# IONOSONDE NETWORK ADVISORY GROUP (INAG)*

## Ionospheric Station Information

## Bulletin No. 61**

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*Under the auspices of Commission G, Working Group G 1 of the International Union of Radio Science (URSI)

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People wishing to be placed on a mailing list to receive this Bulletin should notify the INAG Chair, Phil Wilkinson,

or the INAG Secretary, Ray Conkright, WDC-A for STP, NOAA, Boulder, Colorado 80303, USA.

# 1. A REMEMBRANCE OF ADOLF PAUL, 12 SEPTEMBER 1995

by Bill Wright

It is a sad task to review my memories of Adolf on this occasion, but those memories are nevertheless a great pleasure in my life, and irreplaceable.

It was at a meeting in Nice (December, 1960), when Alan Shapley told me that Karl Rawer had spoken highly of new ideas about ionogram inversion that had been developed by one of the younger people of his institute at Breisach; I went directly there. My limited German of the time just about equaled, word for word, Adolf's limited English; but I got the basic ideas well enough from him to realize that he had made a major advance over Budden's formulation, which had already led to a sort of cottage industry for ionogram inversion in the USA and UK ... perhaps also in the USSR. Clearly, Adolf knew his worth. He said then, and a few times later, that the best things he had done at Breisach were precisely those that Rawer had told him not to do. Of course we know that Rawer knew better than that, but it was fortunate for us that Adolf was ready and eager to see his ideas implemented.

He came to Boulder by contracts during several successive summers, to work with my fledgling group. I resolved a scheduling conflict in 1962 by asking Adolf to accompany me to Florida to help prepare for a series of chemical- release rocket experiments. We went by train, a gesture, I thought, at letting him see part of the USA in relaxation. Late at night in the train's 'Vista Dome', and with rapidly improving English, Adolf told me of his first long train journey in 1945 as a war-captive slave laborer, into the coal mines of the USSR. He spoke of fashioning chess sets which won the interest of (and slight kindnesses from) the Russian barracks guards. He described improvising resistive heaters from bedsprings to supplement a meager ration of heating coal. In that last year of the war, he had been drafted, hurriedly taught to drive a tank, and promptly (perhaps mercifully) captured; he spent the better part of the next three years underground.

In his scientific work, Adolf had a special ability to see simplifications of complicated problems which he could then put into rigorous form. His profile inversion work included implicit invention, before its time, of the cubic spline. To our surprise, he showed how we could get profile information "top down", starting from the F-peak. He contributed original insights (collaborating with Kurt Suchy) to the theory of radio ray tracing. His method of "Anharmonic Frequency Analysis" does correctly for actual data, what the discrete Fourier transform is too often mis-used to do. He saw the "Gibbs phenomenon" unnecessarily cluttering Rydbeck's (and Budden's) computation of pulse dispersion in the ionosphere; Adolf's formulation avoids the Gibbs effect, and allows us to see the dispersion. We now understand radio phase and group paths much more clearly from his arrangement of their relationships, than yet appears in any textbook. He discovered the stimulation of 'Spread F' by radiowave heating of the ionosphere. His dependable judgment was central to our long and successful development of research digital ionosondes, experience which he carried into U.S. Navy employment after 1982.

Adolf Karl Paul was born 6 March 1926 in the Bavarian village of Engen, not far from the Lake of Konstanz. He was a student at the Gymnasium in Konstanz. After capture and coal mining, he was returned by the USSR to Germany in 1948. By 1954 he had completed his Diplom in mathematics and physics at the Albert Ludwig University, Freiburg, whereupon he joined the Ionosphere Institute at Breisach. He married about that same time, and leaves us with four fine, mature citizens, Regina, Gabriele, Winfried and Wolfgang.

Adolf was enticed to emigrate about 1963 and he joined our diverse group. During a long period, it included all sides, all fortunes and misfortunes of the 1939 - 1945 conflicts, with, so far as I could perceive then or since, no lingering disharmonies: Adolf, Sadami Matsushita, Tatsuo Shimazaki, Walt Plywaski, often Mike Pitteway, and "us Americans" with perceptible roots ... Tom Van Zandt, Leonard Fedor, Ed Violette, Dean McKinnis, Herbert Howe, Rachel Laird, Georgellen Smith, Lois Wescott, Huntley Ingalls, Miriam Clore and myself. To an extent far greater by his generous personality than the rest of us would manage to do, Adolf kept us all his personal and permanent friends.

## A personal thought from Tamara Gulyeava

I am deeply upset by the news of Adolf Paul's death. I cooperated with him since 1972 under McCue-Leo McNamara URSI N(h) W.G., and were co-authors of 4 IPS Reports on the N(h)-profiles inversion. When

Leo visited me in 1978, before the URSI meeting, Adolf sent me with him a present - records of the opera 'Jesus Christ - Superstar' which I have shared with many neighbours and friends since. In the Russian tradition the value of a man's life is appreciated by 3 criteria: he should beget a child, build a house, and grow a tree. Adolf completed all these criteria, and much more. He had 4 children, built a house in Boulder of 12 rooms, and grew a garden of 12 acres. He promised to show me all these when I had a chance to visit him in Boulder. I missed this chance forever. I first met him at the Helsinki URSI meeting when he was divorced and where he was with his fiancee. Afterwards we met at Budapest COSPAR meeting, he was alone and he invited me for a dinner. Since then he took a picture at all our following meetings, and sent me photographs afterwards. When I asked him to give me a letter of Reference for my Application for grant to MacArthur Foundation, in 1993, re responded at once and gave me a favourable letter. He was a real gentlemen.

# 2. COMMENTS FROM THE CHAIR

Adolf's sudden death, just after many of us saw him in Boulder, during the IUGG Assembly, came as a great shock. I am sure anybody who had met Adolf will remember him and readily identify with the thoughts expressed about him in this Bulletin.

## 2.1 General

This Bulletin is well overdue and I appologise for the time it has taken me to produce it. Dr Piggott will be almost 82 before he reads about his 80th birthday. My thanks to contributors, especially those who have waited a long time to see their contributions in print.

I experienced a good amount of trouble reproducing some photographs in this issue and finally added them by hand. Regardless of the problems, I welcome further photographs for possible publication. With practice, I will get better.

There are several issues I would like to draw your attention to: this Bulletin contains a questionnaire on the parameters we scale from ionograms. Please give it careful thought and be sure somebody from your organisation, preferably you, answers it. Second, I have some thoughts about the future of INAG in the electronic world and will be interested in your ideas on this.

Finally, please fill in and return the

**1996 INAG Membership Form**

as soon as possible. It is at the back of the Bulletin. If more than one person at your organisation wishes to fill this out, please photocopy the page. If you prefer to send the information to me by email - which I would certainly prefer - please send your information to phil@ips.gov.au.

## 2.2 Scaling Parameters

Who is responsible for maintaining a list of ionospheric parameters that are in common use? INAG gained this role in its inception and the various definitions appear in UAG-23 and UAG-23A. Since the publication of these reports there have been many discussions on parameters and scaling in INAG but over the last few years, little mention has been made of the parameters scaled and archived. At the Boulder IUGG meeting those present indicated they felt INAG had a responsibility in this area that was probably not being met adequately.

The most pressing problem is the number of available code numbers for archiving scaled data from ionograms. To start dealing with this problem, a questionnaire is included with the Bulletin seeking your opinions on all the parameters that can currently be archived.

There is another issue here. Presumably the people, or groups, that generate new parameters should not have the added right to confirm their validity internationally. There will inevitably be a conflict of interest. On the other hand, people will be seeking quick decisions so they can progress to their next goal. This needs to be addressed. One possibility is to set aside a block of codes that can be used freely by anybody, but which have no lasting status for archiving.

## 2.3 Session G5 at URSI General Assembly

I will be producing a proceedings after this meeting, in September, so if you are unable to be in Lille, but wish to put a paper into this Proceedings, please let me know. See comments later in Bulletin.

## 2.4 Home page, Mailing List

I had hoped to set up an INAG Home page on the World Wide Web (WWW) before producing this Bulletin. However, I did not have the time to do it. One problem with WWW is that not everybody has easy access to the INTERNET. However, there is some information that is better displayed on the Web than in print. It is also possible to reach a wider, and different, audience, which is part of the intent of the Bulletin. I expect the INAG Home page will be completed before the forthcoming General Assembly. I also intended to set up a Mail List which would supplement the Web site. The idea of mailing lists is that it gives people an electronic forum to call for help, try ideas, ask questions and generally participate, either actively or passively, in electronic conversations. The first step in creating the mailing list was, I felt, to obtain a good first cut electronic mailing list. I have produced this and you will find it in this Bulletin. As you will see, some of the email addresses do not work for me. If you can offer corrections, it will be most helpful.

Not everyone has access to electronic mail and WWW. I intended to continue publishing the Bulletin where, in addition to the usual articles, I would publish selected contributions from the Mail List and WWW. When this starts it will be experimental. However, in the longer term, I expect that we will migrate more towards electronic outlets. Aside from being cheaper, once you are connected, it is also likely to be more timely.

Please let me hear what you think of these ideas.

My thanks to all the contributors to this Bulletin. If you have anything you would like to have appear in an INAG Bulletin, please send it to:

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# 3. INAG MEETING: BOULDER, COLORADO 10 JULY 1995

The INAG (Ionosonde Network Advisory Group) meeting was held on July 10 and ran from 7:30 PM until around 10:45 PM. It was a very successful meeting attended by 17 people all of whom had some interest in ionosonde data.

## 3.1 Attendees

Terence Bullett,
Phillips Lab, Geophysics, 29 Randolph Road, Hanscom AFB, MA 01731, USA; bullett@plh.af.mil; Interest: Phillips Lab ionosondes

Ray Conkright,
NGDC, 325 Broadway, E/GC2, Boulder, CO 8303, USA; rconkright@ngdc.noaa.gov; interest: NGDC, ionograms and ionosondes

Ivan Galkin,
UMLCAR, 450 Aiken Street, Lowell, MA 01854, USA; reinisch@caedc.uml.edu; interest : Digisondes

Per Hoeg,
Solar Terrestrial Physics Division, Danish Meteorological Institute, Lyngbgvej 100, DK-2100 Copenhagen, DENMARK; hoeg@dmi.min.dk; Interest: Global circulation patterns, Greenland

Vinita Ruth Hobson,
NGDC, 325 Broadway, E/GC2, Boulder, CO 8303, USA; rhobson@ngdc.noaa.gov; Interest: NGDC

Kiyoshi Igarashi,
Communications Research Laboratory, 4-2-1 Nukui-kita, Koganei-shi, Tokyo 184, JAPAN; igararshi@crl.go.jp; Interest: 1 Terabyte Japanese data, Japanese ionosondes

Karen Fay O'Loughlin,
NGDC, 325 Broadway, E/GC2, Boulder, CO 8303, USA; kfo@ngdc.noaa.gov; NGDC, Boulder Ionosonde

Murray L. Parkinson,
School of Physics, La Trobe University, Bundoora, Victoria 3083, AUSTRALIA; tspmlp@lure.latrobe.edu.au; Interest: Beveridge Digisonde 256, Casey DPS

Adolf K. Paul,
7455 Brockway. Boulder, CO 80303, USA; akp@ngdc.noaa.gov; Interest: San Diego Ionosonde

Gerd W. Prolss,
Institut fur Astrophysik, Univ Bonn, Auf dem Hugel 71, 53121 Bonn, GERMANY; Interest: research

Edward Shiffmacher,
NOAA/NGDC (retired), 2155 Emerald Rd, Boulder, CO 80304, USA; Interest:. Ionosonde net

George Talarski,
NGDC, 325 Broadway, E/GC2, Boulder, CO 8303, USA; gtalarski@ngdc.noaa.gov; Interest: NGDC, Processing and quality control

Lucia Villanueva

Phil Williams,
Physics Department, University of Wales, Aberystwyth, WALES; pjw@aber.ac.uk; Interest: Swedish Network

Phil Wilkinson (Chair),
IPS Radio and Space Services, Ionosonde network, (Paul Alekna, coordinator)

Bill Wright,
Svavelgatan 6, S-59338 Vastervik, SWEDEN; wright@plasma.kth.se; Interest: Dynasonde

Dr. Alexander Zaitzev,
IZMIRAN, Troitsk, Moscow Region, 142 092 RUSSIA; zaitzev@charley.izmiran.rssi.ru; Interest: IZMIRAN ground-based geomagnetometers

## 3.2 Ionosonde Networks

### 3.2.1 Status of the US Air Force DISS network:

All DISS (Digital Ionospheric Sounding System) are undergoing a process called baselineing, in order to obtain a common hardware and software platform (Replacing 9 track tape drives with QICs and using uniform software). Changes to the DISS include a re-worked Final Power Amplifier, a more reliable and higher capacity UPS, and a new computer for the ARTIST, which also includes a 150 MB QIC tape cartridge to replace the expensive and unreliable 9-track tape drive. One downside to the new tape drive is that fewer people can handle the new media, but the advantages were sufficiently great that this still seems like a good idea. The status of the sounders in the DISS net are as follows:

**Baselined and Operational:**
Vandenburg Air Force Base (AFB), California, USA
Dyess AFB, Texas, USA
College, Alaska, USA
Wallops Island, Virginia, USA
Eglin AFB, Florida, USA
Ramey, PR
Bermuda
Goose Bay, Newfoundland, Canada
Learmonth, Australia

**Baselined and non-operational:**
San Vito, Italy
Argentia, Newfoundland
King Salmon; Alaska, USA (awaiting operator)

**Non-baselined and operational:**
Qaanaaq, Greenland
Sondrestrom, Greenland
Narsarsuaq, Greenland

**Awaiting Installation:**
Fairford, UK
Osan, Korea
Hawaii
South Pacific (possibly Wake Island)

### 3.2.2 Russian Network

IZMIRAN currently operates 15 Topside sounders and a network of vertical sounders including two at Salekhard, vintage 1957 and 1963.

### 3.2.3 EISCAT Ionosonde Network

Phil Williams supplied a list of the proposed north/south chain of digital ionosondes in association with EISCAT and EISCAT Svalbard Radar.

| | | |
|---|---|---|
| Ny | Digisonde | Exists at present (long term uncertain) |
| Longyear-byen | Dynasonde | Under active discussion |
| Bjomoya | Dynasonde (or Digisonde) | Under preliminary discussion |
| Tromso | Dynasonde and Digisonde | Exist |
| Kiruna | Swedish Digital Ionosonde | Exists |
| Lycksele | Swedish Digital Ionosonde | Exists |
| Uppsala | Swedish Digital Ionosonde | Exists |

### 3.2.4 Faraday Station now Vernadsky Station

John Dudeney updated the present status of Faraday Station (65°S 64°W), in the Argentine Islands. The station was formally transferred from Great Britain to the Republic of the Ukraine in February 1996, together with all the scientific equipment. Under a Memorandum of Understanding, the routine geophysical monitoring program will continue. Data will be available both from the Ukraine and the World Data Centres. The observatory has been renamed Vernadsky Station.

### 3.2.5 Australian Network

The IPS Network is running a continuous five minute sounding program where possible. At some sites, such as Norfolk Island, the RFI from by the 4B ionosonde may possibly cause inconvenience to local people, so a 15 minute sounding program is used. Port Moresby was reopened in Nov 1994. All ionosondes in the Australian network now collect digital ionograms. These are scaled using UNIX based software developed at IPS. However, for ionogram exchange purposes, ionograms can be supplied in a format that is compatible with Titheridge's DIGION program. This ionogram viewer with built in scaling tools, and movie viewer for well sampled sequences, is most convenient for this purpose. The Australian ionosonde network will be significantly increased in size when several ionosondes commence regular operation in Northern Australia in support of the Australian Defence over-the-horizon radar.

New Zealand - Scott Base is now fully operational again with a digion and computers partly funded by the US Navy and IPS. Christchurch is currently installing a radio link so near real time data will be retrieved at least every six hours. All data from both Australia and New Zealand are manually scaled, automatic scaling not being considered trustworthy enough for archive purposes. Data are scaled automatically for real time purposes.

## 3.3 Meetings of Interest

URSI General Assembly meeting in Lille, France. Papers have been requested concerning computer scaling of digital ionograms and Quality control. *(See later note on this).* If possible, a UAG report containing the papers from meeting will be published.

**Note:** copies are still available of UAG-104, Ionosonde Networks and Stations. If you don't have a copy contact either myself (Phil Wilkinson) or Ray Conkright (NGDC, WDC-A for STP, 325 Broadway, Boulder, Co 80303, USA. Some copies are still available.

## 3.4 Codes for Ionospheric Data:

All present agreed that there is a need for new codes and that probably some of the old codes are not useful.

### 3.4.1 Some new codes that have been introduced

IPS added some local codes about 25 years ago for scaling spread F, although then, as now, there was no serious intent to distribute these data widely. These are: Frequency Spread (code = 55), and Range Spread (56). The code numbers were chosen according to the URSI convention.

The URSI IIWG (Ionospheric Informatics Working Group), has been introducing new parameters into the computer codes. INAG has been advised of some of these, but until recently was unaware of all of them. None have been recognised as official URSI codes . *It is expected this will be discussed at the URSI INAG Meeting at Lille, 1997. A list of IIWG and ARTIST parameters with exchange codes is given later in this Bulletin.*

### 3.4.2 Revising the current codes.

The possibility of deleting old codes for use with new parameters was discussed. Do we want to make room in the 10x10 matrix of scaled ionospheric parameters for new parameters or old parameters derived by new or different techniques? There may be further problems if the new derived parameter invalidates the original parameter.

There was much discussion on the issue of hmF2, it's storage and the method by which it was obtained. Terry Bullett offered some good comments on this.

"First, I believe that hmF2 should be a part of the distributed parameters. Our internal disputes as to the accuracy of one hmF2 method versus another, while valid, are secondary in importance to the issue of the use of these data by the scientific community. In the absence of ionosonde-derived hmF2 values, many scientists will use a model, and the differences between model and 'actual' hmF2 are typically several times larger than the uncertainty in the data. Also, being able to provide hmF2 will increase the overall value of ionosonde data, and we will all benefit from this.

Second, relating to our disagreements as to one hmF2 method or another, it may be possible to have an additional parameter which 'qualifies' or indicates the methodology used to determine hmF2. This parameter could also allow for 'version numbers' of methods, such as ARTIST, which change with time.

Third, to maintain scientific integrity, I believe we should make an attempt at putting 'error bars' on our hmF2 data due to the variety of methods used. Now I am personally biased in this realm because I work with the ARTIST method and have seen several comparisons with incoherent scatter radar. Anyway, if we were to make a list of the hmF2 methods in use, and use each on an identical set of data (not too large or small) we could use the variability in the results to get some idea of the uncertainty due to the different methods."

This is probably a typical example of some of the problems likely to be encountered changing the present codes. If hmF2 has been obtained by non-standard methods, should a new, more accurate method get its own code? Is part of this issue caused by INAG opinions and should INAG's internal disputes, such as to the accuracy of one hmF2 method versus another, be more important than providing fairly accurate measurements to model users? To some extent, this is an issue of standards versus opinion and is one of the reasons why changes are not made quickly. There should be plenty of time for others to participate in the debate.

While it will be possible to remove some parameters it may be hard to re-use them in the near future. *Current usage of parameters based on the NGDC CD-ROM data may give some feel for the past use of parameters and has been used as an indicator in the article later in this Bulletin.*

Another suggestion floated at the meeting was to create a pool of codes that could be used freely for experimental purposes. This would allow people to use codes locally, demonstrate both their validity and utility, before proposing a specific code be set aside by URSI for the parameter under consideration.

There is a problem obtaining programs for putting data into exchange formats. The IIWG data format, while compact, is difficult to program. A well documented version should be made available through NGDC.

After the meeting I spoke with Dave Anderson, Chair of IIWG, about the decisions on data formats. Informally, he is happy for INAG to take over responsibility for this work. It is an issue that will be resolved at the Lille General Assembly.

### 3.5 Ionogram Data Formats

The meeting felt that ionogram formats are not freely distributed, and are often considered proprietary information by their creators, for commercial reasons. Why can't we make formats public domain? Is it really the format that is proprietary, or is it the source code that would read this format?

Phil Wilkinson pointed out that while IPS has access to the format of many of the digital ionograms available, IPS has obtained the formats in commercial-in-confidence circumstances. IPS feels that ionogram formats should be freely available and where the format is not freely available, the community should be aware of it. However, in some circumstances, the format may be difficult to release. The IPS raw ionogram format for series 5 ionograms is relatively easy to supply while the cleaned format is not.

Ionograms come in many formats and some data users cannot read some formats. Discussion was held on what an appropriate data exchange format would be. Ideally the rawest form should be available. Formats should be universally available. With this goal in mind, the INAG Home Page (see later) will contain descriptions of formats, programs to read different formats, and the source code when available. Spaces will be left for formats that do not have descriptions or read programs. Where possible, the programmer's name will be attached when available and consent given.

Terry Bullett made several good points on this. He felt there were several difficulties with the ideas, particularly when it comes to source code.

Multiple versions, user support, negative criticism, unlimited distribution are all valid issues. It is also not trivial to create a subroutine to read ionogram data that is generally useful to a scientific user. Even the routines he has, which he feels are very good, well written and fairly general, would require some work to make distributable.

He thought the key to getting this kind of capability is to attempt to address the concerns of the people who are concerned with the distribution of data formats. We should have some 'rules of the road' for the use of these programs, data and formats. Maybe a copyright that would allow reading of data in a given format but not the writing of or conversion to that format without permission of the copyright owner? Is there an unethical use for someone else's data format? What are the concerns of the major players and who are they?

After discussion, all agreed there is a definite need for this information to be more easily obtained and there needs to be much more discussion on the topic. Meanwhile, formats for all the various ionosondes will be sought by those present at the meeting.

### 3.6 INAG Home Page

IPS will set up an INAG Home Page.

The INAG Home Page will contain the following: description of INAG affairs, links to other locations of interest, ionogram format descriptions, and programs for reading ionograms.

### 3.7 Data Availability

"With all these new digital sounders around the world, why can't I get any data from when and where I want it?" - the cry of the modern-day ionospheric scientist.

It is difficult to obtain real-time ionospheric data. Currently, worldwide, 80 stations report data of which 40 are real-time. It was agreed that if a screening program is used, incoming computer-scaled data can be filtered to obtain reliable estimates of ionospheric conditions.

The digital ionosonde has held great promise for promoting ionospheric science, but much of this promise has been unfulfilled, due to lack of data or poor data quality. Terry pointed out that these may be the side effects of a paradigm shift in the world of ionosondes from the manual, film based world to the automatic, digital world. One can lament the fact that few people look at ionograms anymore, but we cannot deny that things have changed. We cannot, for budget reasons and others as well, go back to the days of large numbers of accurately hand-scaled ionograms.

In addition, the issues of data formats, the sheer volume of digital data, the fact that it is generally unwieldy, and the frighteningly short technology cycle between birth and death of a recording medium has truly fragmented our ionosonde database. To attempt to recover from this, Terry is trying to get all the Digisonde data on CD-ROM, but this is far from a complete solution. Baselineing the DISS with a new computer and tape drive is another piece to this puzzle. There are still many issues here, and many must be dealt with to meet the realities of this new world of ionosondes in a new way.

Ray Conkright spoke about attempting to bridge the gap between real-time and archive data with near real-time data being supplied as provisional data.

### 3.8 Miscellaneous

Ray asked for ideas on how to display parameters beyond the usual stack and overlay plots. IDL programs will be used in future on-line NGDC Ionosphere data displays. The code for generating these plots will be shared. The present CD will be on-line soon.

So far, 65 CD-ROMs of ionospheric data have been distributed. During the IUGG and CEDAR meetings, in excess of 20 papers using ionosonde data were presented compared with none at the Vancouver IUGG, eight years ago.

Ray brought up the possibility of using Artificial Intelligence (AI) to improve automatic scaling statistics. Bill Wright suggested an auto-scaling program fed automatically into POLAN may be worthwhile, the autoscale program providing continuity. Ivan Galkin said that second generation ARTIST is already using AI.

Ruth pointed out that NGDC has changed station codes containing an explanation mark ( ! ) to an underscore ( _ ). Both are ASCII, but the ! is reserved as a special operator in some programming languages.

*This was a particularly good Meeting thanks to the open and frank opinions expressed by all present. My special thanks to Ruth, Karen and Terry who jointly produced all the correct parts of these minutes - Phil.*

## 4. DR. W R PIGGOTT'S 80TH BIRTHDAY CELEBRATION

From Mary and Alan Rodger

A celebration dinner in honour of the eightieth birthday of Dr. W. Roy Piggott was held in St. Edmund's College, Cambridge, UK on the 6 August 1994. The dinner was attended by about 75 colleagues, members of the Piggott family, and friends from all walks of life. Some had travelled considerable distances especially for the occasion. During the sherry reception, guests had a chance to read some of the many of the tributes to Roy Piggott that had been received by letter, fax and electronic mail. Much of the evening was spent with everyone telling their favourite 'Piggott story', each one almost more unbelievable than the last. However as everyone knows Piggott, then the stories were likely to be true, no matter how improbable they sounded. Roy Piggott, never one to troubled by tradition, rose after the first course, smoked salmon pate, to invite the gentlemen to remove their jackets as it the evening was very warm.

After an excellent dinner of medallians of lamb, there were three very personal reminiscences given by Les Barclay, Henry Rishbeth and John Dudeney. Each spoke their associations with Piggott over the years spanning his career from its earliest beginnings. Each speaker started their career in a different decade but there were several themes common to all tributes. They all appreciated being exposed to Piggott's questioning mind, his unorthodox approach, his ability to look at a problem from a different, angle, his unquenchable enthusiasm and his indefatigable energy.

Roy Piggott appeared deeply touched and appreciative of the words spoken and written about him, even to the extent of admitting a long-held secret to the assembled company - that he had always had a great fear of speaking in public. Those of us who know him well will agree that this fear was indeed well hidden!

In recognition of the fact that behind every great man lies an even greater woman, Allison Piggott was presented with a bouquet of flowers.

Piggott even at 80 had the stamina to outlast the majority of the guests. He was still heard discussing the merits of different types on antenna systems, the eclipse of 1937, and the scaling of near-impossible ionograms in the corridors of St Edmund's College as the witching hour approached.

In true Piggott style we hear that he and Allison now plan to embark upon a world cruise - may he return refreshed and as enthusiastic as ever to impart his vast experience and knowledge to us all.

A few reminiscences about Piggott are given below. So many were received that unfortunately some have been shortened and some omitted completely. Piggott has spent some time since the celebration, collating all the information, photographs, cards and even a message from the Queen into a couple of scrap books so he has a lasting tribute from his friends and colleagues.

### 4.1 From Peter Bradley, Great Britain

"I joined Slough in August 1956 and was immediately assigned to work for Roy. I could not have wished for a better boss for he showed me great kindness and understanding of the limitations of a raw graduate who knew little more that which end of the soldering iron to use. He was always responsive to personal problems, and nothing was too much trouble to explain. (I later learned that although Roy never said he did not know the answer to any question on any subject, that sometimes his answers were wrong, but they were always worth listening to because with a critical mind they were usually pointers to the right route). Roy taught me to think which there was never time to do at College, and he sent me off on my ionospheric career which I have pursued all my working life. Thank you, Roy."

"On arrival at Slough, I was set to work on helping Roy build an absorption transmitter to go on the Magga Dan to Halley Bay Antarctica for the IGY expedition. The ship had to depart on a particular date, and preparations were hopelessly behind, so we working night and day. There was something peculiar about the final PA tuning, and some big capacitors were being fabricated in the workshop. Roy kept playing with the tuning coil, and switching the transmitter on and off. At one point, I remarked that I didn't seem to be contributing very much. He replied that I was not meant to - my job was to call the ambulance when he touched the wrong spot! Luckily for the ionospheric community, my services were not needed."

"Roy was never shy to express an opinion. I remember one occasion when a technical discussion with a colleague extended into the gentlemen's toilet. Suddenly a voice from the inner sanctum boomed forth 'Well you know why that is.....'."

"Roy always had a healthy disregard for routine administration. His advice was 'When my in-tray gets so full that it begins to topple over, I put it in a cupboard and start another one'."

### 4.2 From the Arctic and Antarctic Institute, Leningrad

"Your contribution to the world ionospheric science is greatly appreciated. We always admire your inexhaustible energy."

### 4.3 From Professor Karl Rawer, former director of the Max-Planck Institut fur Aeronomie, Germany

"I shall always appreciate your broad, original and unconventional scientific spirit, and your

engagement to the people doing routine jobs at stations, and our long lasting friendship."

### 4.4 From Dr Grahame Fraser, New Zealand

"We well remember his visits to Christchurch when he showed his deep understanding of the ionosphere, and characteristically reminded us to look for what the observations were telling us, rather than thinking about pre-conceived notions, when trying to understand Mother Nature"

"Our family also has kind memories of his visits. We made an all-day trip sight-seeing over Banks Peninsula. The car's passengers included three New Zealand teenagers, who tend to express their opinions candidly. They were clearly very impressed and delighted that a world-famous scientist could so easily bridge a couple of generation gaps and chat with them as equals."

### 4.5 From Professor Jean Long, Roy's Chinese brush painting tutor

"His prime aim was to use Chinese painting technique to convey the essence of the Antarctic. He was never totally satisfied with his results, but he did achieve some success, and a great deal of pleasure."

"We have shared a lot of good times, not least of which was with the brandy bottle in his room at the end of a long hard day. I wish I had taken tape recordings during those sessions. I could have written the definitive biography of a fascinating man."

### 4.6 From Professor Ray Wright, Nigeria

The aerial site at the Ibadan ionospheric observatory was know as 'Piggott's piece'.

### 4.7 From Professor Sha Zong, China

"Dr Roy Piggott is a very famous and respectable man"

### 4.8 From Barry Peters, Great Britain

"Calls upon Roy's time were many and various, and in order to think in peace and quiet he used to retire to the toilet and sit in the cubicle. On walking in one day, I saw the Deputy Director of the Laboratory on his knees peering under the door saying "I know you're in there Roy, I can tell by the shoes". At that time Roy was well known for wearing somewhat battered, muddy shoes, often with a lace undone."

"During one Royal Society of London lecture, where dinner suites were worn, Roy's bow tie made a complete circumnavigation of his neck due to his enthusiastic arm movements"

"In 1963, a young lady was dispatched to catalogue and tidy all Roy's papers which were then covering the floor in large heaps. Before the clear up Roy could find any piece of paper unerringly from amongst the piles. For the next 6 months he had no idea where anything was, until he eventually re-established his unique filing system."

"Roy's talents were many. In 1976 he even played Father Christmas at a children's party at British Antarctic Survey - a very convincing performance, but his unique voice was a give away!"

"Roy Piggott - definitely a one off"

### 4.9 From Richard Smith, Great Britain

"I was Roy's personal assistant for almost 10 years from early 1942. During the war he was often away from Slough, working there only at weekends. On Monday morning, I would find a circuit diagram on my desk with a request to build it. I would make a neat and tidy breadboard model and leave it for Roy to test. The next Monday morning, I would find a bird's nest with wires all over the place and a note in his inimitably (unreadable?) script 'This should work now" which it invariably did'."

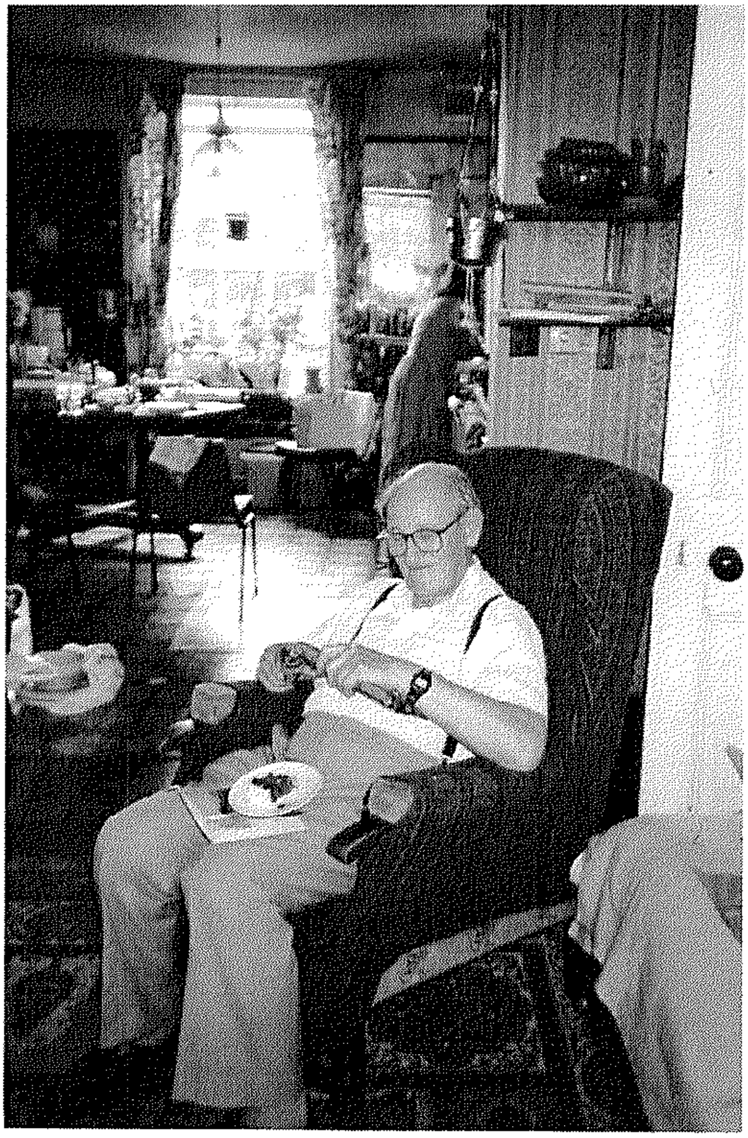
"Roy has immense energy. He had the job of finding radio propagation problems for the military. On some occasions this would involve 24 h schedule for which Roy would insist on doing the entire night shift in a wooden hut in North Park. I well remember arriving on a cold and frosty morning to be welcomed by Roy in the cosy soup smelling atmosphere, in which the coke stove needed almost constant attention. No problem for Roy at the end of the shift; he would jump onto his bicycle, the one with the wicker basket on the front, for his 6 mile journey to Uxbridge. On one occasion, Roy collided with the resident bull in the blackout. There is no record over who was more surprised."

### 4.10 From Dr R V Jones' book

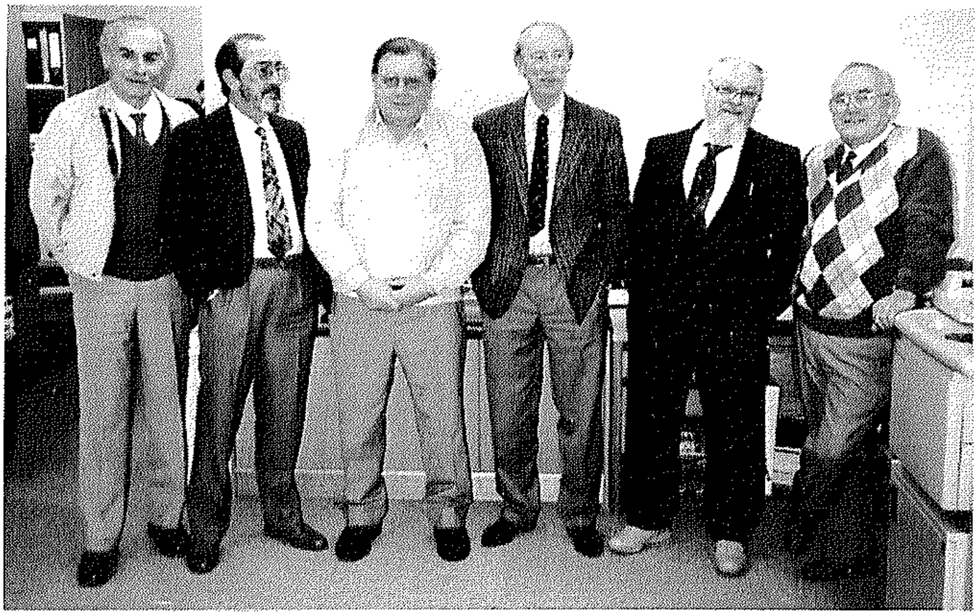
"Had I known more about Piggott, I might not have been misled by his quiet air for this provide to hide an unexpected resource. Shortly after the war, for example, he and his wife had problems cutting their baby's nails, because, whenever they tried to do so, the baby screamed her head off. One night they heard a bump, and rushed into the baby's room, to find that she had climbed out of her cot and fallen on the floor, knocking herself unconscious. Before Piggott went for the doctor he said, 'Here's our chance' and cut the baby's nails."

### 4.11 From Dr Phil Wilkinson, Australia

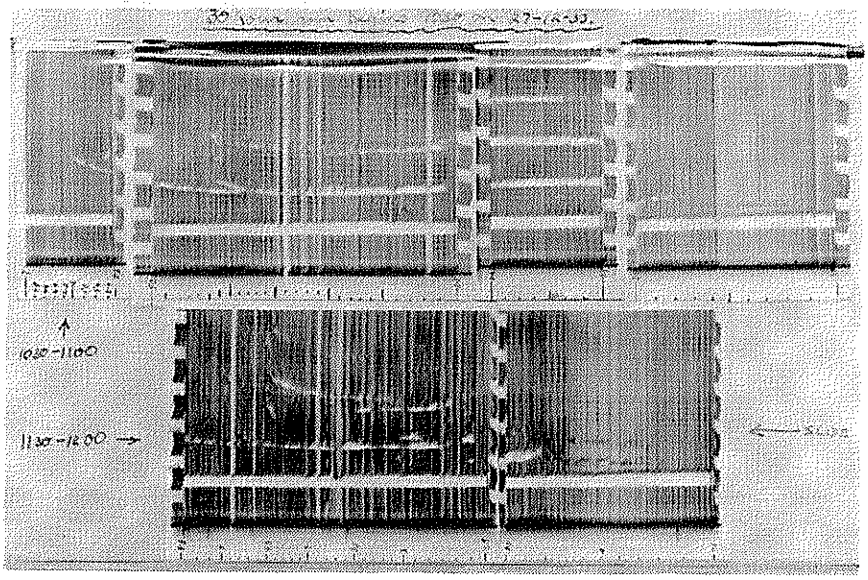
During a meeting with IPS operators, Roy was faced with an apparently ordinary looking ionogram that an operator felt held a mystery. Roy took this seriously, looked carefully at the ionogram, and over a significant period teased out the issues, used additional ionograms, and built an impressive explanation of what was happening. This revealed an understandable, but by no means obvious interpretation for the ionogram. The operator had been quite correct to puzzle over it, and we in the audience were impressed to the point of speechlessness. In the silence that followed, Roy looked around and said 'You know when I gave a description like that to people in America, they normally applaud'. A lone voice from the audience said quietly said 'Yes, I can understand that!'."

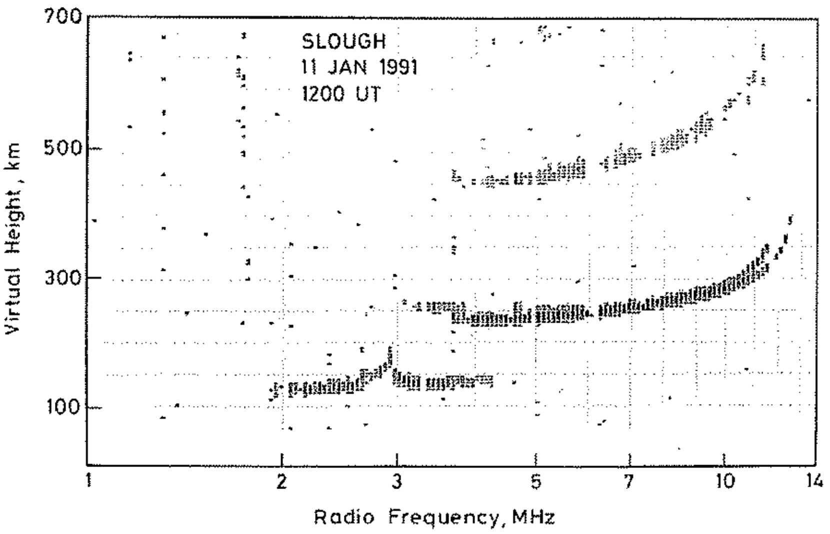


Above: Roy Piggott enjoying his eightieth birthday at home.

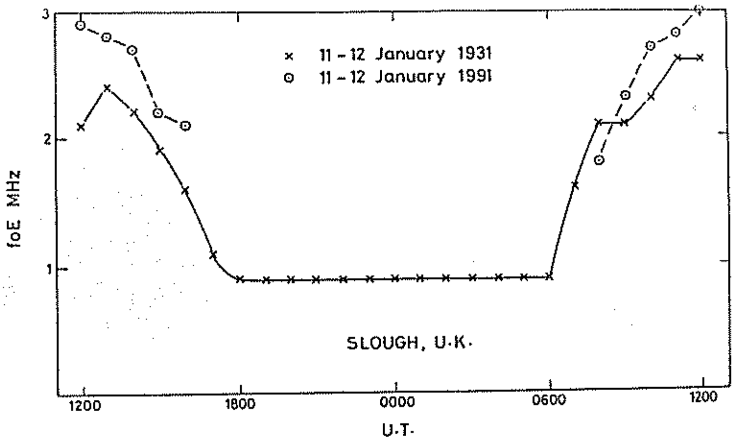


The Australian Ionosonde Operators. See text for details





Sixty Years of Slough Ionospheric Recordings - Figures 1 (upper), 2 (middle) and 3(immediately below)



### 4.12 Last word

We would like to thank all those who sent tributes, and gifts to Piggott. It was a tremendous statement of appreciation by the scientific community; a community to which he has contributed so richly. Piggott was clearly touched by the affection shown by so many from around the world.

Piggott's only personal secretary and Piggott's last student - Mary and Alan Rodger.

## 5. AUSTRALIAN IONOSONDE OPERATORS

In 1994, a short meeting was held at IPS to commemorate Arthur Drury's retirement from service with IPS. Arthur, like our other station operators, then took up a contract to continue running the IPS station at Townsville for a short time and scale ionogram records. The people in the photograph taken at this function are largely responsible for the operation and scaling of all Australian ionosonde data since 1950. They are, from left to right:

- Ivan Bozic - operator and current contractor for Canberra station. Ivan also scales Canberra, Mundaring and Norfolk Island data.
- Arthur Drury - past operator and contractor for Townsville station. Arthur scaled Darwin and Christchurch data until recently when he was diagnosed to be seriously ill.
- Paul Alekna - current manager for the IPS Ionosonde Network. Paul scales Davis data.
- George Goldstone - past operator and current contractor for Hobart station. George scales Hobart and Macquarie Island data.
- Clarrie McCue - past Director of IPS. Clarrie died a few days after this photograph was taken.
- Peter Davies - past station manager and current contractor for scaling data. Peter scales Mawson and recently Biak data.

Ivan, Arthur and George in particular are responsible for scaling over 200 station years, or 2,500 station-parameter years of data between them.

## 6. SIXTY YEARS OF SLOUGH IONOSPHERIC RECORDS

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The first 24-hour sequence of Slough E-layer critical frequency measurements, made on 11-12 January 1931, and the corresponding 60th anniversary sequence, 11-12 January 1991. The differences are : [a] 1931 was near solar minimum, 1991 was near solar maximum; [b] foE could be recorded throughout the night in the quiet radio environment of 1931, but not in 1991. It might be mentioned that Sir Granville Beynon has expressed doubt as to whether someone actually got up every hour during the night to measure foE.

Figure 1 shows two Slough ionograms. These are believed to be the earliest Slough swept frequency ionograms, and were made on 27 December 1933 at 1030-1100 and 1130-1200 UT 1933 [before which, I think, they just measured criticals]. It appears that 30 minutes were required to record a complete ionogram. For comparison, the 60th anniversary ionogram, Figure 2, was made with a digital ionosonde at 1200 UT on 11 January 1991.

The comparison between the first 24-hour sequence of Slough foE on 11-12 Jan 1931 and its 60th anniversary on 11-12 Jan 1991 is shown in Figure 3.

All ionograms are credited to Daresbury & Rutherford Appleton Lab

## 7. DRAFT STP IONOSPHERIC WORKING GROUP REPORT - 1996

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## 7.1 Introduction

*The STP Prediction Workshops are held roughly every four to five years. The last meeting was in Hitachi, Japan, January 1996. While this meeting does not deal only with ionosondes, its conclusions are of general interest to the ionosonde community. At this meeting, as the Draft Report indicates, the Ionospheric Working Group believes a larger, better connected ionosonde network is an important objective for improving our ability to forecast ionospheric change.*

There has been a shift in emphasis for the Ionospheric Working Group since the first STP Workshop in 1979. Ionospheric processes are now better understood and physical models can reproduce reasonable, global synoptic and dynamic features. At Forecasting Centres, practical issues of relevance, and hence funding, have resulted in a shift towards applications and, in some respects, away from seeking greater physical insight. Meanwhile, systems affected by the ionosphere are becoming more complex (e.g. HF Automatic Link Establishment - HF ALE) and diverse (e.g. Global Positioning Satellites - GPS). The future challenge will be to develop our understanding of the ionosphere further, test this by making predictions that are compared against some metric, while demonstrating the relevance greater understanding has for modern systems able to capitalise on the information.

These elements are discussed in greater detail below. Tactical issues, that need to be addressed before the next Workshop, are identified together with strategic issues that will enjoy long term support and should form a theme for future ionospheric prediction developments.

## 7.2 Predictions

What do ionospheric predictions offer? Generally, synoptic predictions for the key ionospheric parameters (e.g. F2 peak, F1 and E region peaks) are readily available. Ionospheric storms can be forecast based on geomagnetic forecasts, but there is little temporal or spatial information in these forecasts of the extent of a depression associated with an ionospheric storm and below some unknown threshold, storms merge with ionospheric variability. Thus the key dynamic process in the F2 region is currently poorly predicted. Other features, such as sporadic E and spread F are not usually predicted at all, although their importance has been appreciated for years.

Are predictions of ionospheric behaviour sufficiently accurate? Surprisingly, this question cannot be answered. No generally accepted measure of prediction accuracy exists. Since a prediction without a measure of accuracy is meaningless, an agreed metric for desirable prediction limits needs to be produced.

This section explores these issues further.

### 7.2.1 Long term: planning predictions

Long term predictions, based on simple empirical models of the ionosphere (e.g. the International Telecommunication Union, ITU; HF Prediction program; International Reference Ionosphere, IRI), have been most successful for planning HF systems and estimating F2 region conditions. These simple models supply information about the ionosphere for a particular epoch of solar activity and, once constructed, may make little use of new ionospheric information. To some extent, their success suggests there is nothing more of significance that needs to be done. Improvements in forecasting long term solar activity will improve these ionospheric predictions.

While the global F2 peak electron density model appears successful it has problems in detail (e.g. low latitude ionisation gradients) and there are also known problems (e.g. at low latitudes again) with the model for the peak height of the F2 region (usually expressed in terms of M(3000)F2 - the M factor). The F1 region peak electron density model also needs to be improved.

### 7.2.2 Short term: Real time information versus forecasting

Accurate forecasts with short lead times can be useful.

Historically, forecasts of significant ionospheric storm depressions contributed to the management of HF services. "Significant" in this context generally meant an ionospheric storm that accompanied a geomagnetic storm with an Ap exceeding roughly 30 units. While forecasts with experience-based thresholds will still be required, modern systems will use more detailed information.

In the most extreme form, systems can sense the current state on the ionosphere and digest this directly for system management, apparently removing the need for forecasts. Real time management - nowcasting - is likely to play a strong future role; data plus technology being emphasised. In some respects, these systems seek to eliminate the ionospheric effects by designing an ionospheric sensing step into the system at the outset. For instance, the HF ALE system sounds each of the operating frequencies available to it, selects the best and uses this for transmissions. Such a system may collect little information for diagnostic studies, making it difficult to assess where it has succeeded or failed. However, where data are available, it appears prediction models can improve system operation, although the role played is somewhat different from the historic setting.

There will be increased use of real time ionospheric data in the near future and the Working Group will need to take account of this.

### 7.2.3 Variability

Ionospheric variability places a natural limit on predictions.

What is understood by ionospheric variability and does this place a limit on the complexity of prediction models? Day-to-day variability, or ionospheric weather as we call it today, is variability in the prime characteristics of the ionosphere which cannot be linked directly to a single recognisable solar/geophysical event. It is due to the summation of a variety of energy inputs including solar EUV/X-ray, particle precipitation, Joule heating, gravity waves, electric fields generated both by magnetospheric processes and by winds driven by stratospheric and mesospheric heating. We still have an incomplete knowledge of how the wind fields generated by these heat sources modulate the ionosphere.

The sum of these effects is parameterised by the ITU decile factors. The factors are based on a rough spatial segmentation of the globe and temporal segmentation based on day/night and the seasons. Magnetic activity, and prior knowledge, are not used so the factors should form a worst case scenario for describing ionospheric variability.

Better estimates of global ionospheric variability will lead to more effective long term predictions. For instance, in the tropics, people using predicted MUFs bring their operational frequencies down much lower than the predicted MUF to allow for the predicted range of variability and thereby guarantee ionospheric support for their frequencies. This results in higher operational powers and greater radio environmental pollution. Even when real time data is available, the decile factors have not been constructed to respond to the additional information.

Improved dynamic estimates of ionospheric variability are needed. Real time data combined in more effective ways can produce narrower, dynamic bounds for ionospheric variability.

Poor predictions of ionospheric variability limit the value that can be obtained from more sensitive models. Because of the deficiencies in the current treatment of variability, it isn't possible to make quantitative comments on how they might limit models.

### 7.2.4 Ionosonde networks

Ionosondes are the primary data source for ionospheric predictions. Consequently, the Working Group strongly supports the continuation and extension of the current, global ionosonde network.

The long term data continuity for basic ionospheric parameters must continue to be collected globally for studying long term ionospheric variability and potentially unknown periodicities in ionospheric behaviour.

Digital ionosondes are becoming more prevalent and can give a good variety of data. In addition, new methods are being developed to estimate neutral winds, using these data. This information has become useful for understanding a number of scientific issues. For example: the neutral temperature and wind anomalies in the equatorial ionosphere anomaly region, the night-time maintenance of the ionosphere and the winter anomaly. Although this new knowledge has yet to be applied to predictions, it demonstrates the wealth of information available and emphasises the importance of the world-wide ionosonde network. A further role for the network is in ground truthing space-based systems. Ground-based data will be needed for comparison, calibration and revalidation of satellite measurements.

For real time data to be useful, the current ionosonde network must be expanded and integrated with other data sources to fill in the ocean regions where no ionosonde data are available. Ionosonde networks need to show even greater cooperation; easier data exchange and better formats, both for the data and the archive media, are urgently required.

### 7.2.5 Summary

The key tactical issue that the Working Group must address is the development of a set of limits that predictions seek to meet and exceed. These limits will be formed from a benchmark that predictions will seek to exceed as well as a target that predictions should attain. Long term predictions, using current sunspot number or preferably ionospheric index predictions, could be the benchmark predictions for the lower bound of ionospheric predictions. Reasonable targets must now be set.

Maintaining the current network is an important tactical goal and expanding and integrating the network with other data sources is a vital strategic goal. To achieve this, freely and readily available real-time ionosonde data are needed.

All predictions, whether short or long term, should to be quantitative, providing an estimate of the most likely ionospheric conditions plus bounds for reasonable outcomes. Currently, empirical models give the estimate and bounds, if mentioned at all, are the ITU decile factors. Using real time data, dynamic decile factors can be constructed so that the bounds can shrink, and expand, according to ionospheric predictability.

Synoptic models can be improved and currently work is taking place in this area. These improvements should be extended to the ITU prediction model.

Finally, there will still be a role for medium term (several days to a few months) ionospheric predictions for at least the next decade.

## 7.3 Models

Physical models aid understanding of the complex coupling web that forecasts seek to describe. Empirical models may well be the interface that puts the forecast into the system environment. Meanwhile, many poorly predicted ionospheric phenomena (e.g. ionisation irregularities, sporadic E, spread F) affect systems and statistical models of these phenomena may be the best support that can be offered at present.

This section looks in more detail at these models.

### 7.3.1 Physical models

The advances in understanding of the ionospheric response to geomagnetic storms have evolved from analysis of results from numerical simulations using mature physically-based models of the upper atmosphere.

One of the most obvious manifestations of an ionospheric storm is the deep "negative phase" (decrease in NmF2), which develops in the main phase of a geomagnetic storm, and often persists well into the recovery phase. The realisation that thermospheric composition changes (increases in molecular species) are a likely cause, has been appreciated for many years, but the cause of the seasonal, local time, and longitude dependence was not understood. Numerical models have recently shed light on the physical processes involved, and provide the hope that an empirical description of ionospheric storms can be developed.

Numerical simulations confirm the theory that the "negative phase" is mainly caused by the changes in neutral composition. During a geomagnetic storm, the magnetospheric sources drive upwelling of molecular rich gas from lower altitudes to F region altitudes. The increase in molecular species forms what is termed a composition "bulge", which can cover a wide geographic region. Numerical simulations now indicate that the local time response is caused by the diurnal migration of this composition "bulge" by the background wind field, and the seasonal dependence is controlled by transport of the "bulge" to mid and low latitudes by the prevailing summer-to-winter circulation.

Modelling also shows that the changes of thermospheric composition are regional, i.e. the composition "bulge" can be preferentially located over one longitude sector, and it will be this sector that experiences the most pronounced decrease in NmF2. The strength of the negative phase, and the longitude sector most affected, will depend on the Universal Time of the main driven phase of the geomagnetic storm. The sector most affected will be that passing through the midnight sector during the times of the main energy input, and the effect will be biggest when this sector also coincides with the longitude containing the magnetic pole. In the latter case, the composition "bulge" is the most asymmetric, creating the greatest longitude dependence in the ionospheric response.

The increase in understanding from the physically-based models have given us hope that a relatively simple empirical expression could be formulated that would capture many of the seasonal, local time, and regional variations.

### 7.3.2 Empirical models

At the 1979 meeting, there were few comments on the ionospheric support for, or affects on, systems. Now, empirical models, sometimes used out of their original context (e.g. ray tracing with the IRI), are being used to support an increasing range of applications. Where is this leading? Most probably towards tailored, empirical models embedded in systems. These models will be based on physical models and will be driven by real time data.

There are many areas where more sophisticated empirical models can be used. Adaptive models, based on empirical models and currently available data are a growing area of interest. For instance, Mikhailov has developed an adaptive system for foF2 for the SPARC model. Patterson, at IPS, has developed another adaptive model, based on ionospheric indices. These models use current data, making effective real time, empirical HF predictions available. In the future, adaptive models may have an even greater role, for instance, combining diverse data sets, such as electron density at one altitude, electron temperature at another, hmF2 from a different place. Such algorithms for finding the final result will obviously be based on theoretical relations between the various ionospheric parameters.

### 7.3.3 Regional models

Real time, regional data are being used more. Because of the regional nature of the ionosphere, global forecasting has limited meaning. Regional forecasts are valuable, although their value will depend on the successful interpretation of good magnetospheric forecasts (i.e. storm models need correct inputs). In the near term, real time data are likely to be communicated to systems using empirical models, rather than physical models, and the empirical models are likely to be simple and heavily tailored to suit the application.

High latitude ionospheric modelling may require a family of regional models; e.g. polar cap, auroral oval, trough, etc. For each region an empirical model can be developed, having its own set of input parameters. While magnetospheric-thermospheric-ionospheric progress may allow coupled models to deal simultaneously with these regions, for practical applications this time could be sufficiently far off to make empirical models an attractive strategic goal.

### 7.3.4 Statistical models

Possibly, the distinction between empirical and statistical models is artificial. Here, empirical models are assumed to have greater physical understanding attached to them and are convenient simplifications of reality. Statistical models may be based completely on data and are a reasonable attempt to summarise gross knowledge of a phenomenon.

Current empirical models of the ionosphere (e.g. ITU, IRI and many others) are based on relatively straightforward statistical models of the main ionospheric characteristics. Other features (e.g. sporadic E, spread F) are still not integrated into prediction systems. While sporadic E models have been available for many years, they are not used regularly and it is unclear how many sporadic E models exist nor which models should be used (e.g. models of foEs or fbEs). Scintillation models (e.g. WBMOD) have obvious value, but are not generally available for wider use. Over the next 5-10 years there could be over 1000 new communication satellites in low Earth orbit. Most will be using K or L band which presumably will be impacted by scintillations. Since physical and empirical models are not very good at predicting scintillation, particularly the changes in the global pattern during a storm, a lot of work will need to be done in this area over the next 5 to 10 years.

### 7.3.5 Summary

The single most important forecasting tool currently missing is a successful storm model. Any reasonable model in this area will be very welcome. Work is in progress to develop such an algorithm and is an important tactical goal for the group. Continued refinement of physical models, leading towards data assimilation models promises to be the most exciting long term prospect for ionospheric predictions.

In the near term, wider use of real time, data driven, empirical models is an important, potential development area that will probably grow over the next few years. Coupled with this is the likely increased importance of regional models.

Increased use of transionospheric systems will make the prediction of scintillations especially important and this will lead to a greater need for statistical models and possibly physical models of other ionospheric features not discussed at this meeting.

## 7.4 Systems

Bulk ionospheric ionisation supports many systems: e.g. HF broadcasting, HF direction finding, LF, VLF, ELF navigation, HF communications. Some of these systems are used less now (e.g. ELF, VLF) while others (e.g. broadcasting) will be in use for many years to come and some are being modernised (HF ALE).

For others systems, the ionosphere is, potentially, a system hazard: e.g. VHF through S-band and higher satellite communications, satellite radar, GPS, DMSP. Ionisation irregularities within the ionosphere may be the main limitation for transionospheric systems of the future.

Different systems react differently. Much more can be done to describe how the ionosphere, and forecasts, effect systems and improve system management. To ensure relevance we must find more customers, learn what their systems do and how ionospheric information can make them more efficient. We need to be sure about what ionospheric parameters have to be forecast. Forecasts have limited value without an application and often the value of a forecast will be measured by the support it gives to a system.

### 7.4.1 Potential for success

In recent years, in some areas, the ionospheric research community has been ignored by some customer groups. A number of reasons can be cited to explain this. Some of the big customers now regard HF as a back-up service and, faced with financial restraints, cut-back on ionospheric investments. Many groups feel there is nothing more of relevance they need to learn about the ionosphere - current F2 region empirical prediction models are reasonably faithful reproductions of past ionospheric behaviour. Also, the ground based, ionospheric community has lost some credibility because the advances in ionospheric research are not as spectacular as in computer and satellite communication systems.

Nevertheless, there are many applications that are sensitive to ionospheric change. Some examples of new service areas are offered here.

In many developing countries, with scattered, rural populations, HF is still attractive and more research is needed to optimise performance of HF digital packages. Furthermore, the tropics are populated by most of the developing countries that need to be educated about the advantages of HF. In an apparently developing mobile satellite communication world, cheaper HF systems have a role to play. There is much more fundamental work yet required to fully understand the low latitude ionosphere and its variations and to integrate this knowledge into modern HF systems.

The effects of irregularities on satellite based systems has been known for many years. Systems, such as GPS, are affected by the bulk ionisation and corrections for this are required for accurate measurements. While dual frequency GPS systems are available, these are still expensive, making ionospheric corrections important. Furthermore, GPS systems are likely to be affected by ionospheric scintillation in the equatorial ionosphere.

Currents flowing in the E region of the ionosphere, induced by magnetospheric changes, produce magnetic changes at the surface of the earth which can add errors to aeromagnetic surveys. While a magnetospheric effect, for logistic reasons this may fall into the category of an ionospheric problem because of the short time scales involved.

For systems to operate, signals must be useable within the ambient noise environment. For instance, HF field strength and atmospheric noise predictions may be region specific, e.g. in India, large departures from ITU predictions are found. While not directly an ionospheric issue, it is a customer issue that often attracts the attention of ionospheric groups.

### 7.4.2 Summary

Understanding the ionospheric contribution to systems covers a wide range of topics, including non-ionospheric effects.

It is difficult to separate the customers' service problems into simple packages labeled: ionosphere and "other". As funds become more difficult to obtain, and relevance takes on a broader meaning, the Ionospheric Working Group will have to become more familiar with the total service problem. Ideally, customers fully understand their systems, recognise the ionospheric needs and seek assistance. In practice, where systems are inherited rather than designed, people are often unfamiliar with their overall needs and appreciate informed assistance. Effort spent on understanding the effects of the ionosphere on systems should improve the application of predictions but it may not improve the predictions themselves. Experience suggests that if reliable predictions are available, customers will probably seek them. However, there is often little interest, aside from curiosity, in services offered unsolicited. For some groups, solving this conundrum is the key tactical goal.

## 7.5 Conclusion

The key tactical issue that the Working group must address is the development of a set of limits that predictions seek to meet and exceed. These limits will be formed from a benchmark that predictions will seek to exceed as well as a target that predictions seek to attain.

For real time data to be useful, the current ionosonde network must be expanded and integrated with other data sources to fill in the ocean regions where no ionosonde data are available. Maintaining the current network is an important tactical goal and expanding the network, and integrating it with other data sources, are vital strategic goals.

The single most important forecasting tool currently missing is a successful storm model. Any reasonable model in this area will be very welcome. Work is in progress to develop such an algorithm and is an important tactical goal for the group. Continued refinement of physical models, leading towards data assimilation models, promises to be the most exciting long term prospect for ionospheric predictions.

For practical reasons, much greater attention will need to be paid to how the ionosphere affects systems and, in the short term, it may be necessary to sell solutions to potential customers to stay in business.

## 8. OBSERVING IONOSPHERIC DYNAMICS WITH THE HALLEY DYNASONDE

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Since 1981, a phase-sensitive digital ionospheric sounder has been in operation at Halley (76°S, 27°W), the most southerly of the British Antarctic Survey's [BAS] research stations. This instrument is a NOAA HF radar (Grubb, 1979) which was upgraded during 1991 with new digital signal processing and time sequence generation boards, standard PC architecture and high capacity optical disc storage for the raw data. This upgrade was a joint venture between BAS and Utah State University (USU), the former concentrating on the machine software and the latter on the hardware. Identical hardware and software is now in operation at the USU Bear Lake Observatory and the European Incoherent Scatter Radar site near Tromso. The instrument at Halley is referred to as the Advanced Ionospheric Sounder [AIS] (Dudeney, 1981) and primarily operates as a dynasonde (Wright and Pitteway, 1979). A rapid-fire, four-pulse transmission sequence is employed at each sounding frequency. For each pulse, two parallel receivers allow the comparison of echo phases between selected pairs of dipoles from an array of four receiving antennas. The coincidence of echoes within the four-pulse set eliminates spurious noise echoes and allows the derivation of a full set of echo parameters including sky-map echo location, wave polarisation sense and Doppler velocity. At Halley an L-shaped pattern of receiving antennas is used (Jarvis and Dudeney, 1986), but many variations are possible (Tsai et al, 1993).

The AIS operates as a dynasonde continuously throughout the year recording ionograms at least every quarter-hour. These soundings are processed computationally at Halley to estimate basic ionogram parameters which are transferred by satellite via Cambridge to NASA on a weekly basis to form part of the International Solar Terrestrial Physics (ISTP) Key Parameter set (Dudeney et al., 1995). In addition, during campaign periods, more frequent ionograms and specialist fixed-frequency sounding modes are employed for specific scientific studies. Data integrity checks are carried out at Halley by the over-wintering field personnel to ensure good system performance is maintained. A preliminary analysis is also made of ionospheric features of particular interest for further study back in the United Kingdom. Once a year the raw data are returned by ship to BAS headquarters where they are processed and entered into an in-house geospace database held on CD-ROM.

This short article describes a dynasonde data sequence recorded at Halley that illustrates the advantages which the spatial and Doppler information bring to the interpretation of standard ionograms. This example was recorded under range-spread-F conditions. Such data are often observed at Halley particularly during the equinox periods when it frequently occurs post magnetic noon. The ability to distinguish the individual sky-map locations of the echoes forming each trace in clearly striated spread-F conditions allows a time-sequence picture to be built up of the prevailing ionospheric dynamics.

The three ionograms shown on the left of Figure 1 are taken from a series of soundings recorded at 3-minute intervals on 17 March 1993. Several distinct traces within the range-spread in each ionogram are apparent which all exhibit a similar plasma frequency between 6.0 and 6.5 MHz. Two particular traces have been highlighted and labelled (traces 1 and 2) so that their progress can be followed from one ionogram to another. The corresponding sky-maps are shown on the right-hand side of Figure 1 and indicate the horizontal location of each echo relative to Halley -it is in these additional data that the full advantage of the dynasonde is seen. The groups of points (labelled 1 and 2) correspond to those highlighted in the ionograms and it is clear that they are composed of echoes from specific horizontal locations. The Doppler velocity of each echo is also illustrated on both the ionograms and the sky-maps by the grey-scale shading; the highlighted groups of echoes (1 and 2) are seen to have distinct, and different, mean Doppler velocities.

During the six-minute period of data shown, groups 1 and 2 both move towards the south-west, passing slightly to the south-east of Halley at closest approach. This horizontal motion is also indicated by the Doppler velocity exhibited by each group of echoes. A negative velocity indicates movement towards Halley and a positive velocity indicates movement away. At ~340 km distant from Halley, Doppler velocities of ~270±20 ms$^{-1}$ are evident

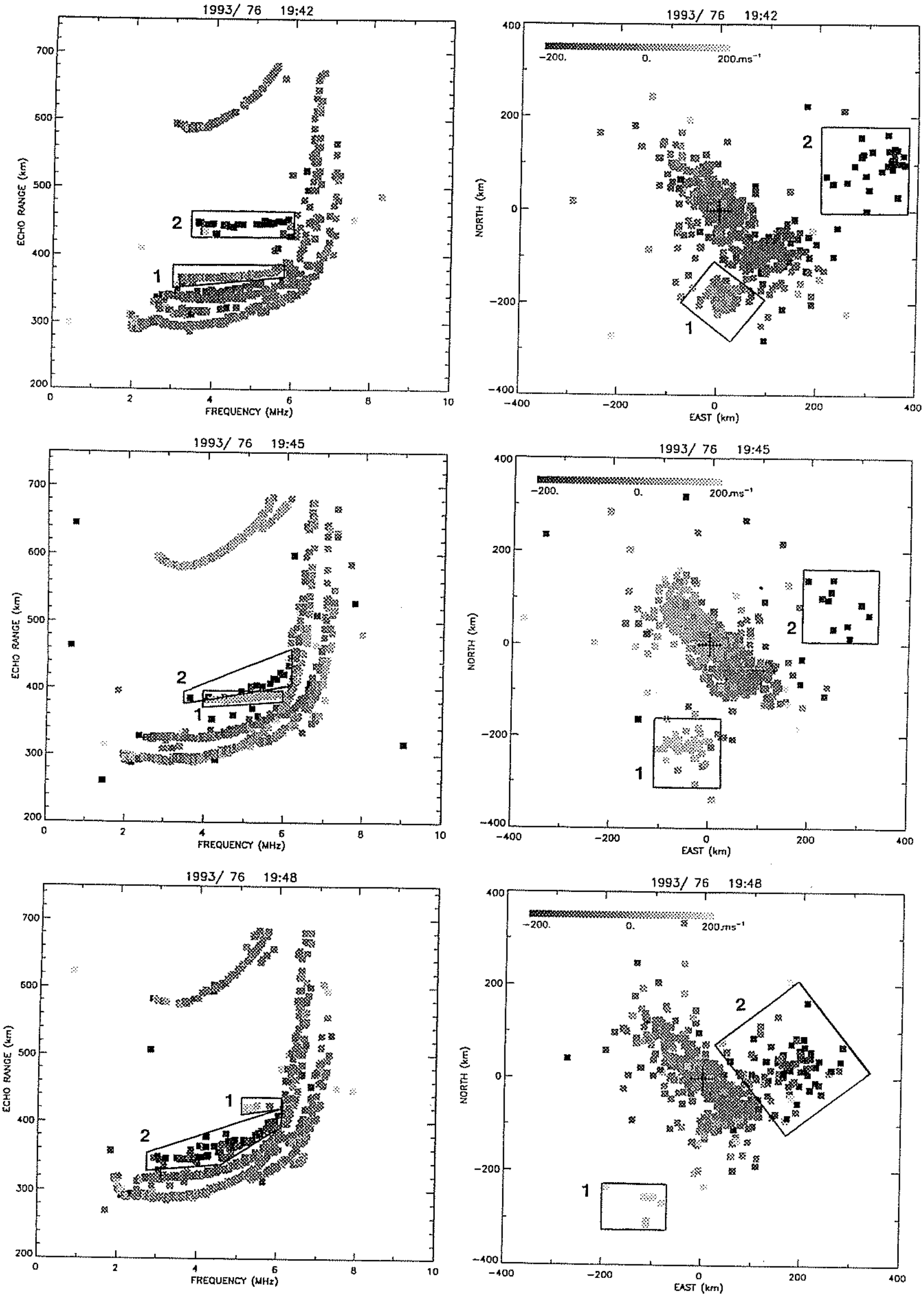

Fig 1: Ionograms (left) and sky-map echo-location plots (right) for a sequence of three soundings from Halley on 17 March (day 76) 1993. Two ionogram traces and their corresponding echo-location positions have been highlighted (1 & 2) . Grey-scale shading indicates line-of-sight Doppler velocity.

(group 2 at 1942UT); at ~290 km distant, the Doppler velocity is ~200±30 $\mathrm{ms}^{-1}$ (group 1 at 1948 UT). At closest approach the Doppler velocities reduce to near zero, as expected, because the line-of-sight component seen at Halley becomes perpendicular to their overall motion. Taking the altitude of the echoes seen from Halley to be between 200 and 250 km, these line-of-sight Doppler velocities translate into an effective horizontal velocity of between ~310±30 and ~330±30 $\mathrm{ms}^{-1}$ for group 2 at 1942UT and between ~240±30 and ~260±30 $\mathrm{ms}^{-1}$ for group 1 at 1948 UT. This may be compared with the positional movement observed during the sky-map sequence; during the 6-minute sequence both group 1 and group 2 move through ~130±10 km. This translates to a velocity of ~360±20 $\mathrm{ms}^{-1}$. The horizontal motion calculated from the Doppler velocity and that calculated from the movement of the echo-location position seen on the sky-map plots between consecutive soundings are therefore in agreement within experimental error and taking into consideration the fact that the former are instantaneous velocities while the latter is the mean over a six minute period. It should be noted however, that a more rigorous calculation must also account for the fact that different sections of an ionospheric scattering region are seen as it passes across the field of view (Lanchester et al., 1993).

The velocities calculated by the two methods above may also be compared with those derived using the method of fitting a bulk flow vector to the data from each ionogram by solution of the multiple set of linear equations (one equation for each echo) that relate the sky-map position and Doppler velocity to that bulk vector (Wright and Pitteway, 1994; Jarvis, 1995). This technique produces values for the horizontal velocity component of 251, 274 and 296 (±~25) $\mathrm{ms}^{-1}$ and velocity bearings towards 51°, 71° and 59° (±~10°) west of south for the ionograms at 1942UT, 1945 UT and 1948 UT respectively. These results are again in reasonable agreement with the other techniques but tend to indicate slightly lower velocities. This may be due in part to the fact that the vector fitting technique also accounts for the vertical component of motion and does not assume that the line-of-sight Doppler velocity is due to purely horizontal movement.

It is probable that the discrete echoing regions observed in this event correspond to scattering from horizontal corrugations in the ionospheric electron density contours characteristic of the passage of travelling ionospheric disturbances or atmospheric gravity waves. This is consistent with the fact that the echoing region observed close to overhead at Halley throughout this period tends to be elongated in the north-west to south-east direction in alignment with the corrugations themselves. The movement of the patches of echoes on the sky-map will be indicative of phase front velocity. Physical interpretation of the velocity derived by the two other techniques, which both depend upon the line-of-sight Doppler velocity, is likely to depend upon the reflection mechanism.

This example has demonstrated just one of the advantages of a phase-sensitive ionosonde over a conventional analogue system. Over thirty scientific research papers have been published using data from the AIS at Halley. Increased computing power and on-line data storage capability combined with the flexibility available to program specialised sounding modes means that the instrument continues to provide much potential for key areas of ionospheric research.

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# 9. LONG TERM VARIATIONS OF SPORADIC E LAYERS OVER FORTALEZA, BRAZIL

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### Abstract

Ionospheric sounding at Fortaleza (3° 41'S,38°25'W), in Brazil started in 1975. The ionospheric data collected till 1990 is used to investigate the long term trends in the sporadic E-layer occurrences over this station, where the secular variation of the geomagnetic field has caused a steady drift of the magnetic equator to north of the station. Systematic decrease in the occurrence rates of the q-type Es, accompanied with increases in the l, f, h and c types of Es, was registered from 1975 to 1990, during which period the magnetic equator drifted to north of Fortaleza by ~400 km. This long term trend manifests competing roles of the equatorial electric fields and wind systems, in the generation of the different Es layers as a function of the distance from the electrojet center.

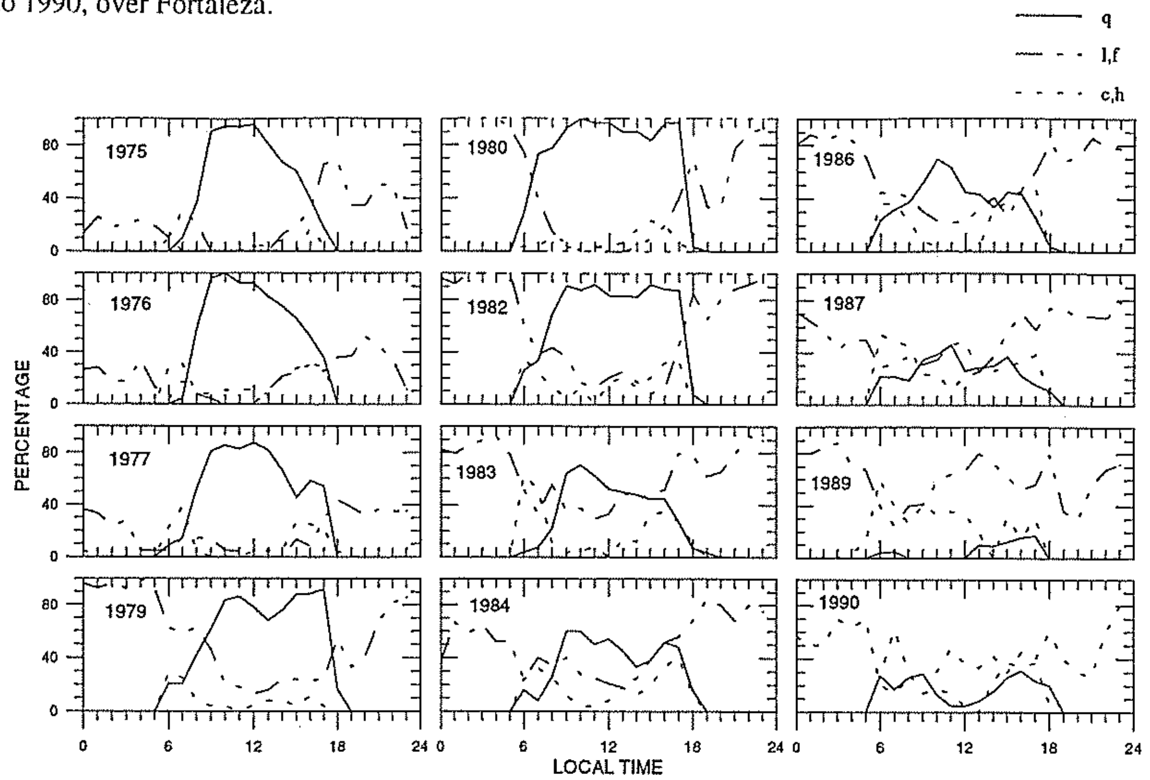
## 9.1 Introduction

A C-4 ionosonde has been in operation at Fortaleza since 1975. In 1993 this was replaced by a Canadian Advanced Digital Ionosonde (CADI). The data for the month of September from 1975 to 1990 has been used in this report to investigate the long term trends in the occurrence features of the different types of Es layers arising from the natural phenomenon of secular variation of the geomagnetic field. During the initial epoch of ionosonde operation at Fortaleza the magnetic equator, that is, the approximate center of the equatorial electrojet (EEJ) current system was located, according to the International Reference Geomagnetic Field (IGRF) model, ~50 km north of Fortaleza, and with the yearly northward drift rate of ~0.2°, the above distance has increased to ~400 km by the year 1990. This has produced systematic long term changes in the sporadic E-layer features over that station, which is the subject matter of this report. The Es-layer formation for equatorial latitudes is known to be quite different from those for the middle and high latitudes. The well-known gradient drift (that is, ExB drift) mechanism is known to be responsible for the equatorial type (widely known as the q-type) Es-layer that occurs inside the equatorial electrojet (EEJ), whereas other different types of Es-layers (such as the l, f, c and h types (see URSI Handbook of Ionogram Interpretation and Reduction, Second Edition, 1972, Report UAG-23), that occur outside the EEJ over low latitudes, and mid latitudes, are known to be produced by wind/wind-shear mechanism (Axford, 1963; Whitehead 1961; Abdu and Batista, 1977). The latter types of Es, contrary to the q-type, could often blanket echoes from the F-region. The l and f type that occur during day and night, respectively, will be denoted here as l/f type Es. The h-type Es develops around 180 km and descending, in sequential ionograms, to lower heights (see for example, MacDougall, 1978; Wilkinson et al., 1992) becomes denoted as c-type Es. We shall from here on consider them as h/c-type Es. We have carried out an extensive analysis on the hourly occurrence statistics separately of the different types of Es layers.

## 9.2 Some Results

The hourly percentage occurrences during an year of the different types of Es layers with respect to the total number of soundings carried out during the year are plotted in Figure 1 as a function of local time. Results for the years, 1975-1977, 1979, 1980, 1982-1984, 1986, 1987, 1989 and 1990 are presented in this figure. The following features of this figure may be noted: 1)The q-type Es occurrence rises sharply after sunrise, reaches the highest rates approaching ~100% before noon and decays soon after midday to reach zero value around sunset. There is an afternoon enhancement in the Es occurrence in the years 1977, 1979-1980 and 1982. (2) The q-type Es occurrence rate starts a steady decline from 1982 (with ~90 percent) to 1989-90 (with 5-20 percent); (3) The h/c type events occur only during the sunlit hours, with maxima in morning and in evening hours. The amplitudes of these maxima show significant increase from 1975 (with ~15%) to 1990 (with up to ~60%). This diurnal double peak parameters is similar to the Es local time distribution pattern over Cachoeira Paulista reported earlier (Abdu and Batista, 1977). Their occurrence rates increasing from 1975 to 1990 shows a correspondingly increasing role of winds and wind shears in the Es layer formation over Fortaleza during this period. (4) The l/f-type Es that occurs generally in the 100-105 km region shows almost negligible daytime

**Figure 1** Diurnal patterns of the q, l/f and h/c types Es hourly percentage occurrences for years from 1975 to 1990, over Fortaleza.



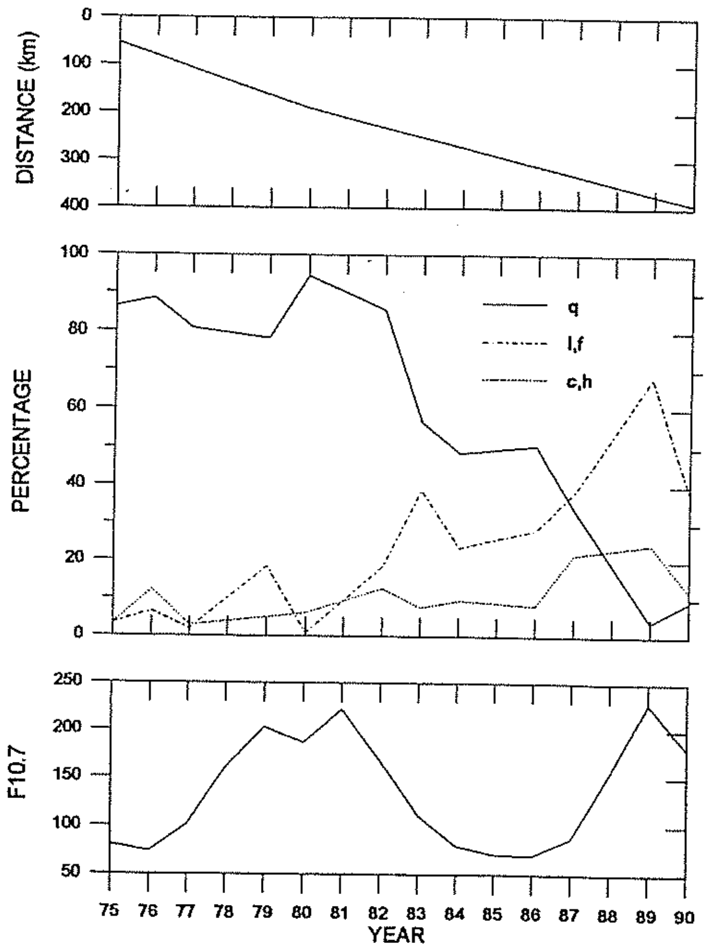


**Figure 2**-*Top panel*: The distance of Fortaleza station from the magnetic equator (in km) from 1975 to 1990, determined using the IGRF model;

*Middle panel*: Percentage occurrences of the q, l/f and c/h types of Es layers over Fortaleza for September as a function of the years from 1975 to 1990;

*Bottom panel*: The F10.7 cm solar radio flux for the period 1975-1990.

occurrence in 1975 and a steady increase to the order of 50 percent in 1990. This feature is in sharp contrast to the trend in the q-type Es occurrence which was exactly opposite during the same period.

The Es occurrence rates averaged for the hours 10-14 LT are presented in Figure 2 (middle panel) together with the yearly average solar F10.7 flux (bottom panel) and the variation of the distance of the Fortaleza station from the magnetic equator as per the International Geomagnetic Reference Field (IGRF) model, as a function of years from 1975 to 1990. This figure permits us to analyse the long term changes in the different types of Es layers as a function of the increasing distance of the station from the center of the EEJ during the 16-year period, as well as in function of the solar activity cycle. We may note the following important parameters: (a) the q-type Es decreases from 90% occurrence in 1975 to almost insignificant values in 1990, as the EEJ drifted to further northward of Fortaleza. In other words the control of the EEJ associated E-field on the q-type Es layer formation decreased drastically from 1975 to almost negligible values in 1990. The other types of Es layers showed significant enhancement towards 1990, suggesting that their occurrences increased with increasing distance of Fortaleza from the EEJ center.(b) there are modulation cycles, superimposed over the long term trend, that are often in opposite phases in the q-type on the one hand and in the l/f and c/h types on the other. These modulations seem to be mainly produced by the solar activity cycle. For example, the broad maximum in the q-type Es centered around 1980 appears to coincide with the solar cycle maximum in the F10.7 cm flux. In contrast l/f and h/c types of Es showed maxima corresponding to the 1989 solar flux maximum

## 9.3 Roles of Electric Fields and Winds in Es-layer Formation.

The long term trends in the occurrences of the different types of Es layers over Fortaleza are, in fact, manifestations of the variations, from the center to the periphery of the EEJ, of the competing roles of electric fields and neutral winds in the formation of these Es layers. At the EEJ center the vertical polarization Hall electric field driven by the primary E-layer dynamo electric field, is responsible for the gradient ExB drift (type II) irregularities that manifests as q-type Es in the ionograms. The Hall field gets weakened with increasing distance from the EEJ center. Thus the observed decrease in the q-type Es formation over Fortaleza from 1975 to 1990 can be attributed to the fact that during this period the Fortaleza station steadily receded from the EEJ center as shown in Fig. 2. On the other hand the l/f and c/h types of Es layers are known to be produced by winds that are expected to be the same in the rather restricted latitude range covered by the EEJ. At the periphery of the EEJ, that is, over Fortaleza towards the end of the analysis period, winds are very efficient in producing the l/f and h/c type Es. However, the formations of such wind induced layers seem to be opposed by the eastward electric field that is uniformly present in the EEJ and its periphery (nearby low latitude) regions. This can be verified from the fact that the decay of q-type Es occurrence that marks decrease of eastward electric field just before 18 LT is always accompanied by rapid rise in the wind induced Es layers, in Figure 1. Thus opposing influences of electric fields and winds are apparent in the formation of low latitude Es-layers. The increasing trend in the occurrences of l/f and h/c types of Es-layers from 1975 to 1990 seen in Figure 2 is, in fact, a net trend resulting from the opposing influence of an ambient eastward electric field in the formation of these layers by winds.

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# 10. FRONTIER TOPICS IN IONOSPHERIC SCIENCE

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The ionosphere is an important component of the upper atmosphere and of the solar-terrestrial system generally. Ionospheric observations, both ground-based and in-situ, give data relevant to many STP topics. Ground-based observations - ionosondes, coherent and incoherent scatter radars, plus more specialized instruments - have a vital role, largely because of the geographic coverage and long data sequences that they provide.

Here are some personal ideas on the "frontier topics", which I sent to Moscow in September 1994, in response to a request from Sasha Feldstein of WDC-B. I thought they may be of interest to the INAG readership, so for this article I have edited out the specifically Russian aspects of the original.

1 "The upper atmosphere as a dynamic system" (or "Vast heat engine") i.e. Global dynamics of the upper atmosphere. The upper atmosphere circulation, locally and globally, is strongly influenced by the ionospheric plasma and the geomagnetic field.

From well-established ionospheric theory, neutral-air parameters [such as pressure and meridional wind speed] can be estimated from ionosonde and other data, with sufficient accuracy to be useful in studies of energy inputs - solar radiation; particles; magnetospheric electric fields, tidal forcing, momentum sources and sinks - and the global energy balance in general.

2 Coupling with the magnetosphere and solar wind. Ionospheric phenomena are a valuable indicator of magnetospheric processes. This is primarily a matter of high-latitude observations, but not entirely; data from lower latitudes are needed too.

3 Coupling with the lower atmosphere. Possible effects on STP parameters of meteorological storms and weather systems; also seismic and volcanic activity. "Sun-weather relationships" may be controversial, but possible physical mechanisms are being found. Short-term and long-term weather forecasts based on STP data are claiming some success, and may have economic importance.

4 Medium-scale structure in the ionosphere (scale size 10-1000 km). What causes it? How is it related to magnetospheric, lower atmospheric, surface and topographical features, and what can we learn about them by studying the ionospheric structure (e.g. by radio tomography)? The scientific literature contains many questions but few answers on the subject.

5 "The ionosphere as a plasma physics laboratory" i.e. study of small-scale structure" scale size 1 km - 1 m); its structure and morphology at high latitudes (auroral and polar), also at equatorial and (to some extent) middle latitudes.

6 "The ionosphere as a communications medium". Despite the use of satellites and cables, the ionosphere retains much of its practical importance; even satellite and cable communications are not immune from ionospheric and magnetospheric effects. This topic requires good ionospheric modelling (both "empirical" and "physical" models) and also involves both long-term "predictions" and short-term "forecasting" of ionospheric parameters.

7 "Predictability of the ionosphere" - at least three aspects:

(i) Long-term predictions of seasonal/solar cycle effects etc., based on solar observations and on comprehensive knowledge and modelling of ionospheric structure and behaviour;

(ii)Forecasts of impending ionospheric storms, essentially depending on solar and interplanetary data;

(iii)Once a storm has begun: Short-term "nowcasting" of the subsequent progress of ionospheric disturbances, and of their effects on communications etc.

8 Long-term global change. Ionospheric datasets extend over several decades. If continued and maintained, they contain information not only on obvious solar, geomagnetic, and seasonal variations, but also on more subtle long-term changes, both natural and man-made. So they are potentially valuable for studying effects of global warming/cooling, ozone depletion, and industrial pollution. It should be noted that other processes, at present unknown, may become apparent in the future. There are many cases in which old datasets suddenly became important for investigating a newly-discovered phenomenon.

Data sets, especially those that go back to the 1930s or even the 1960s, are valuable resources that must be preserved. Though it may be difficult to maintain STP monitoring instruments in many countries, it is important to national and international science to do so. Thus priorities should be set in each country for defining a basic long-term program: see Willis et al., J. Atmos. Terr. Phys. 56, 871 (1994). Experience suggests that these programs only survive if they are seen to meet national needs; but there are educational and cultural aspects to be considered, as well as industrial and commercial benefits.

Not every ionosonde, magnetometer, radar or other instrument can be kept going, nor every research institute or group. Selectivity is essential. There should be a mixture of "research" instruments and "monitoring" instruments (though these categories are not sharply demarcated).

Data have value, but the trap of regarding STP data as a commercial commodity, to be bought and sold, must be avoided. No country, however large, can do good STP / geophysical / environmental studies (whether short-term or long-term) entirely with its own native data. Exchange with other countries is essential, even for basic items as solar-geophysical indices. Any country that puts a commercial price on STP data can expect to find itself at the losing end of the exchange when data from abroad are required.

In connection with 6, it would be very useful to quantify the present-day practical use of the ionosphere, country by country. Could INAG members or the national Commission G reps take on this task ? They are well qualified to do so.

## 11. SPACE PHYSICS INTERACTIVE DATA RESOURCE (SPIDR) ANNOUNCEMENT

V. R. Hobson and R. O. Conkright, National Geophysical Data Center

The Solar-Terrestrial Physics Division (STPD) of the NOAA National Geophysical Data Center (NGDC) announces the release of the Space Physics Interactive Data Resource (SPIDR) system. The SPIDR system is an on-line system to search, browse and access space weather data sets archived at NGDC and the co-located World Data Center A for Solar-Terrestrial Physics. The data sets include ionospheric data, Defense Meteorological Satellite Program (DMSP) satellite images, and geomagnetic data. The on-line user selects the data type, date, and location. The system then searches the relational database, retrieves the requested data, and delivers an image to the user over the World Wide Web. The SPIDR system is continuously being tested and revised. New features and data will be added.

Web users can plot geomagnetic variation data from 32 observatories worldwide. The effect of geomagnetic activity on the aurora can be quickly assessed through links to the DMSP browse imagery.

Web users may select imagery by date and location from DMSP's worldwide satellite coverage. Button controls then allow users to "fly" one of four DMSP satellites about the globe. DMSP imagery displays aurora, city lights, fires, and cloud coverage.

While the SPIDR system includes geomagnetic and DMSP data, our main interest lies with the ionospheric data. Currently one full solar cycle's data (January 1985 through July 1995) are available. The database comes from several data sources. At the beginning of each month NGDC receives real-time preliminary data from the NOAA Space Environment Laboratory Data Acquisition and Display System (SELDADS) for the previous month and places it in the SPIDR database. Data received from the individual stations are quality controlled and the resulting data are copied over the real-time data. The user chooses the month and year from the pull-down menus and clicks the map in the region of interest. The closest station with data available is automatically selected and plotted. The plot displays the foF2 parameter and monthly median. Additional parameters will be available in the near future.

The user may also choose to generate a World Wide Contour Plot, a model of the global ionosphere. The user selects the month and year. The SPIDR system then displays a color contour map of maximum electron density calculated from the month and sunspot number.

World Wide Web access to the SPIDR system can be found through the STPD home page at **http://www.ngdc.noaa.gov/stp/stp.html.**

## 12. GEOMAGNETIC AND IONOSPHERIC LARGE STORMS ASSESSMENT AND FORECASTING - A PROPOSAL

### 12.1 Objectives:

Based on ongoing research in the EU COST 251 projects, this project has as its aim the support and coordination of a ground-based experimental program of vertical-incidence ionospheric sounders, data analysis and real-time exchange, and theoretical effort to develop techniques for the assessment of large geomagnetic and ionospheric storms. The main objectives of the project are:

(i) support of the current program of ionospheric observation and data processing with emphasis on the FSU ionospheric stations,

(ii) development of data assimilation techniques to incorporate all available ionospheric observations over Europe,

(iii) development of techniques for the assessment of large geomagnetic and ionospheric storms, in particular, provide weekly the most disturbed ionospheric day and the most quiet ionospheric day,

(iv) real-time ionospheric data exchange via the new Ionospheric Despatch Centre for Europe (IDCE) at the Space Research Centre in Warsaw and retrieval via the World Wide Web.

## 12.2 Technical Description of Project:

The impact of solar phenomena and correlated geomagnetic, magnetospheric and ionospheric activity on the near-Earth space environment is a central topic of geophysics. Terrestrial and Earth-space radio systems, electric power networks, geophysical exploration, spacecraft control and scientific research campaigns are highly affected by solar-terrestrial activity.

The ionosphere, its electrodynamics and its coupling with the neutral atmosphere at the bottom and the magnetosphere above, are of general interest. Global and regional ionospheric studies are highly dependent on regular high quality data from vertical-incidence sounders. The proposed project will support ionospheric data collection in FSU countries, coordinate real-time data exchange and studies of ionospheric storms.

A cooperative project 'Improved Quality of Service in Ionospheric Telecommunication Systems Planning and Operation' under the auspices of European Union COST (Cooperation in Scientific and Technological Research) Action 251, has been engaged in the development and validation of improved ionospheric models for the European region (10.0W-60.0E, 35.0 - 70.0N), making use of the extensive ionospheric measurement data sets available in Europe. A new Ionospheric Despatch Centre for Europe (IDCE) is to be formed at the Space Research Centre in Warsaw for the distribution of ionospheric forecast information appropriate to scientific studies and communication circuit predictions. The proposed work is highly relevant to these international projects.

## 12.3 FSU Ionospheric Stations

**TABLE 1**. Data available from FSU / Russian ionosondes.

| Station | LAT | LONG | Jun 93 | Nov 95 |
|---|---|---|---|---|
| Druznaya | 81.0 | 58.0 | + | + |
| Preobrazenija | 74.7 | 113.0 | + | |
| Dikson | 73.5 | 80.4 | + | + |
| Loparskaya | 68.0 | 33.0 | + | |
| Wellen | 66.6 | 190.2 | + | |
| Salekhard | 66.5 | 66.5 | + | E |
| Yakutsk | 62.0 | 129.6 | + | |
| Podkamennaya | 61.6 | 90.0 | + | |
| Leningrad | 60.0 | 30.7 | + | + |
| Magadan | 60.0 | 151.0 | + | + |
| Tomsk | 56.5 | 84.9 | + | E |
| Sverdlovsk | 56.4 | 58.6 | + | |
| Moscow | 55.5 | 37.3 | + | + |
| Kaliningrad | 54.7 | 20.6 | + | |
| Novosibirsk | 54.4 | 83.2 | + | + |
| Petropavlovsk | 53.0 | 158.7 | + | E |
| Irkutsk | 52.5 | 104.0 | + | |
| Kiev | 50.5 | 30.5 | + | |
| Khabarovsk | 48.5 | 135.1 | + | |
| Rostov | 47.2 | 39.7 | + | E |
| Alma-Ata | 43.2 | 76.9 | + | |
| Tbilisi | 41.7 | 44.8 | | |
| Tashkent | 41.3 | 69.6 | + | E |
| Ashkhabad | 37.9 | 58.3 | + | + |

(E - only E-layer parameters were available). Therefore, it is proposed to support 11 stations in the next two years. List of stations is given in Table 2.

The list of the FSU ionospheric stations with data availability in June 1993 and November 1995 is given in Table 1. Data were available from 23 stations in 1993. By November 1995 only 12 stations were left, with only seven providing full ionospheric parameter information.

**TABLE 2.** Ionospheric stations from FSU/Russia to be supported. All parameters will be scaled.

| Station | Country | LAT | LONG |
|---|---|---|---|
| Druznaya | Russia | 81.0 | 58.0 |
| Loparskaya | Russia | 68.0 | 33.0 |
| Salekhard | Russia | 66.5 | 66.5 |
| Leningrad | Russia | 60.0 | 30.7 |
| Sverdlovsk | Russia | 56.4 | 58.6 |
| Moscow | Russia | 55.5 | 37.3 |
| Kaliningrad | Russia | 54.7 | 20.6 |
| Kiev | Ukraine | 50.5 | 30.5 |
| Rostov | Russia | 47.2 | 39.7 |
| Alma-Ata | Kazakhstan | 43.2 | 76.9 |
| Ashkhabad | Turkmeniya | 37.9 | 58.3 |

Data are already available from following five Russian ionospheric stations via URSIgram Service at Space Research Centre, Warsaw:

| | | |
|---|---|---|
| Druznaya | (36901, IONDA, IONHA) | - N81E58 |
| Sverdlovsk | (36602, IONDA, IONHA) | - N56E58 |
| Salekhard | (37701, IONDA, IONHA) | - N66E66 |
| Tashkent | (37401, IONDA, IONHA) | - N41E69) |
| Podkamennaya | (39601, MAGHA) | - N61E90) |

However support is needed to maintain the current data sources and increase the number of available FSU stations. As well as support for routine operation of these stations, a PC is required at IZMIRAN to coordinate the FSU data. In addition, financial support for technical visits is needed.

It is expected that real-time ionospheric data exchange via the IDCE will start in January 1997. As well as the standard ionospheric parameters, the IDCE will provide weekly the most disturbed ionospheric day and the most quiet ionospheric day. The data will be available to the international community on the WWW.

## 12.4 Ionospheric Storm Modelling

The proposed work seeks to characterize the ionospheric structure and dynamics during large geomagnetic storms and to determine to what extent valid forecasting of these phenomena can be made.

Since forecasting procedures require a definition of ionospheric and magnetospheric disturbance and quietness levels, a Combined Geomagnetic and Ionospheric Catalogue and a list of storms will be produced. A rank technique will be developed to define the most disturbed periods for European data based on power, maximum amplitude and duration of storm-time, each normalised to their peak values for the whole period of observations. As well as being an essential element of the IDCE database, the resulting classification should be of interest to the scientific community.

**Groups Involved:**

Rutherford Appleton Laboratory, Chilton, Great Britain [Scientific and financial coordination of the project],

IZMIRAN, Academy of Sciences, Moscow, Russia [Coordination of the FSU ionospheric stations],

Space Research Centre, Polish Academy of Sciences, Poland [IDCE coordination],

Royal Meteorological Institute, Brussels, Belgium [Real-time data],

France Telecom CNET, Lannion, France [Data].

Given that the proposed project achieves its objectives it will enhance the capability to process, assimilate and analyse increasingly complex data sets. Real-time data access is also required for validation and initialization of forecasting models. It is expected that regional storm assessments and forecasting should be more reliable, indicating the magnitude and duration of the storm events. Furthermore, a combined list of large geomagnetic and ionospheric storms can be useful to study their adverse effects on communications, human health and biosphere.

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## 13. URSI GENERAL ASSEMBLY MEETING - LILLE 1996

### Symposium G5: Computer Aided Processing of Ionograms and Ionosonde Records

INAG is sponsoring a symposium at the forthcoming URSI General Assembly. This meeting will be mainly interested in computer processing of ionograms and the application of these techniques to ionospheric data problems. The program has now been decided and I will to produce a proceedings containing the papers presented at the meeting in Lille, together with any other papers people contribute on this topic. If you were unable to present a paper at Lille, but will be interested in contributing to the proceedings, please let me know. The format will be similar to UAG-104: six page maximum limit and a copy of the text on disk in Word for Windows or WordPerfect as well as ASCII.

As a reminder of what our interests are, here is the text from the flyer.

- How many different computer methods are being used for scaling ionograms? Which method suits your needs; which method do you use? Do you favour trace following; do you prefer a neural network approach; have you a pattern recognition algorithm you feel is showing success? Where can the different computer scaling packages be obtained? Are semi-automatic scaling methods being developed and are they more reliable?
- How important is the magnitude, and type, of error in computer scaling? Can computer methods do a better job than a person? Do some computer methods have different types of errors than others? What problems do you have? How well is partial blanketing, sporadic E multiples handled? Does spread F cause problems? Are ionograms with angle of arrival information scaled significantly better? How much of an advantage is it to separate the ordinary and extra-ordinary modes when computer scaling ionograms?
- What applications exist for using computer scaled data? How important are errors in the scaled data for these applications? What risk does a group of bad data points present and how is the risk minimised? Does scaling more ionograms limit errors, or does it just disguise the main faults of the computer method? Should ionograms be scaled by two computer methods?
- What information should be scaled? Is the electron density profile more important than the critical frequencies? Are computer scaled electron density profiles accurate; what are the main sources of error? Are there major differences between computer scaling vertical and oblique ionograms?

The majority of oblique and vertical incidence ionospheric records will soon be almost entirely processed by automatic, computer methods. Now is the time to discuss widely the potential as well as the limitations of these methods.

**I look forward to seeing some of you at Lille and receiving contributions from others after the meeting.**

## 14. INAG EMAIL DIRECTORY

I have reproduced here an email directory for the majority of the email addresses I have for INAG members and others I know are interested in INAG activities. The list, at this stage, has problems. A few of the email addresses don't work for me. This probably mean the address is either out of date, or just plain wrong. I have marked the addresses I cannot use with a **. If you know a better address, or if any of the addresses I have quoted here are incorrect, please let me know. I will circulate the latest list after corrections come in. If anybody would like to receive the list electronically, please let me know.

Email address lists are both a convenience and, potentially, a nuisance. The nuisance occurs when they are used for advertising purposes. I hope people appearing on this list regard it an advantage for their address to be circulated. If you feel this is not the case, please let me know and I will take your name off further updates of the list.

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# 15. COMPUTER CODES FOR IONOGRAM PARAMETERS

## 15.1 Introduction

A wide range of parameters scaled from ionograms are supported by URSI, through INAG. At the IUGG INAG meeting, Boulder July 1995, we decided to collect comments from people on these parameters to be included in this INAG Bulletin when all members would be asked to offer their thoughts. The collected comments will be discussed at the URSI General Assembly INAG Meeting in Lille.

Digital systems are introducing new parameters and some of the older parameters appear to have fallen into disuse. Since it is only possible to code 100 parameters with the present two figures, a survey of how the codes are currently being used is warranted. While it will be valuable to retain lists of the older definitions, it is probably not necessary to reserve an archive number for parameters that are most useful in local studies.

As a reminder, the present coding system uses two figures to describe a parameter code for computer archiving - the archive number. This was devised for punched cards. The first column (the tens figure) usually gives the layer:

| | |
|---|---|
| 0 | F2 layer |
| 1 | F1 layer |
| 2 | E layer |
| 3 | Es layer |
| 4 | other |
| 5 | spread F and oblique traces |
| 6 | N(h) profiles |
| 7 | TEC |
| 8,9 | not used |

and the second column (the units figure) gives the type of parameter:

| | |
|---|---|
| 0 | frequency, often ordinary ray |
| 1 | frequency, often extraordinary ray |
| 2 | frequency |
| 3 | M factor |
| 4 | height |
| 5 | height |
| 6 | height usually |
| 7,8,9 | other |

## 15.2 Comments Made to Date

### 15.2.1 Digisonde user:

As part of IIWG's VIM campaign the need arose for the addition of three more parameters, the layer peak heights zmF2 and zmF1, and a measure of the half thickness of the F2 layer, zhalfNm. The decision to add new parameters to the URSI approved parameters file rather than creating a new "VIM format" was made after the Kyoto General Assembly I believe. We discussed the additions at one of the IIWG Business Meetings in Boulder. For our own data files we also made use of the hitherto unused codes 80-89 to store a number of automatically scaled parameters from the Digisonde systems that proved useful for data analysis. While this was our personal decision it was necessary so that no data were lost in our databases. With regards to the community, our choices have been disseminated through the distribution of our data and programs to others. We have freely shared our software with others so that they do not have to repeat the labor. It is at this point that the decisions we made started to reach the community. This was not our original intention but is a reality of quickly developing research. When we made our choice of codes we studied the URSI table, but we were unaware of the "weakly held" URSI naming conventions. Assume we use codes 94 etc. for the peak heights, and zhalfNm, that leaves the question about the automatic parameters (codes 80-89). Do we simply leave them as they are?

It is not too late to change the Digisonde-community adopted set of codes. It will require us to "filter" several hundred megabytes of data to whatever codes are decided upon, but it can be done. As a matter of convenience for the majority of groups that have used the additional parameters, it seems best not to change them. IIWG will submit the format amendments shown below to the Lille GA for URSI approval.

### 15.2.2 Digisonde user:

Where I have answered "Yes" to "Use", I have automatically answered "Yes" to "Used" (i.e. I have worked on the principal that if I am/have been interested in work that has used these parameters, so will/are/have others). Whenever I have answered "Yes" to "Use" - and hence "Used" - I have answered "Yes" to "Keep" (and "No" to "Abandon"). This is because I have worked on the principal that if I have used these parameters then others may have a similar need.

Personally, I think that if the data is in digital form the entire trace ought to be extracted and inverted (for instance using ARTIST, SMARTIST, or similar.). I realise that as they stand these programs are inadequate for the purposes proposed, but perhaps if we could establish a standardised exchange format for the raw ionospheric data, we could then concentrate on updating the image processing (i.e. trace extraction) algorithms used in these programs.

As a consequence of the above, I have suggested that many of the "out-dated" parameters that can be obtained more accurately from an inverted true height profiles be abandoned (e.g. h1, h2, h3 etc.). I do not hold any of my opinions very strongly - except obvious ones like “don't abandon critical frequencies and peak heights”.

### 15.2.3 Research ionosonde user

I hardly ever use hourly values, though I sometimes read papers by authors who do depend on them. I acknowledge a certain value in preserving and augmenting a climatology of more than 50 years' standing, and on this ground alone (and until ‘modern’ methods have had a chance to develop a similar history ...but when will they start, URSI?), I endorse any sensible hourly-value archive effort. Thus, (and although my heart is with research uses of ionosonde methods where ‘anything goes’ EXCEPT doing something because it has always been done that way) I shall try to answer in the spirit of the questions.

I think a simplification could be considered; on the assumption that all parameters will be subject to some kind(s) of machine processing before they are distributed, an option might be to distribute a pre-processing program (a small .exe file) along with any substantial quantity of data, e.g., on CD-ROM. In that case, the following suggestion (and others like it) could be dealt with by the pre-processing program.

In the present case (foF2, fxF2, fzF2; the same remarks can apply to F1, E layers, etc.), just scale the x or z values when o is absent and x or z must be used to get a value representative for the layer. Append (or prefix) the value with x or z. If both x and z are available, give preference to x if it is spread (and report the spread quantitatively; see comments below). The pre-processing program uses the appended character, if any, to give the user the best estimate of fmaxF2 (F1, E), (+- the spread value, if any and if wanted).

### 15.2.4 Comments from scaler with over 40 years experience

I have never scaled some of these parameters so I didn’t make any comments. Some people would like more and some less and different information about parameters. Scaling has changed a few times and different parameters have been added or not scaled. People who are using the data for different reasons (without film or digital ionogram) are better suited to make suggestions for improving parameters than me. The published parameters should be accompanied with a diagram. Scaled parameters should represent the true image of the ionogram, not an interpretation.

**Editor**: This comment was accompanied by a 1947 scaling sheet. The parameters scaled at this time were: fmin, E1 ($f^0$, h’, 1500-MUF, M1500), Es ($f^b$, $f^m$, f, h’), $E_2s$ ($f^b$, f, h’), $E_2$ ($f_0$, h’), $F_1$ ($f^0$, h’, 1500-MUF, M1500, 3000-MUF, M3000), $F_2$ ($f^0$, h’, $h_{max}$, 1500-MUF, M1500, 3000-MUF, M3000, %dep, spread). Not all of these were scaled, but the list indicates how nomenclature has changed.

### 15.2.5 Research scientist

Either I or colleagues have used virtually all the parameters from 00-54, and 90-94 inclusive. We have never used any of the parameters from 55-79. My own view is that there is no need to abandon any of the parameters that have been used in the past. Re-allocation of a number utilised in the past is only likely to lead to confusion, inconsistency and mis-understanding of use through the world. I would prefer to take another approach, namely to identify the new parameters required, and allocate them numbers. Is there any need to remain below 100?

## 15.3

## 15.4 Current Codes Used by ARTIST and IIWG

| ARTIST Code | Parameter | URSI Code | Units | Description |
|---|---|---|---|---|
| 7 | FMINF | 80 | .1 MHz | Minimum frequency of F trace (50 kHz increments). Equals fbEs when Es present |
| 8 | FMINE | 81 | .1 MHz | Minimum frequency of E trace (50 kHz increments). |
| 15 | HOM | 82 | km | Parabolic E region peak height |
| 16 | YM | 83 | km | Parabolic E region semi-thickness |
| 17 | QF | 84 | km | Average range spread of F trace |
| 18 | QE | 85 | km | Average range spread of E trace |
| 22 | FF | 86 | .01 MHz | Frequency spread between fxF2 and fxI |
| 23 | FE | 87 | .01 MHz | As FF but considered beyond foE |
| 25 | fMUF3000 | 88 | .01 MHz | MUF(D)/obliquity factor |
| 26 | h'MUF3000 | 89 | km | Virtual height at fMUF |
|  | zmE | 90 | km | Peak height E layer |
|  | zmF1 | 91 | km | Peak height F1 layer |
|  | zmF2 | 92 | km | Peak height F2 layer |
|  | zhalfNm | 94 | km | True height at half peak electron density |

## 15.5 Comments About the Parameters

To help you form your opinions about the different parameters, below are the details of this first rather small sample of returns. Each parameter is defined, as a reminder of what it is, then the four levels of recommendation are shown as numbers. For instance, for foF2, 5 people said they have used foF2 and 1 said they hadn't. However, 6 said we should not abandon foF2. The tabulated responses are rather variable, but they give an indication of what is regarded as useful and what isn't. Following these responses are some comments on the parameter. The first comment gives the number of station years when the parameter was scaled in January for data on the two NGDC CD-ROMs of ionospheric data and is indicative of available computer accessible data. This count is divided into two sets, one for each CD-ROM, that give a feel for how scaling has changed over time. Note: no count is given if both are zero. Following this are comments from the people whose returns I have received.

A list of all the parameters was circulated asking people how useful the codes are and whether an archive number should be retained for them. Four responses were sought for each code:

| | |
|---|---|
| (a) (Use) | a parameter you sometimes use? (Yes/No) |
| (b) (Used) | a parameter you believe is used by some groups? (Yes/No)<br>Please indicate your reason for thinking this. |

(c) (Keep) a parameter you feel should be retained? (Yes/No)

Please give reasons, if possible.

(d) (Abandon) a parameter that could be abandoned? (Yes/No)

Please give reasons, if possible.

A sample answer could be:

00 foF2 ordinary wave critical frequency from the highest stratification in the F region, called the F2 critical frequency.

(a) Use Y (b) Used Y -. (c) Keep Y (d) Abandon N

- *possibly the most important parameter scaled from an ionogram*

**Code parameter Definition**

**00 foF2** ordinary wave critical frequency from the highest stratification in the F region, called the F2 critical frequency.

(a) Use Y-5/N-1 (b) Used Y-4/N-1 (c) Keep Y-6/N-0 (d) Abandon Y-0/N-6

- 1646 station years 1957/75; 1160 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter and possibly the most important parameter scaled from an ionogram.

**01 fxF2** extra-ordinary wave critical frequency from the highest stratification in the F region, called the F2 critical frequency.

(a) Use Y-3/N-3 (b) Used Y-4/N-0 (c) Keep Y-5/N-0 (d) Abandon Y-2/N-1

- 11 station years 1957/75; 51 station years 1976/90 on NGDC CD-ROM.
- Complementary to fxI with the use of descriptive letter X.
- It is unambiguous and may be useful.

**02 fzF2** Z mode frequency from the highest stratification in the F region.

(a) Use Y-2/N-4 (b) Used Y-6/N-0 (c) Keep Y-5/N-0 (d) Abandon Y-0/N-4

- 44 station years 1957/75; 32 station years 1976/90 on NGDC CD-ROM.
- Used to determine foF2 (ZF), but only has sporadic usefulness.

**03 M(3000)F2** the 3000km MUF factor for the F2 region.

(a) Use Y-5/N-1 (b) Used Y-4/N-1 (c) Keep Y-6/N-0 (d) Abandon Y-0/N-6

- 1518 station years 1957/75; 1090 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter and possibly second, after foF2, in importance.
- Although I would not have expected to be convinced, I feel that Adolf Paul succeeded in establishing the utility of the M values as surrogate parameters for height dependencies.

**04 h'F2** minimum virtual height of the ordinary wave trace for the highest stable stratification in the F region.

(a) Use Y-5/N-0 (b) Used Y-4/N-0 (c) Keep Y-4/N-0 (d) Abandon Y-0/N-2

- 604 station years 1957/75; 773 station years 1976/90 on NGDC CD-ROM.

- Regarded as a standard ionogram parameter by some.
- I suggest changing the rules: archive only when the trace is "flat enough" that the height has a decent chance to approximate a real height (and its dynamics). "Decent Chance" can have a precise definition: the height should be measured only at, and when, the frequency is seen or reasonably believed to be at least a factor of 2 (0.5) from the nearest other-layer penetration frequency (of the same O,X,Z mode). Same remarks apply to F1, E heights.
- Useful for assessing the success with which automatic trace extraction algorithms function (e.g. compared to manual trace extraction)
- I thought this was just the minimum in retardation between foF1 and foF2.

**05** **hpF2** the virtual height of the ordinary wave mode at the frequency given by 0.834 of foF2.

(a) Use Y-3/N-2 (b) Used Y-3/N-1 (c) Keep Y-2/N-0 (d) Abandon Y-1/N-2

- 60 station years 1957/75; 63 station years 1976/90 on NGDC CD-ROM.
- Useful for calculating hmF2 when full h'(f) trace not available.
- Have used, on request, for astronomers.
- Abandon in favor of M3000, on the assumption that the archives already contain mostly M3000.
- Because of its definition, this is likely to confuse. Abandon in favour of less ambiguous terms.

**06** **h'Ox** the virtual height of the X trace at foF2.

(a) Use Y-5/N-0 (b) Used Y-0/N-4 (c) Keep Y-0/N-3 (d) Abandon Y-3/N-0

- 2 station years 1957/75; 0 station years 1976/90 on NGDC CD-ROM.
- Idiot makeshift parameter; abandon.
- Difficult to see this meaning anything these days. Easily calculated from digital ionograms, if really needed, and no longer appropriate for manual scaling.

**07** **MUF(3000)F2** the MUF for a single hop 3000km F2 region mode.

(a) Use Y-2/N-3 (b) Used Y-2/N-2 (c) Keep Y-2/N-2 (d) Abandon Y-3/N-0

- 2 station years 1957/75; 39 station years 1976/90 on NGDC CD-ROM.
- Redundant make-work parameter; abandon.
- Can be deduced from M(3000) & foF2.

**08** **hc** the height of the maximum obtained by fitting a theoretical h'f curve for the parabola of best fit to the observed ordinary wave trace near foF2 and correcting for underlying ionisation.

(a) Use Y-0/N-5 (b) Used Y-0/N-4 (c) Keep Y-0/N-4 (d) Abandon Y-3/N-0

- Redundant make-work parameter; abandon
- No obvious need.

**09** **qc** the thickness of the parabola of best fit used to obtain hc?

(a) Use Y-0/N-5 (b) Used Y-0/N-4 (c) Keep Y-1/N-3 (d) Abandon Y-2/N-0

- Redundant make-work parameter; abandon

**10** **foF1** the ordinary wave F1 critical frequency.

(a) Use Y-5/N-0 (b) Used Y-4/N-0 (c) Keep Y-5/N-0 (d) Abandon Y-0/N-2

- 720 station years 1957/75; 769 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter.

**11** **fxF1** the extra ordinary wave F1 critical frequency.

(a) Use Y-2/N-3 (b) Used Y-2/N-2 (c) Keep Y-3/N-0 (d) Abandon Y-1/N-2

- Default when there is a G condition.
- Difficult to think of an occasion when this would be tabulated for archiving.

**12** -

- fLF1

**13** **M(3000)F1** the 3000km MUF factor for the F1 region.

(a) Use Y-5/N-1 (b) Used Y-3/N-1 (c) Keep Y-3/N-1 (d) Abandon Y-0/N-3

- 407 station years 1957/75; 27 station years 1976/90 on NGDC CD-ROM.
- Useful for assessing the success with which automatic trace extraction algorithms function (e.g. compared to manual trace extraction)
- May still have some propagation value.

**14** **h'F1** presumably, minimum height of F1 layer (=h'F in daytime)?

(a) Use Y-3/N-2 (b) Used Y-3/N-1 (c) Keep Y-3/N-1 (d) Abandon Y-1/N-2

- 2 station years 1957/75; 24 station years 1976/90 on NGDC CD-ROM.
- Useful for assessing the success with which automatic trace extraction algorithms function (e.g. compared to manual trace extraction)
- Hardly ever free from severe group retardation, and therefore useless. abandon

**15** -

- h1LF1

**16** **h'F** minimum virtual height of the ordinary wave F trace.

(a) Use Y-5/N-0 (b) Used Y-4/N-0 (c) Keep Y-4/N-1 (d) Abandon Y-1/N-2

- 880 station years 1957/75; 921 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter.
- Interchangeable with h'F2; see my remarks about changing the rules.
- Can be determined from h'F2 & h'F1.
- A useful limit height from an ionogram with greater nighttime than daytime value possibly.

**17** **MUF(3000)F1** the MUF for a single hop 3000km F1 region mode.

(a) Use Y-6/N-0 (b) Used Y-5/N-0 (c) Keep Y-2/N-2 (d) Abandon Y-1/N-2

- 2 station years 1957/75; 27 station years 1976/90 on NGDC CD-ROM.
- Can be deduced from foF1 & M(3000)F1 so why store it separately?

**18 - 19** -

**20** **foE** the ordinary wave critical frequency corresponding to the lowest thick layer in the E region which causes a discontinuity in the height of the E trace.

(a) Use Y-6/N-0 (b) Used Y-5/N-0 (c) Keep Y-5/N-1 (d) Abandon Y/N-4

- 1063 station years 1957/75; 1004 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter. Often seems a good check on scaling, even though very predictable.
- Predictable, useful only for particle E measurement.
- An indicator of station local time and can alsobe a useful check on scaling.

**21** -

**22** **foE2** the ordinary wave critical frequency of an occulting thick layer which sometimes appears between the normal E and F region.

(a) Use Y-1/N-4 (b) Used Y-4/N-0 (c) Keep Y-4/N-0 (d) Abandon Y-1/N-3

- 17 station years 1957/75; 88 station years 1976/90 on NGDC CD-ROM.
- I think the minor strata of the E-region comprise an important topic (tides, AGWs, etc.) but I think that any worker who seriously intends to study this would be foolish to depend on archived data. Conversely, it is a waste of effort to try to define "rules" which would safely (i.e., without bias) permit generating such an archive. I urge abandoning such details.
- Has value for local archives and possibly group studies.

**23** -

**24** **h'E** minimum virtual height of the normal E layer.

(a) Use Y-5/N-0 (b) Used Y-3/N-1 (c) Keep Y-3/N-1 (d) Abandon Y-1/N-2

- 512 station years 1957/75; 664 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter.
- Useful for assessing the success with which automatic trace extraction algorithms function (e.g. compared to manual trace extraction)
- The height of the E-base could be important, but cannot be measured in a consistent way, and with sufficient precision, by "scaling". On the other hand, it has some chance to emerge from well-designed N(h) inversion schemes. Leave it out of the hourly values, and add thereby to the yield expected of N(h) work.

**25** -

**26** **h'E2** minimum virtual height of the ordinary wave E2 layer.

(a) Use Y-1/N-4 (b) Used Y-3/N-1 (c) Keep Y-3/N-0 (d) Abandon Y-1/N-2

- 17 station years 1957/75; 87 station years 1976/90 on NGDC CD-ROM.
- See remarks about foE2.

**27 - 29** -

**30** **foEs** ordinary wave top frequency corresponding to the highest frequency at which a mainly continuous Es trace is observed.

(a) Use Y-5/N-0 (b) Used Y-4/N-0 (c) Keep Y-4/N-0 (d) Abandon Y-0/N-3

- 958 station years 1957/75; 973 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter.
- All of my general remarks re foF2, E, etc., can apply with little or no modification to Es as well. I consider that a "top Es frequency", converted to foEs in pre-processing (when there is observational basis to mandate this), is important as a measure of Ne in patchy clouds.

**31** **fxEs** extra ordinary wave top frequency corresponding to the highest frequency at which a mainly continuous Es trace is observed.

(a) Use Y-2/N-3 (b) Used Y-3/N-1 (c) Keep Y-3/N-0 (d) Abandon Y-0/N-2

- 0 station years 1957/75; 1 station year 1976/90 on NGDC CD-ROM.

**32** **fbEs** the lowest ordinary wave frequency at which the Es layer begins to become transparent.

(a) Use Y-5/N-1 (b) Used Y-5/N-0 (c) Keep Y-6/N-0 (d) Abandon Y-0/N-4

- 676 station years 1957/75; 695 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter.
- Useful, along with the top frequency of Es, for climatological work bearing on atmospheric dynamics (winds, tides, AGWs), on meteoric input; also for telecommunications. No other ionospheric diagnostic technique can match the ionosonde in this subject area.
- An ambiguous parameter, but worth keeping.

33 **ftEs** the highest frequency at which a mainly continuous Es trace is observed irrespective of magnetoionic component.

(a) Use Y-2/N-1 (b) Used Y-5/N-0 (c) Keep Y-3/N-1 (d) Abandon Y-2/N-2

- 62 station years 1957/75; 26 station years 1976/90 on NGDC CD-ROM.
- Often used inadvertently.
- Redundant with a top-frequency parameter as I would define it.
- Preferable not to have this option as it is ambiguous when scaled.

34 **h'Es** the minimum virtual height of the trace used to give foEs.

(a) Use Y-5/N-0 (b) Used Y-4/N-0 (c) Keep Y-5/N-0 (d) Abandon Y-0/N-3

- 568 station years 1957/75; 668 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter.
- Although Es heights can be important for physics, they cannot be "scaled" by eye to sufficient precision. Digital systems can yield at least 0.5 km precision, and if that is done, the parameter(s) begin to carry usefulness.

35 unknown

- 2 station years 1957/75; 0 station years 1976/90 on NGDC CD-ROM.

36 **type Es** the type of Es used to give foEs.

(a) Use Y-3/N-2 (b) Used Y-4/N-0 (c) Keep Y-5/N-0 (d) Abandon Y-0/N-3

- 225 station years 1957/75; 467 station years 1976/90 on NGDC CD-ROM.
- Still regarded as a standard ionogram parameter.
- We KNOW that several different phenomena are lumped as Es. I believe that the "typing" is potentially useful.
- Probably the wrong types of sporadic E are being scaled, but it is still worthwhile maintaining some effort here. There is also already a large archive.

**37- 39** -

- 2 station years 1957/75; 0 station years 1976/90 on NGDC CD-ROM for 37, 38 and 39 - all unknown.

**40** **foF1.5** the ordinary wave critical frequency of the intermediate stratification between F1 and F2 regions.

(a) Use Y-1/N-4 (b) Used Y-2/N-1 (c) Keep Y-1/N-0 (d) Abandon Y-2/N-1

- 2 station years 1957/75; 0 station years 1976/90 on NGDC CD-ROM.
- Presence of F1.5 'layer' indicated by H

**41** -

**42** **fmin** the lowest frequency at which echo traces are observed on the ionogram.

(a) Use Y-5/N-0 (b) Used Y-4/N-0 (c) Keep Y-5/N-0 (d) Abandon Y-2/N-1

- 997 station years 1957/75; 960 station years 1976/90 on NGDC CD-ROM.
- A standard ionogram parameter.
- A useful equipment parameter.
- Although there may be individual stations and systems where this makeshift parameter has some meaning, I think it is not in proportion to the effort; also, I doubt that comparing fmin among diverse stations is meaningful.

**43 M(3000)F1.5** the 3000km MUF factor for the F1.5 region.

(a) Use Y-0/N-4 (b) Used Y-0/N-2 (c) Keep Y-0/N-2 (d) Abandon Y-4/N-0

**44 h'F1.5** the minimum virtual height of the ordinary wave trace between foF1 and foF1.5.

(a) Use Y-0/N-5 (b) Used Y-1/N-2 (c) Keep Y-0/N-2 (d) Abandon Y-3/N-0

- 1 station year 1957/75; 0 station years 1976/90 on NGDC CD-ROM.

**45 - 46 -**

**47 fm2** the minimum frequency of the second order trace.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-2 (d) Abandon Y-2/N-0

- All my remarks about fmin apply, and more forcefully. Hard to see any value coming from this.

**48 hm** The height of maximum density of the F2 layer calculated by Titheridge's method.

(a) Use Y-0/N-4 (b) Used Y-0/N-3 (c) Keep Y-0/N-1 (d) Abandon Y-2/N-0

- This is surely "better" as a measure of hmaxF2 than hp, M3000, etc.; but we don't have 50 years * 100 stations of it, and we never will. So why bother dragging it along?

**49 fm3** the minimum frequency for the third order trace.

(a) Use Y-0/N-4 (b) Used Y-0/N-2 (c) Keep Y-0/N-1 (d) Abandon Y-0/N-0

- All my remarks about fmin apply, and more forcefully.

**50 foI** highest ordinary wave trace frequency on which reflections from the F region are recorded independent of whether they are reflected from overhead or obliquely.

(a) Use Y-1/N-3 (b) Used Y-1/N-1 (c) Keep Y-2/N-1 (d) Abandon Y-1/N-2

- Idiot makeshift parameter.

**51 fxI** highest frequency on which reflections from the F region are recorded independent of whether they are reflected from overhead or obliquely.

(a) Use Y-5/N-0 (b) Used Y-4/N-0 (c) Keep Y-5/N-0 (d) Abandon Y-1/N-3

- 219 station years 1957/75; 798 station years 1976/90 on NGDC CD-ROM.
- Regarded as a standard ionogram parameter by some.
- Idiot makeshift parameter.
- Aside from its intended uses, this is a convenient measure of the extent of the F region which can, with foEs, be a useful indicator of the upper frequency extent of returns on an ionogram.

**52 fmI** lowest frequency of at which frequency spread is observed from the

F region.

(a) Use Y-2/N-3 (b) Used Y-3/N-0 (c) Keep Y-2/N-0 (d) Abandon Y-2/N-3

- 34 station years 1957/75; 162 station years 1976/90 on NGDC CD-ROM.
- It is well worth while to have some measure of F-region spreading; the result can be interpreted directly as dN/<N> (%). Perhaps the easiest way is just to report the upper-lower limits rather than foF2 (etc.; and see remarks up there), and let a pre-processor interpret properly. This is an important issue, and it deserves study to be sure it is done well.

**53** **M(3000)I** the 3000km MUF factor deduced from the upper frequency edge of the spreading.

(a) Use Y-0/N-5 (b) Used Y-1/N-3 (c) Keep Y-2/N-2 (d) Abandon Y-2/N-2

- 0 station years 1957/75; 30 station years 1976/90 on NGDC CD-ROM.
- Redundant and make-work.

**54** **h'I** minimum slant range of the traces determining fxI.

(a) Use Y-0/N-5 (b) Used Y-1/N-3 (c) Keep Y-1/N-2 (d) Abandon Y-2/N-1

- 0 station years 1957/75; 31 station years 1976/90 on NGDC CD-ROM.
- Too many of these hair-brained inventions are underfoot; they are the province of proper research ionosondes; there is nothing an archive can do to contribute usefully in this way.

**55** **R/S** the extent of range spread present (IPS use this).

(a) Use Y-5/N-1 (b) Used Y-4/N-0 (c) Keep Y-3/N-0 (d) Abandon Y-1/N-3

- 0 station years 1957/75; 5 station years 1976/90 on NGDC CD-ROM, unknown type.
- Never heard of it. Is it taken as a measure of transmitter power? of antenna beamwidth or lobes? Or of all that, plus ionospheric structure-scale?
- This was introduced for scaling spread F in Australia.

**56** **F/S** the extent of frequency spread present (IPS use this).

(a) Use Y-5/N-1 (b) Used Y-4/N-0 (c) Keep Y-3/N-0 (d) Abandon Y-1/N-3

- 0 station years 1957/75; 5 station years 1976/90 on NGDC CD-ROM, unknown type.
- (See remarks about frequency spreading)
- This was introduced for scaling spread F in Australia and other alternates are possible.

**57** **dFs** the total width in frequency of frequency spread traces for the F layer.

(a) Use Y-2/N-2 (b) Used Y-3/N-0 (c) Keep Y-2/N-0 (d) Abandon Y-0/N-2

- Why have one parameter, where 5 will do? (Sorry. It is hard to stay in the spirit of the question, with some of these).
- Same as 86

**58 - 59** -

58 dEs

**60** **fh'F2** The frequency at which h'F2 is measured.

(a) Use Y-1/N-4 (b) Used Y-2/N-2 (c) Keep Y-1/N-1 (d) Abandon Y-2/N-0

- utterly useless.

**61** **fh'F** The frequency at which h'F is measured.

(a) Use Y-1/N-4 (b) Used Y-2/N-2 (c) Keep Y-1/N-1 (d) Abandon Y-1/N-0

**62** -

**63** **h'mF1** The maximum virtual height in the o-mode.

(a) Use Y-0/N-6 (b) Used Y-1/N-3 (c) Keep Y-1/N-2 (d) Abandon Y-3/N-0

**64** **h1** True heights calculated by Titheridge's method at the sampling frequencies f1, f2, f3, f4, f5. This is the height for f1.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

- Not routinely used by anybody I know. Delete 64 to 69 unless there are groups using it.
- See remarks above, about hmF. This, and questions 64 - 69 are really questions of comparing this N(h) method with others. I do not think that a method which gives heights at 5 fixed frequencies is an adequate method for archive purposes

**65** **h2** height for f2.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

**66** **h3** height for f3.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

**67** **h4** height for f4.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

**68** **h5** height for f5.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

**69** **H** The effective scale height at hmF2 calculated by Titheridge's method.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

**70** **I2000 or I(2000)** Ionospheric electron content up to 2000 km (for a geostationary satellite measured by Faraday technique).

(a) Use Y-2/N-2 (b) Used Y-2/N-1 (c) Keep Y-3/N-0 (d) Abandon Y-0/N-1

- Are the TEC people using this format at all? If not, abandon 70 to 72.

**71** **I** Total electron content up to a geostationary satellite.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

(a) Use Y-1/N-2 (b) Used Y-1/N-0 (c) Keep Y-1/N-1 (d) Abandon Y-0/N-1

**72** **Ixxxx or I(xxxx)** Ionospheric electron content up to satellite height xxxx for non geostationary satellites.

(a) Use Y-0/N-5 (b) Used Y-0/N-3 (c) Keep Y-0/N-3 (d) Abandon Y-2/N-0

- How did these get in here? Why are they the province of INAG? Why not include rainfall and snowdepth? Total content measures are undeniably useful, but keep INAG's tasks uncluttered by non-ionosonde matters.

**73-78** -

**79** **T** The total sub-peak content calculated by Titheridge's method.

(a) Use Y-2/N-0 (b) Used Y-0/N-1 (c) Keep Y-2/N-0 (d) Abandon Y-1/N-0

- See comment for 64.
- This is probably more useful than the various heights mentioned above; but I don't think it is a worthy archive effort.

**80-89** -

- 80-89 - Digisonde Autoscaled Values - see earlier table.
- 0 station years 1957/75; 11 station years 1976/90 on NGDC CD-ROM of fmnF (80) and fmnE (81).
- Similarly, it is senseless to haggle over archiving individual profile parameters. An archive pre-processing program can retrieve any of the following, provided that the profile itself is archived in some form.

**90** **hmE** peak of E region from true height analysis.

(a) Use Y-2/N-2 (b) Used Y-2/N-0 (c) Keep Y-3/N-0 (d) Abandon Y-0/N-2

**91** **hmF1** peak of F1 region from true height analysis.

(a) Use Y-2/N-2 (b) Used Y-2/N-0 (c) Keep Y-3/N-0 (d) Abandon Y-0/N-2

**92** **hmF2** peak of F2 region from true height analysis .

(a) Use Y-2/N-1 (b) Used Y-2/N-0 (c) Keep Y-3/N-0 (d) Abandon Y-0/N-2

**93** **h(half)Nm** semithickness of layer from true height analysis.

(a) Use Y-2/N-2 (b) Used Y-2/N-0 (c) Keep Y-3/N-0 (d) Abandon Y-0/N-2

**94-99** -

\- **foF0.5** like foE2, but when the trace shows no cusp.

(a) Use Y-0/N-3 (b) Used Y-1/N-1 (c) Keep Y-2/N-1 (d) Abandon Y-1/N-1

- Indicated by presence of the descriptive letter H.
- Unworthy of comment.

## 15.6 Summary

Clearly, there is a good range of opinion here. If you are aware of parameters using codes that are not mentioned here, please let me know. We want this list to be as comprehensive as possible.

I have included a questionnaire for you to fill out. Please do this as soon as possible and send it back to me. We will discuss this further at the forthcoming INAG meeting at the URSI General Assembly in Lille.

*My thanks to those who offered the early comments listed here.*

## 16. QUESTIONNAIRE: COMPUTER CODES FOR IONOGRAM PARAMETERS

This questionnaire will help gauge interest in the scaled ionogram parameters that should be archived for later, computer access. Please return this questionnaire to

**Phil Wilkinson, P O Box 5606, West Chatswood, NSW 2057, AUSTRALIA.**

If you would prefer to send in an **email** reply, please send an **email** request to me at phil@ips.gov.au.

There are three elements to your response:

- Tick the ☐ if you agree with the definition of the parameter; put a cross (X) if you disagree; or a zero (o) if the definition seems incomplete or vague. If you prefer a different definition which you feel is more accurate, please supply it, preferably separately, with reasons for your preferences.
- For each of the categories (a) - (d) (see table below this text) circle the response that is appropriate (Y for yes or N for no). Note: just because you feel a parameter shouldn't be kept, it *doesn't* follow you think we should abandon archiving it.
- Write beneath, or a separate page, any comments you have on the parameter.

| | |
|---|---|
| (a) (Use) | answer YES even if you only use this parameter occasionally? (Yes/No) |
| (b) (Used) | this is a parameter you **believe** is used by others? ( Yes/No)<br>*If possible, please indicate your reason for thinking this.* |
| (c) (Keep) | this is a parameter you feel should be retained? (Yes/No)<br>*Please give reasons, if possible.* |
| (d) (Abandon) | this is a parameter that **can or should** be abandoned? (Yes/No)<br>*It is especially important to give reasons here if you answered YES.* |

Code parameter Definition

**00** **foF2** ☐ ordinary wave critical frequency from the highest stratification in the F region, called the F2 critical frequency.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

- *Place your comments here, or on a separate piece of paper.*

**01** **fxF2** ☐ extra-ordinary wave critical frequency from the highest stratification in the F region, called the F2 critical frequency.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**02** **fzF2** ☐ Z mode frequency from the highest stratification in the F region.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**03** **M(3000)F2** ☐ the 3000km MUF factor for the F2 region.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**04** **h'F2** ☐ minimum virtual height of the ordinary wave trace for the highest stable stratification in the F region.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**05** **hpF2** ☐ the virtual height of the ordinary wave mode at the frequency given by 0.834 of foF2.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**06** **h'Ox** ☐ the virtual height of the X trace at foF2.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**07** **MUF(3000)F2**☐ the MUF for a single hop 3000km F2 region mode.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**08** **hc** ☐ the height of the maximum obtained by fitting a theoretical h'f curve for the parabola of best fit to the observed ordinary wave trace near foF2 and correcting for underlying ionisation.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**09** **qc** ☐ the thickness of the parabola of best fit used to obtain hc?

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**10** **foF1** ☐ the ordinary wave F1 critical frequency.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**11** **fxF1** ☐ the extra ordinary wave F1 critical frequency.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**12** -

**13** **M(3000)F1**☐ the 3000km MUF factor for the F1 region.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**14** **h'F1** ☐ presumably, minimum height of F1 layer (=h'F in daytime)?

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**15** -

**16** **h'F** ☐ minimum virtual height of the ordinary wave F trace.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

17 **MUF(3000)F1** ☐ the MUF for a single hop 3000km F1 region mode.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**18 - 19 -**

20 **foE** ☐ the ordinary wave critical frequency corresponding to the lowest thick layer in the E region which causes a discontinuity in the height of the E trace.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**21** -

22 **foE2** ☐ the ordinary wave critical frequency of an occulting thick layer which sometimes appears between the normal E and F region.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**23** -

24 **h'E** ☐ minimum virtual height of the normal E layer.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**25** -

26 **h'E2** ☐ minimum virtual height of the ordinary wave E2 layer.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**27 - 29 -**

30 **foEs** ☐ ordinary wave top frequency corresponding to the highest frequency at which a mainly continuous Es trace is observed.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

31 **fxEs** ☐ extra ordinary wave top frequency corresponding to the highest frequency at which a mainly continuous Es trace is observed.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

32 **fbEs** ☐ the lowest ordinary wave frequency at which the Es layer begins to become transparent.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**33** **ftEs** ☐ the highest frequency at which a mainly continuous Es trace is observed irrespective of magnetoionic component.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**34** **h'Es** ☐ the minimum virtual height of the trace used to give foEs.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**35** -

**36** **type Es** ☐ the type of Es used to give foEs.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**37- 39** -

**40** **foF1.5** ☐ the ordinary wave critical frequency of the intermediate stratification between F1 and F2 regions.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**41** -

**42** **fmin** ☐ the lowest frequency at which echo traces are observed on the ionogram.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**43** **M(3000)F1.5** ☐ the 3000km MUF factor for the F1.5 region.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**44** **h'F1.5** ☐ the minimum virtual height of the ordinary wave trace between foF1 and foF1.5.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**45 - 46** -

**47** **fm2** ☐ the minimum frequency of the second order trace.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**48** **hm** ☐ The height of maximum density of the F2 layer calculated by Titheridge's method.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**49** **fm3** ☐ the minimum frequency for the third order trace.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**50** **foI** ☐ highest ordinary wave trace frequency on which reflections from the F region are recorded independent of whether they are reflected from overhead or obliquely.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**51** **fxI** ☐ highest frequency on which reflections from the F region are recorded independent of whether they are reflected from overhead or obliquely.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**52** **fmI** ☐ lowest frequency of at which frequency spread is observed from the F region.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**53** **M(3000)I** ☐ the 3000km MUF factor deduced from the upper frequency edge of the spreading.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**54** **h'I** ☐ minimum slant range of the traces determining fxI.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**55** **R/S** ☐ the extent of range spread present (IPS use this).

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**56** **F/S** ☐ the extent of frequency spread present (IPS use this).

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**57** **dFs** ☐ the total width in frequency of frequency spread traces for the F layer.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**58 - 59 -**

**60** **fh'F2** ☐ The frequency at which h'F2 is measured.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**61** **fh'F** ☐ The frequency at which h'F is measured.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**62** -

**63** **h'mF1** ☐ The maximum virtual height in the o-mode.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**64** **h1** ☐ True heights calculated by Titheridge's method at the sampling frequencies f1, f2, f3, f4, f5. This is the height for f1.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**65** **h2** ☐ height for f2.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**66** **h3** ☐ height for f3.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**67** **h4** ☐ height for f4.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**68** **h5** ☐ height for f5.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**69** **H** ☐ The effective scale height at hmF2 calculated by Titheridge's method.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**70** **I2000 or I(2000)** ☐ Ionospheric electron content up to 2000 km (for a geostationary satellite measured by Faraday technique).

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**71** **I** ☐ Total electron content up to a geostationary satellite.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**72** **Ixxxx or I(xxxx)** ☐ Ionospheric electron content up to satellite height xxxx for non geostationary satellites.

(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**73-78** -

**79** **T** ☐ The total sub-peak content calculated by Titheridge's method.
(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**80-89** -

**90** **hmE** ☐ peak of E region from true height analysis.
(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**91** **hmF1** ☐ peak of F1 region from true height analysis.
(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**92** **hmF2** ☐ peak of F2 region from true height analysis .
(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**93** **h(half)Nm** ☐ semithickness of layer from true height analysis.
(a) Use YES / NO (b) Used YES / NO (c) Keep YES / NO (d) Abandon YES / NO

**94-99** -

Please fill out your comments and send this back by email as soon as possible. If you know of further parameters not on the list above, please send me the information. If you know of anybody else who may like to fill this out, please forward this mail to them. Thanks, in advance, for your assistance.

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