AAS001-01   Room:202   Time:May 25 16:30-16:52

Atmospheric Remote Sensing for Meteorology in Southern Hemisphere and Antarctica -Recent Australian Initiatives

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Recent developments in both ground-based and space-borne geospatial infrastructure have opened exciting opportunities for geodesists to contribute to "big issues" such as atmosphere, climate changes, global warming, and environmental sustainability. GNSS atmospheric remote sensing using GNSS and low Earth orbit (LEO) satellites such as CHAMP, GRACE and COSMIC is a new technique for profiling the atmosphere. Research has demonstrated that GNSS radio occultation technique is capable of measuring the Earth's atmospheric parameters with a high accuracy, unprecedented high resolution and global coverage. It is expected that this new technology will significantly advance our knowledge of Earth's atmospheric structure and processes.

Australia and Antarctica are characterized with a large continent, sparse population and a long coastline. The lack of variety and density of reliable meteorological observations over Australia and Antarctica poses a major challenge for operational weather prediction, long term climate studies, and optimal usages of satellite data. Since the successful launch of the six COSMIC satellites in April 2006, approximately 2,500 global daily GPS radio occultation events (ROEs) and over 100 daily GPS ROEs in Australia have been obtained which represents six times more observations in comparison with CHAMP. Such a large number of retrievals have brought unprecedented opportunities for in-depth regional studies and operational usage of the GNSS RO retrievals in southern hemisphere. The planned new launches in the next a few years from South America, Europe and Asia are offering exciting opportunities for geodesists to tackle big issues such as climate and environment globally.

Recent significant Australian research initiatives along the GNSS positioning, meteorology/climate and space debris tracking will be outlined. We start with a brief introduction of the SPACE Research Centre established at RMIT University including key research directions and projects, and recent international collaborations, particularly in the areas of GNSS atmospheric sounding, weather and climate. The recent Australian government initiative of its space research program scheme will be then outlined. The multiple million dollars space research project in the areas of in-space tracking and navigation, precise satellite positioning, space weather, atmospheric modelling and climate monitoring awarded to a research consortium led by SPACE will be introduced. Key issues related to the research work and challenges confronting Australian space research and space industry will be discussed and some preliminary outcomes will be shown to facilitate discussion and possible international collaboration in atmospheric remote sensing, GNSS and geodesy.

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New scientific and operational application with real-time GNSS monitoring of atmosphere

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GPS has been widely used as new unique sensor for accurate atmospheric sensing. The method is based on the measurement of the atmospheric delay of the phase of a microwave transmitted from a GPS satellite and received at a GPS antenna. This time delay (converted to excess path delay by multiplication with the speed of light) is determined by comparing the observed propagation delay with the computed vacuum delay based on the know positions of transmitting and receiving antennas. The primary part of the delay is caused by the ionosphere, and its contribution can be corrected (observed) with dual frequency observations due to the nature of dispersion of the ionosphere. We can retrieve the integrated refractivity of the neutral atmosphere after removing the contribution of the ionospheric delay.

Improvements in the GNSS processing strategy, geophysical/instrumental models, and satellite orbit/clock products has led to improved GNSS atmospheric sensing. Availability of real-time data has made true real-time solutions that are available within a few seconds of data collection possible. For GPS Earth Observation NETwork (GEONET) in Japan, the most antennas and receivers were replaced around 2003, and real-time data streaming of 1Hz data has been implemented since then. Many other global GPS networks with real-time data streaming have also come on line. Such real-time GPS networks enable new GPS application of monitoring the atmosphere in true real-time and make previous near-real-time (NRT) applications obsolete.

The primary GNSS product in the neutral atmosphere is the zenith tropospheric delay (ZTD). ZTD can be mapped to represent the averaged precipitable water vapor (PWV) in the surrounding of the GPS antenna. NRT ZTD and PWV have been used for operational numerical weather forecast, and the impact of ZTD data has been reported for many severe storm cases globally. The primary impact of real-time PWV can be seen in short-term forecasts with frequent updates. It has also been shown to provide useful information for nowcasting of precipitation. Real-time slant path delay which contains information on the inhomogeneity of the water vapor distribution in active weather conditions can be used for water vapor tomography. All the products mentioned above are now available also for moving platform such as ships and buoys with kinematic processing. Such products can be helpful to improve precipitation forecast if the observation data are transmitted in real-time from ocean platforms. A new application of GNSS environmental monitoring is the determination of soil moisture. This is done by analyzing S/N ratios which fluctuate due to multipath reflections from the ground near the GNSS station. These S/N fluctuations are affected by soil moisture and we attempt to use GEONET data for soil moisture monitoring. The data are potentially useful for farming, as input to flood models and for research of the water cycle.

Monitoring of the ionosphere is also possible under the assumptions of a thin ionospheric layer and stable differential code biases in the GPS receivers on the order of a few days. The vertical and slant total electron content (TEC) is used for monitoring of space weather and ionospheric disturbances. With real-time capability, it is possible to monitor the current status of ionosphere to issue warning, and detect tsunami and rocket launches. We can also use ionospheric model generated from dual frequency network for processing of relatively low cost L1 receiver network to get denser information on water vapor and slant path delay.

The paper briefly introduces the background of neutral and ionized atmospheric sensing with GPS, and reviews the current status of global and Japanese GNSS research on atmospheric sensing. It then introduces new real-time application of GNSS for atmospheric research, and concludes with a near future perspective of GNSS meteorology under consideration of Japan's QZSS and radio occultation.

Keywords: GNSS, Water Vapor, Numerical Weather Forecast, Nowcast, Ionosphere, Soil moisture

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A proposal of GPS occultation receiver system for the ionsphere and atmosphere

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Status feasibility study of GPS occultation/reflection receiver system for ionosphere-atmosphere research will be reported.

Keywords: GPS occultation, GPS reflection, GPS receiver

AAS001-04 Room:202 Time:May 25 17:29-17:44

Ionospheric tomography using ground-based GPS receiver networks in Japan, America and Europe

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An ionospheric tomography algorithm using the GPS Total Electron Content (TEC) data was developed to reconstruct the plasma density distribution from 80km altitude to 20,000km. Observation of the dual frequency radio wave from the Global Positioning System (GPS) can provide the Total Electron Content (TEC) data between satellites and receivers. The set of data from the array of the ground-based GPS receivers and the constellation of the GPS enables to derive the electron density distribution in the ionosphere and the plasmasphere by tomography algorithm. We developed an algorithm to derive the three dimensional distribution of the plasma density using GPS-TEC. We applied this tomography algorithm to the data in Japan, the North America and Europe. The distribution of the ground-based GPS receivers in Japan is denser than that in the North America, and the size of the observational area is wider in the North America than in Japan. Therefore the tomography in Japan is suitable to study the ionospheric structures whose scale is a few hundreds kilometer, and that in the north America is suitable to study the structures whose scale is a few thousands kilometer. The ionospheric plasma density was reconstructed for the cases of the geomagnetically quiet and disturbed times. The spatial and temporal variations of the reconstructed electron density was compared with the observation of the IS radars and satellites.

Keywords: GPS, Ionosphere, Tomography, Plasma density

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Airborne GPS Radio Occultation

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GPS Radio Occultation (GPS RO) techniques use GPS receivers on board LEO satellites, there is another type of GPS RO techniques called the downward-looking (DL) RO. This technique uses a GPS receiver placed inside the Earth's atmosphere such as on an airplane and a mountain top, and provides atmospheric profiles below the altitude of the receiver by the inversion algorithms for GPS DL. DL RO measurements on the top of Mt. Fuji in Japan were carried out in 2001 and succeeded in deriving temperature profiles and water vapor profiles.

We calculate the data distributions of airborne GPS RO measurements with the flights of Garuda Indonesia Airplane between Jakarta and Surabaya in Indonesia on December 1, 2010. There are 11 flights from Jakarta to Surabaya, and 12 flights from Surabaya to Jakarta. Total number of profiles of the flights from Jakarta to Surabaya is 35, from Surabaya to Jakarta is 53. The length of a tangent point trajectory is different between these opposite direction flights. The frequencies of occultations are also different. This may be explained by the characteristics of the orbit of GPS satellites. Because the inclination angle of GPS satellites is 55 and their speed is greater than that of the Earth's rotation, all GPS satellites moves from west to east with respect to the Earth's surface. Therefore, the relative velocity between an airplane and a GPS satellite is low when the airplane flies from west to east, and is high when the airplane flies from east to west. This effect is more marked at low latitudes than at mid or high latitudes.

The effect of the GPS orbit cannot be seen in a GPS RO mission with a LEO satellite. This may be explained by a difference of speed between an airplane and a satellite. While the speed of a normal airplane is approximately 900km/hours, the speed of a satellite at an altitude of 700 km is 22000 km/hours relative to the Earth's surface. Because the speed of GPS satellites is 3000 km/hours, a GPS RO mission with a LEO satellite is not sensitive to this effect.

Next, we compute the airborne GPS RO data distributions over Japan. Here we select nine major airports, and use JAL flights between each selected airports on February 1, 2011. Total number of these flights is 210 and observation data is 1114. For this case the data density near Japan is roughly 5 events/(100 km x 100 km) in a day. This result suggests that airborne GPS RO measurements with commercial flights will produce a number of atmospheric profiles in particular region. So, such measurements are expected to contribute to improve the accuracy of weather forecast around there remarkably.

Keywords: GPS Radio Occultation, LEO, Airborne, downward-looking

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Mesoscale Data Assimilation of Tropical Cyclones with GPS Atmospheric Information

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A four-dimensional variational (4D-Var) mesoscale data assimilation (DA) system in low latitudes was developed and impacts of GPS derived atmospheric information on tropical cyclone prediction was investigated through two case studies.

Prediction of tropical cyclones (TC) including typhoons is one of the most important issues in meteorology. Although accuracies of the operational numerical weather prediction (NWP) in world forecast centers have been considerably improved in recent years, there are still many difficulties in the TC prediction. Resolution and physical processes of NWP model together with mesoscale DA is a key factor for the issue. However, the most mesoscale regional DA systems operated routinely are designed for mid-latitudes.

In this study, to prepare high-resolution (10 - 20 km horizontal grid spacing) initial fields for the simulation of tropical cyclones, the mesoscale 4D-Var DA system (meso 4D-Var) for the JMA hydrostatic meso-scale model (MSM) is modified in order to optimize to use in low latitudes where TCs generate and develop. In addition, the impact of GPS derived atmospheric information such as refractivity profile or precipitable water vapor (PWV) on TC prediction is also investigated thorough the following two case studies.

1. DA of GPS radio occultation (RO) data for typhoon USAGI in 2007

The assimilation period of the experimental meso 4D-Var is 24-hour and typhoon bogus data is not assimilated. Numerical predictions are attempted using JMA non-hydrostatic model (NHM) with 10km horizontal resolution. When the global analysis is used for the initial field, the typhoon is not formed in the forecast. By contrast, when the global analysis is replaced by the meso 4D-Var analysis in the experiment, the generation of the typhoon is successfully predicted. With GPS RO refractivity assimilated, the simulated typhoon intensity is closer to the best-track data.

2. DA of GPS PWV for TC NARGIS in 2008

NHM predictions using initial fields produced by DA experiments that used only ordinary observational data (without GPS PWV) exhibited a large variation of predicted maximum TC intensity (958 to 983 hPa) according to DA period (12, 24, 36, and 48 h). In these experiments, a longer assimilation period did not necessarily result in better prediction. The DA of GPS PWV yielded a smaller variation of predicted maximum TC intensity (964 to 974 hPa), and a longer assimilation period tended to bring deeper depression of TC central pressure. Overall, TC intensities determined by DA experiments with GPS data were closer to the best track produced by the Regional Specialized Meteorological Centre (RSMC) New Delhi than the DA experiments without GPS data.

In those two experiments, it was confirmed through the close inspection that implementation of GPS data contributed to create a more favorable environment for the generation and development of the TCs.

Keywords: Numerical Prediction, Data Assimilation, GPS Meteorology, Remotesensing, Cyclone Nargis

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Improvement of rainfall forecast by assimilations of ground-based GPS data and radio occultation data

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Impacts of three kinds of GPS-derived water vapor data, i.e., precipitable water vapor (PWV), slant water vapor (SWV) and radio occultation (RO) data, were investigated using the Meso 4D-Var system of Japan Meteorological Agency (JMA) for a heavy rainfall case on 16 July 2004. When PWV or SWV data were assimilated individually, water vapor in the rainfall region was increased and on the northern sides was decreased, and then the shape of the rainfall region became similar to the observed one. However, the reproduced rainfall amount remained smaller than the observed one. Compared with PWV, SWV made the horizontal contrast of water vapor larger. When RO data were assimilated, the low-level water vapor was increased so that the rainfall amount was largely increased. However, the rainfall region became wider than the observed one. When SWV and RO data were assimilated simultaneously, low-level water vapor in the rainfall region and on its southern side was increased, and then both shapes of rainfall region and of rainfall amount became similar to the observed ones.

Keywords: Data assimilation, GPS-derived precipitable water vapor, GPS-derived slant water vapor, Radio ccultation data, Heavy rainfall