Towards a more reliable forecast of ice supersaturation

Concept of a one-moment ice-cloud scheme that avoids saturation adjustment

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Contents

- Problem and Motivation
- Status Quo
- New Parameterisation
- Tests of the new Parameterisation
- Summary and Outlook

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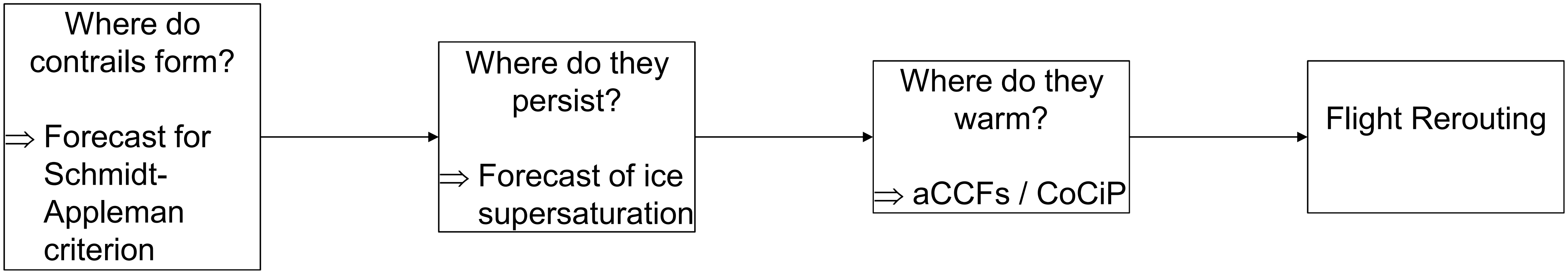
Contents

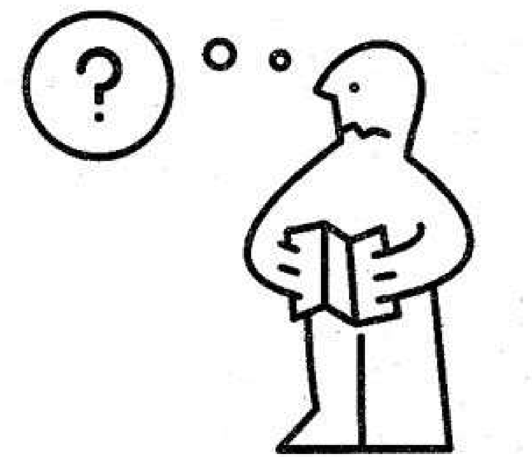
https://eos.org/wp-content/uploads/2019/06/contrails-over-mountains.jpg

Contrail Mitigation in Theory



Contrail Mitigation in Reality

Forecast for Schmidt-Appleman criterion → **BAD** Forecast of ice supersaturation → aCCFs / CoCiP → **BAD** Flight Rerouting



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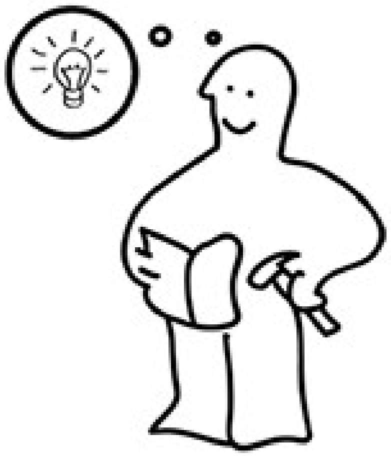
The Plan

Forecast for Schmidt-Appleman criterion → **GOOD** Forecast of ice supersaturation → aCCFs / CoCiP → **GOOD** Flight Rerouting



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Contents

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The Status Quo in the IFS: Saturation Adjustment for Cirrus Clouds

- Supersaturation only allowed in clear sky part of grid box
- All supersaturation deposited instantaneously upon nucleation

⇒Grid-mean supersaturation possible but not large

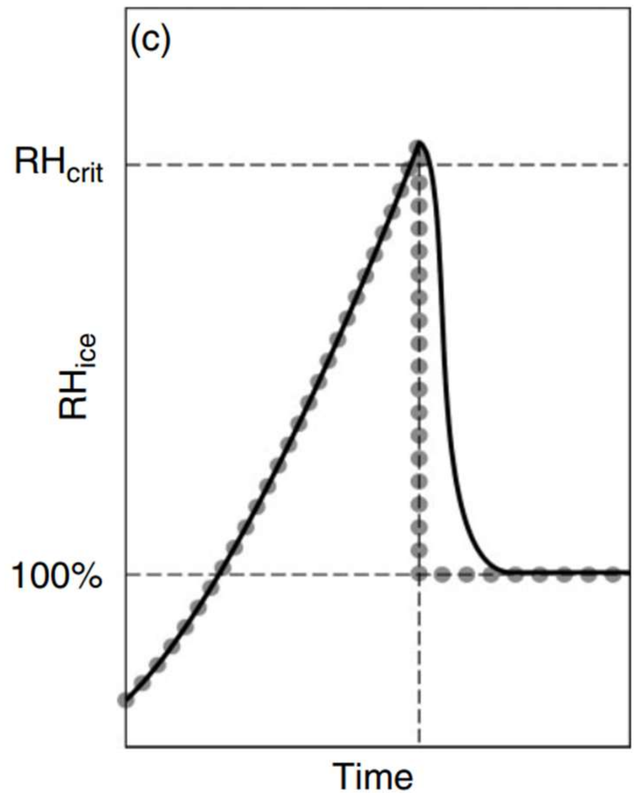
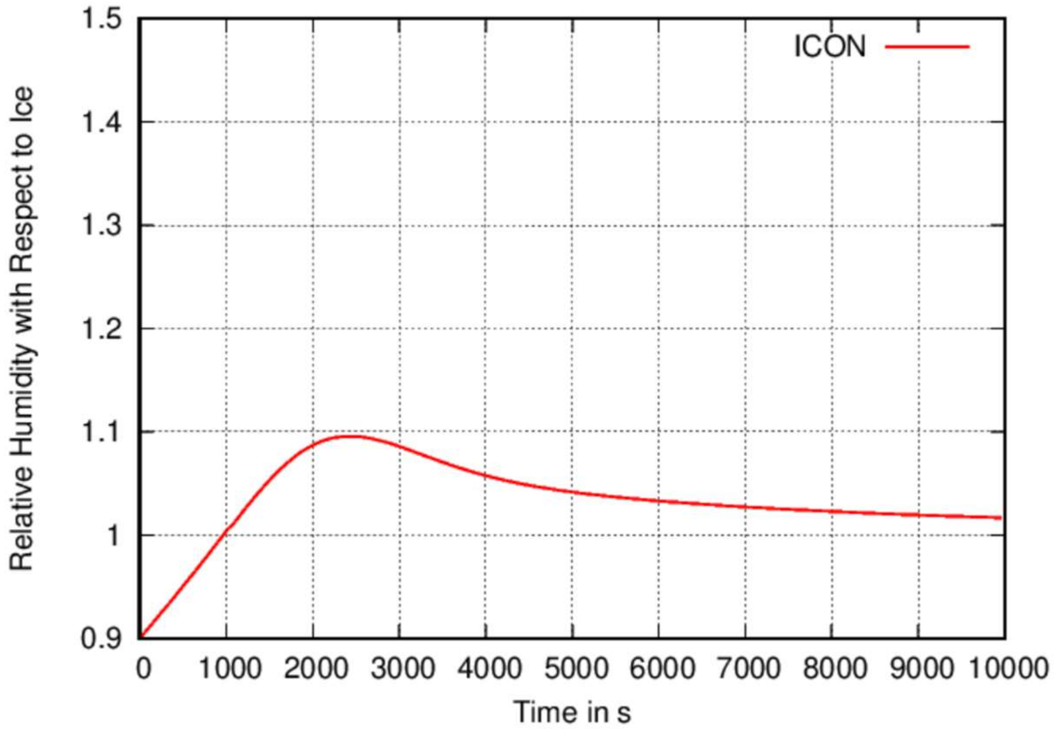


Figure 1(c) of Tompkins et al. (2007)

The Status Quo in ICON: Nucleation at Saturation

- Nucleation in whole grid box occurs as soon as relative humidity exceeds saturation
- Deposition rate increases with increasing specific cloud ice content and increasing supersaturation

⇒Supersaturation limited due to early nucleation of large amount of ice crystals



Contents

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The Plan: A little more Realism

- NWP is time-critical, microphysics needs to be fast
- Two-moment schemes are computationally intensive

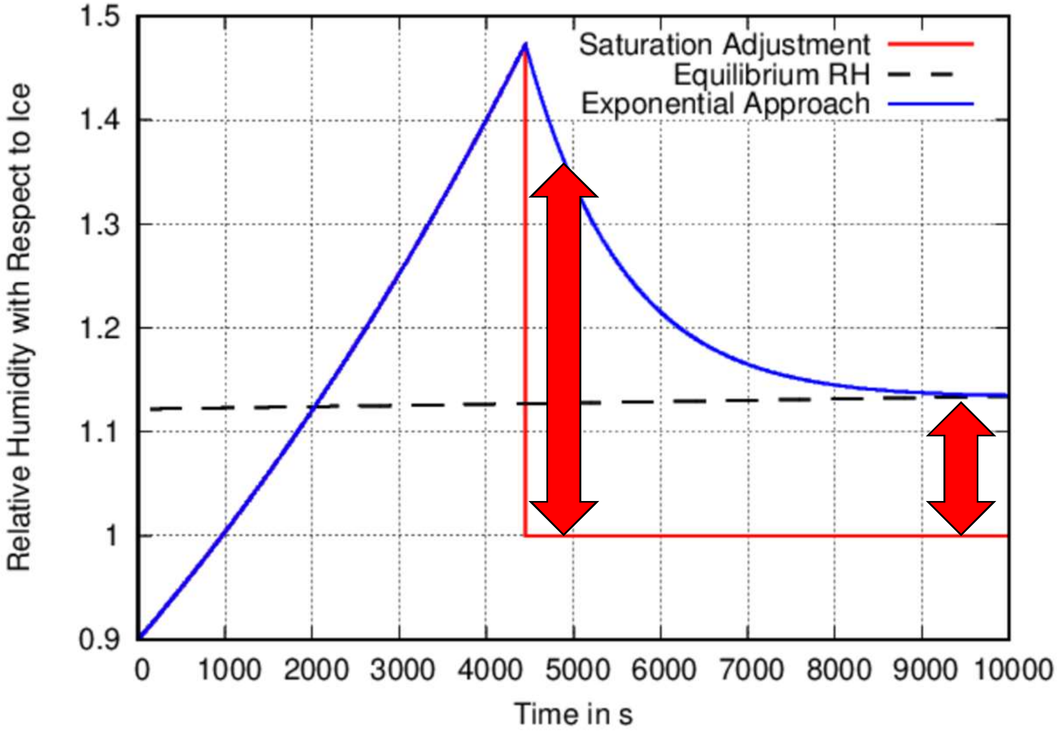
⇒How far can we improve a one-moment scheme?

- Let humidity decay exponentially towards saturation in cloudy air parcels:

$$\Delta q_p = -\alpha\left(q_p - q_{sat}\right)\Delta t, \qquad \alpha = const$$

⇒Two differences to saturation adjustment:

1. Large supersaturation shortly after nucleation
2. Small remaining supersaturation even after long time periods, as long as supersaturation gets restored continuously



The Method

Step 1: Divide grid box into large number of air parcels with different specific humidities

↓

Step 2: Determine in-cloud humidity distribution in developing cloud from initial clear sky humidity distribution

↓

Step 3: Find expression for mean of in-cloud humidity distribution

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Step 4: Use mean in-cloud humidity as a new variable in a new cirrus parameterisation

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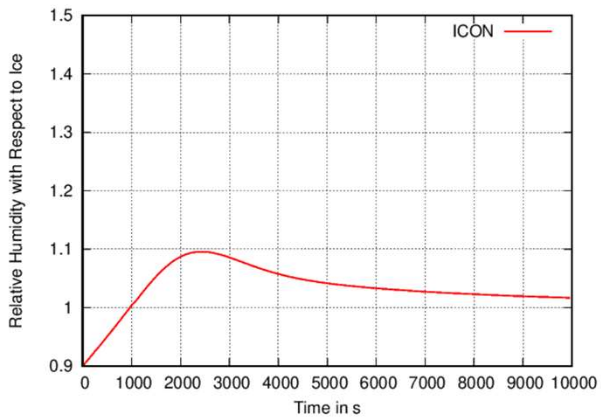
Step 5: Save the world! (Still in progress)

What about α?



- α so far treated as a constant
- In reality α includes information about number, size and shape of ice crystals
- ICON estimates crystal size from specific ice content by assuming constant (large) crystal number
- Large numbers actually measured in cirrus clouds
- **BUT:** Upon first nucleation crystal number small, increase over time due to further nucleation

⇒Possible way of determining α: Increasing crystal number with ice content

Contents

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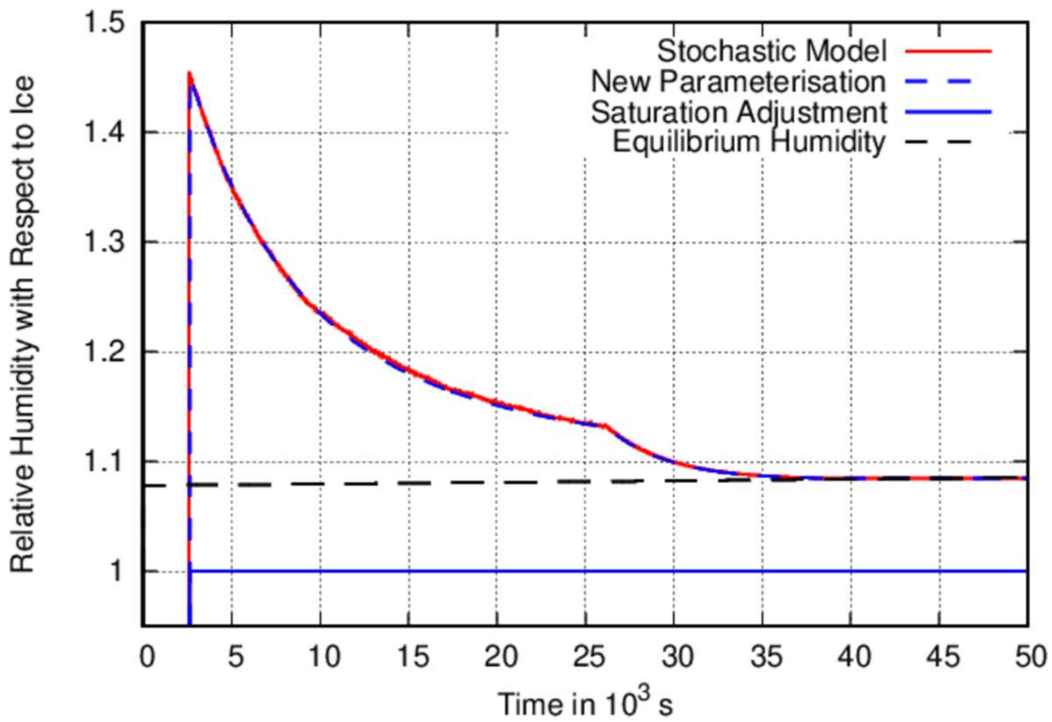
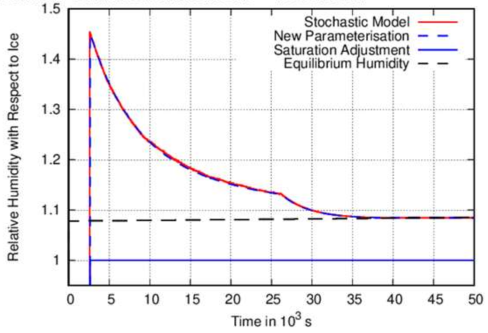
Tests

- Testing new parameterisation against saturation adjustment
- Artificial environment, stochastic box model serves as benchmark for „reality“

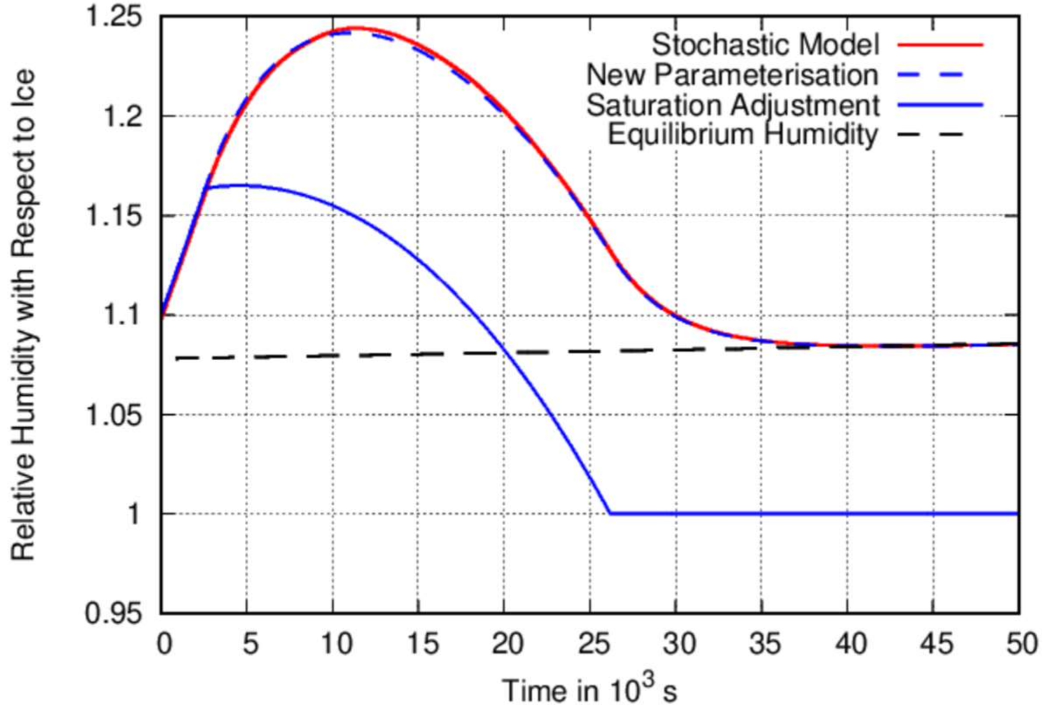
Constant updraught 2 cm/s:
Mean in-cloud humidity

- Obvious underestimation of in-cloud humidity by saturation adjustment
- New parameterisation closely follows stochastic box model





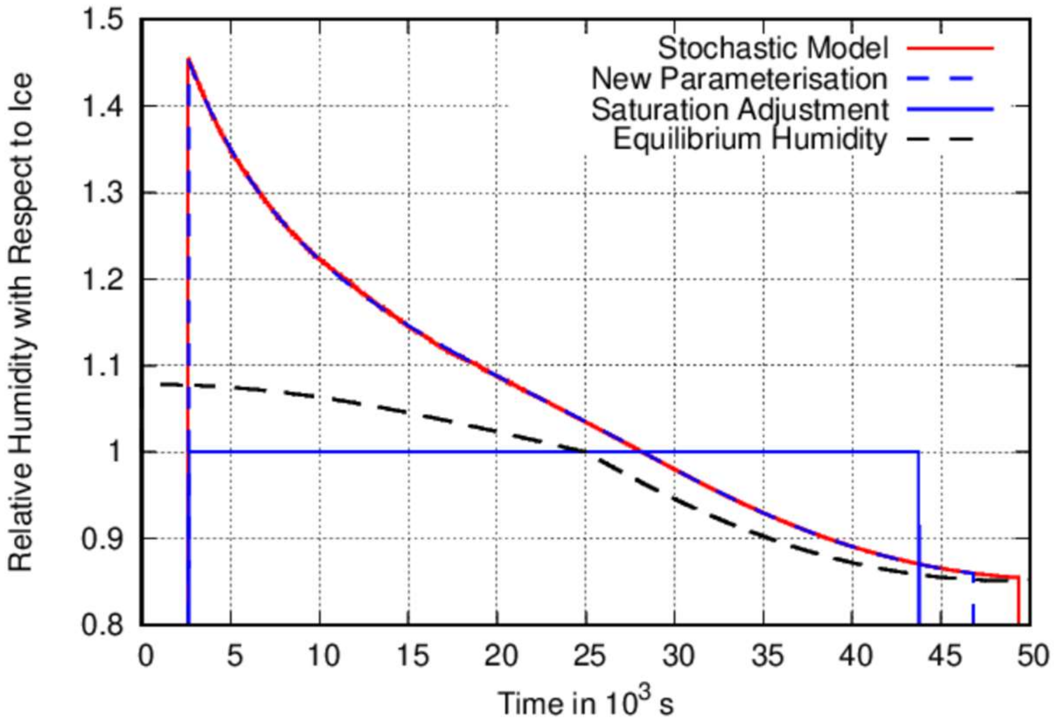
Constant updraught 2 cm/s: Grid mean humidity

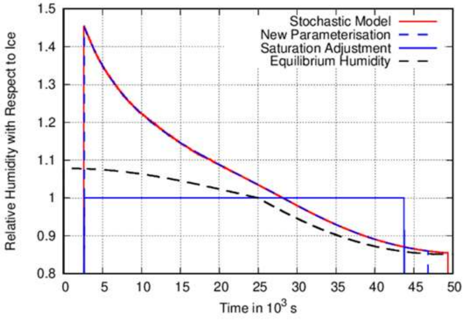


- Further increase in relative humidity after onset of nucleation hardly possible with saturation adjustment

Modulated vertical wind: Mean in-cloud humidity

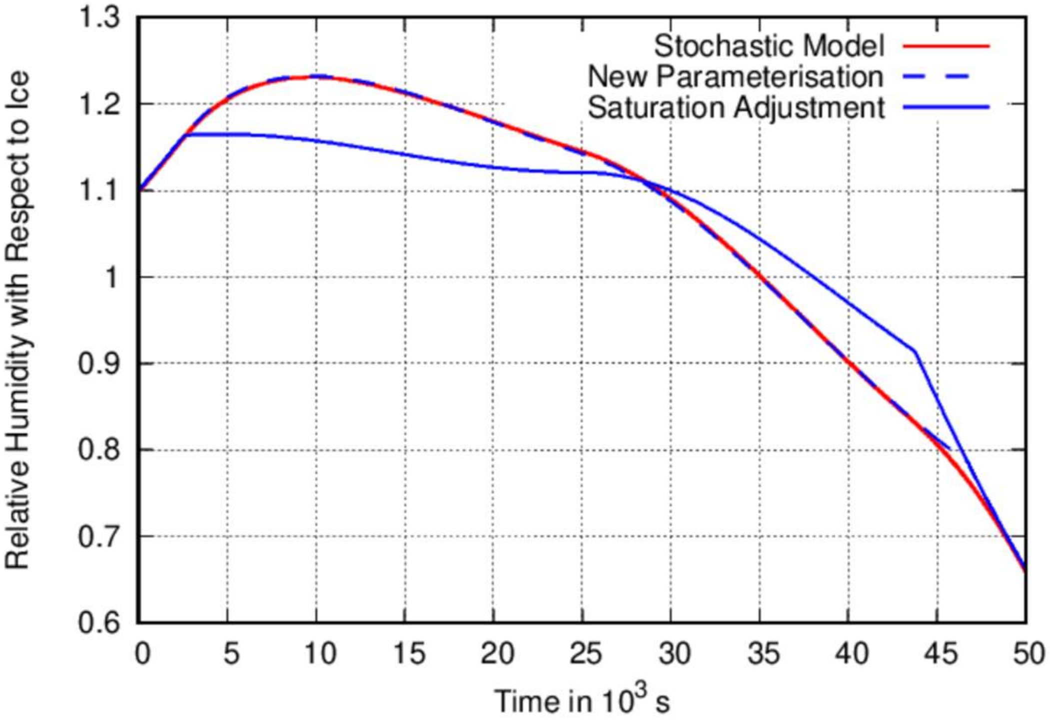
- Cloud quickly becomes subsaturated after onset of warming
- No in-cloud subsaturation with saturation adjustment





Modulated vertical wind: Grid mean humidity

- Saturation adjustment leads to underestimation of humidity in cooling air and overestimation in warming air



Contents

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Summary and Outlook

- New parameterisation shows great improvement to saturation adjustment in artificial environments
- It enables in-cloud sub- and supersaturation
- It creates larger supersaturations than the ICON parameterisation
- New prognostic variable „in-cloud humidity“ is needed => larger computational costs

Ongoing work:

⇒Decision on how to determine value of α

⇒Test new parameterisation in more realistic environment (MESSy-ICON)

Thank you for your attention!

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Further findings

Improvement in comparison with saturation adjustment is enlarged by…

- … slower phase transition (i.e. smaller value of α)
  ⇒Slower decrease of initial supersaturation and larger equilibrium humidity

- … narrower clear sky humidity distribution
  ⇒Quicker increase in cloud fraction increases weight of in-cloud supersaturation in grid mean humidity

- Introduction of heterogeneous nucleation removes moisture from the moistest air parcels
  ⇒Homogeneous nucleation occurs later
  ⇒Can lead to even larger supersaturation