# Nocturnal urban heat island and boundary layer in Oklahoma

Xiaoming Hu

Nov. 2013

at NanJing

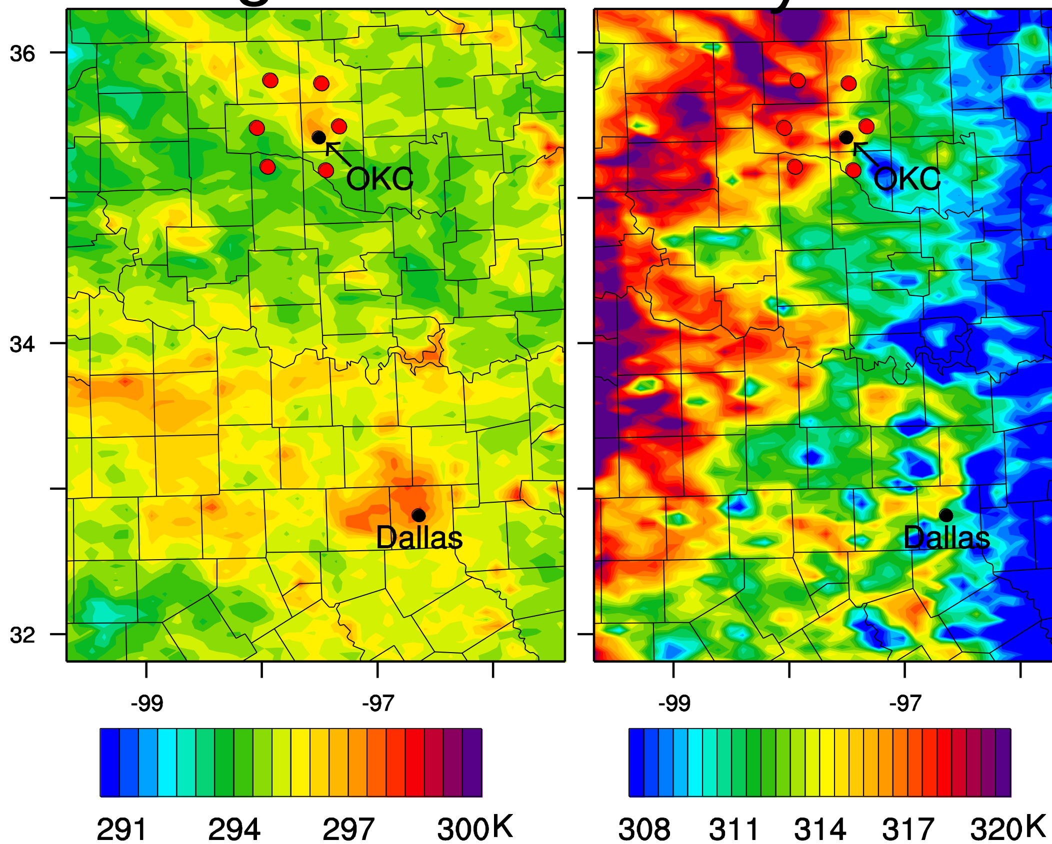
Contributors: Ming Xue, Petra Klein

- Part 1: Impacts of LLJs on the nocturnal Urban Heat Island (UHI)

- Part 2: Coupling in the nocturnal boundary layer

# UHI is prominent during the nighttime

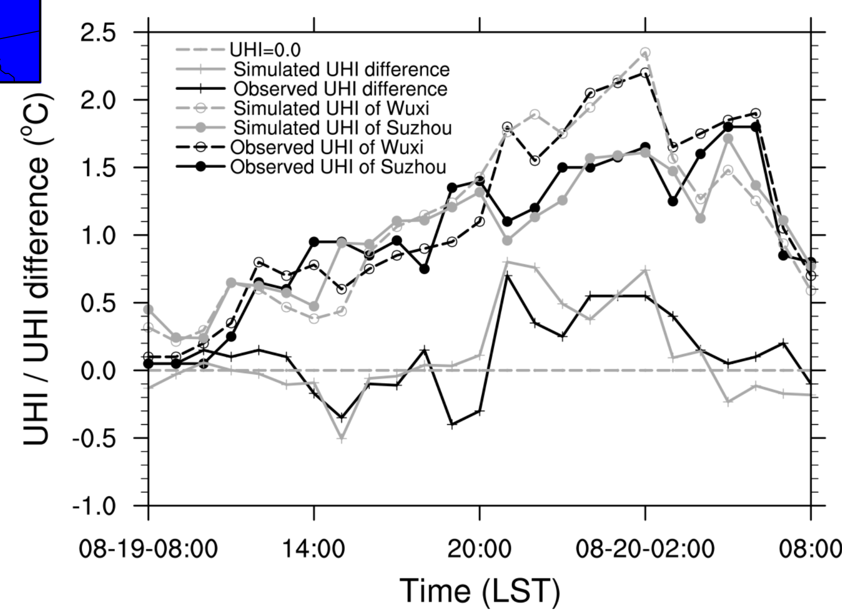
Nighttime Daytime




MODIS-derived land surface T

Red dots around OKC:
Six rural sites

Nocturnal LLJs occur frequently in this region, must play some roles.



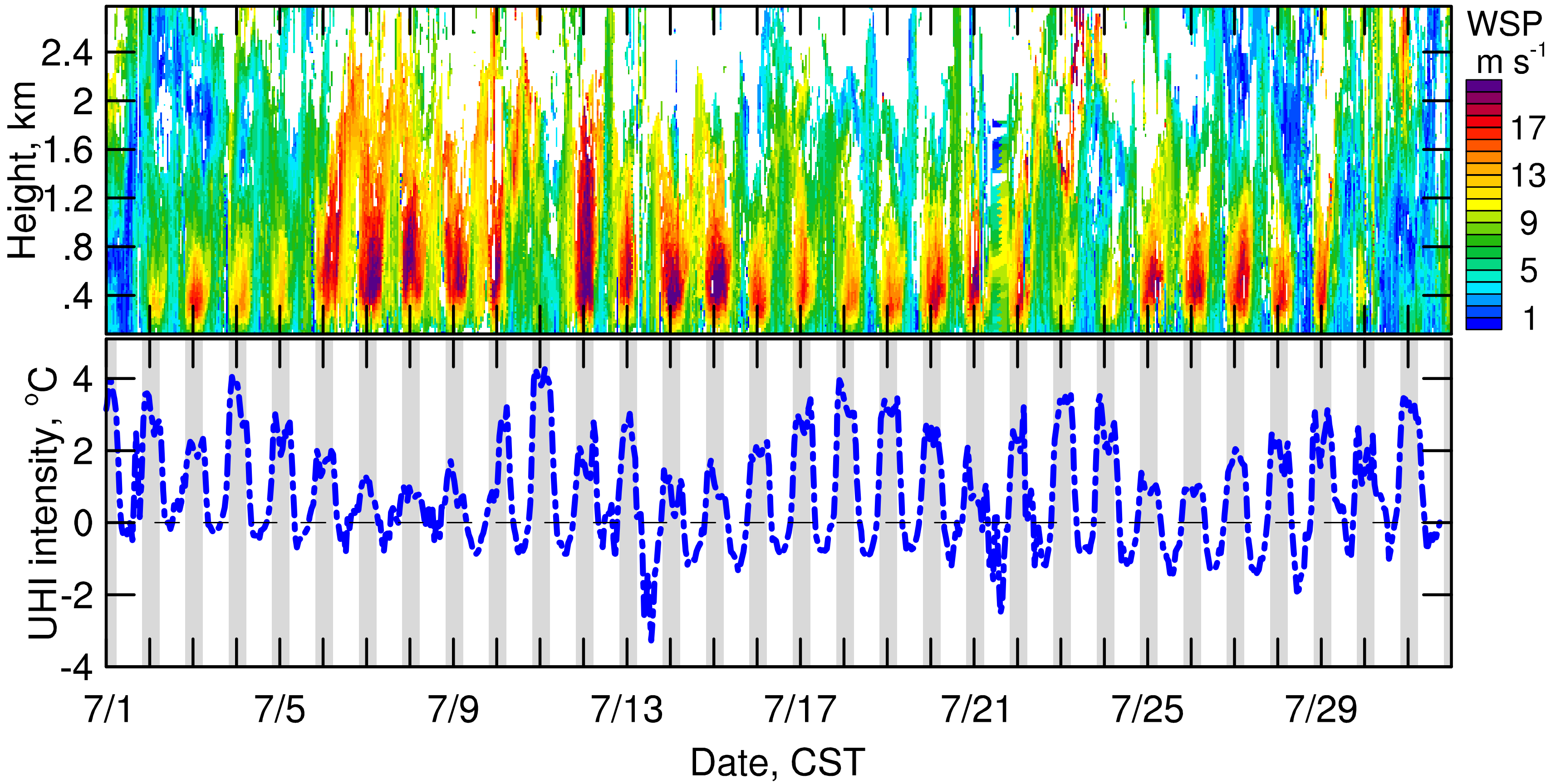

Zhang and Chen (2013, JAMC)

# Factors affecting UHI intensity

- Intrinsic characteristics of a city
  – E.g., canyon geometry, thermal properties of the fabric, anthropogenic heat
- External meteorological factors
  – E.g, cloud, wind, radiation

**Our study will demonstrate the dominant effect of LLJs on UHI intensity in the Oklahoma City (OKC) metro area**

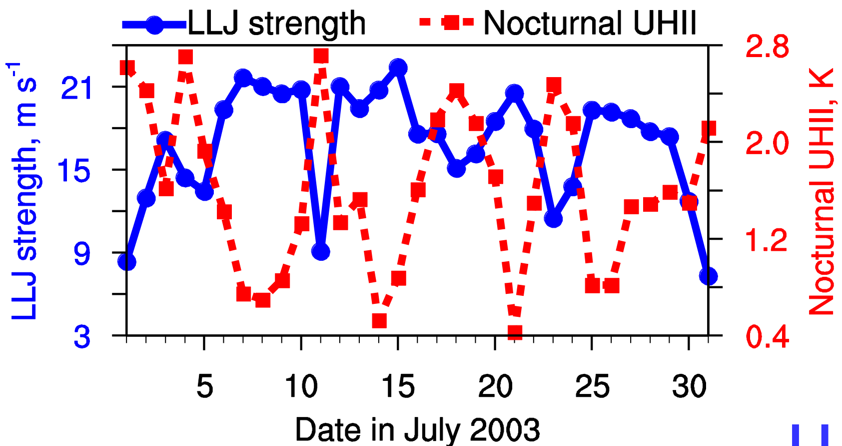
# Relationship between LLJs and UHI intensity

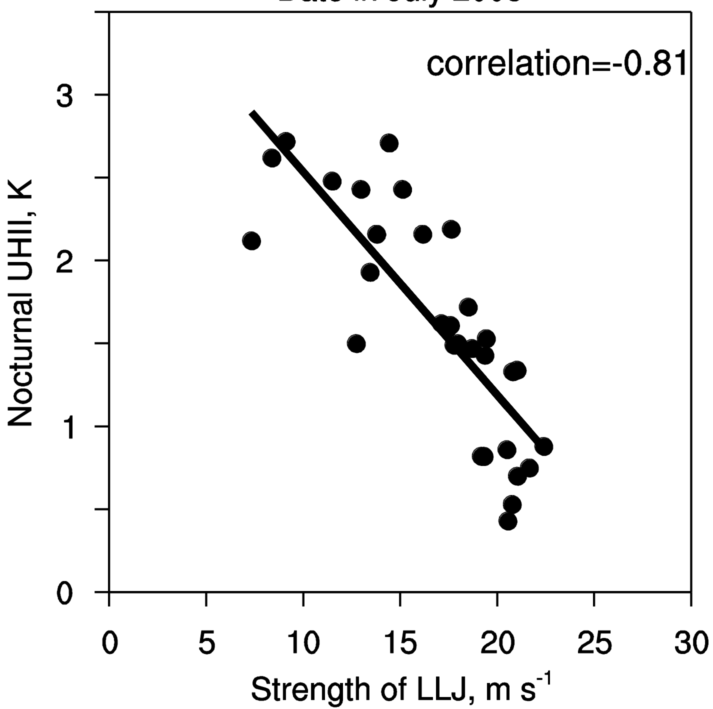



**UHI intensity**: T difference between urban and rural area at 2m

LLJs modulate day-to-day variation of nocturnal UHI intensity

# Relationship between LLJs and nocturnal UHI intensity



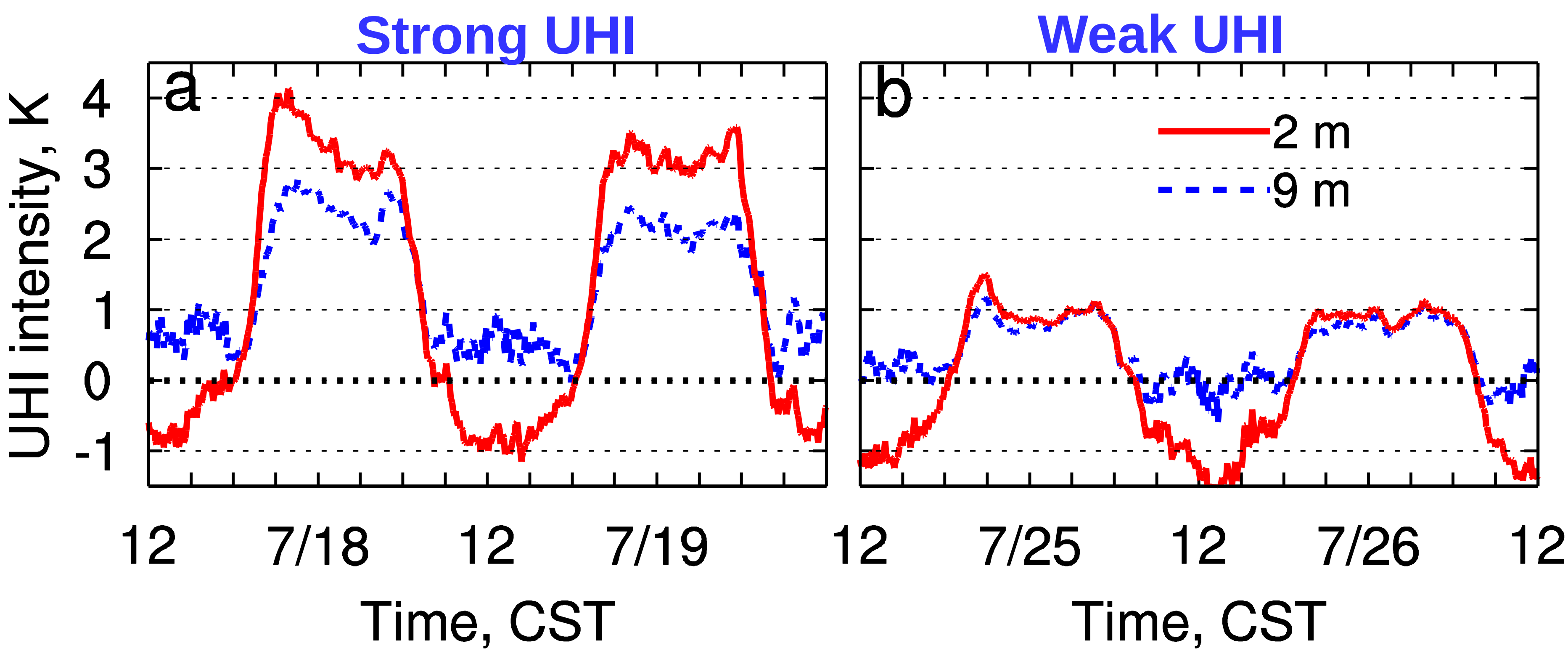




**LLJ strength**: maximum wind speed of a LLJ

**Nocturnal UHII**: mean T difference between urban and rural area during nighttime

LLJs modulate nocturnal UHI intensity

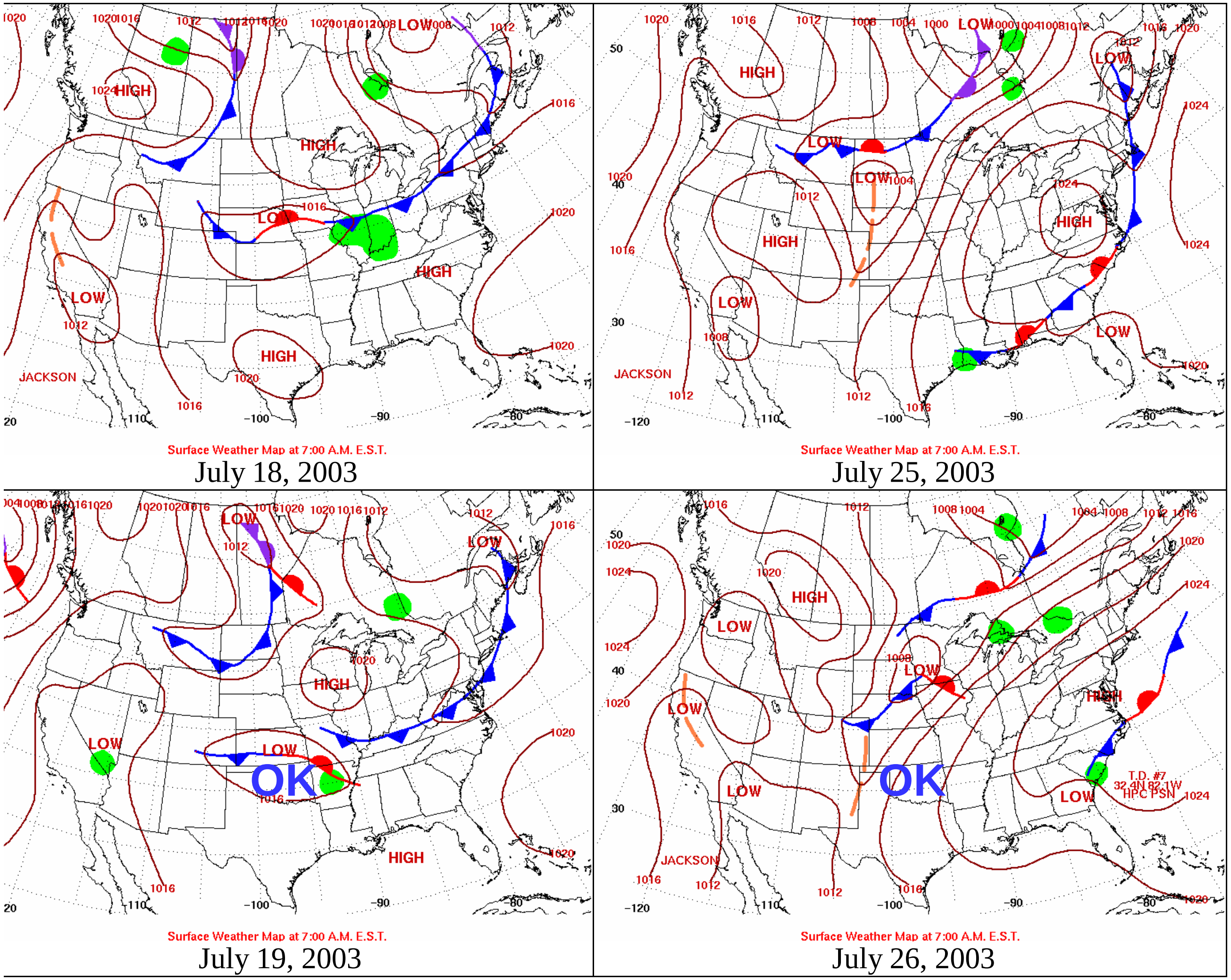
# Two different episodes




**UHI is primarily a nocturnal problem and its day-to-day variation is significant**

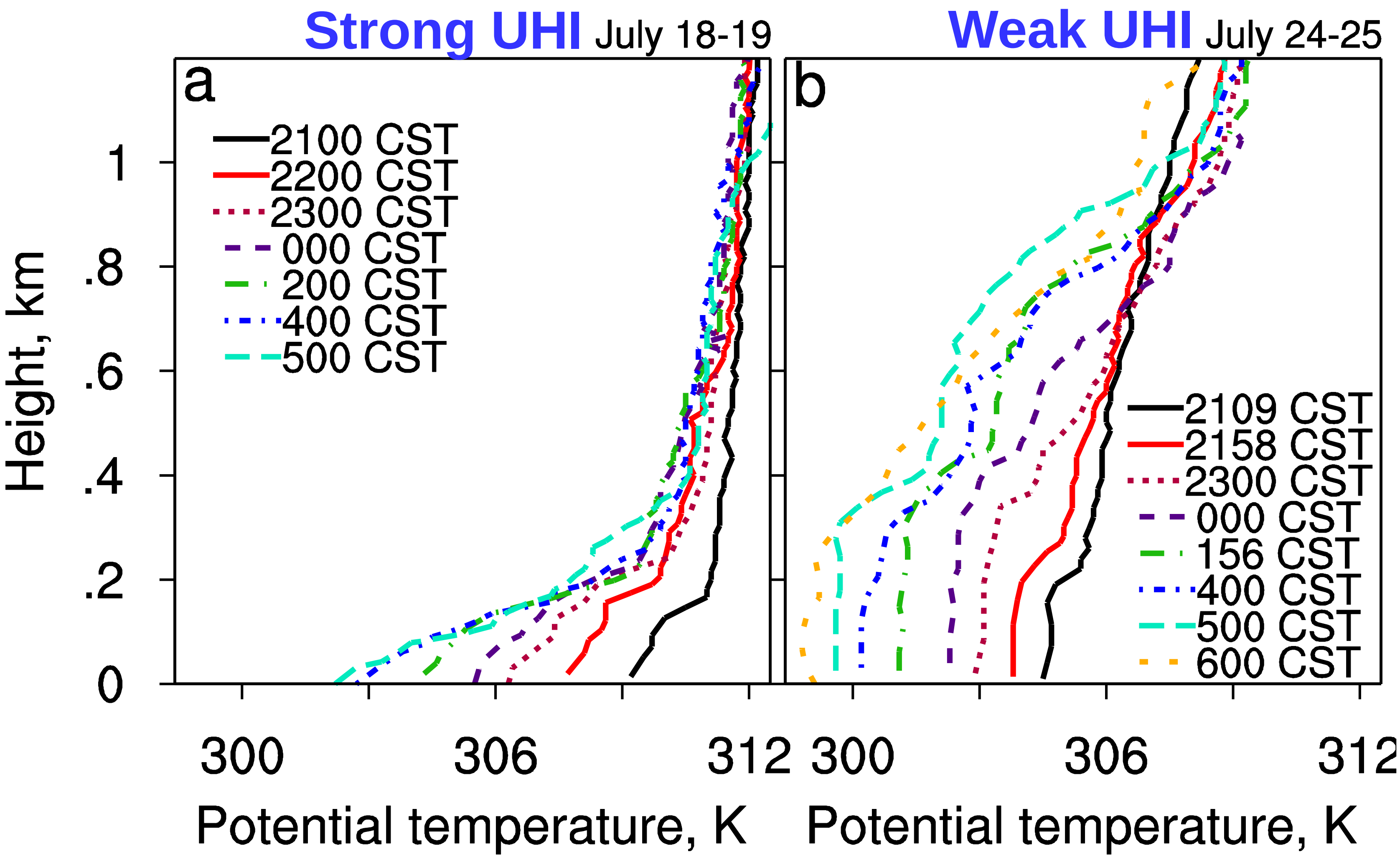
# Two different episodes: large scale forcing

**Strong UHI** | **Weak UHI**



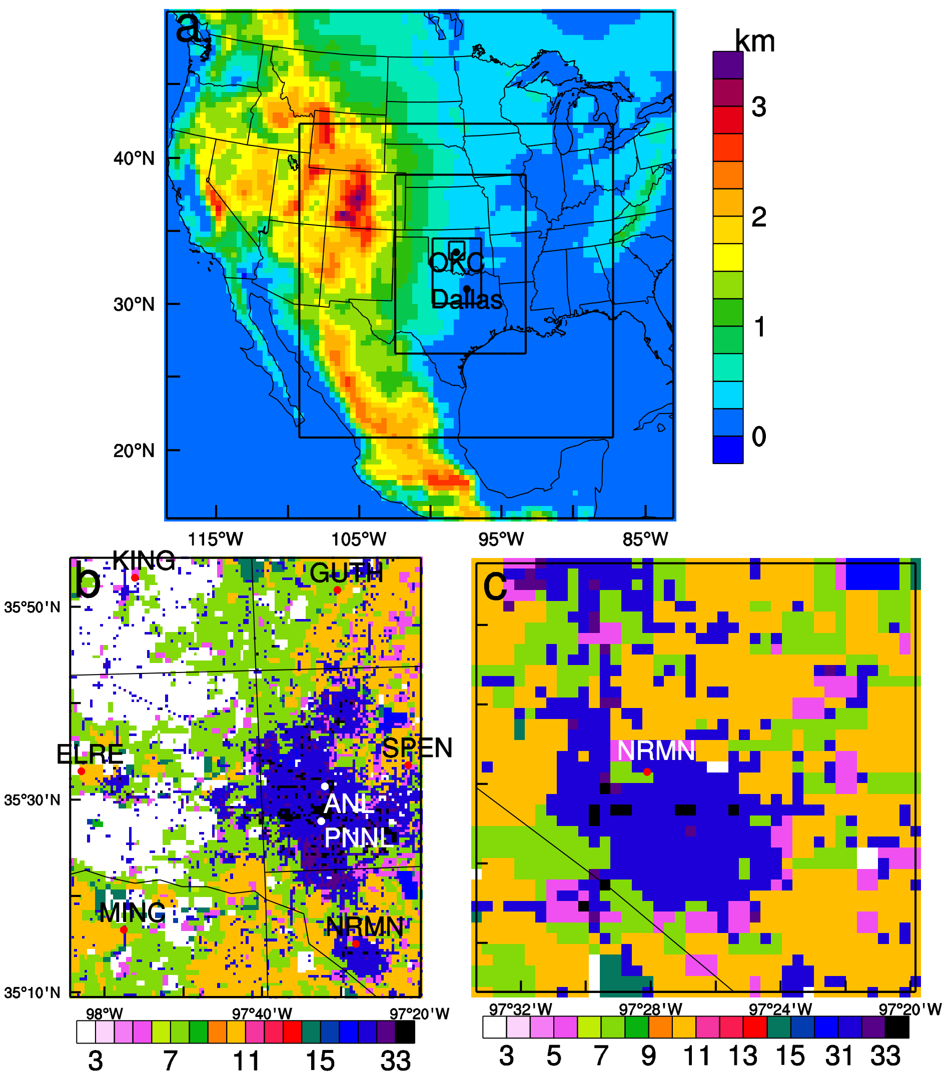

**Large scale forcing plays role in the formation of LLJs**

# Two different episodes: temperature profiles



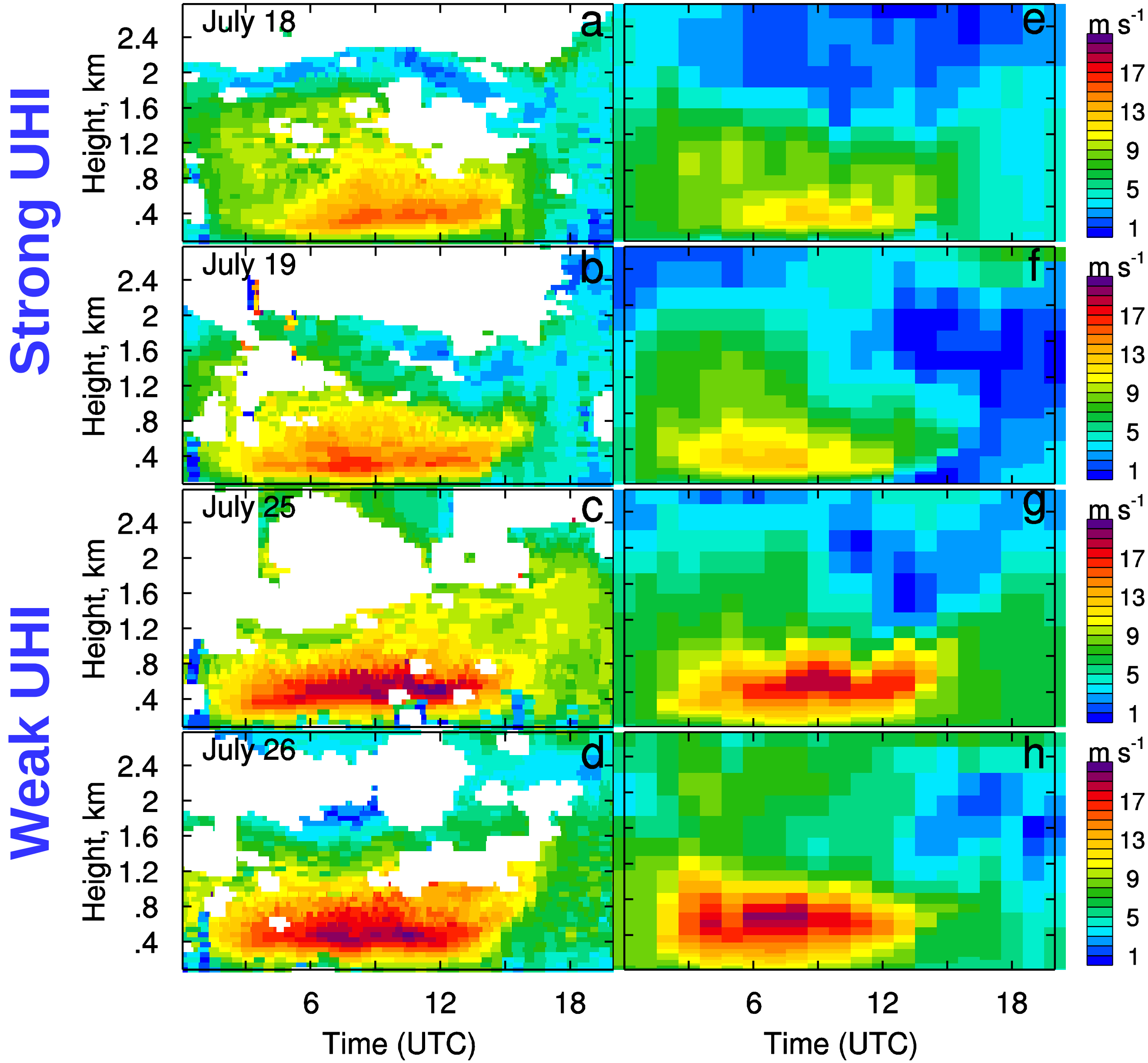

**Near surface thermal structure is different, will investigate the reason and effect**

# Model domains and configurations



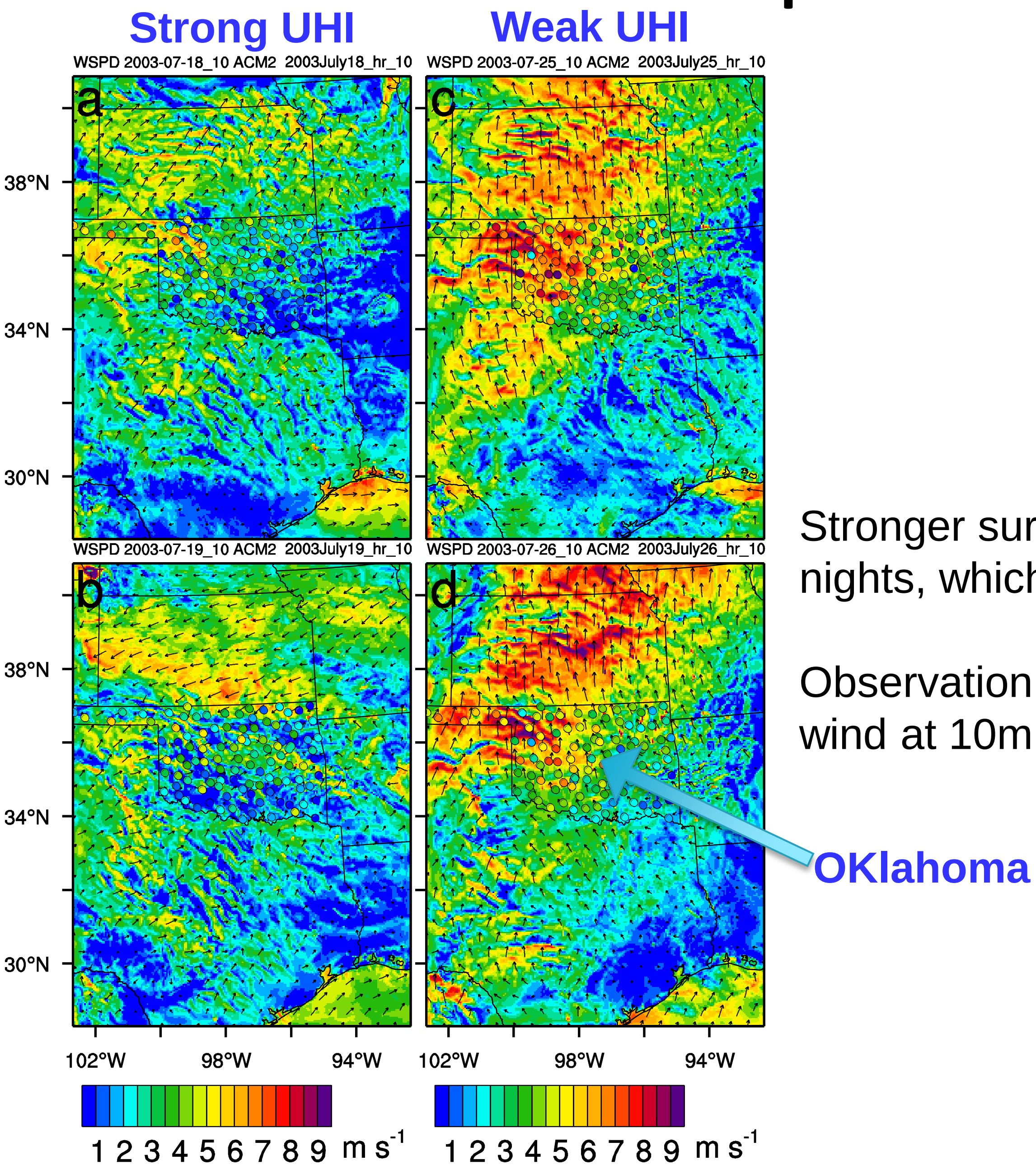

- WRF3.4
- 40.5->13.5->4.5->1.5->0.5km
- NOAH+Urban canopy model
- ACM2 PBL scheme
- NARR for IC/BC

# Time-height diagram of wind speeds




Model reproduces LLJs & Captures day-to-day variation

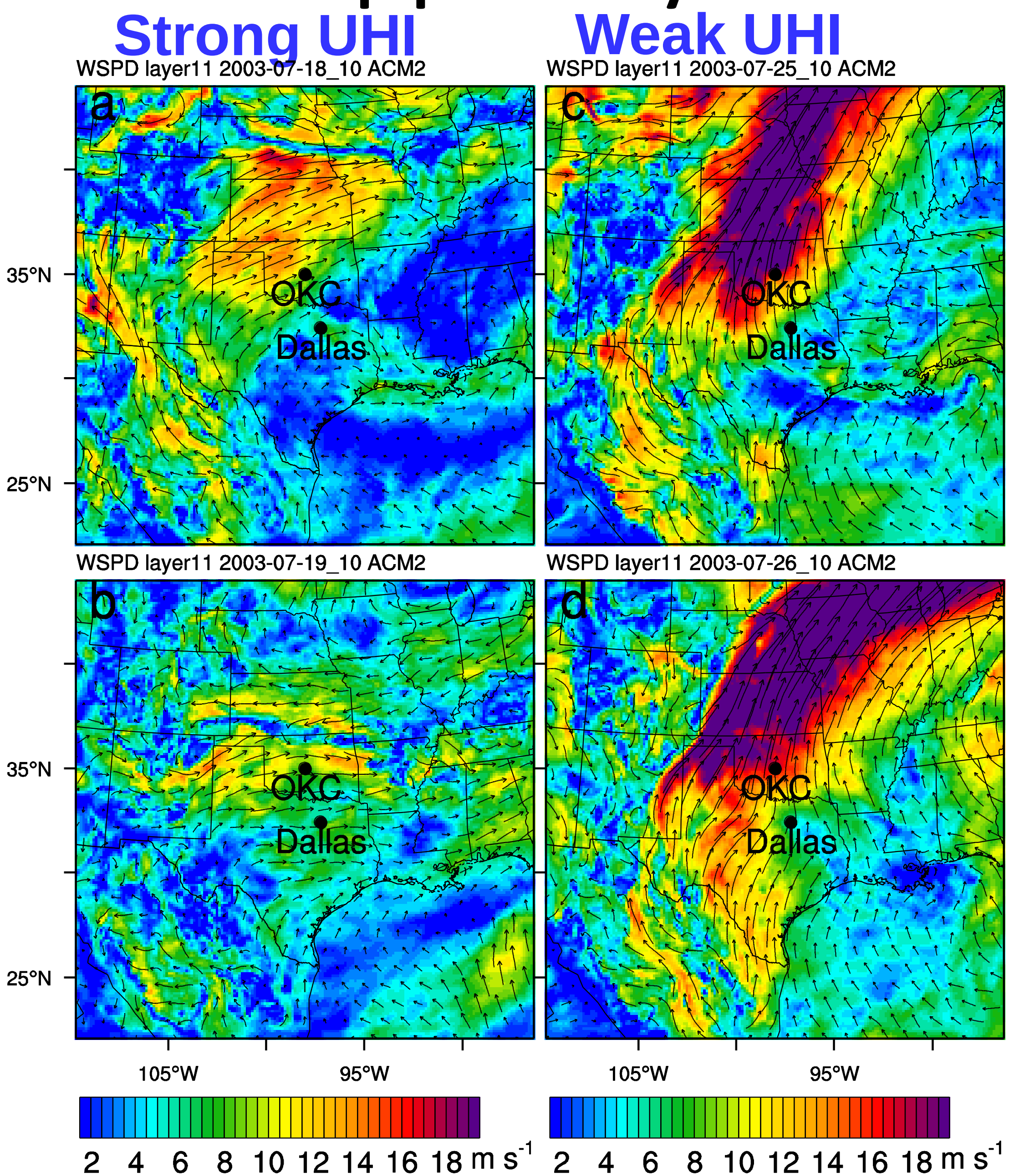
# Surface wind speeds at 0400 LT




Stronger surface wind persists on weak UHI nights, which is related to LLJs

Observation: Oklahoma mesonet provides wind at 10m; T at 2 levels,1.5 & 9 m

# Upper layer wind speeds

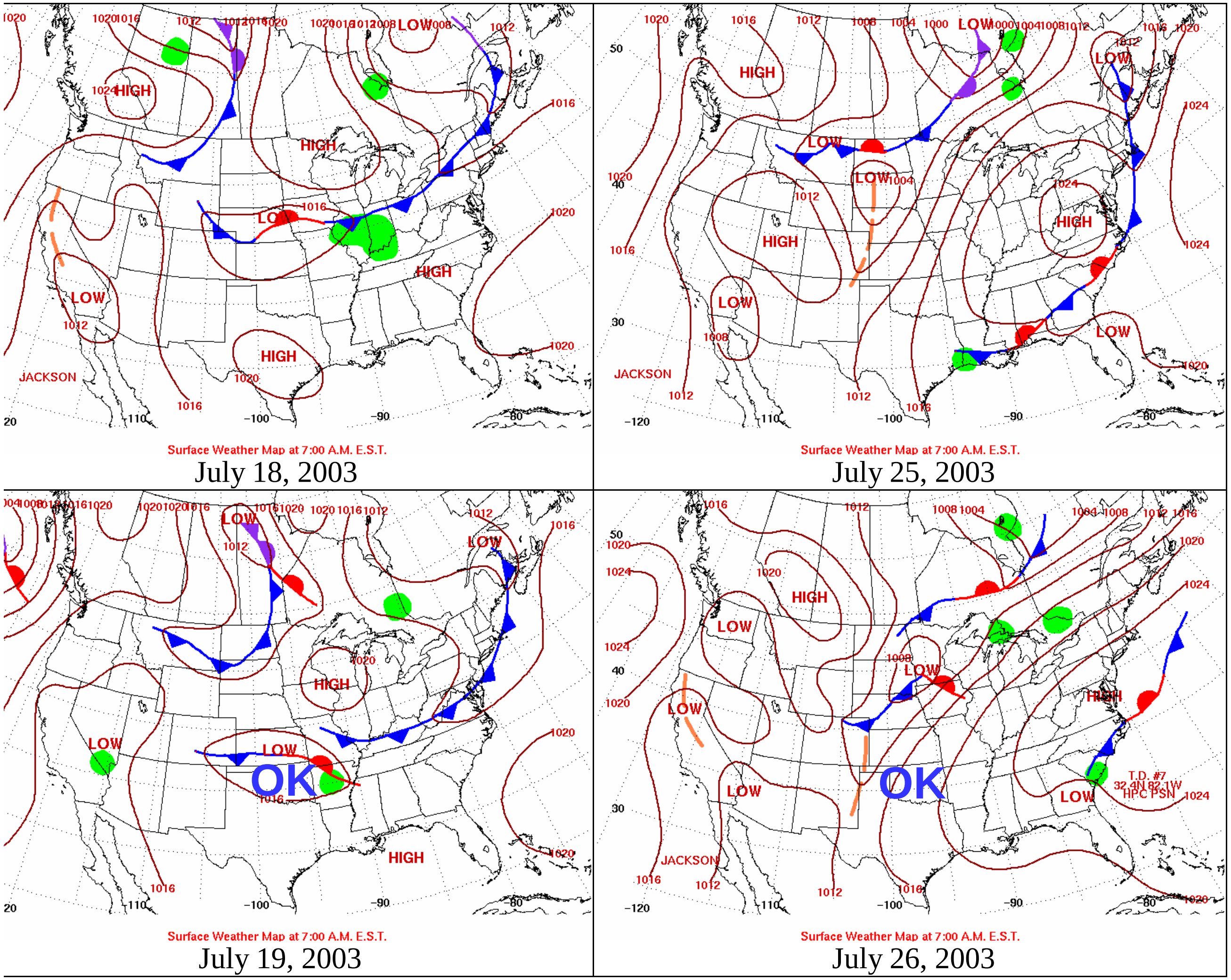



Factors contributing to LLJs:

1. Pressure gradient
2. Thermal wind
3. Meridional variation of Coriolis parameter
4. Inertial oscillation

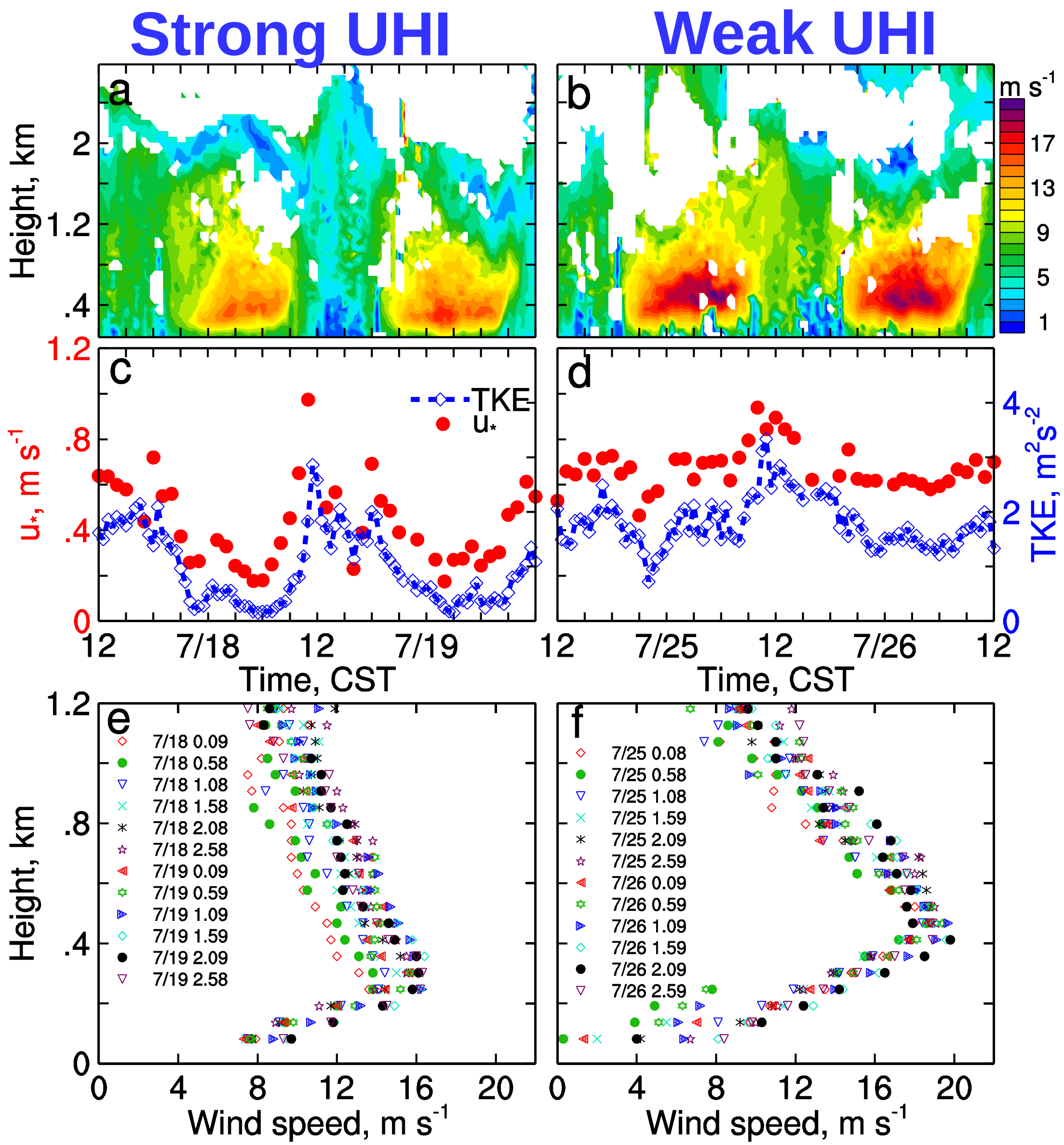
# Two different episodes: large scale forcing

**Strong UHI** | **Weak UHI**



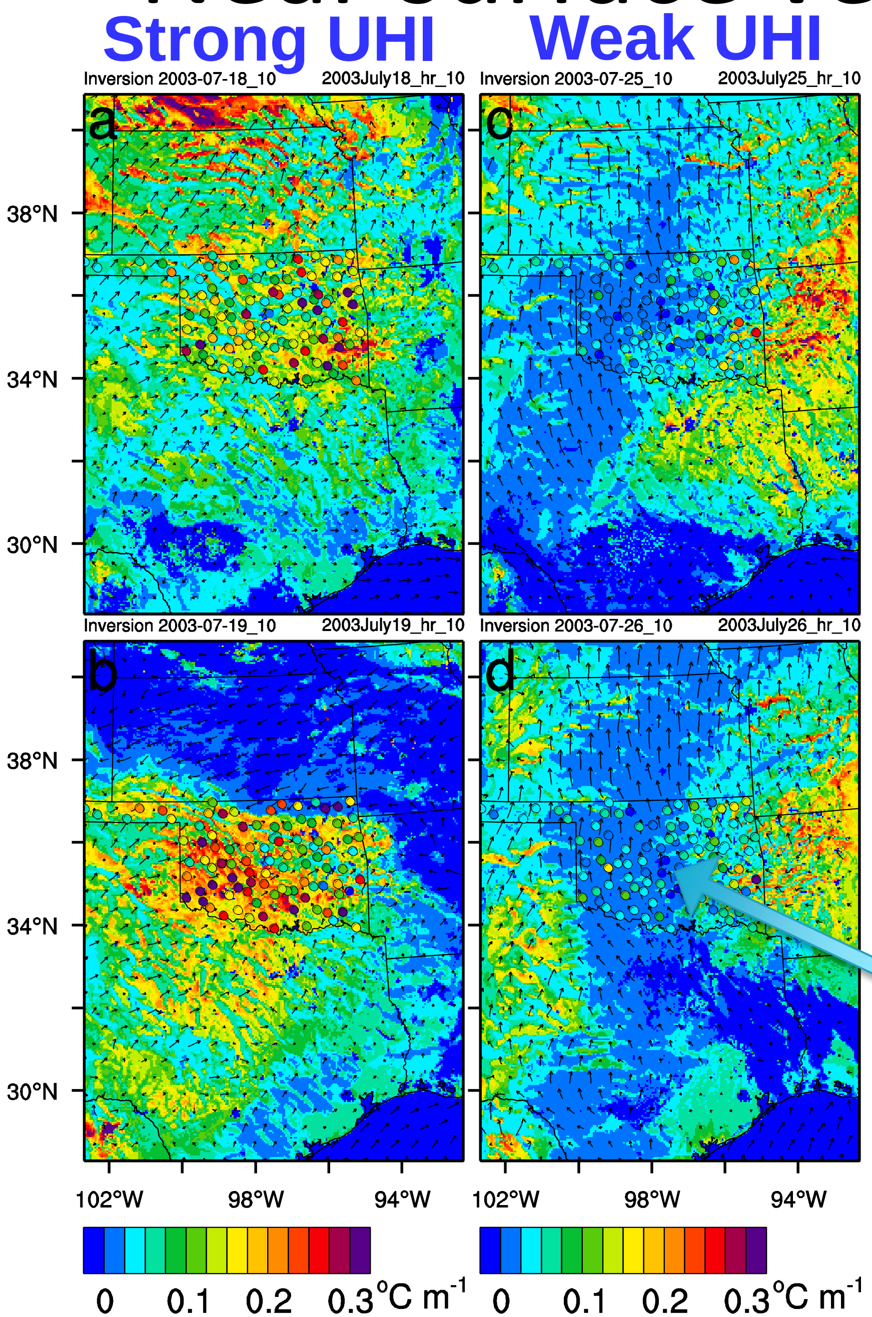

**Large scale forcing plays role in the formation of LLJs**

# Stronger LLJs lead to stronger mixing




**Stronger LLJs=>stronger mixing in a deeper BL=>nearly neutral BL**

# Near surface vertical T gradient

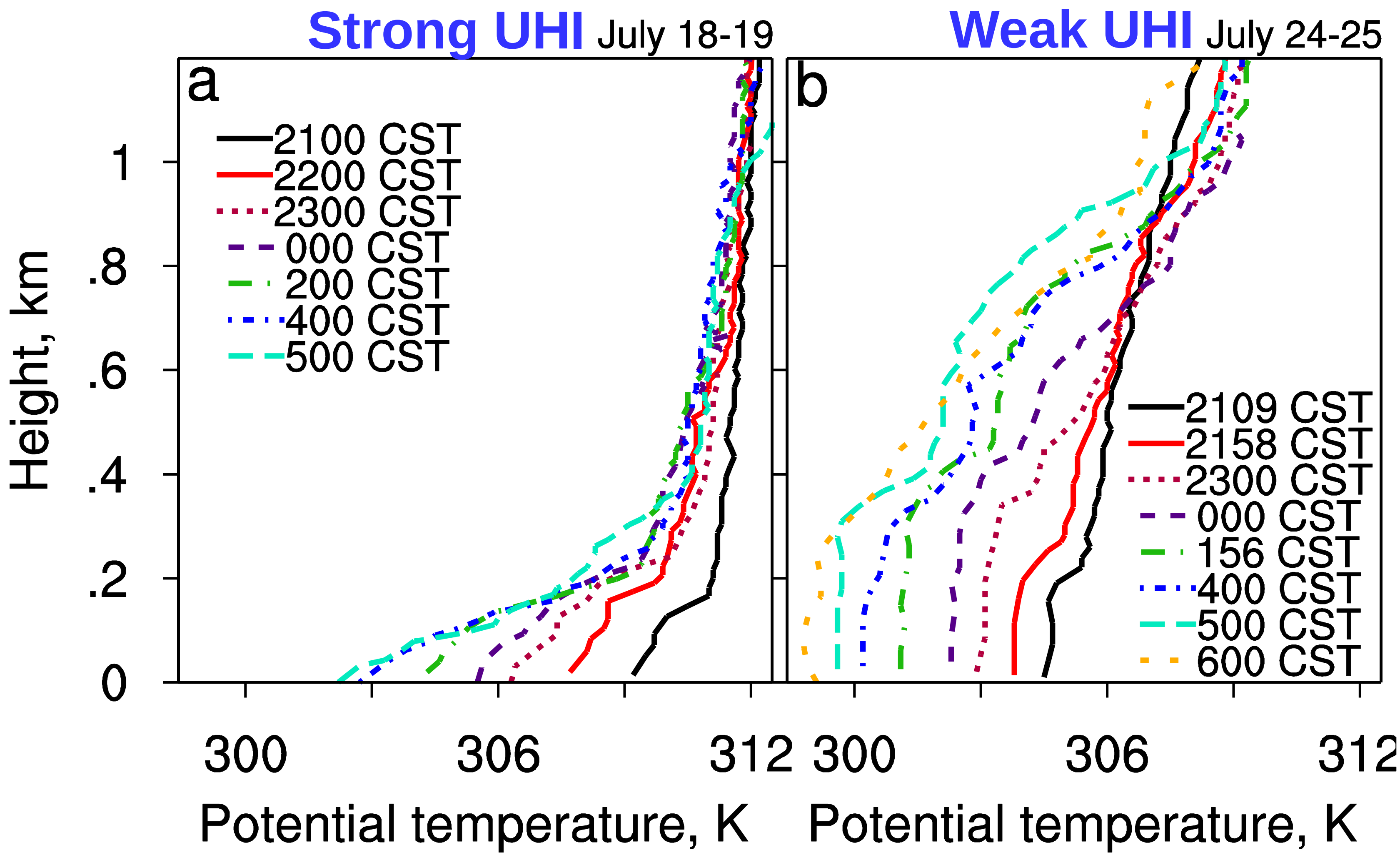



Stronger turbulence induced by LLJs reduced near surface T gradient

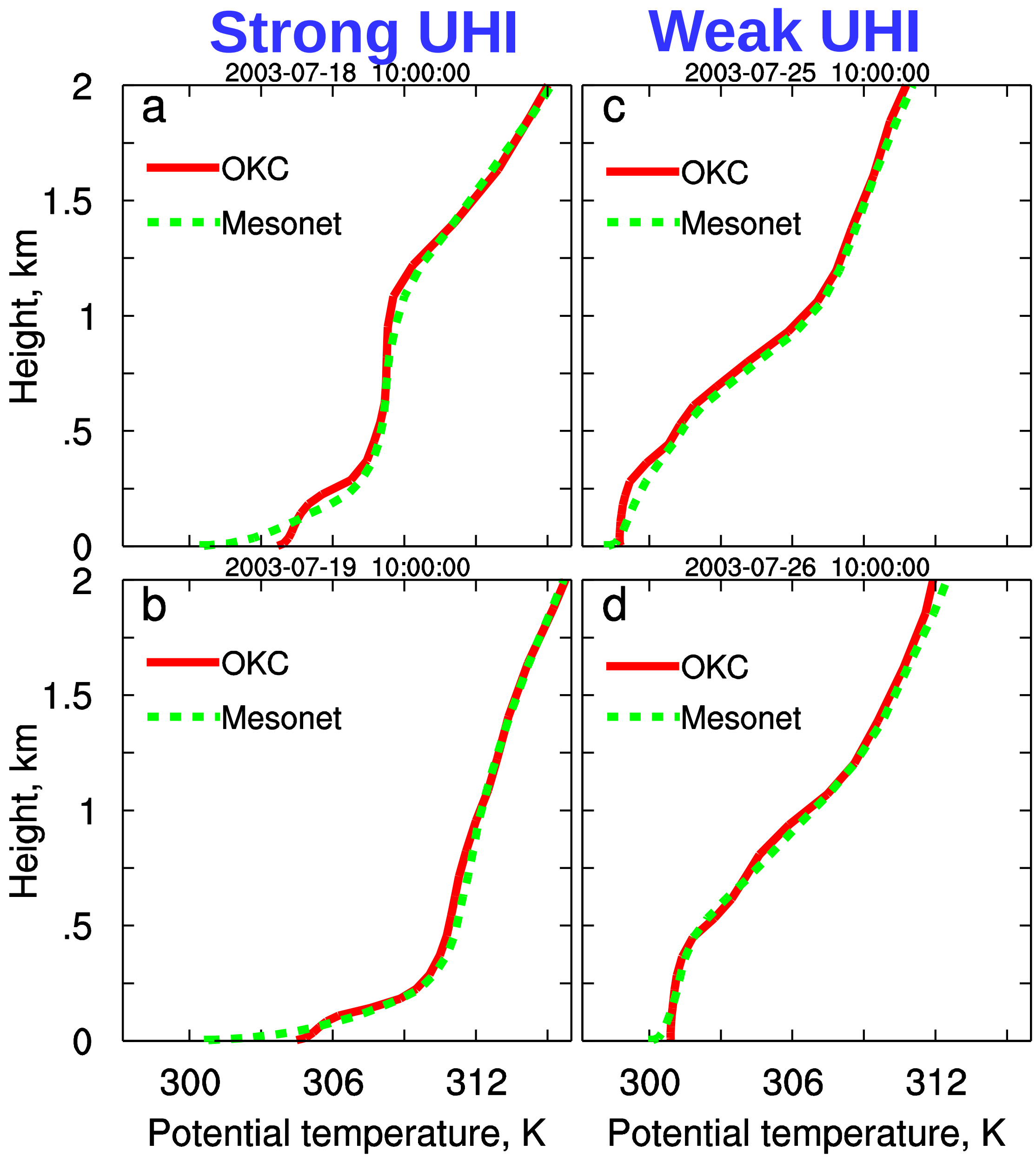
Observed inversion calculated from T at 1.5 & 9 m from Oklahoma mesonet

OKlahoma

# LLJs modulate temperature profiles

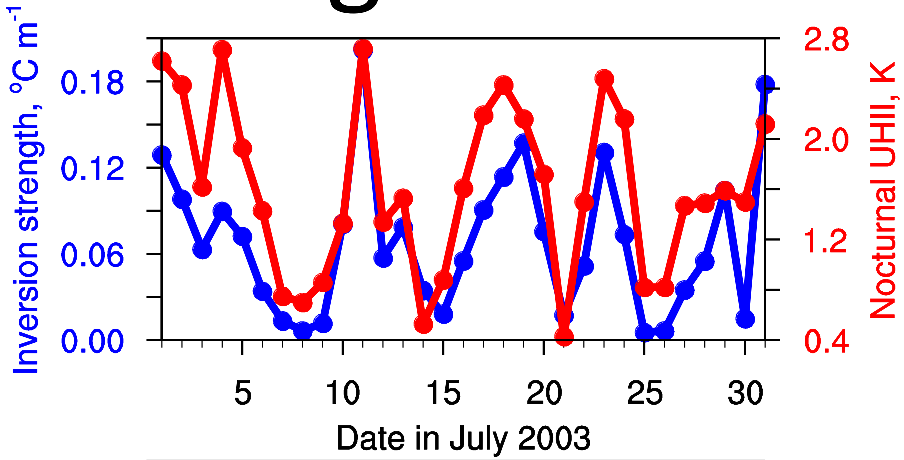


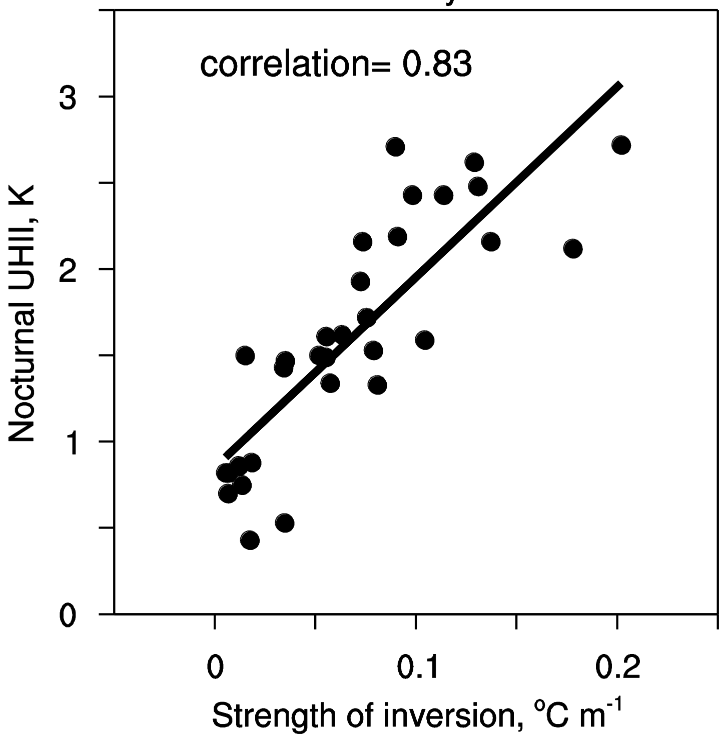
# Vertical T gradients dictate UHI intensity




Stronger vertical T gradients (inversion strength) in presence of weak LLJs lead to larger UHI intensity

# Relationship between inversion strength and UHI intensity




Vertical T gradients (inversion strength) is a good indicator of UHI intensity

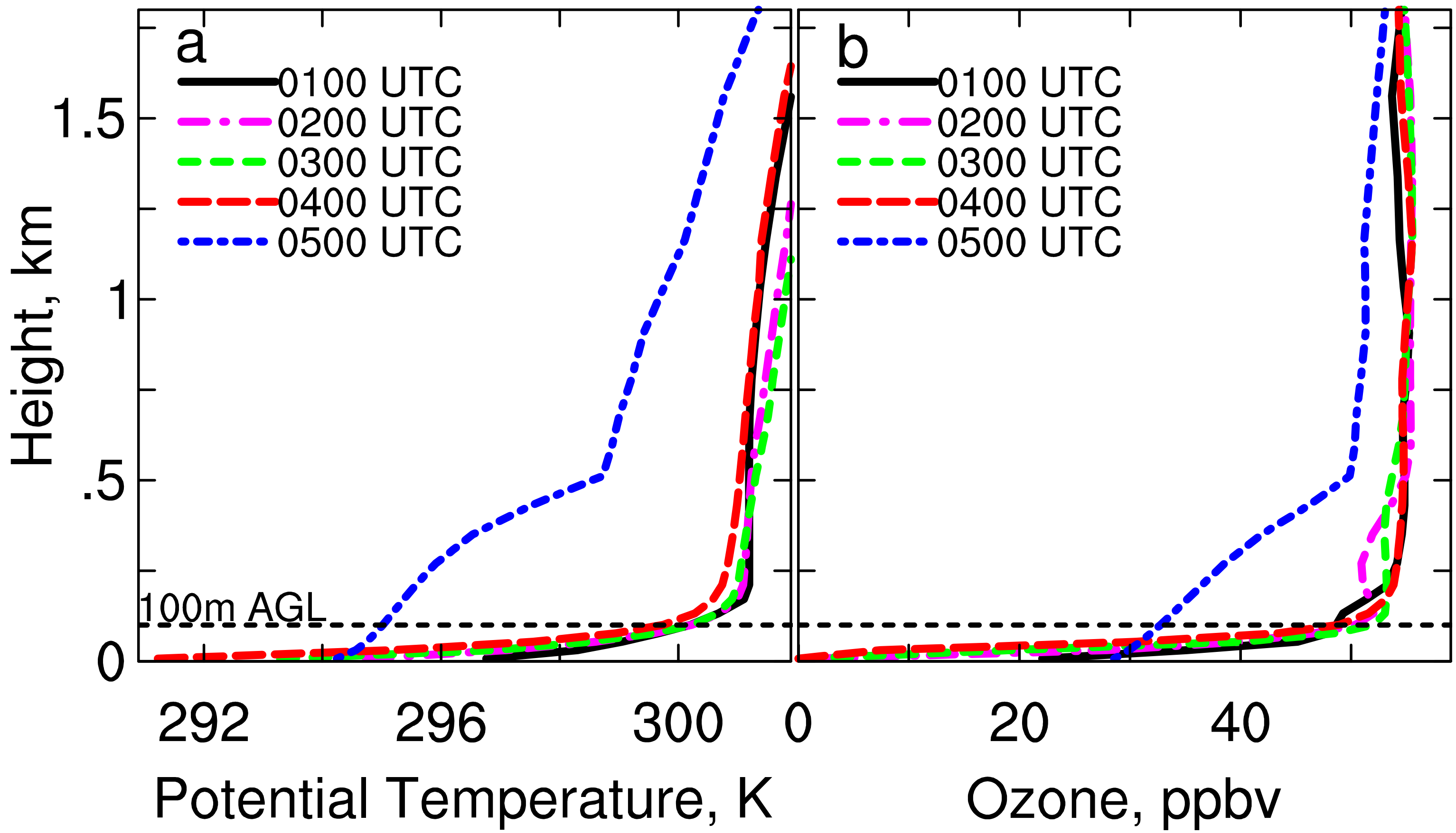
# Conclusions

1. LLJs paly an important role in modulating the nocturnal UHI intensity.
2. Temperature inversion in the surrounding rural area can be used as an indicator for UHI intensity
3. Boundary layer structure is important for UHI assessments

# Further investigation of boundary layer structure

- Part 2: Coupling in the nocturnal boundary layer

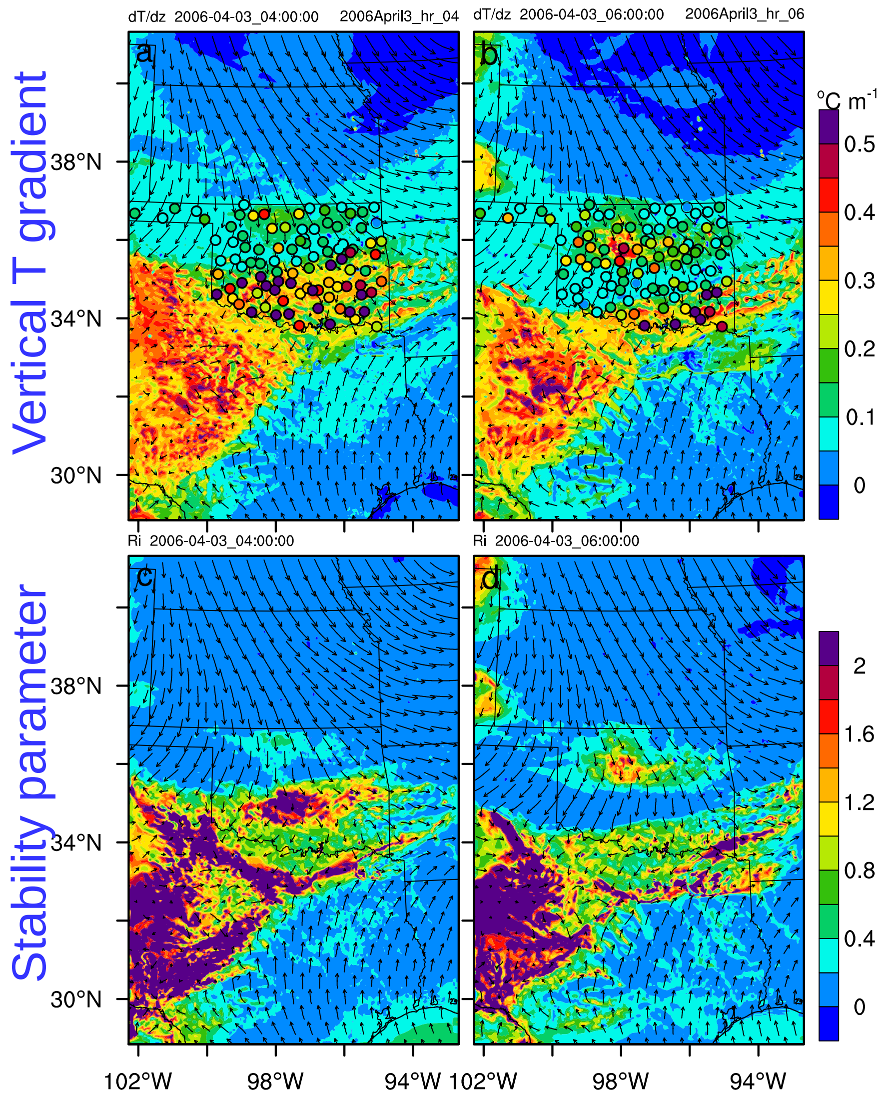
# Example of coupling and decoupling




Decoupling before 0500 UTC; Coupling at 0500 UTC

Vertical temperature gradient is a good indicator of coupling strength

# Example of coupling and decoupling

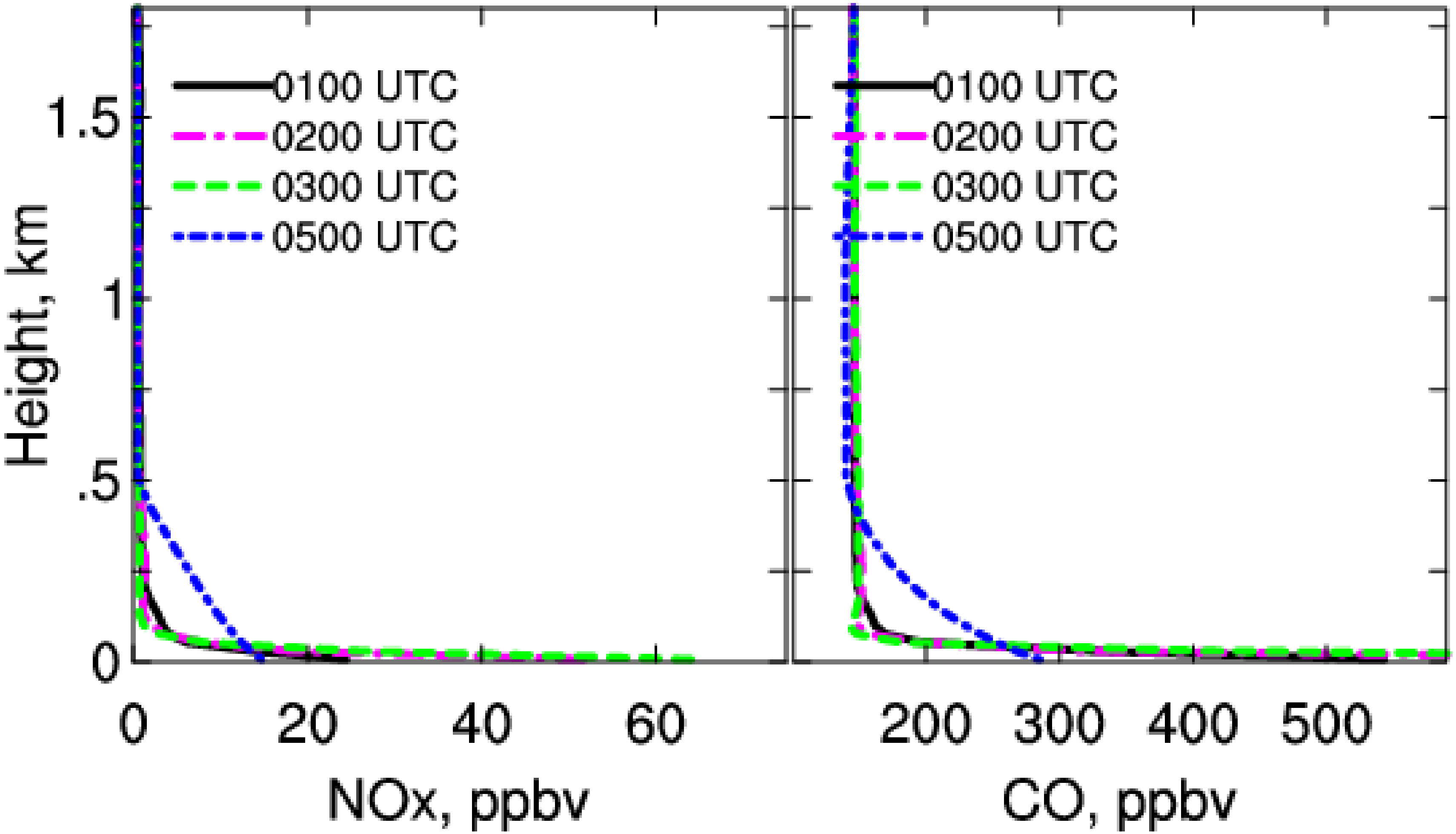



Decoupling before the cold front;

Coupling behind

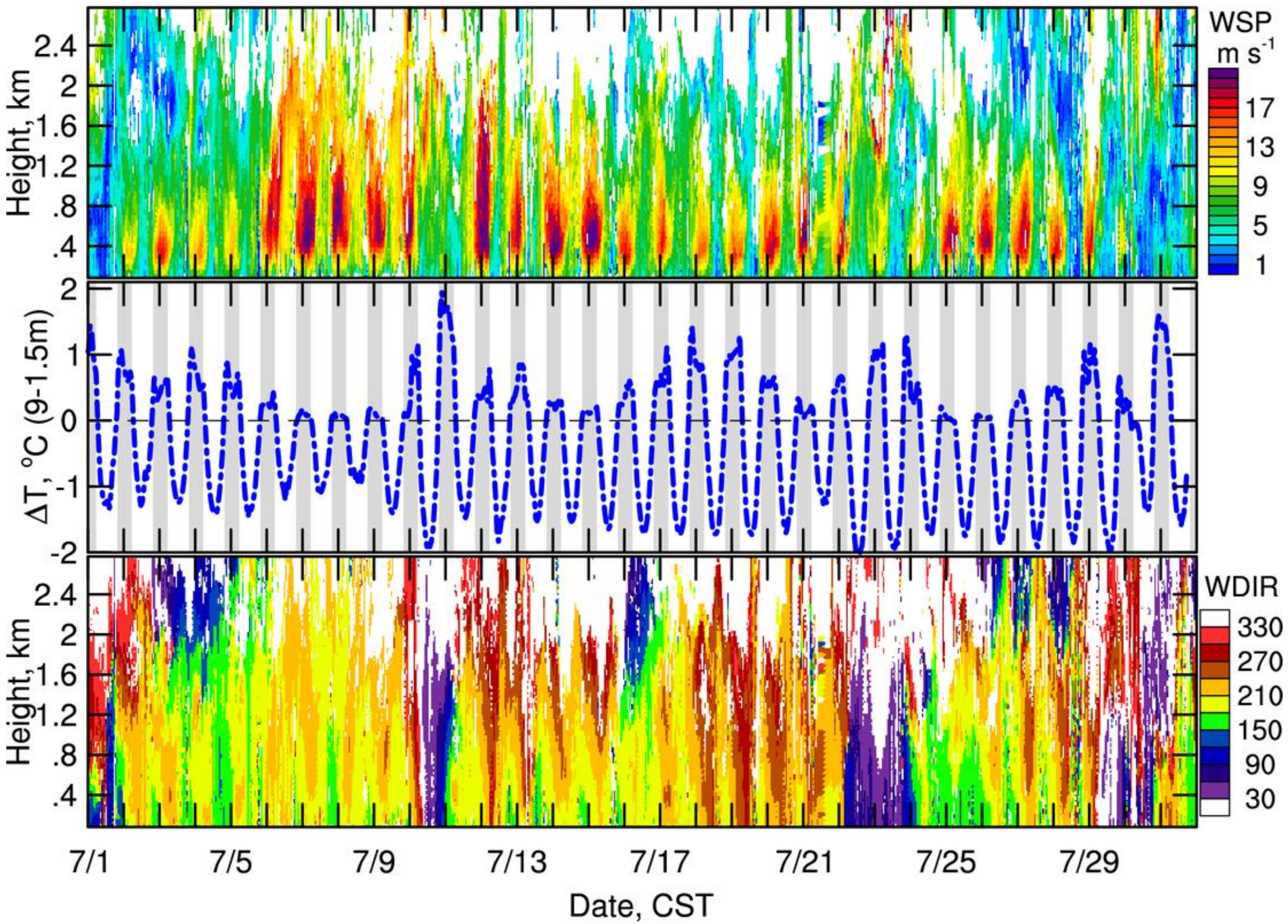
Vertical temperature gradient is a good indicator of coupling strength

# Impact of coupling status on dispersion



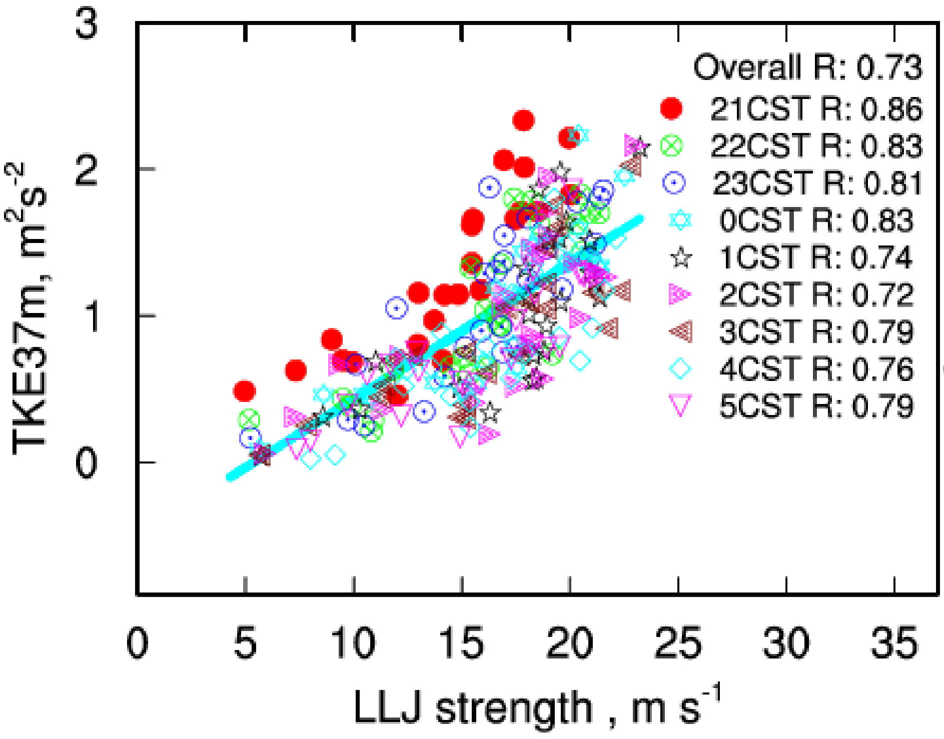

Decoupling leads to pollutants accumulation

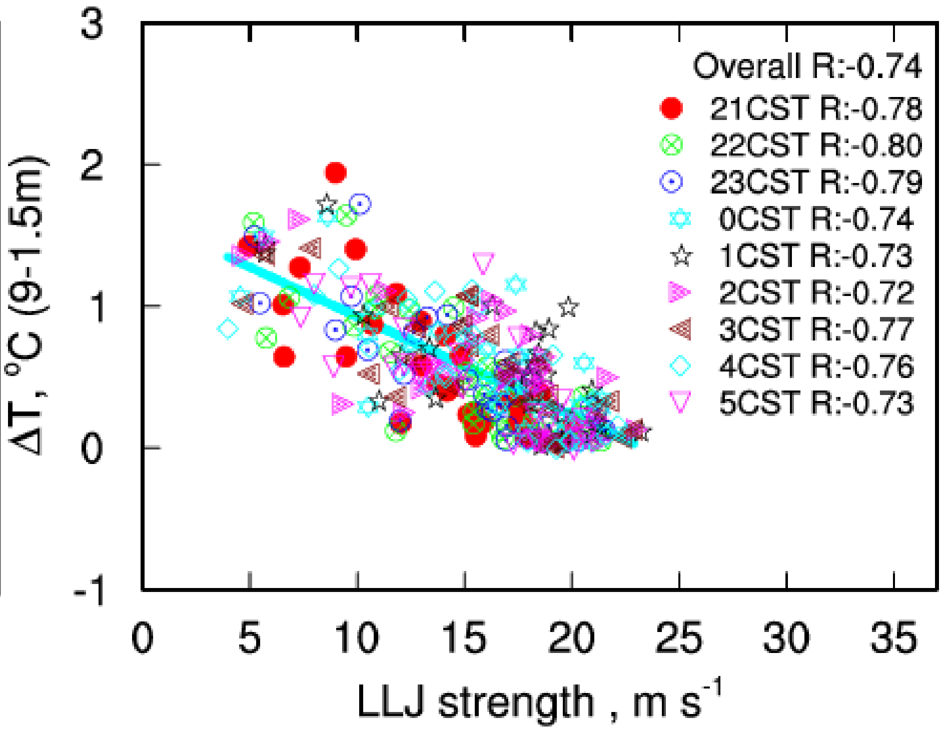
# Impact of LLJs on coupling status




Strong LLJs lead to strong coupling (weaker gradient)

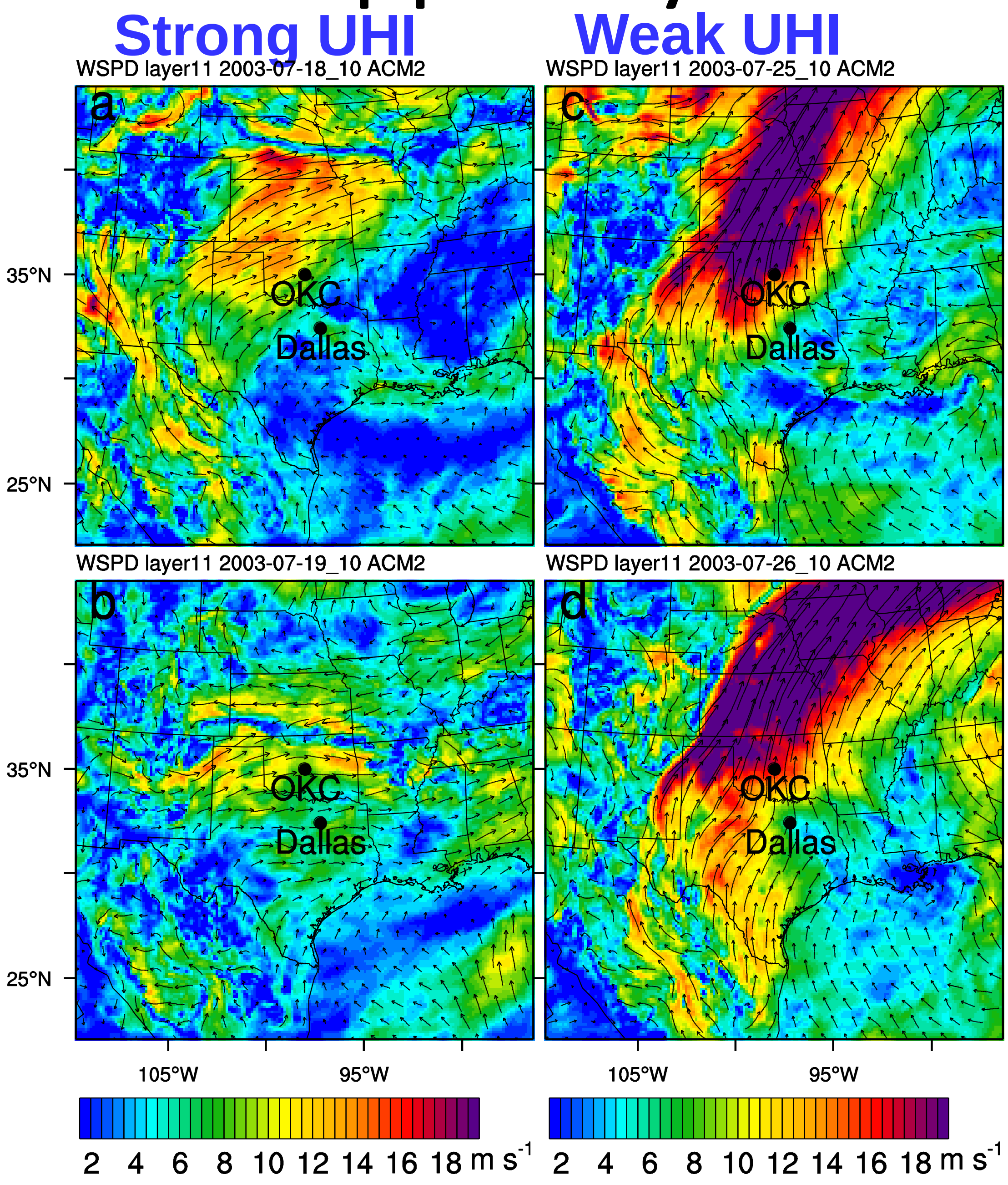
# Impact of LLJs on coupling status




Strong LLJs lead to strong coupling (weaker gradient)

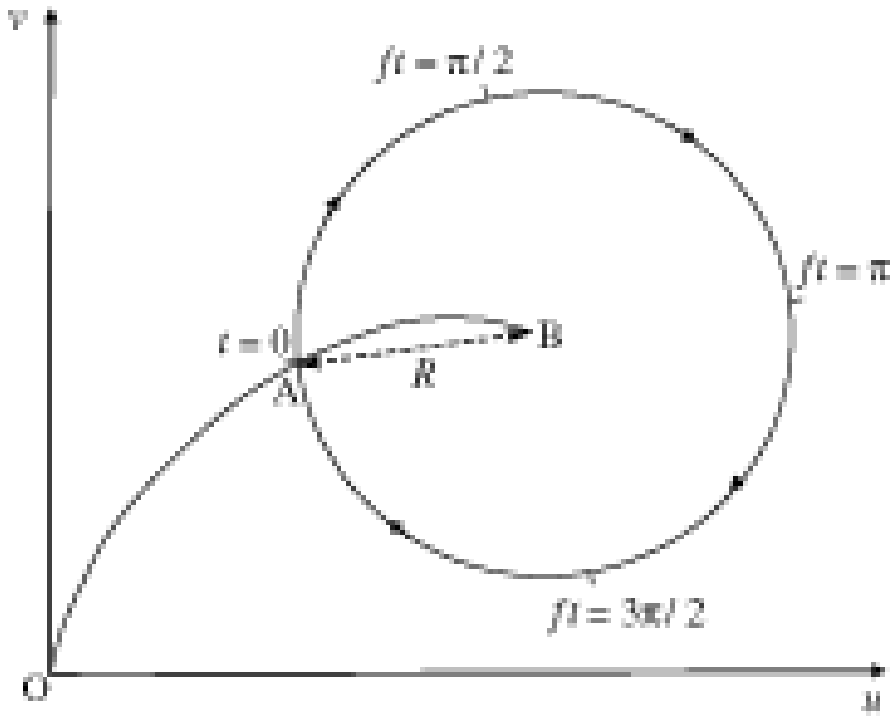
# Upper layer wind speeds




Factors contributing to LLJs:

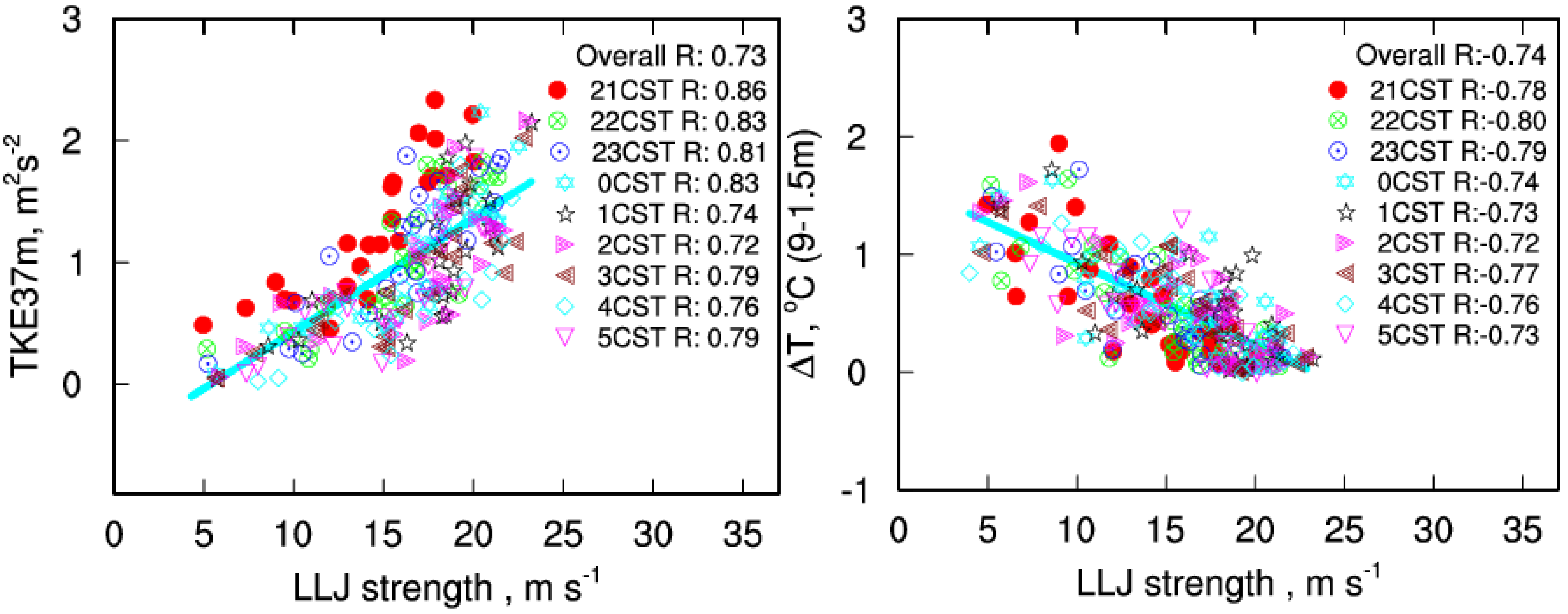
1. **Inertial oscillation**
2. **Thermal wind**

# LLJs formation mechanism(1): inertial oscillation

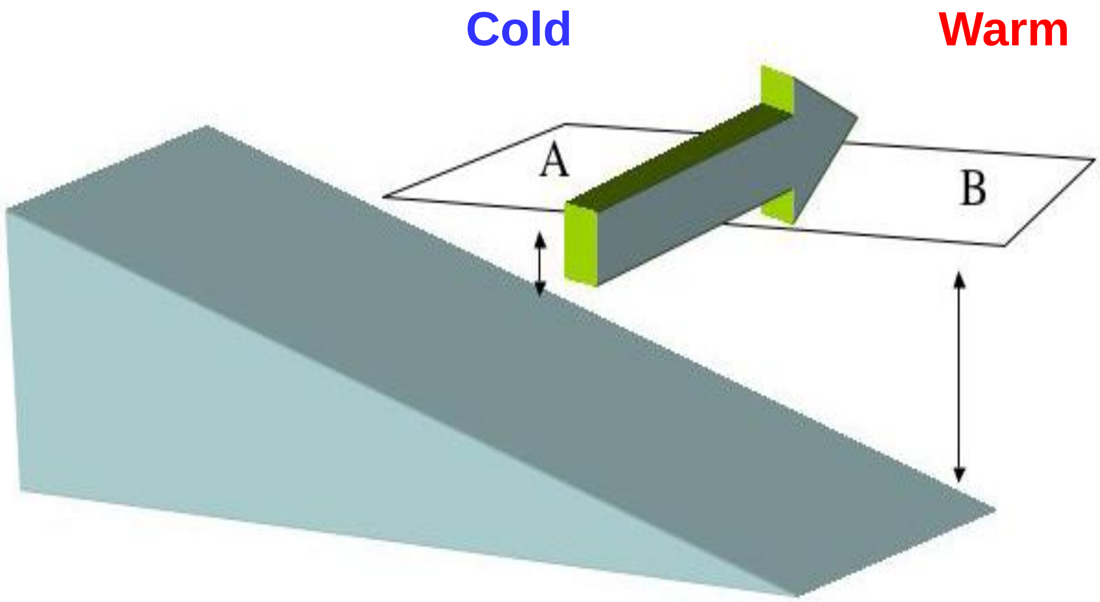


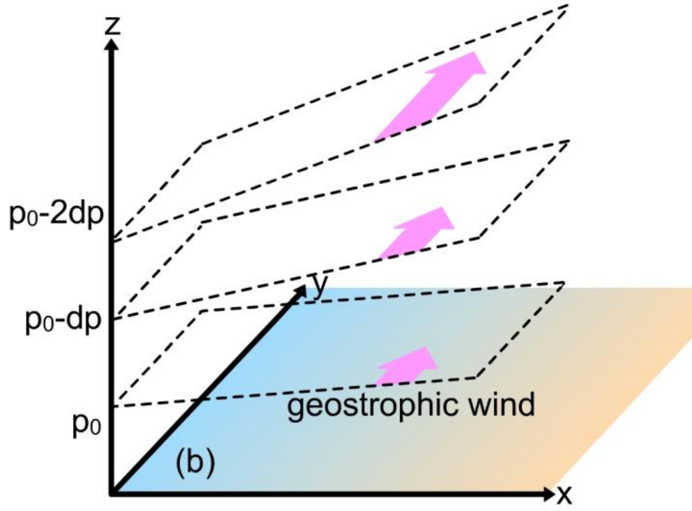

The premise of inertial oscillation is significant decrease of turbulence during the early evening transition. So weaker turbulence, strong decoupling favor LLJs development in this theory. Inertial oscillation also cannot explain LLJ location preference.

# Strong LLJs are normally associated with strong coupling/turbulence



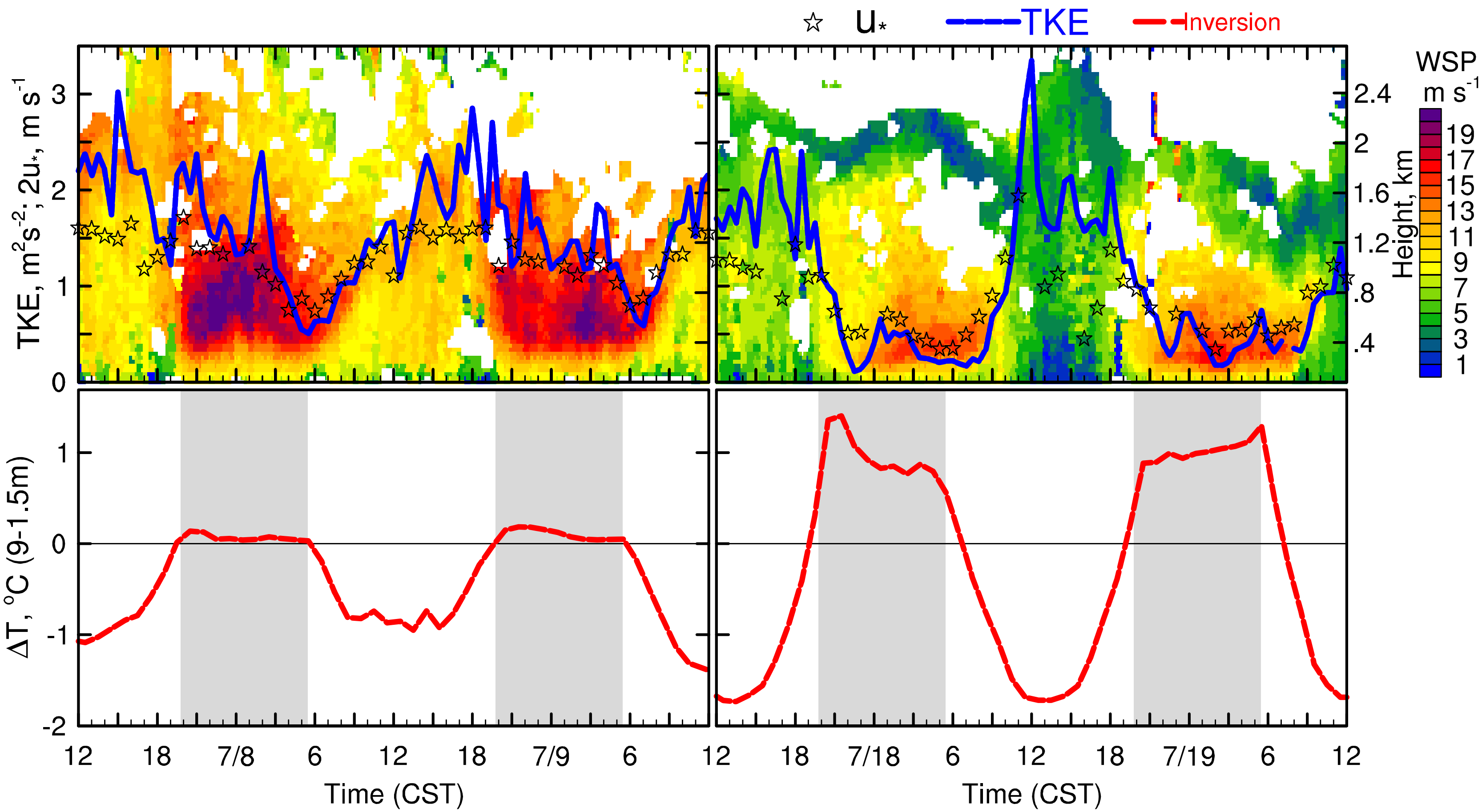
# LLJs formation mechanism(2): thermal wind



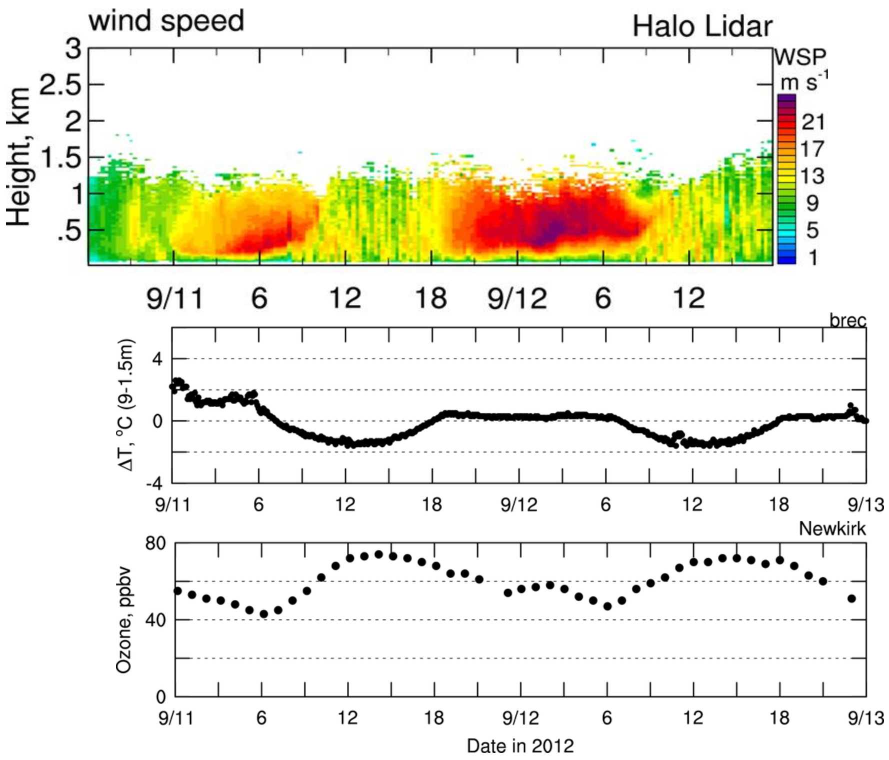

Thermal wind is actually vertical shear of horizontal wind speed

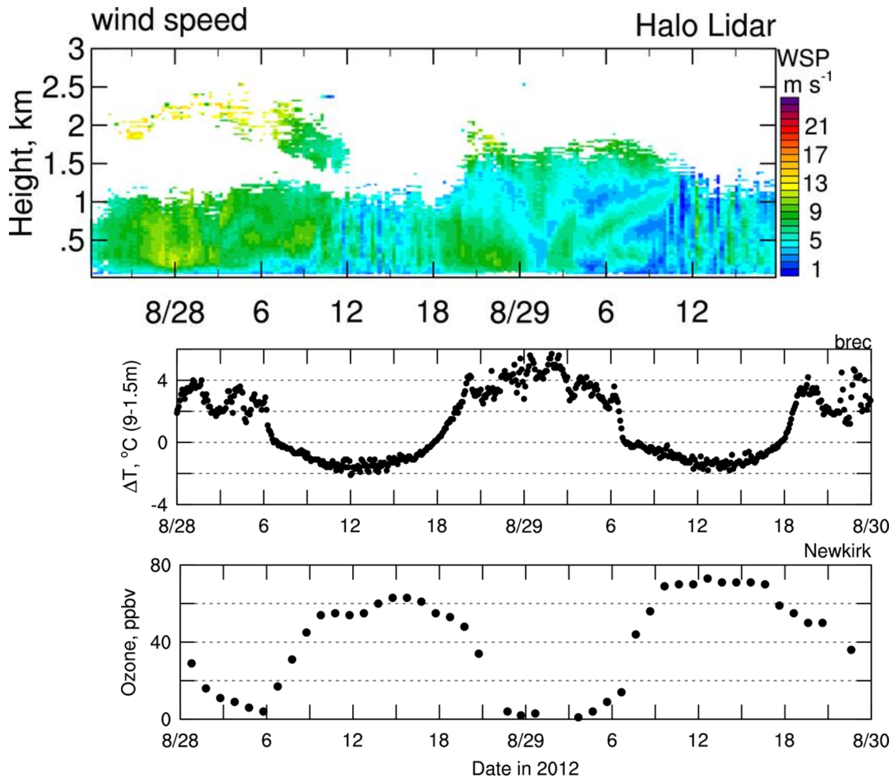
# Inertial oscillation or thermal wind?




Thermal wind is more important for LLJ formation in Oklahoma?

# More LLJ cases




Strong LLJs lead to strong coupling while weak LLJs lead to decoupling

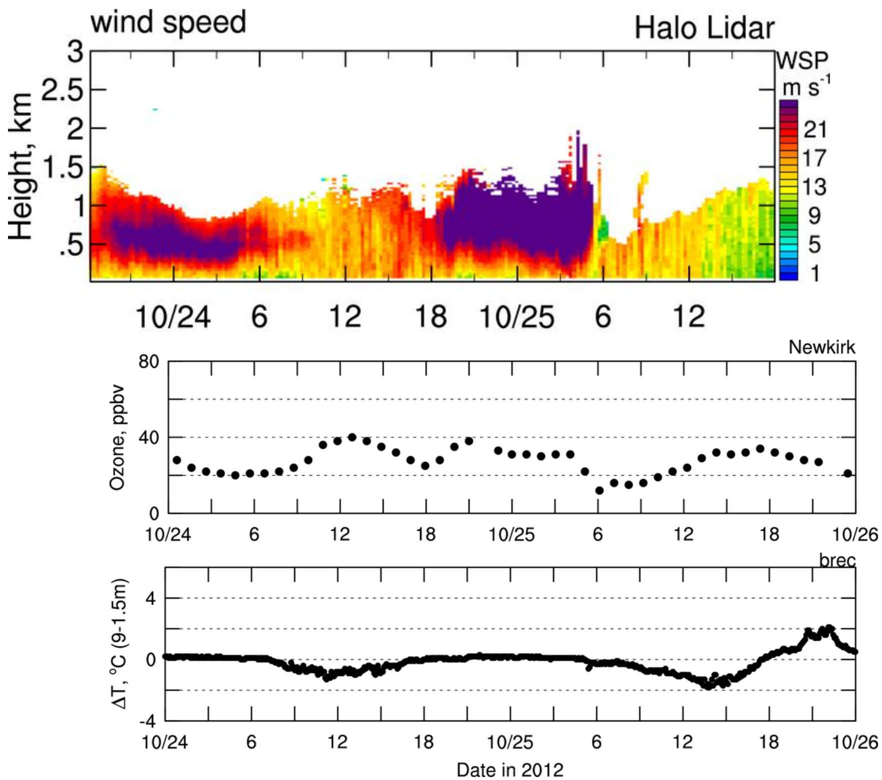
# Conclusions

- Vertical gradients of T are indicators of coupling strength of NBL
- Stronger LLJ induces stronger turbulence and leads to stronger coupling
- Inertial oscillation may be of secondary importance for LLJ formation in OK

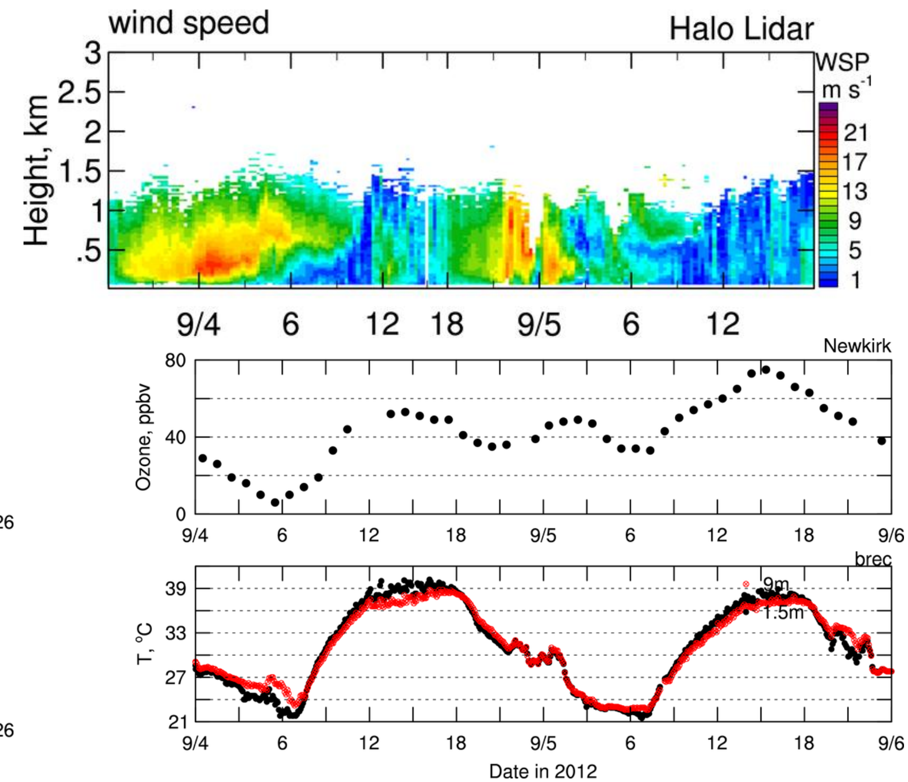
# References


1. **Hu, X.-M.**, P. M Klein, M. Xue, J. K. Lundquist, F. Zhang, and Y., Qi (2013), Impact of Low-Level Jets on the Nocturnal Urban Heat Island Intensity in Oklahoma City. *J. Appl. Meteor. Climatol.*, 52, 1779–1802.
2. **Hu, X.-M.**, P. M. Klein, M. Xue, A. Shapiro, and A. Nallapareddy (2013), Enhanced vertical mixing associated with a nocturnal cold front passage and its impact on near-surface temperature and ozone concentration, J. Geophys. Res. Atmos., 118, 2714–2728, doi:10.1002/jgrd.50309.
3. **Hu, X.-M.**, P. M. Klein, and M. Xue (2013), Evaluation of the updated YSU planetary boundary layer scheme within WRF for wind resource and air quality assessments, J. Geophys. Res. Atmos., 118, 10,490–10,505, doi:10.1002/jgrd.50823.
4. **Hu, X.-M.** , P. M. Klein, M. Xue (2013) Coupling in the nocturnal boundary layer in the presence of low-level jets in Oklahoma, to be submitted.
5. Zhang, N., and Y. Chen (2013), A Case Study of the Upwind Urbanization Influence on the Urban Heat Island Effects along the Suzhou–Wuxi Corridor, *J Appl Meteorol Clim*, 10.1175/jamc-d-12-0219.1.

# More cases




Secondary $O_3$ peak




Nocturnal warming event

# Links

1. http://faculty-staff.ou.edu/H/Xiaoming.Hu-1/
2. http://journals.ametsoc.org/doi/abs/10.1175/2010JAMC2432.1
3. http://journals.ametsoc.org/doi/abs/10.1175/2010MWR3292.1
4. http://www.agu.org/pubs/crossref/2010/2010GL043017.shtml