European Science Foundation

25 CRAF News

The newsletter of the ESF Expert Committee on Radio Astronomy Frequencies

July 2012

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Editorial

It is true; a world radio conference (WRC) has to be experienced to be believed! The last WRC took place in Geneva and lasted for four weeks, ending on 17 February 2012. It was a huge affair with more than 3000 delegates representing 193 countries, 700 Sector Members and Associates from industry, international and regional organisations, as well as academia. Radio astronomy was of course represented by CRAF and IUCAF as sector members. Outside the weather was bitterly cold with snow and ice and gales blowing across Lake Geneva. However, inside the three main conference buildings we were kept warm by a busy schedule, trying to select and keep up with relevant events and involvement in discussions. At my last count, the conference discussed 700 documents and had 152 meeting Agendas. Considering that, and the fact that the subjects for discussion were a mixture of technical details combined with strong national or special organisational interests, then it was with an element of surprise, at least to me it was, that the conference not only managed to deal with all the documents and agree on common regulations and procedures, but also managed to set the stage for the next conference in three years time. However, the very concentrated work, the highly professional attitude of the delegates and, most importantly, the huge amount of detailed preparation undertaken during the preceding four years had made it possible to finish the tasks within the allocated time. CRAF had been involved in the preparations in national and in various ECC committees, where we provided studies and opinion, as a result of which we were able to communicate constructively and effectively with our colleagues in national administrations and with industry from CEPT countries. Being realists, we of course know that radio astronomy isn't the first worry in the minds of administrations and industry, but I can definitely say that in Geneva the support and sympathy for our views and problems was absolutely great. That alone is an encouragement for CRAF to continue being closely involved in the process and to keep our lines of communication open.

CRAF can be very satisfied with the outcome of WRC-12 on most counts, but perhaps it has been over-optimistic to expect that our efforts would be 100% successful, even with the strong and valiant support of CEPT countries and South Africa, and that we would manage to obtain a satisfactory outcome on all the open issues. The reality of life is different. As a result of intense discussions between the US, Australia and Japan on the one side and CEPT and SA on the other, there is now an allocation for airborne radar close to the passive 15.35-15.40 GHz band, with only a purely formal protection for radio astronomy from spurious emissions by any new radar systems. WRCs are known to be full of surprises and the article by our frequency manager will provide more details on what was achieved for radio astronomy.

As they say, after the WRC is before the WRC, and we have learned that we must improve our communications and vigilance within and for radio astronomy even more for the next round.

Let's get on with it!

Axel Jessner, *CRAF Chairman*

Cover
The small array of the Arcminute Microkelvin Imager (AMI) at the Mullard Radio Astronomy Observatory of the University of Cambridge, U.K. AMI is mainly used for detailed observations of the Cosmic Microwave Background, with the results from these observations being used in the study of clusters of galaxies.

Report from the 53rd CRAF meeting

The 53rd CRAF meeting was held on 22-23 September 2011 in Cambridge (UK) at the Cavendish Laboratory, with a visit to the Mullard Radio Astronomy Observatory during the afternoon of the 23rd for interested participants. 16 CRAF members attended the meeting. The following participated as observers or guests to the meeting: W. Baan (ASTRON, the Netherlands), T. Gergely (United States National Science Foundation Liaison Officer), J. McCauley (Trinity College, Ireland), J. Urban (Chalmers University of Technology, Sweden, representing the aeronomy community), Mike Willis (responsible for spectrum management for the UK Space Agency), Roger Carter (UK Meteorological Office spectrum manager), Alastair Price (UK Meteorological Office spectrum manager) and Philippe Tristant (EUMETNET, Belgium).

The following key items were discussed:

• ESF situation and statutory review.

The ESF is undergoing a transition into the new organisation "Science Europe", shedding staff and reducing its budget. In a face-to-face meeting on 27 and 28 June 2011, the CRAF Chairman had been interviewed by a Review Panel comprising Professor Emeritus Martin C.E. Huber (Chair), Professor Wolfgang Baumjohann and Professor Michael Garrett.

The conclusions of the Review Panel were:

a) Most of the recommendations resulting from the previous review have been implemented, although in some cases only partially.

b) The independent voice of CRAF was greatly respected, and its status as an ESF Expert Committee, with European and indeed global recognition, was an essential factor in realising this position. This status, which reflected very well on the ESF and was to its credit and benefit, must be maintained in the era of Science Europe.

c) The quality of CRAF publications was good. These provided not only a communication medium through the newsletters, but also important training material in the handbooks. However, circulation was moderate and coverage appeared to be patchy – a local census at one major European radio observatory showed that less than 10% of senior staff received the newsletters.

d) In general, the achievements of CRAF were not recognised by the community, in particular by scientific (astronomers) and junior staff members, although it was realised that the resources required to tackle this "outreach problem" were also scarce. CRAF's role in organising technical workshops and schools was further encouraged.

e) Communication with the ESF organisation itself (e.g. the production of informative reports and the delivery of advice) appeared to be healthy and operating in accordance with standard practice. The Review Panel would continue to support CRAF in its activities that involve forming links with other passive radio spectrum users, e.g. remote sensing services, and encouraged CRAF to consider and explore whether other passive users might be future members of the organisation.

f) CRAF should seek a closer relationship with the European Commission (EC) in order to inform it about the needs and rights of scientific users of the radio spectrum.

g) CRAF's increased involvement in providing expert advice to the global Square Kilometre Array (SKA) project was greatly welcomed. In the next decade, the SKA would become the premier radio telescope in the world and, as an international facility, European scientists would expect to have full access to it. Together with its sister organisations in North America and Asia, CRAF could play an important role on behalf of the European scientific community in ensuring that the SKA operates within a pristine radio frequency environment. CRAF's experience in dealing with satellite operators was expected to be especially relevant for this.

• Renewal of the Chairmanship.

A Finding Committee had been established during the 52nd CRAF meeting to identify new candidates for the Chairmanship (the statutory end of the current term of office was in December 2011). In the plenary session, the finding committee recommended Axel Jessner for a second term of office as Chairman, which he had indicated he would be willing to undertake. This was approved unanimously.

• RadioNet budget communications.

In the plenary session, the reduced budget, which had been allocated to CRAF within RadioNet3, and the effect of this on the activities that could be supported, were discussed. It was decided to rely more on internet style video conferencing for some future meetings and therefore make a saving on travel expenditure. It was agreed that a trial of the 'GotoMeeting' software should be undertaken. CRAF would consider having only one face-to-face CRAF meeting per year, with the other via the Internet or video conference. It could also be that travel support to attend CRAF meetings would only be covered by special request. Travel to CEPT conferences by CRAF members would continue to be supported. Despite the limited budget, attending WRC-12 would be partially covered by Radionet funds.

- **CRAF WIKI page.**

A new CRAF wiki at http://www.craf.eu/wiki/ has been set up. The WIKI page is only for 'internal' use. The CRAF (http://www.craf.eu/) website is the official site for external users.

- **EUMETNET as a new CRAF Observer.**

The Chairman proposed that Philippe Tristant (EUMETNET) be given 'observer' status within CRAF. The committee agreed unanimously and Mr Tristant indicated his acceptance.

The next meeting will be held in Cagliari (Italy) hosted by the Italian National Institute for Astrophysics' Astronomical Observatory of Cagliari, on 31 May – 1 June.

Pietro Bolli

Report on the World Radiocommunications Conference 2012

Regular readers of this newsletter may remember that in the last issue I provided an introduction to the agenda items (AIs) of interest to the radio astronomy community to be discussed at the WRC-12 shortly to take place in Geneva (23 January 2012 – 17 February 2012). This is a follow-up article to inform readers of the outcome of those discussions.

CRAF's role at the conference was to represent the perspectives of European radio astronomers and observatories of the Radio Astronomy Service (RAS). As a sector member of the ITU-R CRAF had the status of 'observer'. In the run up to the conference CRAF actively participated in the discussions on AIs of interest and contributed technical studies to draw attention to the need for effective regulation to protect RAS bands. In addition, in advance of WRC-12, CRAF published a document giving its formal position on all of the main agenda items of interest to the RAS. This was promoted widely within the CEPT-ECC regulatory community. The outcome of each of these agenda items is given in the summary tables below.

AI 1.3	*to consider spectrum requirements and possible regulatory actions, including allocations, in order to support the safe operation of unmanned aircraft systems (UAS);*
Issue	CRAF's concerns related to potential Out-of-Band (OOB) emissions falling into designated primary RAS bands from components used for the control of UAS. There were proposals for allocations in bands adjacent or near to radio astronomy allocations at both 4990 – 5000 MHz and 15.35 – 15.40 GHz. Technical studies had indicated that an allocation immediately adjacent to the 4990 – 5000 MHz RAS band would require a guard band to be implemented and another suggested the incompatibility of allocations adjacent to the RAS band at 15.35 – 15.40 GHz.
Outcome	UNSATISFACTORY. Near to 4990 – 5000 MHz, some UAS use will be allowed, but limited to internationally standardised aeronautical systems. There will be no allocations adjacent to 15.35 – 15.4 GHz.

AI 1.4	*to consider, based on the results of ITU R studies, any further regulatory measures to facilitate the introduction of new aeronautical mobile (R) service (AM(R)S) systems in the bands 112-117.975 MHz, 960-1164 MHz and 5000-5030 MHz in accordance with Resolutions 413 (Rev. WRC 07), 417 (WRC 07) and 420 (WRC 07);*
Issue	[Res 420] The 5000 - 5030 MHz band under consideration is adjacent to the RAS primary band allocation, 4990 – 5000 MHz. ITU-R studies indicated that compatibility with the RAS operating in this band would require the restriction of the AM(R)S use to only surface applications at airports with separation distances of the order of 150km from RAS observatories. Many European observatories are located nearer to airports than this and so case by case compatibility studies would be needed in many deployment situations.
Outcome	SATISFACTORY. There are to be no allocations immediately adjacent to the 5 GHz RAS band and the resolution was suppressed.

Figure 1.
The CRAF Frequency Manager in a WRC-12 session

AI 1.6	*to review No. 5.565 of the Radio Regulations (RR) in order to update the spectrum use by the passive services between 275 GHz and 3 000 GHz, in accordance with Resolution 950 (Rev. WRC 07),*

Issue

[Res 950] A flagship agenda item for the passive services and radio astronomy in particular, seeking to ensure protection for future use of this part of spectrum. There are as yet no formal allocations and updated provision for the passive services was required until such time as the Table of Frequency Allocations is extended.

Outcome

SATISFACTORY. The text of the agreed revision dealing with frequencies above 275 GHz that was supported by CRAF and having a sympathetic text for the RAS and other passive services was accepted.

AI 1.8	*to consider the progress of ITU R studies concerning the technical and regulatory issues relative to the fixed service in the bands between 71 GHz and 238 GHz, taking into account Resolutions 731 (WRC 2000) and 732 (WRC 2000);*

Issue

Technological development brings the requirement for consideration of active services use of bands above 71 GHz whilst protecting the existing passive users.

Outcome

SATISFACTORY. Recommended emission limits were adopted in line with EESS requirements for the bands under consideration. The texts of Res 731 & 732 were slightly modified and retained with some limited improvement from the RAS perspective.

AI 1.19	*to consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU- R studies, in accordance with Resolution 956 (WRC 07);*

Issue

The principle RAS concerns on AI 1.19 relate to cognitive radio systems (CRS) operating in shared bands or within a defined radio quiet zone. Protection of the RAS implies that the CRS system knows its geographical location and has some means of determining what the regulatory implications of its location are. There was, however, a suggestion that systems that do not have geo-location capabilities might be allowed; these are likely to cause problems for the RAS and contradict the suggested ITU-R definition of a CRS system published in Report ITU-R SM.2152

Outcome

SATISFACTORY. No change to RR & suppression of the resolution.

AI 1.20	*to consider the results of ITU R studies and spectrum identification for gateway links for high altitude platform stations (HAPS) in the range 5850 - 7075 MHz in order to support operations in the fixed and mobile services, in accordance with Resolution 734 (Rev. WRC 07);*

Issue

The HAPS community identified two 80 MHz wide bands for potential use that are near the 6650 – 6675.2 MHz RAS band. CRAF believes that there are clear compatibility issues with HAPS operation near a band of increasing importance to the RAS and opposed allocations.

Outcome

ACCEPTABLE. No HAPS to be deployed in most countries of the world. A country footnote that will allow the operation of HAPS in Australia and a few African countries was agreed. Specific text has been added to the associated resolution to protect the RAS.

AI 1.21	*to consider a primary allocation to the radiolocation service in the band 15.4-15.7 GHz, taking into account the results of ITU R studies, in accordance with Resolution 614 (WRC 07);*

Issue

Via this allocation powerful airborne radar units with significant OOB emissions will be operating adjacent to the RAS 'passive' band primary allocation at 15.35 – 15.4 GHz which is protected by RR footnote 5.340.

Outcome

UNSATISFACTORY. The radio astronomy band at 15.35 – 15.4 GHz is protected by RR 5.340 ('no emissions permitted'). However, unwanted emissions from the adjacent band allocated to these airborne radars may spill over into the RAS band. A footnote was added to the effect that for up to 2% of time, emissions from this radar system into the RAS band would be allowed that could exceed the appropriate pfd limit in Recommendation ITU-R RA.769. CRAF objected to the "2% of time" allowance, on the grounds of principle (no emissions in an RR 5.340 band) and that we believe that compatibility studies have shown that no such exception **is actually required** for acceptable operation of the radar system in question. CRAF's stance was backed by some national administration delegations and opposed by others, who would not agree to the deletion of the "2%" text. The opposing argument was that the "2%" clause gives a clear, explicit limitation on how much interference can be tolerated in the band and without this there would be no such indication. CRAF opposes linking an 'allowable' level of data loss to the RAS within a passive band protected by RR Footnote 5.340. Unfortunately, the eventual outcome was that the "2% of time" text was allowed to remain. The following note was agreed by all parties for inclusion in the conference record in order to close the issue at that point:

"*Some delegations argued for removing the phrase "for more than 2 per cent of the time" from footnote 5.B121. The percentage of data loss for radio astronomy is the subject of Recommendation ITU-R RA.1513, the revision of which should be undertaken during the next ITU-R study cycle. These studies should take into account that in this case the No 5.B121 refers to a band labelled with No 5.340, for which interference thresholds are given in Recommendation ITU-R RA 769'. Furthermore, it should be studied what the operational consequences for the radiolocation service are, in case the phrase: "for more than 2 % of the time" would not be included in the footnote 5.B121".*

Consequently, there will be a need for follow-up action by CRAF in future meetings on both of these points within the ITU-R.

AI 1.22	*to examine the effect of emissions from short-range devices on radio communication services, in accordance with Resolution 953 (WRC 07);*

Issue

CRAF believes that at present there is a lack of clarity in the definition of short-range devices (SRDs), in what bands they may or may not be permitted an allocation, and how global or regional harmonisation may be achieved. SRDs are to operate on a non-interference, non-protected basis and CRAF is concerned that this status may become open to revision. The European emission limits currently proposed still have the potential to generate interference to stations of the RAS in even medium density deployment situations.

Outcome

SATISFACTORY. No change to the RR and suppression of resolution 953.

AI 1.25	*to consider possible additional allocations to the mobile-satellite service, in accordance with Resolution 231 (WRC 07);*

Issue

MSS operators estimated the need for another ~300 MHz bandwidth for both uplinks and downlinks for their systems. Allocations near the 10.6 GHz and the 15.4 GHz RAS bands were being considered. Compatibility studies had shown that there would need to be exclusion zones around observatories for handset uplinks to protect the RAS using the 15.4 GHz passive band and that MSS operators would need to place additional filtering of at least 29 dB in their systems to protect the RAS in the 10.6 GHz band from satellite downlinks.

Outcome

SATISFACTORY. Allocations at all of the frequencies under consideration were rejected by the conference and the resolution was suppressed.

Conclusions and lessons for WRC-15

A review of the tables above shows that the outcomes for most AIs of concern were acceptable to CRAF with only two exceptions: AI 1.3 and AI 1.21. Agenda item 1.3 is clearly now concluded and it only remains for the RAS community to be aware of the new situation, and to monitor and report any resulting incidences of interference. For AI 1.21, the issue is more complicated and, as a result of the debate, further work items were produced upon which CRAF will need to focus future effort. It may be possible to have the disputed "2% time" text removed from the footnote and CRAF has always supported the need for a revision of Recommendation ITU-R RA.1513.

More generally, the most positive elements of the outcomes for the RAS were obtained for those AIs upon which a focussed effort had been made in the run up to the conference. The next cycle of work leading up to WRC-15 has already commenced and CRAF faces some clear challenges. Being successful at the next WRC will require CRAF and its members to undertake thorough preparation work in advance; this means not only making written technical contributions, but also having an increased attendance at the ITU-R WP meetings, and in particular, making the CRAF position clear to members of the CEPT national administrations at each opportunity.

Harry Smith

Path Profile Software

Abstract

This paper covers the recent development of freely available, high-resolution Digital Elevation Models and their use in predicting radio frequency path losses using the "Path Profile" software program.

Introduction

The "Path Profile" software was originally written to extract terrain spot height data along a great circle path. This data could then be used by radio amateurs with an interest in checking out paths for experiments using their upper UHF and microwave bands. The difficulty in making path profiles had always been in acquiring data. Initially, before home computers became commonplace, profiles had to be read off paper contour maps, with corrections for earth curvature made and drawn on graph paper; a laborious process prone to error.

Gradually, machine readable Digital Elevation Models (DEMs) became available, although these tended to be expensive, restricted to national or regional coverage, used different file formats and were based on different Geodetic models. Programs were written using these DEMs and each was customised to local data sources. For example, in the UK the Ordinance Survey of Great Britain (OSGB) released a 50m resolution DEM covering the whole of the UK. This database was extensively used in professional propagation modelling, but came with strict licensing conditions and annual usage fees, so was unaffordable to radio amateurs. In 1990, the "Globe" project formed to produce a global DEM and in 1999 released a product with four key features:

1. It was free to use
2. It was global
3. It was based on a 30 arc second grid
4. It used the WGS84 Geodetic system

The 30 arc second resolution, approximately 1km grid, was poor compared with alternative commercial datasets, but good enough for many amateur applications.

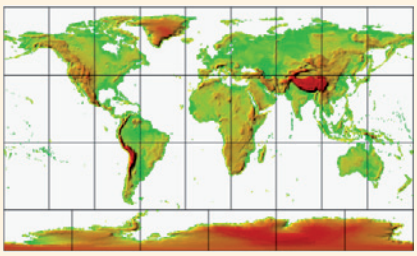

Figure 2. GTOPO30

Unfortunately, copyright issues forced a re-release of Globe, as GTOPO30 with the data degraded for several regions, including the UK. At this point, in 2003 the first version of the 'Path Profile' software was developed. At that time it only produced profiles and did no propagation modelling. Globe had started a trend and NASA soon released a DEM based on data gathered in the 2000 Shuttle Radar Tomography Mission (SRTM). Data to a resolution of 3 arc seconds (~100m) was released for anyone to download. Higher resolution data to 1 arc second (~30m) was also made available for some regions. Finally, data was available in a common format with sufficient resolution to be useful for radio planning and Path Profile was re-written to use the SRTM data and to do some basic path loss modelling based on ITU-R Recommendation P.452.

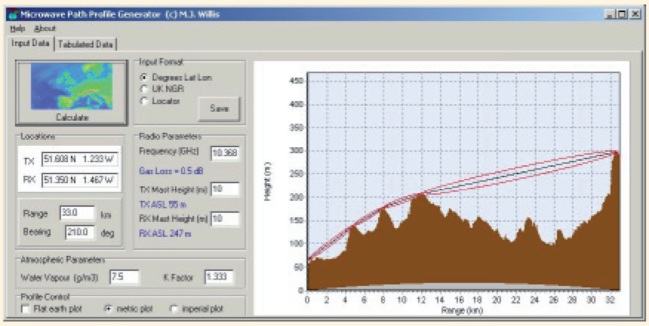

Figure 3. Path Profile V1

The SRTM DEM was not originally global because of the satellite orbit, which only covered all terrain between 56S and 60N. The data also contained many artefacts arising from the limitations of radar terrain height measurement. These included holes in mountainous areas, a lack of distinction between land and sea at the coast, hills in the sea because of waves etc. An active user community soon filled in the gaps in coverage and dealt with the artefacts and the dataset is now very good.

In June 2009, the Japanese Ministry of Economy, Trade, and Industry (METI) and NASA collaborated to release a new 1 arc second global DEM based on stereo radiometry from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on the terra satellite. ASTER data is freely downloadable with favourable licence conditions. Path Profile was updated to use either SRTM or ASTER data. There are good reasons for using both DEMs, not the least of which are the sizes of the data files, which increase with resolution. ASTER data is nine times the size of SRTM and, with a current size of ~550Gbytes, it is impractical to download it all without a very fast internet connection. The data is regularly refined, most recently in 2011 to Version 2.0.

The problem addressed

In spectrum management, we are concerned with estimating the interference between an interference generator, usually a transmitter, and a victim receiver, for example at a radio astronomy telescope site.

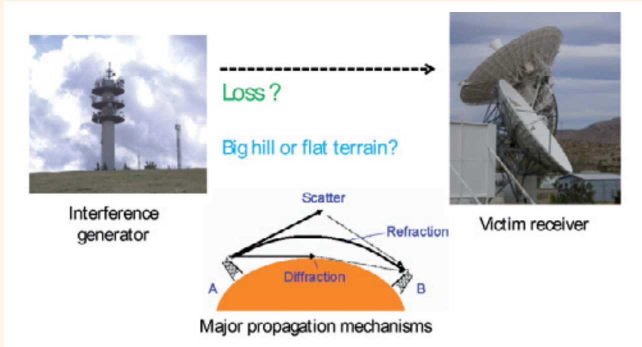

Figure 4. The interference question

Even when bands are exclusively passive there will always be unwanted emissions and adjacent band compatibility issues. Consequently we often want to work out the mitigation we gain resulting from the signal loss along a propagation path. This loss can vary over many orders of magnitude depending on the intervening terrain. Path Profile estimates this loss.

The software

The most recent version of path profile is available from www.mike-willis.com and uses an underlying propagation prediction method based on ITU-R recommendation P.1812-1 with a few enhancements.

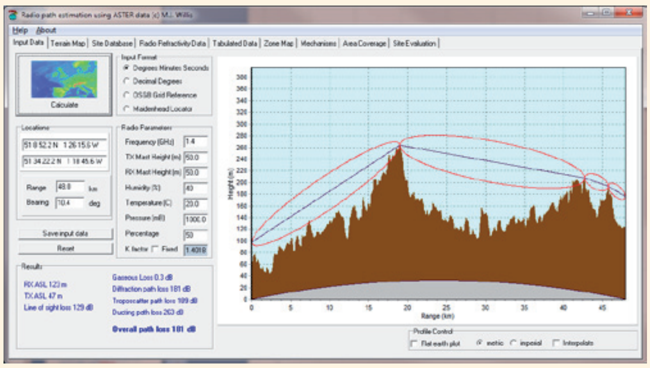

Figure 5. The latest version of Path Profile

Recommendation P.1812 officially covers only the frequency range 30MHz to 3GHz because it ignores gas losses and rain attenuation. Amateurs are generally concerned about enhanced, rather than fading conditions.

However, for higher bands, especially the 24 GHz and 47 GHz bands near the water and Oxygen resonances respectively, gaseous attenuation is important. The full Liebe line-by-line model from ITU-R P.676 has been implemented although it is up to the user to enter a realistic humidity level. Extending the model in this way carries no guarantee but is valid as the underlying models in P.1812 are based on P.452 which works to well above 3GHz. By neglecting rain and atmospheric multipath losses, this becomes a "median to enhanced conditions only" model, which is fine for amateur radio planning. It should also be suitable for evaluating interference to radio astronomy sites from other services.

There are some confusing features based on the UK amateur radio heritage. Location data can be added in various ways, the default being the Maidenhead Locator format, which is used extensively by amateurs, but nobody else. Location can also be input in the more traditional latitude and longitude formats and as an OSGB locator. If the OSGB locator is used, the program translates from the Airy Geoid to WGS84 as this makes quite a difference. Locations can be entered as either two fixed points "Transmitter" and "Receiver" or one fixed "Transmit" location and a distance and bearing. The terms "Transmitter" and "Receiver" are purely conventions as the method is reciprocal.

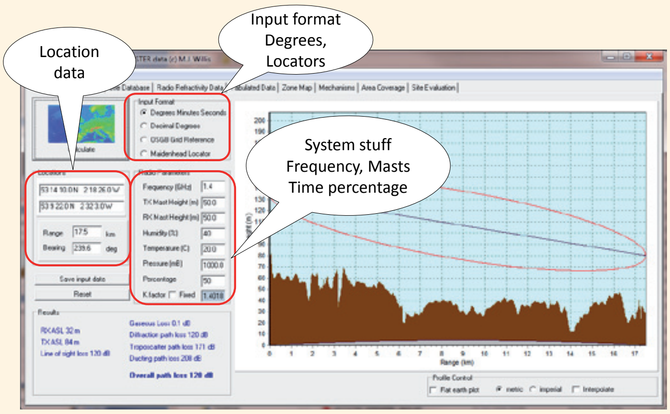

Figure 6

To make a prediction, data relating to the frequency, the mast heights and, if required, the climate should also be entered before clicking on the "Calculate" button.

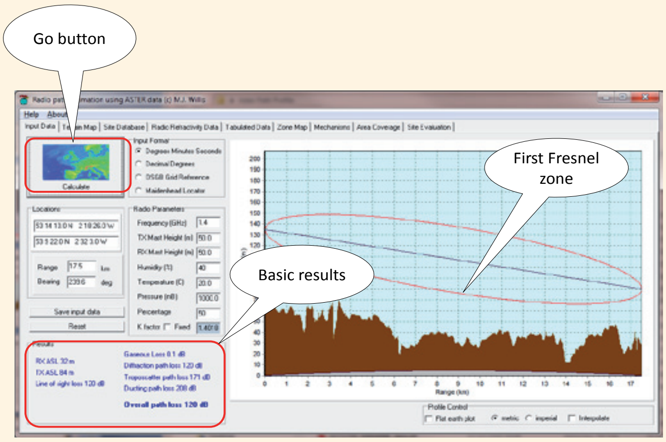

Figure 7

The screen then shows a representation of the terrain, the first Fresnel zone and some basic path loss predictions. Generally, that is all that is needed. There are several other tabs giving information of further tools. The terrain tab shows maps of the terrain local to the transmitter and receiver and also the line of the path.

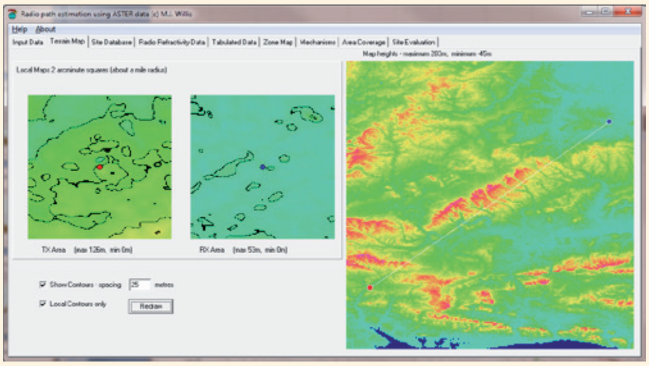

Figure 8. Terrain tab

The site assessment tab uses parameters from the input tab and calculates field strength along a radial. This is useful in evaluating coverage. In the example below, the interference for 1% time along the path from the Winter Hill TV transmitter in the direction of Lords Bridge Observatory is shown.

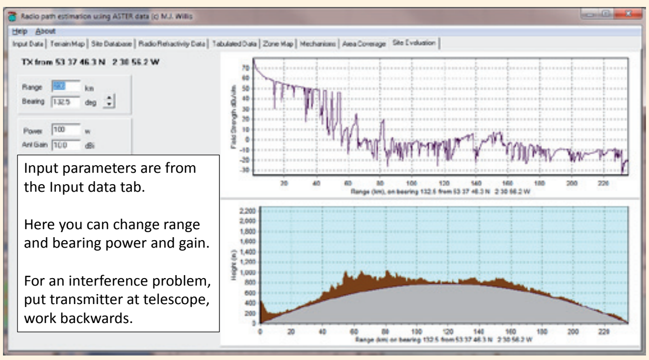

Figure 9. Site assessment tab

The site assessment can be used for estimating co-ordination distances by putting the observatory at the "Transmitter" point. Another method is to use the area coverage tab, but as the program has to extract the terrain profile and then calculate the path loss to every point in the coverage area this can take a long time. Signal strength, the inverse of path loss, can be represented by brightness over terrain coloured by height. An example is shown below for an imaginary 50m high omni-directional transmitter located at Jodrell Bank observatory.

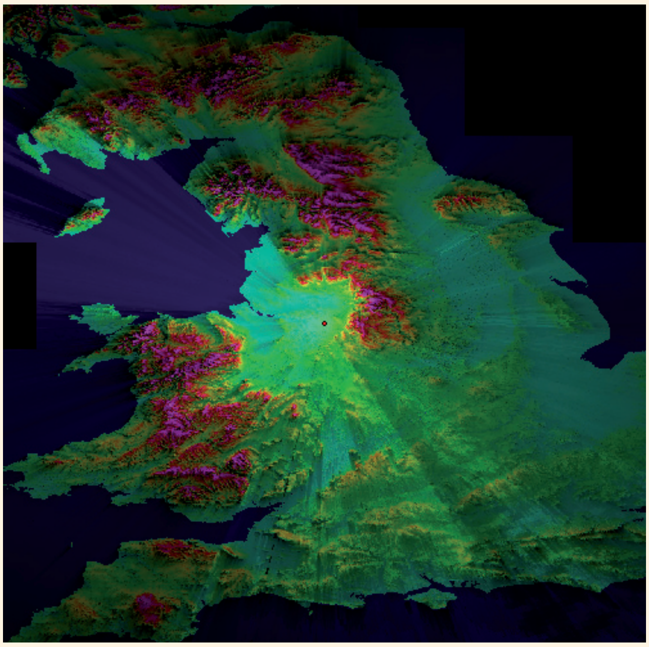

Figure 10. Coverage, Jodrell, 400MHz 1%

This method of visualisation makes for pretty pictures but is of little practical use so the path loss can also be represented as a colormap or a grey scale. This can then be exported as a KML file for more sophisticated visualisation in Google Earth.

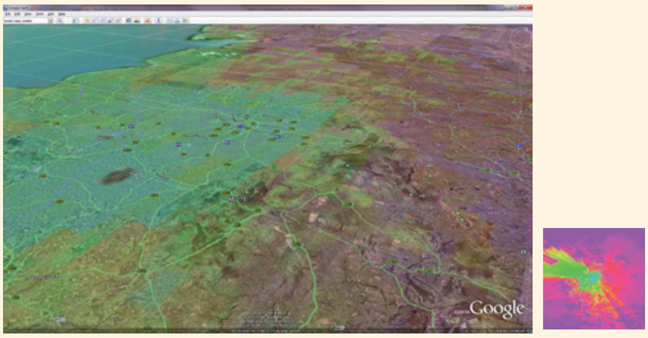

Figure 11. Export to Google Earth (© Google)

Other tabs provide access to a database of sites, so one does not have to keep entering them manually and providing information on the finer points of the propagation modelling; for example, showing the relative strength of each propagation mechanism represented in the model.

Conclusion

In the last 10 years freely available DEMs have improved in resolution from 1km to 30m and are now more than adequate for studying radio paths, for example to see and assess coverage and to evaluate propagation losses for spectrum sharing studies.

The path profile software makes use of the ASTER and SRTM DEMs to model propagation. It was originally designed for amateur radio use but now has a wider applicability. It has gone through several refinements since it was first released in 2003. There is no claim made that the propagation model is more accurate or more useful than any other, but it is free and relatively easy to use.

Mike Willis

Notable retirement

WRC-12 was to be the last in a professional capacity for Chris van Diepenbeek, head of delegation for the national radio administration of The Netherlands. Chris planned to retire soon after the conference, and to mark the occasion the Dutch delegation organised an impressive retirement party during the conference to which representatives from all around the world were invited. The CRAF delegates attending had a very pleasant evening celebrating Chris's achievements and presented him with a small token of our esteem – Swiss chocolates! Chris has supported the protection of the RAS for many years; CRAF would like to thank him and record our best wishes for a long and happy retirement.

Harry Smith

Figure 12.
A happy retirement! From left to right: Anke van Diepenbeek, Mrs van Diepenbeek, Chris van Diepenbeek, Axel Jessner (CRAF Chairman), Harry Smith (CRAF Frequency Manager) & Hans van der Marel (CRAF/ASTRON)

Committee on Radio Astronomy Frequencies (CRAF)

CRAF is an Expert Committee of the European Science Foundation. Established in 1988, it represents all the major radio astronomical observatories in Europe. Its mission is to coordinate activities to keep the frequency bands used by radio astronomers in Europe free from interference.

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