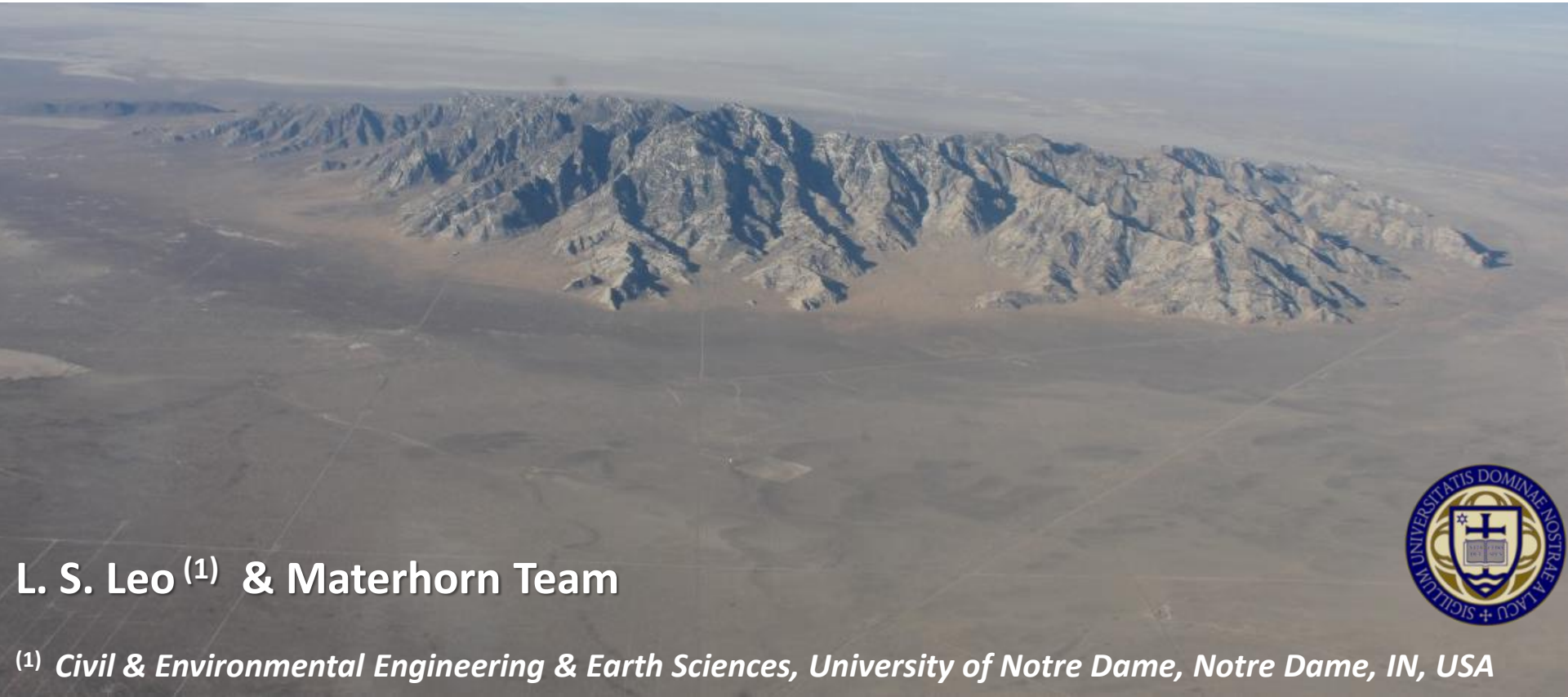
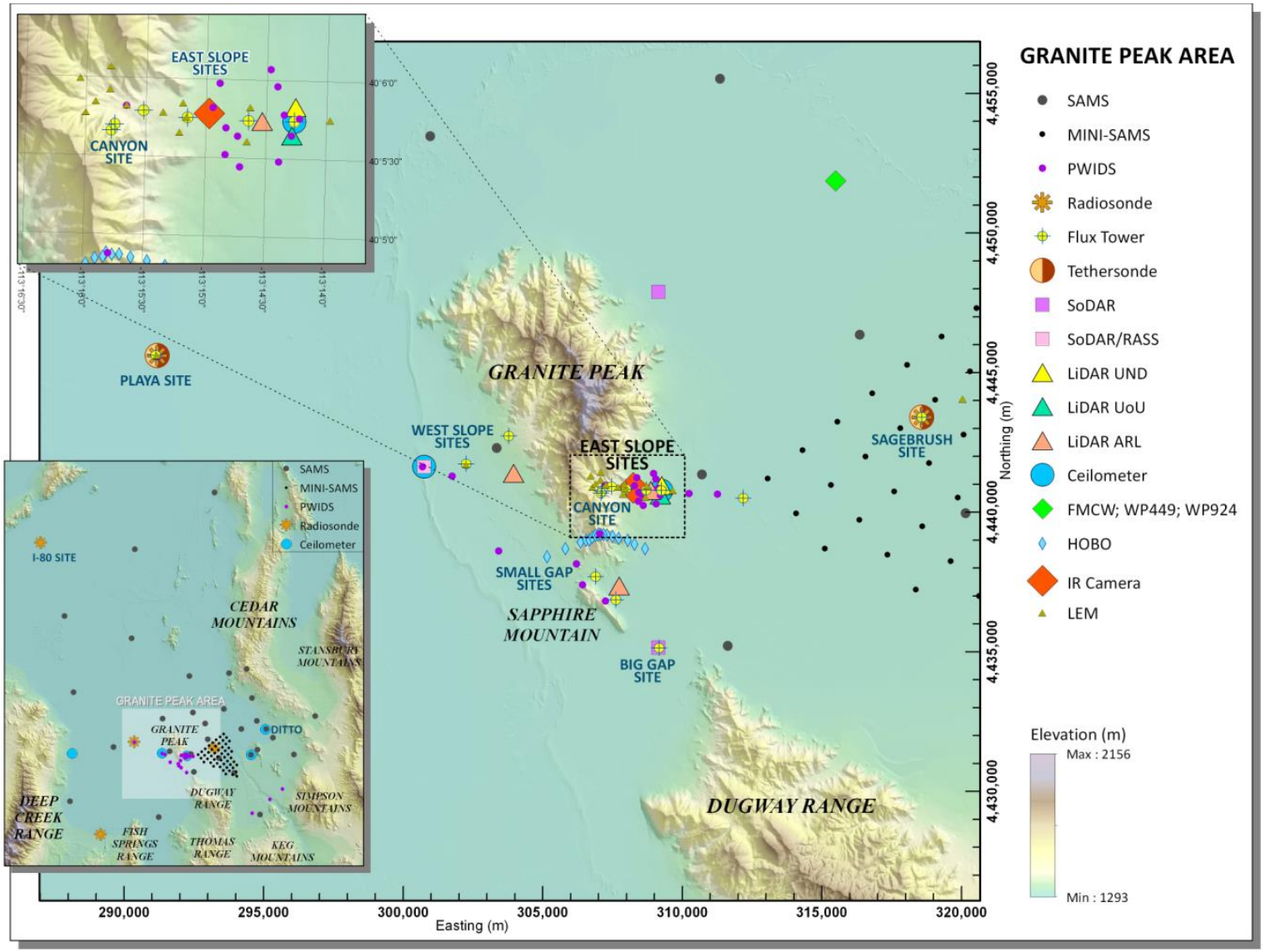
Waves and Turbulence in Katabatic Flows



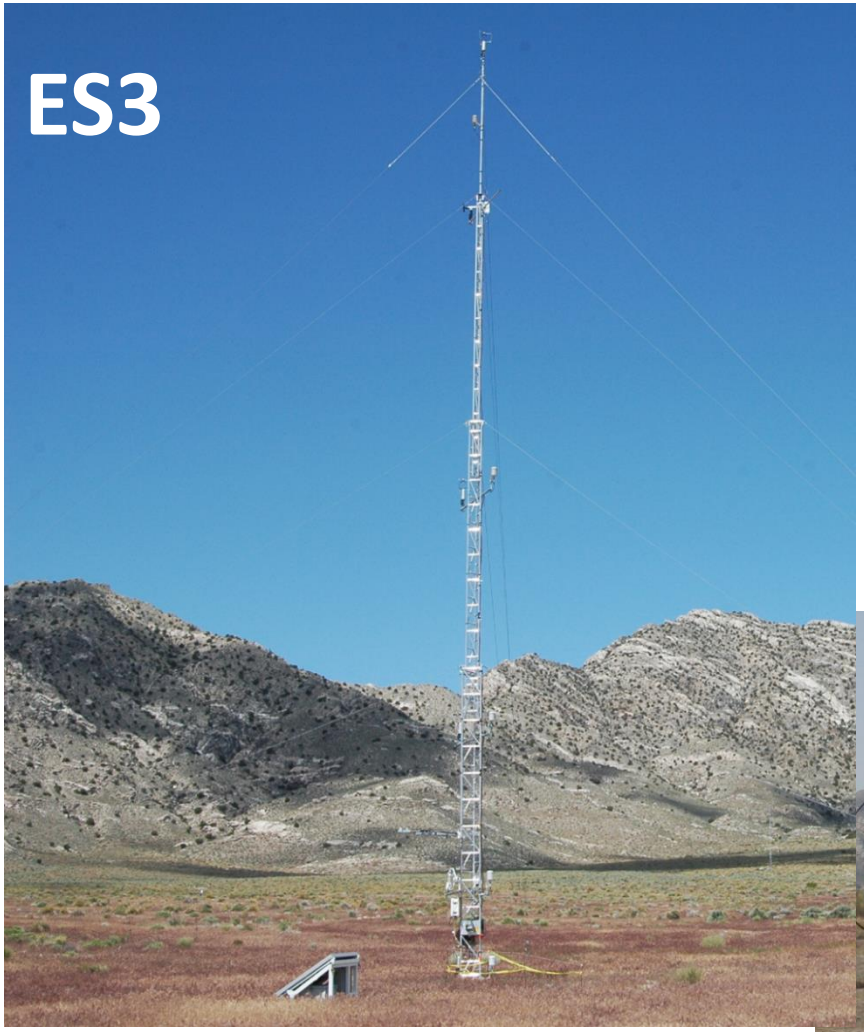
L. S. Leo [1] & Materhorn Team

[1] Civil & Environmental Engineering & Earth Sciences, University of Notre Dame, Notre Dame, IN, USA



Materhorn X-1 : 30-day intense field campaign during **September 25-October 25, 2012** conducted at the **Granite Mountain Atmospheric Science Testbed** (GMAST) of the US Army Dugway Proving Grounds (DPG).

Towers - East Slope of Granite



Ultrasonic Anemometers (20 Hz)
Temperature and Relative Humidity Probes (0.5Hz-1 Hz)

- **ES5 - 20 m tower**

Levels 0.5m , 2m, 5m, 10m, 20m

- **ES4 – 28 m tower**

Levels 0.5m , 2m, 5m, 10m, 20m, 28 m

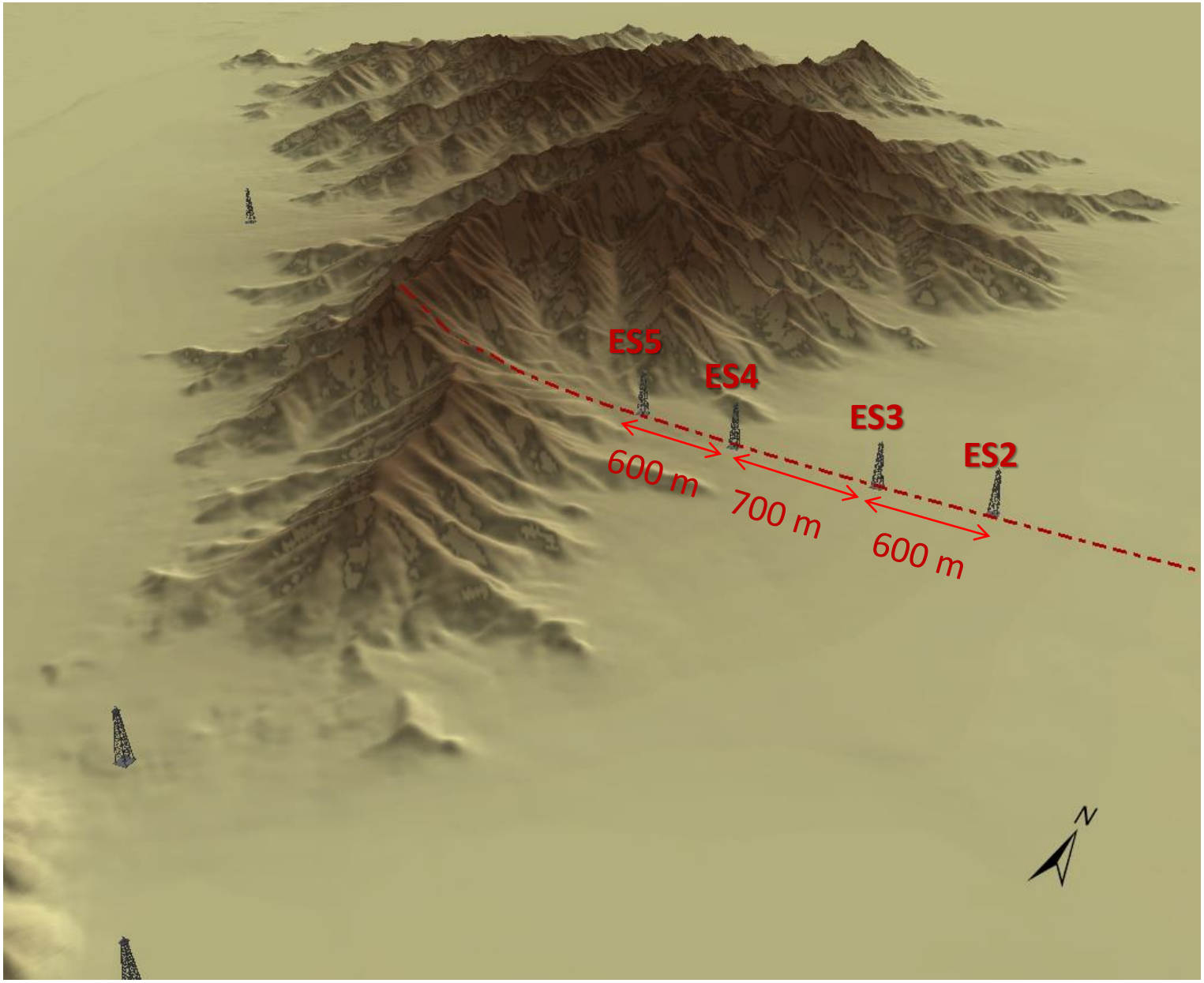
- **ES3 – 20 m tower**

Levels 0.5m , 2m, 5m, 10m, 20m

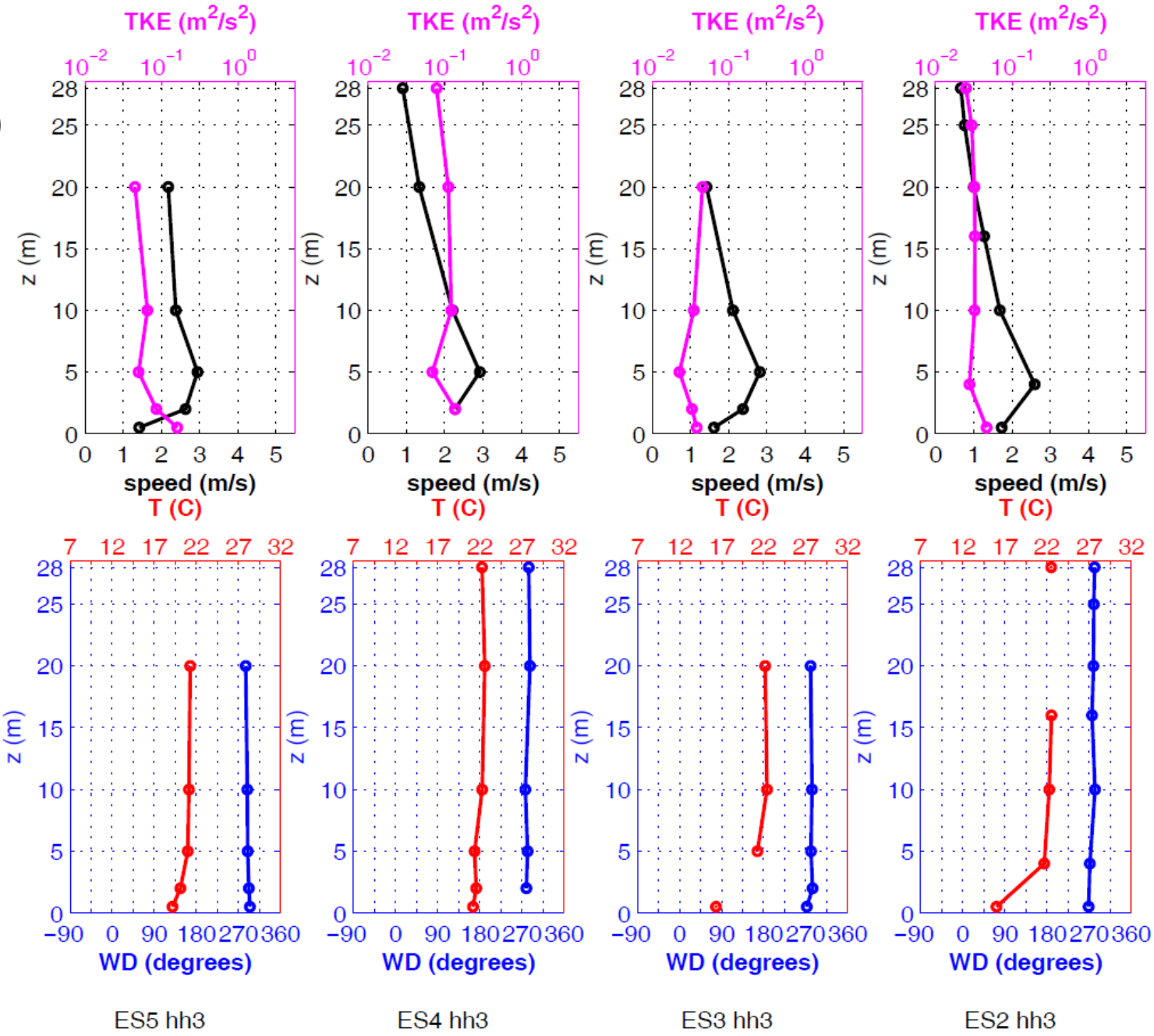
- **ES2 – 28 m tower**

Levels 0.5m , 4m, 10m, 16m,20m, 25m, 28 m

East Slope of Granite

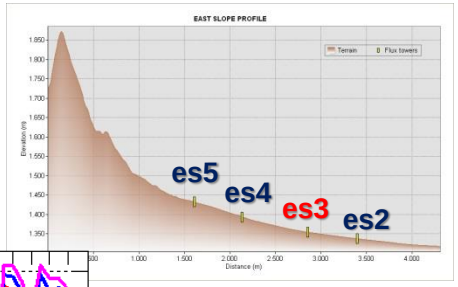


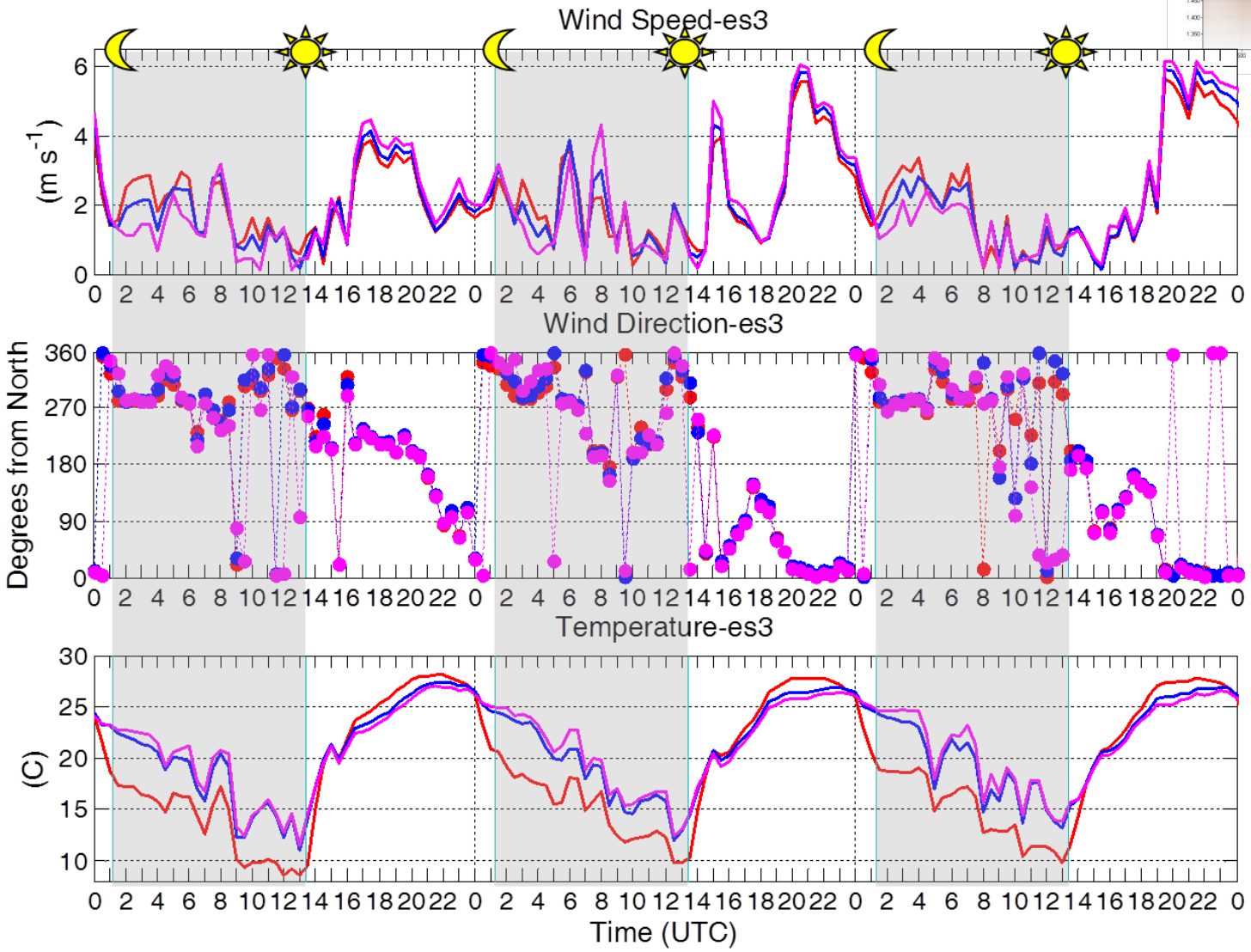
Jday 272
(30 min avg)



ES3 Tower - Jday 272-273 -274

30 min avg timeseries





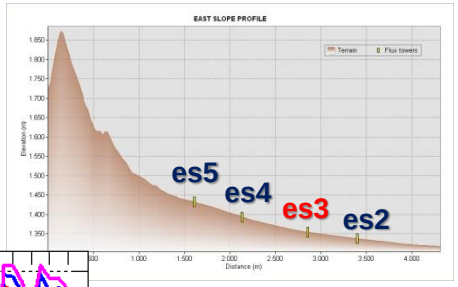
5 m
10 m
20 m

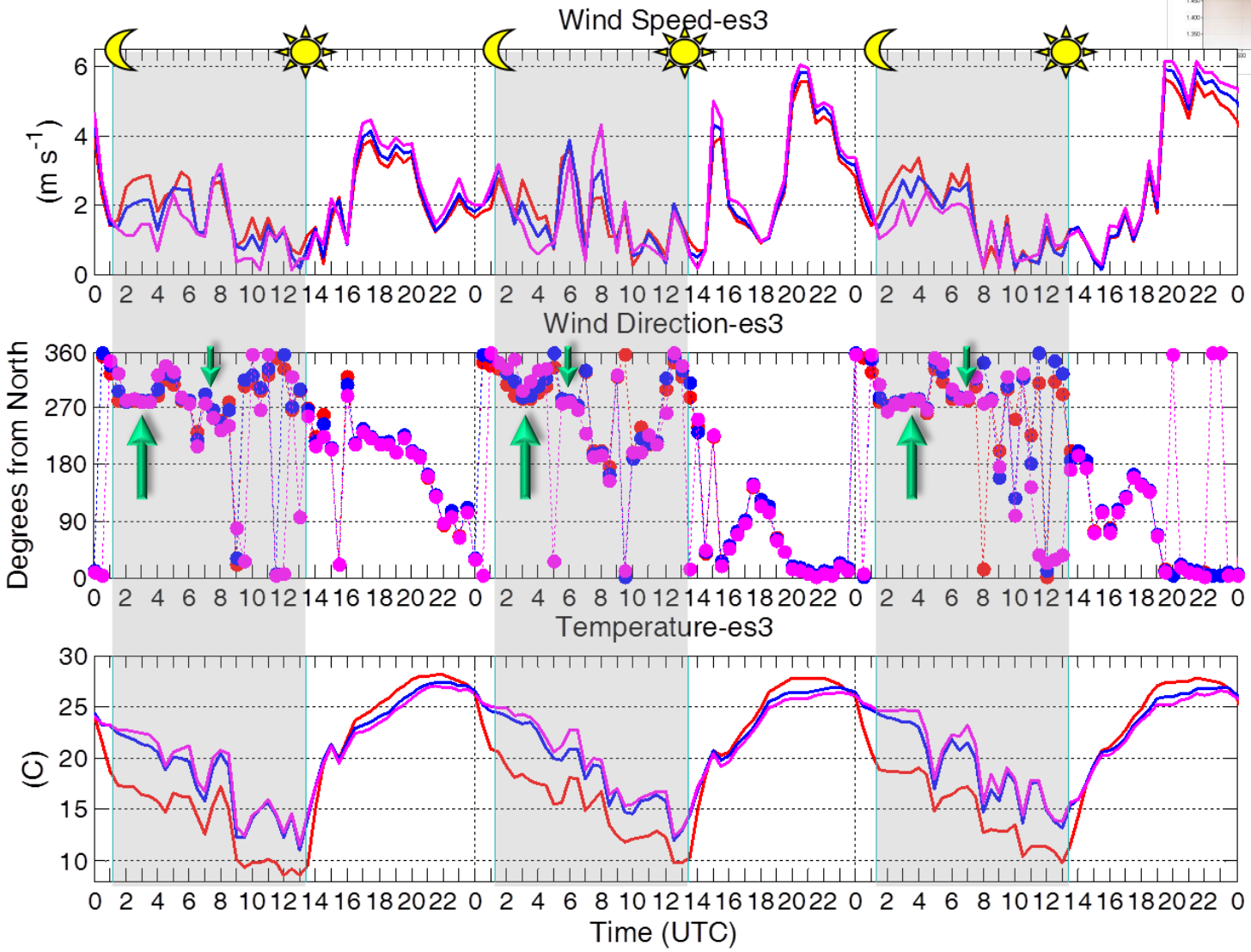
Sunset
01:17 UTC
(19:17 LC)

Sunrise
13:25 UTC
(07:25 LC)

ES3 Tower - Jday 272-273 -274

30 min avg timeseries



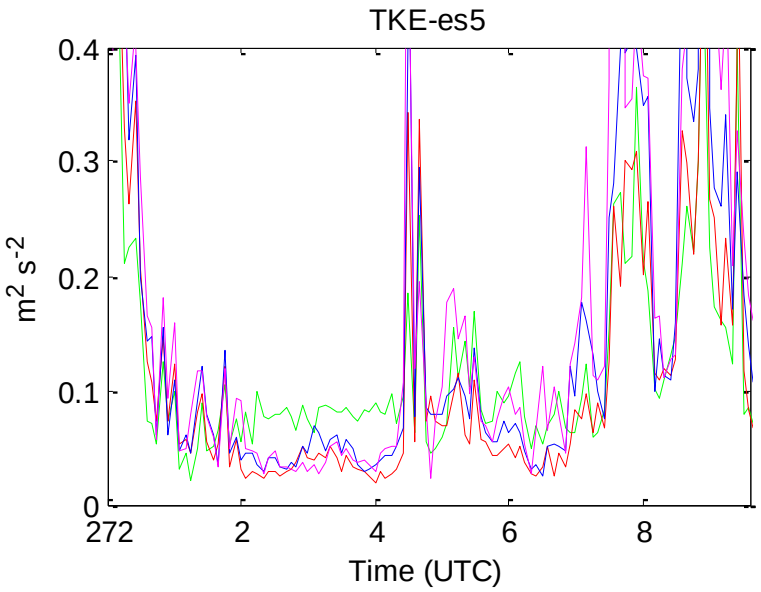


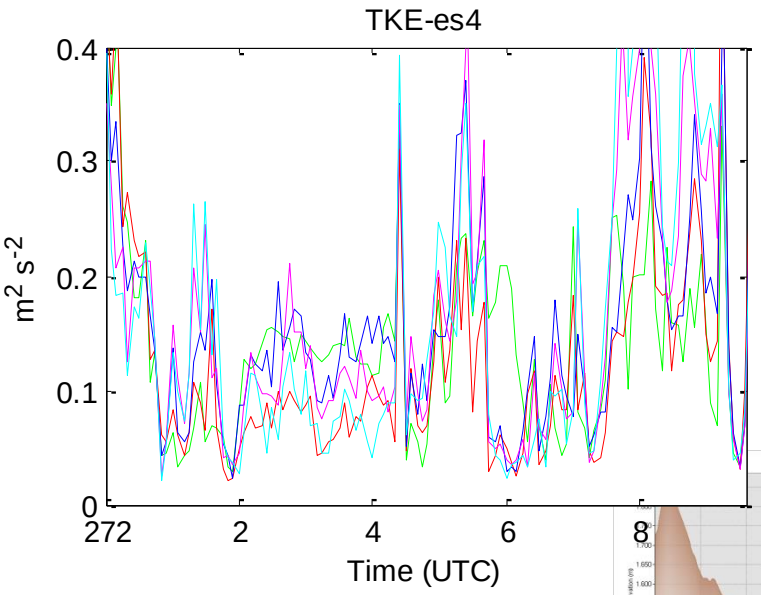
5 m
10 m
20 m

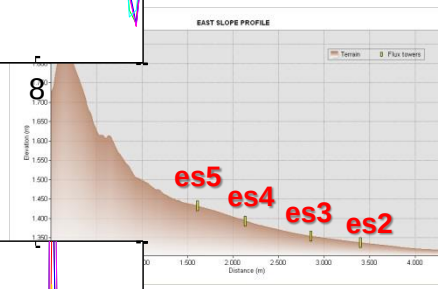
Sunset
01:17 UTC
(19:17 LC)

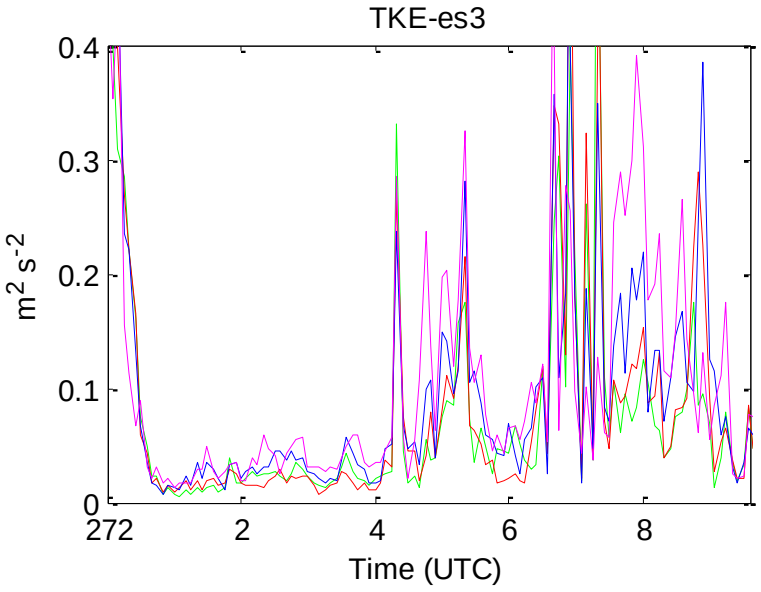
Sunrise
13:25 UTC
(07:25 LC)

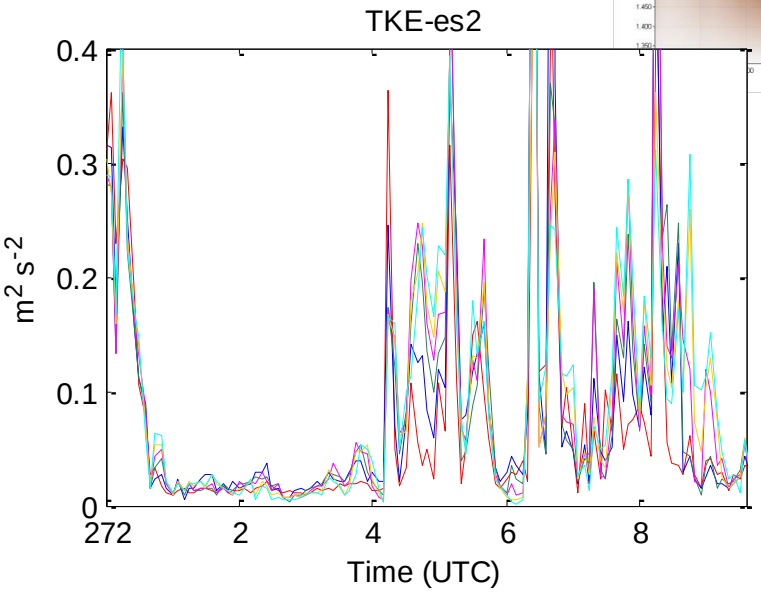
TKE timeseries (5 min avg) along the East Slope (Jday 272)

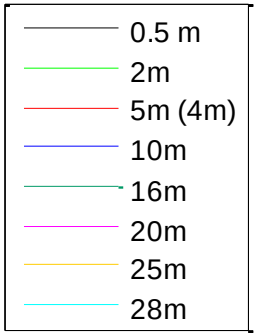






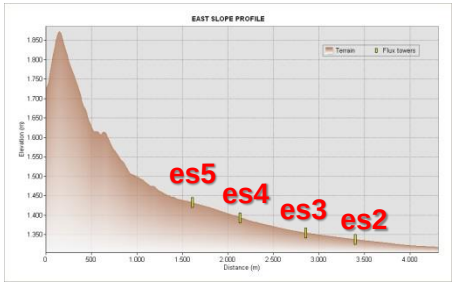


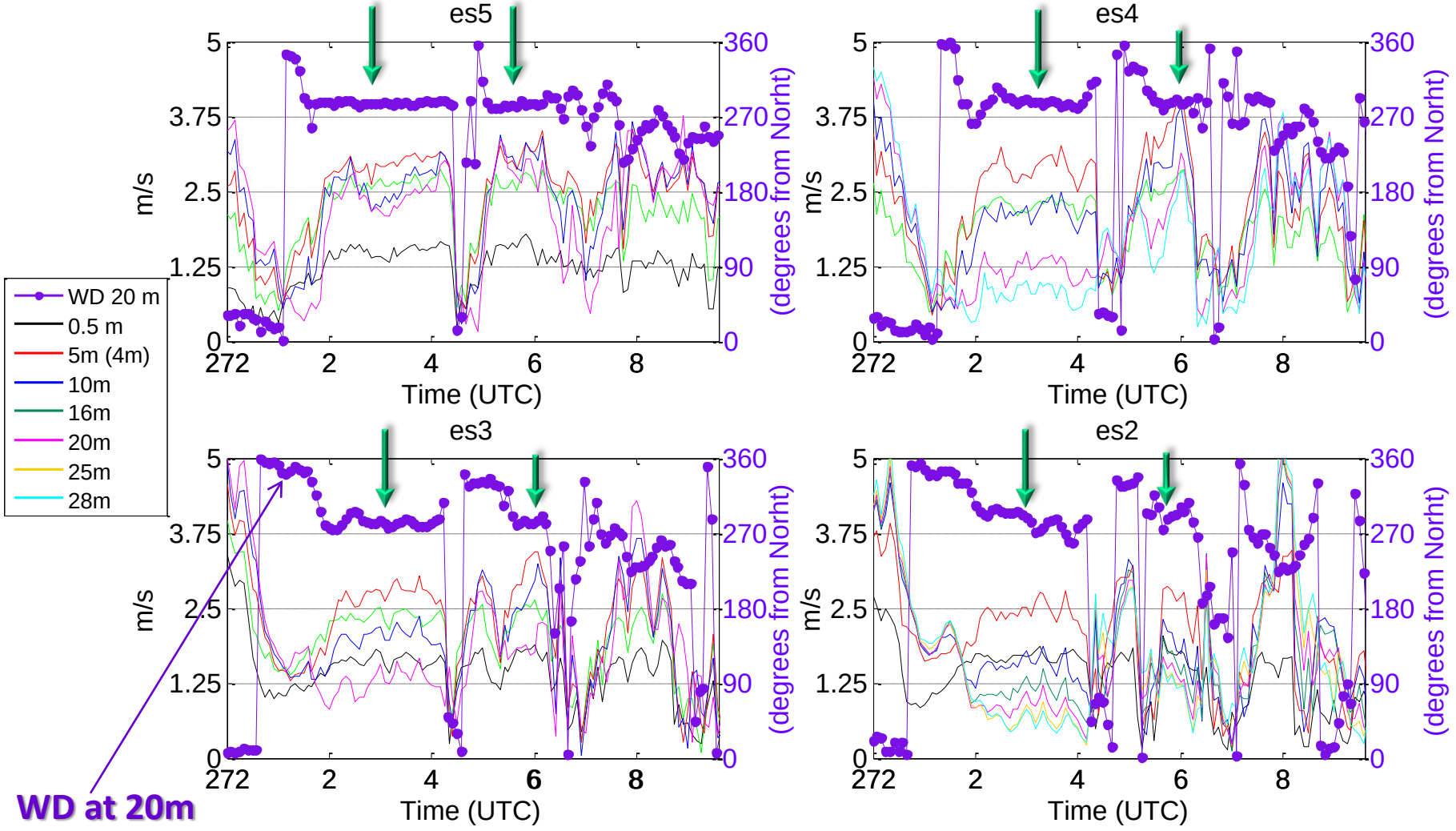




Wind speed timeseries (5 min avg) along the East Slope

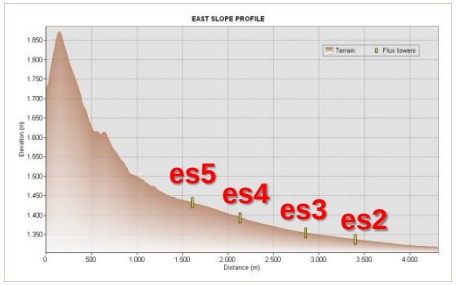
Jday 272 -- hh 0:00-10:00 UTC

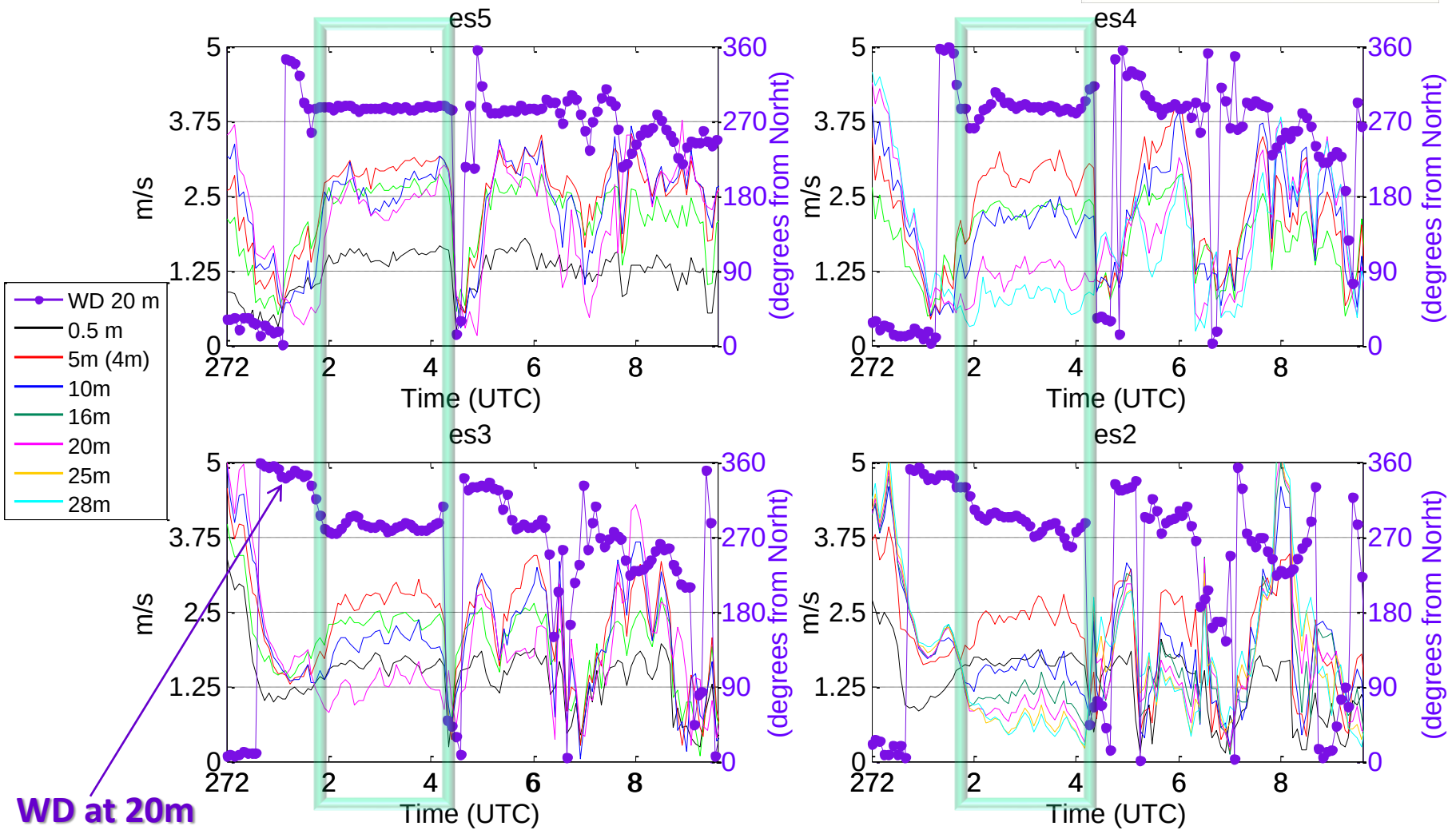




Wind speed timeseries (5 min avg) along the East Slope

Jday 272 -- hh 0:00-10:00 UTC

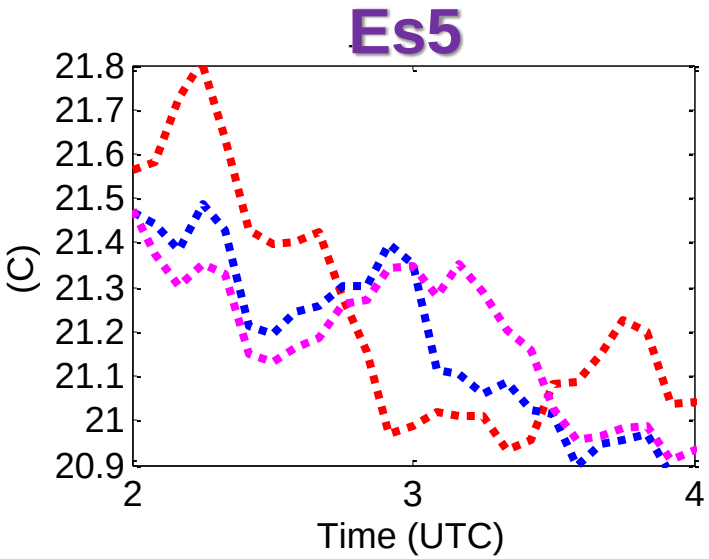


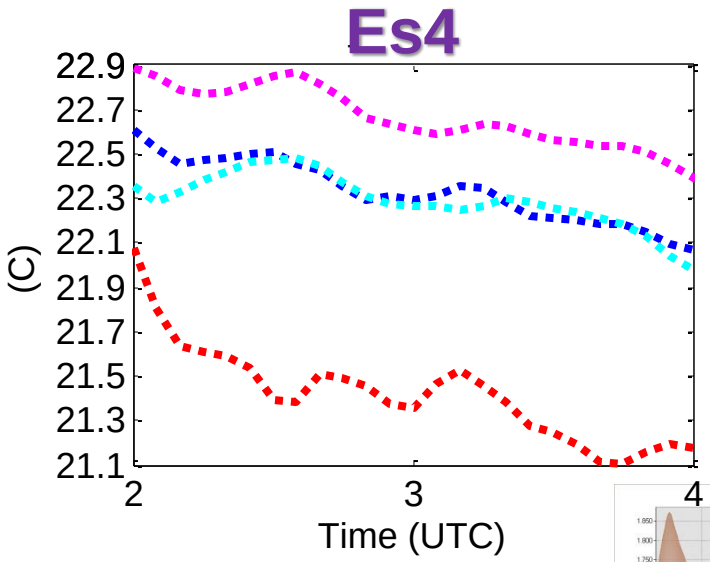


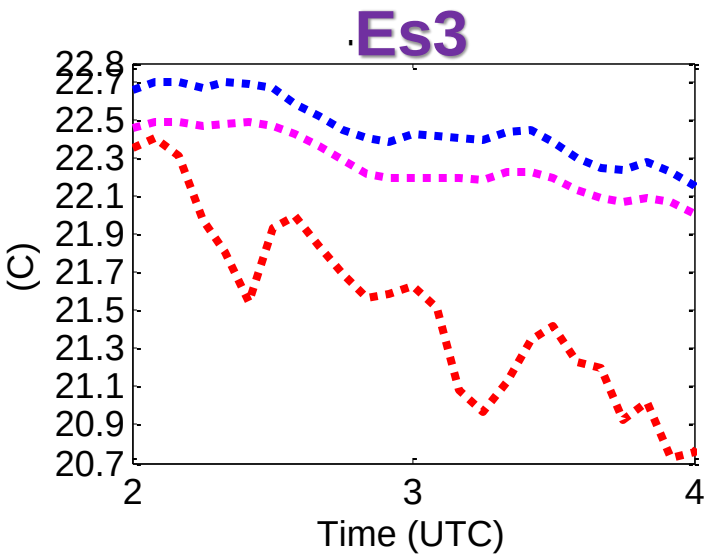
Temperature timeseries (5 min avg) along the East Slope

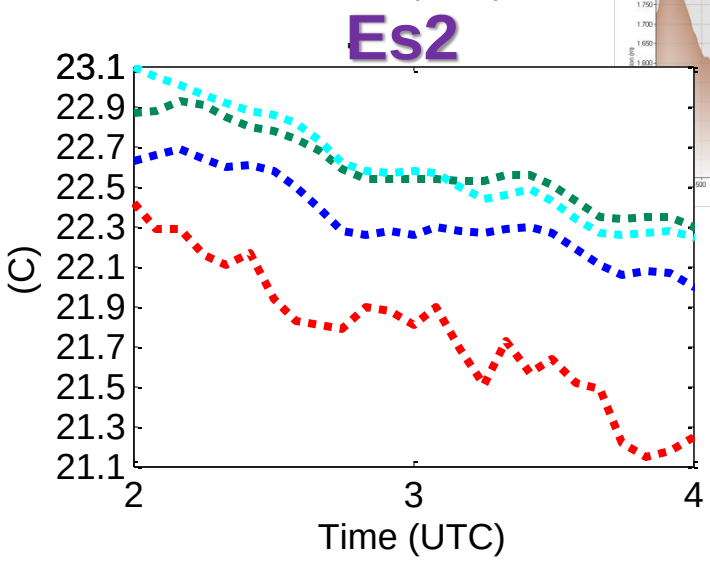
Jday 272

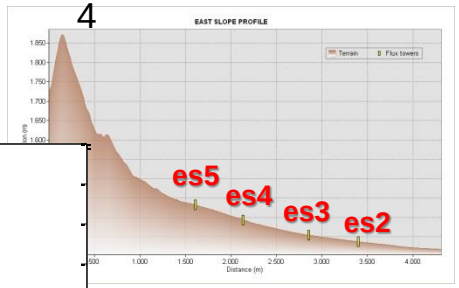
hh 2:00-4:00 UTC

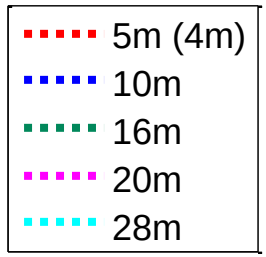




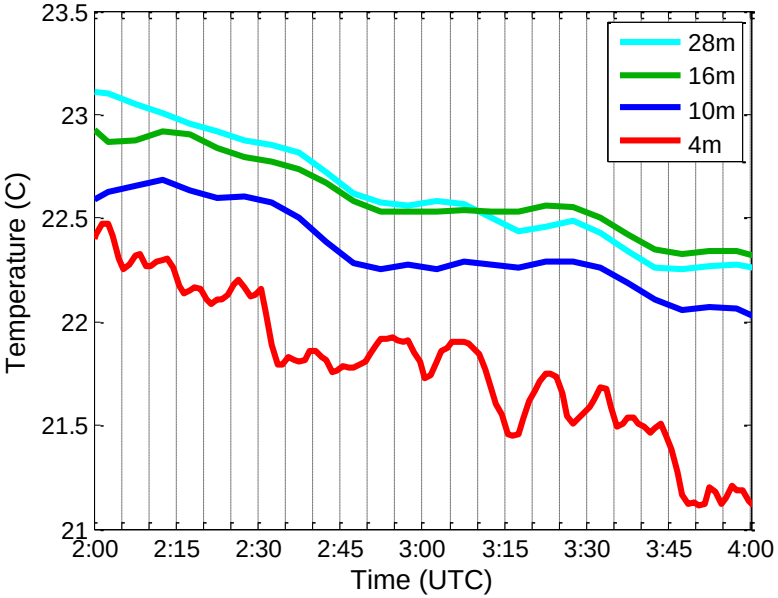




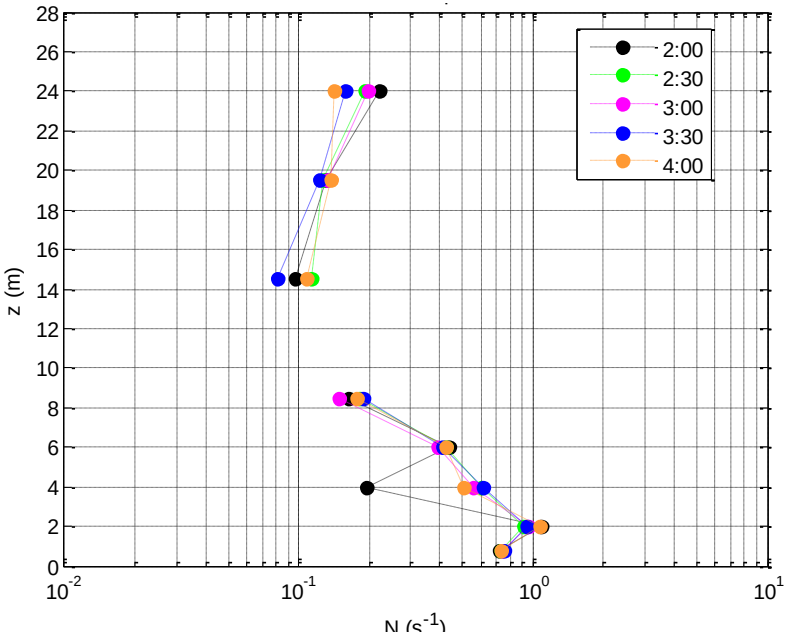




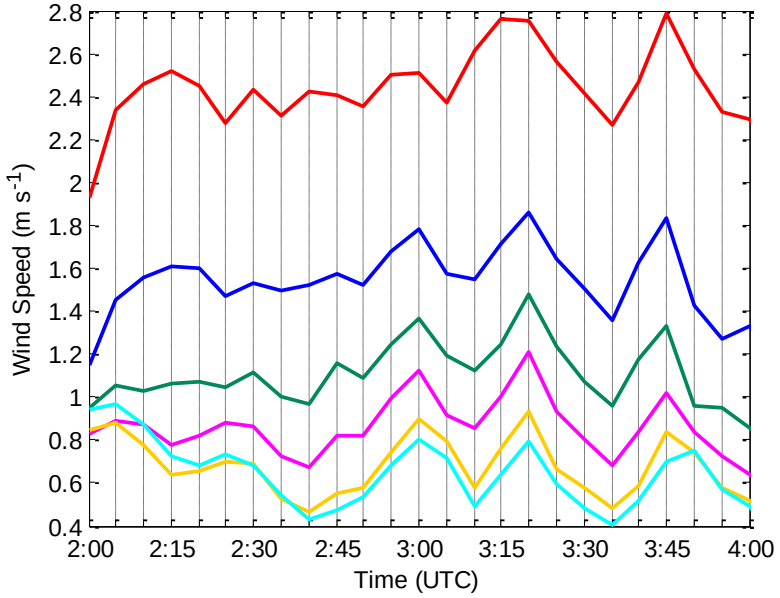
Temperature and wind speed timeseries (5 min avg)

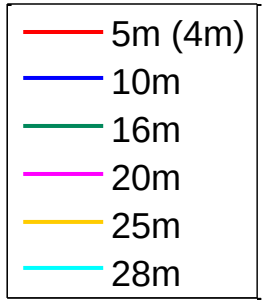


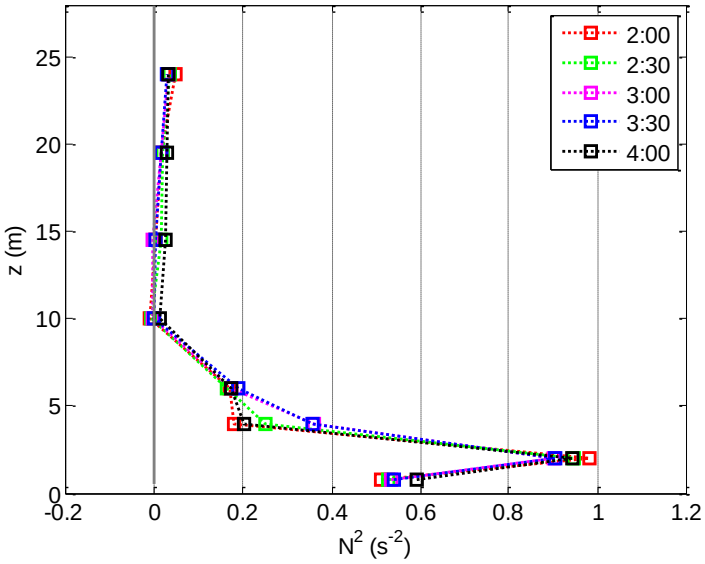
Brunt-Väisälä Frequency profiles

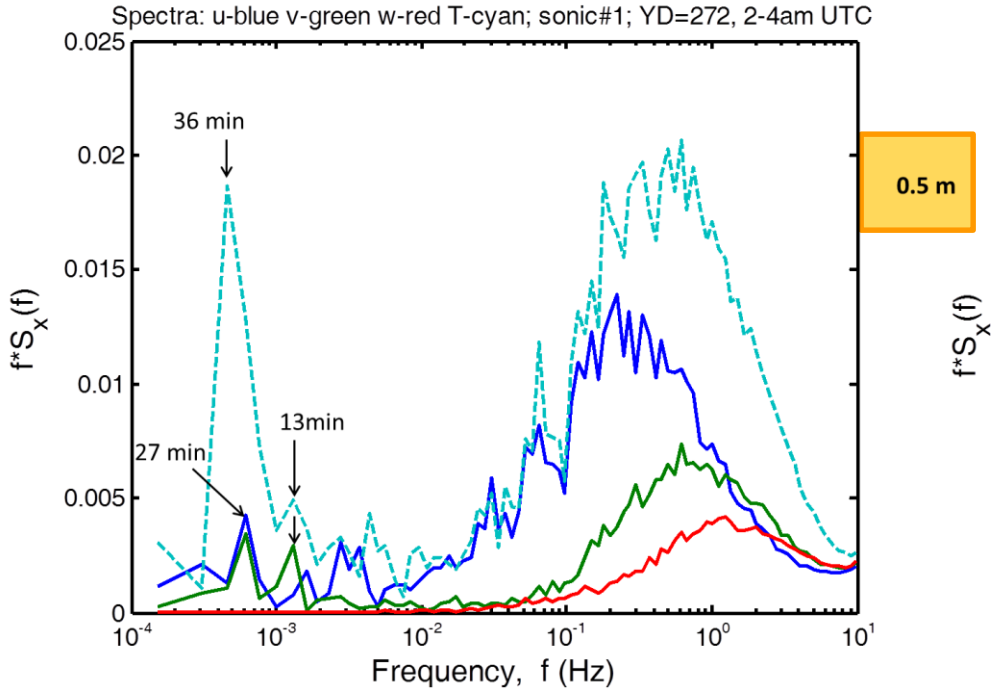


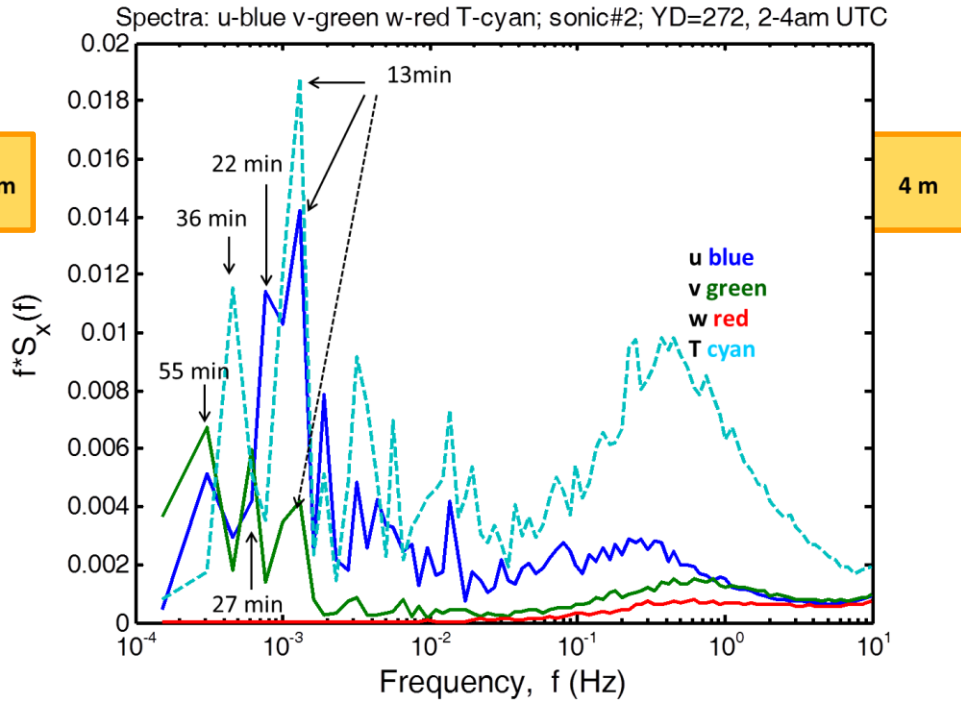
ES2 tower

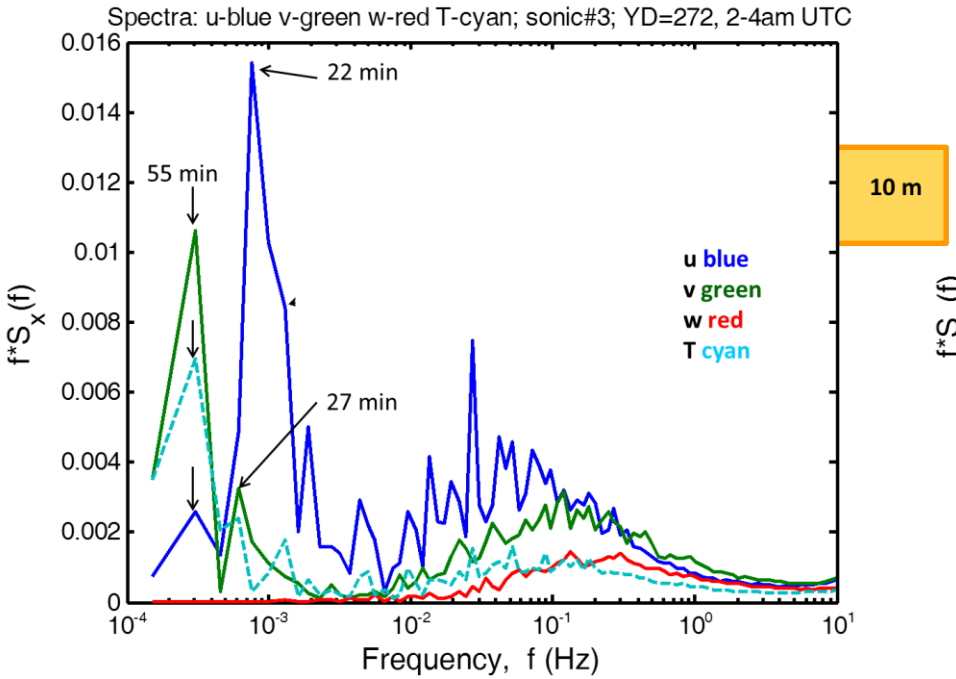


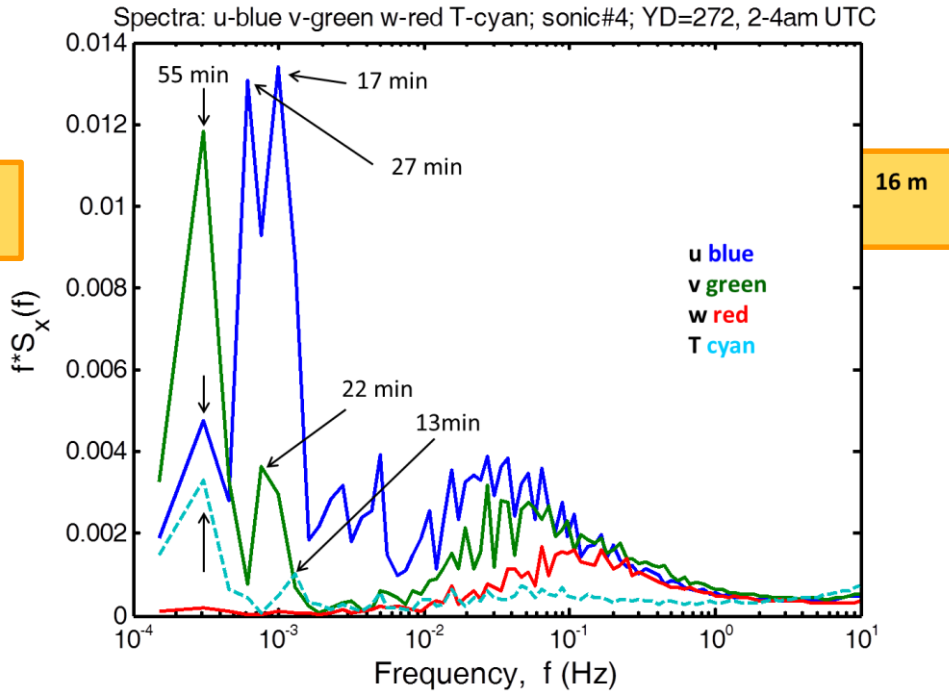


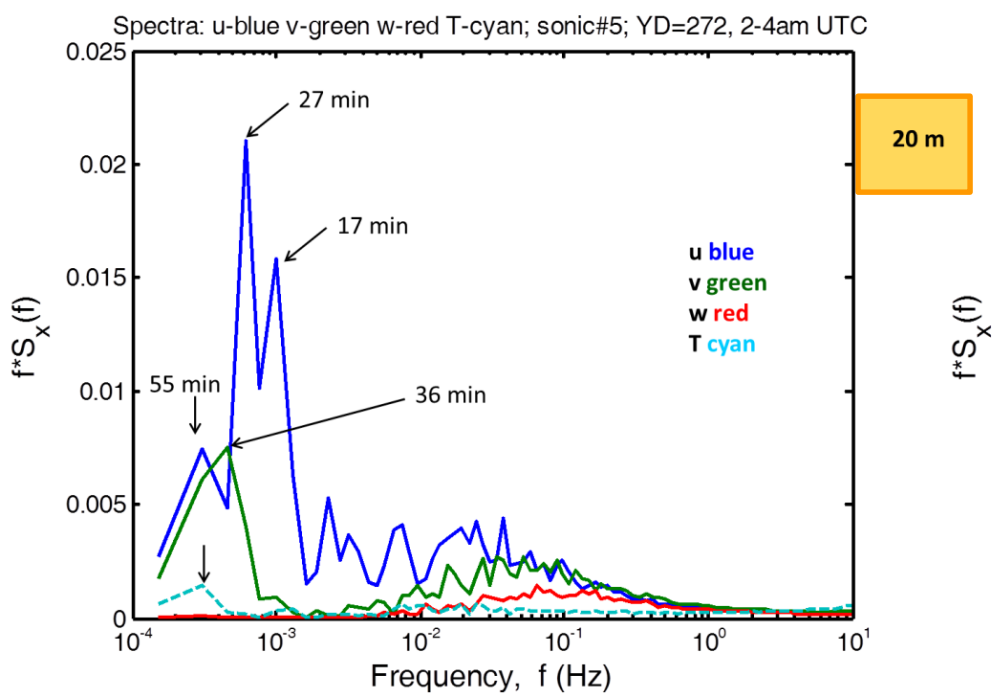


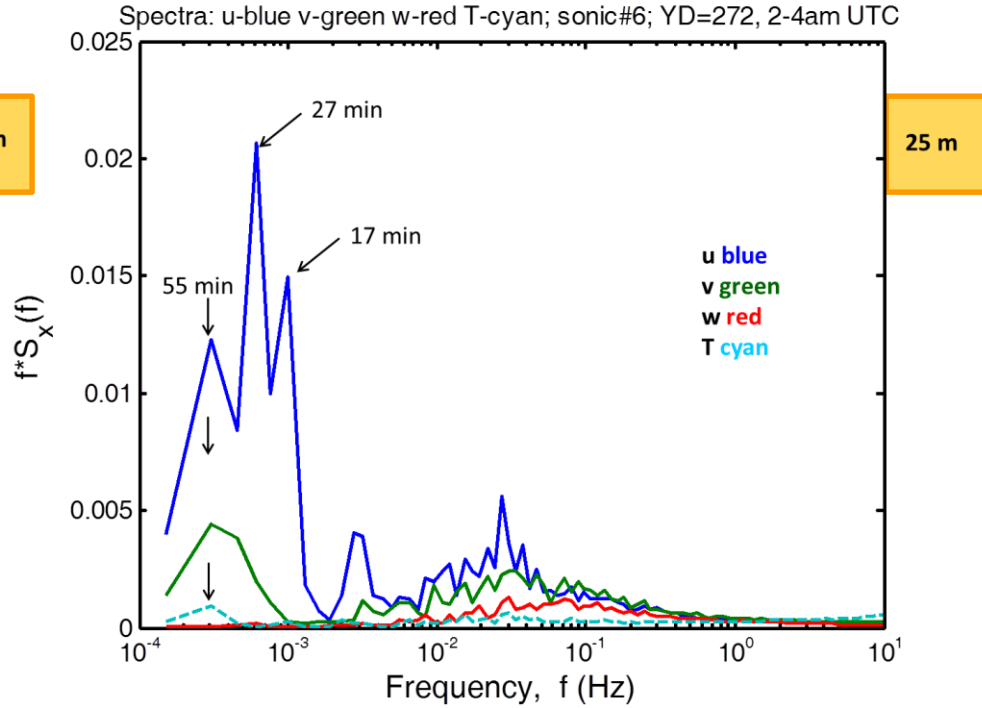

Spectra: u-blue v-green w-red T-cyan; sonic#1; YD=272, 2-4am UTC
36 min
13min
27 min
0.5 m
f*S_X(f)
Frequency, f (Hz)

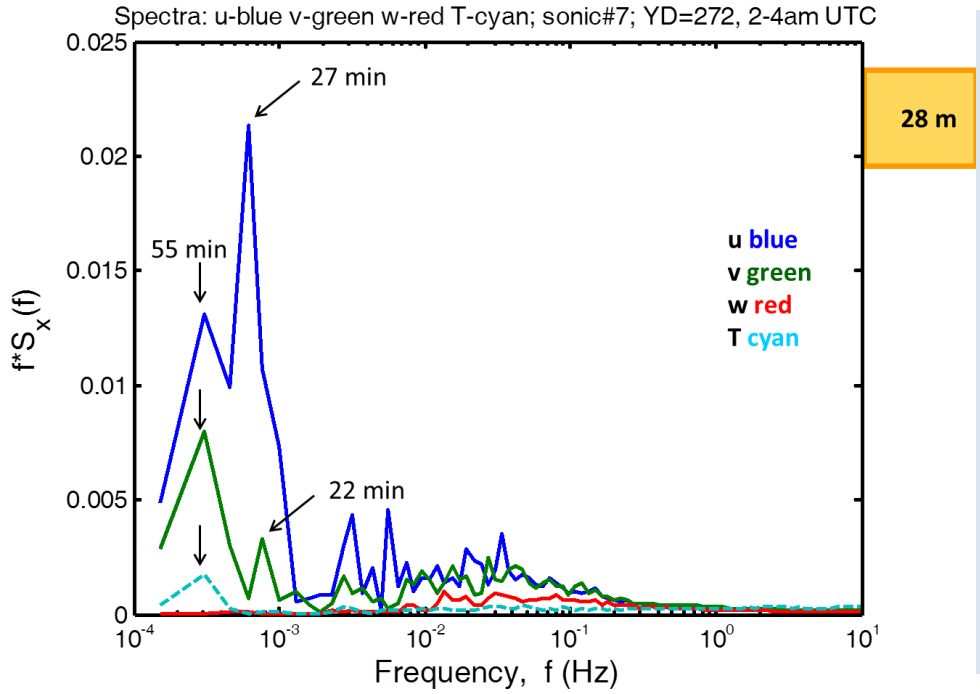

Spectra: u-blue v-green w-red T-cyan; sonic#2; YD=272, 2-4am UTC
13min
22 min
36 min
55 min
27 min
u blue
v green
w red
T cyan
4 m
f*S_X(f)
Frequency, f (Hz)

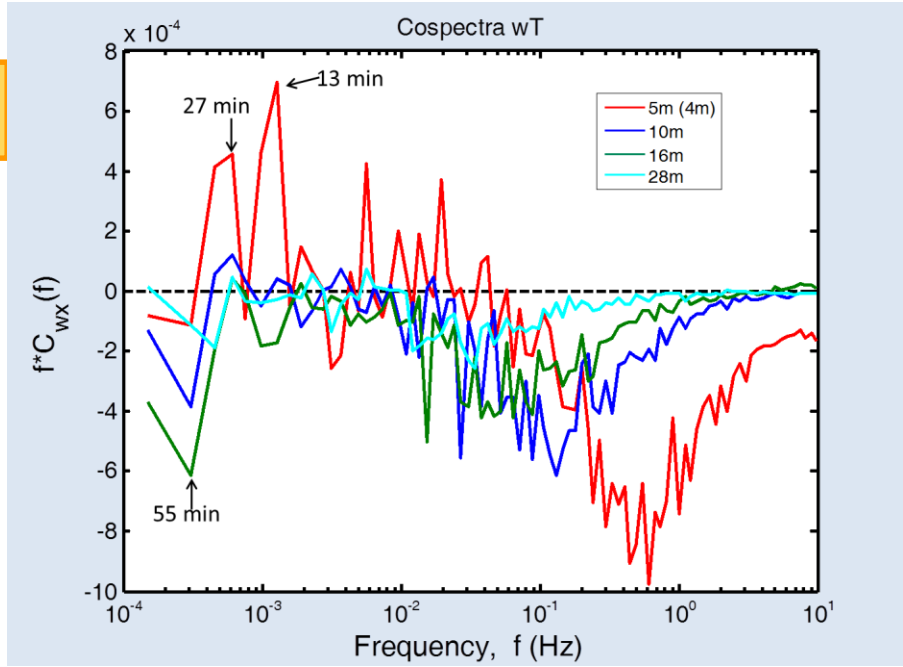

Spectra: u-blue v-green w-red T-cyan; sonic#3; YD=272, 2-4am UTC
22 min
55 min
27 min
u blue
v green
w red
T cyan
10 m
f*S_X(f)
Frequency, f (Hz)

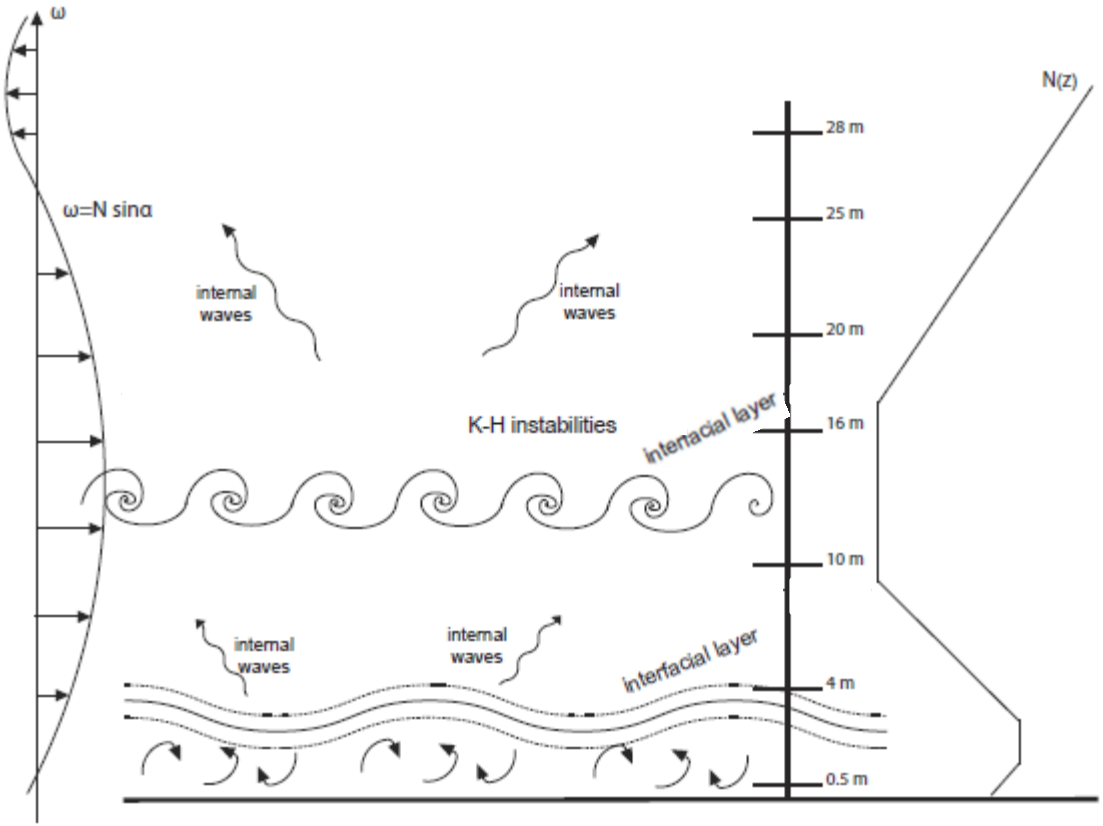

Spectra: u-blue v-green w-red T-cyan; sonic#4; YD=272, 2-4am UTC
55 min
17 min
27 min
22 min
13min
u blue
v green
w red
T cyan
16 m
f*S_X(f)
Frequency, f (Hz)

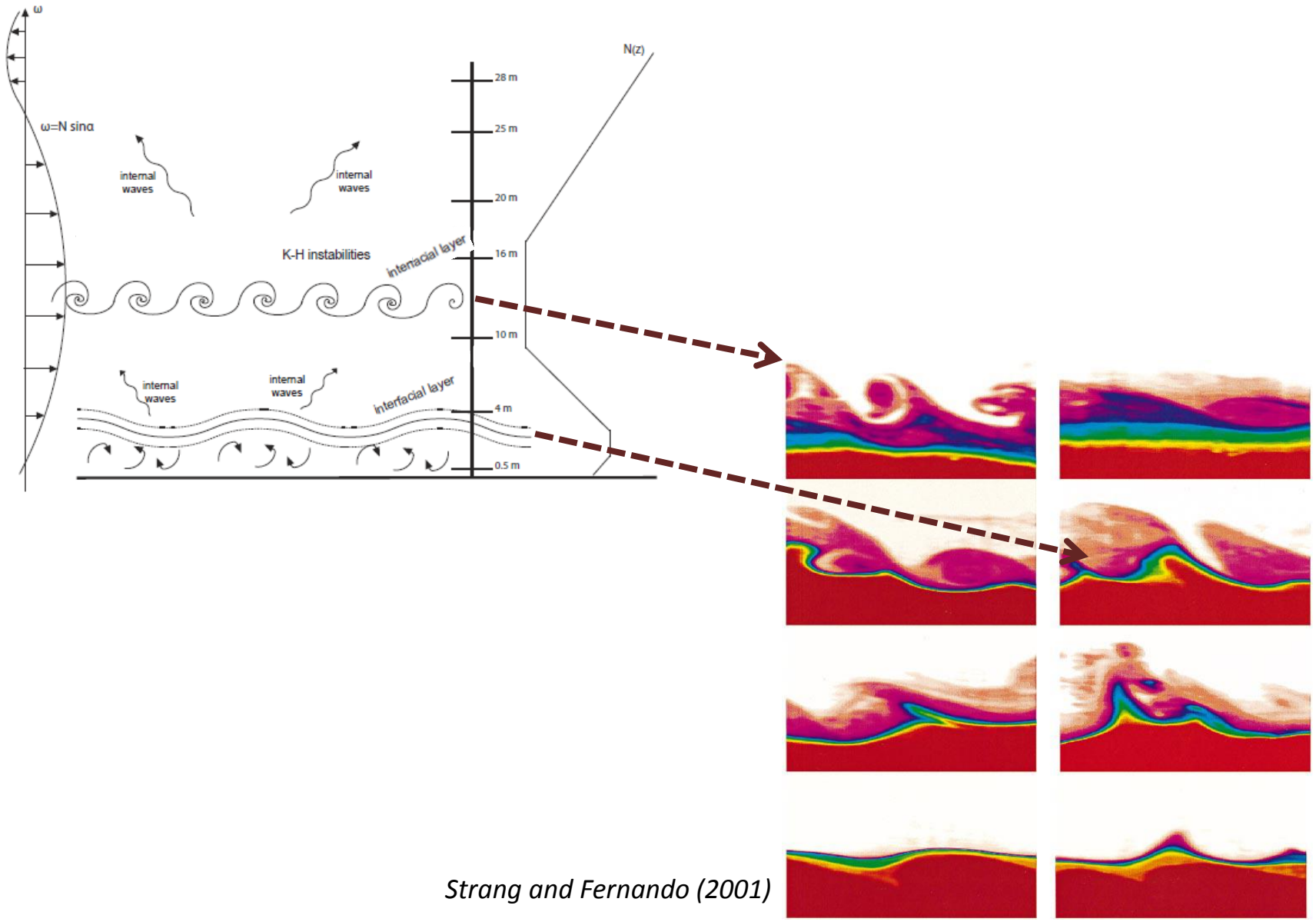

Spectra: u-blue v-green w-red T-cyan; sonic#5; YD=272, 2-4am UTC
20 m
27 min
17 min
55 min
36 min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)


Spectra: u-blue v-green w-red T-cyan; sonic#6; YD=272, 2-4am UTC
25 m
27 min
17 min
55 min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)

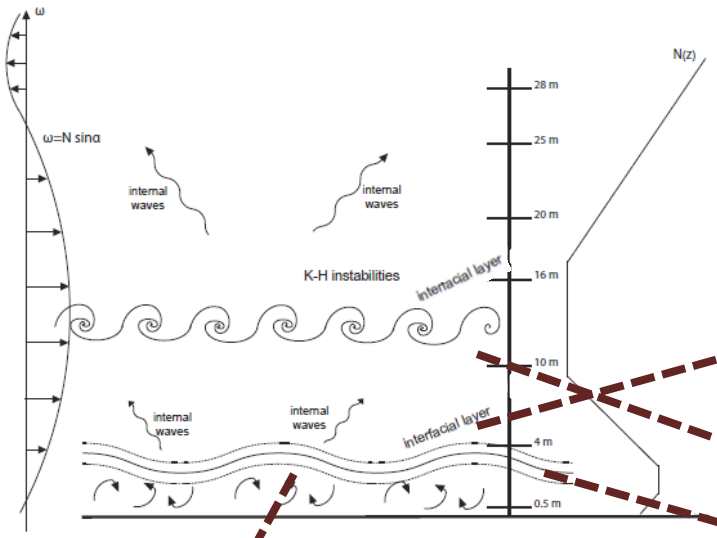

Spectra: u-blue v-green w-red T-cyan; sonic#7; YD=272, 2-4am UTC
28 m
27 min
55 min
22 min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)

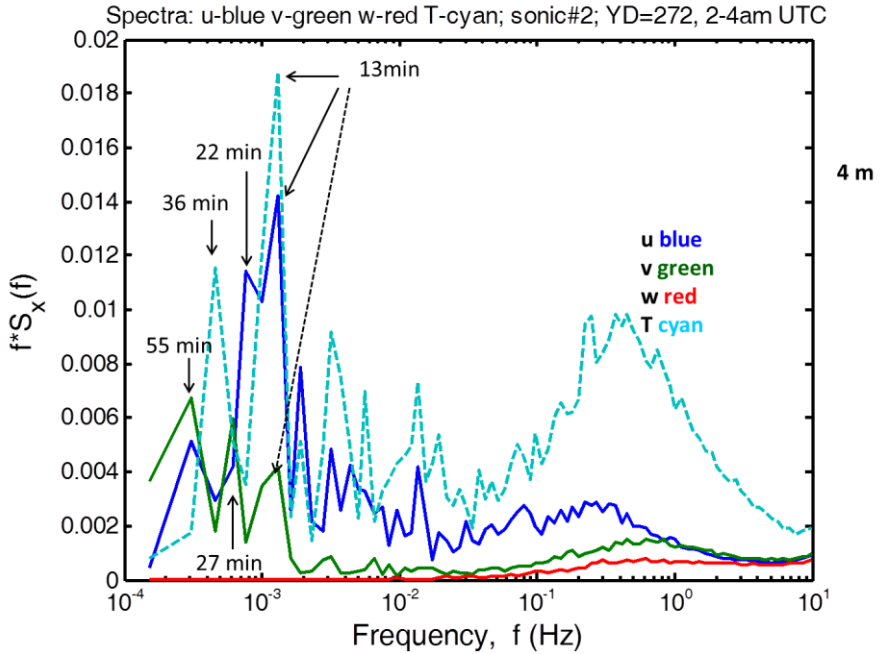

Cospectra wT
x 10^-4
27 min
13 min
55 min
5m (4m)
10m
16m
28m
f*C_wx(f)
Frequency, f (Hz)

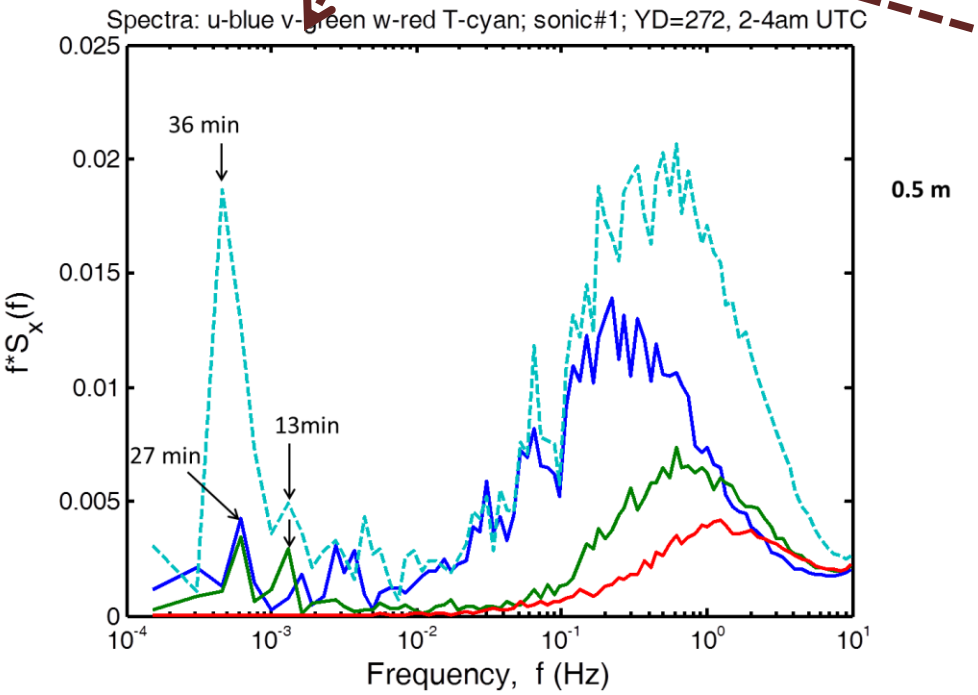

ω
ω=N sinα
internal waves
internal waves
K-H instabilities
interacial layer
internal waves
internal waves
interfacial layer
N(z)
28 m
25 m
20 m
16 m
10 m
4 m
0.5 m

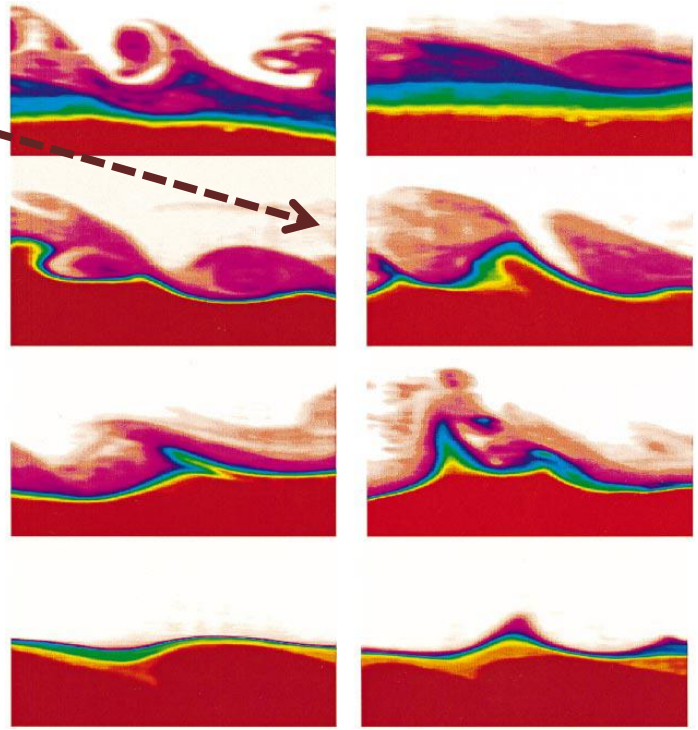


Strang and Fernando (2001)

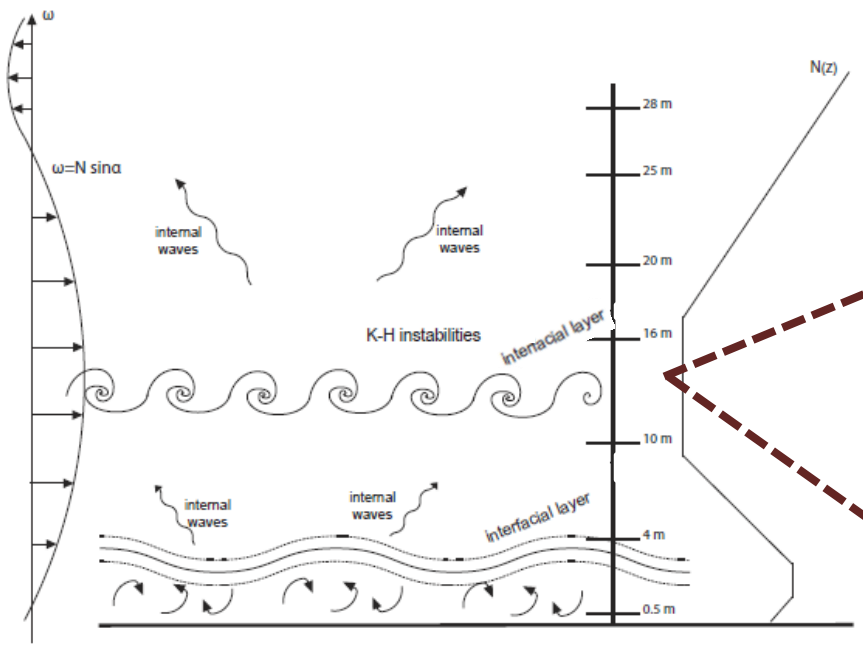


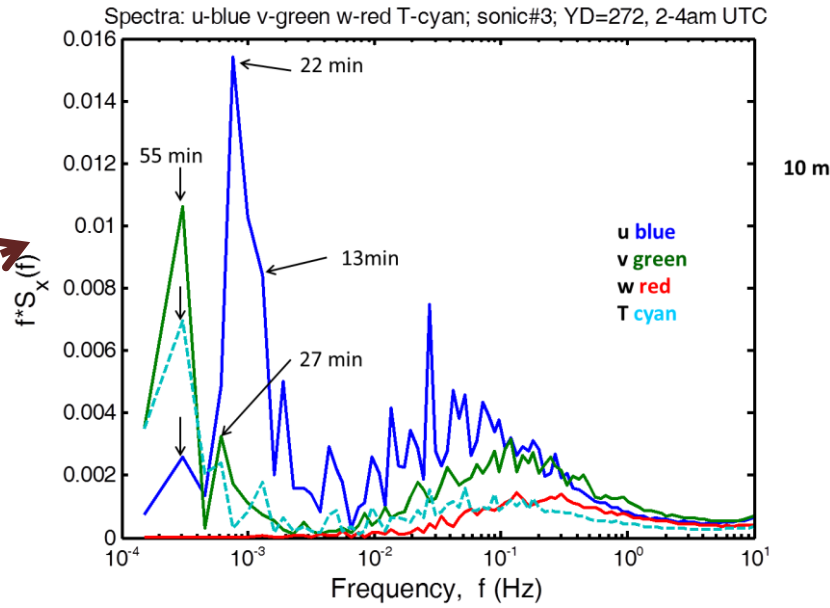


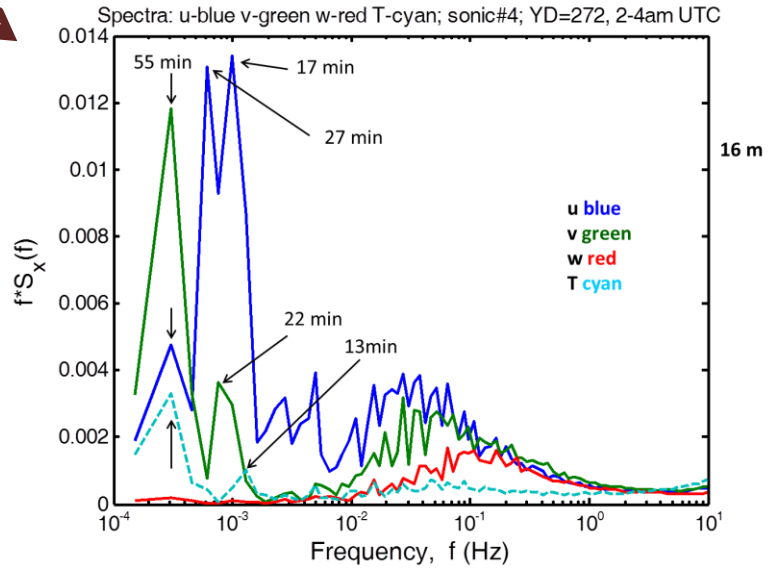


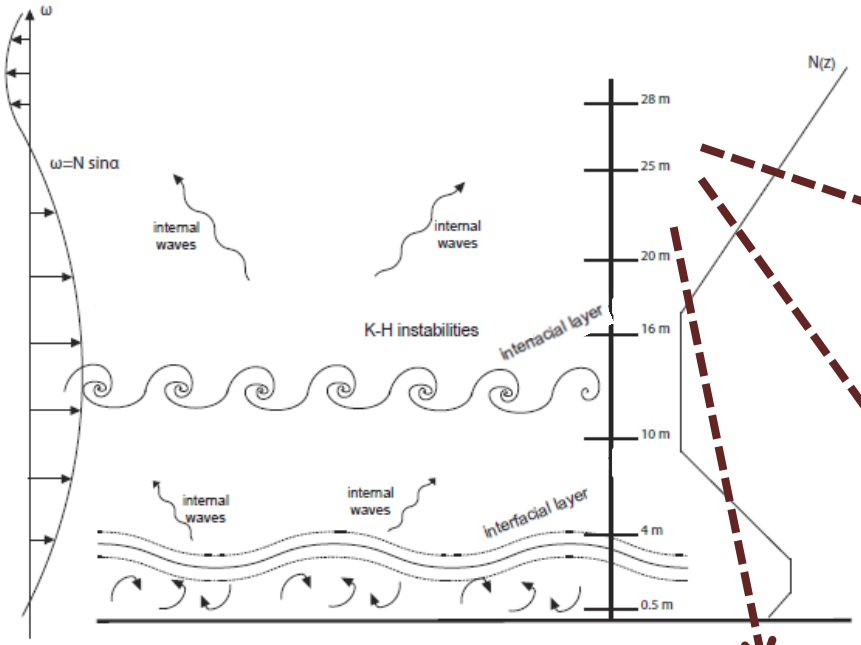


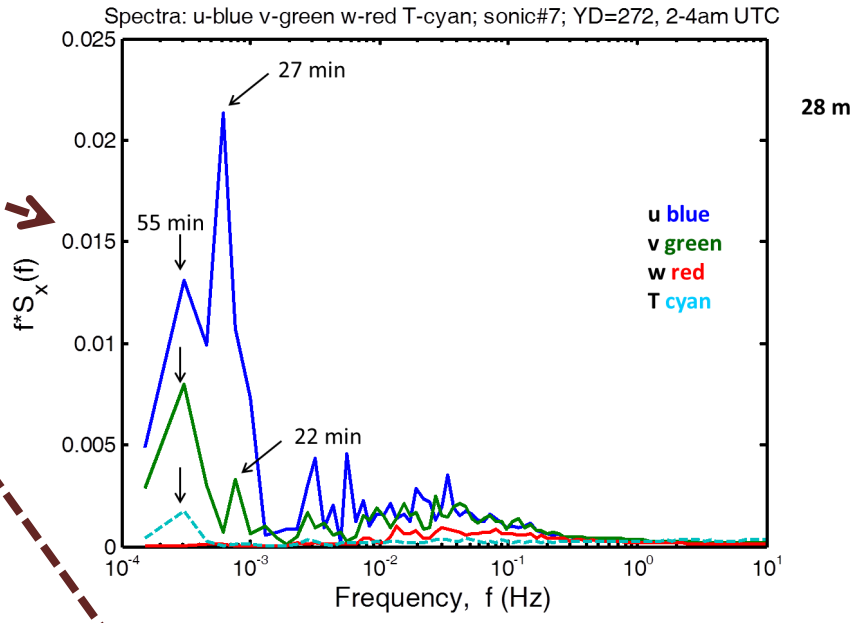
Strang and Fernando (2001)

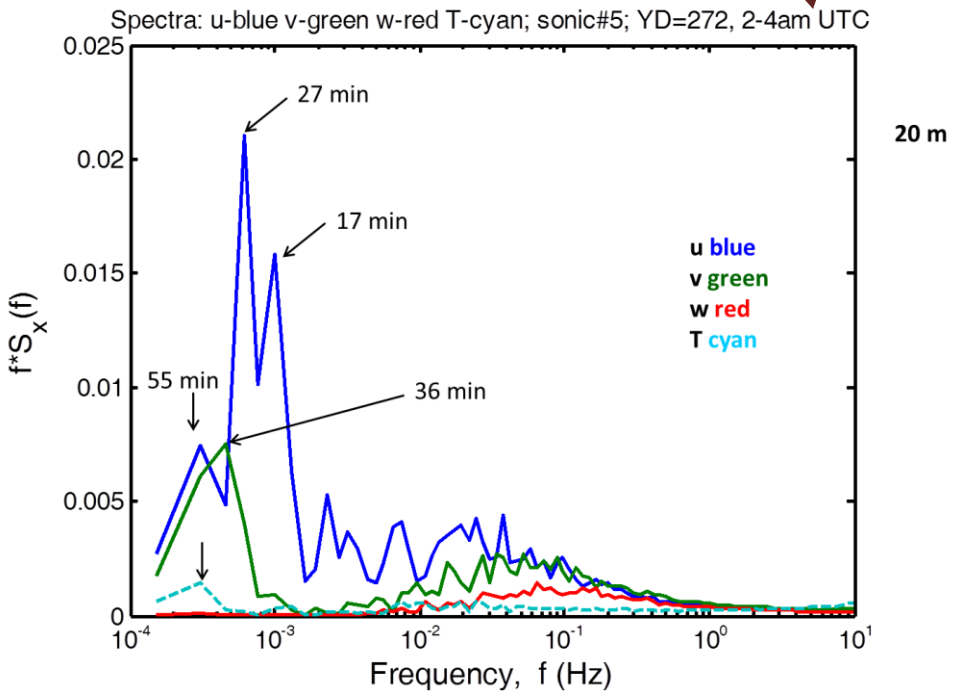

ω
ω=N sinα
N(z)
internal waves
internal waves
K-H instabilities
interfacial layer
internal waves
internal waves
interfacial layer
28 m
25 m
20 m
16 m
10 m
4 m
0.5 m

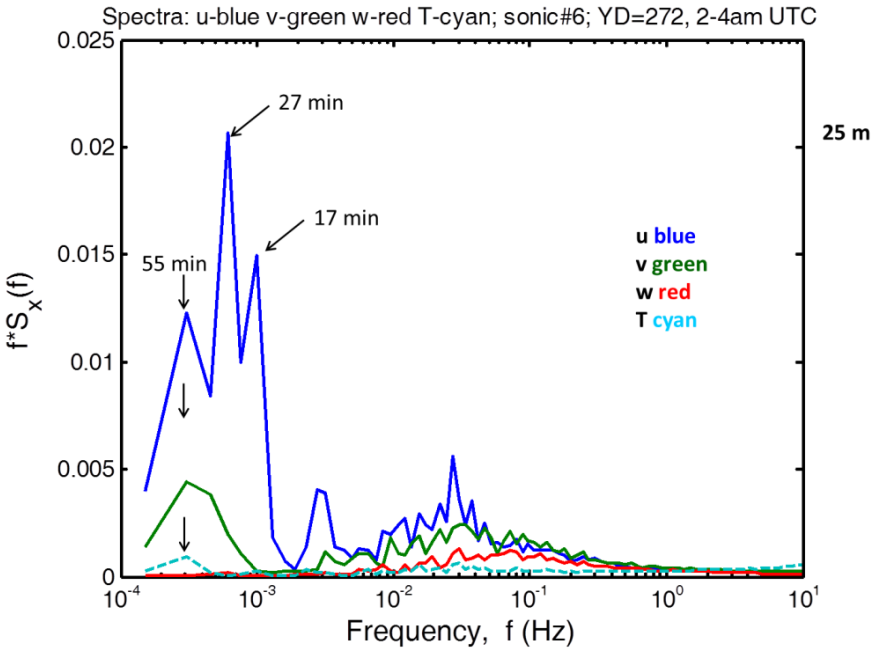

Spectra: u-blue v-green w-red T-cyan; sonic#3; YD=272, 2-4am UTC
22 min
55 min
13min
27 min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)
10 m


Spectra: u-blue v-green w-red T-cyan; sonic#4; YD=272, 2-4am UTC
55 min
17 min
27 min
22 min
13min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)
16 m


ω
ω=N sinα
N(z)
internal waves
internal waves
K-H instabilities
interfacial layer
internal waves
internal waves
interfacial layer
28 m
25 m
20 m
16 m
10 m
4 m
0.5 m


Spectra: u-blue v-green w-red T-cyan; sonic#7; YD=272, 2-4am UTC
28 m
27 min
55 min
22 min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)


Spectra: u-blue v-green w-red T-cyan; sonic#5; YD=272, 2-4am UTC
20 m
27 min
17 min
55 min
36 min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)


Spectra: u-blue v-green w-red T-cyan; sonic#6; YD=272, 2-4am UTC
25 m
27 min
17 min
55 min
u blue
v green
w red
T cyan
f*S_x(f)
Frequency, f (Hz)

CONCLUSIONS & OUTLOOK

- Several occurrences of slope flows during quiescent periods
- Strong interaction between slope flows and the circulation in the valley
- Due to these multiscale flow interactions, slope flows appear to be intermittent and disturbed with tendency to decay through the night
- Slope flow develops rapidly after sunset and usually persists for 2-3 hours. This is also the period where the flow structure resembles a "pure" katabatic flow
- Presence of oscillations were documented in the katabatatic flow and associated to a multi-layer structure of the flow
- We are currently work on the theoretical formulations of this special dynamics for inclusions in mesoscale atmospheric models

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