WDC-A Comments on Ionosonde Data Exchange Formats – Draft

World Data Center A
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Abstract

This paper is a draft comment from the ionosonde team at World Data Center A, regarding the University of Massachusetts Lowell proposal for an XML based ionosonde data exchange format. An update of ionosonde data formats is now needed to accommodate uncertainty estimates or error bars required by data assimilation models. This document proposes several changes to make the format more extensible and applicable across ionosonde types. The changes range in nature from trivial to essential. This proposed format is being strongly considered within the US Government for our ionosonde data exchange. The detailed format specifications in the appendices are incomplete, pending peer review and comments. The authors solicit comments, corrections and additions from the international ionosonde community.

1 Introduction

The new format for ionosonde data exchange SAOXML, proposed by Reinisch, Galkin and Khmyrov[1], represents a critical and bold step forward to keep ionosonde data exchange modern. In the spirit of the extensibility promised by an XML based data format, this article suggests several modifications and extensions that will improve the SAOXML format, especially in the areas of compatibility across different brands and types of ionosondes. We heartily thank the SAOXML authors for such fine work and solid foundation on which to base a commentary. The main article is a detailed review of and comment on the SAOXML proposal explanations of the proposed modifications, and examples. The appendix set is a complete format specification merging both SAOXML and our comments. Of course we borrow heavily from the original SAOXML publication, with full credit given to these authors for their original work.

For brevity, the original SAOXML work will be referred to as the UML proposal and this work as the WDC-A proposal. In aggregate, the proposed extensions warrant, at a minimum, a major version number change, to SAOXML Version 6. A change in format name is not beyond consideration.

This extended format is currently being considered by the US Government for use as the preferred format for exchange of processed ionogram data. It is very likely to be accepted with only minor modifications. As proposed, the UML SAOXML Version 5 does not adequately meet the needs of the US Government.

This paper is partly in draft form. The appendices are not yet complete, pending review and comments from the international ionosonde community, including both data providers and data users. The authors directly elicit comments and help from this community at several places in the document.

This document was written in LaTeX. The source and PDF documents are available at http://www.ionosonde.org/SAOXML/. Sample XML files referenced in these documents are also located at that URL. The authors are willing to maintain this document and coordinate ionosonde community comments and suggestions.

2 General Comments

2.1 Purpose

The intended purpose for this ionosonde data format is to facilitate data exchange of ionogram characteristics (e.g. foF2), scaled or analyzed ionogram quantities (e.g. echoes and traces) and geophysical observations derived from ionogram measurements (e.g. electron density profiles). It is not intended to include raw ionogram data. In fact, XML would be a particularly space inefficient method to exchange ionograms.

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[1] INAG Bulletin 66

2.2 Impetus

The timing and need for a major new ionosonde file format is being both pushed from ionosonde providers and pulled from data users.

On the user side, the driving force in the US is the advent of Kalman filter based data assimilation ionosphere specification and forecast models. The Kalman filter, as a type of optimal fitting algorithm, fundamentally requires uncertainty values for each of its data points. In the absence of these uncertainty values, they must be invented by the modeler, thus possibly over or under estimating the accuracy of the driver data. Given the notorious complexity of ionosonde data, it is critical that ionosounding experts provide careful and well reasoned error estimates on their data if these data are to be properly used by Kalman Filter assimilation models.

Ionosonde data providers are also forcing the need for a new format. In addition to responding to the error bar needs of the data assimilation modeling community, ionosonde measurement technology is being advanced and new observations are being discovered, validated and coming to maturity. Examples of these new observations are velocities, irregularities, tilts, waves and gradients.

The SAO format, first defined in 1989 and published in the 1998 INAG Bulletin 62, is nearing the end of its extensibility. Computer and software technology have also evolved several orders of magnitude over the last decade. The nexus of Need, Opportunity and Practicality strongly suggest it is time for a major leap forward. Failure to evolve in response to need and technology will press the already under-appreciated ionosounding technique further to the backwaters of space science and applications.

Since the intended scope of this format is to store and communicate the relatively small quantity ionogram-derived information such as Scaled Characteristics, Echoes, Profiles, Traces, and Electron Density Profiles, an XML based format is an excellent choice. Storage and exchange of the much larger “raw” ionogram data is beyond the scope of this effort.

2.3 Legacy Software Support

One of the most vexing problems presented by any new standard or file format, something that each organization must face, is one of “Should we upgrade” and “How do we find the resources to upgrade”. At the US National Geophysical Data Center (NGDC), data users are demanding error estimates and quality indicators on their ionosonde data, and NGDC must respond to these customer requests.

NGDC also faces the issues of legacy data formats and resources. To resolve these problems, NGDC intends to write an open-source suite of programs that downgrade the SAOXML data files into various formats to support legacy software applications. These tools will be written in Java, Perl and perhaps other languages, acting as a text filter to an SAOXML file. Conversion output options will include:

- URSI standard SAO 4.2
- Text file of selected scaled characteristics
- Text file of ionogram echoes
- Text file of identified traces
- Text file of Electron Density Profiles and Uncertainties
- Text file based on user-defined configuration file
- Others to be determined

WDC-A will write this code and offers to share these open-source software tools with the global ionosonde community. Such a filter is believed to be a more effective solution to supporting legacy applications and older programming languages such as FORTRAN. The alternative would be complex and fragile FORTRAN code that would be difficult to write and maintain.

2.4 Scope

The scope of this data format standard should be limited to ionosonde data, and its versatility, flexibility and extensibility be directed toward accommodating data from as wide a variety of ionosondes as practical. It is unnecessary to attempt to create a general, universal format specification for all ionosphere instruments and models. The ionosonde information to be conveyed will not include the “raw” ionograms, or receiver outputs versus frequency and range. These data are too bulky for XML storage. It is practical to store some ionogram data, in the form of detected echoes, in this format.

2.5 Attributes versus Elements

The basic philosophy of good XML document design is that attributes should further elaborate and provide metadata for their element. In general, data should be placed in Elements and metadata in Attributes. An attribute is intended to provide atomic unstructured information about its element and should be used so long as it does not need to be further elaborated.

A good rule of thumb is: Given element X and concept Y. If Y directly describes X and Y can be be written as a single text string and Y does not need to be further elaborated, then Y should be an attribute of X, otherwise Y should be a sub-element of X, with it's own further elaboration, if needed.

It is recognized that putting data into attributes reduces the file size by eliminating the ending XML element name sequences. Disadvantages of Attributes include:

- An Attribute cannot occur more than once under a given Element
- Attributes are not easily expandable for future elaboration
- Attributes describe structure poorly

In many circumstances, the attributes versus elements argument comes down to a matter of taste and style. The authors present their opinions for your evaluation.

2.6 Data Tables

Ionosondes vary greatly in their ability to measure the parameters of the returned radio signals, and this variability must be accommodated. Rather than pre-define a superset of observations, which would soon be made obsolete by scientific progress, this WDC-A format proposes to allow a wide latitude in reporting ionosonde data and derived quantities. This requires flexible, efficient, multi-dimensional data storage, something at which standard XML is particularly poor, at least in a space efficient manner. To improve this, the techniques used by the eXtensible Scientific Interchange Language[2] (XSIL) XML extension are particularly attractive.

While XSIL itself seems to be a dead project,or at least static since June 2000, many of its precepts are clever and useful. In particular, the concept of storing a data table with each column having differing meanings, units and labels is very attractive for this application. All elements in a given row are related. With this method, the measurement metadata is stored only once per ionogram. Standard XML would have us store the metadata for that entry with each number, which results in unacceptable file sizes. Samples of these table element types are throughout this document. They usually have the word `Table` as part of the element name, but this is not required. For more details, see Appendix B.1

2.7 Lists

This format frequently uses elements which contain a list of values. These lists have two required features. First, the number of items in the list must be in a `Num="nn"` attribute. Second, the list is comma delimited by default. It is the general intent that the word `List` be part of the element name, but this is not required.

3 Element Name Case and Short Forms

The UML proposal has XML tags (Element or Attribute names) in Lower Camel Case, where the first word of a multi-word tag is lower case and then upper case is used to start all subsequent words. This proposal uses Upper Camel Case for all tags. While partly a matter of style, the primary reason for this is eventual space efficiency. All of the examples in this document contain XML tags with their full names, such as <`IonogramCharacteristics`>. While this is necessary for human readability, it is redundant for Machine-to-Machine communication. Consistent with the US Federal Geographic Data Committee (FGDC) standard http://www.fgdc.gov/, this proposal allows for the reduction of XML tags to a short form. Our method to determine the short form of the XML tag is to use only the capitol letters in the long form of the tag. This will reduce the file size, decrease bandwidth use and unfortunately increase obscurity. For example, <`IonogramCharacteristics`> becomes <`IC`>. Since the vast majority of these XML files will be for machine-to-machine use, this is an important efficiency feature. The use of Upper Camel Case makes this transformation possible. This is also a reason for long-form tags being somewhat longer than otherwise necessary and some otherwise arbitrary changes from the UML proposal. The intent is to make globally unique tags in both long and short form.

4 SAORecord Attributes

In general there is an over-use of Attributes in the UML format. This proposal suggests that most of the Attributes should be data elements in the file.

The use of a **Version** attribute for the <`SAORecord`> element is critical. However, the measurement time, location are more appropriately included as required elements in the body of the <`SAORecord`>. Since the SAOXML file should only include ionosonde data, the **Source** attribute is unnecessary.

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[2] http://www.cacr.caltech.edu/SDA/xsil/

Listing 1: SAORecord Attributes

```
<SAORecord  version="6.0">
```

5 SAORecord Body

The body of the <`SAORecord`> can contain any of the following recognized elements:

- <`SystemInfo`> – System and Measurement metadata
- <`ScaledCharacteristics`> – Standard and custom scaled ionogram characteristics
- <`EchoTable`> – Table with physical properties of the observed echoes
- <`TraceFragmentList`> – Groups of echoes with similar physical properties
- <`TraceList`> – Groups of Tracelets that form standard and custom ionogram traces
- <`ProfileList`> – Electron Density Profiles from this ionogram
- <`VelocityList`> – Velocity vectors from this ionogram

Each of these will be described in greater detail in their own sections. A complete description of the <`SAORecord`> is included in Appendix C.

6 System and Measurement Metadata

The <`systemDescription`> element is somewhat of a catch-all for information that describe either the system that made or processed the ionogram data, such as instrument type or software versions, or information relevant to the observations included in this record. Many of the Attributes of the <`SAORecord`> are either system or measurement metadata. On a minor note the <`SystemInfo`> element name is slightly more accurate than <`systemDescription`>.

This proposal calls for a required <`SystemInfo`> element which should contain virtually all of the information originally proposed for the attributes of the <`SAORecord`> as well as all of the information in the former <`SystemDescription`>. Since these former attributes now are elements, they can in turn have attributes of their own, thus in some cases it makes sense to make some slight reconfigurations. As an example, the attributes <`frequencyStepping`> and <`frequencyStep`> can be combined, with the type of frequency step, such as linear, log or tabulated, being an attribute of the <`FrequencyStep`> element.

A complete list of required and recognized elements in the <`SystemInfo`> is provided in Appendix D. Some minor renaming of the elements from the UML proposal is suggested to aid in accommodating ionosonde data from non-Digisonde systems.

6.1 Time

Instead of including measurement time as an attribute of the <`SAORecord`>, it should be an element in the <`SystemInfo`>, or arguably its own record directly under the <`SAORecord`>. Information about the time, such as its format, should be attributes of this element. Most modern digital ionosondes report the ionogram start time as the time of the measurement, so it should be identified as such. Since the <`StartTime`> of the measurement is the same independent of the timezone used, and XML elements can be repeated, both UT and Local Time can be reported, with the difference being in an Attribute. Listing 2 gives an example. The **TimeZone** attribute must be an ISO8601 recognized value. See `http://www.twinsun.com/tz/tz-link.htm`. It is *strongly* encouraged to only use UTC.

Listing 2: StartTime Example

```
<StartTime Format="ISO8601" TimeZone="UTC"> 2000-02-01 13:45:05.000 </StartTime>
<StartTime Format="ISO8601" TimeZone="-04:00"> 2000-02-01 09:45:05.000 </StartTime>
```

The authors' review of the ISO8601 standard `http://www.iso.org/iso/en/prods-services/popstds/datesandtime.html` and `http://en.wikipedia.org/wiki/ISO_8601` indicate that the time format in the UML proposal `time="2000.02.01 (032) 03:45:05"` is not ISO8601 compliant. Since many data users like having a convenient day of year number <`StartDayOfYear`> element, it is provided as an option in Appendix D.

6.2 Tabulated Frequencies

To accommodate tabular frequency spacing, the <`FrequencyStep Type="tabulated"`> can have actual nominal frequencies of operation, instead of a single increment. This is shown in Listing 3. An identical approach applies to non-uniform range gate spacing using the <`HeightStep Type="tabulated"`> element.

Listing 3: Tabulated Frequency Example

```
 <FrequencyStep Units="MHz" Type="tabulated" Num="7">
1.00,1.50,2.75,3.85,6.67,8.83,12.45
</FrequencyStep>
```

6.3 Doppler Table

For Echoes which convey their information on Doppler shift by means of a Doppler Index and a table of Doppler bins, the associated `<DopplerTable>` is measurement metadata and belongs in this section. Tables are the best way to represent these data, as shown in Listing 4. It is recommended to avoid this method of representing Doppler Shift and put the actual value into the echo table.

Listing 4: Doppler Table for Digisondes

```
<DopplerTable NumColumns="2" NumRows="8">
  <Column Name="DopplerIndex" Type="Int" Description="Doppler␣Index" />
  <Column Name="DopplerFrequency" Type="Float" Unit="Hz" SigFigs="4" Description="Doppler␣Shift" />
  <Stream Delimiter=",">
-4, -1.2800
-3, -0.9600
-2, -0.6400
-1, -0.3200
+1, +0.3200
+2, +0.6400
+3, +0.9600
+4, +1.2800
  </Stream>
</DopplerTable>
```

6.4 Custom Elements

It is strongly recommended that elements specific to one manufacturer, brand or type of ionosonde have names that clearly convey that information. For example, with Digisondes there is a string of hexadecimal values called the “Preface” which is a compact and difficult to interpret set of values which indicate the state of the instrument for the given measurement. While much of the meaning of the preface is decoded into the `<SystemInfo>`, having the actual preface is of great value to those familiar with Digisonde data. An example is provided in Listing 5

Listing 5: Digisonde Preface

```
<DigisondePreface Type="DGS256_Ionogram" >
030811315051132000001000060C31040112112E90841513240021229
</DigisondePreface>
```

Another example is the 3-digit Station Idendification code provided by UMass Lowell for their Digisonde systems. It should be called `<UMLStationID>`, not `<StationID>`.

6.5 Restricted Frequencies

Restricted frequencies are usually issued by frequency regulatory agencies as upper and lower bounds of the RF spectrum on which the particular ionosonde is not allowed to transmit. The `<RestrictedTable>` element in this section should be a table that represents that pairing. Of course if the span is unknown the two numbers can be the same. An example is shown in Listing 6.

6.6 Examples

A usefully complete example of a `<SystemInfo>` element is provided in Listing 6 based on examples given in the UML proposal.

Listing 6: SystemInfo Element for Digisondes

```
<SystemInfo>
   <StartTime> Format="ISO8601" TimeZone="UTC" 2000-02-01 13:45:05.000 </StartTimeUT>
   <UMLStationID> 067 </UMLStationID>
   <URSICode> SMJ67 </URSICode>
   <StationName> Sondrestrom </StationName>
   <GeoLAT>   66.98 </GeoLAT>
   <GeoLON> 309.06 </GeoLON>
   <IonosondeType> DGS-256 </IonosondeType>
   <ScalerType> manual </ScalerType>
   <ScalerName> John Smith </ScalerName>
   <StartFrequency Units="MHz" > 0.500 </StartFrequency>
   <EndFrequency Units="MHz"> 15.500 </EndFrequency>
   <FrequencyStep Units="MHz" Type="linear"> 0.1 </FrequencyStep>
   <StartHeight Units="km" > 80 </StartHeight>
   <EndHeight Units="km" > 1300 </EndHeight>
   <HeightStep Units="km" Type="linear"> 2.500 </HeightStep>
   <RestrictedTable NumColumns=2 NumRows=5>
      <Column  Name="RestrictedLowerBound", Type= "Float", Units="MHz", SigFigs="2"  />
      <Column  Name="RestrictedUpperBound", Type= "Float", Units="MHz", SigFigs="2"  />
      <Stream Delimiter=",">
```

```
2.45, 2.55
2.90, 3.05
3.10, 3.40
4.95, 5.05
5.60, 5.70
      </Stream>
   </RestrictedFrequencies>
   <DopplerTable NumColumns="2" NumRows="8">
      <Column Name="DopplerIndex" Type="Int" Description="Doppler␣Index" />
      <Column Name="DopplerFrequency" Type="Float" Unit="Hz" SigFigs="4" Description="Doppler␣Shift" />
      <Stream Delimiter=",">
-4, -1.2800
-3, -0.9600
-2, -0.6400
-1, -0.3200
+1, +0.3200
+2, +0.6400
+3, +0.9600
+4, +1.2800
      </Stream>
   </DopplerTable>
   <Comments> This is an example data file </Comments>
</SystemInfo>
```

7 Scaled Ionogram Characteristics

These standard and possibly custom scaled values derived from the ionograms are the primary data intended to be stored and exchanged using this XML file format. Most of the recommendations in the UML proposal are excellent, and this WDC-A comment suggests modifications in a few specific areas.

The full list of internationally recognized scaled ionogram characteristics is given in Appendix A in the UML proposal and Appendix K in this document. A partial list of user-defined codes is provided in Appendix B of the UML proposal and repeated here in Appendix L.

7.1 Ionogram Characteristics

It is a minor matter of nomenclature, but scaled values such as foF2 are characteristics of the *ionogram*, not of the *ionosphere*. The element name <`IonogramCharacteristics`> is suggested as being more precise.

This element is a List and should have an attribute that defines the number of <`Item`> sub-elements to expect. For example: <`IonogramCharacteristics Num="22"`>

7.2 Error Bars

The tags <`LowerUncertainty`> and <`UpperUncertainty`> are rather verbose for an element which will be often repeated in the file. WDC-A recommends replacing these with <`UpperBound`> and <`LowerBound`>. The term “Boundary” is also neutral compared to the terms “error” and “uncertainty”.

For boundary values, the meaning of the values must be provided. Without this, it is necessary to guess if the boundary values given are 1σ normal (Gaussian), 3σ normal, quartile, decile, percentile, etc. An attribute element <`BoundaryType`> is suggested, and if absent the default type of boundary limit is 1σ normal.

With symmetric boundary estimates, the element <`Bound`> can be used instead of the (<`LowerBound`>, <`UpperBound`>) pair. In this case, the number represents the magnitude of the uncertainty or error. This option for symmetric or asymmetric error bounds is an option for any ionospheric data or derived quantity in the SAOXML file. It may be necessary to specify both symmetric and asymmetric boundaries, although some user confusion may result from this choice. A full list of BoundaryTypes can be found in Appendix B.3.

7.3 Scaling Attributes and Elements

For each scaled ionogram characteristic, the data values of <`Val`>, <`UpperBound`>, <`LowerBound`> and <`Bound`> should all be Elements, not Attributes, because these are data, not metadata. The <`ID`> of the characteristic is appropriately an Attribute. The other items, such as qualifiers and edit flags are less clearly data versus metadata, so we propose they be kept as Attributes. Representing scaled ionogram characteristics as elements does unfortunately increase the file size.

Use of the <`Description`> attribute should be limited to characteristics which are not URSI standards. Similar arguments can be made for the <`Units`> attribute for standard characteristics. Repeatedly including descriptions and units of standard characteristics is wasteful of storage and communications resources.

7.4 Measurements, not Models

The use of the **predicted** and **model** attributes should only be used for the user-defined values which are model predictions. These are ionosonde data files, not model output grids.

7.5 Examples

A sample of scaled data from an SAO data file is given in Listing 7 and an example where error estimates are added is given in Listing 8.

Listing 7: Ionogram Characteristics Example

```
<IonogramCharacteristics Num="4">
   <Item Name="foF2" ID="00" Units="MHz" QL="U" DL="F" Flag="edited" >
      <Val> 3.5 </Val>
   </Item>
   <Item Name="M(D)" ID="03" QL="/" DL="␣" flag="edited" />
      <Val> 2.7120712 </Val>
   </Item>
   <Item Name="MUF(D)" ID="07" Units="MHz" QL="/" DL="␣" flag="edited" />
      <Val>  9.221042 </Val>
   </Item>
   <Item Name="foF2p" flag="predicted" model="URSI-88" />
     <Val> 5.5 </Val>
   </Item>
</IonogramCharacteristics>
```

Listing 8: Ionogram Characteristics with Error Bars

```
<IonogramCharacteristics Num="3">
   <Item Name="foF2" ID="00" Units="MHz" QL="U" DL="F" Flag="edited" BoundaryType="1sigma" >
      <Val> 3.5 </Val>
      <UpperBound> 3.8 </UpperBound>
      <LowerBound> 3.2 </LowerBound>
   </Item>
   <Item Name="fmin" ID="42" Units="MHz" Flag="auto" BoundaryType="10%tile" />
      <Val> 0.9 </Val>
      <UpperBound> 1.10 </UpperBound>
      <LowerBound> 0.50 </LowerBound>
   </Item>
   <Item Name="fbEs" ID="32" Units="MHz" Flag="auto" BoundaryType="3sigma" />
      <Val> 4.49 </Val>
      <Bound> 1.20 </Bound>
   </Item>
</IonogramCharacteristics>
```

8 Echoes, Tracelets and Traces

The most significant and substantive comment of this paper addresses what we feel is the only clear deficiency in the original format proposal. In the original proposal, the elements called <`traces`> had attributes and data assigned in a fashion that, while very similar to the methods used in the previous SAO format versions and logical for the goal of obtaining electron density profiles from ionograms, possessed some fundamental limitations.

This proposal calls for a different logical arrangement of data within the format that we feel better represents the physical realities of ionospheric sounding, data analysis and interpretation both past, present and future. This also allows for much better and formal error analysis and future data re-evaluation without going back to the raw ionogram records.

In the SAOXML format there needs to be included a logical entity called “Echoes” and a hierarchy between ionosphere echoes and ionogram “Traces”. There also needs to be allowance for the fact that some ionogram traces, such as an E layer trace or F2 trace, have well defined nomenclature and can be directly related to ionosphere characteristics such as electron density profiles. Other traces, such as polar or equatorial “satellite traces” have evolving definitions and their relation to the state of the ionosphere, such as measuring tilts and gradients, is a matter of ongoing research. The data format should accomodate this science.

8.1 Echoes

Ionosphere echoes are distinct and observable entities. They are the result of the ionosonde’s transmitted energy returning from the ionosphere. Echoes possess all of the directly observable properties of the ionospheric return, such as Range, Amplitude, Polarization, Doppler, etc., as a function of frequency. With the very distinct and non-trivial exception of deciding what is an echo and what is not, all of what constitutes an echo is an observation, not an interpretation. As an observation, it focuses on radar signal processing techniques.

The proposed <**EchoTable**> is a table of observed echo parameters. A complete list of the recognized columns is given in Appendix F. The columns Frequency and Range are required, otherwise we are not dealing with ionosonde data. Use of Time, EchoIndex and Amplitude is strongly encouraged, as most ionosondes can provide this information. Other column contents will depend strongly on the type of ionosonde used, mode of operation, data formats or analysis software.

Present day Dynasondes determine a large quantity of information or parameters for each echo in the ionogram. This includes Range, Location, Apparent Velocity, Polarization and an error estimate, with the independent echo parameters being the typical Time and Frequency. A complete description of the observations can be found at `http://www.ngdc.noaa.gov/stp/IONO/Dynasonde/tutorial/tutorial.html`. There are usually several hundred to a few thousand echoes in a Dynasonde ionogram. The number depends strongly on the condition of the ionosphere. The new generation Dynasonde21© promises the possibility of making independent error estimates and second order echo parameters such as wavefront curvature or Doppler spread. Given the table approach to storing echo parameters, the list can be easily expanded to include new observations without breaking older software. A sample <**EchoTable**> element is given in Listing 9.

Listing 9: Sample Echoes for Dynasondes

```
<EchoTable NumColumns="12"  NumRows="4">
  <Column Name="EchoId" Type="Int" Description="Unique␣Echo␣Identifier" />
  <Column Name="Time" Type="Float" Unit="sec"  SigFigs="3" Description="Time␣from␣ionogram␣start" />
  <Column Name="Frequency" Type="Float" Unit="MHz" SigFigs="4" Description="Nominal␣Frequency" />
  <Column Name="Range" Type="Float" Unit="km" SigFigs="2" Description="Stationary␣Phase␣Group␣Range" />
  <Column Name="EP" Type="Float" Unit="deg" SigFigs="2" Description="Total␣Phase␣Error" />
  <Column Name="XL" Type="Float" Unit="km" SigFigs="2" Description="Geographic␣Eastward␣Location" />
  <Column Name="YL" Type="Float" Unit="km" SigFigs="2" Description="Geographic␣Northward␣Location" />
  <Column Name="V*" Type="Float" Unit="m/s" SigFigs="2" Description="Apparent␣Radial␣Doppler␣Velocity" />
  <Column Name="Amplitude" Type="Float" Unit="dB" SigFigs="2" Description="Relative␣Amplitude" />
  <Column Name="Noise" Type="Float" Unit="dB" SigFigs="2" Description="Noise␣Level" />
  <Column Name="PP" Type="Float", Unit="degree" SigFigs="2" Description="Polarization␣Chirality" />
  <Column Name="TraceletIndex" Type="Int" Description="Primary␣Tracelet␣Association"
  <Stream Delimiter=",">
1, 1.500, 1.7275, 117.31, 4.63, 53.41,   0.39, 27.18, 70.75, 60.25, -88.65, 1
2, 1.550, 1.6951, 117.76, 4.00, 49.25,  25.85, 31.55, 74.82, 58.20, -79.08, 1
3, 1.600, 1.7015, 117.88, 4.04, 50.40, -14.27, 11.00, 76.83, 47.77, -73.98, 1
4, 1.650, 1.7080, 117.78, 1.07, 48.93, -20.63, 24.60, 77.33, 46.65, -77.88, 1
  </Stream>
</EchoTable>
```

Digisonde data stored in SAO files contain echo parameters including Frequency, Range, Amplitude, Doppler, Polarization and possibly Arrival Angle information. Echo Polarization and Arrival Angle information are determined by comparing signal strengths with different antenna polarizations and beamforming settings. Precise time at which each frequency is sounded is contained in the raw ionogram files and could be extracted if both files were processed and cross-referenced. These data can be stored in an <**EchoTable**> as shown in Listing 10.

Listing 10: Sample Echoes for Digisonde Ionograms

```
<EchoTable NumColumns="8"  NumRows="4">
  <Column Name="EchoId" Type="Int" Description="Unique␣Echo␣Identifier" />
  <Column Name="Frequency" Type="Float" Unit="MHz" SigFigs="4" Description="Nominal␣Frequency" />
  <Column Name="Range" Type="Float" Unit="km" SigFigs="2" Description="Range" />
  <Column Name="Doppler" Type="Float" Unit="Hz" SigFigs="3" Description="Doppler␣Shift" />
  <Column Name="Amplitude" Type="Float" Unit="dB" SigFigs="2" Description="Relative␣Amplitude" />
  <Column Name="Noise" Type="Float" Unit="dB" SigFigs="2" Description="Noise␣Level" />
  <Column Name="Polarization" Type="Char", Description="Polarization" />
  <Column Name="TraceletIndex" Type="Int" Description="Primary␣Tracelet␣Association"
  <Stream Delimiter=",">
1, 1.6000  110.00, -0.120,  48.12, 40.00, O, 1
2, 1.6500, 112.50, -0.240,  52.00, 38.34, O, 1
3, 1.7000, 115.00, -0.240,  58.50, 32.25, O, 1
4, 1.7500, 120.00, -0.320,  58.00, 30,12, O, 1
  </Stream>
</EchoTable>
```

Note that if the DopplerIndex column is used, an associated <**DopplerTable**> should be included in the measurement <**SystemInfo**> section of the file.

Digisondes also have a Drift mode of operation where precise Doppler and Arrival Angle information is measured. These "SkyMap" data are easily accommodated within the <**EchoTable**> framework. A sample is given in Listing 19.

Authors' Note: Sample Echoes from different ionosondes, such as CADI, IPS, KEL and others would be greatly appreciated!

8.2 Tracelets

Ionosphere echoes naturally form groups which have similar or smoothly varying values of some of the echo parameters. These are the ionogram traces that our eyes see so clearly.

We define a "Tracelet" or "Trace Fragment" as a group of Echoes which are considered sufficiently similar in any combination of their observed quantities to be deemed to "belong together". The purpose of this section of the file is to convey these groupings.

The standards, rules and procedures for considering echoes to be part of a Tracelet is evolving technology and certainly quite different among various ionosonde providers. It is not the intent of this document to suggest or enforce standardization of the process, only to standardize the format of the results. Determination of tracelets, at least for Dynasonde data processing techniques, involves group theory, and this has very different issues of quality, confidence and error propagation from echo measurement and detection. Tracelet identification is a significant step separated from the ionosonde hardware, thus more standardization across ionosonde types is possible.

For Digisonde systems which use the ARTIST versions of ionogram scaling software, the concept of tracelets is currently unnecessary. ARTIST automatically detects traces and echoes simultaneously. However, the Digisonde and ARTIST data fit neatly into this scheme.

Authors' Note: Comments on IPS and ESIR methods are solicited.

The concept of Tracelets will aid in ionogram analysis research, such as automated identification of Auroral E traces and their impact on density profiles, or geolocating large density gradients such as polar cap patches, trough walls or equatorial spread-F plasma depletions.

We use the XML tag <`TraceFragment`> instead of <`Tracelet`> in order to make short form XML files unambiguous.

The <`TraceFragmentList`> element is an optional sub-element of <`SAORecord`>. It has an attribute of the number of tracelets in the element. The <`TraceFragmentList`> may contain zero or more <`TraceFragment`> elements which define each Tracelet. The table element type is a very useful tool to represent the list of Echoes in each Tracelet. For consistency, and to allow other optional parameters for each Tracelet, such as mean or median values of the Echo which comprise the Tracelet, the element <`TraceListTable`> is used. The only mandatory column is EchoID, but possible useful information might include a measure of likelihood that a given echo belongs to the tracelet in question. Such a value might be called "Similarity", a measure of how similar each echo is compared to the others in the group, and might act as an error estimator for the tracelet grouping process. This is speculative at this time, but it is the possibility of such need that suggests using Tables even though they seem unnecessary in this example. Listing 11 contains only two Tracelets, one with 4 echoes and one with three. The second Tracelet in Listing 11 gives a sample of how "Similarity" might be conveyed as a probability from 0.000 to 1.000.

Listing 11: Sample Tracelet List

```
<TraceFragmentList Num="2">
  <TraceFragment TraceFragId="1" >
     <TraceFragmentTable NumColumns="1" NumRows="4" >
       <Column Name="EchoId" Type="Int" Description="EchoId␣of␣Echoes␣in␣this␣Tracelet" />
       <Stream Delimiter="," >
1
18
19
4
       </Stream>
    </TraceFragmentTable>
  </TraceFragment>

  <TraceFragment TraceFragID="2" >
     <TraceFragmentTable NumColumns="2" NumRows="3" >
       <Column Name="EchoId" Type="Int" Description="EchoId␣of␣Echoes␣in␣this␣Tracelet" />
       <Column Name="Similarity" Type="Float" SigFigs="3" Description="Degree␣of␣Similarity␣to␣Tracelet␣Average" />
       <Stream Delimiter=",">
1,  0.975
28  0.885
21  0.037
       </Stream>
    </TraceFragmentTable>
  </TraceFragment>
</TraceFragmentList>
```

8.3 Traces

Traces are the well defined, standard groups of echoes that form the traditional traces, such as those defined in UAG-23A. These are the traces that help define some geophysical characteristic of the ionosphere, such as the electron density profile. Since not all tracelets are complete traces, the concept of a trace as a group of tracelets is necessary. Some tracelets, such as those from multi-hop traces, may have no currently defined nomenclature or use. Other tracelets may belong to the same ionosphere feature, thus must be joined and considered in aggregate for proper ionogram analysis.

A Trace may consist of a group of one or more Trace Fragments or Tracelets, which represent one of the URSI standard ionogram traces. Unique, experimental or site-specific traces may also be defined. The process of combining Tracelets and assigning them standard designations is Trace Classification. Trace classification is a very different logical process from echo detection or echo grouping, thus it has different technical maturity and error propagation mechanics.

Defining a Trace requires at least one Tracelet and a standard layer designation as an attribute. Other optional attributes include the order of reflection, polarization and Es Type for Es layers. An optional Mode attribute is defined that can identify M and N mode reflection and range aliased (i.e. around-the-time-base) traces. See Appendix H for complete details.

As with Tracelets, at first it seems that the use of a table is unnecessary to store Traces. However, to allow for possible information that is different for each Tracelet within the Trace, a table is the best choice. Such information might be a measure of how well the Tracelet fits in the group or how likely a given tracelet is to belong to this Trace.

Listing 12 gives a sample of how an <`TraceList`> element would look.

Listing 12: Sample Trace List

```
<TraceList Num="2" />
  <Trace TraceId="1" Layer="F1" Order="1" Polarization="O"/>
     <TraceTable NumColumns"1" NumRows="3" />
       <Column Name="TraceFragID" Type="Int" Description="ID␣of␣Tracelets␣in␣this␣Trace" />
       <Stream Delimiter="," >
1
5
7
     </TraceTable>
  </Trace>
  <Trace TraceId="2" Layer="Es" Order="1" Polarization="X", TypeEs="f" >
     <TraceTable NumColumns"1" NumRows="3" />
       <Column Name="TraceFragID" Type="Int" Description="ID␣of␣Tracelets␣in␣this␣Trace" />
       <Column Name="Similarity" Type="Float" SigFigs="3" Description="Probability␣of␣Association" />
       <Stream Delimiter=","
3, 0.567
4, 0.876
     </TraceTable>
  </Trace>
</TraceList>
```

9 Electron Density Profiles

The UML proposed scheme for storing ionogram-derived electron density profiles is good, especially the option to have more than one profile inversion or representation per ionogram, and in allowing both polynomial and tabular representations of the profiles. Profile inversion is an evolving art and the option for multiple opinions is useful for the data providers, although confusing for the data users.

This format allows for the storage of multiple ionogram traces. Both different inversion methods, such as NhPC and POLAN can be applied, or different traces may be applied to the same inversion, such as including auroral-E layers. In general, not all <`Trace`> entries will be used in each electron density profile inversion process. An additional element of <`ProfileList`> called <`ProfileTraceList`> will be essential to know which data were actually used in the profile analysis.

9.1 Tabulated Profiles

The table scheme similar to that in the <`EchoTable`> elements should be used. This will allow efficient storage of tabulated profiles and associated error data, including multi-dimensional inversions currently being researched. For example, profile tilts at any altitude resolution can be supported. With the table scheme, multiple error boundaries can be defined, to better represent the typically non-Gaussian error distributions inherent in these data.

9.2 Polynomial Profiles

While it is possible to include both <`ProfileTable`> and <`ProfilePolynomial`> elements in the same <`Profile`>, provided the Traces, Algorithms and such were the same for each representation, it is recommended that these be viewed as separate profiles, thus stored under separate <`Profile`> elements. In some cases, the tabulated profile is just the evaluation of the polynomial, but these can these can be truly different profiles and should be treated as such.

Some of the elements and attributes from the UML version of the format have been rearranged, with the usual emphasis toward Elements and away from Attributes. Some elements, such as the Radius of the Earth, while required for quasi-parabolic representations, are constants and thus do not need to be included in a data file.

For Quasi-Parabolic polynomial representation, the <`ProfileLayer`> will be repeated several times for each ionosphere region, with each entry having a separate `LayerID` attribute. This attribute is superfluous for Chebyschev type polynomials. This proposed structure is versatile enough that a separate element is no longer required to contain both Chebyschev and Quasi-Parabolic formulations. The example in the UML proposal is shown, consistent with the style in this document, in Listing 13.

Listing 13: Sample polynomial Profile from Digisondes

```
<ProfileList Num="1">
   <Profile ProfileID="1" Algorithm="NhPC" Version="4.21"}
     <ProfileTraceList Num="3" > 1, 3, 4 </ProfileTraceList>
     <ProfileValley Model="ULCAR">
        <Width> 80.5 </Width>
        <Depth> 0.2974 </Depth>
     </ProfileValley>
     <ProfilePolynomial Type="Chebyshev" NumLayer="2" >
        <ProfileLayer Region="E" LayerID="1">
           <StartFreq Units="MHz"> 0.20 </StartFreq>
           <EndFreq Units="MHz"> 0.545 </EndFreq>
           <PeakHeight Units="km"> 122.5 </PeakHeight>
           <Error> 0.0 </Error>
           <Coefficients Num="3"> -23.0, 4.8, -0.5 </Coefficients>
        </ProfileLayer>
        <ProfileLayer Region="F2" LayerID="2">
           <StartFreq Units="MHz"> 0.543 </StartFreq>
           <EndFreq Units="MHz"> 4.1 </EndFreq>
           <PeakHeight Units="km"> 386.7 </PeakHeight>
           <Error> 0.0 </Error>
           <Coefficients Num="5" > -69.3, 17.4, 0.0, 0.0, 0.0 </Coefficients>
        </ProfileLayer>
     </ProfilePolynomial>
</ProfileList>
```

9.3 Valleys

The inversion of most ionogram traces into electron density profiles requires the modeling of the E-F valley region or other unobserved, low altitude ionization such as nighttime E layers. This information is critical to the understanding of the profile analysis, even tabulated profiles which may have used this information to create density values for these unobserved regions. Thus the <`ProfileValley`> element is placed within the <`Profile`>, is to be included with both <`ProfileTable`> and <`ProfilePolynomial`> representations.

9.4 Altitude versus Height

It is also worthy to note here that with modern ionosounding techniques, such as the Precision Group Height (PGH) for Digisondes and Stationary Phase Group Range (SPGR) for Dynasondes , the ability to measure echo range to precisions better than 1 km means that station altitude can no longer be ignored. This comes into play when specifying Profiles, thus the Altitude in these profiles should be referenced to Mean Sea Level (MSL), not the historical Above Ground Level (AGL). Of course, given Height in AGL values and station altitude, a profile correction can be made by the end users. Note the distinction, in that Altitude is MSL and Height is AGL. For polynomial profile representations, this is likely to be a distinction without a difference.

9.5 Uncertainty Estimates

Listing 14 gives an example of this representation, including some error bars in both height and density. As with scaled characteristics, error estimates need a **BoundaryType** attribute. Note that in the height error the column name **HeightBound** is used. As in the UML proposal, an asymmetric error estimate **...UpperBound ...LowerBound** pairs or a single **...Bound** may be used.

Listing 14: Sample Tabluated Profile from Digisondes

```
<ProfileList Num="1">
  <Profile ProfileId="1" Algorithm="NhPC" Version="4.21" >
     <ProfileTraceList Num="3" > 1, 3, 4 </ProfileTraceList>
     <ProfileValley Model="ULCAR">
        <Width> 80.5  </Width>
        <Depth> 0.2974 </Depth>
     </ProfileValley>
     <ProfileTable  NumColumns="5" NumRows="4" >
        <Column Name="Altitude" Type="Float" Units="km" SigFigs="1" Description="Altitude(MSL)" />
        <Column Name="Density" Type="Float" Units="cm-3" SigFigs="3" Description="Electron␣concentration" />
        <Column Name="DensityLowerBound" Type="Float" Units="cm-3" SigFigs="2" BoundaryType="1sigma" Description="Density␣Error" /
        <Column Name="DensityUpperBound" Type="Float" Units="cm-3" SigFigs="2" BoundaryType="1sigma" Description="Density␣Error" /
        <Column Name="AltitudeBound" Type="Float" Units="km" SigFigs="2" BoundaryType="1sigma" Description="Altitude␣Error" />
        <Stream Delimiter=",">
120.5, 0.965E05, 0.900E05, 0.997E05,  10.0
129.6, 1.234E05, 1.105E05, 1.300E05,  12.5
180.6, 2.450E05, 2.409E05, 2.565E05,  18.7
355.7, 8.758E05, 8.656E05, 8.976E05,  38.0
         </Stream>
     </ProfileTable>
   </Profile>
</ProfileList>
```

9.6 Multi-Dimensional Profiles

The ability to represent non-horizontally stratified electron density profiles using off-vertical echolocation data is underway by several research teams. This information is generally represented as a tilt to the layer. The tilt can be represented as a pair of angles, a `<TiltZenith>` which defines the magnitude of the tilt from vertical and an `<TiltAzimuth>` which determines in which direction the tilt lies. Depending on the technique, the tilt can be measured with altitude, for each ionospheric layer, or for the entire ionosphere as a whole.

For `<ProfileTable>` data, adding two columns:
`<Column Name="TiltZenith" Type="Float" Units="deg" SigFigs="1" Description="Tilt Zenith">`
`<Column Name="TiltAzimuth" Type="Float" Units="deg" SigFigs="1" Description="Tilt Azimuth">`
and possibly associated error columns will represent the tilts at the same resolution as the data. For `<ProfilePolynomial>` data types, adding `<TiltZenith>` and `<TiltAzimuth>` elements for each `<ProfileLayer>` is efficient.

10 Velocities

Velocity profiles are similar to Electron Density Profiles, but likely to be of lower height resolution. Velocities are vectors and the components can be presented in different coordinate systems (Cartesian, polar, spherical), and have different reference frames (geographic, geomagnetic). These differences can be accommodated by the correct and careful defining of the columns in the `<VelocityTable>` element. Listing 15 represents a hypothetical Dynasonde velocity profile, where the F layer velocity is computed at 4 separate real altitudes.

For all quantities, error estimates in terms of either pairs of values (**LowerBound**, **UpperBound**) or symmetric values of **Bound** are permissible. Since velocities tend to be averaged over a significant range of altitudes, these boundaries can be used to indicate the averaging interval.

Listing 15: Sample Velocities from Dynasondes

```
<VelocityList Num="1">
  <Velocity VelocityID="1" Coordinates="Geographic" Algorithm="DSND" Version="5.55" >
    <VelocityTraceList Num="1" > 7 </VelocityTraceList>
    <VelocityTable NumColumns="6" NumRows="4" >
       <Column Name="Altitude" Type="Float" Units="km" SigFigs="1" Description="Altitude␣(MSL)" />
       <Column Name="VNorth" Type="Float" Units="m/s" SigFigs="2" Description="Northward␣Component" />
       <Column Name="VEast" Type="Float" Units="m/s" SigFigs="2" Description="Eastward␣Component" />
       <Column Name="VUp" Type="Float" Units="m/s" SigFigs="2"  Description="Upward␣Component" />
       <Stream Delimiter=",">
150.0, 100.10,  -22.80,  37.86
200.0,  99.70,  -38.50,  22.49
250.0,  87.50,  -98.75,  10.40
300.0,  88.33, -185.44, -14.50
        </Stream>
     </VelocityTable>
   </Velocity>
</VelocityList>
```

11 Other Geophysical Quantities

The basic nature of the SAOXML format allows for simple, backward compatible extensions of the format to accommodate new geophysical observations that are derived from ionograms. Plasma irregularities, thermospheric estimates, wave measurements and absorptions are just some of the new observables that can easily be accommodated by this data structure. Since these are relatively new technologies, it is premature to define a specific data structure at this time.

12 Additional Examples

Several examples of how data from different ionosonde types might fit into this SAOXML format are provided for illustration and illumination. Due to the large size of these files, these examples and are truncated. Complete data files are available for inspection at `http://www.ionosonde.org/SAOXML/Examples/`.

12.1 Dynasonde Data

The Dynasonde currently provides a rich collection of data. It includes both scaled ionogram data, such as parameters and traces, as well as detected echoes with a large number of parameters for each echo.

Scaled characteristics in Listings 7 and 8 should be very similar for all ionosondes, the difference being in the number, accuracy and precision of these numbers. Echoes in Listing 9, Tracelets in Listing 11 and Traces in 12 were in large part inspired by Dynasonde data. The authors are grateful to the Dynasonde community for their sophisticated data.

12.2 Digisonde Traces

Digisondes represent the vast majority of ionosonde data currently being taken. The SAOXML format was designed for that system, and this format is very well suited to portraying data from these ionosondes. The Digisonde autoscaling software does not provide information on tracelets, but does provide echo data for each of the points on the E, F1, F2 layers. Listing 16 shows the example traces from the UML SAOXML Version 5.0 proposal, and Listing 17 shows that same data in using this proposal's <`EchoTable`>,<`TraceFragment`> and <`Traces`> scheme.

Listing 16: Digisonde Trace Example

```
<TraceList Num="1">
   <Trace layer="F2" polarization="O" numberOfPoints="9">
      <frequencies units="MHz">3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.0 4.1</frequencies>
      <heights units="km">232.5 233.75 235.0 225.0 230.0 230.0 230.0 260.0 485.0</heights>
      <amplitudes units="dB">106 0 106 106 102 102 102 102 106</amplitudes>
      <dopplers noValue="99" units="Hz"> -.391 99 .391 -.391 .391 -.391 .391 .391 -.391</dopplers>
   </Trace>
</TraceList>
```

Mapping these data in Listing 16 into this proposed format in very straightforward, but involves an increase in file size to accommodate the additional metadata and associations between the information.

Listing 17: Digisonde Echoes, Tracelets and Traces

```
<EchoTable NumColumns="6"  NumRows="9">
  <Column Name="EchoId" Type="Int" Description="Unique␣Echo␣Identifier" />
  <Column Name="Frequency" Type="Float" Unit="MHz" SigFigs="4" Description="Nominal␣Frequency" />
  <Column Name="Range" Type="Float" Unit="km" SigFigs="2" Description="Range" />
  <Column Name="Doppler" Type="Float" Unit="Hz" SigFigs="3" NoValue="99" Description="Doppler␣Shift" />
  <Column Name="Amplitude" Type="Float" Unit="dB" SigFigs="1" Description="Relative␣Amplitude" />
  <Column Name="Polarization" Type="Char", Description="Polarization" />
  <Stream Delimiter=",">
1, 3.3000, 232.50, -0.391, 106.0, O
2, 3.4000, 233.75, 99.000,   0.0, O
3, 3.5000, 235.00,  0.391, 106.0, O
4, 3.6000, 225.00, -0.391, 102.0, O
5, 3.7000, 230.00,  0.391, 102.0, O
6, 3.8000, 230.00, -0.391, 102.0, O
7, 3.9000, 230.00,  0.391, 102.0, O
8, 4.0000, 260.00,  0.391, 102.0, O
9, 4.1000, 485.00, -0.391, 106.0, O
  </Stream>
</EchoTable>

<TraceFragmentList Num="1" >
  <TraceFragment TraceletId="1" >
    <TraceFragmentTable NumColumns="1" NumRows="9" >
      <Column Name="EchoId" Type="Int" Description="EchoId␣of␣Echoes␣in␣this␣Tracelet" />
      <Stream Delimiter=",">
1
2
3
4
5
6
7
8
9
     </Stream>
   </TraceFragmentTable>
  </TraceFragment>
</TraceletFragmentList>

<TraceList Num="1" >
  <Trace TraceletId="1" NumTracelets="1" TraceName="1F1">
     <TraceletGroup> 1  </TraceletGroup>
  </Trace>
</TraceList>
```

12.3 Digisonde Drift Data

The concept of echoes in SAOXML allows processed Digisonde drift data, especially the Skymap data, to be represented without information loss.

Listing 18: Digisonde Drift Skymap Data Format

```
1  4.2 0523722081144FD695804300021414400450426006214407310000118  4 5   4 16620
   1  40.0  4.7900 535.0 12  7 29  5  5  5  0
  -2.3 -2.4 -1.3 -4.5 -4.6
   6.1  6.2  7.0  3.3  3.7
    23   29   26   23   21
    -3   -2   -1    1    2
     3    3    2    1    3
   2  40.0  4.7900 540.0 12  7 24  5  5  5  0
  -3.4 -1.1  3.1-15.1 -5.3
   4.4  4.0  3.9  2.4  5.8
    19   24   22   14   14
    -3   -2   -1    1    2
     8    7    5    1    6
   3  40.0  4.7900 545.0 12  7 31  6  5  5  0
  -2.0 -3.6 -3.5 -3.6 -4.7 -4.9
   4.6  4.7  4.3  3.4  1.4  3.1
    20   28   31   28   22   14
    -3   -2   -1    1    2    3
     2    3    3    3    2    8
   4  40.0  4.7900 550.0 12  6 33  4  5  5  0
  -3.0 -2.6 -2.8 -3.3
   3.7  4.3  4.2  4.1
    25   32   33   26
    -3   -2   -1    1
     2    4    4    7
```

The process of "Source Location" in Digisonde Drift data is clearly an echo detection process, so the results can be trivially described as <`EchoList`>. Listing 18 gives a current format Digisonde Skymap entry,[3] the complete file being at `http://www.ionosonde.net/SAOXML/ga762_2005237220800a.sky`. Listing 19 gives the same information in this SAOXML format. Translation into SAOXML <`EchoList`> requires spatial and Doppler translations.[4]

Listing 19: Digisonde Drift Skymap Data Format

```
<SystemInfo>
   <StartTimeUT> Format="ISO8601" 2005-08-25 22:08:10.000 /StartTimeUT>
   <UMLStationID>  062 </UMLStationID>
   <URSICode> GA762 </URSICode>
   <StationName> Gakona </StationName>
   <Latitude>   62.24  </Latitude>
   <Longitude> 214.91 </Longitude>
   <SounderType> DPS-4 </SounderType>
   <ScalerType> auto </ScalerType>
   <Algorithm Version="5.1"> DDAS </Algorighm>
   <StartFrequency Units="MHz"> 4.30 </StartFrequency>
   <EndFrequency Units="MHz"> 4.90 <\EndFrequency>
   <FrequencyStep Units="MHz" Type="linear"> 0.2 </FrequencyStep>
   <StartHeight Units="km" > 120 </StartHeight>
   <EndHeight Units="km" > 500 </EndHeight>
   <HeightStep Units="km" Type="linear"> 5.000 </HeightStep>
   <Comments> This is an example Drift data file provided by Dima Paznukhov </Comments>
   <Digisonde_Preface Type="DPS4_Drift" >
0523722081144FD695804300021414400450426006214407310000118
   </Digisonde_Preface>
</SystemInfo>
<EchoTable NumColumns="11"  NumRows="5">
  <Column Name="EchoId" Type="Int" Description="Unique␣Echo␣Identifier" />
  <Column Name="Time" Type="Float" Unit="Second"  SigFigs="3" Description="Time␣from␣measurement␣start" />
  <Column Name="Frequency" Type="Float" Unit="MHz" SigFigs="4" Description="Nominal␣Frequency" />
  <Column Name="Range" Type="Float" Unit="km" SigFigs="2" Description="Range" />
  <Column Name="YL" Type="Float" Unit="km" SigFigs="2" Description="Geographic␣Northward␣Location" />
  <Column Name="XL" Type="Float" Unit="km" SigFigs="2" Description="Geographic␣Eastward␣Location" />
  <Column Name="Doppler" Type="Float" Unit="Hz" SigFigs="5" Description="Doppler␣Shift" />
  <Column Name="Amplitude" Type="Float" Unit="dB" SigFigs="1" Description="Relative␣Amplitude" />
  <Column Name="Noise" Type="Float" Unit="dB" SigFigs="1" Description="Noise␣Level" />
  <Column Name="Polarization" Type="Char", Description="Polarization" />
  <Column Name="EP" Type="Float", Unit="Deg" SigFigs="1" Description="Echo␣Phase␣Error" />
  <Stream Delimiter=",">
1, 10.240, 4.7900, 535.00, -2.3,  6.1, -0.29297, 23.0, 7.0, O, 3.0
2, 10.240, 4.7900, 535.00, -2.4,  6.2, -0.19531, 29.0, 7.0, O, 3.0
3, 10.240, 4.7900, 535.00, -1.3,  7.0, -0.09765, 26.0, 7.0, O, 2.0
4, 10.240, 4.7900, 535.00, -4.5,  3.3,  0.09765, 23.0, 7.0, O, 1.0
5, 10.240, 4.7900, 535.00, -4.6,  3.7,  0.19531, 21.0, 7.0, O, 3.0
  </Stream>
</EchoTable>
```

---

[3] Courtesy of Dima Paznukhov, UMass Lowell

[4] The authors admit they may have made some errors in the translations, but our intent is to relay the concept.

12.4 Digisonde Ionograms

Although particularly space inefficient for this application, and noting that this is clearly beyond the original intent of this XML based format, it is none the less simple to store thresholded Digisonde ionogram data in this format. In fact, amplitude thresholding is a simple echo detection scheme, and the ionogram frequency-range bins which pass the threshold test typically contain echo data.

AFRL has written a FORTRAN software package that turns the native Digisonde raw ionogram data files into flat text files that are the heart of the data <`Stream`> in the <`EchoTable`>. This software originally worked on the voluminous 16 Channel data from Digisonde 256 ionosondes and is described in INAG Bulletin #63, but has recently been expanded to include most raw ionogram formats from both D256 and DPS ionosondes. A minor modification to produce these data in the SAOXML <`EchoTable`> format is pending. Contact the authors for the most recent version of the code.

The *dgs16c* program can produce data in a flat text file, a small sample of which is shown in Listing 20.

Listing 20: Digisonde 256 16-Channel Data, flat text file

```
# 2003 081 13:15:05  1.0025 03081131505 11320000 010000 60C3104 01121 12E 908 4151 324 002 1229
#             Time      Freq     Range  Polarize      Noise   Doppler        Az        Zn  Ampltude     Phase
2003 081 13:15:15    3.0125   120.000   -90.000     51.750    -1.562     0.000     0.000    67.500   212.344
2003 081 13:15:15    3.0125   120.000   -90.000     51.750     1.562     0.000     0.000    68.625   205.312
#             Time      Freq     Range  Polarize      Noise   Doppler        Az        Zn  Ampltude     Phase
2003 081 13:15:15    3.1025   120.000   -90.000     51.750     1.562     0.000     0.000    67.125   261.562
#             Time      Freq     Range  Polarize      Noise   Doppler        Az        Zn  Ampltude     Phase
2003 081 13:15:21    4.3225   200.000   -90.000     51.000    -1.562     0.000     0.000    70.125   209.531
2003 081 13:15:21    4.3225   200.000   -90.000     51.000     1.562     0.000     0.000    69.000   215.156
2003 081 13:15:21    4.3225   205.000   -90.000     51.000    -1.562     0.000     0.000    78.375   208.125
2003 081 13:15:21    4.3225   205.000   -90.000     51.000     1.562     0.000     0.000    78.375   209.531
2003 081 13:15:21    4.3225   210.000   -90.000     51.000    -1.562     0.000     0.000    70.125   188.438
2003 081 13:15:21    4.3225   210.000   -90.000     51.000     1.562     0.000     0.000    70.500   185.625
#             Time      Freq     Range  Polarize      Noise   Doppler        Az        Zn  Ampltude     Phase
2003 081 13:15:22    4.4025   210.000   -90.000     51.375    -1.562     0.000     0.000    69.000   347.344
2003 081 13:15:22    4.4025   210.000   -90.000     51.375     1.562     0.000     0.000    68.250   343.125
2003 081 13:15:22    4.4025   215.000   -90.000     51.375    -1.562     0.000     0.000    72.750   354.375
2003 081 13:15:22    4.4025   215.000   -90.000     51.375     1.562     0.000     0.000    71.250   352.969
```

The *dgs16c* code has no ionogram scaling, and only primitive threshold-based echo detection. The <`SystemInfo`> entries would be identical to any other Digisonde ionogram, so they will not be repeated here. The equivalent <`EchoTable`> element of the SAOXML file would be as shown in Listing 21. The resulting file is large, but not extremely large.

Listing 21: Digisonde 256 16-Channel Data, SAOXML <`EchoTable`> format

```
<EchoTable NumColumns="8"  NumRows="4">
  <Column Name="EchoId" Type="Int" Description="Unique␣Echo␣Identifier" />
  <Column Name="Time" Type="Float" Unit="Second"  SigFigs="3" Description="Time␣from␣ionogram␣start" />
  <Column Name="Frequency" Type="Float" Unit="MHz" SigFigs="4" Description="Nominal␣Frequency" />
  <Column Name="Range" Type="Float" Unit="km" SigFigs="2" Description="Range" />
  <Column Name="PP" Type="Float", Unit="degree" SigFigs="0" Description="Polarization␣Chirality" />
  <Column Name="Noise" Type="Float" Unit="dB" SigFigs="2" Description="Noise␣Level" />
  <Column Name="Doppler" Type="Float" Unit="Hz" SigFigs="3" Description="Doppler␣Shift" />
  <Column Name="Azimuth" Type="Float" Unit="Deg" SigFigs="1" Description="Geographic␣Azimuth␣East␣of␣North" />
  <Column Name="Zenith" Type="Float" Unit="Deg" SigFigs="1"  Description="Zenith␣Angle" />
  <Column Name="Amplitude" Type="Float" Unit="dB" SigFigs="3" Description="Relative␣Amplitude" />
  <Column Name="Phase" Type="Float" Unit="Deg" SigFigs="2" Description="Phase" />
  <Stream Delimiter=",">
 1, 10.000, 3.0125, 120.00, -90., 51.75, -1.562, 0.0, 0.0, 67.500, 212.34
 2, 10.000, 3.0125, 120.00, -90., 51.75,  1.562, 0.0, 0.0, 68.625, 205.31
 3, 10.500, 3.1025, 120.00, -90., 51.75,  1.562, 0.0, 0.0, 67.125, 261.56
 4, 16.000, 4.3225, 200.00  -90., 51.00, -1.562, 0.0, 0.0, 70.125, 209.53
 5, 16.000, 4.3225, 200.00  -90., 51.00,  1.562, 0.0, 0.0, 69.000, 215.16
 6, 16.000, 4.3225, 205.00  -90., 51.00, -1.562, 0.0, 0.0, 78.375, 208.13
 7, 16.000, 4.3225, 205.00, -90., 51.00,  1.562, 0.0, 0.0, 78.375, 209.53
 8, 16.000, 4.3225, 210.00, -90., 51.00, -1.562, 0.0, 0.0, 70.125, 188.44
 9, 16.000, 4.3225, 210.00, -90., 51.00,  1.562, 0.0, 0.0, 70.500, 185.63
10, 17.000, 4.4025, 210.00, -90., 51.38, -1.562, 0.0, 0.0, 69.000, 347.34
11, 17.000, 4.4025, 210.00, -90., 51.38,  1.562, 0.0, 0.0, 68.250, 343.13
12, 17.000, 4.4025, 215.00  -90., 51.38, -1.562, 0.0, 0.0, 72.750, 354.38
13, 17.000, 4.4025, 215.00  -90., 51.38,  1.562, 0.0, 0.0, 71.250, 352.97
   </Stream>
</EchoTable>
```

13 Summary

The UMass Lowell proposal for an XML based data format for scaled ionosonde data is heartily embraced by the World Data Center A team. However, WDC-A suggests several modifications and extensions to this proposed format. There are many differences, some trivial, many stylistic and a few fundamental. Several areas of this proposal are notably weak, and WDC-A elicits opinions from the world ionosonde community of both data creators and data users as to the content of this proposal. We encourage you to make this *your* proposal.

The collection of appendices are a Format Description that contains all the officially recognized elements, attributes and formats defined in the SAOXML format. These appendices are still in draft form, awaiting inputs and comments from INAG. Eventually, the Appendices will form a stand-alone document that is the official format description document for SAOXML Version 6.

APPENDICIES

A Top Level Structure

An SAOXML file is an ASCII text that is a well-formed XML document. The overall design is such that individual data records can be merged into a single multi-record XML file with minimal effort.

This is an example of the top level structure of an SAOXML file. The file contains a list of individual records:

`<?xml version="1.0"?>` – XML header
`<SAOList>` – Opening root tag for the file
`<SAORecord` *`List of attributes`*`>` – Start of a data record
`</SAORecord>` – Closing tag for a data record
`</SAOList>` – Closing root tag for the file

B General References

Several common structures, elements and attributes are used throughout this specification. They are provided in detail in this Appendix.

B.1 Table Elements

The XSIL[5] style Data Table element type allows for efficient storage of data in columns, where each column can be a unique data type and elements from each row are related. The basic structure of a Data Table is given in Table 1.

Element	Attribute	Description	Example and Options	Req'd
Column		An XSIL-like descriptor defining each data column in the associated `<Stream>`	`<Column Name="EchoId" Type="Int"/>`	Yes
	Name	Short name for the data column.	`Name="Frequency"` `Name="Range"`	Yes

	Type	Data type for the column. Integer, Character and Floating Point are defined	`Type="Int"`
			`Type="Float"`
			`Type="Char"`
				Yes

	Unit	Units of measure for the column	`Unit="km"`	No
	SigFig	Number of Significant Figures for `Float` columns	`SigFig="4"`	No
	NoValue	Indicator of "No Data" for that column	`NoValue="-999"`	No
	Description	Long explanation of column contents	`Description="Nominal Frequency"`	No
Stream		A table of data containing echo parameters	`1, 3.3000, 232.50, -0.391, 106.0, 0`	Yes
	Delimiter	Character used to delimit columns. Rows are delimited by End-Of-Line Default is a comma	`Delimiter=","`	No

Table 1: XSIL style Table data structure

B.2 Lists

There are many XML elements that represent lists of values all of the same type. In general, these are clearly identified as by including the word "List" in the element name. A required attribute of any element that is a list is the number of elements in the list. It is of the format `Num="12"`. The items in the list are comma delimited.

---

[5] `http://www.cacr.caltech.edu/SDA/xsil/`

B.3 Boundary Types

The **BoundaryType** attribute determines what type of statistical function is implied by the numerical value of the <`Boundary`>, <`UpperBoundary`> or <`LowerBoundary`> elements. Table 2 contains all the defined values of **BoundaryType**.

Value	**Description**
1sigma	Gaussian distribution, 1σ point
3sigma	Gaussian distribution, 3σ point
10%tile	10^{th} percentile value
90%tile	90^{th} percentile value
decile	Symmetric 10^{th}, 90^{th} percentile
25%tile	25^{th} percentile value
75%tile	75^{th} percentile value
quartile	Symmetric 25^{th}, 75^{th} percentile

Table 2: BoundaryType attribute values

C SAORecord

The bulk of the SAOXML file content is inside each of the SAORecord elements. The entire file is a concatenated sequence of these SAORecord elements, with a minimal quantity of “glue” added at the start and finish of the file in order to make a valid XML file.

C.1 SAORecord Attributes

The only SAORecord Attribute is the version number. It is required. This document outlines Version 6.0.

Attribute	**Description**	**Example and Options**	**Req’d**
version	SAO version for this record	`version="6.0"`	Yes

Table 3: SAORecord Attributes

C.2 SAORecord Elements

Each <`SAORecord`> element contains the observations and analysis for a single ionogram for a single station. The defined SAORecord Elements are listed in Table 4. Each of these elements are described in a separate Appendix.

Element	**Description**	**Reference**	**Req’d**
SystemInfo	System and Measurement metatata	Appendix D	Yes
ScaledCharacteristics	Scaled Ionogram Characteristics	Appendix E	No
EchoTable	Ionogram Echo Parameters	Appendix F	No
TraceFragmentList	Associations of Echoes into Tracelets	Appendix G	No
TraceList	Grouping and Classification of Tracelets	Appendix H	No
ProfileList	Ionospheric Electron Density Profiles	Appendix I	No
VelocityList	Ionospheric Velocities	Appendix J	No

Table 4: SAORecord Elements

D SystemInfo

The <`SystemInfo`> element contains all desired information about the system and metadata which are needed to comprehend the data provided in other elements of this file. This element has no attributes.

Authors' Note: This section needs additional elements and attributes, especially from other ionosonde types.

D.1 SystemInfo Elements

The defined <`SystemInfo`> Elements and Attributes are listed in Table 5.

Element	**Attribute**	**Description**	**Example and Options**	**Req'd**
StartTime		Measurement Start Time	`2000-02-01 13:45:05.000`	Yes
	Format	Format of the time string	`Format="ISO8601"`	Yes
	TimeZone	Time Zone of the value	`TimeZone="UTC"` [a]	Yes
URSICode		URSI Station Identification Code	`SMJ67` [b]	Yes
GeoLAT		Northward Geographic Station Latitude	`66.98`	Yes
GeoLON		Eastward Geographic Station Longitude	`309.0`	Yes
StationName		Common Station Name	`Sondrestrom`	No
WMOID		World Meterological Orgnaization Identifuer	`04231`	No
IonosondeType		Ionosonde Type or Model	`DGS-256`	No
ScalerType		Type of scaling used.	Must be either `manual` or `auto`	No
ScalerName		Name of manual scaler	`John Smith`	No
ScalingAlgorithm		Name of autoscaling Algorithm for ScalerType=Auto	`ARTIST`	No
AlgorithmVersion		Version number of autoscaling algorithm	`4.51`	No
StartFrequency	`Units="MHz"`	Starting frequency of the ionogram	`0.500`	No
EndFrequency	`Units="MHz"`	Ending frequency of the ionogram	`15.500`	No
FrequencyStep	`Units="MHz"`	Frequency stepping options		No
	`Type="linear"`	Linear frequency step for this ionogram	`0.100`	No
	`Type="log"`	Logarithmic frequency scaling factor	`1.020`	No
	`Type="Tabulated"` `Number="7"`	Table of sounding frequencies Required for `Type="Tabulated"`	`1.00,1.50,2.75,3.85,6.67,8.83,12.45`	No
StartHeight	`Units="km"`	Starting height of the ionogram	`60.0`	No
EndHeight	`Units="km"`	Ending height of the ionogram	`750.0`	No
HeightStep	`Units="km"`	Height stepping options		No
	`Type="linear"`	Linear height step for this ionogram	`5.00`	No
	`Type="log"`	Logarithmic height scaling factor	`1.050`	No
	`Type="Tabulated"` `Number="7"`	Table of sounding heights Required for `Type="Tabulated"`	`100,120,150,175,200,250,300`	No
RestrictedTable	`NumColumns="xx"` `NumRows="xx"`	Restricted frequency bands	See Table 6	No
DopplerTable	`NumColumns="xx"` `NumRows="xx"`	Doppler Translation Table	See Table 7	No

---

[a] See `http://www.twinsun.com/tz/tz-link.htm` for legal TimeZone values.

[b] See `ftp://ftp.ngdc.noaa.gov/STP/IONOSPHERE/CATALOG/station.lst` for a complete USRI code list

Table 5: SystemInfo Elements

D.2 Restricted Frequency Table

This table represents the Restricted Frequencies for the ionogram. It is optional. The defined <`Column`> values under <`RestrictedTable`> are listed in Table 6. Two columns are indicated by the required attribute `NumColumns="2"`. The required attribute `NumRows="xx"` defines the number of restricted bands in this measurement. The column pairs represent the upper and lower bound of each restricted frequency. Additonal columns are allowed, for example to relay information on prohibitions on a dwell measurement versus a scanning measurement.

Name	**Attributes**	**Description**	**Example and Options**	**Req'd**
RestrictedLowerBound		Lower bound of the restricted band		Yes
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="MHz"` ; `Units="kHz"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
RestrictedUpperBound		Upper bound of the restricted band		Yes
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="MHz"` ; `Units="kHz"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes

Table 6: Resticted Frequency Table structure

D.3 Doppler Translation Table

This table sets the relationship between a **DopplerIndex** and the Doppler Shift representd by that index. The table is required if **DopplerIndex** values are used in <`Echoes`>. It is not recommended to use this approach. The preferred method is to provide the actual Doppler value in the <`EchoTable`>.

The defined columns for <`DopplerTable`> Elements and Attributes are listed in Table 7. Two columns are indicated by the required attribute `NumColumns="2"`. The required attribute `NumRows="xx"` defines the number of Doppler bins in this measurement.

Name	**Attributes**	**Description**	**Example and Options**	**Req'd**
DopplerIndex		Doppler Line Index		Yes
	Type	Column Data Type	`Type="Int"` is required	Yes
DopplerFrequency		Doppler Shift		Yes
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="Hz"` ; `Units="mHz"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="4"`	Yes

Table 7: Doppler Translation Table structure

E Scaled Ionogram Characteristics

Scaled Ionogram Characteristics are contained in an element <`IonogramCharacteristics`>. This element is in fact a List and has one required attribute, which is the number of scaled ionogram characterisitcs included under this element.

<`IonogramCharacteristics Num="12"`>

All sub-elements of this list are elements named <`Item`>. The hierarchy of elements and attributes within an <`Item`> is given in Listing 22, and the elements and attributes are defined for <`Item`> are in Table 8.

Listing 22: Hierarchy of Scaled Items

```
<IonogramCharacteristics  Num="2" />
  <Item ...  >
     <Val>  ... </Val>
     <UpperBound>  ... </UpperBound>
     <LowerBound>  ... </LowerBound>
     <Bound>  ... </Bound>
   </Item>

  <Item ...  >
     <Val>  ... </Val>
     <UpperBound>  ... </UpperBound>
     <LowerBound>  ... </LowerBound>
     <Bound>  ... </Bound>
   </Item>
</IonogramCharacteristics>
```

Element	Attribute	Description	Example and Options	Req'd
Item		Generic element for scaled values		Yes
	Name	Element Name	`foF2` See Appendix K and L	Yes
	ID	Element ID ; Index	*00* See Appendix K and L	Yes
	Units	Units of the data item	`Units="MHz"`	No
	Flag	Scaling Type Flag	`Flag="auto"` `Flag="edited"`	No No
	QL	Scaling Qualifier	`QL="U"` See UAG-23A, Section 3.1	No No
	DL	Scaling Descriptor	`DL="F"` See UAG-23A, Section 3.2	No No
	BoundaryType	Boundary Type for the <`Val`>	`BoundaryType="10%tile"` See Table 2	No No
Val		Scaled Value for the characteristic		Yes
UpperBound		Assymetric Upper Uncertainty Boundary		No
LowerBound		Assymetric Lower Uncertainty Boundary		No
Bound		Symetric Uncertainty Boundary		No

Table 8: Scaled Ionogram Characteristics

F EchoTable

The <`EchoTable`> section of the file contains the observed properties of the echoes returned from the ionosphere. As a Table element, it can possess the general properties of a Table, detailed in Appendix B.1.

F.1 Echo Columns

For the <`EchoTable`>, standard names are defined for the columns in Table 9 for echo parameters and their associated errors and uncertainties. Any data column can have an errorbar assigned, the convention is to pre-pend the `UpperBound`, `LowerBound` or `Bound` to the name of the data column. Thus column name Range can have RangeUpperBound, RangeLowerBound error columns. Note that boundary columns require a `BoundaryType` attribute.

Name	**Type**	**Unit**	**SigFigs**	**Description**	**Req'd**
EchoID	Int	–	–	Unique Echo Identifier	Yes
Frequency	Float	MHz	4	Nominal Radio Frequency of the echo	Yes
Range	Float	km	2	Virtual Range Stationary Phase Group Range	Yes
Time	Float	sec	4	Time from start of Ionogram	No
Amplitude	Float	dB dBm	2 2	Relative Amplitude Calibrated Amplitude	No No
Phase	Float	Deg	1	Echo Phase	No
Noise	Float	dB dBm	2 2	Relative noise power Calibrated noise power	No No
EP	Float	deg	2	Echo Phase Error	No
XL	Float	km	2	Geographic Eastward Echo Location	No
YL	Float	km	2	Geographic Northward Echo Location	No
V*	Float	m/s	2	Apparent Radial Doppler Velocity	No
PP	Float	deg	2	Polarization Chirality	No
TraceFragID	Int	–	–	Primary Tracelet Association	No
Doppler	Float	Hz	3	Doppler Shift	No
Doppler Index	Int	–	–	Doppler Table Index	No
Polarization	Char	–	–	Polarization (O,X or Z)	No
Azimuth	Float	Deg	1	Echo Azimuth Angle	No
Zenith	Float	Deg	1	Echo Zenith Angle	No
FrequencyUpperBound	Float	MHz	4	Frequency Upper Error Boundary	No
FrequencyLowerBound	Float	MHz	4	Frequency Upper Error Boundary	No
FrequencyBound	Float	MHz	4	Frequency Symmetric Error Boundary	No
RangeUpperBound	Float	km	2	Range Upper Error Boundary	No
RangeLowerBound	Float	km	2	Range Upper Error Boundary	No
RangeBound	Float	km	2	Range Symmetric Error Boundary	No
...	...	...	...	...	...

Table 9: Defined columns for Echo Parameters

G Tracelets

Tracelets or Trace Fragments are collections of echoes that have similar physical properties. The information in this section of the file provides those associations.

G.1 TraceFragmentList

There are often many trace fragments in an ionogram. A single <`TraceFragmentList`> container is used to hold the multiple <`TraceFragment`> elements. As a List, it has a required attribute of the number of tracelet entries included. The <`TraceFragment`> elements include a required <`TraceFragmentTable`>, and can have other optional elements which quantify the entire Tracelet. One such value might be the mean amplitude of all the echoes in the Tracelet. This hierarchy is shown in Listing 23.

Listing 23: Hierarchy of Tracelet Elements

```
<TraceFragmentList Num="2" />
  <TraceFragment TraceFragId="1" >
    <TraceFragmentTable NumColumns="1" NumRows="9" >
      ...
      ...
    </TraceFragmentTable>
  </TraceFragment>
<TraceFragment TraceletId="2" >
    <TraceFragmentTable NumColumns="1" NumRows="9" >
      ...
      ...
    </TraceFragmentTable>
  </TraceFragment>
</TraceletFragmentList>
```

G.2 TraceFragment

This is a sub-element of <`TraceFragmentList`>. Defining a <`TraceFragment`> requires at least one echo, stored in a <`TraceFragmentTable`>. This element can also contain other optional information, such as mean values of some of the observed echo parameters for the Tracelet.

Element	**Attribute**	**Description**	**Example and Options**	**Req'd**
TraceFragmentList	Num	Number of Tracelets in this ionogram	`Num="12"`	Yes
TraceFragment		Element containing data for each Tracelet		Yes
	TraceFragID	Index for this Tracelet	`TraceFragID="1"`	Yes
TraceFragMeanAmp		Mean amplitude of echoes in this Tracelet	`<TraceFragMeanAmp> 38.7 </TraceFragMeanAmp>`	No
TraceFragMeanRange		Mean range of echoes in this Tracelet	`<TraceFragMeanRange> 235.6 </TraceFragMeanRange>`	No
TraceFragmentTable		Data Table with Echo-Tracelet groupings	See Table 11	Yes
	NumColumns	Number of parameters for this Tracelet	`NumColumns="1"`	Yes
	NumRows	Number of Echoes in this Tracelet	`NumRows="42"`	Yes

Table 10: Trace Fragment List Elements and Atributes

G.3 Trace Fragment Table

Each <`TraceFragmentTable`> element contains, at a minimum, the echo ID's of the Echoes that belong in this Tracelet. Other data items that are relevant to the process by which the echoes were grouped into tracelets and are unique to each echo can be included in this table. One such item could be a measure of similarity of each echo to some central value for the entire tracelet. Table 11 provides the defined columns for this data type.

Name	Type	Unit	SigFigs	Description	Req'd
EchoID	Int	–	–	EchoID of Echoes in this Tracelet	Yes
Similarity	Float	–	3	Probability this echo belongs in this Tracelet	No

Table 11: Trace Fragment Table Specification

H Traces

Traces are the well defined, standard groups of echoes that form the traditional traces, such as those defined in UAG-23A. These are the traces that help define some geophysical characteristic of the ionosphere, such as the electron density profile. The identification of which Tracelets comprise the standard Traces is included in this section of the file.

A Trace may consist of a group of one or more Trace Fragments or Tracelets, which represent one of the URSI standard ionogram traces. Unique, experimental or site-specific traces may also be defined. The process of combining Tracelets and assigning them standard designations is Trace Classification. Trace classification is a very different logical process from echo detection or echo grouping, thus it has different technical maturity and error propagation mechanics.

Defining a Trace requires at least one Tracelet and a standard layer designation as an attribute. Other optional attributes include the order of reflection, polarization and Es Type for Es layers.

The hierarchy of elements in the Traces section similar to that of Tracelets and is given in Listing 24.

Listing 24: Hierarchy of Trace Elements

```
<TraceList Num="2" />
  <Trace TraceID="1" Layer="E" >
    <TraceTable NumColumns="1" NumRows="4" >
      ...
      ...
    </TraceTable>
  </Trace>
<TraceFragment TraceID="2"  Layer="F2" >
    <TraceTable NumColumns="1" NumRows="5" >
      ...
      ...
    </TraceTable>
  </Trace>
</TraceletList>
```

H.1 TraceList

There are normally several traces identified in each ionogram. The <`TraceList`> list element includes all of these. This element has a required attribute of the number of traces in the list.
Example: `<TraceList Num="2">`

H.2 Trace

Defining a Trace requires at least one Tracelet and a standard layer designation as an attribute. This sub-element of <`TraceList`> contains this required and other optional information. Optional attributes include the order of reflection, polarization and Es Type for Es layers. An optional Mode attribute is defined that can identify M and N mode reflection and range aliased (i.e. around-the-time-base) traces.

H.3 Trace Table

Each <`TraceTable`> element contains, at a minimum, the Trace Fragment ID's of the Tracelets that belong in this Trace. Other data items that are relevant to the process by which the Tracelets were grouped into traces and are unique to each Tracelet can be included in this table. One such item could be a measure of similarity of each Tracelet to some central value for the entire Trace. Table 13 provides the defined columns for this data type.

Element	**Attribute**	**Description**	**Example and Options**	**Req'd**
TraceList	Num	Number of Traces in this ionogram	`Num="12"`	Yes
Trace		Element containing data for each Trace		Yes
	TraceID	Index for this Trace	`TraceID="1"`	Yes

	Layer	Ionosphere layer for this Trace
		See UAG-23A
			`Layer="E"`
			`Layer="F1"`
			`Layer="F1.5"`
			`Layer="F2"`
			`Layer="F3"`
			`Layer="Es"`
				Yes

	Order	Order of reflection for this Trace Defaults to 1 if absent	`Order="1"` `Order="2"`	No

	Mode	Mode of reflection for this Trace
		Assumed to be direct reflection if absent or blank. See UAG-23A.
		RA=Range Aliased
			`Mode=""`
			`Mode="M"`
			`Mode="N"`
			`Mode="RA"`
				No

	Polarization	Declared polarization for this Trace	`Polarization="O"`
			`Polarization="X"`
			`Polarization="Z"`
				No

	TypeEs	TypeEs for Es Traces.
		See UAG-23A for a full list
			`TypeEs="f"`
			`TypeEs="l"`
			`TypeEs="c"`
			`TypeEs="a"`
				No

TraceTable	Num	Table of Tracelets forming Trace		Yes

Table 12: Trace List Elements and Atributes

Name	**Type**	**Unit**	**SigFigs**	**Description**	**Req'd**
TraceFragID	Int	–	–	TraceFragID of Traclets in this Trace	Yes

Table 13: Trace Table Specification

I Profiles

Electron density profiles, and their uncertainties, derived from ionogram traces, are stored in this section of the file. Both tabulated and polynomial representations of profiles are accommodated. For ease of use, it is recommended and preferred that tabulated profiles be used.

I.1 Profile List

Multiple profile analysis results can be stored in this file, in both tabulated and various coefficient methods, for each ionogram. Both different inversion methods, such as NhPC and POLAN can be applied, or different traces may be applied to the same inversion, such as including auroral-E layers. The <`ProfileList`> list element includes all of these. This element has a required attribute of the number of profiles in the file.
Example: `<ProfileList Num="2">`

Similar to the Tracelets, but unlike Traces, there is a hierarchy of elements within a <`ProfileList`> that is defined in Listing 25. A <`ProfileList`> can contain multiple <`Profile`> elements, and each <`Profile`> element contains <`ProfileTraceList`>, <`ProfileTable`> and <`ProfilePolynomial`> elements. These are defined in Tables 14, 16 and 17 respectively.

While it is possible to include both <`ProfileTable`> and <`ProfilePolynomial`> elements in the same <`Profile`>, provided the Traces, Algorithms and such were the same for each representation, it is recommended that these be viewed as separate profiles, thus stored under separate <`Profile`> elements, as shown in Listing 25

Listing 25: Hierarchy of Profile Elements

```
<ProfileList Num="2" >
  <Profile ProfileId="1" ...  >
     <ProfileTraceList Num="3" > 1, 3, 4 </ProfileTraceList>
     <ProfileValley>
        ...
     </ProfileValley>
     <ProfileTable NumColumns="1" NumRows="9" >
        ...
        ...
    </ProfileTable>
   </Profile>

   <Profile ProfileId="2" ...  >
    <ProfilePolynomial ...  >
       <ProfileLayer Region ="E" NumPoints="3" >
          ...
          ...
       </ProfileLayer>
    </Profile>
</ProfileList>
```

I.2 Profile

The <`Profile`> elements are sub-elements of the <`ProfileList`> and contain information about a single profile. Attributes of that profile are provided within this element. Table 14 defines the element.

I.3 Profile Trace List

In general, not all <`Trace`> entries will be used in each electron density profile inversion process. A list element called <`ProfileTraceList`> will be essential to know which data were actually used in the profile analysis. This is a simple, required element containing the traces used in this profile, and a list of TraceID values from the Traces section. There is one required attribute, the number of traces in the list.
Example: `<ProfileTraceList Num="3" > 1, 3, 4 </ProfileTraceList>`

I.4 Profile Valley

The inversion of most ionogram traces into electron density profiles requires the modeling of the E-F valley region or other unobserved, low altitude ionization such as nighttime E layers. This information is critical to the understanding of the profile analysis, even tabulated profiles which may have used this information to create density values for these unobserved regions. Thus the <`ProfileValley`> element is placed within the <`Profile`> element, is to be included with both <`ProfileTable`> and <`ProfilePolynomial`> representations. The format of this tag is given in Table 15

Authors' Note: This element definition needs to be expanded to cover other valley models

Element	**Attribute**	**Description**	**Example and Options**	**Req'd**
ProfileList	Num	Number of Profiles for this ionogram	`Num="2"`	Yes
Profile		Element containing data for each Profile		Yes
	ProfileID	Index for this Profile	`ProfileID="1"`	Yes
	Algorithm	Name of the algorithm used	`Algorithm="NHPC"` `Algorithm="POLAN"`	No
	Version	Algorithm Version	`Version="4.21"`	
ProfileTraceList	Num	List of traces used for this profile	`<ProfileTraceList Num="3" > 1, 3, 4 </ProfileTraceList>`	Yes
ProfileValley		Element to contain valley information	See Table 15	Yes
ProfileTable		Tabulated electron density profile	See Table 16	No
ProfilePolynomail		Polynomial representation of the profile	See Table 17	

Table 14: Profile Elements and Atributes

Element	**Attribute**	**Description**	**Example and Options**	**Req'd**
ProfileValley		Valley model used for profile inversion		No
	Model	Specific model type	`Model="ULCAR"` `Model="POLAN"`	No
Width		Valley width or height extent, in km	`<Width> 80.5 </Width>`	No
Depth		Valley depth, in plasma frequency units	`<Depth> 0.2974 </Depth>`	No
StartHeight		Profile inversion model start height, km	`<StartHeight> 90.0 </StartHeight>`	No
StartFreq		Profile inversion model starting plasma frequency, MHz	`<StartFreq> 0.500 </StartFreq>`	No

Table 15: Profile Valley Elements and Atributes

I.5 Profile Table

For tabulated electron density profiles, the <`ProfileTable`> table element is used to convey data of electron concentration and associated height and density uncertainties as a function of Altitude (above Mean Sea Level) or Height (Above Ground Level). Like all tables, it has the required attributes of number of columns and number of rows. The defined columns are given in Table 16. Note that altitude or density error boundaries can be either symmetric or asymmetric; both are not recommended.

Non-horizontal profiles can be represented by layer tilts. Zenith and Azimuth angles represent the vector that is normal to the iso-density plane for each altitude for which the information is provided.

I.6 Profile Polynomial

Ionosonde electron density profiles have historically been computed and conveyed as coefficents on polynomials. While this approach has some limitations, it also has advantages and is still in common use. Tilt azimuth and zenith angles can be specified on a layer by layer basis. Listing 26 defines the hierarchy of elements within the <`ProfilePolynomial`> element. This element is a sub-element of <`Profile`> and on the same level as <`ProfileValley`> and <`ProfileTable`>. Table 17 defines the elements and attributes.

Listing 26: Hierarchy of Polynomial Profile Elements

```
<ProfilePolynomial Type="Chebyshev" NumLayer="1" >
   <ProfileLayer Region ="E" LayerID="1">
      <StartFreq ... </StartFreq>
      <EndFreq  ...  </EndFreq>
      <Error> ... </Error>
      <Coefficients Num="3">  ...  </Coefficients>
```

Name	**Attributes**	**Description**	**Example and Options**	**Req'd**
Altitude		Altitude above mean sea level		Yes
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="km"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="1"`	Yes
Density		Electron Concentration		Yes
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="cm-3" Units="m-3"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="3"`	Yes
PlasmaFrequency		Plasma Frequency		No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="MHz" Units="kHz"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="3"`	Yes
TiltAzimuth		Tilt, Azimuth direction		No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="deg"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
TiltZenith		Tilt, zenith angle		No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="deg"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
DensityLowerBound		Density lower uncertainty boundary		No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="cm-3" Units="m-3"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
	BoundaryType	See Table 2	`BoundaryType="1sigma"`	Yes
DensityUpperBound		Density lower uncertainty boundary		No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="cm-3" Units="m-3"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
	BoundaryType	See Table 2	`BoundaryType="1sigma"`	Yes
AltitudeBound		Altitude symmetric uncertainty boundary		No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="cm-3" Units="m-3"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
	BoundaryType	See Table 2	`BoundaryType="1sigma"`	Yes

Table 16: Profile table structure

```
      <TiltAzimuth> ... </TiltAzimuth>
      <TiltZenith> ... </TiltZenith>
    </ProfileLayer>
 </ProfilePolynomail>
```

For Quasi-Parabolic segments, the profile is reconstructed by summing the contribution of each layer. That contribution is determined from the Equation 1

$$f_n^2 = A/R^2 + B/R + C \tag{1}$$

where:

- F_N is the plasma frequency
- A, B, C are the parabolic coefficients
- R is the layer height, relative to the center of the Earth

These three parabolic equations are in the <`Coefficents`> element in the order A, B, C.

Element	**Attribute**	**Description**	**Example and Options**	**Req'd**
ProfilePolynomial		Polynomial representation of EDP		No

	Type	Type of polynomial	`Type="Chebyshev"`
			`Type="POLAN"`
			`Type="QPSegments"`
				Yes

	NumLayer	Number of polynomial layers	`NumLayer="3"`	Yes
ProfileLayer		Element for each layer	`<ProfileLayer Region="F2" LayerID="2">`	Yes

	Region	Ionosphere region for this layer	`Region="F2"`
			`Region="E"`
			`Region="F1"`
			`Region="Ea"`
				Yes

	LayerID	Integer layer ID	`LayerID="0"`	Yes[a]
StartFreq	Units	Starting plasma frequency, in MHz	`<StartFreq> Units="MHz" 0.543 </StartFreq>`	Yes[b]
EndFreq	Units	Ending plasma frequency, in MHz	`<EndFreq Units="MHz"> 0.543 </EndFreq>`	Yes[b]
PeakHeight	Units	Layer Peak Height, in km	`<PeakHeight Units="km"> 386.7 </PeakHeight>`	Yes [b]
ZHalfNm	Units	Layer height at half of the peak density	`<ZHalfNm Units="km"> 288.5 </PZHalfNm>`	No
StartHeight	Units	Starting segment height R1, in km from Earth Center	`<StartHeight Units="km"> 6460.0 </StartHeight>`	Yes[a]
EndHeight	Units	Ending segment height R2, in km from Earth Center	`<EndHeight Units="MHz"> 6475.5 </EndHeight>`	Yes[a]
Error		Average fitting error, in km	`<Error> 7.50 </Error>`	No
TiltZenith	Units	Layer tilt, in degrees from zenith	`<TiltZenith > 2.5 </TiltZenith>`	No
TiltAzimuth	Units	Layer tilt azimuth angle, in degrees East of Geographic North	`<TiltAzimuth > 322.4 </TiltAzimuth>`	No
Coefficients		Coefficients for the layer	`<Coefficients Num="3"> -23.0, 4.8, -0.5 </Coefficients>`	Yes
	Num	Number of Coefficients	`Num="3"`	Yes

Table 17: Profile Polynomial Elements and Atributes

---

[a] Required for Quasi-Parabilic Polynomials

[b] Required for Chebyshev Polynomials

J Velocities

Ionosphere plasma velocities, and their uncertainties, derived from ionogram traces are stored in this section of the file. Note that the determination of ionospheric velocities from ionosonde data is an area of ongoing research, as these data often contain effects due to electric fields, neutral winds, photochemistry and wave-like phenomena. The format will have to evolve with the science.

J.1 Velocity List

Multiple velocity analysis results can be stored in this file for each ionogram. The <`VelocityList`> list element includes all of these. This element has a required attribute of the number of velocities in the file.
Example: `<VelocityList Num="2">`

There is a hierarchy of elements within a <`VelocityList`> that is defined in Listing 27. A <`VelocityList`> can contain multiple <`Velocity`> elements, and each <`Velocity`> element contains <`VelocityTraceList`> and <`VelocityTable`> elements.

Listing 27: Hierarchy of Velocity Elements

```
<VelocityList Num="1" />
  <Velocity VelocityId="1" ...  >
     <VelocityTraceList Num="3" > 1, 3, 4 </VelocityTraceList>
     <VelocityTable NumColumns="1" NumRows="9" >
        ...
        ...
    </VelocityTable>
   </Velocity>
</VelocityList>
```

J.2 Velocity Trace List

In general, not all <`Trace`> entries will be used in each velocity calculation. A list element called <`VelocityTraceList`> will be essential to know which data were actually used in the analysis. This is a simple, required element containing the traces used in this profile, and a list of TraceID values from the Traces section. There is one required attribute, the number of traces in the list.
Example: `<VelocityTraceList Num="3" > 1, 3, 4 </VelocityTraceList>`

J.3 Velocity

The <`Velocity`> elements are sub-elements of the <`VelocityList`> and contain information about a single velocity profile. Attributes of that velocity are provided within this element. Table 18 defines the element.

Element	**Attribute**	**Description**	**Example and Options**	**Req'd**
VelocityList	Num	Number of Velocities for this ionogram	`Num="2"`	Yes
Velocity		Element containing data for each Velocity		Yes
	VelocityID	Index for this Velocity	`ProfileID="1"`	Yes
	Algorithm	Name of the algorithm used	`Algorithm="DSND"` `Algorithm="DDAV"`	No
	Version	Algorithm Version	`Version="5.56"`	
VelocityTraceList	Num	List of traces used for this velocity	`<VelocityTraceList Num="3" > 1, 3, 4 </VelocityTraceList>`	Yes
VelocityTable		Table of velocity values	See Table 19	Yes

Table 18: Velocity Elements and Atributes

J.4 Velocity Table

The <`VelocityTable`> element is used to convey the velocity data and uncertainties as a function of Altitude. Like all tables, it has the required attributes of number of columns and number of rows. The defined columns are given in Table 19.

Name	**Attributes**	**Description**	**Example and Options**	**Req'd**
Altitude		Altitude above mean sea level		Yes
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="km"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="1"`	Yes
VNorth		Northward Velocity Component	For Cartesian coordinate systems	No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="m/s"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
VEast		Eastward Velocity Component	For Cartesian coordinate systems	No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="MHz"` `Units="kHz"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="3"`	Yes
VUp		Upward Velocity Component	For Cartesian and Polar coordinate systems	No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="m/s"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
VHorizontal		Horizontal Velocity Component	For Polar coordinate systems	No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="m/s"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes
VAzimuth		Azimuth angle of horizontal velocity component	For Polar Coordinate Systems	No
	Type	Column Data Type	`Type="Float"` is required	Yes
	Units	Column Units	`Units="deg"`	Yes
	SigFigs	Number of Decimal places	`SigFigs="2"`	Yes

Table 19: Velocity Table structure

K URSI recognized scaled ionogram characteristics

Table 20: Standard URSI scaled ionospheric characteristics

GROUP	NAME	CODE	UAG23#	DEFINITION
F2	foF2	00	1.11	Ordinary wave critical frequency of the highest stratification in the F region
	fxF2	01	1.11	eXtraordinary wave critical frequency
	fzF2	02	1.11	Z-mode wave critical frequency
	M3000F2	03	1.50	Maximum usable frequency at a defined distance divided by foF2
	h'F2 hpF2	04 05	1.33 1.41	Minimum virtual height of the ordinary wave trace for the highest stable stratification in the F region Virtual height of the ordinary wave mode at the frequency given by 0.834 of foF2 (or other 7.34)
	h'Ox	06	1.39	Virtual height of the x trace at foF2
	MUF3000F2	07	1.5C	Standard transmission curve for 3000 km
	hc	08	1.42	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 ionization
	qc	09	7.34	Scale height
F1	foF1	10	1.13	Ordinary wave F1 critical frequency
	fxF1	11	1.13	Extraordinary wave F1 critical frequency
		12		
	M3000F1	13	1.50	As per Code 03, for the F1 layer
	h'F1	14	1.30	Minimum virtual height of reflection at a point where the trace is horizontal
		15		
	h'F	16	1.32	Minimum virtual height of the ordinary wave F-layer trace taken as a whole
	MUF3000F1	17	1.5C	See Code 07
		18		
		19		
E	foE	20	1.14	Ordinary wave critical frequency of the lowest thick layer which causes a discontinuity
		21		
	foE2	22	1.16	Critical frequency of an occulting thick layer which sometimes appears between the normal E and F1 layers
	foEa	23		Critical frequency of night time auroral E layer
	h'E	24	1.34	Minimum virtual height of the normal E layer trace
		25		
	h'E2	26	1.36	Minimum virtual height of the E2 layer trace
	h'Ea	27		Minimum virtual height of the night time auroral E layer trace
		28		
		29		
Es	foEs	30	1.17	Highest ordinary wave frequency at which a mainly continuous Es trace is observed
	fxEs	31	1.17	Highest extraordinary wave frequency at which a mainly continuous Es trace is observed
	fbEs	32	1.18	The blanketing frequency of the Es layer
	ftEs h'Es	33 34 35	 1.35	Top or highest frequency Es any mode The minimum height of the trace used to give foEs
	Type Es	36 37	7.26	A characterization of the shape of the Es trace
		38		
		39		

Table 20: Standard URSI scaled ionospheric characteristics

GROUP	NAME	CODE	UAG23#	DEFINITION
Other-1	foF1.5	40 41	1.12	Ordinary wave critical frequency of the intermediate stratification between F1 and F2
	fmin	42	1.19	Lowest frequency at which echo traces are observed on the ionogram
	M3000F1.5	43	1.50	See Code 03,for F1.5 layer
	h'F1.5	44 45	1.38	Minimum virtual height of the ordinary wave trace between foF1 and foF1.5 (equals h'F2 7.34)
		46		
	fm2	47	1.14	Minimum frequency of the second order trace
	hm	48	7.34	Height of the maximum density of the F2 layer calculated by the Titheridge method
	fm2	49	1.25	Minimum frequency of the third order trace
Spread, Oblique	foI	50	1.26	Top ordinary wave frequency of spread F traces
	fxI	51	1.21	Top frequency of spread F traces
	fmI	52	1.23	Lowest frequency of spread F traces
	M3000I	53	1.50	See Code 03, for spread traces
	h'I	54	1.37	Minimum slant range of the spread F traces
	foP	55		Highest ordinary wave critical frequency of F region patch trace
	h'P	56		Minimum virtual height of the trace used to determine foP
	dfs	57	1.22	Frequency spread of the scatter pattern
		58	7.34	Frequency range of spread fxI-foF2
		59		
N(h) Titheridge	fh'F2	60	7.34	Frequency at which h'F2 is measured
	fh'F	61	7.34	Frequency at which h'F is measured
		62		
	h'mF1	63	7.34	Maximum virtual height in the o-mode F1 cusp
	h1	64	7.34	True height at f1 Titheridge method
	h2	65	7.34	True height at f2 Titheridge method
	h3	66	7.34	True height at f3 Titheridge method
	h4	67	7.34	True height at f4 Titheridge method
	h5	68	7.34	True height at f5 Titheridge method
	H	69	7.34	Effective scale height at hmF2 Titheridge method
TEC	I2000	70	7.34	Ionospheric electron content Faraday technique
	I	71	7.34	Total electron content to geostationary satellite
	I1000	72	7.34	Ionospheric electron content to height 1000 km using Reinisch-Huang [2001] technique
		73		
		74		
		75		
		76		
		77		
		78		
	T	79	7.34	Total sub-peak content Titheridge method
Other-2	FminF	80		Minimum frequency of F trace (50 kHz increments), Equals fbEs when E present
	FminE	81		Minimum frequency of E trace (50 kHz increments)
	HOM	82		Parabolic E layer peak height
	yE	83		Parabolic E layer semi-thickness
	QF	84		Average range spread of F trace
	QE	85		Average range spread of E trace
	FF	86		Frequency spread between fxF2 and fxI
	FE	87		As FF but considered beyond foE

Table 20: Standard URSI scaled ionospheric characteristics

GROUP	NAME	CODE	UAG23#	DEFINITION
	fMUF3000	88		MUF(D)/obliquity factor
	h'MUF3000	89		Virtual height at fMUF
N(h)	zmE	90		Peak height E layer
	zmF1	91		Peak height F1 layer
	zmF2	92		Peak height F2 layer
	zhalfNm	93		True height at half peak electron density
	yF2	94		Parabolic F2 layer semi-thickness
	yF1	95		Parabolic F1 layer semi-thickness
		96		
		97		
		98		
		99		
IRI	B0	D0		IRI Thickness parameter
	B1	D1		IRI Profile Shape parameter
	D1	D2		IRI Profile Shape parameter, F1 layer
		D3		
		D4		
		D5		
		D6		
		D7		
		D8		
		D9		

L User-defined scaled ionogram characteristics

Name	Description	Units
foF2p	F2 layer ordinary wave critical frequency, predicted	MHz
foF1p	F1 layer ordinary wave critical frequency, predicted	MHz
foEp	F1 layer ordinary wave critical frequency, predicted	MHz
fminEs	Minimum frequency of Es layer	MHz
scaleHpeak	Scale height at hmF2, Chapman model	km
foF0.5	The ordinary wave critical frequency of F0.5 stratification between E and F layers	MHz
h'F0.5	The minimum virtual height of F0.5 layer trace	km
foF3	The ordinary wave critical frequency of F3 layer above foF2	MHz
h'F3	The minimum virtual height of F3 layer trace	km
AQI	Analysis Quality Index: an indicator of autoscaling quality	–
DQI	Data Quality Index: an indicator of raw ionogram data quality	–

Table 21: User-defined ionospheric characteristics for SAOXML