A Case Study of Turbulence in the Nocturnal Boundary Layer During the Indian Summer Monsoon

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RESEARCH ARTICLE

A Case Study of Turbulence in the Nocturnal Boundary Layer During the Indian Summer Monsoon

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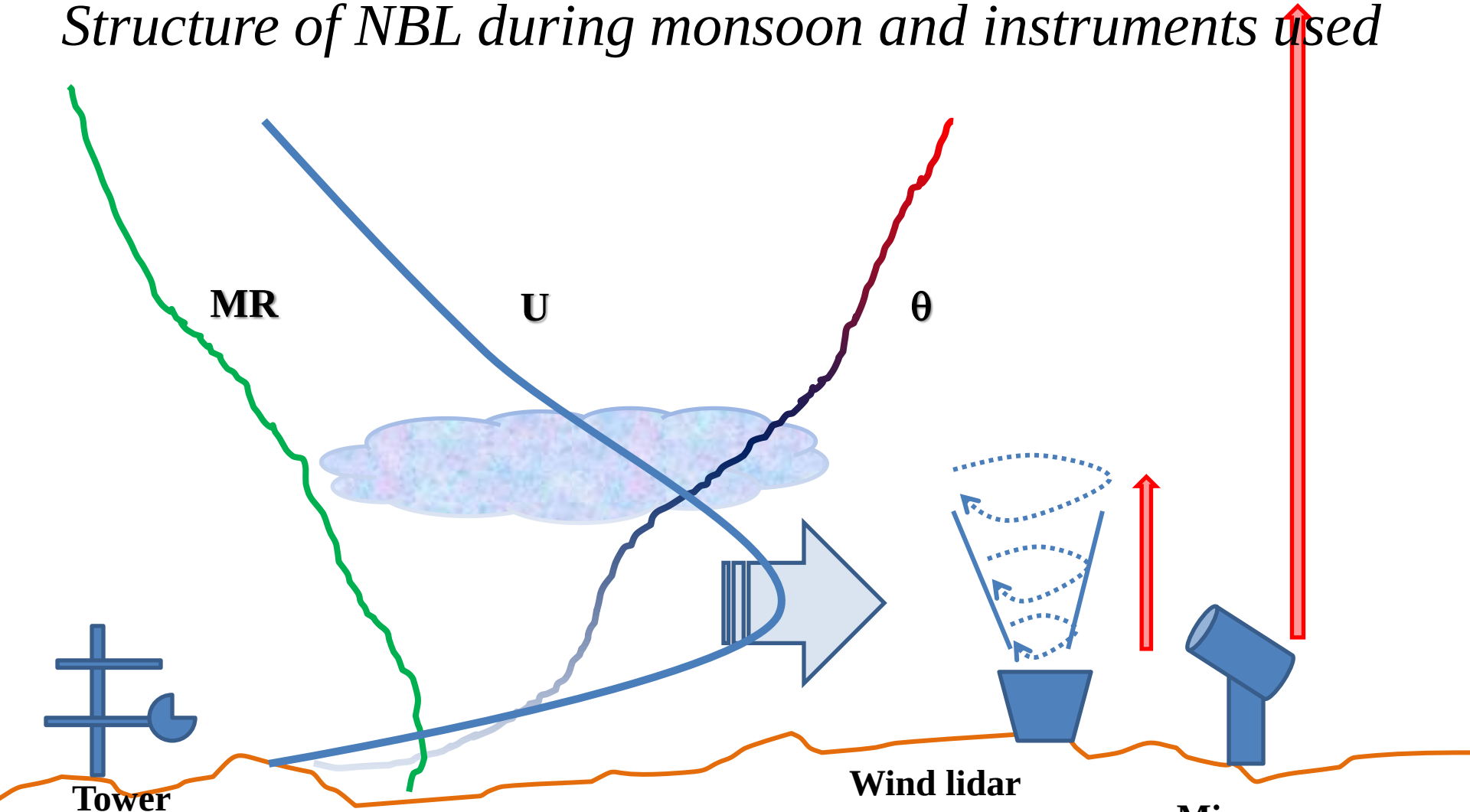
Scientist Induction Project

Thesis title:- Scale Interactions in the Stably Stratified Boundary Layer and the Role of Low-Level Jets

Structure of NBL during monsoon and instruments used



Tower

6 m @ 0.1 s

Eddy covariance Variances, Fluxes, TKE etc.

2 m and 12 m @ 30 min

Slow response sensors Gradients

Wind lidar

100 -500 m @ 50 m

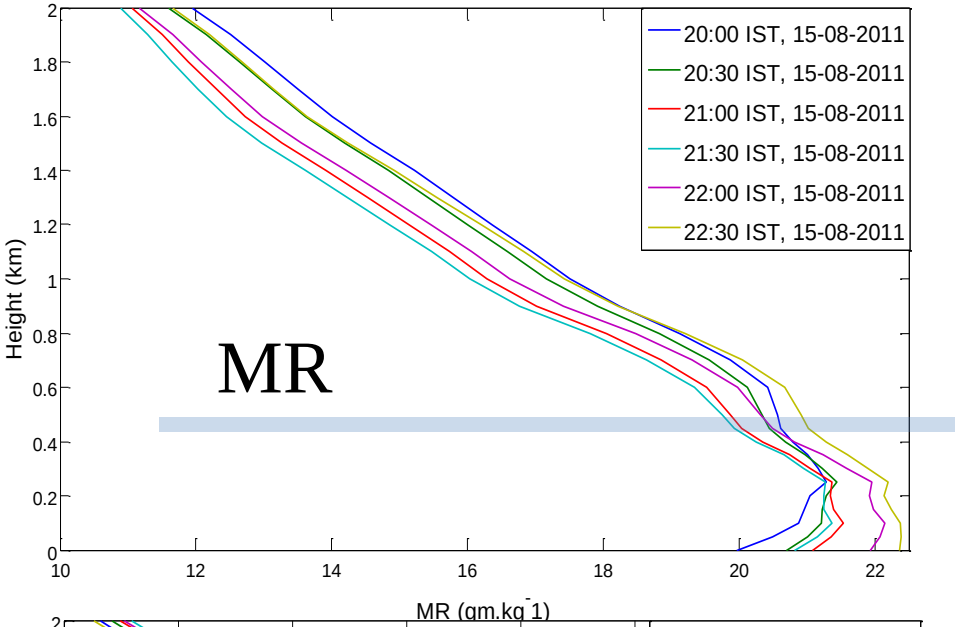
12 s or 5 min

Microwave Radiometer

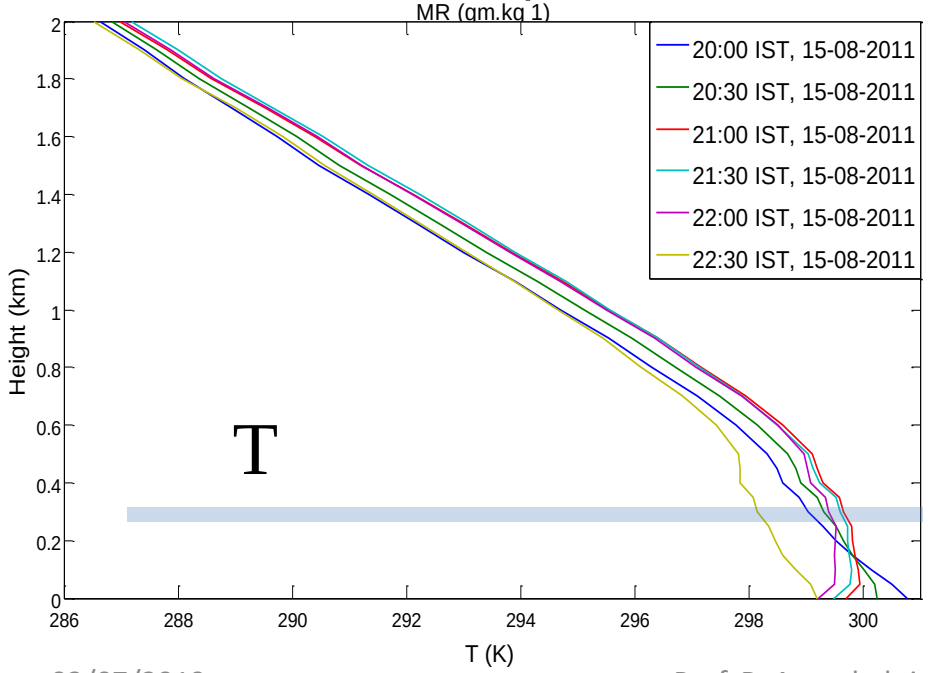
10 km @ 50/100 m

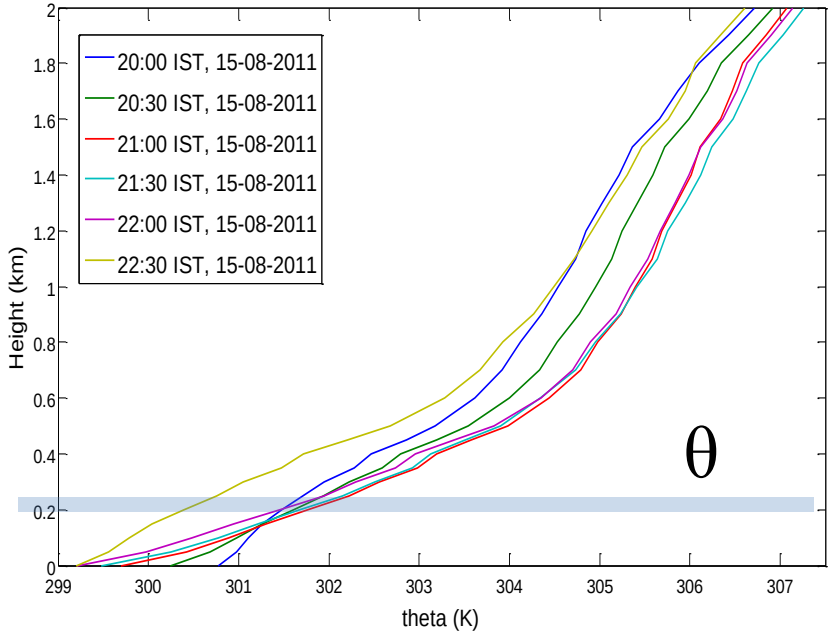
@ 2 min

Vertical profiles of Mixing Ratio (MR), T and θ

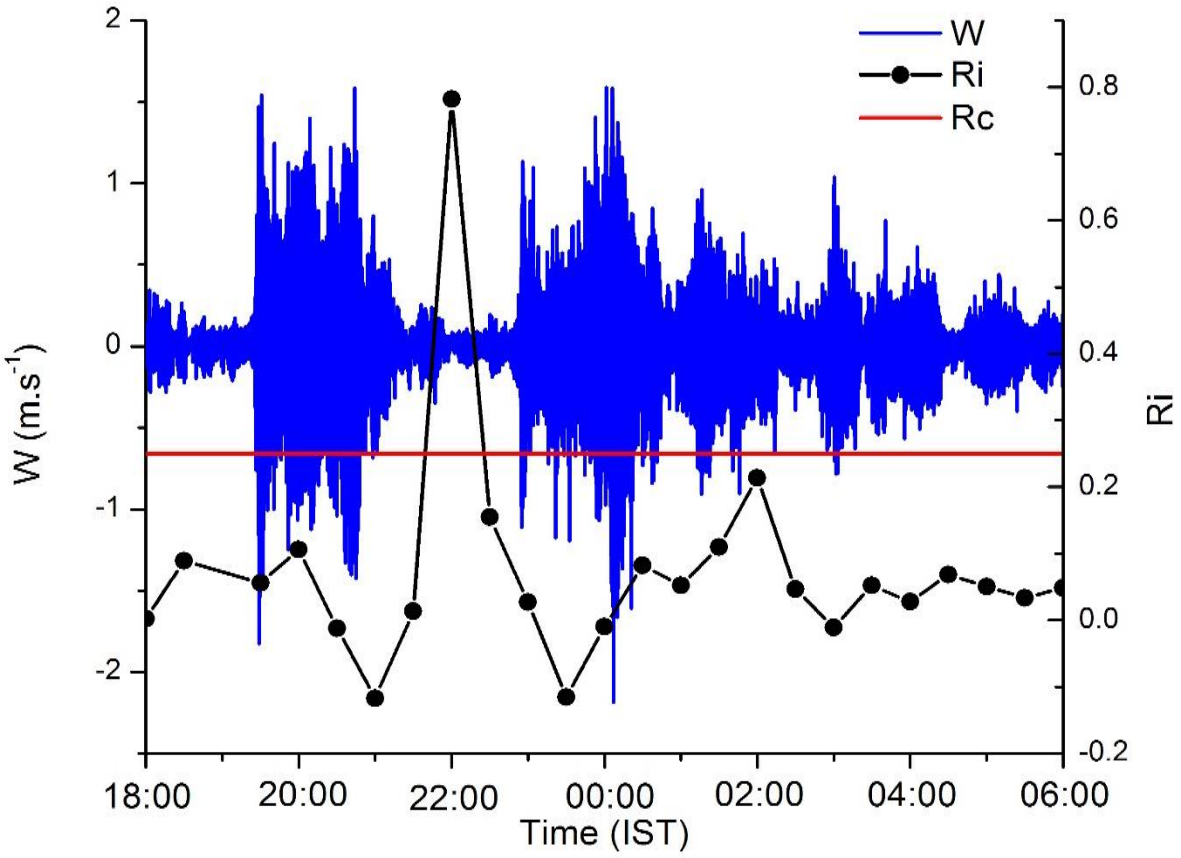


- Boundary Layer height ~ 500 m





EC data processing

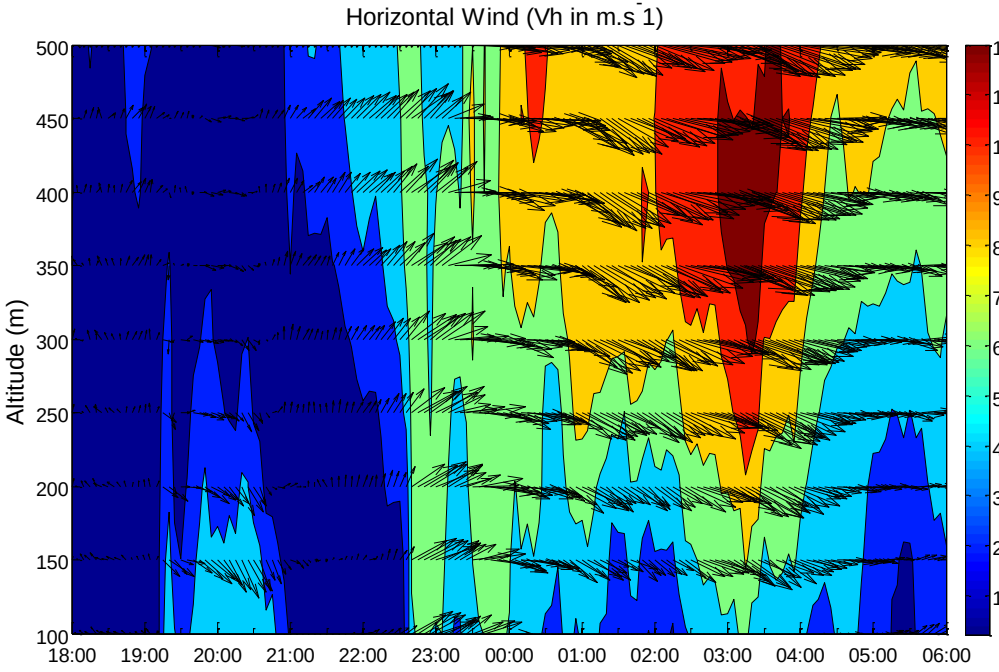


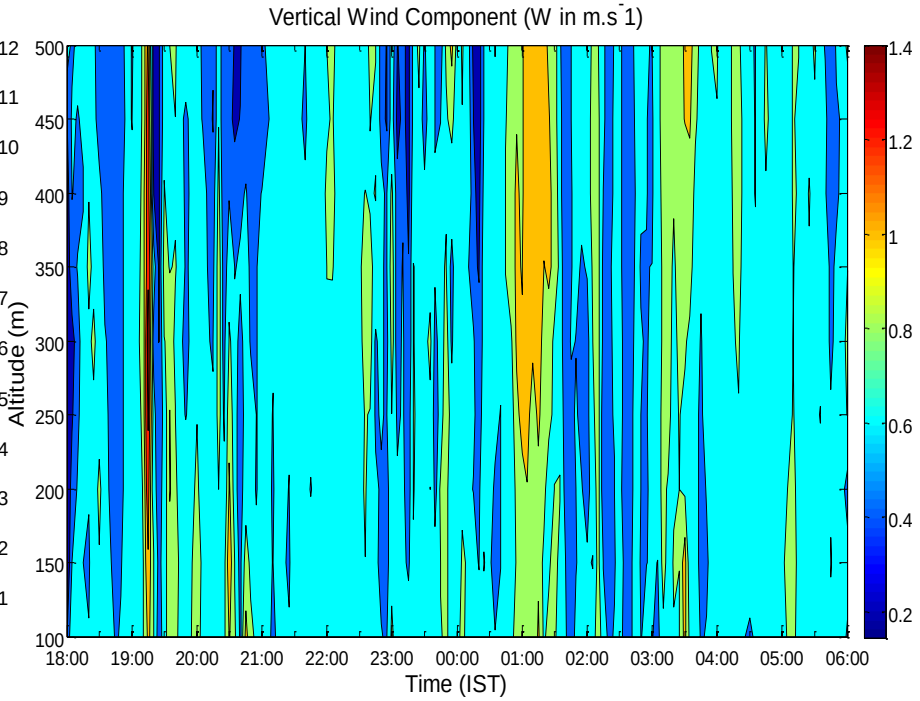
- each record duration = 30 min
- total no of records: 24
- despiked (*Vickers and Mahrt, 1997*)
- co-ordinate rotated (*Kaimal and Finnigan, 1994*)
- detrended (*Kaimal and Finnigan, 1994*)

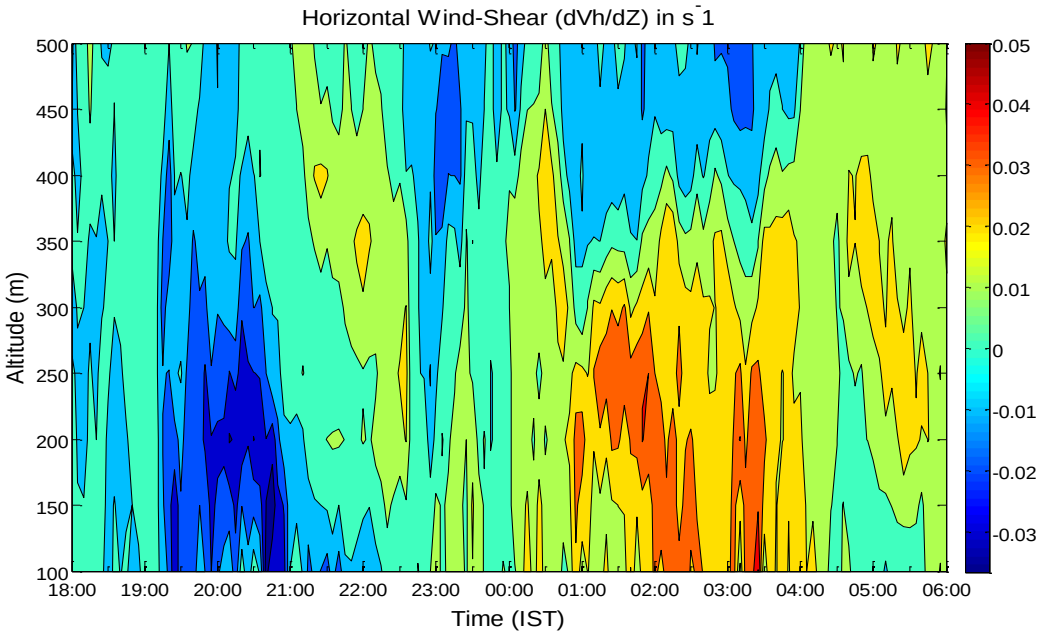
$$Ri = \frac{\frac{g}{\theta_v} . < \frac{\partial \theta_v}{\partial z} >}{< \left(\frac{\partial U}{\partial z}\right) >^2 + < \left(\frac{\partial V}{\partial z}\right) >^2}$$

Gradient Richardson Number

Wind and shear profile from Lidar







- strong vertical shear in horizontal wind near 100 m at around 19:30 and 23:00 IST, 15-08-2011

Wavelet Analysis

Wavelet Power : $$W_n(s) = \sum_{n\prime=0}^{n-1} x_{n\prime} \psi^* \left[\frac{(n\prime - n)\delta t}{s}\right]$$

***Morlet Wave-function*:** $$\psi_0(\eta) = \pi^{-\frac{1}{4}} e^{i\omega_0 \eta} e^{-\frac{\eta^2}{2}}$$

choice of scales: $$s_j = s_0 2^{j\delta j}, \text{ j=0,1,2,3.....J}$$

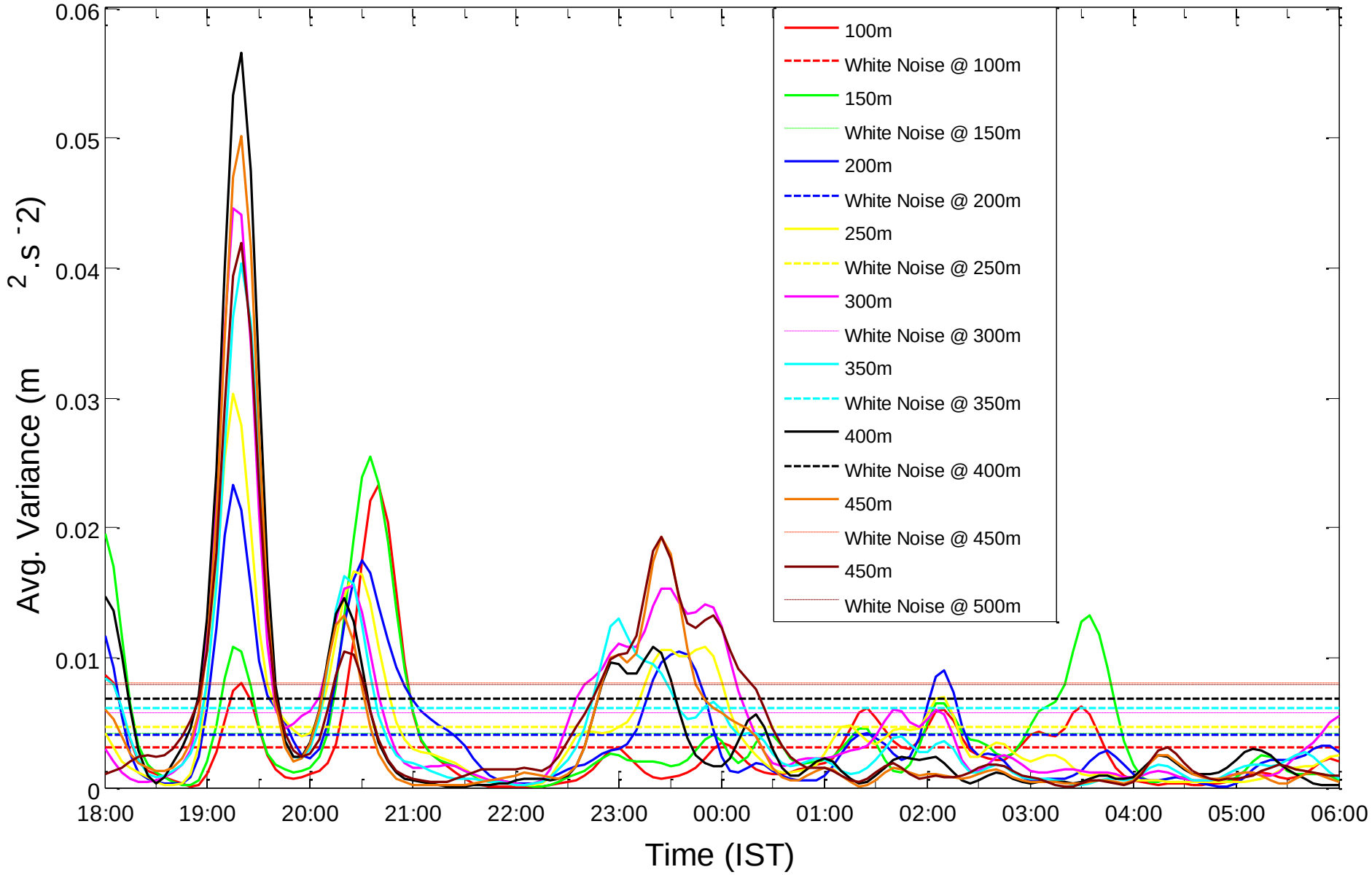
$$J = \frac{1}{\delta j} log_2 \frac{N\delta t}{s_0}$$

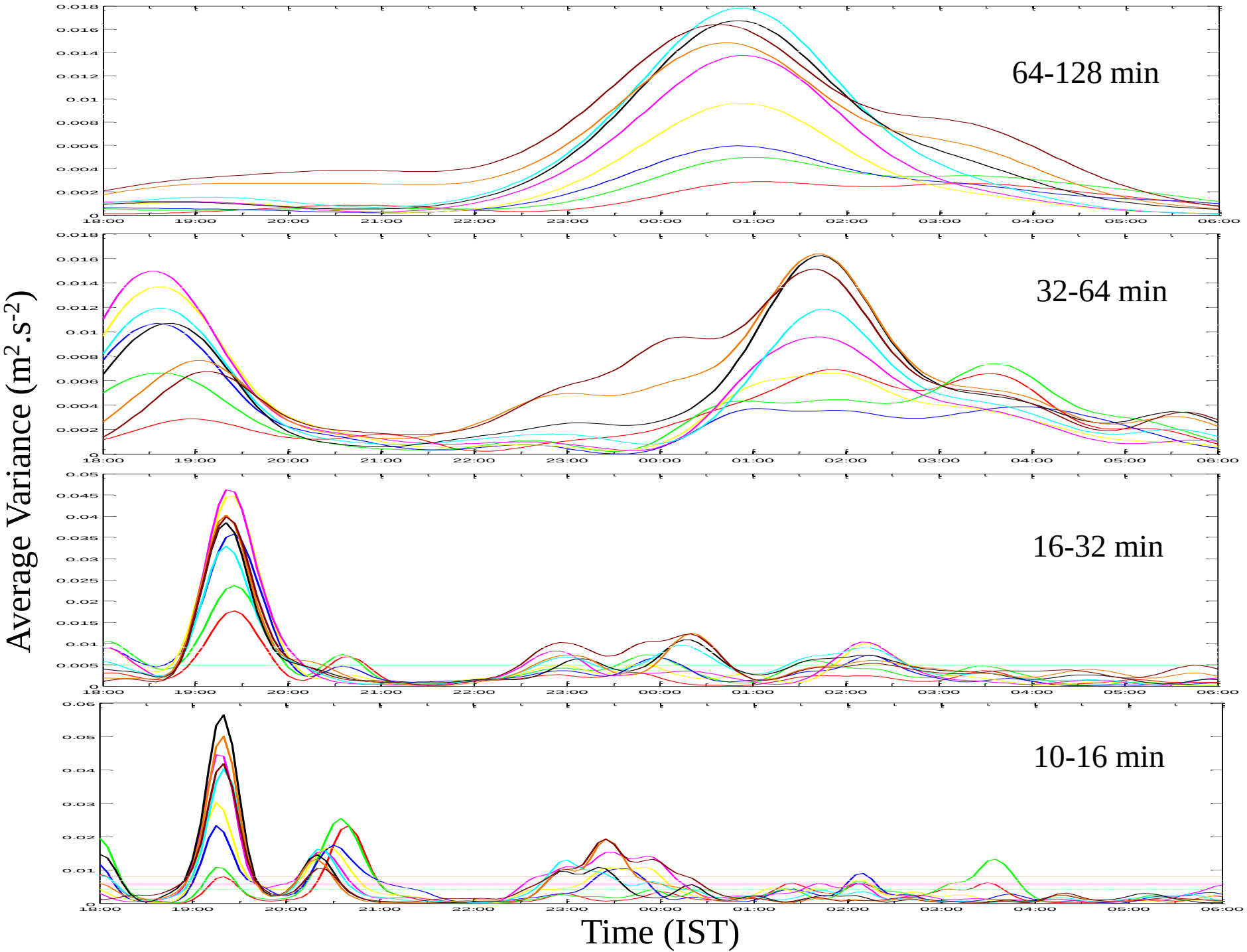
- time-series analysis
- decomposing a signal into both space and time domain
- wavelet = an analyzing function, local in space
- can be orthogonal or non-orthogonal
- continuous wavelet transform requires non-orthogonal basis
- In present work MatLab codes by Torrence and Compo, 1998 has been used

Co-spectra:

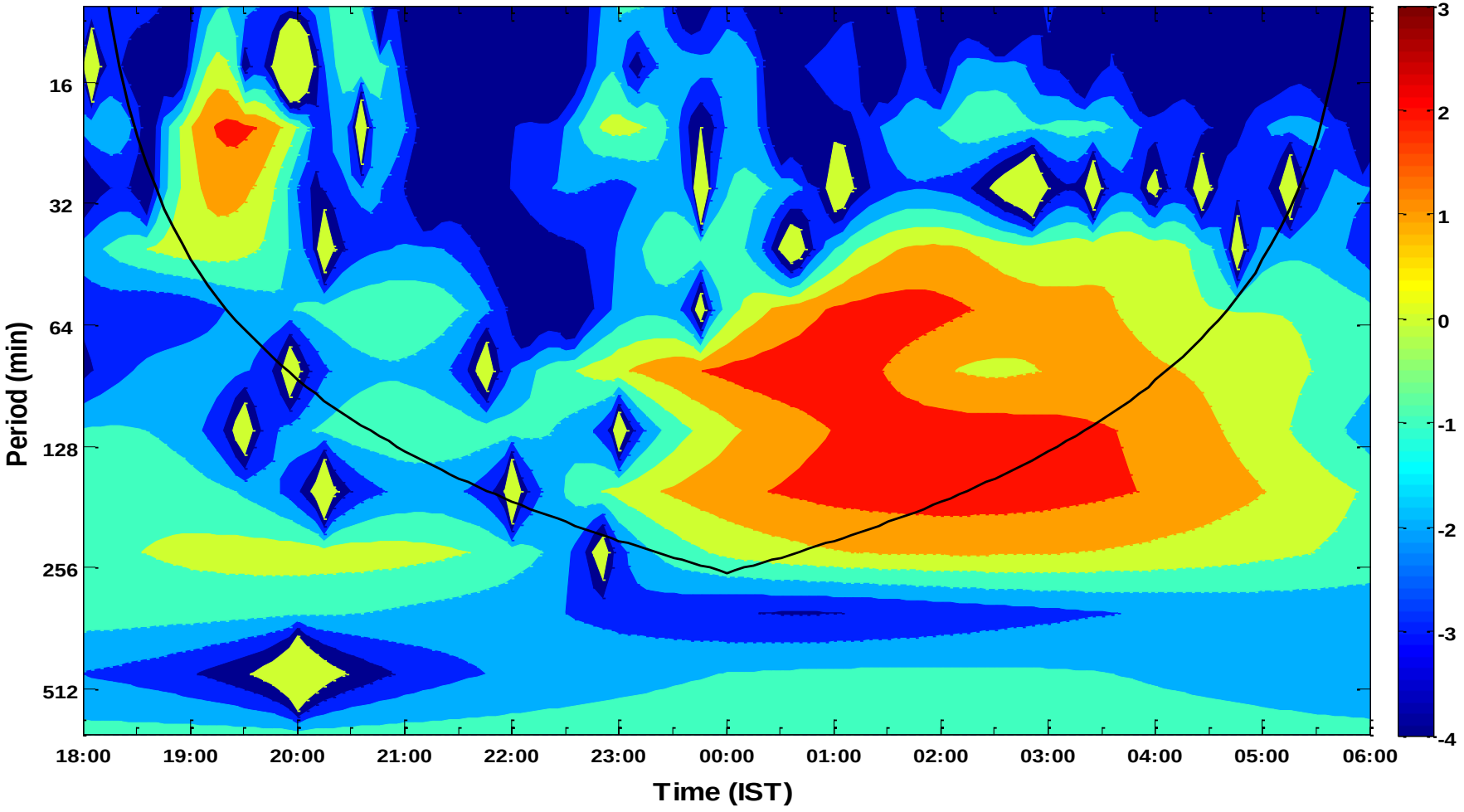
- Cross-spectrum = $W^A{}_n(s).\ W^{B*}{}_n(s)$
- Co-spectra = Re{Cross-spectrum}

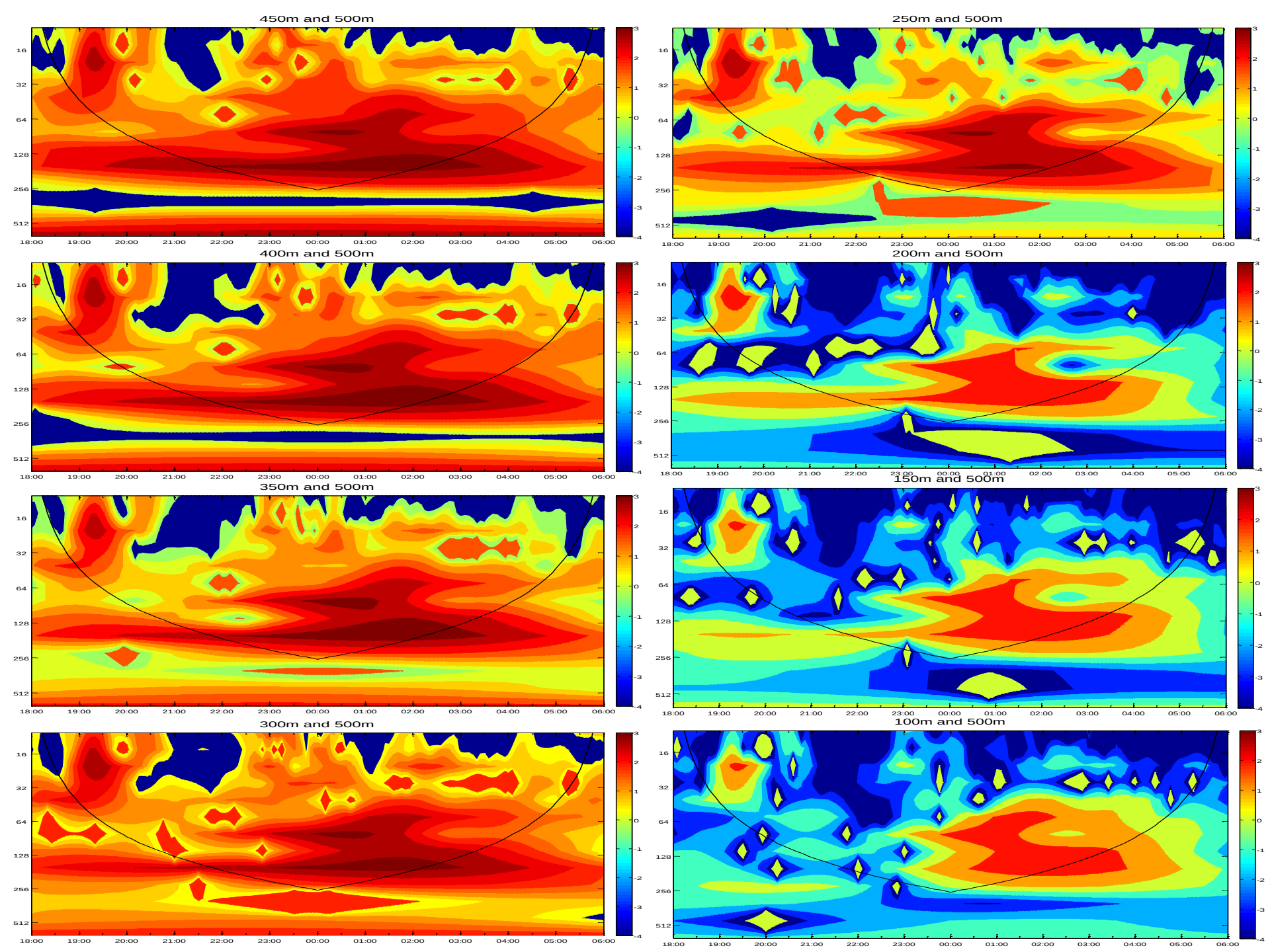
Scale separated variance with periodicity of 10-16 min



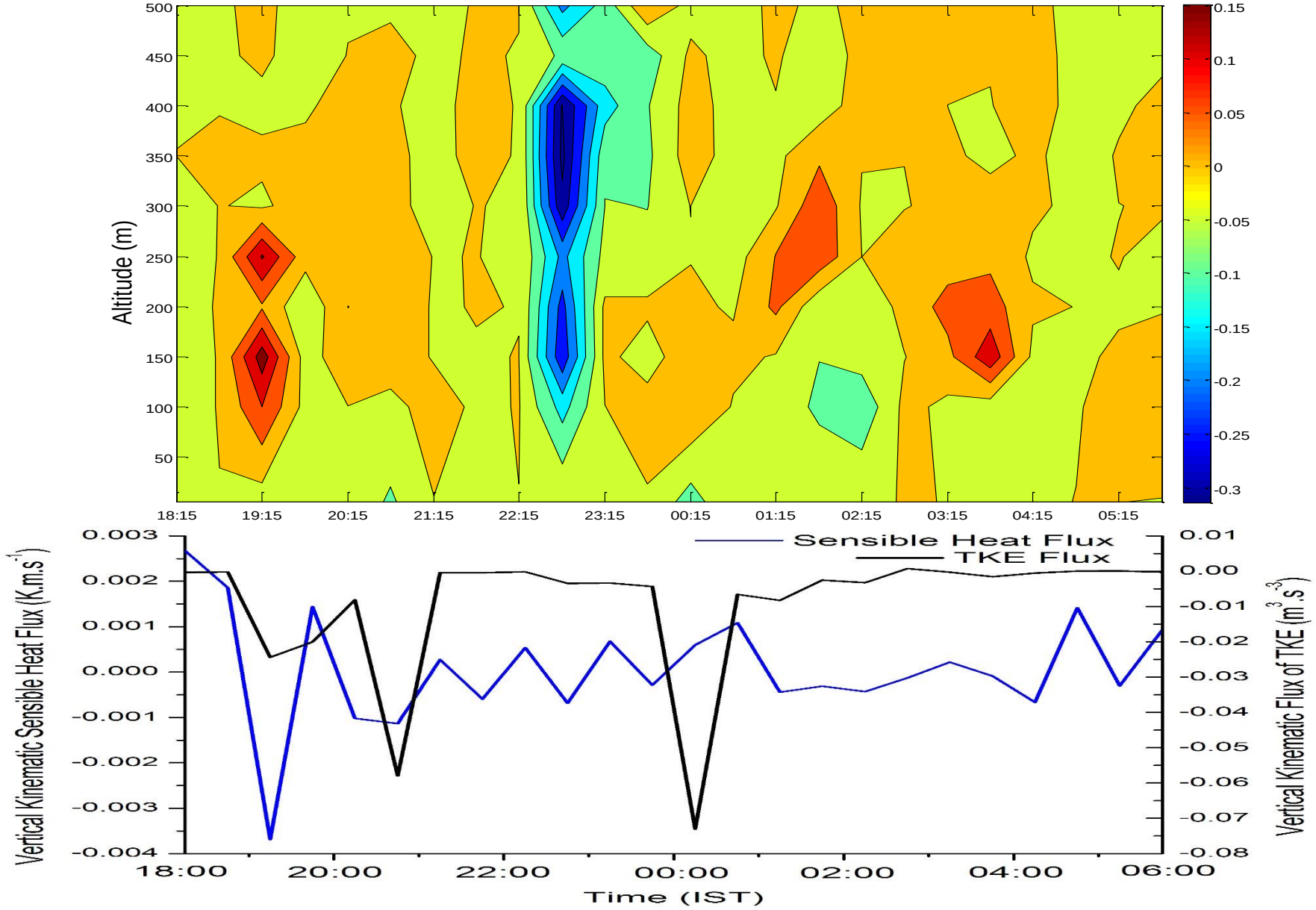

64-128 min
32-64 min
16-32 min
10-16 min
Average Variance (m².s⁻²)
Time (IST)
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00
06:00

Wavelet Co-spectra between W at 100m and 500m Illustrating the co-variation with the LLJ

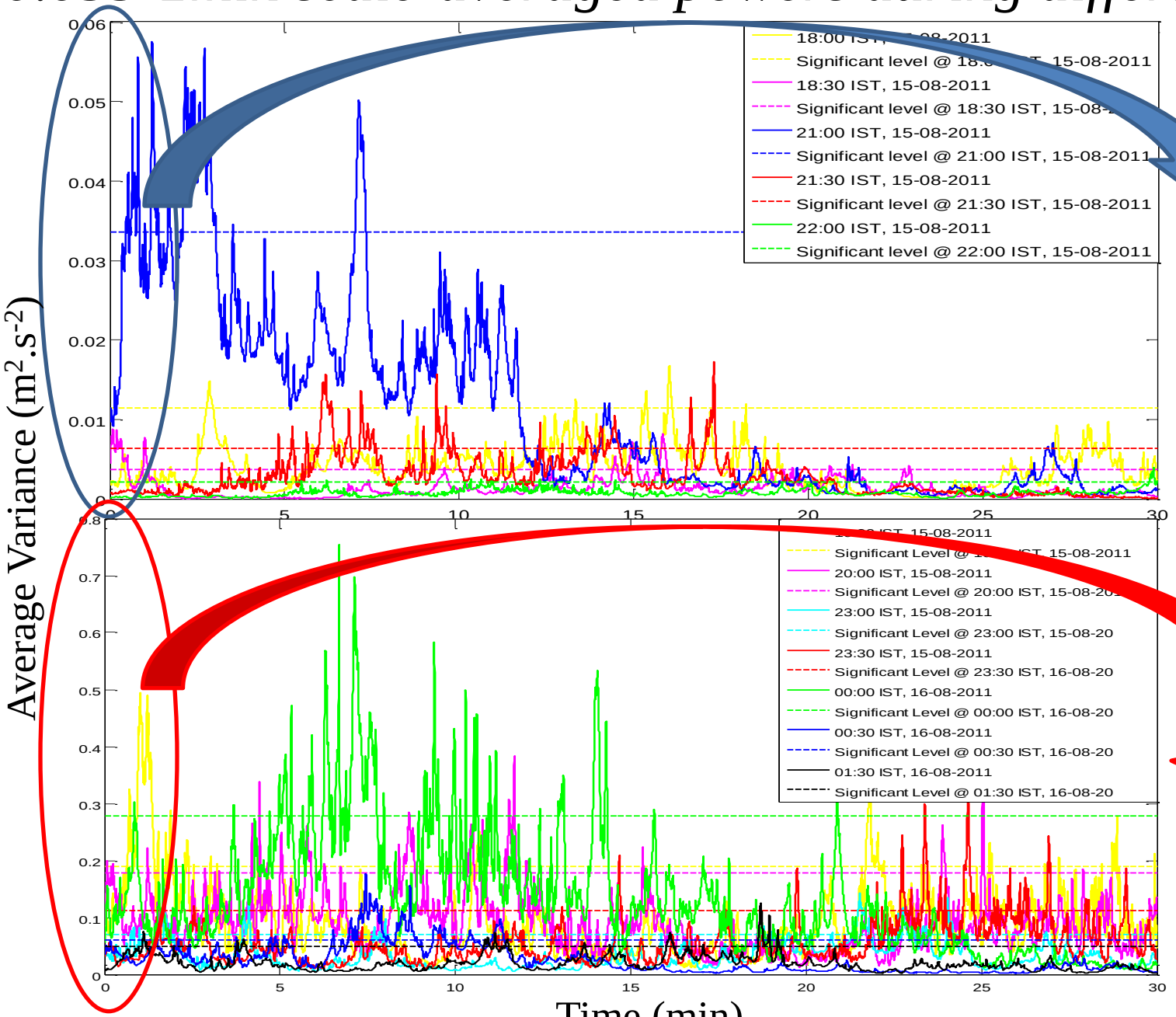



450m and 500m
250m and 500m
400m and 500m
200m and 500m
350m and 500m
150m and 500m
300m and 500m
100m and 500m
16
32
64
128
256
512
18:00
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
3
2
1
0
-1
-2
-3
-4

vertical kinematic fluxes of Turbulent Kinetic Energy [TKE $= \frac{1}{2}(< U'^2 > + < V'^2 > + < W'^2 >]$ *and Sensible Heat from Wind-Lidar and EC*

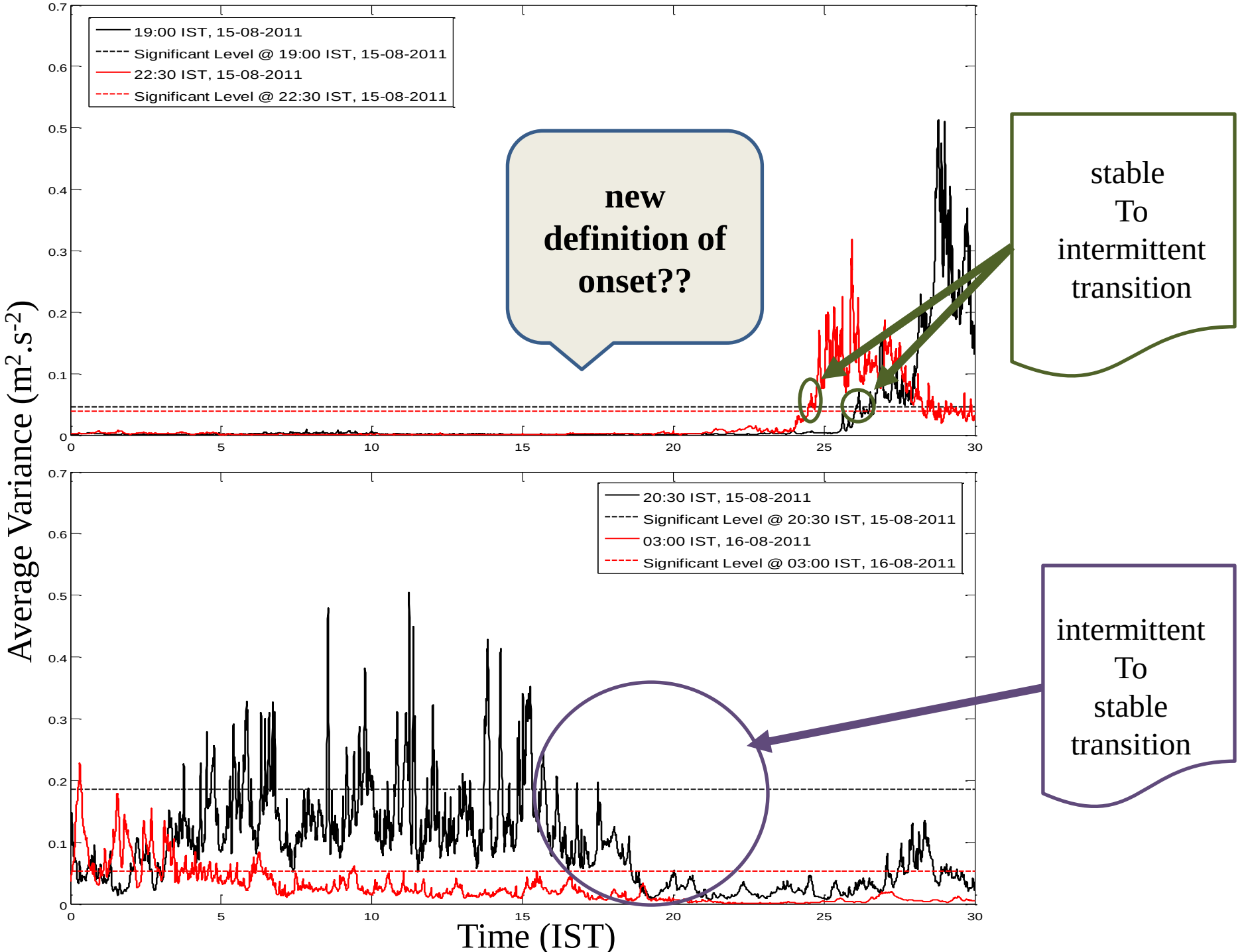


0.033-1min scale-averaged powers during different regimes

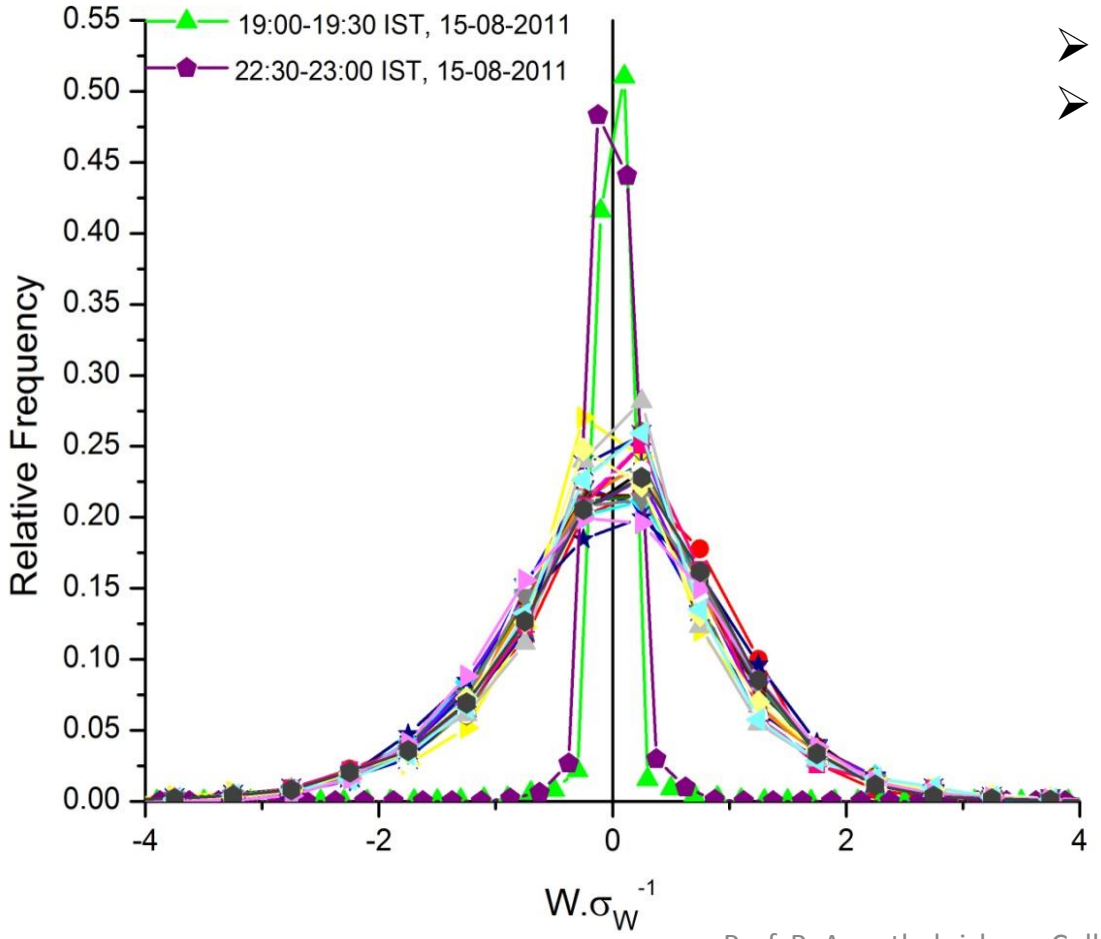


stable

intermittent

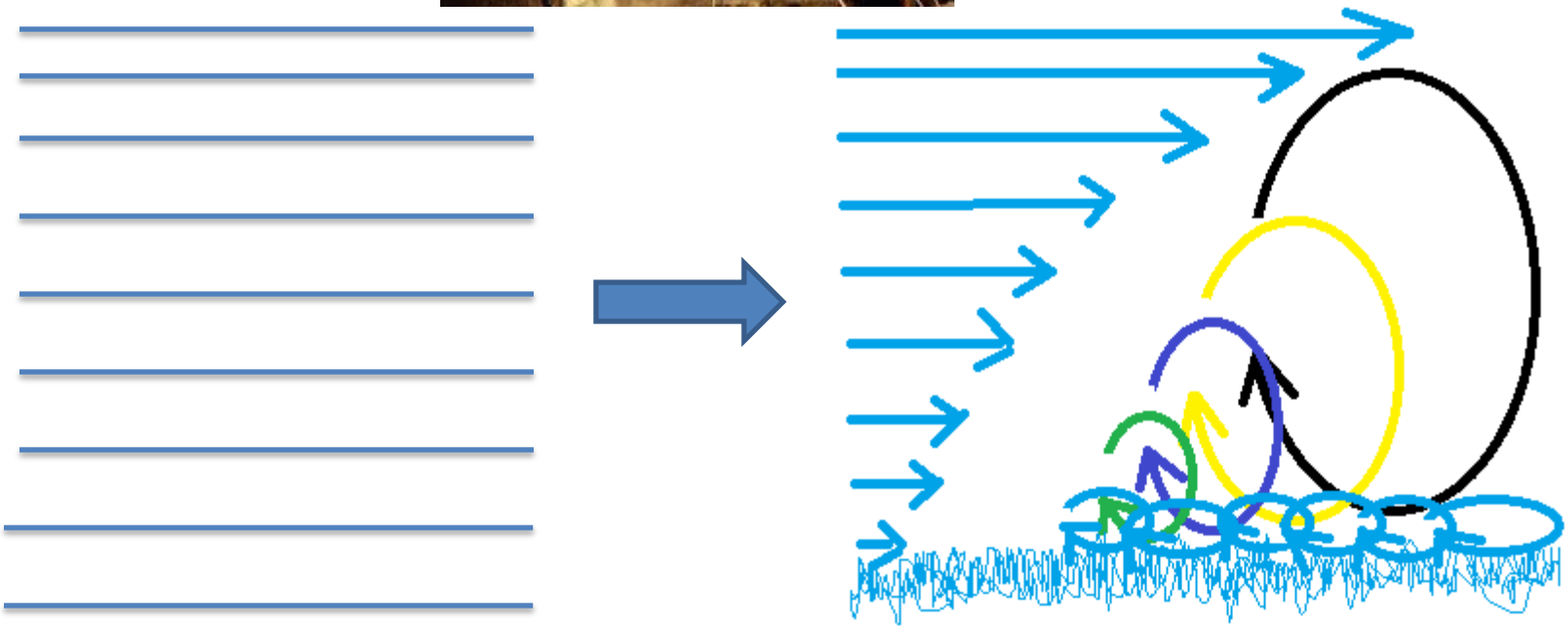

19:00 IST, 15-08-2011
Significant Level @ 19:00 IST, 15-08-2011
22:30 IST, 15-08-2011
Significant Level @ 22:30 IST, 15-08-2011
new definition of onset??
stable To intermittent transition
20:30 IST, 15-08-2011
Significant Level @ 20:30 IST, 15-08-2011
03:00 IST, 16-08-2011
Significant Level @ 03:00 IST, 16-08-2011
intermittent To stable transition
Average Variance (m2.s-2)
Time (IST)

Probability Distribution Function



- normalized by variance
- distribution deviates significantly during stable to intermittent transition periods


UPSIDE
DOWN



Conclusions

- NBL is **not as 'calm'** as claimed in literature i.e. Large-scale eddies are present in Monsoon NBL.
- These do not account for the mixing processes properly [56]. Present work explicitly shows **importance of turbulent eddies** during night-time for mixing and transport.
- LLJ plays crucial role in genesis of turbulence via strong mechanical shear and subsequent propagation downwards. This leads to an **upside-down boundary layer.** Intermittent nature of NBL can be attributed to the shear generated turbulence with the LLJ.
- Interaction among different scales of eddies have been studied. This shows generation of turbulence by LLJ in form of large-scale eddies. These in turn introduce smaller eddies in lower levels resulting in **energy-cascade**.
- Interesting features have been observed during stable to intermittent transition suggesting possibility of formulating a **new definition for onset of intermittence**.
- In this work **well-coherence is observed between TEI and Ri** in predicting the onset of intermittence unlike in Nakamura and Mahrt (2005)
- CAIPEEX-IGOC could provide integrated picture of the cloud layer NBL interactions.

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Thank You !

Cone of Influence (COI):

- Analysis is done in frequency domain. Fourier Transform (FT) is performed for position (r) to momentum (k) space transformation.
- Data is assumed to be cyclic.
- Edge-effects creep in.
- Padded to nearest power of zero.
- COI = e-folding time of auto-correlation of wavelet power at each scale.

Significant level:

- An appropriate back-ground for checking significance.
- White Noise: equal power at all frequencies.

Scale-averaging:

- Averaging of power (variance) within a range of scales
- Reconstructed time-series to look at relative contributions.