

Summary of the Weather during the RICO project – December 8th, 2004 and January 24th, 2005

Kathy-Ann L. Caesar
Caribbean Institute for Meteorology and Hydrology

Abstract

The Rain In Cumulus over the Ocean Experiment (RICO) was designed and carried out to study the properties of the trade wind cumulus and its associated precipitation. The project was focussed on the Caribbean islands of Antigua and Barbuda. The climatology of the islands and surrounding area did exhibit the ideal conditions of such a project. The area is within the Leeward Islands, considered the drier region of the Eastern Caribbean and subject to the prevailing trade wind cumulus clouds as the predominant cloud types. During the two month long operational phase of the project, the weather over the RICO domain was influenced by the expected weather phenomena that normally traverse the region. These included one tropical wave, a number of upper level troughs, and weak cold fronts during the latter part of the project. Rainfall amounts were below the climatological average. The domain was overcast or dominated by deep convective conditions for less than 5% of the period; and on a few occasions, the cumulus clouds were very shallow and sparse. In general, the prevailing weather did allow for good observational conditions and optimal data collection.

1. Introduction

The Rain In Cumulus over the Ocean Experiment (RICO) was focussed on the islands of Antigua and Barbuda in the Leeward Island chain of the Caribbean (FIG. 1). The climatology of the area is conducive to the RICO objectives; which were to investigate the properties of trade wind cumulus and the precipitation associated with cumulus clouds (Rauber et al). The islands are located on the north-eastern edge of the Caribbean island chain; within the transitional region of the trade wind belt and the subtropics. The weather is dominated by the northeast trade winds and subject to the interjection of subtropical highs which often limit the vertical development of cumulus clouds.



FIG. 1- Map of the Caribbean, which includes the RICO domain which will be identified in this and following images by an oval.

Antigua and Barbuda are among the dryer islands in the Eastern Caribbean (FIG. 2). Antigua records a single broad rainfall maximum between July and November. The weather systems of the trade wind belt (in particular tropical waves, tropical cyclones and upper-level troughs) are the main producers of the long, flat peak in rainfall lasting half a year (Burton S. 1999). Outside of the rain maximum period, rainfall is a result of localized convection induced from the passage of trade wind cumulus; and to a lesser extent, weak or lifting cold fronts (shear lines) during the months of January to March.

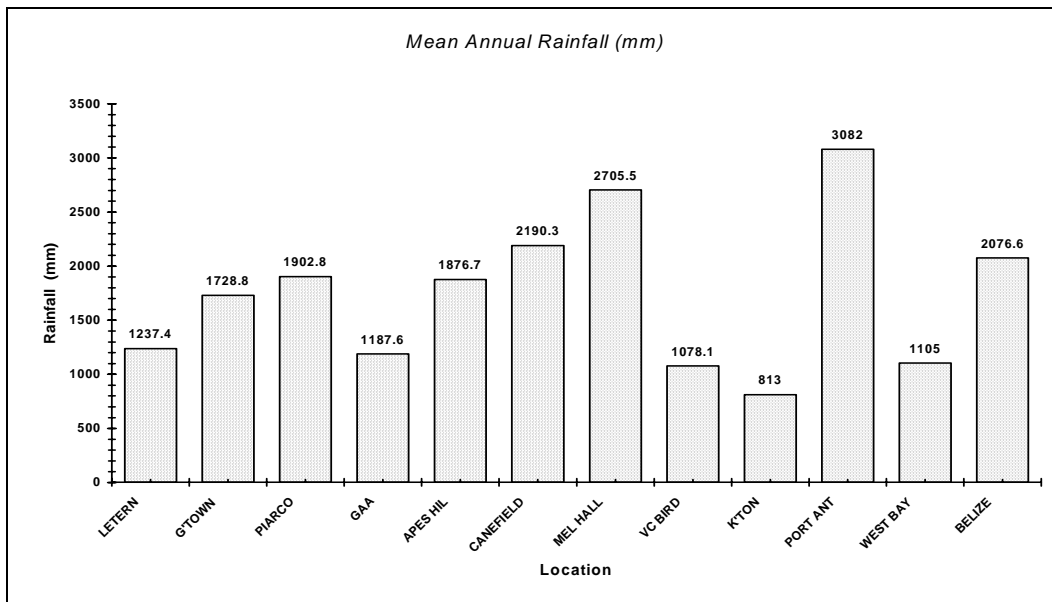


FIG. 2: Mean annual rainfall for selected Caribbean locations (S. Burton 1999). Regional stations include Letern and Georgetown, Guyana; Piarco, Trinidad; Grantley Adams Airport (GAA), Apes Hill and Canefield, Barbados; Melville (Mel) Hall, Dominica; VC Bird Airport, Antigua; Kingston and Port Anthony (Ant), Jamaica; and Phillip Goldson Airport, Belize.

The operation phase of the RICO project was conducted from 7 December 2004 to 25 January 2005. December and January are transitional months between the wet and dry season over the Caribbean. Climatologically*, December and January are cool with average temperatures of 25.7°C (78.3°F) and 25.5°C (77.9°F), respectively. Average monthly rainfall for December is 87.38 mm (3.44 inches) and for January 56.90 mm (2.24 inches). The prevailing surface winds for both months is 090° (Easterly) with a thirty-year mean wind speed of 11.7 kts in December and 12.8 kts in January.

2. Monthly statistics for Antigua/Barbuda during the RICO project

The weather conditions during the RICO project climatology were not far from normal, much unlike the previous months in the region when rainfall amounts were above average. In December 2004, 55.12 mm (2.17 inches) of rainfall was measured at the V.C. Bird Airport. On December 14th a maximum daily rain of 9.9 mm (0.39 inches) was recorded. The winds were from the east at an average of 11.0 kts. The minimum temperature of 21.5°C (70.7°F) was observed on the 29 December (Meade 2004, Antigua/Barbuda Weather Summary December 2004; Appendix C1).

The rainfall in January 2005 was 43.5 mm (1.71 inches) with the maximum daily rain occurred on the 8th, measuring 26.6 mm (0.29 inches). The winds were generally easterly at an average of 11.4 kts. The average temperature was 24.8°C. (Meade 2005, Antigua/Barbuda Weather Summary for January 2005; Appendix C2).

3. Synoptic Weather Summary

In describing the synoptic weather events during the field phase of the RICO project, there were characteristics of the wind regime of the Eastern Caribbean which either stimulated or inhibited deep convection. These regimes are defined and used by some of the regional National Weather Services. In their forecasting routines, the weather services also employ instability indicators, such as Lifted index, Showalter index, Total Totals and K Index. During RICO the K-index was used as the principal instability indicator.

a. Wind systems

1) LOW LEVEL WIND MAXIMA

A low level easterly wind maximum (LLEWM) is defined as wind speed maximum exceeding 25 kts below 5,000 ft. This is one of two low level easterly wind features investigated in an empirical study conducted at the Trinidad and Tobago Meteorological Service (TTMS). Low level wind maxima are very common over the tropical Atlantic and Caribbean but little study has been done to document and define the phenomena and

* Climatological data from V.C. Bird International Airport, Coolidge Antigua

the associated weather. A LLEWM is one of two distinct phenomena identified and found to be associated with trade wind cumulus lines occurring with the occasional turrets and brisk showers mainly over the islands during the night and early morning.

A surge in the easterlies (SITE) is defined as a wind maximum of 25 kts or greater, between 5,000 ft and 10,000 ft. In contrast to the LLEWM, there is more wind shear and thus the cumulus clouds tend to be shallower and there are far less occurrence of showers.

Often the wind maxima are observed from near the surface to just beyond 10,000 ft. In this case the phenomena are designated as a LLEWM/SITE, where strong winds exist from near 10,000 feet down very close to the surface. The associated weather is often a line of showers and/or thundershowers that are extensive and often appear with or are mistaken for tropical waves.

2) VERTICAL WIND REGIME

The vertical wind regime is a description of the zonal wind profile over the RICO domain. The depth of the easterly winds (from the surface upwards) or the prevalence of the upper level westerly wind, is a significant indicator of the ability of the atmosphere to sustain deep convection. Upper level westerly flow above the prevailing easterly trade winds provides a significant vertical shear profile which inhibits the vertical development of deep cumulus clouds. Climatologically (during the ‘wet season’ (June to December) in the Caribbean), the easterly wind regime is usually deep and varies regionally, but can extend vertically through the troposphere. Under these conditions, there is little vertical directional wind shear and thus convective development is uninterrupted. The deepening of the upper level westerly wind (which occurs between November and January) signals the transition from ‘wet season’ (summer) into the ‘dry season’ (winter) in the tropics (Riehl, 1954). The depth of the easterlies can fall as low as 5,000 ft above the surface. The daily change of vertical wind regimes is detailed in Appendix A (table A1) and FIG. A1.

b. Instability indicator

1) THE K- INDEX

The K-index (KI) is a direct calculation of the temperature difference between the 850 and 500 mb levels, plus the 850 mb dew point temperature minus the 700 mb dew point depression (see equation 1). It is therefore, the combination of the 850-500 mb thermal lapse rate, the 850 mb moisture, and the measure of the low level moist layer (Jacovides et. al 1990). This is a good index to use in the tropics since it canvases not only the instability of the 850 – 500 mb layer but it also considers the humidity at 700 mb. This index, referred to as the General Thunderstorm Predictor (**George, 1960**), has a higher probability of detecting stability within the sampled low to mid levels.

$$\mathbf{KI = (T850 - T500) + (Td850) - (T - Td) 700; \quad \text{Eq. (1)}}$$

Equation 1 is a combination of the 850-500 mb thermal lapse rate, the 850 mb moisture, and the measure of the low level moist layer 700 mb dew point depression [(T - Td)700]. The 700 mb dew point depression accounts for the possible buoyancy reduction of the cloud air parcel by evaporative cooling process from entrainment of dry mid-level environmental air.

In a soon to be published study on the effectiveness of various instability indices in the Caribbean, it was found that the K-index performed far better than Lifted Index and Showalter Index. The reason appears to be that the K-index is more sensitive to changes at 700 mb in terms of both temperature and moisture. Thus large values in (T - Td) 700 or a very dry layer above the boundary layer results in lower values of KI. Low KI values imply a shallow unstable layer capped by a stable layer above and an environment not conducive to deep convection (K. Caesar, 2003). The same study examined the predictability of instability indices across the Caribbean and found that there was great variability in the thresholds in different regions of the Caribbean. The thresholds being tested for the northern Caribbean are listed in Table 1.

The KI values observed during the RICO project, using sounding data from Barbuda are shown in Appendix B2 (KI graphic).

TABLE 1. - Critical values for the K-index used during the RICO project.

KI Critical values		
1	K < 23	STABLE- 30% chance thundershower
2	24 < K < 32	MILD INSTABILITY -50% chance of thundershower
3	33 < K < 37	UNSTABLE - 85% chance of thundershower
4	K > 37	VERY UNSTABLE - 99% chance of thundershower

c. Detailed Weather Summary

The following is a detailed summary of the daily weather phenomena affecting the RICO domain during the field phase of the project. This summary starts on 1 December as the development of the last tropical cyclone of the 2004 hurricane season did have some affect on the RICO regime at the start of the project. The occurrences of specific weather features are listed in Appendix A (Table A1).

On 1 December a mid-upper level trough extended from Panama through to the Northern Leeward Islands and into the Atlantic Ocean, producing subsidence over the RICO domain. The trough had spawned Tropical Depression “Otto” a day earlier in the

Atlantic Ocean, and it remained near stationary over the area until 3 December when it was displaced by an upper level ridge strengthened into the area. In the low levels, a weak trough induced by the passage of the upper level trough, moved over the domain, producing scattered showers from late on 3 December into 4 December. There was also a return to a deeper easterly wind regime as the depth of the trade wind easterlies increased from 10,000 ft to 35,000 ft over the period (see Appendix A- table A1; Fig. A1).

The surface trough moved into the Caribbean Sea and strong subsidence and dry air settled over the north-eastern Caribbean on 5 December. Scattered showers occurred over the islands on 6 December into 7 December as another weak middle/upper level trough encroached on the northern islands (Kurk, 2004). The area continued to be dominated by patchy shallow cumulus as the upper level trough moved over the region, producing strong subsidence and no showers on 8 December.

Late on 9 December the foreleg of a tropical wave brought deeper convection to the area. The axis of the wave was identified by both large pressure falls and the veering surface winds from northeast to east, as it moved over the RICO area on the 10 December with light showers. A low level easterly wind maximum (LLEWM) closely followed the wave and instigated a few early morning showers on 11 December, otherwise, fair conditions dominated through 12 December as subsidence associated with the narrow upper level trough continued. Another broad surface trough followed from the east producing showers overnight on the 12 December. This system appeared to have two distinct perturbations (FIG. 3). The first small amplitude perturbation moved rapidly during the day on 13 December and another larger one settled in the domain overnight.

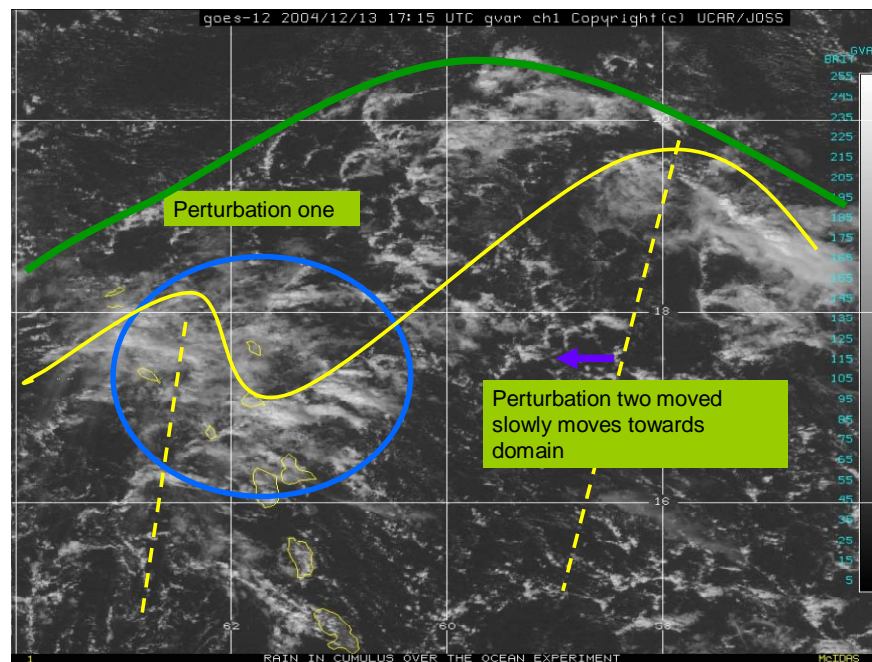


FIG. 3 – 17:15 UTC GOES12 satellite image over the RICO domain on December 13th, illustrating the passage of two perturbations over the area.

Conditions remained very cloudy on 14 December as the trailing confluence band associated with the second trough covered the domain with cumulus towers and outflow debris. In the upper levels, a new trough was elongated along an axis from 20°N 64°W and 13°N 67°W. This set up an upper level deformation zone over the domain and covered the area with patchy cirrus. The 1200 UTC Barbuda sounding on 14 December indicated a K-index (KI) of 36.5 confirming a very unstable environment.

Showers continued on 15 December as the low level trough propagated slowly west into the Caribbean Sea. The motion was slowed by the development of a weak omega (blocking) high over the Atlantic Ocean. The confluence band to the rear of the trough lay over the domain and prevented the forecasted clearing. Deep convection remained across the area with showers and an isolated afternoon thundershower. The observations at V.C. Bird Airport noted 30 mm (1.18 inches) of rainfall between 0000 UTC and 1800 UTC (Appendix C1). There was a 24-hour pressure fall (1200 to 1200 UTC on 14-15 December) of approximately 2.8 mb. At the surface the winds became pronouncedly south easterly. In the upper levels the westerly wind regime lowered below 20,000 feet.

Finally, on 16 December the rear of the large trough slowly exited the area. Following this, a low level ridge brought predominantly clear skies and shallow bands of clouds returned. The 1200 UTC sounding from Barbuda showed the atmospheric column across the area had started to dry out aloft, despite the persistent low-level moisture and a KI around 38.3 (Kurk et. al 2004). A weak trade wind inversion (TWI) also was evident near 10,000 feet (Appendix A). These drying conditions continued through 19 December as a very typical trade wind pattern of shallow cumulus cloud bands, separated by well-defined subsidence zones, covered the region. The soundings showed the atmosphere gradually became more stable and dry as the KI fell to 28.5 on 17 December and surface winds shifted to become more easterly.

Stable conditions were interrupted as surface winds again became south easterly, and thicker cumulus bands and showers moved over the domain on 20-21 December. A total of 23.2 mm (0.91 inches) of rainfall was measured over this two day period (Meade 2004). The trailing subsidence zone lowered the TWI and inhibited showers through 25 December. Note, that the TWI was evident daily for the remainder of the project (Appendix A - table A1). Aloft, a weak mid-upper level trough moved west to east across the Northern Caribbean between 22-25 December, superimposing the very dry air over the area. A KI of 18.3 on 27 December reflected the more stable conditions. The pattern of shallow cumulus cloud bands continued through to 29 December producing rainfall of 5.1 mm and 8.4 mm on 26 and 29 December, respectively. A weak upper level low developed near 30°N 55°W within the upper level trough. On 29 December the trough became stationary across the Virgin Islands and produced deep cumulus towers and showers over the two islands on 31 December.

On 1-4 January the Subtropical jet (STJ) intensified over the Eastern Caribbean as the upper level trough became elongated zonally, north of the Caribbean islands. The upper level low deepened into the low levels and induced north to south moving cumulus cloud

bands and showers during this period. A total of 4.9 mm (0.19 inches) of rainfall was measured on 1 January but it was generally shower free thereafter through 5 January.

The trough meandered north and south over the Virgin Islands as a secondary low and associated deep convection developed in the Caribbean Sea near 14°N 65°W on 4 January (FIG. 4).

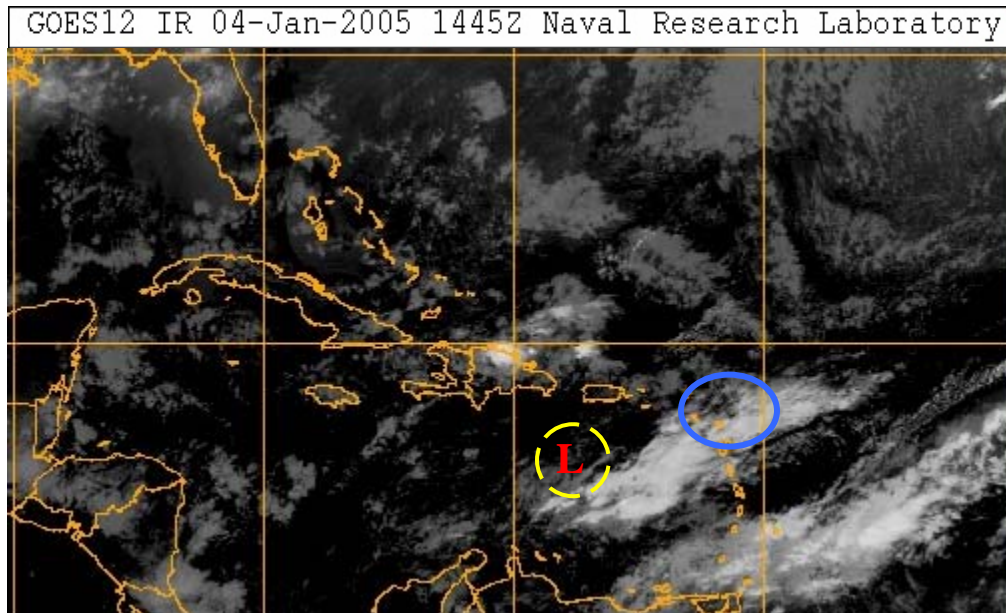


FIG. 4 - GOES12 satellite image on January 4th illustrating cirrus overcast over RICO area.

The very dry mid-levels were clearly evident in the Barbuda sounding on 5 January between the very moist upper levels being advected from the southwest and the resident low level moisture (FIG. 5). The upper level subsidence kept the cumulus clouds shallow, and cirrus clouds appeared intermittently along the subtropical jet (109 kts maximum); the highest observed during the RICO project (Appendix A - table A1). The low level winds were predominantly northeast at 15 kts to 20 kts ahead of the weak low level trough which crossed on 6 January.

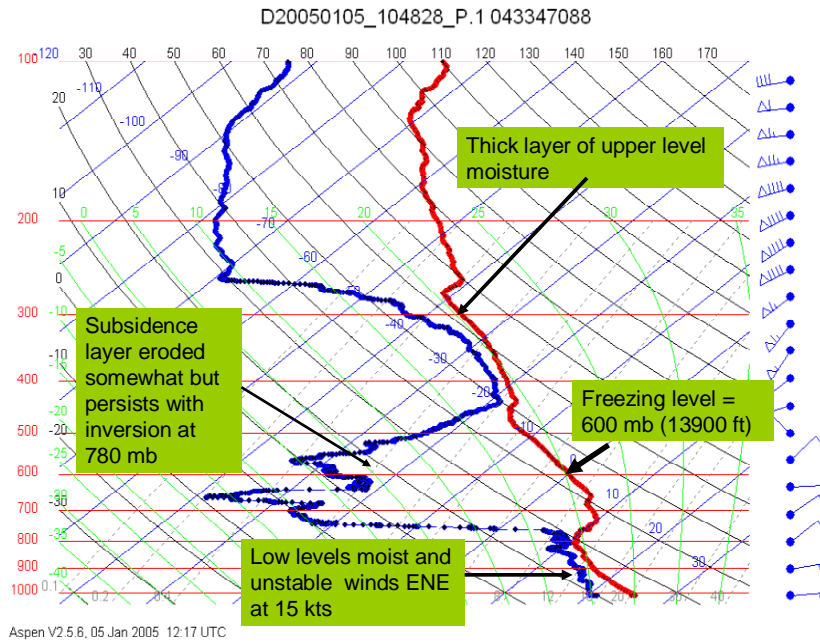


FIG. 5 – the Barbuda 10:48 UTC sounding on the 5th showing the dry air intrusion in the middle levels.

The passage of a small amplitude trough in the low levels temporarily eroded the mid-level dry layer and weakened the inversion (FIG. 6). Throughout the day, the upper level south westerly flow continued to advect copious amounts of upper level moisture and thick cirrus over the entire Lesser Antilles. At the same time, shallow cumulus and stratocumulus cloud spread over the Leeward Islands. However, no showers were reported. The water vapour image showed the extent of moisture over the Eastern Caribbean (FIG. 7).

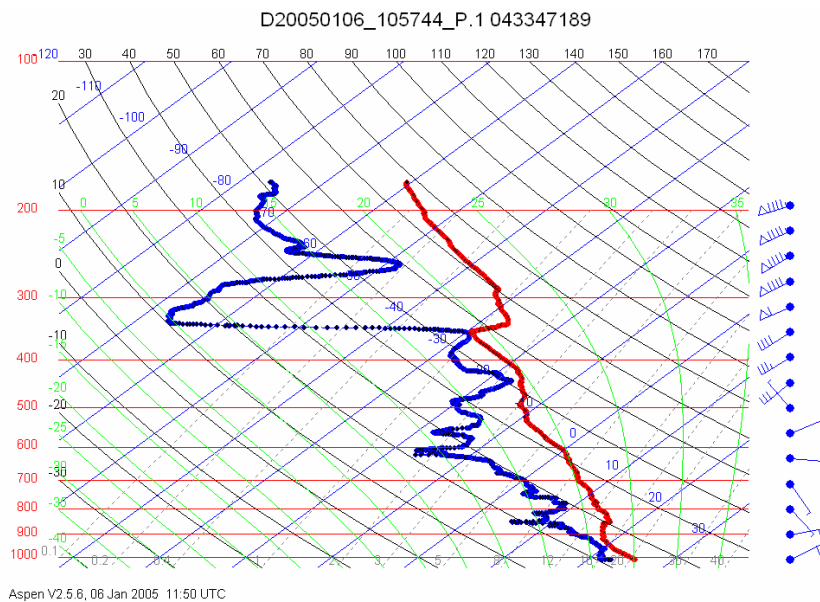


FIG. 6 - the Barbuda 10:47 UTC sounding on the 6th illustrating the rapid moistening of the middle levels.

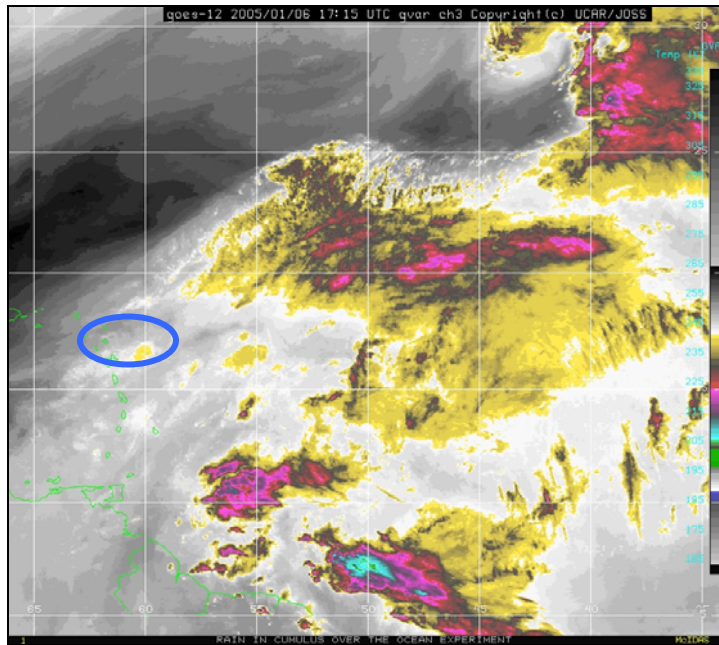


FIG. 7 – 17:15 UTC GOES 12 water vapour image across the Eastern Caribbean on January 6th. The heavier convection remains east of 56°W; however there is moisture (white and coloured areas) over the domain and over the Eastern Caribbean

The conditions gradually dried over the northern Leeward Islands on 7 January while the weather remained intensely cloudy and rainy over the remainder of the Eastern Caribbean (south of 16°N). The upper level trough kept the moist air from moving in from the south and allowed the development of cumulus lines orientated along the strong northeast trade wind flow (FIG. 8). The IR satellite images show that the large mass of clouds to the south of the Lesser Antilles were aligned with the upper level flow. The soundings during the day indicated another gradual intrusion of dry air at the mid and upper level. Transverse cirrus bands were again present and were evidence of the subtropical jet overhead.

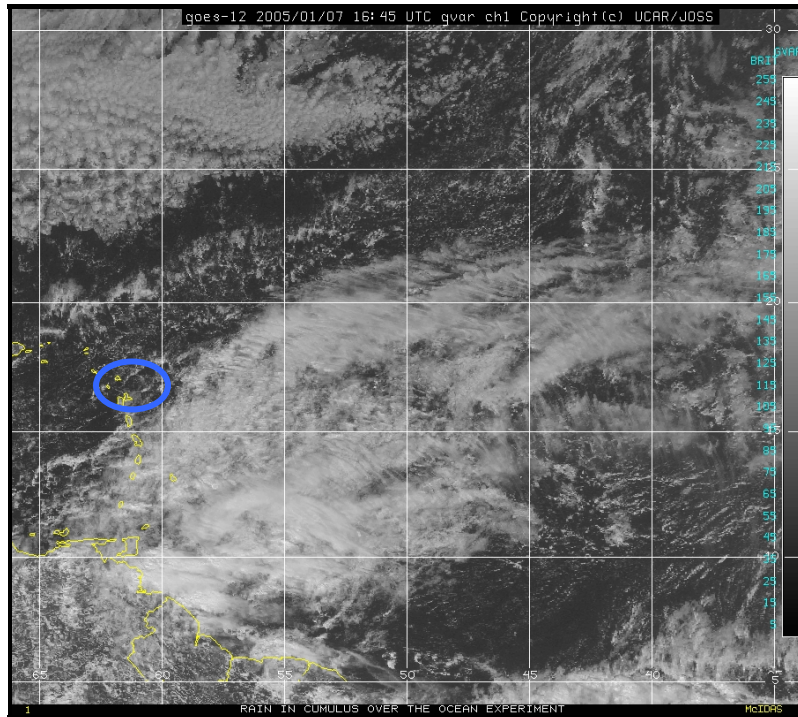


FIG. 8 – 16:45 UTC GOES12 visible satellite imagery on January 7th. Deep convection and thick multi-layer clouds cover the islands south of 16°N while the RICO domain and much of the north-eastern Caribbean is clear.

The trade wind inversion strengthened on 7 January as the surface trough gave way to dryer conditions over the RICO domain. However, later in the day, cirrus clouds streamed off the deep convection to the southwest of the domain and infiltrated the area. Despite a moist and unstable low level environment, only night time isolated showers were reported. The showers were initiated by a LLEWM of 20 to 35 kts between the period 6-8 January. A maximum of 38.5 kts was observed at 127 ft on the Barbuda sounding on 7 January (Appendix A - Table A1). The subtropical jet (maximum of 95 kts) extended from the southwest over the area.

Saturday 8 January was a day of change. Clouds increased throughout the day from scattered cumulus bands and a few isolated showers to a slow progression of the dense clouds and showers from the southeast over the domain with moderate trade winds near 18kts. The showers occurred overnight and produced January's highest rainfall total of 26.6 mm (1.05 inches). The hourly observations from the Antigua Meteorological Service indicated a wind shift from easterly to south-easterly, suggesting the passage of a surface trough as the winds increased to 13.6 kts. A rough seas advisory was issued by the Antigua Meteorological Services for choppy seas (Meade, 2005) (Appendix C2). In the upper levels, the trough to the north of the islands weakened to a shear line and shifted further north allowing a south westerly flow to propagate over the area with more upper level moisture. The 1200 UTC sounding shows increasing low level moisture, interrupted by dry layers.

The overnight showers lingered into mid-morning on Sunday (9 January), but conditions remained overcast for most of the day as dense stratified clouds blanketed the RICO domain and the rest of the Lesser Antilles. There were some breaks in the thick altostratus and cirrus clouds to the south during the afternoon. The 1200 UTC sounding clearly indicated a very moist atmosphere. There was little change over the next two days but dry air advection from upper level westerly flow over the northwest quadrant of the domain gradually cleared the area of clouds. Convection was limited to trade wind cumulus bands over most of the domain with the odd afternoon towering cumulus and isolated cumulonimbus mainly on the southern edge of the domain.

Another LLEWM on 11 January preceded the approach of a surge line. This particular event could be categorized as a LLEWM/SITE since the wind maximum extended to the very low levels (Appendix A). Often these events are associated with an increase in convection and showers due to low level convergence and followed by a significant dust haze. In this case there was a line of convection associated with the LLEWM/SITE and satellite imagery suggested a dust plume to the rear of the surge.

The surge and weak trough slowly moved over the RICO domain on 13 January with associated lines of cumulus, stratocumulus and showers. The 1200 UTC sounding on 13 January showed that the wind maximum was 36.4 kts near 925 mb (2,862 ft). This was reflected at the surface with observations of average south easterly winds of 14.7 kts and a 10-minute maximum of 24 kts with higher gust at 1700 UTC. Northwest winds advected dry air above 500 mb.

Conditions dried out rapidly over the next few days in the wake of the surge. Trade wind cumulus clouds returned but there was only light haze over the region and it appeared to be slightly denser over the Southern Lesser Antilles. Little changed aloft as northwest winds continued to advect cold, dry air over the area. This aided in strengthening temperature inversions at 473 mb (18900 ft) and 775 mb (7000 ft).

Through 17 January cumulus bands continued to form on the easterly flow across the islands. The atmosphere continued to dry out as a weak middle and upper level circulation formed along an associated trough near 24°N 62°W. This forced a northwest upper level flow and resulted in generally clear skies with scattered cumulus over the domain. Upper level divergence east of the islands enhanced an area of deep convection along 18°N between 58° and 60°W (FIG. 9).

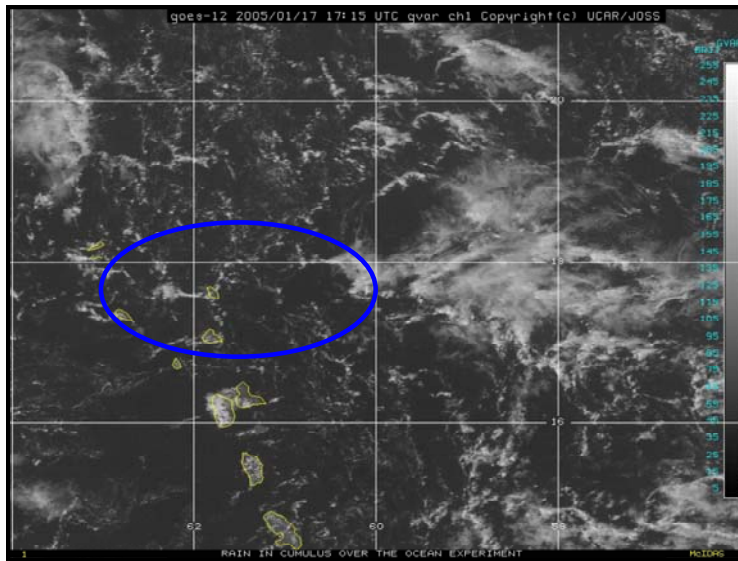


FIG. 9- 17:15 UTC GOES 12 imagery on January 17th thick convection near 17°N and 59°W with outflow cumulus moving west.

On 18 January the approach of a strong cold front from the northwest proved to be another day of transition (FIG. 10). As the front moved towards the domain, a prefrontal trough formed just east of the domain. The increased low level moisture and instability induced thickening clouds, mainly billowing cumulus and broken to overcast stratocumulus with showers. Vertical development of the convection was again capped by very dry air aloft.

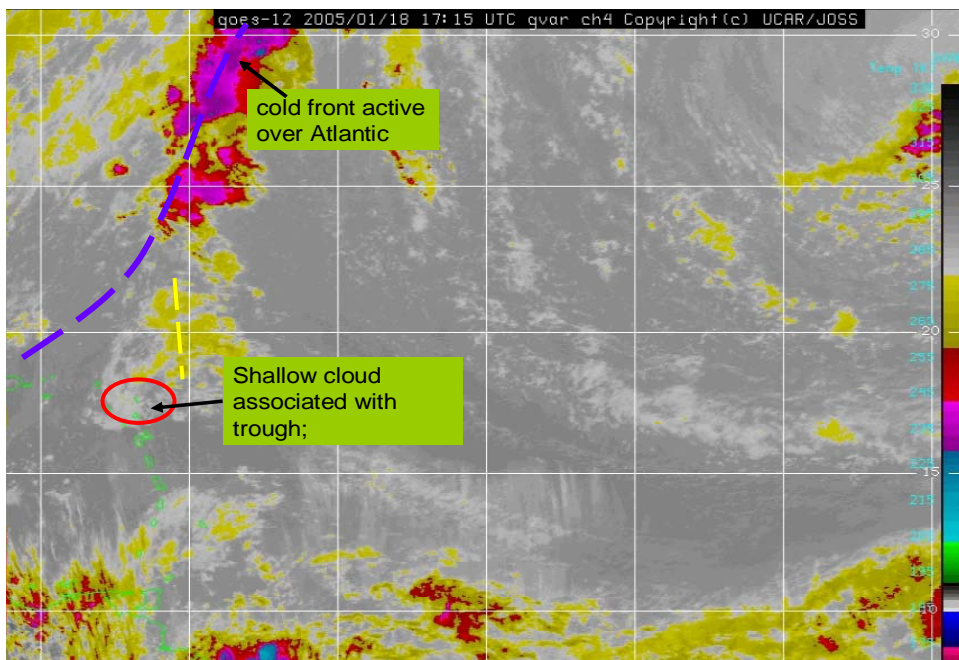


FIG. 10: GOES12 imagery on January 18th, as lifting cold front approaches the north-eastern Caribbean.

As the cold front slowly propagated east-southeast it became more of a shear line with no significant temperature change over the area but a definite discontinuity in the wind field, with the wind maximum to the west of the shear line (FIG. 11). There was very dry air evident aloft behind the shear line as it moved into the RICO area on 19 January. The pre-frontal trough remained near stationary to the northeast of the domain, extending from 10°N 59°W to 22°N 61°W. Aloft, a mid-upper level ridge covered most of the Caribbean Sea and Lesser Antillean island chain.

The shear line eventually moved over the domain on 20 January with increased cumulus and stratocumulus clouds but very little showery activity. This was again mainly due to the dominance of very strong subsidence and very little low level moisture associated with the shear line. The westerly winds decreased in attitude to near 700 mb with the passage of the shear line. Interestingly, from 19 January to the end of the RICO observation period, the westerly flow and the trade wind inversion fell below the freezing level to a height of near 5,000 ft, resulting in a very stable environment.

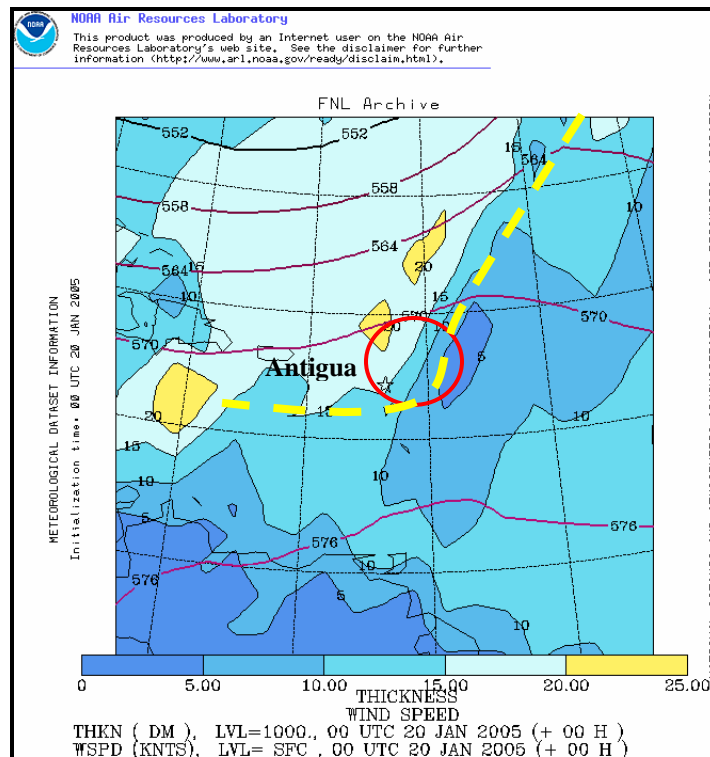


FIG. 11. Archive data of the surface wind field and 1000 – 500 mb thickness field over the Eastern Caribbean on 20 January 2005. Shared contours represent the wind speed at 5 kt intervals and solid lines are thickness contours. The dashed, thick line represents the shear line. (Model data courtesy **The Real-time Environmental Applications and Display sYstem (READY)**).

Very early on 21 January the clouds associated with the shear line cleared as it propagated south, leaving generally clear skies. The low level wind flow became pronouncedly northeast as the anticyclonic flow, in wake of the shear line, settled over the northern Caribbean. Very shallow, tiny cumulus cells formed over the area.

A surface ridge strengthened over the area and the weather on 21-23 January was mostly fair with scattered tiny cumulus and very little precipitation. This was despite the increase in low level moisture over the region from the south as a weak trough (dissipating shear line) propagated north into the domain. Strong inversions formed at 850 mb (3°C) and 670 mb (1.8°C), with mid to upper level westerly winds (STJ - 66 kts) and very dry air aloft on 21 January. The westerly winds continued to be low in the atmosphere.

As the field phase of the RICO project ended on 23 January the area was covered in shallow cumulus, predominantly east of the island chain (FIG. 12). The Barbuda sounding indicated that the westerly winds were close to the 800 mb (5,100 ft), inducing very stable conditions over the domain.

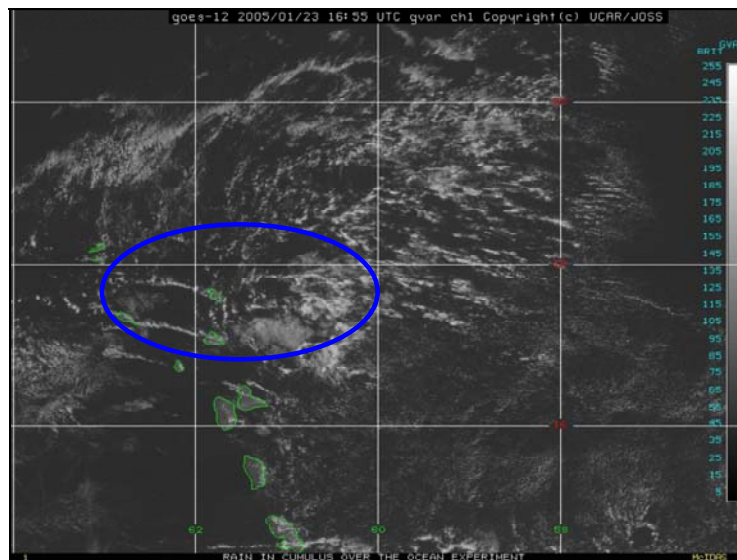


FIG. 12: GOES12 imagery on January 23rd. RICO domain

4. Conclusion

The weather conditions experienced during the field phase of the RICO project were generally normal. Shallow cumulus clouds in the form of bands, clusters and scattered cells were commonly the conditions that dominated the domain during this field phase period.

The most interesting aspect of the regime over the period was the change in the vertical wind profile and its response to the synoptic conditions at the time. At the start of the field phase and again towards the end, the depth of the easterly winds was very low as the upper level westerlies strengthened and were observed as low as 700 mb. It was noted that there was good correlation between the depth of the easterly flow extending above the freezing level and the observation of showers. Undulations in the trade wind inversion also closely mirrored the changes in the vertical regime, especially during the January period of the project. This again exhibited the effects of vertical shear on convective building the tropical oceans.

During the two month long field phase of the project, the weather over the RICO domain was influenced by the expected weather phenomena including a few tropical waves, low level troughs, a number of upper level troughs, and weak cold fronts during the latter part of the project. There was less than 5% of the period that was overcast or dominated by very deep convective conditions. Rainfall amounts were below the climatological average. On a few occasions the cumulus clouds were very shallow and sparse, especially over the Atlantic Ocean. However the prevailing weather did allow for good observational conditions and optimal data collection.

Acknowledgments. This summary benefited from discussions with, suggestions and contributions from Mr. S. Williams, D. Dirks, J. Moore, M. Kurk, K. Meade, S. Burton, H. Burton, E. Jones and fellow forecasters during the RICO project. Technical support was provided by UCAR Joint Office of Science Support (JOSS).

Appendix A

A1. Specifics Weather features

Table A1: Summary of observed forecasting parameters. Observed data taken from the Barbuda RICO rawinsonde. Supplemental data added from Guadeloupe (*MFFR) for information taken before official start of the RICO project and on occasions when wind data was unavailable from the Barbuda rawinsonde.

DATE	LLEWM [WINDS >25KT UNDER 5,000FT] SITE [WINDS>25KT 5,000 TO 10,000 FT] LLEWM/SITE [WINDS >25 KT BELOW 10,000 FT]				STJ MAX: WINDS > 50 KT (* MFFR OBS	0°C LEVEL (FT)	TWI (FT)	VERTICAL WIND REGIME (FT) [DEPTH OF THE EASTERLIES]	K-I
	Base	Top	Max /wd	Max/ Ht					
12/1/2004								*10316	
12/2/2004								*10339	
12/3/2004								*5005	
12/4/2004								*35040	
12/5/2004								*29871	
12/6/2004								*26083	
12/7/2004						16020	9623	27774	26.3
12/8/2004						15102	10888	41228	26.5
12/9/2004	543	8000	38.5	6945		14911		30245	22.0
12/10/2004	488	12305	42.3	7770		16310	10432	26644	32.3
12/11/2004	1704	6966	33.4	4606		15776		24473	30.8
12/12/2004	2616	7568	34.5	487		15499	11953	26638	27.8
12/13/2004	37	7551	40.2	858		15716		22666	36.1
12/14/2004					86	15565		18354	36.5
12/15/2004					86	14913		17547	37.3
12/16/2004					90	15695	11021	18197	38.3
12/17/2004					66	15765		17758	28.5
12/18/2004					86	15360	9997	17296	25.9
12/19/2004					78	16624	10794	13767	31.6
12/20/2004					71	16270	10017	15250	30.7
12/21/2004					80	17122	8583	20347	26.3
12/22/2004	1001	4857	38.9	3669	90	16088	9227	16349	23.2
12/23/2004	1079	7979	36.9	167	85	14289	5025	14056	25.4
12/24/2004					93	13272	5994	9982	29.5
12/25/2004					71	15673		11808	23.0
12/26/2004						17685	7321	23663	22.0
12/27/2004						16240	10918	6405	18.3
12/28/2004						16664	8396	16194	22.5
12/29/2004						16118	7570	14274	32.7
12/30/2004						15890	8305	13478	23.5
12/31/2004						15385	5799	10970	27.5

1/1/2005					85	15630	5877	12070	26.3
1/2/2005	126	2618	34.5	509	*71	15540	4816	13715	25.7
1/3/2005	37	2851	35.1	261	*71	15075	5108	17098	24.7
1/4/2005	35	2853	35.2	471	105	14811	6925	17339	27.1
1/5/2005					109	14440	7488	17269	29.9
1/6/2005	349	3092	34.4	1943	93	14074	7337	19090	27.2
1/7/2005	119	3597	38.5	127	85	14574	7783	15413	28.9
1/8/2005	221	4577	32.9	3495	*65	13289	6786	16758	29.0
1/9/2005						13338	9719	14471	30.0
1/10/2005						14540	6746	9965	28.7
1/11/2005						14432	9652	13120	29.6
1/12/2005	350	1517	28.6	491		14320	18388	18312	29.4
1/13/2005	62	10821	36.5	2862		14528	17469	18935	33.8
1/14/2005	739	5621	28.6	2483	73	14442	7291	17115	24.5
1/15/2005	787	5521	32.9	3821	75	13886	6793	13353	27.4
1/16/2005					80	13469	13468	14327	17.6
1/17/2005					77	17109	13622	14291	26.7
1/18/2005					87	16241	14360	16239	32.4
1/19/2005					76	16836	12707	10362	33.1
1/20/2005					89	16568	4346	7613	22.9
1/21/2005					74	15692	3464	6717	27.0
1/22/2005					79	14938	5471	5041	29.1
1/23/2005					66	15997	5130	5950	16.7
1/24/2005					64	16519	5228	5724	27.5

Graphical representation of the vertical regime over the RICO domain during the project.

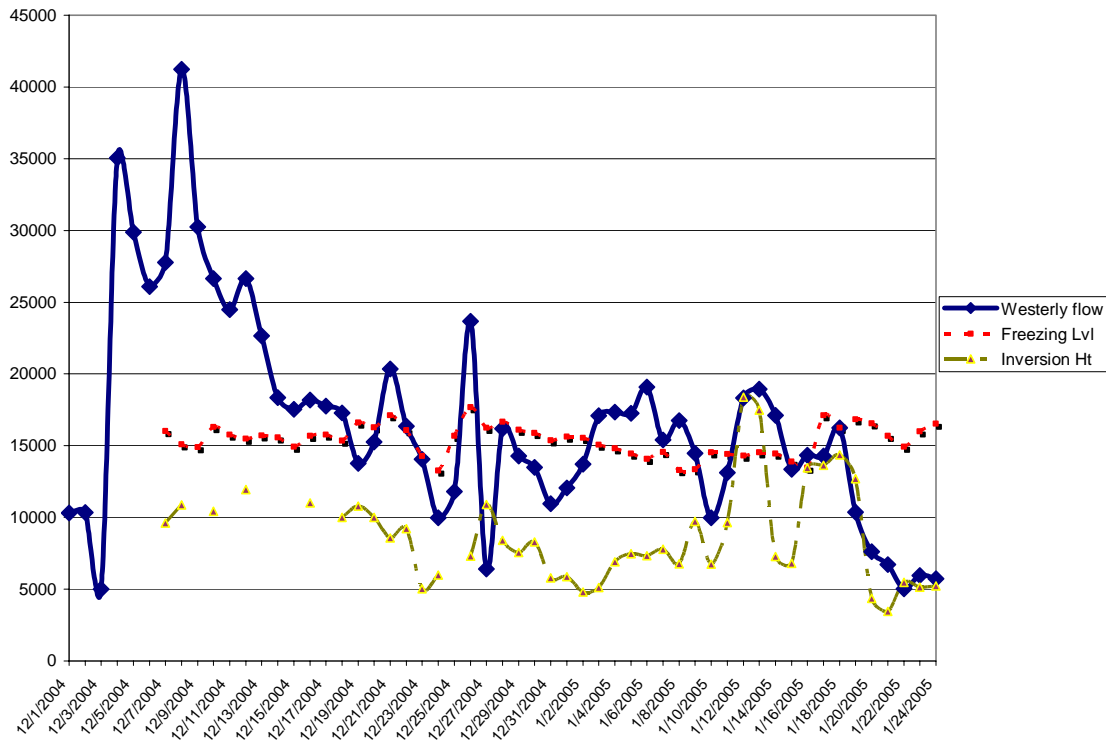


FIG. A1: Vertical regime during the RICO project. The solid line represents the depth of the easterly wind flow (where the flow is easterly from the surface to the given height and westerly above that height). The dotted line represents the height of the freezing level. The dash-dot line indicates the height of the trade wind inversion when present.

A2. Performance of K index-stability predictor

The K-index was used as a measure of the stability of the environment.

Figure A2 illustrates the observed KI during the field phase of the project plotted against the observed weather on Antigua. In a statistical analysis on stability predictors (based on work by Jacovides and Yonetani (1990)), the performance the KI scored a POD (probability of detection) of 44% and a FAR (false alarm rate) of 20%.

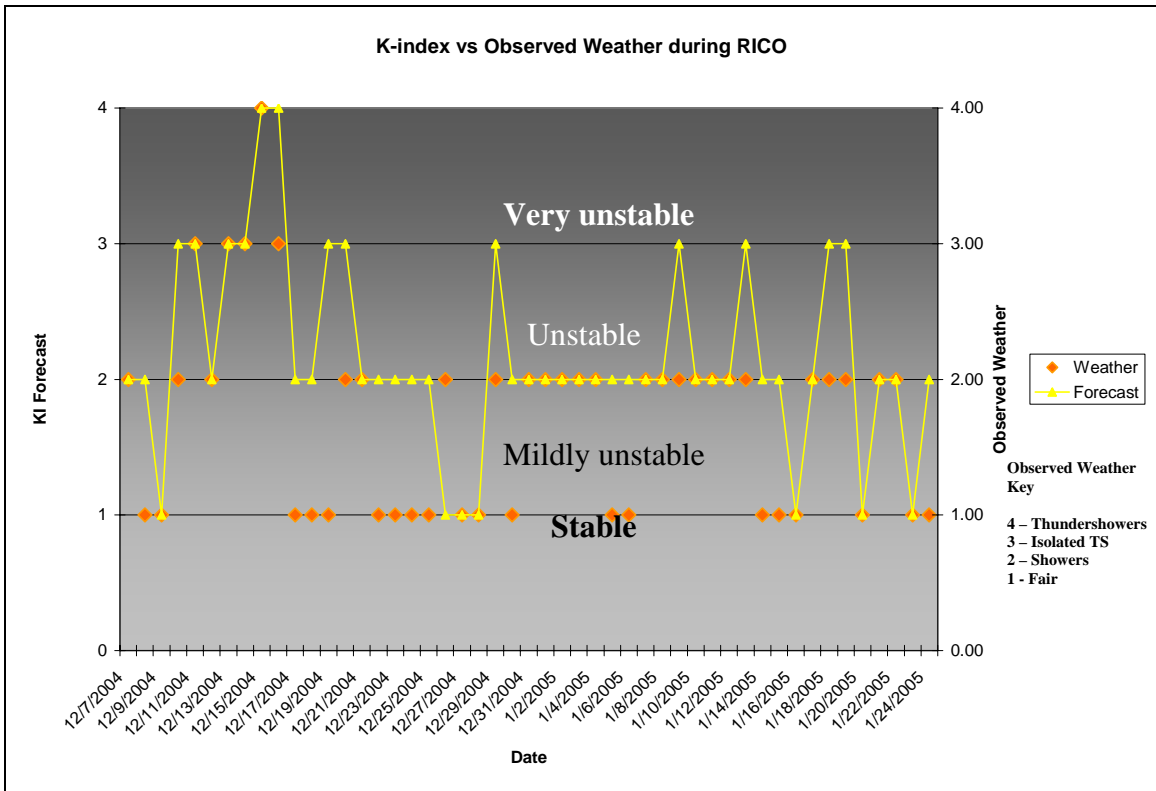


FIG. A2: K index plotted against observed weather during the RICO project. The solid line represents K index. The diamonds represents weather observations reported by V.C. Bird Airport.

Appendix B

Troughs over the RICO domain

B1. Low level Troughs

December 03rd – Weak trough associated with deep trough the spawned T.S. OTTO;

December 10/11th – Low level trough up to 700 mb

December 12/13th – Small amplitude trough associated with mid level trough;

December 13/14th – Broad trough from surface to 600 mb;

January 18/19th – Pre-frontal trough northeast of the domain, extending from 10°N 59°W to 22°N 61°W.

B2. Mid- Upper Level troughs

December 01st/03rd – Deep trough over Central Caribbean, from Panama, cross Northern Leeward Islands into the Atlantic; moving eastward and weakening;

December 13/14th – Mid level trough;

December 28th to 30th – Weak upper level, northeast of Leeward Islands, evident above 200 mb moving east;

January 02nd /03rd – Mid-upper level trough extending from 17°N 56°W to deep low near 30°N 50°W; quasi-stationary;

January 05th/06th – Mid-upper level trough extend from 31°N 44°W to 26°N 50°W southwest north of domain to Mona Pass.

Appendix C

Antigua/Barbuda Weather Summaries

C1. Antigua/Barbuda Weather Summary for December 2004

The month of December produced appreciable rainfall across Antigua and Barbuda capping a productive year in terms of rainfall across the islands. The month yielded 55.1 millimetres at V.C Bird Airport, much more elsewhere, dropping from a monthly average of 3.46 inches. A high pressure ridge was the most dominant feature which affected the weather and this brought a sometimes moderate wind flow which moved patches of moisture from time to time across the islands. Winds were mainly from the East at 11.0 knots. The month also produced the year's minimum temperature 21.5° C on the 29th. The seas were slight to moderate swells 1.5-1.8m/5-6ft becoming locally rough at times with waves 2.1m/6-7ft prompting a small craft advisory for above normal seas.

A high pressure ridge dominated the weather across much of the Eastern Caribbean from the 1st to the 12th. This led to some cloudy periods with a few scattered showers, as low level moisture moving across the islands, generated some partly cloudy to cloudy spells with a few scattered showers on the 4th. A weak mid/upper trough across the Mona passage moved Eastwards, drawing some moisture Northwestwards across the islands and leading to a few showers on the 6th, while a building high pressure ridge continued to move patches of low level clouds and moisture across the islands resulting in showers on the 9th; the prevailing conditions continued until the 12th. Winds were mainly from the East at 11 knots with a 10-min max of 22 knots occurring on the 10th. Seas were slight to moderate with swells 1.5-1.8m/5-6ft becoming locally rough on the 9th with waves 2.1m/6-7ft prompting a small craft advisory for above normal seas.

Weather conditions across the islands became a bit unsettled on the 13th as a trough of low pressure generated some cloudy spells with scattered, occasional moderate, showers across the islands resulting in the month's maximum daily rainfall 9.9 millimetres on the 14th. Thereafter the atmosphere became more stable until the 19th, when a weak trough of low pressure moved Westwards across the islands, generating partly cloudy skies with a few periods of increased cloudiness and scattered showers on the 20th and 21st. Almost half of the month's rainfall 23.2 millimetres, occurred during this period. Winds were mainly from the East South East at 10.7 knots while seas were moderate and occasionally locally rough with waves 1.5 to 1.8 metres or 5 to 6ft. Small craft operators were advised to exercise caution against marginally safe seas.

A high pressure ridge led to stable conditions across most of the islands from the 22nd, which resulted in fairer weather. However, partly cloudy to cloudy skies with scattered showers were sometimes experienced as the result of low level troughs along with some moisture, that moved Westward across the Islands on the 23rd and the high pressure ridge which moved patches of low level clouds and moisture across the islands. These led to 5.1 millimetres on the 26th and 8.4 millimetres on the 29th. A surface trough East of the

islands on the 30th caused a few showers across the islands resulting in 2.3 millimetres of rainfall at V.C Bird on the 31st. Winds were mainly from the East 11.2 knots while seas were locally rough with waves 1.8-2.5 metres or 6 to 8ft. Small craft operators were advised to exercise caution.

**Table C1. MONTHLY WEATHER SUMMARY
FOR THE PERIOD 01/09/2004 AT 13:00 TO 01/10/2004 AT 12:00**

WX: PARTLY CLOUDY

WINDS: E AT 11.0 KNOTS

MAX 10-MIN WIND: 22 KNOTS DATE 10/12/2004 AT 06:00

BARO PRESS: 1014.5 MILLIBARS NORMAL

TOTAL RAINFALL: 55.1 MILLIMETRES 2.17 INCHES **MAX 24-HOUR:** 9.9 MM DATE : 14/12/2004

MAX 6-HR RAINFALL: 7.9 MILLIMETRES DATE: 29/12/2004 AT 24:00

RAINFALL STATUS : BELOW NORMAL

AVG MAX TEMP: 26.7 DEGREES CELSIUS **MAX:** 29.2 DEGREES CELSIUS DATE: 16/12/2004 AT 18:00

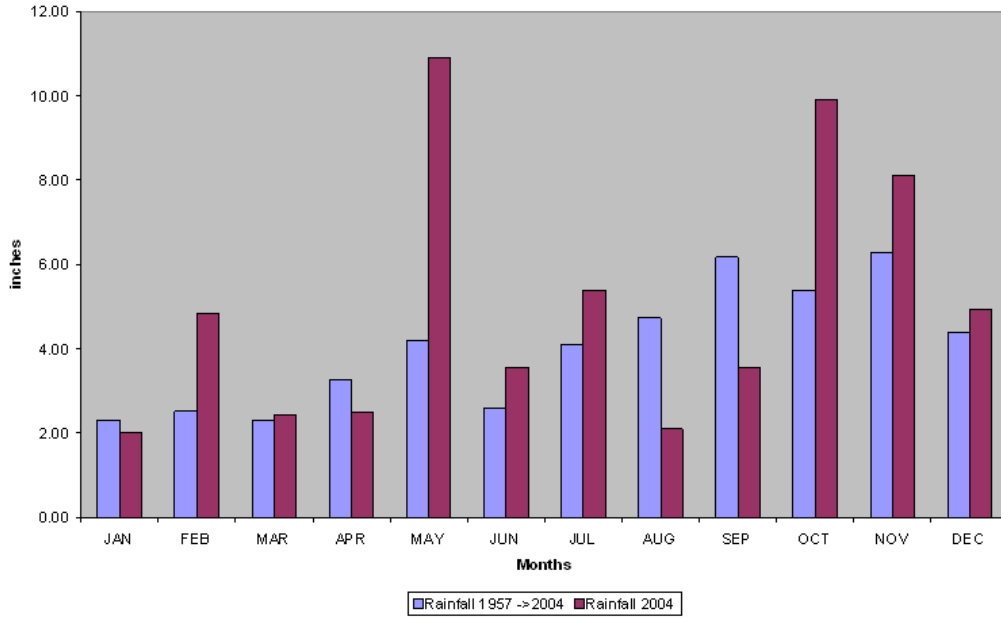
AVG MIN TEMP: 24.2 DEGREES CELSIUS **MIN:** 21.5 DEGREES CELSIUS DATE: 29/12/2004 AT 12:00

AVG TEMP: 25.5 DEGREES CELSIUS **WARMEST DAY:** 26.7 DATE : 10/12/2004
COOLEST DAY: 24.4 DATE : 27/12/2004

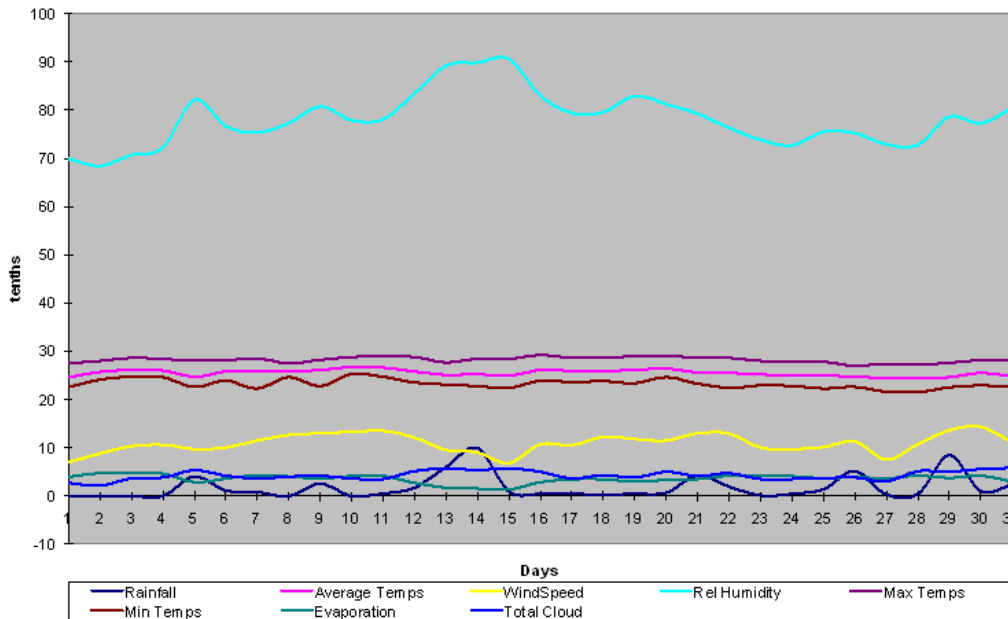
AVG REL HUM: 78.2 % **MOST HUMID-DAY:** 90.6 % DATE : 15/12/2004 **LEAST HUMID-DAY:** 68.4 %

Monthly Comparison with the long-term average Rainfall

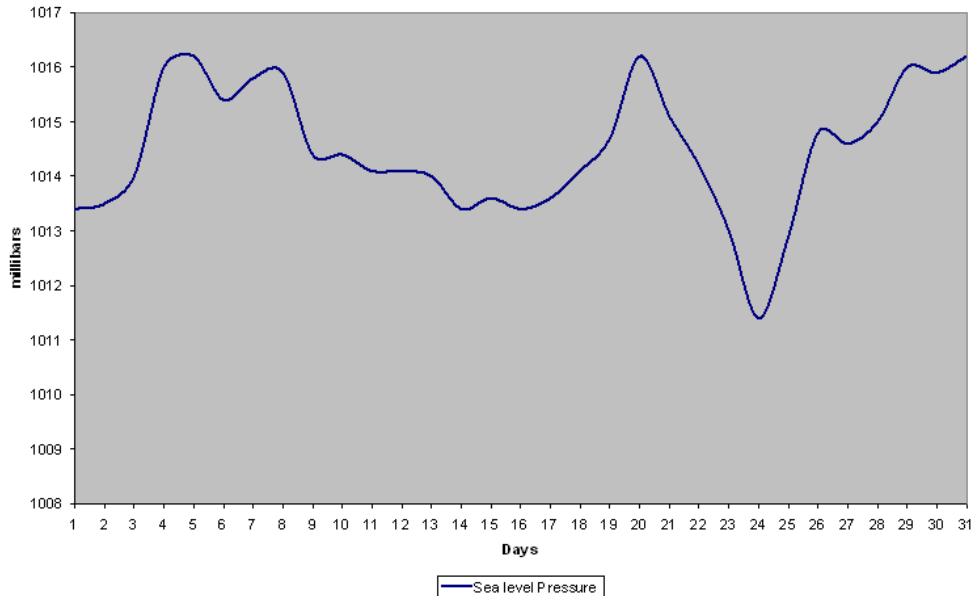
Comparative Rainfall, Greencastle and V.C Bird Int'l Airport



Daily Obs. V.C Bird Int'l Airport



Sea Level Pressure, V.C Bird Int'l airport-Dec 2004



Prepared by: Keithley Meade, Antigua Meteorological Service

C2. Antigua/Barbuda Weather Summary for Jan 2005

As was last year January, a high pressure system dominated the weather across Antigua and Barbuda for most of the month generating cool winds that moved over the Eastern Caribbean. These winds again drove some low level moisture across Antigua and Barbuda producing cloudy spells and showers for most of the month but with less frequency. A fairly persistent mid to upper level trough featured significantly in the month weather history. The month turned out to be a bit cooler than last year's January, 24.8°C as against 25.1°C. Rainfall was also slightly higher, 1.71 inches as against 1.59 inches, at V.C Bird Int'l airport. Most of this month's rainfall however occurred on a single day-26.6 millimetres on the 8th. Winds were mainly from the east at 11.4 knots while seas were moderate to locally rough for most parts, improving down to the end of the month.

The month began with bands of moisture moving southwestward over the Eastern Caribbean generating periods of increased cloudiness with scattered showers. These led to occasional brief cloudy conditions with a few scattered showers, amounting to 4.9 and 1.3 millimetres on the 1st and 2nd but skies remained mostly fair and sunny up to the 5th. A mid to upper level trough, and an associated jet stream kept skies across the Windward islands mostly cloudy to overcast with showers from the 3rd. Some of this

activity eventually spread northwards to Antigua and Barbuda and the other Leeward Islands and, along with some low level moisture and clouds moving across the Eastern Caribbean on a fresh Northeasterly wind flow, generated partly cloudy to cloudy periods with light to moderate showers over the islands. These showers led to the month's maximum rainfall 26.6 millimetres on the 8th, with most of the showers occurring overnight. Winds were mainly from the east at 13.6 knots. Seas were moderate to rough with waves 1.8-2.4 metres or 6-8 feet. A small craft advisory was put in effect for choppy seas and occasional strong wind gusts.

A persistent mid to upper level trough continued to maintain cloudy to overcast skies across the Leeward islands southwards to Trinidad and Tobago and Barbados, with most of the shower activity concentrated across the windward islands. The trough also led to a few daily showers across Antigua and Barbuda and the other Leeward Islands up to the 16th. Meanwhile a strengthening ridge of high pressure generated some brisk winds across the region. The steady wind flow brought patches of cloudiness and showers across the islands leading to light showers on the 13th, 14th, and 15th. Winds were slightly south of east at 14.7 knots with a 10-minute max of knots on the 13th at 17:00 UTC, and higher gusts. Seas were moderate to rough with waves 1.8-2.3m or 6-9ft. A small craft advisory remained in effect for above normal seas and gusty winds.

The period from the 16th to the 23rd saw more stable atmospheric conditions although patches of moisture continued to move across the islands from time to time, resulting in intervals of cloudiness and a few passing showers. The ridge of high pressure in the Atlantic maintained a moderate to brisk wind flow across the islands and kept sea conditions above normal. The system's dominance was interrupted from the 17th, with the retreating of the high pressure ridge to the northeast away from the islands, and the merger of a surface trough and a frontal boundary. The merger caused skies from Hispaniola south to Trinidad and Tobago to be cloudy to be overcast with occasional showers, as was experienced across Antigua and Barbuda on the 18th. Relatively dry and stable conditions with fair to partly cloudy skies resumed over Antigua and Barbuda from the 19th. Winds came mainly from slightly north of east at 9 knots with a 10-minute max of 16 knots on the 20th. Seas were moderate to locally rough for most parts with waves 1.8-2.4m or 6-8ft and slowly decreasing. However, a small craft advisory remained in effect.

The remnants of a cold front moving across the northeast Caribbean caused a few cloudy spells with mainly scattered showers over Antigua and Barbuda on the 24th after which stable, dry and relatively cool conditions were experienced across Antigua and Barbuda as a high pressure ridge established control of the weather across the Eastern Caribbean. This condition continued down to the end of the month apart from a last slight shower producing effort by the diffused frontal boundary on the 30th. Winds were mainly northeasterly at 9.0 knots with a max 10-minute wind of 16 knots on the 31st; winds generally become lighter, mainly overnight. Seas were moderate to locally rough with swells 1.8-2.4m or 6.8ft around coastal waters of the Northeast Caribbean but decreasing to slight to moderate swells 1.2 to 1.5 metres or 4 to 5 feet towards the end of the month.

**MONTHLY WEATHER SUMMARY
FOR THE PERIOD 01/01/2005 AT 13:00 TO 01/02/2005 AT 12:00**

WX: PARTLY CLOUDY

WINDS: E AT 11.4 KNOTS

MAX 10-MIN WIND: 24 KNOTS DATE: 13/01/2005 AT 17:00

BARO PRESS: 1015.1 MILLIBARS NORMAL

TOTAL RAINFALL: 43.5 MILLIMETRES 1.71 INCHES **MAX 24-HOUR:** 26.6 MM
DATE : 8/01/2005

MAX 6-HR RAINFALL: 18.8 MILLIMETRES DATE: 09/01/2005 AT 06:00

RAINFALL STATUS : BELOW NORMAL

AVG MAX TEMP: 26.1 DEGREES CELSIUS **MAX:** 29.5 DEGREES CELSIUS
DATE: 24/01/2005 AT 18:00

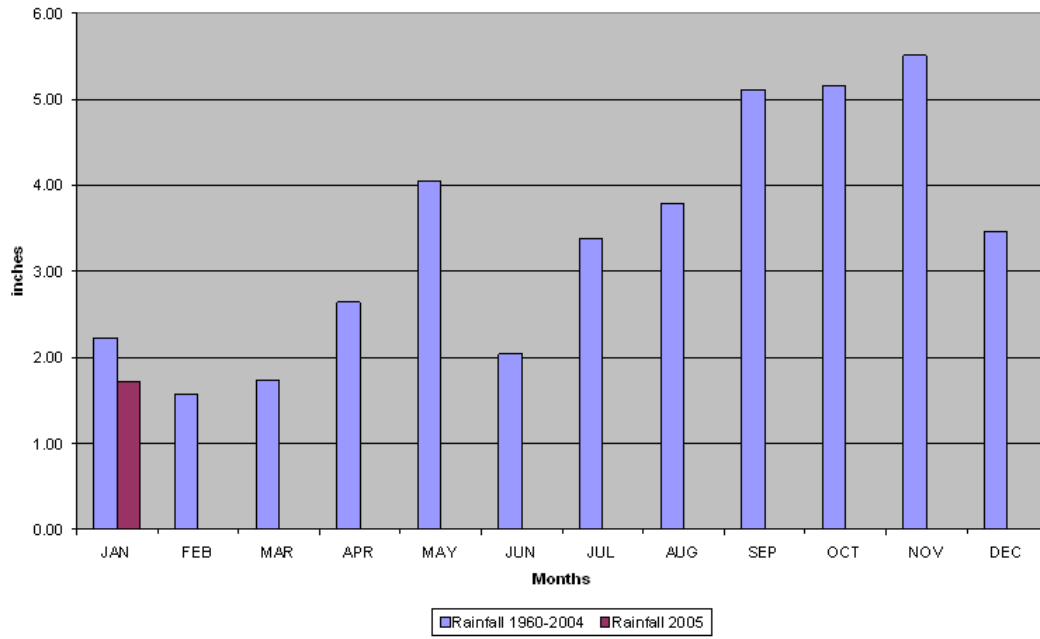
AVG MIN TEMP: 23.7 DEGREES CELSIUS **MIN:** 19.3 DEGREES CELSIUS
DATE: 01/02/2005 AT 12:00

AVG TEMP: 24.8 DEGREES CELSIUS **WARMEST DAY:** 25.6 DATE : 12/01/2005
DATE : 30/01/2005

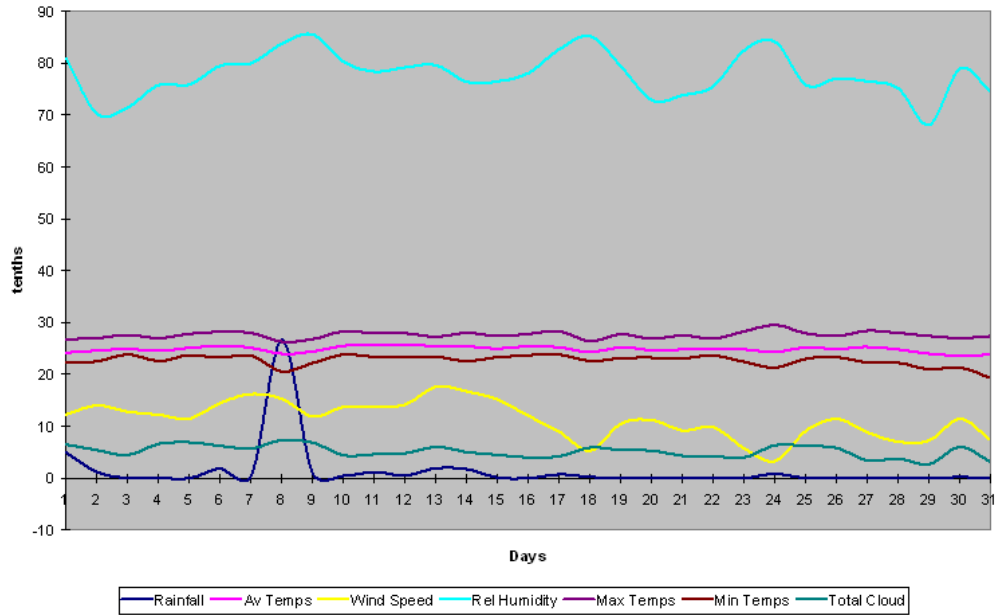
AVG REL HUM: 77.9 % **MOST HUMID-DAY:** 85.5 % DATE : 9/01/2005
LEAST HUMID-DAY: 68.1 % DATE : 29/01/2005

Monthly Comparisons

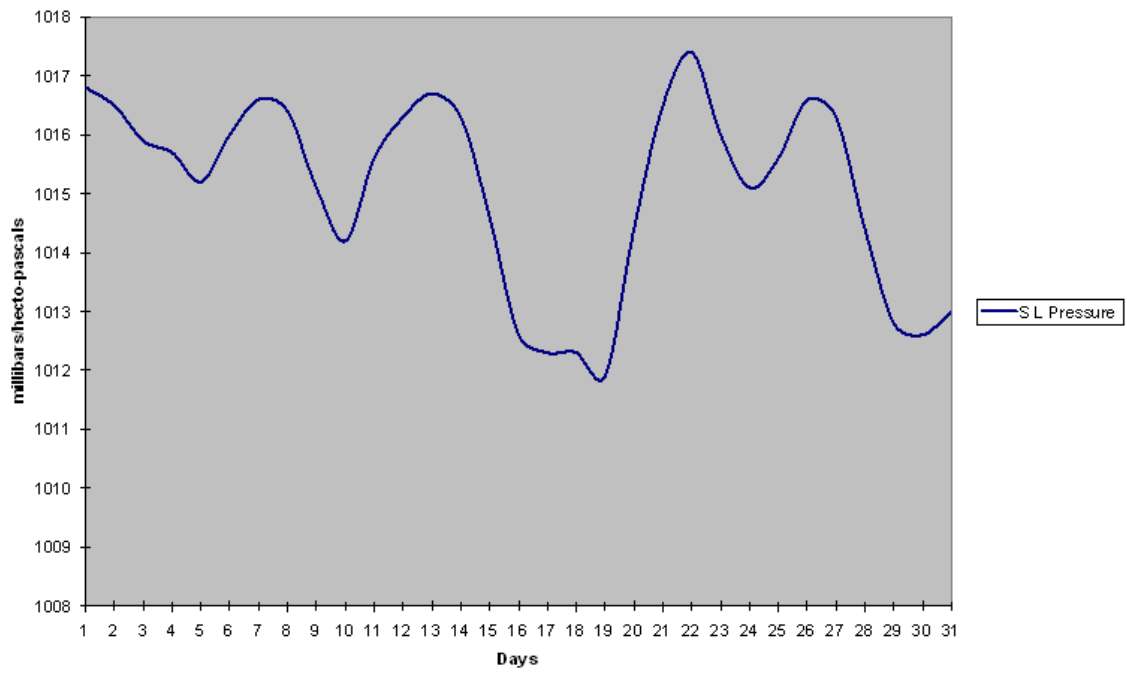
Rainfall comparison, V.C Bird Airport



Daily Obs Jan 2005-V.C Bird Int'l Airport



Sea Level Pressure Jan 2005-V.C Bird Int'l



Prepared by: Keithley Meade, Antigua Meteorological Service

References

- Burton, S. D., 1999: *A course in Tropical Meteorology*. Caribbean Institute for Meteorology and Hydrology
- Caesar, K. L., 2002: *Stability indices in the Caribbean*. Caribbean Institute for Meteorology and Hydrology
- George, J. J., 1960: *Weather Forecasting for Aeronautics*. Academic Press, 673. pp. 411-415
- Jacovides, C.P., T. Yonetani, 1990: *An Evaluation of Stability Indices for Thunderstorm Prediction in Greater Cyprus*. *Weather and Forecasting*: Vol. 5, No. 4, pp. 559–569.
- Kurk, M. 2004: *RICO Daily Weather Discussion Report-December 06th, 2004*.
- Kurk, M., and K.A. Caesar, 2004: *RICO Daily Weather Discussion Report-December 16th, 2004*.
- Rauber, R., H. Ochs, C. Knight, and B. Stevens, 2004: RICO: Rain In Cumulus over the Ocean Experiment; UCAR.
- Riehl, H. 1954: *Tropical Meteorology*. McGraw-Hill, pp. 18.