A brief review of some key issues related to the modelling of cloud and precipitation

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1. Introduction

When modeling clouds and precipitation in atmospheric forecast models it is important to ask the following questions:

1) Can it be quantified from observations that the mesoscale structure of precipitation is significant ? The answer is : Yes

2) Can we summarise typical weaknesses and/or limitations of the methods for cloud and precipitation prediction used in the operational weather prediction models ?

3) Which modelling strategies for high resolution are expected to lead to increasingly realistic operational schemes in the coming years ?

The answers to 3) will apperar as concluding remarks after answering 1) and 2).

2. Examples of mesoscale precipitation features

The influence of orographic features is well established, not only for high mountains, but also for for small hills with a height of less than 50 m. For example, Tor Bergeron writes in Uppsala report No. 6 (1968): "Unexpectedly, small orographic features are reflected in the fine structure of rainfall distribution" (averaged over months). Only a 20m -30m plateau is needed in the Uppsala field is needed to produce approximately a 20 % precipitation increase.

Other studies have pointed to significant mesoscale structures of precipitation. For example, Austin and Houze (J. Appl. Meteor.,925-935 , 1972) in a study of 9 storms in New England concluded that different scales can be identified, from a 'synoptic scale' (100 km * 100km) down to small mesoscales of 3km * 3km. The associated time scales range from typically 24h to 0.5h , respectively. The associated peak precipitation rates increase as the scale is reduced, and heavy rain is observed in both stratiform and showery conditions.

Recently very fine scale structures of precipitation (typically 20-30 % variation) has been measured in Denmark with 9 rain gauges of the same design evenly spaced over a 500m by 500m flat field. The measurement campaign took place over a period of 65 days during Autumn 2003 (for details se http://www.exigo.dk/project/summary).

3. Model uncertainties/weaknesses

Uncertainties exist in the current HIRLAM physics (and in other models) concerning the following processes:

3.1. Microphysics

The formation of ice clouds in the atmosphere has little relation to ice saturation and the onset of cloud formation is complicated (concentration and the type of ice nuclei vary across the globe). A lot of research activities exist, e.g. a COST 723 action (www.cost723.org). In HIRLAM a modified cirrus cloud formation has been implemented recently. Is there a need for further updates ?

Some presently used parameterizations might be too inaccurate, and more detailed microphysics will then be needed. Is it relevant to explicitly forecast droplet/particle size distributions in the near future ?

3.2. Turbulence and convection

The CBR turbulence scheme with conserved moist variables has recently been tested. It provides a better description of the vertical moisture transports in stratus/stratocumulus conditions (e.g. ASTEX), but has difficulties to describe cloud fields for shallow cumulus situations such as BOMEX where the convection scheme takes well care of the vertical transports (has been verified in 1D-HIRLAM simulations with 'moist' CBR and STRACO cloud scheme).

The ideal assumptions connected to convection schemes break down at (very) high horizontal resolution of meso-scale models, but the use of convection schemes might still be desirable (as indicated above), provided that they are used with care (conditionally). Research is probably still needed to optimise the use of convection schemes at very high resolution.

There are still uncertainties about the triggering of convection, that is, how to parameterize the fluctuations of momentum, heat and moisture responsible for initiation of convection.

Assumptions of 'instantaneous' precipitation fallout in the vertical air column becomes increasingly unrealistic at high horizontal resolution due to the actual drift of precipitation with the wind. This effect can easily account for horizontal displacements of more than 10 km, especially for drifting snow.

3.3. Dynamics

Hydrostatic model dynamics is expected to be less realistic than non-hydrostatic dynamics at grid sizes below about 5 km. - Furthermore, if it is a general problem to describe convective cloud cover (and vertical humidity transports) for shallow cumulus conditions from turbulence physics alone (no convection scheme used), does this mean that a reasonable description of shallow cumulus requires explicit dynamics of a LES model ? (e.g. about 100 m or less). The answer depends to some extent of the turbulence scheme used and of the cloud parameterization in use.

4. Tentative recommendations

The following tentative recommendations are made, based on the discussion above:

1) Continue to make high quality 'physiographic databses', partly because stationary forcing (e.g. from orography) shows up in observed precipitation statistics (also very small scale orography has impact).

2) Introduce 'prognostic' 3D precipitation fields with several hydrometeors (rain, snow, etc.) to avoid unrealistics fallout of precipitation.

3) For a given model resolution investigate whether the vertical and horizontal humidity tarnsports can be adequately described by the turbulence parameterization and the dynamics. -If not, continue to develop and use a convection scheme for high resolution, perhaps even at finer scales than 2 km. More restricted use of the convective parameterization is likely at such high resolution.

The observations showing precipitation variability at scales down to about 100 m indicate that very fine scale dynamics on the 'turbulent scale' is playing a role to explain this. A formulation of 3-dimensional turbulence is a natural framework to incorporate these variations. In a real forecasting system a probabilistic component will probably be needed as an additional tool to describe the high variability of the precipitation intensity in space and time.