First results of the Land-Atmosphere Feedback Experiment (LAFE)

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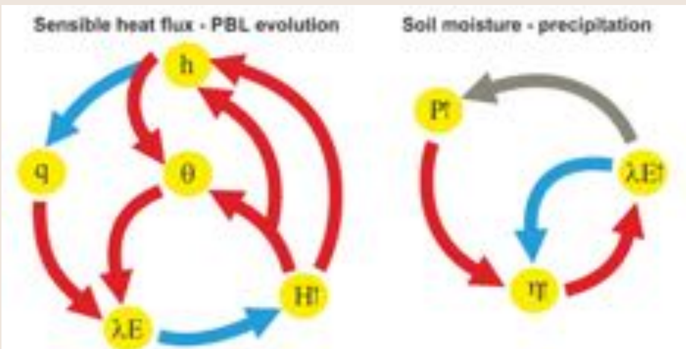
Motivation

- The complexity of land-atmosphere (L-A) interactions can be synthesized into simple processes chain of **Local L-A Coupling ('LoCo')**:

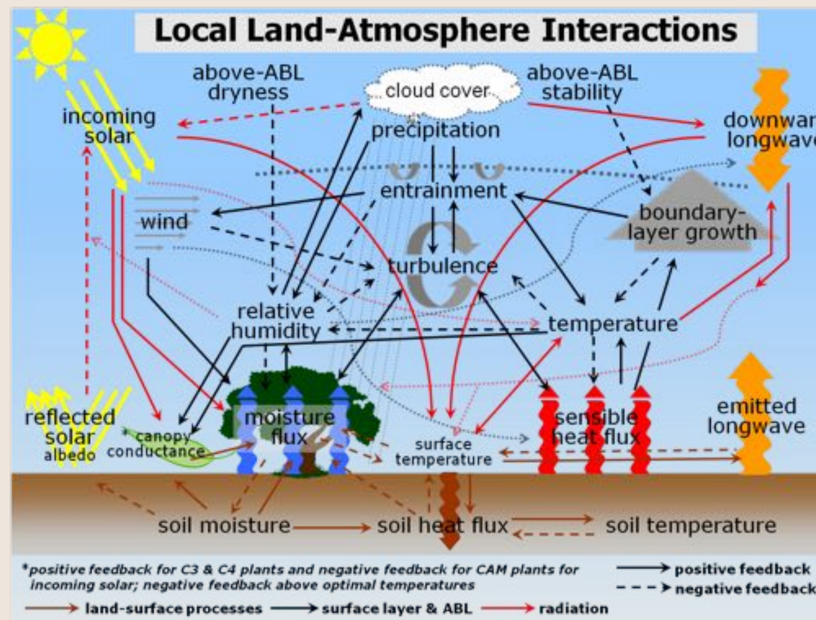
'LoCo Process Chain' $\Delta SM \rightarrow \Delta EF \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T_{2m},Q_{2m}$ ► $\Delta P/Clouds$

(a) (b) (c) (d)



Adopted from van Heerwaarden et al. QJRMS 2009 and Seneviratne et al. ESR 2010

- **Understanding of L-A feedback requires a comprehensive, synergetic observation of the soil-land cover-atmosphere system**
- **Southern Great Plains claimed as hotspot in L-A coupling** ***(e.g., Dirmeyer GRL 2011)***
- **However, metrics depend on model physics and resolution** ***(Hohenegger et al. JC 2009, Santanello et al. BAMS 2018)***



2017 NAS Decadal Survey

- Released January 2018
- Multiple RFI white papers on PBL submitted by GEWEX-GLASS and LoCo
- Additional (independent) PBL submissions by broader community

- **2007 DS: PBL not mentioned as a target**
- **2017 DS: PBL mentioned 129 times(!)**

- Recommended as a high priority, incubator measurement
  - **'High priority'**: Cuts across nearly all panels (Weather, Climate, Hydrology, Ecosystems, Resource Mgmt) and Integrating Themes
    - Most important objective for Weather
  - **'Incubator'**: Measurement/mission approach not mature and needs work – hard problem!

Land-Atmosphere Feedback Experiment (LAFE)

Models are only as good as the data that were used for development and verification.

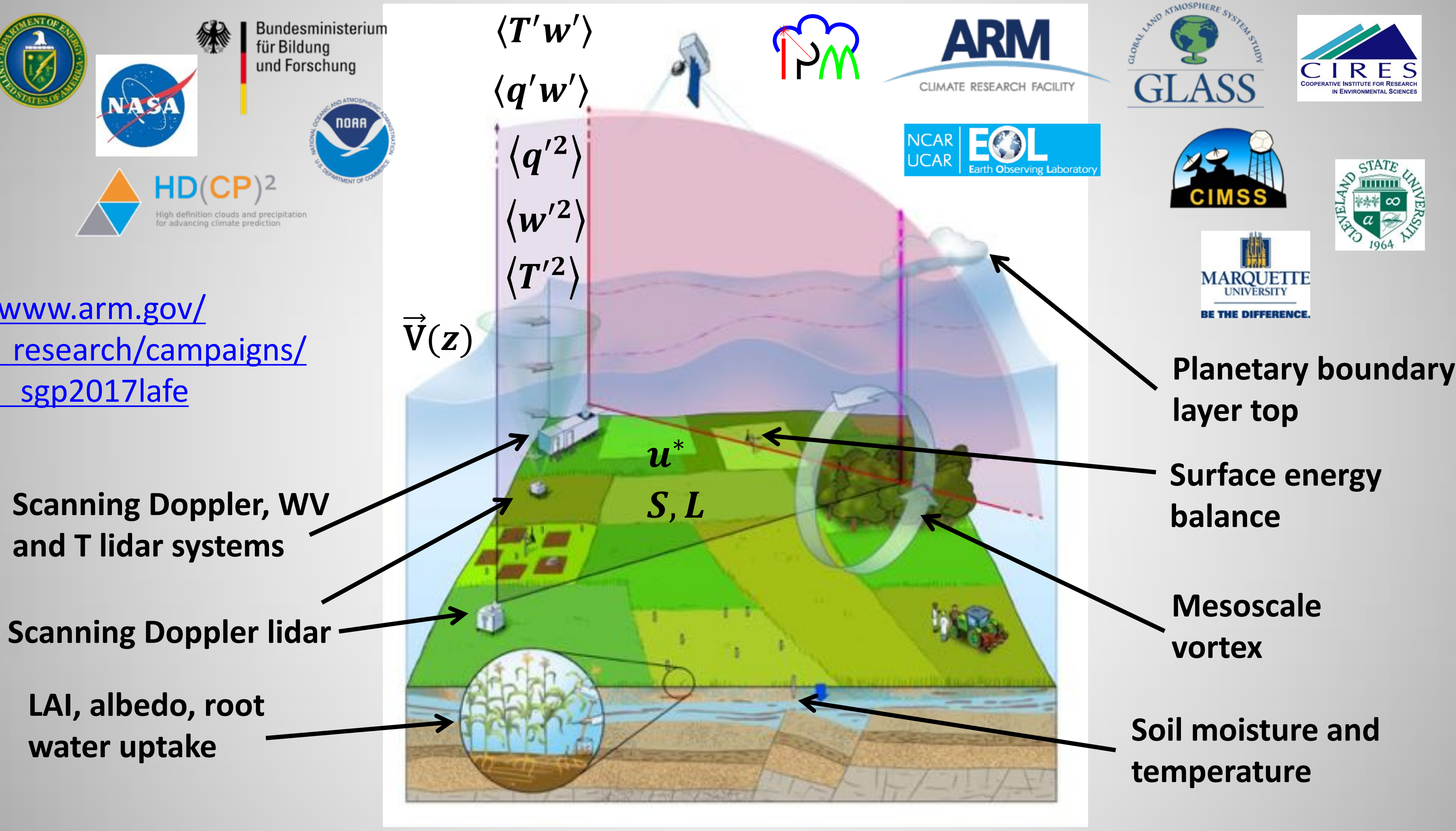
Needed: Thermodynamic profiles, gradients, turbulent fluctuations from the surface to the PBL top.

Recently: Significant progress of remote sensing of thermodynamic varables in PBL.

LAFE Measurement Synergy and Concept

Southern Great Plains Site, USA, 1 – 31 August 2017

www.arm.gov/ research/campaigns/ sgp2017lafe



Novel scanning sensor synergy employed at ARM-SGP site.
Now, it is possible to measure surface and entrainment fluxes simultaneously!

LAFE Objectives and Realization

Wulfmeyer et al., BAMS, 2018.

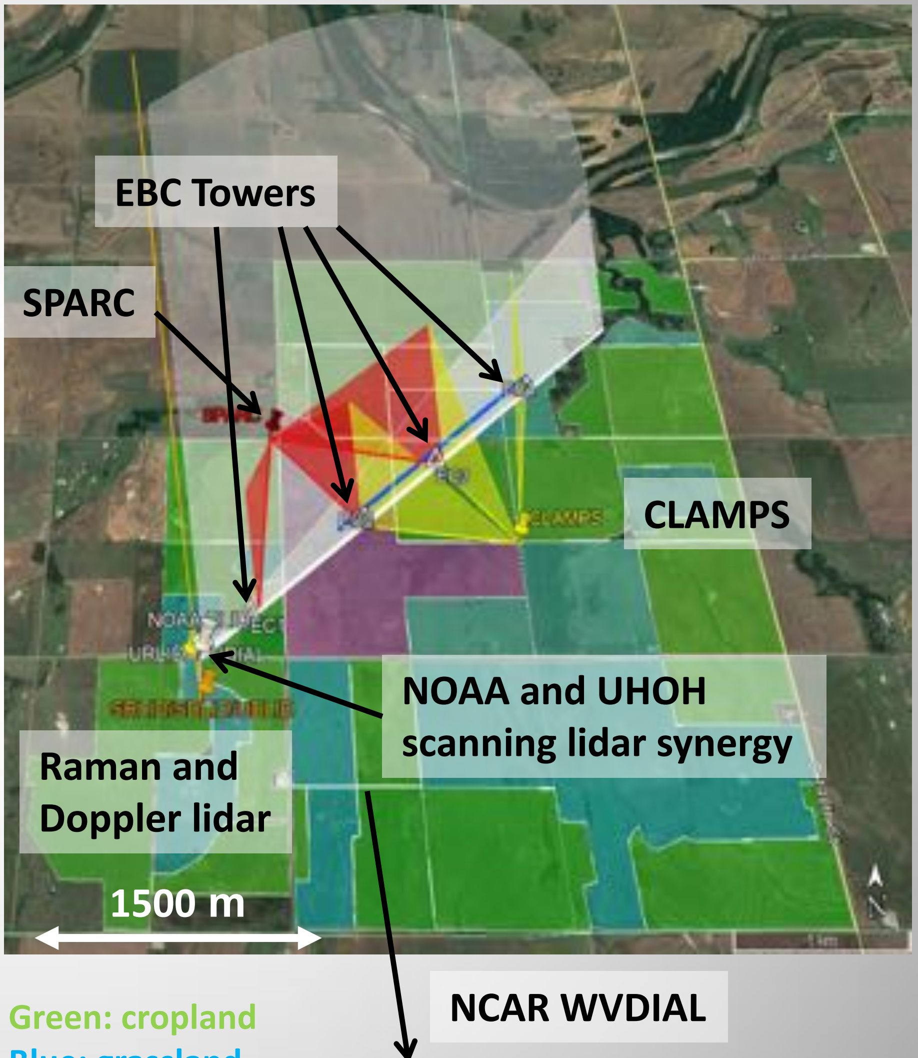
Objectives:

I. Determine turbulence profiles and investigate new relationships among gradients, variances, and fluxes

II. Map surface momentum, sensible heat, and latent heat fluxes using a synergy of scanning wind, humidity, and temperature lidar systems

III. Characterize land-atmosphere feedback and the moisture budget

IV. Verify large-eddy simulation model runs and improve turbulence representations in mesoscale models.



Green: cropland
Blue: grassland
Purple: Natural vegetation mix

Realization:

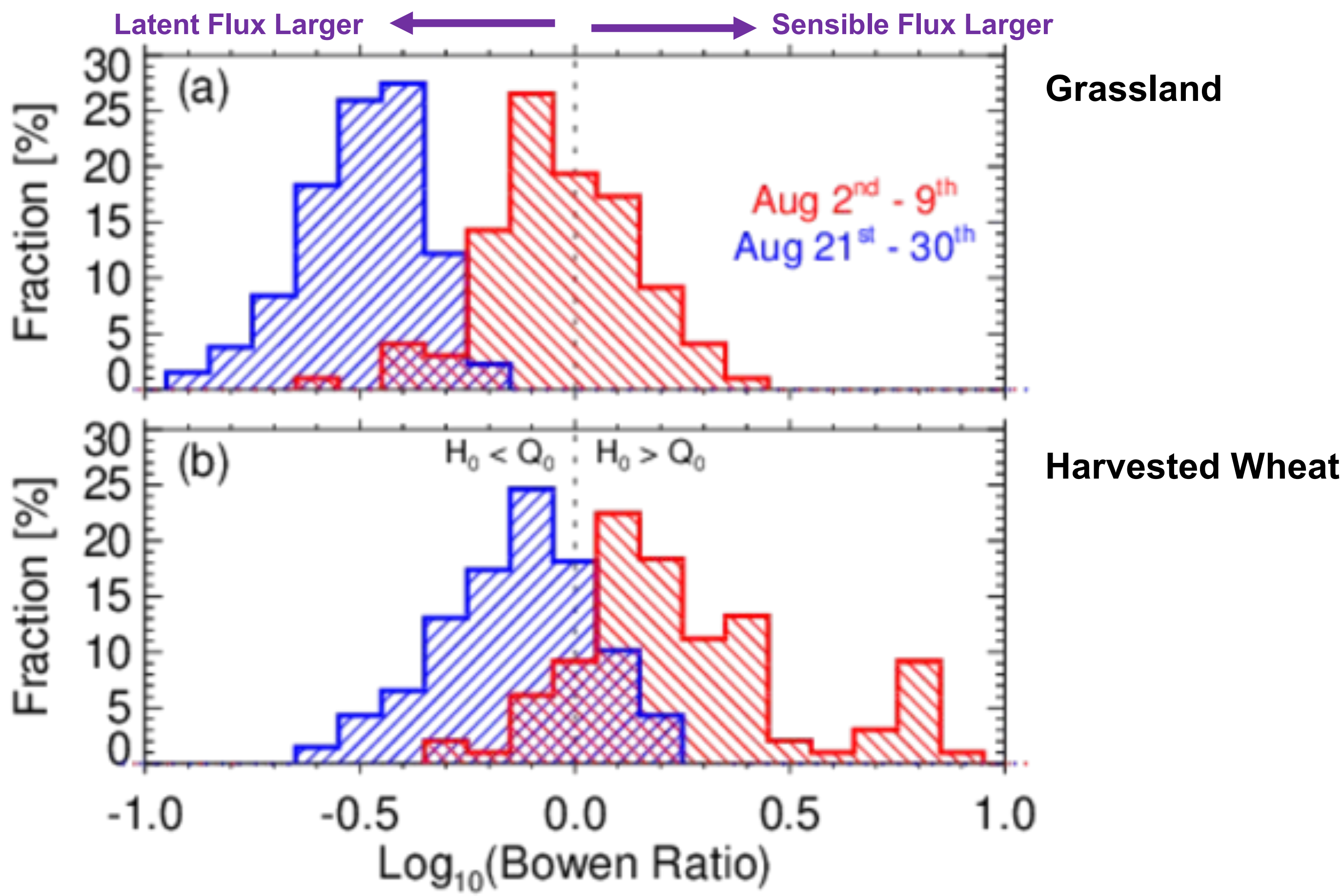
ARM SGP Site, OK, USA, August 2017

8 lidars with synchronized scans

(& more around…)

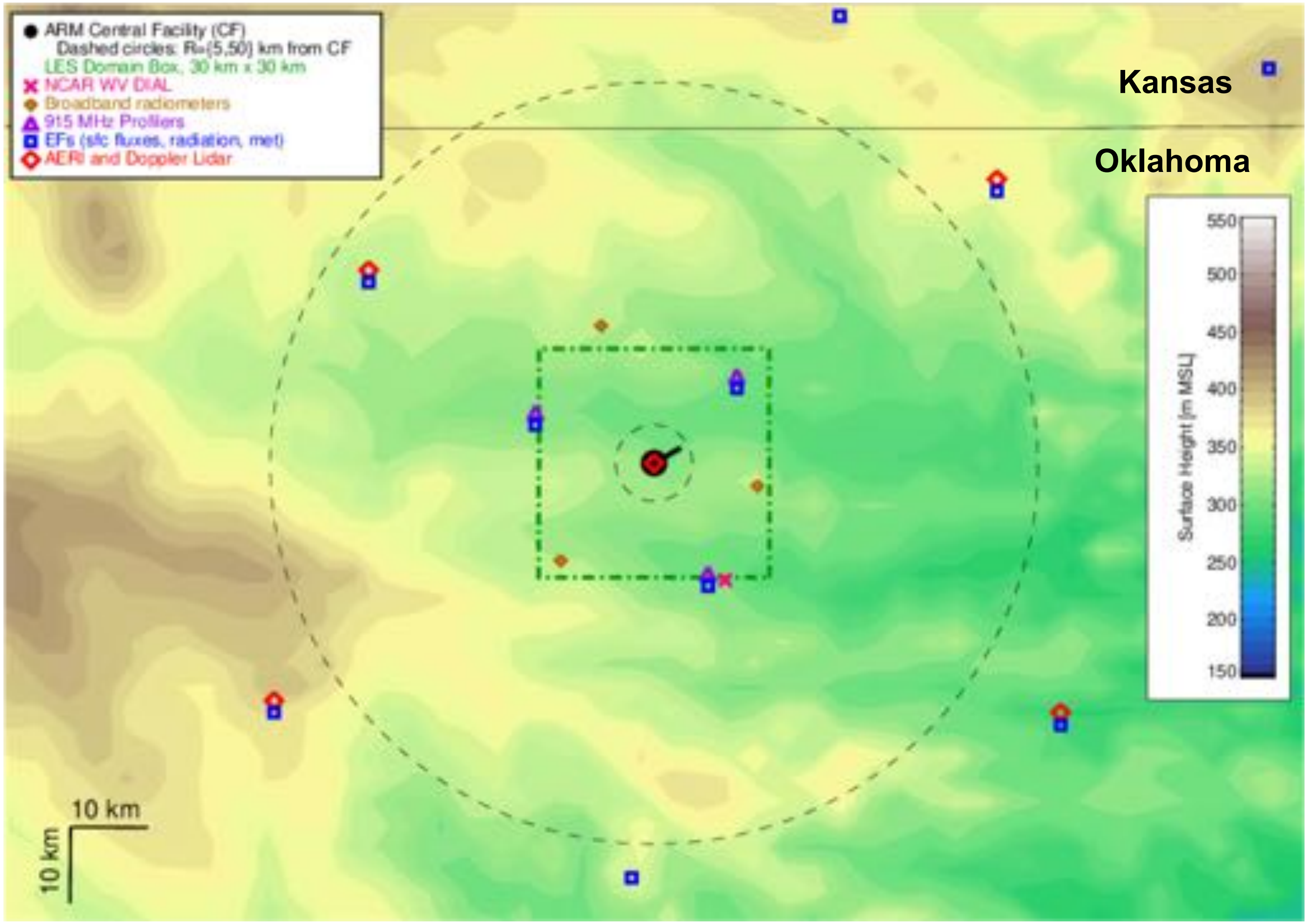
Wide Range of Sfc Conditions

$$Bowen\ Ratio = \frac{Sensible\ Heat\ Flux}{Latent\ Heat\ Flux}$$



Courtesy Dave Turner, NOAA, ESRL

Large Scale Instrument Setup



Three Amigos - Scanning Along Main RHI

NOAA / ESRL / CSD Scanning Doppler Lidar

UHOH Scanning Temperature Raman Lidar

UHOH Scanning Water Vapor Differential Absorption Lidar (DIAL)

IPM 3D Temperature- and Water-Vapor-Raman Lidar

3D scanning, active remote systems with extraordinary turbulence resolution and accuracy.

Radlach et al. ACP 2008,
Wulfmeyer et al. BLM 2010,
Hammann et al. ACP 2015,
Behrendt et al. ACP 2015,
Wulfmeyer et al. JAS 2016

IPM 3D Water-Vapor Differential Absorption Lidar

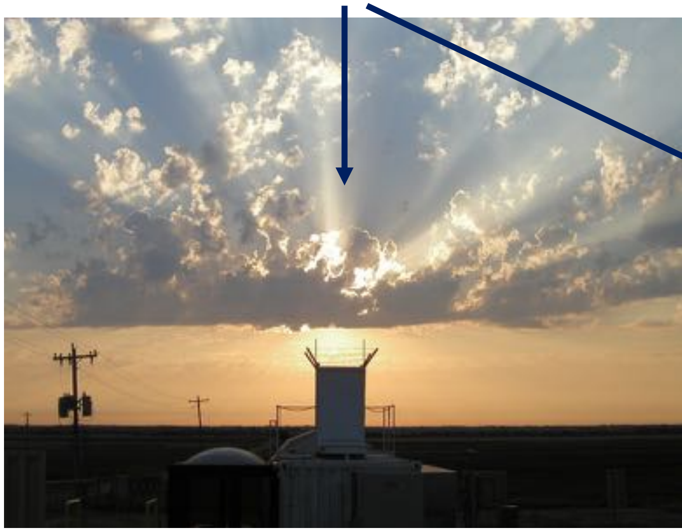
Wagner et al. AO 2011, 2013; Späth et al. AMT 2016; Muppa et al. BLM 2016

SPARC, University of Madison-Wisconsin

CLAMPS, University of Oklahoma

NOAA CSD Doppler Lidar

SGP Raman Lidar



UHOH and SGP Doppler Lidars

EBC Station

3 Scanning Lidars in Action

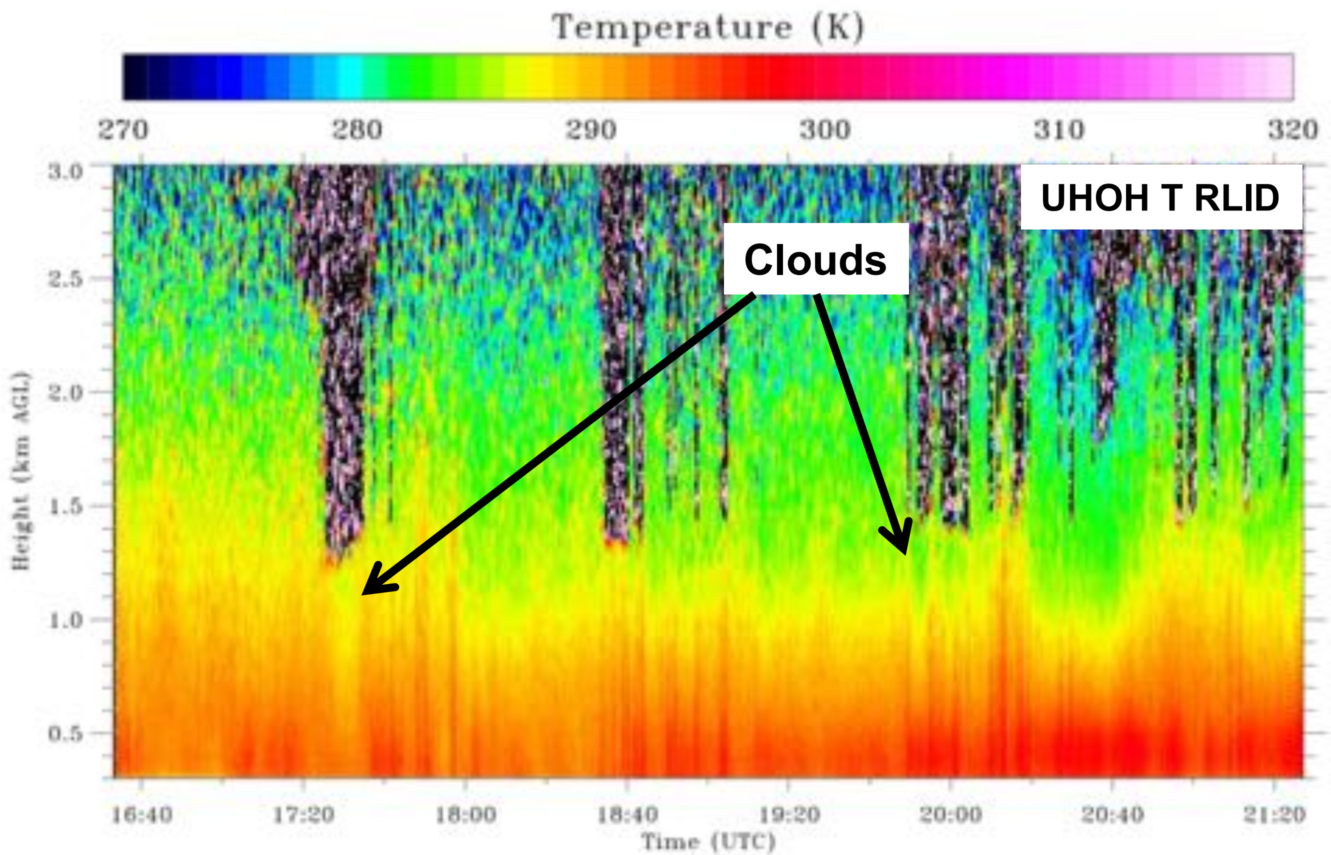
Also important installations...

SGP Site

Power Converter

Barbecue Grill

First Highlights:
I) High resolution T, q, w profiles



SOP2 staring vertically for entire afternoon, August 26, 2017. All resolutions: 10 s, 60 m

Resolutions sufficient for studying mean profiles, gradients, flux profiles, and higher-order moments of turbulent fluctuations.

Evaluation of Turbulence Parameterizations (TP)

Yonsei University (YSU) non-local TP ***(Hong, Noh and Dudhia MWR 2006)*****:**

$$Q_{YSU}(z) = -K_h(z)\frac{\partial q(z)}{\partial z} + \langle w' q' \rangle_I \left(\frac{z}{z_i}\right)^3$$

$$K_h(z) = \frac{K_p(z)}{\Pr(z)}; \quad K_p(z) = -\kappa w^* z \left(1 - \frac{z}{z_i}\right)^2$$

$$\Pr(z) = 1 + (\Pr_0 - 1)\exp\left[-3\frac{(z - 0.1\, z_i)^2}{z_i^2}\right]$$

$$\Pr_0 = \frac{\phi_m}{\phi_h} + c; \quad \langle w' q' \rangle_I = -\frac{d\,\langle w' \theta' \rangle_0}{\Delta\theta|_I}\Delta q|_I$$

Total latent heat flux

Turbulent latent heat flux at the inversion layer

CBL height

Eddy diffusivity for momentum

Eddy diffusivity for q and T

Mixed-layer velocity scale

Von Karman constant = 0.4

Prantl number, depends on z in YSU (!)

Turbulent latent heat flux at the inversion layer

…at top of SL

Turbulent sensible heat flux at the top of the SL

Profile functions according to MO similarity; same for I and SL

Gradients at the inversion layer

Proportionality factor

Evaluation of Turbulence Parameterizations (TP)

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$$\Pr_0 = \frac{\phi_m}{\phi_h} + c; \quad \langle w'q' \rangle_I = -\frac{d\langle w'\theta' \rangle_0}{\Delta\theta|_I}\Delta q|_I$$

from lidar

from EBC systems

deduced

Simultaneous measurements of fluxes and gradients of T, WV, and wind provide unique data for advanced process studies, model verification, and studies of turbulence parameterizations.

Wulfmeyer et al., JAS, 2016.

Evaluation of Turbulence Parameterizations

MYNN local parameterization with TKE (e^2) closure *(Nakanishi and H. Niino, JMSJ 2009)*:

$$\frac{\partial e^2}{\partial t} = \frac{\partial}{\partial z}\left[\overline{\boldsymbol{w}'\left(\boldsymbol{e}^2 + 2\frac{\boldsymbol{p}'}{\boldsymbol{\rho}_0}\right)}\right] - 2\overline{\boldsymbol{u}'\boldsymbol{w}'}\frac{\partial \bar{u}}{\partial z} - 2\overline{\boldsymbol{v}'\boldsymbol{w}'}\frac{\partial \bar{v}}{\partial z} + 2\frac{g}{\theta_0}\overline{\boldsymbol{w}'\boldsymbol{\theta}_v'} - 2\boldsymbol{\varepsilon} \rightarrow \varepsilon = \frac{e^3}{B_1 l}$$

$$\overline{u'w'} = -\boldsymbol{K_m}\frac{\partial \bar{U}}{\partial z} \qquad \overline{v'w'} = -\boldsymbol{K_m}\frac{\partial \bar{V}}{\partial z} \qquad K_m = \boldsymbol{l}e\boldsymbol{S_m}$$

$$\overline{w'\theta'} = -\boldsymbol{K_h}\frac{\partial \bar{\theta}}{\partial z} \qquad K_h = le\boldsymbol{S_h}$$

$$l_t = 0.23\frac{\int_0^\infty ezdz}{edz} \qquad \frac{1}{l} = \frac{1}{\boldsymbol{l_s}} + \frac{1}{\boldsymbol{l_t}} + \frac{1}{\boldsymbol{l_b}}$$

$$S_h = \alpha_c A_2 \frac{\Phi_2 - 3C_1\Phi_5}{D}$$

$$\Phi_2 = 1 - 9\alpha_c^2 A_1 A_2 (1 - C_2)\boldsymbol{G_H}$$

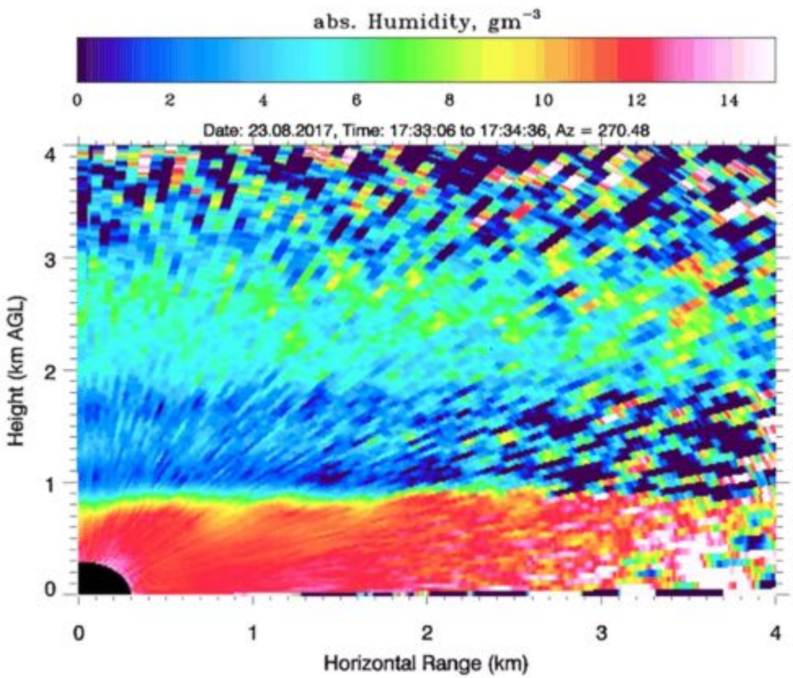
$$G_H = -\frac{l^2}{e^2}\frac{g}{\theta_0}\frac{\partial \theta_v}{\partial z}$$

$$G_M = \frac{l^2}{e^2}\left[\left(\frac{\partial \bar{u}}{\partial z}\right)^2 + \left(\frac{\partial \bar{v}}{\partial z}\right)^2\right]$$

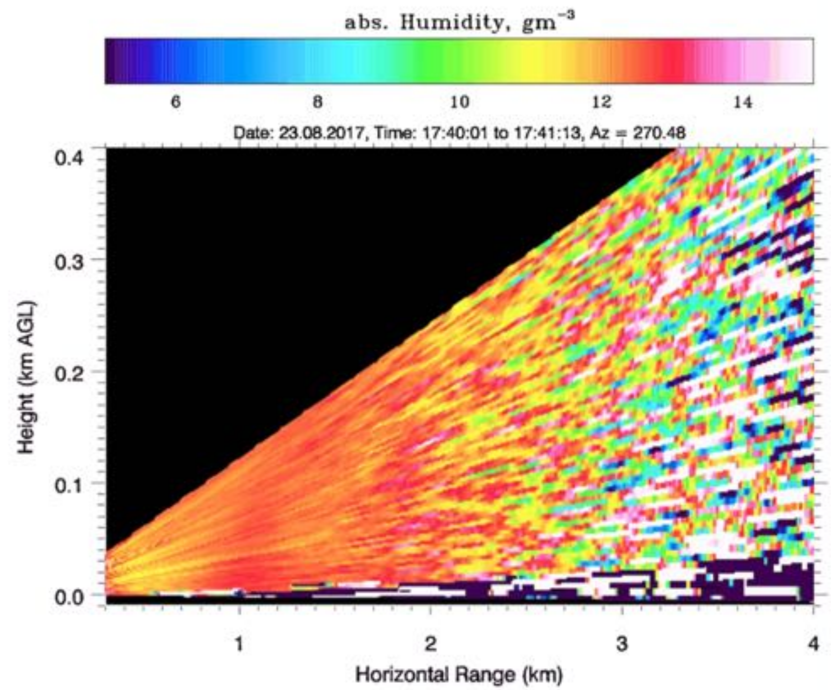
$$\Phi_5 = 6\alpha_c^2 A_1^2 \boldsymbol{G_M}$$

Simultaneous measurements of fluxes, TKE, and gradients of T, WV, and wind provide unique data for studying and deriving turbulence parameterizations.

II) Evening transition, IOP11, Aug. 23, 2017



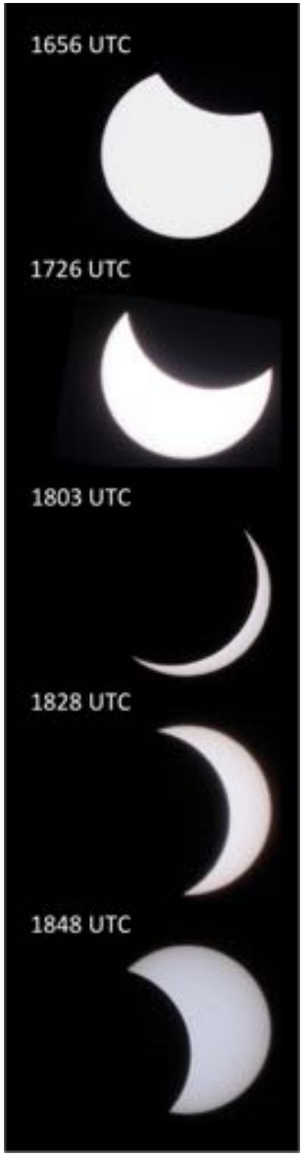
10-Minute Boundary Layer Scans, 0 to 90°

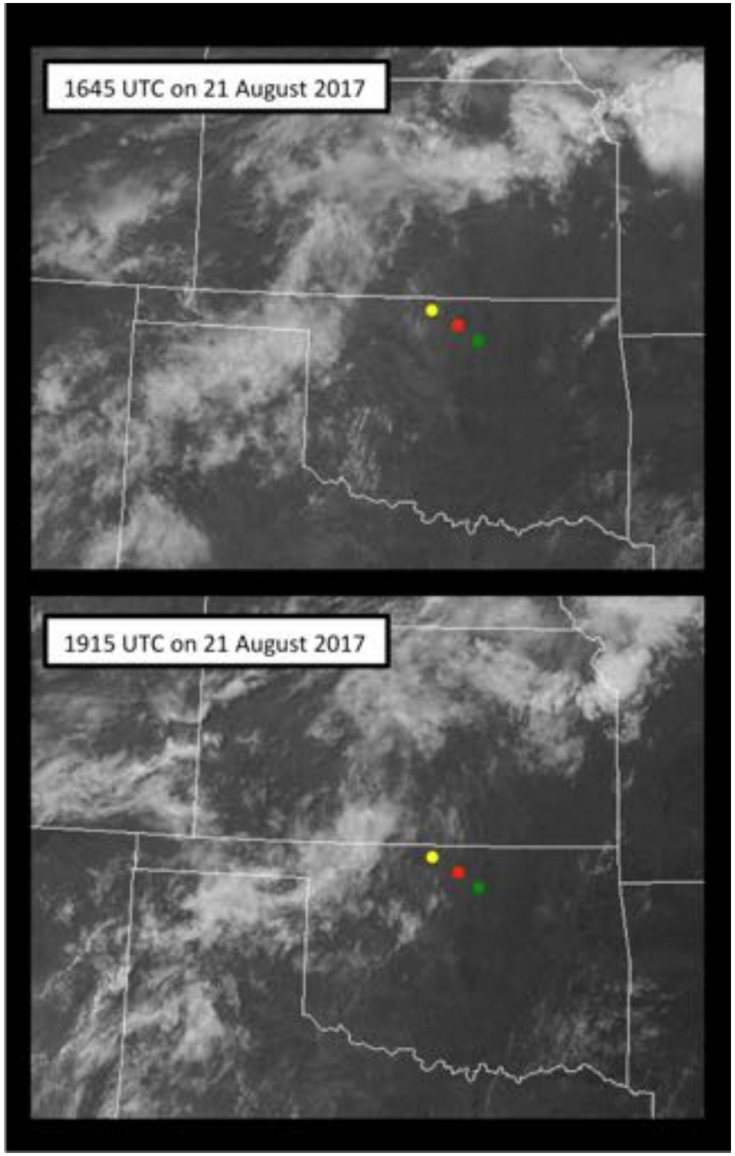


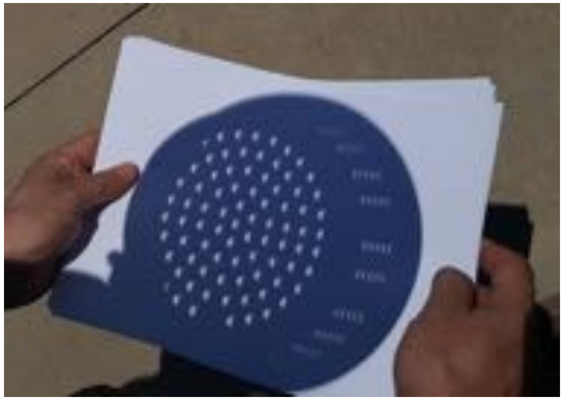
50-Minute Surface Layer Scans, 0 to 7°

Observations question the validity of Monin-Obukhov theory in complex terrain. Development of new parameterizations of surface fluxes in heterogeneous terrain my be necessary.

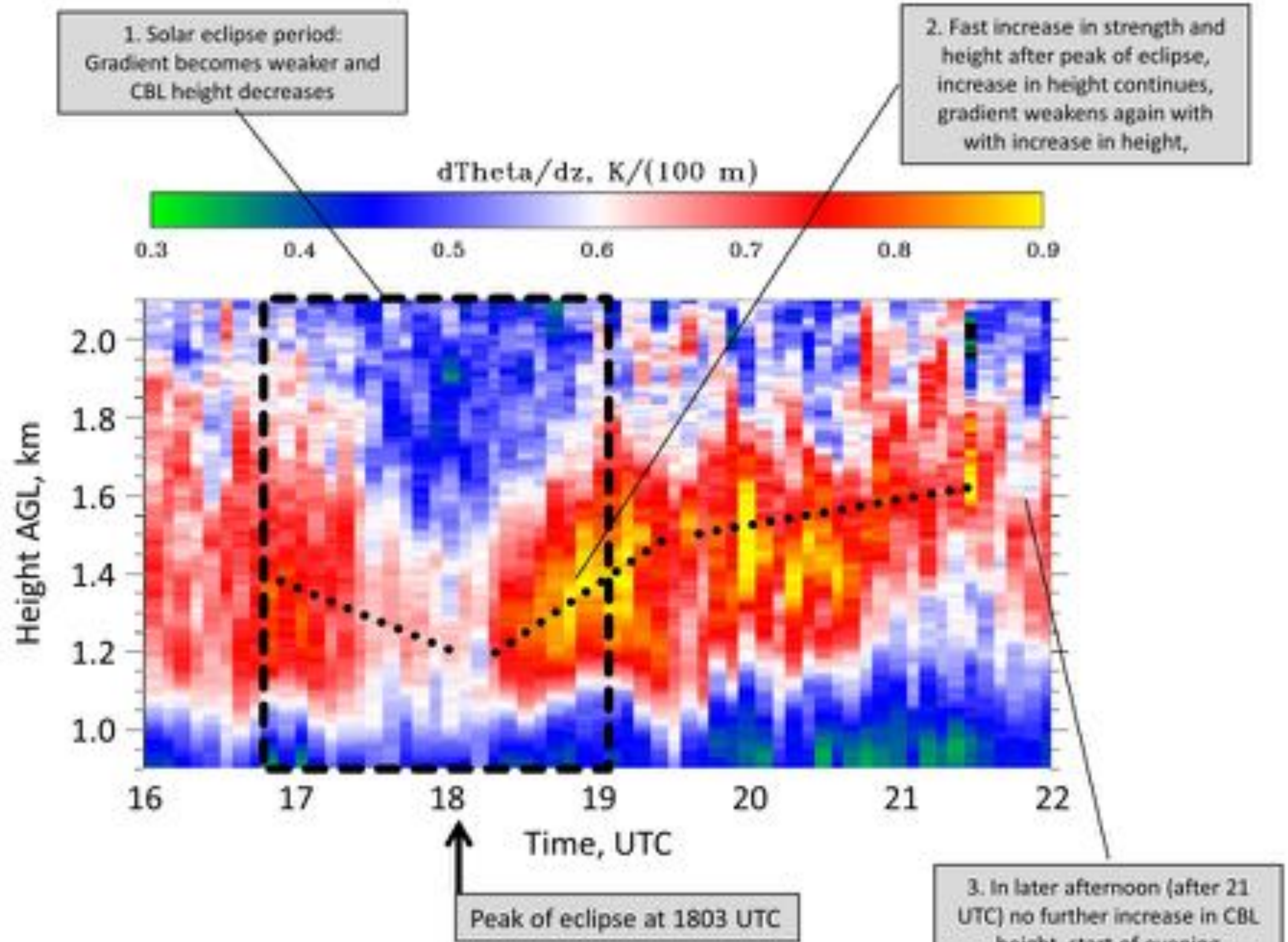
III) Solar Eclipse, August 21, 2017, Some Impressions





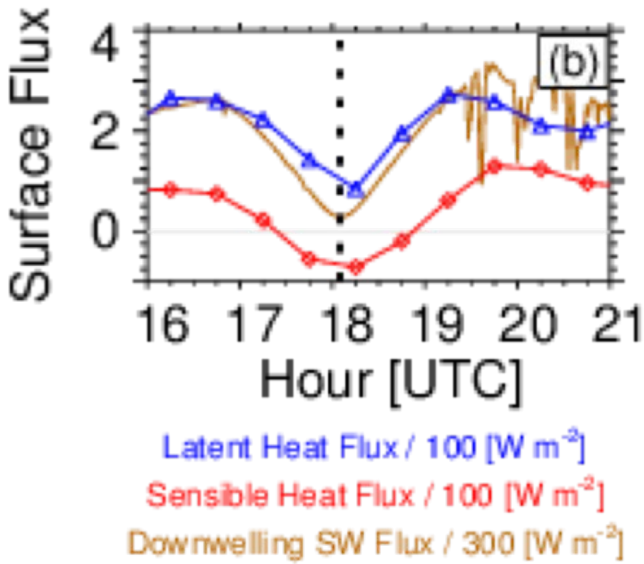


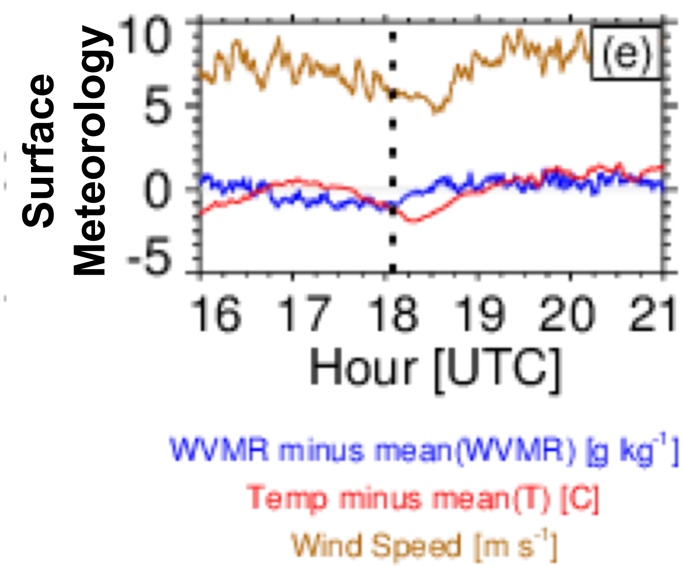
Solar Eclipse, 21 August 2017



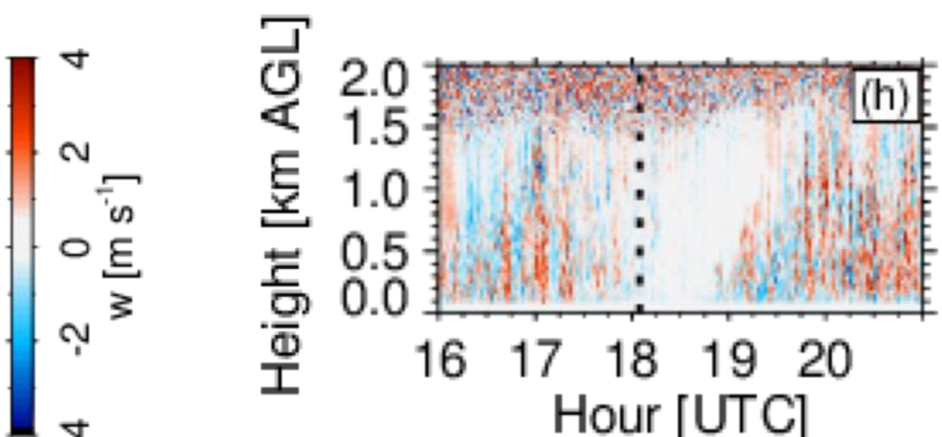
UHOH Temperature RotationalRaman Lidar

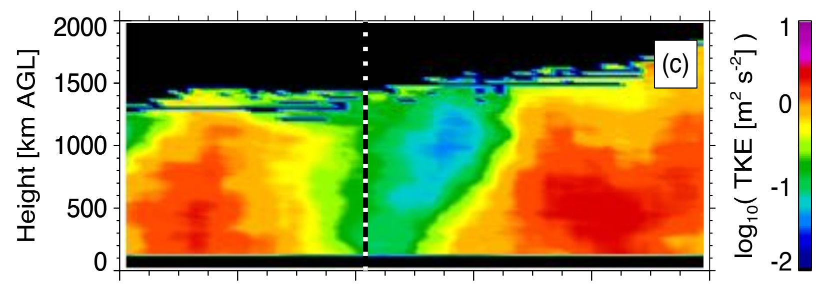
The Input and the Surface Response



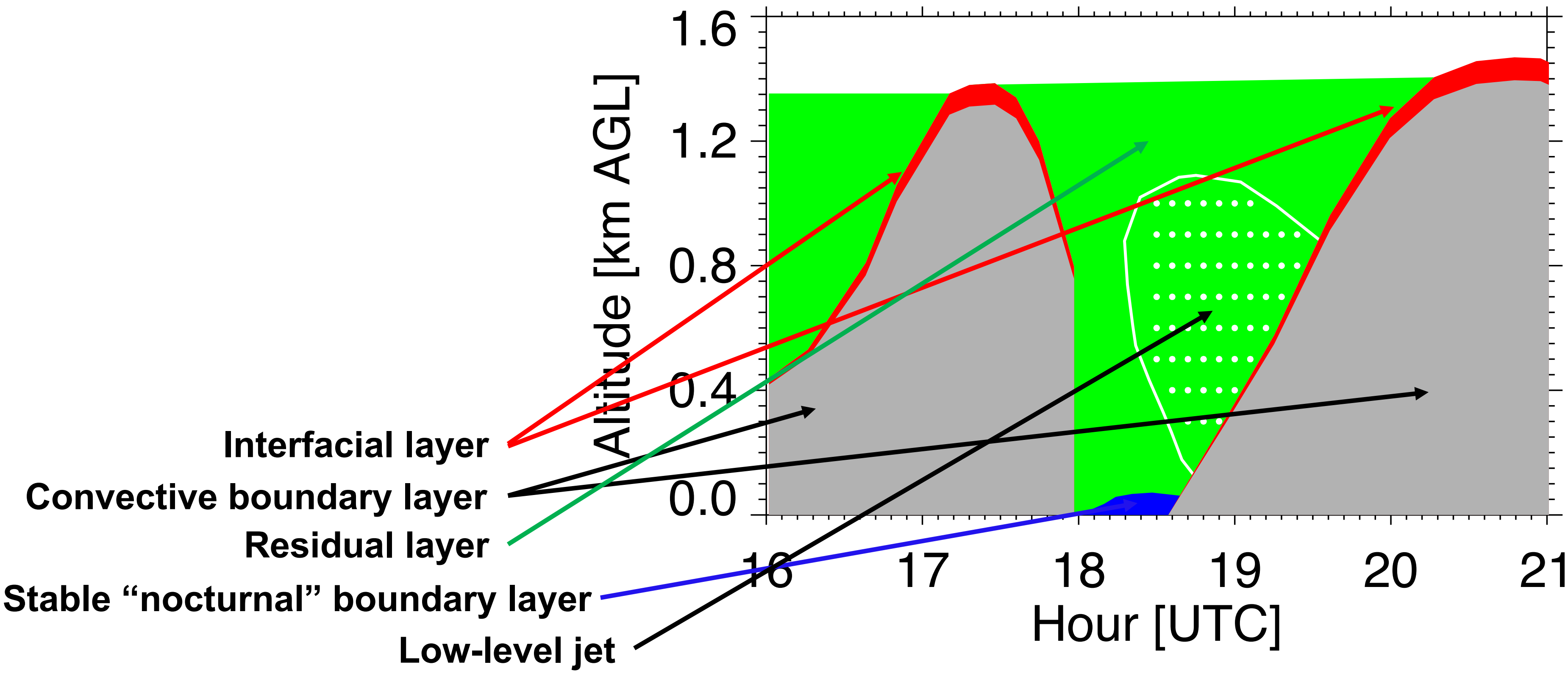


The PBL's Response





Evolution of PBL during the Eclipse



Turner, D.D., V. Wulfmeyer, A. Behrendt, T.A. Bonin, A. Choukulkar, R.K. Newsom, W.A. Brewer, and D.R. Cook, 2017: Response of the land-atmosphere system over north-central Oklahoma during the 2017 eclipse. Geophys. Res. Lett., DOI:10.1002/2017GL076908.

LAFE Modelling Activities

Model	Configuration	Horizontal grid increments	Turbulence parameterizations	Land-surface and vegetation parameterization	Rsearch center and reference
WRF-NOAH-MP	LAM driven by ECMWF analysis with data assimilation	Mesoscale to turbulence permitting (100 m)	MYNN, YSU in the out domains, NA in the inner domain	MOST; Jarvis and Ball-Berry schemes	UHOH (Schwitalla et al. 2017)
WRF-NOAH	LAM driven by analyses	Mesoscale to turbulence permitting (50 m)	e.g., MYNN, YSU in the out domains, NA in the inner domain	MOST, Jarvis and Ball-Berry schemes	ARM LASSO project[1]
PALM	Periodic LAM driven by ECMWF analyses	1-50 m	NA	TESSEL scheme from ECMWF; MOST or surface layer fully resolved	University of Hannover (Maronga et al. 2015)
DALES	Periodic LAM driven by ARM variational analysis	5-100 m	1.5-order TKE	MOST	Cleveland State University (Heus et al. 2010)
COMMAS	Periodic or specified boundaries from analyses	10-500 m	NA	MOST	NOAA ARL
ICON-LES	Global with grid refinement	100 m	NA	MOST; plant type parameterization	to be confirmed

Summary

- **LAFE provides a unique data set for studying L-A feedback and model verification**
- **Excellent performance of all instruments by far exceeding expectations**
- **13 IOPs, from which two contain an evening transition (IOPs 11 and 13) and one includes the solar eclipse (IOP10)**
- **Several special obs. testing vertical pointing and PPI scanning modes**
- **Highlights:**
  - ➢ **First 2D measurements of water-vapor and temperature fields from the surface to the lower troposphere**
  - ➢ **New operation modes of Doppler lidars**
  - ➢ **New synergetic data sets for surface profile and flux derivations**
  - ➢ **Solar eclipse natural feedback experiment**
- **Great opportunity for process studies and collaborations merging observationalists and modelers. Data available from March 1, 2018!**

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