Correlated multipath effects between distant radio telescopes

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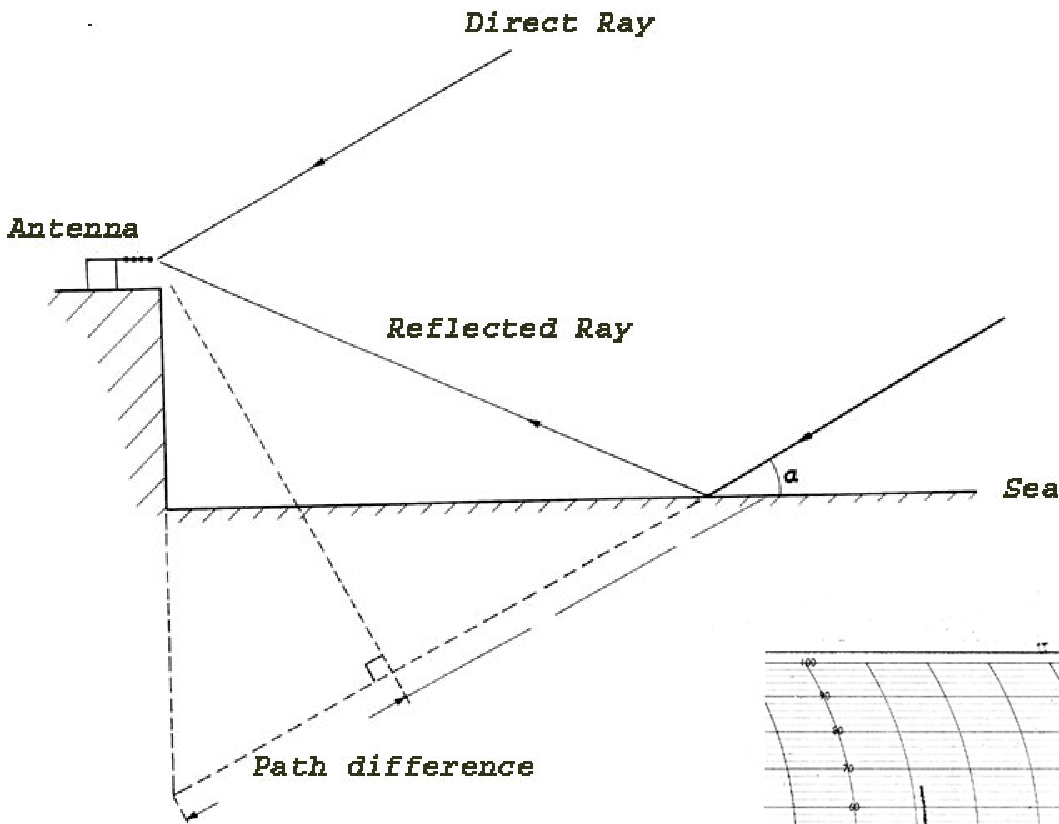
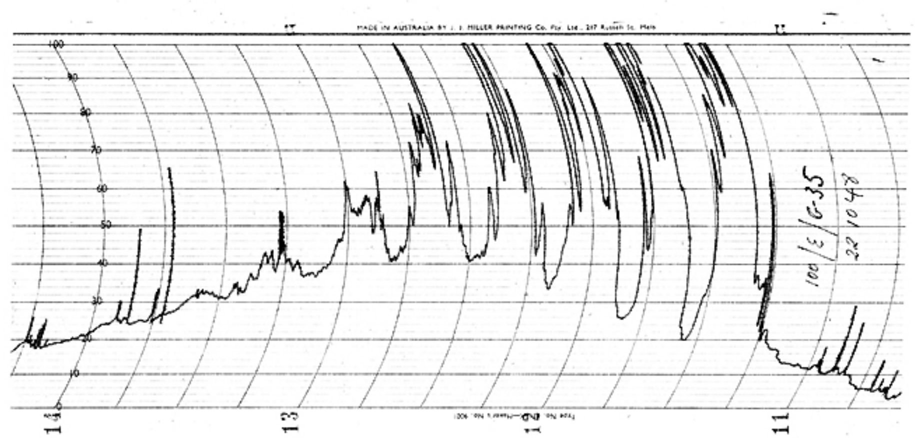
"Sea-cliff interferometer" (Australia, 1948-1949)





Cygnus A

Introduction

The present work is an illustration of **the same mechanism causing correlations** between apparent **solar oscillations simultaneously detected by two distant observatories** (5000 km apart) respectively located in Hanoi (Vietnam) and Learmonth (Australia).

In this case, oscillations are not observed on the rising Sun but at **large elevations**: the reflected wave reaches the antenna in one of its **side lobes**, at large angle with respect to the beam.

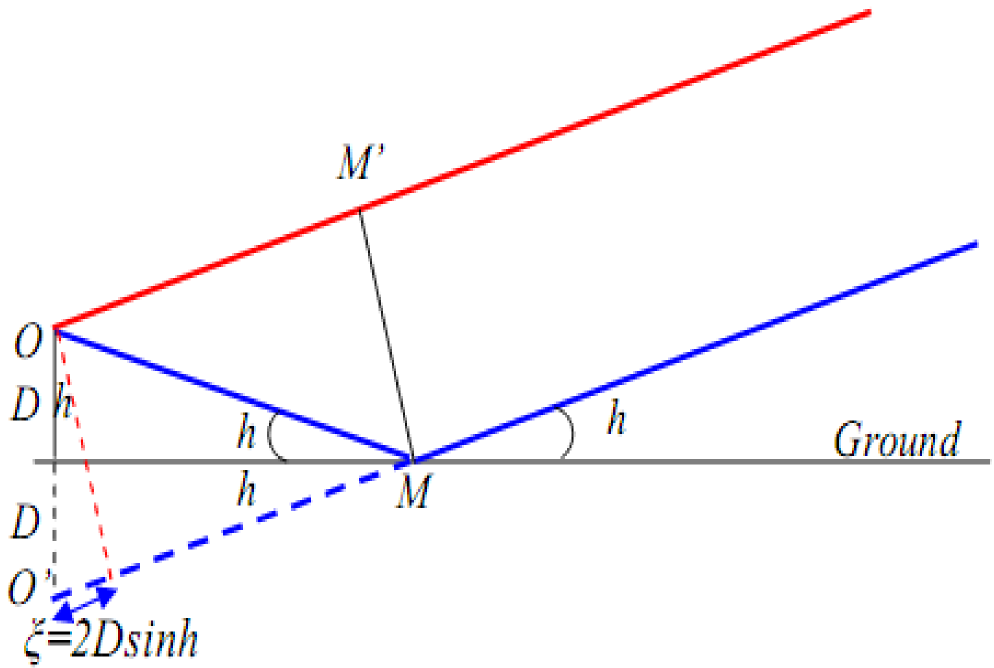
As a result, the oscillations have **amplitudes of a few per mil, rarely exceeding 1%.** They have **periods in the range of a few minutes** and reflections occur on the ground surrounding the antenna.

Multipath from specular reflection on ground

$$S=|e^{i2\pi\nu(t-\frac{1}{2}\Delta t)}+\varepsilon e^{i2\pi\nu(t+\frac{1}{2}\Delta t)}|^2$$
$$=|e^{i2\pi\nu t}|^2|e^{-i\pi\xi/\lambda}+\varepsilon e^{i\pi\xi/\lambda}|^2$$
$$= 1+\varepsilon^2+2\varepsilon\cos(2\pi\xi/\lambda)$$

ξ the difference in path length
ν the frequency (~1.4 GHz)
λ the wavelength (~21 cm)
$\Delta t= \xi/(\lambda\nu)$

ε accounts for the attenuation resulting from the **reflection on ground** and from the **lesser gain of the side lobe** in which the reflected wave is detected.



In an interval around $t=t_0$, this induces oscillations of period T and phase φ of the form:

$$\sin\left(\frac{2\pi[t-t_0]}{T}+\ \varphi\right) \text{ where } T=\lambda/|d\xi/dt| \ \&\ \varphi=\frac{\pi}{2}\pm 2\pi\frac{\xi_0}{\lambda}$$

+ (–) sign is for ξ increasing (decreasing) with t

$T|d\varphi/dt|=2\pi$ is characteristic of the multipathing effect

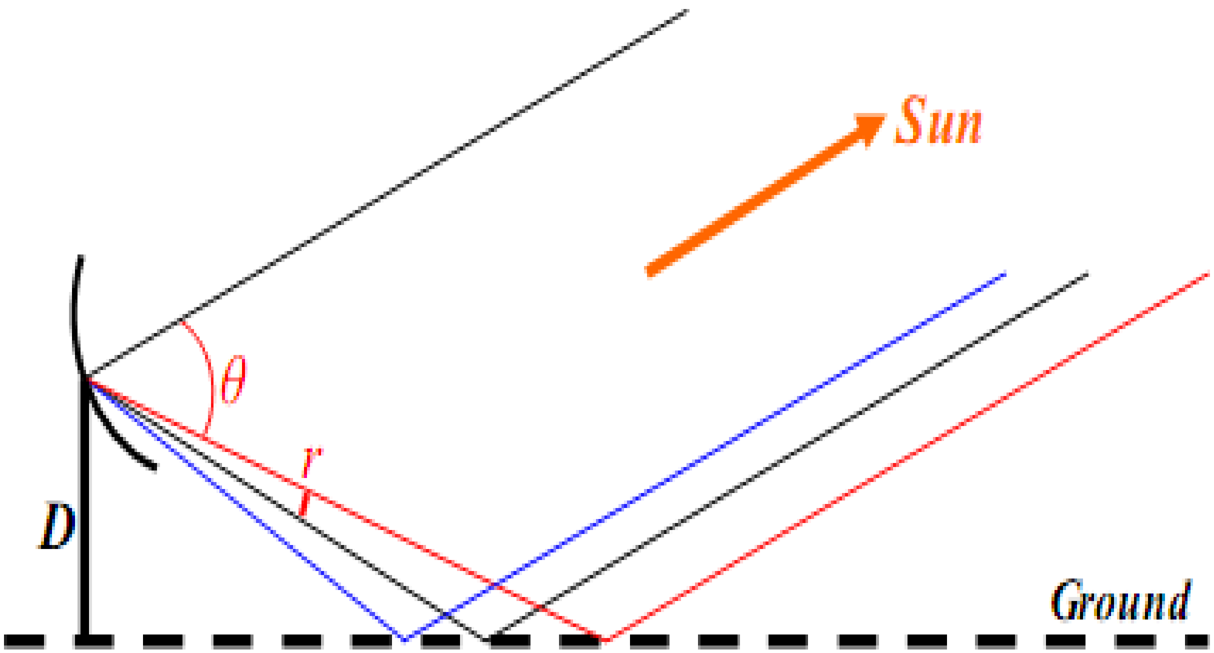
$$\xi=2D\sin(h)$$

At a same time t, from one day to the next:

φ to increase in the morning in the Northern hemisphere between December 22nd and June 21st. Changing from morning to afternoon, or from Northern to Southern hemisphere or from December-June to June-December changes the sign of the daily variation of φ.

The effect is easily simulated using Gaussians to describe

- the deviation from specular reflection, $exp(-\frac{1}{2}r^2/\sigma_r^2)$
- the angular dependence of antenna gain, $exp(-\frac{1}{2}\theta^2/\sigma_\theta^2)$
- irregularities of the reflecting surface, $exp(-\frac{1}{2}\Delta\xi^2/[\xi\sigma_{sm}]^2)$



Height of antenna above ground $=D$, longitude $=\psi$, latitude $=\zeta$

Two telescopes, 1 and 2

Writing $h'=|dh/dt|$, the periods read

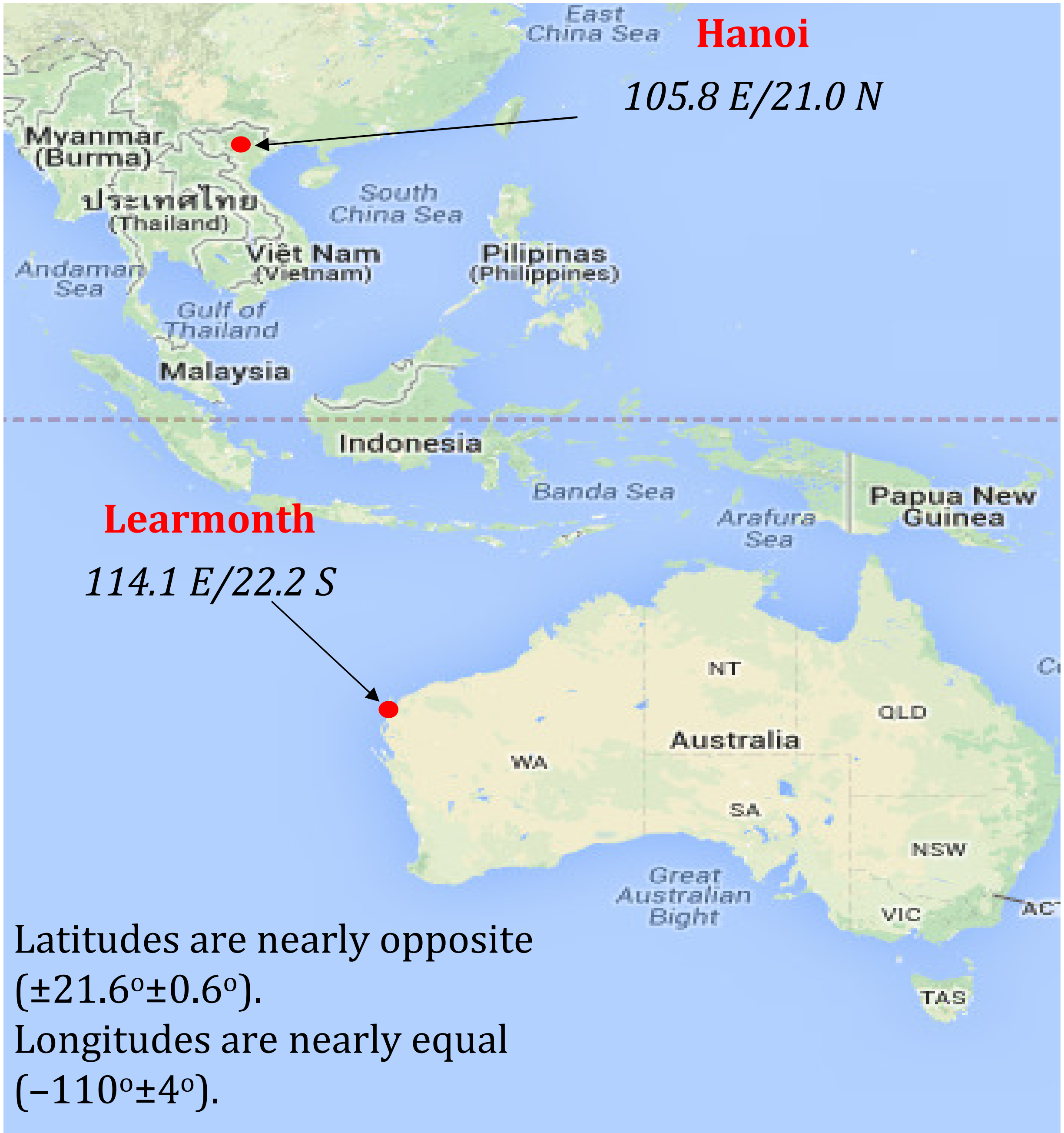
$$T_{1,2} = \frac{1}{2}\frac{\lambda}{D_{1,2}h'_{1,2}\cos(h_{1,2})}$$

In the approximation of a circular Earth orbit, calling δ the Sun declination and $H=t+\psi$ the hour angle

$$sin(h)=sin\delta sin\zeta+cos\delta cos\zeta cosH$$

$T=T^*/[cos\delta|sin(t+\psi)|]$, $T^*=½\lambda/(Dcos\zeta)$ being a constant for each observatory.

Writing $\rho=T/(T^*cos\delta)$, $\rho_1=1/|sin(t+\psi_1)|$ and $\rho_2=1/|sin(t+\psi_2)|$ are trivially correlated, implying a correlation between the periods measured simultaneously by both observatories.



Latitudes are nearly opposite $(\pm 21.6^{o} \pm 0.6^{o})$.
Longitudes are nearly equal $(-110^{o} \pm 4^{o})$.

In the approximation:

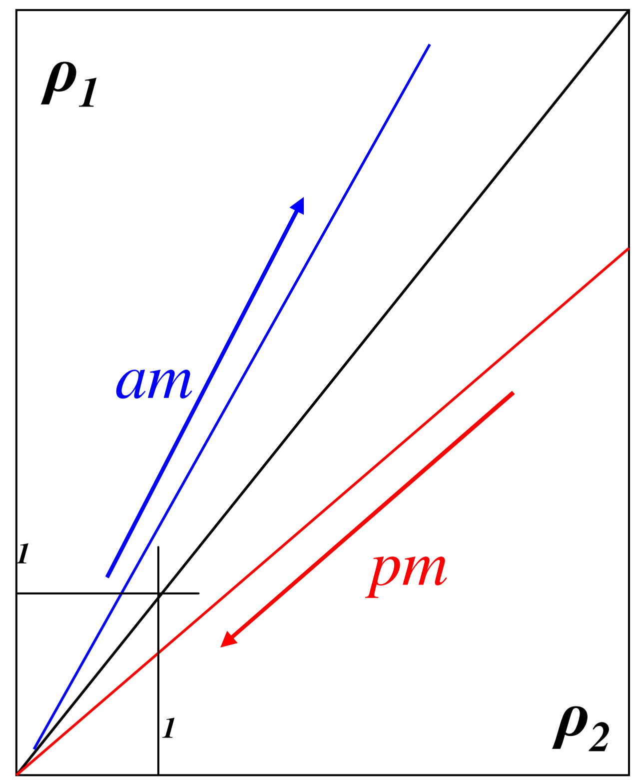
$\psi_1=\psi_0-\Delta$, $\psi_2=\psi_0+\Delta$, $0<\Delta<<1$ rad

(observatory 1 being east of observatory 2)

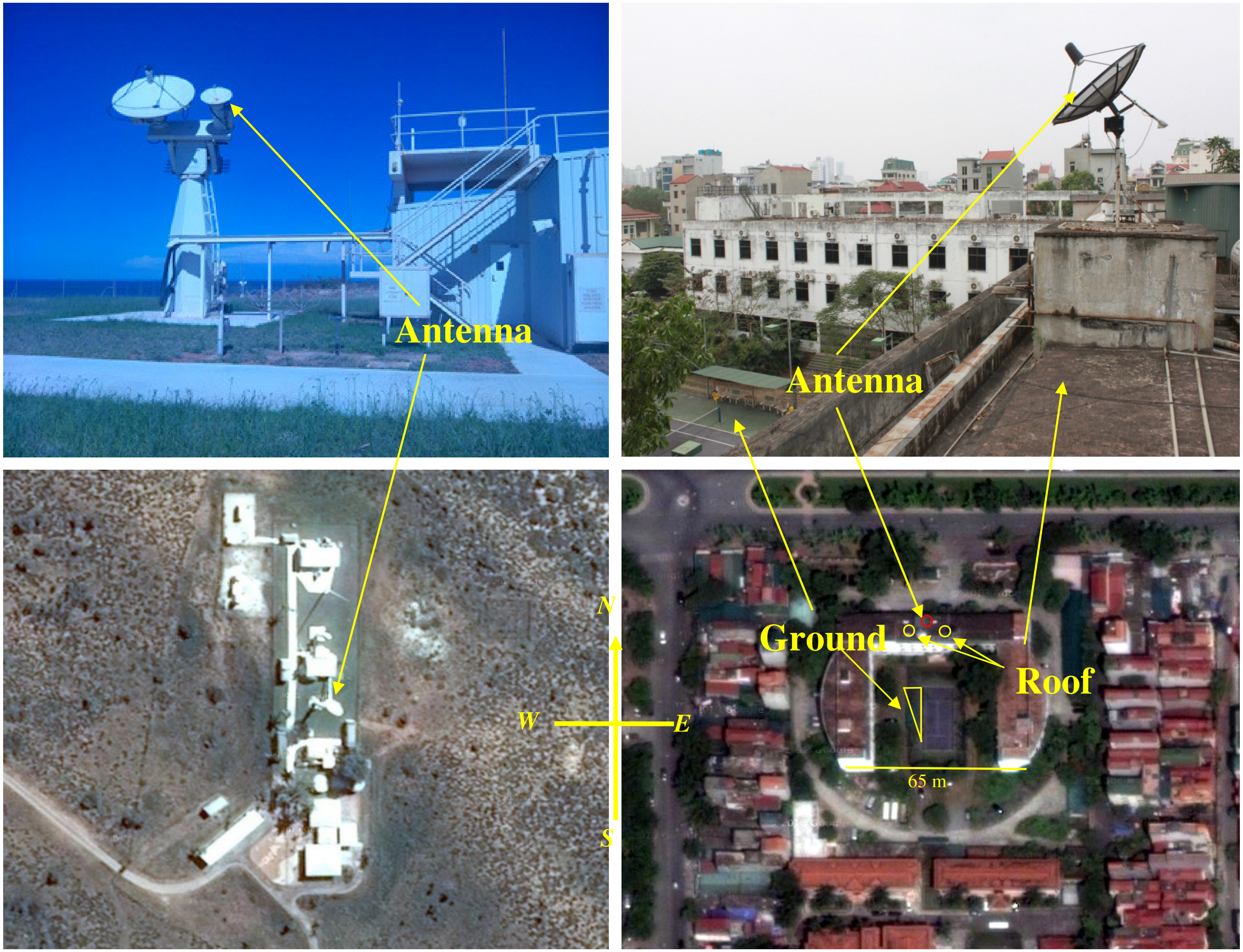
Writing $H_0=\psi_0+t$ the mean hour angle:

$\rho_1=1/|\sin(H_0+\Delta)|$ and $\rho_2=1/|\sin(H_0-\Delta)|$

Around noon, the elevation is stationary and the period of the oscillations takes very large values outside the range where they can be detected. In the morning, $H_0<-\Delta$, the elevation, and therefore the period of the oscillations increase with time. In the afternoon, $H_0>\Delta$, they decrease. Changing H_0 into $-H_0$ changes ρ_1 into ρ_2.

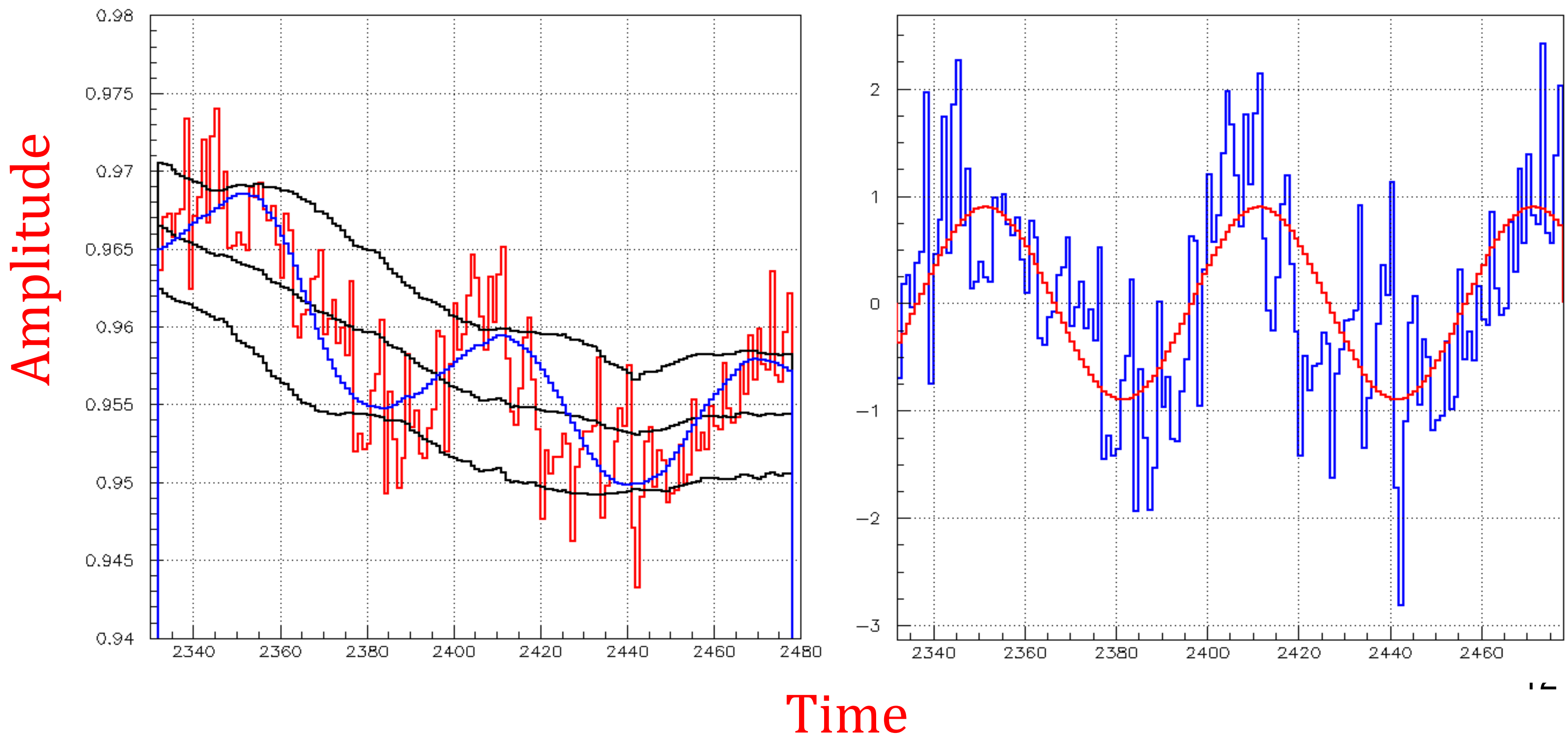


Observed oscillations in Learmonth and Hanoi

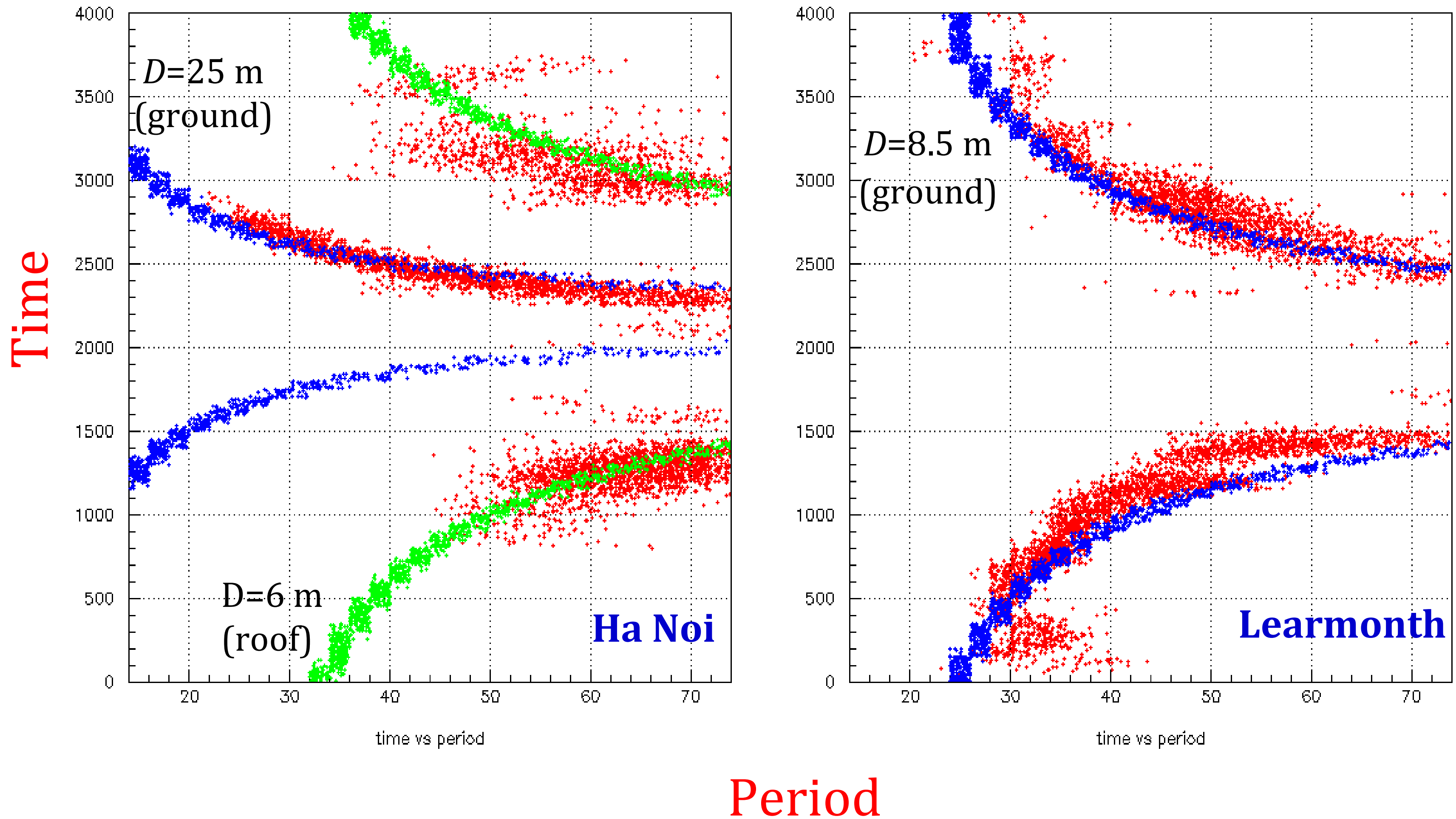


The data cover the period October 24th 2013 to January 31st 2014 for both Hanoi and Learmonth.

We use a simple algorithm to define the period, phase and amplitude of observed oscillations and a quality factor allowing to retain only significant oscillations.

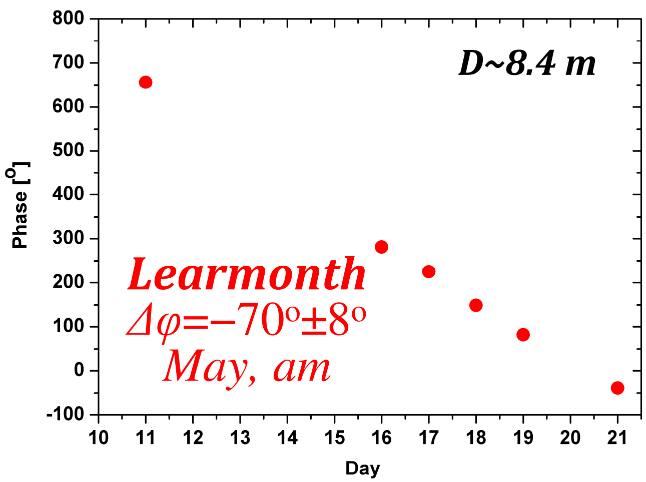


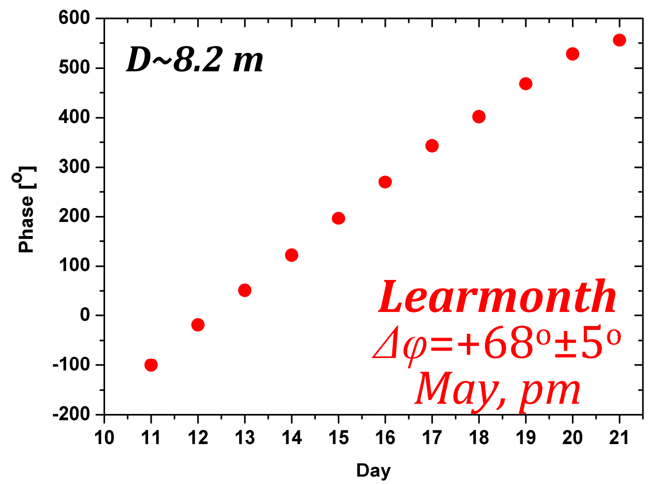
Distributions of **time vs period** using sensible selection criteria display very clear patterns and follow the same trend as expected from specular reflection on ground.

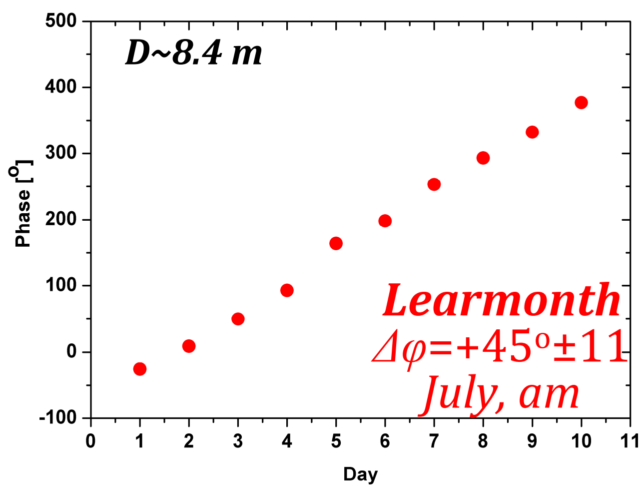


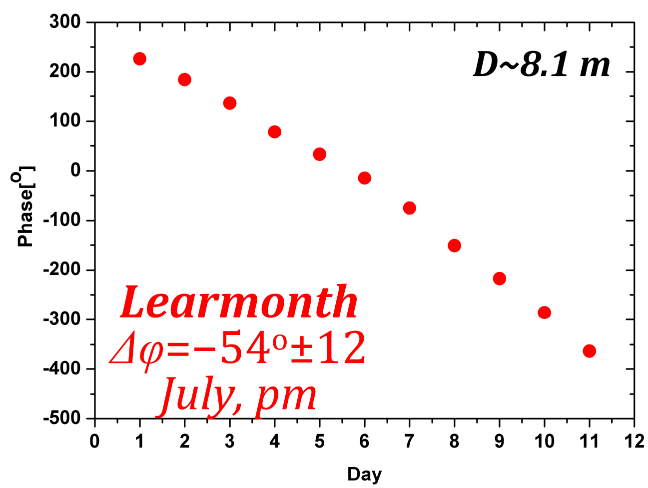
Comparison between observations and predictions

For both Learmonth and Hanoi data, the time dependence on the phase is as expected.



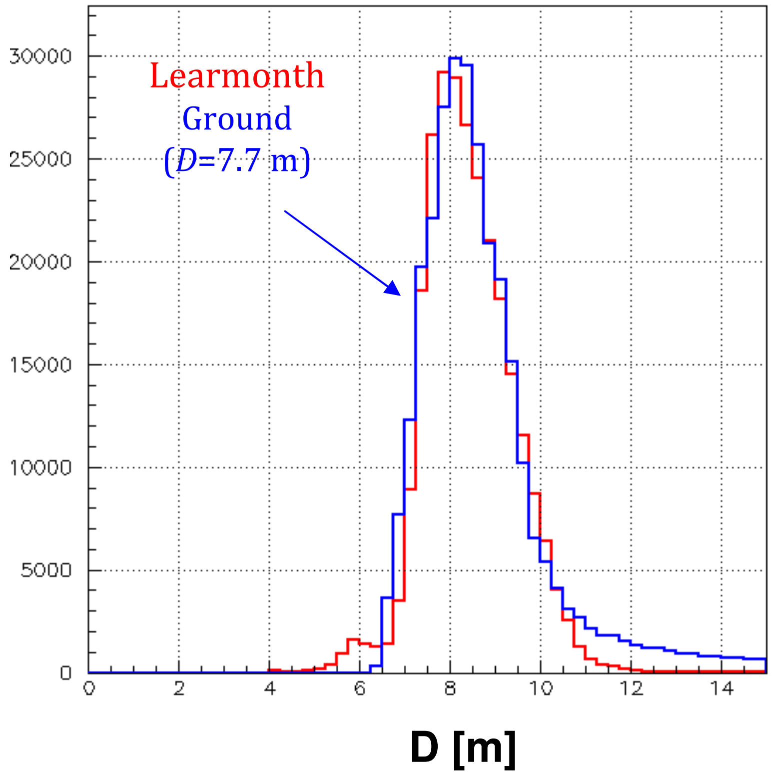


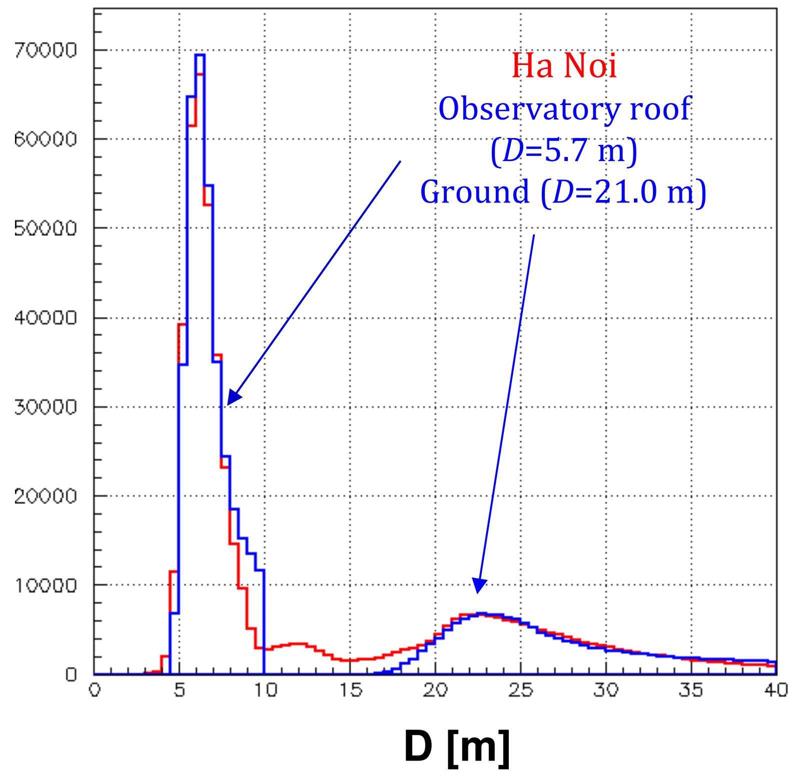




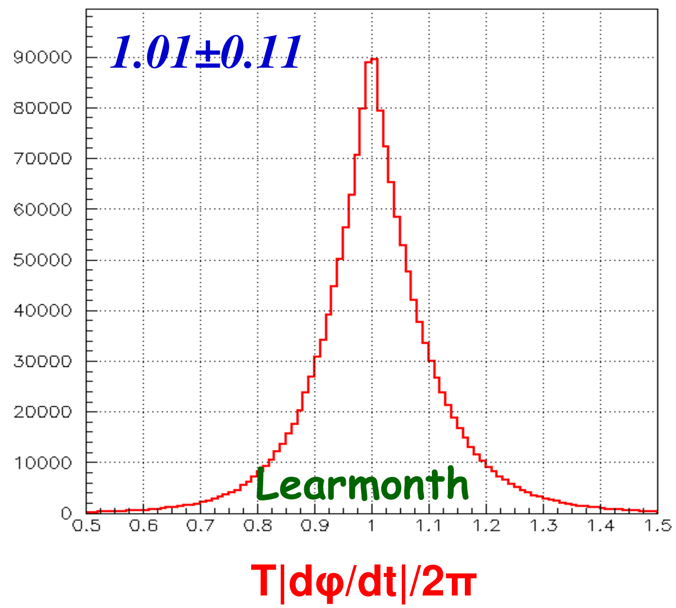
The measurements of the period and phase of the oscillations provide independent evaluations of the altitude D of the antenna above ground.

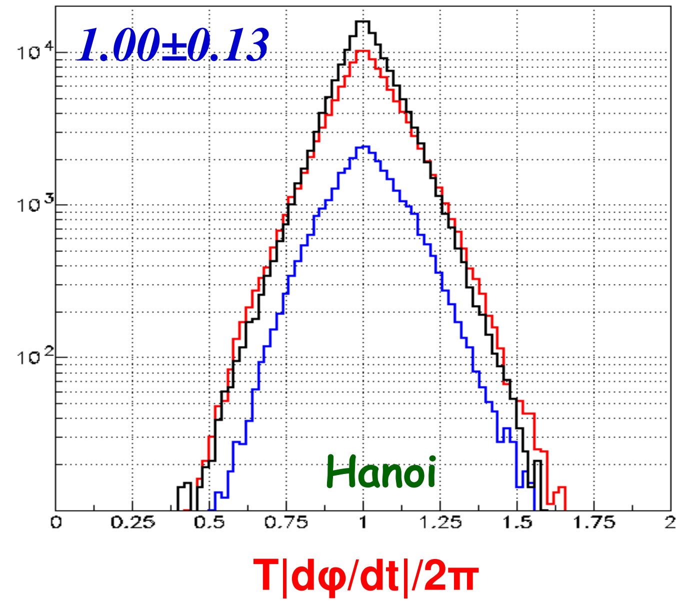
$$T = \frac{\lambda}{|d\delta/dt|} = \frac{1}{2}\frac{\lambda}{D|dh/dt|\cos h} \rightarrow D = \frac{1}{2}\frac{\lambda}{T|dh/dt|\cos h}$$



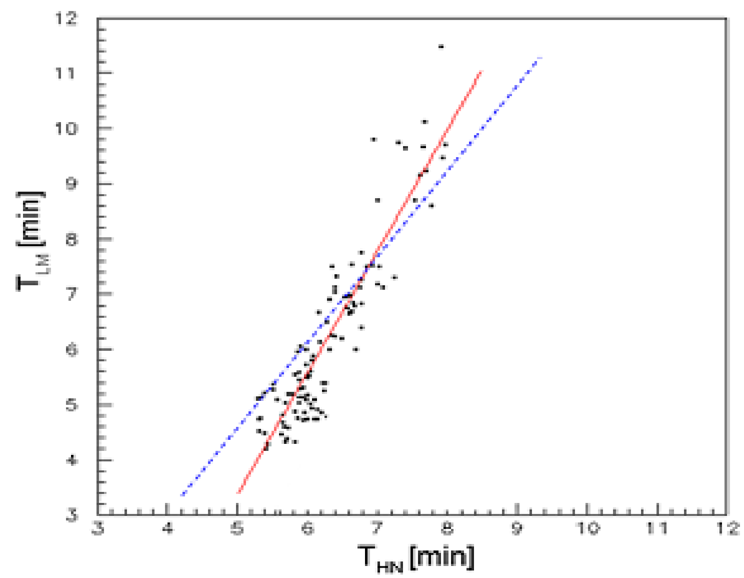


Evidence for multipathing is confirmed with $T|d\varphi/dt|/2\pi$





The correlations between the periods measured simultaneously at Learmonth and in Hanoi are well accounted for by multipathing.



Conclusions

•When observing the Sun, multipath effects have been shown to produce correlations between the periods of oscillations observed independently by two distant radio telescopes.

•Good agreement between observations and model predictions has been obtained and the departure from exact specular reflection that the data can accommodate has been shown to be small.

•The oscillations have periods and phases that are well described by the model. Their amplitudes, at the level of a few per mil, are consistent with the gain drop expected between the main and side lobes of the antenna pattern.

Thank you for your attention !