4.2 PROPAGATION MODELS

WRAP includes a set of propagation models to cover the major relevant modes of propagation from 30 MHz (in some cases down to 10 kHz) to 350 GHz. Planning of HF systems employing ionospheric propagation in the frequency range of 2-30 MHz can be performed in WRAP through the integration with a family of software codes developed by the Institute for Telecommunication Sciences in the USA. The planning of HF systems is described in section 18 and is not treated more in this section.

Usually calculations can be performed with alternative models:

1. Models based on detailed terrain information:

- ITU-R P.526
- ITU-R P.452
- Detvag-90/FOI

2. Models based on coarse terrain and land cover information:

- ITU-R P.370
- Detvag-90/FOI

3. Statistical models:

- Longley-Rice
- Okumura – Hata/COST-231 – Hata
- COST-231 – Walfish-Ikegami
- ITU-R P.619

4. Free space loss:

- Free Space

In addition to all these models the attenuation due to atmospheric gases can be added if selected in accordance with [**A09**] for terrestrial paths or in accordance with **A09**/**[B03]** for space paths if selected by the user.

The user can select the desired model. Detailed terrain models invariably require more computer capacity, which may result in long processing times. The selection of the appropriate model for each type of work will be based on the operator's experience from the operation of WRAP.

Complex terrain dependent models typically incorporate several different models of varying propagation mechanisms to extend the applicability over terrain conditions, atmospheric conditions and frequency range. This may require fitting and weighting of the models to each other and normally adjustments of parameters in order to achieve a physically reasonable result that is continuous over geographical range, terrain conditions and frequency range. The detailed terrain models in WRAP are implemented in this way.

At distances below 100 m a special short-range method is used as described in [**A24**]. The method accounts for coupling between antennas in the near-field and approaches the free-space values at larger distances. It also accounts for the directional properties of the antennas and their three-dimensional relative positions.

4.2.1 Free Space

The basic free-space model is implemented [**A05**].

4.2.2 Longley-Rice

The well-known propagation method (also referred to by ITU- R Rep 239-7) proposed by Longley and Rice [**A06**] is implemented. This method is based on extensive measurements. The terrain parameter Δh can either be an estimate or its value can be calculated using the *Geographic Calculator/Roughness* function based on the terrain database. The median loss is calculated based on two-ray theory and extrapolated diffraction attenuation for radio line-of-sight paths. For trans-horizon systems either diffraction or forward scatter attenuation is used.

The method is applicable for the frequency range 20 MHz – 40 GHz, antenna heights in the range 0.5 – 3000 m and for distances up to 2000 km.

4.2.3 ITU-R Rec. P.370-7

The propagation curves in [**A07**] are implemented. The parameter Δh can be assigned any fixed value used for all azimuths. Its value can also be calculated using the *Geographic Calculator/Roughness* function. Receiver terrain correction can be made in accordance with the terrain clearance angle (fixed value - not read from the terrain database). The compensation for mixed land and sea paths is made in accordance with [**A07**].

The propagation curves are valid for the frequency bands 30 – 250 MHz and 450 – 1000 MHz, for distances between 10 km and about 1000 km. For frequencies between 250 and 450 MHz the propagation curve closest to the used frequency is selected. The validity has been extended for shorter distances by extrapolation down to 1 km and by interpolation between the 1-km value and the free-space transmission loss at 100 m separation between the antennas.

4.2.4 ITU-R Rec. P.526-6

The general method for diffraction over one or more obstacles in accordance with [**A08**] is implemented. This method is based on Deygout's construction, limited to a maximum of three edges, plus an empirical correction. The empirical correction of this recommendation tends to overestimate the loss for paths with a single obstacle. For the single-obstacle case the correction has therefore not been included. The method is fairly quick since only the diffraction loss is calculated. It is mostly useful in the UHF and above frequency range, where the influence of the surface of the earth in most cases can be neglected.

The basic geometrical calculations defined in P.526-6 are only valid for fairly low antenna heights above ground due to approximations. WRAP uses exact spherical geometry calculations, which allows calculations using P.526 for arbitrary antenna heights, even up to satellites in the geo-stationary orbit at about 36000 km above sea level.

4.2.5 Okumura – Hata/COST-231 – Hata

The Okumura – Hata and COST-231-Hata models **A10** are implemented in the same set of formulas. This is a statistical model based on measurements of Okumura et. al., extended upwards in frequency by the COST-231 study. The formulas for Dense Urban, Urban, Suburban, Rural Quasi-Open and Rural Open environments are implemented. A user-defined value of the propagation loss referenced to the Urban environment can also be entered. The applications are restricted to situations where the base station antennas are above rooftop levels of buildings adjacent to the base station.

The method is applicable for the frequency range 150 MHz – 2000 MHz, base station antenna heights in the range 30 – 200 m, mobile heights in the range 1 – 10 m and for distances in the range 1 - 20 km.

4.2.6 COST-231 – Walfish - Ikegami

The COST-231-Walfish-Ikegami model [**A11**] is implemented. This is a statistical model based on measurements performed in the city of Stockholm. This model is more sophisticated than **COST-231 – Hata**.

The method is applicable for the frequency range 800 MHz – 2000 MHz, base station antenna heights in the range 4 – 50 m, mobile heights in the range 1 – 3 m and for distances in the range 0.02 - 5 km.

4.2.7 Detvag-90/FOI

Detvag-90/FOI [**A12**], [**A13**], is a collection of models of the transmission loss for electromagnetic wave propagation. Depending on the settings different propagation models can be chosen to make a trade-off between accuracy and speed. The following models are included within **Detvag-90/FOI**:

- Diffraction models:
  - Epstein-Peterson
  - Giovaneli
  - Vogler
  - Geometrical Theory of Diffraction (GTD)

- Spherical-earth models:
  - The ITU-recommended GRWAVE, including a large number of settings and options.
  - Simplified, fast method accounting for the combination of direct wave, ground reflected wave and surface wave by approximation

- Optional methods:
  - Vegetation methods
  - Methods for urban areas

The terrain dependent calculations are valid for distances above 100 m.

Many selectable models are available to tailor the calculation for specific purposes. In addition, default selections (Quick settings) are available according to the following:

Table 4.1: *Default settings for Detvag-90/FOI propagation model (Quick tab,* **Low/High** *accuracy)*

Method ↓	***Frequency range*** **and** **Accuracy**					
	Below 30 MHz		***30 – 1000 MHz***		***Above 1000 MHz***	
	Low	**High**	**Low**	**High**	**Low**	**High**
Spherical earth	GR Start	GR Millington extended	Old with conductivity	None	None	None
Diffraction No. of obstacles	None -	None -	Giovaneli 3	GTD 7	Giovaneli 3	GTD 7
Urban	None	None	Add cover height	Add cover height	Add cover height	Add cover height
Vegetation	None	None	Add cover height	Add cover height	Add cover height	Add cover height
Effective antenna height	None	None	None	None	None	None

When both a spherical earth model and a diffraction model (except for GTD) are selected weighting between the two is performed according to the square-root model of **A13**. The GTD model is only used without weighting.

The validity of the method depends on many parameters, i.e. in some cases applicable for the frequency range 10 kHz – 10 GHz and for distances up to 2000 km. With addition of attenuation due to atmospheric gases the frequency range is increased upwards.

When using the spherical earth methods *Old* and *Old with conductivity* the following limit on the effective antenna height should be observed, otherwise the result is not valid:

$$h = \frac{2700}{f^{0.67}}$$

The antenna height is given in metres and the frequency is in MHz.

The GTD model is recommended for higher antenna heights at VHF frequencies and above. The calculation time for this method is slightly longer.

When choosing between the *Low* and *High* alternatives there is also a selection whether to *Use effective antenna height for TX and RX (for very high antennas and/or mountainous terrain)*. This selection should be made to improve the accuracy of the calculations in for instance situations where a mountain-top location is used for the station.

4.2.8 ITU-R Rec. P.676-2 and Rec. P.618-6 (Attenuation due to atmospheric gases)

To all of the models above the attenuation due to atmospheric gases [**A09**] can be added if selected. Attenuation due to oxygen according to formula 1a and 1b and water vapour according to formula (2) is added to the loss calculated by the other models. The total atmospheric attenuation along the path is calculated. Temperature corrections are performed and the ground level pressure is assumed to be 1013 ± 50 hPa.

For frequencies 57 GHz ≤ f ≤ 63 GHz the attenuation is calculated according to fig 2 in [**A09**].

Three selections can be made:

- Terrestrial paths: This selects the P.676-2 model, with assumption that the path is terrestrial.
- Space paths: This selects the P.618-6 method, specifically intended for paths between earth and space
- None: No atmospheric attenuation.

4.2.9 ITU-R P.452-9

There is in particular for interference and over-range applications in the UHF and microwave frequency range a need for calculation of the transmission loss for low percentages of time. This is accomplished by a combination type of model as described in **[A26]**, which is particularly adapted to various propagation mechanisms giving rise to over-range situations. The following models are incorporated. Number 1 to 6 form the clear-air model.

1. Line-of-sight
2. Atmospheric gaseous absorption (according to [**A09**])
3. Diffraction (according to [**A08**])
4. Tropospheric scatter
5. Ducting/layer reflection
6. Clutter losses
7. Hydro-meteor scatter

The geographically dependent parameters for this model are entered by the operator based on world maps of the atmospheric refractive index and sea-level surface refractivity.

The ITU-R P.452-9 clear-air model (specifically the tropospheric scatter model) requires antenna gain data for calculating some antenna coupling phenomena. Therefore, for calculations normally not using receiving antenna data as an input, e.g. transmission loss, an antenna gain of 0 dBi is assumed in WRAP. For these calculations the hydro-meteor scatter model should not be used since it requires detailed receiver antenna data..

4.2.10 ITU-R P.619-1

The method ITU-R P.619 specifically intended for propagation paths between earth and space is implemented in accordance with **[B02]**. This method accounts for the following:

- Free-space loss
- Attenuation due to atmospheric gases as defined in ITU-R P.618-6 **[B03]**
- Beam spreading as defined in ITU-R P.618-6 **[B03]**
- Monthly and long-term statistics of amplitude scintillations at elevation angles larger than 4° as defined in section 2.4.1 of ITU-R P.618-6 **[B03]**. Values for elevation angles less than 4° are set to the value for 4°.

- Identification of whether the space station and the point on earth are beyond radio-optical visibility, using a spherical-earth approximation. The propagation loss is set to a very high value if they are outside visibility.

Ray bending is implemented according to ITU-R P.834, **[B07]** to account for the apparent elevation angle from stations on the surface of the earth to space stations due to refraction in the atmosphere.

Precipitation scatter is implemented in the ITU-R P.452 **[A26]** model, which can be selected independently of the earth-space model P.619 to calculate the transmission loss due to this phenomenon.

4.2.11 Notes on Space-to-Space and Space-to-Earth Paths

Calculations of propagation loss between satellites is performed with the free-space model if the satellites are within optical visibility. Paths beyond optical visibility are given a very high transmission loss. The *Class of Station* is used to identify whether this is a space-to-space path, i. e. the condition is that both stations shall be of Class of Station *Space station*.

Only the following propagation models can be used for space-to-earth paths:

- **Free-space**: With the obvious limitation that no consideration is taken to the potential obscuring of the line-of-sight between the stations by the earth curvature

- **ITU P.526**: The geometrical formulas of this model have been extended in the WRAP implementation to account for the full spherical geometry of the space-to-earth path.

- **ITU P.619**: This model has been extended with a geometrical condition to identify the limit of the line-of-sight between the satellite and the points on earth.

When selecting these models to use them for space-to-earth paths it is important to also select the proper *Atmospheric attenuation* model, which is the *Space path*.

The **Coverage** calculations of *Clearance* and *Required antenna height* are valid with the full spherical geometry formulas in addition to these propagation models.

The geometry calculations account as applicable for the earth radius, the eccentricity of the earth and for the change in elevation angle due to refraction.

4.2.12 Consideration to polarisation

WRAP considers the polarisation of the transmitted wave, the polarisation changes caused by the propagation medium and the polarisation of the receiving antenna in the ways described in this section.

The following propagation models inherently consider polarisation:

- Longley – Rice
- CRC
- Detvag-90/FOI (some models).

They consider two cases of polarisation: Vertical and Horizontal. Transmitted polarisations other than vertical are all treated as horizontal when calculating the transmission loss. The other propagation models do not consider polarisation and will thus give identical transmission losses for all polarisations.

Polarisation perturbations in the propagation medium are considered, with the effect being that the defined cross polarisation isolation as defined for the transmitting antenna is changed along the path to a lower value. ITU recommendations and other documents as mentioned in the following form the background for the specific implementation in WRAP.

- Recommendation ITU-R P.1406 states that XPD is in the order of 5-8 dB in urban and residential areas and over 10 dB in open areas. The figures are valid at 900 MHz. XPD increases to about 18 dB at 35 MHz. (These values are valid for the propagation path effects of the XPD.)
- Recommendation ITU-R 419 states that for television services in band I and III (VHF) the median discrimination is 18 dB at roof top level and could be reduced to 13 dB at street level. In band IV and V (UHF) the value 18 dB is valid also. However these figures combine the effect of the XPD and the discrimination provided by directivity.

According to both recommendations the XPD seems to depend little on distance.

- Measurements at 160 MHz show that the propagation path part value of XPD varies from 5 dB in forest to 15 dB in open area (Petersen, G.M., *Path loss measurements at 160 MHz for horizontally polarized transmission and vertical reception antenna, Nordic Radio Symposium*, Aalborg, 1992)
- *"Digital Mobile Radio Towards Future Generation Systems - COST 231 Final Report"* states that XPD is typically 6-20 dB with the higher values in rural or suburban areas. The frequency bands of interest in this report are around 900 MHz and 1800 MHz. However the report states that XPD decreases with distance.

The following formula for cross-polar discrimination XP_{PP} in the propagation medium is implemented in WRAP:

$$XP_{PP} = 26.8 - 5.67 \log_{10} f_{Mhz} \; [dB]$$

The formula is shown in **Figure 4.3**.

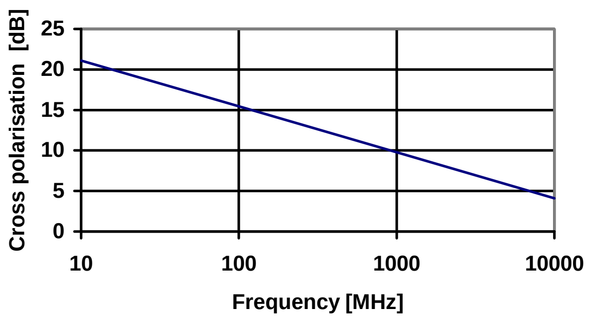

Figure 4.3: *Cross-polar discrimination in the propagation medium.*

Consideration to polarisation changes in the propagation medium can be selected by the user between the following alternatives:

- None (not considered)
- Frequency-dependent (formula as above)
- Fixed value.

The lowest value of the cross polarisation discrimination (XPD) defined for the transmitter antenna, XPD calculated as above for the propagation medium, and the XPD defined for the receiver antenna is used as the resulting XPD value.

Antennas are defined with their cross polarisation value, which defines the ratio [dB] between the radiation of the ordinary polarisation and the orthogonal polarisation. One value is used for all azimuths and elevations. See **Table 4.2** for the definition of which polarisations that are considered to be orthogonal (indicated by XPD) and the hard-coded values of XPD between non-orthogonal polarisations.

Table 4.2: *Values of cross-polarisation discrimination between antenna polarisations. "XPD" denotes value entered as an antenna parameter in the Edit Antenna window.*

Tx → / Rx ↓	H	V	SR	SL	CR	CL	D	M	L
H	0	XPD	3	3	3	3	3	0	3
V	XPD	0	3	3	3	3	3	0	3
SR	3	3	0	XPD	3	3	3	0	3
SL	3	3	XPD	0	3	3	3	0	3
CR	3	3	3	3	0	XPD	3	0	3
CL	3	3	3	3	XPD	0	3	0	3
D	3	3	3	3	3	3	0	0	3
M	0	0	0	0	0	0	0	0	0
L	3	3	3	3	3	3	3	0	0

H: Horizontal	SL: Slant left	D: Dual
V: Vertical	CR: Circular right	M: Mixed
SR: Slant right	CL: Circular left	L: Linear

Note that the "mixed" type of polarisation can be used in WRAP for antennas and radiation where consideration to polarisation discrimination is not desired.

4.2.13 Guidelines for selection of propagation models

All propagation models are selectable through the Propagation Model window. Selection should be made carefully to ensure relevant results for the particular calculation at hand. The following information provides guidelines in this respect. These basic conditions should be considered:

1. Frequency
   - Some propagation models have limited frequency range

2. Terrain dependence
   - Is terrain data available?
   - Is the calculation supposed to be of general applicability or specific for the exact station locations?

   For general applicability a terrain-independent model should be selected.
3. Antenna height above ground
   - Some propagation models neglect the influence of the ground
   - Are one or both antennas close to the ground?

   Select a model that properly accounts for the ground presence if one or both of the antennas are close to the ground (as is typical for ground-to-ground and ground-to-air paths).
4. Calculation speed
   - Terrain-dependent models are generally slower due to their detailed treatment of the height and land cover characteristics

Table 4.3 gives a summary of the properties in this respect for each of the selectable propagation models to assist in choosing a suitable model for each need.

Note 1: Whenever a model is stated to be valid at frequencies above about 5-10 GHz this assumes that the calculation is set to include atmospheric attenuation.

Note 2: Ionospheric propagation in the 2 – 30 MHz range is calculated within the HF tool.

Table 4.3: *Summary of properties of selectable propagation models.*

Model	Frequency range	Terrain dependence	Antenna height above ground	Calculation speed
Free space	No frequency limitation	No terrain dependence. Gives the same transmission loss in all directions.	The model assumes no ground influence.	Very fast
Longley-Rice	20 MHz to 40 GHz	No terrain dependence. Terrain influence is given as a terrain roughness parameter to the model, entered by the operator. Gives the same transmission loss in all directions.	0.5 – 3000 m. The 3000 m above ground level antenna height limitation does not significantly reduce accuracy for higher antenna heights.	Very fast
ITU-R P.370-7	30 – 1000 MHz	Terrain information is taken from the ITU Digitized World Map to determine the path lengths over land and over sea. The operator can enter a terrain roughness parameter. Gives the same transmission loss in all directions, if the path is wholly over land or sea.	One antenna in the interval 1.5 – 40 m and the other antenna 37.5 – 1200 m above ground.	Very fast

Model	Frequency range	Terrain dependence	Antenna height above ground	Calculation speed
CRC	30 MHz to above 100 GHz	Terrain information taken from the height and terrain classification databases. Gives fully terrain-dependent transmission loss.	Valid for all antenna heights.	Slow
ITU-R P.526-6	From about 500 MHz to above 100 GHz. For situations where one or both of the antennas are high above ground (such as in ground-to-air and air-to-air links) it can be used from 100 MHz.	Terrain information taken from the height and terrain classification databases. Gives fully terrain-dependent transmission loss, however neglecting the electrical characteristics of the ground and ground reflections.	Valid for all antenna heights.	Fast
Okumura-Hata/COST-231-Hata	150 – 2000 MHz (no hard limit at 2000 MHz – can be used for 2 GHz cellular applications)	No terrain dependence. The operator can enter a type of environment (urban, suburban, rural etc.). Gives the same transmission loss in all directions. The distance is limited to 1 – 20 km.	One antenna in the interval 30 – 200 m and the other antenna 1 – 10 m above ground.	Very fast
COST-231 – Walfish-Ikegami	800 – 2000 MHz (no hard limit at 2000 MHz – can be used for 2 GHz cellular applications)	No terrain dependence. The operator can enter the type of environment and parameters describing the buildings and streets. Gives the same transmission loss in all directions. The distance is limited to 0.02 – 5 km.	One antenna in the interval 4 – 50 m and the other antenna 1 – 3 m above ground.	Very fast

Model	Frequency range	Terrain dependence	Antenna height above ground	Calculation speed
Detvag-90/FOI	10 kHz to above 100 GHz. Ionospheric propagation is not considered.	Terrain information taken from the height and terrain classification databases. Gives fully terrain-dependent transmission loss. *Note that Detvag includes a number of selectable models and can be set to be non-terrain-dependent as well. This is however not the normal use.*	The fast methods (non-GR ground wave) have limitations on the maximum antenna height: Frequency Height 30 MHz 300 m 100 125 300 59 1000 26 3000 13 *Note that for most practical cases the influence of the ground (apart from diffraction) can be neglected above 1 GHz even at low antenna heights. The default methods of Detvag ("Quick" settings) therefore do not have the above limitations above 1 GHz.*	Fast-to-medium for most settings. Very slow when used with the GR methods (for ground wave below about 30 MHz)
ITU-R P.676-2 and P.618-6	1 – 350 GHz. P.618-6 for space paths does not include the oxygen gap consideration at 60 GHz.	Not applicable. The transmission loss calculated by the atmospheric attenuation models is added to the loss calculated by the selected propagation model.	No antenna height dependence is included (apart from the satellite height for the space path model). This limits the applicability to heights up to a few thousand metres for terrestrial paths.	Very fast
ITU-R P.452-9	0.7 GHz to above 100 GHz	Diffraction calculations are performed using the P.526 method, giving terrain dependence. Rain scatter parameters are read from the ITU Digitized World Map. Otherwise the model is non-terrain-dependent.	The model is intended for stations on the surface of the earth. Antenna heights should be less than a few hundred metres.	Fast for most settings. Slow for very long distances.
ITU-R P.619-1	From about 300 MHz to above 20 GHz. The lower limit is due to neglection of ionospheric scintillation. The upper limit is due to the modelling of tropospheric scintillation.	No terrain dependence, apart from consideration to shadowing by the earth considered as a sphere.	The model is applicable for earth-space paths, with the space station being at non-geostationary orbit height or above and the earth station being on the surface of the earth, with antenna height less than a few hundred metres.	Very fast

The selection of the appropriate propagation model depends to a large extent on the specific application. A number of applications and the corresponding recommendation for propagation models are shown in **Table 4.4**.

Table 4.4: *Recommendation of propagation models for various applications.*

Application	Frequency	Recommended propagation model
Ground-to-ground	<30 MHz, ground wave	Detvag-90/FOI. Quick/Low if terrain data is not available; otherwise Quick/High. Start with very low resolution in Coverage calculations to check the calculation speed before making detailed calculations.
	>30 MHz	**Terrain data available:** Detvag-90/FOI, Quick/Low if antenna height conditions are fulfilled. Otherwise Detvag-90/FOI, Advanced, GTD. CRC (if available) is applicable irrespective of antenna heights. **No terrain data available:** Longley-Rice. For specific services: Broadcast: ITU-R P.370 Cellular: Okumura-Hata/COST-231-Hata or COST-231 – Walfish-Ikegami
Ground-to-air	<30 MHz, ground wave	Detvag-90/FOI. Quick/High.
	30 – 100 MHz	**Terrain data available:** Detvag-90/FOI, Advanced, GTD. CRC (if available) is applicable irrespective of antenna heights. **No terrain data available:** Longley-Rice
	>100 MHz	**Terrain data available:** ITU-R P.526 is the first choice due to its fast calculation speed. Detvag-90/FOI, Advanced, GTD. CRC (if available) is applicable irrespective of antenna heights. These should also be used if there is specific need to account for ground reflections to show occurrence of areas of increased transmission loss due to cancellation between the direct ray and ground reflected rays (normally only relevant over water). **No terrain data available:** Longley-Rice
Air-to-air	>30 MHz (lower frequencies usually of little interest)	Longley-Rice as an overall method at heights where terrain obstructions are not important ITU-R P.526 for cases where the terrain influence due to obstructions are of interest
Earth-to-space	>50 MHz	ITU-R P.619. Make sure to select the *Space paths* atmospheric attenuation model.
Space-to-space	All frequencies	Free space. Note that *Class of Station* should be set to *Space station* for both stations if the calculation is to account for shadowing by the Earth.

4.2.14 Advisor for the selection of propagation model

An automatic advisor for the selection of suitable propagation models is available in all places where the user selects a model. The full details can be found in **[B17]**. Properties that form part of the applicability criteria are taken automatically from the marked station(s) taking part in the calculation and they are entered as default values into their respective fields as shown in **Figure 4.4**. Initially the *Calculation speed* is set to *Medium*. When pressing *Evaluate* the applicable propagation models are listed, and the user selects one (perhaps the only one). If there is no model listed after the evaluation the user should allow all models irrespective of calculation speed.

The advisor can also be used with manual input of all entry parameters.

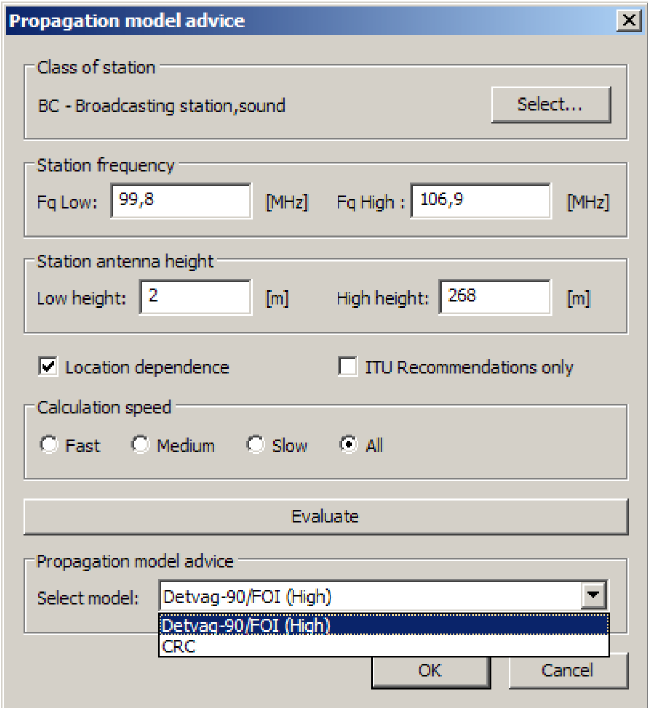

Figure 4.4 *Propagation model advice window.*

4.3 ANTENNA DIAGRAMS

4.3.1 Generation of 3D antenna patterns

The antenna radiation pattern is given in the horizontal and vertical plane. The calculation of the antenna gain value in an arbitrary direction is performed by the following equation,

$$G(\varphi,\theta) = G_{\max} - \left(A(\varphi,0) + A(0,\theta) - A(0,0)\right) \quad [dB]$$