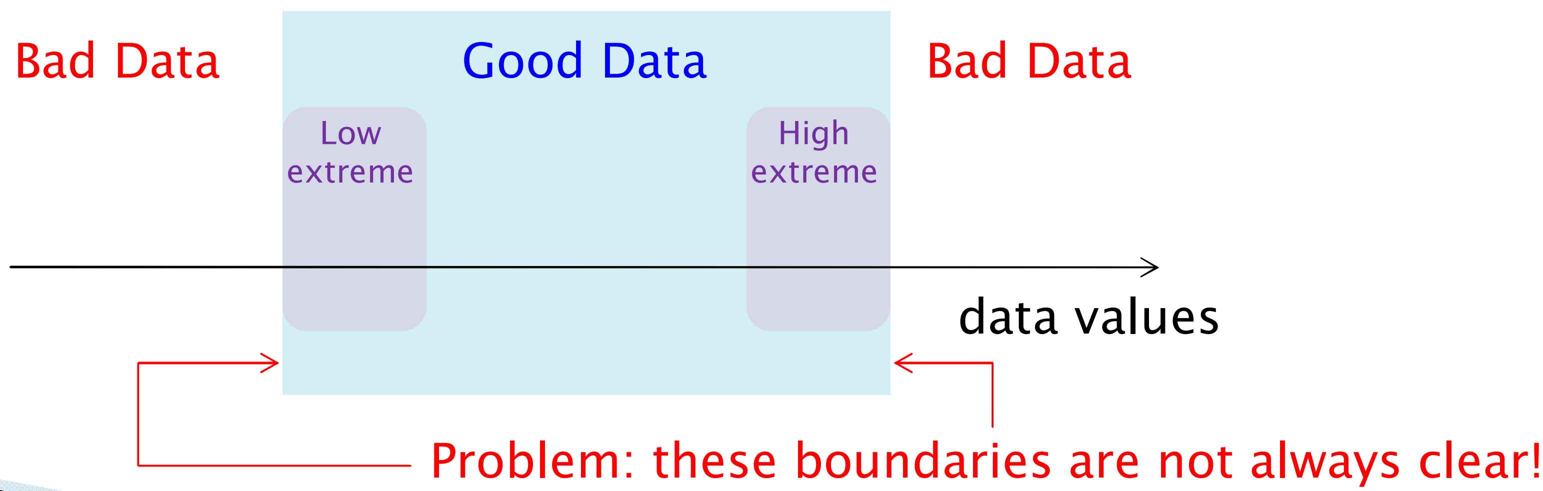
Statistical distribution of tropical radiosonde wind in relation to equatorial wave dynamics

Tieh-Yong KOH
Assistant Professor, School of Physical and Mathematical Sciences
Principal Investigator, Climate Group, Earth Observatory of Singapore
Nanyang Technological University
Singapore

Introduction

- Radiosonde provides the most reliable long-term meteorological records
- Quality control of radiosondes is performed through the application of statistical mathematics, e.g. comparing with means, standard deviations, or known historical bounds.



- What is the basis for separating extreme events from wrong data?

- Could the statistics of a dataset be modelled from the underlying atmospheric dynamics?

STATISTICAL DYNAMICS of regional wind

confined to where the dynamics is similar

- Literature on the statistical characterization of wind speed has mainly focused on the surface layer (e.g., Takle et al., 1978; LaBraga, 1994; Lun, 2000) and to a lesser extent, the PBL (e.g., Frank et al., 1997).
- Exception: Roney (2007) who fitted the Weibull distribution to wind in the lower stratosphere.
- Most employed the Weibull distribution to model wind speed. No justification has been given except that it works.

Shape parameter, *k*

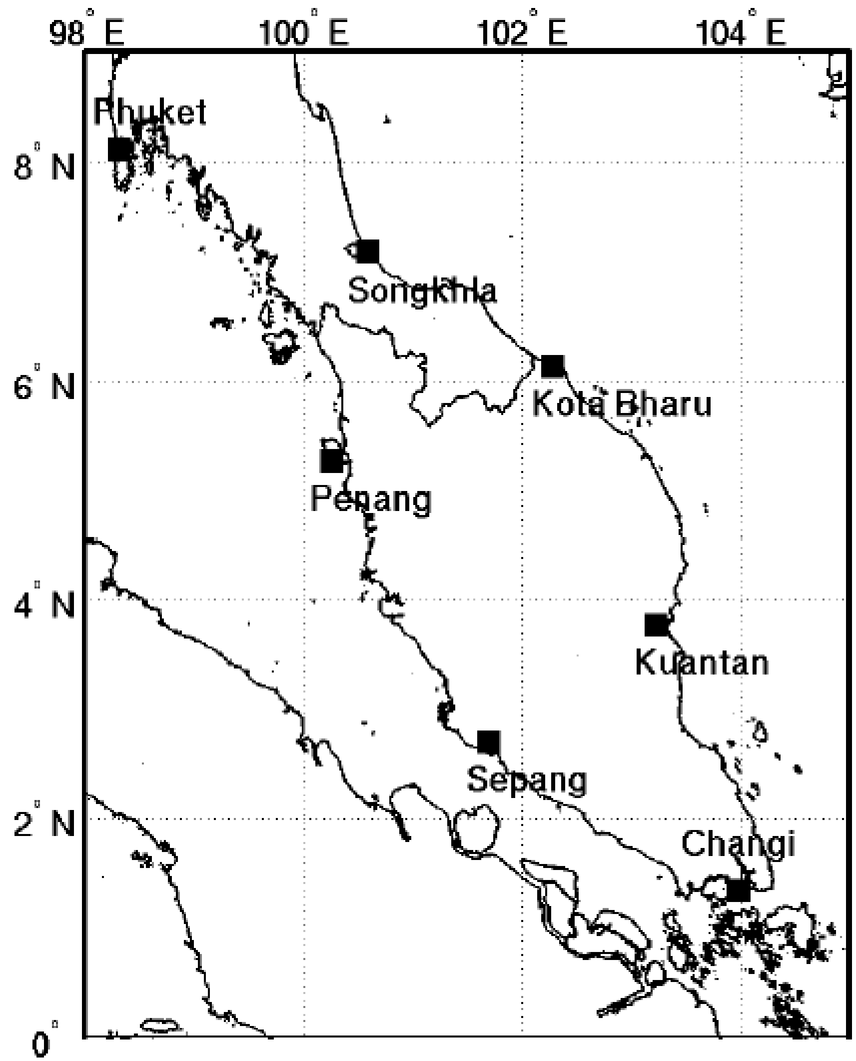
Probability Density

$$P(v;k,c)dv = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^{k}\right]dv$$

Scale parameter, *c*

Data

- Twice daily radiosonde wind speed data
- 11 mandatory pressure levels
- 7 stations on the Malay Peninsula
- 35 years of data from 1973 to 2007 with some gaps interspersed in between.



Location of radiosonde stations on the Malay Peninsula (MP) used in this study.

Another 235 stations between 25ºN and 25ºS were used to explore the extension of the findings to the global tropics.

Equatorial monsoon zone

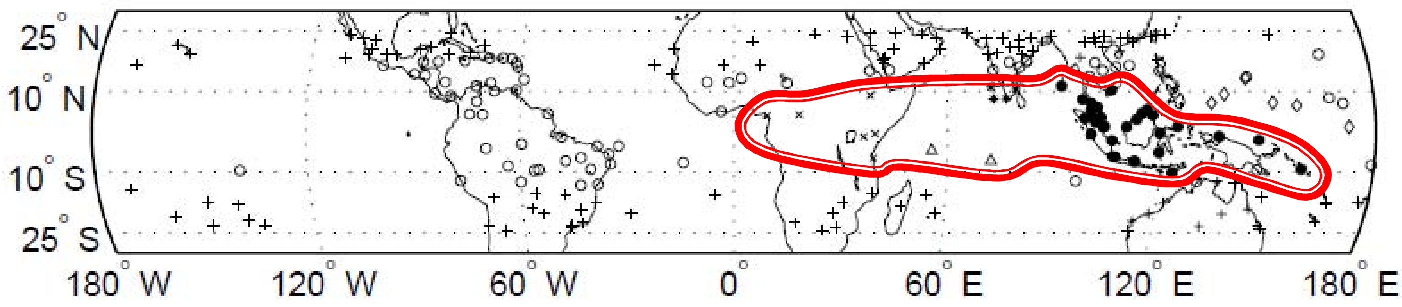
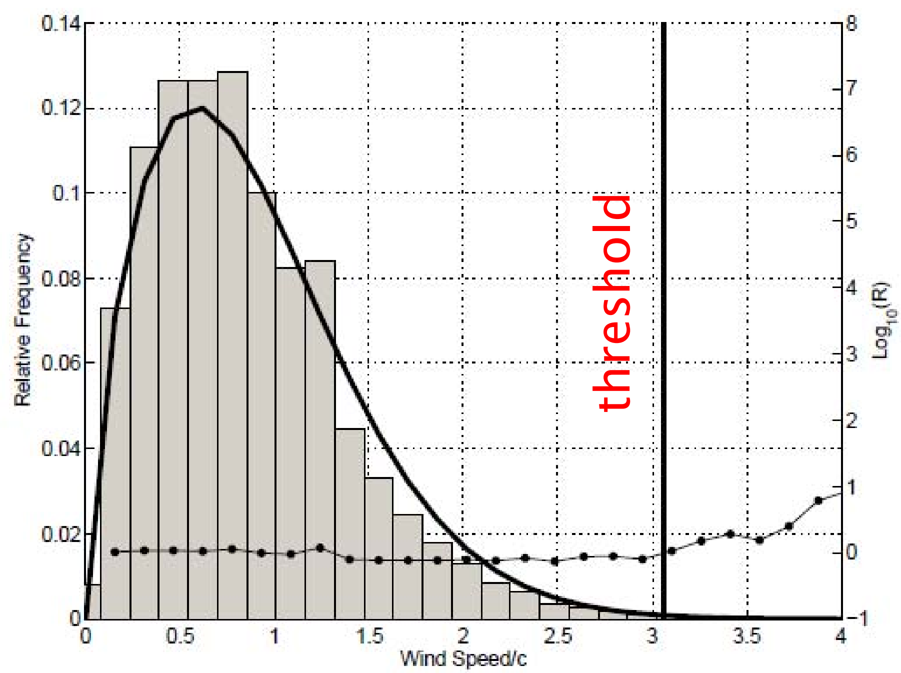


Fig. 6. All 242 tropical radiosonde stations used in the latter part of the study (including the seven stations in MP): "+" signs denote stations in the upper-level (500 mb to 100 mb) westerly zone; circles denote stations in the upper-level mixed wind zone; all other symbols denote stations in the upper-level easterly zone. Within the easterly zone, stations are denoted by their geographical regions (number of stations shown in brackets): "x" sign=Africa (6); asterisk=South Asia (4); dot=Southeast Asia (31); triangle =Indian Ocean (2); diamond= West Pacific (6).

Methodology

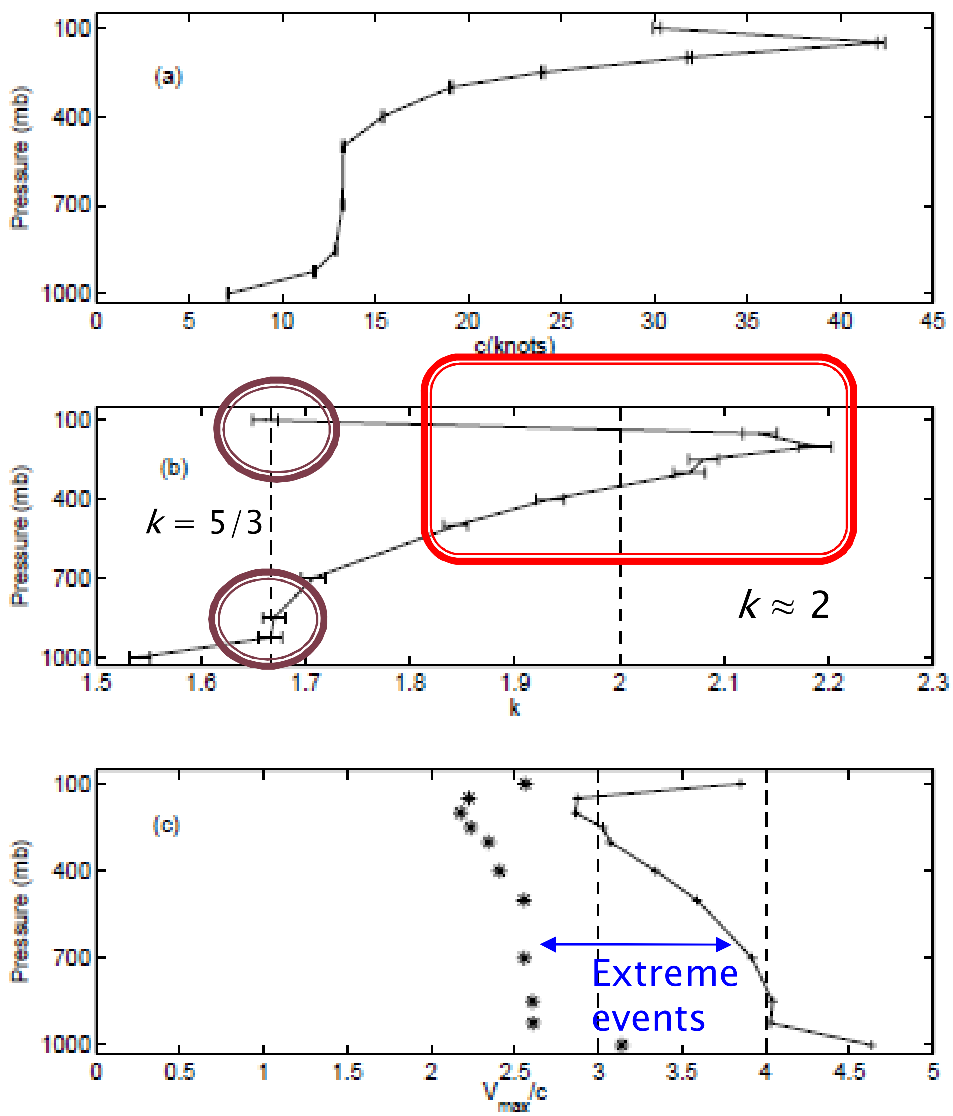
- Use Maximum Likelihood Estimate (MLE) to fit Weibull distributions to tropical radiosonde wind speed data over Malay Peninsula.
- All fits are significant at 90% confidence level using chi–squared statistics.

The wind speed threshold *vmax* was defined such that expected number of data points $n<1$ *for* $vmax>1$.



Results

Malay Peninsula (MP)



Scale parameter, *c*

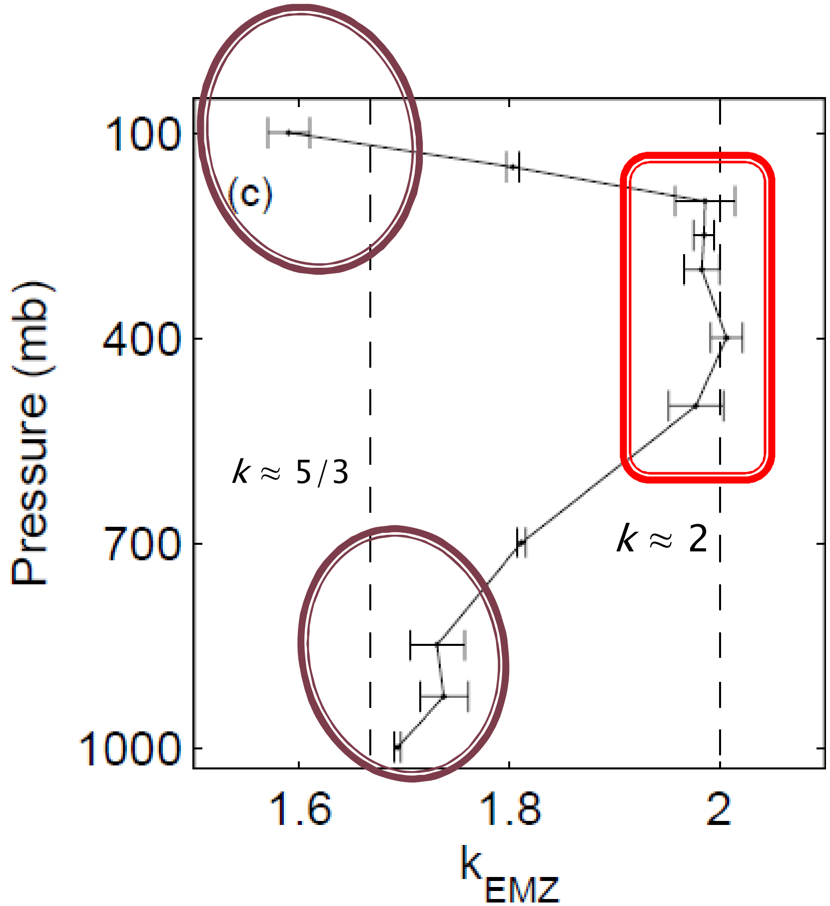
Shape parameter, *k*

Threshold speed (–) compared to mean+3std (*)

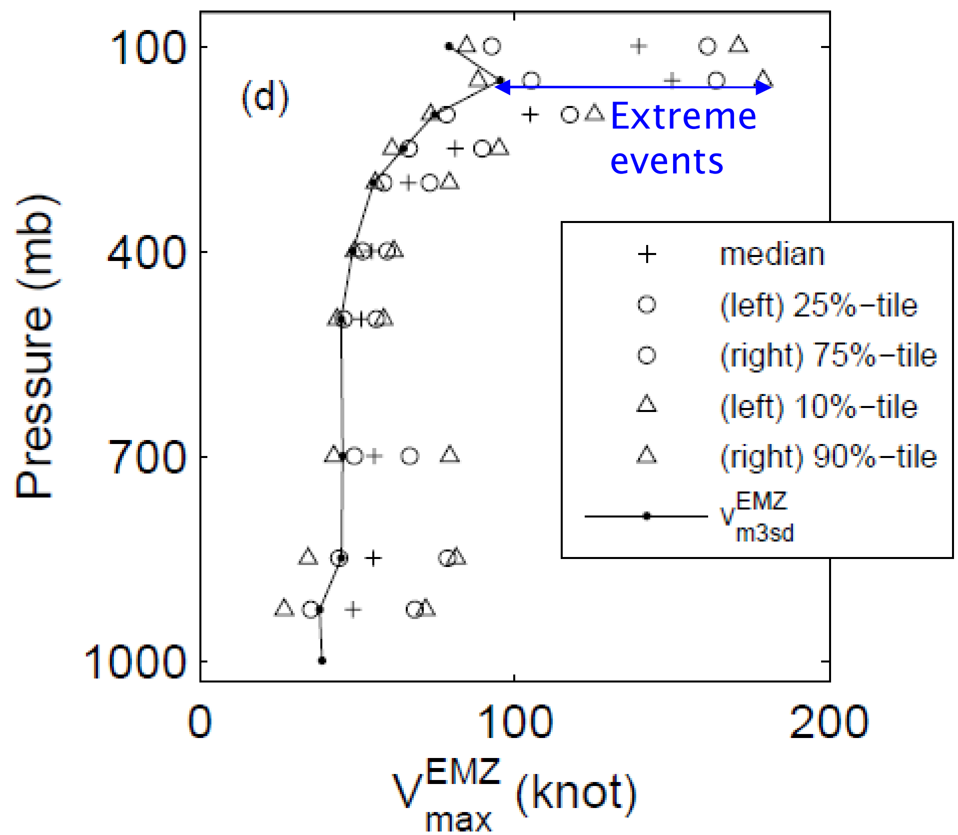
Fig. 3. Plots of empirically fitted attributes of the Weibull distribution for wind speed at different pressure levels in MP: **(a)** scale parameter c; **(b)** shape parameter k, **(c)** scaled threshold v_{max}/c for wind speed. Error bars for c and k are estimated by MLE at 95% confidence level. Vertical dashed lines correspond to k=5/3, 2 in (b) and v_{max}/c=3, 4 in (c). Asterisks in (c) denote the threshold v_{m3sd} (mean plus three standard deviations) at each pressure level.

Equatorial Monsoon Zone (EMZ)

* In this case, before Weibull fitting, wind speed is first normalized by the rms value at each station to make allowance for the local climatology (mean kinetic energy).



Shape parameter, *k*



Local thresholds (symbols) derived from EMZ's normalized threshold, compared to EMZ's mean+3std (line)

The value of *k* is related to Shannon’s entropy *S* of the Weibull distribution.

$$S = -\int_0^{\infty} P(v) \ln P(v)\, dv$$

k → 2 as maximal Shannon’s entropy is attained.

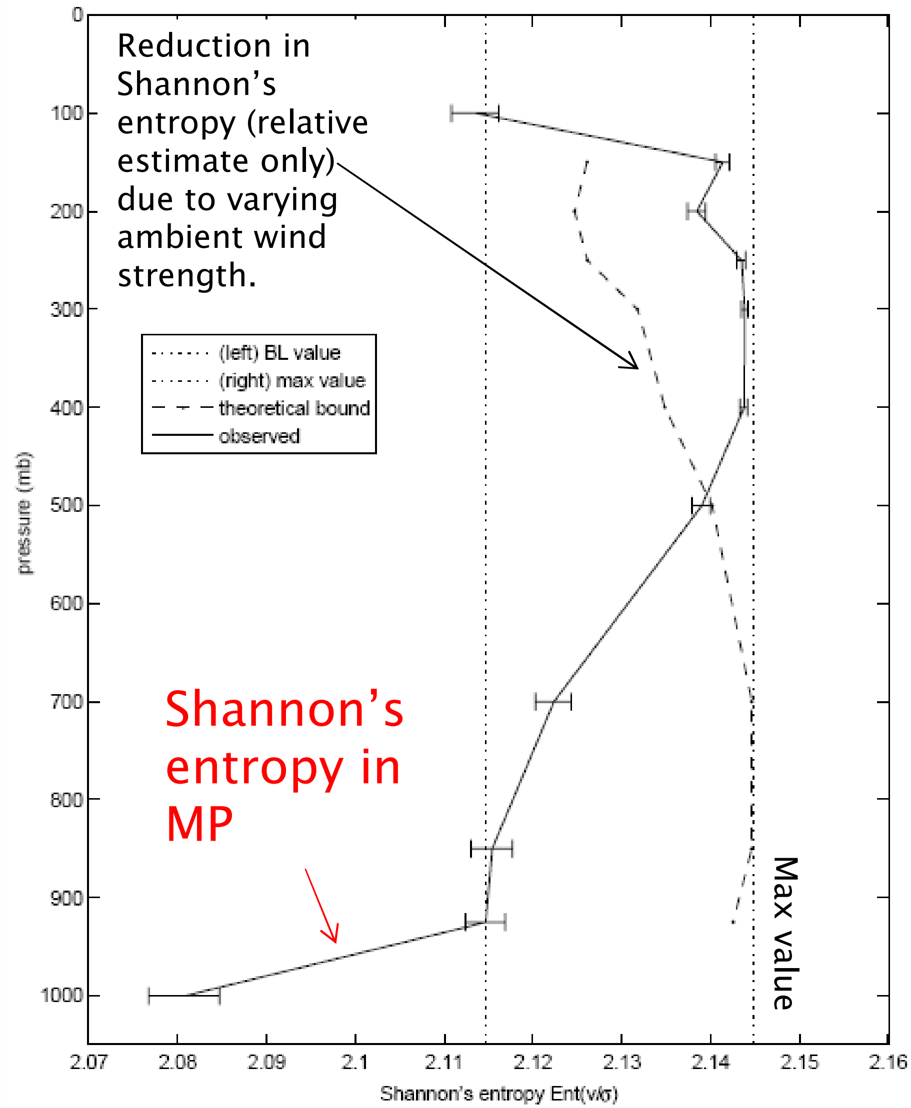


Fig. 4 shows Shannon’s entropy for the Weibull’s distributions fitted to the radiosonde wind speed data from MP (solid line). The wind speed was first normalized by its rms value. The maximal entropy and the value associated with k = 5/3 (dotted lines) are shown, as well as the theoretical bound (dashed line) for reduction from maximal entropy.

Theory

Under Review in *Atmospheric Physics and Chemistry*

A statistical theory of equatorial waves was proposed to explain k based on the following key concepts.

1. Equatorial atmospheric dynamics is well represented by the equivalent shallow water model on the equatorial β-plane.
2. Equatorial waves exist in distinct vertical modes and horizontal wave-packets.
3. In the planetary boundary layer and the internal boundary layer at the tropopause,
   - quasi-2-D turbulence produces an inertial range in the energy density spectrum with a characteristic ($-5/3$)-power law;
   - Boltzmann statistics apply because the number of stations and total energy are constants;
   - contribution by isotropic Rossby waves dominate the PDF of wind speed measured by radiosondes;
   - thus, wind speed follows a Weibull distribution with $k=5/3$ for a small region like MP;
   - for a large region like EMZ, distinction between wave-packets leads to $5/3<k<2$.

4. Within the tropospheric interior,

   - the simultaneous presence of many vertical modes causes Shannon's entropy to increase and the value of k to approach 2 compared to the PBL;
   - the spread of wind variance among wave modes at upper levels prevents Shannon's entropy from attaining the maximal value and causes k either to overshoot 2 (MP) or to remain below 2 (EMZ).

5. External organizing or disorganizing influences may suppress or elevate Shannon's entropy and cause k to deviate further

Conclusions

- Best-fit Weibull distributions of tropical radiosonde wind speed can be understood in terms of the statistical dynamics of equatorial waves.
- Thresholds may be derived for monitoring regional radiosonde wind speed datasets in Malay Peninsula and in the wider Equatorial Monsoon Zone.
- More data is retained and data quality is improved compared to using the statistical mathematical approach of “mean+3std”.

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Atmospheric Chemistry and Physics Discussions

Statistical dynamics of equatorial waves in tropical radiosonde wind data

T.-Y. Koh[1,2,3], **Y. S. Djamil**[1], **and C. K. Teo**[3]

[1]School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore
[2]Earth Observatory of Singapore, Nanyang Technological University, Singapore
[3]Temasek Laboratories, Nanyang Technological University, Singapore

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Correspondence to: T.-Y. Koh (kohty@ntu.edu.sg)

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