Atmospheric processes in the polar regions : Observations and modelling for climate analysis and change predictions: POLARMOB (Polar Meteorology Modelling and Observations)

Partnership: Partners / sub-partners
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1. Introduction

Quoting Chapter 11.8, on the Polar Regions, of the 4th IPCC report (IPCC 2008), « ... processes that are not particularly well represented in the models are clouds, planetary boundary layer processes and sea ice... ». The models are those climate models that are used to tentatively predict global and regional climate change. While the sea-ice issue may be related to the ocean and ice rheology (Rampal et al?), clouds and atmospheric boundary layer (ABL) processes are purely atmospheric issues. Clouds directly impact on radiation, albeit in complex ways, and the issue should be reported as a cloud-and -radiation one really. Although precipitation is not quoted, clouds are also directly related to precipitation. Polar precipitation differs in several ways from precipitation else-where. In the first place, it is solid more often than not, but there are other major differences. The polar ABLs also significantly differ from elsewhere, including and in particular in the fact that they are more often, more strongly, and more durably stable than elsewhere. These differences induce that the parametrisations that have been implemented in the models to represent the corresponding processes in the lower latitudes have drawback in the polar regions. Specific development or adjustment in the polar regions is insufficient because of a lower priority in the climate modelling groups compared to more temperate regions, but also because of a lack of adequate observations to evaluate, calibrate and validate the models. Access to the most extreme parts of the polar regions requires significant, specific and not readily available logistics. Running instruments is correspondingly demanding, both on the instruments themselves and on the operators, because of the harsh conditions. Because the processes differ, the instruments that are used elsewhere and are commercially available cannot be used, or need to be comprehensively adapted for operation in the polar regions. In the case of processes that marginally affect the rest of the world but are ubiquitous and significantly shape the environment and the characteristics of the atmosphere in the polar regions, like blowing snow, the market of instruments is very narrow. This results in limited availability and high cost.

This project aims at collecting available observation that are appropriate to evaluate and improve the polar parametrisations in the models, and fill the gaps where and when observations are missing as logistics is available to do this. Then, observations are use to evaluate the models that are being used in IPCC exercises, that is, at the moment the CLMIP5 dataset. For the French models, better parametrizations and/or calibrations will be searched for and tested. The project builds on existing and ongoing field campaigns, some organized as an observatory framework, launched as part of previous research programs. It also builds on existing expertise on the models, and on research manpower available as of 2011 due to the recruitment of a new scientist and 2 starting PhDs at the coordinating partner institution. Although the project will not deliver for the ongoing preparation of the next IPCC assessment, it will build on the IPCC5 model results archive (CLMIP5) and, considering the time it takes to improve and validate a model, will aim at improving models for the following assessment. The project will address and concentrate on clouds and radiation, precipitation, ABL, and blowing snow in the polar regions. The importance of these issues is further described in section 2. The state of the art in the partnership, both with respect to observation and to modelling is described in the section 3. In section 4, objectives and methods for new observation are described. Finally the evaluation and improvement of the models in described in section 5.

2. Polar clouds and radiation, precipitation atmospheric boundary layer and blowing snow

As the climate gets more extreme (higher latitude, higher altitude, and thus colder), atmospheric and cloud moisture content get thinner, and hydrometeors get smaller. Polar clouds are generally ice although liquid water has been detected at temperatures well below 0°C (reference télédétection). Size, altitude and concentration of liquid or ice particles strongly affect the surface energy balance and, in a meteorological model, the simulated surface temperature (Gorodeskaya and Gallée 2009). but such information is poorly known. Supersaturation, a rather rare instance in the troposphere in non polar regions, is very likely in the coldest Antarctic environment. Figure 1 shows the observation, the analyses by the European Center for Medium-range Forecasts (ECMWF) and the simulation by the Model Atmosphérique Regional (MAR, Gallée et al.) mesoscale model, of the atmospheric relative humidity in the surface ABL at Dome C on the Antarctic plateau (Genthon et al., 2012). Both models suggest significant supersaturation with respect to ice. This is not unlikely as the very clean atmosphere lacks cloud condensation nuclei and heavy frost deposition is observed on every kinds of surfaces. This is probably the reason why the in-situ moisture sensors report close to saturation but no significant supersaturation: Excess moisture deposits on structures near the sensors before it can reach the sensors themselves.

Glaciological reconstructions and stakes observations by the GLACIOCLIM-SAMBA observatory (http://www-lgge.ujf-grenoble.fr/ServiceObs/SiteWebAntarc/background.html) indicate that net annual snow accumulation on the Antarctic plateau is only about 10 cm per year, which converts into only about 3 cm per year of water equivalent. How snow accumulates, how much of it is precipitation versus condensation on the surface, how much of it remains there rather than being evaporated or blown away is currently unknown. None of these components of the surface mass balance on the Antarctic plateau is evaluated through measurement because of the tiny quantities involved and the harsh conditions. Obviously, the traditional methods to measure precipitation elsewhere (rain-snow gauges) don't work in such environment and to measure such low quantities. Observation is also lacking in the peripheral regions of Antarctica. The reasons why the traditional instruments don't work there, although accumulation can reach several tens of cm or even several meters of water equivalent per year, is because of strong and persistent catabatic winds that blows large quantities of snow and affect the measurements. The very contribution of blowing snow to the surface mass balance of the Antarctic ice sheet is unknown and none of the IPCC models simulate this process. The MAR model suggests it may account for up to 30% of the surface mass balance. For any component of the continental ice, including and in particular the Antarctic ice sheet, the issue of the mass balance and change with climate is that of sea-level: any water that is not stored in continental ice ends up in the ocean. Concerning the Antarctic precipitation, all but on of the models that have contributed to the IPCC fourth assessment report (IPCC, 2007) predict an increase of the Antarctic precipitation by the end of the century. However, this increase ranges from almost 0 to up to 50%, depending on the model. This is obviously a huge uncertainty which, with the current rate of snow accumulation, translates in about 3 mm/year of uncertainty on sea-level rise (Genthon et al. 2009).

As quoted in the last IPCC report (Introduction), the polar ABL processes are poorly accounted for in current climate models. This is in part because observations are lacking to adjust and verify parameterizations of strongly and durably stable ABL. Figure 2 shows the vertical profiles of atmospheric temperatures in July at the beginning and at the end of the century above the Antarctic plateau for one of the 2 French climate models that have participated in the last IPCC report. The overall profile of temperature change is typical of that of a climate change induced by an increase in greenhouse gas: warmer in the lower layers, colder higher up. However, a zoom on the lower atmosphere above the surface shows a different story: The predicted temperature change at the surface is larger than just 50 m above the surface. Figure 3 shows that the ABL on the plateau is typically very stable in July (local winter) Thus, the model predicts a decrease in the strength of the strong winter inversion. However, figure 4 shows that, for the model, the winter temperature inversion on the Antarctic plateau is strongly underestimated. Even the summer nocturnal inversion is underestimated in the ECMWF meteorological analyses (Genthon et al. 2009). However, although campaigns have been organized to characterize the polar ABL (SHEBA), there are very few long term records available in the most extreme polar regions.

3. State of the art in the partnership

3.1. The field observation system

SAMBA (SurfAce Mass Balance of Antarctica) is the Antarctric component of the INSU (Institut National des Sciences de l'Univers) GLACIOCLIM (les GLACIers, un Observatoire du CLIMat) observatory (SO, Service d'Observation). GLACIOCLIM aims at monitoring the mass balance of glaciers in various climatic parts in the world (Alps, Andes, Antarctica). SAMBA was devised and set up by the proposed coordinator of the present project (C. Genthon, henceforth CG) in a way that, as best as possible considering the logistical constrains and limitations, optimizes the observation systems to allow the evaluation and validation of climate models. In particular, SAMBA includes a 150 km SMB stakes line that is surveyed every year and allows for sampling spatial variability in the coast-plateau transition region at scales relevant to those of the typical resolution of a meteorological or climate model (Agosta et al. 2011). As logistics is a major aspect of such program, a specific IPEV (Institut Polaire Paul-Emile Victor, the French polar institute) program was set up.

After passing on the responsibility of SAMBA (including the corresponding IPEV program) to newly hired observatory staff, CG then launched complementary field programs to observe some of the atmospheric processes that determine the surface mass balance of Antarctica, and the Antarctic ABL. In particular, after showing with an atmosphere – snowpack model that the observations of negative surface mass balance in the coastal-most part of SAMBA was essentially due to wind erosion and blowing snow (Genthon et al. 2009), CG organized for a LGGE-CEMAGREF collaboration to launch a major blowing snow observation campaign. The campaign is on going, again with support by IPEV (program (CALVA-1013, http://lgge.osug.fr/~christo/calva/home.shtml), and again with a design optimizing the acquisition of observations relevant to evaluate atmospheric models. This includes the MAR model, probably the meteorological model with the most physically based parameterizations of blowing snow (Gallée et al.). The blowing snow observation campaign was recently described in Genthon et al. (2011). Adélie Land is one of the most appropriate region to run such a campaign due to strong and persistent catabatic winds and blowing snow. Although logistical support is crucial, such a campaign would not have been possible without additional financial support to acquire, deploy and maintain instruments. Such funds have been provided by the ICE2SEA FP7 European project (www.ice2sea.org), which will end in 2013.

Estimation of surface friction (e.g. friction velocity) is necessary to evaluate of parameterization of snow erosion. To this end, a 7-meter profiling tower was deployed at one of the observing sites (Figure 5) which has allowed verifying that Kolmogorov theory holds in strong catabatic regime. Actually, CALVA-1013 is an IPEV field program that aims well beyond blowing snow observation. It also hosts observations of the boundary layer at Dome C, near the Concordia permanent station that is jointly operated by IPEV and the Italian polar Institute (PNRA). There, an exceptional facility is available to profile the lower atmosphere: a 45-m tower (figure 6). The tower was equipped with meteorological instruments in early 2008. The data obtained in the first few weeks of observation were already of high interest, and already pointed to failure of models (the ECMWF analyses, rather) in such extreme conditions (Genthon et al. 2010). In early 2009, some of the instrumental system was adapted and/or changed to better sustain the harsh winter conditions and or avoid measurements biases identified in 2008. This includes setting temperature sensors in mechanically aspirated shields to prevent radiation biases that can reach more than 10°C in low wind conditions (Genthon et al. 2011). The currently operated temperature measurements on the Dome C tower are probably the only ones not affected by radiation biases.

The measurement of solid precipitation in the polar regions is a serious issue (Goodison?). There is arguably no credible report of precipitation in Antarctica. Disdrometers have been deployed both in Adélie Land and at the Dome C as part of the current programs. However, again, due to the specific local conditions for which commercial instruments have not been designed, and in Adélie Land due to blowing snow, the reports from those instruments are questionable and clearly erroneous in terms of precipitation quantities.

3.2 Modeling

LMDZ, MAR, MESO-NH, ARPEGE / AROME?

4. Observing scheme

5. Model evaluation and improvement