A Single-Channel Validation Technique for All Available GNSS Observation Types

A. El-Mowafy[1], P.J.G Teunissen[1,2] and N. Raziq[1]

[1]GNSS Research Centre, Curtin University of Technology, Australia
[2]Delft University of Technology, The Netherlands
Email: A.El-Mowafy@curtin.edu.au

ABSTRACT In this contribution, a flexible technique for quality control and validation of multi-GNSS observations is presented. In this approach, un-differenced data of each satellite are independently processed at each epoch, where processing is performed in parallel for all observed satellites and sequentially applied. A geometry-free observation equation model is used and validation is performed using the local Detection-Identification-Adaptation (DIA) method. The presented approach is applicable to data of any GNSS with any arbitrary number of frequencies, and for real-time or post-mission processing. Software utilising this approach is used during the IGS M-GEX experiment to validate GNSS observations collected at Curtin's continuously operating multi-GNSS observing station in Western Australia. Validation is performed for all satellites in view of GPS, Galileo, GLONASS and COMPASS, and for all observation types (L1, L2, L5, E5a, E5b, E5a+b, E6, B1, B2 and B3). Examples on output results, data analysis and diagnostics for satellite observations from different systems are presented. Performance of the method is demonstrated.

Single-Satellite Single-Receiver QC of Multi-freq GNSS Obs.

Data validation is a fundamental pre-processing step for detection of the most severe irregularities in the GNSS observations. The observation equations read[1]:

$$\phi_j(t) = \rho(t) + c\big(\delta t_r(t) - \delta t^s(t)\big) + T(t) - \mu_j I(t) + b_{\phi_j}(t) + \varepsilon_{\phi_j}(t)$$
$$p_j(t) = \rho(t) + c\big(\delta t_r(t) - \delta t^s(t)\big) + T(t) + \mu_j I(t) + b_{p_j}(t) + \varepsilon_{p_j}(t)$$

where $\phi_j(t)$ and $p_j(t)$ denote the observed carrier phase and pseudo ranges at time (t) in (m), $e_{\phi j}(t)$ and $e_{pj}(t)$ are their noise terms. $\rho(t)$ denotes the receiver-satellite range, c is the speed of light, $\delta t_r(t)$ and $\delta t^s(t)$ are the receiver and satellite clock errors, and *$T(t)$ is the tropospheric delay. The parameter I(t) denotes the ionospheric* delay for code observations and advance in phase observations expressed in (m) with respect to the first frequency such that for frequency f_j the ionospheric coefficient $\mu_j = f^2_1 / f^2_j$. The parameters $b_{\phi j}$ and b_{pj} are the phase bias and the instrumental code delay, respectively. The phase bias is the sum of the initial phase, the phase ambiguity and the instrumental phase delay. A geometry free model is used.

Re-parameterise the unknowns [2, 3]:

$$\rho^*(t) = \rho(t) + c\big(\delta t_r(t) - \delta t^s(t)\big) + T(t), \qquad \rho^{**}(t) = \rho^*(t) - \rho^*(t_o),$$
$$b^*_{\phi_j}(t_o) = b_{\phi_j}(t_o) + [\rho^*(t_o) - \mu_j I(t_o)], \quad b^*_{p_j}(t_o) = b_{p_j}(t_o) + [\rho^*(t_o) + \mu_j I(t_o)]$$

such that the observation equations become

$$\phi_j(t) = \rho^{**}(t) - \mu_j\, \delta I(t) + \delta b_{\phi_j}(t) + b^*_{\phi_j}(t_o) + \varepsilon_{\phi_j}(t)$$
$$b_j(t) = \rho^{**}(t) + \mu_j\, \delta I(t) + \delta b_{b_j}(t) + b^*_{b_j}(t_o) + \varepsilon_{b_j}(t)$$

with $\delta I(t)$, $\delta b_{\phi_j}(t)$, $\delta b_{b_j}(t)$ are the ionosphere and bias changes from the initial epoch (t_o).

Detection

- In the observation model: $y_t = A_t\, x_t + e_t \quad [D(y_t) = Q_{y_t}]$
- Determine the error vector: $\hat{\nabla}_t = (C_t^T\, Q_{y_t}^{-1}\, Q_{\hat{e}_t}\, Q_{y_t}^{-1} C_t)^{-1}\, C_t^T\, Q_{y_t}^{-1}\, \hat{e}_t$

  $\hat{e}_t$ and $Q_{\hat{e}_t}$ are the residual and their covariance matrix

  and its covariance matrix $Q_{\hat{\nabla}_t} = (C_t^T\, Q_{y_t}^{-1}\, Q_{\hat{e}_t}\, Q_{y_t}^{-1} C_t)^{-1}$

  C_t is a matrix with zero column vectors except 1 at elements of tested observations
- Determine T_{LOM}: $T_{LOM} = \dfrac{\hat{\nabla}_t^T\, Q_{\hat{\nabla}_t}^{-1}\, \hat{\nabla}_t}{df}$
- Errors are suspected when [3] $T_{LOM} \geq F_\alpha(df, \infty, 0)$

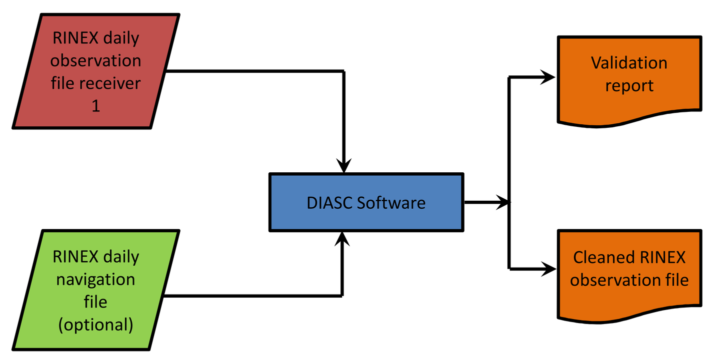
Identification

- when testing individual observations, determine $w_t = \dfrac{\hat{\nabla}_t}{\sigma_{\hat{\nabla}_t}}$
- Suspect identification of errors if [4] $|w_t| \geq N_{\frac{\alpha}{2}}(0,1)$

Software

(DIASC - Curtin University)

Validation of un-differenced data of each satellite is independently performed in parallel for all observed satellites and sequentially applied between epochs.

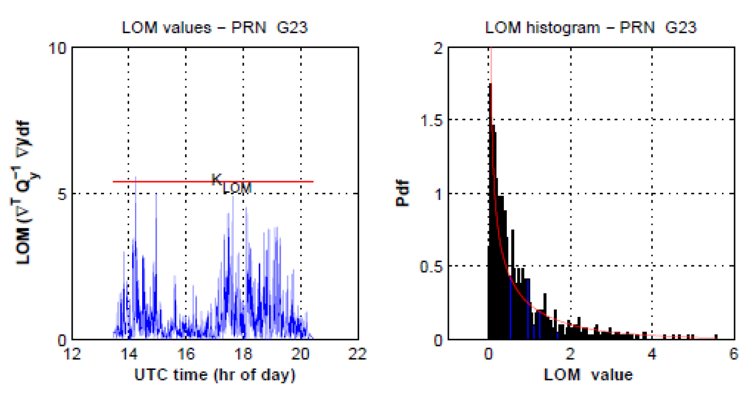


Testing: The single-channel single-receiver method is tested using data spanning several days. Observations from GPS, GLONASS, Galileo and COMPASS were collected in a static mode at a continuously operating reference station at Curtin University, Perth, Western Australia, with 30 seconds sampling interval. A geodetic-grade multi-frequency multi-GNSS antenna (TRM59800.00) and receivers (Septentrio POLARX4 and Trimble NetR9) were used. Tracked signals in the test included L1, L2 and L5 code and phase observations from GPS, L1 and L2 from GLONASS, E1, E5a, E5b and E5a+b, E6 for Galileo, and B1(E2), B2(E5b) and B3(E6) for COMPASS. Over each day, 32 GPS satellites, 24 GLONASS satellites, 4 Galileo satellites, and 10 COMPASS satellites were tested. The shown examples are those of data collected on 16-March-2012.

Results: *detection results (example)*

Table 1: Number of epochs with detected errors

PRN	epochs	detected	percentage
G18	909	0	0.00 %
G29	939	0	0.00 %
G12	970	0	0.00 %
G5	1122	1	0.09 %
G16	992	0	0.00 %
G31	1101	0	0.00 %
R11	1164	0	0.00 %
R3	901	4	0.44 %
R16	1006	0	0.00 %
E12	993	7	0.70 %
E52	752	0	0.00 %
G23	941	0	0.00 %
G17	1105	0	0.00 %
G13	964	0	0.00 %
R17	1000	2	0.20 %



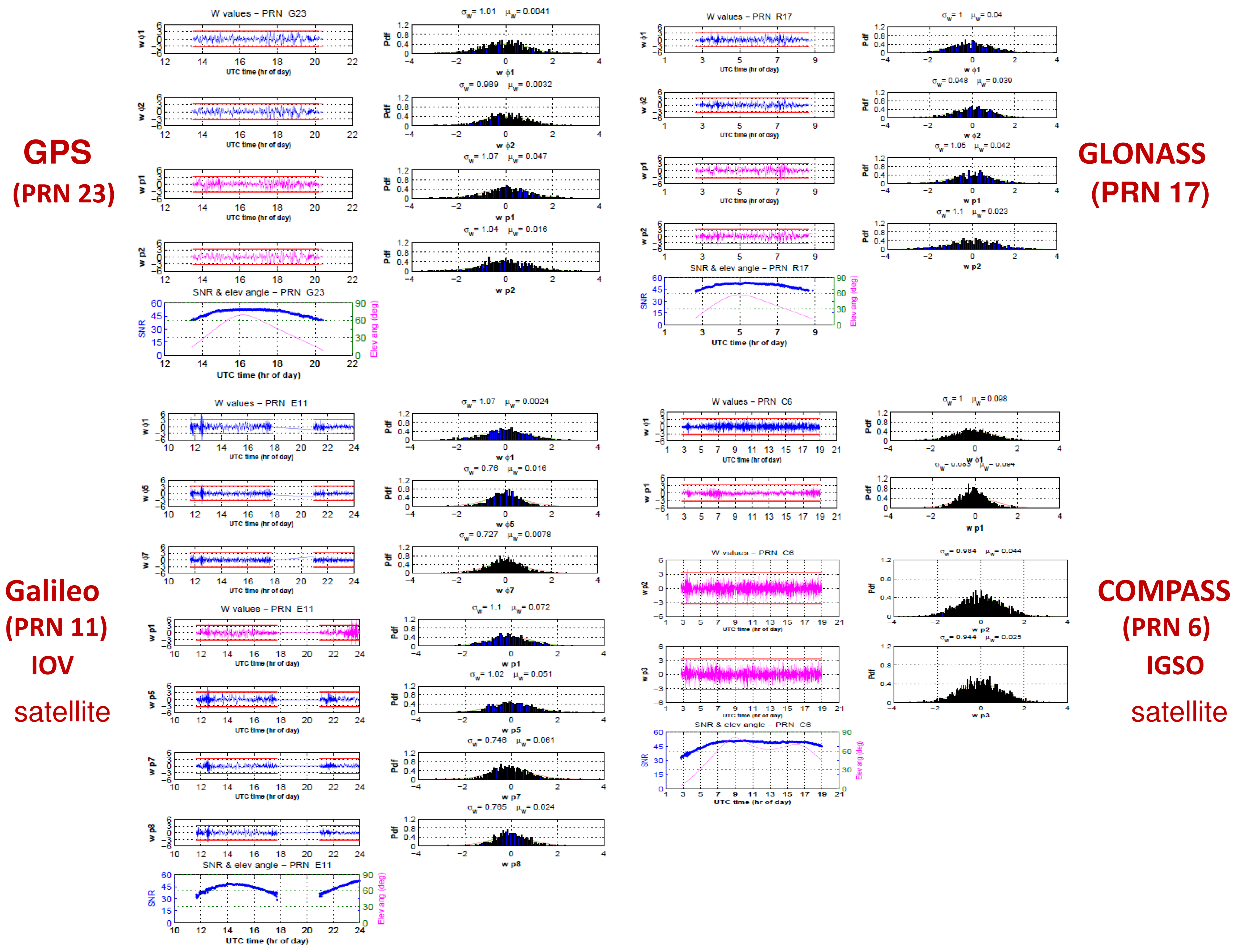
Example of T_{LOM} and its critical value K_{LOM}= *Fα(df, ∞, 0)*. T_{LOM} has a Fisher distribution

Diagnostic Tools:

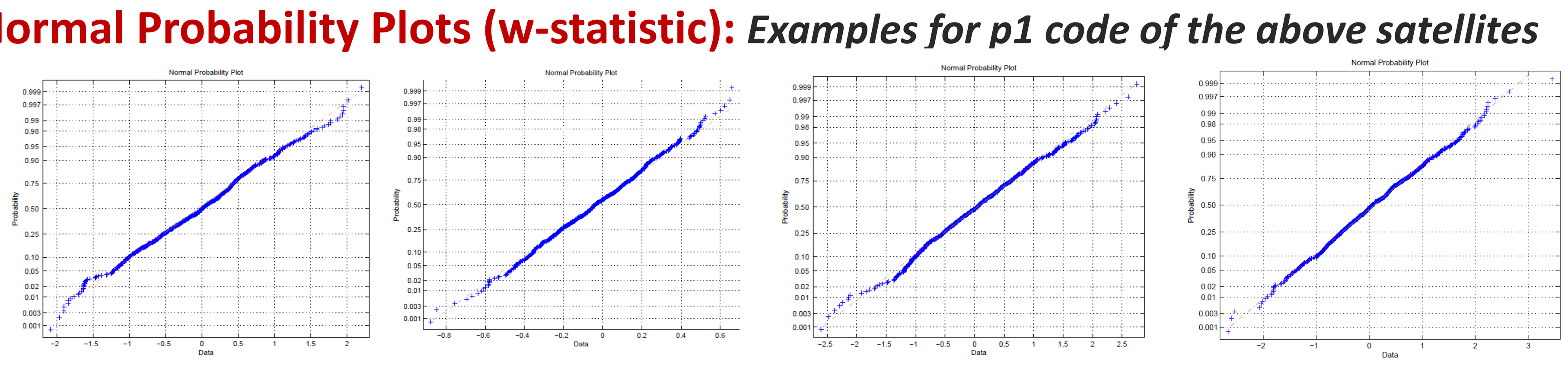
The method offers several diagnostic tools for the GNSS signals and the validation model.

W-test statistic of multi-system multi-frequency GNSS:

The estimated w-test statistic of the observed signals should change in a random manner and come from a standard normal distribution N(0, 1). Examples from different GNSS (16/3/2012):



Normal Probability Plots (w-statistic): *Examples for p1 code of the above satellites*



GPS | Galileo | GLONASS | COMPASS

Performance of the Method

3127 artificial errors were randomly inserted in the data of 16/3/2012 at specific epochs and observations for all observed 32 GPS satellites, 24 GLONASS satellites, and 4 Galileo satellites throughout the 24 hours. The artificial errors range between 0.5 cycle to 10 cycles for phase observations, and 0.6 m to 5 m for code observations. Results are shown in the table:

GPS			GLONASS			Galileo		
#err.	#det.	%	#err.	#det.	%	#err.	#det.	%
1754	1574	89.7	1428	1058	74.1	295	268	91.0

Conclusion

Real-time quality control of GNSS measurements is presented using a single-receiver single-channel local DIA approach. The method is applicable to any GNSS with any arbitrary number of frequencies. The method parameters provide diagnostics for the observed GNSS satellite observations and the model used. Results show that method can detect between 74% to 91% of outliers in GNSS data from different systems depending on the quality of observations and their number, which affects strength of the model.

References

[1] Teunissen, P.J.G., and Kleusberg A. (1998). *GPS for Geodesy*, 2nd ed., Springer, NY.
[2] El.Mowafy A., P. Teunissen, D. Odijk (2010). Single-Receiver Single-Channel Real-Time Validation of GPS, GLONASS, Galileo and COMPASS Data. Proc. International Symposium on GPS/GNSS, 26-28 Oct., 2010, Taiwan.
[3] Teunissen P.J.G. and P.F. de Bakker (2012). Next Generation GNSS Single Receiver Cycle Slip Reliability, *proc. VII Hotine-Marussi Symposium on Mathematical Geodesy*, IAGSymposia 137, 159-164.
[4] Baarda, W. A (1968). *Testing procedure for use in geodetic networks.* Netherlands Geodetic Commission, Publications in Geodesy, New Series, 2(5).