UTAH – 17 AUGUST 2012

Lessons from Previous Studies and MATERHORN - X

Silvana Di Sabatino (1, 2) **and Laura Sandra Leo** (1)
(1) *Environmental Fluid Dynamics Laboratories, Civil Engineering & Geological Sciences, University of Notre Dame, Notre Dame, IN, USA*
(2) *Micrometeorology Lab, University of Salento, Via Monteroni, Lecce, Italy*

In Preparation of Materhorn Fall experiment…

….What has been going on at ND during this year ?

(1) *Research Advancements* (*MATERHORN-X*)

based on archived data from previous field experiments in complex terrain:

- TRANSFLEX
- BIFERNO
- HERMOSA
- VTMX

(2) *Planning of the fall field campaign*

- Operational Plan (in collaboration with the other *MATERHORN –X* groups)
- Test/ calibration/ checking of instruments (in laboratory and open field e.g. White Field experiments)

Findings from previous field studies

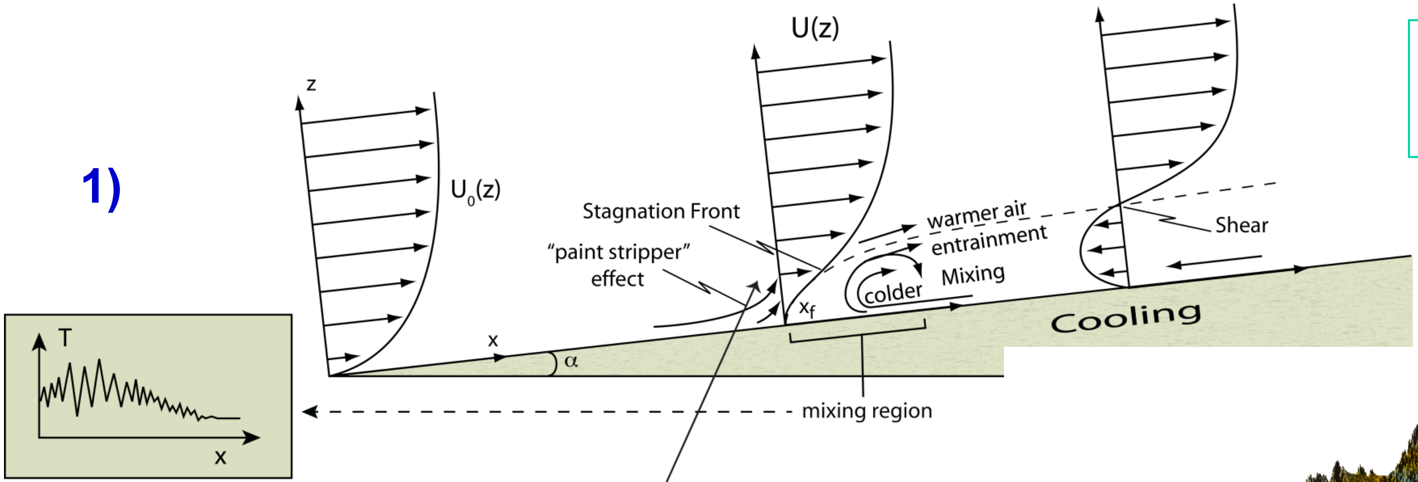
- ➢ Flow transition in complex terrain – results from Phoenix experiments (TRANSFLEX, 2006)
- ➢ Flow circulation under low synoptic in a coastal urban valley (Biferno, Italy 2009)
- ➢ Flow and turbulence parameterization - the role of scales in BL flows (Hermosa Study- Phoenix, 2009)
- ➢ Mixing efficiency in atmospheric flows (VTMX – Salt Lake City, 2000)
- ➢ Turbulence collapse – transition from convective to stable & neutral: the role of air moisture (White Field, ND, 2011)

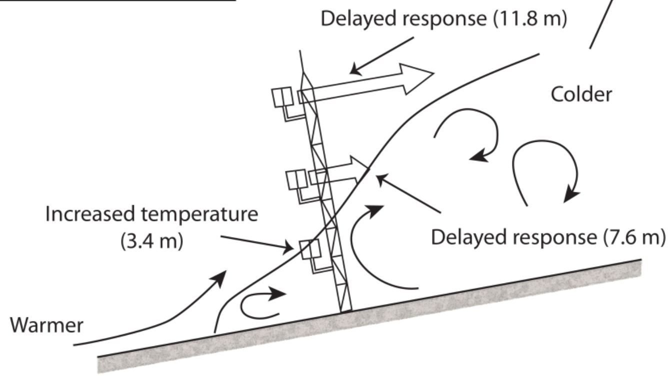
TRANSFLEX EXPERIMENT: Focus on Evening Transition

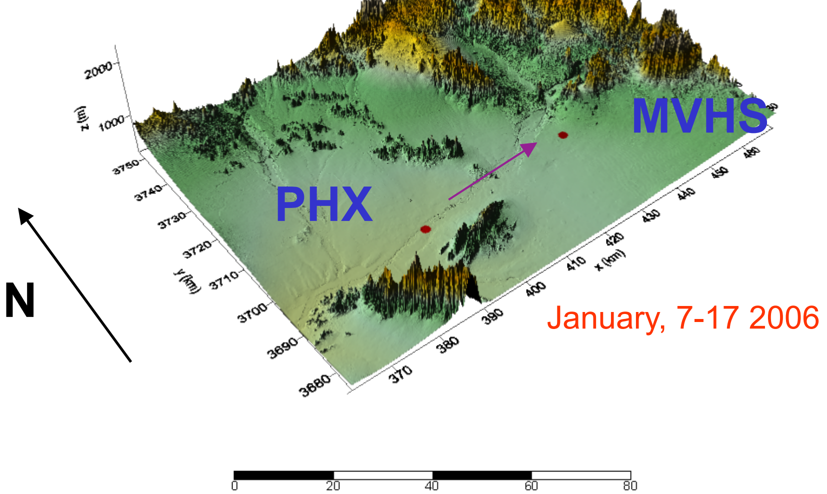
Two scenarios: 1) formation of a transitional front 2) change in buoyancy of a cooled slab of air near the ground

1)

Hunt et al. 2003



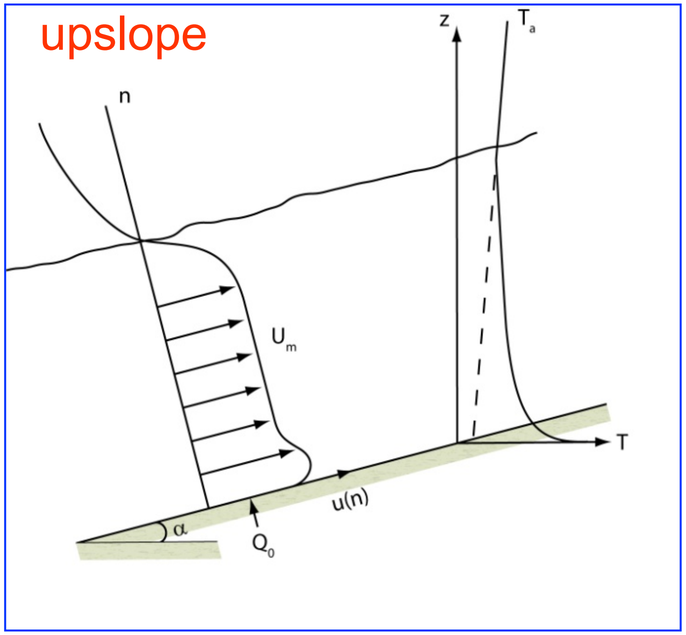


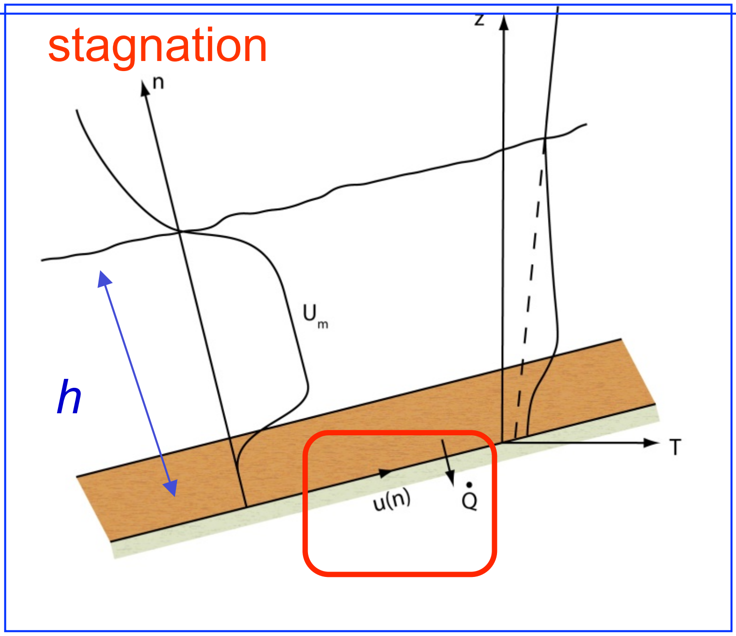


January, 7-17 2006

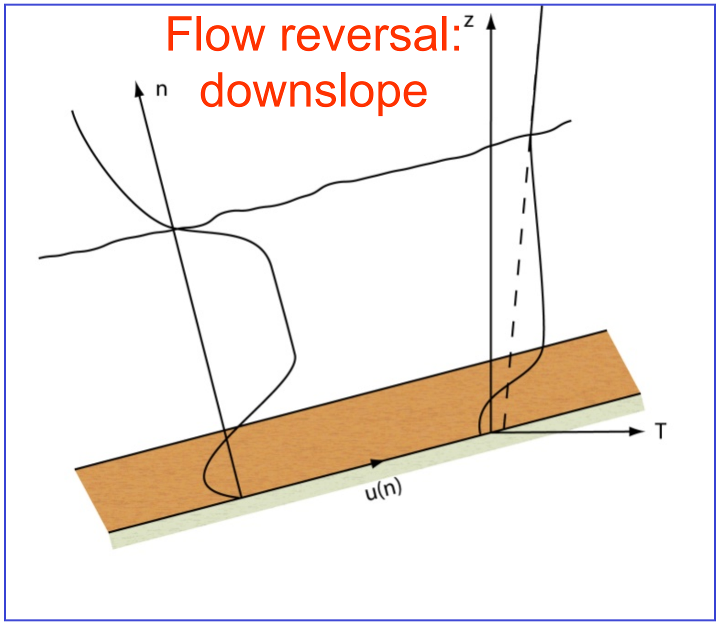
Fernando, H.J.S., Verhoef, B., Di Sabatino, S., Leo, L.S., Park, S. "The Phoenix Evening Transition Flow Experiment (TRANSFLEX). Boundary-Layer Meteorology. Under Review

EVENING TRANSITION MECHANISMS


upslope


stagnation

2) SLAB FLOW of negative buoyant fluid generated by radiative cooling


Flow reversal: downslope

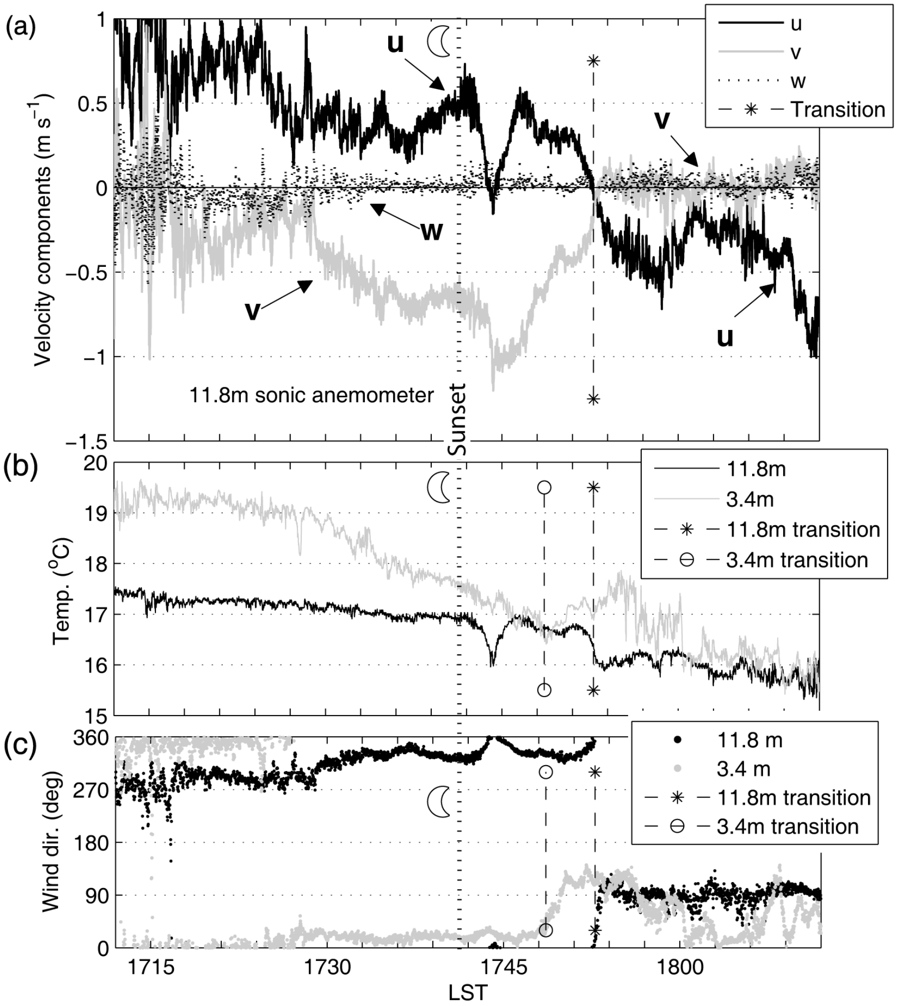
$$\boxed{\frac{d(g\beta\Delta T h)}{dt} \approx \dot{Q}}$$

$$\boxed{\frac{dh}{dt} \approx \frac{k}{h}}$$

$$\frac{\dot{Q}h}{g\alpha\Delta T k} > 1$$

$$\boxed{R = \frac{\dot{Q}h^4 \sin\alpha}{\nu k^2} \gg 1}$$

Ri_g analyses highlighted different mechanism (Strang and Fernando 2001)

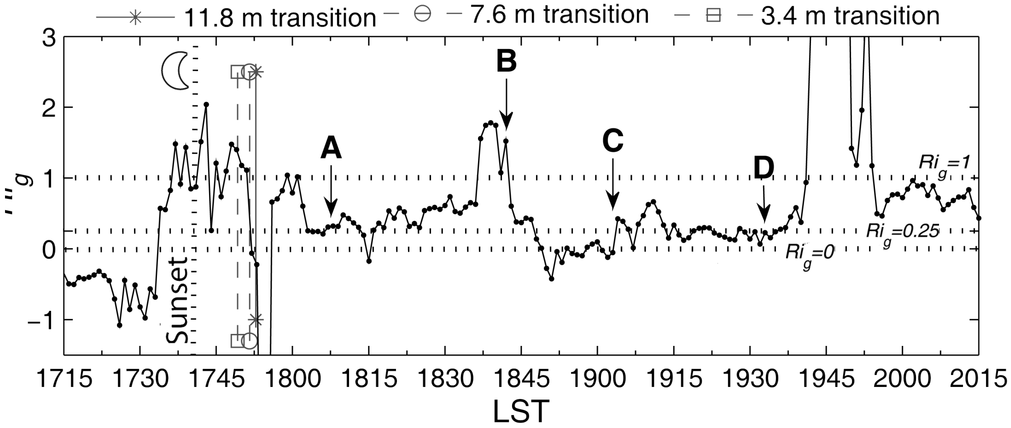


$$Ri_g = \frac{N^2}{\left(\frac{\Delta u}{\Delta z}\right)^2 + \left(\frac{\Delta v}{\Delta z}\right)^2}$$

$Ri_g \leq 0.25$ K-H

$0.25 \leq Ri_g \leq 1$ **K-H and I-waves**

$Ri_g > 1$ Hölmböe instabilities



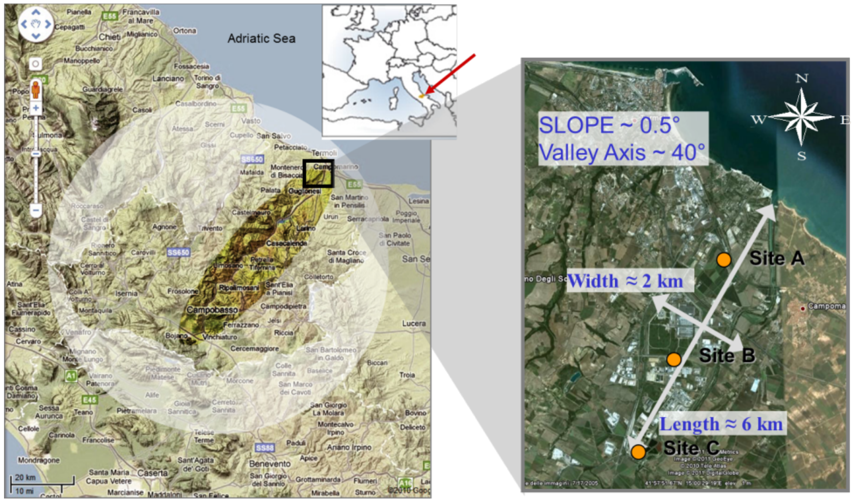
upstream influence causes Ri_g to change before the arrival of front, which is a characteristic of intrusions into stratified fluids (De Silva and Fernando 1998)

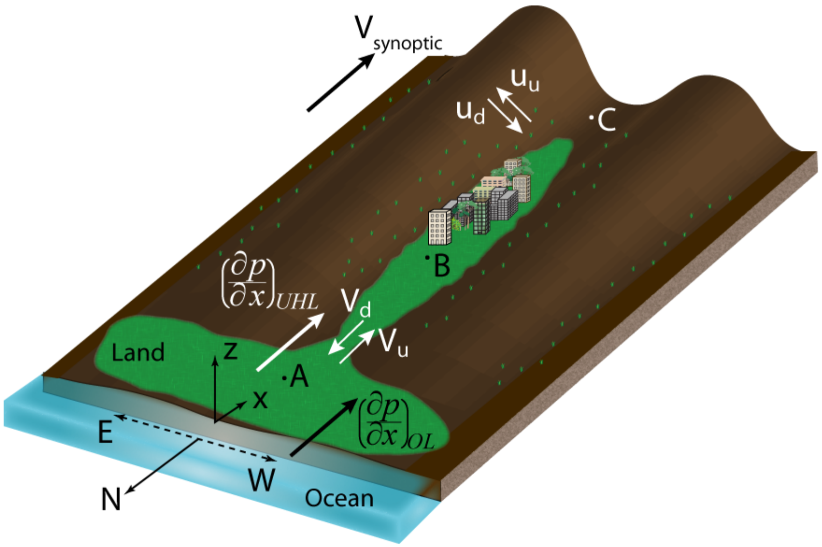
A, B, C, D: events of flow adjustement

Fernando, H.J.S., Verhoef, B., Di Sabatino, S., Leo, L.S., Park, S. "The Phoenix Evening Transition Flow Experiment (TRANSFLEX). Boundary-Layer Meteorology. Under Review

FLOW CIRCULATION IN COASTAL VALLEY: THE BIFERNO PROJECT

Lessons from Previous Studies and MATERHORN - X





Anabatic velocity scale

$$U_a = \Gamma w_* \beta^{1/3}$$

Γ site dependent

$$w_* = (q_0 h)^{1/3}$$

convective velocity scale (Deardorff,1970)

$$\Gamma = f(z_0, L_*) \sim 10$$

Hunt, J. C. R., H. J. S. Fernando, and M. Princevac, 2003: Unsteady thermally driven flows on gentle slopes. *J. Atmos. Sci.*, 60, 2169–2182.

Mean Flow parameterization for a costal valley

“pure” anabatic contribution

Combination of UHI and Ocean-Land contribution

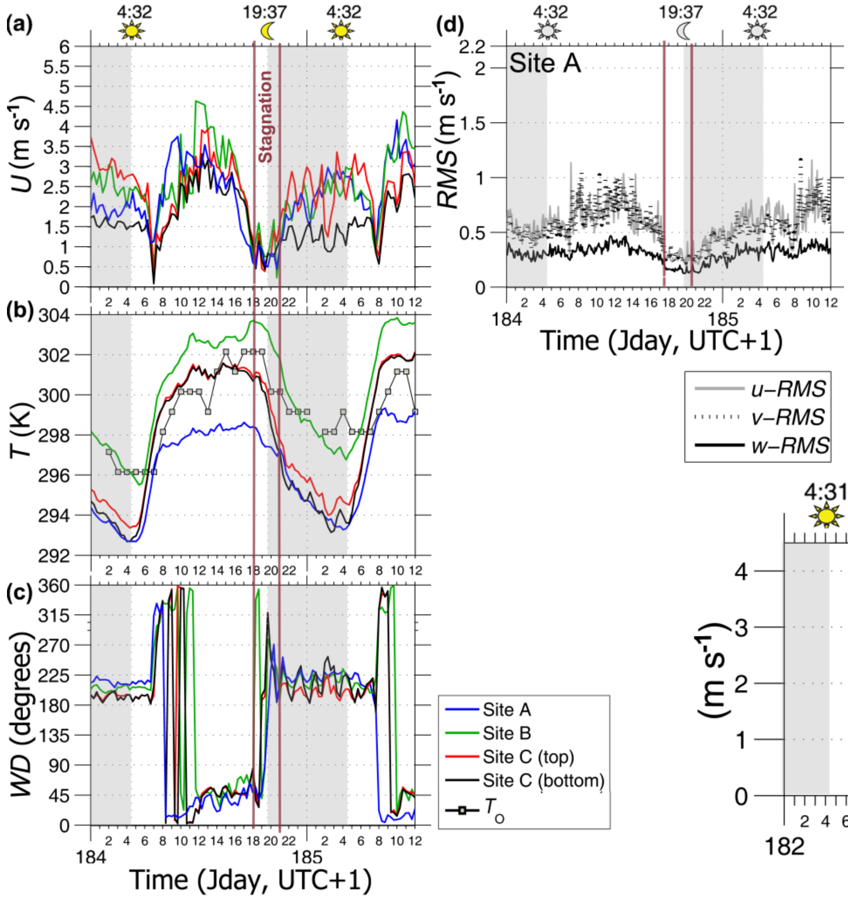
$$U \approx \underbrace{U_a} + \underbrace{U_r}$$

$$U \approx \underbrace{\Gamma w_* \beta^{1/3}} + \underbrace{C(g\alpha\Delta T_{u-r} L)^{1/2}}$$

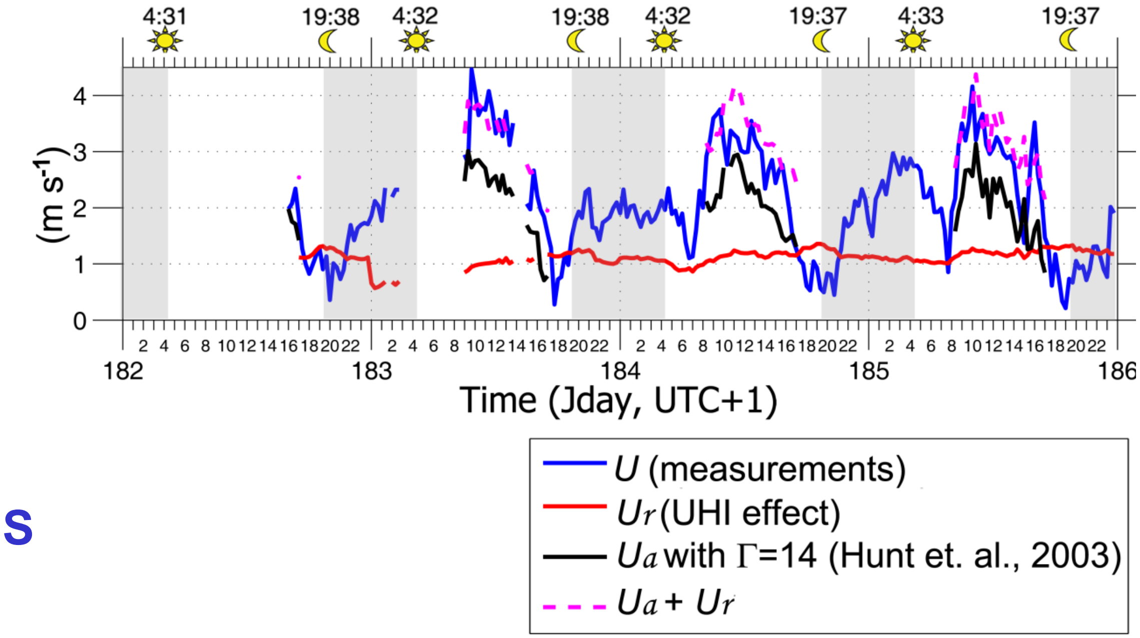
Leo, L.S., Fernando, H.J.S., Di Sabatino (2012)- Flow in Complex Terrain with Coastal and Urban Influence. Journal of Applied Meteorology and Climate. Under review.

FLOW CIRCULATION IN COASTAL VALLEY: THE BIFERNO PROJECT

Lessons from Previous Studies and MATERHORN - X



$$U \approx \underbrace{\Gamma w_* \beta^{1/3}} + \underbrace{C(g\alpha\Delta T_{u-r}L)^{1/2}}$$

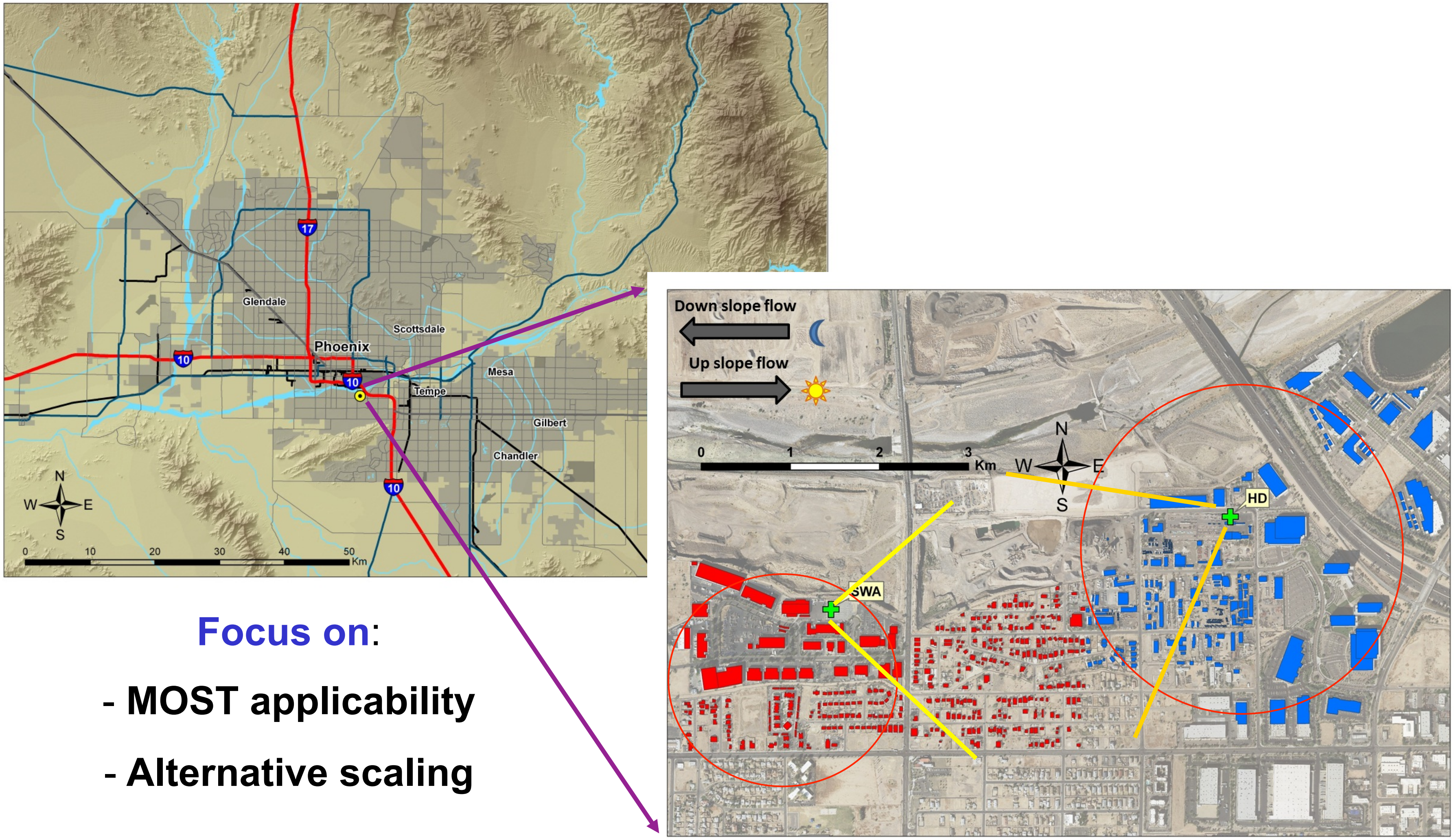


BIFERNO OBSERVATIONS

Slab flow mechanism

Leo, L.S., Fernando, H.J.S., Di Sabatino (2012)- Flow in Complex Terrain with Coastal and Urban Influence. Journal of Applied Meteorology and Climate. Under review.

HERMOSA Study: Turbulence scaling in complex terrain



Focus on:

- **MOST applicability**
- **Alternative scaling**

Dallman, A., Di Sabatino, S and Fernando, H.J.S. Flow and Turbulence in an Industrial / Suburban Roughness Canopy. Submitted to Environmental Fluid Mechanics.

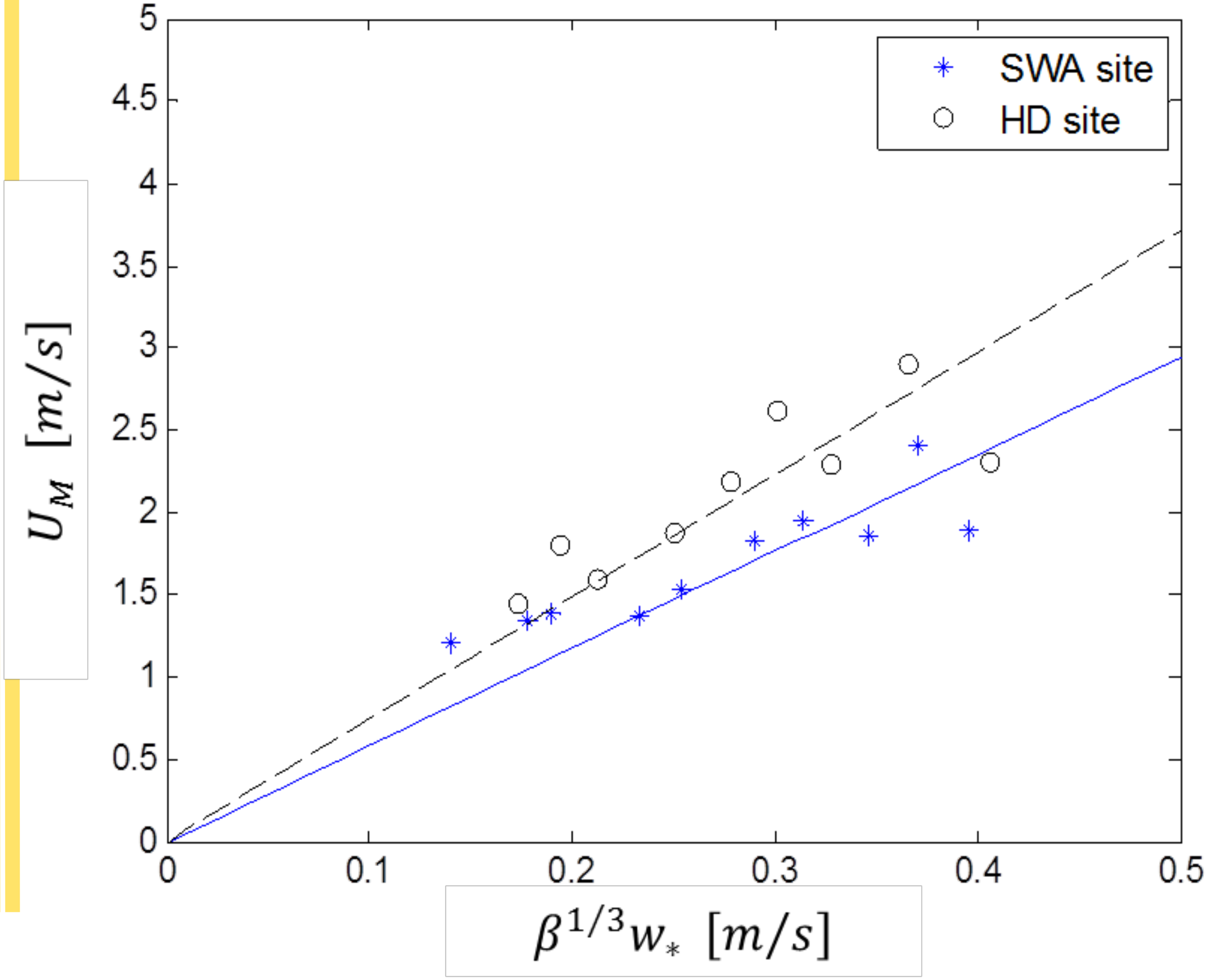
Lessons from Previous Studies and MATERHORN - X

DAYTIME UPVALLEY FLOW

$$\Gamma \approx \left[\frac{ln(L_*/z_0)}{\kappa}\right]\left[\frac{h_s}{z_i}\frac{ln(L_*/z_{0\tau})}{\kappa}\right]^{\frac{1}{3}}$$

$$L_* = (u_*/w_*)^3 z_i$$

$$\Gamma \propto ln\left({}^{1}/{}_{z_0}\right)$$



HD site

$z_{0,270^\circ} = 0.04$ m

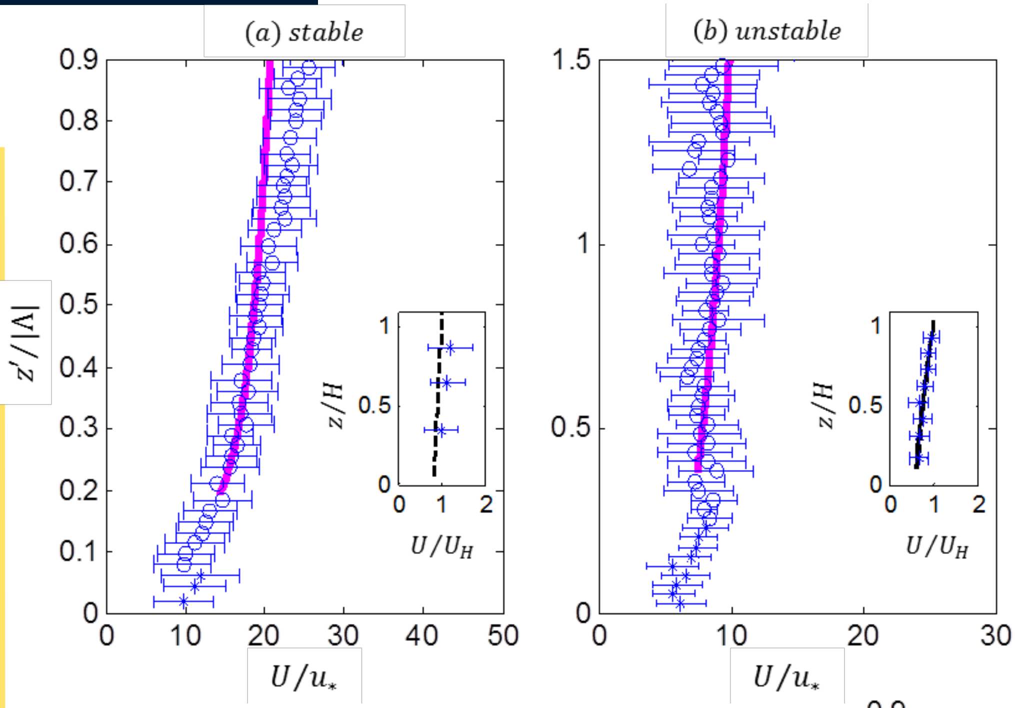
$\Gamma \approx 7.4$

SWA site

$z_{0,270^\circ} = 0.18$ m

$\Gamma \approx 5.9$

Applicability of MOST

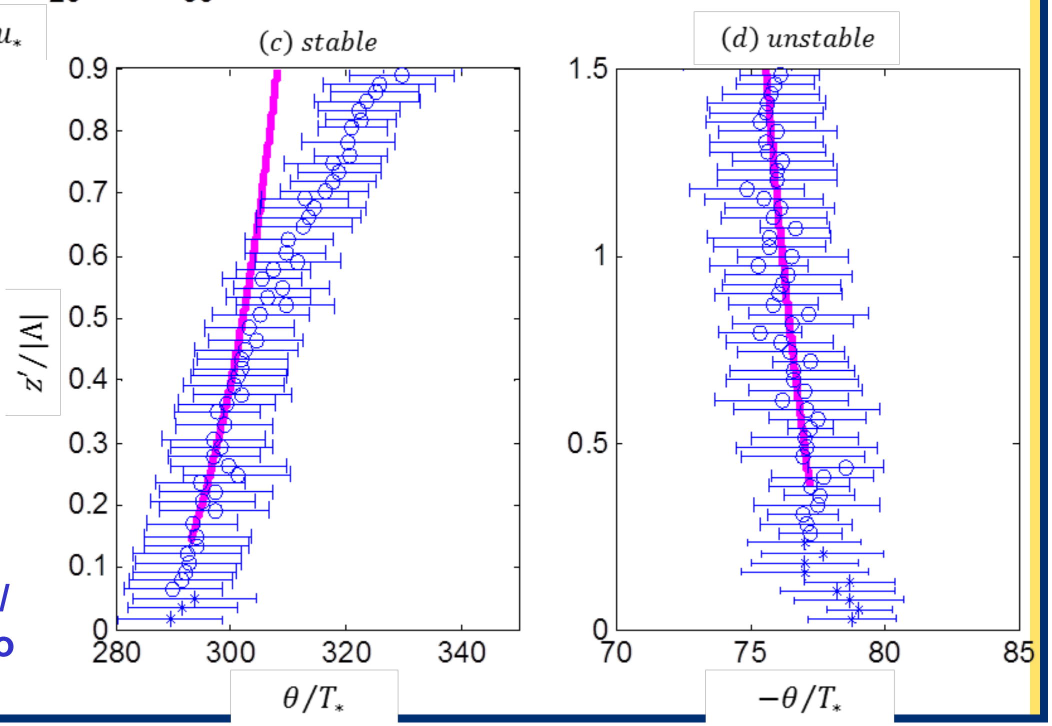


$$u(z) = \frac{u_*}{\kappa}\left[ln\left(\frac{z'}{z_0}\right) - \psi_m\right]$$

vertical profiles predicted by the Monin-Obukhov theory, which is expected to be valid only in the CFL

$$u(z) = \frac{u_*}{\kappa}\left[ln\left(\frac{z'}{z_0}\right) - 5\frac{z}{\Lambda}\right]$$

Temperature profiles



Dallman, A., Di Sabatino, S and Fernando, H.J.S. Flow and Turbulence in an Industrial / Suburban Roughness Canopy. Submitted to Environmental Fluid Mechanics.

Lessons from Previous Studies and MATERHORN - X

$$L_0 = \left(\frac{\varepsilon}{N^3}\right)^{\frac{1}{2}}$$

Buoyancy length scale

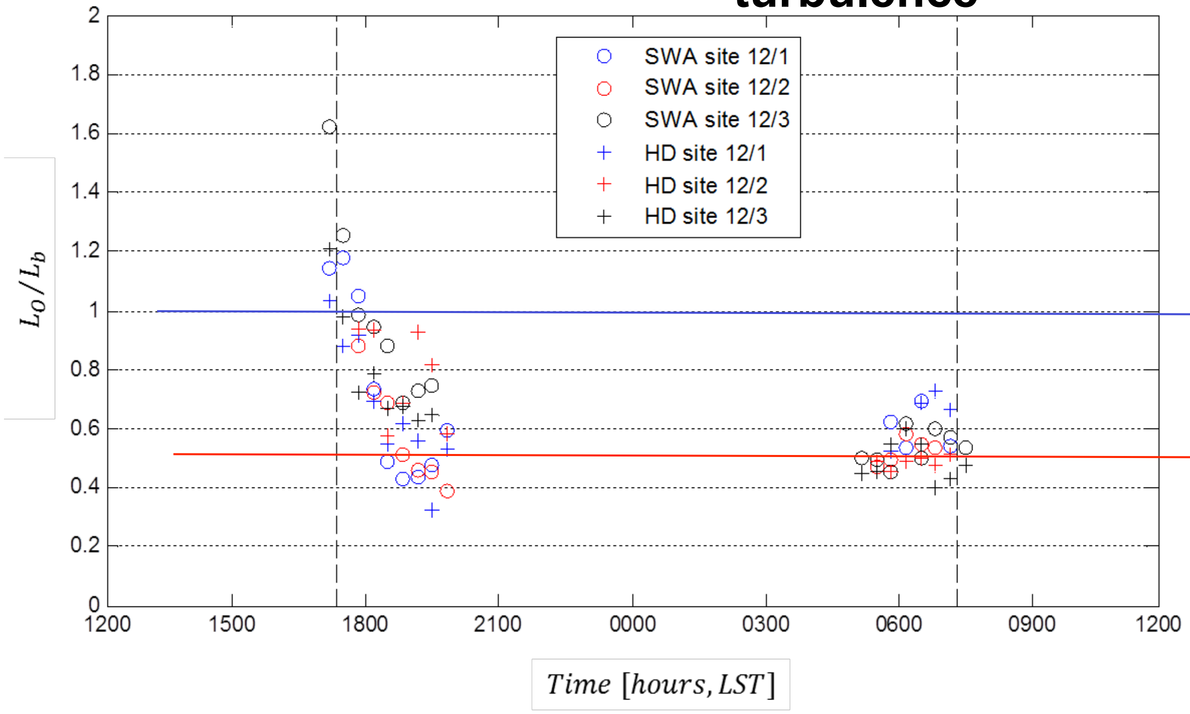
$$L_b = \frac{\sigma_w}{N}$$

Ozmidov length scale

$$L_0 < L_b$$

when buoyancy forces are unimportant in a stratified environment

scales where the buoyancy influences stratified turbulence



Regime 1

Regime 2

Energy constrained by stable stratification

N is calculated from balloon data

Dallman, A., Di Sabatino, S and Fernando, H.J.S. Flow and Turbulence in an Industrial / Suburban Roughness Canopy. Submitted to Environmental Fluid Mechanics.

Lessons from Previous Studies and MATERHORN - X

Mixing efficiency in enviromental flows (VTMX – Salt Lake City, 2000)

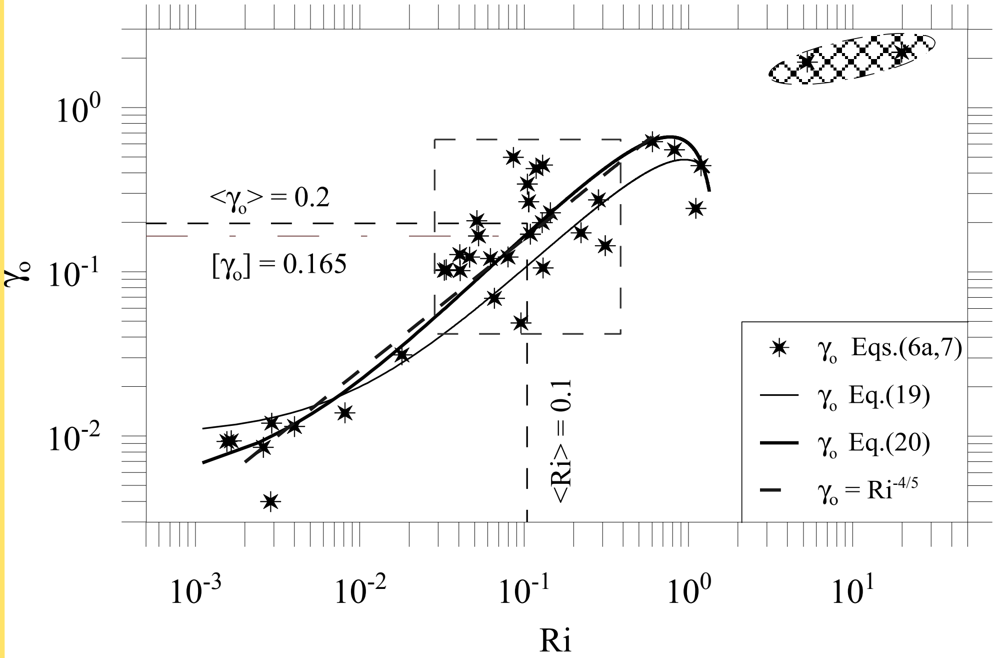
γ Mixing efficiency

$$\gamma = Rf/(1-Rf)$$

Ri gradient

$\mathrm{Re}_b = \varepsilon / \nu N^2$

Buoyancy Reyonolds number



In a wide range, the mixing efficiency increases with *Ri*, but decreases with Re_b

When *Ri* is in the proximity of

$$Ri_{cr} \sim 0.1 - 0.25$$

γ can be considered a constant $\gamma \approx$ 0.16 - 0.2.

Lozovatsky, I.D., and H.J.S. Fernando, 2012. Procedia of Royal Society. Mixing Efficiency in Natural Flows. In press.

Planning of the fall field campaign

OPERATIONAL PLAN
- ND experimental contribution

- Site selection – orographic features, terrain according to objectives – type of instrumentation and time resolution requirements
- Components: flux measurements (5 towers)
- Slope (fluxes and full energy balance) – and gap flows; fine-scale turbulence measurements; lidar, ceilometer, sodar/rass, balloon
- New technologies from ***MATERHORN -T*** advancements (Combo system, instrumented UAV, FASS, RF CROSSHAIR)

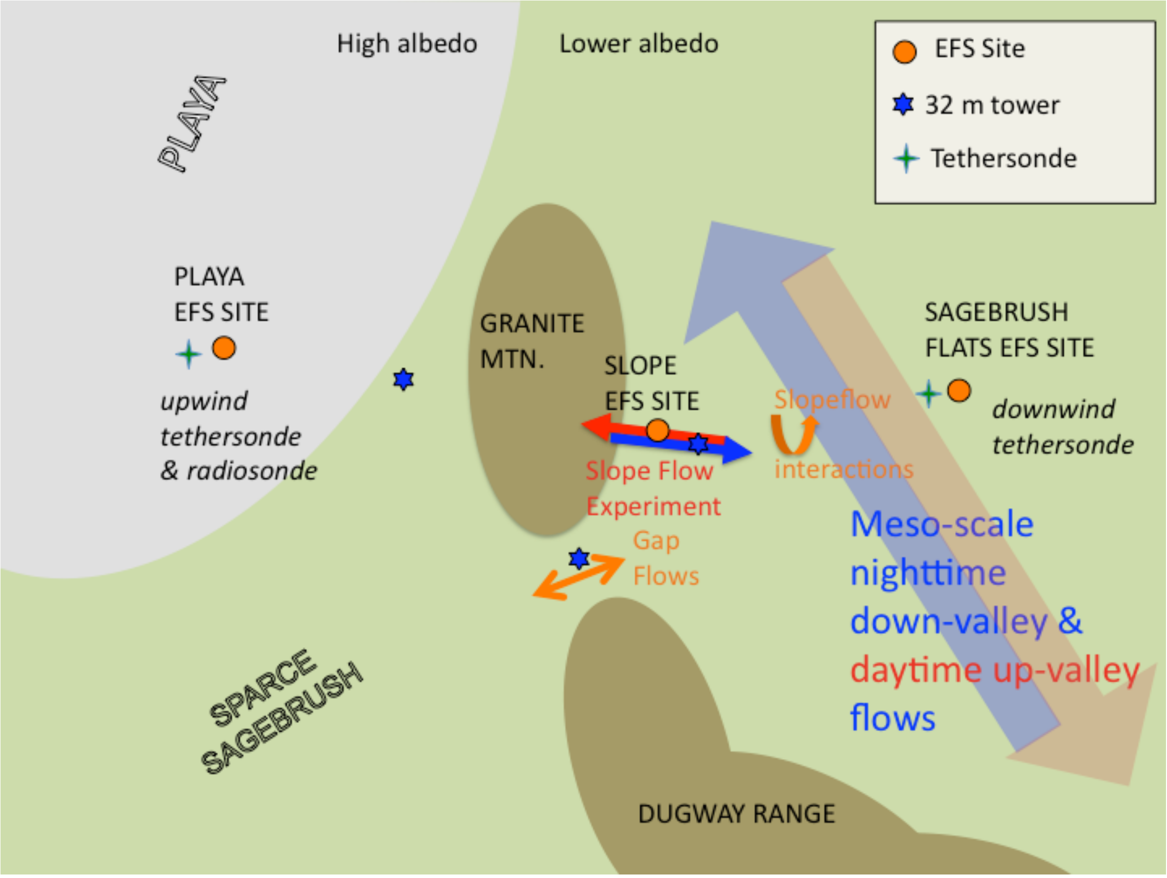
ND experimental contribution

Three heavily instrumented EFS:

EFS-Slope

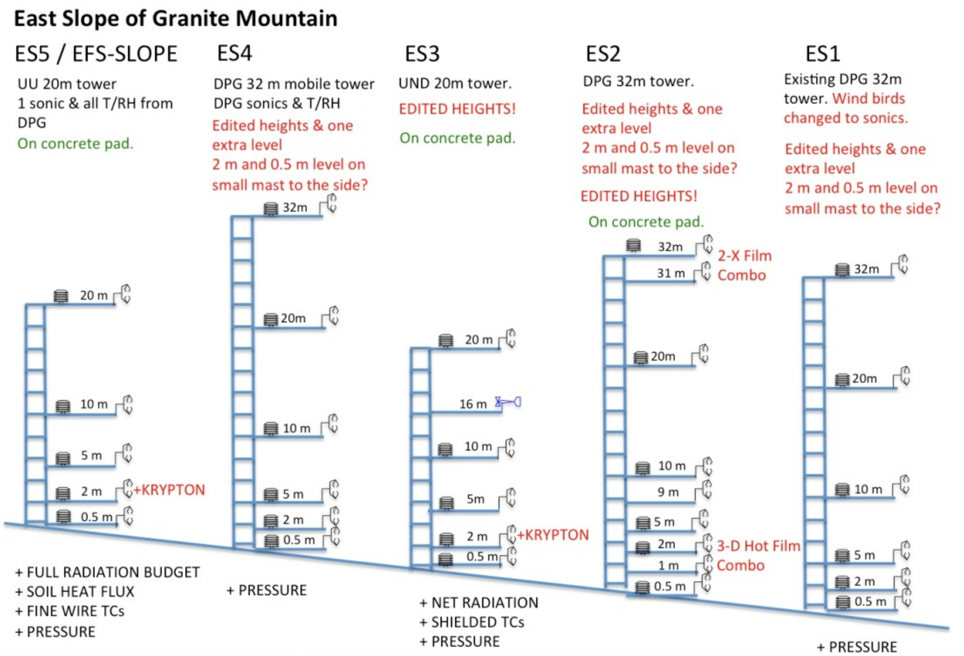
EFS-Playa

EFS-Flats



ND experimental contribution

EFS-SLOPE



East Slope of Granite Mountain

ES5 / EFS-SLOPE
UU 20m tower
1 sonic & all T/RH from DPG
On concrete pad.

ES4
DPG 32 m mobile tower
DPG sonics & T/RH
Edited heights & one extra level
2 m and 0.5 m level on small mast to the side?

ES3
UND 20m tower.
EDITED HEIGHTS!
On concrete pad.

ES2
DPG 32m tower.
Edited heights & one extra level
2 m and 0.5 m level on small mast to the side?
EDITED HEIGHTS!
On concrete pad.

ES1
Existing DPG 32m tower. Wind birds changed to sonics.
Edited heights & one extra level
2 m and 0.5 m level on small mast to the side?

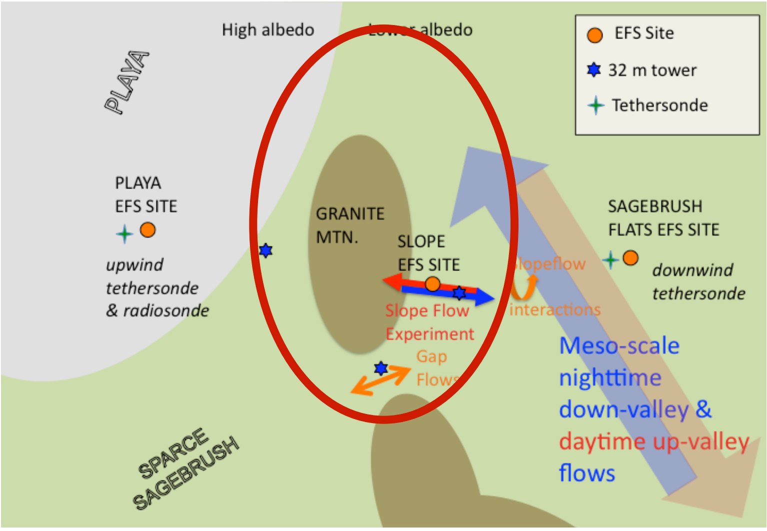
+ FULL RADIATION BUDGET
+ SOIL HEAT FLUX
+ FINE WIRE TCs
+ PRESSURE

+ PRESSURE

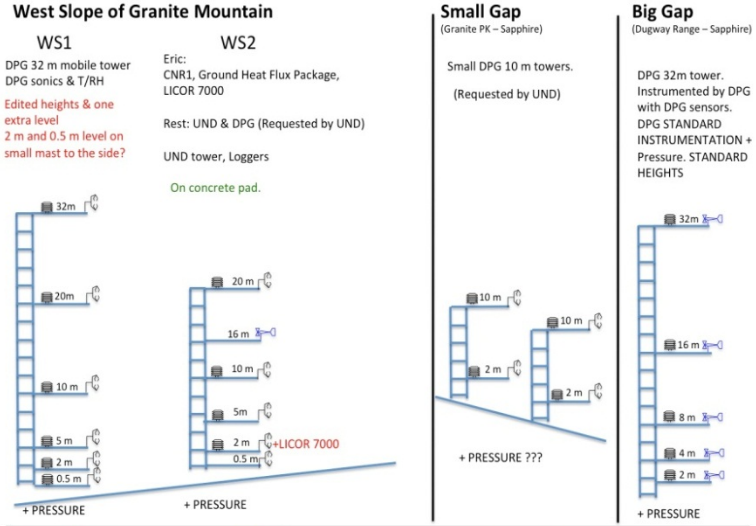
+ NET RADIATION
+ SHIELDED TCs
+ PRESSURE

+ PRESSURE

ES5 / EFS-SLOPE	ES4	ES3	ES2	ES1
Responsible: UU	UU	UND	UND	UU
N 40.09652 W 113.25861	N 40.09586 W 113.25252	N 40.09567 W 113.24405	N 40.09568 W 113.23769	N 40.0938 W 113.2032



Meso-scale nighttime down-valley & daytime up-valley flows



West Slope of Granite Mountain

WS1
DPG 32 m mobile tower
DPG sonics & T/RH
Edited heights & one extra level
2 m and 0.5 m level on small mast to the side?

WS2
Eric:
CNR1, Ground Heat Flux Package, LICOR 7000

Rest: UND & DPG (Requested by UND)

UND tower, Loggers

On concrete pad.

Small Gap
(Granite PK – Sapphire)

Small DPG 10 m towers.

(Requested by UND)

Big Gap
(Dugway Range – Sapphire)

DPG 32m tower. Instrumented by DPG with DPG sensors. DPG STANDARD INSTRUMENTATION + Pressure. STANDARD HEIGHTS

+ PRESSURE

+ PRESSURE

+ PRESSURE ???

+ PRESSURE

WS1	WS2	Small Gap		Big Gap
Responsible: UU	UND / UU ?	UND	UND	UU
N 40.10263 W 113.31998	N 40.11201 W 113.30235	SITING UNCLEAR		N 40.04485 W 113.23700

Lessons from Previous Studies and MATERHORN - X

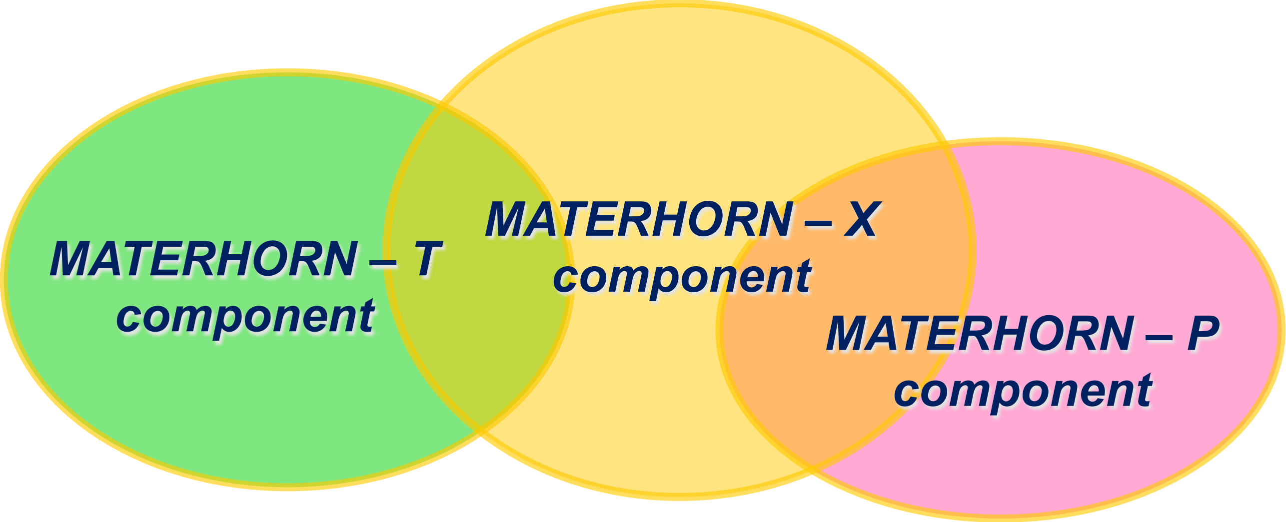
Nighttime (downslope regime)

- **Evening transition mechanism (cold front/ slab formation)**
- **Downslope flow evolution**
- **Thermal stratification**

Daylight (upslope regime)

- **Morning transition mechanism**
- **Anabatic flow regime**
- **Flow separation**

EAST GRANITE SITE



MATERHORN – T component

MATERHORN – X component

MATERHORN – P component

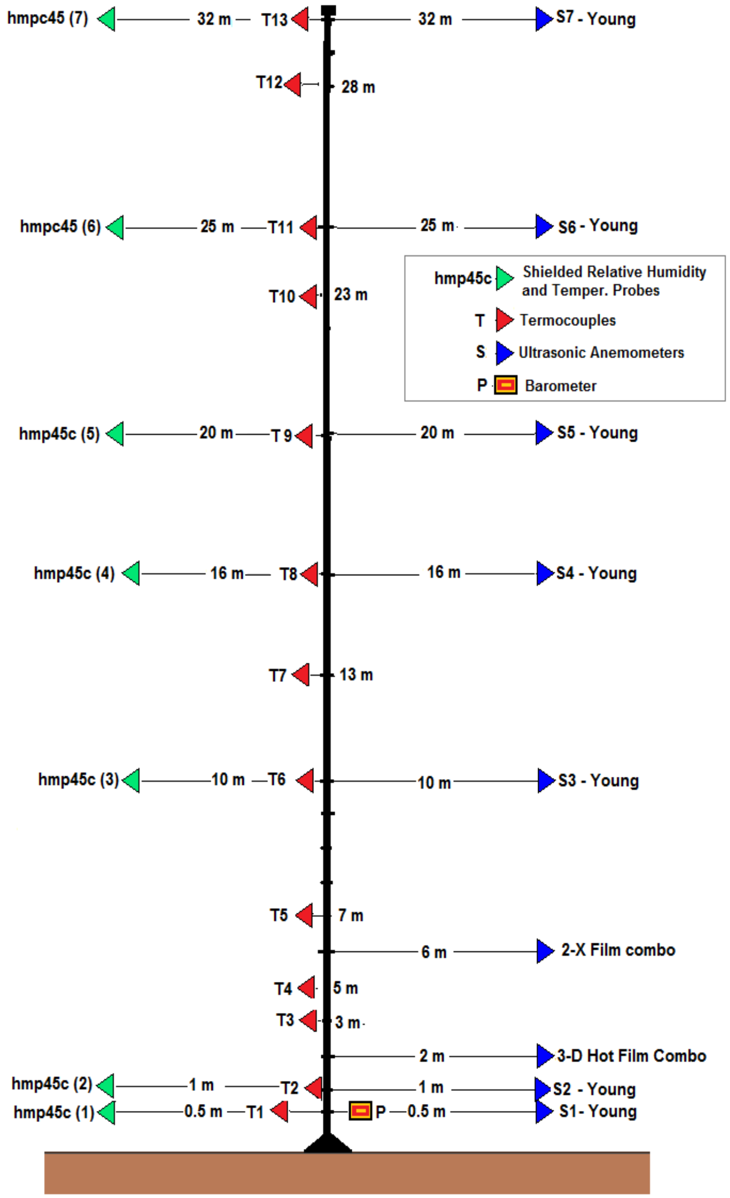
EAST GRANITE SITE – ES2 -

Fluxes of Momentum and Sensible Heat and Kolmogorov scale of TKE dissipation

- 7 levels of turbulence (in combination with fast thermocouples and slow sensors of RH and T)
- 13 fast thermocouples
- 3-D Hot Film Combo System
- 2-X Hot Film Combo System
- *Moisture measurements using FASS (Fog Aerosol Sampling System)*

MATERHORN – T component

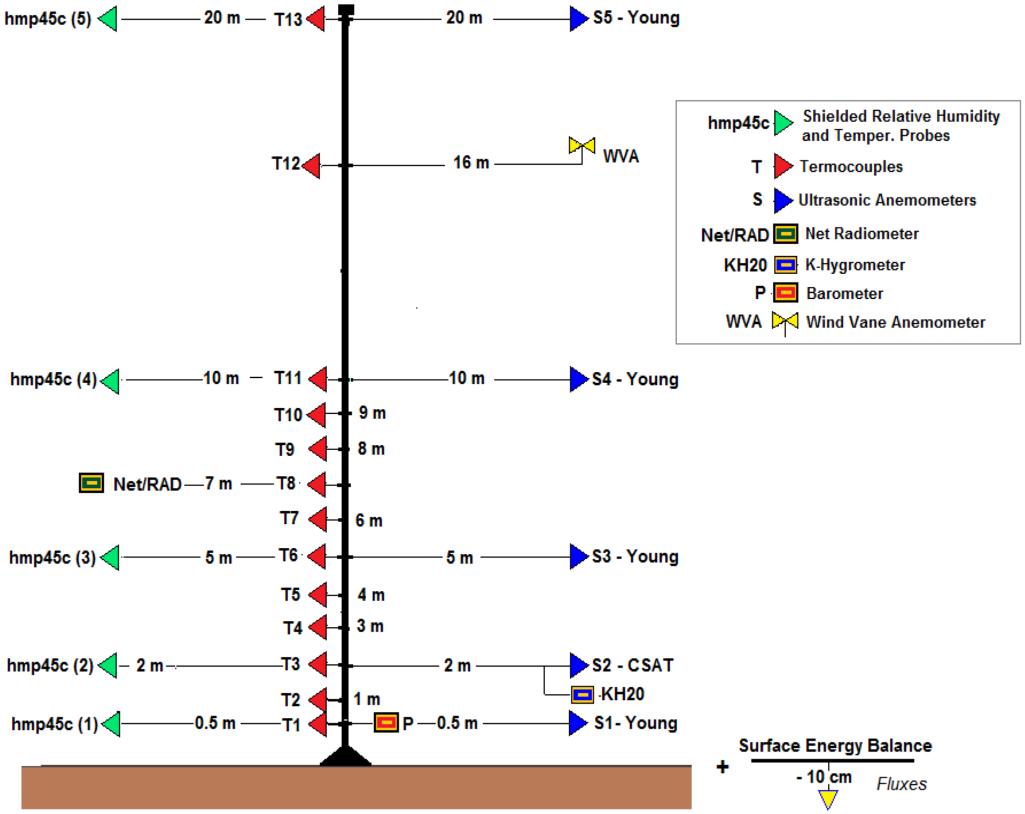
East Lower Slope UND Tower (COMBO)



EAST GRANITE SITE – ES3 -

Complete Surface Energy Balance and Fluxes of Momentum, Sensible and Latent Heat

- **eddy covariance system**
- **5 levels of turbulence (in combination with fast thermocouples (**type K**) and slow sensors of RH and T)**
- **4-component radiation balance measurement**
- **13 fast thermocouples**
- **Soil temperature, soil heat flux, and soil water content measurements**



EAST GRANITE SITE

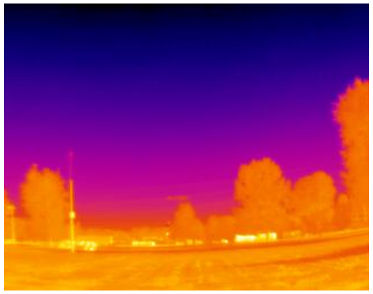
Instrumented UAV

Flamingo F -18
Turbulence, wind velocity, temperature, atmospheric pressure and humidity

Doppler Lidar

Halo Photonics Doppler lidar
1.5 mm pulsed infrared laser to obtain radial velocities and backscatter magnitude (max range of 10 km)

Flow Visualization



FLIR Systems ThermoCAM SC4000 IR camera (sensitivity <0.02 ºK) will be used to investigate spatial and temporal response of surface temperatures along the East slope of Granite Peak.

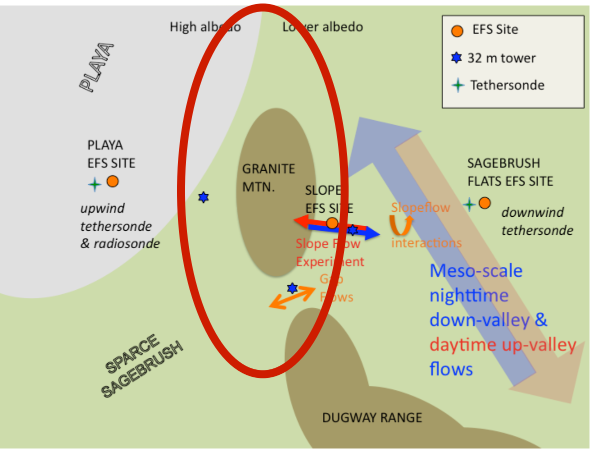
Smoke visualization system ZV40,000 (rapid sustained visual obscuration at a rate of 18 m^3/s)
A high Wattage 1W laser will illuminate a strip of the mountain Video Camera for recording.

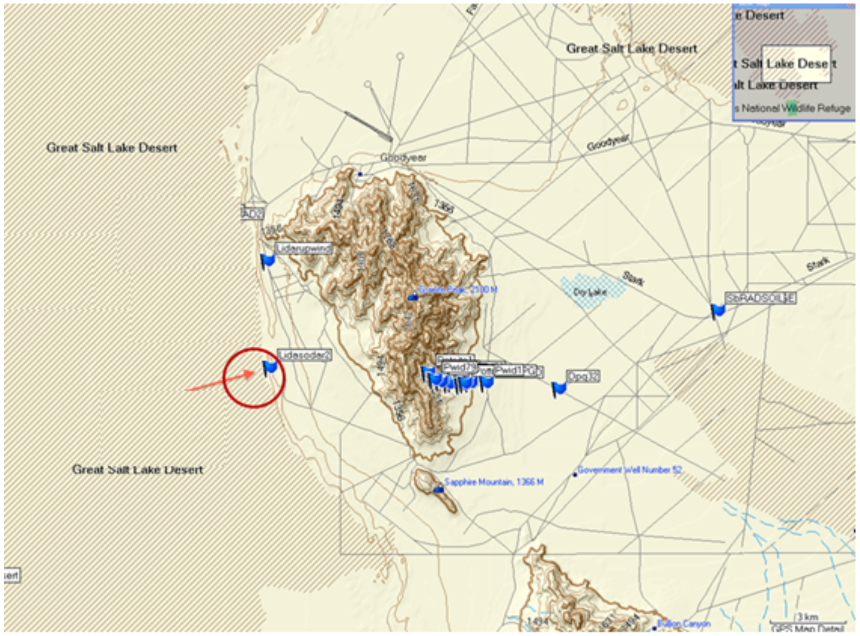
ND experimental contribution

WEST GRANITE SITE

- **interactions of synoptic and slope flows**
- **contrasting development of thermal circulations on the east and west slopes of Granite Peak during transition periods**

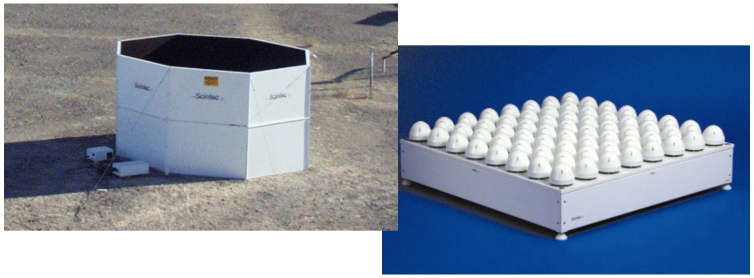
EFS-SLOPE





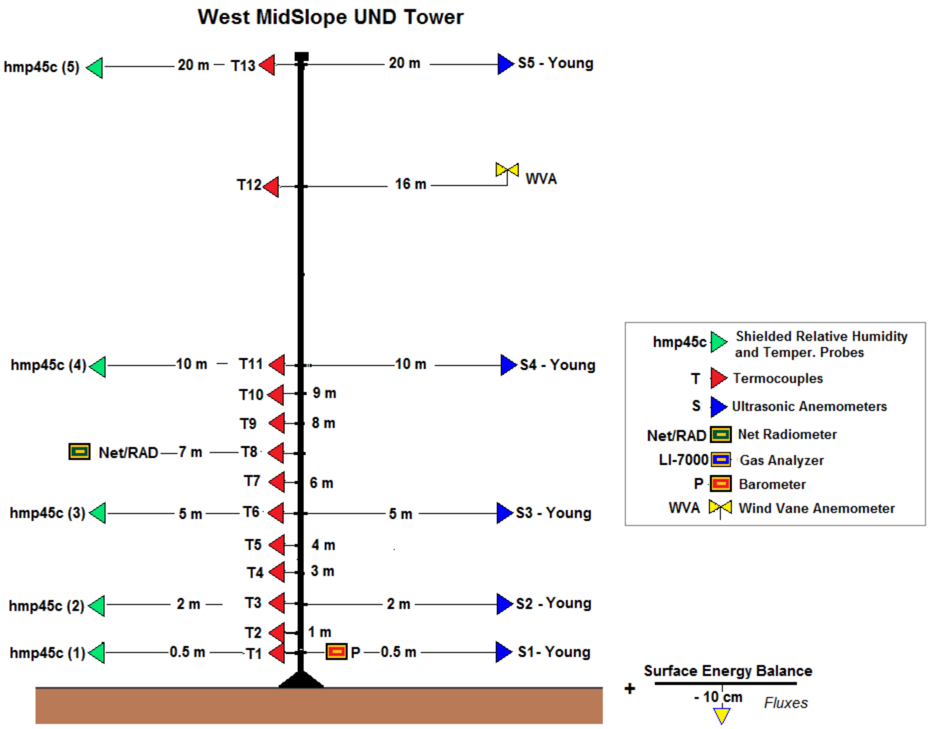
Vaisala Ceilometer CL31

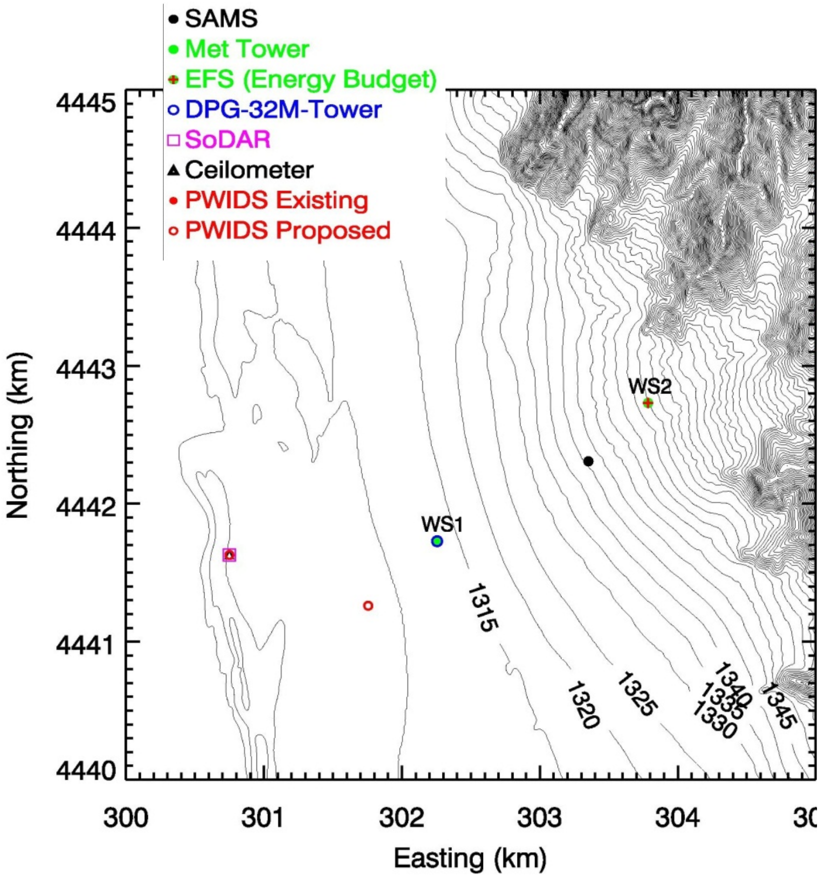
Scintec MFAS with RASS



ND experimental contribution

WEST GRANITE SITE – WS2 -



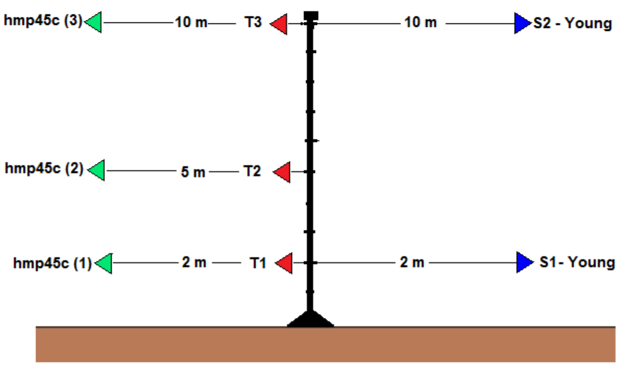


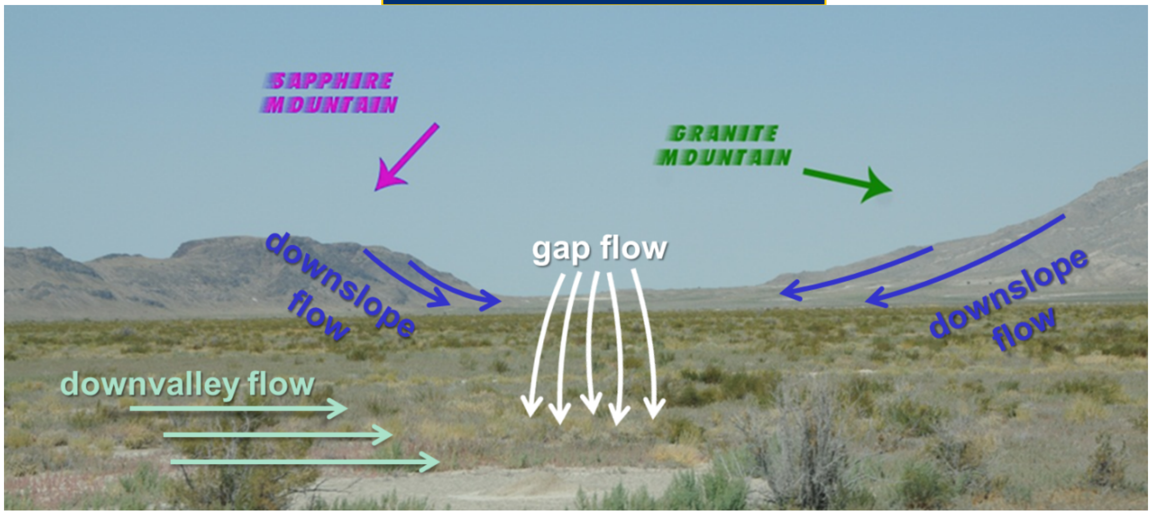
- 5 levels of turbulence (in combination with fast thermocouples and slow sensors of RH and T)
- 4-component radiation balance measurement
- 13 fast thermocouples
- Soil temperature, soil heat flux, and soil water content measurements

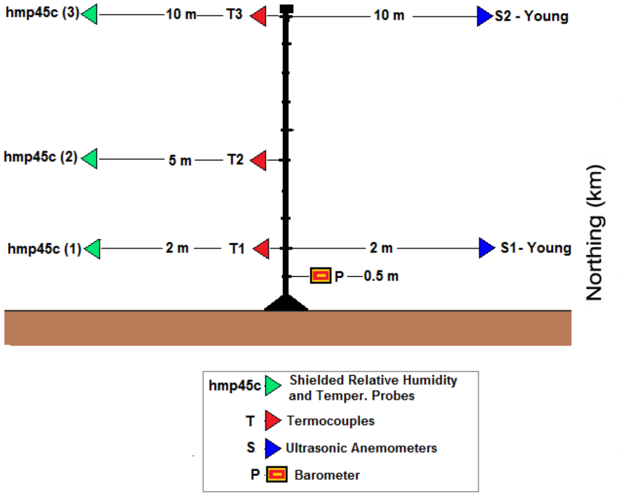
ND experimental contribution

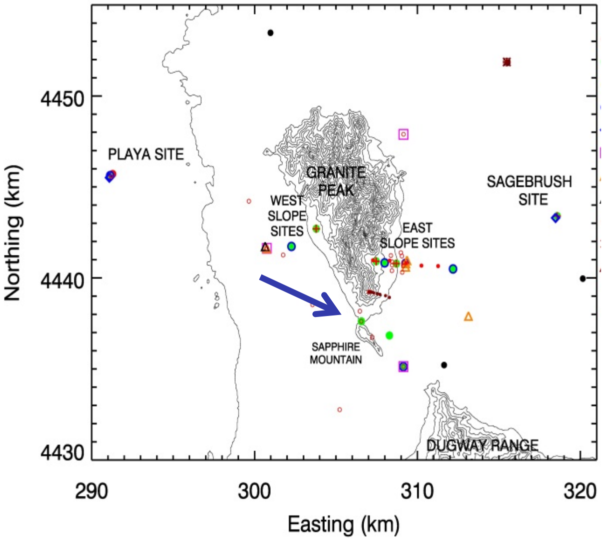
Gap flows

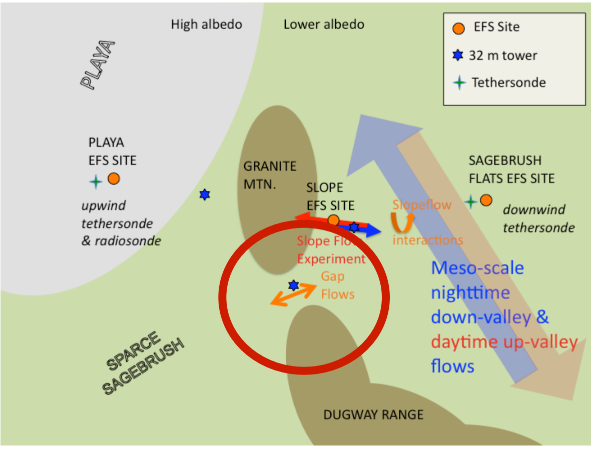
SMALL GAP SITE


small gap UND tower (SG1)




small gap UND tower (SG2)

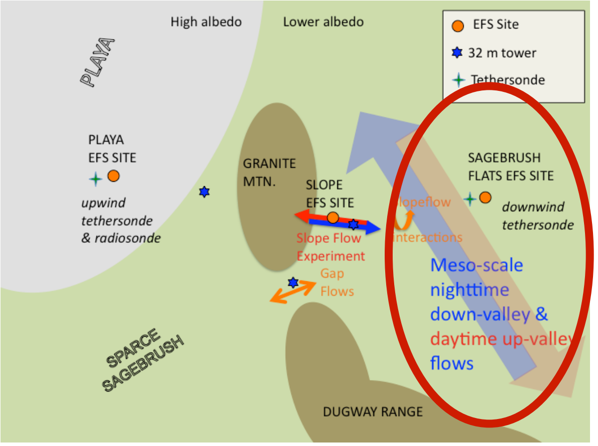




ND experimental contribution

Sagebrush SITE

EFS-FLATS

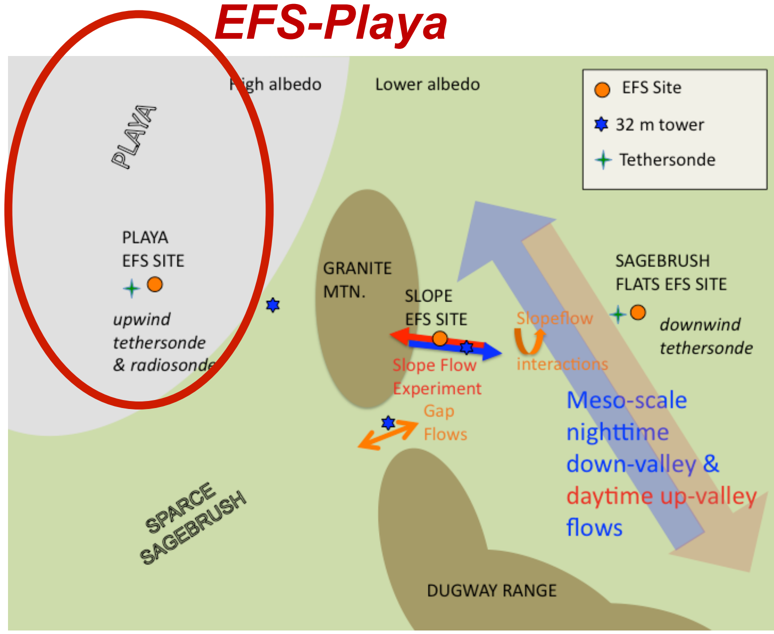


- vertical BL structure
- drainage flow
- Cold pool formation

ND experimental contribution

RF CROSSHAIR
Remote Soil Moisture Sensing System
(3 frequency bands:
470 MHz, 915 MHz, 2.437 GHz)

EFS-Playa



- **Spatial Averaged Measurements of Soil Moisture Content**

- **Analysis of temporal changes (over short and long term) in soil moisture content over a representative area**

Planning of the fall field campaign

Test /calibration/ checking of instruments
(A brief summary)

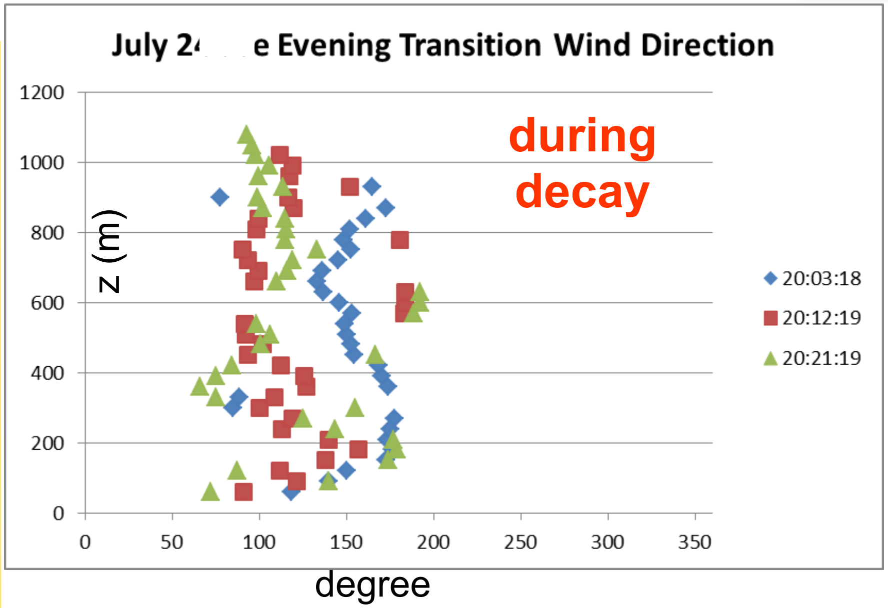
- Pre-Materhorn Experiment (Whitefield campaign)
  - Focus on the evening transition and TKE decay mechanism (**Leo, L.S., Di Sabatino, S., Fernando** ***– Flow Transition under very moist conditions –*** **In preparation for BLM or EFM journal**)
- Datalogger Programming
- Calibration of ND instruments

(***thanks to Patrick Conry, Orson Hyde, Sahan Fernando and Kelly McEnerney***)

Lessons from Previous Studies and MATERHORN - X

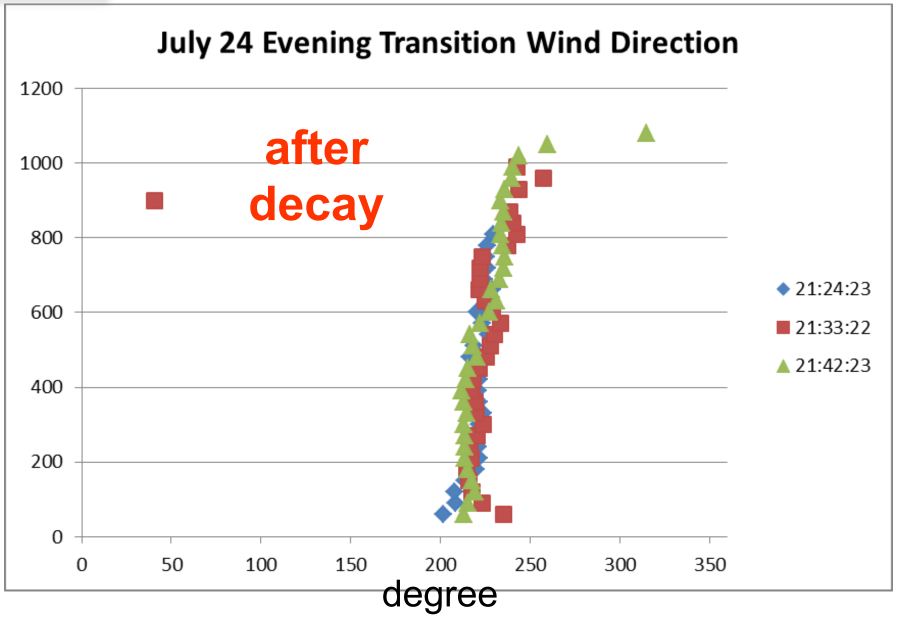
Sunset time: **21:11**

Lidar



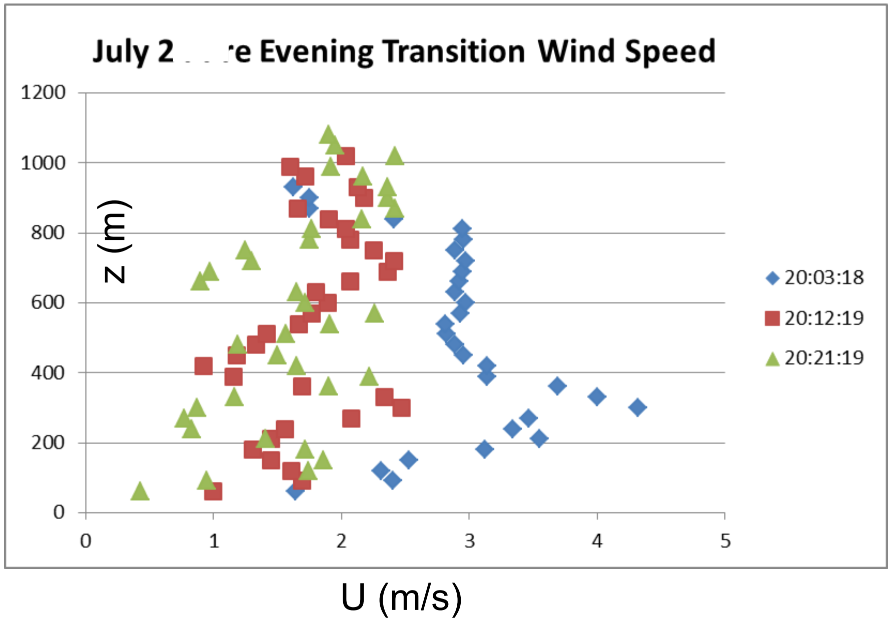
July 24 e Evening Transition Wind Direction

during decay

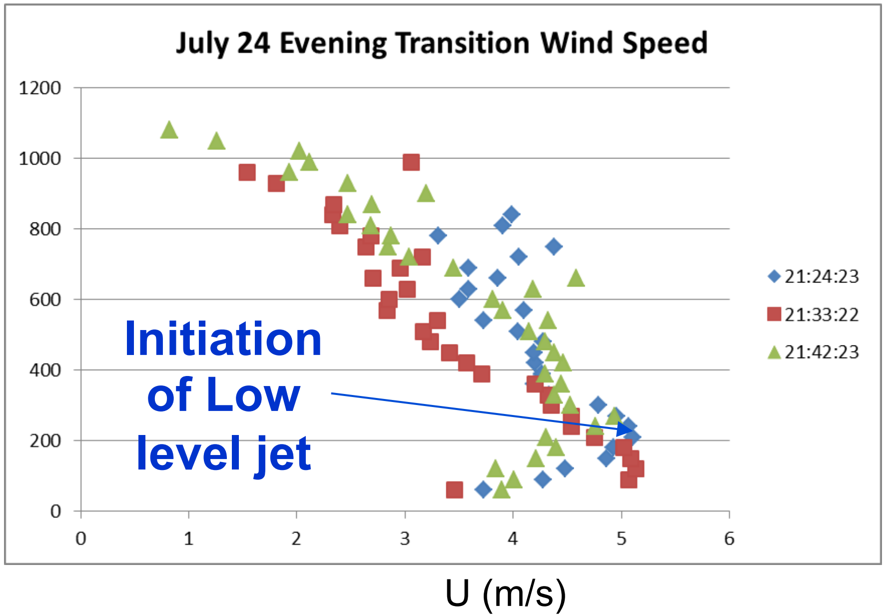


July 24 Evening Transition Wind Direction

after decay



July 2 re Evening Transition Wind Speed



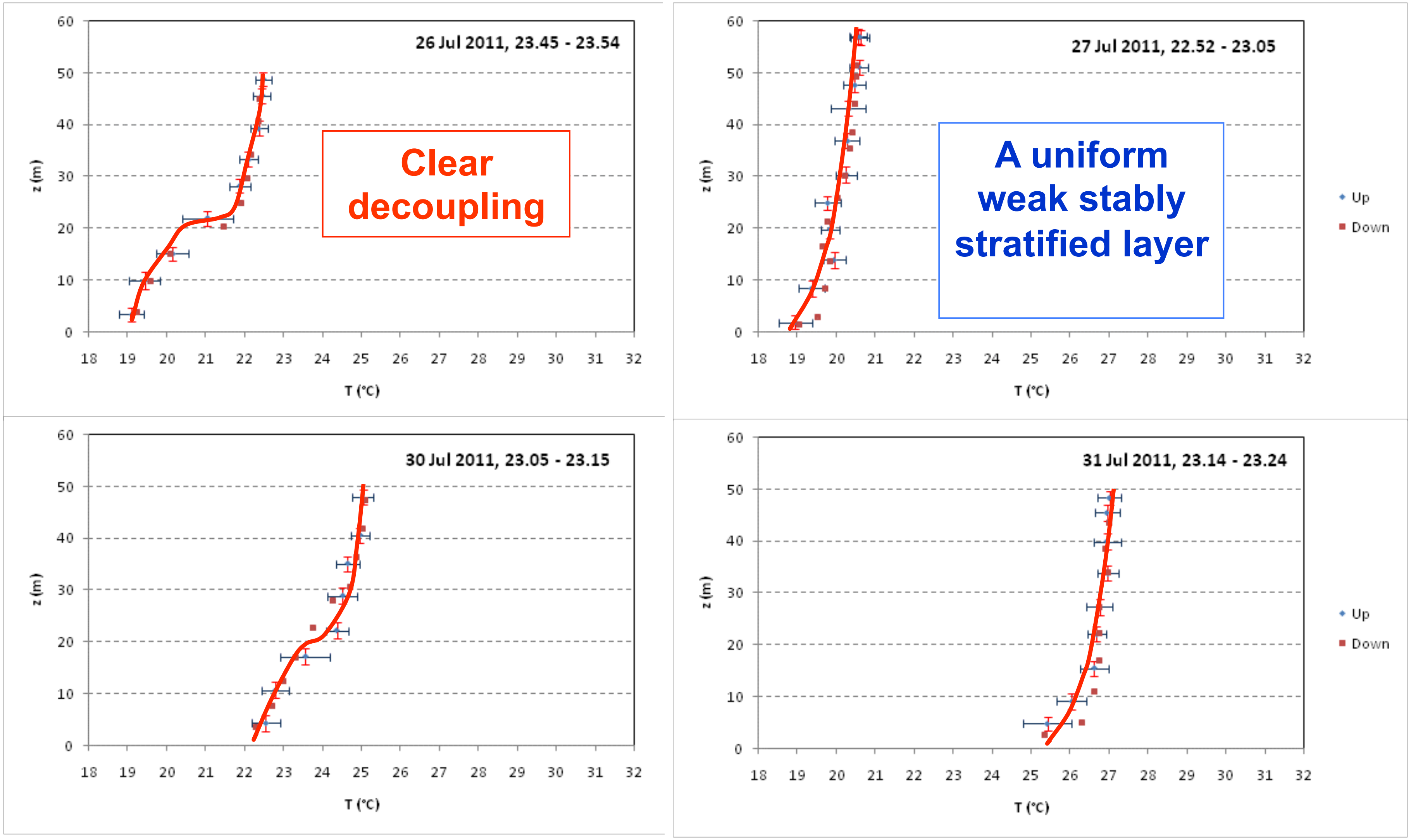
July 24 Evening Transition Wind Speed

Initiation of Low level jet

Lessons from Previous Studies and MATERHORN - X

Planning of the fall field campaign

Pre-Materhorn Experiment


Clear decoupling

A uniform weak stably stratified layer

Planning of the fall field campaign

Pre-Materhorn Experiment

Date	Hour	Evening Transition	Stabilization time
30 July 2011 (26 July)	19.00 – 20.00 (19.52 – 20.03) 20.20 – 20.30 (20.54 – 21.13) 20.55 – 21.05 (21.15 – 21.30) 23.05 – … (22.45 – …)	SLOW decay of TKE Flow becomes weakly stable below the canopy layer, Mixed layer above *Saturated conditions*	**~ 1 hour** **Profiles slowly evolve towards a decoupling with the atmosphere above (with inflection point at canopy height)**
31 July 2011 (27 July)	19.00 – 19.30 19.43 – 19.53	FASTER decay of TKE Flow becomes weakly stable below canopy layer *Unsaturated conditions* Flow becomes stable	**~ less than 1 hour** **Profile slowly evolve towards a decoupling with the atmosphere above** **No clear decoupling but rather homogeneous stable layer**

Leo, L.S., Di Sabatino, S., Fernando – *Flow Transition under very moist conditions* – In preparation for BLM or EFM journal)

Thank you for the attention