Postprocessing model data for fog forecast

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Outline

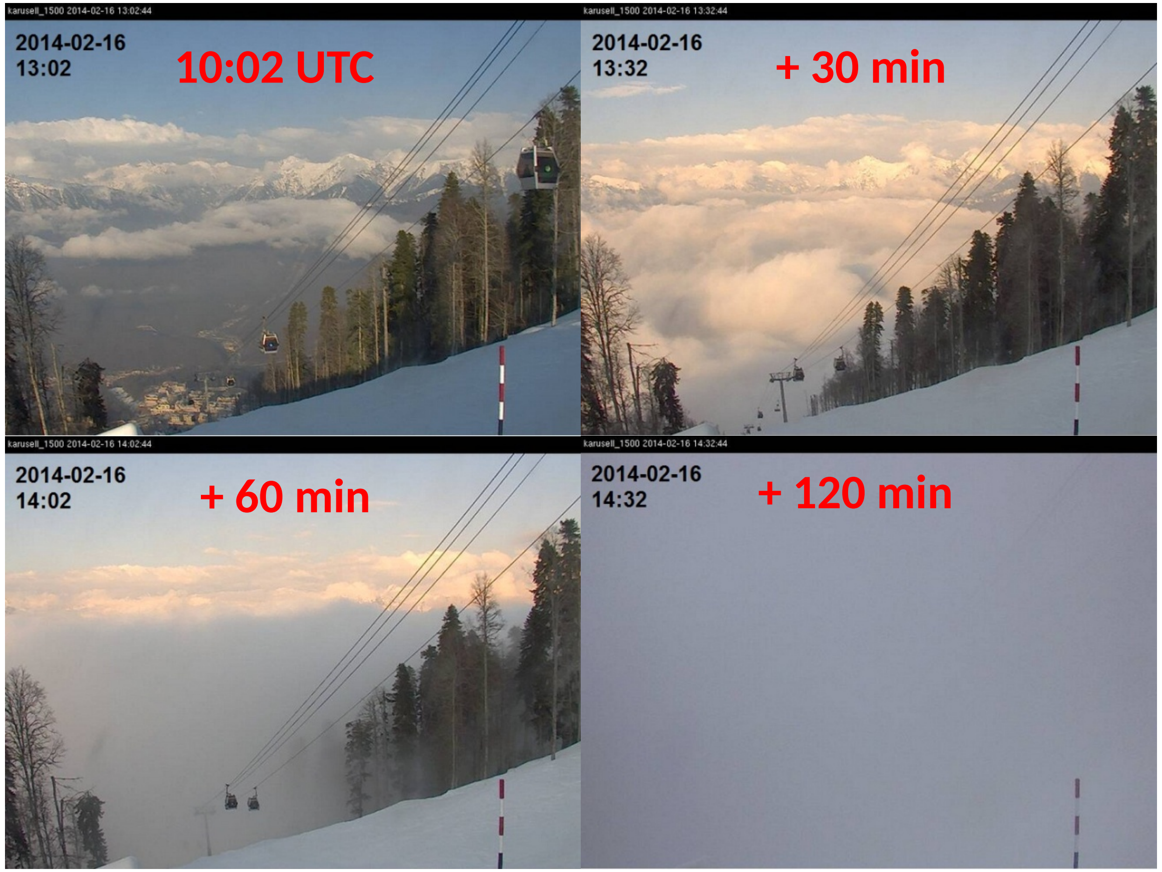
- Fog as severe weather event
- Main fog characteristics
- Basic directions of fog forecast
- Postprocessing model data for fog forecast
- Conclusions

Fog as severe weather event

The fog is suspended cloud particles in the air near surface (1.5-2 m), which reduce the horizontal visibility up to 1 km and less.

Main fog reasons: radiation cooling, moist air mass advection, orography and anthropogenic activity.

Orography fog near Sochi, 16/02/2014



Fog hazards:

- Dangerous take off and landing of aircrafts
- Delayed flights (economic consequences)
- Vehicle accidents
- Difficulties for water and rail transport

The accurate forecast of fog location and intensity helps reduce the effects of severe weather event!

What is the “fog forecast” means?

FOG

intensity

vertical extent

horizontal visibility range (VIS)

time of formation and duration

$$VIS = \frac{ln\left(\frac{1}{\varepsilon}\right)}{\beta_\lambda}$$

β_λ – volumetric attenuation radiation coefficient

λ – wavelength (=550 nm usually)

ε – eye contrast threshold (=0.05 or 0.02 usually)

Attenuation radiation coefficient (β)

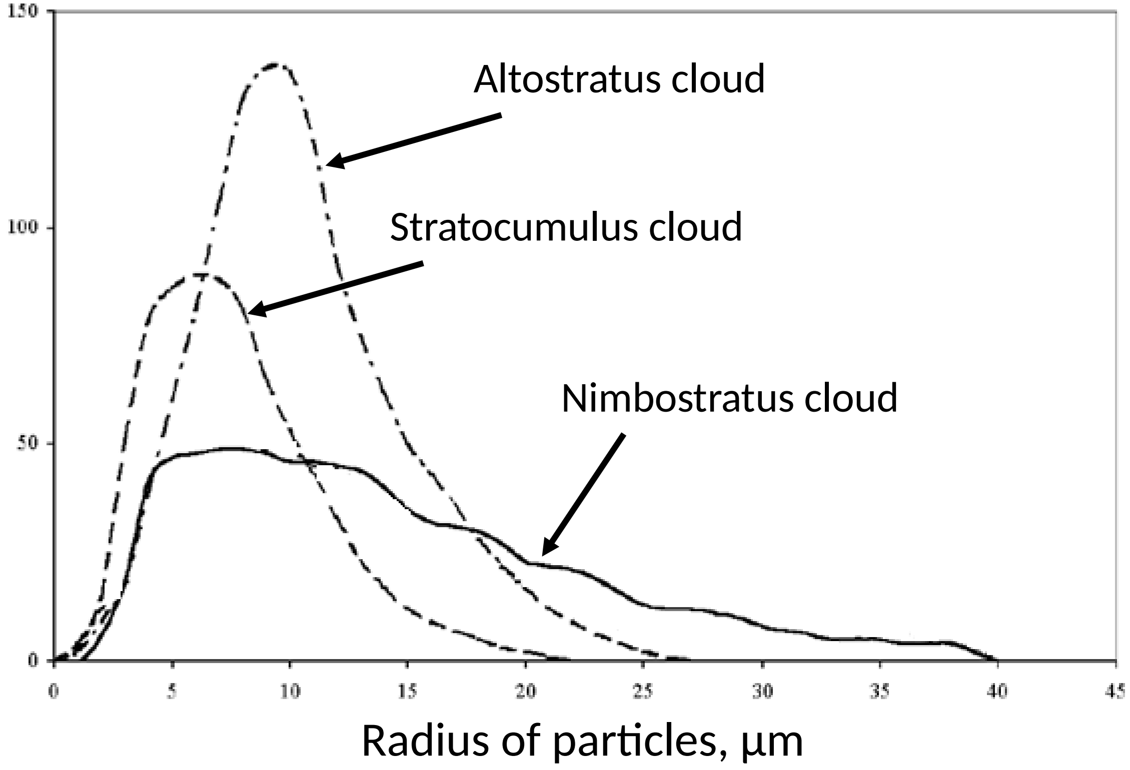
$$\beta_\lambda = \int_0^\infty Q_{ext,\lambda} n(r) r^2 dr \approx$$

The fog effect can be described using meteorological observations or NWP results

The direct modelling of β is a difficult and expensive task because of:

- **Cloud inhomogeneity**
- **The difficulty of accurate description of n(r)**

more appropriate



– Mie efficiency factor

r – cloud droplet’s radius

n(r) – number density of cloud droplets

Directions of fog forecast development

a) Empirical ratios

$$\beta = f(k_1, k_2, k_3 \dots)$$

k_i – meteorological parameters (air temperature, dew point temperature, wind speed, relative humidity).

(Zverev A.S., 1977)

Base: measurements

b) Machine learning methods

– meteorological parameters (air temperature, dew point temperature, wind speed, air pressure, relative humidity).

(Abdulkareem et al., 2019; Zhu et al., 2017; Oguz and Pekin, 2019)

Base: measurements or NWP results

c) NWP forecast (or postprocessing)

$$\beta_\lambda = \int_0^\infty Q_{ext,\lambda} n(r) r^2 dr$$

or need the parametrization of β

(Kunkel B.A., 1984; Wilkinson et al., 2013; Creighton et al., 2014)

Base: NWP results

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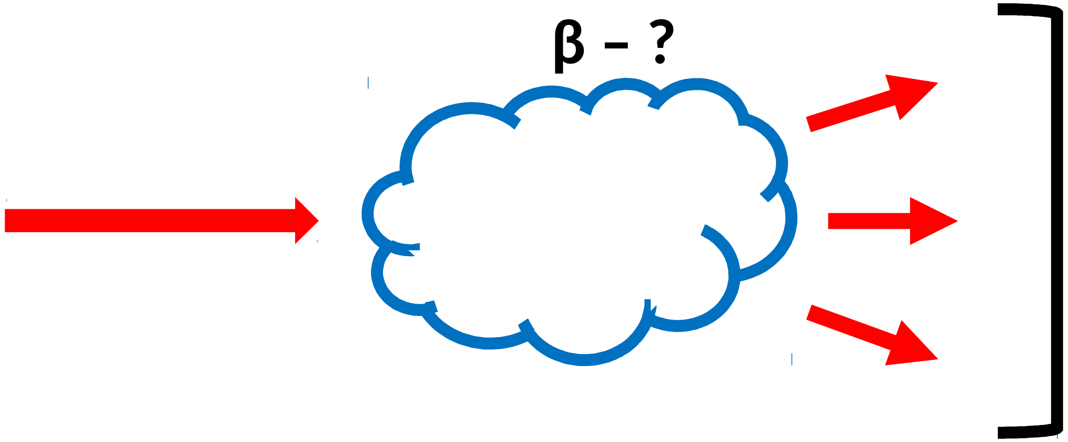
β parametrizations: “meteorological” approach



β is a function of meteorological parameters:

- Air temperature (T, ˚C)
- Dew point temperature (T_d, ˚C)
- Relative humidity (RH, %)
- a_i – constants based on measurement data

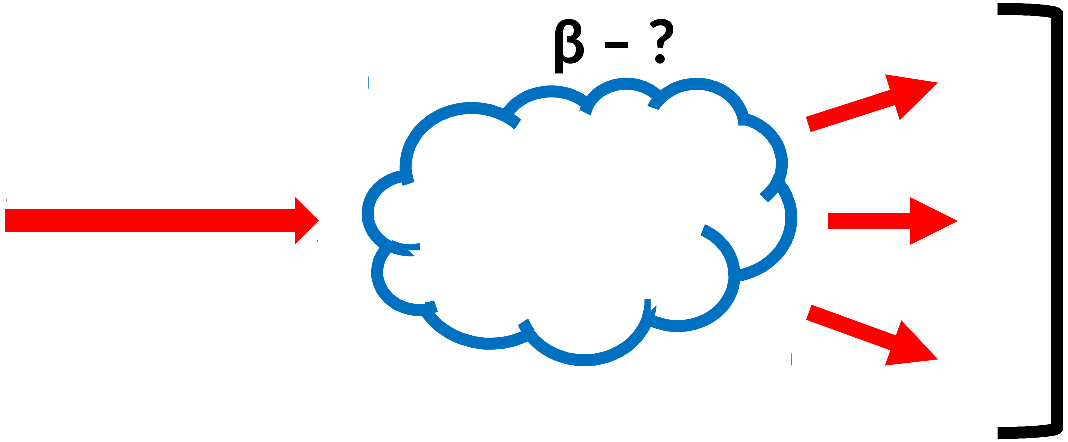
1) $$\beta = a_1 \frac{T - T_d}{RH^{a_2}}$$

(Doran et al., 1999)

2) $$\beta = a_3 \ln(RH) + a_4$$

(Gultepe et al., 2009)

β parametrizations: “meteorological” approach



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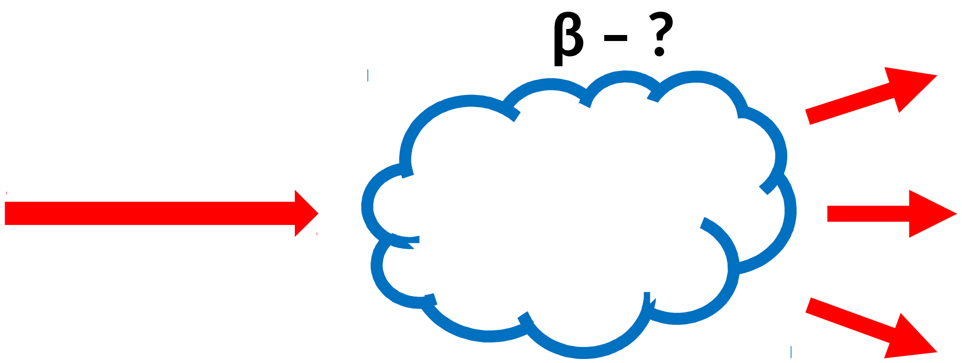
Meteorological parameters are not able to fully describe the cloud structure

β parametrizations: “microphysical” approach



β is a function of cloud characteristics (one-moment or two-moment):

- liquid water content (QC, g/m³)
- ice water content (QI , g/m³)
- number concentration of cloud droplets (N_c, cm^{-3})
- number concentration of ice particles (N_i, cm^{-3}))
- Radius of cloud droplets (r_c, m)
- a_i – constants based on measurement data

1) $$\beta = a_1 QC^{a_2}$$

(Kunkel B.A., 1984; Creighton et al., 2014)

HARMONIE, AROME, WRF

2) $$\beta = a_3 {N_c}^{a_4}$$

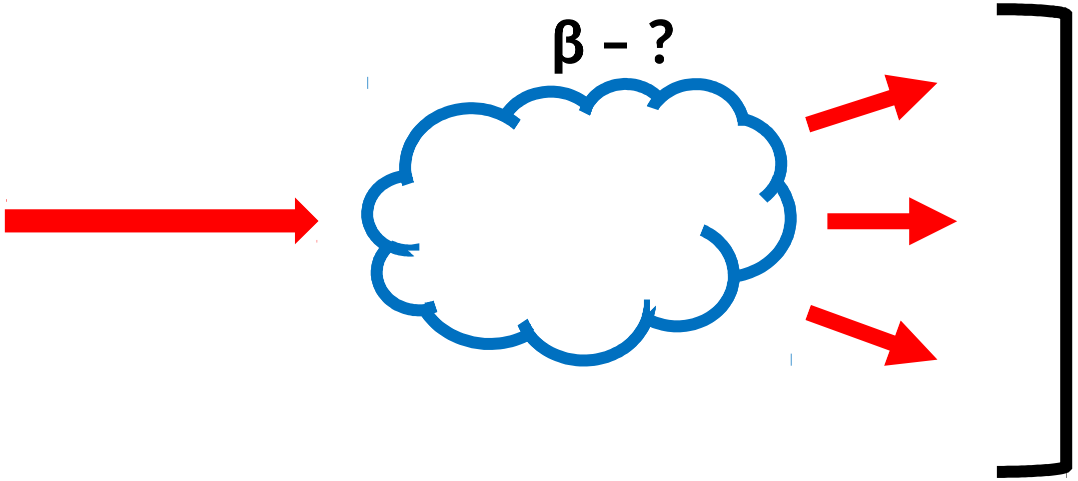
(Meyer et al., 1980)

3) $$\beta = a_5 \frac{r_c}{QC}$$

(Juisto J.E., 1981)

MM5

β parametrizations: “microphysical” approach



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- number concentration of cloud droplets (, cm⁻³)
- number concentration of ice particles (, cm⁻³))
- Radius of cloud droplets (, m)
- – constants based on measurement data

4) $$\beta = a_6 QC^{a_7} N_c^{a_8}$$

(Trautmann and Bott, 2002; Gultepe and Milbrandt, 2007)

$$\beta = a_9 QI^{a_{11}} N_i^{a_{12}}$$

(Gultepe et al., 2015)

PAFOG, COBEL, MM5

5) $$\beta = a_{13} r_c^2 N_c + a_{14}$$

UM

(Clark et al., 2008; Boutle et al., 2016)

Impact of two-moment microphysics

- Low-level cloudiness
- Liquid water clouds mostly

Model: COSMO v.5.08

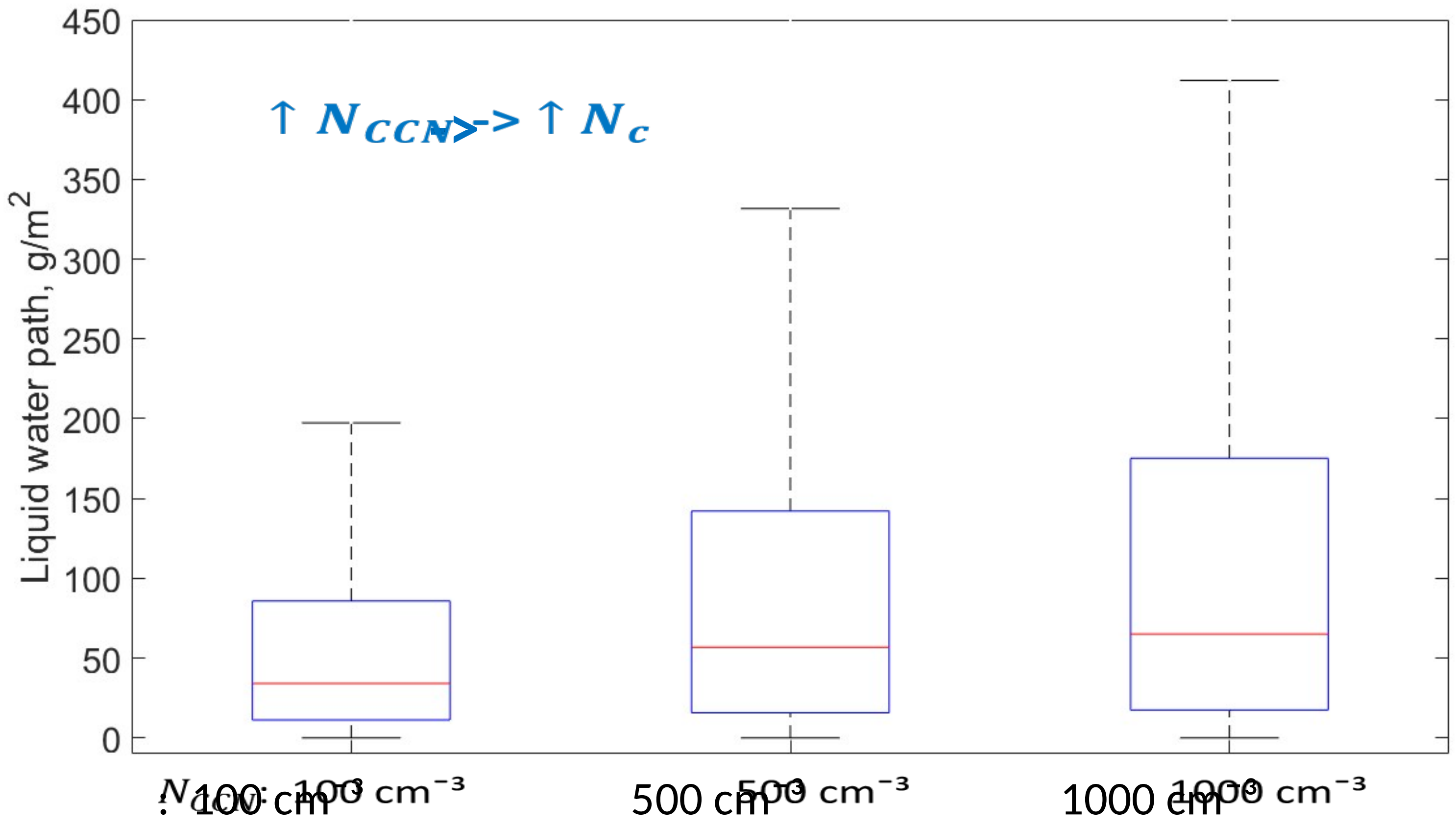
Grid step: 1 km

Microphysics: 2-moment (2797)

Convection: shallow (type 3)

Aerosol-cloud-radiation interaction:

- CLOUDRAD scheme (Hu & Stamnes, 1993; Fu et al., 1996 ;1998) with additions.
- 100, 500 and 1000



$$\beta = a_6 QC^{a_7} N_c^{a_8}$$

(Trautmann and Bott, 2002)

CLOUDRAD&2MOM can use aerosol fields from chemical-transport models for more realistic aerosol effect

Additional information about aerosol typification, solubility and anthropogenic impact

Visibility forecast based on ICON/COSMO results

- **Liquid water content (QC)**

Which one is more appropriate for fog forecast?

need the analysis and comparisons

QC in microphysics scheme

QC in turbulence scheme

QC in radiation scheme

- **Number concentration of cloud droplets ()**

only for two-moment microphysics

Conclusions

- There are three main ways of fog forecast: using empirical ratios, machine learning methods, and numerical weather prediction (or model postprocessing)
- The NWP fog forecast is preferable because it has not only fog intensity, but includes also the fog vertical extent, moment of fog formation and duration
- The microphysical approach of horizontal visibility range calculation is better than meteorological approach
- The two-moment microphysics allows expanding the range of horizontal visibility due to accounting for the geographical location and the level of aerosol pollution
- The visibility forecast using ICON results needs the analysis all liquid and ice water sources (schemes) in the model

Structure of cloudy experiments

Dates: 22/04/2018, 02/05/2019, 08/05/2020, 22/05/2020

Model settings:

Model: COSMO v.5.08

Grid step: 1 km

Forecast: 0-24 UTC, 0.5

Microphysics: 1-moment 4-class and 2-moment (2777 and 2797)

- Ice nucleation (Meyers et al., 1992; Fletcher et al., 1962)
- Liquid water nucleation (Segal & Khain, 2006)
- Warm processes (Seifert & Beheng, 2000; Pinsky et al., 2000)

Convection: shallow (itype_conv = 3)

Aerosol: Tegen climatology (for clear sky)

Cloud-radiation interaction:

- CLOUDRAD scheme (Hu & Stamnes, 1993; Fu et al., 1996 ;1998) with additions. 150, 200 and 300

Latent heat nudging: no

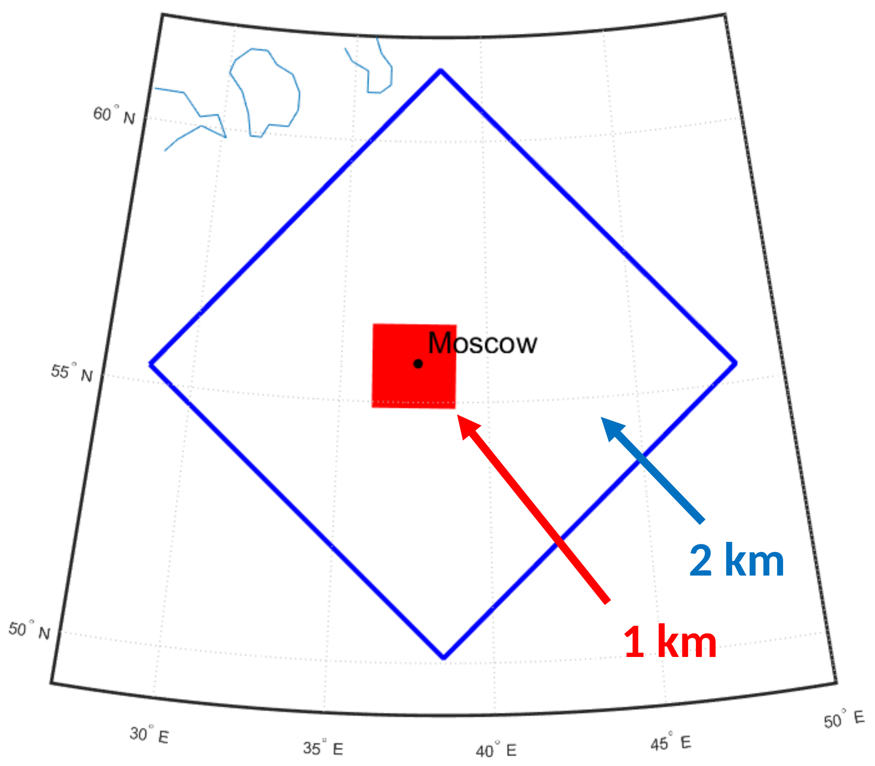
Experiments:

a) one-moment

b) two-moment default (2777)

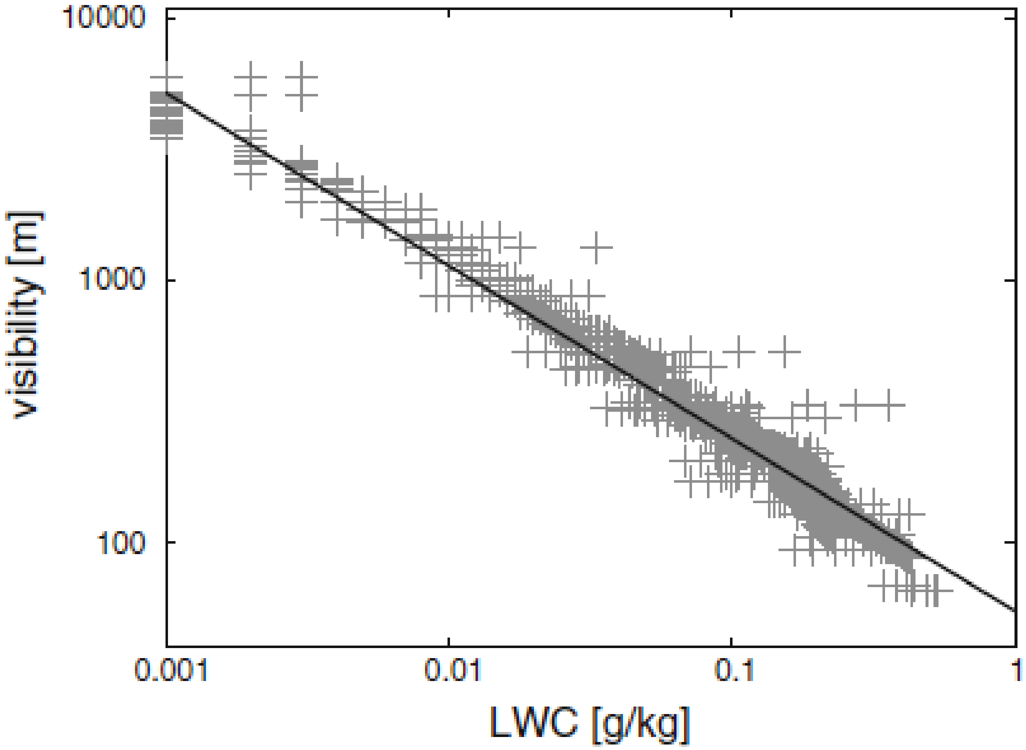
c) two-moment with upper N_{CCN} (2797)

Comparison area (internal red)

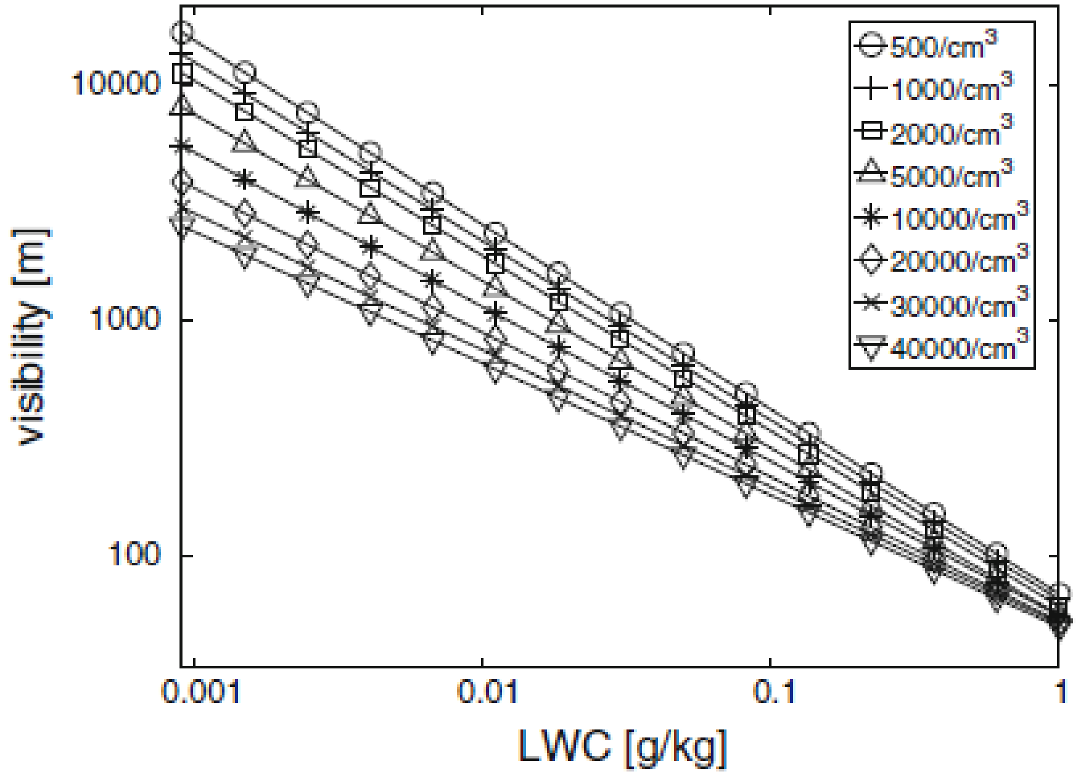


Impact of two-moment microphysics (Thoma et al., 2011)

The accordance of liquid water content (LWC) and horizontal visibility



The effect of number concentration of cloud condensation nuclei () on the horizontal visibility



$$\beta = a_6 Q C^{a_7} \boldsymbol{N_c^{a_8}}$$

(Trautmann and Bott, 2002)