Real-time ray-tracing through numerical weather models for space geodesy

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Introduction:

The Japanese Meteorological Agency (JMA) provides a variety of weather models ranging from global domains to fine-mesh models which cover an area of only a few tens of kilometers. The meso-scale 4D-Var model (i.e. Meso-scale Analysis Data (MANAL)) from the Japanese Meteorological Agency (JMA) with its horizontal resolution of about 10km was found to have the best trade-off between grid-spacing and area size. This model covers large parts of Eastern Asia, including Japan and its Southern islands, Korea, Taiwan and Eastern China (Figure 1 shows the model boundaries of the JMA meso-scale model). Moreover the 3 hour time-resolution of the data-sets makes the appliance of this model for positioning applications feasible. A couple of programs, called Kashima Ray-tracing Tools (KARAT) re-grid and interpolate the numerical weather models and prepare binary files for follow-on processing. Additionally, KARAT handles orbit files and computes the observing geometry for any given RINEX file, under the condition that the receiver is located within the boundaries of the meso-scale weather model. In the final step the ray-tracing itself is carried out for each observation and the calculated troposphere total slant delays are subtracted from code and phase-measurements before modified RINEX files are output.

Application of ray-traced delays for precise point positioning (PPP):

RINEX observations between November 5th, 2006 and February 28th, 2007 from 13 GPS receivers distributed over East Asia (figure 1) were obtained the International GNSS Service (IGS).

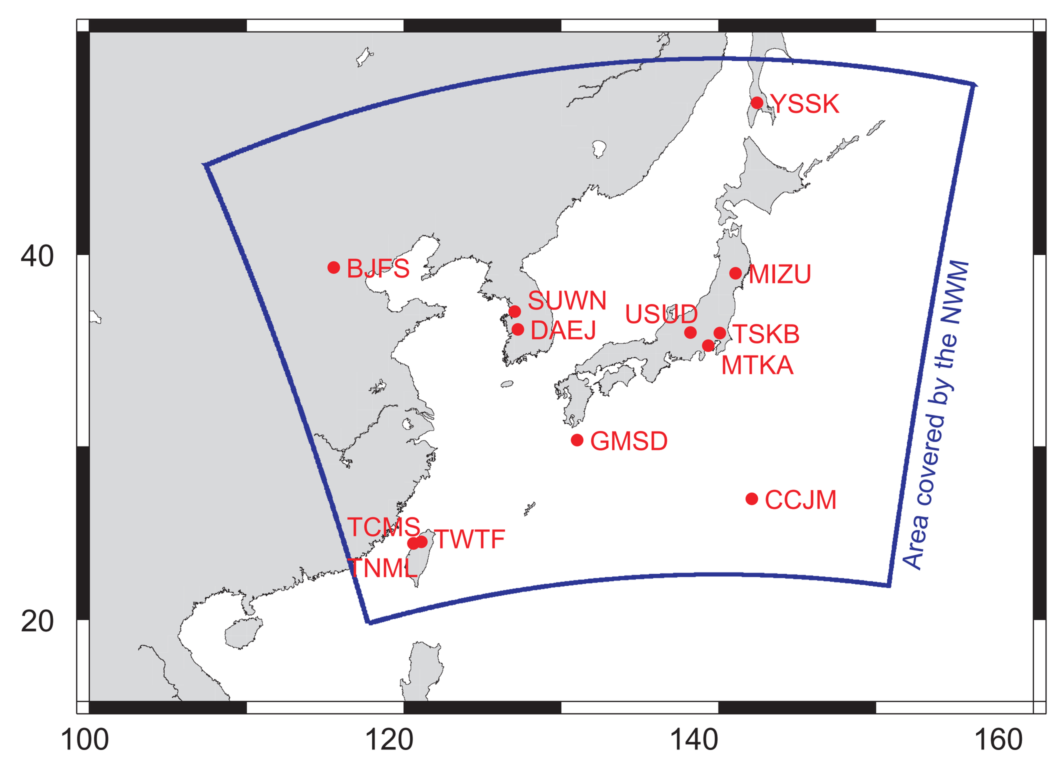

Figure 1: GNSS receivers of the IGS network which are located within the boundaries of the JMA meso-scale weather model and are included in the daily IGS SINEX solution, considered for this study.

Two analysis runs were carried out with GPSTOOLS using the original (hereafter called "standard solution") and the ray-traced data-set ("KARAT solution"). A cut-off elevation angle of 10 degrees was chosen for both runs in order to ensure that troposphere effects can be separated well from clock and height parameters. For the standard solution the a-priori hydrostatic zenith delays were computed from the Saastamoinen model based on standard values for pressure, temperature and relative humidity. The global mapping function (GMF) and linear gradient estimation have been chosen for the troposphere modeling. The Kalman-filter estimation 120 interval was set to 300 seconds, without overlapping data from consecutive days. The second processing, using the ray-traced RINEX files, used identical parametrization except that the a-priori troposphere delays were set to zero and that a simple mapping function (1/cos(z)) was used to model NWM imperfectness. Due to the coarse time resolution (3 hours) of the NWM and the time-interpolation between two consecutive models it could happen that ray-traced delays increased / decreased whereas the true troposphere delays showed opposite behavior. Thus it was necessary to increase the process noise of the residual ZTD by a factor of two (i.e. setting the value to 12 mm/h) to account for slightly larger time-variations of the residual troposphere estimates. In a final stage, the obtained station coordinates from both runs could be compared with the site coordinates of the IGS final solution.

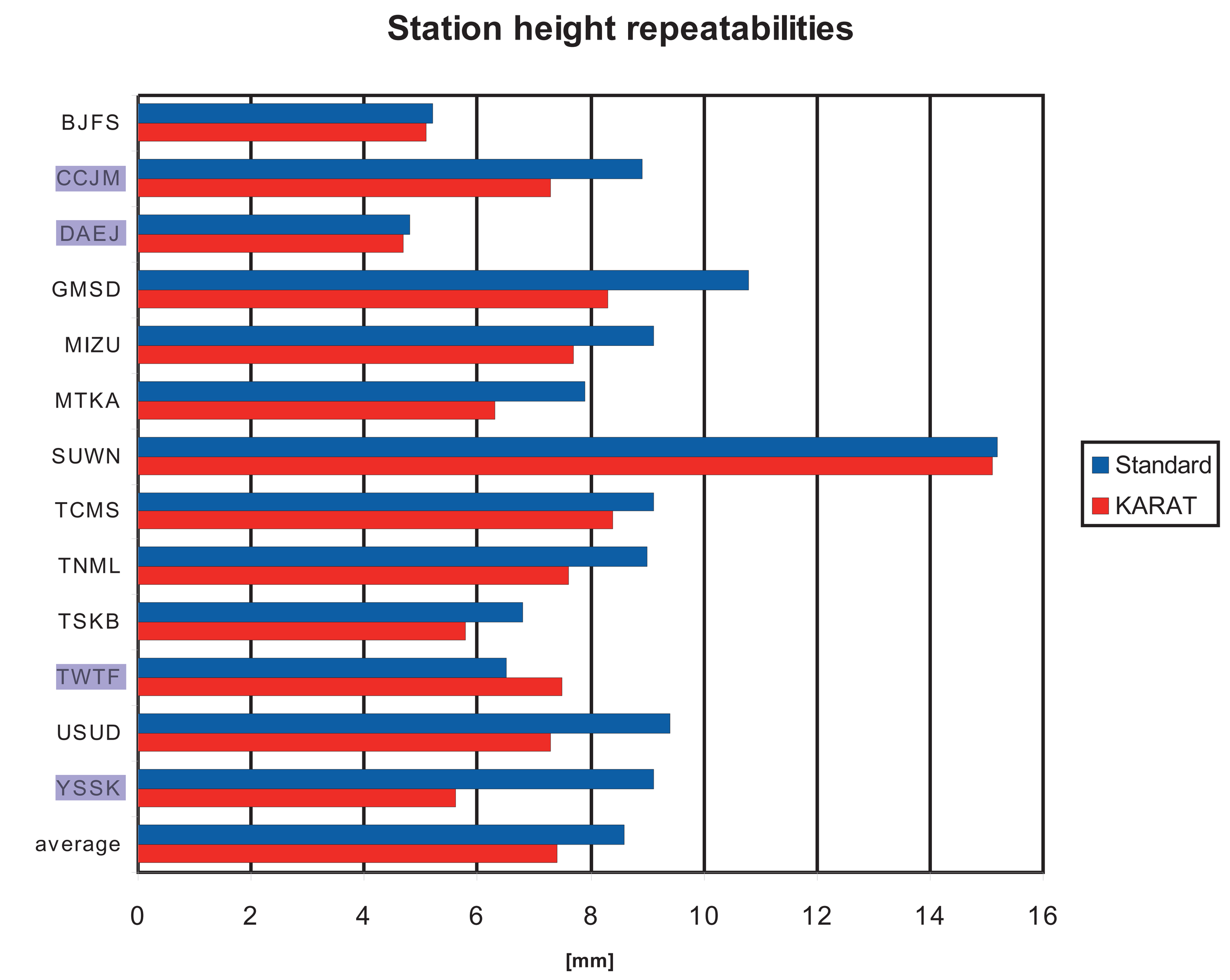

Figure 2: Station heigh repeatabilites w.r.t IGS final solution (stations marked blue rely on PCV models, converted from relative measurements)

It can be seen that station height repeatabilities are improved for all sites, except one (TWTF), when the ray-traced data-set is used instead of the standard RINEX files. On average, KARAT data reduces the height repeatability by about 14%, whereas the horizontal measures are not affected. Since the usage of ray-traced data implicitly defines a new reference frame station coordinates are shifted slightly when KARAT data is used. The RMS of the residuals increases by about 10% when the ray-traced data-set is used. This can be explained by the fact that linear gradient estimation can absorb other asymmetric error sources like un-modeled phase center variations or multi-path effects. The reason why station TWTF does not benefit from the ray-traced data-set is that the antenna used at this site does not have a calibrated absolute phase-center variation model. Since numerical weather models are not accurate enough nor do they allow to consider short-period weather phenomena it is still necessary to account for such imperfectness by estimating a residual troposphere delay. Figure 3 depicts the reconstructed troposphere zenith delays and compares them to the one obtained from an IGS analysis center. Moreover the clock differences of the standard and the KARAT solution w.r.t. the IGS combined values are plotted.

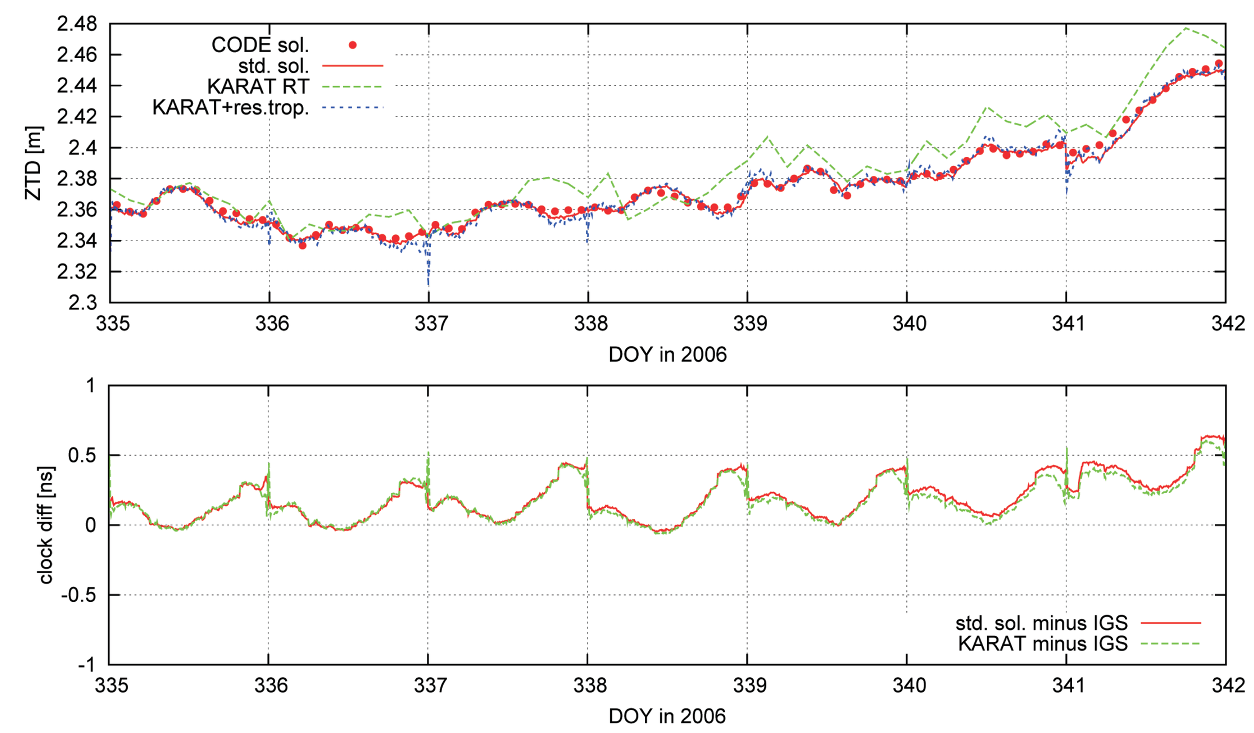

Figure 3: Nuisance parameters for station TSKB from December 1st, 2006 0UT until December 8th,2006 0UT. Upper plot: Zenith total delays (ZTDs) from the standard solution (continuous line), from ray-tracing (dashed line) and ray-tracing + estimated residuals (dotted line). Additionally the solution from the Center for Orbit Determination in Europe (CODE) has been added for reference (dots). Lower plot: Differences of the receiver clock estimates with respectto the IGS combined solution.

Application to VLBI and other space geodetic techniques:

Observations from VLBI experiments within the boundaries of the JMA mesoscale model (see Figure 1) can be corrected for troposphere delays in a similar way as it has been done for GNSS. Estimation of residual delays has to be carried out within the adjustment of the unknowns, whereas a-priori troposphere delay models have to be set to zero. In order to provide corrections for satellite laser ranging (SLR) it is necessary to modify KARAT in order to compute refractivity fields for optical wavelengths.

Kashima Ray-tracing Service (KARATS):

In future our ray-tracing tools (KARAT) will be embedded in an automatic processing chain, called Kashima Ray-Tracing Service (KARATS), which can be started via a web-interface. Figure 4 shows how KARATS is expected to work. Once a user has taken his observations, he can send the data in a common format via Internet to KARATS. Thereafter the web-server will handle the data, compute the geometry and as as soon as a client becomes available, start the ray-tracing computations. Thereafter the ray-traced delays are subtracted from the user's data and a "reduced" observation file is sent to the analyst. KARATS will be free of charge and a turn-around time of less than one minute/file is anticipated. Real-time operation will become available once access to JMA forecast data is granted.

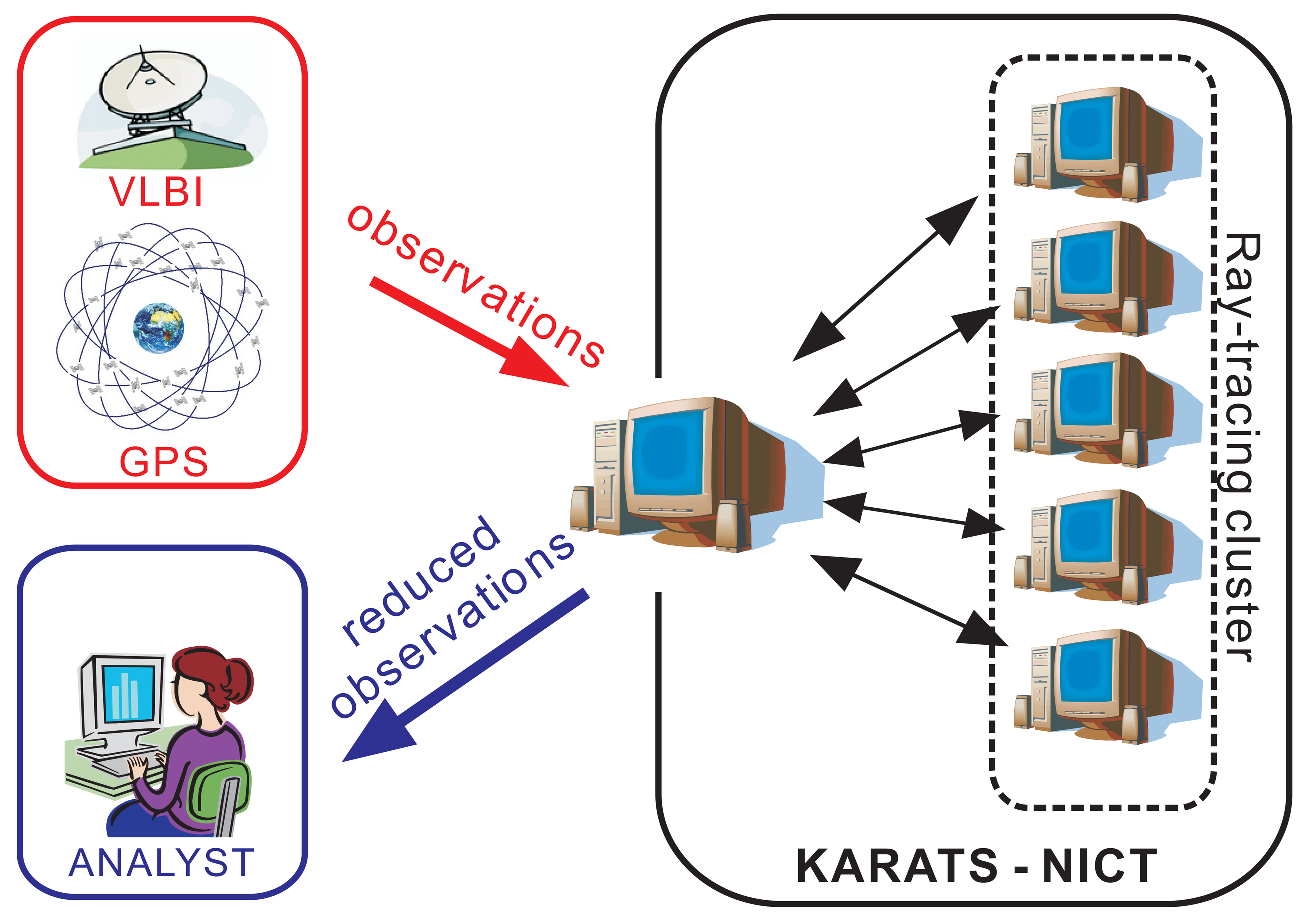

Figure 4: Flow chart of the KARATS processing chain

Further reading:

Hobiger T., Ichikawa R., Takasu T., Koyama Y., Kondo T., Ray-traced troposphere slant delays for precise point positioning, submitted to Earth,Planets and Space, 2008.

Hobiger T., Ichikawa R., Koyama Y., Kondo T., Fast ray-tracing for real-time positioning applications using numerical weather models, to be submitted to Earth And Planetary Science Letters, 2008.

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