SURFACE-LAYER TURBULENCE DURING A FRONTAL PASSAGE

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Photo courtesy of S. Oncley, NCAR/ATD.

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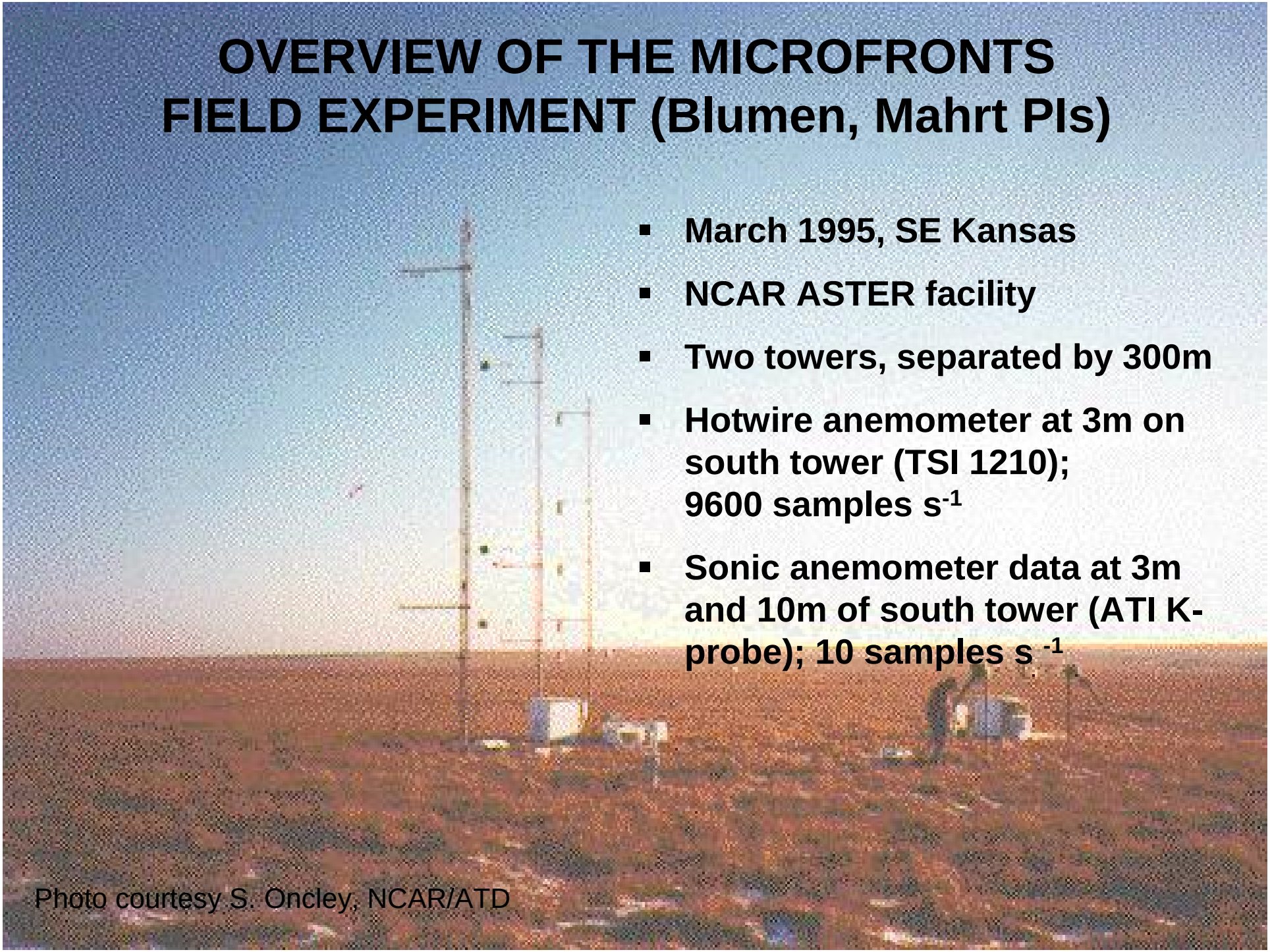
MOTIVATION

- **What are the mechanisms that limit frontal collapse?**
  - **A minimum cross-frontal scale may be reached when frontogenetical forcing is balanced by turbulent mixing and dissipation within the frontal zone (Hoskins and Bretherton, 1972; Williams, 1974)**
  - **Ageostrophic motions develop at the frontal boundary and reduce vorticity generation (Orlanski and Ross, 1984; Orlanski et al., 1985)**
- **Few observations of TKE and TKE dissipation rate in a frontal zone are available to explore the role of turbulent mixing and dissipation w/in frontal zones**

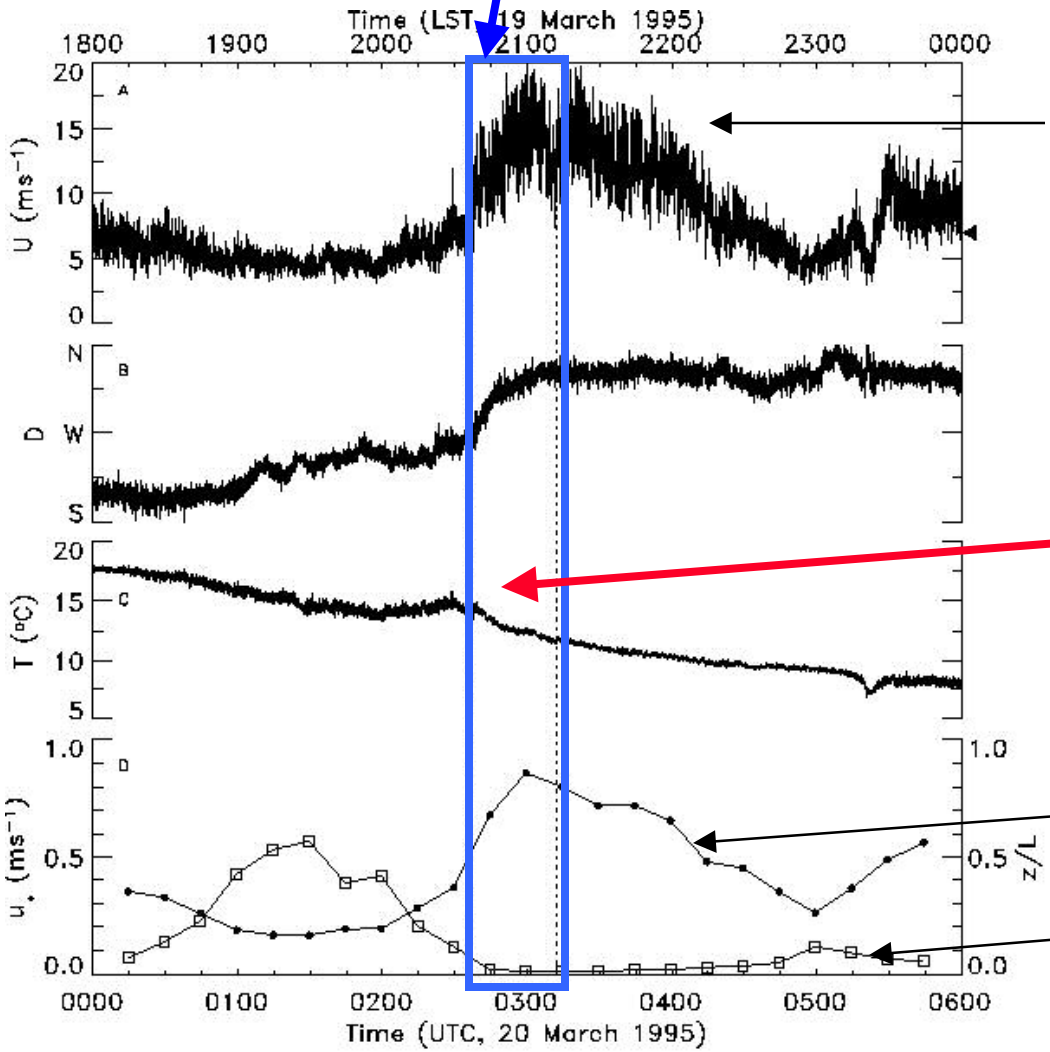
OVERVIEW OF THE MICROFRONTS FIELD EXPERIMENT (Blumen, Mahrt PIs)



- March 1995, SE Kansas
- NCAR ASTER facility
- Two towers, separated by 300m
- Hotwire anemometer at 3m on south tower (TSI 1210); 9600 samples s^{-1}
- Sonic anemometer data at 3m and 10m of south tower (ATI K-probe); 10 samples s^{-1}

Photo courtesy S. Oncley, NCAR/ATD

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

Dissipation rate calculations

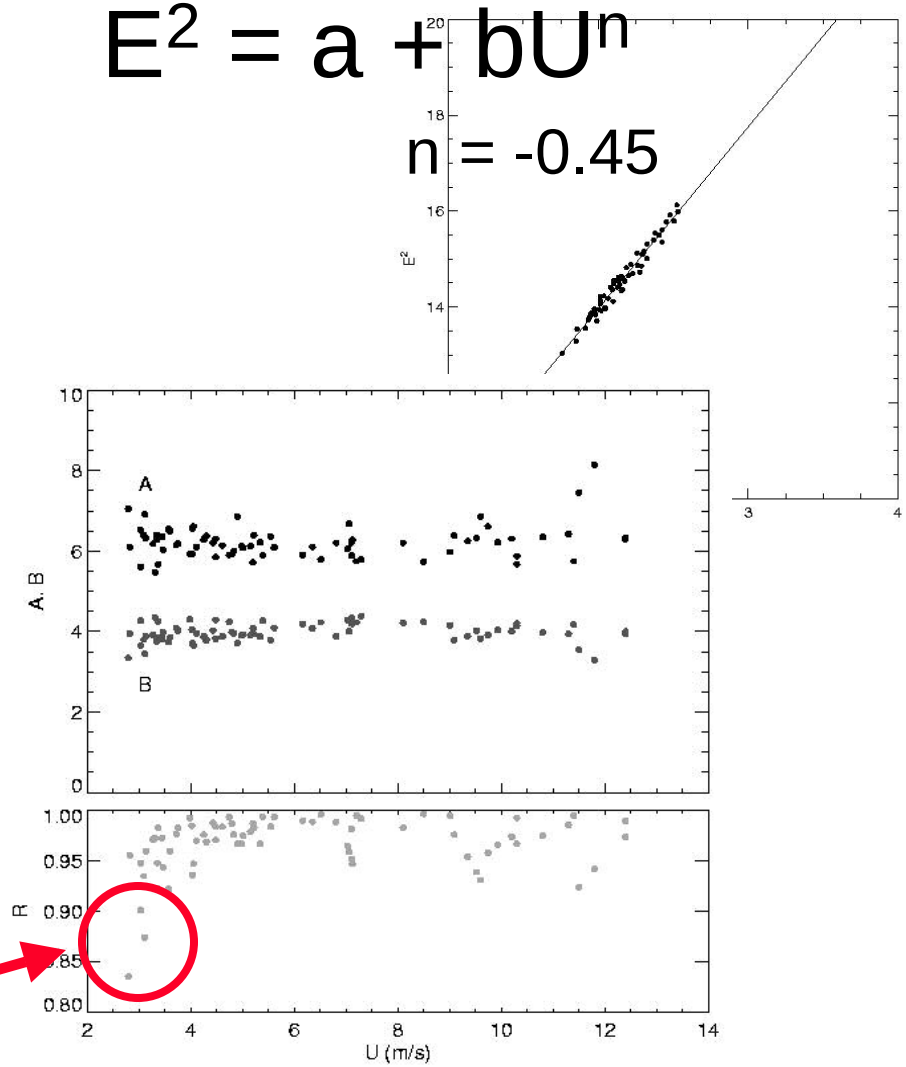
1. Direct dissipation (HD) from hotwire anemometer
2. Inertial dissipation (HI) from hotwire anemometer
3. Inertial dissipation (SI) from sonic anemometer
4. Kolmogorov's four-fifth's law (HK) from hotwire anemometer

DIRECT DISSIPATION CALCULATIONS

- **Hotwire anemometer voltages (E) calibrated with colocated sonic anemometer and King's Law following Oncley et al. (1996)**
- **Sonic wind speeds (U) and hotwire voltages (E) block averaged into nonoverlapping 5-sec bins**
- **Linear least squares fit on King's Law results in 5-min-average values of a and b**
- **King's Law inverted to find hotwire wind speeds**

$$E^2 = a + bU^n$$

$$n = -0.45$$



30-60 min before frontal passage

DIRECT DISSIPATION CALCULATIONS

$$\varepsilon = 15\nu \overline{\left(\frac{\partial u_{HW}}{\partial x} \right)^2}$$

- Apply Taylor's hypothesis to convert x to t
- Apply Heskestad-Lumley correction for high-intensity turbulence (difference between 5% and 10%)
- Recognize that kinematic viscosity ν is a function of temperature; use data from colocated hygrothermometer

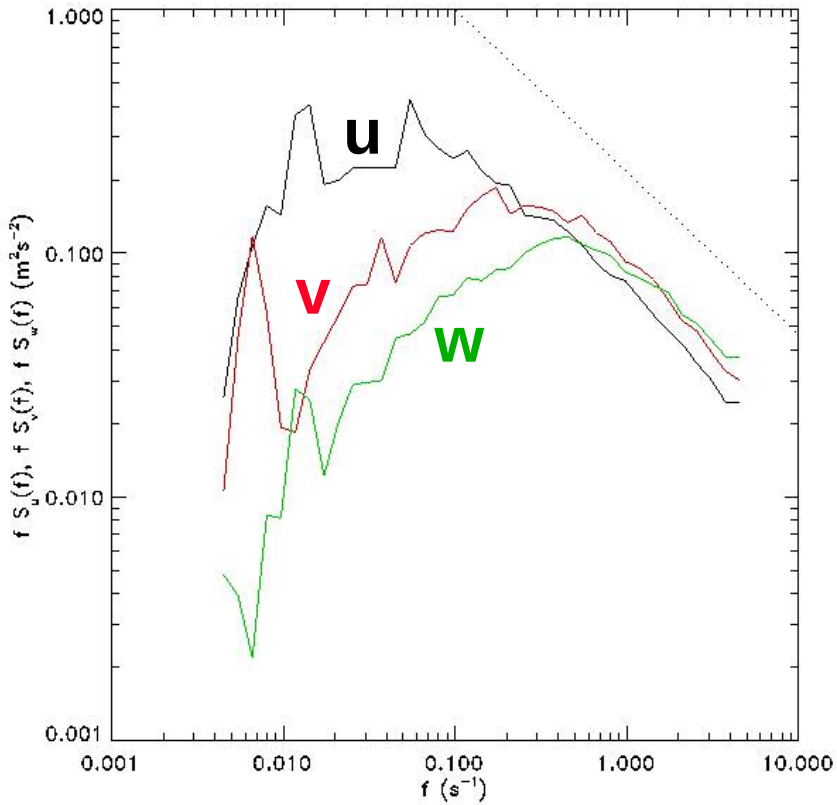
$$\varepsilon = \frac{15\nu}{U^2} \overline{\left(\frac{\partial u_{HW}}{\partial t} \right)^2} \left(1 + \frac{\overline{u^2}}{U^2} + 2\frac{\overline{v^2} + \overline{w^2}}{U^2} \right)^{-1}$$

- Kolmogorov frequency occasionally too high to be resolved by the hotwire anemometer (when U > 7 ms^{-1}).

INERTIAL DISSIPATION METHOD
(used both with sonic and hotwire anemometers)

- **Estimate of the dissipation rate based on the value of the power (S) in the inertial subrange**
- **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.**

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



KOLMOGOROV'S FOUR-FIFTHS LAW

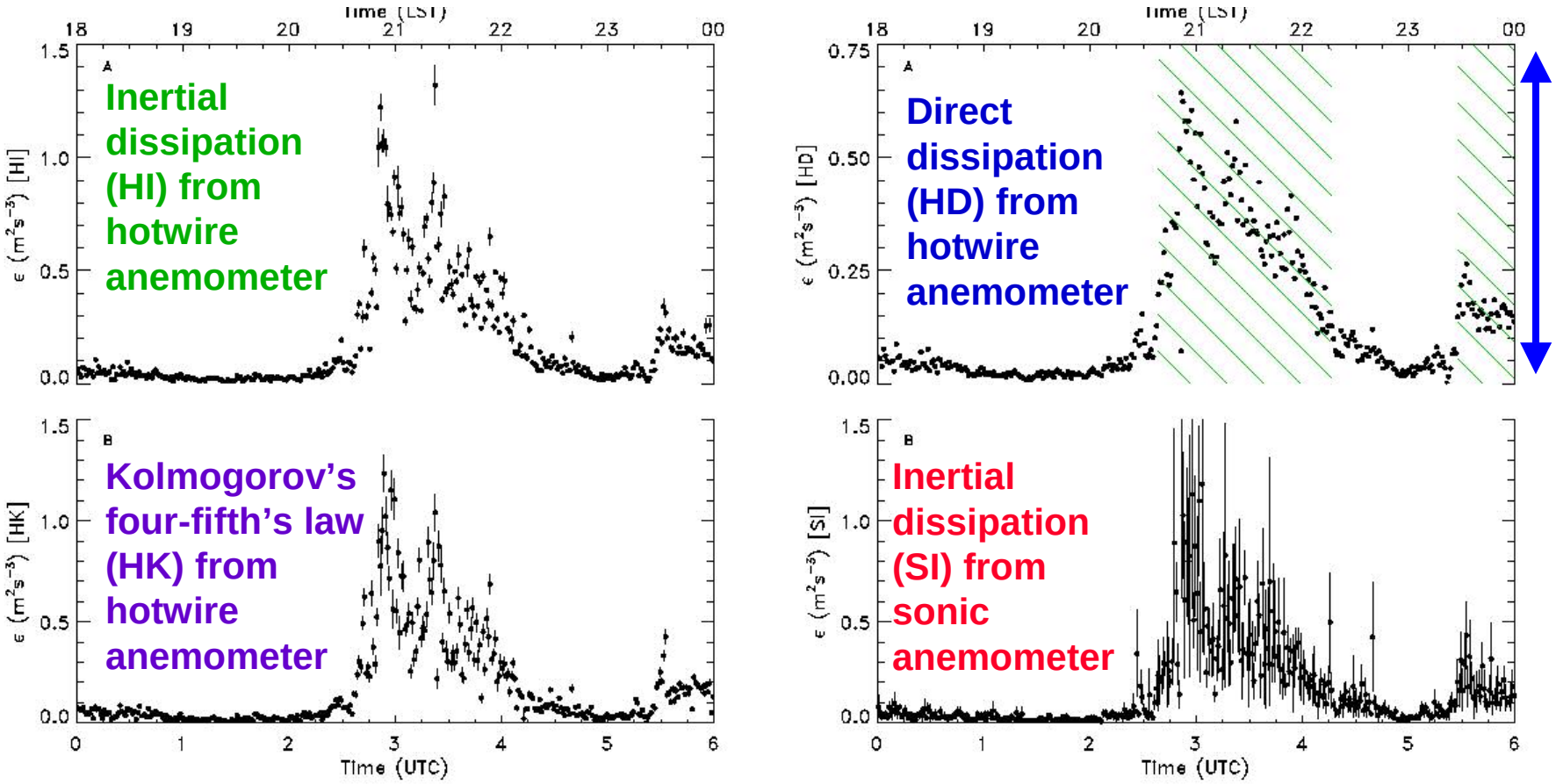
To avoid undetermined coefficients, we assume homogeneity and isotropy:

$$\overline{\Delta u^3} = \overline{[u(x+r) - u(x)]^3} = -\frac{4}{5}\varepsilon r$$

Using Taylor's hypothesis, separation distance $r = U\tau$, and so

$$\varepsilon = -\frac{5}{4}\left(\frac{1}{U\tau}\right)\overline{(\Delta u)^3}$$

TIME SERIES OF DISSIPATION THROUGH FRONTAL PASSAGE: 3m observations



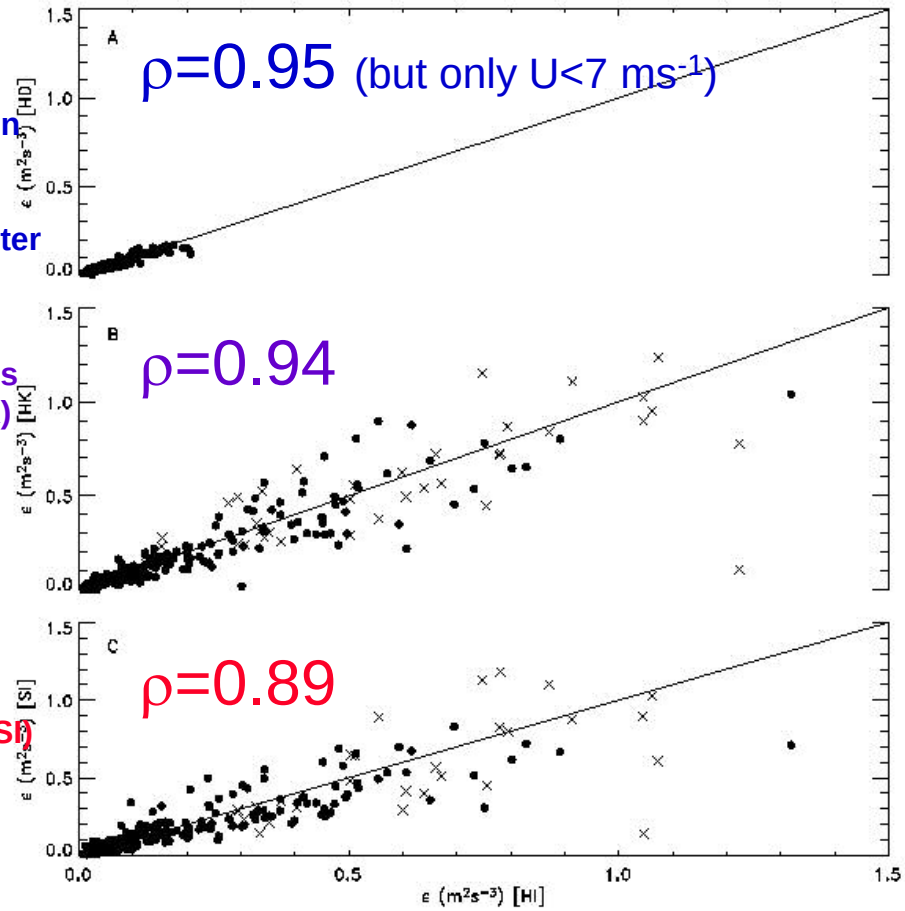
COMPARISON OF METHODS

Linear comparison

Direct dissipation (HD) from hotwire anemometer

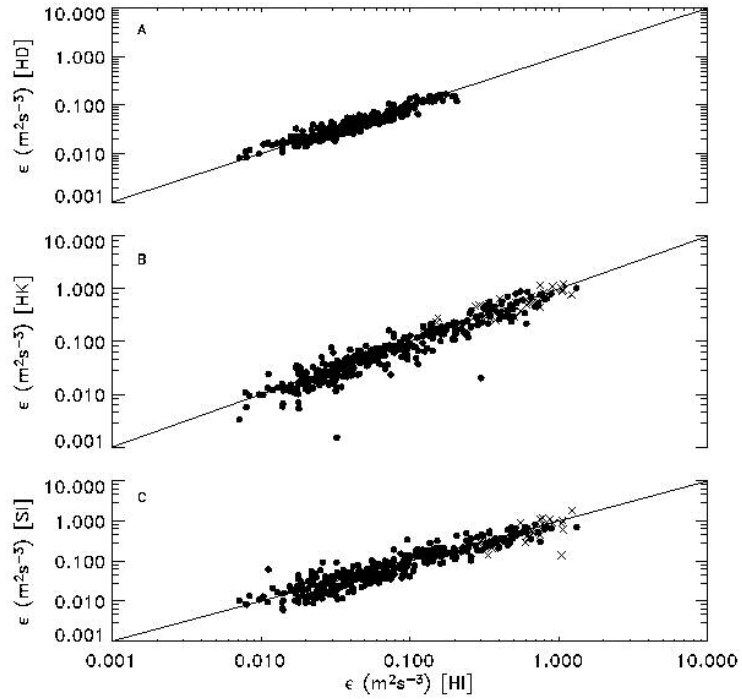
Kolmogorov's 4/5's law (HK) from hotwire anemometer

Inertial dissipation (SI) from sonic anemometer



Inertial dissipation (HI) from hotwire anemometer

Log comparison



SUMMARY

- **Dissipation calculations from direct and indirect methods compare well.**
- **Indirect methods can be used safely to calculate dissipation where no direct calculations of ε are available, even during rapidly-changing situations like frontal passages.**
- **The dissipation rate in the surface layer increases (during one frontal passage) from ~ 0.05 m^2s^{-3} to 1.2 m^2s^{-3}.**
- **Dissipation levels remain high even after the passage of the frontal zone.**