Utilizing COSMIC radio occultation soundings to estimate convective potentials over oceans

Michael Kevin Hernandez

Academic Affiliation, Fall 2007: Senior, University of Miami

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Science Research Mentor: Ying-Hwa (Bill) Kuo, Douglas C. Hunt
Writing and Communication Mentor: Rachal Hauser

ABSTRACT

Over oceans, unexpected convection can adversely affect airplane travel. To mitigate such hazards, the Federal Aviation Agency (FAA) asked the University Corporation of Atmospheric Research (UCAR) to develop techniques that warn of imminent convection. The challenge: few traditional observations are taken over the ocean, and nowcasting techniques, which rely on Doppler weather radar, are not applicable. An atmospheric sounding technique, known as GPS radio occultation (RO), offers a possible solution to this problem. The six-satellite mission Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) provides approximately 2,500 vertical profiles of the Earth’s atmosphere daily, and is uniformly distributed around the globe including the tropical ocean. These GPS RO soundings are of high vertical resolution and accuracy. With the use of one-dimensional variational retrieval, vertical profiles of temperature and moisture can be derived from COSMIC soundings. These profiles could be used to estimate convective potentials of the atmosphere that lie ahead of an airplane travelling over the ocean. This study evaluated the accuracy of Convective Available Potential Energy (CAPE), Convective Inhibition (CIN), K-index (KI), Total Totals (TT), and 700-500mb Lapse rate (L57) calculated from COSMIC GPS RO soundings against observations from balloon-based radiosonde soundings. This study also evaluated whether COSMIC-derived indices values are accurate enough to be useful for the FAA’s over-ocean convective forecasting. With some indices proven to be useful, this technique will eventually provide real-time KI, TT, and L57 value estimates globally. Additionally, COSMIC indices values can be used in studies to map out the diurnal cycle of any index.
1. Introduction

Unexpected convection can compromise flight safety. Updrafts cause turbulence that can lead to catastrophic results. As a result of these updrafts, American Eagle flight 5089 on 28 April 2007, as it was descending over the ocean to its final destination at San Juan, encountered light turbulence during descent, and then a jolt of turbulence. These sets of turbulence resulted in minor injuries to two flight attendants, while one passenger suffered serious injuries (NTSB, 2007). This is just one of many events that occur yearly, some more severe than others. Hence, as a way to improve passenger safety while flying over the ocean, the Federal Aviation Agency (FAA) asked scientists at the University Corporation for Atmospheric Research (UCAR) for help in improving its nowcasting capabilities over the oceans. Over land, use of radars and other meteorological instruments can easily identify these convective cells, but the challenge is doing so over the ocean, where there are few traditional meteorological observations.

Current algorithms for identifying thunderstorms are limited because inferences are made when using satellite visible and infrared 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). Consequently, a potentially useful meteorological index to the FAA is the convective available potential energy (CAPE).

According to the American Meteorological Society (AMS), CAPE expresses the maximum amount of energy of a rising parcel of air (Glossary of Meteorology). Mathematically CAPE is represented by eq. 1

\[
\text{CAPE} = \int_{P_{LFC}}^{P_{EL}} (\alpha_p - \alpha_e) \, dp \tag{1}
\]

where \(\alpha_p\) is the specific volume of the parcel, and \(\alpha_e\) is the environmental specific volume, \(P_{LFC}\) is the pressure where the level of free convection occurs, and \(P_{EL}\) is the pressure at which the parcel becomes neutrally buoyant. For real-life measurements of the atmosphere’s profile, eq. 1 must be expressed as a finite number of pressure levels

\[
\text{CAPE} = \sum_{P_{LFC}}^{P_{EL}} (\alpha_p - \alpha_e) \Delta p \tag{2}
\]

Most CAPE values are derived from balloon-borne instrument packets, radiosondes or even via instruments called dropsondes, which sample the atmosphere as they fall from a plane. Using these meteorological instruments, scientists can take vertical profiles of Earth’s atmosphere. CAPE, which is derived from the atmospheric profile, is a basic index that tells how unstable a parcel of air becomes as it rises in the atmosphere--the more unstable the air parcel is, the more powerful the updrafts. Below is a table that illustrates CAPE values and corresponding atmospheric stability.
CAPE value | Convective potential
---|---
0 | Stable
0-1000 | Marginally Unstable
1000-2500 | Moderately Unstable
2500-3500 | Very Unstable
3500+ | Extremely Unstable

Table 1: This table illustrates how various CAPE values correlate to air parcel stability (Ohio State, CAPE).

Also of equal important, according to the Glossary of Meteorology, is the Convective Inhibition (CIN)--the energy that is needed to lift an air parcel from the surface to the LFC. Mathematically this is represented as

$$CIN = -\int_{p_o}^{p_{LFC}} R_d (T_{vp} - T_{ve}) \, d\ln p$$

where $p_o$ is the surface pressure, $R_d$ is the Dry Gas Constant, $T_{vp}$ is the parcel virtual temperature, while $T_{ve}$ is the environmental virtual temperature. For real-life measurements of the atmosphere’s profile, eq. 3 must be expressed as a finite number of pressure levels

$$CIN = \left( \sum_{p_o}^{p_{LFC}} R_d (T_{vp} - T_{ve}) \right) \ln \left( \frac{p_{LFC}}{p_o} \right)$$

All CIN values are derived at the same time as CAPE using vertical profiles of the Earth’s atmosphere via radiosondes and dropsondes. CIN, which is derived from the atmospheric profile, is another basic index that measures the resistance of the environment (e.g., negative buoyancy) that an air parcel must occur in order for it to rise from the surface to the LFC. A high CIN value indicates large negative buoyancy and strong resistance, and therefore clear skies. In other words, CIN is a cap that prevents an air parcel to rise past the LFC (thus it will sink back down to where it started off), if it does not have enough energy to overcome this CIN cap. The aforementioned illustrates the importance of obtaining CAPE and CIN values for convection forecasting.

In this study, the K-index (KI), and the Total Totals (TT) were also used, and AMS Glossary of Meteorology defines these values as quantities that also evaluate the potential of convection at a certain location. The mathematical representation of the KI and TT indices are shown in equations (5) and (6) respectively.

$$KI = (T_{850} - T_{500}) + D_{850} - (T_{700} - D_{700})$$

$$TT = T_{850} - 2T_{500} + D_{850}$$

where $T_x$ is the temperature at $x$ level of the atmosphere, and $D_x$ is the dewpoint temperature at $x$ level of the atmosphere. Finally the last index used in this study will be the 700-500mb lapse rate, which describes how stable the atmosphere between these two layers. The mathematical representation of this index is as follows:

$$L57 = \frac{T_{700} - T_{500}}{z_{500} - z_{700}}$$

where $T_x$ is the temperature at $x$ level of the atmosphere, and $z_x$ is the geopotential height at $x$ level of the atmosphere (Haby hints, 298). These convective indices calculated from COSMIC soundings can potentially help FAA make inferences about atmospheric stability, and mitigate risks associated with unexpected convection and turbulence.
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.

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:

\[ N = 77.6 \frac{p}{T} + 3.73 \times 10^5 \frac{e}{T^2} - 4.03 \times 10^{-7} \frac{n_e}{f^2} \]  

(3)

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).
CAPE values could not be easily calculated from any of these three satellites over the tropical oceans because the signal tracking algorithms used in these older generation of receiver do not allow deep penetration into the lower troposphere, particularly over the tropics. 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 the Constellation Observing System for Meteorology, Ionosphere, and Climate (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 GPS/MET, SAC-C, and CHAMP, 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/rawinsonde 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. The next step of this project is to apply the Adjusted RIP (Read, Interpolate, and Plot) program (a software package obtained from the WRF modeling system) to calculated these indices for COSMIC RO soundings.

2. Methods

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, CI, KI, TT, and the 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. The KI, TT, and L57 indices were included into the adjusted RIP program.

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 CIN, 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.

Finally this study delved into the diurnal cycle of the five indices. The diurnal cycle data consists of all COSMIC RO data for May 2007 contained in a 30°X30° latitude-longitude box, centered at Hawaii (20°N, 155°W). All the values that met these conditions were plotted for May 2007.

3. Results/Discussion

a. 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.
Fig. 2: This figure illustrates the regression line, correlations, and the $r^2$ values, between the NWS calculated (a) CAPE, (b) CIN, (c) KI, (d) TT, and (e) 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.
<table>
<thead>
<tr>
<th></th>
<th>CAPE</th>
<th>CIN</th>
<th>KI</th>
<th>TT</th>
<th>L57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average difference</td>
<td>373.7021</td>
<td>-262.317</td>
<td>-0.20973</td>
<td>-0.03624</td>
<td>1.32E-05</td>
</tr>
<tr>
<td>Standard deviation of the difference</td>
<td>585.3899</td>
<td>1177.234</td>
<td>0.557408</td>
<td>0.188369</td>
<td>0.000363</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.838123</td>
<td>0.21959</td>
<td>0.999165</td>
<td>0.999505</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: This table describes the numerical values of the average differences, standard deviations of the differences, and correlations between the NWS calculated CAPE, CIN, 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 are 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. CIN had a correlation of 0.21959, which indicates that the Adjusted RIP-calculated CIN is not well related, and is very sensitive to the choice of surface air parcel properties. We conclude that CAPE can be calculated to a much higher degree of accuracy compared to CIN. 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. The reverse is true for CIN, where NWS produces higher CIN values than the methods in the Adjusted RIP-calculated CIN. 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 is 373.7021, while cape is -262.317, which corresponds nicely to the fact that the Adjusted RIP-calculated values for CAPE and CIN are greater than and less than the NWS calculated values, respectively. 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. However the CIN standard deviation of the differences is greater than 1000 which means that the variance is too high and that the Adjusted RIP CIN values are not reliable in this study.

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 1.
### Table 3: This table describes the numerical values of the NWS CAPE thresholds and the equivalent thresholds for the Adjusted RIP CAPE values.

<table>
<thead>
<tr>
<th>NWS CAPE</th>
<th>Physical meaning</th>
<th>Adjusted RIP CAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Stable</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>marginally unstable</td>
<td>1600</td>
</tr>
<tr>
<td>2500</td>
<td>moderately unstable</td>
<td>4000</td>
</tr>
<tr>
<td>3500</td>
<td>very unstable</td>
<td>5600</td>
</tr>
<tr>
<td>3500+</td>
<td>extremely unstable</td>
<td>5600+</td>
</tr>
</tbody>
</table>

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 3.

### b. 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. CIN correlations to other indices are not included because of low correlations and $r^2$ values, as shown previously.
Fig. 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.

c. 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.
Fig. 4: This figure illustrates the regression line, correlations, and the $r^2$ values, between the Adjusted RIP calculated (a) CAPE, (b) CIN, (c) KI, (d) TT, and (e) 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) and CIN (0.44) values than in any other indices. However, 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 and CIN are not robust indices for COSMIC RO soundings to derive at the moment. This result occurs because of the way CAPE and CIN values are calculated, and also because of how COSMIC temperature and moisture profiles are derived. The calculation of CAPE and CIN 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 and CIN 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 and CIN 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 and CIN collocated indices. Just because CAPE and CIN 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.

<table>
<thead>
<tr>
<th></th>
<th>CAPE</th>
<th>CIN</th>
<th>KI</th>
<th>TT</th>
<th>L57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average difference</td>
<td>151.5356</td>
<td>-12.373</td>
<td>-1.26594</td>
<td>-0.44309</td>
<td>0.107364</td>
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<tr>
<td>Standard deviation of the difference</td>
<td>722.6441</td>
<td>94.19186</td>
<td>6.924485</td>
<td>4.986004</td>
<td>0.817005</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.473297</td>
<td>0.443971</td>
<td>0.837995</td>
<td>0.714548</td>
<td>0.683313</td>
</tr>
</tbody>
</table>

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) CIN, (c) KI, (d) TT, and (e) 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.
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) CIN, (c) KI, (d) TT, and (e) 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.

d. Hawaii case study

Time lapse plots of the Adjusted RIP indices values are shown for May 2007 for Hawaii (20°N, 155°W) in the center of a 30° latitude longitude box. These results are shown in the plots below (see figure 5). Note the time when each index reaches its maximum and how many times each of the indices increase or decreases over night for each plot.
Fig. 4: This figure illustrates the time lapse of the Adjusted RIP calculated (a) CAPE, (b) CIN, (c) KI, (d) TT, and (e) L57 for the Hawaii centered in a 30°x30° latitude-longitude box for May 2007 in UTC hours and day of year. The scatter plots above display a total of 400 observations.

Even though the CAPE values are not well correlated to collocated radiosonde data, the actual number isn’t important, but its time variation may be significant. The same concept will be applied with CIN. With this stated, it is possible to conduct diurnal cycle studies of these indices and with KI, TT, and L57.

In Fig. 4., each index seems to have a maximum at 00UTC, or 2PM Hawaii time. Sometimes, a little after 00UTC, the KI, TT, and L57 have reached a minimum. Looking at indices’ diurnal variations over the month of May, we find huge data voids, as suggested by sharp decreases or increases in the index shortly after 00UTC. In nature these sharp decreases and increases do not exist. Thus, sharp decrease or increase shortly after 00UTC suggest that more data must be taken to accurately assess each indices’ diurnal variations.
4. Conclusions

Calculations of CAPE and CIN 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. When conducting a study of the diurnal cycle of the five indices over Hawaii, they all seem to reach a maximum at 00UTC (in the afternoon) and shortly after that they reach their minimum for the latter three indices. At this time, we don’t have sufficient COSMIC soundings to provide a robust estimate of the diurnal variation of convective potentials over Hawaii. In the future, we will try to aggregate soundings from several months to perform such a study.

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 should occur to accurately evaluate each index’s diurnal cycle. Also, further work should be done to assess the accuracy of other indices – apart from CAPE, CIN, KI, TT, or L57 – that could be calculated utilizing COSMIC RO data. Since this study shows that CAPE and CIN 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 and CIN values from COSMIC soundings. Another possible solution to this problem could be creating a special version of CAPE and CIN programs that are specifically tailored to COSMIC RO data and its current methods of moisture and temperature retrieval.

5. Acknowledgements

This project could not have been done without the help of Douglas C. Hunt, so I would like to give a special thanks to him, because he has helped me to debug most of my Perl programs. I am deeply appreciative of Dr. Ying-Hwa (Bill) Kuo for mentoring and helping me on this project. I would like to dedicate this project to my family, who has given me much-needed support while I was working towards my dreams.
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