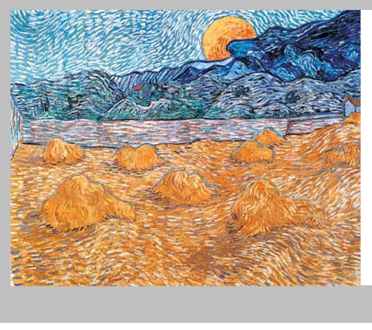

A Simple Model for the Afternoon and Early-Evening Decay of Turbulence over Different Land Surfaces

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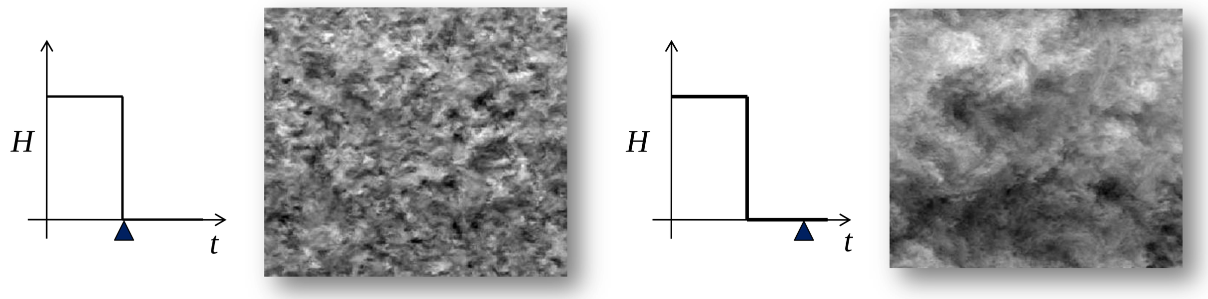
1. Introduction

On a typical clear-sky day, the atmospheric turbulence increases in response to the incoming solar radiation. The associated daytime atmospheric boundary layer is thus characterized by turbulent mixing, buoyancy-driven eddies and unstable stratification.

At night, the scenario is much different. The stable stratification of the atmosphere tends to supress the vertical motions generated by mechanical turbulence.

The physics associated with the transition from the daytime to the nighttime regimes is very challenging to understand. In this work, we propose a simple model to study the convective decay of turbulence during this transition period.

• Horizontal velocities in the middle of the ABL during the decay
(Pino, BLM, 2006)



2. Turbulent kinetic energy budget during the decay

Instantaneous removal of surface flux (Nieuwstadt & Brost, JAS, 1986)

$$\frac{\partial \bar{k}}{\partial t} = -\varepsilon$$

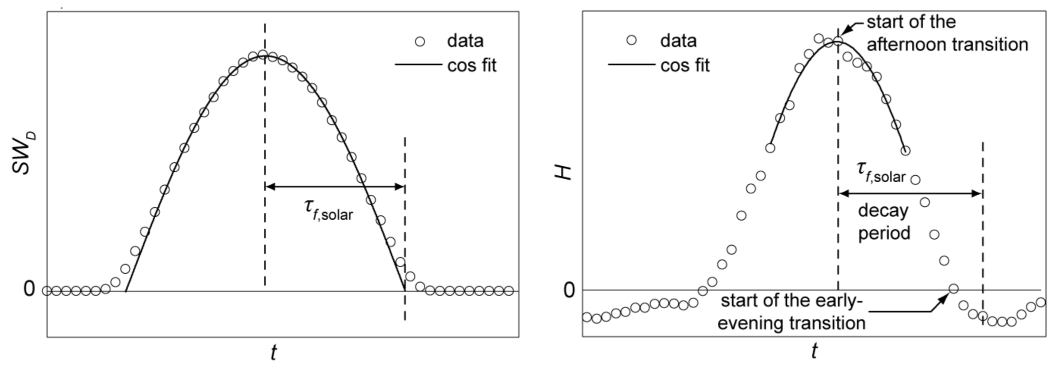
$$\frac{\bar{k}}{w_*^2} = \left(\frac{C_\varepsilon}{2}\frac{t w_*}{h} + \frac{1}{C}\right)^{-2}$$

Modified model to account for time varying buoyancy flux

$$\frac{\partial \bar{k}}{\partial t} = \frac{g}{\theta_v}\left(\overline{w'\theta_v'}\right) - \varepsilon$$

• need to model the buoyancy flux as a function of time during the decay

3. Methods

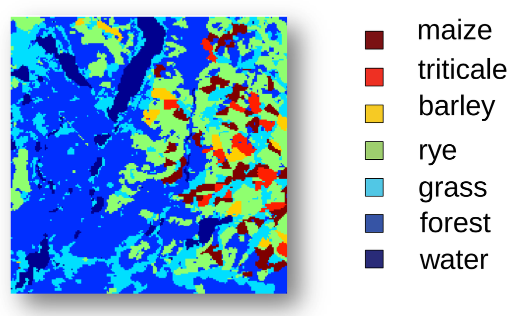


Steps to define the decay period of turbulence

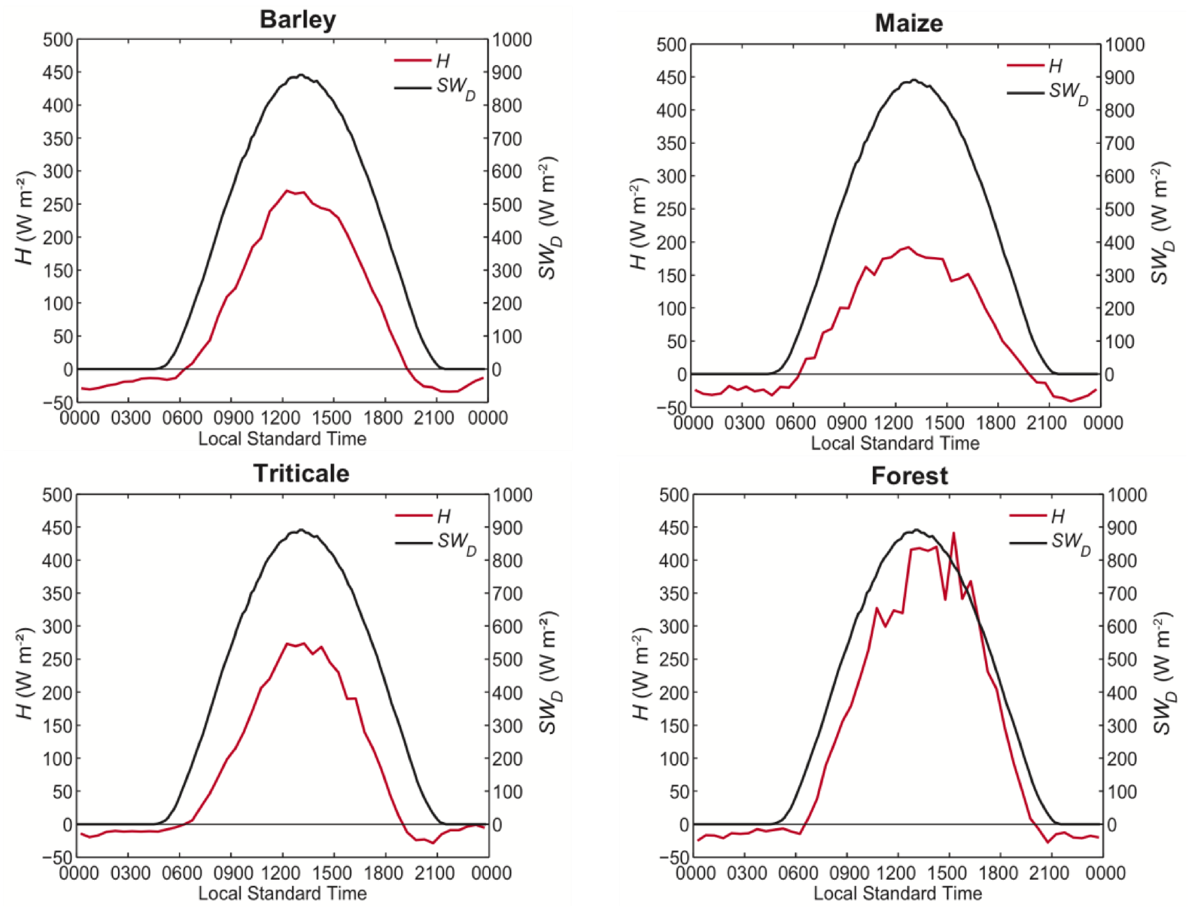
1) determine the solar forcing time scale $\tau_{f,solar}$ from sw down
2) find the start of the afternoon transition (H_{max})
3) decay period is from afternoon transition to $\tau_{f,solar}$ hours later

Experimental dataset used: LITFASS-2003

• consider the data averaged over 3 clear-sky days

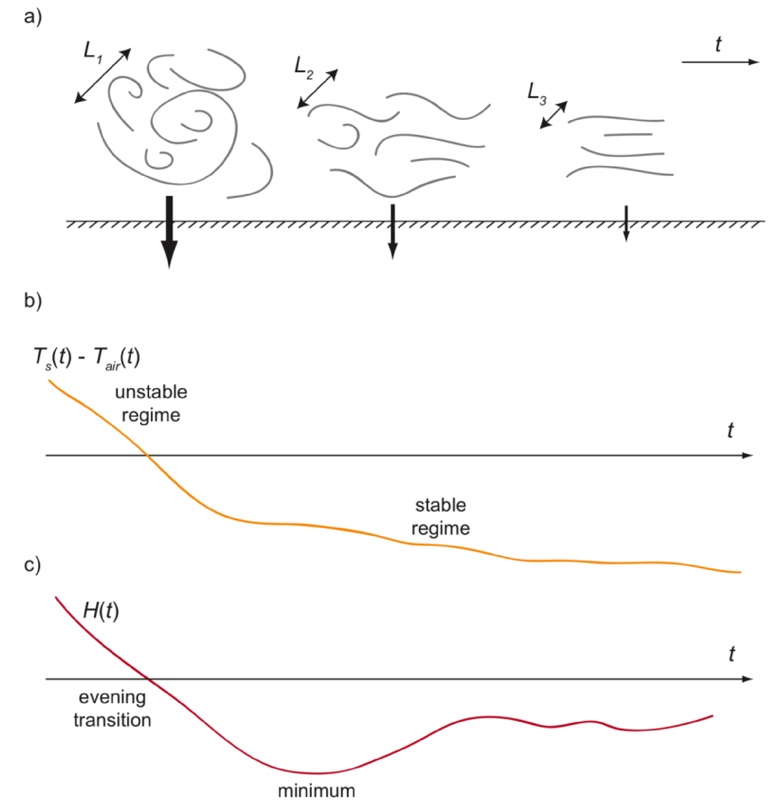


4. Diurnal cycles of sensible heat flux and solar radiation



• as expected, very high correlation between H and SW_D
• change of sign in H occurs a few hours before sunset
• maximum in downward H about 1.5 h before sunset

Heat transfer dynamics around the early-evening transition



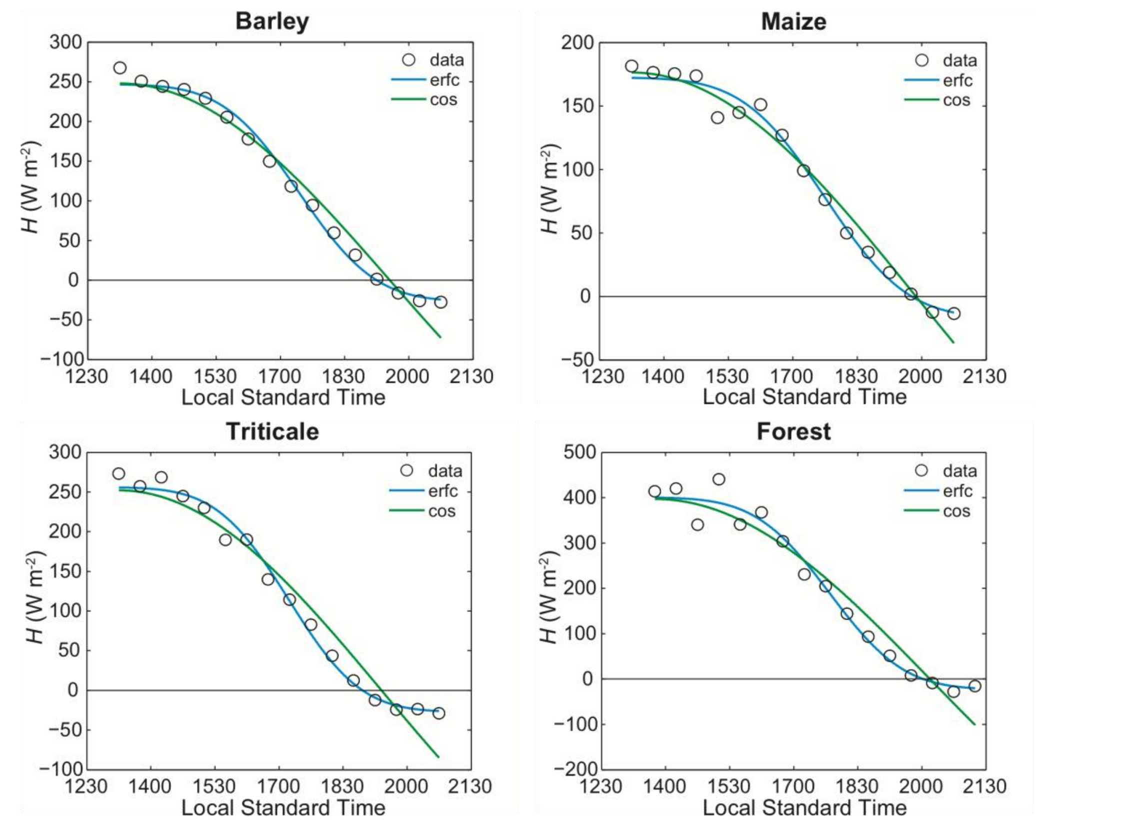
• remnant daytime turbulence efficient at transferring energy from atm to sfc
• light winds prevents mechanical mixing and favors built-up of stable layer
• eventually, stable buoyancy forces inhibits the efficiency of heat transfer
• finally, the magnitude of the sensible heat flux decreases

5. Curve fitting to capture the decay of sensible heat flux

$$H_{erfc}(t) = \frac{(H_{max} - H_{min})}{2}\left[\mathrm{erfc}\left(\frac{t}{\tau_{erfc}\sqrt{2}} - \frac{3}{\sqrt{2}}\right)\right] + H_{min}$$ (in blue)

$$H_{cos}(t) = H_{max}\cos\left(\frac{\pi t}{2\tau_{cos}}\right)$$ (in green)

• erfc captures well the occurrence of early-evening transition
• cos fit is better around the afternoon transition
• erfc fit is great after the early-evening transition, not the cos fit

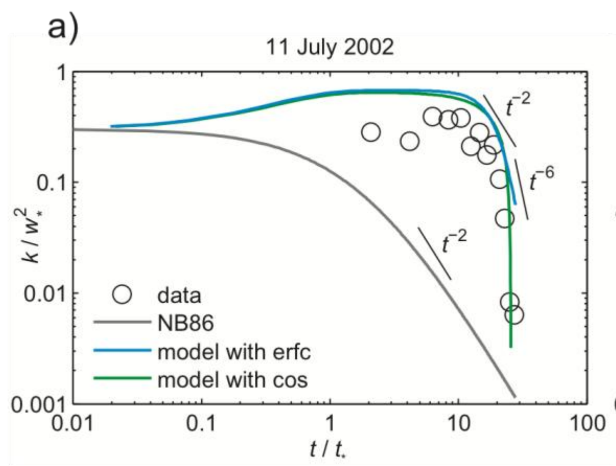


6. Modeling the turbulent kinetic energy decay

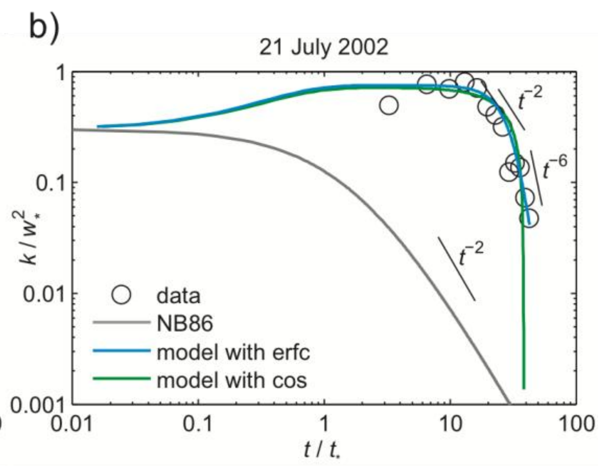
Over a desert (Great Salt Lake Desert, SGS 2002 experiment)

• large sensible heat flux
• extremely smooth surface
• large mid-day boundary layer depth

a)

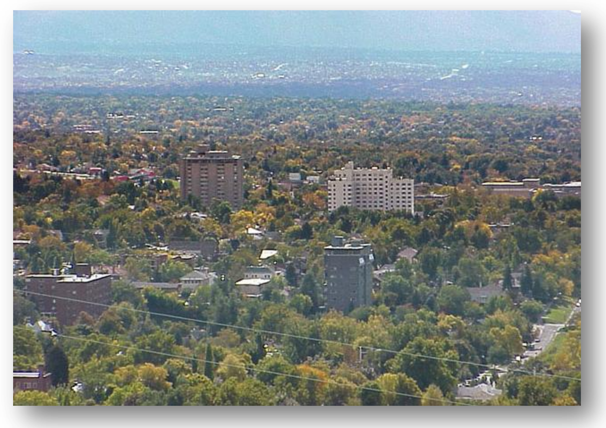


b)

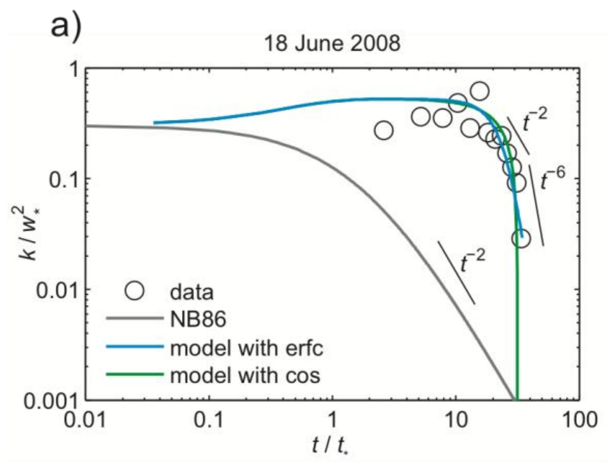


Over a suburban area (Salt Lake City, Murray 2008 experiment)

• data taken in inertial sublayer
• rough surface (houses, trees)
• elevation is 1300 m ASL



a)



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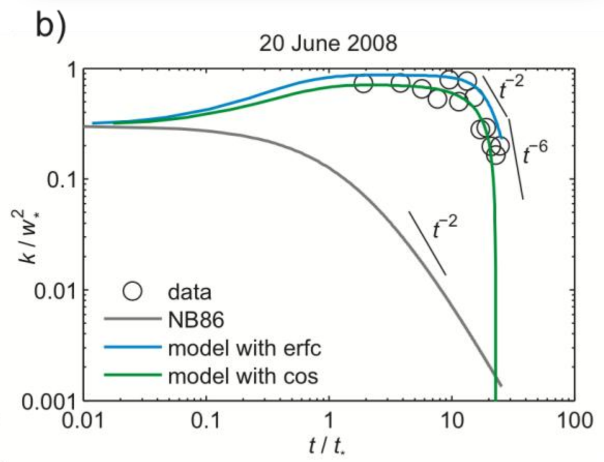
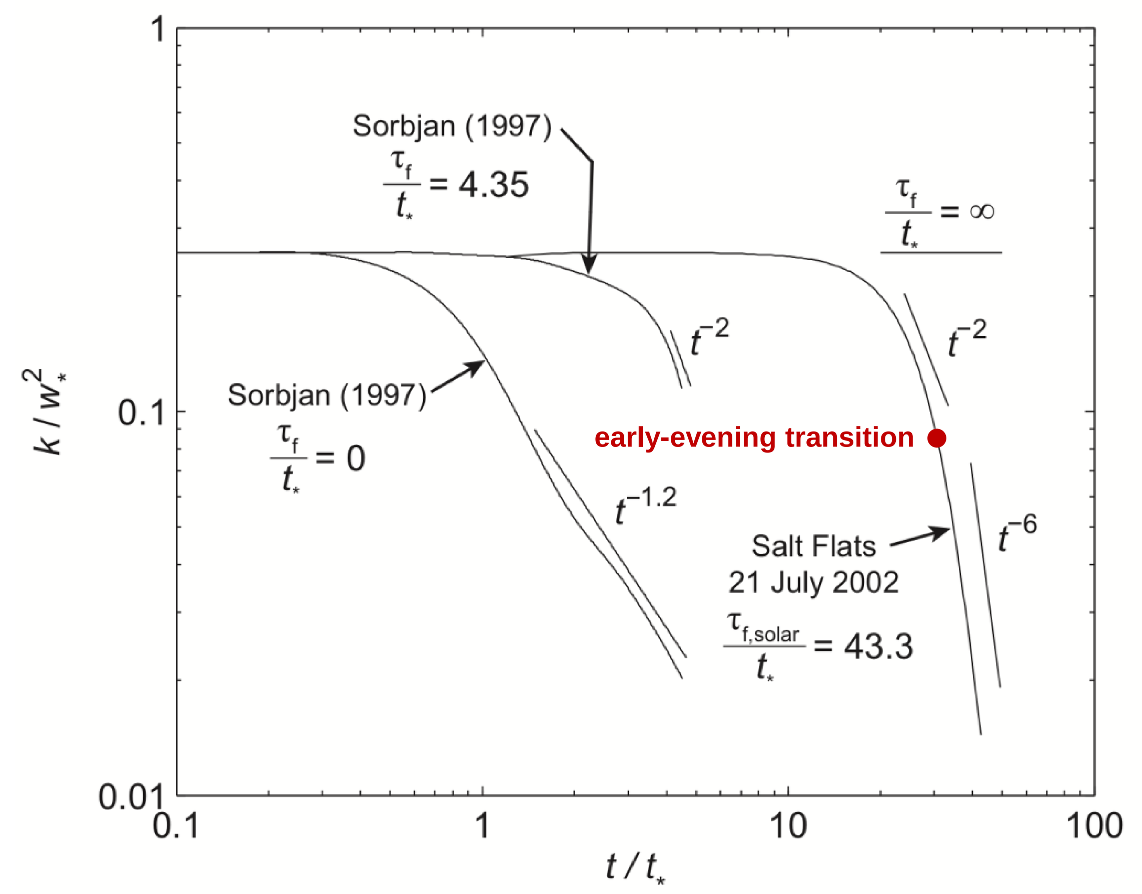


7. Expanded decay picture



Limiting cases

The decay of turbulent kinetic energy lies within these two cases:
• instantaneous shut-off of sensible heat flux ($\tau_f/t^* = 0$)
• sensible heat flux stays constant ($\tau_f/t^* \to \infty$)

Realistic external forcing time scale

21 July 2002, Salt Flats Desert, measurements in sfc layer
• $\tau_{f,\,solar}$ = 6.5 h
• turbulent kinetic energy starts to decay when $t/t^* \approx 15$
• two decay rates:
  t^{-2} at first
  very abrupt (~ t^{-6}) after the early-evening transition

8. Conclusions

Main conclusions

• tremendous variability in the forcing sensible heat flux, even over relatively flat terrain

• need to consider realistic forcing time scales

• the *erfc* function does a good job of modeling the surface sensible heat flux

• two apparent decay regimes
  – afternoon transition: from max heat flux to zero (slow decay)
  – early evening transition: just after the sensible heat flux changes sign (rapid decay and collapse of turbulence)

For more details

Nadeau DF, Pardyjak ER, Higgins CW, Fernando HJS (2010) A Simple Model for the Afternoon and Early-Evening Decay of Turbulence over Different Land Surfaces, *Boundary-Layer Meteorology*, accepted.

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