Development of High-Quality Spatial Climate Data Sets for Caribbean Islands

Prepared for

International Institute of Tropical Forestry
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By

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Background

The overall objective of this cooperative agreement is to produce high-quality maps of mean monthly minimum and maximum temperature, biotemperature, and precipitation for Caribbean Islands.

The first year was spent developing climate maps for the US and British Virgin Islands (USVI and BVI, respectively). The mapping project relies on 1) expert application of state-of-the-art modeling techniques by the Spatial Climate Analysis Service (SCAS), 2) high-resolution digital elevation data (from the Shuttle Radar Topography Mission – Jet Propulsion Laboratory), 3) station data sets from the US National Weather Service (NWS) and Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, and 4) a knowledge base that SCAS developed from site visits to the USVI, and similar modeling in Puerto Rico and other topical islands. The modeling approach that SCAS uses is the Parameter-elevation Regressions on Independent Slopes Model (PRISM), which uses spatial data sets, a knowledge base and expert interaction to generate GIS-compatible grids of annual, monthly and event-based climatic elements. For mapping of biotemperature, the International Institute of Tropical Forestry (IITF) will estimate climate station biotemperatures from mean annual temperatures.

The resulting spatial climate data will be used to support the sustainability assessment for the Forest Health, Legacy, and Stewardship programs for the Virgin Islands. The USVI Dept of Agriculture will be incorporating the data into the State Stewardship Plan.

Scope of Work

SCAS was contracted to:

1. Collect and process climate data for USVI and BVI provided by the US National Weather Service (USVI) and private data sources (BVI).
2. Perform quality assurance procedures on the data to improve consistency and reliability.
3. Develop 1971-2000 averages from the daily data, using newly developed technology to adjust periods of record that are short or not in the 1971-2000 period.
4. Use the PRISM model to create monthly grids of precipitation, and maximum and minimum temperature for the averaging period 1971-2000 for the Virgin Islands. Grid resolution is 3 arc-seconds (approximately 90 meters).
5. Deliver digital climate data via ftp to the USDA Forest Service in ARC/Info ASCII grid format.
6. Prepare metadata for the spatial climate grids and a brief report summarizing methods used to develop the grids.

Methods, Results and Discussion

Digital Elevation Models and Region Definitions

PRISM modeling was performed on a 3 arc-second DEM in geographic (lat/lon) coordinates, obtained from the "finished" Shuttle Radar Topography Mission (SRTM) DEM data set, for the region. The numerical definition of the region is:

Northern Edge: 18:46:00.19275N (deg:min:sec)
Southern Edge: 17:39:25.109713N
Eastern Edge: 64:15:12.146283W
Western Edge: 65:06:24.639027W
Resolution: 0:00:3
Number of Rows: 1332
Number of Columns: 1024
Datum: WGS84

This region included the USVI islands of St. Thomas, St. John, and St. Croix, the BVI islands of Tortola, Jost van Dyke, Anegada, and Virgin Gorda, and numerous other smaller islands. The SRTM DEM coverage was not complete; small areas of missing data, apparently caused by radar signal drop-outs, occurred mainly near coastlines. These areas were in-filled with surrounding DEM grid cell values using a nearest-neighbor approach in ARCGIS.

The 3 arc-second DEM was used to supply gridded elevations for PRISM modeling of minimum and maximum temperature (Figure 1). For precipitation, a modified Gaussian filter (Barnes, 1964) was applied to the 3 arc-second DEM to filter out terrain features up to 5 arc-minutes (~ 9 km) in extent, while retaining the 3 arc-second grid resolution

(Figure 2). While it has been difficult to generalize to all cases, SCAS' experience in modeling precipitation has shown that precipitation processes tend to respond more strongly to larger-scale terrain features than to fine-scale features (Daly et al., 1994). Orographic precipitation enhancement involves the forced uplift of moist air masses over terrain features, which is typically most dominant at larger scales, due to the viscosity of the air masses being lifted. In addition, there was generally insufficient station density to adequately resolve small-scale precipitation patterns, if they occurred.

PRISM estimates were made for all land areas identified in the modeling region. PRISM estimates were also made for small buffer regions offshore of each island. NOTE: The PRISM estimates are valid only over land, and not valid over water. These buffers were created to accommodate discrepancies in the delineation of coastlines from different data sources and at varying resolutions, not to provide over-water estimates.

Station Data

Table 1 lists sources for station data used in the mapping project. Virgin Islands climate data were obtained from three main sources: NWS, CIAT, and private weather stations. NWS data for the USVI were obtained from the National Climatic Data Center via ftp. NWS station data were available as daily precipitation totals and max/min temperatures for the station's period of record. CIAT data for the USVI were obtained *via* IITF. CIAT temperature data were available only as monthly mean temperatures (no max and min) for a period of record with known length, but unknown start and stop dates. No CIAT precipitation data were used. A complete list of stations used in the analysis is given in Appendix A.

Table 1. Sources for station data used in the mapping project.

	US Virgin Islands		**British Virgin Islands**	
Source	**Precipitation**	**Temperature**	**Precipitation**	**Temperature**
NWS	33	15	0	0
CIAT	0	3	0	0
Private/other (BVI)	0	0	4	1
Total	33	18	4	1

Neither the NWS nor CIAT sources had data for the BVI. After an extensive search, the only data obtained from a governmental source were from the BVI Office of Disaster Preparedness. These consisted of annual-only precipitation totals for an unknown location near Road Town, Tortola, for the period 1901-1994. Lacking better information, the data were assigned to the current location of the Office of Disaster Preparedness at Baugher's Bay, just east of Road Town. Data from a relatively new automatic station at Tortola's Beef Island Airport were examined, but had a very short period of record, contained no precipitation data, and had questionable temperature data.

Extensive Web searches, phone calls, and email communications identified three private parties on Tortola who had collected weather data for a sufficiently long period of time, and were generous enough to share them for this project. Roger Downing, located on Chalwell, in the hills above Road Town, had collected daily temperature and precipitation data at his home for the period 1991-2002. Jeff Morgan had taken precipitation data at his residence on Brewers Bay, on the north coast, for the period 1993-2004. Rowan Roy and family had measured monthly total precipitation at their residence in Hodges Creek, on the southeastern coast, for the period 1974-1997. All of these data contacts, as well as the precipitation data for Baugher's Bay, were made possible through the knowledge and generosity of Arthur Swain, a radio communications specialist in Road Town. No data were located for any other islands within the BVI.

Data were processed to remove outliers, develop 1971-2000 monthly and annual averages, and adjust the averages for stations with short periods of record. Methods were also developed to allow the use of stations with data outside the 1971-200 period. Data processing steps are discussed in detail below.

Calculation of Monthly Values

Individual monthly values of precipitation and minimum and maximum temperatures were calculated for all stations for which daily or individual monthly values were available. This was not done for the CIAT data set, for which only monthly means over an unknown period of record were available. "Long-term" minimum and maximum temperatures were calculated from the mean temperature values at CIAT stations by applying temperature ranges at nearby NWS stations to the CIAT mean values.

Monthly values for the annual-only precipitation totals at Baughers Bay, Tortola were estimated using monthly values (as a percent of annual) from the closest relevant stations. Given that no stations had data back to 1901, and that 1971-2000 was the period of interest, use of Baughers Bay precipitation was limited to the period 1971-1994. Hodges Creek, BVI was used to estimate monthly precipitation for 1974-1994; East End, St. John, USVI was used for 1972-1973. Given that there were no other VI precipitation data for 1971, the 1974-1994 average monthly percent of annual precipitation from Hodges Creek was used to estimate 1971.

Total monthly precipitation and mean minimum and maximum temperature were generated from daily data for all years of available record. Values that were null, or equal to various forms of missing values were set to missing. Range checking was done and values out-of-range were also set to missing. Monthly values were set to missing if more than 25% of the daily data were missing.

Overview of Adjustment Process

Station data for each month during the 30 year period 1971-2000 were averaged to create 1971-2000 monthly "normals." For precipitation, a 1971-2000 monthly station normal calculated using data from at least 23 of these 30 years (75% data coverage) was considered to be sufficiently characteristic of the 1971-2000 period, and was termed a "long-term" station. For temperature, a station needed at least 20 years of record to be deemed a long-term station. Stations with fewer years of record was termed a "short-term" station. Short-term station normals were subjected to an adjustment process designed to make them better reflect the 1971-2000 period. The assessment and adjustment of averages was performed for each month individually; therefore, it was possible for a station to be long-term for some months and short-term for others. Stations with long-term normals were used to adjust the short-term normals. A station with a long-term normal was referred to as a potential "anchor" station for that month. A station whose short-term monthly normal required adjusting was referred to as a "target" station.

A target station monthly normal was considered usable (and therefore adjustable) if the normal was calculated using at least three years of data from the 1971-2000 period. A target station monthly normal was also usable if the target station had at least three years of historical data, and at least one of these years was within 23 years of the beginning or end of the 1971-2000 period (an effective period of 1948-2003). A target station monthly normal was not usable if the station had less than three years of historical data, and no data during 1948-2003. Target station monthly normals that could not be used were omitted from the data set.

Since a target station monthly normal was created with less than 23 years of data (20 years for temperature) from 1971-2000, an attempt was made to increase the number of years used to calculate the monthly normal to 23 (75%) by using additional data outside 1971-2000, if available. These additional data were selected from years that were as close to the target period as possible, starting with 2001 and progressing forward in time to 2003, and then with 1970 and extending backward in time.

Choosing Anchor Stations

In the USVI, the long-term station with the longest period of record on each island was chosen as the anchor station for that island's short-term target stations. Anchor stations were all from the NWS COOP network:

St. Croix: Alexander Hamilton Field, ID=670198 (precip and temp)
St. John: Cruz Bay, ID= 671980 (precip); Cathrinburg (temp)
St. Thomas: Wintberg 679450 (precip); Truman Field (temp)

In the BVI, short-term precipitation stations were adjusted using Hodges Creek as the anchor station. For temperature, Alexander Hamilton Field, St. Croix USVI was used as the anchor. Alexander Hamilton was chosen because it was the only VI station with enough available years to cover the period of record of Chalwell, the only temperature station available in the BVI.

The Adjustment Process

After selecting an anchor station, monthly extended normals for the target station and anchor station were calculated using their respective data from the set of common years. These normals were called extended because they may have been calculated from a period of years that extended beyond the target period. For precipitation, an adjustment factor was calculated by dividing the anchor station 1971-2000 normal by the anchor station extended normal. The target station extended normal was multiplied by this factor to determine the target station adjusted normal. For temperature, an adjustment difference was calculated by subtracting the anchor station extended normal from the anchor station 1971-2000 normal. This difference was added to the target station extended normal to determine the target station adjusted normal. Arithmetically, the target adjusted normal (*TAN*) was calculated as:

Precipitation:
$TAN = (AN/AEN) * TEN$

Temperature:
$TAN = (AN-AEN) + TEN$

Where *AN* is the anchor normal, *AEN* is the anchor extended normal, and *TEN* is the target extended normal.

Quality Control

Many reported NWS and CIAT station locations in the USVI suffered from lack of geographic precision. Typically, locations were given to the nearest arc-minute, which is about 1.8 km at this latitude. Assuming no other errors were made in the location, this meant that the true station location could have been within +/- 1.8 km of its reported position. This is a significant distance on these small, steep islands, and can result in stations being plotted well offshore instead of on land, or at the wrong elevation. To overcome this lack of precision, the reported location for each station was plotted on a detailed map of the USVI. If the station was located clearly offshore, or its location clearly did not match its place name, a more suitable location was chosen.

In the BVI, Jeff Morgan of Brewers Bay took the time to obtain a GPS location on both his and Roger Downing's weather stations, insuring precise locational information. We did not have a precise location for Rowan Roy's home, so opted to place the station at what appeared to be the center of the small settlement of Hodges Creek. As discussed in the previous section, no formal information was available for the location of the precipitation data taken by the Office of Disaster Preparedness near Road Town. Lacking better information, the data were assigned to the current location of the Office of Disaster Preparedness at Baugher's Bay, just east of Road Town.

Three precipitation stations were omitted from the modeling process because their data could not be reconciled with those of surrounding stations. These were Good Hope (ID=673609, too dry, short period of record), Cotton Valley (ID=671810, too dry), and Estate Rust (ID=672860, too wet, short period of record), all located on St. Croix.

Modeling

All modeling was done with PRISM (Parameter-elevation Regressions on Independent Slopes Model). PRISM is a state-of-the-art model which is in widespread use and thoroughly tested and documented (see, for example, Daly et al., 1994, 2000, 2002, 2003; Gibson et al., 2002; Johnson et al., 2000). It has been continuously developed and refined at Oregon State University's Spatial Climate Analysis Service since 1991. PRISM climate maps produced by the SCAS are considered the standard in the US, and are the official climate maps of the USDA.

PRISM adopts the assumption that for a localized region, elevation is the most important factor in the distribution of temperature and precipitation (Daly et al., 2002). PRISM calculates a linear climate-elevation relationship for each DEM grid cell, but the slope of this line changes locally with elevation as dictated by the data points. Beyond the lowest or highest station, the function can be extrapolated linearly as far as needed. A simple, rather than multiple, regression model was chosen because controlling and interpreting the complex relationships between multiple independent variables and climate is difficult. Instead, weighting the data points (discussed later) controls the effects of variables other than elevation .

The climate-elevation regression is developed from x,y pairs of elevation and climate observations supplied by station data. A moving-window procedure is used to calculate a unique climate-elevation regression function for each grid cell. The simple linear regression has the form

$$Y = \beta_1 X + \beta_0$$

where Y is the predicted climate element, β_1 and β_0 are the regression slope and intercept, respectively, and X is the DEM elevation at the target grid cell.

Upon entering the regression function, each station is assigned a weight that is based on several factors. In the general PRISM formulation, the combined weight of a station is a function of distance, elevation, cluster, vertical layer, topographic facet, coastal proximity, effective terrain, and topographic index weights, respectively. A full discussion of the station weighting functions is available in Daly (2002) and Daly et al. (2002). The combined weight W of a station is a function of the following:

$$W = f\{ W_d,\ W_z,\ W_c,\ W_f,\ W_p, W_l, W_e, W_t \}$$

where W_d, W_z, W_c, W_f, W_p, W_l, W_e and W_t are the distance, elevation, cluster, topographic facet, coastal proximity, vertical layer, effective terrain, and topographic index weights, respectively. Distance, elevation, and cluster weighting are relatively straightforward in concept. A station is down-weighted when it is relatively distant or at a much different elevation than the target grid cell, or when it is clustered with other stations (which leads to over-representation). Coastal proximity weighting is used to define gradients in precipitation or temperature that may occur due to proximity to large water bodies (Daly et al. 1997, Daly and Johnson 1999, Daly et al. in press). Facet weighting effectively groups stations into individual hillslopes (or facets), at a variety of scales, to account for sharp changes in climate regime that can occur across facet boundaries. Vertical layer weighting is used to simulate situations where rapid changes, or even reversals, in the relationship between climate and elevation are possible (i.e., temperature inversions). When the potential for such situations exists, the climate stations entering the regression are divided into two vertical layers, and regressions run on each separately. Layer 1 represents the boundary layer, and layer 2 represents the free atmosphere above it. Effective terrain weighting accounts for differences in the ability of terrain features to enhance precipitation through mechanical uplift of moisture-bearing air. Features having relatively steep, bulky profiles typically produce strong precipitation-elevation relationships; while low, gently rolling features have weaker relationships (Daly et al. 1997, Daly and Johnson 1999, Daly et al., 2002). Topographic index weighting favors stations having topographic positions (e.g., valley bottom, ridge top) similar to that of the target grid cell. This is especially useful when interpolating temperature in regions where terrain configuration affects the spatial patterns of climate, such as the case of nocturnal cold air drainage and ponding.

PRISM was parameterized for the VI by assessing general climatic patterns through use of the PRISM graphical interface (Daly et al., 2002), and full grid applications at the annual and monthly time step. Once an initial parameterization was determined at an annual time step, PRISM was run for all months in the year, and the resulting grids evaluated for unusual conditions that were not handled well in the initial parameterization. This process was performed repeatedly until all months were modeled appropriately.

It became clear from initial applications of PRISM that there was no justification for an advanced parameterization of the model for the VI. Limited station data resolved only the major elevationally-dominated patterns of precipitation and temperature on the islands. There were insufficient data to resolve any coastal effects, fine-scale terrain aspect affects, and other details. Therefore, the PRISM moving-window climate-elevation regression was operated for precipitation with only the distance, elevation, and cluster weighting functions engaged. For temperature, only the distance and cluster weighting functions were operated; elevation weighting was not needed in the regression functions, due to the low number of stations, and the lack of noticeable changes in the regression function with changes in elevation.

Performance statistics were calculated for each modeling effort. These statistics were generated by performing jackknife cross-validation with replacement. This was done by omitting one station, predicting its precipitation value in its absence, replacing that station, moving to another station, performing the same deletion and prediction procedure, and so on until all stations had been omitted and replaced. The bias was given as:

$$Bias = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

where P_i and O_i are the predicted and observed precipitation for the *ith* station, respectively. The mean absolute error (MAE) was defined as:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}| P_i - O_i |$$

Details for each climate variable are provided below.

Precipitation

The 1971-000 mean annual precipitation map for the Virgin Islands is shown in Figure 3. The highest annual precipitation in the VI occurred over the northwestern hills of St. Croix, USVI, with values exceeding 1300 mm/yr. Maximum precipitation values on St. Thomas, St. John, and Tortola were slightly lower, averaging about 1200 mm/yr. The highest values tended to occur generally over the highest terrain, with the maxima often shifted or spread in a westerly to northerly direction from this center. This displacement is most likely due to downwind carryover of hydrometeors formed over the terrain crests, as moisture from the east and southeast moved over the islands. The lowest precipitation typically occurred along the coastlines of major islands away from major terrain features, or on small, isolated islands, where orographic precipitation enhancement was minimal. In these areas, mean annual precipitation generally averaged 950-1000 mm, with a minimum of 920 mm on Water Isle, off the southern coast of St. Thomas. This value may be representative of the non-orographic, “over-water” mean annual precipitation for the area.

The temporal distribution of precipitation is shown in Figure 4. All islands have a similar pattern: winters and summers are relatively dry, a minor precipitation maximum occurs in spring, and a major maximum occurs in the late summer and fall. November is typically the wettest month, and March the driest.

Table 2 summarizes performance statistics for PRISM precipitation modeling. The bias was very low for all months and the annual, indicating that precipitation at station locations was, on average, not over- or under-predicted to any great degree. The mean absolute error (MAE) was highest in absolute terms during the autumn months, when the mean precipitation was highest. However, when expressed as a percentage of the observed precipitation, MAE was lowest during autumn and highest in the winter and spring. August had the lowest percent MAE at nine percent. March had the highest percent MAE at nearly 15 percent. The percent MAE for mean annual precipitation was a relatively low 6.7 percent. Overall, the predictive errors were no larger than those in other PRISM analyses in complex terrain (Daly et al., 1994; 2003).

Table 2. Cross-validation performance statistics for PRISM monthly and annual precipitation modeling in the Virgin Islands (N=37).

Month	Bias (mm)	Mean Absolute Error (mm)	Mean Absolute Error (%)
January	0.86	7.39	12.62
February	0.77	5.58	12.97
March	-0.17	6.60	14.74
April	0.75	8.63	12.69
May	-0.95	13.75	13.47
June	0.38	7.31	12.24
July	0.35	11.19	14.77
August	0.18	9.02	9.00
September	0.12	13.17	9.11
October	-1.12	13.44	9.19
November	0.27	17.58	11.26
December	0.91	11.72	12.27
Annual	2.34	73.10	6.67

Temperature

Mean 1971-2000 maximum and minimum temperature maps for January and July are shown in Figures 5-8. Spatial temperature patterns were elevationally dependent, with the lowest temperatures occurring over the highest terrain, and highest temperatures over the lowest terrain. The highest terrain in the VI is only about 500 m, on Tortola, resulting in a spatial variation in temperature that is limited to about 4°C. In January, maximum and minimum temperatures ranged from about 26 to 30°C and 19 to 23°C, respectively (Figures 5-6). In July, maximum and minimum temperatures ranged from about 33 to 33°C and 22 to 26°C, respectively (Figures 7-8).

The temporal distribution of temperature is shown in Figure 9. All islands had a very similar seasonal pattern, and were thus plotted together. Maximum temperatures reached a low in January and a high in August; minimum temperatures were lowest in February and highest in August.

Table 3 summarizes performance statistics for PRISM precipitation modeling. The bias was again very low for all months and the annual, indicating that temperature at station locations was, on average, not over- or under-predicted to any great degree. The mean absolute error (MAE) never exceeded 0.5°C for minimum temperature and 1°C for maximum temperature. MAE for minimum temperature was fairly uniform throughout the year, while MAE for maximum temperature showed a slight peak during winter. MAE for maximum temperature was generally a little larger than for minimum temperature.

Table 3. Cross-validation performance statistics for PRISM monthly and annual modeling of minimum and maximum temperature in the Virgin Islands (N=17).

Month	**Bias (°C) tmin/tmax**	**Mean Absolute Error (°C) tmin/tmax**
January	0.00/-0.1	0.38/0.80
February	-0.01/-0.04	0.46/0.62
March	0.00/-0.06	0.47/0.54
April	-0.07/-0.03	0.34/0.52
May	-0.02/0.04	0.34/0.43
June	-0.04/-0.02	0.43/0.51
July	-0.14/0.02	0.44/0.57
August	-0.02/-0.01	0.40/0.59
September	-0.04/0.00	0.42/0.44
October	0.0/-0.06	0.39/0.66
November	0.03/-0.12	0.36/0.59
December	0.02/-0.13	0.42/0.74
Annual	-0.07/-0.04	0.38/0.51

Deliverables

PRISM was used to produce final monthly and annual grids of precipitation and minimum and maximum temperature for the averaging period 1971-2000.

The monthly and annual grids were exported in ARC ASCII GRID format, archived as tar files, and made available via ftp to Dr. Eileen Helmer at IITF. Dr. Helmer downloaded the data sets successfully.

This report documented the methods used, problems encountered, solutions implemented, and final results of the modeling effort. Examples of annual maps and accompanying discussions were presented.

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Johnson, G.L., C. Daly, C.L. Hanson, Y.Y. Lu and G.H. Taylor. 2000. Spatial variability and interpolation of stochastic weather simulation model parameters. *Journal of Applied Meteorology* 39(6): 778-796.

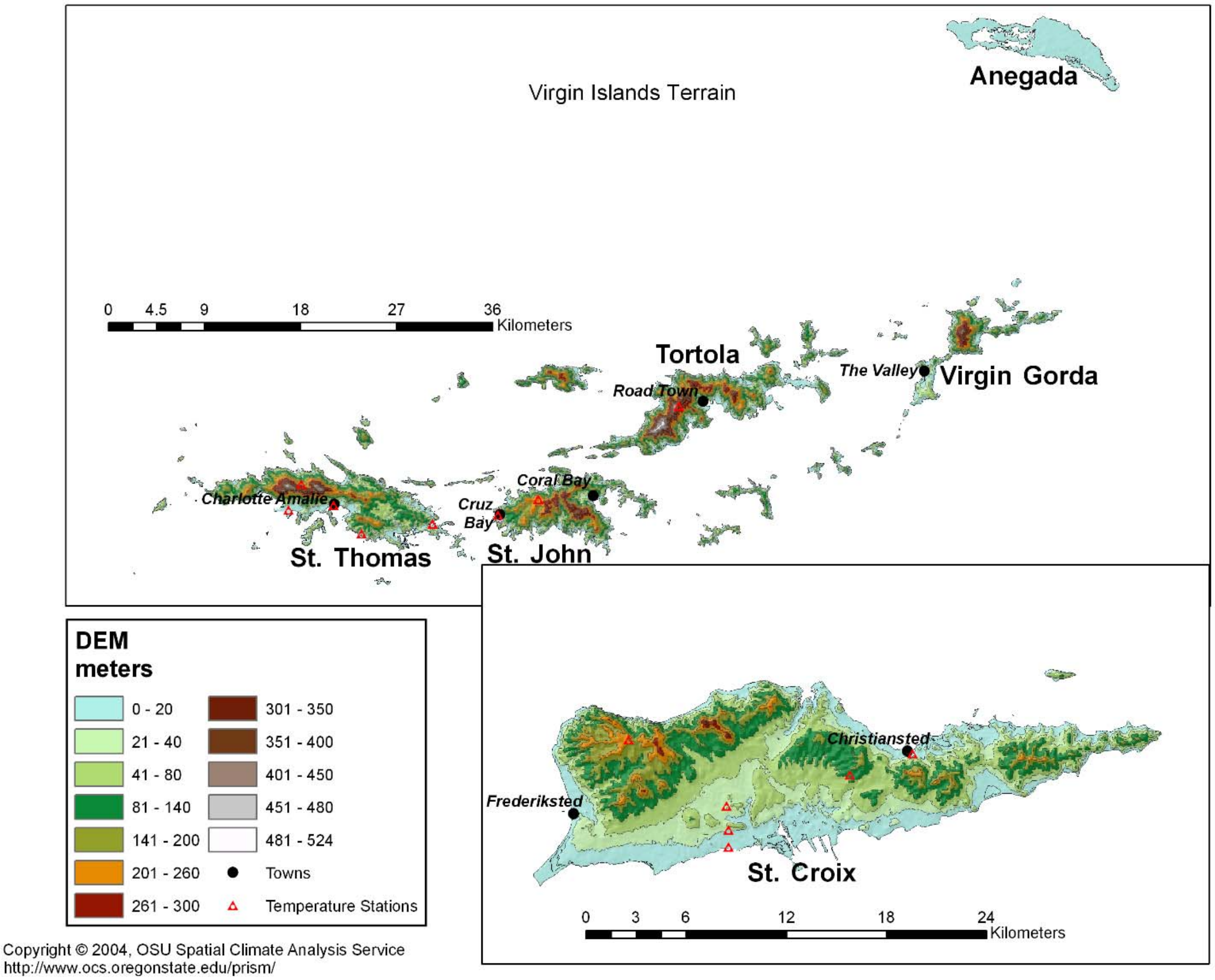

Figure 1. Three arc-second Virgin Islands DEM and modeling region. This DEM was used as the independent variable for PRISM temperature modeling.

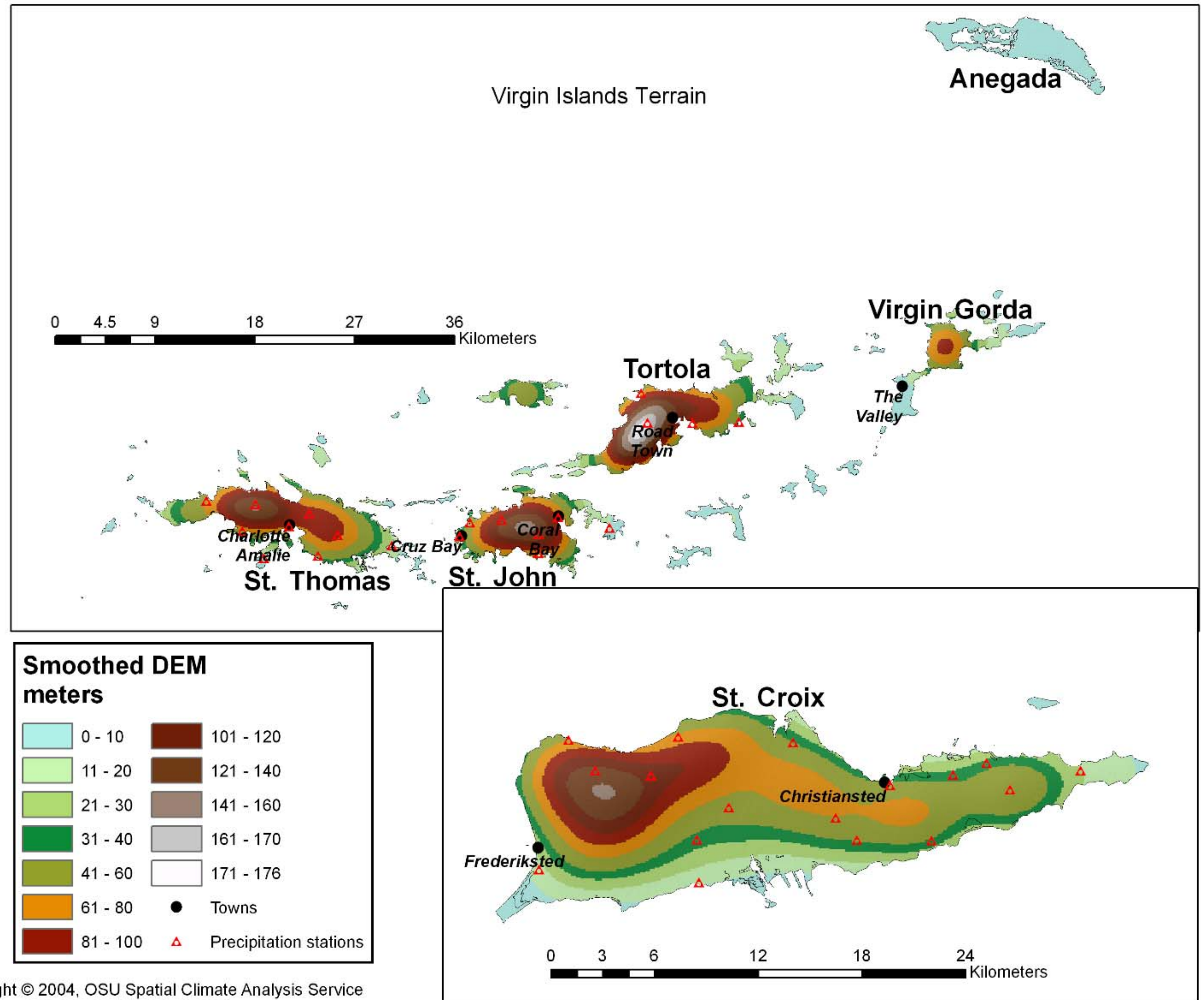
Virgin Islands Terrain
Anegada
Virgin Gorda
Tortola
The Valley
Road Town
Charlotte Amalie
Cruz Bay
Coral Bay
St. Thomas
St. John
0 4.5 9 18 27 36
Kilometers
Smoothed DEM
meters
0 - 10
11 - 20
21 - 30
31 - 40
41 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 170
171 - 176
Towns
Precipitation stations
St. Croix
Christiansted
Frederiksted
0 3 6 12 18 24
Kilometers

Figure 2. Three arc-second Virgin Islands DEM, low-pass filtered to a 5 arc-minute effective wavelength. This DEM was used as the independent variable for PRISM precipitation modeling.

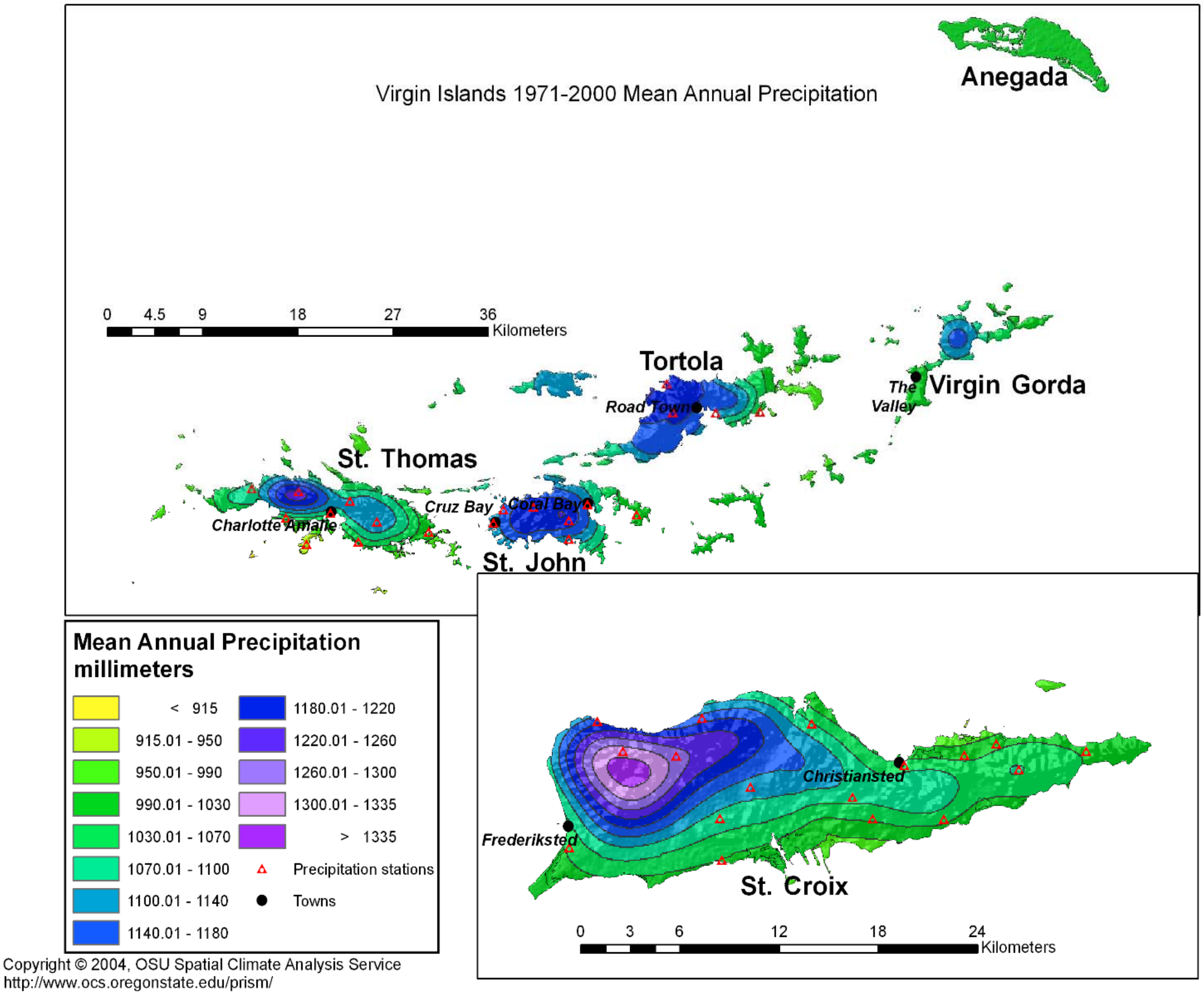

Figure 3. PRISM 1971-2000 mean annual precipitation for the Virgin Islands. Stations used are shown as red triangles.

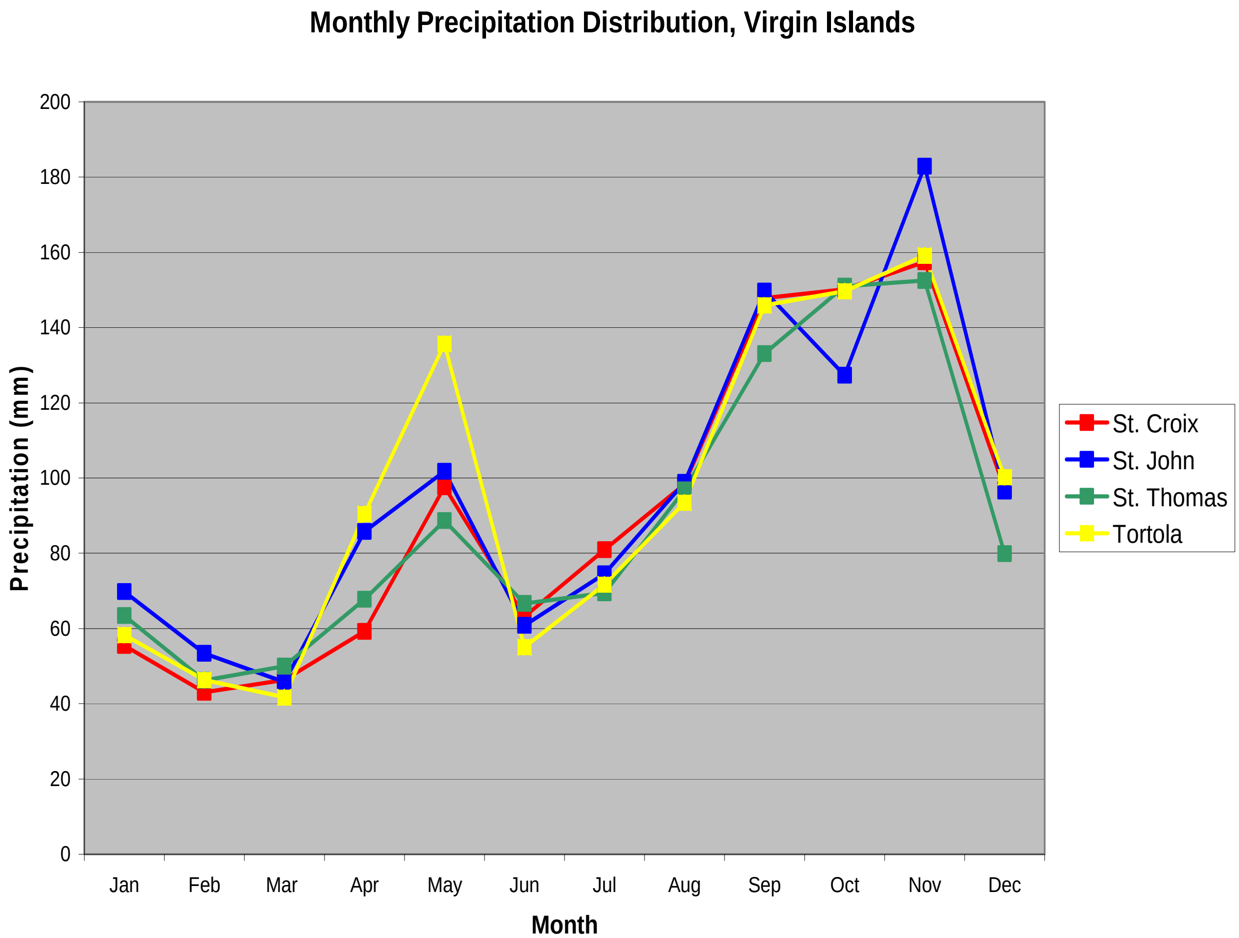

Figure 4. Monthly observed precipitation distribution for the Virgin Islands. Values represent monthly precipitation averaged over all stations on a given island.

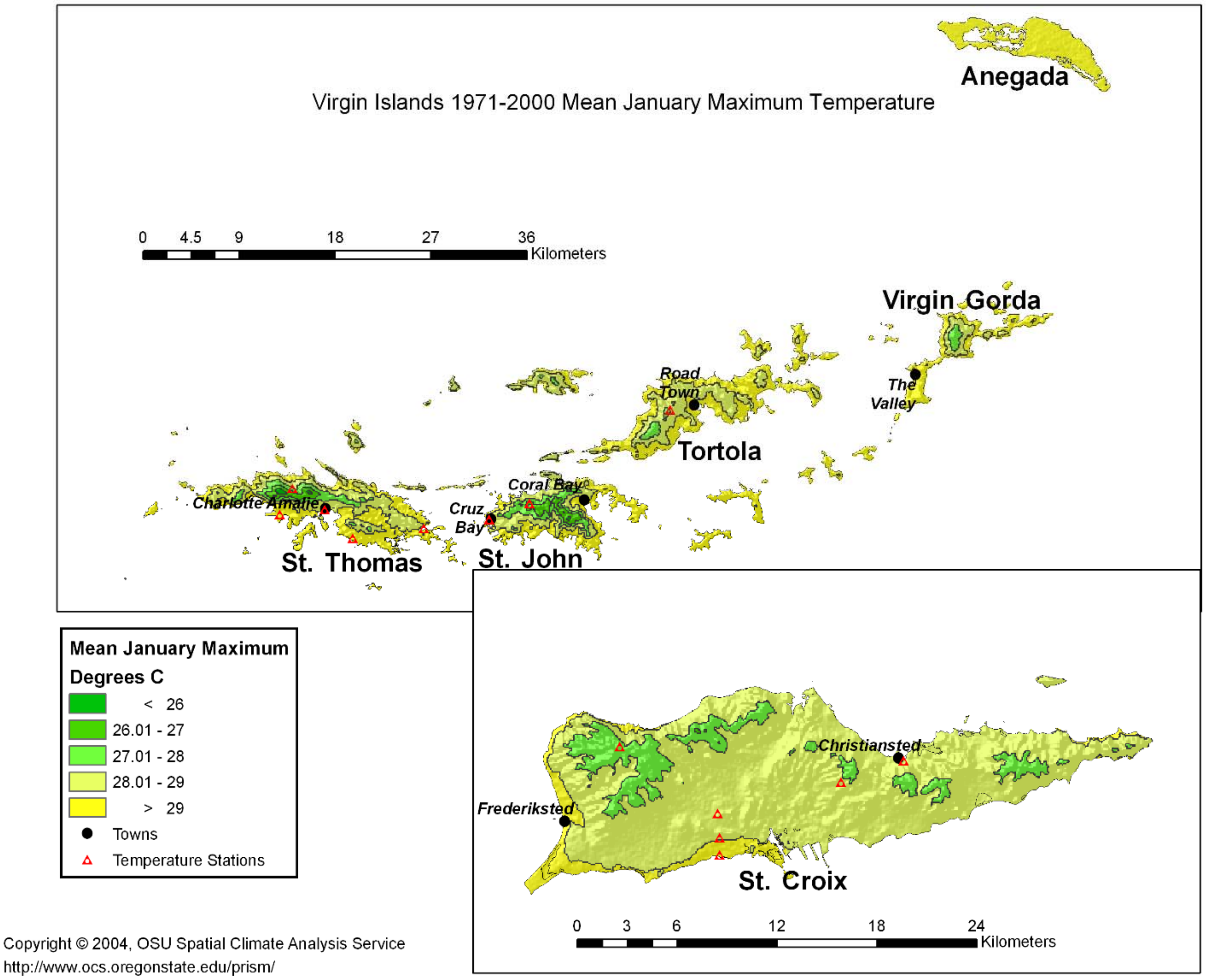

Figure 5. PRISM 1971-2000 mean January maximum temperature for the Virgin Islands. Stations used are shown as red triangles.

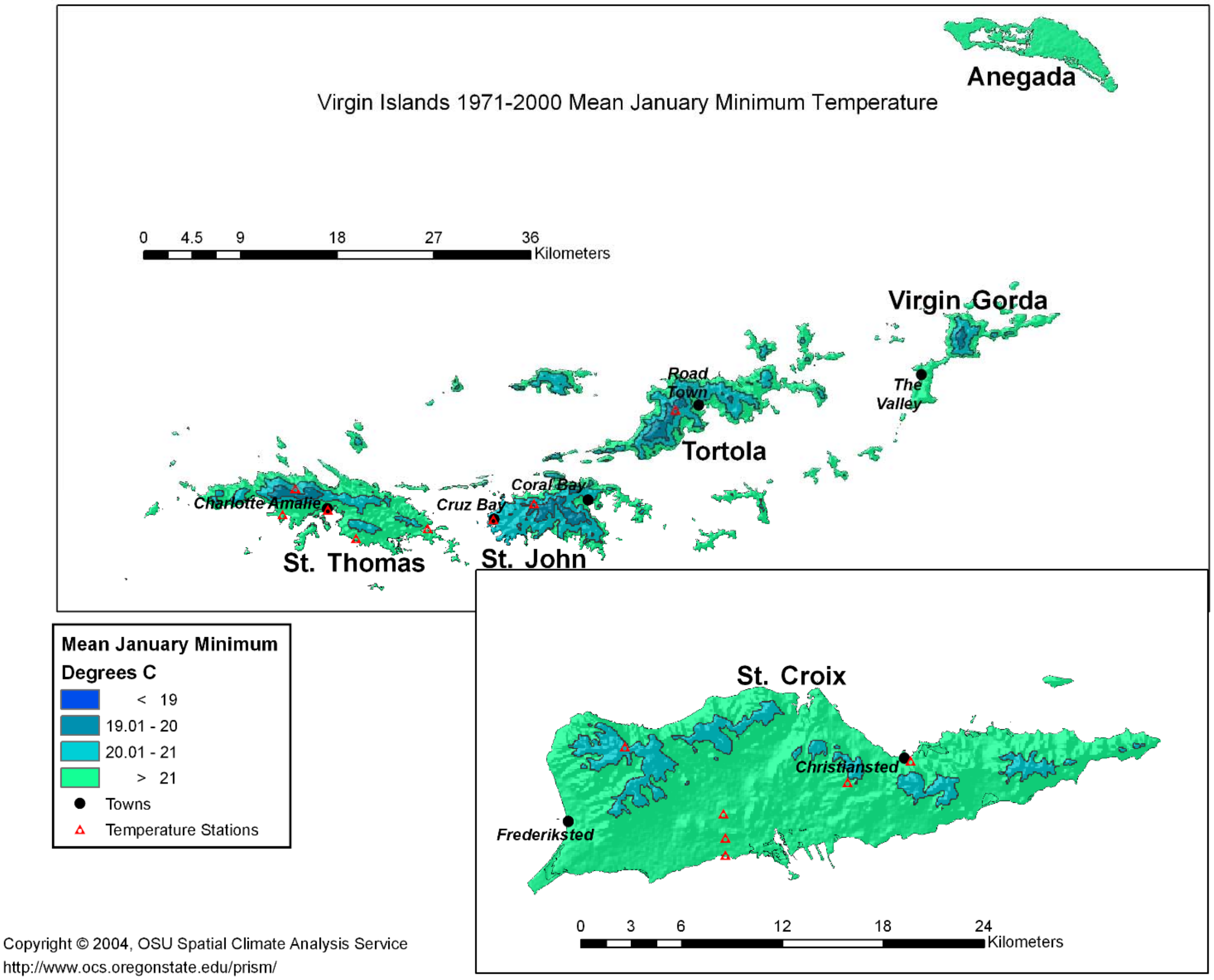

Figure 6. PRISM 1971-2000 mean January minimum temperature for the Virgin Islands. Stations used are shown as red triangles.

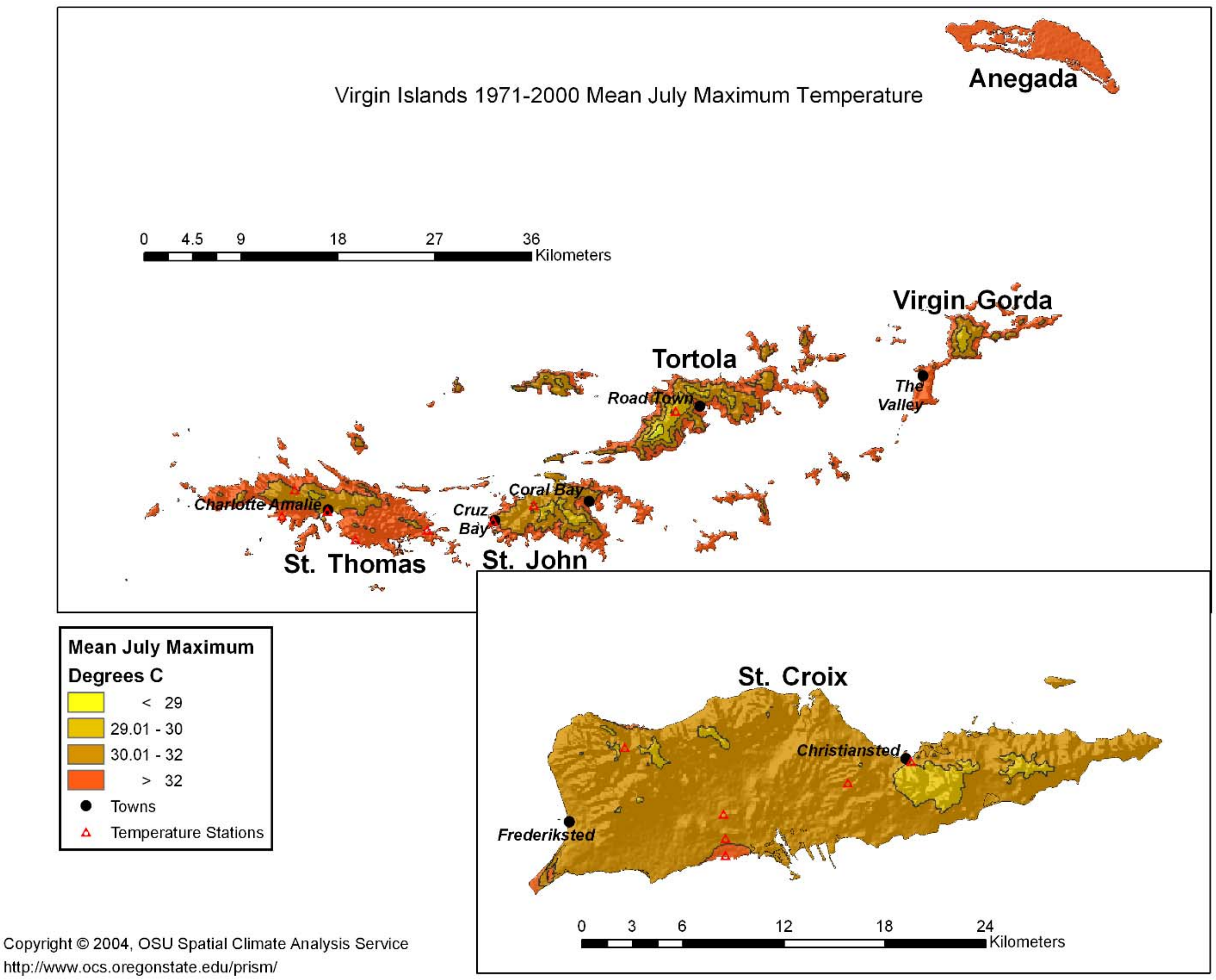

Figure 7. PRISM 1971-2000 mean July maximum temperature for the Virgin Islands. Stations used are shown as red triangles.

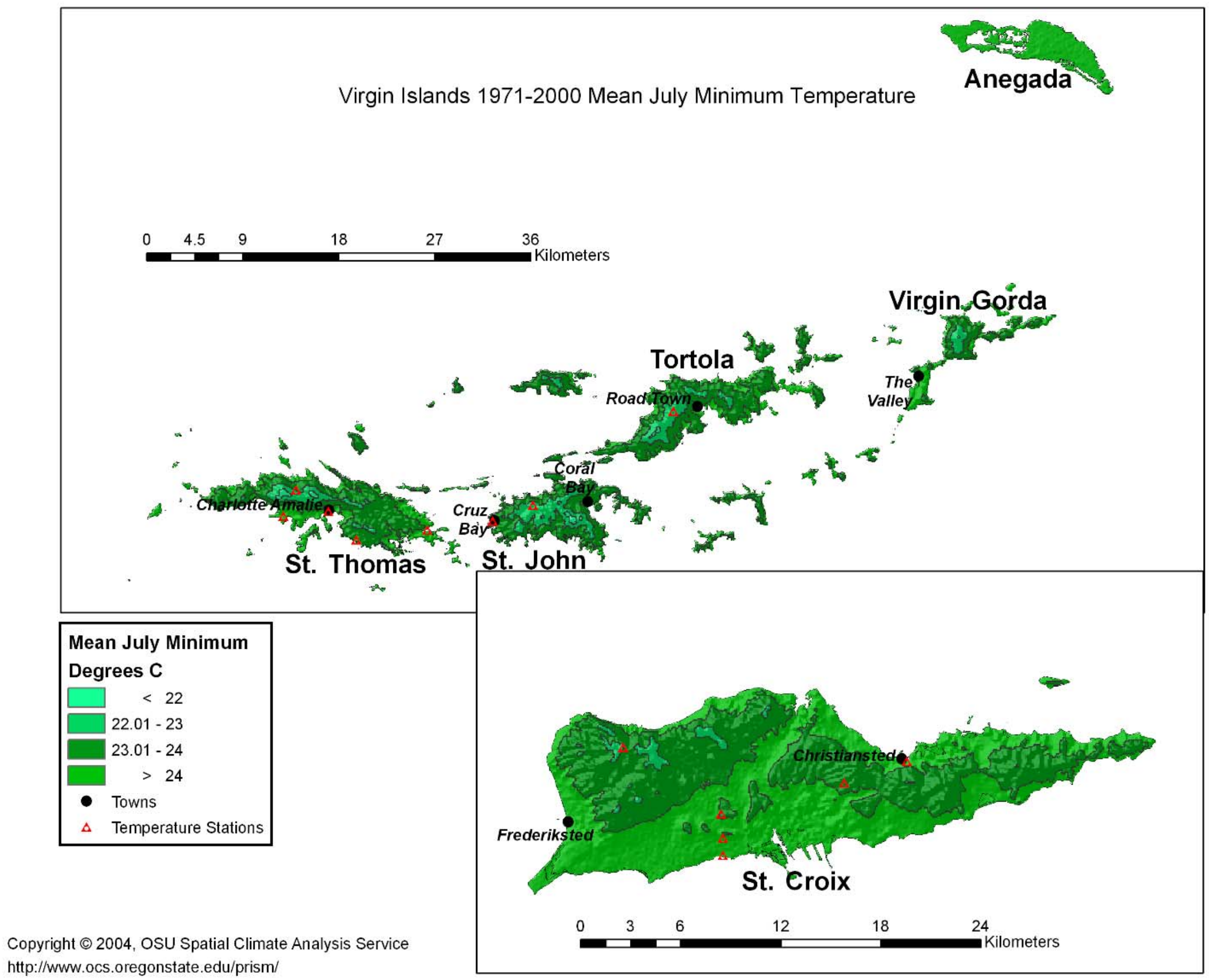

Figure 8. PRISM 1971-2000 mean July minimum temperature for the Virgin Islands. Stations used are shown as red triangles.

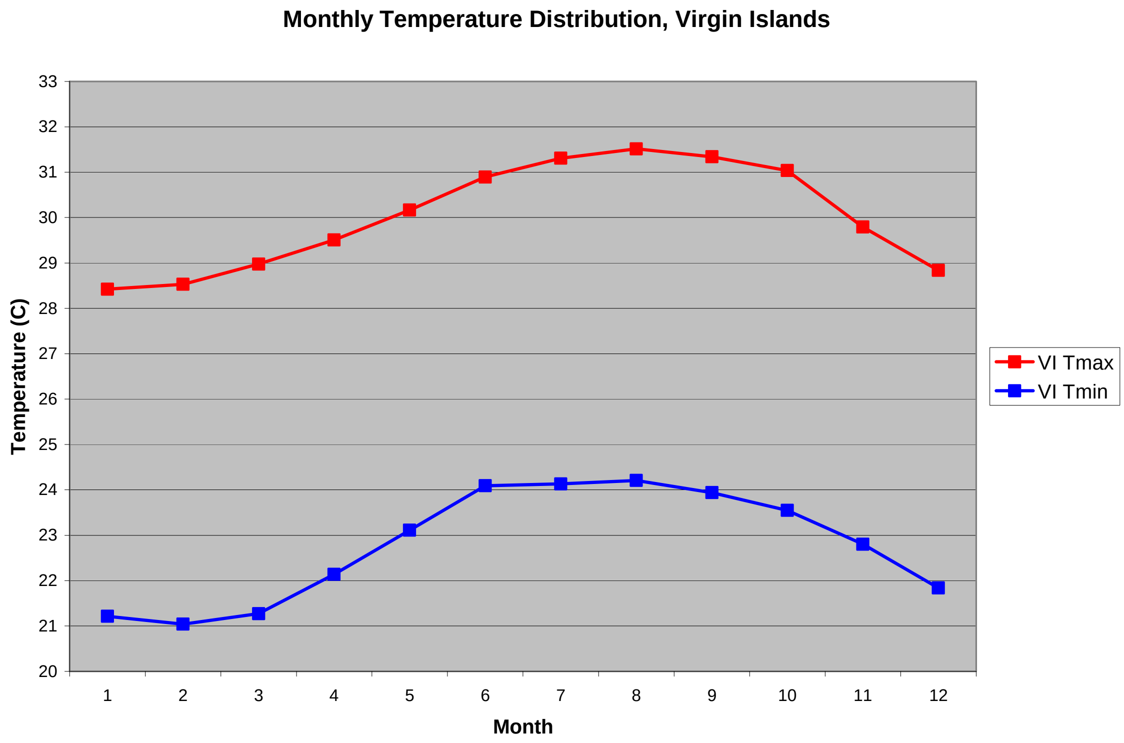

Figure 9. Monthly observed minimum and maximum temperature distribution for the Virgin Islands. Values represent monthly temperature averaged over all stations in the Virgin Islands.

APPENDIX A – Stations used in the Virgin Islands Climate Mapping Analysis

The following stations were used in the precipitation analysis

ID	Name	Elevation(m)	Lon	Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
					1971-2000 AVERAGE PRECIPITATION (mm*10)												
ST. CROIX																	
670198	ALEX HAMILTO	13	-64.7989	17.6946	533	474	455	479	911	572	735	936	1375	1378	1525	827	10199
670240	ANNALY	213	-64.8529	17.7521	724	571	621	755	1080	808	945	1091	1917	1705	1849	1168	13234
670260	ANNAS HOPE	55	-64.7278	17.7279	497	412	468	529	909	638	768	917	1514	1356	1607	813	10428
670480	BETH UPPER N	34	-64.8000	17.7167	516	499	461	556	937	640	726	956	1473	1628	1666	963	11022
671310	CANE BAY	24	-64.8096	17.7696	555	422	469	482	964	567	1143	1001	1579	1823	1425	1403	11834
671740	CHRISTIANSTE	9	-64.6996	17.7446	510	393	414	597	907	682	763	893	1488	1409	1617	827	10498
672560	EAST HILL	37	-64.6494	17.7561	451	383	375	547	914	550	689	912	1292	1296	1310	780	9498
672870	ESTATE THE S	40	-64.6667	17.7500	561	417	409	519	935	615	715	912	1294	1340	1466	886	10068
673150	FOUNTAIN	76	-64.8238	17.7496	724	481	536	692	1216	707	905	1010	1586	1738	1767	1139	12502
673220	FREDERIKSTED	24	-64.8821	17.7013	419	326	400	624	820	637	750	977	1501	1493	1693	765	10404
673677	GRANARD	20	-64.7167	17.7164	528	425	421	544	888	572	708	848	1313	1273	1486	872	9877
673880	HAM BLUFF LI	24	-64.8667	17.7679	650	443	521	880	1071	741	863	916	1488	1724	1602	1214	12114
674600	KINGS HILL	64	-64.7833	17.7333	695	535	514	480	1147	495	1088	1087	1582	1546	1608	1029	11804
674900	MONTPELLIER	61	-64.7500	17.7667	574	470	446	610	1039	655	853	912	1290	1568	1499	889	10804
678621	TAGUE BAY	9	-64.6004	17.7521	437	318	476	586	1077	479	680	1318	1440	1345	1264	1012	10432
671333	CASTLE NUGEN	30	-64.6779	17.7163	501	315	428	597	811	749	619	1054	1524	1405	1809	930	10741
ST. JOHN																	
670820	BORDEAUX MOU	338	-64.7304	18.3338	691	550	370	953	965	570	731	997	1433	1438	2100	923	11722
671316	CANEEL BAY P	18	-64.7863	18.3429	754	494	527	899	1211	691	802	1021	1577	1320	1851	1114	12261
671348	CATHERINEBUR	258	-64.7606	18.3453	704	643	596	921	1221	745	805	1103	1606	1281	1848	1164	12635
671790	CORAL BAY	9	-64.7146	18.3471	832	544	416	804	870	589	753	915	1461	1244	1807	948	11183
671980	CRUZ BAY	2	-64.7946	18.3321	686	521	477	903	1057	612	832	1069	1549	1281	1693	841	11520
672551	EAST END	46	-64.6729	18.3388	550	480	369	684	870	552	641	898	1342	1174	1615	866	10040
ST. THOMAS																	
674820	LAMESHUR BAY	52	-64.7304	18.3188	669	507	450	842	933	497	653	916	1510	1173	1889	899	10937
671625	CHARLOTTE AM	5	-64.9333	18.3400	562	492	558	703	751	628	599	855	1214	1460	1318	713	9853
672440	DOROTHEA AES	244	-64.9604	18.3579	912	585	704	711	1047	741	850	1021	1506	1651	1869	854	12452
672823	ESTATE FORT	61	-64.8938	18.3329	764	531	581	966	1190	828	776	1138	1443	1665	1880	885	12647
672830	ESTATE HOPE	119	-65.0004	18.3604	608	453	789	492	937	719	916	1010	1569	1494	1779	872	11640
673380	FRENCHMANS B	36	-64.9096	18.3163	679	535	366	661	581	551	516	1068	1318	1782	1446	659	10161
677600	REDHOOK BAY	1	-64.8496	18.3246	595	378	294	564	897	594	746	919	1202	1318	1382	871	9759
678905	TRUMAN FIELD	6	-64.9713	18.3363	525	373	377	631	886	675	611	878	1188	1403	1355	714	9616
679222	WATER ISLE	30	-64.9538	18.3146	441	348	348	611	708	566	556	891	1167	1454	1324	771	9183
679450	WINTBERG	197	-64.9167	18.3500	620	461	483	760	984	693	680	937	1372	1361	1371	849	10570

The following stations were used in the precipitation analysis (concluded)

ID	Name	Elevation(m)	Lon	Lat	1971-2000 AVERAGE PRECIPITATION (mm*10) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
TORTOLA																	
BVI003	HODGES CREEK	3	-64.5680	18.4239	540	420	364	741	965	493	546	741	1237	1281	1585	841	9755
BVI004	CHALWELL	382	-64.6422	18.4232	640	523	563	943	1454	480	641	1126	1287	1572	1547	830	11605
BVI005	BREWERS BAY	37	-64.6473	18.4471	601	423	274	999	1883	638	1075	947	1962	1539	1417	1291	13049
BVI006	BAUGHERS BAY	9	-64.6055	18.4230	550	488	467	936	1126	590	607	924	1352	1596	1818	1046	11499

The following stations were used in the maximum temperature analysis

ID	Name	Elevation(m)	Lon	Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
					1971-2000 AVERAGE MAXIMUM TEMPERATURE (C*10)												
ST. CROIX																	
670198	ALEX HAMILTO	13	-64.7989	17.6946	290	291	295	300	307	313	317	319	318	315	305	294	305
670240	ANNALY	213	-64.8529	17.7521	273	276	280	285	298	310	306	305	307	306	290	276	293
670480	BETH UPPER N	34	-64.8000	17.7167	282	284	289	294	300	309	311	309	312	307	299	287	299
671740	CHRISTIANSTE	9	-64.6996	17.7446	284	284	285	290	300	303	304	307	311	308	300	288	297
670260	ANNAS HOPE	55	-64.7278	17.7279	283	285	291	294	301	309	312	313	312	306	298	288	299
ST. JOHN																	
671348	CATHERINEBUR	258	-64.7606	18.3453	262	268	278	287	292	300	305	306	302	295	278	265	287
671980	CRUZ BAY	2	-64.7946	18.3321	289	288	290	296	305	310	317	318	316	314	305	294	304
ST. THOMAS																	
671625	CHARLOTTE AM	5	-64.9333	18.3400	286	286	289	294	300	307	313	318	320	316	304	294	302
672440	DOROTHEA AES	244	-64.9604	18.3579	272	277	285	291	294	307	315	314	303	300	284	276	293
673380	FRENCHMANS B	36	-64.9163	18.3196	304	303	303	310	314	322	327	331	328	319	304	303	314
677600	REDHOOK BAY	1	-64.8496	18.3246	293	296	296	300	312	314	322	325	322	324	303	298	309
678905	TRUMAN FIELD	6	-64.9713	18.3363	299	299	302	307	311	320	324	327	323	319	309	300	312
TORTOLA																	
BVI004	CHALWELL	382	-64.6422	18.4232	278	272	284	288	288	292	297	305	300	306	294	286	291

The following stations were used in the minimum temperature analysis

ID	Name	Elevation(m)	Lon	Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
					1971-2000 AVERAGE MINIMUM TEMPERATURE (C*10)												
ST. CROIX																	
670198	ALEX HAMILTO	13	-64.7989	17.6946	223	223	223	234	245	257	257	256	250	244	236	228	240
670240	ANNALY	213	-64.8529	17.7521	210	208	207	217	225	232	233	239	236	235	230	217	224
670480	BETH UPPER N	34	-64.8000	17.7167	214	208	210	224	236	242	244	241	242	240	232	220	229
671740	CHRISTIANSTE	9	-64.6996	17.7446	217	215	220	228	238	248	246	249	244	242	236	226	234
670198	ALEX HAMILTO	13	-64.7989	17.7039	214	214	216	227	236	247	246	246	240	237	230	222	231
670260	ANNAS HOPE	55	-64.7333	17.7333	215	209	212	224	237	242	245	245	242	239	231	221	230
ST. JOHN																	
671348	CATHERINEBUR	258	-64.7606	18.3453	197	196	198	206	217	225	226	226	225	221	214	203	213
671980	CRUZ BAY	2	-64.7946	18.3321	208	207	209	219	233	242	244	243	238	233	225	213	226
ST. THOMAS																	
671625	CHARLOTTE AM	5	-64.9333	18.3400	225	222	225	231	238	250	247	248	251	245	234	230	237
672440	DOROTHEA AES	244	-64.9604	18.3579	204	206	207	212	214	231	232	235	235	230	221	214	220
673380	FRENCHMANS B	36	-64.9096	18.3163	218	218	221	225	234	244	242	243	242	236	233	224	232
677600	REDHOOK BAY	1	-64.8496	18.3246	218	216	219	228	239	250	251	251	246	240	234	223	235
678905	TRUMAN FIELD	6	-64.9713	18.3363	222	221	223	233	244	252	254	254	250	245	238	227	239
TORTOLA																	
BVI004	CHALWELL	382	-64.6422	18.4232	196	195	198	204	213	227	227	227	221	218	206	199	211