Noise Factor of the Different Modes of the Electromagnetic Waves propagated in the Ionosphere

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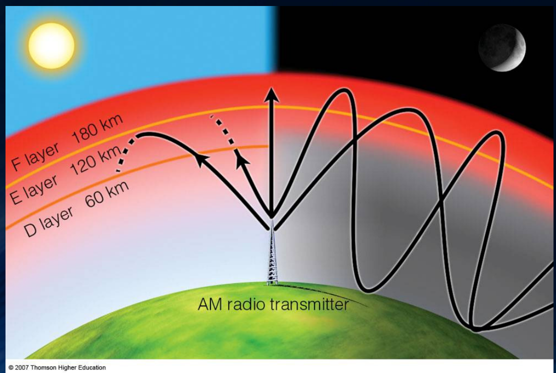
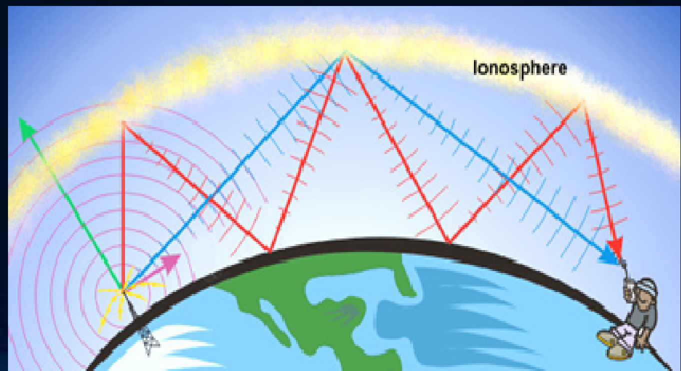
- High frequency (HF, 3-30 MHz) radio waves are propagated long distances by the reflection between the ionosphere and Earth.
- The properties of the ionosphere have been investigated by examining factors affecting the propagation and reflection of the radio waves (Budden, 1988; Sagir et al., 2014, 2015).
- Also the radio waves are absorbed because of the free electron collisions when they are propagating through the ionosphere.
- The absorption of the wave is studied by many scientists and several approximations were done (Unal et al., 2007; Atici et al., 2016)





- All the objects on the Earth or in the sky are the sources of noise because of propagated energy.
- As a result, there are countless radio noise measurement systems in the different parts of the world.
- It is very important to detect a signal correctly in the communication systems.
- Noise can be a limiting factor in the performance of radio communication systems.
- Radio noise measurements in the ionosphere have begun to be made along the orbits with the development of satellites (Cummer and Inan, 2000; Fieve et al., 2007).
- As a result of these measurements, the noise spectrum is galactic, cosmic and solar-induced.
- Electromagnetic waves are influenced by the ionosphere as it travels from the Earth's surface to the satellites.
- Ionosphere acts like a high-pass filter against the energies of electromagnetic waves while traveling through the ionosphere (Rush et al., 1980; Bianchi and Meloni, 2007).

- When the signal is transmitted between two ends, noise is added to the signal due to the noise sources between the two ends.
- The noise of a system is defined by the noise factor.
- The noise factor is the ratio of the input SNR to the output SNR of the system.
- The noise factor is insufficient for precise calculations in the standard form.
- The attenuation of the loss y two ends is equal to the noise factor numerical ly.

- The organization of the presentiation is as follows:
- Theoretical background of noise factor
- Numerical solutions
- Analysis and results

The force acting on the electron is,

$$m\frac{d\mathbf{V}}{dt} = -e(\mathbf{E} + \mathbf{V}\times\mathbf{B}) - m\nu\mathbf{V} \qquad (1)$$

where **E** is electrical field, **B** is magnetic field, **V** and m are the velocity and mass of electron and ν is the total collision frequency of the electron-ion and electron-neutral collisions:

$$\nu = \nu_{ei} + \nu_{en} \qquad (2)$$

in which

$$\nu_{ei} = N_e 10^{-6}\left[59 + 4.18log\left(\frac{T_e^3}{N_e}\right)\right]T_e^{-\frac{3}{2}}$$

and

$$\nu_{en} = 2.33\times10^{-17}[N_2](1 - 1.21\times10^{-4}T_e)T_e$$

$$+1.8\times10^{-16}[O_2](1 + 3.6\times10^{-2}\sqrt{T_e})\sqrt{T_e}$$

$$+8.9\times10^{-16}[O](1 + 5.7\times10^{-4}T_e)\sqrt{T_e}$$

where $[N_2]$, $[O_2]$,[O], N_e and T_e, are densities of nitrogen, oxygen, oxygen atoms, electrons and electron temperature, respectively (Canyılmaz et al., 2013).

The z-axis of the Cartesian coordinate system with its origin located on the ground is vertical upwards. The x- and y-axis are geographic eastward and northward in the Northern Hemisphere. The solution of Eq. (1) can be written as,

$$\mathbf{J} = \sigma\mathbf{E} \tag{3}$$

where **J** is the current density and σ is the conductivity tensor of the ionosphere. The wave equation can be obtained from Maxwell's equations as follows:

$$\mathrm{n}^2\mathbf{E} - \mathbf{n}(\mathbf{n}.\mathbf{E}) = \left[\mathbf{I} + \frac{\mathrm{i}}{\varepsilon_0\omega}\sigma\right].\mathbf{E} = 0 \tag{4}$$

in which I is unit matrix and n(= kc\ω) is the refractive index. The basic dispersion relation can obtain by solving Eq. (4) and the refractive index n can be obtained in terms of plasma parameters.

$$\det(\mathbf{M}) = 0. \tag{5}$$

The different modes of the HF wave have obtained by solving Eq. (5). If the HF wave is travelling in the z-direction in the ionosphere, the solution gives two modes. These are Plasma oscillations and Polarization waves (P-waves). Polarized waves are divided into two as the right (right--handed, R) and left (left-handed, L) (Aydogdu et al., 2004):

$$n_R^2 = 1 - \frac{X(1-Y)}{|(1-Y)^2+Z^2|} + iZ\frac{X}{|(1-Y)^2+Z^2|} \tag{6}$$

$$n_L^2 = 1 - \frac{X(1+Y)}{[(1+Y)^2+Z^2]} + iZ\frac{X}{[(1+Y)^2+Z^2]} \tag{7}$$

Despite of the wave is propagating in the z-direction, there is also a wave which is travelling in the y- (or x-) direction. These waves are Ordinary wave (O-wave) and Extraordinary wave (X-wave):

$$n_o^2 = 1 - \frac{X}{[1+Z^2]} + iZ\frac{X}{[1+Z^2]} \quad (8)$$

$$n_x^2 = 1 - \frac{X[(1-X)(1-X-Y^2)+Z^2]}{[1-X-Y^2-Z^2]^2+Z^2(2-X)^2} + iZ\frac{X[(1-X)^2+Y^2+Z^2]}{[1-X-Y^2-Z^2]^2+Z^2(2-X)^2} \quad (9)$$

where $X = \frac{\omega_{pe}^2}{\omega^2}$, $Y = \frac{\omega_{ce}}{\omega}$ *and* $Z = \frac{\vartheta}{\omega}$

Above equations show that the refractive index $n^2 = (\alpha + i\beta)^2 = M + iN$ becomes complex. The complex component defines characteristics of the absorption, while real component defines properties of dispersion. In this case, the complex component of the refractive index is given by

$$\beta^2 = \frac{1}{2}\left[(M^2 + N^2)^{\frac{1}{2}} - M\right] \tag{10}$$

Absorption in the ionosphere L is (in dB),

$$L = 8{,}68 \int \kappa \, ds \tag{11}$$

where $\kappa = \frac{\omega}{c}\beta$ is the absorption coefficient (Aydogdu et al., 2007). The noise factor of the two lossy ends is numerically equal to attenuation.

The noise factor values have been evaluated from the Eq.(11) for geographic coordinates of 39◦E; 40◦N. Day, time and year are taken as equinox, local time (12:00), 2015, respectively. The used ionospheric parameters have been obtained by using International Reference Ionosphere (IRI-2012) and MSIS-E90 Atmosphere model (https://omniweb.gsfc.nasa.gov/vitmo/iri2012_vitmo.html;https://cohoweb.gsfc.nasa.gov/vitmo/msis_vitmo.html).
All calculations were done for 3,4,5 and 6 MHz frequencies.

In addition, to find the reflection heights depending on the frequencies of the vertically propagated electromagnetic waves in the ionosphere, the real part of the refractive indices given in Eq. (6-9) must be equal to zero. The collision frequency is neglected beside the plasma oscillation frequency at the solution of these expressions. Frequency-dependent reflection heights of equinox days are given in Table 1. The calculations of the noise factor for ordinary, left and right polarized and extraordinary waves variations depending on the frequency and equinox days are shown in Figure 1, 2, 3, 4, respectively.

Table 1.

Frequency-dependent reflection heights of different wave modes for equinox days

	Reflection Heights (km)															
Equinox days	21 March				21 June				23 September				21 December			
Frequency (MHz)	3	4	5	6	3	4	5	6	3	4	5	6	3	4	5	6
Ordinary	99	140	173	189	98	135	176	201	99	155	191	208	106	153	170	187
Right polarized	95	103	150	178	94	100	144	184	95	103	168	197	97	137	160	175
Left Polarized	108	155	181	196	103	149	188	212	108	173	199	215	141	162	178	194
Extraordinary	95	105	149	178	94	101	143	183	95	106	167	196	97	136	159	175

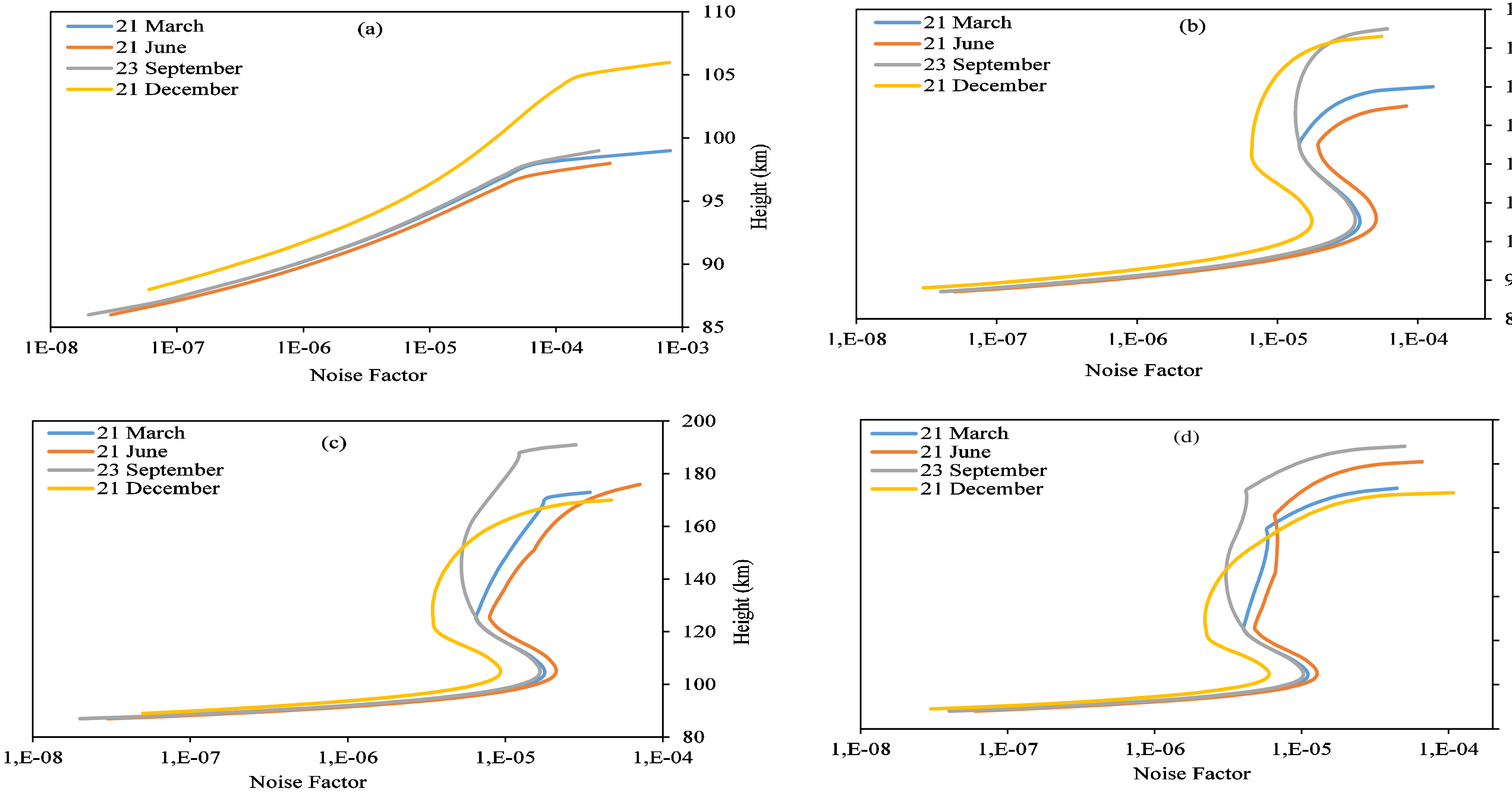


Figure 1. Ordinary wave (a) 3 MHz, (b) 4 MHz, (c) 5 MHz, (d) 6 MHz.

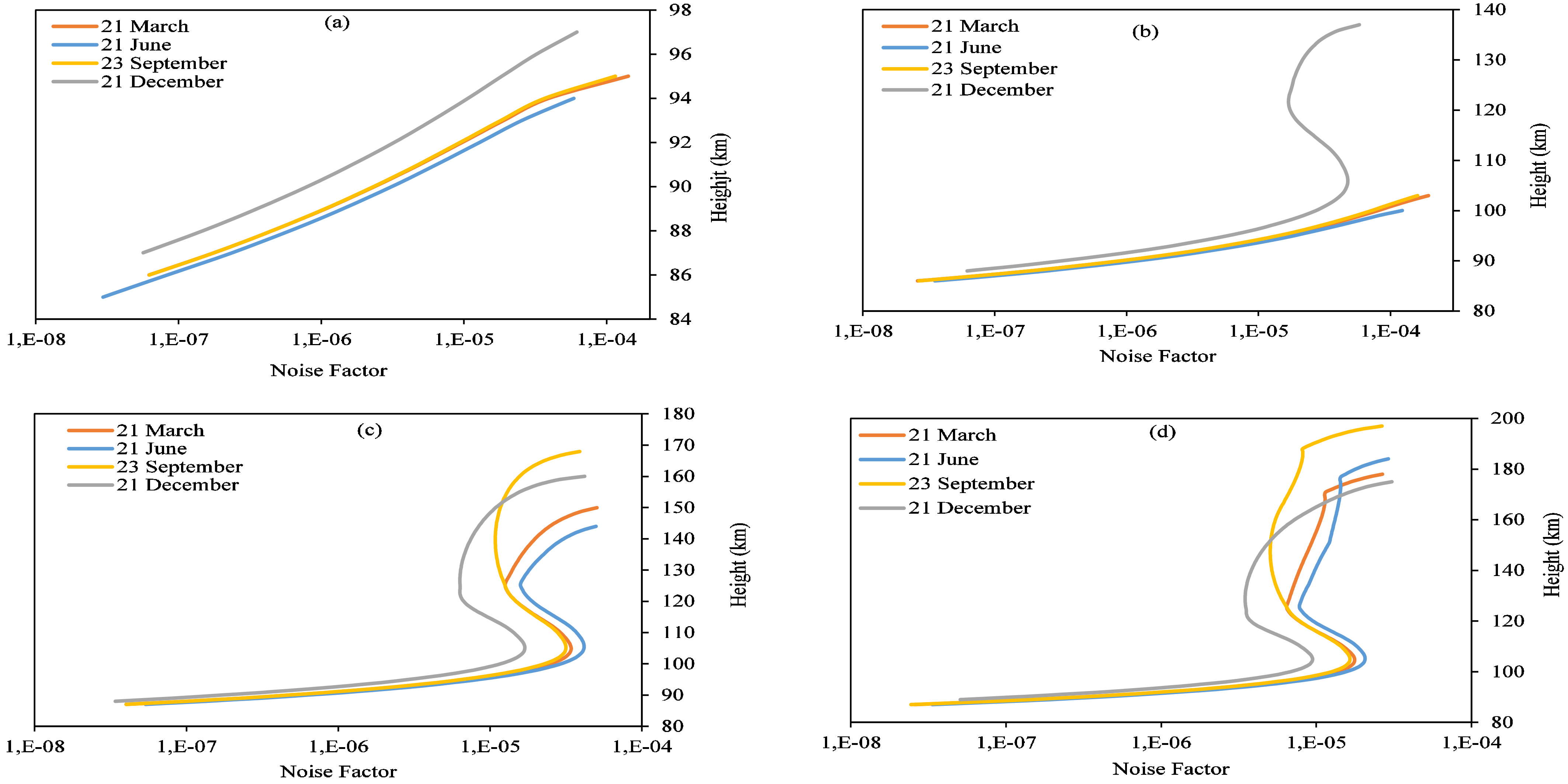


Figure 2. Right polarized wave (a) 3 MHz, (b) 4 MHz, (c) 5 MHz, (d) 6 MHz.

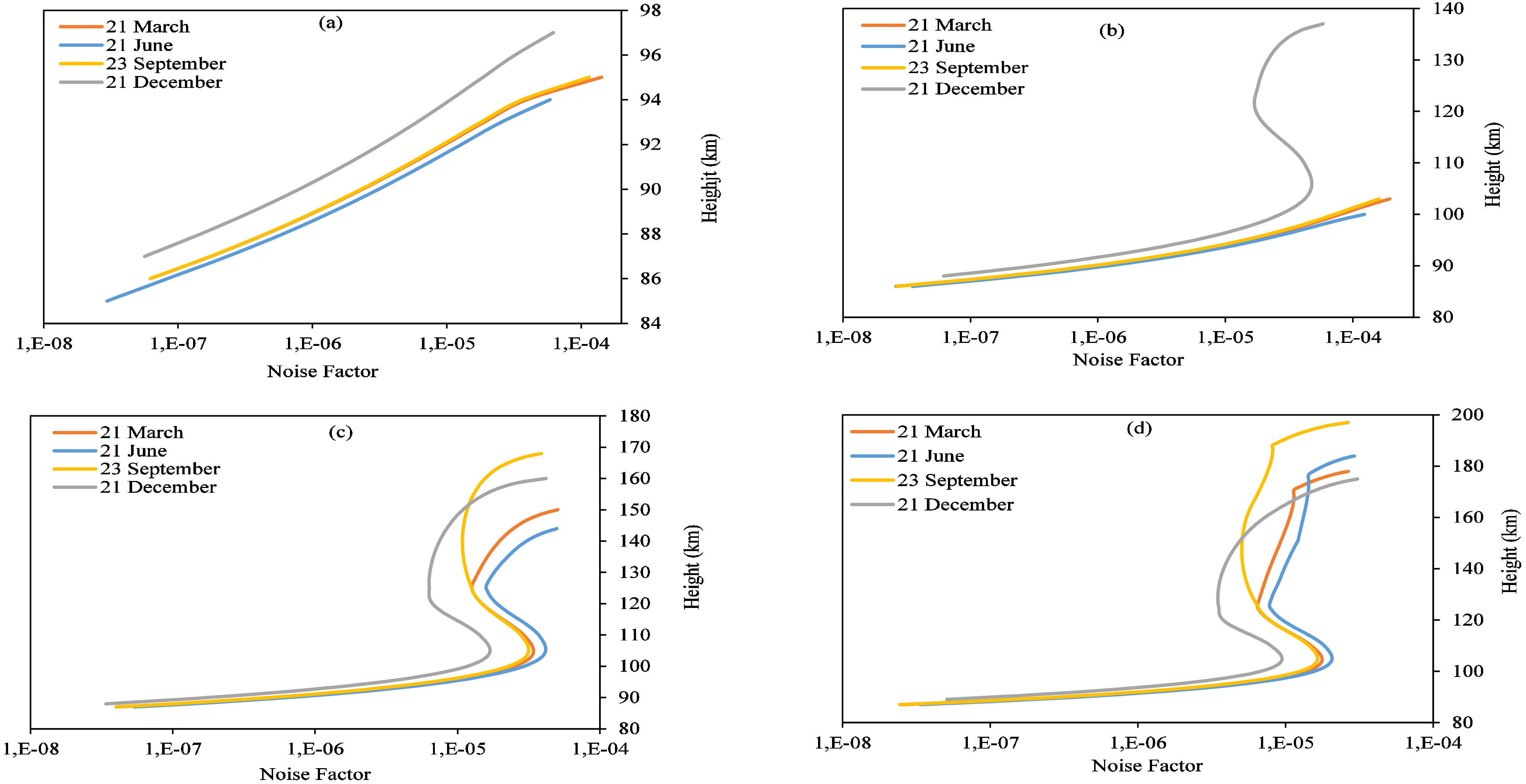


Figure 3. Left polarized wave (a) 3 MHz, (b) 4 MHz, (c) 5 MHz, (d) 6 MHz.

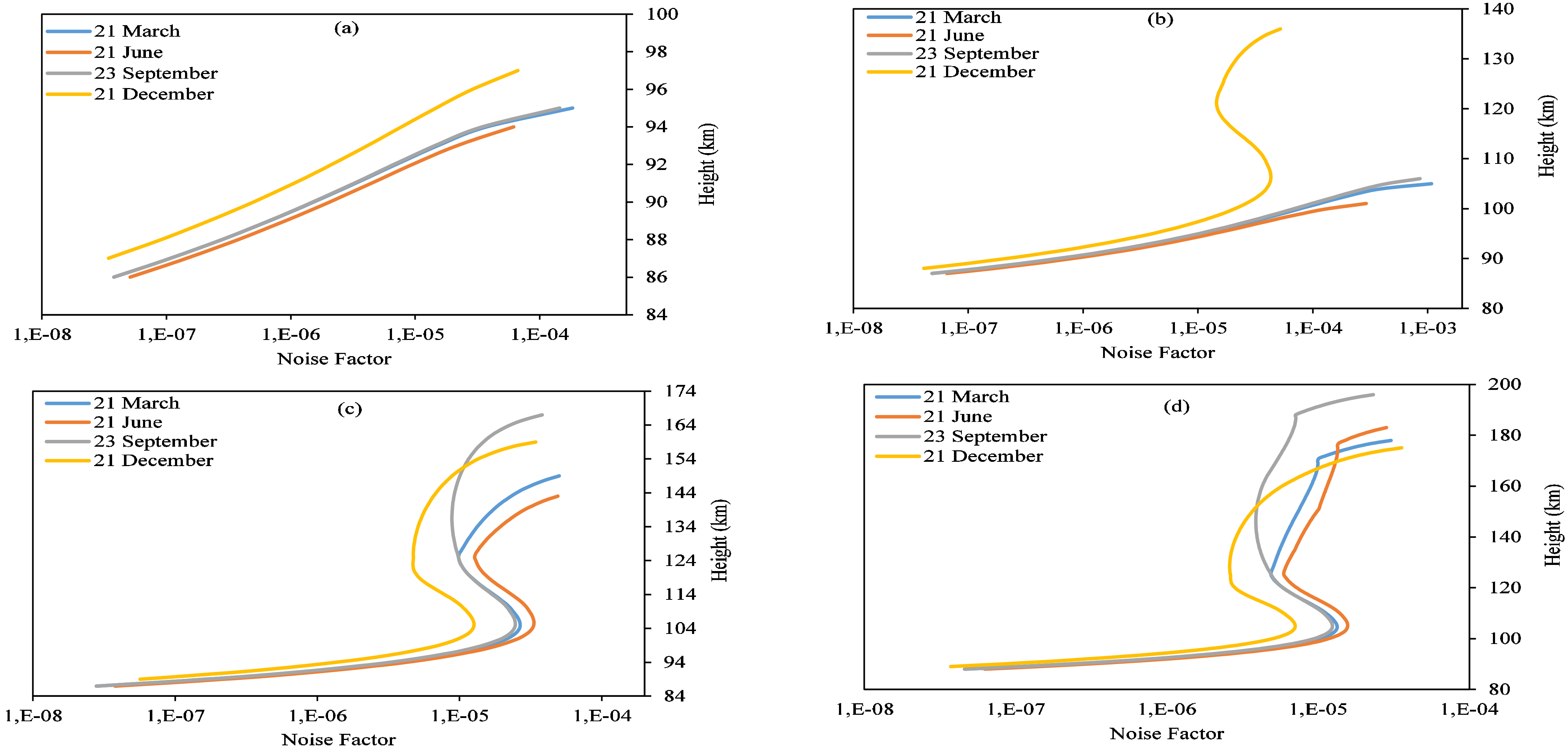


Figure 4. Extraordinary wave (a) 3 MHz, (b) 4 MHz, (c) 5 MHz, (d) 6 MHz.

The electromagnetic waves propagated in the ionosphere are affected due to its variable structure with daily, seasonal and altitude. Although electron density is the the main source of the changes occurring in the ionosphere, there are also other sources at the different parts of the ionosphere and these sources are not negligible.

The following results have been obtained by studying noise factor of different modes of the electromagnetic wave travelling vertically in the ionosphere.

(i) The noise factor values are ranged between 10^{-8} and 10^{-3} at all days, frequencies and modes;

(ii) The noise factor values generally increased in height to reflection point at all days, frequencies and modes;

(iii)The frequency of the wave increases the noise factor values periodically depending on the electron density.

(iv) Since, the 3 MHz wave is reflected below 105 km, the noise factor values increase linearly.

(v) There is a slight reduction in noise factor value of around 105 km for different modes and 4,5,6 MHz waves in equinox days and then shows an increase again. The reason for this is that the nitrogen, oxygen and atomic oxygen values used in the expression of the collision frequency are very small from this height.

(vi) 3 and 4 MHz waves reached the same noise factor values on 21 December at longer distances than the other days for ordinary, left polarized and extraordinary modes, but for 5 and 6 MHz waves on September 23. For right polarized mode this is the exact opposite.

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