Investigation of the decay of turbulence over a forest during the Boundary Layer Late Afternoon and Sunset Turbulence Experiment

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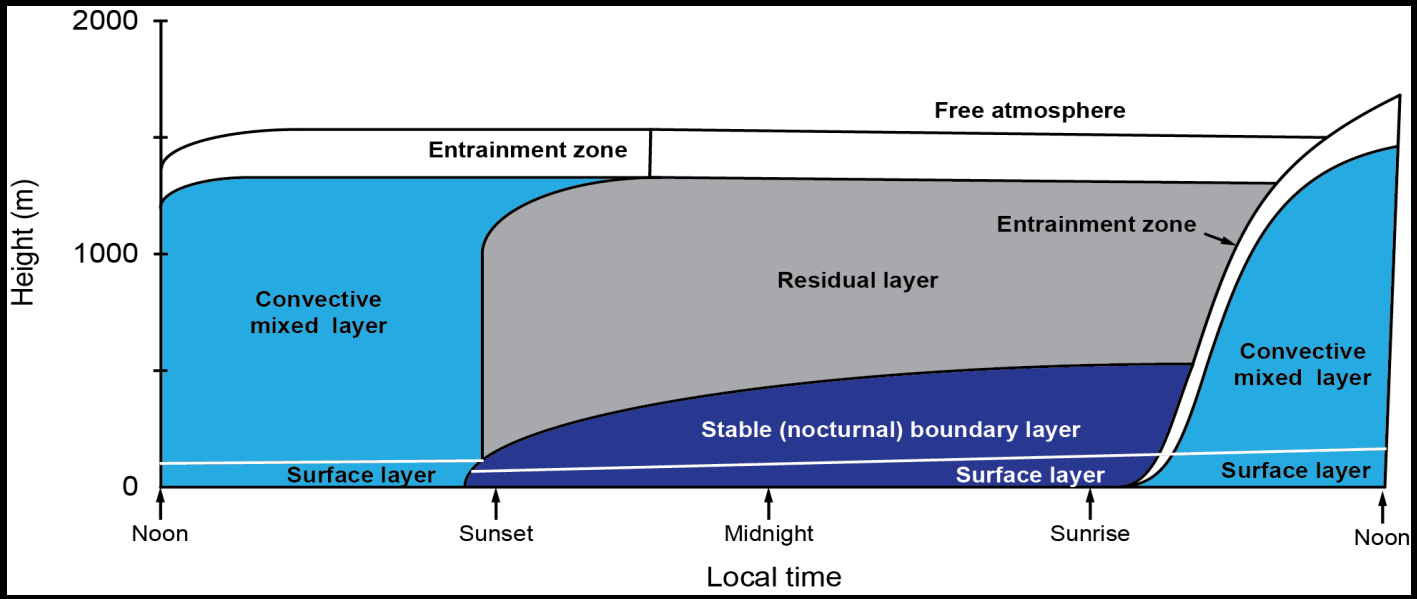
Motivation



- Gaining an improved understanding of the various transitory processes associated with the afternoon boundary layer

Figure adapted from Stull by Dan Nadeau

Outline

- Brief review of evening decay hypotheses in current literature
- Description of the Boundary Layer Late Afternoon and Sunset Turbulence (BLLAST) experiment and setup
- Comparison of BLLAST TKE decay results to Nadeau (2010), Goulart (2010), and Sorbjan (1997)
- Discussion of the competing buoyancy and mechanical TKE production processes during the decay

Authors	Method of Study	Region of Interest	Key Findings
Caughey et al. (1979)	Field Obs., Minnesota	Entire ABL	Top down heat flux
Nieuwstadt & Brost (1986)	LES, Ug = 0; inst. rem. flux	Integral quantities entire ABL	See H1, t^{-n}
Beyrich & Klose 1988	Field Obs., Wangara	Entire ABL	t* ~ u*/h
Sorbjan (1997)	LES, Ug = 0;	Integral quantities entire ABL	See H1, H2
Grant (1997)	Field Obs. Cardington, UK	Entire ABL	heat flux profiles strong cooling near the surface, t* ~ u*/h
Cole & Fernando (1998)	Laboratory	Entire boundary layer	σ_T & σ_w decay t ~ DT/(dTs/dt)
Acevado & Fitzgerald (2001)	Field	Surface Layer	Spatial Heterogienity
Pardyjak 2001	Field Obs., Phoenix	Surface Layer	Simple decay model σ_T & σ_w decay at different rates
Shaw & Bernard (2002)	DNS		Delay of decay due to shear
Grimsdell & Angeine 2002	Field Obs., Urbana-Champaign	Entire ABL	inversion layer separation (ILS) and descent, demixing
Goulart et al 2003	Theoretical Spectral form of tke equation	Integral quantities entire ABL	

Authors	Method of Study	Region of Interest	Key Findings
Riley 2003	Laboratory Measurement, overlying stratification	Entire ABL	Overlying stratification effects u'^2 more than w'^2
Pino et al 2006	LES, shear and overlying stratification	Entire ABL	Decay length scales, scaling exponents
Kumar et al. 2006	LES, diurnal cycle	Entire ABL	
Pardyjak et al. 2008	Field Observations Phoenix, AZ	Surface Layer	Spatial Heterogeneity of decay
Goulart et al. 2010	LES, contribution of shear production term to TKE	Entire ABL	Shear production dominates buoyant production in lower CBL
Nadeau et al. 2011	Model for afternoon and early evening decay of CBL	Surface Layer	Erfc fit to sensible heat flux along with H1

Hypotheses from the Literature

- H1 – Surface Heat Flux "Instantly set to zero" The volume integrated turbulence quantities are only a function of the initial CBL state and t/t* (Nieuwstadt & Brost)
- H2 – Gradually Decaying Surface Heat Flux Turbulent decay is dependent on 2 time scales t* and t_f (Sorbjan)
- H3 – Limiting Cases (Sorbjan)

$t_f / t^* \to 0$ Hs=0 @ t_f=0

$t_f / t^* \to \infty$ Constant Hs

Hypotheses (cont.)

- H4 –Mechanical effects in the boundary layer increase with decreasing z/L to the extent that in the lower part of the convective boundary layer, the mechanical term is dominant (Goulart)

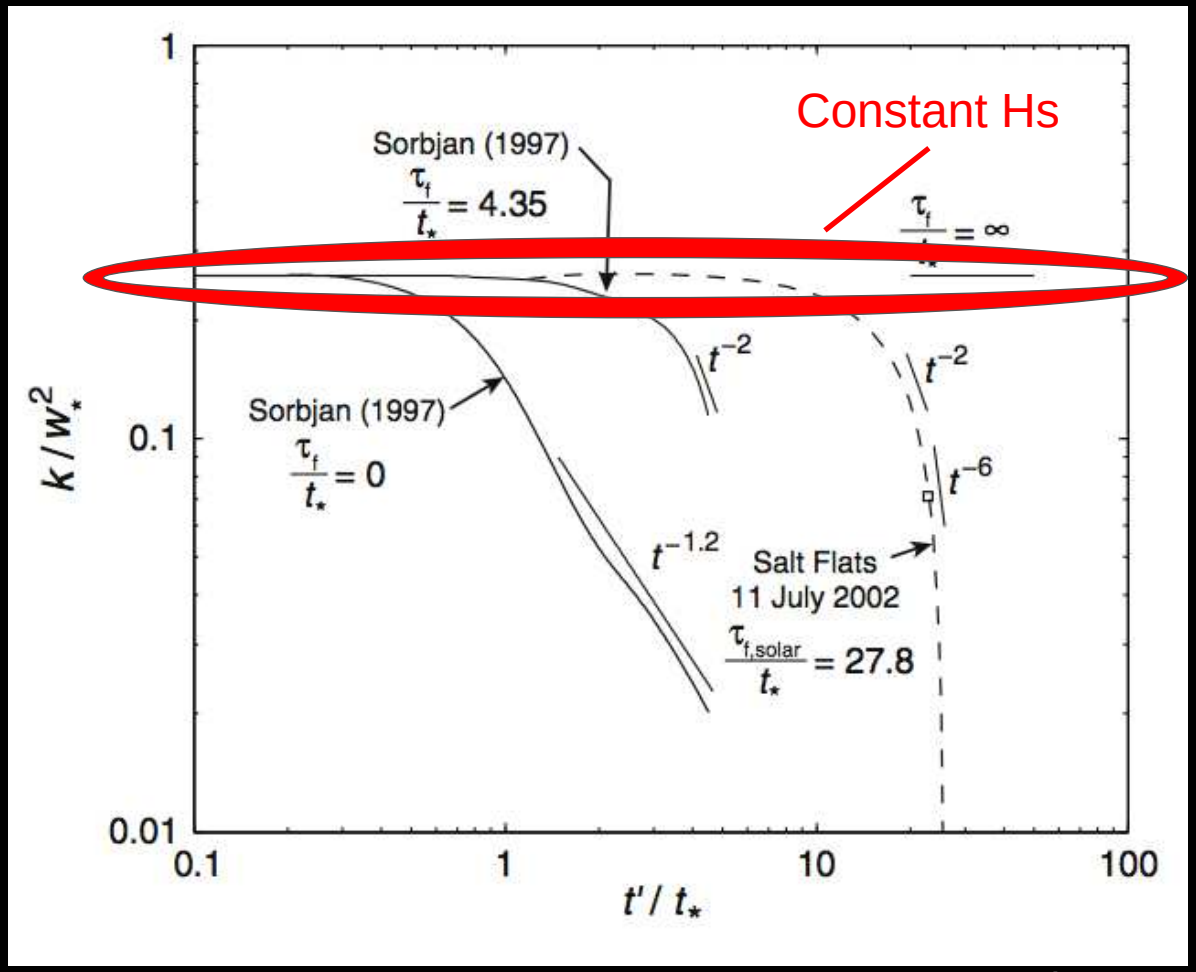
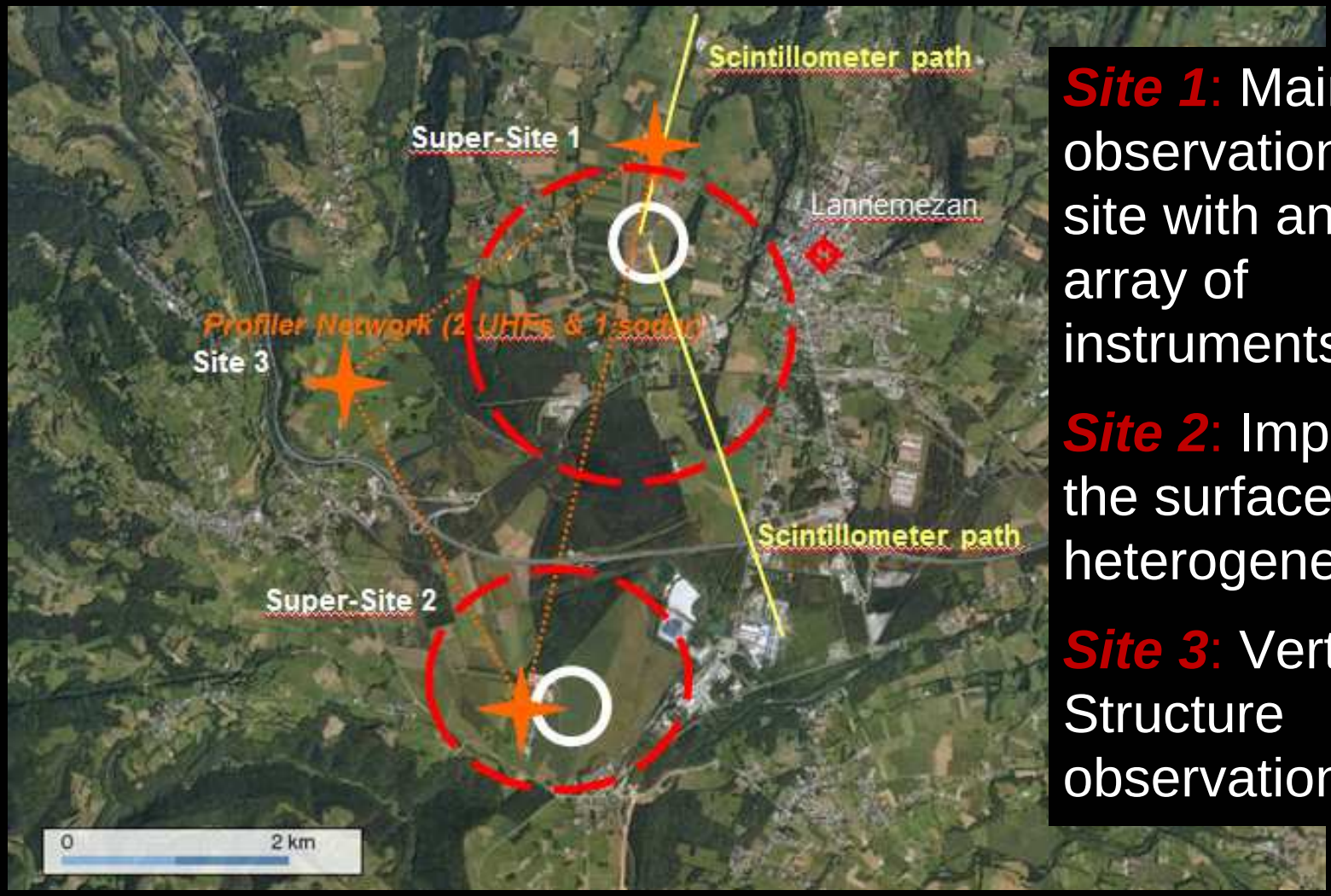


Figure adapted from Sorbjan by Dan Nadeau

Experimental Setup


Carnac
Loire Valley
France
Basle
St Nazaire
Nantes
Tours
Dijon
Bern
Switzerland
Lausanne
Geneva
La Rochelle
Atlantic Ocean
Chamonix
Aiguille du Midi
Clermont-Ferrand
Annecy
Sarlat-La-Caneda
Lyon
Val d'Isere
Menbel
Grenoble
Alps
Italy
Bordeaux
Massif Central
Bay of Biscay
Alpes de Haute Provence
Monaco Principality
Avignon
Nimes
Les Baux de Provence
Nice
Cannes
Bilbao
Biarritz
Bayonne
Toulouse
Montpelier
Arles
Aix-en-Provence
San Sebastien
Carcassonne
Marseilles
St Tropez
Lourdes
Narbonne
Toulon
Pamplona
Pyrenees
Andorra Principality
Gulf of Lion
Cote d'Azur
Perpignan
Corsica island
Spain



Site 1: Main observational site with an array of instruments

Site 2: Impact of the surface heterogeneity

Site 3: Vertical Structure observation

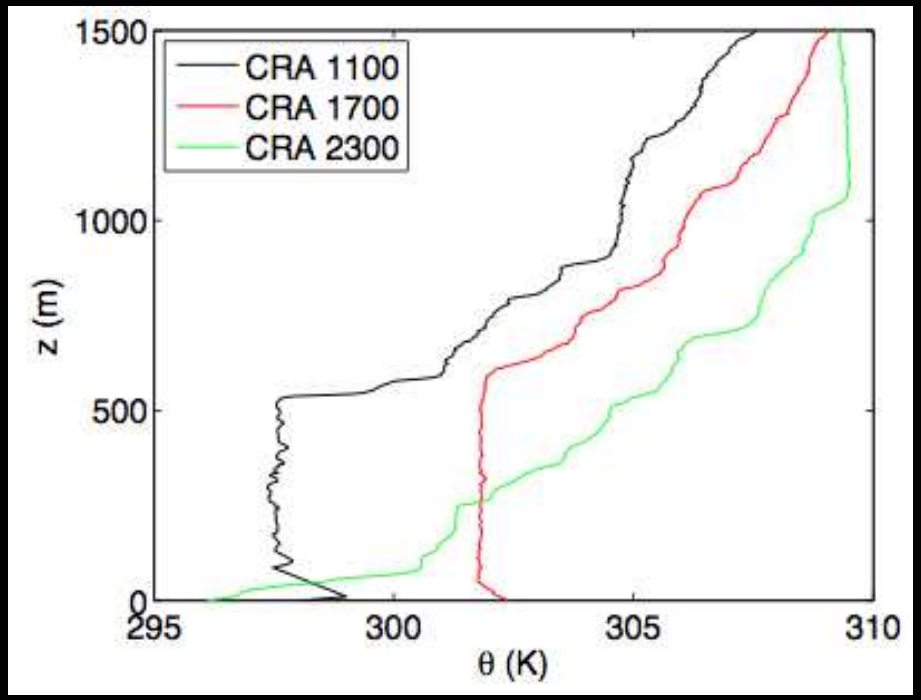
MECHANICAL ENGINEERING
The BLLAST Experiment

Parameter	Sensor	Sampling frequency (or period)	Height of measurement
Wind component U	CSAT Campbell sonic anemometer (UTAH)	10 Hz	31.55 m
Wind component V			
Wind component W			
Sonic temperature			
Specific humidity CO2 concentration	LICOR 7500 (LA)	10 Hz	
Black body temperature of radiometer	CNR1 KIPP & ZONEN (LA)	1 Hz	28.69 m
Outgoing global radiation			
Incoming global radiation			
Outgoing longwave radiation			
Incoming longwave radiation			
Temperature	Campbell HMP45 (LA)	1 Hz	29.02 m
Relative humidity			
Wind component U	CSAT Campbell sonic anemometer (UTAH)	10 Hz	21.84 m
Wind component V			
Wind component W			
Sonic temperature			

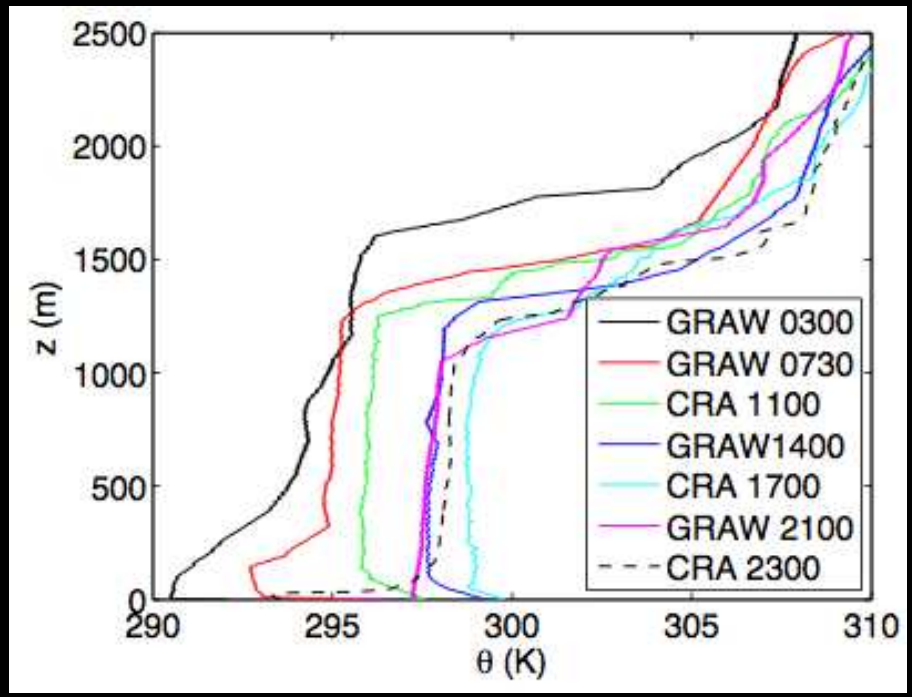
IOPs

- IOP 1 – 15 June 2011
- IOP 2 – 19 June 2011
- IOP 3 – 20 June 2011
- IOP 4 – 24 June 2011
- IOP 5 – 25 June 2011
- IOP 6 – 26 June 2011
- IOP 7 – 27 June 2011
- IOP 8 – 30 June 2011
- IOP 9 – 01 July 2011
- IOP 10 – 02 July 2011
- IOP 11 – 05 July 2011

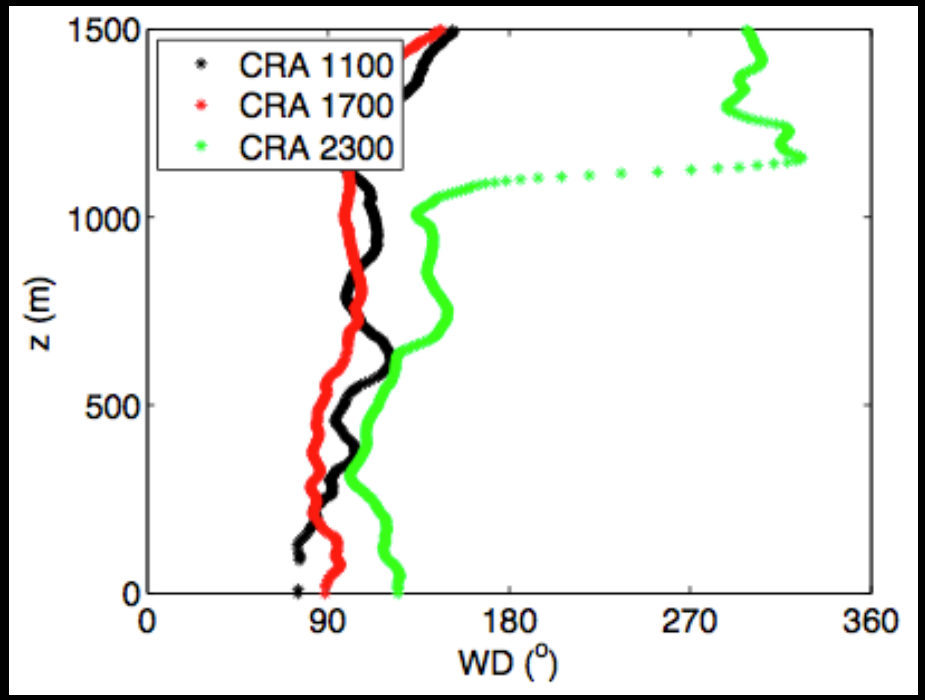
IOP 5


CRA 1100
CRA 1700
CRA 2300
z (m)
θ (K)
0
500
1000
1500
295
300
305
310

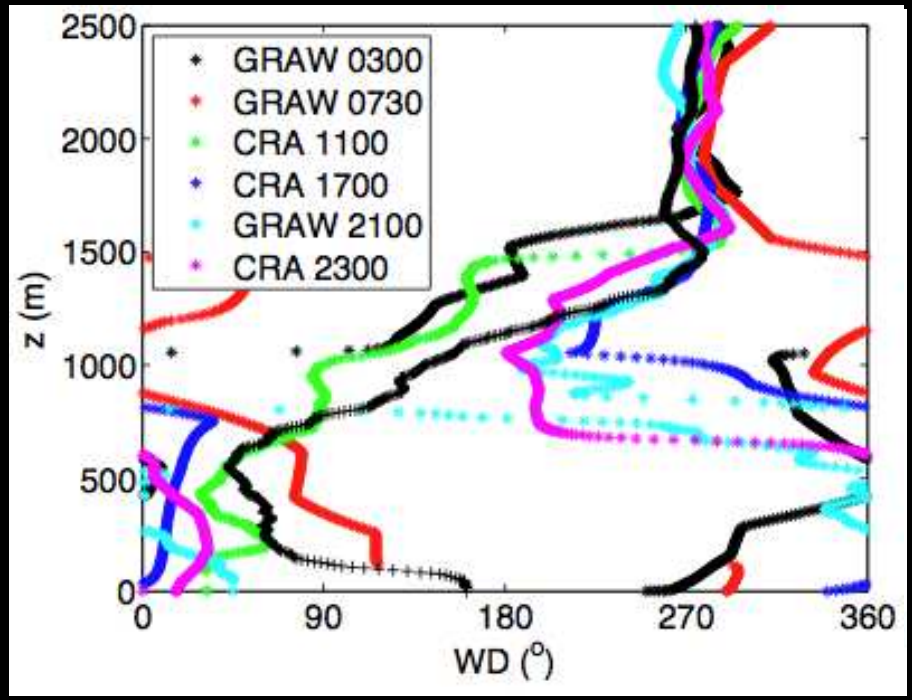
IOP 9

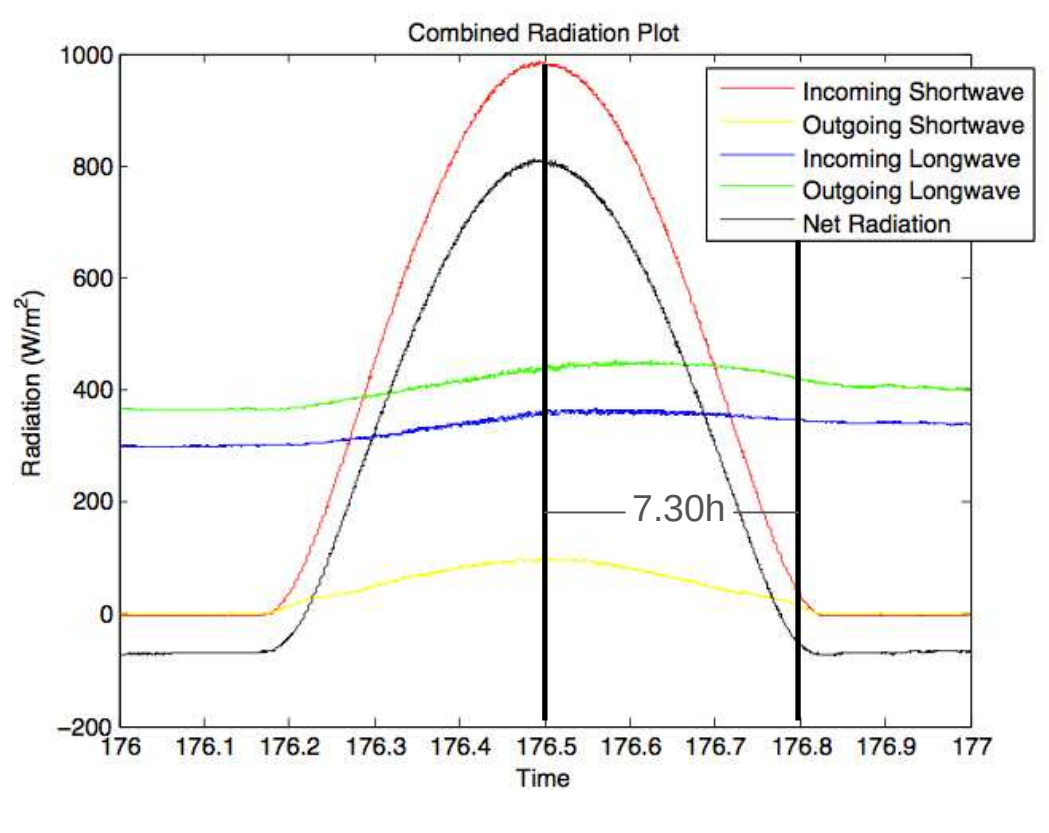

GRAW 0300
GRAW 0730
CRA 1100
GRAW1400
CRA 1700
GRAW 2100
CRA 2300
z (m)
θ (K)
0
500
1000
1500
2000
2500
290
295
300
305
310

IOP 5


CRA 1100
CRA 1700
CRA 2300
z (m)
WD (°)
0
500
1000
1500
0
90
180
270
360

IOP 9


GRAW 0300
GRAW 0730
CRA 1100
CRA 1700
GRAW 2100
CRA 2300
z (m)
WD (°)
0
500
1000
1500
2000
2500
0
90
180
270
360



$$H_{\cos}(t') = H_{\max}\cos\left(\frac{\pi t'}{2\tau_{\cos}}\right)$$

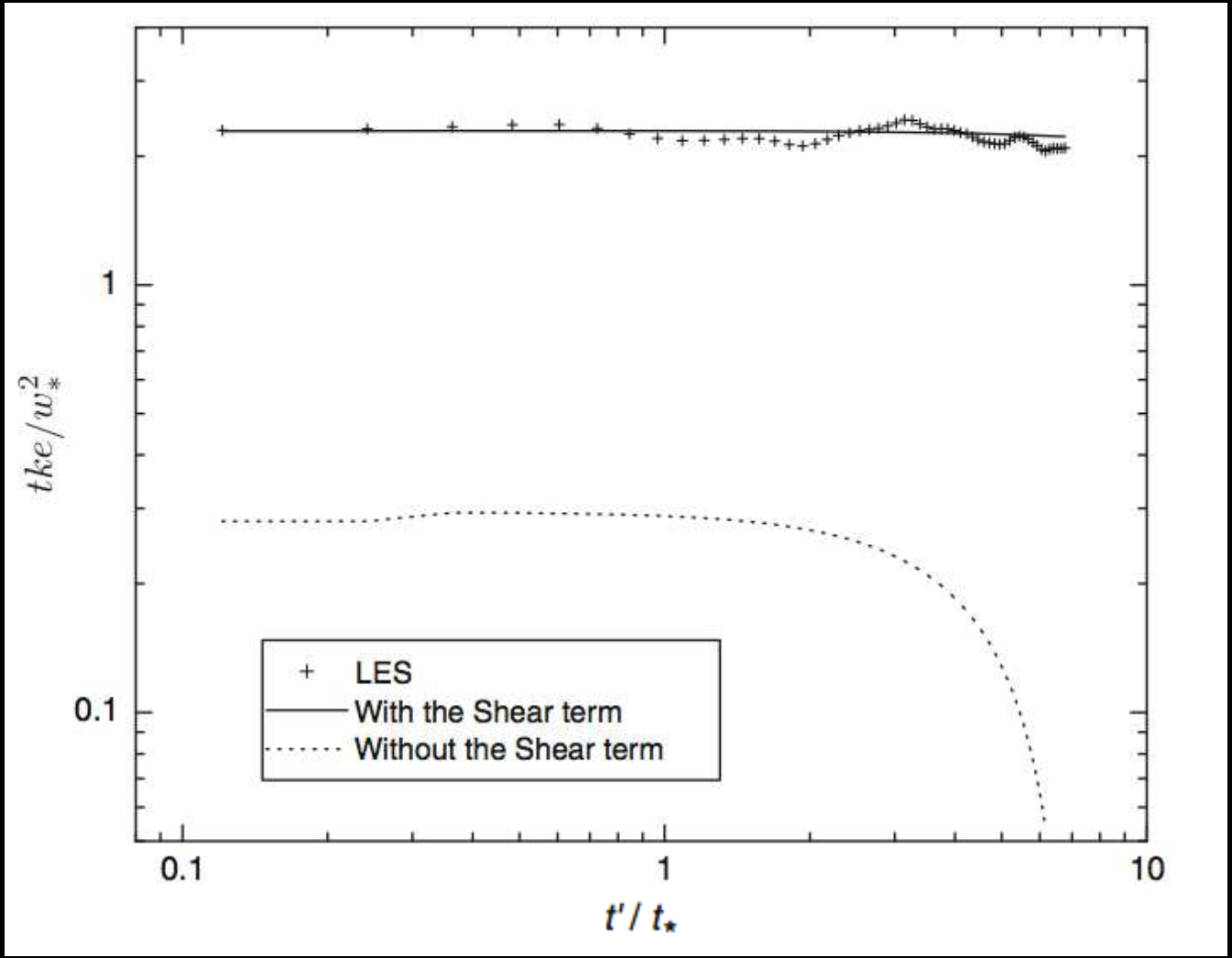
Application of Nadeau modell

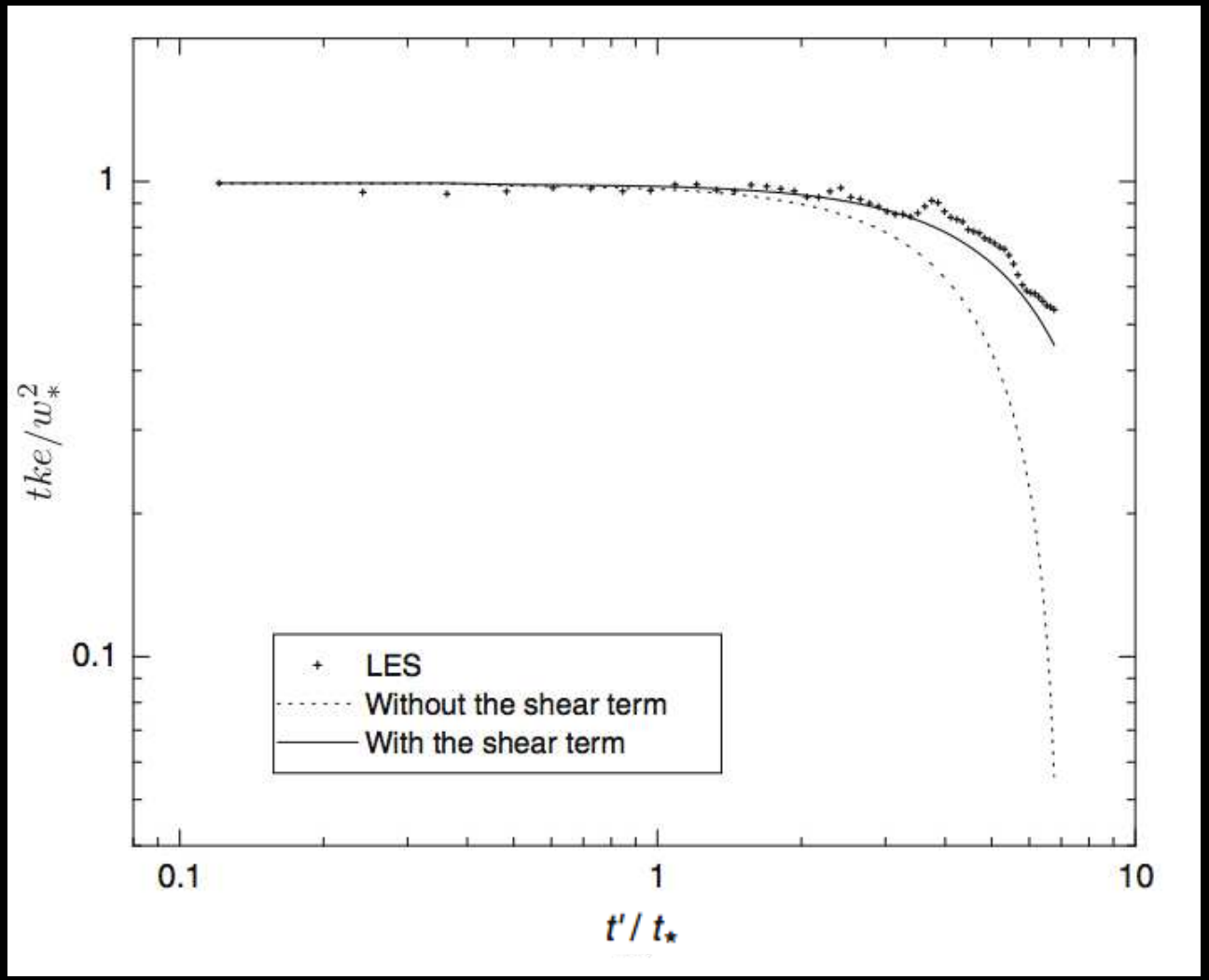
$$t_* = \frac{t' w_*}{z_i}$$

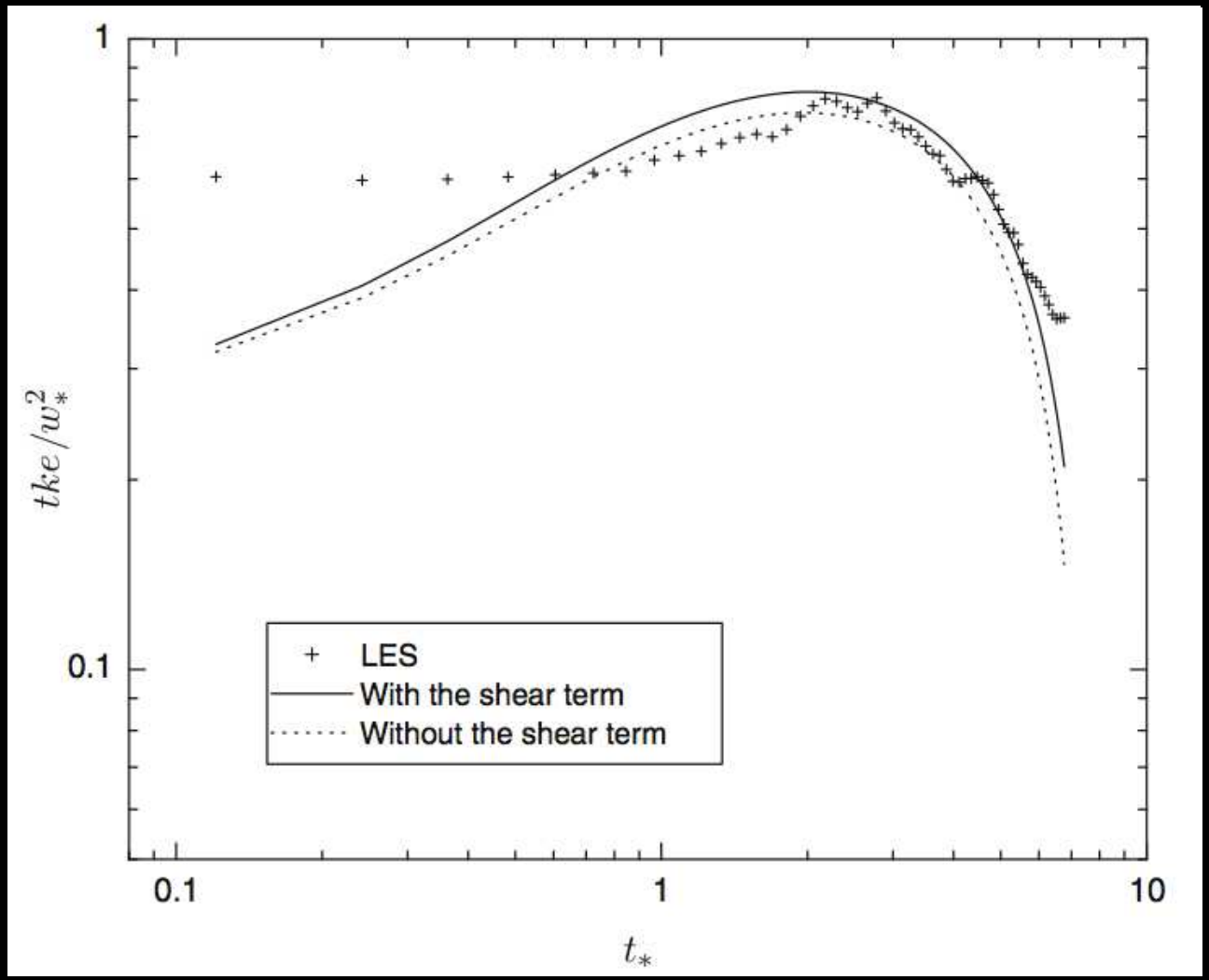
$$w_* = \left[\frac{g}{\theta_v} z_i F_{Hsfc} \right]^{1/3}$$

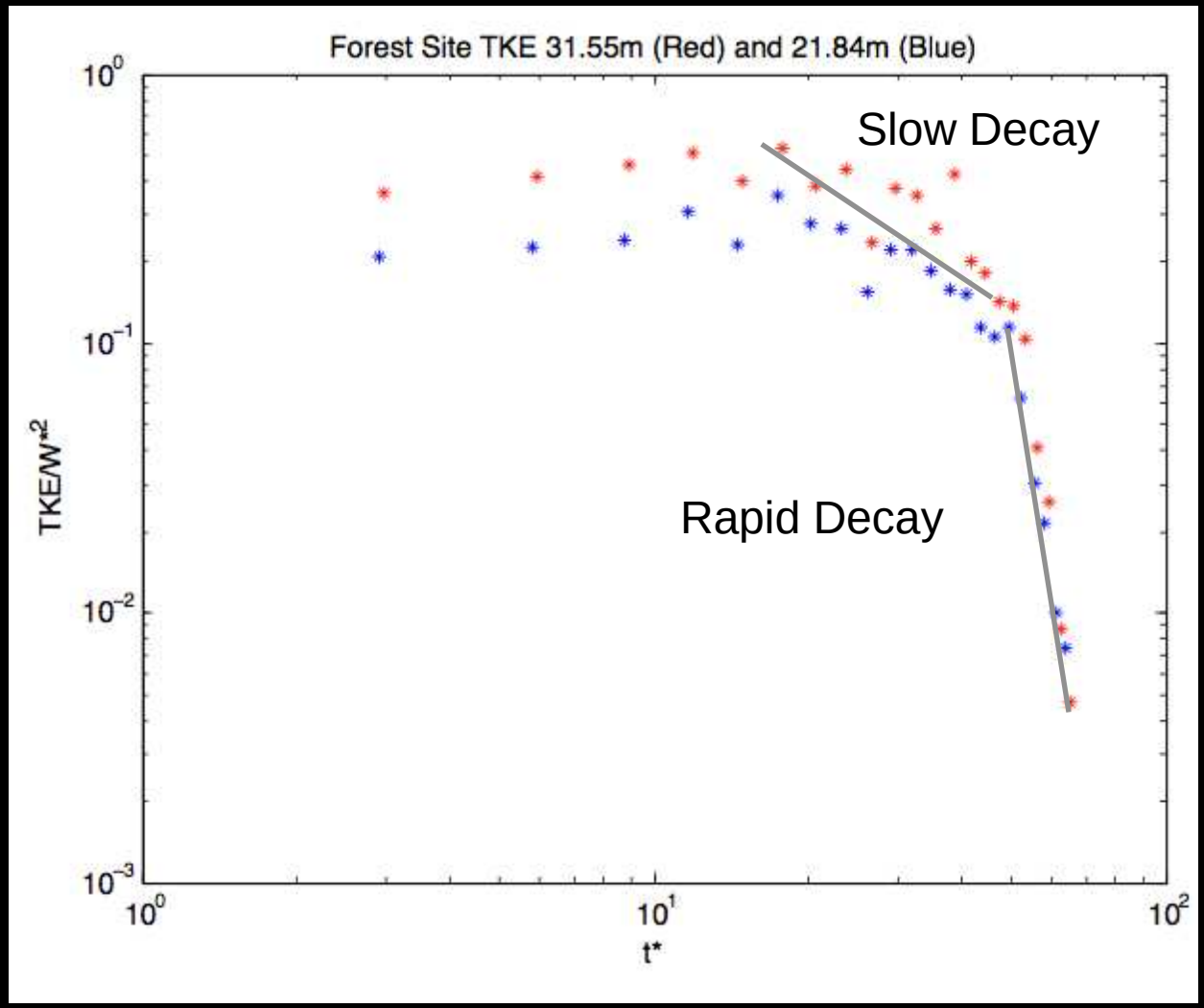
$$TKE = .5\left[\overline{(u')^2} + \overline{(v')^2} + \overline{(w')^2} \right]$$

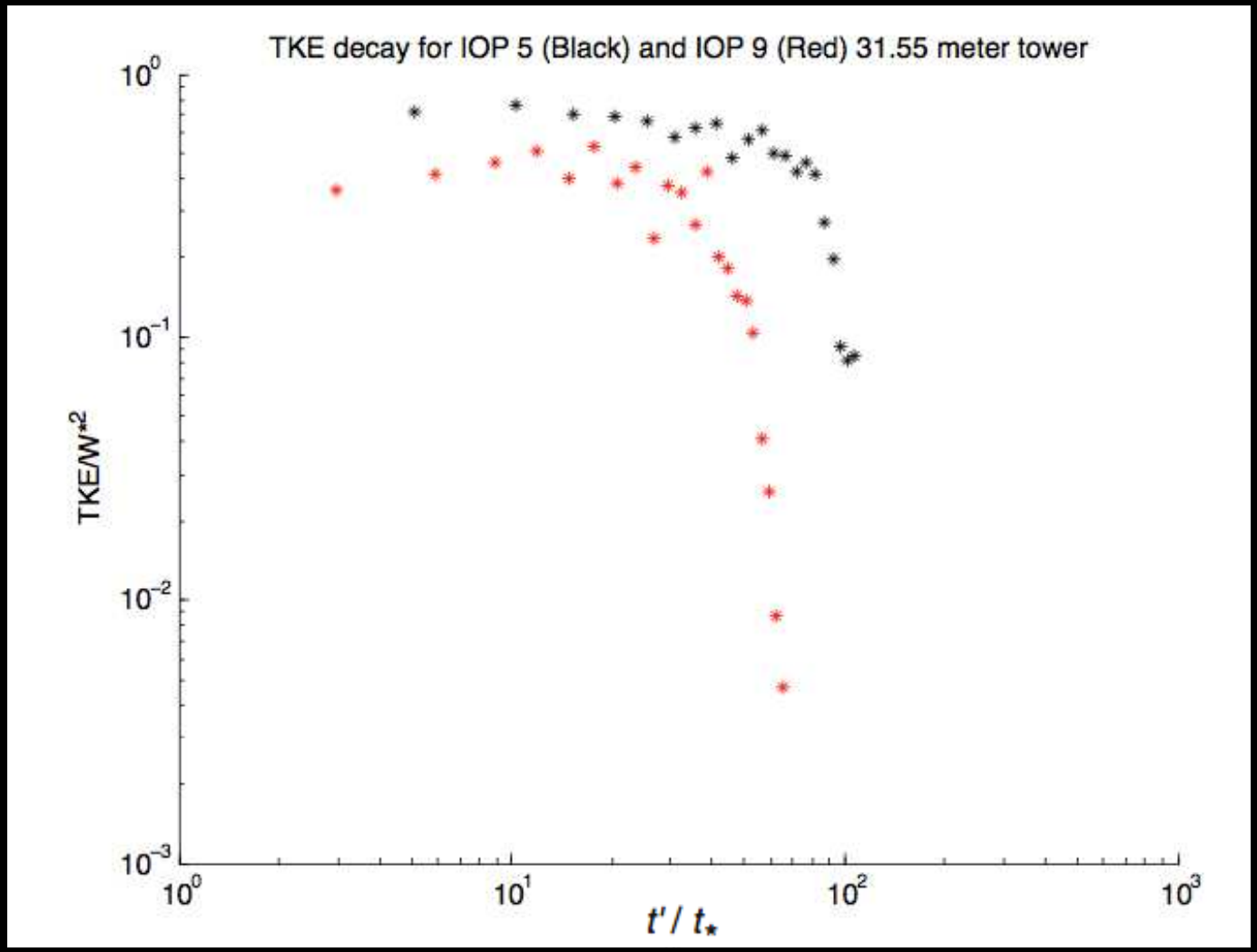
- t' • Time from start of decay
- w_* • Deardorff Velocity
- z_i • Depth of ABL at t' = 0
- F_{Hsfc} • Kinematic Sensible Heat Flux
- θ_v • Potential temperature
- u' • Perturbation from u mean vel.
- g • Acceleration due to gravity

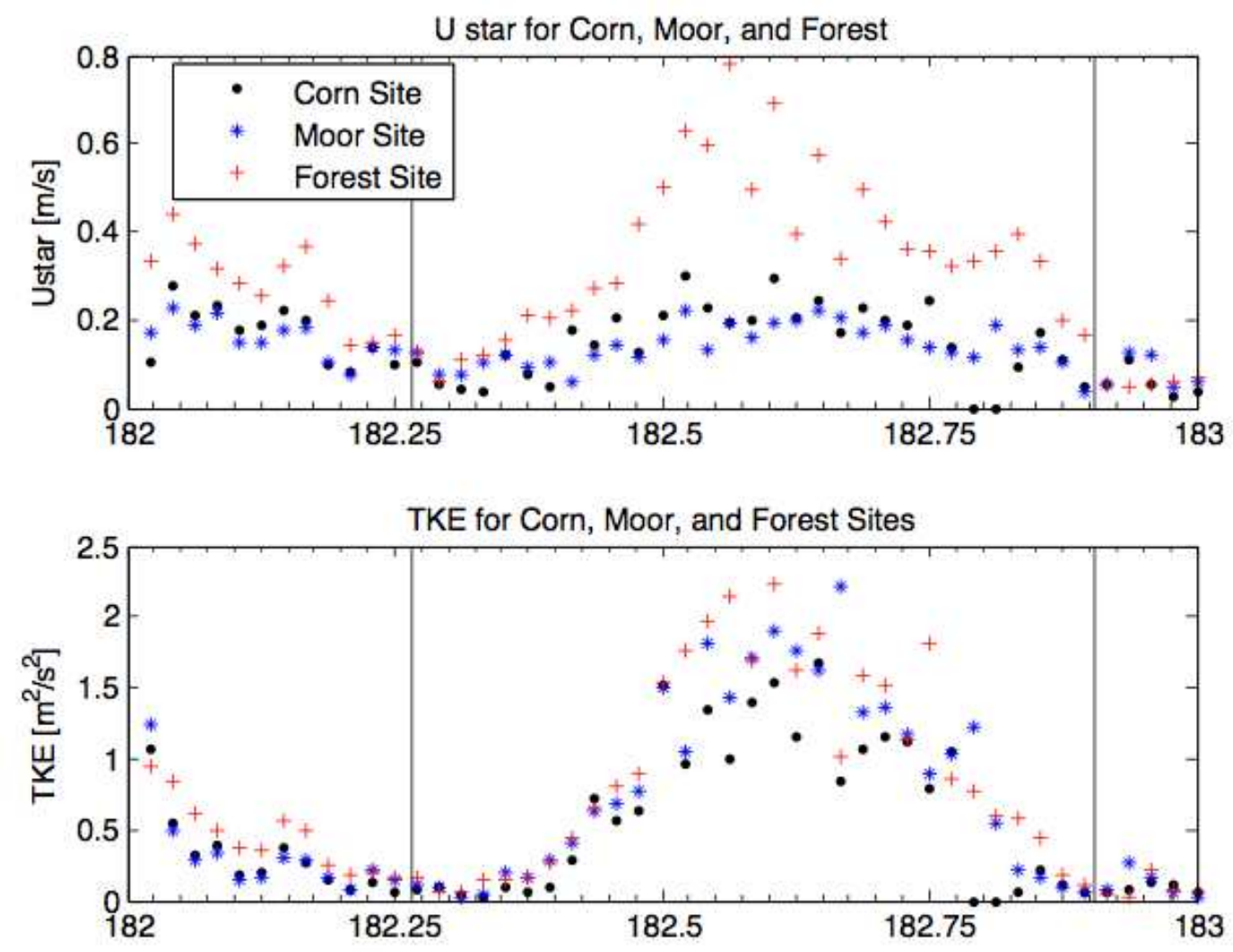

1
0.1
tke/w_*^2
0.1
1
10
$t'/t_\star$
LES
With the Shear term
Without the Shear term

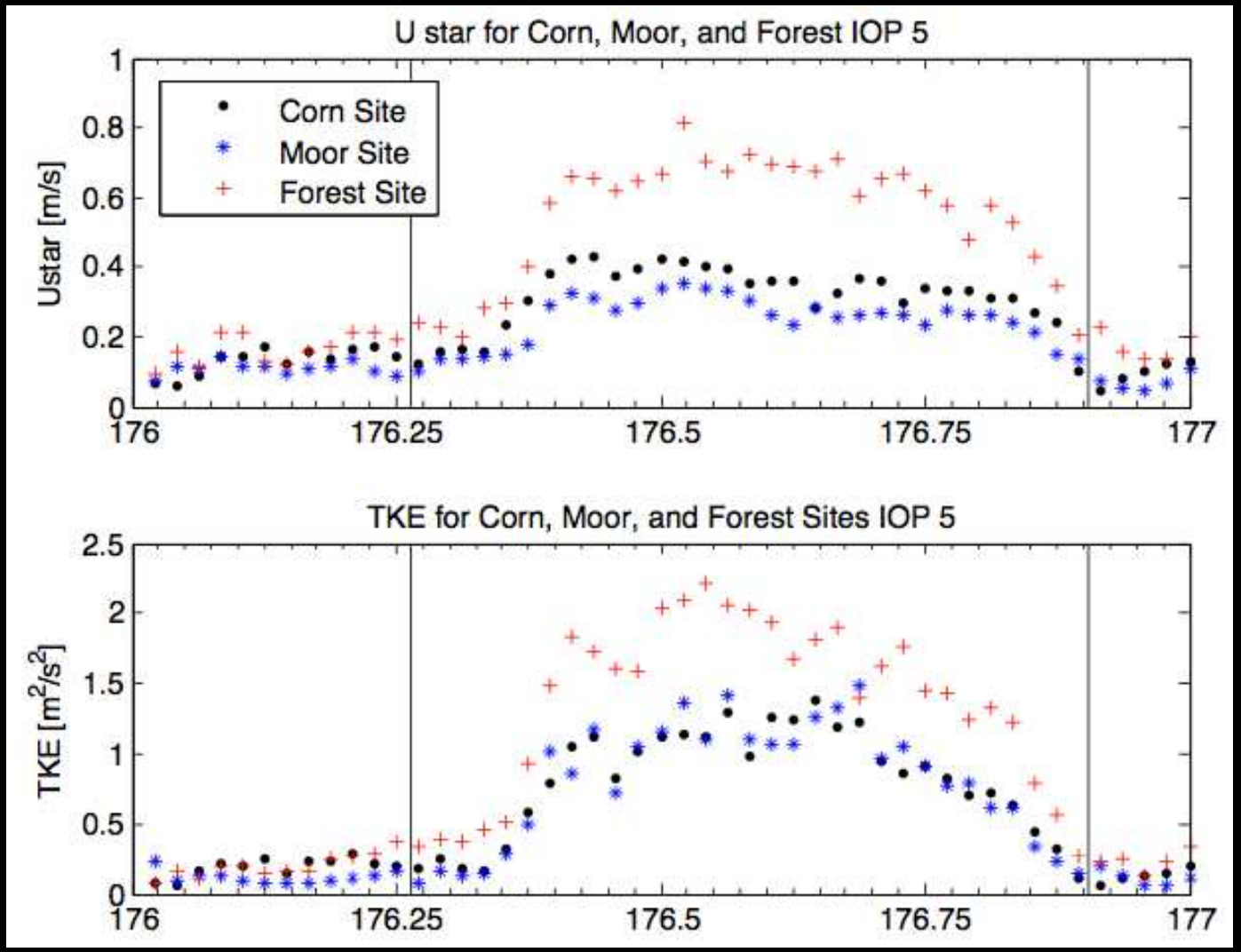

1
0.1
tke/w_*^2
LES
Without the shear term
With the shear term
0.1
1
10
$t'/t_\star$


1
0.1
0.1
1
10
tke/w_*^2
t_*
LES
With the shear term
Without the shear term


Forest Site TKE 31.55m (Red) and 21.84m (Blue)
Slow Decay
Rapid Decay
TKE/W*2
t*
10^0
10^-1
10^-2
10^-3
10^0
10^1
10^2

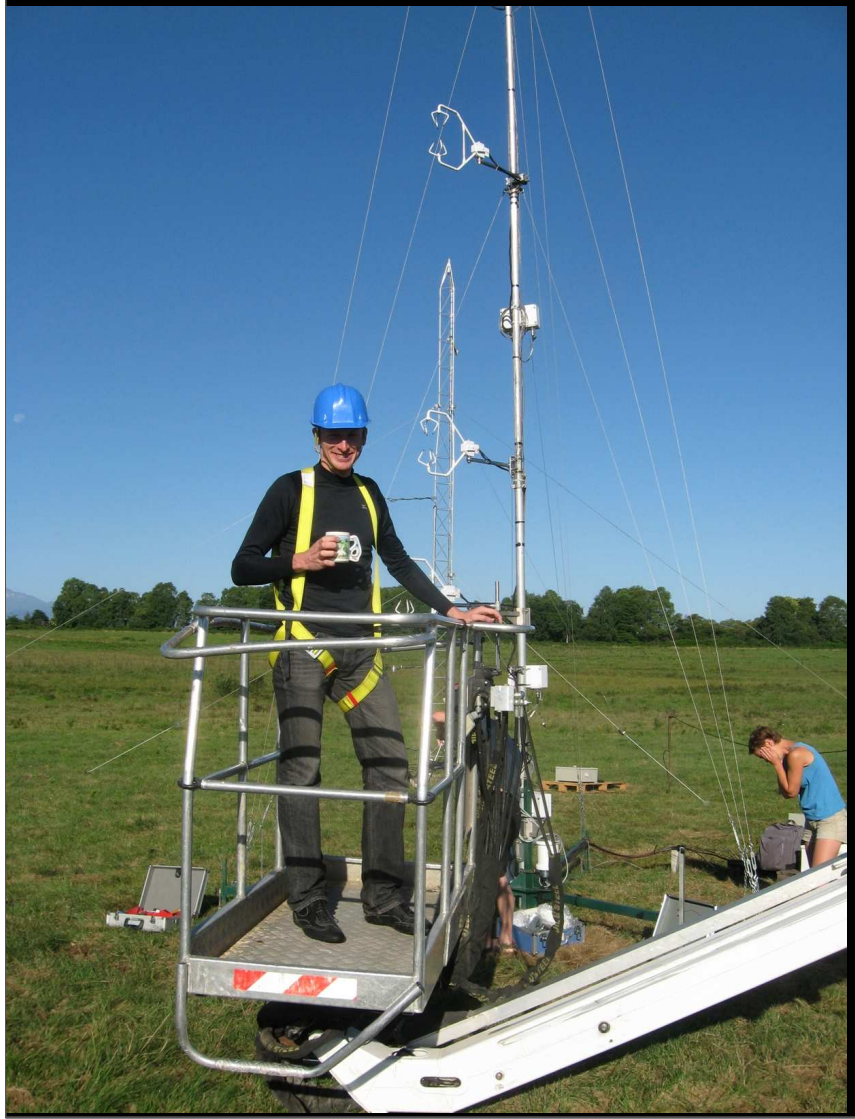

TKE decay for IOP 5 (Black) and IOP 9 (Red) 31.55 meter tower
TKE/W*2
t' / t*
10^0
10^-1
10^-2
10^-3
10^0
10^1
10^2
10^3


U star for Corn, Moor, and Forest
Corn Site
Moor Site
Forest Site
Ustar [m/s]
0.8
0.6
0.4
0.2
0
182
182.25
182.5
182.75
183
TKE for Corn, Moor, and Forest Sites
TKE [m²/s²]
2.5
2
1.5
1
0.5
0
182
182.25
182.5
182.75
183


U star for Corn, Moor, and Forest IOP 5
Corn Site
Moor Site
Forest Site
Ustar [m/s]
0
0.2
0.4
0.6
0.8
1
176
176.25
176.5
176.75
177
TKE for Corn, Moor, and Forest Sites IOP 5
TKE [m²/s²]
0
0.5
1
1.5
2
2.5
176
176.25
176.5
176.75
177

Summary

- Two decay regimes are observed in the roughness sub layer
- Mechanical Shear within the boundary layer varies as the transition nears requiring models to consider additional atmospheric conditions when calculating the mechanical production of TKE
- There is a possible delay of the start of the rapid decay period with increased mechanical production of TKE



Questions?