COLLABORATIVE PROJECT PROPOSAL

TO THE

EUROPEAN GNSS SUPERVISORY AUTHORITY (GSA)

FOR

IONOSPHERIC DISTURBANCES EARLY ALERTS VIA LOFAR (IDEAL)

PART B

Work programme topics addressed: Galileo.2011.1.3-1

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ACRONYMS AND ABBREVIATIONS

ACF	AUTO CORRELATION FUNCTION
ADC	ANALOGUE TO DIGITAL CONVERTER
AI	ARTIFICIAL INTELLIGENCE
AIT	ASSEMBLY INTEGRATION AND TEST
ANASTASIA	AIRBORNE NEW ADVANCED SATELLITE TECHNIQUES & TECHNOLOGIES IN A SYSTEM INTEGRATED APPROACH
API	APPLICATION PROGRAMMING INTERFACE
AR	ACCEPTANCE REVIEW
ATH	ASTROTEC HOLDING B.V.
ATM	AIR TRAFFIC MANAGEMENT
BBS	BLACK-BOARD SELF-CALIBRATION
CCF	CODE CORRELATION FUNCTION
CDR	CRITICAL DESIGN REVIEW
CNS	COMMUNICATIONS, NAVIGATION AND SURVEILLANCE
EC	EUROPEAN COMMISSION
ECSS	EUROPEAN COOPERATION FOR SPACE STANDARDIZATION
EGNOS	EUROPEAN GEOSTATIONARY NAVIGATION OVERLAY SERVICE
EM	ELECTROMAGNETIC
EUMETSAT	EUROPEAN ORGANISATION FOR THE EXPLOITATION OF METEOROLOGICAL SATELLITES
ESA	EUROPEAN SPACE AGENCY
ESOC	EUROPEAN SPACE OPERATIONS CENTRE
ESRIN	EUROPEAN SPACE RESEARCH INSTITUTE
ESTEC	EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE
ESTRACK	EUROPEAN SPACE TRACKING
EU	EUROPEAN UNION
GEA	GNSS END-USER APPLICATION
GNSS	GLOBAL NAVIGATION SATELLITE SYSTEMS
GPS	GLOBAL POSITIONING SYSTEM
HGA	HIGH GAIN ANTENNA
HW	HARDWARE
IDEAL	IONOSPHERIC DISTURBANCES EARLY ALERTS VIA LOFAR
ICD	INTERFACE CONTROL DOCUMENT
ILT	INTERNATIONAL LOFAR TELESCOPE
IOV	IN ORBIT VALIDATION
IR	INFRA RED
IRI	INTERNATIONAL REFERENCE IONOSPHERE
IVOA	INTERNATIONAL VIRTUAL OBSERVATORY ASSOCIATION
JIVE	JOINT INSTITUTE FOR VLBI IN EUROPE
KO	KICK-OFF
LBS	LOCATION BASED SERVICES
LEO	LOW-EARTH-ORBIT
LOFAR	LOW FREQUENCY ARRAY
LTA	LONG TERM ARCHIVE
MGT	MANAGEMENT
MIDAS	MULTI-INSTRUMENT DATA ANALYSIS SYSTEM
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ACRONYMS AND ABBREVIATIONS

NEO	NEAR EARTH OBJECT
NOVA	NEDERLANDSE ONDERZOEKSCHOOL VOOR DE ASTRONOMIE/NL ASTRONOMY RESEARCH SCHOOL
NRT	NEAR-REAL TIME
OBCP	ON BOARD CONTROL PROCEDURES
PDR	PRELIMINARY DESIGN REVIEW
PM	PROJECT MANAGER
PROBA	PROJECT FOR ON-BOARD AUTONOMY
PVT	POSITION VELOCITY AND TIME
QR	QUALIFICATION REVIEW
RTD	RESEARCH AND TECHNOLOGY DEMONSTRATION
SCB	S-CURVE BIAS
SESAR JU	SINGLE EUROPEAN SKY ATM RESEARCH JOINT UNDERTAKING
SHM	SYSTEM HEALTH MANAGEMENT
SIS	SIGNAL IN SPACE
SISNET	SIGNALS IN SPACE THROUGH THE INTERNET
SKA	SQUARE KILOMETRE ARRAY
SMF	SIGNAL IN SPACE MONITORING FACILITY
SOHO	SOLAR AND HELIOSPHERIC OBSERVATORY
SPENVIS	SPACE ENVIRONMENT INFORMATION SYSTEM
S/T	SCIENCE/TECHNOLOGY
SW	SOFTWARE
SWWT	SPACE WEATHER WORKING TEAM
TEC	TOTAL ELECTRON CONTENT
TECU	TOTAL ELECTRON CONTENT UNITS
TID	TRAVELLING IONOSPHERIC DISTURBANCES
VOEVENTS	VIRTUAL OBSERVATORY EVENTS
WP	WORK PACKAGE
WSRT	WESTERBORK SYNTHESIS RADIO TELESCOPE

PROPOSAL ABSTRACT

The *objective* of the project is to develop an ionosphere monitoring system with early-warning capabilities that have specific applications for the correction of GNSS signal degradation resulting from ionospheric disturbances. The system will characterise the state of the ionosphere in terms of TEC, providing alerts of disturbances in real-time and highly detailed TEC maps in NRT. These timely, high-resolution TEC maps will improve on existing resources in the following ways:

- Short time delay
- Rapid cadence
- High spatial resolution
- High dynamic range and resolution

Deriving TEC maps via ionospheric data assimilation models in order to study GNSS accuracy is an established idea. Our *concept* proposes an innovative departure from the usual satellite-based methods in order to achieve such improvements in data accuracy and provision. Our method adopts techniques developed for deep-space radio astronomy by the LOFAR project to derive the TEC maps. Once derived, these maps can be used to:

- Characterise the state of the ionosphere, and
- Predict certain key effects resulting from its variability

The added-value of high-resolution TEC data is demonstrated by the work proposed by the *end-user* partner who will use the early warnings and TEC maps to provide rapid and accurate GPS/GNSS correction in near real time. Furthermore, in parallel, we will extend current knowledge of how the ionosphere will distort the modern wideband GNSS signals. We will analyze the signal distortion in terms of receiver characteristics using a highly accurate GNSS receiver and relating the characterization with the obtained high-resolution TEC maps. This represents a level of added-value to the services that will be available to both the current GNSS system and future Galileo system.

The consortium are committed to seeing that as many potential end-users as possible across a diverse range of communities are able to benefit from the high-resolution TEC information and will use all possible means, resources, contract and contacts to ensure this. The Alerts and Added-Value Products themselves sit naturally at a relatively high level and the proposal discusses how they can subsequently be adapted to satisfy a broad range of End-User Requirements arising in GNSS-dependent markets. The project will initially focus on providing the added-value services in a limited geographical region, due to the location of the current operational network. A key aspect of the project will be a *feasibility study*, including cost estimates, for expanding the network to provide a *broader European-level* service.

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1.1 Concept and Objectives

The objective of the IDEAL project is to develop an ionospheric monitoring system with early-warning capabilities that have specific applications for the correction of GNSS signal degradation resulting from ionospheric disturbances. There are many error sources associated with GNSS, more specifically single-frequency GPS, however, the most significant is due to the ionosphere (Langley 1997). The ionosphere both slows and refracts GNSS signals as they propagate through it and this highly variable unknown delay is dependent upon many factors, including: time of day, latitude, solar activity and season (Davies 1990). The effect is proportional to the Total Electron Content (TEC). GPS satellites broadcast ionospheric corrections to users, using a model designed to correct for at least 50% of the ionospheric error (Klobuchar 1987). This has been shown to be highly inaccurate during particularly testing times. For example, 4D ionospheric imaging (using MIDAS) is compared to the Klobuchar model and shown to significantly reduce the ionospheric errors witnessed during the ionospheric storms of October 2003 (Rose et al. 2009, in press). An additional error source that is currently not compensated for in most of the commercial receivers is the ionospheric dispersion within the whole frequency band of the GNSS signal. The ionospheric distortion on the lower frequency differs from the distortion on the higher frequencies in the signal band. It has been shown that an additional phase bias of 14^{o} may be introduced for electron content values of 100 TECU (Henkel et al. 2009). This effect is most profound for the modern wideband GNSS signals (such as the Galileo E5 signal). Although these signals are intended to supply a superior tracking accuracy and improved multipath performance, the additional ionospheric distortion may adversely affect the performance of receivers. As future users will make use of these signals, a thorough analysis of these wideband receiver errors for real observed ionospheric conditions is needed to guarantee accurate position, velocity and timing (PVT) solutions.

Our concept proposes a ***monitoring and early-warning system*** will detect the onset of ionospheric storms from their very first stages, and subsequently characterize the state of the ionosphere in terms of TEC. ***Two key advances*** that this project will bring the community are*:* ***early-warnings of disturbances*** likely to lead to degradation of GNSS-dependent services, and the availability of ***highly detailed TEC maps in NRT***. Such timely alerts and high-resolution TEC maps will improve on existing resources in the following ways:

- The earliest possible alerts of likely GNSS degradation, within <10s
- Alerts entirely independent of GNSS infrastructure, helping assess its performance
- Short time lag - maps available in NRT
- Rapid cadence - maps updated every ~10s
- High spatial resolution
- High dynamic range and resolution

The resulting temporal and spatial resolution of the data products generated by the system will depend in part on which elements of the LOFAR array are used as well as computational resources. Limiting the processing to shorter baselines can generate the highest time resolution event streams. However, such a filtering will by necessity result in lower spatial resolution. Conversely, by including the longer European baselines in the processing, higher spatial TEC maps become possible with an increase in computational cost and the consequent increase in time cadence for events that naturally follows. In principle, these two cadences of short and longer time cadence events can be interleaved. An event could be detected rapidly at lower resolution with a higher resolution map following some time later.

Deriving TEC maps via ionospheric data assimilation models in order to study GNSS accuracy is an established technique (Mitchell and Spencer 2003, Spencer and Mitchell 2007). A thorough review of the history, current state and future of ionospheric tomography is given by Bust and Mitchell (2008). We propose a novel departure from the usual methods in order to achieve the large improvements in data accuracy and provision listed above; our method adopts cutting-edge techniques developed for deep-space radio astronomy observations at the LOFAR network to derive the TEC maps. An additional advantage of this ground-based system over satellite-based systems is that the hardware involved is stationary and thus the space-time ambiguity is removed and errors reduced. Once derived, these maps can be used to:

- Characterise the state of the ionosphere, and
- Predict certain key effects resulting from its variability

The effect of the ionosphere on GNSS signals (and therefore accuracy) is well known and documented in existing and continuing research. The effects on GPS positioning and timing are shown by Allain and Mitchell (2009) and Rose et al. (2009) respectively. The greater the TEC, the greater the delay imposed upon the GNSS signals as they propagate through the ionosphere, which results in increases in the number of errors in the GNSS solution. Most studies on the effect of ionospheric delay do not take into account the distortion over the whole band of the signal, with a notable exception of Gao et al. (2007). Especially the newer GNSS signals (especially Galileo's E5 which has a bandwidth over 50 MHz), however, have a bandwidth much greater than the GPS L1 C/A signal. The differences in delay for the lower frequencies and the higher frequencies can no longer be ignored, and must be well characterized for accurate positioning and navigation applications. GNSS essentially works by the inter-comparison of different EM signals propagating through the ionosphere; thus its accuracy is both safety-critical and vulnerable (Parkinson and Spilker, 1996). This project aims to protect the crucial asset of GNSS accuracy by warning of imminent degradation of the signal in real-time, and producing reliable, graded correction data in NRT, and to characterize the error of the wideband GNSS signals in terms of various receiver characteristics.

The developments that need to be conducted include:

1. Auto-detection of ionospheric disturbances in real time from LOFAR data
2. Implementation of an Alerts system to notify of these disturbances
3. Characterization of the ionosphere in terms of TEC maps in NRT, to provide added-value higher level products and services
4. Benchmarking of LOFAR-only and MIDAS-enhanced correction systems against existing methods
5. Assessment of requirements to extend the network beyond its current capability, including costing exercise
6. Broader dissemination of TEC-level data to users directly and via established data access systems – e.g. for further enhancement and development of ionospheric models and tools
7. Characterizing the distortion of the GNSS Signal In Space (SIS) due to ionospheric delays

The development will make use of already existing facilities; for example:

a) Ionospheric Characterization will be done by the calibration facility of the LOFAR array
b) All software will be fully integrated within the native LOFAR pipeline processing
c) Measuring the actual effect of the different TEC-levels upon EM signal propagation especially for the wide-band GNSS signals, will be performed by accurate GNSS measurements (e.g., on the Code/Carrier Coherency) using one of the WSRT HGAs with high accuracy SIS analysis software.
d) Planned Integration into existing European Space Weather and GNSS assets and Networks, enabling wide distribution/access to the user community.

The IDEAL project will result in a **functional system,** capable of generation and distribution of graduated TEC data and derived products for third party use. At the time of writing, the LOFAR system hardware and software components are largely complete and currently undergoing scientific commissioning. Fully automated processing of LOFAR imaging data is expected to be fully operational early in 2011. The TEC data will be available and suitable for a variety of applications but the IDEAL project will focus on a target application: ***GNSS error alert in real-time and error correction in near real-time.*** We stress that all the required hardware is already in place and fully operational. The system implementation requires only the development of software and systems, many of which will be modifications to existing versions.

The key advantage of IDEAL over existing GNSS error correction systems is that it will demonstrate the viability of using a single, rapid datastream to gather its real-time information, and benchmark it with respect to a second system using a diverse range of ionospheric instrumentation. IDEAL is not as vulnerable to a single-instrument-type failure mode due to, for example, interference or jamming of signals over a local area. The planned range of instrumentation will provide a robust ionospheric monitoring network that will reliably diagnose the up-to-the-minute ionospheric condition and broadcast the information to the user. Just some of the user applications are discussed in Section 1.2.5.

IDEAL will complement and enhance the service provided by EGNOS. EGNOS has not been tested during solar maximum conditions. Using LOFAR to enhance EGNOS will increase the resolution and allow various TEC gradients to be measured. LOFAR will operate during solar maximum and as such, provide valuable information to the EGNOS service, which has not been tested during periods of high geomagnetic activity. The service will display the ionosphere in near real-time and/or offer a real-time alert system. Two categories of service will be offered: a free service and one that requires a subscription. The free service will provide ionospheric information updated regularly, whereas the subscription service would offer real-time ionospheric information via range of added-value products derived from LOFAR data via on-site post-processing. Fundamental to the service, would be a dynamic website with a public area for the free service. Subscription services would be accessed online via a secure portal In addition to that, an application that users could download would be available (eg iPhone app). Real-time alerts could be sent to subscribers via email and/or text message. Historic ionospheric data could also be available: allowing the end-user to input a date and time, to reveal an ionospheric map to cross-reference against GNSS-based service degradation. The precise range of free and added-value products will be determined by an End User Requirements study following project kick-off and will involve consultation with end users, GNSS experts and regulatory bodies.

During the last solar maximum - a period of increased solar activity which occurs roughly every 11 years - GNSS were not so widely used or relied upon. During such times, huge outbursts of ionising solar radiation bombard the Earth and greatly increase the TEC in the ionosphere. As the next solar maximum approaches, peaking at around 2012/2013, the world is currently (and will be) much more dependent upon GNSS for positioning/navigation and timing/synchronisation purposes. This project is very timely, as there is a great need to monitor the ionosphere and provide an early warning system in time for solar maximum conditions, which many GNSS users (and applications) may not have anticipated, nor experienced. To further compound the problem for GNSS early-adopters, most of the systems that have recently become available will have been developed and tested during the recent unusually deep solar minimum (Hathaway and Rightmire, 2010), which led directly to prolonged constant, quiescent ionospheric conditions (Lui et al, 2010; Luhr and Xiong, 2010). These systems will thus far have not been tested during active or stormy ionospheric conditions, such as can be expected during the rising phase of the 24th solar cycle.

Due to the increasing dependency of modern infrastructure on spaceborne technology like GNSS, governments are becoming increasingly aware and interested in space weather and its effects. Once launched, each Galileo satellite will need to operate at the heart of the outer radiation belt – an extremely harsh environment - for its 12+yr life expectancy The US National Academy of Sciences recently published a workshop report (NAS, 2008) studying the societal and economic impact of severe space weather events concluding with the worst-case scenario costing up to $2 trillion per year. The potential impact of a repeat of the most intense space weather storm yet recorded (the so-called Carrington event of 1859) could lead to the loss of operation of the entire MEO fleet, including GPS, Glonass and Galileo (Odenwald et al, 2006), amongst many catastrophic losses. Whilst events of this magnitude occur infrequently (every ~500 years), in 2008 ESA approved its Space Situational Awareness programme to develop a unified system to mitigate against hazards posed by space weather, space debris and NEOs. This 10-year, 700+M€ programme is currently in the Precursor phase, and the first space weather contracts have been awarded and started.

Whilst IDEAL concentrates on GNSS signals, many conclusions will be valid for a variety of problems in the broader domain of EM signal propagation and processing. In addition, the high resolution of the TEC maps will enhance the various dynamical physics-based models of the ionosphere, while improvements to the standard radio astronomy pipeline processing should be applicable to radar tracking of space debris and NEOs further mitigating risk to GNSS systems. The LOFAR network currently covers a limited geographic range while the EU and ESA's assets are more broadly spread. Negotiations for expanding the network are in progress (and are advanced in some cases) and the project will include a detailed study of the resources needed to extend to a pan-European system: development cost, manpower and other resources. It is anticipated that the eventual European network would be a combination of existing resources with some augmentations of hardware and software/systems, plus some new dedicated resources at key locations. The full functionality of a 'typical' LOFAR site is not expected to be needed at all locations to provide full coverage at high resolution so the baseline considered for each site will represent the baseline for the study.

1.2 Description of the LOFAR system

The construction of the Low Frequency Array (LOFAR) is rapidly nearing its completion. As one of the first of a new generation of radio instruments, the International LOFAR Telescope (ILT) will provide a number of unique and novel capabilities for the astronomical community. These include among others remote configuration and operation, data processing that is both distributed and parallel, dynamic real-time system response, and the ability to provide multiple simultaneous streams of data to a community whose scientific interests run the gamut from lighting in the atmospheres of distant planets to the origins of the universe itself. Due to the tremendous data rates generated, LOFAR will also be one of the first radio observatories to feature automated processing pipelines to deliver fully calibrated images rather than raw visibilities.

The LOFAR system is optimized for a frequency range from 30 MHz to 240 MHz and utilizes two types of antennas to cover this frequency span. A low-cost Low Band Antenna (LBA) is used for the lower frequencies and a High Band Antenna (HBA) tile for the higher frequencies. Sets of LBA dipoles and HBA tiles are grouped together into stations. At the station level, the individual antennae are combined digitally into a phased array. This station-level beam-forming serves as an initial reduction in the total data rate early in the processing chain, but also makes the LOFAR system agile. Although station-level beam-forming reduces the instantaneous field of view, it also allows for rapid repointing of the telescope as well as the potential for multiple simultaneous observations from a given station. These individual stations are then correlated to produce standard radio interferometric images.

In the Netherlands, a total 40 LOFAR stations are being constructed each consisting of 96 LBA dipoles and 48 HBA tiles. An additional 8 international LOFAR stations are currently under construction throughout Europe. With the addition of these longer European baselines, LOFAR has the potential to achieve unparalleled spatial resolution in the low frequency regime. The data from all LOFAR stations is sent via a high-speed fibre network infrastructure to a central processing facility located in Groningen in the north of the Netherlands. At this central processing (CEP) facility, data from all stations can is aligned, combined, and further processed using two racks of a flexible Blue Gene/P supercomputer offering about 28 TFlop of processing power. In the Blue Gene/P supercomputer, a variety of processing operations are possible including correlation for standard imaging, tied-array beam-forming for high time resolution observations, and even real-time triggering on incoming station datastreams. Combinations of these operations can also be run in parallel.

After processing in the Blue Gene/P, raw data products are written to a storage cluster for additional post-processing. The current size for this storage cluster is expected to be between 1 - 2 PByte. Once on the storage cluster, a variety of reduction pipelines are then used to further process the data into the relevant scientific data products depending on the specific type of observation. In the case of the standard imaging pipeline, subsequent processing includes flagging of the data for the presence of radio frequency interference, compression, calibration, and creation of the final images. This and other science-specific pipelines run on a dedicated compute cluster with a total processing power of approximately 10 TFLOPS. After processing, the final scientific data products are exported to the LOFAR long-term archive (LTA) for cataloguing and distribution to the community.

This default processing system has been designed to produce high quality, low frequency images of the radio sky. With a minimal amount of enhancement, this same system can be expanded to produce the IDEAL monitoring system. As part of the standard LOFAR calibration processing, the ionosphere is modeled on short timescales (~10 sec) and corrections are applied based on that model to produce radio maps. These corrections are primarily computed based on the positional deviations for a set (~100) of known, strong astronomical radio sources (see, eg, Figure 1-1). The positional deviations are monitored as a function of time and use to constrain a simple multi-layer model for the ionosphere. This model in turn is used to compute corrections to the raw data to remove the blurring effects of the turbulent ionosphere. With the current specifications, the LOFAR system expects to be able to compute and apply these corrections on timescales of ~10 secs.

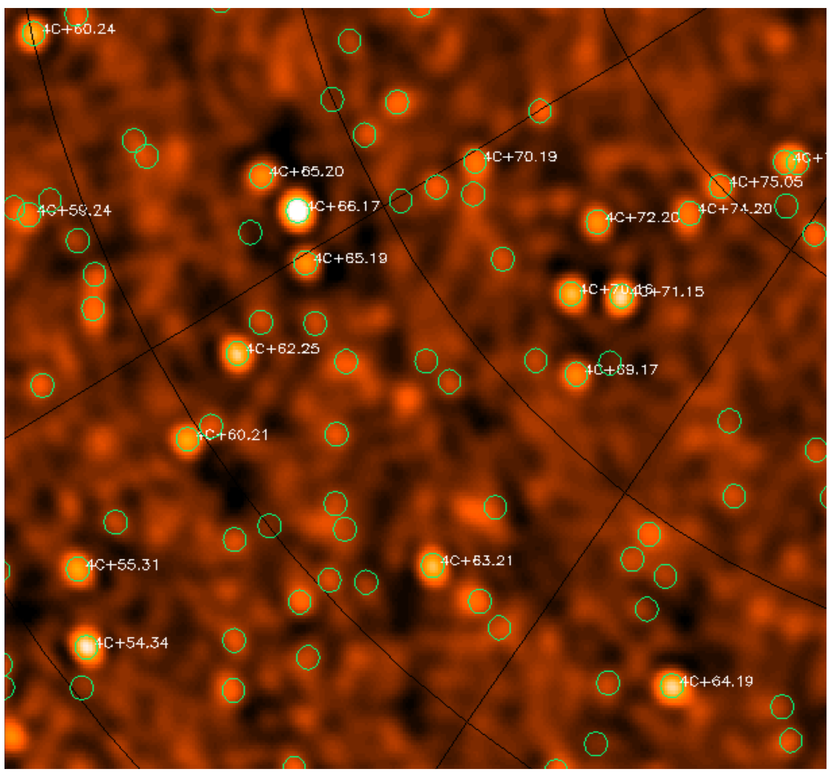

Figure 1-1: Sample LOFAR Image at 50 MHz

Figure 1-1 shows a sample LOFAR image at 50 MHz showing many of the known, strong radio sources. Deviations in the positional accuracies of these known sources are used in the LOFAR calibration pipeline to model and correct for ionosphere activity. In the IDEAL system, these same corrections can be monitored to produce an alert system for ionospheric disturbances. These same ionsopheric corrections, computed as part of the standard LOFAR imaging process, form the heart of the IDEAL alert system. The magnitude of the computed corrections as a function of time form an effective means of monitoring the level of ionosphere activity. If we separate the computation of the corrections from the feedback loop of actually applying the corrections, the system can in principle achieve even shorter response times. Finally, the resulting ionospheric model fits can be used to derive TEC maps albeit with some additional processing and a subsequent timelag in terms of delivering the products.

1.2.1 System Overview

The following diagram gives an overview of the main components of the IDEAL system, each of which is described in more detail below.

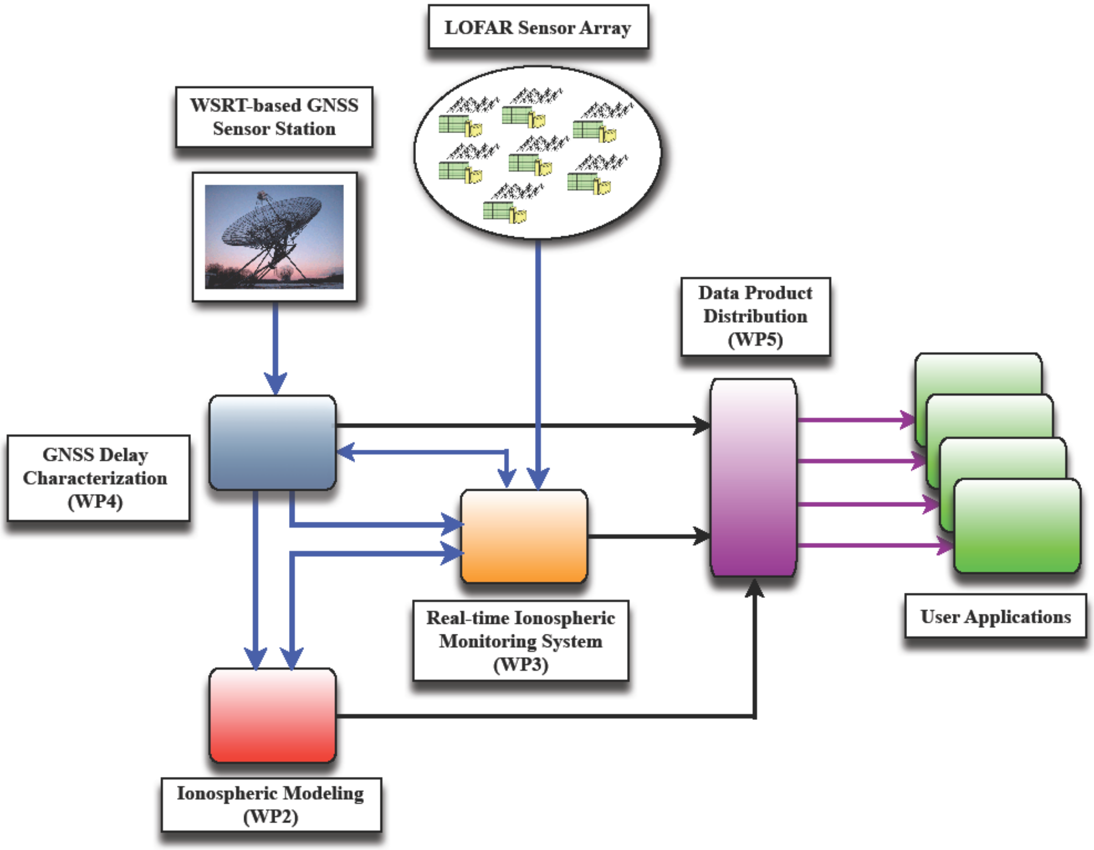

Figure 1-2: IDEAL System Overview

The LOFAR and GNSS signals will be processed in tandem and each produce TEC data independently. Analysis of these parallel datasets will be conducted (in post processing) as part of the project in order to support the characterisation of each.

1.2.2 Ionospheric Modelling

Solar storms and space weather events can seriously degrade the accuracy and integrity of radio-based systems, such as GNSS. Radiation from the Sun ionises the upper region of the Earth's atmosphere, the ionosphere. The radiation leads to free electrons and ions, which form a plasma (Bust and Mitchell 2008). The levels of ionisation are controlled by solar extreme ultraviolet radiation and particle precipitation. The electron density is the most important parameter to monitor and measure because it governs all of the effects on radio signals. The line integral of the electron density is known as the Total Electron Content (TEC) and is proportional to the ionospheric error. A snapshot of the ionosphere is shown in Figure 1-3.

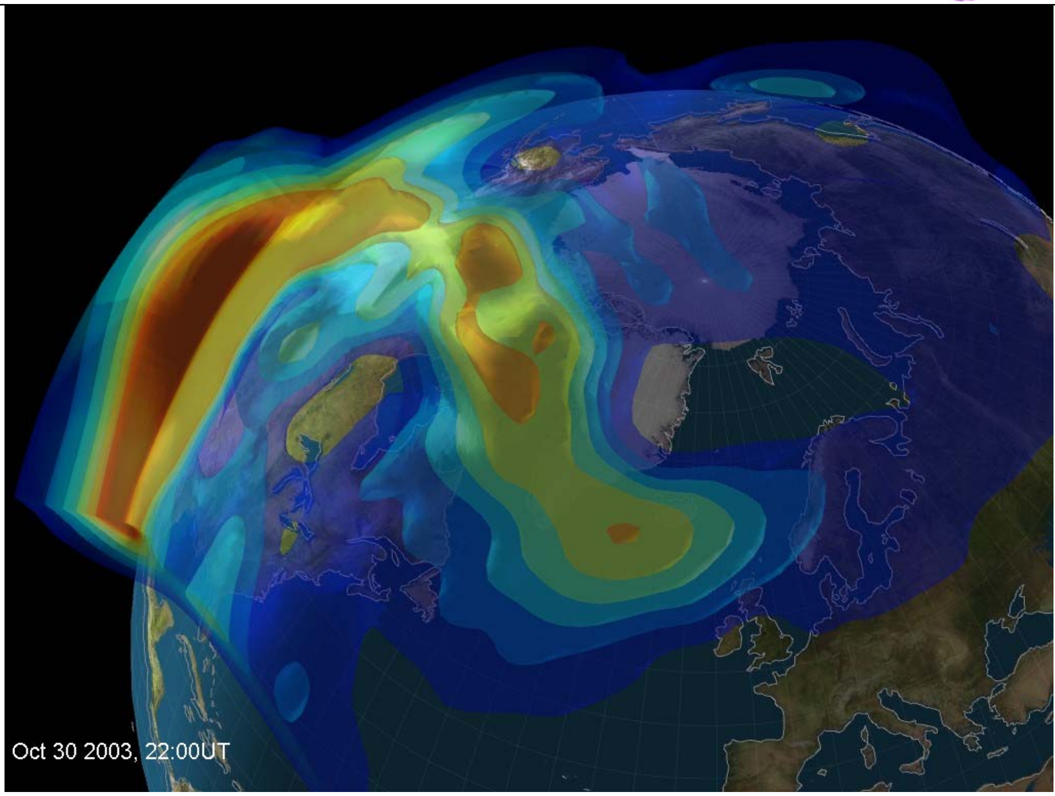

Figure 1-3: Ionospheric Map Showing 3-D TEC

The above diagram shows a snapshot of the ionosphere during an intense geomagnetic storm, following an outburst from the Sun in October 2003. The red/orange areas show regions of high TEC, where GNSS signals would be worst affected for example, whereas yellow shows areas of moderate TEC. The areas shown in blue are regions of low TEC. The ionosphere is highly variable and the level of TEC depends upon several factors: season, solar activity, latitude and time of day are just a few. Although there are models that '*predict'* the ionosphere's behaviour (e.g. Klobuchar (1987) and IRI: Bilitiza and Reinisch (2008)), they have been proven to be inaccurate during both calm and stormy ionospheric conditions (Allain and Mitchell 2009, Rose et. al 2009). In contrast, the system proposed here would use MIDAS, which is incorporates real-time data from monitoring stations and model the ionosphere in three spatial dimensions, plus time (4-D). This provides a more accurate representation of the current behaviour of the ionosphere.

An existing infrastructure already exists across Europe, consisting of hundreds of GNSS monitoring stations, constantly collecting data. The stations record dual-frequency GNSS data, which are used to help construct the 4D ionospheric maps. Signals from GNSS satellites have to penetrate the ionosphere before they can reach us here on Earth. By mapping the ionosphere in real-time, we are able to derive the expected delay, or error, that would be imposed upon GNSS signals. Quantifying this error enables it to be corrected for within the positioning or timing solutions for example.

In summary, snapshots of the TEC and its evolution in time are provided by MIDAS. This allows for the ionospheric errors to be largely removed from GNSS solutions and since the ionosphere accounts for the largest error in GNSS solutions, the result is a significantly more accurate solution. Radio frequency users may therefore apply corrections by employing these maps and gain an understanding of the plasma and its evolution in time. Ionospheric effects on radio systems are discussed by McNamara (1991). Van Dierendonck et al. (1993) discuss ionospheric monitoring and effects on GNSS signals.

1.2.3 Real-time Ionospheric Monitoring System

The illustration below shows how radio interferometers can be used to track Travelling Ionospheric Disturbances (TIDs). TIDs are variations in electron content due to ionozation fraction and this variability leads to characteristic phase delays in radio data. The coloured trace in Figure 1-3 show the phase differences between a reference radio antenna (MK2) near Manchester and other elements of the MERLIN interferometer observing the point source OQ208 at 1.4 GHz during solar maximum in 2003 (plot is from paper in preparation jointly between Oxford and Bath). The passage of a TID is clear in the 200km baseline between Manchester and Cambridge, as shown by the blue trace; the inset shows the TEC variability calculated for it. LOFAR will have similar length baselines but will be far more efficient for TID tracking by virtue of its much lower operating frequencies (where ionospheric effects are much more pronounced).

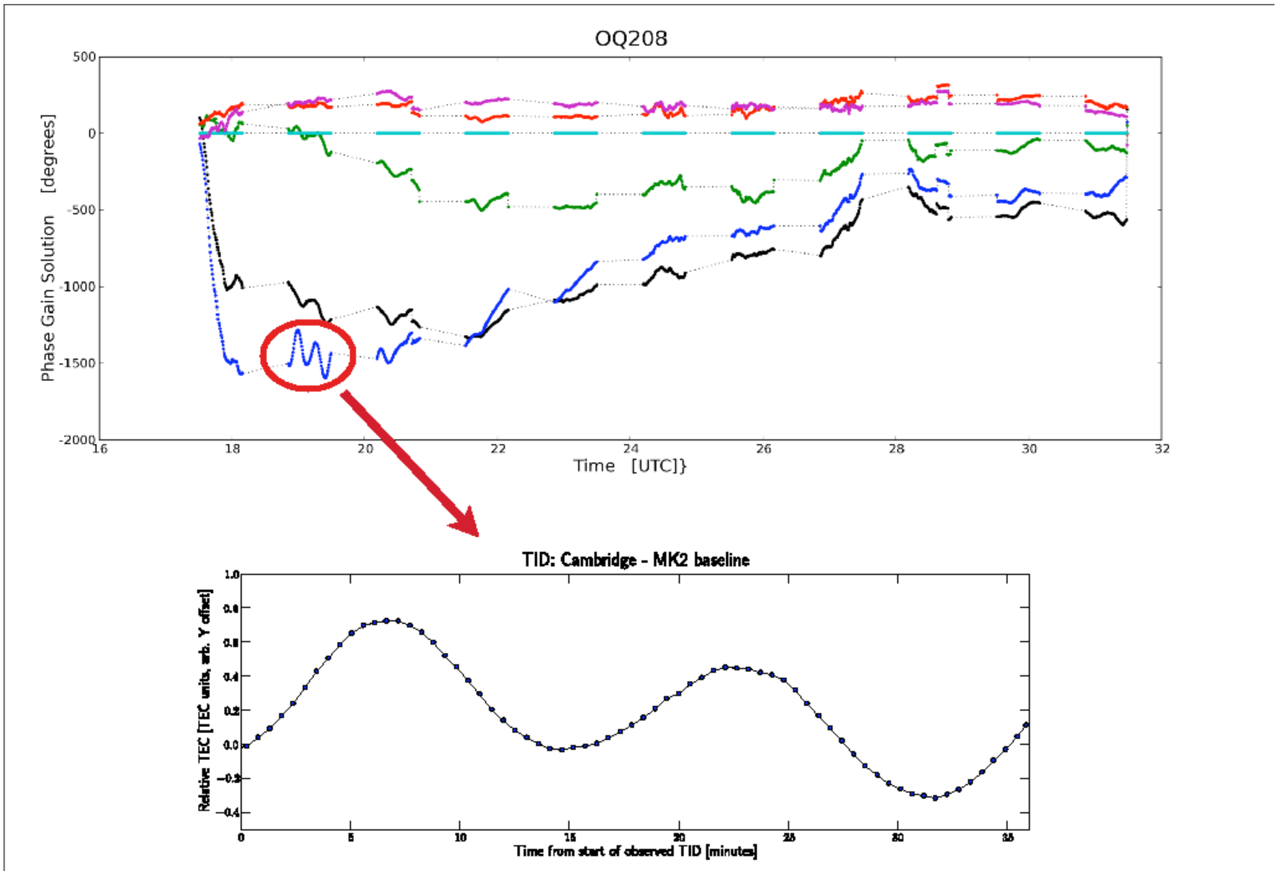

Figure 1-4: Example of a TID as Observed in Radio Data

The greater number and broader distribution of LOFAR stations plus the rapid processing of data will allow the detection of TIDs and other ionospheric disturbances on a wider range of spatial and temporal scales, and provide warning of ionospheric disturbances below the detection threshold of single-frequency GNSS-based system. In this way IDEAL will provide early warnings of disturbances on all scales, from fine to coarse, that can affect GNSS signal stability. We note that part of the baseline science pipeline processing for LOFAR is an autonomous 'flare mode' designed to detect and alert of intensity variations due to astrophysical processes such as stellar flares and novae. The Ionospheric Alerts will be developed as a complementary system sharing the same hardware and using algorithms optimised for autonomous detection of characteristic data signatures using lessons learned during the implementation of the science systems.

1.2.4 GNSS Delay Characterization

It is well known that the Total Electron Contents (TEC) of the ionosphere affects the delay of the (GNSS) signal, see, e.g., Klobuchar (1996). For example, for single frequency GNSS receivers, correction algorithms are available that take as ionosphere parameters that are transmitted in the navigation message. These parameters are computed based on an average of TEC values during the last 24 hours and measured at dedicated sensor stations. Dual frequency receivers can make use of the difference in delays as measured for the two frequencies to further correct these signals. The basic assumption underlying these methods, however, is that the bandwidth is relatively small (basically, the formulas are correct for the center frequencies). A trend in modern GNSSs is the increase in signal bandwidth (e.g. Galileo's E5 signal with a bandwidth of 51 MHz) to allow for more accurate tracking and better multipath properties.

For these wideband GNSS signals we cannot ignore the difference in delay for the lower frequencies compared to the delay for the higher frequencies, see, e.g., Gao et al (2007). One of the objectives of this study will be to further characterize the distortions on the Signal In Space due to the ionospheric delays for real observed TEC values. The accurate estimations of the electron content of the ionosphere that will be generated by the LOFAR system will be indispensible to be able to analyze the distortions for various TEC values.

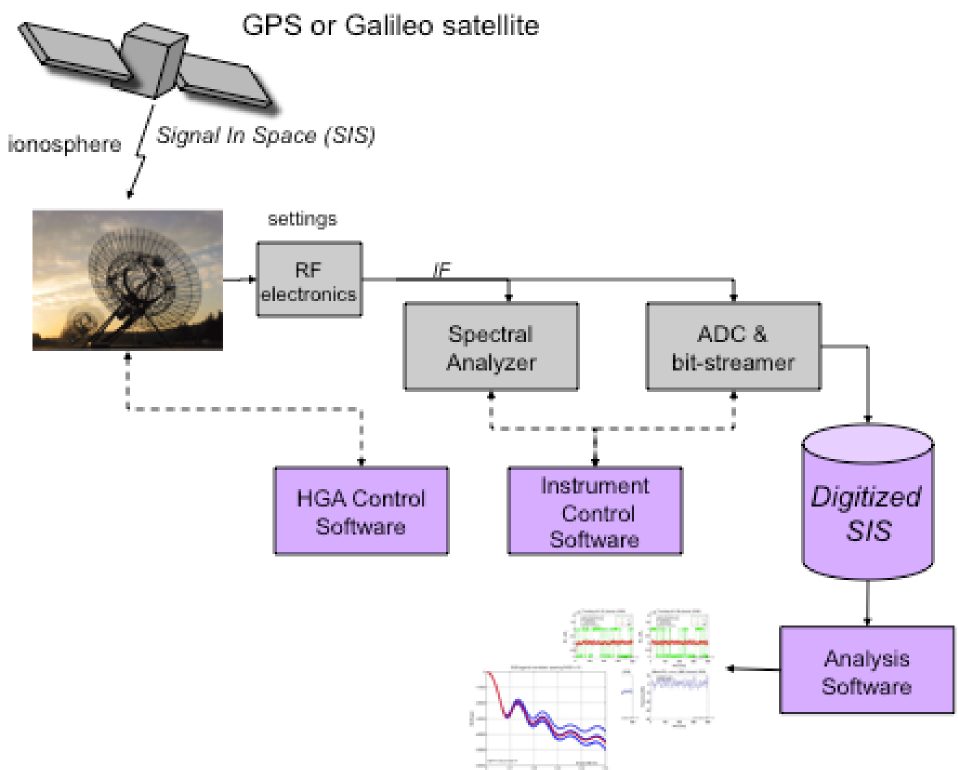

Figure 1-5: Overview of the GNSS Measurement Infrastructure

The above figure gives the basic architecture of the measurement infrastructure for the characterisation of the GNSS delay. The system will be able to track and analyze the SIS of one of the GNSS (GPS or Galileo) space vehicles. A high gain (48.8 dB) telescope antenna with a 25m dish from the WSRT facility will be used to capture the SIS. The signal will be down converted to Intermediate Frequency (IF) range. This signal will be monitored by a Spectral Analyzer (SA) for quick-look analysis, and sampled by a high-end ADC. The ADC will have a typical sample frequency of 400 Msps. The digitized signal will be stored on disk ready to be analyzed in post-processing mode. The SIS analysis software will derive the basic signal characteristics such as:

- C/N0 of the carrier signal
- Carrier phase
- Code and Carrier tracking error
- Code/Code and code/data coherency
- Pilot/data quadrature quality
- Code correlation peak
- Signal distortion using S-Curve Bias (SCB) analysis which is a model of a non-coherent code discriminator function, see Soellner et al (2008)
- Group delay of the signal
- Correlation Loss analyses

During various measurement campaigns these characteristics will be measured so that is possible to study the degree and nature of the distortions for various TEC values.

1.2.5 Data Product Distribution and Representative User Application

The data distribution and dissemination module is concerned with enabling maximum use by third parties and penetration into external systems. This is achieved by taking a multi-solution approach, including:

- Display Application that allows good visualisation of the data products.
- Web Display/Distribution of datasets {this will be made available on the project web site}.
- Web Services implementation, allowing access to the data by third party applications.
- Integration of the Data/Product/Datastreams into established Space Weather infrastructure and products, including appropriate websites, portals and databases.

GNSS has been described as the “fourth utility” after heat, electricity, and water. It is so ingrained into the daily habits of many users that the absence of satellite navigation services would be seen as an unmitigated disaster. Countless applications exist that were barely foreseen 25 years ago. Personal positioning services, from commercial “where to shop” to critical safety-of-life applications, bound the spectrum of uses. The global core GNSS projected market divided by key markets is shown in Figure 1-5 below (from GSA, 2010).

In addition to these mainstream GNSS applications, there are numerous applications that rely themselves on GNSS for *synchronisation* but which are not intuitively considered GNSS dependent, such as:

- Banking (ATM and Financial transactions): transaction synchronisation, enabling accurate time stamping (enforced by regulatory bodies)
- Mobile phone operators: for communication protocols synchronisation
- Power supply networks (national grids): for system synchronisation, and also mitigation against Geomagnetic Induced Currents (GIC’s)

and also a growing set of GNSS niche applications, such as:

- Seismology
- Surveying
- Maritime docking

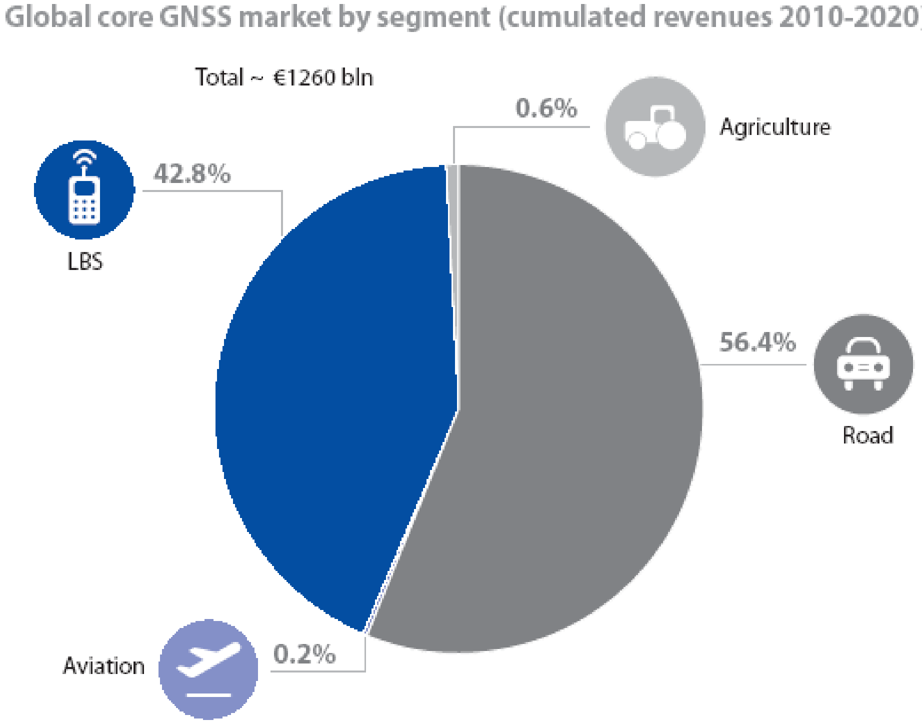

Figure 1-6: GNSS Key Markets

All the above applications have already recorded, with different level of severity, the impact of severe space weather events. For example, severe space weather events during October-November 2003 have been reported as direct causes of a 30-hour outage of the GPS Wide Area Augmentation System (WAAS). Consequently, the transition of GNSS as a utility requires easier tools to be established, that can help users understanding the impacts on their day-to-day operations. As part of this project, a prototype GNSS service performance prediction shall be implemented. The main objective is to convert the ionospheric information and forecasting into a service that presents its information for the context of each user community. We can divide GNSS users' requirements into 4 primary GNSS service characteristics:

- Position precision.
- Timing precision.
- Outage duration
- Time-to-Fix.

These above characteristics can be then classified in terms of user sensibility to their effects as follows:

- + Minor Relevance
- ++ Medium Relevance
- +++ Major Relevance

The table below presents a characterization of each user community grouped by major segments, where each segment has been further divided in separated applications, in order to evaluate each user community sensibility to each the identified GNSS service characteristics.

	Sub-Segment	Time-to-Fix	Position precision	Timing precision	Outage duration	Comment
Road	Virtual Tolling	+	++	+	+++ (not acceptable)	Outages will severely damage tolling companies to enforce users to pay. With early warnings tolling companies may deploy temporary pseudolites
	Insurance pay per mile	+	++	+	+++	Contractual clauses may me included in contracts linking GNSS service level to estimated usage.
	Car navigation	+	+	+	++	Service outage may severely impact user mobility. Alerts may be used for conditioning travel decisions
	Fleet Management/ Logistics	+	+	+	+++	Service outage may severely impact user mobility. Alerts may be used for conditioning logistics decisions
	Emergency Call	+	+++	+	+++	Outages and Position degradation may impact service operation. With early warnings civil protection institutions may deploy temporary pseudolites or take order preventive measures

	Sub-Segment	Time-to-Fix	Position precision	Timing precision	Outage duration	Comment
LBS (Location Based Services)	Personal Nav	+	++	+	++	Currently no actual service guaranty is in place , nevertheless users rely increasingly on navigation functionalities. A GNSS service Alert system may be combined with mobile phone operators to support alerts dissemination.
	Vulnerable people tracking	++	+++	+	+++	Outages and Position degradation may impact service operation. With early warning institutions may disseminate instructions to restrict vulnerable persons movements.
	Professional Services	++	+++	+	+++	Outages and Position degradation may impact service operation. With early warning more accurate logistic decisions can be taken.
	Mobile Commerce	+	++	+	++	Currently no actual service guaranty is in place , nevertheless users rely increasingly on navigation functionalities. Alert system may be combined with mobile phone operators to support alerts dissemination.
	Location-Based games	++	++	+	++	No major impact are expected for this user segment. Nevertheless Geoching and other GNSS dependent games could use alerts and service levels forecasting prior to starting competitions or even individual practitioners.
Agriculture	Precision farming	++	+++	+	+++	Outages and Position degradation may limit the tractors and other equipments mobility and may restrict some of the precision farming activities. With early GNSS service warning, activities can be rearranged according to the level of expected GNSS service

	Sub-Segment	Time-to-Fix	Position precision	Timing precision	Outage duration	Comment
Aviation	Airlines	+++	+++	+	+++	Airlines are specially concerned with the GNSS service level forecasting. The capability of global GNSS level forecasting is currently missing
	ATM	+++	+++	+	+++ (not acceptable)	Although EGNOS is currently pending the certification for ILS cat. I (currently only en-route and LNAV), the usage of GNSS in aviation will have to be complemented by local performance evaluation and alert generation. Supported by enhanced Ionospheric forecasting data , this activity can be much more efficient giving operators extra time to react
	Airport Operators	++	+++	+	+++ (not acceptable)	Airport operations are increasingly relying in GNSS technologies to improve coordination of aircraft and taxiway / runway support. Outages and Position degradation may impact Airports operations. Degradation alerts and GNSS service levels forecasting will enable better contingency planning.
Other	Banking (ATM)	+	+	+++	+++	Transactions synchronization based on GNSS can suffer due to GNSS service outages depending on their equipments "freewheel" capabilities . The capability of receiving alerts estimating the forecasted clock errors would enable the activation of contingency measures.
	Telecom Operators	+	+	+++	+++	Protocol synchronization based on GNSS can suffer due to GNSS service outages depending on their equipments "freewheel" capabilities . The capability of receiving alerts estimating the forecasted clock errors would enable the activation of contingency measures.
	Power supply Operators	+	+	+++	+++	Not only synchronization problems can affect Power Supply operators (similar to Telecom a Operators) but also the generation of Geomagnetic Induced Currents . Generation of alerts covering GICs would allow the correct contingency measures implementation

	Sub-Segment	Time-to-Fix	Position precision	Timing precision	Outage duration	Comment
Other	Seismology	+	+++	+	+++	Both outages and position degradation may lead to gnss recorded data misinterpretation .The possibility to crosscheck gnss recorded data with alerts and estimated precision data shall minimize these effects.
	Surveying	+++	+++	+	++	Since surveying is a labour intensive activity any impact on the time-to-fix or system outage may compromise the activities execution. Also position errors may not allow gathered data to be used. Alerts covering Precision, Time-to-Fix and outages shall enable better activities planning
	Maritime Docking	+	+++	+	+++	As a precision maneuver. Maritime docking activities shall increase its reliability through the planning of operations taking into consideration gnss service degradation alerts.

Figure 1-7: Projected GNSS End-user Requirements

Each type of user has its own tolerance to these parameters; for instance, industrial agriculture may be able to tolerate an increase of 10% on the time-to-fix but surveying operators would be severely disrupted by this situation. Similarly, while mobile phone operators are especially affected by any impact on the timing precision, precision agriculture won't consider it a relevant issue. On the other hand, farmers benefit greatly from position precision since it helps them optimise land use and crop yields.

In terms of alerts mechanism, every user community has its own requirement. For a farmer it may be a simple, cheap SMS, while other user communities such as precision drilling will require a much more reliable and detailed source of alerts, and will be prepared to pay accordingly.

The service shall also provide several levels of alerts:

- **Public** – providing information of the global alerts issued with a delay relatively to the other service levels
- **Free** – the user registers its location of interest and its preferred alert mechanism (email, SMS or website) and periodically (every 2 hours for instance) its location and its alerts levels are analysed and if necessary an alert is issued
- **Professional** – the periodicity of the analysis are increased and more reliable alerts mechanisms will be made available; alert thresholds etc can be tailored
- **Custom** – customer made solutions implemented so that the service can be integrated on the enterprise/institution IT systems.

The figure below shows how the inherently high level nature of the IDEAL alerts lends itself flexibly to a multitude of end-user requirements, all with individual performance requirements. The end-user requirements survey will establish to which user group the value added products are optimally targeted, while the basic alerts will be marketed to the entire GNSS dependant domain.

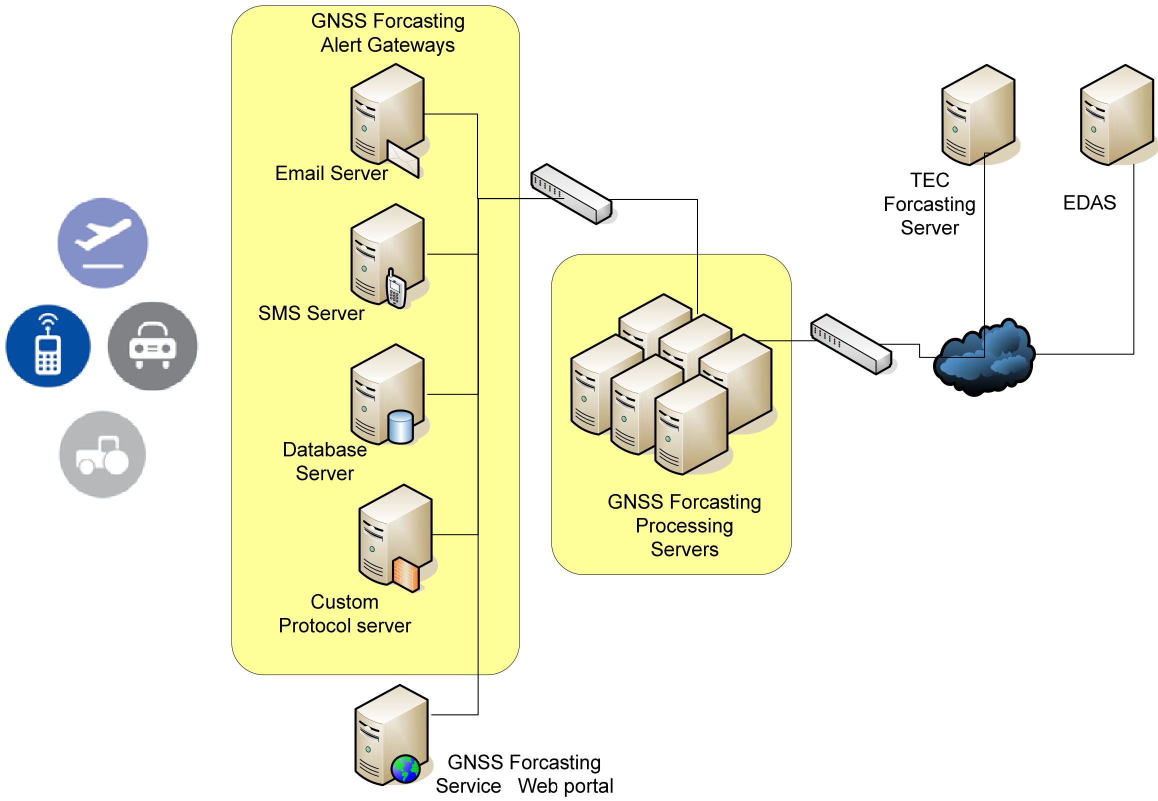

Figure 1-8: GNSS Service Performance Prediction Architecture

1.3 Progress Beyond the State-of-the-Art

The IDEAL project represents an opportunity to significantly advance the capabilities for ground-based ionospheric monitoring systems. Compared to existing systems, the IDEAL monitoring network provides a number of unique strengths that make it an excellent complement to extant facilities. First and foremost, there is no current operational system warning in real time of the onset of ionospheric disturbances which might compromise the performance of GNSS-based or dependent systems. Clearly, as society becomes increasingly dependent upon GNSS the need for such an Alerts system becomes very urgent. Furthermore, the Alerts are generated via the LOFAR system and infrastructure which is entirely independent of the GNSS system that it supports, thereby providing an invaluable reference resource for that system's performance assessment. In addition, the use of LOFAR would provide sub-grid resolution capabilities (<10 km), compared to the existing capability of EGNOS RIMS stations for example (few hundred km), and would enable more gradients and delays (due to TEC) to be measured. As a secondary benefit, the development associated with deploying a working IDEAL system will simultaneously yield a major step forward in terms of ionospheric correction techniques for radio astronomy, and conceivably onward into other domains involving transionospheric signal propagation. The ability to determine and apply accurate corrections due to ionospheric effects in near real-time will be crucial for many of LOFAR's science applications as well as the demands of such next-generation radio instruments as the SKA.

1.3.1 International State-of-the-Art

The EGNOS system, developed in partnership with ESA, the European Commission and Eurocontrol, represents in many ways the state-of-the-art in ionospheric monitoring capabilities. This system provides the ability to use navigational signals from GPS and GLONASS satellites for safety critical applications. It provides a routine positional accuracy of less than 2 meters, informs users of the errors in the position measurements, and warns of satellite signal disruptions with a latency of six seconds.

EGNOS utilizes three geostationary satellites and a network of ground stations to achieve this functionality. As with traditional GPS satellites, the EGNOS satellites deliver a ranging signal but also encode integrity data by a modulation of this signal. The integrity data allows users to determine whether the incoming positional information is sufficiently accurate for their purposes. Unlike traditional GPS satellites, the three EGNOS satellites, located over the eastern part of the Atlantic, the Indian Ocean, and Africa, receive an uplink signal from a network of ground stations. This signal is received, modulated to encode the integrity data, and transmitted back to the ground. All signal processing for the EGNOS system is accomplished at the ground stations and distributed using a private, purpose-built communications network.

As has already been stated, EGNOS does not yet have a fully developed and validated system for identifying ionospheric disturbances and alerting users of the fact. Indeed, the testing of EGNOS may be inherently compromised since research indicates that static models like the IRI have routinely over-estimated TEC levels during the recent deep minimum (Luhr and Xiong, 2010). Furthermore, it is not clear what the delay time will be between the EGNOS system being compromised by ionospheric disturbances and the system itself reacting to this, will be. This is in large part due to the almost total absence of ionospheric activity during the recent deep solar minimum, which coincided with EGNOS implementation and testing. Since EGNOS is due to be verified and accepted for Safety-of-Life use imminently, the case for a rapid, flexible and independent early-warning system is very strong.

1.3.2 Technical Limitations of Existing Products, Processes and/or Service

A comparison of the major, existing methods for ionospheric measurements is provided in Table 1-1, (from Gaussiran, Bust, and Garner, 2004). The "Time" column indicates the overall temporal coverage while "Cadence" gives the typical measurement rate. The "field of view" gives the approximate horizontal extent of instrumental coverage while the last column refers to the spatial distribution and density of the measurement data. Thus, "Global" systems, such as GPS, are those whose coverage is dense enough to allow overlapping fields of view. Similarly in situ satellite measurements are considered global since typical satellite orbits cross all lines of longitude eventually albeit at widely separate temporal spacings. The measurement types include:

a) **GPS** - dual frequency beacons from the GPS satellites measured by either ground-based or space-based GPS receivers.
b) **CIT** - Computerized Ionospheric Tomography where measurements are processed to produce 2D electron density map.
c) **Beacon** – TEC measurements made using dual frequency radio beacons aboard Low Earth Orbiting satellites.
d) **Sounder** - ground based radio transmitters which sweep a frequency band typically from 1 to 20 MHz.
e) **In situ** - measurements of the electron density at a specific point in space made by onboard spacecraft instruments.
f) **ISR** – an Incoherent Scatter Radar (ISR) system measures various ionospheric parameters from the backscattered power along the beam path.

Table 1-1: Comparison of Various Methods and Capabilities for Measuring the Ionosphere

Type	Time	Cadence	Field of view	Spatial resolution	Coverage
GPS	Continuous	30 s	100 km	100 km	Global

Type	Time	Cadence	Field of view	Spatial resolution	Coverage
CIT	Intermittent	20 min	1000 km	10 km	Regional
Beacon	Intermittent	1 ms	1000 km	Integrated point	Regional
Sounder	Continuous	15 min	100 km	100 km horiz. (1 km vert.)	Local
In situ	Continuous	4 s	Point	Point	Global
ISR	Intermittent	1 s	1000 km	10 m	Regional
IDEAL	Continuous	1-10 s	1000 km	2–100 m	Regional

The equivalent, expected performance characteristics of the LOFAR-based IDEAL system are also included in Table 1-2. As this comparison shows, no single source of ionospheric measurement data, including the proposed IDEAL system, provides the perfect combination temporal resolution, spatial resolution, and wide-field continuous coverage. In this sense, the IDEAL monitoring network provides an excellent complement to these existing methods, and its performance both against and alongside various methods will be benchmarked during the project.

1.3.3 Main Innovation

As with all the techniques presented in the previous section, the proposed IDEAL system will have limitations. It does however have a number of unique and unprecedented capabilities as an ionospheric probe. We detail some of these capabilities here.

Performance

The IDEAL system is designed to utilize the existing LOFAR infrastructure for ionospheric measurements, with the regional, national and European distribution of stations as shown below:

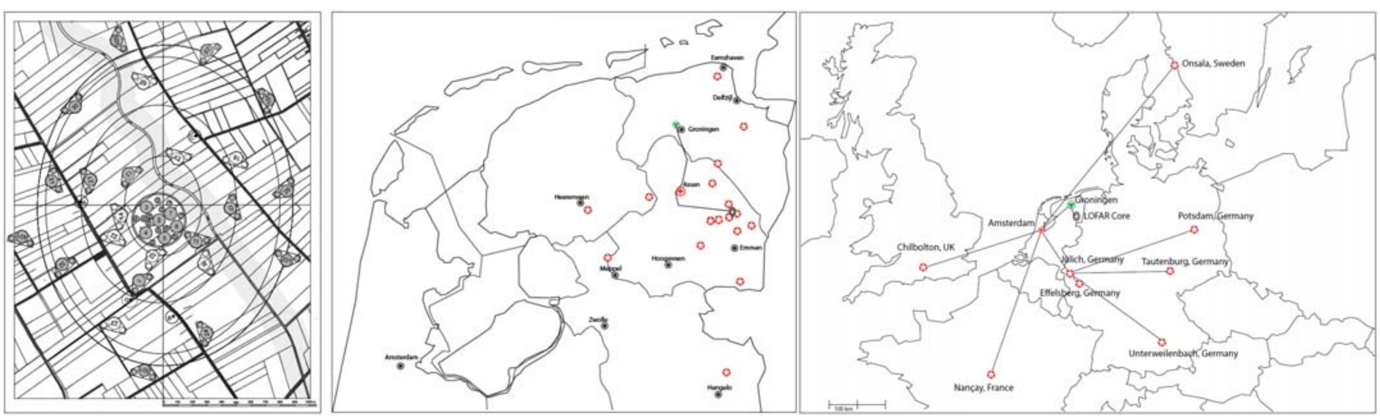

Figure 1-9: Geographical Distribution of LOFAR Stations

This infrastructure includes:

- observational baselines from 400-1000 km
- adaptive calibration giving continuous ionospheric measurements with a data cadence in seconds
- broad-brand frequency coverage from 10-90 MHz and 110-240 MHz
- a distributed network of ground stations that is dense in the core and extends over Europe
- a site well-suited for observing the equatorial ionosphere

- multiple, digitally-steered beams from each ground station

These aspects of the LOFAR system translate into the ability to perform ionospheric measurements with typical characteristics listed in Table 1-2.

Table 1-2: Ionospheric Measurement Capabilities of LOFAR Infrastructure

Characteristic	**LOFAR**
Horizontal resolution	2 m
Vertical resolution	2 m
Temporal resolution	1 s
Map cadence	10 s
Relative accuracy	<0.001 TECU

The high spatial resolution of the resulting TEC maps reflected in Table 1-2 is in particular one of the strengths of the proposed IDEAL system. Two-dimensional TEC maps with these resolutions will be produced by the system by default. With additional processing, a fully 3D analysis of the ionospheric conditions over the array can be constructed using a tomographic reconstruction such as employed by MIDAS. Such 3D analyses take advantage of LOFAR's unique ability to create multiple, independently steerable pencil beams from each station. Beams from multiple stations can be oriented to view the same area of the ionosphere from different angles thus providing the necessary inputs to tomographic analysis.

Robustness

The IDEAL system has a number of built-in aspects that make the resulting datastreams robust to interruption. The LOFAR adaptive ionospheric calibration algorithm is based on measurements of the positions of known, bright astronomical radio sources. Therefore, although LOFAR can detect existing GPS signals (using the HBA antennas that cover the 120-240 MHz frequency range), it is not dependent upon them. Among other advantages, this means that the IDEAL system can continue to record and provide updates on ionospheric conditions even during strong storm events where traditional GPS receivers may lose their tracking lock.

In addition, the distributed nature of the LOFAR network make the system fault tolerant to the failure of one or even several of the ground stations. With 36 stations densely arrayed in the core and a minimum of 8 international stations deployed across northern Europe, the IDEAL system can adjust to drop-outs from multiple stations with little or no loss in the quality of the outgoing datastreams.

Redundancy

Given the highly accurate and detailed characterisation of the ionosphere by the LOFAR calibration function, we will have a much better detailed description of the ionosphere. Simultaneously, we also perform high accuracy GNSS measurements where we concentrate on the signal deformation (e.g. deformation in the receiver function --or also known as the S-Curve, and Code / Carrier and Code Data Coherency) over the whole band of the signal. Consequently, we can obtain better insight into how the ionosphere actually deforms the (wideband) GNSS signal in space, and how this deformation is reflected in its observable characteristics.

This kind of analysis will be unique. Never before have we had the opportunity to set up a measurement campaign where we have: (i) an instantaneous characterisation of the TEC of the ionosphere; and (ii) this characterisation directly linked (in post-processing mode) to a highly accurate GNSS SIS analysis.

1.4 S/T Methodology and Associated Work Plan

1.4.1 Overall Strategy of the Work Plan

This project is very much focussed on the design and development of a working operational system. We are supported by academia in the selection of relevant existing research and its application to this project's innovative approach.

This project will be conducted in accordance with the relevant standards of ECSS http://www.ecss.nl/, in particular:

- ECSS-Q-80 Software Product Assurance
- ECSS-E-40 Software Engineering

These standards are wholly relevant to this kind of project. Although oriented towards software it does allow for the type of systems engineering that will be relevant here. The ECSS standards are long established for Space Developments such as these. One of the early tasks for the project manager will be to prepare a project specific tailoring of the E-40 standards, and a project Quality Plan, to account for the specific nature of this project.

As such, it is entirely appropriate for the project manager/coordinator to have a strong background in the development and deployment of Space Ground Systems. RHEA's experience in management of Space Development projects under the ECSS standards is extensive.

The project Work Package Descriptions have been formulated 'top down' by functional area, allowing for clear allocation of roles for the different organisations within the team. We then propose to 'overlay' a structure of sub-work packages that correspond to the logical phases of the project in accordance with the ECSS project lifecycle. Level 1 work packages are assigned to main project partners (RHEA, ASTRON, S&T, OXFORD) who are individually responsible for the Level 2 work packages below.

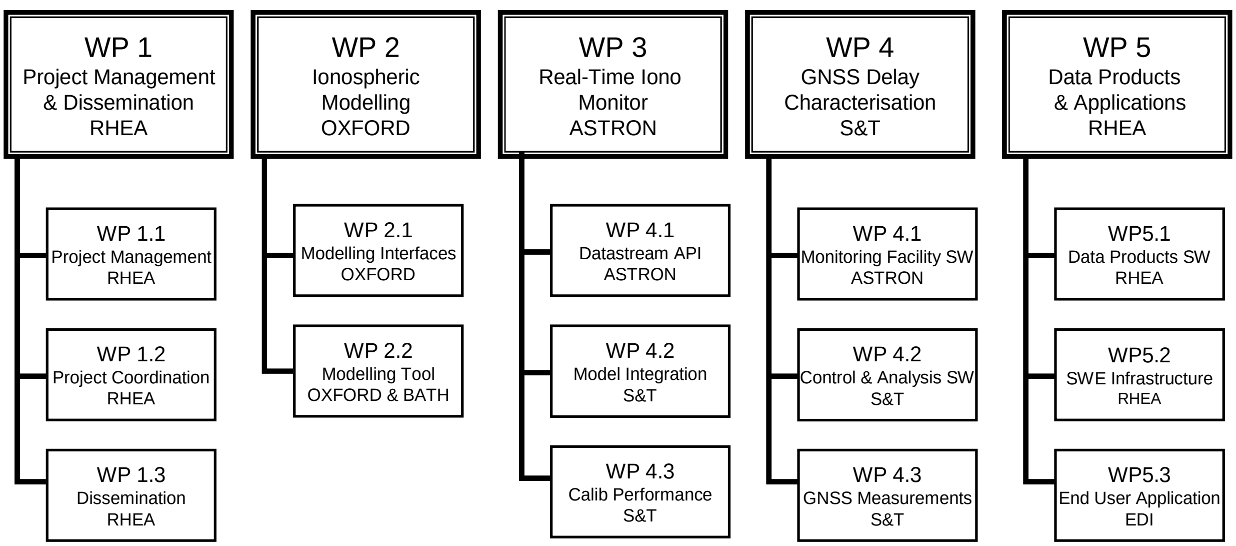

Figure 1-10: Project Work Package Structure

1.4.2 Planning

ID	WBS	Task Name	Duration	Start	Finish
1	M0	M0 Kick-Off	0 days	Mon 5/2/11	Mon 5/2/11
2	PD	RQ & PRELIMINARY DESIGN	4 mons	Mon 5/2/11	Fri 8/19/11
3	M1	M1 PDR Preliminary Design Review	0 days	Fri 9/2/11	Fri 9/2/11
4	4	DETAILED DESIGN AND IMPLEMENTATION	9 mons	Fri 9/2/11	Thu 5/10/12
5	M2	M2 CDR Critical Design Review	0 days	Fri 5/11/12	Fri 5/11/12
6	6	INTEGRATION AND TESTING	9.5 mons	Mon 5/14/12	Fri 2/1/13
7	M3	M3 QR Qualification Review	0 days	Mon 2/4/13	Mon 2/4/13
8	8	DEPLOYMENT AND TRIALS	62 days	Mon 2/4/13	Tue 4/30/13
9	M4	M4 AR Acceptance / Final Presentation	0 days	Tue 4/30/13	Tue 4/30/13
10	**WP 1**	**IDEAL Project Management & Dissemination**	**520 days**	**Mon 5/2/11**	**Fri 4/26/13**
11	WP 1.1	Project Management	26 mons	Mon 5/2/11	Fri 4/26/13
12	WP1.2	Project Coordination	26 mons	Mon 5/2/11	Fri 4/26/13
13	WP1.3	Project Dissemination	13.55 mons	Mon 5/2/11	Fri 4/26/13
14	**WP2**	**Ionospheric Modelling**	**269 days**	**Mon 5/2/11**	**Thu 5/10/12**
15	WP2.1	Ionospheric Modelling Software Interfaces	4.15 mons	Mon 5/2/11	Fri 9/23/11
16	WP2.2	Ionospheric Modelling Software Tool	9.95 mons	Mon 5/2/11	Thu 5/10/12
17	**WP3**	**Real-Time Ionospheric Monitor**	**370 days**	**Mon 5/2/11**	**Fri 9/28/12**
18	WP3.1	Datastream API	9.15 mons	Mon 5/2/11	Wed 5/23/12
19	WP3.2	Enhanced Ionospheric Model Integration	11.75 mons	Mon 8/8/11	Fri 6/29/12
20	WP3.3	Calibration Performance Enhancement	3 mons	Mon 7/9/12	Fri 9/28/12
21	**WP4**	**GNSS Delay Characterisation**	**470 days**	**Mon 5/2/11**	**Fri 2/15/13**
22	WP4.1	Monitoring ionospheric delays using GNSS	12 mons	Mon 5/2/11	Wed 5/2/12
23	WP4.2	GNSS analysis and control SW development	14.25 mons	Mon 5/2/11	Fri 2/15/13
24	WP4.3	Conducting GNSS measurements	3 mons	Mon 5/14/12	Fri 8/3/12
25	**WP5**	**Data, Products and User Requirements**	**503 days?**	**Mon 5/2/11**	**Wed 4/3/13**
26	WP5.1	Data and Data Products	13.25 mons	Mon 5/2/11	Fri 12/7/12
27	WP5.2	Space Weather Infrastructure	4 mons?	Mon 5/2/11	Tue 12/4/12
28	WP5.3	Prototype End User GNSS Application	180 days?	Mon 5/2/11	Wed 4/3/13

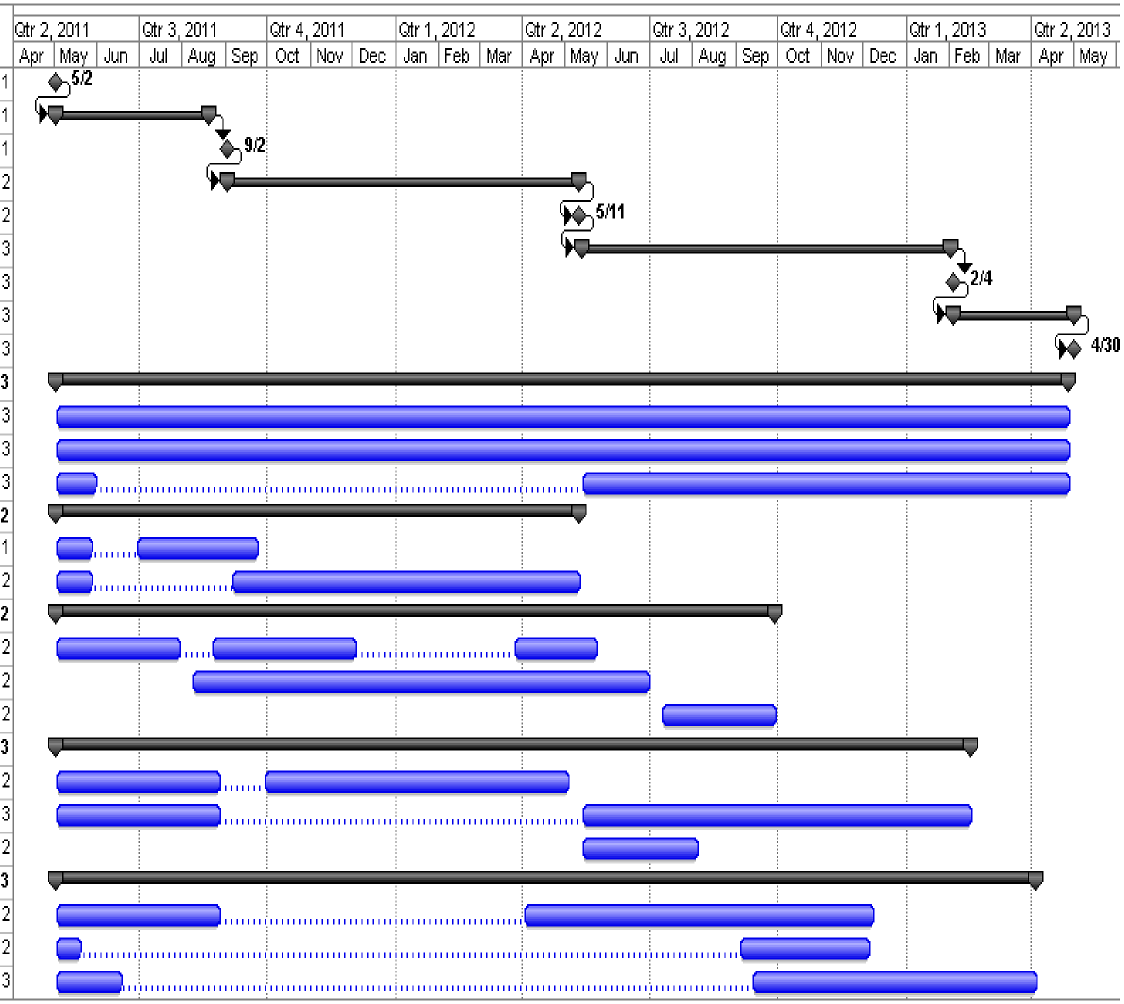

Figure 1-11: Project Gantt Chart

1.4.2.1 Risk Planning

As stated in the introduction, the project utilises resources that are already in place and fully operational to the greatest possible extent. No new hardware is anticipated as either a requirement or a deliverable. Also, many of the systems and software that the project will derive are expected to be modifications and refinements of existing systems – for example, the pipeline processing of the deep-space radio astronomy observations from LOFAR, the ionospheric data assimilation model used to compile TEC maps, and the GNSS correction methodology. All three are fully operational systems and need primarily only to be modified to process a new and alternative datastream. The consortium has been assembled to ensure that the necessary expertise is in place to perform these various modifications:

- ASTRON is the project management team for LOFAR and so knows the datastream and processing pipeline in minute detail
- the Oxford University group is pre-eminent in the area of characterising signal vs. noise issues in radio astronomy data
- the Bath University group are noted for world-class research in ionospheric modelling particularly utilising diverse data sources via the MIDAS project
- both university teams already collaborate on a variety of problems relating to ionospheric effects on signal propagation
- S&T is a current subcontractor for both LOFAR and Galileo with expertise in real-time processing of large datastreams
- RHEA is a current subcontractor for both Galileo and ESA and has contracts with ESA for the large-scale distribution and dissemination of data, and the promotion of space weather products

The Risk Management approach applied on the IDEAL project will have the following characteristics:

- The methodology to assess the risk will be based on the ECSS, which includes a section on Risk Management (ECSS-M-ST-80C).
- There will be a clear identification of roles and responsibilities within the consortium with regards to risk.
- Risk Management is an iterative task in any project. Risk has to be assessed and reassessed as the project progresses. The risk will be reassessed prior to each milestone of the project.
- Four categories of risks have been classified as Scope, Quality, Cost, and Schedule, depending on what aspect of the project they impact.
- It is difficult to make a precise estimation of a probability of risks. At this stage only a very general estimation can be done. Therefore, the probabilities are estimated as low, medium or high but they could be further refined when the reassessments start taking place.
- Risks will be closely tracked during the project.

The Table 1-3 shows the high level assessment that has been conducted during the definition of the project. This is by no means a definitive Risk Matrix, as it will evolve during the End User Requirements survey. However it shows the main risks that can be identified at this stage. After this assessment, we are confident that all project goals are achievable and that the consortium is optimally assembled to do so.

:

Table 1-3: Potential Risks and Mitigations

Major Issue/Risk Identification	Risk Category	Impact	Assessment			Issue/Risk Mitigation
			Impact	Prob	Result	
Cost/Schedule Overruns	Scope Quality Cost Schedule	These types of tasks are high risk for both contractors and the Client but can yield the highest returns when managed appropriately. The impact of inadequate management and controls could have an adverse impact on any risk categories.	High	Med	High	▪ RHEA will assign a qualified and trained Manager to monitor and maintain this risk element. ▪ The RHEA Project Manager (PM) has the full support of, and reports to, the RHEA Executive Management to hasten issues internal to RHEA. ▪ RHEA's client-centric delivery model will provide a means of early identification of potential risk items related to project activities. ▪ The RHEA PM has a technical, environmental and project management background to quickly and regularly assess the progress of tasks. ▪ The RHEA PM's technical background will aid in ensuring appropriate scope definition. ▪ RHEA's Quality Management Plan will ensure rigorous and continuous monitoring of tasks and projects. ▪ RHEA will utilize its Human Resource (HR) Management Plan to the fullest extent possible to ensure highest calibre personnel are obtained and appropriately compensated and motivated. ▪ The application of established processes and procedures from RHEA's Quality Management Plan is applied to minimize project risk.
The critical path of the project lasts for almost 24 months.	Schedule	If the project has a slight delay, it could last more than the duration limit of 24 months established in the section II.4 of the "Description of topic GALILEO – 2011.1.3-1" document	High	Low	Med	▪ The project plan could be rearranged to last a shorter period. ▪ The allocation of resources would be revised so some tasks of the critical path can be executed on shorter delays. ▪ This could be addressed during the negotiation of the contract.

Major Issue/Risk Identification	Risk Category	Impact	Assessment			Issue/Risk Mitigation
			Impact	Prob	Result	
The models used to validate EGNOS appear to misrepresent the ionosphere during extremely quiet period of solar activity	Quality	The models and information system resulting from IDEAL could inherit these calibration issues	Low	Med	Med	▪ We propose to use dynamic modelling rather than static modelling. ▪ This risk pertains to the EGNOS system itself and not to IDEAL
Delays on the scientific commissioning of LOFAR hardware and software	Schedule	A fully operational LOFAR system is necessary for the IDEAL developments	High	Low	Med	▪ The schedule has some slack that can be used to wait for eventual delays on LOFAR. ▪ If LOFAR is not fully operational, there's data already available that could be used for testing at the beginning of the IDEAL developments.

1.4.3 Work Packages

Table 1-4: Work Package List

Work package No	Work package title	Type of activity	Lead participant No	Lead participant short name	Person-months	Start month	End month
1	Project management and Dissemination Activities	MGT	1	RHEA		1	24
2	Ionospheric modelling	RTD	4	OXFORD		1	24
3	Real-time iono-monitor	RTD	2	ASTRON		1	24
4	GNSS delay characterisation	RTD	3	S&T		1	24
5	Data and data products	Other	1	RHEA		1	24

1.4.4 Deliverables

Table 1-5: Deliverables List

Del. no.	Deliverable name	WP no.	Nature	Dissemination level	Delivery date
D1.1	Minutes of the milestone meetings	1	MGT	Public	Every milestone
D1.2	Website requirements document	1	MGT	Public	T0+2
D1.3	Project website prototype	1	Other	Internal	PDR
D1.4	Project intranet prototype	1	Other	Internal	PDR
D1.5	Operational project website	1	Other	Public	CDR
D1.6	Operational project intranet	1	Other	Internal	CDR
D1.7	Annual project report	1	MGT	Public	T0+12m
D1.8	Interim financial report	1	MGT	Public	T0+12m
D1.9	Quarterly progress reports	1	MGT	Internal	Every 3 months after T0
D1.12	Detailed Project Plan	1	MGT	Internal	T0+1m
D1.13	Business Model & Plan (including commercial feasibility study, potential market assessment, and economic aspects)	1	MGT	Internal	AR
D1.15	Dissemination plan	1	MGT	Public	CDR
D2.1	Automated LOFAR DPS	2	RTD	Internal	CDR
D2.2	Automated ionosonde algorithms	2	RTD	Internal	CDR
D2.3	MIDAS TEC map output system	2	RTD	Public	CDR
D2.4	TEC map validation report	2	RTD	Public	QR
D3.1	Data API definition ICD	3	RTD	Internal	PDR
D3.2	Alert format ICD	3	RTD	Internal	PDR
D3.3	API implementation SW	3	RTD	Internal	CDR
D3.4	LOFAR calibration BBS SW	3	RTD	Internal	CDR
D3.5	Performance tests reports	3	RTD	Public	QR
D4.1	Upgraded WSRT analysis SW	4	RTD	Internal	CDR
D4.2	SIS control SW	4	RTD	Internal	CDR
D4.3	SIS analysis SW	4	RTD	Internal	CDR

Del. no.	Deliverable name	WP no.	Nature	Dissemination level	Delivery date
D4.4	GNSS characterisation measurement validation	4	RTD	Public	QR
D4.5a	Prototype operational IDEAL system	4	RTD	Internal	QR
D4.5b	Validated operational IDEAL system	4	RTD	Public	AR
D5.1	Data product user requirement study report	5	RTD	Public	PDR
D5.2	SWE Infrastructure ICD	5	RTD	Public	PDR
D5.3	General End-User survey report	5	RTD	Public	PDR
D5.4	IDEAL system expansion study report	5	RTD	Public	AR
D5.5	GEA requirements document	5	RTD	Public	PDR
D5.6	GEA prototype MMI mockup	5	RTD	Internal	PDR
D5.7	GEA test scenario plan	5	RTD	Public	CDR
D5.8	GEA prototype architecture design	5	RTD	Internal	PDR
D5.9	GEA prototype SW	5	RTD	Internal	QR
D5.10	GEA validation report (includes technical and user-experience from the target users)	5	RTD	Public	AR
D5.11	Technical feasibility assessment	5	RTD	Internal	PQR
D1.10	Final project report	1	MGT	Public	AR
D1.11	Final financial report	1	MGT	Public	AR
D1.14	Dissemination material (including presentation, posters, etc.)	1	MGT	Public	AR

The "Description of topic GALILEO – 2011.1.3-1" document for the Area 7.4.1.3 "Scientific Applications" gives in its section II.3 a minimal list deliverables for the call. The fulfilment of these deliverables by the proposed deliverables in Table 1-5 can be seen in the fulfilment matrix shown in Table 1-6.

Table 1-6: Deliverables Fulfilment Matrix

Section II.3 of the Description of topic		Table 1-5 Deliverables	
Nr.	**Description**	**Del No.**	**Del. Name**
1	Detailed project plan	D1.12	Detailed Project Plan
2	Quarterly progress reports	D1.9	Quarterly progress reports
3	Meeting minutes of all reviews	D1.1	Minutes of the milestone meetings
4	Technical feasibility study	D5.11	Technical feasibility assessment
5	Commercial feasibility study	D1.13	Business Model & Plan
6	Dissemination plan	D1.15	Dissemination plan
7	Presentation/slide show, report, poster and animated audiovisual presentation on project outcomes	D1.14	Dissemination material (including presentation, posters, etc.)
8	Report on market trial	D5.10	GEA validation report
9	Rough business and exploitation plan	D1.13	Business Model & Plan
10	Analysis of specific aspects	D1.13	Business Model & Plan
11	Final report	D1.10	Final project report
12	Source code and related documentation of main developments	D5.5	GEA requirements document
		D5.6	GEA prototype MMI mockup
		D5.7	GEA test scenario plan
		D5.8	GEA prototype architecture design
		D5.9	GEA prototype SW

1.4.5 Milestones

Table 1-7: List of Milestones

Milestone number	Milestone name	Work package(s) involved	Expected date	Means of verification
0	KO: Kick-Off		T0	
1	PDR: Preliminary Design Review	Requirements Definition and Preliminary design under each formal WP	T0+4m	Formal Review according to ECSS
	DDKP: Detailed Design Key Point will be added if required	DDKP will be inserted if necessary at a suitable time in the DD phase	As required, to be announced	
2	CDR: Critical Design Review	Detailed Design and Implementation under each formal WP	T0+12m	Formal Review according to ECSS
3	QR: Qualification Review	Validation and Verification under each formal WP	T0+20m	Formal Review according to ECSS
4	AR: Acceptance Review / Final Presentation		T0+24m	EC

T0 is the date of the Kick-Off which is anticipated to take place after mid April 2011.

1.4.6 Work Package Descriptions

Table 1-8: Work Package 1 Summary

Work package number	WP1	**Start date or starting event:**				T0: Kickoff
Work package title	Project Management and Dissemination					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:	11					

Objectives
The objective of WP1 is the overall Management and Co-Ordination of the IDEAL project, including dissemination of all data, data products, key results, and reports. RHEA will apply a rigorous project management approach, with well-defined processes and procedures providing the infrastructure necessary to ensure organized and effective project delivery. They will commit to provide the EC with continuing insight into the conduct and progress of work carried out under terms of a contract. Overall, this will ensure the approach establishes project control while at the same time maintaining flexibility.
Description of work (possibly broken down into tasks), and role of participants
Project Manager (PM) is responsible for task monitoring, cost and schedule control, as well as for the presentation of status to both RHEA and the EC and is responsible to manage the delivery of these services in accordance with the contract, our documented procedures and industry-standard best practices. The Project Manager will: • Coordinate the overall legal, contractual, financial and administrative management;

- Have total responsibility for the team agreement and manage the share of work between the team members;
- Ensure quality parameters of the activities and initiatives conducted within the project;
- Guarantee the adequate progress of the project outputs, ensuring timely deliveries and achieving milestones; and
- Represent the Team vis-à-vis the EC.

Constant monitoring and diligent management will be required by the PM to ensure that the project schedule is maintained and that potential issues are identified and addressed before they become a problem. The PM is responsible to review the results produced by various team members to ensure document quality/content targets are achieved. RHEA senior management will support the PM by ensuring that all resources necessary for completion of the work are available for ensuring client satisfaction, and for monitoring costs

The project co-ordination role provides overall support to the PM in the general internal management and conduct of the project, namely:

- Contract Monitoring: time reporting of the work performed against the task using electronic timesheets
- Cost, Quality and Schedule Control: cost analysis against budgets, schedules and expenditures
- Reporting: monthly progress reporting to RHEA senior management and EC with respect to schedule, performance, financial, and any other issues relevant to task completion
- Project Documentation Production and Control: report production support, file and document list maintenance, meeting minutes and action item lists, risk register, etc.
- Meetings: setting up of regular meetings and preparation of meeting materials and minutes
- Interface: co-ordinates the PM interfaces with the EC and consortium members

WP1 is divided into three activities:

- WP1-1: Project Management
- WP1-2: Project Co-ordination
- WP1-3: Dissemination Activities

Table 1-9: Work Package 1-1: Project Management

Work package number	WP1-1	**Start date or starting event:**				T0: Kickoff
Work package title	Project Management					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:	4.8					

Objectives
Overall management of the IDEAL project
Description of work (possibly broken down into tasks), and role of participants
The project management ensures the success of the project and consists of ensuring the overall administrative, financial and communication requirements of the EC are met. The WP features the following tasks: • Steer the project ensuring its progress in administration and scientific-technical co-ordination; • Address, manage and problem solving issues; • Ensure exchange of information among partners and to organize meetings; • Meet deadlines for each WP and to guarantee deliverables;

- Assess progress and the quality of results and prepare progress reports for EC;
- Manage liaisons with on-going projects; and
- Provide the overall legal, contractual, financial and administrative management (including obtaining audit certificates and maintaining the consortium agreement).

Deliverables (brief description and month of delivery)

-
- D1.7 Annual project report, including Form Cs (T0+12)
- D1.8 Interim financial report (T0+12)
- D1.10 Final project report, including CFS Audits (T0+24) and results of the Acceptance phase
- D1.11 Final financial report (AR)
- D1.12 Detailed Project Plan (T0+1m)

Table 1-10: Work Package 1-2: Project Co-ordination

Work package number	WP1-2	**Start date or starting event:**				T0: Kickoff
Work package title	Project Coordination					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:	4					

Objectives

General co-ordination of the IDEAL project

Description of work (possibly broken down into tasks), and role of participants

The co-ordination role is associated with internal management of the project and the co-ordination between the partners.

Responsibility for overall scientific and technical co-ordination plus communication management that includes organizing meetings, setting-up facilities, ensuring communications, checking project progress, objectives and costs.

Deliverables (brief description and month of delivery)

- D1.1 KO Minutes of the milestone meetings (due at milestones KO, PDR, CDR, QR, and AR)
- D1.9 Quarterly progress reports (every 3 months, due at months T0+3, T0+6, T0+9, T0+12, T0+15, T0+18, T0+21, and T0+24)

Table 1-11: Work Package 1-3: Dissemination Activities

Work package number	WP1-3	**Start date or starting event:**				T0: Kickoff
Work package title	Dissemination Activities					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:	3					

Objectives

Disseminate relevant project outcomes to the general public, Space Weather Community, GNSS community and relevant user communities.
A specific series of actions are foreseen to plan the additional tasks to be accomplished once the project is finished in order to market the product resulting in awareness raising and dissemination at regional and EU level.

• Establish a Dissemination Strategy; • Develop a sustainable Business Model & Plan including a commercial feasibility study, market potential assessment, and economic aspects; • Identify and produce the most suitable dissemination means/products for the needs and goals of the project (Dissemination Plan); • Raise awareness, developing clustering and co-ordination activities between relevant projects active in the GNSS, Space Weather and ICT related area to cross-fertilise and share data and peer review; and
Description of work (possibly broken down into tasks), and role of participants
Define Dissemination Strategy and Execute it • Project Web Site • Targeted Community publications, seminars, workshops, conferences for Space Weather, GNSS, General Public Define Exploitation Plan / Business plan for future development
Deliverables (brief description and month of delivery)
• D1.2 Website requirements document (T0+2) • D1.3 Project website prototype (PDR) • D1.4 Project intranet prototype (PDR) • D1.5 Operational project website (CDR) • D1.6 Operational project intranet (CDR) • D1.13 Business Model & Plan (including commercial feasibility study, potential market assessment, and economic aspects, due at AR) • D1.15 Dissemination plan (CDR) • D1.14 Dissemination material (including presentation, posters, etc. due at AR)

Table 1-12: Work Package 2 Summary

Work package number	WP2	**Start date or starting event:**				T0: Kickoff
Work package title	Ionospheric Modelling					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:				13	8	

Objectives
The primary objective of this work package is to provide the interfaces and software tool needed to efficiently generate (in near real-time) four-dimensional (three space, one time) movies of the distribution of ionization in the ionosphere and the plasmasphere. The software tools will enhance and extend the Multi-Instrument Data Analysis System (MIDAS) to efficiently combine data on the ionosphere derived from GNSS, radio occultation (GNSS to LEO satellites), sea-reflecting radar, in situ devices and ionosondes with the LOFAR data described in WP3.
Description of work (possibly broken down into tasks), and role of participants
Tomography based on GNSS data is now routinely used for four-dimensional (spatial-temporal) mapping of the ionosphere using the MIDAS software package. This package has been developed by Bath, but its extension to incorporate radio astronomy data will be led by the Oxford group that has expertise in radio astronomy, high-performance computing and software engineering. These skills are essential to delivering robust, efficient and tested software that will optimally combine 'ionospheric' and 'radio astronomy' data in a near real-time system. This combination of data removes space-time ambiguities in the ionospheric model. The software tool must be interfaced with LOFAR data requiring close collaboration with ASTRON.

The current real-time MIDAS system uses only GNSS data as input. The MIDAS system will be extended in the following ways. The software interfaces will be developed to automate the inclusion of all relevant ionospheric data from the GNSS, radio occultation, sea-reflecting radar, in situ devices and ionosondes. Data is currently sourced from the International GNSS Service (IGS) (Dow et al., 2009) and the Regional Referene Frame Sub-Commission for Europe (EUREF) Permanent Network (EPN) (Bruyninx, 2004). Together, they encompass hundreds of fixed GNSS stations that provide many GNSS products and this infrastructure is already in place across Europe. The number of basis functions describing horizontal and vertical variations in the TEC will be determined by Bayesian evidence, ensuring optimal spatial and temporal resolution, and combined optimally with the IRI to minimize edge effects. Where Faraday rotation observations are available from LOFAR the ionospheric model will be extended to jointly fit TEC and magnetic field improving vertical resolution; this is particularly important whenever ionosonde and radio occultation data are sparse. A hybrid (Singular Value Decomposition plus Bayesian evidence) inversion algorithm will be developed to optimize both the temporal and spatial resolution of the derived ionospheric data products.

Oxford will be responsible for the automation of the real-time collection of the new data inputs and the calibration of those data. Bath will be responsible for the upgrade of MIDAS to ingest those inputs in a consistent manner. This will enable high resolution maps of the ionosphere to be output as stills and in the form of a movie. Oxford will be responsible for the validation of the methods by comparison to independent data by post-processing, particularly assessing the performance of a real-time LOFAR-only method as compared to a full MIDAS method including LOFAR data.

Table 1-13: Work Package 2-1

Work package number	WP2-1	**Start date or starting event:**				T0: Kickoff
Work package title	Ionospheric Modelling Software Interfaces					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:				5	3	

Objectives

To develop automated software interfaces to combine all other relevant ionospheric data with the LOFAR data described in WP3.

Description of work (possibly broken down into tasks), and role of participants

There are a wealth of data constraining the ionosphere that need to be combined with LOFAR data to efficiently generate ionospheric data products optimised for both temporal and spatial resolution. These include the IRI that provide a default model and datastreams from the GNSS, radio occultation, sea-reflecting radar, in situ devices and ionosondes.

The main deliverable of this work package will be an automated system for downloading relevant ionospheric datasets from resources available on the internet (called the “Automated LOFAR DPS”). The relevant interfaces will include a standard API for the input of these ionospheric datastreams (as well as LOFAR data outputs from WP3) to the software tool (to be developed in WP2-2), and for the output of IDEAL ionospheric data products. The deliverables will include a set of ICDs describing these interfaces and a library of software routines implementing these interfaces. We will support existing protocols where possible, for example the standards approved by the IVOA.

Deliverables (brief description and month of delivery)

- D2.1 Automated LOFAR DPS (CDR)

Table 1-14: Work Package 2-2

Work package number	WP2-2	**Start date or starting event:**			T0: Kickoff
Work package title	Ionospheric Modelling Software Tool: Development and Testing				
Activity Type	RTD				
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:				8	5	

Objectives

To develop and test ionospheric modelling software enhancing and extending the MIDAS system

Description of work (possibly broken down into tasks), and role of participants

There are both horizontal and vertical variations in the TEC that need to be modelled in the context of patchy, diverse and often sparse constraints on the ionosphere. The software tool will extend on MIDAS by perturbing a default model (from the IRI) using a variable number of basis functions chosen to best represent the form of the horizontal and vertical spatial variations alongside smooth (low-order) variations in time, allowing for TIDs. A hybrid algorithm will be developed in which an efficient inversion technique (e.g. Singular Value Decomposition) will be combined with calculations of Bayesian evidence to ensure fast performance (NRT performance), and optimal temporal resolution, whilst determining the number of basis functions supported by the data, optimizing spatial resolution.

The LOFAR datastreams will produce constraints on both the TEC (through phase variations) and on a combination of TEC and the magnetic field (through Faraday rotation) in the ionosphere. This yields the great benefit of improving vertical resolution in the ionospheric model which is often a major limitation due to the lack of ionosonde and radio occultation data. IDEAL ionospheric data products will also include information on the magnetic field that greatly enhances their influence on ionospheric physics studies.

The software developed will deliver movies of the ionosphere at much higher time and spatial resolution over the regions probed by beams from LOFAR stations. A critical part of this workpackage is therefore to check for correct and unbiased registration of radio astronomy data with the ionospheric data. The testing programme for the software will rigorously check for, and where necessary calibrate out, any system biases. Integration of radio astronomy calibration data into MIDAS imaging requires test procedure across a range of algorithms, basis functions and independent GNSS and radio astronomy datasets.

Deliverables (brief description and month of delivery)

- D2.2 Automated ionosonde algorithms (CDR)
- D2.3 MIDAS TEC map output system (CDR)
- D2.4 TEC map validation report (QR)

Table 1-15: Work Package 3 Summary

Work package number	WP3	**Start date or starting event:**			T0: Kickoff
Work package title	Real-time ionospheric monitoring system				
Activity Type	RTD				
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:		16	4			

Objectives

The primary objective of this work package is to adapt and enhance the ionospheric calibration components currently built by the ILT as part of its radio astronomical imaging pipeline for use as a near real-time ionospheric monitoring system.

Description of work (possibly broken down into tasks), and role of participants

One of the key technical requirements of the ILT is the ability to create high quality radio images of the sky at low frequencies (30-240 MHz). To reach many of its core scientific objectives, these images need to achieve excellent spatial resolution, positional accuracy, and dynamic range. One of the main challenges to producing such high quality scientific images in the low frequency radio regime are the effects of the active ionosphere over the detector array on signal propagation through the earth's atmosphere. Although relevant at higher frequencies, the degradations caused by ionospheric activity can easily be the limiting factor in producing high quality images in the 30-240 MHz regime.

As part of its standard operations, LOFAR will routinely perform imaging observations of the radio sky. These observations will be processed automatically using a set of data reduction pipelines designed to deliver calibrated science-quality images to the astronomy community. Given its potential impact on the quality of the scientific end-products, correcting for the effects of the ionosphere has been one of the main design drivers for the LOFAR imaging pipeline. The timescale on which these corrections must be computed and applied is still somewhat uncertain and also potentially a strong function of observing frequency. As an initial technical specification, the current pipeline design calls for a cadence of 10 secs. A first version of this imaging pipeline incorporating a simple, single-layer phase screen model for the ionosphere is already available and currently being tested. A production version of this pipeline will be deployed in mid-2010 when LOFAR begins routine science operations.

This core development, already invested by LOFAR to produce astronomical images of the sky, makes an excellent framework on which to build a near real-time ionospheric monitor. Several enhancements and adaptations will however be necessary to expand the current LOFAR system into the IDEAL monitoring system. This work can be grouped into a number of sub-tasks each of which is described in detail individually below.

Table 1-16: Work Package 3-1

Work package number	WP3-1	**Start date or starting event:**				T0: Kickoff
Work package title	Datastream API					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:		7	2			

Objectives

To define a standard set of interface control specifications to allow dissemination of the model data, calculated ionospheric corrections, and ionospheric activity alerts.

Description of work (possibly broken down into tasks), and role of participants

In the current LOFAR system, the ionospheric monitoring data is maintained internally within the system. Corrections to the imaging datastream are produced by evaluating the ionospheric model and applied to the data. A record of these model evaluations and correction factors is saved in a database for later inspection and improvement. The core work of this task is to define a standard set of interface control specifications to allow this data to be exported. These products will constitute the information content of the alerts delivered by the IDEAL monitoring system.

The relevant interfaces will include a standard API for the transmission of ionospheric model parameters and calculated correction factors. The deliverables will include a set of ICDs describing these interfaces and a library of software routines implementing these interfaces. An ICD will also be produced describing the information content of the ionospheric alerts generated by the IDEAL system. We will support existing protocols where possible as well as adhere to the VOEvents alerts standard approved

by the IVOA.
Deliverables (brief description and month of delivery)
• D3.1 Data API definition ICD (PDR)

Table 1-17: Work Package 3-2

Work package number	WP3-2	**Start date or starting event:**			PDR
Work package title	Enhanced Ionospheric Model Integration				
Activity Type	RTD				
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	UOXF.DB	Bath	EDI
Person-months per participant:		7	2			

Objectives
To define a standard set of interface control specifications to allow dissemination of the model data, calculated ionospheric corrections, and ionospheric activity alerts.
Description of work (possibly broken down into tasks), and role of participants
This task will focus on the integration of additional and improved models for the ionsphere into the LOFAR calibration machinery. The description and definition of these improved models is the essence of WP2. Depending on the complexity of the new models in question, this integration may consist of a modified version of the current LOFAR calibration software or alternatively a standalone software component interfaced to the LOFAR calibration. Deliverables in this case will consist of improved versions of the LOFAR calibration software BBS (developed in partnership with S&T) and accompanying documentation.
Deliverables (brief description and month of delivery)
• D3.2 Alert format ICD (PDR) • D3.3 API implementation SW (CDR) • D3.4 LOFAR calibration BBS SW (CDR)

Table 1-18: Work Package 3-3

Work package number	WP3-3	**Start date or starting event:**			CDR
Work package title	Calibration Performance Enhancement				
Activity Type	RTD				
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:		2				

Objectives
To improve the overall system performance in order to achieve an alert latency of 10 seconds.
Description of work (possibly broken down into tasks), and role of participants
Increasing the complexity of the ionospheric models used in the IDEAL system will yield a more useful stream of monitoring information to potential users. The price of this complexity will be increased computation time and a potential increase in the lag time between model evaluation, correction calculation, and alert dissemination. The work in this task will focus on a detailed performance profiling of the calibration software components and modifications to decrease the overall system latency. Deliverables for this sub-task will comprise a report compiling the results of the performance tests (before and after improvement), and an improved version of the primary calibration components.
Deliverables (brief description and month of delivery)
• D3.5 Performance tests reports (QR) • D3.4 Improved LOFAR calibration BBS SW (QR)

Table 1-19: Work Package 4 Summary

Work package number	WP4	**Start date or starting event:**				T0: Kickoff
Work package title	GNSS Delay Characterisation					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:		4	16			

Objectives

The objective of WP4 is to link the TEC of the ionosphere to actual distortions on GNSS signals

Description of work (possibly broken down into tasks), and role of participants

This WP exploits the fact that a LOFAR station is closely located to the WSRT. By using one of the 25m dishes of the WSRT, this facility provides a highly sensitive monitoring equipment to analyse the distortions on the SIS of GNSS satellites due to ionospheric variations. Thus, WP4 allows us to gain much more detailed insight in the distortions on GNSS signals (as specially for the wideband GNSS signals) to the TEC-values as computed in (near) real-time by the activities in WP3 than currently is available.

The GNSS measurement facility shall be analyzing the SIS of both GPS and Galileo satellites.

WP4 is divided into three sub work packages:

- WP4-1: Development of monitoring facility
- WP4-2: Development of SW functionality including control and analysis SW
- WP4-3: Conducting measurements

Table 1-20: Work Package 4-1

Work package number	WP4-1	**Start date or starting event:**				T0: Kickoff
Work package title	Monitoring ionospheric delays using GNSS					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:		2	7			

Objectives

Realization of a measurement facility based on one of the WSRT dish antennas allowing GNSS signals to be analyzed by signal processing SW (See WP4-2)

Description of work (possibly broken down into tasks), and role of participants

- HW adjustment of the High Gain Antenna, electronics, and ADC.
- Development of calibration approach (gain and phase characterisation of the receiver).

Deliverables (brief description and month of delivery)

- D4.1 Upgraded WSRT analysis SW (CDR)

Table 1-21: Work Package 4-2

Work package number	WP4-2	**Start date or starting event:**				T0: Kickoff
Work package title	GNSS analysis and control SW development					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:		2	7			

Objectives

Realization of the software to:

- Control the experiments
- Analyse the measured GNSS signals

Description of work (possibly broken down into tasks), and role of participants

- Development of control SW (for antenna and ADC).
- Development of SIS analysis for GPS and GALILEO signals.

The SIS analyses include:

- C/N0 of the carrier signal.
- Carrier phase.
- Code tracking error.
- Carrier tracking error.
- Code/Code and code/data coherency: The edge of each data symbol coincides with the edge of a code chip. Periodic spreading codes start coincides with the start of a data symbol.
- Pilot/data quadrature quality.
- Code correlation peak.
- Signal distortion using S-Curve function or code discriminator.
- ACF and CCF of the received SIS.

Deliverables (brief description and month of delivery)

- D4.2 SIS control SW (CDR)
- D4.3 SIS analysis SW (CDR)
- D4.5a Prototype operational IDEAL system (QR)
- D4.5b Validated operational IDEAL system (AR)

Table 1-22: Work Package 4-3

Work package number	WP4-3	**Start date or starting event:**				CDR
Work package title	Conducting GNSS measurements					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:			2			

Objectives

Realization of the software to:

- Performing the GNSS measurements to relate the measured ionosphere TEC values to distortions

Description of work (possibly broken down into tasks), and role of participants

- Measurement preparations
- Performing measurements

• Analyzing the signals • Reporting of the signals
Deliverables (brief description and month of delivery)
• D4.4 GNSS characterisation measurement validation (QR)

Table 1-23: Work Package 5 Summary

Work package number	WP5	**Start date or starting event:**			T0: Kickoff
Work package title	Data, Products and User Requirements				
Activity Type	Other				
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:	15					39.5

Objectives
The objective of WP5 is to define: - the data and data products to be generated by the delivered fully operational working system - end-user requirements specific to EDISOFT and the GNSS Forecasting Alert Gateways prototype - end-user requirements generally within the relevant communities - feasibility study for strategic expansion of LOFAR network
Description of work (possibly broken down into tasks), and role of participants
WP1 is divided into three activities: • WP5-1: Data and Data Products • WP5-2: Space Weather Infrastructure Requirements • WP5-3: Prototype End-User GNSS Application

Table 1-24: Work Package 5-1

Work package number	WP5-1	**Start date or starting event:**			T0: Kickoff
Work package title	Data and Data Products				
Activity Type	Other				
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:	11					

Objectives
Definition of the Data and Data Products to be generated by the IDEAL project and assess their feasibility.
Description of work (possibly broken down into tasks), and role of participants
• Define interfaces between LOFAR data and pipeline processing, and ionospheric modelling inputs • Define data format for intermediate and final TEC datasets • Define higher-level data products to be derived, including formats • Develop software for deriving high-level data products in NRT • Develop server system for provision of data and data products to the community in NRT
Deliverables (brief description and month of delivery)
• D5.2 SWE Infrastructure ICD (PDR)

Table 1-25: Work Package 5-2

Work package number	WP5-2	**Start date or starting event:**				T0: Kickoff
Work package title	Space Weather Infrastructure					
Activity Type	Other					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:	4					

Objectives

Definition of the general End-User Requirements of the Space Weather community

Description of work (possibly broken down into tasks), and role of participants

- Comprehensive study of prospective end users of both data and high-level data products
- Define user requirements for standard high-level data products
- Define interfaces between data and data products, and existing resources for space weather data dissemination, e.g. SWENET, eSWEP, SPENVIS
- Identify potential end-users for further services based on data and data products
- Comprehensive study of requirements and costing for extending the IDEAL project to pan-European coverage by extending the LOFAR network
- Feasibility study for strategic expansion of LOFAR network

Deliverables (brief description and month of delivery)

- D5.1 Data product user requirement study report (PDR)
- D5.3 General End-User survey report (PDR)
- D5.4 IDEAL system expansion study report (AR)

Table 1-26: Work Package 5-3

Work package number	WP5-3	**Start date or starting event:**				T0: Kickof
Work package title	Prototype End User GNSS Application					
Activity Type	RTD					
Participant number	1	2	3	4	5	6
Participant short name	RHEA	ASTRON	S&T	OXFORD	BATH	EDI
Person-months per participant:						39,5

Objectives

Develop a prototype GNSS Forecasting Alert Gateways that convert the ionosphere information and forecasting, into a service that presents its information for the context of each user communities. Each user communities will be able to receive GNSS alerts through different mechanisms and periodicity.

At the end of the project, report on the suitability and quality of data received and make suggestions for further improvements.

Description of work (possibly broken down into tasks), and role of participants

- Requirements Definition for the prototype GNSS Forecasting Alert Gateways
- Define Requirements for TEC Map characteristics
- Development of a MMI mock-up
- Development of the test scenario plan
- Development of the prototype Architecture design
- Development of the prototype SW test specification
- Development of the prototype SW
- Perform the prototype SW Test activities

• Perform a pre-operational demonstration and gather users feedback
Deliverables (brief description and month of delivery)
• D5.5 GEA requirements document (PDR) • D5.6 GEA prototype MMI mockup (PDR) • D5.7 GEA test scenario plan (CDR) • D5.8 GEA prototype architecture design (PDR) • D5.9 GEA prototype SW (QR) • D5.10 GEA validation report (AR) including feedback from the target users on the technical and user experience matters

1.4.7 Staff Effort

Table 1-27: Summary of Staff Effort

Participant no./short name	WP1	WP2	WP3	WP4	WP5	WP6	Total person months
1 RHEA	**11**				**15**		26
2 ASTRON			**16**	4			20
3 S&T			4	**16**			20
4 OXFORD		**13**					13
5 BATH		8					8
6 EDI					39.5		39.5
Total							**126.5**

2. IMPLEMENTATION

2.1 Management Structure and Procedures

2.1.1 Management Overview

The main management tasks and responsibilities are listed below.

- Project Planning including Project Management Plan including a tailoring of ECSS-E-40 procedures
- Organisation of consortium meetings and technical meetings
- Planning and co-ordination of Work Packages
- Reporting at management, technical, progress level
- Quality and Risk Management
- Management of financial reporting procedure: preparation of cost statement and integrated cost statement, follow-up of the budgetary overview and changes
- Follow-up of communication flows between partners and the EC
- Assistance for strategic general co-ordination of project and in particular respect of industrial needs, exploitation aspects management

The project will be managed according to ECSS standards, tailored to the needs of the project. The project management philosophy is to be *efficient* and *effective*, with necessary plans and controls in place but deliberately avoiding ‘bloat’ with unnecessary documents and management activity. This approach derives from RHEA’s wealth of experience of large-scale developments to fixed priced conditions.

2.1.2 Management Capability of the Co-ordinator

RHEA has many years of successful experience in the management of numerous multi-million euro contracts in parallel. This includes a wide range of contract types including the development of mission-critical software systems, under tight deadline under fixed priced conditions. Research and Development projects have constantly been a significant part of the company’s business, which has included acting as partner in some projects funded by the framework-6 programme.

An important element in the company’s success has been its ability to combine strong *domain* knowledge with IT systems engineering expertise. Project success derives from a proper, deep understanding of what the system needs to achieve from a user/customer perspective.

Careful and considered recruitment and assignment of key ‘front line’ staff is a major factor in the successful management of any contract, but the real strength comes from the strength of the company’s management and back office support organisation. This organisation allows each Project Manager to spend all of his time wisely, with the ability to easily delegate administrative or specialist tasks. Management controls and active checking mechanisms are in place to ensure that all projects remain on track.

The background experience and existing organisation means that leadership of the IDEAL project presents no particular new challenge to RHEA from a management point of view. We are very aware of reluctance of some organisations to take the project co-ordination role due to the administrative management responsibilities that this entails.

The following diagram presents the management structure of RHEA, identifying responsible persons including the financial and administrative support staff. Gareth Lawrence is a project manager in the ‘Space Weather Systems Engineering’ section, reporting to Simon Reid.

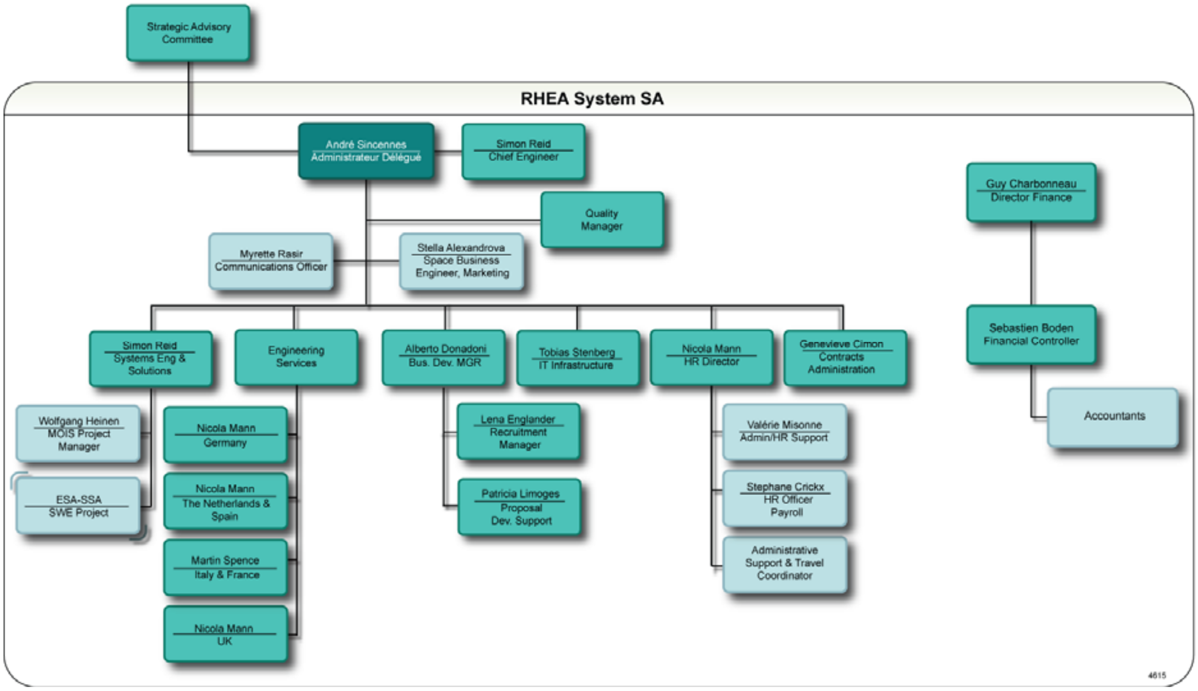

Figure 2-1: RHEA System Organisation Chart

2.1.3 Project Management Structure and Decision-making Structure

Whereas the internal project management culture in RHEA is already strong, the IDEAL project is a collaborative venture with partners. The following diagram depicts how the project will be organised.

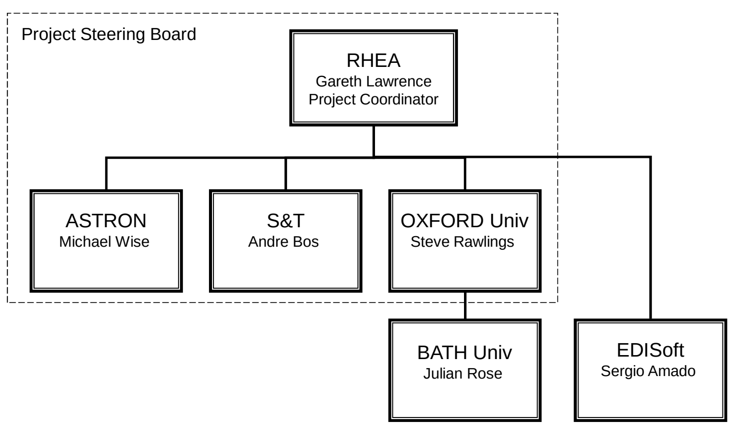

Figure 2-2: IDEAL Project Management Structure

The project comprises a set of 'core' partners who sit on the project steering board, representing the main decision making body for the project's technical and scientific direction. This board will take decisions on the work allocation, distribution of funds and resources, intellectual property rights and conflict resolution. The board will steer the project direction and will address any unforeseen problems, review financial and technical progress, and approve any corrective actions or changes put forward by the Coordinator. The main functions of the steering board will be to make sure that:

i) All planned collaborations, envisioned within the research programme, occur as scheduled in due time and according to the planned criteria.
ii) The data, deliverables and researchers are exchanged among the different laboratories as planned.
iii) All results and deliverables are produced as scheduled and approved by all partners.

The board is led by the Project Co-ordinator Gareth Lawrence, though he will be supported by Simon Reid from a Project management and System Engineering perspective. Each board member is responsible for close interaction of oversight with remaining project partners (respectively EDISoft and Bath Uni).

It can easily be seen that this structure is closely aligned with both the Work Package Breakdown (see section 1.3) as well as the structure of the consortium (see section 2.3).

2.1.4 Communication Strategy

The communication strategy will keep all the partners fully informed about the project status, the planning and all other issues to obtain maximum transparency. The collaborative, open approach supported by suitable tools is expected to engender strong teamwork throughout the lifetime of the project.

We benefit significantly from having a relatively small number of partners in total and a clear team organisation within the project. We aim to minimise the number of travels by organising meetings by teleconference or video conference as much as possible. All project participants use Skype, which has been put to good effect during the production of this proposal.

It is expected that the team will be collocated at each of the major review milestones, when key decisions about the project are due to take place. These reviews will be organised, as much as possible, to coincide with progress reviews that are necessary to meet the reporting needs to the EC.

The project website, which is to be created for the purposes of public project dissemination, will include some private areas accessible to the project members, the EC and any additional external bodies that we shall choose to invite. This will feature a central documentation library including ‘collaboration’ features that allow project members to view and modify the project documentation. We expect also to set up project email accounts and a ‘forum’ section that ensures all communication during the course of the project is also recorded centrally. It is envisaged also that a special area of the forum will be opened to external ‘customers’ of the data.

Progress against technical, scientific and quality will be monitored closely by the project lead with a monthly reporting cycle. Reports from partners will be assimilated in to a project level status report that will be distributed to RHEA management personnel for approval. Actions will be taken in case of unsatisfactory progress or performance.

Communication outside the Consortium is especially important, so RHEA will oversee a co-ordinated approach for all partners interested or involved in promoting or discussing the project with the outside world. Planning for publications to be made, presentations to be given and conferences to be attended on behalf of the Consortium will be a topic for discussion by the steering board.

2.2 Individual Participants

2.2.1 Participant 1 – RHEA

Legal Entity Description
RHEA System S.A. (RHEA) is an independent Space Engineering Consulting and Software SME that offers knowledge-based services and innovative solutions to the space industry. RHEA has supported over 37 space missions in the last 17 years, including comet chasers, planetary and Moon missions, deep space astronomy experiments to understand the fundamental laws of physics, climate monitoring, meteorology, navigation and communications. The group's technical knowledge base, together with the practical experience of its engineers gained through the most demanding projects, ensure that RHEA can provide on demand the highest level of expertise required by our customers, such as ESA, Eumetsat, EADS Astrium, Thales Alenia Space and others. RHEA provides engineering solutions in spacecraft Assembly Integration and Test (AIT), spacecraft and payload operations, ground segment definition, on board software development, system engineering, mission analysis and radiation analysis. RHEA has extensive experience in providing engineering support to astrophysics missions, such as XMM, Planck and Herschel. RHEA offers a range of system solutions for spacecraft planning, operations, spacecraft testing, requirements verification and development of On Board Control Procedures (OBCP). Our flagship product is MOIS, an integrated software tool for spacecraft and ground segment testing and operations. MOIS is amongst the most successful examples of commercialisation of ESA derived software. MOIS allows manual, semi-automatic and fully automatic execution of the commands to the spacecraft or ground segments and the easy creation, modification and monitoring of flight and ground procedures. RHEA is the market leader for procedure management systems. RHEA has successfully brought together engineers and scientists from 13 nationalities to support its clients across seven European countries, Canada and the USA.
Main Tasks
WP1: Project Management and Dissemination Activities WP5: Data Products and Applications
Previous Relevant Experience
• R&D project management via ESA-ESTEC frame contracts • data centre management via ESA-ESRIN frame contracts • technical operations and management via ESA-ESOC and EUMETSAT frame contracts • EU FP6 projects via the ANASTASIA ATM project, including an ionospheric effects work package • ECSS protocols via a series of MOIS (developed under ECSS) software contracts, ESOC frame contracts, and the SEPEM and SPENVIS projects • ionospheric and radiation environment research projects, via the SPENVIS and SEPEM projects
Staff Member Profiles
• **Dr. Gareth Lawrence** is currently the Space Environment Business Engineer for RHEA with special responsibility for Space Weather and Radiation Effects projects at the RHEA head offices in Belgium. He is the RHEA project manager for the SPENVIS and SEPEM projects and is preparing RHEA's role within ESA's Space Situation Awareness programme. He has 15 years experience in solar and solar-terrestrial physics and space weather, having previously worked in research and operations for the ESA-NASA *SOHO* mission, and research and mission development for the ESA *PROBA2* mission.

2.2.2 Participant 2 – ASTRON

Legal Entity Description

ASTRON is the Netherlands Institute for Radio Astronomy. Its main mission is to make discoveries in radio astronomy happen, via the development of new and innovative technologies, the operation of world-class radio astronomy facilities, and the pursuit of fundamental astronomical research. Engineers and astronomers at ASTRON have an outstanding international reputation for novel technology development, and fundamental research in galactic and extra-galactic astronomy.

Main Tasks

WP2: Requirements, interface design, model adaption, system integration, testing

WP3: Requirements, real-time calibration system design, real-time calibration system development, system integration, testing

Previous Relevant Experience

ASTRON is currently building the LOFAR telescope and will ultimately operate the ILT as an astronomical observatory. The ILT will open up a new window on the Universe by observing at very low radio frequencies (30-220 MHz). It is also an important scientific and technological pathfinder for the next generation of radio telescopes - the SKA - a global project in which ASTRON plays a leading role. ASTRON also operates the WSRT, one of the most sensitive radio telescopes in the world. ASTRON hosts JIVE and the NOVA Optical/IR Laboratory. ASTRON has also established the ATH holding company in order to facilitate the transfer of the technology developed by ASTRON for astronomy to the market place. As part of the valorization of ASTRON technology and expertise, ASTRON has strong collaborations with regional partners and other major industrial players.

Staff Member Profiles

- **Dr. Michael Wise** is currently the LOFAR Project Manager and a staff astronomer in the Radio Observatory at ASTRON. His primary responsibilities include oversight of the combined development and commissioning effort required to deploy the ILT as an astronomical observatory. He has been involved in the design of the LOFAR science pipelines and is part of the team setting up the LOFAR LTA. Scientifically, he is part of both the Transients and Surveys Key Science Projects and has been an active researcher in the field of extragalactic astronomy for over 15 years using both theoretical tools and observational data ranging from the X-ray to low frequency radio.

2.2.3 Participant 3 – S&T

Legal Entity Description
Science & Technology BV (S&T) is a private company (SME) conducting high-tech projects and consultancy. S&T started in 2000 and has grown to a diverse group of 50 scientists and engineers. Typical customers and partners are: ESA, TNO, EADS, ASTRIUM, TAS-I, VEGA, Siemens, SNECMA, Logica and others. S&T focuses on three lines of business. Firstly S&T develops software for `high impact systems'. These systems often require extreme performance, accuracy and may involve huge datasets. Furthermore S&T has a highly skilled `pool of experts'. These experts, working on-site at our customers' sites and combine excellent information technology skills with sound knowledge of applied physics. Finally S&T generates business from the in-house developed SHM technology and associated tools. The objective of SHM is to optimize the operation of complex systems by managing its "health". Typical functionality includes: fault detection, diagnosis of system failures, prediction of system failures, and management of failures by e.g. system reconfiguration. Implementation of SHM-systems is based on, among other techniques, signal processing, data and model interpretation, statistical analysis, AI reasoning. S&T is involved as major subcontractor in the development of LOFAR and the In Orbit Validation of the Galileo GNSS (in particular the Signal In Space analysis).
Main Tasks
WP3: Development of (near) Real-Time SW for LOFAR calibration. WP4: Development of control and analysis SW for GNSS Signal In Space Analyses.
Previous Relevant Experience
S&T is highly experienced in the development of scientific data processors coping with high data volumes in the following areas: earth observation data (ESA/ESRIN, ESA/ESTEC), GNSS data (TAS-I), mass spectrometers (TNO), and calibration of optical instruments (TNO). Specific experience S&T includes: • S&T is one of the SW contractors for the LOFAR, including SW development on the calibration algorithms, and health management of the LOFAR infrastructure. • S&T is the SW subcontractor of the Galileo Signal In Space Monitoring Facility and is responsible for the Signal In Space Analysis algorithms and the control software.
Staff Member Profiles
• **Dr. André Bos** is currently the responsible for the SW development of the In Orbit Validation (IOV) Signal In Space Monitoring Facility (SMF) for the GALILEO GNSS. He has been involved in numerous SW and data analysis projects in the scientific (including astronomical, mass spectrometers and optical spectrometers), aerospace (including health management for the Joint Strike Fighter, data analysis for GNSS, calibration and data analysis of remote sensing applications), and military applications (JSF).

2.2.4 Participant 4 - OXFORD

Legal Entity Description
The **University of Oxford** is over 700 years old and is a world-renowned centre of excellence in research and teaching. IDEAL researchers will be directly associated with the Department of Physics (sub-Department of Astrophysics) and the Oxford e-Research Centre (OeRC). The project will exploit strong links with other Physics sub-Departments (e.g. Atmospheric, Oceanic and Planetary Physics and Theoretical Physics) and other Departments (e.g. Engineering).
Main Tasks
WP2: Requirements, interface design, software development, system integration, testing WP3: Requirements, system integration, testing
Previous Relevant Experience
Oxford Astrophysics houses internationally-established researchers with expertise in the Cosmic Microwave Background, experimental and theoretical cosmology, galaxy formation and evolution, exotic compact objects, and radio astronomy. It hosts the world's fastest-growing radio astronomy group outside those associated with bids for the site of the Square Kilometre Array (SKA). Oxford Astrophysics led European SKA science simulation and digital signal processing efforts within the FP6 SKA Design Study (SKADS), and fulfills similar roles in its successor FP7 programme PrepSKA. It is active in eMERLIN Legacy Surveys, LOFAR, RadioNET, SAINT (The Strategic Alliance for the Implementation of New Technologies at the Chajnantor Observatory in Chile) and the UK ALMA Regional Centre. The Oxford e-Research Centre (OeRC; http://www.oerc.ox.ac.uk) enables the exploration of new research areas in the sciences, and increasingly in the humanities and social sciences. The focus of its activities is the development and use of new advances in information technology to allow groups of researchers to tackle problems with increasing scale and complexity, facilitating interdisciplinary research and creating appropriate e-Infrastructure for the support of research. The OeRC, and its sister organization the Oxford Supercomputing Centre (OSC) play a major role in software development for the SKA and its pathfinders through SKADS and PrepSKA. It also provides a natural interface with industrial and commercial software companies.
Staff Member Profiles
• **Prof. Steve Rawlings** is an expert on galaxy evolution, observational cosmology and radio astronomy; 44 refereed papers published, 7 PhD students supervised, and 10 postdoctoral researchers directly line-managed since 2005. He is Head of Oxford Astrophysics (comprising 130 members), is an ex-chair and continuing member of the International SKA Science Working Group, was a co-editor of the SKA science case, is a member of the SKA Science and Engineering Committee, and is the incoming (Jan 2010) Chair of the European SKA Consortium. As vice-Chair of LOFAR-UK, he led negotiations and fund raising leading to the participation of UK researchers in LOFAR. • **Dr. Stef Salvini** is an expert in High-Performance computing and algorithms and OeRC Research Fellow. Within SKADS he managed a team delivering the SKA station simulation software OSKAR, and is hugely experienced in managing software development and testing teams in industrial and academic environments.

2.2.5 Participant 4 – BATH

Legal Entity Description
The University of Bath is an internationally renowned research University offering high quality teaching in an innovative learning environment and attracting eminent scholars and outstanding students from a global recruitment market. The University is structured around 15 Departments. The University has around 13,000 students and competition for places is keen resulting in an intake of exceptionally high quality. The Mission of the University is to advance knowledge through high quality research and teaching in partnership with business, the professions, the public services, the voluntary sector and other research and learning providers. The University has a distinct academic approach that emphasises the education of professional practitioners, fosters high achievement and promotes original inquiry, innovation and collaboration. The University is a centre of academic excellence, where high quality research and high quality teaching are mutually sustaining. Bath has participated in more than 2,000 European and national RTD projects. In 2008 UK Research Assessment Exercise, 60% of the University's total research activity was judged to be world-leading or internationally excellent. The RAE 2008 profile consolidates Bath's position as one of the top research universities in the UK. The University is ranked 9th out of 117 universities in The Guardian University Guide 2010 and 13th by the Times Good University Guide 2010. The University has an annual income of some £164 million and hosts excellent facilities on campus, including a 24 hour library. The research carried out at the University of Bath covers a wide range of subjects in science, engineering, social science and the humanities.
Main Tasks
WP2: Ionospheric Modelling
Previous Relevant Experience
Tomographic imaging of the ionosphere - over 50 papers (CNM and JR) Member of ESA Galileo Science Advisory Committee (CNM) As PI 6 Million Euros in UK research council grants over the last 10 years (CNM and JR)
Staff Member Profiles
• **Julian Rose** is a Post Doctoral Research Officer at the Invert Centre, University of Bath. He graduated from Bath with a first class Honours MEng in Electrical and Electronic Engineering in 2007. He stayed on to complete a PhD in 'Ionospheric Imaging to Improve GPS Timing', which will be awarded in 2011. Julian has collaborated with many companies and institutes throughout his PhD and has excellent communications skills, recently winning both the Westminster and Engineering medals at SET for Britain 2010, hosted at the Houses of Parliament, UK. • **Prof. Cathryn Mitchell** conducts research into the development and application of new algorithms in tomography and in particular has extensive experience in ionospheric imaging. She leads a team of fifteen researchers in the Engineering Faculty. She held a Fellowship in GPS ionospheric scintillation (2004-2009) and is currently the recipient of a Royal Society Wolfson Research Merit Award and a UK EPSRC Challenging Engineering Award, both in tomographic imaging.

2.2.6 Participant 6 – EDISOFT

Legal Entity Description
EDISOFT S.A., established in 1988, is a specialised Portuguese company offering technologically advanced solutions and qualified consulting services to networking, computer security and the integration of command, control, communications, computer and intelligence (C4I) systems. Among its shareholders are important companies such as Thales NL, a Dutch company producing defence systems, NAV – Empresa Pública Navegação Aérea de Portugal (Portuguese Air Traffic Control Authority) and EMPORDEF – Empresa Portuguesa de Defesa, SGPS, S.A. (Holding of Portuguese Defence Industry). Throughout the years, EDISOFT has gathered an impressive curriculum of projects and programmes that help to reinforce the firm's commitment to creative thinking, permanent updating and constant training while emphasizing its ability to innovate, offer state-of-the-art solutions and respond to the challenges posed within the Defence and Security, Business and Organisational Systems, Computer and Communications Networking and Information Security, Transports and Space market segments.
Main Tasks
EDISOFT is responsible for developing a prototype GNSS Prediction application to support the air traffic operator/controllers and pilots in their activities. It shall provide means not only to support the route planning by providing quality of services forecasts (GNSS/COMMs), but also to support operational status alert, in case of high probability of any of the safety requirements are to be violated.
Previous Relevant Experience
Early did EDISOFT firm its credits as a specialist provider of air traffic control and management systems, being the prime responsible entity for the maintenance and software upgrades of the Air Traffic Management System in the Lisbon Flight Information Region. Within a consultancy framework contract, EDISOFT recently developed an incident management system that comprises a cadastre management subsystem concerning all technical equipment and a control centre that manages the operational teams. On satellite navigation topics, EDISOFT has been the leading Portuguese company working with the European Space Agency in two of its major programmes, EGNOS and GALILEO.
Staff Member Profiles
• **Sérgio Amado** graduated in Computer Science, at Instituto Superior Técnico of Lisbon's Technical University. He as been responsible for the project management of several EDISOFT GNSS projects either on the infrastructure side, with the participation on the GALILEO project, but also on the application side with the participation on LIASON project. For the GALILEO project, he has been in charge of the development of the Message Generation Facility Monitoring and control component and Mission Support Facility components: Common Service function and Signal Spectrum Analyser Tool. • **Vital Teresa** graduated in Aerospace Engineering, Avionics Field, at Instituto Superior Técnico of Lisbon's Technical University. He as technically co-ordinated and participated in the development of some E-PATS Galileo analysis tools. For Galileo he has also participated in the analysis of the Ionosphere Scintillation effects on the Galileo ground stations. As a software engineer, he as participated in the EGNOS SISNET lab project developing some application modules, namely the ionosphere monitoring and Ionosphere pierce point computation. He as an extensive professional expertise in software engineering in the fields of implementation, validation and integration (main projects: GALILEO, EGNOS, ESTRACK). • **Susana Mendes** holds a Master degree of Science in Aerospace Engineering – Simulation & Control, from Delft University of Technology. In the aeronautic field she was responsible for developing three controllers, a throttle-to-speed/elevator-to-altitude controller, a throttle-to-altitude/elevator-to-speed controller, and an energy controller, included in the "Tunnel in the Sky" display development. As a SW eng. she has taken part in the GALILEO project, being responsible for the down flow and management of client requirements. In addition she has been included in the PA team, performing unit tests.

2.3 Consortium as a Whole

2.3.1 Consortium Overview

The project has deliberately been identified, formulated and proposed to be as compact and self contained as possible: *viz.,* six consortium partners in four (mainly) geographically close countries, using existing and operational resources and groups to the maximum possible extent, with a short duration (24 months) and low budget (~2M€, ~1M€ EC contribution). The project has been structured in terms of multiple parallel work packages with minimal inter-dependencies: the RHEA lead team will be responsible for the co-ordination and dissemination of WPs (1 and 5) with the other RTD partners each leading a WP. There are clear demarcations of milestones and deliverables which have been planned to minimise: *a)* overlaps between WPs for any one partner; and *b)* knock-on delays to the schedule in the case of missed milestones. Thus at any stage all partners ought to be in a position to concentrate fully towards their scheduled WPS and deliverables as outlined in the WP breakdown and Gantt chart.

2.3.2 Role of the Participants

The consortium partners have been chosen because they satisfy the following criteria: *a)* they represent the entity best qualified to undertake the tasks assigned; and *b)* they already benefit from working relationships and/or formal contracts with their WP partners specifically, and the other partners generally. As outlined in the partner profiles, and summarised in the risk assessment, the proposal draws together:

- The project management team for the LOFAR hardware system with access to the full extent of LOFAR expertise regarding systems, capabilities, requirements, and data: **ASTRON**
- The pre-eminent European group for advanced processing LOFAR-type (in particular, characterising signal-noise issues in such data) and a long-term LOFAR partner and subcontractor: **OXFORD**
- The pre-eminent European group for comprehensive ionosphere studies, including data assimilation methods from diverse data sources (including GPS and GNSS), tomographic inversion techniques, and provision of high-resolution TEC maps in near real times via the MIDAS project: **BATH**
- A software/system solutions SME specialising in high-impact problems and high data volumes in critical systems, and long-term LOFAR and Galileo subcontractor: **S&T**
- A dynamic and flexible SME end user developing innovative solutions to problems involving security of space assets, in particular GNSS accuracy for the ATM industry: **EDI**
- A lead SME team with experience of a range of frame contracts across all scales, in particular: data centre management; commercialisation/exploitation of space systems/products; FP6, 7: **RHEA**

2.3.3 Complementarity of the Participants

As shown by the work package breakdown, the project has partly been based around existing relationships and often formal contracts between the partners:

- ASTRON and OXFORD are long term collaborators on radio astronomy projects with LOFAR
- OXFORD and BATH have a long standing project to extract ionospheric signatures present in radio astronomy data, in particular the 'noise'
- ASTRON and S&T are involved in ongoing projects for LOFAR calibration and processing methods
- RHEA, S&T and EDI are all currently Galileo GNSS subcontractors
- RHEA and ASTRON have previously participated in exploratory studies of space weather topics at SWWT level

The first two of these relationships led directly to WP2, while WPs 3 and 4 emerged from the third. WP5 will clearly benefit from the Galileo connection and shared experiences while RHEA's experience with frame contracts and FP projects provided the impetus to adopt the WP structure in its final form and will continue to motivate the project management and co-ordination.

2.3.4 Industrial Involvement and Exploitation of the Results

The consortium is confident that the combination of established working relationships, innovative and adaptable personnel, and sound project management processes will culminate in the project being completed successfully on time and within budget. A major factor feeding this confidence is the flexibility afforded it by involving SMEs and smaller but highly focused and qualified research groups. Each of the SMEs involved in the project are well placed within the industry not only to complete the WPs allocated within the schedule and budget outlined, but equally importantly to derive a direct commercial benefit from the outcome of the project. RHEA will undertake a comprehensive end-user requirements study which will identify prospective customers and the required related services; S&T will develop high-impact processing techniques applicable in other areas of their consultancy work; EDISoft will develop a highly marketable product custom-tailored for a safety-critical industry. In addition, if a plan to develop IDEAL and LOFAR into pan-European systems are eventually implemented then this would result in numerous construction and infrastructure projects, often in depressed or disadvantaged areas.

Exploitation of deliverables will be a priority item for the project. As stated in the introduction, the consortium has chosen to focus upon a specific application of the key deliverable, namely the correction of GNSS signals using the high-resolution TEC maps. However, these TEC maps can be expected to provide similar benefits and advantages in a wide range of other problems across diverse fields and so every measure will be taken to ensure *a)* their availability is broadly publicised, and *b)* ease of access by end users and all interested parties. As an SME responsible for development and dissemination of data and data products, RHEA will use its position within the industry to ensure maximal exposure, publicity and provision, often using services offered by other SMEs not directly involved in the project; for example SWENET and the EU Space Weather Portal, eSWEP. Such is the importance of this aspect of the project that an entire WP has been dedicated to it as well as a substantial portion of the budget and anticipated resources.

2.3.5 Sub-contracting, other Countries and Additional Partners

An important aspect of the project will be to derive a comprehensive strategy outline for expanding the IDEAL system, via the LOFAR network, into a genuinely pan-European system. At present this task is envisaged to be undertaken by ASTRON though it may be sub-contracted to the LOFAR foundation.

Additionally, certain research elements contained within WP2 and WP3 may prove to be ideally suited to Ph.D. and /or M.Sc. projects undertaken by graduate students at either the University of Bath, Oxford University, or Leiden University. In such a case, the work would be performed under the supervision of the named investigator at the institute in question.

2.4 Resources to be Committed

The required resources for the project, including personnel and supporting equipment, are largely already available at the respective partner institutions. The level of effort required for the individual work packages are detailed in Section 1.3.3. Individual resources to be committed by the partner institutions in the IDEAL collaboration are described in detail below:

2.4.1 Partner 1: RHEA System S.A.

RHEA will bring the experience of project management across a broad range of space projects covering all scales, and the necessary infrastructure and professional environment to ensure the project is completed within budget and schedule. In addition to the space engineering and space weather project management and consultancy background of the project manager and co-ordinator, Gareth Lawrence, the IDEAL project will benefit from RHEA's in-house financial and contractual experts, and systems and software engineering personnel. RHEA's extensive experience in verification and validation of all key phases of mission development will provide a consistent framework for the development and validation of a number of key deliverable items. RHEA's highly qualified and experienced IT support and software and systems engineers will create a custom environment internal to the project to optimise the process of intra-project information transfer and dissemination, as well as an external portal via the project website that conforms fully to the comprehensive user requirements study that will precede and define it. RHEA's existing contracts and contacts and experience and exposure in all areas of the aerospace industry will be brought to bear upon the user requirements study in order to exploit fully the great potential of this essential EC funded study to protect a key space asset against vulnerability to space weather events.

2.4.2 Partner 2: ASTRON

ASTRON is leading the development and deployment of the LOFAR array. Within the ASTRON Technical Lab (TL), in-house expertise includes the design teams responsible for the LOFAR antennas, digital signal processing electronics, and the primary scientific processing pipelines. Personnel involved in the proposed IDEAL project will have close interactions and support from these teams. The EC-supported developers will be supervised by Dr. Michael Wise (ASTRON, with expertise in radio astronomy) who, as LOFAR Project Manager, is also supervising development of LOFAR's imaging calibration pipeline upon which the IDEAL system is based. In addition, the Radio Observatory at ASTRON operates the ILT as an open facility for the greater astronomical community. Through the auspices of the Radio Observatory, ASTRON and the LOFAR Foundation will provide access to the LOFAR infrastructure for the purposes of this project. ASTRON will provide IDEAL personnel with computing and administrative support. They will also benefit from the research environment at ASTRON that features a mixture of world-class technical and scientific expertise.

2.4.3 Partner 3: Science & Technology BV

S&T is leading the development of the GNSS delay characterisation. Personnel that will be involved in this WP will have ample experience in signal processing with respect to GNSS signals as S&T is currently responsible for the SIS analysis for the IOV of the Galileo system. The work in WP-4 will be supervised by Dr. A. Bos (responsible for the development work for the Galileo IOV analyses at S&T). With respect to analysis environment, S&T will supply the programming environments for signal processing: Matlab and IDL, and personal workstations.

ASTRON will support the activity with one of the telescopes of the WSRT-radio astronomy facility.

2.4.4 Partner 4: University of Oxford

Oxford Astrophysics has considerable in-house supercomputing resources that can be used in the IDEAL project in tandem with the resources available at the Oxford e-Research Centre (OeRC). The EC-supported software developers will be supervised by both Steve Rawlings (Oxford Astrophysics, with expertise in radio astronomy) and Stef Salvini (OeRCC, with expertise in high-performance computing). The developers will be provided with computing and administrative support and encouraged to benefit from the fertile Oxford academic environment both within participating departments (Astrophysics, OeRC, Engineering) and in the wider University and associated colleges. Oxford Astrophysics also hosts a digital signal processing group (led by Prof. Mike Jones) and a software group (led by Dr Stef Salvini) that are collaborating on delivering both hardware and software for SEPCAM: a real-time imager being developed for the LOFAR-UK station at Chilbolton Observatory in the UK. This camera will continuously monitor the Faraday Rotation towards the brightest radio sources, providing a unique datastream useful for monitoring the ionosphere over the UK. It is hoped that clones of this camera (which will provide significantly enhanced capabilities, e.g. processing speed, will be available for other LOFAR stations across Europe.

2.4.5 Partner 5: University of Bath

INVERT Centre of University of Bath has expertise in imaging the ionosphere through data assimilation methods. The PDRA will be supervised by Prof Cathryn Mitchell, who has extensive experience in ionospheric imaging and leads a team of fifteen researchers in the Engineering Faculty. Julian Rose has experience in ionospheric imaging to improve the accuracy of GPS applications. He also has experience in outreach and communicating his research to non-specialist audiences (Overall winner of SET for Britain 2010: communicating research to UK Members of Parliament). The Multi-Instrument Data-Analysis System (MIDAS) tomographic software was originally designed in 2000-2001 and has since been continually modified and used extensively in ionospheric research, both at Bath and internationally. MIDAS will be used as a part of this project for validation of LOFAR maps. We also contribute knowledge and expertise in ionospheric science, inversion and imaging. The group has sufficient computational resources, e.g. four Linux workstations and data storage facilities.

2.4.6 Partner 6: EDISOFT

Edisoft will make available to the project, its current IT platform including not only the necessary HW server infrastructure but also the complete set of SW tools available on the company.

Three main sets of operating systems are available for EDISOFT staff:

- Windows XP, Windows 2000 and Windows NT
- Unix based operating systems (SunOS, Sun Solaris, VxWorks and Linux)
- Vax VMS

On the above-mentioned platforms, different software tools are available to facilitate and support EDISOFT staff work:

- Several compilers including C, C++, Ada, Java and Fortran, some are GNU compilers
- Project management tools (MS Project)
- Configuration management tools, like CVS
- Databases, like Oracle, My SQL, MS Access
- Mathematical tools, like Matlab
- Office automation tools, like word processors (MS Word, Framemaker, Adobe Acrobat), presentation products (MS PowerPoint), Spread Sheets (MS Excel), Graphic applications (Visio)
- And other Software development tools (DOORS, Enterprise architect and Cantata++)

3. IMPACT

3.1 Expected Impacts Listed in the Work Programme

High levels of impact may be achieved via this project. European governments are becoming increasingly aware of space weather and the need to monitor its effects in real-time. Much of modern infrastructure relies upon GNSS, from power systems and worldwide telecommunications systems to satellite navigation. This project will provide a vehicle to publicise space weather and increase not only government, but public awareness. The successful outcome of this project will coincide perfectly with the onset of the impending solar maximum. Being able to monitor and provide alerts in real-time will become key to the ever-growing reliance on GNSS and space-based systems. This service will notify end-users of potential disruptions to GNSS services, allowing suitable alternative means to be employed instead

The IDEAL project described in this proposal has the potential for broad impact at many levels. In addition to its primary goal of providing an enhanced, cost-effective, and robust augmentation to existing space-based GNSS assets, the IDEAL system will yield an important source of data for solar and atmospheric researchers which in turn can feed back into the IDEAL system in an iterative sense so that IDEAL can further benefit from improved understanding and modelling of ionospheric physics. Finally, the techniques and software developed as part of the project will have the additional benefit of improving the calibration capabilities of both current and future ground-based radio astronomy facilities. The methodology derived thus will further potentially feed back to improve the pipeline processing of radio and radar facilities including space debris and NEO tracking stations. These improvements naturally translate into an increased effectiveness for European radio-based science and technology assets.

We can summarize the primary impacts from this proposal as follows:

a) Improved early warning system for space weather-related ionospheric disturbances:
One of the prerequisites to apply GNSS in safety-critical applications will be an accurate and timely dissemination of information that might affect the accuracy of GNSS-applications. The improved understanding of the ionosphere and the concurrent analysis of GNSS signals will lead to a better understanding of how the ionosphere affects GNSS signals. The work proposed here will be demonstrated initially using a subset of the LOFAR array, but ultimately expanded to utilize the full set of stations. The scalable nature of the LOFAR infrastructure allows for straightforward expansion given the addition of more stations and associated computing hardware. With such expansion, a near real-time ionospheric monitoring system with pan-European and even global coverage is well within reach and for a fraction of the cost of space-based assets.

b) Better assessment of signal quality of Galileo signals (including during Solar Max):
The near real-time data stream with ionosphere TEC-levels can be used to better assess and characterise the ionospheric distortion on the (wideband) GNSS signals, as we will already demonstrate in WP4 of this proposal. A dedicated analysis campaign can be set up to analyze the signal quality of the European Galileo system.

c) Ionosphere and the effect on other applications:
Signal distortion by the ionosphere is, of course, not limited to GNSS signals alone. Once we have set up the analysis facility pairing TEC estimation with GNSS analysis, we can extend this work to characterise the effects on systems, such as communication satellites, as well.

d) Ionospheric research datastream:
The primary target for the IDEAL system is the production of a near real-time alert system for ionospheric data. Appropriately archived however, the datastreams generated by this system will have tremendous research value for the Space Weather research community. Ionospheric researchers can utilize the data products offline for developing improved models. When coupled with ground and space-

based Solar monitoring data, the information from the IDEAL system can be used to calibrate the effects of solar activity on the ionosphere. Ultimately both types of data will be necessary to test predictive models for Space Weather activity which can then be fed back into the original system to enhance performance and reliability.

e) Improved ionospheric calibration techniques for radio astronomy:
As a by-product of the work proposed here, we will deploy an improved LOFAR calibration system featuring more accurate models for calculating ionospheric phase corrections in radio astronomical imaging datastreams and with near-real time performance. These improvements will result in scientific imaging with enhanced spatial resolution, positional accuracy, and dynamic range. The ability to apply such corrections in real-time will be critical for new generation radio instruments like LOFAR, ASKAP, MeerKat, and ultimately the SKA. The ever-increasing size of the raw datastreams from such new instruments make the traditional practice of calculating and applying such corrections during post-processing infeasible. To keep up with the incoming data volume, these corrections will increasingly need to be applied in real-time. The IDEAL monitoring system, especially over European scales, will be an important step towards the functionality required for calibrating the SKA – which in turn can be designed to incorporate hardware and software to provide enhanced IDEAL-type services.

3.1.1 Strategy for Impact Achievement

The IDEAL project proposed here serves as both prototype and proof of concept. Using the LOFAR infrastructure, we intend to demonstrate the effectiveness of this technique for monitoring ionospheric activity and generating real-time alerts. By adapting the existing LOFAR calibration pipeline, we can deploy a working version of the IDEAL system within the expected two year timescale of the proposal. This working system represents the initial phase of the project.

The initial use of the LOFAR infrastructure for the purposes described in this proposal will be contributed by ASTRON and the LOFAR Foundation. Regular operation of the IDEAL system as an ionospheric alert system will however require considerable additional support and infrastructure. Similarly, the research potential described above will require archiving facilities. Support for these expanded capabilities and regular operations can potentially be achieved by income generated from users of the data products produced. In preparation for this second phase, the collaboration will develop a sustainable business model to support these activities. Development of this business model will be undertaken by the LOFAR Foundation as a sub-contractor on behalf of the IDEAL collaboration.

Ultimately the full potential of the IDEAL system as an ionospheric monitor and alert system will require the addition of more ground stations possibly in the form of new, dedicated and lower cost stations. For modest cost compared to space-based monitoring systems, the existing IDEAL system can be expanded to a truly pan-European or even global scale. Designs for such large-scale expansion of the present system will comprise part of the work in this project.

3.1.2 European Dimension

EGNOS, Galileo, GMES and SSA are four major European collaborative projects that will all benefit from the results of the IDEAL project. All are major technology driven infrastructure programmes whose hardware is sensitive to ionospheric condition, be it for positioning, timing or communications. At the lowest level, all four would clearly benefit from a rapid, robust, independent system of Alerts to announce of potential degradation of service capability. The added value products that will be demonstrated via the production of TEC maps will provide clear, tangible advantages to systems engineers and operations engineers during design, LEOP and routine operations. The

The benefits to End Users across the European commercial sector are discussed in detail in Section 1.1.5. Increasingly, European infrastructure and business are becoming highly dependent on GNSS, often by stealth since the dependence is not always evident. The recent Market Report (GSA, 2010) outlines the current status and growth projections for a wide range of End Users across a variety of domains, all of which are projected to grow and become increasingly dependent on GNSS – and increasingly vulnerable to the risks that can compromise that system's integrity. As for the major European projects, a majority of them will benefit from the Alerts of imminent ionospheric disturbances and a key element of the Dissemination effort will be to engage with as many End User Groups as possible and make them aware of their vulnerability – and of the solution. This will particularly be true of 'stealth' applications. Additionally, during the End User survey we will identify at an early stage the optimal target group for added-value products and engage with them to define the optimal target User Group for the prototype added value services, and target them accordingly. Whilst this might immediately sound non-committal, it is an inevitable consequence of the inherently high-level nature of both the Alerts and Added-Value products and it is not practical to make a final selection for target group at the proposal stage.

Through processes like ASTRONET (http://www.astronet-eu.org/http://www.astronet-eu.org/) in Europe and the Decadal Review in the USA, the international astrophysical community is setting the strategy towards the future. There is a consensus on the big questions of astrophysics, cosmology and astro-particle physics to be addressed and the instrumentation needed for them. The SKA is a key element in this strategy and European leadership in this project is internationally established, and explains the prominence of the SKA in the ESFRI road map. The SKA pathfinders, like LOFAR, are both excellent science instruments in their own right, and provide unique opportunities for training and building up experience. The SKA and its pathfinders will provide scientific and technical career opportunities for large numbers of scientists. Collaborations between radio astronomers and private technology partners have been highly successful at a national level. This proposed programme carries this to a European level, thus significantly increasing the expected impact.

Dealing optimally with ionospheric phase calibration for aperture arrays is a key technological challenge for the SKA, and IDEAL impacts directly on this via the SKA pathfinder LOFAR. The future SKA European knowledge base has a firm scientific and technological basis of a high-tech nature. Both the radio astronomical research and the technology are highly advanced. Europe adopted the phased array antenna concept as its key technology. The FP6 SKA Design Study (SKADS) demonstrated the potential of this concept, which is now firmly embedded in the SKA specification. These technologies have a very large technological and economical (spin-off) potential. The European-wide impact aimed for in this project, creating a large European knowledge base in these technologies and having industry as one of the target groups will thus help increase the European technological and industrial competitiveness.

3.1.3 Contribution to Community Societal Objectives

The impacts of extreme space weather events on modern technology are well known and well documented. In addition to the obvious hazard to space-based assets, these events can produce power grid outages, high frequency communication blackouts. The potential societal and economic impacts of such disruptions is however less well documented and potentially much more costly. Protecting society's expensive technological systems from such events is a clear priority. The development of space weather monitoring data and services represent such as that proposed here represent a crucial means of risk management for the damages produced by extreme space weather events. The societal and economic impacts of extreme events have been studied in detail in recent years (NSA, 2008; Odenwald et al, 2006) and faced with such a potentially huge loss of infrastructure in the worst case scenario, ESA have begun implementation of a major programme –SSA – to mitigate against the risks.

3.1.4 Other Relevant European or National Funded Research

The LOFAR Project has received funding from national (NL) sources for both the research and development and construction phases. While funds for construction have come from national (BSIK) and regional (The Northern Provinces) funds, preparation for the scientific (astronomical) use of the radio telescope has been funded by grants from NOVA (the Netherlands Research School for Astronomy) and NWO. We note that none of these funds are eligible to support the work associated with the IDEAL project directly, although the NOVA and NWO funding in particular does continue to contribute to the development of LOFAR's default scientific processing pipelines. These national (NL) funds for support of LOFAR's science pipelines are also supplemented by resource contributions from LOFAR's international partners including the UK, Germany, France, and Sweden. These pipelines include the imaging pipeline on which the IDEAL system is based.

In addition to the previously mentioned FP6 SKA Design, the European SKA Consortium (led by Steve Rawlings) are also proposing an FP7 Marie Curie ITN Path2SKA (and an associated IAPP proposal, CART: Calibration Algorithms for Radio Telescopes) focussing exclusively on PhD student projects in ASTRON, Oxford, Germany and Portugal. These projects are aimed at addressing key challenges on the scientific and technical pathway to the SKA, and if funded would provide a set of academic 'end-users' for the ionospheric system developed through the IDEAL project.

3.2 Dissemination and/or Exploitation of Project Results, and Management of Intellectual Property

3.2.1 Exploitation and Dissemination Plan for use of Project Results

3.2.1.1 Industrial and Commercial Routes for Exploitation

The target End User Application identified for the project – namely, GNSS signal accuracy warnings – is a prime example of identifying a scientific and technological solution to a space weather related problem that has clear and direct value to vulnerable industries. A new way of generating an improved version of a specific type of data known to be useful to a particular industry has been proposed, and an end user identified and integrated into the consortium. As outlined in WP5.3 the end user, EDISoft, has a clear and detailed plan to exploit the data and data products that are direct output of the scientific theory and technological system that underpin the IDEAL project. They plan to incorporate them into their regular products and services and promoting their availability and added value throughout industries dependent upon space-based assets to provide a range of products and services, and therefore susceptible to space weather hazards. They are in a prime position to capitalise from existing contracts and contacts within that industry to exploit the potential of the project to its fullest extent.

Additionally, EDISoft enjoy a significant comparative advantage as an SME in that regard since they are better placed to adapt their systems and working practices to accommodate new data and products into their systems and product than a larger, less flexible entity would be. For instance, once the value of the IDEAL system has been demonstrated to GNSS-dependant industries and early adopters, then the rest of the navigation domain opens up. Within the domain of navigation, for example, there are numerous possibilities: GNSS systems are not yet sufficiently accurate for smart in-car traffic management systems. However, that remains a stated aim of the automobile industry than the gains in accuracy offered by the IDEAL system could lead to significant progress in that area. The shipping industry is another potential user for very high accuracy systems since such detail could enable the safe passage of large vessels through dangerous passages such as the new trans-arctic routes that are now opening between northern America, Asia and Europe as the ice sheets melt. Such routes are up to 35% shorter than traditional routes and so the potential for reducing both transport overheads and environmental impact are great. The potential for utilisation within precision timing is arguably greater since the above industries are more tolerant of accuracy drift in position than the finance and banking industry are on precision timing, for example. The potential market with requirements for precision timing applications is discussed in detail in Section 1.1.5.

However, as has been mentioned repeatedly in this proposal, navigation and timing accuracy are by no means the sole industrial application of the high-resolution TEC-based products that the IDEAL system will produce. EM signal propagation is in general affected by ionospheric conditions and increasingly modern society is becoming dependent on systems whose performance can be compromised by space weather events and conditions. Both satellite television broadcasts and telephony are susceptible to interference such as distortion, breakup or dropout due to ionospheric conditions. Broadening the scope again it follows that both the CNS and GMES communities will realise a need for high resolution data and data products like these once they progress somewhat further in their respective requirement definition phases. Whilst it is beyond the scope of this proposal to discuss those particular problems, or indeed the project to consider possible solutions, RHEA will consider such diverse domains when defining the comprehensive lists of prospective end users, and end user requirements.

One clear end user of the data and products are the research and operational space weather and space engineering communities. One of the main foci of the end user requirements definition study will be to clearly identify the data and products needed by both; then ensure that they are subsequently provided in accordance with the customer requirements, and to take the greatest advantage of the inherent high resolution of the data. RHEA anticipates providing different levels of data within different times following receipt to allow different levels of processing and calibration (and therefore different levels of absolute accuracy) and also a variety of higher level derived data products. Additional details are provided below and we note here that RHEA is currently engaging with the SWWT as an industrial partner with responsibility for a general customer and end-user requirements study within the space weather domain – covering research, institutional/agency and commercial requirements alike.

The business model for an innovative project like this with a strong proof-of-concept element is necessarily high level since it can be presented to such a wide range of eventual End-User Applications – in some cases without the user being aware of it. IDEAL should be regarded as a Foundation rather than an Application, in that a wide range of Applications can use or adopt it, or be developed around it. The basic element – Alerts of ionospheric disturbances – are fundamental to system performance throughout GNSS-dependent industry and we will make extended efforts to engage those groups to inform them of the risks and the solution.

Beyond that, the Added-Value products need to validated and benchmarked, and the End-User survey will establish the optimal target group to engage. However, a preliminary study suggests that diverse industries like GSI, precision agriculture, remote surveying, precision timing for finance/banking in the highly populated area surrounding the dense core of LOFAR hardware are the most appropriate starting point, for logistical and technical reasons. We further note that the dense core of the LOFAR network coverage includes the airspace around a major international hub airport: Schiphol, and the extended network covers Charles de Gaulle, Frankfurt, Heathrow (plus numerous other smaller airports) and the importance of integrated satellite based CNS systems is underlined by the SESAR JU. GNSS accuracy is safety-critical during all phases of flight but especially during take-off and landing, while communications systems are becoming increasingly susceptible to space weather effects as high-altitude and high-latitude and trans-polar flight frequencies and durations increase. With EGNOS due to be certified for Safety-of-Life applications in 2011, IDEAL will provide invaluable support in operations to support the ATM industry.

An essential element will be a feasibility study and costing exercise for a 'LOFAR-in-a-box' installation where the most basic elements of the LOFAR system would be placed at strategic locations to provide essential services in that region and augment the overall service. The motivation would be to develop a pan-European system over the course of time to complement and protect other major infrastructure programmes like GNSS, Galileo, GMES and SSA.

3.2.1.2 Validation of the Technology

Several technological aspects of the project will need to be validated, including:

- Accuracy and viability of the end user application: GNSS corrections
- Performance of the IDEAL system compared to the stated anticipated baseline
- Performance of the Monitoring SW
- Performance of the Control and Analysis SW
- Performance of the real-time TEC data derived by LOFAR methods alone as compared to the standard comprehensive, but less prompt, data assimilation methods
- Conformity with ECSS requirements

RHEA has extensive experience of requirements verification across a broad range of missions and project and for all key phases of development. A comprehensive verification plan will be drawn up for each of the tasks identified above in accordance with industry standard practices.

3.2.1.3 Dissemination of Results and Technology Transfer

The primary results obtained by the project will be the high resolution TEC data generated in near real time. Several higher-level data product will be derived from these maps in real time. As part of the space weather infrastructure requirements study in WP5.2 RHEA will undertake a full study of requirements on these products and their provision but several assumptions can be made at the proposal stage.

The initial point of entry for the project will be the dedicated project website, which will be hosted by RHEA as part of WP1 (RHEA has the requisite infrastructure and experience to host a project of this scope via e.g. the MOIS software project, ESRIN data centre frame contracts). The website will provide all necessary and relevant information about the project and consortium. Once the IDEAL system is operational the homepage will feature centrally the current NRT TEC plot in graphical form, and a variety of links, thumbnail images etc to a variety of other data products. The most recent data and higher-level products will also be made available in a choice of formats (TBD during end user requirements phase) directly from the project website, while older data will be archived and made available via e.g. FTP from various sources, including a dedicated project data server. Full ECSS documentation and online help will be available via the website, and reports hosted as they are written and submitted to the EC.

In addition to the project-specific resources we anticipate making broad use of existing European space weather infrastructure facilities, such as SWENET, SEISOP, ESWePi, SPENVIS, and other so-called 'virtual observatories' and data assimilation frameworks following the requirements study. As result of full integration into MIDAS the IDEAL TEC data will be available there too, and the project team commit to engage actively with anybody interested in incorporating IDEAL TEC data or maps into their model, product or service; for example. Of the infrastructure services listed above - which are aimed, respectively, at the research and analysis, operations, education, and engineering domains - we choose as an example SWENET to portray how (lower-resolution) TEC are typically represented and hosted via such a data access portal.

In addition to the myriad websites and portals that will offer the IDEAL project and data 24/7 access and visibility, the consortium will promote the project and disseminate the data and projects via: conference presentations, peer-reviewed publications, press releases and other media-related activities, public and educational outreach.

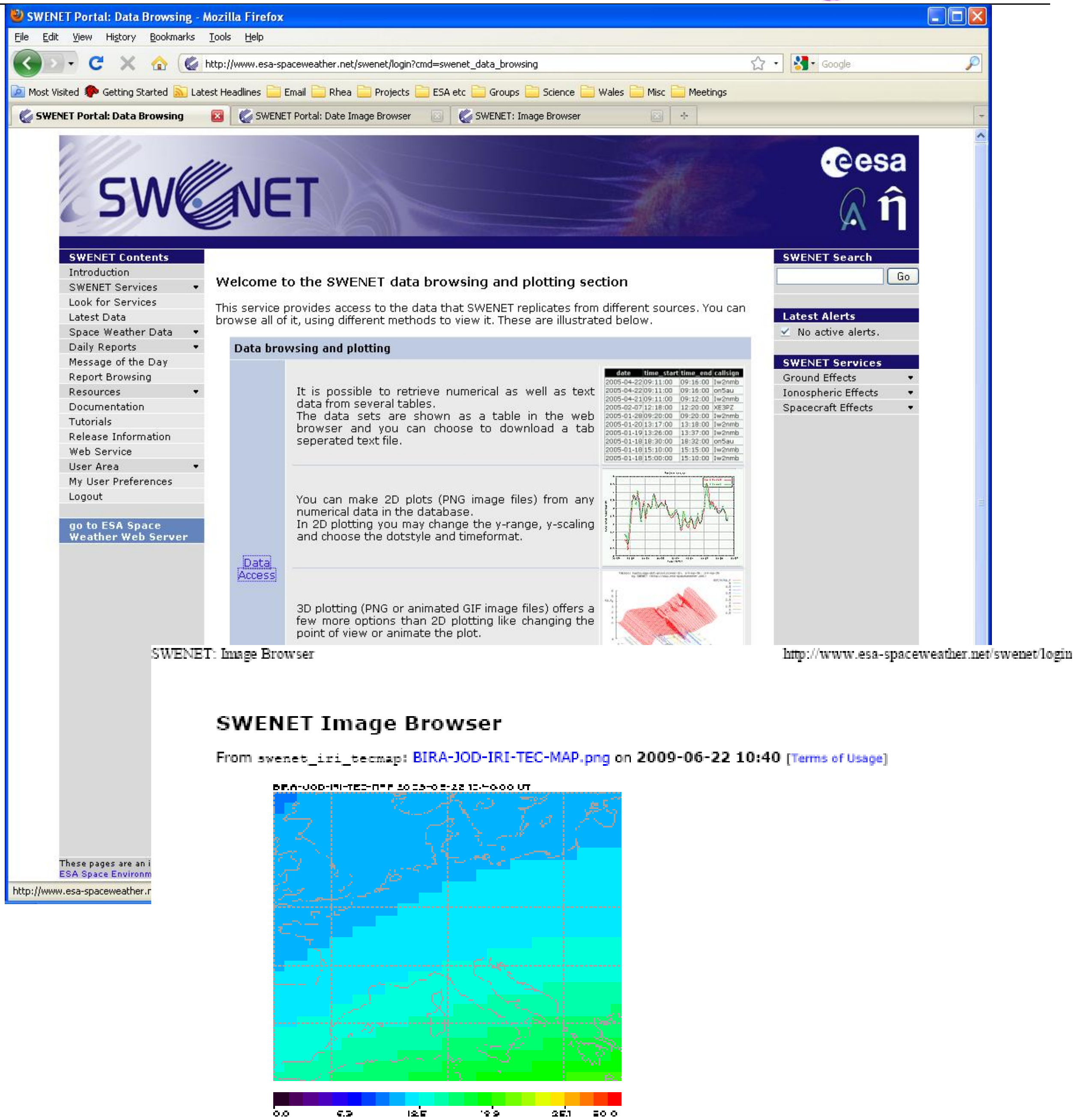

Figure 3-1: TEC Map Made Available via a Data Access Portal

3.2.2 Management of Knowledge and Intellectual Property: IPR Management and Consortium Agreement

The consortium fully recognises the importance of making a suitable provision for Intellectual Property used and developed during the course of this project. This highly complex subject can affect the feasibility of any project. IDEAL will use existing assets and aims to exploit as an ongoing commercial concern.

RHEA has substantial experience in the field of intellectual property as it relates to the space industry due to various contracts to develop, promote and commercialise a variety of space operations and space environment projects. This (uniquely) includes company ownership of a software product (MOIS) that is used by ESA as 'operational software'. RHEA is also prime contractor for the ESA Space Situational Awareness (SSA) Space Weather Element SN-1 project. ESA SSA programme aims to exploit existing, wide ranging institutional capability across Europe and develop into an operational system. RHEA's responsibilities in this role specifically include identification and assessment of IPR issues.

IPR will be managed by a Project IPR and exploitation committee, chaired by RHEA and dedicated to considering IPR and dissemination activities. IPR will be formally regulated in the Consortium Agreement (CA) to be signed by all partners before any eventual signature of the contract with the Commission to specify or supplement the provisions of the contract. This agreement will describe the partner's access rights to background knowledge necessary to carry out the project and the procedure partners must adhere to in order to access, use and exploit the knowledge being developed in the project. The CA will specify duty and power of the committee, contractors, the technical responsibility, the basic aspects of the IPR management Confidentiality / Ownership of results / joint ownership of results / difficult cases / Legal protection of results (patent rights) / Commercial exploitation of results and any necessary access right / Commercial obligation / Relevant Patents, know-how, and information / Sub-license/ access rights and general principles applicable to the use of foreground and background knowledge.

It is worth noting that the IDEA project proposes a high-resolution TEC map service that will be offered by RHEA via the dissemination system to be produced. The Edisoft contribution represents a single example value-added service that is essentially independent but dependent on the general service developed by the rest of the project. This state of affairs will be reflected in the granting of access rights to Edisoft which should be in some way representative of other potential customers of the service.

The consortium proposal has been prepared on the basis of the following key principles. The principles act as the draft/baseline approach reflected in the consortium agreement, subject to detailed examination by the committee on a case by case basis.

- Project IPR management is conducted in accordance with the FP7 Guide and principles
- Each consortium partner declares background IPR held or owned by themselves needed for the benefit of this project and grants appropriate access rights to partners. Most or all these IPR arise from previous investments from European Space Agency, EU public bodies. In these cases the IPR is either owned by a partner or they hold a non-exclusive, irrevocable, free, worldwide licence to exploit the software in question.
- Each partner will own foreground IPR for the work that they produce on the project, granting access rights as appropriate to ensure the on-going coherency of the project development and exploitation.
- Foreground IPR will be protected with due regard to the interests all partners in a coordinated fashion.
- Dissemination (explored above) will take place once foreground IPR has been suitably protected.

4. ETHICAL ISSUES

(Note: Research involving activities marked with an asterisk * in the left column in the table below will be referred automatically to Ethical Review)

Table 4-1: Ethical Issues Tables

	Research on Human Embryo/ Foetus	YES	Page
*	Does the proposed research involve human Embryos?		
*	Does the proposed research involve human Foetal Tissues/ Cells?		
*	Does the proposed research involve human Embryonic Stem Cells (hESCs)?		
*	Does the proposed research on human Embryonic Stem Cells involve cells in culture?		
*	Does the proposed research on Human Embryonic Stem Cells involve the derivation of cells from Embryos?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	**X**	

	Research on Humans	YES	Page
*	Does the proposed research involve children?		
*	Does the proposed research involve patients?		
*	Does the proposed research involve persons not able to give consent?		
*	Does the proposed research involve adult healthy volunteers?		
	Does the proposed research involve Human genetic material?		
	Does the proposed research involve Human biological samples?		
	Does the proposed research involve Human data collection?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	**X**	

	Privacy	YES	Page
	Does the proposed research involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?		
	Does the proposed research involve tracking the location or observation of people?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	**X**	

	Research on Animals	YES	Page
	Does the proposed research involve research on animals?		
	Are those animals transgenic small laboratory animals?		
	Are those animals transgenic farm animals?		
*	Are those animals non-human primates?		
	Are those animals cloned farm animals?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	**X**	

	Research Involving Developing Countries	YES	Page
	Does the proposed research involve the use of local resources (genetic, animal, plant, etc)?		
	Is the proposed research of benefit to local communities (e.g. capacity building, access to healthcare, education, etc)?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	**X**	

	Dual Use	YES	Page
	Research having direct military use		
	Research having the potential for terrorist abuse		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	**X**	

5. Consideration of Gender Aspects

Discrimination can occur and RHEA is a company that is committed to fight against it, whether it is related to gender, ethnic origin, disabilities or sexual orientation. As a Belgian company, RHEA is following the rules established in the Collective Agreement n°25 of October 15th 1975 regarding equal salary between men and women. This is why salaries are established based on qualifications, experience and responsibilities. RHEA has achieved good results in the aerospace industry regarding gender diversity, mostly with flexibility offered to both sexes such as part-time work, parental and paternity leaves. In fact, aside from legal obligations, it is always made sure that a real balance exists between private and professional life: RHEA considers that quality of life encourages high levels of motivation, which is not only a question of money but seen as a multidimensional issue.

The results up to now are positive: one employee out of four is a woman and those women are concentrated in high qualification positions; three out of seven of the company's management and middle-management staff are women.

S&T has been co-founded, co-directed and co-managed by a female. It is active policy within S&T to promote females in positions in which they are visible to the general public as decision maker within the company.

The University of Oxford's "…Integrated Equal Opportunities Policy provides for an inclusive environment, which 'promotes equality, values diversity and maintains a working, learning and social environment in which the rights and dignity of all its staff and students are respected to assist them in reaching their full potential'. It also provides that no student or member of staff will be treated less favourably on the grounds of gender or gender identity."

The Ionospheric Physics Grout at the University of Bath University currently has a ratio of five to eleven female to male members of staff. It is led by Professor Cathryn Mitchell who is a world renowned expert in the field of Ionospheric Physics effects on GNSS.

There shall be equal treatment, meaning that no discrimination regarding: origin, **gender**, sexual orientation, political or religion positions, union filiations or any disability. Restrictions to nationality are strictly limited to exceptions foreseen on National Legislation concerning the national interest's protection."

As part of the project action plan in what concerned gender aspects, EDISOFT will encourage women's participation in the activities from among their own staff.

In fact, it must be remarked that the project key personnel form EDISOFT already considerer that a relevant part of the work shall be developed by women.

Diversity is an important aspect for the ASTRON organisation. ASTRON has used it's position as a knowledge institute in the region to act as a forerunner in this area. At ASTRON, diversity is not limited to gender balance ("women in science and technology") but includes ethnic minorities and handicapped people. The ASTRON Diversity Committee monitors the proper balance in the organisation with respect to these target groups, and proposes policies and stimulation programs to increase gender balance and diversity.

In the Hiring & Selection procedure, candidates from target groups are selected solely on the basis of equal fitness for the job. There is a stimulation program for young handicapped people to give them the opportunity to prepare for a job. There is a female visitor program (the Helena Kluyver Fund) to facilitate visits from female astronomers and engineers. ASTRON actively promotes science and technologies at schools, with the intention to increase participation of women in these fields.

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