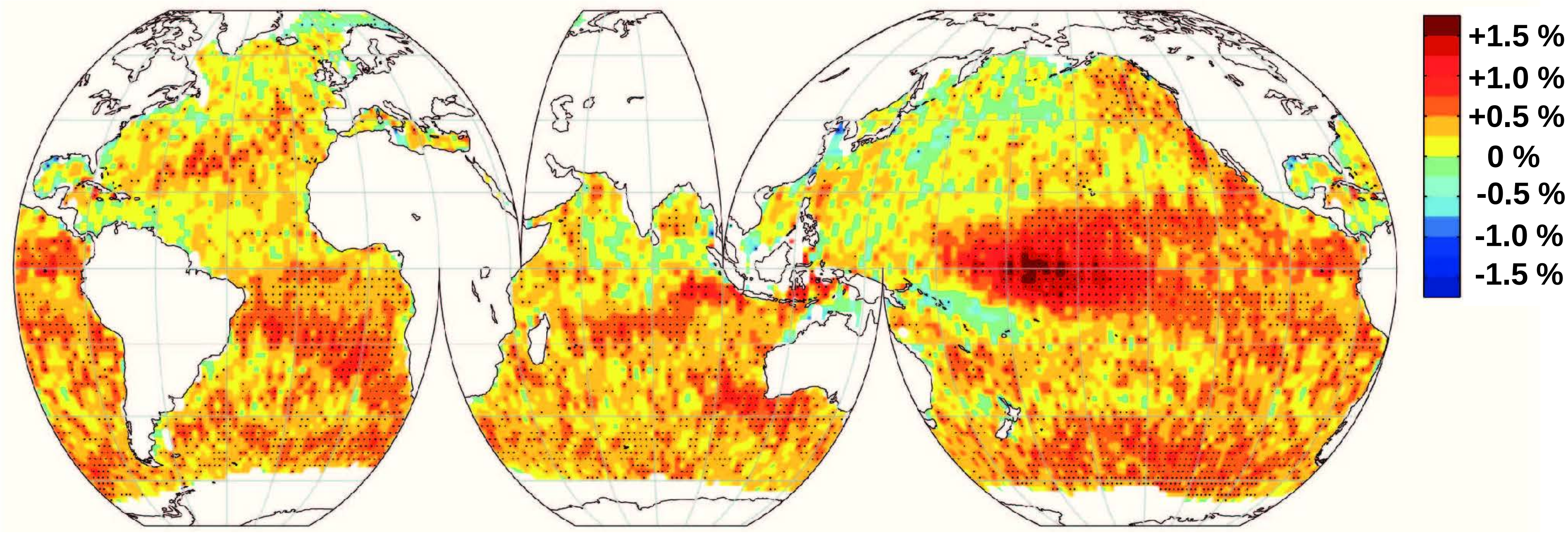
Cloud-climate feedbacks:

What cloud-system resolving simulations tell about marine non-precipitating Sc response to wind speed

Jan Kazil, Graham Feingold, Takanobu Yamaguchi

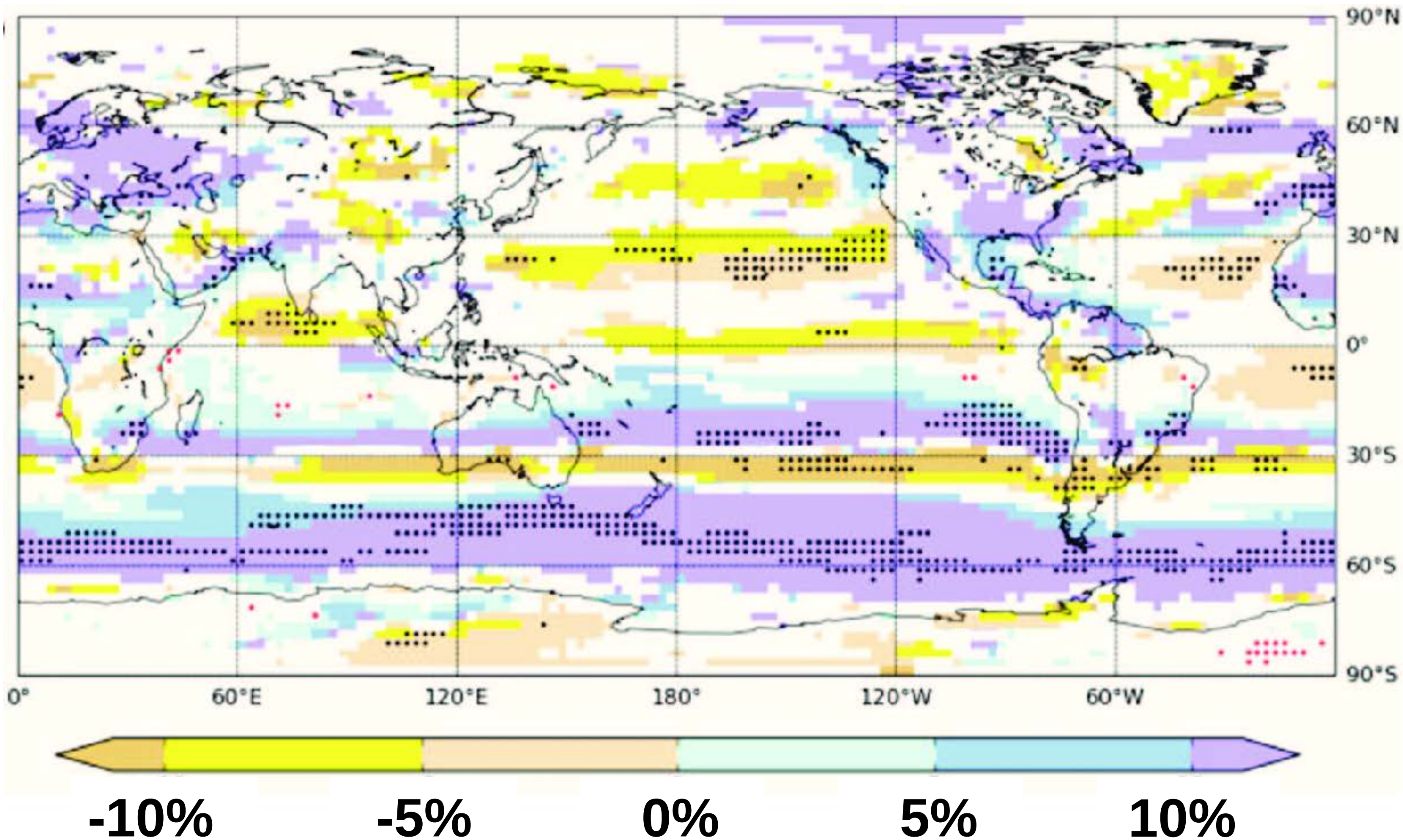
Annual 10 m wind speed trend 1991-2008



Young et al. (Nature, 2011)

- **Satellite radar altimeter**
- **Wave height**
- **10 m wind speed**

JJA 10 m wind 2081-2100 relative to 1981-2000



McInnes et al. (Atm. Sci. Lett., 2011)

- **WCRP CMIP3 model mean**
- **19 coupled climate models**
- **A1B emission scenario**

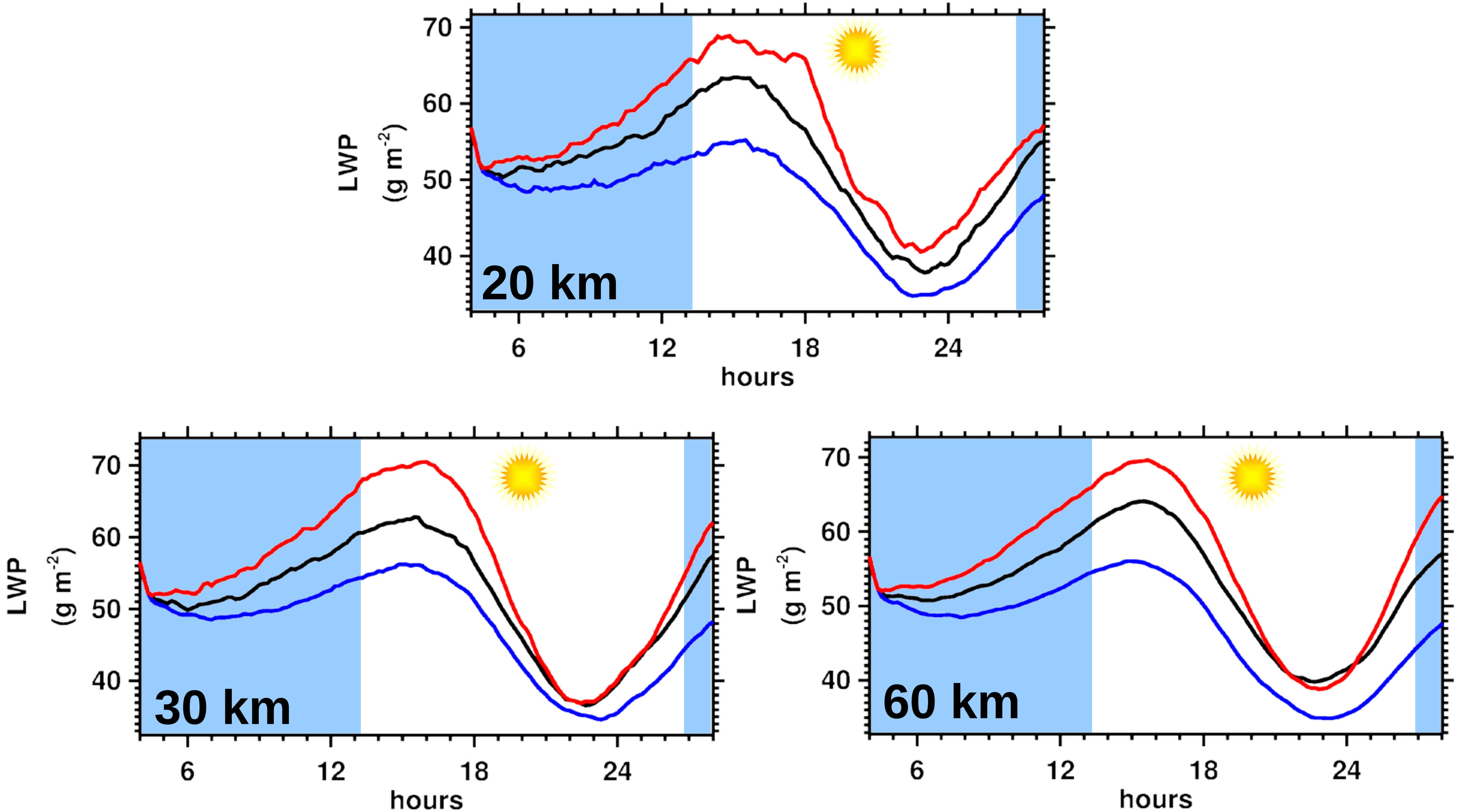
LWP response to wind speed

  - Non-monotonic

- Role of:
  - Decoupling
  - Buoyancy-driven circulation
  - Domain size
  - Resolution
  - Free tropospheric water vapor

Wind speed and LWP

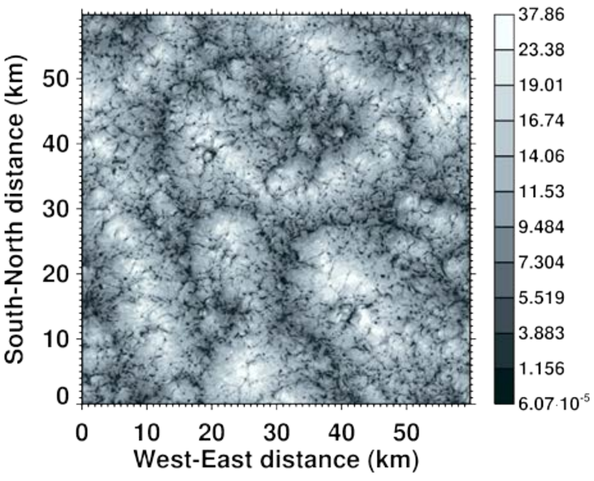
Wind speed: — **- 20 %** — **DYCOMS II RF 01** — **+ 20 %**



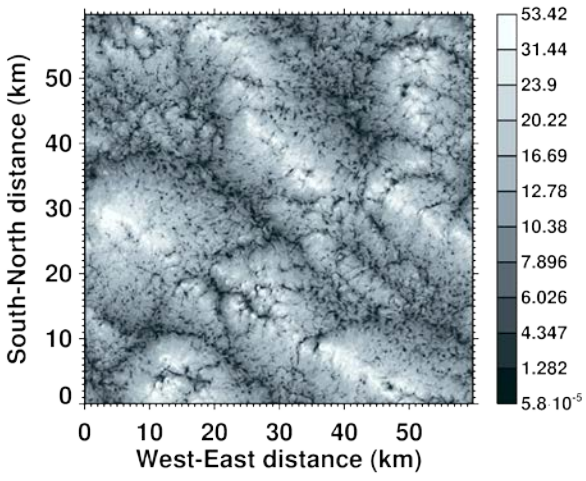
(dx = dy = 150 m, dz = 15 m, dt = 1.5 s)

Simulations

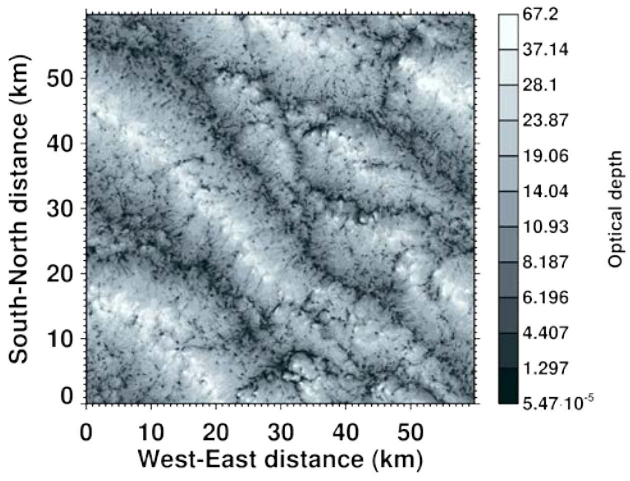
- **WRF-Chem**
- **DYCOMS II RF01, 300 CCN mg^{-1}**
- **Domain size: 20 km, 30 km, 60 km**
- **Resolution:**
  - **dx = dy = 150 m, dz = 15 m, dt = 1.5 s**
    (20 km, 30 km, and 60 km)
  - **dx = dy = 75 m, dz = 7.5 m, dt = 0.75 s**
    (20 km and 30 km)



- 20 %

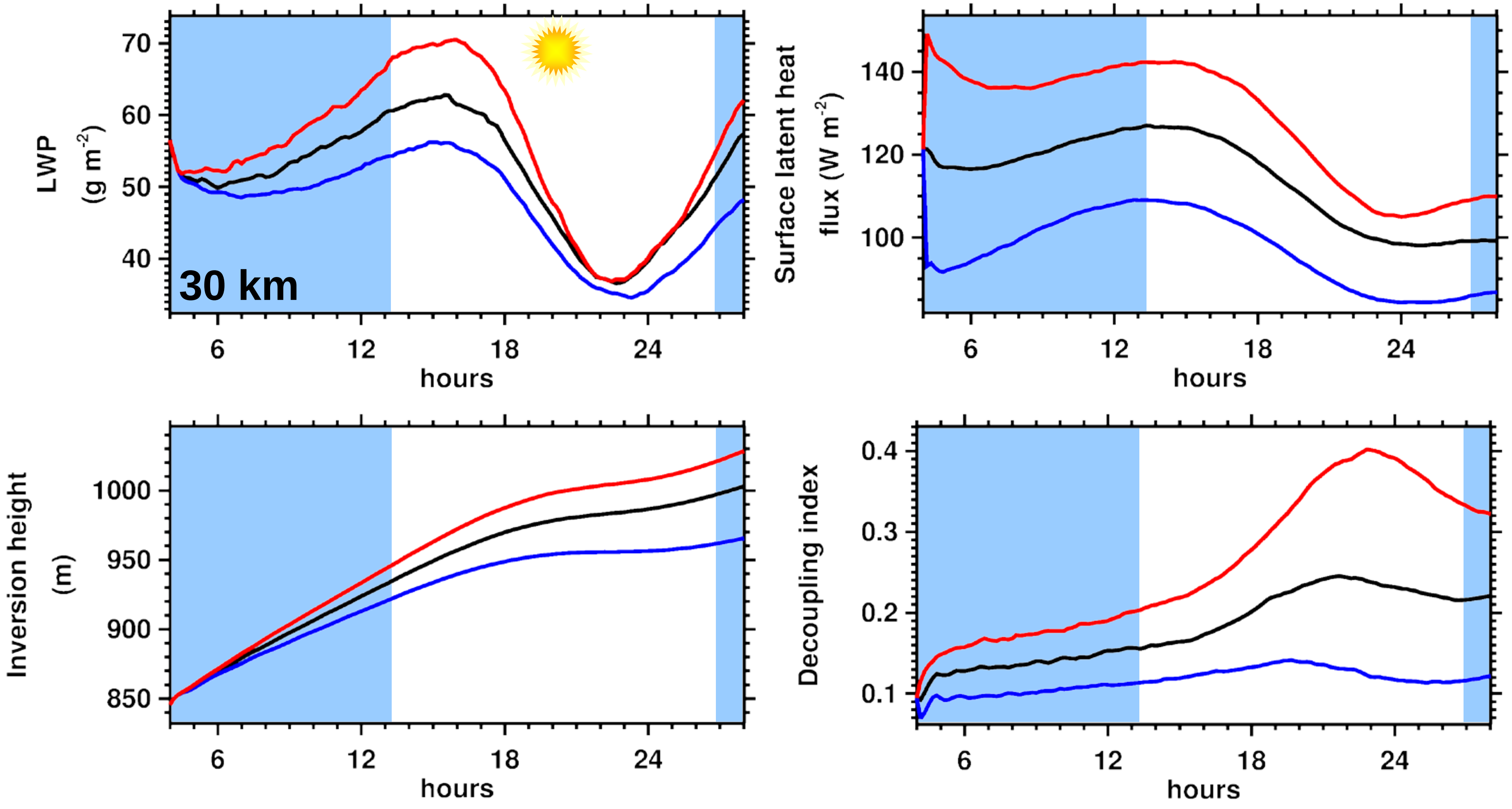


DYCOMS II RF01



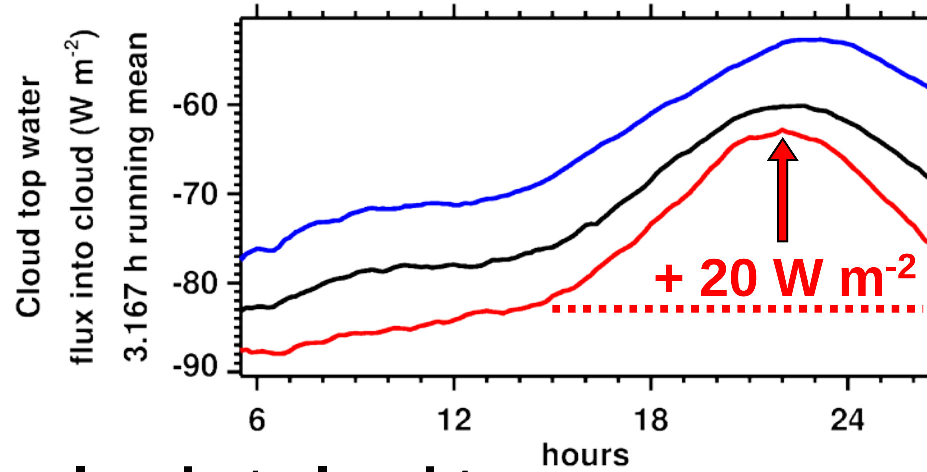
+ 20 %

Decoupling

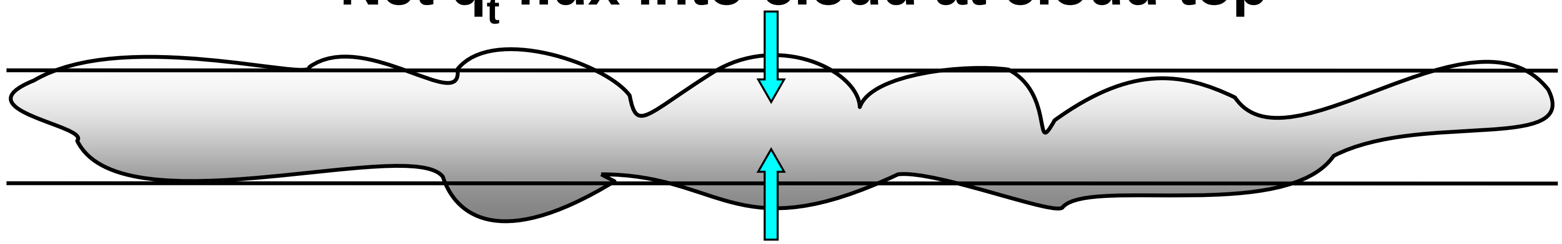


$$\text{Decoupling index} = \frac{\langle\text{cloud base height}\rangle - \langle\text{LCL}\rangle}{\langle\text{cloud base height}\rangle}$$

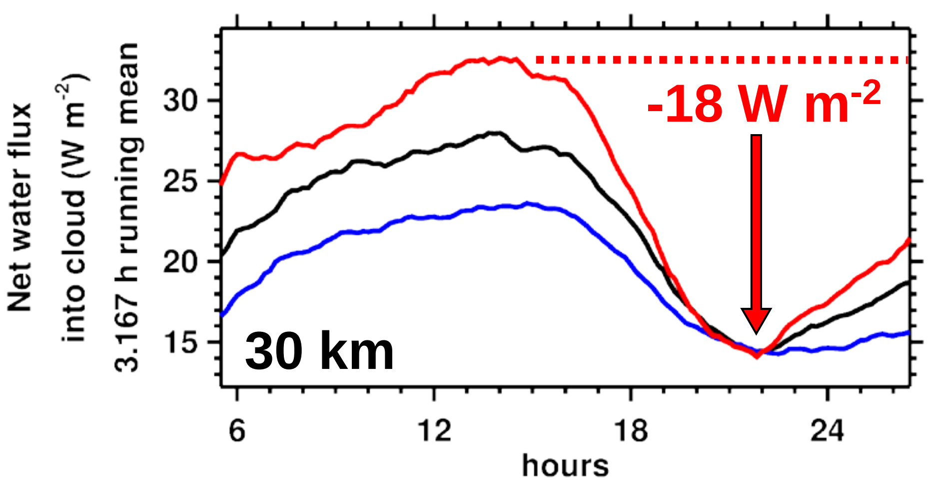
Effect of decoupling at cloud level

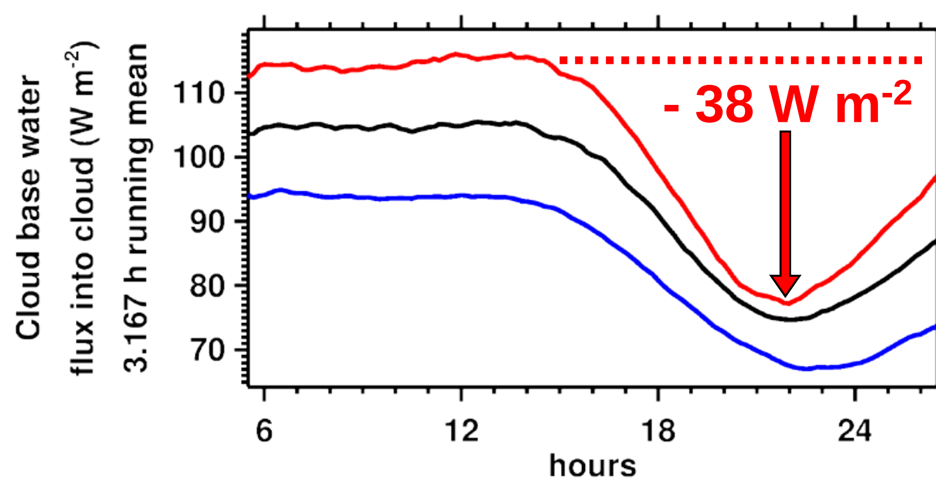


Net q_t flux into cloud at cloud top



Net q_t flux into cloud at cloud base





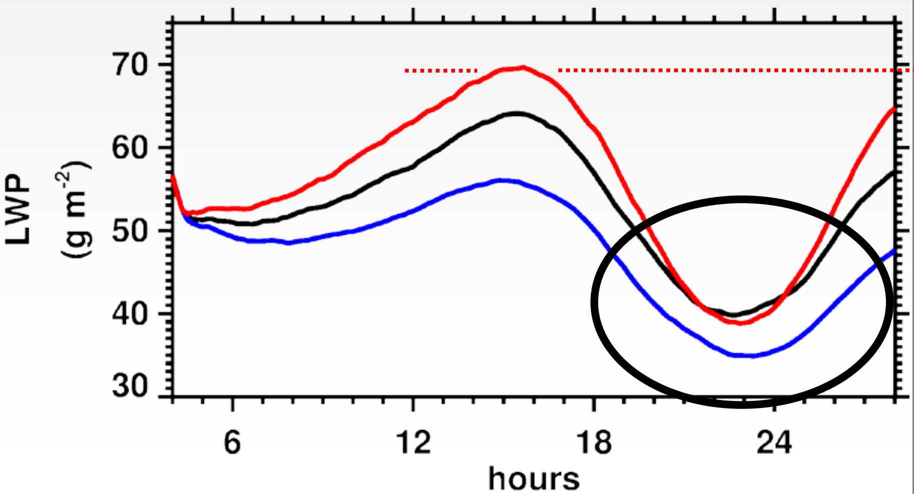
Role of buoyancy-driven circulation

"Buoyancy + shear"

Prescribed geostrophic wind

➔ Drives surface heat fluxes

- Circulation due to:
  - Buoyancy-generated TKE
  - Shear-generated TKE

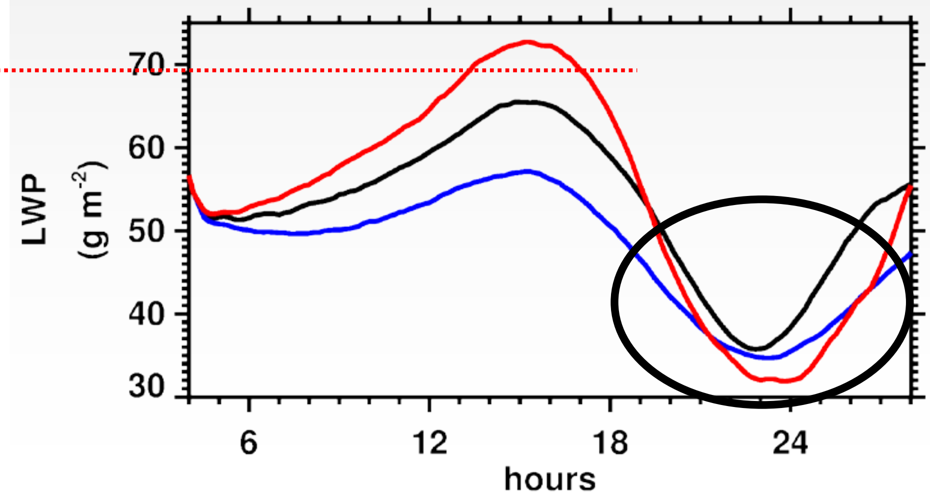


"Buoyancy only"

Zero geostrophic wind

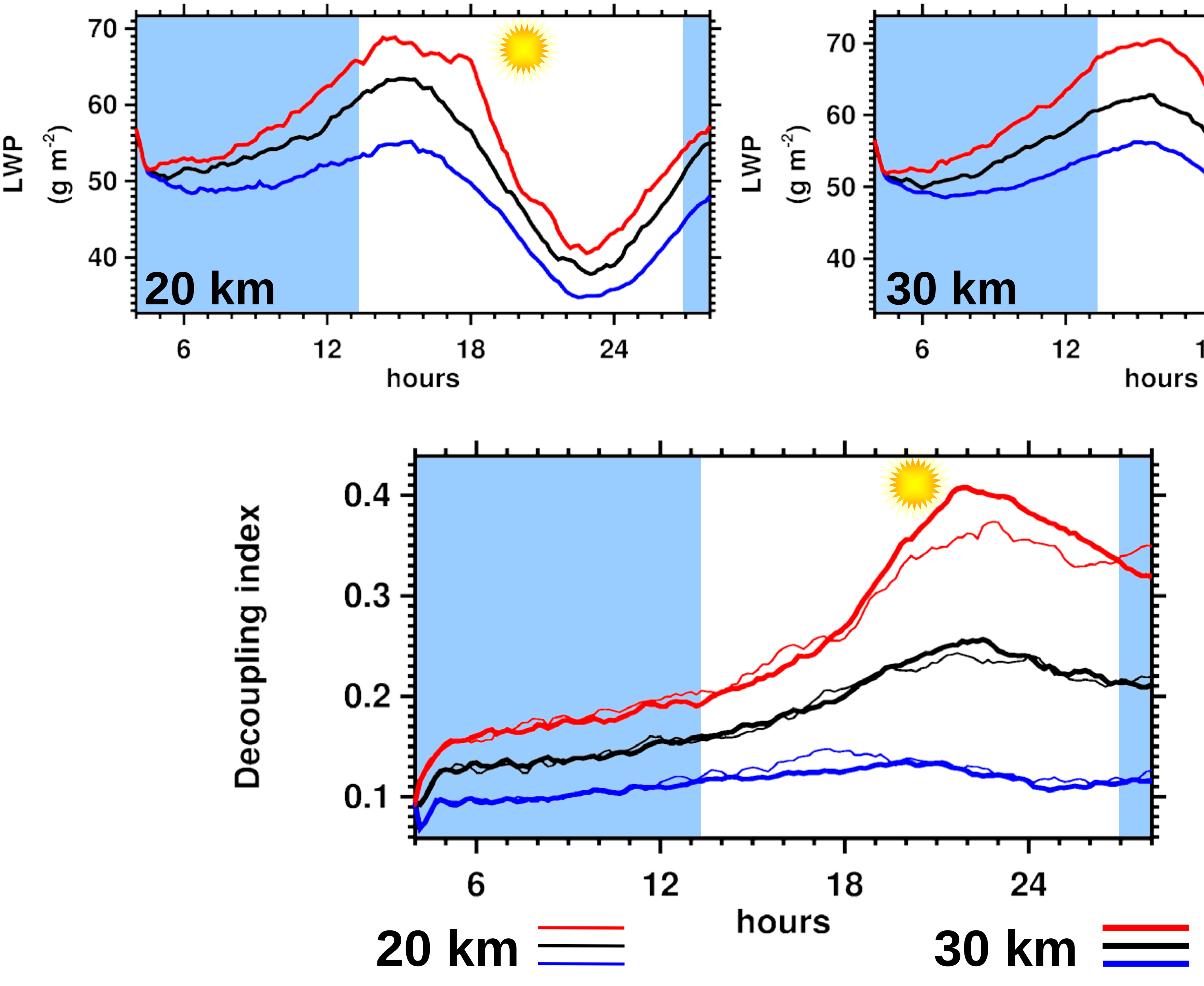
➔ Surface heat fluxes from "buoyancy + shear"

- Circulation due to:
  - Buoyancy-generated TKE



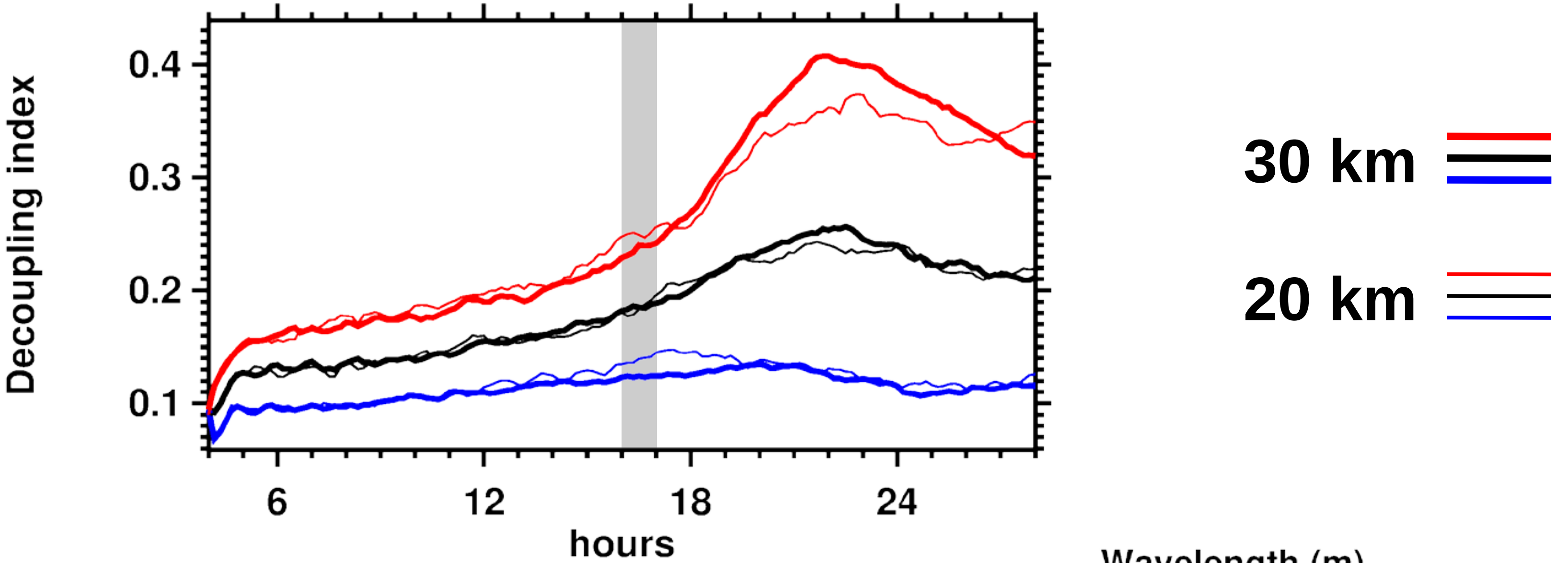
- Buoyancy- driven circulation ➔ non-monotonic LWP response
- Geostrophic wind: suppresses LWP during the night
  reduces decoupling during the day

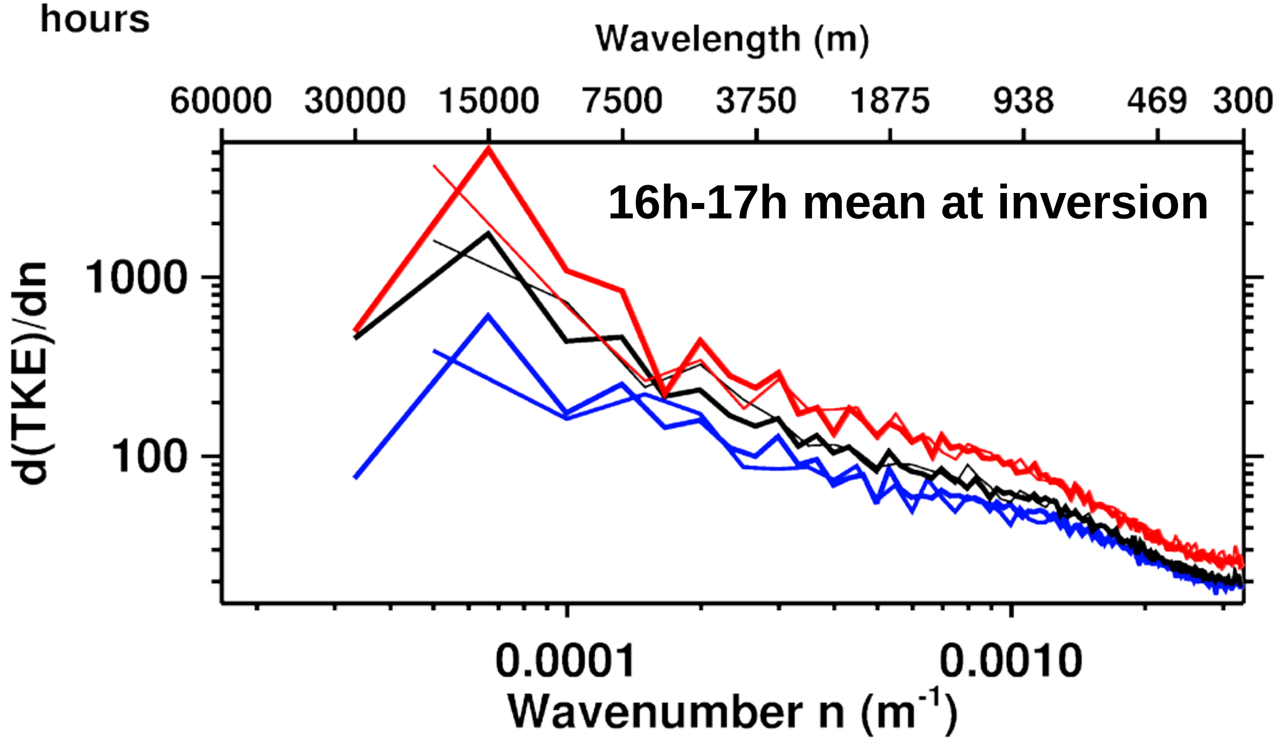
Domain size



LWP
(g m-2)
70
60
50
40
20 km
6
12
18
24
hours
30 km
Decoupling index
0.4
0.3
0.2
0.1
20 km
30 km

Domain size


Decoupling index
0.4
0.3
0.2
0.1
6
12
18
24
hours
30 km
20 km

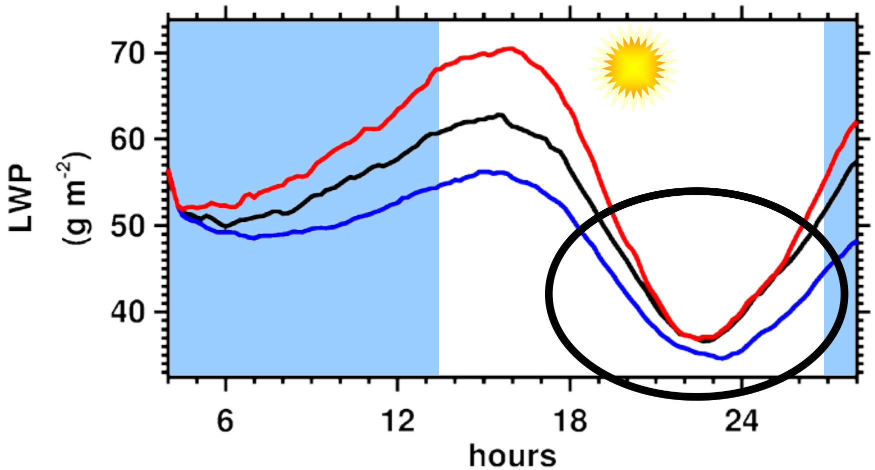

Wavelength (m)
60000
30000
15000
7500
3750
1875
938
469
300
16h-17h mean at inversion
d(TKE)/dn
1000
100
0.0001
0.0010
Wavenumber n (m⁻¹)

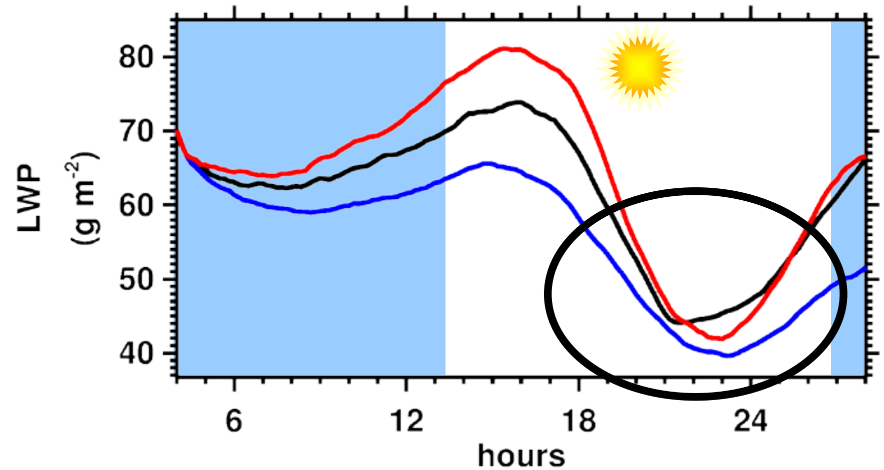
Resolution

dx = dy = 150 m
dz = 15 m
dt = 1.5 s

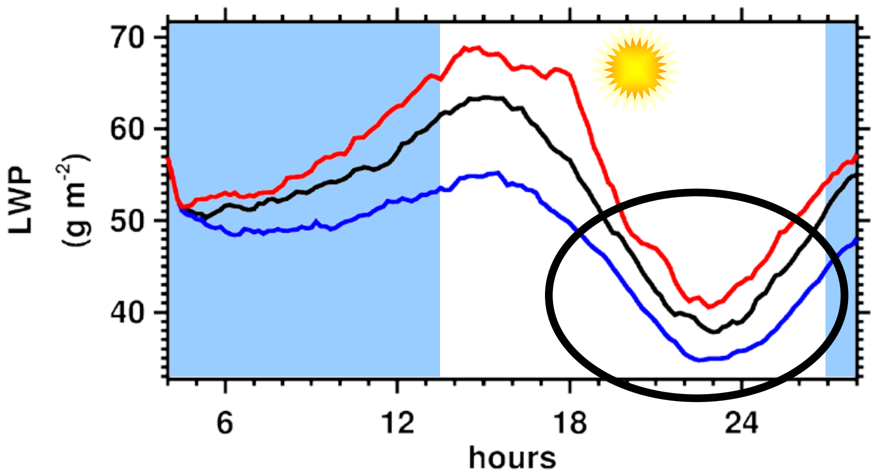
dx = dy = 75 m
dz = 7.5 m
dt = 0.75 s

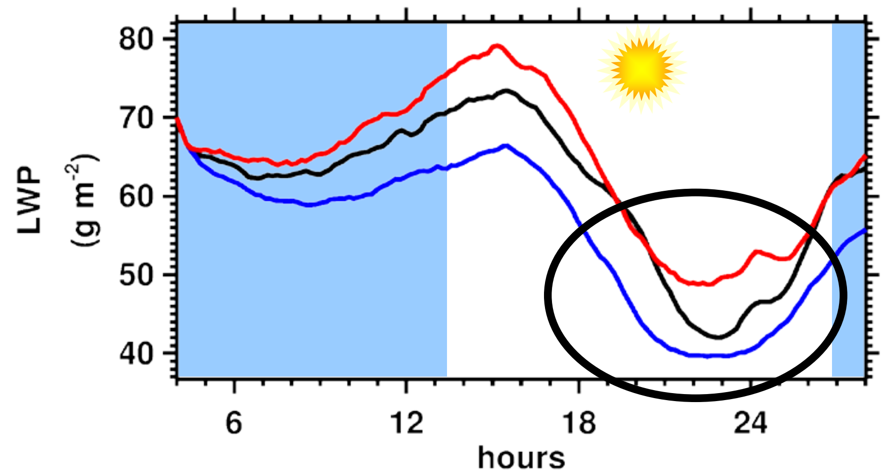
30 km





20 km





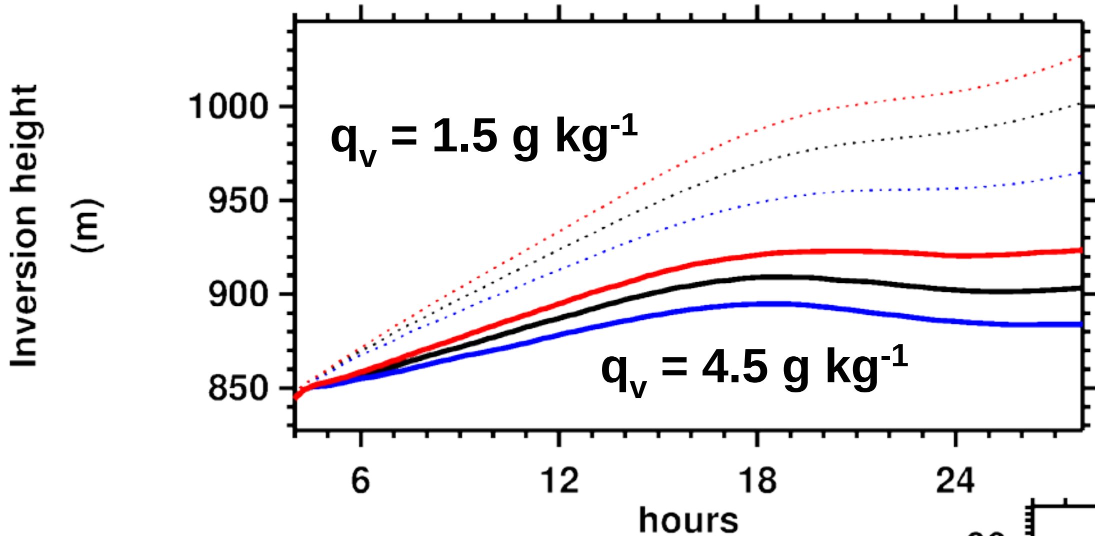
Role of FT water vapor

q_v = 1.5 g kg^{-1} (DYCOMS II RF01)

LW out: ~ 102 W m^{-2}

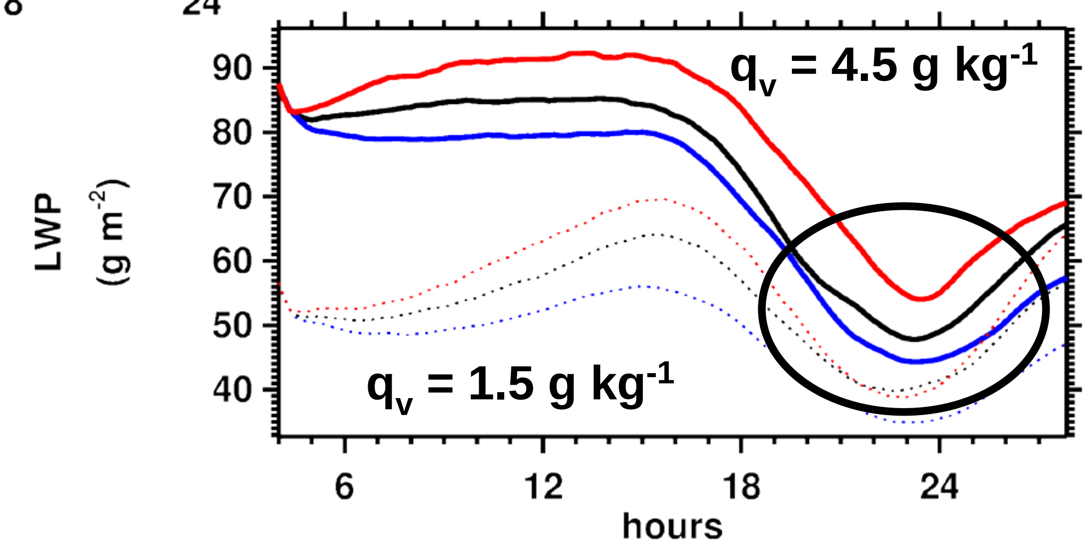
q_v = 4.5 g kg^{-1}

LW out: ~ 74 W m^{-2}



BL <u>grows faster</u> because of more effective LW cloud-top cooling

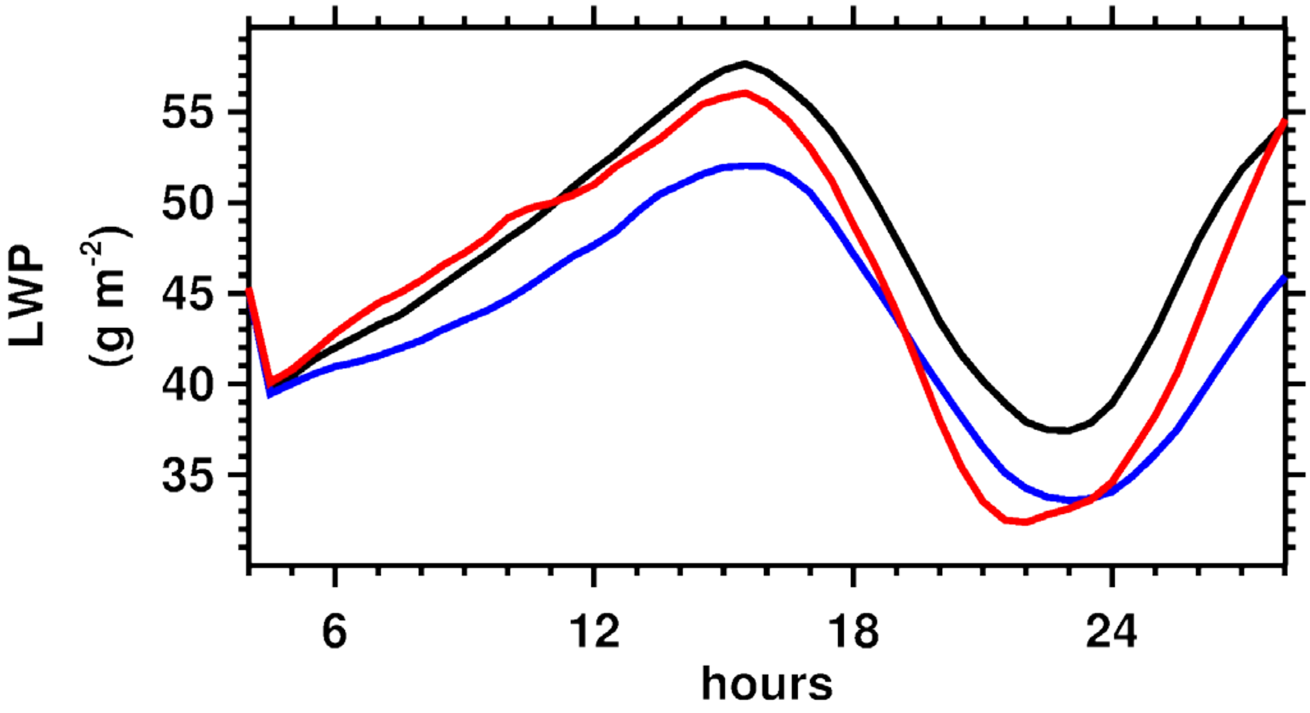
BL <u>grows slower</u> because of less effective LW cloud-top cooling



LWP response to wind speed

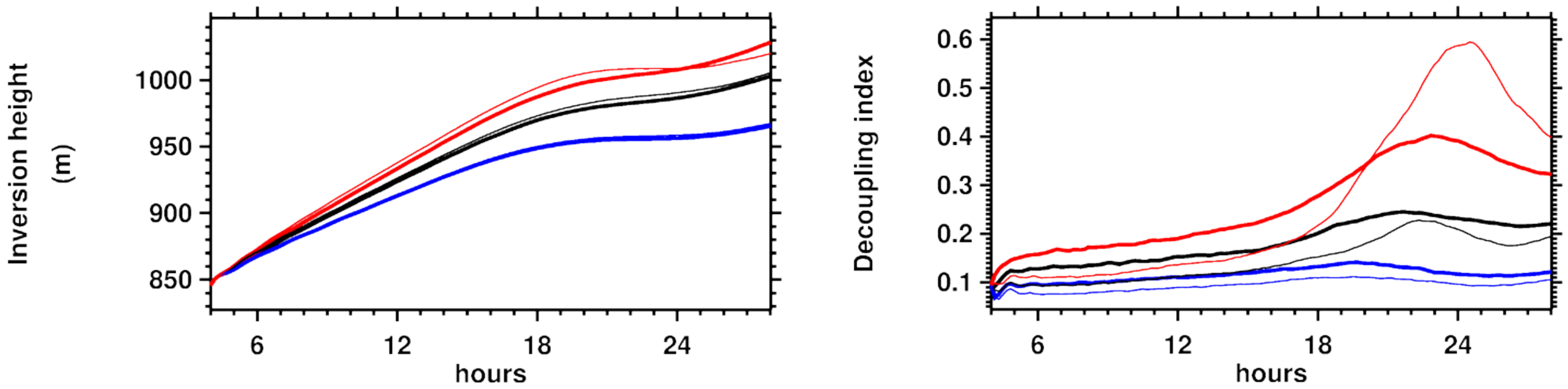
- Non-monotonic during daytime
- Caused by decoupling, driven by
  - Solar heating
  - Buoyancy-driven circulation
  - Entrainment/mixing from cell-scale eddies
- Present when:
  - FT sufficiently dry
  - Domain sufficiently large
- Absent when:
  - FT sufficiently moist
  - Domain too small
- Robust against a doubling of resolution (4D)
- Depending on conditions, a sufficiently large domain more important than higher resolution

Reduced aspect ratio (1:5 instead of 1:10)



dx = dy = 75 m, dz = 15 m, dt = 1.5 s

Buoyancy-driven circulation



"Buoyancy + shear" "Buoyancy only"