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Low ionospheric observations by means of the software receiver for Omega signal

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Abstract
Two receiving stations of Omega signal (10-14 kHz in the lower end of the VLF band) have been installed in Rome and Florence to record phase and amplitude of signals transmitted by the stations of Norway, Liberia and La Reunion. The receiving stations are equipped with a multifrequency software receiver that is a useful tool to investigate the low ionosphere. The night-day phase changes along the paths will be shown in the quiet and disturbed days for various epochs of the year. Under quiet conditions there are marked variations in the *D*-region due to the effects of diurnal and seasonal changes in solar illumination. In addition, data from disturbed periods are presented to show the relation between propagation parameters and solar ionizing radiation.

Key words *low ionosphere physics – VLF propagation*

1. Introduction

The Omega navigation system, used for positioning purpose, is based on the phase difference of radiowaves from seven transmitters (table I). Radiowaves can propagate over long distances with small attenuation rates, typical 2-3 db per Mm (Swanson, 1983).

The propagation of VLF radio waves can conveniently be considered in a spherical earth surrounded by a concentric reflecting layer of electronic density into which VLF waves are launched and where they propagate. The propagation is controlled by the lowest region of the ionosphere (Budden, 1961).

During the day-time this includes the lower *D*-region and, at night, the lowest part of the *E*-region.

In this specific network the two Omega receiver stations are at least 2.5 Mm of distance from the transmitters.

As is well known, phase and amplitude of VLF propagation can be described in a waveguide of the Earth-ionosphere (Davies, 1990). The relation between the phase and height changes, over long distances, is given by

$$\Delta\phi = -\frac{2\pi d\Delta h}{h\lambda}\left(\frac{h}{2a}+\frac{\lambda^2}{16h^2}\right)$$

where: h is the mean height of reflection in the *D*-region, d the path length, ϕ the phase, λ the wavelength and a is the Earth radius (Budden, 1985; Wait, 1970). Phase shift can be expressed in radians or in seconds by $\Delta t = \Delta\phi\lambda / 2\pi c$.

The amplitude of the electric field over

Table I. The three transmitting Omega stations with latitude, longitude, frequency and distance from Rome and distance from Florence in km. The distance between the two receiving stations is 231 km.

Stations	Latitude	Longitude	Frequency kHz	d R	d F
Norway	66.25 N	13.9 E	10.2	2709	2504
Liberia	6 N	10 W	10.2	4567	4684
La Reunion	20.58 S	55.17 E	12.3	8215	8437
Norway	66.25 N	13.9 E	12.1	2709	2504
La Reunion	20.58 S	55.17 E	10.2	8215	8437
Liberia	6 N	10 W	12.0	4567	4684
Liberia	6 N	10 W	11.05	4567	4684

long paths in a waveguide mode is approximately

$$E = \frac{300e^{-\alpha d}}{h}\left[\frac{p\lambda}{a \cdot \sin(d/a)}\right]^{0.5}$$

where α is the attenuation rate and p the radiated power (in kW).

The amplitude of the signal is generally dependent on the interferences of various propagation modes, that change with the variations of the waveguide parameters.

Observed phase and amplitude of the signals can therefore be used to study, by means of the previous formulas, variability, morphology and other phenomena occurring in the low ionospheric region.

Great phase variations and amplitude occur near the sunrise and sunset, while more steady levels of amplitude are observed during daytime and night-time. Moreover, many natural phenomena like Trimpi, solar flare etc. can be observed by means of VLF propagation (Okada and Iwai, 1988).

2. Observations

For more than two years the receivers in the two stations have not been operating continuously. In table I are indicated the names of transmitting stations, the distances from the receiving stations, their latitude and longitude and the selected frequencies.

The receivers employed in this experiment have been designed following the software approach to develop instrumentations for the observations of the ionosphere (Ciraolo and Spalla, 1989, 1990). A simple stylus amplified antenna, installed at the top of buildings, has been employed in the two receiving Omega stations. The software receiver can select any of the transmitted Omega frequencies. A digital tuning filter, realized by real time digital signal processing (DSP), synchronizes the required segment yielding phase and amplitude values at the sampling rate of 30 s.

The processing board of software receiver is based on the microprocessor Texas Instruments TMS 320C25; data (phase and amplitude) are acquired by means of a PC, connected to the software receiver via RS232, that records also the time of sampling on diskettes for successive off-line analysis (Capannini and Ciraolo, 1991). To determine the phase difference, a long time stability $2 \cdot 10^{-10}$ day^{-1} standard frequency crystal XSD 2 of Rhode Swhwarz is employed.

3. Data interpretation and analysis

Diurnal and seasonal behaviours have been examined at different frequencies and stations (see table I). Quiet and disturbed

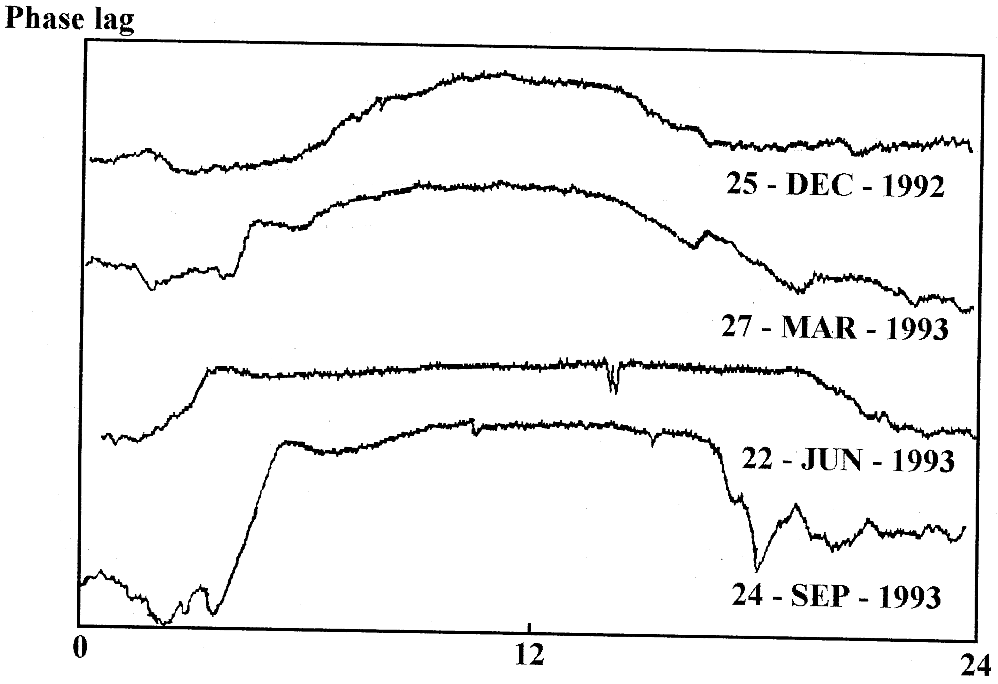

Fig. 1. Typical diurnal variation of the phase (ϕ_{DN}) of the signal received in Rome from Norway (10.2 kHz) in the seasonal period indicated.

periods have been studied comparing also Rome and Florence data, in order to point out local low ionosphere variations.

If it is assumed that the phase velocity is $v_p \approx c$, the phase difference between Rome-Florence is $\approx$ 1 *ms*. Because of the differences of the phase velocity night-day v_{pND}, it is expected that the differences of phase night-day ϕ_{DN} Rome-Florence should be $\approx$ 2.7 μs (normally the differences of phase night-day is $\approx$ 8 μs per Mm).

Considering that the instruments resolution is better than 1 μs, it is possible to detect local variations of low ionospheric regions too.

3.1. *Quiet days*

Typical diurnal variations of the phase ϕ_{DN} of the Omega signal at 10.2 kHz received in Rome from Norway are shown in fig. 1. The periods considered correspond to the equinoxes and the solstices. Figure 2 and 3 refer respectively to the signals coming from Liberia and La Reunion in the same periods.

For the signals transmitted from Norway, also a plot of amplitude is shown in fig. 4. Variations are evident during sunrise and sunset transitions, when various propagating modes interfere with each other producing fading.

In the analysis of the Omega signal from Norway, apart from the night-day phase transition, it is remarkable that, in the quiet days during night-time when the waves propagate next to the *E*-region, the phase profiles systematically show more or less complicated variations. On the contrary, during daytime, the phase profiles show a plateau with high phase stability during the summer (see the third trace in fig. 1).

To study the morphology, the weekly mean values are plotted in different seasons: in the time period indicated in fig. 5 is shown, for example, the peak after sunrise followed by a decrement in the phase plots. This fact is probably connected with the negative ions production at dusk and with releasing of the electrons during sunrise.

3.2. *Disturbed days*

The phase plots of signals received from Norway (path practically along the meridian) during disturbed ionosphere in daytime period show several peaks in coincidence with a series of flares. The flares, that are recognizable as sudden ionospheric disturbance (SID), were observed also by means of the ionosonde in the same observatory as an increased $f_{\min}$ characteristic in the ionogram traces.

In this case waveguide parameter h changes dramatically along the path. The change of h depends on the solar zenithal angle χ, that sometime (fig. 6) produces relevant phase variations that are of the same order of magnitude as the night-day phase transitions.

During night-time, not remarkable variations in the phase signal are produced even if a more confused trend is present in the phase plots. Normally, it is found that waves in the range of observed frequencies propagating in the ionosphere waveguide are strongly influenced in daytime by UV and X-ray radiation, while in night-time magnetic disturbances have not great influence.

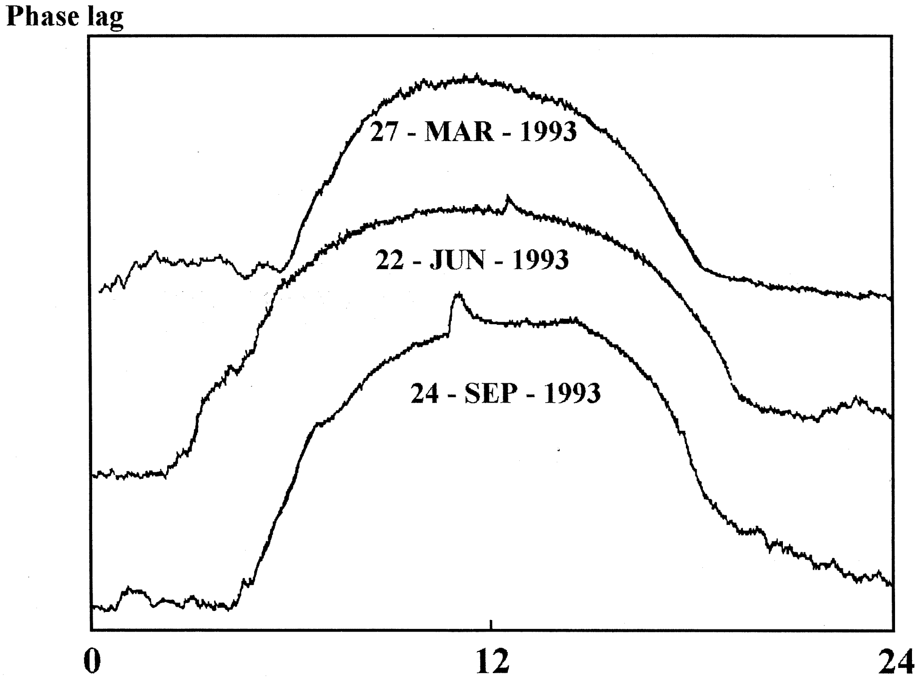

Fig. 2. As in previous figure for the signal received from Liberia.

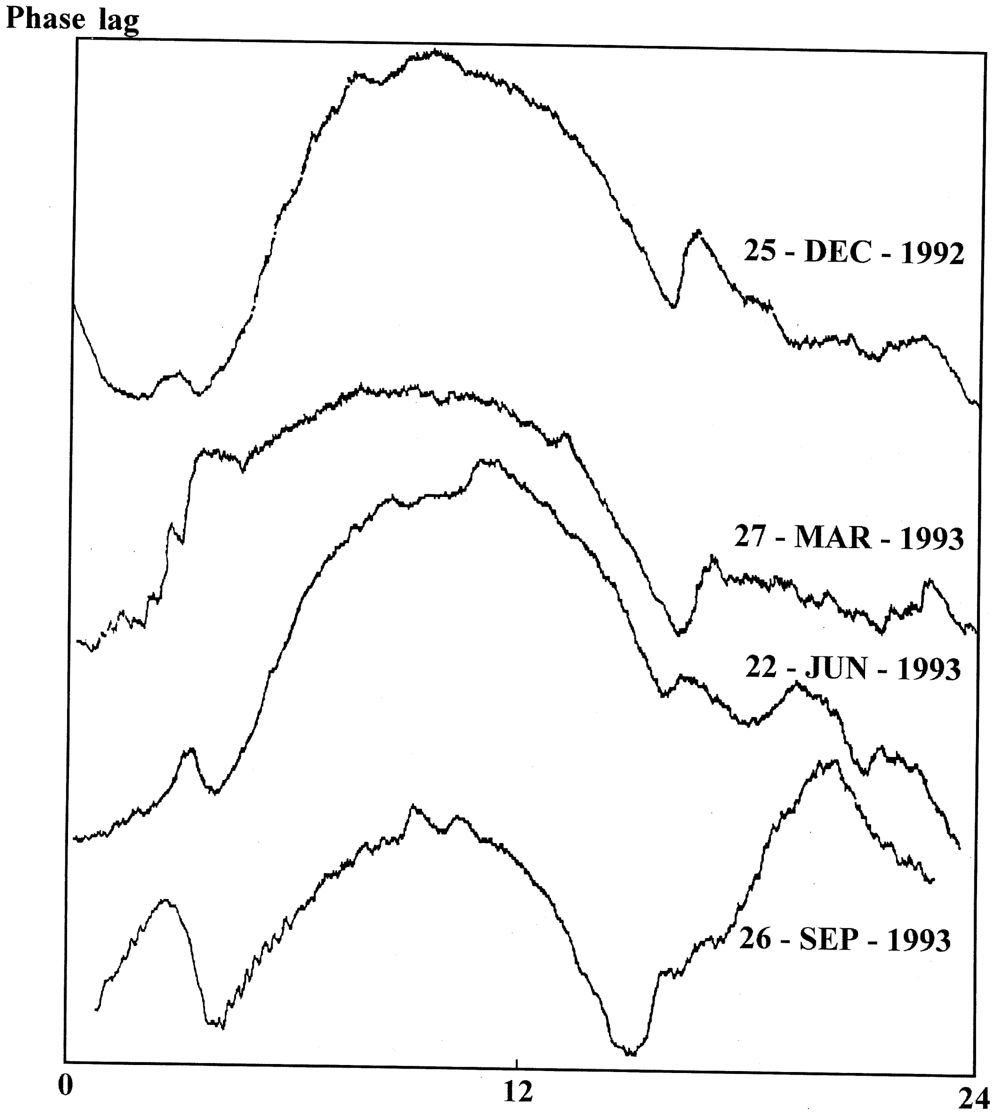

Fig. 3. As in previous figures for the signal received from La Reunion.

4. Discussion

As is well known, waves in the VLF range propagating in the ionosphere-ground waveguide are generally very stable both in phase and amplitude during night-time and daytime.

The trapezoidal phase variation implies that the first order mode of propagation is predominant on this path (Kikuchi 1983, 1986). During the sunrise and the sunset other propagation modes can interfere with the first normally propagating mode and cause the observed fadings. The transition

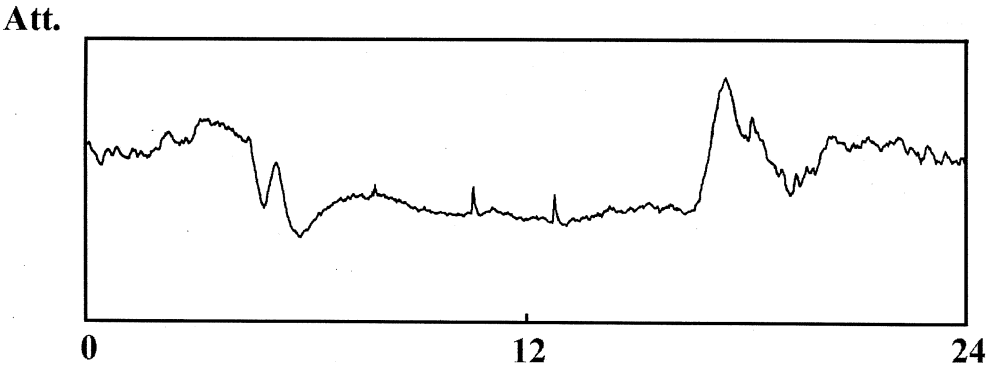

Fig. 4. Typical diurnal variation of the amplitude of the Omega signal (10.2 kHz) received in Florence from Norway.

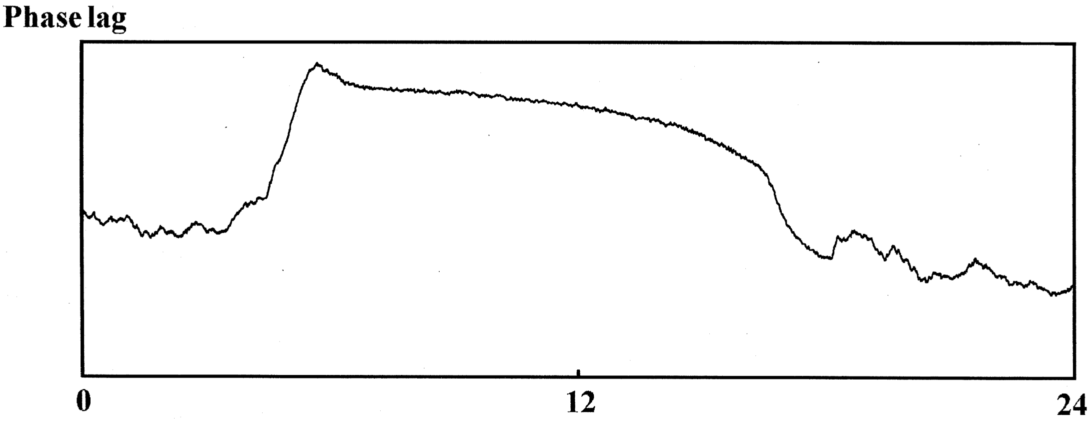

Fig. 5. Phase plot of weekly mean values of the Omega signal from Norway (10.2 kHz) received in Rome. The peak after sunrise is probably due to production, at dawn hours, of negative ions followed by a rapid loss.

hours day-night and night-day are (apart from disturbed periods) hours in which the phase and amplitude suffer more heavy variations.

Waves with a frequency of 10.2 kHz propagate in the waveguide of height 90 km in the night 70 km in the day. The seasonal solar change is well evident for the signal coming from Norway, both for the short distance and the simple path. The frequency of the signal in the range 10.2-13.6 kHz seems not to be influent. Only not relevant fluctuations in signals, having higher frequency, are more valuable because of their different height of penetration in the *D*-layer. For this reason, Norway's signal can be considered for a further analysis of local low ionosphere. Data from other

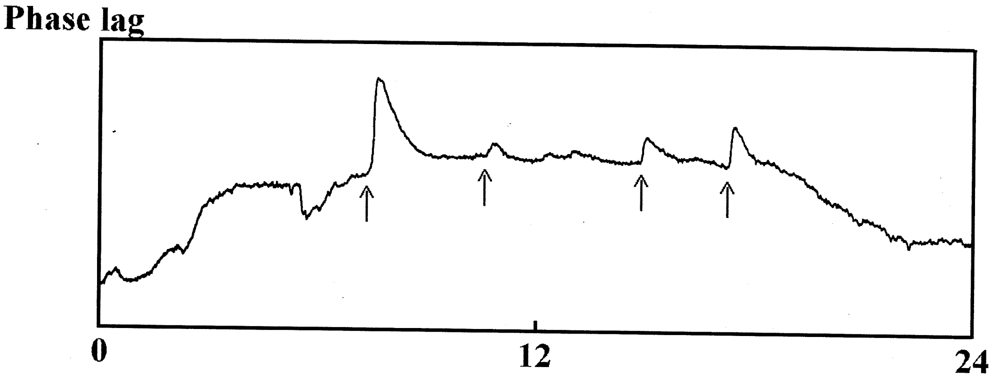

Fig. 6. Phase plot of the Omega signal of 10.2 kHz from Norway during a series of flares, indicated by the arrows (24 June 1993).

transmitting stations are difficult to interpret in order to describe low ionospheric phenomena. This kind of measurement can be useful also in disturbed days because it gives information concerning the photoionization of low ionosphere during SID and other local low ionospheric events.

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