

Meteorological and chemical phenomena in the nocturnal boundary layer in Oklahoma

Xiaoming Hu

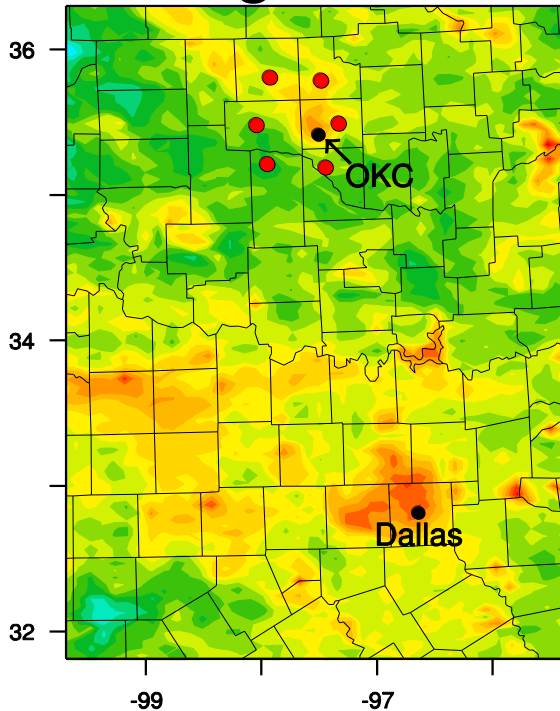
Nov. 14, 2013

at Lanzhou University

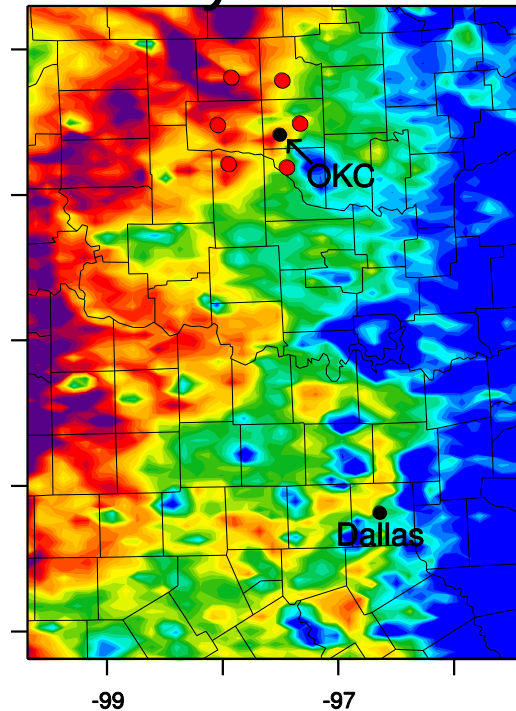
- Part 1: Impacts of LLJs on the nocturnal Urban Heat Island (UHI)
- Part 2: Coupling in the nocturnal boundary layer

UHI is prominent during the nighttime

Nighttime



Daytime



Red dots around OKC:
Six rural sites

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



291 294 297 300K



308 311 314 317 320K

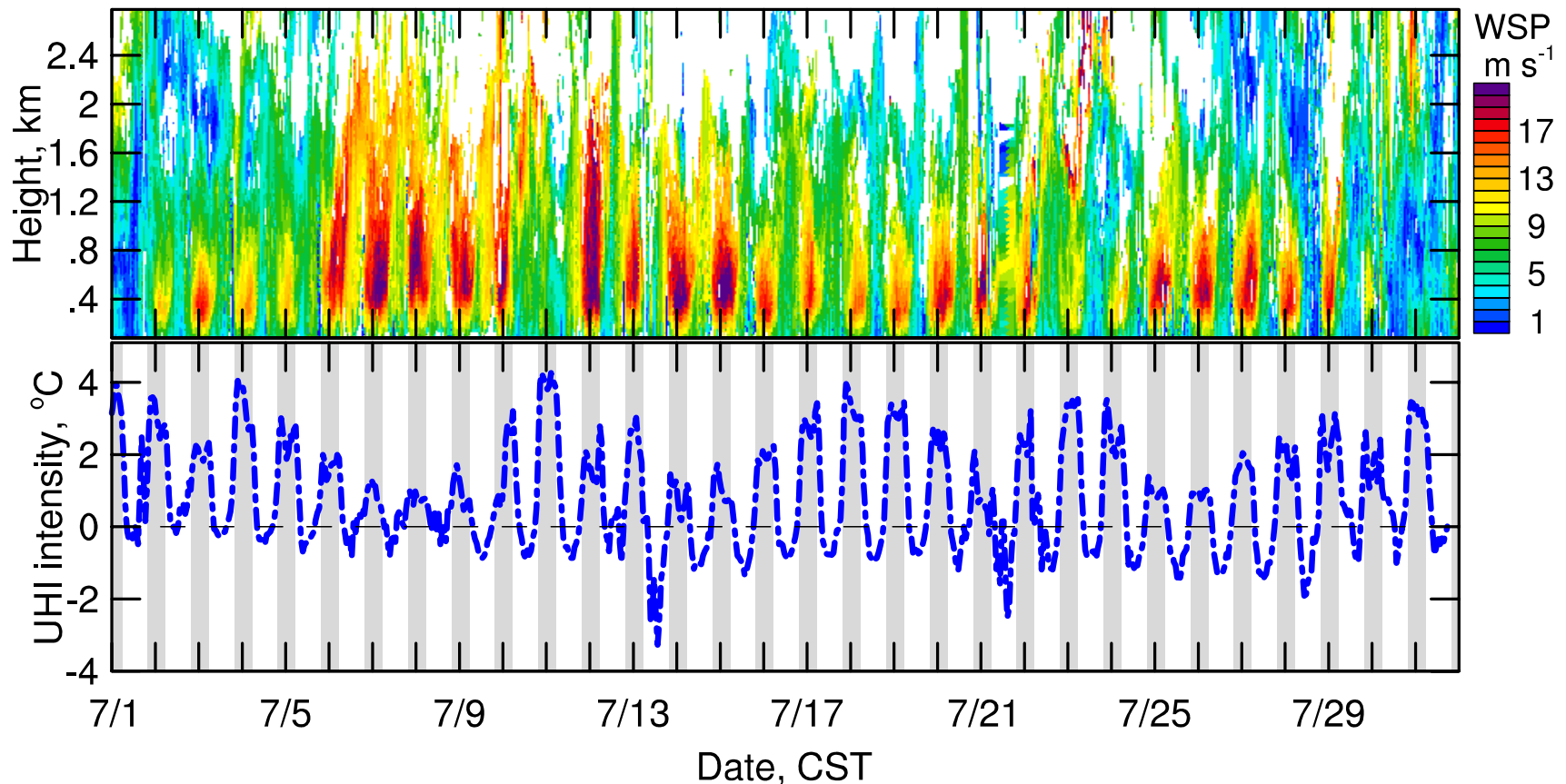
MODIS-derived land surface T

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

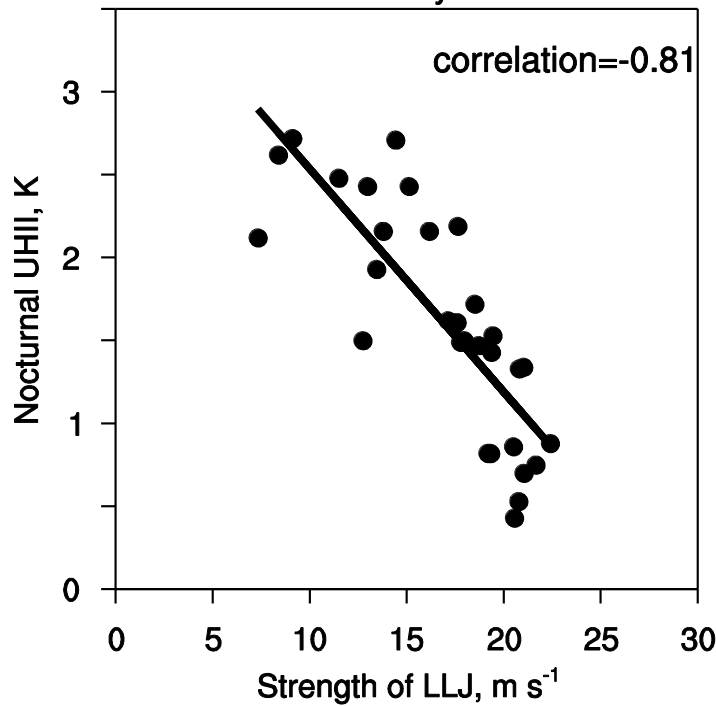
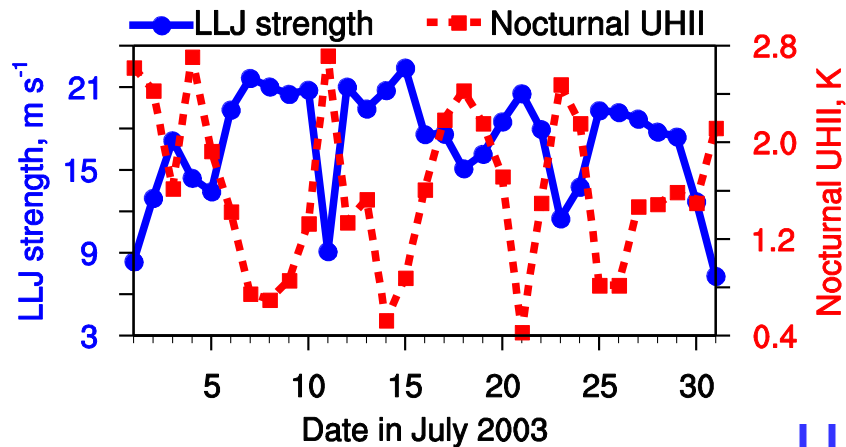
Relationship between LLJs and UHI intensity



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

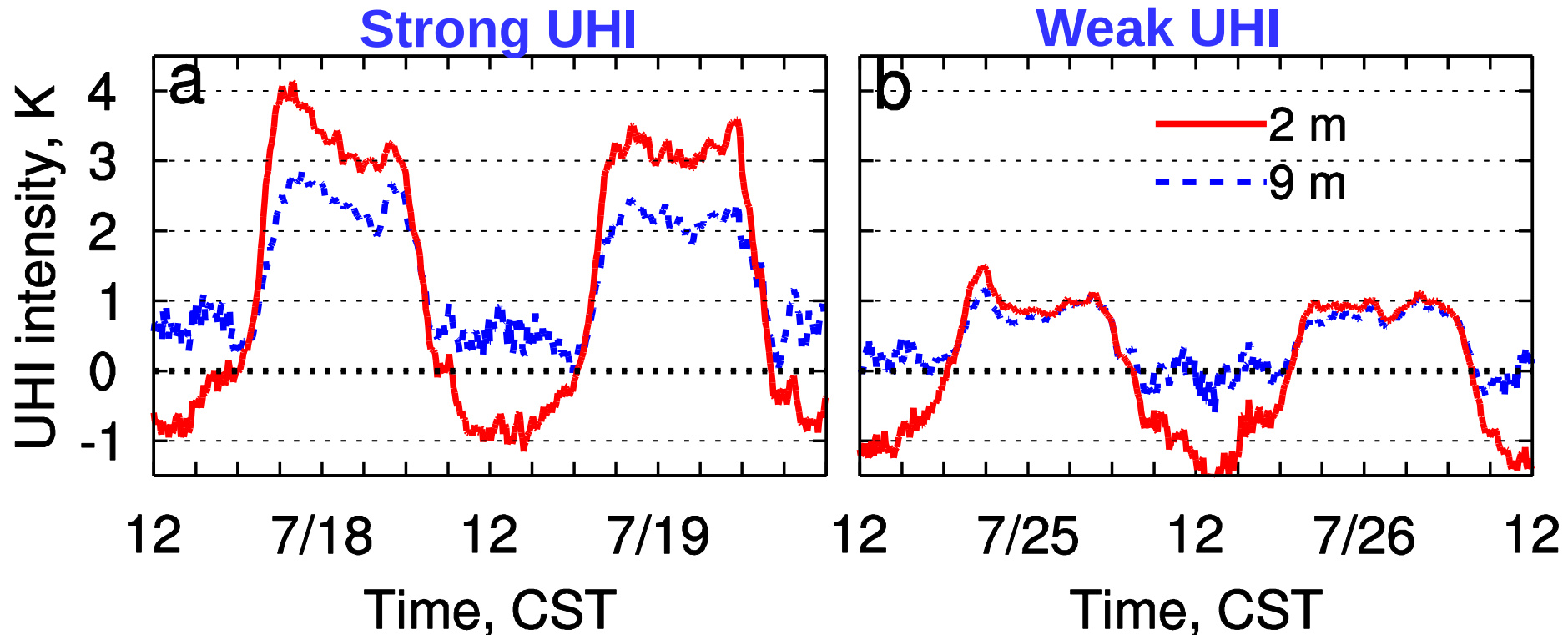


LLJ strength: maximum wind speed of a LLJ

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

LLJs modulate nocturnal UHI intensity

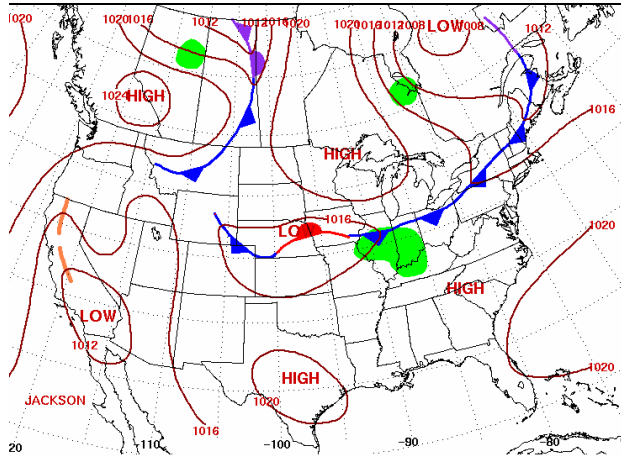
Two different episodes



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

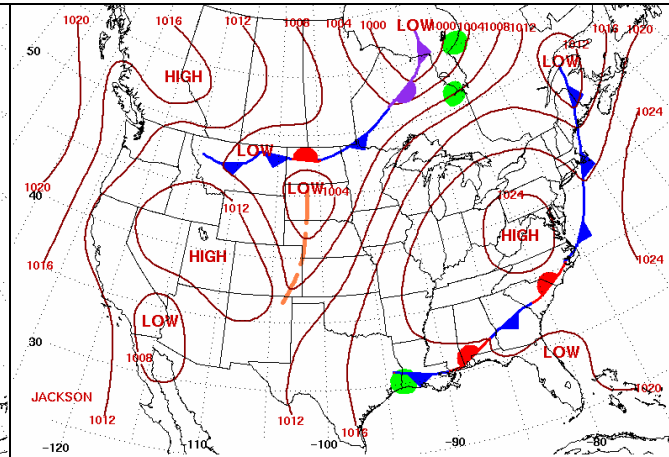
Two different episodes: large scale forcing

Strong UHI

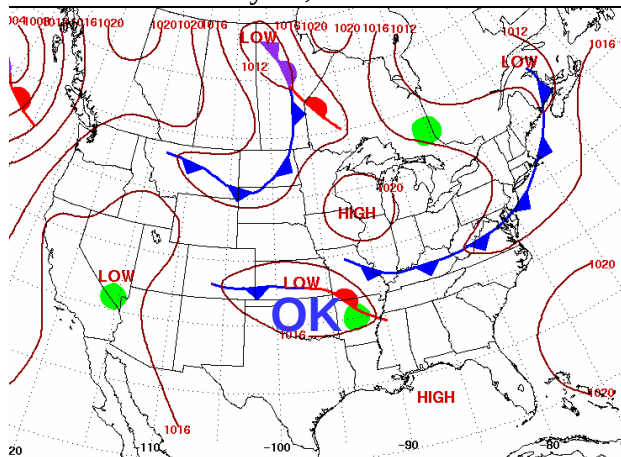


Surface Weather Map at 7:00 A.M. E.S.T.
July 18, 2003

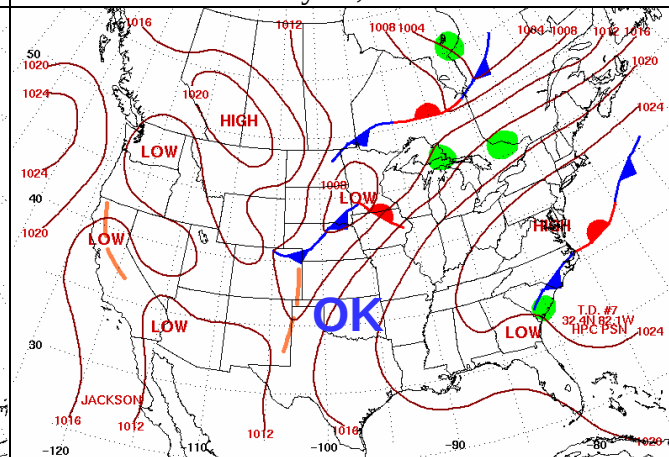
Weak UHI



Surface Weather Map at 7:00 A.M. E.S.T.
July 25, 2003



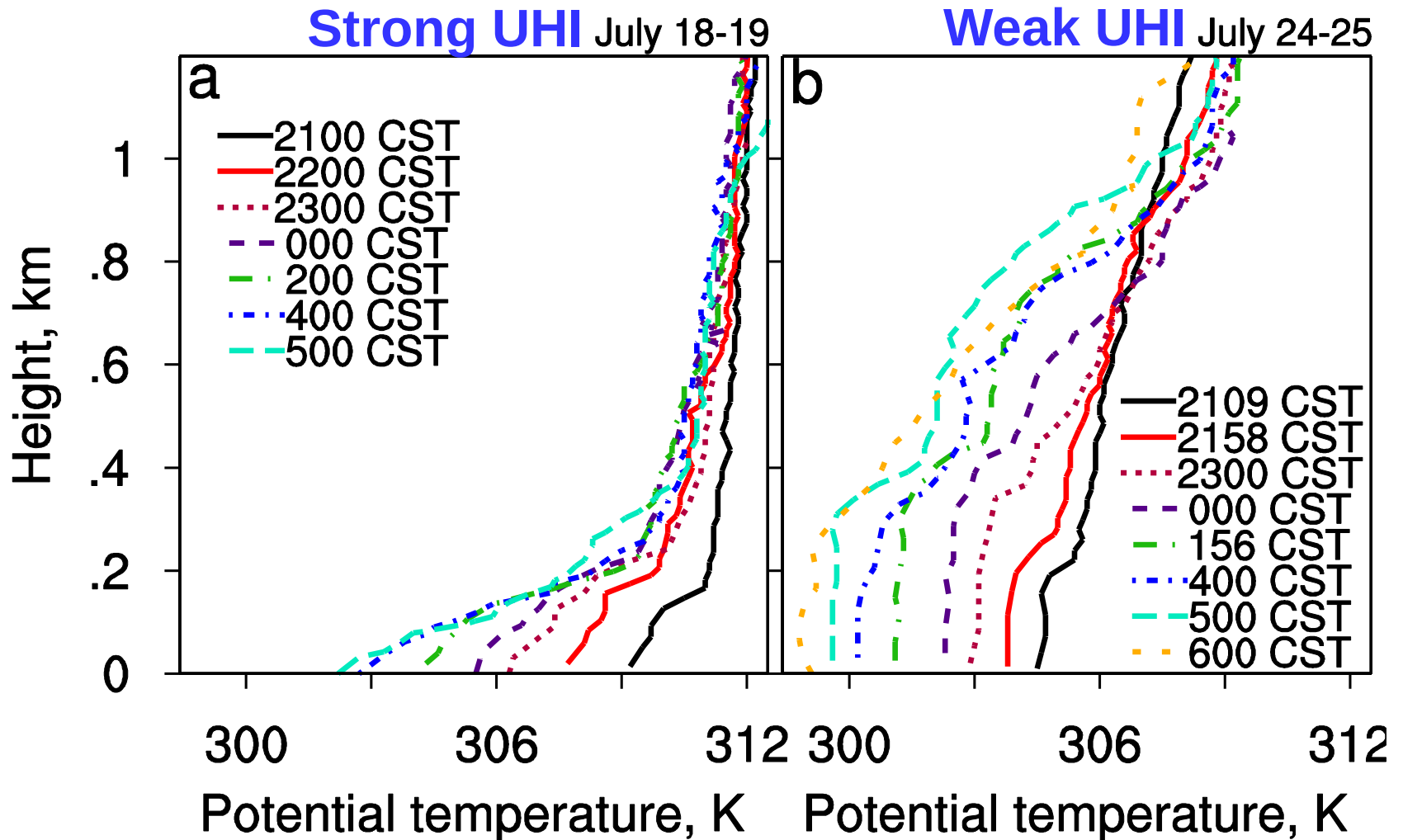
Surface Weather Map at 7:00 A.M. E.S.T.
July 19, 2003



Surface Weather Map at 7:00 A.M. E.S.T.
July 26, 2003

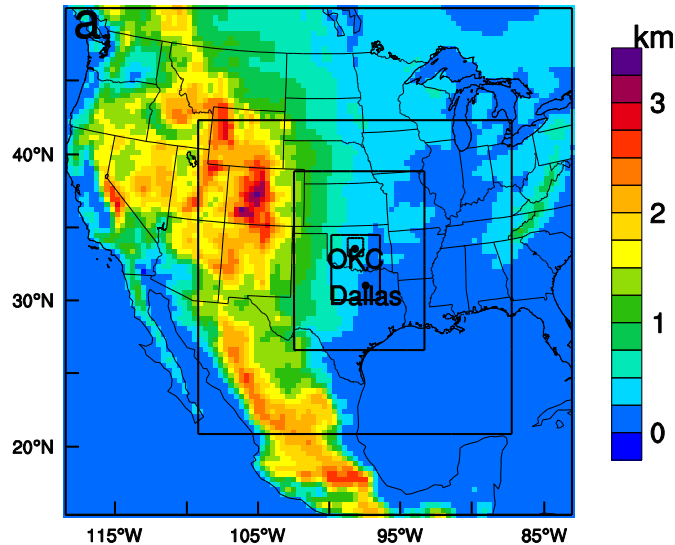
Large scale forcing plays role in the formation of LLJs

Two different episodes: temperature profiles

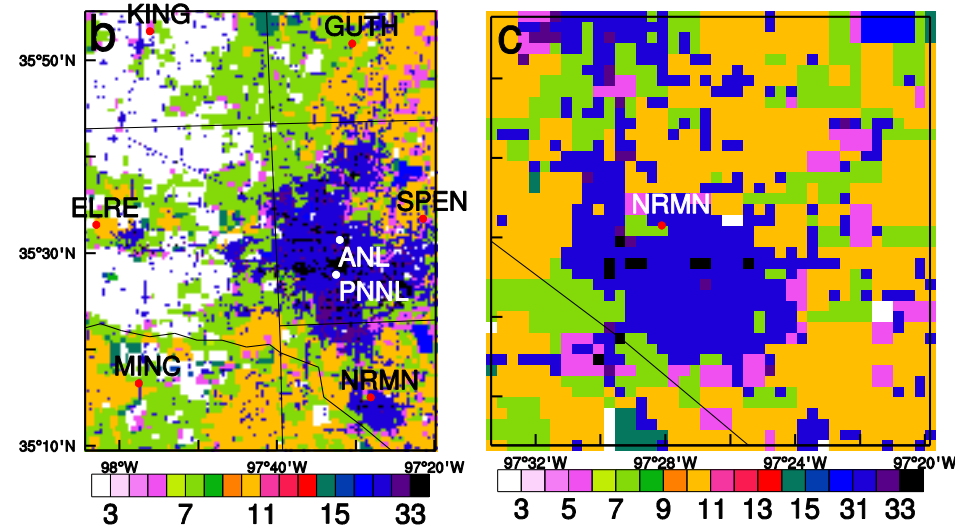


Near surface thermal structure is different, will investigate the reason and effect

Model domains and configurations



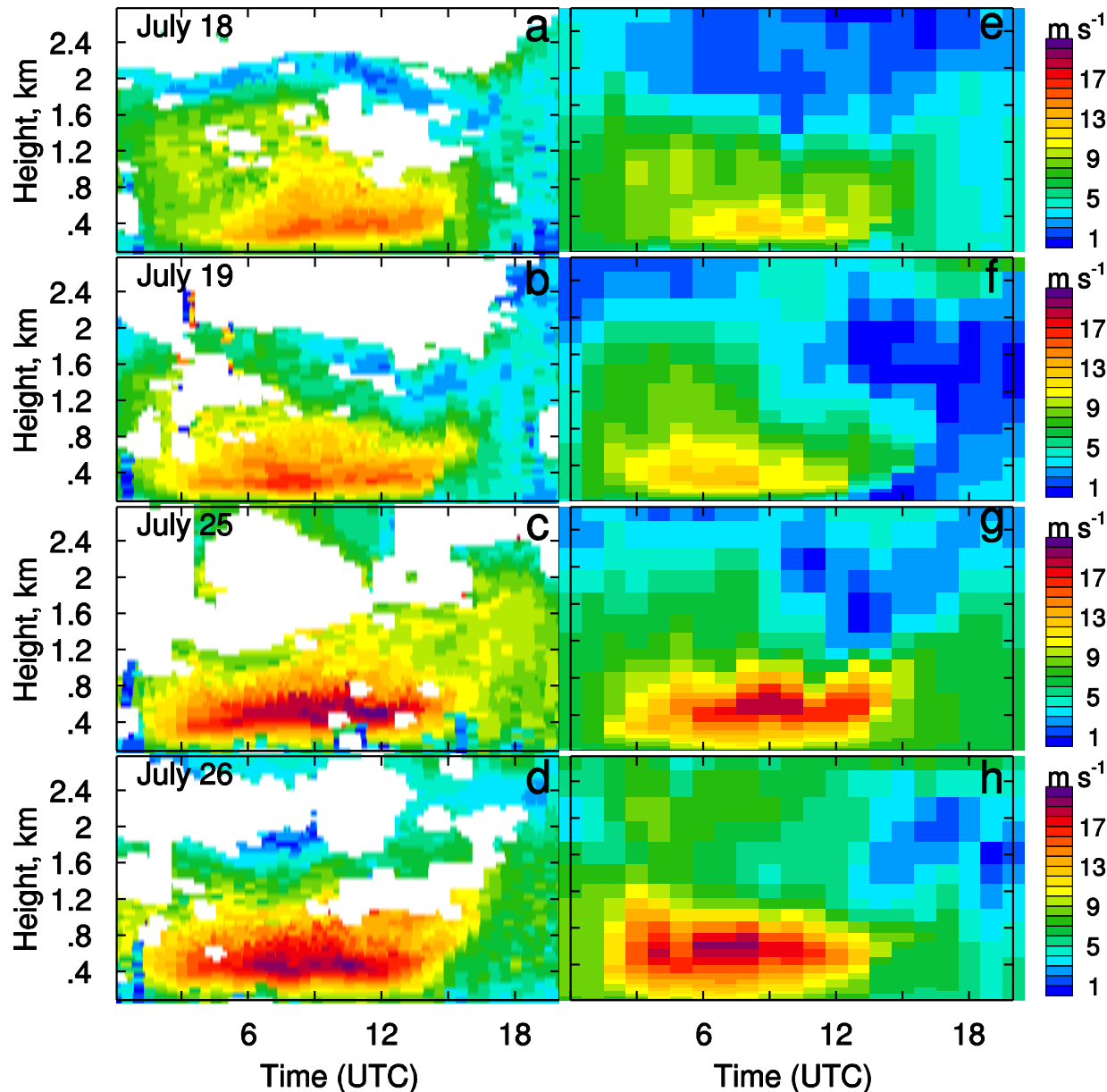
- WRF3.4
- 40.5->13.5->4.5->1.5->0.5km
- NOAH+Urban canopy model
- ACM2 PBL scheme
- NARR for IC/BC



Time-height diagram of wind speeds

Strong UHI

Weak UHI

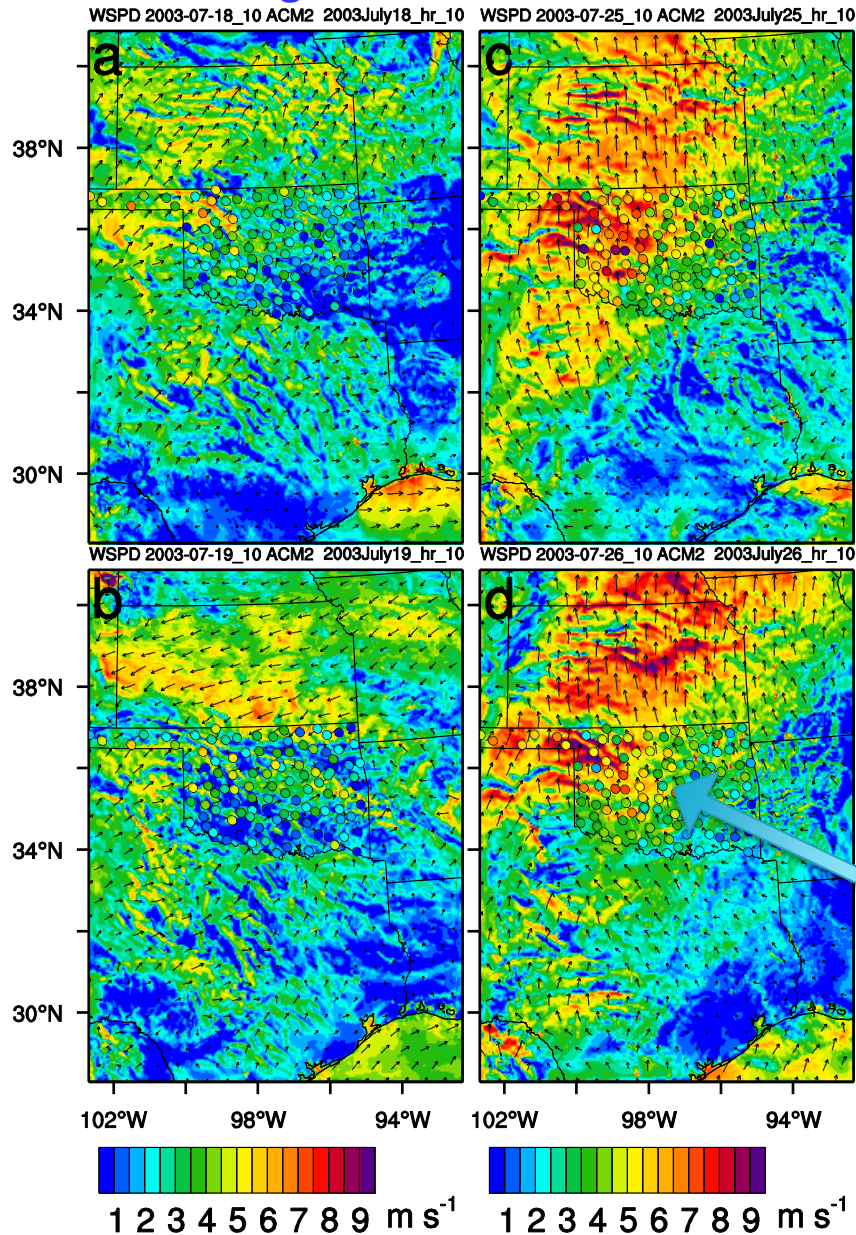


Model reproduces LLJs &
Captures day-to-day
variation

Surface wind speeds at 0400 LT

Strong UHI

Weak UHI



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

OKlahoma

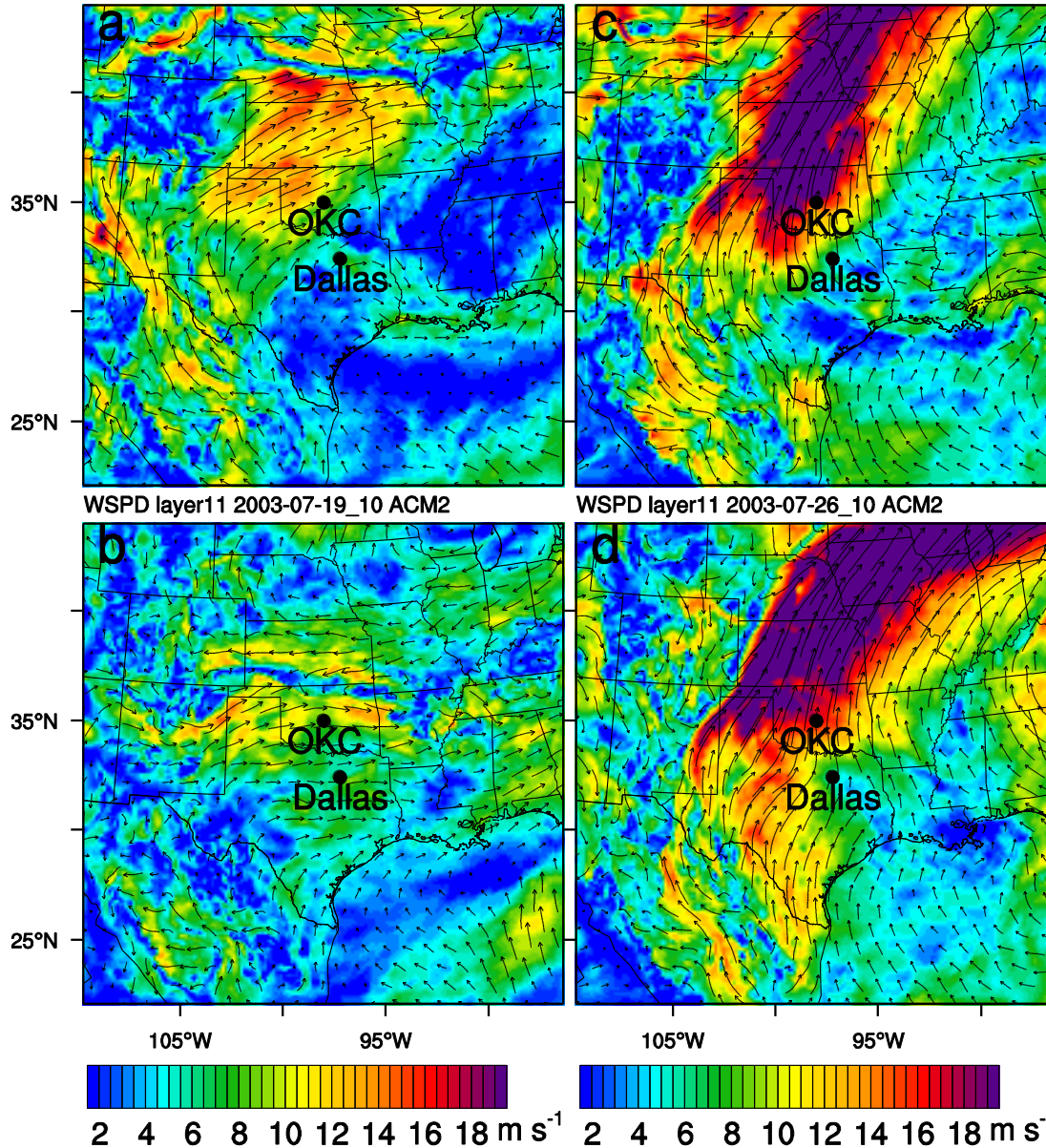
Upper layer wind speeds

Strong UHI

WSPD layer11 2003-07-18_10 ACM2

Weak UHI

WSPD layer11 2003-07-25_10 ACM2

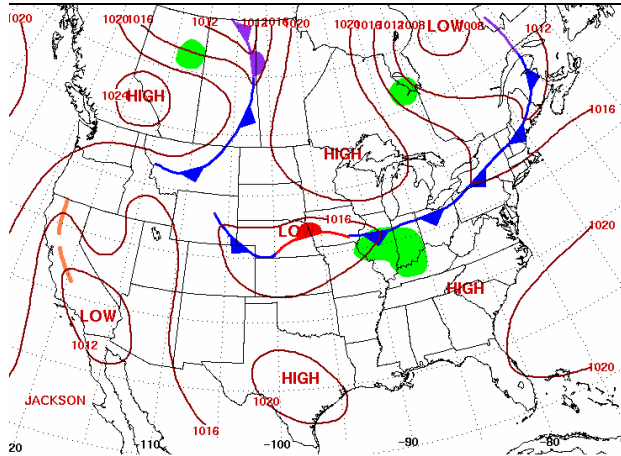


Factors contributing to LLJs:

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

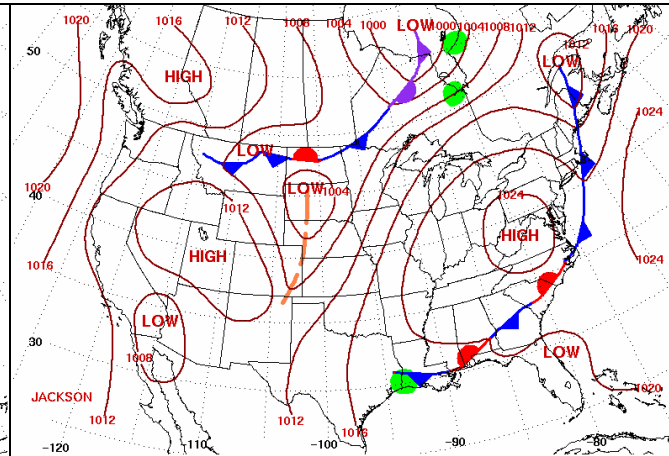
Two different episodes: large scale forcing

Strong UHI

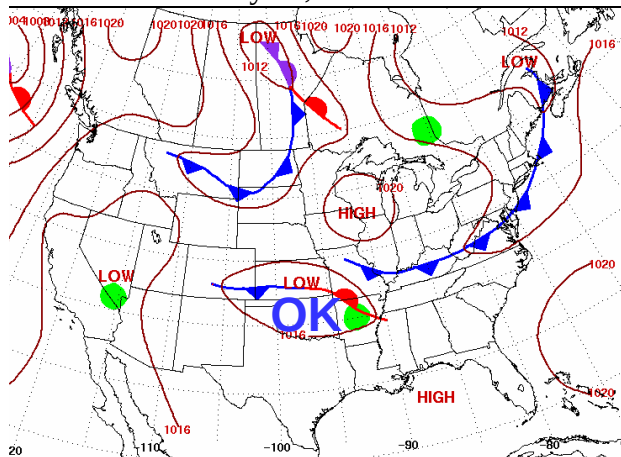


Surface Weather Map at 7:00 A.M. E.S.T.
July 18, 2003

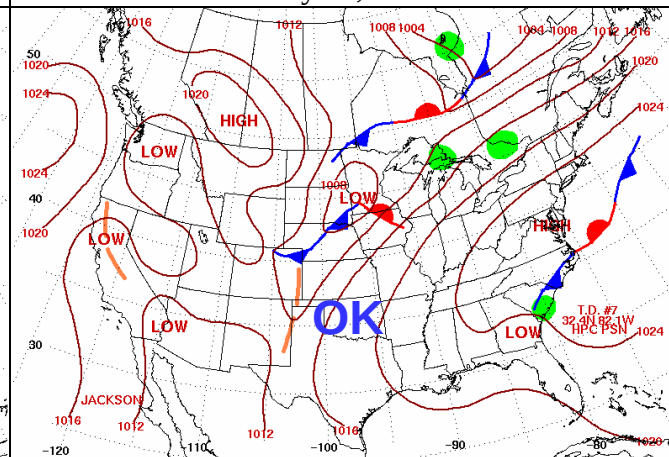
Weak UHI



Surface Weather Map at 7:00 A.M. E.S.T.
July 25, 2003



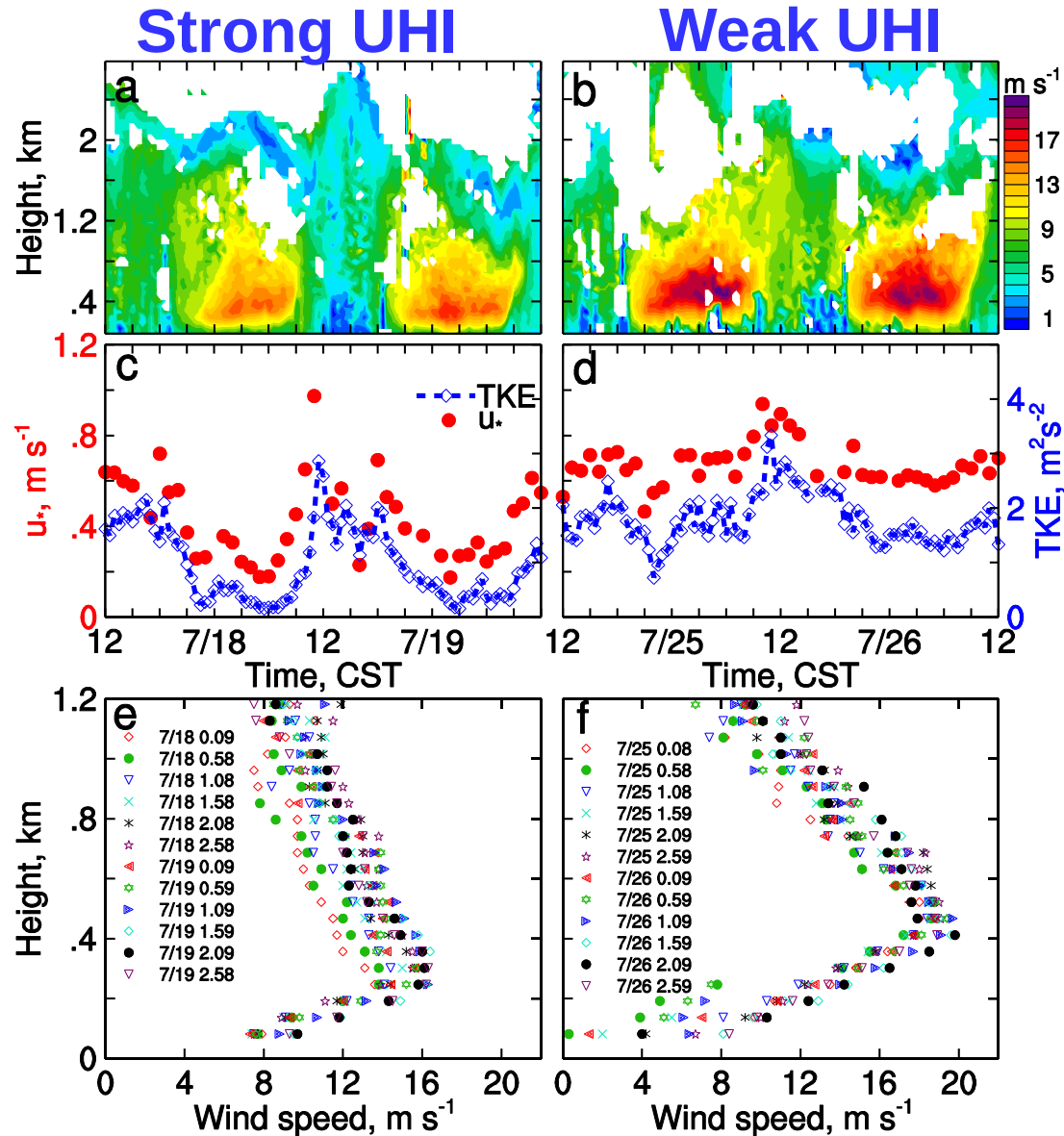
Surface Weather Map at 7:00 A.M. E.S.T.
July 19, 2003



Surface Weather Map at 7:00 A.M. E.S.T.
July 26, 2003

Large scale forcing plays role in the formation of LLJs

Stronger LLJs lead to stronger mixing

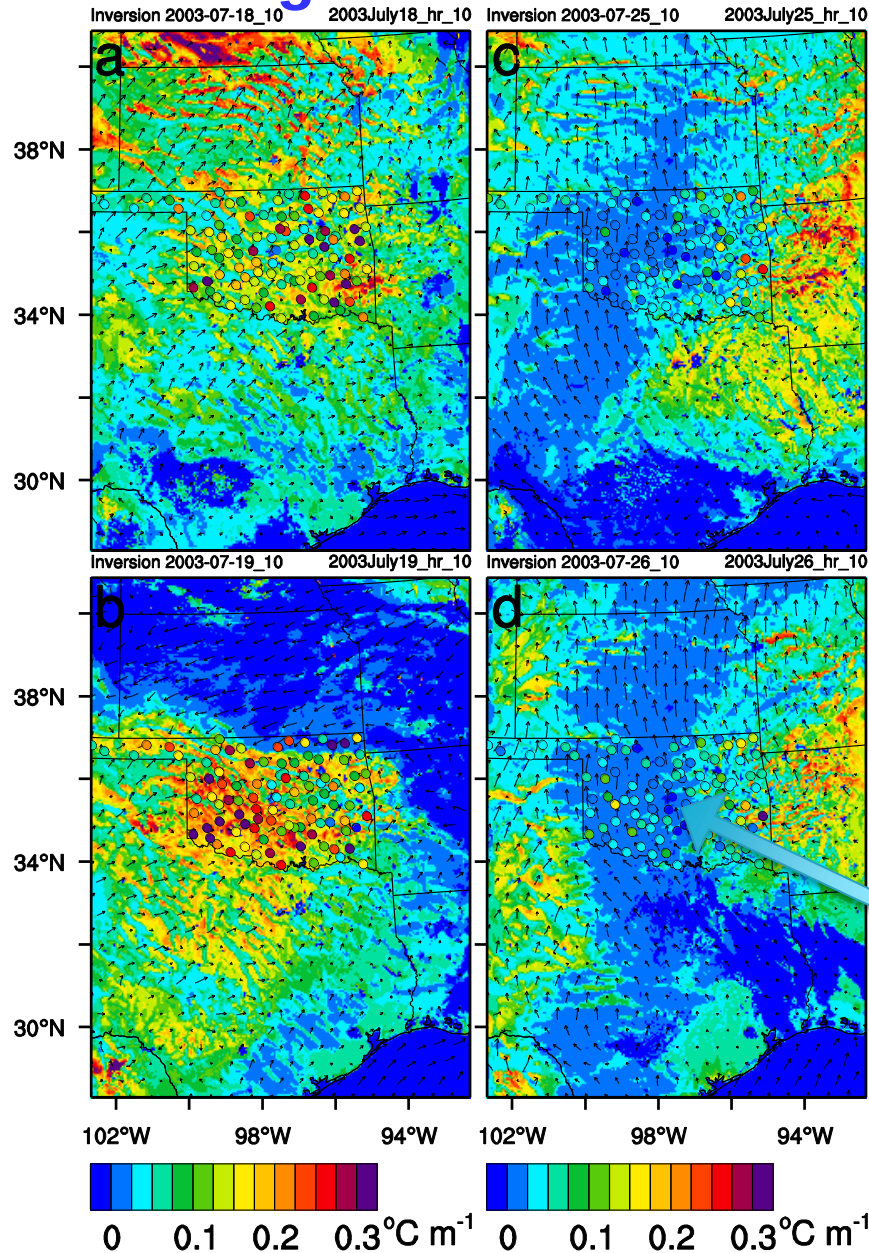


Stronger LLJs=>stronger mixing in a deeper BL=>nearly neutral BL

Near surface vertical T gradient

Strong UHI

Weak UHI



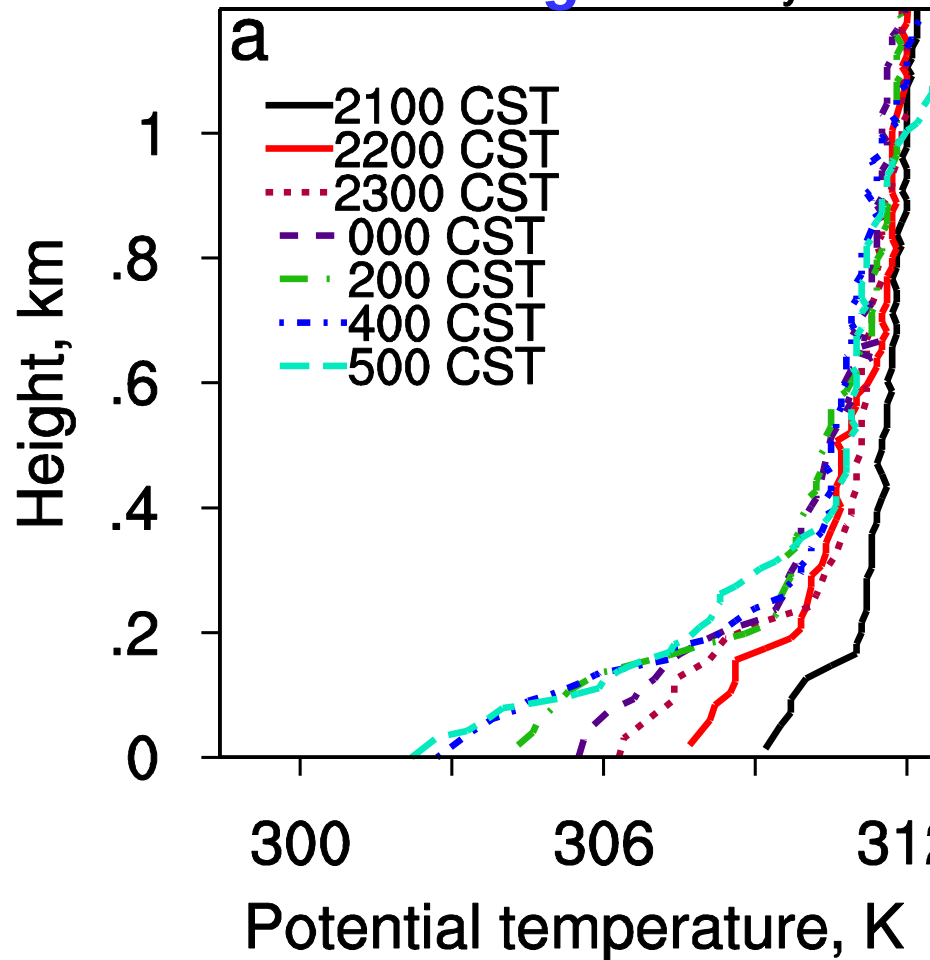
Stronger turbulence induced by LLJs
reduced near surface T gradient

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

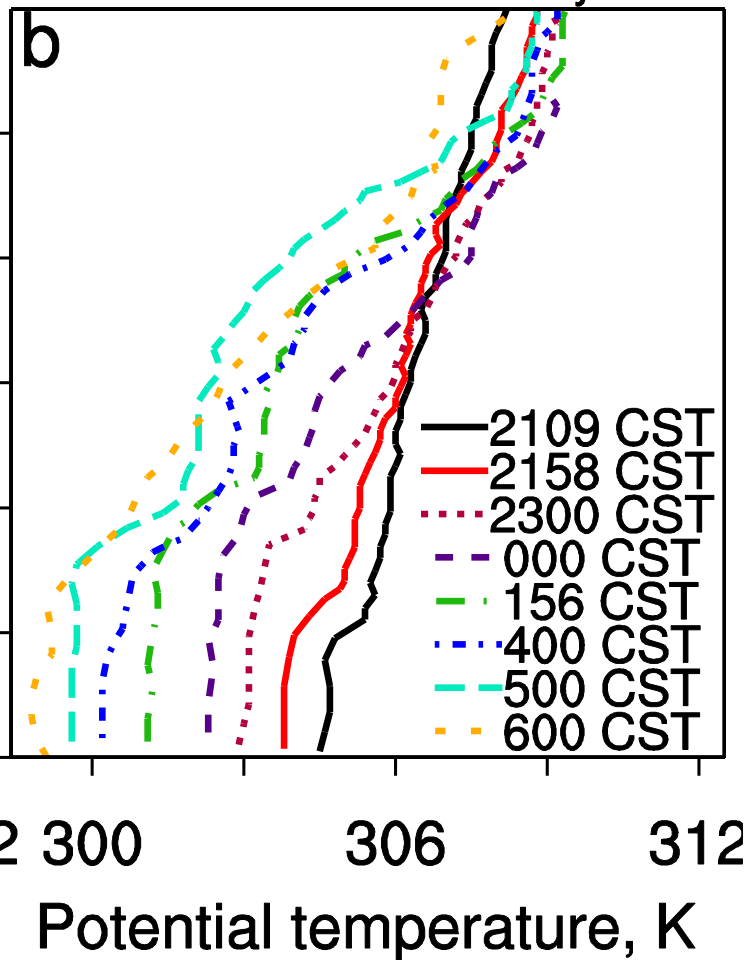
OKlahoma

LLJs modulate temperature profiles

Strong UHI July 18-19



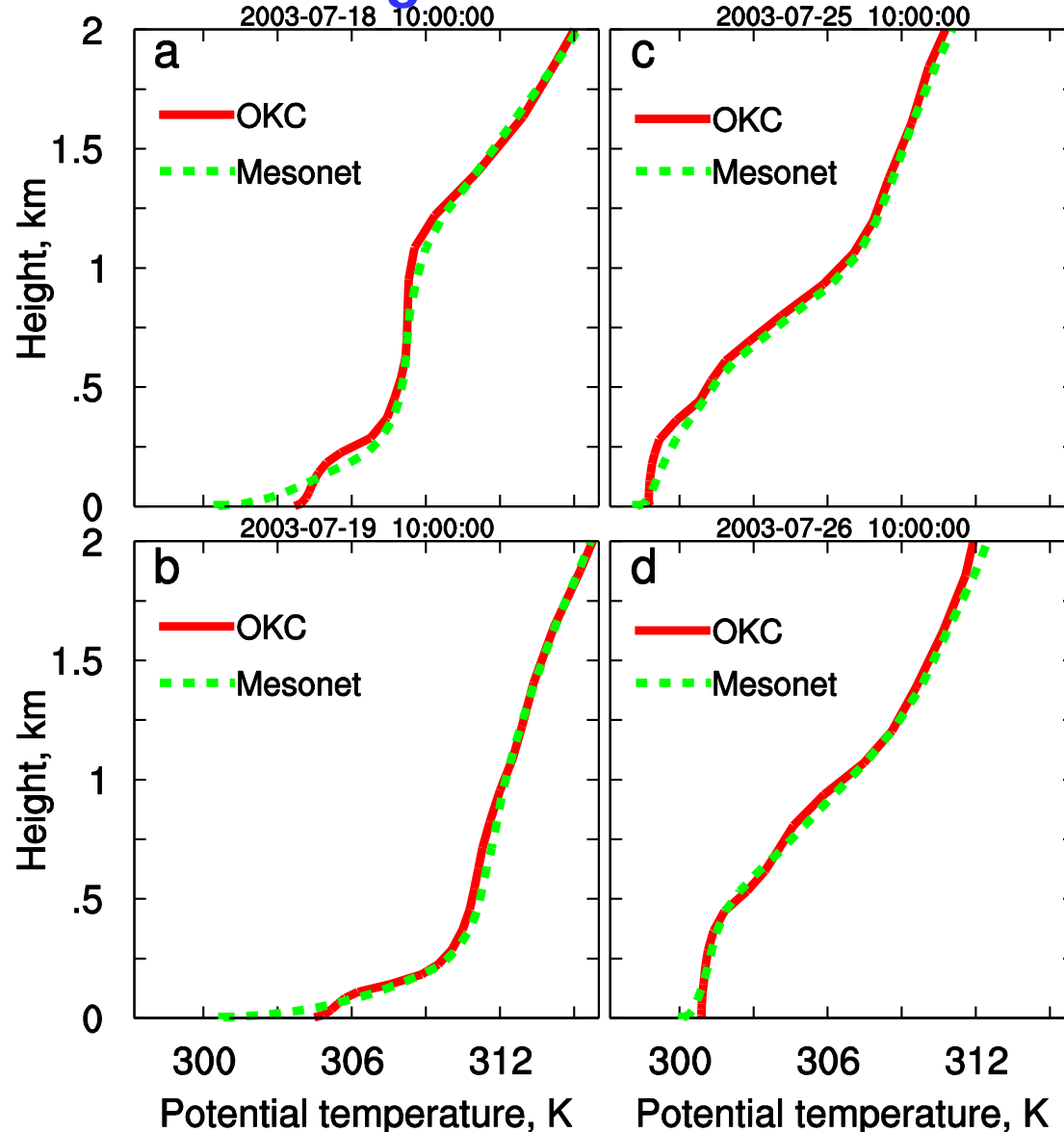
Weak UHI July 24-25



Vertical T gradients dictate UHI intensity

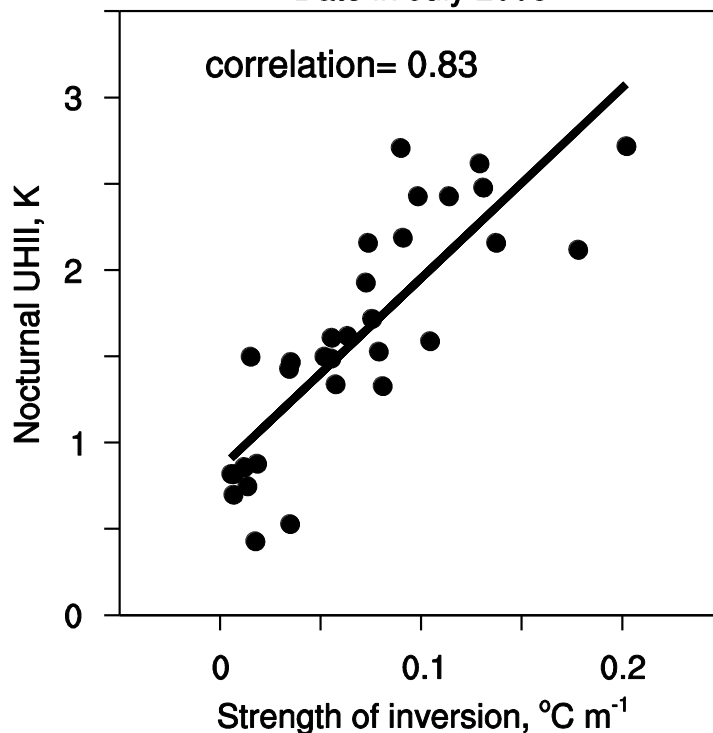
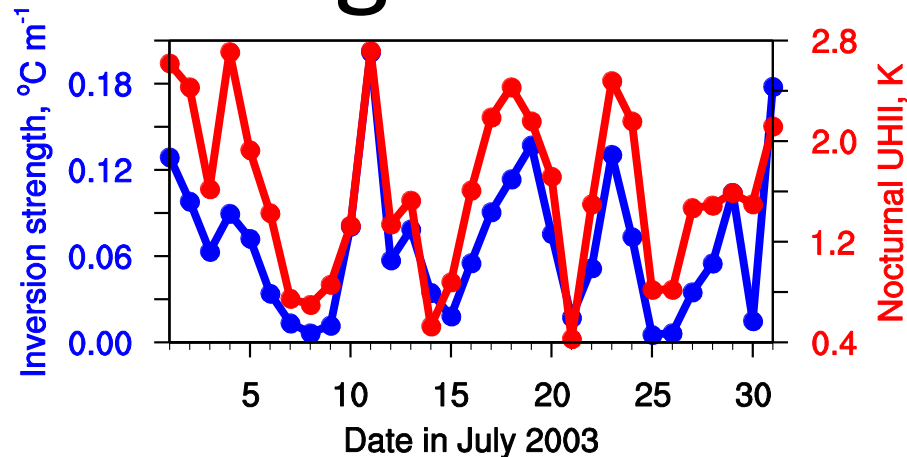
Strong UHI

Weak UHI



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

Relationship between inversion strength and UHI intensity



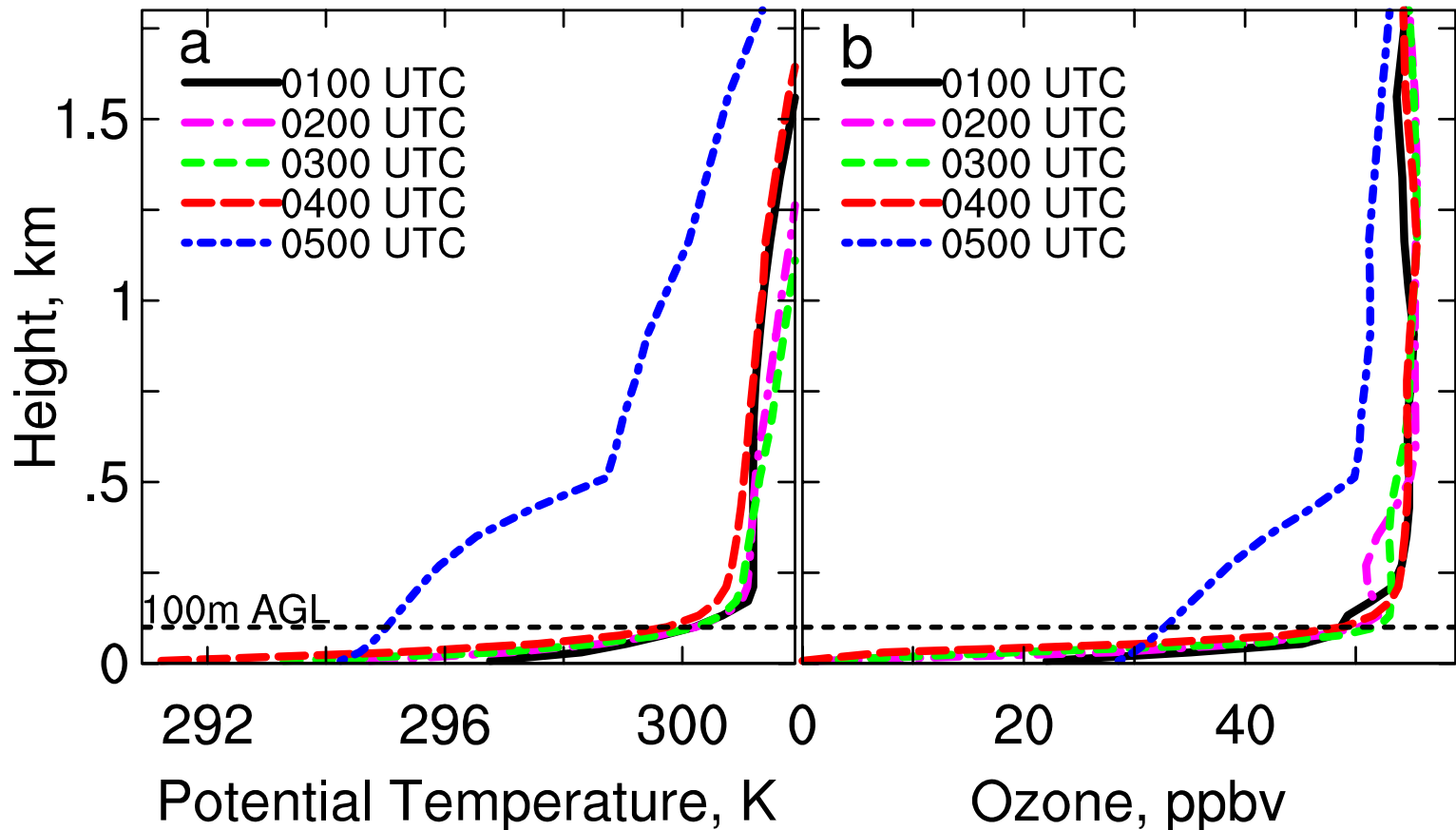
Conclusions

1. LLJs play 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

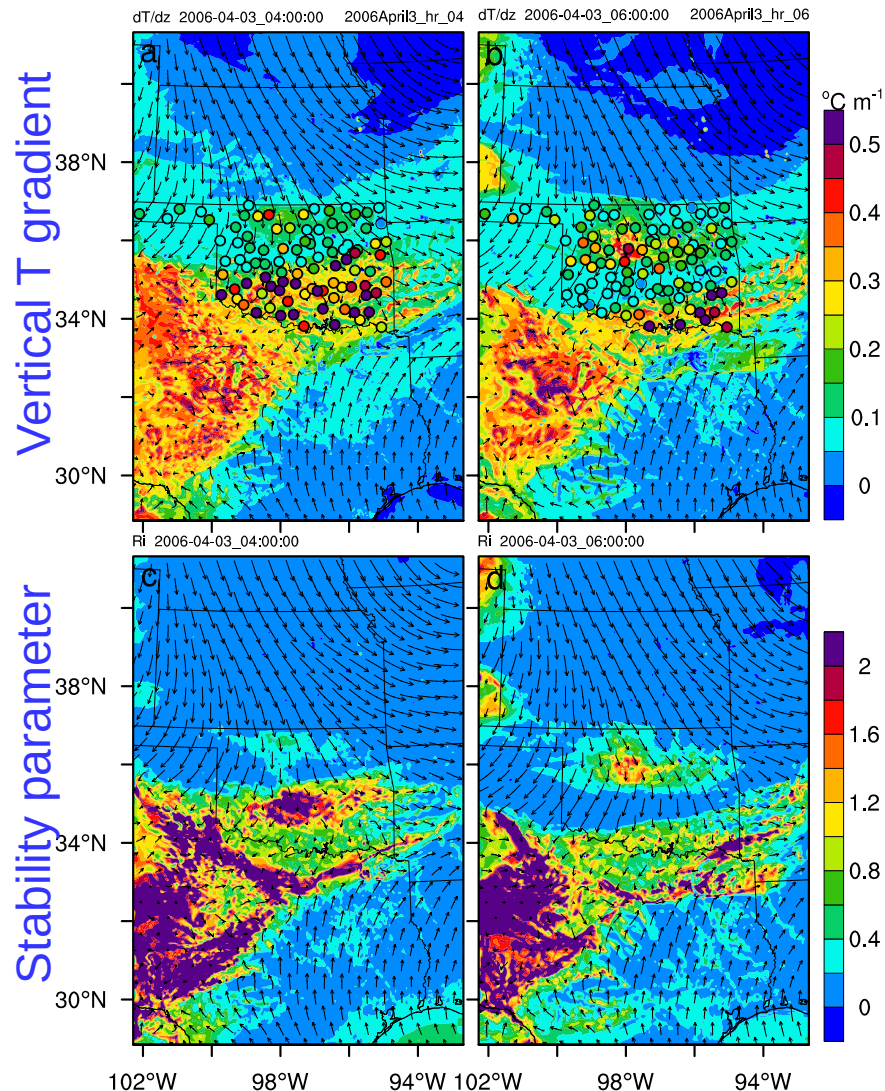
Example of coupling and decoupling



Decoupling before 0500 UTC; Coupling at 0500 UTC

Vertical temperature gradient is a good indicator of coupling strength

Example of coupling and decoupling

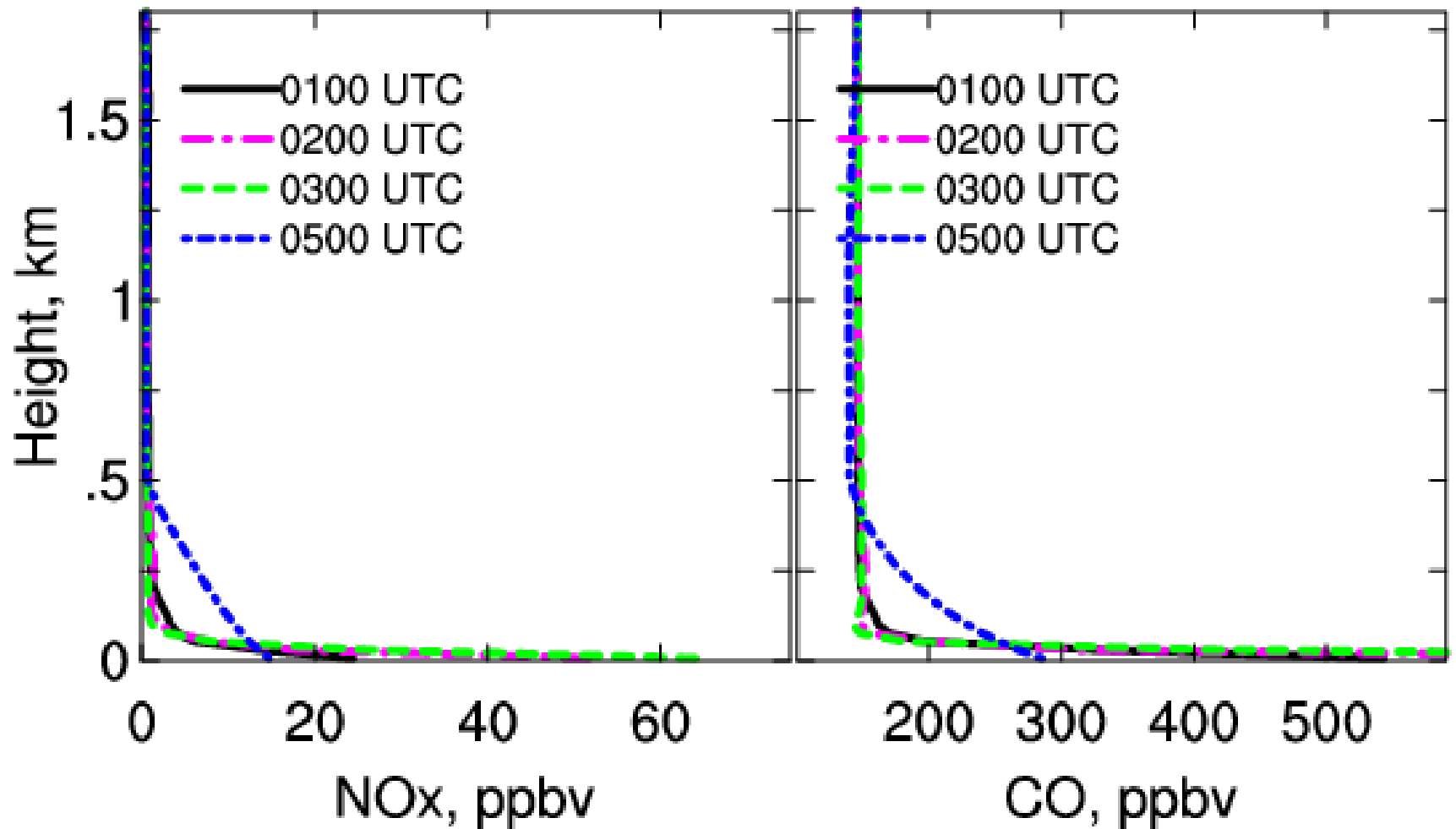


Decoupling before the cold front;

Coupling behind

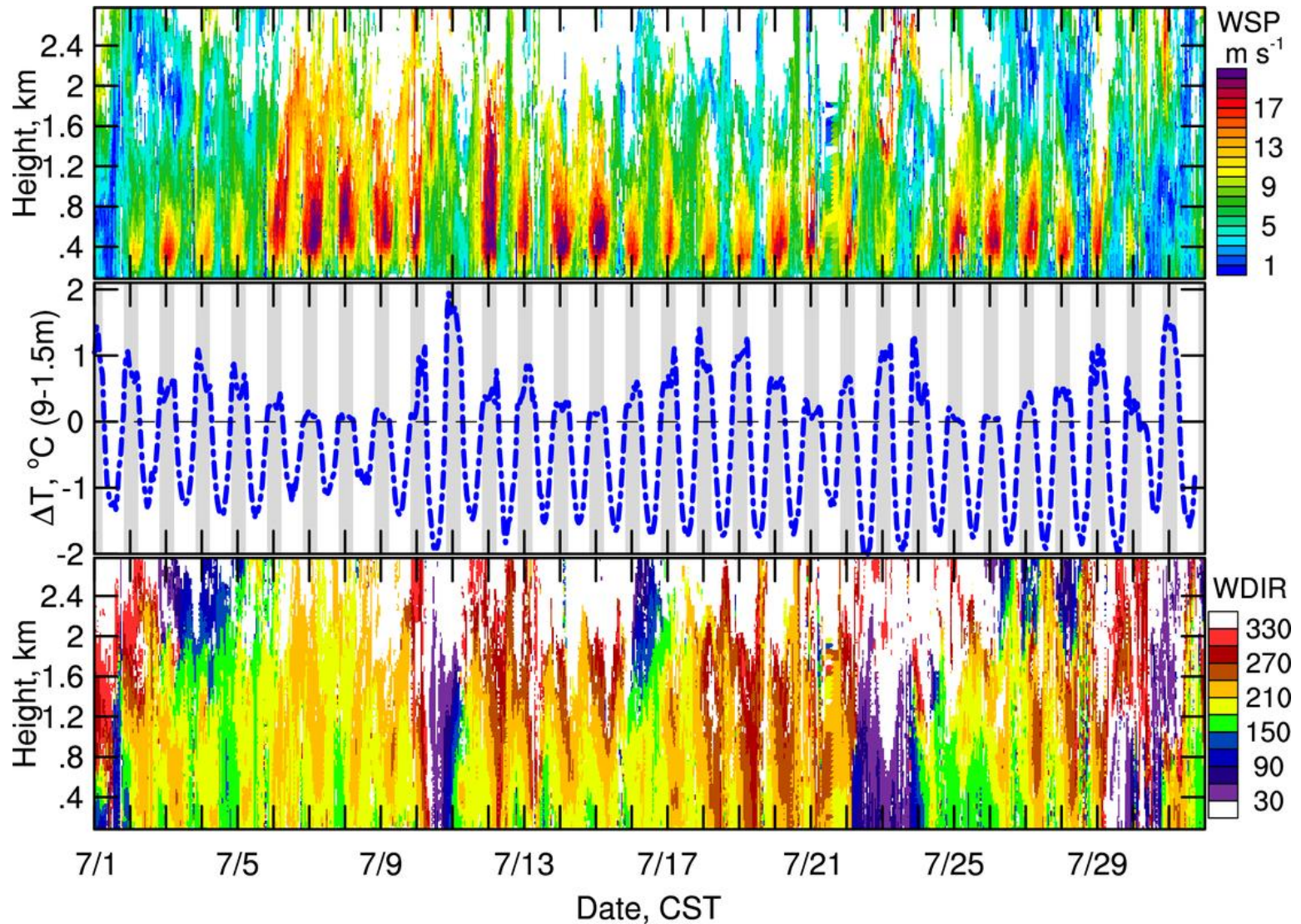
Vertical temperature gradient is a good indicator of coupling strength

Impact of coupling status on dispersion



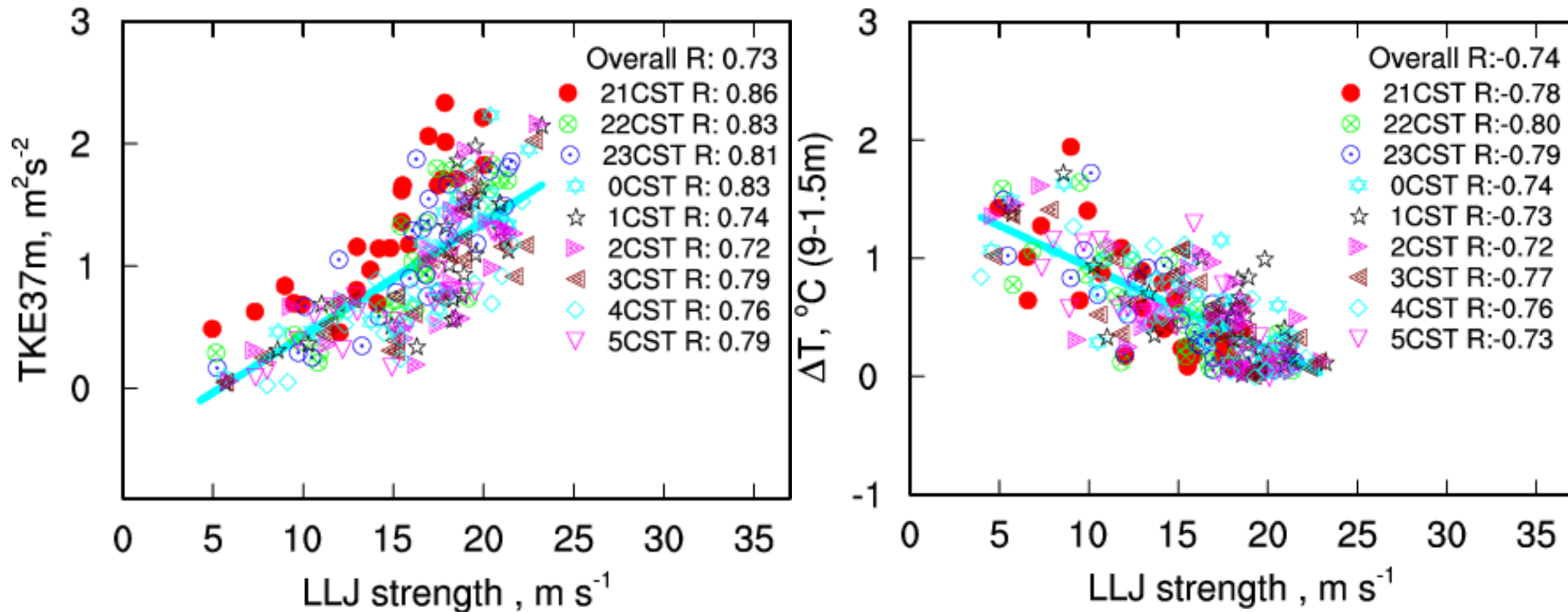
Decoupling leads to pollutants accumulation

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)

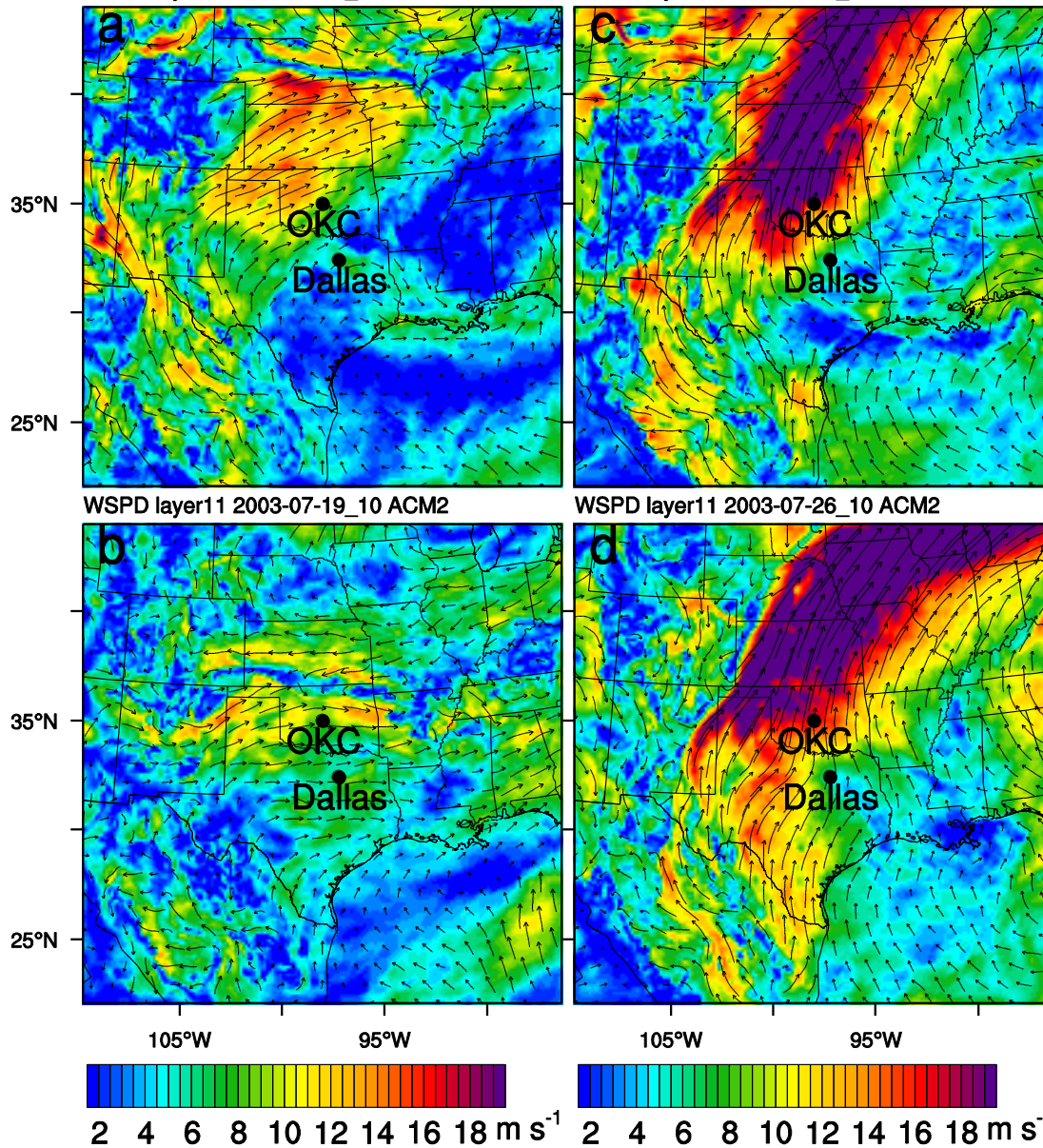
Upper layer wind speeds

Strong UHI

WSPD layer11 2003-07-18_10 ACM2

Weak UHI

WSPD layer11 2003-07-25_10 ACM2



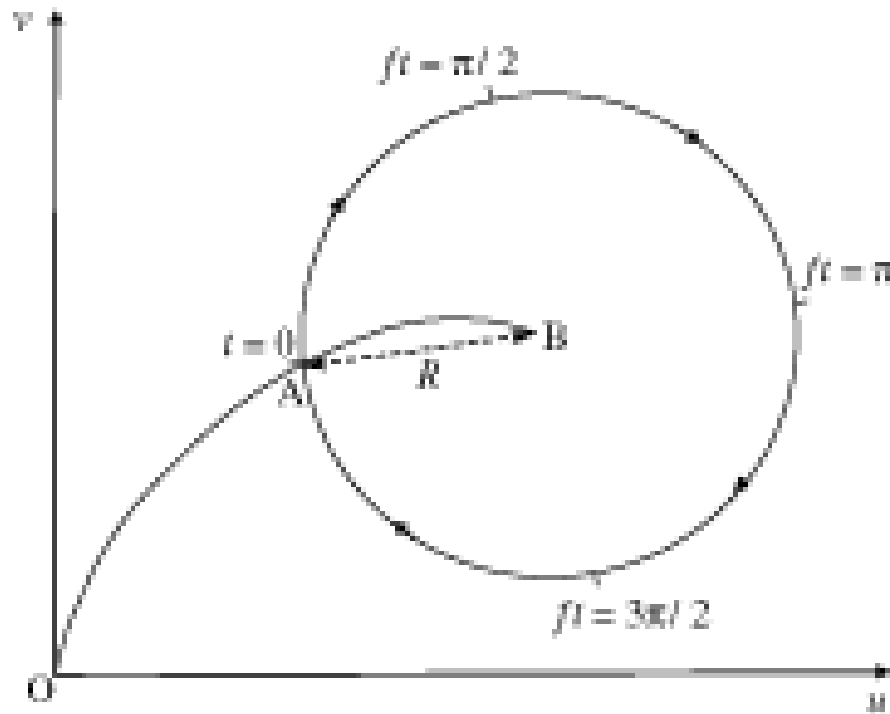
Factors contributing to LLJs:

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

Still controversial!

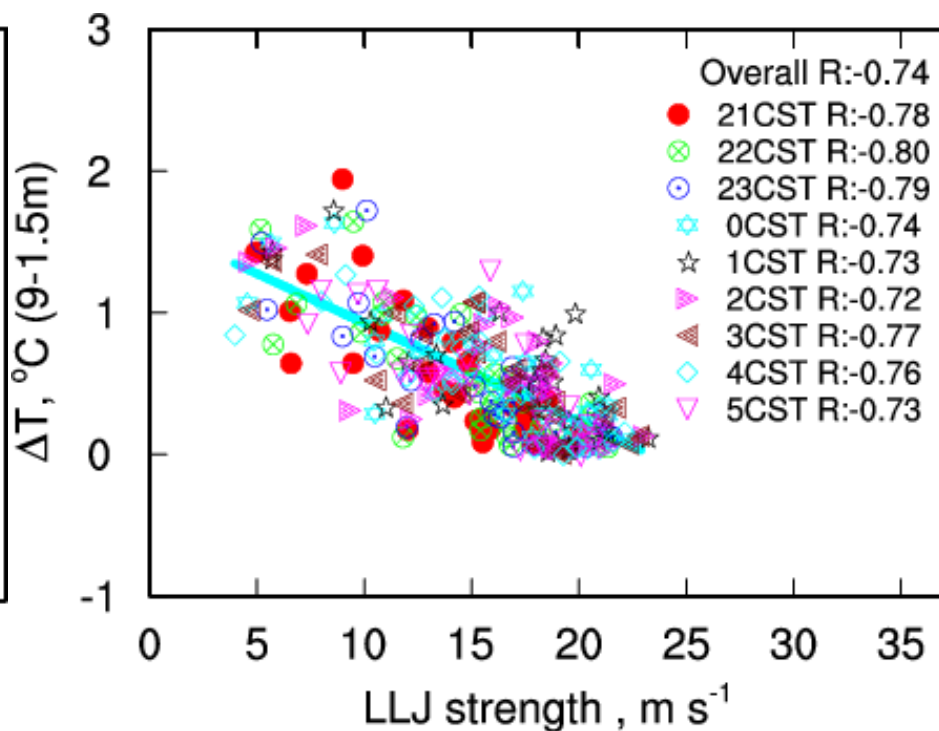
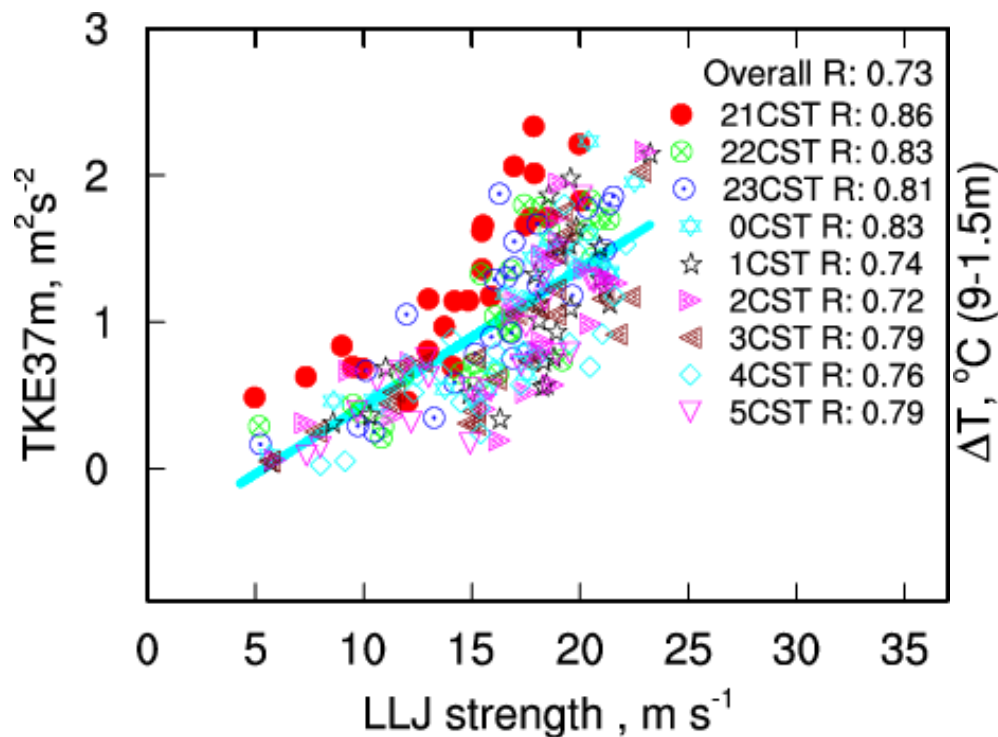
(Shapiro and Fedorovich, 2009)

LLJs formation mechanism(1): inertial oscillation

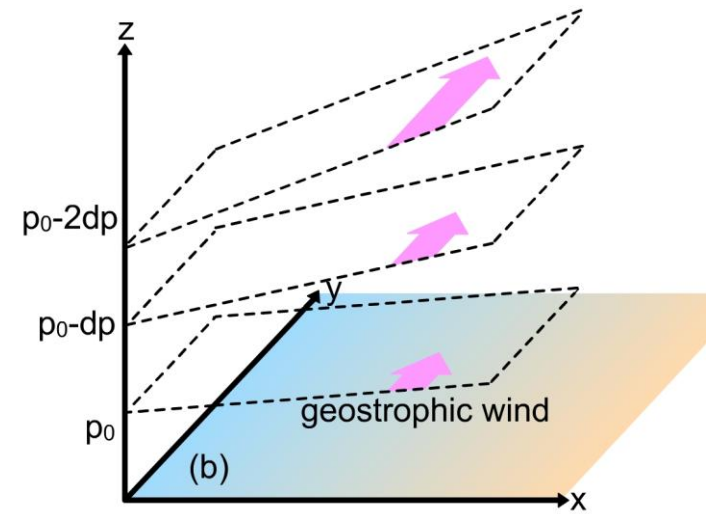
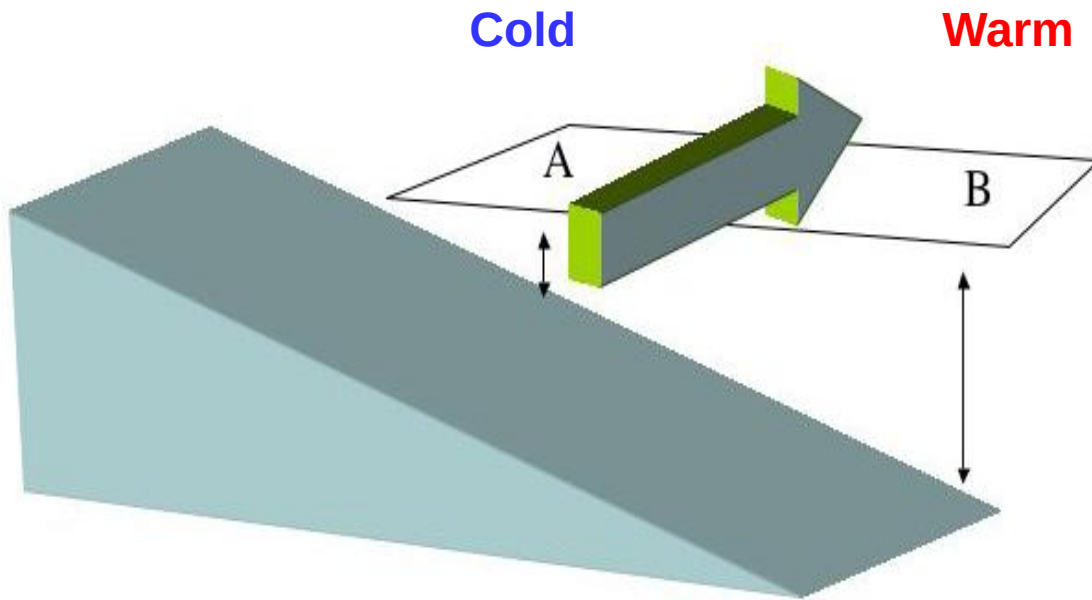


The premise of inertial oscillation is significant decrease of turbulence during the early evening transition. So weaker turbulence, strong decoupling favor LLJs development in this theory. Inertial oscillation also cannot explain location preference.

Strong LLJs are normally associated with strong coupling/turbulence

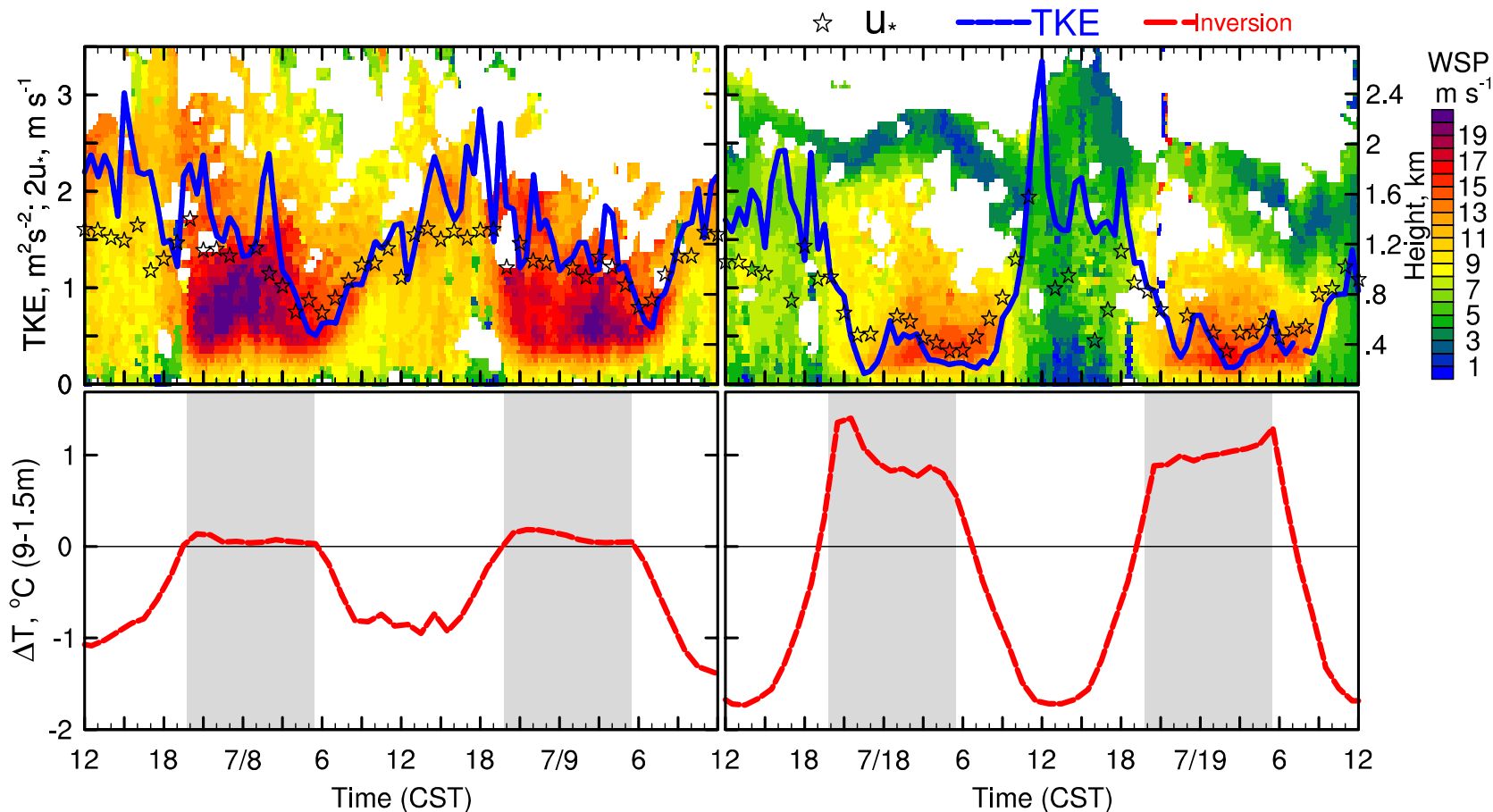


LLJs formation mechanism(2): thermal wind



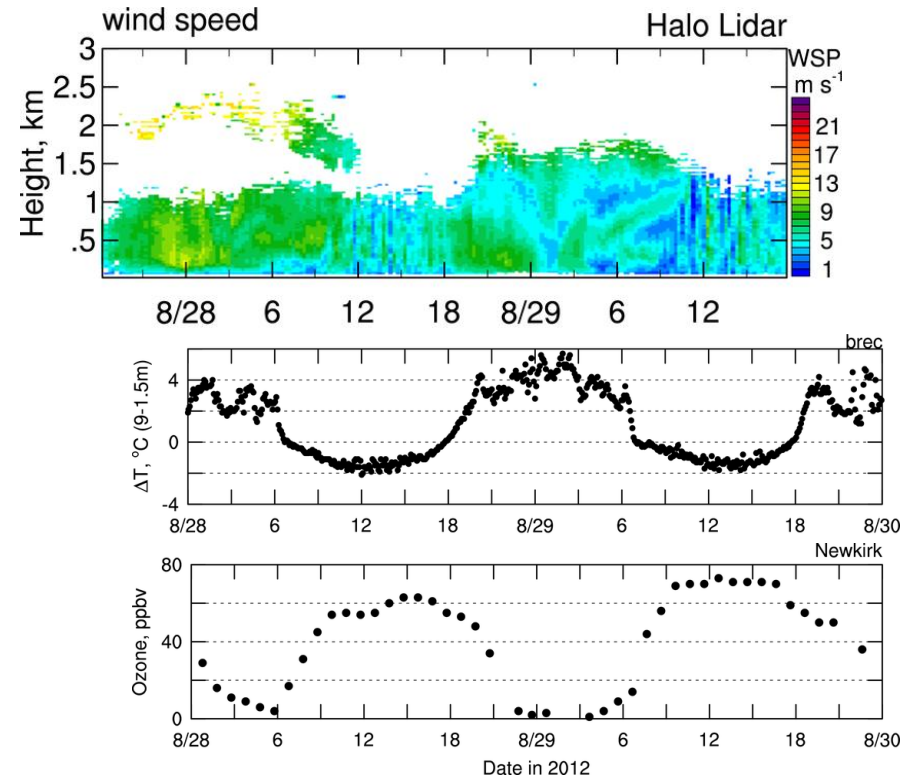
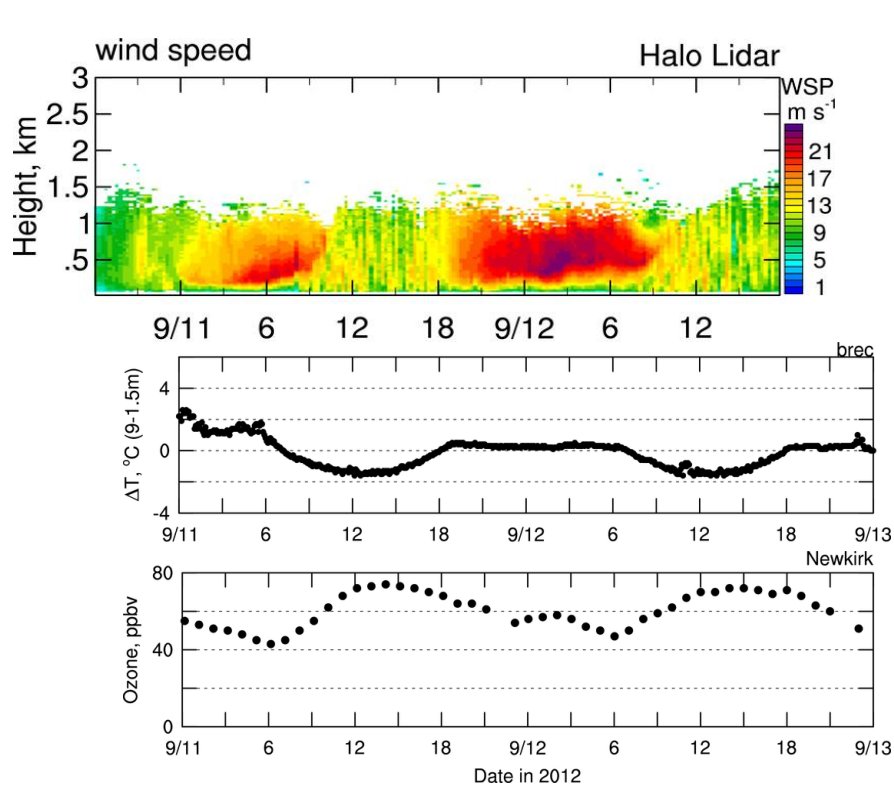
Thermal wind is actually vertical shear of horizontal wind speed

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

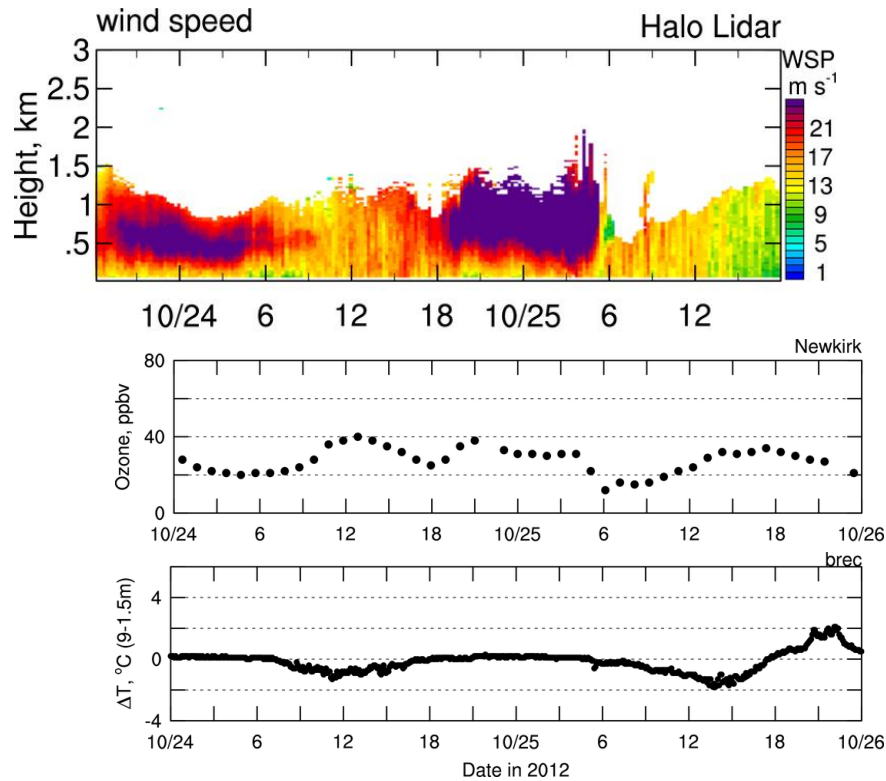
Conclusions

- 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

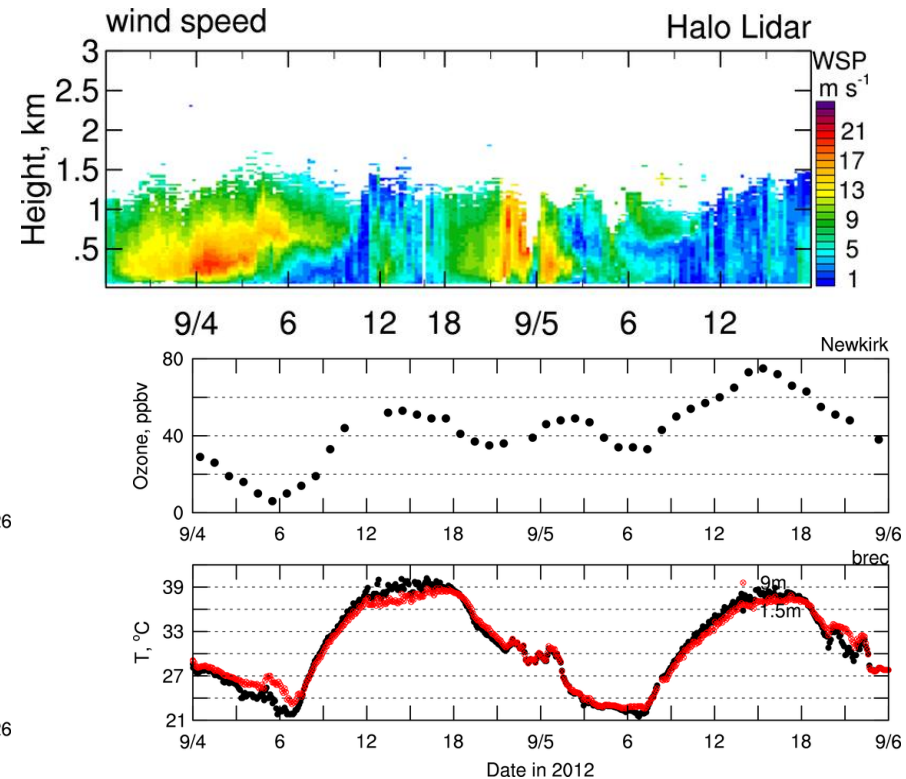
References

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.

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>