Simulation of the FIRE stratocumulus case: What have we learnt?

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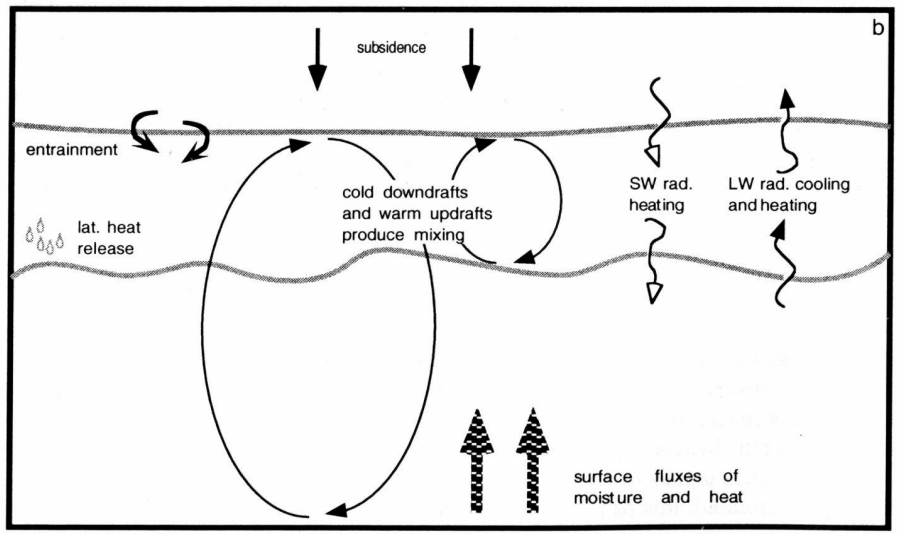
Outline

- Introduction
- LES of FIRE stratocumulus
- Runs with ECHAM-SCM of FIRE stratocumulus
- Conclusions
- Outlook

Simulation of stratocumulus

Marine stratocumulus clouds are

- part of the general circulation
- important modulators of the earth's radiation budget
- of importance to our understanding of the physics of the atmosphere



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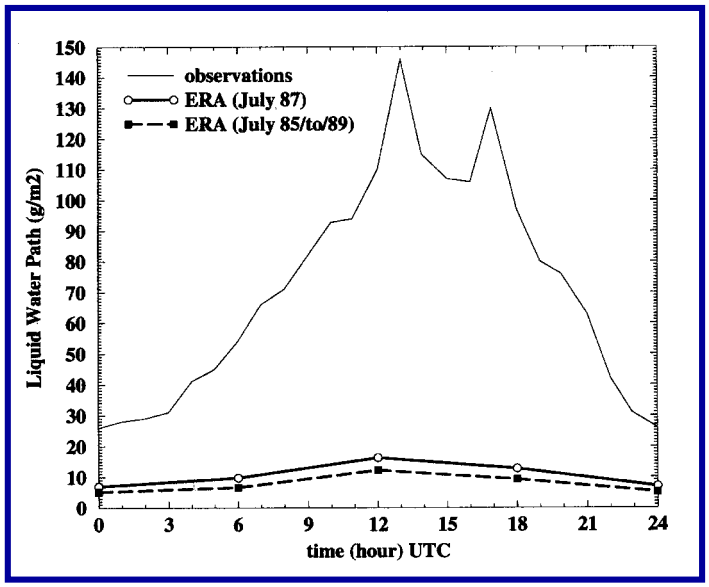
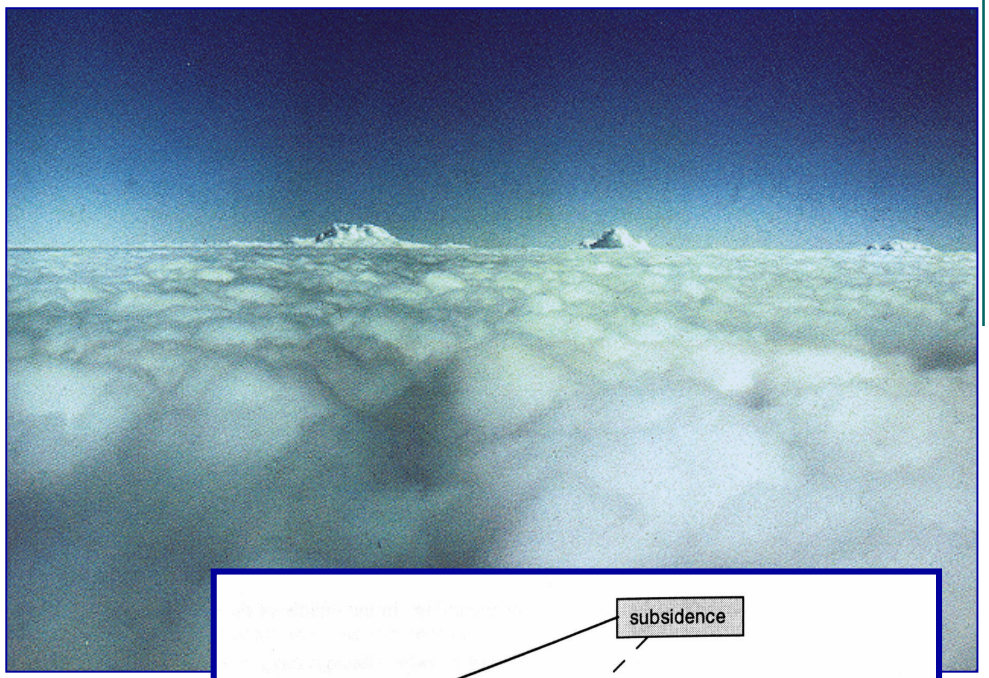
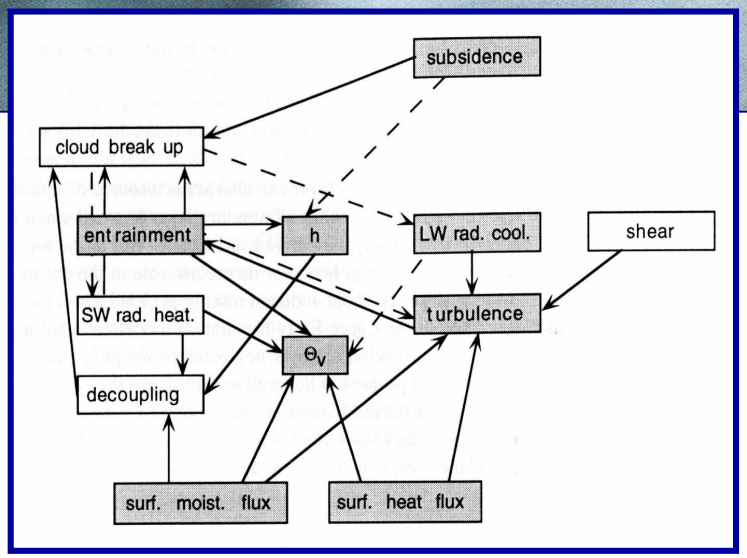
Simulation of stratocumulus (FIRE)





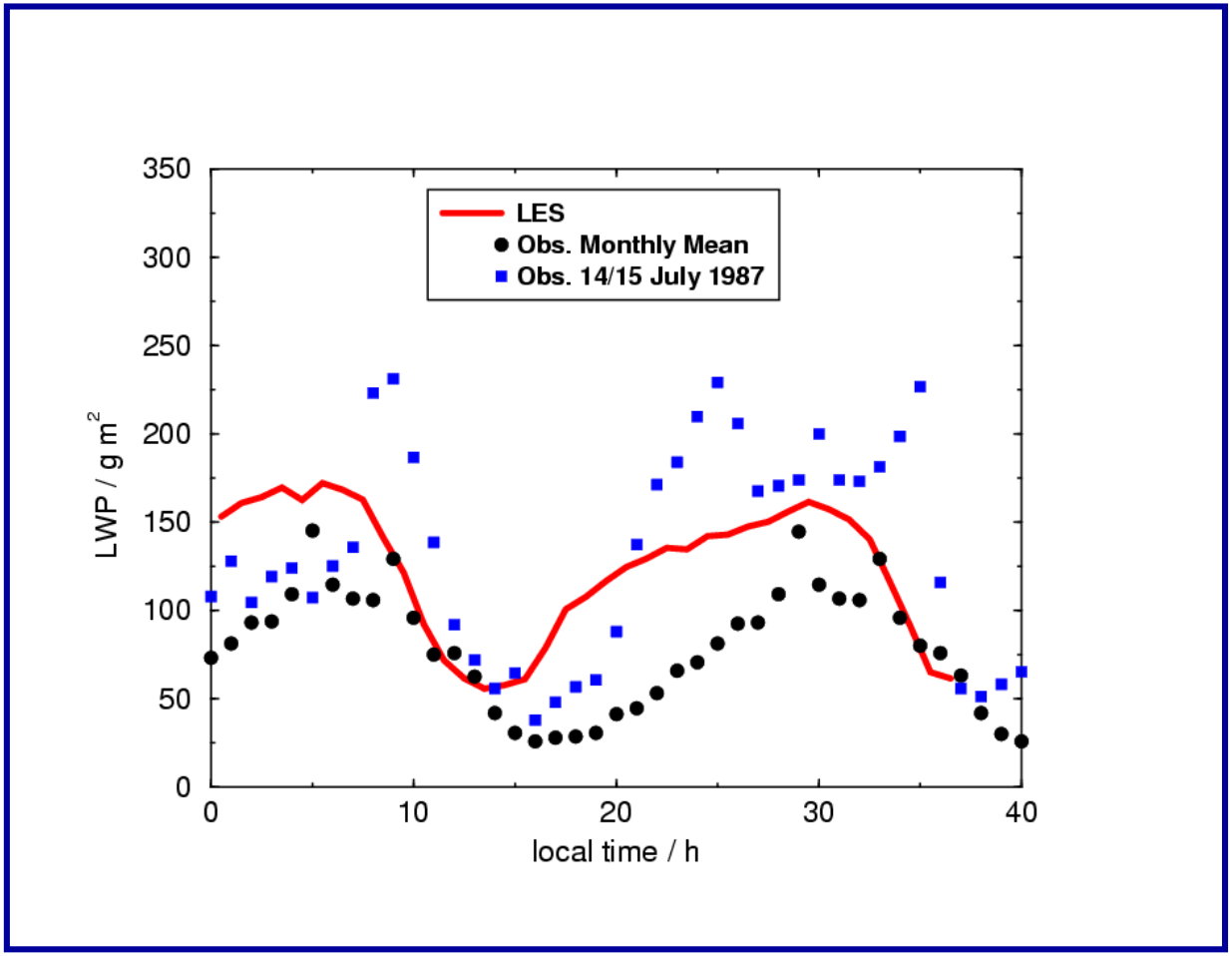


Challenge: diurnal cycle

Which factors determine:

- cloud cover, LWP, BL-height
- entrainment rate
- turbulence structure
- microphysical properties

LES: Diurnal variation of LWP (FIRE)

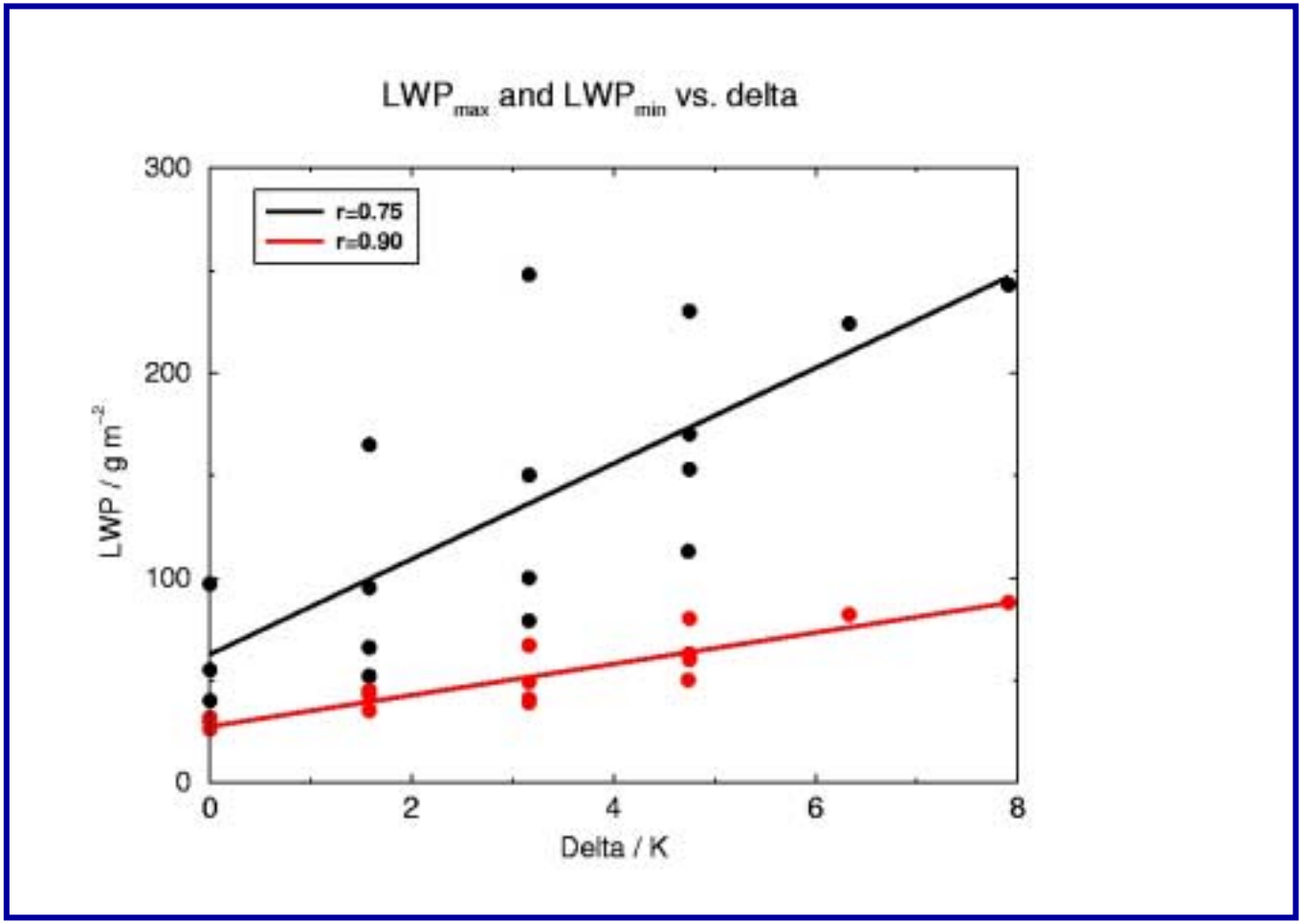


LES of FIRE stratocumulus case

Sensitivity runs:

- LES ensemble runs to investigate the statistical significance
- Response of LES with respect to SST and large-scale forcing
- Modified subsidence (how important is LS-subsidence?)
- Sensitivity of LES with respect to inversion properties
- Lagrangian runs with time dependent SST (break-up of cloud deck?)
- LES with drizzle

LES: Sensitivities with respect to inversion properties (FIRE)



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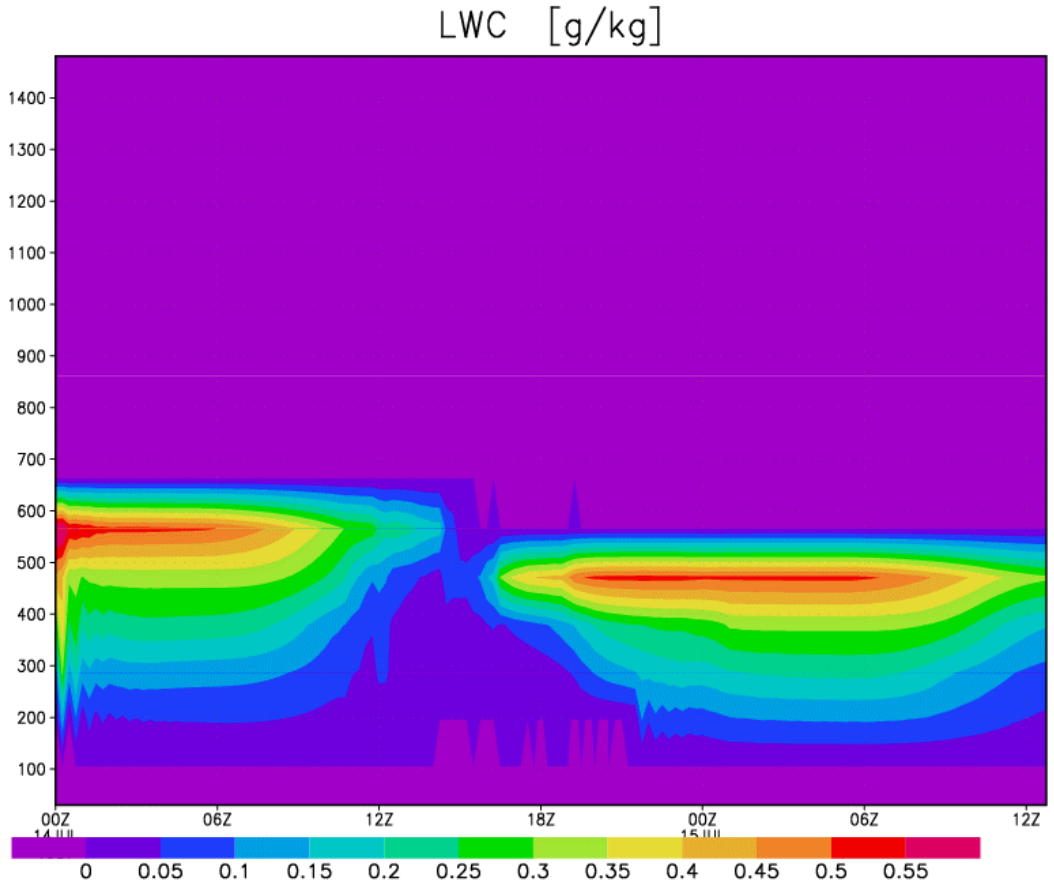
Runs with ECHAM-SCM of FIRE sc



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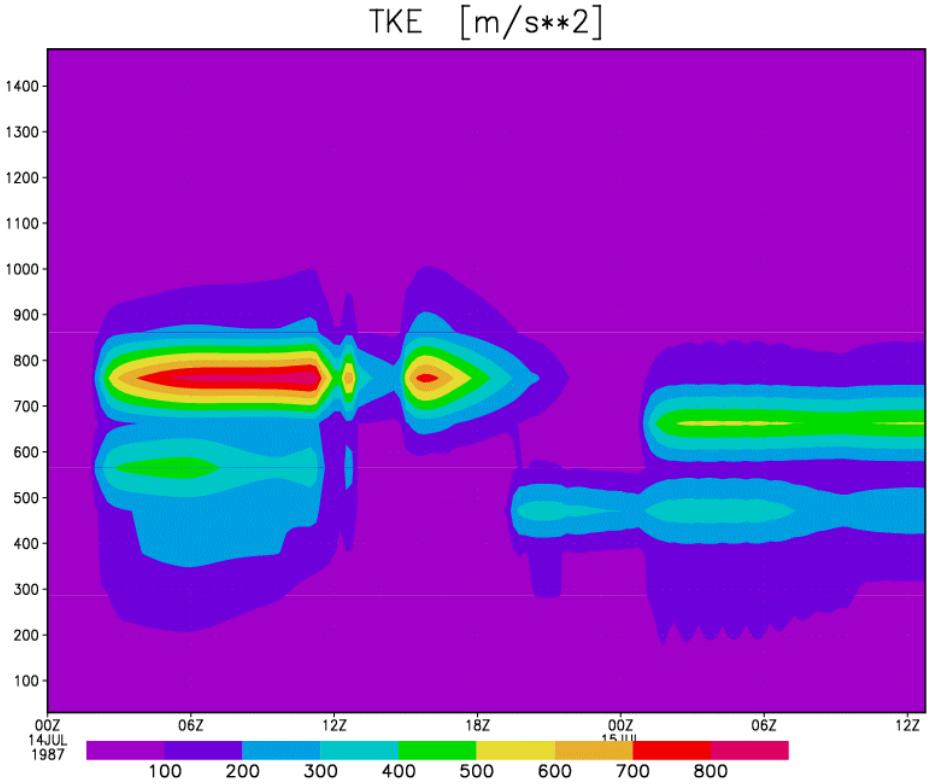
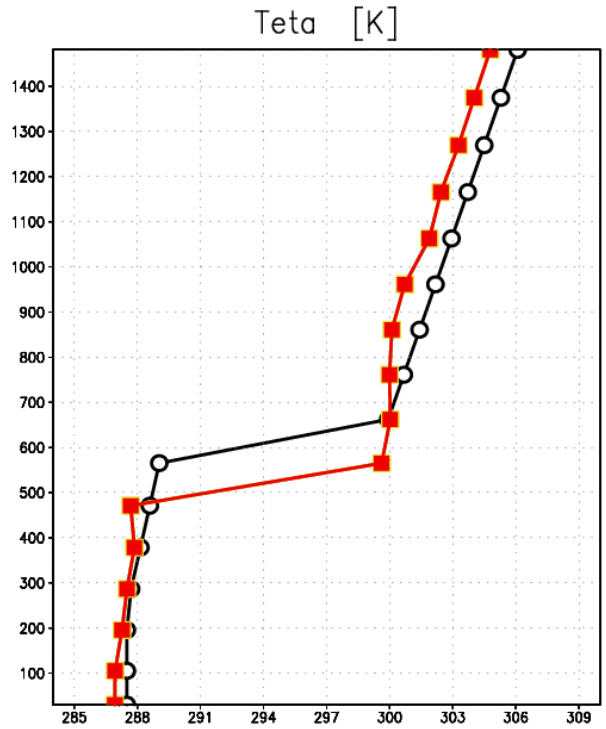
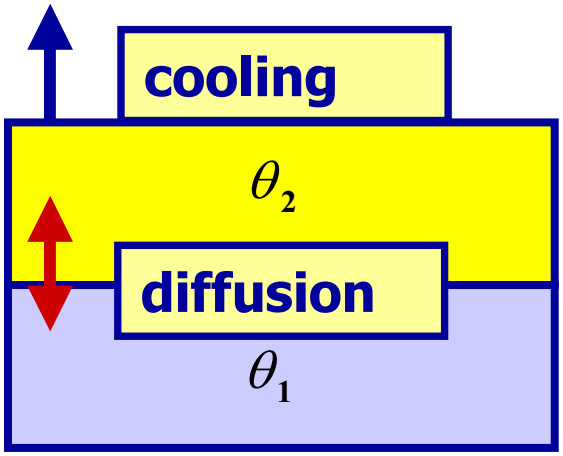
ECHAM-SCM results: TKE vs time and Θ-profile





Radiative-diffusive equilibrium

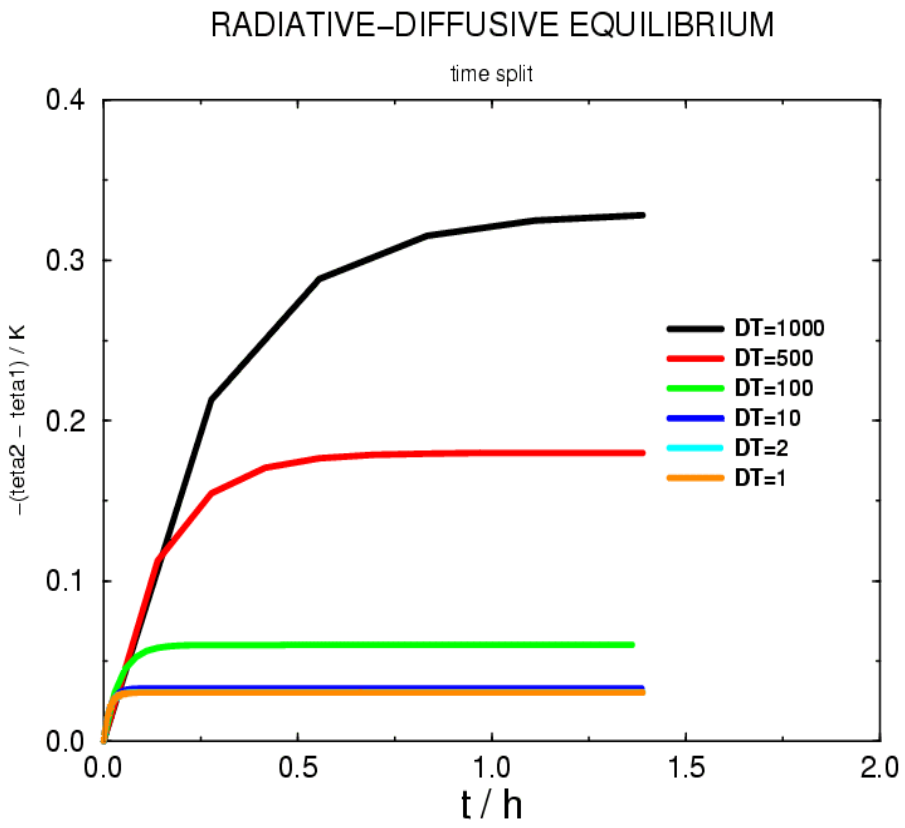


$$\frac{\partial \theta_2}{\partial t} = -\gamma \cdot (\theta_2 - \theta_1) - R_{cool}$$

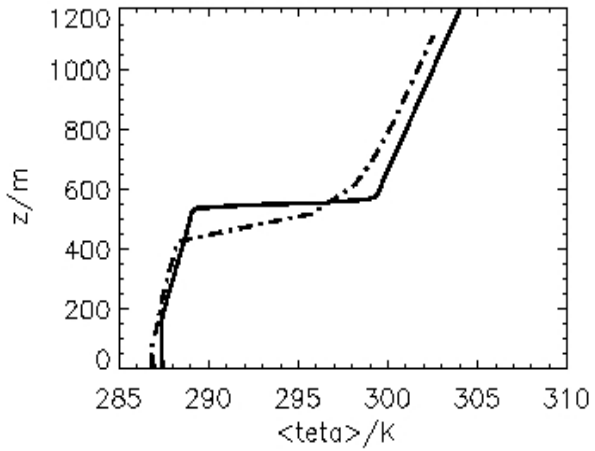
$$\frac{\partial \theta_1}{\partial t} = +\gamma \cdot (\theta_2 - \theta_1)$$

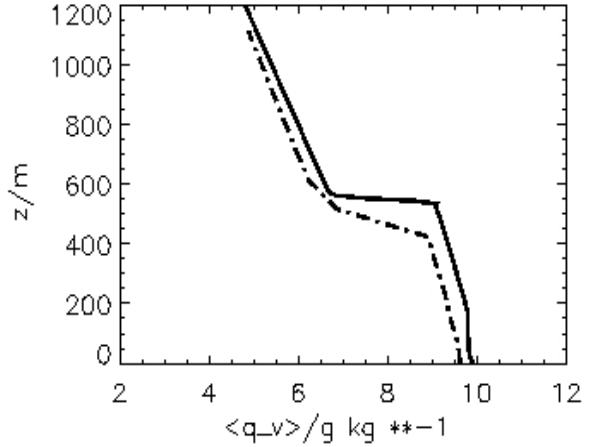
solution:

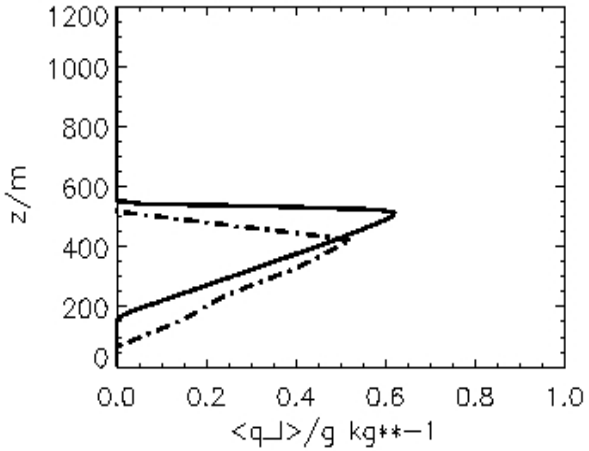
$$\Delta\theta(t) = -\frac{R_{cool}}{2 \cdot \gamma} \cdot (1 - e^{-2 \cdot \gamma \cdot t})$$

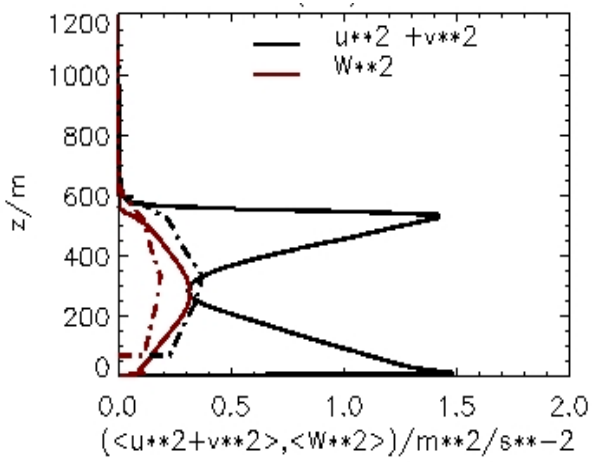


LES versus improved ECHAM-SCM









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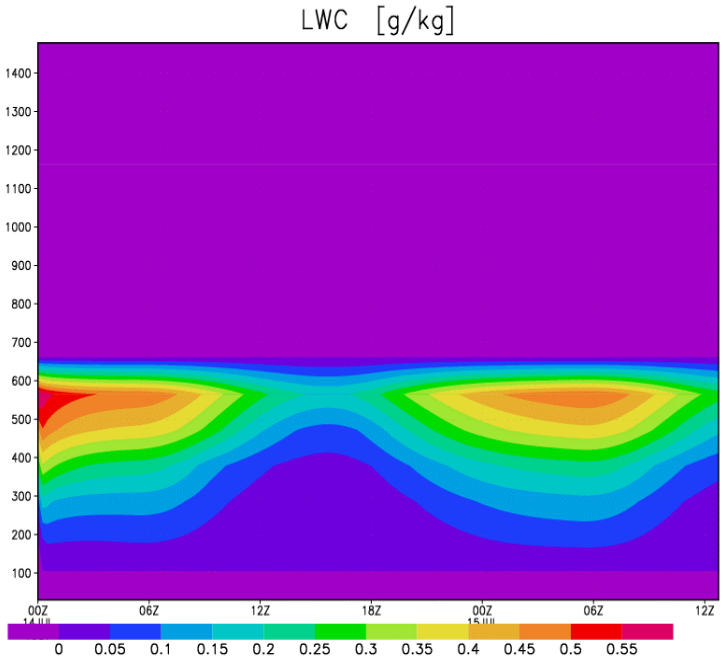
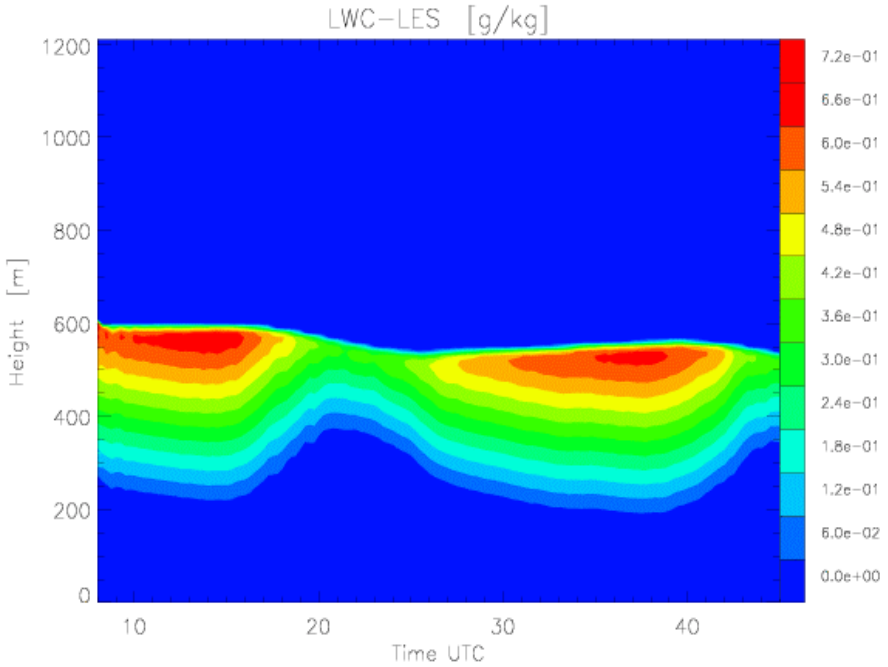
ECHAM-SCM with explicit entrainment parameterization: LWP vs time

SCM



LES



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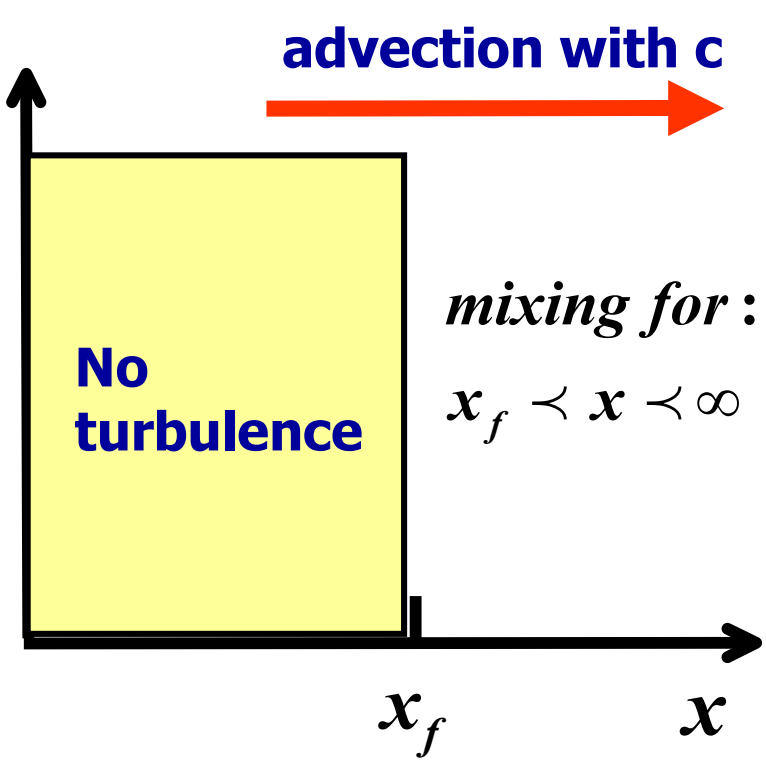
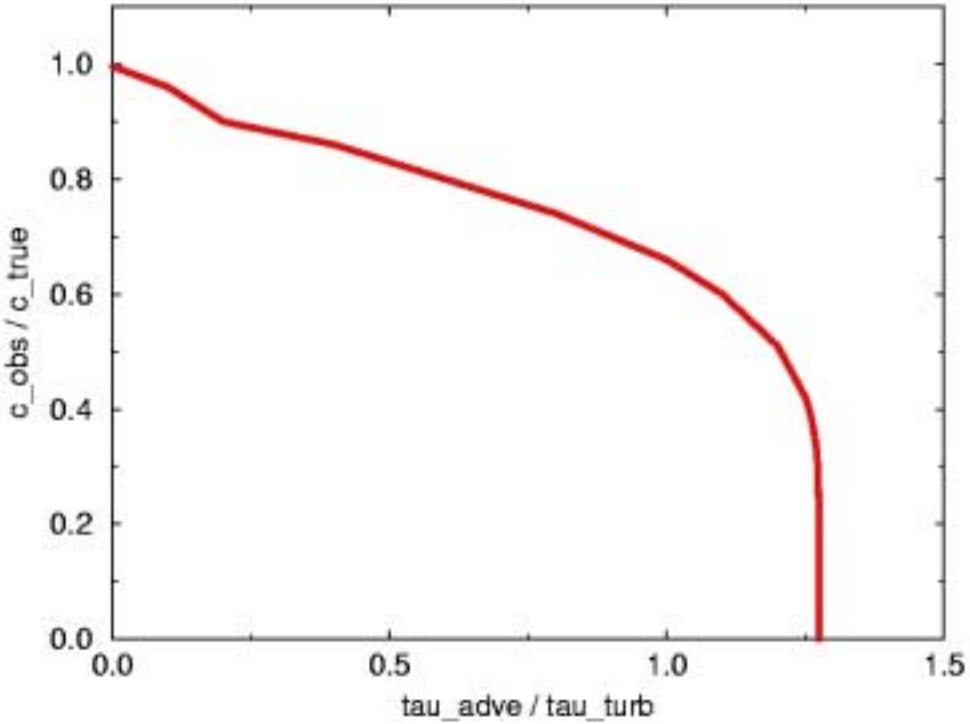
Entrainment across a moving density interface

$$\Phi(x-ct,t) = \Phi(x,0)$$





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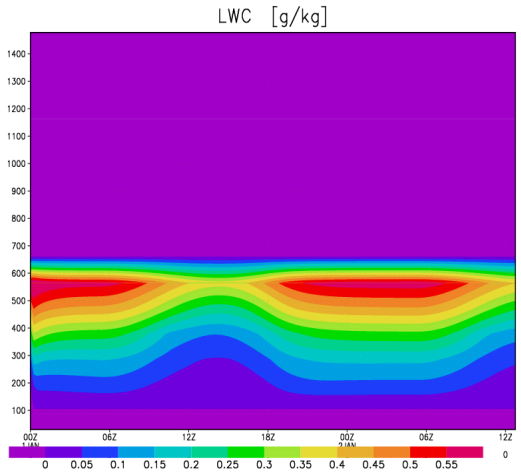
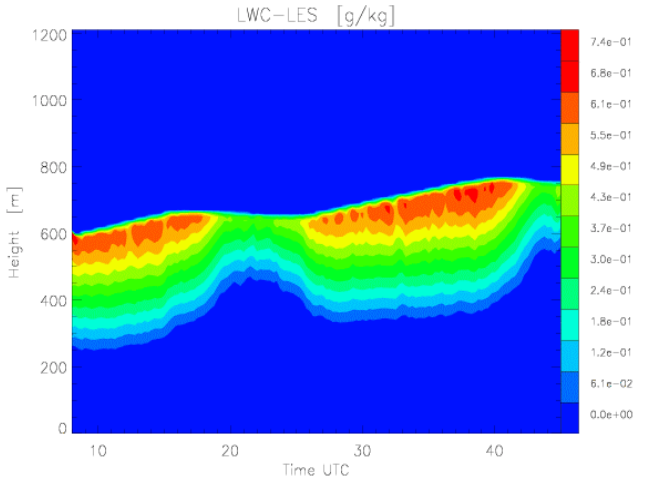
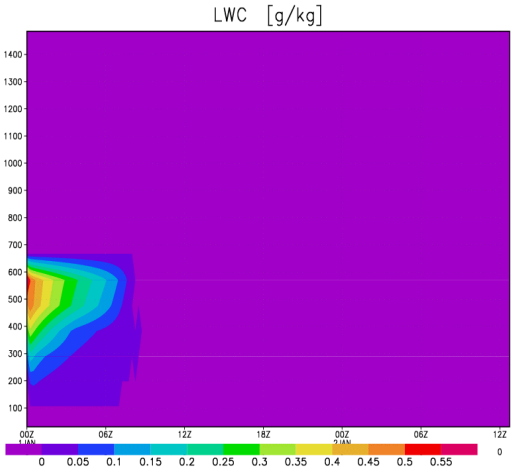
Sensitivity with respect to w_{LS} SCM (left) vs LES (right)

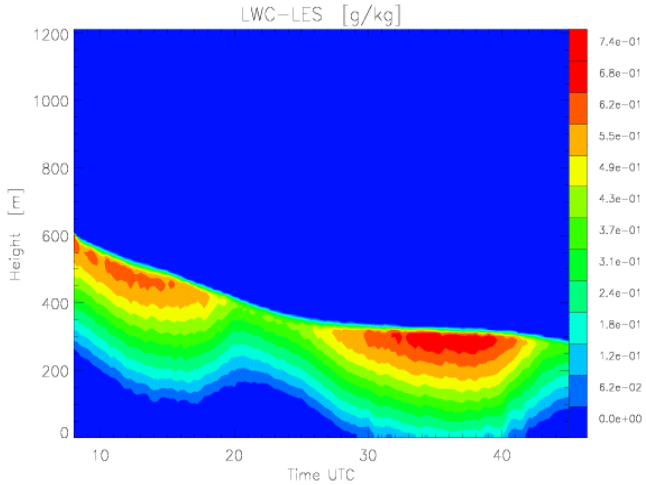


$$w_{ls} = 0.5 \cdot (w_{ls})_{ref}$$





$$w_{ls} = 2 \cdot (w_{ls})_{ref}$$



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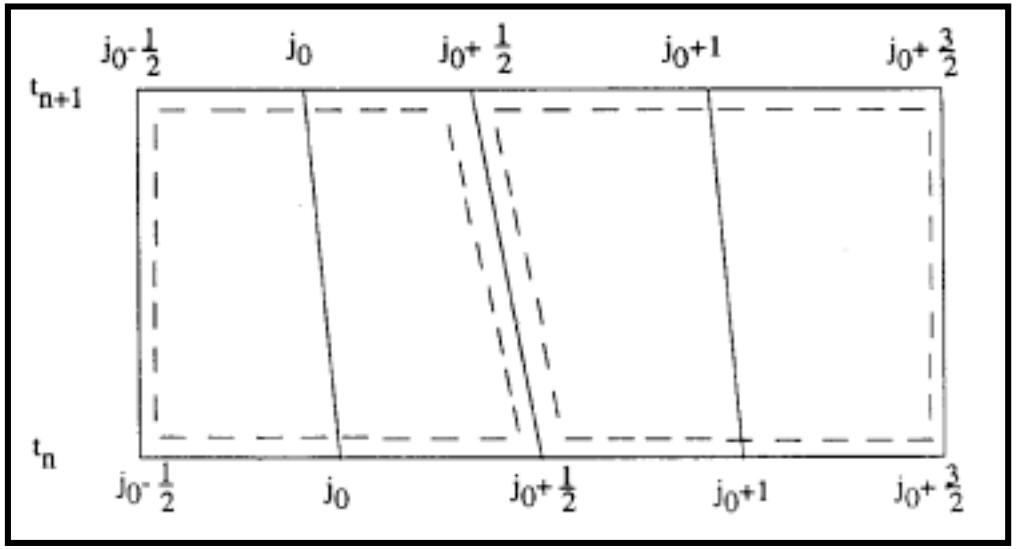
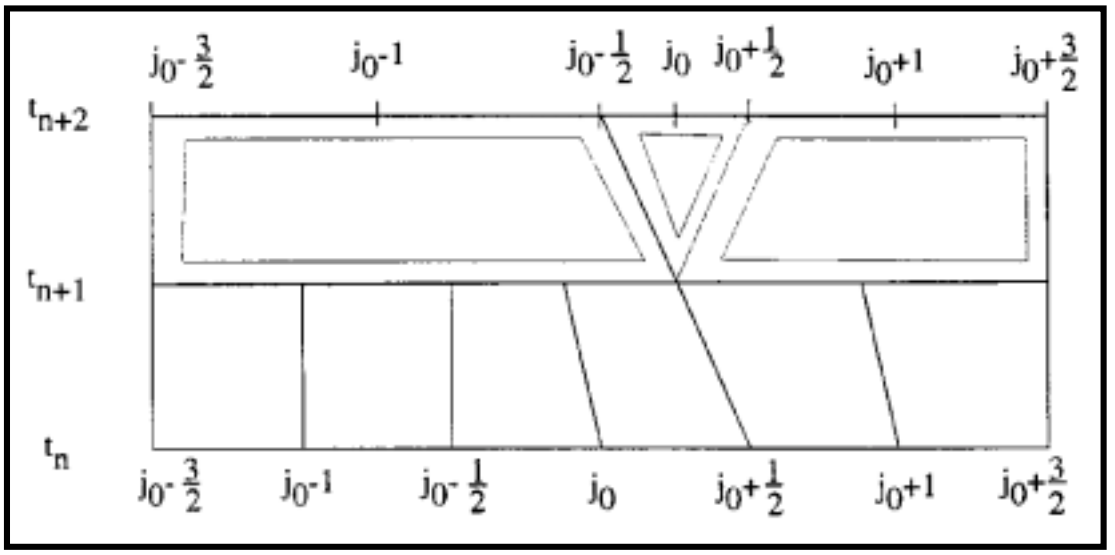
A computational method for propagating phase boundaries



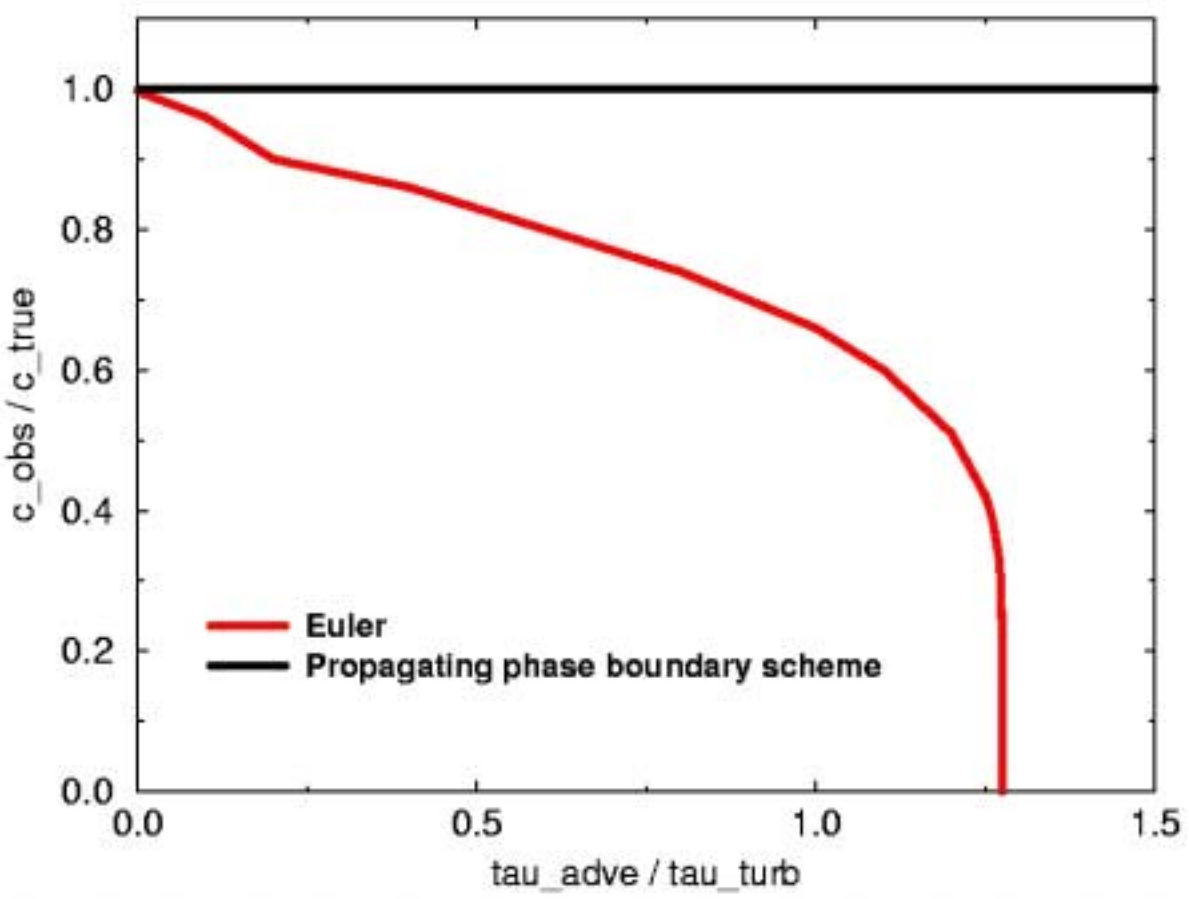
- Shift grid points locally $\Rightarrow$ locally nonuniform grid due to two cells moving
- $X_{j_{0+1/2}}$ represents position of moving phase boundary
- Subsequently locations of j_0, and j_{0+1} will change as function of time
- When one cell is too small, we adjust the location of one grid point

Procedure:



- Compute Ψ_j^{n+1} from std. eq. for all cells not containing the phase boundary
- Compute phase propagation speed $w_{ph} = w_{LS} + w_e$
- Shift grid cells j_0 and j_{0+1} locally and update cell averages
- If $\left|x^n_{j_{0-1/2}} - x^n_{j_{0+1/2}}\right| \le h/2$, relabel phase boundary as $j_{0\ -1/2}$, positions j_{0-1}, j_0, j_{0+1} are changed accordingly for the three adjusted cells
- Recompute cell averages associated with the modified cells

Phase boundary propagation



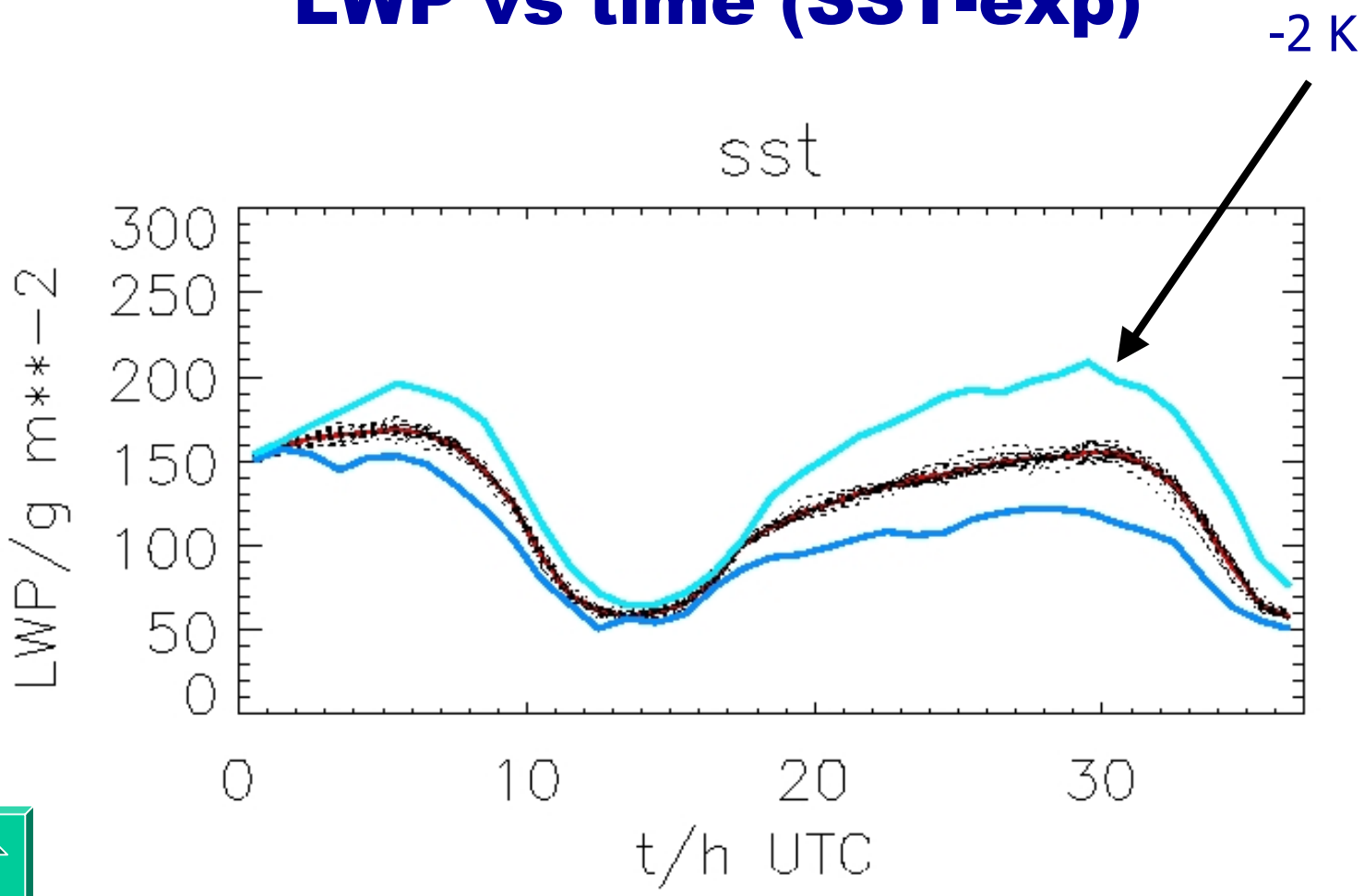
Conclusions (LES)

- Diurnal cycle is easy to simulate within the LES-framework
- results show relatively small sensitivity with respect to initial conditions
- inversion strength turns out to be an important external parameter
- SST and LS-forcing variations produce a significant modification of boundary layer structure
- large-scale subsidence is an important external parameter
- breaking up of stratocumulus occurs in Lagrangian simulations with time dependent SST
- The effect of drizzle is to reduce the buoyant production of turbulent kinetic energy, resulting in shallower boundary layers due to reduced entrainment rate

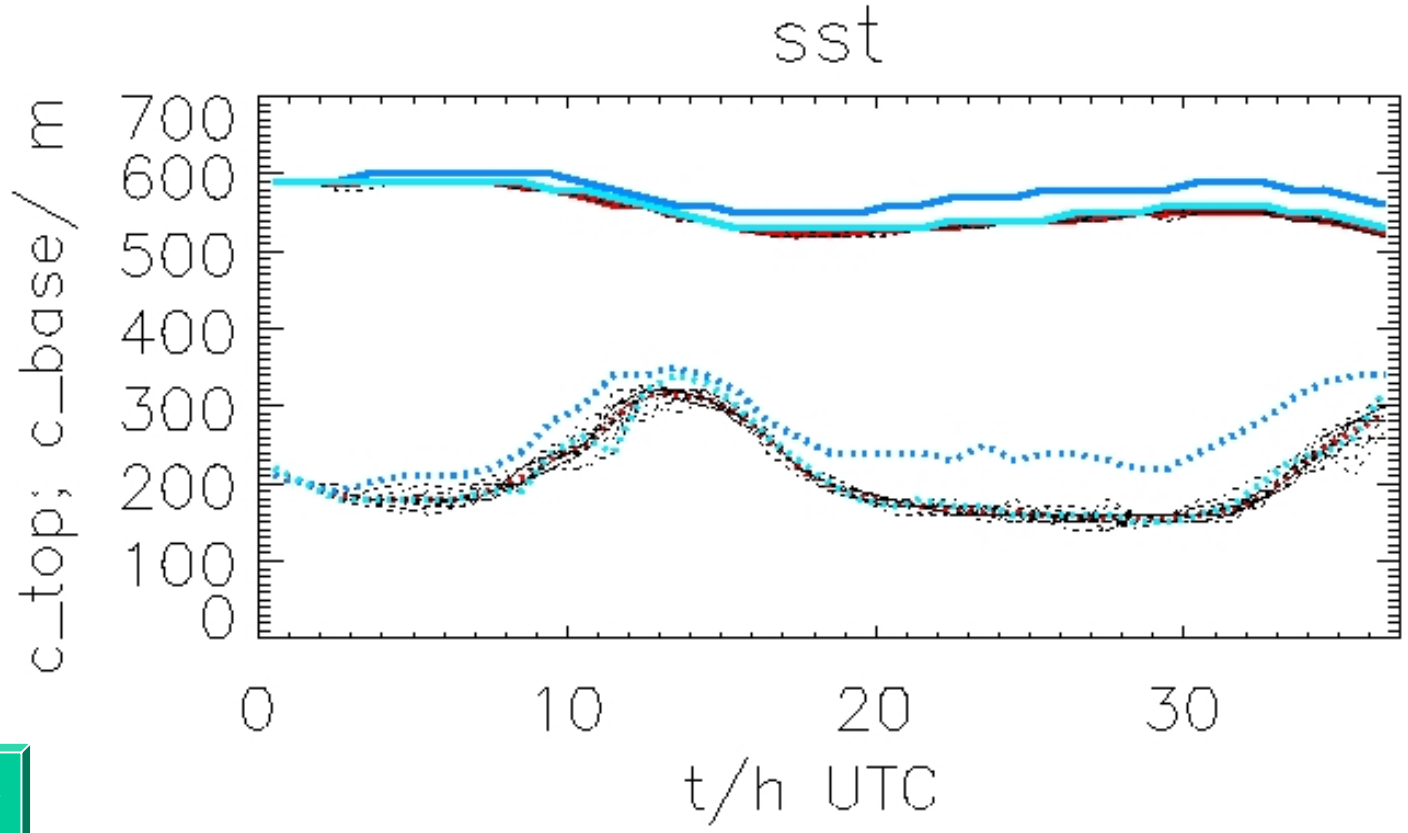
Conclusions (SCM)

- ECHAM-SCM produces quite reasonable results
- Improvements have been achieved due to:
  - Modification of the vertical advection scheme
  - Adequate treatment of the radiative-diffusive interaction process
  - Explicit entrainment parameterization in conjunction with a front tracking/capturing scheme to model the propagation of the phase boundary

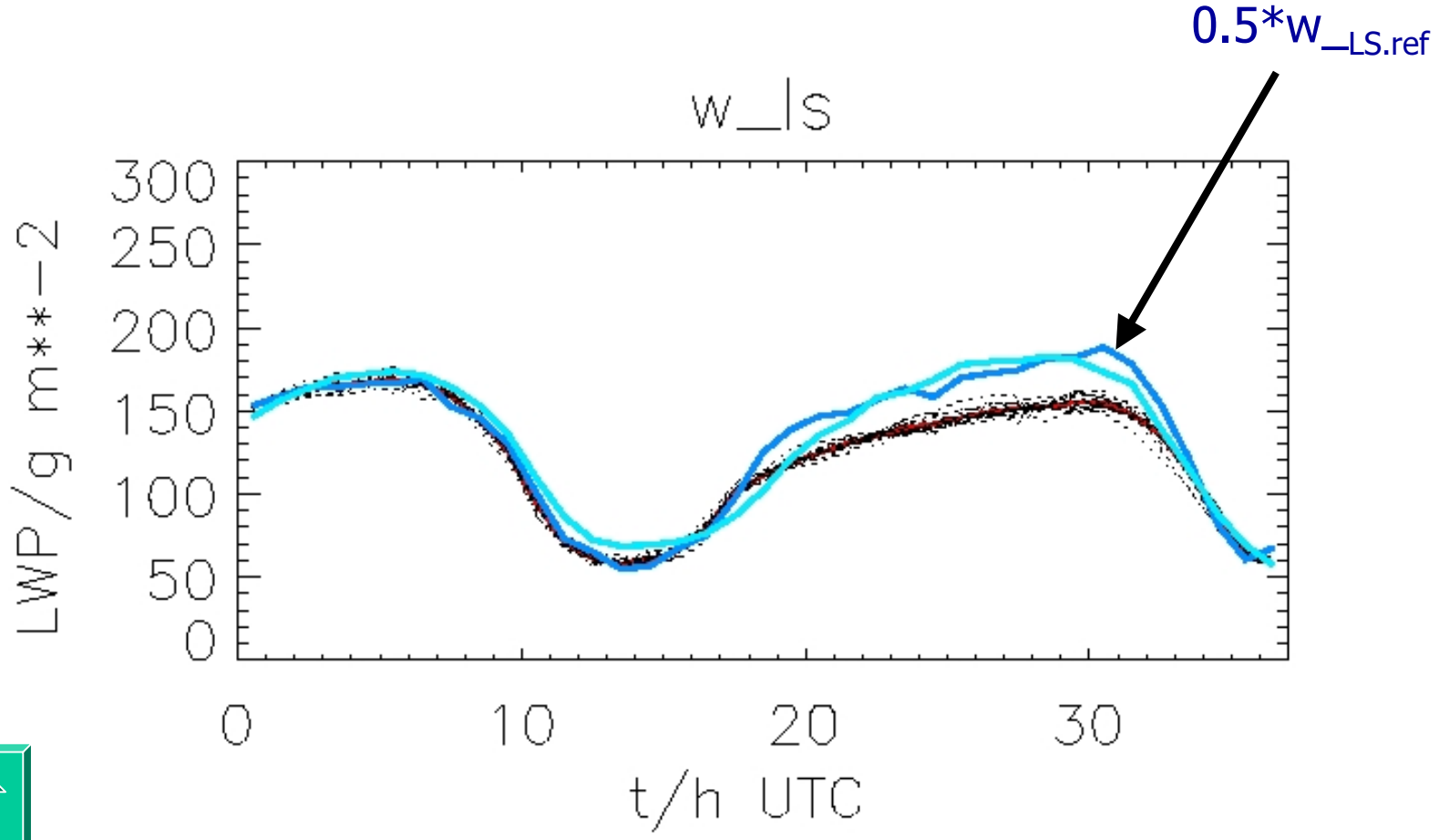
LWP vs time (SST-exp)



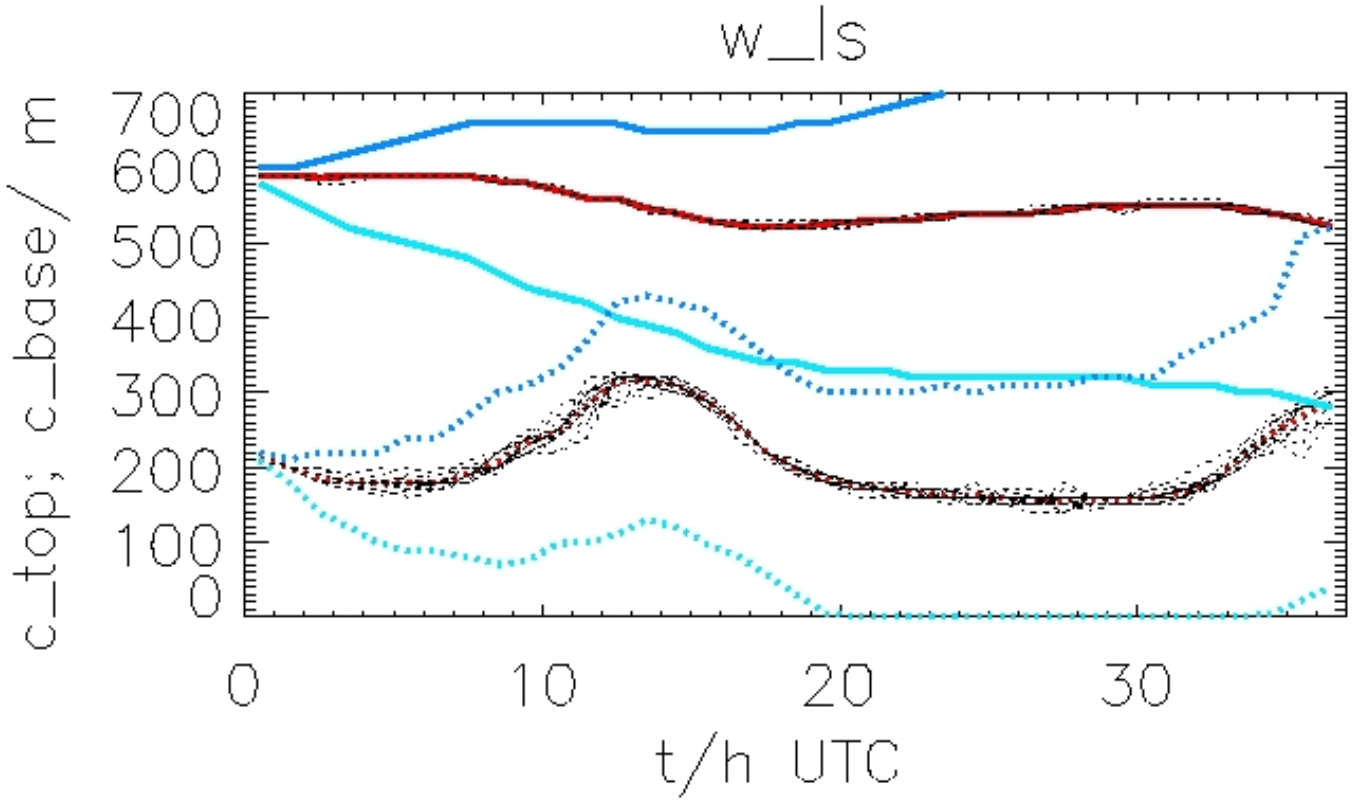
Cloud height vs time (SST-exp)



LWP vs time (w_{LS}-exp)

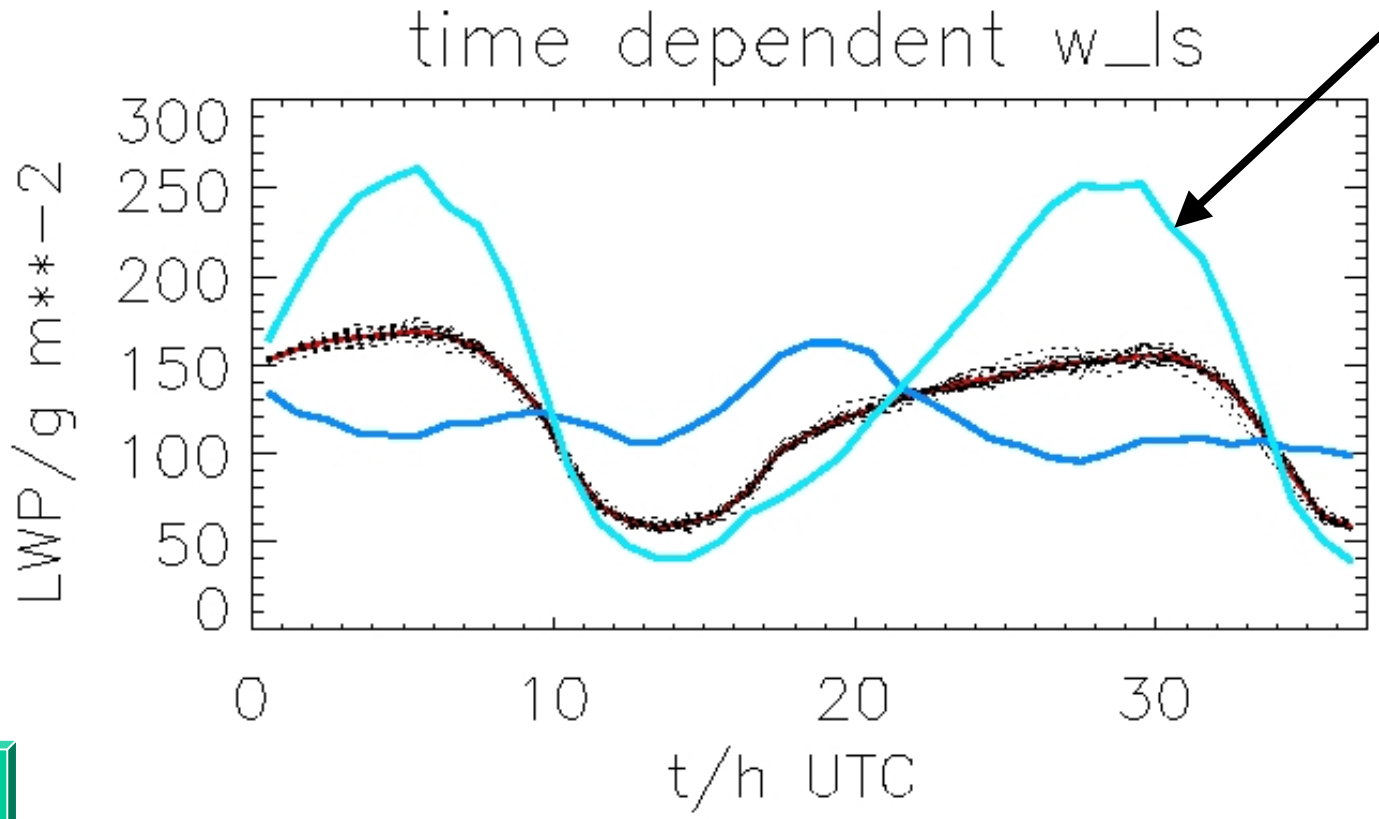


Cloud height vs time (w_{Ls}-exp)

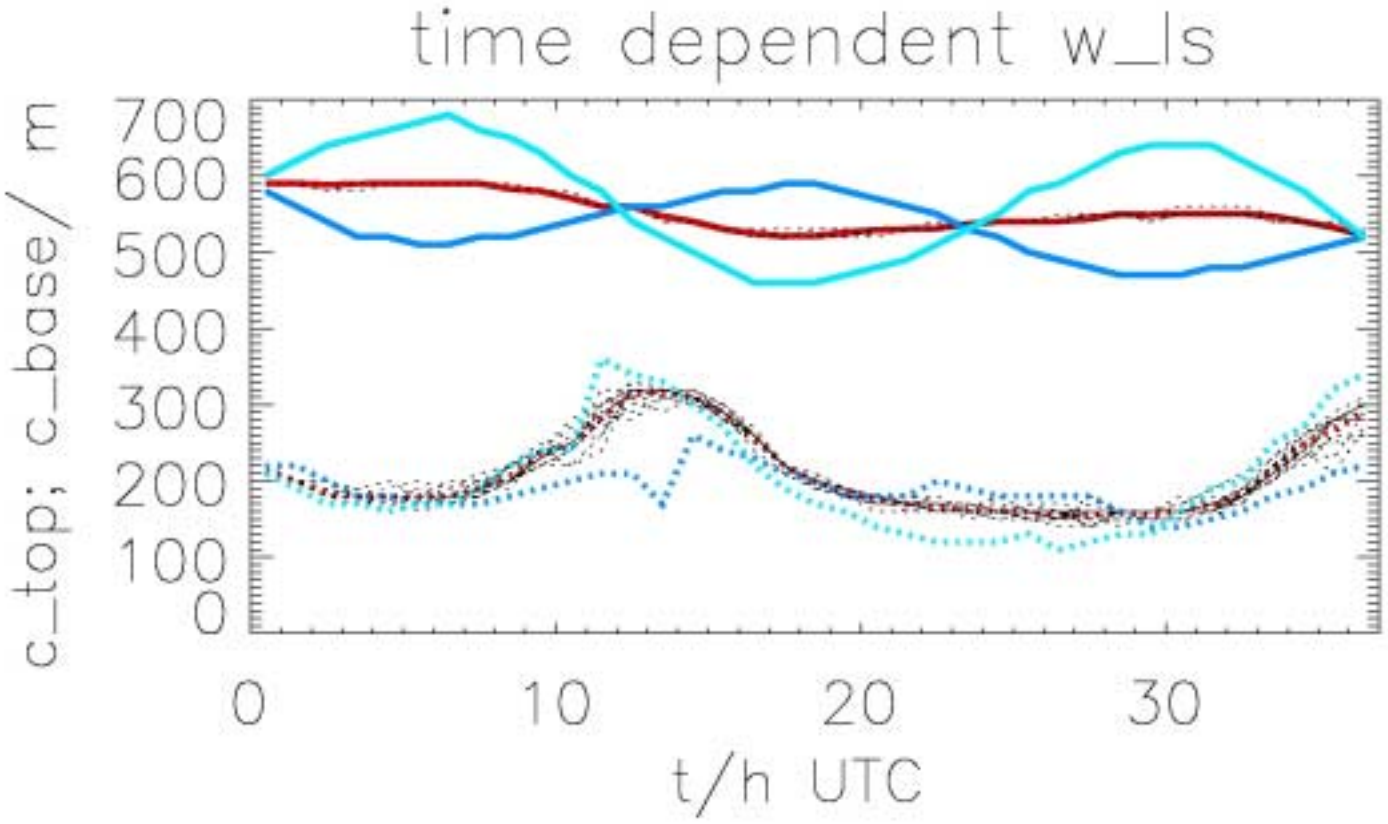


LWP vs time (time-w_ls-exp)

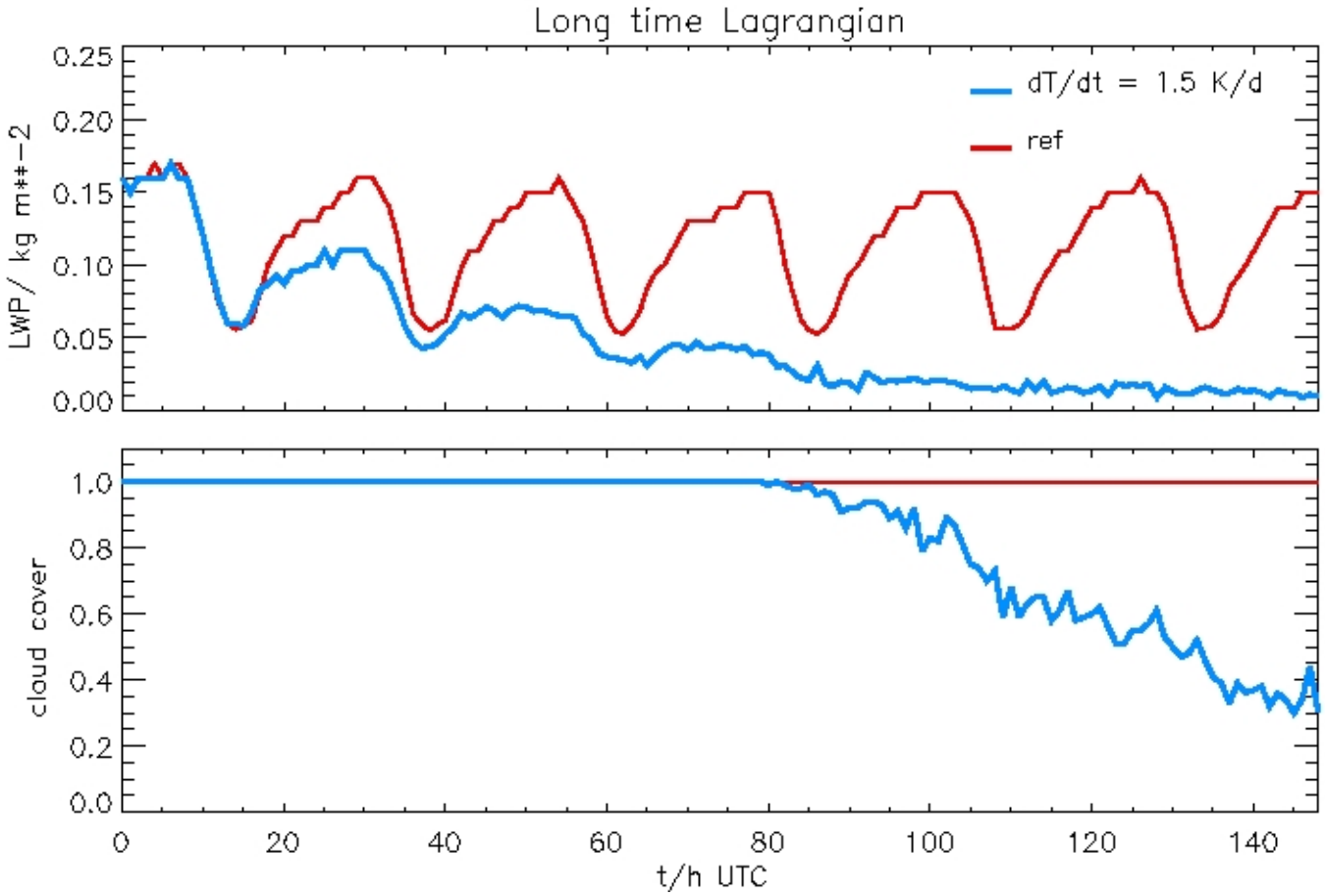
Noon max.



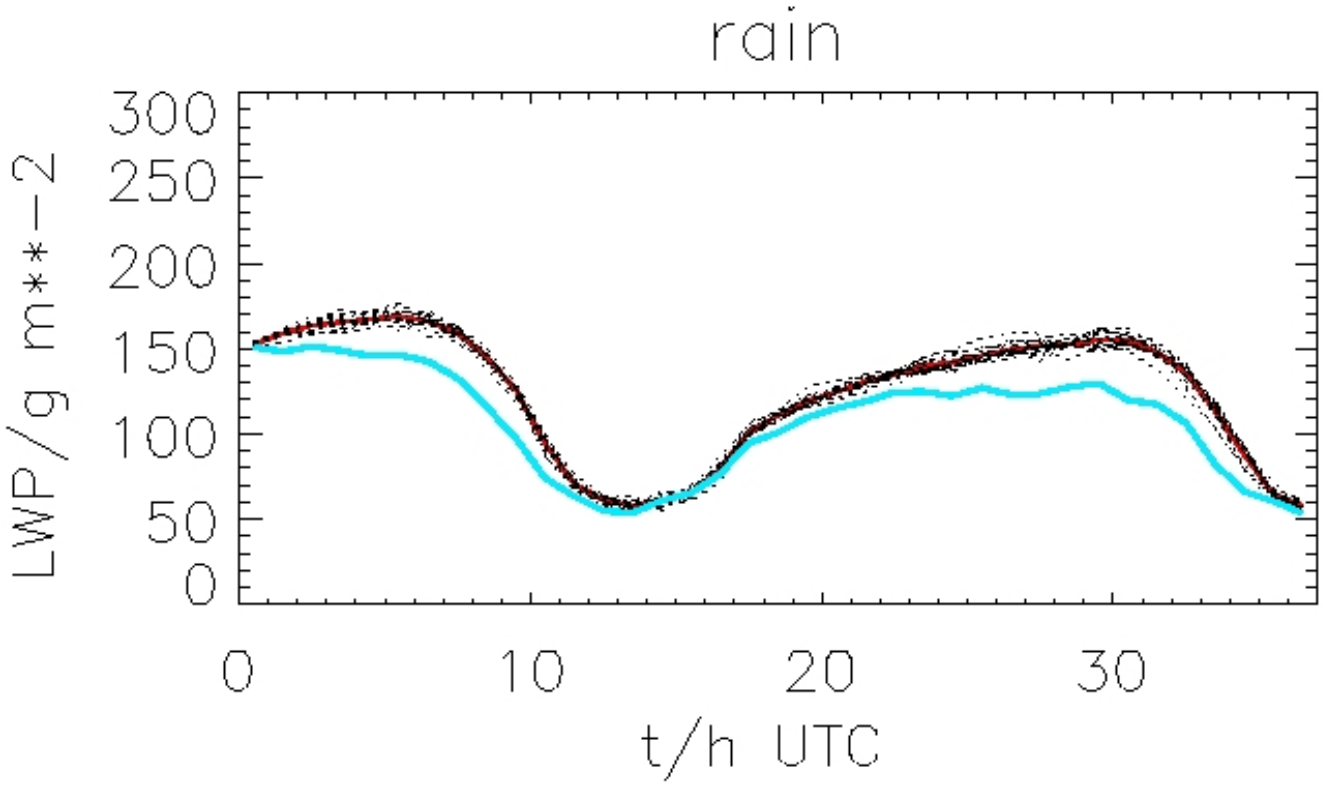
Cloud height vs time (time-w_Ls-exp)



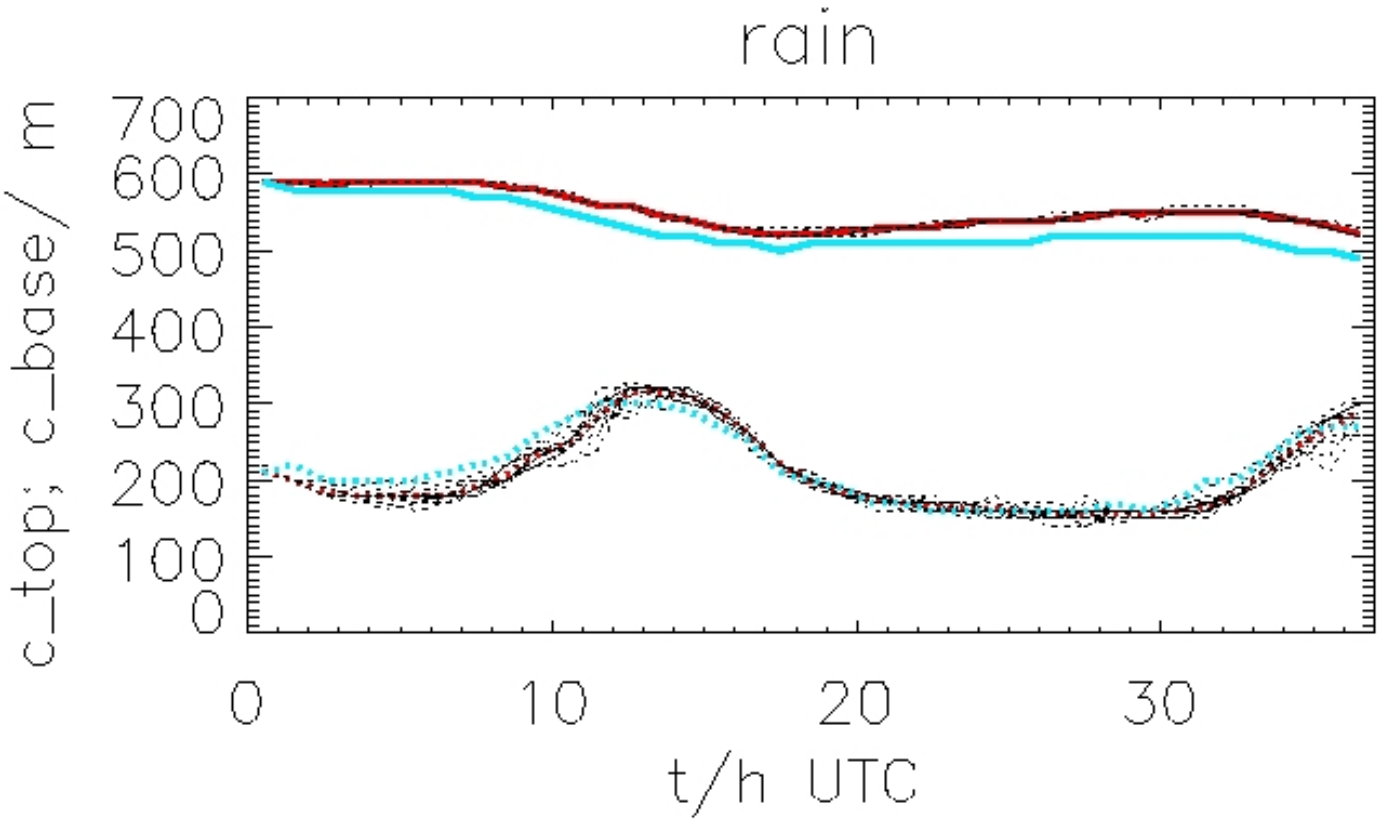
LWP vs time (Lagrangian)



LWP vs time (drizzle-exp)



Cloud height vs time (drizzle-exp)



Rain rate vs time (drizzle-exp)