TKE BUDGETS AND DISSIPATION RATES IN DISTURBED STABLE BOUNDARY LAYERS

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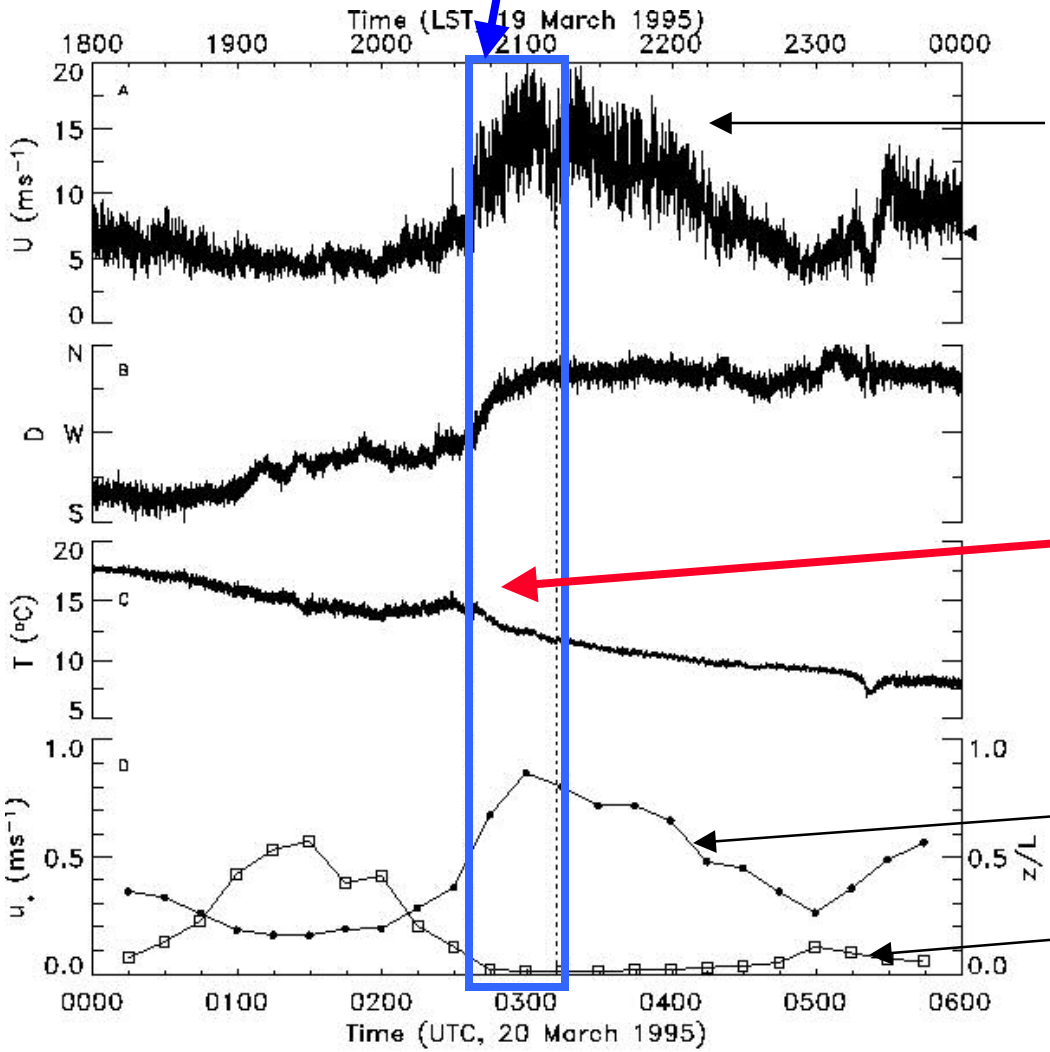
l_ε is a fundamental underpinning of boundary-layer parameterizations

- **Problems with TKE parameterizations frequently occur in stably stratified nocturnal conditions (Holtslag & De Bruin, 1988; Beljaars & Holtslag, 1991; McNider et al., 1995; Derbyshire, 1999; Poulos & Burns, 2003)**
- **Representation of TKE dissipation, ε, is often in terms of a dissipation length, l_ε (Louis et al., 1983; Schumann, 1991; Cheng and Canuto, 1994)**

$$\varepsilon = \frac{e^{3/2}}{l_\varepsilon}$$

So can we look at two disturbances of stable boundary layers, a frontal passage and a density current, and generalize how TKE and l_ε behave through these disturbances?

A dry Arctic cold front sweeps through Kansas (MICROFRONTS, 1995; Blumen & Mahrt, PIs)



Increased wind speed and wind speed variance coincident with the front

Slight warming preceding the front; partially masked by nocturnal cooling

u* increases

Developing stability is eroded to near-neutral

CALCULATIONS OF TKE BUDGETS

Using sonic anemometers at 10m, we can evaluate most of the terms within the TKE budget.

STORAGE — SHEAR PRODUCTION, S — BUOYANT PRODUCTION, P — DISSIPATION

$$\frac{\partial}{\partial t}\overline{e} = -U_j\frac{\partial \overline{e}}{\partial x_j} - \overline{u_i u_j}\frac{\partial U_i}{\partial x_j} + \delta_{i3}\frac{g}{\theta_v}\overline{u_i\theta_v} - \frac{\partial}{\partial x_j}\overline{u_j e} - \frac{1}{\rho}\frac{\partial}{\partial x_i}\overline{u_i p} - \varepsilon$$

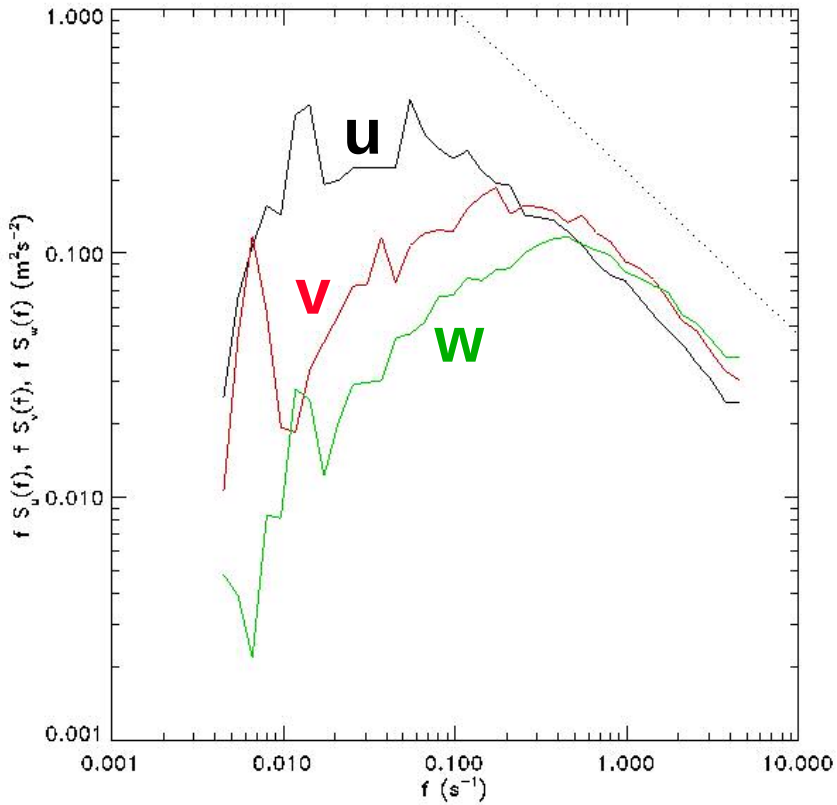
MEAN ADVECTION — TURB TRANSPORT — PRESSURE TRANSPORT

All remaining terms can be calculated from observations and evaluated to within the accuracy of the instrumentation.

Dissipation rate is calculated from sonic anemometers within the surface layer using the inertial method

- **Estimate of the dissipation rate based on the value of the power (S_u) in the inertial subrange and mean wind speed U**
- **Existence of inertial subrange accepted when power drops with $f^{-5/3}$**
- **We use average S_u in the inertial subrange, f > 0.5 Hz: by only using one component, we are assuming isotropy.**

$$\varepsilon = \frac{2\pi}{U}\left(\frac{f^{5/3}S_u(f)}{\alpha}\right)^{3/2}$$



IS ISOTROPY FOUND IN THE INERTIAL SUBRANGE OF THESE DATA?

Isotropy exists when spectral ratios approach 4/3.

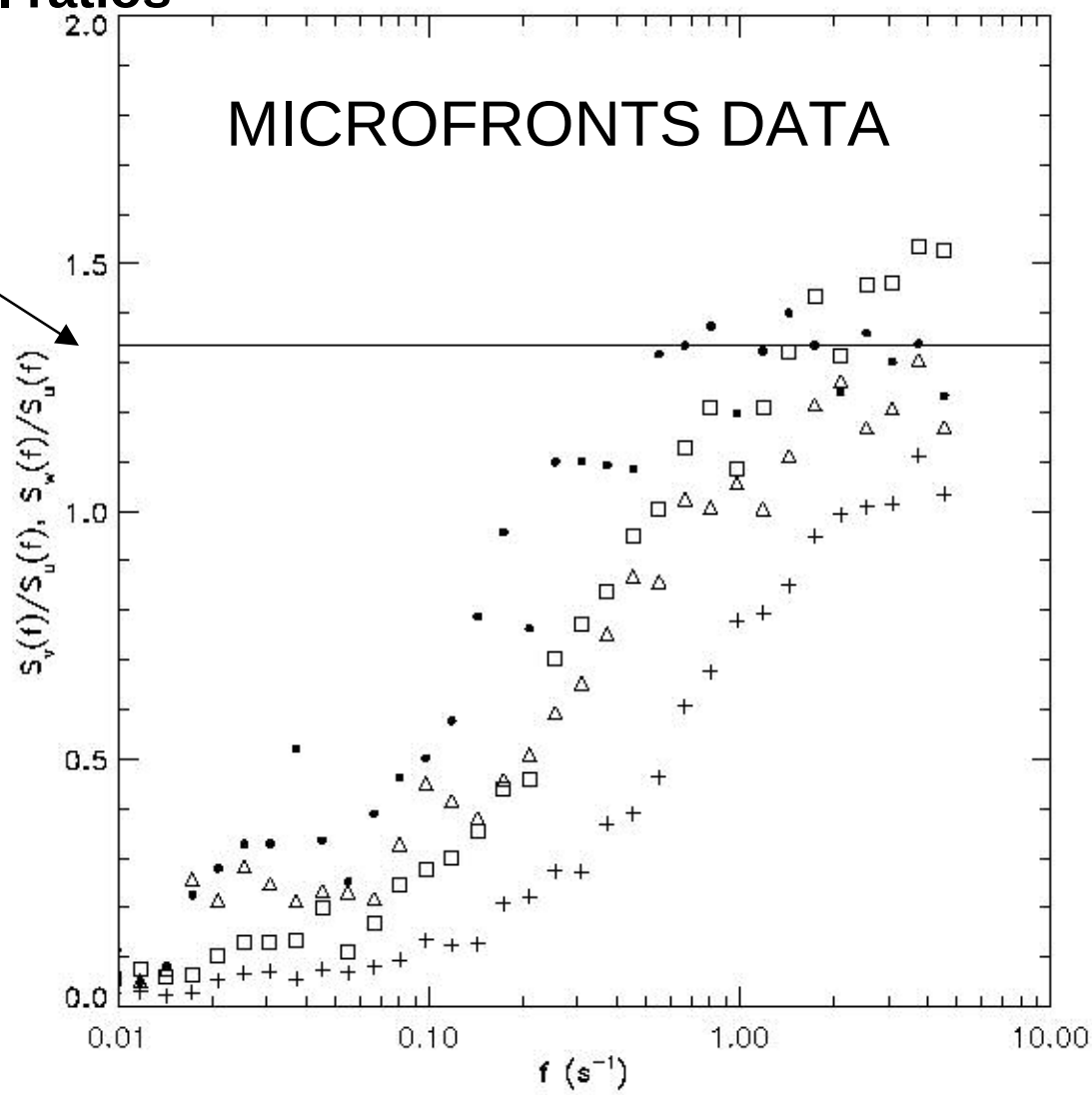
Data from 10m:

- • (v/u)
- ◻ (w/u)

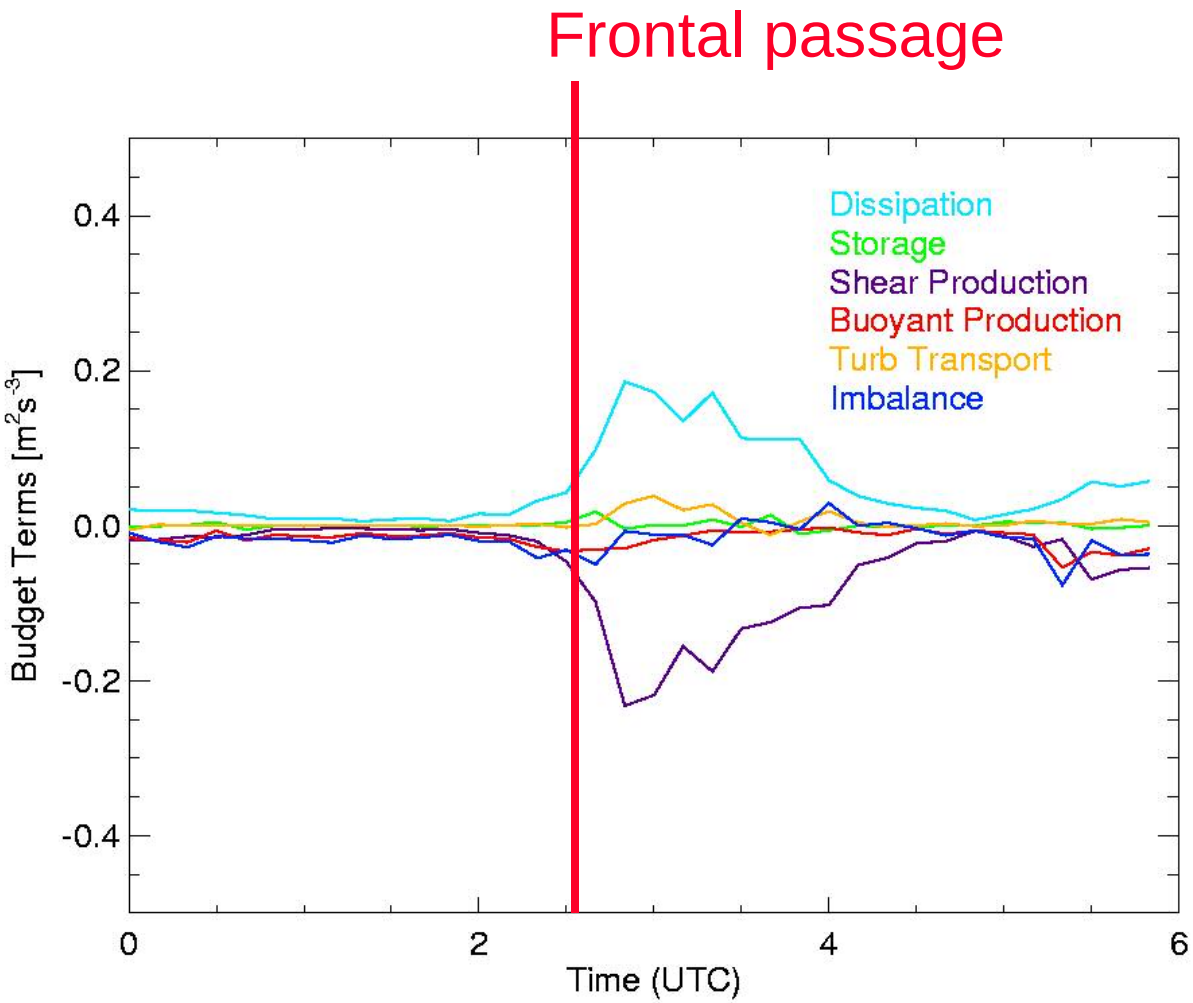
Data from 3m:

- Δ (v/u)
- + (w/u)

Inertial subrange is questionable at 3m, but certainly exists at 10m.



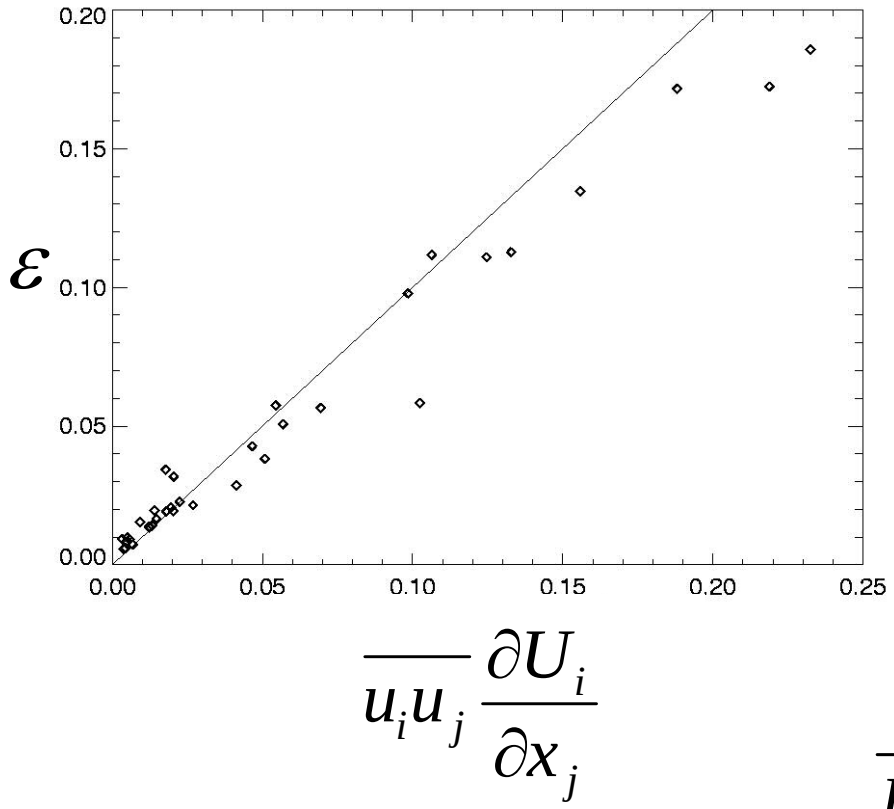
TKE BUDGET FOR MICROFRONTS NEARLY BALANCES



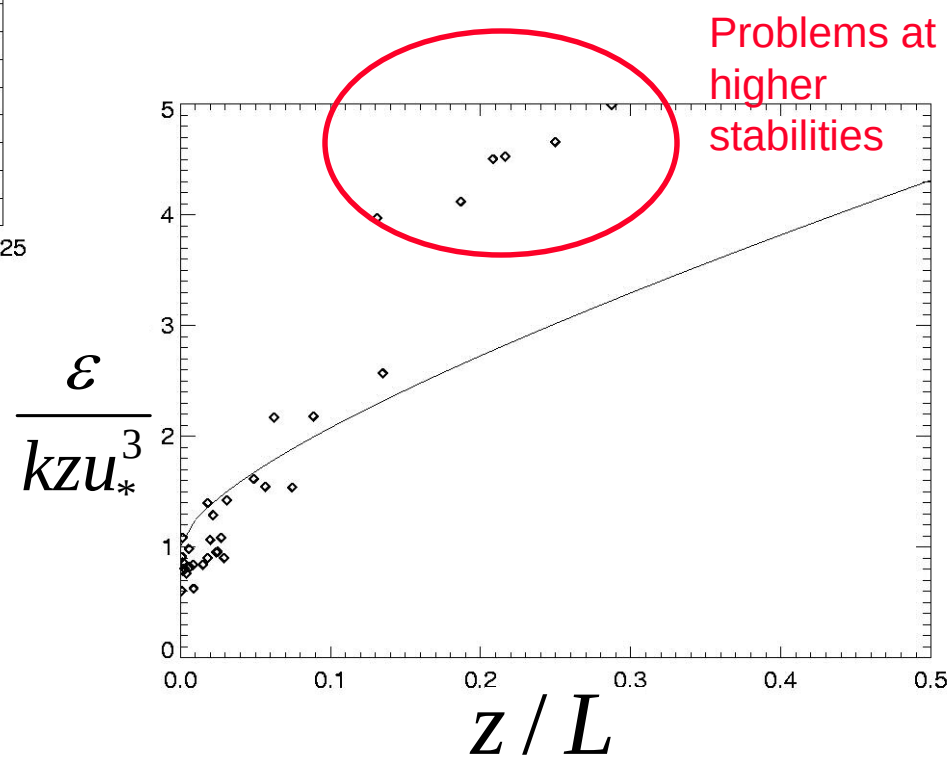
Data from 10m level

The dominant terms are shear production and dissipation.

ε CALCULATIONS FOR MICROFRONTS REFLECT INCREASED TKE PRODUCTION BY FRONTAL PASSAGE



Buoyant production or destruction plays an insignificant role



And yet scaling with z/L is appropriate:
(fit from Wyngaard & Cote, 1971)

SCALING FOR DISSIPATION LENGTH IS SUCCESSFUL FOR THIS CASE

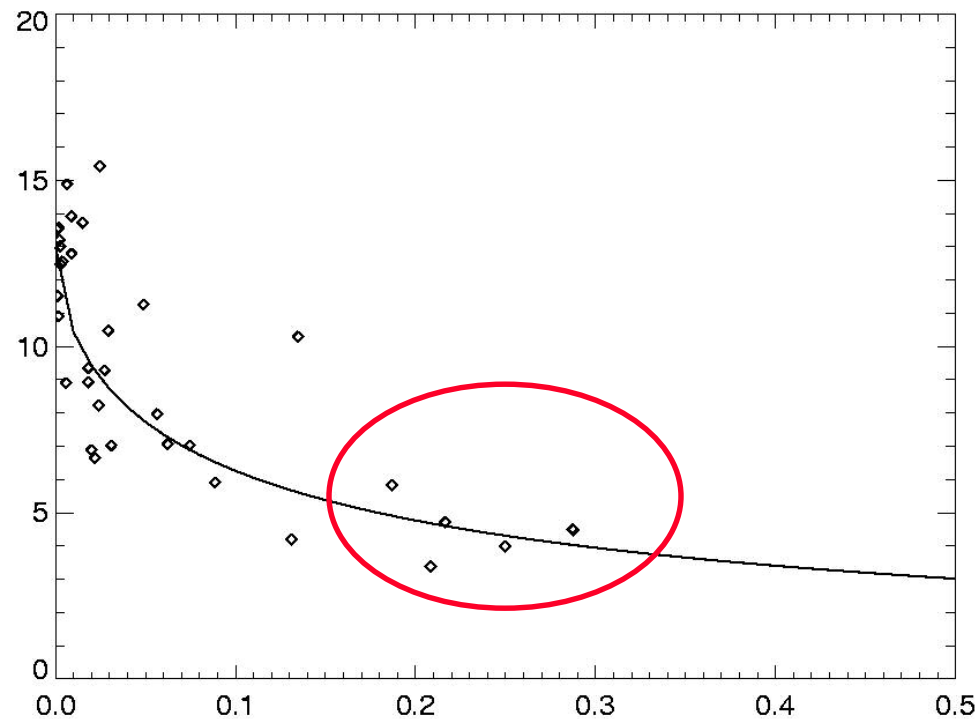
Wyngaard and Cote (1971) suggested

$$\frac{kz\varepsilon}{u_*^3} = \left(1 + 2.5\frac{z}{L}^{3/5}\right)^{3/2} ;$$

combined with Stull's velocity variance functions, and

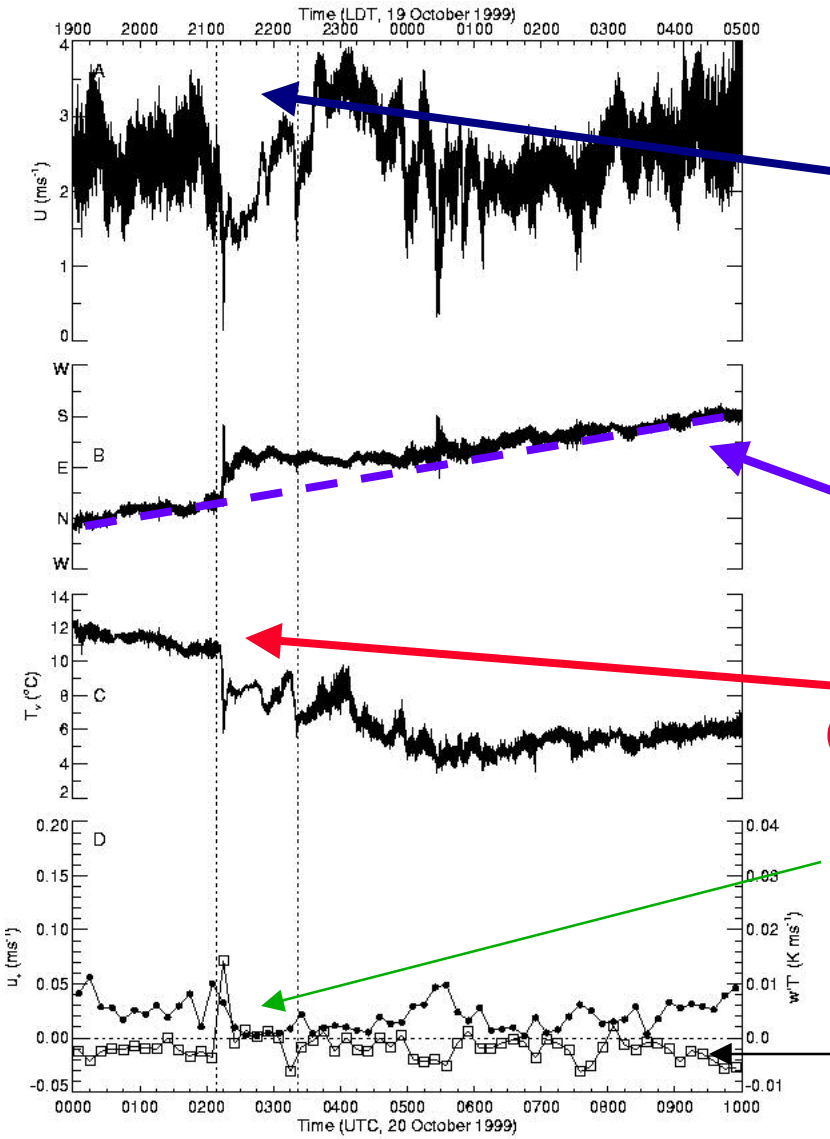
$$l_\varepsilon = \frac{e^{3/2}}{\varepsilon}$$

$$\frac{l_\varepsilon}{kz} \cong 13\left[1 + 2.5\left(\frac{z}{L}\right)^{3/5}\right]^{-3/2}$$



is appropriate in the changing stability of a developing stable layer and frontal zone

A subtle density current slides through Kansas (CASES-99, 1999; Blumen, Poulos, & Fritts PIs)



Reduced wind speed and wind speed variance coincident with the density current

Density current marks abrupt wind shift, but gradual shift occurs overnight

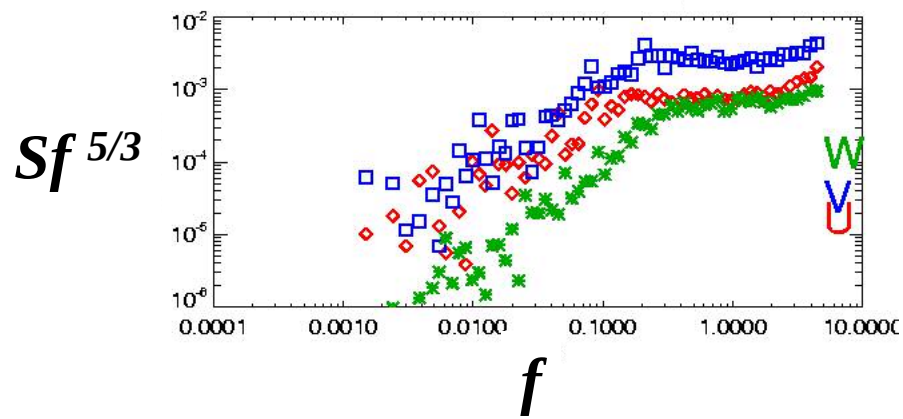
Cooling of 5° C

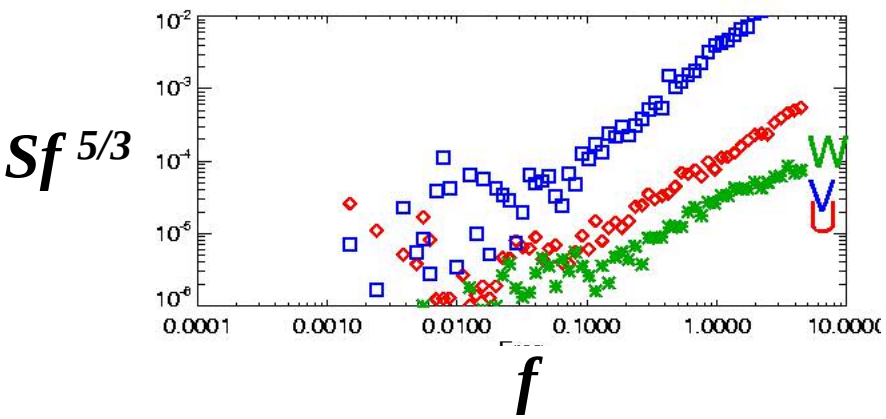
u* decreases dramatically at head of current, but suppressed afterwards

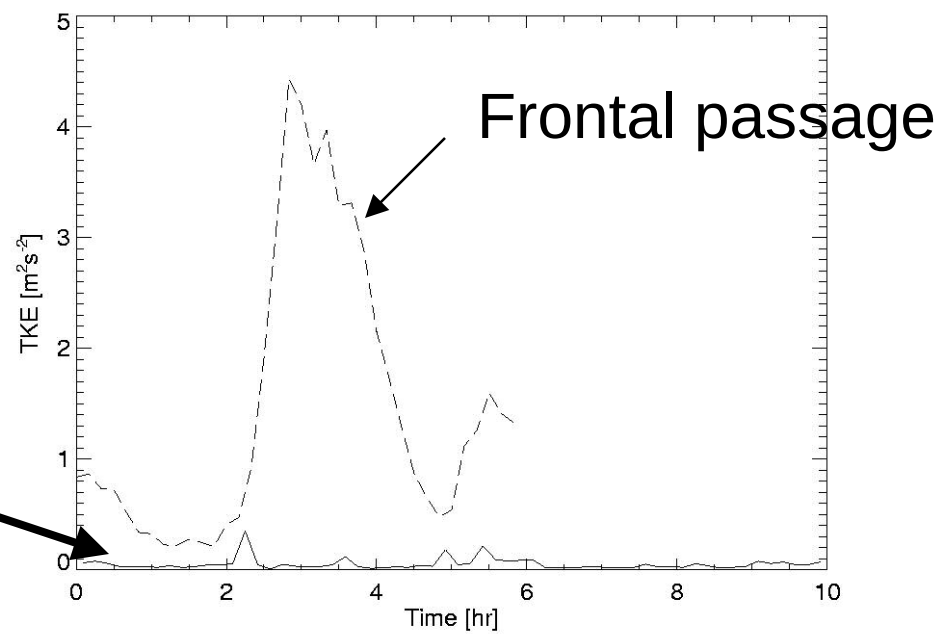
Heat flux becomes briefly positive at 5m: uplift

The inertial dissipation method may not be appropriate for studying extended quiescent periods

Inertial dissipation method requires inertial subrange for spectral estimates: but during the density current, we find no inertial subrange.







Density current seems to relaminarize the flow, suppressing TKE.

SUMMARY & NEXT STEPS

- **Previously-proposed scaling rules agree with data in the case of a frontal intrusion into a stable boundary layer: slightly stable, moving towards neutral.**
- **The strong stability seen in the density current case will challenge these parameterizations – and our ability to provide data to compare with those parameterizations.**
- **Dissipation calculations for quiescent periods are non-trivial: inertial subranges are too short or nonexistent.**
- **Next: identify another density current in which we can use hotwire anemometer data for direct dissipation calculations.**

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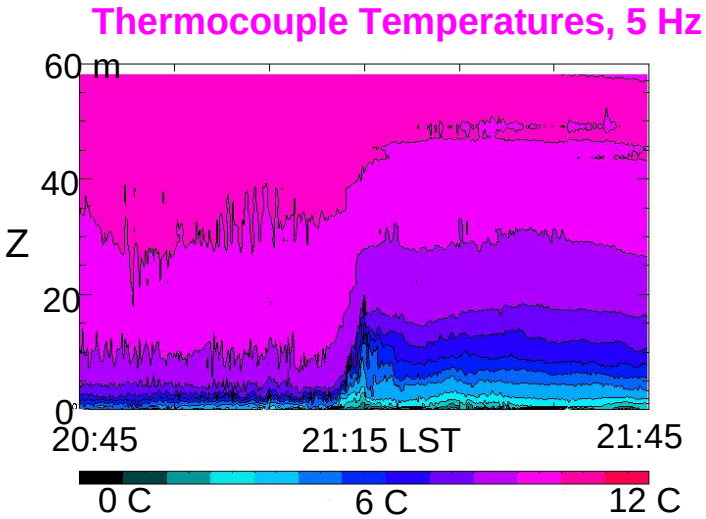
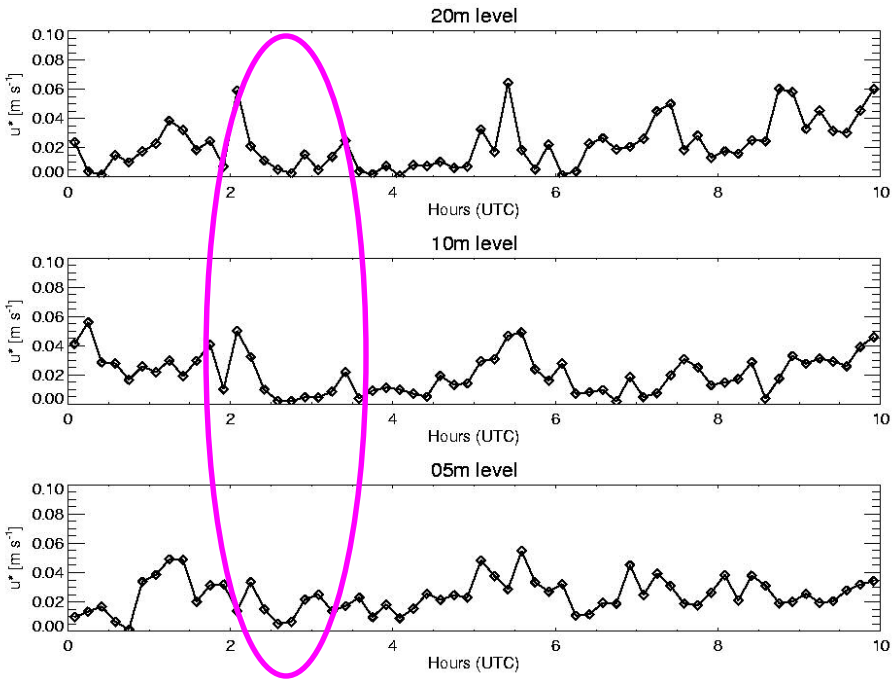
Another view of the density current

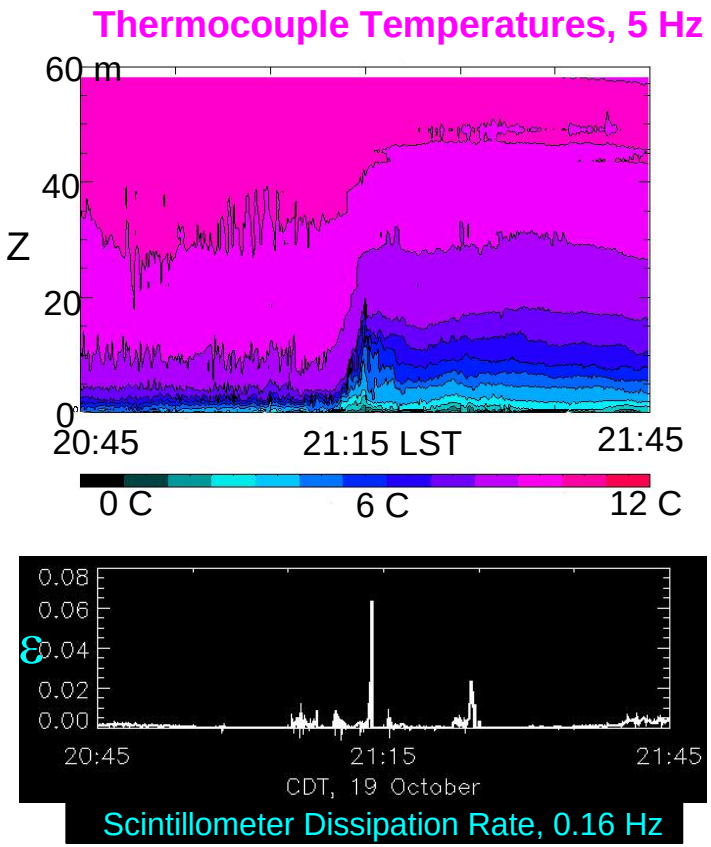


Profiles of u*: less than 0.005 ms-1



Supression of mixing during the density current

Another view of the density current



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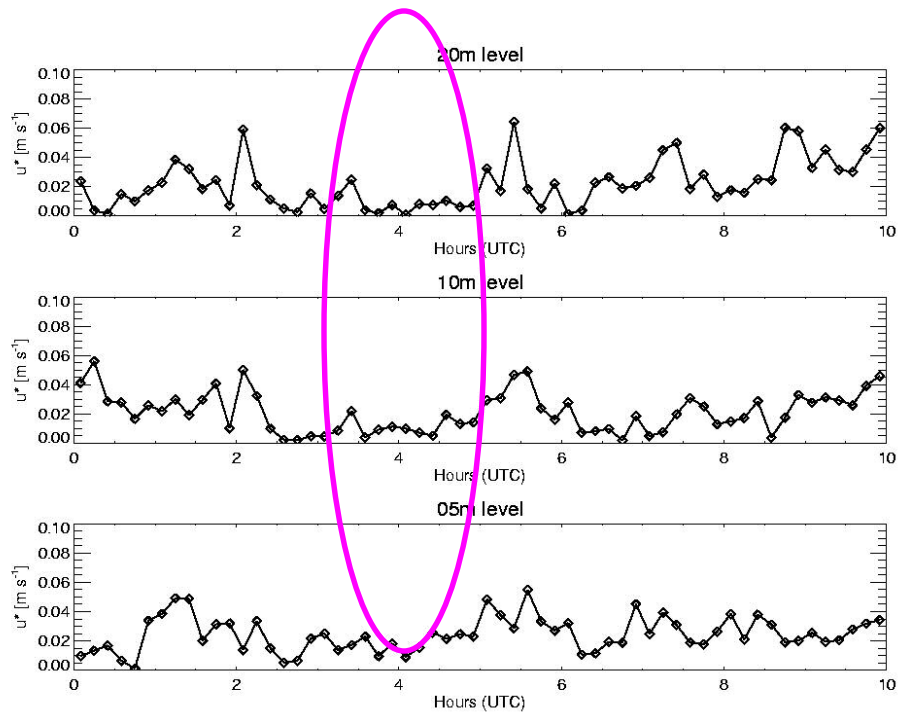

Supression of mixing during the density current