3-D Atmospheric Moisture Retrieval using GNSS

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Water vapour, one of the dominant greenhouse gases, is a highly variable constituent of the Earth's atmosphere with a high latent heat. These two factors give it a key role in the development of atmospheric dynamics. Knowledge of the behaviour and distribution of water vapour in the atmosphere is crucial for understanding and predicting weather and climate. Unfortunately, atmospheric water vapour cannot be accurately determined from surface relative humidity measurements and information at higher altitudes is obtained via atmospheric sounding (i.e. radiosondes) and microwave profilers. The cost of these instruments limits their use to sparsely deployed networks and, in the case of soundings, routine launches are usually performed only twice per day. Over the past decade, however, Global Navigation Satellite Systems (GNSS) have become optimistically regarded as powerful and novel tools to measure water vapour at a fraction of the cost of traditional methods.

GNSS signals are affected by water vapour in the Earth's atmosphere. Researchers have demonstrated that in the process of mitigating the effect of the signal range delay, a measure of tropospheric water vapour can be obtained with accuracies comparable to that of a microwave radiometer. Moreover, tomographic techniques commonly used in seismic research and medical imaging can be employed in conjunction with GNSS measurements to determine three-dimensional atmospheric refractivity distributions over GNSS reference networks. The integration of GPS-derived water vapour information to numerical weather prediction models has shown promise for improved weather forecasting and climate monitoring.

Tomographic techniques used in wet refractivity modeling discretize the overlying atmosphere in some fashion. For example, one method commonly employed uses three-dimensional volume boxes, voxels, and the wet refractivity value within each voxel is estimated. Horizontal and vertical smoothing constraints may be applied to improve the solution for under-determined voxels. Another method uses a functional approach to describe the horizontal distribution of wet refractivity within discrete vertical layers of the troposphere. The coefficients describing wet refractivity distribution for each layer are related via covariance information. Both methods can be combined to recover wet refractivity fields with varying degrees of success, depending on network scale and geometry.

Most GNSS-based tomographic techniques employ single path slant wet delay (*SWD*) observations as model input. In order to recover *SWD* observables with sufficient accuracy, a number of error sources must be removed including orbital uncertainty, satellite and receiver clock biases, and ionospheric propagation delays. Double difference, ionosphere-free GPS observations with fixed L1 and L2 ambiguities are necessary as well as precise orbit products and station coordinates. After error sources apart from the neutral atmospheric range delay are mitigated, single path delays must be recovered from the double-differenced observations. One technique to recover single-path *SWD* information uses a 'zero-mean' assumption while another employs a batch estimate of the average total atmospheric delay (and average gradients) overlying a reference station. In both cases, limiting assumptions are made about spatial variations of properties in the neutral atmosphere. This paper investigates the feasibility of an alternate approach - using double difference residuals as tomography model input directly without first recovering single-path *SWD* information.

Testing is conducted using a regional GPS network installed in Southern Alberta by the University of Calgary. This network consists of fourteen GPS reference stations, ten of which are co-located with MET3A meteorological sensors. A water vapour microwave radiometer (WVR) and a profiler are also located at the University of Calgary. Variable weather conditions occur in the foothills of the Rockies near Calgary, and the Southern Alberta network allows great opportunities to assess detection and modeling of severe weather events using GPS.

In a collaborative effort with the Meteorological Service of Canada, atmospheric soundings were made from three locations within the network. Strong horizontal gradients associated with hail and thunderstorm development were present over the region. Initial findings from the campaign indicate good agreement between tomographic model results and truth data derived from a WVR. Testing was conducted under both normal and storm conditions to provide recommendations for the best overall combined model for 3-D atmospheric moisture retrieval using a GNSS ground-based network.