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INTERNATIONAL UNION OF RADIO SCIENCE
IONOSONDE NETWORK ADVISORY GROUP

IONOSONDE DATA EXCHANGE FORMATS

SAOXML 5.0

SAOXML 5.0 FORMAT SPECIFICATION PROPOSAL

Revision 2.01

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1. SCOPE, OBJECTIVES, AND DESCRIPTION

1.1 Purpose

The purpose of this document is to establish a unified data exchange interface between ionosonde data producers and users of ionogram-derived characteristics by describing a standard data format acceptable to both sides. Once accepted, the format specification will serve as the reference for development of input and output interfaces for the software projects that read and write ionogram-derived characteristics.

1.2 Scope

The unified data exchange format shall regulate presentation of the following physical quantities:

- Ionogram-scaled and derived ionospheric characteristics (e.g., foF2, zhalfNm, iTEC, etc.), both recognized by the URSI as standard (Reinisch, 1998a) and custom (i.e., user-defined),
- Ionogram-derived altitude profiles of ionospheric characteristics (e.g., electron density profiles),
- Source ionogram traces used for derivation of reported characteristics, and
- Auxiliary data (such as the model prediction of ionospheric conditions) used in the ionogram analysis and interpretation.

The unified data exchange format is not intended for storage of the ionogram itself. A unified approach to storage and visualization of the raw ionogram data is hardly feasible because of the great variety of the instrument-specific issues to accommodate in such standard, incurred losses of the storage efficiency, and arguably little value of the final product in comparison to the native analysis tools developed for the instrument. Should the need to match ionogram-derived information to the appropriate source ionogram arise, the instrument-specific analysis tool can be readily used to unpack and display the raw binary ionogram data properly. Closely related to the question of ionogram storage in SAOXML is the concept of separate storage of ionogram and ionogram-derived data discussed below in Section 1.3.4.

The unified data exchange format is not intended to serve as the primary storage format for data from other sensor instrumentation or ionospheric models.

1.3 Philosophy of SAOXML

Several important design concepts went into this document in order for the final product to withstand time. The proposed format draws its strength from the existing experience of operating large databases holding ionosonde-related data, heritage formats for ionogram-derived data (Reinisch, 1998b), and design contributions from many members of the ionospheric community.

1.3.1 Completeness

SAOXML shall be able to serve as the complete, primary storage format for ionogram-derived information obtained using any ionosonde system. To sustain completeness of the format across different ionosonde models and with time and progress in ionospheric research, flexible mechanisms for extending the format shall be allowed. In particular, it should be possible to add custom information to the measurement record without release of a new format version. At the same time, these custom, user-defined data elements shall co-exist with the standard nomenclature of the format captured at the version release time, preserving the integrity of the data record and its compatibility with existing software applications.

1.3.2 User friendliness

The format shall be user-friendly in various modes of operation, from software development to troubleshooting. The following list of requirements is suggested as the guidelines:

- Readability: the key components of the data shall be easily identifiable in the data without the need to match data records with the external format description.
- Self-descriptiveness: proper metadata shall be provided together with the data to explain properties of the stored information.
- Clarity of presentation: names, data types, units shall be clear, precise, not abbreviated, and helpful in understanding of the data contents.

1.3.3 Upward compatibility

Existing SAOXML readers that encounter data records containing new, previously unknown data elements (either custom or newly introduced in future revisions of the standard) shall continue to work within the scope of their original design. In order to be upward compatible, the format organization shall admit operation of skipping unknown elements.

1.3.4 Design simplicity

Where possible, simpler solutions are preferred. Particular objection has been raised against internal and external links between data elements, whose proper management requires preservation of the referential integrity. Need for advanced, proprietary software engineering shall be avoided.

1.3.5 One ionogram – many ionogram-derived records

As the same ionogram can be analyzed by more than one scaler, the relationship between recorded ionograms and sets of available scaled and derived ionospheric characteristics is “one to many”. Three possible scenarios of handling this relationship in software are possible:

1. Separate storage: one SAOXML record keeps derived data by one scaler only
2. Combined storage: newly scaled data are added to the same SAOXML record
3. Updated storage: newly scaled data replace existing data in the same SAOXML record

Updating existing values with values provided by a different scaler (e.g., manual scaler correcting an autoscaled value) results in a mixed content record, which adds complexity to its management. Keeping track of changes by multiple scalers makes such SAOXML record a miniature database where each reported data element has to be linked to an appropriate description of the scaler responsible for its creation. Management of such mixed content elements with links to other elements requires an advanced engineering effort to sustain the referential integrity of the document during operations of element addition and removal.

Combining multiple ionogram interpretation results into one SAOXML record would further complicate management of its contents, as it adds necessity to intelligently select one representative value out of multiple available alternatives.

This proposal calls for separate storage of ionogram-derived records provided by different scalers. Separate storage of files produced by the ARTIST autoscaling software and manual scalers is the preferred data management concept for digisonde data for over 20 years[1].

These considerations also warrant storage of the unprocessed (raw) ionogram data separately from the SAOXML in order to avoid duplicate storage of the same voluminous information in the multiple records submitted by different scalers. The proposed SAOXML format is not intended for storage of raw ionosonde sounding data.

1.3.6 Storage by column

Scaled ionogram traces, as well as derived ionospheric profiles, admit a natural presentation in tabular form (Table 1):

Table 1. Sample ionogram trace in tabular form

Frequency kHz	Virtual height km	Amplitude dB	Doppler shift Hz
2.0	326	130	-0.098
2.1	335	122	0.098
2.2	350	126	0.293
2.3	366	134	0.293

In order to fulfill the upward compatibility requirement, this proposal calls for arrangement of the tabular data storage by column, thus holding only homogeneous values within one data element. In this case it becomes considerably simpler to build software readers that can handle ionospheric data of varying richness of their contents. Unknown characteristics of traces and profiles can be skipped as a whole entity. Skipping unknown data items in other models of data presentation (such as storage by rows or by tables) requires tokenizing and identification of known/unknown token positions for every row of the stored table.

2. FORMAT VEHICLE : XML

XML (eXtensible Markup Language) is an excellent choice of format vehicle that meets the requirements listed in Section 1.3. An XML document is a plain text file that can be opened in a text editor or, better yet, in any Internet browser that allows intelligent parsing of the XML document structure. The associated overhead due to storage of data in ASCII representation is negligible, considering the relatively small volume of ionogram-derived information to be stored.

Simply put, an XML document is a hierarchy of “**elements**”, where each element has

- Named **tags** that delimit it from other elements,
- Collection of **attributes** describing the contents, and
- Text contents, some free-form text that may contain other elements.

[1] Separate storage of data produced by different scalers should not lead to creation of small and fragmentary SAOXML records containing only a few manually edited values. By accepted convention, manual scalers take responsibility for the full record once they start editing it. The rule of thumb for a scaler is “do not commit a new scaled record if there are remaining mistakes in the scaling”. To minimize the manual effort, original values can be imported to the edited record without changes. Such imported values are considered “verified”. Manually edited values can be distinguished from the verified values by adding an “edited” flag to their description. The edited values are considered to be the “ground truth”.

For example:

Listing 1. Simple example of an XML record

```
<Book>
    <Editor>H. Kohl</Editor>
    <Editor>H. Ruster</Editor>
    <Title>Modern Ionospheric Science</Title>
    <Editor Email=”schlegel@linmpi.mpg.de” >Kristian Schlegel
        <Affiliation> Max Planck Institute for Solar System Research</Affiliation>
    </Editor>
</Book>
```

Listing 1 shows an XML record consisting of one data element “Book” delimited by two tags <Book> and </Book>. This element has four sub-elements: three elements <Editor> and one element <Title>. One of the <Editor> elements has an attribute <Email> and sub-element <Affiliation>, others don’t. Because XML elements are named and separated from other elements by tags, XML is a good candidate for format expandability that preserved compatibility with new format releases and custom elements. Old software will easily skip new elements and element attributes whose names it cannot recognize. Addition of new elements (e.g., Address or Telephone in Listing 1, together with their attributes and sub-elements) does not disrupt the work of existing reading software.

An XML document may refer to a DTD (Document Type Definition) that expresses its structure in a formal way and defines various constraints on the contents of data elements, both syntactical and structural. It is possible to automatically verify and enforce compliance of individual XML documents to their master DTD definition.

3. DESCRIPTION OF SAOXML 5.0

One SAOXML 5.0 document holds a single element SAORecordList that can have multiple sub-elements <SAORecord>, each corresponding to one set of ionogram-derived data obtained for one ionogram by one scaler (Table 2).

Table 2. SAORecordList consisting of SAORecords

Element	Attributes	Sub-elements
<SAORecordList>	-	**<SAORecord>** - multiple instances *One set of ionogram-derived data corresponding to one ionogram processed by one scaler*

3.1 <SAORecord> element

One <SAORecord> holds one set of ionogram-derived data obtained for one ionogram by one scaler (Table 3). The SAORecord contains:

- Descriptive information about the measurement and data processing
- List of ionospheric characteristics
- List of ionogram traces
- List of ionospheric profiles

Figure 1 shows the top-level diagram of the elements constituting one SAORecord.

Table 3. SAORecord = one set of scaled/derived information for one ionogram and one scaler

Element	Required Attributes	Sub-elements
<SAORecord>	**FormatVersion** *"5.0"* **StartTimeUTC** *Standard timestamp of ionogram measurement start in UTC* **URSICode** *URSI code for the ionosonde location* **StationName** *Ionosonde location name* **GeoLatitude** *Geographic latitude, degrees* **GeoLongitude** *Geographic longitude, degrees* **Source** *Data source ("Ionosonde", "Model", "ARP", other sensor instrument)* **SourceType** *Type (model) of the data source ("IRI-2001", "Digisonde 256", etc.)* **ScalerType** *"Manual" or "Auto"*	**<SystemInfo>** - one instance, optional Optional descriptive information about measurement location and equipment **<CharacteristicList>** - one instance, required List of scaled and derived ionospheric characteristics **<TraceList>** - one instance, optional List of ionogram traces used to derive reported characteristics **<ProfileList>** - one instance, optional List of altitude profiles of ionospheric characteristics

Appendix A contains a detailed description of the required SAORecord attributes. Optional and custom attributes are allowed. Contents of the <SAORecord> sub-elements are further detailed in Sections 3.1.1-3.1.5.

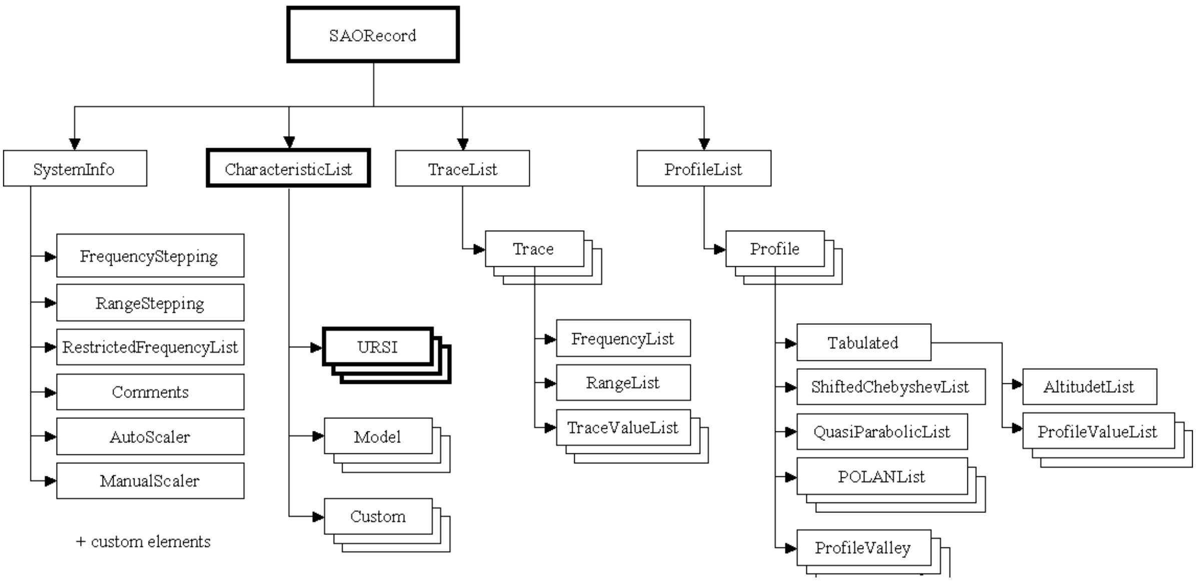

Figure 1. Block diagram of SAORecord elements. Minimum required set of elements is shown in bold. Other elements are optional. Addition of custom elements is possible.

3.2 <SystemInfo> element

<SystemInfo> is an optional element containing descriptive information about the measurement and data processing for the <SAORecord> (Table 4).

Table 4. <SystemInfo> = optional descriptive information

Element	Optional Attributes	Optional Sub-elements
<SystemInfo>	-	**<FrequencyStepping>** - one instance *Description of the ionogram frequency stepping* **<RestrictedFrequencyList>** - one instance *Description of the frequency bands restricted for transmission* **<RangeStepping>** - one instance *Description of the ionogram range stepping* **<AutoScaler>** - one instance *Autoscaling software description* **<ManualScaler>** - one instance *Scaler name* **<Comments>** - one instance *Operator's comments* **<StartTime>** - multiple instances *Start time of ionogram measurement in arbitrary format* **<ContactPerson>**- one instance *Contact person name, address, e-mail* **<SolarTerrestrialData>**- one instance *Information on geomagnetic field and other conditions*

Custom attributes and elements of <SystemInfo> element are allowed. Example of a custom attribute:

UMLStationID="027"

Example of a custom element:

<DigisondePreface version="FE" >
20000320201034505000320345051932000000500000B31000011611E06741D7334006123F0
</DigisondePreface>

Appendix B provides detailed description of the sub-elements of the <SystemInfo> element.

3.3 <CharacteristicList> element

<CharacteristicList> is a required element containing list of scaled and derived ionospheric characteristics for the <SAORecord> (Table 5, 6, 7, and 8).

Table 5. <CharacteristicList> = list of scaled and derived ionospheric characteristics

Element	Optional Attributes	Sub-elements
<CharacteristicList>	**Num** *Total number of provided items*	**<URSI>** - multiple instances *One standard URSI ionospheric characteristic* **<Modeled>** - multiple instances *One predicted ionospheric characteristic* **<Custom>** - multiple instances *One custom ionospheric characteristic*

<CharacteristicList> can include a number of standard URSI characteristics (refer to Appendix C for the list). Each <URSI> sub-element holds one characteristic (Table 6).

Table 6. <URSI> = URSI standard ionospheric characteristic

Element	Required Attributes	Optional Attributes
<URSI>	**ID** *2-letter URSI ID, see Appendix C* **Val** *Value of characteristic*[2]	**Name** *Characteristic name* **Units** *Measurement units* **QL** *UAG-23 Qualitative Letter* **DL** *UAG-23 Descriptive Letter* **SigFig** *Number of significant figures* **UpperBound** *Upper uncertainty bound* **LowerBound** *Upper uncertainty bound* **Bound** *Symmetric uncertainty bound* **BoundaryType** *Description of uncertainty bound calculation* **Flag** *Description of scaler action (“edited”)*

Table 7. <Model> = Predicted ionospheric characteristic

Element	Required Attributes	Optional Attributes
<Modeled>	**Name** *Characteristic name* **Units** *Measurement units* **Val** *Value of characteristic*	**ModelName** *Model name* **ModelOptions** *Model options*

Table 8. <Custom> = custom ionospheric characteristic

Element	Required Attributes	Optional Attributes
<Custom>	**Name** *Characteristic name* **Units** *Measurement units* **Val** *value of characteristic*	**Description** *Description of the characteristic* **SigFig** *Number of significant figures* **UpperBound** *Upper uncertainty bound* **LowerBound** *Upper uncertainty bound* **Bound** *Symmetric uncertainty bound* **BoundaryType** *Description of uncertainty bound calculation* **Flag** *Description of scaler action (“edited”)*

[2] Attributes are expected to hold metadata, and a more logical place for **Val** would be a sub-element. Formatting Val as an attribute simplifies SAOXML programming effort.

Listing 2 gives a sample of <CharacteristicList> element.

Listing 2. Sample <CharacteristicList> element

```
<CharacteristicList>
<URSI ID="00" Val="10.707" />
<URSI ID="03" Name="M(3000)F2" Val="2.9197" />
<URSI ID="07" Name="MUF(3000)" Val="31.241" Units="MHz" />
<URSI ID="42" Name="fmin" Val="1.7" Units="MHz" Flag="edited"/>
<URSI ID="20" Name="foE" Val="3.30" Units="MHz" Flag="edited" Bound="0.15" BoundaryType="3sigma"/>
<URSI ID="30" Name="foEs" Val="17.3" Units="MHz" Flag="edited" UpperBound="19.3" LowerBound="16.8"
  BoundaryType="10%tile"/>
<URSI ID="10" Name="foF1" Val="7.70" Units="MHz" Flag="edited" UpperBound="8.3" LowerBound="7.2"
  BoundaryType="1sigma" QL="/" DL=" "/>
<Modeled Name="foEp" Val="3.68" Units="MHz" ModelName="CCIR-79" />
<Modeled Name="foF2p" Val="9.53" Units="MHz" ModelName="URSI-88" ModelOptions="NoStorm"/>
<Custom Name="Delta-foF2" Units="MHz" Val="0.07"
  Description="Correction to foF2 from profile inversion algorithm" />
</CharacteristicList>
```

3.4 <TraceList> element

<TraceList> is an optional element that contains a list of scaled ionogram traces for the <SAORecord> (Table 9-10).

Table 9. <TraceList> = list of scaled ionogram traces

Element	Optional Attributes	Sub-elements
<TraceList>	**Num** *Total number of traces*	**<Trace>** - multiple instances *Ionogram trace*

Table 10. <Trace> = scaled ionogram trace

Element	Required Attributes	Sub-elements
<Trace>	**Type** *Trace type (standard or non-standard)* **Layer** *Ionospheric layer responsible for forming the trace* **Multiple** *Order of multiple reflection* *Optional attribute for 1st multiple* **Polarization** *Wave polarization for the trace* **Num** *Total number of trace points*	**<FrequencyList>** - one instance, required *List of frequencies* **<RangeList>** - one instance, required *List of group ranges* **<TraceValueList>** - multiple instance, optional *List of particular trace characteristic values such as amplitudes or Doppler velocities. See Appendix D for details.*

Each <Trace> element contains two required sub-elements, <FrequencyList> and <RangeList>, without which the trace cannot exist, plus other optional trace characteristics derived from the ionogram measurement, such as the echo amplitudes, Doppler frequencies/velocities, angles of arrival, etc. Additional characteristics are stored separately in <TraceValueList> elements. Each <TraceValueList> is a set of values of particular characteristic, appropriately described by the element attributes *Name*, *Type*, *Units*, *SigFig*, etc. For further details refer to Appendix D.

Sample TraceList is shown in Listing 3.

Listing 3. Sample <TraceList> element

```
<TraceList Num=”2”>
<Trace Type=”standard” Layer="F2" Multiple=”1” Polarization=”O” Num="76">
<FrequencyList Type=”float” SigFig=”5” Units="MHz" Description=”Nominal Frequency”>
3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5 5.6 5.7 5.8 5.9 6.0 6.1 6.2 6.3 6.4 6.5 6.6 6.7
6.8 6.9 7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 8.0 8.1 8.2 8.3 8.4 8.5 8.6 8.7 8.8 8.9 9.0 9.1 9.2 9.3 9.4 9.5 9.6 9.7 9.8
9.9 10.0 10.1 10.2 10.3 10.4 10.5 10.6 10.7 10.8 10.9 11.0 11.1 11.2
</FrequencyList>
<RangeList Type=”float” SigFig=”4” Units="km" Description=”Group Range”>
206.0 204.2 202.3 202.3 204.2 209.7 217.0 224.4 231.8 235.4 241.0 246.5 252.0 255.7 259.4 261.2 263.0 268.6 270.4
272.2 275.9 275.9 279.6 285.1 288.8 292.5 294.3 298.0 301.7 303.5 305.4 309.0 310.9 316.4 318.2 320.1 323.8 323.8
333.5 335.5 338.0 340.5 343.5 344.5 346.5 349.0 352.0 354.0 357.0 361.0 364.0 367.0 370.0 374.0 381.0 384.0 387.0
391.0 394.0 398.0 402.0 406.0 410.0 414.0 419.0 424.0 430.0 434.2 445.2 458.1 469.1 483.8 502.2 524.3 579.5 655.0
</RangeList>
<TraceValueList Name="Amplitude" Type="integer" SigFig="3" Units="dB" NoValue="0" Description="Relative
Amplitude">
75 78 72 66 72 75 75 78 81 81 60 57 0 0 78 84 78 84 84 87 87 75 78 84 84 75 84 84 81 87 84 90 84 90 90 90 90 93
81 90 90 93 84 90 93 87 90 90 90 84 90 90 81 87 84 81 90 84 78 78 84 72 78 0 78 78 78 75 75 57 57 57 63 66 0 0
</TraceValueList >
<TraceValueList Name="DopplerShift" Type="float" SigFig="4" Units="Hz" NoValue="99.0" Description="Doppler
Frequency Shift">
0.293 0.293 0.293 0.293 -0.293 -0.293 0.293 -0.293 0.293 -0.293 -0.293 -0.293 2.051 2.051 0.293 0.293 0.293 0.293
0.293 -0.293 -0.293 0.293 0.293 0.293 0.293 0.293 0.293 0.293 -0.293 0.293 -0.293 -0.293 -0.293 0.293 0.293 -0.293
-0.293 -0.293 0.293 0.293 -0.293 -0.293 0.293 -0.293 0.293 -0.293 -0.293 -0.293 -0.293 0.293 -0.293 -0.293 0.293
0.293 0.293 -0.293 -0.293 -0.293 -0.293 -0.293 -0.293 2 -0.293 99.0 -0.293 -0.293 -0.293 -0.293 -0.293 -0.293 0.293
-0.293 -0.293 -0.293 -0.879 1.465
</TraceValueList >
</Trace>
<Trace Type=”standard” Layer="E" Polarization="O" Num="22">
<FrequencyList Type=”float” SigFig=”5” Units="MHz" Description=”Nominal Frequency”>
1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6
</FrequencyList>
<RangeList Type=”float” SigFig=”4” Units="km" Description=”Group Range”>
97.61 98.00 98.42 98.87 99.37 99.90 100.48 101.1 101.7 102.5 103.3 104.1 105.1 106.2 107.4 108.7 110.2 112.0
114.1 116.8 120.4 126.3
</RangeList>
<TraceValueList Name="Amplitude" Type="integer" SigFig="3" Units="dB" NoValue="0" Description="Relative
Amplitude">
69 69 0 63 0 60 63 57 69 69 66 69 78 69 75 75 84 84 84 81 78 78
</TraceValueList >
<TraceValueList Name="DopplerShift" Type="float" SigFig="4" Units="Hz" NoValue="99.0" Description="Doppler
Frequency Shift">
1.465 0.293 0.293 -0.293 1.465 -0.293  -0.293  -0.293  -0.293  0.293 0.293 0.293 0.293 -0.293  -0.293  -0.293  0.293
-0.293  -0.293  -0.293  0.879 0.879
</TraceValueList >
</Trace>
</TraceList>
```

3.5 <ProfileList> element

<ProfileList> is an optional element that contains a list of altitude profiles of ionosphere (Table 11-13).

Table 11. <ProfileList> = list of altitude profiles of ionosphere

Element	Optional Attributes	Sub-elements
<ProfileList>	**Num** *Total number of profiles*	**<Profile>** - multiple instances *Altitude profile of ionospheric characteristics*

Each <Profile> element is provided with a flexible mechanism of storing multiple functions of altitude (e.g., plasma density/frequency, horizontal/vertical velocity, electron temperature, etc., etc.) in the tabular and various polynomial representations. Alternative algorithms can be applied to the same trace data to produce multiple <Profile> elements reported within the same <ProfileList>. Profiles calculated by ionospheric models and obtained by other sensor instrumentation can be stored in the SAOXML format for comparison purposes. Averaged representative profiles can be calculated over various periods of time.

Profile data are relatively easy to manage, as they do not admit point-by-point editing and may only be completely recalculated. The only concern is proper labeling of the <Profile> so that SAOXML readers can consistently locate correct profiles among multiple instances. The following rules are suggested:

- One <Profile> shall store profile data obtained by one algorithm / one instrument
- Algorithm name and version are required attributes of the <Profile>. Algorithm abbreviations have to be uniform across various data providers using the same algorithm.

Table 12. <Profile> = altitude profile of ionospheric characteristics

Element	Required Attributes	Sub-elements
<Profile>	**Algorithm** *Algorithm name* **AlgorithmVersion** *Algorithm version*	**<Tabulated>**- multiple instance, at least one required *Profile specification in tabulated form* **<ShiftedChebyshevList>**- one instance, optional *Profile specification in form of shifted Chebyshev coefficients* **<QuasiParabolicList>**- one instance, optional *Profile specification in quasi-parabolic segments* **<POLANList>**- multiple instances, optional *Profile specification in one of POLAN form* **<ProfileValley>**- multiple instances, optional *Model of the E-F valley, see Appendix G.* **<AlgorithmOptions>** - one instance, optional *Options of the algorithm*
	Optional Attributes	
	Type *Profile type, ("vertical", "off-vertical", "average", "auroral")* **Description** *Profile content description*	

Listing 3 provides a sample of <ProfileList> element in SAOXML.

<Tabulated> profile presentation holds multiple columns of information that includes profile data (plasma densities, tilts) and associated uncertainties of their evaluation. These data are presented by column with respect to the altitude (above sea level). The list of altitudes is a required sub-element of <Tabulated> element. At least one <ProfileValueList> sub-element shall be present to report profile data. The <ProfileValueList> element can be used universally to report a variety of profile data and their uncertainty bounds. See Appendix E for further details.

<ShiftedChebyshev> elements store coefficients of shifted Chebyshev representation of electron density profiles (See Table 14). Refer to (Reinisch and Huang, 1983) for description of the method.

<QuasiParabolic> elements store representation of electron density profiles by quasi-parabolic segments (See Table 15 and Appendix F).

Listing 3. Sample <ProfileList> element

```
<ProfileList Num="1">
<Profile Type="vertical" Algorithm="NHPC" AlgorithmVersion="4.21">
<Tabulated Num="48">
<AltitudeList Units="km">
91.3 100.0 110.0 120.0 130.0 136.833 140.0 150.0 160.0 163.667 170.0 180.0 190.0 190.5 200.0 210.0 220.0 230.0
240.0 242.4 250.0 260.0 270.0 280.0 290.0 300.0 310.0 320.0 330.0 340.0 350.0 360.0 370.0 380.0 390.0 400.0 410.0
420.0 430.0 440.0 450.0 460.0 470.0 480.0 490.0 500.0 510.0 520.0
</AltitudeList>
<ProfileValueList Name="PlasmaDensity" Units="cm^-3">
495.0 2760.0 3680.0 3270.0 2060.0 759.0 759.0 759.0 759.0 759.0 1250.0 2270.0 3600.0 3680.0 58900.0 109000.0
156000.0 191000.0 207000.0 208000.0 205000.0 191000.0 172000.0 150000.0 127000.0 106000.0 86900.0 70500.0
56700.0 45300.0 36000.0 28400.0 22400.0 17600.0 13800.0 10800.0 8470.0 6620.0 5170.0 4040.0 3150.0 2460.0
1920.0 1490.0 1160.0 907.0 707.0 551.0
</ProfileValueList>
</Tabulated>
<ShiftedChebyshevList>
<ShiftedChebyshev Region ="E" Num="3" StartFrequency="0.2" EndFrequency="0.545" PeakHeight="110.0"
Error="0.0"> -23.0 4.8 -0.5
</ShiftedChebyshev >
<ShiftedChebyshev Region="F2" Num="5" StartFrequency="0.545" EndFrequency="4.1" PeakHeight="242.4"
Error="0.0" zHalfNm="208.947">-69.3 17.4 0.0 0.0 0.0
</ShiftedChebyshev >
</ShiftedChebyshevList>
<ProfileValley Model="ULCAR" Width="80.5" Depth="0.2974"/>
</Profile>
</ProfileList>
```

Table 13. <Tabulated> = Table of ionospheric characteristics as functions of altitude

Element	Optional Attributes	Sub-elements
<Tabulated>	**Num** *Total number of profile points*	**<AltitudeList>**- one instance, required *Altitudes above sea level* **<ProfileValueList>**- multiple instances, at least one shall be present *List of values of a profile characteristic such as plasma density* *See Appendix E.*

Table 14. <ShiftedChebyshevList> , <QuasiParabolicList>, <POLANList> = lists of polynomial profile representations

Element	Attributes	Sub-elements
<ShiftedChebyshevList>	**Num** *Total number of ShiftedChebyshev sets of coefficients*	**<ShiftedChebyshev>** - multiple instances *Shifted Chebyshev coefficients of profile representation*
<QuasiParabolicList>	**Num** *Total number of QP segments* **EarthRadius** *The Earth's radius, km*	**<QuasiParabolic>** - multiple instances *Quasi-parabolic segment of profile representation*
<POLANList>	**Num** *Total number of POLAN coefficient sets*	**<POLAN>** - multiple instances *POLAN coefficients of profile representation*

Further details on polynomial representations of profile can be found in Appendix F.

4. Ionogram-derived data elements currently not in SAOXML

4.1 EchoTable (Dynasonde)

Further understanding of the data analysis concept of Dynasondes is required in order to understand whether the EchoTable, a voluminous subset of source ionogram databins labeled as useful (i.e., considered to be an echo), shall be included in the SAOXML. With the possibility of detecting thousands of echoes per ionogram sounding, it appears as though the EchoTable does not admit manual editing of its contents and remains unchanged in the process of ionogram interpretation. In order to avoid repeating the EchoTable in newly created SAOXML records containing alternative interpretation of ionograms, separate storage of the EchoTable seems like a more efficient approach.

5. References

Reinisch, B. W. and X. Huang, Automatic Calculation of Electron Density Profiles from Digital Ionograms, 3, Processing of Bottomside Ionograms, *Radio Sci.*, 18, 477-492, 1983.

Reinisch, B.W. "Chars": URSI IIWG Format For Archiving Monthly Ionospheric Characteristics, INAG Bulletin No. 62, January 1998a.

Reinisch, B.W., SAO (Standard ADEP Output): Format For Ionogram Scaled Data Archiving, INAG Bulletin No. 62, January 1998b.

URSI Handbook of Ionogram Interpretation and Reduction. Ed. W.R.Pigott and K.Rawer. UAG-23, WDC-A for STP, 1972.

Appendix A. <SAORecord> Attributes

Attribute	Description	Example
FormatVersion	SAOXML version of this record	*Version="5.0"*
StartTimeUTC	UT Measurement time in ISO 8601 standard format: year, month, day, day of year, hour, minute, second, millisecond.	*StartTimeUTC ="2000-02-01 –032 13:45:05.000"*
URSICode	URSI station code assigned by the World Data Center A for Solar-Terrestrial Physics	*URSICode="SMJ67"*
StationName	Name of ionosonde location	*stationName="Sondrestrom"*
GeoLatitude	Geographic latitude of the station or the spacecraft footprint, degrees	*GeoLatitude="66.98"*
GeoLongitude	Geographic longitude of the station or the spacecraft footprint, degrees	*GeoLongitude="309.06"*
Source	Data source ("Ionosonde", "Model", "ARP", other sensor instrument)	*Source="Ionosonde"*
SourceType	Type (model) of the data source	*SourceType="Digisonde 256"*
ScalerType	"Manual" or "Auto"	*ScalerType="Auto"*

Example:

```
<SAORecord
Version="5.0"
StartTimeUT="2000-02-01 -032 03:45:05.000"
URSICode="SMJ67"
StationName="Sondrestrom"
GeoLatitude="66.98"
GeoLongitude="309.06"
Source="Ionosonde"
SourceType="Digisonde-256"
ScalerType="manual"
>
<SystemInfo>…</SystemInfo>
<CharacteristicList>…</CharacteristicList>
<TraceList>…</TraceList>
<ProfileList>…</ProfileList>
</SaoRecord>
```

Appendix B. <SystemInfo> Attributes and Sub-elements

Optional Sub-element	Attributes	Sub-elements / Contents
FrequencyStepping	**StartFrequency** *Start frequency in MHz* **StopFrequency** *Stop frequency in MHz*	**<LinearStepping>** - one instance *Description of the linear frequency stepping* **<LogStepping>** - one instance *Description of the logarithmic frequency stepping* **<TabulatedStepping>** - one instance *Description of the free-form tabulated frequency stepping*
RestrictedFrequencyList	**Num** *Number of bands* **Units** *MHz*	**<LowerLimitList>** - one instance *Lower frequency of restricted band* **<UpperLimitList>** - one instance *Upperr frequency of restricted band*
RangeStepping	**StartRange** *Start range in km* **StopRange** *Stop range in km*	**<LinearStepping>** - one instance *Description of the linear range stepping* **<LogStepping>** - one instance *Description of the logarithmic range stepping* **<TabulatedStepping>** - one instance *Description of the free-form tabulated range stepping*
AutoScaler	**Name** *Algorithm name* **Version** *Algorithm version*	-
ManualScaler	**Name** *Scaler name*	-
Comments	-	*free-form text comments*
StartTime	**Format** **TimeZone**	*Arbitrarily formatted timestamp*
ContactPerson	-	**<Name>** - one instance *Person name* **<Affiliation>** - one instance *Name of organization* **<Address>** - one instance *Address of organization* **<Email>** - one instance *Person e-mail*
SolarTerrestrialData	-	**<GyroFrequency>** **<DipAngle>** **<Kp>** **<SunSpotNumber>** **<F107>**

Sub-Element	Attributes	Example
LinearStepping	**Step** *Linear step* **Units** *MHz for frequency, km for range*	*<LinearStepping Step=”0.1” Unit=”MHz”/>*
LogStepping	**StepPercent** *Logarithmic step*	*<LogStepping StepPercent=”3”/>*
TabulatedStepping	**Num** *Number of steps* **Units** *MHz for frequency, km for range*	*<TabulatedStepping Units=”MHz” Num=”100”>* *1.00 1.50 2.20 2.95 3.60 5.90 …* *</TabulatedStepping>*

Appendix C. Standard URSI ionospheric characteristics

GROUP	URSI name	URSI code	UAG23 ref.#	DEFINITION
F2	foF2	**00**	1.11	The ordinary wave critical frequency of the highest stratification in the F region
	fxF2	**01**	1.11	The extraordinary wave critical frequency
	fzF2	**02**	1.11	The z-mode wave critical frequency
	M3000F2	**03**	1.50	The maximum usable frequency at a defined distance divided by the critical frequency of that layer
	h'F2	**04**	1.33	The minimum virtual height of the ordinary wave trace for the highest stable stratification in the F region
	hpF2	**05**	1.41	The 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	The virtual height of the x trace at foF2
	MUF3000F2	**07**	1.5C	The standard transmission curve for 3000 km
	hc	**08**	1.42	The height of the maximum obtained by fitting a theoretical h'F curve for the parabola of best fit to the observed ordinary wave trace near foF2 and correcting for underlying ionization
	qc	**09**	7.34	Scale height
F1	foF1	**10**	1.13	The ordinary wave F1 critical frequency
	fxF1	**11**	1.13	The extraordinary wave F1 critical frequency
		12		
	M3000F1	**13**	1.50	See Code 03
	h'F1	**14**	1.30	The minimum virtual height of reflection at a point where the trace is horizontal
		15		
	h'F	**16**	1.32	The minimum virtual height of the ordinary wave trace taken as a whole
	MUF3000F1	**17**	1.5C	See Code 07
		18		
		19		
E	foE	**20**	1.14	The ordinary wave critical frequency of the lowest thick layer which causes a discontinuity
		21		
	foE2	**22**	1.16	The critical frequency of an occulting thick layer which sometimes appears between the normal E and F1 layers
	foEa	**23**		The critical frequency of night time auroral E layer

	h'E	**24**	1.34	The minimum virtual height of the normal E layer trace
		25		
	h'E2	**26**	1.36	The minimum virtual height of the E2 layer trace
	h'Ea	**27**		The minimum virtual height of the night time auroral E layer trace
		28		
		29		
Es	foEs	**30**	1.17	The highest ordinary wave frequency at which a mainly continuous Es trace is observed
	fxEs	**31**	1.17	The 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	**33**		Top frequency Es any mode.
	h'Es	**34**	1.35	The minimum height of the trace used to give foEs
		35		
	Type Es	**36**	7.26	A characterization of the shape of the Es trace
		37		
		38		
		39		
Other 1	foF1.5	**40**	1.12	The ordinary wave critical frequency of the intermediate stratification between F1 and F2
		41		
	fmin	**42**	1.19	The lowest frequency at which echo traces are observed on the ionogram
	M3000F1.5	**43**	1.50	See Code O3
	h'F1.5	**44**	1.38	The minimum virtual height of the ordinary wave trace between foF1 and foF1.5 (equals h'F2 7.34)
		45		
		46		
	fm2	**47**	1.14	The minimum frequency of the second order trace
	hm	**48**	7.34	The height of the maximum density of the F2 layer calculated by the Titheridge method
	fm2	**47**	1.25	The minimum frequency of the third order trace
Spread F, Oblique	foI	**50**	1.26	The top ordinary wave frequency of spread F traces
	fxI	**51**	1.21	The top frequency of spread F traces
	fmI	**52**	1.23	The lowest frequency of spread F traces
	M3000I	**53**	1.50	See Code 03
	h'I	**54**	1.37	The 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	The frequency spread of the scatter pattern
		58	7.34	Frequency range of spread fxI-foF2
		59		
N(h) Titheridge	fh'F2	**60**	7.34	The frequency at which h'F2 is measured
	fh'F	**61**	7.34	The frequency at which h'F is measured
		62		
	h'mF1	**63**	7.34	The 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
T.E.C.	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 Digisonde 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
	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		

Appendix D. Attributes and sub-elements of <Trace>

Attributes of <Trace>

Attribute	Description	Example
Type	Trace type: standard per UAG23 or non-standard	*Type="Standard"*
Layer	Ionospheric layer responsible for forming the trace	*Layer="1F2"*
Polarization	Wave polarization for the trace O or X	*Polarization="O"*
Num	Number of points	*Num="67"*

Sub-elements of <Trace>

Sub-element	Attributes	Optional Sub-elements
<FrequencyList> **<RangeList>**	**Type** *Data type ("float" or "integer")* **SigFig** *Number of significant figures* **Units** *Physical units* **NoValue** *Value used for missing values* **Description** *Description*	**BoundList** *List of symmetric uncertainty bound for given values* **UpperBoundList** *List of upper uncertainty bound for given values* **LowerBoundList** *List of lower uncertainty bound for given values*
<TraceValueList>	**Name** • *"Amplitude"* • *"Noise Level"* • *"DopplerShift"* • *"DopplerVelocity"* • *"Chirality"* • *"PhaseError"* • *"EastwardLocation"* • *"NorthwardLocation"* **Type** *Data type ("float" or "integer")* **SigFig** *Number of significant figures* **Units** *Physical units* **NoValue** *Value used for missing values* **Description** *Description*	

Sub-elements of <FrequencyList>, <RangeList> and <TraceValueList>:

Element	Required Attributes	Contents
<BoundList> **<UpperBoundList>** **<LowerBoundList>**	**BoundaryType** *Description of uncertainty bound calculation*	*List of uncertainty bound values*

Appendix E. Sub-elements of <Tabulated>

Sub-elements of <Tabulated>

Sub-element	Attributes	Optional Sub-elements
<AltitudeList>	**Type** *Data type ("float" or "integer")* **SigFig** *Number of significant figures* **Units** *Physical units* **NoValue** *Value used for missing values* **Description** *Description*	**BoundList** *List of symmetric uncertainty bound for given values* **UpperBoundList** *List of upper uncertainty bound for given values* **LowerBoundList** *List of lower uncertainty bound for given values*
<ProfileValueList>	**Name** *Name:* • *"PlasmaDensity"* • *"PlasmaFrequency"* • *"TiltZenith"* • *"TiltAsimuth"* • *"VelocityNorthward"* • *"VelocitySouthward"* • *"VelocityVertical"* **Type** *Data type ("float" or "integer")* **SigFig** *Number of significant figures* **Units** *Physical units* **NoValue** *Value used for missing values* **Description** *Description*	

Sub-elements of <AltitudeList> and <ProfileValueList>:

Element	Required Attributes	Contents
<BoundList> **<UpperBoundList>** **<LowerBoundList>**	**BoundaryType** *Description of uncertainty bound calculation*	*List of uncertainty bound values*

Appendix F. Polynomial presentation of <Profile>

Table E-1. <ShiftedChebyshev> = Shifted Chebyshev coefficients for representation of altitude profile of ionosphere

Element	Required Attributes	Contents
<ShiftedChebyshev>	**Region** *Ionospheric region (E, F1, F2)* **StartFreq** *Start frequency, MHz* **EndFreq** *End frequency, MHz* **PeakHeight** *Peak layer height, km* **Error** *Average fitting error, km* **zHalfNm** *Layer height at half of the peak density, km* **Num** *Total number of shifted Chebyshev coefficients*	**Layer coefficients, space separated**

Table E-2. <QuasiParabolicList> = Representation of electron density profile in quasi-parabolic segments

Element	Required Attributes	Contents
<QuasiParabolicList>	**Num** *Total number of QP segments* **EarthRadius** *The Earth's radius, km*	**<QuasiParabolic>** - multiple instances *Quasi-parabolic segment of profile representation*

One quasi-parabolic segment is

$$f_N^2 = A/R^2 + B/R + C$$

f_N is the plasma frequency in MHz,
A, B, and C are the parabolic coefficients
R is the distance from the center of the Earth in km, which varies from R1 to R2 for the segment.

Table E-3. <QuasiParabolic> = Representation of electron density profile in quasi-parabolic segments

Element	Required Attributes	Example
<QuasiParabolic>	**ID** *Segment ID running from 1 to Num* **StartDistance** *Starting height of the segment in km from the Earth's Center* **EndDistance** *Ending height of the segment in km from the Earth's Center* **A** *Coefficient A* **B** *Coefficient B* **C** *Coefficient C* **Error** *Average fitting error, km*	*<QuasiParabolic ID="0" StartDistance="6460.004" EndDistance="6480.0" A="-1.19421967E12" B="3.68586304E8" C="-28440.03" Error="0.0144"/>*

Appendix G. Profile Valley

Table F-1. <ProfileValley> = Model of the E-F valley

Element	Attributes	Example
<ProfileValley>	**Model** *"ULCAR" or "POLAN"* **Width** *Valley width in km* **Depth** *Valley depth in plasma frequency units* **StartHeight** *Profile inversion start height, km* **StartFrequency** *Profile inversion starting plasma frequency, MHz*	*<ProfileValley Model="ULCAR" Width="80.5" Depth="0.2974"/>*