Expedia's Best Blue Sky: Experiments and Results

Heather Pegrum, Ruth Montgomery, Nigel Fox, John Mountford, Saber Salim, Peter Woolliams, Mike Pointer, Laura Crane, Magdalena Chapman

July 2006

1. The National Physical Laboratory (NPL)

NPL is the UK's national measurement institute and is responsible for the establishment and maintenance of all physical measurement quantities e.g. the kilogram, second and the metre. Any measurement made in the UK is ultimately traceable to NPL. It is not only these well-known quantities that NPL is responsible for however, but also things like light and colour.

The concept of colour and the ability to describe it in standardised terms dates back to 1931 and is based on work carried out by scientists at NPL in conjunction with Imperial College London during the 1920s. This colour system was adopted internationally and although refined, still remains the basis of modern colorimetry. *(Colorimetry is the science that describes colours using numbers, or provides a physical colour match using a variety of measurement instruments).*

1.1. Why are NPL involved?

NPL became involved in this project to provide Expedia's Best Blue Sky explorer with the necessary equipment so that measurements of the sky can be made accurately, using techniques developed by the NPL.

This enabled the measurements to be traceable to the International System of Units (SI), so we can confidently determine where in the world has the best blue sky holiday destination! (At least on the day of the measurement).

1.2. What is colour?

Colour is defined using a combination of three numbers (representing the colour selective receptors of the human eye, analogous to the Red, Green and Blue emitters of a television screen). By combining these three primaries all colours can be realised or detected (perceived).

2. Why is the sky blue?

White light from the Sun, containing all wavelengths ("colours") in the spectrum, enters the Earth's atmosphere. The sunlight is then scattered by the molecules present in the atmosphere. This scattering, called Rayleigh scattering, is more effective at short wavelengths (the blue end of the visible spectrum) and so the sky is preferentially blue.

Figure 1: Photograph of sunrise over the Amazon Jungle (courtesy of Heather Pegrum).

3. Why are sunsets red?

As the Sun sets or rises (Figure 1), the light from the Sun propagates towards the Earth and has to pass through an ever-increasing thickness of atmosphere. When the Sun is nearly on the horizon, the sunlight's path through the atmosphere is so long that much of the blue and even yellow light is scattered away from the Earth, leaving the sky and the clouds to appear red at sunrise and sunset.

4. Blue Sky Science

Scientists of NPL's Optical radiation measurement team, led by Dr Nigel Fox, have ensured that Expedia's blue sky explorer, Anya, was able to observe the world's best blue sky and unequivocally assign a set of internationally accepted colorimetric coordinates so that it can be fully defined.

In most natural situations, light sources (Sun, tungsten room lamps etc) emit a complete spectrum of "white light" and the "colour" observed depends on the selective reflection or absorption of this continuum of wavelengths (colours) of light. Thus by using an instrument to measure the full spectrum of light and analysing its shape compared to standardised values, the colour values can be accurately determined.

Such instruments are called spectrometers and consist of a device to split the light into its constituent colours, which is coupled to a set of detectors to measure each spectral band "colour", in very fine intervals. The spectrometer Anya used is a portable device, which is controlled using software developed by NPL.

Anya took the spectrometer with her on her travels so that she could make measurements of the sky around the world! NPL ensured that the spectrometer was calibrated, thereby providing reliable measurements at each location. All data from the measurements made with the spectrometer, were sent back to NPL via email for processing and analysis.

5. The Experiments

Anya travelled to the 25 destinations where she conducted a series of measurements to determine which had the best blue sky. The measurements were to help determine the ‘blueness’ of the sky more accurately. If the sun was obscured or there were no large areas of blue sky present, then these experiments could not be performed.

Anya took various pieces of equipment (Figure 2) to enable her to take a series of measurements. The main piece of equipment was the spectrometer, with a fibre optic cable and a tripod. These were all packed into a small black box to transport around the world!

Figure 2: Pictures of the equipment provided by NPL.

To specify the skies' colour, the spectrometer's measurements need to be corrected so that it corresponds to that of an internationally agreed standard eye. This was done at NPL for all measurements made by Anya on her travels. While travelling, Anya also conducted some calibration measurements, which were carried out in the "comfort " of her hotel room, to maintain the calibration of the spectrometer. The procedure simply required Anya to position an LED torch at a fixed distance from the spectrometer and made a measurement.

This process is equivalent to that used at NPL (although using a lower power light source) and is also analogous to the calibration procedure used historically.

5.1.1. “Sky Brightness/Clarity”:

The spectrometer has a diffuser attached to its entrance port and it was aligned to point directly at the Sun (using a tripod). Anya extended a Sun shader (a black telescopic rod with a small black disk attached to one end) and positioned herself out of the field of view of the spectrometer. The solar blocking disc was held in the air to block the light from a small patch of sky, and a measurement was then taken by the spectrometer (named the *‘solar-direct’* measurement). Anya then held the Sun shader in the air so that the blackened disk blocks out the Sun as seen by the spectrometer/diffuser. i.e. a shadow will fall upon the spectrometer. Another reading was taken, (named the *‘solar-shaded’* measurement).

To determine the sky brightness/clarity, the ratio of these two measurements was calculated. The results show that Rio de Janeiro in Brazil had the clearest sky. The destination, which was the murkiest on the day of the measurements, was Rock in Cornwall! The results are shown in Figure 3.

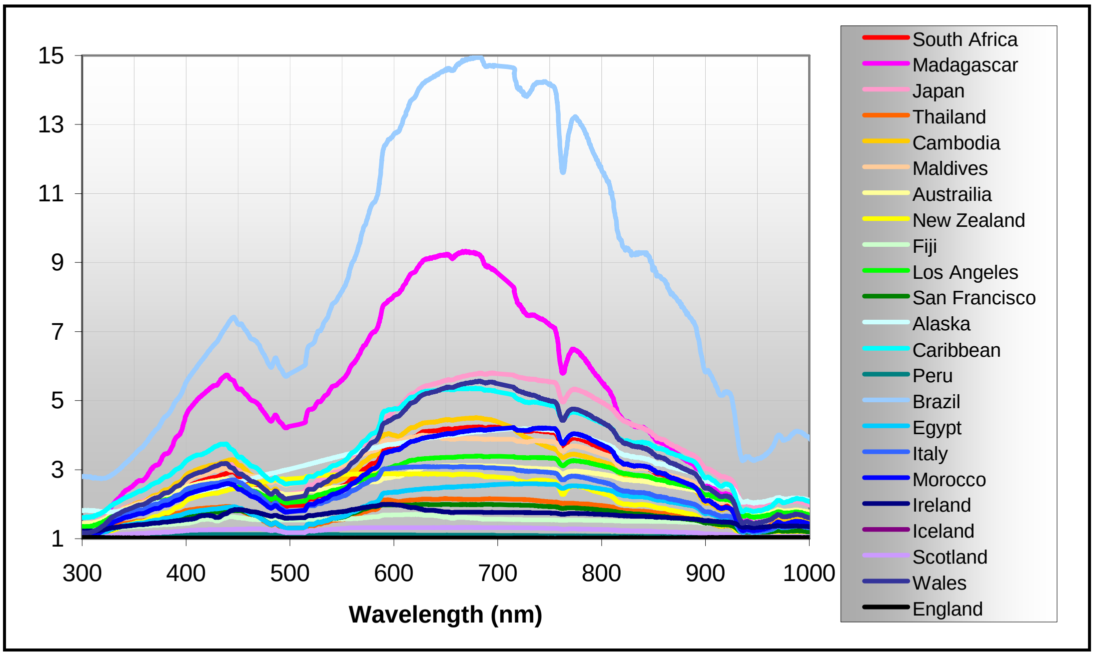

Figure 3: Sky Clarity results - the clearest sky has the highest values.

5.1.2. Blue Sky

To determine the 'Best Blue Sky' measurements with the spectrometer were taken with the lens attached to the fibre and with it directed straight up at the sky (Figure 4). Another measurement was also taken at an angle of 45-degrees (in the opposite direction to the sun). Both of the measurements were analysed in the same way.

Figure 4: Pictures of the fibre and lens being set-up to take the 'Blue Sky' measurements.

The spectrometer results from each of the destinations were corrected using the spectrometer responsivity that was determined at NPL prior to its journey around the world. This meant that the spectral power distribution for each location could be determined.

The spectral power distribution for each destination could then be used to calculate and assign "colorimetric coordinates", so the best blue sky can be determined. These are all plotted on the chromaticity diagram in Figure 5.

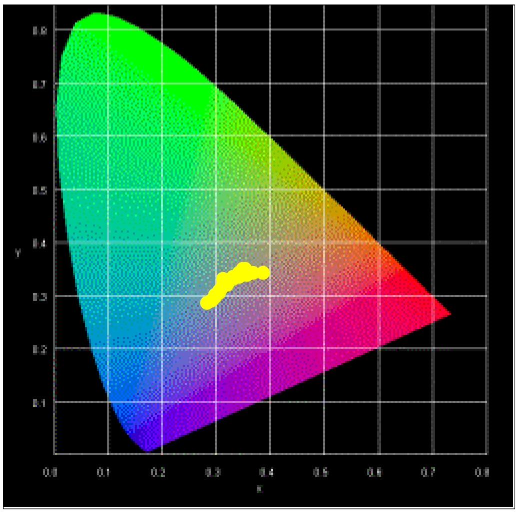

Figure 5: Chromaticity diagram - showing the coordinates of all the destinations.

The destination, which is closet to the bluest part of the chromaticity diagram, is the one that has the Best Blue Sky.

6. Photography

The simplest method for determining the sky colour is to take a picture with a digital camera. Everyone who goes on holiday will probably have one and as Anya was provided with a camera to record her progress around the world, it was decided to make use of it to help with the work.

Whereas the spectrometer detects all the colours of light and allows the spectrum of light to be determined, a digital camera works much like the human eye. It uses red, green and blue filters and measures the amount of light seen through them. This data can then be manipulated on a computer and displayed or printed out.

To determine the true colour of the sky a number of standard images were taken at each location. This allowed the most accurate comparison of the different locations. The analysis of the photographs showed that the colour of the sky at the different locations was measured well by the camera and when viewing similar scenes as the spectrometer gave a similar 'blue sky' ranking. The advantage of using a camera is that it is cheaper and more available than a calibrated spectrometer. Also judging from some of the photographs taken at some of the sites, it is possible to determine a sky colour when there are clouds present, something the spectrometer cannot do. However as we all know there can be variations between different types of cameras and it is difficult to reliably assign an absolute value to a colour.

7. Expedia's Best Blue Sky is ……

Brazil

The sky colour can be specified as: **x = 0.2775 y = 0.2842** and is equivalent to a "colour temperature" of **10,637 K (10,910 °C),** a tungsten lamp has a colour temperature of around 3000 K**.** The test pictures from Brazil are shown in Figure 6.

Figure 6: Test pictures from Brazil

8. Summary

The summary of the spectrometer based results, and the Best Blue Sky Ranking, is shown in Figure 7. The centre of the chart shows each destination's chromaticity coordinates, on an extract of the chromaticity diagram. The pictures around the outside show the fisheye photographs of each destination in order of which has the Best Blue sky, running clockwise around the chromaticity diagram, starting with Brazil with the Best Blue Sky and San Francisco with cloudy hazy sky!

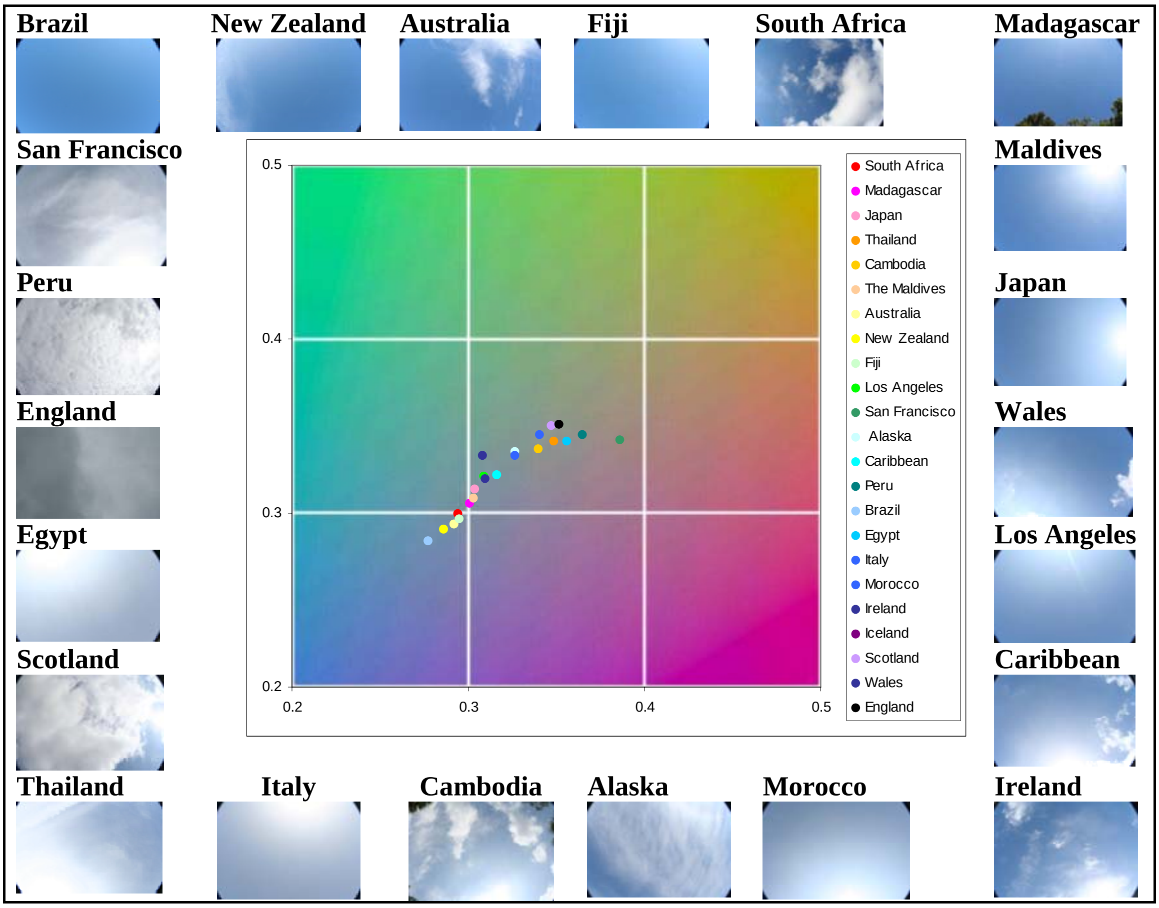

Figure 7: Summary of the spectrometer results.