Roadmap for collaborations in incoherent scatter radar operations

COOPEUS Deliverable 2.5

Prepared by EISCAT Scientific Association

2015-04-23

In Task 2.5 of the COOPEUS project, a common approach to facility scheduling and operating procedures is developed in order to optimise the coordination of European and US incoherent scatter radar facilities at the operational and observational levels.

1 Background

The incoherent scatter radar technique is one of the most powerful methods for detailed measurements of the conditions in the ionosphere, the uppermost and partially ionised part of the atmosphere.

Similar to the case of standard radar techniques, the incoherent scatter radar technique involves transmission of a radio signal in the direction of a target, and detection and analysis of the signal returning back. The main difference is that the target using the incoherent scatter radar technique is the electrons in the ionosphere in a volume filling the full radar beam. The returned signal from the electrons is very weak, meaning that the transmitted radio wave must be powerful in order for the detected returned signal to be sufficiently strong compared to the background noise, and also that the receivers must be sensitive. High power large aperture (HPLA) radars are radar systems satisfying these conditions, and are thus used as instruments for incoherent scatter radar measurements.

The typical set of parameters obtained from an incoherent scatter radar measurement includes the electron density, the electron and ion temperatures, and the bulk plasma velocity along the direction of the radar beam. The dependence of these parameters on time and the distance from the receiver are recorded. By using three or more geographically separated receivers looking at the same volume of the ionosphere it is also possible to determine the full three-dimensional bulk plasma flow velocity within that common volume. Thus, a system using the incoherent scatter radar technique functions as a plasma weather station making detailed observations of the state of the ionosphere above the radar system.

Importance of incoherent scatter radar observations

The Sun is fundamental for the environmental conditions on Earth. It does not only give us direct heat and light but it also provides the energy to power the motion of the atmosphere and oceans which determines the weather and climate on Earth. The Sun also produces the solar wind, which is a fast stream of charged particles travelling from the Sun outward through the solar system. The solar wind also carries a magnetic field which interacts with the Earth's inherent magnetism to form the magnetosphere. Solar-terrestrial physics is the scientific branch concerned with exploring all aspects of the connection between the Sun and the Earth, including processes behind conversion of energy from one form to another and how all these processes combine to affect the environment on Earth.

Being such a broad topic means that solar-terrestrial physics overlaps with many other areas of science, including atmospheric physics and chemistry, solar physics, and plasma physics. There are several goals for applied studies in this field such as enhancing the potential of modelling the ionosphere for communications and global positioning applications and clarifying the contribution of natural variability to global change, both in the short-term and the long-term perspective.

Now that the world is becoming more and more dependent on space-based systems it has put space weather processes increasingly more into focus. The term space weather refers to the conditions in the environment of the Earth's ionosphere and magnetosphere due to the Sun and the solar wind that have the potential to influence the reliability of space- and ground-based technological systems and services. The search for improvements in the prediction and mitigation of space weather effects is now at the top of the scientific and political agenda worldwide, and solar-terrestrial physics has thus become one of the key science areas for the twenty-first century.

The driving factor of progress in the field of solar-terrestrial physics is the observations. The continual variations in the solar-terrestrial system and the complexity of the processes involved limit the potential to apply current theoretical models of the response from the solar influence on the Earth's environment. There is thus a need for high-quality observational data covering all key regions of the Sun-Earth system. One of these key regions is the ionosphere connecting the Earth's magnetosphere with the lower atmosphere. HPLA radars applying the incoherent scatter radar technique are the most powerful instruments to be used for ionospheric observations in this framework.

Trends in ionospheric research

There is an increased interest in environmental science in general, and this requires a higher level of international collaboration to make the observations more efficient and covering larger geographical areas. Ionospheric research is not an exception to this trend, and thus the ionospheric scientists are moving more towards coordinated observational efforts in order to enhance the understanding of specific ionospheric processes occurring on a global level.

In the area of solar-terrestrial physics, space weather prediction has recently become a focus point because of the potential for devastating space weather effects on essential modern technology such as interruptions to radio communications and global navigational satellite systems (such as GPS and Galileo), disruption of power grids, and damage to spacecraft. In order to understand the effects on the ionosphere coming from space weather events, reliable models of the response of the near-Earth space have to be developed. These models are improved by combining them with observations of the ionosphere. There is thus a demand for continuous ionospheric data on a global scale to provide input to real-time space weather prediction services.

New technological capabilities that can be applied in incoherent scatter radar systems have made it possible to perform observations essentially continuously with minimal staff effort. One side-effect of these new capabilities that modern radar systems produce significantly larger amounts of data than systems based on older technology. This, in combination with a higher demand from both society and researchers for analysed and reliable ionospheric parameters, requires a much larger focus on the processing, storage and accessibility of incoherent scatter radar data already during the planning of new research radar systems than what was needed earlier.

Incoherent scatter radar observations in a global context

The environment is global in nature, meaning that any ambitious effort to fully observe one particular aspect of it should preferably be made on a global scale. There is thus a need for global ionospheric observations. HPLA systems, capable of incoherent scatter radar measurements of the ionosphere, are however expensive equipment to develop and operate, and a well-coordinated effort of a world-wide research community will therefore be required for the global picture.

Incoherent scatter radar facilities worldwide

The specific objective of Work Package 2 of the COOPEUS project is to coordinate the European and American radar operations. However, a description of the state of the incoherent scatter radar community would not be complete without mentioning all HPLA radar systems in the world that are capable of incoherent scatter radar measurements.

There are now more than fifteen HPLA radar facilities worldwide capable of applying the incoherent scatter technique. Three of these facilities belong to EISCAT (the EISCAT Svalbard Radar, and the EISCAT UHF and VHF radars). A further seven are funded by the US National Science Foundation (PFISR, RISR-N, Sondrestrom, Millstone Hill, Arecibo and Jicamarca) and the US Army (ALTAIR). Of the other systems, three (MU, EAR and PANSY) are operated by Japan, one (Irkutsk) by the Siberian Branch of the Russian Academy, one (Kharkiv) by the Ukrainian Academy, one (RISR-C) by University of Calgary, one (Kunming) by China Research Institute of Radio Propagation and one (MAARSY) by the Leibniz-Institute of Atmospheric Physics.

Most of these systems (Arecibo, EISCAT UHF, EISCAT VHF, Irkutsk, Jicamarca, Kharkiv, Millstone Hill, Sondrestrom and ALTAIR) have been in operation for 25 to 50 years. Apart from Jicamarca, these older radars are dish-based, with single beams, and either limited or slow steering capabilities. Most newer radars (MU, EAR, PANSY, Kunming and MAARSY) are primarily constructed for middle atmosphere research and thus have limited capabilities for incoherent scatter measurements. The PFISR and RISR radars, while phased array systems, are single-site, with neither multi-beam nor aperture synthesis imaging capabilities.

The incoherent scatter radar facilities that are covered by the COOPEUS project are briefly described in the following. These descriptions are here to make it clear that the systems are very diversely designed and their ages cover a large time span, and also that there are significant differences at the various levels of governance and funding.

EISCAT UHF

- Operator: EISCAT Scientific Association
- Owner: EISCAT Scientific Association
- Funder: Funding agencies and organisations in China, Finland, Japan, Norway, Sweden and the United Kingdom (the EISCAT members)

- Location: Tromsø, Norway
- First operation: 1981
- Antenna type: 32 m steerable parabolic dish
- Centre transmit frequency: 929 MHz
- Peak power: 2 MW

EISCAT VHF

- Operator: EISCAT Scientific Association
- Owner: EISCAT Scientific Association
- Funder: Funding agencies and organisations in China, Finland, Japan, Norway, Sweden and the United Kingdom (the EISCAT members)
- Location: Tromsø, Norway; Kiruna, Sweden (receiver); Sodankylä, Finland (receiver)
- First operation: 1985
- Antenna type: Four 30×40 m steerable parabolic cylinders (Tromsø); 32 m steerable parabolic dish (Kiruna and Sodankylä)
- Centre transmit frequency: 223.7 MHz
- Peak power: 1.6 MW

EISCAT Svalbard Radar

- Operator: EISCAT Scientific Association
- Owner: EISCAT Scientific Association
- Funder: Funding agencies and organisations in China, Finland, Japan, Norway, Sweden and the United Kingdom (the EISCAT members)
- Location: Longyearbyen, Svalbard
- First operation: 1996
- Antenna type: 42 m fixed and 32 m steerable parabolic dishes
- Centre transmit frequency: 500 MHz
- Peak power: 1 MW

EISCAT_3D

- Operator: EISCAT Scientific Association
- Owner: EISCAT Scientific Association
- Funder: Not yet fully clarified
- Location: Five sites in northern Scandinavia
- First operation: Around 2020
- Antenna type: Crossed dipole phased array (one on each site)
- Centre transmit frequency: 233 MHz

- Peak power: 10 MW

Millstone Hill

- Operator: Massachusetts Institute of Technology
- Owner: Massachusetts Institute of Technology
- Funder: National Science Foundation
- Location: Westford, Massachusetts, USA
- First operation: 1960
- Antenna type: 46 m steerable parabolic dish, 68 m zenith antenna
- Centre transmit frequency: 440 MHz
- Peak power: 2.5 MW

Jicamarca Radio Observatory

- Operator: Cornell University
- Owner: Instituto Geofísico del Perú
- Funder: National Science Foundation
- Location: Lima, Peru
- First operation: 1961
- Antenna type: Crossed-dipole phased array
- Centre transmit frequency: 50 MHz
- Peak power: 4.5 MW

Arecibo Observatory

- Operator: SRI International
- Owner: National Science Foundation
- Funder: National Science Foundation
- Location: Arecibo, Puerto Rico
- First operation: 1963
- Antenna type: 305 m fixed dish
- Centre transmit frequency: 430 MHz
- Peak power: 2.5 MW

Sondrestrom

- Operator: SRI International
- Owner: National Science Foundation
- Funder: National Science Foundation
- Location: Kangerlussuaq, Greenland

- First operation: 1983
- Antenna type: 32 m steerable parabolic dish
- Centre transmit frequency: 1290 MHz
- Peak power: 3 MW

PFISR

- Operator: SRI International
- Owner: National Science Foundation
- Funder: National Science Foundation
- Location: Poker Flat, Alaska, USA
- First operation: 2007
- Antenna type: Crossed dipole phased array
- Centre transmit frequency: 449 MHz
- Peak power: 2 MW

RISR

- Operator: SRI International
- Owner: National Science Foundation (RISR-N), University of Calgary (RISR-C)
- Funder: National Science Foundation (RISR-N), University of Calgary (RISR-C)
- Location: Resolute Bay, Nunavut, Canada
- First operation: 2009 (RISR-N), 2011 (RISR-C)
- Antenna type: Crossed dipole phased array
- Centre transmit frequency: 449 MHz
- Peak power: 2×2 MW

2 Goals of this roadmap

This document presents a roadmap for collaborations in the field of incoherent scatter radar observations. The roadmap is constructed as an effort to organise future activities between the international operators of radar facilities performing incoherent scatter measurements. This roadmap is the outcome from a collaboration between EISCAT and its US counterparts, but the idea is that the recommendations is contains should be of general value for all operators of HPLA radar facilities internationally.

The contents of this roadmap include many aspects of data formats and access because of the trend for incoherent scatter radar observations to become increasingly more data intensive, and accordingly the suggestions in the roadmap should be in line with the capabilities and standards followed by e-infrastructure providers that have the experience needed for transferring and storing large data volumes. The suggested solutions should of course also be both technologically and economically feasible to be of any use for an HPLA radar operator, and they should be scalable so that future, potentially larger and more data intensive, systems also could benefit from consulting this roadmap.

It should not be forgotten that the roadmap additionally must be consistent with the requirements and expectations of the users of the radar facilities. The reason for the radar facilities to exist in the first place is to provide scientists with the means to perform observations and experiments as part of a wide range of research activities.

The completion of this roadmap is timed very well since EISCAT Scientific Association is planning to build a large new incoherent scatter radar system, called EISCAT_3D, within the next couple of years. This facility will be a defining radar system for the future thanks to its versatile capabilities, and thus it needs to be ensured that it is designed in a consistent way. This will provide the potential of interoperability with other radar systems, through harmonisation, and define future standards for HPLA radars to follow.

Interoperability and harmonisation

The present roadmap is meant to function as a guide for both the different HPLA radar systems and their corresponding organisations to be able to work together in a consistent manner on the global level. This means that common standards on different aspects of the data that are produced should be defined, but also that procedures for the initiation of collaborative measurements and identification of common standard radar operations should be determined. The degree of interoperability that the roadmap identifies requires work towards harmonisation both on technical as well as on organisational and policy levels.

3 Areas for collaborative efforts

In this roadmap, a number of areas are identified where collaborative efforts between incoherent scatter radar system providers are both suitable and of great value. These areas are presented in this section together with explanations of why harmonisation efforts would be useful in the different cases.

Definition of data levels

In order to be able to efficiently combine data obtained by different incoherent scatter facilities, the different levels of data have to be clearly defined so that there is no confusion on what kind of data is under consideration. This definition of data levels is also helpful while interchanging data between the facilities. The policies for data access at the different data levels have to be harmonised for this interoperability to be possible.

Data format

Having well defined formats for the data is advantageous at all data levels. This allows for direct data interchange as well as standardisation and exchange of software for data analysis.

Access

The procedures for exchange of data between the facilities have to be negotiated so that they are reciprocal. A situation where the interchange of data is only one-directional is not desirable. The data should, potentially after some time of embargo, be made as openly accessible as possible.

Ideally, the access rights to use the different HPLA radar facilities should be harmonised in such a way that studies of a wider scope than what is available from one single radar site could be promoted.

Standard operations

Each incoherent radar facility has a well-defined set of standard modes of operations. By harmonising these standard operations across the different facilities it will be possible to gain added value to the local measurements by the possibility to gain a more global view of the state of the ionosphere and how it changes over longer time-frames.

Non-standard operations

The definition of clear procedures for the planning of coordinated special operations is important in order to enable investigations of common scientific objectives using multiple incoherent radar facilities. In addition, protocols should be in place also for unplanned interoperation on a global level following large external events, such as coronal mass ejections.

Training and education

The community running HPLA radars is small, and the technology involved in running these radars is specialised to a large degree. Hence the training of radar engineers is most efficiently performed through exchange activities between different radar facilities. Such exchanges are naturally best optimised if they are made in a planned and well-coordinated fashion. Similarly, education aimed at users of the HPLA radar facilities is also best performed through coordinated activities in order to simplify attracting the most experienced instructors to provide hands-on experience working at the radar systems.

Outreach

It is important that the incoherent scatter radar community has a common voice in the contacts with policy makers as well as with the general public. In this way the potential impacts of the observations and findings from the systems are maximised, and the requirements for the system operations can be properly addressed.

4 Status and needs for coordination activities

Now that the areas for coordination activities have been identified, their present status and needs for improvements are examined in this section.

Data levels

The different data levels used in the European and US incoherent scatter radar systems were identified during the gap analysis that was performed as Task 2.2 within this project (COOPEUS) and they were reported in Deliverable D2.2 (Gap analysis report on incoherent scatter data)[1]. This gap analysis clearly showed that these systems produce vast amounts of raw data that can be stored and transferred at different levels of reduction, but also that there are similarities at the fundamental level between the data organisation of the different

1 http://www.coopeus.eu/wp-content/uploads/2013/05/GapAnalysis.pdf

incoherent scatter radar facilities. These similarities allow a high degree of standardisation to be made, which would facilitate increased scientific cooperation between users of the different systems. The data obtained at the radar facilities can in principle be classified as follows:

Data level 1 (RF signal voltage) represents the lowest accessible level of digital sampled and filtered data in the radio frequency (RF) voltage domain. The formats and rates of these data are system-specific and usually also depend on experimental configurations. Level 1 data are normally not stored except for some specific applications. Future systems, like EISCAT_3D, will perform much of their fundamental processing, such as beam-forming, digitally on level 1 data instead of in the analog receiver chains as in present systems.

Data level 2 (correlated products) consist of correlated products produced by signal chain elements applying auto- and cross-correlation operators to level 1 data. These data have been used for long-term storage by most present incoherent scatter radar systems.

Data level 3 (plasma parameters) consist of the physical parameters describing the ionosphere that are derived from the level 2 data. These data are by far the most requested data by the users.

Sometimes an additional level of the data is introduced. This level (level 4) then consists of graphical visualisations and published articles for which the data have been used. Providing a good set of visualisation tools will become increasingly important as more systems with three-dimensional measurement capabilities will be taken into use in the future. This also points to the importance of citing the data used in publications by a common identification system, for instance through the use of digital object identifiers (DOIs).

We must note that all data levels also should include a certain amount of metadata in order to enable the measurements to be put into context. The set of metadata should be appropriate for the data level to which it is attached.

The different data levels can be referred to by using their numbers or by what they contain. Referring to them by number is useful for internal discussions within the community, while referring by what they represent is clearer when discussing the data structure with people outside of the field of ISR data so that terminology confusion can be avoided.

Data format

Since the level 1 data formats are system dependent to such high degree and not normally subject to long-term storage, there has not yet been a need for any inter-system harmonisation at this data level. The main reason for this is that these data have a relatively low information content per stored amount of data, making it impractical to store the required volumes of data except for short time intervals. However, since there have been significant advances in the digital receiver, computing, and storage capabilities, there is now a trend at incoherent scatter radar facilities to start storing level 1 data which introduces a need for standardisation also at this level. It is useful for the development of new measurement and data analysis techniques to have the possibility to exchange level 1 data between different operators and systems. The HDF5 experience of AMISR and Millstone Hill has been identified as a starting point for discussions aimed at defining a common RF voltage format across the community.

Data level 2 has been the most common level for long time storage of incoherent scatter radar data, because at that level the data volume has been sufficiently reduced by the correlation to be manageable while it still retains sufficient information for further analysis to be made. For this reason it is also the data level that should be most suitable for data exchange purposes. However, there are no standardised formats today for level 2 data so this is an area where there is a great need for harmonisation efforts. Common features of level 2 data formats between EISCAT and the US systems were identified and reported in COOPEUS Deliverable 2.2 and they could function as a starting point for the definition of a common format for these data. Further work is needed for this harmonisation to happen.

The incoherent scatter radar community has a well established data container for the storage of level 3 data as functions of space and time: the Madrigal distributed database system[2]. Its development begun in 1980 at Millstone Hill and it is now the standard repository for all participating incoherent scatter radar data systems. Data stored in Madrigal are retrievable by means of a web-based graphical user interface or through web services with application programming interfaces (APIs) for several popular programming languages. The underlying record data format was defined by the US CEDAR community in the late 1980s and is based on 16 bit integers, with significant restrictions on precision. Therefore Madrigal aims at using the standardised and flexible HDF5 format in future releases in order to remove these limitations of the format. The HDF5 format will also allow Madrigal to handle three-dimensional volumetric data when the EISCAT_3D system is implemented. This will, however, require changes in its design.

A strategy is needed for how to handle the practical aspects of future data migration. This should include both general plans about protocols for future changes of data formats and for changes in the data depositories.

Data at all levels should include sufficient amount of relevant metadata, and efforts should be made to ensure that the long-term saved data are fit to be used in common data portals. A service or project could be identified with the purpose to handle activities related to meta-data from all ISR facilities worldwide in a harmonised fashion.

Access

Madrigal provides open access to data at level 3 from all collaborating facilities, and to some extent also graphical visualisations. Madrigal is financed by NSF, but was implemented with contributions from the operators of the participating incoherent scatter radar systems. Other data portals could be offered for incoherent scatter radar data level 3, and possibly also level 4 provided that the corresponding scientific articles are published with open access in mind.

Data are also made available on request from users. This is an important way to get data for many users of the HPLA systems since they require access to data at levels 1 and 2 for their studies. The review process for these situations is at the present not standardised across the different facilities, but could potentially be made in a coordinated fashion.

The ENVRI reference model[3] could function as a guideline for characterisation and description of the framework of data acquisition, access, curation, and processing. The reference model was produced as part of the EU-funded ENVRI project[4], targeting common operations of environmental research infrastructures.

Policy issues for data access are already addressed within the COOPEUS project. The COOPEUS joint data policy is included in Appendix A in this text. The structural and

2 http://cedar.openmadrigal.org/
3 http://confluence.envri.eu:8090/display/ERM/Start
4 http://envri.eu/

organisational conditions for data access are also discussed in other coordination projects. EISCAT participates in projects aimed at the construction of data portals (ESPAS[5], ENVRI) in order to encourage and facilitate access across disciplines. There could also be ways to connect other incoherent scatter radar systems in the same way.

The access to the radar systems depends both on technical aspects and on the access rights. The possibilities for trans-national access to the incoherent scatter radar facilities are not fully reciprocal on paper at the present, but they are however in practice. EISCAT offers a limited fraction of its observation time to transnational access, based on the scientific merit of submitted proposals. The NSF funded radars are also in principle open to non-American users. In both cases most applications for access come from previous users, so an effort to expand the ISR user community would be desirable.

Standard operations

The production of continuous incoherent scatter radar data sets over long time frames requires possibility for essentially unattended operation of the system. This is typically only possible using radar systems based on phased array technology. The operating modes used by these systems for this kind of studies are already chosen to give a fairly detailed overview of the ionospheric conditions and their changes over a long time. A common problem for future operators of continuously running radars is how to fund the high operation costs, mainly due to power consumption, in order to obtain data products whose value come from the very existence of these long time series, i.e. data that can be used to detect slow trends in the ionosphere (the so-called “space climate”).

Non-standard operations

A programme of globally coordinated observations, the incoherent scatter radar world days, already exists. Its purpose is to provide a data set of synoptic ionospheric parameters world-wide by coordinating two or more involved incoherent scatter radars for investigations on some common scientific objective. There are roughly twenty world days every year, and they are scheduled well in advance. The world days days are coordinated through the Incoherent Scatter Working Group (ISWG) at the International Union of Radio Science (URSI). The ISR data obtained during the world days are made available from online databases as soon as possible after the measurements are obtained.

Occasionally there are large geospace events, for example related to space weather, where it is interesting to follow the ionospheric response with incoherent scatter radar observations at more than one site. No protocol exists at the moment for the coordination of such measurements, and this coordination also depends on the personnel situation at the site and if the radar facilities are not used for other (scheduled) experiments. Thus, protocols for triggered non-standard collaborative operations should be prepared for such situations, including a reasonable time-scale needed for the coordination. A standardised policy should also exist for the access of the data from these events, and observation modes for these events should be defined in advance.

5 https://www.espas-fp7.eu/portal/

Training and education

Operation of incoherent scatter radar facilities requires technicians and engineers specialised in HPLA radars. The most efficient way to train this personnel is through coordinated training efforts between the different facilities. However, this coordination does not happen automatically in the way that the ISR community is organised at the moment. Dedicated projects should be identified in order to facilitate such collaborations.

There have been regularly organised international courses on incoherent scatter radar science for several years, usually offered as summer schools. The aims of these courses are to provide the participants with hands-on experience in the design and running of incoherent scatter radar experiments, and to ensure that this experience will be useful when applied at any one of the incoherent scatter radars worldwide. The courses demonstrate how to request, design and analyse incoherent scatter radar experiments, and to combine the obtained data with complementary data sets such as those from optical measurements. These activities should continue in the way that they are done at the present.

During the regular ISR workshop activities the vast majority of new users are people interested primarily in the final data products. This means that the number of new people interested in changing and developing the radar systems and analysis methods tends to be quite small, which in the long run will lead to diminishing numbers of radar system operators. A common strategy is needed for connection with academic institutions to attract more students interested in the ISR technology and analysis methods.

Outreach

The outreach from the incoherent scatter radar community should be coordinated to a higher degree than it is now. However, the joint outreach from the operators should be limited to commonalities such as protection of radio frequencies for transmission and reception and for the importance of ISR/HPLA observations (aside from basic research) for measurements of direct relevance for the society, such as the observation of space weather events and the monitoring of space debris. Collaborative projects for streamlining this coordination should be identified and implemented.

5 Channels for collaborations

All the coordination activities that have been suggested here will not work if there is no arena where the needed discussions can be performed. The recent experiences from the COOPEUS project have both shown where improvements in coordination can be made as well as how difficult the practicalities regarding this coordination can be. The channels of collaboration have to be clearly defined and maintained to enable efficient coordination also in the future, after the end of the COOPEUS project.

The URSI incoherent scatter working group, with meetings every three years, is suggested as a starting point for these discussions, but it is not suited for many of the areas of coordination that are identified in this roadmap. An arena for international coordination in the ISR community needs to be organised and it needs to be funded in a sustainable way. International coordination in the areas of environmental sciences is too important to be neglected.

6 Recommendations on the organisational level

Following the discussions above, a set of recommendations has been identified for the organisations operating incoherent scatter radar systems.

- Identify a sustainable arena that is suitable for discussions on international coordination.
- Follow the COOPEUS joint data policy (see Appendix A).
- Work towards the introduction of persistent data identifiers.
- Agree on a level 2 data standard and make sure that it is suitable for long term storage.
- Make sure that the level 3 data produced are fit to be used in common data portals by connecting sufficient amount of meta-data.
- Prepare protocols for migration of data, both to new formats and new depositories.
- Open for possibilities to implement a common scheduling and operational philosophy.
- Continue the incoherent scatter world days planning as it is done now.
- Make sure that protocols exist for event-driven observations, where one facility/organisation can suggest operation of other facilities/organisations.
- Make efforts to expand the ISR community through high visibility and good connection to academic institutions.
- Identify projects for training and exchange of radar operating engineers.
- Continue the incoherent scatter radar summer schools.
- Identify projects for coordinating outreach efforts.

7 Recommendations on the facility level

A set of recommendations has also been identified on the facility level, both for planned new systems and for updates and upgrades of existing systems.

- Aim for using harmonised level 1 data format for the internal data processing.
- Ensure that data migration activities follow strategy protocols.
- Use the ENVRI reference model as a guideline for the data framework.
- Ensure that standard operating modes are defined for producing long-term continuous data sets that can be used to observe ionospheric changes over time.
- Open for activities involving exchange of engineers for training purposes.

Appendix A

The COOPEUS joint data policy

An analysis of the existing data policies for the research infrastructures involved in the COOPEUS project has been produced as Deliverable D7.2 ("Joint core data and IPR policy")[6]. It was used to define a set points that could be used as a joint data policy for the COOPEUS partners. These points were as follows:

1. Research infrastructures under the umbrella of COOPEUS strongly support free and open access to data produced by their facilities and feel committed to work towards the realisation of this principle.
2. Access to data provided by COOPEUS research infrastructures depends on national and international legal and ethical frameworks as well as on their own data policies. COOPEUS infrastructures acknowledge potential reasons to restrict public access to each others data resulting from these obligations.
3. COOPEUS infrastructures aim to identify unnecessary or obsolete barriers towards open access to their data and will continuously work towards the stepwise elimination of these obstacles.
4. Free and open access without any restrictions shall be granted to the metadata of the data holdings of each COOPEUS infrastructure in order to enable and ease data discovery and fitness-for-use evaluation of the data holdings of each infrastructure.
5. COOPEUS related infrastructures will make such metadata publicly available without undue delay.
6. Metadata associated with COOPEUS infrastructures data shall meet accepted international standards and shall contain the necessary information to attribute identification, authorship, geographical and temporal coverage, type of measurements and observations, access constraints as well as the responsible organisation and when possible, the principal investigator (PI) for each data set.
7. Data produced by COOPEUS infrastructures will be made available through appropriate e-infrastructures. Published data formats shall meet accepted international standards.
8. Data published by COOPEUS infrastructures shall be made available free of charge. RI specific regulations deviating from this general rule may apply when data is used for e.g. non-scientific or commercial purposes. Separate fees may apply for the reproduction and delivery of data when web-based transfer of data is not possible.
9. In general, data shall be made available by COOPEUS infrastructures as soon as possible and without undue delay. COOPEUS infrastructures may apply exclusive scientific usage rights which need to be defined within their own data policies. Such exclusivity periods shall not exceed two years.

6 http://www.coopeus.eu/wp-content/uploads/2013/01/D7.2-Joint-core-data-and-IPR-policy-WP7-prepared-by-University-of-Bremen.pdf

10. Non-publicized research data shall be made available on demand to researchers representing COOPEUS infrastructures - as possible within the legal, ethical and policy framework of the data holding infrastructure. Each COOPEUS infrastructure shall nominate ‘data stewards’ to facilitate such data requests.
11. COOPEUS infrastructures acknowledge national and international intellectual property rights regulations. Each infrastructure is responsible for the warranty of copyrights and intellectual property rights which may apply for its data holdings.
12. COOPEUS infrastructures will clearly indicate licences and terms of use for each dataset in the corresponding metadata.
13. If data or information produced by COOPEUS research infrastructures is used in published or unpublished work, attribution for the used resources is required. Data citations shall exclusively use the information provided within the metadata of each data set. Data which is not publicly accessible but has been disclosed to individual researchers through COOPEUS requires explicit permission of the responsible PI prior to the publication of results derived from this data if requested by the data use policy.