Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities

PITHIA-NRF

MS1

Preliminary report on PITHIA-NRF capacities

Version 1.0

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Abstract

This Document (MS1) is a preliminary report describing the PITHIA-NRF capacities, including data, metadata, research models and research facilities.

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Executive Summary

Research agencies and laboratories in several EU member states operate a large number of excellent facilities for the observation of the Earth's Ionosphere, Thermosphere and Plasmasphere. However, their operation is mainly uncoordinated using different standards and different policies for access and exploitation, which are primarily tuned to national interests and priorities. Due to the uncoordinated operation of the facilities, researchers in Europe and worldwide cannot optimally exploit their full potential without spending substantial resources and time, despite the significant investment made mainly through national and regional funds.

PITHIA-NRF establishes a unique European Infrastructure that provides open access to data, models and experimental facilities and to e-science tools that will enable research advances and innovation. PITHIA-NRF has the ambition to become a European hub that will act as facilitator for coordinated observations from ground and space, for provision of data, processing tools and modelling advances and for software and data-products standardization.

This Document (MS1) is a preliminary report describing the PITHIA-NRF capacities, including data, metadata, research models and research facilities.

Abbreviations

AARDDVARK	Antarctic-Arctic Radiation-belt (Dynamic) Deposition - VLF Atmospheric Research Konsortium
ACE	Advanced Composition Explorer
AGW	Atmospheric Gravity Wave
AIS-INGV	Advanced Ionospheric Sounder – INGV
ASTRON	Netherlands Institute for Radio Astronomy
AWDA	Automatic Whistler Detection and Analyzer
BGD	Borealis Global Designs Ltd
BIRA-IASB	Royal Belgian Institute for Space Aeronomy - Institut royal d'Aéronomie Spatiale de Belgique
CCMC	Community Coordinated Modeling Center
CDSS	Continuous Doppler Sounding System
CHAMP	Challenging Minisatellite Payload

CNES	Centre National d' Etudes Spatiales (National Centre for Space Studies)
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
D2D	Digisonde-to-Digisonde
DEMETER	Detection of Electromagnetic Emissions Transmitted from Earthquake Regions
DIAS	European Digital Upper Atmosphere Server
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DPS	Digital Ionospheric Sounder
DSCOVR	Deep Space Climate Observatory
DTM	Drag Thermosphere Model
EFM	Electric Field Mills
EGI	European Grid Infrastructure
EISCAT	European Incoherent Scatter Scientific Association
EPN	EUREF Permanent GNSS
ESA	European Space Agency
ESPAS	Near-Earth Space Data Infrastructure for e-Science
eSWua	electronic Space Weather upper atmosphere
EUHFORIA	EUropean Heliospheric FORecasting Information Asset
EUREF	Regional Reference Frame Sub-Commission for Europe
EUV	Extreme Ultraviolet
FAIR	Findable, Accessible, Interoperable and Re-usable
GBSC	Ground-Based Scintillation Climatology
GFZ	Helmholtz Centre Potsdam GeoForschungsZentrum (German Research Centre for Geosciences)
GIRO	Global Ionospheric Radio Observatory
GNSS	Global Navigation Satellite System
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
H2020	Horizon 2020
HF	High Frequency
IAP	Ustav Fyziky Atmosfery AV CR,v.v.i. (Institute of Atmospheric Physics)
ICTP	International Centre for Theoretical Physics

ICSU-WDS	International Science Council - World Data System
IGS	International GNSS Service
IMAGE	Imager for Magnetopause-to-Aurora Global Exploration
INGV	Istituto Nazionale di Geofisica e Vulcanologia (National Institute of Geophysics and Volcanology)
IONORT	IONOspheric Ray Tracing
IPIM	IRAP Plasmasphere Ionosphere Model
IRAP	Institut de Recherche en Astrophysique et Planétologie
ISIS	International Satellites for Ionospheric Studies
ISR	International Symbolic Representation
ISWI	International Space Weather Initiative
KAIRA	Kilpisjärvi Atmospheric Imaging Receiver Array
LASCO	Large Angle and Spectrometric Coronagraph Experiment
LOFAR	Low Frequency Array
LYRA	Large Yield Radiometer
MCM	MOWA Climatological Model
MOWA	Model of the Whole Atmosphere
NASA	National Aeronautics and Space Administration
NOA	National Observatory of Athens
NPSM	Neustrelitz PlasmaSphere Model
OE	Observatori de l' Ebre (Ebro Observatory)
ORB	Observatoire Royal de Belgique (Royal Observatory of Belgium)
R&D	Research and Development
RayTRIX	RayTracing through Realistic Ionosphere eXplorer
RELEC	Relativistic ELECtrons
RFA	Radio Frequency Analyzer
RION	Realistic Ionosphere
RO	Radio Occultation
RPI	Radio Plasma Imager
SET	SPACEARTH Technology
SGO	Sodankylä Geophysical Observatory
SISTED	Sunlit Ionosphere Sudden TEC Enhancement Detector

SKiYMET	All-Sky Interferometric Meteor Radar
SLICE	Sodankylä-Leicester Ionospheric Coupling Experiment
SMEs	Small and Mid-size Enterprises
SOHO	Solar and Heliospheric Observatory
SOLERA	SOLar Euv Flux Rate
SRC PAS	Space Research Centre of Polish Academy of Sciences
SSA	Space Situational Awareness
SuperDARN	Super Dual Auroral Radar Network
SWAMI	Space Weather Atmosphere Model and Indices
SWAP	Sun Watcher using Active Pixel System detector and Image Processing
Swarm	ESA's first constellation mission for Earth Observation
SWE	Space Weather Service
SWIF	Solar Wind driven autoregression model for Ionospheric short-term Forecast
TaD	Topside Sounder Model-assisted Digisonde
TEC	Total Electron Content
TechTIDE	Warning and Mitigation Technologies for Travelling Ionospheric Disturbances Effects
TOMION	TOMographic IONosphere
UNT	National University of Tucumán
UPC	Universitat Politècnica de Catalunya (Polytechnic University of Catalonia)
UTN	Universidad Tecnologica Nacional
VLF	Very Low Frequency
WHISPER	Waves of High Frequency and Sounder for Probing of Electron Density by Relaxation

1. Introduction

Europe operates a large number of excellent facilities for the observation of the Earth's Ionosphere, Thermosphere and Plasmasphere with sizes ranging from small ground-based instruments to spacecraft. However, their operation is mainly autonomous and independent using different standards, different policies for access and exploitation that are mainly tuned to national priorities. Due to the fragmentated operation, and different access policies, researchers in Europe and worldwide cannot exploit sufficiently the full potential of these important research facilities, despite the significant investment made mainly through national and regional funds. As indicative examples we can report the investment of several hundred million Euro by ESA and national space agencies for key science space missions for observing the Earth's Ionosphere, Thermosphere and Plasmasphere (Cluster, Swarm, CHAMP, DEMETER, to name a few), and an equivalent amount for ground-based experiments (HF sounders, the EISCAT ISRs, the LOFAR and GNSS receivers). Corresponding effort and national funds of several million Euro have been invested to develop advanced empirical and physics-based models for the prediction of disturbances in the key characteristics of the Ionosphere, Thermosphere and Plasmasphere (ITP) and their drivers. These models provide results to space agencies for operational applications and are among the best models internationally. This heritage has to be exploited and to become the basis for an integrated research environment that will facilitate significant advances beyond the state of the art.

PITHIA-NRF aims at building a European distributed network that integrates observing facilities, data processing tools and prediction models dedicated to ionosphere, thermosphere and plasmasphere research. For the first time, PITHIA-NRF integrates on a European scale, and opens up, to all European researchers, key national and regional research infrastructures such as EISCAT, LOFAR, Ionosondes and Digisondes, GNSS receivers, Doppler sounding systems, riometers, and VLF receivers, ensuring optimal use and joint development. PITHIA-NRF is designed to provide organized access to experimental facilities, FAIR data, standardized data products, training and innovation services. Furthermore, PITHIA-NRF facilitates drastically research advances in the field of upper atmosphere and near-Earth space, through the integration of data collections from satellite missions (such as Cluster, DEMETER, Swarm and CHAMP) and results from key prediction models (such as IPIM-IRAP, MCM-SWAMI, SWIF and EUHFORIA) that can be accessed by scientific users for join exploitation with the data collected from the research infrastructures of the network.

2. PITHIA-NRF capacities

2.1. Research facilities

The main concept of PITHIA-NRF is to integrate key research facilities and provide efficient access for researchers to facilitate research advances and transition of data products and models from research to application and to innovation.

Observing facilities that contribute in PITHIA-NRF integration programme are listed in Table 1. The locations of these facilities are shown in the maps presented in Figure 1.

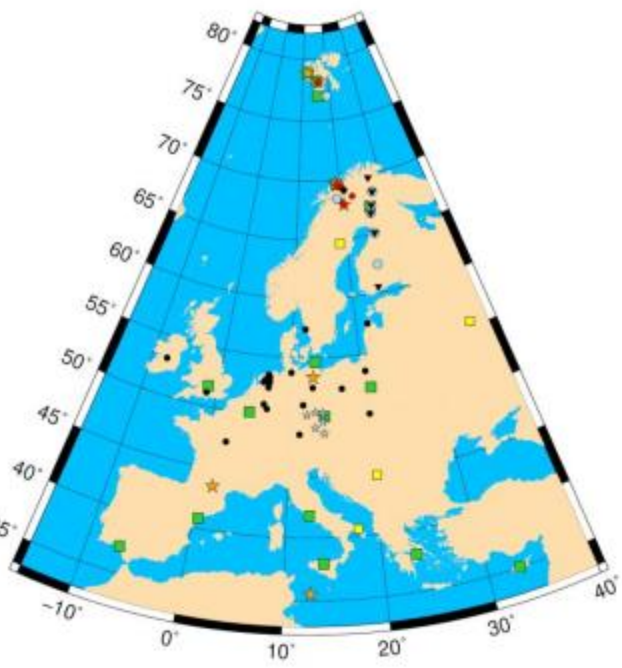
Table 1. Observing facilities that contribute in PITHIA-NRF integration programme

Digital Ionospheric Sounders DPS4D
▪ Vertical soundings ▪ Oblique soundings ▪ Drift measurements ▪ Supervised operations in bi-static link mode DPS4D experimental facilities operated by NOA, OE, IAP, IRM/KMI, INGV who can adjust the operations schedule to fit the PITHIA-NRF requirements for synchronized operations and special campaigns.
Ionospheric Sounders
▪ Ionosondes operated by INGV in Rome, in Gibilmanna (Italy). ▪ Ionosonde operated by SRC PAS in Warsaw and Hornsund (Poland). ▪ Dynasonde operated by EISCAT in Tromso (Norway). ▪ AIS-INGV ionosonde in San Miguel de Tucumán, managed in collaboration with the National University of Tucumán (UNT), Low Latitude Observatory for Upper Atmosphere. ▪ AIS-INGV in Bahia Blanca, in collaboration with the Universidad Tecnologica Nacional (UTN), Facultad Regional Bahia Blanca.
Continuous Doppler Sounding System CDSS
▪ Doppler shift measurements; monitoring of AGW propagation (direction, velocity, periods, for special cases – amplitudes); detection of infrasound signatures in the ionosphere; CDSS is operating by IAP in Central Europe, South Africa and Argentina.
Incoherent Scatter Radars
▪ EISCAT operates three incoherent scatter radar systems, at 224 MHz, 500 MHz and 930 MHz in Northern Scandinavia and on Svalbard. ▪ EISCAT_3D, with sites in Sweden, Norway and Finland, is being constructed and will be operational in 2022. ▪ EISCAT operates a powerful HF heater/radar in Tromso for plasma physics/magnetospheric studies.

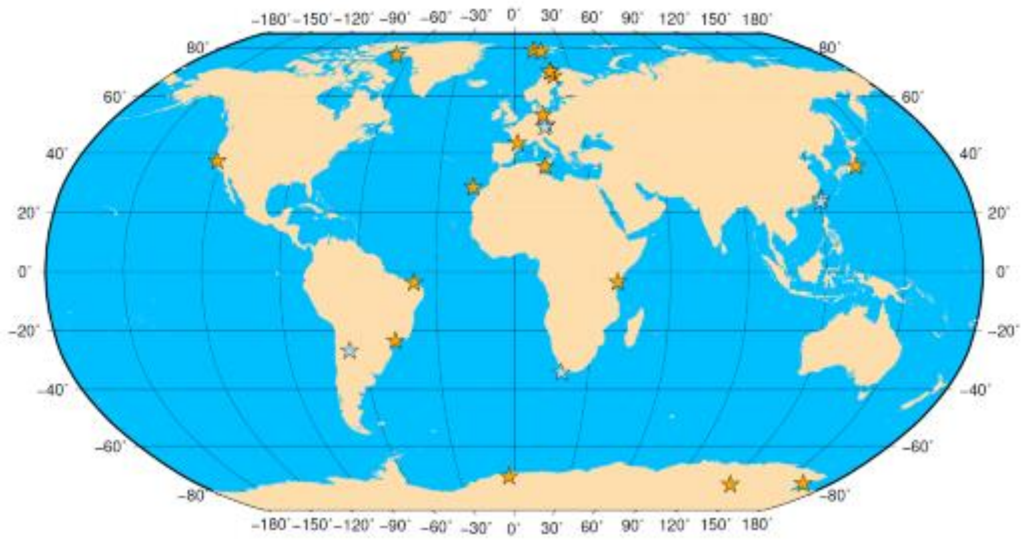
Low Frequency radio telescope
▪ The Low-Frequency Array (LOFAR – van Haarlem et al. (2013)) is Europe's largest low-frequency radio telescope, operating across the frequency band 10-250 MHz, with a dense array of stations in the Netherlands and, at the time of writing, 13 stations internationally from Ireland to Latvia. It was conceived and designed for radio astronomy but, at these frequencies, the ionosphere can also have strong effect on the radio astronomy measurement (de Gasperin et al., 2018). ▪ LOFAR provides normalised dynamic spectra of ionospheric scintillation of strong natural radio sources from all available LOFAR stations obtained during several years of ad-hoc observations. Dynamic spectra are provided with 1s time, and 195kHz frequency, resolution, in a standardised format. The measurements are non real-time of various radio sources (e.g. Cassiopea A, Cygnus A) and typically cover the frequency range 10-90 MHz. A simple processing procedure will be provided for the data. LOFAR measurements are provided by ASTRON and SRC PAS.
GNSS ground based receivers
▪ ORB collects data from the from EUREF Permanent GNSS (EPN) and International GNSS Service (IGS) networks in real-time and post-processes RINEX files to calculate TEC at IPP, vertical and slant TEC, both regionally and globally. ▪ INGV operates ionospheric scintillation and TEC data from 50 Hz GNSS receivers in Italy, Svalbard, Antarctica, Greenland, Brazil, Kenya. ▪ DLR operates high rate GNSS receiver (>= 50 Hz) for ionospheric scintillation monitoring and research. ▪ SRC PAS collects measurements of GPS L1 and L2 signal phase and amplitude scintillation with 1/50s resolution, from the Polish Polar Station on Spitsbergen. ▪ UPC collects real-time GPS measurements in internal well defined OBS format, and near real-time and post-processing multi-GNSS measurements in RINEX format (v3 and v2), that could be kept permanently accessible.
Riometers
▪ Riometer measurements started 1965 and all Finnish stations since 1970. The Finnish Riometer Chain maintained by SGO includes observation sites in Kilpisjärvi, Ivalo, Sodankylä, Rovaniemi, Oulu, Jyväskylä and Nurmijärvi. ▪ Kilpisjärvi Atmospheric Imaging Receiver Array (KAIRA) was officially opened in 2013 and is regularly used for multi-frequency and imaging riometry.
All Sky Cameras
▪ Aurora Borealis observations with digital All-Sky Camera are done since November 2000. ▪ An All Sky Imager installation already funded and planned to be installed in late 2020 by INGV at mid latitude for TID detection Meteor Cameras and Radars ▪ Meteor Camera: SGO operates WATEC 902-H3 Ultimate CCD camera with Fujinon 1:1.3/2.8-8mm lens giving field-of view 112°x81°pointed to zenith for optical meteor detection. Automatic detection software of Swedish Fireball Network has been in use since Jan 2015. ▪ Sodankylä-Leicester Ionospheric Coupling Experiment (SLICE) operates a SKiYMET meteor radar

at SGO since 2008.
VLF receivers
▪ SGO operates three narrow-band VLF receiver stations within the AARDDVARK Network. ▪ BIRA-IASB operates 2 VLF antennas (0-20 kHz), 1 in Belgium and 1 at Princess Elisabeth station in Antarctica (both from AWDA network) with the goal to detect whistler waves ▪ DLR operates a network of VLF receivers for solar flare monitoring and the related analysis of the ionospheric response (Wenzel et al., 2016).
Infrasound network
▪ SGO hosts one of the stations of the Swedish-Finnish Infrasound Network. The station was moved from Uppsala to Sodankyla in October 2006.
Electric Field Mills
▪ Atmospheric electricity (electrostatic field) in Czech and Slovak Republic using Electric Field Mills (EFM).

Figure 1: PITHIA-NRF ground-based observing facilities location.



European region with sites of facilities and instruments contributing to the project.



The World map shows GNSS high sampling rate and CDSS sites only.

Legend
green squares: ionosondes with real-time data delivery
yellow squares: ionosondes without real-time data delivery
light blue stars: IAP CDSS transmitters and receivers (on both maps)
orange stars: INGV + DLR GNSS scintillation receivers (on both maps)
red circles: EISCAT transmitters and receivers light blue circles: SGO riometer chain
black triangles: SGO pulsation magnetometer chain
black circles: LOFAR sites and sites associated with LOFAR
GNSS sites of standard networks (such as EUREF and IGS) are too numerous to be shown.
The ionosondes (mostly Digisondes) with near real-time data provision are owned or operated by consortium partners or outside the consortium but offer free data access.

2.2. Data

The origin, the type and other characteristics of the data collected or produced in the frame of the project are described to the tables that follow. The tools to be applied for data curation and quality assurance are described too.

Table 2 and Table 3 provide a list of diverse data and data-products collections from regional data e-infrastructures and from space missions (ended and on-going) to be registered in PITHIA-NRF e-science center. The data-products will be generated either in near real-time or with a specific latency and, applying the PITHIA-NRF integration tools, will be registered in the open access e-science center.

Table 2. List of data to be registered in PITHIA-NRF

s/n	*Source*	*Types of data & provider*
1	Experimental facilities (§2.1)	Raw data from the experimental facilities.
2	Digisonde-to-Digisonde (D2D) experiments	Raw DOP files extracted from D2D experiments between European Digisondes with 128 chip transmitter capability.
3	DIAS database	Raw RSF and SBF ionogram files.
4	Madrigal open	Neutral wind and neutral temperature at 240 km over 3 sites in Scandinavia.
5	EISCAT data server	EISCAT is a multi-national project that enables research on the lower, middle and upper atmosphere and ionosphere using the incoherent scatter radar technique, a very powerful ground-based tool for these research applications.
6	EISCAT_3D data portal	EISCAT_3D is a new generation radar with extended capabilities being constructed and is on the list of ESFRI Landmarks since 2018. The application of PITHIA-NRF tools for data quality control and model validation will be important for EISCAT_3D developments.
7	Malvern ISR database	Electron density profiles to be provided by NOA.
8	Cluster mission	Cluster/WHISPER data of electron density in the plasmasphere (BIRA-IASB). Cluster/WHISPER, it consists in an active sounder instrument onboard the 4 Cluster satellites, providing electron density data in the plasmasphere from 2001 to 2022.
9	DEMETER mission	In situ electron density to be provided by NOA/ESPAS database.
10	CHAMP, GRACE missions	Electron density reconstructed profiles and RO profiles by UPC.
11	Swarm mission	In situ electron density data, TEC and neutral atmosphere data by NOA.
12	CHAMP, GRACE, GOCE, Cryosat2, Stella ATMO missions	Raw neutral density data along the orbit, daily-mean densities (to be provided by CNES).
13	RELEC	Data from radio frequency analyzer (RFA), three electric field components of electromagnetic waves occurring within the 50 kHz to 15 MHz range (SRC PAS).

s/n	*Source*	*Types of data & provider*
14	IMAGE mission	Radio Plasma Imager Data (BGD).
15	FORMOSAT-3/COSMIC	Electron density profiles, RO data, TEC data (UPC).
16	ACE, DSCOVR	Interplanetary magnetic field, solar wind density and velocity (NOA).
17	ISIS/Alouette database	Electron density profiles from the NASA database (NOA).
18	GNSS ground based receivers	Rapid (1 day of latency) and ultra-rapid (predicted) GNSS orbits, to be provided by UPC.
19	World Data Centers and Regional Warning Centers	Geomagnetic indices from WDC and ICSU-WDS. Solar indices from sislo (SIDC.BE) and from swpc.noaa.gov. Sun irradiance from SOHO: GOES X-rays flux, MgII index, EUV lines. LASCO coronagraph observations (SOHO). Data from SWAP coronal imager (PROBA2). Data from LYRA EUV radiometer (PROBA2).

Table 3. List of data-products

s/n	*Source*	*Types of data*
1	DIAS database (NOA)	▪ Ionograms and scaled parameters from European Digisondes ▪ Thermospheric parameters calculated with the IRI model for European Digisonde locations ▪ Nowcasting foF2 regional maps with the SIRMUP model (Zolesi et al., 2004 and its validation by Tsagouri et al. 2005; Pietrella and Perrone, 2005)
2	TechTIDE database (NOA)	▪ TID characteristics based on D2D data analysis (Reinisch et al., 2018) ▪ European maps of electron densities at various heights and deviation from median conditions (Belehaki et al., 2020) ▪ LSTID index over Digisonde stations (Belehaki et al., 2020) ▪ Running medians with standard deviation and averages of ionospheric characteristics ▪ European maps of ionospheric characteristics foF2 and hmF2 ▪ HF Interferometry results (Altadill et al., 2020) for the detection of LSTIDs occurrence and propagation in near real time

s/n	*Source*	*Types of data*
3	SuperDARN database (UPS)	Global convection maps obtained from the complete set of SuperDARN radars for Northern and Southern Hemispheres. SuperDARN convection maps will also be made available through the 3DView visualisation tool developed by CDPP, hosted by IRAP-CNRS-UPS.
4	eSWua database (INGV)	▪ TEC warning and forecasting (Veettil et al., 2019; Cesaroni et al., 2020 minor revision) ▪ Ionospheric scintillations warning and forecasting (Veettil et al., 2019)
5	TOMographic IONosphere (TOMION) ionospheric mapping products (UPC)	▪ OMION-v1: Based on the Rapid Global ionospheric map (UQRG) model, the UQRG GIM is computed on a daily basis with latencies of 1-2 days, from dual-frequency GNSS carrier phase data only (Hernández-Pajares et al. 1999; 2017, Orus et al. 2005, Roma-Dollase et al., 2018). They are provided following the IGS standards. ▪ TOMION-v2 provides interpolated global VTEC GIM every 15 minutes (see validation details in Liu et al. 2020), with a spatial resolution of 5 deg. x 2.5 in longitude and latitude in IONEX format (Schaer et al., 1998).
6	SOLar Euv Flux Rate (SOLERA) and Sunlit Ionosphere Sudden TEC Enhancement Detector (SISTED) products (UPC)	Proxies of EUV solar flux rate thanks to a first-principles based SOLERA model of the overionization generated in the ionosphere (Hernández-Pajares et al. 2012b, Singh et al. 2015). The associated indices of solar flares occurrence SOLERA-drift and SISTED obtained from GNSS measurements taken from the overall daylight ionosphere (Hernández-Pajares et al. 2012).
7	GFZ data, product and services	Kp-index and Hp-index. The latter is a high-cadence geomagnetic index currently developed within SWAMI/H2020 project and will be provided by GFZ

All datasets that will be registered in the PITHIA-NRF e-science center need to be verified for their quality. Each data provider will be responsible for the quality assurance of the datasets. Table 4 provides a list of tools to be applied for data curation and quality assurance.

Table 4. PITHIA-NRF data analysis/curation tools

s/n	*Model*	*Provider*	*Description*
1	Digisonde data analysis	BGD	▪ Custom software tools for Digisonde data analysis, SAO Explorer and Drift Explorer. ▪ Data quality evaluation criteria for the ionogram data.

s/n	Model	Provider	Description
2	Digisonde data analysis	OE	Data processing algorithms to read data from .sao and .dvl files to obtain bottom-side electron density (Ne) and ionogram derived parameters.
3	Ionosonde data analysis	INGV	Autoscaling ionogram software (Scotto et al., 2019 and references therein).
4	Dynasonde data analysis	EISCAT	Dynasonde software for autoscaling, density profiles and vector drifts.
5	Neutral density data smoothing algorithm	CNES	Algorithm that provides smoothed neutral density data along the orbit, daily-mean densities from CHAMP, GRACE, GOCE, Cryosat2, Stella ATMO missions.
6	Data filtering algorithms	NOA	Algorithms able to address data quality issues for autoscaled ionospheric characteristics such as data outliers/spikes and data gaps.
7	Data conjunctions	BGD	Codes to calculate conjunctions between GIRO Digisondes and RPI topside profiles.

2.3. Models

The models to be registered, in the frame of the project, in PITHIA-NRF e-science center for on-request execution are described in Table 5.

Table 5. PITHIA-NRF models to be registered in the e-science center for on-request execution

s/n	Model	Provider	Description
1	EUHFORIA	KU LEUVEN	A model developed originally at the KU Leuven (Pomoell & Poedts, 2018) with functionalities that are beyond those of ENLIL (a similar operational model in the USA). The background solar wind is data-driven and described on the base of the coronal magnetic field derived from extrapolation of observed photospheric magnetograms, and empirical relations determining the wind speed, its density, and temperature. The innovation is currently in 1) the evolution of ICMEs for which magnetic flux rope models are implemented, shown that is capable of providing meaningful results for the observed magnetic Bz component at L1; and 2) in the coupling of EUHFORIA to magnetosphere and geo-effects models, which enables to use the synthetic solar wind data at L1 to predict the geomagnetic indices (Dst, Kp, magnetopause stand-off distance) and even ionosphere indices (like AE) several days in advance.

s/n	***Model***	***Provider***	***Description***
2	3D-Kinetic plasmasphere model	BIRA-IASB	The model uses the mechanism of interchange instability to provide the number density and the temperature of the electrons and protons inside and outside the plasmasphere in the plasma trough. The plasmasphere model has been coupled with the ionosphere using the empirical IRI as boundary conditions (Pierrard and Stegen 2008; Pierrard and Voiculescu 2011; Bandic et al. 2016, 2017; Verbanac et al. 2015; 2018).
3	IPIM (IRAP Plasmasphere-Ionosphere Model)	UPS	A kinetic-fluid coupled model solving transport equations along magnetic field lines for the main ionized species (ions, thermal and suprathermal electrons) from the ionosphere to the plasmasphere. The main outputs are the densities, temperatures, velocities, heat flux of the main species, as well as electron heating rate, conductivities and Joule heating. The model is planet-independent (Marchaudon and Blelly 2015, 2020; Marchaudon et al. 2018; Sanchez-Cano et al. 2018; Pitout et al. 2015). IRAP will provide the interface with the CDPP for the online version of the IPIM model called Transplanet (Blelly et al., 2019; André et al. 2018).
4	MCM SWAMI model	CNES	A model of the whole atmosphere (MOWA) with a science as well as operations-focused approach. Two existing models of the atmosphere, the UM and the DTM, are extended and blended to produce this unique new whole atmosphere model, which provides estimates of both climatology and space weather variability. The model is validated by the SWAMI/H2020 project team against observations and other models. The operational model MCM for satellite operations, re-entry and launch applications is developed based on MOWA and DTM, with a specification guided by consultation with relevant users (Bruinsma, 2018).
5	Drag Thermosphere Model (DTM)	CNES	It is a semi-empirical model that is mainly used for orbit computation and prediction. It requires solar and geomagnetic activity indices (Bruinsma, 2015).
6	Neustrelitz PlasmaSphere Model (NPSM)	DLR	The model predicts electron density in the topside ionosphere and plasmasphere considering L-shell dependencies of the electron density as well as the coupling processes between the ionosphere and plasmasphere (Jakowski and Hoque, 2018).

s/n	Model	Provider	Description
7	Topside Sounder Model-assisted Digisonde (TaD)	NOA	Ionospheric topside electron density reconstruction models based on the TaD model concept. TaD is based on the TSM core empirical model and using ionospheric parameters from the peak of the electron density for a specific location and TEC data from a co-located GNSS receiver, the model reconstructs the electron density from the peak height up to 20,000 km. TaD is available in 1D and 3D versions (Kutiev et al. 2012; 2016; Belehaki et al. 2012;). The model provides topside electron density maps to the ESA SSA Space Weather service.
8	Solar Wind driven autorgressive model for Ionospheric short-term Forecast (SWIF)	NOA	The model supports ionospheric forecasting services of DIAS and ESA SSA Space Weather Service (http://swe.ssa.esa.int/). The model is designed to provide single site and regional forecasts of the foF2 critical frequency up to 24 hours ahead, as well as alerts for upcoming disturbances, exploiting interplanetary magnetic field data from L1 point, while recently it was upgraded to expand its forecasting capabilities to the total electron content (TEC) ionospheric characteristic (Tsagouri et al. 2009; Tsagouri, 2011; Tsagouri and Belehaki 2015; Tsagouri et al. 2018).
9	Bottomside Thickness	OE	Models for the thickness and shape of the bottom-side of the F2 layer, B0 and B1 respectively, for quiet conditions. The models have been validated and they are used by the IRI model as the recommended option. (Altadill et al. 2009; Bilitza et al. 2014).
10	F-peak height	OE	Model for the density peak height, hmF2, for quiet conditions. The model has been validated and used by the IRI as the recommended option. (Altadill et al. 2013; Bilitza et al. 2017).
11	IRI and NeQuick Open access reference models	CCMC, ICTP	PITHIA-NRF will provide the interface with the IRI model at https://ccmc.gsfc.nasa.gov/modelweb/models/iri2016_vitmo.php and the NeQuick model at https://t-ict4d.ictp.it/nequick2/nequick-2-web-model.
12	TEC model	ORB	Basic processing software to calculate TEC at IPP from near real-time and post-processing RINEX files collected from EUREF Permanent GNSS (EPN) and International GNSS Services (IGS) networks. The ORB-IONO software (Bergeot et al. 2014) provides vertical and slant TEC regionally and globally.
13	RayTRIX	BGD	RayTRIX (RayTracing through Realistic Ionosphere eXplorer) uses numerical ray tracing to simulate the properties of HF signals propagating in the ionospheric channels specified by IRTAM with added knowledge of TID activity and local tilt of the ionosphere (based on Huang and Reinisch, 2006).
14	IONORT HF ray tracing	SET	A software tool for calculating a 3-D ray-tracing for high-frequency waves in the ionospheric medium (Azzarone et al., 2012; Settimi et al., 2013).

s/n	Model	Provider	Description
15	Equatorial Plasma Detection	OE	Equatorial Plasma Detection method (Blanch et al., 2018) is able to identify the occurrence of Equatorial Plasma Bubbles (EPBs) with data gathered from receivers of Global Navigation Satellite System (GNSS).
16	Ground-Based Scintillation Climatology (GBSC)	INGV	GBSC was created by INGV to describe the ionospheric scintillations/TEC climatology sorted by different time/space reference frame, geomagnetic activity/solar activity level, IMF conditions (Spogli et al., 2009; Alfonsi et al., 2011; Spogli et al., 2013, Cesaroni et al., 2015; De Franceschi et al., 2019; Materassi et al., 2020).
17	Realistic Ionosphere (RION)	BGD	RION is an ISWI instrument suite dedicated to continuing accurate and prompt nowcast of the 3D global plasma density distribution in Earth's subpeak ionosphere, based on the real-time data feeds from a global network of ionosondes with installations in 26 countries. (Galkin, Ivan A. ; Reinisch, Bodo W. ; Bilitza, Dieter, 2018).

2.4. Metadata

Metadata files are provided along with the PITHIA-NRF products. Some products use standard metadata vocabularies and others generated individual well readable metadata files which are easy to convert in any standard. Due to the large number of project partners providing different kinds of products, a harmonization of metadata within PITHIA-NRF is necessary. Search keywords will also form a part of the metadata.

3. PITHIA-NRF uniqueness

- **Standardization of data registration, discovery and access**, based on the domain-specific ontology.
- **Standardization of scientific models' registration,** and delivery of high-level data products and workflow solutions for research, development and innovation.
- **Standardization of policies for the optimized operation of experimental facilities**.
- **Subsidized trans-national access** to research facilities for academics and SMEs ensuring a continuous cooperation and interaction with data providers and scientists.
- **E-science tools** to support R&D projects, while ensuring compliance with FAIR criteria.
- **Innovative solutions** for software development, for high-level data products definition and for the development and deployment of new experimental facilities.