Production of High Resolution Irradiance Data for Central America and Cuba

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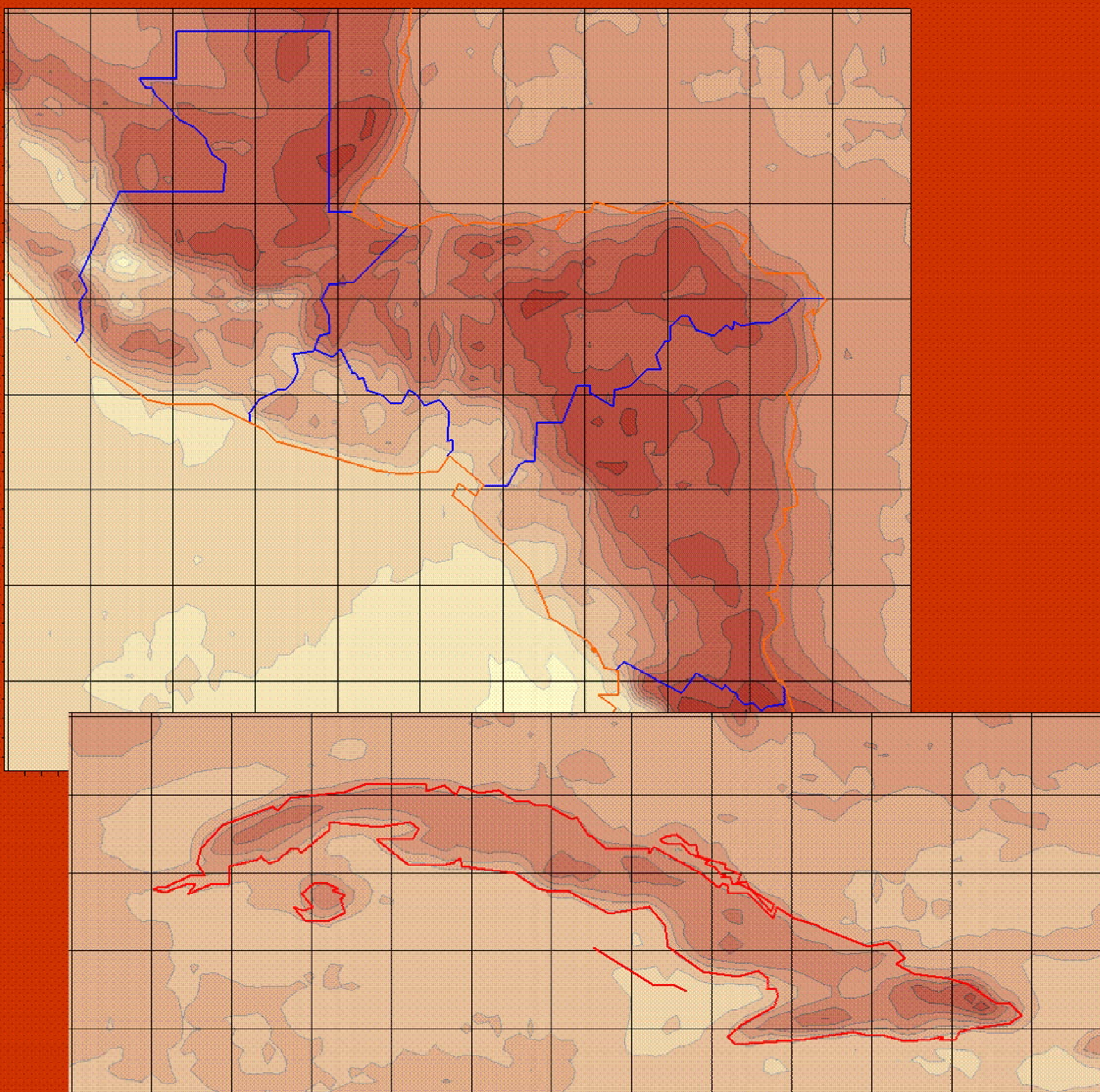
Richard Perez & Marek Kmiecik, the University at Albany

UNEP SWERA



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Production of high Resolution Irradiance Data
For Central America and Cuba

Prepared by

Richard Perez
ASRC, the University at Albany (SUNY)

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The main objective of the SUNY task for SWERA is to prepare high resolution global irradiance (GHI) and direct irradiance (DNI) data sets for the countries of Cuba, El Salvador, Guatemala, Honduras and Nicaragua.

Much of our initial effort focused on building up the satellite data archive, and in strengthening and validating the models capable of converting that data into ground surface irradiances. Three research articles, acknowledging all or partial funding from UNEP/SWERA have been published on this subject. These articles are:

- *A New Operational Satellite-to-Irradiance Model. Solar Energy 73, 5, pp. 307-317 (2002), by R. Perez, P. Ineichen, K. Moore, M. Kmiecik, C. Chain, R. George and F. Vignola.* This article describes the model used for SWERA and includes ground truth validations from climates ranging from arid to sub-tropical.
- *Producing satellite-derived irradiances in complex arid terrain. Proc. ASES Annual Meeting and submitted to Solar Energy (2003) by R. Perez, P. Ineichen, M. Kmiecik, K. Moore, R. George and D. Renne.* This article describes modifications to the models for a better operation in complex terrain marked by high contrast between the ground reflectivity of microstructures often encountered in arid areas as well as coast lines.
- *Cross validation of satellite radiation transfer models during SWERA project in Brazil (2003) Proc. ISES World Congress, Göteberg, Sweden by E. Pereira, F. Martins, S. Abreu, H.G. Beyer, S. Colle, R. Perez and D. Heinemann.* This article describes the initial results of the cross model cross platform satellite model ground truthing experiment in Brazil.

Production of High Resolution Irradiance data

Using the model described in the above publications, we processed a total of five years of hourly visible-channel GOES East images from January 1, 1998 through December 31, 2002. In addition to GOES 8 data, the model uses turbidity, water vapor and ozone input. At this time we have used information assembled by NREL for their medium resolution data processing. NREL is currently upgrading and standardizing the turbidity input. Our intent is to rerun the model and repost data as soon as the new input becomes avaialble – note that we expect only minor changes from the current models runs.

The nominal resolution of our operational archive is 0.1° latitude by 0.1° longitude, amounting to roughly 11km by 11 km in the considered Central American and Caribbean regions. From that data, we produced high-resolution hourly GHI and DNI data sets encompassing every image pixel for each country. The hourly irradiance data sets are being made available to NREL for incorporation into the GIS-based user products.

It is anticipated that detailed hourly data and derived products will be made available to the participating countries via this GIS interface currently under development at NREL.

In this report, we present an overview of the selected countries' solar resource in advance of the GIS-based products.

We present DNI and GHI maps derived from the high-resolution data including
- 5-yr average,
- Average highest month, and
- Average lowest month.

In addition, we present and discuss monthly DNI and GHI profiles for three locations in each country – the capital city, the clearest, and the cloudiest location.

Overall Resource: The five-year average solar resource for the 4 Central American Countries is mapped in Figures 1 and 2 as quantified by GHI and DNI, respectively. Units are average Watts per square meter[1]. The maps show well defined micro-climatic regions, with GHI spanning 195 to 280 W/sq.m, and DNI spanning 150 to 300 W/sq.m. As would be expected from the prevailing motion of weather systems driven by easterly trade winds, there is a gradual overall increase in solar resource from the Atlantic to the Pacific coast. Superimposed on this general trend, orographic effects are clearly visible with cloudy elevations and "rain shadows

[1] Other frequently used units may be easily inferred from average W/m^2

To convert to % capacity Factor , divide by 10 and 8, respectively for GHI and DNI

To convert to kWh/m^2/day, multiply by 0.024.

To convert to kWh/m^2 per year multiply by 8.76

downwind on the Pacific coast as well as in protected valleys such as the upper reaches of the Rios Usamacinta and Grijalva in NW Guatemala. The southern part of Nicaragua is characterized by intensified cloudiness, as this reaches into the equatorial weather system regime.

We observe little year-to-year variability as can be seen in Figures 3 and 4. Note that variability is higher at sea than on land where the 5-yr standard deviation is well within ± 2% for global and ± 3% for direct.

Overall GHI and DNI resource maps for Cuba are presented in Figures 5 and 6, while the 5-yr standard deviation maps are shown in Figures 7 and 8. Orography is the dominant feature in Cuba, with cloudiness peaking on higher relief, particularly at the eastern "bulk head" of Sierra del Purial. Because of the island's east-west layout, rain shadow resource enhancement regions are not as pronounced as in Central America. The highest solar resource is found on the coast of the Golfo de Guacanayabo and the southern barrier Islands, where some rain shadow intensification is noticeable. Year-to-year variability is also minimal, pointing to a stable solar resource[2].

Highest month for GHI: For each of the four considered Central American countries and Cuba, the month with the highest solar resource quantified in terms of GHI is April. GHI maps for this month are shown in Figures 9 for Central America and 10 for Cuba. The features are quite similar to the overall average map, but the micro climatic effects are intensified with a larger high-low regional range.

Highest month for DNI: The highest month for DNI is March for El Salvador, Guatemala, Honduras and Nicaragua, but is April for Cuba. The maps for highest DNI are presented in Figures 11 (Central American countries) and 12 (Cuba). As for global, features are similar to the overall maps, but with more contrasted difference -- e.g., for direct ,the high-low range in Central America is 130% in March up from 90% year-around.

Lowest month for GHI: The lowest month for global irradiance for all countries is December – see maps in Figures 13 (Central America) and 14 (Cuba). Note that the overall east-west trend tends to shift to a north south trend because of solar geometry effects – the sun is lower in the sky as one moves northward – and because more weather systems reach from the north in this season. This is also visible in Cuba where rain shadow enhancement occurs on the shores south of the two highest mountainous regions.

Lowest month for DNI: Unlike for global, the lowest month for direct is June in the four Central American countries (see Figure 15). However it remains December in Cuba (see Figure 16). The latitude effect is less of a factor for DNI than for GHI, because DNI is measured facing the sun at all time. On the other hand, the summer

[2] Important note: The period of observation only includes the tail end of the last major El Nino event

season exhibits higher atmospheric moisture hence higher turbidity and more cloudiness. This penalizes DNI more than GHI. Also note that for this month the regional resource is more balanced with a disappearance of the east-west trend – in fact the highest DNI resource is found on the Atlantic side, on the northern coast of Honduras. The minimum DNI for Cuba is in December because the combined impact of northern winter weather systems and solar geometry exceed the impact of summer enhanced cloudiness.

Monthly Trends

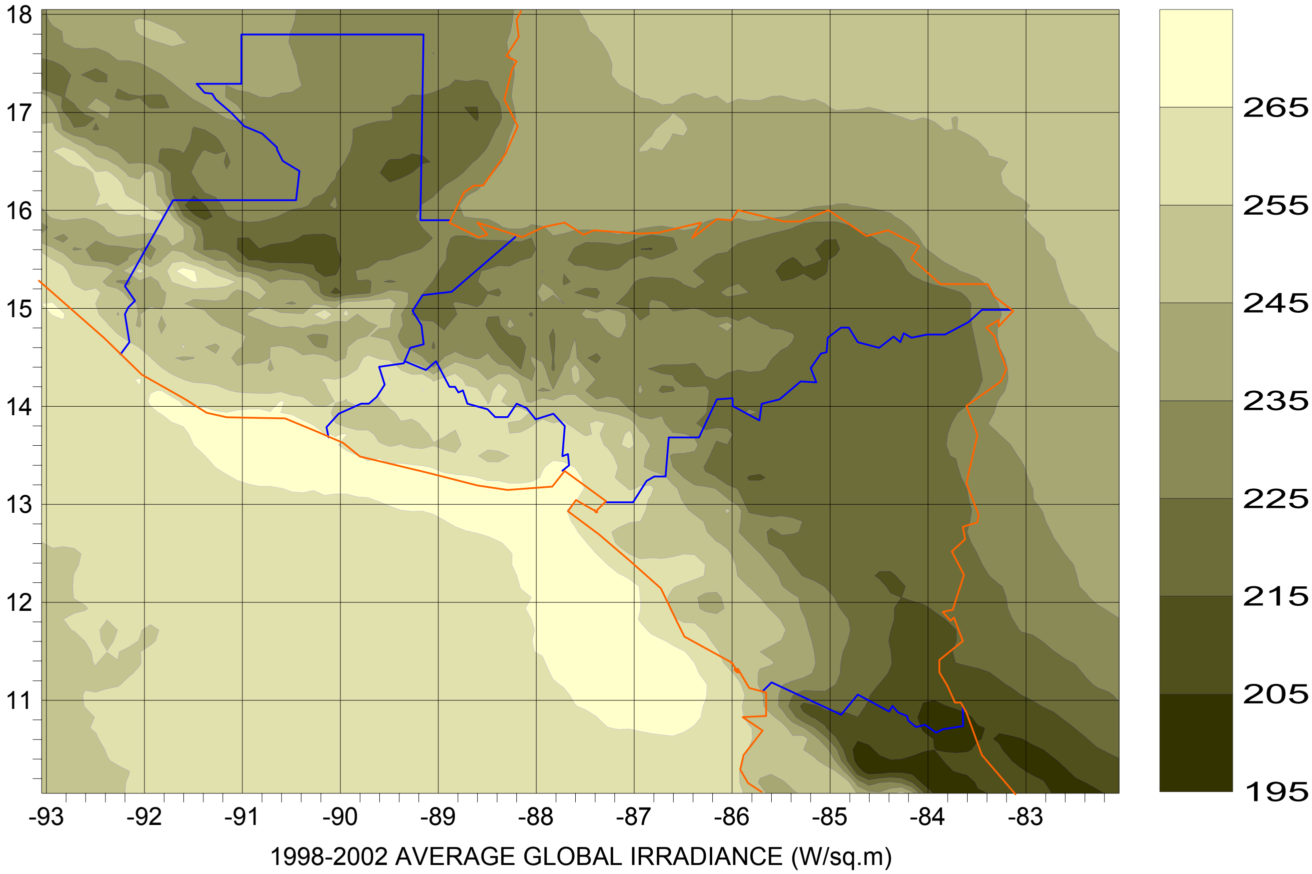
Cuba: monthly trends for the capital city, Havana, are provided in Figure 17. The dominant factor for GHI is solar geometry (i.e., clearly marked winter minimum). Summer DNI is curtailed by increased turbidity/cloudiness. The clearest location on the main island (Figure 18) is on the coast of the Golfo de Guacanayabo, while the cloudiest location is in the Sierra del Purial, at the eastern end of the island (Figure 19).

El Salvador: The monthly GHI and DNI trends for San Salvador are provided in Figure 20. The city – and the country as a whole – exhibits a high solar resource benefits thanks to its position on the Pacific “rain shadow”. The clearest location is on the Pacific coast near the Gulf of Fonseca (Figure 21). The county’s lowest solar resource is found in the vicinity of Cerro el Pital, the country’s highest point near the border with Honduras (Figure 22).

Guatemala: Guatemala City is located just on the downwind side of a region of secondary cloudiness enhancement due to its location southeast of the Rio Motagua upper valley (Figure 23). The highest resource location for this country is not on the coast, but in the rain shadow of the Huehuetenango Mountains. This location features the highest resource of all the considered countries (Figure 24). The cloudiest location in Guatemala is ~ 120 km north of Guatemala City on the lower northern slopes of the Sierra de Chama (Figure 25).

Honduras: Tegucigalpa is located on the Atlantic – cloudier - side of the divide. Its resource is not as high -- although still significant -- as that of the other considered Central American capitals which are located closer to the Pacific coastline (see Figure 26). The clearest region is on the coastline near the city of Nacaome (Figure 27). The cloudiest region is the Sierra de Agalta which is in direct line of Atlantic-borne orography-enhanced cloudiness (Figure 28).

Nicaragua: The capital city, Managua, is located near the Pacific coast and benefits from a good solar resource (Fig. 29). The high spot for the Country is on the shore of the Gulf of Fonseca (Figure 30). The cloudiest spout is on the eastern edge of the border with Costa Rica, where cloudiness is enhanced both by the relief near the Atlantic and the effect of the higher mountains to the south (Figure 31).



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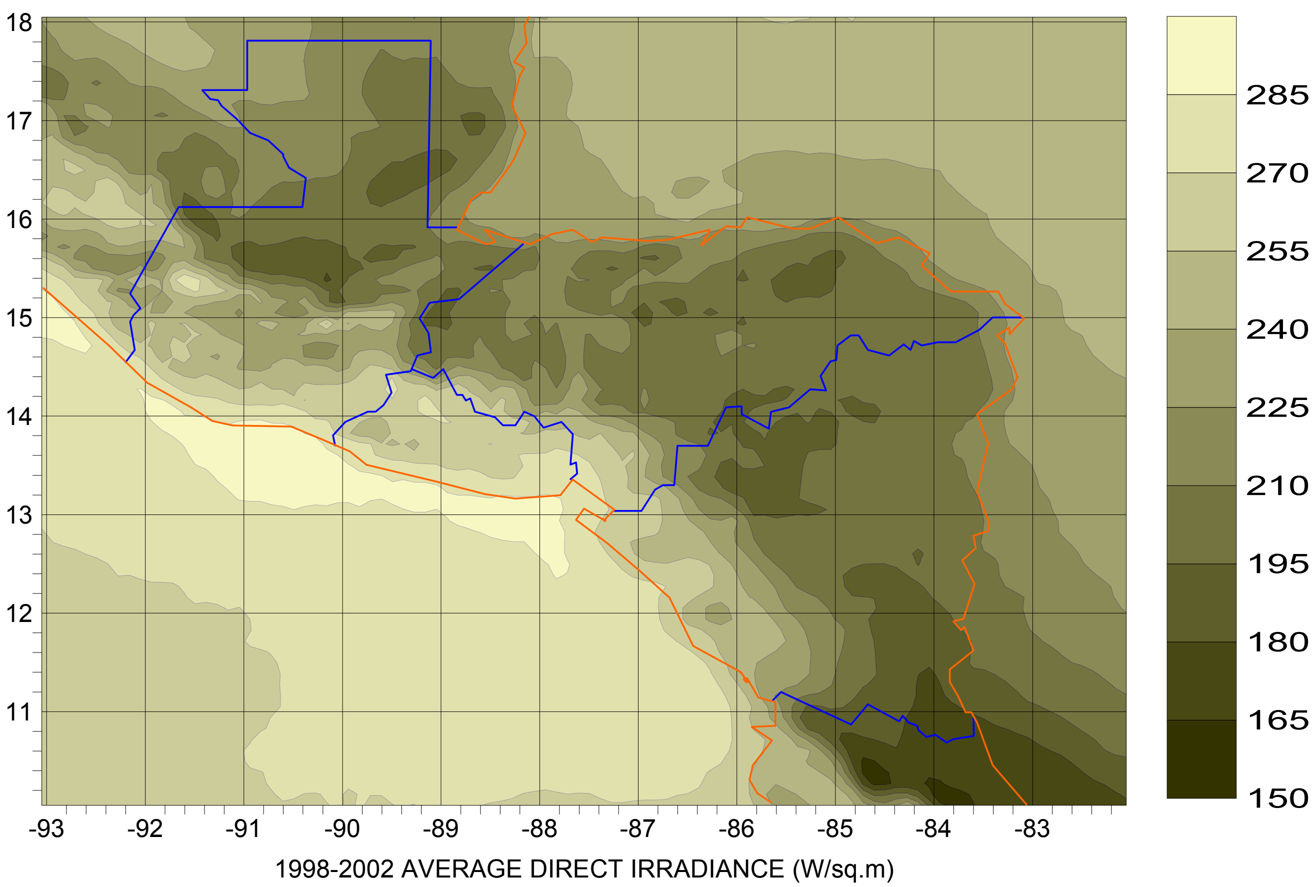

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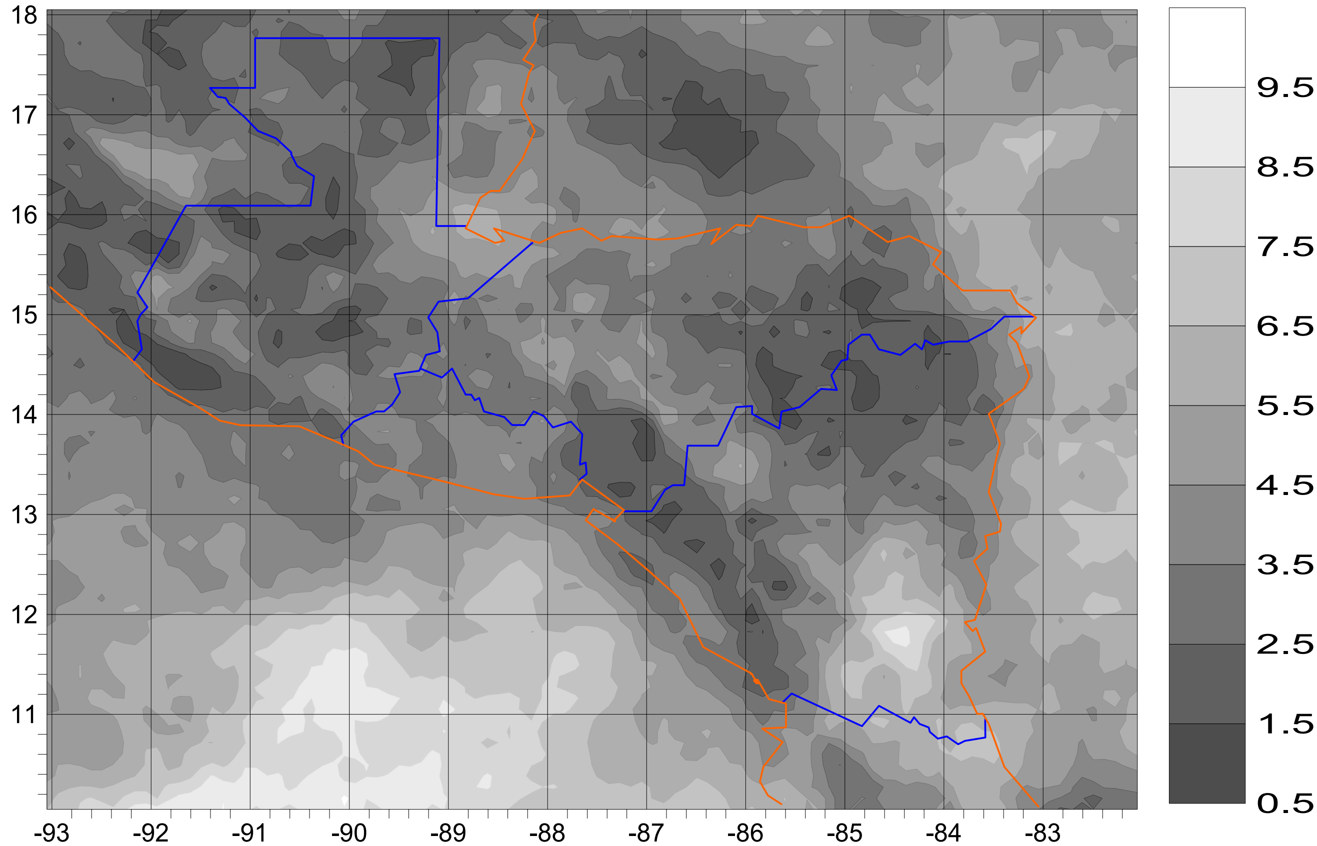

1998-2002 YEARLY STANDARD DEVIATION FOR GLOBAL IRRADIANCE (W/sq.m)

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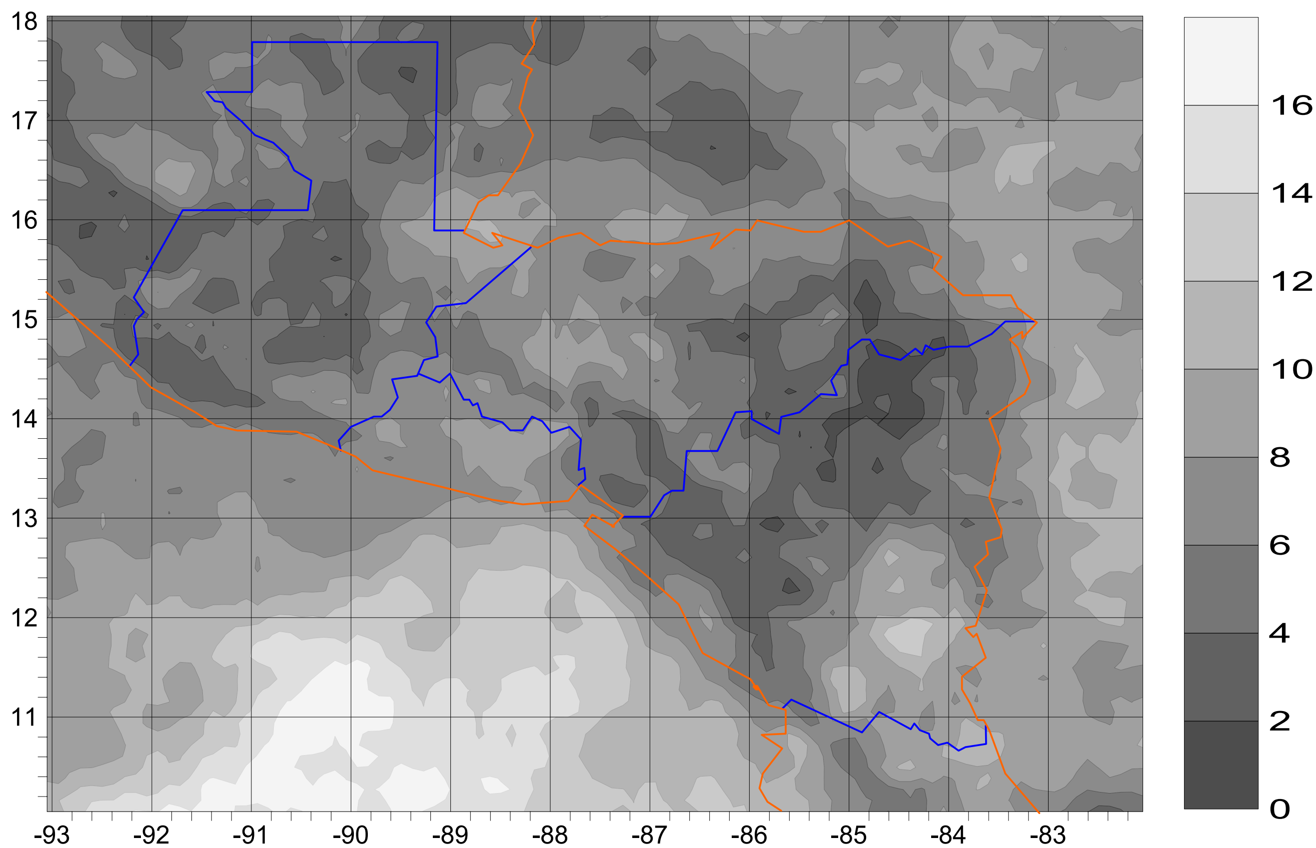

1998-2002 YEARLY STANDARD DEVIATION FOR DIRECT IRRADIANCE

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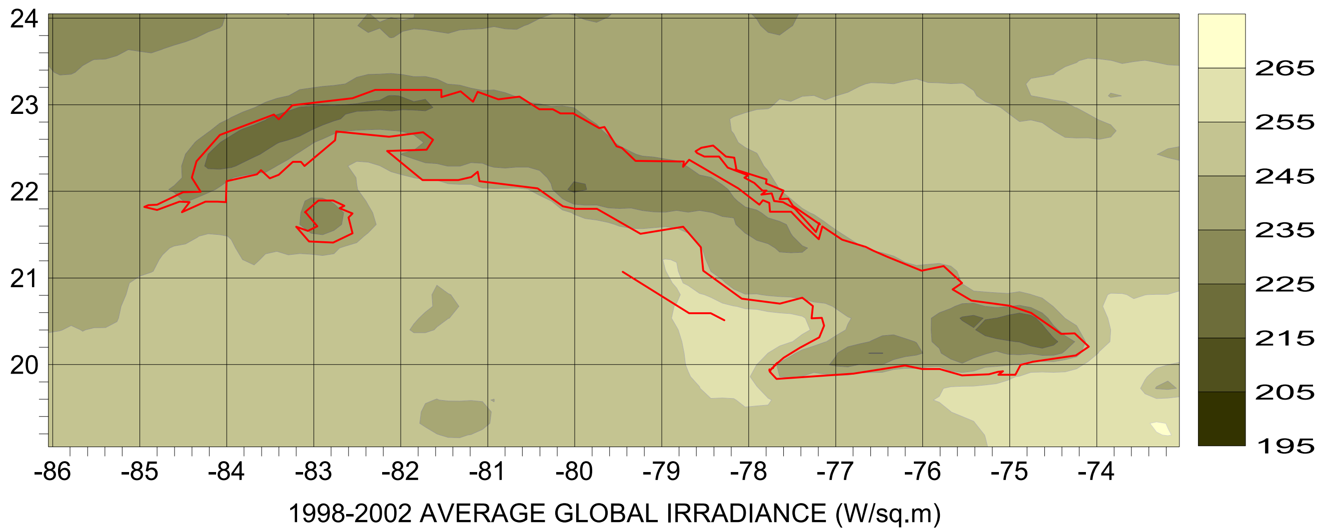

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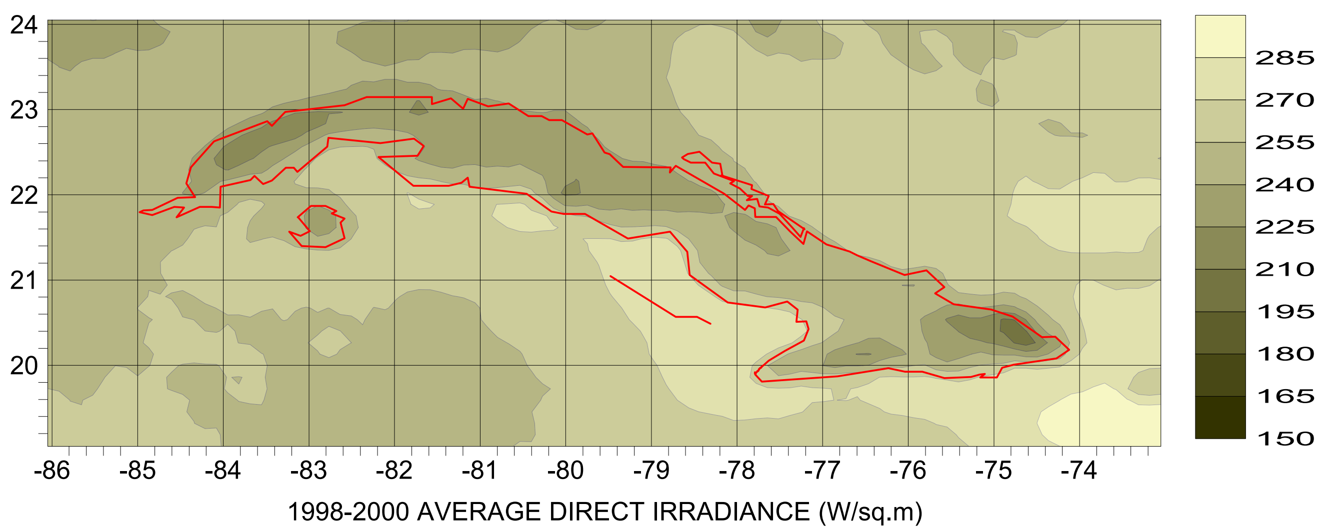

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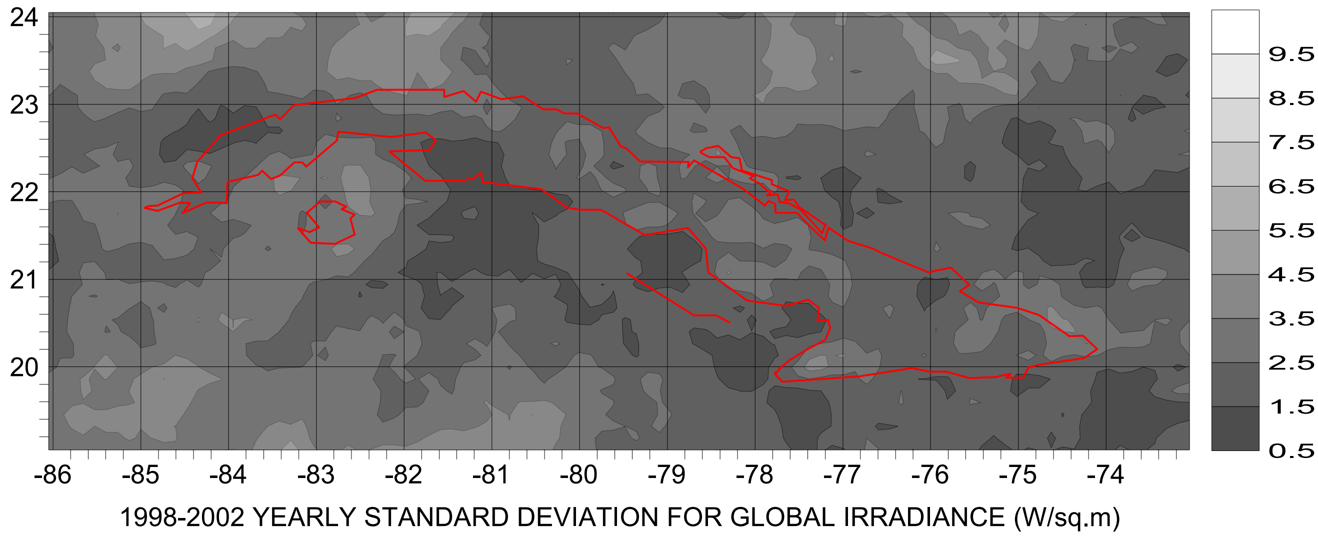

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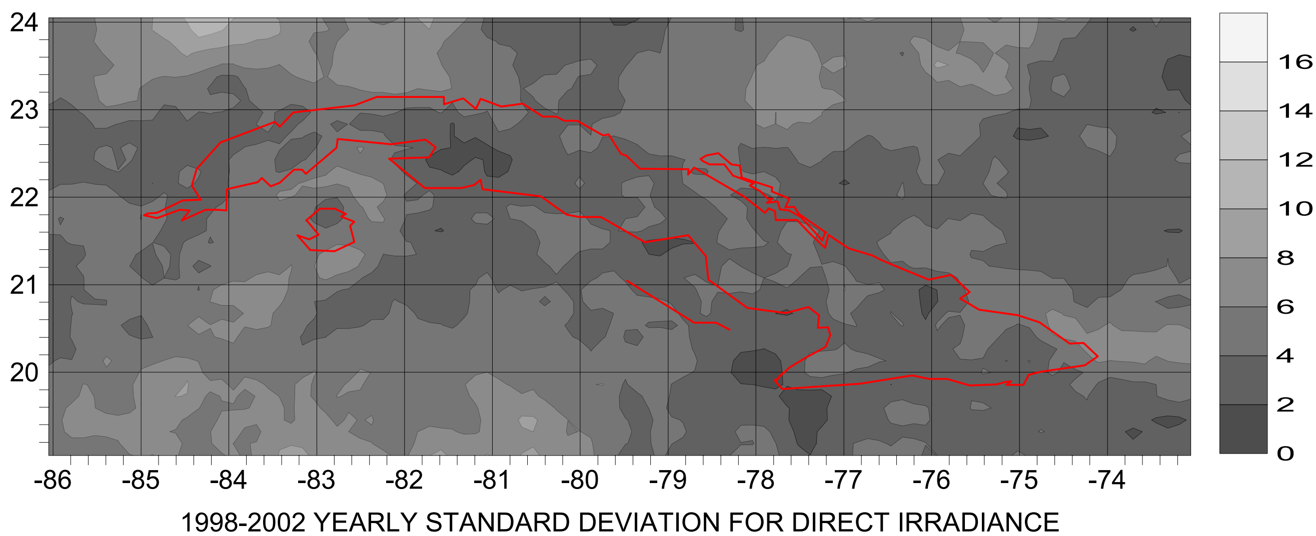

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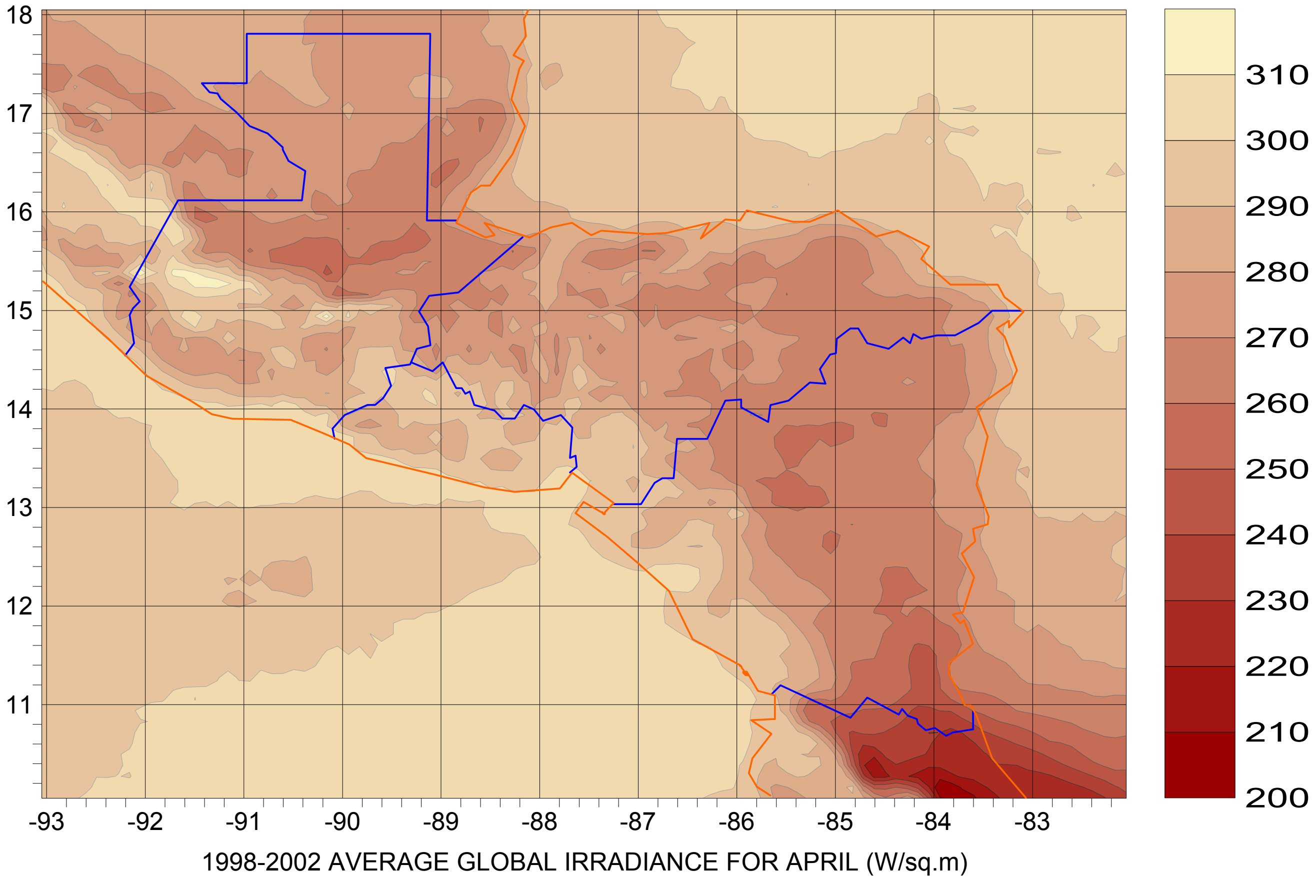

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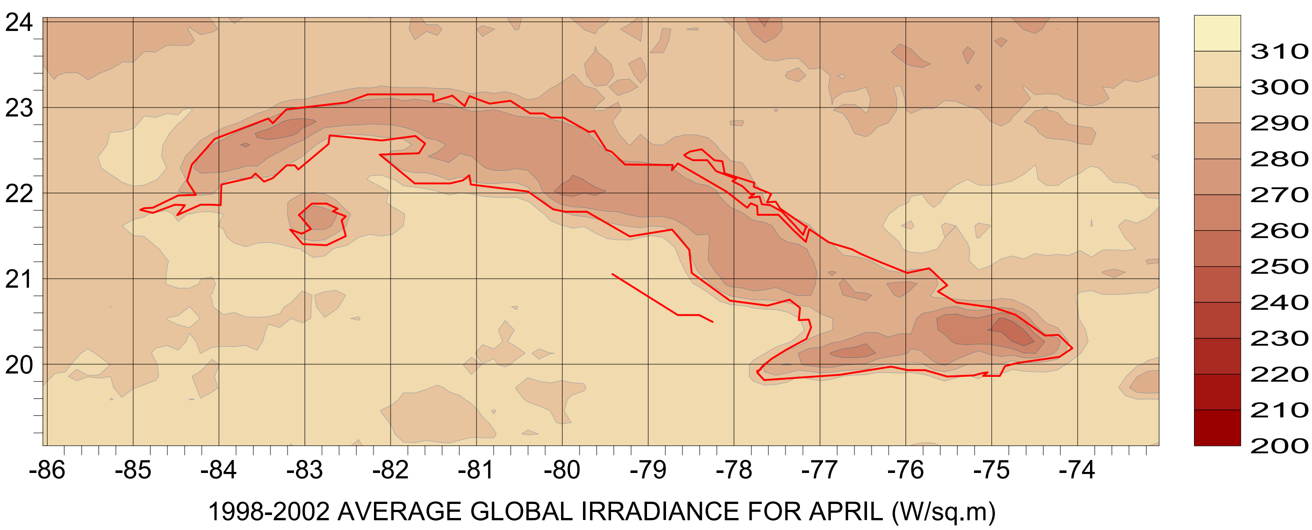

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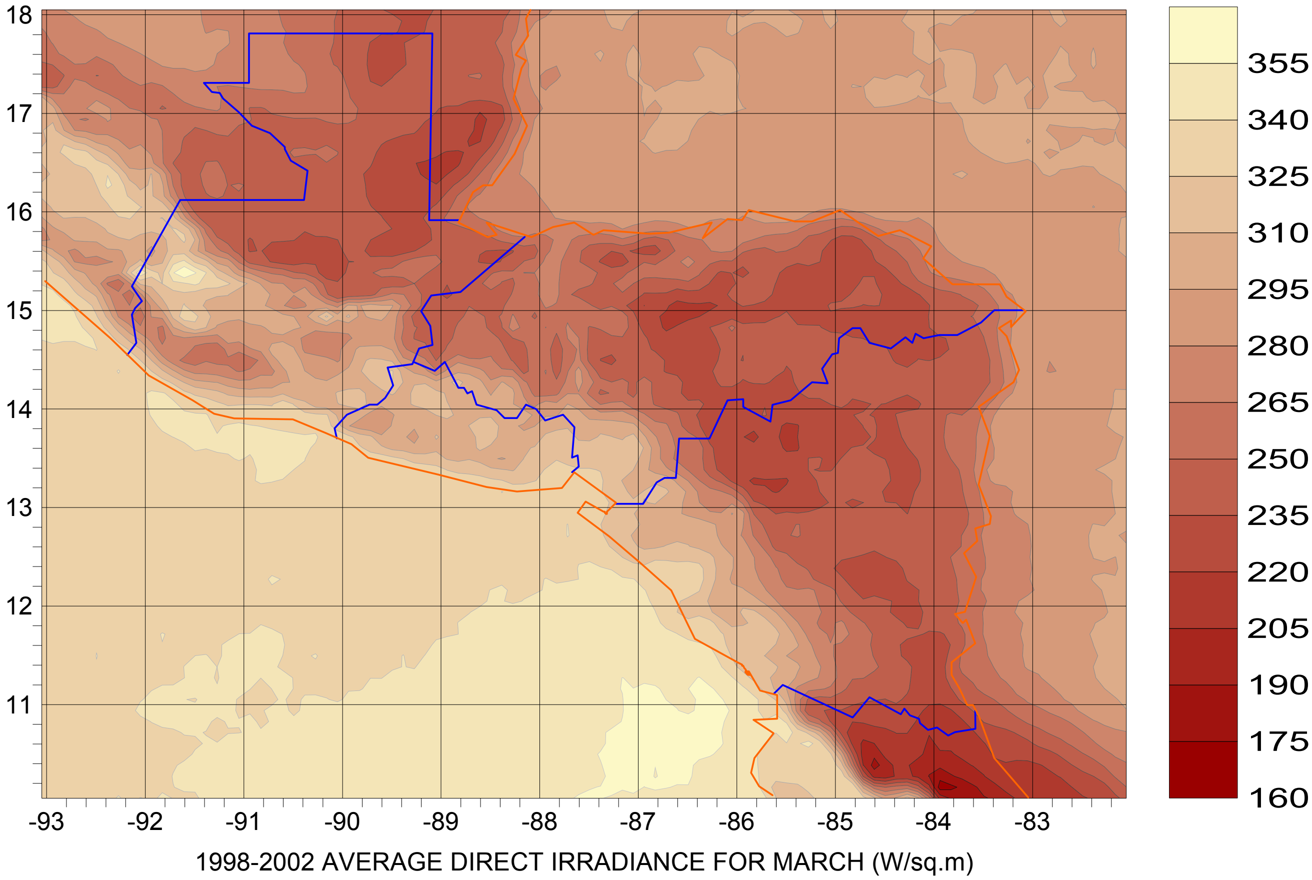

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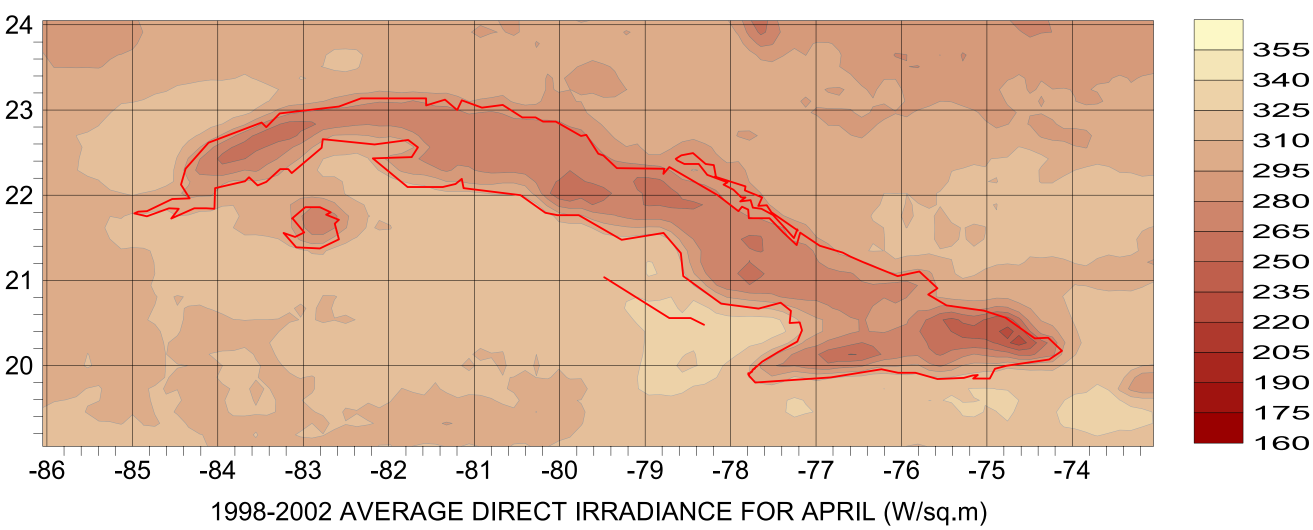

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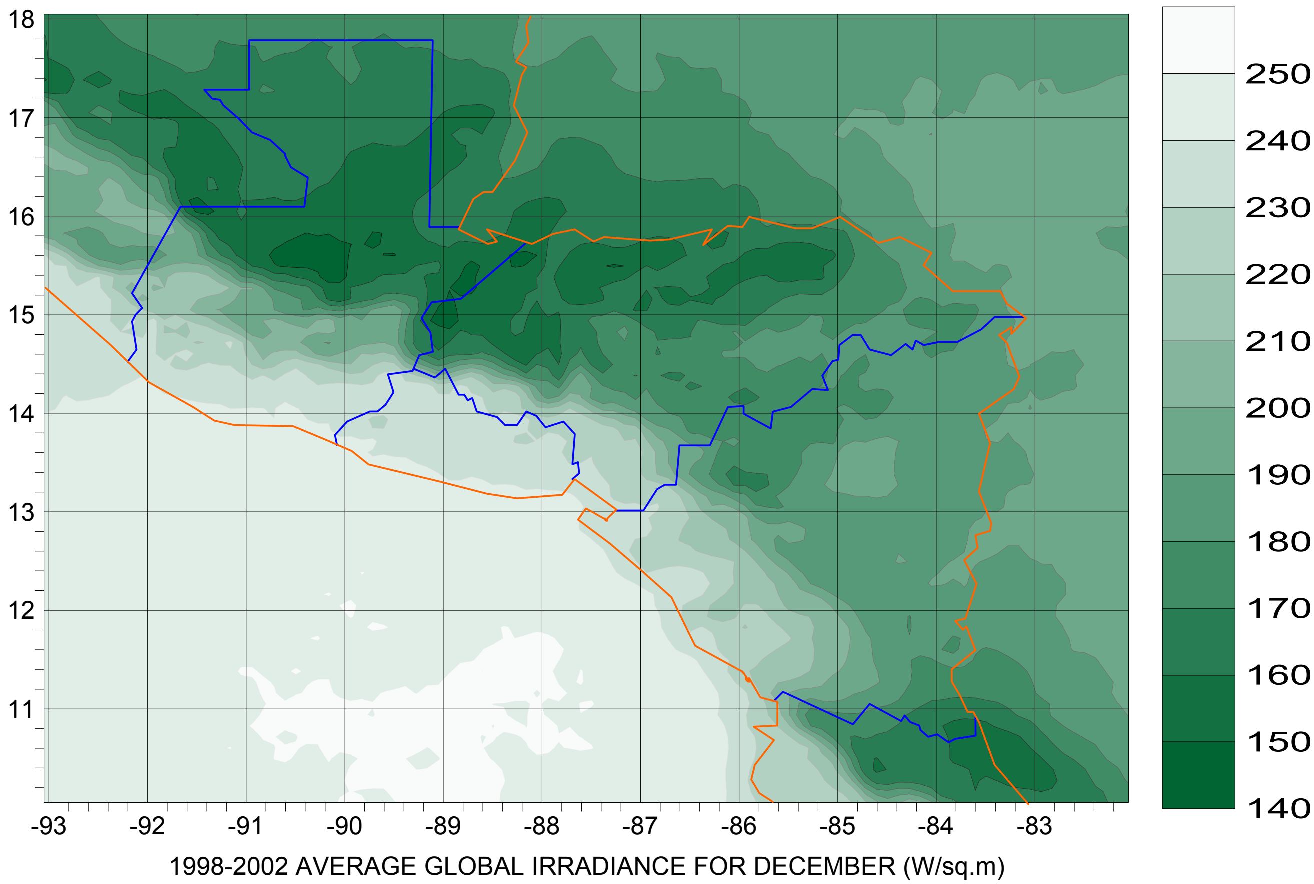

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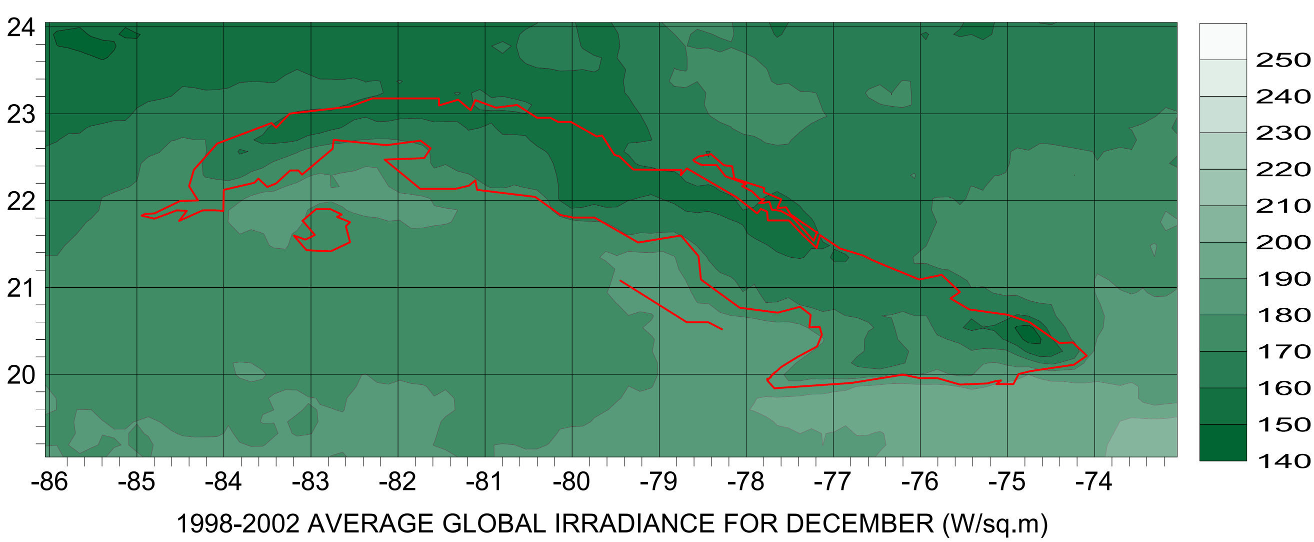

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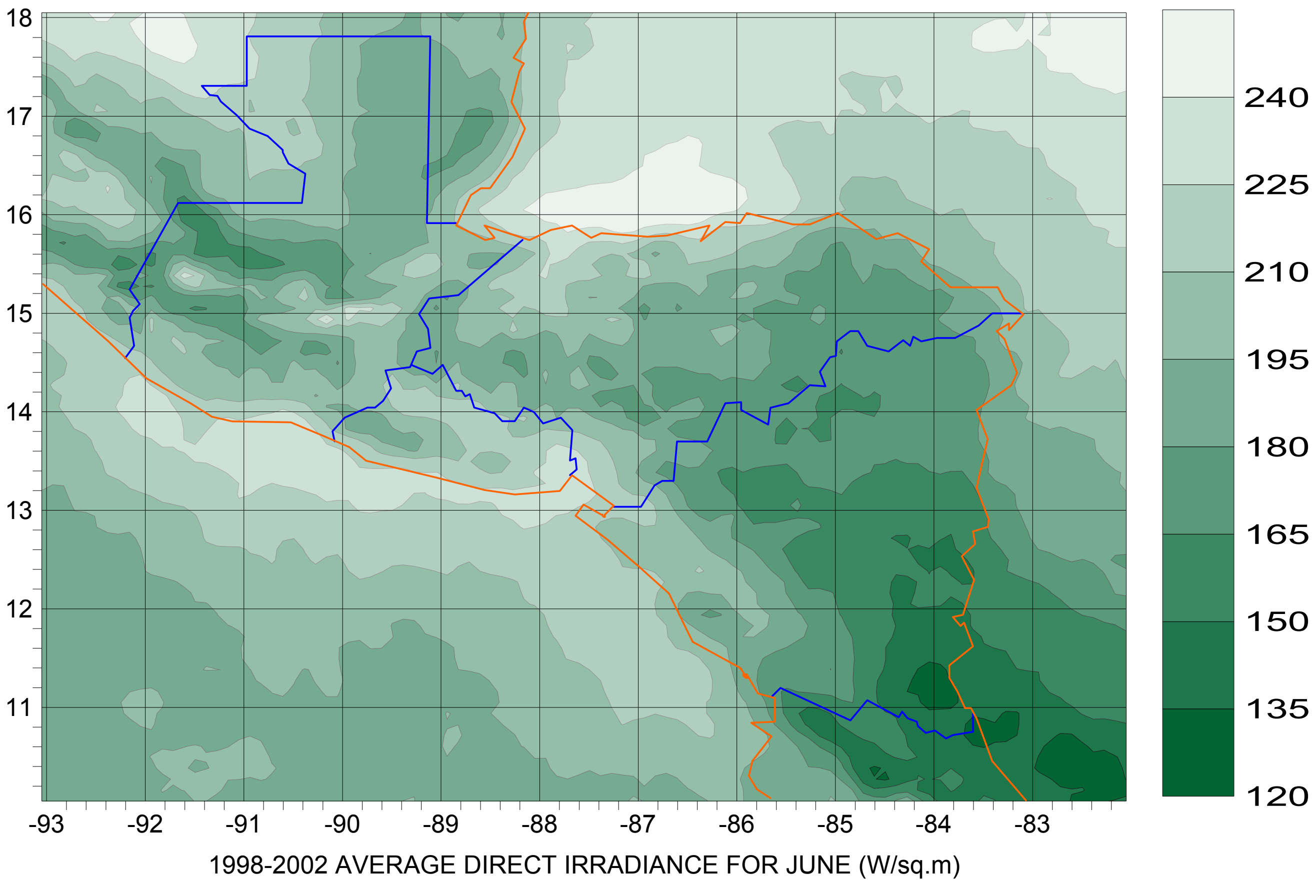

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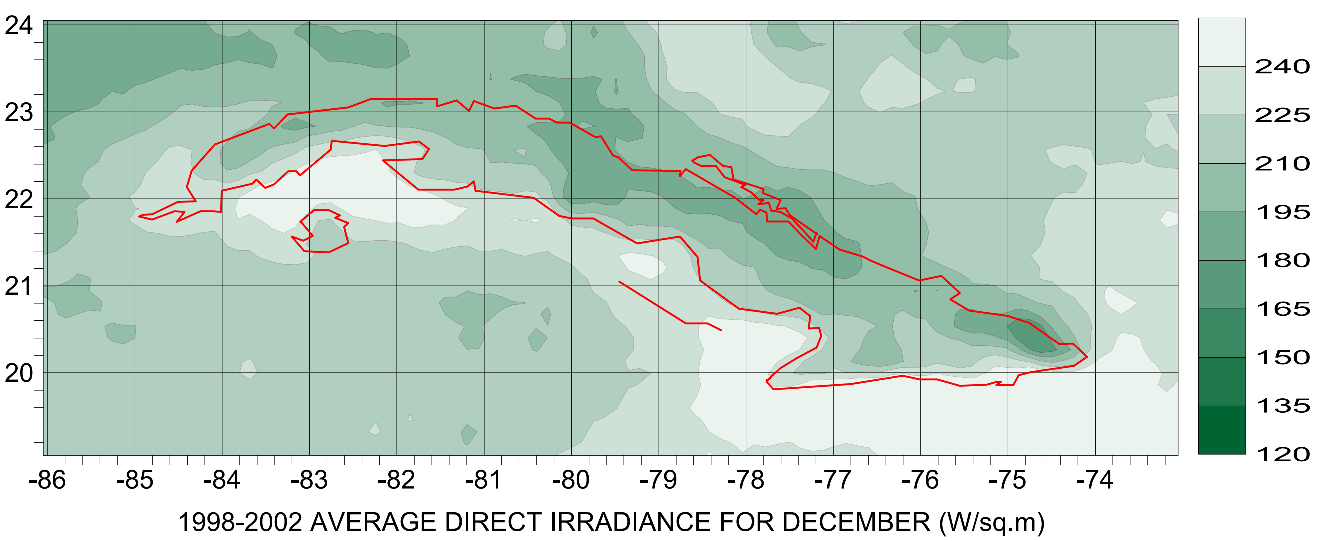

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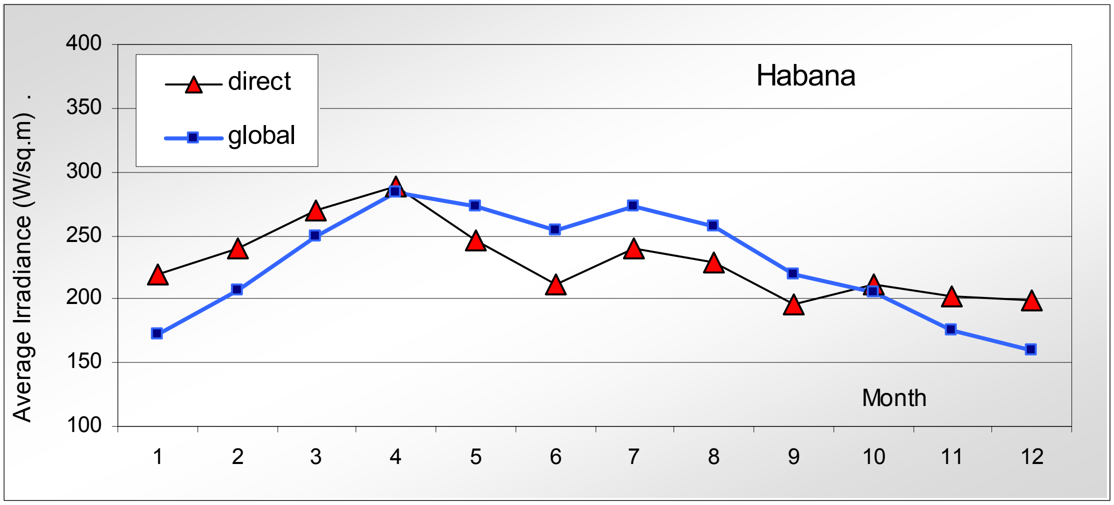

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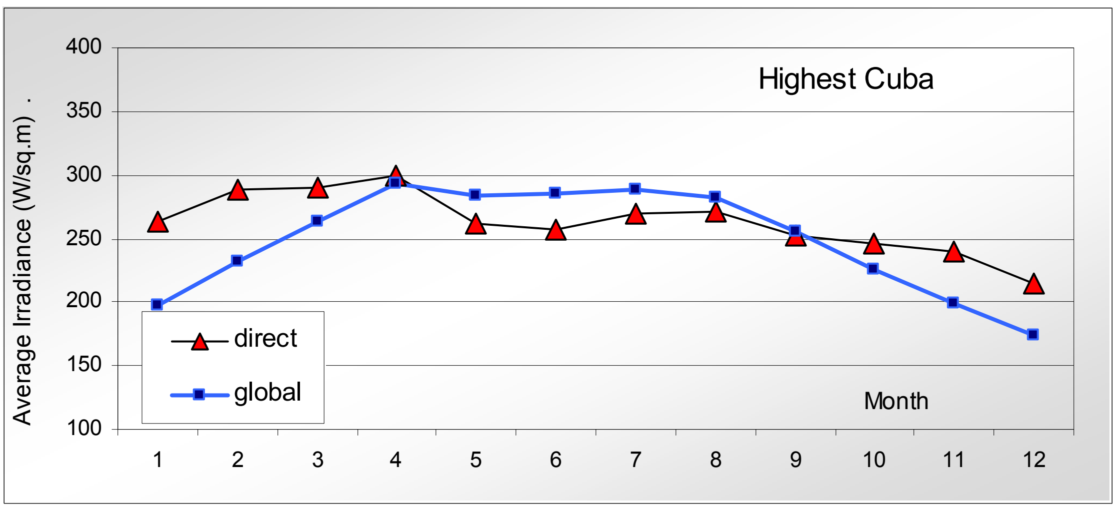

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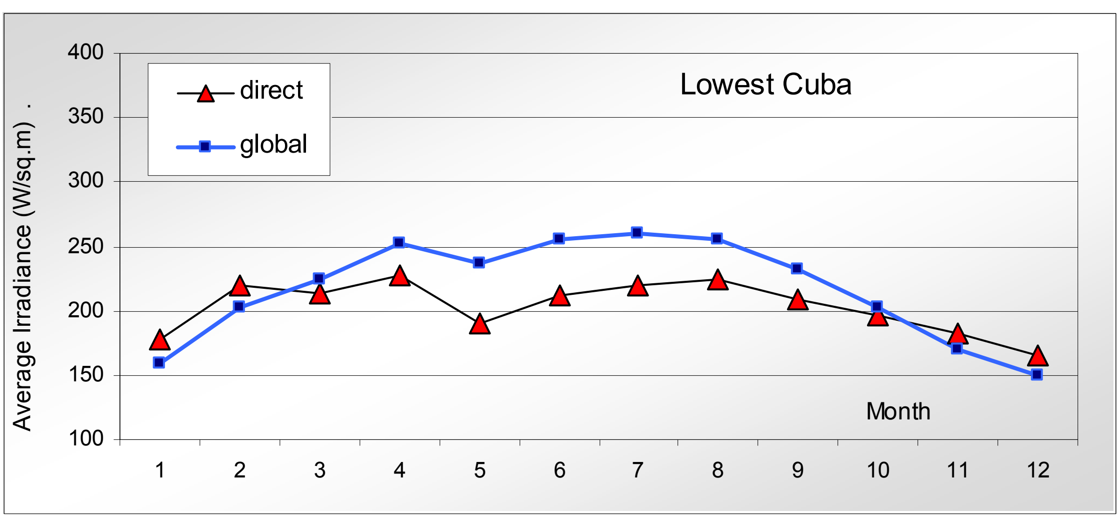

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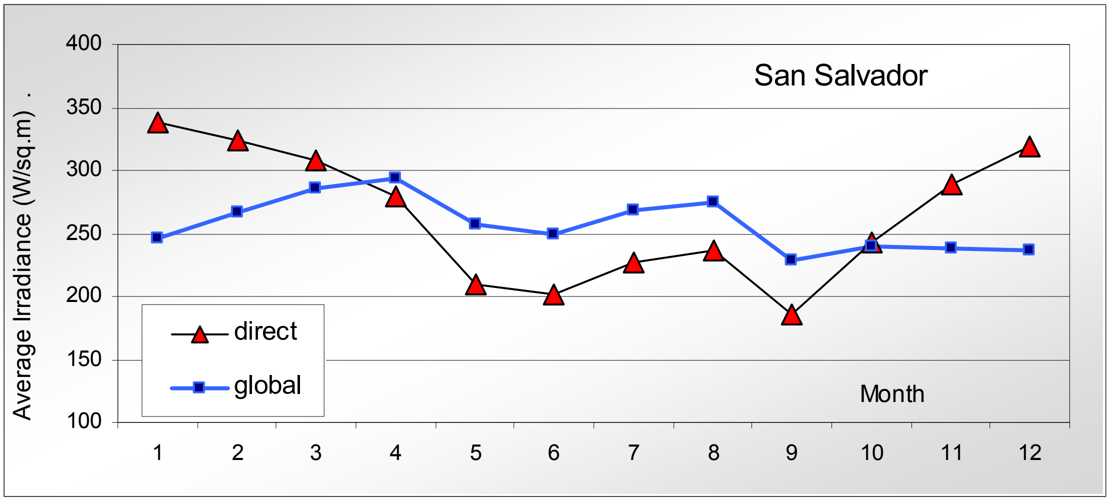

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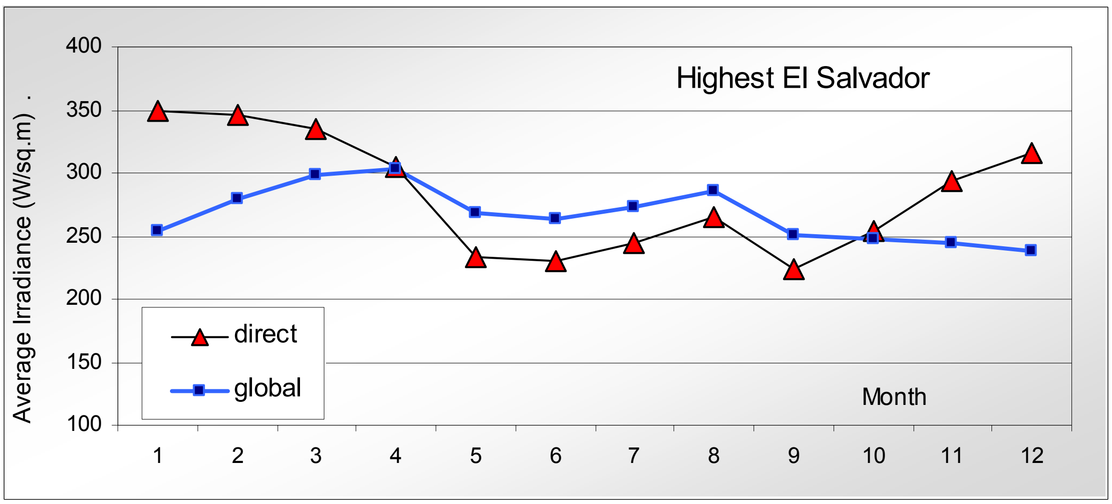

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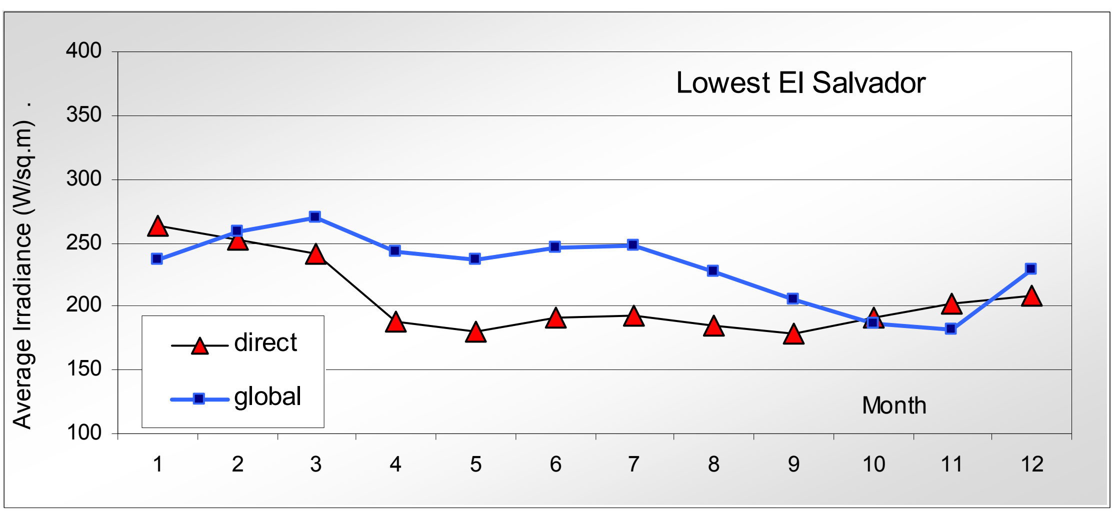

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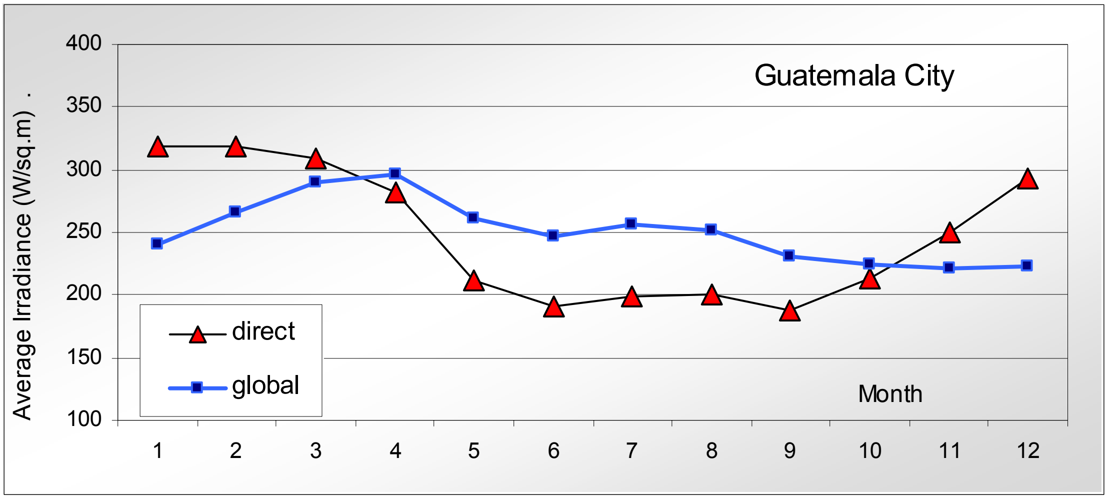

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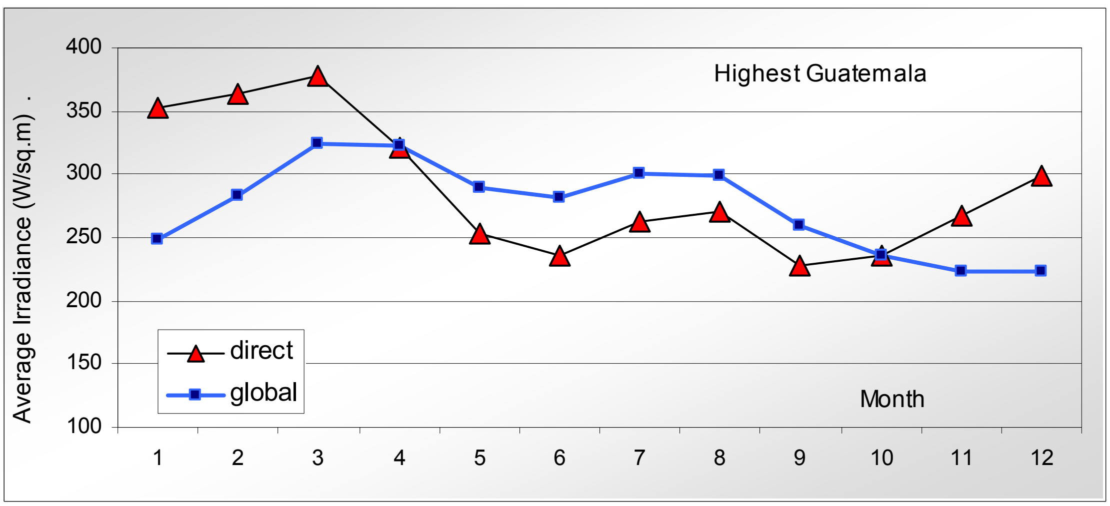

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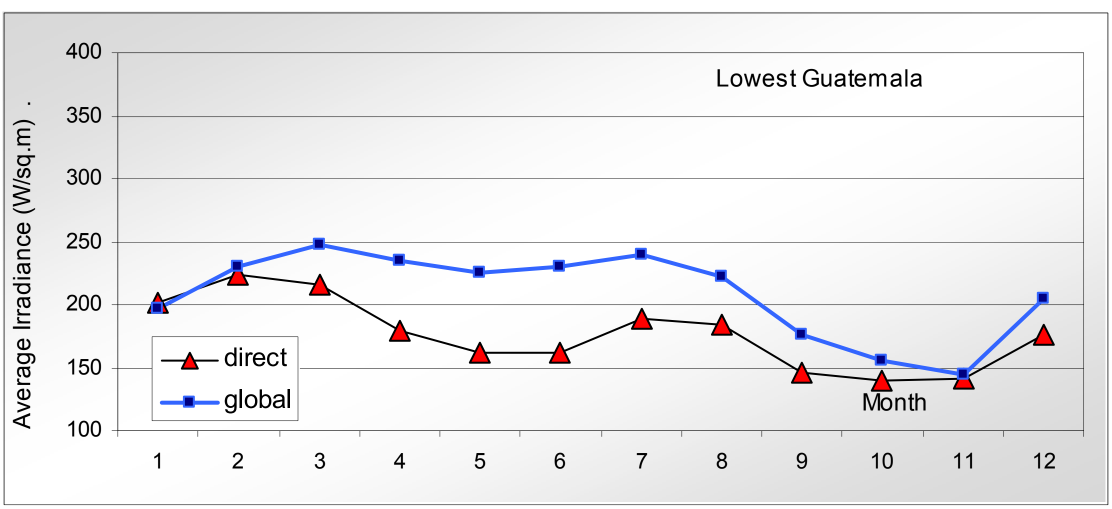

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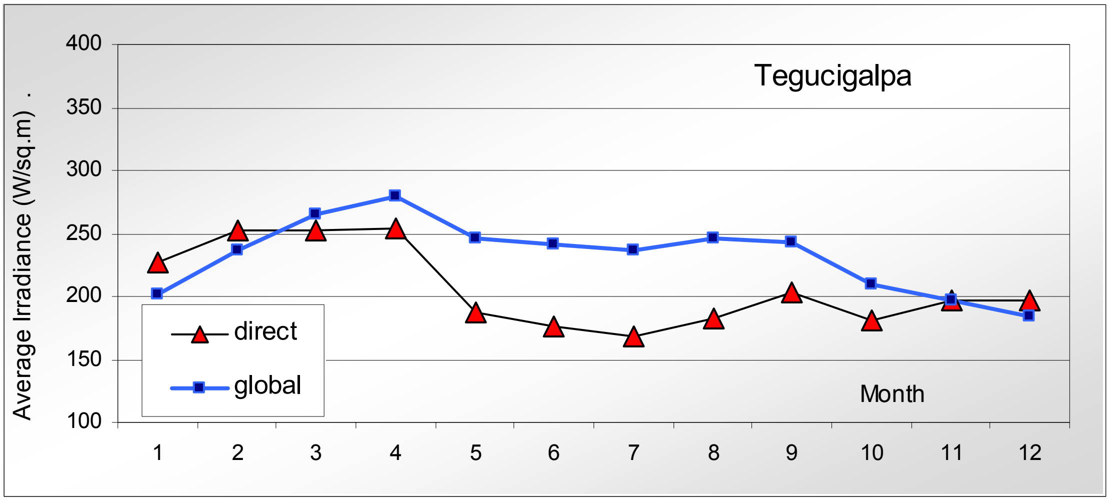

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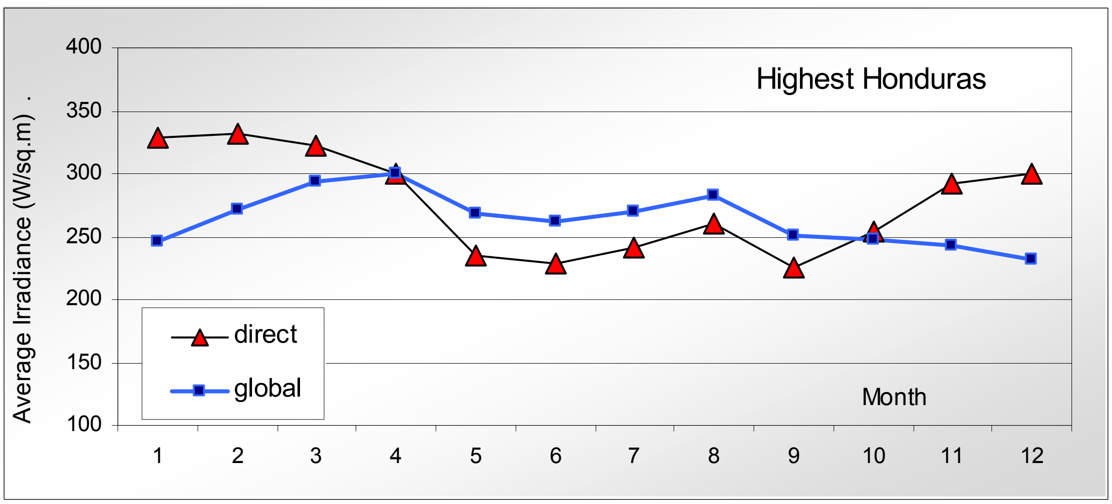

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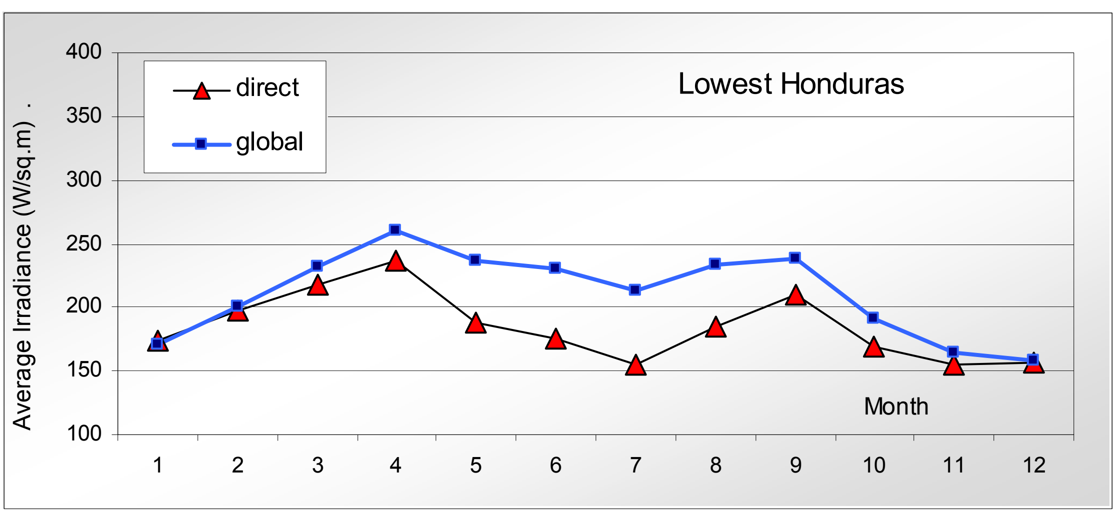

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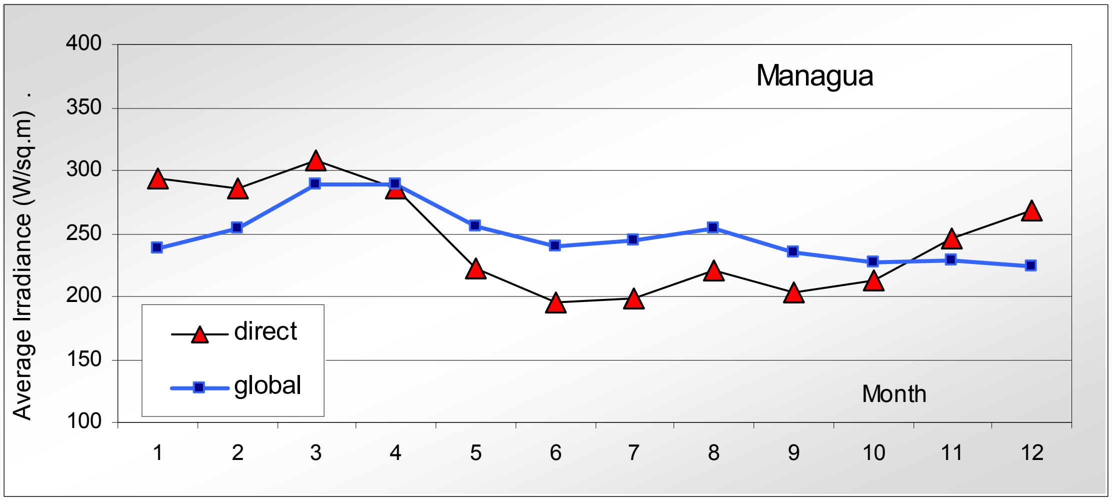

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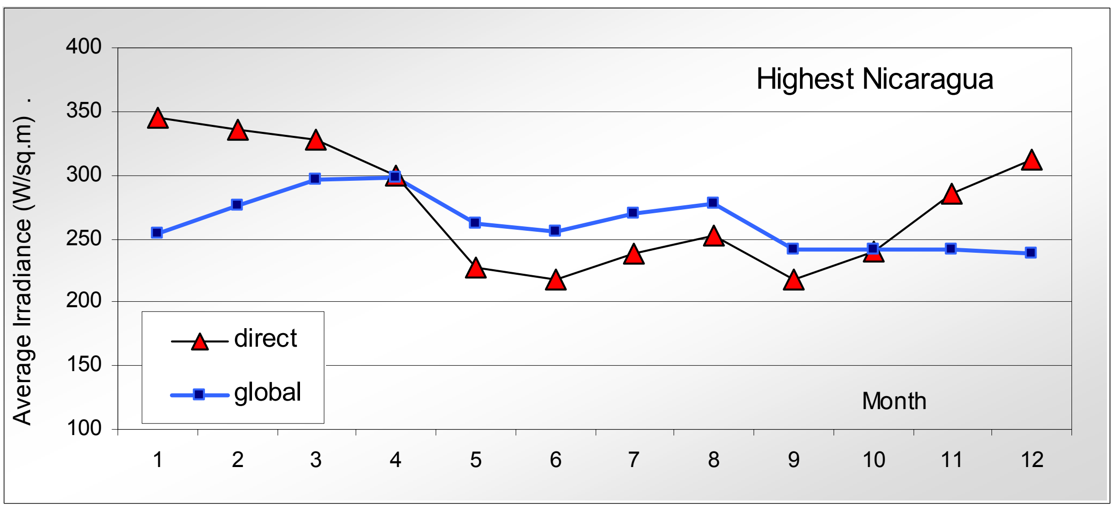

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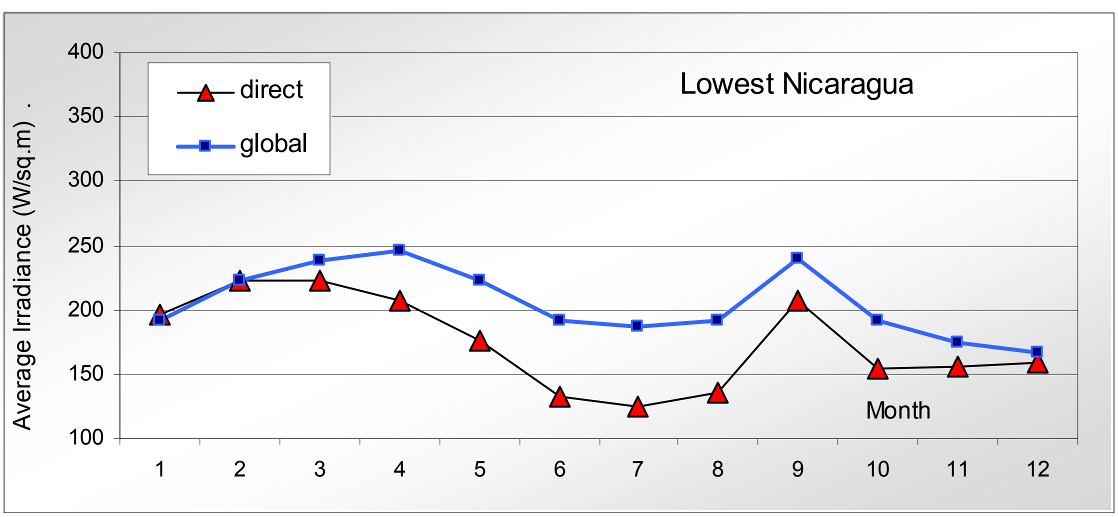

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