6.26 FOG PREDICTION IN A 3D MODEL WITH PARAMETERIZED MICROPHYSICS

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1 Introduction

In complex terrain advection plays a dominant role. Fog formation is favored in regions where cold air accumulates. These processes cannot be resolved with a 1D approach and have to be treated explicitly using a 3D model. However the current operational weather forecast models are run at resolutions that are too coarse for an appropriate simulation of fog. Of special importance is the vertical resolution, where nowadays the first atmospheric layer has typically a thickness between 50 to 100 m. This resolution is unable to model the slow and steady growth of radiation fog due to cooling at the surface. In operational models the coarse vertical resolution is not just to save computational cost, but also to prevent excessive cooling of lower levels during the night. The thin layers have a small heat capacity and thus cool rapidly producing a strong inversion. The turbulence scheme fails under such conditions and a cold bias in the lower layers develops. In terms of cloud microphysics the condensation and evaporation as well as the sedimentation of cloud water is normally treated in a simple way. For condensation/evaporation a simple bulk adjustment is computed. The sedimentation flux of cloud droplets has to be parameterized assuming some sedimentation velocities and threshold values. For precipitating clouds this is often a quite accurate representation but for fog, which contains very little liquid water, a higher degree of sophistication is needed. Therefore the detailed fog microphysics of the 1D model PAFOG (Bott & Trautmann (2002)) was incorporated and fully coupled with the 3D nonhydrostatic mesoscale model (NMM) of NOAA/NCEP (Janjic et al. (2001),Janjic (2003)).

2 The fog microphysics model

Numerical simulation requires high horizontal and vertical resolutions combined with sophisticated cloud physics. PAFOG microphysics is limited to the lower part of the atmosphere which extends from the ground up to a prescribed height, currently 1500 m. In this lower part, where fog and low stratus clouds form, the condensation and evaporation processes, as well as the settling of cloud droplets, but not precipitation, are modeled with the detailed cloud microphysics of PAFOG. Processes including the ice phase, autoconversion, accretion and evaporation of precipitation are modeled using the NMM microphysics developed by Ferrier (2002). Liquid water content already is a prognostic variable in the NMM, and once formed, is transported by turbulence and advection. Now a new prognostic variable, the concentration of cloud condensation nuclei (CCN) is introduced into the dynamical framework. The three dimensional link of the PAFOG microphysics to the other model equations is done by the transport of CCN and liquid water. The implementation has to consider horizontal and vertical advection as well as the turbulent transport of CCN.

Prognostic equations for the total number concentration N_c of cloud droplets and for the total specific cloud water content q_c are solved.

$$\frac{\partial N_c}{\partial t} = ADV(N_c)+DIF(N_c)+\left(\frac{\partial N_c}{\partial z}\right)_{sed}+s(N_c) \tag{1}$$

$$\frac{\partial q_c}{\partial t} = ADV(q_c)+DIF(q_c)+\left(\frac{\partial q_c}{\partial z}\right)_{sed}+s(q_c) \tag{2}$$

The operators ADV and DIV are computed by the dynamical framework of the NMM and stand for advection and turbulent diffusion, respectively. The third term represents sedimentation of cloud droplets and the source-sink terms $s(N_c)$ and $s(q_c)$ describe phase changes between the gaseous and liquid phase. From the continuity equations [1,2], the following two prognostic equations are solved with the PAFOG microphysics.

$$\frac{\partial N_c}{\partial t} = \left(\frac{\partial N_c}{\partial t}\right)_{act}+\Delta(\bar{S})\left(\frac{\partial N_c}{\partial t}\right)_{eva}+\left(\frac{\partial N_c}{\partial t}\right)_{sed} \tag{3}$$

$$\frac{\partial q_c}{\partial t} = \left(\frac{\partial q_c}{\partial t}\right)_{con/eva}+\left(\frac{\partial q_c}{\partial t}\right)_{sed} \tag{4}$$

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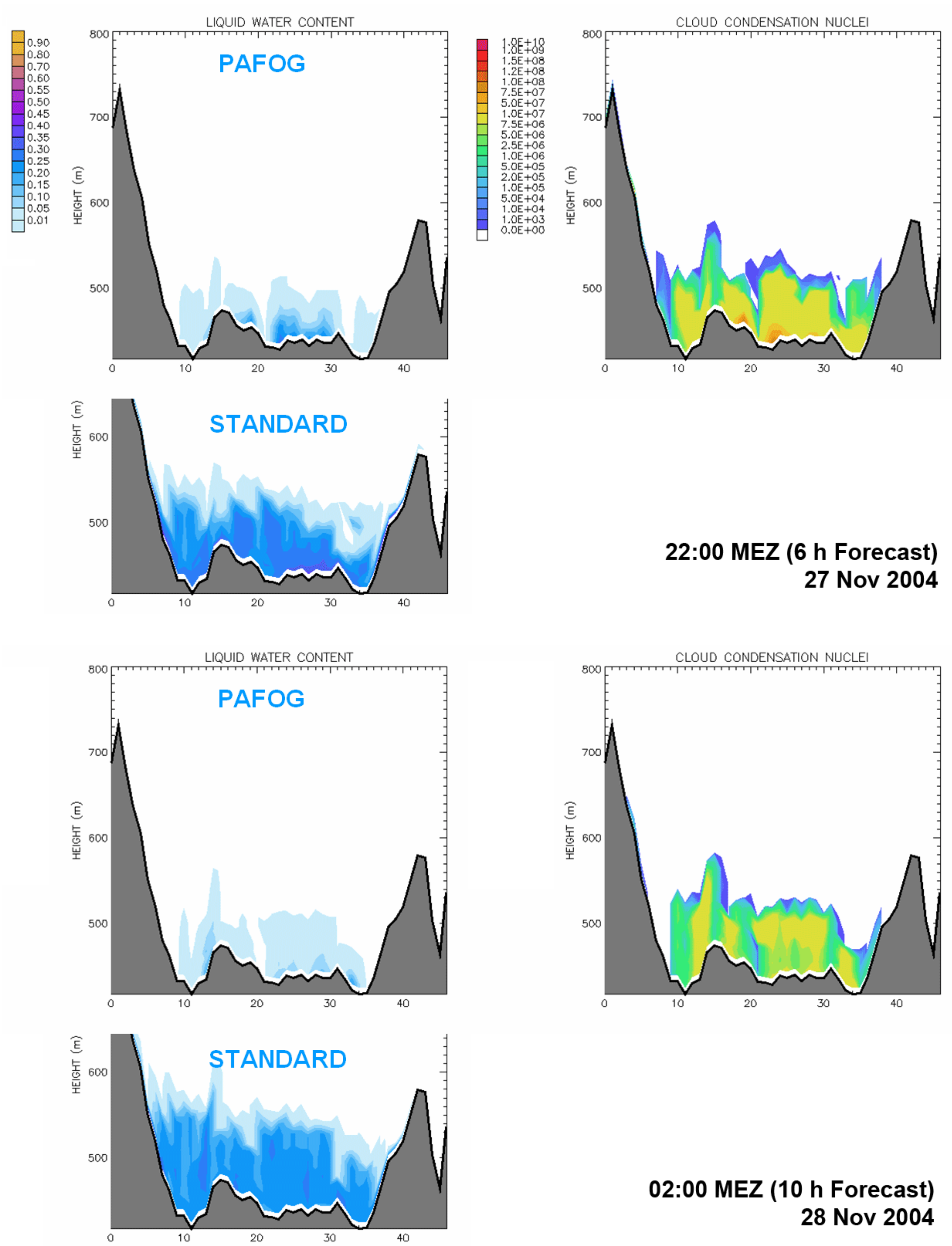

Figure 1: Vertical cross sections of liquid water content and cloud condensation nuclei, respectively.

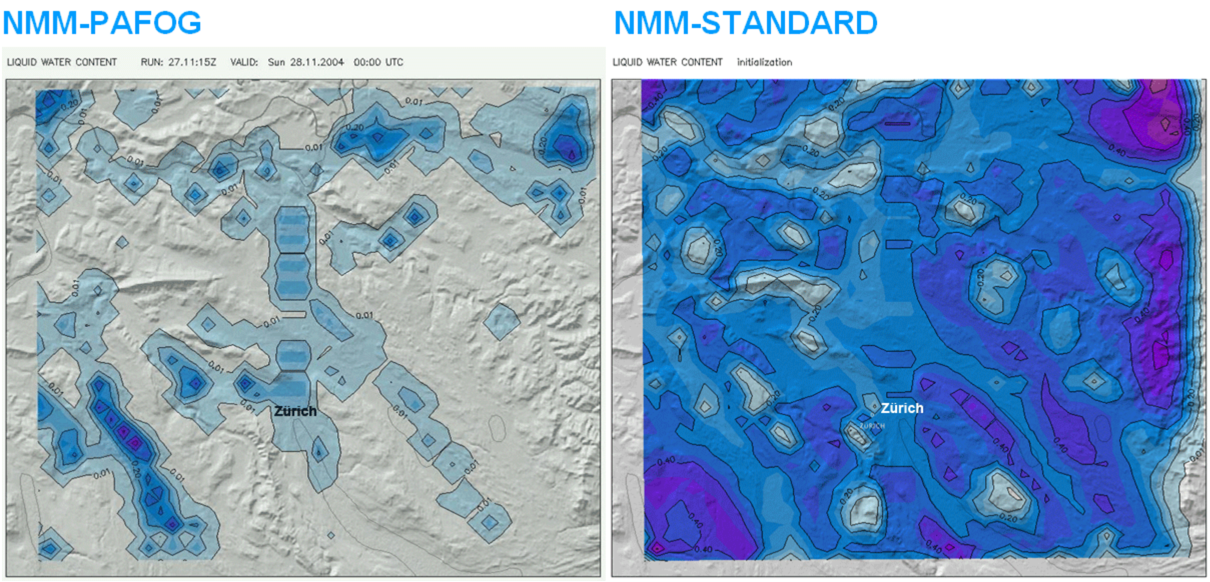

Figure 2: Liquid water content of the lowest 5 m above ground computed with NMM using PAFOG and standard microphysics, respectively. Liquid water concentrations above 0.01 g/kg are colored and the black contour lines have a 0.1 g/kg interval.

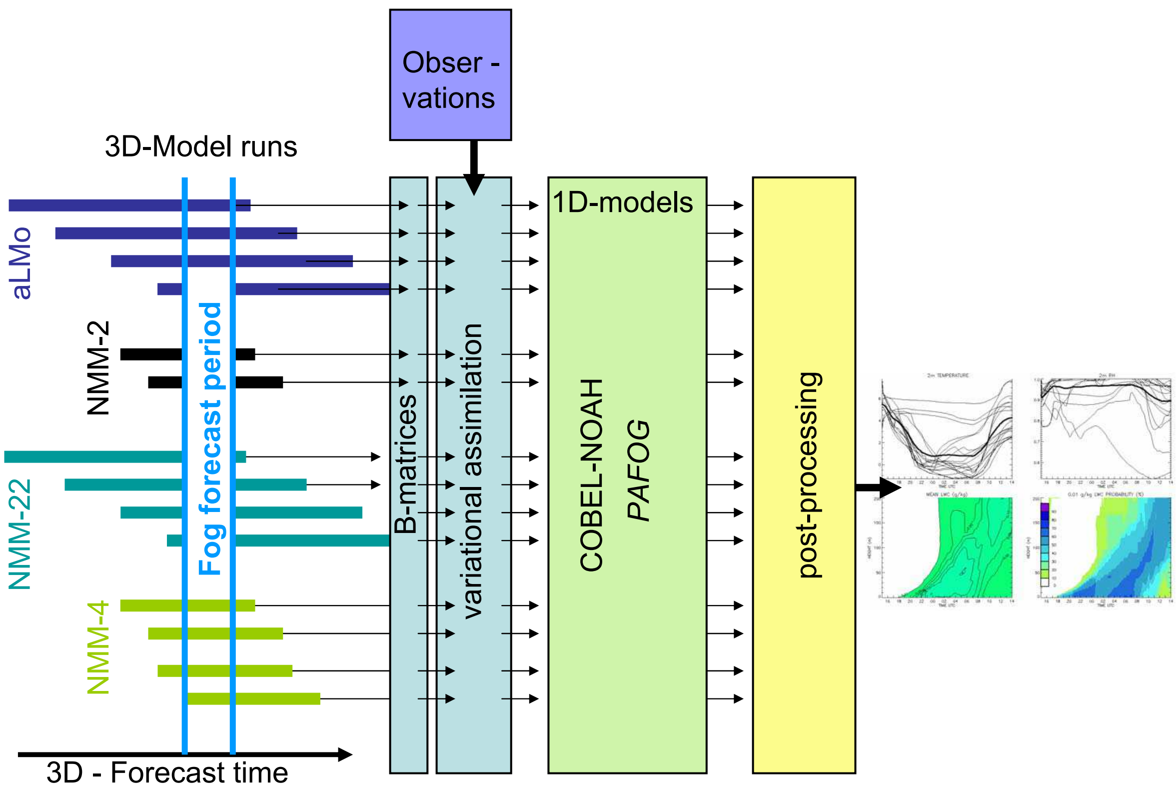

Figure 3: Schematic of the 1D ensemble prediction system. Every 3D run provides initial conditions that are used as a background for an individual variational assimilation.

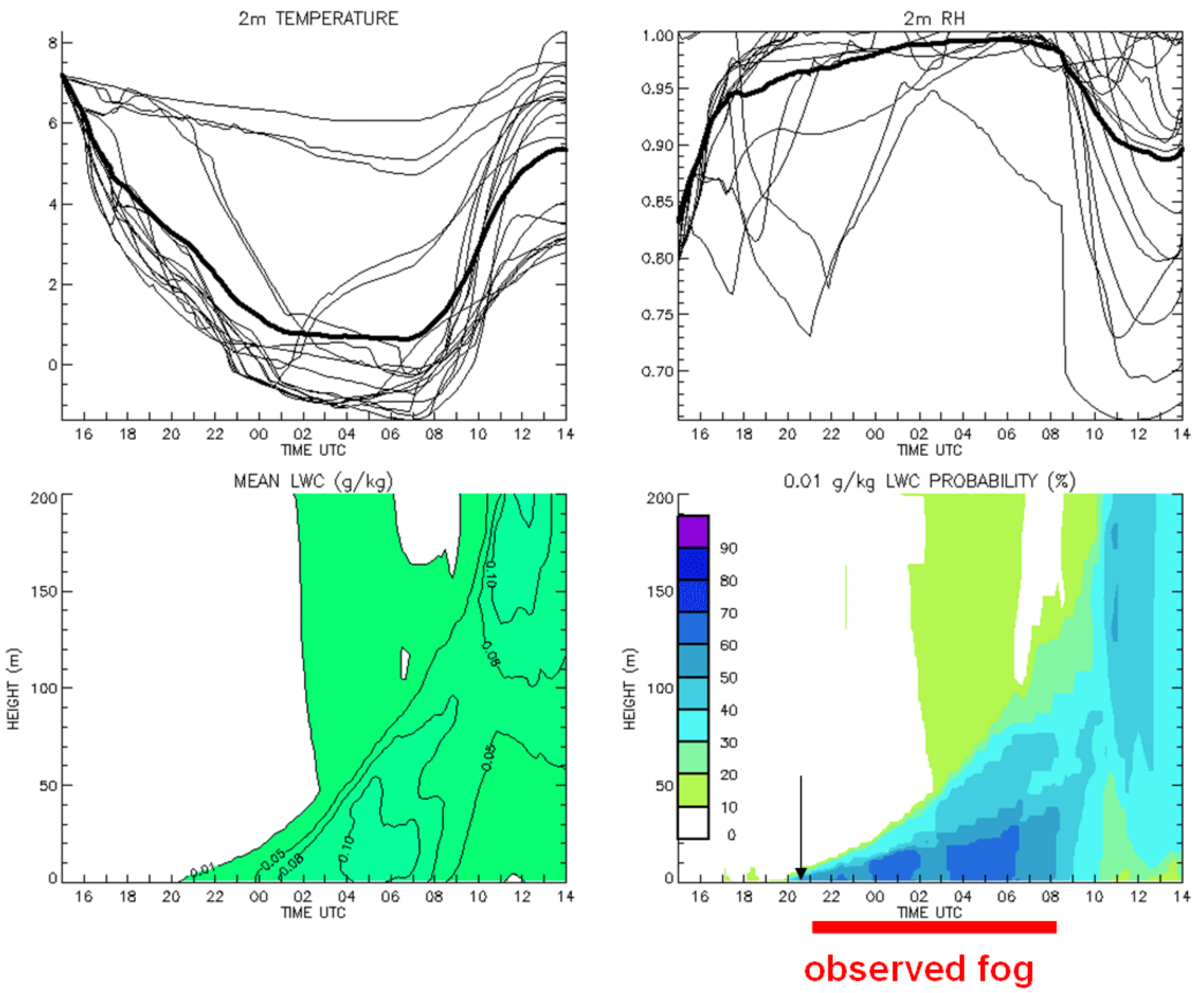

Figure 4: 1D ensemble prediction of the fog event from 27-28 November 2004. The first two panels show computed temperature and humidity at 2m height for each member (thin lines) as well as the ensemble mean (thick line), respectively. In the lower left panel the ensemble mean liquid water content is contoured and the last panel indicates the probability for a liquid water content of 0.01 g/kg

$$\Delta(\bar{S}) := \{ \begin{array}{ll} 1, & \text{for } \bar{S} < 0 \\ 0, & \text{for } \bar{(S)} \geq 0 \end{array} \quad (5)$$

where S is the supersaturation. Hence besides the dynamic transports due to advection and turbulence, the concentration of CCN and liquid water content can be changed due to microphysical processes. The interactions are quite complex and an increase in liquid water doesn't necessarily change the CCN concentration. This is because existing droplets may grow without new droplets being formed. The inverse is true for evaporation of cloud water. Sedimentation is always directed downward and the same flux divergence may increase or decrease CCN and cloud water differently, depending on the size of settling droplets. At the ground, liquid water is treated like precipitation and CCN disappear due to deposition. For a detailed description of the individual terms the reader is referred to Bott & Trautmann (2002) and references therein. Furthermore an assumption on the droplet size distribution has to be made. In PAFOG this is a log-normal function of the form

$$dN_c = \frac{N_c}{\sqrt{2\pi}\sigma_c D} \exp\left(-\frac{1}{2\sigma_c^2}\ln^2(\frac{D}{D_{c,0}})\right) dD \quad (6)$$

where D is the droplet diameter, $D_{c,0}$ is the mean value of D and σ_c is the dispersion parameter of the given droplet size distribution ($\sigma_c = 0.2$).

3 First results

3.1 3D simulation

For the 3D simulations, a domain of 50 by 50 km^2 with a horizontal resolution of 1 km centered on Zürich Kloten Airport in Switzerland is defined. The vertical discretization uses 45 levels of which 27 are within the lowest 1000 m above ground. In the soil, prognostic equations for heat and moisture are solved on 11 layers, where the first is only 0.25 cm thick. The thin layers are especially important for the water balance. Evaporation or fog sedimentation can only change the water content of a thin layer during a typical integration time of one day. Thus the high resolution is necessary if e.g. evaporation has to be controlled not just by the atmospheric conditions, but also by the current availability of water in the soil. Initial and boundary conditions for the 3D fog model are derived from the 4 km resolution NMM weather forecasts of the University of Basel. The 4 km grid is nested into a 22 km grid covering Europe which is driven by GFS.

In Figure 1, vertical cross sections of liquid water content and CCN at different times are shown for the standard microphysics (control run) and for the PAFOG microphysics simulation, respectively. Note that the control run does not have CCN as a prognostic variable and no cross section can be shown. With the standard microphysics a very thick fog layer grows several hundred meters high. In the case of PAFOG microphysics the fog has a more realistic liquid water content that is reduced by the detailed computation of the sedimentation flux. It can be seen how liquid water and CCN in the middle of the fog decreases.

Differences are even more apparent when the liquid water content of the lowest atmospheric layer is plotted as in Figure 2. In the control run fog is virtually everywhere, even on the slopes and tops of mountains that are several hundred meters high.

The model also shows a cold bias caused by the high vertical resolution of the atmospheric grid.

3.2 1D ensemble forecast

The 1D ensemble forecasts are computed using COBEL (Bergot & Gudalia (1994*a*), Bergot & Gudalia (1994*b*)) which has been coupled to the NOAH land surface model (Chen et al. (1997), Ek et al. (2003)). Furthermore the 1D PAFOG model is used (Bott et al. (1989),Bott & Trautmann (2002)), which integrates the same initial conditions as COBEL. Recall that the microphysics of PAFOG was implemented into the 3D model. Initial conditions are obtained from 1D variational assimilation. Profiles of temperature and humidity are assimilated using forecasts from different 3D models as a background and observations from a temperature profiler, surface observations on nearby mountains and data from a radiosonde, located about 150 km away from the airport. Since background estimates from different 3D forecasts validating at the same time, as well as from different 3D models are included, a whole set of initial conditions is assimilated and used to compute an ensemble 1D forecast. The error covariance Matrix $\mathbf{B}$ needed in the variational assimilation was derived for every 3D model using the NMC-method. In Figure 3 a schematic of the ensemble forecast system is given.

An ensemble forecast of the fog event during the night of 27-28 November 2004, also shown in the 3D cross section, is presented in Figure 4. As can be seen the fog onset and dissipation time is predicted quite well for this case. The probability for a liquid water content above 0.01 g/kg is about 50 %. Unfortunately the system produces many false alarms even when the predicted probability is higher.

4 Conclusions

For the simulation of fog in 3D, a model with high horizontal and vertical resolution is needed that takes into account detailed microphysical processes of fog. The dynamical core of the NMM is well suited for high resolutions and also computationally very efficient. The PAFOG microphysics introduces CCN as a new prognostic variable and allows for a more detailed treatment of condensation/evaporation as well as for the sedimentation of cloud droplets. With PAFOG microphysics the liquid water content is less than in the case of standard microphysics and fog develops mainly in valleys, rather than almost everywhere. However a detailed verification of spatial patterns for many cases is needed. The use of satellite imagery will be a valuable source of information for this purpose. Probabilistic forecasts with a 1D model were also carried out at Zürich airport for the winter season 2004/2005. But the complex topography as well as the abundant occurrence of advection limits the applicability of this approach.

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