1. Motivation

The presence of fog and low clouds in the lower atmosphere can have a critical impact on both airplane and ground transports and is often connected with serious accidents. The improvement of localization, duration, and variations in visibility therefore holds an immense operational value.

2. Methods

In order to evaluate the potential of the three-dimensional fog forecast model (COSMO-FOG), several case studies, considering radiative fog as well as valley fog episodes, have been chosen. The model verification takes place over three different sites:

- Lindenberg, Germany (lon: 52.2°N, lat: 14.1°E), grassland and forest, submountainous area (<400 m)
- Cabauw, The Netherlands (lon: 51.97°N, lat: 4.9°E), grassland, flat terrain.
- Zürich, Switzerland (lon: 47.4°N, lat: 8.5°E), lake, grassland, forest, complex mountainous terrain (>2000m).

To overcome the restriction of the model verification with surface point measurements, the spatial accuracy of the fog forecast obtained in 3D modelling was assessed in a comparison with satellite data (Fig. 3). The satellite products are derived from Meteosat 8 SEVIRI data (Cermak et al., 2006, Cermak et al. 2008).

3. New 3D Fog Model

We developed a new 3D model based on the coupling between the PAFOG two-moment cloud water scheme (Bott & Trautmann, 2002) and the non-hydrostatic three-dimensional model COSMO (Steppeler et al., 2003). Below 200m the PAFOG microphysics compute the formation/dissipation of clouds (fog). In the upper part, the cloud processes are computed with the standard microphysics of COSMO (Fig. 2).

STEP 1: Activation (Twomey (1954)):

\[ N_{c} = N_{c} + \frac{S}{D} \]

STEP 2: Detailed Condensation/Evaporation:

- parametrised Köhler relation [Chaumerliac et al. (1987) and Sakakibara (1979)]
- Time dependent relation between supersaturation S and diameter D

STEP 3: Droplet size dependent sedimentation (Berry and Prang (1974))

Positive Definitve Advection Scheme [Bott (=1989)]

4. Setup of COSMO-FOG

<table>
<thead>
<tr>
<th>Time step</th>
<th>4 seconds</th>
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<tr>
<td>Hz. Resolution</td>
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<tr>
<td>No. of grid points</td>
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<td>Azimuth</td>
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<td>Resolution</td>
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<tr>
<td>∆y</td>
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<tr>
<td>∆x</td>
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<td>Soil model</td>
<td>TERRA (Schroed and Heise, 2001)</td>
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<td>Models equations</td>
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<td>Turbulence scheme</td>
<td>Prognostic TKE (Melor and Yamada, 1962)</td>
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<tr>
<td>Initialisation</td>
<td>COSMO 7km (Steppeler et al., 2003)</td>
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<td>Lateral Boundary conditions</td>
<td>Every hour</td>
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<td>Microphysics</td>
<td>Reinhardt et al. (2005) &amp; PAFOG (&gt;2000 m) (Bott et al., 2002)</td>
</tr>
<tr>
<td>Visibility</td>
<td>Koschmieder (1924)</td>
</tr>
</tbody>
</table>

5. Results

A three-dimensional fog forecast model is an improvement for the forecast of fog:

- Cloud microphysics considering droplet settling are necessary for an accurate fog forecast.
- Cloud microphysics gives promising results in some case studies of valley fog. The main process driven by horizontal dynamical transport in the valley can be precisely described.
- The vertical dynamical transports have also been defined in a reliable approach:
  - Fog forecasts on flat terrain stay difficult due to heterogeneity of the soil structure and of the vertical exchange between soil and atmosphere (Fig. 3).
  - The turbulence scheme plays a central role to obtain a reliable fog structure. Some restrictions are to be considered by increasing the vertical resolution.
  - The accuracy of the initial thermalodynamical and dynamical fields stays one of the decisive factors for the forecast of radiative fog events. By formation of advection fog or valley fog, its influence is significantly reduced.

6. Conclusion & outlook

Fog is generally a small scale phenomenon and mostly affected by local advective transport, radiation, turbulent mixing at the surface as well as its microphysical structure. The complexity of various fog formation processes (Fig. 1) causes inadequacy of simple forecast solutions. Therefore, we developed a new three-dimensional fully physical fog forecast model.

Fig. 2: Cross-section of COSMO-FOG. Nc=total number concentration of cloud droplets (prognostic), q0=horizontal water content

Fig. 3: Spatial distribution of fog on the Lindenberg area as seen by satellite (black shaded area) and liquid water content simulated by COSMO-FOG (blue areas).

Fig. 4: Influence of microphysics on fog pattern. A & B with PAFOG microphysics. C with COSMO microphysics (radiation adjustment method - Lindenberg Observatory – 2005 September 27th (03 UTC after 27 hours forecast).

Fig. 5: Fog microphysics:

COSMO-FOG underlines the decisive role of fog microphysics considering the cloud droplet setlement (Fig. 4):

- Cloud heterogeneity due to sedimentation
- Droplet sedimentation influences significantly the fog duration
- More accurate visibility parameterization depending on water content and cloud droplet concentration

Fog forecasts on flat terrain stay difficult due to heterogeneity of the soil structure and of the vertical exchange between soil and atmosphere (Fig. 3).

- The turbulence scheme plays a central role to obtain a reliable fog structure. Some restrictions are to be considered by increasing the vertical resolution.
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