Large-eddy Simulation of a Stratocumulus To Cumulus Cloud Transition as Observed During ASTEX

stratocumulus, Netherlands (photo Kees Floor)

cumulus penetrating stratocumulus, France

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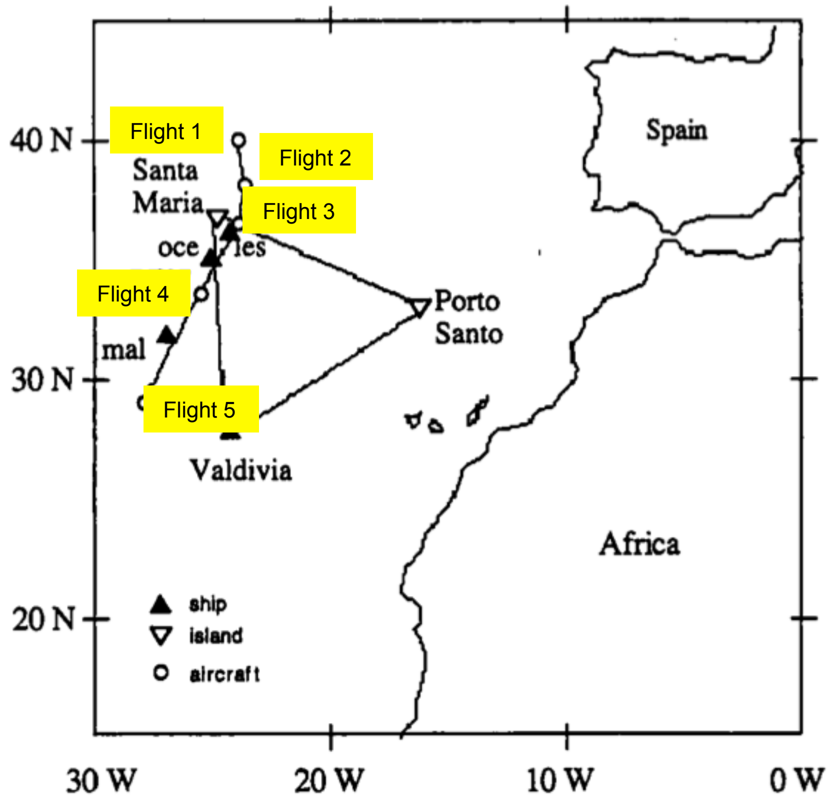
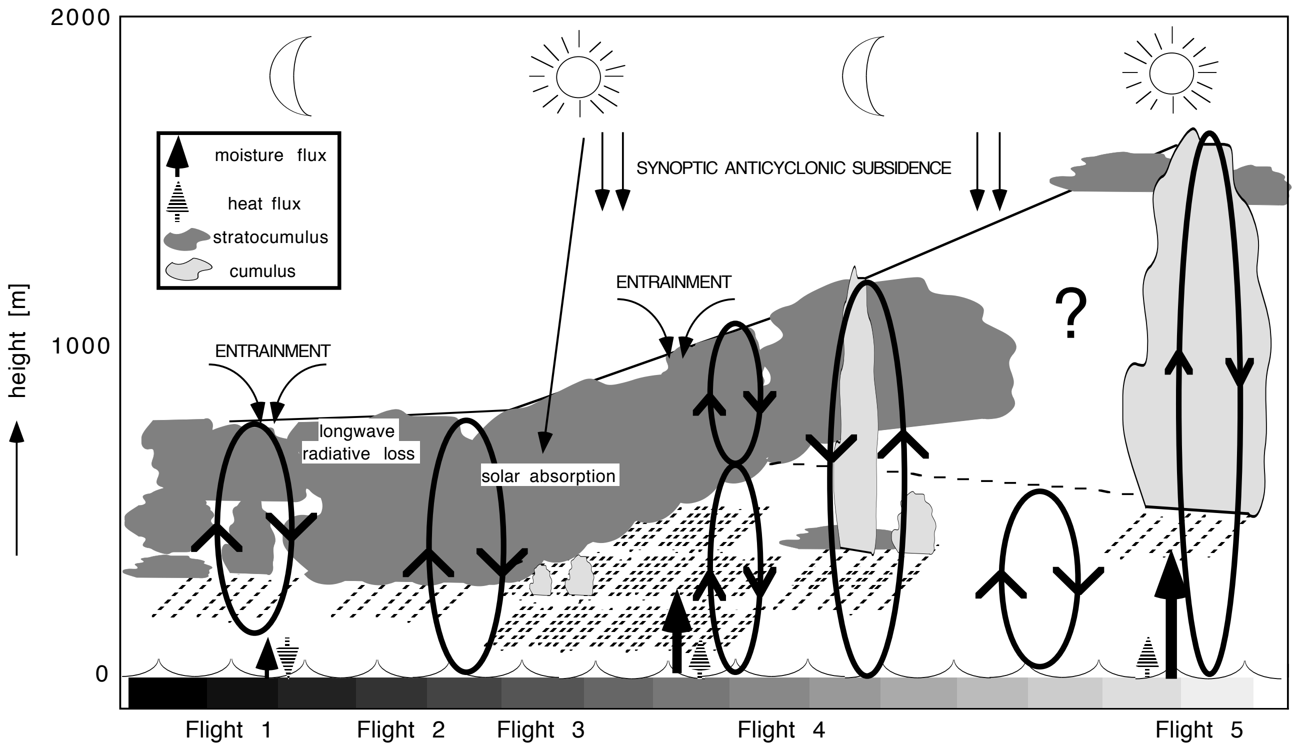
thanks to Irina Sandu (MPI), Chris Bretherton (UW), and Adrian Lock (UKMO)

The ASTEX First Lagrangian (June 1992)



- Lagrangian evolution of cloudy boundary layer observed
- Five aircraft flights
- Duration: two days

Schematic of the ASTEX Lagrangian



- Sea surface temperature increases with 4.3 K
- Stratocumulus breaking up and replaced by shallow cumulus

Large-Eddy Simulation of the ASTEX Lagrangian

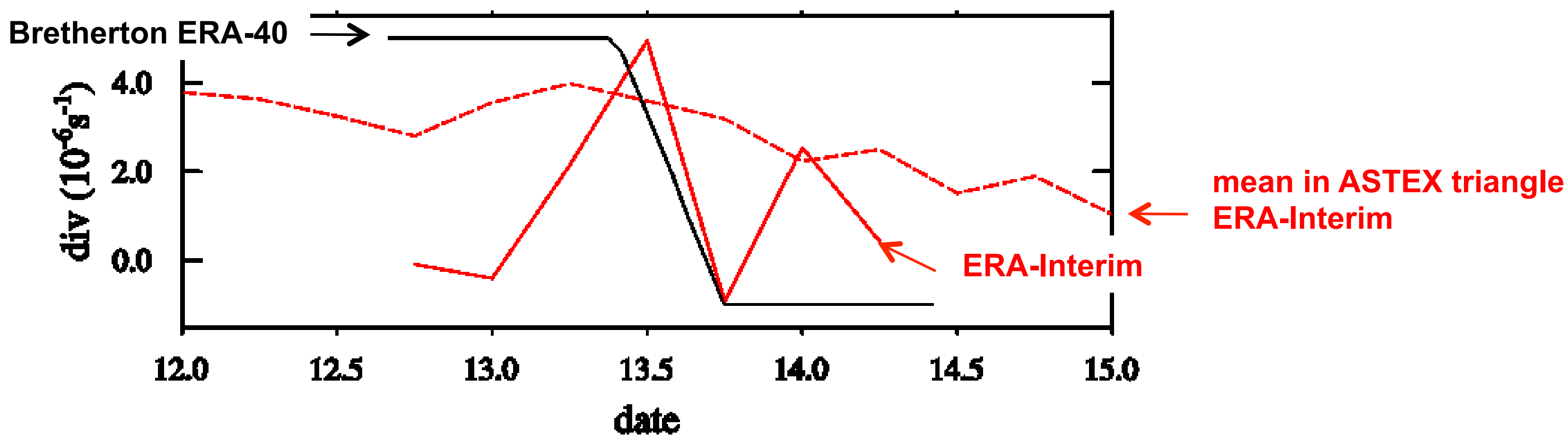
Motivation

- Can LES models reproduce the observed transition?
    - Compare evolution of mean state, turbulence and entrainment

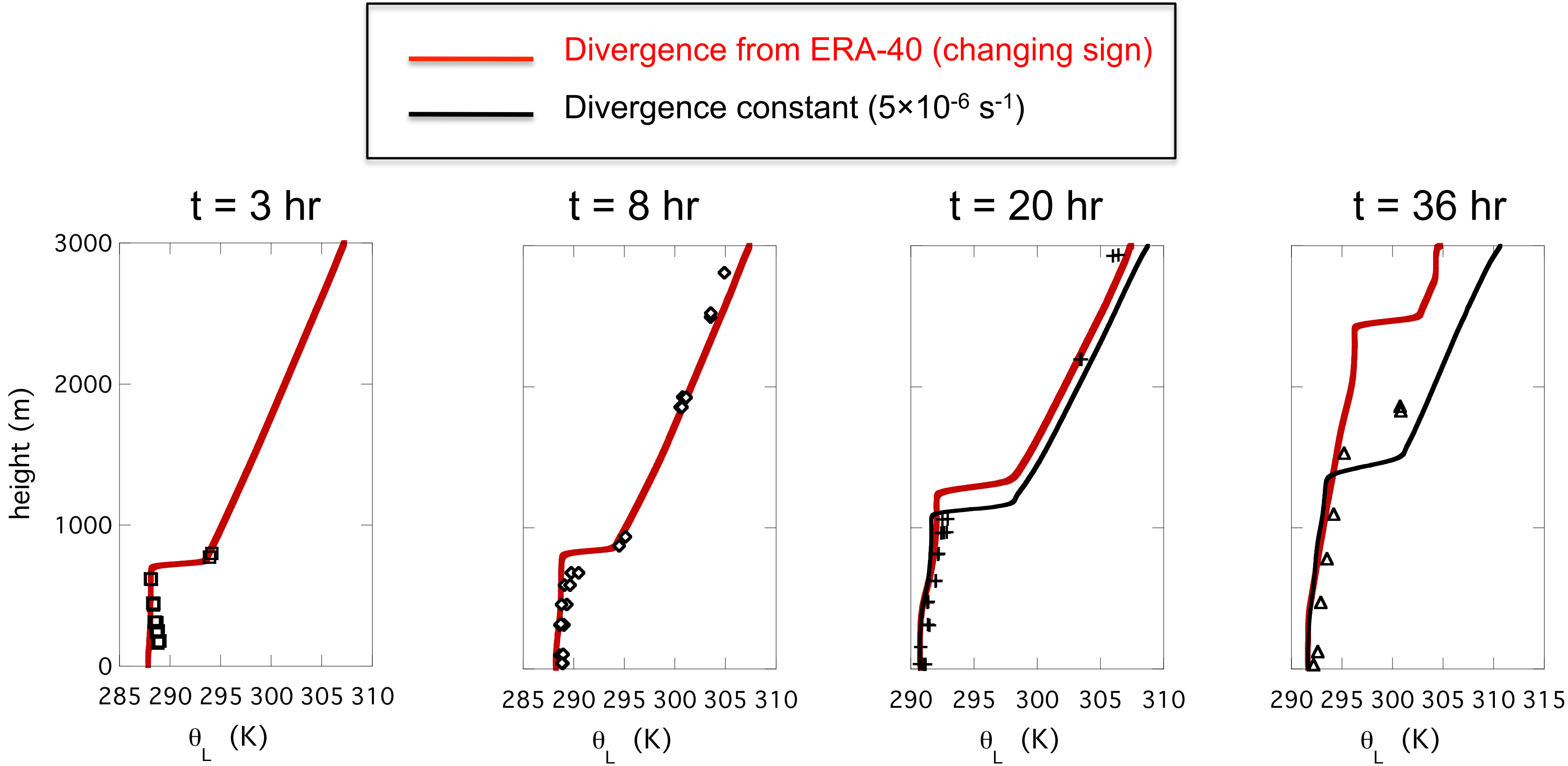
Large-Eddy Simulation of the ASTEX Lagrangian

Model set up and large-scale forcing

- Large-scale forcing (SST & large-scale subsidence) from Bretherton et al. (1995, 1999)
- Model initialization from Flight 2 (A209)
  - Identical to first GCSS ASTEX "A209" modeling intercomparison case

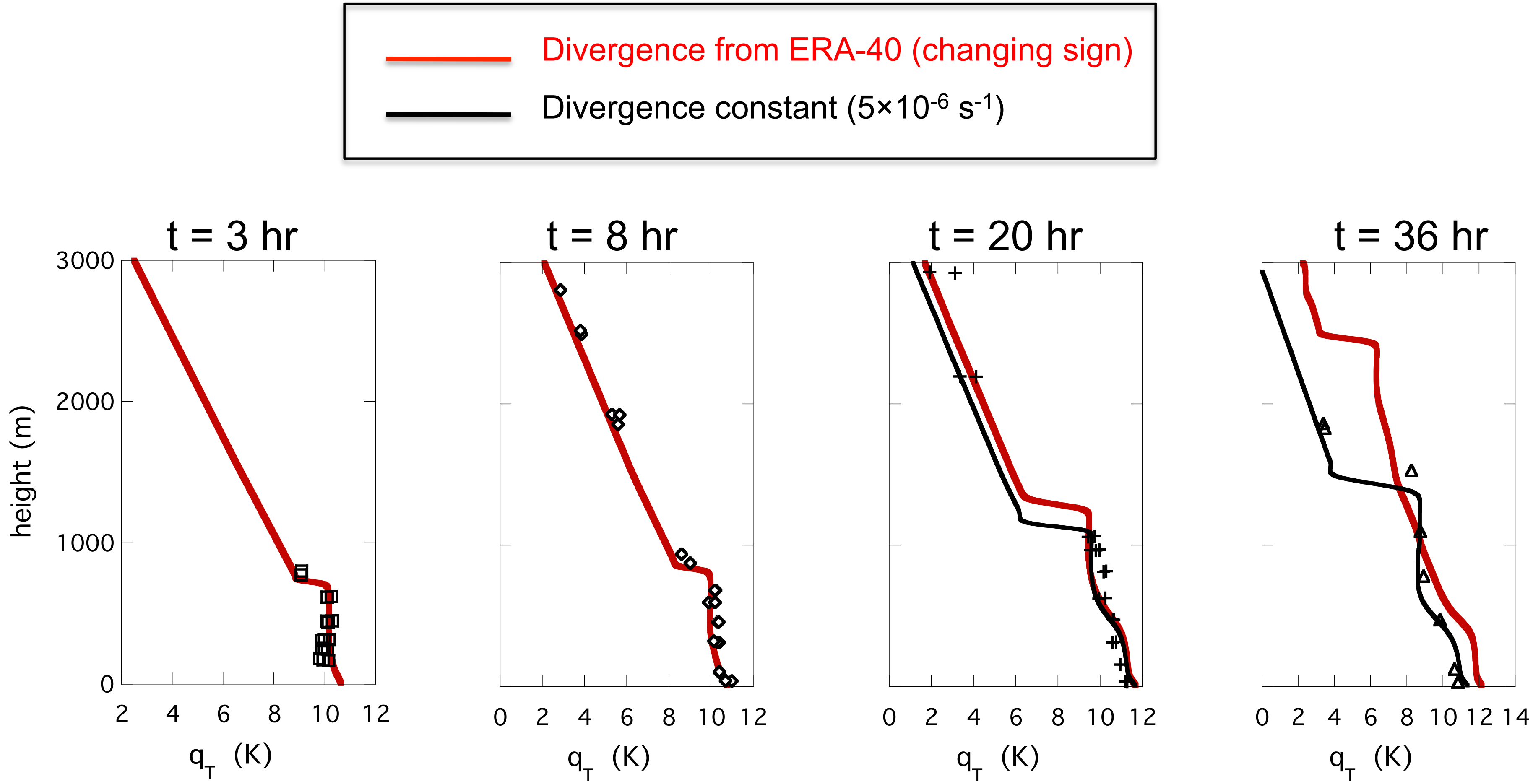


Mean state evolution: liquid water potential temperature



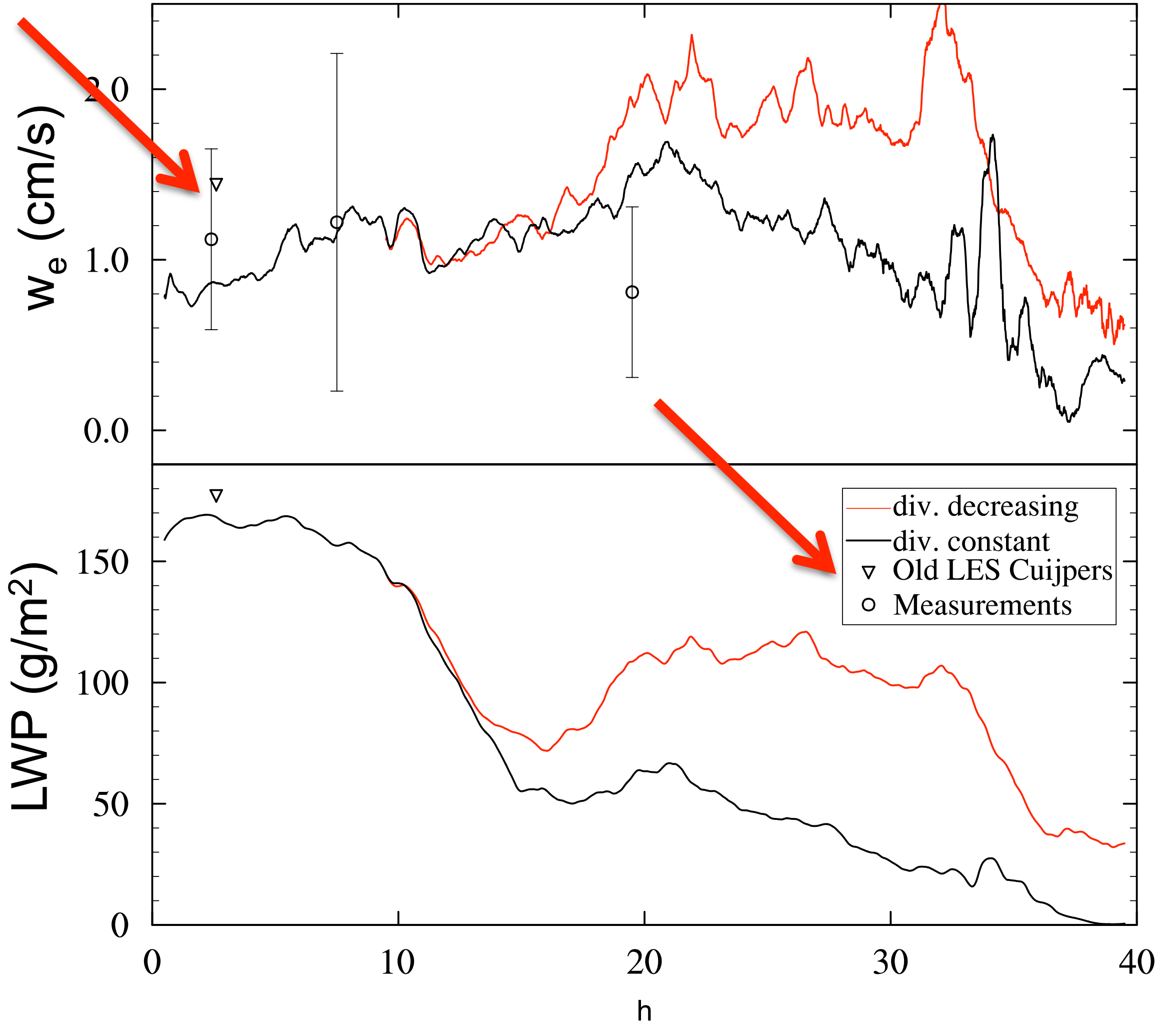
- t < 20 hr : very good agreement
- t > 20 hr : boundary height differs considerably

Mean state evolution: total water content



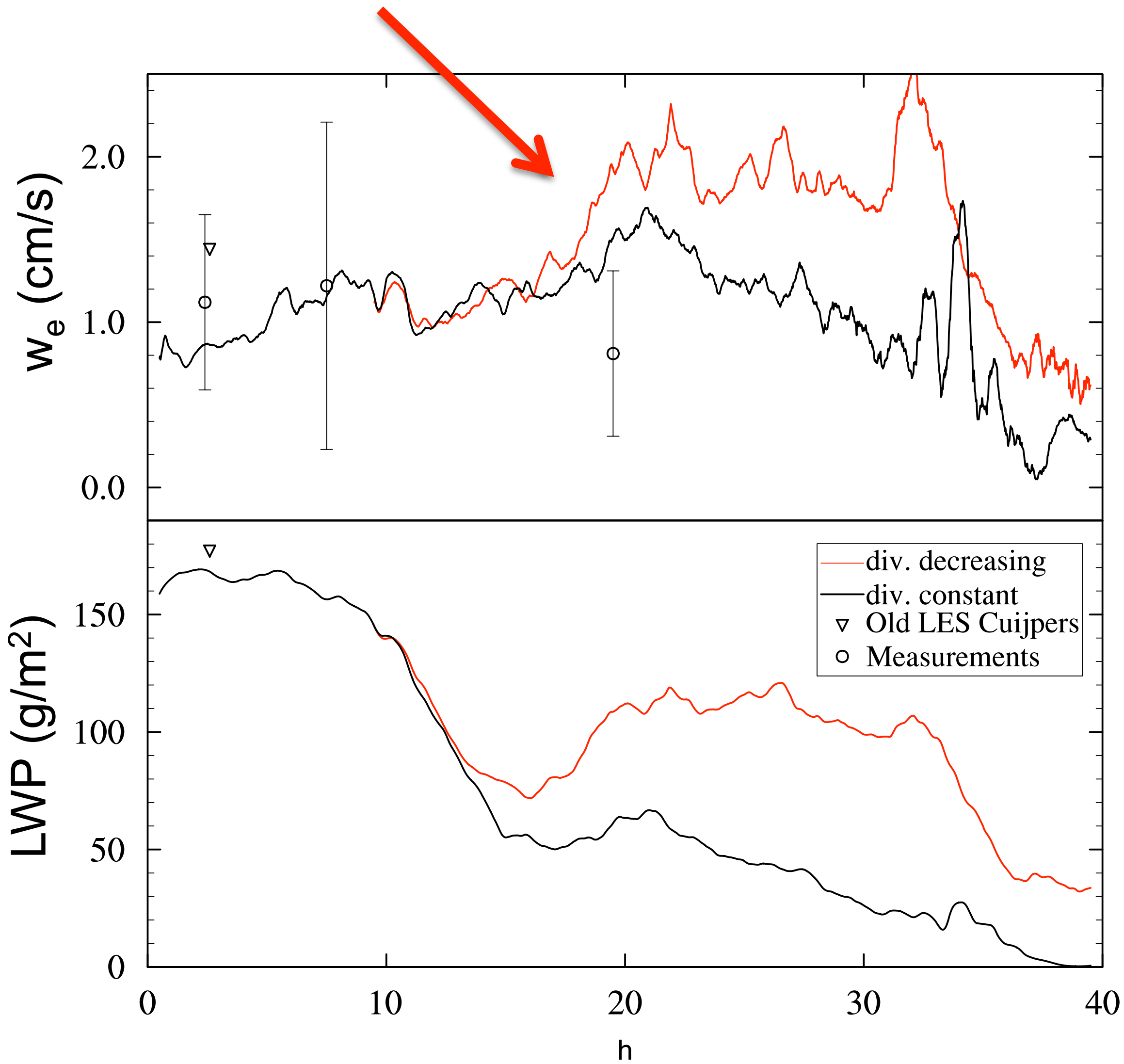
- t > 20 hr : boundary height differs considerably
- is this due to divergence only?

Entrainment (w_e) and liquid water path (LWP)



1. Lower entrainment rate when including microphysics

Entrainment (w_e) and liquid water path (LWP)



2. Divergence has effect on entrainment rate

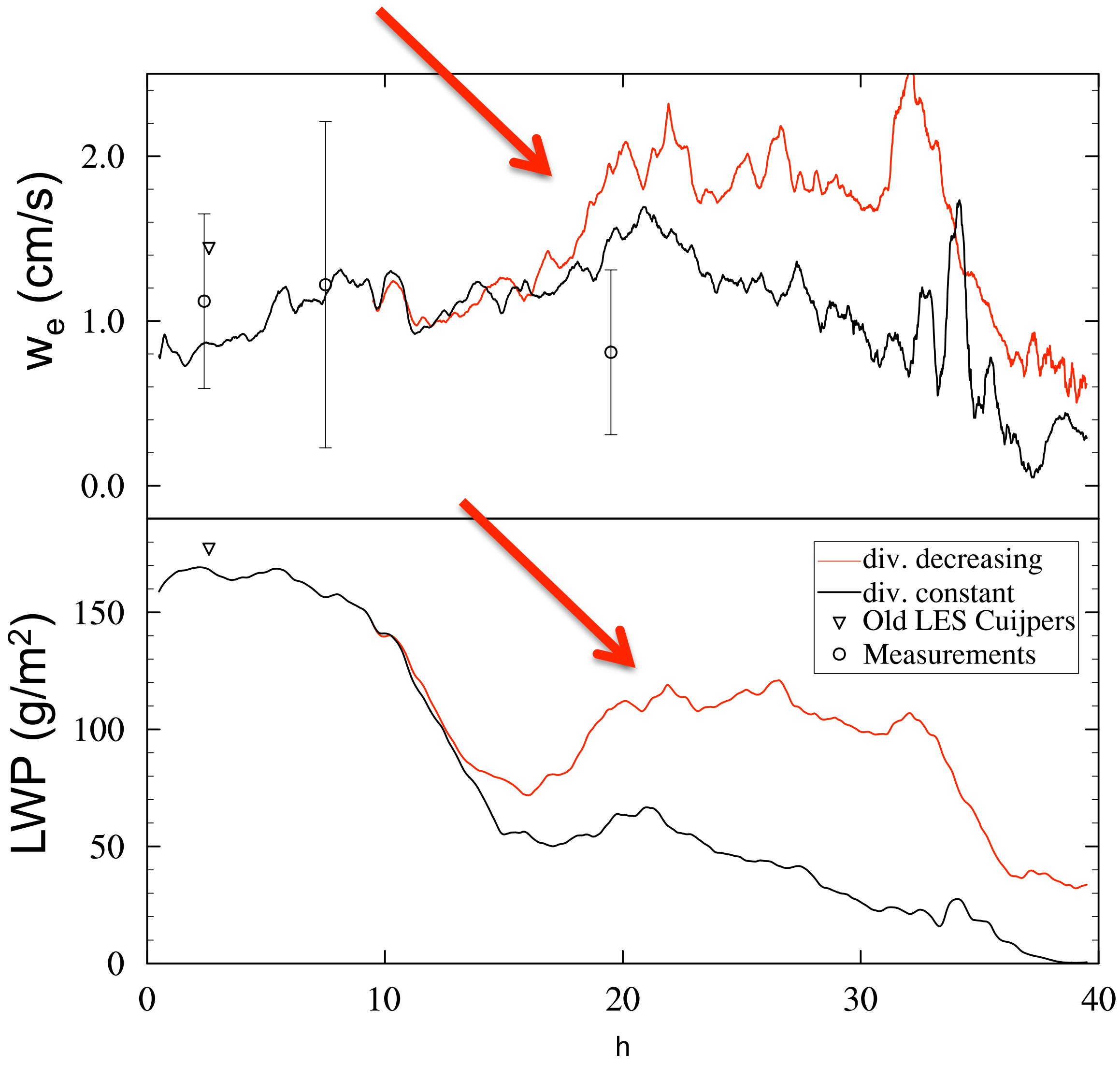
This is due to a change in the inversion stability

$$\left.\frac{\partial \overline{\theta_L}}{\partial t}\right|_{subs} = -\overline{w}\,\frac{\partial \overline{\theta_L}}{\partial z}$$

$$\left.\frac{\partial \overline{q_T}}{\partial t}\right|_{subs} = -\overline{w}\,\frac{\partial \overline{q_T}}{\partial z}$$

Subsidence warms and dries the free atmosphere

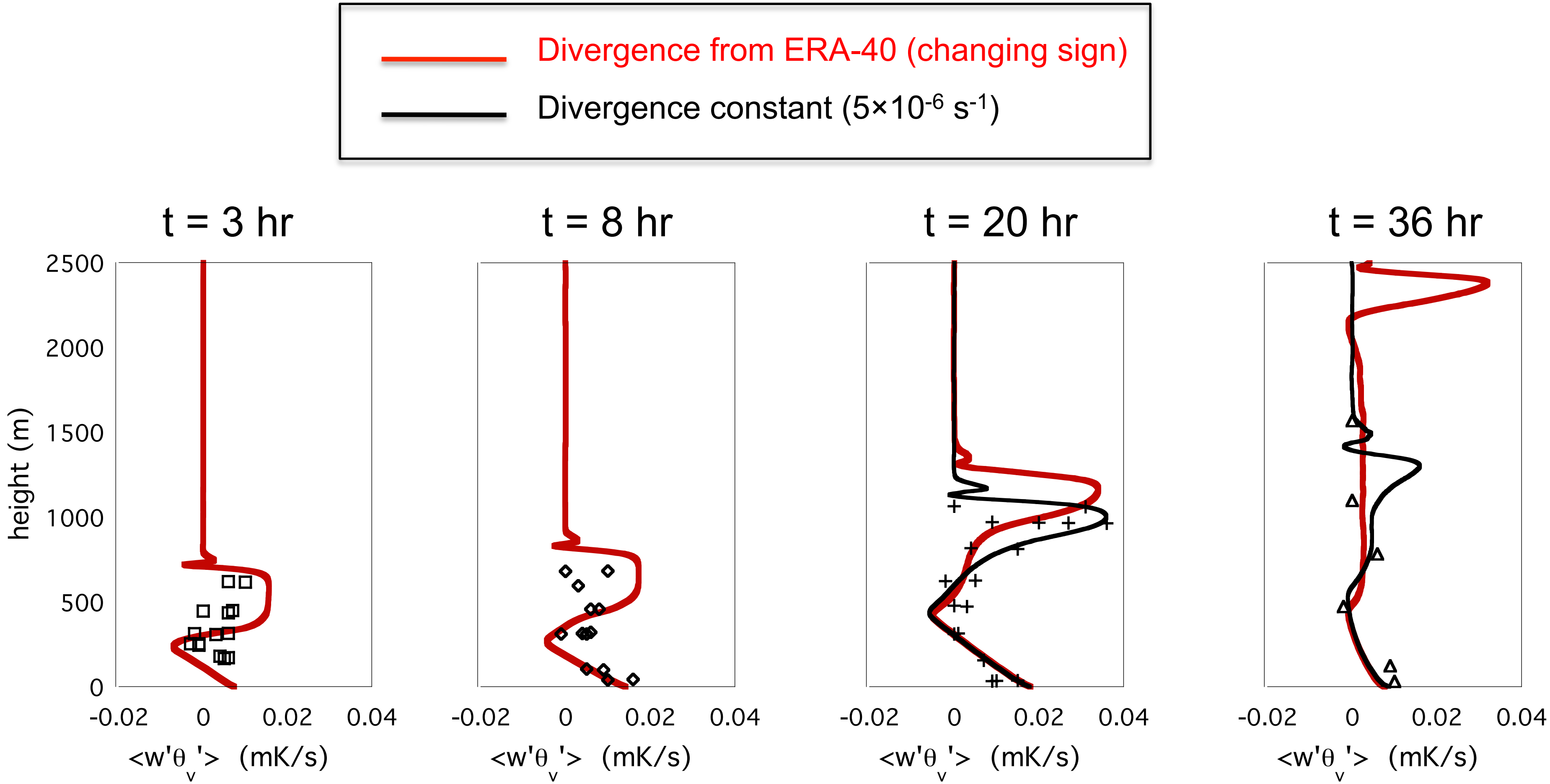
Entrainment (w_e) and liquid water path (LWP)



3. Despite larger entrainment rates, LWP is larger

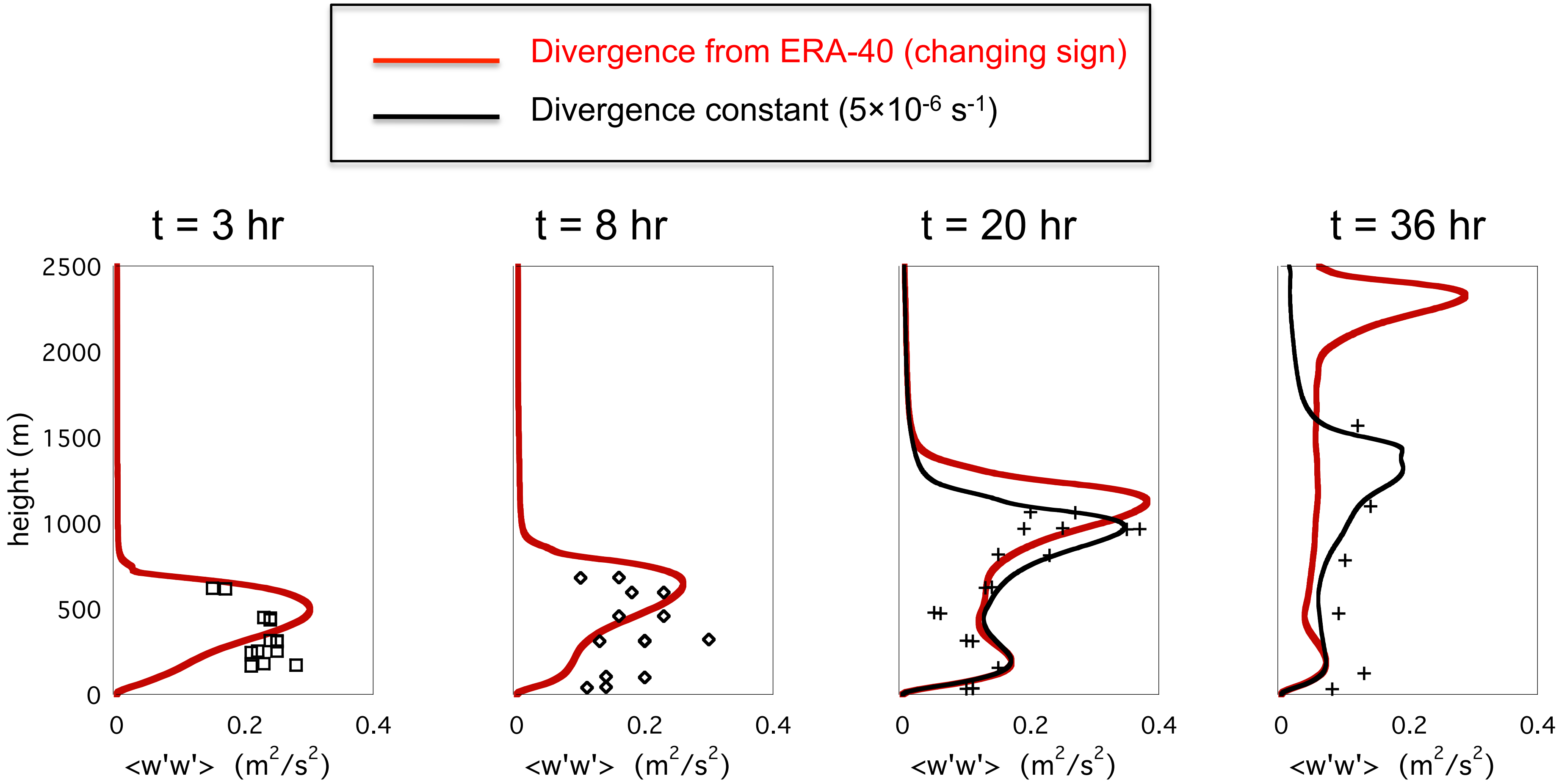
In constant divergence run stratocumulus vanishes, and longwave radiative cooling at cloud top becomes very small

Buoyancy fluxes



- Order of magnitude of the buoyancy fluxes seems OK

Vertical velocity variance



- Strong peak in vertical velocity variance at t=20 hr

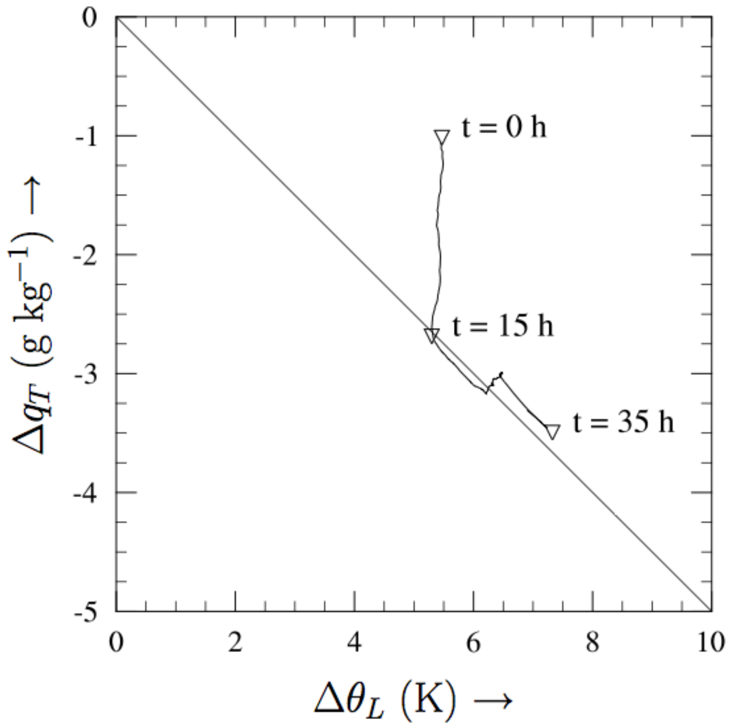
Conclusions/outlook

- Mean state and turbulence evolution
  - hour 0-24: good agreement, lower entrainment rates than in previous LES run without drizzle
  - hour 24-40: stratocumulus/cumulus amount strongly depends on large-scale divergence
  - too deep BL: is entrainment rate too large in LES?

- ASTEX Lagrangian is a new GCSS/EUCLIPSE modeling intercomparison case for LES & SCMs

GCM/NWP	Parameterization scheme	Relevant quantities to be diagnosed from LES
Turbulent transport	EDMF	Massflux, cloud fraction, entrainment
Radiation	McICA	PDFs of temperature, humidity, liquid water path
Resolved/subgrid dynamics	High-resolution NWP Δx -> 1 km	Scale analysis of turbulent transport

Inversion jumps



- Model does not pass the buoyancy reversal criterion