INTERNATIONAL UNION OF RADIO SCIENCE
IONOSONDE NETWORK ADVISORY GROUP

IONOSONDE DATA EXCHANGE

SAO.XML 5.0

SAO.XML DATA MODEL SPECIFICATION
Version 5.0

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1. SCOPE, OBJECTIVES, AND DESCRIPTION

1.1 Purpose

The purpose of this document is to establish a unified data exchange environment for producers and users of the ionogram-derived ionospheric characteristics. The purpose is accomplished by defining a logical data model and accepting a physical data format for the ionogram-derived data. Such logical and physical model definitions, cumulatively called SAO.XML to denote the logical (SAO: Standard Archival Output [1]) and the physical (XML: eXtensible Markup Language [2]) model constituents, will serve as the reference for development of the input and output data interfaces for the software projects that operate with ionogram-derived data.

1.2 Scope

The standard data exchange regulates standard presentation of the following physical quantities:

- Ionogram-scaled and computed ionospheric characteristics (e.g., foF2, hmF2, etc.),
- Ionogram-derived altitude profiles of ionospheric characteristics (e.g., electron density profile),
- 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 SAO.XML model is not intended for unified exchange of the raw ionogram data and data from other sensor instrumentation or ionospheric models.

1.3 Philosophy of SAO.XML

Several important design concepts went into SAO.XML design in order for it to withstand time.

1.3.1 Completeness with upward compatibility

SAO.XML serves as the complete, primary data exchange model for ionogram-derived information, regardless of the ionosonde design specifics. To sustain completeness of the data model across different ionosonde instrumentation and with time and progress in the ionospheric research, flexible mechanisms for extending the model are available. The extension mechanisms ensure that additions of new data elements or attributes to the SAO.XML record do not affect integrity of existing data collections and sustain compatibility with existing software applications based on previous model releases. In particular, when previous versions of SAO.XML reading software encounter data records containing new, previously unknown data elements, they continue to work within their original design scope. In order to be upward compatible, the model organization admits operation of skipping unknown data elements and attributes.

1.3.2 User friendliness

The SAO.XML model is designed for user-friendliness in various scenarios ranging from software development to management and troubleshooting, so that it ensures:

- Readability: the key components of the data are identifiable in the file without the need to match data records with the external model description,

- Self-descriptiveness: proper metadata are provided together with the data to explain properties of the stored information,

- Clarity of presentation: names, data types, units are clear, precise, not abbreviated, and helpful in understanding of the data contents.

1.3.3 Design simplicity

Where possible, preference has been given to simpler technical solutions. In particular, SAO.XML design does not contain internal and external association links between data elements to avoid additional software development that ensures their referential integrity.

1.3.4 Separate storage of multiple ionogram interpretations

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”. The SAO.XML model uses separate storage concept in which one SAO.XML record is provided for each record of ionogram interpretation, without attempting to combine contributions from different scalers in one record.

1.3.5 Storage by column

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

TABLE 1. Sample ionogram trace stored in tabular form

Frequency kHz	Virtual Height, km	Doppler shift, Hz	AmplitudedB
2.0	326	-0.098	130
2.1	335	0.098	122
2.2	350	0.293	126
2.3	366	0.293	134

The SAO.XML model arranges the tabular data storage by column, thus keeping only homogeneous values within a data element. This arrangement simplifies development of the upward-compatible software that has to handle ionospheric data of varying richness of their contents, allowing skipping of unknown characteristics of traces and profiles as a whole entity.

2. SAO.XML MODEL COMPONENTS

2.1 LOGICAL MODEL : SAO

The logical model represents organization of the ionogram-derived data in a hierarchical structure. It is based on a conceptual model that defines top-level contents of the SAO.XML as shown in Table 2. The conceptual model for ionogram-derived data remains unchanged since introduction of SAO in 1980s.

TABLE 2. Conceptual model defining SAO.XML data contents

Item	Comments
Measurement Attributes	Measurement time, location, content descriptors
System Information	Additional information on measurement location and equipment
Characteristics	Scaled characteristics with qualifiers, descriptors, error bars
Traces	Traces of ionospheric reflections extracted from the ionogram image
Profiles	Height profiles of geophysical data derived from ionograms, e.g., electron density profile.

The logical model uses concepts of *elements* and *attributes* throughout the rest of the document. The element is a data structure with well-defined start and end, some content, and attributes with additional properties of the element (Fig.1). The content of an element can be simple or complex (consisting of other sub-elements).

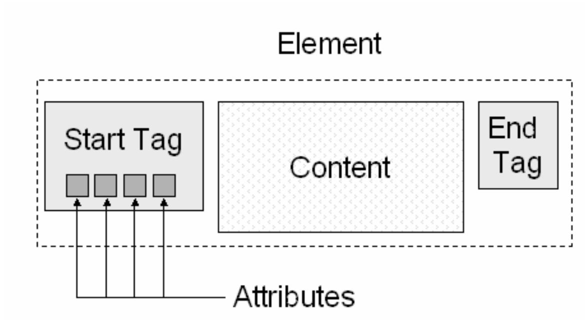

FIGURE 1. Element.and its attributes

Figure 2 provides a detailed diagram of the internal SAO Record structure. In the diagram, individual data elements are shown as boxes. When an element can exist in multiple instances (e.g., more than one trace can be found on ionogram), it is shown as a box triplet. SAO elements whose content is an array of multiple items of the same kind use "List" suffix in their name. The SAORecord element, its attributes, and CharacteristicList element with multiple URSI elements are shown with bold outlines as they constitute the minimum set that one SAORecord has to contain. Other data elements are optional.

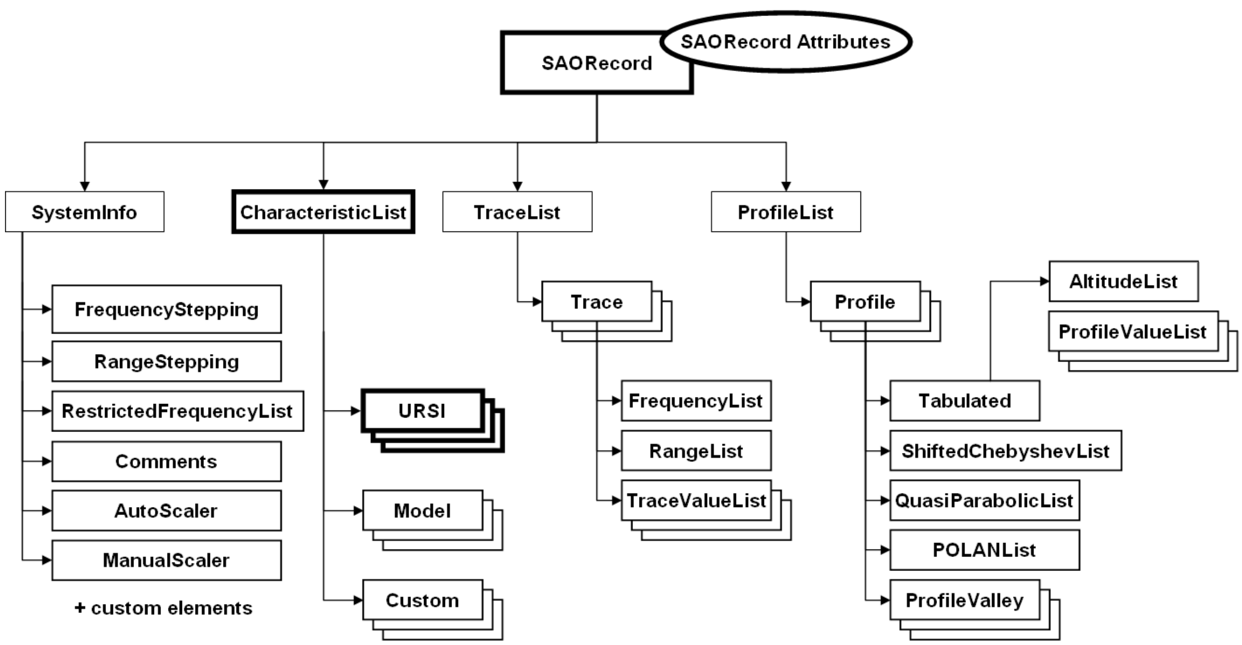

FIGURE 2. Logical model of SAO.XML

Two upper levels of the logical model hierarchy directly match definition of the conceptual model in Table 2. Further description of the SAO.XML model elements is made in Section 3 below.

2.2 PHYSICAL MODEL : XML

XML (eXtensible Markup Language) has been selected as the format vehicle for the physical model. Its organization matches the logical concepts: an XML document is a hierarchy of data elements that are clearly identified and delimited by their named tags, with the attributes describing the content. It satisfies general requirements listed in Section 1.3.

3. DESCRIPTION OF SAO.XML 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 3).

TABLE 3. Top level: 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 4). The SAORecord contains:

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

TABLE 4. 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.

3.2 <SystemInfo> element

<SystemInfo> is an optional element containing descriptive information about the measurement and data processing for the <SAORecord> (Table 5).

TABLE 5. <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" >
2000032020103450500032034505193200000050000 0B31000011611E06741D7334006123F0
</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 6, 7, 8, and 9).

TABLE 6. <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 7).

TABLE 7. <URSI> : URSI-standard ionospheric characteristic

Element	Required Attributes	Optional Attributes
<URSI>	**ID** *2-letter URSI ID, see Appendix C* **Val** *Value of characteristic*	**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 8. <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 9. <Custom> : custom, user-defined 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")*

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 10-11).

TABLE 10. <TraceList> : list of scaled ionogram traces

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

TABLE 11. <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 12-16).

TABLE 12. <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 13. <Profile> : altitude profile of ionospheric characteristics

Element	Required Attributes	Sub-elements
<Profile>	**Algorithm** *Algorithm name* **AlgorithmVersion** *Algorithm version* **Optional Attributes** **Type** *Profile type ("vertical", "off-vertical", "average", "auroral", "internal-bound", "external-bound")* **Description** *Profile content description*	**<Tabulated>**- multiple instance. optional *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.* **<ProfileValley>**- multiple instances, optional *Model of the E-F valley, see Appendix G.* **<TopsideChapman>** - one instance, optional *Fixed scale height model of topside profile, see Appendix G* **<TopsideVaryChap>** - one instance, optional *Varying scale height model of topside profile, see Appendix G* **<AlgorithmOptions>** - one instance, optional *Options of the algorithm* At least one element of <Tabulated>, <ShiftedChebyshevList>, <QuasiParabolicList> or <POLANList> shall be provided in <Profile>

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 15). 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 16 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 14. <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 15. <ShiftedChebyshevList> , <QuasiParabolicList>, <POLANList> : lists of polynomial profile representations

Element	Required 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. Acknowledgements

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Ioanna Tsagouri

Space Research Centre, Polish Academy of Sciences
Iwona Stanislawska

5. References

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

[2] http://www.w3.org/XML/

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 frequencies of restricted band* **<UpperLimitList>** - one instance *Upper frequencies 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>** **<DeclinationAngle>** **<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
	fm3	**49**	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="F2"*
Multiple	Number of hops that signal traveled to form the trace (default is 1)	*Multiple="1"*
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"* • *"NoiseLevel"* • *"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

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)* **StartFrequency** *Start frequency, MHz* **EndFrequency** *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 and Topside Profile

TABLE F-1. <ProfileValley> = Model of the E-F valley, <TopsideChapman> = Chapman model of topside density profile with the fixed scale height, <TopsideVaryChap> = Chapman model of topside density profile with the varying scale height

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"/>*
<TopsideChapman>	**PeakHeight** *Profile peak height in km* **PeakDensity** *Profile peak density in* cm^{-3} **PeakScaleHeight** *Scale Height at peak height, km*	*<TopsideChapman PeakHeight="288.762" PeakDensity="229404.47" PeakScaleHeight="34.62" />*
<TopsideVaryChap>	**PeakHeight** *Profile peak height in km* **PeakDensity** *Profile peak density in cm-3* **PeakScaleHeight** *Scale Height at peak height, km* **TransitionHeight** *Transition Height, km* **TransitionScaleHeight** *Transition Scale Height, km* **ShapeFactor** *Shape factor*	*<TopsideVaryChap PeakHeight="288.762" PeakDensity="229404.47" PeakScaleHeight="34.62" />*