Gravity wave characteristics over equator observed during 1st CPEA campaign using simultaneous multiple station's data

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Radiosonde Campaign (Apr 10- May 9, 04)

① 6 hourly soundings for 30 days at
(5) EAR, (7) Bandung and (6) Jambi (6),
and 2-4 launches/day at (4) Padang.

②Enhanced soundings at routine sites of the Malaysia and Singapore Met. Office
3/day at (3) Singapore, and
4/day at (1) KL and (2) Kuching in Malaysia

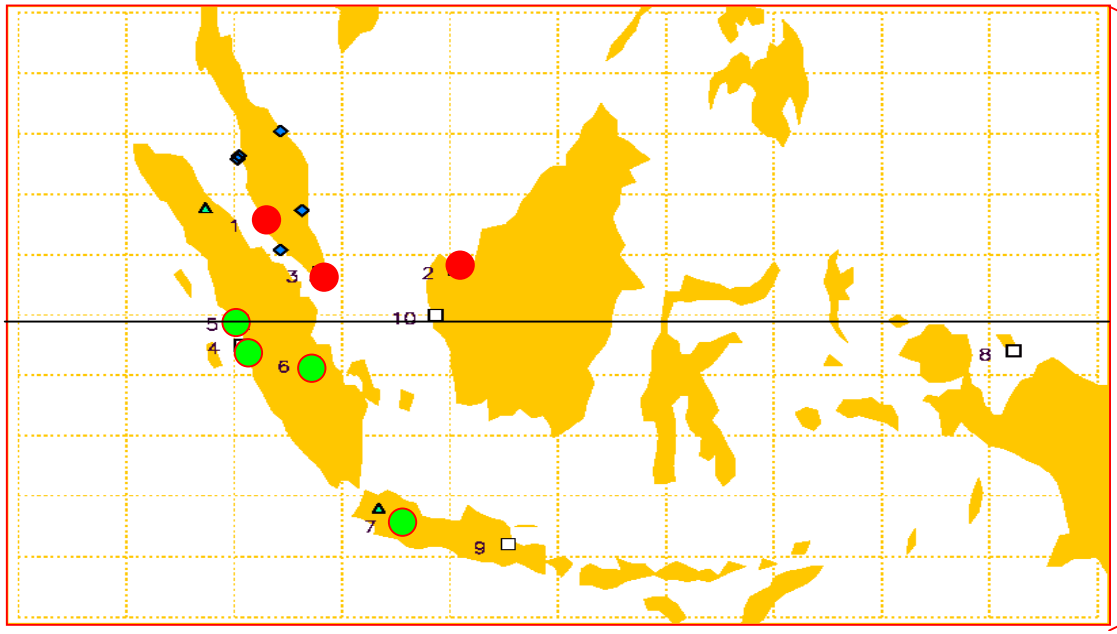
Intensive Soundings (April 18-23)

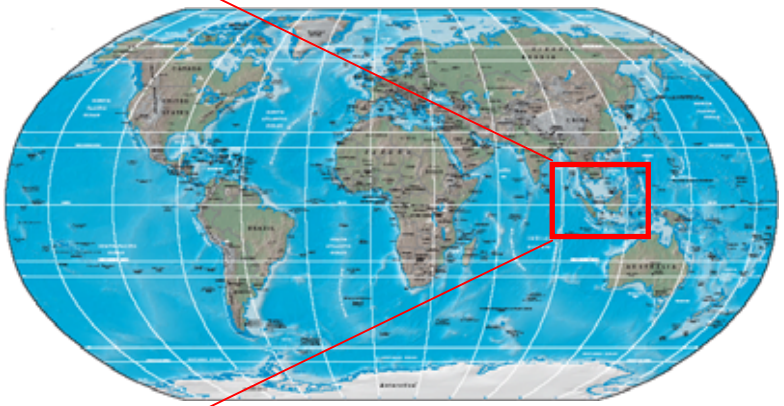
3 hourly soundings for 5 days at
(5) EAR, (4) Padang, (6) Jambi and (1) KL.

Radiosonde Launch Sites

(1) Kuala Lumpur (2.73N, 101.70E)
(Malaysia Met. Office)
(2) Kuching (1.48N, 110.33E)
(Malaysia Met. Office)
(3) Singapore (1.34N, 103.89E)
(Singapore Met. Office)

(4) Padang (0.88S, 100.35E)
(5) Koto Tabang (EAR) (0.2S, 100.32E)
(6) Jambi (1.63S, 103.64E)
(7) Bandung (6.89S, 107.59E)

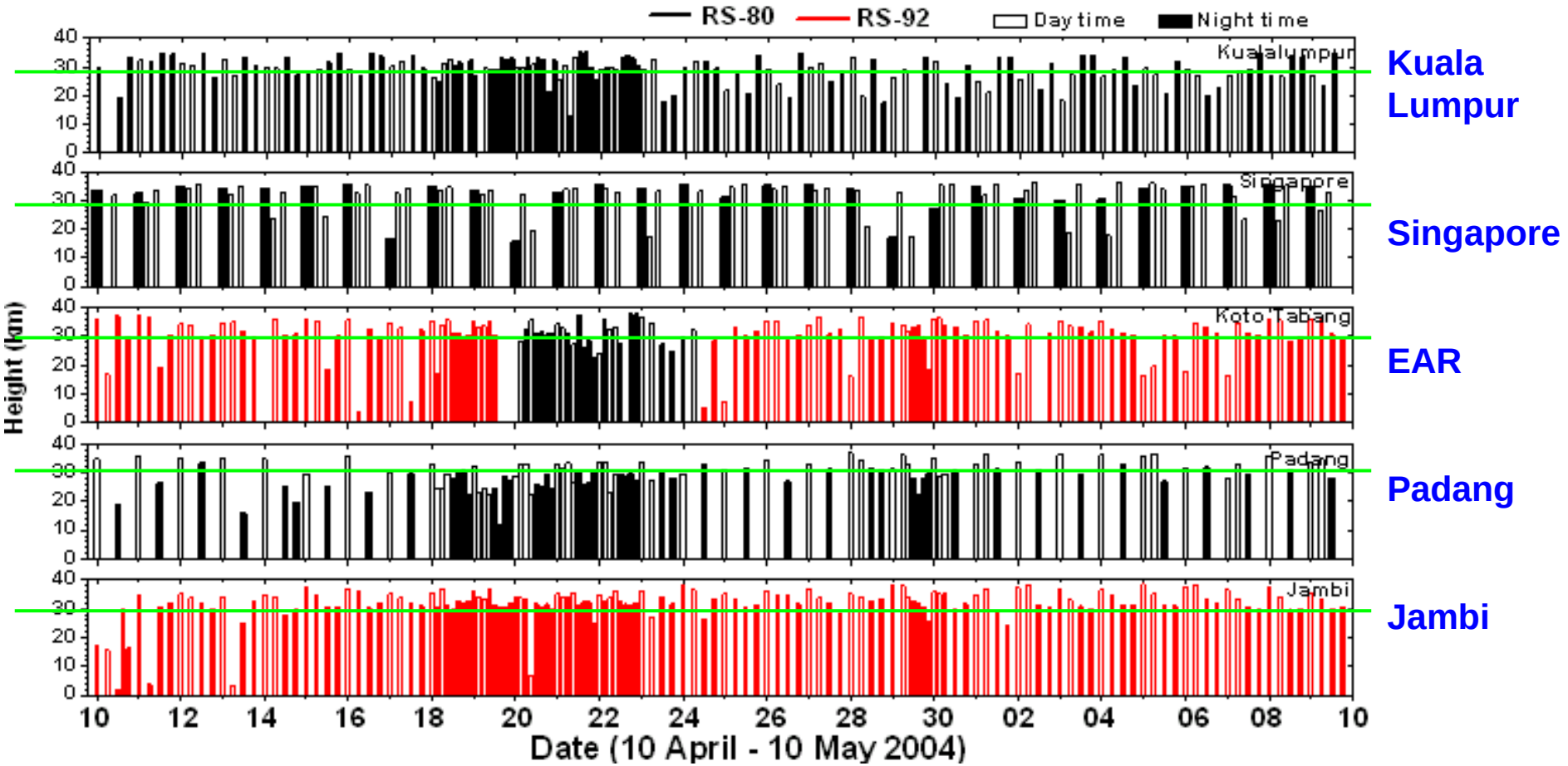




Balloon Burst Height

A total of 851 radiosondes were launched from 7 sites during the CPEA campaign. Balloon burst heights at 5 sites are shown below.

Site	H <16km	Total	H>25 km	H>30 km
KL	1	135	83.0%	48.1%
SG	1	81	85.4	79.8
KT	4	122	87.0	71.7
PD	2	103	84.1	50.5
JB	6	138	93.8	82.9
Total	14	615	86.6	66.6



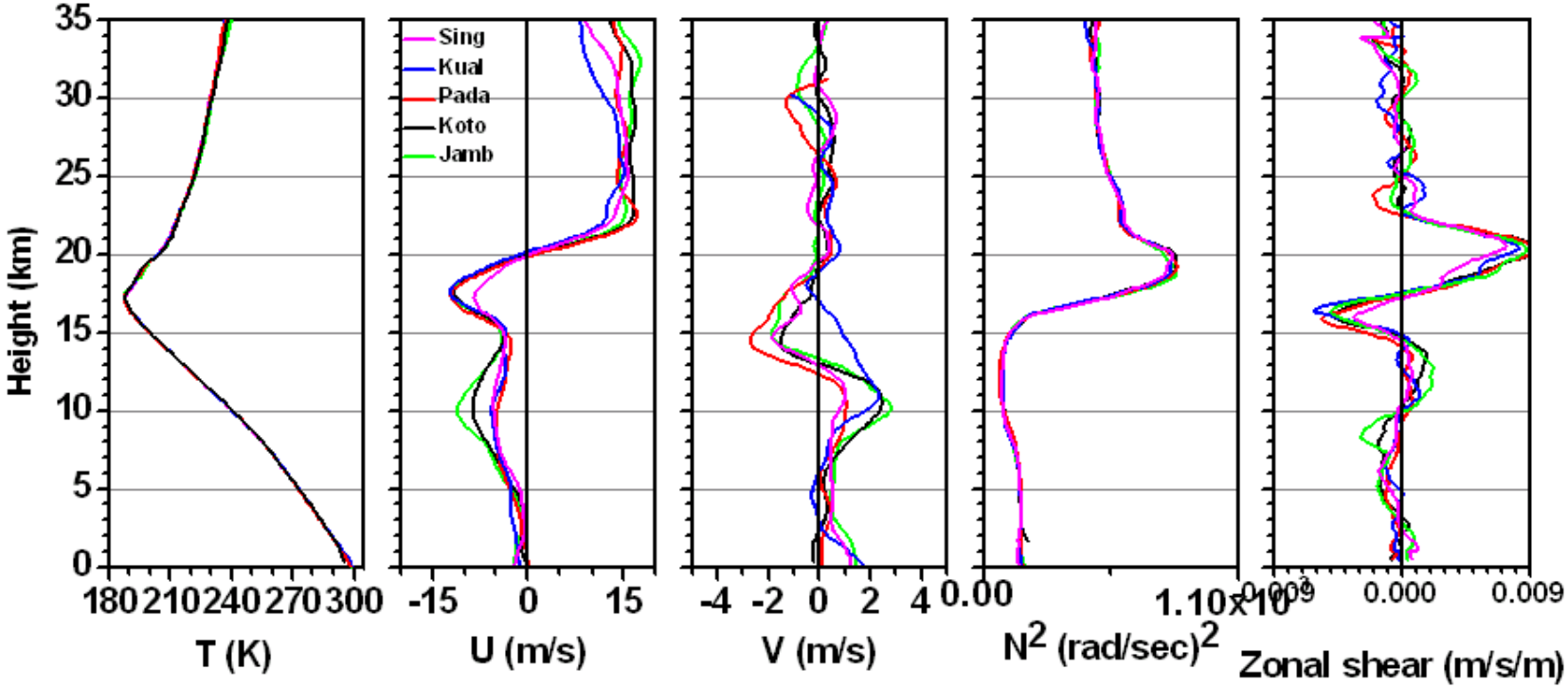
Background Meteorological Conditions

Tropopause
Ht: 17.5 km
Tp: 187.4K

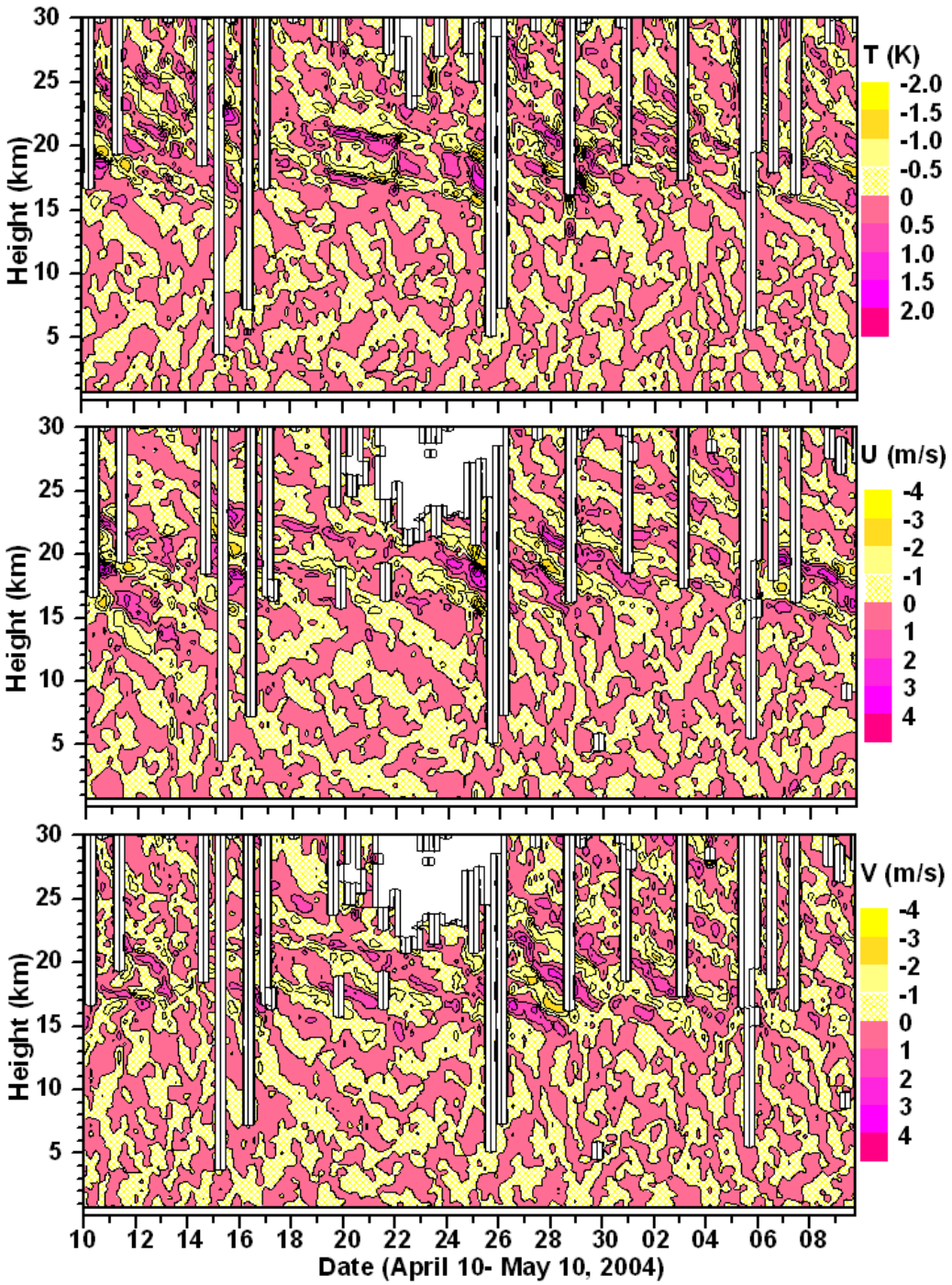
Zonal wind:
Westward<20km
~15m/s

Meridional wind:
Northward<12km
~3m/s

Zonal shear:
Peak at 22km



Mean vertical profiles of temperature (K), zonal wind (m/s), meridional wind (m/s), Brunt Vaisala Frequency square (rad/sec)2, and vertical shear of zonal wind (m/s/m) averaged over campaign period during CPEA conducted at five sites.



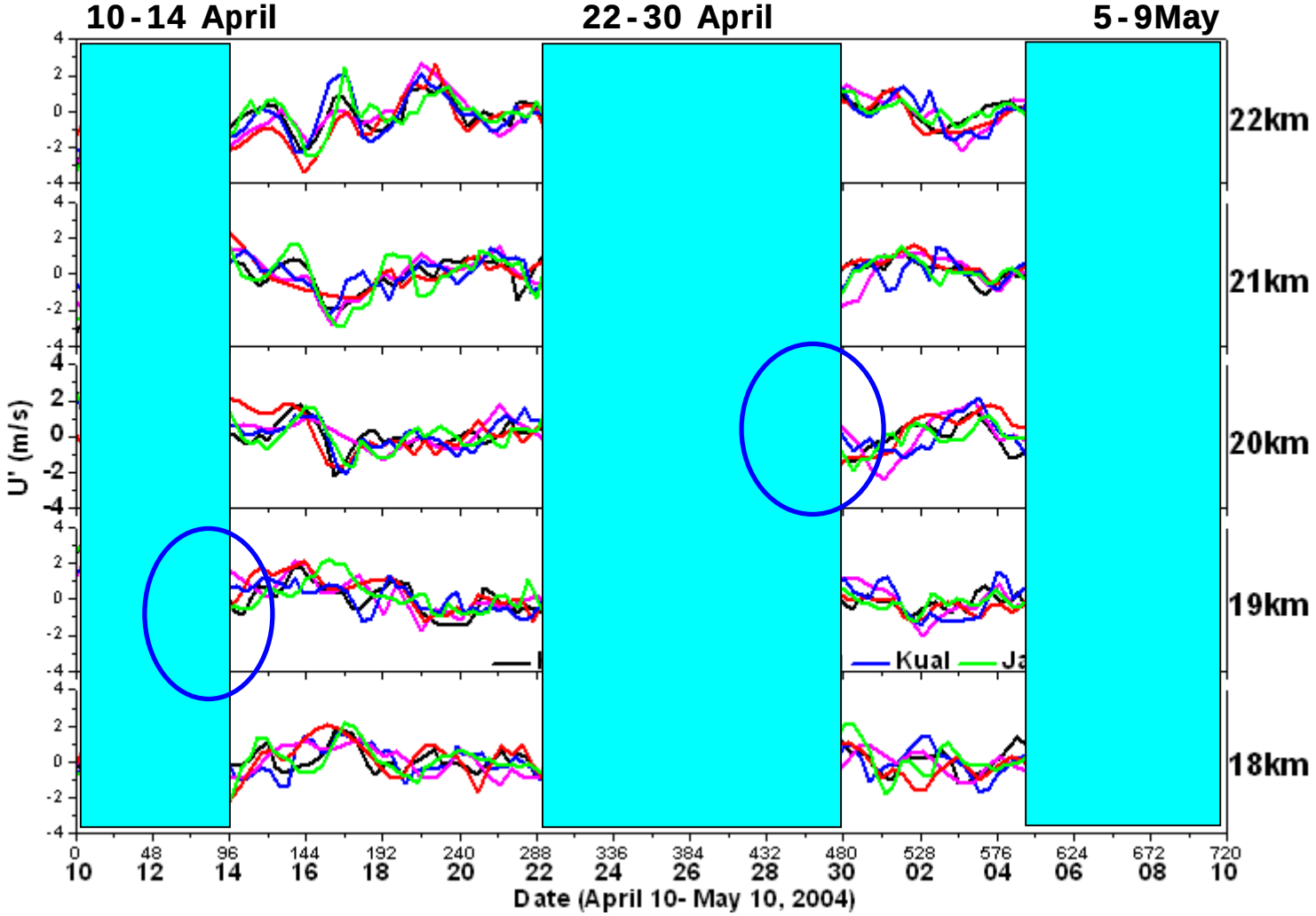
Wind velocity and Temperature Perturbations during the CPEA campaign at Koto Tabang

A high-pass filter (HPF) with a cutoff at 3 days along time, and a band-pass filter (BPF) with a pass-band of 1.5-5 km along altitude are applied to extract gravity waves.
(top) Temperature, T
(middle) Eastward wind velocity, u
(bottom) Northward wind velocity, v

In the Stratosphere, gravity waves with downward phase propagation (upward energy propagation) are clearly seen, which are concistent between T, u and v.

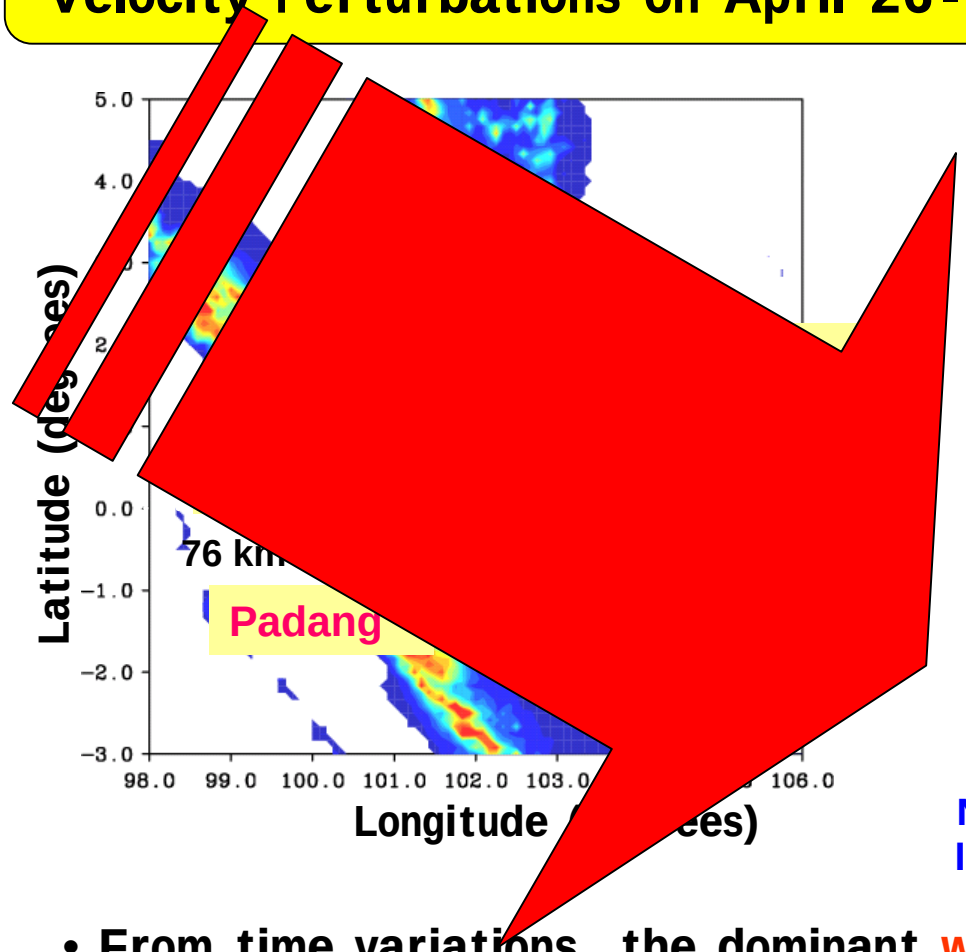
Both upward and downward pahse propagations coexisted in the troposphere.

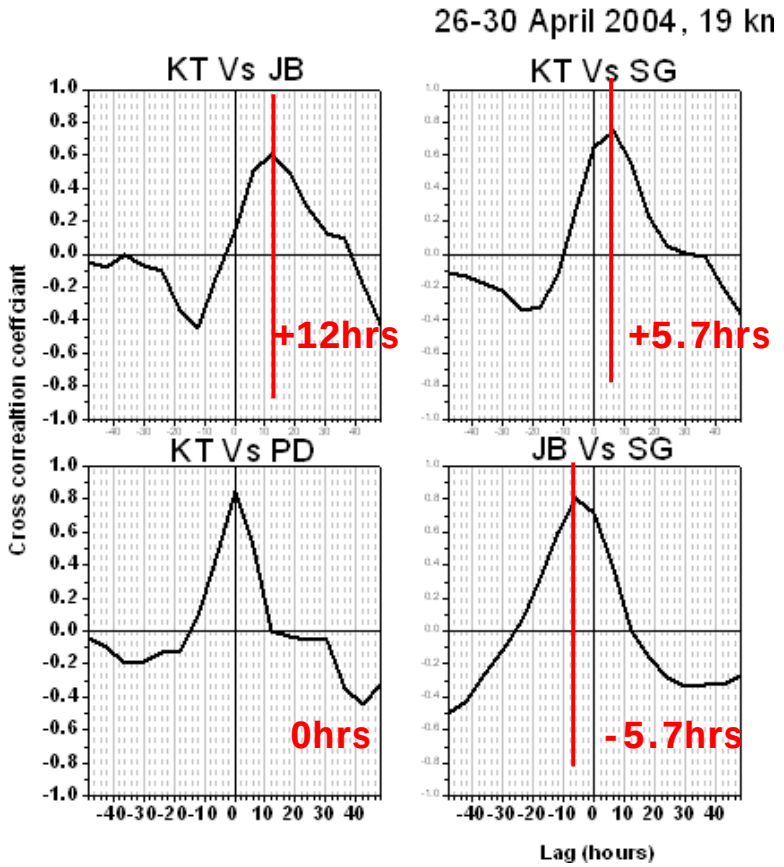
Time variations of zonal wind velocity observed at 5 nearby radiosonde sites



- Oscillations with the dominant periods of 2-3 days are detected, and the enhancement particularly occurred on 10-14 April, 22-30 April and 5-9 May.
- Overall structures resemble each other among the 5 launch sites, although slight phase shift can be seen probably due to the horizontal propagation of the waves.

Cross Correlation Analysis of Wind Velocity Perturbations on April 26-30





No lag between KT and PD or KT and KL, but KT is leading SG and JB, while JB is lagging SG and KL

- From time variations, the dominant wave period is estimated as 48 hrs.
- A CCF analysis between two sites provides a phase delay, then, an apparent horizontal wave length can be inferred.
- Using all combination of the CCF analysis among the 5 stations, we determined the horizontal propagation direction as -30 deg from East and the horizontal wave length as 1,700 km.

CCF ANALYSIS

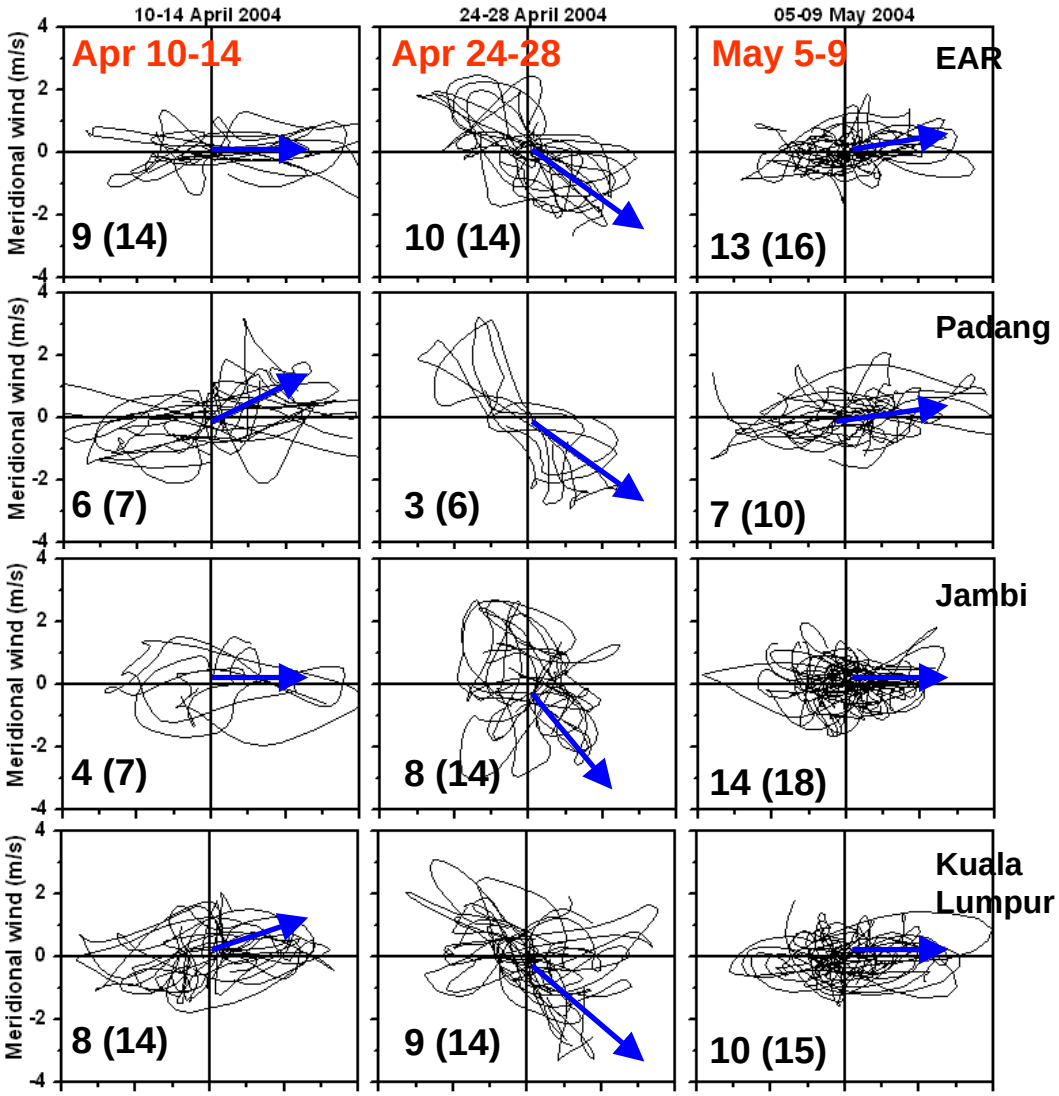
(a)	(b)	(c)
April 10-14	April 26-30	May 5-9
+ 26° from E	- 30° from E	+ 3° from E
λ_H=2,700 km	λ_H=1,700 km	λ_H=3,250 km

HODOGRAPH ANALYSIS

The preferential direction of the wave propagation is inferred by using a hodograph on April 10-14, 24-28 and May 05-09 at 17-23 km.

The arrow indicates the mean direction of the wave propagation averaged for all of available hodographs showing a clear ellipsoid.

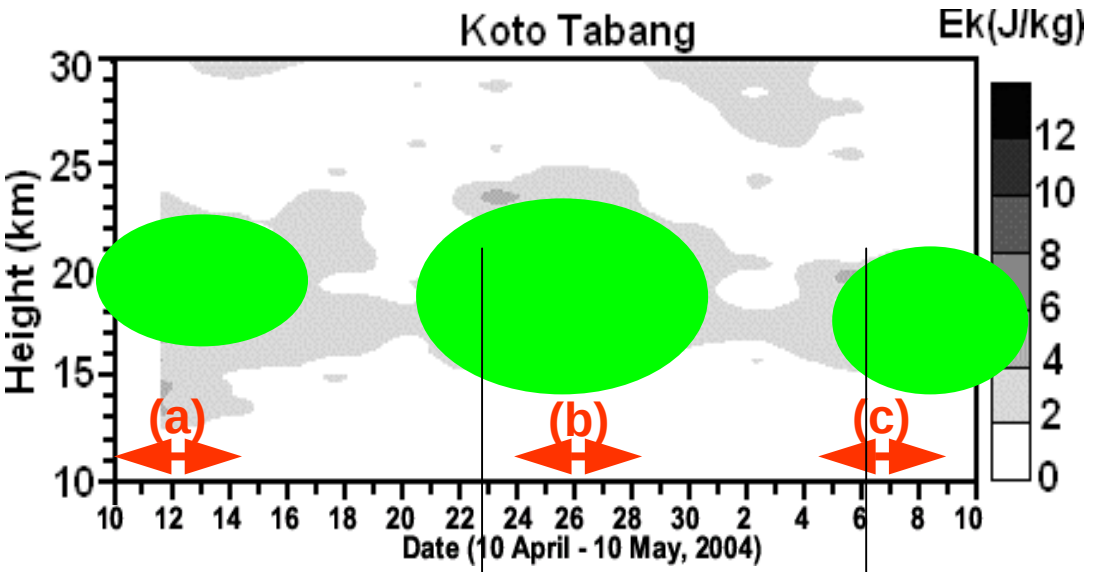
Number in each panel is the number of hodographs out of the total profiles.

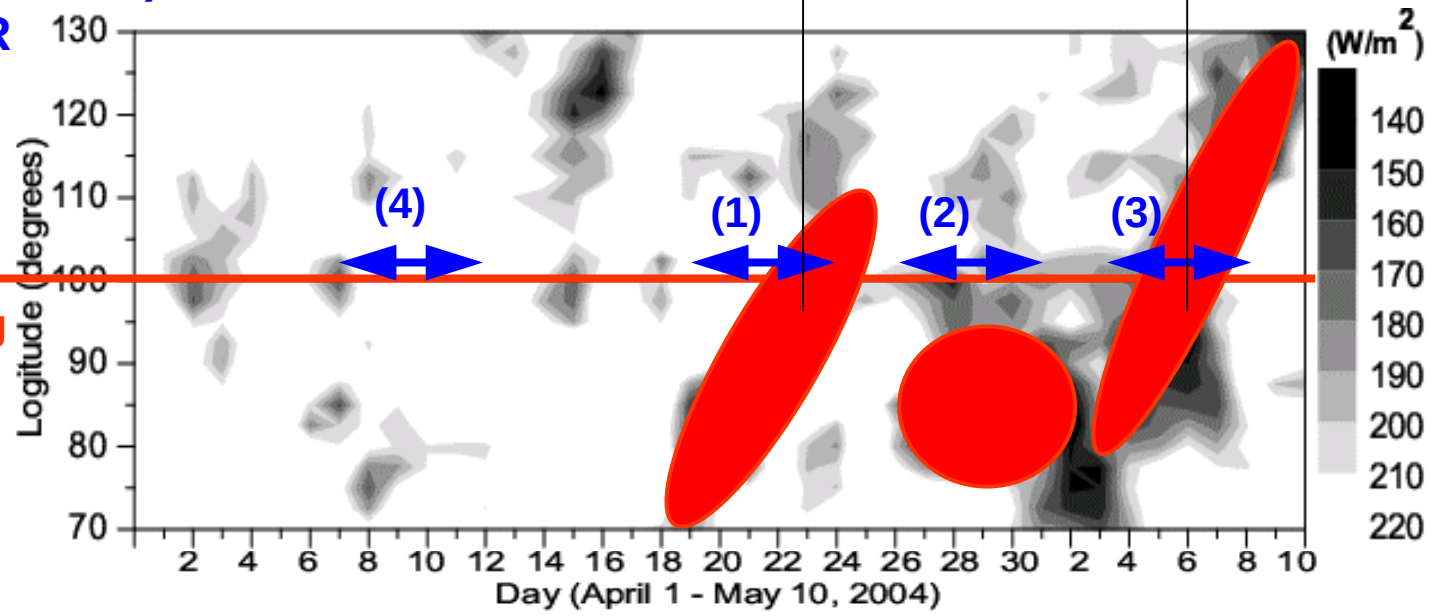


Distribution of Gravity Wave Energy and Cloud Convection

Time-height distribution of gravity wave energy (E_k, wind velocity variance) over EAR site with radiosondes

Time-longitude distribution of OLR (cloud convection) around EAR

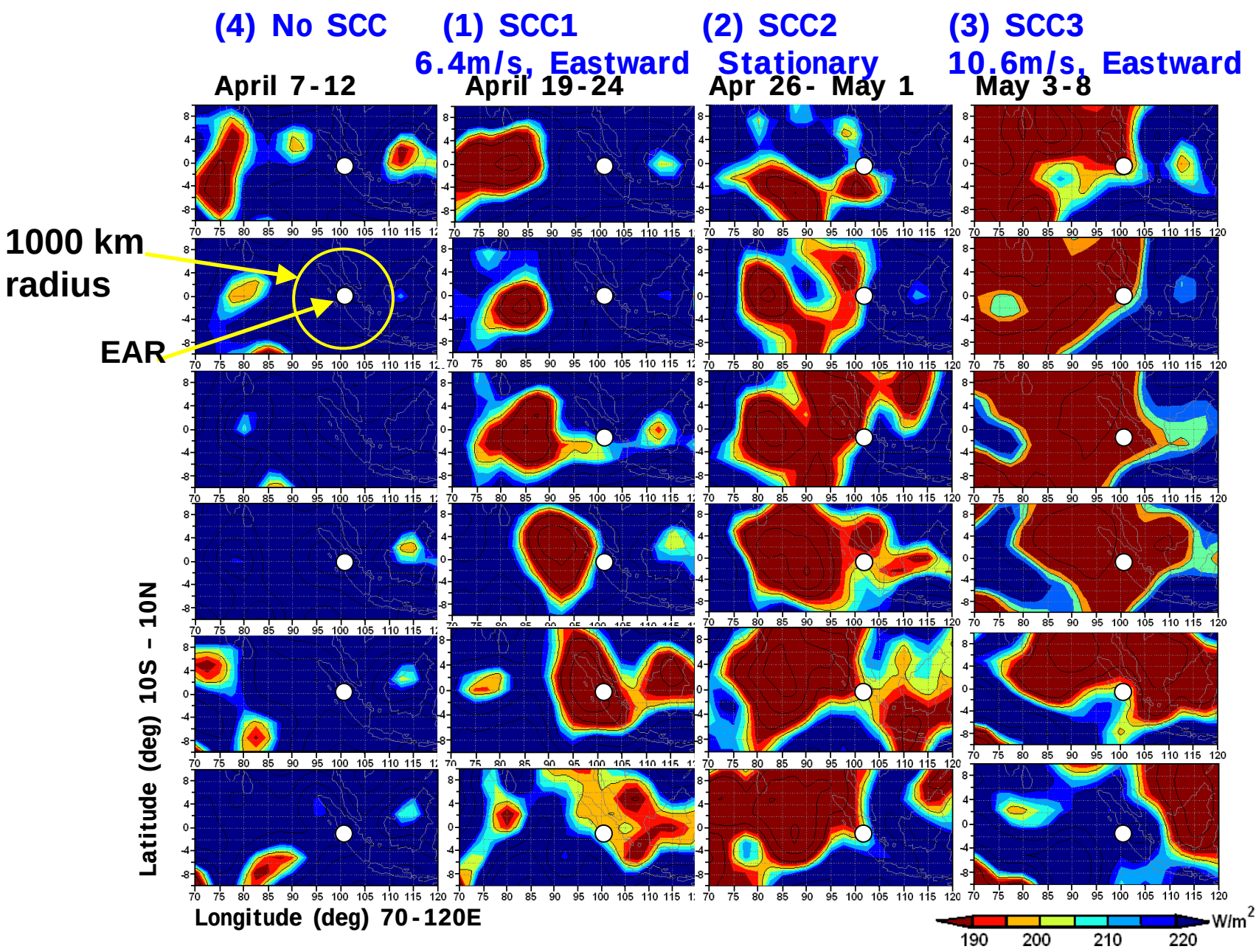


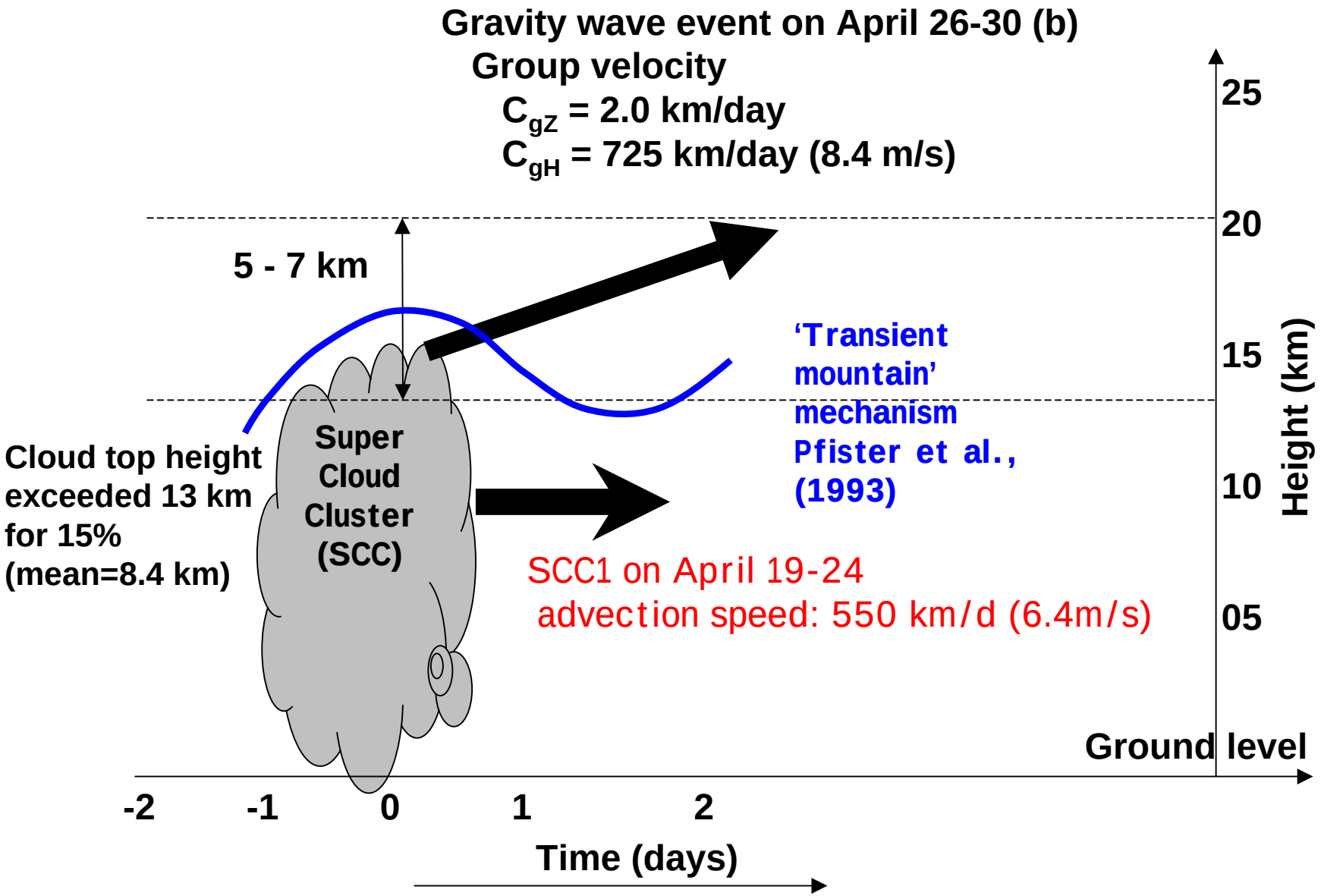


$$E_k = \frac{1}{2}\left[\overline{u'^2} + \overline{v'^2}\right]$$

OLR: 2.5°N & S

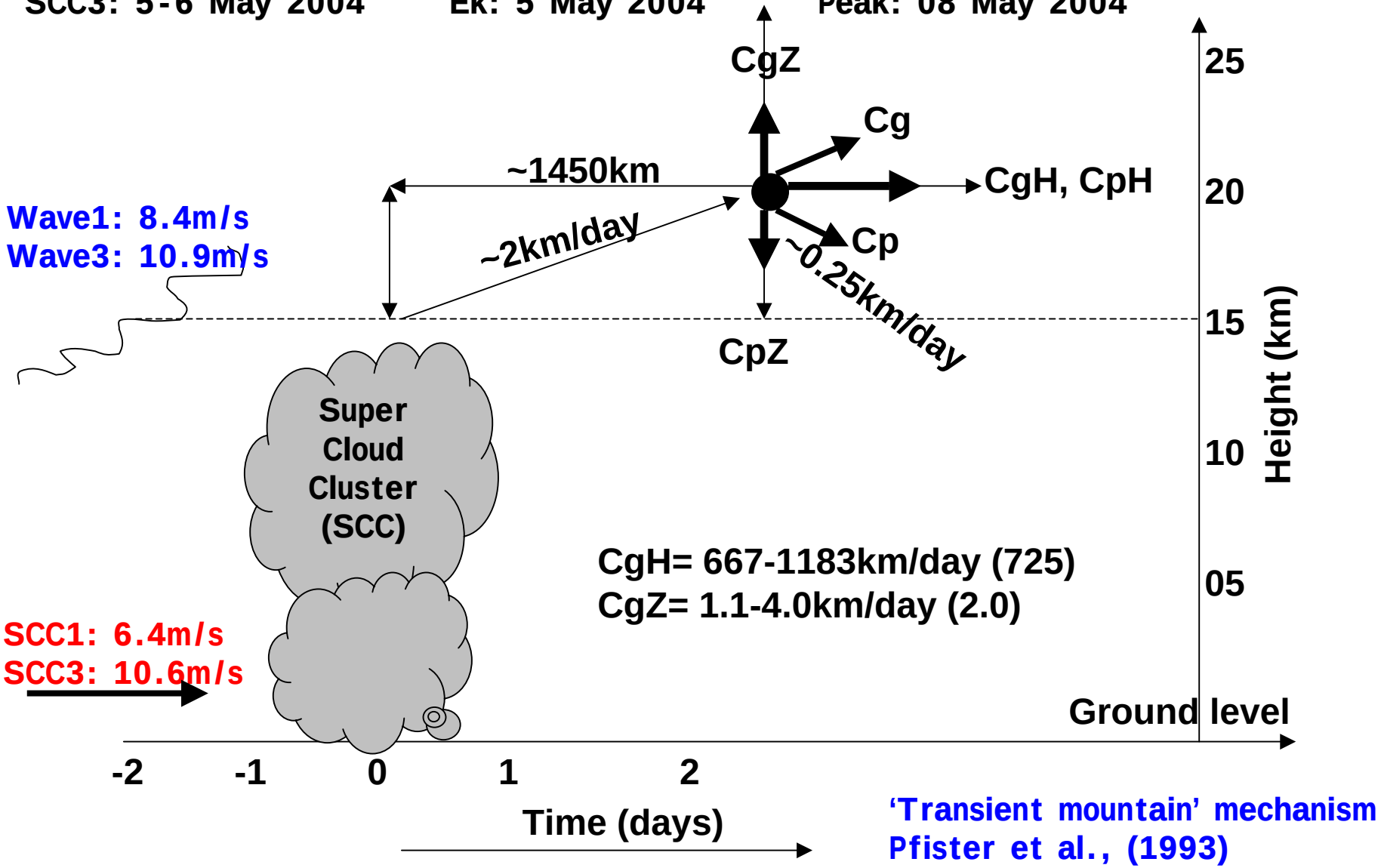
Distribution of Super Cloud Cluster (SSC) inferred from OLR




Gravity wave event on April 26-30 (b)
Group velocity
C_{gZ} = 2.0 km/day
C_{gH} = 725 km/day (8.4 m/s)
5 - 7 km
'Transient mountain' mechanism Pfister et al., (1993)
Cloud top height exceeded 13 km for 15% (mean=8.4 km)
Super Cloud Cluster (SCC)
SCC1 on April 19-24
advection speed: 550 km/d (6.4m/s)
25
20
15
10
05
Height (km)
Ground level
-2
-1
0
1
2
Time (days)

Summary of GW characteristics

SCC0:	No cloud	Ek: 11 April 2004	Peak: 12 April 2004
SCC1:	23-24 April 2004	Ek: 22 April 2004	Peak: 26 April 2004
SCC2:	29 April 2004	No	No
SCC3:	5-6 May 2004	Ek: 5 May 2004	Peak: 08 May 2004

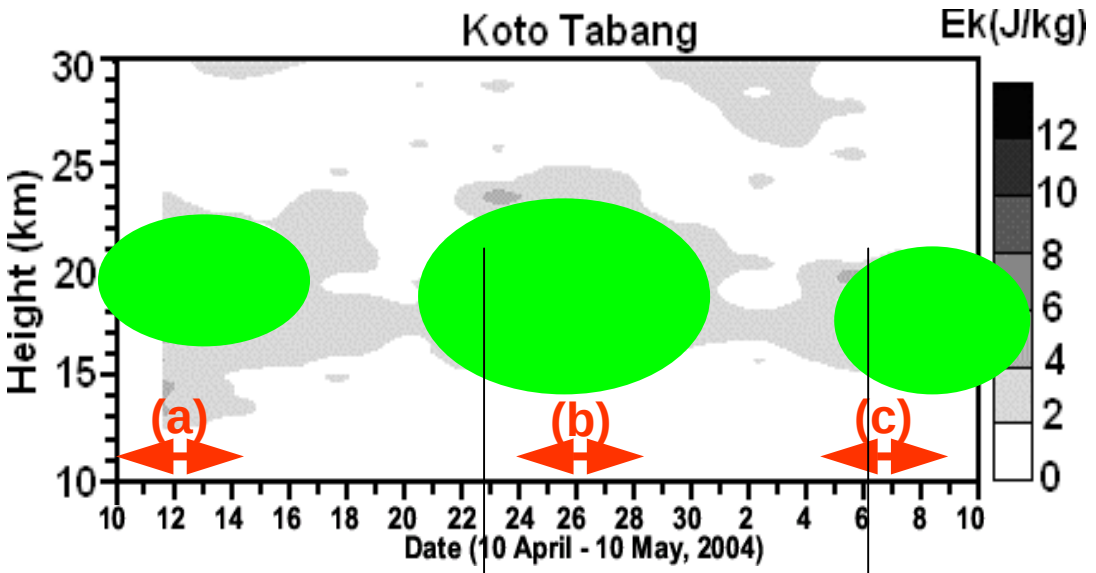


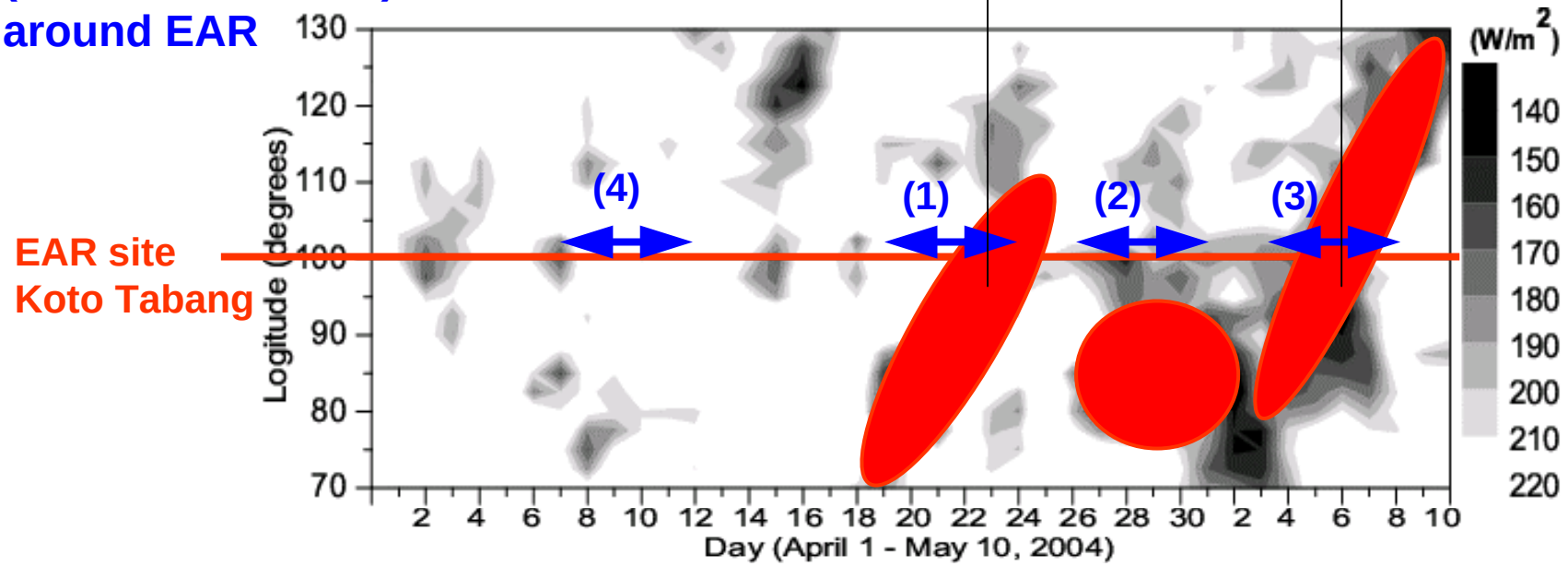
'Transient mountain' mechanism
Pfister et al., (1993)

Distribution of Gravity Wave Energy and Cloud Convection

Time-height distribution of inertia-gravity wave energy (wind velocity variance) over EAR site with radiosondes

Time-longitude distribution of OLR (cloud convection) around EAR





SUMMARY

- The behavior of inertia-gravity waves is analyzed by means of an intensive radiosonde campaign conducted in April-May, 2004 at 5 sites around Equatorial Atmosphere Radar (0, 100.3E) in Indonesia.

- Dominant gravity waves (periods: 2-3 days, vertical wavelengths: 3-5 km) were detected in the upper troposphere and lower stratosphere (UTLS) region, although the event was not entirely continuous, but intermittent.

- For individual wave event, the wave structure was similar at all 5 sites, having a slight phase shift, i.e., the horizontal extent of the wave is larger than the distance between the balloon launch sites (75-400km).

- For the event on April 26-30, 2004, a correlative analysis is applied to determine the horizontal wave length (1,700km) and propagation direction (30^{o} south from East), which are verified by hodograph analysis. On April 10-14 and May 5-9, the wave parameters were 2,700 km/3,250 km and 26^{o}/3^{o} north from the east, respectively.

- Generation of (eastward propagating) gravity waves seems to be related to Super Cloud Cluster (SCC) characterized by eastward advection from the Indian Ocean to the maritime continent. The gravity waves reaching over EAR seem to be generated far distant sources over Indian ocean.

- However, stationary convection was not associated with a stratospheric gravity wave event. In addition, we found a case in which the wave activity did not correspond to particular cloud convection.

Unexplained issues…….

- **During the case of SCC2, the enhancement in the wave activity has not been noticed perhaps due to waves that generated do not propagate towards the observational sites although the convective centers are noticed to be stationary. It is not known whether there exists any connection between the motion of the convective centers and the propagation direction of the gravity waves.**

- **Another enhancement in the wave activity is noticed during 10-14 April 2004 but not connected to any particular cloud convection. Although observations from X-band radar reflectivity suggest that there exists strong reflectivity over Koto Tabang during 7-8 April 2004, however, it is though not to be generated by local convection since the horizontal extent of this wave activity is also large enough as it was observed more or less similar at all the sites.**

OLR Proxy, Good enough always?

- **The results are presented qualitatively here and demands further research showing more cases, in particular, showing the relation between the propagation direction of the gravity waves and motion of the sources, in order to quantify the observed process by both observations and modeling.**