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Scenario of GPS Meteorology Project of Japan

Hiromichi Tsuji[1], Isao Naito[2], Hajime Nakamura[3]

[1] GSI, [2] Div. of Earth Rotation, National Astronomical Observatory, [3] MRI

GPS Meteorology is an interdisciplinary challenge to obtain water vapor fields from microwave signals of GPS satellites, and to apply them for Meteorology and related Earth Science. Japan launched a GPS Meteorology project in 1996, inspired by the establishment of the GPS Earth Observation Network (GEONET), that consists of nearly 1,000 permanent GPS stations spread all over Japan. With the joint efforts of more than 21 national agencies and universities, the 5-year project yielded scientific discoveries on water vapor distributions, and marked technical advancements in feeding GPS data to a numerical weather forecast.

From the mid 1990s, GEONET has been monitoring crustal deformation in Japan, serving as a sensor for long-term earthquake predictions. However, time series of station coordinates occasionally contain seasonal trends and outliers of about a few cm, which are prominent in heights in summer. This suggests an improper modeling of a tropospheric delay. It was expected that sophisticated data and models from numerical weather forecasts could reduce noises from water vapor, so as to improve the geodetic accuracy of GPS.

For meteorologists, water vapor is an important signal in predicting local and torrential rainfalls. The radiosonde observation is made at 18 points in Japan and twice a day, which is insufficient in resolution, while a water vapor radiometer is high in time resolution but no use on rainy days. If GEONET could provide reliable information on Precipitable Water Vapor (PWV), an integrated value of water vapor in atmospheric column, it could be effective in prediction of torrential rains.

Therefore, the GPS Meteorology project in Japan pursued the dual aims of 1) generation of PWV from GEONET and its application to numerical weather forecasts, and 2) improvement of geodetic accuracy of GPS using data and models from numerical weather forecasts.

As to the first goal, the project successfully attested a reliability of GEONET-derived PWV, no less accurate than those of radiosonde, and GEONET capability of tracking such atmospheric phenomena of 100-1000km scale as typhoons, weather fronts, thunderstorms at a 3 hour / 25 km resolution. Data assimilation of GEONET-derived PWV in meso-scale numerical weather forecast proved valid for precipitation prediction. Water vapor tomography was applied to generate 3-D fields using slant range delays of the satellites in various directions.

Efforts for the second goal produced technical developments; Detection of error sources correlating with tropospheric delays, incorporation of antenna phase pattern and ocean tide loading models into a GEONET analysis, and a software improvement for atmospheric delay gradient estimation. Gradient estimation with a mapping function with elevation and azimuth dependence showed a better positional accuracy. Further, GPS campaigns with dense arrays were conducted for identifying the effect of super-fine movements such as cumulus convection.

GPS Meteorology using receivers mounted on Low Earth Orbiters (LEO) led to a high-resolution estimation of vertical distribution of atmospheric refraction rate. Using the data from the GPS/MET experiment, a global distribution of temperature changes was estimated and verified. Thus dawned Space-based GPS Meteorology, while initial effort is called a ground-based GPS Meteorology.

For the ground-based GPS Meteorology in Japan, the focus will be on a better precision of PWV, development of slant delay applications, implementation of a real-time analysis, and modification of mapping functions. As to the space-based GPS Meteorology, a real-time analysis of LEO occultation data and global data assimilation are of interest. A technical development is planned for measurement of global temperatures, snows and ices, ground water and sea surface level along with the gravity and altimetry LEO missions, aiming at an efficient monitoring of the global environmental changes.