Contributions to the climatology around La Gamba, Costa Rica

Birgit Eibl & Reinhold Steinacker

When observing weather phenomena in the greater area of the tropical research station in La Gamba, Costa Rica, high rain rates and precipitation sums are to be expected. This is due to the fact that the described area is influenced by the south-westerly trade winds, forcing warm moist air from the Pacific to rise at the leeward sides of 3 orographic elevations on its way east. Deep convective cloud development is highly variable in the predominantly complex terrain and is reinforced when the inner-tropical convergence zone passes the area from the south in June. To back up the frequently used description "heavy precipitation" with numbers, several measuring campaigns were carried out. An evaluation of the droplet spectrum of various precipitation events revealed that a difference between stratiform and convective precipitation can be observed in the distrometer measurements. Radiation investigation of light availability on vertically and horizontally oriented surfaces in vegetation of different densities provides an indication of the quantitative influence of various cloud appearances on the light intensity reaching the ground. To determine the significance of these findings, and whether they constitute the norm or more of an exception, long-term observations would be necessary.

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Werden Wettererscheinungen im Großraum um die Tropenstation in La Gamba, Costa Rica untersucht, so erwartet man in jedem Fall hohe Niederschlagsmengen und Regenraten. Das liegt vor allem daran, dass das Untersuchungsgebiet direkt vom Südwestpassat beeinflusst wird. Dieser transportiert feuchtwarme Luftmassen vom Pazifik an die Leeseiten verschieden hoher topografischer Erhebungen. Damit werden räumlich höchst variable, hochreichende konvektive Systeme ausgelöst, die teilweise von der innertropischen Konvergenzzone verstärkt werden können. Um die Variabilität und Intensität der Niederschläge zu messen wurden verschiedene Messkampagnen durchgeführt. Die Auswertung des Niederschlagstropfenspektrums unterschiedlicher Niederschlagsereignisse ergab, dass eine Unterscheidung zwischen stratiformem und konvektivem Niederschlag auch durch Distrometermessungen möglich ist. Strahlungsuntersuchungen über die Lichtverfügbarkeit an vertikal und horizontal orientierten Oberflächen in unterschiedlich dichter Vegetation quantifizieren den Einfluss des Bedeckungsgrads und -charakters auf die Lichtbedingungen am Boden. Eine signifikante Aussage darüber, ob die Ergebnisse der vorliegenden Untersuchungen die Norm oder eher eine Ausnahme darstellen, kann nur nach langzeitlichen Beobachtungen getroffen werden.

Keywords: Heavy precipitation, light intensity, convection, droplet spectrum, radiation.

Introduction

Equatorial fully humid climate (Kottek et al. 2006), as it is observed in the South of Costa Rica, is characterized by higher diurnal than annual temperature changes and a total precipitation amount of up to 6000 mm per year. To understand the following investigations and results, a brief description of the surrounding environment is provided. The orography in the South of Costa Rica can be described as complex terrain with three elevated terrains oriented southeast – northwest like the Pacific coastline. The outer border is marked by the Osa Peninsula, with a mountain ridge of 600 m in height. Between the peninsula and the mainland lies the Golfo Dulce, a shallow warm water bay with temperatures of around 30° C throughout the year.

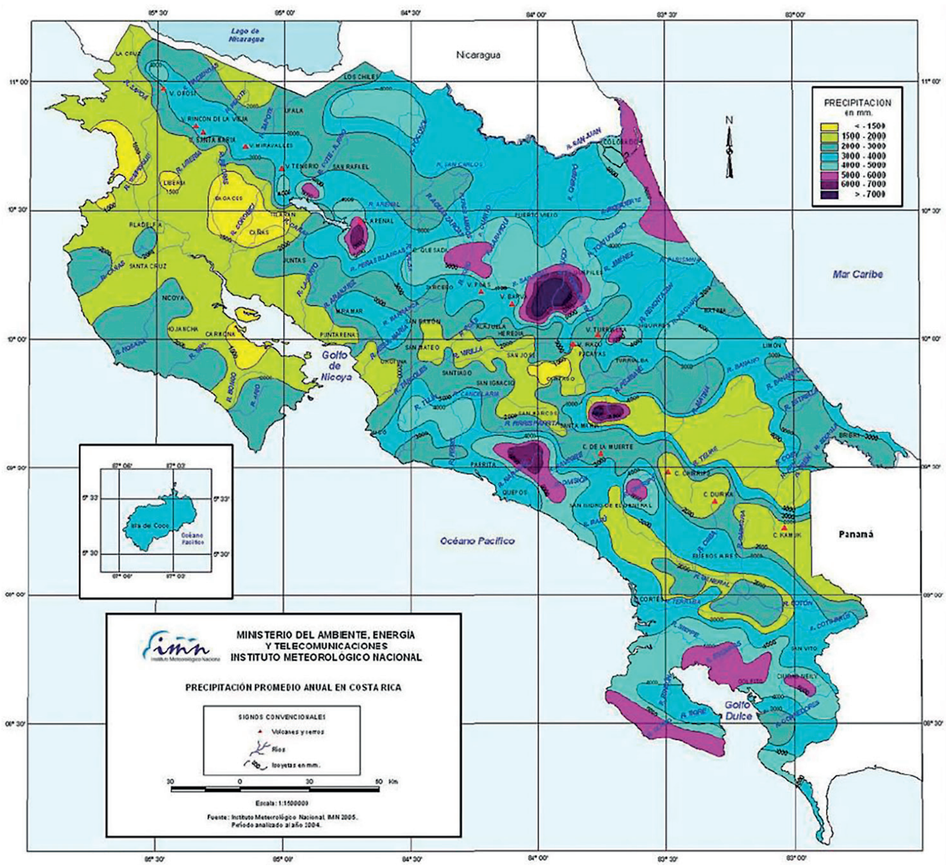

Fig. 1: Map of the annual precipitation sum in Costa Rica. In the South, the purple precipitation field at the leeward side of the mountain ridge on the Osa Peninsula and at the shore of the mainland of the Golfo Dulce (including the area of the "Regenwald der Österreicher") indicates up to 6000 mm of precipitation per year (Instituto Meteorológico Nacional, 2014). – Abb. 1: Karte der jährlichen Niederschlagssummen in Costa Rica. Die violetten Felder im Süden Costa Ricas an der an der Leeseite der Halbinsel Osa und an der Leeseite des Küstengebirges auf der Festlandseite des Golfo Dulce (inklusive des Gebiets des „Regenwald der Österreicher") markieren eine jährliche Niederschlagssumme von bis zu 6000 l m^{-2} (Instituto Meteorológico Nacional, 2014).

Continuing towards the Caribbean side, the next elevation relevant to the investigations is the Fila Cal, a mountain ridge of 800 m, followed by the Talamanca mountains (Fig. 1). The main mesoscale dynamics influencing the daily weather conditions in the Piedras Blancas Region are the south-westerly winds, bringing warm, moist air from the Pacific first to the Osa Peninsula, where air masses are lifted as they reach the mountainous terrain. The consequences are convection and heavy rain showers, nearly every day. If the wind from the southwest is very weak or the weather conditions are very calm, convective clouds form on top of the mountain ridge due to heating and evaporation from the rainforests covering the Osa Peninsula. Short, heavy showers and downbursts can be seen from the Golfo Dulce, as is shown in Figure 2.

Fig. 2: Downburst over the Osa Peninsula, seen from Golfo Dulce (Photo: B. Eibl). – Abb. 2: Fallwindböe aus einer Schauerwolke über der Halbinsel Osa, vom Golfo Dulce aus gesehen (Foto: B. Eibl).

As air moves forward towards the mainland of Costa Rica, moisture from the Golfo Dulce is soaked up by the downflow of air overflowing the Osa mountain ridge. This now very moist and warm air flow is forced to an uplift again at the coastal mountain ridge, producing another area with high precipitation amounts throughout the year. Since the mountain ridge is only 400 to 600 m high, a significant amount of the moist air continues further inland until it reaches the next mountain ridges, triggering more convective clouds which each lead to heavy precipitation in turn. Additionally, mesoscale convective systems arising in the Pacific Ocean around Panama's North are often advected through the south-westerly winds to the Pacific coast of Costa Rica (Duran-Qesada et al. 2010). Depending on the wind speed and intensity of the spatially widespread cloud formations, the systems penetrate inland more or less intensely. Observations in June and July 2008 showed that, not rarely, only stratiform rain out of the edge zones of these convective systems reaches parts of the Piedras Blancas regions. It is interesting to note that, in contrast to the Pacific Northwest of Costa Rica and the central part of Panama, The Golfo Dulce region receives considerable precipitation amounts even during the northern hemisphere winter. The reason for this is that the high Central Cordilleras of Costa Rica block the north-easterly trade winds and both deflected branches in the west and east of the High Cordilleras lead to a south-westerly counterflow towards the Pacific southeast coast of Costa Rica.

With this in mind, an investigation of convective clouds and the resulting precipitation in the surroundings of La Gamba was conducted. The first aim was to find objective evidence for subjectively experienced differences in precipitation amounts within the region. The second aim was to find differences in the precipitation events, whether they are of a stratiform or convective character, by examining the cloud droplet spectra.

The droplet size distribution is different and exclusive for every precipitation event, since the cloud regions from where precipitation drops originate are never the same. A precipitation drop spectrum can therefore be seen as the fingerprint of a precipitating cloud. Since clouds are basically categorized in cumulus-like and stratus-like types, precipitation is distinguished as being either convective or stratiform. When it comes to deep convection, high convective clouds and extended warm convective clouds, cloud droplet distribution, and in consequence the precipitation drop distribution, are not so easy to distinguish. Droplet development in warm convective clouds is expected to lead to an according precipitation droplet spectrum, just as stratiform precipitation is mostly expected to be observed originating from stratus clouds. Mesoscale convective systems and large deep convection clouds themselves have parts with so-called stratiform precipitation. During the observational period, a distrometer was used to determine the precipitation fingerprint of clouds passing the tropical station in La Gamba. The overall subjective impression in a tropical wet forest – that every precipitation event is of a heavy character with large drops and of short to extended duration, depending on rainy/dry seasonality, could not be verified in this observational period.

The precipitative temperature cooling during precipitation events and heavy rainfalls is also shortly discussed. One heavy downburst event was documented directly at the tropical station in La Gamba, with an associated temperature drop of 5 degrees within half an hour. The precipitative cooling is caused by melting and evaporation of hydrometeors on the way downwards. Due to the high melting level of precipitation (above 4000 m msl) only longer-lasting intense precipitation events may cause a significant cooling at the earth's surface, whereas evaporative cooling needs a certain layer in the lower troposphere, where a significant spread (difference between air temperature and dew point temperature) occurs. The generally high relative humidity in the tropical climate makes significant evaporative cooling less frequent than in drier climates.

Aside from precipitation climatology, solar radiation conditions have also received considerable interest in tropical rainforests, because the high degree of cloudiness and the dense canopy of vegetation leads to an extreme reduction of radiation, which can prohibit the germination and growth of plants. There are not many investigations on how different types of vegetation with different densities affect solar irradiance. Reforestation attempts may profit greatly from better knowledge about changing radiation conditions in the course of plant growth. Different height growth of different plant species may have a selective effect.

The basic principles of global solar radiation on the earth are shortly outlined in the following (see e.g. Landolt-Börnstein 2005): the extraterrestrial solar radiation-flux-density (solar irradiance) shows a distinct gradient on our planet. Due to the angle of inclination of the earth's axis, the average annual solar irradiance decreases from nearly 540 Wm^{-2} in the tropics to roughly 210 Wm^{-2} in the polar regions. Annual solar energy supply is often indicated instead of average irradiation: extraterrestrial 4700 $kWhm^{-2}a^{-1}$ in the tropics versus 1800 $kWhm^{-2}a^{-1}$ in the polar regions. The factor to obtain the annual solar energy supply ($kWhm^{-2}a^{-1}$) from the average solar irradiance (Wm^{-2}) is 8,766. For solar energy considerations as well as biologically relevant processes (e.g. photosynthetically active radiation), the extraterrestrial solar irradiation is only of limited theoretical value. The spectral solar irradiance is strongly affected by absorption (by atmospheric gas components, aerosol), as well as reflection and scattering processes (clouds, hydrometeors, aerosol) within the atmosphere. Due to the high degree of cloud cover in the tropics, the extraterrestrial solar irradiance is reduced by roughly 60 % to roughly 210 Wm^{-2}, i.e. the same value as the extraterrestrial irradiation in the polar regions! Only in the subtropical dry regions with low average cloudiness is the solar irradiation at the earth's surface higher, up to a global maximum of roughly 300 Wm^{-2} in the high desert regions of the Andes (Altiplano) or on the Tibetan plateau. If we compare typical average solar irradiance values for Austria (approximately between 120 Wm^{-2} and 160 Wm^{-2}) to tropical values, we still see a considerably higher value in the tropics, despite the large reduction against the extraterrestrial value due to tropical cloud cover. This means that, for solar energy production as well as for photosynthesis, there is still plenty of solar radiation available in the tropics.

The availability of low-cost, robust and easy to handle radiation sensors has opened the way for detailed investigations of differences in irradiance in different parts of a rainforest with high temporal and spatial resolution. As solar radiation is not isotropic (radiation is rather concentrated around a specific space angle), not only the radiation flux to a horizontal plane but also to vertical planes can and should be observed. This leads to a more realistic estimate of the absorptive potential of differently inclined surfaces (e.g. leaves).

The experiment carried out in the immediate area of the biological Station in La Gamba may be seen as a pilot study for more specific investigations on the radiation climate of a tropical rainforest.

One basic problem has to be pointed out here: whereas usually in climatology the "global radiation" (the complete direct solar plus diffuse sky irradiance in the solar spectrum with wavelengths between 0,3 and 3 µm) hitting a horizontal surface is measured with pyranometers, the illuminance (the part of the solar irradiance in the wavelengths perceptible for the human eye, e.g. 0,4 to 0,7 µm) is measured by LUX-meters. Some radiation instruments restrict the spectrum to the photosynthetically active radiation (PAR-meters). Not only are the physical units of the three different radiation sensors different (Wm^{-2}, LUX, µmol of photons $m^{-2}s^{-1}$), but direct conversion of the units is also not possible due to the variable spectral irradiance of the solar radiation.

Methods and Data

Precipitation

Data for precipitation evaluation was available from different measuring campaigns carried out by staff of the Meteorology department of the University of Vienna.

For the precipitation studies, ONSET (HOBO) tipping bucket devices were set up at the tropical station in La Gamba (Fig. 3), at the Finca Modelo near the tropical station at the same altitude, and at the Finca Alexis. The latter is located 16 km further east on a mountain ridge, surrounded by tropical forest at an altitude of 400 m (Fig. 4). The measurement principle of the tipping bucket is that precipitation droplets are collected in a tilt tray with a volume equivalent of 0.2 mm of precipitation water. Every tilting and the exact time of the tilting moment are recorded. In a post processing step, the rain rate and precipitation

Fig. 3: Rain gauges at the Tropical Station La Gamba (Photo: B. Eibl). – Abb. 3: Regenmesser auf der Tropenstation La Gamba (Foto: B. Eibl).

Fig. 4: Rain gauges at Finca Alexis (Photo: A. Weissenhofer). – Abb. 4: Regenmesser auf der Finca Alexis (Foto: A. Weissenhofer).

sums in different time resolutions can be calculated. Additionally, and for validation purposes, daily precipitation amounts from totalizator measurements at the tropical station, recorded by the staff of the tropical station are available. The tipping bucket measurements include a temperature sensor which is not used for proper temperature declarations but can be used for quantitative precipitation cooling effects. Temperature measurements are available for La Gamba only.

For the investigation of the droplet spectrum of different precipitation events, a THIES distrometer was installed 1 m above the laboratory's roof in the tropical station in La Gamba. When droplets fall through a laser beam emitted and reflected horizontally by the distrometer, the disturbances of the beam are measured. Since disturbances are different for every droplet, an algorithm, containing the droplet calculation of Marshall & Palmer (1948) directly calculates the droplet size and fall velocity of every droplet. Hence the droplet spectrum is directly calculated by the device, as is the precipitation amount and precipitation rate. Due to power loss during heavy precipitation events, droplet spectrum data was not available for some events with high precipitation amounts and high rain rates. Data for the precipitation droplet distribution is available during recorded events in minutely detailed resolution.

Fig. 5: Setup of the radiation sensors, one positioned horizontally (top) and four vertically in the main directions (Photo: R. Steinacker). – Abb. 5: Aufstellung der Strahlungssensoren, einen horizontal (oben) und vier vertikal, die in die Haupthimmelsrichtungen zeigen (Foto: R. Steinacker).

Radiation

There exist only a few high-quality long-term radiation measurement sites in the tropical belt of our planet. The reason for this lies in the difficulty to keep radiation instruments running under continuously moist and rainy conditions. Dew or rain droplets and dirt or insects on the protection cover may produce biased values and require more or less permanent maintenance and frequent re-calibration. Moreover, standard radiation measurements according to WMO standards (WMO 1986) should be carried out at locations with no or minimal horizontal obstruction (mostly on towers of observatories). These values cannot be directly transferred to a vegetated tropical site. Therefore, several publications deal with the possibility of estimating radiation conditions from satellite observations, or to model the radiation field by geometrical assumptions, see e.g. Etuk

& Akpabio 2002, Maracchi & Miglietta 1988, McCaskill 1990, Samani et al. 2007 or Turton 1991.

Aside from the climatological distribution of the global radiation according to WMO standards, a biological application should also consider the variability of the radiation within a vegetated zone, because plant growth usually starts on the ground below the canopy. To receive comparative values for solar radiation in different parts of the canopy, instruments were set up in the area of the biological station in La Gamba in the framework of a field study of the Institute of Meteorology and Geophysics of the University of Vienna.

The radiation sensors were mounted on a pole, roughly 1 m above the surface, positioned horizontally as well as vertically in the 4 main directions N, E, S and W (see Fig. 5). The instruments were low cost Lux-meters (ONSET Hobo Pendant Temperature/Light 8K Data Logger). They were chosen because they are suited for wet, even immersed, conditions, which is an important requirement for long-term functioning under a tropical wet climate. Four such setups with five sensors each were deployed a) in a clearing in the garden of the tropical station, b) under low vegetation (bushes), c) at the edge of dense tropical rainforest, and d) inside dense tropical rainforest.

Before the initial setup at the different locations, a calibration period of the instruments was carried out, during which all setups were positioned close together in the clearing of the garden. The relative difference of the sensors was mostly within ± 10 % of the average value of each direction and was used to correct the values of the single sensors during the whole experiment. Instead of evaluating the recorded LUX-values, all values were transferred to dimension-less relative values (in %) according to the maximum observed values (= 100 %).

Whereas the time interval of measurements was set to 1 min during the three-day calibration period, the interval during the six-month observing period was set to 10 min, so as not to exceed the capacity of the data loggers.

Results

Spatial precipitation distribution and variability

Precipitation measurements were taken at Finca Werner Klar (N8°46'50,6" W83°10'1,6", 568 m msl), Finca Alexis (N8°45'53,0" W83°9'49,8", 400 m msl) and at the tropical station and Finca Modelo (N8°42'1,8" W83°11'37,4", 80 m msl) in La Gamba (N8°42'2,3", W83°12'8,2", 80 m msl) for different, short time periods. Due to the high variability of precipitation and the short time series, no climatological statements as to significant differences in precipitation amount between the aforementioned locations can be made. The physically explainable altitude-dependency explains some of the higher precipitation amount at Finca Alexis and Finca Werner Klar.

Figure 6 shows an evaluation of different monthly precipitation sums of the devices located at La Gamba (tropical station and Finca Modelo) and at Finca Werner Klar. Data for Finca Modelo was not available for the time span marked by the red box because the device was blocked by plant material and sheltered by a nearby tree. The hand sample was performed by staff of the tropical station. Since tipping bucket devices tend to underes-

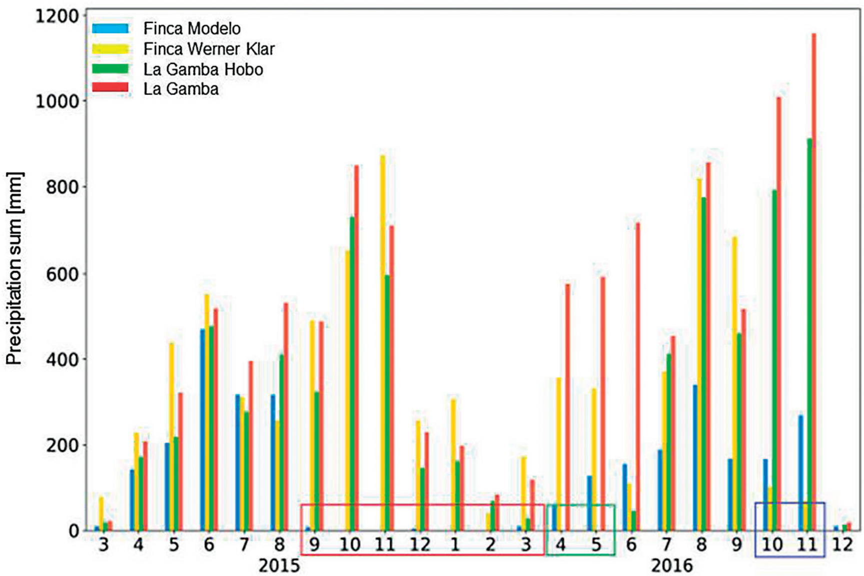

Fig. 6: Monthly precipitation sum for Finca Modelo, Finca Werner Klar and tropical station La Gamba (Bachelor's thesis, Th. Aistleitner, 2018). – Abb. 6: Monatliche Niederschlagssummen gemessen an der Finca Modelo, an der Finca Werner Klar und an der Tropenstation La Gamba. (Bachelorarbeit, Th. Aistleitner, 2018).

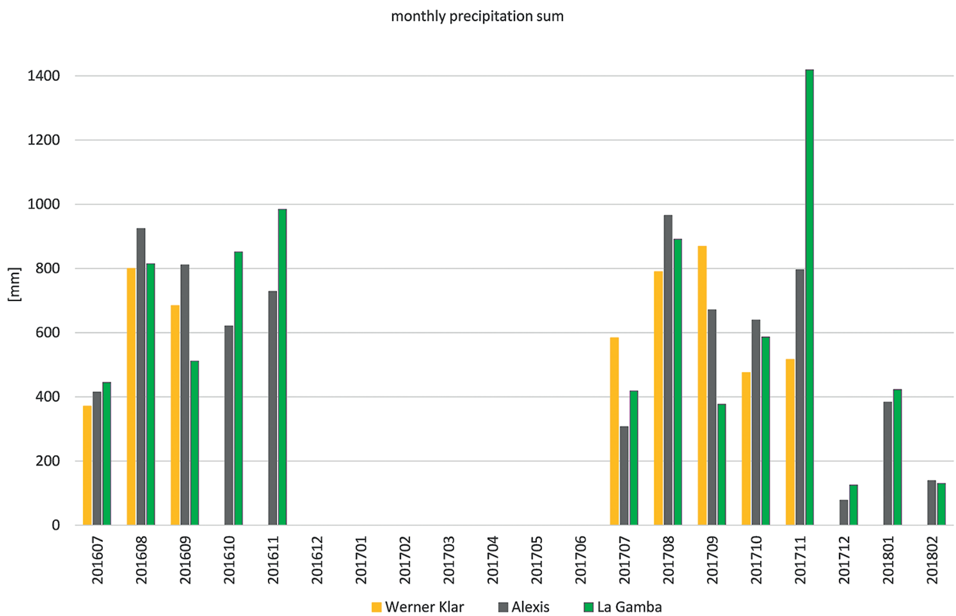

Fig. 7: Monthly precipitation sum from tipping bucket measurements at Finca Werner Klar, Finca Alexis and the tropical station La Gamba. No measurements were available from December 2016 until June 2017. – Abb. 7: Monatliche Niederschlagssummen, mit Niederschlagswippen an der Finca Werner Klar, an der Finca Alexis und an der Tropenstation La Gamba gemessen. Von Dezember 2016 bis Juni 2017 sind keine Messdaten verfügbar.

timate high precipitation rates, the monthly sums measured by the tipping bucket at La Gamba station (green) are lower than the hand samples (red). The high spatial variability of the precipitation events and the short observation time do not allow for a significant conclusion as to whether the precipitation amount was higher at Finca Werner Klar at 600 m height or La Gamba at 80 m. There are months where the sum is higher at the elevated Finca (yellow), for example in May, June and December 2015, and vice-versa in April and May of 2016.

In Figure 7, monthly precipitation sums for Finca Werner Klar, Finca Alexis and the tropical station for July until November 2016 and from July 2017 until February 2018 are shown. No significantly higher precipitation amount for a single location can be ascertained. For some months, precipitation sums are highest at Finca Werner Klar (July, September 2017), while in August 2017 and 2018 precipitation sums are highest at Finca Alexis. In October and November 2017, as well as in November 2018, the highest precipitation amount was observed at the tropical station. For a climatological conclusion as to systematically higher precipitation sums in any one location, longer time series would have to be collected.

Precipitation cooling effect

During heavy rain showers, a significant temperature drop due to evaporative and melting energy loss of the surrounding air can be observed.

As shown in Figure 8, within a precipitation event that did not last longer than 10 minutes, a temperature drop of nearly three degrees was observed. Two sensors, one within a tip-

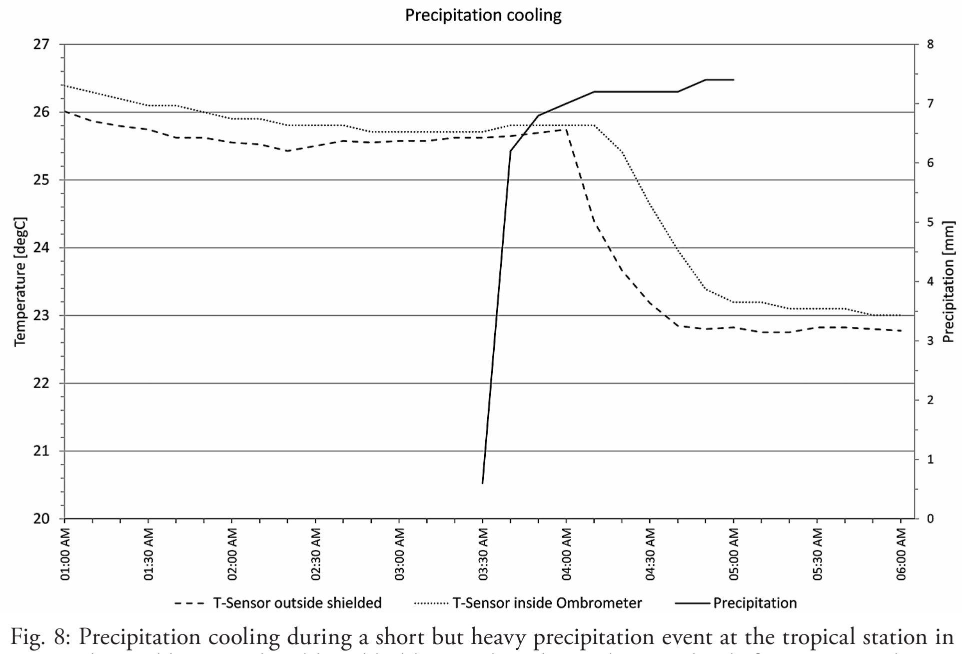

Fig. 8: Precipitation cooling during a short but heavy precipitation event at the tropical station in La Gamba. - Abb. 8: Niederschlagsabkühlung während eines kurzen aber heftigen Regenschauers an der Tropenstation La Gamba.

ping bucket and the other one in a radiation shield outside the bucket, were compared. The temperature was nearly equal before the precipitation event. Shortly after the beginning of the precipitation event, the temperature drop began. With decrease of the precipitation rate, the temperature stops declining. This phenomenon is not restricted to the tropical zone and can be observed at higher latitudes as well, in cases of heavy precipitation. But the high recurrence in the tropics brings an additional cooling effect to the nightly radiation cooling on a regular basis.

Droplet size distribution differences

Analysis of droplet distribution from different precipitation events revealed that, for heavy deep convective precipitation, droplet distribution was broader and droplet density per minute was much higher than the distribution from precipitation originating from stratiform parts of convective clouds. At several precipitation events in July 2018, distrometer measurements were performed and satellite images (IR and VIS) were simultaneously studied to ascertain whether deep or low convection was prevalent.

Examples of stratiform precipitation droplet distribution are shown in Figures 9–11. It can be seen that droplet number per minute can vary, but the variation is slight. The raindrops nearly have the same diameter with a maximum at 0.125 mm in Figures 10 and 11. This is due to the lower collision rate between the droplets during precipitation drop development

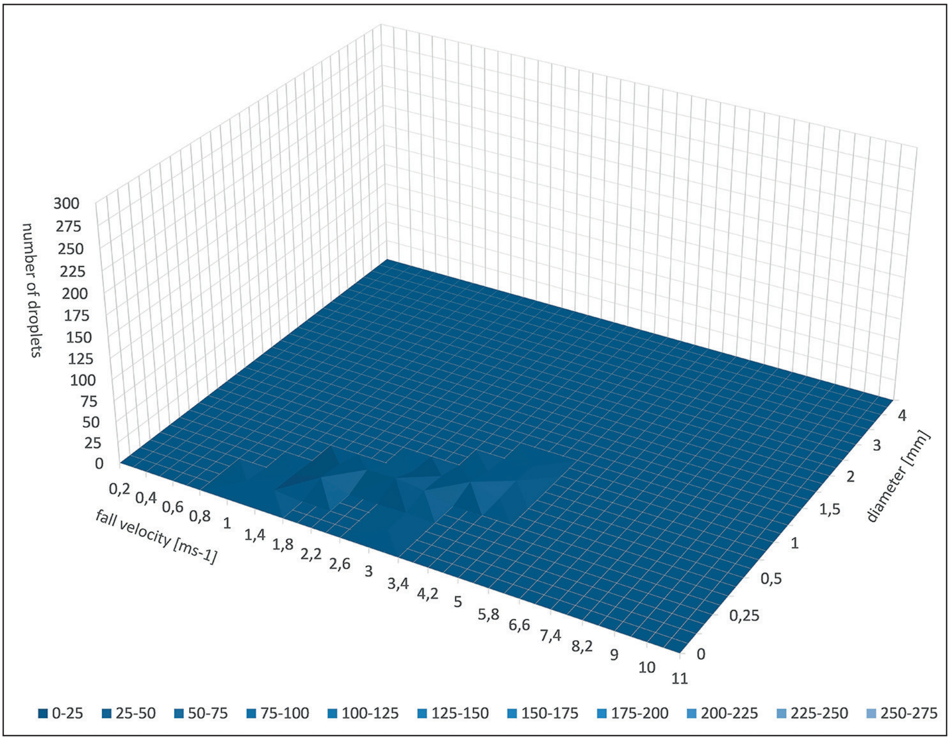

Fig. 9: Precipitation droplet distribution for 1 minute of precipitation within a stratiform precipitation event on 10 July 2018. – Abb. 9: Niederschlagströpfchenverteilung der einminütigen Niederschlagssumme während eines stratiformen Niederschlagsereignisses am 10. Juli 2018.

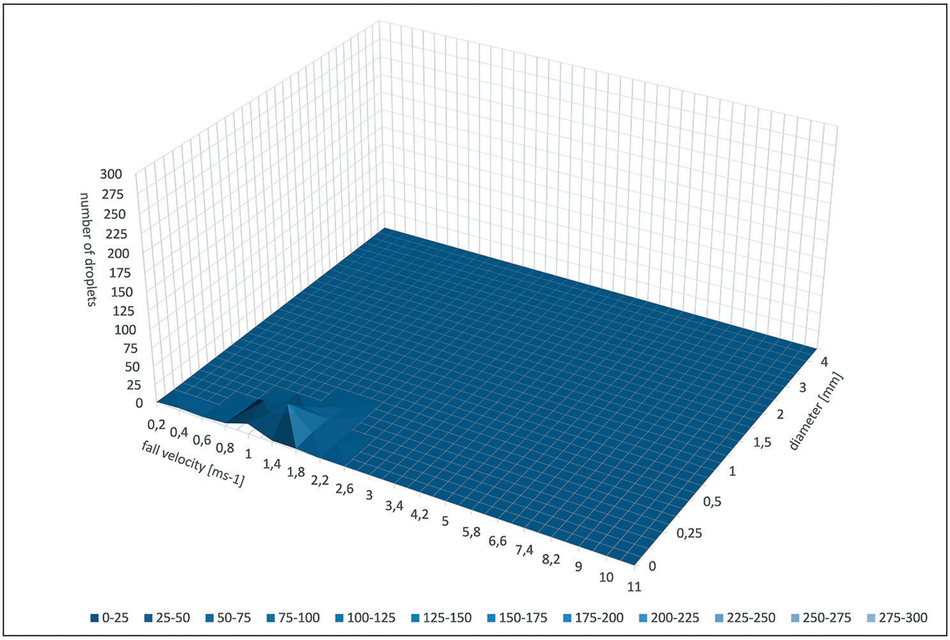

Fig. 10: Precipitation droplet distribution with an amount of 111 droplets per minute during a stratiform precipitation event. – Abb. 10: Niederschlagströpfchenverteilung von 111 Regentropfen, die innerhalb 1 Minute während eines stratiformen Niederschlagsereignisses gefallen sind.

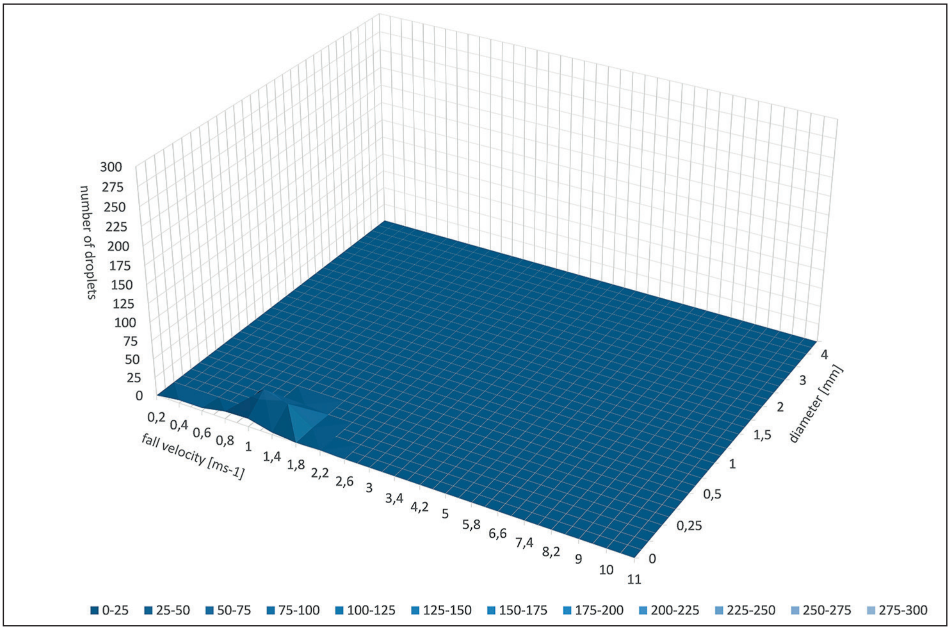

Fig. 11: Precipitation droplet distribution with an amount of 92 droplets per minute during a stratiform precipitation event. – Abb. 11: Niederschlagströpfchenverteilung von 92 Regentropfen, die innerhalb 1 Minute während eines stratiformen Niederschlagsereignisses gefallen sind.

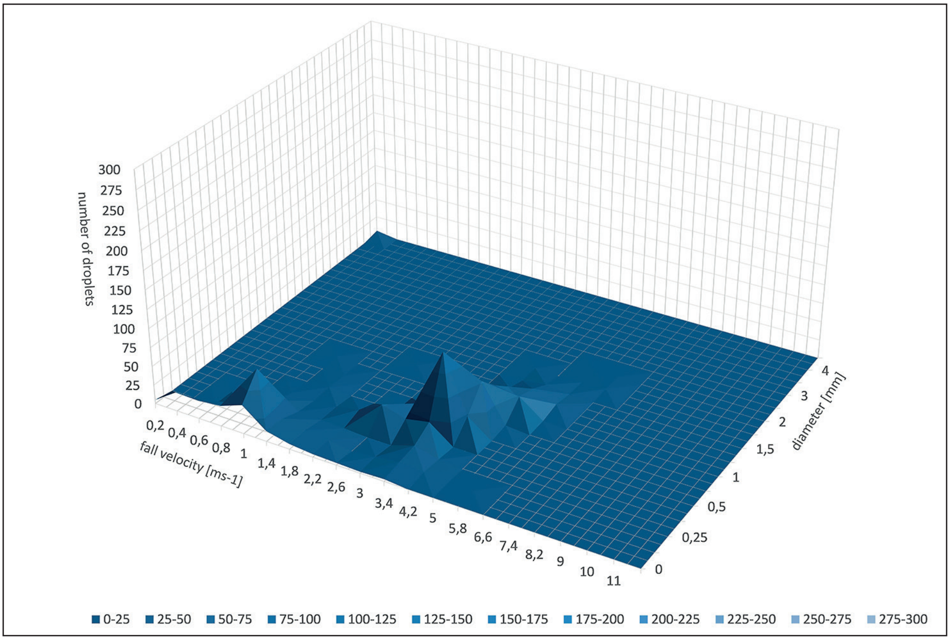

Fig. 12: Precipitation droplet spectrum with an amount of 721 droplets per minute during a convective precipitation event. – Abb. 12: Niederschlagströpfchenverteilung von 721 Regentropfen, die innerhalb 1 Minute während eines konvektiven Niederschlagsereignisses gefallen sind.

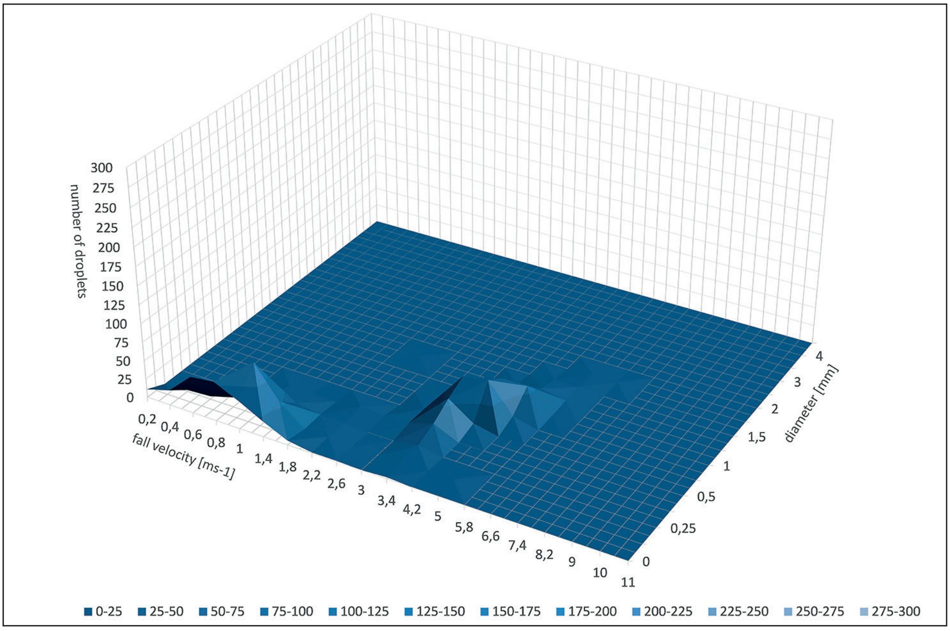

Fig. 13: Precipitation droplet spectrum with an amount of 630 droplets per minute during a convective precipitation event. – Abb. 13: Niederschlagströpfchenverteilung von 630 Regentropfen, die innerhalb 1 Minute während eines konvektiven Niederschlagsereignisses gefallen sind.

in stratiform clouds. The updrafts are not as high as in deep convective clouds, where it is more likely for droplets to collide with each other when higher up- and downdrafts are present within the cloud.

For precipitation originating in deep convective clouds, the droplet distribution was rather broad with two maxima, as is shown in Figures 12 and 13. The droplet distribution in Figure 12 with a total of 721 droplets per minute shows a maximum of faster rain drops of 1 mm diameter. The total number of droplets is the result of summing up all droplets at every fall velocity and diameter. In Figure 13, the maximum with smaller droplet diameters was at 0.25 mm. A second maximum with much faster drops was at 1 mm diameter. Both figures show that the rain was heavier and the rain rate higher, as more droplets per minute came down in comparison to the example of stratiform precipitation (Fig. 10). Droplets were only a little larger than the stratiform droplets, but were falling faster, accelerated by the downdraft of a deep convective cloud. For heavy tropical rain events, droplets in this example were rather small. Due to power loss during heavy rainfalls with large raindrops, it was not possible to capture a droplet distribution with droplet diameters larger than 3.5 mm.

Figure 14 shows the distribution of 1726 droplets per minute, most of which were under 1 mm in diameter and had a small fall velocity. Faster and slightly larger droplets fell at the same time, as can be seen in a smaller and broader maximum of the distribution in Figure 14.

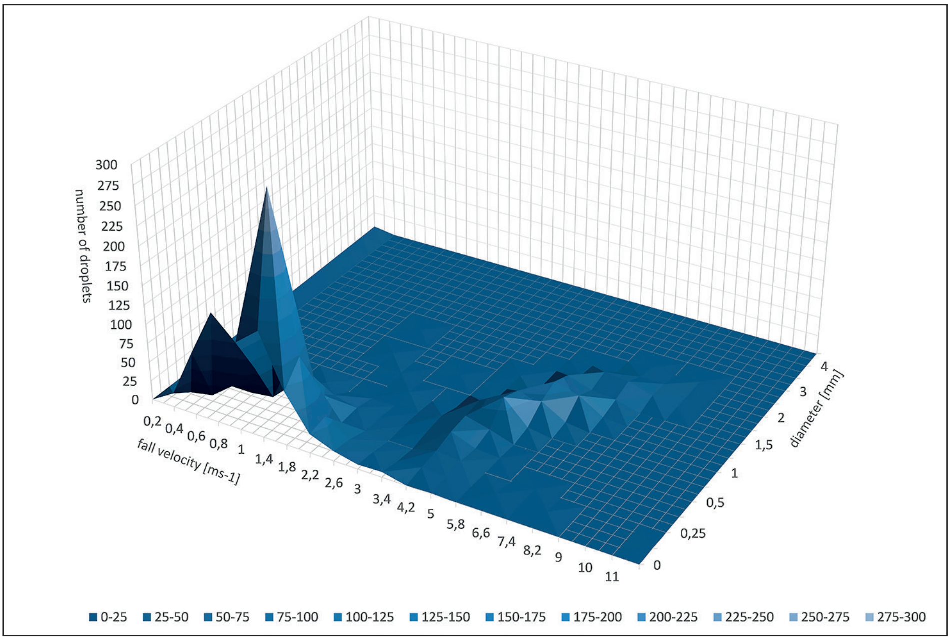

Fig. 14: Precipitation droplet spectrum with an amount of 1726 droplets per minute during a convective precipitation event. – Abb. 14: Niederschlagströpfchenverteilung von 1726 Regentropfen, die innerhalb 1 Minute während eines konvektiven Niederschlagsereignisses gefallen sind.

Radiation conditions

The radiation conditions were analyzed with regard to orientation.

The plot for the horizontal plane is shown in Figure 15. It is interesting to note that, despite the location of La Gamba being close to the equator, a definite annual cycle is visible. Around 1 September the sun is at its zenith at noon and around 21 December the sun is only at an elevation of 68 degrees at noon. Hence the average daily global radiation in the clearing on a horizontal plane is significantly lower (by roughly a factor of three!) in December as compared to September. One has to consider, however, that the variation is not only explained geometrically but also that the average cloudiness differs from month to month. The variation between the maximum and minimum daily value in the whole period is roughly a factor of 10! The values for the edge of the rainforest and the bushes are quite similar, however the annual cycle seems to be different due to different shading. As could be expected, the lowest average values were observed in the rainforest location. There, the average global radiation was roughly 10 % of the clearing site. The ratio varies considerably, which is an indication that even on the ground beneath a rainforest canopy there are some angles where more (direct solar) radiation can penetrate. An upward-facing fish-eye photograph could easily prove this hypothesis (Turton 1991). The day with the absolute minimum in the rainforest was only 1 % of the maximum value in the clearing. The day to day variability was also considerable. On 19 November, a distinct minimum was recorded on a day with continuous rain and deep cloud layers. The global radiation was only about 10 % of the day with the maximum global radiation on a sunny day at the end of September. It is interesting to note that the ratio of roughly 10 between the maximum and minimum daily global radiation is rather constant for all locations and all orientations. This means that the ratio must be the same for the direct as well as the diffuse part of the global radiation.

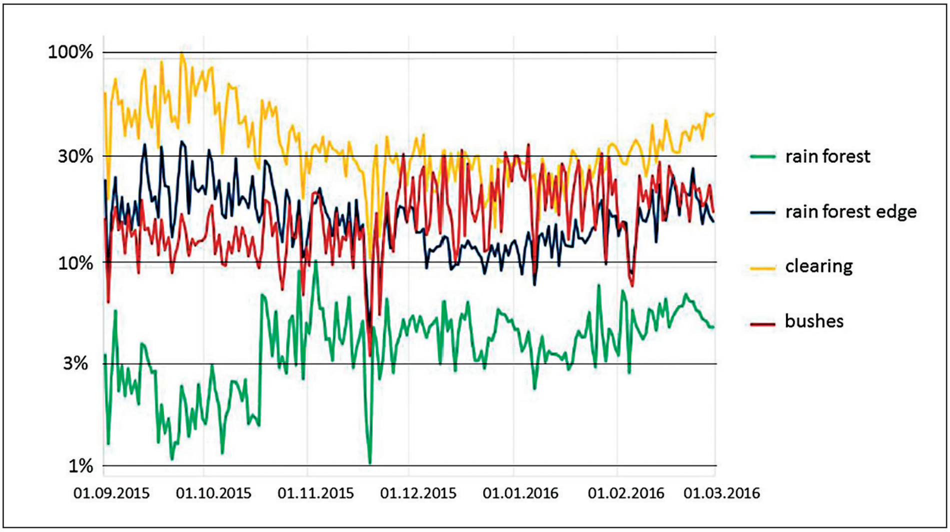

Fig. 15: Daily average global radiation at a horizontal surface in relative units on a logarithmic scale. – Abb. 15: Tägliche mittlere Globalstrahlung an einer horizontalen Fläche in relativen Einheiten, auf einer logarithmischen Skala.

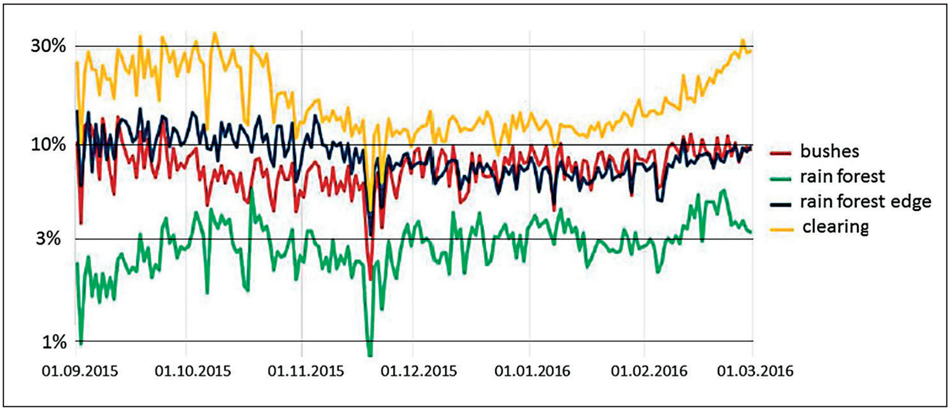

Fig. 16: Daily average global radiation at a vertical surface, facing East, in relative units on a logarithmic scale. – Abb. 16: Tägliche mittlere Globalstrahlung an einer vertikalen Fläche, nach Ost ausgerichtet, in relativen Einheiten, auf einer logarithmischen Skala.

If we compare the average global radiation on a vertical plane, facing East (Fig. 16), in the clearing a reduction by roughly a factor of 3 is apparent. The East-facing plane in the rainforest, however, shows much less reduction, which means that the tiny spots where the direct radiation comes through the canopy are not only found around the zenith, but also at lower angles. Hence, under the canopy, the orientation becomes less important than in a clearing. The results for the other directions of vertical planes (not shown), confirm the findings of Figure 16. The South-facing surface shows a somewhat different behavior concerning the annual cycle. In this case, in winter, when the solar elevation angle is lowest, no minimum like with all other orientations was observed, because the South-facing plane receives more direct solar radiation at this time.

Discussion

For long-term climate assertions, at least 30 years of observational data are required. When it comes to the tropics, especially, simply setting up high-quality devices for data collection is by far not enough. Since only long-distance measurements without regular maintenance of the instrumentation were manageable from our side, a proper timeline of meteorological parameters is pending. The higher the variability of a weather phenomenon, the longer the timeline of observation has to be to reach a significant conclusion. This is even more important if different sites are compared and a systematic difference is to be deduced. The long-term precipitation measurement provided by the tropical station is the most robust available for the moment.

Measuring extreme weather phenomena is always challenging. Instrumentation is generally built for the most likely range it will be operating in. What we learned from this investigation was that heavy precipitation rates made the distrometer automatically record those events as failures. The reason is that the device is not able to dissolve rainfall if more than one droplet falls through the laser beam at the exact same time, which is the case when it comes to very heavy rainfall.

To reach a more complete picture of the precipitation droplet distributions, an additional observation period with a distrometer should definitely be conducted in October or November in this same region, when heavy convective precipitation events are more frequent and huge amounts of rain are measured. But even then the bottle up effects on the different mountain ranges would lead to the presumption that several spectra would be of stratiform character.

One interesting experiment could focus on the change of radiation conditions during a reforestation period, while another could investigate the impact of topography, slope inclination, orientation, altitude, etc. on the specific radiation conditions.

Concerning solar radiation, the field study pointed towards the importance of taking into account the spatial variability of global radiation due to the vegetation canopy. As the vegetation is not a constant, the investigation of the feedback mechanism between the radiation conditions and the vegetation dynamics would be an interesting field of research. Long term investigations are quite difficult to perform under humid tropical conditions. Therefore, a different approach would appear promising. Instead of placing several instruments in different vegetation zones, one could profit from mobile equipment making radiation measurements along fixed transects in the rainforest. Especially the profiling of an area of reforestation could give interesting insights into the vegetation dynamics. Measurements along such transects could be carried out in certain intervals or on a selection of days (sunny, rainy, etc.) during the annual cycle extended over years without too much personal and technical effort. It is clear, that we can still learn a lot more about the relation and feedback mechanism between radiation and vegetation growth in the tropics.

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Adresses:

Mag[a] Birgit Eibl, Salesianergasse 7/9, A-1030 Wien. E-Mail: birgit.eibl@gmail.com

Emer. o. Univ.-Prof. Dr. Reinhold Steinacker, Hofzeile 11/10, A-1190 Wien.
E-Mail: reinhold.steinacker@gmail.com