Very long Distance Propagation in the 144 MHz Band

Part 3: Use of satellite and aerial images to analyse double hop sporadic E radio links

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1 Introduction

In 2003, a number of remarkable 144 MHz dx QSOs between the Canary Islands and central Europe has been analysed to understand its geophysical origin and to study the radiowaves' propagation path along the distance of more than 3.000 kilometers. [1]. Two models have been discussed, i.a. a cascade of tropospheric over-the-horizon radio propagation and sporadic E forward scatter and, on the other hand, *double hop* ionospheric radio propagation involving two sporadic E patches at appropriate geographical positions, see Fig. 1. The latter case requires the assumption of ground reflection of VHF radiowaves at the path center which has motivated a closer inspection of the topographical features within the actual *footprint* areas on the Iberian peninsula.

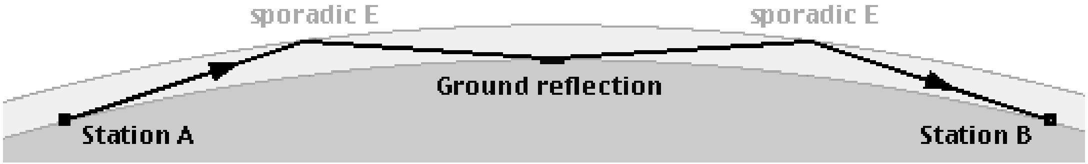

***Fig. 1.** Schematical view of a double hop sporadic E QSO.*

In sixty percent of all cases, rivers, dams and lakes were found in close vicinty to the radiowaves' footprints on the Earth surface which has raised the speculation of radiowaves reflected at the surface of rivers and lakes or, alternatively, radiowaves reflected at the topside of local tropospheric inversion layers correlating with the geographical position of major rivers and inland lakes [1]. This hypothesis was however controversially discussed within the community of radio amateurs, see, e.g., [2]. In a second study, the results are extrapolated to other regions on the European continent, e.g. the lake Balaton in Hungary and the river Dnieper in the Ukraine, which permits the interpretation of 'historical' 144 MHz dx observations between the southern tip of Norway and Crete and also between Northern Germany and the Caspian Sea [3], [4]. In 2004 and 2005, few very long distance QSOs were reported by VHF radio amateurs but, again, rivers and lakes were found at the midpoint of the corresponding radio paths [6].

In 2006, the number of very long distance QSO has increased considerably which is documented, e.g., in [12], [13], [16], [18]. Two 144 MHz dx QSOs represent radio distances of more than 4.000 kilometers, one between the Canary Islands and Romania (4.295 km, EA8AVI – YO4FNG, June 25) and another one between Portugal and Russia (4.080 km, CT1HZE – RA6DA, July 12) which strongly supports the assumption of double hop sporadic E propagation because a combination of tropospheric and (single hop) sporadic E propagation can hardly explain this long radio paths.

Having received dx reports from VHF radio amateurs [11], [15], [17], [19] and having received KRAFT's (DL8HCZ/CT1HZE) consolidated list of all European very long distance QSOs published in 2006 [14], a database of 128 dx QSOs became available which is analysed in this paper. Contrary to the discussion in [1], the radio path's geometrical midpoint is no longer considered identical to the radiowaves' footprint on the Earth surface. It is shown, that both positions may indeed deviate considerably if the two sporadic E patches differ in height. Rivers, dams and lakes are therefore not searched at the geometrical path center but within an elongated geographical corridor (*footprint search area*) which is aligned to the great-circle path between the transmitter and the receiver. By referring to satellite and aerial images of the GOOGLE EARTH internet service, this paper benefits from a geographical resolution which exceeds the geographical accuracy in [1] considerably. In all cases, large water expanses are found within the footprint search areas, i.e. 24 percent of the 2006 dx QSOs represent seasurface reflection in the ocean, all the remaining QSOs obviously represent ground reflection of radiowaves correlating to the position of major rivers and big lakes. This paper strongly supports the above hypothesis and concludes that, to a very high degree of certainty, 144 MHz double hop dx QSOs are indeed enabled by major rivers and lakes located in the middle of the zigzag radio path between the Earth surface and the E region of the ionosphere.

2 Geometrical model of double hop sporadic E QSOs

In double hop sporadic E QSOs, there is no chance to identify the true geographical position of ground reflection with certainty. These positions may be however estimated by implementing a model which can describe the double hop geometry with sufficient accuracy. Terrestrial radio propagation is a complicated subject though which is controlled by many parameters and by many effects and we can indeed imagine a large variety of anomalies and complications which could make any model questionable. Thus, if we wish to develop a model which can describe all possible scenarios in double hop ionospheric propagation, we better give up by realizing it is not worth the trouble because we cannot win. With this philosophy, this paper would end right here.

In a more moderate approach, we may focus on a model which cannot interpret all double hop scenarios but can explain at least, say seventy, eighty or ninety percent of the dx events on a statistical basis. A model brings thoughts and ideas into position without verifying its correctness unless we start feeding the model with data. If the results appear inappropriate, the model is inappropriate too, so are the thoughts and ideas which have been implemented in the model. However, if the model can provide consistent results (and, in particular, can provide predictions which may be verified in practice), there is reason to assume that the model is based on thoughts and ideas which cannot be considered totally wrong, at least. This is the purpose of this chapter, i.e. designing a simple model which can describe the 2006 dx QSOs to a certain degree even if it cannot explain all dx QSOs in every aspect. If the model turns out to be too simple, the initial assumptions, idealisations and simplifications may be replaced by more sophisticated concepts - at a later stage of discussion though because we wish to keep the initial model as simple as possible. However, what happens if the model is not successful at all and fails from the beginning? In this case, this paper would be a rather short document, but it isn't.

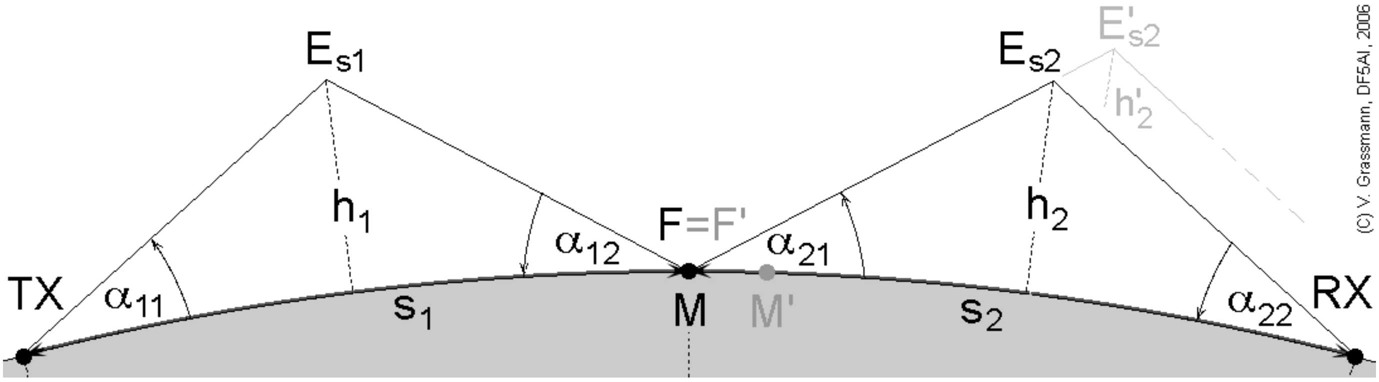

***Fig. 2.** Schematical view of the double hop geometry. The right hand side displays the second skip in two alternative scenarios, i.e. identical $\mathrm{E_s}$-layer heights ($h_1 = h_2$, black lines) and $h'_2 > h_1$ (gray lines).*

Fig. 2 displays a simplified picture of a double hop sporadic E radio path where TX and RX denote the transmitter and the receiver, $\mathrm{E_{s1}}$ and $\mathrm{E_{s2}}$ the two sporadic E patches in the E region of the ionosphere (first and second hop) and where M is the geometrical path center (midpoint) which is considered identical to the position of ground reflection which is referred to as the radiowaves' *footprint* F on the Earth surface (the reader is requested to ignore the gray symbols and drawings at this stage of discussion). In fact, the midpoint and the footprint are assumed identical geographical locations in the papers [1] and [3]. This assumption, however, has been challenged by other radio amateurs, e.g. by ZIMMERMAN (W3ZZ) who argues that the two places, i.e. M and F, are very likely geographically separated by 50, 150 or even 350 kilometers [23]. The identity of the midpoint and the footprint is indeed a critical question and has actually motivated the studies presented in this paper. In the following, we will first discuss the requirements which can justify the hypothesis of identical geographical locations. Further below, however, the hypothesis of identical locations will be removed because the author agrees to ZIMMERMAN's scepticism. It will be shown that the midpoint and the footprint may indeed deviate by 130 kilometers from a theoretical perspective and by, say 20 to 50 kilometers in practice.

Two-dimensional geometry

Fig. 2 interprets the double hop scenario by a two-dimensional geometry because the locations TX, RX, $\mathrm{E_{s1}}$, $\mathrm{E_{s2}}$, M and F are all located in the same geometrical plane. Neglecting this assumption, the radiowaves would no longer travel along the great-circle path i.e. the receiver would observe maximum fieldstrength at an azimuth different from the transmitter's azimuth (which is the case, for example, in Aurora and FAI backscatter). The author is however not aware that this type of radio propagation has been ever reported in (double hop) sporadic E[1] dxing - if it is, the model will ignore this rare phenomenon anyway. The two-dimensional double hop geometry will indeed play a major role in the discussion further below.

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[1] The term 'sporadic E' refers to ham radio terminology which exclusively denotes the forward scatter of radiowaves contrary to the scientific term 'sporadic E scatter' which comprises forward as well as backscatter scenarios.

Sporadic E positions

It is furthermore assumed that the sporadic E layer E_{s1} separates the first skip into to identical legs, the same assumption applies to the second skip, i.e. E_{s1} and E_{s2} is located above the midpoint of the line s_1 and s_2, respectively, see Fig. 2. Thus, the model introduces a geometrical symmetry with the first skip and also with the second skip without postulating that the first skip is identical to the second skip (which will be introduced further below when discussing the sporadic E heights). With this assumption, we may conclude that $\alpha_{12} = \alpha_{11}$ and also that $\alpha_{22} = \alpha_{21}$, respectively. Without this local symmetries, a much more complicated model is required which would lead, for example, to the assumption of sporadic E layers tilted relative to the local horizontal plane. In fact, *slanted sporadic E layers* are indeed occasionally observed in the ionosphere but there are reasons to neglect this phenomenon here. Considering sporadic E layers in a non-horizontal direction, the radiowaves' angle of incidence at the position E_{s1} will increase (if not here then at the position E_{s2}) which would make the rare phenomenon of 144 MHz double hop sporadic E QSOs even more unlikely.

Also, if the postulated geometrical symmetry would not exist, radio amateurs would have noticed this effect even in single hop sporadic E QSOs. Whenever a sporadic E cloud connects dx stations in different geographical areas, we obtain spider web displays similar to Fig. 3 which results from the radio paths intersecting each other at the sporadic E position. In all cases, this cross section is found at the corresponding path centers (which is not obvious in Fig. 3 though). Sporadic E clouds not located at the path center would manifest in an asymmetrical spider web pattern which isn't observed in practice though, the author is at least not aware of any sporadic E event in which the intersection appears shifted to one or the other end of the propagation path.

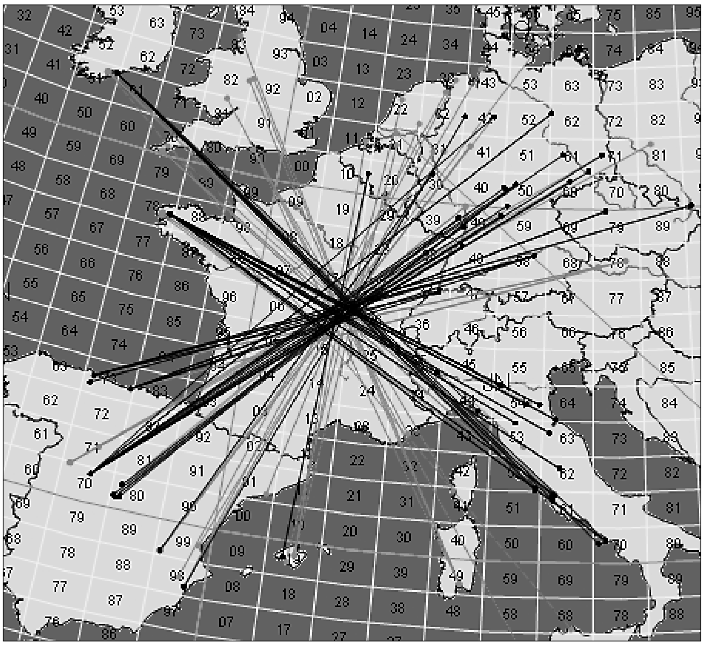

Fig. 3. *144 MHz sporadic E QSOs on July 17, 2006 [18].*

Horizontal plane of ground reflection

In double hop sporadic E QSOs, we are forced to assume 'some sort' of ground reflection of radiowaves at the footprint position F. Relative to the plane of reflection, the angle of incidence equals the angle of reflection (which introduces further assumptions which are however not discussed in the following). If the plane of reflection is directed parallel to the Earth surface, both angles may be interpreted by the elevation angle α_{12} and α_{21}, see Fig. 2, i.e. we obtain $\alpha_{21} = \alpha_{12}$. Assuming ground reflection of 144 MHz radiowaves would exist in hilly terrain, the assumption of a horizontal plane of reflection is evidently not justified at all. However, discussing ground reflection of radiowaves at the surface of large rivers and lakes, this assumption is indeed perfectly fulfilled which is also true when discussing the reflection of radiowaves at the topside of tropospheric inversion layers (neglecting slanted inversion layers which could play a role too, perhaps).

Line-of-sight propagation versus atmospheric refraction

In the practice of sporadic E dxing, the elevation α_{12} and α_{22} both represent angles of 3° to 4°, i.e. the radiowaves' takeoff angle is rather low resulting in a relatively long propagation path through the atmosphere. From this perspective, refraction and bending of the radio path needs to be taken into consideration contrary to the line-of-sight propagation displayed in Fig. 2. Although shown in the graphics, the model refers neither to line-of-sight propagation nor to a refractive bending of the radio path, i.e. the straight lines in Fig. 2 may be considered a graphical feature not necessarily identical to the true radio path. In fact, the model focuses exclusively on the relative position of TX, E_{s1}, M, E_{s2} and RX but does not consider the path which the radiowave actually travels from one position to the other. Thus, introducing atmospheric refraction into the model, the straight lines in Fig. 2 may be replaced by bended lines, neither the two sporadic E patches nor the path center will change its geographical position though. These positions will only change if the model would consider a horizontal gradient in the refractive index but this approach would result in a much more complex model which is not intended here.

Identical sporadic E heights

The model considers further simplifications (e.g. the assumption that the Earth represents by a perfect sphere which affects the accuracy when calculating the geometrical path center) but all this assumptions appear less important and are therefore not discussed in detail here. However, a critical assumption needs to be addressed which is not yet mentioned, i.e. the hypothesis of identical sporadic E heights. Having obtained the identities $\alpha_{12} = \alpha_{11}$, $\alpha_{22} = \alpha_{21}$ and also $\alpha_{21} = \alpha_{12}$, we may conclude that all elevation angles are identical, i.e. $\alpha_{11} = \alpha_{12} = \alpha_{21} = \alpha_{22}$. By introducing identical sporadic E heights too, i.e. $h_1 = h_2$, we obtain a symmetrical geometry in which the second skip is fully identical to the first skip. In consequence, the radiowaves' footprint F on the Earth surface is identical to the path center M by pure geometrical reasons. Because of this geometrical symmetry, the papers [1] and [3] have focused on rivers and lakes in close vicinity to the geometrical path center.

Introducing variable sporadic E heights

In the analysis of the May 30, 2003 dx event [1], the above simplifications and idealisations result in a, say *success rate* of sixty percent, i.e. this amount of dx QSOs reveals major rivers, dams and lakes at the actual path center which has motivated the hypothesis of double hop sporadic E QSOs enabled by radiowave reflection on water surfaces or, alternatively, on local tropospheric inversion layers. Evidently, the model cannot verify this hypothesis with sufficient confidence because a success rate much higher than sixty percent would be required. However, we may also argue that the above hypothesis cannot be rejected in general, at least not at this stage of investigation. Referring to above discussion (see chapter 2), the initial thoughts and ideas do not appear totally wrong, however, they do not appear fully correct either.

The weakest point in the above model is probably the assumption of identical sporadic E heights. In double hop sporadic E QSOs, we are facing two sporadic E layers which are geographically separated by 1.500 to 2.000 kilometers, i.e. its individual heights may perhaps differ more or less significantly. In this case, the first and the second skip would be no longer identical which is best seen when replacing the sporadic E height h_2 by the higher height h'_2, see the gray lines in Fig. 2. Note that the angle of incidence still equals the angle of reflection at the footprint position, i.e. $\alpha_{21} = \alpha_{12}$ is still a valid statement. Note also that the footprint's geographical position does not change (i.e. $F' = F$) but the midpoint's position does (see M' in Fig. 2) because the second skip is longer than the first skip in this scenario.

Thus, rejecting the assumption of identical sporadic E heights removes the identity of the footprint's and the midpoint's geographical position. Calculating the geometrical details of a 3.000 km dx QSO, the offset between the footprint and the path center may exceed 130 kilometers when considering the maximum height variation of sporadic E layers in the ionosphere which ranges from 90 to 120 kilometers (which appears to justify ZIMMERMAN's estimation in chapter 2 to a certain degree). In practice, the height difference is typically much smaller, so is the geographial offset between the footprint and the geometrical path center. For example: with h_1=100 km and h_2=110 km, the offset is 50 kilometers, it is 25 and 15 kilometers if h_2 becomes 105 and 103 km, respectively. Considering a rather small height difference of only 1 kilometer, the offset is still 5 kilometers.

The grid locators' geographical accuracy

There is quite a drastic contrast between, on the one hand, the geographical displacements of some ten kilometers and, on the other hand, the radio path lengths which are measured in thousands of kilometers. Does it actually make sense to analyse a 3.000 km dx QSO by considering a geographical resolution of a few kilometers? This is indeed a critical question because the dx stations' exact geographical position remains unknown in general. In fact, the radio amateur's *Maidenhead grid system* (see, e.g., [22]) does not describe spots on the Earth surface but geographical areas which are 5' wide and 2'30" high. Thus, calculating the transmitter's geographical position by using the central position of its QTH locator, the geographical accuracy is not better than, say 3 to 5 kilometers. The same argument applies, of course, to the receiver's geographical position and, in consequence, to the geographical position of the path center (in some cases, however, the transmitter's and the receiver's geographical inaccuracy may cancel each other when calculating the geometrical path center). The midpoint's geographical ambiguity finally affects the footprint's position error too which is – in accordance to the above paragraph - furthermore connected to an unknown displacement of 10, 20 or 50 kilometers. From a geographical perspective, all these dx QSOs therefore appear to represent an unsharp and blurry picture of the geographical setup which apparently prevents analyses on small scale lengths.

The true size of the footprint area

Another geographical uncertainty results from the directional behaviour of sporadic E forward scatter. The sporadic E reception area is generally highly localized, i.e. the fellow radio amateur from next town may work one dx QSO after the other but our receiver cannot pickup even a faint dx signal. Measurements of the footprint's actual geographical size were never made (and are probably difficult to manage in practice) but we may estimate from the many ham reports that the signal reception is restricted to an area of, say 20 kilometers in diameter, more or less (LANGENOHL, DK5YA, reports an example where he wasn't able to contact a dx station which his ham colleague could easily work although the two fellow hams were geographically separated by only five kilometers [1]). Note that the signal reception area may appear much larger in practice which is however less controlled by a large footprint area but by the very high variability of the sporadic E channel, i.e. the footprint area may sweep across large geographical regions within a few seconds without changing its actual geometrical size though. In the scope of this paper, we conclude that the size of the footprint area adds another geographical ambiguity which is larger than the inaccuracy caused by the Maidenhead grid system.

Designing a simple model is no simple process, obviously. Considering the true complexity of ionospheric radio propagation, we would obtain a rather complex model with lots of parameters and quantities which are difficult to handle in practice (because we cannot access measurements which could tell us the quantities' actual value). Therefore, the model is kept as simple as possible by focusing on the most fundamental features in double hop sporadic E propagation. Feeding the model with data, it could happen, perhaps, that we are forced to accept that all this simplifications represent a much too drastic approach. In this case, we would go back to the simplifications and would try to replace them by more sophisticated concepts. However, it isn't wise to push complexity into the model from the beginning. In this case it could happen, perhaps, that the model fails because of its complexity even if the model's initial idea may be considered an appropriate description of the scenario which needs to be analysed.

Nevertheless, even this simple model presents us a quite confusing picture: the calculated path center M is connected to a geographical inaccuracy of at least some kilometers, the footprint F may deviate from the geometrical path center M by 20, 50 or even more kilometers and, finally, this footprint does not correspond to a spot like geographical feature but to an area of 20 or 30 kilometers width, or so. Evidently, we may not expect to identify rivers and lakes at predetermined locations. Assuming a river which is precisely located at the geometrical path center, it is obviously relevant in the scope of this paper. However, identifying a river separated from the geometrical path center by, say 500 kilometers, it is evidently not relevant at all. Thus, we need to define a, say *footprint search area* in which the existence of rivers and lakes is considered relevant to the analysis, i.e. rivers and lakes located outside of this area will be ignored all together.

3 Designing the footprint search area

Note that the above discussed displacement between the geometrical path center and the footprint does not represent a displacement in any direction but represents an offset along the great-circle path (see Fig. 2, in which the footprints F and F' remain identical, i.e. it is the midpoint which moves along the great-circle path from M to M'). Perpendicular to the great-circle path, the geographical accuracy is much higher because it is exclusively controlled by the QTH locators' geographical accuracy and, even more important, by the size of the true sporadic E footprint area.

Thus, the *footprint search area* is described by an elongated geographical corridor along the great-circle path with the geometrical path center in the middle. The corridor's length is, say 40 or 50 kilometers but its width is only 20 kilometers, or so. The *footprint search area* is obtained as follows:

- Calculation of the transmitter's and the receiver's geographical coordinates by referring to the central point of the corresponding grid locators.
- Calculation of the midpoint's geographical coordinates (geometrical path center).
- Generation of a map display indicating the great-circle path and also the geometrical path center.
- Identification of major rivers, dams and lakes located 20 to 30 kilometers up or down the great-circle path with a maximum transverse offset to the great-circle path of 5 to 10 kilometers.

Using GOOGLE EARTH to analyse the dx QSO between

EA8AVI (Canary Islands, IL28GC) and
DH4FAJ (Germany, JN48EX)
on July 16, 2006, 1618 UT

- Enter EA8AVI's position, i.e. **28.1042 N 15.4583 W**, into the so-called **Fly to** edit field of the GOOGLE EARTH client software. This position denotes the center of the IL28GC grid square which is located 300 meters northwest of a sports stadium.
- Activate the **measure tool** which opens a small window floating on top of the screen map. Select the **line** option and click the **clear all** button in order to remove all lines already existing on the screen map.
- Click on EA8AVI's position once which draws a line from EA8AVI's position to the actual mouse cursor position on the screen – do not click a second time in order to keep this *rubber band effect* alive.
- Enter DH4FAJ's position, i.e. **48.9792 N 8.3750 E**, into the **Fly to** edit field. This position denotes the center of the JN48EX grid square which is located close to a motor highway.
- Click on DH4FAJ's position once which completes the great-circle path connecting the two dx stations. Zoom out in order to see the entire dx path from the Canary Islands towards Germany.
- Enter the geometrical path center, i.e. **39.1380 N 5.3155 W**, into the **Fly to** edit field. Note that the geographical region, contrary to the above positions, is displayed in low image resolution.
- Zoom out to study the *footprint search area*, i.e. the terrain surrounding the geometrical path center (30 kilometers "up" and "down" the great-circle path and 10 kilometers "left" and "right" from it). Compare your results to Fig. 4.

With 128 double hop dx QSOs, this procedure will turn into a cumbersome effort though. The manual process which has been applied in the first paper [1] is no longer suitable here, from a practical perspective and also from the requirement of a much higher geographical accuracy. We will therefore refer to the GOOGLE EARTH internet service [10] which provides almost perfect tools in the purpose of this paper. The service allows the user to download a free client software which accepts coordinates of any place on the Earth surface. The software retrieves satellite and aerial images from the GOOGLE EARTH database which supports a surprising high image resolution (displaying even buildings and cars in many cases). Using the software's drawing tool, the footprint search area may be easily identified, the flexible zoom function allows the user to analyse topographical features within the footprint search area in detail. A detailed step-by-step procedure is described in the gray box encouraging the reader to follow these steps on his or her personal computer in practice (analysis of the dx QSO between EA8AVI and DH4FAJ on July 16, 2006). Doing so, the reader will discover the river *Guadiana*, see Fig. 4, which is directed almost parallel to the great-circle path along a distance of more than 50 kilometers. The river is displaced from the great-circle path by about 7 kilometers at the image center and crosses the great-circle path at the map's lower left corner. The river's width is 400 meters at the image center and opens to more than 2.5 kilometers in the south-west (this dimensions, by the way, may be easily measured by using the *ruler* function in the GOOGLE EARTH software). Note that another river is also visible at the bottom, i.e. the river *Zújar* which is also 20 to 30 kilometers long reaching a maximum width of 4 to 5 kilometers. The river *Guadiana*, at least, is located within the footprint search area and may be perhaps interpreted the origin of the double hop sporadic E QSO between EA8AVI and DH4FAJ on July 16, 2006.

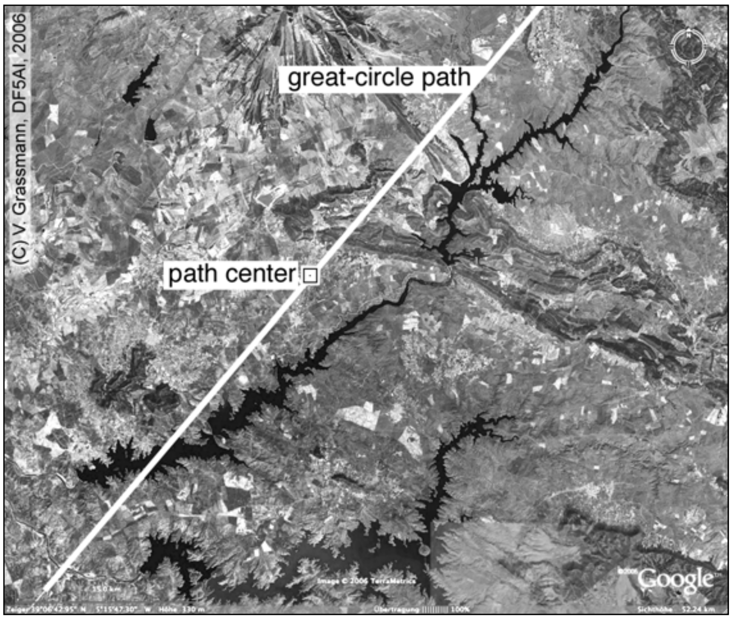

Fig. 4. *Footprint area of the 144 MHz dx QSO between EA8AVI and DH4FAJ on July 16, 2006, 1618 UT. The horizontal and vertical size of the terrain is 60 x 50 kilometers. The geat-circle path denotes the radiowaves' direction when travelling from the Canary Islands to Germany. The path center denotes the geometrical midpoint of the 3.162 km dx path between EA8AVI and DH4FAJ. The black area parallel to the great-circle path displays the river Guadiana around 200 kilometers south-west of Madrid, Spain. The river Zújar is displayed at the bottom. The map display was taken from GOOGLE EARTH [10].*

Unfortunately, the author cannot provide detailed information on GOOGLE EARTH's geographical accuracy, not from the image resolution perspective, which is impressive, but with respect to the handling of map projections. Assuming the map projection would be handled less carefully, the great-circle path displayed on the screen map may deviate from the true great-circle line considerably which would cause complications in the analysis. The opposite is true, apparently, because the geometrical path center (which is calculated independently from the great-circle path) hits the displayed great-circle more or less perfectly, see Fig. 4, which also applies to all the other dx QSO which were analysed in the same way. We may therefore assume that the GOOGLE EARTH service handles map projections more or less perfectly.

4 The data

The GOOGLE EARTH service represents a perfect tool to analyse the 2006 double hop dx QSOs in practice. The required input parameters (i.e. the dx stations' geographical coordinates derived from the grid locators and also the actual coordinates of the geometrical path centers) were calculated by using a special version of the *BeamFinder* analysis software [5]. With this information, all dx QSOs were analysed by using the GOOGLE EARTH client software, version 4.0.1694.0 (Macintosh) from July 2006 [10].

The list of QSOs represents information submitted by fellow radio amateurs [11], [15], [17], [19] and information which is distributed by the *Dubus* magazine [12] extended by additional dx infomation compiled by KRAFT (DH8HCZ/CT1HZE), [14]. The entire database comprises 128 double hop sporadic E QSOs (2.900 to 4.200 kilometers), see Fig. 5, covering the dx events on June 11, 25 and 27, on July 6, 12, 16, 18 and 26 and also on August 13, 2006.

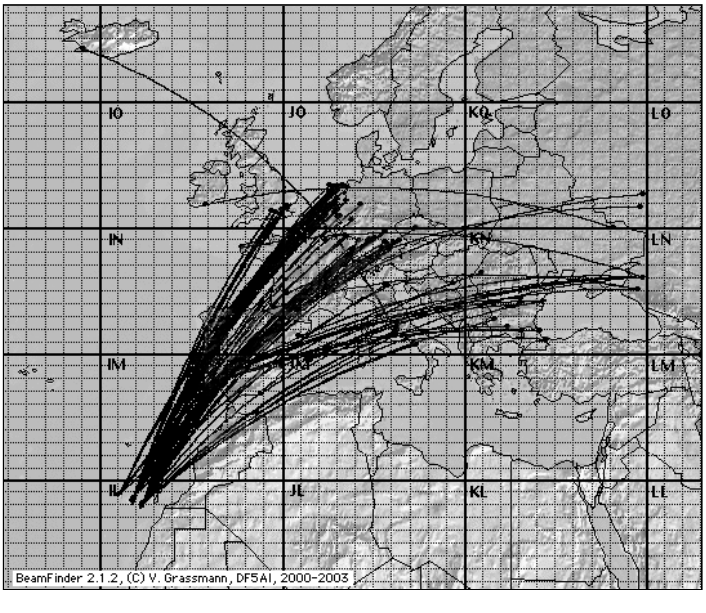

Fig. 5. *144 MHz double hop dx QSOs in 2006. The map display was taken from the BeamFinder software [5].*

Fig. 6 displays the calculated path centers by date. Note the path centers of four noteworthy 144 MHz dx events, i.e. the 4.293 km QSO between the Canary Islands and Romania (EA8AVI worked YO4FNG, June 25, see A in Fig. 6), the 4.080 km QSO between Portugal and Russia (CT1HZE worked RA6DA, July 12, see B), the dx observation between Iceland and Italy (TF3BX heard IK0SMG, July 18, see C) and the dx observation between Ireland and the Ukraine (UY5ON heard EI5FK, July 6, see D). The two latter ones are mentioned here because of the path centers' high geographical latitude. The case of TF3BX and IK0SMG probably represents the most northern 144 MHz double hop observation ever made by radio amateurs because one of the two sporadic E patches was obviously located around 60° northern latitude.

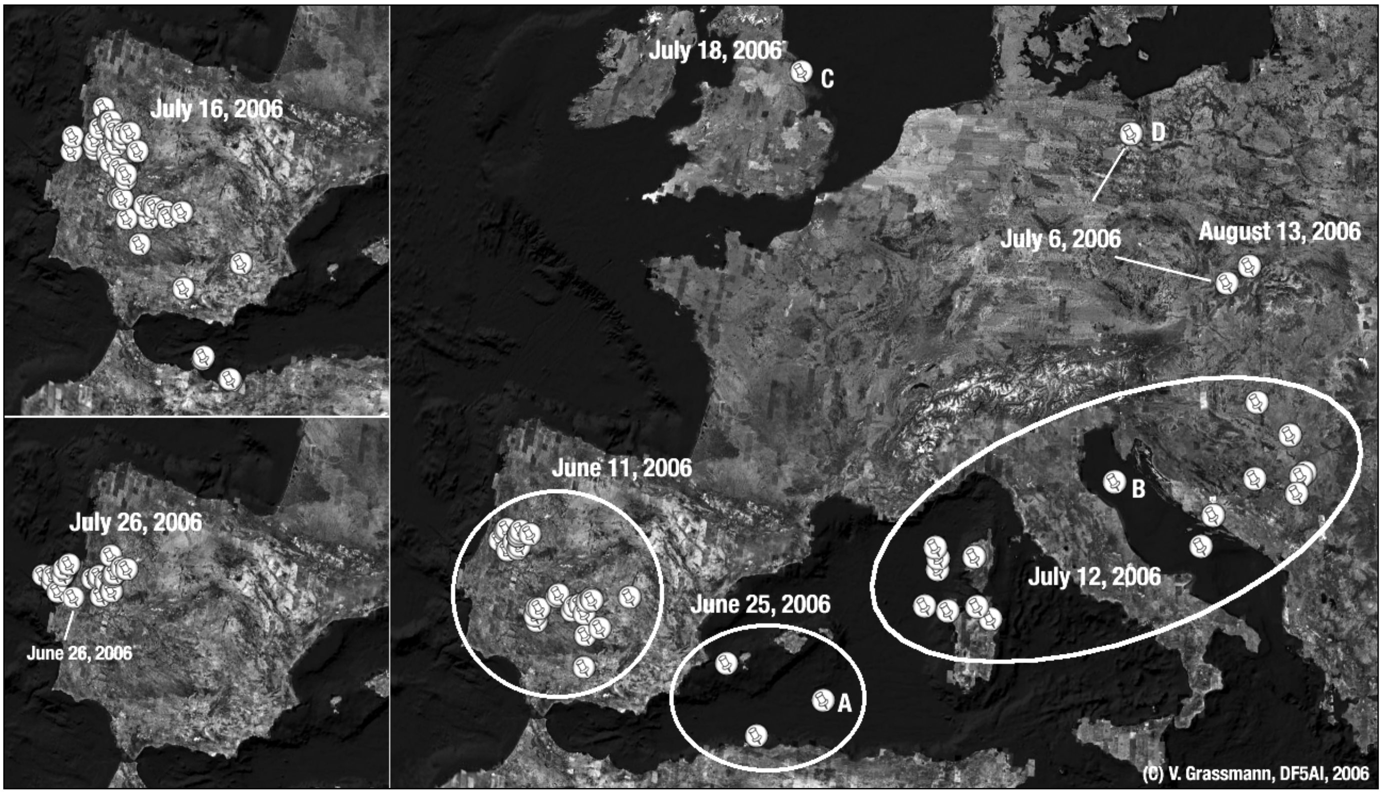

Fig. 6. *Geographical position of the geometrical path centers by date. The map display was taken from Google Earth [10].*

Hundreds and thousands of single hop sporadic E QSOs are reported by VHF radio amateurs every year, double hop sporadic E QSOs represent a rare phenomenon though. Fig. 6 therefore displays an extract of the corresponding sporadic E openings indicating only one double hop event on June 26, July 18 and August 13 and two events on July 6. Many double hop dx QSOs were however reported in the dx openings on June 11, 25 and also on July 12, 16 and 26 which reflect high sporadic E activity in the European sector that was probably associated with wide-spread sporadic E layers. Note that the path centers do not show a random geographical distribution but show bulks of path centers accumulating within areas of a few hundred kilometers width. In the July 12 dx event, however, this area is surprisingly large extending from Corsica/Sardinia into the Balkans.

5 Discussion of results

Almost a quarter (24 percent) of the dx QSOs indicate footprint search areas located in the Mediterranean, in the Adriatic Sea or in the Atlantic Ocean close to the Portuguese seacoast. Thus, the remaining 97 dx QSOs correspond to ground reflection on land and Fig. 4 is indeed a representative example because all the other QSOs exhibit major rivers and lakes within the footprint search areas too (in one case only, poor image resolution has prevented a detailed analysis of the topographical features). Compared to the analysis in [1] where major rivers and lakes are found in 60 percent of the double hop dx events, the new model results in a 100 percent match which is indeed very surprising. Typical examples of the rivers and lakes within the footprint search area are displayed in Fig. 7.

The results show a systematic behaviour which is documented by Fig. 8. The panel Fig. 8a illustrates the three distances which were measured with each individual dx QSO, i.e. river's/lake's distance to the geometrical path center, its vertical offset relative to the great-circle path and its horizontal displacement along the great-circle path. Note that Fig. 8 only refers to dx events corresponding to ground reflection on land, i.e. footprints located in the ocean are neglected here. All rivers and lakes identified in this analysis represent large water expanses, i.e. the rivers correspond to a width of at least a few hundred meters, the lakes typically correspond to a size of at least 1x1 kilometers, i.e. small rivers, creeks and pools were systematically ignored in the site survey.

Note also that the distances are measured from the path center to the lakes' central position or, alternatively, to the place where the corresponding river shows its broadest width or its widest opening, respectively. In many cases, more than one river or lake was found within the footprint search area, the data then represents the water surface which is largest or which is closest to the path center. It is perhaps worth to mention that, in some cases, the search process has identified the same river and lake even with independent QSO data (see the examples in Fig. 7).

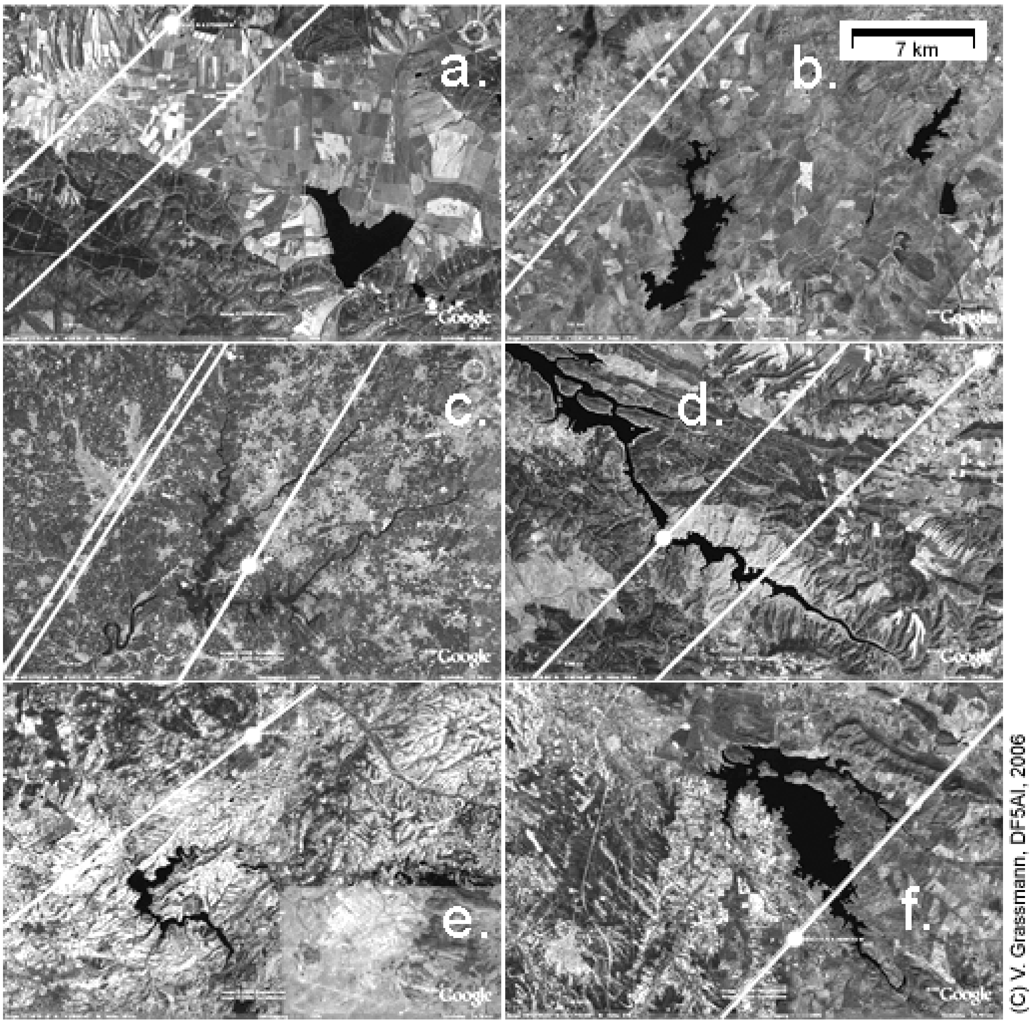

Fig. 7. Examples of the footprint search areas in the dx opening from June 11, 2006. The white lines denote the corresponding great-circle paths. Note the rivers and lakes which are displayed together with two or three great-circle paths indicating independent dx QSOs which result in almost identical search areas. The white dots denote the position of the corresponding geometrical path center. All images are shown with identical scale. The map displays were taken from GOOGLE EARTH [10].

Distance to the geometrical path centers

40 percent of the rivers and lakes are found within a distance of less than 10 kilometers relative to the geometrical path center, in 90 percent of all cases the distance is not longer than 30 kilometers, see Fig. 8b. Only few examples are found corresponding to rivers and lakes at distances beyond 30 kilometers. This result indicates a strong correlation between the geographical position of the path centers and the geographical position of major rivers and lakes.

Distance to the great-circle paths (vertical offset)

The majority of rivers and lakes (more than 90 percent) is located close to the great-circle path, i.e. in a distance of less than 10 kilometers, see Fig. 8c. 30 percent of all cases represent a vertical offset of less than 2 kilometers, i.e. the great-circle paths are crossing the position of rivers and lakes more or less perfectly. Hence, the position of rivers and lakes correlates not only to the geometrical path centers but also to the great-circle paths.

Displacements along the great-circle paths (parallel offset)

Fig. 8d displays the rivers' and lakes' offset parallel to the great-circle path. The parallel offset is measured in positive quantities if the river or lake is displaced to the north-east when considering QSOs between the Canary Islands and central Europe or is displaced eastwards when considering the east-west dx QSOs, e.g. between Portugal and Russia, the displacement is measured in negative quantities otherwise. In 50 percent of all cases, the parallel displacement does not exceed 10 kilometers, in almost 80 percent of the cases the rivers'/lakes' offset is less than 20 kilometers relative to the geometrical path center and very few examples are found with a parallel offset of more than 30 kilometers. Interpreting the parallel offset by variable sporadic E heights, see Fig. 2, the two sporadic E patches appear not to differ in altitude significantly, the estimated height difference is 1 to 2 kilometers; in a few cases, a larger height difference is apparently present though.

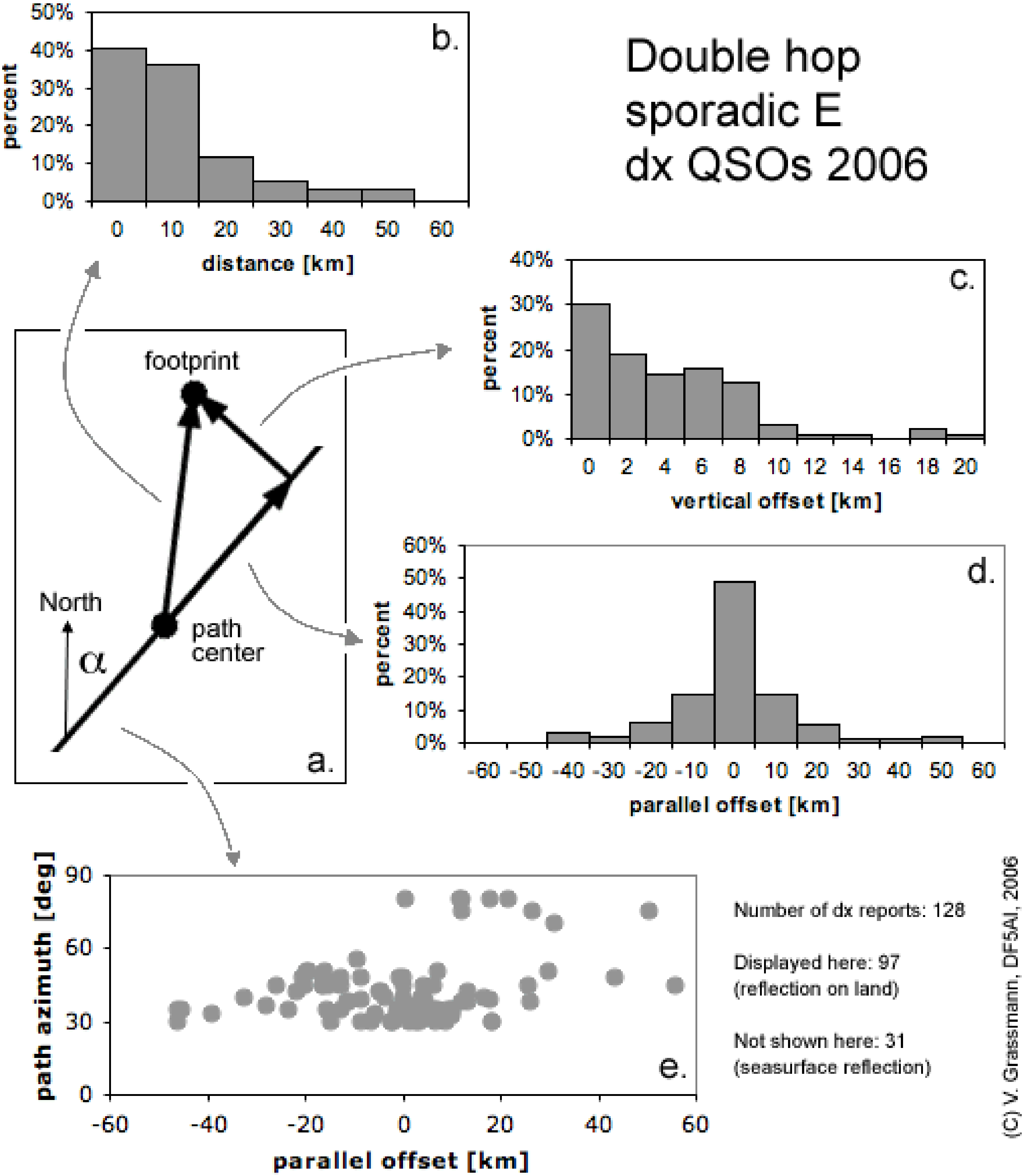

Fig. 8. *Analysis of double hop sporadic E QSOs using satellite and aerial images from the* GOOGLE EARTH *internet service in order to identify rivers and lakes at the radiowaves' footprint on the Earth surface. a) schematical diagram of the great-circle path, the corresponding path azimuth* α*, the geometrical path center, the footprint position estimated from the satellite images and also the three distances which have been analysed; b) distribution of the footprints' distance to the geometrical path center; c) distribution of the footprints' vertical offset relative to the great-circle paths; d) distribution of the footprints' parallel offset relative to the great-circle paths (negative and positive signs indicate displacements 'up' or 'down' the great-circle path, respectively), e) distribution of the path azimuth as a function of the parallel offset.*

Long displacements along the great-circle paths

A striking feature is obtained by plotting the path azimuth versus the parallel offset along the great-circle path, see Fig. 8e. Note, for example, the data points between 30° and 40° path azimuth: as already mentioned, the majority of footprints is displaced by less than 20 kilometers relative to the path center which is indicated by the bulk of data points between -20 and +20 kilometers. However, we also find offsets between 20 and 50 kilometers and all this displacements are exclusively found along the negative axis, i.e. positive offsets do not exist at all. The azimuth range of 30° to 40° corresponds to dx QSOs between the Canary Islands and central Europe, i.e. the footprints are all shifted from the path center to the southwestern direction towards the Canary Islands. Thus, the sporadic E skips between the Canaries and the Iberian peninsula (first skip) appear to be gradually shorter than the skips between the Iberian peninsula and central Europe (second skip), compare to Fig. 2.

Considering the data points around 90° path azimuth, the maximum parallel offset is obtained between +20 and +50 kilometers, i.e. negative displacements do not exist here. This data points correspond to dx paths in east-western direction and it appears that the sporadic E skips in the west are gradually longer than the skips in eastern Europe.

Note that the above statements on the skip lengths only refer to the few cases indicating relatively long parallel offsets, i.e. the majority of QSOs correspond to short displacements which apparently show no systematical behaviour in azimuth.

In accordance to Fig. 2, the variable skip lengths may be interpreted by different sporadic E heights. In the case of double hop sporadic E QSOs between the Canary Islands and central Europe, we are apparently facing relatively low sporadic E layers at southern latitudes (around the west African sea coast) and higher sporadic E layers in mid-latitudes. Considering the east-west propagation paths, on the other hand, the sporadic E height appears to be higher in the west compared to the sporadic E height in eastern Europe. In both cases, the height difference is estimated 5 to 10 kilometers.

This is indeed a surprising result but there are reasons to interpret the findings very carefully: 1) Because of the few data points, an accidental result cannot be excluded. The author therefore plans to analyse the double hop dx QSOs from recent years too in order to increase the number of data points; 2) The model used in this paper is forced to interpret the parallel offsets by different sporadic E heights because the model can principally provide no alternative interpretations due to the simplifications which were introduced in the beginning. However, this does not imply that the offsets need to be interpreted this way, i.e. the offsets may perhaps find a very different interpretation with a more sophisticated model. The findings are still under investigation and a final explanation cannot be given at the moment.

The rivers' geographical orientation relative to the great-circle path

Fig. 4 and also Fig. 7c displays rivers which are directed almost parallel to the great-circle path, i.e. the incidient radiowave may illuminate the river lengthwise which appears to represent a favourable scenario in the generation of double hop dx QSOs. However, rivers directed transverse to the great-circle path appear to represent another favourable scenario too because a broad wavefront of incident radiowaves may be reflected at an identical phase angle. Indeed, Fig. 7d displays an example where the river is directed orthogonal to the great-circle path. This raises the question of the rivers' optimum orientation relative to the great-circle path. Similar to the path azimuth, the rivers' azimuth was also measured in the site survey but, unfortunately, no correlation is found between the riverbeds' and the radio links' azimuth which is worth to be mentioned here.

Seasurface reflection

Fig. 6 shows many examples of seasurface reflection within in oceans but the lack of meteorological data prevents a detailed discussion of this highly interesting footprint areas. Footprint areas within the ocean do not necessarily imply the reflection of VHF radiowaves at the water surface, i.e. the hypothesis of radiowave reflection on tropospheric inversion layers applies to all this cases too, perhaps.

However, there is one finding which should be mentioned here although a consistent interpretation is not yet available. Most examples of seasurface reflection represent footprints close to land. In the June 25 event, see Fig. 6, one footprint is found close to the African seacoast and another one close to the Spanish seacoast near Ibiza and Formentera, on July 12 the footprints accumulate west of Corsica and also west of Sardinia, on July 26 a large number of footprints is present very close to the Portuguese seacoast and, finally, also this remarkable dx observation on July 18 (see above) is associated with a footprint very close to the English Northsea coast. Thus, very few footprint areas are found in the oceans far away from land which is perhaps an accidental result controlled by the geographical distribution of VHF radio amateurs on the continent. However, it could also indicate, perhaps, the influence of tropospheric inversion layers on double hop dx QSOs when considering the hot air masses above land in summer time which perhaps drift or diffuse towards the sea with rather moist air masses which may lead to the formation of tropospheric inversion layers. At this stage of investigation, this is however nothing else than a vage speculation.

6 Concluding comments

The analysis in [1] is challenged by a counter-argument which appears to apply to the present analysis too. The footprint search areas represent geographical corridors of 300 to 500 square kilometers, i.e. rivers and lakes may exist within these areas all the time, at least in geographical regions comprising many lakes and lots of rivers which is indeed true for the Iberian peninsula. However, chapter 5 very likely represents no accidental results for the following reasons: 1) The Fig. 8b, c and d clearly indicate a geographical correlation between the rivers and lakes on the one hand and the geometrical path centers on the other hand

(and also to the great-circle paths) which appears inconsistent with the assumption of an accidental result because the rivers and lakes would then show a random distribution within the search areas which is obviously not the case. 2) Because of the many rivers and lakes on the Iberian peninsula, double hop sporadic E QSOs between the Canary Islands and central Europe represent an every year experience contrary to alternative dx paths in Europe. Considering, e.g., the dx path between Israel and western Europe, the number of double hop dx QSO is more or less negligible which is actually surprising because the number of active VHF radio amateurs in Israel is probably in the same range as the number of VHF hams on the Canary Islands. This discrepancy may be easily explained by considering the few rivers and lakes on the Balkans which represents the footprint target area in this case. Thus, the above counter-argument is no counter-argument at all, it represents a supportive argument, in fact: the many rivers and lakes on the Iberian peninsula indeed support the hypothesis of double hop sporadic E radio propagation enabled by inland lakes and rivers because it explains the high number of dx QSOs between the Canary Islands and central Europe and it explains the absence of similar dx QSOs in other geographical regions of Europe.

However, it should be mentioned that double hop radio paths between Israel and the Baltic sea coast (e.g. Lithuania and Estonia) may benefit from seasurface reflection in the Black Sea but this type of dx QSOs is not reported either. A detailed discussion of the 144 MHz double hop sporadic E probability in Europe therefore needs to consider the latitudinal and longitudinal sporadic E probability on the European continent. GRAYER (G3NAQ) has demonstrated this type of analysis for 50 MHz mid-latitude sporadic E QSOs in Europe [9] which he has obtained by referring to the contour lines of the percentage of time the critical frequency f_{0Es} exceeds 7 MHz which corresponds approximately to a *maximum-usable-frequency* of 50 MHz, see, e.g., [8] and the references cited therein. His analysis appears relevant here because GRAYER emphasises the relatively low sporadic E probability at the west coast of the Black Sea which perhaps may explain the absence of double hop dx QSOs between Israel and Europe.

Independent from the above results, the physical nature of the radiowaves' ground reflection remains an open question. We are still facing two competing concepts (and there are perhaps even more), i.e. the reflection of radiowaves at the surface of rivers and lakes and, on the other hand, the reflection of radiowaves at the topside of local tropospheric inversion layers correlating with the geographical position of rivers and lakes. By analysing the vertical profile of air temperature and air humidity, there is perhaps a chance to investigate the importance of tropospheric inversion layers in double hop dxing. Information of upper air sounding data is indeed available, see, e.g., [20] and [21]. However, this data only considers few places on the Iberian peninsula which only allows the identification of wide-spread inversion layers. In the scope of this paper, however, we need to identify local (and perhaps relatively low) tropospheric inversion layers close to the many rivers and lakes representing footprint areas in double hop dx QSOs, this type of meteorological data is however not available, unfortunately. From this perspective, this paper cannot provide any significant progress in the interpretation of ground reflection of VHF radiowaves.

Nevertheless, the above results are closing the case which was opened with the analysis of 144 MHz very long distance QSOs in 2003 [1]. Only the double hop model can consistently explain the dx QSOs, which becomes in particular obvious when considering the QSOs exceeding the distance of 4.000 kilometers. From the author's perspective, the speculation of a cascade of troposheric and ionospheric propagation needs to be rejected (this statement, however, does not affect the very long distance QSOs between the Canary Islands and UK/Ireland which are observed almost every year and which may be interpreted by pure tropospheric dx propagation, see, e.g., [7]). The hypothesis of rivers and lakes enabling double hop dx QSOs is strongly supported by this paper. It is actually safe to say that the hypothesis is verified to a high degree of certainty.

Comparing the results in [1] with the present findings, it is perhaps worth to clarify the reasons why the first analysis results in a 'hit rate' of only 60 percent while the current analysis indicates a 'hit rate' of 100 percent. Note that the analysis in [1] has implicitly introduced footprint search areas too, i.e. circular areas of around 20 to 30 kilometers in diameter in order to consider the limited geographical resolution of the maps which were used in 2003 (see, e.g., Fig. 6.19 and 6.20 in [1]). However, the present analysis introduces a geographical corridor which comprises much more square-kilometers than the circular markers in [1]. Thus, we may speculate that larger footprint search areas will of course result in a higher number of rivers and lakes identified in the site survey. This is not the case though. Fig. 8b indicates that this paper reveals a much higher number of rivers and lakes even within a distance of 20 (or 30) kilometers, with other words: implementing the circular search areas from [1] even in this analysis, the 'hit rate' is almost 80 (or 90) percent in contrast to the 60 percent in [1]. The discrepancy between [1] and the present analysis is more or less exclusively controlled by the much higher geographical resolution of the GOOGLE EARTH service compared to the maps which were used in [1], i.e. this analysis may take rivers and lakes into consideration which simply do not appear in the maps.

The author plans to repeat the above analysis method with the dx data from 2003, 2004 and 2005 to compare the results with the findings in Fig. 8b, c and d. By combining all the data, Fig. 8e will benefit from more data points which hopefully clarifies the open question on skip lengths and sporadic E height variations. Another finding needs to be addressed too, although not yet mentioned in this document. Fig. 7 indicates QSOs which all lead to the same river and lake which is however not surprising in some situations. Assuming the same dx station on the Canary Islands works two or three German fellow hams located in the same town or in the same grid field, the corresponding great-circle paths are almost identical and, in consequence, the footprint search areas are identical too, more or less. However, if the same river is obtained in different band openings and with different dx stations, we may conclude that this river has enabled double hop dx QSO not only once but more often. The 2006 data indicates several rivers and lakes which appear to have this quality. Note, for example, that the dx events on June 11, July 16 and July 26 (see Fig. 6) all show an accumulation of footprints in the north of Portugal and in the northwest of Spain which often involves the same rivers and lakes when analysing the corresponding footprint areas. This feature could perhaps support the hypothesis of local tropospheric inversion layers supporting the generation of double hop dx QSOs. Final results are not yet available though.

Although the occurrence of double hop sporadic E events cannot be predicted, VHF radio amateurs may develop strategies to increase the chance of observation. By searching all major rivers and big lakes surrounding the radio station at a distance of, say 1.400 to 2.000 kilometers, the VHF operator may identify potential footprint areas in double hop sporadic E dxing. By doubling the distance between the radio station and a particular river/lake, the VHF operator may identify the corresponding *dx target area* where he or she may expect dx stations to be worked in double hop dx openings (in most cases, however, this area is located somewhere in the oceans). This procedure has been already described in detail in the second part of the series of papers, see [3] and [4]. By referring to the GOOGLE EARTH service, this concept may be realized very easily and with high geographical accuracy on a personal computer.

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