Ionospheric Consortium at Dôme C
SuperDARN – ALFA – FPI

Introduction

The ionosphere, situated between 90 and ~2000 km altitude, is the interface between the totally ionised magnetosphere and the neutral atmosphere. Plasma processes couple the ionosphere with the magnetosphere and the interplanetary medium. Solar wind pressure variations and fluctuations in the interplanetary magnetic field are responsible for the penetration of plasma, momentum and energy across the magnetopause, a process which also affects the high-latitude ionosphere through mapping and propagation along the earth magnetic field lines. The ionosphere is also coupled with the neutral atmosphere through the chemical processes of ionisation-recombination-charge exchange, and through the transport processes of material and energy. The objective of the proposed set of optical and radar experiments at the Concordia-Dome-C Antarctic station is twofold: *i*) carry in-situ scientific studies with a set complementary experiments; *ii*) contribute to global networks of observations and their objectives. These experiments will take advantage from the situation of the Concordia site, namely its position in vicinity of the geomagnetic pole and the high level of atmospheric transparency. Data collected at Concordia will be interpreted with the help of modelling and will contribute to the development of these models. Space missions dedicated to the study of the atmosphere-ionosphere-magnetosphere-solar wind system will also support and be supported by the Concordia observations.

1 The experimental set-up at Concordia

Pertinent parameters of atmospheric dynamics and ionospheric electrodynamics will be measured by three instruments, namely the two ionospheric HF SuperDARN radars, the optical all-sky camera (ALFA) and the Fabry-Perot interferometer (FPI). They will be supported by the magnetometer measurements already installed at Concordia and more generally by the network of ionospheric measurements already operating in Antarctica.

1.1 The SuperDARN radars

The SuperDARN (Dual Auroral Radar Network) radars are designed to study ionospheric convection. In the HF frequency range, between 8 and 20 MHz, the radar wave is refracted in the ionosphere and the radar energy is partly backscattered by plasma density spatial fluctuations. The Doppler frequency shift is a measure of the radial component of the plasma velocity. The radar beam can be oriented into 16 directions inside a sector of 53° and reach targets up to 3000 km. Using two radars situated at separated sites, but sharing a common field of view, both the intensity and the direction of the plasma velocity can be determined. The spatial and temporal resolutions are respectively 45 km and 1 minute in routine mode. Specific modes of operation will allow observations at short ranges, conjugate with optical instruments. Two sets of radars, distributed in longitude in each hemisphere, thus covering the northern and southern auroral and polar zones, form the SuperDARN network which has been developed through multi-national cooperation. The radars pair at Concordia will complete the coverage of polar cap and auroral regions of the southern hemisphere.

1.2 The all-sky camera ALFA

The ALFA (Auroral Light Fine Analysis) camera is designed to measure optical emissions in the visible (400-900 nm) due to energetic electrons, which have been accelerated in the distant magnetosphere and precipitated into the ionosphere. The "Concordia" version of the instrument includes an "all-sky" camera and photometers. The field of view of the camera is 3000 km in diameter at the altitude of 200 km, with a spatial resolution of 200 m at zenith and 7 km at horizon, and a temporal resolution of ~1 RGB image/minute. The camera will survey the intensity, spatial distribution and temporal variations of the emissions in three frequency ranges. Three photometers will monitor temporal variations of wide-band, OH and O emissions respectively. The first one will be used to determine in real time several parameters such as sensitivity, exposure time and temporal resolution, which will be used for automatic camera control. The two other photometers will be used to survey specific emission lines, respectively in the mesosphere and in the ionosphere. The ALFA instruments are planned to be integrated in the international network of optical cameras in Antarctica, which currently includes 2 cameras at South Pole (USA), 2 at Penguin P1 and P2 (USA) and 2 at Zhongshan (China). Optical observations by ALFA will be opened to the community involved in astronomical measurements at Concordia.

1.3 The Fabry-Perot interferometer (FPI)

The multi-emission FPI measures three auroral emissions lines, namely the OH line (892.0 nm) and two O lines (557.7 and 630.0 nm). The instrumental setup includes an optical system, a set of filters to select the line and an interferometer which produces the fringes to be recorded on a CCD. The analysis of the interference fringes gives access to neutral winds and temperatures at mesospheric or thermospheric altitudes according to the selected line. Measurements are performed in 5 directions, zenith and 4 cardinal directions at 45° elevation. Integration time in each direction is 3 min. for OH and O-557.7 nm and 5 min for O-630.0 nm. The full cycle for the 3 lines lasts about 1 hour. The instrument will be built by our US colleagues at NCAR, based on the design of a similar instrument operating at Resolute Bay, Canada. It will enhance the coverage of the Antarctic network of FPI instruments already operating at South Pole, Mac Murdo, Davis and Mawson (since March 2007).

2 The scientific objectives

2.1 Solar wind – magnetosphere - ionosphere interactions

Reconnection between the interplanetary magnetic field (IMF) and the terrestrial magnetospheric field is principally driven by the orientation of the interplanetary field. The reconnection process is the main source of plasma transport along (precipitation, ionospheric escape) and across (convection) the magnetic field lines in the magnetosphere and ionosphere. At the ionospheric level these transports result in numerous effects such as the variation of the ionospheric conductivity, electric field and plasma convection, plasma heating, emissions etc. In addition, solar wind pressure variations, interplanetary Alfvén waves and shocks also contribute into the ionospheric dynamics. Polar cap and auroral oval are distinguished by their topological differences. The polar cap magnetic field lines are directly connected to the interplanetary medium, while the auroral zone is at the boundary with closed magnetic field lines linked with the opposite hemisphere.

Using the full SuperDARN network, the topology of **plasma convection in the polar cap and auroral zone** can be studied in relation with interplanetary conditions (magnetic field, solar wind pressure) and solar UV flux. Convection cells are now fairly well described during stable interplanetary conditions, but the **dynamics of convection reorganisation** during transient interplanetary conditions remains an open subject.

The transpolar potential, defined as the potential difference between the centres of two main vortices, is a measure of the convection intensity. Its variations with interplanetary conditions are proved to be essential for **space weather studies.**

Inter-hemispheric asymmetries in plasma flows are mainly due to seasonal effects and to the dawn-dusk component of the interplanetary magnetic field. The conjugate inter-hemispheric studies will benefit from the extended coverage of the southern hemisphere provided by SuperDARN/ALFA at Concordia.

The **dynamics of the auroral oval** will be studied in relation with the intensity of the convection and with the reconnection rate and its localisation on the magnetopause. From the size of the polar cap, the amount of open magnetic flux, which is a robust indicator of the disturbance state of the magnetosphere, can be deduced.

Meso-scale convection structures related to the reconnection events and the **evolution of the plasma content inside the convecting newly-opened flux tubes** from their reconnection site on the dayside magnetopause to the night side will be analysed from SuperDARN/ALFA observations and also modelled with TRANSCAR.

Transpolar arcs, which are observed during periods of northward interplanetary magnetic field, are the signature of the intrusion of closed magnetic field lines into the polar cap. Associated emissions, called theta aurora, are less frequent than usual auroral emissions. Using both ALFA and SuperDARN, it will become possible to study the dynamics of these arcs and their role in plasma exchange between the magnetospheric tail and the conjugate ionospheres.

2.2 Ionosphere - thermosphere interactions

The ionospheric plasma and the upper neutral atmosphere, called the thermosphere, interact directly. Processes like collisions, charge exchange, recombination dynamically couple these two populations. Each population is driven by the appropriate force, i.e. the electric field for the plasma and the solar heating and atmospheric tides for the thermosphere. These forces which have different magnitudes and time constants can be studied by SuperDARN and FPI, respectively. For instance, the ionospheric convection is more complex for northward interplanetary magnetic field. In the centre of the polar cap, the convection can be either sunward or anti-sunward, whereas the thermospheric pressure gradient is always sunward. Because **thermospheric neutral winds** depend on both sources, the analysis of neutral winds will allow studying the balance between these two sources, thanks to the central position of Concordia in the polar cap.

The thermosphere behaves as a sink for the Joule energy generated by horizontal currents and for the energy carried by precipitations. These heat sources are particularly strong during magnetospheric storms. Both radar and optical data from Concordia will help describing this process (ionospheric convection with SuperDARN, atmospheric dynamics and thermodynamics with ALFA and FPI).

Gravity waves are low frequency density perturbations which propagate both horizontally and vertically in the atmosphere. The **propagation of gravity waves in the thermosphere-ionosphere system** carries energy away from its source (auroral, tropospheric etc). Their amplitude increases strongly upwards due to the vertical density variation and wave breaking often occurs, due to non-linear effects. The set of proposed instruments will allow to observe **horizontal propagation** of the gravity waves and to study their **vertical evolution** using multi-wavelength measurements (ALFA, FPI).

2.3 Mesosphere and lower thermosphere

High latitude mesosphere and thermosphere tides are very prominent feature of the polar mesosphere dynamics. Dome-C is a location where transition in the mesosphere 12-hour tide from non-migrating (s=1) to migrating (s=2) modes occurs. Measurements from FPI-Concordia combined with data from the other FPI stations and MF-radars stations will allow to better characterize the tidal features. Comparison with the 2002 Global Scale Wave Model (GSWM02) and Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation model (TIME-GCM) runs will help to understand the origin of the 12-hour non-migrating (s=1) tide at high latitudes.

Stratospheric warming events are commonly observed in the northern hemisphere, but are not expected to occur in the south because of the strong winds associated with the polar vortex. Such events have however been observed in Antarctica. The study of the **mesospheric response to stratospheric warming events** is also an objective of the FPI experiment. It is an important issue to our understanding of stratosphere-mesosphere coupling.

Meteor trails created by meteoric bodies impacting the dense layers of the lower thermosphere can be observed as perturbations in the plasma density, and optical emissions. The motion of these trails can be observed by SuperDARN radars. They will act as **tracers of atmospheric dynamics** by providing the line of sight component of the mesospheric wind. Optical observation of the light emissions from the meteoritic bodies can be used to monitor the altitude of the radar echoes.

2.4 Ground-space collaborations

A thorough understanding of the magnetospheric system is based on the multi-instrument observations which are carried simultaneously from space and from the ground. To give examples, we can cite the studies, which were carried in our scientific teams and related to the recent space missions, like Demeter and Cluster. New opportunities in the near future are the following.

- The **Themis mission** (NASA) dedicated to magnetospheric substorm studies. A substorm is the sudden release of plasma and energy accumulated in the distant plasma sheet. This release is associated with parallel currents, associated auroral emissions, horizontal currents, intensifications of the plasma convection etc. Coordinated ground-space campaigns are already scheduled and the Concordia experiments will naturally contribute to the study of the energy/material exchange between the tail and night-side ionosphere.

- The **SWARM mission** (ESA) which has two objectives. First, it is aimed at monitoring the earth magnetic field. Separating external from internal sources of the field implies, among others, a precise evaluation of the parallel currents. Our past work based on the Demeter, Ørsted and Champ missions coordinated with SuperDARN have demonstrated the validity of that approach. Second, SWARM will provide a monitoring of the atmospheric density variations from the drag exerted on the satellites. Here again, our recent work based on CHAMP data has demonstrated the complementarities between ground and space measurements.

- The **KuaFu mission** (CSSR, ESA) including three satellites. Its objective is to study the magnetosphere-ionosphere-thermosphere system during magnetic storms. Conjugate observations of magnetic storm effects will be carried in the auroral/polar regions of both hemispheres simultaneously by two satellites, in addition to the solar wind monitoring made on-board the third satellite placed in the Lagrangian point.

3 Modelling

Several numerical models will be used for interpreting experimental data. Among them, the most useful will be the TRANSCAR ionospheric model which describes the vertical distribution of the ionospheric plasma.

- The TRANSCAR ionospheric model is made of two coupled parts: a kinetic code for the transport of supra-thermal electrons and a fluid code for thermal electrons and the six ion species. The dynamics of the various species, the electron production and the moments of the velocity distribution function (density, bulk velocity, temperature, heat flux) are calculated in a 1-D model (along the magnetic field line assumed to be vertical for high latitudes). The motion of the flux tube due to the convection electric field is taken into account, which makes

TRANSCAR a pseudo-3D model. With adequate inputs (UV solar flux, particle precipitation, electric field), TRANSCAR is able to provide realistic values of the main plasma parameters as a function of time and space in the polar cap ionosphere. A version of TRANSCAR for middle latitudes using a dipole magnetic field is currently under development. It will allow studying particle and energy exchange between conjugate ionospheres and also to deal with the opening / closing of flux tubes during their convection.

- Ray-tracing programs applied to HF waves and using realistic ionospheric density models will help localising the altitudes of the SuperDARN echoes. This will be most useful when comparing radar and optical measurements patterns.

4 Synthesis: Association between instruments and scientific objectives

Table 1 below indicates associations of instruments to be used for the various scientific objectives described above.

Solar wind – magnetosphere- ionosphere interaction	
SD network	- variations of transpolar potential. - plasma convection in the polar and auroral regions. Response to solar wind and IMF variations.
SD network + All-skies network	- effect of Alfvén waves and magnetic field reconnection at the magnetopause and in the tail on the convection. - inter-hemispheric symmetries / asymmetries.
SD Dôme C	- survey of the plasma convection across the polar cap.
ALFA Dôme C	- energy and plasma exchange inside transpolar arcs.
SD Dome C ALFA Dome C	- relation between plasma convection and field-aligned plasma motions.
ALFA Dome C	- formation of the density irregularities in regions of precipitated energetic particles. - fine analysis of light emissions in the ionosphere: small- and meso-scale structures. - interaction of energetic electrons with the ionosphere.
Thermosphere-ionosphere interaction	
SD Dome C FPI ALFA	- gravity wave propagation up/down between mesospheric and ionospheric altitudes (breaking or amplifications ?). - gravity waves features related to different sources (auroral, tropospheric). - multi-scale interaction. - relation between emission intensity and electron density perturbations.
FPI network SD network	- Thermospheric neutral wind morphology during northward IMF.
Mesosphere-Lower thermosphere	
SD Dome C FPI network ALFA	- tidal features : mesospheric wind in relation to the seasonal variations and solar wind conditions.
FPI network	- mesosphere response to stratospheric warming events.

Table 1

Besides their standard modes of operation, the Concordia ionospheric set of instruments will be used for campaigns dedicated to specific scientific objectives. Table 2 gives a few examples of coordinated campaigns of observation and the mode and type of operation of the various experiments.

SuperDARN ALFA all-skies	- survey of reconnection processes at the magnetopause with consequent motion of the reconnected tubes across the polar cap. - plasma motion inside and outside the reconnected tubes. - relation between emission intensities and density perturbations.
SuperDARN FPI ALFA	- survey of the mesospheric wind by - "conjugate" observations of the longitudinal component along SD East-West beams at appropriate ranges and E/W FPI ; - complementary observations of the meridian component along the closest SD beam at appropriate ranges and N/S FPI, height of 90 km. - relation between emission intensities associated with meteor trails and backscattered HF power. - study of gravity waves features using simultaneous observations of the density perturbations (backscattered HF power), O and OH emission intensities at ionospheric and mesospheric heights.
ALFA FPI other optical instruments	- survey of ionospheric emissions in the range 400-900 nm. - survey of the OH, O emissions using ALFA photometers. - survey of the atmospheric absorption (using stars). - survey of the moon, human activities, bad meteo-conditions.
Themis - ground- based instruments	- plasma and energy exchange between the magnetospheric tail and the ionosphere during magnetic substorms.
Modelisation	- Interaction of precipitated electrons and protons with the ionosphere/thermosphere (variation of the ion-neutral density, temperature, velocity; associated emissions, their intensities, characteristic height). - Propagation of gravity waves in ionosphere/mesosphere (associated density perturbations, optical emissions)

Table 2 - Coordinated Campaigns

5 Participants

Name	**Laboratory**	**Field of interest**
Cerisier Jean-Claude	CETP, Saint Maur	SuperDARN, ALFA
Godefroy Michel	CETP, Saint Maur	ALFA
Lathuillère Chantal	LPG, Grenoble	FPI
Marchaudon Aurélie	LPCE, Orléans	TRANSCAR, SuperDARN
Pitout Frédéric	LPG, Grenoble	FPI, TRANSCAR
Seran Elena	CETP, Saint Maur	ALFA, SuperDARN

Villain Jean-Paul	LPCE, Orléans	SuperDARN