DACA-13
Davos Atmosphere and Cryosphere Assembly DACA-13
Davos, Switzerland
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C4.3c Atmospheric boundary layers in complex terrain and over ice, snow and vegetated surfaces

Spatial and Temporal Evolution of Katabatic Flows in MATERHORN 1

L. S. Leo[1] –S. Di Sabatino[1,2] –A. A. Grachev[1,3]–C.M. Hocut[1] –H.J.S. Fernando[1]
E.R. Pardyjak[4] – D. Jensen[4]– S.W. Hoch[5]– C. D. Whiteman[5]

[1]Dep. of Civ. & Environ. Engineering & Earth Sciences, University of Notre Dame, IN, USA
[2]DiSTeBA, Lab. di Micrometeorologia, Universita' del Salento, Lecce, IT
[3]NOAA ESRL / University of Colorado CIRES, Boulder (CO), USA
[4]Dep. of Mech. Engineering, University of Utah, UT, USA
[5]Dep. of Atmospheric Sciences, University of Utah, UT, USA

Introduction

Previous works on katabatic flows

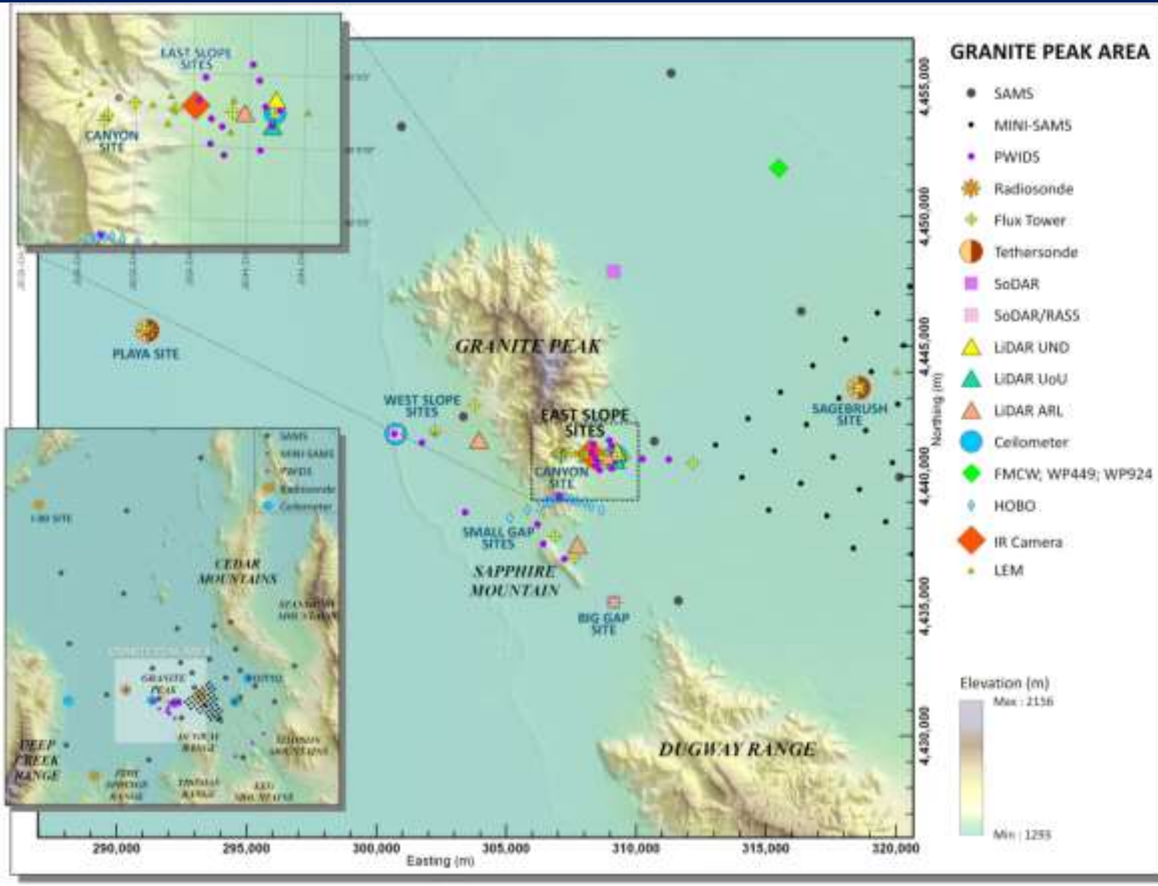
	Slope angle	Observations	Analytical/ Numerical	Oscillations (U, T)	Gravity Waves	Katabatic layer height	Stability
Fleagle (1950)		no	Analytical & numerical	Yes (theory of compressible warming) ~20 min (damped oscillatory motion)	No discussion	Some suggestions 100 m for a steep slope (over 40°)	based on dθ/dz (prescribed)
Manins & Sawford (1979)	Test for 7°	no	Analytical & numerical – a new model based on hydraulic approach (integrated equations)	Not specifically	No discussion	Yes	N, Ri
Doran & Horst (1981)	Not reported	Yes (1 tower, 30 m at the base of several drainage currents)	Analytical & numerical (a simple model adapted from Manins and Sawford 1979). It includes both surface and interfacial drag	Yes (though no conclusion on the mechanism of Fleagle 1950) Period observed ~90 min	No discussion	No	based on dθ/dz
McNider (1982)	Variable (5°-30°)	no	Analytical (extension from Fleagle). two regimes depending on k (damping coefficient) It includes surface drag	Yes; $\omega = N \sin\alpha$	No discussion	No	based on dθ/dz (free parameter)
Doran & Horst (1983)	21°; 8°	Yes (3 towers - 6,9,18 m and 1 balloon up to 500 m)	Yes (eddy-diffusivity related to local TKE)	Yes	No discussion	$0.75\left[0.05(\sin\alpha)^{2/3}\right]s$ (derived from Manins and Sawford)	based on dθ/dz
Helmis & Papadopoulos (1996)	34°-9°	Yes – 4 met stations: towers up to 25 m	Analytical (extension from McNider (1982). Interesting analysis of phase of velocity	Yes (the first to observe phase lag $(\pi/2+\varphi) \propto$ Friction. Period of oscillation 30 min	Yes though not directly (they suggest that McNider not conclusive and gravity waves and instability may cause oscillations	Not explicitly. They are the first to recognize that the work of McNider ignores the vertical structures and is applicable below the velocity maximum. These authors tend to dismiss Fleagle hypothesis but the aye cautious.	N, Ri
Monti et al. (2002)	4 °	yes	Theoretical considerations	Yes. Period of oscillation 30 min	Yes	No specific discussion	N, Ri

Introduction

Previous works on katabatic flows

	Slope angle	Observations	Analytical/ Numerical	Oscillations (U, T)	Gravity Waves	Katabatic layer height	Stability
van Gorsel et al. (2004)		Yes. Two towers, balloon, microwave temperature profiler (passive)		Yes. Period of oscillations from 10 min to 25 min	Yes. They seem to adopt the model of Fleagle although aware that Gryning et al. 1985 suggest modulation of the flow by gravity waves	No specific discussion. They discuss interaction between slope and valley flow. This may change the period of oscillations	N, Ri
Princevac et al. (2008)	4 °	yes	Analytical extension from Manins and Sawford (1979)	Yes. T=2π/Nsinα Period of oscillation 50 min	Yes. They propose that internal waves are the main mechanism for velocity oscillations. They seem to struggle to interpret phase lag between velocity and temperature…	$h \sim \left(\frac{3}{2}D\right)^{1/2}(\tan\alpha)^{1/2}s$	N, Ri
Viana et al. (2010)		Yes. Tower 100m using 3 sonic levels and microbarometers	Wavelet analyses	Yes	Yes. They imply that gravity waves are generated by the katabatic flow…they are found even along the slope	No specific discussion	N
Fedorovich and Shapiro (2009)	30 °;60 °	no	DNS based on Prandtl model	These oscillatory wave-type motions result from interactions between turbulence and ambient stable stratification despite the temporal constancy of the surface buoyant forcing (Nsinα)	They discuss existence of internal gravity waves in the core of the katabatic flow	Yes – Arguments presented to indicate how h is invariant along the slope (Prandtl model)	N
Largeron et al. (2013)	Variable (the work is for deep valley)	no	Numerical work	Two system of oscillations in the katabatic (ωk) and in the gravity wave (ωw)	ωK=Nsinα ωw=0.7-0.95 N	No specific discussion (interpretation is given for the formation of the gravity waves at the bottom of the valley – so different mechanism from Fleagle)	N

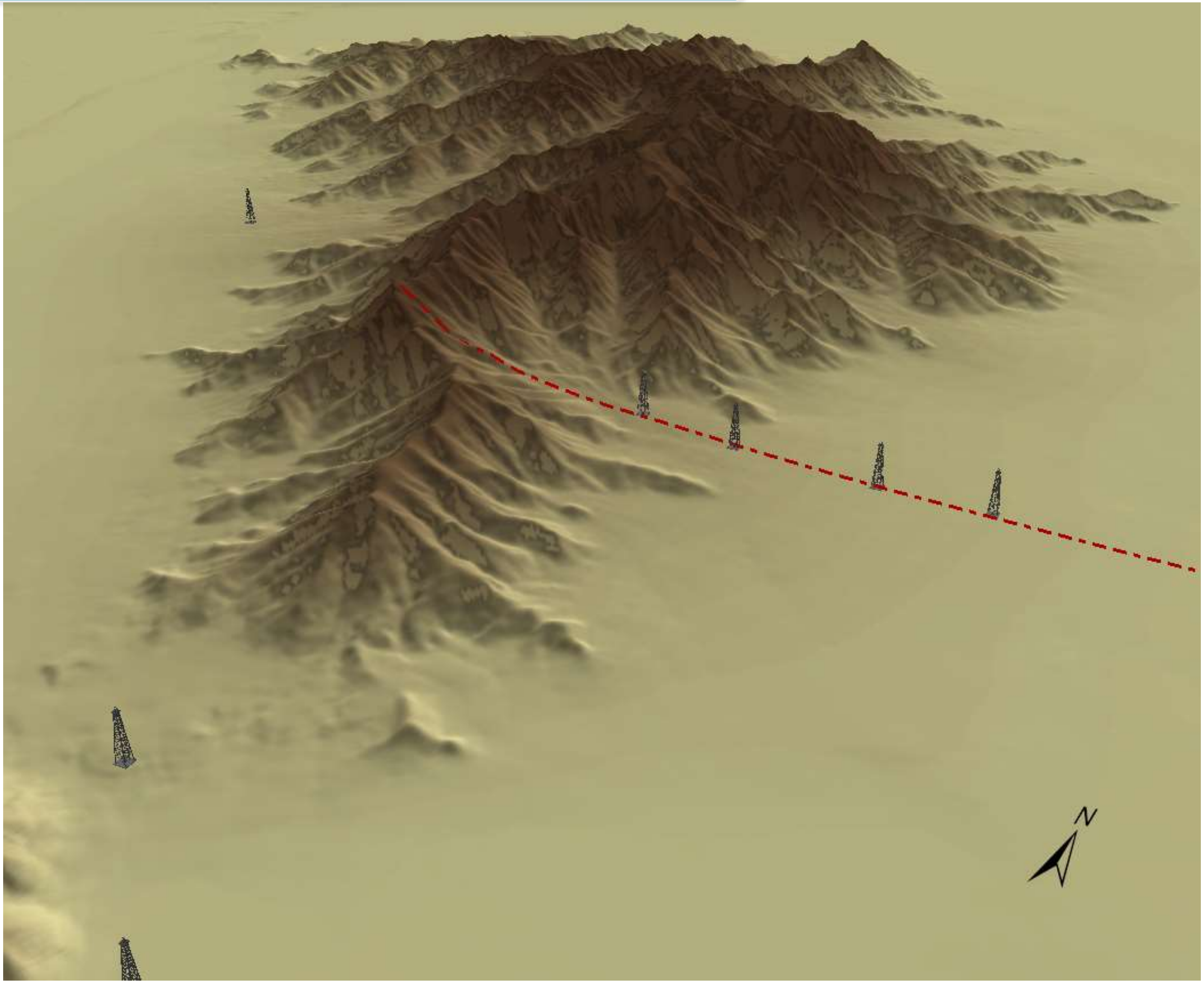
Introduction



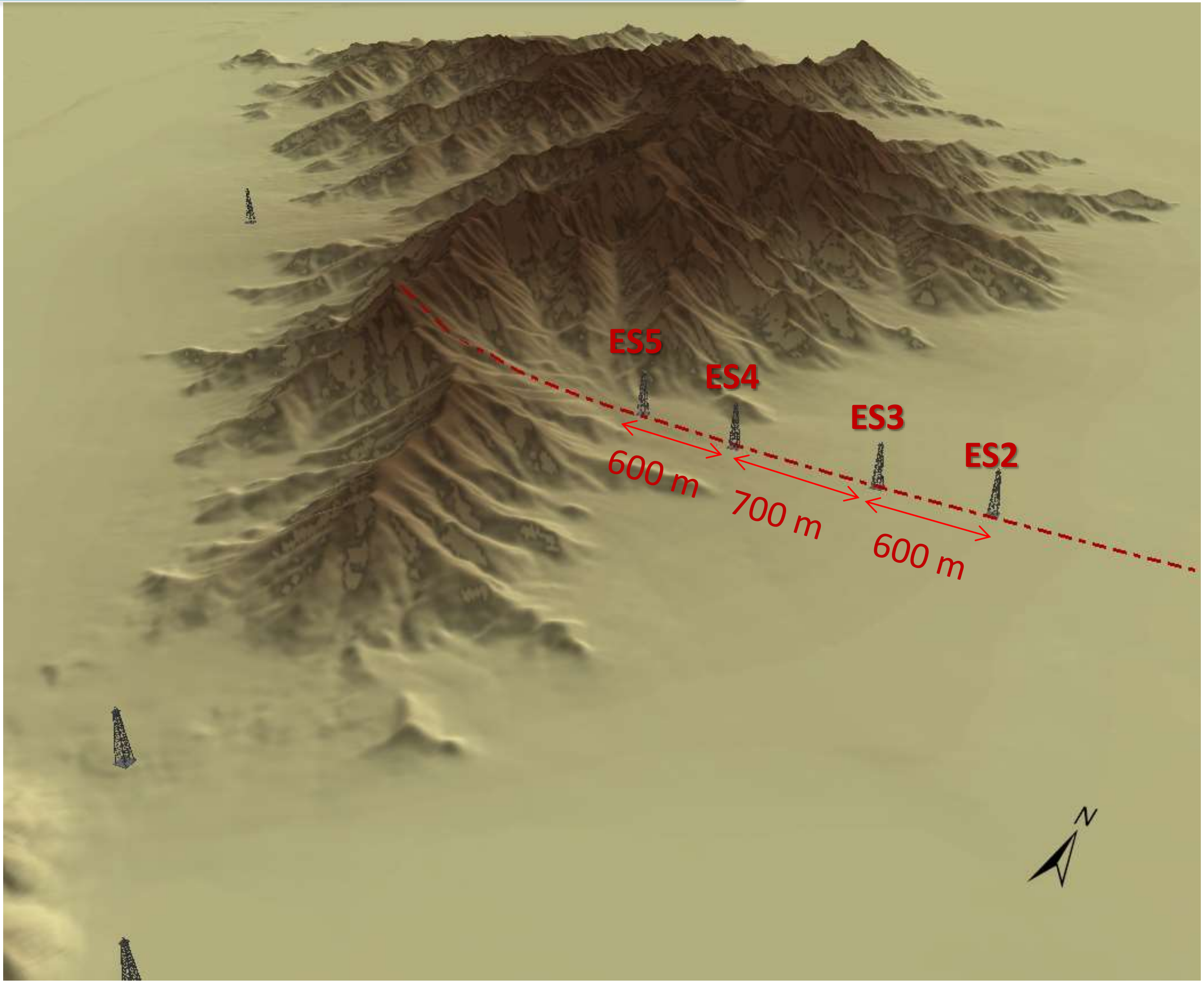
The Mountain Terrain Atmospheric Modeling and Observations (**MATERHORN**) Program is a Multidisciplinary University Research Initiative (MURI) designed to improve weather predictability in mountain terrain.

Materhorn X-1 : 30-day intense field campaign during **September 25-October 25, 2102** conducted at the **Granite Mountain Atmospheric Science Testbed** (GMAST) of the US Army Dugway Proving Grounds (DPG).

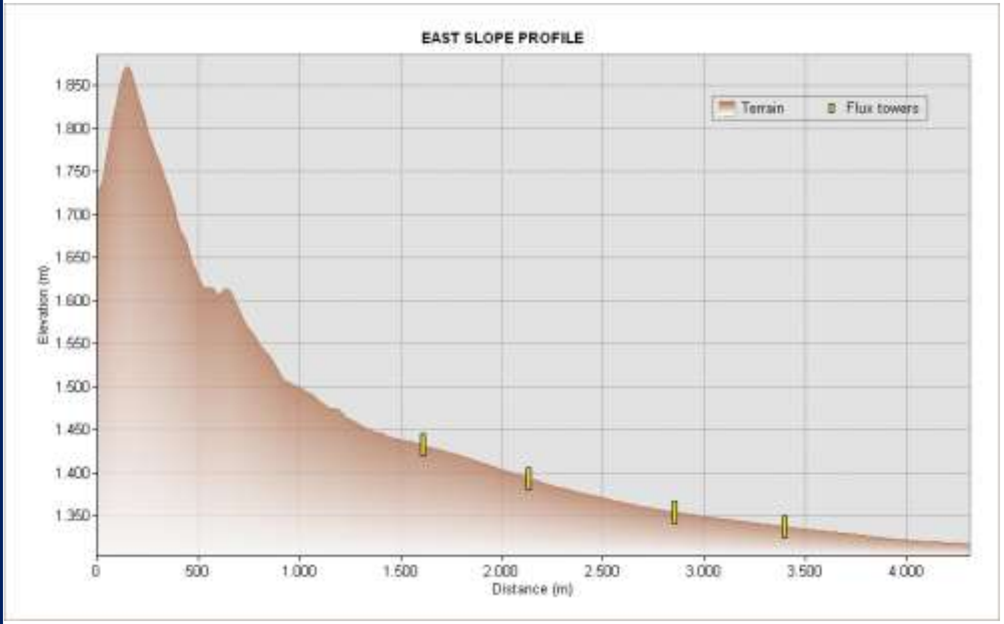
Experimental Site- East Slope of Granite

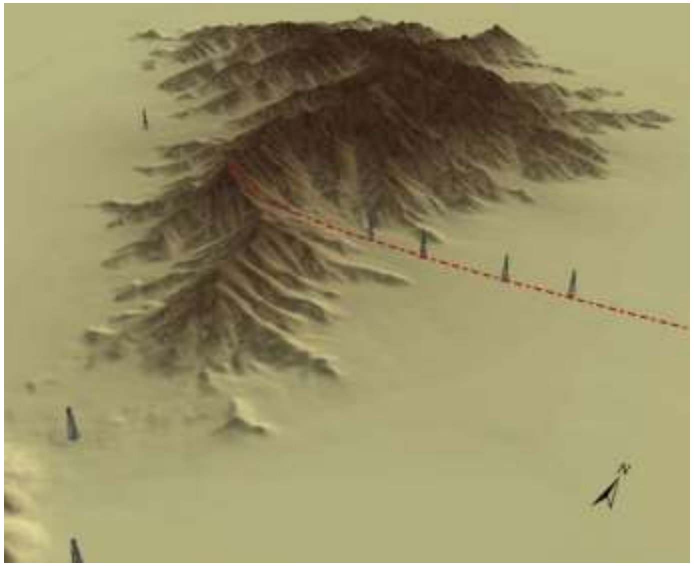


Experimental Site- East Slope of Granite



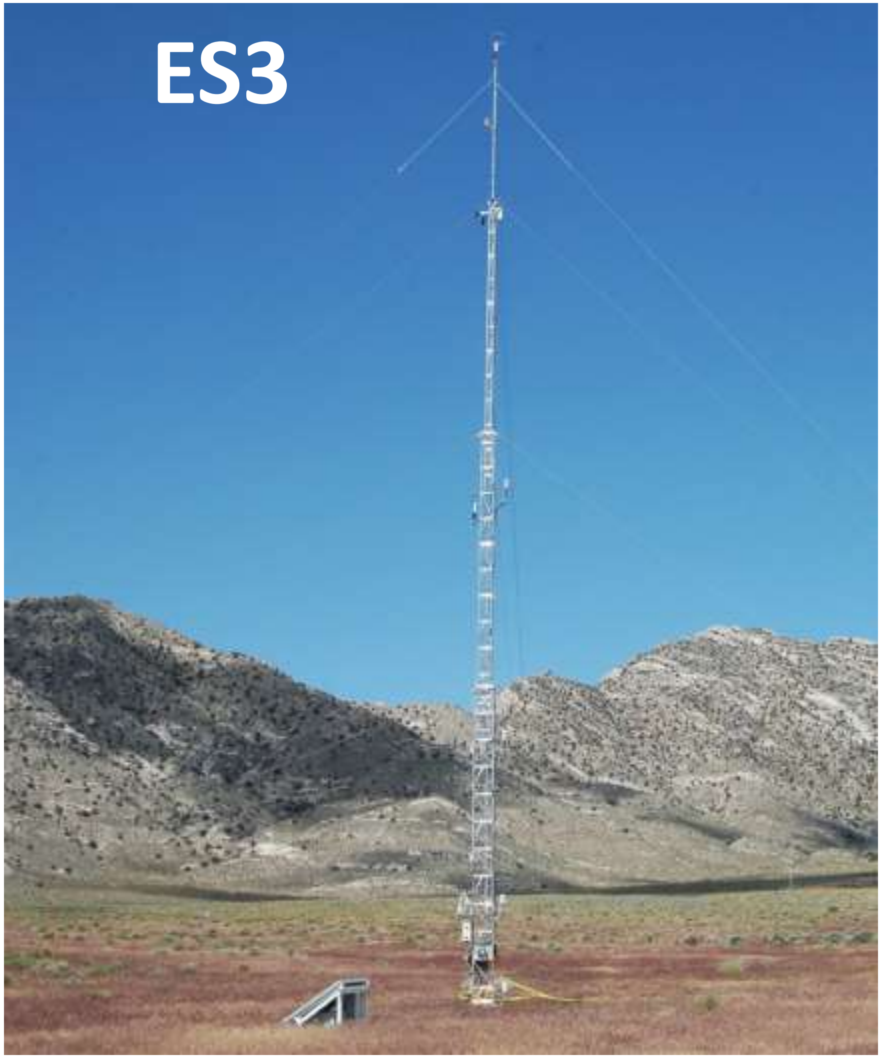
Estimation of the height of katabatic flow at East Slope of Granite





ES5 ~ 500 m	h ~ 3 m (Horst and Doran 1983)	h ~ 5 m (Princevac et al. 2008)
ES4 ~ 1100 m	h ~ 7 m	h ~ 11 m (Princevac et al. 2008)
ES3 ~ 1800 m	h~ 9 m	h ~ 17.5 m (Princevac et al. 2008)
ES2 ~ 2400 m	h ~ 13 m	h ~ 23 m (Princevac et al. 2008)

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

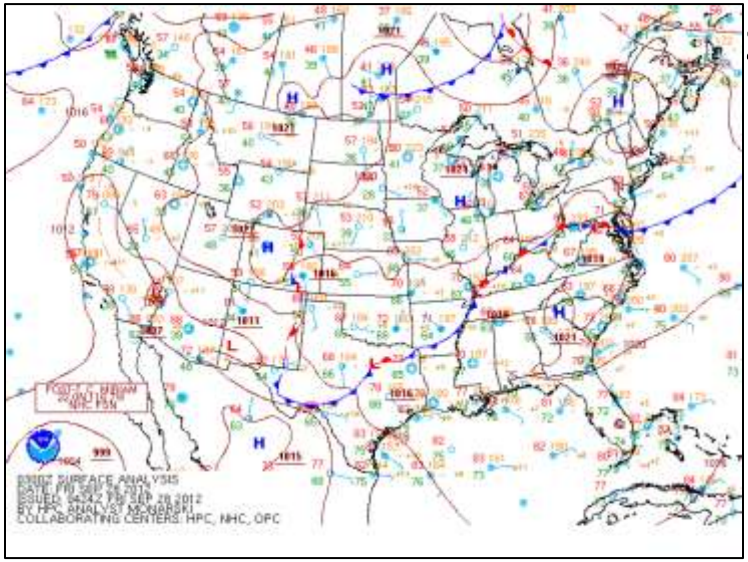
- **ES3 – 20 m tower**

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

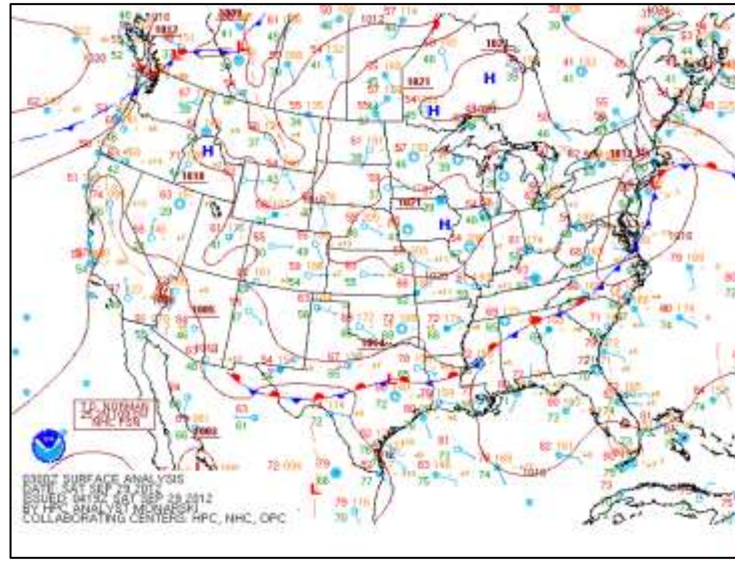
- **ES2 – 28 m tower**

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

Surface weather maps for Jdays 272-273-274 in the evening (03:00 UTC)



272



273

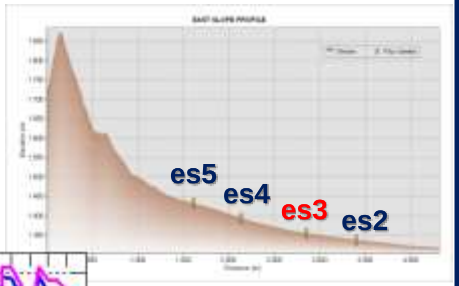
274

Sunset
01:17 UTC
(19:17 LC)

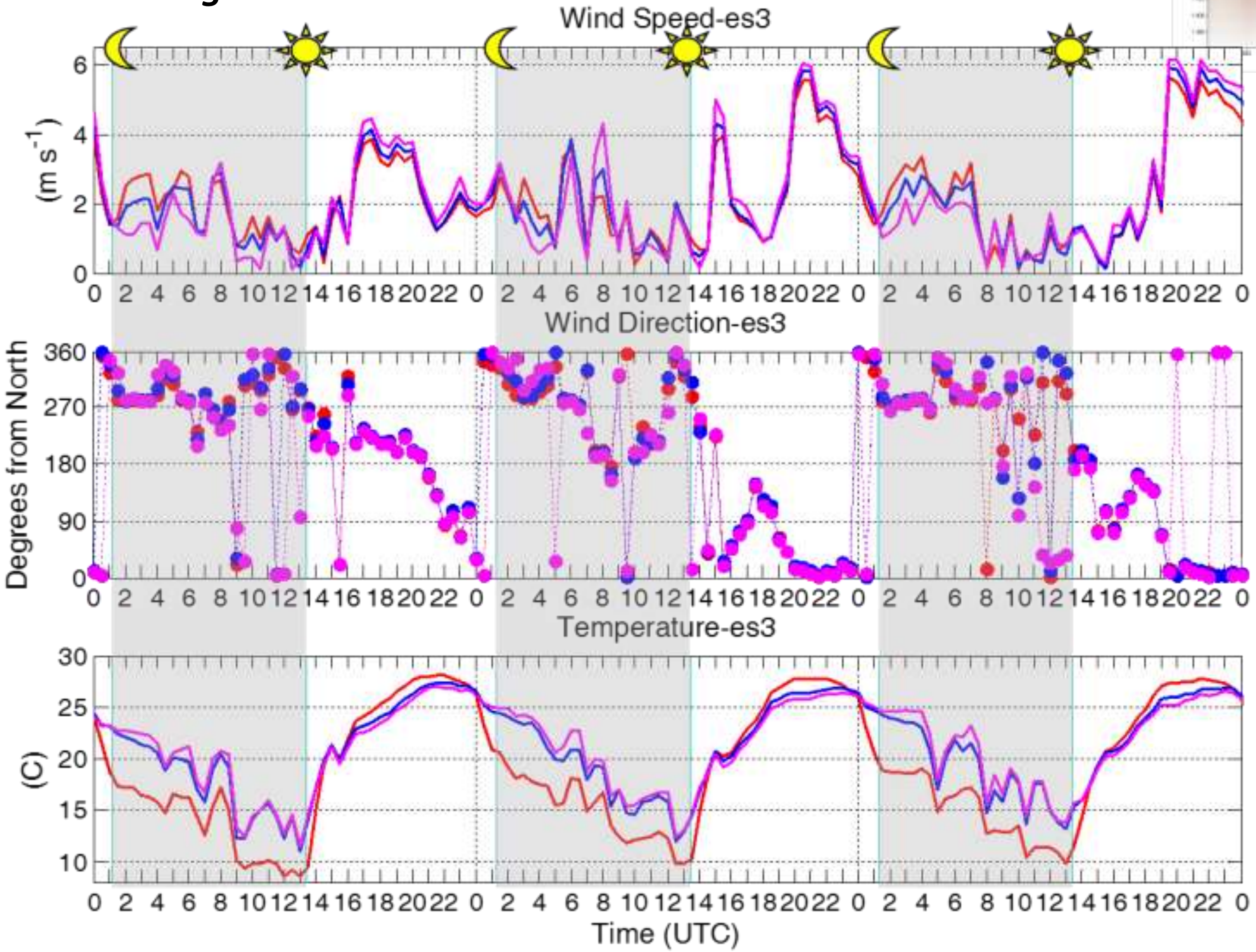
Sunrise
13:25 UTC
(07:25 LC)

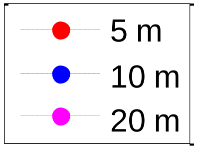
Preliminary Results

ES3 Tower
Jday 272-273 -274



30 min avg timeseries



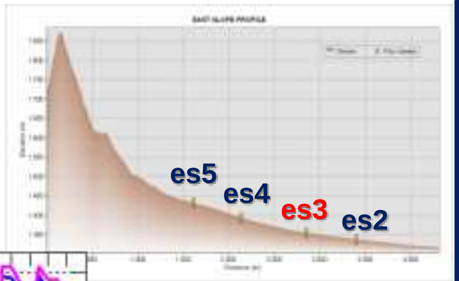


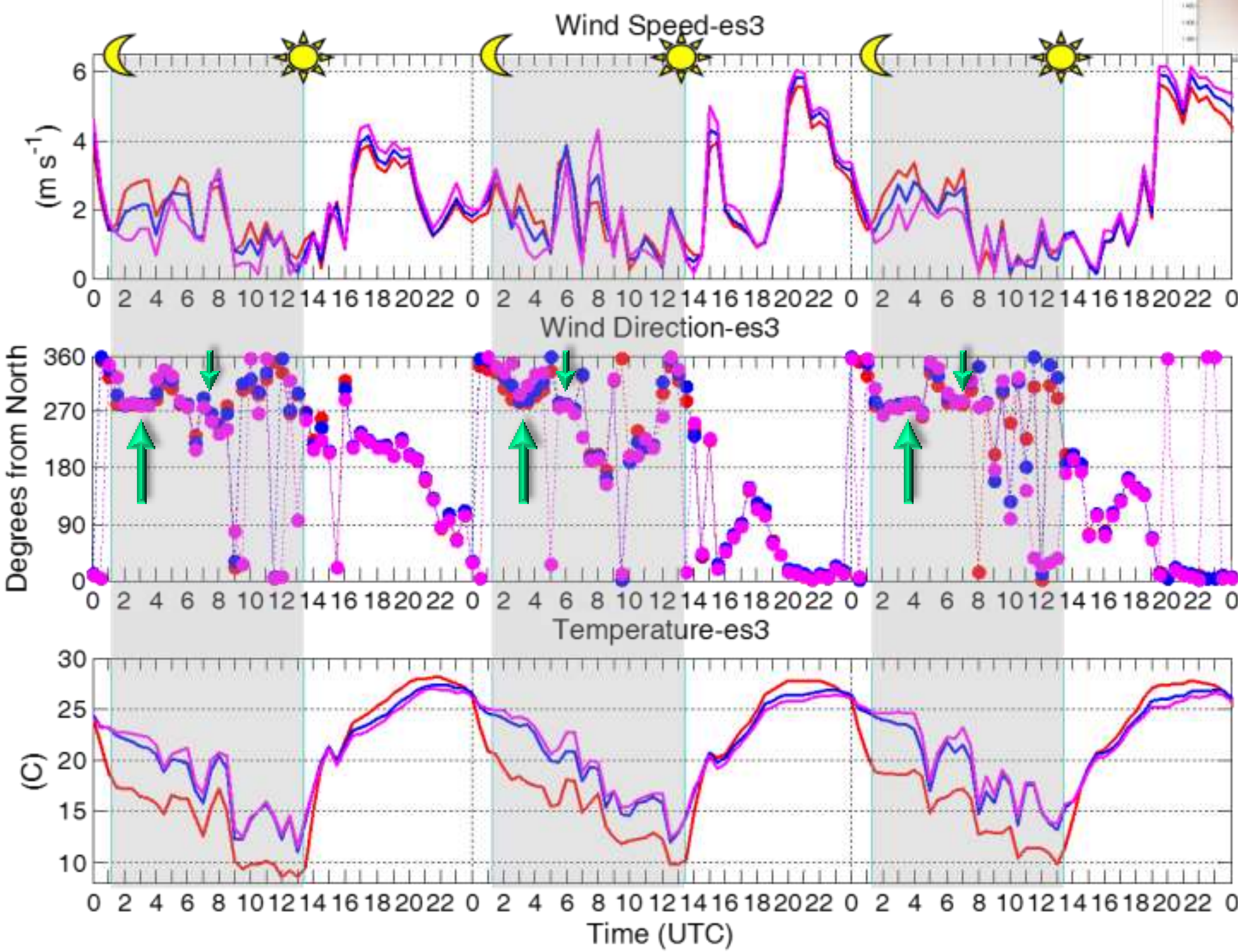
Sunset **01:17 UTC (19:17 LC)**

Sunrise **13:25 UTC (07:25 LC)**

Preliminary Results

Jday 272-273 -274
ES3 Tower

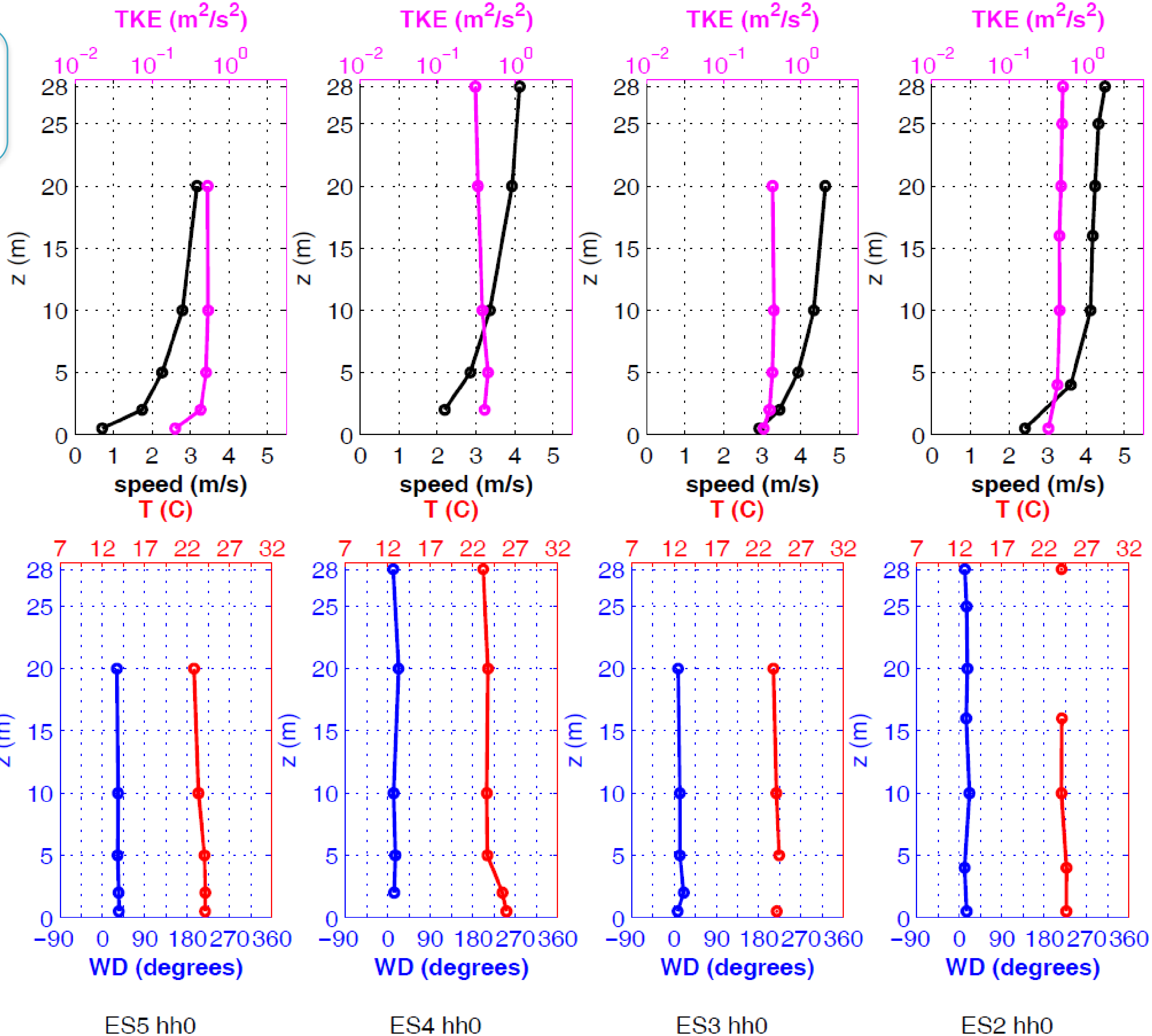




Sunset
01:17 UTC
(19:17 LC)

Sunrise
13:25 UTC
(07:25 LC)

Jday 272 (30 min avg)



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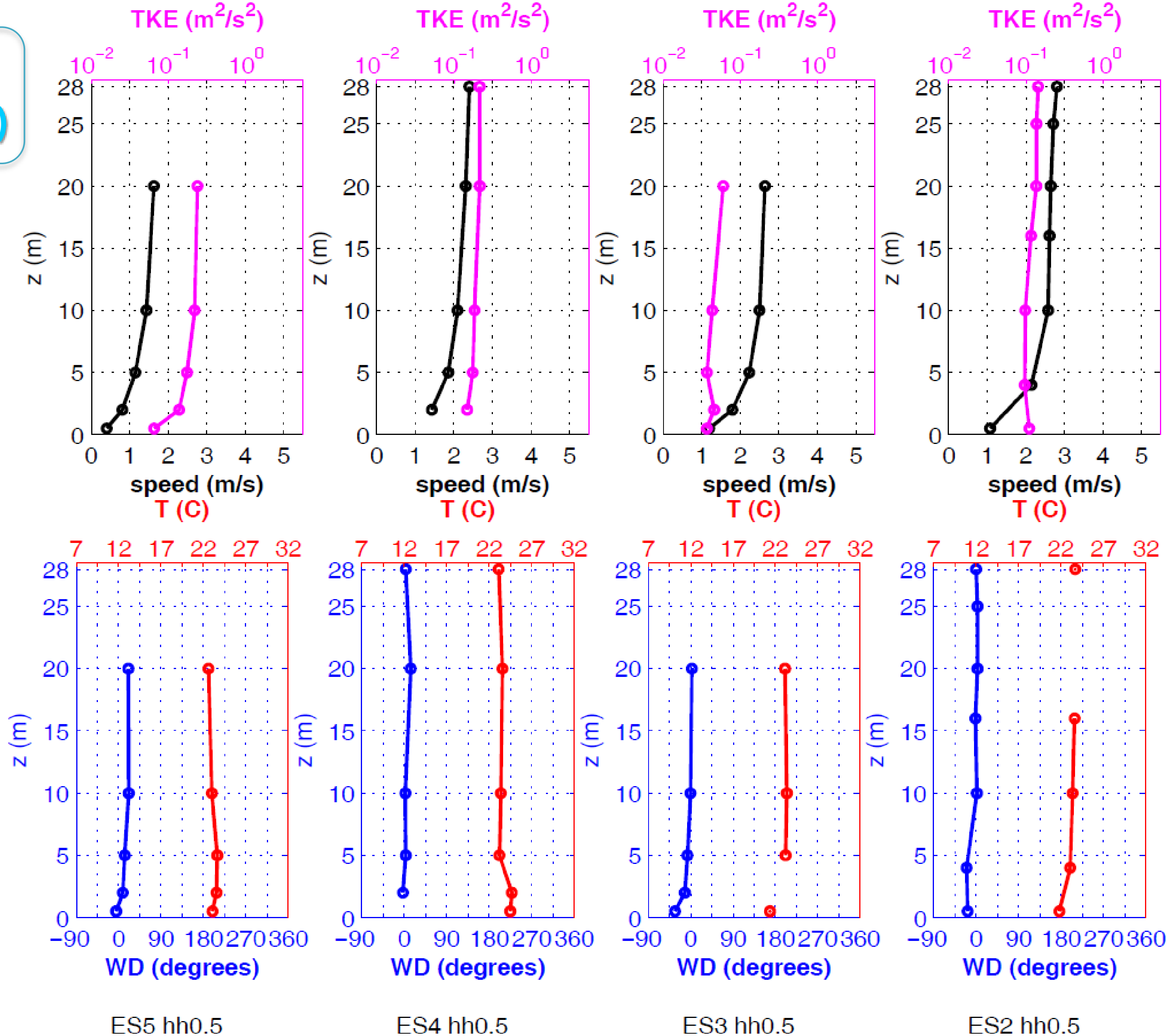

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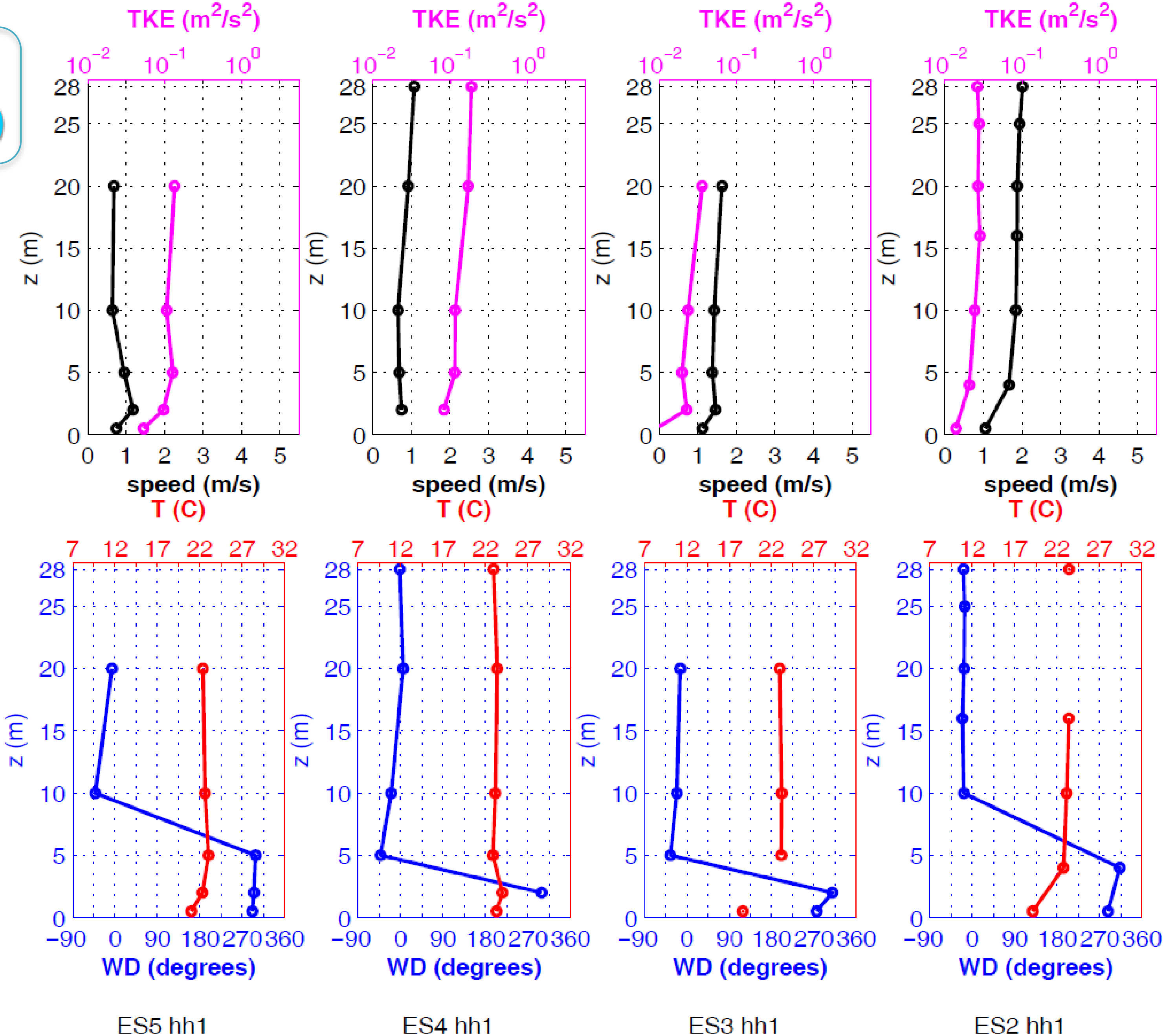

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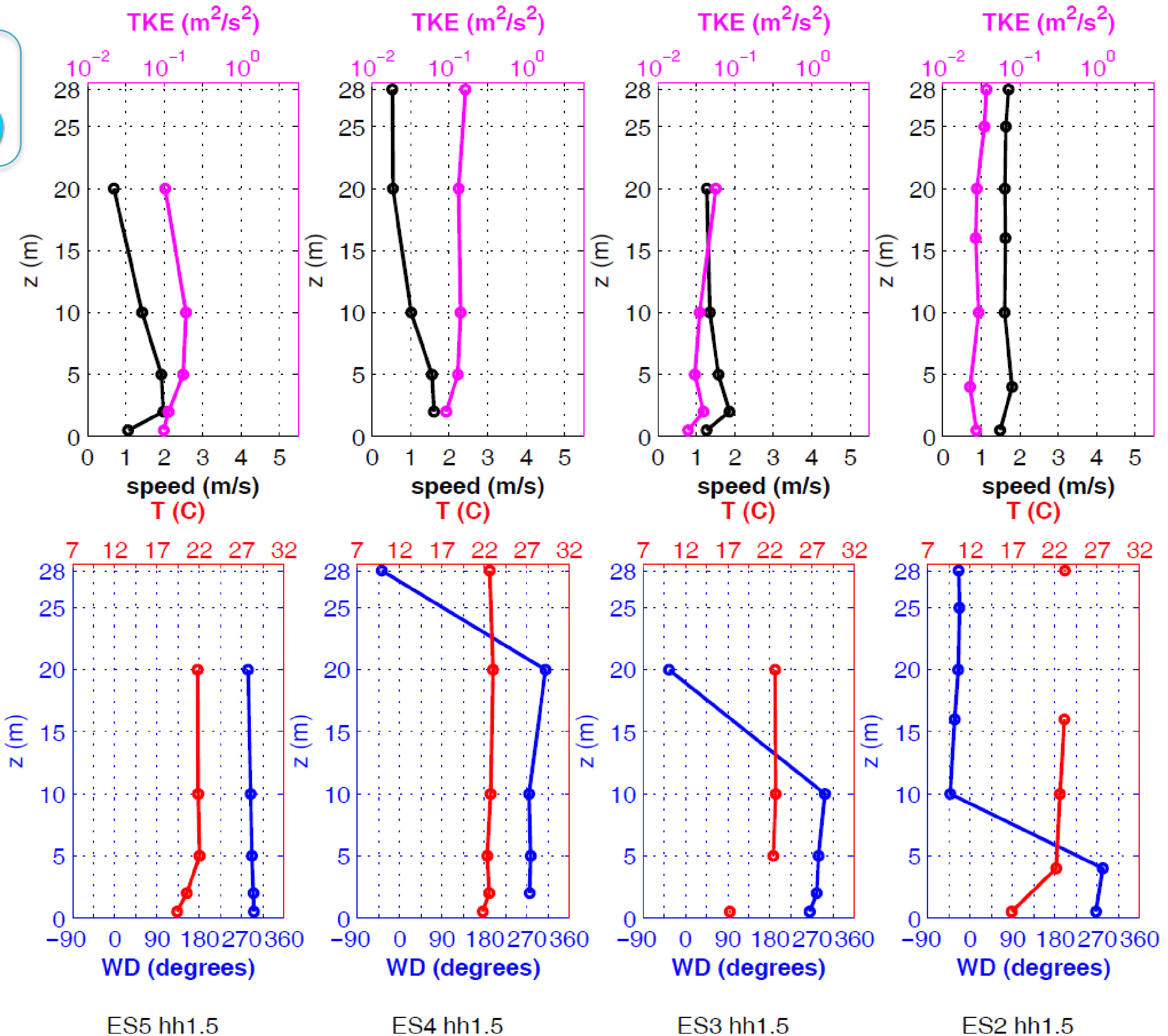

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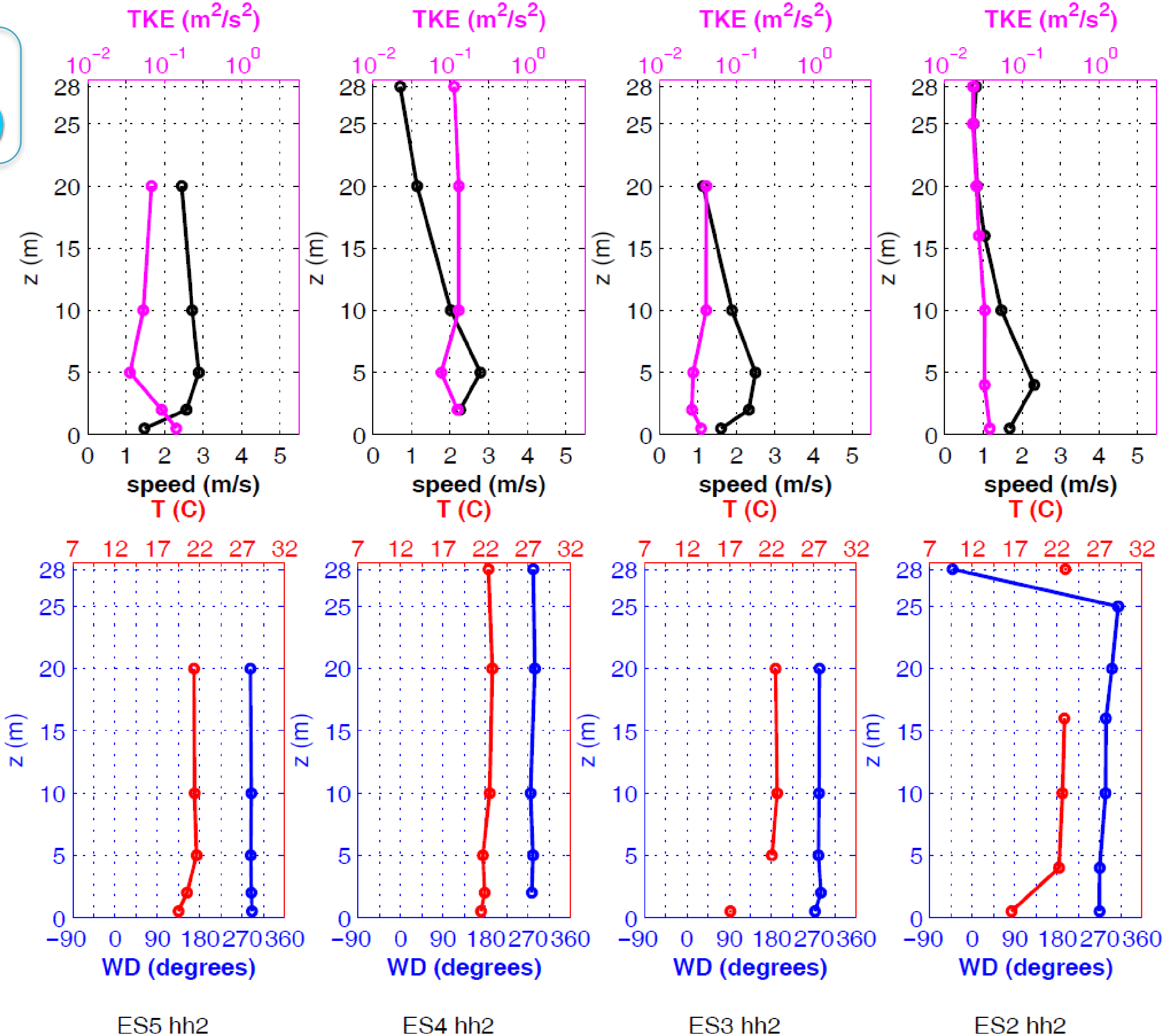

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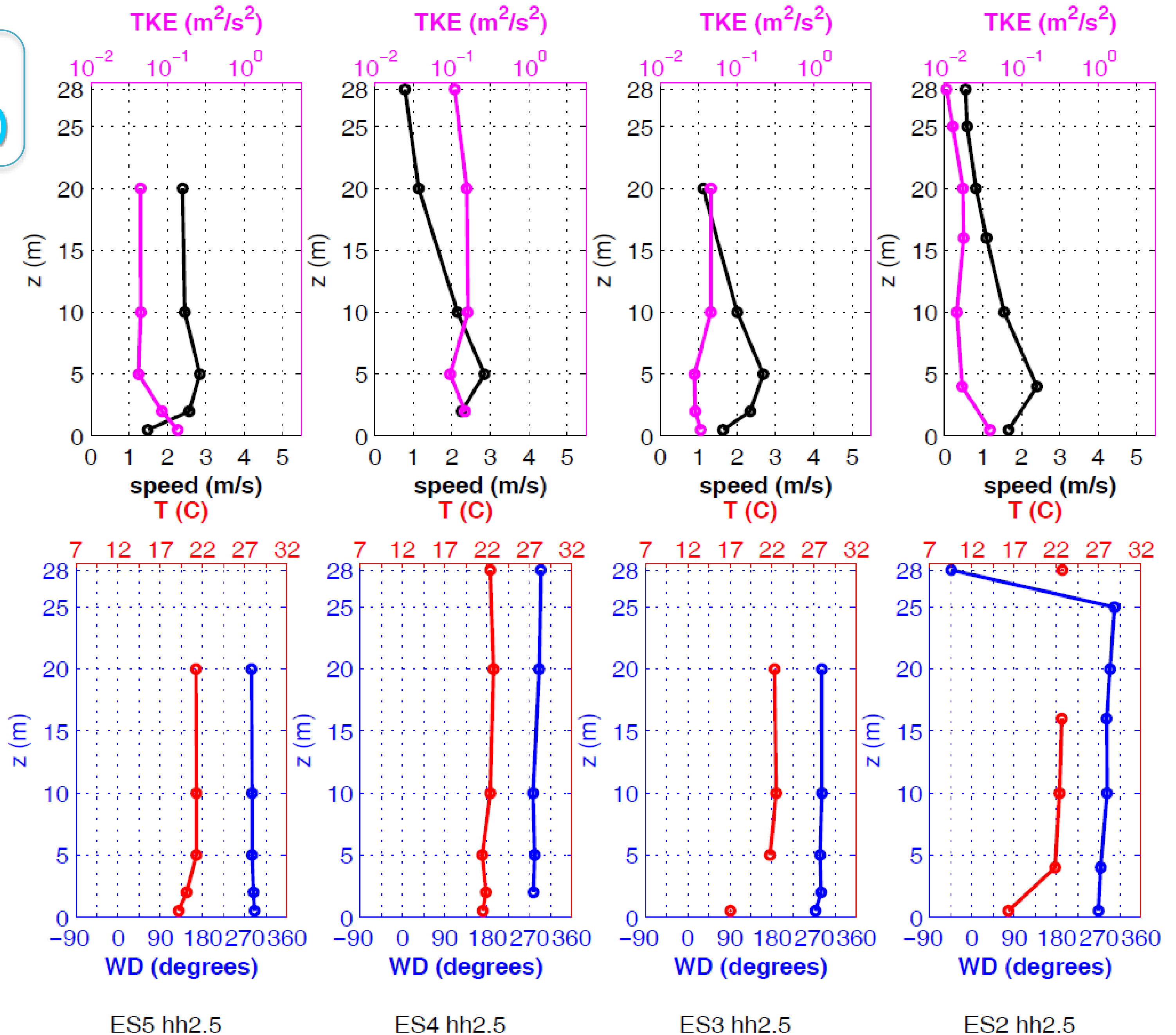

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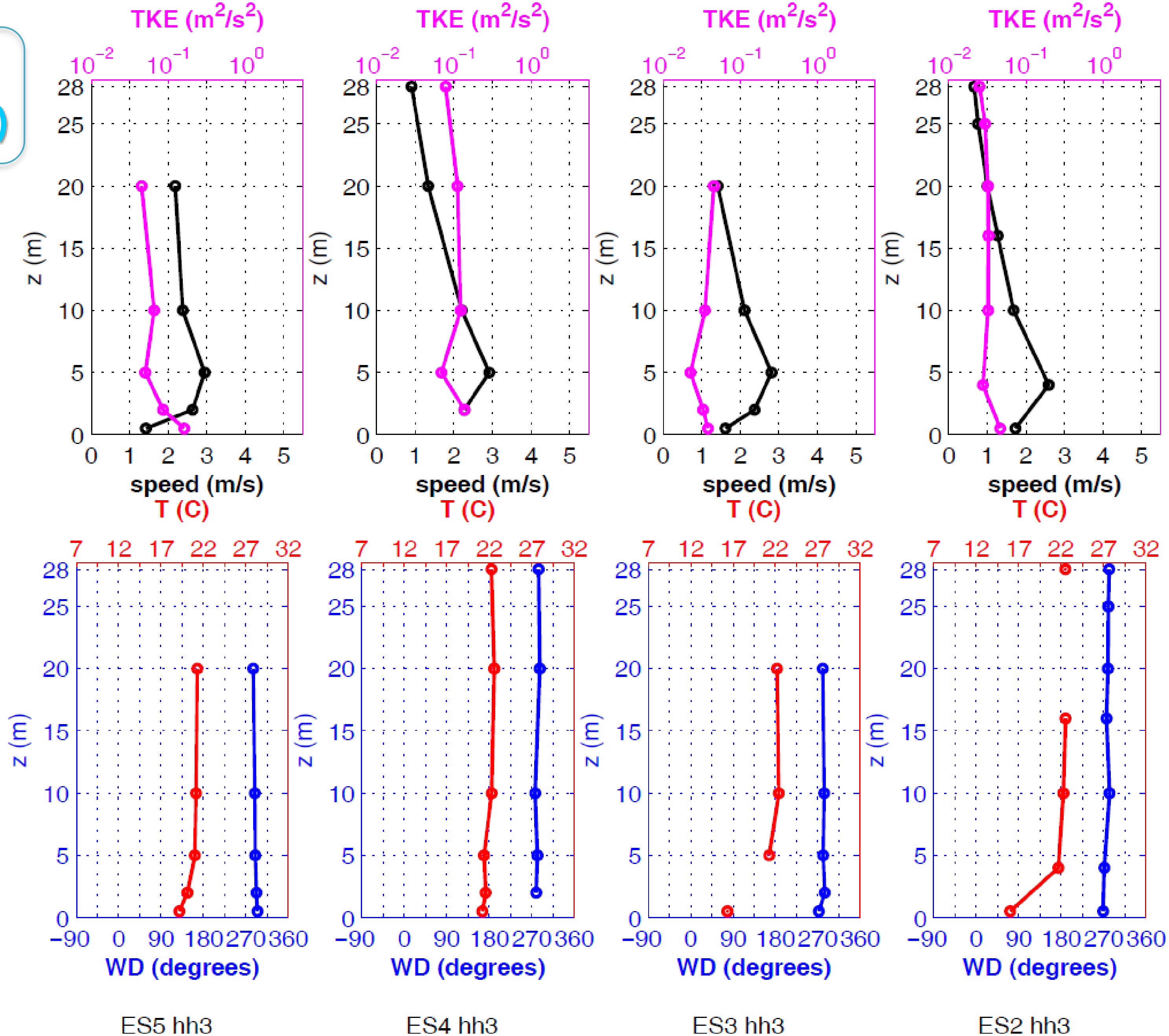

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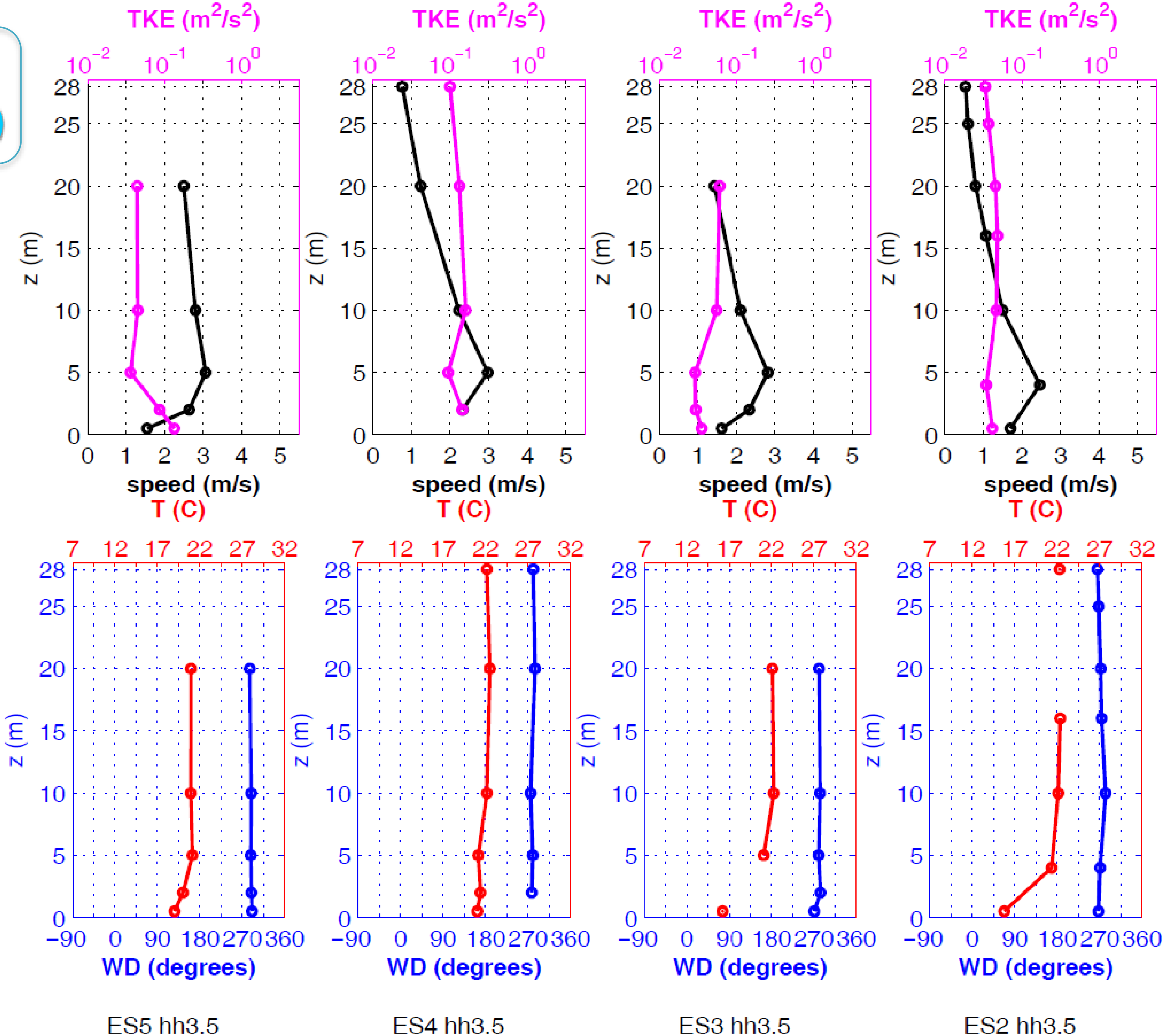

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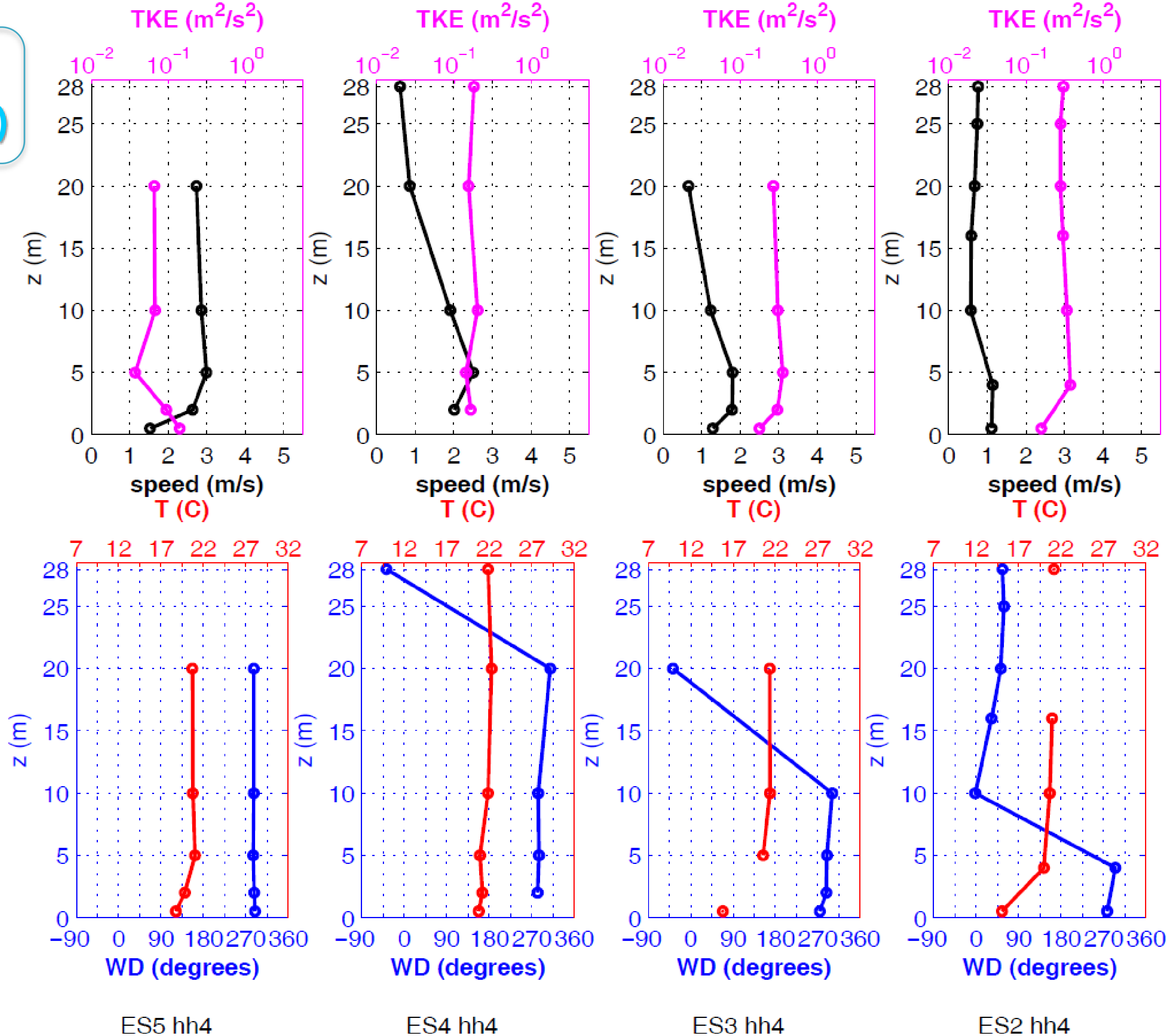

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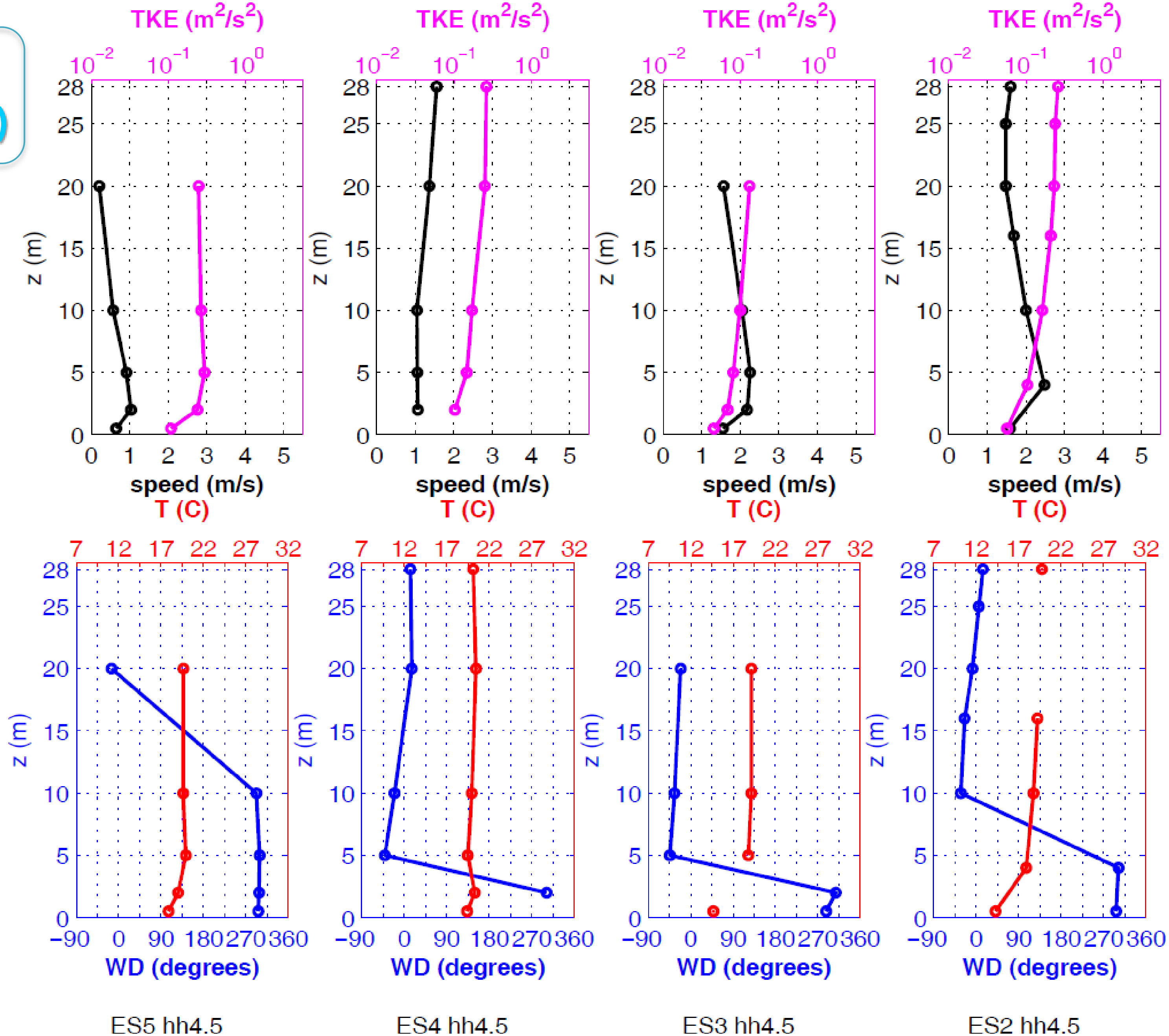

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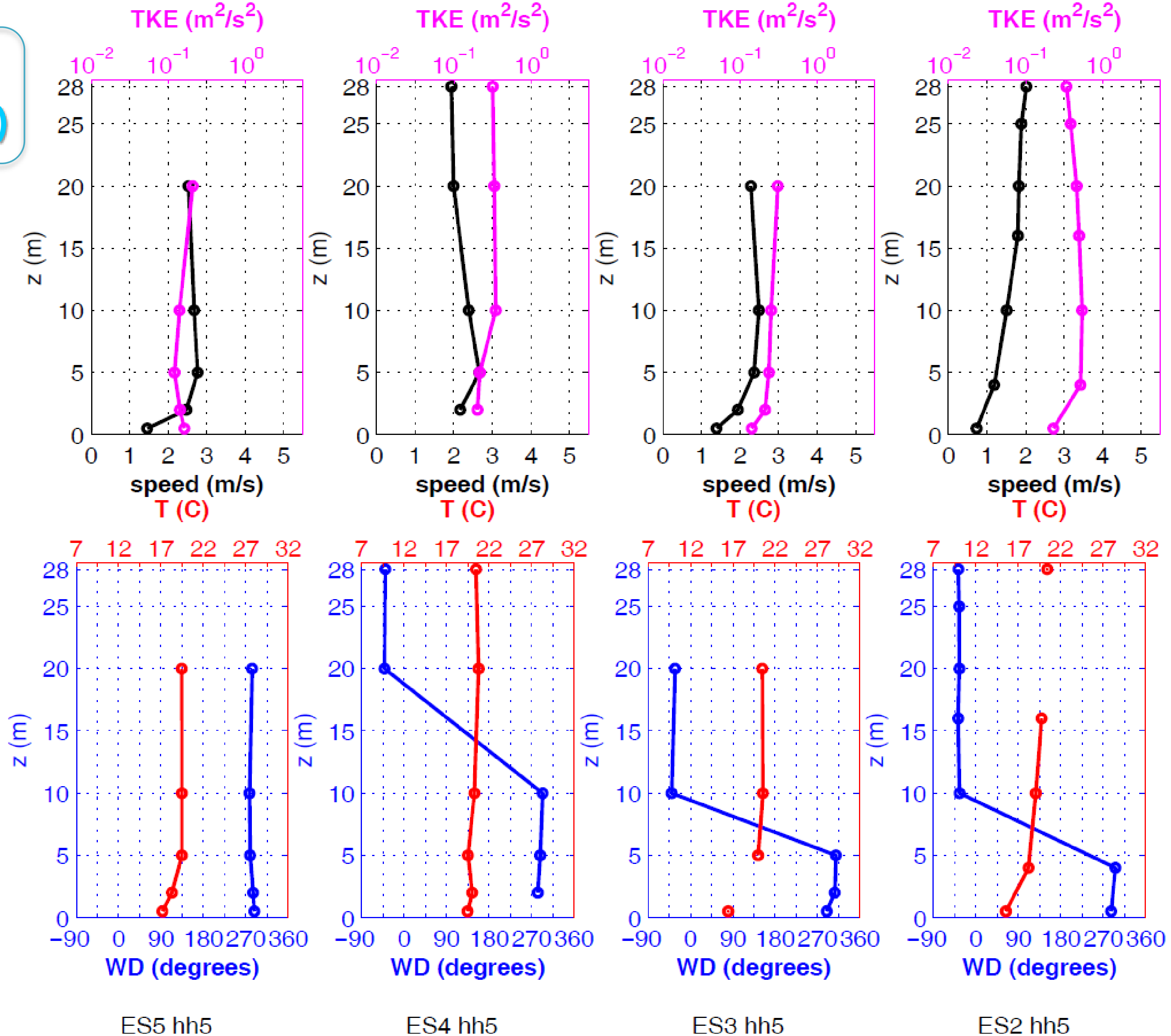
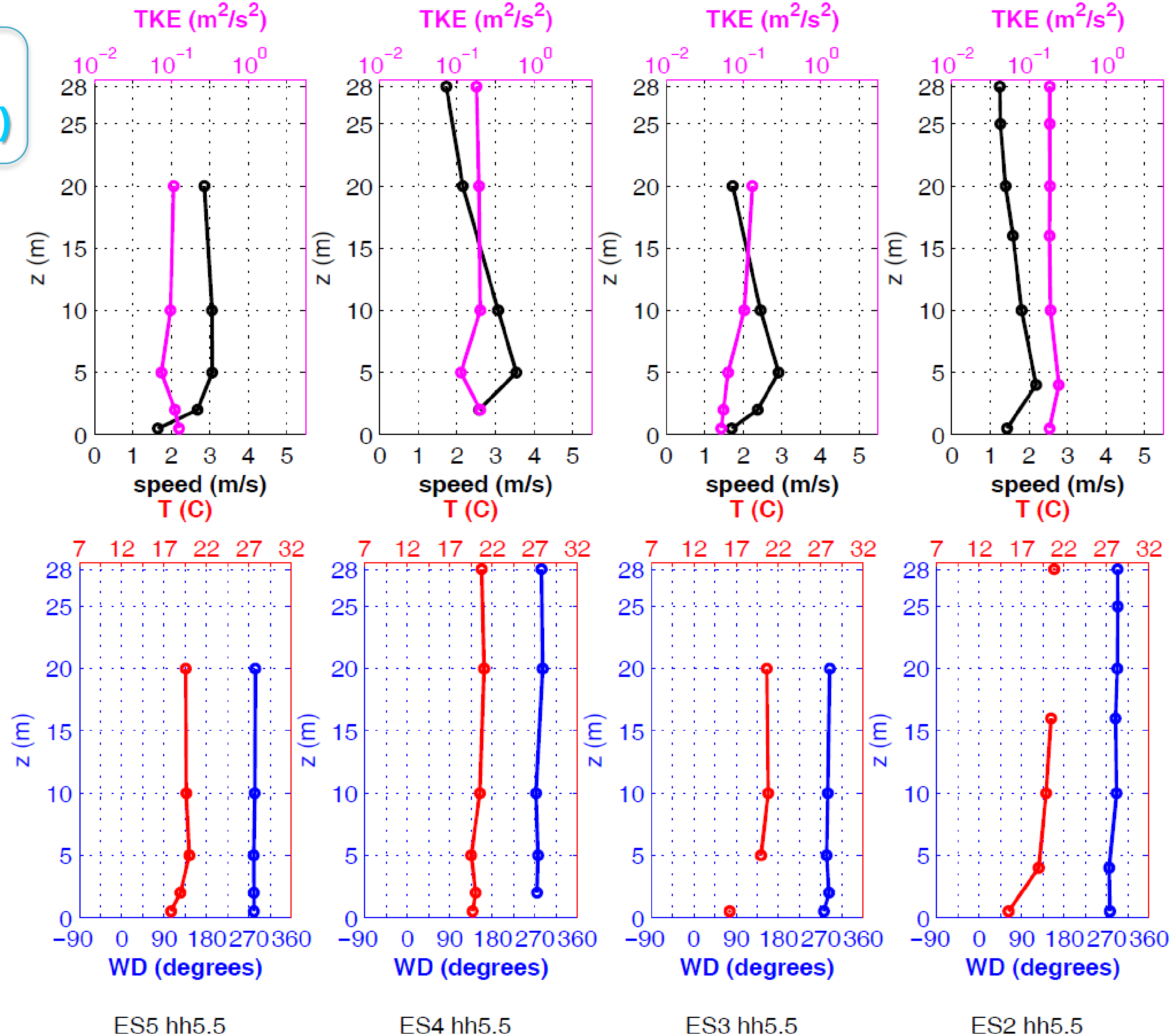


**Jday 272
(30 min avg)**



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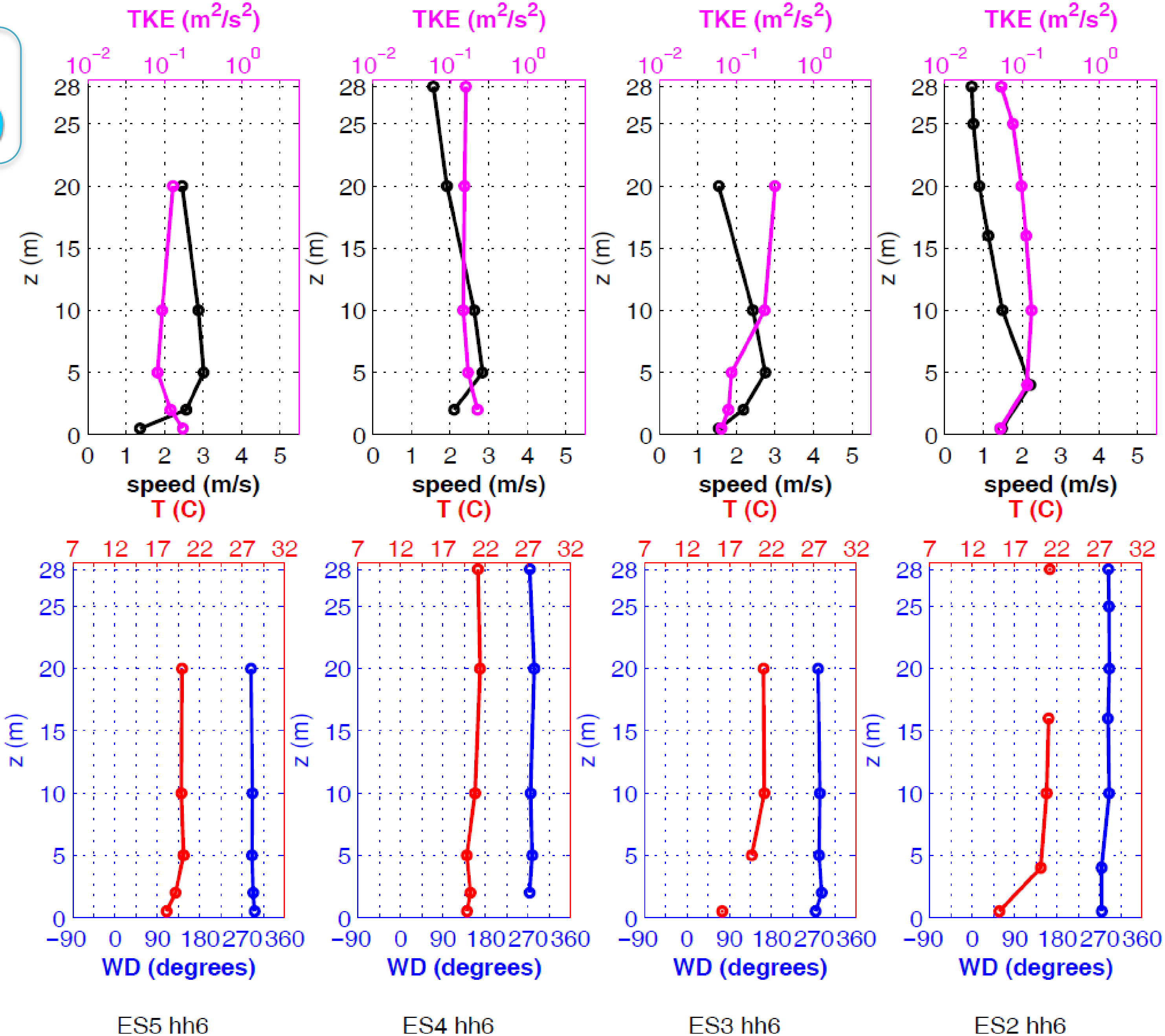

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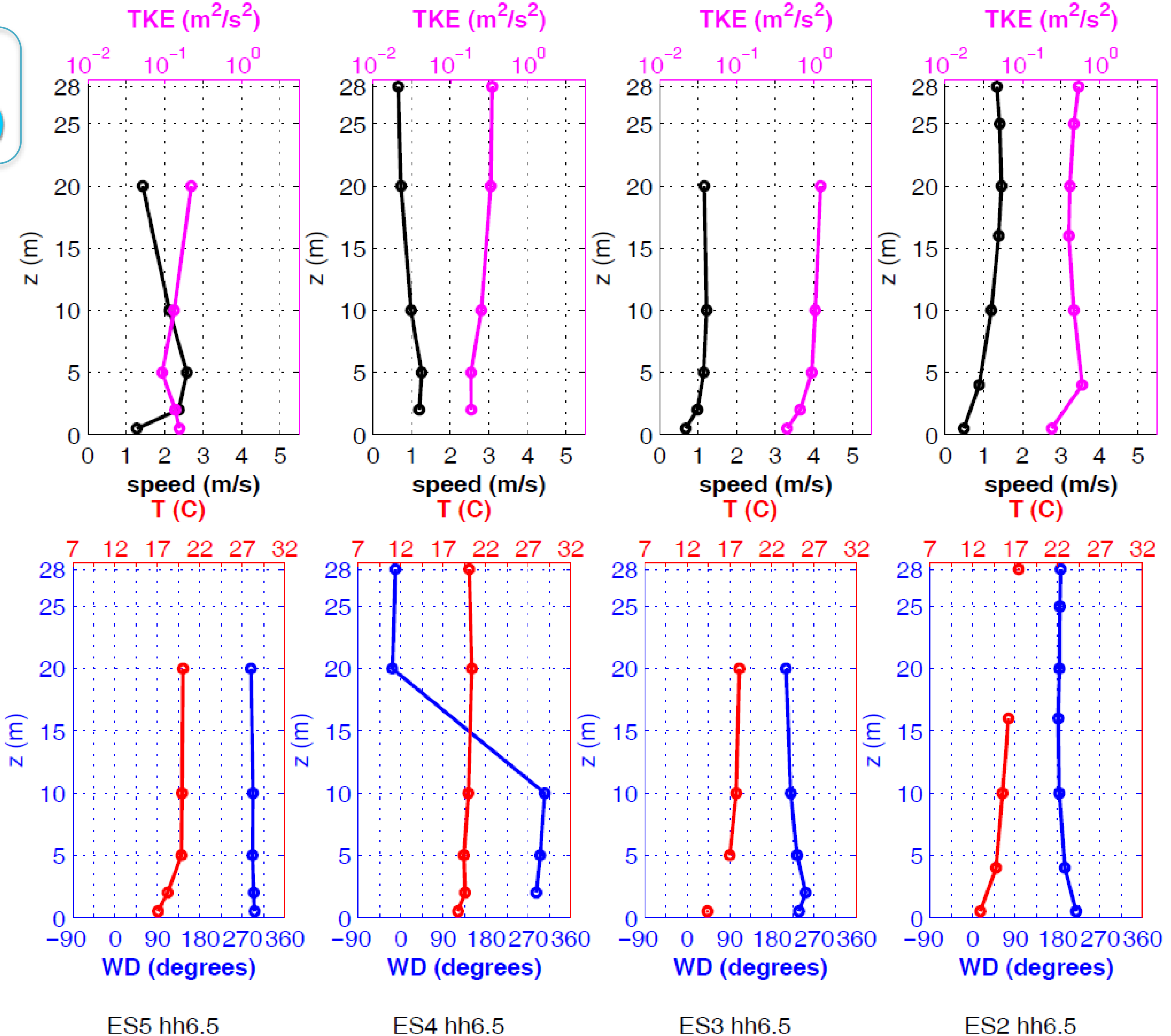

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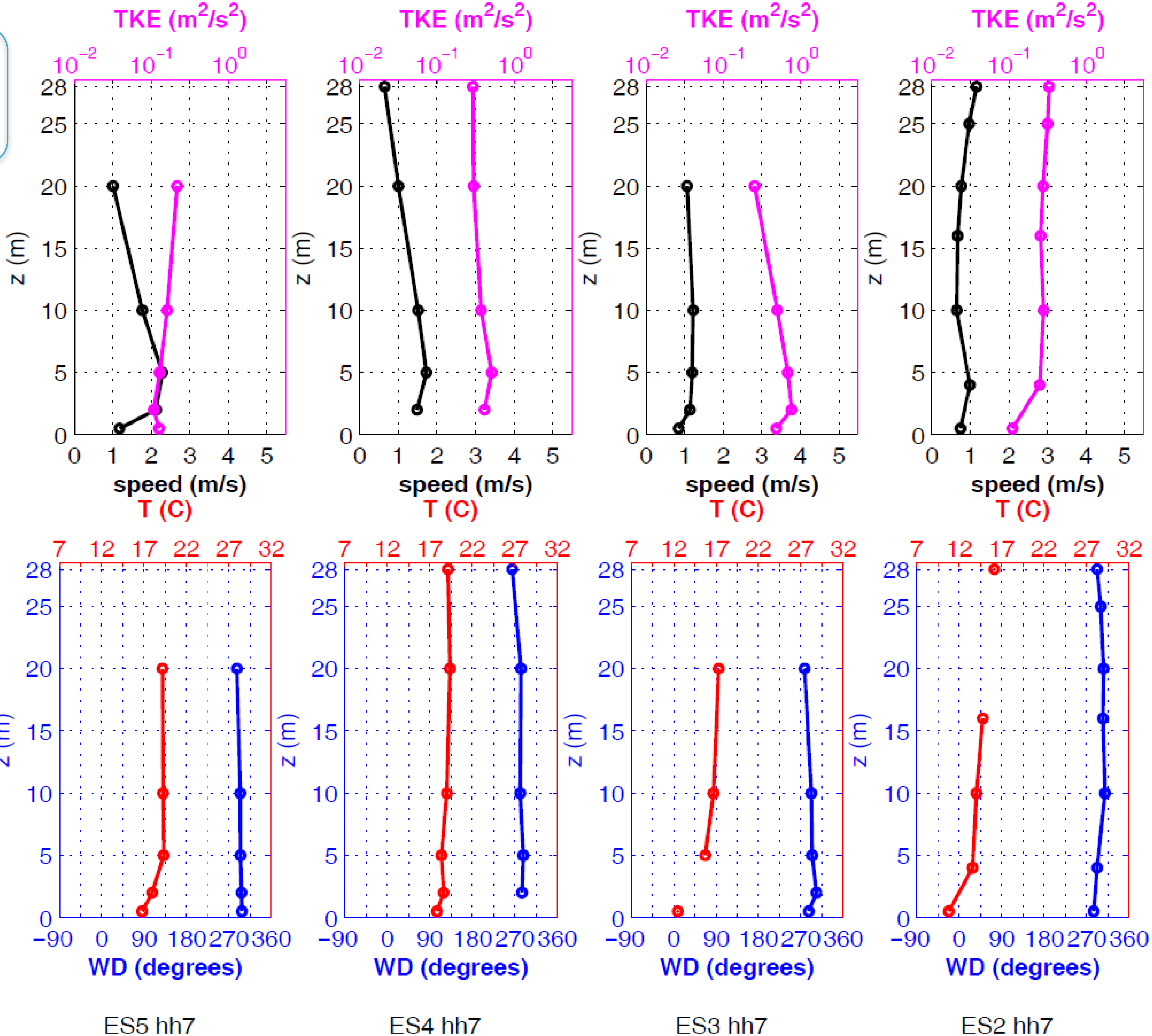

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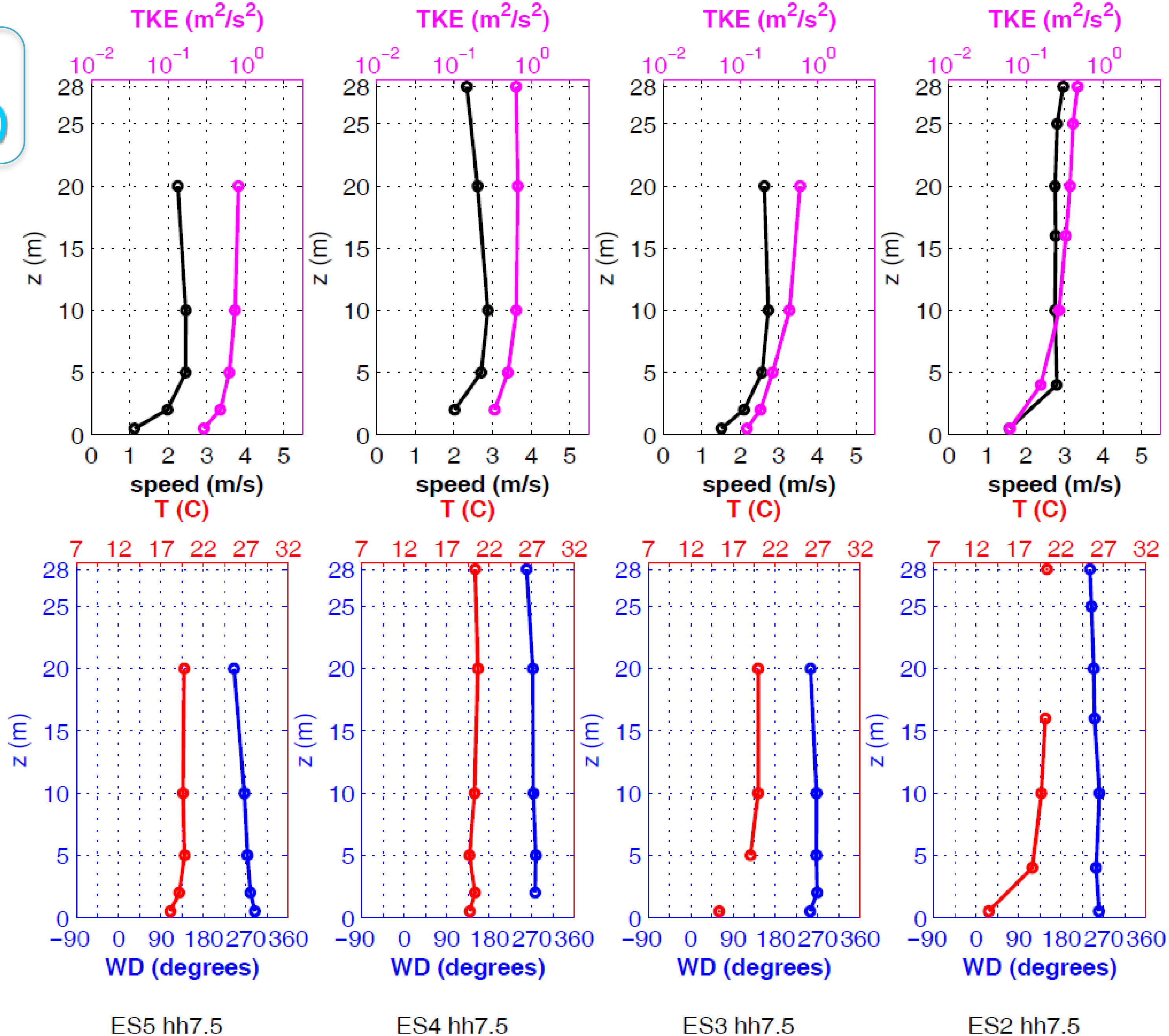

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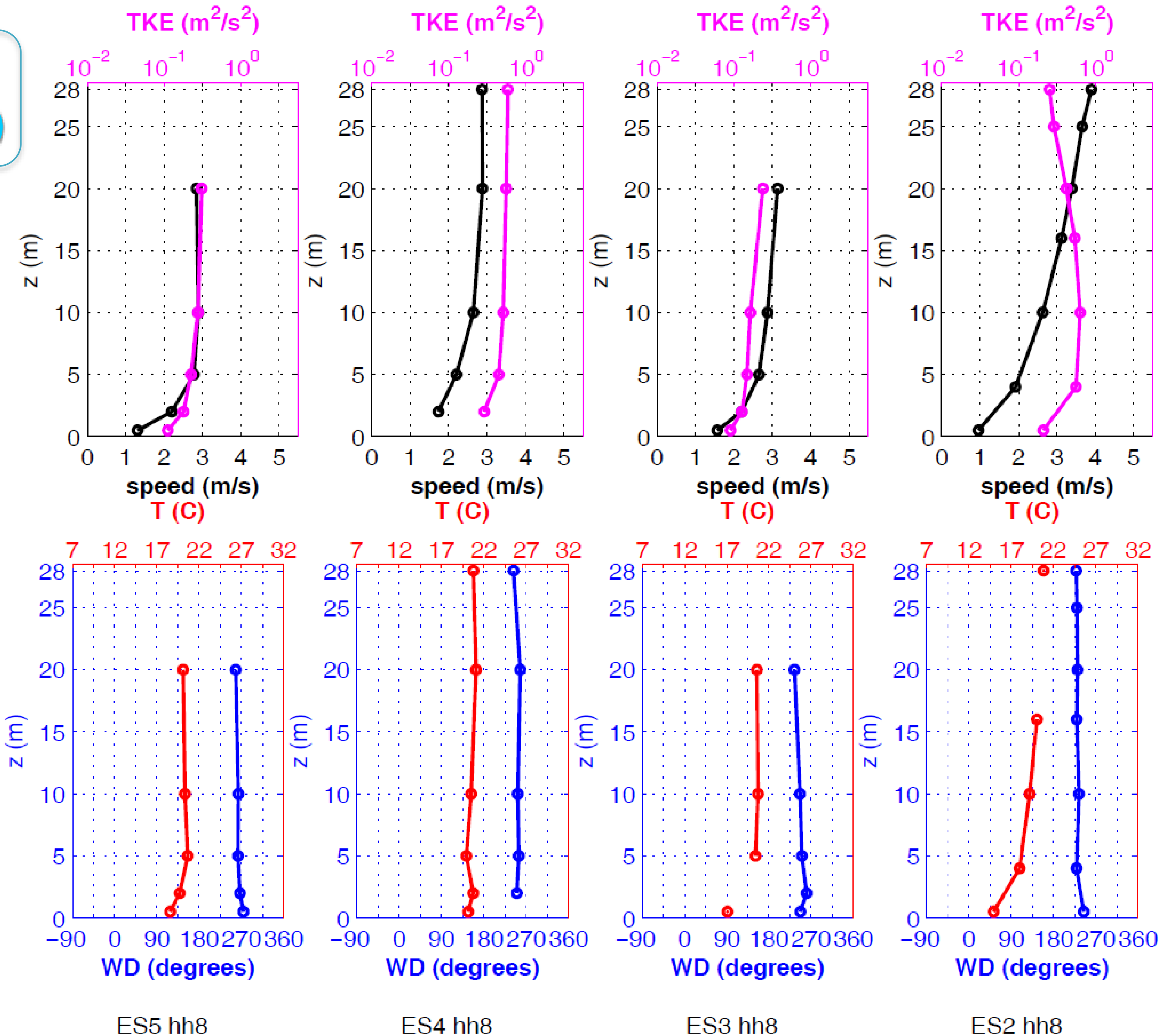

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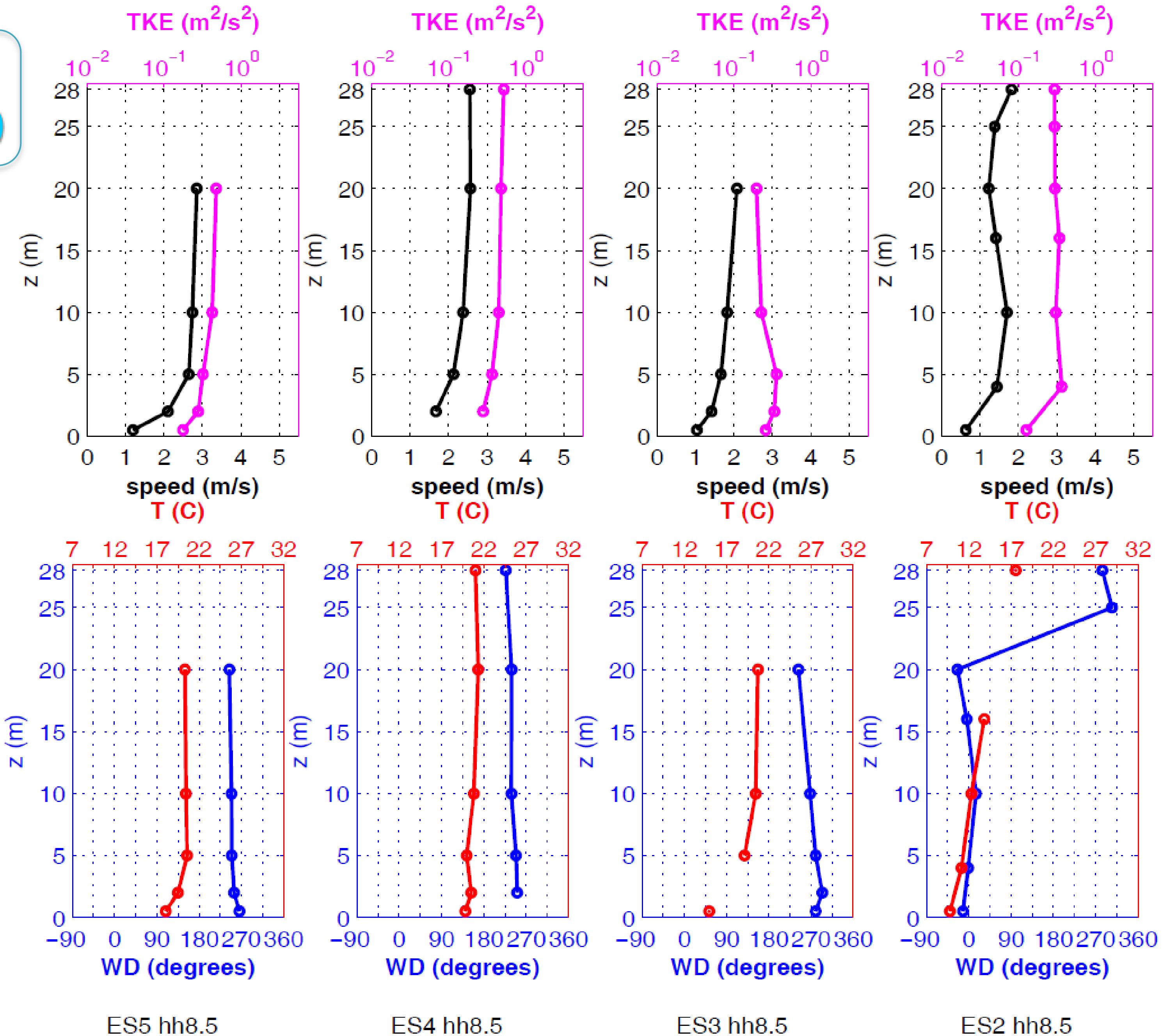

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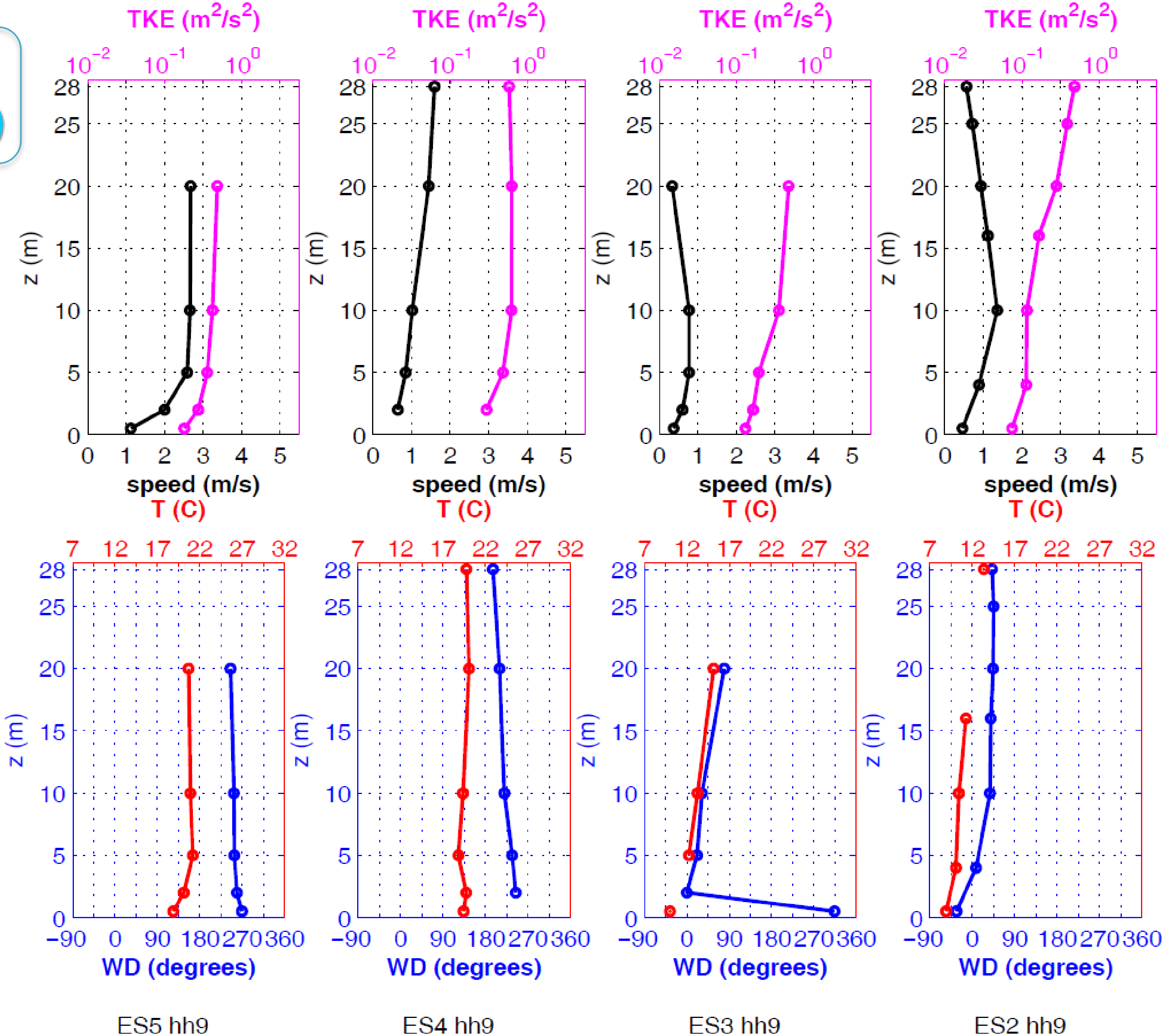

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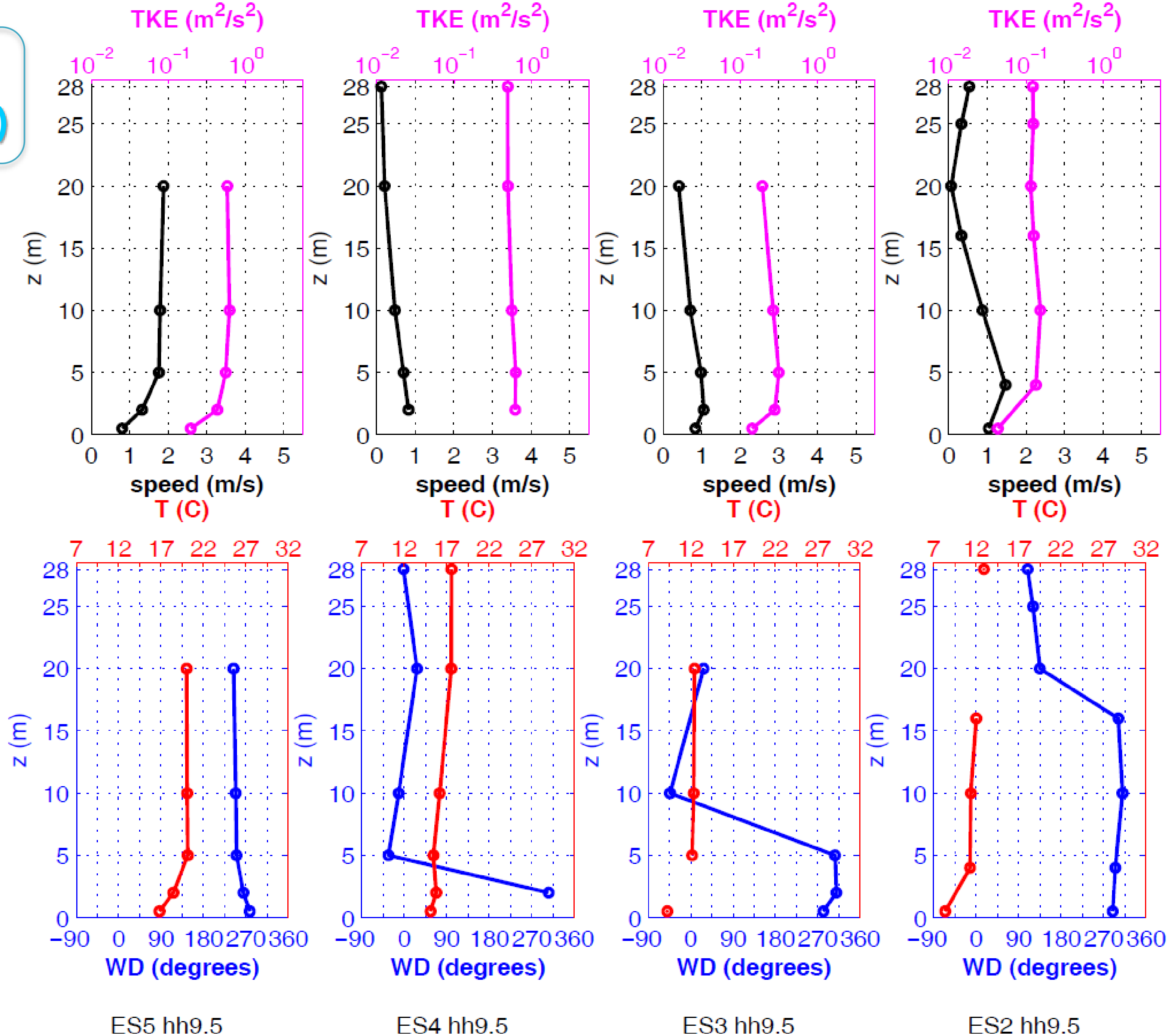

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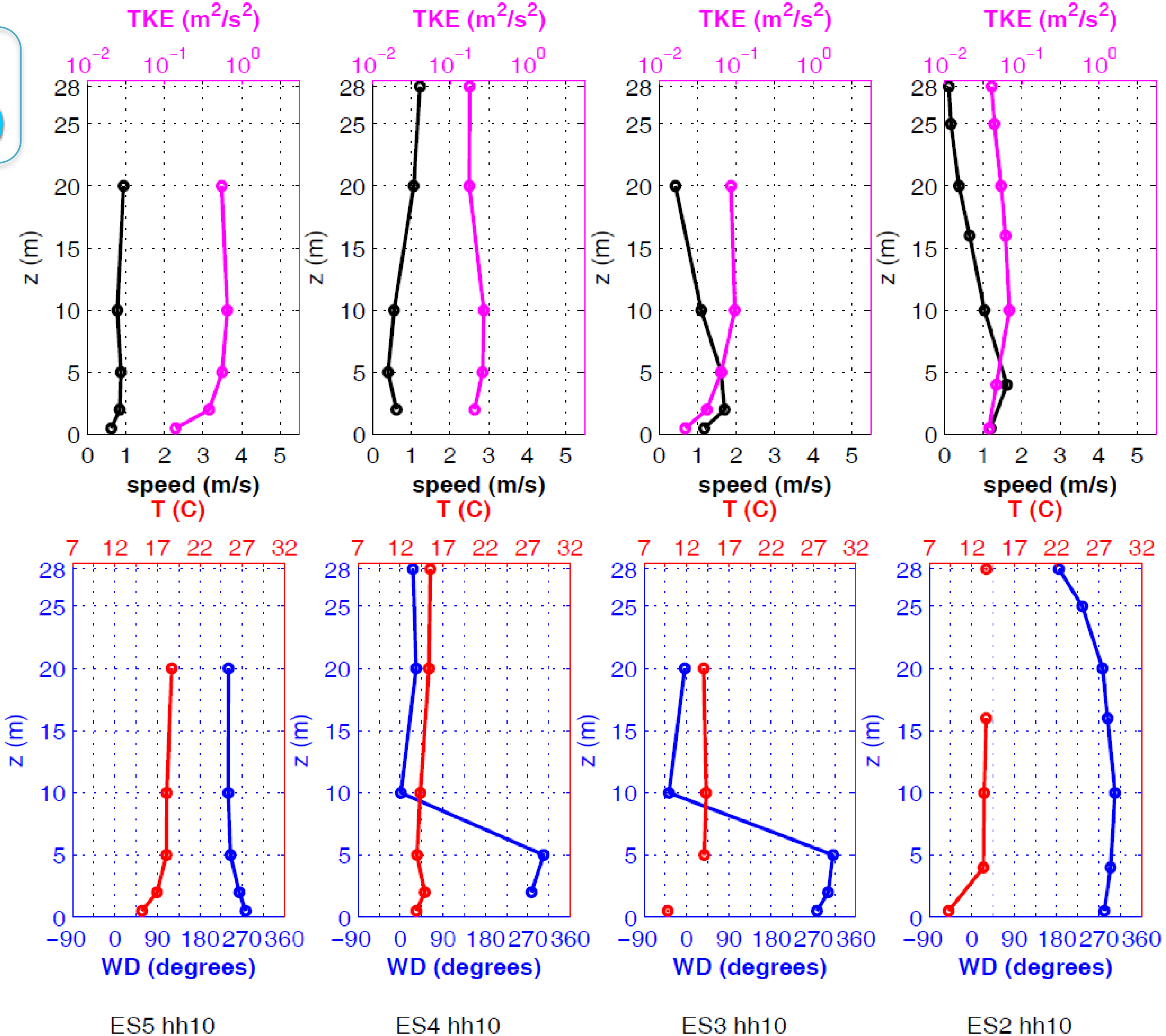

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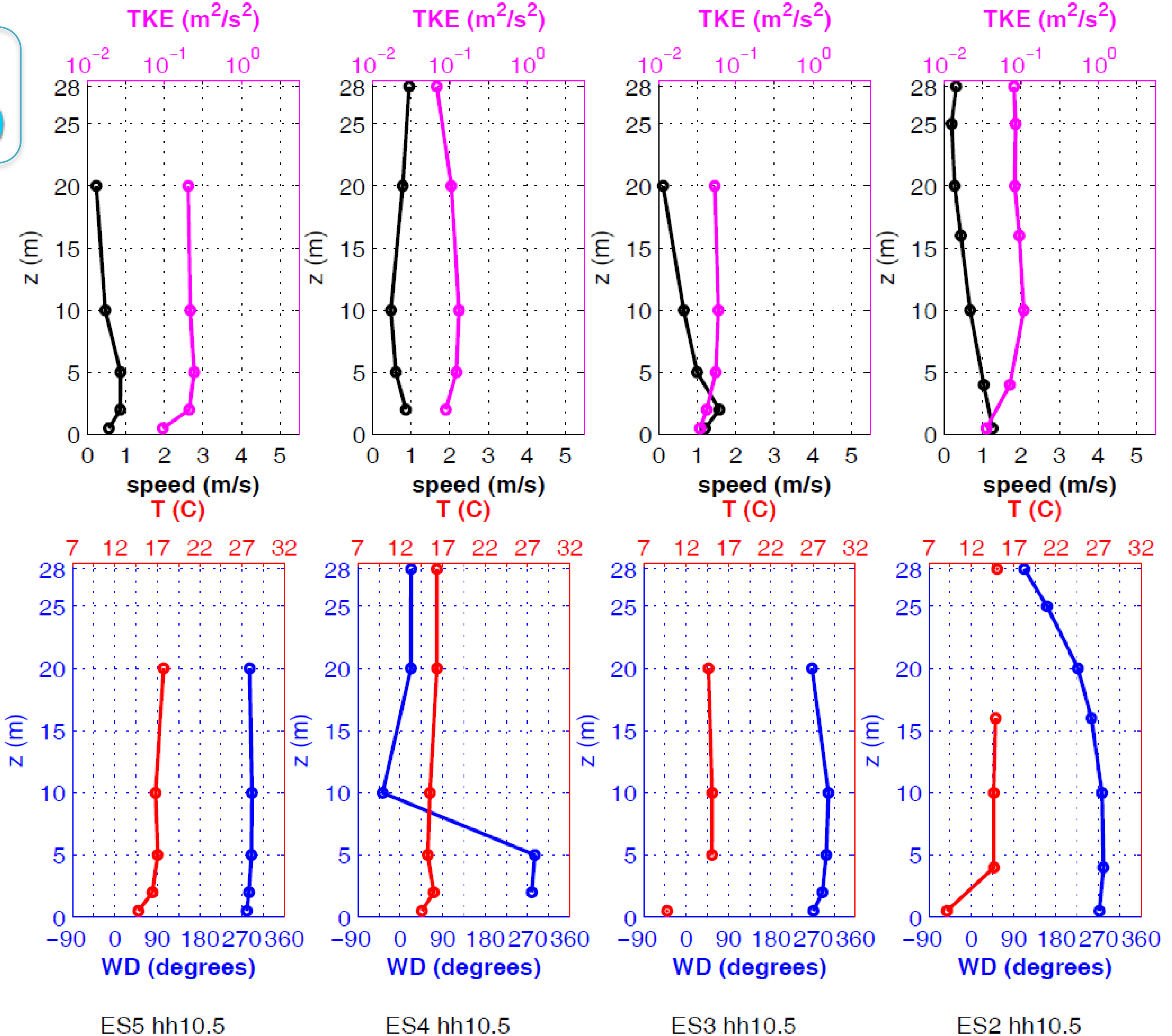

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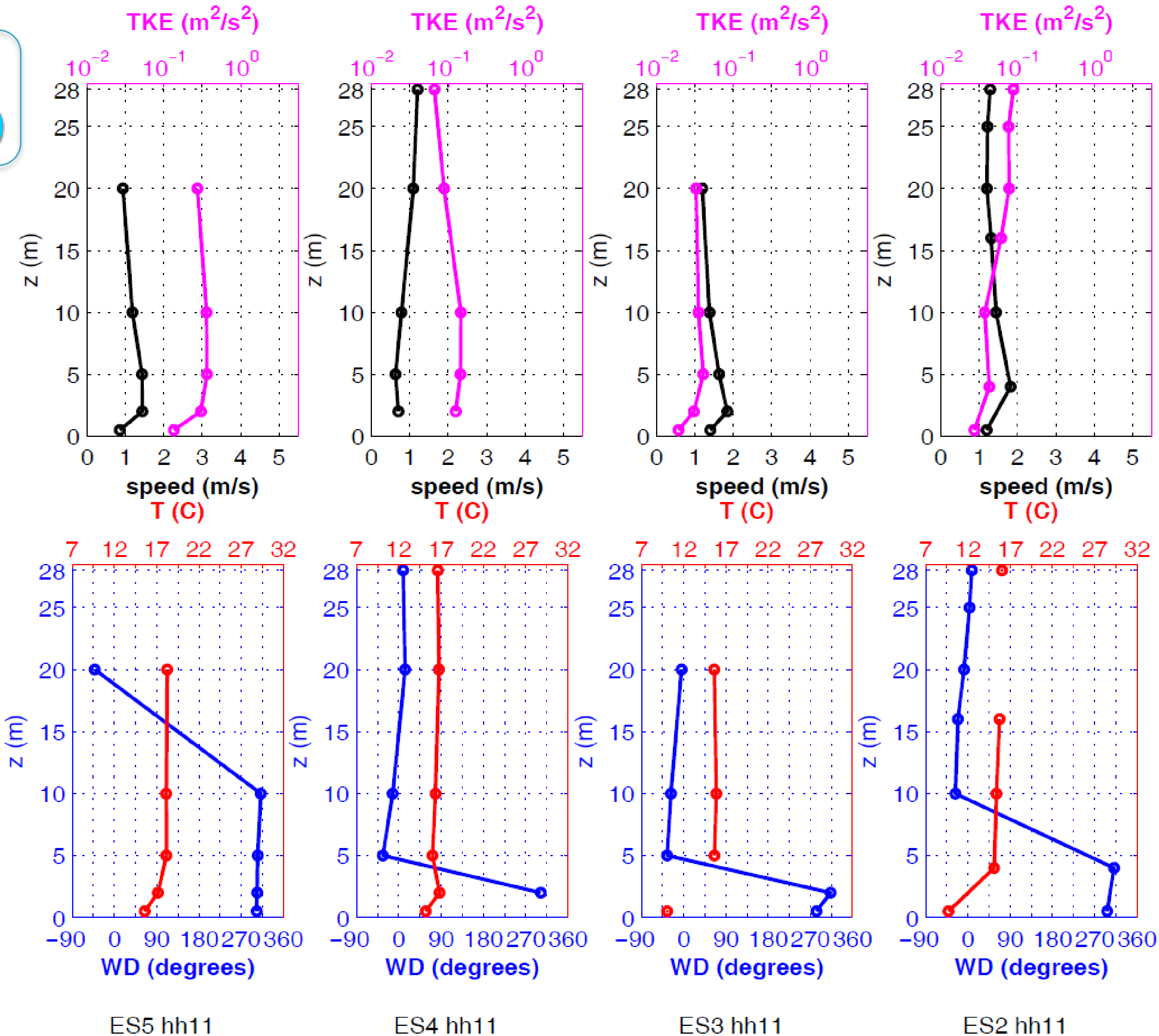

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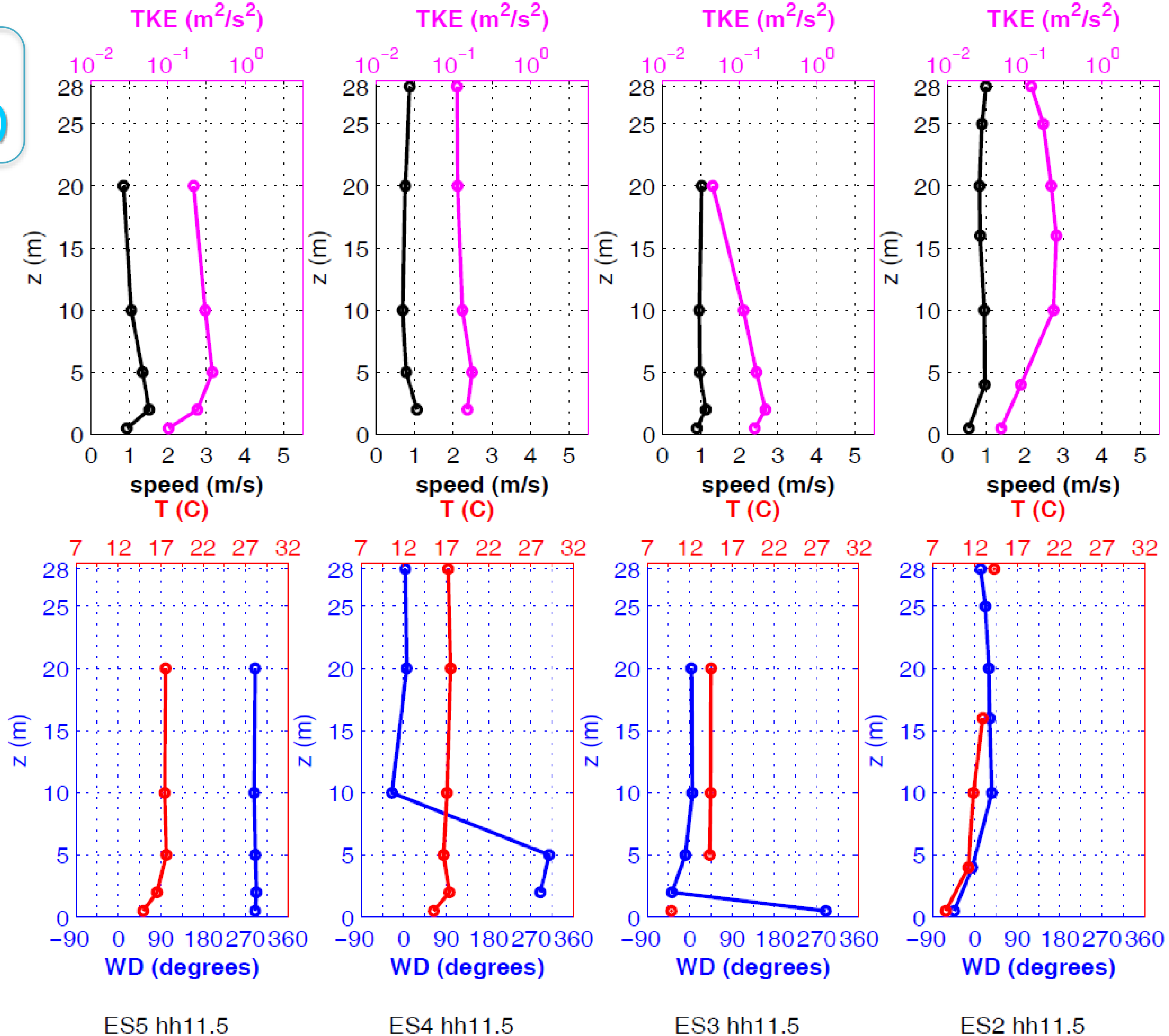

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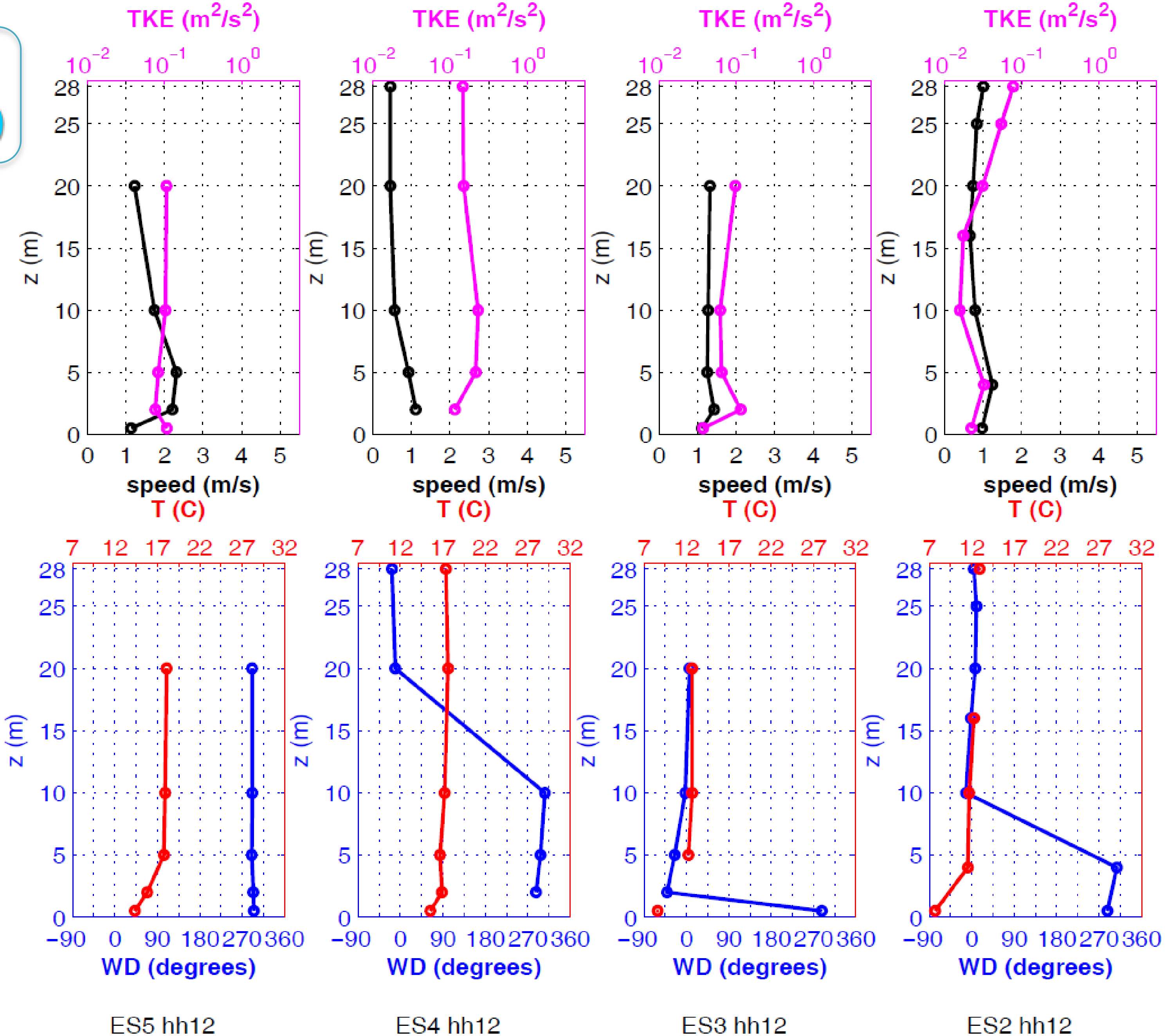

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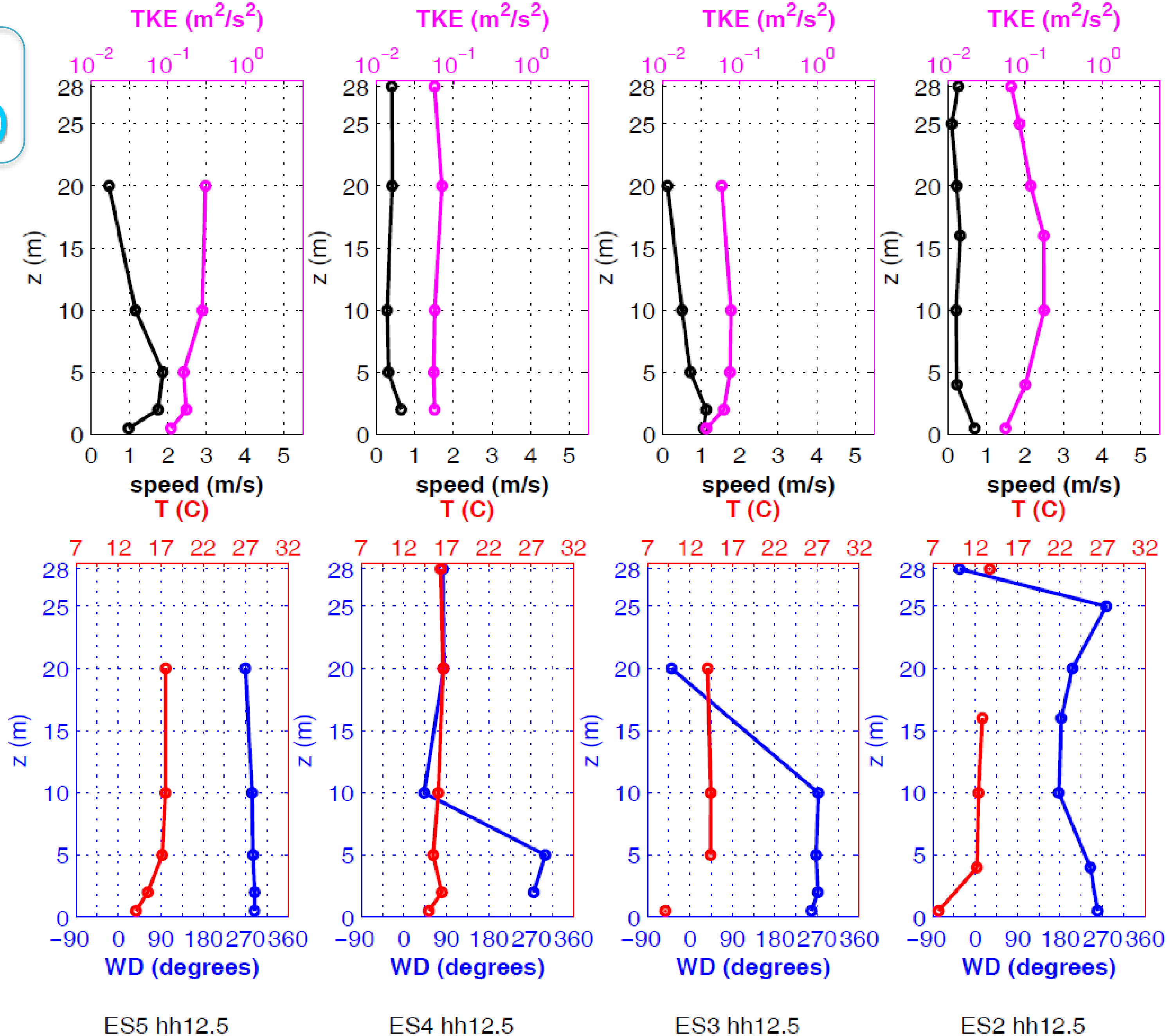

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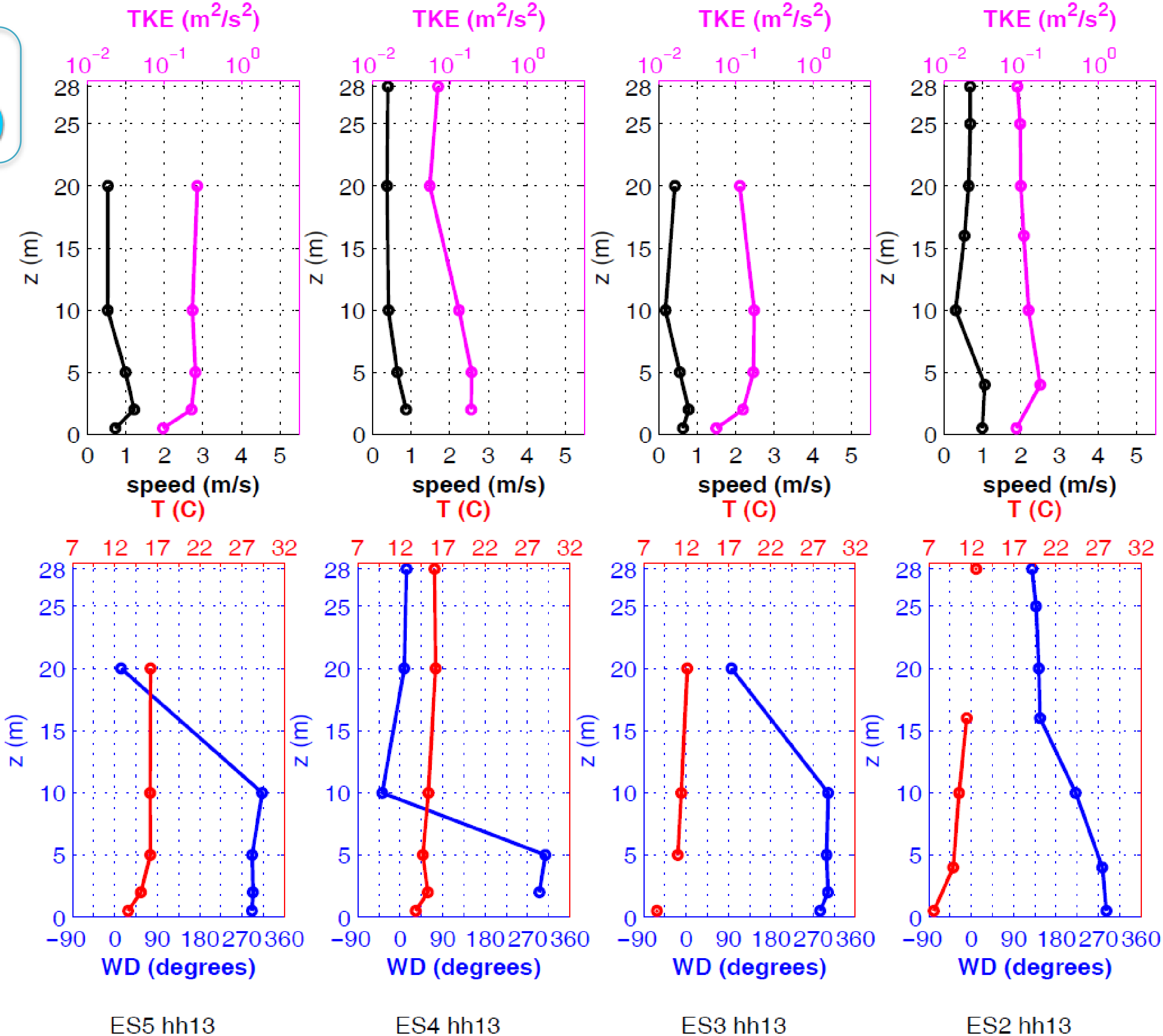

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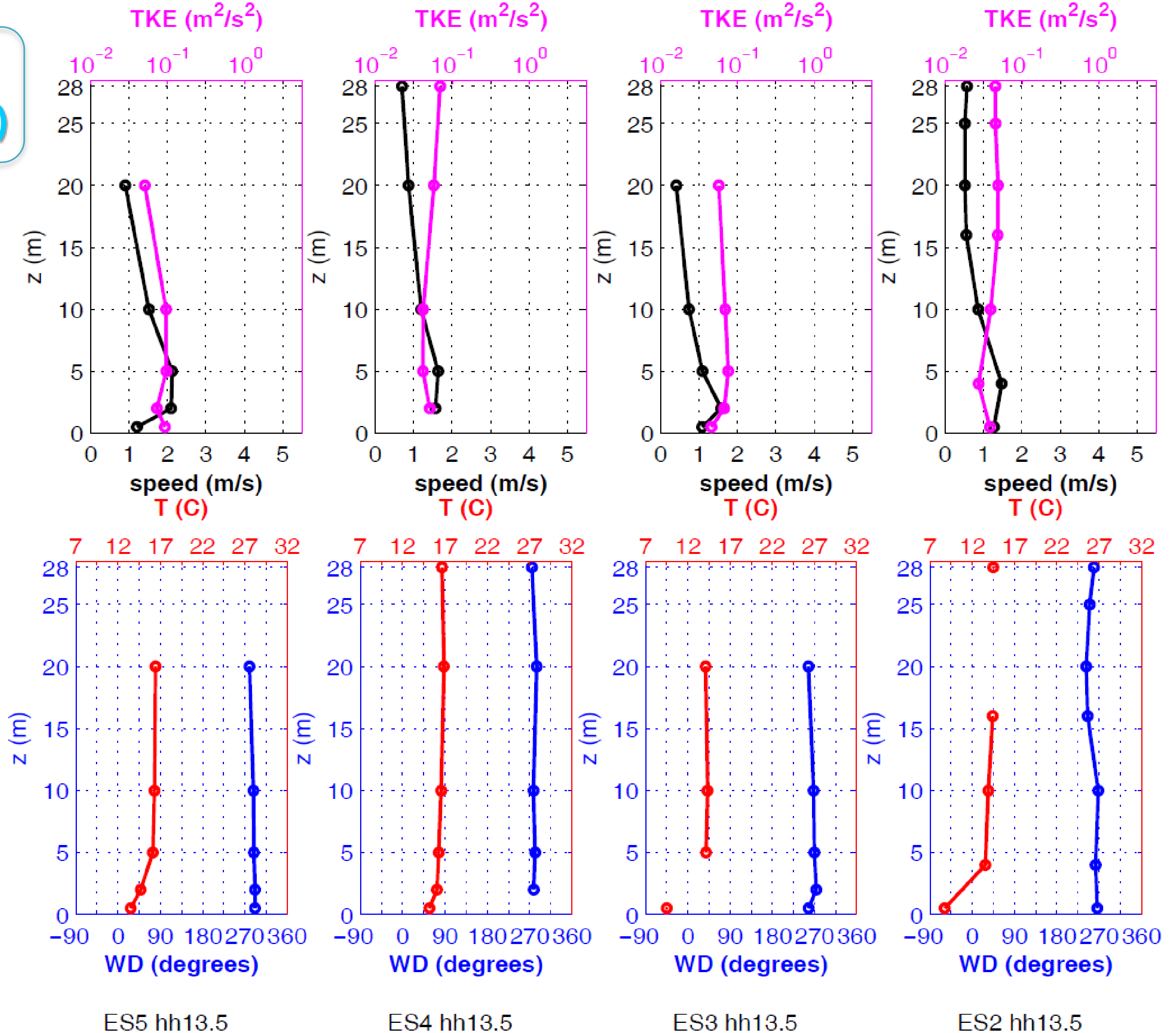

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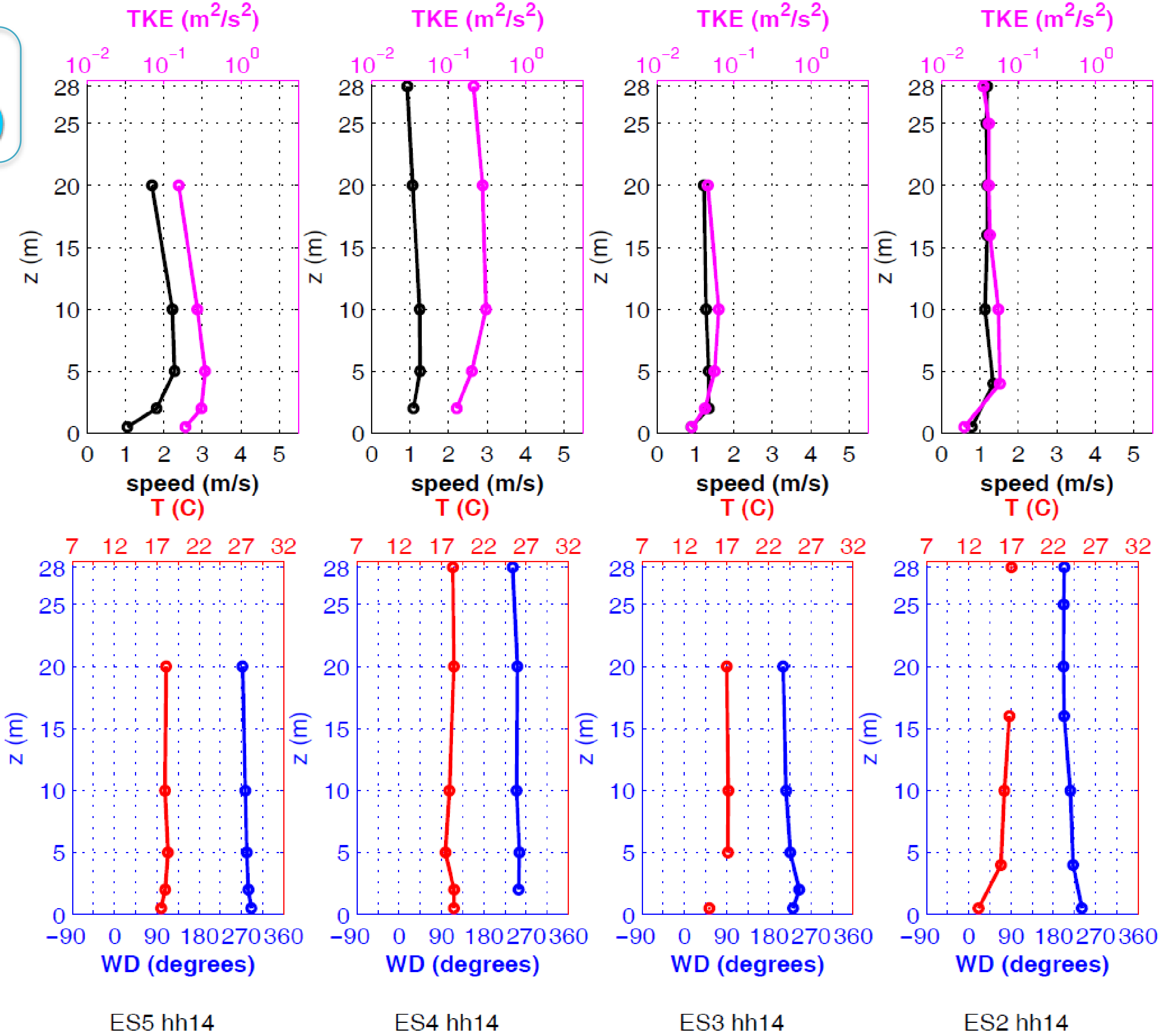

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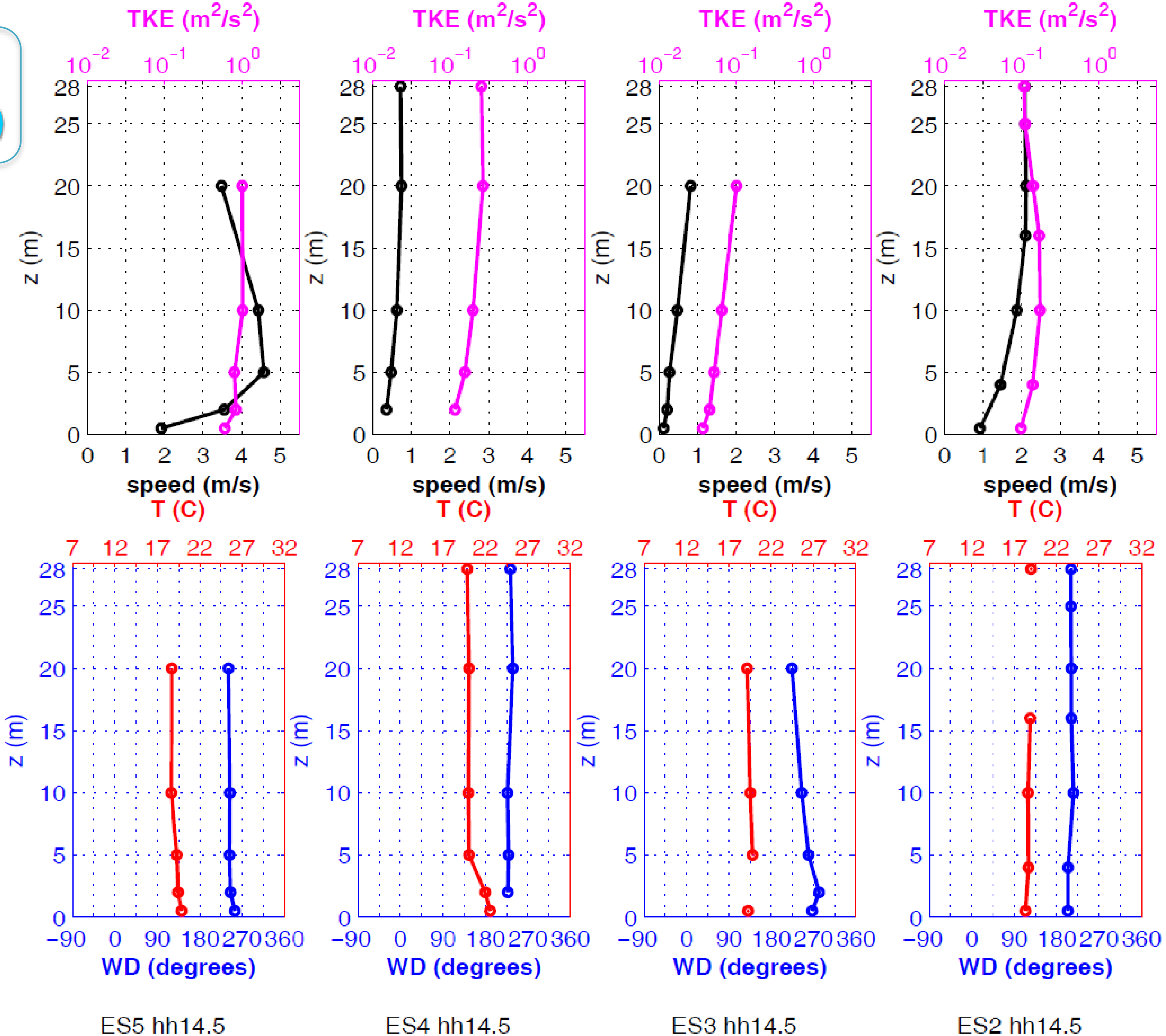

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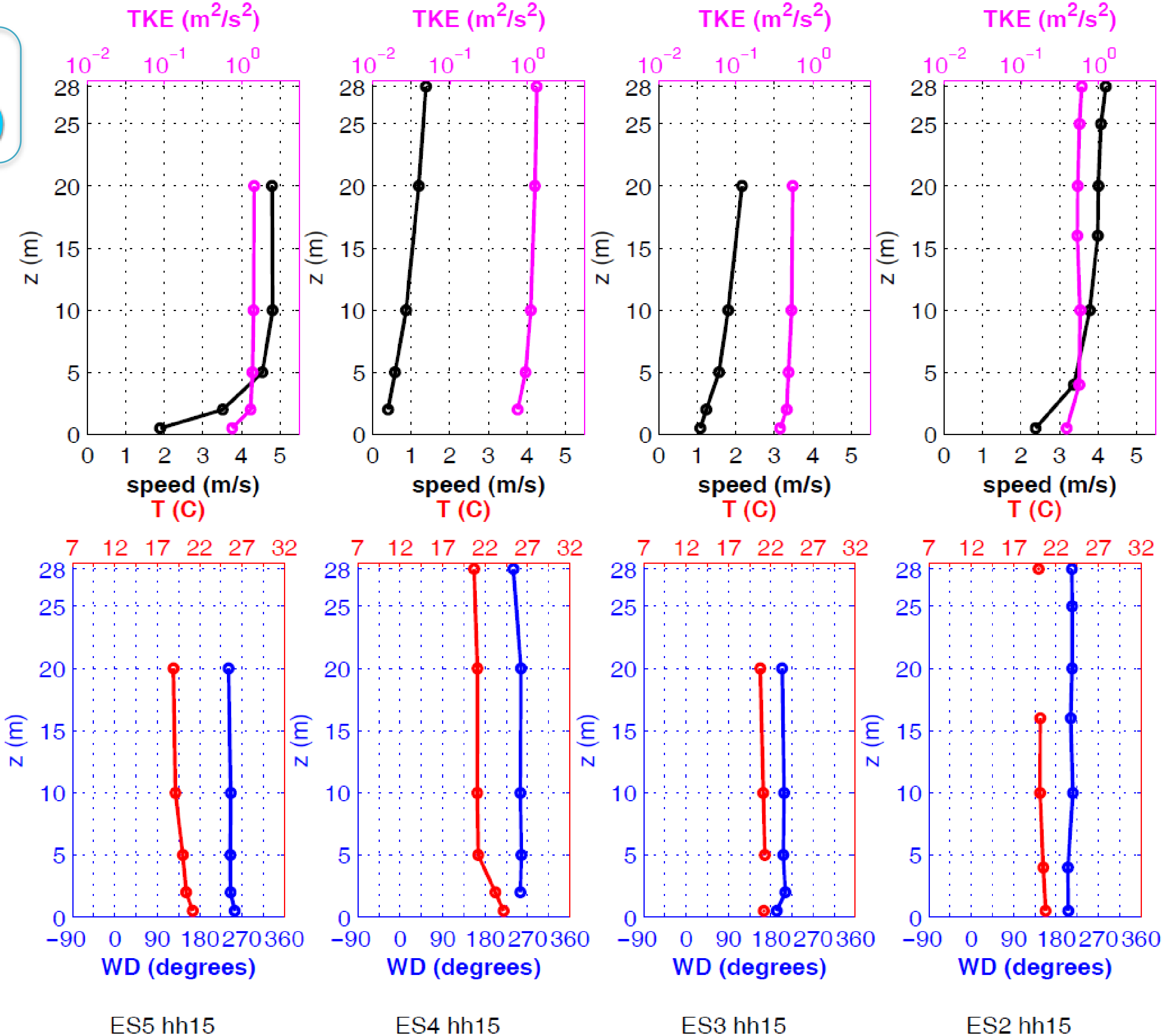
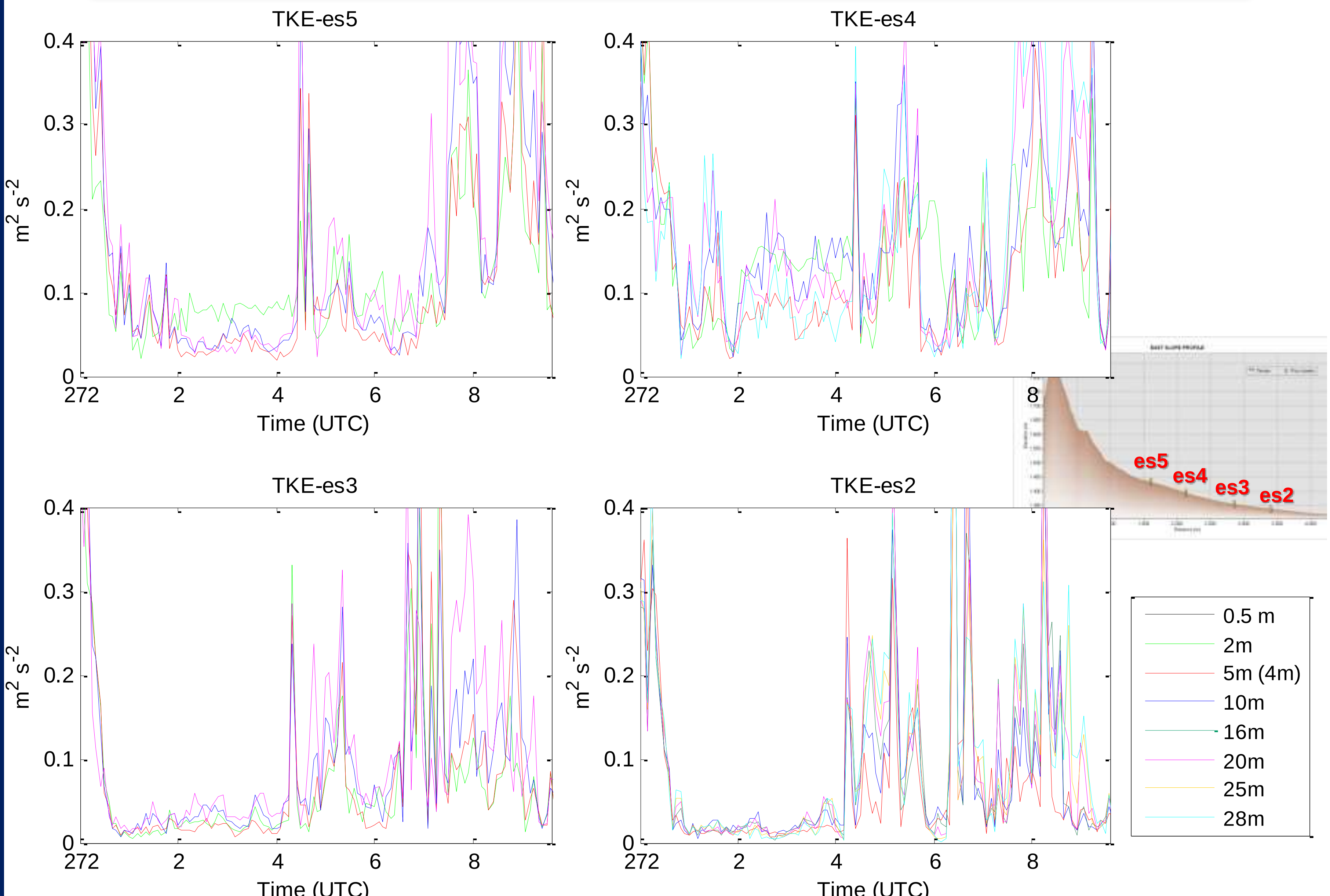
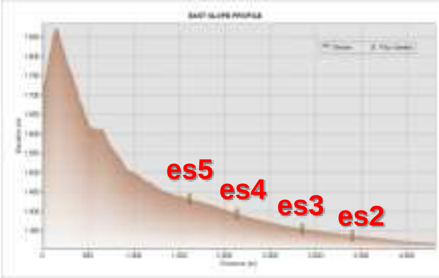


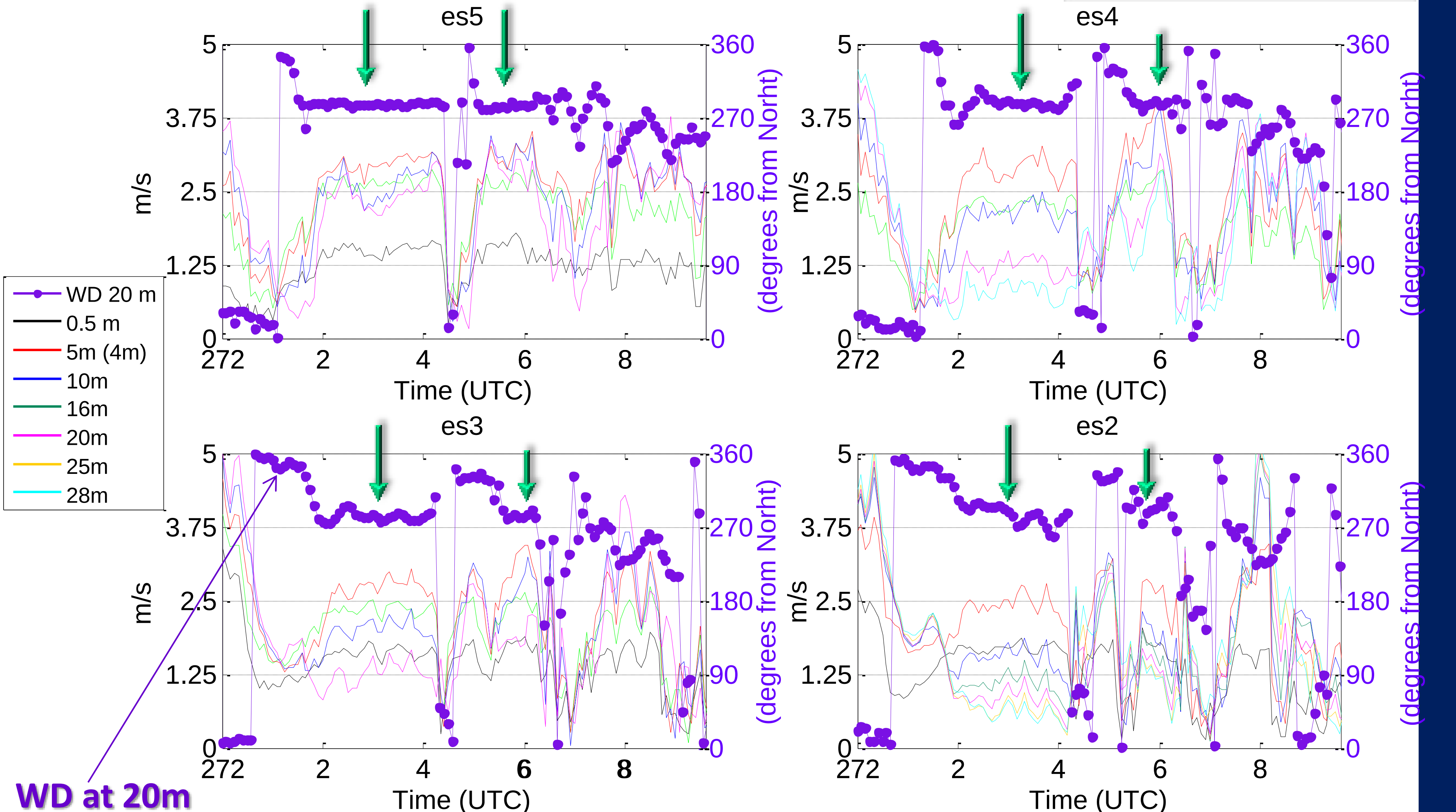
TKE timeseries (5 min avg) along the East Slope (Jday 272)



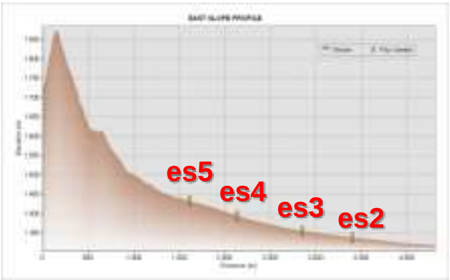
Wind speed timeseries (5 min avg) along the East Slope

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

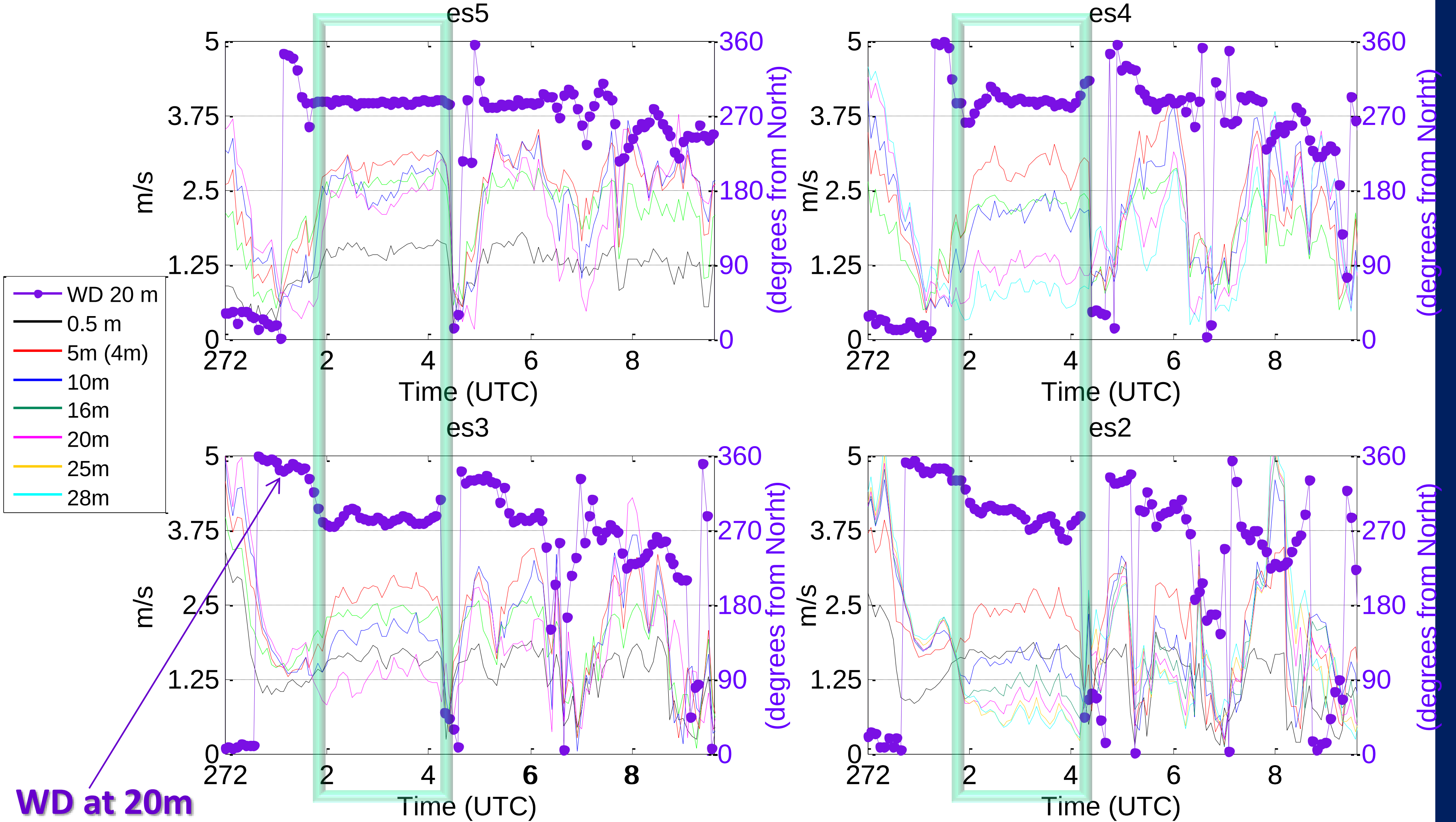




Wind speed timeseries (5 min avg) along the East Slope

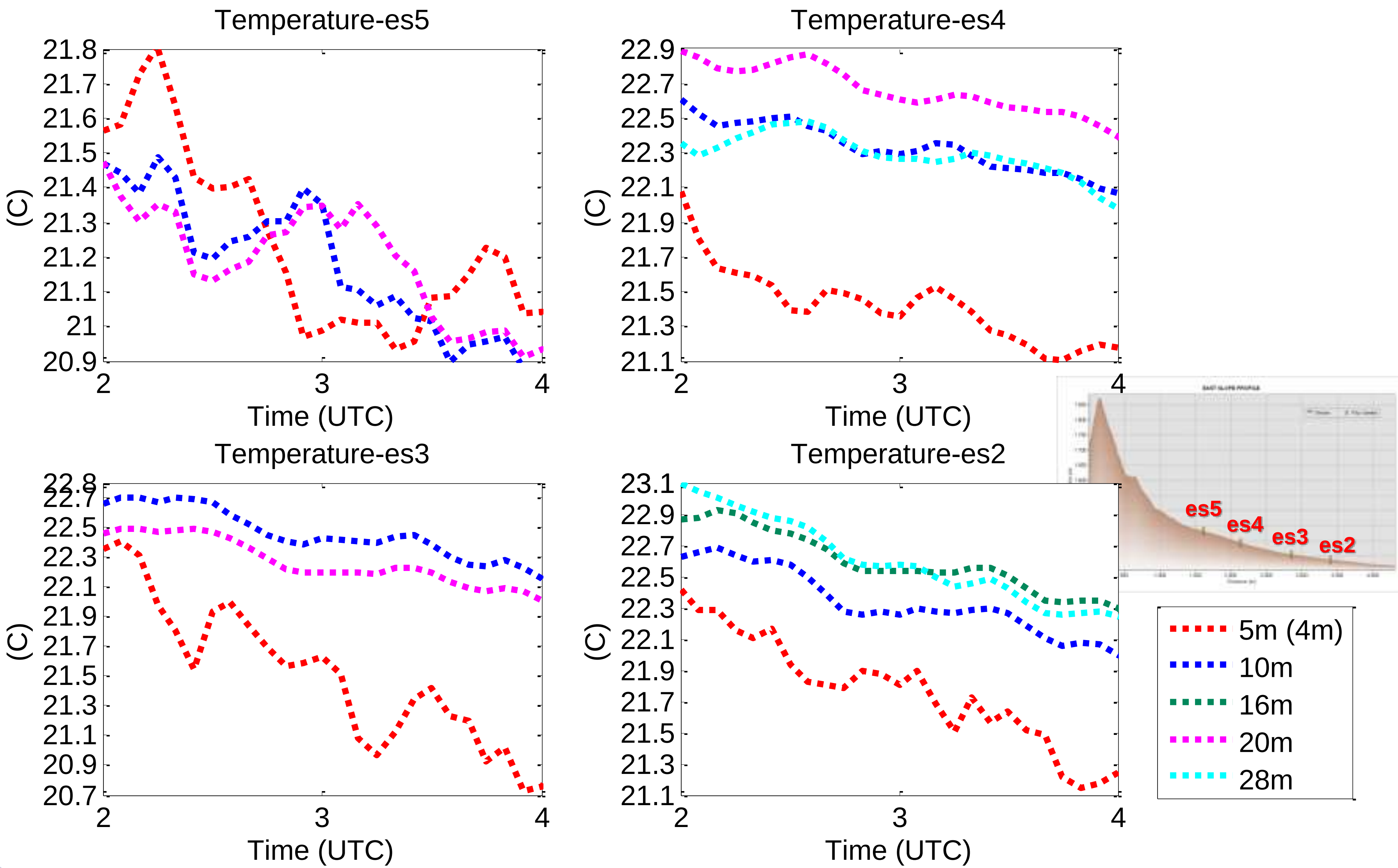


Jday 272 -- hh 0:00-10:00 UTC



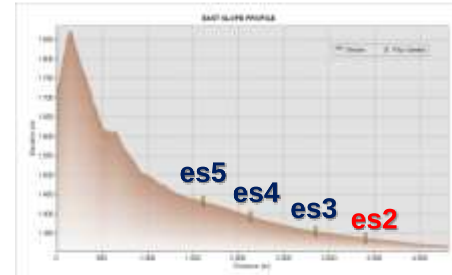
Temperature timeseries (5 min avg) along the East Slope

Jday 272 -- *hh 2:00-4:00 UTC*

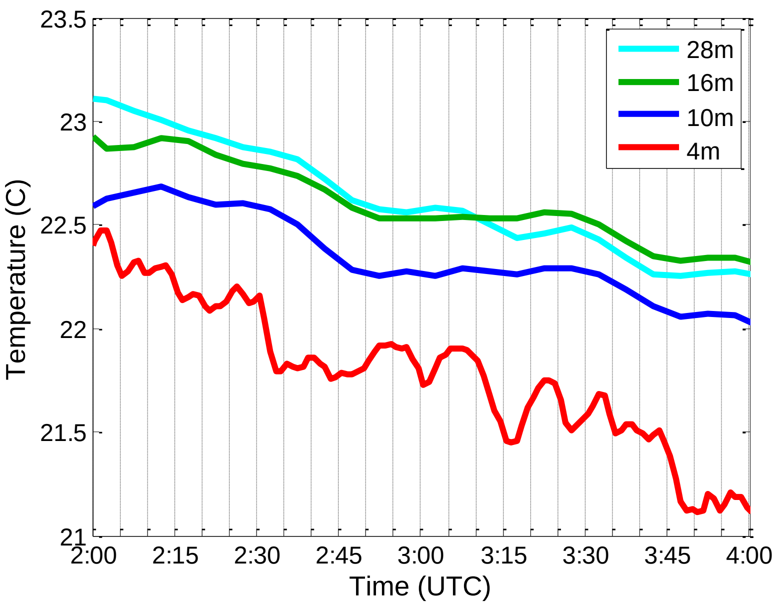


Temperature and wind speed timeseries (5 min avg) at ES2 tower

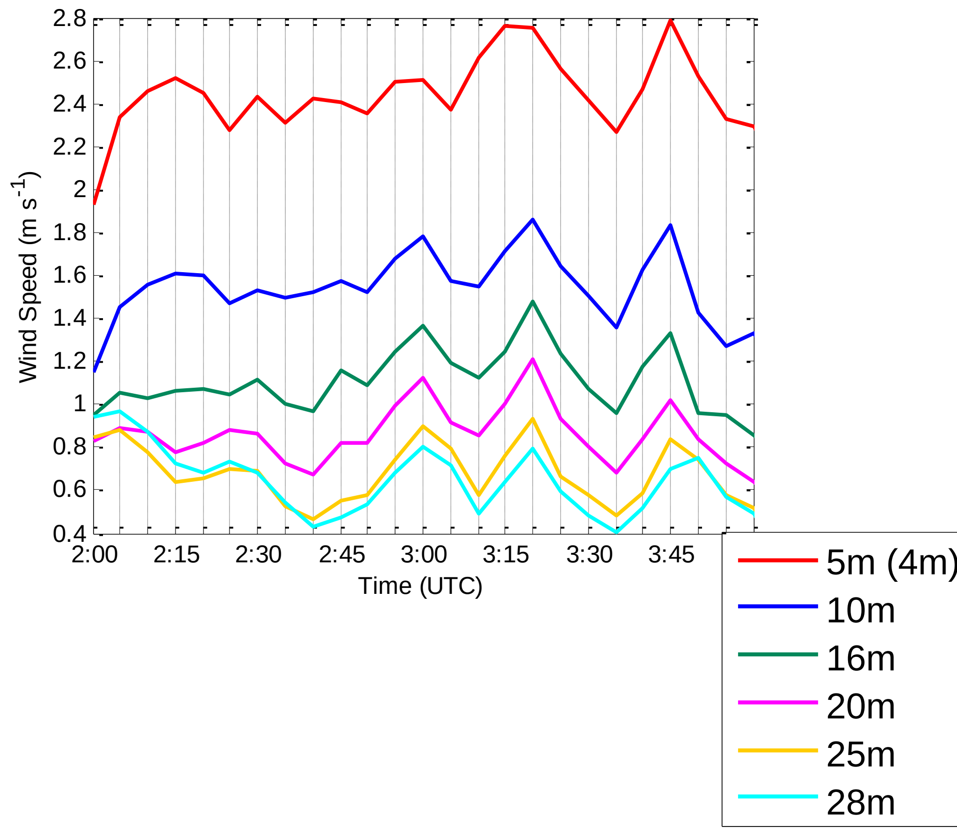
Jday 272 -- *hh 2:00-4:00 UTC*



Oscillations are detected in both temperature and wind speed signals

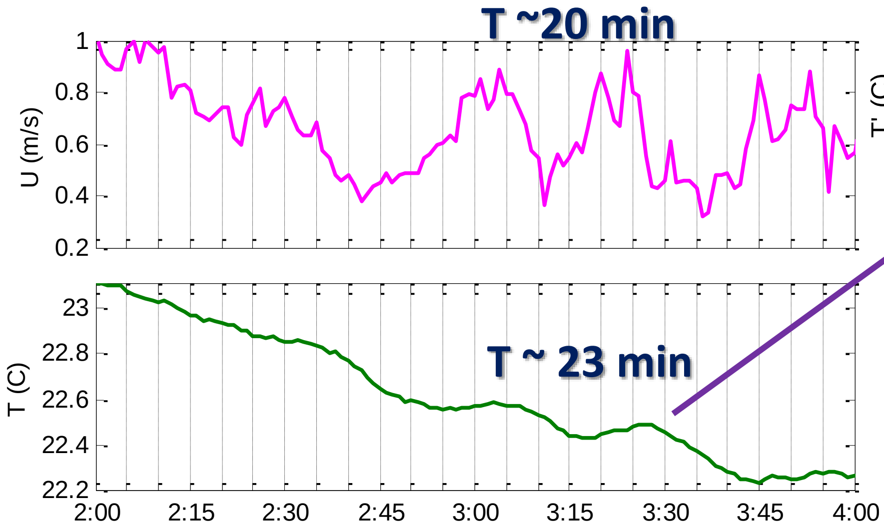


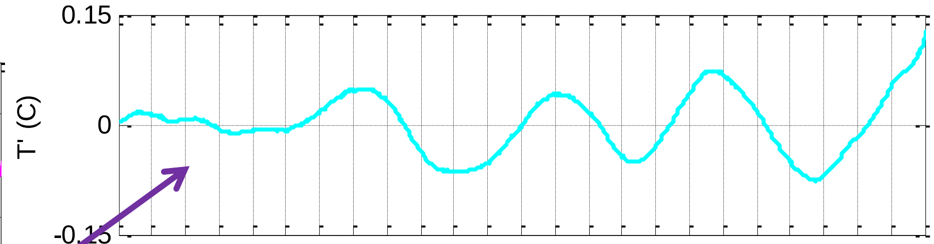
Temperature -ES2 Tower
(5 min average for all levels but 4m where data are 1min averaged)



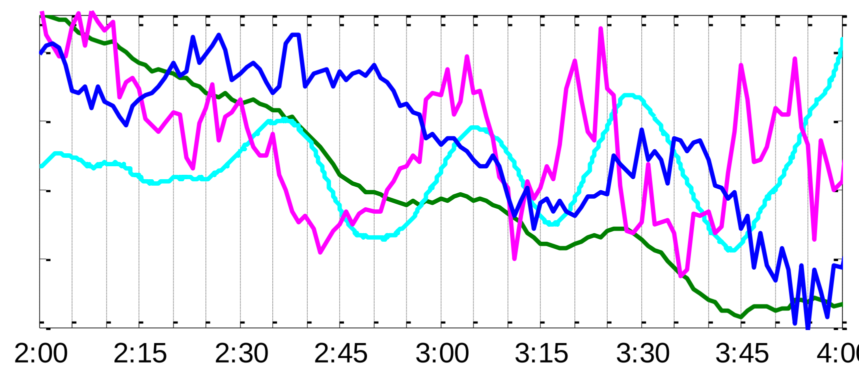
ES2 TOWER - level 28 m - (1min avg data)

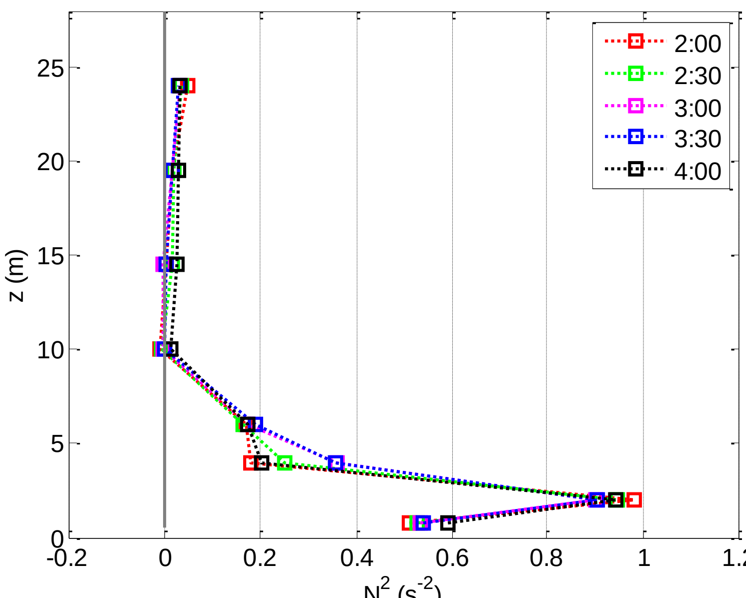
Jday 272 -- *hh 2:00-4:00 UTC*





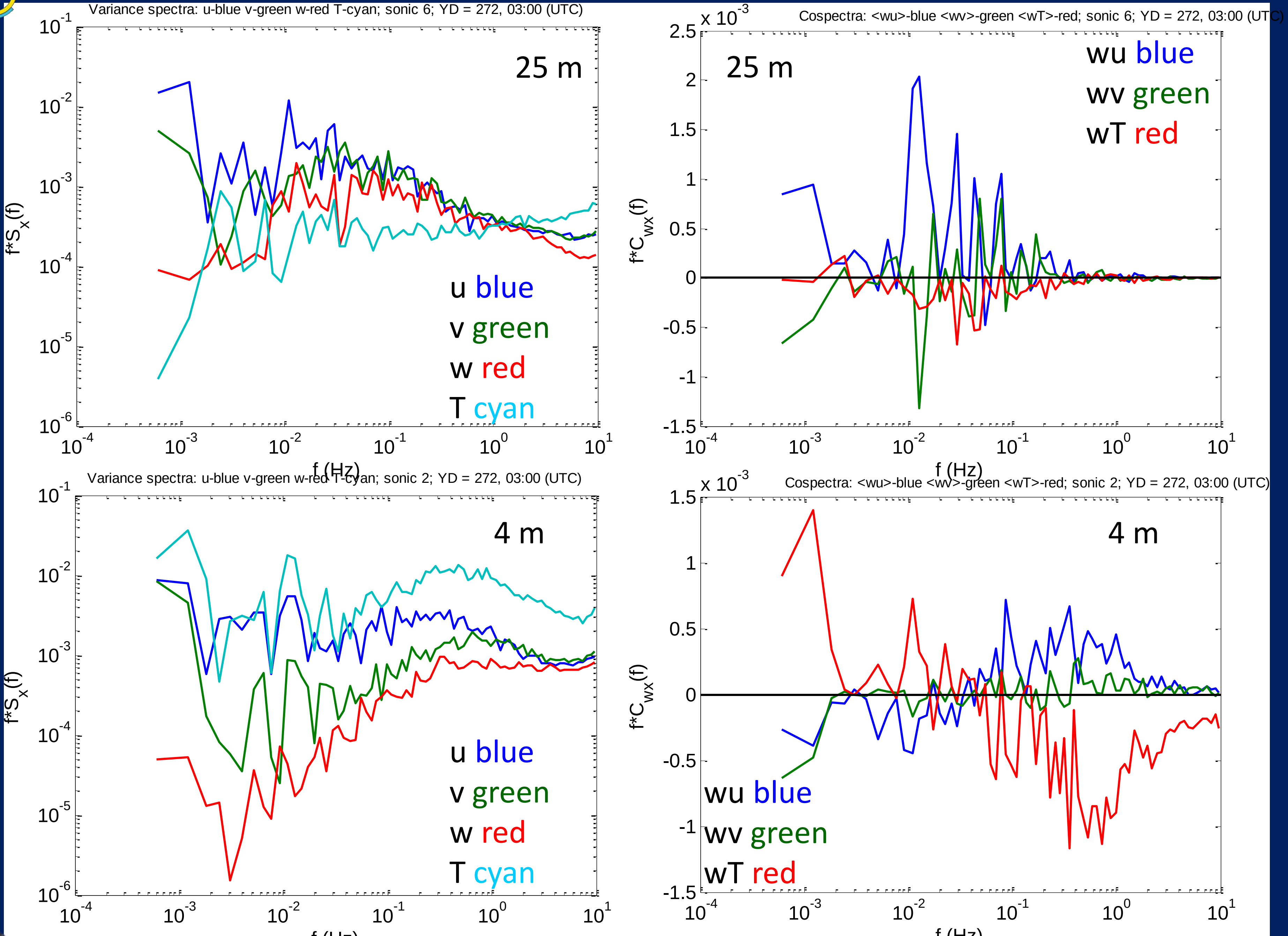
Fluctuations are obtained by running a 40-min running average filter in order to subtract the slow variation of the flow





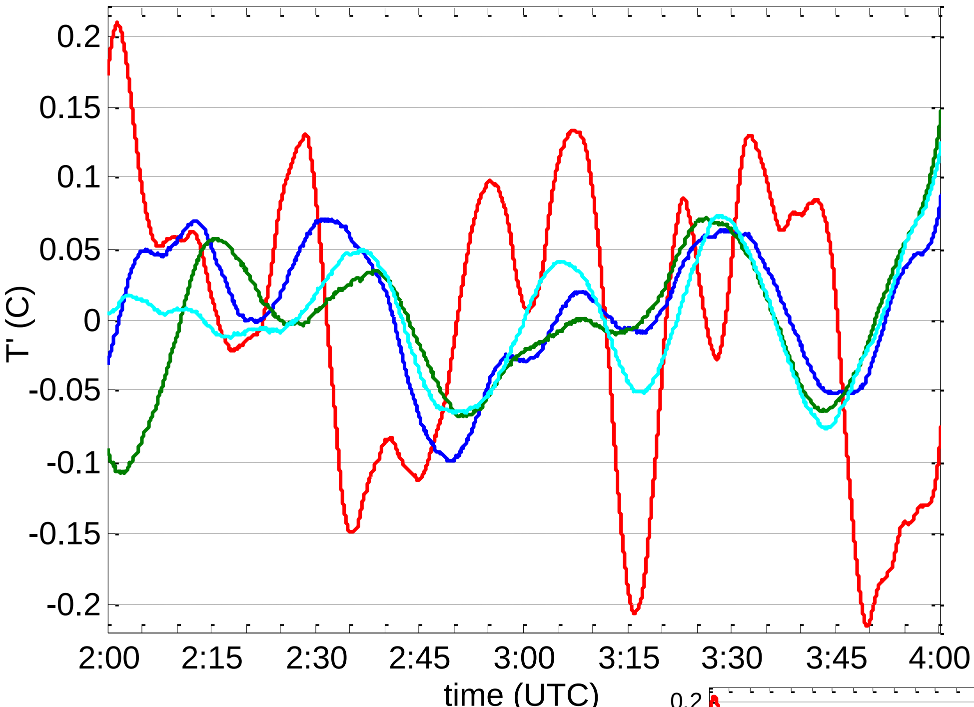
Internal oscillations of the flow at frequency $N sin\alpha$

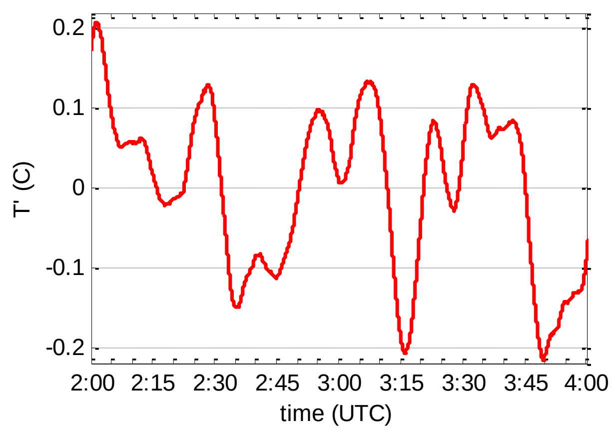
$$N^2 = \frac{g}{\theta_0}\frac{\partial\theta}{\partial z}$$

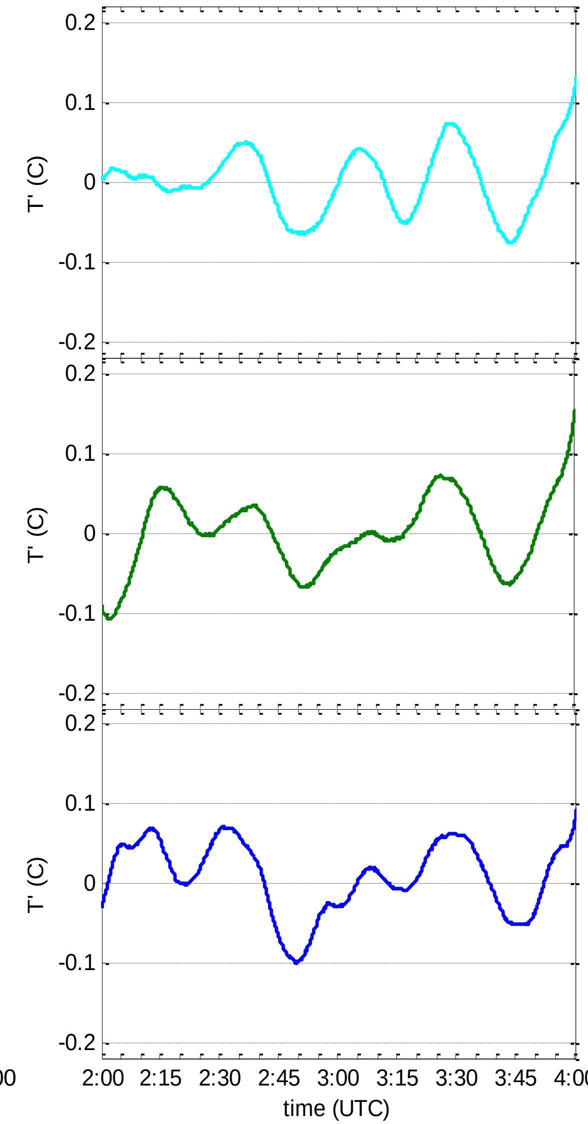

Variance spectra: u-blue v-green w-red T-cyan; sonic 6; YD = 272, 03:00 (UTC)
25 m
u blue
v green
w red
T cyan
f*S_x(f)
f (Hz)
Cospectra: <wu>-blue <wv>-green <wT>-red; sonic 6; YD = 272, 03:00 (UTC)
x 10^-3
25 m
wu blue
wv green
wT red
f*C_wx(f)
f (Hz)
Variance spectra: u-blue v-green w-red T-cyan; sonic 2; YD = 272, 03:00 (UTC)
4 m
u blue
v green
w red
T cyan
f*S_x(f)
f (Hz)
Cospectra: <wu>-blue <wv>-green <wT>-red; sonic 2; YD = 272, 03:00 (UTC)
x 10^-3
4 m
wu blue
wv green
wT red
f*C_wx(f)
f (Hz)

Temperature oscillations at ES2 tower

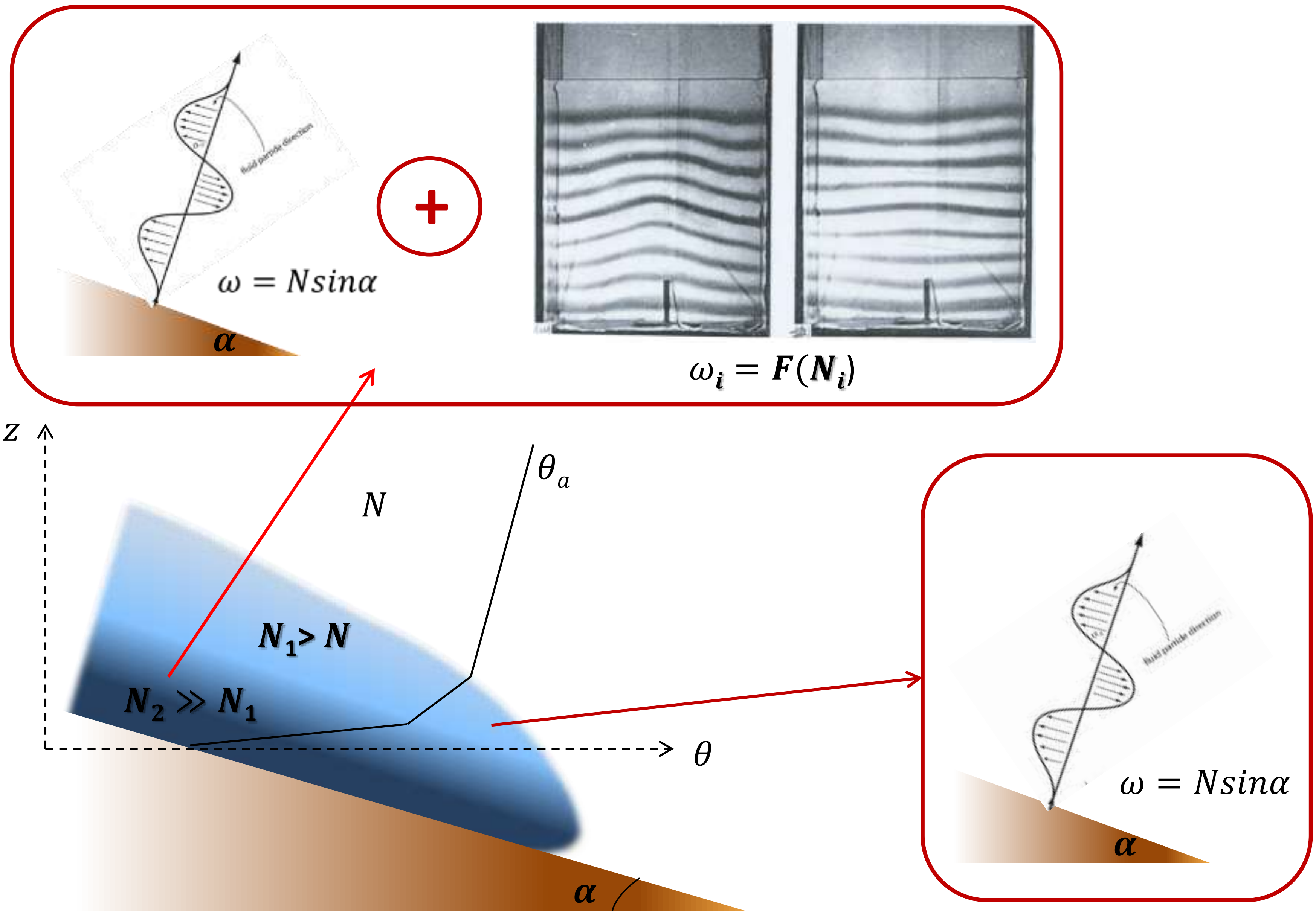
Jday 272 -- *hh 2:00-4:00 UTC*







Fluctuations are obtained by using a 50-min running average filter in order to subtract the slow variation of the temperature


$\omega = N sin\alpha$
α
$\omega_i = F(N_i)$
z
θ_a
N
$N_1 > N$
$N_2 \gg N_1$
θ
α
$\omega = N sin\alpha$
α

CONCLUSIONS & OUTLOOK

Preliminary analysis of measurements at East Slope of Granite Mountain showed:

- Several occurrences of slope flows during quiescent periods
- Strong interaction between slope flows and the circulation in the valley (cf. Chris Hocut talk)
- Due to these multiscale flow interactions, slope flows appear 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.
- We found clear evidence of pulsations within the katabatic flow at the 4 measurement sites along the slope. Future work will focus on a deep investigation on the nature and the type of such pulsations also taking into account the possible coexistence of different oscillation systems.


THANK YOU!
QUESTIONS?