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Strategies and measures for determining the skill of dynamical downscaling

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Dynamical Downscaling

The basic idea of downscaling is that a link $X_s = f(X_l, p_s)$ exists, with X_s representing the small-scale dynamics, X_l the large scale dynamics and p_s the physiographic forcing on small scales; f is supposed to be a transfer function, which may be stochastic. If such a link exists, then one can determine the small-scale dynamics if the large-scale dynamics and the small-scale forcing are known. In the present case we consider only the case of atmospheric dynamics.

The presence of such an f implies that details of the small scale dynamics do not matter for the large-scale dynamics; indeed, all full climate models implicitly employ such an assumption, when parameterizations of sub-grid scale "physics" are applied. Parameterizations are physically motivated but semi-empirical closures, which specify a suitable effect of the considered processes on the resolved scales – conditional upon the large state. This suitable effect can be the conditional mean effect, or a randomly chosen effect from an ensemble of effects available for the prevailing large-scale state.

The existence of f implies that through regional modeling an improvement of the representation of large-scale states cannot be achieved by doing a better job with describing the details the small-scales. Instead, misrepresentations in the large-scales will inevitably lead to misrepresentations in the small scales, no matter how good the regional atmospheric model is. Improvement of the large-scales needs improvements of the global models, in particular the paramterizations.

One could argue that in some cases, in particular in the tropics, such an f does not exist, because the details of the small-scale processes, for instance convection, has an effect around the world, i.e., on all scales. However, at mid-latitudes, where the weather regime is typically flushing every limited area in relatively short time, the assumption of an existing f is plausible – when $X = X_l+X_s$ is a realization of the real world.

One may also argue that the downscaling mechanism with such an f would not work in case of purely GCM-generated states, when, $X = X_l$ and $X_s = 0$. While one may use the same method to construct an f, no hard testing has been devised to test the plausibility of the existence of such an f.

The practical problem is to determine f. One way is to use a dynamical limited area model; another to use in the spirit of "perfect prog" an empirical downscaling approach. The former returns complete and space-time detailed atmospheric states, while the empirical calculates mostly realizations of weather streams at some sites or fields of statistical descriptors such as mean, variances or extremes. In the talk, only the dynamical approach will be discussed.

Indeterminacy

Formally, the limited area simulations generate solutions of an instationary boundary value problem, where values at the lateral and lower boundaries determine what is going on in the interior. The problem is that the latter assertion is simply false – mathematically, the boundary value problem is not well posed, and given the lateral and lower boundary values different weather streams can emerge – and they do. This problem can be overcome by adding forcing terms in the interior so that the solution is not deviating too strongly from the large scale state prescribed by observations or coarse grid simulations.,

Another problem is that the phase speeds of waves in the interior would not fit the phase on the coarse grid, from which the lateral boundary values are taken. This problem has been long solved by an ad-hoc measure, namely the so-called sponge zone, which enforces as smooth transfer from the interior to the outside and vice versa.

When no large-scale constraint is applied, different weather streams will emerge in different simulations with the LAM, and differences between observations and a simulation may reflect the indeterminacy of the mathematical problem and not errors, as was naively believed in the early years of regional modelling. Thus, in this case ensembles of model runs need to be done, to determine the significance of changes and differences – just as with global climate models

Added Value

As outlined above, the added value is expected in the small-scale dynamics. One would hope that the model is improving the description of these dynamics – first of all it should have higher variability on these scales than the driving analyses or simulations. To determine this, a method is needed to separate the scales – Thus a decision is needed about what is "large". Usually "small" is everything that is "not large". The separation can be done by expansion into orthogonal functions, such as spherical harmonics or trigonometric's, or by using digital filters.

When comparing with observed states, then sometimes (operational forecast or satellite) data is available, which describe for a shorter time and maybe limited regions high-resolution dynamics. Then again, after filtering, it may be worthwhile to compare with the model output.

Finally, one would expect added value in regions, where the physiographic detail p_s matters, near coasts, near mountain ranges and the like. Also, certain dynamical processes, such as polar lows may be better described and therefore may undergo a more realistic dynamic within the LAM when the grid resolution is improved. In that case, specific algorithms to determine such events are needed, so allow if the downscaling returns better and useful statistics of such events.