FloraMap Climate Phase Angles, their calculation and extension to the nontropical world

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In order to compare climates in different parts of the world we have to eliminate the artefact of seasons occurring at different calendar dates depending on the climate type and position on the globe. In the FloraMap Users Manual we gave the following explanation of the method used in release 1.0 of FloraMap.

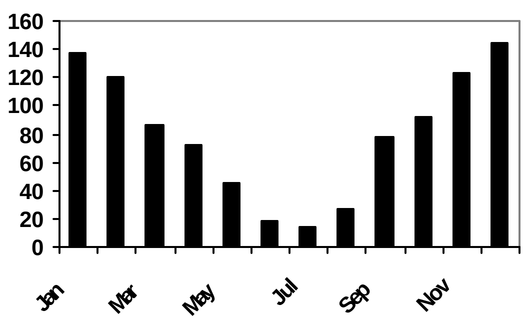
Climate Date Standardisation (Rotation)

The climatic events that occur through the year, such as summer/winter and start/finish of the rainy season, are of prime importance when comparing one climate with another. Unfortunately, they occur at different dates in many climate types. The most obvious case is where climates are compared between points in the Northern and Southern Hemispheres, but more subtle differences can be seen in climate event timing throughout the tropics. What we need is a method of eliminating these differences to allow us to make comparisons free of these annual timing effects.

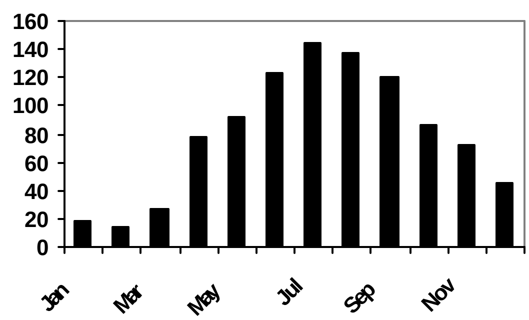
Let us look at two hypothetical climate stations. They are in a typical Mediterranean climate—warm wet winters, hot dry summers. Northville could be somewhere in California, and Southville might be in Chile. The August rainfall in Southville is received in January in Northville. If we plot these rainfalls in polar co-ordinates, we can readily see that to compare them we need to rotate them to a standard time.

Monthly rainfalls for Northville and Southville.

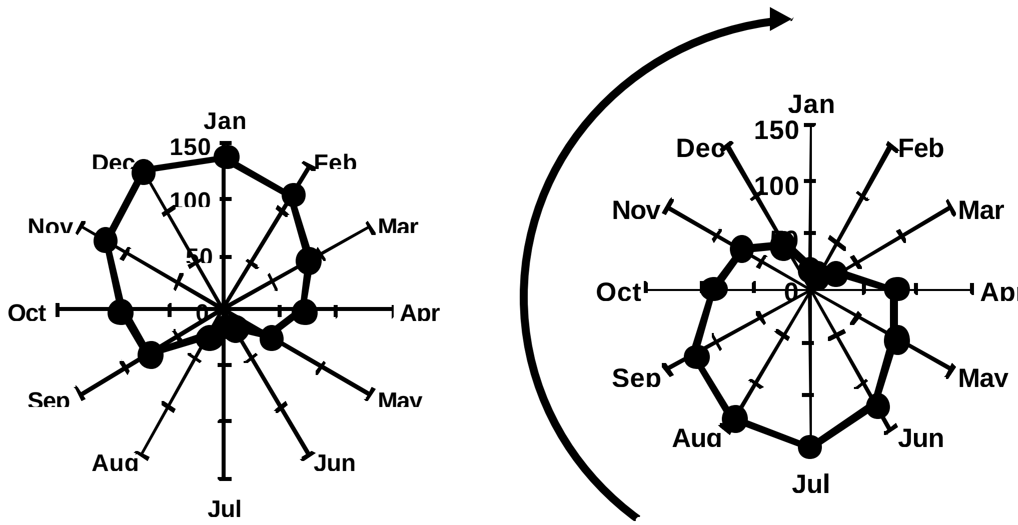
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northville	137	120	87	72	46	18	14	27	78	92	123	145
Southville	18	14	27	78	92	123	145	137	120	87	72	46



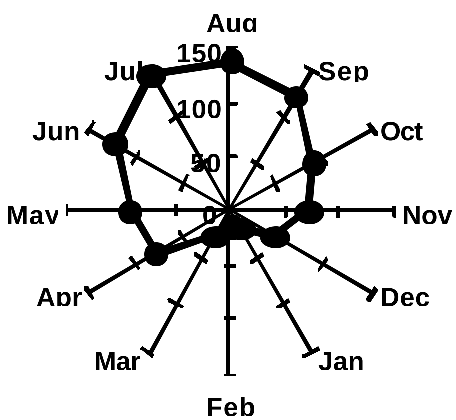
Northville monthly rainfall



Southville monthly rainfall



Northville Southville



Southville rainfall rotated to coincide with timing of Northville

How do we do this automatically? The answer is the 12-point Fourier transform. This is fortunately the simplest of all the possible Fourier transform algorithms. It is highly computationally efficient and fast. In fact, it is the basis of nearly all Fast Fourier transform algorithms that break the problem down sequentially into the simple 12-point case. It takes the 12 monthly values and converts them to a series of sine and cosine functions. The one used in FloraMap has a modification to make it conserve the monthly total values (Jones 1987). The equation produced is:

$$r = a_0 + \sum_{i=1}^{6} a_i \cos(ix) + b_i \sin(ix)$$

This can be rewritten as a series of frequency vectors, each with an amplitude a_i and a phase angle, q_i:

$$a_i = \sqrt{a_i^2 + b_i^2} \qquad\qquad q_i = \sin\frac{b_i}{a_i} = \cos\frac{a_i}{a_i}$$

If we subtract the first phase angle from all the other vectors in the set then we have produced a rigid rotation of the vectors. This is the rotation that we are seeking. It puts the maximum of the first frequency at a phase angle of zero and places the rest in positions equivalent to their angular separation in the original data. We then use the first phase angle for rainfall to rotate the data for temperature and diurnal temperature range, and these variates are rigidly rotated along with the rainfall.

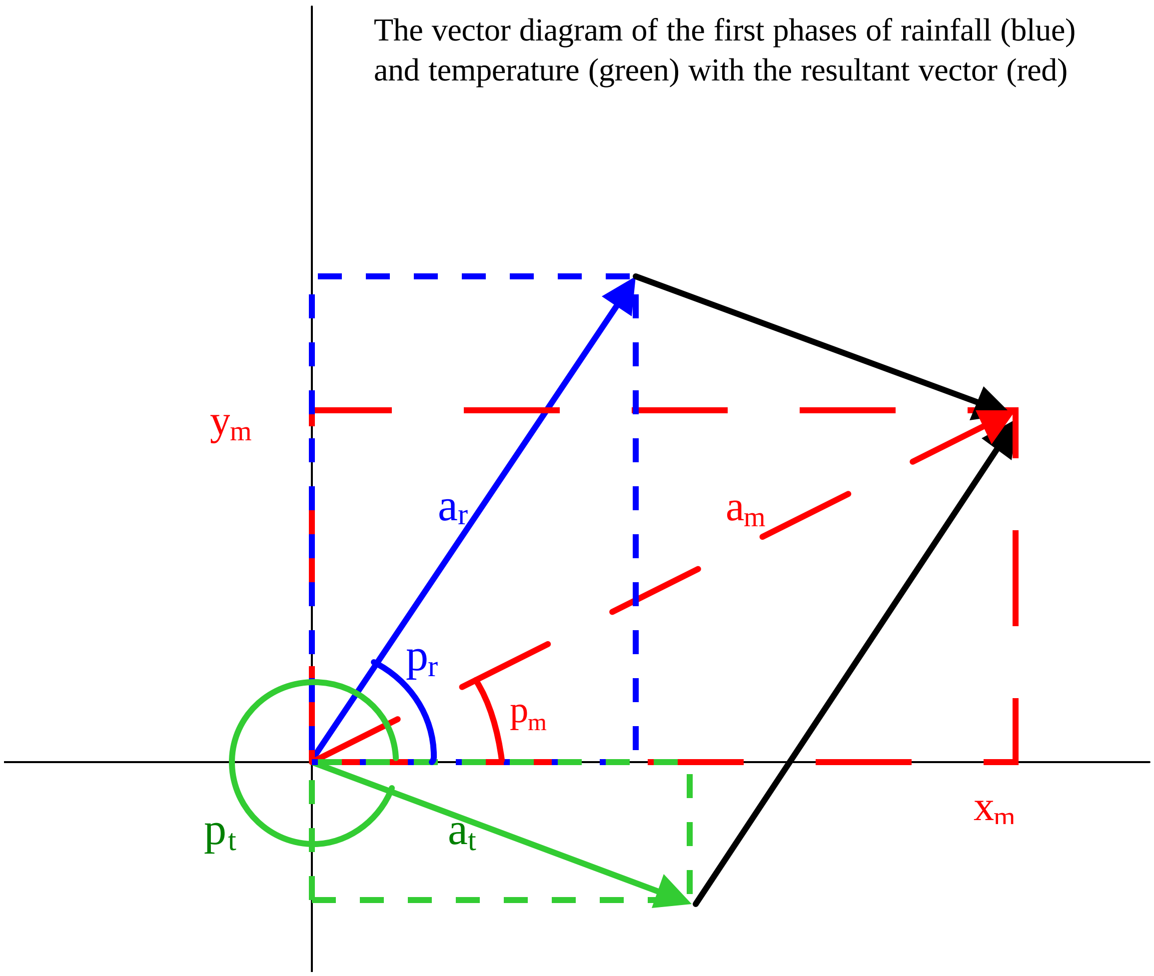
It is obvious how this algorithm works for climate records with uni-modal rainfall. Climates could exist that are ambivalent with respect to a first frequency rotation. In practice, these are hardly ever encountered, the only serious case being where no rainfall occurs at all throughout the year.

This explanation is fine for the tropics and works almost everywhere as stated in the Release 1.0 FloraMap manual. There was a small chance of the procedure going off the rails if an accession set was fitted to a model in latitudes high enough to exhibit Mediterranean climates (as used in the example above). In the case when some of the accessions fall in the winter rainfall areas and some in strongly summer rainfall (non-Mediterranean) areas, the resulting model could have a very poor fit. As this is botanically unlikely I do not believe that it has yet been observed in practice. Although I have come across the case in running an artificial test set across the Andes in Chile/Argentina.

This worked well until Dr Ian Makin of the International Water Management Institute (IWMI) kindly offered me access to the IWMI World Water and Climate Atlas to make climate grids to extend the range of FloraMap. I chose to try the grid for Europe because I know we have a number of potential users wanting to look at this area. The problem then arose. Temperature is by far the dominant climate determinate in Western Europe. The rainfall patterns can be winter, summer, or quite indeterminate over quite short distances.

We therefore have the possibility of rotating on rainfall or temperature, but when to decide which is the dominant? I tried many combinations of rules, but unfortunately came to the conclusion that none were acceptable. They all resulted in a hard line across the map at some point where the rotation basis changed. This led to climates that should have been grading imperceptibly from one type to another suddenly jumping at a discontinuity. This would have given the users serious problems when fitting models in these areas.

The best solution I can find is to use BOTH the rainfall and the temperature in calculating the rotation phase angle. Thus:



The vector diagram of the first phases of rainfall (blue) and temperature (green) with the resultant vector (red)

The resultant phase angle and amplitude are then:

$$y_m = a_r \cos p_r + a_t \cos p_t$$

$$x_m = a_r \sin p_r + a_t \sin p_t$$

$$a_m = \sqrt{y_m^2 + x_m^2}$$

$$p_m = \text{angle}\left({x_m}/{a_m}, {y_m}/{a_m} \right)$$

Unfortunately, this does not completely solve the problem of fitting a model to climates with different weather determinants. However, the vast majority of climates in the world are either:

(1) Rainfall determined where temperature is not an important seasonal effect (large areas of the tropics and subtropics).
(2) Temperature determined where rainfall is even throughout the year (most of the rest of the tropics and some temperate climates)
(3) Rainfall and temperature determined when the two variates are highly correlated (summer rains - most of the rest of the world).

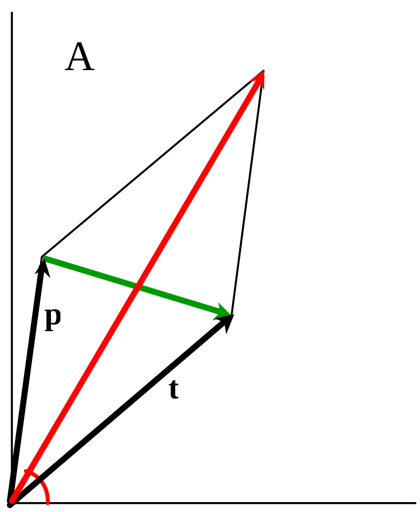
The Odd Man Out is

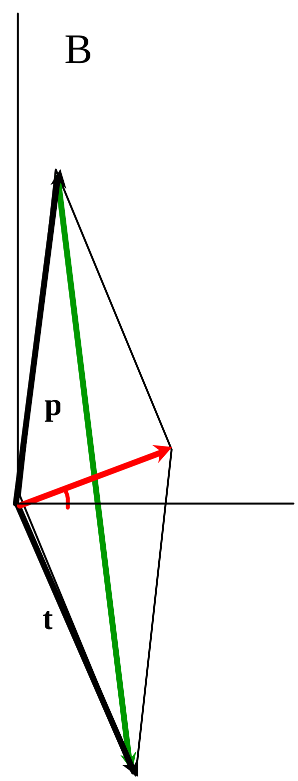
(4) Winter Rains and Hot Dry Summers. (Almost only Mediterranean climates)

Luckily the Mediterranean climates are at moderately high latitudes and we can afford to have the rotation dominated by temperature without losing generality in the rotations and comparisons. We therefore need to increase the weighting for the temperature vector smoothly as we approach the Mediterranean climates (in order to avoid a sudden swing).

I have found that the following weightings work well:

p = rainfall mm
t = temperature x 2 x abs(latitude)





There is a potential trap when the two vectors almost cancel each other. This could result in wild swings of the rotation angle for small changes in the rainfall and temperature vectors. This becomes more likely as the situation passes from that in A (above) to B and beyond. The red arrows are the rotation vectors as before, but calculated on the weighted rainfall and temperature vectors.

Where the rotation vector is the vector sum **r** + **t,** the green counter-diagonal vector is the difference **r – t**. It can be readily seen that the dangerous areas will be when **r – t** is much greater than **r + t.** We can therefore use a handy index of stability, s.

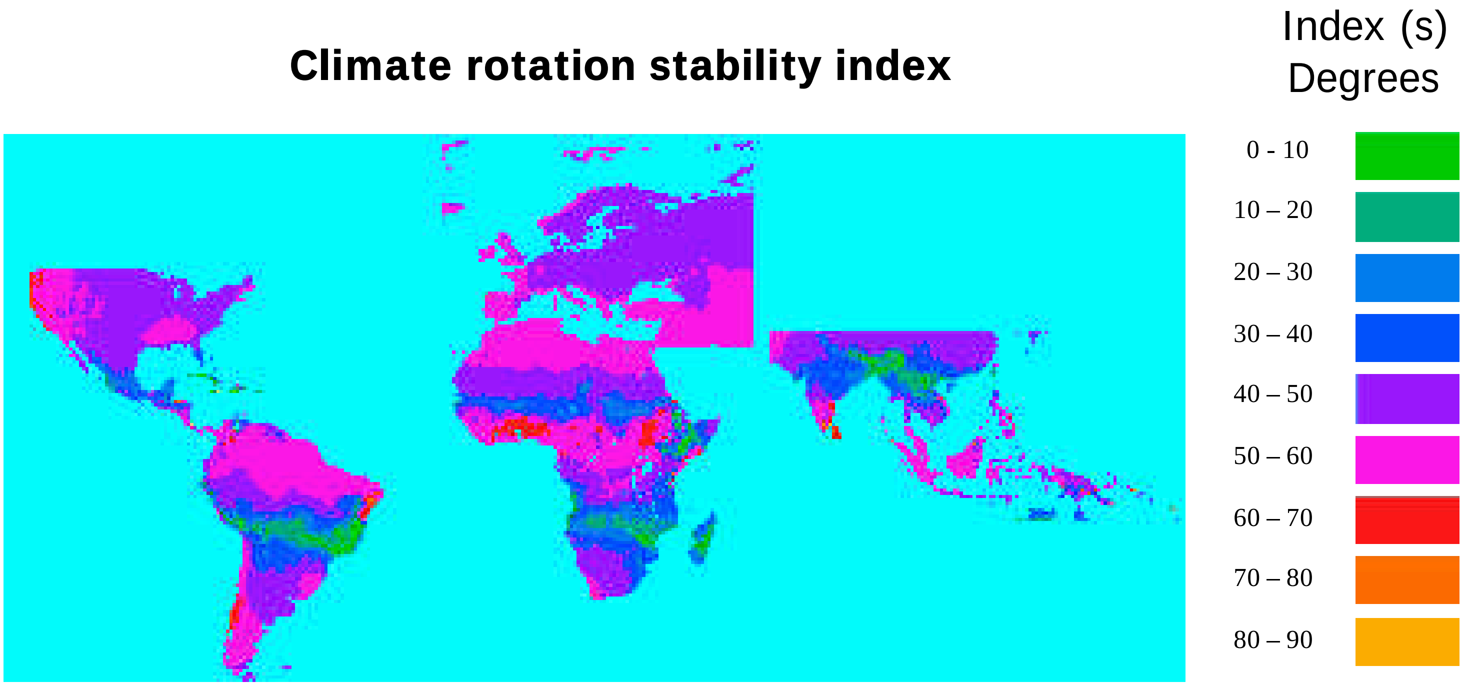
$$s = \arctan\left(\frac{|\mathbf{r}-\mathbf{t}|}{|\mathbf{r}+\mathbf{t}|}\right)$$

This will be zero for stable states where the rotation angle is dominated by rainfall, by temperature, or by both acting in concert. It will approach $\pi/2$ as the vectors tend towards cancelling their effects. Because we can map this index we can check for areas where this indeterminate rotation might occur.

The maps on the following page show the stability index (s) and the phase angle. There are areas of relatively high s (potential instability) on the USA pacific coast, in Chile, north-eastern Brazil and Sri Lanka and through some areas of Central Africa. However there are no areas where the index reaches 80 degrees. Although this appears high, the phase angles are rotated correctly and there is in fact very little chance of a spurious rotation.

If you are uncertain of the model fits when including accessions from these areas please use the ClimateDiagram tool to investigate the situation. In the case of high precision grids there may by the occasional pixel which rotates in an odd way and we will review this possibility when we create the new grids. However for the present FloraMap grids there will be no problem.

Climate rotation stability index



Climate Phase Angle