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Analysing systematical features in tropospheric dx QSOs between 144 MHz and 5.8 GHz exceeding the distance of 3.000 kilometers

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Abstract. Tropospheric dx QSOs exceeding the distance of 3.000 kilometers must be considered a true rarity in amateur radio. By referring to various ham radio resources, a list of almost 100 examples of very long distance tropo QSOs is obtained which reveals a number of systematical features. All these QSOs accumulate in few geographical areas located around 20° and 30° latitude north and south of the Earth's equator and represent radiowave propagation across large water expanses excluding continental radio paths. The frequency of occurrence appears to indicate a periodical behaviour between years of high and low dx activity. It is shown that all very long distance tropo QSOs are closely related to each other and result from the special meteorological conditions at the horse latitudes which are caused by the Hadley convection cells on both sides of the equator. The paper discusses the possible correlation between the occurrence of very long distance band openings and seasurface variations in the oceans. The results are extrapolated to other regions in the world which indicate a number of future dx opportunities in ham radio.

Contents

1 Introduction

In the 1950s, the pioneer QSOs between Ralph (KH6UK) and John (W6NLZ) have documented the existence of tropospheric ducting of radiowaves across the eastern Pacific, i.e. from Hawaii to the mainland of USA (see, e.g., [23] and Table 2.1). In Europe, very long distance QSOs have been studied from a scientific perspective by Ray (G3LTP) in the early 1980s including one 144 MHz QSO between Anglesey and the Canary Islands corresponding to a path length of 2.944 kilometers [3]. It became clear that the band openings between the British and the Canary Isles also result from tropospheric ducting caused by intense inversion layers. Since then, this phenomenon has been covered by various ham radio resources, see, e.g., [4]. In 2000, an important contribution to the meteorological interpretation of very long distance tropo QSOs has been given by Walter (VK6KZ) who has analysed dx QSOs across the Great Australian Bight which also includes a comparison of the dx openings in Australia with the openings between Hawaii and California, see [7]. The most recent analysis was conducted in 2005, in which the author has analysed the dx QSOs between England/Ireland and the west coast of northern Africa also indicating intense inversion layers along the 3.700 km radio path [30].

Thus, this type of very long distance QSOs find a meteorological explanation (and is therefore referred to as “tropo QSOs”) and there seems to be little reason to look into this dx events in more detail. However, understanding the meteorological background of individual dx QSOs does not necessarily imply the understanding of the general nature of tropospheric very long distance radio propagation. European and US radio amateurs appear to consider very long distance tropo openings an every year experience but can other regions of the world exhibit very long distance tropo openings too? Can we estimate the time, location and frequency of occurence and what is the maximum dx range we may expect in tropospheric radio propagation? Evidently, there is still a number of open questions.

2 The QSO database

VHF dx QSOs exceeding distances of 3.000 kilometers in tropospheric radio propagation must be considered a true rarity in ham radio. How many QSOs have been actually managed in recent decades? Nobody knows the correct number. By referring to ham radio web sites and ham magazines (see the below references) and by launching an inquiry in the ham radio email reflectors [36], approximately 100 examples of very long distance QSOs have been identified covering the period from 1959 to 2005, see Fig. 2.1 and Table 2.1, respectively.

The database compiles information from various sources, e.g. the *IARU Region 1 Dx Records* table which lists long distance QSOs in Europe and Africa, see, e.g., [32], *The World above 50 MHz* table in which the *QST* magazine keeps track of the North American distance records [22], the *DX Sherlock V-U-SHF DX-Spot QSO Database* which is managed by Gabriel (EA6VQ), see [29] and [34], the *Dubus toplist* [31] which compiles the dx results of the most active European ham radio stations, the *OH9W/OH2AQ DX Cluster* [44] which files dx observations from recent years and from other resources too. Valuable information was also obtained, in particular, from the personal web sites of Charles (EI5FK, see [26]), Paul (KH6HME, see [6]), Russ (KH6FOO, see [17]) and Tim (G4LOH, see [25]), respectively. The author has also received valuable assistance by many radio amateurs, in particular from Gene (W3ZZ, *QST Magazine*), Joachim (DL8HCZ, *Dubus Magazine*), John (VK3KAW, *Wireless Institute of Australia*), John (ZL2TWS, *New Zealand Association of Radio Transmitters*), Leigh (VK2KRR) and Gabriel (EA6VQ).

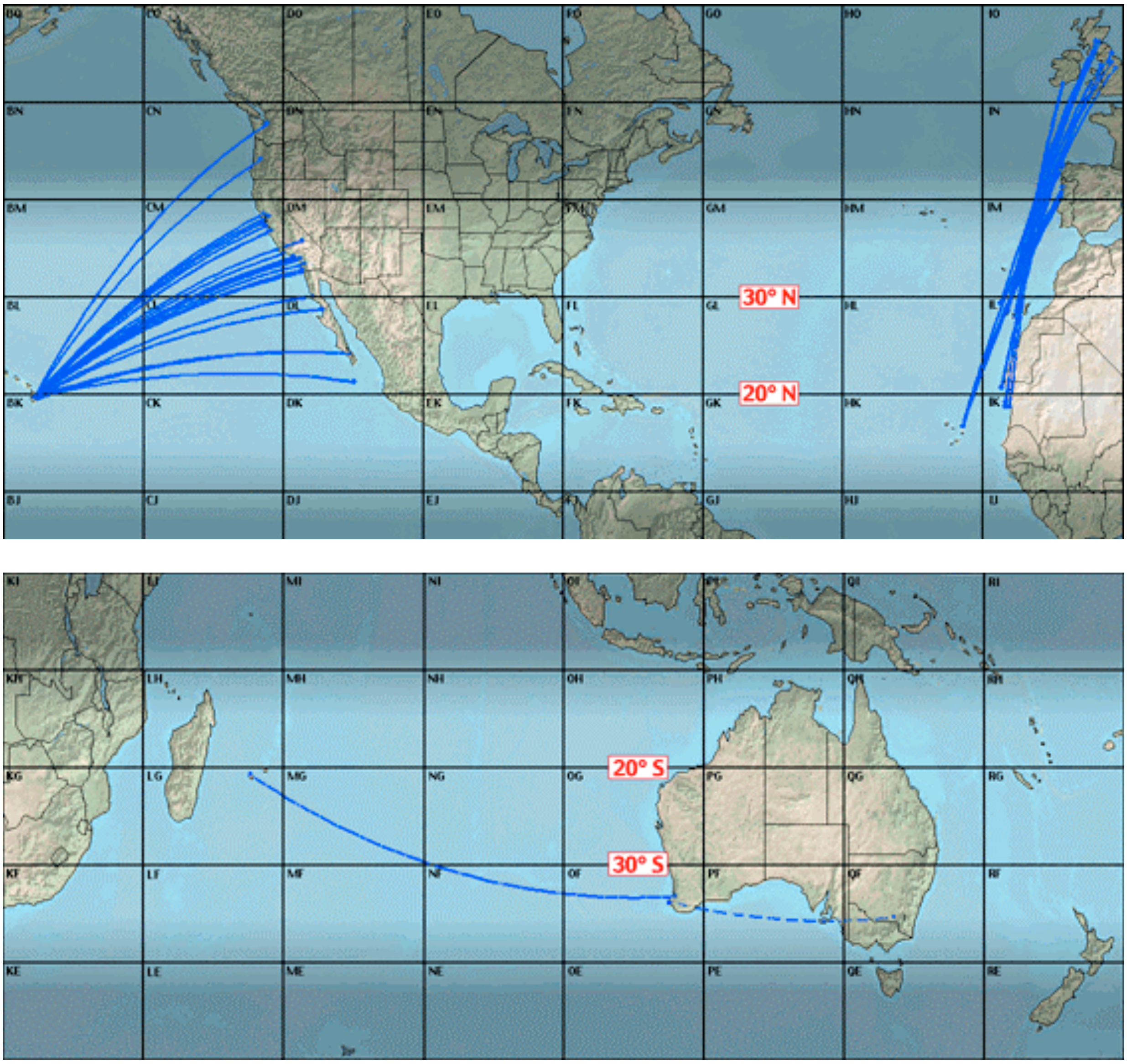

Fig. 2.1. Geographical distribution of tropospheric dx QSOs exceeding the distance of 3.000 kilometers on very high frequencies (144 MHz to 5.7 GHz). The QSO along dotted line across the Great Australian Bight misses the 3.000 kilometer criterion but will be discussed in chapter 4.6.

Call	Location	Call	Location	Freq.	Dist.	Date
KH6UK	Hawaii	W6NLZ	???	222 MHz	4087 km	Jun 22, 59
KH6IAA	BK29GO	KD6R	DM13NI	432 MHz	4109 km	Jul 28, 80
GD8EXI	IO74UD	EA8XS	IL28GA	144 MHz	3025 km	Sep 4, 81
GM0BWU	IO84BW	EA8BML	IL27GX	144 MHz	3140 km	Sep 9, 88
GM0KAE	IO86CD	EA8BML	IL27GX	144 MHz	3264 km	Sep 9, 88
GM4COX	IO85JX	EA8BML	IL27GX	144 MHz	3260 km	Sep 9, 88
EB8BTV	IL18QI	GM4JJJ	IO86GB	144 MHz	3252 km	Sep 9, 88
GM0BQM/p	IO85CE	EA8BML	IL27GX	144 MHz	3168 km	Sep 9, 88
GM8COX	IO85BS	EA8BML	IL27GX	144 MHz	3223 km	Sep 9, 88
G0EHV	IO94FW	EA8BML	IL27GX	144 MHz	3198 km	Sep 10, 88
KH6HME	BK29GO	XE2/N6XQ	DL28UQ	144 MHz	4281 km	Jul 13, 89
KH6HME	BK29GO	XE2GXQ (N6XQ)	DL29CX	220 MHz, 432 MHz, 1296 MHz	4152 km	Jul 15, 89
KH6HME	BK29GO	N6CA	DM03TR	3456 MHz	3982 km	Jul 28, 91
KH6HME	BK29GO	N6CA	DM03TR	5760 MHz	3982 km	Jul 29, 91
KH6HME	BK29GO	N6CA	DM03TR	903 MHz	3982 km	Aug 23, 93
KH6HME	BK29GO	N6XQ	DM12JR	903 MHz	4064 km	Jul 13, 94
KH6HME	BK29GO	N6CA	DM03TR	2304 MHz	3982 km	Jul 14, 94
KH6HME	BK29GO	W7FI	CN87WS	144 MHz	4333 km	Jul 1, 95
KH6HME	BK29GO	N7MWV	CN87VR	144 MHz	4325 km	Jul 1, 95
KH6HME	BK29GO	W7YOZ	CN87VR	144 MHz	4325 km	Jul 1, 95
KH6HME	BK29GO	N6XQ	DM15JR	902 MHz	4061 km	Jul ?, 95
FR1GZ	LG79RD	VK6RBU	OF76WR	144 MHz	6025 km	May 30, 96
FR1GZ	LG79RD	VK6RBU	OF76WR	144 MHz	6025 km	Jun 4, 96
G4LOH	IO94EA	EB8BTV	IL18QI	144 MHz	3103 km	Aug 8, 98
K6QXY	CM88QL	KH6HME/B	BK29GO	144 MHz	3788 km	Dec 14, 98
K6QXY	CM88QL	KH6HME/B	BK29GO	144 MHz, 432 MHz, 1296 MHz	3788 km	Dec 15, 98
KG7FU	CN84KA	KH6HME/B	BK29GO	144 MHz	4041 km	May 09, 99
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	Jul 08, 99
K6ODV	DM13GV	KH6HME/B	BK29GO	144 MHz	4065 km	Jul 08, 99
K6KLY	CM87	KH6HME/B	BK29GO	144 MHz	3710 km	Jul 09, 99
KH6HME	BK29GO	K7JA	DM03XS	432 MHz	4013 km	Jul 11, 99
N6CA	DM03TR	KH6HME/B	BK29GO	144 MHz, 432 MHz	3982 km	Jul 16, 99
N6CA	DM03TR	KH6HME/B	BK29GO	144 MHz, 1296 MHz, 3456 MHz	3982 km	Jul 18, 99
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	Aug 17, 99
KH6HME	BK29GO	W1LP/mm	DL51CE	144 MHz	4754 km	Aug 21, 99
N9JIM (K6QXY)	CM88QL	KH6HME/B	BK29GO	144 MHz	3788 km	Dec 15, 99
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	Jun 02, 00
N6YM	CM88XF	KH6HME/B	BK29GO	144 MHz	3823 km	Jun 17, 00
K5KT	DM03TS	KH6HME/B	BK29GO	144 MHz	3979 km	Jun 17, 00
K6NPS	CM96AO	KH6HME/B	BK29GO	144 MHz	3762 km	Jun 18, 00
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	Jul 23, 00
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	Aug 02, 00

K7JA	DM03XS	KH6HME, KH6HME/B	BK29GO	144 MHz	3967 km	Aug 12, 00
K7JA	DM03XS	KH6HME	BK29GO	144 MHz	3967 km	Aug 13, 00
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	Apr 23, 01
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	May 05, 01
G4LOH	IO94EA	EB8BTV	IL18QI	144 MHz	3103 km	May 26, 01
K7JA	DM03XS	KH6HME	BK29GO	144 MHz	3967 km	Jun 18, 01
G4LOH	IO94EA	EB8BTV	IL18QI	144 MHz	3103 km	Jun 21, 01
XE2EED	DM12KM	KH6HME/B	BK29GO	144 MHz	4063 km	Jun 23, 01
K7JA	DM03XS	KH6HME	BK29GO	144 MHz	3967 km	Aug 11, 01
K7JA	DM03XS	KH6HME	BK29GO	144 MHz	3967 km	Aug 30, 01
D44TD	HK86NO	CT1DYX	IN50QD	144 MHz	3157 km	May 18, 02
D44TD	HK86NO	EA1DIH	IN53TL	144 MHz	3280 km	May 18, 02
D44TD	HK86NO	CT1DYX	IN50QD	144 MHz	3157 km	May 19, 02
D44TD	HK86NO	CT1DYX	IN50QD	144 MHz	3157 km	May 30, 02
D44TD	HK86NO	CT1DYX	IN50QD	144 MHz	3157 km	May 31, 02
XE2HWB	DL44UC	KH6HME/B	BK29GO	144 MHz	4676 km	Jun 04, 02
N6HY	DM04SA	KH6HME/B	BK29GO	144 MHz	3980 km	Jun 28, 02
D44TD	HK86NO	CT1DYX	IN50QD	144 MHz	3157 km	Jul 23, 02
K7JA	DM03XS	KH6HME/B	BK29GO	144 MHz	3967 km	Jul 26, 02
N6PEQ	DM13CS	KH6HME/B	BK29GO	144 MHz, 432 MHz	4032 km	May 21, 03
N6HY	DM04SA	KH6HME/B	BK29GO	144 MHz	3980 km	May 21, 03
N6PEQ	DM13CS	KH6HME/B	BK29GO	145 MHz, 432 MHz	4033 km	May 22, 03
N6HY	DM04SA	KH6HME/B	BK29GO	144 MHz	3980 km	May 23, 03
D44TD	HK86NO	CT1DYX	IN50QD	144 MHz	3157 km	May 26, 03
D44TD	HK86NO	CT1DYX	IN50QD	144 MHz	3157 km	May 26, 03
N6PEQ	DM13CS	KH6HME/B	BK29GO	144 MHz	4032 km	Jun 16, 03
N6HY	DM04SA	KH6HME/B	BK29GO	144 MHz	3978 km	Jun 16, 03
KB6NAN	CM87TF	KH6HME	BK29GO	144 MHz	3753 km	Jul 13, 03
KH6HME	BK29GO	N6PEQ	DM13CR	220 MHz, 432 MHz	4035 km	Jul 13, 03
N6HY	DM04SA	KH6HME/B	BK29GO	144 MHz	3979 km	Jul 14, 03
N6HY	DM04SA	KH6HME/B	BK29GO	145 MHz	3979 km	Jul 16, 03
KB6NAN		KH6HME	BK29GO	144 MHz		Jul 16, 03
N6HY	DM04SA	KH6HME/B	BK29GO	146 MHz	3980 km	Jul 18, 03
G0FYD	IO83LS	EA8BPX	IL18SK	144 MHz	3019 km	Aug 8, 03
G4LOH	IO94EA	EA8BPX	IL18SK	144 MHz	3089 km	Aug 8, 03
XE2HWB	DL44UC	KH6HME/B	BK29GO	144 MHz	4676 km	Jun 4, 04
XE2ED	DM12KM	KH6HME/B	BK29GO	144 MHz	4063 km	Jun 4, 04
WA6LIE	CM96EQ	KH6HME	BK29GO	144 MHz	3804 km	Jun 6, 04
KH6SX	BK29	XE2HWB	DL44UC	144 MHz	4669 km	Jun 7, 04
EA8BPX	IL18SK	GD4GNH	IO74QD	144 MHz	3044 km	Jul 2, 05
EA8BPX	IL18SK	G3CKR/p	IO93??	144 MHz	3061 km	Jul 2, 05
K7JA	DM03XS	KH6HME, KH6HME/B	BK29GO	144 MHz	3967 km	Jul 18, 05
K6OYY	DM04CK	KH6HME/B	BK29GO	144 MHz	3872 km	Jul 28, 05
WA6LIE	CM96EQ	KH6HME/B	BK29GO	144 MHz, 432 MHz	3804 km	Jul 28, 05
G4LOH	IO70JC	RW1ZC/mm	IL19GF	144 MHz	3493 km	Aug 7, 05
CT1EEB	IN50QR	D44TD	HK86NO	144 MHz	3011 km	Aug 15, 05
EI5FK	IO51RT	RW1ZC/mm	IK18PQ	144 MHz	3751 km	Aug 15, 05

EI5FK	IO51RT	RW1ZC/mm	IK18WQ	144 MHz	3722 km	Aug 15, 05
EI5FK	IO51RT	RW1ZC/mm	IK19PA	144 MHz	3714 km	Aug 15, 05
G4LOH	IO70JC	RW1ZC/mm	IL10IP	144 MHz	3444 km	Aug 29, 05
D44TD	HK86NO	CT1ANO	IN51RE	144 MHz	3072 km	Aug 29, 05

Table 2.1. Chronological list of tropospheric very long distance QSOs exceeding the distance of 3.000 kilometers on very high frequencies. The blue, yellow and green colour indicates the eastern Pacific sector, the European/African sector and the Indian Ocean sector, respectively (compare to Fig. 2.1). The data was taken from [5], [6], [7], [25], [26], [27], [29], [32], [33], [34], [37], [41], [42], [44], [45], [47], [48], [49] and [50]. Note that this table does not consolidate the actual distance values which may vary from one publication to the other.

The total amount very long distance tropo QSOs in the world is unknown which is in particular true for the Hawaiian path where most of the dx contacts never appeared anywhere. Thus, Table 2.1 can only describe a fraction of all dx events but even if we could double or triple the number of list items, the data would still represent a small database compared to the huge amount of general VHF dx QSOs which were established from the 1950s until now. It is also important to note that the 3.000 kilometer threshold represents nothing else than an arbitrary value. Assuming this paper would consider a smaller value, e.g. 2.000 kilometers or so, we would obtain a list which is probably much longer than the entire document. From this perspective, we are dealing with the "top of the tops" here or, with other words, we are investigating the upper tail of the unknown distribution function analysing the dx range of all tropo QSOs ever made by VHF radio amateurs.[1]

Referring to the *Dubus 144 MHz toplist* [31], 3.000 km QSOs in double hop sporadic E occur with a probability six to seven times higher than in tropospheric radio propagation - and double hop sporadic E is a rare phenomenon too. Surprisingly, the most spectacular long distance observation ever made in terrestrial VHF ham radio did not generate the awareness it actually deserves. FR1GZ's oberservation of the west Australian 144 MHz radio beacon VK6RBU (see, e.g., [5], [7], [22]) is indeed remarkable and this observation was made twice on Reunion Island, its path length of more than 6.000 kilometers outperforms any 2-way record in VHF, UHF and SHF considerably. Referring to the QSOs between Paul (KH6HME) and Chip (N6CA), we are facing another pioneer result which should generate more awareness in the ham community too. Bridging almost 4.000 kilometers on 5.76 GHz is indeed remarkable too[2] because it sets tropospheric radio propagation in contrast to ionospheric propagation modes such as Aurora, FAI and sporadic E which exclude very long distance QSOs on UHF and, in particular, on SHF. Even transequatorial radio propagation cannot compete with the results in very long tropo dx because TEP has never been observed on this high frequencies.

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[1] Such distribution functions, by the way, were generated by Geoff, G3NAQ, who has analysed the "dx operator's maximum ranges" in tropospheric ducting by referring to the Dubus toplist 1989, see [4].

[2] Paul and Chip currently experiment with even higher frequencies, i.e. with 10 GHz QSOs between Hawaii and California, see [35].

3 Characteristics and systematical features

Can Table 2.1 provide an representative overview on all very long distance tropo QSOs in the world? Is the list biased by European and US dx reports because of the very high geographical density of VHF amateur radio stations in this regions? Assuming very long distance tropo QSOs may be observed in all regions of the world, very likely the list would be dominated by QSOs across the European and North American continent – no such dx QSO has been reported though. Instead, dx reports from the Canary Islands and Hawaii are clearly dominating, the total number of VHF dx stations, however, is rather small on these islands. This is certainly no accidental result and even more systematical features become visible in Table 2.1.

3.1 All observations accumulate in only three geographical regions

A striking feature in Table 2.1 is the accumulation of the dx QSOs in only three geographical areas which is the eastern Pacific between Hawaii and the US mainland (see the blue items in Table 2.1), the west coast of northern Africa and western Europe (including the west coast of the Iberian peninsula, see the yellow items) and the Indian Ocean between Reunion and western Australia (green). We will also refer to a fourth region, i.e. the Great Australian Bight although the 3.000 kilometer criterion is not met here, see Fig. 2.1.

3.2 All QSOs involve dx stations located around 20° and 30° latitude

Remarkably all QSOs in the northern hemisphere accumulate or terminate in the L- and K-row of the Maidenhead grid system (see Fig. 2.1). In the southern hemisphere, however, it is the F- and G-row. Note that the L- and G-row both represent geographical latitudes between 20° and 30° on both sides of the equator (see the highlighted range of latitudes in Fig. 2.1). Evidently, we are facing no accidental result here either.

3.3 All QSOs represent ocean radio paths

It is also important to note that all dx QSOs represent propagation paths across large water expanses and that the dx records in the USA (KH6HME-W1LP/mm, 4.754 km, 1999) and in the IARU region 1 (EI5FK-RW1ZC/mm, 3.751 km, 2005) are both associated with maritime mobile radio stations. A small number of dx QSOs have traveled over land, for a short distance though: see the QSOs into Scotland and northern England (note the Irish Sea which appears to act as an ocean gateway here) and the QSOs into the inland of California and Washington state, respectively (Fig. 2.1). The dominance of ocean radio paths is certainly no accidental result.

3.4 Recurring and persistent band openings

Intuitively, we may expect that tropospheric ducts of several thousands kilometers length must represent fragile and unstable entities because meteorological dynamics may easily interrupt the duct along this long distance. In consequence, we may also expect that all this band openings must represent dx events of short duration, more or less.

The opposite is true, in fact: Table 2.1 indicates many band openings persistent over days and weeks. The beacon VK6BRU, for example, was received on Reunion on May 30 and June 4, 1996, i.e. within four days. The band opening between the British and the Canary Isles were persistent over at least two days in September 1988 and, apparently, three weeks in 2001, several weeks in May 2002 and another couple of weeks in July 2005. In August 2005, this extraordinaty dx QSOs between England/Ireland and the west coast of Africa spreaded over a period of three weeks. US radio amateurs have worked long tropo dx over three days in July 1989, two days in July 1991 and another two days in July 1994. In July 2005, the KH6HME radio beacon on Hawaii was received at the US west coast two times within ten days. The recurring and persistent nature of the band openings is no accidental result, obviously.

3.5 Number of QSOs per year

Between Hawaii and the mainland of USA, no QSOs have been reported earlier than April. From April to June, the monthly number of dx observations increases steadily reaching a significant peak in July, see the blue bars in Fig. 3.1. Surprisingly, the dx openings disappear abruptly in late summer, more or less, because the number of dx QSOs drops sharply in August and is zero in September altogether. Also surprising: some dx QSO have been managed even in the month of December which must be considered an anomaly.

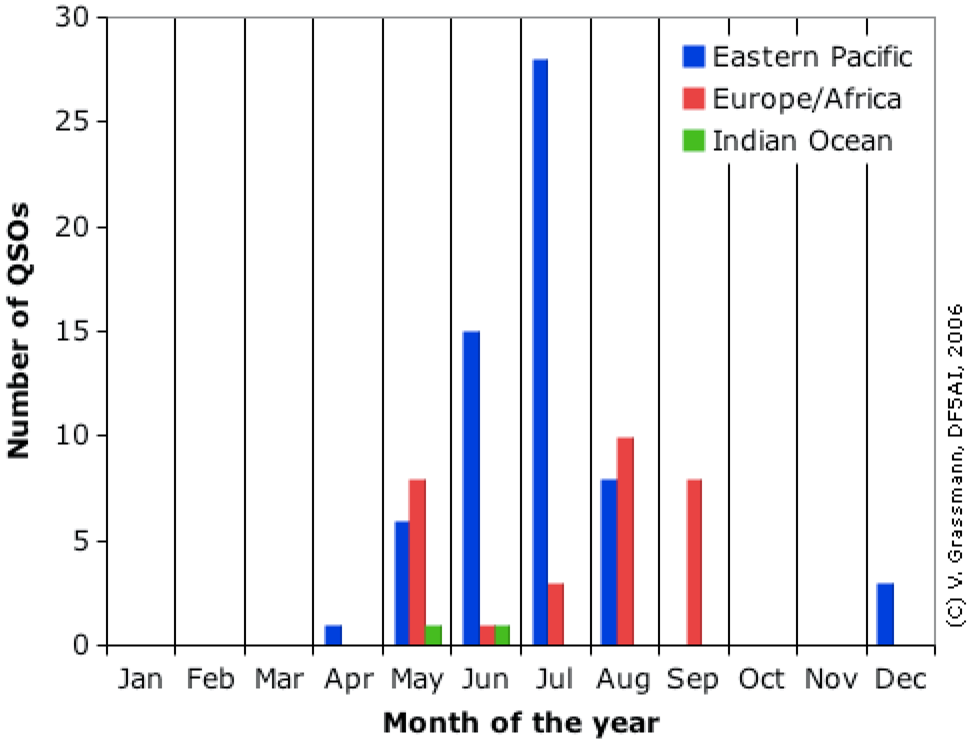

Fig. 3.1. Number of dx QSOs per month of the year.

In the European/African sector, the monthly distribution displays no dx QSOs in April but a surprising high number in May, see the red bars in Fig. 3.1. This is indeed a disturbing feature because the distribution function would show similarities to the east Pacific sector if the peak would be smaller or would not exist at all. In this case, the dx season may be characterized by a more or less steady increase peaking in August and, again, by a more or less drastic cutoff afterwards which removes all band openings within less than two months. However, a remarkable discrepancy would remain between the continents anyway: in the European/African sector, the number of dx QSOs peaks in August contrary to the eastern Pacific where maximum dx activity is observed in July.

Very few data is available in the southern hemisphere, unfortunately. In the Indian Ocean, we find two dx observations in May and June, respectively (see the green bars in Fig. 3.1). Further comments do not appear appropriate with this little amount of data.

3.6 Number of “open days” per year

The number of dx QSOs is actually no good measure to identify the band openings’ frequency of occurrence which is in particular true with small databases. The bars in Fig. 3.1 often represent one or two QSOs only, i.e. with some more dx observations the picture may change considerably. Although still imperfect, the number of “open days” per month appears more appropriate for analysis purposes. In fact, European radio amateurs actually refer to the number of open days rather than to the number of dx stations when considering tropospheric band openings between the British and Canary Isles an every year experience (see, e.g., [12] and the references cited therein).

East Pacific sector

Similar to the Europeans, US radio amateurs also regard band openings between Hawaii and California an annual phenomenon, see, e.g., the review in [13] and the report in [18] featuring William's (WA6CAX) dx observations aboard of his Cessna airplane where he can receive the Hawaiian beacon KH6HME every year in July and August when “entering the duct around 1.500 feet altitude”. The frequent occurence of these dx events has been documented by Russ (KH6FOO), see [17] and Fig. 3.2, respectively. In the period from 1979 to 2003, he has identified 322 open days contrary to the 45 open days (east Pacific sector) listed in Table 2.1. This gives important information on the data analysed in this paper which apparently comprises only 14 percent of all dx observations made in the eastern Pacific (the percentage is even less if Russ’ database is incomplete too).

However, if both databases may be equally considered representative, our material must show the same temporal variations as the KH6FOO data, with a different scaling though. Surprisingly, this is not true at all, see Fig. 3.2 and the upper panel in Fig. 3.3 which displays the KH6FOO data and the data used in this paper, respectively.

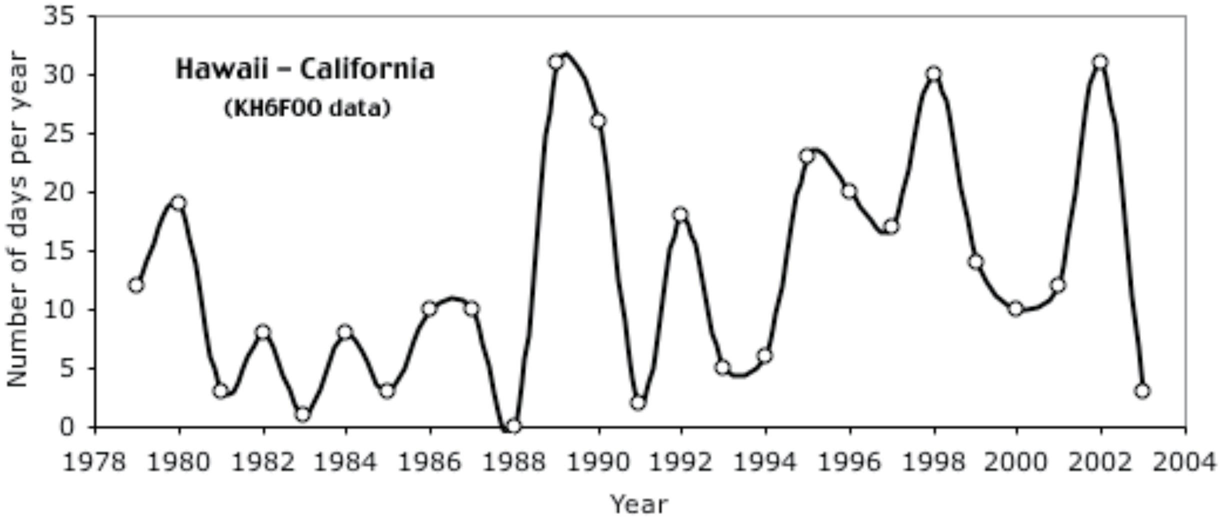

Fig. 3.2. Number of “open days” between Hawaii and California. The data was taken from the diagram in [17].

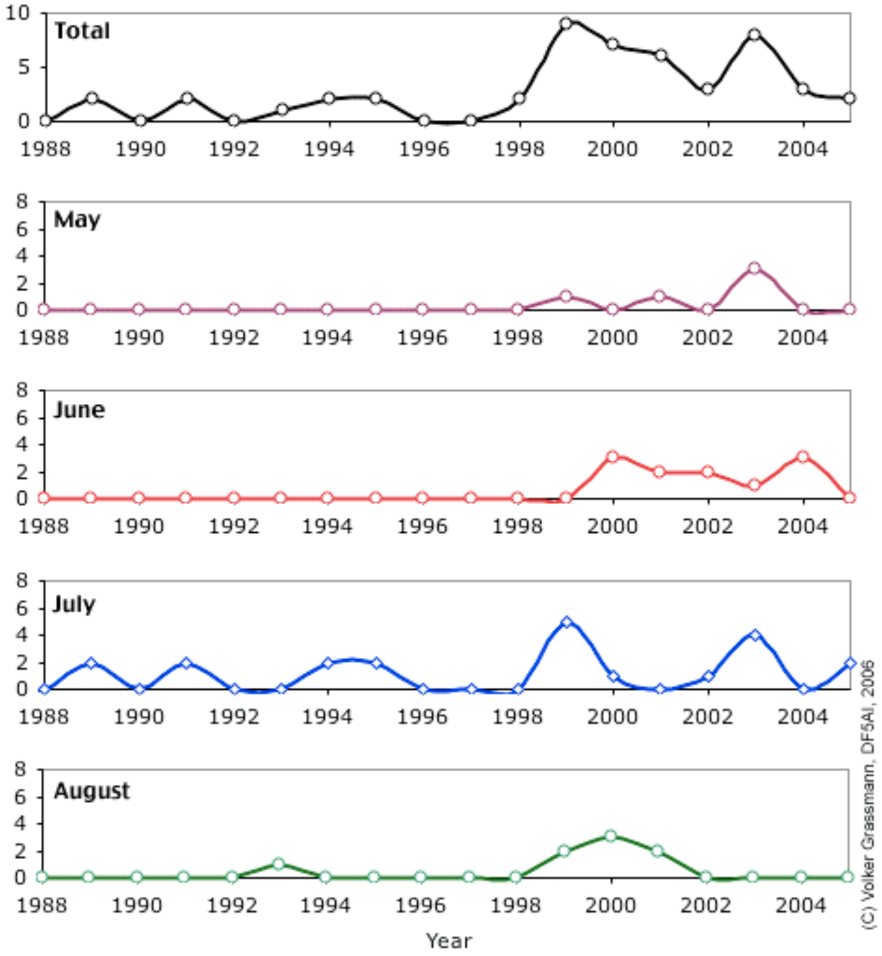

Fig. 3.3. Number of open days in the east Pacific sector enabling tropospheric dx QSOs exceeding the distance of 3.000 kilometers.

Thus, we are facing a dilemma here: which diagram is most representative to very long distance propagation and its frequency of occurence? On the one hand, the

KH6FOO data comprises much more information than this paper, the QSO database, on the other hand, focuses on ham radio observations which very likely does not apply to the KH6FOO data. Unfortunately, no raw data or any further information is given in [17] which could explain the origin of the KH6FOO data material. The author believes that Russ has also considered FM broadcast and TV observations in his analysis which is a different perspective, in fact. The difference results from the transmitter power because FM broadcast and TV transmitters deliver an output power which is measured in kilowatts contrary to ham radio transmitters which operate with some tens or some hundreds watts radio power - with higher transmitter power, the number of open days will increase considerably, of course. One or the other approach is fully acceptable but we must not be astonished by the discrepancies in the results then.

Beside the descrepancies between Fig. 3.2 and the upper panel in Fig. 3.3, it is also worth to identify the similarities in the two diagrams. In fact, Russ' data shows two striking features, i.e. this wavelike oscillation which seems to reflect a periodicity between years of high and low dx activity and this positive trend which seems to indicate a more or less steady increase in the number of open days. This positive trend may be explained, perhaps, by the enhanced awareness of very long distance tropo QSOs within the ham community which is stimulated, for example, by the various internet dx alert systems. This oscillation, however, cannot be explained by varying observation efforts. Surprisingly, this oscillation becomes visible even in the smaller QSO database analysed in this paper.

Fig. 3.3 confirms the results which were already discussed in chapter 3.5, i.e. highest dx activity is obtained in the month of July. However, this is only true from a statistical perspective and does not apply in every year, see, e.g., July 2001 in comparision to all the other months in 2001. In fact, the dx activity in July varys considerably from one year to the other and appears to reflect a periodic behaviour, i.e. after one or two years of high dx activity, the number of band openings drops to zero for two years before it starts increasing again. A similar feature is visible in the May data too and the August data also shows four years of no activity (1994 – 1998) followed by four years of high activity (1998 – 2002). Another surprising feature: May openings have been observed not earlier than 1999, and June openings not earlier than 2000, respectively. For some reason, band openings represent a rare phenomenon in August except of this four year period already mentioned. This results are indeed highly surprising.

European/African sector

Analysing the open days in the European/African sector, we can hardly see any systematic behaviour in the monthly distributions which basically results from the few data points, see Fig. 3.4. Note that the few data points in the number of open days does not imply an insufficient number of dx QSOs. The opposite is true, i.e. the database indeed files many dx QSOs between north-western Africa and western Europe. Thus, the monthly number of open days in the European/African sector is indeed smaller than in the east Pacific sector. On the other hand, a side effect must be taken into consideration here: the vast majority of dx QSOs between the British and Canary Isles correspond to distances slightly shorter than 3.000 kilometers and are therefore neglected in this paper. Fig. 3.4 must be therefore interpreted with great care, i.e. the number of open days does not reflect all band openings but band openings enabling distances longer than 3.000 kilometers, and this number is indeed small.

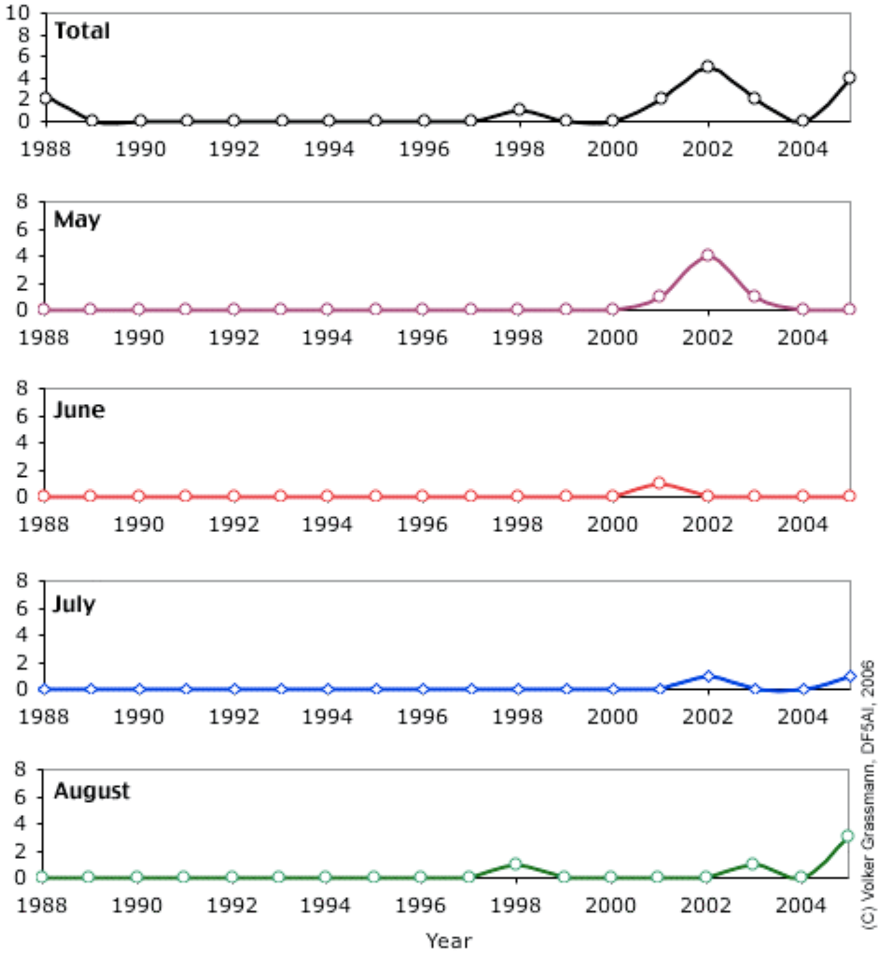

Fig. 3.4. Number of open days in the European/African sector enabling dx QSOs exceeding the distance of 3.000 kilometers.

However, by focusing on the annual number of open days independent from the month of occurrence (see the upper panel in Fig. 3.4), we are facing a surprising feature again, i.e. another periodic waveform indicating a small maximum in 1998 succeeded by two years of minimum dx activity (1999 – 2000) which then results in three years of maximum dx activity (2001 – 2003) and another minimum in 2004. Also surprising: from one maximum to the other, the number of open days appears to increase, see the gradients 1997-1998, 2000-2001 and 2004-2005, respectively. If the latter one represents the initial phase of a new maximum, does this mean we may expect a high number of dx openings in 2006?

Critical comments

It is important to emphasize the descriptive function of the above paragraphs. Terms such as “periodicity” and “oscillation” describe the appearance of the data which does not imply, in no way, the physical existence of periodical and oscillatory processes. If the data presents variations which look like an oscillatory behaviour, it should be mentioned in the data description because it may provide hints and directions in the data analysis that follows. The data description, however, cannot predetermine the physical nature of the processes which manifest in the data.

In fact, the above mentioned features may be also interpreted by accidental results and statistical variations which is best seen in the July panel of Fig. 3.3. Considering the data between 1988 and 1992, for example, we are actually facing nothing else than a sequence of numbers changing between the values 0 and 2. The analysis software, however, presents a highly suggestive visualisation, i.e. a wavetrain which is perhaps not justified at all. The data between 1993 and 2005, on the other hand, can resolve the wavetrains with higher accuracy but, nevertheless, we are dealing (by definition) with annual data values, i.e. with a sample rate insufficient to pinpoint an oscillation (if it exists) also corresponding to a 1 year period.

Interpreting the annual variation in the upper panel of Fig. 3.4 by an oscillatory process is problematic too: it looks like an oscillation but we can actually only see two maxima around 1998 and 2002 and the latter one is higher than the other – the increase from 2004 to 2005 appears to indicate the commencement of a third maximum but this is nothing else than a speculation at this stage of the discussion.

4 Interpretation of results

The above chapter appears to indicate that all this QSOs have something in common in addition to the obvious feature of very long radio paths caused by tropospheric ducting. This chapter will interpret the findings by referring to the global atmospheric circulation system. Very likely, the following results are obvious to those radio amateurs who have thought about these type of dx propagation for a long time but this paper wishes to assemble the bits and pieces step by step.

The weather system is controlled by temperature and pressure gradients causing air flow (winds) from high to low pressure areas. We are all aware that this simple physical law (and some others which play an important role too) results in highly complicated and dynamical weather patterns which are difficult to predict. Although unpredictable over a longer period of time, the weather system also shows systematical features, e.g. typical weather conditions and recurring pressure areas such as, for example, the anti-cyclone over the Azores.

Intuitively, we have the two-dimensional weather map in mind when discussing typical weather patterns, systematical patterns however also exist in the vertical direction. On both sides of the equator, the Earth atmosphere has developed three main circulation systems, i.e. the *Polar cells*, the *Ferrel cells* and the *Hadley cells*, respectively, which revolve air masses in horizontal and vertical direction within a particular band of latitudes, see Fig. 4.1.

4.1 The Hadley convection cells and the subtropical calms

At the equator, maximum solar energy is deposited into the atmosphere, i.e. the air is warming and ascends into the upper troposphere which forms a band of low air pressure centered at the equator, see Fig. 4.1 and Fig. 4.2, respectively. At ground level, the ascending air is replaced by air flowing from the northern and southern hemisphere towards the equator which forms the *Northeast and Southeast Trades* (Fig. 4.1), the equatorial region is therefore called the *innertropical convergence zone* (ITCZ). The rising air transports heat and moisture into the upper troposphere resulting in this band of clouds around the Earth's equator which we all know from weather pictures taken by geostationary satellites, see Fig. 4.2 and, e.g., [17].

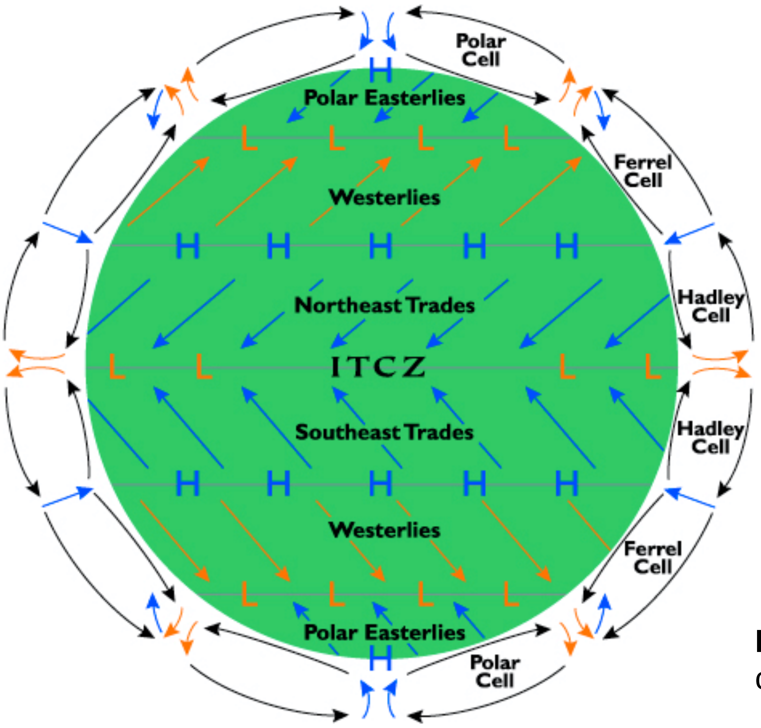

Fig. 4.1. Global atmospheric convection system, [38].

The ascending air together with the Trade winds represent segments of the *Hadley cells* which form two convection systems north and south of the equator (Fig. 4.2). In higher latitudes, each Hadley cell has a *Ferrel cell* as a neighbour, both are separated at around 30° latitude. The separation zone creates a band of high air pressure around the Earth, i.e. the *subtropical high* (see the letters “H” in Fig. 4.1) which is characterized by calm winds, cloud-free skies and hot and dry weather.

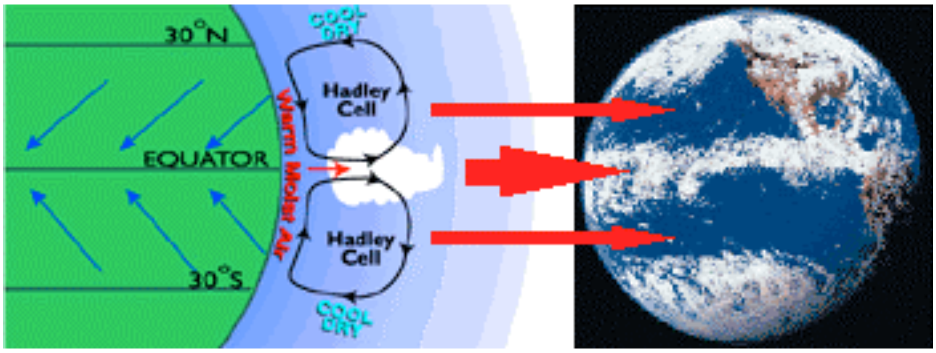

Fig. 4.2. The Hadley cells cause the subtropical calms between 20° and 30° northern and southern latitude with high air pressure and cloud-free skies (the left and right image was taken from [38] and [40], respectively).

Geographically, these latitudes are known as the *subtropical calms* or *horse latitudes*, also called *calms of Cancer* in the north and *calms of Capricorn* in the south, respectively (see, e.g., [38]). It is perhaps also worth to mention that the equatorial region between the *tropic of Cancer* (23.5° N) and the *tropic of Capricorn* (23.5° S) is referred to as the *tropics*, i.e. the sun reaches a point overhead within this band of latitudes at least once during the year, see, e.g., [38]. The *subtropics*, on the other hand, denote the geographical band between the tropics and mid-latitudes which is located between 23.5° and, say 35° latitude on both sides of the equator. The upper value is indeed not exclipicitly defined, i.e. the reader may find other values depending on the actual resource (the above figure was taken from [38], the German version of the same resource defines 40° latitude the upper limit [39]). Similar discrepancies also exist with the geographical position of the horse latitudes, i.e. with the band of latitudes which is in particular important in this paper. Because we need to discuss this region from a meteorological rather than a geographical perspective, this region does not correspond to fixed latitudes anyway but varies with the sun's annual motion north and south of the equator.

4.2 Tropospheric inversion layers

Tropospheric inversion layers are characterised by discontinuities in the vertical distribution of air temperature and air humidity which both control the atmospheric refraction index N and, in consequence, the propagation of radiowaves in the lower atmosphere. Calculating the refractive index N, we obtain a summation of two terms, i.e. $N = N_d + N_w$ where N_d and N_w denote the so-called *dry* and the *wet term*, respectively. The dry term is mainly controlled by air temperature and air pressure, the wet term considers the air humidity in particular.

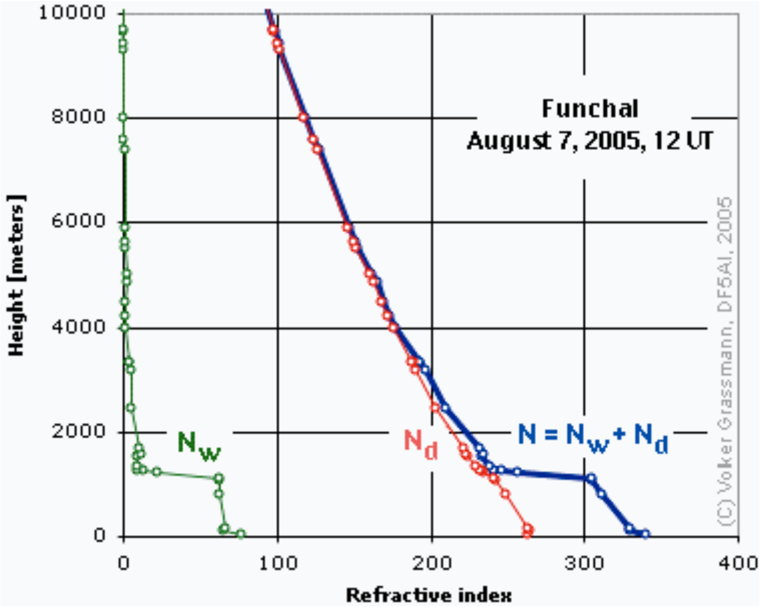

Fig. 4.3. Example of the atmospheric refraction index indicating the intense inversion layer which has enabled the dx QSOs between England/Irland an the west coast of northern Africa in August 2005. N_d and N_w denote the so-called dry and wet term of the total refraction index $N = N_d + N_w$ [30].

In practice, the dry term contributes about eighty percent to the actual value of N, i.e. the wet term only contributes around twenty percent [1]. However, N_w is typically more important than N_d in tropospheric radio propagation because the wet term is a much more variable than the dry term [1]. This feature has been documented in practice too, see the analysis of the dx QSOs between England/Irland and the west coast of Africa [30].

4.3 Interpretation of long persistent inversion layers

The subtropical calms represent ideal conditions for the generation of inversion layers. We find descending, dry and relatively cool air masses which originate from the Hadley cell circulation (referred to as “Hadley air” in the following), opposed by ascending, warm and moist air from ground level which results from the solar radiation on the seasurface in cloud-free skies with calm winds. Intense inversion layers are obtained, if the warm and moist air accumulates in horizontal layers embedded within the ambient cool and dry Hadley air. Without significant winds, turbulence and mixture of air masses, the atmospheric stratification is little affected by distortions which indeed supports persistent inversion layers and even if an distortion has occured, e.g., by the day-to-night-variation, the original layering recovers easily.

4.4 Interpretation of very long tropo distances

The Hadley cells and the subtropical calms represent features of the global atmospheric circulation system extending over thousands of kilometers. The corresponding inversion layers therefore represent large-scale phenomena too which explains the difference between the relatively short dx ranges in mid-latitudes and this extraordinary long QSO distances in the subtropical calms.

Note that the longitudinal and latitudinal size of the subtropical calms differ significantly. In longitude, the subtropical calms spread around the Earth (not along a great-circle though, see paragraph 5.1) but only 20°, or so in latitude. We may therefore speculate that east-west radio paths can support much longer dx ranges than north-south propagation paths which is fully consistent with the longest tropospheric dx range ever observed by VHF radio amateurs, i.e. the dx path between Reunion and western Australia. This feature also explains the longer dx ranges in the eastern Pacific (east-west propagation) compared to the dx QSOs in the European/African sector (north-south propagation) which is furthermore supported, of course, by the geographical positions of the Hawaiian and Canary Islands.

4.5 Interpretation of the latitudinal distribution of dx QSOs

Fig. 2.1 displays the subtropical calms by highlighting the geographical area around 20° and 30° latitude and, indeed, all tropospheric very long distance QSOs reside within this band of latitudes or terminate in it. This systematical feature, i.e. the lack of even one counter-example, is one of the surprising results of Table 2.1 and documents the special nature of tropospheric very long distance QSOs. Thus, the bandopenings in the eastern Pacific, in the European/African sector and also in the Indian Ocean must not be considered totally independend but are closely related to each other.

By referring to the geographical definitions, Table 2.1 lists dx stations spreading over three geographical regions, i.e. the mid-latitudes (geographical positions higher than, say 40° latitude, e.g. dx stations in Washington state, England, Ireland and Portugal), the subtropics (23.5° to 40° latitude, e.g. stations in Mexico, California, Australia and the Canary Islands) and the tropics (below 23.5° latitude, e.g. Hawaii, Reunion and the Cap Verdes). Thus, very long distance tropo QSOs is no feature which exclusively occurs within the subtropics, this QSOs may originate in this band of latitudes but may leave and cross this band of latitudes too.

From the dxer’s perspective, QSOs crossing the subtropics are the most interesting dx contacts in the north-south direction. We may speculate that subtropical inversion layers must link to inversion layers in higher latitudes in this case, the dx QSOs cannot extend into mid-latitudes otherwise. On the other hand, there is reason to believe that “linked inversion layers” are less important in practice and are possibly not required at all, even the above mentioned geographical nomenclature appears irrelevant, in fact.

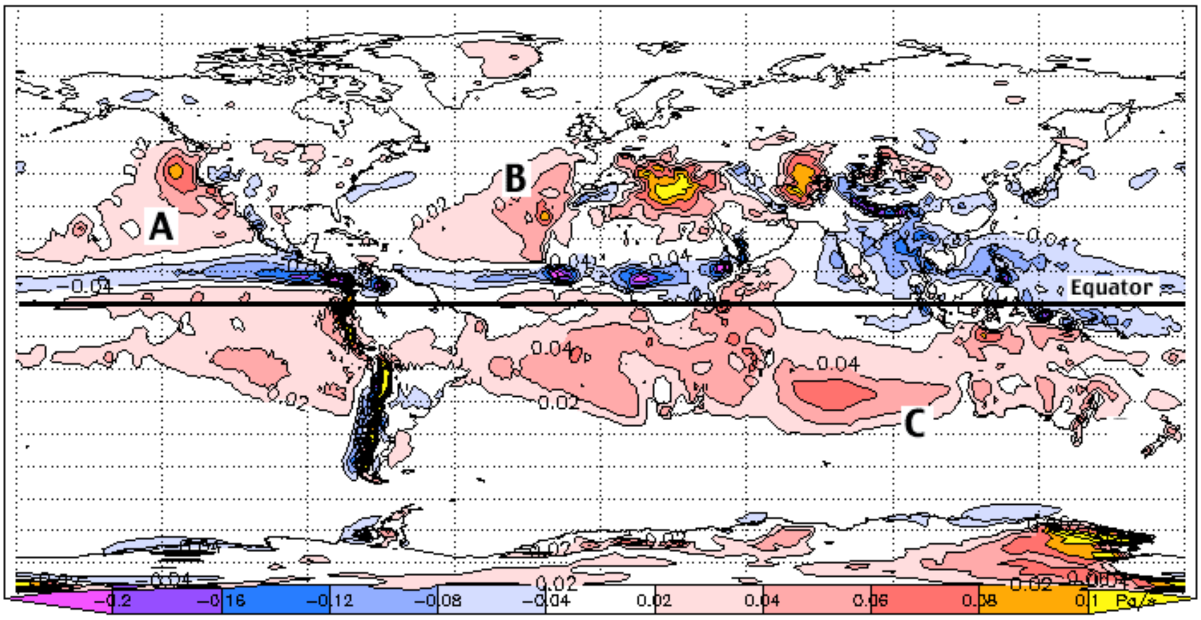

Fig. 4.4. Vertical air velocity at the 500 hPa height level (July 1979 average). The blue and red color indicates ascending and descending air, respectively [38].

In practice, the Hadley cells represent an ever changing convection pattern including subfeatures that “shift, merge and decouple in a complicated process over time” [38] (nevertheless, this is a slowly varying process which again explains the existence of durable band openings). The convection pattern is shown in Fig. 4.4 which displays the average vertical air velocity in July 1979 [38]. Note the more or less sharp band of ascent (blue) and the diffuse pattern of descent (red) and also the northern shift of the entire circulation system caused by the actual position of the sun in the month of July.

This example documents the signature of the Hadley cell circulaton and it documents descending air masses which include mid-latitudes too. This leads to the assumption that many, if not all, dx openings actually result from the variable nature of the cell's fine structure. Fig. 4.4 reveals the very surprising result that the area between Hawaii and the US west coast (see A), the area between the west coast of northern Africa and western Europe (B) and the area between Reunion and western Australia (C) all correspond to regions of wide-spread decend, i.e. we are facing a visual correlation between the Hadley circulation pattern and the geographical areas of very long distance radiowave propagation. However, Fig. 4.4 displays the special example of July 1979 and it remains unclear whether this pattern may be considered representative from a more general perspective too. If it does, the interpretation of very long distance tropo band openings will receive a very interesting verification.

4.6 Interpretation of the ocean radio paths

All dx QSOs benefit from the intense inversion layers which are specific to the subtropical calms, the durable band openings result from the stability of the atmospheric stratification and the absence of continental dx QSOs is explained by the important role of the oceans which inject warm and moist air into the ambient cool and dry Hadley air. All QSOs listed in Table 2.1 therefore represent propagation paths across the oceans.

However, continental dx QSOs are not excluded in general but the meteorological requirements are rarely met. This assumption is in particular supported by the lack of very long distance tropo QSOs between the Canary Islands and, say France, the Benelux countries, Germany or even Poland which obviously results from the geography. Contrary to the British Isles, dx QSOs into this countries need to travel long distances over the European continent which eliminates this type of radio propagation very efficiently, obviously.[3]

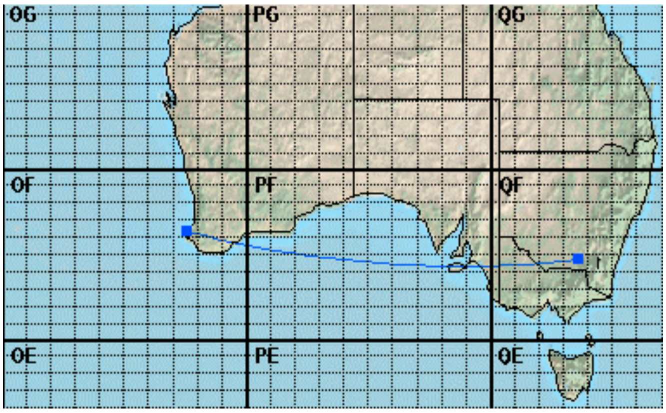

Fig. 4.5. Dx QSO between Leigh (VK2KRR) and Wayne (VK6JR) on January 2, 2006 over 2.927 km.

Just recently, another long distance QSO has been established between Leigh (VK2KRR) and Wayne (VK6JR) which however represents a combination of ocean

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[3] Dx QSOs between the Canary islands and central Europe have been indeed reported several times in recent years. However, there is strong indiacation that all this QSOs must not be interpreted by tropospheric but ionospheric radio propagation (double-hop sporadic E), see the detailed discussion in [12].

and land radio propagation, see [46] and Fig. 4.5. This QSO misses the 3.000 kilometer criterion by some tens of kilometers, unfortunately, but dx propagation across the Great Australian Bight is indeed important in the scope of this paper. Here, we may study the formation of tropospheric inversion layers by the interaction of warm, dry air from the Australian continent with moist air above the sea and we may study tropospheric ducts at the sea/land interface, see the detailed discussion in [7].

4.7 Possible correlation to the seasurface temperature

The seasurface temperature may be considered important in very long distance tropo QSOs because discontinuities in the atmospheric refractive index are mainly caused by discontinuities in the vertical distribution of air humidity (see paragraph 4.2). However, the dry Hadley air cannot provide a contribution here, i.e. it is the ocean and its actual surface temperature which controls the atmospheric water vapor content in the lower troposphere.

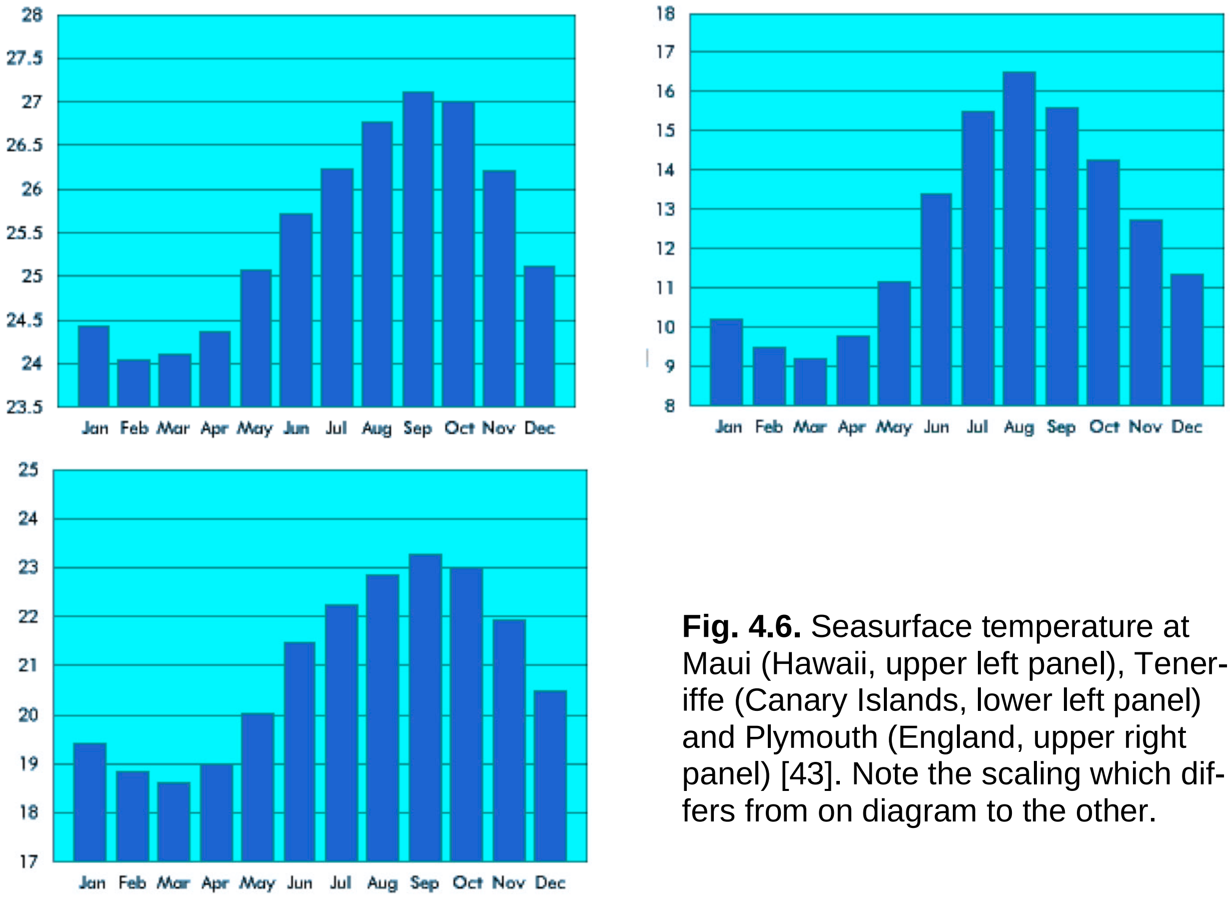

Fig. 4.6. Seasurface temperature at Maui (Hawaii, upper left panel), Teneriffe (Canary Islands, lower left panel) and Plymouth (England, upper right panel) [43]. Note the scaling which differs from on diagram to the other.

Variations in the seasurface temperature result from drafts and currents in the ocean but are basically associated with the intensity of solar radiation, of course. On June 21/22, the sun has reached its most northern position at 23.5° latitude (*summer* *solstice*, see, e.g., [38]), the month of highest seasurface temperature, however, is delayed by approximately two months due to the oceans' large heat capacity, see Fig. 4.6. Referring to *winter solstice* on December 21/22 where the sun is positioned at 23.5° southern latitude, highest seasurface temperature is obtained between, say late January and early March.

On the other hand, the seasurface temperature in the eastern Pacific is high at all times and varies by only 3° during the year (a similar statement applies to the Canary Islands too), contrary to mid-latitudes where we find a much lower sea temperature but a much higher annual variability (see Fig. 4.6). We may therefore conclude that very long distance QSOs in the eastern Pacific and also in the Indian Ocean are little affected by the seasurface temperature because a high temperature level is given along that radio paths anyway. If the radiowaves travel into higher latitudes, however, the correlation between the seasurface temperature and the occurence of dx QSO should increase with increasing latitude.

European/African sector: QSOs between the British and Canary Isles

In the European/African sector the radiowaves travel from subtropical regions into mid-latitudes, i.e. from regions of permanent high ocean temperature into regions where a high seasurface temperature is only obtained in late summer. The Plymouth seasurface temperature data (see Fig. 4.6) is representative to this QSOs and, indeed, the annual variation of the seasurface temperature and the maximum dx activity both peak in the month of August. Thus, the frequency of occurence of very long distance QSOs between north Africa (i.e. around 20° latitude) and mid-latitudes (i.e. around 50° latitude) appears correlated with the seasurface temperature north of the subtropical calms (i.e. between, say 40° and 50° latitude).

European/African sector: QSOs between the Cap Verdes and the Iberian peninsula

However, the dx activity in the European/African sector also shows another peak in May (see Fig. 3.1) which appears disturbing but it may be explained too. That peak is primarily caused by only one dx station, i.e. D44TD, which appears to work dx QSOs independent from the above mentioned peak in August. Compared to all the other dx stations listed in Table 2.1, D44TD is located closest to the equator. From the Cap Verdes at 17° latitude he targets dx stations at the west coast of the Iberian peninsula around 40° latitude with radio paths that reside within the subtropical calms, more or less (see the band of highlighted latitudes in Fig. 2.1). This QSOs therefore benefit from a permanent high ocean temperature which removes the importance of seasurface temperature variations.

Eastern Pacific

In the eastern Pacific, the seasurface temperature peaks in September (similar to the Canary Islands which are positioned on the same latitude), the number of dx events, however, peaks in July with few dx events in June and August (see Fig. 3.1 and Fig. 4.6, respectively), some QSOs have been reported even in December. Evidently, the occurence of very long distance QSOs is not controlled by ocean temperature variations, see also chapter 4.8.

Indian Ocean and south Australia

In the Indian Ocean, the dx observations were made in winter time (May and June), i.e. the dx event between Reunion and western Australia does not correlate to the peak time of the seasurface temperature because the ocean temperature is high at all times. The dx QSO between VK2KRR and VK6JA (which corresponds to a higher southern latitude, see Fig. 4.5) was however made in January which corresponds to the month of highest ocean temperature. On the other hand, with only two examples of very long distance QSOs in this geographical area, the data does not have any statistical relevance, in fact.

Critical comments

Thus, the QSO data seems to confirm the initial assumptions and expectations but there are counter-arguments too. During the year, the dx activity builds up within, say three months before it develops a peak maximum, the dx activity however decays within less than two months, see Fig. 3.1. We may argue, from a general perspective, that this asymmetrical time function can hardly be explained by slow processes such as the annual seasurface temperature variation and the change of the sun's actual geographical position.

Furthermore, the Hawaiian inversion layer "is much more stable over a wide tropical ocean than over other continents" [20] and may be observed "on most days" [20]. We may therefore expect a broad dx season providing very long distance QSOs in many months. Instead, we find a pronounced maximum in July dominating the number of dx QSOs considerably, i.e. the frequent presence of an inversion layer does not result in frequent dx QSOs during the year, obviously. For an unknown reason, it is the month of July which can enable inversion layers extending from Hawaii towards the mainland of USA, i.e. this capability is not (or less) given with all the other months which is surprisingly also true for June and August, i.e. the two months adjacent to the peak maximum.

4.8 Ocean-atmosphere interactions

Thus, the seasurface temperature may play a role in the generation of very long distance tropo openings, it is no dominating role though because other processes appear to make a contribution which is much more important. Discussing seasurface temperature variations and tropospheric ducts, we are actually dealing with very different subjects, i.e. with ocean dynamics on the one hand and with atmospheric phenomena on the other. Scientists indeed refer to the *ocean-atmosphere system* because of the many phenomena indicating links between the oceans and in the Earth atmosphere.

The *El Niño/La Niña/Southern Oscillation* phenomena, see, e.g., [38], have been discussed even in public[4] but there are other phenomena too which might affect the formation of tropospheric inversion layers and, in consequence, very long distance VHF propagation. Fig. 4.7 shows an example of the so-called *tropical instability wave* (TWI)

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[4] It is perhaps worth to mention that this phenomena cannot be identified in the QSO data. However, Walter (VK6KZ) concludes that favourable dx conditions across the Great Australian Bight, and also between Hawaii and California, may be affected by the El Niño effect, see [7].

representing seasurface temperature variations on the order of 1° to 2° C travelling westwards with wavelengths of 1.000 kilometers and periods of thirty days, see, e.g., [8] and [28]. The TWIs are observed along the equator and are apparently associated with intense inversion layers in the atmosphere, see, e.g., [8]. Although the details are not yet fully understood, scientists found strong indication that the so-called *atmospheric boundary layer* (ABL, see, e.g., [38]) responds significantly on variations in the seasurface temperature [8].

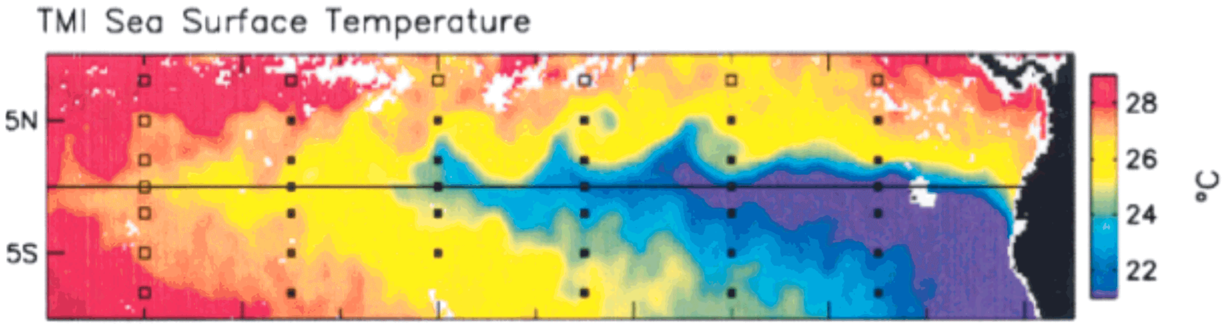

Fig. 4.7. Example of a tropical instability wave (TIW) visible in the seasurface temperature meandering along the equator west of South America on Sep. 2-4, 1999 [15].

The TWI phenomenon is presented here to document an example of an oscillatory feature in the ocean-atmosphere system. However, it can explain neither the general frequency of occurrence nor the apparent periodical behaviour of tropospheric band openings, unfortunately: TWIs are only observed between 5° northern and southern latitude and peak in the second half of the year (see, e.g. [15]) which appears inconsistent with the ham radio observations.

Thus, the interpretation of very long distance dx QSOs comes to an end here. In the paragraphs 4.1 to 4.6, we have obtained a consistent and transparent “big picture” which can explain the first order effects but we do not yet understand the details, obviously, see also chapter 6.

5 Extrapolation of results

Apparently, more experimental studies are required because we wish to understand this type of VHF dx propagation in more detail and we wish to obtain hints and recommendations with practical relevance in VHF dxing, of course. In fact, we all wish to know what dx opportunities are still awaiting its discovery?

5.1 Limitation of the maximum dx range

The subtropical calms spread around the Earth within two bands around 20° and 30° northern and southern latitude, respectively, i.e. longest dx ranges may be expected along this bands with dx QSOs directed from east to west, or the other way around. At

25° latitude, the Earth circumference is around 36.000 kilometers which is slightly less than the equatorial circumference (40.000 kilometers) but, nevertheless, this is an impressive upper limit for future dx records.

Unfortunately, it is not, i.e. the true maximum dx range is considerably shorter. The above mentioned latitudes represent *small-circles* on the globe, its circumference equals $2 \cdot \pi \cdot R_E \cdot \cos\varphi$ kilometers where R_E and φ denote the Earth radius and the actual geographical latitude, respectively. The radiowaves, however, travel around the Earth along *great-circles* with a length identical to the equatorial circumference $2 \cdot \pi \cdot R_E$ of the Earth, i.e. around 40.000 kilometers. Thus, the radiowaves cannot be trapped within the subtropical calms which is displayed by the graphical example in Fig. 5.1: if the radio station X starts transmitting to the east, the radiowaves will exit this particular band of latitudes at the point B in a distance of a few thousand kilometers.

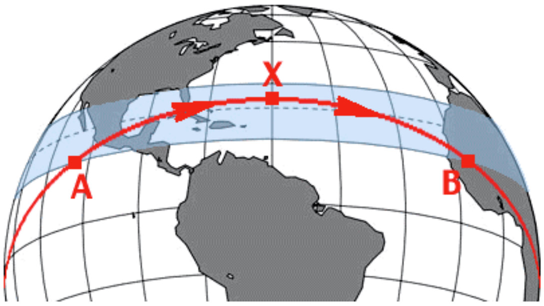

Fig. 5.1. Radiowaves travel along great circles (red) and cannot be trapped within an interval of small circles (blue).

However, we may double the path length by replacing the transmitter X by the transmitter A. Note that A and B share the same latitude at the lower limit of the blue band, the radiowaves however cross almost all latitudes within that band (station A therefore transmits with north-eastern antenna direction). We also need to keep in mind that very long distance tropo QSOs represent ocean radio paths, i.e. radio propagation paths across the continents need to be excluded. Equipped with the geometrical and geographical requirements and with the visionary perspective of the FR1GZ-VK6RBU observation, we may now address possible dx opportunities in practice.

5.2 Dx opportunities in other regions of the world

Dx stations located at the west coast of the Iberian peninsula find a perfect position for QSOs crossing the Atlantic Ocean towards the Caribbean, see Fig. 5.2. Referring to the FR1GZ-VK6RBU dx observation as a reference, QSOs between southern Portugal and, e.g., Puerto Rico indeed appear a possible scenario.

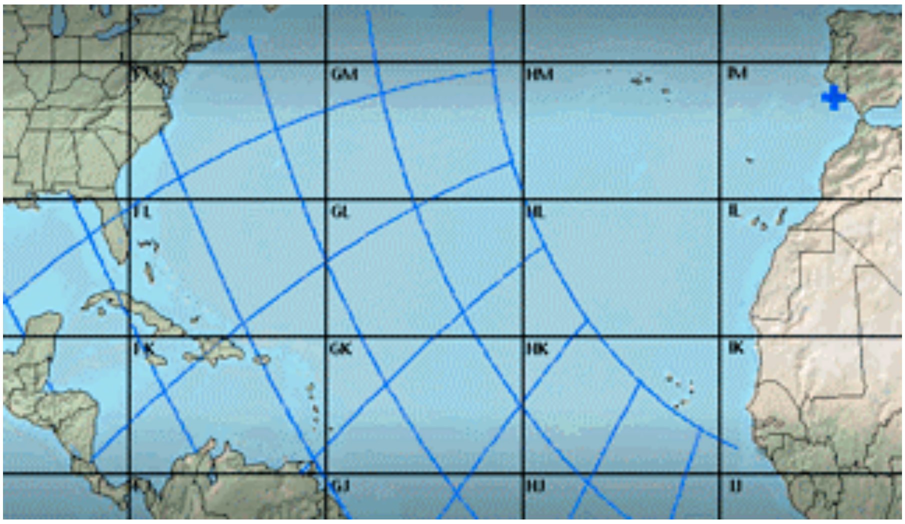

Fig. 5.2. Dx opportunities for VHF radio stations located in the south of Portugal. The spacing of the circles is 1.000 kilometers, the first circle denotes 3.000 kilometers.

This throws a light on the discussions on possible transatlantic QSOs in 144 MHz which typically focus on the shortest distance between the European and the North American continent, i.e. the Ireland – New Foundland path. Ev's (W2EV) statement "longer is better" is not generally accepted within the ham community (see the discussion, e.g., in [13]) but Fig. 5.2 indeed supports the assumption of transatlantic dx QSOs involving radio stations in the Caribbean.

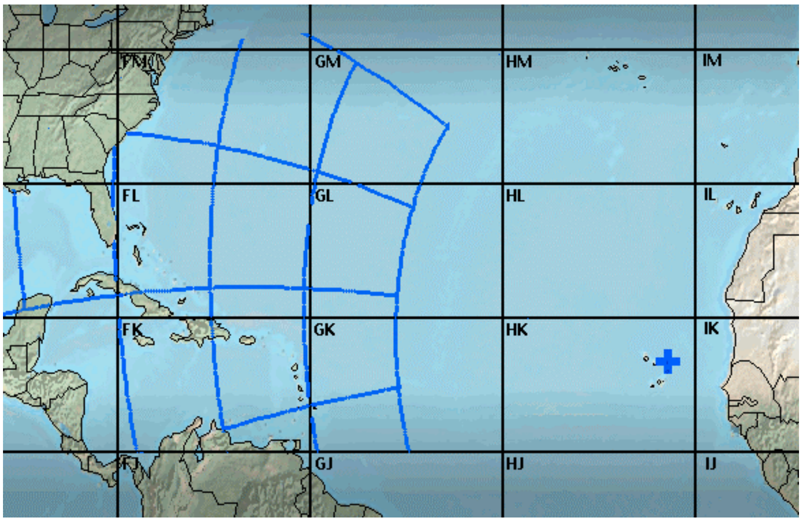

Fig. 5.3. Dx opportunities for VHF radio stations located on the Cap Verdes.

An even higher chance for transatlantic QSOs is given for VHF radio stations located on the Azores, Madeira, the Canary Islands and also on the Cap Verdes, see Fig. 5.3. The dx range between the Cap Verdes and Puerto Rico is identical to the distance between Hawaii and California and QSOs to Florida would correspond to the dx observation between Reunion and western Australia.

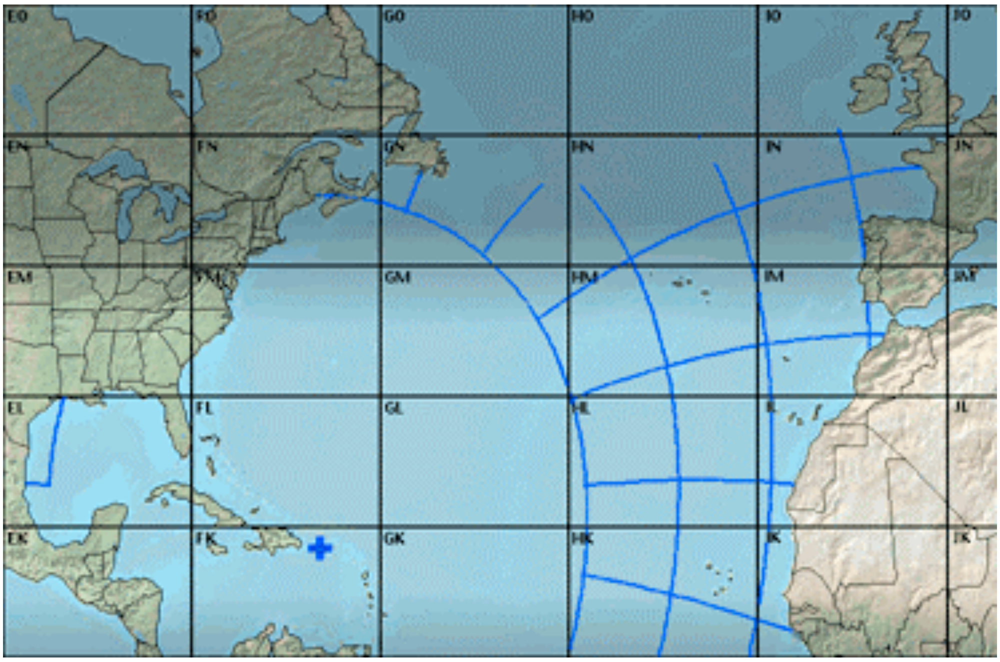

Fig. 5.4. Dx opportunities for VHF radio stations located on Puerto Rico.

Puerto Rico may be indeed considered a perfect location in tropospheric very long distance communication, see Fig. 5.4. In the west, dx QSOs may target the north-west coast of the Gulf of Mexico, in the north we may speculate about dx QSOs towards New England and New Foundland (which would represent a counterpart of the dx contacts between western Europe and the Canary Islands). The entire west coast of northern Africa corresponds to distances shorter than 6.000 kilometers, at even longer distances we may bring the Iberian peninsula, northern France, western England and southern Ireland into play too. From Puerto Rico, we may even beam right through the street of Gibraltar into the Mediterranean area.

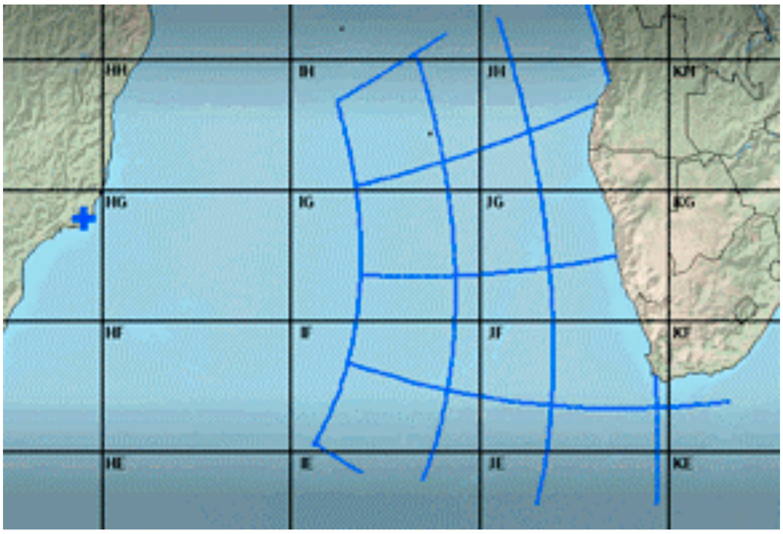

Fig. 5.5. Dx opportunities for VHF radio stations located at the east coast of Brazil.

Radio amateurs in Brazil and in the south of Africa are the author's personal "hot candidates" for record breaking dx contacts on very high frequencies, see Fig. 5.5 (and also the discussion of Fig. 4.4). Here, we find the shortest distance across the Atlantic

Ocean and the author has already speculated that the “transatlantic race” may be decided in this part of the world [10], [11]. In fact, the distance between, e.g., Rio de Janeiro and the African sea coast is “only” 5.600 kilometers, the distance to St. Helena Island (grid square IH74) is even less than 4.000 kilometers. This is also seen by other radio amateurs, of course, and Orlando (PY2ANE) has already started an initiative to launch test runs with VHF radio amateurs in south Africa [16], [52]. Hopefully, these efforts will continue and will involve even more amateur radio stations.

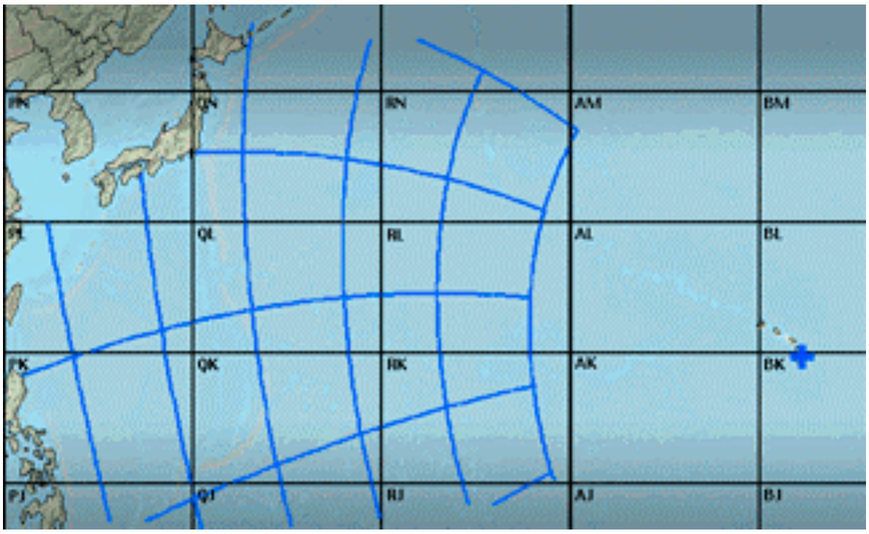

Fig. 5.6. Dx opportunities for Hawaiian VHF radio stations with western antenna directions.

Very interesting dx opportunities appear possible if Hawaiian radio amateurs would look not only towards the US west coast but in the opposite direction too. The southern part of Japan corresponds to a range of 7.000 kilometers, at 8.500 kilometers Taiwan comes into play too, see Fig. 5.6. This are indeed ambitious targets but it is worth to keep an eye on it, perhaps.

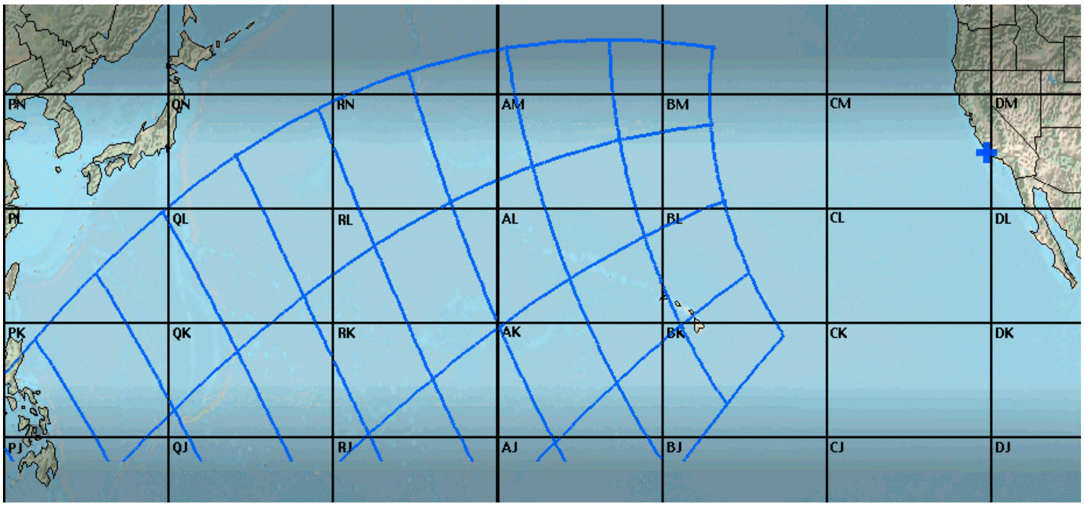

Fig. 5.7. Dx opportunities for Californian VHF radio stations.

Because of the high number of well-equipped VHF amateur radio stations in California, it is also worth to analyse their dx opportunities as well, see Fig. 5.7. Dx QSOs towards Japan appear less attractive because the radiowaves would travel into relatively high latitudes when crossing the Pacific Ocean. Test runs towards the Midway and the Marshall islands, however, appear worth to be examined in more detail.

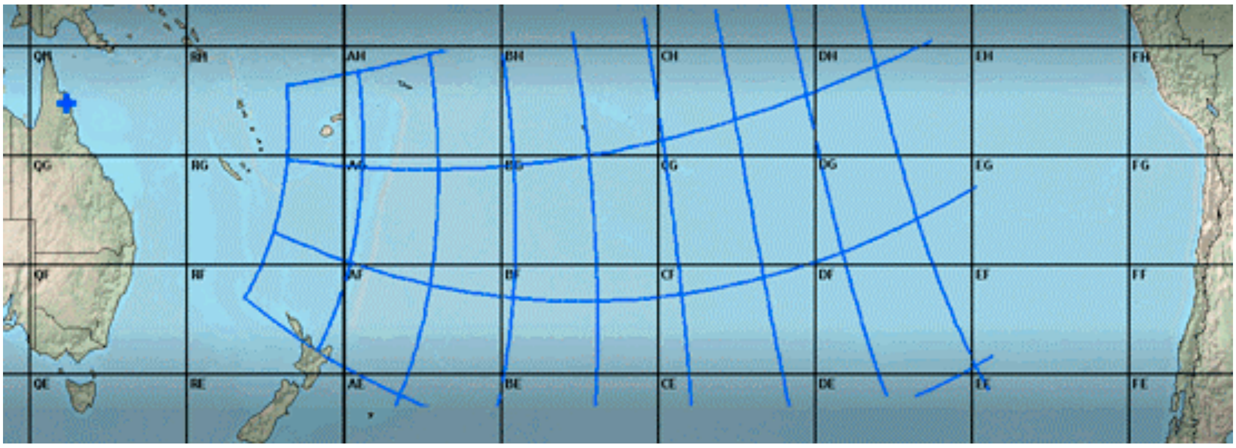

Fig. 5.8. Dx opportunities for VHF radio stations located at the east coast of Australia.

The longest dx ranges, from a theoretical perspective, appear reserved to radio amateurs in the southern hemisphere, see Fig. 5.8. However, identifying suitable test partners in the Pacific Ocean appears to become an obstacle. Maritime mobile radio stations and all the holiday resorts in that area may therefore play an important role here.

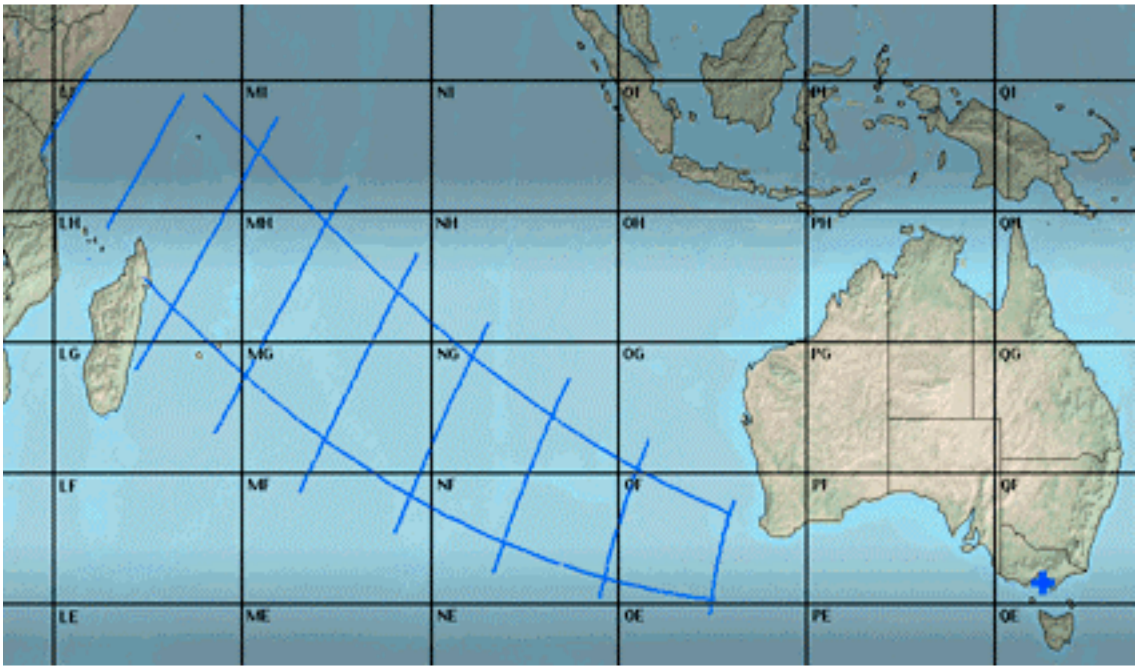

Fig. 5.9. Dx opportunities between south-east Australia and the Indian Ocean.

Leigh (VK2KRR) brings another fascinating dx opportunity into play: he speculates about dx opportunities between south-east Australia and the Indian Ocean by extrapolating his dx QSO (see Fig. 4.5) even further to the west, i.e. across the Great Australian Bight into the Indian Ocean [51]. Dx QSOs from Melbourne to Reunion (8.500 kilometers) is indeed an intriguing perspective, see Fig. 5.9.

The above compilation can only provide an imperfect outlook and may be considered an, say appetizer which may encourage other radio amateurs to investigate further. It is perhaps worth to mention, that alternative radio paths also exist outside of the ocean areas, see, e.g., Gabriel's (EA6VQ) discussion on "long path maritime tropo in the Mediterranean" [9].

6 Concluding comments

By compiling dx reports from various ham radio resources, a list of very long distance tropo QSOs was obtained which represents dx ranges between 3.000 and more than 6.000 kilometers in four geographical regions of the world observed between 1959 and 2005. It was clear from the beginning that tropospheric ducting can enable such type of dx QSOs, no comprehensive survey was yet available though analysing this extraordinary dx contacts in detail.

Surprisingly, the small database reveals a number of systematical features which may be all interpreted by a consistent picture that finally explains all this dx QSOs by only one mechanism, i.e. the Hadley cell convection system on both sides of the equator or, more precisely, the special nature of tropospheric inversion layers within the subtropical calms. From a retroperspective view, the results do not appear that surprising and were, perhaps, intuitively considered by VHF radio amateurs already. However, it is hoped that this paper has documented the charcteristics of very long distance tropo QSOs in a more systematical manner.

Therefore, the term *Hadley cell propagation* has been suggested in the paper's title which is actually no perfect choice but more pleasing than the term, for example, *subtropical calms propagation* or, alternatively, *horse latitude propagation*. In any case, all this dx QSOs clearly indicate special characteristics different from "ordinary" tropospheric dx QSOs in mid-latitudes which indeed motivates the introduction of a special term in the practice VHF dxing.

Understanding the big picture which correlates with the global atmospheric convection system, we however do not yet understand the details, unfortunately. Since the 1950s, where the dx QSOs between Hawaii and California have been interpreted by troposheric ducting, many (not all) radio amateurs have apparently closed the book believing this dx phenomenon is already explained in sufficient detail. From the author's perspective this is not true at all, i.e. the book needs to be reopened. Even the process of tropospheric ducting (which is not addressed in this paper) is still associated with many open questions. We do not yet understand, for example, the details of the mechanism which couples radio signals into and out of the duct and we are confronted with a bulk of open questions with respect to the sea/land interface which interrupts tropospheric ducting of radiowaves in most but not in all cases, see, e.g., the analysis in [7], the discussion in [13] and [21].

Also, the current 2-way dx record of more than 4.700 kilometers path length marks no upper limit in 144 MHz dxing, obviously, i.e. lots of dx opportunities become visible if DX-peditions and maritime mobile radio stations would move into strategic positions along the seacoasts, on the islands and even aboard of vessels travelling across the oceans.

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