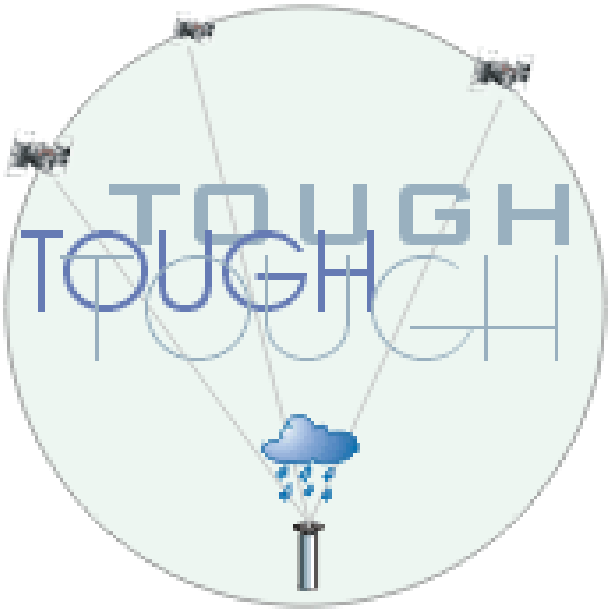
TOUGH



Targeting Optimal Use of GPS Humidity Measurements in Meteorology

EVG1-CT-2002-00080

6'th Periodic Report

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Section 5. Final executive summary

Co-ordinator: Dr. Henrik Vedel

email: tough@dmi.dk, http://tough.dmi.dk

SECTION 5: EXECUTIVE PUBLISHABLE SUMMARY FOR THE TOUGH PROJECT

Contract n°	EVG1-CT-2002-00080	Project Duration:	2003-02-01 to 2006-01-31
Title	Targeting Optimal Use of GPS Humidity Measurements in Meteorology		

Objectives:

The overall goal of TOUGH is to improve European weather forecasting through utilisation of a new type of atmospheric observations derived from ground based GPS data. The rationale is, that while GPS receivers are normally used for positioning (e.g. surveying or navigation), the signals are in fact sensitive to important properties of the atmosphere, such as water vapour. The cycle of water vapour is responsible for much of the energy transfer to the atmosphere, it is the most important green house gas, and obviously a key ingredient in the prediction of precipitation and severe weather. However, the current meteorological observing systems provide only little information about water vapour. It is therefore expected that inclusion of GPS water vapour observations in weather models will improve the skill of the forecasts, with rain being an appreciated example. Pilot studies have shown the feasibility of extracting from GPS data properties useful to meteorologists, such as the so-called zenith total delay (ZTD) and integrated water vapour (IWV), and of getting the data into numerical weather prediction models. In TOUGH those methods are being strongly refined, and new methods are being developed. The methods are being tested on a European scale, to assess whether the GPS data are useful in the meteorological models. Among other things the objectives include:

- Continuous near real time production of GPS ZTDs on European scale, making tools for exchange and storage of GPS ZTDs
- Error studies of GPS ZTDs. Methods for correction of the errors, long term and short term. Important both for weather forecasting and long term climate monitoring.
- Development and refinement of methods for assimilation of GPS ZTD data in weather models.
- Demonstration that the chain: GPS observation, GPS ZTD estimation, assimilation of GPS ZTD in weather models can be done at the speed needed for operational use.
- Long term and case studies to assess whether use of GPS ZTDs improve weather forecasts.
- Pilot study: Development of tools for use of so-called slant delays, which will potentially increase the amount of atmospheric information from each GPS station describing the local atmospheric variability
- Spreading of results enabling other groups and the public to gain from TOUGH results.

Scientific achievements:

- 12 processing centres now determine GPS ZTDs for local networks of GPS stations and send them to common data servers in near real time. Automatic continuous monitoring of the data delivery is performed. Validation is done against data from meteorological models and ordinary meteorological measurements. The number of operational GPS sites used has increased to about 550 at the end of the project.
- Errors of different types have been estimated (including spatial and temporal correlations and long term offsets). Correction methods have been developed, implemented and tested.
- A method for combining GPS ZTD observations with humidity measurements at the 2 metre level have been developed and tested with good results.
- Extensive seasonal and case studies reveal a mainly positive impact of GPS ZTD observations upon weather forecasts.
- Based on the TOUGH system evaluation recommendations have been made regarding transfer to an operational phase. This includes changes leading to a more homogeneous ZTD product on the European scale with smaller errors, as well as improvements regarding handling of the ZTD data at the weather offices.
- Methods for both determinations of GPS slant delays and assimilation of those into weather models have been developed and tested. The first results are promising.
- The results have been disseminated in scientific articles, at conferences, at a TOUGH User Workshop, and via the TOUGH homepage, http://tough.dmi.dk.

Main deliverables:

- Methods for consistent near real time processing of ZTD from ground based GPS data on a European scale.
- Methods for assessment and correction of errors.
- Methods for inclusion of GPS ZTD data in different European weather models.
- Recommendations regarding a future European near real time GPS ZTD processing system.

- Recommendations regarding future use of GPS ZTD in weather forecasting.
- Methods for estimation and use of GPS slant delays in weather forecasting..

Socio-economic relevance and policy implications:

1. Improved weather forecast. Leading to both better everyday planning for businesses and public, and to more secure warnings in case of severe weather. Yielding economic benefits and improved life.
2. Cost sharing among European organisations, the same GPS stations are providing positioning information for geodesists and atmospheric information to meteorologists.
3. EUMETNET, an inter European meteorological organisation, is in 2005 starting a project (E-GVAP) to collect, process, monitor and distribute GPS atmospheric data. This can be seen a gradual transfer from scientific projects on GPS meteorology, such as TOUGH and COST716, into operational NWP and now-casting.
4. Shows potential for utilisation of Galileo satellite system data to improve weather forecasts in connection with use of slant delays.

Conclusions:

TOUGH has been a successful project, showing significant progress on all main objectives.

It has been demonstrated that production and use of GPS ZTD data in near real time is possible on a European scale, and that it is beneficial to weather models. Based on the TOUGH results recommendations have been made regarding setup of a future operational observing system for GPS ZTDs (which is being made under EUMETNET), resulting in a product which is more homogeneous and have smaller errors than today. Thanks to the project the software for assimilation of ZTD data now exist in many weather models. Certain issues require attention prior to making use of GPS ZTD operational at the weather agencies, in particular quality control of ZTD data and handling of humidity during data assimilation.

Results from TOUGH are of importance also for climate monitoring, and should taken into accord when databases of GPS ZTD/IWV are being made for such purposes.

Within TOUGH methods were developed to both estimate slants delays and include them in weather models. This results in many more observations per GPS receiver site. An impact test study gave very promising results. In view of the European Galileo system being launched, which double the amount of observations and thereby improve the sampling of the local atmospheric variability, we recommend allocation of research funds to study slant delay meteorology.

Dissemination of results:

The results of TOUGH have been made available in scientific articles and at the TOUGH homepage, http://tough.dmi.dk. A workshop was made to inform potential users about the results.
The majority of the specialised software and methods developed in the project has already been shared with colleagues in European geodesy and meteorology, through the widespread sharing of knowledge, programming software and observational data within these communities.

Keywords:

Numerical weather prediction (NWP), Global Positioning System (GPS), GPS data processing, data assimilation, water vapour, humidity, zenith total delay (ZTD), integrated water vapour (IWV), slant delay, error modelling, climate monitoring.