P2.3

UTILIZING RADIO OCCULTATION SOUNDINGS TO ESTIMATE CONVECTIVE POTENTIALS OVER

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1. INTRODUCTION

Unexpected convection associated with thunderstorms over the oceans can compromise flight safety. Currently, algorithms for identifying convection over the oceans are limited to inferences made using visible and infrared satellite information only. About 90% of all hazardous cells are detected by using three different algorithms, but about 40% of the time, these algorithms give out false alarms, and thus exaggerate the potential for hazardous flight conditions (Donovan et al., 2007).

Stability indices are numerical values that characterize the state of our atmosphere. These indices are derived from vertical profiles of the atmosphere. This project will use the Convective Available Potential Energy (CAPE), K-Index (KI), Total Totals Index (TT), and the Lapse Rate between the 500-700mb (L57). Thus, these indices will help identify unexpected convection cells over the oceans.

In the most recent decade, three satellites, GPS/Meteorology (GPS/MET), CHAllenging Minisatellite Payload (CHAMP), and Satellite de Aplicaciones Cientificas-C (SAC-C) were used as proof-of-concept vehicles to inexpensively obtain vertical profiles of the atmosphere from space. These satellites used radio occultation (RO) technique to obtain these profiles.

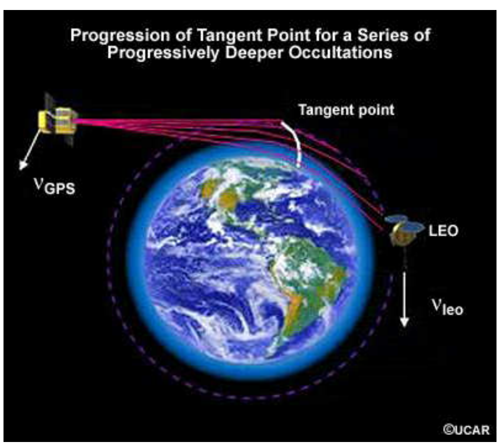

Figure 1: This figure illustrates the concept of how the LEO and receiver satellite work in unison to create an occultation. (COSMIC Webcast, http://www.meted.ucar.edu/COSMIC/)

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The receivers onboard the low Earth orbiting (LEO) satellites were used to receive radio signals from GPS satellites, which transmit radio waves that pass through the Earth's atmosphere. The receivers can accurately measure the phase and amplitude of the GPS radio signal at two frequencies: L1 (1575.42 MHz) and L2 (1227.6 MHz). With the information on the precise position and velocities of GPS and LEO satellites, we can measure the bending of radio waves as they pass through the atmosphere, resulting in a vertical profile of bending angles. The vertical profiles of bending angles can, in turn, be used to derive vertical profiles of atmospheric refractivity, which can be expressed as the following:

$$N = 77.6\frac{p}{T} + 3.73*10^{5}\frac{e}{T^{2}} - 4.03*10^{-7}\frac{n_e}{f^{2}} \qquad (1)$$

where p is pressure, T is temperature, e is the water vapor pressure, n_e is the electron density, and f is the frequency of the GPS carrier signal (COSMIC: CDAAC Description, Anthes et al. 2007).

These three satellites older than COSMIC, with RO capability, could not easily calculate CAPE values over the Tropics; because the signal tracking algorithms used in these older generation of receivers do not allow deep penetration into the lower troposphere. Since the calculation of CAPE is very sensitive to temperature and moisture profiles near the lower troposphere, it would not be meaningful to calculate CAPE for a sounding that misses the bottom 5 km of data. The new signal tracking technique employed on COSMIC satellites, called open-loop tracking, allow 90% of COSMIC soundings to penetrate below 1 km. Therefore, this offers the possibility of evaluating the convective potentials over the ocean, using the aforementioned convective indices.

On April 15, 2006, a cluster of six satellites known as COSMIC was launched. These six satellites provide approximately 2500 GPS RO soundings a day, distributed uniformly around the globe. With soundings from COSMIC penetrating to altitudes close the Earth's surface, as opposed to older RO satellites, it would be possible to derive CAPE values from COSMIC soundings. In Kuo et al. (2005) CHAMP RO soundings were compared to radiosondes to assess the accuracy of five different, widely used radiosonde/rawindsonde systems. RO data were used as a basis for the comparison due to their high accuracy, all-weather retrieving capabilities, and independence in terms of geographic.

2. METHODOLOGY

Currently scientists rely on three algorithms–each of which is based on geostationary satellite observations-to identify convective cells that could present a problem when flying over the oceans. The first, Cloud Top Height product, determines cloud height, and can also indicate presence of deep convection and other cloud properties. The second method, the Cloud Classification algorithm, classifies satellite images into several cloud types and layers, using a combination of the infrared and visible channels. The final method takes the difference between the temperatures taken at the 11-micron and 6.7-micron channel. If the temperature difference is less than 1K, that indicates an unstable atmosphere. Values greater than 1K indicate shallow, non-threatening clouds. Differences higher than 1K are due to the shallow cloud's radiative properties (Donovan et al., 2007). However, COSMIC can provide a unique opportunity to help with nowcasting techniques over the oceans.

This project was conducted at the COSMIC division at National Center for Atmospheric Research, where we looked at radiosonde and the wet profile data obtained from COSMIC RO data measured on May 2007. The Read, Interpolate, and Plot (RIP) calccape3d.f program was adjusted in order to calculate the CAPE, KI, TT, and L57 values from the Radiosonde and COSMIC RO data. The adjusted RIP program would take the maximum equivalent potential temperature in the first 1km of the atmosphere, which gave us our parcel's initial values. This adjusted RIP program was also set to one-dimension, the parcel averaging section was removed, and the KI, TT, and L57 indices were included.

These changes to the assumption of the initial properties of an air parcel at the surface were different than that of the National Weather Service (NWS). These differences in assumptions of the initial properties of an air parcel at the surface will result to differences in the calculated values for CAPE and CIN. The National Weather Service (NWS) takes the average of the bottommost 100mb of the atmosphere and sets these values as their initial values. As mentioned earlier the RIP calccape3d.f program was adjusted. This adjustment to the RIP program took the maximum equivalent potential temperature in the first 1km of the atmosphere, was set to one-dimension, and the parcel averaging section was removed, which gave us our parcel's initial values.

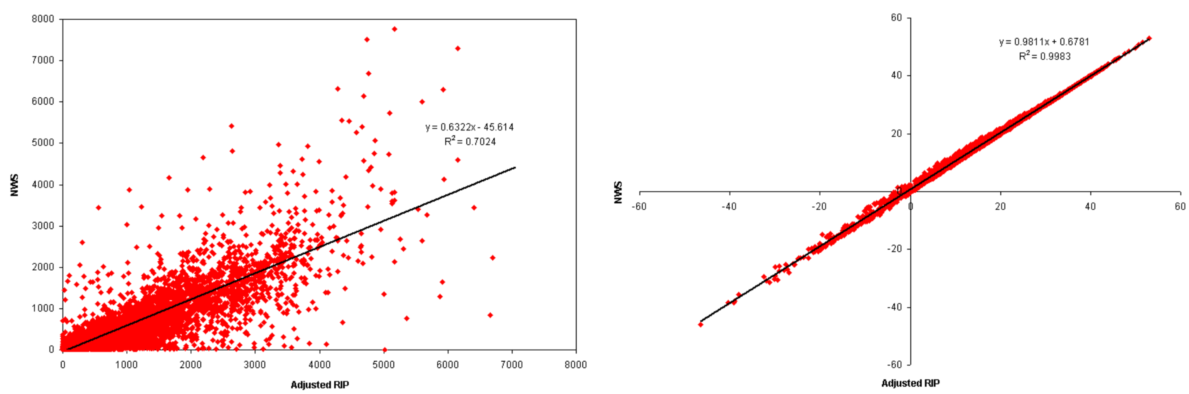
All of these indices were calculated first from NWS radiosonde data, and were verified against the NWS provided values for May 2007. Using similar methods as in Blanchard in 1998, this study compared the CAPE to the KI, TT, and L57, to prove that the adjusted RIP program's indices values were valid. Once proven to be accurate the Adjusted RIP program was then applied to the COSMIC RO data.

To assess the accuracy of COSMIC-derived indices, a Perl program was written to collocate the radiosonde data with the Adjusted RIP program's index values to COSMIC RO indices values which were 200km and ±2hr apart. These collocated COSMIC RO indices were then compared with the radiosonde Adjusted RIP indices. After this initial run, the collocation program was run once more using a 400km radius.

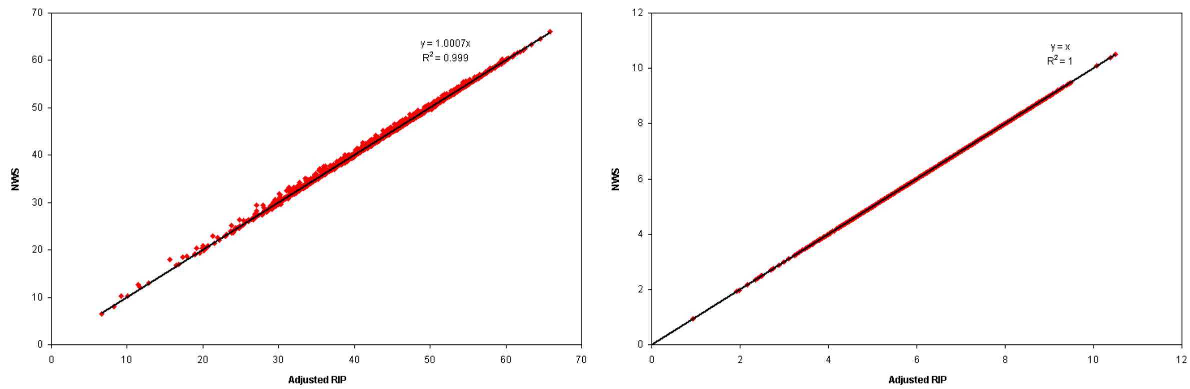
3. RESULTS/DISCUSSION

3.1 *Comparison of convective indices calculated from Adjust RIP program and NWS using the radiosonde soundings*

Comparison of convective indices calculated by NWS and the Adjusted RIP program using the same radiosonde data for May 2007 are shown in the scatter plots below (see Fig. 2). Note the steepness of the slopes and r^2 values for each plot.



(a) (b)



(c) (d)

Figure 2: This figure illustrates the regression line, correlations, and the r^2 values, between the NWS calculated (a) CAPE, (b) KI, (c) TT, and (d) L57 with the Adjusted RIP version of these indices from the same radiosonde data for May 2007. The scatter plots display a total of 6077 observations.

	CAPE	KI	TT	L57
Average	373.70	-0.21	-0.04	1.32E-5
Standard deviation	585.39	0.56	0.19	0.00
Correlation	0.84	0.99	0.99	1

Table 1: This table describes the numerical values of the average differences, standard deviations of the differences, and correlations between the NWS calculated CAPE, KI, TT, and L57 with the Adjusted RIPS version of these indices, which were based on the same radiosonde data for May 2007. These values above represent a total of 6077 observations.

When correlating CAPE values we should note that the r^2 value is 0.7024, which means that 70.24% of the variances between the two calculations can be explained by the regression line formula. Note that the correlation is 0.838123, which means that the NWS calculated CAPE, compared to the Adjusted RIP-calculated CAPE were well correlated to each other. This suggests that the method used to pick and set an air parcel at the surface isn't a major factor in deciding whether the environment is convectively unstable or not, and that achieving high correlations when using two different methods of generating CAPE values is possible. On other hand, the large mean difference of 373.7 J/kg also indicates that the value of CAPE itself is sensitive to the choices of surface air parcel properties. We conclude that CAPE can be calculated to a high degree of accuracy. The other three indices KI, TT, and L57 had a perfect correlation of 1.00, and an r^2 value of near 1.00.

The slope of the regression line on these scatter plots tell another story. For CAPE the slope of the regression line is less than 1 which means that the methods used in the Adjusted RIP-calculated CAPE is giving larger CAPE values than what the NWS calculated. For the other indices the relationship for the most part is 1:1 with the exception of round-off error, which is why the KI and the TT indices have a slight deviation of 1.00 for their slope, and have a y-intercept slightly off from the origin.

The average differences between the two CAPEs are 373.7021, which corresponds nicely to the fact that the Adjusted RIP-calculated values for CAPE are greater than and less than the NWS calculated values. The average differences between the other indices are near 0 and so are the standard deviation of the differences, which means the data is nearly a 1:1 relationship.

Recall, that 70.24% of the variance in the differences between the two calculations can be explained by the regression line. Thus new CAPE thresholds can be calculated given the current NWS CAPE thresholds shown in table 2.

NWS CAPE	Physical meaning	Adjusted RIP CAPE
0	**Stable**	0
1000	**marginally unstable**	1600
2500	**moderately unstable**	4000
3500	**very unstable**	5600
3500+	**extremely unstable**	5600+

Table 2: This table describes the numerical values of the NWS CAPE thresholds and the equivalent thresholds for the Adjusted RIP CAPE values.

Also recall that the slope of the CAPE regression line is 0.6322 which is less than 1, meaning that the Adjusted RIP CAPE calculations are overestimating CAPE, hence a greater CAPE threshold values are observed in table 2.

3.2 *Correlation of the CAPE to KI, TT, and L57 values*

Correlations between NWS calculated CAPE with the other NWS calculated indices and Adjusted RIP CAPE with the other Adjusted RIP-calculated indices out of the same radiosonde data for May 2007 are shown in the scatter plots below (see Fig. 3). Note the r^2 values for each plot and their respective magnitude of CAPE to each other index.

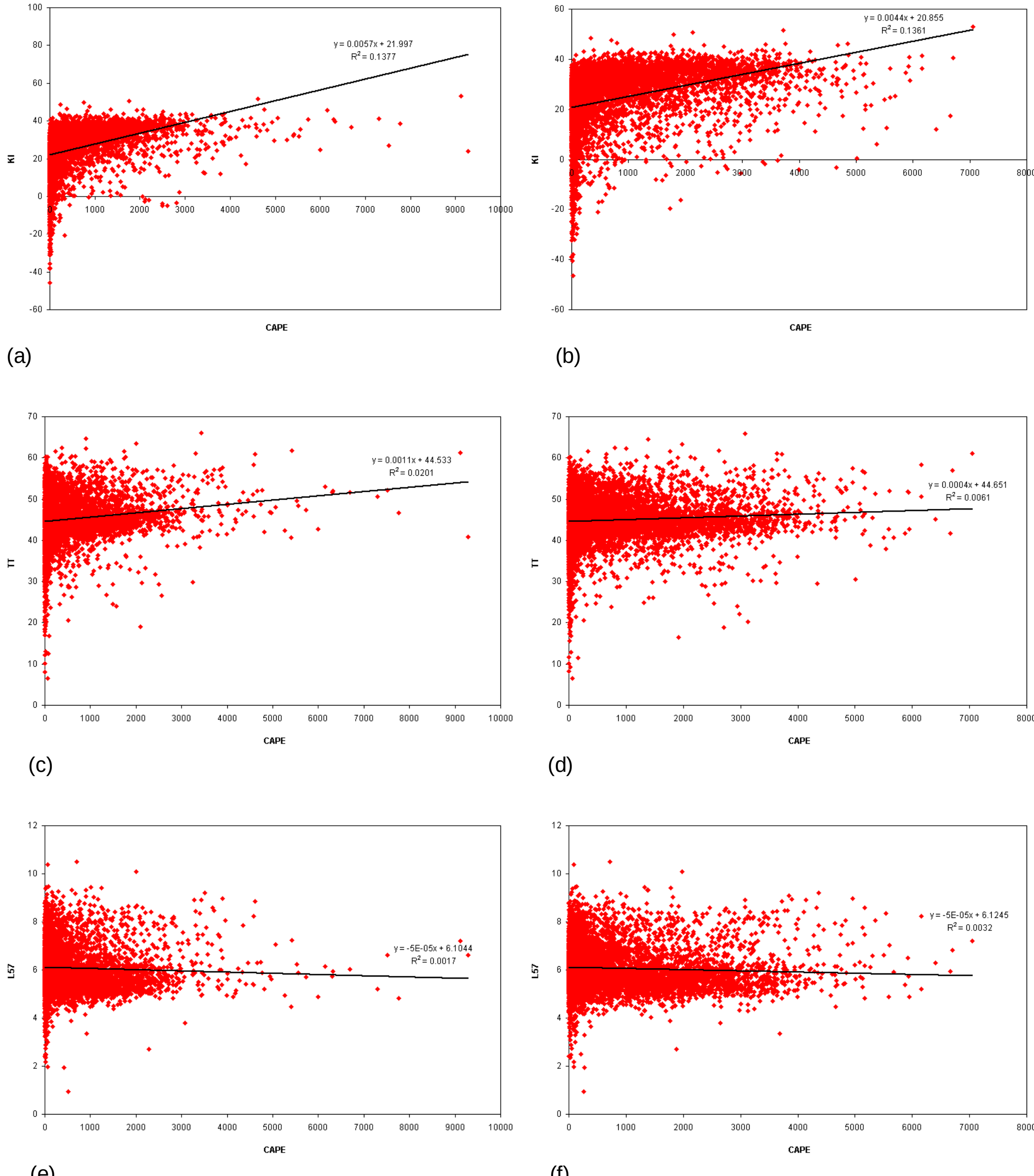
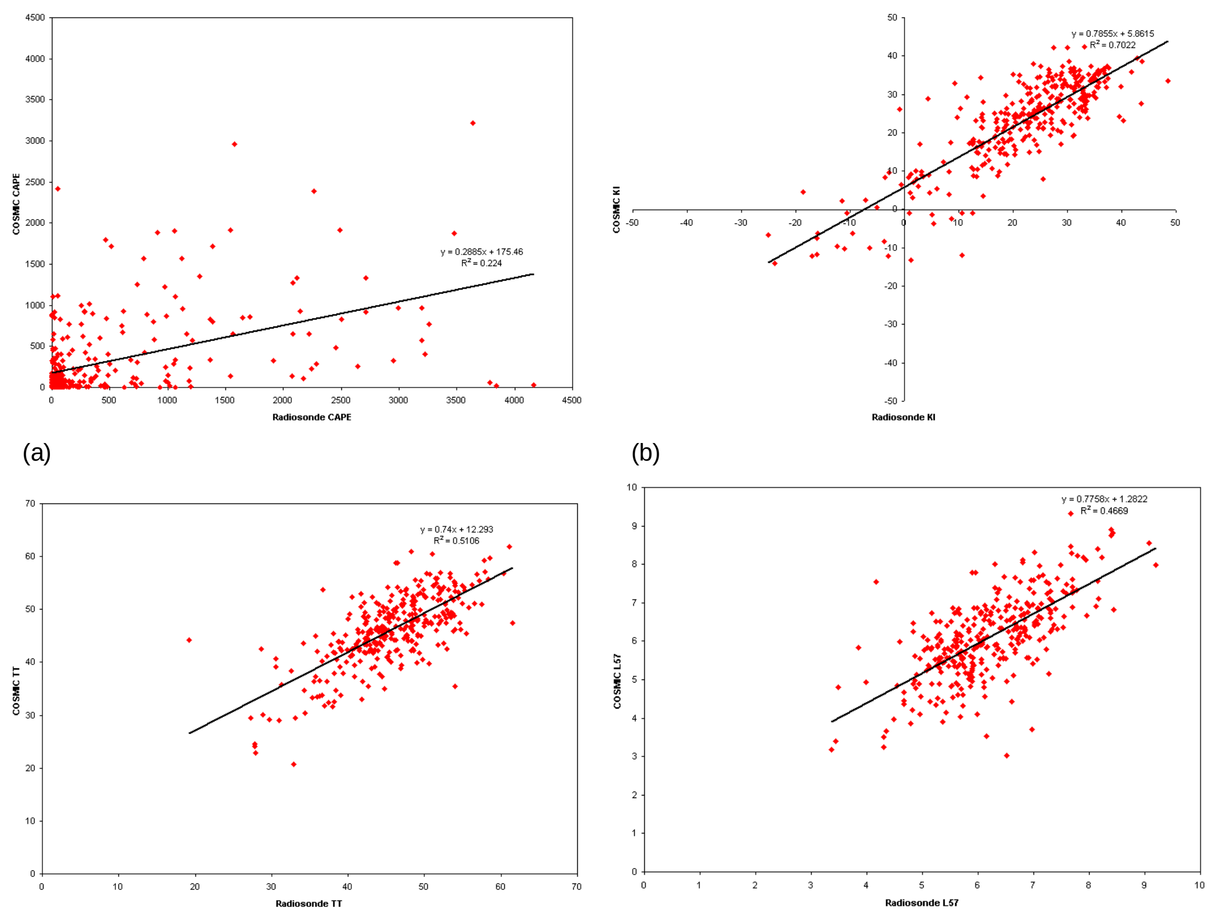


Figure 3: This figure illustrates the regression line, correlations, and the r^2 values, between NWS calculated CAPE to the NWS calculated (a) KI, (c) TT, and (e) L57, and between the Adjusted RIP CAPE to the Adjusted RIP-calculated (b) KI, (d) TT, (f) L57; from the same radiosonde data for May 2007. The scatter plots above display a total of 6077 observations.

The idea of comparing CAPE to other indices is based on a study conducted previously by Blanchard (1998) where CAPE values were correlated to the Lifted Index (LI) and a weak correlation was found. The weak correlation of CAPE to LI in this previous study was due to the fact that the CAPE was an integration of multiple levels as opposed to the LI index, which was a point value. Even though the data from Fig. 3 show that CAPE compared to other indices were not well correlated with each other, the magnitudes between CAPE versus each index for the NWS, and Adjusted RIP-calculated values have all the same magnitude. This provides further support for our conclusion that CAPE is being calculated correctly regardless of how high or how low the numbers are and where the parcel's initial properties are assumed to be.

3.3 *Correlation of Co-located COSMIC RO and Radiosonde data*

Correlations between COSMIC RO soundings which are 200km apart and ±2 hours apart from radiosonde data were plotted using the Adjusted RIP-calculated indices for both data sets for May 2007. These results are shown in the scatter plots below (see Fig. 4). Note the r^2 values for each plot.



(c) (d)

Figure 4: This figure illustrates the regression line, correlations, and the r^2 values, between the Adjusted RIP calculated (a) CAPE, (b) KI, (c) TT, and (d) L57 for the collocated COSMIC RO to radiosonde data for May 2007. The scatter plots above display a total of 1327 pairs of soundings.

From Fig. 4, it should be noted that there are weak correlations between the collocated COSMIC RO and radiosonde data. These weak correlations occur more for the CAPE (0.47) values than in any other indices. Note, that the KI has a correlation of 0.837995, while TT and L57 have correlations of 0.714548 and 0.683313, respectively. These correlation values suggest that CAPE is not robust index for COSMIC RO soundings to derive at the moment. This result occurs because of the way CAPE values are calculated, and also because of how COSMIC temperature and moisture profiles are derived. The calculation of CAPE values is sensitive to the lower tropospheric temperature and moisture structure in the sounding. Meanwhile, the retrieval of temperature and moisture profiles from COSMIC current 1D-Var retrieval approach is sensitive to first-guess profiles, particularly in the lower troposphere. This limits the accuracy of calculating CAPE from the derived COSMIC temperature and moisture soundings (even though the COSMIC measured value of atmospheric refractivity profiles can be of very high accuracy). Since these indices are very sensitive to moisture in the lower troposphere, as opposed to the latter indices, the calculation of CAPE from COSMIC data is subjective to large uncertainties.

The method used to determine the property of an air parcel at the surface isn't a key factor to these low correlations between the collocated data, but its sensitivity to moisture is what affects the correlations of the CAPE collocated indices. Just because CAPE values calculated from collocated COSMIC and radiosondes aren't showing high correlations and currently there is no promise that COSMIC RO data can provide robust estimates of these values, it doesn't mean that other indices that are not as sensitive to surface moisture and temperature (and are more robust) can't be derived from RO soundings.

	CAPE	KI	TT	L57
Average	151.54	-1.27	-0.44	0.11
Standard deviation	722.64	6.92	4.99	0.82
Correlation	0.47	0.84	0.71	0.68

Table 4: This table describes the numerical values of the average differences, standard deviations of the differences, and correlations between the Adjusted RIP calculated (a) CAPE, (b) KI, (c) TT, and (d) L57 for the collocated COSMIC RO to radiosonde data, which are within 200km and ±2hr for May 2007. These values above represent a total of 1327 pairs of observations.

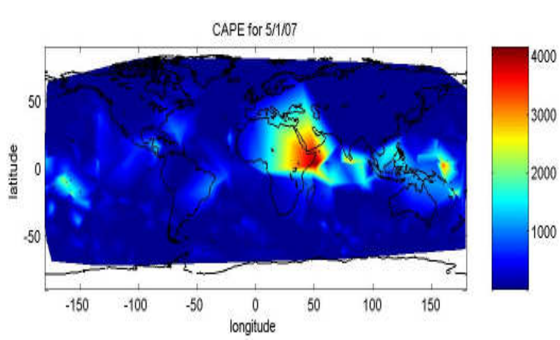
This study was extended to include collocations of COSMIC RO soundings to radiosondes that were within 400km and ±2hr and the results are shown in table 5 (below). Note that the values of each indices' average difference and the standard deviation only vary by at most ~30 units. Also note that the correlations between the 200km and the 400km spatial radius suggests that with more data being collected due to a bigger spatial radius yields to lower correlation values between the collocated data.

	CAPE	KI	TT	L57
Average	181.30	-1.56	-0.29	0.10
Standard deviation	762.66	9.93	6.13	0.96
Correlation	0.47	0.71	0.59	0.58

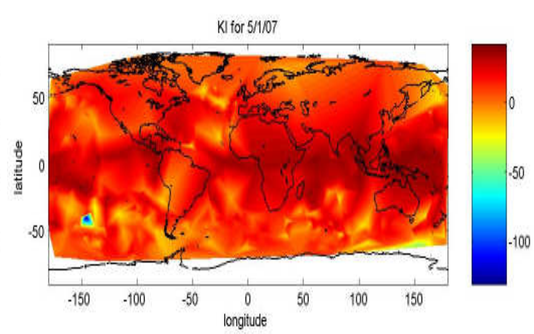
Table 5: This table describes the numerical values of the average differences, standard deviations of the differences, and correlations between the Adjusted RIP calculated (a) CAPE, (b) KI, (c) TT, and (d) L57 for the collocated COSMIC RO to radiosonde data, which are within 400km and ±2hr for May 2007. These values above represent a total of 1327 pairs of observations.

4. CONCLUSIONS

Calculations of CAPE are sensitive to the choice of surface air parcel's initial properties. However, the relationship of CAPE with other indices is robust. Also, CAPE values calculated from the COSMIC retrieved temperature and moisture do not correlate well with those calculated from nearby radiosondes, due to the fact that the retrieval of COSMIC temperatures and moistures (particularly in the lower levels) are very sensitive to the retrieval method of RO data. Other convective indices, such as KI, TT, & L57, calculated from COSMIC soundings, correlate well with those from nearby radiosondes. They provide useful indication of convective potentials over the oceans. From these data we can eventually obtain horizontal distribution maps of these indices, which can then be provided for aviation use to assess potential threat of unexpected convection and turbulence that could lie ahead of an airplane, an example of the future final product is shown in figure 5.



(a)



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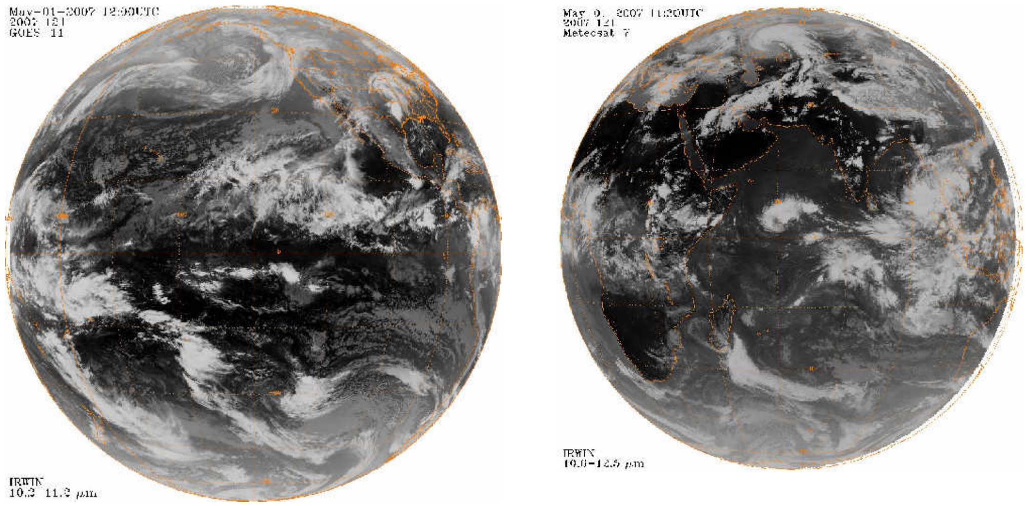

(c) (d)

Figure 5: The above illustrations are examples of horizontal distributions of (a) CAPE, and (b) KI which could be used in the future by aircrafts for predicting unforeseen convective cells for the first of May 2007. Also images (c) from the GOES-11 IR 12Z satellite image (d) from the Meteosat-7 IR 12Z satellite image is used to compare the accuracy of this new product.

With the COSMIC satellite gradually reaching their final orbits, these six satellites will be able to take 2,500 soundings daily. Once this happens, further analysis could occur to evaluate each index's diurnal cycle. Also, further work should be done to asses the accuracy of other indices – apart from CAPE, KI, TT, or L57 – that could be calculated utilizing COSMIC RO data. Since this study shows that CAPE values are very sensitive to the accuracy of retrieved temperature and moisture profiles derived from COSMIC soundings, and the retrieval of these profiles are, in turn, sensitive to the first guess fields, further improvement in the retrieval method is needed before we can robustly produce CAPE values from COSMIC soundings. Another possible solution to this problem could be creating a special version of CAPE programs that are specifically tailored to COSMIC RO data and its current methods of moisture and temperature retrieval.

5. REFERENCES

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