香港天文台
HONG KONG OBSERVATORY

Reprint 889

Performance of Instability Indices of the Troposphere as Derived from a Ground-based Microwave Radiometer

P.W. Chan & K.K. Hon

The 11th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment, 1-4 March 2010

Washington, DC, USA

PERFORMANCE OF INSTABILITY INDICES OF THE TROPOSPHERE AS DERIVED FROM A GROUND-BASED MICROWAVE RADIOMETER

P.W. Chan and K.K. Hon

Hong Kong Observatory, Hong Kong, China

ABSTRACT

The ground-based microwave radiometer provides a unique opportunity to continuously derive instability indices of the troposphere based on the temperature and humidity profiles. In the present study, three different kinds of instability indices are considered: (a) based on the temperature and dew point values at selected levels only, e.g. K index, (b) based on the energy available for convective development and calculated from the area bound by the temperature profile and the saturated adiabatic lapse rate curve, e.g. CAPE, and (c) based on the curvature of the thermodynamic profile, e.g. shape factor as derived from the vertical gradient of equivalent potential energy. The performance of the various instability indices in the nowcasting of thunderstorms is studied in two spring- and summer-time periods in Hong Kong. Based on the thunderstorm reports at a manned synoptic weather station in Hong Kong, it is found that K index and CAPE have better indication of the occurrence of thunderstorms. In particular, using a dataset larger than that employed in a previous radiometer study by Chan (2009), the temporally averaged K index has good correlation with the frequency of lightning flashes within a distance of several tens of kilometres from the radiometer.

Index Terms— radiometer, stability index, convection

1. INTRODUCTION

The ground-based microwave radiometer makes continuous measurements of the temperature and the relative humidity profiles of the troposphere (10 km). The profiles so obtained could be used to derive stability indices, which give an indication of the degree of convective instability of the troposphere. The use of radiometer-based K index, one of the most common instability indices, in the monitoring of severe convective weather has been discussed in Chan (2009).

This paper extends the previous study by considering different kinds of instability indices, including (a) indices depending on the temperature and dew point at specific heights only, such as K index (KI), humidity index (HI) and total totals index (TT); (b) an index relating to the energy available for convection, namely, Convective Available Potential Energy (CAPE), which is the area bound by the temperature profile of the atmosphere and the saturated adiabatic lapse rate in the tephigram, and (c) an index relating to the curvature of the equivalent potential energy profile of the atmosphere, namely, the shape factor (Walker et al., 2008).

The continuous availability of temperature and humidity profiles of the atmosphere from the radiometer allows frequent updates of the above index values. The indices so calculated are then compared with the occurrence and the total number of lightning strokes occurring within a certain distance from the radiometer, which is taken to be an indication of the degree of convective instability of the atmosphere. As such, the radiometer makes it possible to study the performance of the different indices in the monitoring of the tropospheric instability.

2. COMPARISON WITH RADIOSONDE DATA

First of all, the quality of the radiometer-derived indices is studied by comparing with those derived from the nearly simultaneous measurements from the radiosonde. The radiometer is located at the Hong Kong International Airport (HKIA) in the present study, which is about 25 km to the west of the radiosonde station at King's Park in Hong Kong. The upper-air ascent measurements are only made available twice a day, namely, 00 and 12 UTC. The study period covers one year, namely, June 2008 to May 2009.

The comparison results are given in Figure 1. In general, the radiometer-based and the radiosonde-based indices are well correlated. The correlation coefficients at the various scatter plots are generally less than that reported for KI in Chan (2009). This may be due to the relatively large separation between the two instruments in the present study. In Chan (2009), the radiometer was located at about 1 km south from the radiosonde station.

3. FREQUENCY DISTRIBUTIONS OF THE STABILITY INDICES

The performance of the various indices in the indication of convective instability of the troposphere is first established by examining the frequency distributions of the indices in "clear periods" and "lightning periods". The radiometer data are updated every 10 minutes. The 10-minute intervals centred at the radiometer observation times are considered. This 10-minute interval is defined as a "period". As an indication of the convective instability, the lightning strokes from the lightning location information system (LLIS) over southern China are considered. As a start, a distance of 50 km from the radiometer is adopted. If there is at least one lightning stroke within this 50-km radius of the radiometer in the 10-minute interval, it is regarded as a "lightning period". Otherwise, it is defined as a "clear period". Apart from the 50-km range, a radius of 90 km centred at the radiometer has also been considered and the frequency distributions look generally similar (not shown).

To study the seasonal behaviour of the frequency distributions, two study periods have been considered in this paper, namely, (a) June 2008 to August 2008 and May 2009, which is taken to be summer time, and (b) September 2008 to April 2009, which is taken to be non-summer time.

The frequency distributions in the summer time are shown in Figure 2. The results for KI, TT and HI are generally consistent with the thresholds of convective instability commonly adopted in the literature, namely, KI value of 30, TT value of 40 and HI value of 10 may be used as thresholds. The frequency distributions of "clear periods" and "lightning periods" show some degree over lapping. In general, the "clear periods" have wider distributions of index values, whereas the index distributions of "lightning periods" are narrower.

On the other hand, for CAPE and SF (not shown), the distinction between the frequency distributions of "clear periods" and "lightning periods" is not so trivial. For each index, the distributions in these two kinds of periods look similar in term of the range of index values and the frequency values themselves. Based on these results, it appears that those instability indices calculated from the specific heights of the temperature/dew point profiles are more skillful in distinguishing between lightning and non-lightning situations, at least for the climatological conditions in Hong Kong.

4. RELATIVE OPERATING CHARACTERISTIC (ROC) DIAGRAMS

The performance of radiometer-based indices in the indication of tropospheric instability could also be studied using ROC diagrams. For each particular index, the threshold for indicating convectively unstable atmosphere is varied. For a specific threshold value of the index, if the index meets the criteria and a lightning stroke occurs within 30 km from the radiometer in the 10 minute interval centred at the radiometer observation time, this event is taken to be a hit. Otherwise, if the index meets the criteria but there is no lightning stroke within 30 km, the event is taken to be a false alarm. The data of summer time and non-summer time are considered in calculating the probability of detection (POD) and probability of false detection (POFD) of the various index thresholds.

The resulting ROC curves are shown in Figures 3(a) to (e). There are a number of observations:

(a) The indices based on temperature/dew point values at specific heights are more skillful than CAPE and SF. This could be seen more clearly in the area under the ROC curves as shown in Figure 3(f).

(b) In general, the indices are more skillful in the non-summer time than the summer-time, i.e. where the ROC curves get closer to the "ideal situation" at the upper left corner of the plot. This is also shown in the area under the ROC curves in Figure 3(f). It appears that, in the summer time, the atmosphere may remain convectively unstable for extended periods of time, but there may be lightning or no lightning within each period, making the indices less skillful in correlating with the occurrence of lightning.

(c) For non-summer time, in order to achieve optimum performance (i.e. the intersection between the ROC curve and the "optimal performance" straight line from the upper-left corner to the lower-right corner of the plot), a lower threshold may be adopted for KI (29 vs. common value of 30) and TT (38 vs. common value of 40) and a higher threshold may be adopted for HI (17 vs. common value of 10). On the other hand, in the summer time, a higher threshold may be adopted for KI (34) and TT (41) as well as for HI (13).

5. LIGHTNING EPISODE

Chan (2009) studied in the correlation between the averaged KI and the total number of lightning stokes in a lightning episode. A similar study is repeated here but using a more objective way to establish an episode. In this paper, a lightning episode is defined as a period of 10 minutes or longer (multiples of 10 minutes) in which the total number of lighting strokes within a certain distance from the radiometer in each 10-minute interval of this period is at least 20. An example of a lightning episode, together with the time series of the various radiometer-based instability indices, is shown in Figure 4.

After considering all the indices, it turns out HI has the best correlation with the total number of lightning strokes. Figure 5 shows that scatter plot between the minimum HI within the lightning episode and the logarithm of the total number of lightning within a distance of 30 km from the radiometer. As could be expected from the definition of HI, as the minimum value of HI decreases, the atmosphere is more humid and thus the total number of lightning strokes increases. The correlation coefficient is less than that in a similar study before (Chan, 2009), probably because more cases (data over a year) are considered in the present paper.

The above correlation for minimum value of HI is studied by considering lightning strokes within different distances away from the radiometer, viz. from 10 km to 90 km. The variation of the correlation coefficient of the resulting scatter plot with the distance from the radiometer is shown in Figure 6. It turns out that the correlation coefficient is the highest at about 30 km. This is in generally the same order of magnitude for the distance considered in the study of frequency distributions and ROC curves of the instability indices above (namely, a distance of 50 km from the radiometer). The present study result is also consistent with that reported in Chan (2009), namely, in terms of the correlation with the number of lightning strokes (as a proxy of the tropospheric instability), the ground-based microwave radiometer may be considered to be making measurements representative over a distance of about 30 km away.

6. CONCLUSIONS

The continuously available instability indices of the atmosphere as obtained from the ground-based microwave radiometer at HKIA are studied in the present paper over a period of one year. It is found that the indices calculated from the temperature/dew point values at specific heights are more skillful in depicting the degree of tropospheric instability based on the ROC curves. Different thresholds may be adopted for summer and non-summer periods. The indices in general show more skills at non-summer times. Moreover, the minimum value of HI in a lightning episode has reasonable correlation with the total number of lightning strokes. The radiometer may be regarded as making measurements that are representative of a region within 30 km away from the radiometer, as far as convective instability is concerned.

[1] P.W. Chan, "Performance and Application of a Multi-wavelength, Ground-based Microwave Radiometer in Intense Convective Weather," *Meteorologische Zeitschrift*, Vol. 18, pp. 253-265, 2009.

[2] Ira Walker, Venkatesan Chakrapani, and Widad Elmahboub, "The Development of a Shape Factor Instability Index to Guide Severe Weather Forecasts for Aviation Safety," *Meteorological Applications*, Vol. 15, pp. 465 – 473, 2008.

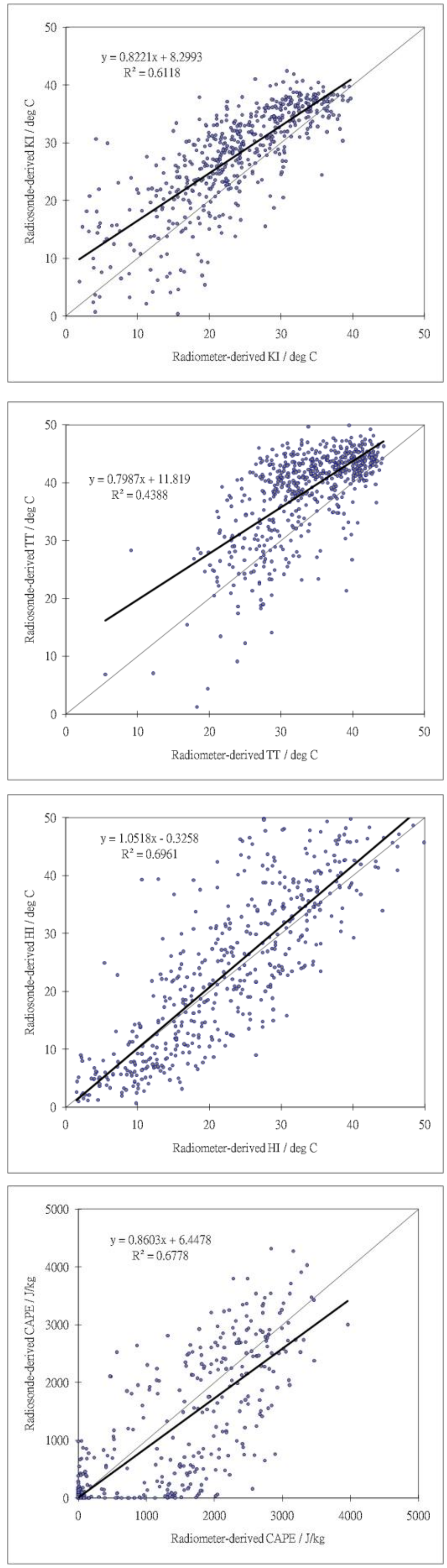

Figure 1 Comparison of the instability indices derived from the radiometer and radiosonde – from top to bottom: K index, TT, HI and CAPE.

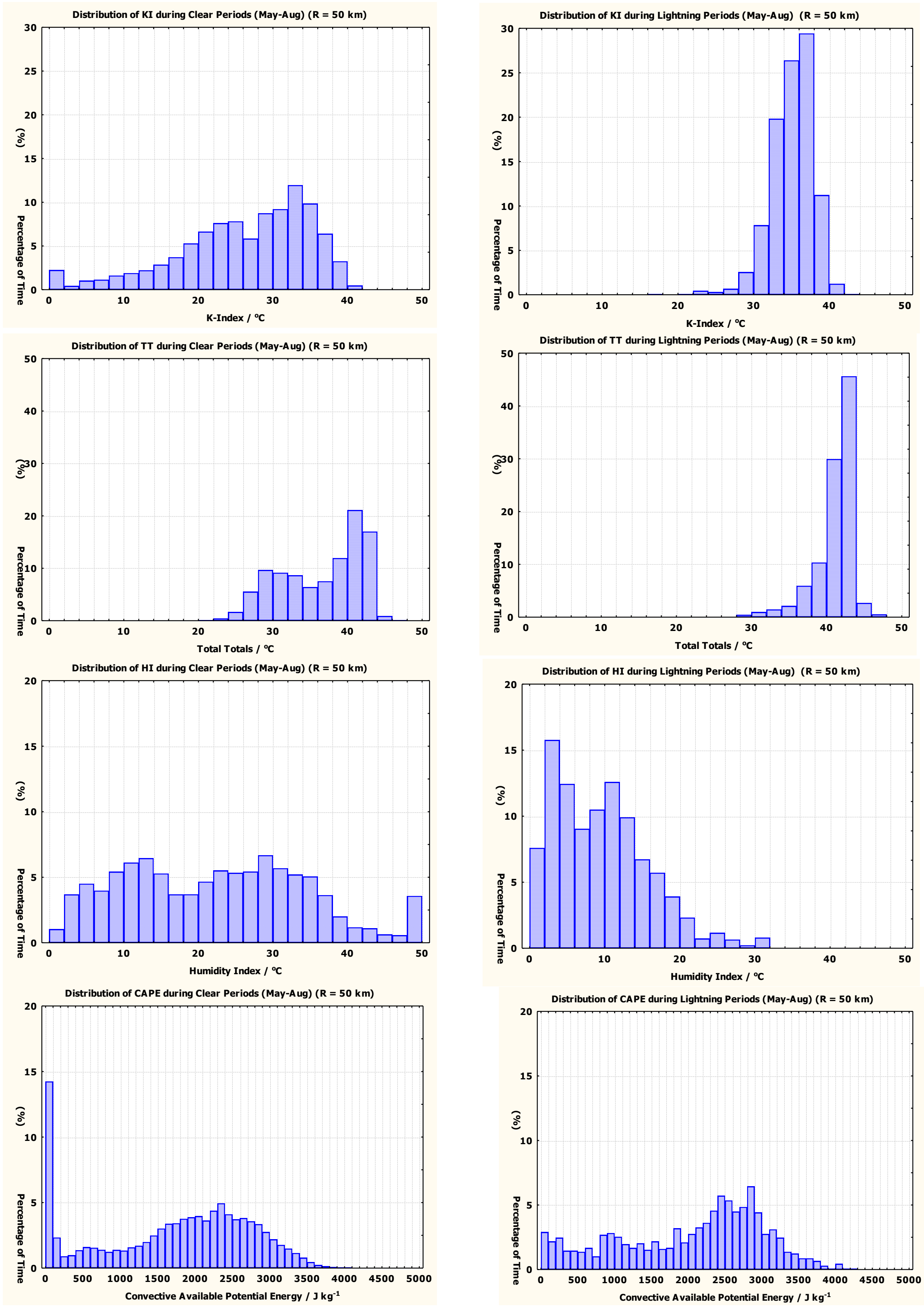

Figure 2 Frequency distributions of the instability indices during periods without lightning (left hand side, the so-called "clear periods") and with lightning (right hand side, the so-called "lightning periods"). From top to bottom: K index, TT, HI and CAPE.

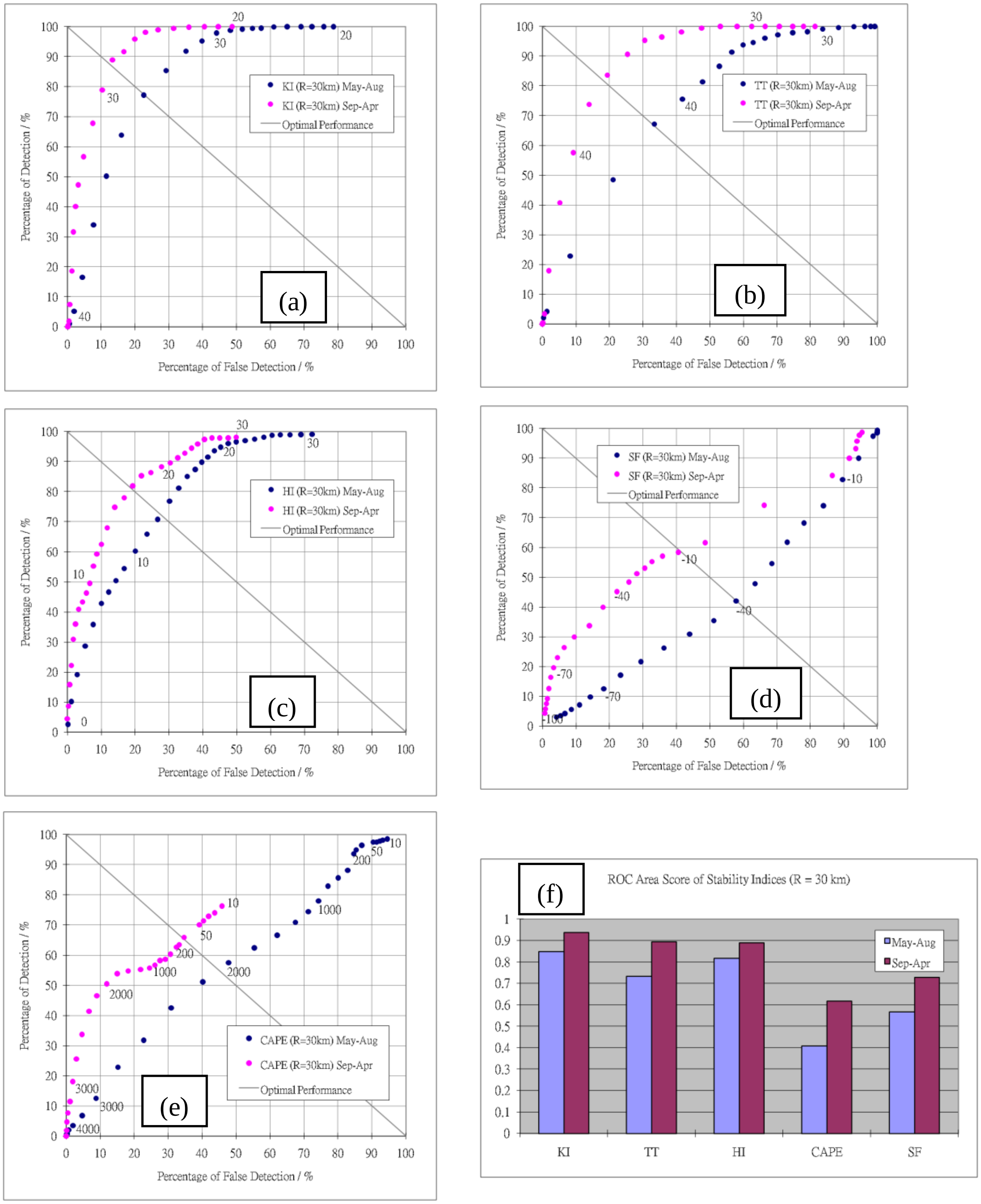

Figure 3 (a) to (e) are the ROC curves for various radiometer-based instability indices for summer (May to August) and non-summer (September to April) periods, including K index, TT, HI, SF and CAPE. (f) gives the areas under the ROC curves.

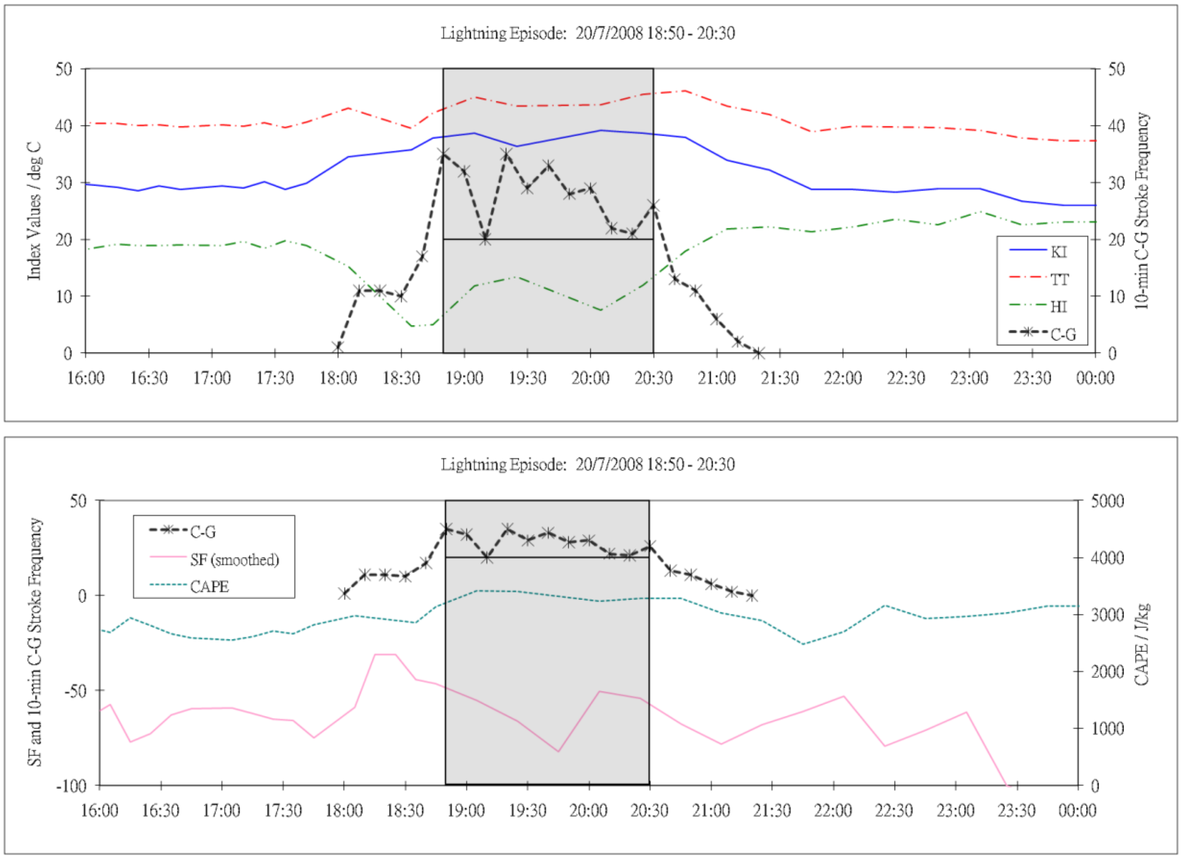

Figure 4 Time series of the number of cloud-to-ground lightning strokes and the values of the various instability indices for the sample lightning case of 20 July 2008. Upper panel: KI, TT and HI; lower panel: SF and CAPE. The "lightning episode" defined in Section 5 is highlighted in grey.

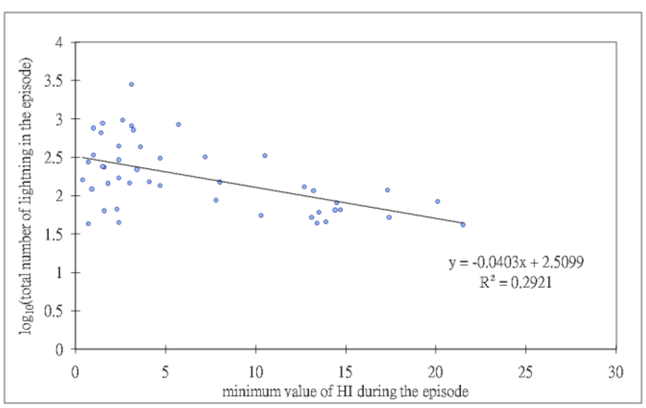

Figure 5 The scatter plot of logarithm of the total number of lightning strokes in the episode against the minimum value of HI during the episode for the study period in the present paper with the distance of 30 km from the radiometer.

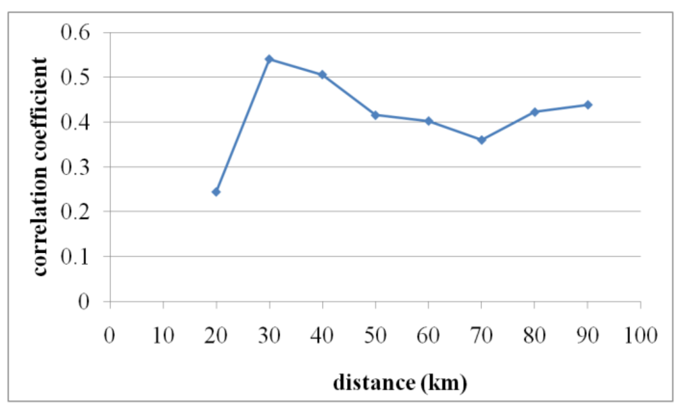

Figure 6 The variation of the correlation coefficients for the scatter plots similar to Figure 5 with the distances over which lightning strokes are counted.