2.2

Lecture 2.2 Vertical Scaling

'Vertical' observations from GPS dropsondes released by the NOAA Gulfstream 4 aircraft, and ascents and descents from the G4 and the NASA WB57F.

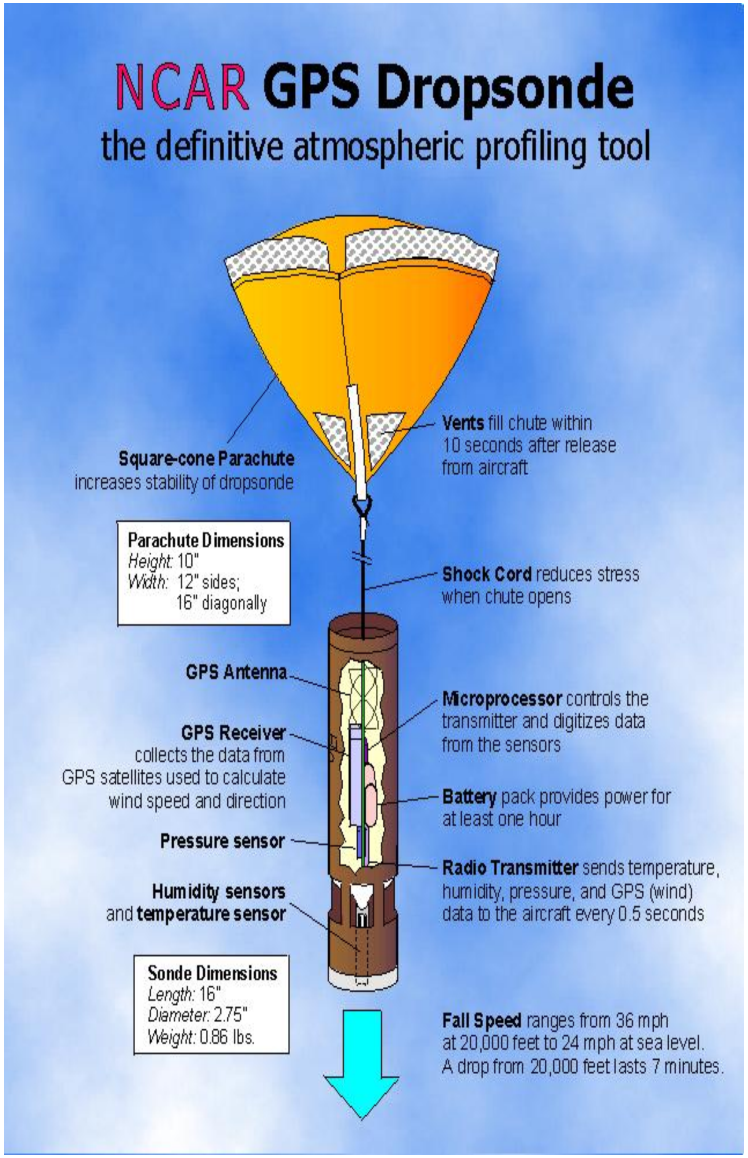
Recall theoretical prediction: $H_{\mathrm{vertical}} = 3/5$

NOAA Gulfstream 4

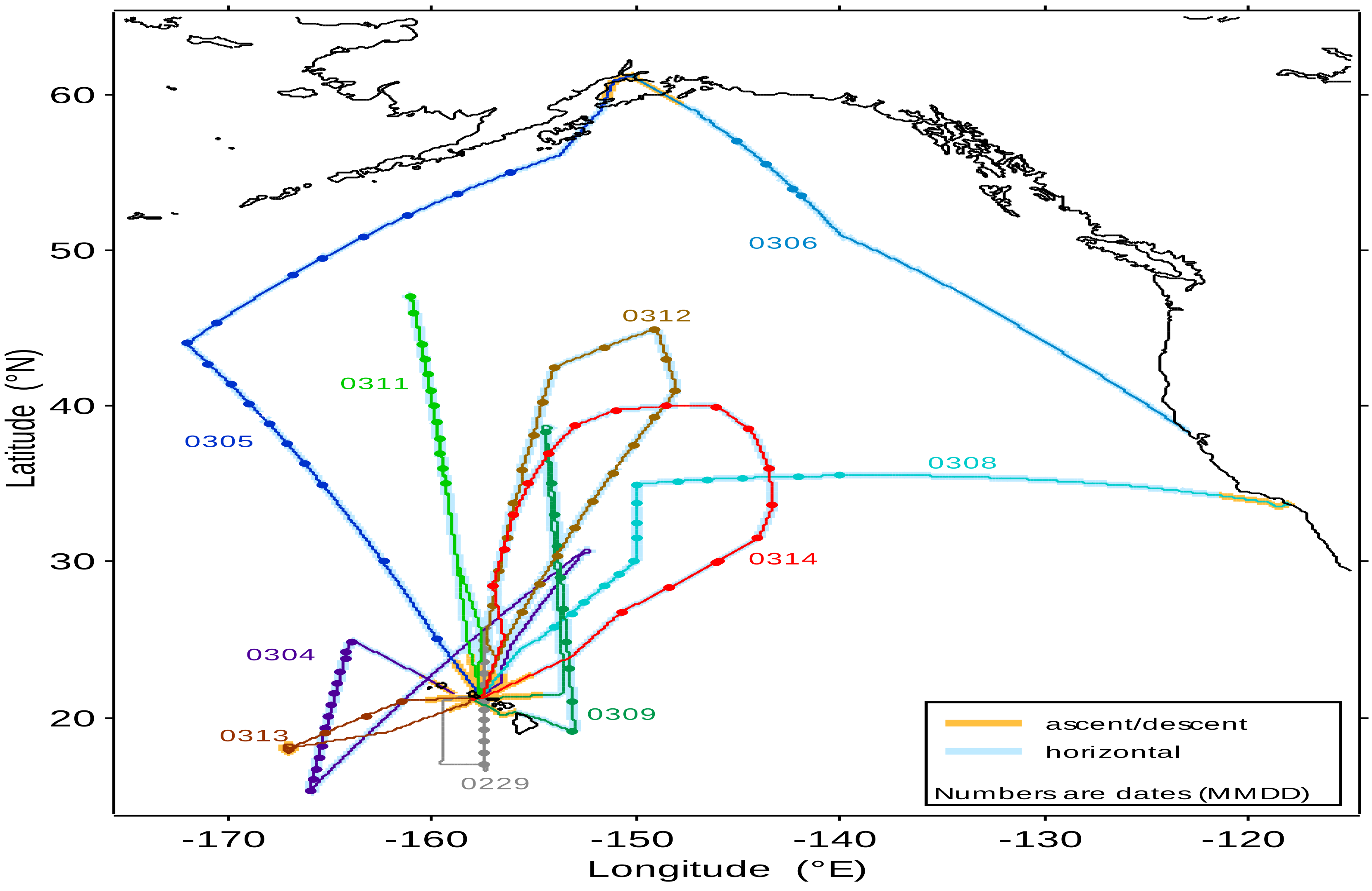
Dropsonde

GPS Dropwindsonde Specifications

	Operate	Accur-acy	Resolu-tion	Time Const.	Typ. Error
Pressure	1060-20mb	0.5mb	0.1mb	<0.01 sec	1.0mb
Temperature	-90 to 45°C	0.2°C	0.1°C	2.5 to 3.7 s	0.2°C
Humidity	0 to 100%	2.0%	0.1%	0.1 to 10 sec	<5%
Winds	0 to 150 m/s	0.5 m/s	0.1 m/s		0.5 to 2.0ms

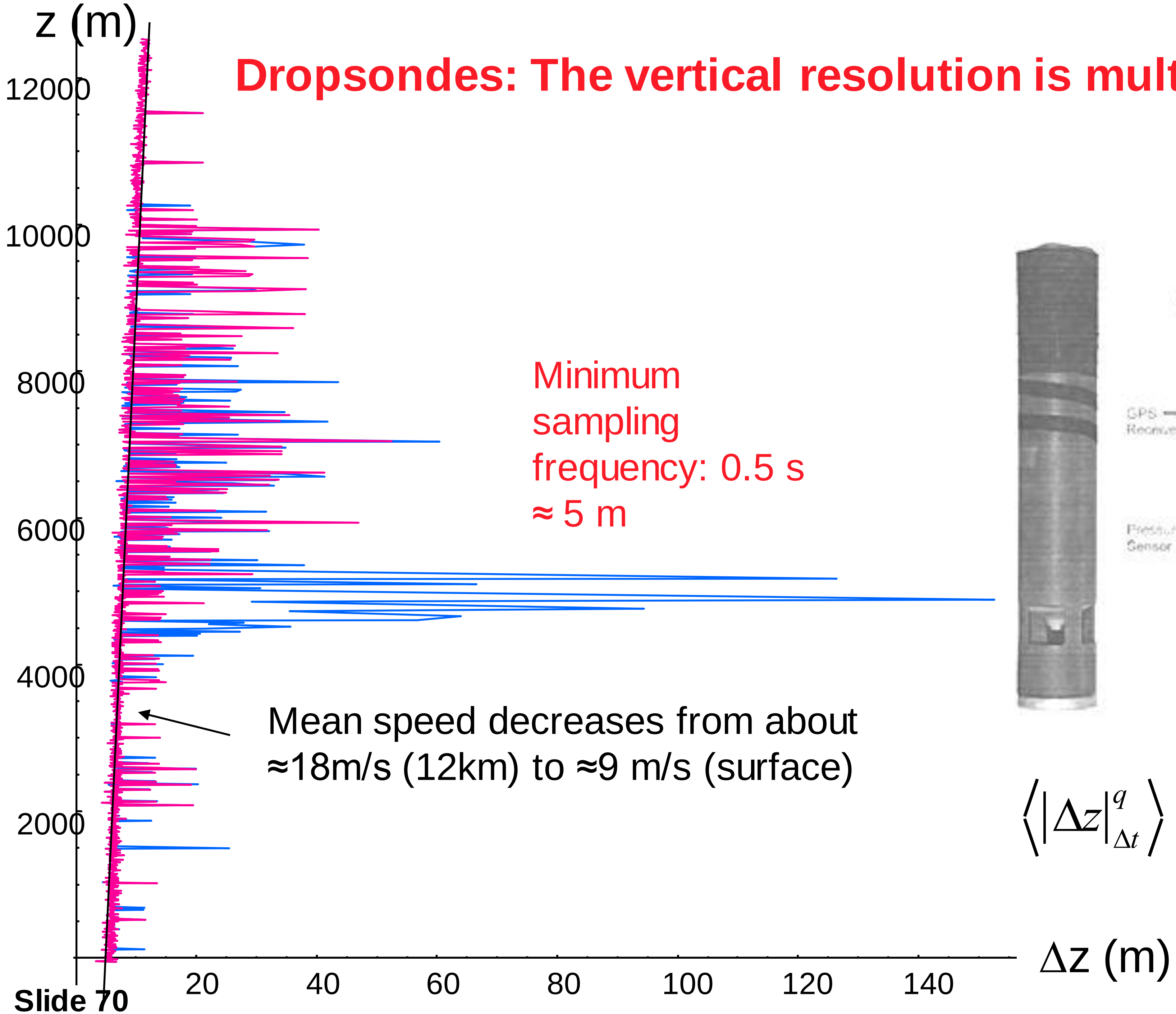


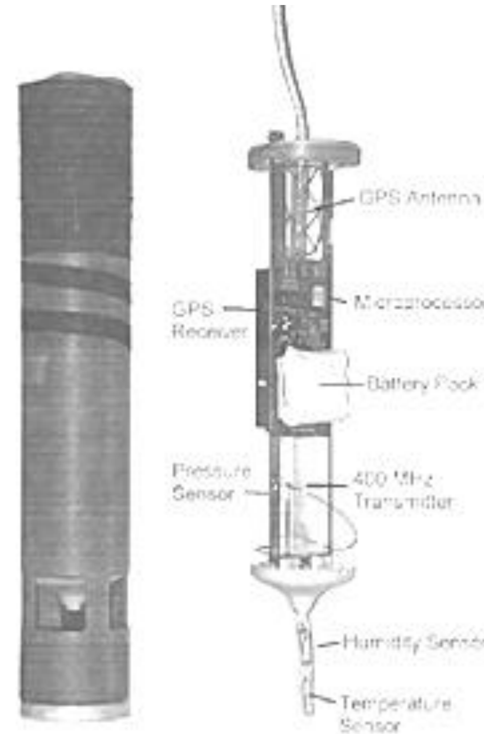
Winter Storms 2004229 - 20040314



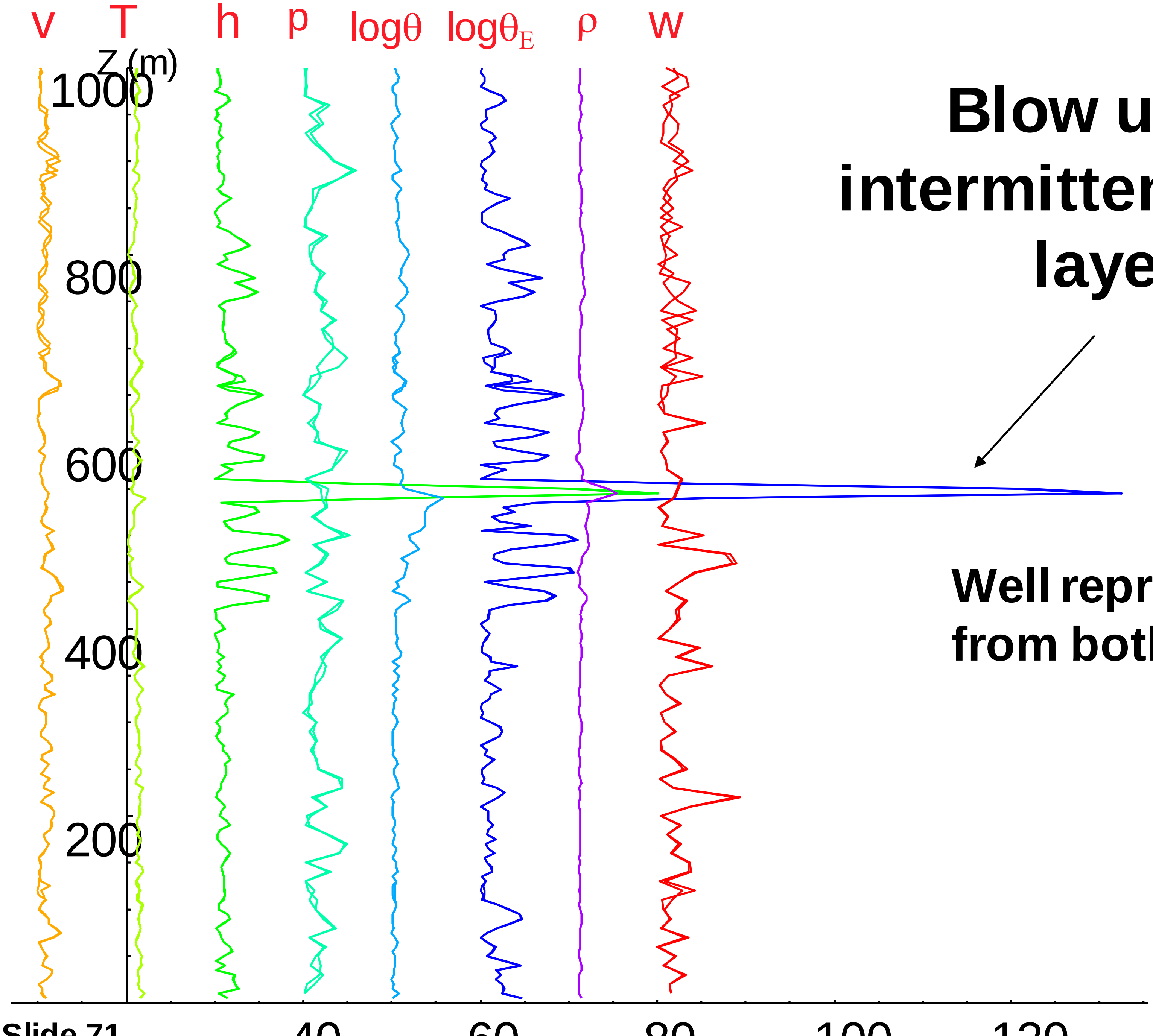
Slide 69

Dropsondes: The vertical resolution is multifractal





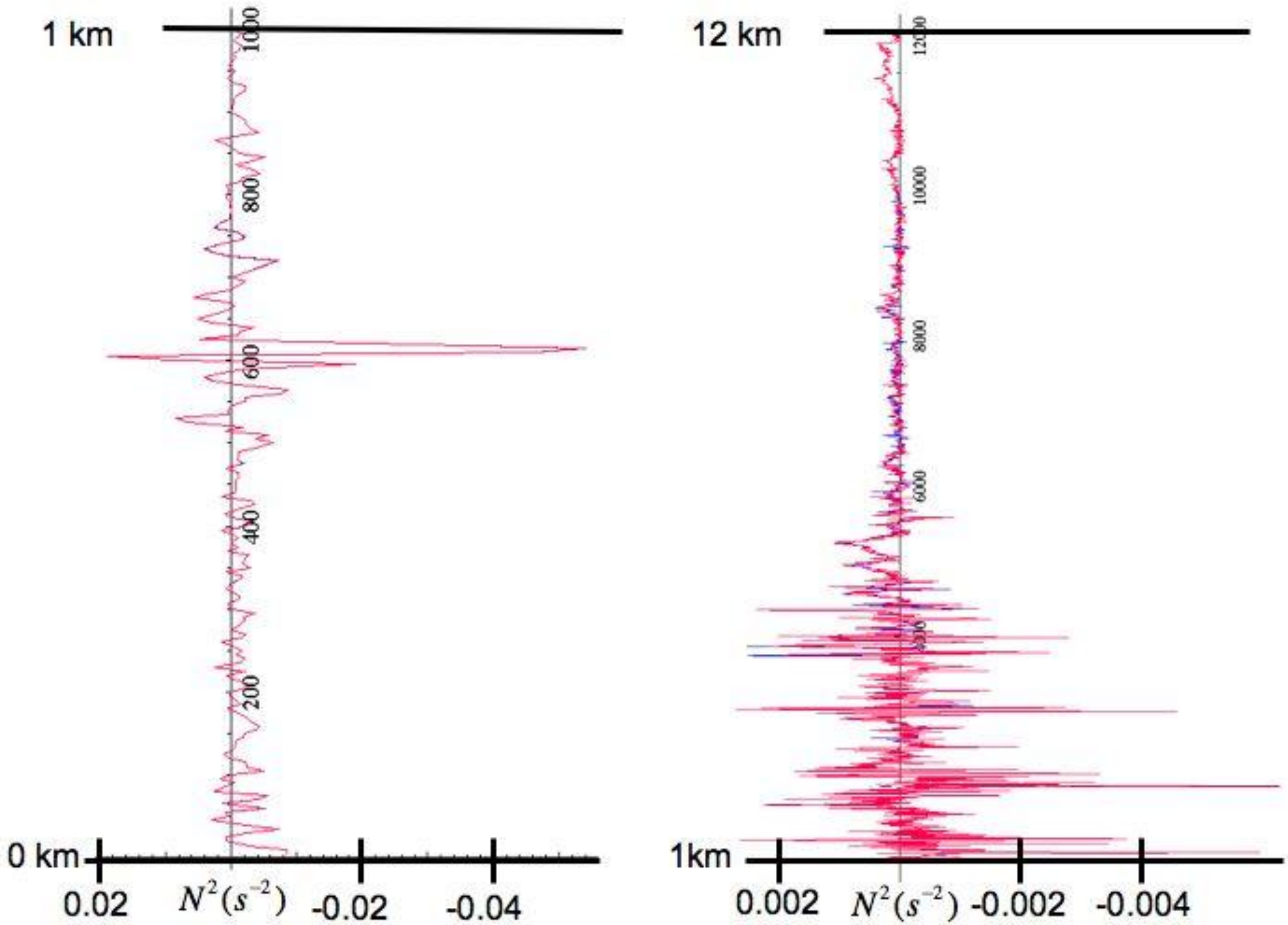
$$\left\langle \left| \Delta z \right|_{\Delta t}^{q} \right\rangle \approx \Delta t^{-\varphi(q)}$$



Blow up of intermittent lower layer

Well reproduced from both sondes

Dynamic stability: marine boundary layer, troposphere



Potential Temperature, θ

- **θ is an alternative vertical coordinate in meteorology.**

- **It is the temperature an air element would have if it was brought adiabatically to the surface.**

$$S = C_p \ln\theta + \text{constant}$$

where *S* is entropy

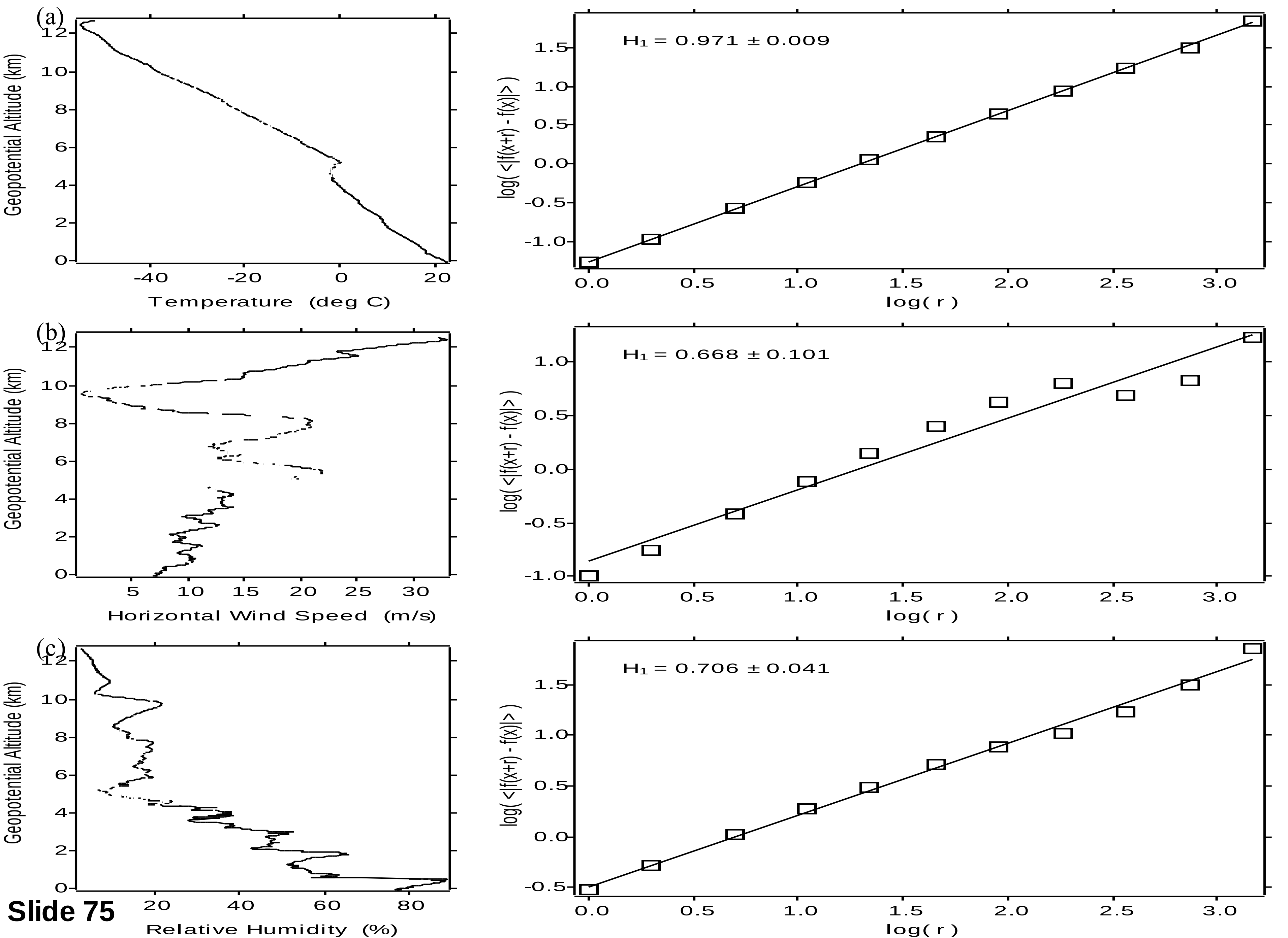
Generalised Scale Invariance: Exponents

- H Hurst or conservation exponent ($0<H<1$)
- C_1 intermittency exponent ($0<C_1<1$)
- α multifractality exponent ($0<\alpha<2$)

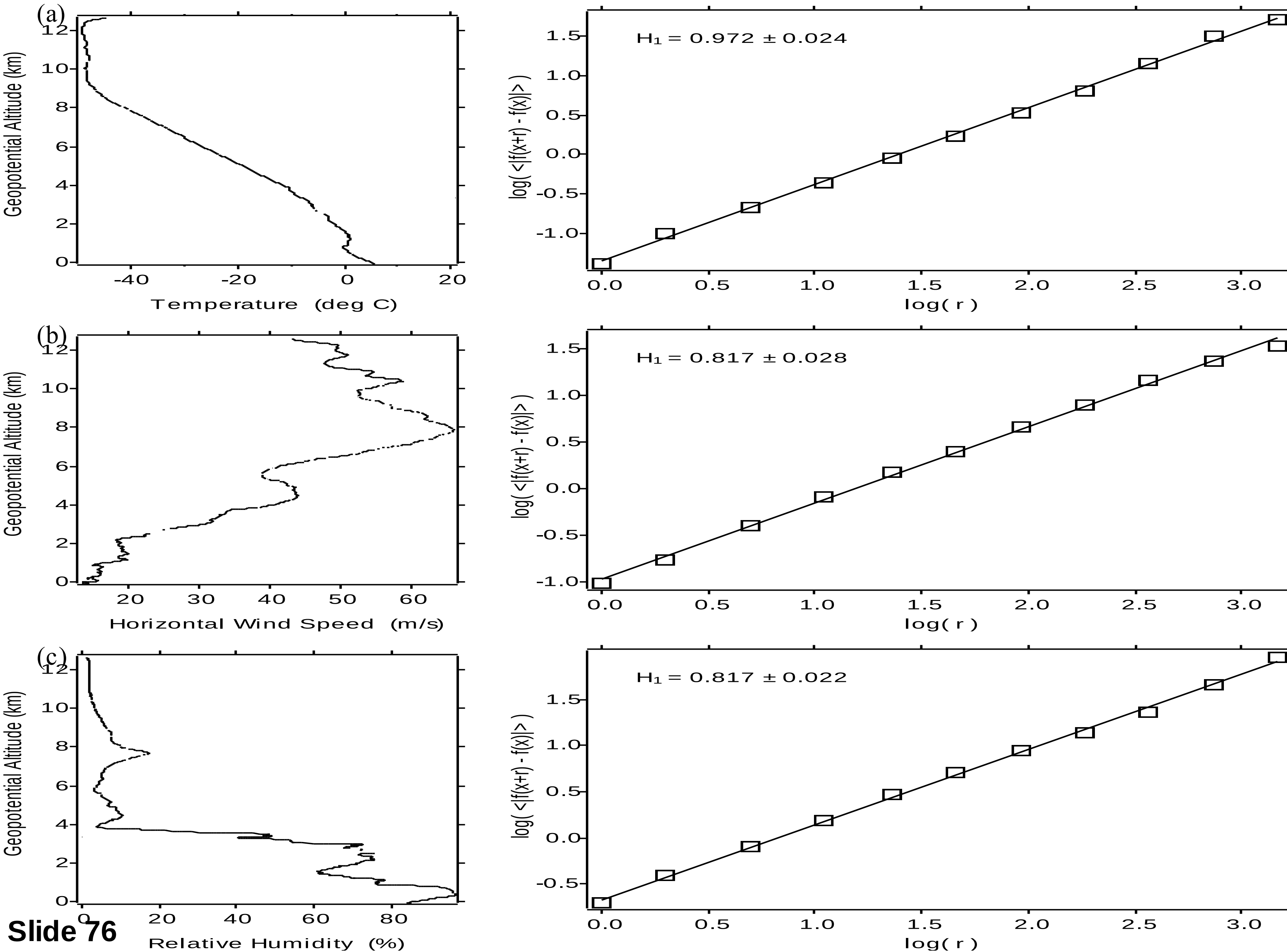
*Atmosphere has $H = 0.56$, $C_1 = 0.05$, $\alpha = 1.6$ from horizontal aircraft observations.

*Gaussian has $H = 0.5$, $C_1 = 0$, $\alpha = 2$

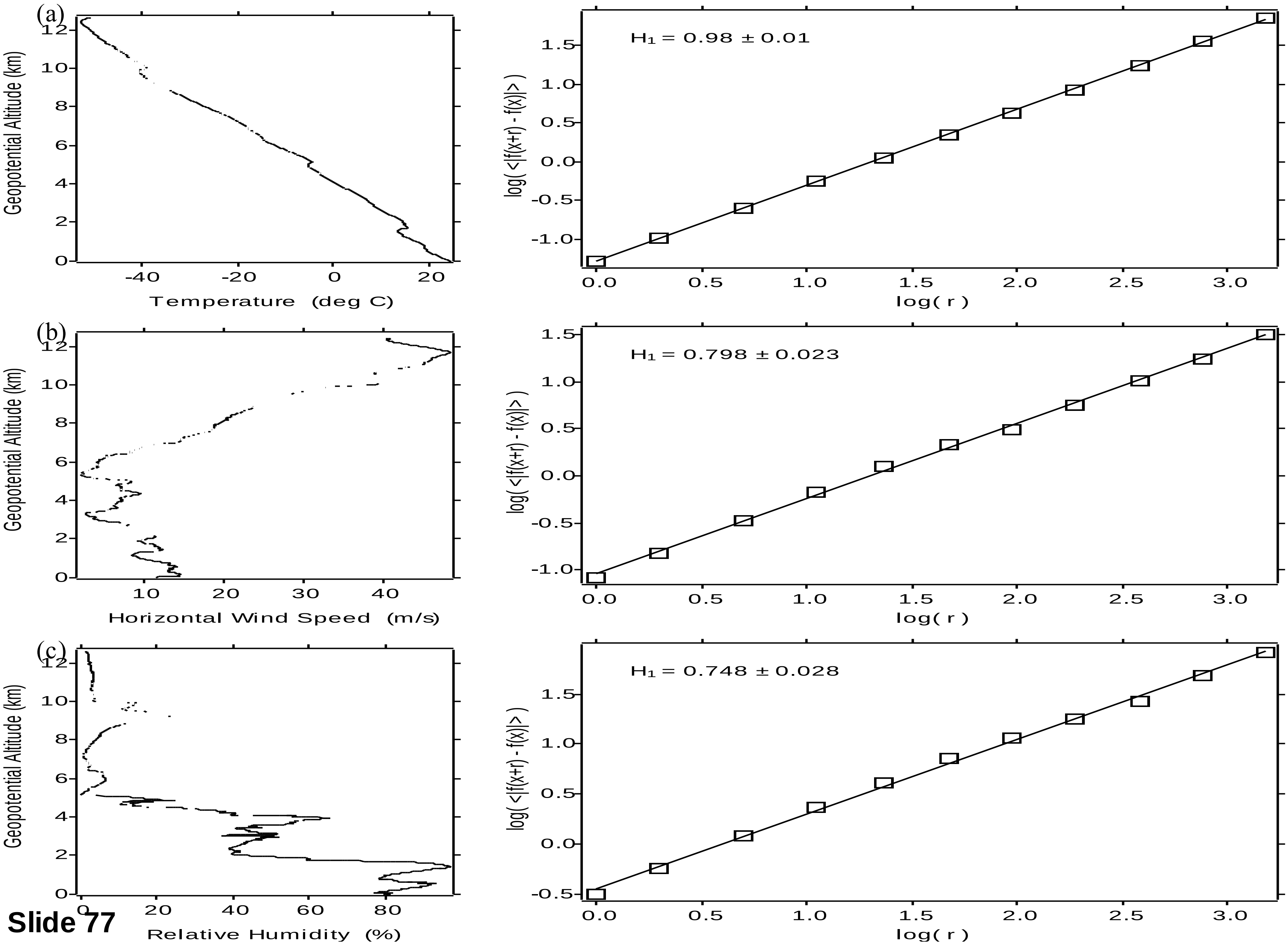
*What of the vertical scaling?


(a)
Geopotential Altitude (km)
Temperature (deg C)
$H_1 = 0.971 \pm 0.009$
log(<|f(x+r) - f(x)|>)
log(r)
(b)
Geopotential Altitude (km)
Horizontal Wind Speed (m/s)
$H_1 = 0.668 \pm 0.101$
log(<|f(x+r) - f(x)|>)
log(r)
(c)
Geopotential Altitude (km)
Relative Humidity (%)
$H_1 = 0.706 \pm 0.041$
log(<|f(x+r) - f(x)|>)
log(r)

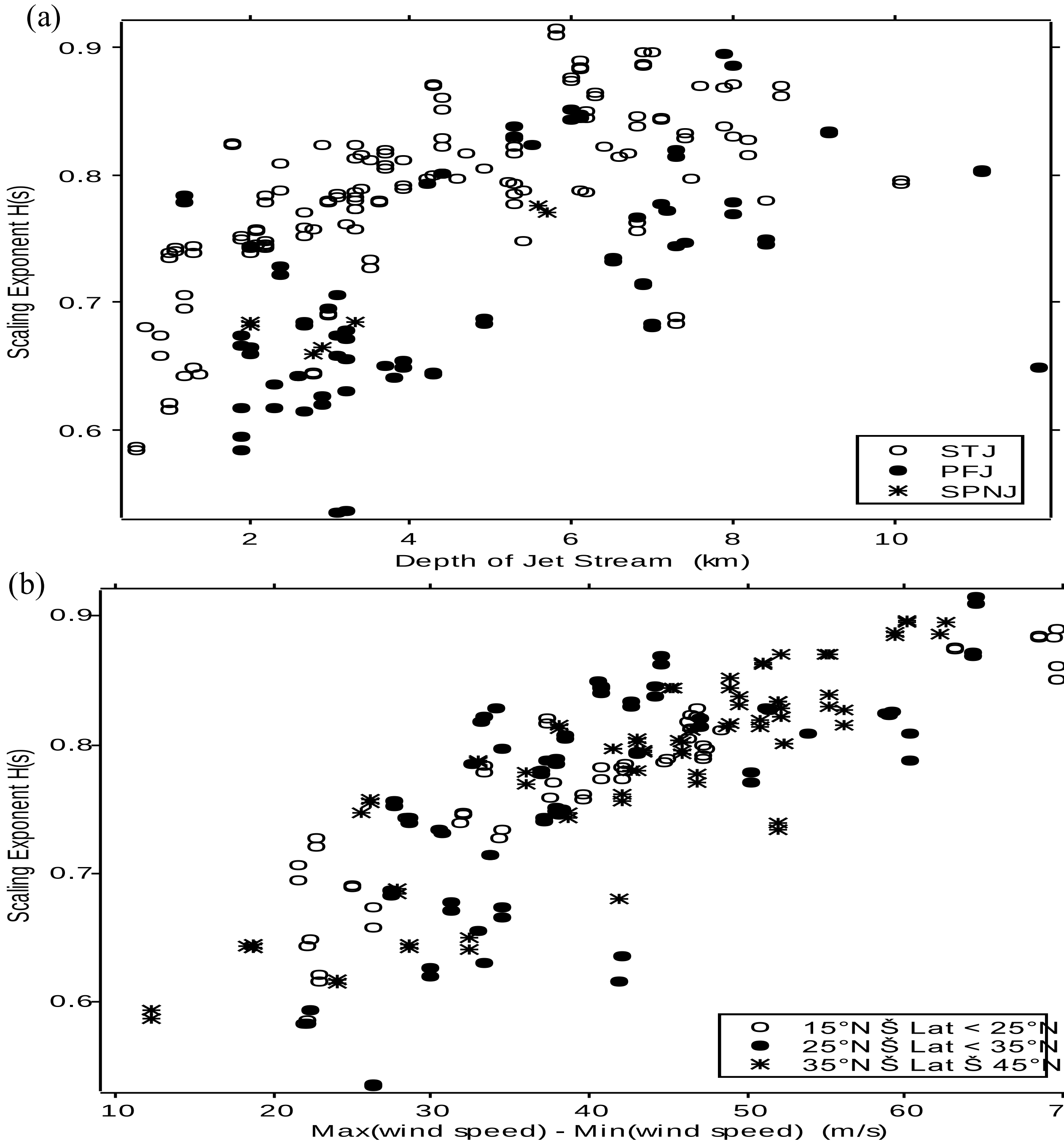
Slide 75



(a)
Geopotential Altitude (km)
Temperature (deg C)
H1 = 0.972 ± 0.024
log(<|f(x+r) - f(x)|>)
log(r)
(b)
Geopotential Altitude (km)
Horizontal Wind Speed (m/s)
H1 = 0.817 ± 0.028
log(<|f(x+r) - f(x)|>)
log(r)
(c)
Geopotential Altitude (km)
Relative Humidity (%)
H1 = 0.817 ± 0.022
log(<|f(x+r) - f(x)|>)
log(r)

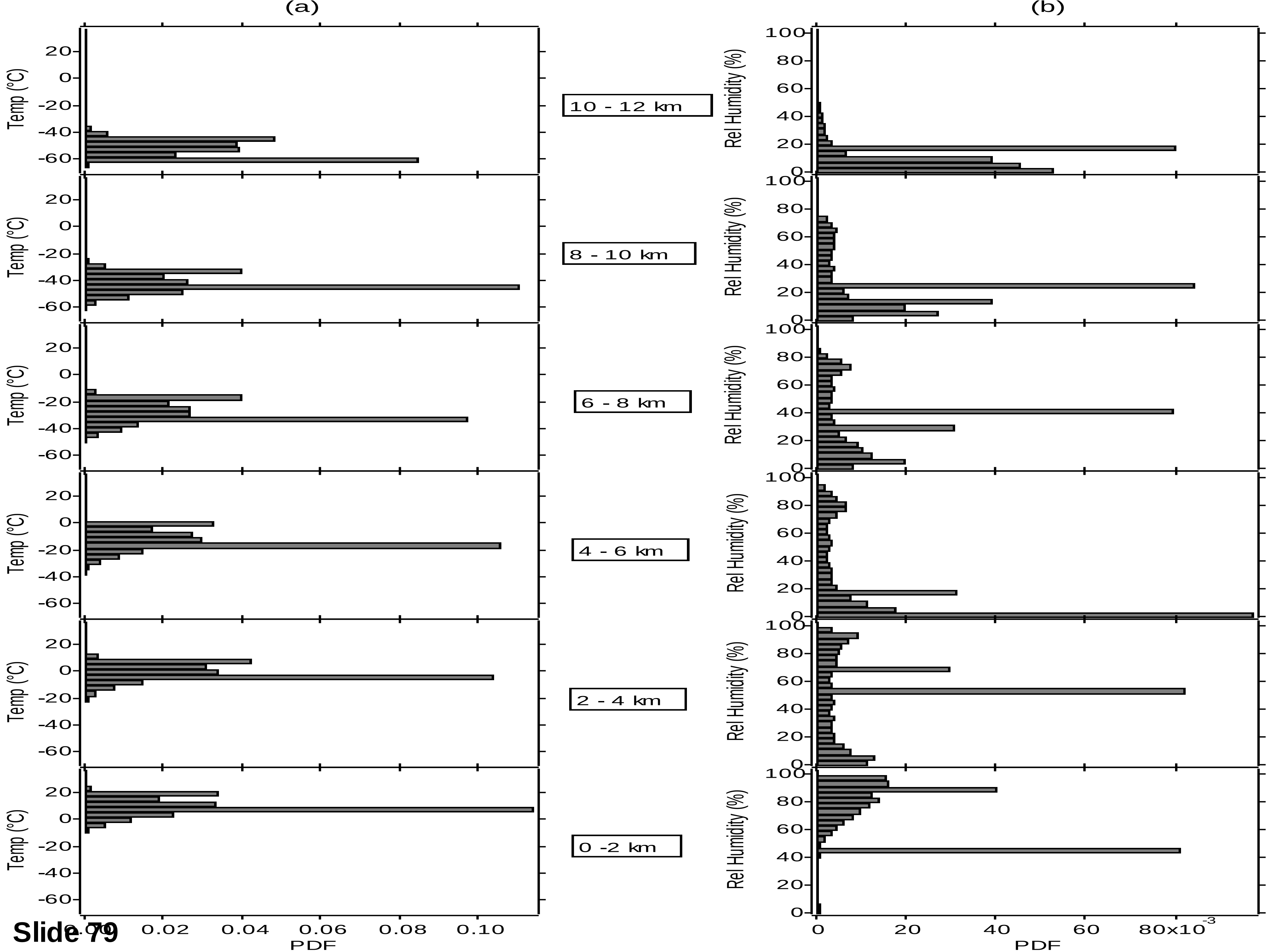

(a)
Geopotential Altitude (km)
Temperature (deg C)
H₁ = 0.98 ± 0.01
log(<|f(x+r) - f(x)|>)
log(r)
(b)
Geopotential Altitude (km)
Horizontal Wind Speed (m/s)
H₁ = 0.798 ± 0.023
log(<|f(x+r) - f(x)|>)
log(r)
(c)
Geopotential Altitude (km)
Relative Humidity (%)
H₁ = 0.748 ± 0.028
log(<|f(x+r) - f(x)|>)
log(r)

Slide 77



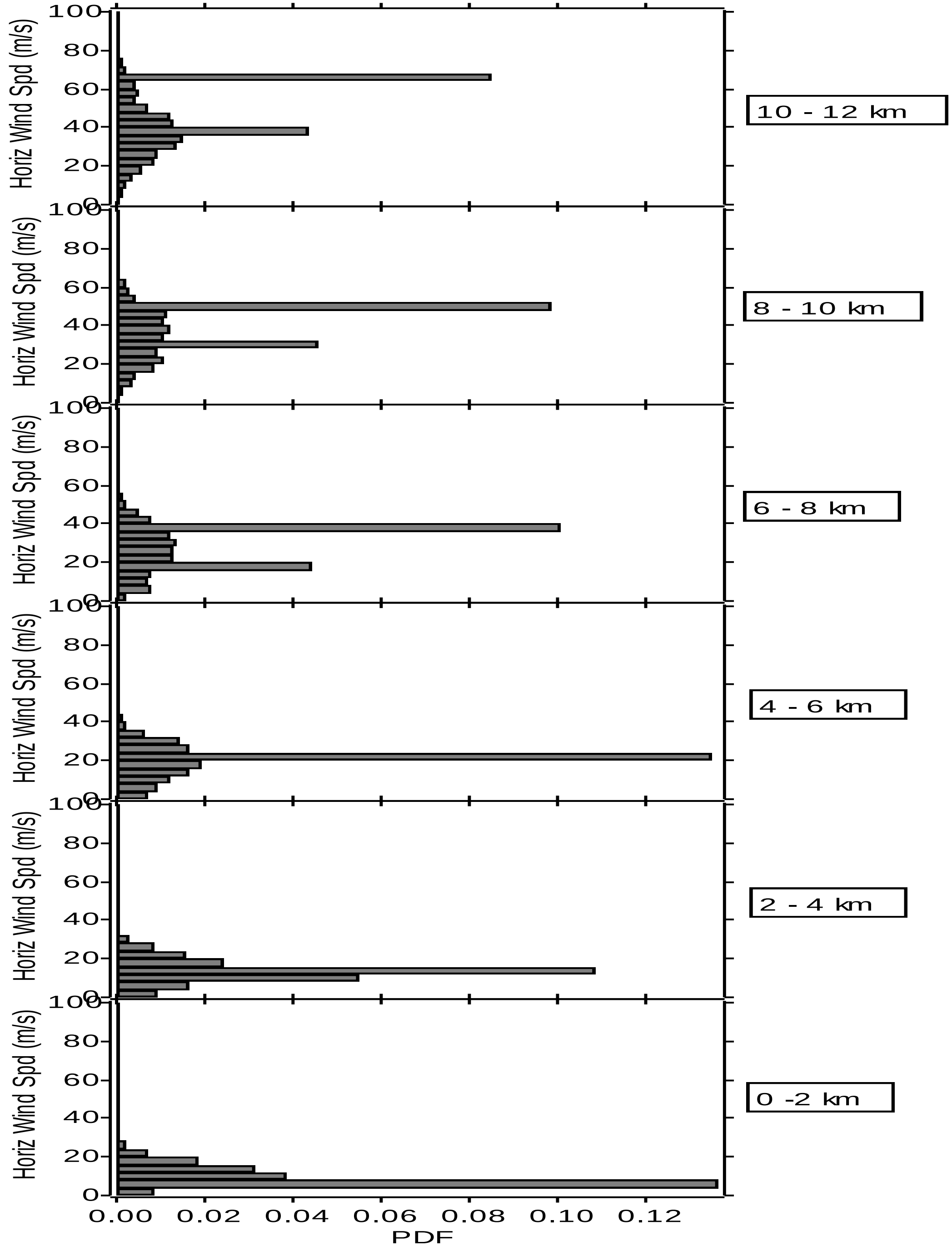
(a)
Scaling Exponent H(s)
0.9
0.8
0.7
0.6
2
4
6
8
10
Depth of Jet Stream (km)
STJ
PFJ
SPNJ
(b)
Scaling Exponent H(s)
0.9
0.8
0.7
0.6
10
20
30
40
50
60
70
Max(wind speed) - Min(wind speed) (m/s)
15°N Š Lat < 25°N
25°N Š Lat < 35°N
35°N Š Lat Š 45°N

Slide 78



(a)
(b)
Temp (°C)
Rel Humidity (%)
10 - 12 km
8 - 10 km
6 - 8 km
4 - 6 km
2 - 4 km
0 -2 km
0.00
0.02
0.04
0.06
0.08
0.10
PDF
0
20
40
60
80x10^-3
-60
-40
-20
0
20
40
60
80
100

Slide 79


10 - 12 km
8 - 10 km
6 - 8 km
4 - 6 km
2 - 4 km
0 -2 km
Horiz Wind Spd (m/s)
0
20
40
60
80
100
0.00
0.02
0.04
0.06
0.08
0.10
0.12
PDF

Slide 80

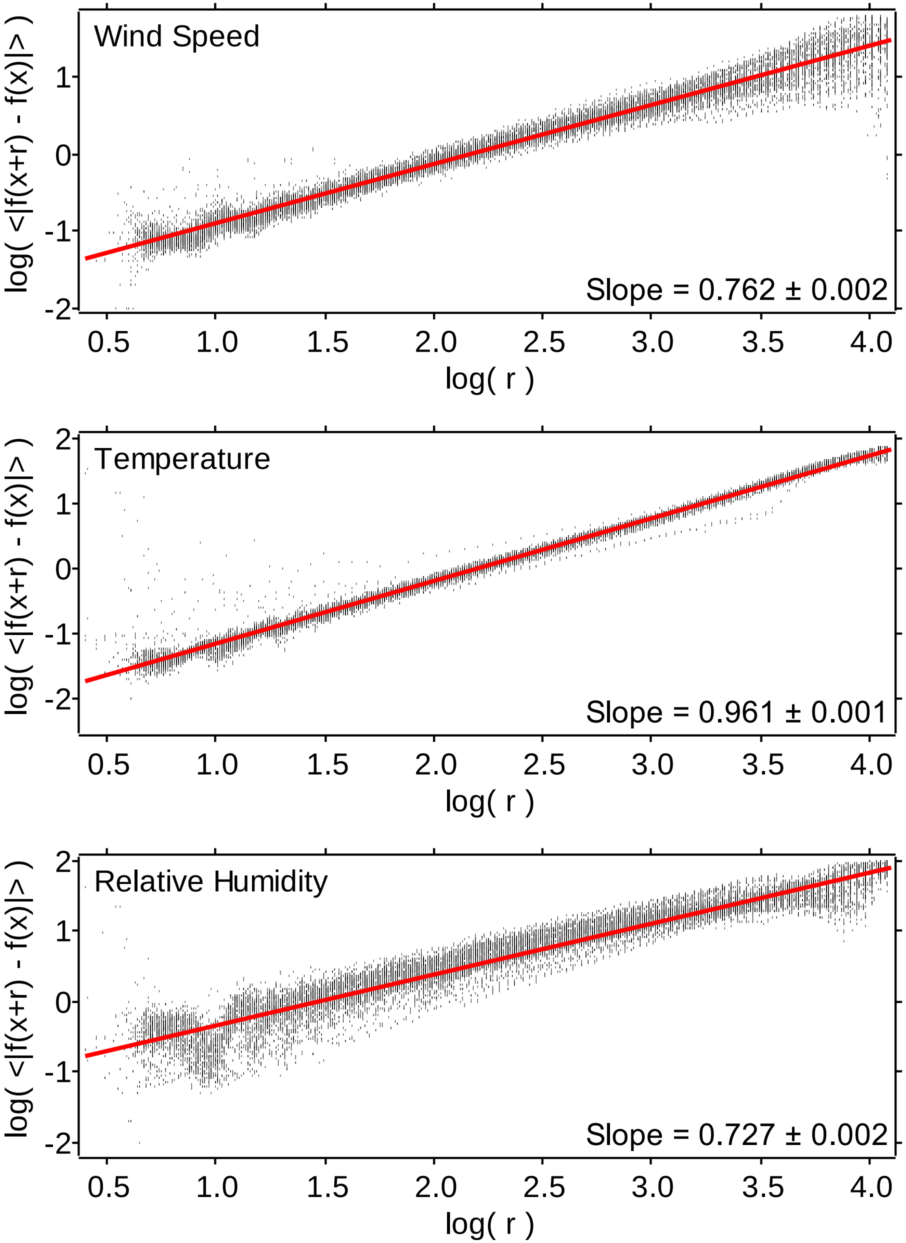
The figures to the right are *composite variograms*, created by overlaying the individual variograms computed for each dropsonde and then fitting a line to the aggregate.

While variograms typically involve variance, we use the first order structure function in order to minimize intermittency corrections and to facilitate comparison with theoretical (dimensional analysis) exponents.

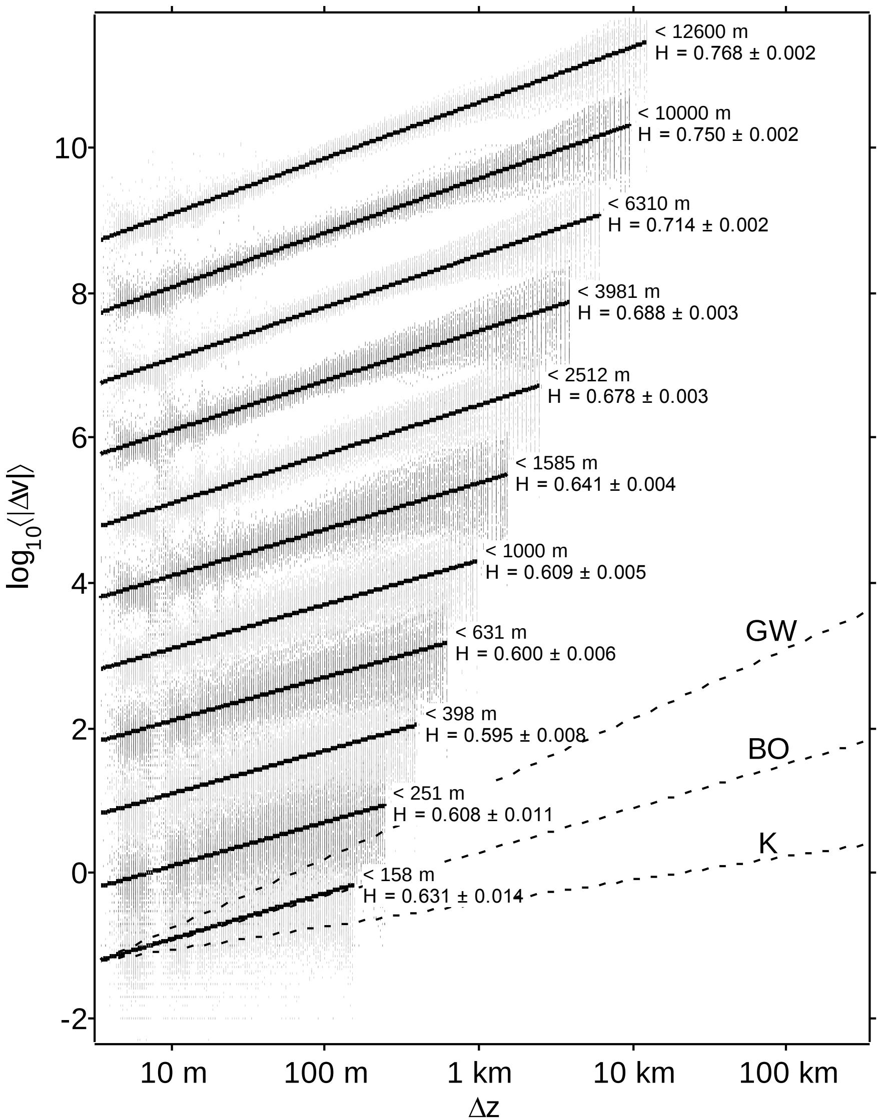
Each individual variogram contained about 100 points, and there were 235 drops that successfully measured wind speed, and 246 that measured temperature and relative humidity. Therefore the lines to the right are each fitting roughly 24,000 points. The errors are 95% confidence intervals.

The surprise is that the slope (i.e. H) for horizontal wind speed, came out appreciably higher than the Bolgiano-Obukhov theoretical value of 0.6. This indicates smoother than expected horizontal wind speed profiles. It is clear also that temperature behaves differently in the vertical than the other variables.

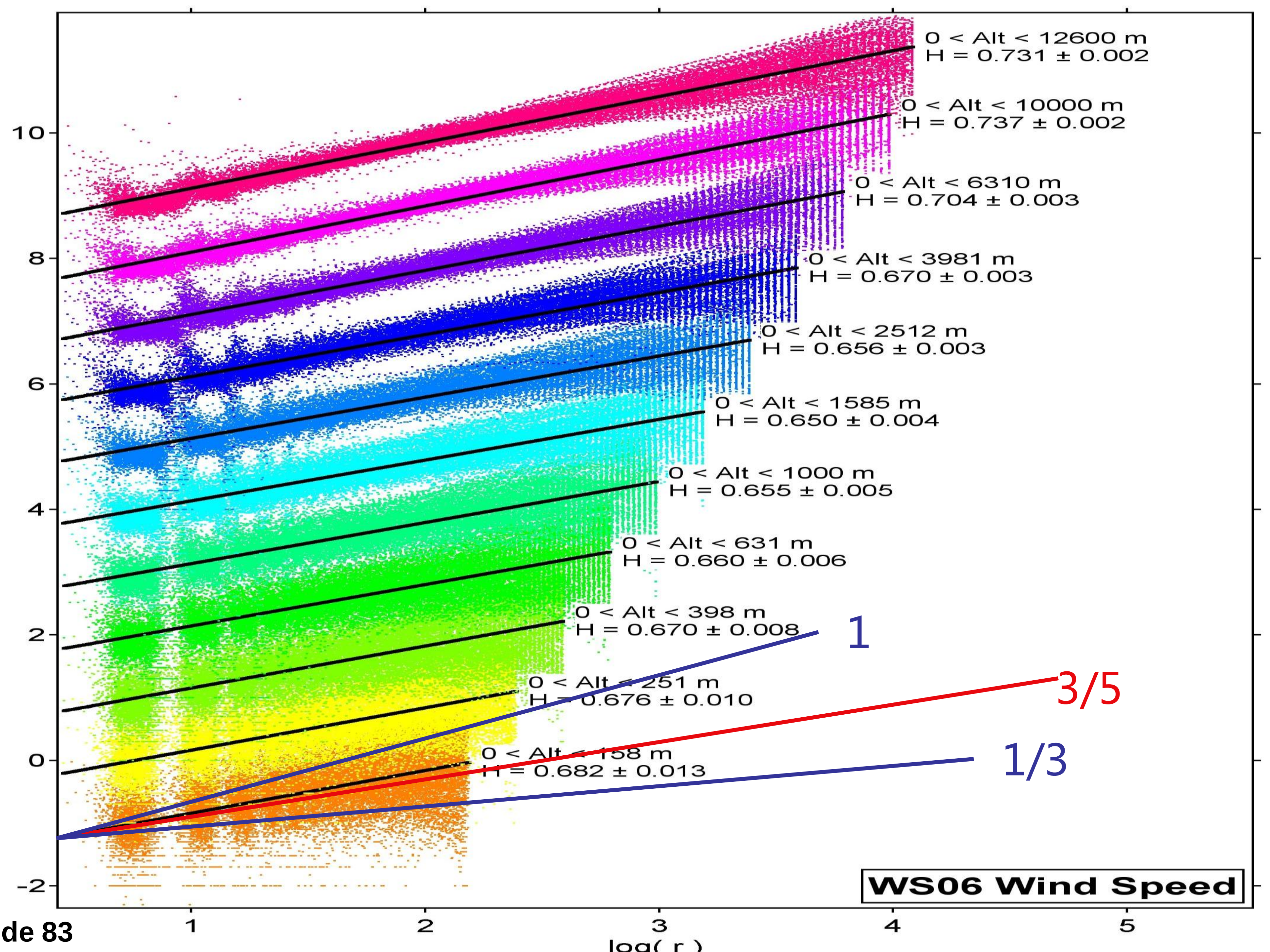
Subsequent spectral analysis has shown that the near-unity value of H for temperature is an artifact of the structure function method, which does not produce a good estimate of H when $H > 1$ or $H < 0$. For the data of 20040229, the spectral method yielded $H \approx 5/4$, again a value unique to temperature.



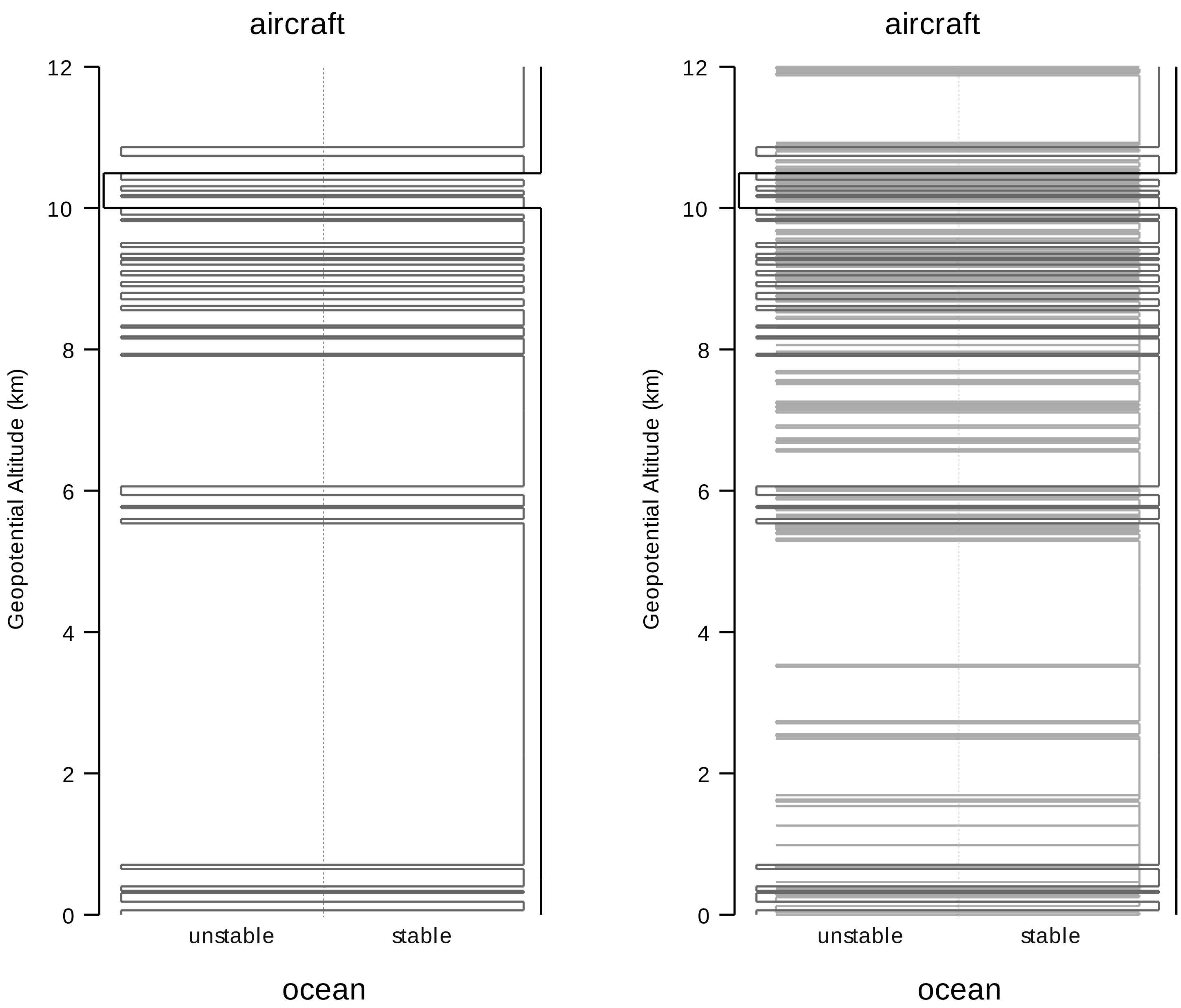
Vertical scaling of horizontal wind, 235 dropsondes, Winter Storms 2004. Scaling is not Kolmogorov or gravity wave; Bolgiano-Obukhov is close in boundary layer, but none are correct at jet altitudes.



WS 2004


0 < Alt < 12600 m
H = 0.731 ± 0.002
0 < Alt < 10000 m
H = 0.737 ± 0.002
0 < Alt < 6310 m
H = 0.704 ± 0.003
0 < Alt < 3981 m
H = 0.670 ± 0.003
0 < Alt < 2512 m
H = 0.656 ± 0.003
0 < Alt < 1585 m
H = 0.650 ± 0.004
0 < Alt < 1000 m
H = 0.655 ± 0.005
0 < Alt < 631 m
H = 0.660 ± 0.006
0 < Alt < 398 m
H = 0.670 ± 0.008
0 < Alt < 251 m
H = 0.676 ± 0.010
0 < Alt < 158 m
H = 0.682 ± 0.013
1
3/5
1/3
WS06 Wind Speed
10
8
6
4
2
0
-2
1
2
3
4
5
log(r)

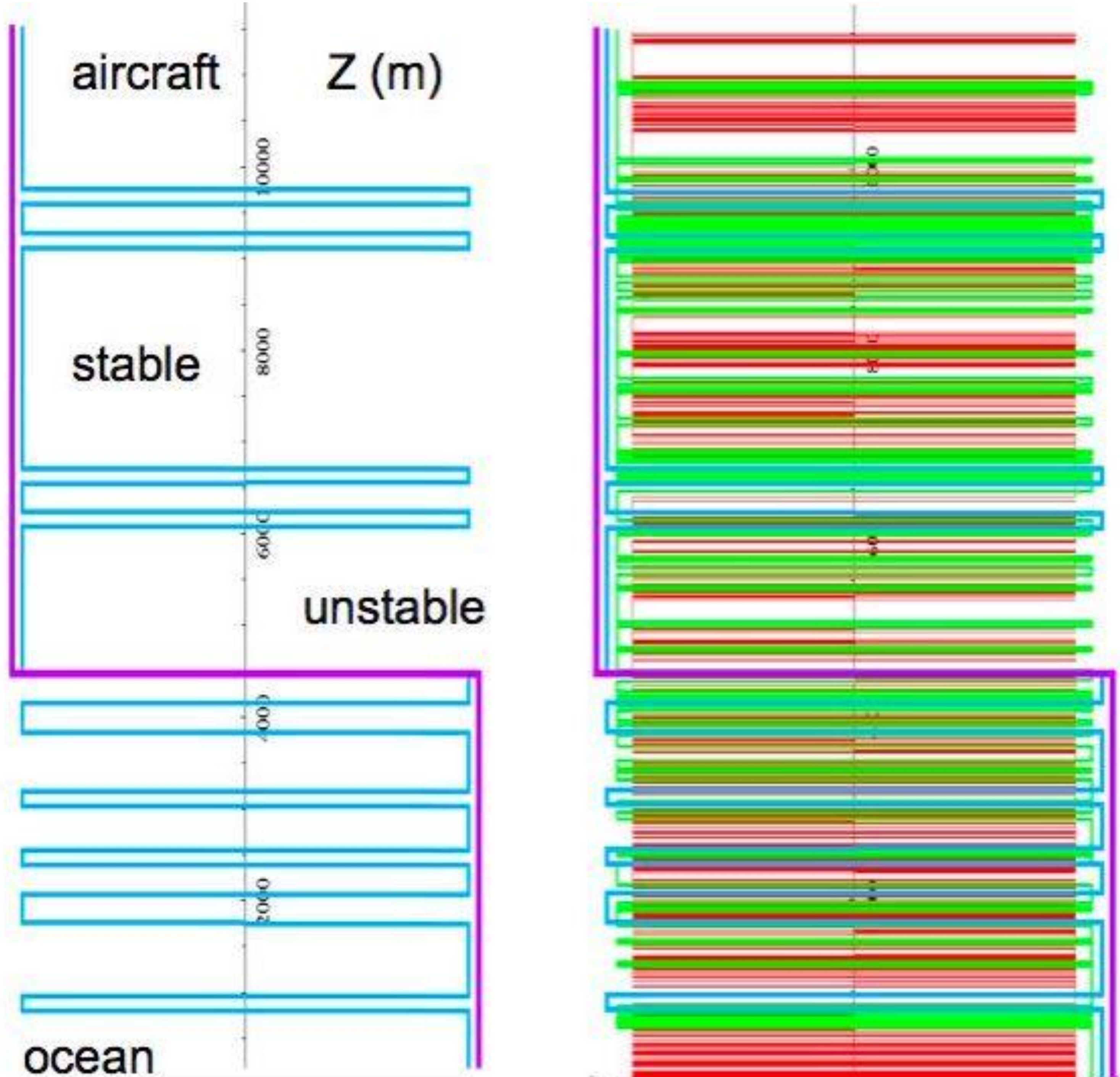
Dynamical stability [Ri>0.25] at 500 & 150 m(left),50 & 10 m(right) Dropsonde (25˚N,157˚W) on 20040229. The ‘Russian doll’ structure.



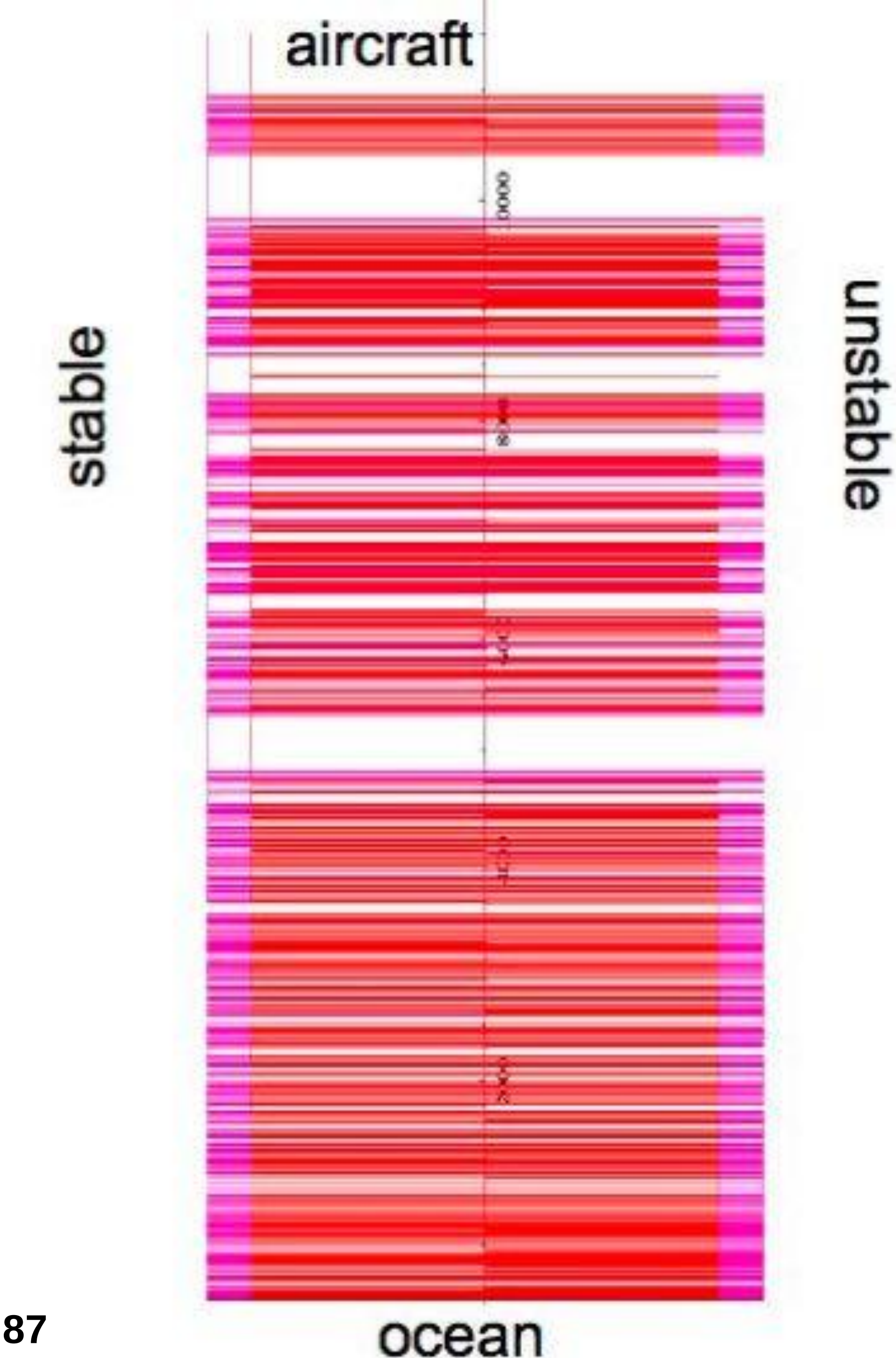
QuickTime™ and a
decompressor
are needed to see this picture.

QuickTime™ and a
decompressor
are needed to see this picture.

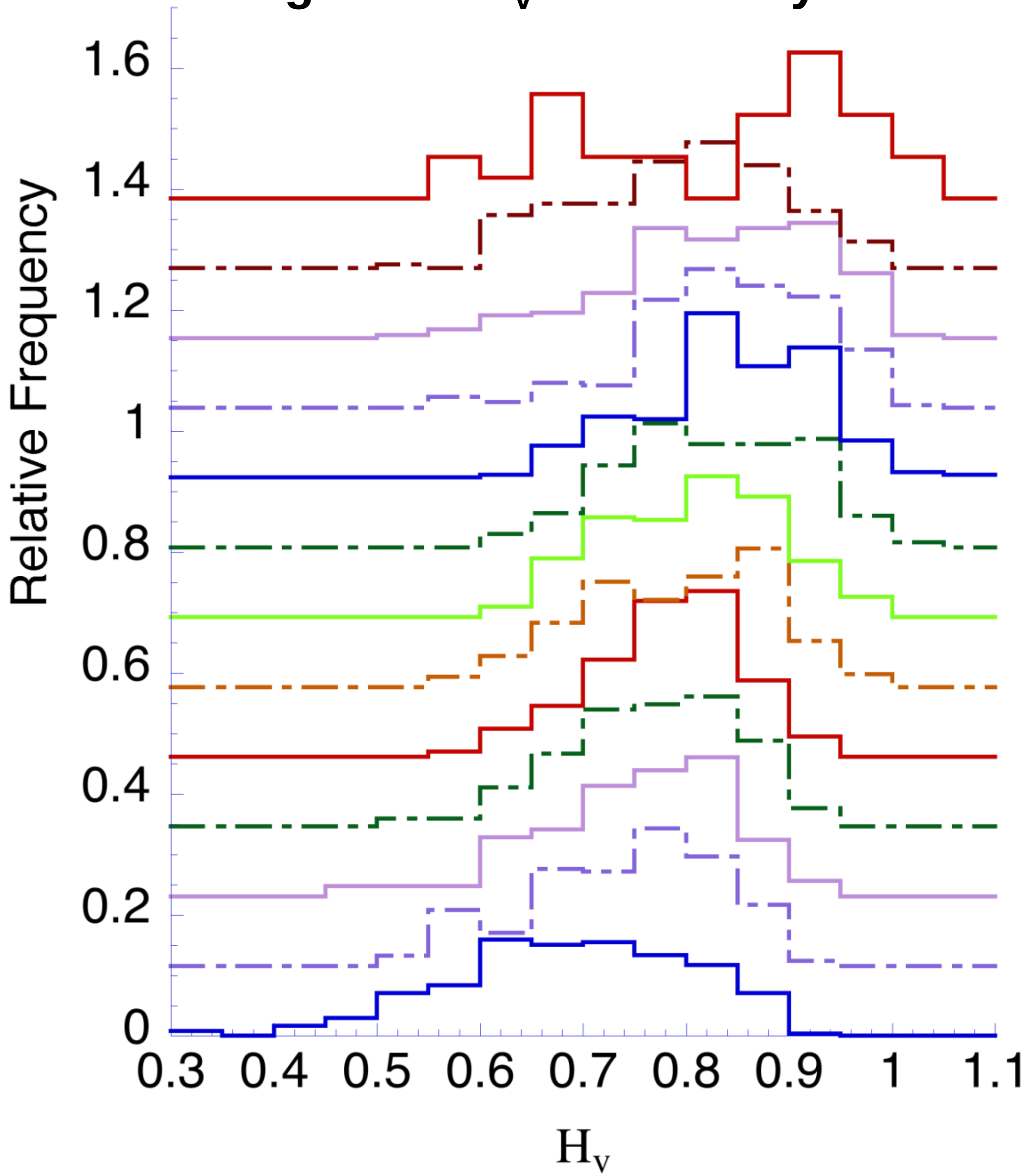
Slide 85



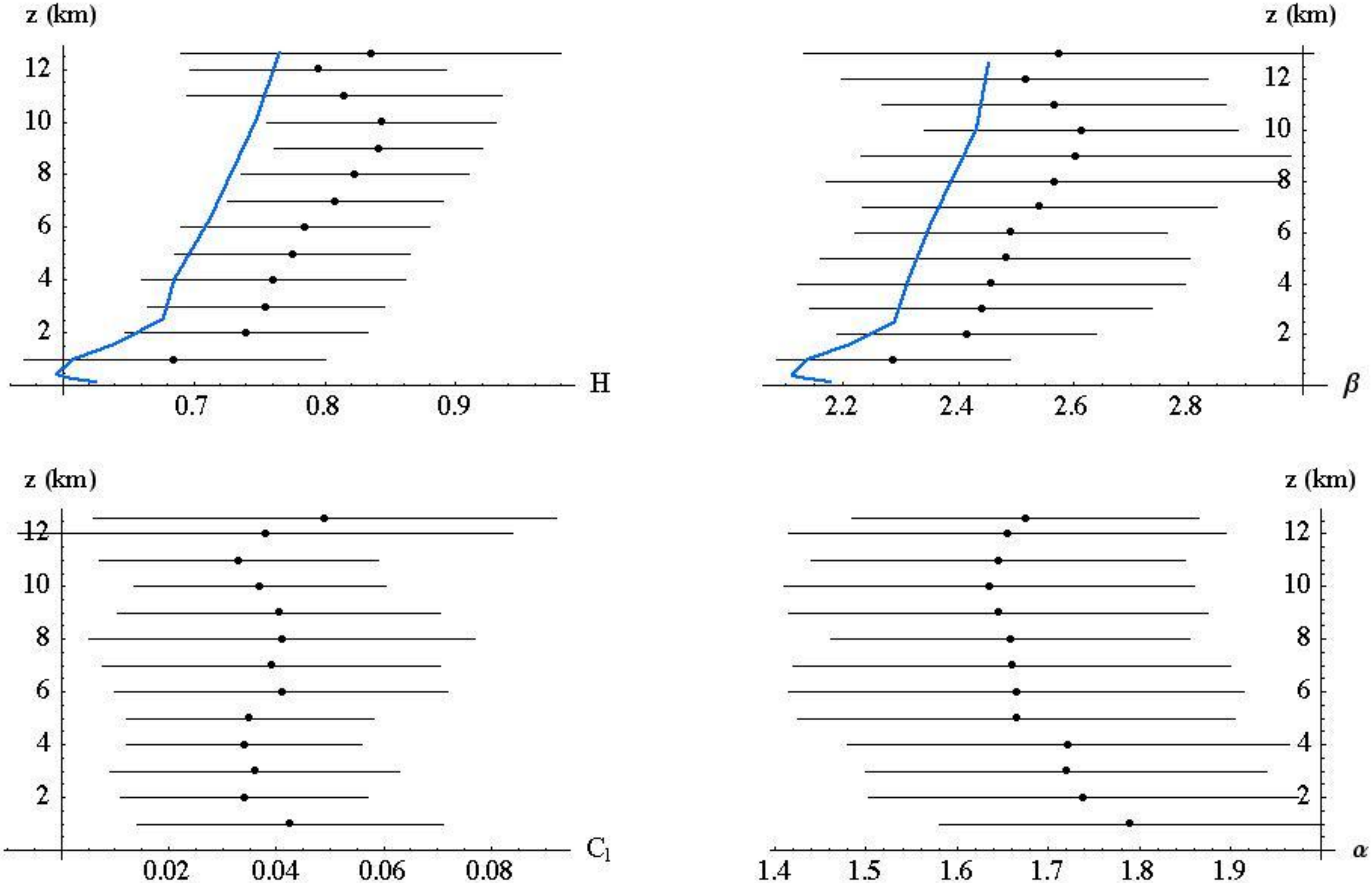
aircraft
Z (m)
stable
unstable
ocean


aircraft
stable
unstable
ocean

Histogram of H_v for 1 km layers

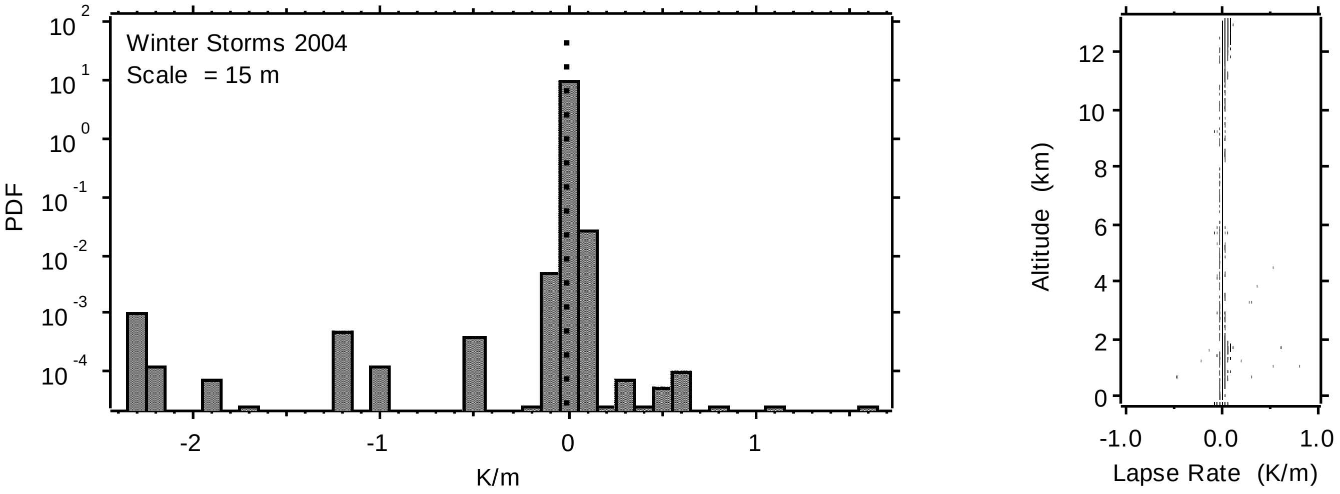


Velocity scaling exponents H, β, C_1 and α

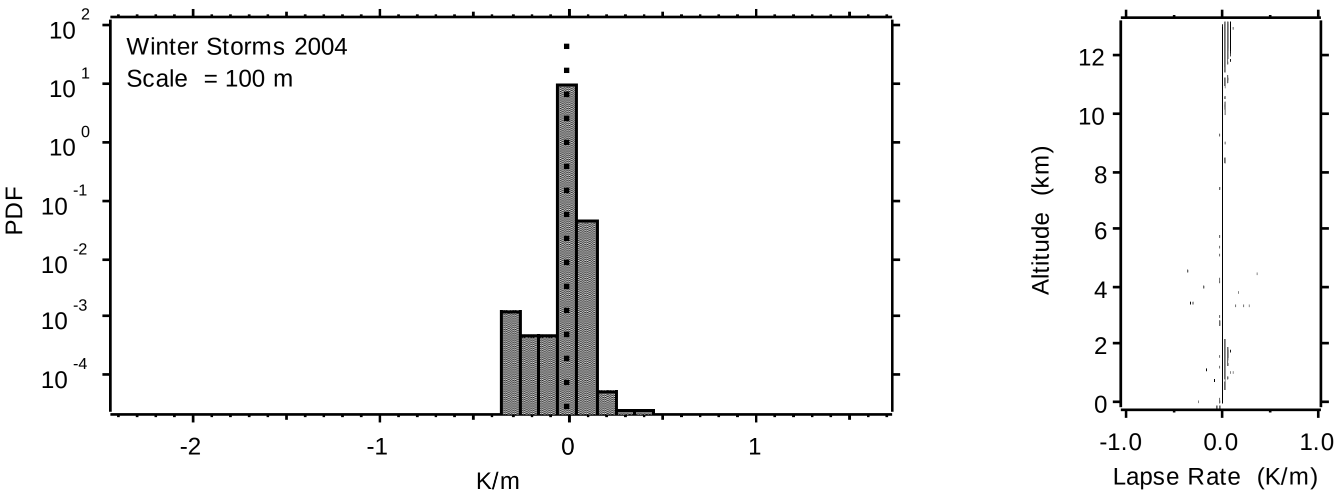


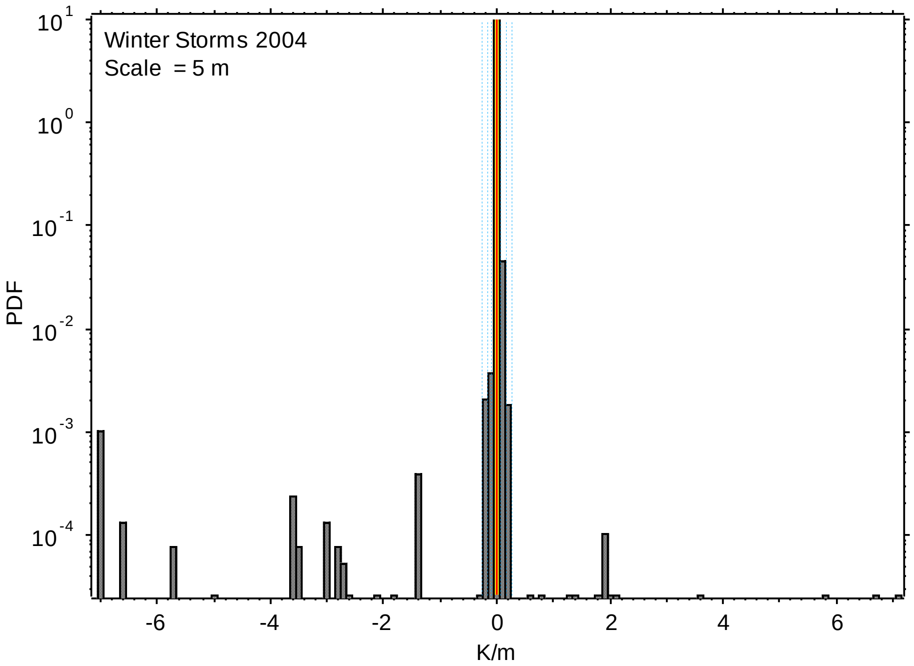
Lapse rate PDFs at different vertical resolutions, dropsondes from NOAA G4, 20040229 - 20040315, eastern Pacific Ocean.

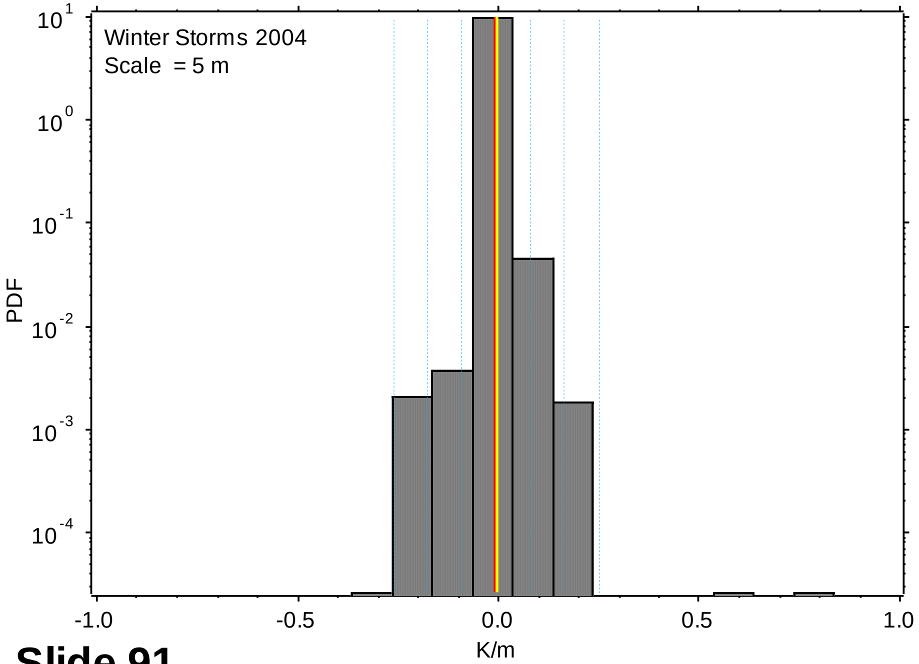
(a)

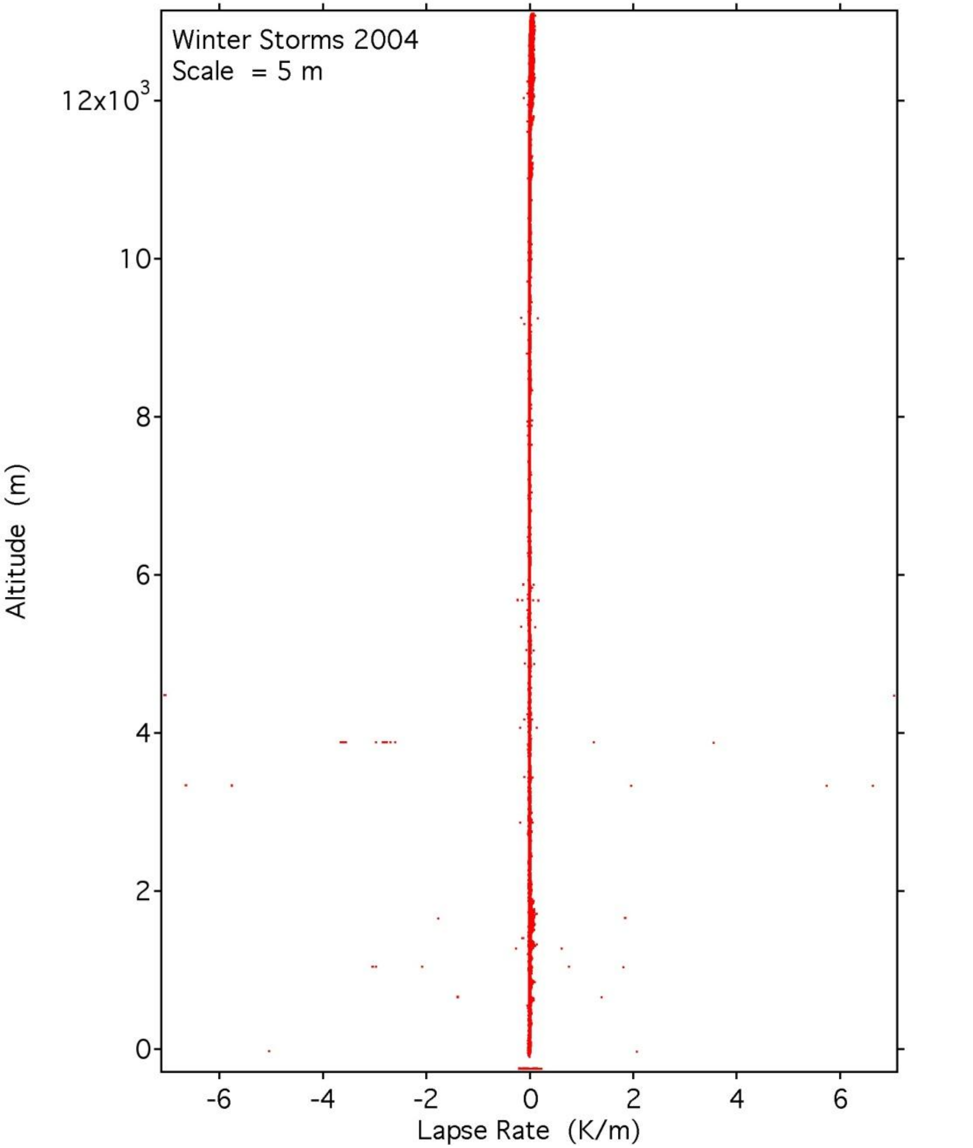


(b)

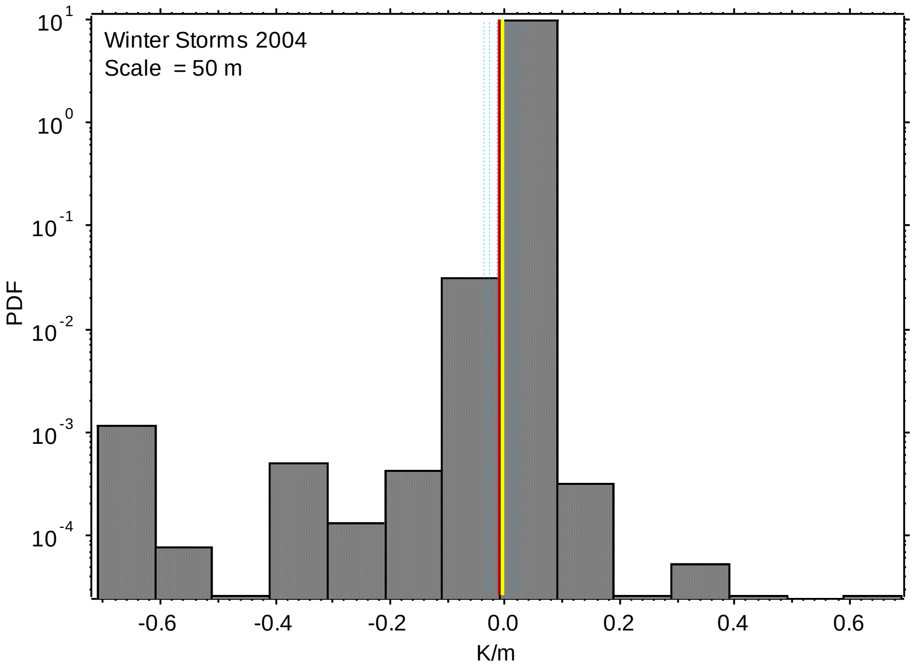


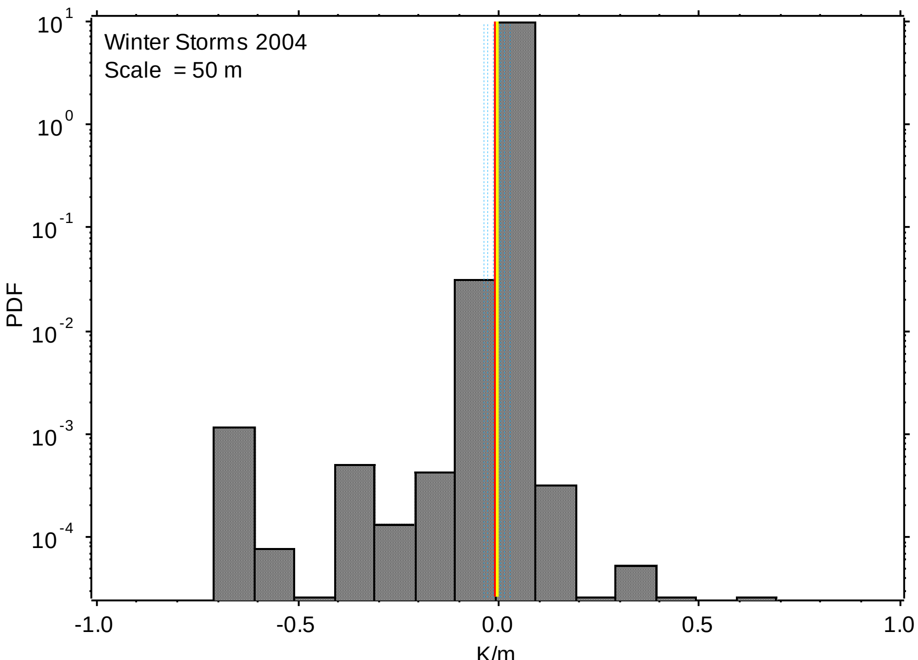

Winter Storms 2004
Scale = 5 m
PDF
K/m
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
-6
-4
-2
0
2
4
6

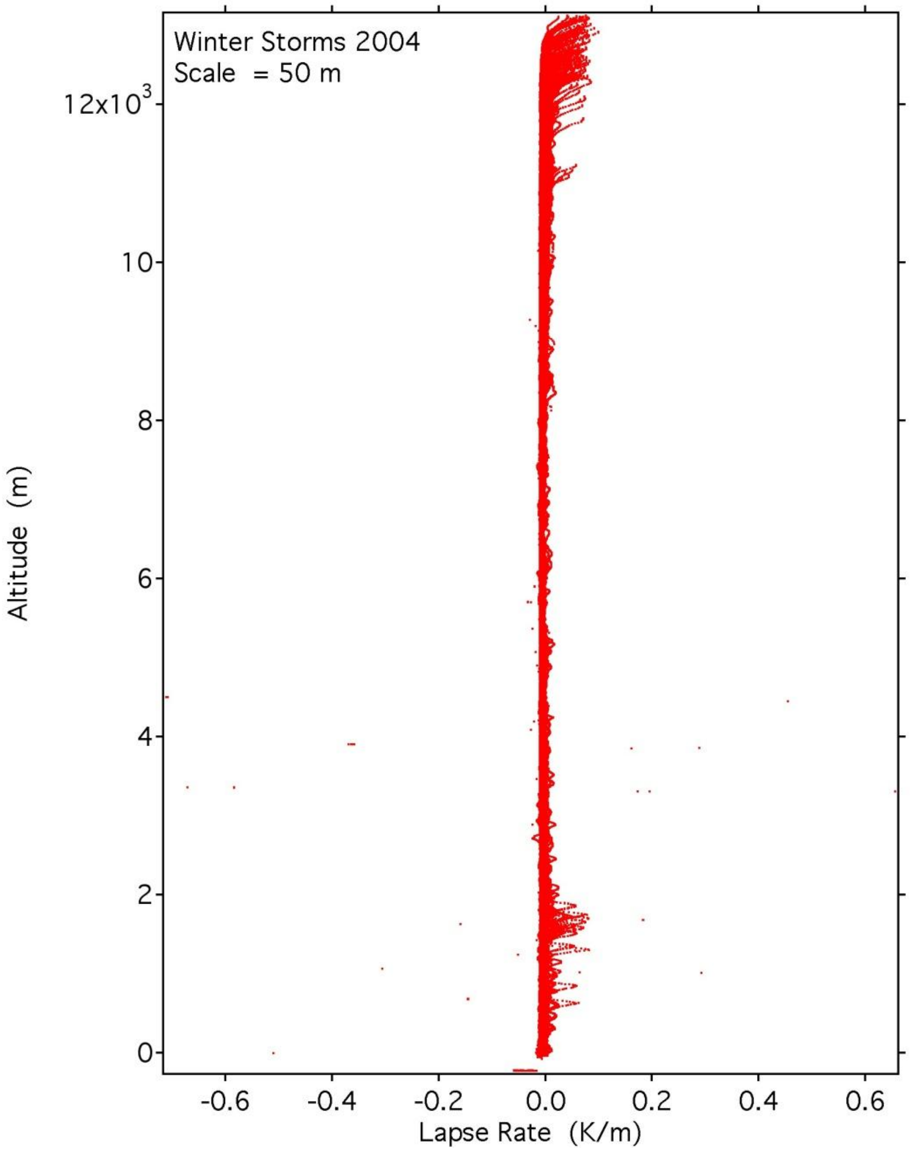

Winter Storms 2004
Scale = 5 m
PDF
K/m
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
-1.0
-0.5
0.0
0.5
1.0


Winter Storms 2004
Scale = 5 m
Altitude (m)
Lapse Rate (K/m)
$12x10^3$
10
8
6
4
2
0
-6
-4
-2
0
2
4
6

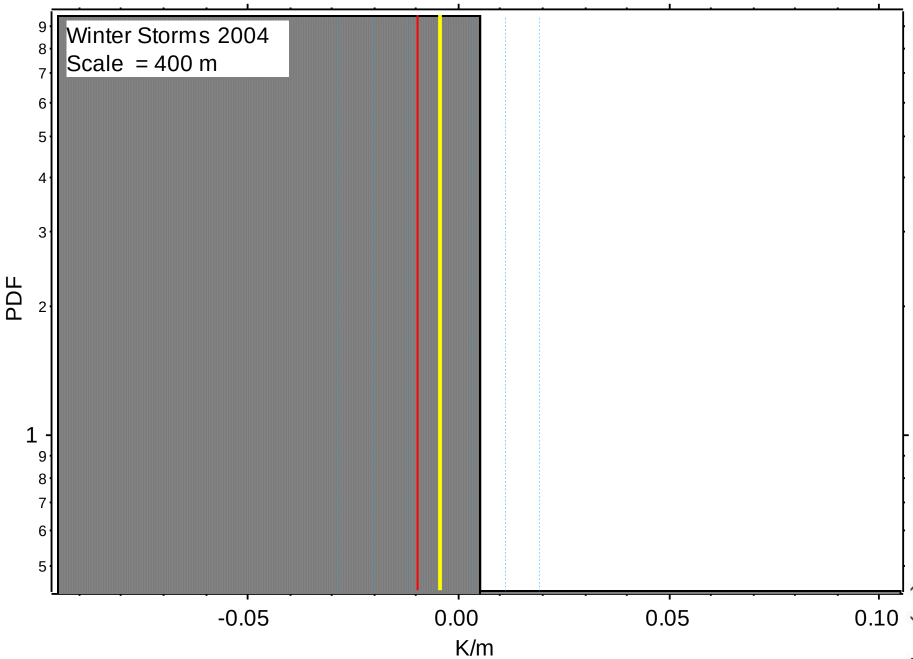
Slide 91

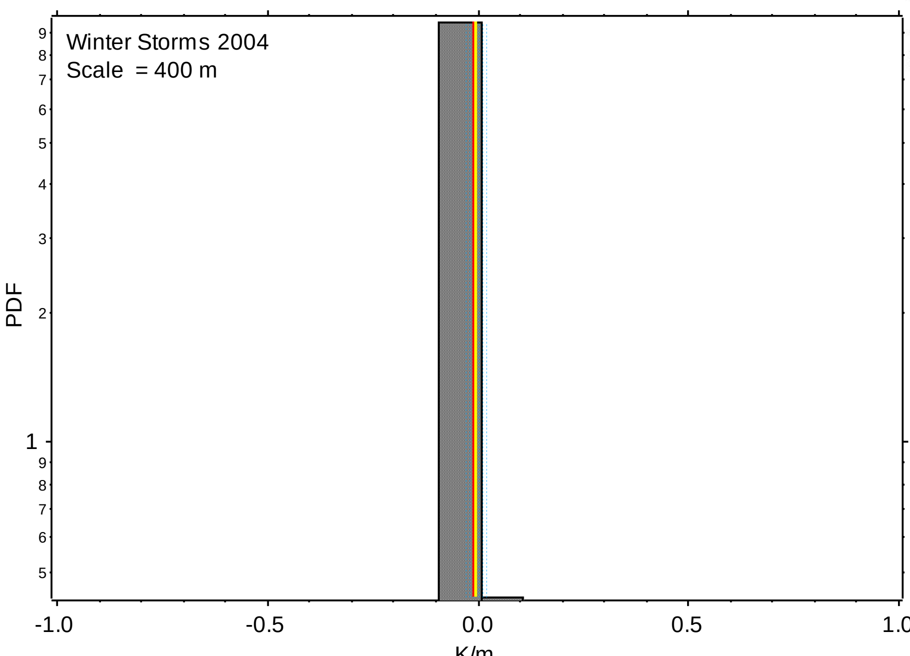

Winter Storms 2004
Scale = 50 m
PDF
K/m

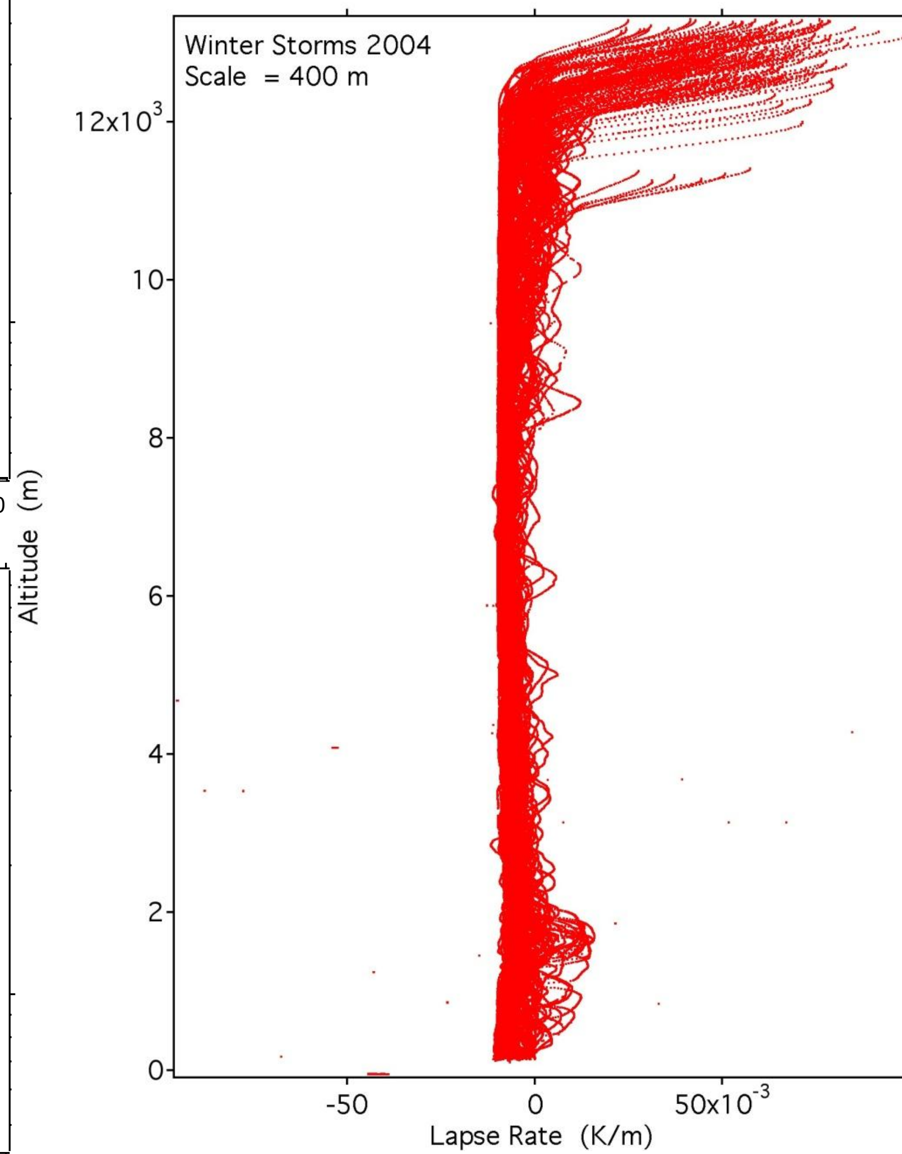

Winter Storms 2004
Scale = 50 m
PDF
K/m


Winter Storms 2004
Scale = 50 m
Altitude (m)
Lapse Rate (K/m)

Slide 92

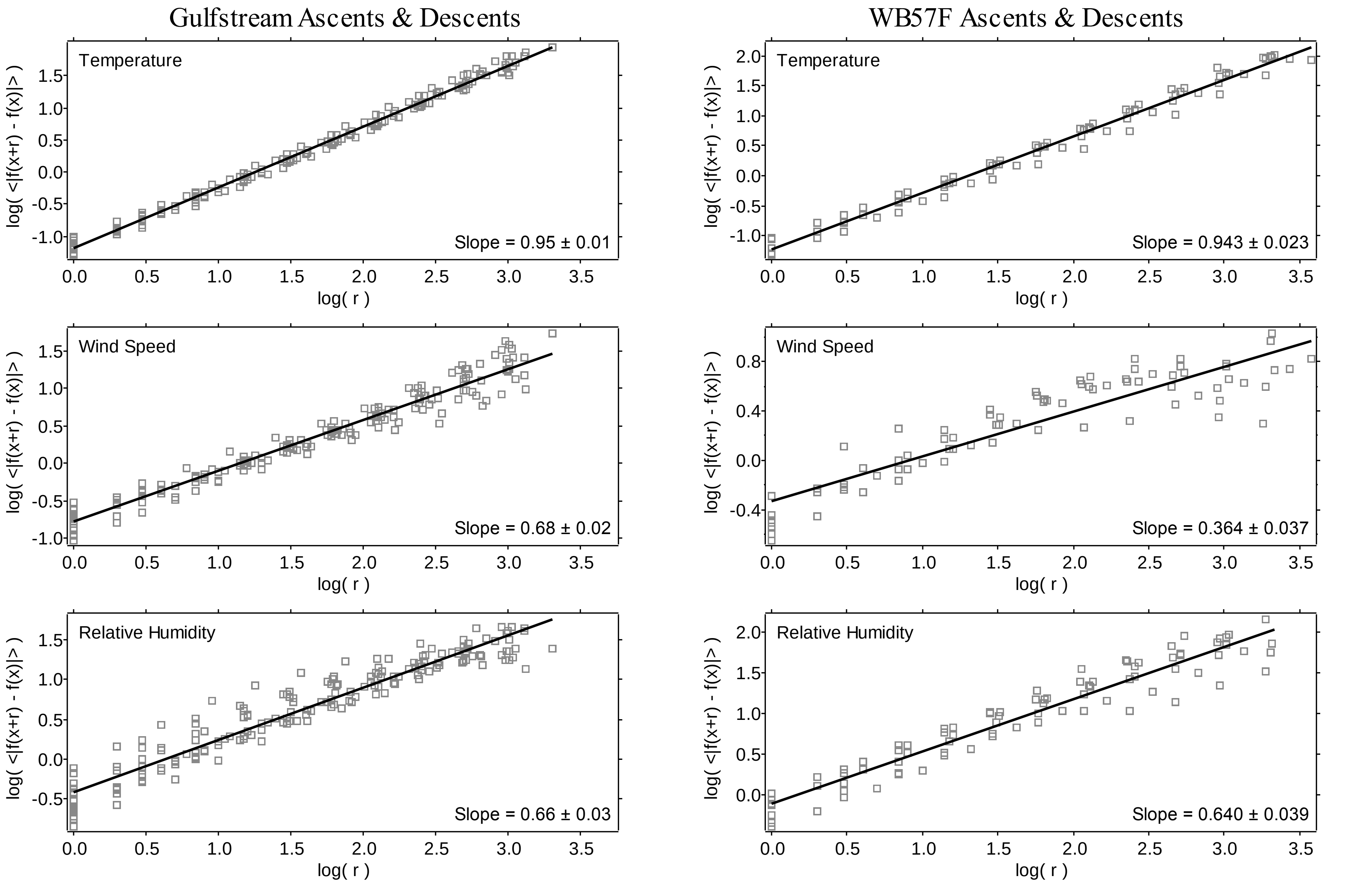

Winter Storms 2004
Scale = 400 m
PDF
1
-0.05
0.00
0.05
0.10
K/m


Winter Storms 2004
Scale = 400 m
PDF
1
-1.0
-0.5
0.0
0.5
1.0
K/m

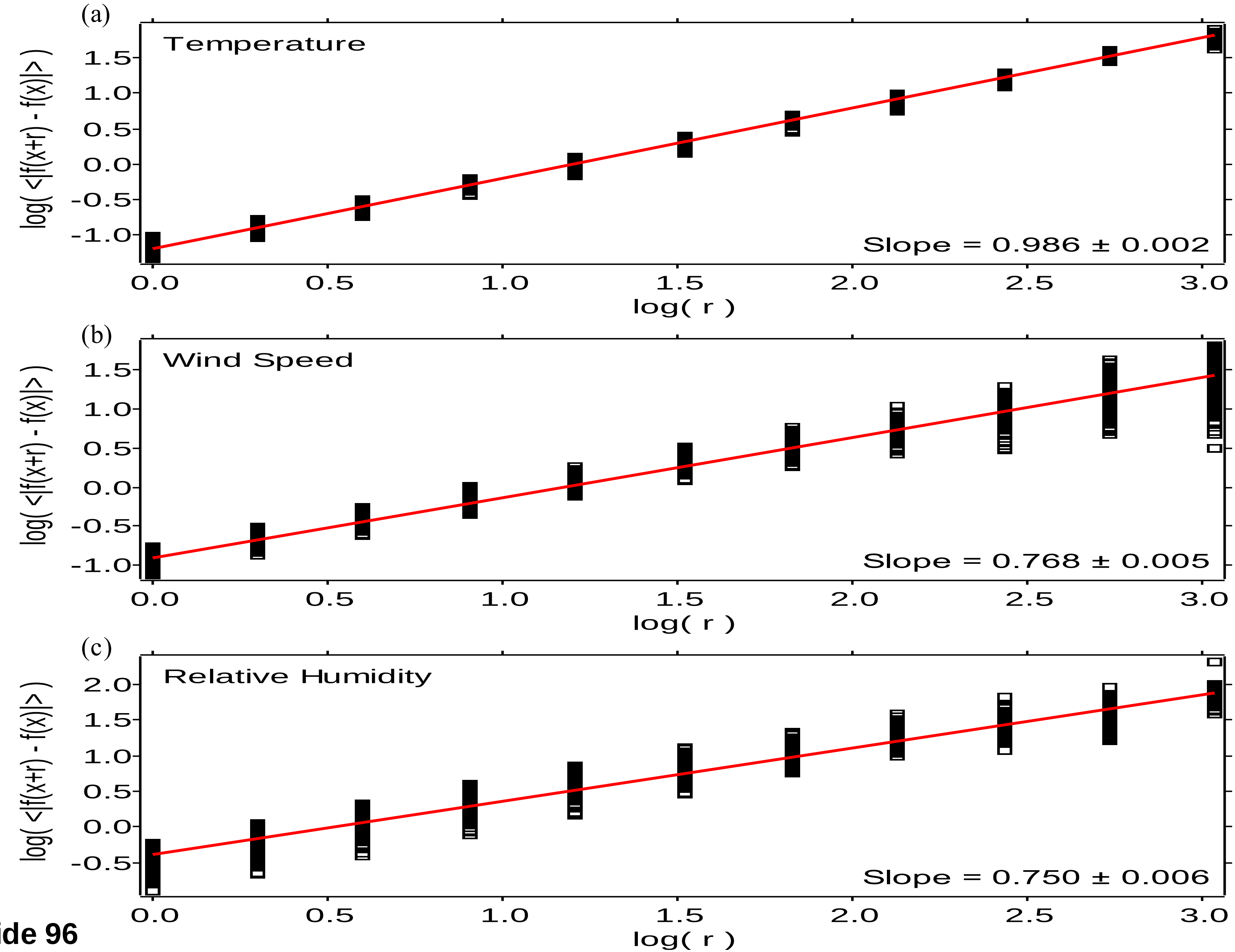

Winter Storms 2004
Scale = 400 m
Altitude (m)
$12x10^3$
10
8
6
4
2
0
-50
0
$50x10^{-3}$
Lapse Rate (K/m)

Slide 94

Aircraft ascents and descents,Jan-Mar 2004,10˚- 60˚N,84˚- 158˚W



Variogram, all 261 dropsondes during the mission



Scaling from G4 in Winter Storms 2004

	Dropsondes	Vertical Aircraft Segments	Horizontal Aircraft Segments
Temperature	0.986 ± 0.002	0.95 ± 0.02	0.52 ± 0.02
Wind Speed	0.768 ± 0.005	0.68 ± 0.02	0.56 ± 0.02
Relative Humidity	0.750 ± 0.006	0.66 ± 0.03	0.45 ± 0.03

Vertical & horizontal exponents are different; no isotropy!

Co-dimensions of vertical stability criteria

CRITERION	**CO-DIMENSION**
$N^2(\theta) = g\partial\log\theta/\partial z$ Brunt-Väisälä (dry)	0.36 ± 0.06
$Ri = N^2(\theta)\,[\partial v/\partial z]^{-2}$ Richardson Number	0.22 ± 0.04
$N^2(\theta_w) = \partial\theta_w/\partial z$ Moist static stability	0.15 ± 0.02

Water - via its latent heat entropy - makes a big difference to atmospheric stability *on all scales.*

Lecture 2.2 Summary

*** GPS dropsondes are very effective at observing the vertical structure of wind, temperature and humidity.**

*** Variables do not follow Gaussian statistics. They show statistical multifractal scale invariance.**
***No monolithic stable layers; no isotropic turbulence.**
***Jet streams alter scaling exponent *H* , horiz & vert.**

*** Atmospheric moisture greatly affects vertical scaling.**

*** Vertical scaling of temperature different than in horizontal.**