# COASTAL ENVIRONMENT REFRACTIVITY AND PROPAGATION PREDICTIONS USING NUMERICAL ATMOSPHERIC MODELS

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## ABSTRACT

This paper is concerned with modelling the radio-refractivity structure due to atmospheric circulations such as coastal sea breeze or land breeze phenomena, and in applying the modelled refractivity structure to propagation prediction relevant to fixed terrestrial radio links. The equations of hydrodynamics and thermodynamics are solved assuming the non-hydrostatic approximation. This approximation is required for regions where forced or thermal convection are major processes. Radio –refractivity is calculated from the model outputs and can be incorporated into propagation prediction codes in order to determine the possible temporal variations in signal strength across fixed radio links or to model interference.

## INTRODUCTION

In the atmospheric boundary layer, wind flow on mesoscales can be strongly affected by surface boundary conditions such as terrain type, orography, temperature and the soil moisture content. Variations in conditions across the surface boundary can lead to quite complicated circulations. For example there are marked differences between the sea and land surfaces and also between the air masses above these surfaces. As a result wind patterns such as sea and land breeze circulations can develop over a diurnal cycle and can dominate coastal regions for periods lasting several hours.

Atmospheric temperature, pressure and water vapour content together with the wind field can be modelled by numerically solving the thermo-hydrodynamic equations. Once these quantities are known, the computation of the radio-refractivity is quite simple as it depends directly on these meteorological quantities. One way to proceed is to solve the equations assuming the hydrostatic approximation as has been reported in [1] and [2]. However to model the coastal refractivity for Australian conditions, we have relaxed this assumption and have solved the equations for the non-hydrostatic case. Strong thermal convection is evident during daytime over land due to the high temperatures that exist over the sandy soil that covers much of the Australian coastline and interior. Forced convection is also an important phenomenon along rugged coastlines. Both these processes are best modelled by considering a non-hydrostatic atmosphere.

The main application of the mesoscale meteorological modelling is to investigate temporal variations in the refractive index over timescales of minutes to hours. Suitable propagation methods such as the parabolic equation method (PEM) can then be used to investigate the diurnal signal level variations across a terrestrial radio link, for example. PEM techniques can make signal level predictions based on realistic refractivity structure that may vary in the lateral dimensions as well as with height. Recent developments in numerical techniques [3] make it possible to implement the PEM over rough terrain and also to incorporate it with other techniques such as geometric optics approaches, to form hybrid propagation models.

When the refractive index structure derived from the mesoscale models is used in the definition of the parabolic equation, the propagation modelling can be applied to produce the mean signal levels for a fixed radio link. At this stage, turbulent effects from the meteorological model results are not included in the refractive index calculation and thus are excluded in the propagation modelling Nevertheless, atmospheric turbulence is expected to be important over the land at heights up to several hundred metres and also in the first 50 or so metres over the sea [4].

## MODEL INITIALISATION

The thermo-hydrodynamical equations are solved using a non-hydrostatic mesoscale model. Details of the model can be found in [5] and [6]. Nevertheless it is useful to discuss the model input parameters. The temperature and humidity fields are assumed to be horizontally homogenous and a representation of these fields can be obtained from radiosonde data for the time and area of interest. The wind field is assumed to be initially geostrophic and set constant throughout the model domain. A boundary layer adjustment for the wind is used to fullfill the zero wind condition at the surface. Important for all simulations are surface parameters like land use characteristics, soil type and soil moisture content. Surface temperatures including sea surface temperatures are also included as input parameter fields. Due to the simplification of the initial stage a topographical diastrophy is also implemeted in the model. This means the simulation starts with zero topography height but once the simulation has commenced, the topography grows slowly into the model area during the first half hour of the simulation in order to adjust the developing wind field to the given topographic structure without producing to much noise in the numerical scheme.

In our example, the region that was modelled covered an area of 120x120 km$^2$ . The horizontal grid resolution was set to be 2 km in north-south and east-west direction and a variable vertical resolution (starting from 10 m at the surface and increasing to several 100 m at the model top) was used. This variable resolution ensures the quality of the results in the boundary layer and for the expected coastal phenomena such as sea/land breezes. The model top can be varied depending on the atmospheric necessities and usually occupies most of the troposphere up to 10 km.

In order to increase the resolution of the model, especially if high vertical resolution is required for phenomena like elevated ducts (experimental data show duct thicknesses as little as 10's of metres), and at the same time avoiding boundary problems for the model domain, the model can be nested in itself. This means a higher resolution domain (eg a 1 km x 1 km horizontal grid and a vertical grid spacing of 5 m near the surface) is computed using the boundary fields from the larger domain as input data during the simulation.

## EXAMPLES OF COASTAL REFRACTIVITY STRUCTURE AND PROPAGATION PREDICTIONS

Experiments to validate both the mesoscale meteorological modelling and the propagation modelling have been carried out in March 2002. Unfortunately, at the time of writing, the analysis of these results is very much still in progress and a detailed report cannot be given here. The experiments involved airborne measurements of the refractive index profile between Mt Westall and the Franklin Islands off the coast of Eyre Peninsula in South Australia, together with signal level monitoring from a microwave transmitter positioned at Mt Westall for a three day period. Although the data from this experiment is currently being analysed, the mesoscale modelling for the region is complete for the relevant period and we can use the simulated refractivity structure to specify the parabolic equation. In cylindrical coordinates $(x, \theta, y)$ the equation can be written as

$$\frac{\partial^2 u}{\partial y^2} + 2ik\frac{\partial u}{\partial x} + k^2\left(m^2(x,y) - 1\right) = 0 \tag{1}$$

where $x$ is the distance from the cylinder axis, $k$ is the wave number and the amplitude function $u(x,y)$ is related to the electromagnetic field which for horizontal polarisation is the transverse electric field

$$E(x,y) = u(x,y)\exp(ikx)/\sqrt{kx} \tag{2}$$

For low heights (compared to the Earth's radius) the refractive index $m(x,y)$ in equation 1 can represent the modified refractive index, assuming the usual Earth flattening formulation. This quantity is related to the refractive index $n(x,y)$ and in turn to the atmospheric pressure, temperature and water vapour content by the equation

$$m(x,y) = n(x,y) + \frac{h}{a} = 1 + \frac{h}{a} + \left(\frac{1}{T}\left(Pc_1 + \frac{ec_2}{T}\right)\right)\ 10^{-6} \tag{3}$$

where $a$ is the radius of the Earth, $y$ is the height above the Earth's surface, $T$ is the atmospheric temperature expressed in Kelvin, $e$ is the water vapour pressure in hPa and $P$ is the atmospheric pressure also in hPa. The two constants $c_1$ and $c_2$ are 77.6 and 373000 respectively. Furthermore, the modified refractivity M is defined as

$$M = (m - 1)10^6 \tag{4}$$

The quantities $P$, $T$ and $e$ are obtained from the meteorological model. As an example fig. 1 shows five profiles along the Mt Westall – Franklin Islands path during late afternoon on 5th March 2002. The model was initiated by use of a radiosonde profile from a nearby meterological station and appropriate land and sea surface data. The profiles display conditions ranging from super-refractive to ducting.

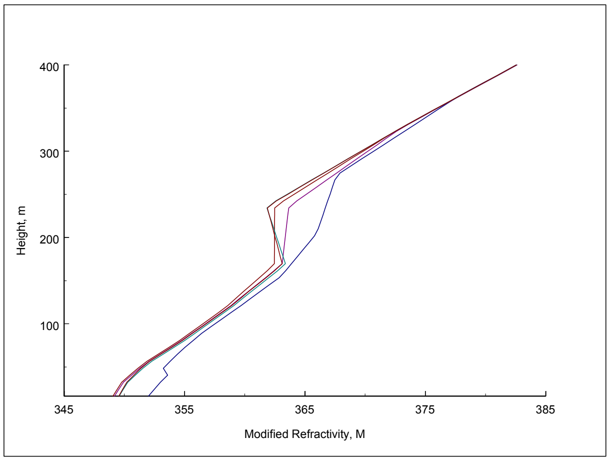

Fig. 1 Examples of modified refractivity profiles, M for the Mt Westall to Franklin Islands link.

By late afternoon, the sea breeze circulation is fully developed and the super-refractive profiles are due to the local subsidence of dry air. Further out to sea near the Franklin Islands, the subsidence is more dominant and results in this case in an elevated duct. The summer of 2002 was the coldest summer on record in South Australia. (This was unfortunate for us, as the usual hot land surface temperatures did not occur.) In contrast to this year's weather pattern, simulations of sea breeze circulations for typical summer temperatures show the development of elevated ducts on or near the coast and surface ducts several kilometres beyond the coast. Nevertheless, this refractivity structure produces some interesting propagation effects. Fig.2 shows examples of one-way pathloss for 3, 6 and 9 GHz at the location of the Franklin Islands for transmissions originating at 60 metres above mean sea level at Mt Westall. The distance between Mt Westall and the Franklin Islands is 55km. Fig.2 also shows pathlosses for the same link and frequencies during the early morning when the atmosphere is near standard.

At the lowest level, the meteorological model resolution is 10 metres and therefore the formation of the evaporation duct cannot be simulated properly. With one or two grid points covering the heights where evaporation ducts dominate, conclusions about these duct parameters cannot be drawn. Experimental studies around Australia have shown that evaporation duct parameters are linked to wind speed and sea surface temperature. For the surface temperature and wind conditions experienced in early March off the west coast of Eyre Peninsula, it is quite likely that evaporation duct heights would lie somewhere between 11 and 16 metres by late afternoon. The result of incorporating a 14m duct into the propagation modelling is shown as a dotted line in each plot in fig. 2. The effect of the evaporation duct is to further concentrate the lobes toward the surface. Comparing the afternoon results with the morning results in fig.2, one sees that there is a significant mean variation in signal pathloss over several hours. This is due to the establishment of the super-refractive and ducting conditions caused by the sea breeze circulation.

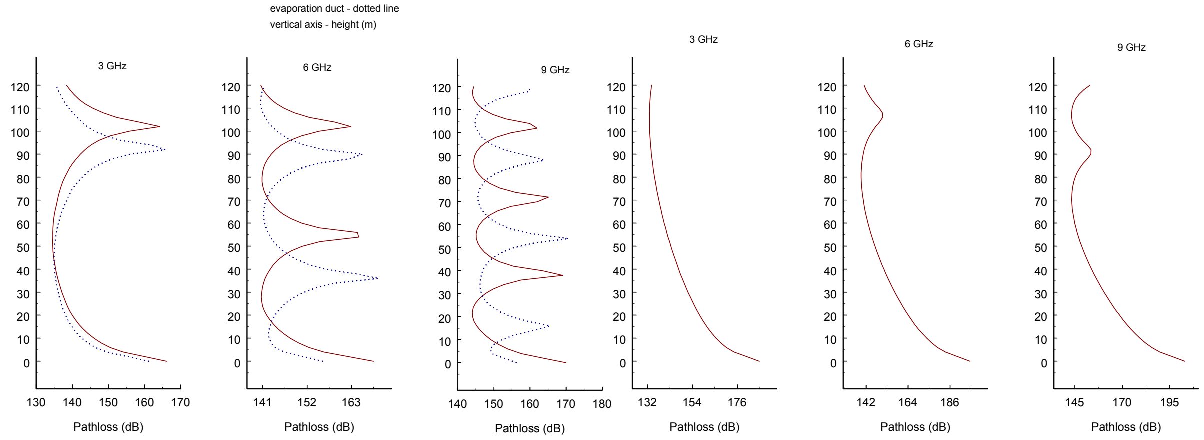

Fig. 2 The three graphs on the left are examples of signal pathloss in the direction of Mt Westall to Franklin Islands taking into account the refractivity structure obtained from mesoscale modelling (solid curve) for late afternoon. The refractivity structure obtained from the mesoscale modelling combined with an evaporation duct height estimate taken from an earlier statistical study of duct heights, is represented by the dotted curve. The three graphs on the right are examples of signal pathloss for the same link for early morning.

## CONCLUDING REMARKS AND CONTINUING STUDIES

Mesoscale meteorological numerical modelling provides detailed structure of temperature humidity, pressure and wind fields in space and time. These quantities experience large variations especially in coastal areas. The transition from land to sea causes strong horizontal gradients in temperature and humidity. Both horizontal and vertical variations in temperature and humidity result in a complicated refractive index structure that can vary from sub –refractive (in some cases) through to ducting conditions over relatively short distances (e.g. tens of kilometres) and the structure evolves over a diurnal cycle due to atmospheric circulations. One can physically model propagation effects by incorporating the detailed refractivity structure into propagation models such as the PEM. An important application of this is the modelling of terrestrial radio link performance as a function of time.

At present we are analysing meteorological and RF data taken by an aircraft which made extensive measurements of meteorological quantities ranging in height from around 15 metres to the top of the boundary layer while flying between Mt Westall and the Franklin Islands. In addition to this the aircraft logged RF data from a microwave transmitter located at Mt Westall. The analysis should provide valuable results for validating the prediction models described here.

## REFERENCES

[1]T.Tjelta and S. Lystad “Line of Sight microwave propagation and clear air climatic conditions for coastal regions under the northern polar circle , *Proceedings of Climpara ’94* pp. 8-2-1 to 8-2-5.,1994

[2] Lystad, S. & Tjelta, T., “High resolution meteorological grid for clear-air propagation modeling in northern coastal regions”. *NATO/AGARD Conf. Proc. CP-567, North Atlantic Treaty Organisation, Paris, France 41.1-41.12,* 1995

[3] Levy, M., “Parabolic Equation Methods for electromagnetic wave propagation”, IEE Electromagnetic wave series, no. 45, London, UK., 2000

[4] Kulessa, A.S, Ewenz, C.M., Hermann, J.A. (2002) “Important aspects of modelling microwave propagation through turbulence in the littoral environment: a progress report” DSTO Research report (*in press to appear in* 2002)

[5] Brücher, W, “Numerische Studien zum Mehrfachnesting mit einem nicht-hydrostatischen Modell”, *Mitteilungen aus dem Institut für Geophysik und Meteorologie der Universität zu Köln*, vol. 119, 115 pp, 1997

[6] Bruecher,W., Sperling, T., Steffany F., M.J.Kerschgens, “Wind-Transport und Klimatologie-Programsystem, Dokumentation und Benutzeranleitung version 2.5, Institut Fuer geophysik und Meteorlogie der Universitaet zu Koeln, 233pp.,1999