Key Parameters for the Life Cycle of Nocturnal Radiation Fog

Results from a Comprehensive Large-Eddy Simulation Study

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1 Motivation

Fog can have a high impact on the economy and personal safety (Bergot, 2013). Gultepe et al. (2009) estimated the total economic loss that is associated with fog events on aviation, marine and land transportation to be comparable to those of winter storms. There is thus increasing demand in precise fog forecasting (e.g. for airports, see e.g. Bergot, 2016). Despite the improvements in numerical weather prediction (NWP) models over the last years, accurate forecasting of fog is still challenging (e.g. Wilkinson et al., 2013; Steeneveld et al., 2015). The main reason is fog's considerable variability in space and time as a result of the nonlinear interaction between several processes, such as radiation, turbulent mixing, cloud microphysics, and energy transfer in the atmosphere-surface-soil continuum (e.g. Haeffelin et al., 2010; Holtslag et al., 2010).

This study investigates the role of turbulence in nocturnal radiation fog and its interaction with microphysics, radiation, and the vegetation-surface-soil continuum in order to derive key parameters for the accurate simulation and prediction of fog. A deep fog case as observed at Cabauw/CESAR, Netherlands, 23 March 2011 (see Boers et al., 2013) is used for validation and as reference for a comprehensive set of large-eddy simulations. This poster gives an overview of the results that were published in Maronga and Bosveld (2017).

2 LES Model

General

- The LES model PALM (Maronga et al., 2015).
- Finite differences, Cartesian grid.
- Cyclic lateral boundary conditions.
- 1D model for precursor runs.

Cloud microphysics

- Two-moment liquid phase (Seifert and Beheng, 2001; 2006)
- Constant cloud droplet number concentration

Land surface scheme

- TESSEL based land surface scheme
- Energy budget solver for skin temperature, 4-layer soil model
- Radiation scheme: RRTMG (1D vertical), coupled to PALM

3 Fog case and simulation setup

Observed fog at Cabauw

- Midnight: $u_g \approx 5.5\,\mathrm{m\,s^{-1}}$, 6 K near-surface inversion.
- Fog formation: 0000 UTC. Deepening: 10-140 m between 0300-0600 UTC.
- Dissipation: 0800 UTC. Clear-sky conditions: 0900 UTC.

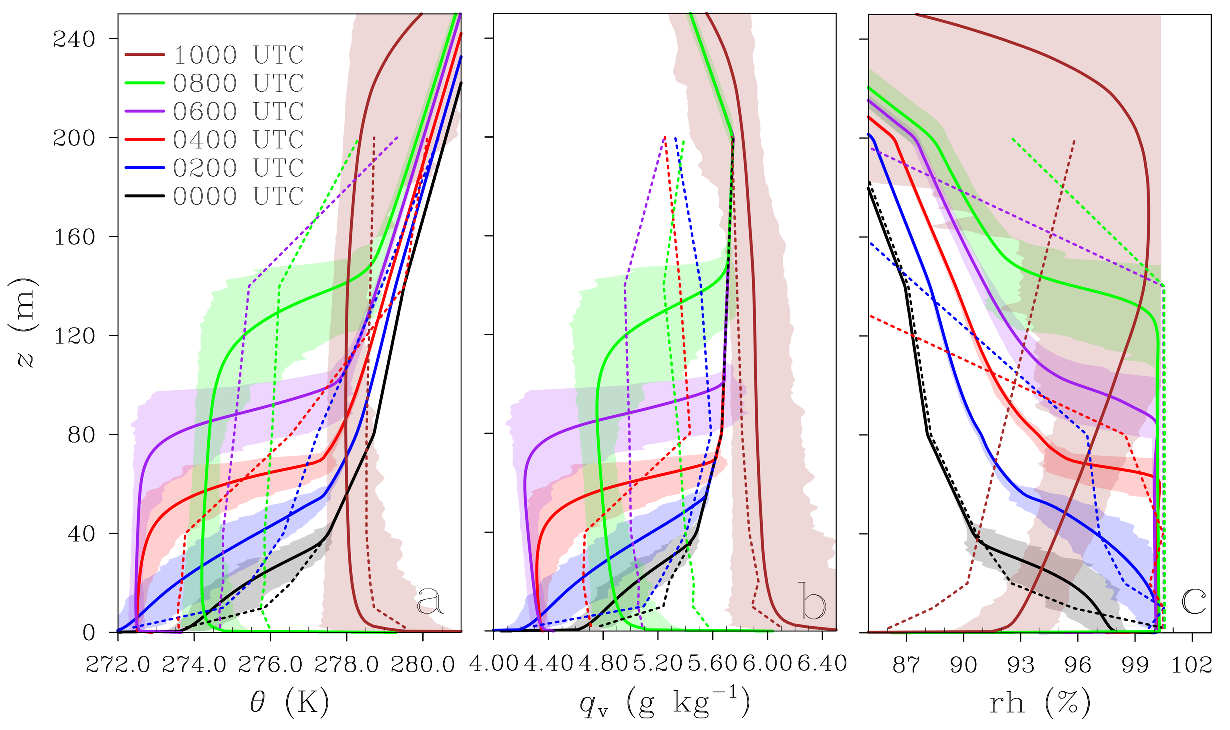
General setup

- Model domain: $768\,\mathrm{m} \times 768\,\mathrm{m} \times 384\,\mathrm{m}$.
- Grid spacing: $\Delta = 0.5 - 4.0\,\mathrm{m}$, equidistant.
- Cloud droplet concentration $N_c = 150\,\mathrm{cm^{-3}}$

Cabauw simulations

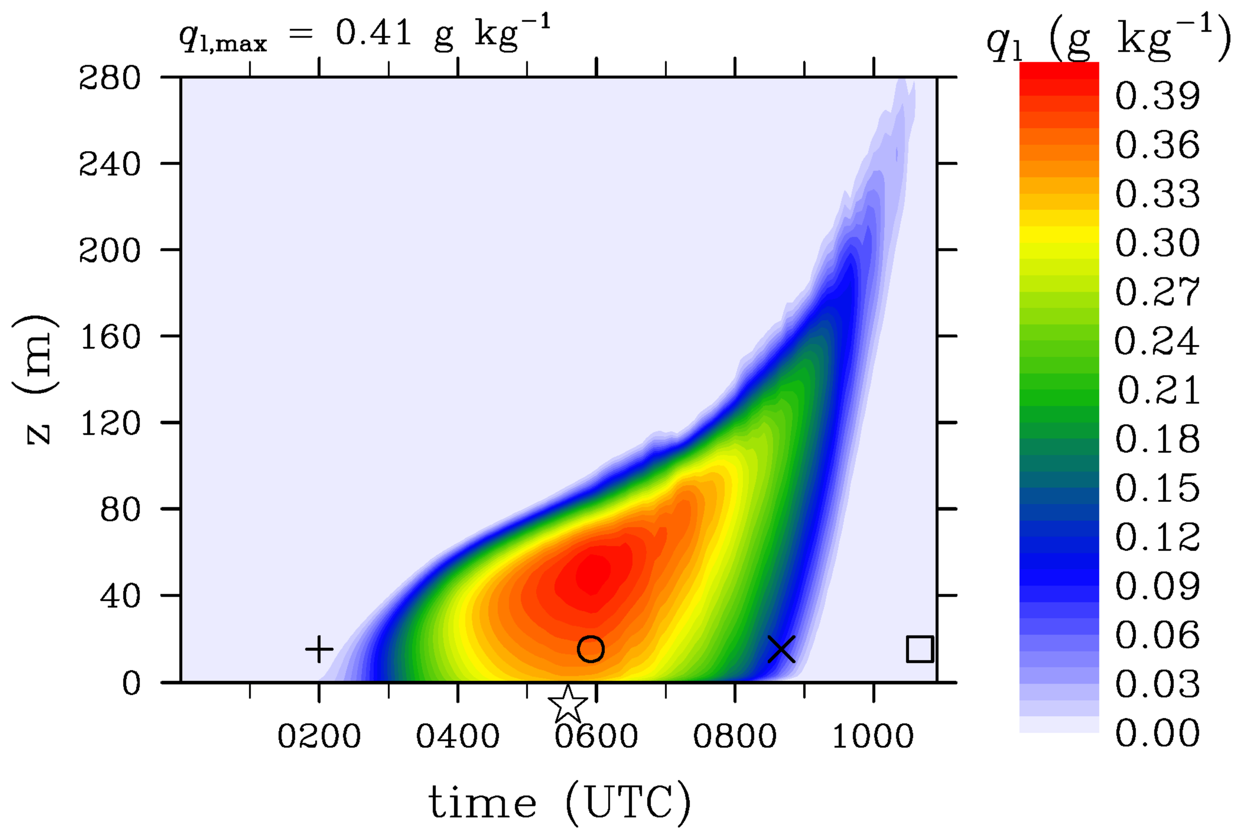
Cabauw runs	Feature
CAB (reference)	$\Delta = 1\,\mathrm{m}$
GRID_40	$\Delta = 4\,\mathrm{m}$
GRID_20	$\Delta = 2\,\mathrm{m}$
GRID_05	$\Delta = 0.5\,\mathrm{m}$
ADV_PT_05	cold-air advection ($-0.05\,\mathrm{K\,h^{-1}}$)
ADV_PT_10	cold-air advection ($-0.1\,\mathrm{K\,h^{-1}}$)
MEA_PT_-	colder $d\theta$: $-0.1\,\mathrm{K}$
MEA_PT_+	warmer $d\theta$: $+0.1\,\mathrm{K}$
MEA_QV_-	dryer dq_v: $-0.1\,\mathrm{g\,kg^{-1}}$
MEA_QV_+	wetter dq_v: $+0.1\,\mathrm{g\,kg^{-1}}$
NC_100	$N_c = 100\,\mathrm{cm^{-3}}$
NC_200	$N_c = 200\,\mathrm{cm^{-3}}$
Sensitivity runs	
REF (reference)	simplified CAB, $u_g = 4\,\mathrm{m\,s^{-1}}$
DYN_02	$u_g = 2\,\mathrm{m\,s^{-1}}$
DYN_03	$u_g = 3\,\mathrm{m\,s^{-1}}$
DYN_05	$u_g = 5\,\mathrm{m\,s^{-1}}$
DYN_06	$u_g = 6\,\mathrm{m\,s^{-1}}$
INI_ST_-2	colder soil (dT_s: $-2\,\mathrm{K}$)
INI_ST_+2	warmer soil (dT_s: $+2\,\mathrm{K}$)
INI_SQ_20	dryer soil (dm_s: $-0.3\,\mathrm{m^3\,m^{-3}}$)
INI_SQ_35	dryer soil (dm_s: $-0.2\,\mathrm{m^3\,m^{-3}}$)

4 The Cabauw case: fog life cycle



Development of temperature and humidity

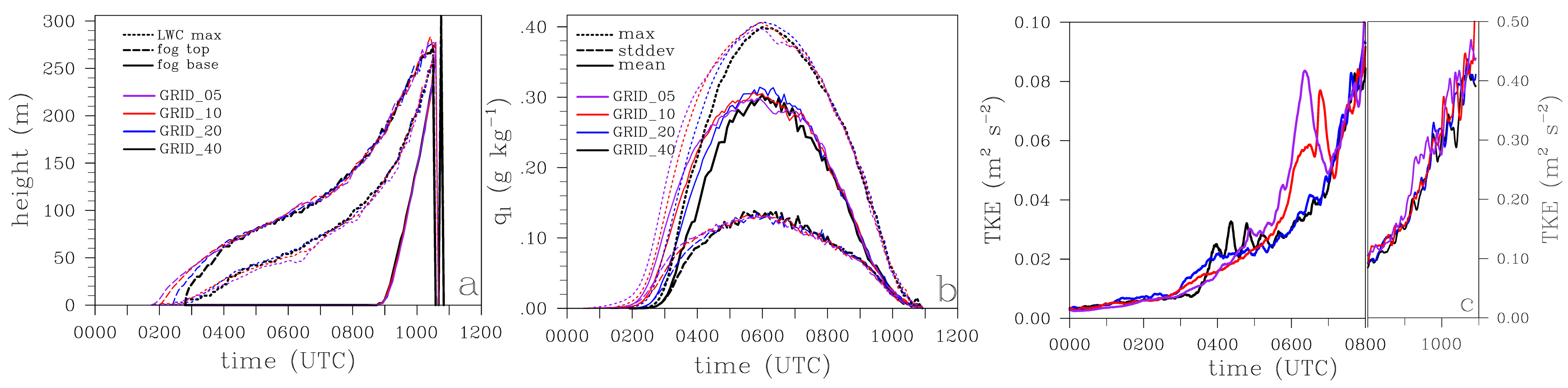
- Stable boundary layer at 0000 UTC
- Development of convective (top-down) convective layer at 0300 UTC
- Simulated fog remains colder and shallower than observed



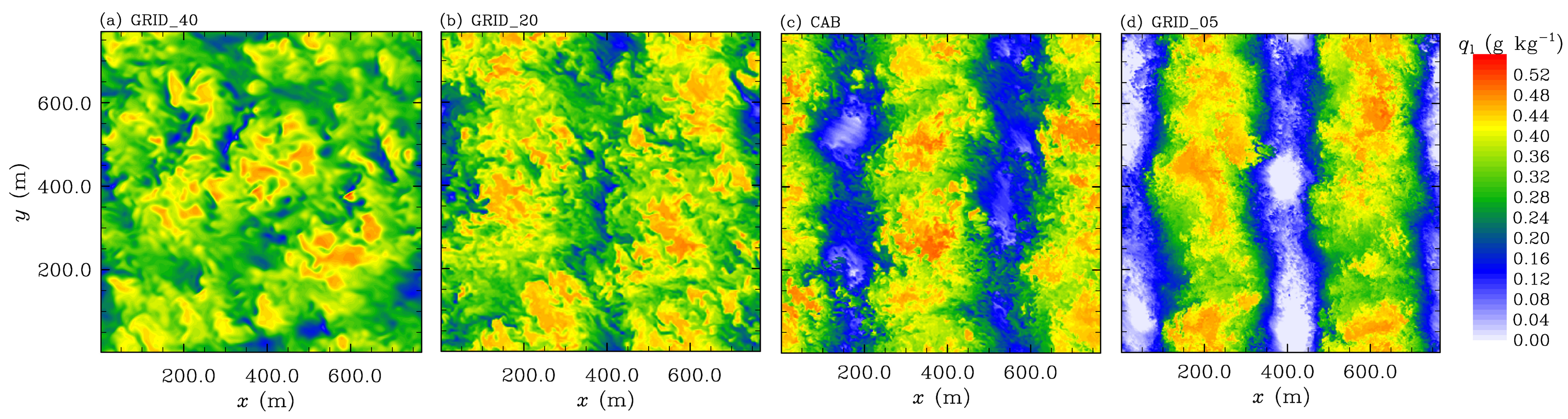
Key time marks of fog life cycle

- Formation (+)
- Maximum (○)
- Lifting (×)
- Dissipation (□)

5 Effect of grid spacing



- Fog formation time: strong dependence
- Liquid water does not depend on grid spacing
- TKE peaks for $\Delta \leq 1\,\mathrm{m}$



- Development of Kelvin-Helmholtz waves at the top of the fog layer are only resolved for fine grid spacings
- **$\Delta = 1\,\mathrm{m}$ is required to resolve all relevant processes**

6 Sensitivity analysis

Case	Formation	Maximum	Lifting	Dissipation
CAB	0200 UTC	0550 UTC	0840 UTC	1040 UTC
Advection				
ADV_PT_05	-35 min	0 min	+15 min	+45 min
ADV_PT_10	-55 min	+35 min	+30 min	+80 min
Measurement uncertainty				
MEA_PT_-	-40 min	-25 min	+5 min	+5 min
MEA_PT_+	+30 min	+10 min	0 min	-5 min
MEA_QV_-	+105 min	+35 min	-5 min	-35 min
MEA_QV_+	-105 min	+25 min	+15 min	+25 min
Cloud droplet number concentration				
NC_100	0 min	+5 min	-10 min	-25 min
NC_200	0 min	0 min	+15 min	+20 min

Case	Formation	Maximum	Lifting	Dissipation
REF	0105 UTC	0550 UTC	0850 UTC	1120 UTC
Turbulent mixing (dynamic stability)				
DYN_02	+30 min	-15 min	+15 min	+10 min
DYN_03	+45 min	0 min	+5 min	+5 min
DYN_05	+30 min	+5 min	-5 min	+5 min
DYN_06	+85 min	+10 min	-10 min	+5 min
Initial state				
INI_ST_-2	-35 min	0 min	+10 min	+10 min
INI_ST_+2	+90 min	0 min	-10 min	-10 min
INI_SQ_20	0 min	0 min	-70 min	-175 min
INI_SQ_35	0 min	0 min	-30 min	-120 min

The following sensitivities were found concerning the time marks formation, maximum, lifting and dissipation:

- Advection: all time marks
- Measurements: formation, maximum, dissipation
- Droplet number: dissipation
- Turbulent mixing: formation
- Soil temperature: formation
- Soil moisture: lifting and dissipation

Outlook

- Improved bulk microphysics: What is the impact of different nucleation and condensation parameterizations on the fog life cycle?
- Combine LES with Lagrangian cloud model: fog droplet spectra in 4D and explicit aerosol activation
- What is the effect of fog on the daytime boundary layer?
- How do surface heterogeneities affect the fog life cycle?

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The PALM model system: `http://palm-model.org`, Mail: `maronga@muk.uni-hannover.de`.