July 24, 2003

Radio propagation studies powered by BeamFinder

Very Long Distance Propagation in the 144 MHz Band

Discussion of the May 20, 2003 dx opening

Volker Grassmann, DF5AI
Udo Langenohl, DK5YA

Abstract. On May 20, 2003 radio amateurs from the Canary Islands reported many 144 MHz QSOs to central Europe corresponding to radio path lengths between 3.000 and more than 3.500 kilometers. A variety of possible propagation modes is discussed to identify each model's strengths and deficiencies in the interpretation of the May 20, 2003 opening. We exclude pure tropospheric radio propagation except with the QSOs between the Canary and Bristish Isles. Ionospheric single hop propagation is ruled out but long inner-ionospheric radio paths are considered an interesting interpretation of the May 20 opening. We have some objections to accept the concept of tropospheric propagation extending the dx range of single hop Sporadic E, the so-called "tropo+Es" model isn't totally excluded though. Double hop propagation is considered a consistent interpretation of the May 20 opening. The analyses are based on dx reports from radio amateurs published in the literature and in the internet, on meteorological data providing vertical profiles of air temperature and humidity, on ionograms from the Spanish digisondes and on the BeamFinder analysis software. A model is presented which interprets ground reflection in double hop propagation by radiowaves reflected on the topside of tropospheric inversion layers. Analysing terrain features in double hop propagation, we speculate that ground reflection may also result from inland water surfaces ('radioglint in lakes and rivers') and from mountain ridges, respectively. The absence of Sporadic E QSOs in central and western Spain ('secret of the Extremadura') is explained by the formation of local inversion layers above inland water surfaces preventing radiowaves from reaching ground level. This document was almost completed when more 144 MHz dx openings became available between the Canary Islands and the European continent. The dx events from June 22, July 2, 8 and 9, 2003, respectively, are briefly discussed in the appendix.

Contents

1. Introduction

On May 20, 2003 radio amateurs from the Canary Islands (EA8) reported many 144 MHz QSOs to central Europe (F, HB9, DL and OK) and England corresponding to dx distances between 2.500 and 3.570 kilometers [11], [12]. At the same time, 144 MHz Sporadic E QSOs were reported between Spain, Portugal, Italy and western and central Europe. Surprisingly, long distance tropospheric radio propagation was available as well, i.e. 144 and 432 MHz QSOs from Portugal to the Canaries and to Madeira Island [11], [12]. Fig. 1.1 displays the dx scenario and the distribution of dx distances on May 20, 2003.

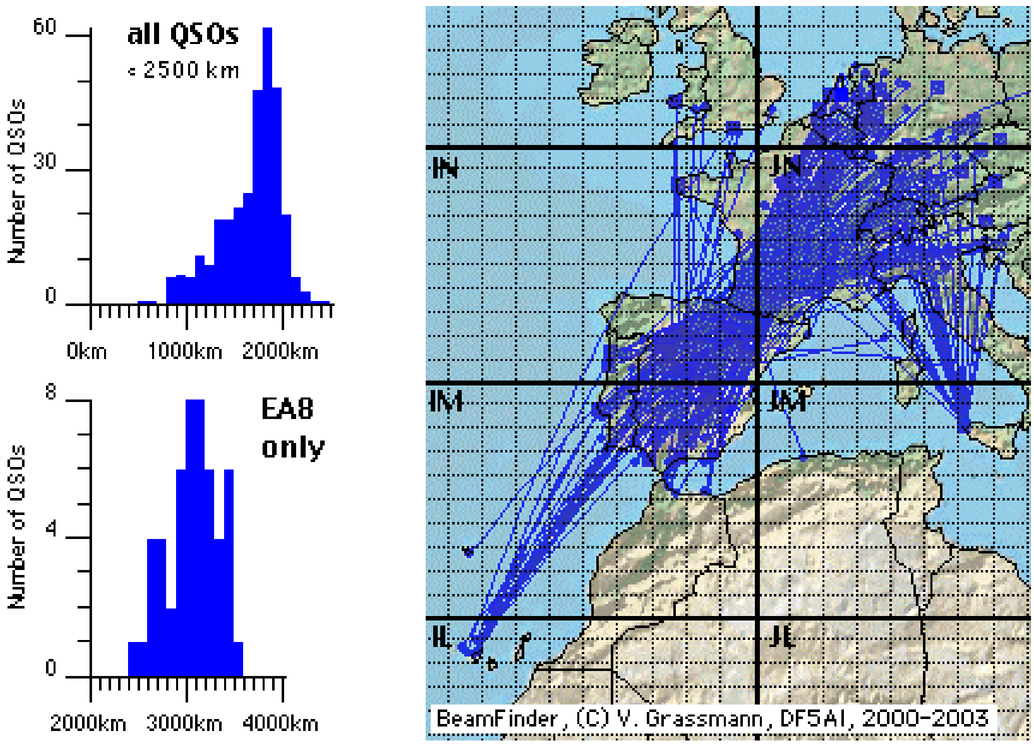

Fig. 1.1. QSOs reported on May 20, 2003.

In the past, 144 MHz dx propagation between the Canary Islands and central and western Europe was observed several times (e.g. [14], [25], see also Fig. 6.24 on page 30). Similiar long distance propagation is also reported from the Mediterranean. In 1998, for example, one of the authors (DK5YA) attended a dxpedition to the island of Crete resulting in various 144 MHz QSOs to northern Italy, the Netherlands, northwest Germany and to the UK and Norway [32].

In previous examples of very long distance propagation, ionospheric and tropospheric radio propagation modes may be distinguished more or less easily (generally based on plausibility though). In this particular case, radio amateurs discuss two alternative scenarios, i.e. double hop Sporadic E propagation and, on the other hand, enhanced tropospheric radio propagation extending the dx radius of single hop Sporadic E (“tropo+Es”), see, e.g., [13], [14].

In the following, we will discuss a variety of propagation modes which could have played a role in the May 20, 2003 dx opening. Each model is discussed separately to identify its particular strengths and deficiencies in the interpretation of this dx event. Most of the analyses are supported by the *BeamFinder* analysis software [18].

2. Ionospheric single hop propagation

In Fig. 2.1, the May 20, 2003 dx opening is interpreted by single hop propagation, i.e. the radiowaves traveled from the Canary Islands into the ionosphere and from here back to the Earth surface.

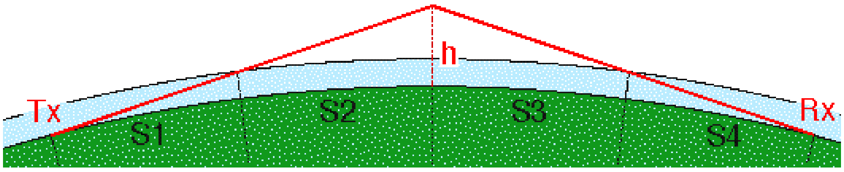

Fig. 2.1. Ionospheric single hop propagation.

The corresponding reflection height is (negleting bending of the radio rays)

$$(1) \qquad h = R_E \cdot \sin\varphi \left(\tan(El + \varphi) - \tan\frac{\varphi}{2} \right),$$

where R_E is the radius of the Earth (6.371 km), El is the elevation in degree and $\varphi = \frac{s}{222.4\,km}$ with s the great-circle-distance of the dx stations[1]. Assuming an antenna elevation of 0° and dx distances between 2.500 km and 3.500 km, the reflecting layer is estimated between 125 km and 250 km. In this height interval, we typically find minimum electron density in the ionosphere because the E-region is much lower (105 km) and the F-region is generally much higher (around 300 km). In fact, we are not aware of any dx reports in the literature considering 144 MHz radiowaves reflected in this height. We therefore exclude this model in the interpretation of the May 20, 2003 dx opening.

3. Inner-ionospheric radio paths

In shortwave communication, radiowaves may travel long distances within the ionosphere before returning to the Earth surface, see the schematics in Fig. 3.1. A mathematical model was given by *Försterling* and *Lassen* in 1931 based on a parabolic height profile of electon density, see, e.g., [53] (the original publication is unfortunately not available to us). That model can explain many characteristics of shortwave communication, e.g. the variation of skip distance as a function of the take-off elevation (see Fig. 3.2), in VHF communication it is not applicable though. However, the model is presented here because we wish to address a problem in, so to say, 'shortwave models tuned for VHF Sporadic E applications', see, e.g., [20] and [37].

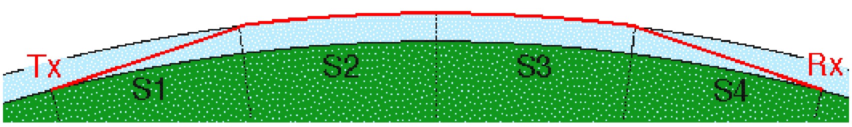

Fig. 3.1. Schematic view of ionospheric ducting.

[1] Using Eq. (1) in double hop propagation, φ is replaced by $\varphi = \frac{s}{444.8\,km}$.

VHF Sporadic E propagation is not equivalent to 'shortwave communication extended to much higher frequencies' because it is associated with plasma instabilities which may cause strong scatter of radiowaves. Thus, 144 MHz Sporadic E propagation is related to geophysical phenomena which are not considered by the theory of electromagnetic wave propagation in an ionized media (i.e. in the basic versions we generally find in textbooks). However, we actually refer to this theory when applying models such as [20] and [37] in VHF Sporadic E analyses (the same is true if we decide to apply the model of *Försterling* and *Lassen* in the interpretation of the May 20, 2003 opening).

This models actually *simulate* the effect of plasma instabilities on VHF dxing by introducing an extraordinary high critical frequency and an extraordinary high electron density, respectively. Very dense Sporadic E layers may exceed 16 MHz [34] but this models result in critical frequencies around 25 MHz (144 MHz band) or even 35 to 39 MHz (222 MHz band). Thus, the models are operated in a parameter range which no longer reflects the true ionosphere. However, if those amateur models can provide some reasonable results, for example, in geometrical considerations and MUF estimates, there is perhaps no reason to argue against it (the models' performance was never studied systematically though) – unless we do not start to believe there is an element of truth in critical frequencies of 39 MHz.

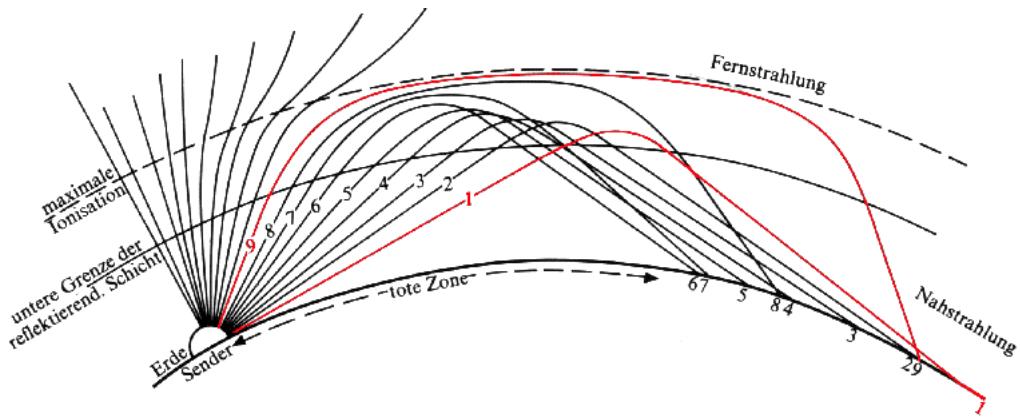

Fig. 3.2. Ray paths in ionospheric propagation [53].

The model in Fig. 3.2 cannot explain the May 20, 2003 opening anyway: taking into consideration that the path length S2-S3 in Fig. 3.1 corresponds to at least 1.000 kilometers, we must compare the EA8-QSOs to the radio rays 8 and 9 in Fig. 3.2 which implies relatively high take-off angles. 144 MHz Sporadic E propagation however corresponds to take-off angles much lower than 10 degree elevation similar to the ray 1 and 2, that rays do not support long inner-ionospheric radio paths though. Finally, the rays 1 and 9 show almost similar dx distances along the Earth surface, i.e. this model cannot explain VHF dx communication beyond 3.000 kilometers.

However, *Zimmerman*, W3ZZ, and *Greene*, K1JX, [1] consider long inner-ionospheric radio paths by refraction a possible interpretation of the May 20, 2003 opening. They discuss radiowaves penetrating a Sporadic E cloud without returning to Earth but to another Sporadic E cloud which then reflects the radiowave back to Earth. This might explain very long distance propagation beyond 3.000 kilometers and might explain the absence of single hop Sporadic E QSOs between the Canary Isles and the Iberian Peninsula (we will discuss this topic as the 'secret of the Extremadura' in chapter 6.6). *Zimmerman* considers this interpretation 'far from theoretical' because of numerous cases in the 50 MHz band in which dx QSOs were reported at double hop distances but no QSO was available to the midpoint of the radio path. *Greene* emphasizes that this effect may be observed frequently in the 10m and 15m shortwave bands.

Lehtoranta, OH2LX, [17] also prefers inner-ionospheric radio paths rather than double hop propagation in the interpretation of the May 20, 2003 opening. He in particular considers slanted Sporadic E layers which could support radiowaves travelling from 'one point of the ionosphere to another' or, alternatively, could enable 'ducted components' similar to the Pedersen ray in shortwave communication (see radio ray 9 in Fig. 3.2).

We believe similar models have been discussed by radio amateurs many years ago but we are not aware of any 144 MHz dx observation supporting the model of long inner-ionospheric radio paths and 'Sporadic E hopping' within the ionosphere. Comparable concepts are indeed discussed in transequatorial radio propagation (see, e.g., [33] and [51]) but F-region propagation models and properties of the equatorial ionosphere are not applicable here.

4. Tropospheric ducting of radiowaves

Tropospheric long distance propagation of more than 3.000 kilometers is a rariety in VHF communication. However, there are more than just a few examples reported by radio amateurs, e.g. between California and Hawaii (3.800 km) and Washington state and Hawaii (4.300 km) [35]. A very surprising example is the reception of an Australian 144 MHz radio beacon on Reunion Island in 1996 corresponding to a distance of more than 6.000 km [35].

In the European *144 MHz Toplist* [21], two radio amateurs (from a total number of 214 list members) report tropospheric QSOs of more than 3.000 km. *Butler*, G4ASR, [25] even considers dx paths between the British and the Canary Isles an every year experience. A detailed discussion of anticyclonic VHF propagation is given by *Flavell* who also reports 144 MHz dx QSOs between the Canaries and the Irish Sea (see fig. 1 in [41]). A discussion of long tropospheric radio paths across the Mediterranean Sea is given by *Sampol*, EA6VQ, [26] which is possibly applicable here too. Tropospheric dx propagation is therefore considered a potential candidate in the interpretation of the May 20, 2003 dx opening.

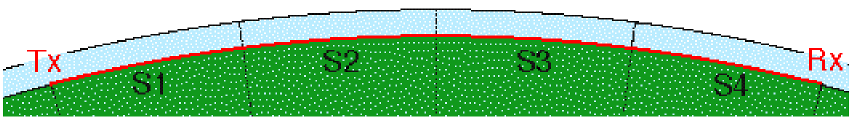

Fig. 4.1. Schematic view of the tropospheric model.

On May 20, 2003, an intense high pressure system extended from the Canary Islands to Spain and south-western France, see Fig. 4.2 and Fig. 4.3. There was increasing stability, with high-level subsidence and surface high pressure moving over the Iberian Peninsula from northwest [10]. On the south-eastern border of this system very warm and dry air was transported towards the western Mediterranean (Fig. 4.3). For a period of six days, air temperature was above 30 C with calm winds in the whole area and water temperatures around 21 C. Note, in particular, the spot of high ground temperature in southern Spain (Fig. 4.2) which we will again address in chapter 6.5.

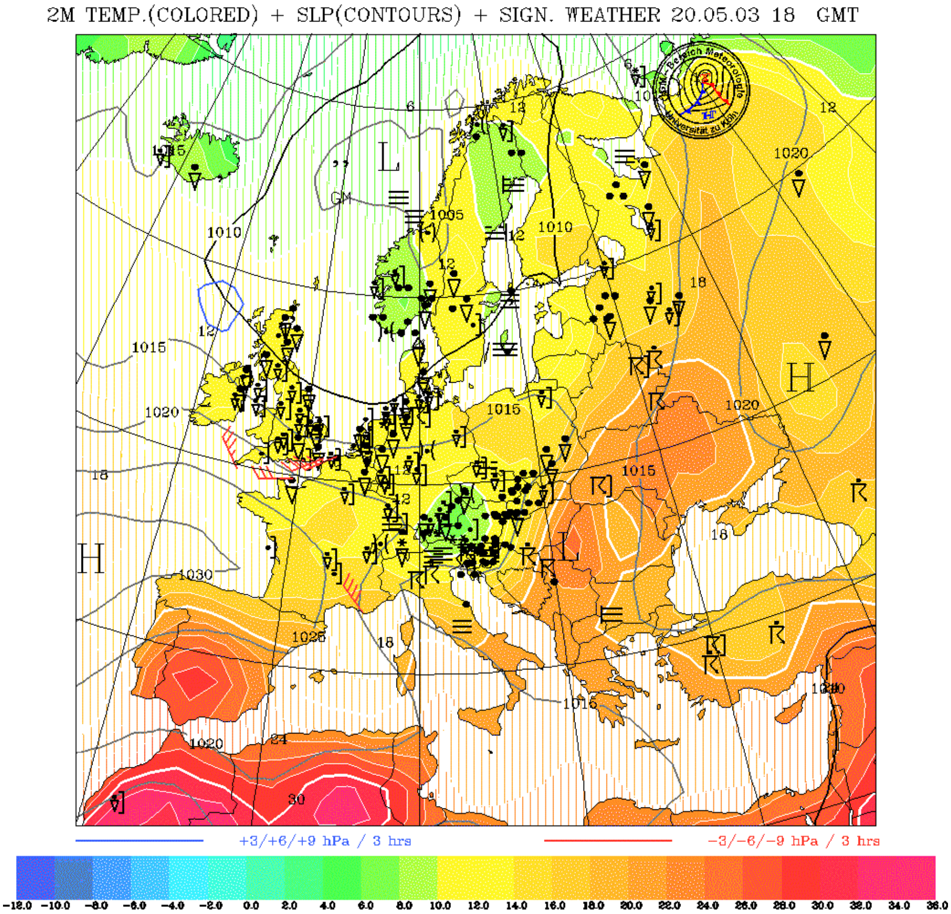

Fig. 4.2. Ground weather on May 20, 2003, 18 UT. Courtesy of University of Cologne [16].

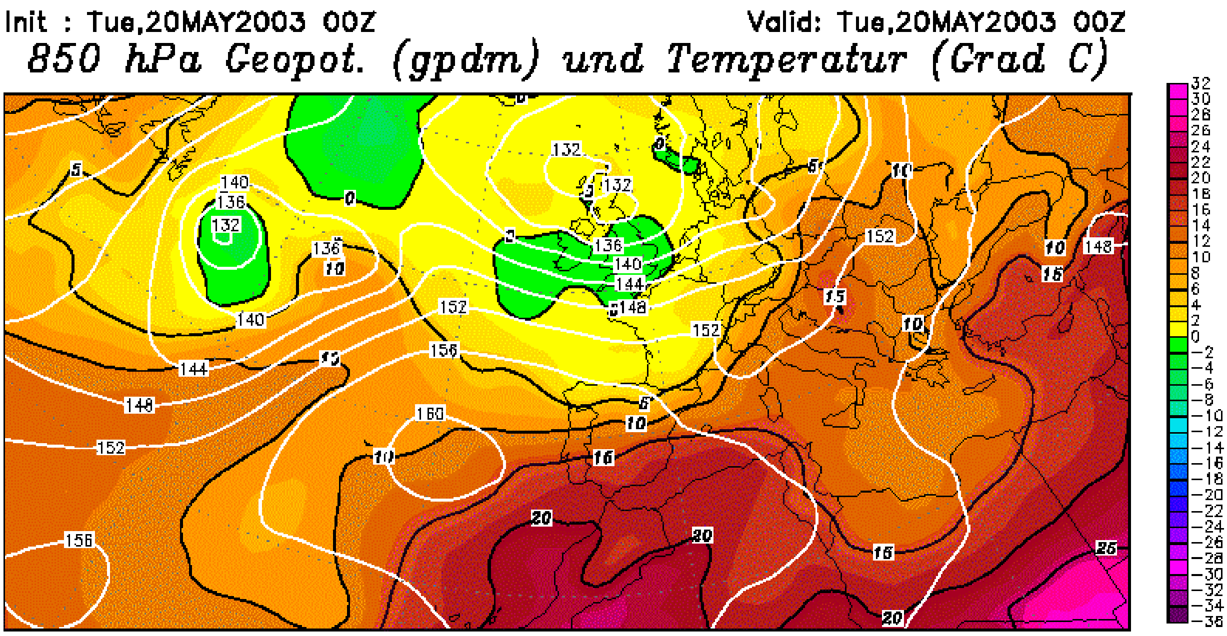

Fig. 4.3. 850 hPa weather map (approx. 1.500 – 1.600 m altitude) for May 20, 2003, 00 UT [27].

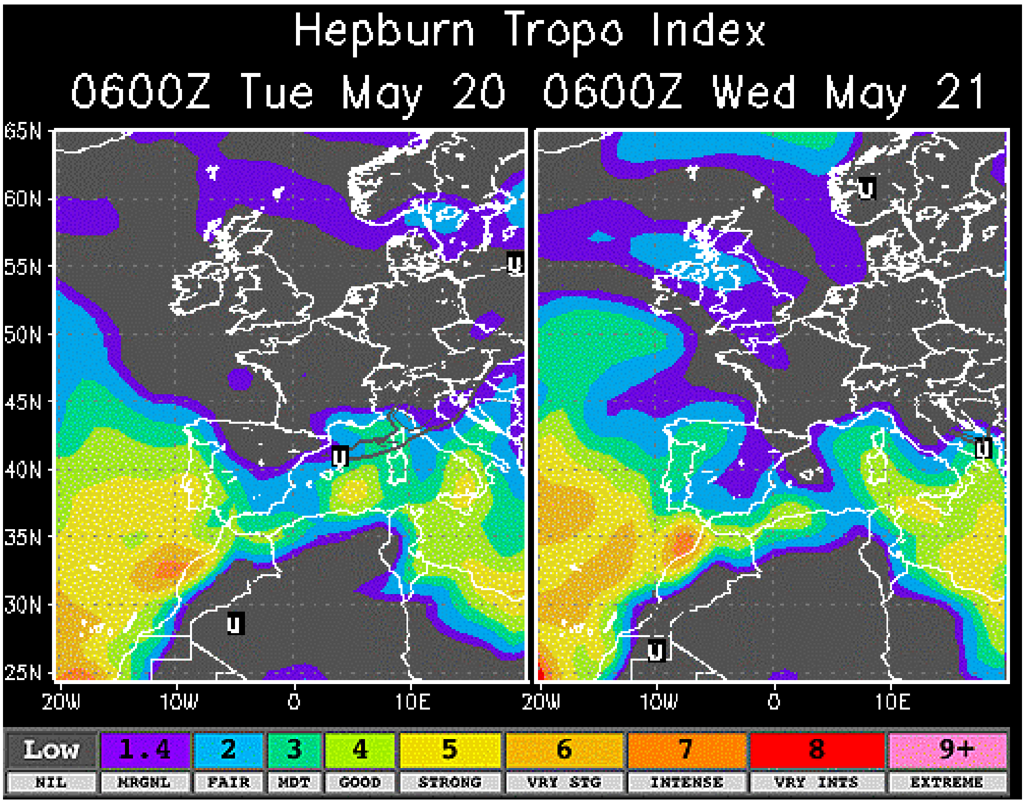

Fig. 4.4. Hepburn Tropo Index for May 20, 2003, 06 UT (left) and May 21, 06 UT (right), adopted from [7].

Refering to the *Hepburn Tropo Index* [7], there is indication for tropospheric ducting between the Canary Islands and the Iberian Peninsula on May 20 and 21, 2003 (see Fig. 4.4). As far as we know, tropo dx was indeed available between EA8 and CT, EA7 and D44 from May 16 to May 21. The vertical profiles of temperature and dew-point indicate some tropospheric inversion along the sea path from Tenerife to La Coruña on the north-western tip of Spain and even in Brest at the French Atlantic coast, see Fig. 4.5 and Fig. 4.6, respectively. From this perspective, tropospheric ducting cannot be excluded in particular in the QSO between the Canary Islands and the south coast of England (see Fig. 6.5 on page 15). We obtained information that Irish radio amateurs received stations from the Canaries on May 20, 2003 which could be interpreted by tropospheric dx propagation too. On the other hand, the inversions in Fig. 4.5 do not show very high intensity and the Funchal sounding (Madeira Island) does not show any temperature inversion at all.

Even if tropospheric ducting was available over the ocean, there is no evidence for tropospheric ducting in the very long distance QSOs between the Canary Islands and central Europe. *Hepburn* [7] considers extraordinary tropospheric conditions across land unusual at this time of the day (16 – 18 UT) but ‘a good time’ for Sporadic E.

In fact, the EA8-QSOs clearly coincide with the Sporadic E QSOs in southwest Europe: the Sporadic E QSO are all reported between 1540 and 1820 UT (negleting one QSO at 1442 UT and three others between 1944 and 2020 UT) and the EA8-QSOs are all reported between 1600 and 1805 UT corresponding to the main phase of the Sporadic E opening [11], [12]. We would be surprised if tropospheric ducting would develop and would decay in parallel to a wide spread Sporadic E opening. In our view, Sporadic E played an important role in the EA8-QSOs, i.e. we exclude tropospheric ducting between the Canaries and central Europe in the interpretation of the May 20, 2003 dx opening.

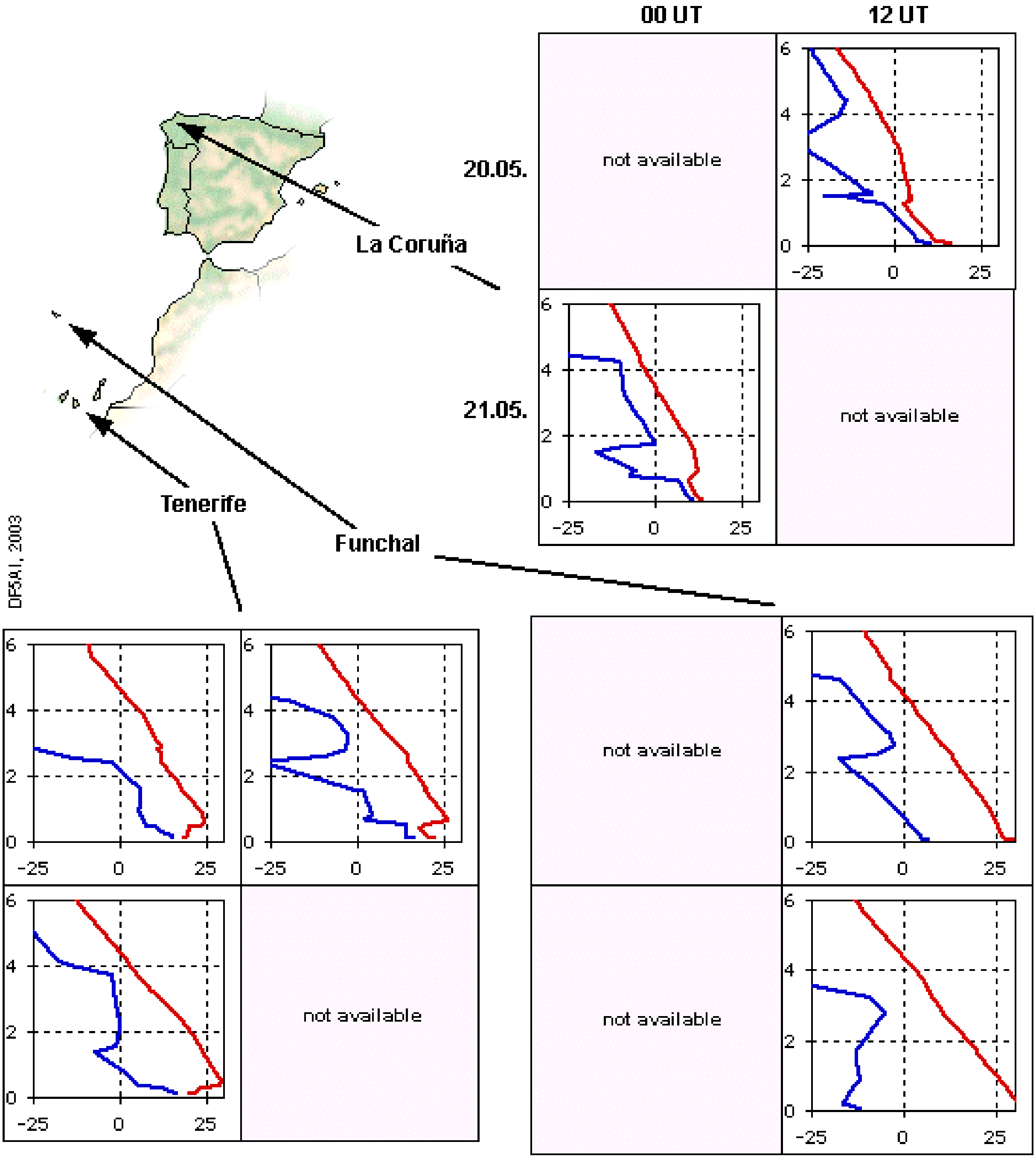

Fig. 4.5. Vertical profiles of air temperature (red) and dew-point (blue) indicating various tropospheric inversion layers (using data in [29]). The upper and lower diagrams denote sounding data for May 20 and May 21, respectively. The left hand side of the panels correspond to 00 UT and right hand side to 12 UT. The vertical scale denotes kilometers, i.e. 0, 2, 4 and 6 km altitude. The horizontal scale indicates the temperatue in degree Celsius. Please refer to Fig. 6.16 on page 23 to view the Gibraltar vertical profiles.

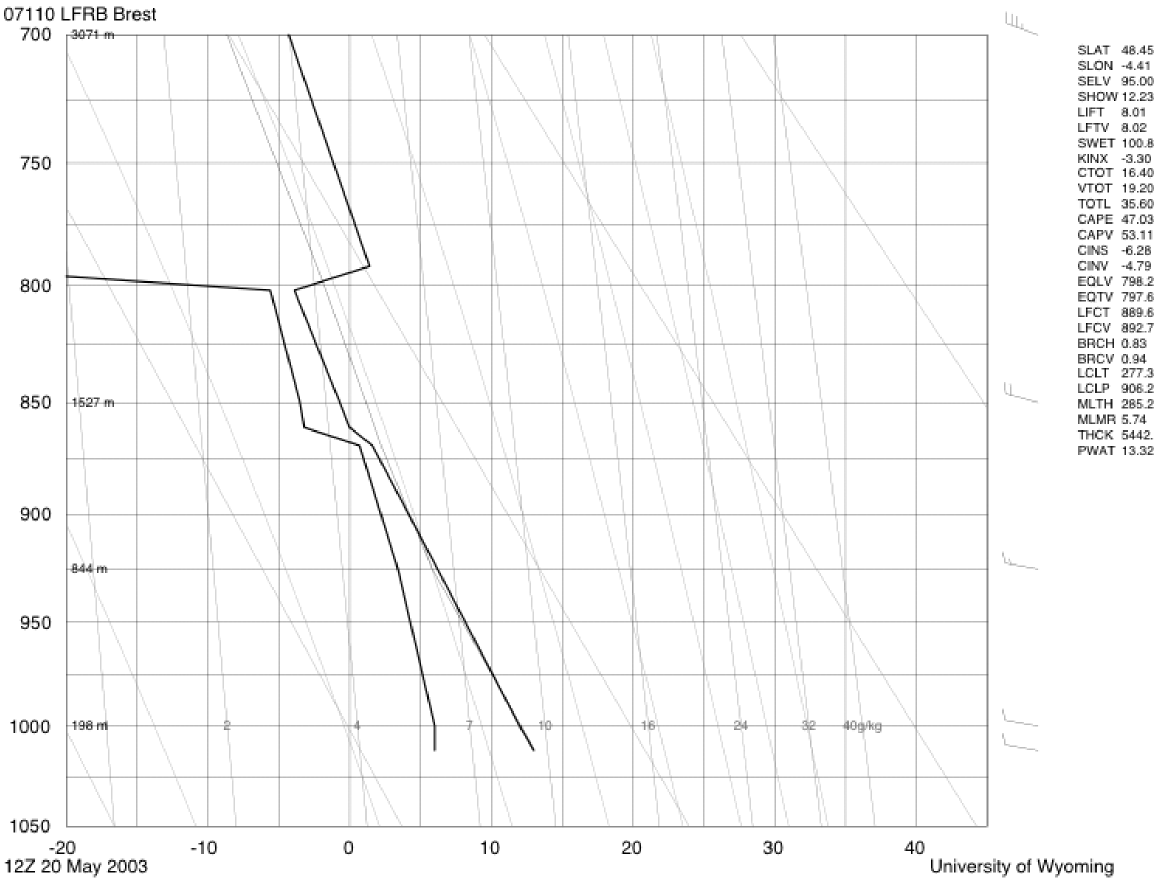

Fig. 4.6. Temperature (right) and dew-point (left) at Brest/France, May 20, 2003, 12 UT [29].

5. Tropospheric/ionospheric radio propagation

Many radio amateurs speculate about enhanced tropospheric radio propagation extending the range of Sporadic E propagation (see, e.g., [13]). This assumption is probably motivated by the fact, that long distance tropospheric propagation was available between the Canary Islands and the Iberian Peninsula, note the 432 MHz QSOs between the Canaries and Portugal (1.340 km) and between the Island of Madeira (IM12) and Portugal (960 km) [12]. At the same time, Sporadic E propagation was available between the Iberian Peninsula and central Europe. Thus, linking both propagation modes together (see Fig. 5.1) we obtain the "tropo+Es" concept which can perhaps explain very long distance communication between the west coast of Africa and central Europe.

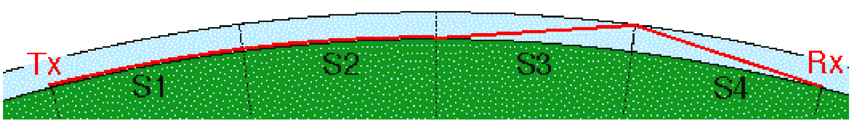

Fig. 5.1. Schematic view of the "tropo+Es" concept.

Evidently, there is a complication with this concept because tropospheric ducting needs to be 'transformed' into ionospheric skip propagation an vice versa, somehow. We do not have an appropriate model available which can explain the 'coupling mechanism' between radiowaves in the troposphere and radiowaves in the ionosphere.

However, an attempt is made at identifying this mechanism's geographical origin. Taking into consideration that the radiowaves must maintain a low take-off angle to enable VHF Sporadic E propagation, we may estimate the mechanism's geographical position. Fig. 5.2 displays the actual Sporadic E location by using the results in [15]. Within the red circle, all positions in the troposphere (2 km height) have a line-of-sight to the Sporadic E spot in 110 km height. The intersection of the red circle and the great circle path between the Canaries and the Sporadic E region is the place where something unusual must have happened on May 20, 2003, i.e. if tropospheric radio propagation somehow developed into ionospheric skip propagation, we must search for unusual meteorological conditions in the center of the IM grid square (see the blue square in Fig. 5.2). Viewed from the Canary Islands, this position corresponds to –4° elevation at a distance of 950 kilometers.

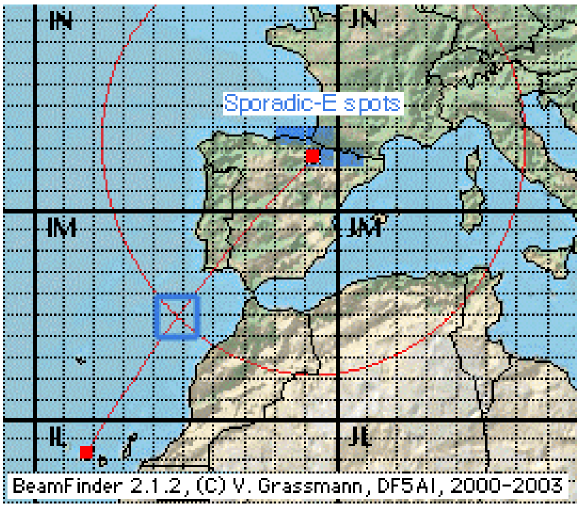

Fig. 5.2. Sporadic E position on May 20, 2003 (adopted from [15]).

Meteorological data is available for this geographical position, see Table 5.1. However, we cannot see any evidence of unusual meteorological conditions or discontinuities in the data. The sounding data of Funchal, Madeira Island (Fig. 4.6), shows a sharp increase of dew-point temperature at approxiamtely 2.500 m height (without showing a similar inversion in air temperature though) but this feature cannot sign responsible for radiowaves escaping from the troposphere into the ionosphere. On the other hand, all data was taken at 12 UT (which is at least four hours earlier than the dx opening's commencement) and it cannot provide information on the horizontal structure of the troposphere which, perhaps, is the type of information required to identify that unknown coupling mechanism. We however think that this mechanism does not exist at all.

There is one feature though which should be mentioned here: refering to the May 20 profiles at 12 UT (see the upper right diagram in all panels of Fig. 4.5), two inversion layers appear at Tenerife, i.e. an intense inversion at, say, 500 m altitude and little inversion at 2.500 m. In La Coruña, on the other hand, only one inversion layer is found around 1.500 m. We initially thought this features might indicate an ascending radio path that finally releases radiowaves into the upper atmosphere if the duct would abruptly disappear at the sea coast of the Iberian Peninsula. We however gave up this idea but will return to an alternative combination of tropospheric and ionospheric radio propagation in chapter 6.4.

FNL Archive
SOUNDING DATA

GRID POINT 97.1 65.0
LAT/LON 35.50 10.00

05 20 2003 12 Z

PRES	HGT(MSL)	TEMP	DEWP	WDIR	WSPD
HPA	M	C	C	DEG	M/S
20.	26540.	-51.	-273.	40.	3.
50.	20696.	-60.	-273.	194.	3.
100.	16409.	-65.	-273.	280.	12.
150.	13922.	-62.	-273.	270.	20.
200.	12137.	-59.	-273.	265.	24.
250.	10713.	-50.	-273.	270.	23.
300.	9498.	-41.	-54.	279.	19.
400.	7482.	-26.	-44.	304.	17.
500.	5827.	-13.	-34.	310.	14.
700.	3174.	5.	-18.	330.	11.
850.	1559.	16.	3.	337.	5.
925.	832.	23.	6.	352.	3.
999.	31.	31.	10.	52.	2.

Table 5.1. Vertical sounding data (central position in the IM grid square, i.e. 35.5°N, 10.0° E) from May 20, 2003, 12 UT [28].

6. Double Hop Sporadic E

Some radio amateurs are in doubt about ionospheric double hop propagation in the 144 MHz band (e.g. [14]). On the other hand, Sporadic E studies conducted by the *International Amateur Radio Union* clearly declare examples of very long distance communication as 2-hop Sporadic E, see, for example, the dx QSOs between Germany and the former Soviet Union (2.800 km) and between Germany and Israel (2.700 km) in [46]. In the 'Es' category of the European *144 MHz Toplist* [21], twenty radio amateurs (i.e. more than nine percent of the 214 list members) report Sporadic E QSOs of more than 3.000 kilometers and some historical examples of VHF dx communication can only be explained by double hop propagation, e.g. the 144 MHz dx QSO between Portugal and the Lebanon (more than 3.800 km) in 1979 [50].

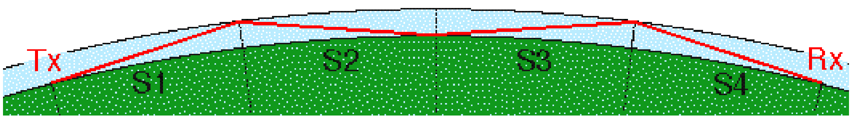

Fig. 6.1. Double hop Sporadic E.

In the following, we will discuss the geographical distribution of dx targets available to radio amateurs in the Canary Islands (chapter 6.1). The analysis then focuses on the geographical position and size of the Sporadic E clouds (chapter 6.2). In double hop propagation, we may expect ground reflection of radiowaves in the path center, these positions are analysed in chapter 6.3. In chapter 6.4 and 6.5, respectively, we discuss possible scenarios which could explain the physical origin of ground reflection in VHF long distance communication. In chapter 6.6, we address a complication in the double hop interpretation of the May 20, 2003 opening.

6.1 Available dx targets

Fig. 6.2 displays the geographical distribution of dx stations which radio amateurs on the Canary Islands may reach in double hop propagation. Compared to the schematics in Fig. 6.1, the red square corresponds to the Tx location and the blue area corresponds to all possible Rx locations, respectively.

Note the shading in Fig. 6.2, i.e. the dark blue and the light blue colour which indicates reflection of radiowaves by sea and by land, respectively. For example: Double hop propagation from the Canaries to, say, Ireland requires a first skip reflected somewhere in the Atlantic Ocean. Because the first skip is not shown here, the terrain information is implicitely given by the colour of the corresponding double hop target (note the dark blue colour of the dx targets in Ireland). On the other hand, double hop propagation from the Canary Islands to Germany never results from sea surface reflection, i.e. all dx targets in Germany are displayed in light blue colour.

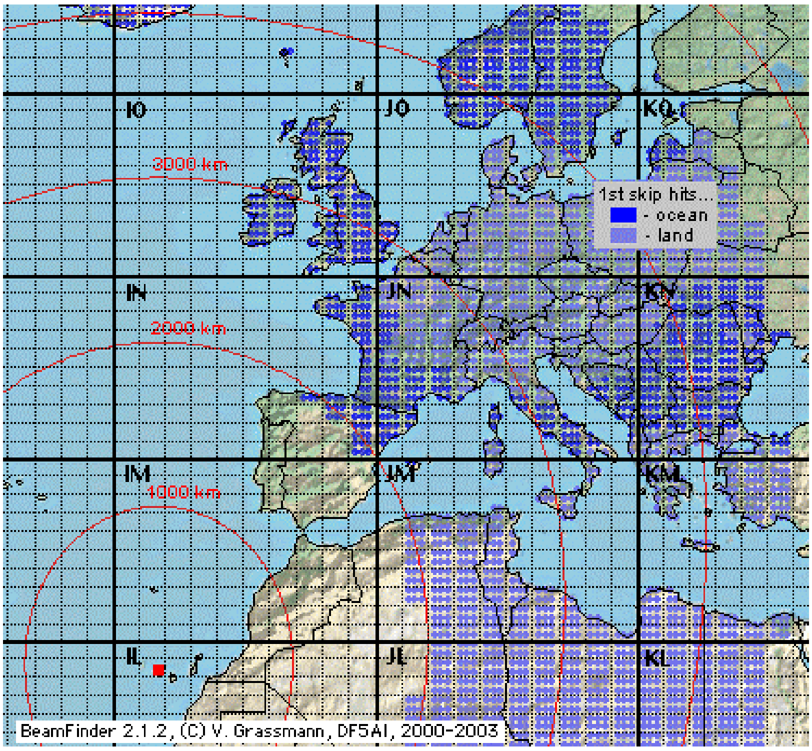

Fig. 6.2. Potential dx targets in double hop propagation (calculated for the IL18 grid square, maximum elevation 10°).

Dx targets are potentially available in all regions of western, central and southern Europe. Major areas of eastern Europe are also included as well as the south of Scandinavia and the Baltic Sea region. In recent years, 144 MHz dx QSOs were indeed reported, for example, between the Canaries and Denmark (3.656 km), the south coast of Norway (3.788 km) and Hungary (3.865 km) [9]. An overview of all this dx QSOS is available in Fig. 6.24 on page 30 (the geographical distribution of dx stations on May 20, 2003 is discussed further below in chapter 6.6.1).

On the other hand, we are not aware of any 144 MHz dx QSO between the Canary Isles and, for example, Bulgaria, Romania, Moldavia and the Ukraine. We in particular mention this countries because sea surface reflection could enable dx distances around 4.000 kilometers in this examples. The same is true for central Norway and Sweden and even for Iceland (> 3.930 km) the south coast of Greenland (> 4.080 km) and Newfoundland (> 3.800 km). Thus, there is much potential for spectacular dx QSOs in the future.

6.2 Geographical position of Sporadic E

6.2.1 Notes on position and size of the Sporadic E clouds

Double hop propagation from the Canary Islands to the European continent requires Sporadic E clouds in apppropriate geographical position, see Fig. 6.3. Viewed from the Canary Islands, the first reflection zone (105 km height) is centered, more or less, in the IM grid square ('a'). Little displacements of the first Sporadic E cloud may therefore change the geographical position of the dx targets considerably. Note, for example, that all QSOs to Ireland and Great Britain result from Sporadic E in the fields IM24 and IM25 (left of 'a'), i.e. shifting that cloud eastwards by only one grid position (IM34 and IM35) cancels all double hop propagation to EI, G, GW and GM. On the other hand, a large Sporadic E cloud in the center of the IM grid square may support double hop propagation to almost any place in Europe (within a certain distance, of course). In this case, the geographical position and the size of the second Sporadic E cloud becomes the dominating factor in double hop propagation.

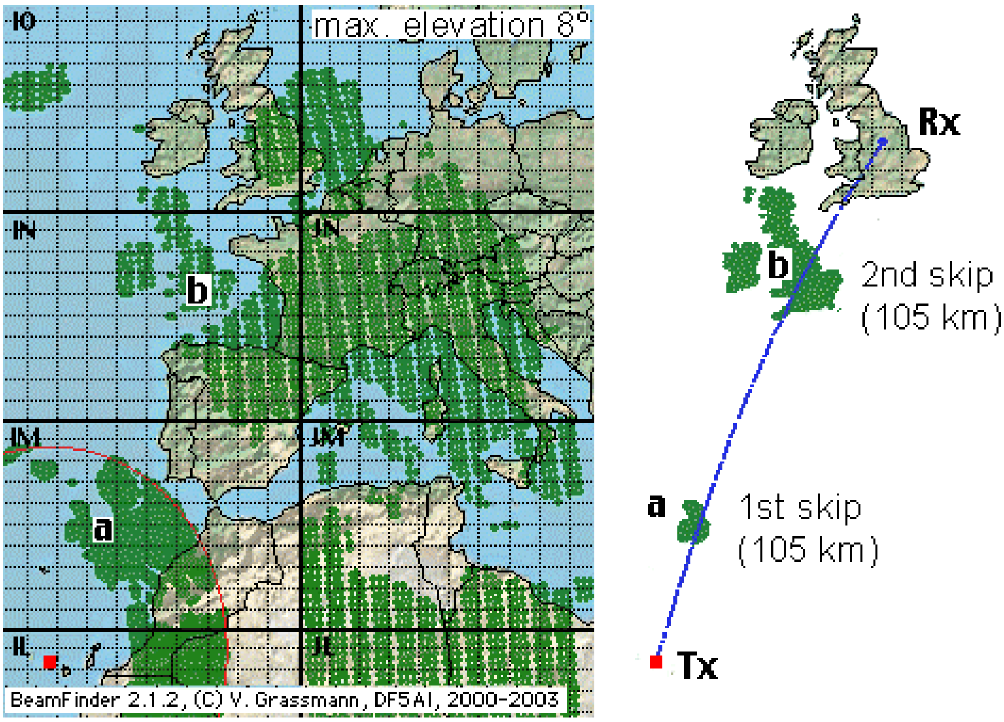

Fig. 6.3. Left: Potential Sporadic E positions in double hop propagation. The first Sporadic E cloud is always located within the red circle (0° elevation). Right: Example of double hop propagation from the Canary Isles to central England.

The second reflection zone is much larger than the first zone, see, for example, the green contour of Ireland and Great Britain in the Gulf of Biscay (IN grid square). Note that a very large second Sporadic E cloud is required to enable double hop propagation to Ireland and Great Britain at the same time. In practice, the Sporadic E cloud is typically much smaller than the green area which results in high directivity in double hop communication. For example: assuming a Sporadic E cloud would exist in the field IN75 and IN76 (right of 'b'), dx propagation is only available to the west coast of England (see the green area in that grid squares). Thus, double hop propagation from the Canary Islands to central Europe requires a relatively small Sporadic E cloud in the center of the IM grid square and a large Sporadic E area above Spain and France.

It is important to understand that the first reflection zone in double hop propagation (see the green area within the red cirle of Fig. 6.3) is not applicable in single hop Sporadic E, see Fig. 6.4. Comparing the figures, we may identify Sporadic E positions in double hop propagation which cannot support single hop propagation and vice versa.

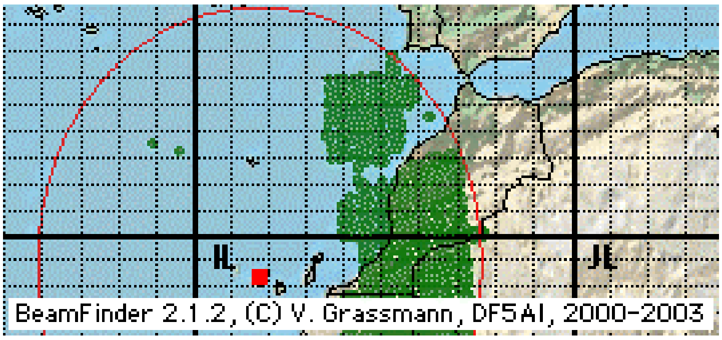

Fig. 6.4. Potential Sporadic E positions in single hop propagation.

This effect results from the requirement of dx targets located on land, i.e. a Sporadic E cloud may of course exist, for example, in the Atlantic Ocean west of the Canary Islands and it may of course support single hop as well as double hop propagation. However, this cloud woud not appear in the BeamFinder analysis because dx stations are generally not available in that direction.

6.2.2 Locating the reflection points

In Fig. 6.5, the Sporadic E positions are calculated by using the QSO data from May 20, 2003 (see the circular markers). Due to the geographical distribution of the dx stations (i.e. many stations in central Europe 'opposed' by only a few stations in the IL18 grid square), the Sporadic E positions appear scattered in the north and accumulated in the south. The southern Sporadic E region is not available in *Sampol's* (EA6VQ) results [15], the position of the northern region is however in good agreement to his findings. Using Eq. (1) and assuming a layer height of 105 km, the southern cloud was viewed under 3° to 7° elevation in the Canaries.

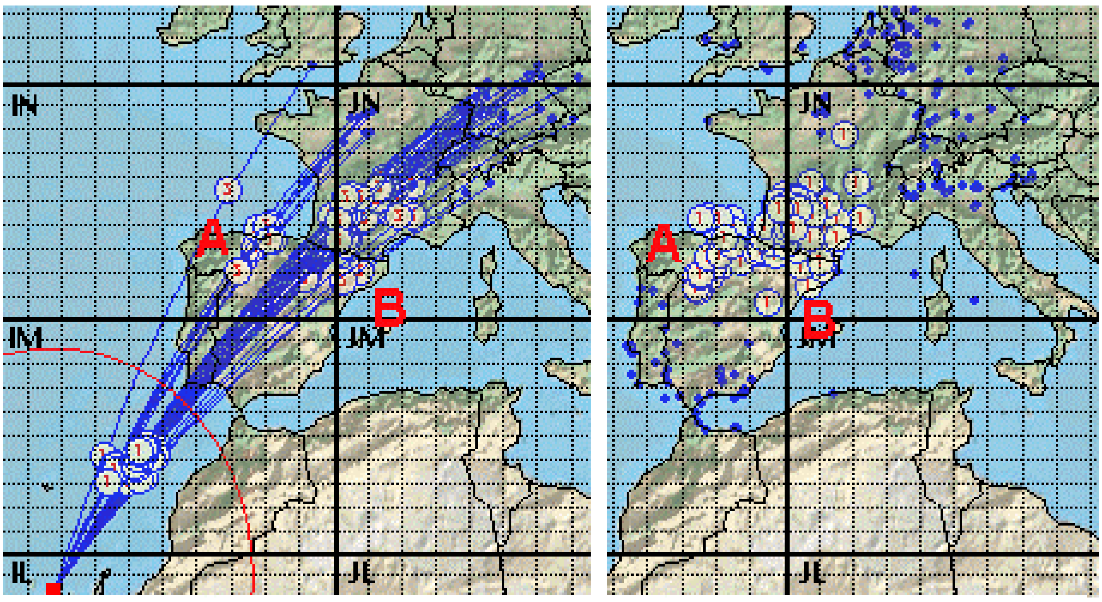

Fig. 6.5. Left: Sporadic E clouds in double hop propagation, May 20, 2003. Right: Sporadic E clouds in single hop Sporadic E. Note that a period of two hours is displayed, i.e. 16 – 18 UT.

Fig. 6.5 displays a very large Sporadic E region which extends from northern Spain to southern France and, by comparing the left and right hand side of the figure, we can identify the areas which have contributed to the double hop QSOs.

It is important to note that the left and right hand side of Fig. 6.5 result from different calculation methods. On the right, single hop geometry is assumed considering all QSO except the EA8-QSOs. On the left, double hop geometry is assumed considering EA8-QSOs only. In both calculation methods, the distribution of reflection points shows similar features, i.e. a chain of reflection points in northern Spain extending from southwest to northeast (A), a bulk of reflection points in the Barcelona region (B), a gap between this two features and, considering the overall shape of the Sporadic E region, a geographical extend which is almost identical in longitude as well as latitude. Assuming the EA8-QSOs would *not* correspond to double hop Sporadic E, calculations based on double hop geometry would certainly result in wrong position of the reflection points. In this case, the left hand side of Fig. 6.5 would display wrong results, i.e. all this identical features would be wrong even on the right hand side which is however difficult to accept. We therefore believe that Fig. 6.5 provides strong support to the double hop interpretation of the May 20, 2003 opening.

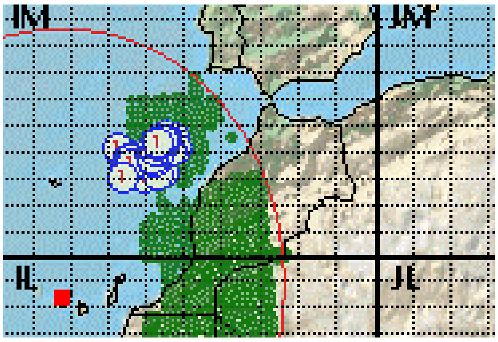

Fig. 6.6. Estimating single hop opportunities associated with the southern Sporadic E cloud.

We may assume that the southern Sporadic E cloud (Fig. 6.5, left) can also enable single hop QSOs between the Canary Islands and Portugal and Spain. Projecting the southern cloud into Fig. 6.4, we may identify the corresponding target areas, see Fig. 6.6. Surprisingly, no such such dx report is available. Actually, very few QSOs are reported between the Canary Islands and the Iberian Peninsula, see the red radio paths in Fig. 6.7. Note that all this QSOs were directed the west coast of Portugal which, in our view, indicates tropospheric radio propagation rather than ionospheric skip propagation. In fact, at least two of this QSOs are declared tropospheric dx in the reports [11].

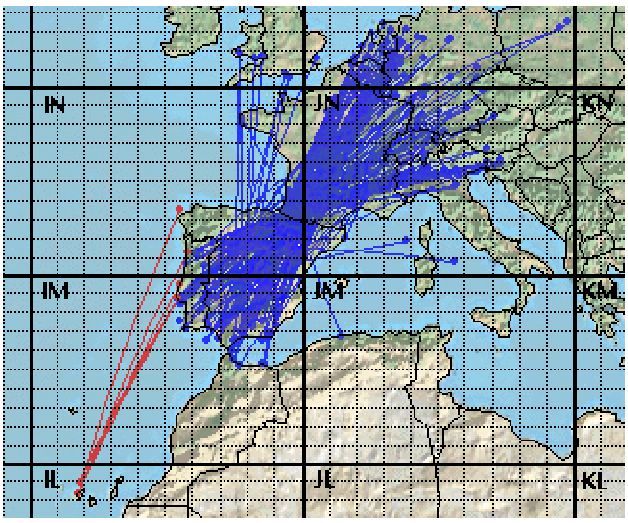

Fig. 6.7. QSOs on May 20, 2003, 16-18 UT between the Canaries and Portugal (red) and QSOs between the Iberian Peninsula and central Europe (blue) at the same time. Note the absence of Sporadic E QSOs between the Canaries and Spain/Portugal.

The majority of EA- and CT-stations have possibly turned their antennas towards central Europe, i.e. they missed all dx opportunities which were available in opposite direction. We think, this argument is not acceptable because it is very unlikely that an existing dx opening stayed hidden for more than two hours. It is perhaps worth to mention that very few examples of Sporadic E QSOs between the Canaries and the Iberian Peninsula are documented even in the literature, see, e.g., [23], [38], [39], [42], [43], [44], [45], [47], [48]. On the other hand, this does not explain missing Sporadic E QSOs in the May 20, 2003 opening – this example clearly indicates the possibility of single hop Sporadic E QSOs between EA8 and EA/CT but no such QSO is reported.

The absence of single hop Sporadic E QSOs between the Canaries and the Iberian Peninsula is indeed a serious argument against double hop propagation in the interpretation of the May 20, 2003 opening. In our view, this dx opening cannot be interpreted properly unless an explanation is found which is consistent with all the other features, aspects and characteristics associated with this dx event (this document was actually motivated by the search for an explanation).

For the moment, we will however ignore this complication and will continue to interpret the May 20, 2003 opening in terms of double hop propagation. In chapter 6.6, we will return to this subject and will address the above findings in full detail.

6.2.3 Ionosonde data

The Spanish Digisonde sounder *Roquetes* is located close to the northern Sporadic E cloud (compare Fig. 6.5 to Fig. 6.8). Its ionogram (Fig. 6.9) indeed indicates intense Sporadic E with a critical frequency f0Es of 12.9 MHz (16 UT). No ionogram is available of the southern Sporadic E cloud, unfortunately.

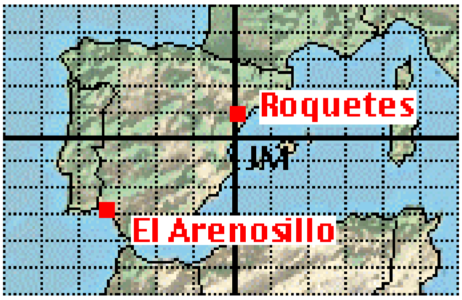

Fig. 6.8. Geographical position of the Digisonde Ionospheric sounders.

However, the Spanish Digisonde in *El Arenosillo* provides the ionogram in Fig. 6.10 which also displays intense Sporadic E (f0Es was 9.9 MHz at 16 UT). *El Arenosillo* is located almost in the center of the propagation path, i.e. close to the geographical footprint of the first skip. Thus, another Sporadic E cloud was available between the two clouds we have already identified. Perhaps, there was one cloud only, i.e. a very large reflection area which extended from the Pyrenees down to west coast of Africa. However, radio amateurs on the Canary Islands cannot access Sporadic E clouds above the Iberian Peninsula (see the red circle in Fig. 6.5), i.e. there was little chance for even longer dx distances in the 144 MHz band.

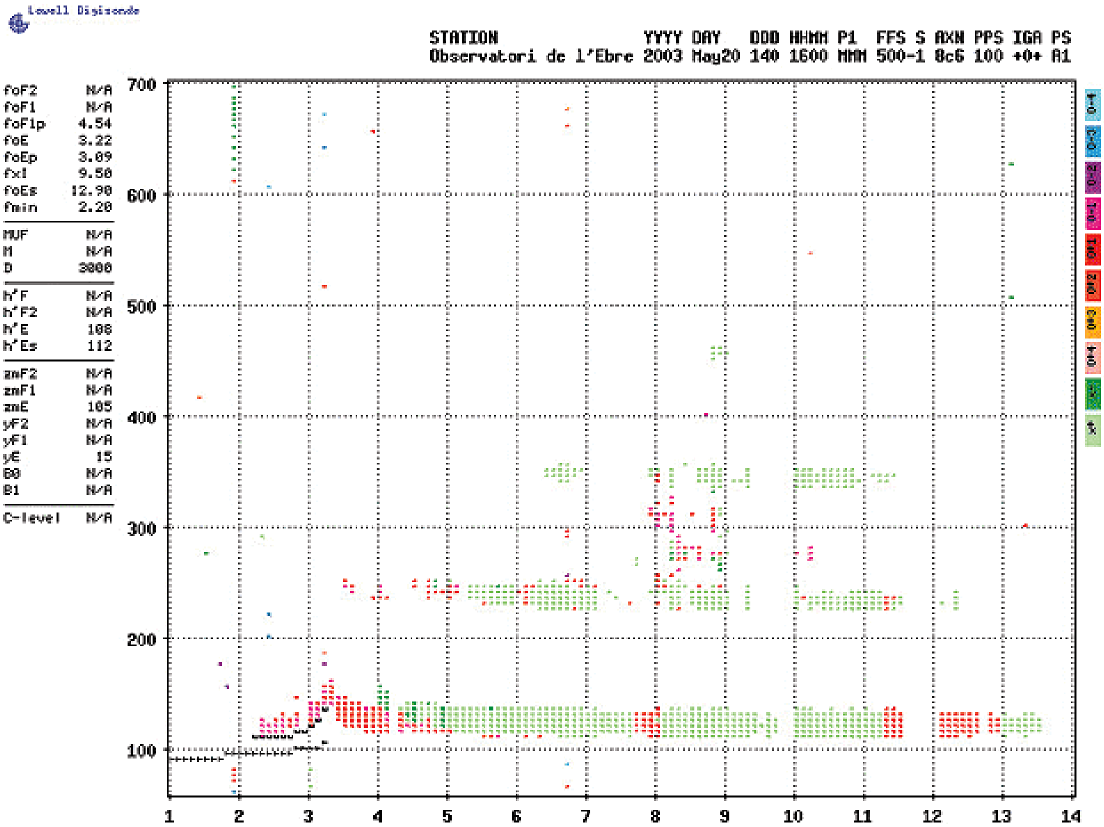

Fig. 6.9. Ionogram (May 20, 2003, 16 UT) from Observatori de l'Ebre, Roquetes [31]: f0Es at 12.9 MHz.

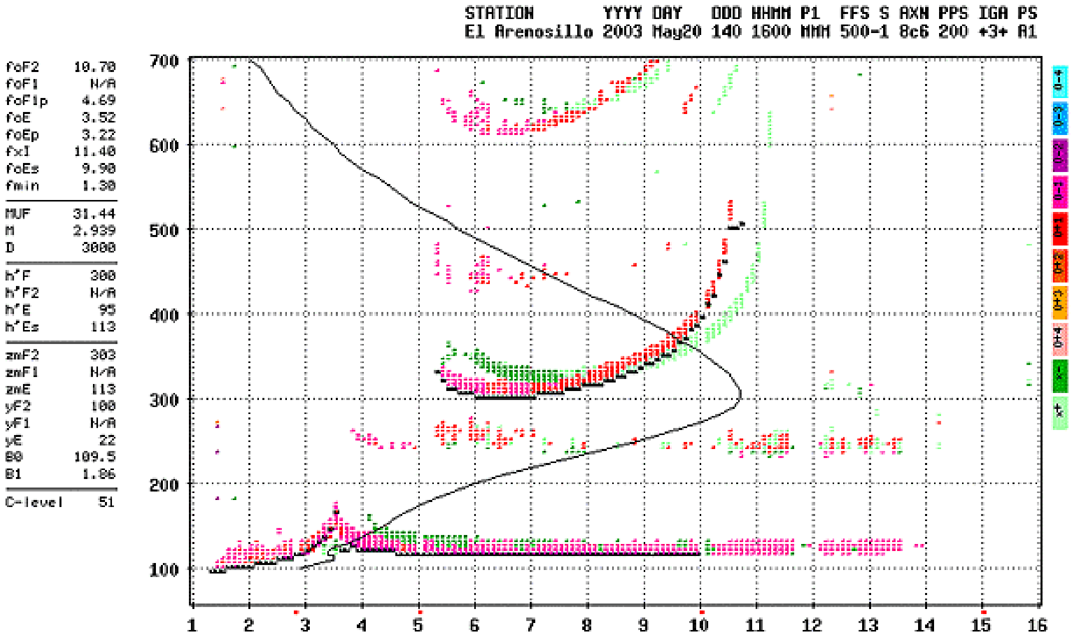

Fig. 6.10. Ionogram (May 20, 2003, 16 UT) from Digisonde station El Arenosillo, Huelva, south-west Spain [30]: f0Es at 9.9 MHz.

6.3 Geographical position of ground reflection

6.3.1 Identifying first skip locations

In chapter 6.1, we have considered reflections of radiowaves by sea and by land when discussing potential dx targets in double hop propagation. Fig. 6.11 now displays the geographical position of ground reflection on May 20, 2003.

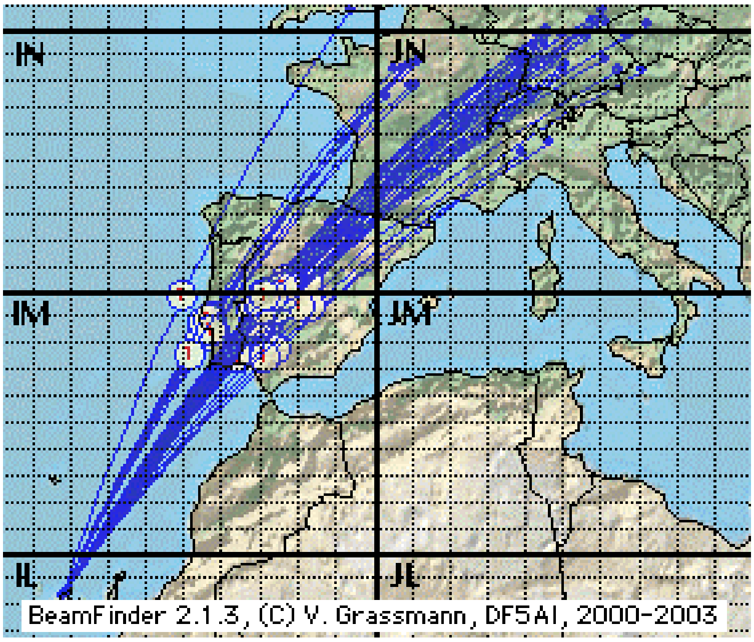

Fig. 6.11. Geographical position of ground reflection on May 20, 2003 (using the data in [12]).

Some QSOs are apparently related to sea surface reflection, see the markers in the ocean west of Portugal. The majority of dx QSOs however correspond to first skips reflected by land in western and southern Spain and in western Portugal, respectively.

Many radio amateurs probably agree to the statement that sea surface reflection of radiowaves is much more effective in VHF double hop propagation than reflection by land. In fact, historical examples of 144 MHz double hop communication are very often associated with sea surface reflection. From this perspective, it might appear surprising that the May 20, 2003 opening is apparently dominated by reflection of radiowaves by land.[2]

6.3.2 Discussion of asymmetrical skip lengths

Zimmerman, W3ZZ, [1] is sceptical about Sporadic E clouds correctly aligned to permit 3.500 km dx contacts. He in particular considers equal skip lengths not likely because the northern Sporadic E cloud has ‘probably’ reached a *maximum usable frequency* (MUF) of 220 MHz (17 UT) which would result in rather short skip distances, i.e. the skip lengths in the south must then correspond to a quite long distance.

Assuming a very high MUF in the north, the corresponding skip lengths would indeed decrease, i.e. all reflection points would move northeast towards the Pyrenees. In our view, nothing is gained with this assumption because we again need to deal with reflection of radiowaves by land similar to Fig. 6.11.

[2] EME operators consider reflection of radiowaves by land less surprising, see, e.g., the discussion of *ground gain* in [22].

The opposite scenario is perhaps more useful, i.e. assuming very high MUF with the southern cloud. In this case, the reflection points would move from the Iberian Peninsula into the ocean southwest of Spain and Portugal. Thus, complications resulting from reflection of radiowaves by land no longer exist, i.e. the May 20, 2003 opening may be interpreted by double hop propagation associated with sea surface reflection of radiowaves. The displacement of the reflection points by several hundred kilometers is however quite drastic.

Anyhow, a schematic view is displayed in Fig. 6.12 in which two elevation angles need to be considered, i.e. α and β corresponding to the short and long skip, respectively. However, the angle of the incident radiowave is identical to the angle of the reflected wave, i.e. $\alpha = \beta$ (this is in particular true because sea surface reflection is assumed in this scenario, i.e. the reflecting surface is in perfect horizontal position). Because the first skip was assumed short, α corresponds to a relatively high elevation, i.e. the same high elevation applies to β and, as a consequence, the long skip is reflected far above the E layer of the ionosphere. Thus, the requirement of identical elevation is inconsistent with the requirement of constant Sporadic E heights around 105 km.

We just obtained an important rule in double and multiple hop Sporadic E propagation, i.e. all skip lengths are more or less identical, always. This geometrical result is strongly influenced by the assumption of straight radio rays, of course. Considering bending of radio rays similar to the discussion in chapter 3, the above statement is not necessarily true any more (note that the take-off angles α and β are actually not important but the angle of incidence in the vicinity of the corresponding Sporadic E layer).

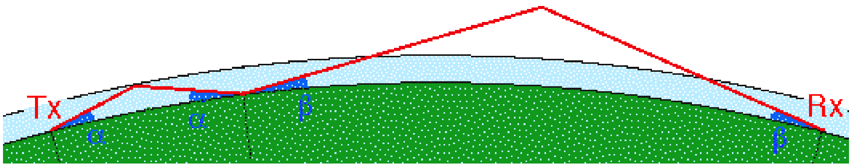

Fig. 6.12. Double hop propagation assuming unequal skip lengths.

However, the above result raises a more general question on the nature of double hop Sporadic E propagation because identical skip lengths and identical elevation also imply identical electron densities. From this perspective, VHF double hop propagation appears a highly unlikely scenario and 50 MHz multiple skip propagation (see, e.g., [24]) appears almost impossible because of the many requirements which need to be fulfilled simultaneously. This is however a too pessimistic view which results from the erroneous assumption of two or more *twin clouds* which have to develop in identical manner in independent geographical position.

Fig. 6.13 shows the schematic view of two Sporadic E clouds, each exceeds 144 MHz *maximum usable frequency*, the MUFs are not identical though. Each MUF corresponds to the Sporadic E cloud's individual maximum electron density which however decreases when moving from the center to the cloud's peripherials. In the peripherials, we may find *usable frequencies* of 144 MHz enabling double hop propagation although the two clouds may differ considerably in size and maximum electron density. This scenario has its own requirements, of course (large Sporadic E clouds in appropriate geographical position with MUFs exceeding 144 MHz) but this simple picture may demonstrate that no *twin clouds* are required in double hop propagation.

Note that the requirement of identical elevation also applies in this example, i.e. double hop propagation may be considered a filter mechanism which selects certain radio paths in the scenario of Fig. 6.13. Radio amateurs in the path center may therefore experience a much wider dx target area in single hop Sporadic E than radio amateurs located on either end of the path using double hop propagation. This feature is possibly visible in the May 20, 2003 opening, see Fig. 6.25 and Fig. 6.26 on page 31.

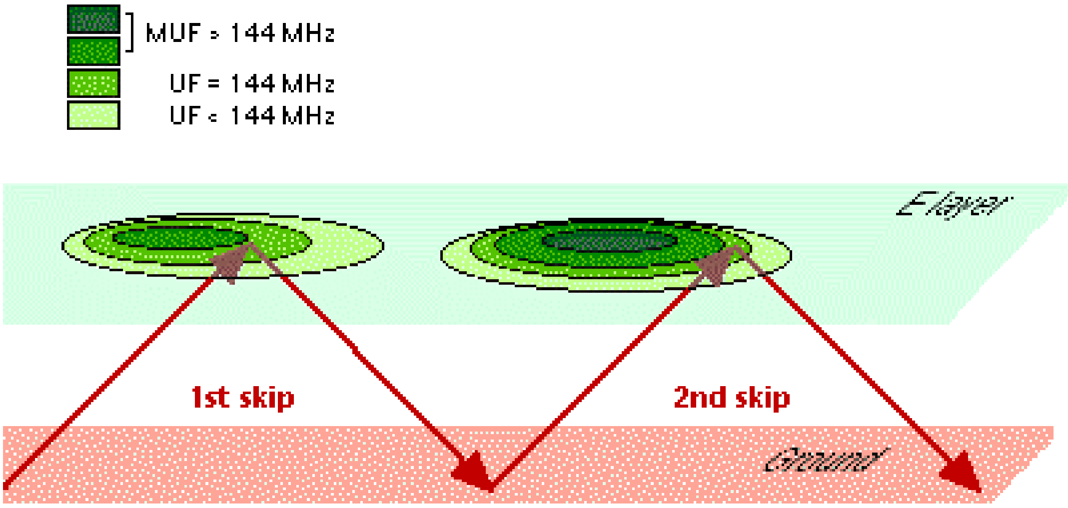

Fig. 6.13. Horizontal structure of Sporadic E clouds enabling double hop propagation.

Summarizing the above results, we have identified a scenario which interprets the May 20, 2003 opening very nicely in terms of double hop propagation associated with sea surface reflection originating in the ocean southwest of the Iberian Peninsula. Nevertheless, that model remains excluded in the following because we see no justification to abandon symmetrical skip lengths in Sporadic E geometry. Maintaining the model of equal skip lengths, the analysis must therefore consider ground reflection of radiowaves between Madrid and Lisbon. In the following chapters, the possible nature of ground reflection is discussed in more detail.

A final comment is perhaps useful at this point of the discussion. In this section, we implicitly refered to the model which was earlier described by the term 'shortwave communication extended to much higher frequencies' (see chapter 3), i.e. we did not refer to the scattering properties of the ionosphere associated with plasma waves and plasma instabilities. Actually, we are not aware that double and multiple hop propagation was ever discussed from this perspective in the scientific community, it appears an attractive research opportunity though.

6.4 Reflection on the layer topside of tropospheric inversion

Identifying first skip locations *on* land does not necessarily mean reflection of radiowaves *by* land. In this chapter, we speculate that inversion layers in the troposphere may support ionospheric double hop propagation, i.e. reflection of radiowaves by land is replaced by reflection on the topside of inversion layers, see Fig. 6.14.

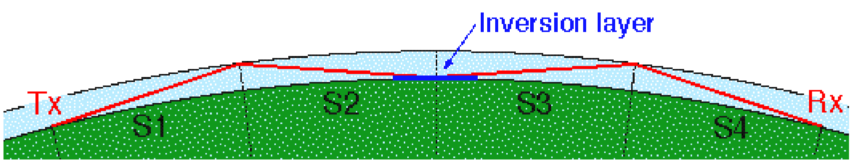

Fig. 6.14. Double hop propagation supported by an inversion layer.

VHF radio amateurs are familiar with tropospheric dx communication resulting from inversion layers which typically develop in a height of 200 to 300 meters above ground. However, *free inversion layers* may be found much higher even above 2.000 meters [52], i.e. hilly terrain and even mountains may hide underneath an inversion layer and, as a consequence, the Earth's rough surface no longer controls the reflection of the first skip. Radiowaves reflected from the ionosphere towards Earth may therefore experience the Earth's surface a smooth area with high reflectivity.

There is indeed evidence that grazing incidence of radiowaves on the topside of an inversion layer may result in strong reflection. *Lehtoranta*, OH2LX, [17] reports significantly reduced fieldstrengths with Finnish tv transmitters in high location if an inversion layer was present in lower altitude. This effect was observed in many cases and is interpreted by reflection on the layer topside which prevents radiowaves from reaching ground level. *Röttger* [8] reports a similar phenomen with the air surveillance radar in San Juan, Puerto Rico: there was a concern about air safety because the radar (located on the nearby mountain in 1.100 m asl) often lost contact to aircrafts approaching the airport from the seaside. He interpreted this phenomenon by inversion layers above the sea which was finally verified by measurement. Inversion layers were found at an altitude just below the mountain radar, i.e. the radar beam was reflected upwards by grazing incidence on the layer topside resulting in cancellation of all radar echoes by low flying aircrafts. *Röttger* [8] finally draws our attention to a well known phenomenon in radar meteorology, i.e. the *capping inversion* which is often found in a height of 1 to 3 kilometers separating the *Planetary Boundary Layer*[3] from the free atmosphere.

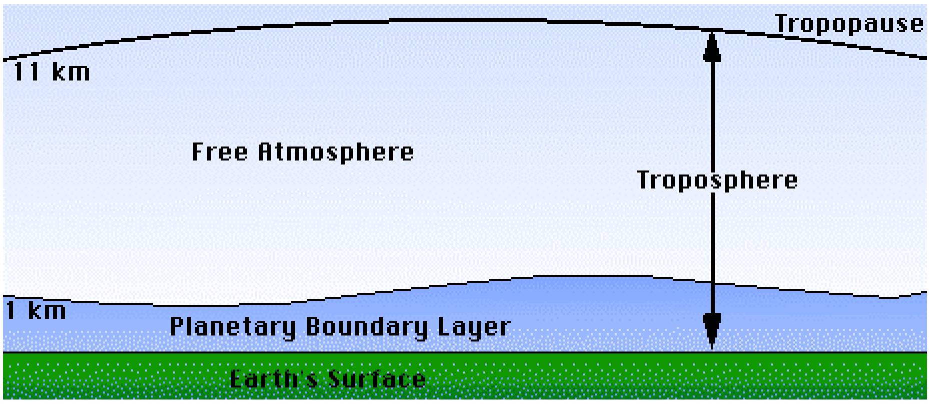

Fig. 6.15. Schematic view of the Planetary Boundary Layer [36].

The concept of double hop Sporadic E supported by inversion layers appears consistent with some characteristsics of the May 20, 2003 dx opening, for example:

- the observed dx distances between of 3.000 to 3.500 kilometers correspond to double hop Sporadic E propagation
- we would expect that amateur radio stations located in the center of a double hop path may establish (single hop) Sporadic E QSOs even if they cannot benefit from double hop; such dx reports are not available though – we think the shielding function of inversion layers may explain the absence of Sporadic E observations in western Spain (see the detailed discussion in chapter 6.2.2)
- the existence of inversion layers is consistent with enhanced tropospheric radio propagation and tropospheric ducting in south-western Europe on this particular day

[3] The Planetary Boundary Layer (PBL) is the atmosphere's lowest part which is strongly influenced by the presence of the surface of the Earth, see, e.g., the introduction in [36]. Investigating the influence of the capping inversion on VHF dxing appears an attractive research opportunity in amateur radio. It may perhaps explain 144 MHz dx QSOs which do not correlate to any band opening.

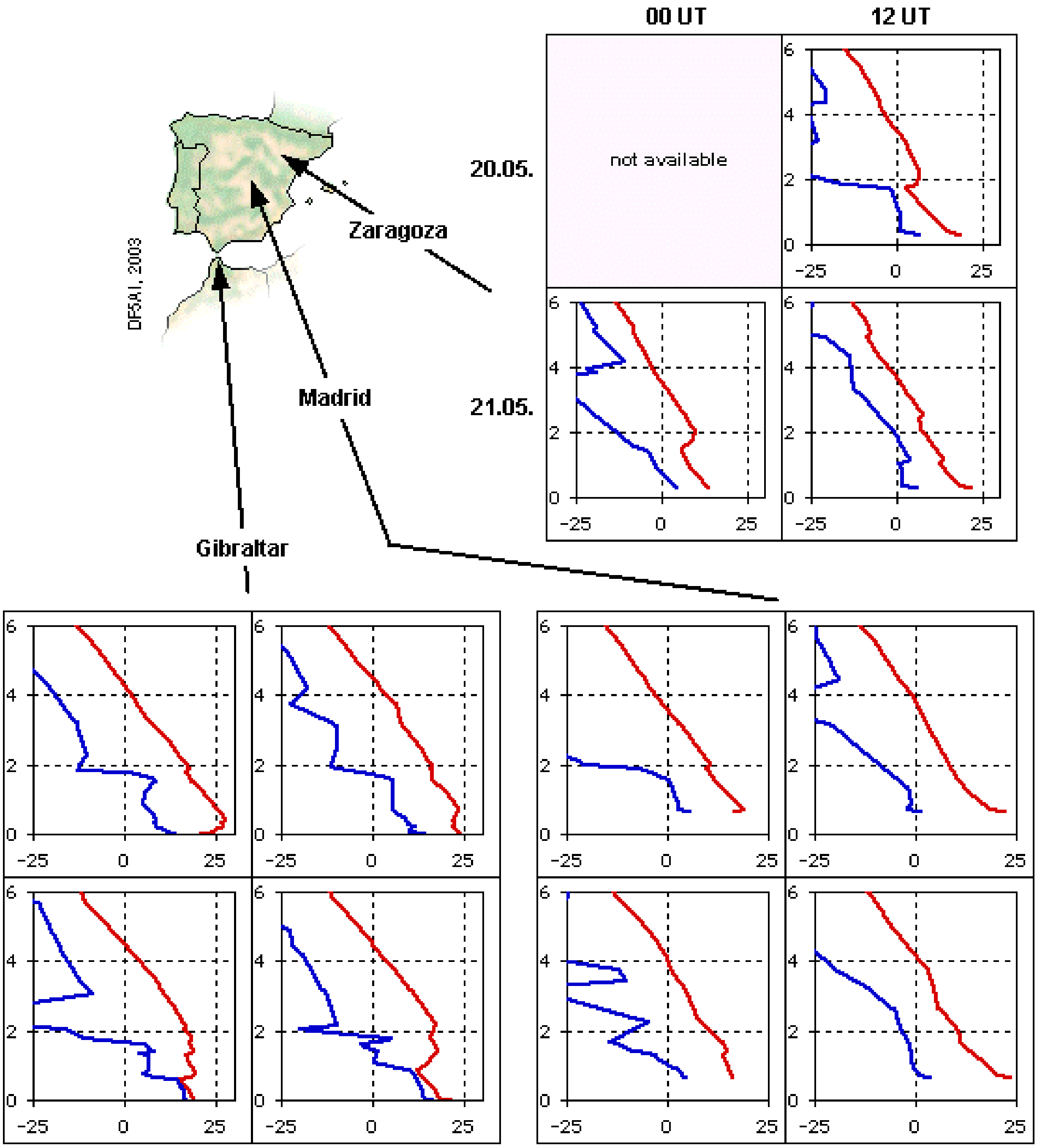

Fig. 6.16. Vertical profiles of air temperature (red) and dew-point (blue) indicating various examples of tropospheric inversion layers (using data in [29]). The upper and lower panels denote sounding data for May 20 and May 21, respectively. The left hand side of the panels correspond to 00 UT and right hand side to 12 UT. The vertical scale denotes kilometers (i.e. 0, 2, 4 and 6 km altitude). The horizontal scale indicates the temperatue in degree Celsius. Note the decreasing height of the inversion layers which is in particular evident in the Gibraltar data.

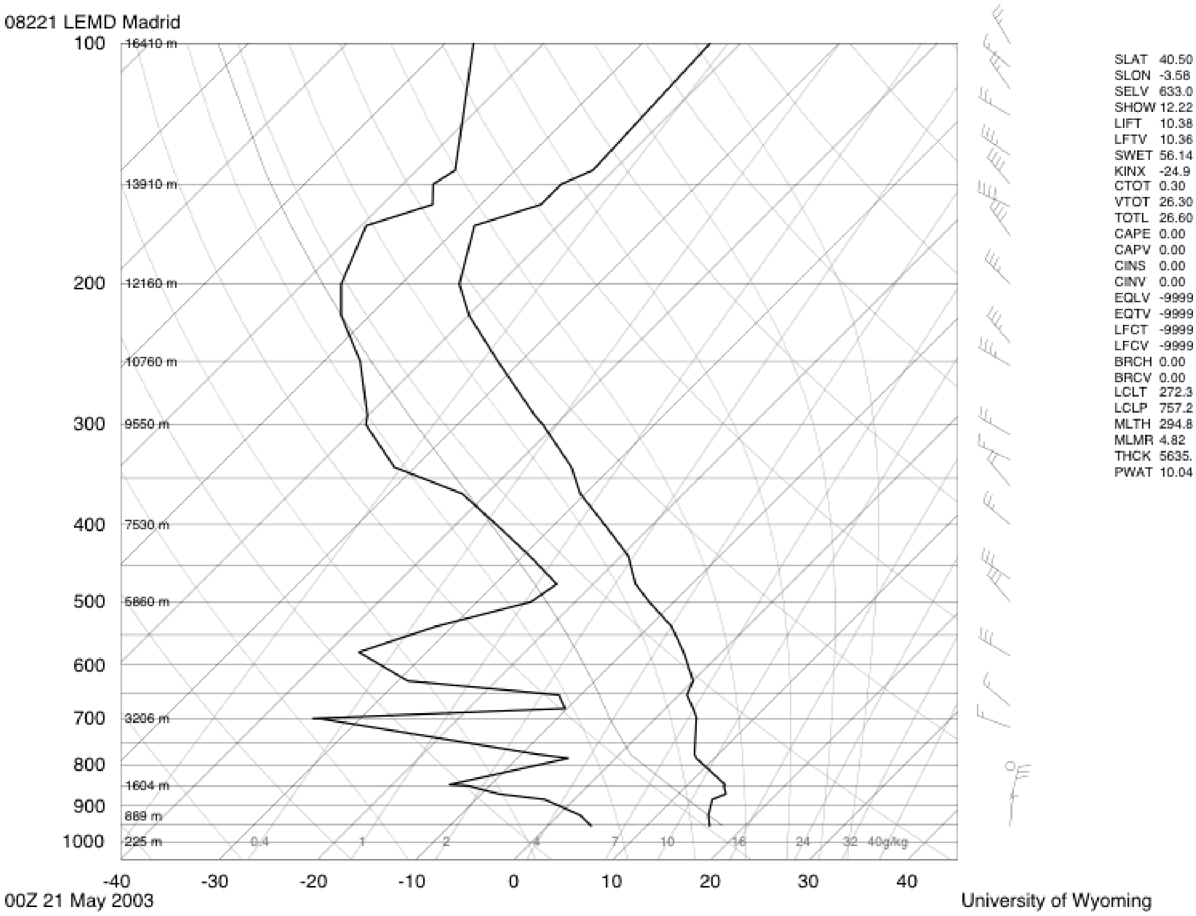

Fig. 6.17. Temperature (right) and dew-point (left), Madrid, May 21, 2003, 00 UT [10].

On May 20 and 21, 2003 intense inversion layers were indeed detected at nighttime all over Spain, see the left diagrams in all panels of Fig. 6.16 (Zaragoza, Madrid and Gibraltar). At noon, the situation varied with geographical position: in Zaragoza an inversion was available on May 20, 12 UT persisting until midnight at 00 UT, at least in temperature. We may therefore assume that at least temperature inversion was available during the dx opening between 16 and 18 UT.

In Madrid, no inversion was available at noon (May 20) but at midnight (May 21, 00 UT), see the enlarged view in Fig. 6.17. Thus, we cannot judge about the availability of inversion layers in the Madrid region between 16 and 18 UT.

In Gibraltar, inversion appeared in different heights on May 20, 12 UT intensifying around midnight. Hence, inversion layers were also available in southern Spain during the dx opening.

Thus, reflection of radiowaves by tropospheric inversion layers appears consistent with the meteorological data, the concept isn't proved to be true though. In the following chapter, we will discuss an alternative model to interpret ground reflection of radiowaves between Madrid and Lisbon. In chapter 6.6, we finally discuss a possible link between both concepts.

6.5 "Radioglint" in lakes and major rivers

6.5.1 Introduction

In this chapter, we speculate that large lakes and major rivers represent reflecting surfaces which may support double hop propagation in 144 MHz. Although we cannot compare radiowaves to optical wavelengths, Fig. 6.18 is presented to motivate this concept.

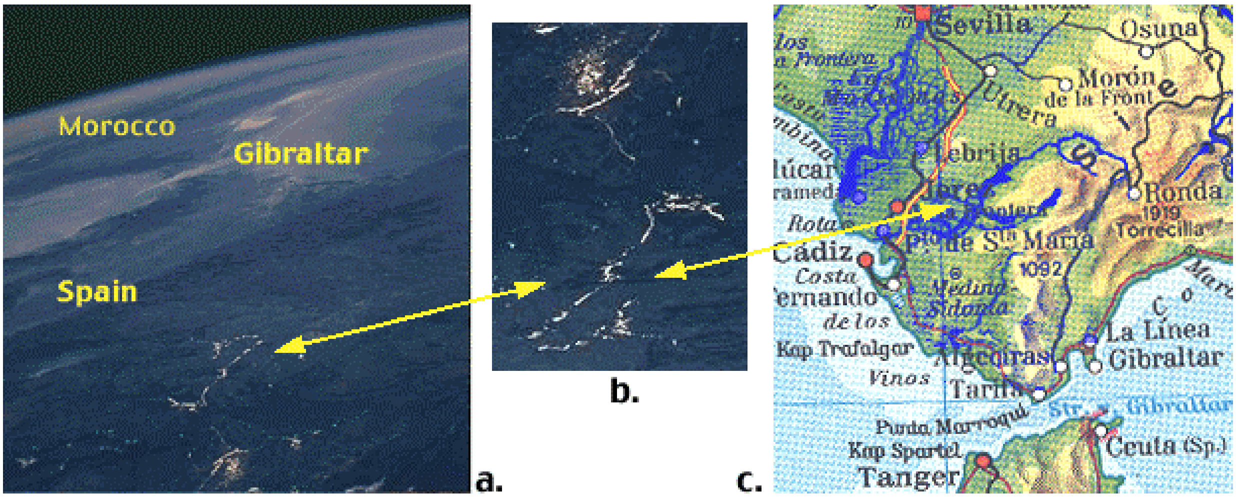

Fig. 6.18. a) Space view of southern Spain showing bright sunglint in a river (note the reverse north-south orientation) [19]; b) enlarged view, note the large water area on the top; c) map of the Gibraltar region.

We think a similar phenomenon might exist with radiowaves, i.e. *radioglint* in lakes and rivers. This assumption might appear surprising because historical examples of sea surface reflection in 144 MHz double hop propagation are typically related to large water expanses, e.g. the Bay of Biscay, the Mediterranean and the Black Sea, respectively. This is a statistical effect in our view because oceans and its neighbouring countries imply much less restrictions on Sporadic E positions than inland lakes, i.e. an appropriate double hop geometry is more likely with large water expanses. Thus, the dominant role of ocean surface reflection does not result from a general requirement of large water areas in 144 MHz double hop propagation.

In fact, the footprint of Sporadic E skips correspond very often to small geographical areas. Note, for example, the remarkable directivity in many 144 MHz Sporadic E QSOs, i.e. fellow hams located in an adjacent grid square may receive Sporadic E signals at very high fieldstrength while we can pick no radio signal from the same dx station at all (one of the authors, DK5YA, made this experience within a radius of only five kilometers). We may conclude that this footprint is a small geographical region (the footprint may however vary considerably in very short time, i.e. it may change its size and its geographical position within seconds). Hence, the first skip in double hop propagation corresponds to small geographical footprints too, i.e. large lakes and major rivers may support ground reflection in double hop QSOs. Inland lakes, by the way, are advantageous in skip propagation for another purely geometrical reason: the horizontal water surface can maintain the required low take-off angle of the radiowaves which is difficult to maintain in oblique terrain (on May 20, 2003 the elevation was 3° to 7°, see chapter 6.2.2).

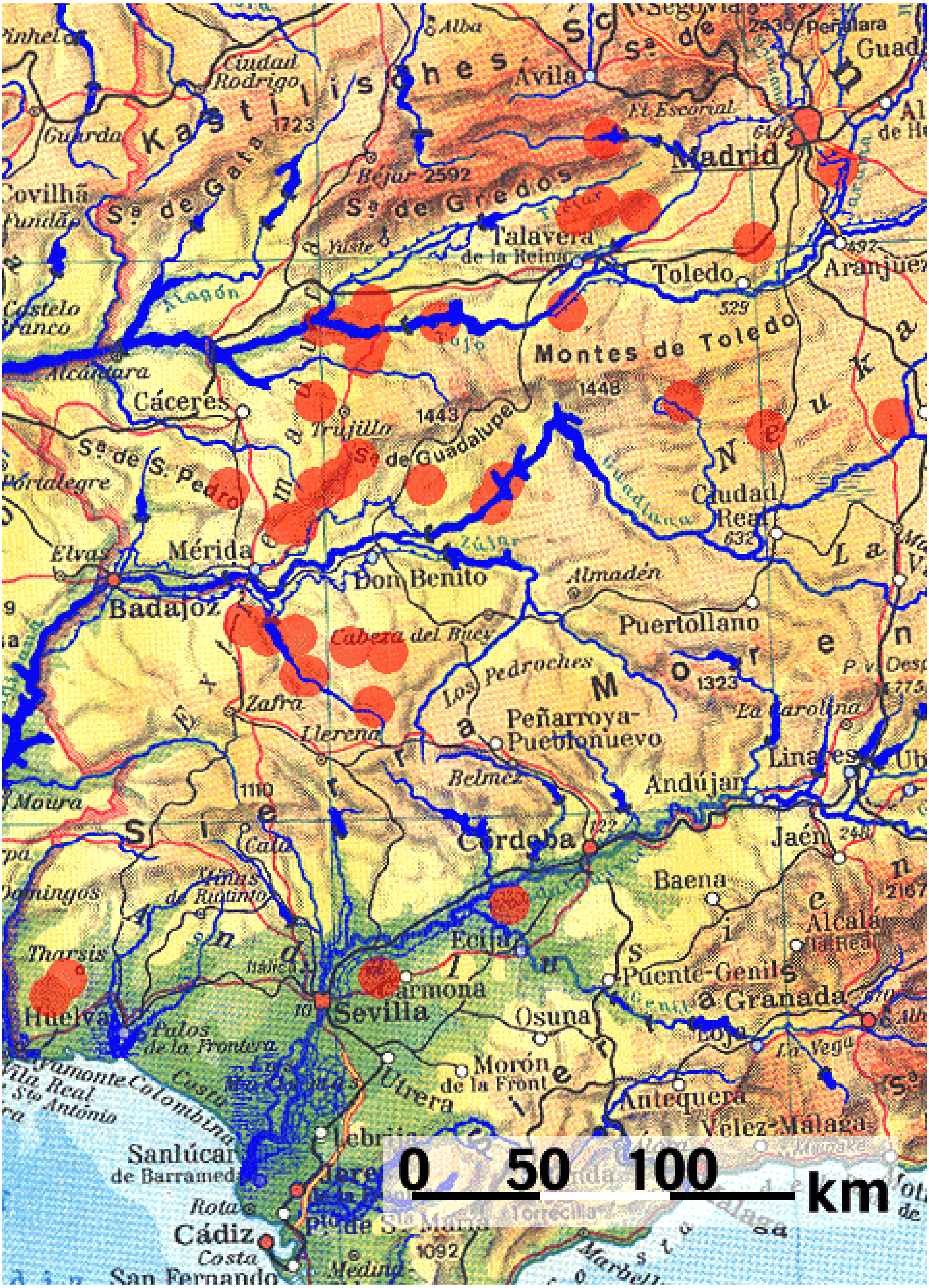

Fig. 6.19. First skip positions, part 1.

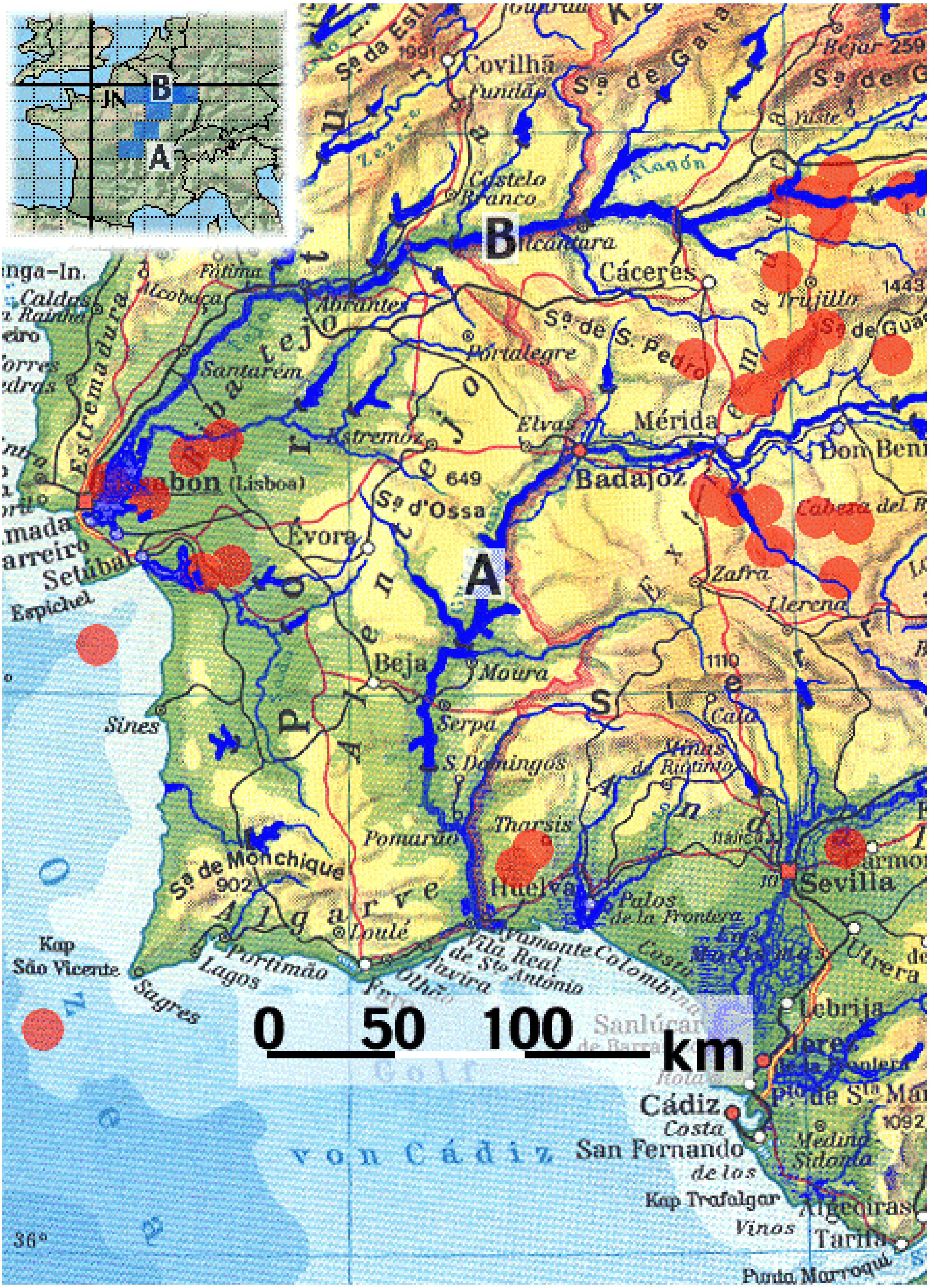

Fig. 6.20. First skip positions, part 2.

6.5.2 Identifying ground reflection in higher geographical resolution

In Fig. 6.19 and Fig. 6.20, the geographical position of ground reflection is displayed on a map of Spain and Portugal (note that the red circles correspond to the circles in Fig. 6.11, see page 19). This positions are calculated geometrically by considering the center of the corresponding propagation path. The propagation path, on the other hand, is calculated by using the grid locators of the corresponding dx stations. It is believed that the geographical accuracy of the red circles mainly depend on the assumption of equal skip length (i.e. S1-S2 equals S3-S4 in Fig. 6.1, see page 12) rather than the accuracy of the dx stations' grid locators. Taking into consideration that the width of a six-digit grid square is 6 minutes in longitude [49], the grid locators provide a geographical accuracy better than 2 kilometers in this latitudes. Thus, the red circles will slightly change position even if a dx station is not centered in the corresponding grid square and even if one or both dx stations specify grid squares erroneously shifted by one ot two grid positions. The assumption of equal skip length is however difficult to verify; we have therefore introduced circles with a diameter of approximately 15 kilometers.

Inspecting the geographical position of the red circles, three categories may be identified (negleting all cases of ocean surface reflection), i.e.

- *water:* ground reflection of radiowaves associated with lakes and major rivers (see Fig. 6.21); this category comprises about sixty percent of all circles (the percentage is even higher when considering the number of QSOs rather than the number of circles because many positions correspond to multiple QSOs)
- *mountain ridges:* ground reflection associated with hill tops and ridges of mountains (note in particular the two chains of red circles in Fig. 6.22), about 25 percent of the circles correspond to this category
- *unknown:* seven circles (15 %) correspond to none of the above categories, see Fig. 6.23

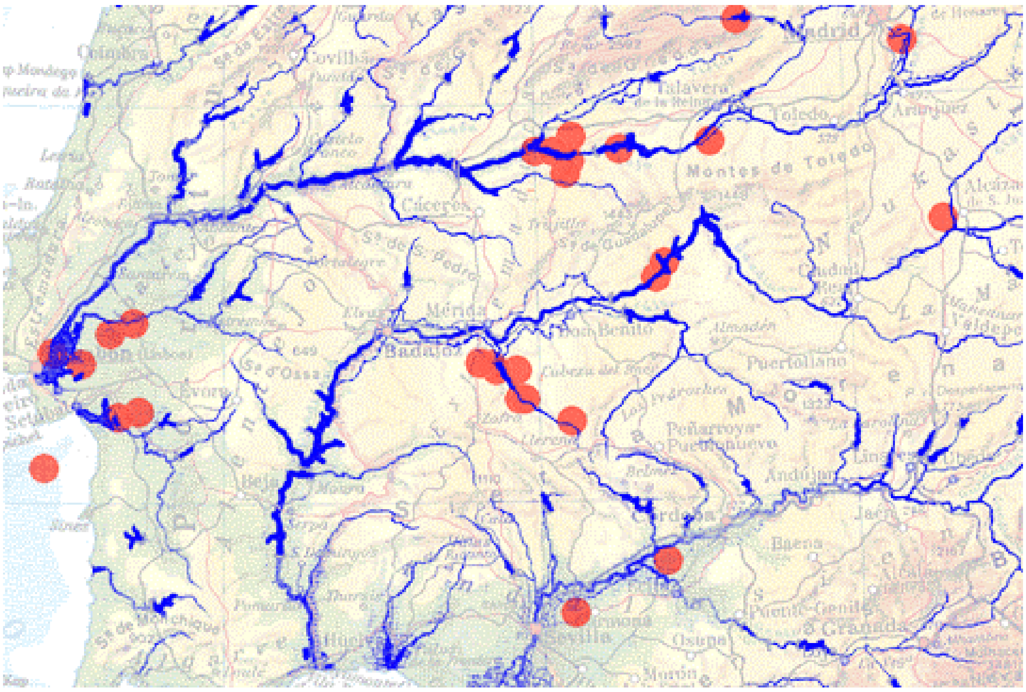

Fig. 6.21. Category "water".

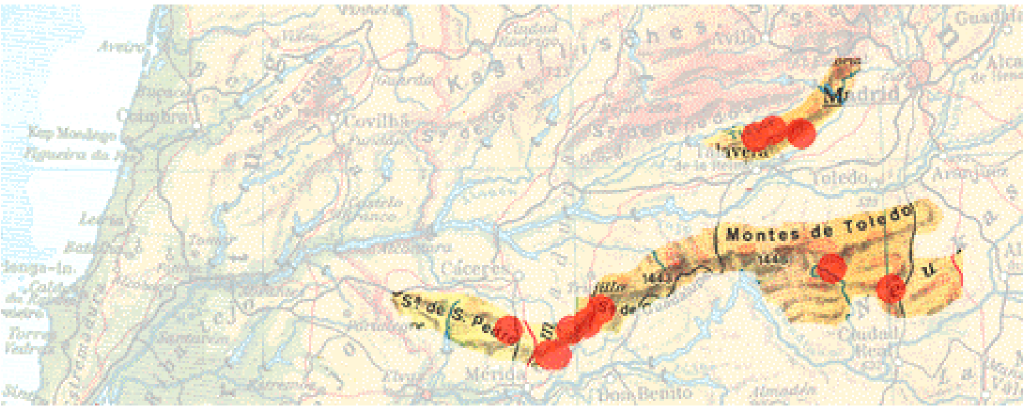

Fig. 6.22. Category "mountain ridges".

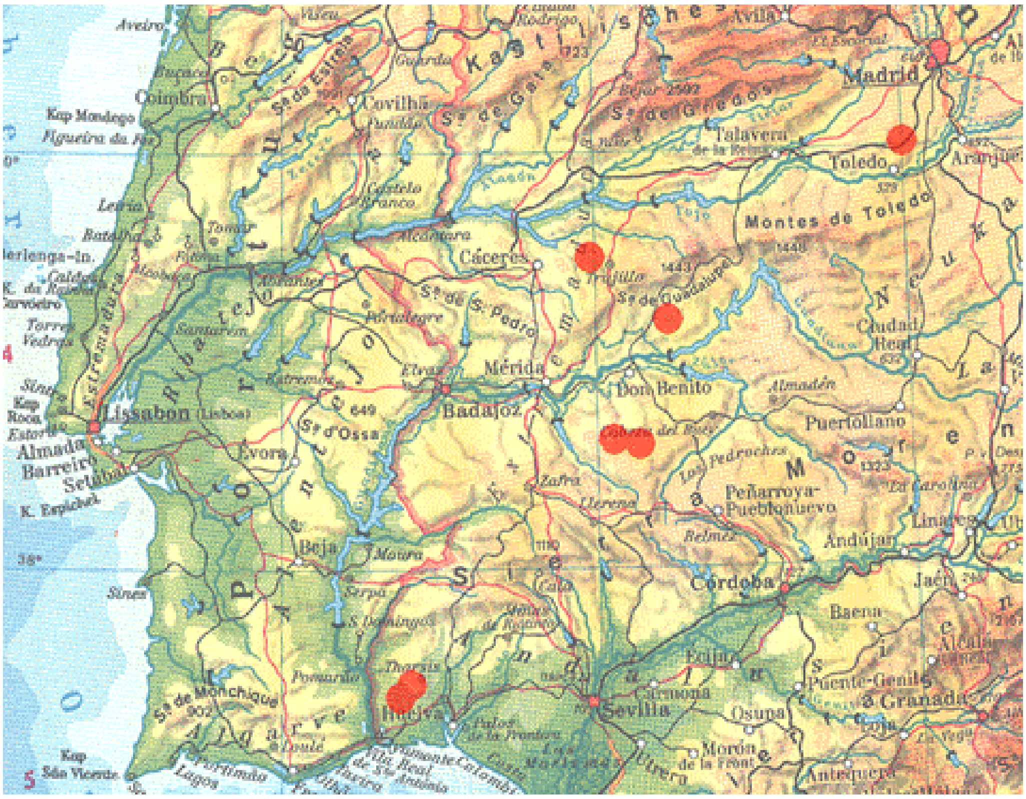

Fig. 6.23. Category "unknown".

We learnt from various internet resources that the *Extremadura* southwest of Madrid (see Fig. 6.19) is a large water supply area in Spain. The rivers *Tajo* and *Guadiana* (north and south of the *Montes de Toledo*) provide an extended network of lakes and dams [54] resulting in the 'longest inland coast line' in Spain [55]. Considering pictures of the scenery, we may indeed find large lakes and reservoirs [56], [57]. On the other hand, we may also find pictures in the internet giving the impression that the river *Tajo* is quite narrow in some places [58].

Considering the figures, we may assume that ground reflection of radiowaves by lakes and rivers indeed plays a major role in the May 20, 2003 opening. In fact, the majority of the circles correspond to open water (see the Lisbon region), lakes and major rivers (often associated with dams), i.e. just a few circles exclusively represent dry terrain. We also get the impression that many circles appear to follow the course of a river, see, for example, the arm of the river

Guadiana southeast of the city of Badajoz, the river *Guadalquivir* between Sevilla and Córdoba and the many circles along the river *Tajo* southwest of Madrid (Fig. 6.19).

Assuming we would randomly distribute the same amount of circles in the same geographical area, would we obtain a similiar result, i.e. a high number of circles in adjacent position to lakes, rivers and dams? In fact, many rivers and lakes exist in this region and perhaps we would again obtain a large number of circles associated with water areas. We however think, an arbitrary distribution of circles will result in much more positions excluding all rivers and lakes contrary to the above findings. On the other hand, no first skip location is found along the river *Tajo* and *Guadiana* on Portuguese territory, see A and B in Fig. 6.20. Does this mean, there was no first skip available or does it mean no station catched the second hop in France (see the calculated target areas in the upper left corner of Fig. 6.20)? One of the authors (DF5AI), by the way, requested observation reports from France in the ham radio email forums, but no such report was actually received.

We hope similar band openings will be available again in the future providing clarification at least of some open questions. In Fig. 6.24 the river *Tajo*, *Guadiana*, *Guadalquivir* and *Douro/Duero*, respectively, is projected into central Europe by considering the double hop geometry from May 20, 2003. This display is applicable in future band openings too, i.e. the geographical position of European radio stations may be directly compared to the projected course of the rivers. We believe, amateur radio stations located in the red areas and along the red lines in Fig. 6.24 have a higher chance of 144 MHz communication to the Canary Islands than radio amateurs located in other regions. We hope, more observation data may verify this assumption statistically. The blue dots denote all QSO data from the most recent EA8 openings as well as available information from literature, see [23], [38], [39], [42], [43], [44], [45], [47], [48].

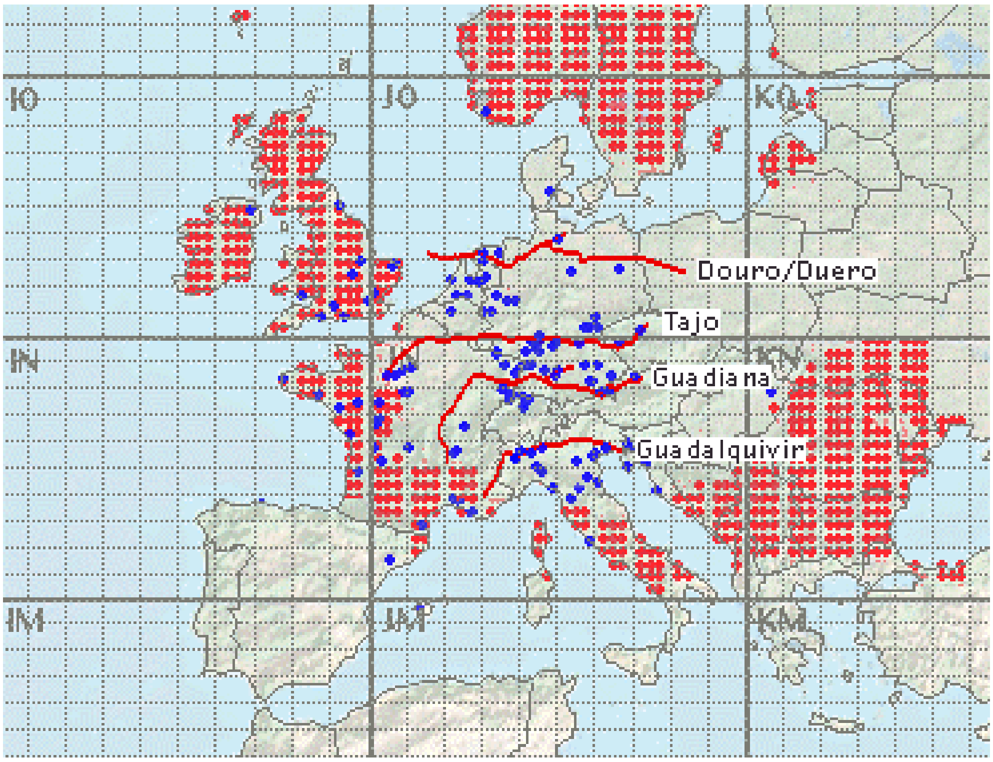

Fig. 6.24. The rivers Guadalquivir, Guadiana, Tajo and Douro/Duero mapped into central Europe. The red dots denote target areas resulting from ocean surface reflection (compare to Fig. 6.2 on page 13), the blue dots denote 144 MHz amateur radio stations having worked or heard EA8 in recent years (including data from May 20, June 22 and July 2, 7 and 9, 2003).

6.6 The "secret of the Extremadura"

6.6.1 Geographical distribution of dx stations

Fig. 6.25 displays the geographical distribution of all amateur radio stations having worked or heard EA8 stations on May 20, 2003. The majority of stations is located in a geographical band extending from the southwest of Germany to the Czech Republic. Some stations are also found in northern France (upper left corner of the JN grid square) and a few stations appear randomly scattered over southern England, the west and south of France and northern Italy, respectively.

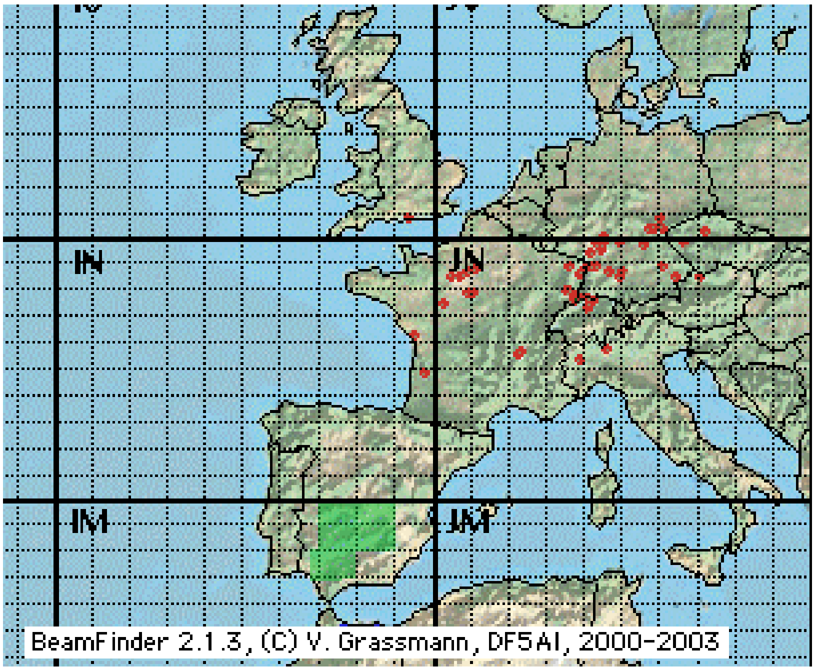

Fig. 6.25. Geographical distribution of amateur radio stations having worked or heard EA8 stations. The green area denotes the *Extremadura* region.

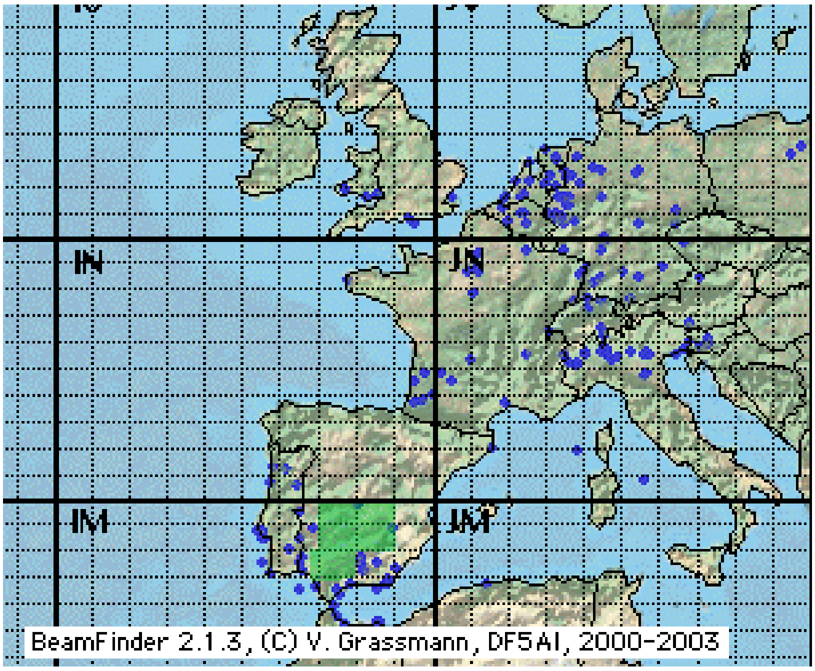

Fig. 6.26. Geographical distribution of amateur radio stations having worked or heard QSOs via single hop Sporadic E.

Fig. 6.26 displays the geographical distribution of all amateur radio stations having worked or heard QSOs via single hop Sporadic E. Note that stations on both ends of the corresponding radio circuits are shown, i.e. the stations in the southwest and south of the Iberian Peninsula have worked the stations shown in central Europe and vice versa.

Comparing this figure to Fig. 6.25, the dx target areas in single hop propagation differ considerably from double hop. Here, the majority of amateur radio stations is located in the Benelux countries and in western Germany, another bulk of radio stations extend across northern Italy. We also notice a large number of stations scattered from Wales to southern France, in southwest and central Germany and even in Poland. The stations near Bordeaux on the southwest coast of France mainly correspond, by the way, to short distance Sporadic E QSOs to Portugal (around the IM58 grid square) indicating high MUF in the northern Sporadic E cloud (see 'A' on the right hand side of Fig. 6.5, page 15). *Zimmerman*, W3ZZ, probably refers to this QSOs when mentioning a *maximum usable frequency* of 220 MHz at 17 UT, see chapter 6.3.2.

We are not surprised that the geographical distribution of radio stations is much wider in single hop propagation than in double hop (see the discussion in chapter 6.3.2). However, we are surprised about the small number of radio stations between southwest Germany and the Czech Republic, i.e. in the area in which many stations worked long distance dx to the Canary Islands. We cannot imagine that those stations could work EA8 via double hop but couldn't access EA/CT via single hop. We think, the corresponding dx reports are strongly influenced by the radio operators' strategy in dx hunting, i.e. they no longer focused on single hop QSOs to the Iberian Peninsula as soon as EA8 became available in the 144 MHz band.

6.6.2 Absence of Sporadic E QSOs in the Extremadura region

In chapter 6.5.2, we have analysed the terrain features at the geometrical center of all double hop paths resulting in a systematical pattern, i.e. first skip locations corresponding to the position of lakes, rivers and mountain ridges. Even if we would neglect the idea of radioglint in lakes and rivers, that pattern may be interpreted the geographical footprint of incident radiowaves in the *Extremadura* region southwest of Madrid. In chapter 6.2.2, the absence of single hop Sporadic E QSOs between the Canary Islands and the Iberian Peninsula was already considered surprising, the absence of Sporadic E QSOs in the *Extremadura* is even more surprising. Here, first skip radio signals were apparently available but local radio amateurs in this region couldn't manage any Sporadic E QSO by using the same ionospheric skip.

We believe, another striking feature needs to be considered in this discussion, i.e. the absence of blue dots in the green area of Fig. 6.26. Note that this figure refers to the northern Sporadic E cloud, i.e. the absence of Sporadic E QSOs in the *Extremadura* does not appear an exclusive feature of the southern cloud but a general feature of the May 20, 2003 opening. Investigating the finding in more detail, we refered to the 'secret of the Extremadura' in our internal discussion and we found very interesting results (we therefore decided to report the findings in this chapter 6.6).

The general absence of Sporadic E QSOs in the *Extremadura* also affects the concept of tropospheric dx propagation in combination with Sporadic E, i.e. the "tropo+Es" theory. This model only consideres the Sporadic E cloud above the Pyrenees, i.e. the southern cloud is not available because it is replaced by the assumption of tropospheric ducting in the IM grid square. In chapter 5, we discussed radiowaves which somehow changed from tropospheric propagation into ionospheric propagation, the transient region is estimated in the center of the IM grid square, see Fig. 5.2 on page 11. On their way into the ionosphere, the radiowaves finally approached the *Extremadura*, i.e. we can hardly assume that the radiowaves still traveled at tropospheric heights in this geographical region. Thus, the *Extremadura* cannot play any role in the "tropo+Es" theory. The absence of Sporadic E QSOs in the *Extremadura* must therefore remain an open question in the "tropo+Es" theory. This is a major deficiency, in our view, which disqualifies the "tropo+Es" model to a certain degree.

6.6.3 Inversion layers above inland water surfaces

In chapter 6.4 and 6.5, we discussed reflection of radiowaves on the layer topside of tropospheric inversion and radioglint in lakes and rivers, respectively. This models are highly incompatible, of course, because ground reflection of radiowaves is excluded in the first model but is required in the second model. We however realized that this discrepancy may be removed by introducing little modification to the models. In this process, we obtained a consistent picture and we were surprised to notice, that the same picture may also explain the 'secret of the Extremadura'.

We speculate that inversion layers developed more or less exclusively above inland lakes and rivers. From this perspective, double hop propagation was supported by reflection of radiowaves on the topside of inversion layers but this effect was only available above large lakes, major rivers, reservoirs and dams (see the category "water" in Fig. 6.21 on page 28). Thus, the first skip locations indeed correlate to the position of inland water areas, the idea of radioglint in lakes and rivers becomes obsolete though (in the case of the Extremadura, i.e. we are reluctant to reject the radioglint model in general).

Formation of local inversion layers associated to inland water surfaces may result from the high air temperature in the *Extremadura* on May 20, 2003 (see the spot of high temperature in Fig. 4.2 on page 7). *Fink* [16] points out that even small lakes may disrupt atmospheric convection in certain meteorological situations, i.e. calm winds, high air temperture but low water surface temperature. This effect becomes visible by the absence of cumulus clouds above and downstream the lake. He clearly states that this feature is observed often but, nevertheless, it does not provide any evidence for inversion. However, it indicates (in our view) that even small water surfaces may create 'local features' within the ambient atmosphere.

Using this idea in the interpretation of the May 20, 2003 opening, the 'secret of the Extremadura' is interpreted by local inversion layers at the path center which prevented radiowaves (approaching from the E layer of the ionosphere) from reaching ground level. Thus, amateur radio stations in the middle of the path had no access to the Sporadic E clouds. No single hop Sporadic E was therefore available in neither direction, i.e. from Spain to the Canaries and to central Europe, respectively.

This model may also explain another feature, i.e. first skip locations displaced from lakes and rivers by, say, twenty to thirty kilometers: the inversion indeed forms locally above the water surface but ambient wind fields in the lower atmosphere may cause horizontal drifts of the inversion. Assuming a wind speed of 2 meters/second (i.e. calm winds corresponding to two Beaufort units), the drift is 14.4 kilometers in two hours time (the duration of the double hop opening). Taking into consideration that some first skip locations are precisely located above water and others appear displaced by twenty to thirty kilometers (see in particular the category "unknown" in Fig. 6.23 on page 29), the above value appears consistent with the average positioning accuracy of the red circles in the figures. The assumption of calm winds is justified by the measured wind speed below 2.000 m in the Madrid region, see Fig. 6.27. Unfortunately, comparison of the wind direction and the direction of displacement is almost impossible because the wind direction changes considerably with height in Fig. 6.27.

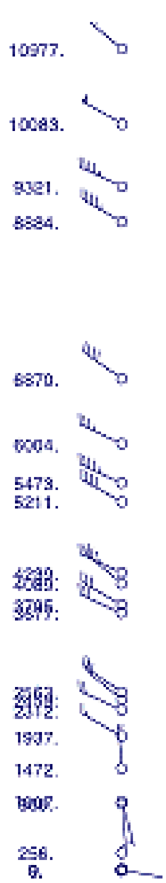

Fig. 6.27. Vertical profile of wind speed, Madrid, May 20, 2003, 12 UT, [10].

7. Summary

7.1 Pros and cons in the double hop interpretation

From our perspective, the double hop interpretation can provide a highly consistent picture of the May 20, 2003 opening, i.e.

- the observed dx distances (2.500 to 3.600 km) may be easily explained by double hop propagation
- an extended Sporadic E opening was available between Spain/Portugal and central Europe, the corresponding Sporadic E cloud may be considered the northern cloud in double hop propagation (see Fig. 6.5, page 15)
- estimating the cloud's size and geographical position, we obtain almost identical results with two alternative calculation methods (see chapter 6.2.2)
- the assumption of an additional Sporadic E cloud further south is reasonable because of the *El Arenosillo* ionogram (see chapter 6.2.3) and because only a relatively small cloud is required in the IM grid square (see Fig. 6.5)
- all EA8-QSOs were made in the main phase of the Sporadic E opening

Negleting the speculative elements we have added to the double hop interpretation, the following open questions remain:

- in double hop propagation, we may expect single hop Sporadic E QSOs from the path center to either end of the circuit, i.e. from the *Extremadura* region in Spain to the Canary Islands and also to central Europe – no such QSO is however reported in neither direction ('secret of the Extremadura')
- the majority of first skips terminates on land between Madrid and Lisbon indicating reflection of radiowaves by land which many radio amateurs are relucant to accept
- tropospheric ducting was available between the Canaries Isles and the Iberian Peninsula but it is totally ignored by the double hop interpretation

Considering the results of the chapters 6.4 to 6.6, we may argue the first two objections do not really exist, i.e. the ignorance of tropospheric ducting reflects the only deficiency in the double hop interpretation.

7.2 Pros and cons in the "tropo+Es" interpretation

The "tropo+Es" interpretation is supported by the following arguments:

- the *Hepburn Tropo Index* (Fig. 4.4, page 8) and the sounding data (Fig. 4.5, page 9, and Fig. 6.16, page 23) indicate tropospheric ducting between the Canary Islands and the Iberian Peninsula and even at the French Atlantic coast (Fig. 4.6, page 10)
- all EA8 QSOs coincide with the main phase of the Sporadic E opening (the same argument applies in the double hop interpretation though)

- only this model considers the fact that tropospheric and ionospheric propagation was available at the same time
- double hop propagation in general and reflection of radiowaves by land in particular, must be considered a highly unlikely scenario, i.e. rejecting the double hop interpretation forces acceptance of the “tropo+Es” theory

However, the following aspects do not support the “tropo+Es” theory:

- no model is available capable to explain the transient between tropospheric propagation and ionospheric propagation and vice versa (see chapter 5), i.e. “tropo+Es” must be considered an idea rather than an elaborated model
- meteorological data does not provide any evidence for unusual conditions which could motivate the assumption of radiowaves ascending from the troposphere into the ionosphere (see chapter 5)
- the absence of Sporadic E QSOs in the *Extremadura* must be interpreted an accidental result which does not appear very likely in a 2-hour-opening
- all features which apparently support the double hop interpretation (see, for example, the discussion of Fig. 6.5 on page 15) must be considered accidental results too which appears difficult to justify

7.3 Concluding comments

In comparison to the double hop and “tropo+Es” interpretation, long inner-ionospheric radio paths were only briefly discussed in this document (see chapter 3). Nevertheless, this concept may also provide an appropriate interpretation of the May 20, 2003 opening. This model indeed has a special beauty because we may deal with long distance ionospheric propagation but may neglect all complications caused by ground reflection of radiowaves, i.e. the ‘secret of the Extremadura’ does not exist at all in this model. We regret that no data material is available allowing detailed investigation of this model (and all its variants).

The authors themselves are in doubt which model best explains the May 20, 2003 opening. One of us (DF5AI) favours the double hop interpretation because he considers that model most consistent with all the aspects, features and characteristics associated with the band opening. The other author (DK5YA) prefers the “tropo+Es” interpretation because he considers tropospheric ducting between the Canaries and the Iberian Peninsula a very important feature which must not be ignored.

We wish to emphasize that all findings are not restricted to 144 MHz dx communication, of course, i.e. all results may be applied, for example, in FM broadcast dxing too. Because Sporadic E propagation is more common around 90 MHz than in 144 MHz, monitoring frequencies of VHF broadcast stations on the Canary Islands is considered a valuable contribution to double hop propagation studies.

Acknowledgements. The authors are grateful to J. M. Cano, Instituto Nacional de Meteorologia, Madrid, and A. Fink, University of Cologne, for providing and interpreting the meteorological data. We are grateful to W. Hepburn for providing the Hepburn Tropo Index. We thank J. Röttger and K. Schlegel, Max-Planck-Institute for Aeronomie, for useful discussions and comments. Many thanks to J. Kraft, DL8HCZ, for recherching the geographical position of many dx stations and V. K. Lehtoranta, OH2LX, and E. Zimmerman, W3ZZ, for many valuable contributions and for reading the manuscript.

8. References

[1] Personal communication
Zimmerman, E., W3ZZ, 2003

[2] Personal communication
Scherer, N., EA8/DL6FAW, 2003

[3] Sporadic E in 2003: July 9, 2003 – Almost a copy of yesterday
Langenohl, U., DK5YA, 2003
http://www.dk5ya.de/es_summary_03_july_09.htm

[4] Sporadic E in 2003: July 8, 2003 – Southwest again - twice?
Langenohl, U., DK5YA, 2003
http://www.dk5ya.de/es_summary_03_july_08.htm

[5] Sporadic E in 2003: July 2, 2003 – A big cloud down south
Langenohl, U., DK5YA, 2003
http://www.dk5ya.de/es_summary_03_july_02.htm

[6] Sporadic E in 2003: June 22, 2003 – Es becomes usual or what?
Langenohl, U., DK5YA, 2003
http://www.dk5ya.de/es_summary_03_june_22.htm

[7] North Atlantic Hepburn Tropo Index for May 20 and 21, 2003
Hepburn, W. personal communication, June 24, 2003
see also http://www.iprimus.ca/~hepburnw/tropo.html

[8] Personal communication
Röttger, J., DJ3KR, 2003

[9] Personal communication
Kraft, J., DL8HCZ, 2003

[10] Personal communication
Cano, J. M., Instituto Nacional de Meteorologia, 2003

[11] Sporadic E 144 MHz – Reports 2003
Göttsche, N., DL8LAQ, Dubus, 2, p. 89-90, 2003

[12] Sporadic E in 2003: May 20, 2003 - And another big one...
Langenohl, U., DK5YA, 2003
http://www.vhfdx.de/es_summary_03_may_20.htm

[13] 144 MHz Es
Graham Daubney, F5VHX, May 2003
http://mailman.qth.net/pipermail/meteor-scatter/2003-May/000602.html

[14] 144 MHz Es
Naylor, K., G4FUF, May 2003
http://mailman.qth.net/pipermail/meteor-scatter/2003-May/000603.html

[15] Sporadic E clouds evolution maps
Sampol, G., EA6VQ, 2003
http://www.vhfdx.net/esmaps.html

[16] Personal communication
Fink, A., University of Cologne, 2003

[17] Personal communication
Lehtoranta, V., OH2LX, 2003

[18] BeamFinder Analysis Software
Grassmann, V., DF5AI, 2003
http://www.df5ai.net

[19] The gateway to Astronaut Photography of Earth
Earth Sciences and Image Analysis, NASA-Johnson Space center, 2003
STS099-724-75.JPG
http://eol.jsc.nasa.gov/sseop/clickmap/

[20] MUF calculator
Edwards, D., G7RAU
http://www.g7rau.co.uk/muf/default.asp

[21] Dubus 144 MHz Toplist
Goettsche, N., DL8LAQ, Dubus, 3, p. 92-93, 2002

[22] Ground Gain and Radiation Angle at VHF
Preben-Hansen, P., OZ1RH
10. International Amateur Radio Moonbounce Conference, Prague, August 2002
http://www.emecz.cz/ftp/outcoming/cd_eme2002/proceed/eme_s02.pdf

[23] Sporadic E, 144 MHz reports 2002
Goettsche, N., DL8LAQ, Dubus, 2, p. 77, 2002

[24] 50 MHz opening between Europe and North America,
multiple hop propagation in the 6m band
Grassmann, V., DF5AI, Febuary 2002
http://www.df5ai.net/ArticlesDL/NAEU171101/naeu171101.html

[25] Tropo News
Doelle, T., DG3FK, Dubus, 2, p. 79, 2001

[26] Long tropospheric paths over the Mediterranean
Sampol, G., EA6VQ
http://www.qsl.net/ea6vq/trmed.html

[27] Re-analysis of 500 and 850 hPa NCEP archives
http://www.wetterzentrale.de/topkarten/fsreaeur.html

[28] FNL archives of vertical temperatures, NOAA Climate Diagnostic Centre
http://www.cdc.noaa.gov/map/clim/glbcir.shtml

[29] University of Wyoming, College of Engineering
Department of Atmospheric Science
http://weather.uwyo.edu/upperair/sounding.html

[30] El Arenosillo Digisonde 256 Ionospheric Sounder
Instituto Nacional de Técnica Aeroespacial

http://www.inta.es/iono/

[31] Sección Ionosférica
Observatori de l'Ebre, Roquetes
http://www.readysoft.es/observebre/9index.htm

[32] Expeditionsbericht aus Kreta, 22.5.-7.6.98
Langenohl, U., DK5YA, Funktelegramm, 8, p. 35-36, 1998

[33] Equatorial Propagation
Cracknell, R., G2AHU
http://www.uksmg.org/equitorialpropagation.htm

[34] The ionogram
Davis, C., 1996, http://www.wdc.rl.ac.uk/ionosondes/ionogram_interpretation.html

[35] Kurze Meldungen: 6000 km Tropo auf 2m
Funktelegramm 6, p. 9, 1996

[36] The Planetary Boundary Layer
Lee, G.W., Shodor Education Foundation, Inc., 1996
http://san.hufs.ac.kr/~gwlee/session7/session7.html

[37] Ein einfaches Modell zur Identifizierung von Sporadisch-E
Grassmann, V., DF5AI, Dubus, 2, p. 128-132, 1988
http://www.df5ai.net/ArticlesDL/EsModell.pdf

[38] Summary Es Report 1987
Dubus, 1, p. 35, 41-43, 1988

[39] Summary Es Report 1986
Neie, C., DL7QY, Dubus, 1, p. 58, 1987

[40] Es informations, Summary Es Report Season 1983
Neie, C., DL7QY, Dubus, 4, p. 327-328, 1983

[41] Studies of an extensive anticyclonic propagation event and of some short-term enhancements observed at VHF and UHF
Flavell, R.G., 3. International Conference on Antennas and Propagation, Norwich 1983
Dubus, 3, p. 242, 1983

[42] Es informations
Niefind R., DK2ZF, Dubus, 2, p. 152, 1982

[43] Es informations 1981, Part 2
Niefind R., DK2ZF, et al., Dubus, 1, p. 66-67, 1982

[44] Es informations
Niefind, R., DK2ZF, Dubus, 4, p.281, 285-286, 289, 1981

[45] Es informations
Niefind, R., DK2ZF, Dubus, 3, p. 228, 1981

[46] VHF Sporadic E Activity during July 10, 1978 – A Preliminary Short Study
IARU Region 1 Division Conference

Canivenc, S., F8SH, Dubus 2, p. 150-157, 1981

[47] Es informations
Niefind, R., DK2ZF, Dubus, 2, p. 147-148, 1981

[48] Es informations
Niefind, R., DK2ZF, Dubus, 4, p. 263, 270, 1980

[49] World Wide Locator
Rasvall, F., SM5AGM, Dubus, 1, p. 57, 1980

[50] Es informations
Niefind, R., DK2ZF, Dubus, 4, p. 293, 1979

[51] Transäquatoriale DX-Verbindungen auf 144 MHz
Röttger, J., DJ3KR, cq-DL, 5, p. 198-200, 1979

[52] Wellenausbreitung I
Grosskopf, J., BI Hochschultascherbücher 141/141a, ch. 2.1.5, Mannheim 1970

[53] Wellenausbreitung II
Grosskopf, J., BI Hochschultascherbücher 141/141a, ch. 2.3, Mannheim 1970

[54] Junta de Extremadura: Visión General
http://www.turismoextremadura.com/aleman/extremadura/extre01.html

[55] Extremadura Vista
http://www.extremaduravista.com/aleman/rutas.htm

[56] Exkursionsberichte.
http://www.uni-weimar.de/Bauing/iww/exkursionen/berichte/Bericht_Spanien.html

[57] Extremadura: Naturparadies im Westen Spaniens.
http://www.bme.es/adenex/aleman/paraiso/naturaleza.html

[58] Charles Newsom: Travels in Spain, Page 3
http://www.physics.uiowa.edu/~cnewsom/travels/spain/page3.html

9. Appendix

The spectacular May 20, 2003 dx opening was a big surprise in a surprising series of many Sporadic E openings in 2003. Several times, we considered this document completed but the actual Sporadic E saison presented one EA8 opening after the other. The frequency of Sporadic E openings is indeed remarkable and we may possibly expect even more dx openings this saison. In the following, the dx openings from June 22, July 2, 8 and 9, respectively, are briefly discussed.

9.1 The June 22, 2003 dx opening

On June 22, 2003 we may actually consider two openings, i.e. one at noon and another one in the afternoon around 16 UT, see the corresponding dx QSOs in Fig. 9.1.

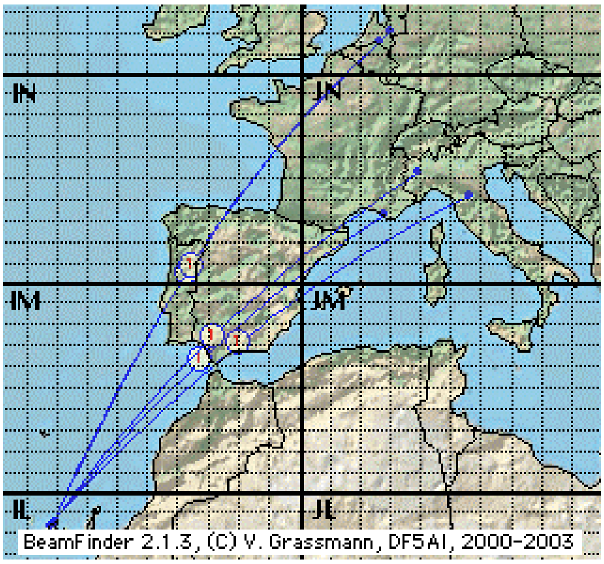

Fig. 9.1. Dx QSOs from June 22, 2003 (using data in [6]).

9.1.1 Dx QSOs between 1149 and 1214 UT

Compared to the May 20, 2003 dx event, the noon opening was of short duration and less intense so that only three QSO were actually made between the IL18 grid square and southern France and northern Italy, respectively [6].

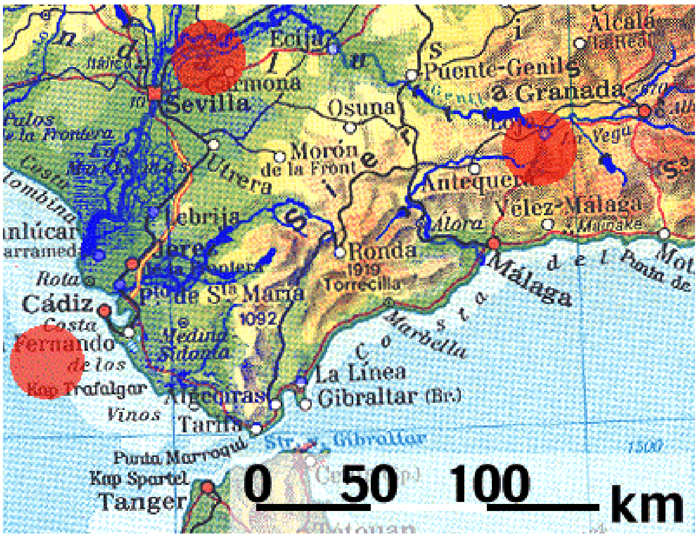

Fig. 9.2. First skip locations corresponding to QSOs to France and northern Italy, June 22, 2003.

One QSO (southern France, JN23) results from sea surface reflection southwest of the city of Cádiz, see Fig. 9.2. The QSO to northern Italy (JN35) is related to the river *Guadalquivir* north-east of the city of Sevilla and the third QSO (JN54) is associated with a lake 50 kilometers west of the city of Granada.

9.1.2 Dx QSOs at 1622 UT

On May 20, 2003 radio amateurs in the grid squares JO21 and JO22 were totally excluded from dx QSOs to the Canary Islands [12]. On June 22, 2003 they however got an exclusive band opening to EA8 – for a period of just 1 minute [6].

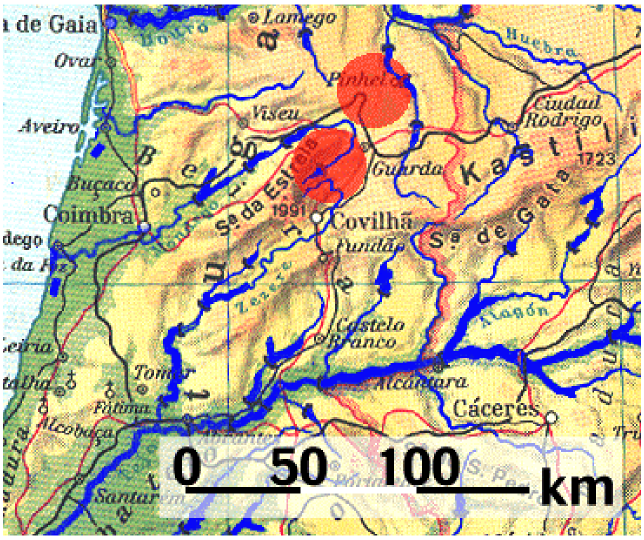

Fig. 9.3. Geographical positions of ground reflections (first skip) corresponding to QSOs to the Netherlands.

It is difficult to judge which category (i.e. *water*, *mountain ridges* and *unknown*, respectively) applies to the corresponding skip locations, see Fig. 9.3. Simultaneously to this QSOs, many (single hop) Sporadic E QSOs were reported from the same region (IN60, IN61) to western and central Germany [6]. We are therefore convinced that this two examples indeed represent double hop Sporadic E propagation in the 144 MHz band.

9.2 The July 2, 2003 dx opening

On July 2, 2003, another Sporadic E opening was reported between the Canary Islands and Spain and France [5], see Fig. 9.4.

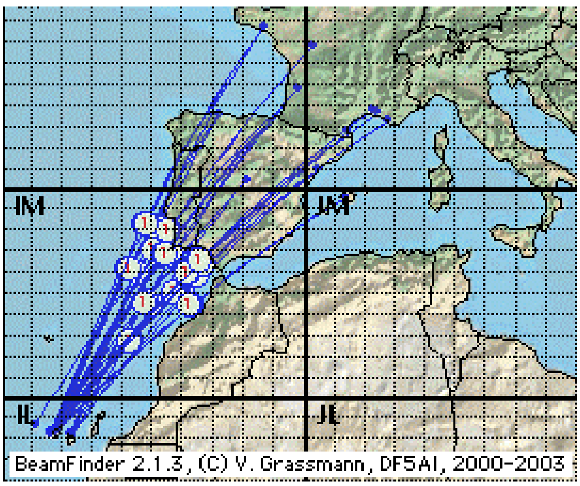

Fig. 9.4. Sporadic E QSOs from July 2, 2003.

Fig. 9.4 identifies ocean surface reflection in all QSOs (neglecting obvious examples of single hop Sporadic E to Spain), i.e. this dx event is not related to any first skip location on land.

9.3 The July 8, 2003 dx opening

Only one EA8 QSO was reported on July 8, 2003 [4], see Fig. 9.5. The reflection point is found on the western tip of the mountain *Sierra de Gredos* (Fig. 9.6). The black line passing through the red circle denotes, by the way, a railway track (we have observed first skip locations on railway lines quite often but we do not dare to draw any conclusion from it).

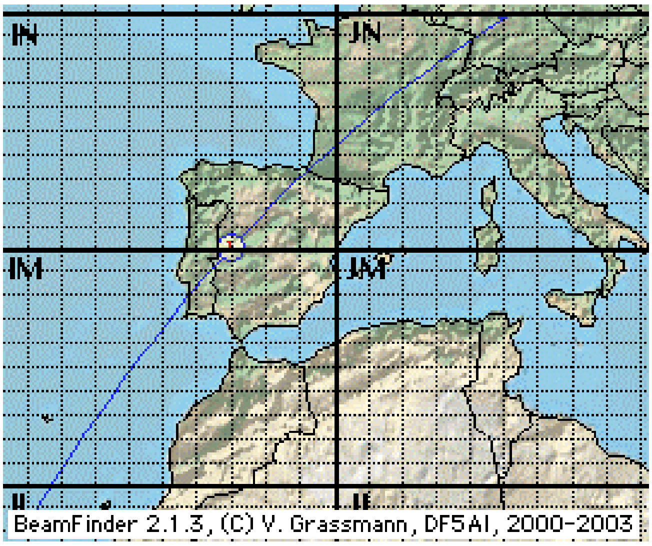

Fig. 9.5. Dx QSO from July 8, 2003.

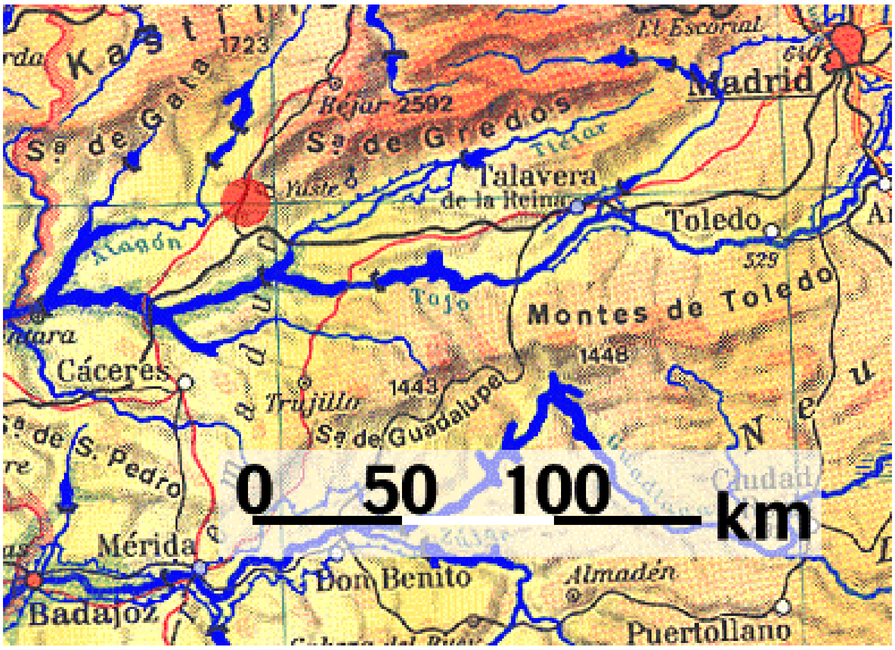

Fig. 9.6. Ground reflection corresponding to the QSO in Fig. 9.5.

9.4 The July 9, 2003 dx opening

In this case, data is available of four QSOs [2], [3], see the propagation paths in Fig. 9.7. The reflection points are again found north of the line Madrid – Badajoz in the *Extremadura*, see Fig. 9.8. Two first skip locations hit water reservoirs, both are associated with a dam. The third location corresponds to the river Tajo about 50 kilometers upstream of a position we have already discussed with different QSOs in the May 20, 2003 opening (see Fig. 6.19). The fourth position is found in the *Sierra de Gredos* about 100 kilometers west of Madrid. That position corresponds neither to a large lake nor a river and even the category "mountain ridges" appears not approriate in this case.

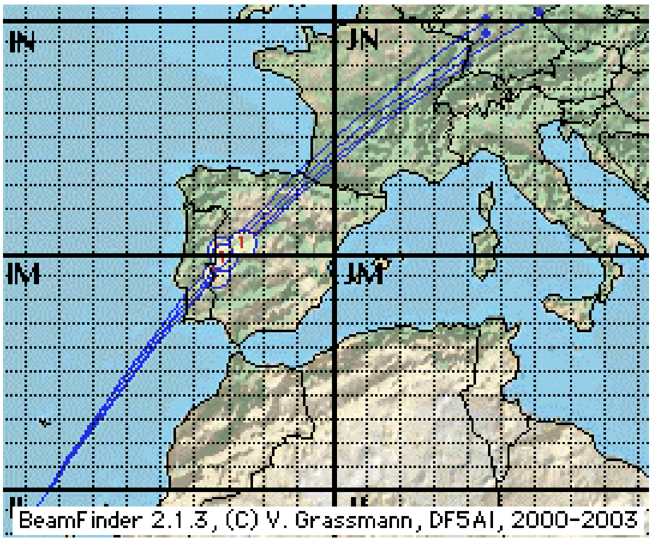

Fig. 9.7. Dx QSOs from July 9, 2003.

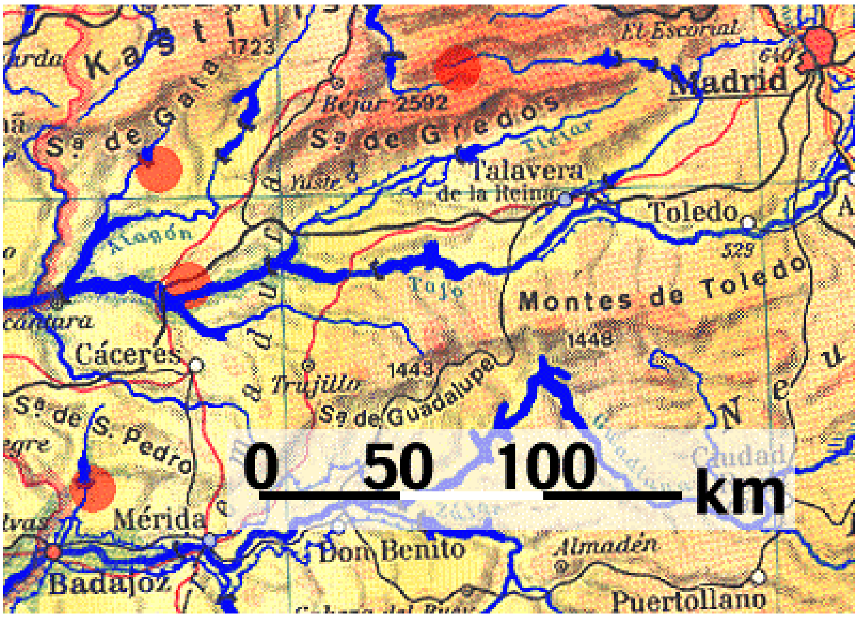

Fig. 9.8. First skip locations from July 9, 2003.