Conceptual basis and applications of Regional Climate Modeling

Hans von Storch

Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany
Storch@gkss.de

Introduction

A major purpose of Regional Atmospheric Models (RCMs) is to describe in detail the trajectory of weather in a limited area conditional upon a prescribed large-scale state. This "weather stream" is then used to infer details of the weather statistics (i.e., climate). In this contribution, three theses related to these climate applications of RCMs are discussed:

- Regional climate modeling is a downscaling problem.
- Regional climate modeling suffers from Intermittent Divergence in Phase Space (idps)
- The purpose of regional climate models is to study the regional climate and its impact, not the improvement of such models.

Regional climate modelling is a downscaling problem

We conceptualize the genesis of climate by the functional "downscaling" relationship (Giorgi et al., 2001):

$$C_s = f(C_l, \Phi_s)$$

with

C_l = larger scale climate
C_s = smaller scale climate
Φ_s = physiographic detail at smaller scale.

The validity of this concept (von Storch, 2001) is supported by the observations that a simple energy-balance model, without any reference to spatial details, is adequately explaining global mean temperature; that an atmosphere at rest on an aqua planet is establishing the well known three cell-structure, with trade winds and extratropical baroclinic zones within a few weeks; that empirical downscaling method successfully specify regional and local weather and climate as a function of large scale states (Giorgi et al. 2001).

This concept of downscaling does NOT imply that smaller scales are irrelevant for the larger scales. Small scale processes, such as convection, play a key role in forming the global climate. However it is only the overall effect of these processes which matter, not the space-time details. Therefore parameterizations of small scale processes are sufficient for global (and regional) models. It is this fortuitous arrangement, which allows us simulate the global and continental climate well – even without simulating any small-scale climate adequately.

To implement the downscaling philosophy into regional atmospheric modeling, the application of the state space concept is useful (e.g., von Storch, 2001):

State space equation $\Psi_{t+1} = F(\Psi_t;\eta_t) + \varepsilon_t$
Observation equation $d_t = G(\Psi_t) + \delta_t$

with ε_t, δ_t = model and observation errors
F = dynamical model
G = observation model

Forward integration : $\Psi^*_{t+1} = F(\Psi_t;\eta_t)$
$d^*_{t+1} = G(\Psi^*_{t+1})$
$\Rightarrow \Psi_{t+1} = \Psi^*_{t+1} + K(d^*_{t+1} - d_{t+1})$
with a suitable operator K.

Here, Ψ_t, is a 3-dimensional state vector representing all relevant meteorological variables described by an RCM, **F** is the RCMs itself, ηt describes the physiographic details. G is the "observation operator", which relates the state vector to an "observable" d_t. Thus F represents theoretical knowledge about the dynamics of the regional atmosphere, whereas d_t empirical knowledge. The two terms δ_t and ε_t are unknown but non-zero error terms, reflecting the unavoidable simplifications of the dynamical model and the uncertain observations. The combined state space and observation equation is integrated forward in time by first "guessing" with the state space equation the state and the observable in future, and then by correcting this "first guess" by a term proportional to the difference of guessed observable and actually observed observable.

Obviously, this concept has little to do with conventional boundary value problems. Instead the problem is to skillfully merge different types of knowledge. In case of past weather reconstructions and of plausible future weather sequence scenarions, the empirical knowldege is about the large scale state; the dynamical knowledge is encoded in the dynamical model. The correction step, which is blending the simulated and the prescribed large-scale state is called "spectral nudging method" (SN; von Storch et al., 2001), and has been shown in a series of analyses to provide superior regional states consistent with prescribed large scale states (Meinke et al., 1994, Sotillo, 2003)

Regional climate modeling suffers from Intermittent Divergence in Phase Space (idps)

Regional climate dynamics are also chaotic – very different trajectories may emerge from very slightly disturbed initial conditions if the large-scale states are not constrained by, for instance, spectral nudging – long after the predictive influence of the initial state has disappeared. The phenomenon is intermittent – as soon as the influence of the boundary is recovering, the "divergence in phase space" is vanishing.

The RCM tendency to exhibit IDSP depends on the degree of "flushing" the area, i.e. the time needed for disturbances travel from the boundaries through the area. For midlatitude marine climate with moderate longitudinal extension (e.g., 4000 km) lateral control is mostly sufficient (Weisse et al., 2000), while in the Arctic idps seems to be a frequent phenomenon (Rinke and Dethloff, 2000). To what extent idps is a problem in the tropics is not really known despite early numerical experiments (Yi and Vernekar, 1997). It would be rewarding theoretical exercised to infer from a given field, if the systems tends to diverge or converge in phase space.

A major conclusion to be drawn from the idps phenomenon is that deviations between observed state and RCM modeled state may be due to model errors, or insufficient lateral control. Thus, the assessment of the effect of different, for instance, parameterizations of sub-grid scale processes needs the same statistical analysis as is common since the 1970s in global climate numerical experimentation (e.g., Chervin and Schneider, 1976).

The SN (spectral nudging) method overcomes this problem to large extent, since it constrains the available part of the phase space significantly, so that major deviations can not develop (Weisse and Feser, 2003).

The purpose of regional models is <u>not</u> validation and improvement by making them more complex <u>but</u> to apply them in building of new knowledge about the real world.

Presently, RCMs are used in reconstructing detailed past weather streams of the recent past with, for instance, applications to analyzing coastal sea climate. These data sets, on wind, storms, waves, currents and surges are used in a variety of projects dealing with the assessment of oil drifts in case of accidents, the assessment of fatigue in ships and off-shore constructions, the planning of harbor constructions and of off-shore wind energy, the assessment of coastal defense measures, and the analysis of wave conditions and risks in estuaries. Other applications deal with historical and paleoclimate climates. Finally, such models are in routine use for downscaling global climate change scenarios to the impact-relevant small scales, which need responses in terms of mitigation and adaptation.

The general experience is that presently available models are suitable for these applications. Thus, requests for further improvement – as legitimate as they may be and actually are – should not be used as an argument to further postpone the use of such models. Validation and improvement are important technical aspects of regional modeling, but these important efforts should be guided by the needs of present and future applications of such models.

Conclusion

- Regional climate modeling is a downscaling problem – *thus, continental scale information should be assimilated into RCMs.*
- Regional climate modeling suffers from Intermittent Divergence in Phase Space (idps) – *thus either SN or ensemble simulations should be done. Differences "RCM versus observations" are not necessarily reflecting model errors.*
- The purpose of regional climate models is to study the regional climate and its impact, not the improvement of such models – *in fact, contemporary climate model output is used for various applied studies.*

References

Chervin, R.M. and S.H. Schneider, 1976: On determining the statistical significance of climate experiments with general circulation models. J. Atmos. Sci., 33, 405-412

Giorgi, F., B. Hewitson, J. Christensen, M. Hulme, H. von Storch, P. Whetton, R. Jones, L. Mearns and C. Fu, 2001: Regional climate information - evaluation and projections. In J.T. Houghton et al (eds.): *Climate Change 2001. The Scientific Basis*, Cambridge University Press, 583-638

Meinke, I., H. von Storch and F. Feser, 2004: A validation of the cloud parameterization in the regional model SN-REMO. submitted

Rinke, A., and K. Dethloff, 2000: On the sensitivity of a regional Arctic climate model to initial and boundary conditions. Clim. Res. 14, 101-113.

Sotillo, M.G., 2003: High resolution multi-decadal atmospheric reanalysis in the Mediterranean Basin. PhD dissertation. UCM, Madrid. pp 216

von Storch, H., H. Langenberg and F. Feser, 2000: A spectral nudging technique for dynamical downscaling purposes. Mon. Wea. Rev. 128: 3664-3673

von Storch, H., 2001: Models. In: H. von Storch and G. Flöser (Eds): *Models in Environmental Research*. Springer Verlag, 17-33

Weisse, R. and F. Feser, 2003: Evaluation of a method to reduce uncertainty in wind hindcasts performed with regional atmosphere models. Coastal Eng. 48, 211 - 255

Weisse, R., H. Heyen and H. von Storch, 2000: Sensitivity of a regional atmospheric model to a sea state dependent roughness and the need of ensemble calculations. Mon. Wea. Rev. 128(10), 3631-3642

Yi, Y.M. and A.D. Vernekar, 1997: Simulation of the Asian summer monsoons of 1987 and 1988 with a regional. J. Climate 10, 1965-1979.