Chapter 2
General Background

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J. Jones et al. (eds.), *Advanced GNSS Tropospheric Products for Monitoring Severe Weather Events and Climate*, https://doi.org/10.1007/978-3-030-13901-8_2

Abstract This Chapter gives a general overview of the motivations behind the COST Action, a state-of-the-art at the start of the Action, plus an overview of the EIG EUMETNET GNSS Water Vapour Programme, E-GVAP. The Chapter also gives a breakdown of the structure of the COST Action including the objectives, percieved benefits and a detailed breakdown of the scientific plans of each working group, as per the Memorandum of Understanding agreed with COST.

2.1 Introduction

To improve the forecasting of severe weather and monitoring climate change, it is vital to obtain atmospheric water vapour observations with high temporal and spatial resolutions. GNSS signal propagation is sensitive to atmospheric water vapour, and as many ground-based GNSS receivers are already installed, collection of those data is a cost-effective way to increase spatial resolution of water vapour observations. Furthermore, improved modelling of the atmospheric influence can contribute to the speed and precision of GNSS positioning, navigation, and timing services, making the collaboration between the geodetic and atmospheric communities mutually beneficial. This COST Action focuses on new and improved capabilities from concurrent developments in both the geodetic and atmospheric communities, to develop new GNSS tropospheric products and exploit the full potential of multi-GNSS (GPS, GLONASS, and Galileo readiness) observations on a wide range of temporal and spatial scales in weather forecasting and climate research.

The use of GNSS tropospheric products in climate science has been advertised for several years, but they are still not widely used, despite the excellent time stability of the observing system. This is in clear contrast to the advances of GNSS meteorology. The existence of more than 25 years of observations from permanent GNSS stations worldwide shows high potential for monitoring trends and variability in atmospheric water vapour. This COST Action looked to exploit homogeneous reprocessed GNSS tropospheric products, to detect climatic signals and to evaluate independent climate data records of IWV, which is recognised as an essential climate variable by the Global Climate Observing System (GCOS).

Successful development of new GNSS tropospheric products requires interaction and coordination between the meteorological and geodetic communities, as both data providers and data users. High-level expertise in these areas is available in relatively few countries and institutions, and needs to be spread across all of Europe. For such effort, COST constitutes a relevant mechanism for supporting a well-structured international effort, enabling scientists from European universities, National Meteorological and Hydrological Services (NMHSs) and geodetic institutions to cooperate.

Short-Term Scientific Missions (STSM), Expert Meetings, Training Schools and Workshops are ideally suited to enhance networking and cooperation between European experts, and are used to generate a higher level of scientific and technological interaction than otherwise possible.

2.2 The State-of-the-Art at the Start of the Action (E-GVAP)

Application of GNSS for Numerical Weather Prediction (NWP) was the focus of a number of previous EU projects (WAVEFRONT, MAGIC, TOUGH and COST Action 716). Following their successes, the application of GNSS for NWP is now a well-established technique in Europe. Since 2005, E-GVAP (EIG EUMETNET GNSS Water Vapour Programme, http://egvap.dmi.dk) has been responsible for the collection and quality control of operational GNSS tropospheric products for NWP in Europe.

The main purpose of E-GVAP is to provide its EIG EUMETNET members with GNSS-derived ZTD estimates and IWV in near real-time (NRT) for operational meteorology. A secondary purpose is to help advance the processing of GNSS data for estimation of atmospheric properties of importance to meteorology, and to advance the usage of such data in NWP and nowcasting schemes. Additionally, E-GVAP continues to attempt to expand into areas where coverage is currently poor, increase the homogeneity of data, validation and active quality control, and encourage the move to sub-hourly data processing and distribution. E-GVAP continues to help members access global data sets and also monitors research of next generation GNSS products.

Figure 2.1 shows the overall E-GVAP data flow, with the Analysis Centres (ACs) on the left, the data exchange and monitoring facilities to the right. Figure 2.2 shows a list of ACs. Notice that some of the ACs deliver several different ZTD products,

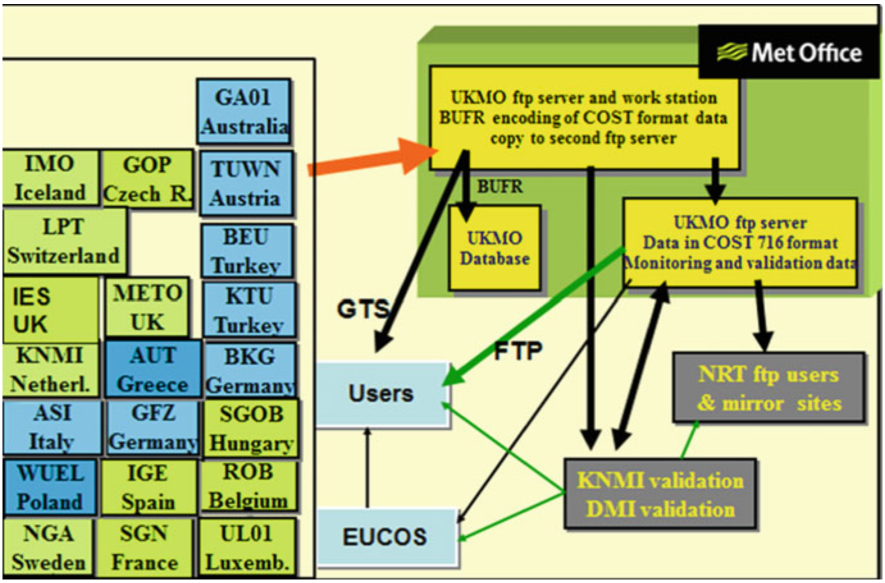

Fig. 2.1 The E-GVAP general setup

AC	Institution
AUT	Aristotle Univ. of Thessaloniki Analysis Center, Greee.
ASI	e-geos/Telespazio, Italy
BEU	Zonguldak University of Technology, Turkey
BKG	Federal Agency for Cartography and geodesy. Germany
GA01	Geoscience Australia New
GFZ	Helmholz Centre Potsdam, GFZ German Res. Cen. f Geosciences
GOPE	Geodectic Observatory Pecny, Czech Republic
IES	Inst. of Eng., Surv. And Space Geodesy, Univ of Nottingham, UK
IGE	Instituto Geografica National, Spain
IMO	Icelandic Met Office
KNMI	Royal Meteorological Institute of the Netherlands
KTU	Karadeniz Technival Univ. Analsis Center, Turkey
LPT	SwissTopo, Switzerland
METO	UK Met Office
NGA1	Lantmateriet (Swedish Mapping. Cadestre and Land Reg. Authority), Gavle, Sweden
ROB	Royal Observatory of Belgium
SGN	Institut Geographigue National, France
SGOB	Satellite Geod. Obs, IGCRS + Technical Univ. Budapest, Hungary
TUWN	Technical University Vienna, Austria
UL01	University of Luxembourg, Fac. Of Science and Communication
WUEL	Wroclaw University + Inst. Of Geodesy and Geoinformatics, Poland

Fig. 2.2 E-GVAP ACs

Table 2.1 Timeliness criteria for the ZTD timeliness monitoring

Level	Hourly ZTD estimation	Percentage	Sub-hourly ZTD estimation	Percentage
Threshold	120 min	–	30 min	90%
Target	90 min	90%	15 min	75%
Goal	60 min	75%	5 min	–

such as hourly, sub-hourly and/or global. The different products are identified by different solution naming, e.g. the AC METO (UK Met Office) provides three ZTD products; METR (UK region, sub-hourly), METG (global, hourly) and METO (European, hourly).

E-GVAP is based on a volunteer collaboration between GNSS geodetic institutions, the ACs and EUREF, and E-GVAP/EUMETNET. On the national level, E-GVAP members attempt to liaise with national geodetic institution to access raw GNSS data and ZTD estimates. In countries where there is no E-GVAP member, E-GVAP attempts to liaise with geodetic institutions directly on behalf of the national meteorological service. In Fig. 2.1 the blue ACs are ACs in non-member countries.

Timeliness

An essential requirement is to improve timeliness, to fulfill requirements from local, rapid refresh NWP and nowcasting. The timeliness criteria are shown in Table 2.1.

Quality
The criteria for ZTD precision is that ZTD OmB (GNSS ZTD estimate (Observation) minus NWP ZTD estimate (Background) standard deviation is <15 mm. The real ZTD uncertainty is significantly lower, as the main part of the OmB offsets are due to the NWP model itself (known from previous validation studies of GNSS vs radiosonde, vs. post-processed GNSS ZTDs, and also vs. IWV derived from microwave radiometers and VLBI.

Data Flow
Currently, more than 20 E-GVAP ACs produce GNSS tropospheric products for over 2500 ground-based GNSS stations, worldwide.The ACs uploads ZTDs to an ftp-server at the UK Met Office in COST716 format. Various checks on the content and format are carried out, the data is then BUFR encoded and distributed via the GTS. Additionally E-GVAP is developing an Active Quality Control (AQC) system which will be based on inter-comparison of ZTDs from GNSS sites for which ZTDs from at least three different ACs are available, valid at (approximately, fraction of hour) the same time. The full results of the AQC will be available via ftp. An automated warning will be submitted to users in case the AQC detects an AC & solution wide problem.

Organisation
Currently E-GVAP has two expert teams; the expert team on GNSS data processing and standards and the expert team on GNSS data usage. The teams meet annually in a combined meeting to which members of E-GVAP are also invited to enable efficient sharing of knowledge and guidance between data producers, data users and members. The expert team on GNSS data processing is extremely important to E-GVAP as it addresses common issues and helps AC coordination. Besides addressing E-GVAP specific issues, the meetings help coordinate activities on future research in GNSS-meteorology as many members of both expert teams are involved in such research besides their E-GVAP-specific work.

E-GVAP Expert Team on GNSS Data Processing and Standards
The main purpose of this team is to:

- Exchange knowledge on GNSS data processing, leading to best practices and improved homogeneity of the E-GVAP GNSS atmospheric delay products.
- Exchange knowledge on "next generation" GNSS data processing.
- Provide advice to E-GVAP on technical and scientific matters.
- Liaise with geodetic community

E-GVAP Expert Team on Data Usage
The main purpose of this team is to:

- Exchange knowledge on usage of E-GVAP data in meteorology, thereby providing feedback to the E-GVAP data producers, and provide material assisting members in using E-GVAP data.

- Exchange knowledge on usage of "next generation" GNSS in meteorology.
- Provide advice to E-GVAP on technical and scientific matters
- Liaise with the geodetic community.

Benefits to Users

Figure 2.3 is a recent example of NWP impact from different observing systems on a per-observation basis, with GNSS delays having the second largest impact. It both demonstrates that GNSS delays are useful, and that the NWP system is far from saturated with this type of humidity data. Hence, additional GNSS ZTDs will benefit the NWP system.

The current state-of-the-art is generally data assimilation in NWP models of hourly-updated Zenith Tropospheric Delays (ZTDs). However, there are big benefits to be obtained from innovation of the current GNSS products: most E-GVAP ACs analyse GPS-only, provide ZTD-only (no information on local in-homogeneities) and process GNSS data in a network solution (due to lack of high-quality, near real-time estimate of GNSS satellite clock errors, preventing use of the potentially faster Precise Point Positioning (PPP) technique). While the production, exploitation and evaluation of operational GNSS tropospheric products for NWP is well established in Northern and Western Europe, it is still an emerging R&D field in Eastern and

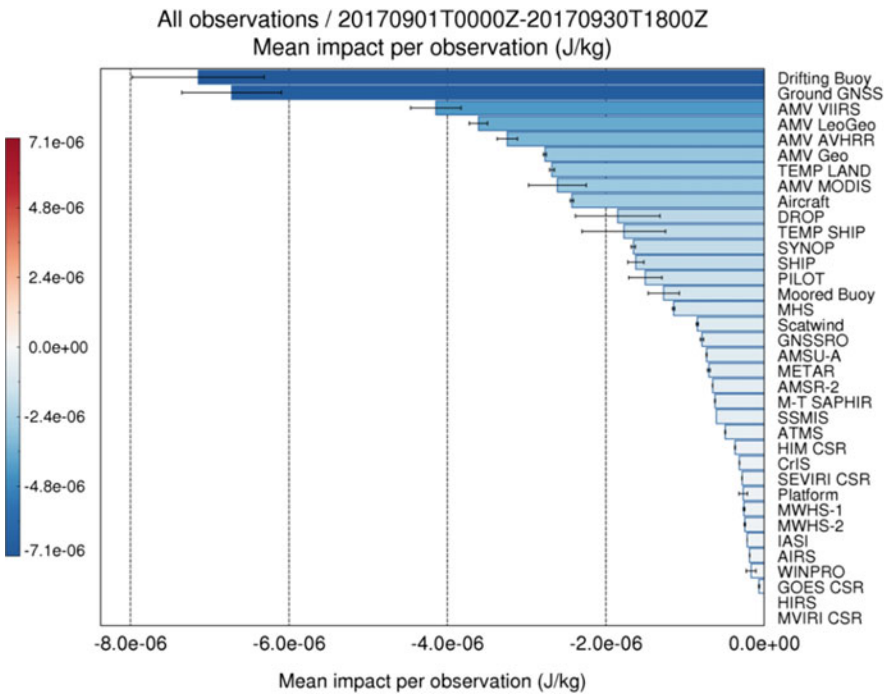

Fig. 2.3 Impact per observation of various types of observations in Met Office global NWP (Courtesy of Data Assimilation, UK Met Office)

South-Eastern Europe. More than 15 years of GNSS meteorology in Europe has already achieved outstanding cooperation not demonstrated elsewhere, overcoming difficulties such as cross-border data access.

It is now feasible to develop next-generation GNSS tropospheric products and applications that can enhance the quality of weather forecasts and monitoring of climate change, contributing to important societal and political needs. Of special interest in Europe are heavy precipitation events, flash floods, and heat waves. Such regional meteorological extremes are expected to increase in the future, as a result of global warming (IPCC AR5). Relevant areas of research are:

1. Severe weather forecasting: new GNSS products are required to provide more information on the spatial heterogeneity and rapid temporal variability of humidity in the troposphere.
2. Nowcasting: providing rapid updates in the analysis of the atmospheric state requires a transition from near real-time GNSS network processing (as implemented in E-GVAP) to real-time PPP processing.
3. Multi-GNSS analysis combining data from GPS, GLONASS, and Galileo in the future is expected to provide improved tropospheric products. Processing algorithms need to be modified and impact of use of additional observations needs to be assessed.
4. Climate monitoring through the evaluation of trends and variability in IWV for which the quality of reprocessed GNSS data and homogenised IWV estimates need to be assessed. The goal is to establish a new climate data record, taking benefit of more than 15 years of reprocessed ZTD estimates from hundreds of global and regional GNSS stations (e.g. http://acc.igs.org/reprocess.html and http://acc.igs.org/reprocess2.html).

2.3 Reasons for the Action

Coordinate the development and testing of new multi-GNSS products for operational NWP and forecasting of severe weather: Short-term, high-resolution NWP 'nowcasting' models require more detailed humidity observations, especially to resolve small-scale phenomena like deep convection. More advanced products such as horizontal ZTD gradients, slant delays (signal delay in the direction of each satellite) and 3-D refractivity or humidity fields (using tomography) can now be produced. Furthermore, multi-GNSS processing will improve the accuracy of tropospheric products due to improved coverage of azimuth and elevation angles.

Coordinate the development and testing of real-time GNSS processing algorithms for high-resolution, rapid-update analysis and nowcasting applications: New algorithms will be developed and tested in collaboration with ends users (forecasters).The benefits of rapid-update cycle NWP (e.g. with hourly data assimilation) will be assessed by coordinated case studies of severe weather events.

Enhance production, exchange and use of reprocessed GNSS products for climate monitoring: To meet the long-term stability requirement for climate data record observations, the quality of GNSS data acquisition and processing are crucial. The Action will provide a framework for agreeing equipment standards, data formats, optimal data reprocessing using state-of-the-art GNSS algorithms and homogenisation methods to remove data discontinuities. The uncertainties in existing reprocessed GNSS IWV records, as well as those of data released during the course of the Action, will be assessed.

Improve GNSS processing and positioning: NWP data has recently been introduced as an input to GNSS processing for deriving improved mapping functions. In real-time GNSS processing there is currently an interest in using atmospheric NWP data to initialise PPP processing algorithms which can provide shorter convergence time and improve positioning. Establishing an atmospheric NWP data repository will drive the exploitation of NWP model data in real-time GNSS processing.

Strengthen the collaboration between GNSS experts and end-users: Workshops, Training Schools and STSMs will be efficient tools in bringing together scientists from various disciplines as well as linking with public and private data owners helping to promote free data exchange. Tighter cooperation between researchers and representatives from International and European organisations (GCOS, IAG, EGU, WMO, ECMWF etc.) will help guarantee that efforts will be conducted along high-priorities of both the scientific community as well as of political and economic stakeholders.

Increase observing network size, homogenise data quality and support knowledge transfer: This Action will encourage and facilitate the transfer of knowledge with possible establishment of GNSS ACs in Eastern and South-Eastern Europe, in cooperation with the European Position Determination System (EUPOS). Additionally, North African meteorological services are starting to use NWP models capable of assimilating GNSS tropospheric products and several national mapping agencies in this region already maintain operational GNSS networks.

2.4 Objectives

The aim of the Action is to enhance existing and develop new, ground-based multi-GNSS tropospheric products, to assess their usefulness in forecasting of severe weather and climate monitoring, and to improve GNSS real-time positioning accuracy through enhanced atmospheric modelling. A main focus is to strengthen and intensify this inter-disciplinary collaboration on a European level and to encourage cross-border cooperation.

Specific Objectives

- Develop new GNSS tropospheric products and assess their benefits in operational NWP and nowcasting, with a special focus on forecasting of severe weather.
- Coordinate the analysis of case studies to target known problems with modelling and forecasting of severe weather.

- Strengthen and extend the dialogue between GNSS tropospheric product providers and end-users from the meteorological and climate communities, stimulate transfer of knowledge and data exchange.
- Stimulate the exploitation of NWP data as an input to GNSS processing schemes, and assess the benefits for real-time GNSS positioning, navigation, and timing services.
- Generate recommendations on optimal GNSS reprocessing algorithms for climate applications and standardise the method of conversion between propagation delay and atmospheric water vapour with respect to climate standards.
- Coordinate the collection, archiving and exchange of raw GNSS data from various regional networks in Europe.
- Establish a database of reprocessed GNSS tropospheric products at global and regional scales and assess their quality by inter-comparison with in-situ and remote sensing techniques.
- Collaborate with the climate and meteorological communities, to assess and improve reanalyses and climate models (e.g. by assimilation of reprocessed GNSS tropospheric products) and investigate climate signals (trends and variability).

2.5 Impacts and Benefits

2.5.1 Societal Benefits

Better information about atmospheric humidity, particularly in climate-sensitive regions, is essential to improve the diagnosis of global warming, and for the validation of climate predictions on which socio-economic response strategies are based. The Action will foster a better understanding of atmospheric humidity and reduce uncertainties in climate predictions, enabling improved national, EU, and global policies mitigating negative effects of climate change. Furthermore, the Action will lead to improved forecasting of severe weather, which will have a positive impact on hazard management, lowering the risk of loss-of-life and the risk to national infrastructure. Direct and indirect societal benefits can be expected in the fields of disaster management, health, energy, water, agriculture and biodiversity.

2.5.2 Scientific Benefits

The Action will:

- Develop new multi-GNSS processing techniques, exploiting all GNSS constellations, leading to tropospheric products with improved timeliness, accuracy and reliability.

- Assess the quality of existing reprocessed GNSS tropospheric products, and define the requirements for the establishment of a GNSS climate data record.
- Coordinate the exploitation of ground-based GNSS and atmospheric data for the mutual benefit of both communities.
- Improve satellite-based positioning by using advanced signal propagation modelling and by use of NWP data to initialise PPP processing algorithms for real-time positioning.
- Link the activities of the existing tropospheric working groups (IGS, EUREF) and work in support of the operational goals of E-GVAP.
- NWP reanalysis, climate modelling, and calibration and validation of satellite water vapour related products will benefit from improvements in GNSS data processing.
- Work in support of GCOS, and spread expertise across Europe about GNSS atmospheric science through a well-organised panel of European experts and in liaison with the International Association of Geodesy.

2.5.3 Technological Benefits

The Action will provide recommendation on GNSS equipment standards, needs for collocated observations, optimal data processing, and methods for producing a GNSS climate dataset. Better modelling of tropospheric path delays in the processing algorithms will result in improved GNSS services for positioning, navigation, and timing.

2.5.4 Economic Benefits

A better understanding of atmospheric water vapour will improve mitigation of natural hazards, reducing the risk of economic disruption on national and international scales. Coordination throughout Europe is more cost-effective than solitary R&D in the atmospheric, climate, and geodetic communities. Long-term testing and validation will provide impetus to manufacturers to develop suitable, reliable, and cost-effective instruments.

2.5.5 Target Groups and End-Users

Target groups/end users of this Action are NMSs, climate research centres, and operational and research geodetic services, including those involved in E-GVAP, international boards for geodesy and geophysics (IUGG and IAG), and institutions working on climate change and weather watch (e.g., IPCC-AR5, GCOS, GEOSS and GMES). They will be provided with data, scientific results and recommendations for operational use of GNSS observations and products.

2.6 Scientific Programme

The key questions to be addressed in this Action are:

- Which new GNSS processing techniques can deliver enhanced, more detailed GNSS tropospheric products suitable for high-resolution and rapid-update cycle NWP models?
- How far can new GNSS tropospheric products improve weather forecasting, and in particular forecasting of severe weather events?
- What is the added-value of combining observations from multiple GNSS systems (GPS, GLONASS, and Galileo readiness) on tropospheric products?
- What are the benefits of reprocessed GNSS tropospheric products (currently GPS-only) to the current state-of-the-art climate research?
- How can atmospheric NWP data improve real-time GNSS navigation, positioning and timing services?

The research activities will be contributing to five main areas:

1. Developing and testing of advanced GNSS processing techniques, making new products for use in operational nowcasting and forecasting of severe weather. Software developments are required to improve timeliness, enlarge data volume (more GNSS stations, new signals, higher resolution of tropospheric parameters) and to provide extended products. This task needs cooperation among experts in GNSS data processing, software developments, and end-users (forecasters).
2. Updating processing techniques and software and tackling specific problems to permit optimal usage of multi-GNSS data (e.g. combination of orbits, clocks, Earth rotation parameters). This task needs cooperation between geodesists and international bodies on references, conventions, and precise products (IAG, IERS, IGS, EUREF).
3. Optimising of present and future operational NWP systems to use of new ground-based GNSS tropospheric products for monitoring and forecasting severe weather. This task will assess the impact of assimilating new products (gradients, slant delays and new observables) on the quality of weather forecast. This task needs strong collaboration between the NWP and geodetic communities.
4. Evaluating and improving the quality of reprocessed ground-based GNSS tropospheric products for climate research (estimating water vapour trends and variability). This task will need cooperation between geodesists and climatologists, to agree on diagnostics for assessing the data records, and on recommendations on equipment, data reprocessing, and data formats. This task may also achieve a GNSS climate data record and assess and improve NWP reanalyses and climate models simulations.

5. Assessing atmospheric NWP data as an input to better GNSS navigation and precise real-time positioning products. This task will need a close cooperation of NWP operators and GNSS software and service developers.

2.7 Scientific Work Plans

The Action is organised into three Working Groups (WGs).

2.7.1 Working Group 1: Advanced GNSS Processing Techniques

This WG will coordinate the development of new/advanced GNSS processing techniques and products. The activities are:

- Develop, validate, and exchange GNSS processing algorithms and software, to enhance the existing temporal and spatial resolution of the operational GNSS tropospheric products suitable for high-resolution, rapid-update NWP and forecasting of severe weather and validate these new products.
- Assess methods for estimating gradients and slant delays for different GNSS processing methods (PPP and network solution).
- Study the potential of the IGS real-time precise orbits and clocks service to enable the faster and more efficient PPP GNSS data processing.
- Develop, validate and exchange GNSS processing algorithms to extend current GPS-only tropospheric products into the multi-GNSS products:
- Develop GPS and GLONASS products, and prepare for Galileo inclusion.
- Assess the consistency between stand-alone GPS and GLONASS products.
- Determine the potential of atmospheric NWP data as an input in real-time GNSS positioning, navigation, and timing services. Various approaches will be assessed.
- Enhance the production of multi-GNSS products, and check consistency and benefits of them.
- Develop new GNSS tropospheric products (gradients, slant delays, 3D water vapour and refractivity fields provided by tomographic reconstruction). Assess their potential for use in forecasting of severe weather and in high-resolution rapid-cycle NWP (hourly data assimilation).

Expected outcomes of WG1:

- Assessment reports and guidelines on new ultra-fast/real-time processing techniques, data format and products satisfying the needs for high-resolution, rapid-update NWP and forecasting severe weather.

- Assessment reports on the impact of multi-GNSS solutions on various GNSS tropospheric products.
- Define specific benchmark datasets designed for evaluation of the new tropospheric products.
- Prototype and report on use of atmospheric NWP data in support of real-time GNSS navigation and precise positioning.
- Establishment of GNSS Analysis Centres in Eastern Europe.

2.7.2 Working Group 2: Use of GNSS Tropospheric Products for High-Resolution, Rapid-Update NWP and Severe Weather Forecasting

This WG will coordinate the application of existing and development of new GNSS tropospheric products for high-resolution rapid-update NWP and forecasting of severe weather. The activities are:

- Create a standardised exchange format, and provide the gradients and slant delays from current networks through a central hub facility.
- Define and generate specific benchmark datasets in the form of GNSS observations, alternative water vapour and refractivity observations, and NWP products, for assessment and validation.
- Evaluate and validate the information content of the enhanced, new products provided by WG1, such as of gradients and slant delays (determine error sources, correlations etc.).
- Develop, validate, and exchange methods for initialization of NWP models using GNSS gradients and slant delays.
- Exchange methods of nowcasting applications of GNSS gradients and slant delays:
- Organize detailed analyses of special case studies.
- Establish a database with case studies of severe weather events.
- Organize user Workshops (audience forecasters/NWP modellers).
- Coordinate multi-model initialization experiments to obtain insight in the quality of different methods and models used in nowcasting and NWP.
- Assess the benefit of multi-GNSS tropospheric products in NWP and for severe weather forecasting.

Expected outcomes of WG2:

- Assessment reports and guidelines on standardised methods and data formats (in collaboration with WG1) for the initialization of NWP models using new/enhanced operational GNSS tropospheric products and for use in nowcasting.
- Promotion and dissemination of these standardised methods (STSMs, Training Schools, Workshops).

- Produce requirements for enhanced and new operational GNSS tropospheric products.
- Benchmark datasets for test, assessments and validations (for each method/ product).
- Database with severe weather case studies.
- Recommendations and methods for operational GNSS nowcasting tools.
- Identify new ground-based GNSS data providers for operational NWP and severe weather monitoring in the data sparse regions such as Eastern and South-Eastern Europe.

2.7.3 Working Group 3: Use of GNSS Tropospheric Products for Climate Monitoring

This WG will coordinate the evaluation of existing and forthcoming GNSS tropospheric products and assess their potential for climate research. The activities are:

- Collect and intercompare various reprocessed GNSS tropospheric products (e.g. produced by IGS, EUREF ACs, and those released by several independent groups).
- Develop, validate and exchange methods to convert between ZTD and IWV. Models and methods will be re-assessed and clear standards will be defined.
- Detect and mitigate discontinuities in IWV time series due to changes in equipment. Test various algorithms used by the geodetic and the climate communities.
- Establish a GNSS climate data record based on existing and reprocessed and homogenised tropospheric products (ZTD and IWV).
- Intercompare and quantify reprocessed ground-based GNSS tropospheric products against IWV and ZTD from independent geodetic techniques (VLBI and DORIS) and atmospheric in-situ and remote sensing techniques (radiosondes, microwave radiometers, sun photometers, satellite water vapour products such as those from GOME(2), SCHIAMACHY, IASI, SSM/I, SSMIS and RO instruments and climate products from the EUMETSAT Climate and ROM SAFs).
- Evaluate the accuracy of NWP reanalysis products (e.g. ERA-Interim, MERRA, CFSR) and climate models simulations (e.g. IPCC-AR5, CORDEX), and provide feedback for improving modelling products through assimilation of high-quality reprocessed GNSS products in future global or regional reanalyses (e.g., ERA-CLIM, EURO-4M).
- Assess relevant diagnostics and indexes for quantifying climate trends and variability (e.g., inter-annual, intra-seasonal, and synoptic variability, seasonal and diurnal cycle) at global and regional scales.
- Bring together GNSS data owners, both private and public, on a European scale, with the goal of including additional Mediterranean partners, to attempt to agree on a strategy for collection of past, present and future data.

Expected outcomes of WG3:

- Assessment report of potential and existing GNSS datasets, metadata, and products for use in climate research.
- Guidelines on the data formats, processing, and homogenisation methods for enhanced use of reprocessed GNSS tropospheric products in climate research.
- A database of raw GNSS data and a consortium of GNSS data providers for climate research, at European and Mediterranean scale, and with connections to worldwide organisations (IGS, EUPOS, national positioning services, GNSS campaigns etc.).
- A new climate data record of GNSS ZTD and IWV, suitable for analysing climate trends and variability, and calibrating/validating independent datasets at global and regional scales.