TRANSEQUATORIAL VHF PROPAGATION AND EQUATORIAL PLASMA BUBBLES

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Massive depleted zones in the equatorial ionosphere, stretching in field-aligned interhemispherical arcs, have been observed experimentally in recent years. Theoretical explanations of the gross features have been put forward. This paper argues the case for collecting a further round of experimental data and outlines a low-cost way of using VHF trans-equatorial propagation, available to Radio Amateurs, to study behaviour patterns of individual equatorial plasma bubbles.

1976 WAS A YEAR OF GOOD VINTAGE for equatorial aeronomy. It brought with it the first reports of so-called equatorial plasma bubbles, and with them the basis of the new way of thinking about irregularities in the equatorial ionosphere. The classic account was given by Ron Woodman and Cesar La Hoz [1], where they present records showing rising plume-like structures in the equatorial ionosphere recorded on the 50 MHz radar at Jicamarca in Peru. The radar, operating in the conventional mode of power return from a range-gate, receives echoes from ionospheric irregularities having a scale size of three metres. A sketch of one of their records is shown in figure 1 where the vertical axis has been converted from pulse time-delay into height. The horizontal axis is more complicated. It is like the photo-finish record at Cluden, where the film moves past a slit at the expected speed of galloping horses. Here the moving record assumes that the ionospheric plasma is galloping eastwards at 125 ms^{-1}, which is about average for the early evening. On this basis a conversion from a distance of 450 km gives a time lapse of one hour. The plume structures are therefore drifting eastwards at more or less 125 ms^{-1} and they rise to higher altitudes as time progresses.

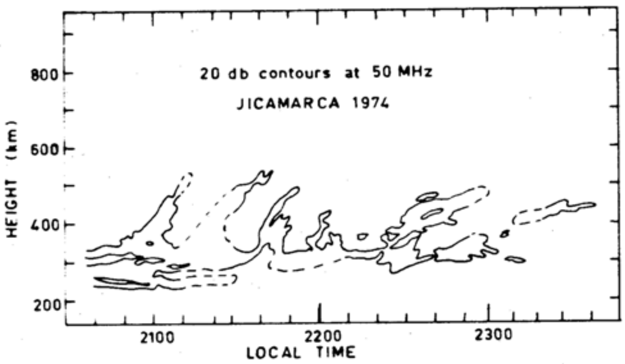

Figure 1. **20 dB contours of the backscatter power from small scale F region structure on the 50 MHz Jicamarca radar. The broken lines are interpolated sections. After Woodman and La Hoz (1976).**

The next significant revelation was the data of McClure, Hanson and Hoffman, working at the University of Texas at Dallas, who published some results in 1977 taken from ion density probes on board the equatorial orbiting satellite AE-C [2]. This satellite flew in a near equatorial orbit and showed a wide range of holes or bubbles in the ionospheric plasma typically 100 km in width and having plasma density reduced by 10 to 1000 times the background level. The fact that many of these holes rise up engendered the use of the word 'bubbles' and indeed the theory has been developed often with the aid of the analogy with air bubbles in water.

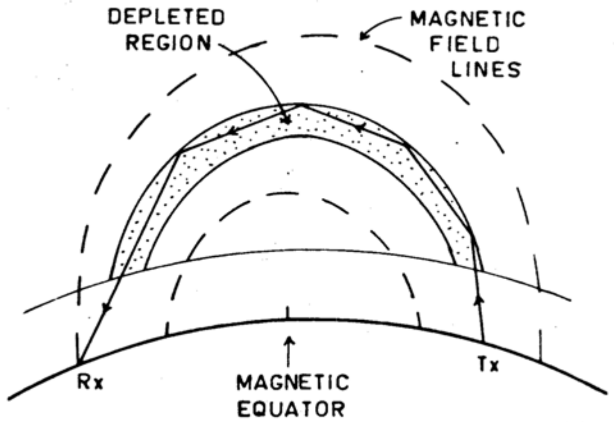

Figure 2. **The wave-guide structure of the field-aligned inter-hemispheric equatorial plasma bubbles.**

BANANAS OR SPHEROIDS?

One thing that the theoreticians are now agreed upon, in a maze of general uncertainty about bubble growth, is that the bubbles must faithfully extend along the magnetic field lines right across the equator as depicted in figure 2. This must be so, because diffusion time constants parallel to the magnetic field in the ionosphere are much less than a second, whereas horizontal drifts and vertical rises across the field (figure 1) are measured in tens of minutes.

The concept of elongated bubbles has been verified experimentally by Dyson and Benson [3] and by Heron and Dorling [4]. Peter Dyson, a Melbournian, has even dared to suggest that the word "bananas" be used to describe the bubbles. In his defence it should be said that the banana image needed to be argued to dispell the false concept of oblate spheroids as in air-in-water bubbles. And this shape question has most important consequences in transequatorial VHF propagation.

SYMBIOSIS OF THEORY AND EXPERIMENT

Before we think about propagation, interference and the rash of transequatorial two metre QSOs we should note the interaction to and fro between theory and experiment. Very quickly after the initial experimental data, a flurry of theoretical modelling and prediction began [5] [6] so that now, some three years later, we have models of fully field aligned depletions in plasma density, moving upwards (at the equator) as time proceeds and drifting eastwards [7]. In fact the theories have predicted more than the currently known observations and since they don't all agree it is now the experimenters' turn for the next move. Specifically, we need to have observations of the growth and decay of individual bubbles to be able to test the theoretical time histories, and also we need more observations of the ionospheric conditions which allow bubbles to form on some nights but not on others.

One approach which allows a path for interaction between theory and experiment was the numerical modelling by the author and Leo McNamara of the Ionospheric Prediction Service in Sydney (8). The idea was to treat individual bubbles as ducts for radio wave-guiding so that if a transmitter (at VHF) had a line of sight access to the end of a bubble then energy may be directed into a certain prescribed geographical region in the other hemisphere. A "best model" for the bubble cross-section, height above the equator, plasma densities, and velocities both upwards and eastwards was synthesized from the most reliable theories and experiments and a numerical study of the possible transequatorial propagation paths was done on the NOAA CDC-6600 computer in Boulder, Colorado in 1978.

The resulting parameters of frequency dependence, latitude dependence and Doppler shifts agreed well with the published record of transequatorial propagation and gave some confidence to the assertion that VHF transequatorial propagation in the evening is via these bubble waveguides. While relative powers on the TEP link agreed with observations, the absolute power levels predicted by this numerical model were far too high. Clive Winkler of DSE at Salisbury is following this up by applying some concepts of wave-guiding in optical fibres [9].

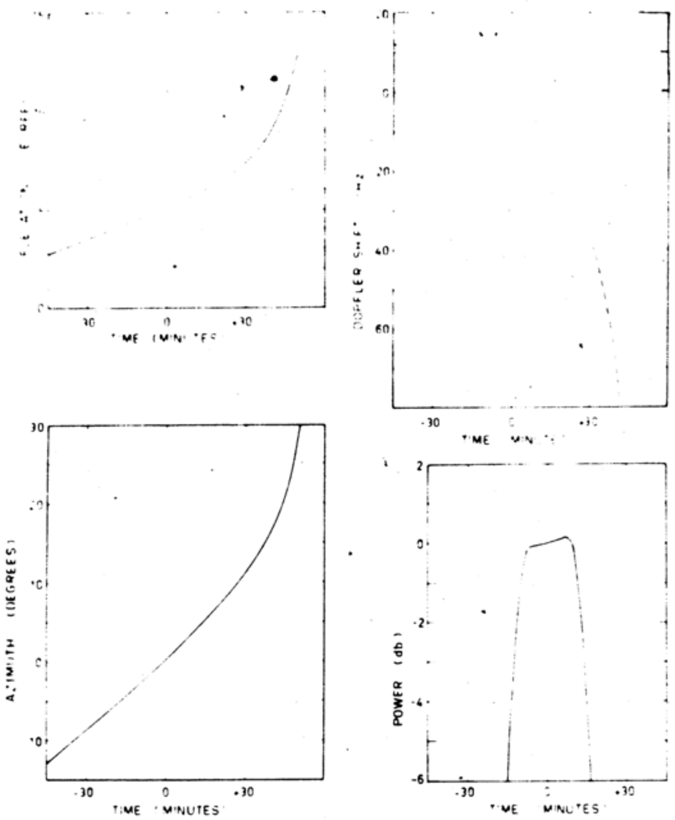

Figure 3. **The type of azimuth, elevation, power and Doppler shift variations which might be observed from a conjugate VHF transmitter. Here we have assumed a bubble growth; in practice we would go from the observed parameters to specifying the bubble development. The time is taken from a zero value when the bubble is at the longitude of the receiver. The frequency for these calculations was 100 MHz and the bubble was assumed to be rising at the equator with an exponentially increasing velocity.**

WHERE FROM HERE?

We have enough accumulated wisdom to be able to take another step. Let's reiterate: (i) the plasma bubble phenomenon was discovered experimentally; (ii) theoretical studies have explained the general formation of bubbles but do not agree too well about the growth and movement; (iii) numerical models relate VHF transequatorial propagation to bubbles. The next step is to use VHF transequatorial observations to shed light on the detailed growth and movement of individual bubbles. This will allow the theoreticians to go through another cycle of refinement. Ultimately one would hope that the phenomenon and its ramifications in communications will be understood to the point where it is predictable — at which point we can use it (TEP contacts), abuse it (intertropical interference) or avoid it (VHF scintillation) as we see fit.

THE ROLE OF THE AMATEUR

Radio Amateur operators on the two metre band have already made a contribution to the development of ideas which form the current knowledge of equatorial plasma bubbles. The transequatorial QSO reports, for example, support the banana shape and also indicate the integrity of the bubbles right across the interhemispheric connection, as opposed to the idea of unconnected 'spread-F' or "scintillation" irregularities. QSO logs have enabled some degree of evaluation of the size of the conjugate region typically available for potential two metre contacts.

On a limited study (we would like more QSO logs) it seems that a receiver within 1000 km of the magnetic conjugate point of a transmitter on two metres has some chance of a contact. The conjugate point needs to be accurately calculated from magnetic field tables rather than from any dipole model.

Jürgen Rottger of the Max-Planck Institut für Aeronomie in West Germany has produced some graphs of S-meter readings plotted against time every minute by SV1AB in Zimbabwe-Rhodesia and ZE2JV in Greece during contacts. The two metre transequatorial openings lasted typically 40 minutes to one hour which agrees reasonably well with the concept of moving ducts. An important implication is that some properties of individual bubble waveguides can usually be observed without interference from nearby bubble structures. Occasionally a double-peaked power curve suggested closely spaced ducts.

Such power level graphs and even QSO reports alone are useful for basic statistics but the potential for involvement of radio amateurs on two metres now extends further. There is the possibility of using direction-finding techniques to locate the point on the base of the ionosphere where the interhemispheric duct terminates. If the bubbles do indeed move eastwards and do rise upwards at the equator whilst remaining field aligned, then the duct termination should move eastwards and appear higher and higher above the horizon. Observations of azimuth and elevation angle of arrival at one minute intervals are required to check the theory of these movements. The expected variations of angle of arrival are indicated on figure 3.

A further observation which is a little more sophisticated is that of the frequency shift due to the varying path length between a transmitter and conjugate receiver communicating along one of these ducts. At the beginning of a contact the Doppler shift should be small, perhaps a few Hertz positive, and then over 30-40 minutes the Doppler shift should normally go negative to several tens of Hertz, if the theoretical dynamics are anywhere near correct.

The four observations of elevation, azimuth, frequency shift and power, if made accurately can be interpreted via the numerical models to go a long way towards giving the behaviour patterns of the equatorial plasma bubbles. Unfortunately, many Australians are too far south, magnetically speaking, to be in the action, but the Northern half of the country and particularly west of the Gulf of Carpentaria is well placed for Asian conjugate stations. Darwin and Yamagawa are very nearly conjugate.

EPILOGUE

It is interesting to speculate on two points. One is that this phenomenon was due for a rapid development because of technological moves. If the two metre activity explosion had occurred before the last sunspot maximum then the discovery of the propagation mode may well have been made by radio amateurs. The second point is a challenge. The Jicamarca record shown in figure 1 clearly shows the bubble phenomenon. It was made in 1974, very near sunspot minimum. Are we kidding ourselves that the two metre path through equatorial plasma bubbles is restricted to high sunspot epochs?

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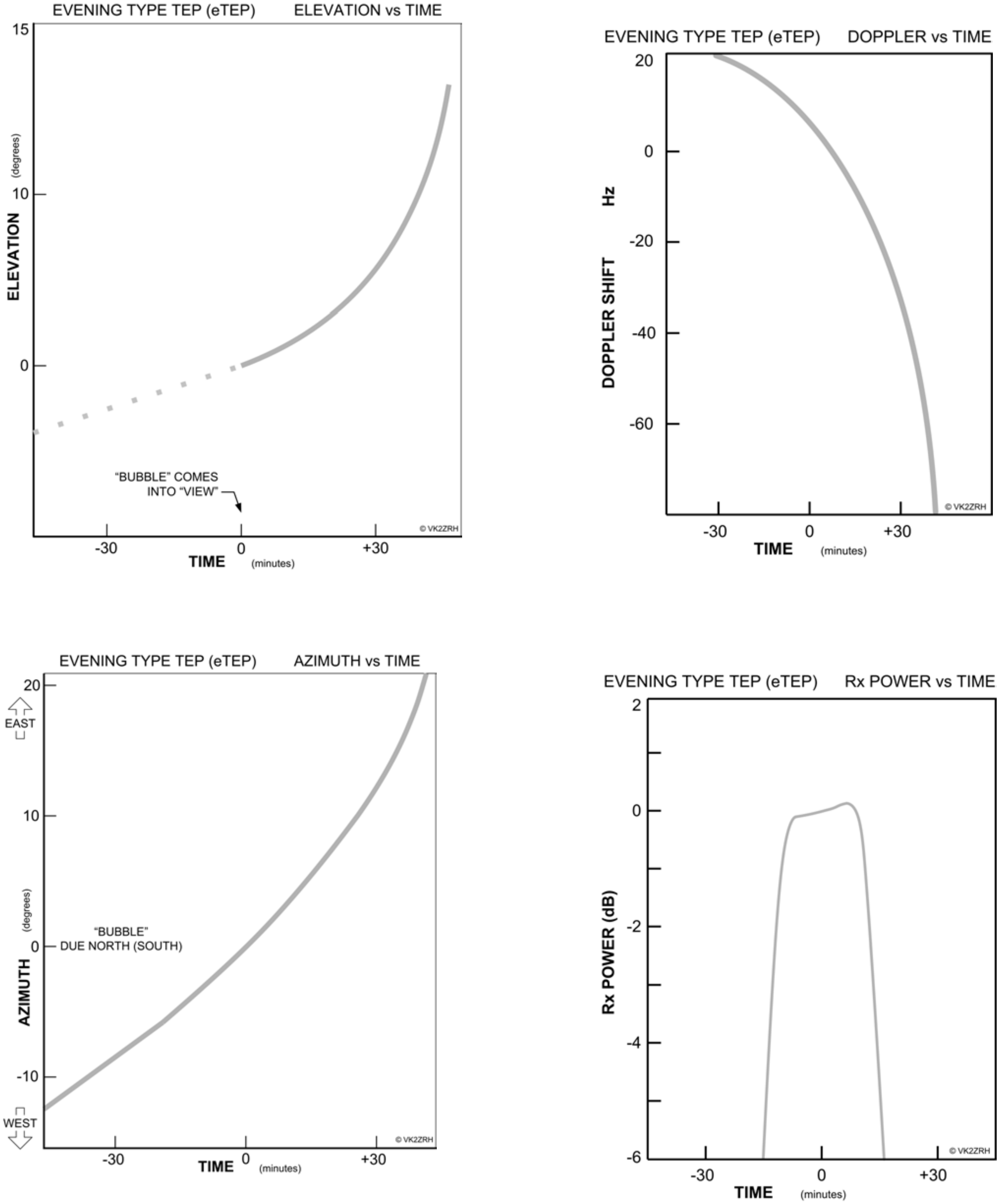

***Figure 3* diagrams re-traced.** Note: these show 'ideal', smoothed, characteristics calculated from the numerical model, which are applicable to a frequency of 100 MHz.