Usability of NWP Model Liquid Water Output for In-Flight Icing Forecasts

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Motivation and Objectives

Open Questions

? Are NWP models able to forecast the liquid water content (LWC) in a high quality?

Our comparison of LWC forecasts to pilot reports shows: NO!

? Are NWP models just good enough to forecast the precipitation on the ground satisfactorily?

For now we have to say: Unfortunately YES!

More research is needed on this, not only in Germany!

Because LWC is directly correlated to **aircraft icing intensity**, we explored the usability of LWC forecasts, provided by a German NWP model. COSMO-EU is the operationally run mesoscale NWP model of Deutscher Wetterdienst. Its name is an acronym for *Consortium for Small-Scale Modeling* - Europe [2].

Characteristics of COSMO-EU

Non-hydrostatic compressible NWP model

Arakawa-C-Grid
40 vertical hybrid layers

Rotated Latitude/ Longitude Grid
Geographic north pole is found in the Pacific

High Horizontal Resolution
0,0625° (≈ 7 km)

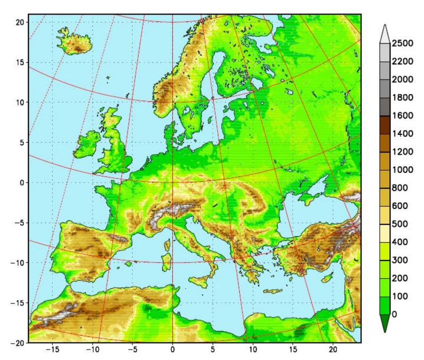


Fig. 1: Model domain of COSMO-EU [2].

Cloud Microphysics Scheme

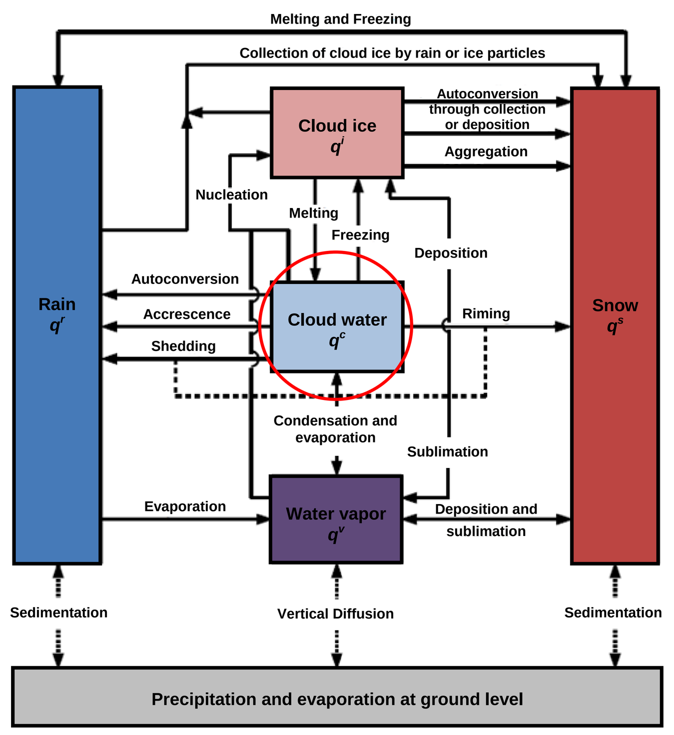


Fig. 2: Cloud Microphysics Scheme of COSMO-EU [2].

A **Two Category Ice Scheme** is realized in COSMO-EU.

There are five microphysical classes:

- Cloud water
- Cloud ice
- Water vapor
- Rain
- Snow

Each class is defined by its mass concentration q^ψ. A **Bulk parameterization** is implemented to describe the conversion terms S_ψ between the several classes. The conversion processes are displayed in Fig. 2.

$$q^\psi = \frac{\text{Mass of class } \psi}{\text{Total mass of the air}} \qquad M^\psi = q^\psi \cdot M = \int_V q^\psi \rho dV \qquad S^\psi = \frac{dM^\psi}{dt}$$

Evaluation of the COSMO-EU LWC forecast

An evaluation of the COSMO-EU predicted three-dimensional cloud water fields was done with the aid of pilot reports (**PIREPs**) over the US. The main idea was:

Wherever pilots observe icing conditions, supercooled liquid (cloud) water has to be present.

1st Step: Combining PIREP observations with model data

The aircraft icing intensity, reported via PIREP, has to be translated into model output values so that the forecast can be compared to the observation.

Reported Icing Intensity	Meaning	New Intensity	Associated LWC*
0	No icing	No icing	LWC = 0.00 g/m³
1 2 3	Trace icing Trace to light icing Light icing	Light icing	0.00 < LWC ≤ 0.60 g/m³
4 5	Light to moderate icing Moderate icing	Moderate icing	0.60 < LWC ≤ 1.20 g/m³
6 7 8	Moderate to severe icing Severe icing Heavy icing	Severe icing	LWC > 1.20 g/m³

* The associated LWC values are taken from [3].

2nd Step: Comparing observed LWC amount to LWC forecast

Neighborhood verification was used with a box of five grid points (~40km) in horizontal direction and three grid points (~1km) in vertical direction placed around the location of the PIREP. The following results of this comparison are for February 22nd, 2010 at 15 UTC and are representative for eleven other investigated days.

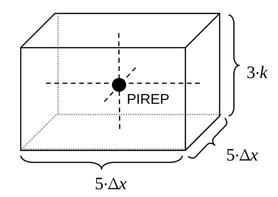
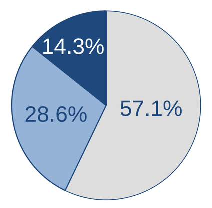
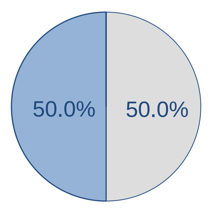


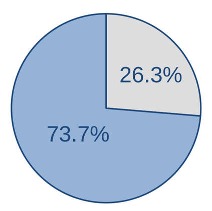
Fig. 3: Neighborhood verification.



PIREP information: "*No icing*"
Number of PIREPs: 7 (=100% in pie chart)
Mean value of COSMO LWC_{max}: 0.19 g/m³
Expected value: LWC = 0.00 g/m³



PIREP information: "*Light icing*"
Number of PIREPs: 74
Mean value of COSMO LWC_{max}: 0.06 g/m³
Expected value: 0.00 < LWC ≤ 0.60 g/m³



PIREP information: "*Moderate icing*"
Number of PIREPs: 19
Mean value of COSMO LWC_{max}: 0.17 g/m³
Expected value: 0.60 < LWC ≤ 1.20 g/m³

→ The predicted LWC amounts are too small!

Legend for pie charts

Illustrated are the LWC forecast values:
- No icing
- Light icing
- Moderate icing

3rd Step: Comparing PIREP location to LWC forecast

The spatial distribution of LWC forecasts shows unacceptable deficiencies mentioned in the table on the right hand side. **ROC analysis** was used for this evaluation.

		PIREP Icing Observation	
		Yes	No
LWC Forecast	Yes	Hits: 51 (H)	False Alarms: 3 (FA)
	No	Misses: 42 (M)	Correct Rejections: 4 (CR)
Hit Rate = H/(H+M) = **0.55** , **False Alarm Rate** = FA/(FA+CR) = **0.43**			
Corresponding **AUC-Value**: **0.56** → **inadequate forecast quality!**			

Case Study after Weisman and Klemp

The question is now **why** COSMO-EU predicts a too small amount of LWC with an incorrect spatial distribution. For this reason, a case study after Weisman & Klemp [7] was arranged to investigate the cloud microphysical scheme and its conversion processes in a more detailed way.

3D model domain
100 x 100 x 20 km³ without orology

High resolution
horizontal: 1km
vertical: 64 layers

Compressible, nonsteady case
Constant inflow in x

Horizontal homogenous, vertical profiles
for T, rH, v

COSMO-EU cloud microphysical scheme

Initialization of a warm bubble
inducing convection

Development of the convection cell

To investigate developing convection and its microphysical classes, x-z-slices were created (see Fig. 4). After 42 minutes, warm rain starts to leave the cloud. These rain drops are a **sink of cloud water** because they are formed by collision of cloud droplets. After 78 minutes, obviously a big part of the cloud consists of snow. Snow can only form with the aid of cloud ice (see also Fig. 2). At the end of the simulation, no cloud water is found. It has been depleted while the ice classes could form and grow.

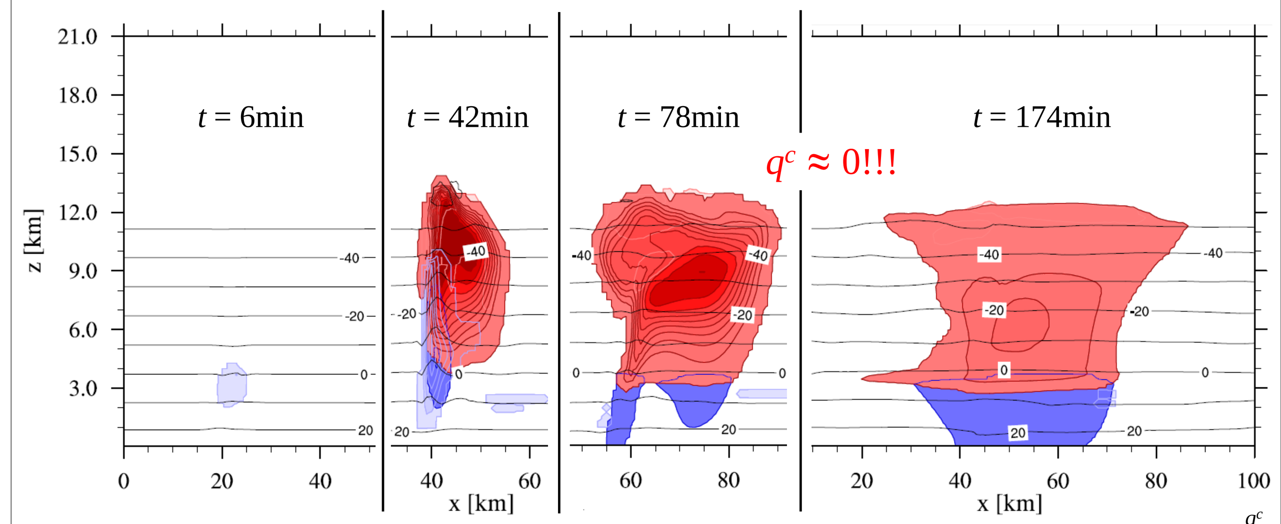


Fig. 4: Development of the initialized convection cell and the microphysical classes, described by their mass concentration q^ψ. The black lines are isotherms for T in °C. The simulation time is mentioned within the subfigures.

Investigation of the conversion terms

The marked area in Figure 5 shows that the conversion rates of cloud water, cloud ice and rain are nearly constant while these of snow and water vapor are inverse. In COSMO-EU's cloud microphysical scheme snow can just form and grow with the aid of cloud water and ice. The conclusion is that freezing proceeds too fast in COSMO-EU, namely faster than one simulation time step.

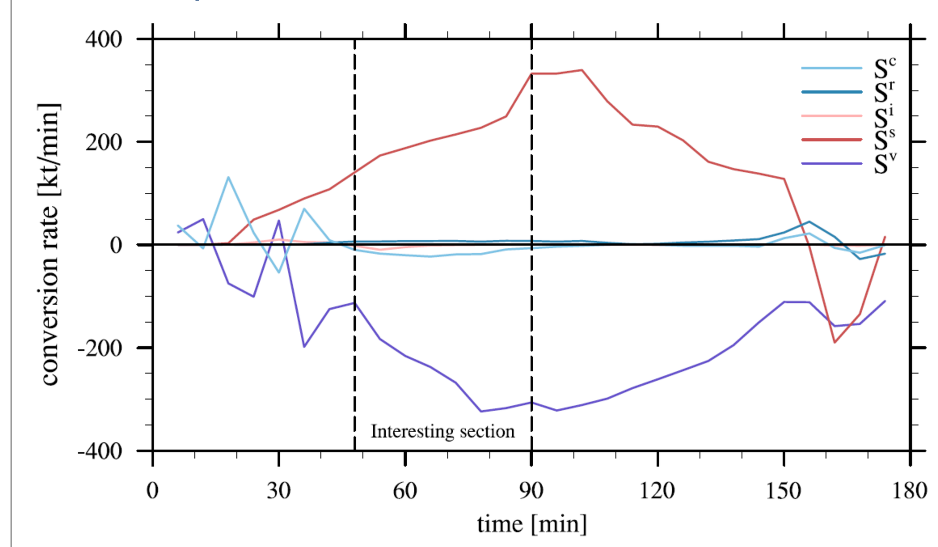


Fig. 5: Time series of the conversion terms S^ψ.

Conclusions and Future Work

The results of this investigation are:

1. COSMO-EU forecasts too small amounts of LWC in the vicinity of icing PIREP observations.
2. The predicted spatial distribution of LWC shows unacceptable deficiencies in comparison to icing PIREPs.
3. With a case study after Weisman & Klemp, the authors pointed out that freezing processes are simulated too fast in the microphysical scheme of COSMO-EU. Cloud ice and snow form and grow while cloud water is depleted within a model time step.

These results are not only valid for German NWP models (see also [5]). Because of a lack of observational data, precipitation was the only way to evaluate microphysical schemes until now. In the future, cloud water should be used as well to evaluate the microphysics of NWP models!

Future work

More research on microphysical schemes
International exchange needed!
→ **Improvement of NWP models and their physical parameterizations**
→ **Revision of existing expert systems to improve forecasts of aircraft icing conditions**

Expert systems like ADWICE [6], CIP/FIP [1] or SIGMA [4] can benefit from international research initiatives on this topic!

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