749	dX	1.6	3.0	3.0	2.2	2.6	2.7	
		dY	0.4	9.2	4.6	1.2	2.6	2.7
13.661	dX	-22.4	-12.2	12.7	3.8	2.7	2.7	
		dY	-0.9	5.9	7.2	6.7	2.7	2.7

Note. Corrections are estimated from the different VLBI global solutions (see Table 1) and feature the median amplitude, range and the median of the formal errors for each term. As and Ac correspond to sine and cosine components, respectively. Units: μas .

Main outcomes of the research on ocean geostrophy:

This research has been carried out by the SG RG, in the framework of several international projects, participating the leader of the SG RG as PI in the Ocean Surface Topography and the SARAL/AltiKa Mision Science Teams. Our main contributions are the following:

1. For the first time, we have obtained weekly and monthly global Surface Geostrophic Current (SGC) climatology using only satellite data from altimetry and GOCE missions (Sanchez Reales et al., 2016a). The proposed approach combines 18 years of altimetry data with an independent estimate of the geoid based on the third release of GOCE data. Our approach overcomes the main limitations of existing approaches based solely on altimetry data (which suffer from lack of an independent estimate of the geoid which can be used as a reference for the altimetry derived Absolute Sea Level maps), and approximations based solely on in-situ data (which are characterized by sparse and inhomogeneous coverage in time and space).

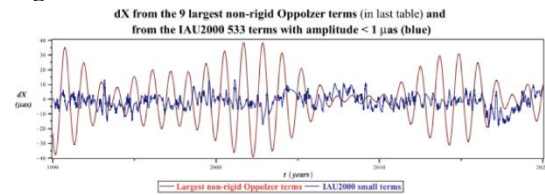
Table 2

Largest Opolzer terms of planetary origin for the Earth's figure axis. Units: amplitudes in μas , periods in mean solar days.

L_{Ve}	L_E	L_{Ma}	L_J	p_A	Period (days)	dX_{in} (sin)	dX_{out} (cos)	dY_{in} (cos)	dY_{out} (sin)	Origin code
0	1	0	-1	0	398.884	0.2	0	0.2	0	0
2	-4	0	0	2	-487.638	-1.8	-0.1	1.7	-0.1	1
0	1	0	-2	0	439.332	1.1	-14	1.3	14.3	1
0	3	-4	0	0	418.266	-3.2	0.5	-3.1	-0.4	1
3	-4	0	0	0	416.688	-2.9	8.2	-2.9	-7.9	1
0	1	0	-1	0	398.884	-18.8	-3	-17.2	3	1
0	2	-2	0	0	389.968	-4.3	-0.4	-3.8	0.4	1
2	-4	0	0	2	-487.638	-5.6	-0.5	5.6	-0.5	2
0	1	0	-1	0	398.884	1.6	0.2	1.5	-0.2	5

(a) Effect origin code: 0 indirect Moon; 1 indirect Sun; 2 direct Venus; 5 direct Jupiter

Figure 2



2. The annual variations of the SGC that we report are in agreement with several regional studies and enable them to be placed in a global context. High significant variability is observed for the SGC for the equator band and for the major current areas (the Kuroshio, Gulf Stream, Antarctic Circumpolar Current, and the Malvinas currents) mainly because of the zonal component. Most of this variability is related to inter-seasonal variations except for some areas in the equator band, as is also observed for the Eastern Pacific and the Atlantic Ocean, where the seasonal cycle explains most of the variance of the currents. The estimated climatology is in general agreement with that obtained from in-situ drifter buoy measurements.

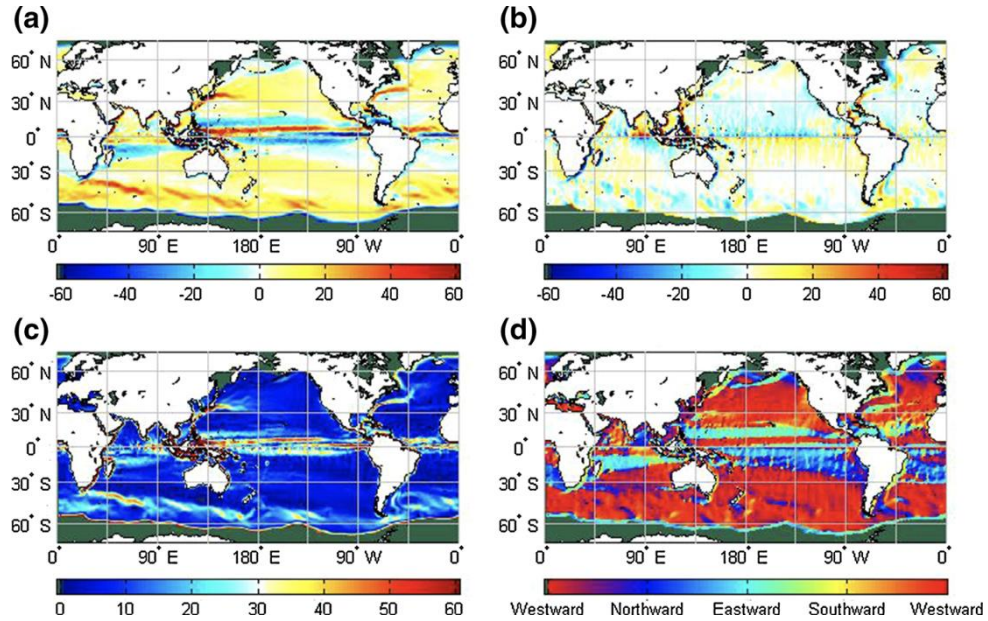


Figure 1. Annual mean SGC climatology estimated from altimetry and GOCE data: a zonal component; b meridional component; c velocity; d direction (from Sánchez-Reales, 2016b)

3. Study of SGC variability on a smaller scale would require finer resolution of the geoid and use of more advanced filtering methods. Further research on anisotropic filters has been carried out in order to provide a useful tool to address these problems. Thus, with increased geoid resolution provided by the gravity and steady-state ocean circulation explorer (GOCE) mission, the ocean's mean dynamic topography (MDT) can be now estimated with an accuracy not available prior to using geodetic methods. However, an altimetric-derived MDT still needs filtering in order to remove short wavelength noise unless integrated methods are used in which the three quantities are determined simultaneously using appropriate covariance functions. We studied nonlinear anisotropic diffusive filtering applied to the ocean's MDT and introduce a new approach based on edge-enhancing diffusion (EED) filtering (Sanchez-Reales et al., 2016a). EED filters enable controlling the direction and magnitude of the filtering, with subsequent enhancement of computations of the associated surface geostrophic currents (SGCs). Applying this method to a smooth MDT and to a noisy MDT, both for a region in the Northwestern Pacific Ocean, we found that EED filtering provides similar estimation of the current velocities in both cases, whereas a non-linear isotropic filter (the Perona and Malik filter) returns results influenced by local residual noise when a

difficult case is tested. We found that EED filtering preserves all the advantages that the Perona and Malik filter have over the standard linear isotropic Gaussian filters. Moreover, EED is shown to be more stable and less influenced by outliers. This suggests that the EED filtering strategy would be preferred given its capabilities in controlling/preserving the SGC

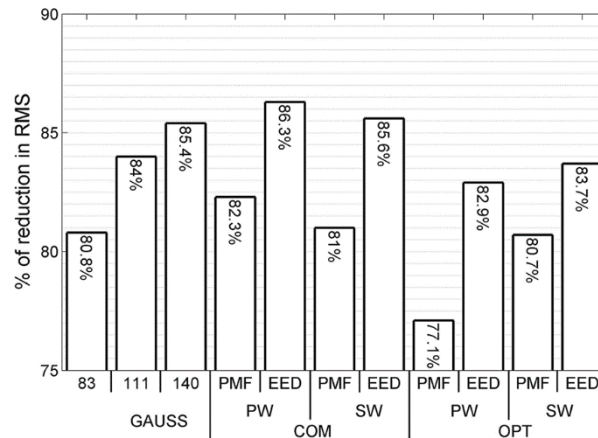


Figure 2: Percentage of reduction in RMS differences with buoy measurements (from Sanchez-Reales et al., 2016a)

- This geodetic based approach to surface circulation has been tested in small basins as the Mediterranean Sea that exhibits smaller scales and lower dynamic intensities in comparison with open oceans, making of it a challenging test case for our satellite-based analysis. In particular, we study the Surface Geostrophic Circulation (SGC) of the Mediterranean Sea, in (Vigo et al 2018a) we provide a mean and a monthly climatology for the Mediterranean SGC using 22 years of satellite ocean altimetry data and the geoid determination from the GOCE mission (Release 4). We reproduce the general known patterns of the Mediterranean Sea Circulation at the basin scale and sub-basin scale, and also report new findings. For the Ionian basin, see figure 3, decadal variations of the circulation associated to well-marked events such as the Eastern Mediterranean Transcend and the Adriatic–Ionian BiOS evidenced are well reproduced. Our approach overcomes the main limitations of existing approaches, those based solely on altimetry data in lack of independent geoid as a reference for the altimetry derived SSH maps, while approximations based on in situ data are sparse and inhomogeneous in temporal and spatial coverages.

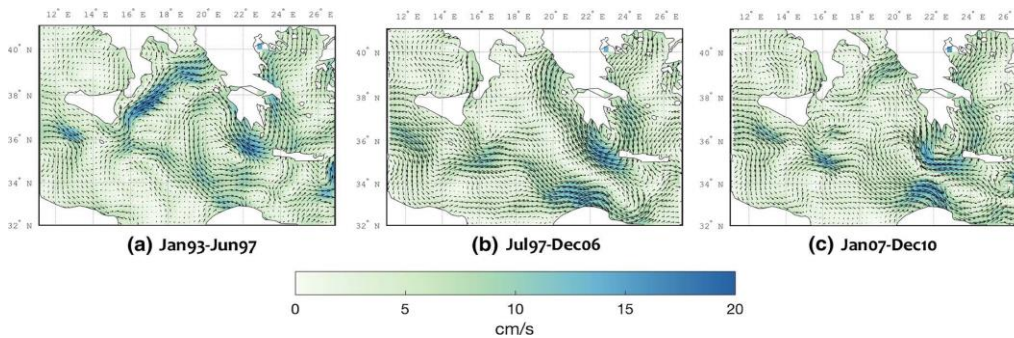


Figure 3: Mean Ionian Surface Geostrophic Currents as estimated from satellite gravity and altimetry data for three different periods: a) from January 1993 to June 1997; b) from July 1997 to December 2005; and c) from January 2006 to December 2010 (from Vigo et al. 2018a)

5. We have shown the capability of the combination of altimetry, space gravimetry missions, and in-situ Argo measurements, to yield realistic geostrophic current and volume transport estimates up to 1975 m depth (Vigo et al., 2018b). This new approach enables the possibility of new studies in oceanography at global scales and up to 2000 meters depth. In particular, the 3D geostrophic current and the associated volume transport in the Southern Ocean has been estimated based on data from satellites (altimetric SSH, and a GOCE-based geoid) and Argo floats. The use of an independent geoid from the altimetric SSH is of paramount importance for to better estimate ocean circulations, and the utility of a geoid derived from GOCE is a notable advancement in precision and resolution over those based on the GRACE geoid in previous studies.

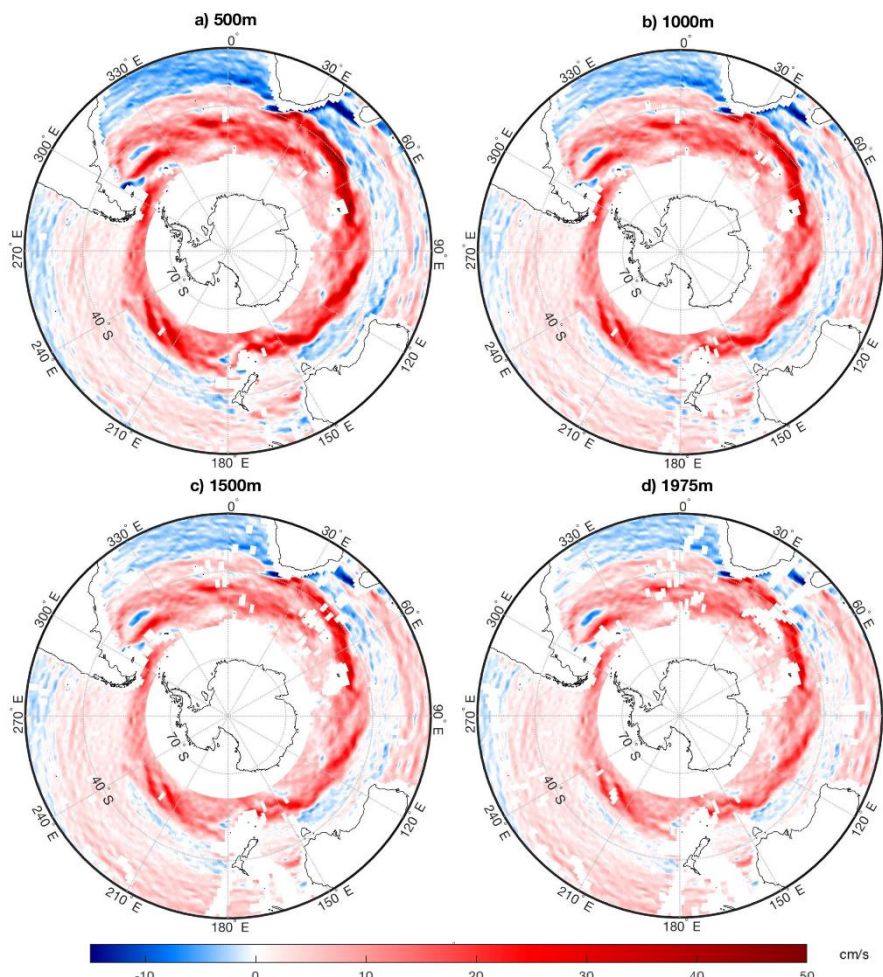


Figura4: 2004–2014 Mean zonal geostrophic current (obtain from GOCE, Altimetry and Argo floats) at depths of: (a) 500 m, (b) 1000 m, (c) 1500 m, and (d) 1975 m. Positive (red) values represent eastward direction while negative (blue) westward. The zonal geostrophic currents reach values up to 60 cm/s (the color scale is saturated at 50 cm/s to better resolve the interrelation between different depths) (from Vigo et al. 2018b).

Main outcomes of the research on climate teleconnections:

The SG RG has established a teleconnection between the continental precipitation annual amplitude, which represents the annual range between minimum and maximum (monthly) rainfall, and a linear combination of the Atlantic Multidecadal Oscillation (AMO) and low-frequency variations in the El Niño–Southern Oscillation (ENSO) on a decadal to multidecadal scale with a correlation coefficient of 0.92 ($P < 0.01$) (García-García and Ummenhofer, 2015). The teleconnection is a result of changes in moisture transport in key regions. This result is important to quantify the expected intensification of the hydrological cycle in a warmer world, where water vapor content in the atmosphere scales with temperature. Therefore, reported trends in the annual amplitude of global precipitation in recent decades need to be assessed in light of this substantial low-frequency variability, which could mask or enhance an anthropogenic signal in hydrological cycle changes

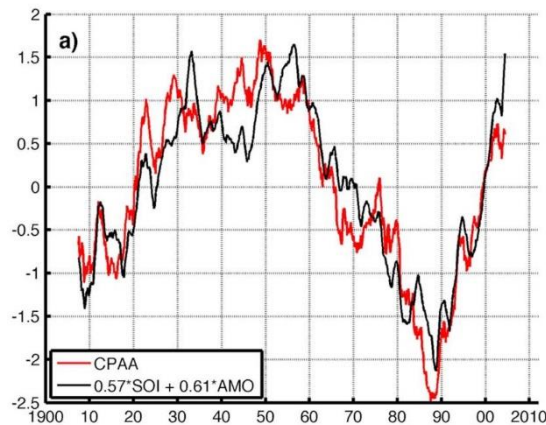


Figure 5. The red line is the global continental precipitation annual amplitude estimated in 13 year moving windows. The black line is $0.57 \times \text{SOI} + 0.61 \times \text{AMO}$. SOI and AMO are smoothed with 13 year running windows. All the time series are centered on 0 and normalized to 1 standard deviation.

Main outcomes of the research on time-variable gravity

The CG has developed a filter to reduce the noise in high degree and order geopotential spherical harmonics Stokes coefficients (SC) from the release 05 (RL05) Gravity Recovery and Climate Experiment (GRACE) mission (Belda et al., 2015). The filter has been optimized for global applications and to: (1) balance the noise reduction and the geophysical signal attenuation produced by the filtering process; (2) minimize the differences between GRACE and model- based data and (3) maximize the ratio of variability between continents and oceans.

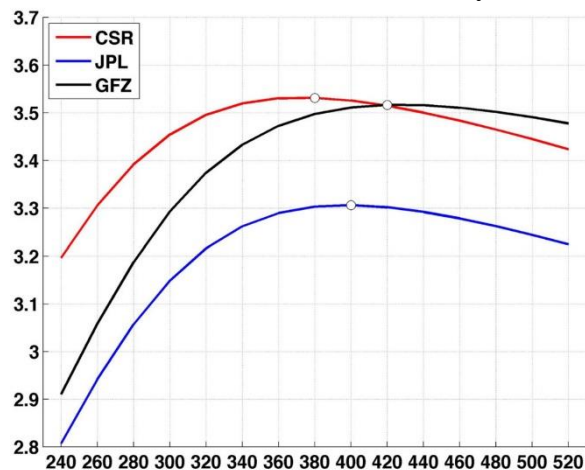


Figure 6. Ratio of variability between continents and ocean for GRACE data from: (a) CSR, (b) JPL and (c) GFZ,

as a function of the radius r of the Gaussian filter. GRACE data have been previously decorrelated. Ocean points closer to 500 km to the continents are avoided.

Publications in referred journals

- Baenas, T., Escapa, A., Ferrándiz, J.M. (2019) Precession of the non-rigid Earth: Effect of the mass redistribution. *Astronomy & Astrophysics* DOI: 10.1051/0004-6361/201935472
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- Yu Y., Chao B.F., García-García D., Luo L. (2018). Variations of the Argentine Gyre Observed in the GRACE Time-Variable Gravity and Ocean Altimetry Measurements *Journal of Geophysical Research: Oceans* 123, 1-13. DOI: 10.1029/2018JC014189

(The information of this Institution has been remitted by J.M.Ferrándiz)

3. DEPARTMENT OF APPLIED GEODESY. ARANZADI SOCIETY OF SCIENCES

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Research interests

- GNSS Networks.
- GNSS Network densification.
- Multiyear analysis of GNSS solutions.
- Dense velocity field estimation.
- Analysis of crustal deformations in active tectonic and volcanic areas.

Publications (Reports, Papers and Book Chapters)

Alessandro Caporali, Joaquin Zurutuza: EUREF Densification: “CEGRN Network“ EUREF Symposium, Leipzig, June 2015. EUREF TWG Validation request.

Alessandro Caporali, Carine Bruyninx, Rui Fernandes, Athanassios Ganas, Ambrus Kenyeres, Martin Lidberg, Guenter Stangl, Holger Ste_en, Joaquin Zurutuza: “Stress drop at the Kefhalonia Transform Zone estimated from the 2014 seismic sequence”. *Tectonophysics* Volume 666, 15 January 2016, Pages 164 to 172.

J. Zurutuza, M. J. Sevilla, A. Aguinaga, A. Uriarte, J. Mader, I. Galparsoro: “Infraestructura geodésica para estudios del nivel del mar: GEOLAB Pasaia”. III Cross border conference on climate and coastal change. Extended abstracts. *Revista de Investigación Marina, AZTI*, 25(2): 32-113, 2018. ISSN: 1988-818X. Pages 50-52.

Martín, A., Sevilla, M. J. and Zurutuza, J.: “Western Pyrenees geodetic deformation study using the Guipúzcoa GNSS network”. *Journal of Applied Geodesy*, ISSN (Online) 1862-9024, ISSN (Print) 1862-9016, DOI: <https://doi.org/10.1515/jag-2017-0041>.

Alessandro Caporali, Carla Braitenberg, Paola Montone, Giuliana Rossi, Gianluca Valensise, Alfo Vigan, Joaquin Zurutuza; “A quantitative approach to the loading rate of seismogenic sources in Italy”. *Geophysical Journal International*, Volume 213, Issue 3, 1 June 2018, Pages 2096-2111, <https://doi.org/10.1093/gji/ggy112>

Conferences and meetings:

a) Organised:

Co-organizer of EUREF 2016 Symposium

b) Attended

- J. Zurutuza, A. Caporali, M. Barlik, M. Becker, L. Gerhatova, G. Grenerczy, J. Hefty, D. Medak, G. Milev, M. Mojzes, M. Mulic, T. Rus, J. Simek, G. Stangl, G. Virag: “A contribution to ETRS89 in Central Europe: results from the CEGRN Activity”. EUREF2015 Symposium. 2015-06-03 to 2015-06-05, Leipzig, Germany. **TALK.**
- Caporali, L. Nicolini, J. Zurutuza, M. Bertocco, R. Corso: “Interoperability of the GNSSs for positioning and timing applications”. EUREF2015 Symposium. 2015-06-03 to 2015-06-05, Leipzig, Germany. **TALK.**
- J. Zurutuza, L. Nicolini, M. Bertocco, A. Caporali: “The Italian Network of Permanent GNSS sites”. EUREF2016 Symposium. 2016-05-25 to 2016-05-27, Donostia – San Sebastián, Spain. **TALK.**
- J. Zurutuza, A. Caporali, O. Khoda, G. Stangl, M. Becker, M. Bertocco, L. Gerhatova, M. Mojzes, M. Mulic, Yu. Stopkhay, C. Nagorneac, A. Mihailov, S. Lazi, J. Papo, B. Stopar: “The CEGRN network”. EUREF2016 Symposium. 2016-05-25 to 2016-05-27, Donostia - San Sebastián, Spain. **TALK.**
- A. Caporali, J. Zurutuza, M. Bertocco: “On the alignment of the cumulative EPN solutions to IGB08 at epoch 2005.0”. EUREF2016 Symposium. 2016-05-25 to 2016-05-27, Donostia - San Sebastián, Spain. **TALK.**
- J. Zurutuza, Miguel J. Sevilla de Lerma, M. C. Ruiz, Andoitz Antzizar, Aitor Aguinaga, M. Elorza: “ARA GEODETIC AND GNSS ACTIVITIES TO SUPPORT THE SEA LEVEL CHANGES AND THE EPN DENSIFICATION PROJECT”. EUREF2016 Symposium. 2016-05-25 to 2016-05-27, Donostia - San Sebastián, Spain. **TALK.**
- A. Caporali, C. Bruyninx, R. Fernandes, A. Ganas, A. Kenyeres, M. Lidberg, G. Stangl, H. Holger, J. Zurutuza: “An analysis of the Kephallonia/Lefkada seismic sequences of 2014/2015”. 35TH GENERAL ASSEMBLY OF THE EUROPEAN SEISMOLOGICAL COMMISSION. Trieste (Italy), 4-10 September 2016. **TALK.**
- A. Caporali, J. Zurutuza: “Analysis of time series of permanent GNSS sites in the area of the Amatrice earthquake” 35 edizione e si terr a Lecce (Italy) dal 22 al 24 novembre. Gruppo Nazionale per la Geodesica della Terra Solida (GNGTS). **TALK.**
- A. Caporali, C. Braitenberg, P. Montone, G. Rossi, G. Valensise, A. Vigano, J. Zurutuza: “A quantitative approach to the loading rate of seismogenic sources in Italy”. 35 edizione e si terr a Lecce (Italy) dal 22 al 24 novembre. Gruppo Nazionale per la Geodesica della Terra Solida (GNGTS). **TALK.**
- A. Caporali, J. Zurutuza, M. Bertocco: “The alignment to IGB08 of the EPN cumulative solutions”. EUREF2017 Symposium. 2017-05-17 to 2017-05-19, Wroclaw (Poland). **TALK.**
- J. Zurutuza, A. Caporali, O. Khoda, G. Stangl, M. Becker, M. Bertocco, L. Gerhatova, M. Mojzes, M. Mulic, Yu. Stopkhay, C. Nagorneac, A. Mihailov, S. Lazi, J. Papo, B. Stopar: “The CEGRN campaigns and densification of the ETRF in Central Europe”. EUREF2017 Symposium. 2017-05-17 to 2017-05-19, Wroclaw (Poland). **TALK.**
- J. Zurutuza, A. Caporali, M. Bertocco, E. Brockmann, M. Lidberg: “3D Deformation in time of the ETRF2000 grid”. EUREF2017 Symposium. 2017-05-17 to 2017-05-19, Wroclaw (Poland). **TALK.**

- J. Zurutuza, A. Caporali, M. Bertocco: “Crustal deformation implied by permanent GNSS sites in the area of the 2016 Central Italy earthquakes”. EUREF2017 Symposium. 2017-05-17 to 2017-05-19, Wroclaw (Poland). **TALK**.
- J. Zurutuza, A. Caporali, M. Bertocco: “The UPA LAC Status and Contribution to the EPN Densification”. EUREF Analysis Centres Workshop, Brussels, Belgium, October 25-26, 2017. **TALK**.
- J. Zurutuza, A. Caporali, O. Khoda: “Progresses in the Central European densification of the 3D velocity field: the CEGRN2017 Campaign”. EUREF Analysis Centres Workshop, Brussels, Belgium, October 25-26, 2017. **TALK**.
- J. A. Sánchez, A. Barón, M. Blanco, M. Valdés, J. Zurutuza: “A new ETRS89 realization in Spain”. EUREF Analysis Centres Workshop, Brussels, Belgium, October 25-26, 2017. **TALK**.
- J. Zurutuza, M. J. Sevilla, A. Aguinaga, A. Uriarte, J. Mader, I. Galparsoro: “Infraestructura geodésica para estudios del nivel del mar: GEOLAB Pasaia”. UHINAK: III Cross border conference on climate and coastal change. Irún, Spain, March 6-7, 2018. **TALK**.
- J. Zurutuza, A. Caporali, N. Cenni, M. Bertocco: “Italian GNSS Network: Status of the Processing and Position/Velocity Results”. EUREF2018 Symposium. Amsterdam (The Netherlands), 30 May - 01 June, 2018. **TALK**.
- J. Zurutuza, A. Caporali,: “Progresses in the Central European Densification of the 3D Velocity Field: the CEGRN Network”. EUREF2018 Symposium. Amsterdam (The Netherlands), 30 May - 01 June, 2018. **TALK**.
- N. Cenni, A. Caporali, J. Zurutuza: “Present Kinematic and Deformation Pattern in the Central and Eastern Europe Area”. EUREF2018 Symposium. Amsterdam (The Netherlands), 30 May - 01 June, 2018. **POSTER**.

c) Working Groups meetings

- 2016: Invited to the 71th TWG Meeting in San Sebastián (Spain).
- 2016: Invited to the 2016 CEGRN Annual TWG Meeting in San Sebastián (Spain).
- 2016: Invited to the 2016 CEGRN Annual TWG Meeting in San Sebastián (Spain).
- 2017: Invited to the 2018 CEGRN Annual Meeting in Wroclaw (Poland).
- 2018: Invited to the 77th GB Meeting in Amsterdam (The Netherlands).
- 2018: Invited to the 2018 CEGRN Annual TWG Meeting in Amsterdam (The Netherlands).

(The information of this Institution has been remitted by J.Zurutuza)

4. DEPARTMENT OF ASTRONOMY AND GEODESY. UCM

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PEOPLE AT DEPARTMENT OF ASTRONOMY AND GEODESY

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Maite Benavent Merchán. *Professor Facultad de Matemáticas (Coordinator U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Marta Folgueira López *Associate Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Fuensanta González Montesinos. *Associate Professor. Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Jesús Otero Juárez. *Associate Professor (retired). Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Gracia Rodríguez-Caderot. *Associate Professor (retired). Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Gema Rodríguez Velasco. *Professor Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Pilar Romero Pérez *Associate Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid. Instituto de Matemática Interdisciplinar. Research Group UCM Mars Exploration Science (MES): Analysis, modelling and exploitation of data (Ref: 910711)*
Miguel J. Sevilla de Lerma (until 2016). *Full Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Carmen de Toro y Llaca. *Associate Professor Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*

Research Group 'Geodesy-UCM' <http://www.mat.ucm.es/grupogeodesia/>:

Co-Directors: Fuensanta González Montesinos *Associate Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid* and Carmen de Toro y Llaca. *Associate Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*

MEMBERS

José Arnosó Sampedro. *Tenured Scientist - Instituto de Geociencias (CSIC-UCM) - Consejo Superior de Investigaciones Científicas*
Maite Benavent Merchán. *Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*
Isabel Blanco Montenegro. *Associate Professor - Escuela Politécnica Superior (Dpto. Físicas) - Universidad de Burgos*

Gema Rodríguez Velasco. *Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*

Umberto Riccardi. *Researcher. Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR) - Università "Federico II" di Napoli*

Sergio Sainz-Maza Aparicio. *Titulado Superior de Actividades técnicas y profesionales del Instituto Geográfico Nacional; Professor- Facultad de Ciencias Físicas de la UCM*

Miguel J. Sevilla de Lerma (until 2016). *Full Professor - Facultad de Matemáticas (U.D. Astronomía y Geodesia) - Universidad Complutense de Madrid*

Vicente Soler Javaloyes. *Tenured Scientist - Instituto de Productos Naturales y Agrobiología (Estación Volcanológica de Canarias) - Consejo Superior de Investigaciones Científicas*

Emilio J. Vélez Herranz. *Research Technician I+D+i - Instituto de Geociencias (CSIC-UCM) - Consejo Superior de Investigaciones Científicas*

WORKING AREAS AND RESEARCH LINES

Earth rotation

Reference systems

GPS

Satellite orbit Control.

Optimization methods

Remote sensing

Inversion of potential fields

Geodetic monitoring and control networks

Earth tides and ocean tide loading

SUMMARY OF RESULTS DESCRIPTIONS – GRUPO 'GEODESIA-UCM'

Inversion of potential fields and modelling of crustal structure

Our group develops new methodology for inversion of potential fields through gravimetric and geomagnetic approaches. The knowledge of the Earth's crust at different depths is the aim of this topic by means three-dimensional models calculated from the analysis and inversion of magnetic and gravity anomalies maps.

Geodetic monitoring and control networks

Study of deformations of the Earth's crust in active volcanic areas using geodetic control networks, continuous gravity measurements and GPS displacements is being conducted by this research groups. The increase of GNSS observing sites allow us to obtain detailed displacement patterns and velocity maps. We are using those results to characterize the mechanism of the current deformation in volcanic active areas as Canary Islands (Spain) and Campi Flegrei caldera (Italy).

Earth tides and ocean tidal loading (OTL)

A big research effort is done for gathering long-term records of ground based gravimeter, tiltmeter and strainmeter measurements with the purpose of studying the elasticity of the Earth's crust at tidal frequencies. The group explores new approaches of time series analysis to develop and validate tidal analysis software used to process gravity, tilt and strain long-term series. As well, developments of OTL models and

software to compute the oceanic load is of main interest focussed on GPS and gravity OTL computations for studying the behaviour of the crustal structure at regional scale.

Geodynamic and gravimetric laboratories

The group continues to investigate geodetic and gravimetric methods and observational techniques in the geodynamics laboratory of Lanzarote Island (Spain), being the main applications focussed on volcano deformation and eruption forecasting. The study of calibration methods through gravity calibration lines and gravimeter intercomparisons made at the gravimetric laboratories of Strasbourg, in France, and Yebes and Madrid, in Spain, reports interesting benefits to further research in gravimetric monitoring in volcanic areas.

PUBLICATIONS (PAPERS AND BOOK CHAPTERS)

Arnosó, J., Montesinos, F.G., Gómez-Ortiz D., Martín-Crespo T., Blanco-Montenegro I., Gorbatikov A., Benavent T., Vélez E., Solla M., Calvo-Rathert M., Lorenzo H., Riccardi U.,

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Barderas, G., Plaza, C., Romero, P. Comparison of the methodology used for orbital parameters determination in the International GNSS Service Analysis Centers. Comparación de la metodología utilizada para el cálculo de los parámetros orbitales en los Centros de Análisis del Servicio GNSS Internacional (IGS). Física de la Tierra, 26 (2014), 163-173. doi: 10.5209/rev_FITE.2014.v26.46978.

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Logic, Mathematics and Consistency in Literature: Searching for Don Quixote's Place. *Advances in Complex Societal, Environmental and Engineered Systems. Springer Series in Nonlinear Systems and Complexity* (2017) pp. 221-245. ISBN 978-3-319-46163-2

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Hybrid gravimetry monitoring of Soultz-sous-Forets and Rittershoffen geothermal sites (Alsace, France). *Geothermics*, 76 (2018), 201-219, doi:10.1016/j.geothermics.2018.07.008

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Romero, P., Barderas, G., García-Roldán, J.M.

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Riccardi U., Arnosó J., Benavent M., Vélez E., Tammáro U., Montesinos F.G.

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Rosat, S., Calvo, M., Hinderer, J., Riccardi, U., Arnosó, J., Zürn, W.

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Tasas de deformación GPS en la cuenca del Bajo Segura (Cordillera Bética oriental) *Geogaceta*, , Nº. 56, (2014), pp.3-6

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Changes of spin axis and rate of the asteroid (99942) Apophis during the 2029 close encounter with Earth: a constrained model.. *Astronomy and Astrophysics* 617, A74, 11 (2018)

Tammáro U., Riccardi U., Masson, F., Capuano, P., Boy, J.P.

Atmospheric precipitable water in Somma-Vesuvius area during extreme weather events from ground-based GPS measurements. International Association of Geodesy Symposia, 147 (2016), 293-302, doi:10.1007/1345_2016_240

Vella, J. Carlut J., Valet, Maxime Le Goff J.P., Soler V., Lopes F., Remagnetization of Lava Flows Spanning The Last Geomagnetic Reversal. Geophysical Journal International 212, (2017) doi: 10.1093/gji/ggx2124

Zaczek K., Troll V.R., Cachao M., Ferreira J., Deegan F.M., Carracedo J.C, Soler V., Meade F.C., Burchardt S, Nannofossils In 2011 El Hierro Eruptive Products Reinstate Plume Model For The Canary Islands Nature Scientific Reports 5, 7945 (2015) doi:10.1038/Srep07945

RESEARCH PROJECTS

Desarrollo y análisis de modelos de estructuras corticales en Canarias. Implicaciones en estudios de deformación y variaciones de gravedad en El Hierro y Lanzarote. Ref.CGL2015-63799-P (2016-2019). Ministerio de Economía y Competitividad.. Coordinator: J. Arnosó.

Caracterización estructural del Parque Nacional de Timanfaya mediante uso combinado de técnicas y métodos geodésicos y geofísicos
Ref: 320/2011 (2011-2015). Ministerio de Medio Ambiente y Medio Rural y Marino. Coordinator: J Arnosó.

Modelización geodésica y geofísica avanzada en Gran Canaria. Integración en el contexto estructural y dinámico de Canarias
Ref.CGL2011-25494. (2011-2015) Ministerio de Ciencia e Innovación
Coordinator: J. Arnosó

Estudio e interpretación de medidas geodésicas y geofísicas aplicadas al establecimiento del peligro volcánico en la isla de El Hierro
Ref. BIL/14/P2/063. (2015) Fundación MAPFRE. Convocatoria de Ayudas a la Investigación Ignacio H. de Larramendi.
Coordinator: M. Benavent.

Estudo e caracterização geofísica de estruturas tectónicas do campo geotérmico do Pico Alto (Isla Terceira – Azores): uma abordagem microgravimétrica
Ref. Contrato Art. 83 LOU (2016-2017) Support: GEO.AZ – CONSULTORIA EM GEOLOGIA LDA

Coordinators: F.G. Montesinos J. Arnosó

Control de deformaciones mediante distanciómetría submilimétrica

Ref.. Contrato art. 83 LOU (2018-2019) Support: Universidad Politécnica de Valencia

Coordinator: F.G. Montesinos

Research Group 910505 – GEODESY Programa de Financiación Grupos de Investigación UCM validados

Ref. GR3/14. (2014-2015). Universidad Complutense de Madrid- Banco Santander Central Hispano

Coordinator: F. G. Montesinos

BIGMAG: En Busca del desencadenante de Inversiones Geomagnéticas.
Ref. CGL2017-92285-EXP. (2018-2020) Ministerio de Economía, Industria y Competitividad

Coordinator: M.L. Osete. Participant: M.Folgueira

Analysis, Modeling and Data Exploitation in the Mars Exploration: Missions ExoMars2016 and ExoMars2018.

Ref.ESP2016-79135-R (2016-2019). Ministerio de Ciencia e Innovación.

Coordinators: L. Vázquez P. Romero. Participant; G. Barderas

Methodological developments in hybrid 4D gravimetry: potential applications in geothermal areas

Ref. G15_17_(2015-2017) Università Italo-Francese. Galileo

Coordinator: Umberto Riccardi and Jacques Hinderer

Análisis, modelización y explotación de datos en la exploración de Marte.

Ref. PR26/16-20246 (2015).Universidad Complutense de Madrid.

Coordinator: L. Vázquez. Participants; P. Romero, G. Barderas

Participación científica en la misión a Marte MEIGA-METNET PRECURSOR.

Ref.AYA2011-29967-C05-02.(2012-2015).Ministerio de Economía y Competitividad.

Coordinator: L.Vázquez. Participants; P. Romero, G. Barderas

Geospatial based Environment for Optimisation Systems Addressing Fire Emergencies. GEO-SAFE.

Ref 691161. (2016-2020). European Commission: H2020: Excellent Science

Coordinator: B. Vitoriano. Participants; P. Romero G. Barderas

Conceptos y Aplicaciones de los Sistemas Inteligentes
Ref. S2013/ICE-2845. (2015-2019) Comunidad de Madrid
Coordinator: J. Montero. Participant; P. Romero

INTERNATIONAL COMMITTEES

-Jose Arnosó is member of the Joint Study Group 3.1: Gravity and height change intercomparisons of the International Association of Geodesy (IAG), from 2015

-Jose Arnosó is member of the International Geodynamics and Earth Tide Service (IGETS) of the International Association of Geodesy (IAG), from 2015

CONFERENCES AND MEETINGS ATTENDED

Alfaro P., Martín-Rojas I., Estévez A., García-Tortosa F.J., Sánchez Alzola A., Borque M.J., Rodríguez Caderot G., de Lacy C., García-Armenteros J.A, Avilés M., Herrera-Olmo A., Molina S., Rosa-Cintas S. y Gil A.J. (2014)

Red GPS de la Cuenca del Bajo Segura (Cordillera Bética Oriental). Implicaciones sobre las tasas de desplazamiento de las fallas del Bajo Segura y de Crevillente. Segunda reunión Ibérica sobre fallas activas y paleosismología Lorca Spain

G. Barderas, P. Romero (2018). An Alternative Dynamical Approach to the Algebraic Method for Estimating the Figure Parameters for the Solar System Planets. 2nd Fractional Calculus Meeting. Madrid. (España).

G. Barderas (2018). Herramientas geodésicas como soporte de modelos de decisión. Curso de doctorado IMEIO. 11^a Jornada FuzzyMAD+IMEIO de CASI-CAM-CM. Universidad Complutense de Madrid.

G. Barderas, J. Valles, T. Chapa and I. Ortiz (2018). Non-invasive instrumentation for archaeological studies: Combined application of multi-channel 3D GPR and photogrammetry from UAVs for the study of archaeological sites. I jornada Iberoamericana de astronomía cultural. Universidad Complutense, Madrid (España)

G. Barderas (2017). Curso de Verano de la Universidad Complutense de Madrid "Matemáticas, ¿para qué?". Seminario *Creación de Mapas* georeferenciados: coordenadas y uso de receptores GPS, y mesa redonda Operaciones humanitarias y matemáticas, ¿un binomio que funciona?

G. Barderas, M.M. Sánchez-García and P. Romero (2018). Optimal minimum-energy Earth-Mars transfer trajectories. ESA-ESAC & IAA-CSIC Scientific Workshop: “From Mars Express to ExoMars”. ESAC faculty, Villafranca del Castillo (España).

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I., Blanco-Montenegro, FG. Montesinos, J. Arnos, E.J. Vélez, M. Benavent, (2015). Features of the subsurface structure of the Timanfaya volcanic area (Lanzarote) from a joint analysis of magnetic and gravimetric maps 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics, Praga (Rep. Checa)

J Fernandez, A G Camacho, F Luzon, JF Prieto, J Escayo, G Rodríguez-Velasco, K French Tiampo, M Palano, J Velasco, T Abajo, E Perez, I Gomez, T Herrero, G Bru, J Aguirre, H Mateos, (2017). Displacement field in Lorca (Murcia, Spain) subsidence area: Observation and modelling, AGU Fall Meeting, Washington, D.C.,

J Fernandez, J F Prieto, J Escayo, A G Camacho, F Luzón, K French Tiampo, M Palano, T Abajo, E Perez, J Velasco, T Herrero, Ge Bru, I Molina, JC Lopez de Herrera, G Rodríguez-Velasco, Il Gomez, Julian Aguirre, H Mateos, J Fabrega, I Marzán, S Lopez-Cuervo, J J Mallorqui, (2018), Results obtained from the multiple geodetic observations at Lorca (Murcia, Spain) subsidence area, AGU Fall Meeting, Washington, D.C

M Folgueira, V. Dehant, M. Puica, and The RotaNut team. (2018) Analytic Computation of the Total Topographic Torque at the Core-Mantle-Boundary and its Impact on Nutations. Americal Geophysical Union – AGU Fall meeting. Washington, D.C

D. Gómez-Ortiz, Blanco-Montenegro, I., Martin-Crespo, T., Arnos, J., Solla, M., Montesinos, FG., Vélez, EJ., Calvo-Rathert, M., Sánchez, N., Lorenzo, H., Soler, V., (2017) Identification of shallow geothermal anomalies in the Timanfaya National Park (Lanzarote, Canary Islands) through combined geophysical prospecting techniques, European Geosciences Union. General Assembly 2017, Viena (Austria)

A. Gorbatiokov. Arnos, J., Stepanova, M., Montesinos, FG., Benavent, M., Vélez, E.J., Blanco-Montenegro, I., Soler, V.,(2015). Features of the deep structure of some volcanic islands of the Canary Archipelago from the passive seismo-prospecting

method, 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics Praga (Rep. Checa)

FG. Montesinos, J. Arnosó, M. Benavent, E.J. Vélez, T. Martín-Crespo, D. Gómez-Ortiz, Gorbatióov, A., (2015). A new gravity study to model crustal structures of the volcanic island of Gran Canaria (Spain) 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics Praga (Rep. Checa)

FG. Montesinos, I., Blanco-Montenegro, J. Arnosó, (2015). 3D inversion of magnetic anomaly data using a genetic algorithm 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics, Praga (Rep. Checa)

B. Pablos, P. Romero, C. Amorós, G. Barderas y G. Rodríguez-Caderot (2015). Infraestructuras de datos espaciales en la optimización de trayectorias de vehículos pilotados por control remoto. FuzzyMAD 2015. Madrid (España).

M. Rodríguez-Bouza, M. Herraiz, G.Rodríguez-Caderot, C. Papparini, X. Otero, S. Radicella. (2016). Comparison between the effect of two geomagnetic storms with the same seasonal and daily characteristics and different intensity on the European ionosphere. EGU General Assembly Vienna Austria

JF Prieto, J Fernandez, M Palano, T Abajo, E Perez, J Escayo, J Velasco, T Herrero, AG Camacho, G Bru, I Molina, JC Lopez de Herrera, G Rodríguez-Velasco, I Gomez, (2016). GNSS 3D displacement field determination in Lorca (Murcia, Spain) subsidence area, AGU Fall Meeting, Washington, D.C.,

V. Puente, J. R., N. Capitaine and M. Folgueira. (2018). Nutation determination by means of GNSS: Status and Prospects. EGU-European Geosciences Union-General Assembly, Session: "Open Session in Geodesy ". Vienna,

U: Riccardi., Arnosó, J., Benavent, M., Vélez, EJ., Tammáro, U., Montesinos, FG., (2017). Active tectonics on Lanzarote (Canary Islands) from the analysis of CGPS data, European Geosciences Union. General Assembly 2017 Viena (Austria)

J.Y. Richard, C. Bizouard, N. Capitaine, V. Puente, M. Folgueira, Q. Chevreuil and A. Malecot. (2018). Nutation rate determination by means of GNSS observations. Journées du SYRTE 2018", Paris

I. Rodríguez Bilbao S. Radicella, G. Rodríguez Caderot, M. Herraiz, (2015) Precise point positioning degradation in the presence of a SITEC. 1st URSI Atlantic Radio Science Conference (URSI AT-RASC)

P. Romero, M.M. Sánchez-García and G. Barderas (2018). Long Term Orbit Propagation Using a Semi-analytical Theory: Numerical Test Case for Space Debris. 2nd Fractional Calculus Meeting. Madrid. (España).

P. Romero, G. Barderas, B. Pablos, G. Rodríguez-Caderot and C. Amorós (2016). Optimización 2D/3D para la navegación ortodrómica de RPAS basada en Infraestructuras de Datos Espaciales. 9^a Asamblea Hispano Portuguesa de Geodesia y Geofísica. Madrid (España)

M. M. Sánchez García, G. Barderas and P. Romero (2017). Determination of optimal minimum-energy Earth-Mars trajectories. FuzzyMAD 2017. Madrid (España).

M. Solla, D. Gómez-Ortiz, FG. Montesinos, T. Martin-Crespo, J. Arnosó and E.J. Vélez. (2015). Characterization of volcanic structures using ground penetrating radar and additional inverse modeling”: 8th International Workshop on Advanced Ground Penetrating Radar - IWAGPR 2015, Florencia (Italia)

PH.D: THESIS

Laura García Cañada

Análisis de series temporales en estaciones permanentes GPS.

Universidad Complutense de Madrid Facultad de Ciencias Matemáticas. . Score: Sobresaliente Cum Laude. (2015)

Advisor: M. J. Sevilla de Lerma

Marta Calvo García-Maroto.

Analysis of long-term gravity records in Europe; consequences for the retrieval of small amplitude and low frequency signals including the Earth's core resonance effects.

University Complutense of Madrid and University of Strasburg. Score: Sobresaliente Cum Laude. (2015)

Co-Advisors: J. Arnosó and J. Hinderer

Jorge Luis Andrés García

El problema de Lagrange en cartografía. Universidad Complutense de Madrid. Score: Sobresaliente Cum Laude. (2016)

Advisor: J. Otero Juez.

Izarra Rodríguez Bilbao

Analysis and physical interpretation of ionospheric plasma irregularities effect on positioning. Score: Sobresaliente Cum Laude. (2017)

Co-Advisors: G. Rodriguez Caderot and M.Herraiz

Marta Rodríguez Bouza,

Estudio de perturbaciones ionosféricas a través del contenido total de electrones en Europa meridional. Score: Sobresaliente Cum Laude. (2017)

Co-Advisors: G. Rodriguez Caderot and M.Herraiz

Eleonora Vitagliano

Multi-component and multi-source approach to model subsidence in deltas. Application to Po Delta Area.

Universita Degli Studi Di Napoli Federico II. Score: Sobresaliente Cum Laude. (2018)

Co Advisors: Prof. Rosa Di Maio, Prof. D. Calcaterra, Dr. U. Riccardi.

MSC DISSERTATIONS

Yaiza Jiménez Briongos (2018)

Influencia del terreno en el gradiente vertical de la gravedad.. Máster en Ingeniera Matemática. Facultad de Matemáticas. UCM

Co-Advisors: S. Sainz-Maza (IGN) y F. G-Montesinos

Ana Adell Lamora (2018)

Integración de datos InSAR y GPS para el análisis de deformaciones en las Islas Canarias.

Máster en Ingeniera Matemática. Facultad de Matemáticas. UCM

Co-Advisors: L. García Cañada (IGN), E. Gonzalez Alonso (IGN)) and F. G-Montesinos.

Andrea Balduin (2018)

Analysis and interpretation of continuous GPS data collected at Lanzarote Island (Canary Islands, Spain).

Laurea Magistrale in Geologia e Geologia Applicata. Universidad Federico II de Nápoles, Italia.

Co-Advisors: U. Riccardi, J. Arnoso and U. Tammaro

Olivia Lozano Blanco (2018)

Gravimetría aplicada al estudio de la corteza terrestre en la isla de San Miguel.
Máster en Geofísica y Meteorología. Universidad de Granada.
Advisor: J. Arnoso

Miguel Álvarez del Río (2018)

La defoliación como indicador del deterioro de la masa forestal en los Parques Nacionales de España y su correlación con el clima;
Máster Interuniversitario Universidad Complutense - Universidad Politécnica de Madrid en Gestión de desastres
Co-Advisors: P. Romero, G. Barderas.

Mijalis Alexandros Méndiz Pazos (2018)

Estudio de deformaciones del terreno mediante GNSS. Aplicación en Canarias..
Máster: Tecnologías de la Información Geográfica. Facultad de Geografía e Historia, UCM
Advisor: M.T. Benavent

Marta-María Sánchez. (2017).

Optimización de Maniobras en Órbitas de Transferencia Tierra-Marte
Máster en Ingeniería Matemática Facultad de Ciencias Matemáticas. UCM
Co-Advisors: P. Romero, G. Barderas.

Manuel Lanchares Prieto. (2017)

Nonlinear methods for orbital covariance propagation
Máster en Ingeniería Matemática Facultad de Ciencias Matemáticas. UCM
Advisors: M. Folgueira and A. Antón Sánchez (GMV)

Meritxell Arsuaga Zalacain (2017)

Análisis de outliers de series temporales de datos atmosféricos y su correlación con series de coordenadas de estaciones permanentes GPS.
Máster en Ingeniería Matemática. Facultad de Matemáticas. UCM
Co-Advisors : L. García Cañada (IGN) and F. G-Montesinos.

Blanca Pablos Martín (2016).

Analysis of Perturbed Orbit Estimation Accuracy for Areostationary Satellites
Máster en Ingeniería Matemática Facultad de Ciencias Matemáticas. UCM
Advisor: P. Romero.

Denis Coccolo Góngora. (2015).

Enhancement and expansion of the perturbation forces model in a semi-analytical propagator.

Máster en Ingeniería Matemática Facultad de Ciencias Matemáticas. UCM

Advisors: P. Romero and A. Lozano (GMV)

(The information of this Institution has been remitted by P. Romero)



5. Instituto de Geociencias (IGEO)

(Consejo Superior de Investigaciones Científicas-Universidad

Complutense de Madrid, CSIC-UCM)

**Calle del Doctor Severo Ochoa, 7. Facultad de Medicina (Edificio Entrepabellones 7 y 8, 4^a
planta). Ciudad Universitaria. 28040-Madrid.**

May, 2019

Members of the Research Group working in Geodesy

Tamara Abajo Muñoz, Graduated in Geology, PhD Student, hired Researcher.

José Arnosó Sampedro, Ph.D. in Mathematics, Tenure Scientist.

Guadalupe M. Bru Cruz, Graduated in Geology, PhD Student, hired Researcher.

María Charco Romero, Ph.D. in Mathematics, Tenure Scientist.

Joaquín Escayo Menéndez, Graduated in Physics, PhD Student, hired Researcher.

José Fernández Torres, Ph.D. in Mathematics, Research Professor.

Ruben Gómez Fuentes, Graduated in Computer Engineering, hired Technician (2018).

Antonio J. González Camacho, Ph.D. in Mathematics, Tenure Scientist.

Ignacio L. Marzán Blas, Ph.D. in Physics, hired Researcher.

Sara Rodríguez Molina, Graduated in Physics, PhD Student, hired Researcher.

Emilio Vélez Herránz, Graduated in Mathematics, Technician.

RESEARCH INTERESTS

The scientific objectives of IGEO in Geodesy can be summarized as follows:

a) **SPACE GEODESY, POSITIONING SYSTEMS AND REMOTE SENSING:** The use of artificial satellites for the Earth observation allows the detection of deformation and gravity variations associated to geodynamic processes (e.g., volcanic eruptions, earthquakes and ground instabilities) or global change (changes in the mass of the water, etc.), representing a fundamental area of the Earth Sciences, with a growing importance. For this reason, among others, the development, implementation and validation of the new mathematical techniques of data analysis, and new mathematical methods for the integration of different kinds of geodetic terrestrial and space data, are goals of the IGEO's research.

b) **GEODETIC MONITORING OF GEOLOGICAL AND ANTHROPOGENIC HAZARDS:** Geological and man-made hazards, which threaten an important part of the world's population and can have tremendous economic and human costs, can cause deformation and gravity variations. Therefore the geodetic techniques are useful in its surveillance, being it a main research line, covering aspects of observation and interpretation through the use of theoretical models and inversion techniques. Some objectives are: the development of deformation models for volcanic loading, earthquakes and land instability; the development of techniques of interpretation of geodetic observations on active zones; the application and validation of these models and techniques; and the development of new methodologies for monitoring and interpretation, in particular in quasi real time, useful for decision-making.

c) **GRAVIMETRY, TIDES AND GEODYNAMICS:** Earth tides and ocean tidal loading for studying of the elasticity of the Earth's crust. Study of deformations of the Earth's crust in active volcanic areas using geodetic control networks, continuous gravity measurements and GPS displacements. Time series analysis and study of disturbing effects on terrestrial based geodetic measurements. Modelling of the Earth's crust through gravity inversion. Investigation of geodetic and gravimetric methods and observational techniques in geodynamic laboratories. Studying of calibration methods through gravity calibration lines and intercomparisons made at gravimetric laboratories.

c) **MATHEMATICAL MODELS IN GEODESY:** The amount of high precision geodetic observation data of the Earth increases continuously, exceeding the current exploitation capabilities. The development of the required new methods for processing data, modeling and interpretation, which consider its high quality, variety, origin, temporal and spatial distribution (punctual or almost continuous data), are also objectives. Development of numerical models in the field of Volcano Geodesy focusing on a comprehensive understanding of the mechanisms that promote Earth's surface deformation around volcanic areas. This is accomplished through the integration of large quantities of remote sensing data such as GPS, differential InSAR and gravity data in order to provide critical information on the nature and scale of deformation. The research includes improvements into accurate models of the geophysical sources. Significant contributions include development of effective inversions for the sources of surface deformation associated with volcanic hazard by using numerical models (Finite Element Models) for the realistic simulation of geomorphological and mechanical features of the medium.

d) **DETERMINATION OF CRUSTAL STRUCTURE:** To know the crustal structure is a fundamental aspect to explain the measurements of deformation and gravity change, allowing to make a realistic interpretation of geophysical and geodetic observations. For this reason, the development and implementation of new techniques to study and determine the crustal structure and to carry out prospecting by means of geodetic and geophysical data (e.g., using gravity data and combining these with seismic data) is another objective.

Other fundamental objective of the IGEO is to promote national and international (including companies) collaborations, strengthening existing ones and creating new ones. It is also to be developed within the framework of the CSIC and IGEO. All these objectives are pursued in the framework of national, of the EU H2020 Programme and of different space agencies research projects currently under development. An example of this is the participation in the ESFRI EPOS infrastructure, where the CSIC is the Spanish representative. Jose Fernández is the coordinator of EPOS Espacio España and of the EPOS Spain Thematic network. Currently it is under development (jointly with the Remote Sensing Laboratory of IGEO) the implementation of the Spanish 3D-def service in the framework of the EPOS infrastructure.

PUBLICATIONS

1) SCI Journals

2015

- Boní, R., Herrera, G., Meisina, C., Notti, D., Béjar-Pizarro, M., Zucca, F., González, P.J., Palano, M., Tomás, R., Fernández, J., Fernández-Merodo, J.A., Mulas, J., Aragón, R., Guardiola-Albert, C., Mora, O., 2015. Twenty-year advanced DInSAR analysis of severe land subsidence: The Alto Guadalentín Basin (Spain) case study. *Engineering Geology*, 198, 40–52, doi: 10.1016/j.enggeo.2015.08.014
- Camacho, A.G., Carmona, E., García-Jerez, A., Sánchez-Martos, F., Prieto, J.F., Fernández, J., Luzón, F., 2015. Structure of alluvial valleys from 3-D gravity inversion: The Low Andarax Valley (Almería, Spain) test case. *Pure and applied geophysics*, 172/11, 3107-3121, doi: 10.1007/s00024-014-0914-8.
- Cannavò, F., Camacho, A.G., González, P.J., Mattia, M., Puglisi, G., Fernández, J., 2015. Real Time Tracking of Magmatic Intrusions by means of Ground Deformation Modeling during Volcanic Crises. *Scientific Reports*, 5, 10970, doi: 10.1038/srep10970 (10 pp más de material suplementario).
- Fernández, J., P.J. González, A. G. Camacho, J.F. Prieto, G. Bru, 2015. An Overview of Geodetic Volcano Research in the Canary Islands. *Pure and applied geophysics*, 172/11, 3189-3228, doi: 10.1007/s00024-014-0916-6.
- Fullea, J., A. G. Camacho, A. Negredo, J. Fernández, 2015. The Canary Islands hot spot: new insights from 3D coupled geophysical-petrological modelling of the lithosphere and uppermost mantle. *Earth and Planetary Science Letters*, 409, 71-88, doi: 10.1016/j.epsl.2014.10.038.
- Fullea, J., Rodríguez-González, J., Charco, M., Martinec, Z., Negredo, A.M. and Villaseñor, A., 2015, Perturbing effects of sub-lithospheric mass anomalies in GOCE gravity gradient and other potential field data modelling: application to the Atlantic-Mediterranean transition zone, *International Journal of Applied Earth Observation and Geoinformation*, 35 (A), 54-69 doi: 10.1016/j.jag.2014.02.003.
- Orive, R., Osete, M.L., Díaz, J.I., Fernández, J., 2015. Introduction to Mathematics and Geosciences: Global and Local Perspectives, Volume I. *Pure and applied geophysics*, 172/1, 1-5, doi: 10.1007/s00024-014-0961-1.
- Palano, M., González, P.J., Fernández, J., 2015. The diffuse plate boundary of Nubia and Iberia in the Western Mediterranean: crustal deformation evidence for viscous coupling and fragmented lithosphere. *Earth and Planetary Science Letters*, 430, 439-447, <http://dx.doi.org/10.1016/j.epsl.2015.08.040>.
- Rosat, S., Calvo, M., Hinderer, J., Riccardi, U., Arnosó, J., Zürn, W., 2015. Comparison of the performances of different spring and superconducting gravimeters and STS-2 seismometer at the Gravimetric Observatory of Strasbourg, France. *Studia Geophysica et Geodaetica*, 59, 58-82, 2015, doi: 10.1007/s11200-014-0830-5.

2016

- Bonforte, A., González, P.J., Fernández, J., 2016. Joint terrestrial and aerial measurements to study ground deformation: application to the Sciara del Fuoco at Stromboli volcano (Sicily). *Remote Sensing*, 8, 463, doi: 10.3390/rs8060463.
- Charco, M., Orive, R., Díaz, J.I, Osete, M.L., Fernández, J., 2016. Introduction to Mathematics and Geosciences: Global and Local Perspectives. Volume II. *Pure and applied geophysics*, 173/3-4, 731-737, doi: 10.1007/s00024-016-1255-6.
- Montesinos, FG, Blanco-Montenegro, I., Arnosó, J., 2016. Three-dimensional inverse modelling of magnetic anomaly sources based on a genetic algorithm. *Physics of the Earth and Planetary Interiors*, 253, 74-87, doi: 10.1016/j.pepi.2016.02.004.
- Polcari, M., Palano, M., Fernández, J., Samsonov, S.V., Stramondo, S., Zerbini, S., 2016. 3D displacement field retrieved by integrating Sentinel-1 InSAR and GPS data: the 2014 South Napa earthquake. *European Journal of Remote Sensing*, 49, 1-13, doi: 10.5721/EuJRS20164901.

2017

- Béjar-Pizarro, M., Notti, D., Mateos, R.M., Ezquerro, P., Centolanza, G., Herrera, G., Bru, G., Sanabria, M., Solari, L., Duro, J., Fernández, J., 2017. Mapping vulnerable urban areas affected by slow-moving landslides using InSAR. *Remote Sens.*, 9, 876; doi: 10.3390/rs9090876.
- Bru, G.; González, P.J.; Mateos, R.M.; Roldán, F.J.; Herrera, G.; Béjar-Pizarro, M.; Fernández, J., 2017. A-DInSAR Monitoring of Landslide and Subsidence Activity: A Case of Urban Damage in Arcos de la Frontera, Spain. *Remote Sens.*, 9(8), 787; doi: 10.3390/rs9080787.
- Fernández, J., Pepe, A., Poland, M.P., Sigmundsson, F., 2017. Volcano Geodesy: Recent developments and future challenges. *Journal of Volcanology and Geothermal Research*, 344, 1-12, doi: 10.1016/j.jvolgeores.2017.08.006.
- Polcari, M., J. Fernández, M. Albano, C. Bignami, M. Palano, S. Stramondo, 2017. An improved data integration algorithm to constrain the 3D displacement field induced by fast deformation phenomena tested on the Napa Valley earthquake. *Computers and Geosciences*, 109, 206–215, doi: 10.1016/j.cageo.2017.09.002.
- Sainz-Maza, S., Montesinos, FG, Martí, J., Arnosó, J., Calvo, M., Borreguero, A., 2017. Structural Interpretation of El Hierro (Canary Islands) rifts system from gravity inversion modelling. *Tectonophysics*, 712-713, 72-81, doi: 10.1016/j.tecto.2017.05.010.
- Tiampo, K.F., González, P.J., Samsonov, S., Fernández, J., Camacho, A., 2017. Principal component analysis of MSBAS DInSAR time series from Campi Flegrei, Italy. *Journal of Volcanology and Geothermal Research*, 344, 139-153, doi: 10.1016/j.jvolgeores.2017.03.004.

2018

- Ashena, Z.B., Ardestani, V.E., Camacho, A.G., Dehghani, A., Fernández, J., 2018. Moho Depth Determination Beneath Zagros Mountains from 3D Inversion of Gravity Data. *Arabian Journal of Geoscience*, 11(3), 52, <https://doi.org/10.1007/s12517-018-3385-x>.

- Blanco-Montenegro, I., Montesinos, F.G., Arnosó, J., 2018. Aeromagnetic anomalies reveal the link between magmatism and tectonics during the early formation of the Canary Islands. *Scientific Reports*, 8, Article number: 42 doi: 10.1038/s41598-017-18813-w.
- Camacho, A.G., J. Fernández, F. Cannavó, 2018. PAF: A software tool to estimate free-geometry extended bodies of anomalous pressure from surface deformation data. *Computers and Geosciences*, 111, 235-243, doi: 10.1016/j.cageo.2017.11.014.
- Bru, G., J.A. Fernández-Merodo, J.C. García-Davalillo, G. Herrera, J. Fernández, 2018. Site scale modelling of slow-moving landslides, a 3D viscoplastic finite element modelling approach. *Landslides*, 15(2), 257–272, doi: 10.1007/s10346-017-0867-y.
- Bru, G., Escayo, J., Fernández, J., Iglesias, R., Mallorquí, J.J., Iglesias, R., Sansosti, E., Abajo, T., Morales, A., 2018. Suitability assessment of X band A-DInSAR techniques for monitoring site scale slow moving landslides: The Leintz Gatzaga (Guipúzcoa, Spain) test-case. *Remote Sensing*, 10, 936; doi: 10.3390/rs10060936.
- Fernández, J., J. F. Prieto, J. Escayo, A. G. Camacho, F. Luzón, K. F. Tiampo, M. Palano, T. Abajo, E. Pérez, J. Velasco, T. Herrero, G. Bru, I. Molina, J. López, G. Rodríguez-Velasco, I. Gómez, J. J. Mallorquí, 2018. Modeling the two- and three-dimensional displacement field in Lorca, Spain, subsidence and the global implications. *Scientific Reports*, 8:14782, <https://www.nature.com/articles/s41598-018-33128-0>.
- Riccardi, U., Arnosó, J., Benavent, M., Vélez, E.J., Tammaro, U., Montesinos, F.G., 2018. Exploring deformation scenarios in Timanfaya volcanic area (Lanzarote, Canary Islands) from GNSS and ground based geodetic observations. *Journal of Volcanology and Geothermal Research*, 357, 14-24, doi: 10.1016/j.jvolgeores.2018.04.009

2) Edition of Topical issues of SCI Journals

- Díaz, J.I, Fernández, J., Orive, R., Osete, M.L., 2015 (Editors). *Pure and Applied Geophysics (Pageoph)*, Topical Issue “Mathematics and Geosciences. Global and Local perspectives: Volume I”. 172/1, 1-196.
- Charco, M., Díaz, J.I, Fernández, J., Orive, R., Osete, M.L., 2016 (Editors). *Pure and Applied Geophysics (Pageoph)*, Topical Issue “Mathematics and Geosciences. Global and Local perspectives. Volume II”. 173/3-4, 731-1009.
- Fernández, J., Pepe, A., Sigmundsson, F., Poland, M., 2017 (Editors). *Journal of Volcanology and Geothermal Research*. Special Issue: “Measuring Changes at Volcanoes using Geodesy: an update of Methods and Results”, 344, 1-288.

3) Data sets

- Camacho, A. G., J. Fernández, R. Vieira, J.F. Prieto, 2017. Lanzarote (Canary Islands) observed gravity data (Datum GRS80) [Dataset, retrieved from <http://hdl.handle.net/10261/153762>].

4) Other Journals

- Bru, G., Gascón, B., Camacho, A.G., Prieto, J.F., Mallorquí, J.J., Morales, A., Fernández, J., 2015. Deslizamiento de Leintz Gatzaga: Instrumentación Geotécnica y Monitorización

del Movimiento con Técnicas Terrestres y Espaciales. Proyecto Eoslide. *Ingeniería Civil*, 180, 55-75.

Fernández J., 2017. Las matemáticas en el estudio de la Tierra sólida. *Boletín de la Titulación de Matemáticas de la UAL*. Vol. X, nº 2, 18-19, ISSN: 1988-5318.

5) Books and books chapters

Arnosó, J., Montesinos, FG., Gómez-Ortiz, D., Martín-Crespo, T., Blanco-Montenegro, I., Gorbátikov, A., Benavent, M., Vélez, E., Solla, M., Calvo-Rathert, M., Lorenzo, H., Riccardi, U., 2017. Caracterización estructural del Parque Nacional de Timanfaya mediante técnicas y métodos geodésicos y geofísicos. Proyectos de investigación en parques nacionales 2012-2015 (Serie Investigación en la Red de Parques Nacionales). Pep Amengual (Ed.). ISBN: 978-84-8014-907-5, pp. 89-106.

Bonì, R., Herrera, G., Meisina, C., Notti, D., Béjar-Pizarro, M., Zucca, F., González, P. J., Palano, M., Tomás, R., Fernández, J., Fernández-Merodo, J. A., Mulas, J., Aragón, R., Guardiola-Albert, C., and Mora, O., 2015. Application of multi-sensor advanced DInSAR analysis to severe land subsidence recognition: Alto Guadalentín Basin (Spain), Proceedings of the International Association of Hydrological Sciences (Proc. IAHS), 372, 45-48, doi:10.5194/piahs-372-45-2015, 2015.

Fernández, J., J. Gallart, R. Carbonell, J. Díaz, A. Villaseñor, A. Azor, F.J. González-Matesanz, A. Geyer, J.J. Curto, M. Mattesini, L.R. Rodríguez-Fernández, J.L. Fernández-Turiel, 2017. EPOS (EUROPEAN PLATE OBSERVATION SYSTEM). Primer Congreso en Ingeniería Geomática, CIGeo, Valencia, 4-5 de Julio de 2017. Libro de actas. Universidad Politécnica de Valencia. ISBN: 978-84-9048-669-6, doi: <http://dx.doi.org/10.4995/CIGeo2017.2017.7176>.

Solla, M., Montesinos, FG., Gómez-Ortiz, D., Martín-Crespo, T., Arnoso, J., Vélez, E., 2015. Characterization of volcanic structures using ground penetrating radar and additional inverse modelling: Multidisciplinary geophysical investigation in the Timanfaya National Park (Spain). IEEE Xplore Abstract. Advanced Ground Penetrating Radar (IWAGPR), 2015 8th International Workshop. doi: 10.1109/IWAGPR.2015.7292641.

RESEARCH PROJECTS

1) European Union

- “Earth’s Critical Zone Early Warning System (CZ-EWS) by integrating SAR and seismic data in a mining context (Minas Riotinto, SW Iberia)”. Copernicus for Skills – Raw Material Post-Doc Programme. Grant Agreement No.: 248/G/GRO/COPE/16/9077- Lot 2 (01/07/2017-30/06/2018). EIT Raw Materials GmbH. PI: José Fernández. Support: 86.400,00 €
- “EPOS Implementation Phase (EPOS IP). (Grant agreement no: 676564-EPOS IP)” (01/10/2015-30/09/2019). EU VII Framework Program, ESFRI. Convocatoria INFRADEV-3-2015: Individual implementation and operation of ESFRI projects. Coord.: M. Cocco (INGV, Italia). PI CSIC: R. Carbonell (ICTJA Almera, Barcelona), J. Fernández (IGEO, Madrid). Support: 18,374,344.00 € (CSIC: 460,349.90 €; IGEO: 139.025 €).
- “MEDiterranean SUPersite Volcanoes (MED-SUV)” (308665) (01/06/2013-31/05/2016). EU VII FP. Coord.: G. Puglisi (INGV, Italy). PI CSIC: José Fernández. Support: 5.998.851 € (CSIC: 250.000 €).

2) Space Agencies

- “Study of surface deformation due to groundwater exploitation in southern Spain. (Science proposal ID 408)”. Italian Space Agency (ASI) (28/03/2016-27/03/2018). Centres: IGME (España), Instituto de Geociencias (IGEO, CSIC-UCM) (España), Department of Civil Engineering, University of Alicante (Spain); University of Leeds (UK), IREA-CNR (Italy), INGV-OE (Italy), Dares Technology (Spain). PI: M. Béjar (IGME), Co-PI: J. Fernández (IGEO)
- “Measurement of time-dependent surface displacement associated with ground water extraction at Lorca (Murcia, Spain). (GEO3155)”. German Space Agency (DLR) (15/02/2016-14/02/2018). Centres: Instituto de Geociencias (IGEO, CSIC-UCM) (Spain), Universidad Politécnica de Cataluña (Spain); University of Leeds (UK), IREA-CNR (Italy), INGV-OE (Italy), Universidad Politécnica de Madrid (Spain), IGME (Spain), ESOC-CIRES (USA), CCMEO (Canada), Dares Technology (Spain). PI: T. Abajo (IGEO), Co-PI: J. Fernández (IGEO), J. Escayo (IGEO).
- “A new methodology to monitor critical hydrologic structures using Advanced DInSAR techniques: Testing of frequency range and pixel size.” (Cat.-1 32229). European Space Agency (ESA) (12/02/2016-11/02/2018). Centres: Instituto de Geociencias (IGEO, CSIC-UCM) (Spain), Universidad Politécnica de Cataluña (Spain); University of Leeds (UK), IREA-CNR (Italy), INGV-OE (Italy), Universidad Politécnica de Madrid (Spain), IGME (Spain), ESOC-CIRES (USA), CCMEO (Canada), Dares Technology (Spain). PI: J. Escayo (IGEO), **Co-IP:** J. Fernández (IGEO), T. Abajo (IGEO).
- “Modeling of the 2012-214 volcanic unrest occurred in El Hierro Island (Canary Islands, Spain) using combination of GPS and SAR data. (Cat.-1 29252)”, European Space Agency (ESA) (01/01/2015-31/12/2017). Centers: Instituto Geográfico Nacional (Spain); Instituto de Geociencias (CSIC-UCM, Spain); Nordic Volcanological Center (University of Iceland, Iceland). PI: M.A. Benito-Saz (IGN). Co-IP: M. Charco (IGEO).
- “Ground deformation in El Hierro Island after the 2011-2012 submarine eruption (Cat.-1 31045)”, European Space Agency (ESA) (01/01/2015-31/12/2017). Centers: Instituto Geográfico Nacional (Spain); Instituto de Geociencias (CSIC-UCM, Spain); Nordic

Volcanological Center (University of Iceland, Iceland). PI: M.A. Benito-Saz (IGN). Co-IP: M. Charco (IGEO).

- “Investigation of ground surface displacements associated to a long-lived seismic swarm at La Loma region (Jaén, Spain). (Cat.-1 31947)”. European Space Agency (ESA). (18/12/2015-31/12/2017). Centres: Instituto de Geociencias (IGEO, CSIC-UCM) (Spain), Universidad Politécnica de Cataluña (Spain); University of Leeds (UK), INGV-OE (Italy), UPM (Spain), ICTJA-CSIC (Spain). PI: Guadalupe Bru (IGEO), Co-PI: J. Fernández (IGEO).

- “Study of surface displacement associated with the exploitation of aquifers at regional and local scales in the southern part of the Iberian Peninsula. (Cat.-132005)”. European Space Agency (ESA). (21/12/2015-31/12/2017). Centres: Instituto de Geociencias (IGEO, CSIC-UCM) (Spain), Universidad Politécnica de Cataluña (Spain); University of Leeds (UK), IREA-CNR (Italy), INGV-OE (Italy), Universidad Politécnica de Madrid (Spain), IGME (Spain), ESOC-CIRES (USA), CCMEQ (Canada), Dares Technology (Spain). PI: T. Abajo (IGEO), **Co-PI:** J. Fernández (IGEO), J. Escayo (IGEO).

- “Study of land instability using X-band Advanced DInSAR observation at different geological settings”. Italian Space Agency (ASI). (19/09/2013-18/09/2016). Centres: Instituto de Geociencias (IGEO, CSIC-UCM) (Spain), Universidad Politécnica de Cataluña (Spain); Western University (Canada), IREA-CNR (Italy), Natural Resources Canada (Canada). PI: J. Fernández (IGEO).

- “Study of the 1992-2010 displacement field produced by land instability around Leintz Gatzaga, Alava, Spain”. (Cat.-1 13933). European Space Agency (ESA). (20/02/2013-31/12/2016). Centres: Instituto de Geociencias (IGEO, CSIC-UCM) (Spain), Universidad Politécnica de Cataluña (Spain); University of Western Ontario (UWO, Canada), IREA-CNR (Italy), UPM (Spain), Euroestudios S.L. (Spain). PI: J. Fernández (IGEO), **Co-PI:** P.J. González (UWO), J.J. Mallorquí (UPC), G. Bru (IGEO).

- “Determination of the 1992-2010 deformation field in the Canary Islands by means of ERS-1/2, ENVISAT and ALOS radar images: Implications in the volcano monitoring system definition”. (Cat.-1 11021). European Space Agency (ESA). (04/2012-03/2015). Centres: Instituto de Geociencias (CSIC-UCM) (Spain), UPC (Spain), University of Western Ontario (UWO, Canada). PI: J. Fernández (IGEO), **Co-PI:** P.J. González (UWO), J.J. Mallorquí (UPC).

3) Spanish Research Program

- Development and analysis of crustal structure models in the canaries. Implications for studies of deformation and gravity changes in El Hierro and Lanzarote (CGL2015-63799-P) . Ministerio de Economía y Competitividad. Centre: Instituto de Geociencias (CSIC-UCM). Dates: 01-01-2016 to 31-12-2019. PI: J. Arnosó. Support: 123.299,00 €

- Thematic network EPOS SPAIN (CGL2016-81965-REDT) (01/07/2017 al 30/06/2019). Ministerio de Economía y Competitividad, España. Convocatoria de Redes de Excelencia 2016. PI: J. Fernández. Support: 18.000,00 €.

- Computer cluster and web service of the Spanish node of EPOS Space Data. (UCMA15-EE-3294). (01/01/2016-30/06/2018). Ministerio de Economía y Competitividad, España. Convocatoria de Infraestructura Científico Tecnológica 2015. PI: J. Fernández. Support: 107.056,00 €.

- Geologic and geodetic data integration for interpreting magmatic deformation and related hazards in Canary Islands: Numerical modeling (CGL2014-58821-C2-1-R). MINECO (01/01/2015-31/12/2018). PI: M. Charco. Co-PI: A.M. Negro. Support: 70.000,00 €.
- Multi-satellite and multi-frequency radar observation for critical hydraulic infrastructure monitoring. (mufSARem) (RTC-2014-1922-5). (01/09/2014-30/06/2018). Ministerio de Economía y Competitividad, España. Convocatoria Retos-Colaboración 2014. Centres: Euroestudios S.L., IGEO (CSIC-UCM). Thecnical Coord.: A. Morales (Euroestudios S.L.), PI CSIC: A. J. González Camacho. Scientific Coord.: J. Fernández (CSIC). Support: 326.752,14 € (182.769,24 CSIC).
- Study of geological-geotechnical hazards by exploiting aquifers using space and terrestrial techniques. (AQUARISK) (ESP2013-47780-C2-1-R). (01/01/2014-30/06/2018). Ministerio de Economía y Competitividad, España. Centres: IGEO (CSIC-UCM), IGME. Coordinator: José Fernández, Total support: 366.630,00 €. Sub-project 1: CSIC, PI1: José Fernández, PI2: Antonio Jesús González Camacho, Support CSIC, sub-project 1: 209.330,00 €.
- Searching the geomagnetic invasions trigger. (BIG-MAG) (CGL2017-92285-EXP). (01/01/2018-31/12/2019). Ministerio de Economía y Competitividad. PI: M.L. Osete. Members of the research team: J. Fernández, A.J. González Camacho. Support: 36.300 €.
- Geodynamic modeling and joint inversion of geophysical and petrological data. Characterizing the lithospheric-sublithospheric upper mantle system: its composition, thermal state and dynamic evolution. (CGL2012-39471). Ministerio de Economía y Competitividad. (1/01/2013-31/12/2015). PI: J. Fullea (till 31/12/2014); M. Charco (2015). Support: 46.800 €.
- Structural characterization of the national park of Timanfaya by means of combined use of geodesic and geophysical techniques and methods (320/2011). Ministerio de Medio Ambiente y Medio Rural y Marino. Centre: Instituto de Geociencias (CSIC-UCM). Dates: 29-11-2011 to 30-10-2015. PI: Jose Arnos. Support: 69.115,00 €
- Advanced geodetic and geophysical modelling in Gran Canaria. Integration into the structural and dynamic context of the Canary Islands (CGL2011-25494). Ministerio de Ciencia e Innovación. Centre: Instituto de Geociencias (CSIC-UCM). Dates: 01-01-2012 to 31-12-2015. PI: J. Arnos Support: 90.750,00 €

4) Other Spanish Research Projects

- Apoyo a la implementación del servicio 3D-def de EPOS España Espacio. (201830E017). (01/03/2018- 29/02/2020). CSIC. Support: 70.783,26 €. PI: José Fernández.
- Observación radar de satélite aplicada al estudio de deformaciones en las Islas Canarias. (201530E019). CSIC. (1/1/2015- 31/12/2016). Support: 10.000 Euros. PI: José Fernández.
- Study and interpretation of geodetic and geophysical measurements applied to volcanic hazard assessment in El Hierro Island (BIL/14/P2/063). Fundación MAPFRE. Convocatoria de Ayudas a la Investigación Ignacio H. de Larramendi. Centre: Facultad de Matemáticas. Universidad Complutense de Madrid. Dates: 01-01-2015 to 31-12-2015. PI: M. Benavent. Support: 13.397,00 €

5) Committee on Earth Observation Satellite (<http://www.ceos.org/>) (CEOS)

- Mt. Etna Supersite Volcano. CEOS. From June 2014. Point of Contact (PoC): G. Puglisi, INGV-OE. Member of the research team: J. Fernández.
- Vesuvius – Campi Flegreii Supersite. CEOS. From June 2014. Point of Contact (PoC): S. Borgstrom, INGV-OV. Member of the research team: J. Fernández.

Ph. D. THESIS

- Title: Analysis of long-term gravity records in Europe; consequences for the retrieval of small amplitude and low frequency signals including the Earth's core resonance effects. Student: Marta Calvo García-Maroto. Co-Advisors: Jose Arnosó (CSIC, Spain), Jacques Hinderer (IPGS, France). University Complutense of Madrid and University of Strasburg. Date: 24-04-2015
- Title: Estudio de posibles relaciones entre la actividad sísmica en la península Ibérica y otros fenómenos geodinámicos. Student: Luis Miguelsanz del Alamo. Advisor: José Fernández (CSIC). University Complutense of Madrid. Department of “Física de la Tierra, Astronomía y Astrofísica- I. Astronomía y Geodesia.”. Date: 22-01-2016.
- Title: Métodos diferenciales e interferométricos para la evaluación de deformaciones de la corteza terrestre mediante técnicas GNSS e InSAR. Student: Juan Francisco Prieto Morín. Co-Advisors: José Fernández (CSIC), Tomás Herrero (Universidad Politécnica de Madrid). University Politécnica de Madrid. Date: 26-01-2016.
- Title: Modeling of crustal and Lithosphere structure beneath Central Zagros Mountain (Iran) by gravity data. Student: Zahra Baqeri Ashena. Co-advisors: Vahid Ebrahimzade Ardestani (University of Tehran, Institute of Geophysics), José Fernández (CSIC), Ali Dehghani (University of Kiel, Germany), Antonio G. Camacho (CSIC). University of Tehran, Irán. Date: 15-03-2018.
- Title: Site scale slow moving landslides: characterization by monitoring and modeling. Student: Guadalupe Bru Cruz. Co-Advisors: José Fernández (CSIC), José A. Fernández (IGME); Pablo J. González (University of Bristol, UK). University of Almería. Date: 19-10-2018.

SPANISH AND INTERNATIONAL COMMITTEES

- José Fernández is member of the Volcanology Section of the Spanish Commission on Geodesy and Geophysics (Comisión Española de Geodesia y Geofísica, CEGG), from February, 2005.
- José Fernández is Member of the Steering Committee of the Commission on Volcano Geodesy. Joint Commission of the International Association of Geodesy (IAG) and the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), from January 2017.
- Jose Arnosó is member of the Joint Study Group 3.1: Gravity and height change intercomparisons of the International Association of Geodesy (IAG), from 2015
- Jose Arnosó is member of the International Geodynamics and Earth Tide Service (IGETS) of the International Association of Geodesy (IAG), from 2015
- José Fernández is member of the IC-SG 28: “Geophysical Modelling of time variations in deformation and gravity” of the International Association of Geodesy (IAG), 2016-2019.

CONFERENCES AND MEETINGS ATTENDED

2015

- Arnosó, J. Caracterización estructural del Parque Nacional de Timanfaya mediante técnicas y métodos geodésicos y geofísicos. Jornadas de Investigación Programa Científico OAPN. Red de Parques Nacionales. Parque Nal. Cabañeros, Ciudad Real, (Spain), October 2015
- Charco, M., P.J. González, P. Galán del Sastre and A.M. Negrodo. FEM-based Surface Displacement Modeling of Magma Intrusions at Kilauea Volcano. American Geophysical Union Fall Meeting 2015, San Francisco (USA).
- Fullea, J., A.M. Negrodo, M. Charco, I. Palomeras, A. Villaseñor and J.C. Afonso. Lithospheric structure of the Iberian Peninsula from coupled geophysical-petrological inversion. Annual TOPO-EUROPE workshop, 2015, Antibes (France).
- Valverde, A., M. Charco, A.M. Negrodo, A. Villaseñor, J. Fullea and P.J. González. Modelling volcano deformation accounting for mechanical heterogeneities and topographic effects: application to the 2011-2012 El Hierro eruption. Annual TOPO-EUROPE workshop, 2015, Antibes (France).
- Solla, M., D. Gómez-Ortiz, FG. Montesinos, T. Martín-Crespo, J. Arnoso y E.J. Vélez. Characterization of volcanic structures using ground penetrating radar and additional inverse modelling. 8th International Workshop on Advanced Ground Penetrating Radar - IWAGPR 2015, Florence (Italy), July 2015
- Montesinos, F.G., J. Arnoso, M. Benavent, E.J. Vélez, T. Martín-Crespo, D. Gómez-Ortiz, Gorbatiĸov, A. A new gravity study to model crustal structures of the volcanic island of Gran Canaria (Spain). 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics. Prague (Czech Republic), July 2015
- Gorbatiĸov, A., Arnoso, J., Stepanova, M., Montesinos, FG. , Benavent, M., Vélez, E.J., Blanco-Montenegro, I., Soler, V. Features of the deep structure of some volcanic islands of the Canary

- Archipelago from the passive seismo-prospecting method. 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics. Prague (Czech Republic), July 2015
- Montesinos, F.G., I., Blanco-Montenegro, J. Arnosó. 3D inversion of magnetic anomaly data using a genetic algorithm. 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics. Prague (Czech Republic), July 2015
- Blanco-Montenegro, I., FG. Montesinos, J. Arnosó, E.J. Vélez, M. Benavent. Features of the subsurface structure of the Timanfaya volcanic area (Lanzarote) from a joint analysis of magnetic and gravimetric maps. 26th IUGG. General Assembly 2015. International Union of Geodesy and Geophysics. Prague (Czech Republic), July 2015
- Borgstrom, S., F. Buongiorno, A.G. Camacho, C. Del Gaudio, P. De Martino, F. Giglielmino, R. Lanari, A. Pepe, G. Puglisi, M. Silvestri, V. Siniscalchi, J. Fernández. The Italian Supersites volcanoes: a long-term monitoring experiment in active volcanic areas prone to natural hazards. FRINGE 2015 Workshop. Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR Workshop. 23-27 March, 2015. ESA-ESRIN, Frascati (Rome), Italy. European Space Agency.
- Samsonov, S., A.G. Camacho, J. Fernández, K.F. Tiampo, P.J. González. Modelling of ground deformation at Mt Etna observed with the MSBAS InSAR during 2009-2013. FRINGE 2015 Workshop. Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR Workshop. 23-27 March, 2015. ESA-ESRIN, Frascati (Rome), Italy. European Space Agency.
- Fernández, J., A.G. Camacho, D. Carbone, A. Bonforte, F. Guglielmino, G. Puglisi. Joint inversion of displacements and gravity changes at Mt. Etna volcano during the 1995-2000 period: results and conclusions. EGU General Assembly, Vienna, April 12-17, 2015.
- Polcari, M., J. Fernández, M. Palano, M. Albano, S. Samsonov, S. Stramondo, S. Zerbini. The 2014 Napa Valley earthquake constrained by InSAR and GNSS observations. EGU General Assembly, Vienna, April 12-17, 2015.
- Tiampo, K.F., P.J. González, S.V. Samsonov, J. Fernández. Principal component analysis of InSAR data. Joint Assembly, Montreal, Canada, 3-7 May 2015.
- Fernández, J., S.V. Samsonov, A.G. Camacho, K.F. Tiampo. Modelling of ground subsidence in Mexico City observed by RADARSAT-2 DInSAR during October 2008 – December 2010 time period. Joint Assembly, Montreal, Canada, 3-7 May 2015.
- Fernández, J., S.V. Samsonov, A.G. Camacho, K.F. Tiampo, P.J. González. 2009-2013 ground deformation at Mt. Etna observed with advanced DInSAR: Results and modelling. Joint Assembly, Montreal, Canada, 3-7 May 2015.
- Prieto, J.F., J. Fernández, J.A. Fernández-Merodo, A.G. Camacho, G. Herrera, M. Palano. Analysis of geological-geotechnical risks due to groundwater exploitation using space and terrestrial techniques: Lorca area (Spain) test case. Joint Assembly, Montreal, Canada, 3-7 May 2015.
- Brú, G., B. Gascón, A.G. Camacho, J.F. Prieto, J.J. Mallorquí, A. Morales, J. Fernández. Deslizamiento de Leintz Gatzaga. Instrumentación geotécnica y monitorización del movimiento con técnicas terrestres y espaciales. Proyecto EOSLIDE. Jornadas sobre OBRAS DE INTERÉS GEOTÉCNICO, Ciclo: Empresas Consultoras, 48ª Sesión. Madrid, 10 de junio de 2015. Sociedad Española de Mecánica del Suelo e Ingeniería Geotécnica, con la Colaboración del Colegio de Ingenieros de Caminos, Canales y Puertos. (INVITED)

Tiampo, K.F., Camacho, A.G., Fernández, J., González, P.J., Samsonov, S.V.. Advanced DInSAR analysis at Campi Flegrei and Vesuvius, Italy. AGU Fall Meeting 2015, San Francisco, USA, 14-18/12/2015.

2016

Bru, G., P.J. Gonzalez, J.A. Fernandez-Merodo, J. Fernandez. Stability analysis of Western flank of Cumbre Vieja volcano (La Palma) using numerical modelling. EGU General Assembly, Vienna, April 17-22, 2016.

Fullea, J., A.M. Negredo, M. Charco, I. Palomeras, A. Villaseñor and J.C. Afonso. Lithospheric structure of the Iberian Peninsula from coupled geophysical-petrological inversion. European Geosciences Union General Assembly 2016, Vienna (Austria).

Charco, M., P. Galán del Sastre, P.J. González and A.M. Negredo. Some insights about inversion of volcano deformation based on finite element models: An application to Kilauea volcano, Hawaii. The 19th European Conference on Mathematics for Industry, 2016, Santiago de Compostela (Spain).

Benito-Saz, M.A., F. Sigmundsson, M.M. Parks, M. Charco, L. García-Cañada y A.M. Negredo. Intrusiones magmáticas en la isla de El Hierro entre los años 2012 y 2014. 9 Asamblea Hispano-Portuguesa de Geodesia y Geofísica, 2016, Madrid (Spain).

Rodríguez-Molina, S., M. Charco y A.M. Negredo. Modelización viscoelástica de la deformación volcánica en Three Sisters (Oregon, E.E.U.U.). 9 Asamblea Hispano-Portuguesa de Geodesia y Geofísica, 2016, Madrid (Spain).

Rodríguez-Molina, S., V.C. Ruiz-Martínez. Evaluación de las discrepancias entre Polos Paleomagnéticos de Iberia y la Curva de Deriva Polar Aparente Global Placas Tectónicas. 9 Asamblea Hispano-Portuguesa de Geodesia y Geofísica, 2016, Madrid (Spain).

Valverde-Pérez, A., M. Charco, A.M. Negredo, A. Villaseñor, J. Fullea, M.A. Benito y P.J. González. Modelización de deformaciones volcánicas: efecto de la topografía y heterogeneidades mecánicas del medio. Aplicación a la erupción de El Hierro. 9 Asamblea Hispano-Portuguesa de Geodesia y Geofísica, 2016, Madrid (Spain).

Rodríguez-Molina, S., V.C. Ruiz-Martínez. Cinemática de la placa Ibérica desde el Pérmico: Polos paleomagnéticos frente a modelos de circuitos de placas. IX Congreso Geológico de España, 2016, Huelva (Spain).

Polcari, M., M. Albano, J. Fernández, M. Palano, S. Samsonov, S. Stramondo, S. Zerbini. Three-dimensional (3D) coseismic deformation map produced by the 2014 South Napa Earthquake estimated and modeled by SAR and GPS data integration. EGU General Assembly, Vienna, April 17-22, 2016.

Puglisi, G., F. Brito, H. Caumont, L. D'Auria, J. Fernandez, P. Mazzetti, P.Ph. Mathieu, S. Nativi, F. Papeschi, A. Pepe, D. Reitano, A. Sangianantoni, G. Scarpato, L. Spampinato. The implementation of the Open Access paradigm to the EC-FP7 MED-SUV (Mediterranean Supersite Volcanoes) project. EGU General Assembly, Vienna, April 17-22, 2016.

Manunta, M., M. Mandea, J. Fernández, S. Stramondo, T. Wright, T. Walter, P. Bally, F. Casu, G. Zeni, S. Buonanno, I. Zinno, P. Tizzani, R. Castaldo, E. Ostanciaux, M. Diament, A. Hooper, F. Maccaferri, R. Lanari. EPOS TCS Satellite Data. EGU General Assembly, Vienna, April 17-22, 2016.

Palano, M., P. J. González, J. Fernández. Crustal deformation evidences for viscous coupling and fragmented lithosphere at the Nubia-Iberia plate boundary (Western Mediterranean). EGU General Assembly, Vienna, April 17-22, 2016.

Cannavò, F., A.G. Camacho, P.J. González, G. Puglisi, J. Fernández. Sensitivity analysis of distributed volcanic source inversion. EGU General Assembly, Vienna, April 17-22, 2016.

Escayo, J., A.G. Camacho, J.F. Prieto, J.J. Mallorquí, J. Fernández. New A-DInSAR study of La Palma, Canary Islands, Spain. Results and interpretation. EGU General Assembly, Vienna, April 17-22, 2016.

Fernández, J., J. Escayo, A.G. Camacho, J.F. Prieto, J.J. Mallorquí. Surface deformation study of La Palma Island using C-Band radar imagery and GNSS data. 18th International Symposium on Geodynamics and Earth Tides – G-ET Symposium, Trieste, 5-9, June, 2016.

Abajo, T., J. Fernández, J. Escayo, F. Luzón, P.J. González. Surface displacement due to groundwater exploitation in the Lorca (Murcia, Spain) region. 18th International Symposium on Geodynamics and Earth Tides – G-ET Symposium, Trieste, 5-9, June, 2016.

Matute, M. C.; Herrero, T.; Palano, M.; Perez, E.; Herrera, G.; Fernández, J.. Algunos datos para la monitorización del acuífero Alto Guadalentín. XI Congreso Internacional de Geomática y Ciencias de la Tierra", 26/10/2016-30/10/2016, Toledo, España.

Fernández, J., Fernández, J.A., Camacho, A.G., Herrera, G.. Proyecto AQUARISK: Estudio de riesgos geológico-geotécnicos por explotación de acuíferos mediante técnicas espaciales y terrestres. XI Congreso Internacional de Geomática y Ciencias de la Tierra", 26/10/2016-30/10/2016, Toledo, España.

Prieto, J.F., Fernandez, J., Palano, M., Abajo, T., Perez, E., Escayo, J., Velasco, J., Herrero, T., Camacho, A.G., Bru, G., Molina, I., Lopez, J.C., Rodríguez-Velasco, G., Gomez, I.. Proyecto AQUARISK: Uso de técnicas GNSS para el estudio de monitorización de acuíferos. XI Congreso Internacional de Geomática y Ciencias de la Tierra", 26/10/2016-30/10/2016, Toledo, España.

Prieto, J.F., J. Fernandez, M. Palano, T. Abajo, E. Perez, J. Escayo, J. Velasco, T. Herrero, A.G. Camacho, G. Bru, I. Molina, J. C. Lopez, G. Rodríguez, I. Gomez. GNSS 3D displacement field determination in Lorca (Murcia, Spain) subsidence area. AGU Fall Meeting 2016, San Francisco, USA, 12-16/12/2016.

Fernandez, J., G. Centolanza, J. Escayo, J. Duro, J.J. Mallorqui, P. Garcia-Cerezo, A. Morales. A deep analysis of the Siles dam (Jaén, Spain) area with Sentinel-1 data. AGU Fall Meeting 2016, San Francisco, USA, 12-16/12/2016.

Abajo, T., J. Fernandez, K.F. Tiampo, F. Luzón. Surface displacement due to groundwater exploitation using spatial and terrestrial techniques. AGU Fall Meeting 2016, San Francisco, USA, 12-16/12/2016.

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Fernandez, J., J.F. Prieto, M. Palano, T. Abajo, E. Perez, J. Escayo, J. Velasco, T. Herrero, A.G. Camacho, G. Bru, I. Molina, J.C. Lopez, G. Rodriguez-Velasco, I. Gomez. Study of the 3D displacement field in Lorca (Murcia, Spain) subsidence area. EGU General Assembly 2017, Viena, 23-28/Abril/2017.

Fullea, J., A.M. Negredo, M. Charco, I. Palomeras, A. Villaseñor and J.C. Afonso. The topography of the Iberian Peninsula from coupled geophysical-petrological inversion of multiple data sets. European Geosciences Union General Assembly 2017, Vienna (Austria).

Rodríguez-Molina, S., M. Charco, P.J. González, A.M. Negredo, M.P. Poland. Intereruptive deformation at Three Sisters volcano, Oregon, USA: a strategy for tracking volume changes through coupled hydraulic-viscoelastic modeling. American Geophysical Union Fall Meeting 2017. New Orleans (USA).

Rodríguez-Molina, S., M. Charco, A.M. Negredo, P.J. González, M. Poland, D.A. Schmidt. Coupling the effects of conduit magma flow into a viscoelastic chamber to model volcano surface deformation: An application to Three Sisters volcano, Oregon, USA. IAVCEI 2017 Scientific Assembly “Fostering Integrative Studies of Volcanism”, Portland, Oregon (USA).

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(The information of this Institution has been remitted by J.Fernández)

6.



2015-2018 ICGC geodetic activities memorandum

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15/05/2019



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1

Introduction

The ICGC (Institut Cartogràfic i Geològic de Catalunya) Geodesy Unit main goals are related with the SPGIC (Integrated Geodetic Positioning Service of Catalonia), understood as a set of permanent geodesic stations, networks, instruments, procedures, data, communications, software, hardware and technical support, which aims to facilitate the determination of coordinates in Catalonia through:

- The deployment, maintenance and modernization of the 16 GNSS permanent stations CatNet network, guaranteeing the public access to the geodetic derived data, densifying and disseminating them according to the technologies and the needs related to geodetic positioning.
- The maintenance and improvement of the classical benchmarks network (XU) of Catalonia and the establishment of collaborative services to improve its maintenance status. From 2015 to 2018, 298 vertices have been deployed all around Catalonia, and the network has currently 4483 benchmarks.
- The improvement of the altimetric reference system in Catalonia, computing the direct undulation of around 500 RedNAP (High Precision Accuracy Network) levelling benchmarks, by the differentiation of the official published orthometric height and the ICGC observed ellipsoidal heights.
- The maintenance and publication of the databases with the information generated in the field of the SPGIC, guaranteeing its coordination with the state authorities, European and international standards that exist in its scope.
- The establishment and publication of the procedures and standards for determination of the official coordinates according to article 10.4 of the Law 16/2005, and for compatibility with



the SPGIC system, together with the evaluation and checking of geodetic system changes in cartography.

- The integration, in the SPGIC, of the local geodetic networks that meet the technical specifications of this service, accordingly with the specifications of the CCCC (Cartographic Coordination Commission of Catalonia).

The uniqueness of the reference system used to georeference any type of information that has a spatial component is fundamental to guarantee a coherent positioning on the territory. In this way, it is the ICGC responsibility to manage, conserve and improve the physical infrastructure and the technological systems necessary to build and manage the SPGIC, and the maintenance of the topographic databases that provides support properly.

Within the scope of the Generalitat de Catalonia attribution, the SPGIC provides support for large-scale cartographic series, in territorial and urban planning, to the rustic and urban cadastre, to the activity of the public works in Catalonia and in all the analogous activities in which it is applicable. The SPGIC and its results are coordinated with the national and European standards applicable in this field.

As a conclusion, the SPGIC facilitates efficient access to the official geodetic reference frame in Catalonia, that is based on the official frame in Spain, materialized with the ReGeNTE (National Geodetic Network by Spatial Techniques) network and checked against the densification of the European ETRS89 (European Terrestrial Reference System 1989) framework, materialized with the european EPN (EUREF Permanent Network).

2

Areas of research

2.1 Specific projects

2.1.1 GNSS CatNet network

In 2015, ICGC engaged the modernization of the whole GNSS infrastructure. In 2016, with the new hardware and software available at ICGC headquarters, the technicians started with the upgrade of the remote receivers and antennas, and with the installation of the acquired software to manage the new GNSS infrastructure. At the beginning of 2017 the new infrastructure was fully deployed and tested, so it started the provisioning of GPS+GLONASS services all over Catalonia, and fully substituted the old one.

For all the antennas, the corresponding absolute calibration ANTEX files were also published and made available to users. To finalize the modernization, in mid-2018, and thanks to a new update in the software and configuration, ICGC added Galileo and BeiDou constellations to the real time and post-processing services.

In parallel to the update, ICGC tried to reinforce the collaboration with neighbouring GNSS networks, to improve the real time services in the Catalonia border areas. In this way, ICGC signed agreements with the Servicio de Información Territorial de Aragon, in 2015, with TERIA in 2016 and with GEODATA Diffusion in 2018, to share real time data with all the



institutions, and to provide a better and more reliable service to the final users. In addition, ICGC also improved and updated the real time links with the remote stations and performed specific tests to mitigate interferences at some locations.

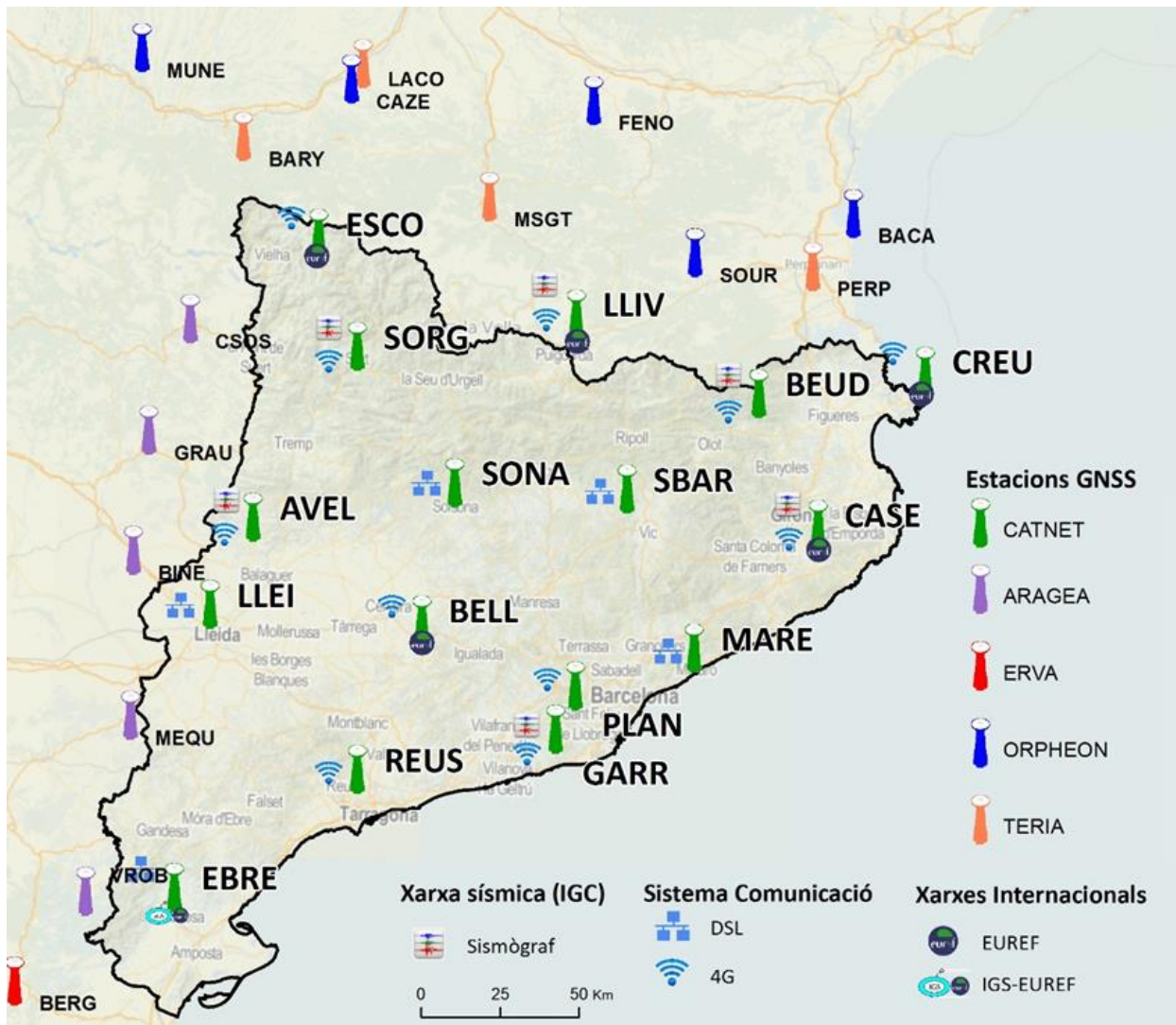


Figure 1 GNSS permanent stations CatNet network

Furthermore, in 2015, an ICGC self-implemented procedure based on the Bernese software, allowed to start the continuous monitoring of the CatNet network coordinates in IGB08. The first group of coordinates studied considered the computation of all the daily sessions from 2007 to September 2015, which then started to be monitored in a continuous way. Thanks to this implementation, for the first time on the CatNet network, a displacement velocity field was computed and published in 2015. In 2017, the reference frame for the coordinate's computation was updated to ITRF2014.

All this was developed to guarantee the coherence between the reference frame and the reference system associated and allowed to update the stations' coordinates and to maximize the coherence with the classical networks in the territory. Furthermore, during 2017 and 2018, a specific procedure was studied and written to keep the CatNet network coordinates up to date and monitored, in the way that its accuracy requires. ICGC has also published the web portal



[GNSS processing Webserver at ICGC](#), to show the availability of RINEX files, some QC graphics and the station coordinates together with their velocities.

Considering EPOS (European Plate Observing System) as a system that facilitates, in the long term, the integrated use of distributed data, products and tools of research infrastructures related to the Earth's sciences in Europe. ICGC has signed an agreement with them, to distribute the data of the 16 stations of the CatNet network through the EPOS platform, and thus increase its dissemination to new users and projects. Finally, the goal is to ease the usage of the services and to widespread it in the scientific international community. Furthermore, a processing effort has started at ICGC to catalogue and disclose as much historical data from the CatNet network as possible, so that users can download observations beginning on 1998.

2.1.2 Classical network

The classical network deployment was finalized in 2017, and the maintenance phase has started afterwards to keep the associated information as much updated as possible, and to start planning the new field campaigns required.

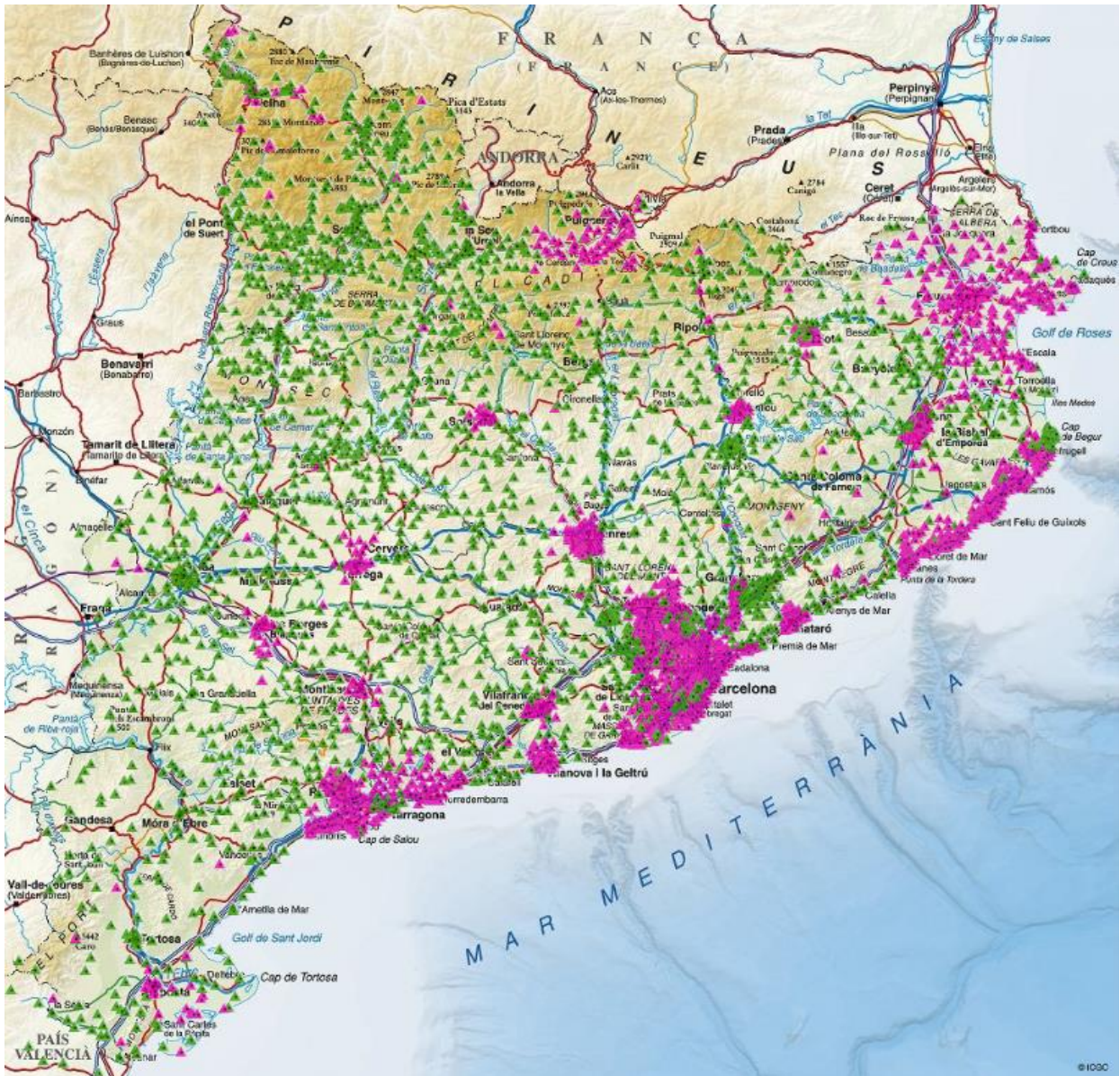


Figure 2 Classical benchmarks network of Catalonia (XU)

2.1.3 Flight campaigns

The Geodesy Unit has also been involved in supporting the flight trajectories computation, with its GNSS related tasks and the coordinate computation. This has been not only performed in Catalonia but also in some other regions where the ICGC planes have been capturing data. The final goal has been also to keep the reference frames updated, to guarantee the calculations traceability in the future.

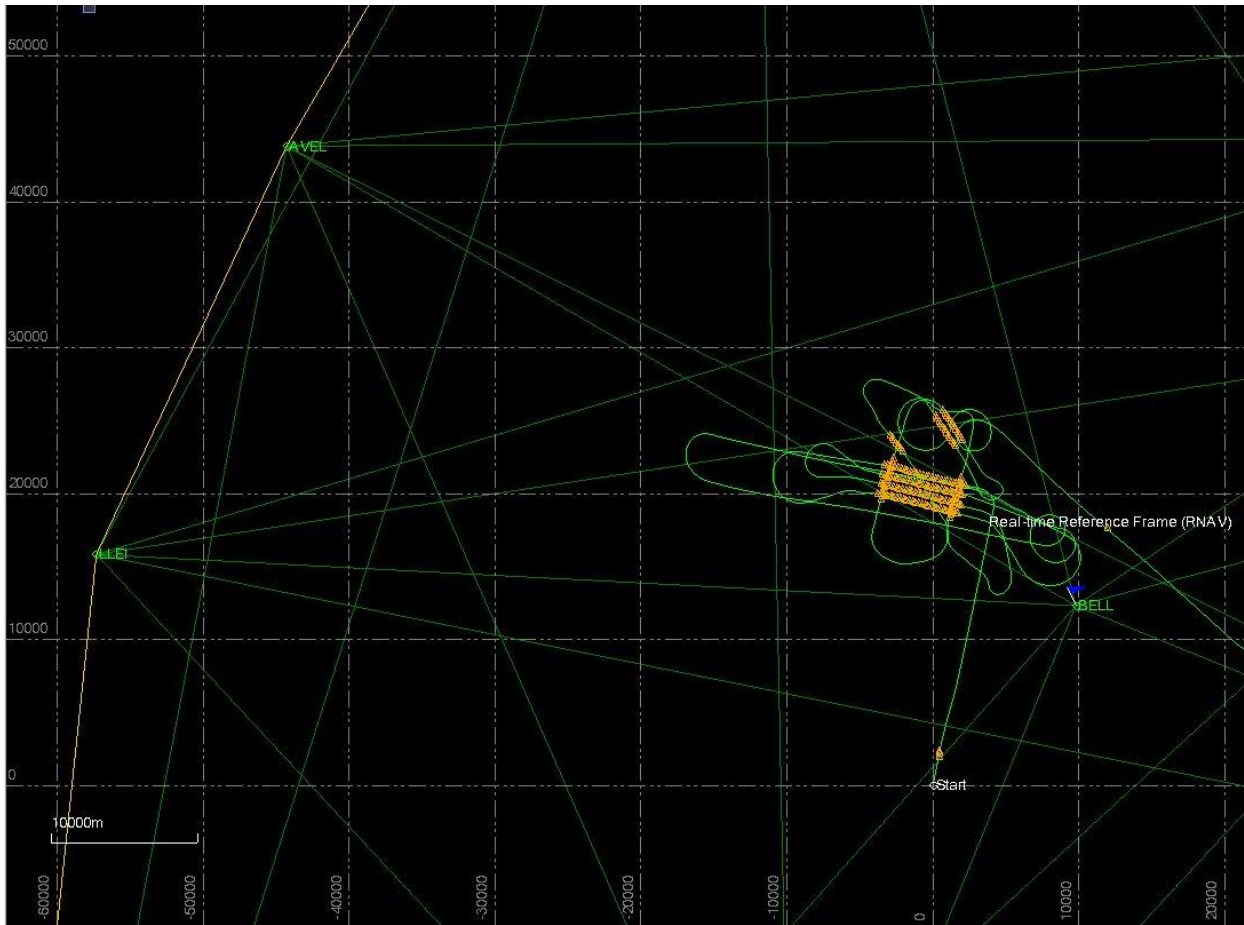


Figure 3 Trajectory computation graphic with GNSS permanent stations

Furthermore, technical support has been provided for the setup and maintenance of sensors, GNSS receivers and antennas, positioning and orientation systems, and inertial systems. As a continuous effort, the Geodesy Unit has been working to improve the trajectory orientation processes, to update the manoeuvres for the calibration and alignment of sensors, and to support the installation of the newly acquired equipment and cameras.

2.1.4 Catalonia 100 summits

In the 100 Summits project, the ICGC compiled a selection of the most emblematic peaks of Catalonia, according to their geographic significance, their consideration in the world of hiking or according to their cultural, historical or emotional notoriety. After the selection, ICGC engaged the measurement for all of them and calculated the orthometric height to make it available for public.



Figure 4 Pica d'Estats measurement (Géomètre-Expert and ICGC)

Also, in the framework of this project, an expedition was made in 2015 for the calculation and update of the Pica d'Estats summit, as the highest peak in Catalonia. The expedition was formed by the Union Nationale des Géomètres-Experts, the ICGC, and had the collaboration of the following French entities: Réseau Teria - Exagone, Bornes Feno, L'Ariégeois magazine, Geomesure and eDF. This expedition made new GNSS measurements and calculated the coordinates of the peak with an achieved accuracy that gave more consistency to the specific observations done in the 100 summits campaign, in 2010, and confirming the value of its orthometric level at 3 143.45 m.

2.1.5 Geodetic adjustment software

ICGC developed a geodetic adjustment software from the very beginning of the institution. On the period involved here, new versions have been implemented, modifying specific models for adjusting, for example, SPOT5 satellite images and to expand the capabilities to adjust bigger projects with increasing number of aerial photographs.

In the framework of technological development and support for the productive chain, some tools have also been adapted, to process images in 23 x 23 cm format since, to date, it was only prepared to work with images of the DMC, in format 7 680 x 13 824 pixels.



3 Scientific program

3.1 Specific projects

3.1.1 Weather forecast with MeteoCAT

Thanks to the implemented DAC (Densification Analysis Centre), ICGC engaged a collaboration with the Catalan public agency in charge of managing meteorological observation and prediction systems in Catalonia. It has been agreed that the Meteorological Service of Catalonia could use the zenith tropospheric delays (ZTD), that are being generated in a daily basis calculation, for the CatNet network or for the network processed as an EUREF DAC.

The final goal has been to improve the meteorological forecasts, extending the procedures currently implemented in other meteorological services throughout Europe, promoting synergy between the different companies of the public administration and thus improving the final service provided to the users and citizenship.

3.2 Conferences and meetings attended

- Grau, J.: “Gravity and height for National Mapping and Geodetic Surveying”, EuroSDR. Dublin Institute of Technology. Dublin, February 2015.
- Baron, A. M.: “EUREF symposium 2015”, EUREF – IAG Reference Frame Sub-Commission for Europe. Bundesamt für Kartographie und Geodäsie, Leipzig, June 2015.
- Baron, A. M.: “EUREF Analysis Centre Workshop”, EUREF – IAG Reference Frame Sub-Commission for Europe. Astronomical Institute, University of Bern. Bern, October 2015.
- Baron, A. M.: “ICGC services provisioning to scientific & professional communities”. GNSS Excellence Week 2016. Grup de Recerca d’Astronomia i Geomàtica (gAGE), Universitat Politècnica de Catalunya. Barcelona, January 2016.
- Gómez, D.: “Sesión informativa infraestructura EPOS”, Ministerio de Economía y Hacienda. Madrid, February 2016.
- Bosch, E.: “Munich satellite navigation summit”, Institute of Space Technology & Space Applications. Munich, March 2016.
- Baron, A.M.: “EUREF symposium 2016”, EUREF – IAG Reference Frame Sub-Commission for Europe. Sociedad de Ciencias Aranzadi, Donostia, May 2016.
- Grau, J.: “Airborne gravity for geodesy summer school”, National Geodetic Survey. Silver Spring, Maryland, May 2016.



- Grau, J.: “9a Asamblea Hispano Portuguesa de Geodesia y Geofísica”, Comisión Española de Geodesia y Geofísica, Secção Portuguesa das Unios Internacionais Astronomica e Geodésica. Universidad Complutense de Madrid, June 2016.
- Grau, J.: “INSPIRE Conference 2016”, Institut Cartogràfic i Geològic de Catalunya. Palau de Congressos de Catalunya, Barcelona, September 2016.
- Bosch, E.: “Munich satellite navigation summit”, Institute of Space Technology & Space Applications. Munich, March 2017.
- Baron, A.M.: “EUREF symposium 2017”, EUREF – IAG Reference Frame Sub-Commission for Europe. Wroclaw University of Environmental and Life Sciences and Institute of Geodesy and Geoinformatics, Wroclaw, May 2017.
- Grau, J.: “IGS Workshop 2017”, Institut Géographique National France. Paris Diderot University, July 2017.
- Baron, A.M.: “EUREF Analysis Centre Workshop”, EUREF – IAG Reference Frame Sub-Commission for Europe. Royal Observatory of Belgium, October 2017.
- Gómez, D.: “European Geosciences Union – General Assembly 2018”, Copernicus Meetings. Viena, April 2018.
- Baron, A. M.: “European Navigation Conference”, European Group of Institutes of Navigation. Chalmers Conference Center, Göteborg, May 2018.
- Grau, J.: “EUREF symposium 2018”, EUREF – IAG Reference Frame Sub-Commission for Europe. Nederlandse Samenwerking voor Geodetische Infrastructuur, Kadaster, Rijkswaterstaat and the Nederlands Centrum voor Geodesie and Geoinformatica. Amsterdam, May 2018.

3.3 Committees and International representation

3.3.1 EPN Densification Analysis Center

In 2015, ICGC fully started with the computations as an EUREF DAC. The main task has been the daily computation of the precise coordinates for a GNSS network with approximately 150 GNSS stations. The final goal of this computation has been to support the calculation of a dense displacement velocity field for Europe. The network encompasses the entire Pyrenean mountain range, the Baetic system, the peninsular Mediterranean east coast and the Balearic Islands.

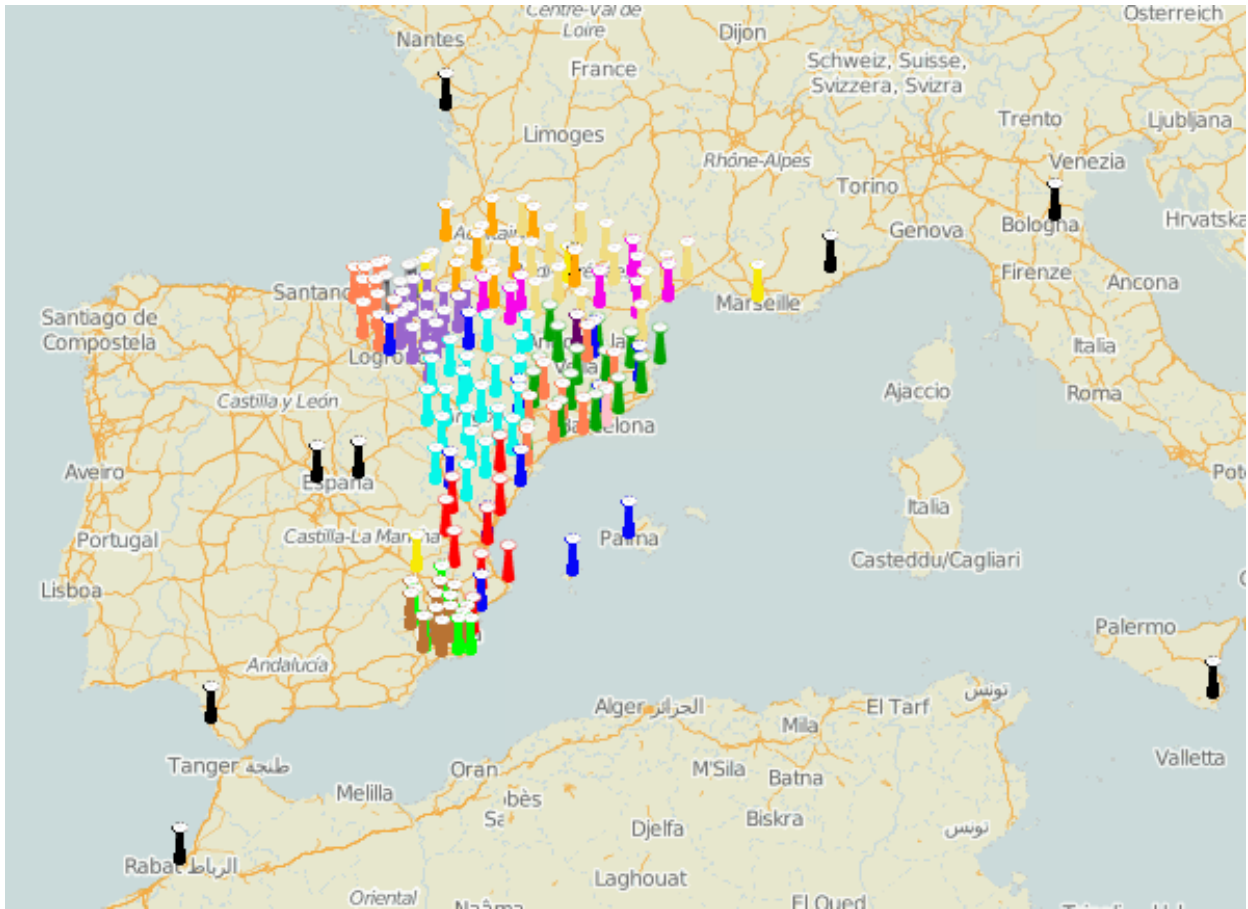


Figure 5 ICGC DAC stations network

Based on this implementation and computation, ICGC has also published a web portal [GNSS processing Webserver at ICGC](#) to widespread the results and to ease the reusability of data in the geodetic community. Currently, the Analysis Center at ICGC is processing all the network in ITRF14 (International Terrestrial Reference Frame 2014) and considering all the available Galileo observations (together with GPS and GLONASS).

The EPN DAC establishment also allowed ICGC the monitoring of the stations around the Pyrenees, to evaluate if the velocity field could provide valuable information on the seismic potential of the area. However, the displacements currently detected, and deformations studied, are not conclusive at all.

3.3.2 GNSS Performance Monitoring IGS-IGMA

The IGS (International GNSS Service) launched the IGMA (International GNSS Monitoring and Assessment) project to monitor and evaluate the operation of the GNSS constellations currently operating. The ICGC has been participating in this project as a GNSS observation provider with the 16 stations in the CatNet permanent stations network, as a data center that compiles and distributes observations from other networks that participate and as a data analysis center.

ICGC has completed and delivered the calculation of the pilot test for the supervision and evaluation of the GNSS constellations proper functioning. This test consisted the monitoring and evaluation of the parameters' quality, such as the orbits and clocks' accuracy in the



broadcast messages, in the error observed by a user when using the navigation messages, in the differences between the constellations reference time and the UTC time, and in the dilution of the precision to a global level.

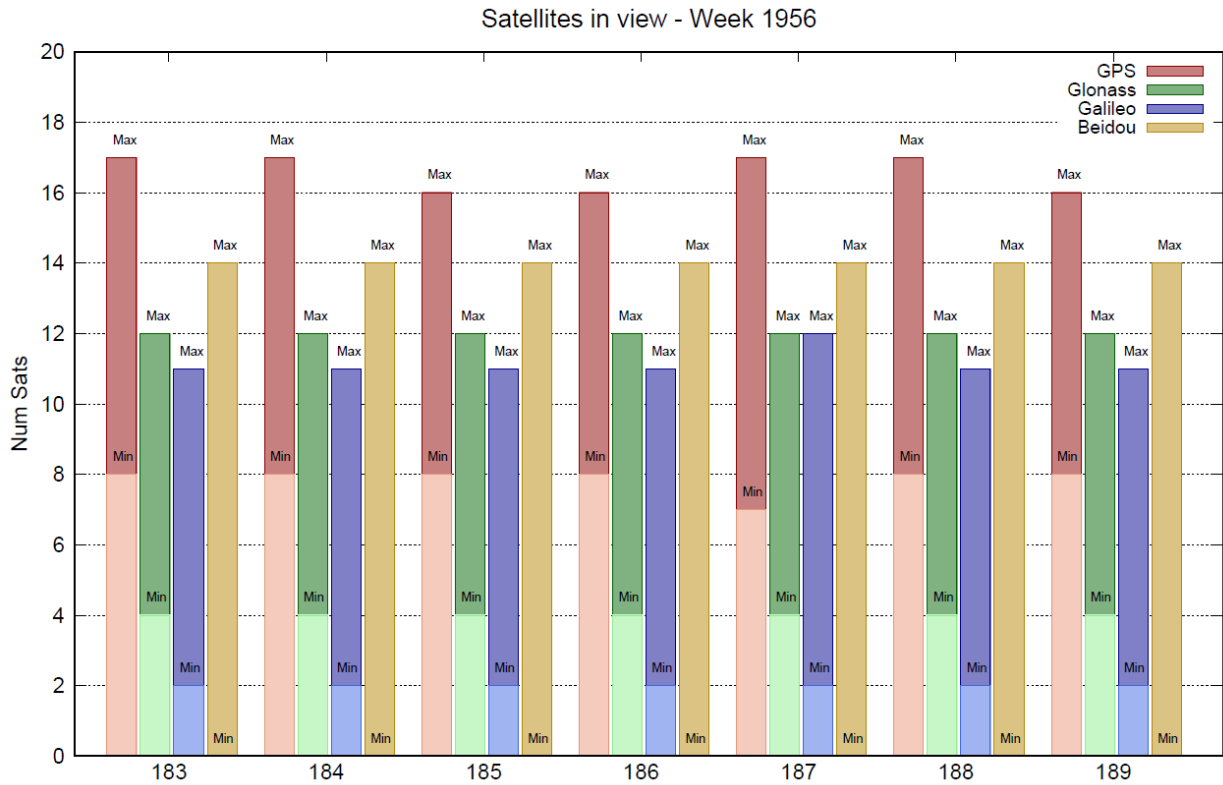


Figure 6 Analysis of the satellites in view for a GNSS station (pilot test)

3.3.3 EU Dense velocities group

Considering the already implemented analysis center at ICGC, a specific collaboration on the EU Dense velocities group has been engaged. The main goal has been to provide coordinates and velocities for a GNSS stations network as much dense as possible, to be able to compute a dense velocity field to be correlated and to complement the one already computed by EUREF.

3.3.4 Consejo Superior Geográfico

ICGC has been collaborating in both the computation and web subgroups, belonging to the geodetic system specialized commission workgroup at the CSG (Consejo Superior Geográfico):

- Computation subgroup: The subgroup has been mainly focused on the computation of the official reference frame for ETRS89, and ICGC has been participating from 2016 as an analysis center, calculating a specific set of GNSS stations in Spain and collaborating in the final combination of the different institutions results.
- Web subgroup: The subgroup has been mainly focused on the development and publication of a common [web](#) portal to inform and provide access to the positioning services provided for the public GNSS networks available in Spain. To reach this goal, the subgroup has also been working on the implementation of a GSAC (Geodetic



Seamless Archive Centers) server, the normalization of the services' nomenclature, the information on FTP servers, the generation of LOG files...

3.3.5 Cartographic Coordination Commission of Catalonia

In the SPGIC project framework, and in a close collaboration with local authorities and the professional sector, a specific procedure has been written for the establishment of official coordinates in Catalonia.

Given that the SPGIC already has GNSS permanent stations, networks, data and information, the main goal of this document was to establish the appropriate procedure for the determination and formalization of coordinates.

The document has been presented and finally approved by the working group for the elaboration of technical specifications, belonging to the geographical information technical commission number 2 at the Local Administration of Catalonia (GT CT2:IG-ALC ET).

3.3.6 TechTIDE Project

Since many operational systems could be affected by TIDs (Travelling Ionospheric Disturbances), European Union's Horizon 2020 programme founded the TechTIDE project, to detect with high accuracy the state of the ionosphere.

In this sense, the main objectives of the TechTIDE project are: to develop a real time TID warning system; to improve the understanding of TID impact; to support mitigation technologies for those impacts, and to specify the physical drivers.

The Expert Advisory Board, brought together influential international scientists, service developers and users, as well as representatives from international organizations who are active on space situational awareness programmes, with interests relevant to the project, but who are independent of it. In this way, ICGC became a member bringing its expertise on N-RTK (Network – Real Time Kinematic) operations.



Figure 7 Testing and measurement field at ICGC headquarters

Specifically, ICGC implemented an application to monitor the TTF (Time To Fix) parameter of GNSS ambiguities, based on a couple of receivers installed at the ICGC headquarters and connected to real-time positioning services. Automatically restarting the ambiguities after a



gained fix solution, allowed to know the required time to fix and, consequently, to evaluate if there is any external effect, like TIDs, that could provoke any effect on this solution and so that can be transferred to users based on this aspect.

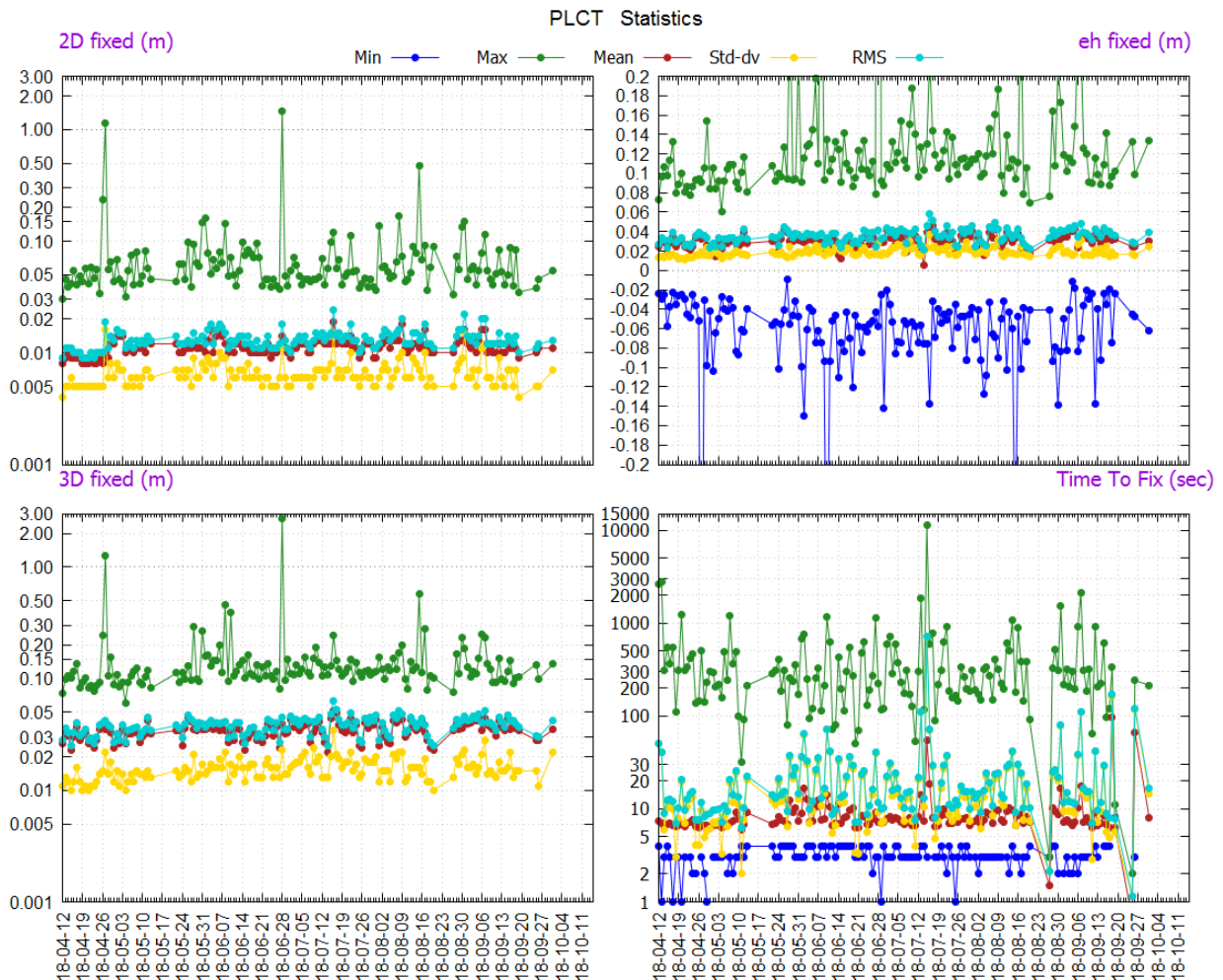


Figure 8 Semestral statistics of the TTF and accuracy analysis

3.4 Events organization

- “Jornada d’usuaris SPGIC”, Institut Cartogràfic i Geològic de Catalunya, Barcelona, 26 de gener de 2017.

4 Publications

- Grau, J., Boixareu, O., Bosch, E.: “Xarxa utilitària de Catalunya. Finalització del desplegament”, a *Revista Catalana de Geografia*, núm. 52. ICGC. <http://www.rcg.cat/articles.php?id=339>
- Kenyeres, A., Baron, A., et al: “EPN Densification prepared to publish.” a EUREF 2017 Symposium. Institute of Geodesy and Geomatics, Wroclaw University, May 2017.



- Baron, A., Sanchez Sobrino, J. A., Blanco, M., Zurutuza, J.: “A new ETRS89 realization in Spain” a EUREF Analysis Centre Workshop. Royal Observatory of Belgium, October 2017.

(The information of this Institution has been remitted by E.Bosch)

7. « MICROGEODESIA JAÉN » RESEARCH GROUP

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1. Introduction

The “MICROGEODESIA JAÉN” research group was set up in 1997 in the Department of Cartographic, Geodetic and Photogrammetric Engineering of the University of Jaén. It is mainly focussed on GNSS and InSAR applications. The main researches carried out are in the Geodetic Monitoring of Earth crustal deformation, Engineering Geodesy, Galileo...

2. Research Projects

Monitorización remota de Infraestructuras hidráulicas mediante Interferometría Radar de Sa-télite. IP: Antonio Miguel Ruiz Armenteros. Programa estatal de investigación, desarrollo e innovación orientada a los retos de la sociedad. ESP2017-89344-R. 01/01/2018-31/12/2020. 54.450 €.

Deformación activa y reciente a través del sector central de las Cordilleras Bético-Rifeña y mar de Alborán: factores de riesgo geológico. IP: Jesús Galindo Zaldívar. MINECO, CGL2016-80687-R, 30/12/2016-29/12/2019. 220.000 €.

Pcube Positioning software. IP: M. C. de Lacy. Agencia Espacial Europea (ESA). 26/06/2015 – 31/12/2017. 50.000 €.

PAIUJA 2017-2018: RNM282. IP: Antonio J. Gil, Universidad de Jaén. 2017/00293/001. 01/01/2017-31/12/2018. 40.000 €.

Integración de las técnicas espaciales InSAR y GNSS para la monitorización del sistema Béti-co-Rifeño. IP: Antonio J. Gil Cruz. Universidad de Jaén. 12/02/2015-31/12/2015. 6.500 €.

3. Publications

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1. Committees and international representation

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8. Instituto Geográfico Nacional (IGN) Geodetic Activities Memorandum 2015-2018



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1 Introduction

The IGN (Instituto Geográfico Nacional) is the institution of reference in Geodesy depending of the Central Government in Spain from the XIX century. Our first Director was the first president of the "Association Géodésique Internationale". Since then, IGN has managed the national geodetic infrastructures of the country. Currently, the Government have assigned us by law, R.D. 953/2018, the next missions related with Geodesy.

- Planning and management of active and passive geodetic networks of national scope, of the high-precision leveling network and the network of tide gauges that make up the framework and Spanish Geodetic Reference System, exploitation and analysis of geodetic observations, the development of applications on navigation systems and positioning, as well as the execution of geodynamic studies.
- Technological development and operational management of instrumentation and infrastructures for radio astronomy, space geodesy and geodynamics, especially for operation as a singular scientific technical installation.
- The planning and management of surveillance systems and communication to institutions of volcanic activity in the national territory and determination of the associated hazards, as well as the management of observation systems in the field of geodynamics, geophysics, volcanology, gravimetry and geomagnetism and the realization of related studies.

2 Areas of research

2.1 GNSS National Reference Stations Network (ERGNSS).

ERGNSS is the acronym of the GNSS Reference Stations National Geodetic Network of the National Geographic Institute of Spain. The installation of the first station was in March 1998 and currently, ERGNSS is constituted by 106 stations fulfilling the requirements of IGS and EPN respecting monumentation, stability and equipment.

IGN and Autonomous Regions share some of the stations of the national network through agreements in order to not duplicate stations and optimize spatial distribution of them. These shared stations are re-monumenting or adapting the equipment in order to fulfill the IGS guidelines.

All stations belonging to this national network are being connected to the Spanish National High Precision Levelling Network (REDNAP) and most of them also connected with the absolute gravimetric network. The EUREF Local Data Center of IGN-E provide public access to RINEX files data (1, 5, 15 and 30 seconds rate) through a FTP server: <ftp://ftp.geodesia.ign.es>. Daily and hourly RINEX2 and RINEX3 files of all stations can be retrieved from this FTP. Respecting the participation of the ERGNSS in the international networks, 4 of them (YEBE, MELI, LPAL and RAEG) are IGS stations and 25 more stations are part of the EUREF Permanent Network (EPN).



National GNSS Reference stations network (ERGNSS).

2.2 National High Precision Levelling Network (REDNAP).

The National Geographic Institute of Spain (IGN) has continued with the densification of the New High Precision Levelling Network of Spain (REDNAP) and with new links to the network of GNSS permanent stations and tide gauges facilities. The IGN has also started a maintenance plan for this network, which currently consists of more than 29,000 benchmarks along about 23,000 km. There are about 400 levelling lines, 350 branches and 260 nodal points. These observations are complemented by GNSS and gravity observations on the benchmarks.

2.3 Tide Gauges Network

The tide gauges network of the IGN has expanded with a new station at Alboran Island. The network has now 10 operating stations throughout the coast of the Peninsula, the Canary Islands and and Alboran Sea: Alicante1, Alicante2, Cartagena, Almería, La Coruña, Santa Cruz de Tenerife, Puerto de la Cruz, Los Cristianos, Puerto del Rosario and Alborán. The restoration of historical tide gauge data has continued with data from Santander, comprising between 1876 and 1928, and Alicante comprising between 1870 and 2019. The web-based query access and data download was completed and GNSS-antenna installation has been completed on all tide gauges.

2.4 National Classical Geodetic Networks

There are two national classical Geodetic Networks in Spain. REGENTE Network observed with GPS that consist of more than one thousand benchmarks spread on the country with an accuracy better than 5 cm. And ROI network observed with GPS and classical angular observations that consist of around eleven thousand benchmarks spread on the country and accuracy worse that the before one. Both of them provide their coordinates in ETRS89. These networks are maintained and re-observed where is needed.

2.5 Absolute and Relative Gravity

2.5.1 Instrumentation.

Relative gravimeters:

- Lacoste&Romberg LRG#301, Lacoste&Romberg LRG#307. Graviton G#1183, Scintrex CG5#811, gPhone#054.
- GWR SG#064 superconducting gravimeter.

Absolute gravimeters:

- FG5#211, A10#006.

2.5.2 Reference stations.

- *Madrid Astronomical Observatory*. The reference point is located inside the main building. It is the oldest absolute gravity reference in Spain

dating from 1882. There is an IGSN71 point next to these pillars (MADRID-A).

- *Gravimetry Laboratory of IGN* headquarters in Madrid is a fundamental point since 1933, where an IGSN71 fundamental station Madrid-C and absolute piers coexist in the same room.
- *San Pablo de los Montes* geophysical observatory located in the Sistema Central Mountain. The geological stability and low noise (far from big roads), allows to join geodetic, magnetic, seismological and gravity instruments in the same site. Two pillars are set up to measure gravity.
- *Gravimetry Pavilion at Yebes: Belonging to a project* at the Yebes Astronomical Observatory which includes the combination of different geodetic and astronomical techniques (VLBI, Laser ranging, GPS and continuous gravity measurement) at the same. This pavilion contains seven gravity pillars. where one of them allows the colocation of several gravimeters in parallel to the superconducting one

2.5.3 Absolute gravity network.

Since 2001 IGN has been establishing a National Absolute Gravity Network, which is composed of several stations and divided into into two sub-networks: the Zero Order Network and the First Order Network.

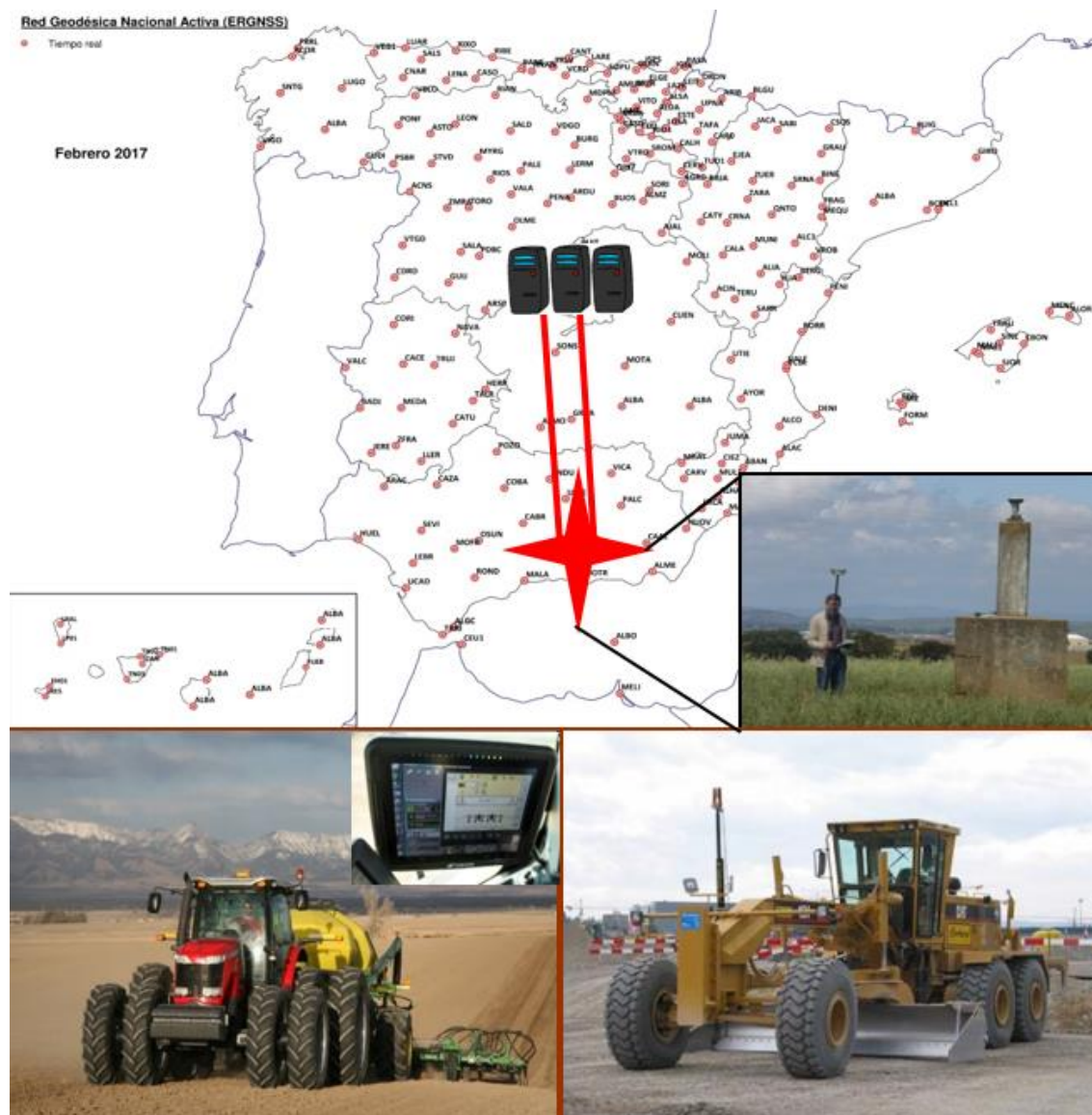
- *Zero Order Network*: (5 μGal accuracy (1 μGal = 10^{-8} m/s²))
 - New observations: Cartagena, Loiola and Pasaia. 2017
 - Reobserved : Pillar C from IGN, Valle de los Caidos Station, Faculty of Mathematics (UCM) and Cuatro Vientos observatories, 2015, Yebes Observatory, 2015, 2017, 2018, 2019
- *First Order Network* (10 μGal accuracy (1 μGal = 10^{-8} m/s²))
 - New observations: Madrid 2018
 - Reobserved : Badajoz, Castuera, Fuenlabrada de los montes, Llerena, Montanech, Navalvillar de la Pela, Piedrabuena y Valverde del Camino.

2.5.4 Continuous recording.

- GWR SG#064 superconducting gravimeter, Yebes station (2011 Dec-Present)
- gPhone#054.
 - 2015 Jan -2015 July : El Hierro. "Aula de la Naturaleza" station.
 - 2015 Aug- 2016 Feb: Yebes station.
 - 2016 Apr-2016 Dec: J9 Observatory Strasbourg.
 - 2017 Jan-Present: El Hierro. "Pinar Town Hall" Station.
- LRG#307, Experimental Tunnel of Tarifa (Cádiz) (2018 July-Present).
- Graviton G#1183, Santa María (Azores) (2019 April-Present).

2.6 National Real-time GNSS Positioning Service (SPTR).

From 2015 a new service of real time positioning with network-based solutions was implemented using ERGNSS and almost all stations of Autonomous Regions networks. Currently the service is available in all the country with about 230 stations participating in this public free of charge service. Running over GNSMART (Geo++) the stations are divided geographically in 20 clusters with overlapping and 10 servers are processing in parallel. The service provides VRS, MAC, FKP and single point solutions to the users, all with GPS or GPS+GLONASS. The precision tests carried out in several areas along the country fulfill the expected accuracy of RTK service (better than 2 cm in planimetric and better than 3-4 cm in altimetry). This service is freely available in <http://ergnss-tr.ign.es> port 2101 for network solutions and port 2102 for single point solutions (register for user and password must be done previously in <http://ergnss.ign.es/gnuserportal/>).



Stations currently used for real-time positioning service.

2.7 Geodetic Analysis Centre at IGN

There are several projects where IGN is involved with a continuous GNSS and VLBI processing.

2.7.1 EUREF Analysis Centre

2.7.1.1 EUREF Local Analysis Centre

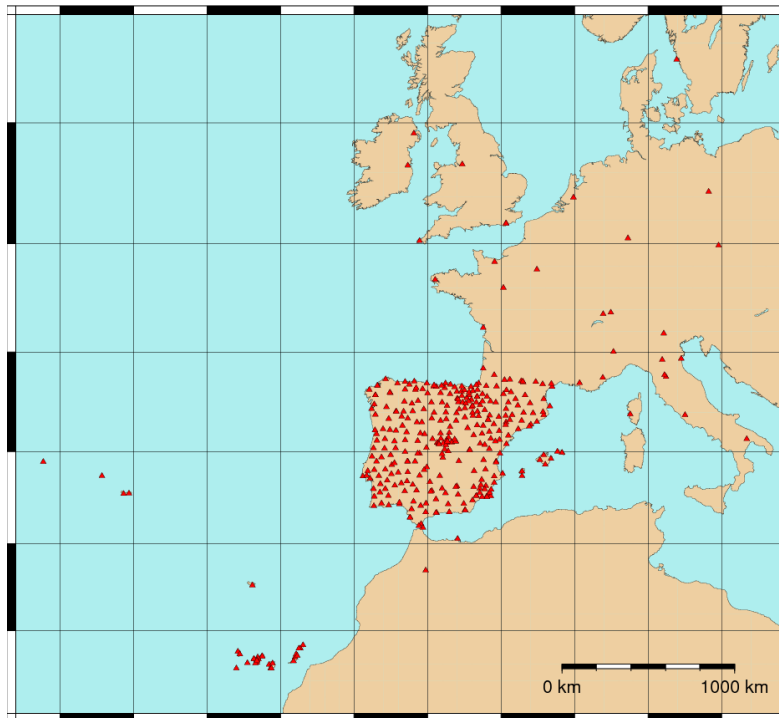
The IGN geodetic department became a EUREF Analysis Centre since September, 2001 (GPS WEEK 1130) under the acronym of IGE. Currently, the processing is being carried out with Bernese Processing Engine, BPE of Bernese 5.2 under LINUX platforms in an automatic procedure. Weekly (final orbits) and daily (rapid orbit) solutions are reported in SINEX format (Solution Independent Exchange format) together with a weekly SUMMARY of results and troposphere parameter files (zenith path delays).

The current number of EPN stations that are being processed is around 90, most of them with GPS + GLONASS + GALILEO observations and about 30 of them with individual calibration antennas. If available, observations from these three constellations are being processed

2.7.1.2 EUREF Dense velocity field project.

IGE Analysis Centre is also processing an Iberian Network with geodynamic purposes with stations of our area which provide public data. This include stations of IGN, Autonomous Region networks, private companies, Portugal (IGP), south of France (IGN-F) and other public institutions. The name of this network is called IBERRED. As a result of this process IGN is also making time series analysis of the coordinates for monitoring and geodynamical studies and calculating its derived velocities.

Currently IGE is processing about 400 stations in this project, collaborating at the same time with the "Regional Dense Velocity Field" Project managed by EUREF. In 2018 IGN has finished the reprocessing of the data with BSW5.2 following almost the same configuration that in EUREF LAC processes in order to obtain a homogeneous set of coordinates and velocities.

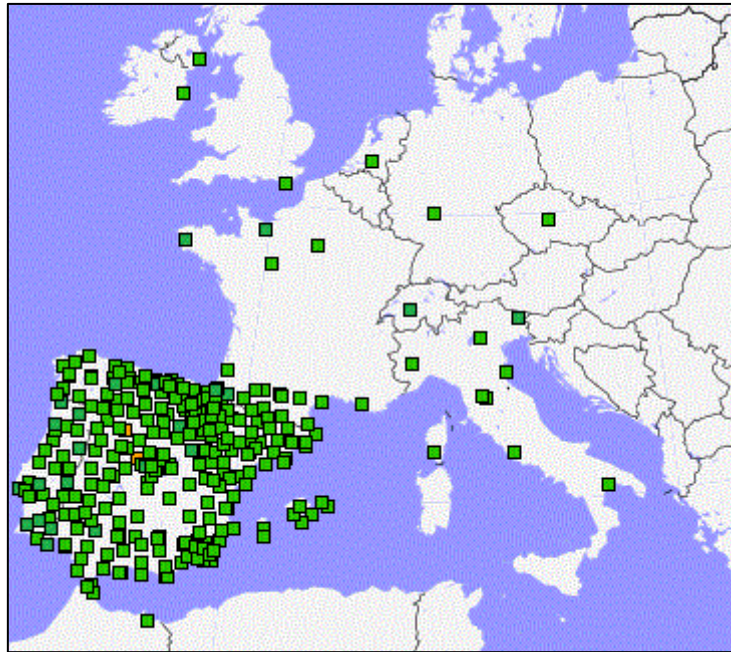


IBERRED network. Stations processed for the Dense Velocity field project.

2.7.2 E-GVAP Analysis Centre.

IGE Analysis Centre began the collaboration with AEMET, the Spanish Meteorological Institution, in the frame of E-GVAP since March 2009. In this project Zenith Troposphere Delay (ZTD) is estimated in "near real time" each hour in a set of stations covering all the Iberian Peninsula and adjacent archipelagos (Azores, Canary and Balearic Islands) in order to be used in Numerical Weather Prediction by meteorological agencies integrated in the EUMETNET organization. The project is called E-GVAP (EUMETNET EIG GNSS water vapour programme). For this purpose hourly data are collected by IGN immediately after every hour from 15 different networks. In minute 20 of each hour the process starts with BSW 5.2 and ZTD data in COST file format are sent to Met-Office (GB) around minute 30, which disseminates the information between the meteorological agencies of EUMETNET.

Currently processing of IGE consists of about 400 stations, the same that in IBERRED project. The hourly process is done using the precise coordinates from the first process, with double differences strategy and using ultra rapid CODE products. Finally, the 6 last hours of normal equations are combined to get the hourly ZTD.



E-GVAP network processed by IGE (<http://egvap.dmi.dk>)

2.7.3 National official coordinates of permanent GNSS stations

A new set of official coordinates in ETRS89 were needed due to the huge number of new permanent GNSS stations were installed in Spain in the past decade, most of them belonging to Autonomous Regions. The "Comisión del Sistema Geodésico de Referencia" depending on the "Consejo Superior Geográfico" was the institution coordinate a new working group to achieve the processing of the permanent GNSS stations. This project has provided a homogeneous ETRF00 set of coordinates to all Spanish GNSS permanent networks in collaboration with Autonomous Spanish Regions managing GNSS active networks. Several regional institutions together with IGN participated in the reprocessing of data from 2011 to 2017 in order to establish a consistent reference frame agreed by all regional networks and IGN, following the recommendations for EUREF densifications. Because of this project, all the Spanish GNSS networks are working in ETRF00 coordinates in a homogeneous and consistent frame from 15th March 2018.

2.7.4 VLBI Analysis Centre

National Geographic Institute of Spain (IGE) has been taking part on geodetic VLBI since 2008 through the participation of Yebes 40-meter radio telescope on VLBI observation campaigns. It also encourages the continuous development of RAEGE project for an Atlantic Network of Geodynamical and Space Stations, as part of the VLBI Geodetic Observing System.

Currently, IGE is expanding its contribution to geodetic VLBI by taking the first steps on VLBI data analysis. An initial analysis is being carried out using VieVS 3.0 (University of Vienna) and Where (Norwegian Mapping Authority) as processing software. One-year series of Earth Orientation Parameters obtained

from R1 and R4 IVS sessions have been compared with IERS 14 C04 series and those from other VLBI Analysis Centers. In addition, secondary VLBI products such as zenith troposphere delay and clock offsets has been also compared with GNSS-based products in stations in which VLBI and GNSS antennas collocation make this analysis possible

2.8 Volcanic Deformation Monitoring

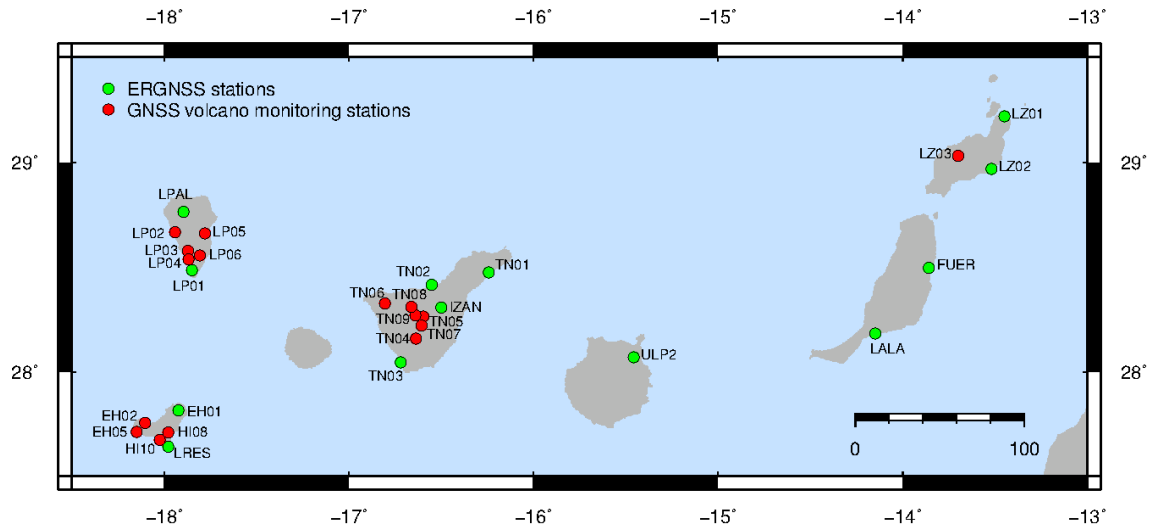
Canary Island is an archipelago with active volcanoes. For this reason, the Spanish Government decided to develop a Volcanic Monitoring System project in 2004 after several seismic movements affected Tenerife Island that year. The Spanish National Geographic Institute (IGN) is developing a network in order to monitor the islands using different techniques: geodetic, seismic, geochemical and geomagnetic.

Due to volcanic process, land movements can occur at different spatial and temporal scales and the measurement of these possible deformations can be useful precursors of active volcanoes. Therefore, it is necessary to have a geodetic network covering each island using land and space techniques.

Apart from the IGN geodetic infrastructure, ERGNSS network, REGCAN network (REGENTE Canary Island) and the National High Precision Levelling Network (REDNAP), the volcano deformation monitoring system consists of permanent GNSS stations, GNSS periodic campaigns, RTK surveys, tiltmeters, a robotic total station and InSAR techniques, that are being used for the volcanic deformation monitoring.

2.8.1 Continuous GNSS

Permanent GNSS stations has been installed to densify the ERGNSS network, in order to control ground deformation. Nowadays there are a total of 28 IGN GNSS stations (Figure 1). Data are sampled every second and downloaded hourly in an analysis centres at Observatorio Geofísico Central (OGC) in Madrid. In this centre, quality is checked using TEQC software and data are processed together with GRAFCAN, IGS and EUREF stations around the area using the Bernese Processing Engine (BPE) of Bernese 5.2 and RTKLIB software.



IGN GNSS permanent stations in Canary Islands.

The processing strategy depends on the type of movement expected in the deformation monitoring. In the case of volcano monitoring the deformation is expected to be slow or not present during quiescence periods. Nevertheless ground movements of increasing magnitude can occur in the hours to days prior to a magma intrusion. This is why different strategies are being used to process GNSS data:

- Hourly processing using RTKLIB for baseline computation with ultra-rapid orbits. Results are sampled every 30 seconds thus a Kalman Filter is used to obtain a final solution.
- Rapid daily processing mode occurs with minimum delay (the day after) in static sessions of a day in length using ultra-rapid orbits.
- Daily Post-processing mode with static sessions of a day in length to measure slow deformation, such as a constant rate, using precise orbits and Earth rotation parameters to improve the quality of the solution.

The network solution is connected to the ITRF2014 through some IGS core stations. In this way, daily solutions are reported in SINEX files and coordinate time series from our stations in ITRF2014 are obtained to control ground deformation associated with volcanic activity in Canary Islands.

2.8.2 GNSS campaigns

A GNSS high-density network has been created in Tenerife adding 11 points to the permanent GNSS network around Teide volcano. This network, called RCT (Red de Control del Teide, Figure 2), is observed periodically since May 2009.



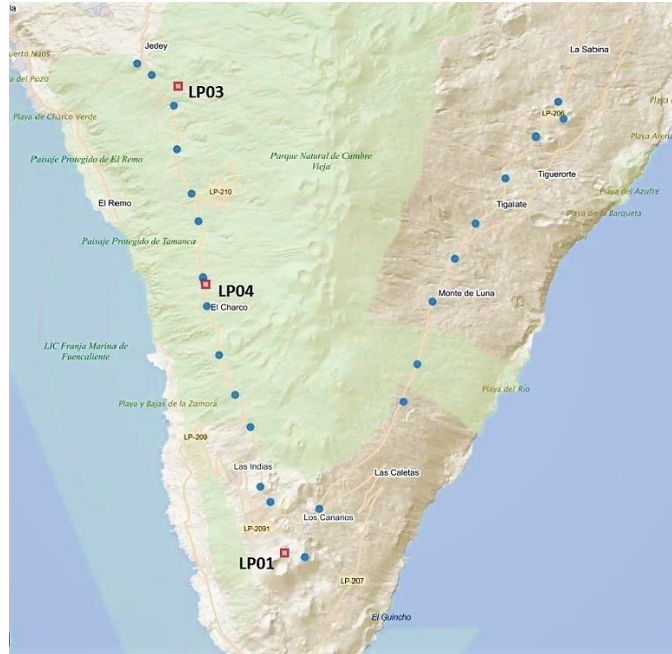
RCT network

In each campaign simultaneous GNSS observations of half of the network were carried out for two days with an interval of 5 hours per day. The other half of the network was observed for another two days, 5 hours per day too. There were some points in common in all the observations apart from the continuous GNSS stations. The RCT as it was raised up to now requires a deployment of people (10 people / day), transport (4 all-terrain cars) and a number of instruments (8 GNSS devices plus auxiliary material) that has made impossible to carry out with the measurements during the last years.

From 2017, with the maturity of the differential GNSS corrections in all the islands, the use of the RTK methodology was proposed. The good results obtained in the RTK network of the south of La Palma in 2017 and 2018, as well as the minimum need for people and material (1 car and 2 people for 2 days, 1 GNSS RTK device), invited to make a first campaign of the RCT with this method, in August 2018. The prevision is to go on with RTK measurements twice per year, and repeat one more time, if it is possible, the traditional measurements, in order to compare both techniques. Solutions obtained for each campaign are compared with previous ones to detect any possible deformation that could be taken place.

2.8.3 RTK survey in La Palma

As a densification of the network of permanent GNSS stations in La Palma island, a monthly RTK measurement is being made in points around Cumbre Vieja on the South part of La Palma (Figure 3). The RTK corrections are always received from simple point, with the same permanent GNSS station LP01 so, in case of ground deformation in such station, it will be easily detectable. The results obtained do not show any significant deformation that may be associated with volcanic activity.



Distribution of the points observed in RTK (in blue) and the permanent GNSS (in red) in 2018.

2.8.4 Robotic total station in Tenerife

Within the densification and improvement actions of the Volcanic Monitoring System in the Canary Islands, for the IGN is of special interest the monitoring of the north slope of Teide Volcano, in Tenerife.

The North Slope is a source of risks associated with volcanic activity, such as debris, and in addition, an eventual contribution of material in the magmatic chamber under the volcano can generate a detectable surface deformation with the right instrumentation.

At the end of 2018, were carried out the necessary works for the installation and start-up of a deformation control station composed by (Figure 4):

- Total robotic station of 1s centesimal of precision, with device of recognition of prism of centimetric precision up to 3000 m of distance.
- 21 prisms distributed along the North slope, between reference and control points.
- A triple prism, special for long distances, on the north slope of the Teide crater.
- A permanent GNSS station, in order to detect possible displacements in the total station itself.
- Weather station, for correction of measurements.
- Webcam.



Multiparametric station (up) and prisms (down)

Along with the mentioned instrumentation, there is a seismic station and a biaxial surface tiltmeter is planned to be set up in the near future, making this site the most important multiparametric station in the northern part of the Teide-Pico Viejo complex.

2.8.5 Tiltmeters.

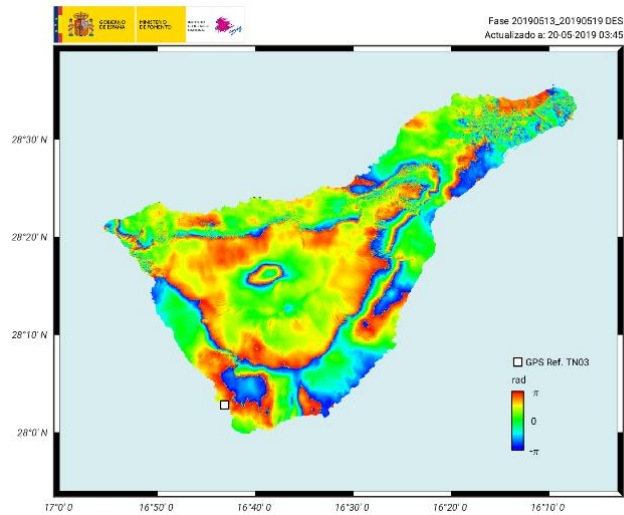
Volcanic deformation may produce changes in ground inclination. Tiltmeters monitor ground inclination angle and can detect those changes. IGN has deployed three biaxial surface tiltmeters in El Hierro, one in La Palma and another one in Tenerife that transmit real-time tilt and temperature data.

Ground inclination information is complemented with that obtained by GNSS to enhance volcanic deformation monitoring.

2.8.6 InSAR

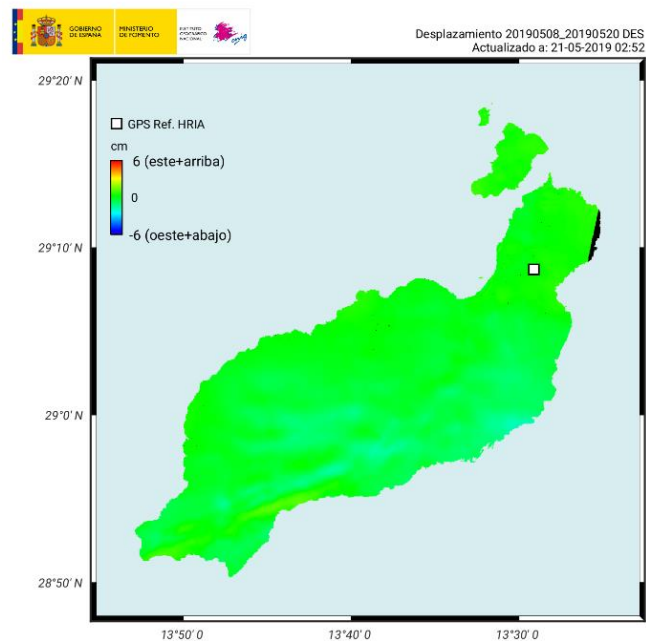
SAR Interferometry technique (InSAR) can detect changes in the position of the Earth's surface using two radar images of the selected area taken from

approximately the same position in space but at two different epochs. Basically, an interferogram shows the phase difference between the two radar signals. So, if a deformation has occurred between the two passes there will be a change in the total length of the returned signal of the second image, regarding to the first one. This is showed in the interferogram as a pattern of certain fringes.



Automatic interferogram over Tenerife island with a temporal resolution of six days.

IGN operates an automatic system which uses Sentinel1 images over every island in the Canary Archipelago. Twice per day the system checks if there is a new image available and in case it exists, an interferogram with the last acquisitions is computed over the area, typically every six or twelve days, which is the temporal resolution of the satellite. Because of the area covered by the radar images is typically of several squared kilometres, this methodology allows to measure deformations over large areas, being a complementary technique to GNSS. Moreover, there are radar images available since 1992 (ERS mission) to date what makes possible the study of the deformation processes in the past.



Automatic displacement map over Lanzarote Island between six days.

For monitoring purposes, thanks to the open policy of the Copernicus program, we can provide automatically interferograms and displacements maps within several hours since the image is acquired by the satellite. This new paradigm allows to create a deformation monitoring system based on InSAR, which was not possible until the launch of Sentinel-1 satellites in 2014.

Currently, we are involved in U-Geohaz European project, co-funded by the European Commission, whose main objective is monitoring geohazard-associated ground deformations, using Sentinel-1 data, as a key prevention action specifically addressed to urban areas and critical infrastructures (<https://u-geohaz.cttc.cat/>)

3 Scientific Program

3.1 Research Projects

Name of the project: GeoActiva. Monitorización geodésica y Modelización cinemática de Sistemas de Fallas Activas (CGL2017-83931-C3-3-P)
 Entity where project took place: Universidad Complutense de Madrid, Universidad Politécnica de Madrid, Instituto Geominero, Instituto Geográfico Nacional
 Name principal investigator: Alejandra Staller
 Funding entity or bodies: Ministerio de Economía y Competitividad
 Start-End date: 01/01/2018 - 30/12/2020
 Total amount: 84.700,00 €

Name of the project: INTERGEO. Análisis del potencial sísmico de las zonas intersegmento de fallas de desgarre mediante análisis y monitoreo geológico, geodésico y geofísico (CGL2013- 47412-C2-1-P)
Entity where project took place: Universidad Complutense de Madrid, Universidad Politécnica de Madrid, Instituto Geominero
Name principal investigator: Alejandra Staller
Funding entity or bodies: Ministerio de Economía y Competitividad
Start-End date: 01/01/2014 - 30/12/2017
Total amount: 162.000 €

Name of the project: Integrated Geohazards impact assessment for urban areas (U-Geohaz)
Entity where project took place: Centre Tecnològic i Telecomunicacions de Catalunya (CTTC)
Name principal investigator: Oril Monserrat
Funding entity or bodies: European Commission, Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO). Unit A/4 – Civil Protection Policy. Union Civil Protection Mechanism
Start-End date: 01/01/2018 - 30/11/2019
Total amount: 990.602,31 €

Name of the project: CGL2014-53044-R Caracterización multiparamétrica de la actividad del complejo volcánico Teide-Pico Viejo
Entity where project took place: Observatorio Geofísico Central (CNIG-IGN)
Type of entity: R&D Centre
City of entity: Santa Cruz de Tenerife, Spain
Name principal investigator: Itahiza Domínguez Cerdeña
Nº of researchers: 11
Start-End date: 01/01/2015 - 31/12/2018
Total amount: 87.000 €

Name of the project: Sentinel-1 for geohazard prevention and forecasting (SAFETY)
Entity where project took place: Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)
Name principal investigator: Oriol Monserrat
Funding entity or bodies: European Commission, Directorate-General Humanitarian Aid and Civil Protection (ECHO)
Start-End date: 01/01/2016 - 31/12/2017
Total amount: 85.818 €

Name of the project: CGL2014-58821-C2-1-R Integración de datos geológicos y geodésicos para la interpretación de deformaciones magmáticas y riesgos asociados en las Islas Canarias: modelización numérica
Entity where project took place: Instituto de Geociencias (CSIC-UCM)
Type of entity: State agency
City of entity: Madrid, Spain
Name principal investigator: María Charco Romero; Ana Negrodo Moreno
Nº of researchers: 7
Start-End date: 01/01/2015 - 31/12/2017

Total amount: 70.000 €

3.2 Organized Meetings

- Co-organizer of EUREF 2016 Symposium

3.3 Thesis and Dissertations

3.3.1 PhD Thesis

- L. García Cañada (2015) "**Análisis de series temporales en estaciones permanentes GPS**", M. J. Sevilla de Lerma, Universidad Complutense de Madrid.
- H. Lamolda Ordóñez (2017) "**Desarrollo e implementación de un procesamiento GPS subsidiario para el control de deformaciones en áreas volcánicas**", A. Bethencourt Fernández, Universidad Politécnica de Madrid.

3.3.2 Msc. and Grade Dissertations

- Project title: Estimación del retraso troposférico con GNSS en tiempo casi real: Análisis de precisión del cálculo en función de diversas variables.
Type of project: Trabajo Fin de Máster
Co-directors: José Juan Arranz, José Antonio Sánchez Sobrino
Entity: Universidad Politécnica de Madrid
Student Esther Azcue Infanzón
Date of reading: 03-02-2015
- Project title: Integración de datos InSAR y GPS para el análisis de deformaciones en las Islas Canarias
Type of project: Trabajo Fin de Máster
Co-directors: Elena González Alonso; Laura García Cañada, Fuensanta González Montesinos
Entity: Universidad Complutense de Madrid
Student: Ana Adell Lamora
Date of reading: 26/09/2018
- Project title: Análisis de outliers de series temporales de datos atmosféricos y su correlación con series de coordenadas de estaciones permanentes GPS
Type of project: Trabajo Fin de Máster
Co-director: Laura García Cañada, Fuensanta González Montesinos
Entity: Universidad Complutense de Madrid
Student: Meritxell Arsuaga Zalacain
Date of reading: 11/09/2017

- Project title:
Modelización matemática de la influencia sobre satélites de la Tierra debido al acercamiento de asteroides. Aplicación a Apophis
Type of project: Trabajo Fin de Grado
Co-directors: Marta Folgueira López, Víctor Puente García
Entity: Universidad Complutense de Madrid
Student: Alonso Antonio Chicharro Cobo
Date of reading: 26/02/2019

4 Publications

4.1 Reports, Papers and Book Chapters

- Matesanz, F.J., Valdés, M.: "Evolucion del posicionamiento y los Sistemas Geodésicos de Referencia en España" included in "Los mapas de la Naturaleza" pag. 13-43 ISBN 1132-0869. Real Sociedad Española de Historia Natural 2017.
- Puente, V., Folgueira, M. 2018, ITRS/GCRS transformation: Uncertainty propagation analysis and short-term modelling of IAU 2006/2000A developments. Adv. Space Res
- Azcue, E., Gomez-Espada Y., Puente, V., Garcia-Espada, S., Lopez-Ramasco, J., Valdes, M., 2018. Initial VLBI data analyses at the National Geographic Institute of Spain, in 10th International VLBI Service for Geodesy and Astrometry 2018 General Meeting Proceedings, edited by D. Behrend and K.D. Baver. In press
- Covián, E., Puente, V., Casero, M, 2017, Uncertainties estimation in surveying measurands: Application to lengths, perimeters and áreas. Measurement Science and Technology, 28(10), p. 105010- (2017); doi:10.1088/1361-6501/aa7b9d.
- J.L. Granja, R. Vegas, M.A. Sentre, A. Muñoz-Martín, S. Sainz-Maza. "Gravity modeling of the lithosphere in the Calatrava Volcanic Province (Spain): geodynamic implications". 2015, Journal of Iberian Geology 41 (2) 2015: 233-252. http://dx.doi.org/10.5209/rev_JIGE.2015.v41.n2.47617.
- S. Meletlidis, A. Di Roberto, I. Domínguez Cerdeña, M. Pompilio, L. García-Cañada, A. Bertagnini, M.A. Benito-Saz, P. Del Carlo, S. Sainz-Maza. "New insight into the 2011-2012 unrest and eruption of El Hierro Island (Canary Islands) based on integrated geophysical, geodetical and petrological data", 2015. Annals of Geophysics, Vol 58, No5, DOI: 10.4401/ag-6754.
- P. Zahorec, P. Vajda, Juraj Papčo, S.Sainz-Maza, J. Pereda. "Prediction of vertical gradient of gravity and its significance for volcano monitoring – example from Teide volcano", 2016. Contributions to Geophysics and Geodesy, Vol 46, 3 doi: <https://doi.org/10.1515/congeo-2016-0013>.
- S. Sainz-Maza, F. G. Montesinos, J.Martí, J. Arnosó, M. Calvo, A. Borreguero. "Structural Interpretation of El Hierro (Canary Islands) rifts system from gravity inversion modelling", 2017. Tectonophysics, Vol, 712-713, Pag 72-81. <https://doi.org/10.1016/j.tecto.2017.05.010>

- Klügel, A.; M. A. Longpré; L. García-Cañada; J. Stix (2015) Deep intrusions, lateral magma transport and related uplift at ocean island volcanoes. *Earth and Planetary Science Letters*. 431, pp. 140-149.
- Meletlidis, S., A. Di Roberto, I. Domínguez Cerdeña, M. Pompilio, L. García-Cañada, A. Bertagnini, M.A. Benito-Saz, P. Del Carlo, S. Sainz-Maza Aparicio (2015) New insight into the 2011-2012 unrest and eruption of El Hierro Island (Canary Islands) based on integrated geophysical, geodetical and petrological data, *Annals of Geophysics*, Vol 58, No5, DOI: 10.4401/ag-6754.
- Benito-Saz, M. A., Michelle M. Parks, Freysteinn Sigmundsson, Andrew Hooper, Laura García-Cañada (2017) Repeated magmatic intrusions at El Hierro Island following the 2011–2012 submarine eruption. *Journal of Volcanology and Geothermal Research*, ISSN 0377-0273, <https://doi.org/10.1016/j.jvolgeores.2017.01.020>.
- Lamolda, H., A. Felpeto, and A. Bethencourt (2017), Time lag between deformation and seismicity along monogenetic volcanic unrest periods: The case of El Hierro Island (Canary Islands), *Geophys. Res. Lett.*, 44, 6771–6777, doi: 10.1002/2017GL074494.
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- López, C., M. A. Benito-Saz, J. Martí, C. del-Fresno, L. García-Cañada, H. Albert, and H. Lamolda (2017). Driving magma to the surface: The 2011–2012 El Hierro Volcanic Eruption, *Geochem. Geophys. Geosyst.*, 18, 3165–3184, doi:10.1002/2017GC007023.
- López C., L. García-Cañada, J. Martí, and I. Domínguez Cerdeña (2017) Early signs of geodynamic activity before the 2011–2012 El Hierro eruption. *Journal of Geodynamics*, 104, 1-14, doi: <http://dx.doi.org/10.1016/j.jog.2016.12.005>
- Blahut, J., Baroň, I., Sokol, L., Meletlidis, S., Klimeš, J., Rowberry, M., Melichar, R., García-Cañada, L., Martí, X. (2018) Large landslide stress states calculated during extreme climatic and tectonic events on El Hierro, Canary Islands, *Landslides*, pp. 1-14, <https://doi.org/10.1007/s10346-018-0993-1>.
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- Domínguez Cerdeña, I., L. García-Cañada, M.A. Benito-Saz, C. del Fresno, H. Lamolda, J. Pereda de Pablo, C. Sánchez Sanz (2018) On the relation between ground surface deformation and seismicity during 2012–2014 successive magmatic intrusions at El Hierro Island, *Tectonophysics*, Volume 744, Pages 422-437, ISSN 0040-1951, <https://doi.org/10.1016/j.tecto.2018.07.019>.

4.2 Conferencias attended

- Azcue, E., Sánchez-Sobrino, J.A., Valdes, M., 2015. IGE EUREF LAC Report, EUREF2015 AC Workshop.
- Kenyeres, A., Valdés, M., et al: "Regional Densification of the ITRF through the Integration of National Active GNSS Network Products" EGU2015-9591, Viena, 2015.
- Kenyeres, A., Valdés, M., et al: "EPN Densification prepared to publish." a EUREF 2017 Symposium. Institute of Geodesy and Geomatics, Wroclaw University, May 2017.
- Kenyeres, A., Valdés, M., et al: "Global Reference Frame Realization on National Level Based on the Integration of National CORS Networks" 2015AGUFM.G23B1070K 2015 Fall Meeting, San Francisco 14-18 December 2015.
- Valdes, M. Baron, A., Sanchez Sobrino, J. A., Blanco, M., Zurutuza, J.: "A new ETRS89 realization in Spain" a EUREF Analysis Centre Workshop. Royal Observatory of Belgium, October 2017.

- Azcue, E., Sánchez Sobrino, J.A., Valdés, M. "Assessment of different variables influence to determinate the tropospheric delay with near real-time GNSS". EUREF 2016 Symposium. San Sebastián, 25-27 May 2016.
- Azcue Infanzón, E., Calvo Ferruelo, S., Gonzalo López, P., Sánchez Sobrino, J.A., Valdés Pérez de Vargas, M. "Current status of the National GNSS Permanent Stations Network". EUREF 2016 Symposium. San Sebastián, 25-27 May 2016.
- Azcue Infanzón, E., Calvo Ferruelo, S., Gonzalo López, P., Sánchez Sobrino, J.A., Valdés Pérez de Vargas, M. "Estado de la Red de Estaciones Permanentes GNSS del Instituto Geográfico Nacional". Asamblea Hispano Portuguesa de Geodesia y Geofísica. Madrid, 28-30 June 2016.
- Sanchez Sobrino, J.A., Azcue, E., Calvo, S., Gonzalo, P., Valdés, M. "Principales proyectos del Centro de Análisis de Datos GNSS del Instituto Geográfico Nacional". Asamblea Hispano Portuguesa de Geodesia y Geofísica. Madrid, 28-30 June 2016.
- Azcue, E., Sánchez Sobrino, J.A., Valdés, M. "Evaluación de la influencia de diversas variables en la estimación del retraso troposférico con GNSS en tiempo casi real". Asamblea Hispano Portuguesa de Geodesia y Geofísica. Madrid, 28-30 June 2016.
- Puyol B, Fraile M.A., Vaquero P.A., Valdés M.: "IGN-E Tide Gauges Network". EUREF 2016 Symposium. San Sebastián (España). 25-27 May 2016.
- Azcue E, Calvo S, Gonzalo P, Sánchez, J.A., Valdés M: "Current status of the National GNSS Permanent Stations Network". EUREF 2016 Symposium. San Sebastián (España). 25-27 May 2016.
- Vaquero P.A., Valdés M., Sainz-Maza S., Fraile M.A.: "Levelling and gravimetry in the National GNSS Permanent Network (ERGNSS) and Tide Gauge Network of Spain". EUREF 2016 Symposium. San Sebastián (España). 25-27 May 2016.
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- P.A. Vaquero, M. Valdés and S. Sainz-Maza. "Integrating gravity, levelling, GNSS and tide gauge networks in Spain". GGHS2016 "Gravity, Geoid and Height Systems 2016". Thessaloniki, Greece September 19-23, 2016.

(The information of this Institution has been remitted by M.Valdés)

9. ROYAL INSTITUTE AND OBSERVATORY OF THE SPANISH NAVY. SAN FERNANDO

REAL INSTITUTO Y OBSERVATORIO DE LA ARMADA (ROA).
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The “Real Instituto y Observatorio de la Armada” (ROA), is a Naval Institution working on geodesy since its foundation on the mid XVIII century. Now, activities on this area are focused on Satellite Laser Ranging (SLR) and Global Positioning System (GPS) measurements and applications.

1. Satellite Laser Ranging (SLR)

Installed on the top of the main building, under a dome, ROA has a SLR station that has been successively improved since 1968. During the period 2015-2019, the station has been upgraded, partially funded through the following research projects:

- 1. Contribution of the artificial satellite tracking station of the ROA: a) the determination of the International Terrestrial Reference System and b) monitoring of space debris.** (ITRF-SFEL-BE). The fundamental scientific objective is the improvement of the quality of the data produced by the laser ranging station, as well as the realization of modifications and tests aimed at monitoring space debris. The data of the Laser Tracking Station (SLR) is provided to the International Earth Rotation Service (IERS), through the International Laser Ranging Service (ILRS), responsible for the generation of the successive models of International Terrestrial Reference Frame (ITRF).
- 2. Infrastructure project to update and improve the artificial satellite tracking station (SLR).** The main objective of this project was the acquisition and integration of a new laser telemetry bench thus ensuring viability over time of the SLR observations. This project was requested in February 2016, being approved in the month of July. In the middle of December 2016, the picosecond laser bench was received. Along 2017 it was integrated becoming fully operative.

The main scientific objective during this period has been to track non-collaborative objects. For this reason, with funds provided from the European Union, the following project was approved:

- 3. Project "Studies for the improvements of ROA SLR laser station". [EXPTE. 10/2016 NEG LOT 3 (DPI / DPA)].** Between February 16 and November 24, 2017, a project is carried out to update the laser telemetry station in order to track non-collaborative objects. As a result, a laser bank model EKSPLA NL-317 is purchased with EU funds, carrying out its

installation and integration taking advantage of the electronics and tracking system used until then. In November 2017, the first trackings on non-collaborative objects were obtained.

Table 3
Summary of tracking and echoes obtain on collaborative and non-collaborative objects 2015-2019

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2015	ECOS	126.117	71.512	133.280	116.908	118.014	138.603	243.343	62.410	68.271	60.310	113.497	50.864
	TRACKINGS	320	157	333	230	318	479	566	268	340	214	560	221
2016	ECOS	31.455		3.387	56.155	24.190	89.731	46.011	75.015	20.037	27.961	4.514	27.233
	TRACKINGS	104		9	167	191	343	231	317	105	67	19	64
2017	ECOS	35.373	21.448	33.327	18.377	60.410	69.605	213			450	8.790	
	TRACKINGS	141	51	135	70	244	183	4			5	42	75
2018	ECOS	677	476		5.187	32.869	21.337	10.996	12.436	16.287	13.258	5.340	35.923
	TRACKINGS	2	2		38	220	127	90	60	106	81	43	107
2019	ECOS	28.867	39.739	57.236	22.412	12.215							
	TRACKINGS	87	105	145	70	44							

Besides San Fernando laser-ranging station has taken part on different observational campaigns lead by the European Union, as follows:

- December 2015: S3T Phase 1 Observation campaign
- July 2016 – July 2017: Operation and maintenance of San Fernando SLR and TFRM telescope contribution of Spain to the European Union SST framework.
- July 1st – December 31st 2017: Post-initial operations and maintenance of the optical phase sensors, contribution of Spain to the European Union SST framework.
- January 1st – December 31st 2018: Optical sensor data supply for spatial surveillance service provided by CDTI to the European Commission.
- January 1st – March 29th 2019: Extension of optical sensor data supply for spatial surveillance service provided by CDTI to the European Commission.

2. GPS geodetic activity

The main geodetic GPS contribution is the maintenance of the network. It has nine stations located in the southern area of the Iberian Peninsula, Balearic Sea and North Africa. This distribution allows the analysis of the data of the Eurasian and African continental plates at their confluence in the area of the Gulf of Cádiz and the Alboran Sea. The main one of these stations is located in the Observatory itself and is integrated into the international IGS (International GNSS Service) network.

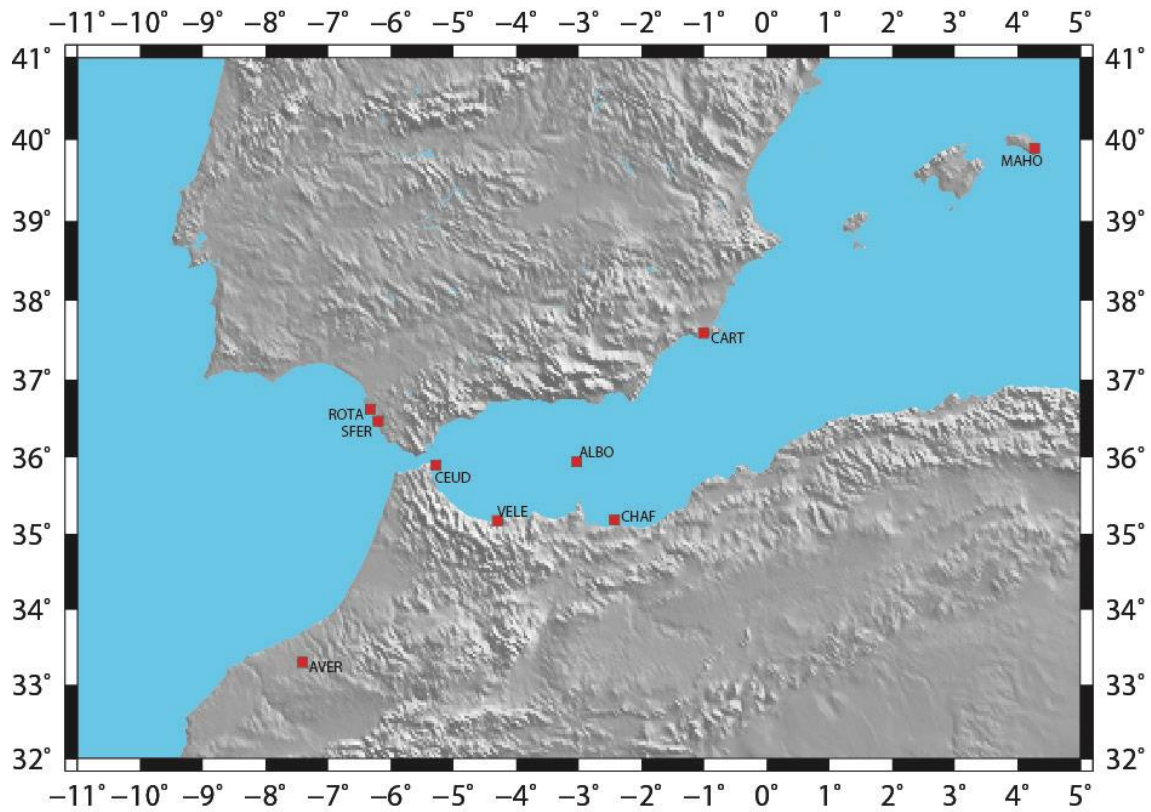


Figure 5: ROA Geodynamic GPS Network

3. Publications

- **Title:** San Fernando laser station updates and new improvements.
Conference: ESA NEO and Debris Detection Conference 2019.
Date: 22nd to 24th January 2019.
Authors: M. Catalán, M. Larrán, A. Vera, F. della Prugna.
- **Title:** Employing fast orbit prediction algorithm for optimization of satellite visibility computation.
Conference: ESA NEO and Debris Detection Conference 2019.
Date: 22nd to 24th January 2019.
Authors: M. Sanchez Piedra, S. Setty, B. Jilete, T. Flohrer.
- **Title:** Performance improvements of tracking station at ROA.
Conference: ESA NEO and Debris Detection Conference 2019.
Date: 22nd to 24th January 2019.
Authors: M. Sanchez Piedra, S. Salata, C. Ortega, M.A. Carrera.
- **Title:** The threat of space debris.
Journal: Spanish Defence Journal.
Date: November 2018.
Authors: M. Catalán.

- **Title:** Photon pressure force on space debris TOPEX/Poseidon measured by Satellite Laser Ranging.
Journal: Earth and Space Science.
Date: October 2017.
Authors: D. Kucharski, G. Kirchner, J. C. Bennett, M. Lachut, K. Sośnica, N. Koshkin, L. Shakun F. Koidl, M. Steindorfer, P. Wang, C. Fan, X. Han, L. Grunwaldt, M. Wilkinson, J. Rodríguez, G. Bianco, F. Vespe, M. Catalán, K. Salmins, J. R. del Pino, H.-C. Lim, E. Park, C. Moore, P. Lejba, and T. Suchodolsk.
- **Title:** Space debris tracking at San Fernando laser station.
Conference: Mexican Journal of Astronomy and Astrophysics.
Date: January 2017
Authors: M. Catalán, M. Quijano, A. Pazos, J. Martín Davila, Luis M. Cortina
- **Title:** Tracking on non-active collaborative objects from San Fernando Laser Station.
Conference: EGU General Assembly 2016. Vienna.
Date: 17th to 22nd April 2016
Authors: M. Catalán, M. Quijano, Luis M. Cortina, A. Pazos, J. Martín Davila
- **Title:** Tracking on space debris using laser techniques.
Conference: 9th Hispanic - Portuguese Assembly of Geodesy and Geophysics.
Date: 28th al 30th June 2016
Authors: M. Catalán.
- **Title:** Measuring ranges to space debris from San Fernando Laser ranging station.
Conference: 2015 ILRS Technical Workshop.
Date: 26th to 30th October 2015.
Authors: M. Catalán, M. Quijano, L.M. Cortina, A. Pazos, J. Martín-Davila
- **Title:** ROA's Real Time GNSS Network and its viability in Alertes-Rim system
Conference: European Geophysical Union General Assembly.
Date: 12nd to 17th April 2015.
Authors: A. Cibeira; J. Gárate; L. Mendoza.

(The information of this Institution has been remitted by M.Catalán)