THE CONCORDIASI FIELD EXPERIMENT OVER ANTARCTICA

First Results from Innovative Atmospheric Measurements

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Concordiasi is a multidisciplinary effort jointly operated by France and the United States to study the lower stratosphere and troposphere above Antarctica as well as the land surface of the Antarctic continent. Concordiasi field experiments took place in austral springs 2008, 2009, and 2010, including surface measurements and radiosoundings at the Concordia Antarctica station at Dome C and radiosoundings at the Dumont d'Urville and Rothera sites on Antarctica. In 2010 an innovative constellation of balloons provided a unique set of measurements covering both volume and time. The balloons—13 driftsondes and six balloons with tethered gondolas dedicated to middle atmosphere measurements—drifted for several months on isopycnic surfaces in the lowermost stratosphere around 18 km, circling over Antarctica in the winter vortex. The balloon flotilla formed a regional observatory of the atmosphere, which provided in situ measurements inside

CONCORDIASI WORKSHOP

WHAT: Twenty-seven participants from the United States and Europe gathered to share and discuss the first results obtained from the 2010 Concordiasi field campaign in Antarctica. This is the second international workshop on Concordiasi.

WHEN: 21–22 October 2011

WHERE: Boulder, Colorado

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the winter stratospheric polar vortex and allowed the performance, on command, of hundreds of soundings of the troposphere. The in situ measurements included position, temperature, pressure, ozone, and aerosol particles, as well as profiles below the balloonborne gondolas, which included temperature, pressure, humidity, and winds. The launch campaign took place from the U.S. McMurdo Station, located at 78° south latitude. Nineteen balloons were launched between 8 September and 26 October that year. The mean flight duration was 69 days, while the longest flights lasted 95 days. The total number of days for the flotilla was 1,316 (summing up the flight days for each of the balloons), and the size of the constellation (balloons in the air at the same time) peaked at 17 balloons.

A meeting to exchange details of the 2010 Concordiasi balloon campaign as well as earlier observations and findings occurred in the fall of 2011 at the National Center for Atmospheric Research (NCAR). Discussion and results presented at the workshop[1] covered the following areas, which are detailed in this summary of the meeting: atmospheric gravity waves, the GPS/radio occultation technique, ozone and aerosol particle observations, the driftsonde instrument and dropsonde dataset, satellite comparison and validation, performance of numerical weather prediction (NWP) models, data assimilation, and modeling of Antarctic surface and near-surface properties.

STRATOSPHERIC BALLOONS, GRAVITY WAVES, AND GPS/RADIO OCCULTATION MEASUREMENTS. A constellation of long-duration balloons over Antarctica had first been deployed in the late winter 2005 by France's National Centre for Space Studies (CNES) and Laboratoire de Météorologie Dynamique (LMD). Concordiasi was aimed at wider scientific goals, making use of new balloon systems that offer more capability. Its larger balloons could carry payloads three times heavier than standard balloons used for atmospheric study; a renewable energy system was developed, increasing onboard power by an order of magnitude; and a control system built on satellite communications systems was set up for flight control as well as for monitoring instruments and downloading data. Data were indeed distributed fast enough to be placed on the Global Telecommunication System (GTS) in real time.

In-situ balloonborne meteorological observations are useful to study the activity of mesoscale gravity waves above Antarctica and the surrounding oceans. Because of the quasi-Lagrangian behavior of long-duration balloons, the gravity wave intrinsic frequencies and momentum fluxes can be directly inferred from these observations. During Concordiasi, these observations were made every 30 seconds so as to resolve the whole spectrum of gravity waves. First analyses indicate the signature of mountain waves above the Antarctic Peninsula and significant activity above the ocean. The analysis will be expanded by examining the soundings performed during the campaign as well as by the precise-positioning GPS measurements, from which the vertical wavelengths and phase speeds can be derived. A proof-of-concept balloonborne GPS radio occultation system was furthermore deployed on two of the Concordiasi campaign balloon flights to provide refractivity and derived temperature profiles for validation and improving satellite data assimilation. The two systems recorded 711 occultations, which is comparable to the total number of dropsonde profiles. Preliminary data analysis showed that the observed excess phase delay profiles agree with those simulated from models and data from dropsonde profiles. Of these profiles, 32% descended to 4 km above the surface, without open-loop receiver tracking technology, demonstrating that it is possible to retrieve useful information with relatively simple low-cost instruments.

OZONE AND PARTICLE OBSERVATIONS. The in situ observations of temperature, ozone, and particle size from the Concordiasi balloons provided new observations, along near-Lagrangian trajectories, of the evolution of ozone and particle size as the sun returned to the Antarctic stratosphere. The instruments were designed to take advantage of this unique opportunity to observe, along air parcel paths, changes in ozone due to photochemical destruction and changes in particle size due to temperature changes. The ozone measurements were made on six balloons, four of which were launched in early September. Comparisons of ozone measured on the long-duration balloons with observations from satellite [*Aura* Microwave Limb Sounder (MLS)] and specially launched ozonesondes show good agreement. The Concordiasi payloads provided unique observations of ozone from which near-instantaneous ozone loss

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[1] The Concordiasi workshop was coorganized by NCAR's Earth Observing Laboratory (EOL) and the National Centre for Meteorological Research's Research Group of Atmospheric Meteorology (CNRM-GAME) [a joint effort between Météo-France and France's National Centre for Scientific Research (CNRS)].

rates can be determined. Initial calculations suggest that ozone is being lost at rates up to 10 ppb per sunlit hour, which is slightly larger than published values. Further analysis will include comparisons between observed ozone loss rates and those calculated with various photochemical models along the balloon trajectories. These evaluations are expected to shed light on some of the remaining uncertainties in polar stratospheric chemistry. On two of the particle flights, one lasting 5 days and the other 19 days, only a few particles larger than 0.25-μm radius were observed, even though the balloon entered regions cold enough for polar stratospheric clouds to grow on the background aerosol. Perhaps this highlights the difficulty in nucleating nitric acid trihydrate particles when temperatures remain above the ice point. In contrast, on the last flight, lasting 30 days, particles larger than 0.5 μm were nearly continuously sampled, even at relatively warm temperatures for polar stratospheric clouds. Understanding the source of these particles remains a challenge for these observations.

DRIFTSONDE DATA. The needs of the Concordiasi field campaign spurred technological advances of the NCAR driftsonde system, which provided unprecedented high-quality, high-vertical-resolution upper-air observations from float level to the surface. Its usability and reliability exceeded that of past driftsonde projects. Technical changes improved the dependability of dropsonde releases from the gondola, incorporated solar panels and internal sensors to maintain the gondola's internal temperature, and greatly improved the reliability of information transfer through the Iridium satellite constellation. Ground software allowed scientists to easily schedule dropsonde releases from any of the driftsondes—for example, to coincide with an Infrared Atmospheric Sounding Interferometer (IASI) overpass. Scientists and driftsonde specialists could view the data and monitor the status of all gondolas. Overall, the 13 driftsonde gondolas returned 644 high-quality profiles, with only 14 failed drops. To optimize the deployment of the ~640 dropsondes, the CNRM and NCAR/EOL predicted colocations with other observing platforms and dropped accordingly. Colocations with the *Meteorological Operation (MetOp)-A* satellite were used to calibrate IASI data assimilation in numerical models. Colocations with Concordia station allowed the dropsonde measurements to be checked against radiosonde ascents, which enriched the study of the boundary layer over the plateau. Further deployments targeted gravity wave–prone regions and areas with high sensitivity for numerical weather prediction to study the predictability of the tropospheric flow. The realized colocalizations are generally of high although variable quality.

The National Oceanic and Atmospheric Administration (NOAA) Products Validation System (NPROVS) is being used to collect and compare colocated dropsonde/radiosonde and multiple satellite temperature profiles. Consistent cold biases are found in all satellite data except those from the Microwave Integrated Retrieval System (MIRS) in the upper troposphere and the IASI retrievals in the lower troposphere. The cold bias is larger in the dropsonde data than the radiosonde data. Since nearly all radiosonde stations are located along the coast, this difference reveals a larger cold bias over the Antarctic continent than the coast and ocean. The satellite data can reproduce observed temperature profiles reasonably well in spite of the biases. In addition to temperature and humidity profiles, cloud properties can be retrieved from IASI measurements. A pragmatic approach is the CO_2-slicing technique, which returns the cloud-top pressure and the cloud effective amount of an equivalent single-layer cloud within the IASI spot. Such retrievals are highly dependent on the quality of the temperature and humidity profiles used as input to the algorithm. The IASI cloud retrievals over sea ice and over Antarctica have been compared to retrievals from the A-Train constellation of satellites in coincidence with dropsondes. The main limitations for an accurate IASI cloud retrieval are shown to be an accurate surface temperature description and orography.

IMPACT OF THE DATA IN NWP MODELS IN THE SOUTHERN POLAR AREA. It was shown that the performance of NWP analyses and forecasts have dramatically improved over the last decade. However, large systematic differences remain in analyses from various models for temperature over Antarctica and for winds on the surrounding oceans. Concordiasi meteorological observations, both at the gondola level and from the dropsondes, were used in real time at NWP centers. A comparison between short-range forecasts and the data was investigated for centers in the United States, France, Canada, Japan, Germany, and the United Kingdom. Results show that models suffer from deficiencies in representing near-surface temperature over the Antarctic high terrain. The very strong thermal inversion observed in the data is a challenge in numerical modeling because models need both a very good representation of turbulent exchanges in the atmosphere and of snow processes to be able to simulate this extreme atmospheric behavior. Dropsondes were shown to have a positive impact on the forecast performance in four different models, with an impact of the same order of magnitude as the one brought by radiosondes. The total short-range forecast error reduction produced by assimilation of dropsonde observations from Concordiasi is smaller than that provided by satellite radiance and wind observations, although the average error reduction per observation is much larger for dropsondes compared to satellite data. For the dropsonde observations, both temperature and wind data have more impact when they are closer to the pole, with temperature information contributing most at low levels while wind information dominates at high levels (<400 hPa). On a per-observation basis, however, both wind and temperature have larger impact closer to the surface (lower troposphere). This corresponds to areas where there are very few other competing observations, mainly because of the difficulty of using satellite radiance information close to the surface, especially over high terrain.

The development of a Lagrangian approach to assimilating the driftsonde positions into the Goddard Earth Observing System model, version 5 (GEOS5) assimilation system at NASA's Global Modeling and Assimilation Office was presented. Lagrangian assimilation utilizes position observations by producing a forecast of the balloon positions through a forward model of the balloon trajectory. The correction to the wind fields is done through the tangent linear and adjoint of this model. Initial testing of the Lagrangian assimilation in three-dimensional variational analysis (3DVAR) mode showed that it is essentially equivalent to assimilating derived winds from the balloons. The full impact of this approach requires 4DVAR assimilation (to make use of the adjoint model), which will be done in a near-future investigation.

INTERACTIONS OF THE LOWER ATMOSPHERE WITH THE SNOW OVER ANTARCTICA. At the surface, particular attention has been paid to observing and modeling the interaction between snow and the atmosphere, which controls surface and near-surface temperatures and strongly influences the radiances as measured by the IASI satelliteborne sensor. The Dome-C Concordia station has been the focal point of this activity, thanks to its exceptional instrumentation, which allowed for profiles of the atmosphere from a 45-m tower as well as turbulence and radiation observations, and snow profiles, among others. Both NWP operational and research models have been evaluated. This research has led to an improvement of snow representation over Antarctica in the Integrated Forecasting System (IFS) model at the European Centre for Medium-Range Weather Forecasts (ECMWF). Coupled snow–atmosphere simulations performed at Météo-France with the Crocus and Applications of Research to Operations at Mesoscale (AROME) models have been shown to realistically reproduce the internal and surface temperatures of the snow as well as boundary layer characteristics.

OUTLOOK. Concordiasi data will continue to be used to calibrate satellite retrievals and data assimilation in the challenging Antarctic environment and to understand ozone loss linked with polar stratospheric cloud formation and gravity wave activity. Data will also be used for testing and attempting to improve climate and weather prediction models. Several specifics include the ability of the models to represent the observed pattern of complex cloud structures, the strength of the stable boundary layer profile over the interior of the continent, and the ability of the model to predict the spatial pattern and amplitude of gravity waves and the accompanying momentum flux.

Concordiasi data can be accessed online at www.cnrm.meteo.fr/concordiasi-dataset/.

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