3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

From Aberystwyth to Hunga Tonga – lessons in ionospheric imaging

Cathryn N. Mitchell
University of Bath, Claverton Down, Bath, BA2 7AY, UK, e-mail: C.N.Mitchell@bath.ac.uk

If science proceeds by *strides* and *shuffles*, then I can honestly point to three major strides that I have been part of in my career. The first was made by a remarkable scientist, K C Yeh. The second came from the Sun, and the third from the Earth.

In 1986 K C Yeh proposed the application of tomography (CAT scans) to navigation signals to produce a spatial representation of electron density on the ionosphere. K C had started the era of ionospheric tomography and data assimilation. The roll out of personal computers for everyone, internet access to data and the publication of Numerical Recipes in Fortran meant that all of the 'stars' aligned to start a production line of '*data into images*'- the ionosphere could be pictured from anywhere you were willing to put out a chain of VHF/UHF receivers to collect Cicada or Transit satellite data.

I chose my PhD at the start of this exciting new topic in 1993. K C Yeh had made the stride and I would be the shuffler! But there were advantages for me to be learning at the coal face – in the summer before my PhD began I was employed to edit/mend TEC phase curves and that allowed be to be the first person to spot waves in the curves. Hence in the first few weeks of my PhD I made the first tomographic images of travelling ionospheric disturbances (back to those at the end of the talk!). Then Aberystwyth (Pryse and Kersley) ran the EISCAT radar/tomography campaign and that allowed me to produce the most celebrated tomography result in the field - the 15 October 1993 at 21:36 UT image of the ionosphere over Scandinavia. It was presented in conference after conference – in fact I saw it presented by other groups in six different international presentations over the subsequent three years as 'the gold standard example.' I will mention a funny story about my experience of first presenting it in 1994 at the International Beacon Satellite Symposium.

The next major stride started from the seemingly mundane decision to record geodetic GPS data in RINEX format and to share it. The proliferation of GPS receivers globally offered up a new opportunity to image the ionosphere in 3D anywhere the receivers were deployed. This meant that the costly VHF/UHF field campaigns were no longer needed – you could simply ftp the data from the comfort of your office. But this also brought challenges and three groups – Bath, ARL:UT and Barcelona had all independently developed ionospheric imaging algorithms for GPS by the year 2000. There was much excitement at this time with the rapid advancement of the WAAS system in the USA and the feeling the 'we had finally got this pesky ionosphere under control' – we could image it in real time and we could correct our systems or at least bound the navigation errors. Then the 14/15 July 2000 Bastille Day / St Swithen's Day solar storms hit and we started to question our understanding of the bounds on just how big TEC enhancements would get. The Halloween storms of 2003 confirmed that we really were in trouble – the 30 October 2003 events were so dramatic over the USA ionosphere that the community argued about the physics for several years, until agreement was largely reached in 2007 at the Chapman Conference in Yosemite.

Then, just as the topic of lower atmosphere/ionosphere coupling is getting really interesting and advanced with fully coupled and assimilative models, nature throws up Hunga Tonga–Hunga Ha'apai on 15 January 2022 - *the Halloween storm of the modern era*. By that I mean that this event is so significant in its global impact on our atmosphere that this could change our understanding of atmosphere/ionosphere coupling in the way that the Halloween storm changed our perspective on the ionosphere and system impacts. We are right in the middle of the third major stride I have seen in this field.

As my focus turns to TIDs again and back into the physics I return to the work of K C Yeh. The breadth and depth of his work and that of other scientists of his generation leaves me humbled. Yet we are still learning new things about the ionosphere and it is a very exciting time to be in this field of research.

I will conclude my talk with a few lessons learned and with a look ahead to a bright future.