# MONITORING CHANGES IN VLF RADIO SIGNAL PROPAGATION PARAMETERS OF TERRESTRIAL ORIGIN

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## ABSTRACT

We monitor changes in Very Low Frequency (VLF 3-30 kHz) radio wave propagation parameters of NWC/19.8 kHz signal, transmitted from H. E. Holt in Australia (21.8° S, 114.16° E) towards Belgrade receiver site (44.85° N, 20.38° E) in Serbia. The VLF data used were from Absolute Phase and Amplitude Logger (AbsPAL) receiving system of Belgrade's Institute of Physics database. Time span encompasses December 2005 to June 2007. We investigate possible relationship between NWC signal amplitude and phase delay characteristics and seismic activity reported by Helmholtz-Zentrum Potsdam - Deutsches GeoForschungs Zentrum GFZ. Main results are presented in this paper.
**Keywords:** Seismo-ionospheric effect, Ionosphere–lithosphere interactions, Earthquake, VLF propagation

## 1. INTRODUCTION

Changes in Very Low Frequency (VLF, 3-30kHz) radio signal propagation parameters, primarily in terms of amplitude and phase delay (A&Ph) perturbations, are nowadays widely used as remote sensing tool for exploration of wide range of extraterrestrial and terrestrial causative agents' influences onto Earth's lower ionosphere (e.g. [1] and references therein). D region electron density increasing mechanism related to increased tectonic activity induced by earthquake's preparation period and occurrenceis often referred asseismo-iospheric effect.

Terminator shifting during earthquake activity technique (e.g. [2-3]), was applied on monitored NWC/19.8 kHz signal's propagation parameters in period 2005-2007. Propagating along Great Circle Path (GCP) with 12 mM long trace, from transmitter in Australia (H. E. Holt, 21.8° S, 114.16° E) towards the Absolute Phase and Amplitude Logger (AbsPAL) receiving system stationed in Serbia (Belgrade, 44.85° N, 20.38° E), this both over-water/over-land signal passes over many seismically active regions, where seismo-iospheric effect is possible (Indian Ocean including western outskirts of Java and Sumatra Islands, southern Indian subcontinent, Iran, Turkey, Bulgaria, Romania). NWC/19.8 kHz signal propagation path ($path_{NWC}$) within Earth-Ionosphere wave guide is given in red in Figure 1.


**Fig.1:** Propagation path NWC along GCP (red line), as transmitted from E. H. Holt (AU) towards Belgrade (SRB)

## 2. RESULTS AND DISCUSION

Favorable geographical position makes NWC signal receptive for seismo-ionospheric effect analysis, aside the stable and continual emitting features and despite long $path_{NWC}$ [4-6]. In general, NWC signal records in Belgrade are of good quality. $A\&Ph_{NWC}$ registrations are of the same form, normally with heavy noise during dawn and especially during dusk conditions, in some cases with completely masked signal. Readings related to dusk conditions are far less reliable, sometimes even impossible. $A_{NWC}$ is more stable than $Ph_{NWC}$, which is very susceptible to external effects and thus often gives unreliable or even impossible readings. A and/or $Ph_{NWC}$ readings in cases of intense noise with large scatter in data, were excluded from analysis.

Seasonal dependence of terminator times is easily recognizable on 24h patterns of VLF signal registrations. Dawn or dusk at the receiver site in regular ionospheric conditions is defined by local zenith angle, as characteristic of given season. Deviation from this characteristic scheme is indication that disturbed propagation conditions inside the Earth-ionosphere waveguide took place and is considered as perturbation. Transition from stable nighttime to stable daytime ionospheric conditions and vice versa is dependent of seasonal and solar activity factors. Since very long $path_{NWC}$, it should be noted that at local dawn at Belgrade receiver site, entire trace became sunlit, while during local dusk, trace segments closer to the receiver, gradually enter nocturnal ionospheric conditions.

Survey of NWC signal propagation parameters encompassed period 12-2005 –06-2007. $A\&Ph_{NWC}$ showed perturbation that lasted 37 days, which has abruptly started on 30-08-2006, abruptly ended on 05-10-2006, too. Further on, terminator times went back to their normal and expected values. This behavior is more accurate in case of dawn than in case of dusk conditions. Terminator time dependence related to local dawn conditions ($terminator_{ND}$) during analyzed period is shown in Figure 2.

Values of $A_{NWC}$ related to terminator time sat local dawn and dusk conditions ($terminator_{ND\&DN}$) are in Figure 3 given. Critical days of perturbation beginning and end are indicated by dashed black lines, while readings related to perturbed ionospheric conditions are rounded by red ellipse. During analyzed period, only one perturbation appeared on NWC signal propagation parameters, so seismic activity reported by Helmholtz-Zentrum Potsdam - Deutsches GeoForschungs Zentrum GFZ including all regions covered by $path_{NWC}$, within this time frame with few days before and after the disturbance extent, was inspected thoroughly, with some events discussed in more detail (Figures 4 and 5).

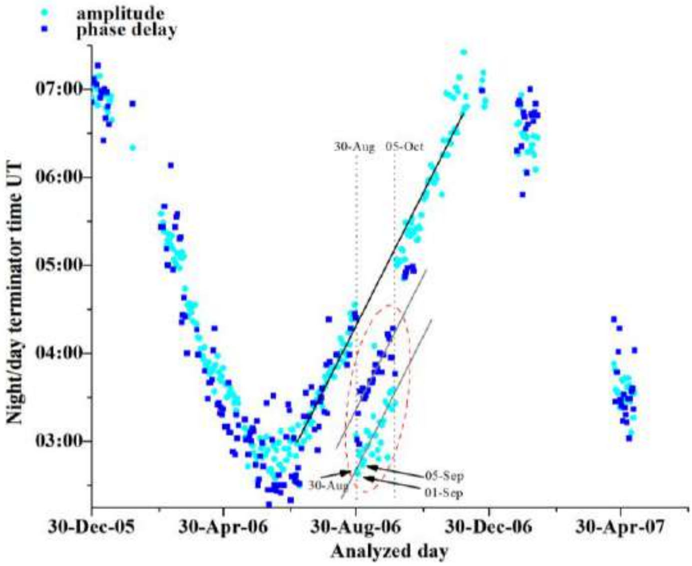


**Fig. 2:** A&Ph$_{NWC}$ terminator $_{ND}$ times (dark and light blue, respectively) during analyzed period 12-2005 – 06-2007, with disturbance-related perturbed readings indicated by red oval

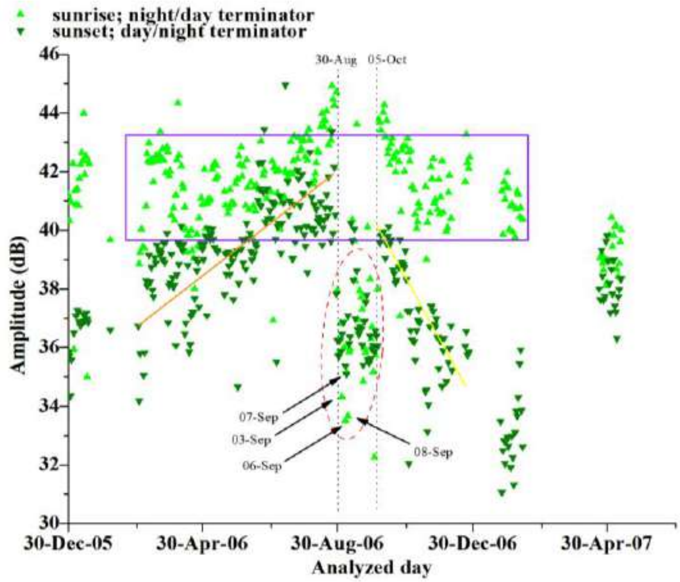


**Fig.3:** Values of A$_{NWC}$ related to terminator$_{ND_and_DN}$ times (light and dark green, respectively) during analyzed period 12-2005 – 06-2007, with disturbance-related perturbed readings indicated by red oval.

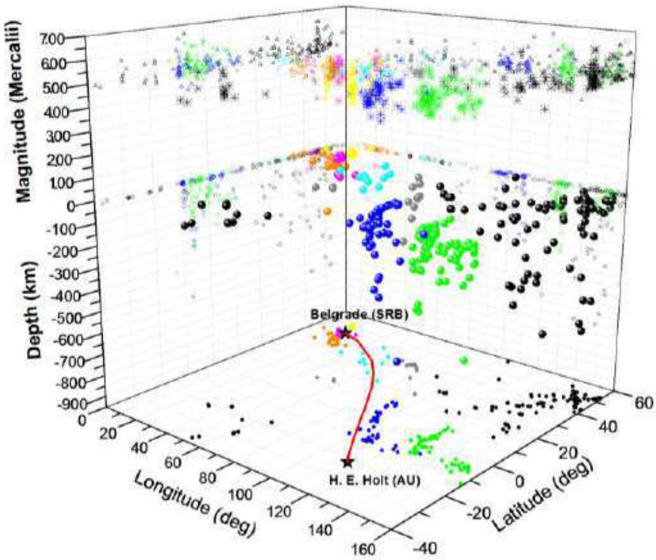


**Fig. 4:** Reported events' depths and magnitudes according to seismic activity reported by GFZ Potsdam in observed area during inspected period 15-08-2006 – 06-10-2006, enclosing pertrubation extent 30-08-2006 – 05-10-2006.

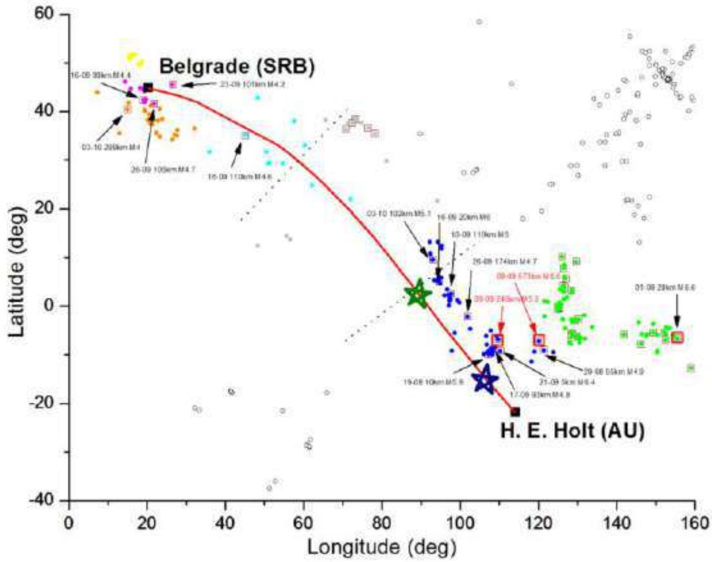


**Fig. 5:** Discussed events selected from seismic activity data reported by GFZ Potsdam in observed area during inspected period 15-08-2006 – 06-10-2006, enclosing pertrubation extent 30-08-2006 – 05-10-2006.

The perturbation is particularly striking at terminator$_{ND}$ times trend related to local dawn conditions from A$_{NWC}$readings (light blue in Figure 2). In case of Ph$_{NWC}$ readings (dark blue in Figure 2), despite some scattering, the disturbance can still be obviously recognized and distinguished from readings on regular trend. The much more distinct and convincing depiction given by A$_{NWC}$, is a consequence of its significantly lower sensitivity to external influences compared to Ph$_{NWC}$, as previously mentioned. In both cases during perturbation, it is cleraly evident that terminator$_{ND}$ times trend was the same, as in pre and post distrubed conditions (solid gray and black lines in Figure 2, respectively), but was just shifted towards earlier timesthan are expected for that time of season. After perturbation, terminator$_{ND}$ times related to local dawn conditions went back to expected values.

The perturbation is also distinct in A$_{NWC}$ values readings related to terminator$_{ND}$ times during dawn conditions (light green in Figure 3). In case of terminator$_{DN}$ times readings of A$_{NWC}$ values related to dusk conditions (dark green in Figure 3), such dependence is not so clearly observable, although it is still recognizable. During the disturbance, in both cases, A$_{NWC}$ were very similar both in behavior and in values and showed significant decay during disturbance compared to pre distubance period (shifted downward in Figure 3) and no trend in data. In case of A$_{NWC}$ readings related to terminator$_{ND}$ times (light green in Figure 3), even with somewhat higher amount of scattering present, it is cleraly visible that after disturbance A$_{NWC}$ went back to values relatively in the same range as they were in pre disturbed conditions (violet rectangle in Figure 2b). Not so regular behaviour is present in A$_{NWC}$readings related to terminator$_{DN}$ times related to local dusk conditions (dark green in Figure 3), where A$_{NWC}$ values after the disturbance stayed somewhat lower compared to pre distubance period (trend shown in yellow and orange solid lines in Figure 3, respectively).

Perturbation went through its extremum early in September 2006, with minimum round dates 30-08 – 01-09 – 05-09-2006in case of terminator$_{DN}$ times, while round dates 03-09 – 08-09-2006 in case of A$_{NWC}$ values (both indicated by arrows in Figures 2 and 3), showing a good match.

During 2006, within observed area enclosed by longitude (0° E, 160° E ) and latitude (40° S, 60°N), according to GFZ Potsdam (more details at http://geofon.gfz-potsdam.de), no significantly stronger earthquake occurred. Only 4 relatively stronger events with magnitudes above 6.5 degrees on Mercalli intensity scale were reported, with two occurred during September 2006 (Table 1). In period 15-08-2006 – 06-10-2006 that encloses pertrubation, there were 349 earthquakes reported within observed area.

**Table 1** –Earthquakes reported by GFZ Potsdam during September 2006, with magnitude greater than 6.5 degrees on Mercalli intensity scale

| No. | Date and Time UT | Intensity (M) | Lat. (°) | Long. (°) | Depth (km) | Region |
|---|---|---|---|---|---|---|
| 1 | 01-09-2006; 10:18 | 6.6 | 6.7 S | 155.5 E | 28 | Solomon Islands |
| **2** | **09-09-2006; 04:13** | **6.6** | **7.2 S** | **120.1 E** | **573** | **Flores Sea** |
| # | **09-09-2006; 17:48** | **5.3** | **6.9 S** | **109.7 E** | **245** | **Java, Indonesia** |

# weaker earthquake

Considering very long $path_{NWC}$ and that due to technical reasons observed area had to be of regular shape, the size of anlyzed area was very large with longitude (0° E, 160° E) and latitudes (40° S, 60° N). Events reported in far north-east and south-west zones, that were to far away from $path_{NWC}$ (114 events), were manually excluded from analysis (black in Figures 4 and 5). The rest of 235 events were analyzed in detail and manually grouped in several categories according to their locations related to $path_{NWC}$ (presented by different colures in Figures 4 and 5). In region of $path_{NWC}$ close to transmitter (the first third of trace - dashed black line in Figure 5), events relatively close to the $path_{NWC}$ are presented in dark blue, while those far from the $path_{NWC}$ in green. Events relatively close to middle region of trace, are presented in gray and light blue, while in region close to Belgrade receiver (the last third of trace- dashed black line in Figure 5) in orange, pink and yellow.

In block-diagram in Figure 4, reported earthquakes are presented by their projections onto the Earth's surface with filled dots in x-y plane, their hypocenters in lower sector are presented by solid spheres, while magnitudes in upper sector by crosses. On vertical projection planes, depths and magnitudes are presented by hollow diamonds and triangles, respectively. Zero on vertical axis refers to ground level in case of depth, while to no occurrence in case of magnitude. Although the deepest reported earthquake was of 650 km hypocenter depth (in far zone), for the sake of visibility, depths are plotted up to 900 km.

Depending on magnitude and depth, 50 events were analyzed in detail, while 3 events from early September stood out (rounded by brown and red hollow squares in Figure 2d, respectively). Two of them were the strongest reported events with M6.6 (1-2 in Table 1), while two were especially deep (573 km and 254 km) and from the same day 09-09-2006 within ≈18.5h interval (bold 2 and # in Table 1, indicated by red arrows in Figure 5).

Taking into consideration all seismically active regions along $path_{NWC}$, it can be assumed that observed perturbation is of seismotectonic origin, eventhough there was no notably strong event reported that could be potentially assumed as indicator of seismic activity and directly brought into the relationship with observed disturbance. It is certain that change in the scheme of terminator time variation of NWC signal in period 30-08-2006 – 05-10-2006 could not be of technical nature and that observed perturbation is related to increased ionization levels within the waveguide alone.

It is possible to correlate reported seismic activity from early September 2006 and observed disturbance on NWC signal propagation parameters, although stating conclusions of any direct relationship is quite uncertain. There is a relative coincidence between somewhat stronger 2 events from early September (Table 1) and disturbance start on one hand and its extremum around September 5$^{th}$ on the other (Table 1, bold), but stating any certain and direct relationship is fairly inconclusive. Particularly, the deep earthquake that occurred near transmitter on September 9$^{th}$ and in relative vicinity to $path_{NWC}$ (precisely the position of regular daily signal's I modal minimum, blue star in Figure 5) should be stressed out.

Nevertheless, constantly present and frequent low and/or mid-level seismic activity with numerous shallow events [7], distributed in relative vinicity of $path_{NWC}$and especially near locations of regular daily signal's modal minima (blue and green stars in Figure 5, respectively), could impacted ionization state change within the wave guide. However, it cannot be stated with certainty, that this type of earthquakes actually caused such perturbation.

## 3. CONCLUSIONS

The possible relationship between monitored NWC/19.8 kHz signal propagation parameters changes, as registered by AbsPAL receiving system in Belgrade (Serbia) and seismic activity reported by GFZ Potsdam in period 2005-2007 was investigated. During perturbation detected in period 30-08-2006 – 05-10-2006, lasted 37 days, terminator times related to local dawn and dusk conditions at Belgrade receiver site, have been shifted indicating disturbed ionospheric conditions with increased electron densities. Regardless the long $path_{NWC}$[4-6], distinct terminator time shifting and amplitude changes cannot be explained by variations in the VLF wave reflection height. Assumption about seismotectonic origin of observed perturbation can be drawn based on data readings. Considerable noise suppression in data, appearing not only at perturbation beginning (suggested as possible new earthquake precursor, [8]), but also during the entire perturbed period, supports this assumption. However, the precise cause and voltage state change location that induced disturbanceof such extent and characteristics, cannot be determined with certainty, due to complex conditions within the waveguide allong path$_{NWC}$.

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