Response to referees' comments.

We would like to thank both referees for the comments and respond as follows.

D. G. W. Johnson (Referee)

We believe that most of Dr Johnson's comments can be answered through the work of Safar et al (2010) who considers in detail the performance of the receiver used in this study.

Safar, J., Lebekwe, C.K., and Williams, P.: Accuracy performance of eLoran for maritime applications, Annual of Navigation, 16, 109-122, 2010.

The receiver used is a Reelektronika LORADD Differential eLoran Reference station[1] *(operated by the General Lighthouse Authorities of UK and Ireland at Harwich).*

[1] http://www.reelektronika.nl/products-a-services/differential-eloran-reference-station.html

For this reference station, Safar et al (2010) suggests that the time-of-arrival (TOA) variance σ^2 *(as expressed as a pseudo-range) is given in* m^2 *(by their Eq. 2) as:*

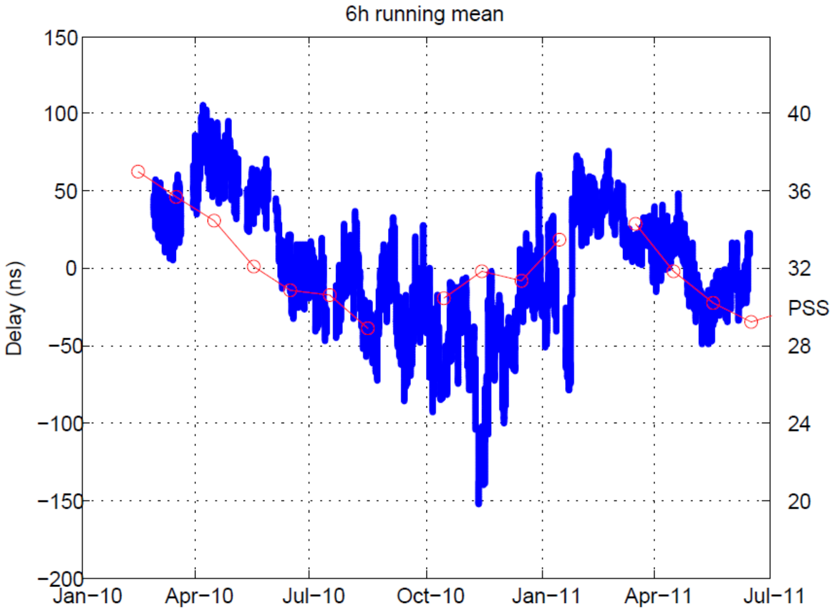
$$\sigma^2 = \frac{337.5^2}{n \times SNR} + \frac{36}{n} + 12$$

where n is the number of Loran pulses integrated together and SNR is the <u>*linear*</u> *signal-to-atmospheric noise ratio at the receiver. The first term on the right-hand-side comes from Lo et al (2009) and was found by Safar et al (2010) to hold 'at least in the range of SNR from –10 dB to +40 dB'. The second term is the contribution of the transmitter (time-of-emission variation) to the TOA variance. The constant term,* $12m^2$*, covers other sources of error including receiver noise and interference from other Loran transmissions. Converted to time, the latter corresponds to a (minimum) standard deviation in time-of-arrival of ~11.5ns* $\{as\ (\sqrt{12})/(3 \times 10^8)\}$.

Lo, S., Leathem, M., Offermans, G., Gunther, G. T., Peterson, B., Johnson, G., and Enge, P.: Primary, Secondary, Additional Secondary Factors for RTCM Minimum Performance Specifications (MPS), 693–715, 38th Annual Convention and Technical Symposium of the International Loran Association October 2009 Portland, Maine, USA, 2009.

Some specific technical questions that I have are: Pg 2973 – I am not sure exactly what you are doing when you say you apply a 24h filter – please elaborate on this.

The original data we use were recorded by the receiver with 30s integration. However, the resolution of the atmospheric and SST data used was 24h. So the 24h running mean, chosen to match this resolution, is somewhat arbitrary and it makes little difference to overall shape of the residual delay if say a 6h running mean is used (see below). This chimes with the results of Safar et al (2010) above who find that initially TOA variance falls rapidly with integration or averaging time, but that there is a contribution to the time-of-arrival (TOA) variance for this receiver that cannot be integrated or averaged out.



Pg 2973– most Loran receivers correct for PF prior to outputting the TOA measurement using a standard and constant PF correction – this would need to be removed prior to using the newly calculated PF based on actual atmospheric conditions – was this done (is not clear)?

Yes, the receiver assumes a constant PF with distance from the transmitter. (Found by assuming a constant atmospheric refractive index η=1.000338 (e.g. Lo et al, 2009; Johler, 1957). This was accounted for in the analysis.

Johler, J. R.: Propagation of the Radiofrequency Ground Wave Transient over a Finitely Conducting Plane Earth, Geofisica Pura e Applicata, 37, 116, 1957.

Similar comment regarding the secondary factor – a typical Loran receiver will also correct for the SF before outputting the TOA measurement using the standard SF correction – this would also need to be removed, again it is not clear if this was done or not.

Yes, the receiver also assumes that the SF is constant with distance from the transmitter (based on a constant conductivity $\sigma=5Sm^{-1}$). This and the above PF were accounted for using the method of Paul Brunavs, as described in Lo et al, 2009).

Another factor that needs to be considered is the Loran time of emission (TOE) – although the Loran signal is synchronized to UTC there is some variable offset from the nominal TOE – these offsets are usually recorded at the transmitter. These variances would need to be removed from the recorded TOA data as well.

The nominal TOEs are handled within the receiver processing. The results of Safar et al (2010) suggest that the contribution of the variation in TOE to the TOA variance in m^2 is no more than (36/n) where n is the number of Loran pulses integrated together (there are 15 pulse sets per second). This is less than 2ns at 30s integration (resolution) and would seem to become negligible for the much longer integrations used in this paper.

And finally, it is not clear how accurately the receiver can track TOAs - there is no information on the receiver performance or stability (all receivers have some amount of error).

See initial comments above. For this reference station, Safar et al. (2010) suggests that the time-of-arrival (TOA) variance σ^2(expressed as a pseudo-range) in m^2 is given by:

$$\sigma^2 = 12 + \frac{337.5^2}{n \times SNR} + \frac{36}{n}$$

where n is the number of Loran pulses integrated together and SNR is the linear signal-to-atmospheric noise ratio at the receiver.

Some Grammatical corrections: Pg 2972 Line 16: delete comma and insert “and the” before NASA Pg 2973 Line 7: spell out acronym GPS the first time used Pg 2974 – eta is not defined – please define

These have now been done