A proposal to SCAR seeking transformation of the **"GPS for Weather and Space Weather Forecasting"** (GWSWF) Action Group into an Expert Group (4 years project)

Names/Acronyms/Logos? (previously suggested name to be replaced when a new one is agreed upon)
GPS **T**ropospheric Water, **I**onospheric **T**EC and **S**cintillation for **W**eather and **S**pace **W**eather **F**orecasting **(GTWITS/WSWF)**

GRAPE: GNSS Research and Application for Polar Environment

……other acronym suggestions?

BACKGROUND

The evolution of the new solar cycle towards the upcoming maximum and beyond offers opportunity to investigate the influence of solar activity on the ever increasing complexity of human society and its dependence on technology. Never in the past have technological arrays and utility networks been so widely dispersed and intensively operated as at present. The impacts of solar terrestrial interactions on technology systems and communications arrays are going to be most intense and disturbances most felt by the general public during the upcoming solar maximum. Higher exposure of technology to solar perturbations, particularly in polar region, will require more extended investigations, both in variety of approaches and spatial coverage. One particular technological system that has rapidly grown in recent years is the Global Navigation Satellite System (GNSS), which includes GPS, GLONASS and Galileo arrays. Increased coverage in the Arctic and Antarctic will provide remote sensing tools to map the ionospheric total electron content (TEC) and precipitable water vapour (PWV) that will make it possible to assess the impact of solar disturbances on the newly attained precision positioning during the next solar maximum that is expected for 2013, and throughout the declining phase of the solar cycle. It may also help in improving short term weather forecasts and in remote sensing for climate change studies.

The International Polar Year (IPY) and International Heliophysical Year (IHY) initiatives left an important heritage in terms of data sharing, expertise exchange and increasing awareness of the current scientific capabilities. In particular, the GWSWF Group took advantage of the Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research (ICESTAR) and the Polar Earth Observing Network (POLENET) experiences that lead to creation of working groups on specific themes such as the use of geodetic data to study space weather events. The multidisciplinary approach of IPY is the key in overcoming relevant difficulties, above all, the poor coverage of Antarctica. We intend to continue to follow this route, intensifying the efforts to build a robust network of collaborations in order to answer a variety of space weather related needs through ad hoc data sharing and model development.

This proposal is based on the use of the classical GPS POLENET array and the growing coverage of modern GNSS systems, on the availability of advanced modelling and on the opportunity offered by the advancing solar cycle. The present program naturally falls within the realm of "space weather studies", and builds up on the results of the ICESTAR SRP, which has just concluded its work.

INTERNATIONAL PERSPECTIVE

Global Navigation Satellite Systems (GNSS), such as the American GPS (Global Positioning System) and the Russian GLONASS, have a multi-billion Euro world-wide industry - the EC has predicted an annual global market for GNSS of €300bn by 2020. Europe is currently developing its own GNSS system Galileo that will become operational over the next decade. The main threat to the reliable and safe operation of GNSS is the variable propagation conditions encountered by GNSS signals as they pass through the Earth's upper atmosphere (the ionosphere). The ionosphere delays the signals causing a positioning error of up to tens of metres, but more importantly can cause sudden rapid signal fading and operational outages. These intermittent problems have limited the expansion of the GNSS market in mission-critical high-precision applications such as air, rail and marine transport and even autonomous machinery in areas such as agriculture. In parallel with the current development of Galileo, in Europe there is a need for new generation of engineers who are trained with ionospheric expertise directly connected through to their GNSS knowledge.

The gravity of the problem can be illustrated by the disruption and cost to society caused by the Halloween storm that took place in Oct/Nov 2003, when one of the most intense solar flares ever was recorded: companies delayed high resolution land surveying, postponed airborne and marine surveys, cancelled drilling operations and resorted to backup systems; the US Wide-Area Augmentation System (WAAS), counterpart of the European Geostationary Navigation Overlay System (EGNOS), was seriously impacted, causing commercial aircraft being unable to use WAAS for precision approaches; air traffic centres reported degradation of service, leading to rerouting of polar flights; HF communications underwent a range of problems, including a complete blackout.

SCIENTIFIC SCOPE AND CHALLENGES

Tropospheric gas concentration causes the tropospheric delay, which is composed of hydrostatic and wet delays, and which influence the GPS/GNSS positioning accuracy. These delays can be estimated using troposphere mapping functions based on weather forecast models, interpolated for a given GNSS station and can be applied in Precise Point Positioning (PPP) processing. Conversely, mapping functions can be used in the retrieval of total precipitable water vapor (PWV) that is valuable as an input to weather forecast (Wolfe et al., 2000) and for atmospheric sensing in remote areas, which may be crucial for short term forecasts as well as climate change studies (Vey et al., 2010, Thomas et al., 2011).

Ionospheric irregularities cause rapid fluctuations of transionospheric radio signal amplitude and phase, called scintillation, that can affect performance of radio communication and navigation systems. Severe scintillation events lead to losses of phase lock, which result in cycle slips. GPS scintillation receivers measure amplitude and phase scintillation from L1 GPS signals and total electron content (TEC) from L1 and L2 GPS signals to study the relative role that various ionospheric irregularity generation mechanisms have in producing scintillation. These measurements can be used in development of methods to mitigate the effects of the ionospheric scintillation on receiver tracking performance but can also be an important tool for studying the ionosphere and provide input to ionospheric models. The goal is to develop a scintillation climatology model that can be used in scintillation forecasts. A tracking error predictor/model may improve receiver ability to track GNSS signals and a mitigation model may improve the GNSS positioning accuracy in the presence of scintillation.

Ionospheric scintillation-causing irregularities can also be studied with satellites either *in situ* or using on-board radio instruments including GPS receivers. An example is CASSIOPE Enhanced Polar Outflow Probe (ePOP) to be launched on a high-inclination orbit (Yau et al., 2006). It will collect a variety of ionospheric data sampled at high rate in both hemispheres. In conjunction with ground facilities such as EISCAT, AMISR, SuperDARNand GISTM (GPS Scintillation and TEC Monitor) networks in Europe, Canada (CHAIN) and Antarctica, the ePOP mission will provide a new perspective to study the radio wave propagation in the F-region and topside ionosphere. The 3-dimensional structures of ionospheric irregularities can be imaged using tomographic techniques. In addition, high-resolution *in situ* measurements of ionospheric plasma density spectra can be used in the scintillation modeling (Wernik et al., 2007). It is planned to compare modeled and observed scintillation occurrence in northern and southern high latitudes using the ePOP in situ measurements and GPS scintillation data, respectively.

SCIENCE OBJECTIVES

- Create and maintain distributed networks of specialized GPS/GNSS Ionospheric Scintillation and TEC Monitors particularly at high latitudes.

- Identify and quantify mechanisms that cause scintillation and control interhemispheric differences, asymmetries and commonalities in scintillation occurrence and intensity as a result of the geospace environment conditions.

- Develop ionospheric scintillation climatology, tracking and mitigation models to improve prediction capabilities of space weather.

- Retrieve tropospheric PWV for input to weather forecast models and to develop regional PWV climatology for atmospheric sensing in remote areas.

KEY QUESTIONS

1. How does the structure of Earth's ionosphere change, qualitatively as well as quantitatively, with solar wind conditions and how do these conditions impact TEC variability and scintillation occurrence?

2. How to develop or improve scintillation forecasting techniques for high latitudes?

3. Are scintillation and TEC affected by mechanical and electrodynamic inputs from the lower atmosphere?

4. How accurate are the GPS–based PWV measurements and what is their impact on numerical weather prediction models accuracy?

5. What are the short- and long-term variations of PWV in the Arctic and Antarctic regions and what roles do they play in weather and climate?

RATIONALE

- ***Ionospheric TEC mapping/imaging.*** Aim at realistic 3-D tomographic inversion using the Multi-Instrument Data Analysis System – MIDAS (Mitchell and Spencer, 2003) or the Global Assimilative Ionospheric Model – GAIM (Hajj et al., 2004).
- ***Interhemispheric regional differences, asymmetries and commonalities of scintillation occurrence over the Arctic and Antarctic.*** Aim at understanding the control mechanisms due to interhemispheric conjugacy, interplanetary or seasonal conditions and the resulting ionospheric structure.
- ***Specification and forecasting of scintillation at high latitudes.*** Aim at understanding the major solar wind drivers of scintillation including corrotating interaction regions (CIRs) and coronal mass ejections (CMEs) in order to develop appropriate forecasting techniques.
- ***Novel countermeasure techniques to mitigate the presence of scintillation and PWV, and to improve GNSS applications like PPP.*** Aim at understanding the underlying causes of ionospheric scintillation, applications of appropriate mapping functions and spatial interpolation techniques for input from weather forecast models, in order to develop and use of a scintillation model and tracking error predictor with a mitigation model.
- ***Atmospheric sensing in remote areas.*** Aim at resolving large differences that are found in the seasonal signals, anomalies and variability of PWV between the GPS and reanalysis data in the Southern Hemisphere.
- ***Vertical coupling between the lower and upper atmosphere.*** Aim at understanding the interaction between the ionosphere and neutral upper/middle/lower atmosphere, and momentum/energy transfer upward or downward.

METHODOLOGY AND IMPLEMENTATION

- Create a data portal to facilitate sharing and utilization of the GNSS/GPS and geophysical databases. The data portal will be linked to other useful databases for easy access, and encourage the collaboration, data sharing and help in interpretation of the results.

- Pursue joint studies on relevant scientific topics, development of models and mitigation techniques will be planned and coordinated. Annual meetings/workshops will provide forum for discussions and focus the community efforts towards the GWSWF project goals.

- Form working groups to focus on areas such as data formats and archiving, common software development and data handling, quantifying the causes of scintillation and the role of solar wind interaction with the Earth's magnetosphere-ionosphere system, development of scintillation and tropospheric PWV climatology, scintillation forecasting, and tracking and mitigation models.

INDIVIDUAL PLANS

(national representation?, please fill with a couple of sentences your main involvement in the Expert Group)

Argentina.
Australia
Brazil
Canada

- *Physics Department, University of New Brunswick, Fredericton, NB, Canada*
- *Communications Research Centre Canada, Ottawa, ON, Canada*

The main contribution is the Canadian High-Arctic Ionospheric Network (CHAIN), an array of GPS receivers and ionosondes for studying ionospheric structure at high temporal resolution and spatial scales (http://chain.physics.unb.ca/chain/pages/home). Climatology of scintillation to be developed at high latitudes in the North American sector to complement similar climatology studies in Antarctica and Europe. CHAIN is supported by radars, riometers, optical instruments and magnetometers, which are part of the Canadian GeoSpace Monitoring (CGSM) program conducted by space science community at Canadian universities and government agencies. The Canadian Space Science Data Portal (CSSDP) is being developed: https://cssdp.ca/ssdp/app/login.

China
Finland
Germany

Italy

The Italian Institutions supporting the Action Group GWSWF and expressing the interest in supporting this proposal are listed below:

- *Istituto Nazionale di Geofisica e Vulcanologia, Rome (National representative)*
- *Istituto dei Sistemi Complessi, Sesto Fiorentino, Firenze*
- *IFSI-INAF-CNR, Area di ricerca di Tor Vergata, Rome*
- *Università di Modena e Reggio Emilia*
- *Istituto di Radioastronomia - IRA, Istituto Nazionale di Astrofisica - INAF, Bologna*

The main contributions are the managing of high rate GNSS receivers network in the Arctic and Antarctica for TEC and scintillation studies, the multi-instruments data analysis (www.eswua.ingv.it), the GBSC (Ground Based Scintillation Climatology) and models development.

Poland
Slovenia (still no-SCAR member Country)
South Africa
UK
USA

STRUCTURE OF THE PROPOSED EXPERT GROUP

In the frame of ICESTAR and POLENET some groups have shared their GPS data collected in Antarctica for different purposes (geodesy, upper atmosphere investigation, water vapour retrieval, etc...) to study space weather events “visible” in the HF sounding from the ground. Building on this initial success the Expert Group aims to enhance collaboration networks to work in synergy with other SCAR EGs or SRPs on the assessment of the ionosphere over the poles. The task is very challenging especially because different scientific contexts mean different data format, different data processing and different data interpretation. On the other hand, we consider such heterogeneity as a strong point to stimulate advancement of our understanding of space weather effects in polar regions.

We consider the multi-instrument and multi-disciplinary approach a great opportunity for the Expert Group. If, for instance, we only consider SuperDARN that is effectively mapping the ionospheric convection and decametre irregularities, high rate sampling GNSS (L-band) data supported by other instrumentation like ionosonde network can provide new insights into the state of the polar ionosphere. In fact, a complementary use of these measurements turns out to be promising especially to reveal the general recurrent features of the plasma dynamics under disturbed conditions.

Considering the main objective and the multi-instruments and multi-disciplinary approach, the proposed expert group can be structured into working subgroups as follows:

1. S-T interactions and ionospheric effects in the current solar-cycle (**chair: Paul Prikryl, co-chair: Emilia Correia**)

    - Multi-instruments investigation of the upper atmosphere plasma dynamics and scintillation generation (SuperDARN, GNSS, ionosondes, VLF, etc..)

    - Scintillation climatology, TEC fluctuations, structure scale, C/N statistics, etc...

2. Lower atmosphere delay in GNSS based systems (water vapor reconstruction etc...)(**chair: Monia Negusini, co-chair: Andreja Susnik)**

3. Modelling and models testing (**chair: Cathryn Mitchell (suggested), co-chair Marcin Grzesiak**)

4. Data management strategy (**chair: Vincenzo Romano, co-chair: Pierre Cilliers (suggested))**

5. Coordination with other programs inside and outside SCAR (e.g. URSI, CAWSES II, SuperDARN, EISCAT 3D,…) (chair: M. Candidi**, co-chair: P. Wilkinson (suggested)**)

DELIVERABLES

1. GNSS data format definition for atmospheric studies (Upper atmosphere and lower atmosphere) (**Coordination TBD**)
2. Maps of ionospheric scintillation over Arctic and Antarctic as function of IMF, Solar activity, season, MLT, etc…(**Coordination TBD**).
3. Maps and vertical profiles of water vapour content (**Coordination TBD**)
4. Website development, outreach and dissemination of the results (**Coordination TBD**)

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