Status of and scientific results from the ISIS-I Topside Digital Ionogram Data Enhancement Project

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OUTLINE

BACKGROUND OF ALOUETTE/ISIS PROGRAM

TOPIST-PROCESSED ISIS-II TOPSIDE ELECTRON DENSITY PROFILES $N_e(h)$

VERSION-2 ISIS-I DIGITAL TOPSIDE IONOGRAMS

RESULTS USING VERSION-2 ISIS-I IONOGRAMS

BACKGROUND OF ALOUETTE/ISIS PROGRAM

6 satellites in the International Satellites for Ionospheric Studies program (ISIS)

4 Canadian-built & US-launched (contained swept-frequency radio sounders)

Alouette 1: 29 Sep 1962 launch operated for 10 yrs
Alouette 2: 29 Nov 1965 launch operated for 10 yrs
ISIS I: 30 Jan 1969 launch operated for 21 yrs
ISIS II: 01 Apr 1971 launch operated for 19 yrs

60 satellite-yrs of topside swept-frequency sounding
ISIS I & ISIS II also included fixed-frequency sounding
ISIS II included the first satellite-based auroral scanners

2 US-built & US-launched

Explorer 20 25 Aug 1964 fixed-freq sounding at 6 freq (1.5 to 7.22 MHz)
Explorer 31 29 Nov 1965 also known as Direct-Measurements Explorer A (DMEA) - it was launched with Alouette 2

Alouette/ISIS topside sounders produced analog data

Recorded on 7-track analog telemetry tapes at a global network of telemetry stations

Cost considerations ~ not all sounder data converted to 35-mm film ionograms

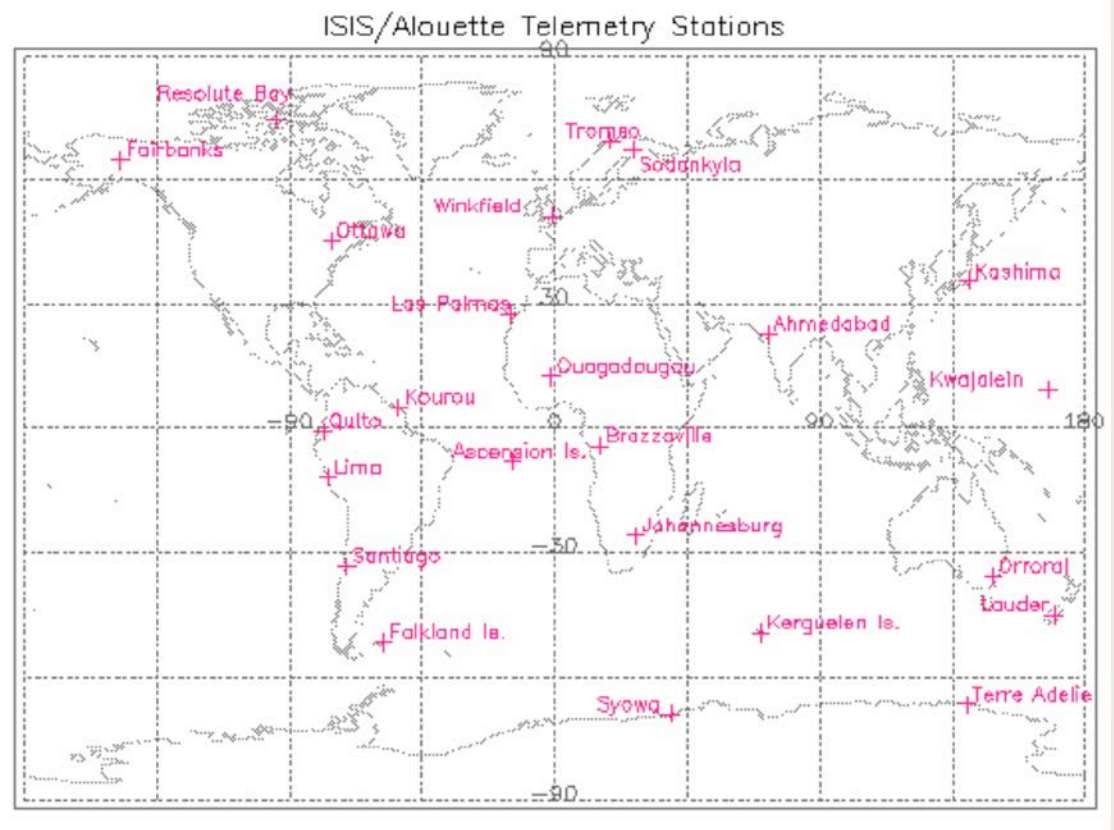
Only ~ 177,000 of millions of film ionograms manually converted to Ne(h)

1996: Analog-to-Digital (A/D) effort initiated on ~ 16,200 telemetry tapes

Tapes selected from 24 globally-distributed telemetry stations

> 588,000 digital topside ionograms produced

Benson [IES, 1996]
Bilitza et al [RS, 2004]
Benson & Bilitza [RS, 2009]



TOPIST-PROCESSED ISIS-II TOPSIDE ELECTRON DENSITY PROFILES $N_e(h)$

TOPIST ~ TOPside Ionogram Scaler with True height algorithm

Huang et al [*Ann. Geophys*. 2002]; *Bilitza et al* [*RS*, 2004]

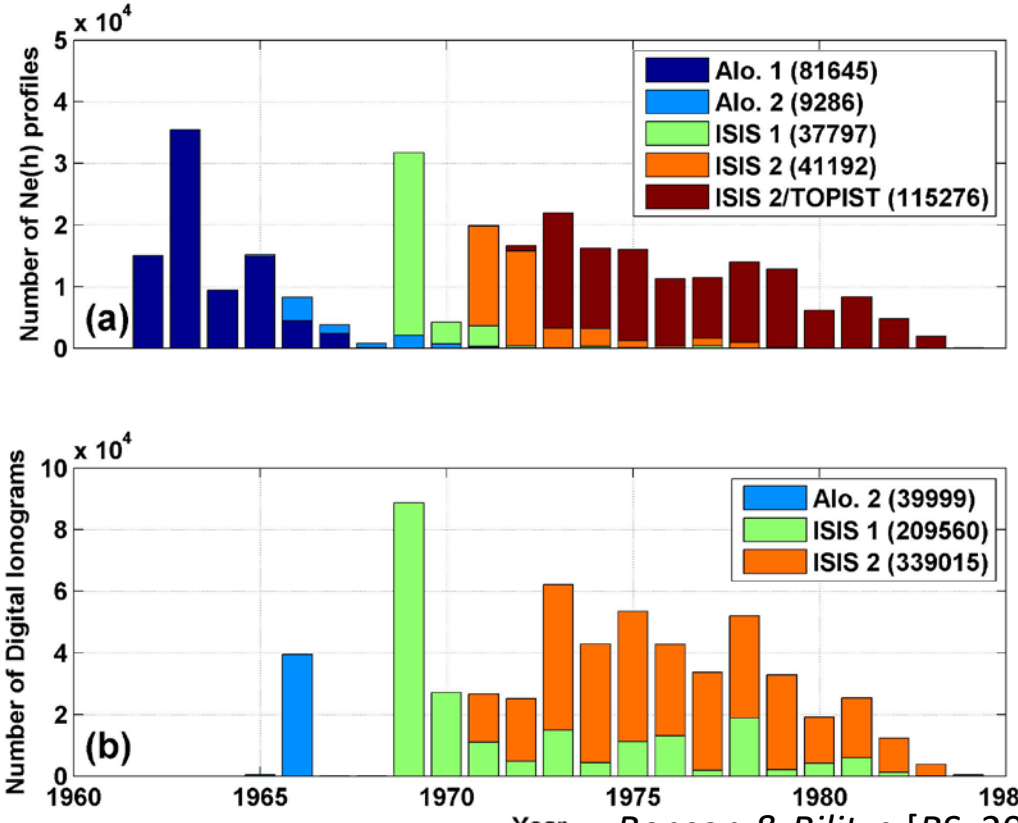
TOPIST designed to automatically produce Ne(h) from ISIS-II digital ionograms

Only 34% of the ISIS-II topside digital ionograms could be processed by TOPIST
Many files reflected problems encountered during the A/D process
Often it was not clear why TOPIST processing failed

TOPIST-processed ISIS-II files did not always yield Ne(h):

passive operation
fixed-frequency operation
incomplete reflection traces
field-aligned echoes
spread F
Interference
misidentification of traces
file problems during A/D

Note: TOPIST total = # of files
In Fig. (a) not # of Ne(h)



Benson & Bilitza [*RS*, 2009]

TOPIST-processed ISIS-II files: 4 possible outcomes indicated by quality flags (q):

no q: reflection trace data insufficient to produce Ne(h)

q = 1: severe spread F or trace calculated from Ne(h) & scaled trace do not agree

q= 2: conditions of q = 1 not satisfied but

deduced height of F peak differed from IRI model by more than 50 km, or

real foF2 likely beyond maximum swept frequency based on scaled cusp shape

q= 3: considered to be of the highest quality because none of the above are true

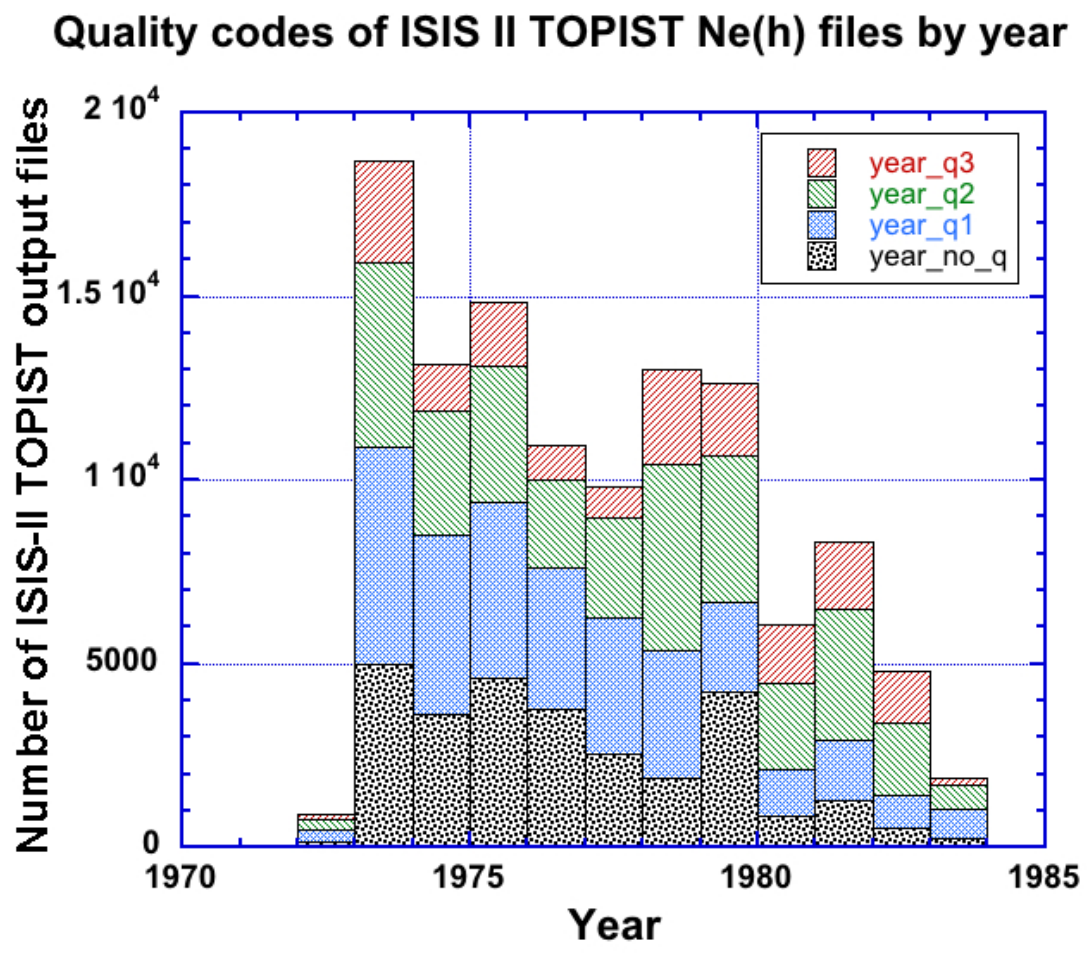
86,545 TOPIST ISIS-II Ne(h)

17,278 q = 3

35,201 q = 2

34,066 q = 1

28,725 no q value



Examples of science enabled by large database of topside digital ionograms & Ne(h)

Search for cases with fixed-frequency sounding = electron cyclotron frequency (fce) provided support for theoretical interpretation of the sounder-stimulated plasma resonance at fce – resolving a decades-long mystery [*Muldrew*, *RS*, 2006]

Identified topside digital ionograms and topside Ne(h) during large magnetic storms to compare storm-induced changes in high-latitude Ne(h) to changes in solar-wind parameters [*Benson et al*., *RS*, 2016]

TOPIST ISIS-II Ne(h) combined with higher-altitude field-aligned Ne profiles from the Radio Plasma Imager on the IMAGE satellite to improve the International Reference Ionosphere (IRI) and to extend it into the plasmasphere [*Reinisch et al*., *ASR*, 2007]

VERSION-2 ISIS-I DIGITAL TOPSIDE IONOGRAMS

More than 200,000 ISIS-I topside digital ionograms available from the NASA Space Physics Data Facility (SPDF) Coordinated Data Analysis Web (CDAWeb) system and the NASA Heliophysics Virtual Wave Observatory (VWO).

These files designated as av for average files (apparent-range information averaged to yield 15-km resolution)

Many files have problems due to the lack of proper frame-sync detection during the A/D process

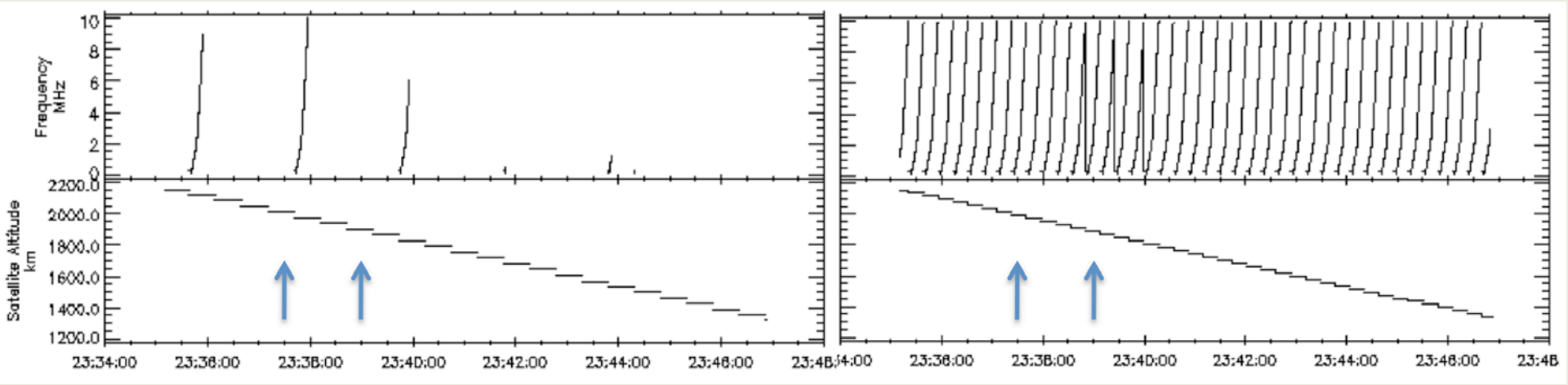
Data-enhancement project initiated to correct these problems
[*Benson et al.*, *RS*, 2012; *Wang et al.*, *IES*, 2015]

New ISIS-I version-2 files are designated as av2

The difference between these enhanced av2 files and the original av files is illustrated in the following figures based on CDAWeb displays

Comparing frequency information available from 0 to 10 MHz in av files (top left) and av2 files (top right) during a pass of ISIS I over the Ottawa (OTT) telemetry station in a 14-minute interval on 25 Jan 1976

ISIS-I av files **ISIS-I av2 files**



2334 UT **2348 2334** **2348**

Altitude steps (bottom panels from 1,200 to 2,200 km) indicate the satellite altitude at the time of ionogram frame sync-pulse detection during the A/D operation

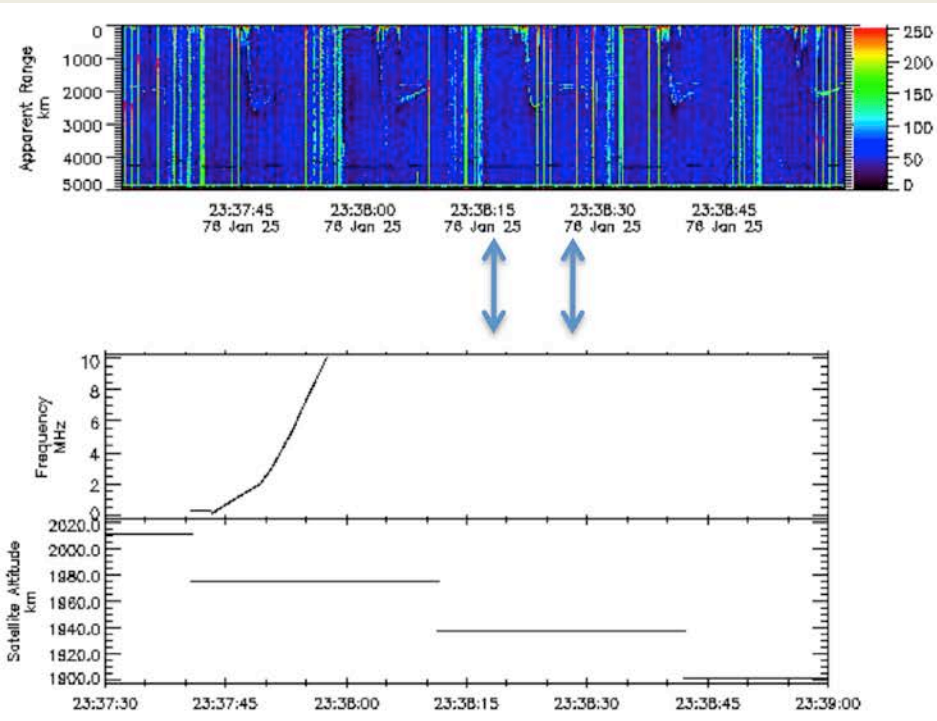
Incorrect frame sync detection results in missing frequency information (left)

After correcting frame-sync detection – possible to add frequency information (right)

1½ minute portions between arrows expanded in next figure (with sounder data)

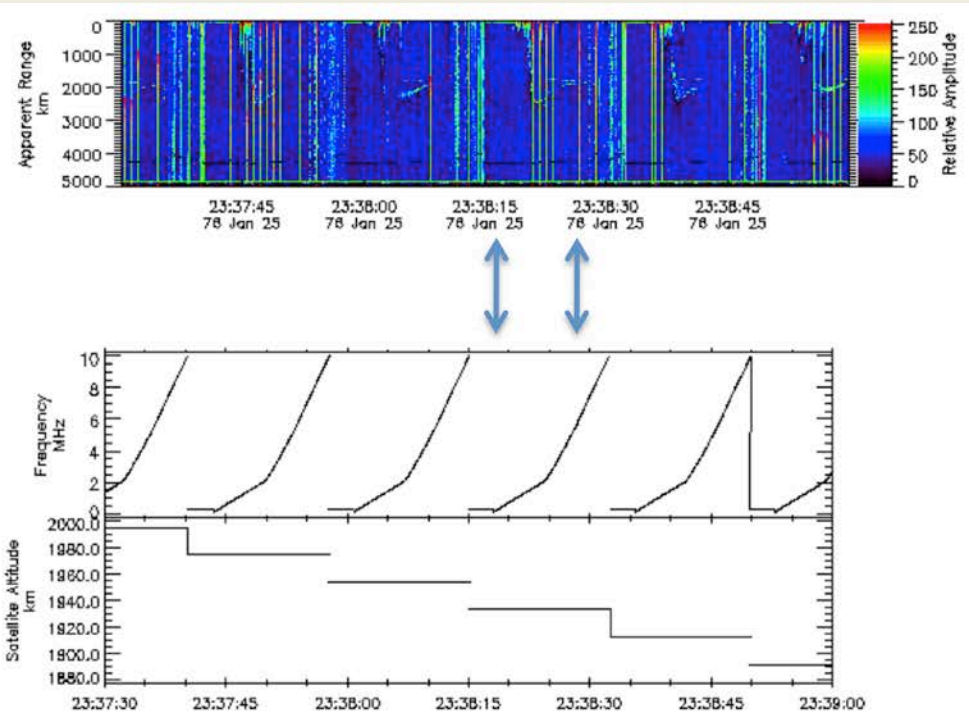
Comparing 1½ minute portions of ISIS-I av and av2 sounder data (top), frequency information (middle), and altitude steps (bottom) from OTT pass on 25 Jan 1976

ISIS-I av files



2337:30 UT 2339:00

ISIS-I av2 files



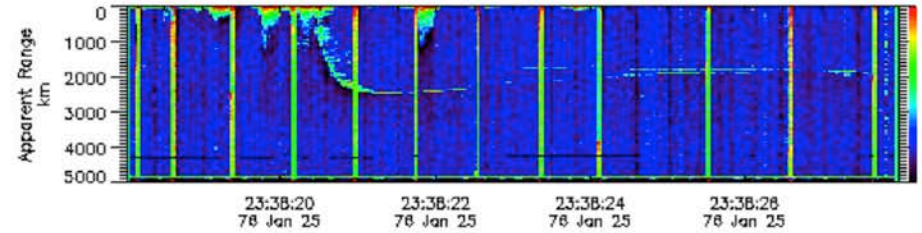
2337:30 2339:00

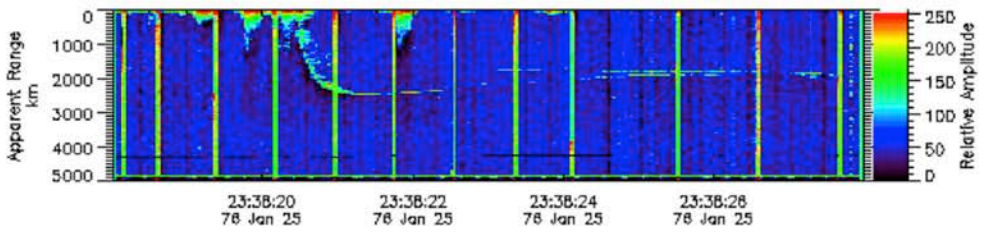
10 second portions between arrows expanded in next figure

Comparing 10 second portions of ISIS-I av and av2 sounder data (top), frequency information (middle), and altitude steps (bottom) from OTT pass on 25 Jan 1976

ISIS-I av files

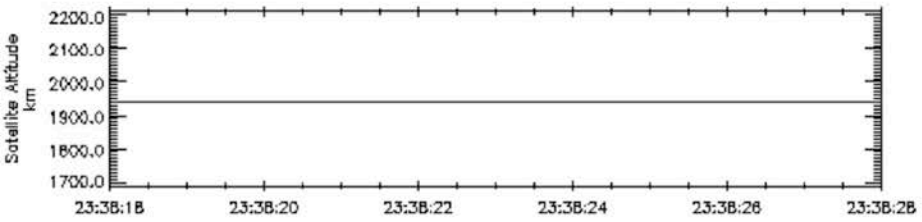
ISIS-I av2 files

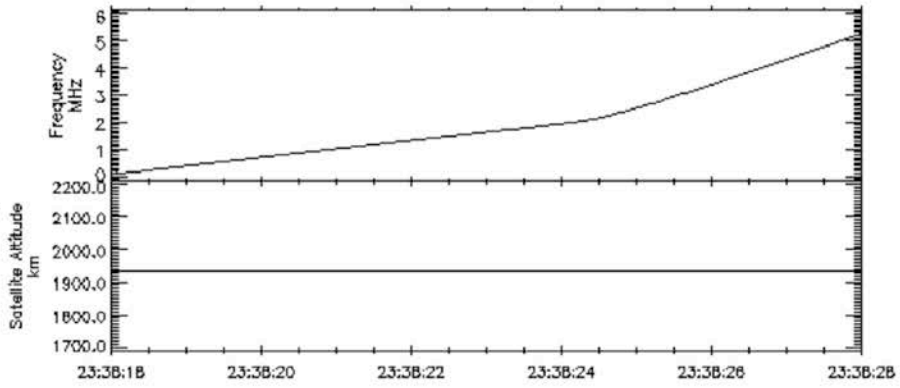




No frequency information on av ionogram

Full frequency information on av2 ionogram





2338:18 UT **2338:28** **2338:18** **2338:28**

The av2 file (right) contains frequency information and can be auto-processed by TOPIST to invert the ionospheric reflection trace into a topside Ne(h)

RESULTS USING VERSION-2 ISIS-I IONOGRAMS

Major goal: produce ISIS-I topside ionospheric $N_e(h)$ in order to expand the $N_e(h)$ profile coverage in latitude, longitude, and epoch available from the NASA/SPDF

More than 80,000 av2 digital topside ionogram files from all ISIS-I data from the Ottawa (OTT) telemetry station (from 1969-1983) have been produced

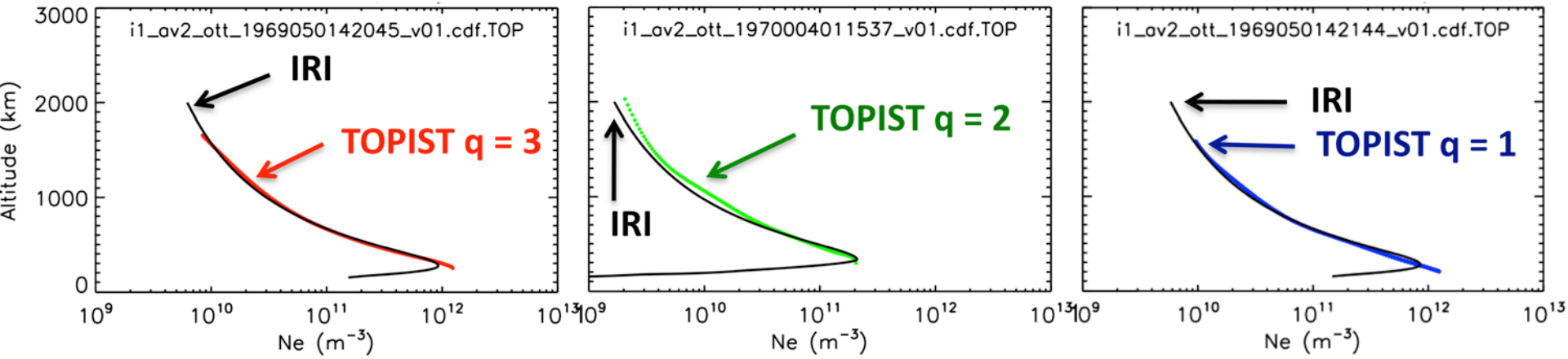
Currently, we are processing ISIS-I digital topside ionogram files from the Quito (QUI), University of Alaska (ULA), and Santiago (SNT) telemetry stations

Many of the av2 ISIS-I digital topside ionograms have been processed by TOPIST and the resulting $N_e(h)$ have been compared with those obtained from IRI2016

Sample comparisons are given in the next Figures both when the agreement in the topside ionosphere is good and not good

Sample comparisons between TOPIST and IRI2016 Ne(h) for each of the TOPIST quality flags (q = 3 for best; q = 2 for medium, and q = 1 for lowest quality)

Examples where IRI2016 is in good agreement with TOPIST Ne(h) in the topside ionosphere for different q values



Examples where IRI2016 is not in good agreement with TOPIST Ne(h) in the topside ionosphere for different q values