ESA Cloud_cci+

Report on User Case Study 2:

Designing a "Sunny Vacation Map" based on Satellite Observations on Clouds and Radiation

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Contents

Scope of this document

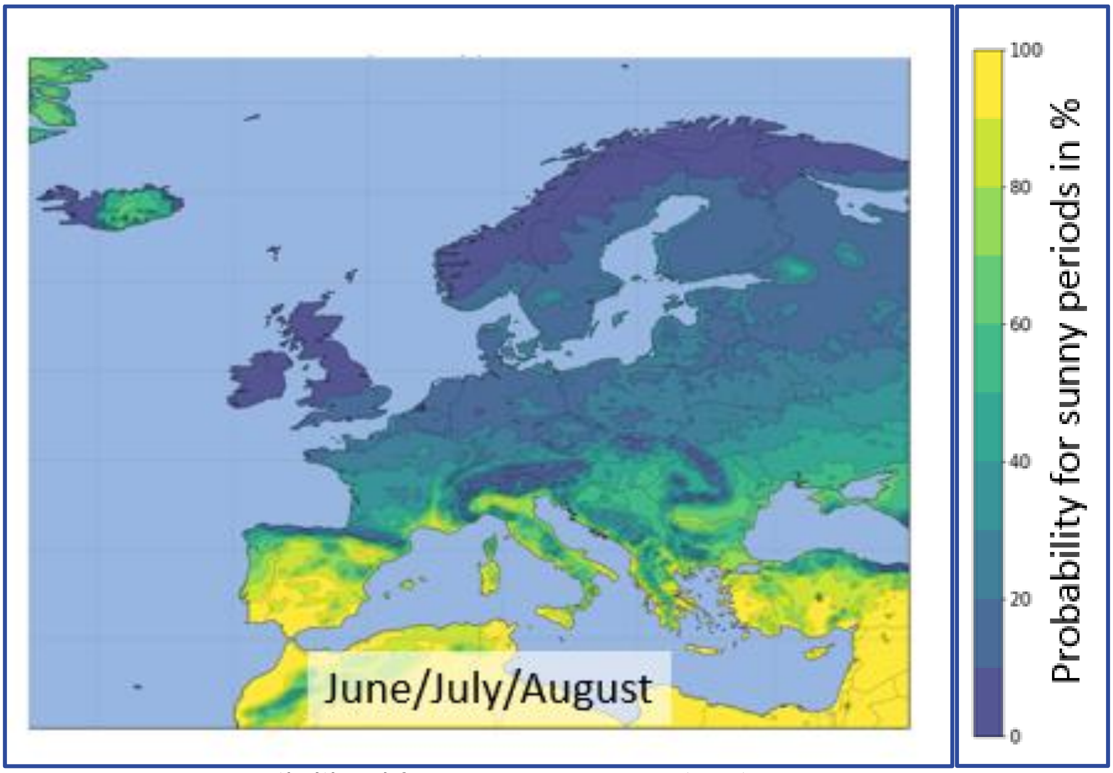
This document contains the possibility to use Cloud_cci data in a helpful way for a wide group of users, namely everyone. Definitions of “sunny days” and “sunny periods” are made based on the ratio of “received shortwave radiation” to the “maximum amount of global shortwave radiation under clear sky conditions” of the “Cloud_cci AVHRR-PM v3” dataset, compiled within ESA’s Climate Change Initiative (CCI). The definition of a sunny day, obviously depending on personal preferences, is here set to need at least 85% received shortwave radiation compared to the maximum possible under clear sky conditions. A sunny period needs to contain at least 5 sunny days in the following 7 days. This calculation is made for every 0.5° x 0.5° grid cell (0.05° x 0.05° for European area) and every day.

Averaged data from 1982-2016 leads to the so-called “sunny vacation maps” for either global coverage or the European area differentiated between the probability for sunny days or sunny periods from which one can see the chance for a sunny vacation in a certain region and annual quarter based on climatological historic satellite data.

In addition two case studies are made for typical vacation-spots. The number of sunny days/periods per annual quarter are shown for the period from 1982-2016 with some additional useful information to find a preferred choice.

Plain text summary

Imagine you are planning your long-awaited holidays and are looking forward to enjoy a full week of ultimate refreshment, full of relaxation, pleasure, and time to rest, leaving everyday life behind you to recharge your batteries. And this time, without all that rain from last year's annual leave, but with plenty of sunny days – at least five out of seven days! Fair enough. But where are you going to travel?



Likelihood for sunny summer vacations in Europe

We have analysed 35 years of satellite observations to compose global "sunny vacation maps" that can help you increasing the likelihood for sunny holidays. With a spatial resolution of about 5 kilometres and stratified by season, our data resolves climatological peculiarities at continental, regional, but also down to local scales, thus can a helpful companion for your vacation planning.

Disclaimer:
This is a teaser study, not implemented operationally yet. Although being statistically sound, our data reflects mathematical analyses of geophysical data of the past summarized as climatological likelihood, thus does not present actual predictions of future weather condition neither in space nor in time.

1 Introduction

This study highlights a specific aspect of how long-term satellite observations of cloud and radiation properties facilitate real-life applications. Having more than three decades of those observations available provides a very sound basis for a statistical analysis of not only the occurrence of sunny days (more or less the inverse of cloud fraction), but also how these are clustered.
In this report the determination of sunny days is described and how sunny periods are defined as function of the sunny day sequences. Global maps of the likelihood of sunny periods are shown, stratified by season, and discussed.

In addition, two pairs of European cities were selected to compare the general likelihood of sunny periods and elaborate on the temporal evolution of this information throughout the whole time series.

This study is considered as teaser for a potential operational application.

2 Approach

When conducting this study, we came across multiple options for designing such a "sunny vacation map" based on the frequency of sunny days. The following questions were guiding our approach:

- Should it simply show the mean probability for sunny days?
- Or wouldn't the probability for a certain number of sunny days in a row, hence sunny periods, be even more helpful?
- If yes, how many sunny days do we need to speak of a sunny period in accordance with our own perception of what makes good holidays?
- Do they need to be fully consecutive?
- And anyway, how do we define a sunny day?

We carefully thought about these questions by taking into account what we believe a holidaymaker might be mostly interested in, by considering preceding similar studies[1], and by testing different approaches. We finally came up with the following strategy of analysis, defining a sunny day on the basis of the obtained global radiation field, and a sunny period as a total amount of at least 5 sunny days within a time period of 7 days. We will elaborate in more details on both points in the following subsections.

2.1 Data Basis

Basis of our analysis is the Cloud_cci AVHRR-PMv3 dataset (Stengel et al., 2020), compiled within ESA's Cloud Climate Change Initiative (Cloud_cci) Phase 2. It is a global dataset on clouds and radiation covering the period of 1982 to 2016, which results in a long-term data record of 35 years – long enough to consider it a climatology.
Cloud and radiation properties were retrieved from passive remote sensing measurements recorded by the Advanced Very High Resolution Radiometer (AVHRR) – in particular by those flying on afternoon (PM) polar orbiting satellites of the National Oceanic and Atmospheric Administration (NOAA). They encircle the Earth from pole to pole about a dozen times per day, gathering information from all around the globe. PM satellites are those satellites that have an equator crossing time in the afternoon (local solar time). See Figure 2-1 for an overview of all satellites included and their respective equator crossing times.

1 E.g. User consultation (tourism sector, solar energy sector and more) and definition of new indices based on cloud cover data within ESA's Cloud_cci project (UCNIv2.1)

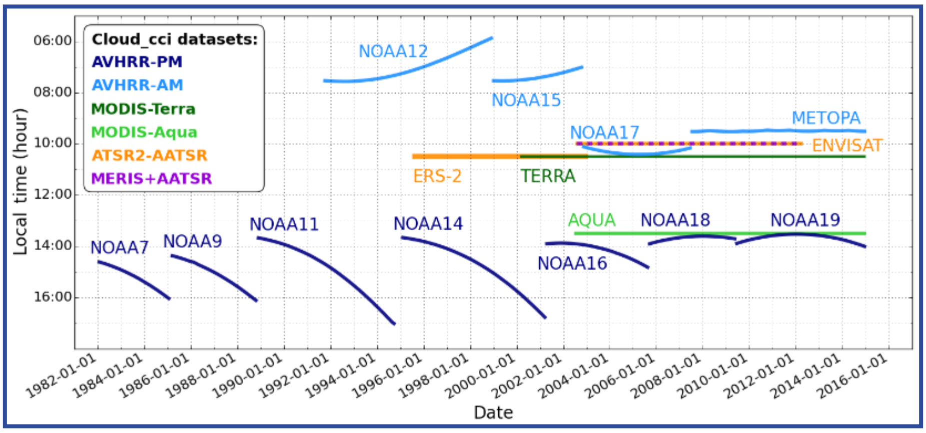


Figure 2-1 *NOAA-Satellites with time periods and equator crossing times – Only the AVHRR-PM satellites are part of the study (Stengel et al., 2017)*

Starting point of our analysis is the radiation dataset processed to Level-3U (daily global composites, see Stengel et al. (2020) and ATBDv6.2 for more details). That means that we look at global gridded data, which were subsampled (not averaged) from the original satellite swath, meaning that the data collected along the orbit were projected onto a global grid, without combining any observations of overlapping orbits. In case that two measurements for the same pixel were available for the same day the one considered best in terms of viewing geometry was chosen. The dataset has a (remarkably high) spatial resolution of 0.05 degree, corresponding to a maximum distance of about 5.5 km at the equator. Observations are available for almost all days in the whole time period. Overall, this results in a total amount of about three billion data points.

2.2 Definition of sunny days

There is no official meteorological definition for a "sunny day", so we defined and tested two approaches. First, we used the fractional cloud cover, inferred from the binary cloud mask (either "1" or "0" per pixel and day for sunny or cloudy conditions, respectively), as the basis for the decision on whether a day is sunny or not. We later found this approach a little inappropriate, because it does not reflect well the actual amount of radiation passing through the clouds, which varies with the cloud type and which might play a role for humans perceiving a particular day as sunny or not. Thus, we decided to define a sunny day more directly, on the basis of the received global radiation at the surface. Therefore, we compared the incoming shortwave radiation (that is, the solar radiation reaching the Earth's surface) to the maximum amount of global shortwave radiation possible under clear sky conditions, accounting for the irradiation angle and the length of days (that is, accounting for the season). The considered ratio yields high values under sunny conditions and small values if the sky is cloudy. Setting the threshold value defining "sunny conditions" is not straightforward, but subject to personal preferences. The definition of a "sunny day" is further complicated by the fact that not only the intensity of sunshine matters, but also its duration during the day. We finally found a value of 85% for the ratio of obtained to possible solar radiation to be most reasonable when defining a sunny day in our case. This is similar to the threshold value taken within the CM SAF sunny day application[2], which was based on a rough comparison between sunshine duration and global radiation obtained from ground-based measurements. Please bear in mind that the definition above is not the "one and only" true way for defining a sunny day, but by all means it is simply handy and reasonable.

[2] see https://www.cmsaf.eu/EN/Products/Tools/Map/Map_sunny_days_node.html

2.3 Definition of sunny periods

This study is intended to provide prospects for experiencing an adequate amount of sunshine when travelling to a selected spot on Earth, based on statistical information inferred from the past. When conducting this study, we became aware that there is a multitude of options for providing this information, depending on what you like to know exactly. Is it the overall, general probability for finding sunny days? Or is it the particular probability to fly into or face a longer lasting period of sunny days, thus sunny periods? Do we call for consecutive sunny days, or do we allow for a one or two days break? After thorough considerations, we concluded that it is the probability to get at least “x” days of sunshine within a total amount of “n” days of vacation, which might be one of the most valuable information for a holiday maker. In the following, we exemplarily examined this for a number of x=5 sunny days within a total amount of n=7 days of vacation, which possibly matches well the duration and expectations of an ordinary holiday trip. This (“at least 5 sunny days within 7 days”) we define a “sunny period”.

2.4 Analysis

In order to design our “sunny vacation map” of sunny periods, a sequence of steps is taken. We carry out the analysis once for the full globe and once only for the region of Europe, to get a more detailed view on that domain. We proceed as follows:

1) For our global analysis, we start by reducing the huge amount of data points to a manageable size. Instead of analyzing each single small (0.05° x 0.05°) pixel of the dataset for sunny days and periods, we take the mean of an aggregated area of pixels as the basis for our analysis. We do so by spatially averaging the dataset over 10 x 10 pixels, corresponding to a grid resolution of 0.5° x 0.5°. For the more detailed view on Europe, we keep the original grid size of 0.05° x 0.05°.

2) We calculate the ratio of “obtained global shortwave radiation” to “maximum global shortwave radiation being possible” for each (0.5° x 0.5° or 0.05° x 0.05°) grid cell and for each daily time step. We only take values from the ascending path of the satellite (corresponding to the northward motion of the satellite), during which mostly daytime values are gathered, whereas it is night almost all over the place during the descending path, the southward motion of the satellite. To be thorough, we only consider values with an illumination flag of “1” (denoting “day”) and filter out especially those with a flag of “2” (“twilight”).

3) Based on our definition for sunny days, we create a binary spatial field for every day, consisting of two possible values at each grid cell: sunny and cloudy (“sunny” meaning the ratio of obtained to possible shortwave radiation being bigger than 0.85, and for “cloudy” being smaller than 0.85). Thus, we get, for each grid cell, a time series of sunny and cloudy days.

4) Based on this time series, we determine the probability of sunny periods, inferred from their frequency of occurrence. Therefore, we count, in each single time series, the number of days which are followed within the next 7 days (the starting day included) by at least 5 sunny days. This number we then divide by the total number of considered days, which (multiplied with a factor of 100 to get the values in percent) finally results in the frequency of occurrence of sunny periods as we defined them. Figure 2-2 illustrates exemplarily our approach. As we consider in this study 35 years of observations, thus a large number of days, we can interpret this frequency of occurrence as a probability (or likelihood), the probability for facing at least 5 sunny days when going on a one-week trip. As the time of year often matters, we carry out this analysis separately for each season.

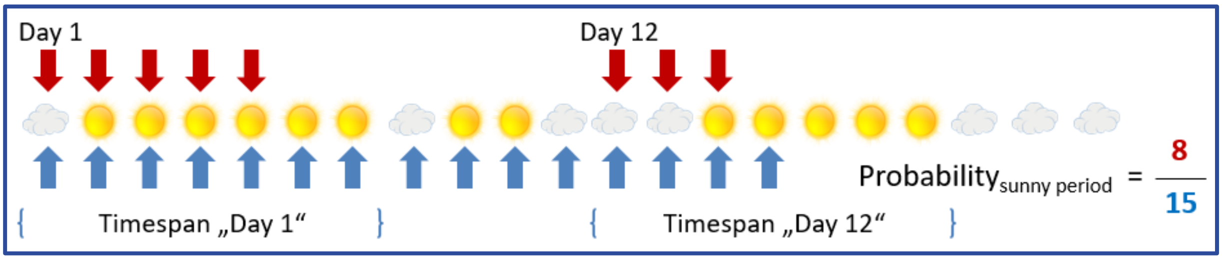


Figure 2-2 *Schematic illustration of the way of calculating the probability for sunny periods*

Red arrows highlight days legitimately called sunny periods. E.g. Day 1 is called a sunny period, as this and the following 6 days include 6 sunny days. Also Day 12 is called a sunny day, the following 6 days include 5 sunny days. Day 6, the first day without a red arrow, is indeed sunny but not called a sunny period, as this day and the following 6 days include just 4 sunny days. The blue arrows highlight the days that can be verified in terms of sunny periods. The last 6 days are ignored, as the number of following days is too small and not decidable. The ratio of red-arrowed days and blue-arrowed days defines the probability at this exemplary spot and time span.

3 Results

3.1 Global and European Sunny Vacation map

Figure 3-1 illustrates the results of our global analysis, the global “sunny vacation map” of sunny periods: It gives the likelihood to get at least 5 sunny days within 7 days of vacation lying ahead, spatially resolved on global scale (albeit slightly coarser than possible, see above) and depending on the time of the year. Oceanic regions are masked out as the typical holiday resort is on land, unless it is a sailing trip or cruise. The map reveals that, globally seen, the whole range of possible probabilities for sunny periods is covered, ranging from nearly 0% in e.g. the inner tropics near the equator to almost 100% in desert regions like the Sahara. Primarily, the probability for sunny periods varies with latitude. It is generally large (more than 60% in the mean) in the subtropics, where large-scale subsidence typically supresses the formation of clouds. It is rather small (less than 20% in the mean) in the outer tropics, where strong insolation triggers intense cloud formation. And it is moderate (between 10 to 40%) in the mid-latitudes, where highs and lows frequently alternate, usually bringing a diverse mix of sun and clouds.

In other words, you can be virtually certain not to get 5 fully sunny days within your 7 days trip if you go to Panama, Equatorial Guinea, or Singapore (all three in the tropics), whereas the chances are fifty-fifty in Spain (mid-latitudes) and really good if you fly to e.g. the western coast of South Africa, Saudi Arabia, or Algeria (subtropics).

On top of the latitudinal dependence, we find, as expected, strong seasonal variations of the probability for sunny periods, especially prominent in the tropical and subtropical regions. These mainly arise from seasonally varying large-scale dynamics, resulting from the north- and southward shift of the sun with the time of the year. If you have a look at India for example, catching 5 sunny days within your 7 day trip is a safe guess in winter, when the probability exceeds 80%, while you cannot expect a sunny period in summer when the probability is below 10%, in that case due to monsoonal activity. Similar restrictions occur in the north of Australia, big parts of Brazil, countries in central Africa, the western part of Mexico, and the regions at the southern edge of the Sahara (referring here to the actual summer and winter months at the respective hemisphere). In contrast to that, we find a significantly greater chance for sunny periods in summer than in winter (difference up to about 60%) in the regions surrounding the Mediterranean Sea, in the US (especially at the west coast), and in the countries east of the Caspian Sea like Turkmenistan, Uzbekistan, or the south of Kazakhstan.

The rather unsurprising bottom line from that is: Be aware of the season before booking your trip to Mumbai, Darwin, Brasilia, Los Angeles, or Málaga – if you catch the wrong season, the chance is pretty high to experience many days of cloudiness instead of vast blue sky, even if the year-long average suggests otherwise. In addition, one should not forget, especially in the European winter months a sunny day could result from an anticyclone and come around with very cold temperatures.

If we have a closer look at Europe (Figure 3-2), we also see an overall latitudinal dependence, especially obvious in autumn: The more south we go, the higher the probability to experience a sunny period. For northern countries like Norway or Sweden, for example, the probability does not exceed 20%, whereas it almost achieves remarkably 90% to 100% in the south of Spain, Italy, Greece, and Turkey in summer – the typical holiday destinations for the Europeans. Furthermore, a clear seasonality is also visible here, especially where we have high values in summer. This is firstly due to the northward shift of the large-scale subsidence zone in summer (see above). Secondly, it is due to less cyclonic activity, which means fewer low-pressure areas passing over Europe, because of a smaller temperature difference between North and South Europe. On top of that, one can recognize very well, due to the high geographical resolution, regional small-scale variabilities. In particular, mountain regions like the Alps, the Pyrenees, or the Carpathians stick out with relatively low probabilities for sunny periods, due to air mass lifting at mountain ranges and subsequent cooling. The same applies for the Italy's or Greece's inland, for example.

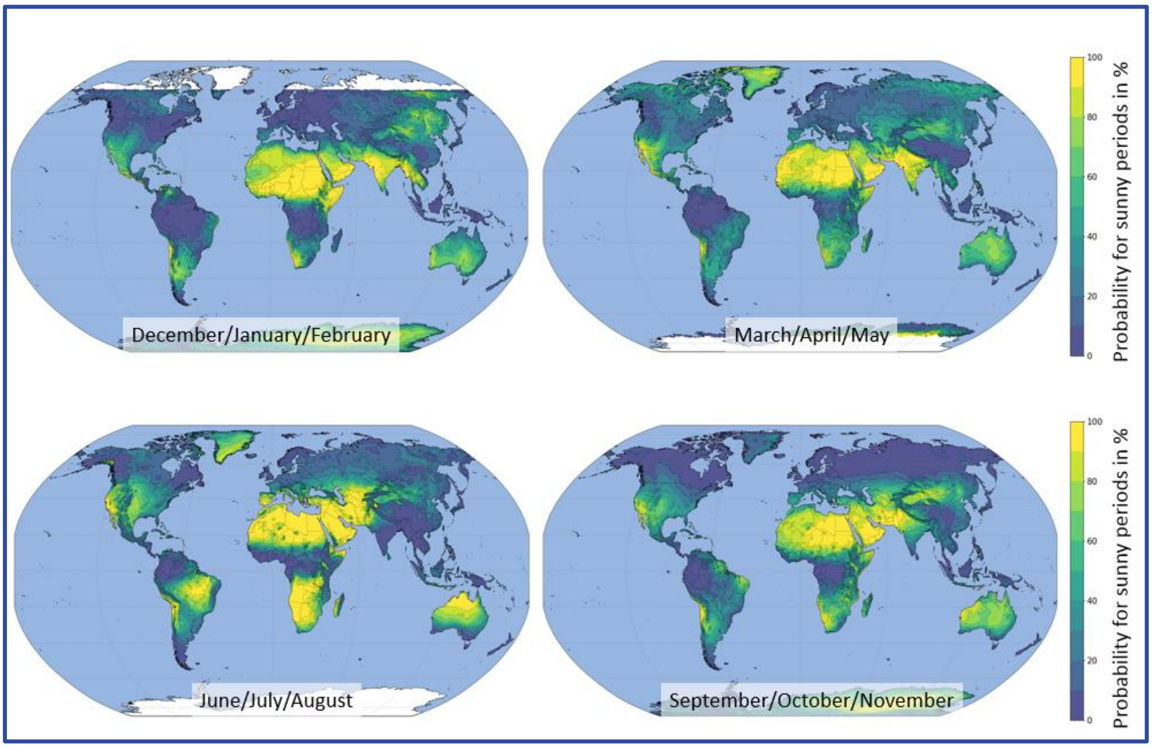


Figure 3-1 *Global "sunny vacation map" of sunny periods*

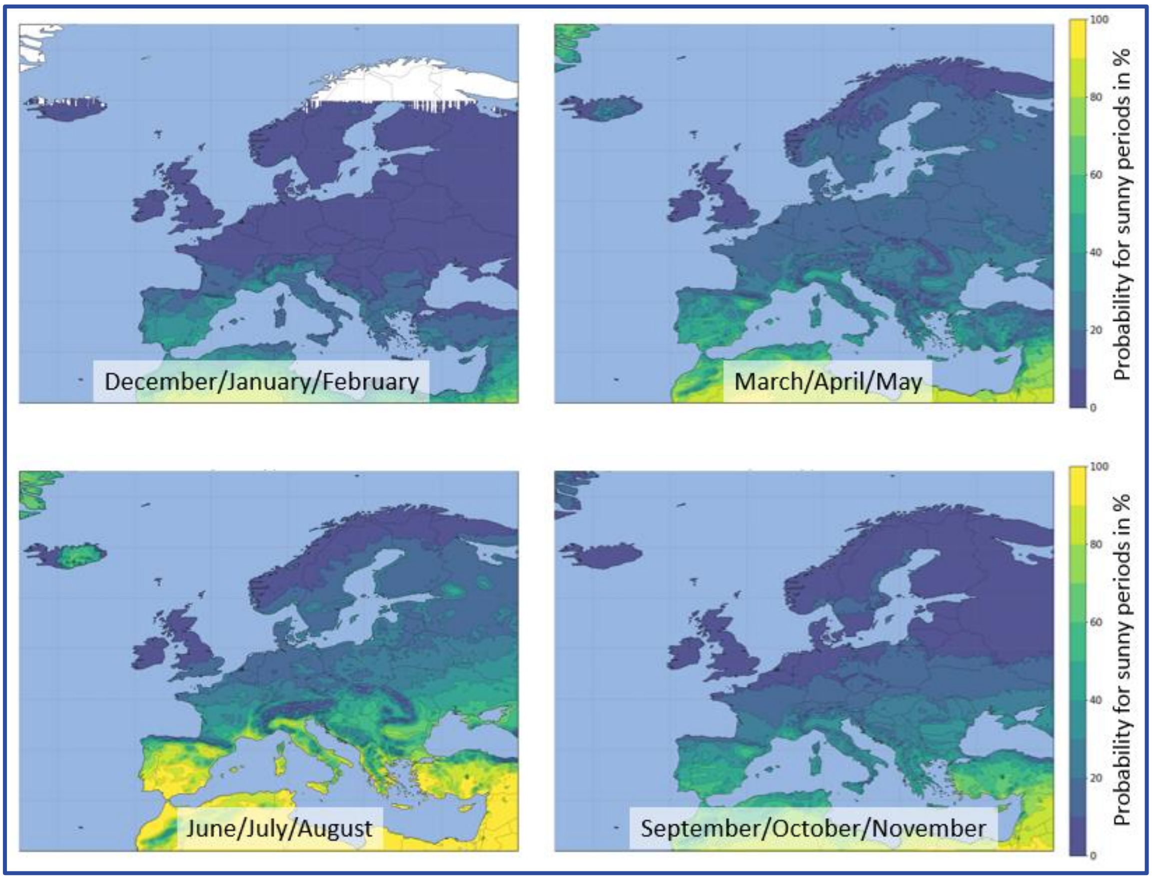


Figure 3-2 *European "sunny vacation map" of sunny periods*

3.2 Sunny days and periods for selected spots

In order to make progress on your vacation plans, the "sunny vacation map" provides valuable initial advices about a certain continent, country or region (the latter is at least seen in the European map). Otherwise, it is not easy to locate an exact spot on the map and due to the coarse color scale it is rather an approximation than a precise look at a number (the number itself is just a probability with later mentioned uncertainties). In addition, the number of sunny periods varies every year (as you can probably tell about your regions last summers and winters) and this is, regarding to the map, not visible (e.g., two likelihoods of 50% are on average the same as likelihoods of 25% and 75%). The average probability of sunny days over the land area of Europe varies between 56% and 61% in the past 10 years. Accordingly, the variability in the temporal and spatial average is not clearly visible but still existent as it is apparent in a time series of one/two spots (see Figure 3-3). The factor of constancy should be kept in mind so the standard deviation is introduced in order to give indications. Figure 3-3 illustrates the number of sunny periods of every year's summer from 1982-2016 for two different locations. Therefore, the perspective is a little bit different compared to the "sunny vacation map", as it is limited to a specific point on earth (or two in this case) and comes without probabilities but indeed with a number of sunny periods per summer. Actually, a number of sunny periods or the probability is pretty much the same, as the probability is the number of sunny periods in relation to all periods over a certain time span. However, looking into the past and talking about probabilities seems misleading. This alternative way to investigate the next vacation spot has still, despite the missing spatial coverage, some advantages and completes the analysis, as it provides additional attributes like the average number of sunny days, standard deviation and the "best day of the year" to travel.

Two user cases are following and illustrated in Figure 3-3 and Figure 3-4. Figure 3-3 is a comparison between Barcelona and Rome for a one-week trip in summer. This requires the index of sunny periods and the results just for the summer months[3]. The result is then the number of sunny periods per summer of every year from 1982-2016, the according average and standard deviation, the probability of a sunny period for an exemplary date (maybe the first day of the holidays) and the probability of the “best day of the year” (for sure only regarding sunny conditions) to travel.

The second user case (Figure 3-4) is about a one-day trip to either Paris or Venice in spring. This case requires the index of sunny days and the results just for the spring months. The result is then the number of sunny days per spring of every year from 1982-2016, the according average and standard deviation, the probability of a sunny period for an exemplary date and the probability of the “best day of the year” to travel.

There is usually that one question about vacation preferences: Sea or mountains? Opinions differ on that and there are cases for both. There is no correct or wrong answer for subjective feelings and everyone has its own favourites. And at the end probably a mix of both from time to time is the best. However, what about big cities? There is a lot to see and exciting things to discover like museums, shopping, historic buildings or even the local football club. Barcelona/Spain and Rome/Italy could be interesting, as the sea is nearby and the outback is mountainous as well by the way.

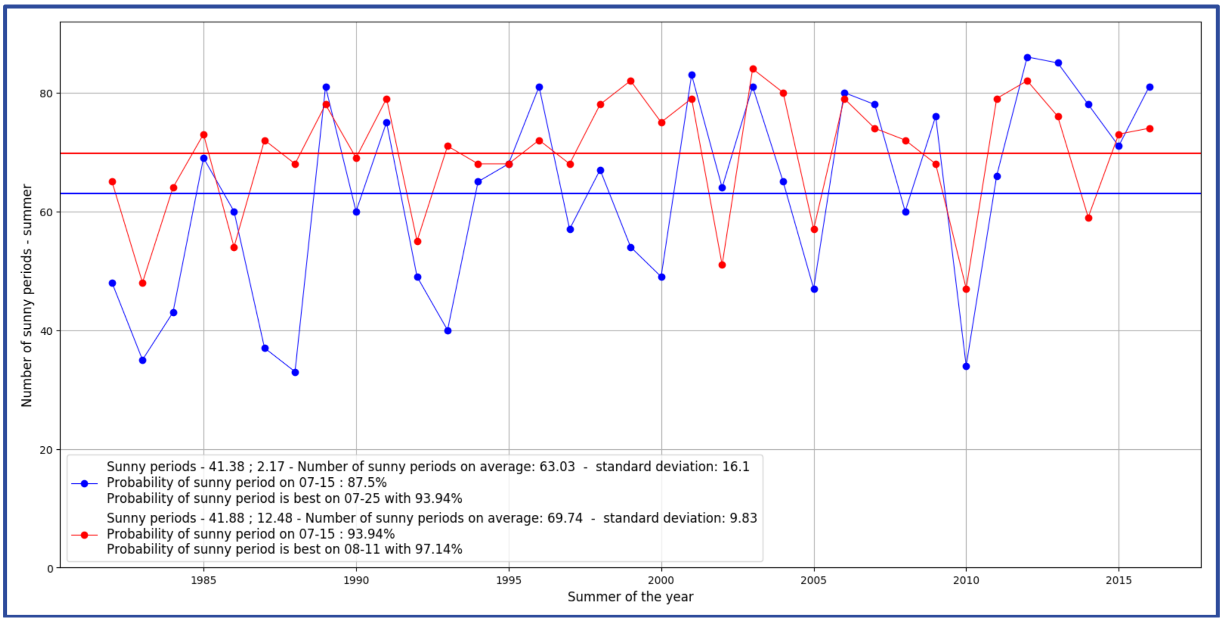


Figure 3-3 *Sunny periods in Barcelona, Spain (blue) and Rome, Italy (red)*

Figure 3-3 is about those two popular cities in Europe: Barcelona (blue), located in the northeast of Spain at the coast of the Mediterranean Sea and Rome (red), located in the middle of Italy near the west coast and the Tyrrhenian Sea. A decision between these two cities could be close and maybe the factor of enjoying a sunny period could be crucial. Figure 3-3 includes the number of sunny periods (the number of days, which should be good to start a 7-day-vacation) for the summer of every year from 1982–2016. The maximum possible number of sunny periods per summer is 86 (30+31+31=92, the last 6 days are out as the number of following days is too small).

The solid lines marks the average number of sunny periods, which gives an early first guess overall. Rome has a higher number of sunny periods on average with almost 70 compared to the 63 days of Barcelona. The number is noted in the bottom text field. As both cities are located nearly at the same

[3] Seasons are defined as follows: Spring (March, April, May), Summer (June, July, August), Autumn (September, October, November), Winter (December, January, February)

latitude, no bigger differences are expected. The difference of 7 days is probably a result of local characteristics and maybe derived by the distance to the sea. Furthermore, the typical westerlies could be significant, as there is landmass on the west side of Barcelona and sea on the west side of Rome.

One can see indeed a higher number of sunny periods in Rome but there is another parameter to look at: The standard deviation. The standard deviation is a number identifying the spread of numbers around its mean. The smaller the standard deviation is, the less are the numbers fluctuate around the mean. In case of Barcelona, the average distance of every summer to the mean (63.03) is 16.1 days and therefore higher than in Rome (9.83). This is also noted at the text field.

To complete the picture a third statistic is provided: The probability of a sunny period for an exemplary day and the “best day of the year”. This statistic is calculated for every spot and every day of the year (e.g. the probability for January 1st at a specific spot is the averaged probability of every years January 1st on that spot – therefore, 366 values for a specific spot are calculated and the day with the highest probability picked out). Finding a time gap in which the whole family is not busy is sometimes a planning masterpiece. School holidays, available free time of one, two or more family members, other activities … Due to planning, the timespan for vacation stands often already at the beginning of the year. This is another factor to affect the decision-making process. In case of Barcelona or Rome, the result is heading in the same direction like the probability of a sunny period (at least for July 15th), with advances for Rome, just more exactly for an exemplary date. Just in case your schedule is nearly empty and you are free to travel whenever you want: A “best day of the year” is provided, the day of the year with the highest probability for a sunny period. Overall, Rome looks not just like the “on average” winner; it seems like it is also more reliable and does not fluctuate that much.

It is up to the user to make something out of the numbers, one prefers the saver guess with a low standard deviation and one is gambling and taking the risk with a chance of more sunny days … or not. Still, the top 3 sunniest summer were in 2012 (Barcelona), 2013 (Barcelona) and 2003 (Rome) with 100% sunny periods in Barcelona 2012. Accordingly, the higher risk of Barcelona could pay of, as four out of the last five summer had a higher number of sunny periods.

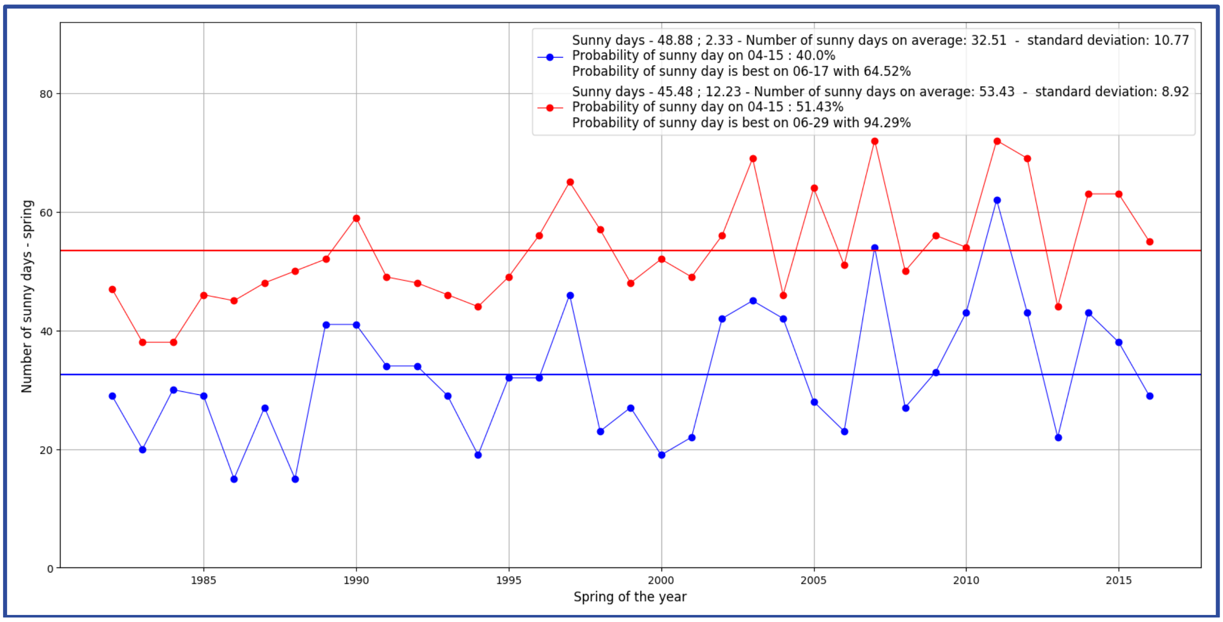


Figure 3-4 *Sunny days in Paris, France (blue) and Venice, Italy (red)*

Of course, Spain and Italy are competing on a high level in summer (or probably all year) and the chance of getting constant cloudy (and maybe rainy) conditions is negligible. (Except you chose the summer of 2010 and are annoyed that you chose just that year.) In addition to the yearly summer trip, another trip would be great. Let's say just for one day or a weekend earlier the year. Fortunately, information about the separated spring months and sunny days (instead of sunny periods) are possible as well.

Imagine you and your family want to enjoy the first sunny days of the year. Paris would obviously be great. Stroll between the monumental buildings, eating croissants at the Avenue des Champs-Elysees and looking up to the Eiffel tower with a blue background sounds wonderful. On the other hand, a trip to Venice with its countless rivers and bridges is worth a consideration. A ride with a gondolier or eating pizza at the St. Marcus Square would be even greater without a jacket but indeed sunglasses. So maybe Figure 3-4 can help, as the differences are not small in this case.

Figure 3-4 provides the number of sunny days per spring (maximum is 92; 31+30+31=92, this time every day is capable as the following days are out of interest) for every year's spring from 1982-2016. As you can see immediately, the chance of getting a sunny day is much higher in Venice (red points) compared to Paris (blue points). The average number of sunny days in Venice is 53.43 and therefore 64% higher compared to Paris (32.51). Venice is located in the north east of Italy at the north end of the Adrian Sea. The Adrian Sea is responsible for moderate climate conditions. Paris is located a bit above the centre of France and thereby much further north than Venice. This fact alone suggests more sunny days in Venice. As mentioned above and visualized in the European "sunny vacation map", there is a north-south gradient with increasing probability of sunny days/periods to the south.

There was not a single year with a higher number of sunny days in spring in Paris, so even the slightly higher standard deviation advises against a risk. In case of sunny conditions around spring, Venice is probably a better place than Paris. This is confirmed by the probability to catch a sunny day at the (e.g. 15th of April): 51% for getting a sunny day in Venice is more likely than the 40% for Paris. Nevertheless maybe you are so lucky to catch a spring like 2011, where only eight out of 35 springs in Venice had more sunny days. Or you choose Venice this time but have also a look at the "best day of the year" for Paris, which is the 17.06. (64,52%), and plan a second trip.
But besides all the considerations, sometimes the weather just doesn't matter and when it rains there is a possibility to see a rainbow over the triumphal arch, which is probably an unforgettable moment.

4 Final remarks

There are several aspects or caveats, which you should keep in mind when considering the "sunny vacation map" of sunny days as decision guidance for booking you next trip.
First of all, the analysis is completely based on measurements taken by remote sensing from space, which are highly complex, especially in their retrieval algorithms, and which therefore always bring along a certain degree of inaccuracy, especially over bright surfaces for example (although to be fair, as mentioned at the beginning, the quality of observations has increased significantly in the past decades).

Secondly, a potential inaccuracy in this study comes from using Level-3U data, which only contain one instantaneous measurement, one snapshot, per day and pixel, thus no daily mean. Probably, this is not crucial, because we could assume that the temporal variability is superimposed by the long time period (and number) of observations and therefore negligible. But it brings in a certain degree of uncertainty which you should keep in mind.

Thirdly, the actual occurrence of sunny or cloudy periods are not entirely random as laid out in our approach, but depends on the meteorological circumstances, that can vary periodically from year to year or even be subject to trends. Thus, please note the disclaimer all information is provided to the best of our knowledge, based on data of the past, and does not come with any guarantee.

Last but not least, the reader should also be aware that the requirement of 5 sunny days in a total of 7 is rather strict and that, in many cases, also a smaller amount of sunny days should be absolutely sufficient to spend a restful, lovely holiday, as "there is no bad weather, only inappropriate clothing." (Ranulph Fiennes). So don't feel discouraged if the holiday destination you chose for your next vacation does not exhibit the most possible chance for sunny periods – you can still have a fine holiday! After all, it is not the sunny days alone which matter!

5 References

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UCNIv2.1 Cloud climate indices: User consultation and new indices, v2.1. ESA Cloud_cci.

6 Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CCI	Climate Change Initiative
CM SAF	EUMETSAT Satellite Application Facility on Climate Monitoring
DWD	Deutscher Wetterdienst
ESA	European Space Agency
NOAA	National Oceanic & Atmospheric Administration
RAL	Rutherford Appleton Laboratory