THE CONCORDIASI PROJECT OVER ANTARCTICA DURING THE INTERNATIONAL POLAR YEAR (IPY)

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Abstract

The most outstanding goals of the Concordiasi project over Antarctica are:
a) To improve the assimilation of satellite data over the southern polar region, with an emphasis on the data provided by the new IASI sounder. The enhancements in the skill of weather predictions and accuracy of the climate record resulting from such improvements will contribute to the IPY's legacy
b) To improve understanding of the stratospheric ozone budget through examination of the interaction of ozone observations at flight level and stratospheric NAT clouds, together with the improved characterization of the polar vortex.
c) To provide recommendations on the design of the global observing system over the southern polar region by determining the extent to which additional observations (e.g., improved use of satellite observations vs in-situ targeting) over Antarctica can improve the prediction of high impact weather over lower latitudes.
d) To advance understanding of the Earth system by examining the two-way interactions between the climates of Antarctica and lower latitudes.

MOTIVATION

One feature of the Antarctic climate that has received considerable public and scientific attention is the decrease in stratospheric ozone observed since the 1980's. While the role of polar stratospheric clouds in ozone depletion over the poles has been recognized for over two decades, critical questions remain unanswered on the chemistry and microphysics of these clouds, such as the nucleation mechanism for the nitric acid hydrate. Questions also exist on the interactions among these clouds with the dynamics of the southern stratosphere. Another critical question for society is whether climate change will result in a significant change of the mass budget of the Antarctica ice sheet. Investigations of both the distribution of precipitation to provide insight to the mass budget over Antarctica and the issue of ozone depletion provide a strong motivation for improved multi-scale measurements over the region. To date, the remote, isolated location, very harsh conditions, and high elevations of the Antarctic plateau make it difficult to launch intensive field campaigns from locations in the continent. Antarctica and surrounding ocean are relatively data sparse in terms of the operational stream of in-situ atmospheric measurements, even in comparison to the Arctic. The contribution of satellite measurements to fill such data gap presents unique challenges and difficulties as well as opportunities for progress. These challenges must be overcome and errors need to be reduced to produce accurate reanalyses for climate studies that are based primarily on observed conditions. Accurate real-time analyses are also of importance for the weather forecasts locally (used in field operations) and more globally through interactions with lower latitudes.

Concordiasi is a joint French-US initiative. The project, which is integral part of the International

Polar Year (IPY) will take place over Antarctica during August to November 2008. Concordiasi is part of the IPY-THORPEX cluster of research activities approved by the ICSU-WMO panel. Participation in the Concordiasi project includes scientists in France, United States (US), Italy, Australia, and involves international organizations such as the European Centre for Medium Range Weather Forecasts (ECMWF). Concordiasi is a multi-disciplinary effort based on a constellation of long duration (months) instrumented stratospheric balloons and on additional in situ observations at the Concordia station (75S and 123E) and the Dumont d'Urville station (66S, 140E) on the Antarctic dome and coast, respectively. The research foci include investigations ranging from ozone transport and depletion, microphysics of polar stratospheric clouds, and use of satellite data to improve operational analyses and reanalyses used for climate research. The project will also address the meteorology of the Plateau, including precipitation accumulations over Antarctica. The modelling component will be inherently multi-scale using high-resolution mesoscale models, numerical weather prediction systems and regional and global climate models. The modelling and data sets provided will result in collaborative efforts into satellite data assimilation, Antarctic precipitation and the interplay between polar stratospheric clouds, gravity waves, vortex dynamics and ozone depletion.

AN OVERVIEW OF THE CONCORDIASI EXPERIMENTAL DESIGN

The field activities are based on a constellation of up to sixteen long duration stratospheric balloons deployed from the McMurdo station of the US National Science Foundation (NSF) by the Centre National d'Etudes Spatiales (CNES, the French space agency). Similar stratospheric balloon systems have been extensively utilized for atmospheric research. In the southern Spring of 2005, the VORCORE project deployed a constellation of 25 CNES stratospheric balloons from McMurdo (78S, 166E). VORCORE balloons drifted in the lower southern stratosphere and gathered meteorological data at 15 minute intervals. The average balloon duration was 58.5 days with the longest duration of 109 days. The trajectories of VORCORE balloons are shown in Figure 1.

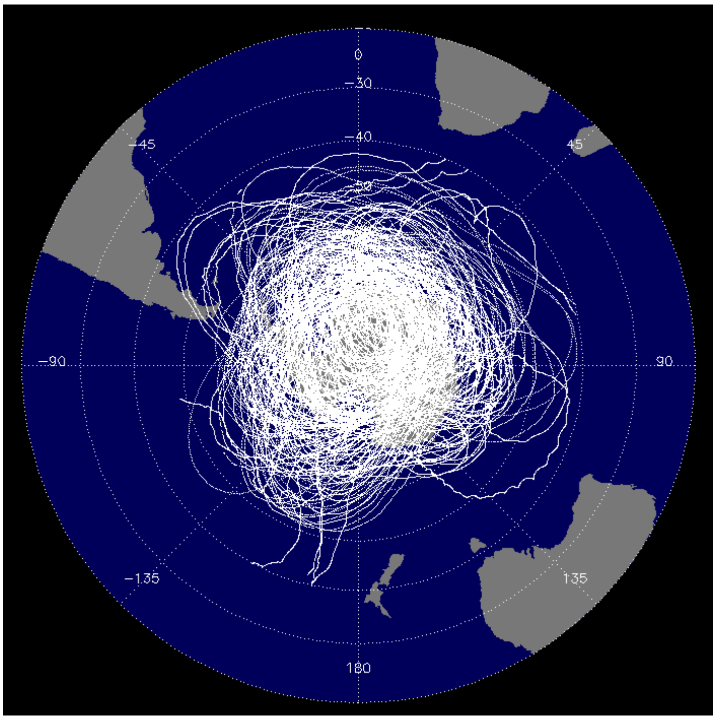

***Figure 1*: Balloon trajectories during the VORCORE experiment.**

The scientific results of VORCORE include a better knowledge of the gravity wave field, and the dispersion regime inside the polar vortex, insight into ozone depletion rates in the southern Spring, and assessment of the accuracy of analyses by operational centers. The papers resulting from VORCORE and preparatory campaigns include Cocquerez et al., 2006; Vial et al. 2006; Hertzog et al. 2007; Vincent

et al., 2007.
The potential of such balloons as research platforms is improving rapidly due to revolutionary developments in computational hardware, global positioning and communication, together with the development of low-power, miniature sensors. The balloons used in Concordiasi will have dramatic improvements over those used in VORCORE. A change in the communication system employed by CNES will increase the frequency of observations of meteorological parameters flight level from 15 to 1 min intervals, thus allowing dynamical features such as gravity waves to be directly resolved. Six of the Concordiasi flights will be dedicated to chemistry and microphysical missions. The corresponding balloons will be launched during August and September 2008, and will be designed for four-month durations. For these flights, the Laboratoire de Meteorologie Dynamique (LMD) in France is developing a small lightweight sensor able to measure ozone. Linnea Avallone from LASP also proposes to measure ozone with a LED-based UV photometer. In addition, the balloons will carry four particle counters designed for the study of polar stratospheric clouds developed by Terry Deshler's group at the University of Wyoming.

Jennifer Haase of Purdue University is proposing to upgrade the CNES balloons to carry high accuracy, dual frequency GPS receivers. Such receivers have the potential to produce GPS radio occultation profiles of refractivity. GPS radio occultation was first developed for receivers on low Earth orbiting satellites, which would record signals from higher orbit GPS satellites as they set behind the Earth's limb (Kursinksi et al., 1997). As the line of sight of the GPS signal passes successively deeper into the atmosphere, the signal path is refracted (bent and delayed) as a function of atmospheric density. The refraction is measured by the Doppler shift of the carrier frequency of the GPS signal providing information on the pressure, temperature and humidity structure of the atmosphere. The refractivity is of great value for research and for assimilation in the numerical models. GPS receivers could be fitted on aircraft (Garrison et al., 2005) and also on high altitude balloons. The best-case scenario would provide on average about 2 occultation profiles per hour for each balloon in a region that normally has over order 20 soundings per day above 60 degrees southern latitude

Concordiasi will further extend the concept of moving beyond a flight level research platform by launching up to 12 balloons in September and October 2008 that carry gondolas called driftsondes, each containing up to 50 GPS dropsondes. These dropsondes can be released upon command from the balloon flight level falling slowly to the surface producing a high-resolution vertical profile of temperature, humidity, winds and pressure. In the past, these GPS dropsondes have been extensively deployed from aircraft for research and operational prediction. The driftsonde has been successfully flown on CNES stratospheric balloons during the 2006 hurricane season for flights with durations over Africa and the tropical Atlantic (Drobinski et al. 2006).

Routine measurements are taken over Antarctica mostly along the coast, except for Amundsen-Scott and Concordia. Amundsen-Scott (US base at the South Pole) performs two radiosoundings a day. Concordia (operated by Italy and France) is located at DOME C (75S and 123E) on the plateau, and provides radiosoundings on the GTS at 12UTC. It is quite a recent site, with the first winter stay starting in February 2005 for 13 technicians and scientists. Terrestrial travel from Dumont d'Urville to Concordia takes 10 to 15 days. Concordia is ideally located to validate satellite data assimilation since the Antarctic plateau is extremely homogeneous compared to many other environments. For sun-synchronous satellites such as Aqua and MetOp, the orbital inclination is generally around 98° and the pole itself is not directly under the satellite swath, although it is covered by the edge of swath. The main idea is to enhance the radiosounding coverage at Concordia, to bring it up to the level of twice a day, similarly to Amundsen-Scott. Furthermore, additional radiosoundings will be taken at specific times to document local weather conditions for more detailed precipitation studies over the plateau. In addition to the soundings, specific instruments for meteorological, snow fall and accumulations observations will be deployed at Concordia by the Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE) with funds from the Institut Paul Emile Victor (IPEV), the French Polar Institute. It is also envisaged to enhance the frequency of soundings at Dumont d'Urville on the coast.

In addition to the observational component, Concordiasi comprises an extensive modelling and data assimilation effort. Meteo France will conduct global and high-resolution simulations. The French global model ARPEGE (eg Fourrié et al., 2006), developed in collaboration with ECMWF, uses Four-

Dimensional Variational Assimilation and will be adapted to have a higher spatial resolution over Antarctica. The French limited area model, MesoNH, or its numerically efficient version AROME, will be nested, with a grid as fine as 2.5km. Simulations will also be conducted with the Antarctic Mesoscale Prediction System (AMPS) project (Powers et al 2003), run jointly by NCAR and The Ohio State University. AMPS was designed to provide numerical weather prediction (NWP) support to the US Antarctic Program (USAP) and a host of foreign nations. The high-resolution models will prove valuable in resolving many processes critical to the climate system over the region such as vertically propagating gravity waves that can influence stratospheric clouds, orographically-induced circulations and mesoscale vortices that result in intense precipitation events. The global models will allow for investigations of the teleconnections between Antarctica and lower latitudes. The regional climate model will provide the link between these two systems, and will support efforts aimed to a better parameterization of critical physical processes in the coarse grid models. The French modelling effort will also have a strong data assimilation component aimed at improving the analysis and reanalysis products over Antarctica. The validation at fine scale will be performed in particular by Christophe Genthon from Laboratoire de Glaciologie et Géophysique de l'Environnement, LGGE, (Genthon et al., 2005, Krinner et al, 2006). The impact of these improvements to the simulations and forecasts of the ozone profile will also be assessed using a chemical-transport model.

SCIENTIFIC GOALS

Ozone depletion, NAT clouds and stratospheric dynamics

The largest ozone depletion on Earth's atmosphere occurs in southern-hemisphere polar stratosphere. Most of the interannual variability of the Antarctic ozone-hole is caused by dynamical factors, such as the activity of stratospheric waves that significantly modulate the background temperatures and thus the potential for Polar Stratospheric Cloud (PSC) formation. Long-duration balloons deployed during Concordiasi will carry instruments aimed at providing information of high relevance to those stratospheric processes, and particularly to the links between stratospheric chemistry, dynamics and microphysics.

VORCORE and previous superpressure balloon flights have shown that mesoscale gravity waves can be fully characterized from in-situ observations on-board superpressure balloons. During Concordiasi, the in-situ meteorological observations will be performed more frequently than during VORCORE (1 obs/min. instead of 1 obs/15 min.), which will allow for more detailed information on high-frequency gravity waves that can also be generated by orographic effects. In comparison with the VORCORE dataset, the accuracy of pressure and temperature observations will also be higher. This will permit to improve the estimation of gravity-wave momentum fluxes, and thus to better characterize the role of those waves in driving the middle-atmosphere global-scale Brewer-Dobson circulation.

In conjunction with these meteorological observations, LMD is currently developing a small lightweight sensor able to perform ozone observations during long-duration flights. Since superpressure balloons behave almost as Lagrangian tracers, the information gathered along their trajectories will allow for direct estimations of ozone-loss rates. There are still uncertainties on the rates of catalytic reactions involved in ozone depletion: laboratory estimates of those rates are generally too small to explain the observed ozone loss. Observations of temperature, position (and thus solar zenith angle) every minute, and of ozone concentration typically every 30 minutes during the flights will provide strong constraints on the catalytic rates. They will also help to determine if there are regions in the Antarctic polar vortex where ozone depletion is more likely to occur (for instance in the lee of the Antarctic Peninsula).

Meteorological and chemical observations will be complemented by microphysical measurements. Particle counters designed for PSC study and developed by Terry Deshler's group at the University of Wyoming will be flown on the same flights than the ozone sensors. It will thus be possible to get direct Lagrangian information on the links between particle nucleation (especially NAT nucleation) and temperature history of air parcels, and in particular to determine the relative importance of synoptic-scale and meso-scale (gravity wave) cooling in the formation of PSC, which is still uncertain at the present time.

The impact of improvements on the simulations and forecasts of the ozone profile will also be assessed using the French chemistry and transport model and assimilation system MOCAGE-PALM, developed in collaboration between CNRM/GAME, Laboratoire d'Aérologie and CERFACS. This model has the capability to assimilate level 2 satellite chemical data, generally using a variational 3d-fgat technique. MOCAGE-PALM presents several options for the representation of chemistry, ranging from cost-efficient linear parameterizations to a comprehensive tropospheric and stratospheric scheme (118 species, including also heterogeneous chemistry processes on PSCs). Good performances have already been obtained with this system (for instance : Geer et al., 2006, Bencherif et al., 2007; Massart et al., 2007; Semane et al., 2007). The specific aspects of stratospheric ozone data assimilation within Concordiasi will be the use of a high horizontal and vertical resolution (0,5°, L60 or L90), now available with MOCAGE-PALM, thus with an interesting potential for better representing and quantifying chemical and dynamical processes in this region of large horizontal and vertical gradients. The expected advances in meteorological data assimilation and the independent verification data which will be obtained are major added value to this study also.

Data assimilation

Observations and analyses of the atmosphere are essential for scientific studies at various time scales. Analyses can be used as initial conditions for real-time forecasts which can then be used to understand and predict polar meteorology, in particular in support of operations in the Polar regions. For climate research, re-analyses are very powerful tools to document past atmospheric conditions. The construction of analyses/reanalyses relies on numerical models and the fields produced by these models can be used for a variety of purposes including deriving parameters in poorly sampled areas, defining the relationship between variables and their behaviour in space and time and to detect errors in the observations. The general goal of data assimilation, particularly for studies related to the climate record, is thus to incorporate as much data as possible to avoid drawing conclusions that are model dependent. Over Antarctica, the scarcity of conventional data coverage needs to be compensated by satellite data particularly those in polar orbit. Thus studies have shown that satellite data have a much larger impact in Antarctica than in other better-observed areas such as the Arctic for instance. The satellite data impact brought successes in data assimilation. However, challenges remain and the usage of satellite observations still needs to be optimized (eg Fourrié and Rabier, 2004). This is particularly true for the new generation of advanced hyperspectral sounders, such as AIRS on Aqua, IASI on MetOp and the future CrIS on NPOESS.

Fig. 1 shows examples of IASI spectra over Antarctica indicating the spatial variations in the spectra measurements. These spectra in the infra-red possess information on temperature and humidity profiles, as well as on trace gases. The signal over the polar regions is weaker than in other areas due to the very cold atmosphere. However, absorption lines are clearly visible and signal can be extracted from these data. Key impediments for a successful assimilation of advanced sounders over polar regions are cloud detection and surface contribution to the measured signal. As an example, clouds over very cold surfaces in a stable atmosphere will appear warmer in infrared data compared to the underlying surface. This signal is the opposite to that expected in most cloud detection schemes.

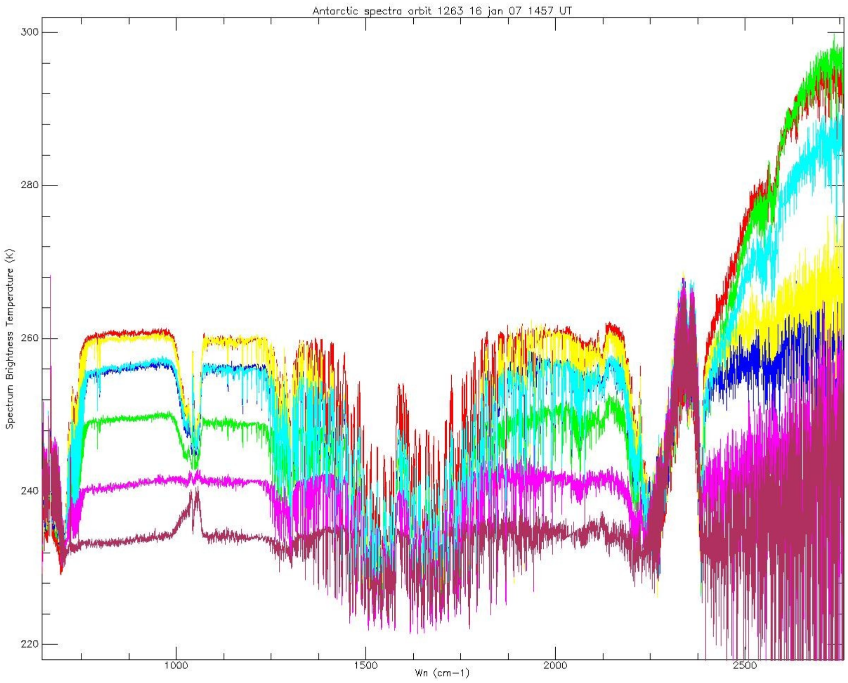

***Figure 1*: a) Real spectra from IASI data over the Antarctic. The spectrum shows brightness temperature values as a function of wavenumber. The various locations (latitude, longitude) for the spectra are -70,-108, -80,-145, -81,-167, -78,-134, -76,-124, -78, 140 and -74, 125 respectively. b) Latitudinal variations in IASI spectra (equatorial regions are at the top, Antarctic at the bottom. Courtesy T. Phulpin, CNES.**

Furthermore, polar stratospheric clouds are difficult to detect and can alias the temperature signal.

Another issue in the use of satellite data is the significant variability of the polar surface (particularly in terms of temperature and microwave surface emissivity away from the more homogeneous conditions over the high plateau), since channels designed to provide temperature information in the mid-troposphere still have a 10% sensitivity to the surface. Thus errors in modelling surface emission in these channels can be harmful for retrieving the useful atmospheric signal. An example of the variability of retrieved emissivity (Karbou et al., 2006) is provided in Figure 2. Studies will be performed on how to improve the estimation of microwave emissivity over Antarctica.

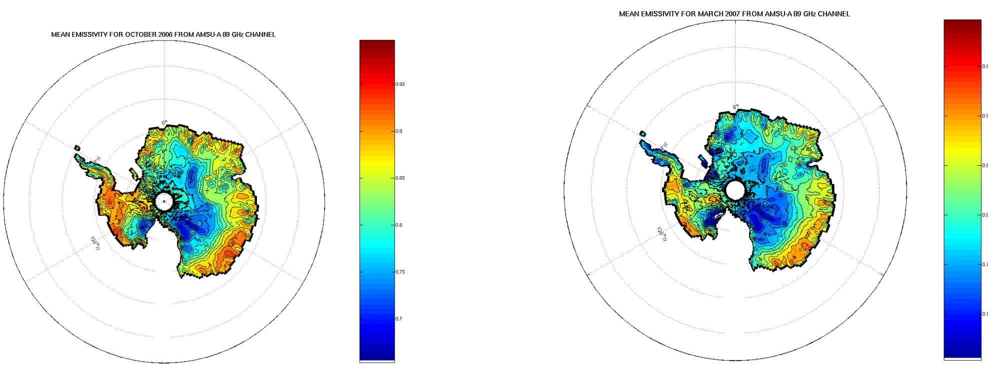

***Figure 2*: Estimated mean emissivities for AMSU-A at 89 GHz for October 2006 (left-hand panel) and March 2007 (right-hand panel).**

As a consequence of both these issues, usage of low-peaking channels is very limited over the poles, and should be enhanced. In-situ measurements can provide ground truth to validate our assumptions/methods, in particular over inland Antarctica.

Predictability studies: Precipitation and Impacts on Lower Latitudes

As stated earlier in this paper, one of the major goals of Concordiasi is the improved predictions of high impact weather events over the southern polar regions and a better understanding of the predictability of such events. For the mid-latitudes, it has been shown that addition of "targeted" in-situ data based on predictability information can result in higher forecast skill (e.g., the Winter Storm Reconnaissance Program). The general concept is to enhance data gathering in regions where increases in the analyses accuracy (e.g., the initial conditions quality) has large pay-offs in terms of improving predictions from those initial conditions. A scientific question is whether this scenario holds for the polar regions, particularly since the approach seems to have larger impacts in data sparse initial conditions. The driftsonde observations are ideally suited for experimentation in that context. It is planned to gather information about predictability from a version of the ECMWF Ensemble Prediction System focused on the lower latitudes in collaboration with ECMWF, and to deploy observations in the sensitive areas as well as quite uniformly. This will give us the opportunity to perform data assimilation experiments with various observation scenarios. It will then be possible to evaluate the potential of the driftsondes to improve the NWP system over the polar areas, and possibly more generally over the Southern Hemisphere. Impact at lower latitudes will be evaluated in particular in collaboration with BMRC (Australia).

A critical component of Concordiasi is the better understanding and predictions of precipitation accumulation over Antarctica. Substantial amount of work will focuss on the Plateau region. This work will use high-resolution models and in-situ measurements in Concordia. The analysis of the results from the multi-scale model approach will suggest ways to improve the treatment of precipitation-related processes in the models.

For more information about Concordiasi, please visit the site http://www.cnrm.meteo.fr/concordiasi/

ACKNOWLEDGEMENTS

The support from IPEV, PNRA, NCAR, the NSF and CNES is warmly acknowledged.

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