Science & Technology Facilities Council

RCRU

Wide-range propagation model

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dB Spectrum Services Ltd

ÆGIS spectrum engineering

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1 Progress report:

The Wide Range Propagation Model (WRPM) project was started in May 2008, and is scheduled to last for two years. The report presented here summarises the current position of the project, coming to the end of the first year of work, and puts the work done into context in the wider project plan. The main aim of the study is:

- To develop a unified propagation model for the prediction of signal levels on terrestrial paths in a frequency range of approximately 30MHz–50GHz, considering both availability and interference, which covers times from 0–100%.

There are two issues. The first is dealing in a uniform way with time percentages above and below the median (50%), representing both fading and enhancement. Current ITU-R methods tend to focus on one half or other of the distribution. The second issue is dealing with the extreme time percentages at either end of the scale, i.e. time percentages below 0.001% or above 99.999% of the time. In practice it will be necessary to limit, smoothly, the percentage time, probably to about 0.00001% to 99.99999%, but this requires attention to the formulation of models.

For the WRPM this is dealt with by considering individually and then combining the underlying "sub models" for each propagation mechanism shown in Table 1-1.

Clear-air/anomalous propagation (ducting and multipath)
Terrain diffraction
Gaseous absorption
Tropospheric scatter
Rain attenuation
Ionospheric reflection

Table 1-1: Significant propagation mechanisms

This "sub-model "approach is used by P.452 and to some extent by P.530 though there are significant differences in how the mechanisms are modelled. The structure of the project is to develop a uniform 0–100% approach to sub models in Work package 1, and deal with the issues of combining the sub models including all correlation issues in work package 2. Work package interactions and outputs are shown in Figure 1-1.

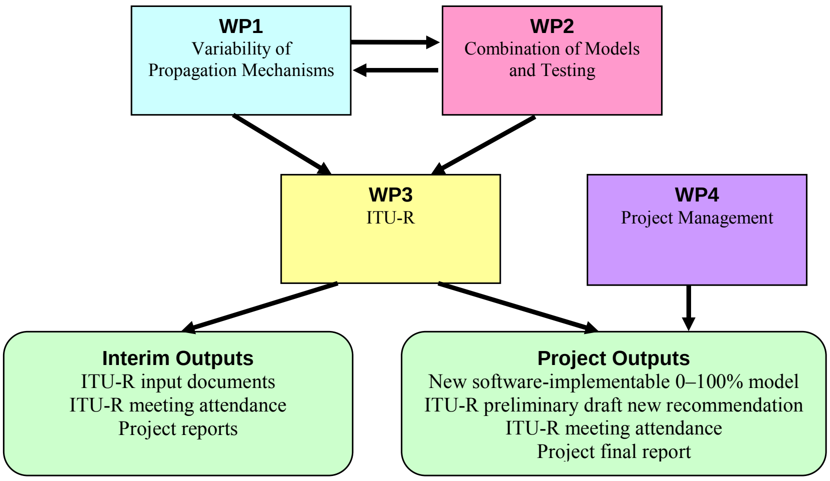

Figure 1-1: Work package structure

The areas where work is needed were explained in the project bid and developed at the kick-off meeting. Table 1-2 shows the tasks agreed for the first year and their status. The following sections then provide an overview of the technical work done so far in the project with further details presented in the related annexes (attached as separate documents).

Variability of propagation mechanisms:		Annex number
WP1a Diffraction, multipath and ducting	Analyse atmospheric data (10 years ~7,000 ascents. Need method to get beyond 0.1%)	1
	Extend ducting model to low frequency (introduced after ITU-R SG3 meetings in June 2008)	4
	Extend k-factor model to 0-100% time	1
	Contrast 452 and 530 multipath models and select best	Ongoing work
	Work on reducing standard deviation of error in the diffraction model	2 and 9
	Work on spherical earth diffraction (introduced after ITU-R SG3 meetings in June 2008)	3
WP1b Rain and atmospheric gases	Research databanks for water vapour variability	1
	Model rain fading using full rain rate distribution for 0-100% time	8
	Investigate diurnal variability gaseous attenuation due to water vapour	1
	Correlation of water vapour attenuation in ducting/non-ducting conditions	1
WP1c Troposcatter and sporadic-E	Correct troposcatter model error allowing unrealistic common volume heights	6
	Extend troposcatter model to cover both ends of the time distribution.	6
	Sporadic-E – Add this effect into the WRPM and produce mapping for FoEs probability	7
Combination of models		
WP2a Correlation of mechanisms	Clear air effects – correlation between line of sight and diffraction enhancements – search for available data of concurrent measurements of key parameters	1
	Joint statistics of clear air and precipitation	1
ITU-R		
WP3 ITU-R liaison	Provide input documents and technical support for meeting at Boulder, Colorado, June 2008	5

Table 1-2: Tasks for year 1 as agreed at the kick-off meeting

1.1 Sporadic E (WP1)

The WRPM is required to operate down to 30MHz and to cover time percentages to arbitrarily low values. At low VHF the Sporadic E propagation mechanism becomes important as a source of interference. (This relates to WP1 Activity C.)

Sporadic E is an ionospheric propagation mode whereby signals are reflected from concentrated patches of metallic ions that occur in the E layer at an altitude of around 90km. A suitable path loss model has been implemented (see Annex 7) and an example of the predicted field strength is given in Figure 1-2. As well as a clear reduction in the significance of sporadic E as the frequency increases there is also a strong distance dependence resulting in a notable skip zone. Sporadic E occurrence is difficult to predict and must be dealt with statistically. It is independent of the other propagation mechanisms considered in the WRPM. As the ionisation is generated by solar radiation, sporadic E propagation tends occur most frequently in the daytime during the summer.

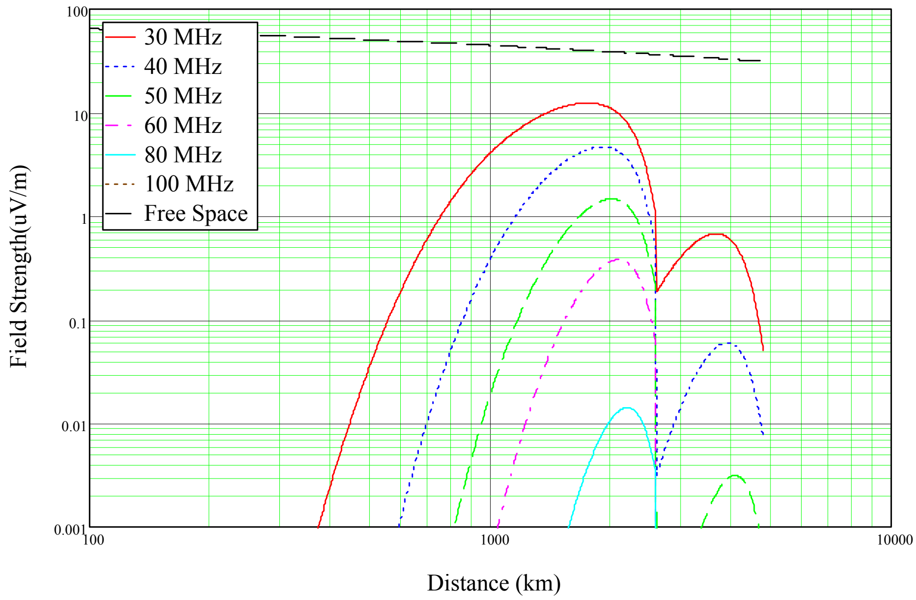

Figure 1-2: Sporadic E field strength 1% time for Europe for a 1kW EIRP transmission

To allow Sporadic E to be incorporated in the WRPM, the ITU-R model given in Recommendation P534-4 has been adopted with digitized maps of the parameter FoEs, the critical frequency of sporadic E against time percentage generated by an analysis of 25 years of global Ionosonde data. The new maps compare well observation data. Further work to improve the global mapping is proposed.

1.2 Modelling of Meteorological Statistics (WP1 and WP2)

Central to WRPM is the element of time-variability. This will be represented by statistical distributions that give transmission loss as a function of time percentage. In WRPM, the time-variability is caused by variability of the Earth's atmosphere. There is obviously a link between the statistics of the meteorological variables and the statistical distributions of propagation path loss. Sometimes this relationship is fairly direct (for example the dependence of rain fading on rainfall rate) and sometimes it is indirect, even obscure (as is the case of the ducting model).

A number of issues have been investigated which relate to the statistics of the underlying meteorology that is relevant to the propagation models. This has two aims:

(a) To provide justification for assumptions made in current models (such as the way the distributions from different mechanisms are combined), and

(b) To develop new models where necessary. The methodology was to derive new statistics from a 20-year dataset of radiosonde ascents, together with co-sited rainfall measurements.

The work is presented in Annex 1. It comprises essentially three self-contained studies. Each addresses a particular issue in the context of the WRPM:

1. A new global model for the full cumulative distribution function of ΔN in the range 0–100% has been developed. It is based on three ΔN-related parameters, specified by means of global maps. (The maps are available as data files in the standard ITU-R format.) ΔN is used to calculate the effective Earth radius that provides the time dependence of the diffraction model.

2. The statistics of water vapour were investigated. Atmospheric absorption depends directly on the water vapour density. In current propagation models (P.452 and P.1812), the water vapour density is specified in a very simple, time-independent way. This study compares the surface value and vertical profiles of water vapour density obtained from the radiosonde database with the ITU-R P.836 and P.835 models. The seasonal and diurnal variation is investigated at the surface and as a function of height. Improved modelling of water vapour density is proposed for WRPM.

3. The statistical correlations between four meteorological mechanisms were examined: ΔN, ducting, rainfall and water vapour. These mechanisms provide the time-variability in the terrain diffraction, ducting/layer reflection, rain fading and gaseous absorption propagation models, respectively. All six pair-wise combinations of these mechanisms were considered. The issue of how to combine the transmission losses predicted by these separate models was not dealt with in detail, although it is possible to make recommendations in those cases where the meteorological correlations are simple and the link between the meteorology and the propagation loss is clear.

These studies contribute to the following activities:

- WP 1a: Refractivity effects—variability of propagation mechanisms
- WP 1b: Attenuation effects—rain and atmospheric gases
- WP 2a: Correlation of mechanisms

1.3 Diffraction modelling (WP1)

1.3.1 Objective for diffraction model

Within the context of this project the desirable features of a diffraction model are:

(a) Predicted loss varies smoothly over a wide range of ΔN;

(b) Low mean and standard deviation of discrepancies against measured data;

(c) Good agreement with spherical-earth diffraction for sea or smooth paths;

(d) Avoidance of need for an empirical correction.

A reservation on b) is that existing models already have discrepancies which in some cases are smaller than the differences between different measurement datasets. In other words, although it can be clear that a new model is worse than an existing model, it can be difficult to identify a more accurate model. A further point is that few measurements exist for paths longer than 100 km, and most are short-term measurements with little reliable refractivity information.

1.3.2 Potential methods for development

One candidate is the existing 3-edge model, as used in P.452 and P.1812. This fails a), is acceptable for b), and is an approximation to c). It fails d), having a simple, but sometimes large, empirical correction. An alternative is the Bullington model, as discussed in CG 3K-1. This satisfies a). It was shown within

3K-1 that, with a large and complicated empirical correction, it gives similar performance to the 3-edge model. Thus it also fails d), and is similar to the 3-edge model for b) and c).

There was also discussion within the project of finding a basically new approach to modelling diffraction over terrestrial paths. This includes corrections needed for clutter (buildings, etc) and ground reflections. These are recognised as mainly, although not necessarily exclusively, affecting losses close to the terminals. Unfortunately, no promising new methods were found. The useful development work has taken the existing models as starting points.

1.3.3 Development of diffraction modelling

Work conducted within the project has devised and tested a number of novel techniques for improving the existing models. Several did not produce useful results, and in these cases details are not presented.

Details of developments which have produced what appear to be valuable results are presented in Annex 2. These results are summarised as follows:

(a) It is possible to extend the Bullington method by taking account of additional knife-edge losses for the segments into which the construction divides the path. This introduces small discontinuities. These are undesirable, but they might be tolerated if the extension gives substantially better agreement with measured results. Noting the reservation on the usefulness of the present measured results, no significant change in the agreement is evident at present. Thus the only advantage in extending the Bullington method is that it makes the model appear more satisfactory. Within the ITU-R context this can, in fact, be significant, but it is commented that it should not play any role within this project.

(b) A novel technique has been developed referred as the “Delta” method (see Annex 9). This combines a profile-interpretation model with spherical-earth diffraction, producing the best available results for both irregular and sea/smooth paths. When used with Bullington and the spherical-earth method in P.526-10 §3.1.1 and §3.2, results are generally similar to the 3-edge model when compared with measured data, and they coincide accurately with P.526 results for a smooth or sea path. Moreover, there is no need for an empirical correction. This is therefore viewed as a promising development.

(c) However, testing the “Delta-Bullington” model, particularly for variable ΔN, revealed serious problems with the P.526 method. A relatively minor issue is that at antenna heights of a few metres and at 30 MHz the predicted loss does not vary monotonically with distance. Just beyond the horizon it falls as distance increases. This effect is restricted to quite a small range of low antenna heights and low frequencies.

(d) A more serious problem, in the context of the project, is that over a much wider range of antenna heights and frequencies results do not vary monotonically with ΔN, essentially equivalent to percentage time.

(e) A major advance within the project which contributes to the solution of these issues is an expression for the minimum valid distance for the spherical-earth model. This has been combined with a geometrical construction which comes close to guaranteeing reasonable and monotonic results from the spherical-earth model. This appears to be close to a satisfactory solution. There remain a few small cases of non-monotonic behaviour which need to be addressed, and it would be preferable for the slope discontinuity produced by the construction to be removed, provided this can be done without compromising other objectives.

Figure 1-3 shows an example of the above development to the P526 method. It shows spherical-earth diffraction loss plotted against log(distance) for 7 values of ΔN. The dashed traces are results from P526. The sequence of curves for ΔN cross over between about 30 and 120 km, illustrating non-monotonic variation with ΔN. The solid traces are the corresponding results using the new definition of minimum valid distance, and the geometrical construction.

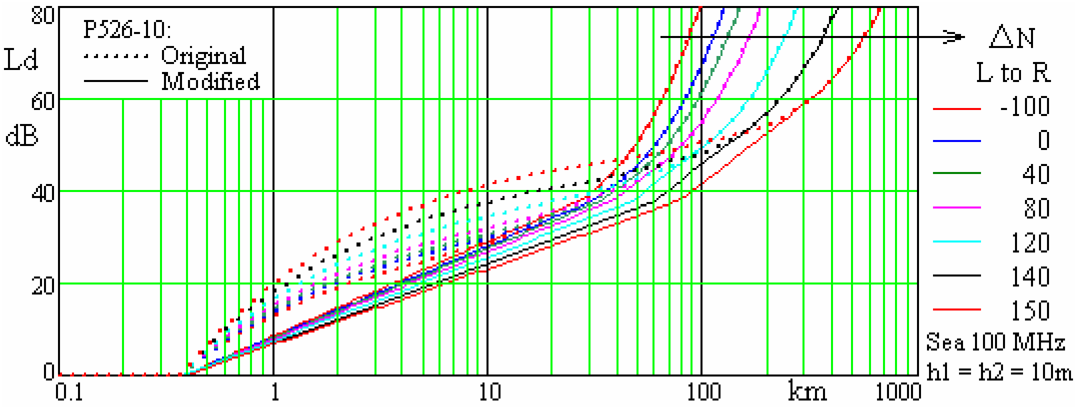

Figure 1-3. P526 original and modified spherical-earth model

1.3.4 Spherical Earth Diffraction (WP1)

It is proposed to use the spherical Earth diffraction model of ITU-R Recommendation P.526-10 §3.1 within WRPM as a component of the "Delta-Bullington" diffraction model [section 1.3.3] At the June 2008 ITU-R meetings in Boulder, questions were raised regarding possible errors in P526-10, and the way in which the residue series result could be used near the radio horizon and within the line-of-sight region.

The equations of P.526-10 were re-derived from the residue series and compared with other results in the literature. It was shown that the equation in question is in fact correct, and the problem was the expectation that the method of P.526-10 should be applicable into the line-of-sight region. The re-derivation of the P.526-10 equations provided a significant new result: formulae that can be used to determine the ranges of distances and antenna heights for which the model is valid. This is required in WRPM.

In addition, discrepancies were found in the P.526-10 equation defining β and the height-gain functions, and improved formulations proposed. There are also a number of corrections proposed to the equations of P.526-10 §3.2 relating to the diffraction loss for line-of-sight paths with sub-path diffraction. Annex 3 contains a proposed UK SG3 submission for a revision of Recommendation ITU-R P526-10 covering the above points.

1.3.5 Conclusions at present stage of diffraction modelling

A potential diffraction model appears to exist which has the required characteristics. It provides an accurate match to the P.526 spherical-earth model; although in practice the latter needs to be modified to make the overall model satisfactory.

This will require some additional development and more extensive testing, but these would appear to be achievable.

Since a diffraction model for the WRPM must be selected fairly soon, to permit assembly and testing of the complete method in the second year of the project, three alternatives appear to be available:

(a) Continue with what is hoped to be a relative small additional development of the Delta-Bullington method with the spherical-earth model modified. Monotonic variation with ΔN must be guaranteed, and if practicable slope discontinuities should be removed. This option offers to the prospect of a good overall outcome, but carries the risk that it may prove impracticable to complete the additional work within the time available.

(b) Decide that the risk in a) is too high, and adopt the Bullington method with the empirical correction defined in ITU-R CG 3K-1 documents (known as the "C2" correction). This would be expected to give approximately the same performance as the 3-edge method, but with the advantage of having discontinuities removed, or at least greatly diminished. The model would need to be tested over a wide range of ΔN.

(c) Lastly, and what might be assumed to be the most conservative choice, continue with the 3-edge model. If this is used with varying ΔN it is known that discontinuities, sometimes exceeding 10 dB, can exist, which in some cases will change in the "wrong" direction. This is viewed as highly undesirable, and it is thus assumed that if the 3-edge model is retained it should use a better method of interpolating the 3-edge method between anchor-points, or the equivalent. This also will require additional development and testing.

Our preference is a), but we would value Ofcom's comments, taking into account the present stage, approximately half-way through the project.

1.4 Comparison of P.1812 and P.1546 at lower frequencies for sea paths at small percentage times (WP3)

At the Boulder meeting of WP3K, concern was expressed regarding the sizeable differences between predictions made by P.1812 and P.1546 at lower frequencies for sea paths at small percentage times. Some delegates suggested that these discrepancies rendered P.1812 unusable, but it was noted by members of the UK delegation that it was by no means clear that the predictions given by P.1546 were themselves reliable or directly comparable.

A review has now been made of the performance of the VHF/low-UHF performance of the ducting and layer reflection algorithm of P.452 / P.1812, which has been compared with historical empirical data. This data relates to a number of paths across the North Sea for which the loss statistics were recorded at four frequencies between 90 MHz and 800 MHz. This comparison showed a very sizable discrepancy between the model and measurements at the lowest frequencies, falling to zero at around 500 MHz.

On the basis of this comparison, a simple 'coupling correction' has been proposed for the P.1812 algorithm; application of this correction has been shown to reduce the mean error of predictions for all paths in the 3K/1 Correspondence Group database by ~10dB and ~3dB at 100 MHz and 200 MHz respectively, with corresponding reductions in standard deviation of ~5dB and ~1.5dB.

The proposed correction will eventually be submitted to WPs 3K and 3M, but further work is continuing to examine its applicability to land and mixed paths. It is expected that this work will be concluded by the end of February 2009. A full description of the comparison and of the basis for the proposed correction is given in Annex 4.

1.5 ITU-R interaction (WP3)

The project team attended the meetings of the ITU-R Study Group 3, held in Boulder, Colorado in June 2008. A report from these meetings is attached in Annex 5.

2 Progress towards a complete wide-range model

Work in the first year of the project has concentrated on sub-models, and statistical aspects concerning how they should be combined as a function of percentage time, p%, for which the predicted loss is not exceeded. A global model giving the statistics of ΔN has been developed which can be used over the required wide range of percentage time, as have global maps of F_{oEs} for the sporadic-E model.

2.1 Sub-models

The sub-models to be included in the complete wide-range model can be commented as follows:

1. **Line-of-sight clear-air enhancements and fading:** This refers to focusing and de-focusing due to atmospheric layering in clear air. Such models exist in both P.452 for enhancements only and in P.530 for enhancements and fading, both within the context of a LOS path. The models differ greatly between the two Recommendations. The model in P.530 uses a larger amount of input information. In general the LOS/NLOS distinction tends to be problematic. This does not arise in P.530, which applies to LOS links, but it has proved a source of difficulty in P.452. At present it is not clear how this type of mechanism will be modeled.
2. **Diffraction:** The favoured model is "delta-Bullington", as described in Annex 2, including various modifications which appear to be necessary in the P.526 spherical-earth part of the model [Annex 2, Annex 3]. It is expected to predict the variation with p% time via the ΔN model developed within the project [Annex 1]. This gives values for arbitrarily small and large values of p%, although some limitations will in practice be accepted at $\Delta N = 157$ due to the need to maintain finite and positive effective earth curvature in the spherical-earth model.
3. **Ducting:** The anomalous propagation model will probably be based on the corresponding model in P.452, possibly modified to permit it to operate where ducting is prevalent for more than 50 % of the time. It will also be adapted for use at VHF as described in Annex 4.
4. **Troposcatter:** The troposcatter model is expected to be similar to the model in P.452, extended for p > 50%, as discussed in Annex 6.
5. **Sporadic-E:** It is expected to add a model for sporadic-E propagation based on P.534. This will be effective at VHF, as discussed in Annex 7. Global maps have been generated for F_{oEs} exceeded for 50, 10, 1 and 0.1% annual time. These are not everywhere equally reliable, but are the best available with the current information.
6. **Rain attenuation:** It is intended that the rain model will be based on the complete rain cumulative distribution of rainfall rate, for which a global ITU model is given in the files associated with P.837, as discussed in Annex 8.
7. **Gaseous absorption:** P.676 defines comprehensive line-by-line methods for terrestrial and slope paths, plus "simplified" equations which, in later versions, have become extremely complicated. Sub-models in P.452 include gaseous absorption via an unqualified reference to P.676, thus not indicating whether the line-by-line approach should be used. It is thought that the exact method should be stated in the WRPM. Options are the line-by-line method, the present complicated "simplified" equations, or to base it on much simpler earlier version of the "simplified" equations. In P.452, the value of the water vapour density is a constant. This will be generalised to take account of geographical variation using the maps of P.836 [Annex 1]. Another major issue is to what extent to account for correlations between water-vapour content and other tropospheric parameters.

2.2 Combining sub-models

It is expected that sub-models will be combined on the basis that correlations approximate to one of the following:

1. **Correlated losses:** If their variations are correlated, losses can be combined by power-summation. This is very simple to implement. It is applied to the diffraction, ducting and troposcatter sub-models in P.452 and P.1812 for $p < 50\%$.
2. **Losses due to mutually exclusive mechanisms:** If loss mechanisms are mutually exclusive they can be combined on an equal-loss basis. This is more complicated, because in general it requires the models to be iterated towards the loss for which the separate values of p% sum to the required value.

For this reason it can be referred to as time-summation. It is the method recommended for clear-air and rain fading in P.530.

3. **Statistically-independent losses:** The most complicated situation is where losses due to different mechanisms are statistically independent. This requires the separate loss probability distributions to be combined. One solution is to use a Monte-Carlo method, with which there will be a trade-off between accuracy and speed of execution. Based on the Multiple Interferers project, it is possible that an adequate approximation could be formulated in closed-form equations, but this has not yet been investigated.

The combination method must also allow for how mechanisms interact. Diffraction, ducting, troposcatter and sporadic-E effectively act in "parallel", such that the mechanism giving the lowest basic transmission loss at a given time will tend to dominate. Rain and gaseous absorption, on the other hand, cause attenuation additional to other mechanisms. How LOS enhancements and fades should be combined will depend on how their prediction is formulated. It may prove more suitable to incorporate them into the diffraction model.

2.3 Proposed combination methods for the WRPM

The results obtained in Annex 1 support the combination methods currently used in P.452, P.530 and P.1812. That is, diffraction, ducting and troposcatter are combined by power summation, and rain and clear-air fading by time-summation.

Proposed extensions to this situation for the WRPM are as follows:

- It is wished to define all sub-models for the complete range of p% time, rather than the division between enhancements and fades. One reason is that some sub-models do not fit into the division. Diffraction must be formulated over the complete range of p%, and it cannot be assumed globally that ducting is restricted to $p < 50\%$. Another reason is that it is wished to avoid a slope discontinuity in the loss cumulative distribution at $p = 50\%$, and the best approach to this is to define sub-models as continuous functions through this point.

- A sporadic-E sub-model needs to be added for WRPM application at VHF. It is assumed, at the present stage, that ionospheric and tropospheric losses are independent, although this is not certain. Thus adding a sporadic-E sub-model possibly carries the complications of statistical independence. As discussed in 2.2 above, this is the most difficult case to cover. For this reason it is expected that the sporadic-E sub-model will be switched off for the higher frequencies at which it would not be significant, although this frequency itself may depend on other inputs. A complicating factor is that the time-related statistics of sporadic-E are quite different from tropospheric mechanisms, with variations caused by solar activity, and marked seasonal and diurnal cycles. It is intended to formulate the model to approximate to average-annual statistics, but to accommodate other factors either by additional inputs or guidance.

- Strong positive correlation has been found between ΔN and surface water-vapour density. It thus seems appropriate to take this into account, particularly when adding gaseous absorption to the diffraction sub-model, since this is dominated by mechanisms close to the surface. In this case the positive correlation of ΔN and surface water-vapour density leads to a negative correlation of the corresponding losses.

2.4 Summary

The position at the end of the 1st year of the project can be summarised as follows:

a) Statistical analysis of tropospheric records has produced valuable information on correlations, necessary for deciding how to combine sub-models, and global models for ΔN and F_{oEs}.

b) Progress has been made on the various sub-models, particularly a new diffraction model, a correction for the ducting model at VHF, extending the troposcatter model for $p > 50\%$, and a sporadic-E model.

c) A fairly clear picture has emerged as to how the overall WRPM will be assembled from the sub-models, although much detailed work remains for the 2nd year of the project.

d) A software implementation of the complete model has been started in skeletal form, but is not yet ready for useful testing.

2.5 Project technical outputs

The following technical outputs will be delivered at the end of the two-year project duration.

1. **A software-implementable model demonstrating the feasibility of a 0-100% prediction method.** This will be couched in the language of an ITU proposed draft new recommendation, as covered by the next deliverable, and implementability will have been demonstrated by means of independent computer implementations by members of the consortium.

2. **Information papers and proposed draft new recommendation into the ITU-R SG3.** Results from work packages 1 and 2 will form ITU submissions on separate elements of the project. The main output will be a description of the wide-range model in the form of a Preliminary Draft New Recommendation (PDNR), suitable for ITU submission. Supporting contributions will also be produced as appropriate.

In view of the well-established nature of P.452, and its association with P.620 and earth-station coordination, we think it unlikely that the wide-range model will replace P.452 and P530 within the two-year span of this project. Thus it is expected, as the most favourable outcome at the end of the project, that the new recommendation, possibly as a PDNR, will exist alongside P.452, P.530, P.1812 and P.617. There is a requirement that recommendations provide unambiguous guidance and thus where they overlap in general purpose or ranges of input parameters, guidance must be given on the selection of which to use. This should be perfectly feasible in this case. The key feature of the new recommendation will be that it predicts signal levels varying smoothly with percentage time over the full 0% to 100% range, thus being particularly applicable to simulation studies, and methods using joint signal-level probability distributions.