European Cooperation in the field of Scientific and Technical Research - COST -

Brussels, 21 November 2012

ES1206

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action ES1206: Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)

Delegations will find attached the Memorandum of Understanding for COST Action as approved by the COST Committee of Senior Officials (CSO) at its 186th meeting on 20 - 21 November 2012.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action ES1206
ADVANCED GLOBAL NAVIGATION SATELLITE SYSTEMS TROPOSPHERIC PRODUCTS FOR MONITORING SEVERE WEATHER EVENTS AND CLIMATE (GNSS4SWEC)

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4154/11 "Rules and Procedures for Implementing COST Actions", or in any new document amending or replacing it, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to enhance existing and develop new, ground-based multi-Global Navigation Satellite Systems (GNSS) tropospheric products, assess their usefulness in severe weather forecasting and climate monitoring, and to improve GNSS accuracy through enhanced atmospheric modelling.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 92 million in 2012 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter V of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

Global Navigation Satellite Systems (GNSS) have revolutionised positioning, navigation, and timing, becoming a common part of our everyday life. Aside from these well-known civilian and commercial applications, GNSS is now an established atmospheric observing system which can accurately sense water vapour, the most abundant greenhouse gas, accounting for 60-70% of atmospheric warming. Severe weather forecasting is challenging, in part due to the high temporal and spatial variation of atmospheric water vapour. Water vapour is under-sampled in the current meteorological and climate observing systems, obtaining and exploiting more high-quality humidity observations is essential to weather forecasting and climate monitoring.

This Action will address new and improved capabilities from concurrent developments in both the GNSS and meteorological communities. For the first time, the synergy of the three GNSS systems (GPS, GLONASS and Galileo) will be used to develop new, advanced tropospheric products, exploiting the full potential of multi-GNSS water vapour estimates on a wide range of temporal and spatial scales, from real-time monitoring and forecasting of severe weather, to climate research.

In addition the Action will promote the use of meteorological data in GNSS positioning, navigation, and timing services.

The Action will stimulate knowledge transfer and data sharing throughout Europe.

A.2 Keywords: Global Navigation Satellite Systems (GNSS), ground-based atmospheric sounding of water vapour, monitoring and forecasting of severe weather, climate change trends and variability, global warming

B. BACKGROUND

B.1 General background

To improve forecasting of severe weather and monitoring of 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 15 years of observations from permanent GNSS stations worldwide shows high potential for monitoring trends and variability in atmospheric water vapour. This Action will exploit homogeneous reprocessed GNSS tropospheric products, to detect climatic signals and to evaluate independent climate data records of Integrated Water Vapour (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 need to be spread across Europe. For such effort COST constitutes a relevant mechanism for supporting a well-structured international effort, enabling scientists from universities, National Meteorological Services (NMSs) and geodetic institutions in Europe 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 will be used to generate a higher level of scientific and technological interaction than otherwise possible.

B.2 Current state of knowledge

Application of GNSS for Numerical Weather Prediction (NWP) was the focus of previous EU projects (WAVEFRONT, MAGIC, TOUGH) and COST Action 716. Following their success, 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) is in charge of the collection and quality control of operational GNSS tropospheric products for NWP in Europe. More than 10 E-GVAP Analysis Centres (ACs) produce GNSS tropospheric products for over 1700 ground-based GNSS stations, with a target latency of 90 minutes, and make them available to NMSs. The state-of-the-art is 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 a near real-time estimate of the GNSS satellite clock errors, preventing use of the faster Precise Point Positioning (PPP) technique). While the production, exploitation and evaluation of operational GNSS tropospheric products for NWP is well established in the Northern and Western Europe, it is still an emerging R&D field in Eastern and South-Eastern Europe. More than 10 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).

B.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.

B.4 Complementarity with other research programmes

This Action will be developed in close collaboration with existing national, European and International research and operational programmes such as:
FP7-PEOPLE-2010-RG Marie Curie Action "GNSS Meteorology" aiming at the exploitation of ground-based GNSS for meteorology and climate studies in Bulgaria/Southeast Europe.
FP7-ENV.2010.4.1.3-1 GfG^2 exploring GNSS applications for Global Environmental Earth Observation (GEEO) and Global Earth Observation Systems of Systems (GEOSS).
HYMEX (Hydrological Cycle in Mediterranean Experiment) which is an internationally coordinated 10 year research programme
E-GVAP (EIG EUMETNET GNSS Water Vapour Programme).
WMO GCOS Reference Upper Air Network (GRUAN).
COST Action EG-CLIMET, focused on the use of ground-based profiling systems (not including GNSS) for improving weather forecasts.

C. OBJECTIVES AND BENEFITS

C.1 Aim

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.

C.2 Objectives

To achieve the main goals the following objectives will be addressed:

- 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).

C.3 How networking within the Action will yield the objectives?

The application of GNSS techniques for atmospheric studies requires combined efforts from both the meteorological and geodetic communities. These communities have their own associations, and collaborative projects are rare. The Action will coordinate efforts of national research programmes at universities and research institutes on a European scale, and improve cross-border data and knowledge transfer in the fields of GNSS processing, general NWP and severe weather forecasting and climate monitoring. The coordination will be linked with the development programmes within the geodetic community (including IGS and EUREF), and with the developments at NMSs (including those coordinated through EUMETNET and WMO expert teams). See Part D of this text

for details.
This Action's participants include geodesists, atmospheric, climate, remote-sensing and data assimilation scientists. All scientists involved in the Action will coordinate with the wider climate, meteorological, and geodetic communities to ensure the end user needs are met.

C.4 Potential impact of the Action

C.4.1 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.

C.4.2 Scientific Benefits

- 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.

- The Action will 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 (IAG).

C.4.3 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.

C.4.4 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.

C.5 Target groups/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.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

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 re-analyses 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.

D.2 Scientific work plan methods and means

It is planed that the work in each area will be detailed further once the Action is started, to enable participation and influence from other interested parties. The Action is organised into three Working Groups (WGs).

D.2.1 Advanced GNSS processing techniques (WG1)

This WG will coordinate the development of new/advanced GNSS processing techniques and products. This COST Action will:

- 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.

D.2.2 Use of GNSS tropospheric products for high-resolution, rapid-update NWP and severe weather forecasting (WG2)

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.

D2.3 Use of GNSS tropospheric products for climate monitoring (WG3)

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 inter-compare various reprocessed GNSS tropospheric products (e.g. produced by IGS, EUREF ACs, and those released by several independent groups). This comparison will enable definition of optimal data processing strategies.
- 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 the 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).
- Inter-compare 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, SSMI/S and Radio Occultation 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.

E. ORGANISATION

E.1 Coordination and organisation

The Action coordination will be performed by the Management Committee (MC), led by a Chair and a Vice-Chair, and organised in three Working Groups (WGs), each being coordinated by a Chair and Co-Chair, who will report back to the MC. The MC Chair, MC Vice-Chair, WG Chairs and Co-Chairs, will constitute the leading structure of the Action (Steering Committee).
The WGs will meet each year and plan coordinated annual Workshops. The WG Chairs will

compile progress reports to the MC at 12 month intervals, as indicated in the timetable (F). External experts will be invited to MC and WG meetings to seek advice, if required.
The activity of non-COST participants and international bodies, and the liaison and interaction with other research programmes, will be monitored and supported. Various liaisons are achievable via the members involved in the Action.
The MC will review progress, prioritise activities and recommend actions to overcome obstacles to the progress. High priority will be given to STSMs for maximizing the exchange of expertise among the participants. Early Stage Researchers will be encouraged to assume leading roles.

E.2 Working Groups

The Action will be organized in three Working Groups which have strong relationships:
WG1: Advanced GNSS processing techniques
WG2: Use of GNSS tropospheric products for high-resolution, rapid-update NWP and severe weather forecasting
WG3: Use of GNSS tropospheric products for climate monitoring
Each Working Group will be developing and coordinating research activities as described in section D.1. Several of the activities require strong interaction and cooperation between the WGs (e.g. the new GNSS products will be developed by WG1 and their impact in NWP systems will be assessed by WG2, feedback from assessment tests will help further improving the products).
Within the WGs several expert teams may be established, depending on the size and composition of the consortium, to address specific topics. The work of these expert teams should be facilitated by appropriate use of STSMs and Expert Meetings, as required.
STSMs will help young scientists to share and improve knowledge, and to help meet the Action objectives.

E.3 Liaison and interaction with other research programmes

Collaboration/cooperation will be developed with researchers from national, European and international organisations in liaison with established programmes through participation of experts to Working Groups of the Action and invitation of representatives to Workshops.

- GfG² is an EU 7th Framework Program with its mission to better assess the value of GNSS for Global Environmental Earth Observation (GEOS) and GEOSS. Members of the COST Team contribute to the GfG² project as experts in weather, climate and disasters.

- E-GVAP: new GNSS analysis methods and products developed by the Action will be tested with the geodetic and NWP partners from E-GVAP and transferred to operations upon validation.

- WMO GCOS Reference Upper Air Network (GRUAN): closer collaboration with the groups involved in research and development of new GNSS products and applications to climate monitoring, and standardization of equipment at reference upper air sites.

- HYMEX (Hydrological Cycle in Mediterranean Experiment) is one of the major research programmes in Europe studying atmospheric and climate processes over a period of 10 years (2010-2020). HYMEX GNSS task-team and meso-scale atmospheric modelling groups (real-time and research) will cooperate both with E-GVAP (for the assimilation of permanent network in operational NWP models) and with this Action (for research modelling and assimilation of new GNSS products). Collaboration with HYMEX will also be useful for studying cases of heavy precipitation in the Mediterranean during the field campaigns in 2012 and 2013.

- IGS (International GNSS Service) and EUREF (IAG Reference Frame Sub-commission for Europe): cooperation will concern research on methods for real-time GNSS processing, on dissemination of new single and multi-GNSS tropospheric products as well as reprocessed ZTDs for positioning, meteorology and climate purposes.

The COST Action will integrate a number of nationally funded research projects in the field of GNSS meteorology (Belgium, Bulgaria, the Czech Republic, Germany, Greenland, France, Hungary, Luxembourg, Italy, Poland, Portugal, Switzerland and the United Kingdom). The Action focuses on complementary developments and goals, benefiting from close cooperation with all the above mentioned programmes, projects and organizations.

E.4 Gender balance and involvement of early-stage researchers

Gender balance will be encouraged by ensuring several female members are given leadership roles in the Steering Committee and within expert teams. Special effort will be made to identify new female scientists as potential members of the Action and to encourage young female scientist participation in STSMs and Training Schools.
The present estimate is that at least 25 Early Stage Researchers will be involved in the Action. Aside from the STSMs, two Training Schools will be organized; one in the second year and one in the fourth year of the Action. During the Schools, attention will be paid to pair graduate, post-graduate students and Early Stage Researchers from different countries and communities and create small teams of 2-4 members that will select particular tasks to work on during the Action. The WG Chairs and Co-Chairs will prepare tasks and will be in charge of advising and mentoring Early Stage Researchers with annual progress reports provided during the annual plenary Workshops.

F. TIMETABLE

	Year 1	Year 2	Year 3	Year 4
MC Meeting	**oo**	**oo**	**oo**	**oo**
WG Meeting	**o**	**o**	**o**	**o**
WG Report	**o**	**o**	**o**	**o**
Reports to DC	**o**	**o**	**o**	**o**
Final Report				**o**
Workshop	**o**	**o**	**o**	
Final Workshop				**o**
Training School		**o**		**o**
STSM	**ooo**	**ooooo**	**ooooo**	**ooo**
Website	**o**	**o**	**o**	**o**
Dissemination of products	**o**	**o**	**o**	**o**

Note: circles indicate the number of events (meetings, reports, Workshops, Training Schools) per year. In the case of STSMs, the duration would be up to 3 months. Website activity dissemination of products will be conducted as continuous processes.

WG1 Milestones and Deliverables

	Year 1	Year 2	Year 3	Year 4
Workshop on reviewing the state-of-the-art.	X			
Support for establishment of new GNSS ACs, to cover gaps within Europe.	X	X	X	X
Develop new multi-GNSS processing algorithms (GPS+GLONASS+Galileo ready) in collaboration with the IGS and EUREF working groups.	X	X	X	X
GNSS processing Workshop on 1) ultra-fast/real-time tropospheric products for nowcasting and on 2) exploitation of NWP data in real-time GNSS data processing.		X		
Develop tropospheric models based on NWP data for enhancing real-time GNSS processing in close collaboration with WG2.		X	X	X
Develop new operational GNSS tropospheric products (gradients, slant delays, 3D water vapour and refractivity by tomographic reconstruction) in close coordination with WG2.		X	X	X
GNSS processing Workshop on 1) GPS and GLONASS processing and 2) assessment of new GNSS tropospheric products (gradients, slant delays, etc).			X	
Transfer of enhanced GNSS tropospheric products to E-GVAP for operational status in cooperation WG2.				X
Final Workshop.				X

WG2 Milestones and Deliverables

	Year 1	Year 2	Year 3	Year 4
Workshop on reviewing the state-of-the-art.	X			
Review/define requirements for data exchange format for GNSS gradients, slant delays etc. in collaboration with WG1.	X			
Set up of atmospheric NWP data repository for support of GNSS positioning, in collaboration with WG1.	X			

Identify periods of severe weather cases to define WG1 campaign periods (for estimation of gradients, slant delays etc).	X			
GNSS NWP Workshop: Strengths and weaknesses of the current NWP models regarding assimilation of ground-based GNSS data.		X		
Establish database of observations and products for severe weather case studies.		X	X	X
Evaluation of data quality of GNSS processing algorithms including GLONASS.		X	X	
Evaluation of new operational GNSS tropospheric products (gradients, slant delays, 3D tomography) based on selected test cases in collaboration with WG1.		X	X	X
GNSS nowcasting Workshop on tools and practices for monitoring and forecasting severe weather.			X	
QC of the operational GNSS tropospheric products delivered by the new ACs.		X	X	X
Develop/fine tune and test methods for initialisation of NWP models with the new GNSS tropospheric products.		X	X	X
Test impact of new operational GNSS tropospheric products for selected severe weather cases.		X	X	X
Development of operational tools for severe weather forecasting, in collaboration with E-GVAP and EUCOS.			X	X
Recommendations for quality control and data monitoring.				X
Final Workshop.				X

WG3 Milestones and Deliverables

	Year 1	Year 2	Year 3	Year 4
Workshop on reviewing the state-of-the-art.	X			
Set up of database of reprocessed GNSS tropospheric products in close collaboration with IGS and EUREF working groups and in cooperation with WG1.	X			

Develop, evaluate, and standardize methods of ZTD to IWV conversion in collaboration with WG1 and WG2.	X	X		
Detect and mitigate discontinuities in the ZTD and IWV time series.	X	X	X	X
GNSS climate Workshop on the assessment of reprocessed GNSS tropospheric products.		X		
Exploit reprocessed GNSS tropospheric products for evaluation of NWP reanalysis products, in collaboration with WG2 (e.g. ERA-Interim, MERRA, CFSR) and climate models simulations (e.g. IPCC-AR5, CORDEX) in collaboration with climate community.		X	X	X
GNSS climate Workshop on climate trends and variability of water vapour on regional and global scales.			X	
Development of relevant diagnostics and indexes for quantifying climate trends and variability.		X	X	X
Guidelines on the data formats, processing, and homogenisation methods for enhanced use of reprocessed GNSS tropospheric products in climate research in collaboration with the EUREF and IGS working groups.				X
Final Workshop.				X

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, BE, BG, CH, CZ, DE, DK, EE, EL, ES, FR, HU, IT, LU, LV, NL, NO, PL, PT, SE, SK, TR, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 92 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The target audiences for the dissemination of the Action results will be:

- Universities, Research Institutes and Early-Stage Researchers in the fields of:
    - Geodesy.
    - Meteorology.
    - Climatology.
- Scientific groups studying atmospheric processes associated with severe weather and climate:
    - HYMEX : hydrological cycle.
    - FP7-EUCLIPSE : role of cloud processes and feedbacks in the climate system.
- Operational Centres producing and using GNSS data and products:
    - IGS, EUREF and national geodetic analysis centres.
    - Numerical weather prediction and data assimilation centres (ECWMF and National Meteorological Services).
- European and international Earth observing infrastructures:
    - EUPOS (European Position Determination System).
    - EPOS (European Plate Observing System).
    - GMES (Global Monitoring for Environment and Security).
    - GEOSS (Global Earth Observation System of Systems).
- World/European Organizations:

- EUMETNET observation, forecasting and climate programmes (E-GVAP, EUCOS, SRNWP, ECSN, among others).
- WMO planning groups for observations (GOS and GCOS).
- WMO groups associated with instrument development, standardisation and network design (GRUAN expert team).
- European Commission research and innovation programmes.
- COST.

- Policy makers, planner/managers and authorities at European and national level:
  - Policy makers for Earth System Science and Environmental Management.
  - European planners for Galileo, GEO and GEOSS systems.
- GNSS public and private data providers.

H.2 What?

Scientific and technical knowledge generated by this COST Action will be disseminated to the target groups through:

- Publications: papers in scientific journals, Workshop and meeting proceedings (scientific), guidelines, reports, publications for the general public (technical).
- Capacity building: STSMs, Training Schools, public seminars.
- Events: Action Workshops, national and international conferences and symposia.
- Links: with existing European networks, organizations, projects and bodies.
- Website: public access website and password protected website.
- Establish a GNSS climate data record.

- Database and documentation for benchmarking multi-GNSS data processing solutions.
- Database and documentation on case studies for assessing the impact of GNSS products on monitoring and forecasting severe weather.

H.3 How?

Publications: The results of the Action will be presented in two types of publications: scientific papers and technical reports. The MC will promote co-authored papers in peer-reviewed international journals. In particular, 1) a GNSS meteorology review paper and 2) publication in separate thematic issues from at least one of the COST Workshops. This acknowledges the scientific value and justifies the COST support. Technical reports are a very useful mechanism to disseminate the results to the recipients, particularly policy makers, legislative and executive bodies and private companies, both in the geodesy and meteorology domains. The general public, and in particular high school and undergraduate student audience, will be reached via dedicated brochures and leaflets, whenever possible in the native language.
Capacity building: The Short-Term Scientific Missions (STSMs) will enable the dissemination of knowledge, especially to Early-Stage Researchers (ESRs). Assuming that at least 25 early-stage researchers will be involved in the Action, the MC will aim to fund at least 16 STSMs and will target knowledge transfer West-East, geodesy-meteorology and also research-industry. STSMs will facilitate information transfer within the Action, increase the opportunities for networking and allow the creation of an international profile for early-stage researcher. Two Training Schools will be organized to stimulate interdisciplinary knowledge transfer and networking between the two communities.
Events: Workshops will be used to bring together the scientific communities, to develop a detailed plan for progress, review progress and circulate ideas to the relevant bodies. A close level of cooperation with E-GVAP and HYMEX will be sought in particular. Special efforts will be made to invite external keynote speakers from Europe and worldwide. Wherever possible the Action will host Workshops jointly with other international meetings like ESA's International Colloquium - Galileo Science, International GNSS Workshop or EUREF Symposium.
Links: Direct links will be established with the European Commission (relevant DGs, e.g., Research, Environment and Space) and existing European networks, projects and bodies. Links will also be established with the National and International Societies interested of the topics covered by

the Action (e.g. EUREF, European Meteorological Society, etc.). Every year, during the meeting of MC and WGs, international agencies involved in the fields of the COST activity, and representatives of the users, will be invited for exchange of information, coordination and developing synergies and collaborations.

Website: A public access website will be established to provide the stakeholders and the scientific community with information about the Action. Information will include the Action organization, activity and results, as well as information on STSMs and Training Schools; links to other COST Actions and programmes. The website will also contain a restricted area with a password access for communication among the Action members.

The dissemination plan will be updated during the course of the Action, taking into account the progress of the Action as well as the results of its evaluation.

Members of the Action will be prepared to provide information to the relevant planning and policy making bodies as requested.