Differing Effects of Subsidence on Marine Boundary Layer Cloudiness

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Subsidence and Stratocumulus

- Climatologically, subtropical marine stratocumulus and large MBL cloud fraction generally occur in regions and seasons of strong subsidence

  however…

- Recent observational and modeling studies** indicate that weaker subsidence promotes more stratocumulus and greater cloud fraction

  How can these be reconciled?

** Selected References

Bretherton, C. S., P. N. Blossey and C. R. Jones, 2013. Mechanisms of marine low cloud sensitivity to idealized climate perturbations: A single-LES exploration extending the CGILS cases. *J. Adv. Model. Earth Syst.*, **5**, 316-337, doi:10.1002/jame.20019

Mauger, G., and J. R. Norris, 2010: Assessing the impact of meteorological history on subtropical cloud fraction. *J. Climate*, **23**, 2926-2940

Myers, T. A., and J. R. Norris, 2013: Observational evidence that enhanced subsidence reduces subtropical marine boundary layer cloudiness. *J. Climate*, **26**, 7507-7524

Sandu, I., and B. Stevens, 2011: On the factors modulating the stratocumulus to cumulus transitions. *J. Atmos. Sci.*, **68**, 1865-1881

Hypotheses

Strong Subsidence and Stratocumulus

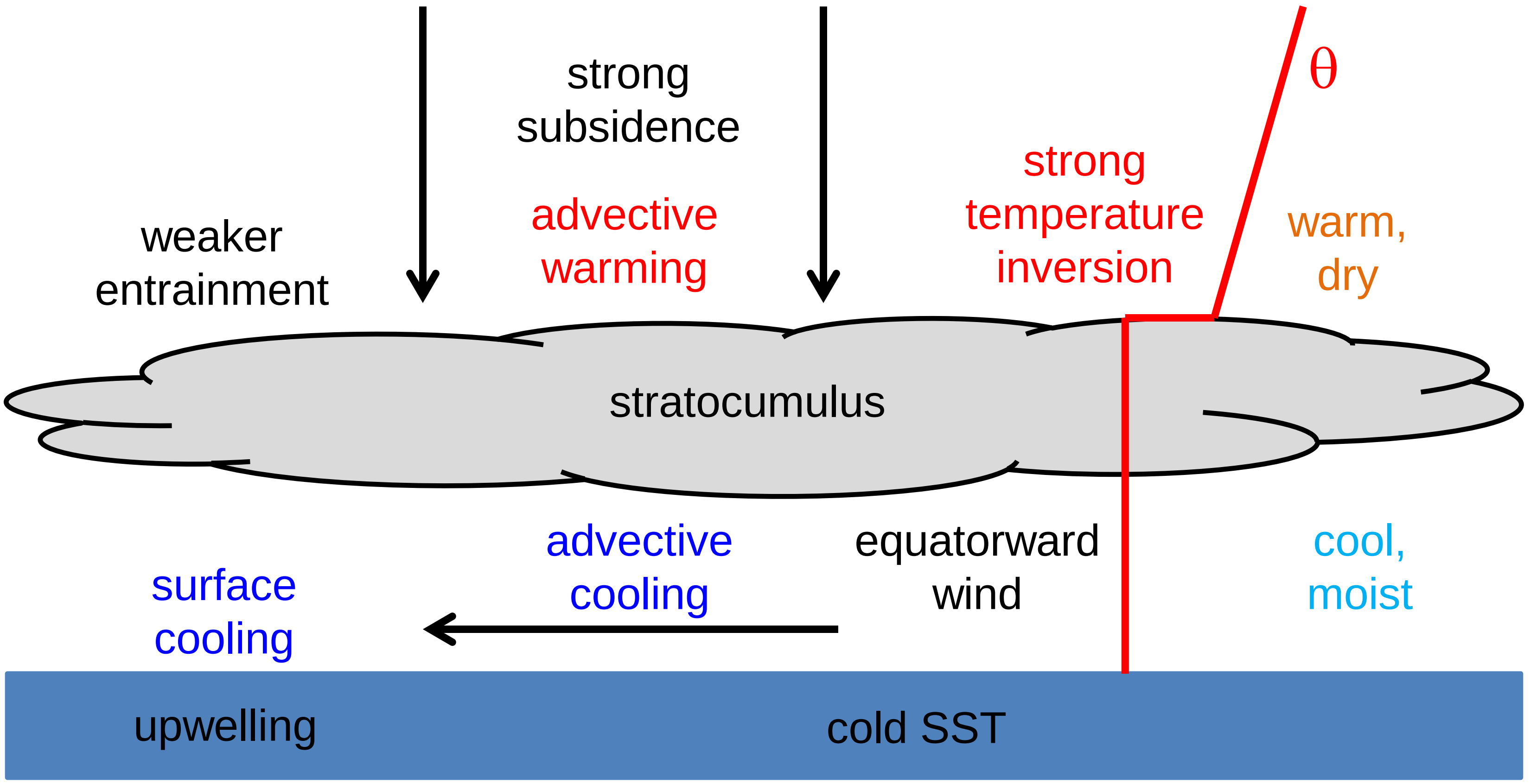
How are they connected?

Stronger subsidence is dynamically associated with:

- greater warming aloft from vertical advection
- greater equatorward wind and surface cold advection
- colder SST due to surface fluxes and upwelling by equatorward wind

All of these promote a stronger temperature inversion

- Stronger subsidence ←→ stronger inversion
- Stronger inversion → more stratocumulus
- Stronger subsidence ≠ more stratocumulus (through a direct mechanism)

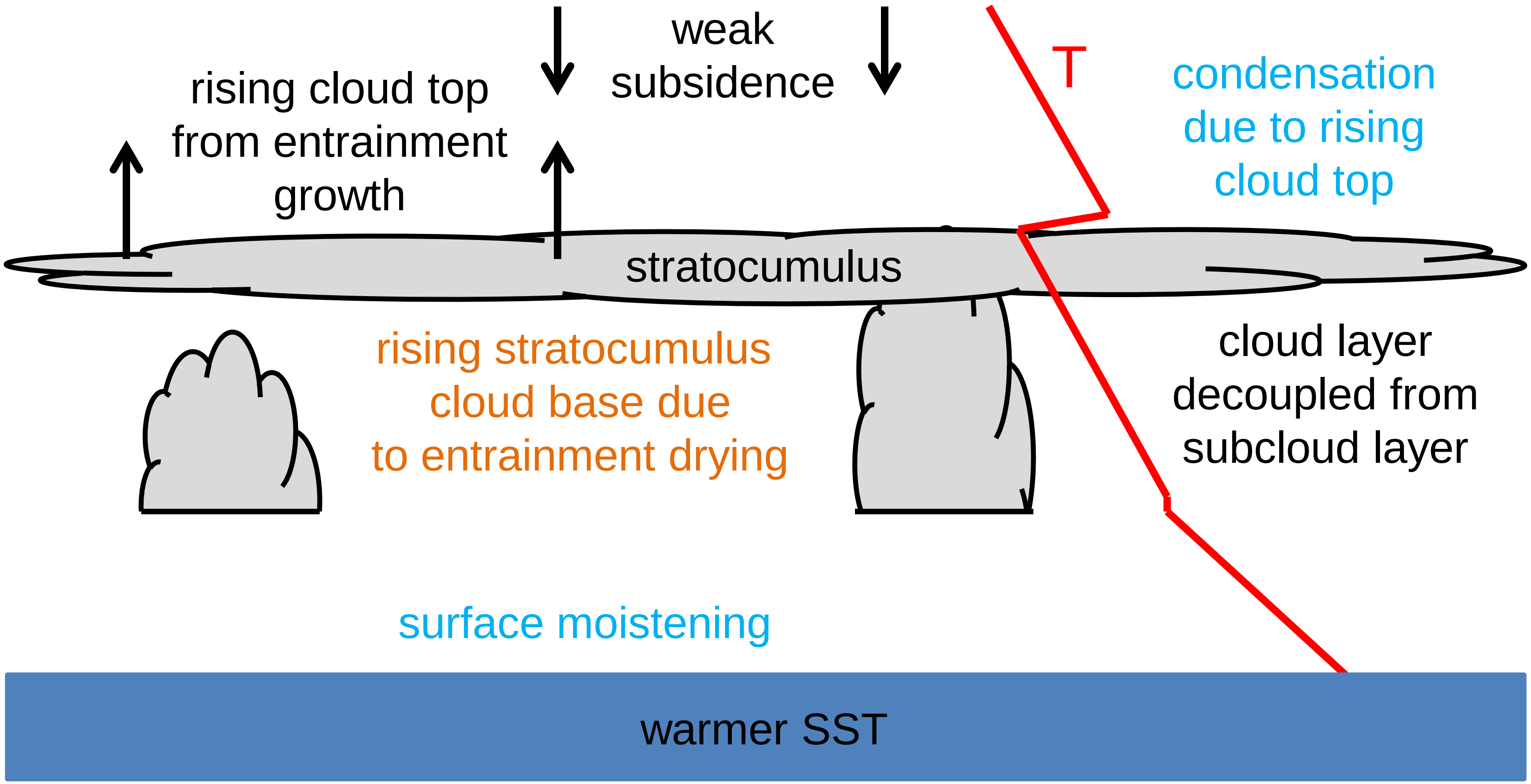

strong
subsidence
θ
strong
temperature
inversion
advective
warming
weaker
entrainment
warm,
dry
stratocumulus
advective
cooling
equatorward
wind
cool,
moist
surface
cooling
upwelling
cold SST

Weak Subsidence and Stratocumulus

How are they connected?

- Subsidence weaker than cloud top entrainment rate → rising cloud top
- Cooler cloud top and lower saturation mixing ratio → more cloud condensation
- Cloud condensation outpaces entrainment drying → stratocumulus is maintained

- Weaker subsidence → thicker cloud than otherwise
- Weaker subsidence → slower stratocumulus breakup


weak
subsidence
rising cloud top
from entrainment
growth
T
condensation
due to rising
cloud top
stratocumulus
rising stratocumulus
cloud base due
to entrainment drying
cloud layer
decoupled from
subcloud layer
surface moistening
warmer SST

Observational Evidence

Lagrangian Trajectory Composites

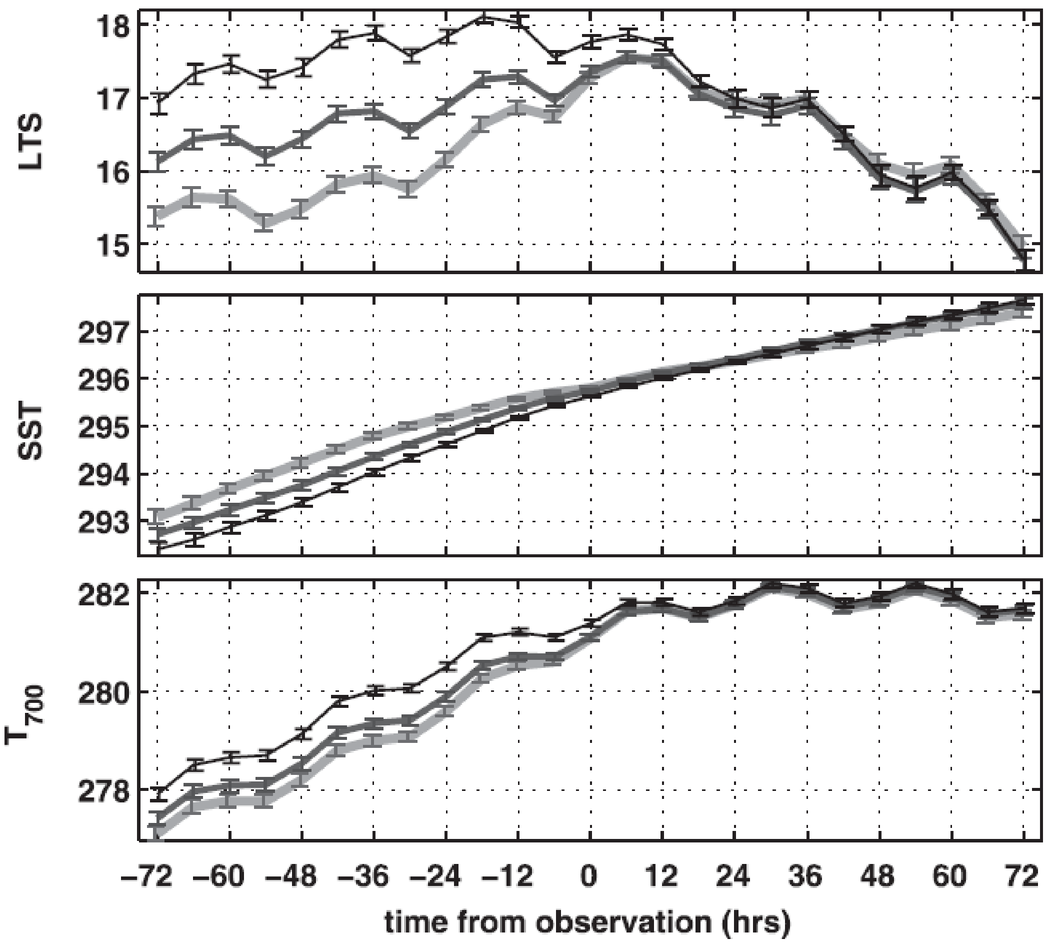


FIG. 6. Composite trajectories showing LTS (defined as $\theta_{700} - \theta_{SFC}$; K), SST (K), and 700-hPa temperature (T_{700}; K) and moisture (q_{700}; g kg^{-1}), all obtained from ECMWF analyses. Note that variations from one time to the next reflect large-scale trends as well as the diurnal cycle.

Large fraction occurs with:

- Colder SST prior to cloud observation
- Warmer temperature aloft prior to cloud observation
- Stronger inversion prior to cloud observation

from Mauger and Norris (2010)

Lagrangian Trajectory Composites

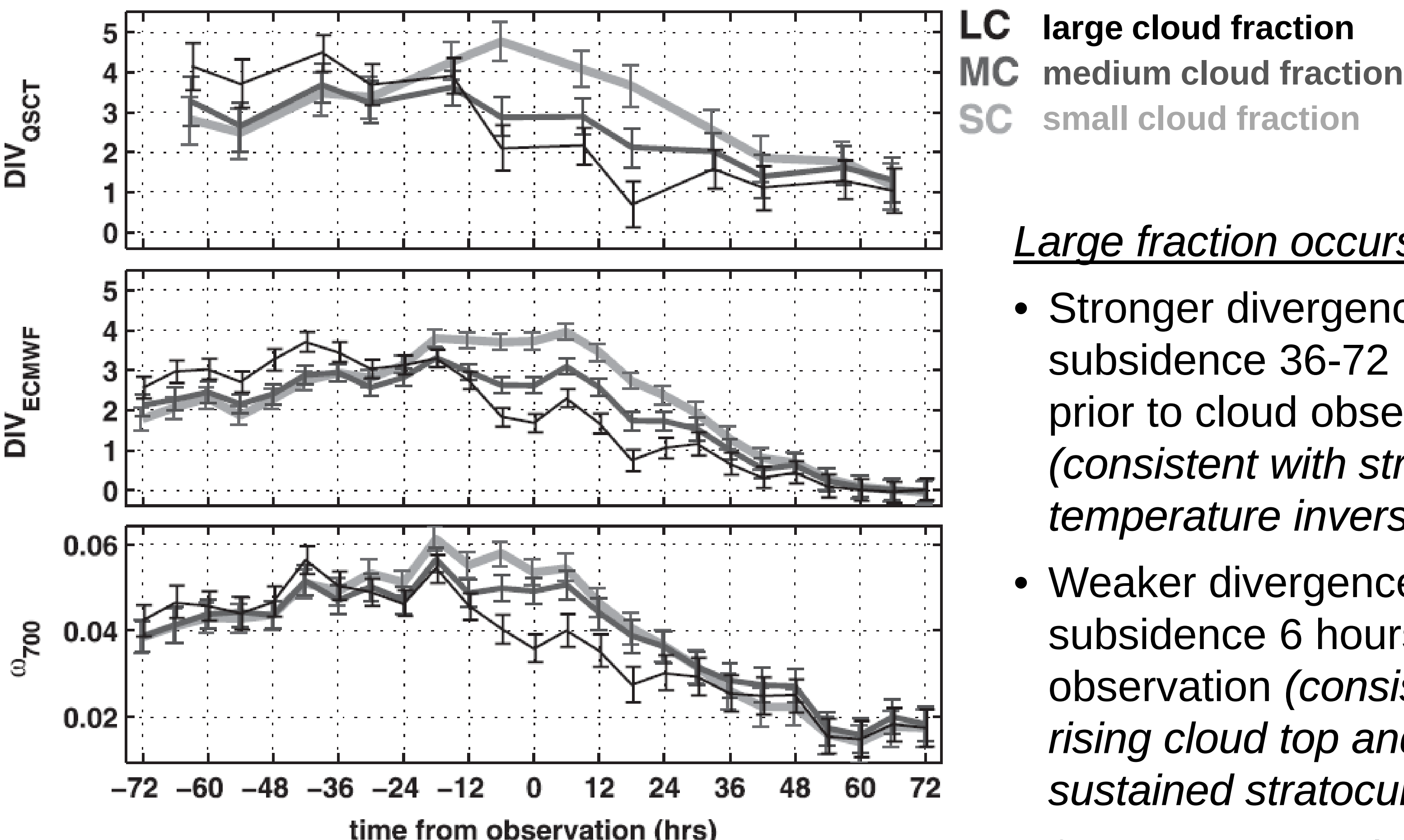


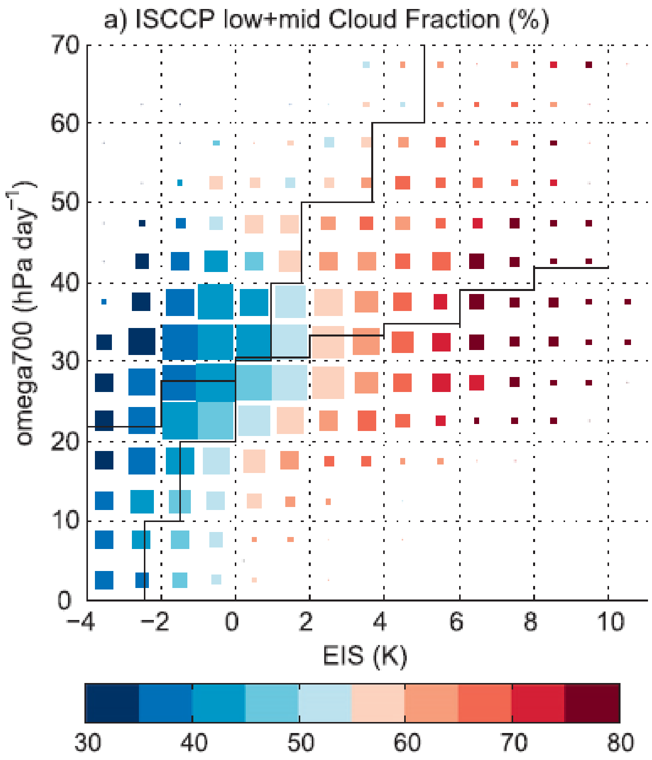
FIG. 8. Composite trajectories showing QuikSCAT and ECMWF surface divergence DIV_{QSCT} and DIV_{ECMWF} ($\times 10^{-6}$ s^{-1}) and ECMWF 700-hPa pressure vertical velocity ω_{700} (Pa s^{-1}).

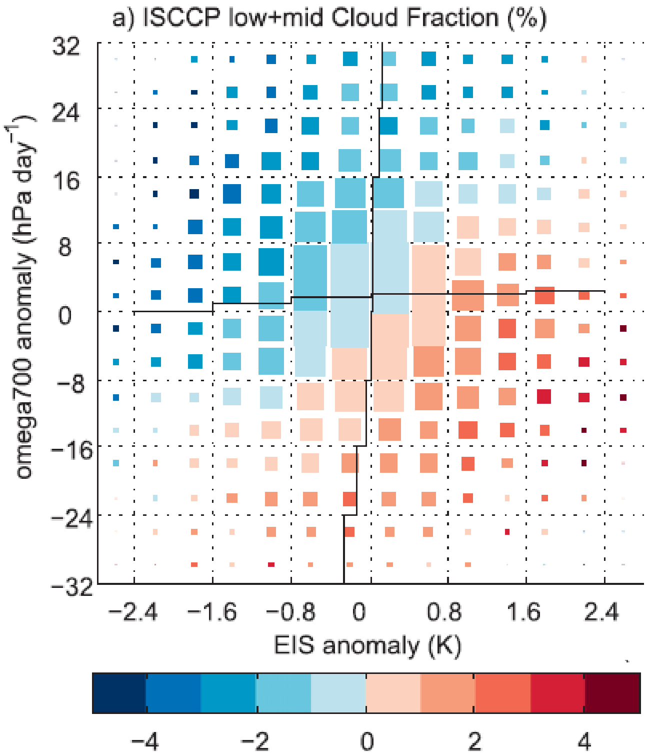
Large fraction occurs with:

- Stronger divergence and subsidence 36-72 hours prior to cloud observation *(consistent with stronger temperature inversion)*
- Weaker divergence and subsidence 6 hours prior to observation *(consistent with rising cloud top and sustained stratocumulus)*

from Mauger and Norris (2010)

Partial Derivative Eulerian Composites

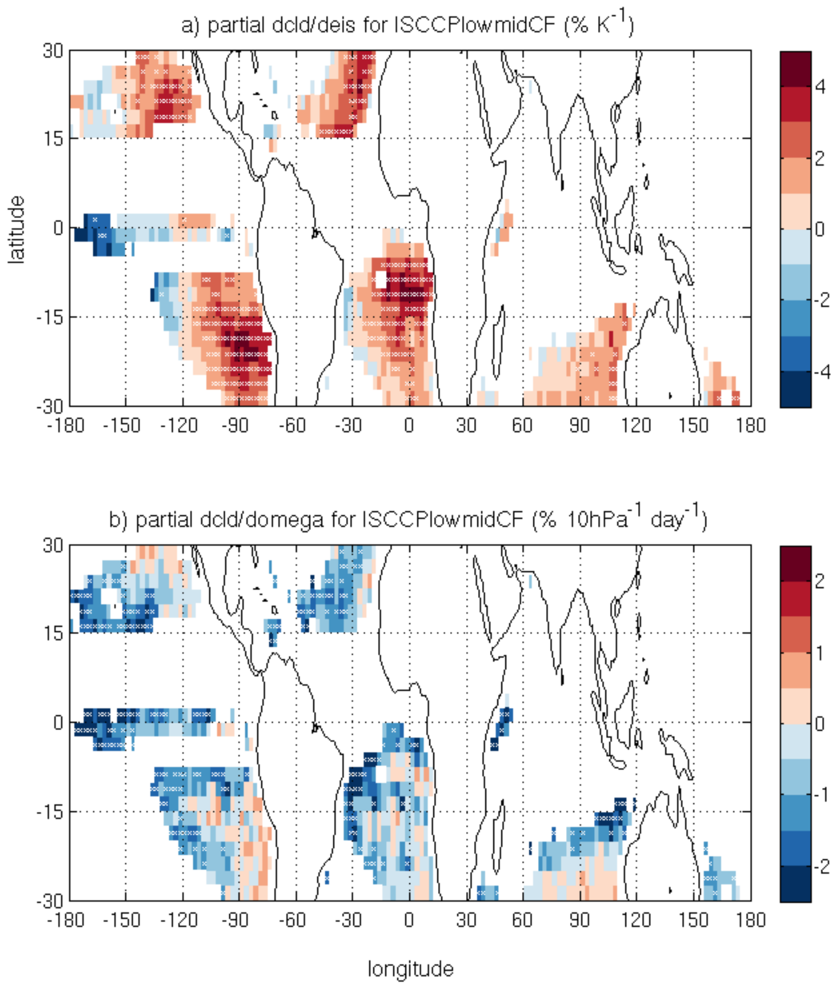




For climatology and anomalies, cloud fraction decreases with increasing subsidence when inversion strength stays the same

from Myers and Norris (2013)

Partial Derivative Eulerian Composites



$$\left.\frac{\partial cld}{\partial EIS}\right|_{\omega}$$

$$\left.\frac{\partial cld}{\partial \omega}\right|_{EIS}$$

cld = cloud fraction

ω = subsidence at 700 hPa

EIS = estimated inversion strength

- Stronger inversion strength promotes more cloud fraction
- Effect often largest near climatological maximum of stratocumulus
- Weaker subsidence promotes more cloud fraction
- Effect largest in breakup region of stratocumulus

Modeling Evidence

LES Experiments

- Vertical profile from ASTEX GCSS intercomparison case
- Time varying SST from Bretherton et al. (1999)

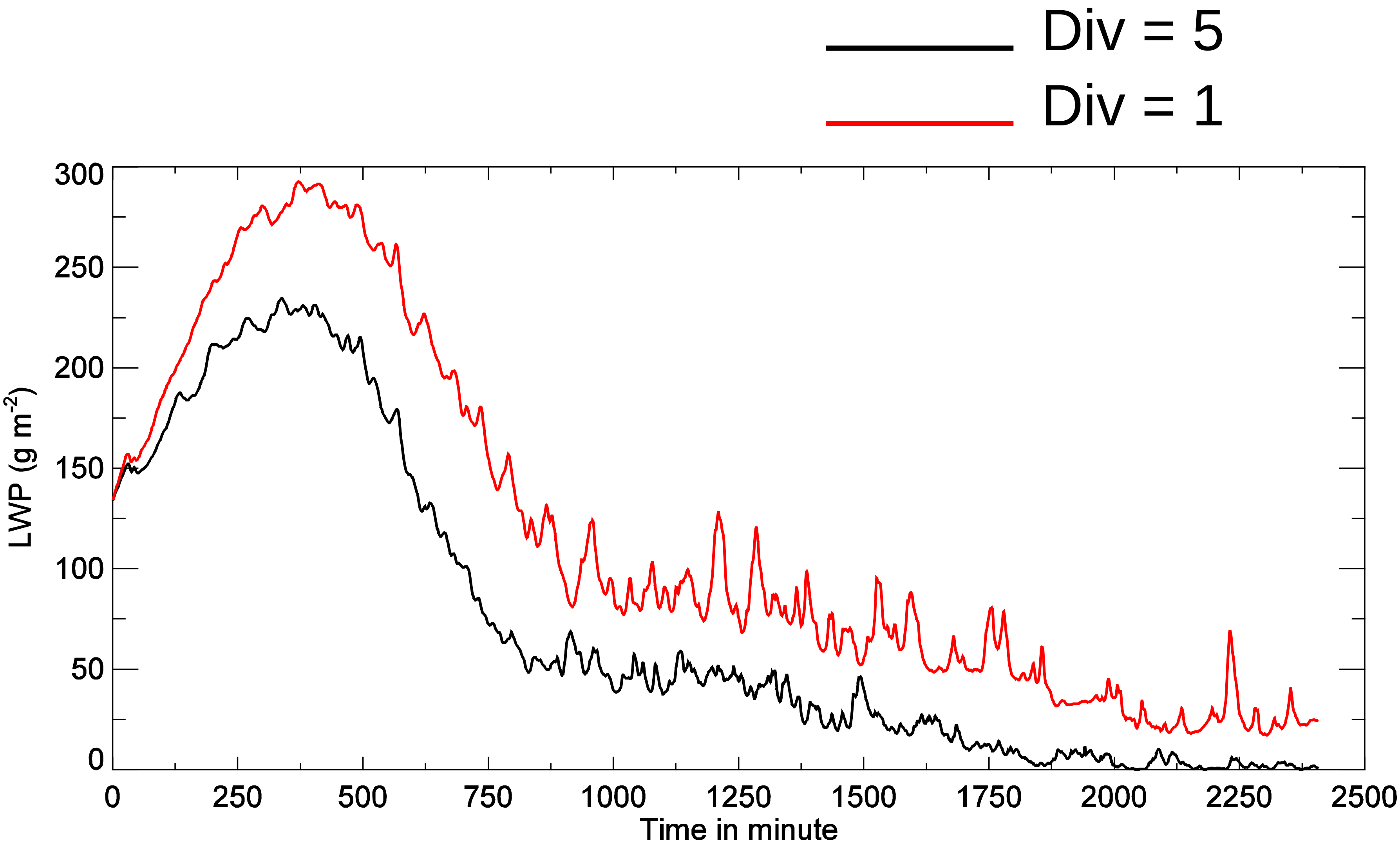
Two Experiments

- Divergence held constant at 1×10^{-6} s^{-1}
- Divergence held constant at 5×10^{-6} s^{-1}

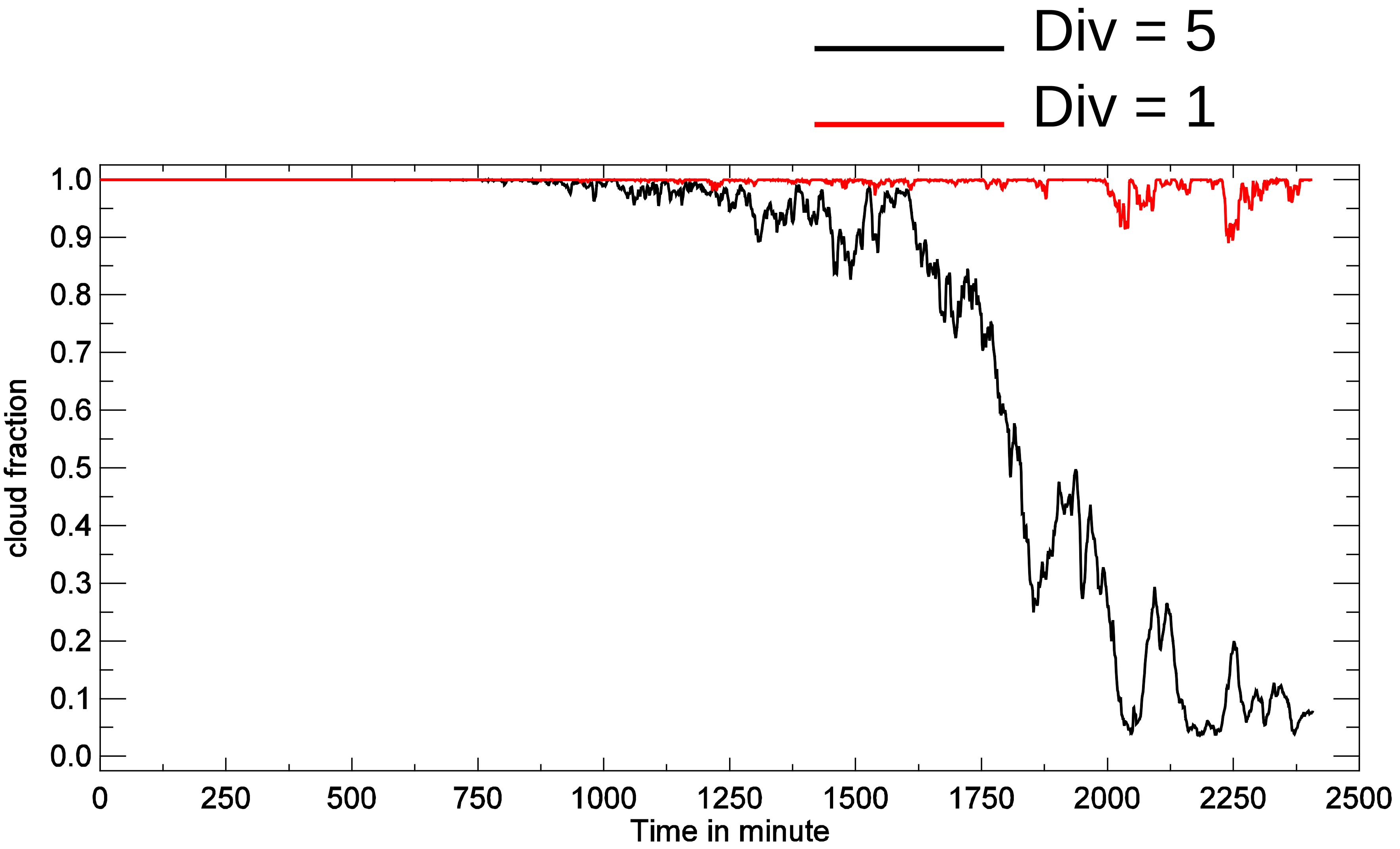
Results

- Weaker divergence case larger cloud fraction, higher cloud top, and greater LWP

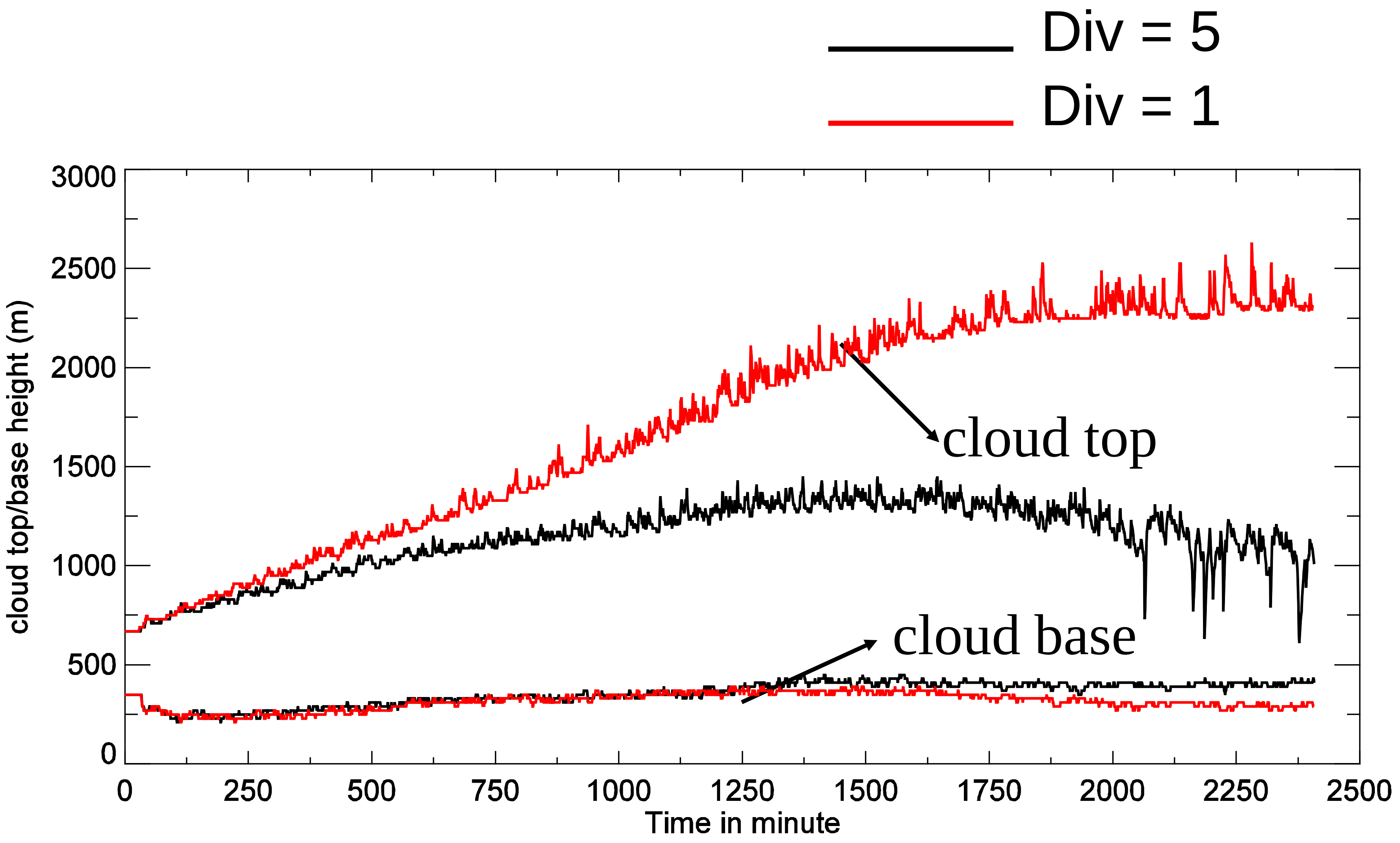
Time Evolution of Liquid Water Path



Time Evolution of Cloud Fraction



Time Evolution of Cloud Top and Cloud Base height



Summary

- Stronger subsidence is associated with greater stratocumulus it occurs with a stronger inversion
- Weaker subsidence allows stratocumulus to persist longer as cloud top is able to grow and remain saturated
- Subsidence has a larger impact on cloud fraction in stratocumulus breakup regions

- Data from the Marine ARM GPCI Investigation of Clouds (MAGIC) will provide detailed information on cloud structure in the marine boundary layer useful for investigating effects of subsidence on stratocumulus