Dynamical impacts of the Andes on the Argentinian and on the global climate

proposed research for collaborations within the IFAECI
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The climate in South America is largely controlled by the presence of the Andes. In the tropics and subtropics they deflect toward the south and on their eastern flanks the trade winds coming from the Atlantic yielding the South American Low Level Jet (SALLJ, Vera et al. 2006). This jet transports a considerable amount of moisture from the Amazon region to the La Plata basins. The southward extent to which the SALLJ transport moisture is modulated by synoptic and mesoscale systems (Liebmann et al. 2004). In summer and spring, this moisture contribute to the development of the Mesoscale Convective Systems (MCSs, Durkee and Mote 2009) that develop over the continent in the subtropics and in the lee of the Andes (Machado and Laurent 2004, Saliot et al~2007). Note nevertheless that for a good fraction of the MCS, or for the Mesoscale Convective Complex which contain fews MCSs (Maddox 1980), the moisture flux also comes from the Atlantic (Teitelbaum et al. 2008). In winter the southward intrusion of the LLJ can be limited by the cold surges that initiate in the southern midlatitudes and produce cold air masses that travel toward the subtropics along the eastern flank of the mountain (Garreaud 1999, Lupo et al. 2001). At even smaller horizontal scale, the Andes produce large gravity waves that can also have a direct local impact on precipitations. Although the timing of this different sub-synoptic scale and mesoscale phenomenon is largely controlled by the synoptic systems that develop over the Pacific ocean and cross the continent, so is quite predictable, their intensity and individual duration are more difficult to predict. As an illustration, it is a well known fact that the simulation of the SALLJ by General Circulation Models (GCMs) or Numerical Weather Prediction models (NWPs) is strongly sensitive to the model formulation (for instance its horizontal resolution in Silva Dias et al. 2001). As another illustration, some of these phenomena cannot be resolved in GCMs, like a good part of the mountain gravity waves, simply because their horizontal scale is smaller than the horizontal gridscale of the models.

Because the Andes have a very high elevation, they modify the large-scale and synoptic dynamics in an essentially nonlinear way. As a consequence, the separation of scales made above to briefly classify the impact of the Andes on the local weather is not really justified. The small-scale dynamics affect the mesoscale and sub-synoptic scales dynamics, which themselves affect the large scale dynamics. This leads to model biases, and important processes like model precipitations, surface T variability are not well represented in the state-of-the-arts Earth Simulation Models that will be used to predict the future evolution of the Earth Climate. For the Argentinian and South American climate this can be a very significant issue. In fact, these errors can be strongly amplified since these regions are known to respond strongly to the ENSO, that is the leading mode of inter-annual climate variability. For the global climate these issues can also be very significant since the Andes are the major sources of gravity waves in the southern hemisphere, and an important source of Rossby waves, both largely driving the mean climate and variability in the southern-hemisphere stratosphere. Accordingly, there is a strong need to address the dynamical role of the orography representation in these models, and to improve their representation.

This objective is composed by three steps, first by making an objective evaluation of the way models represent the Andes, second by improving their representation using parameterizations of the GWs dynamics and of the boundary layer dynamics, and third by evaluating the impact of these improved parameterization on the local and global climate.

Evaluation of the representation of orography in state-of-the Art GCMS.

Concerning the dynamical evaluation, the separation of scale we assumed before, together with the large variety of phenomena considered, call for diagnostics that rely on fundamental fluid dynamics. One among these diagnostics is the Atmospheric Angular Momentum budget, since all the phenomenon described before tends to modify it in a quite comparable way, that is through exchange of momentum with the earth surface building up torques . This diagnostics has already been used for the Tibetan plateau (Mailler and Lott 2010) and to measure how it affects the pre-conditionning phase of the cold surges. If we keep this example, it can also help in understanding the precipitation variability in a similar way as was found in far-east Asia where the late phase of the cold surges impacts on the winter monsoon variability over the South China sea (Mailler and Lott 2009). Even more recent analyses show that these diagnostics applied to GCMs can be used to measure the impact of subgrid scale parameterizations of orography.

Another diagnostics to quantify the exchange of momentum is using inverse techniques. Sources of model errors may be determined using data assimilation techniques. In particular, they can be used to estimate the effects of subgrid-scale dynamical processes (Pulido and Thuburn, 2008). The drag exerted by the subgrid scale in the Andes may be determined so that an optimal representation in GCMs is obtained. The evaluation of GCMs needs to be carried out not only against analysis but also against high-resolution simulations where dynamical processes coupled to the Andes in the range of 30km-1km are fully represented.

Improvement of the representation of the Andes in GCMs

To improve the representation of the Andes in GCMs, three tasks need to be undertaken. The first two will be performed in the LMDz-GCM in France, and eventually on the WACCM model implemented at the UNN. The advantage of using the LMDz-GCM is that it is part of the IPSL-ESM, so that it can be also used coupled with ocean and sea-ice models. The last task is related to the representation of convection and will be undertaken on the WACCM model.

The first is an evaluation of the impact of the low level force imposed at the lowest model levels in GCMs, and that is used to represent the low level flow blocking and the lateral bypass of individual mountain peaks (Lott and Miller 1997). An other is to test if the lateral forces, introduced in Lott (1999) to represent that at the sub-synoptic and synoptic scale the flow do not see dynamically mountains valleys, are also beneficial for the South American weather. Interestingly, and if we return to the evaluation part above, this last force can make a detectable contribution to the equatorial components of the mountain torque. Even more interestingly, these parameterizations have essentially been tested for the northern hemisphere global climate and not much for the southern hemisphere. This is of course justified by the fact that the Andes are almost the only large elevation mountains in the southern hemisphere, whereas in the Northern hemisphere the mountains are much more broadly distributed. Accordingly, the role of mountains in the southern hemisphere is not as large for the global climate as it is in the Northern hemisphere. Nevertheless, this does not preclude that on a regional scale they play a major role, and the evaluation of the various representation of the mountains at these scales is at the same time challenging and innovative.

The second is a complete revision on how the unresolved mountain gravity waves are parameterized. In the current models their representation are essentially based on the hydrostatic approximation. It permits to treat each harmonics of the the entire spectrum of the mountain waves at the same time, whereas in reality these different harmonics can have very different propagation properties. On top of this, recent studies have shown that mountain gravity waves emission strongly depends on small scale details, like the exact structure of the boundary layer (Smith et al. 2005) and can not be exclusively deduced from the large scale flow characteristics and few subgrid scale parameters. This idea is supported by high resolution model simulations (Doyle et al. 2004), which show that mountain waves structure and amplitude are highly sensitive to very small changes in the upstream flow condition. Accordingly, one needs to consider a stochastic representation of these waves, which will permit to treat with more details the behavior of each harmonics, and to handle with more realism their breaking. This formulation will also permits to treat the trapped mountain waves in a more realistic way, since the propagation properties of the harmonics that stay confined in the low troposphere will be taken into account explicitly. This new formulation will be tested in GCMs versions that include the middle atmosphere, since it becomes more and more evident that the mountain waves play a very substantial role in the climate variability at high altitudes (for the northern hemisphere and the future climate changes, see Mc Landress et al. 2009).

These efforts will be done in conjonction with observationnal analysis of mountain waves by the Andes and near Antactica. The two places selected are Mendoza and the Island of Marambio where long series of vertical atmospheric soundings exist since 2003. In both places, the analysis of the soundings will be supported by mesoscale simulations done with the model MM5, following the work by Spiga et al. (2008). One motivation is to identify to which extent mountain gravity waves can also lead to the secondary inertio gravity waves which are ubiquitous in the stratosphere aloft mountains (Scavuzzo et al. 1998). A second motivation is two analyse the relation between the orographic waves and the triggering of convection, an issue that could serve as a guidance to link orgraphic and convective parameterizations, both working quite separately in the present days models.

The third task is even more directly related to the fact that GCMs still have many problems to adequately represent the distribution of precipitation associated with convective clouds in the region and the sensitivity of the simulated precipitation climatology in the region is largely dependent upon the convective scheme (Pessacq 2009). Several studies also showed that convection over the Amazon could modulate the strength and direction of the LLJ east of the Andes. Errors associated with the intensity and frequency of the convection affects low level circulation introducing significant bias in the simulated precipitation, this kind of biases can be also detected in short range forecasts from regional models. For this reason the improvement of parameterizations over the region is proposed . Data assimilation approach will be used to adjust the value of the parameters associated with the convective schemes in a regional model to evaluate the potential improvement in the representation of low level circulation east of the Andes. An approach similar to that proposed by Aksoy et al. 2006, will be used. The time evolution and spatial distribution of the optimal parameter values will also be explored in order to obtain information that could help to improve the convective parameterization schemes.

Validation and impacts

<u>Data assimilation techniques:</u>

To evaluate the parameterization of subgrid scale processes (orography and convection) we will use the recent results from data assimilation experiments which show that these techniques are a useful tool to evaluate parameterizations (Pulido and Thuburn 2005). They can be used to estimate optimal parameters and also to determine the drawbacks of parameterizations which can be used to guide to improvements of them. This project seeks to tie the development of the stochastic parameterization to the diagnostics of the data assimilation technique.

Regional Aspects:

As was mention in the introductory section, a central issue concerning the effect of mountains on the climate, is that many errors on the climatological prediction of precipitations by GCMs occur near and above them. As we believe that a proper representation of mountains in the lowest model levels can limit the air ascent over the model orography and can help confining the low level jets, we expect beneficial impacts on the precipitation, so we will test in climatological and AMIP type runs the impact of the new parameterizations on the precipitations. On top of this we will also address how the sub-grid scale low level mountain parameterization also affect the climatology of the cold-surges and more generally the synoptic variability over the region.

Hector and Luiz could place somewhere here or before, or in yet an other completely different section, mesoscale simulations at high resolution, as well as on the evaluation of these simulations by comparison of the models result to satellite data.

Global Aspects:

We could develop there on the impact of the gravity waves parameterization on the middle atmosphere dynamics.