Brazilian climate normals for 1981–2010

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Abstract – In the last decades, especially since 2000, the natural vulnerability of Earth's climate system has been a cause of great concern as to the status of global climate change due to the interference of natural and/or anthropic activities. Instituto Nacional de Meteorologia (Inmet), the government body officially responsible for monitoring weather and climate in Brazil, and also a member of the World Meteorological Organization (WMO), is proud to release the new edition of the climate normals for the period of 1981–2010. The new edition aims to analyze and register the climate changes that occurred during the two decades following the previous edition of 1961–1990. For that purpose, Inmet created a working group to prepare and edit these normals, as a basis of knowledge for different spheres of meteorology, aiming to strengthen the study and research of climate variability, as well as the Paris Agreement, which limits global warming to 1.5°C above pre-industrial levels. Finally, the publication intends to offer guidance, information, and assistance to the communities of climate sciences, agribusiness, and public and private institutions, both national and international. Overall, activities related to climate have expanded in practically every sphere of human life, especially in the fields of science and public policies.

Index terms: climate, environment, meteorological variables, society.

Normais climatológicas do Brasil 1981–2010

Resumo – Nas últimas décadas, principalmente desde 2000, a vulnerabilidade natural do sistema climático da Terra tem causado preocupações quanto à mudança climática global devido a processos naturais e/ou atividades antropogênicas. O Instituto Nacional de Meteorologia (Inmet), responsável por monitorar o tempo e o clima no Brasil, e também membro da Organização Meteorológica Mundial (OMM), tem o orgulho de lançar a nova edição das normais climatológicas 1981–2010. Esta nova edição visa analisar e registrar as mudanças climáticas que ocorreram durante as duas décadas após a edição anterior de 1961–1990. Com esse propósito, o Inmet criou um grupo de trabalho para preparar e editar essas normais, como base para conhecimento em diferentes esferas da meteorologia, para fortalecer o estudo e a pesquisa da variabilidade climática, bem como o Acordo de Paris, que limita o aquecimento global a 1,5°C acima dos níveis da era pré-industrial. Por fim, a publicação visa oferecer diretrizes, informações e assistência a comunidades de ciências climáticas, agronegócios, instituições públicas e privadas, tanto no âmbito nacional quanto internacional. No geral, as atividades relacionadas ao clima têm expandido em praticamente todas as esferas da vida humana, sobretudo nas áreas de ciências e políticas públicas.

Termos para indexação: clima, meio-ambiente, variáveis meteorológicas, sociedade.

Introduction

According to the technical regulations of World Meteorological Organization (WMO, 1989), "normals" are defined as the averages computed over a uniform and relatively long period, which should cover at least three consecutive 10-year periods. The same regulations define "climatological standard normals" as the averages of climatological data calculated for the following consecutive 30-year periods: January 1, 1901, to December 31, 1930, and January 1, 1931, to December, 31, 1960, and so forth. In case there are stations for which the most recent climate normal is unavailable, whether because the station was not in operation for a period of 30 years or any other reason, "provisional normals" can be calculated; these are short-term averages, based on observations extending over a minimum period of 10 years.

In 1989, aiming to establish general procedures for the calculation of monthly and annual averages for the period of 1961–1990 and subsequent years, WMO published the Technical Document WMO-TD/No. 341 (WMO, 1989), which allows determining climatological standard normals and provisional

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normals, further suggesting other climate variables. Coherently, it was established that all member countries should comply with these procedures. According to WMO, climate data are often more useful when comparable with climatological standard normals, which should be obtained according to their own technical recommendations. Therefore, the calculation and publication of climatological "standard" normals is of utmost importance. In the absence of these, due to the nonexistence or poor quality of data, the use of "simple" or "provisional" normals are acceptable alternatives.

In Brazil, as systematic meteorological observations only began in 1910, the meteorological service of Ministério da Agricultura, Pecuária e Abastecimento published the first climate normals in 1970, referring to the period of 1931–1960 (Brasil, 1970). The publication was restricted to monthly and annual average values of the following variables: atmospheric pressure, maximum temperature, minimum temperature, absolute maximum temperature, absolute minimum temperature, mean temperature, relative humidity, cloudiness, total precipitation, maximum precipitation in 24 hours, total evaporation, and total insolation.

In 1992, Instituto Nacional de Meteorologia (Inmet), then called Departamento Nacional de Meteorologia of Ministério da Agricultura e Reforma Agrária, published the 1961–1990 climate normals (Brasil, 1992), gathering data from 209 weather stations, comprising the same set of variables as the 1931–1960 normals.

In 2009, commemorating the centennial of the institution, an updated and expanded version of the Brazilian climate normals for the period of 1961–1990 (Ramos et al., 2009) was published. Data from 411 surface weather stations of Inmet, all operational in that period, were analyzed according to the procedures recommended by WMO. The studied variables, presented in the form of tables and maps, were expanded to 31: compensated average, maximum, and minimum temperatures; absolute maximum values of maximum and minimum temperatures; atmospheric pressure (hPa) at a station level; insolation; evaporation; wind intensity, prevailing and resulting direction, and zonal and meridional components; monthly and hourly cloudiness at 00:00, 12:00, and 18:00 Coordinated Universal Time (UTC); monthly and hourly air relative humidity at 00:00, 12:00, and 18:00 UTC; accumulated precipitation; absolute maximum value for accumulated precipitation in 24 hours; number of days within a month or a year with precipitation greater or equal to 1 mm; 10-day precipitation; number of days within a period of 10 days with precipitation greater or equal to 1 mm; number of periods with 3 or more consecutive days without precipitation; number of periods with 5 or more days without precipitation; and number of periods with 10 or more consecutive days without precipitation.

This paper aims to present the updated version of the Brazilian climate normals for the period of 1981–2010 (Inmet, 2018). This new publication was initially motivated by the interest to widely disseminate the normals for the period established by WMO, updating the meteorological variables of 1961–1990 to 1981–2010, in addition to aggregating new meteorological parameters as requested by the general community that uses the normals for several types of studies. Even though agroclimatology stands as the main technical area benefiting from the information provided in this publication, virtually all human activity depends on climatological information, from the productive to the public health sector, and from sport activities to leisure, for example.

The normals presented here in the form of tables and maps correspond to the following variables:

1. compensated average temperature (°C);
2. maximum temperature (°C);
3. minimum temperature (°C);
4. dew-point temperature (°C);
5. wet-bulb average temperature (°C);
6. absolute value of maximum temperature (°C);
7. absolute value of minimum temperature (°C);
8. absolute value of minimum wet-bulb temperature (°C);
9. number of days with maximum monthly and annual temperatures for ≥ 25°C;
10. number of days with maximum monthly and annual temperatures for ≥ 30°C;
11. number of days with maximum monthly and annual temperatures for ≥ 35°C;
12. number of days with maximum monthly and annual temperatures for ≥ 40°C;
13. number of days with minimum monthly and annual temperatures for ≥ 10°C;
14. atmospheric pressure (hPa) at a barometer level;
15. pressure (hPa) at mean sea level;

16. average vapor pressure (mB) calculated by the Tetens equation;
17. total insolation (hours);
18. total evaporation (mm) using the Piché evaporimeter;
19. cloudiness (tenths);
20. hourly cloudiness (tenths);
21. compensated air relative humidity (%);
22. hourly average air relative humidity (%);
23. absolute maximum value of relative humidity (%);
24. absolute minimum value of relative humidity (%);
25. accumulated precipitation (mm);
26. absolute maximum value of accumulated 24-hour precipitation monthly and anual (mm);
27. number of days, within a period of 10 days, with precipitation greater or equal to 1 mm (days ≥ 1 mm);
28. number of periods, within a month or a year, with 3, 5, and 10, or more consecutive days without precipitation (periods);
29. number of days with monthly and annual precipitation for ≥ 1 mm;
30. number of days with monthly and annual precipitation for ≥ 5 mm;
31. number of days with monthly and annual precipitation for ≥ 10 mm;
32. number of days with monthly and annual precipitation for ≥ 15 mm;
33. number of days with monthly and annual precipitation for ≥ 35 mm;
34. number of days with monthly and annual precipitation for ≥ 50 mm;
35. wind intensity (m s^{-1});
36. wind zonal component (m s^{-1});
37. wind meridional component (m s^{-1});
38. resulting wind direction (degrees);
39. wind prevailing direction (cardinal and collateral points); and
40. potential evapotranspiration (mm).

Climate normals: importance and how to use them

All climate studies are based on meteorological observations. By characterizing the climate of a particular region, it is possible to obtain an overview of the rainfall regime, temperatures, and set of elements that determine its natural conditions. An example is agroclimatic zoning, which studies the possibility and risks (whether low, medium, or high) of implementing a determined crop in a particular region, in order to ensure water and food security, considering that each crop depends on several parameters, such as the amount of water available. In recent years, extreme climate events have become more frequent, directly impacting societies due to associated natural disasters, which are attributed to climate type, topographical layout, and the established urban occupation (Pachauri & Meyer, 2014).

Many of these events have been reported in studies on anomalies in meteorological variables such as precipitation, temperature, atmospheric pressure, wind, air humidity, and the analyses of their respective deviations. The normal state of these variables shows varying patterns – longer or shorter cycles, more continuous or more anomalous periods –, which may cause extreme events and natural disasters like floods, inundations, mass movements, droughts, heat waves, frosts, hail, power failure, and building collapses. Therefore, it is interesting to evaluate the averages of a long data set referring to these meteorological variables in order to establish patterns and identify anomalies.

The environmental variables presented in this publication are based on data obtained on a daily basis, at 12:00, 18:00, and 24:00 UTC, by Inmet's network of surface observations, limited quantitatively and qualitatively as discussed in the methodology. Tables are used to organize data in a self-explanatory manner, allowing the user to obtain direct and derived information, which can be employed for the construction of graphs and tables for isolated or combined variables, for climate studies with different objectives and configurations, as illustrated in the examples hereinafter. Figure 1 shows the average monthly variation of the atmospheric pressure measured by a barometer in the localities of Belém, in the state of Pará, and Florianópolis, in the state of Santa Catarina. It is possible to observe a greater barometric amplitude in Florianópolis, in contrast with Belém. This condition, deriving from the difference in latitude between both localities, partly explains the differences in weather and climate between the two cities.

The following figures show other combinations between different localities for the same climate element and between different climate elements for the same locality. Analyzing the average temperatures for cities located in different latitudes, such as Cuiabá in the state of Mato Grosso, Macapá in the state of Amapá, Recife in the state of Pernambuco, and Porto Alegre in the state of Rio Grande do Sul (Figure 2), the effect of latitude on monthly temperature becomes clear, with decreasing amplitudes from the south to the north of Brazil. In Macapá, in the extreme north of the country, the monthly average temperature fluctuates slightly, maintaining elevated average values throughout the year, whereas in Porto Alegre, in the south of Brazil, a significant variation is observed from summer to winter. The city of Cuiabá, located at an intermediate latitude, between both extremes, has more defined summers and winters, which is also observed for Recife.

Figure 3 illustrates the striking difference between the rainfall regimes of four localities that are close in terms of latitude: Salvador and Cuiabá, distant from each other in terms of the climate factor continentality, and Belém and Curitiba, located in extreme regions of the country. Salvador, located on the coast, shows higher accumulated precipitation, with maximum precipitation in autumn and early winter, whereas Cuiabá, a continental locality of the Midwestern region of Brazil, presents scarcer rains, with maximum levels at the end of spring and throughout summer. In contrast, in Belém, located in the rainiest region of the country and lying approximately at mean sea level, precipitation increases from December to June and is practically consistent throughout the year, while in Curitiba, located at about 1.000 m above mean sea level, precipitation has a quite consistent distribution, with maximum levels in summer and minimum in late winter.

Figure 4 refers to Brasília, located in Distrito Federal, showing a discrepancy of almost 180 degrees between the curves of air relative humidity and evaporation. The humid summer, with monthly humidity averages of around 75%, limits evaporation to approximately 100 mm per month, contrasting with the dry winter, with averages of around 50% and elevated evaporation rates, which come close to 300 mm per month.

By comparing the climate normals for 1931–1960 and 1961–1990 with the climate normals for 1981–2010, all published by Inmet, it is possible to have an idea of the climate variability among the three periods,

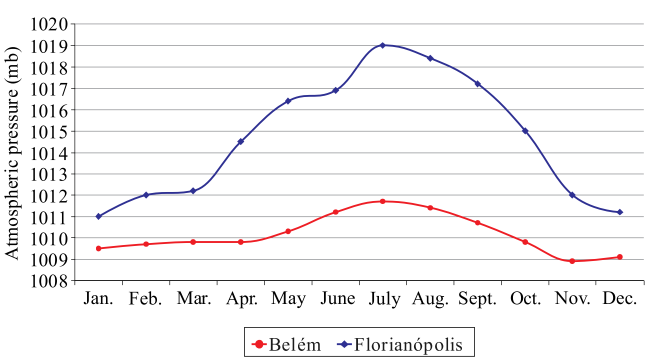

Figure 1. Comparison of the 1981–2010 climate normals of atmospheric pressure at a station level for Belém in the state of Pará and Florianópolis in the state of Santa Catarina, Brazil. Source: Inmet (2018).

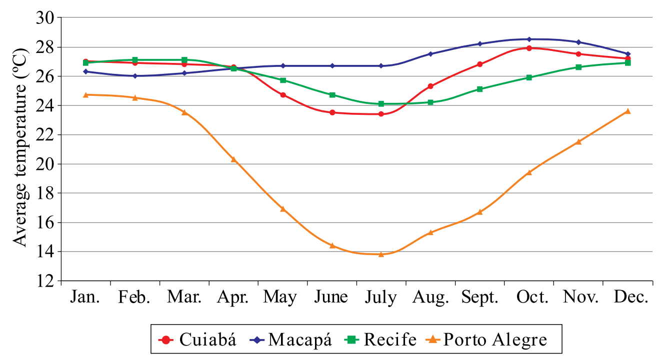

Figure 2. Comparison between the 1981–2010 climate normals of compensated average temperature for Cuiabá in the state of Mato Grosso, Macapá in the state of Amapá, Recife in the state of Pernambuco, and Porto Alegre in the state of Rio Grande do Sul, Brazil. Source: Inmet (2018).

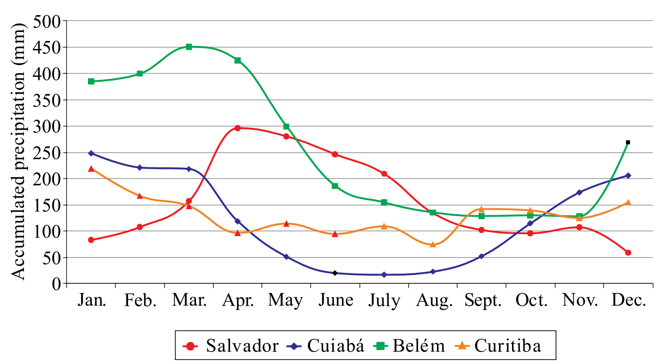

Figure 3. Comparison between the 1981–2010 climate normals of the monthly accumulated precipitation for Salvador in the state of Bahia, Cuiabá in the state of Mato Grosso, Belém in the state of Pará, and Curitiba in the state of Paraná, Brazil. Source: Inmet (2018).

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as shown in Figures 5, 6, and 7. In Manaus, in the state of Amazonas, while the precipitation regime remained stable and total precipitation slightly changed, with a small increase in August and December (Figure 5), the temperatures gradually increased about 1°C throughout the year (Figure 6). However, in Goiânia, in the state of Goiás (Figure 7), the average compensated temperature showed an increase of approximately 2°C, which should not be immediately interpreted as climate change associated with global warming, since it is more likely to be due to the effects of urbanization, a hypothesis that will require more detailed studies.

Figure 8 presents an example of one of the new calculated variables, within a set of new parameters, for the period of 1981–2010, i.e., the potential evaporation of regions with very different climates, in this case, of Cuiabá in the state of Mato Grosso, Recife in the state of Pernambuco, and Porto Alegre in the state of Rio Grande do Sul. This variable is very important, especially for the management and planning of water resources and of agricultural activities that require large amounts of water.

In this context, evaporation is one of the elements that, aside from precipitation, characterize the climate of a region and have been widely used in meteorological, climatological, and hydrological studies. It is possible to observe that Porto Alegre presents a seasonal variation with low values, mainly in the trimester May-June-July, whereas Recife shows a smoothed variation throughout the year. Cuiabá presents an elevated seasonal variation, mostly in the second semester, indicating the maximum amount of water that can evaporate from a soil covered entirely by vegetation, developed under optimum conditions and

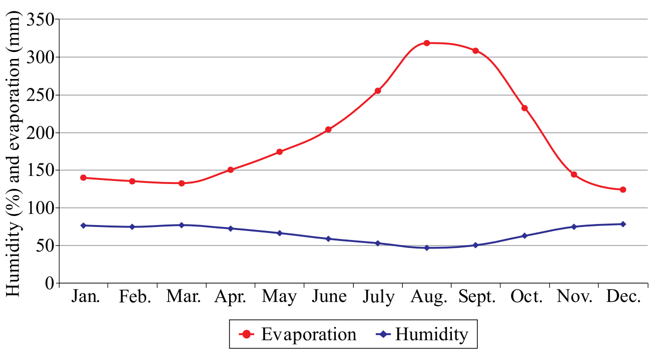

Figure 4. Comparison between the 1981–2010 climate normals of air evaporation and relative humidity for Brasília in Distrito Federal, Brazil. Source: Inmet (2018).

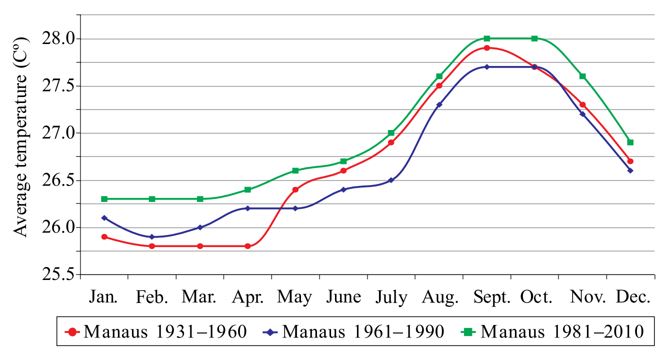

Figure 6. Comparison between the 1981–2010, 1961–1990, and 1931–1960 climate normals of average temperature for Manaus in the state of Amazonas, Brazil. Source: Inmet (2018).

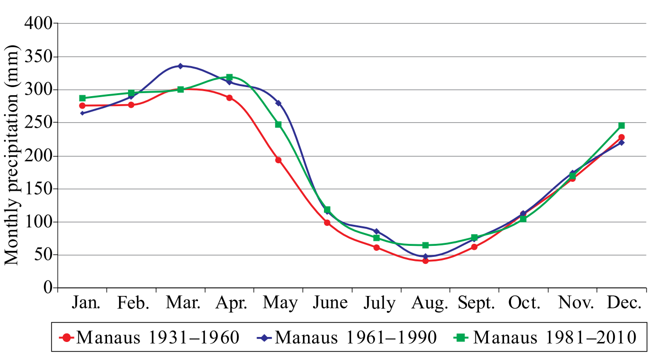

Figure 5. Comparison between the 1981–2010, 1961–1990, and 1931–1960 climate normals of the monthly accumulated precipitation for Manaus in the state of Amazonas, Brazil. Source: Inmet (2018).

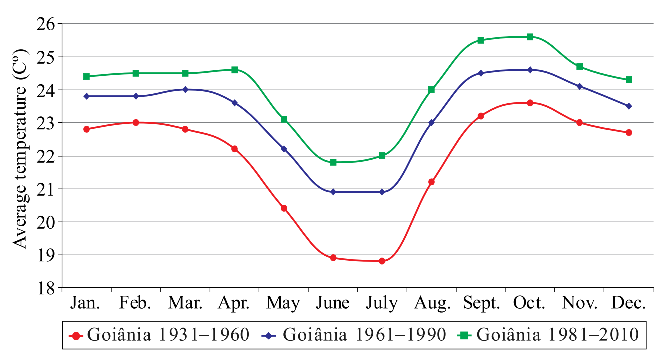

Figure 7. Comparison between the 1981–2010, 1961–1990, and 1931–1960 climate normals of average temperature for Goiânia in the state of Goiás, Brazil. Source: Inmet (2018).

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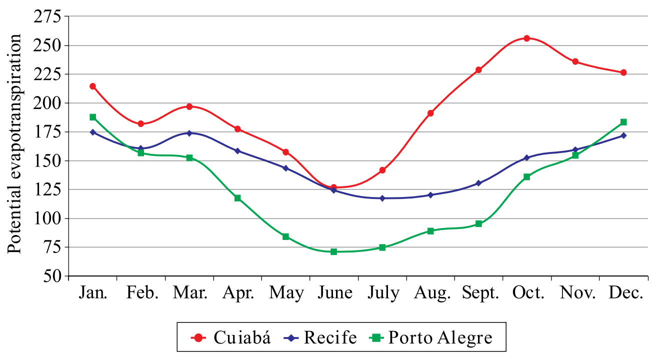

Figure 8. Comparison between the 1981–2010 climate normals of monthly potential evapotranspiration for Cuiabá in the state of Mato Grosso, Recife in the state of Pernambuco, and Porto Alegre in the state of Rio Grande do Sul, Brazil. Source: Inmet (2018).

assuming the absence of water availability limitations, especially due to soil storage capacity.

In practical terms, the quantification of this variable is a bit more complex, since it is affected by several climatic factors, such as solar radiation, wind speed, temperature, humidity, and local factors including albedo, soil emissivity, and type of vegetation.

The historical average or climate normal may be used, for example, to define the concept of "deviation" or "anomaly" of a variable, often adopted in meteorology to determine the difference between the observed value and the corresponding climate normal.

Figure 9 illustrates the use of this concept in one of the products developed by Centro Regional del Clima para el Sur de América del Sur (CRS-SAS). CRS-SAS is an organization created in alignment with the

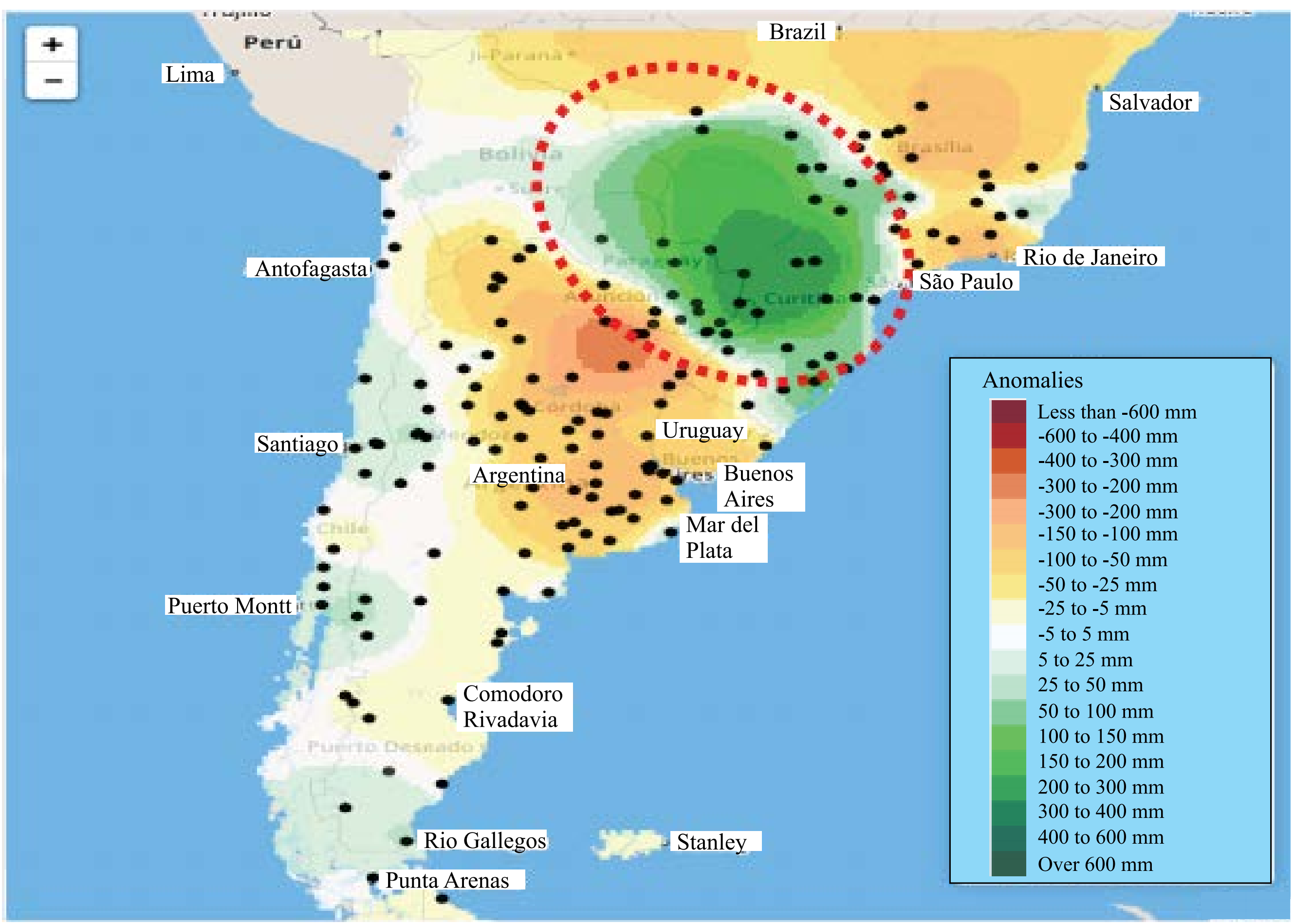

Figure 9. Deviation (anomaly) of the expected quarterly rainfall in relation to the 1981–2010 climate normals for the trimester October-November-December of 2017 in the south region of South America. Source: CRS-SAS (2018).

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principles defined by WMO, which aims to provide climate services in support of national meteorological services and other users from countries with part of their territory located in the south region of South America. Using the climate normals for 1981–2010 as a reference, the Figure 9 shows precipitation anomalies predicted for the trimester October-November-December 2017, for the countries located in the southeastern and southern regions of South America, with positive anomalies affecting mainly regions of Brazil, Argentina, and Paraguay.

The estimation of terms of climatological water balance from temperatures and average monthly rainfall data using the Thornthwaite (1948) and Thornthwaite & Mather (1955) methods is an example of how climate information can be indirectly used for socioeconomic purposes, particularly for agriculture, with graphical visualization of the data from the stations. On a 10-day scale, the greatest relevance lies in agricultural applications, particularly, in the selection of crops and agricultural practices that are more appropriate for a region. The comparison between the monitored real time and the average 10-day values will allow the identification of favorable or anomalous conditions for agricultural practices, otherwise applicable to any other productive or social activity. In particular, the 10-day water balance is an essential tool in agricultural monitoring, especially for the calculation of water deficit and potential and real evapotranspiration, which are parameters that allow quantifying the level of water stress to which a crop is subjected to, besides estimating aridity and productivity rates.

Temperature monitoring is also crucial in all phenological stages of the crop, being a critical factor in some processes such as, for example, flower abortion in the coffee crop, when the plant's tolerance limits are exceeded in that phenological phase. Considering the regional representativeness of each meteorological station, a careful analysis of the normal monthly and 10-day values is of great importance in choosing: varieties that are more suitable for a region, the best seeding period, management and cultivation practices, harvest processing activities, as well as other technical-scientific and socioeconomic applications.

The statistics for number of rainy and dry days, and for consecutive dry intervals are useful information for many activities, from the estimation of workable days with machines in the field to the quantification of summer or wintering periods. Such information is relevant for agriculture, livestock, urban life, and many other human activities. The funding of agricultural crops and general security activities are highly dependent on the knowledge of climate conditions, particularly of extreme events, which can be identified by the comparison of routinely observed meteorological conditions and by 10-day, monthly, and annual averages.

From another angle, the maps presented after the respective tables allowed the spatial visualization of the climatological information for a panoramic analysis and were useful tools for the decision making process by authorities, planners, and executors of agrosilvopastoral activities, among others.

The map in Figure 10, for example, illustrates the accumulated annual rainfall normally expected throughout Brazil. If, for example, a given crop requires accumulated annual rainfall higher than 1,500 mm, a farmer from the state of Minas Gerais can only grow it in some areas of the Southern region and of Triângulo Mineiro (in the west of the state of Minas Gerais), where such amounts are normally

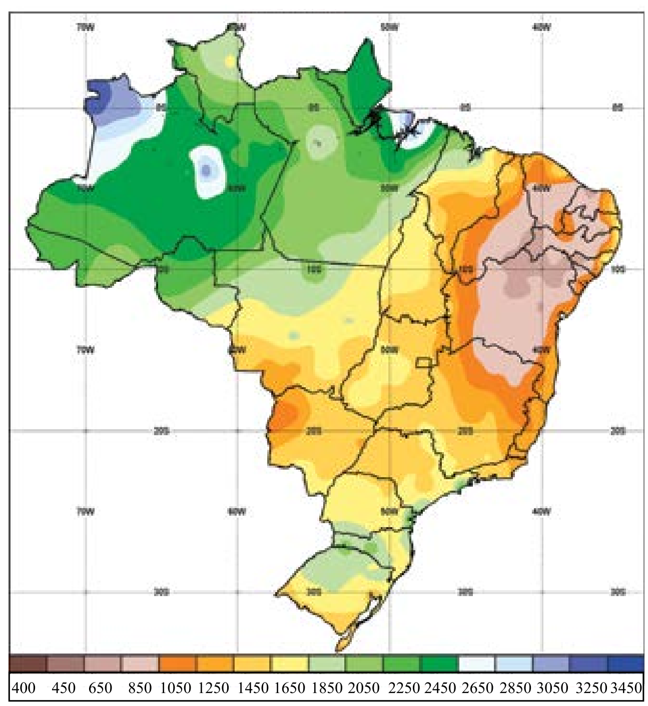

Figure 10. Climate normals of accumulated annual precipitation (mm) for the period of 1981–2010 in Brazil. Source: Inmet (2018).

obtained. Although other climate requirements must also be analyzed, especially temperature, this is a basic analysis of agricultural zoning.

The seasonal climate forecast illustrates another important application of the quarterly climatological average maps, which can be obtained from the sum of the values of the normals for the months covered. Since these forecasts are usually expressed in terms of the probability of the occurrence of values above, below, or within the climatological average, the map with the historical average for the period in question complements the information from the forecast. This allows to evaluate immediately and quantitatively the value of the predicted parameter in any region of interest, with its respective probability of occurrence.

Figure 11 presents the forecast prepared by CRS-SAS using quarterly probabilistic forecasts for precipitation and also indicates a higher probability of occurrence of above-average rainfall over the state of Santa Catarina. When reading the climatological map of Figure 12, the user can verify that the average rainfall for this period varies from 450 to 650 mm in the region, according to the climate normals for 1981–2010.

This forecast would, therefore, indicate that the rainfall in these regions would likely score above this level in the first quarter of 2018, which in fact occurred according to subsequent verification. That is, in that quarter, positive anomalies were recorded in the region, varying from 400 to 600 mm of accumulated rainfall, highlighting the relevance of the information for agricultural activities and for the civil defense, among other beneficiaries.

Therefore, it is possible to carry out countless analyses using tables and maps from the climate normals, depending only on the needs of the research to be developed.

Methodology for calculating climate normals

The climate normals published here are averages from January 1, 1981, to December 31, 2010, corresponding to Inmet's network of 438 meteorological surface stations in operation during that period (Figure 13). In general, these are provisional normals, according to the concepts and procedures of WMO, established in document WCDP No. 10 (WMO, 1989).

Calculation procedures

In general, in order to determine the normals of a variable for a given meteorological station, it is necessary to initially calculate the X_{ij} value corresponding to each month i and each year j belonging to the period of interest – in this case, 1981–

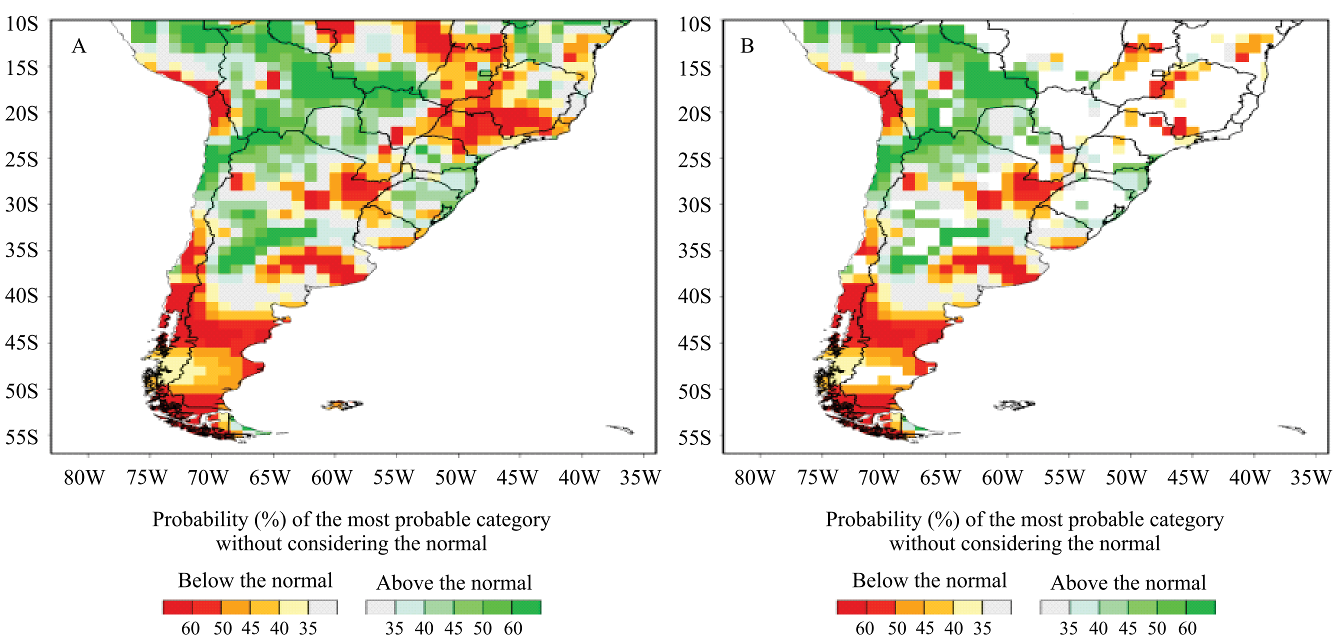

Figure 11. Seasonal probabilistic forecast of accumulated precipitation: quarterly evaluation (A) and ≥0.3 Pearson correlation (B) for the trimester January–February–March of 2018, in the south region of South America. Source: CRS-SAS (2018).

2010. WMO recommends that, in cases like these, the "3:5 rule" should be applied, discarding the months with absence of data on 3 or more consecutive days, or 5 or more alternate days.

For the variables of Group I associated with daily values, such as temperature, atmospheric pressure at a station level and at mean sea level, vapor pressure, air relative humidity, cloudiness, and wind, X_{ij} is computed as:

$$X_{ij} = \sum_{k} X_{ijk} \Big/ N$$

where X_{ijk} is the observed value of variable X on day k, of month i, of year j; and N is the number of days in month i, of year k, for which observations are available.

For the calculation of vapor pressure, the Tetens equation was used:

$$e_s = A \times \exp^{17.3t/23.7+t} \text{ or } e_s = A \times 10^{7.5t/237.3+t}$$

where the parameter A corresponds to 610.8 Pa (for results in Pa) or 0.6108 kPa (for results in kPa), and t is the temperature given in Celsius (°C).

For the variables of Group II associated with accumulated values in the period of interest, such as precipitation, evaporation, and insolation, X_{ij} is calculated as the accumulated value in month i of year j, namely, as the sum of all available daily values for that month and that year:

$$X_{ij} = \sum_{k} X_{ijk}$$

In these cases, WMO recommends that only full months should be considered, that is, months with no missing data.

A particular case is the calculation of 10-day precipitation for the first, second, or third 10 days of each month. The 10-day value is calculated by the sum of the daily values for the days in question. It should be noted that, according to WMO guidelines, only complete periods of 10 days – with no missing data – should be considered.

The variables of Group III represent events observed in a period of interest, such as a month or a determined 10 days of a month. Examples are days with rainfall or temperature above a certain threshold, or periods with consecutive days without rainfall, within a month or in a given 10 days of the month. In these cases, the variable corresponds to the total of observations recorded in month i, of year j. As an example, take the number of days with rainfall higher or equal to 1 mm in the first 10 days of a month: if i corresponds to the month of March, and j to the year of 1975, then X_{ij} will correspond to the total number of days with

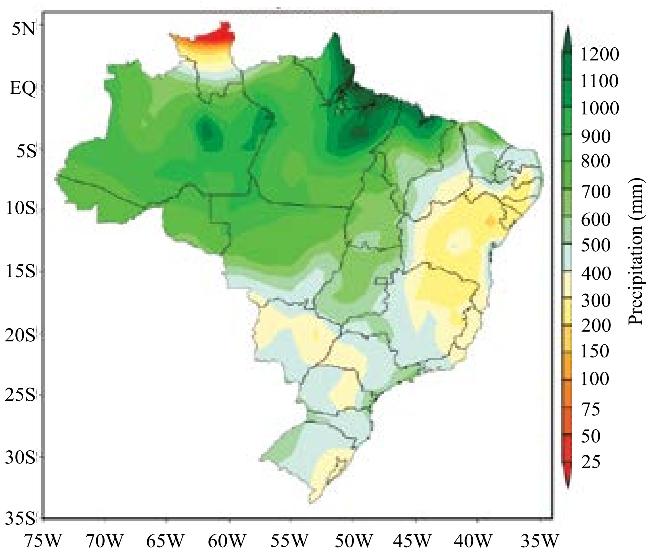

Figure 12. Historical average of the accumulated precipitation in the trimester January–February–March of 2018, in Brazil, using the climate normals for 1981–2010 as a reference. Source: Inmet (2018).

Figure 13. Spatial distribution of the 411 meteorological stations in Brazil, recalculated for the period of 1981–2010. Source: Inmet (2018).

rainfall, meeting that condition during the first 10 days of March 1975. Again, following the procedures recommended by WMO, the observation period should be complete, i.e., only months with rainfall data available for every single day should be considered for the 10-day average and only the month that has rainfall data for every single day should be taken into account for days with rainfall in a certain month. For variables in any of the three groups, the normal corresponding to month i will then be calculated as:

$$\bar{X}_i = \sum_j X_{ij} \Big/ m_i$$

where m_i is the number of years for which X_{ij} values are available.

According to WMO's nomenclature, if m_i is equal to 30, starting on January 1, 1961, and ending on December 31, 1990, $\bar{X}_i$ will be a standard normal or standardized. If m_i is lower than 10 but equal to or greater than 10, $\bar{X}_i$ will be a provisional normal. In case m_i is lower than 10, the $\bar{X}_i$ value will be discarded.

The potential evapotranspiration corresponds to the maximum water capacity that can be lost as vapor in a given climate condition by a continuous vegetation covering the entire surface, whether at or above field capacity. This includes soil evaporation and vegetation transpiration in a specific region and in a given time interval. The potential evapotranspiration (ETp, in mm per month) was indirectly calculated using the Thornthwaite method (1948), based on the correlation between measured evapotranspiration and air temperature data, according to the following empirical method:

$ETp = b\times(Tm)^a$

where

$a = (67.5x10^{-8}\times I^3) - (7.71x10^{-6}\times I^2) + (0.01791\times I) + 0.492$;

$I = \sum_1^{12}(Tm_i/5)^{1.514}$ (sum of the 12 months of the year);

$B = (N/12)$, day length adjustment factor;

N is the maximum daily insolation, latitude, and month function; I is the heat index; and Tm is the average daily temperature.

The Thornthwaite (1948) method, as an empirical formula, loses accuracy especially when applied at a daily scale. However, it is still one of the most adopted methods because it only uses air temperature, whose monthly and annual averages can be estimated even for regions without climate information through regression equations of temperature versus altitude, latitude, and longitude; when applied for periods longer than 10 days, its estimates are reasonable.

In the case of the variables of Group I, the annual normal ($\bar{X}$) of variable X in the meteorological station in question is calculated as the average of the $\bar{X}_i$ 12 monthly values, i= 1, ...,12. For the variables of Groups II and III, the annual normal $\bar{X}$ will be calculated as the sum of the 12 monthly values. If there is no $\bar{X}_i$ for any of the 12 months of the year, the annual amount will not be calculated.

Calculation of daily values

Data collection at Inmet's conventional meteorological stations is carried out at 12:00, 18:00, and 24:00 UTC. However, in a few stations, the observations are carried out only twice a day, usually at 12:00 and 24:00 UTC.

The X_{ijk} daily values used in the calculations described above result from these observations, according to the rules summarized hereinafter.

The minimum and maximum daily temperatures are recorded in special thermometers (maximum-minimum thermometer) and read by the observer, usually at 12:00 and 24:00 UTC, respectively.

The average compensated temperature, used in this publication, is calculated by the formula:

$$T_{MC,ijk} = (T_{max,ijk} + T_{min,ijk} + T_{12,ijk} + 2T_{24,ijk}) / 5$$

For the calculation of the daily value of air relative humidity, Inmet also uses the compensated average value given by:

$$UR_{C,ijk} = (UR_{12,ijk} + UR_{18,ijk} + 2UR_{24,ijk}) / 4$$

For the other variables of Group I, namely, atmospheric pressure, cloudiness, and wind direction and intensity, the daily value is calculated by the simple arithmetic mean of the values recorded in the three observation times. When one of these data sets is missing, it is not possible to obtain a daily value for these variables, or for the compensated average temperature and the compensated air relative humidity.

In the case of the variables of Group II, i.e., precipitation, evaporation, and insolation, the daily values are calculated as accumulated totals throughout the day, measured at 12:00 UTC (9 hours from Brasília at a standard time or 10 hours during daylight saving time). Therefore, for example, the value of rain associated with today will correspond to the total accumulated rainfall from 12:00 UTC of yesterday until 12:00 UTC of today.

Days with or without rainfall

To count the days with or without rainfall in a month or a period of 10 days, the two following recommendations of WMO were taken into consideration: 1, using only periods with complete data, that is, months or 10-day periods with precipitation data registered daily; and 2, considering days with or without rainfall as those in which accumulated precipitation was higher or equal/lower than 1 mm.

Being, by definition, an integer variable, when the normals for number of days with rainfall in a month (or a year) were calculated, the fractional values obtained were rounded to the nearest integer. However, since the loss of information deriving from the rounding would be much more significant in terms of percentage for 10-day averages, these were expressed with one decimal point, leaving the user with the task of transforming them into integer values, whenever convenient.

Periods of consecutive dry days

The aforementioned rounding does not apply, however, to the case of number of periods with 3 or more, 5 or more, and 10 or more consecutive days without rain. The interpretation of the obtained values, in this case, becomes easier if translated in terms of number of observed events, on average, for a period of 10 or 30 years or in terms of the probability (relative frequency) of the event at hand occurring. Take, for example, the case of number of periods with 10 or more consecutive dry days. Suppose that, for a given locality and for a given month of the year, a normal value of 0.3 was obtained. This is to say that 3 events would be observed on average over a period of 10 years or 30 events in 30 years. To translate this result in terms of probability (or relative frequency), it is necessary to compute the maximum number of events that could be observed in a typical month. It is easy to verify that, at any given month of the year, only a maximum of two distinct periods with 10 or more consecutive dry days would be possible. Therefore, in 10 years, a maximum of 20 events could be observed in the month in question. In this case, the probability of occurrence of the normal value of 0.3, mentioned above, can be estimated as 3/20 or 15%. As a general rule, the probability, in percentage values, can be estimated as:

Probability [Normal Value = x] = (x / Max_Num_Dry_Days) * 100

where Max_Num_Dry_Days is the maximum number of dry days that can be observed in a typical month. The reference values for 5 or more and 3 or more consecutive dry days are, respectively, 5.0 and 7.6 (approximately). In order to facilitate the interpretation of the values presented in the tables and map subtitles referring to the number of periods with 3 or more, 5 or more, and 10 or more consecutive dry days, frames that are presented in the introductory pages of the maps were produced, being equally valid for the interpretation of the respective tables.

Wind at 10 m

Wind intensity was treated as a normal variable of Group I. Furthermore, the hourly values of wind intensity were analyzed in zonal (variable u) and meridional (variable v) components. The daily value of these variables was calculated as the mean of the values of the three measurement times, and the climate normal of these quantities was, then, calculated by the standard rules of Group I.

Figure 14 illustrates the definitions of wind speed, θ, and the zonal (u) and meridional (v) components used in meteorology. In this paper, wind direction was addressed in two complementary forms. The first consisted of the direct calculation of the value resulting from wind direction using the following expression:

$$n(\theta) = \begin{cases} |\tan^{-1}(n(v)/n(u)) - 270^{\circ}|, \text{ if } n(u) > 0 \\ |\tan^{-1}(n(v)/n(u)) - 90^{\circ}|, \text{ if } n(u) < 0 \end{cases}$$

where the counter-domain of the arc tangent function, $\tan^{-1}(x)$, is the interval (-0º, 90º) and n(u) and n(v) represent the climate normals of the zonal and meridional components, respectively.

The second form consisted in collecting, for each station and each month of the year, the prevailing direction of the wind. To this end, the relative frequencies were obtained for the wind originating from eight main directions, namely: north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), and northwest (NW).

For this purpose, every hourly measurement of wind direction referring to the month in question, available at the station for the period of 1961–1990, was categorized in the eight ranges of direction previously specified. Thereafter, the band (direction) of highest relative frequency was determined, subject to the restriction that this frequency was higher than 20%. Whenever this condition was not met, the prevailing direction was considered indefinite (INDEF).

Final adjustments

Rule of 10

The values of the climate normals resulting from the analysis described in the previous section were subjected to a filter: a minimum of 10 years of available data in the Weather Information System (SIM) for each station combination, meteorological variable, and month under consideration. As explained before, this condition is required by WMO for a provisional normal. Thereafter, for each variable, those stations that only had climatological averages for a number of months inferior to 10 were also discarded.

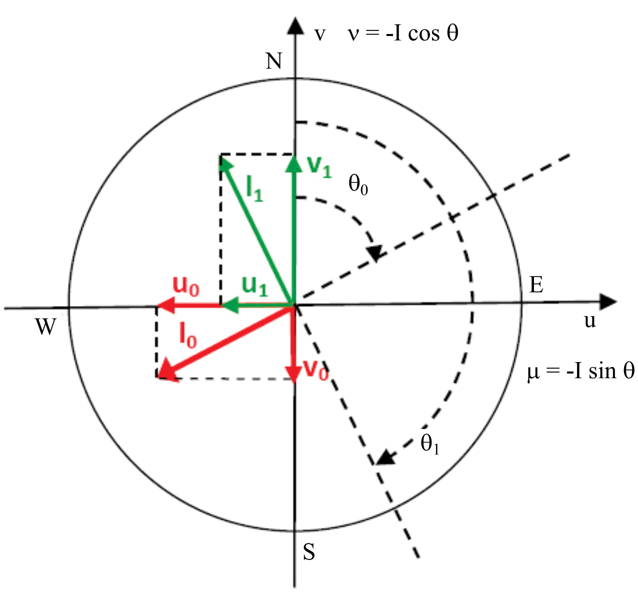

Figure 14. Diagram illustrating the definition of the angle that determines wind direction and decomposition in zonal (u) and meridional (v) components, for two wind vectors of intensities I_0 and I_1 and directions θ_0 (northeast) and θ_1 (southeast). N, north; E, east; S, south; and W, west.

Concluding remarks

The new version of the 1981–2010 Brazilian climate normals will be available at Inmet's webpage (http://www.inmet.gov.br/portal/index.php?r=clima/normaisClimatologicas). It will contain maps and Excel sheets corresponding to all parameters, as well as explanatory texts that can provide the information necessary for the desired research. In case there is no information on your city, it is possible to analyze nearby cities, which can be used as references.

As in any complex work, the results consolidated in this paper are naturally prone to error and improvements and, therefore, always subject to criticism. The executing team strived for the best possible product, within limitations of time and available resources. However, we are certain that the user community of the information presented here will now have at their disposal a more complete and improved product. Certainly, new updates will be produced by Inmet in a near future, focusing on other periods such as 1971–2000 and 1991–2000, since WMO advocates that the climate normals should be calculated in consecutive periods of 30 years (1901–1930, 1931–1960, 1961–1990, 1991–2020…). However, the calculation of intercalated periods, like 1971–2000, has also become a common practice as done by National Oceanic and Atmospheric Administration (NOAA). It is hoped that, with the accumulated experience, future products will be increasingly better. This is a natural process of evolution, which, in no way, diminishes past achievements when theoretical shortcomings and the absence of computational resources required greater dedication and efforts from the preceding teams.

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