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Expedia's Best Blue Sky: Experiments and Results

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Expedia's Best Blue Sky: Experiments and Results

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ABSTRACT

This report describes the science and experiments behind the Expedia's Blue Sky Explorers' trip of a lifetime, to travel around the world, to discover where in the world has the 'Best Blue Sky'!

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1. Introduction

This report describes the science and experiments behind the Blue Sky Explorers trip of a lifetime, to travel around the world, to discover where in the world has the 'Best Blue Sky'!!

2. 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).*

2.1. 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 enables the measurements to be traceable to the International System of Units (SI), so we can accurately determine where in the world has the best blue sky holiday destination!

3. 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).

Colour fills our lives and affects our choices and preferences of objects as diverse as cars, clothes and food. It is used to promote corporate identity, to camouflage and provide information. Colour is among the 'newest' of measurements and significant advances are still taking place today. NPL has always been deeply involved in the development of colour specification and measurement.

The brain uses the sensation of colour to code proportions of different wavelengths of light. The colour of objects depends on: how they are illuminated, how they absorb or scatter light, and how our eyes and brains react.

As spectral information is encoded by the eye and brain into three signals, only three numbers are needed to represent all possible colours. The most popular systems plot colours within a cylindrical colour space with three co-ordinates: Hue, Brightness and Colourfulness.

3.1. How do we measure colour?

To measure colour, instruments attempt to replicate the extremely complicated human visual function. They start by evaluating the relative amounts of spectral light emitted, reflected, or transmitted by objects, and convert these to colour values such as Hue, Brightness and Colourfulness using a model of the human visual system known as the 'Standard Observer'.

The 'Standard Observer' is a model representing human colour vision internationally adopted by the International Commission on illumination (CIE) in 1931.

3.1.1. Colour at NPL

The Standard Observer is based on experiments conducted in the late 1920s at NPL and Imperial College, London. NPL develops and accurately measures colour standards, which are used throughout the world to ensure that colour measuring equipment from Bolton to Bangladesh will produce compatible results.

3.1.2. Adding and subtracting light generated ranges of colours

As colour is encoded using three numbers, only three 'primaries' are needed to create most colours. Close inspection of a TV shows that the wealth of screen colours are generated solely by dots of red, green and blue light. There are no yellow dots. Yellow is produced by ADDING equal amounts of red and green light. In colour printing and painting, three inks SUBTRACT red, green and blue light from the white paper to create a wide colour range. Magazines don't use green ink, an overlay of cyan and yellow absorbs all but the green (Figure 1).

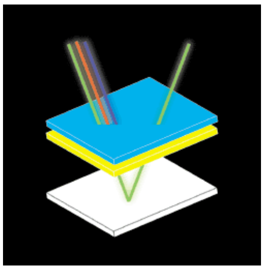


Figure 1: The ink subtracts the red and blue light making it appear green.

3.1.3. Why do surfaces change colour?

Two surfaces - say a bathroom suite and a painted wall - can match perfectly under daylight, but appear totally different when illuminated by a domestic tungsten lamp. This is because two different combinations of source spectra and object spectra may produce identical sets of signals in the visual system, so the objects have the same perceived colour. Changing the source spectrum means the same visual signals are no longer generated, so the colours no longer match. This effect, called metamerism, is the reason astute shoppers check that clothes combinations match in colour both within store and by daylight through the window.

3.1.4. Colour appearance

Colour is not seen in isolation (Figure 2). Artists know that red can be made to appear redder by surrounding it by a complementary green. Classifying isolated colours in terms of three signals is just the start. Until very recently it was just not practical to research and measure the complexities of colour of real world scenes. However, the fastest of today's computers combined with digital imaging technology are making this possible for the first time.

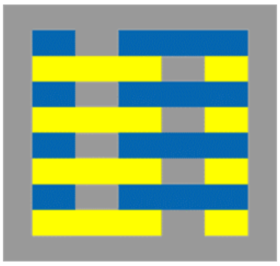


Figure 2: Do these greys look the same?

3.1.5. What you see is not what you get

It seems perfectly reasonable to expect computer monitor image colours to print faithfully. Yet the more critical users of multimedia are painfully aware that this just doesn't happen. Even for high quality, carefully adjusted systems, the different methods of generating colour means that the two devices will offer different gamuts of colour - some reds just won't print. Reflected printed colour is perceived differently from luminous monitor colour, and of course the perception of the monitor and printed colour will change under different lighting conditions.

3.1.6. Spectral Colours

In 1669, Newton, aged only 27, was appointed Lucasian Professor at Cambridge. His first work in this post was in the area of optics. During the two plague years, he concluded that white light is not a simple entity. This idea contravened every scientist since Aristotle, but chromatic aberrations seen by Newton in a telescope lens convinced him otherwise.

When he passed a thin beam of sunlight through a glass prism Newton noted the spectrum of colours that was formed (Figure 3).

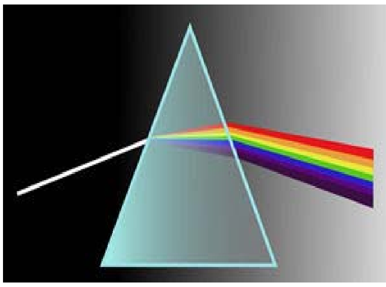


Figure 3: Spectrum of colours produced by a glass prism

Newton argued that sunlight is a mixture of many different types of rays, each refracted at slightly different angles, and that each type of ray produces a different spectral colour. The names he used to describe these colours became known as Newton's spectrum. He pointed out that the rays themselves are not coloured.

These spectral colours are shown below in order of energy (proportional to frequency and inversely proportional to wavelength.

Ultraviolet
Ultraviolet is not strictly light as it is invisible - mostly screened from the retina by the lens. Some substances absorb UV and re-emit as visible wavelengths (fluorescence).

Violet
Violet is at the extreme high energy limit of human vision. The edge of visibility changes significantly with age as the lens becomes more yellow.

Indigo
Indigo is a vegetable dye once used to give denim its distinctive colour. Possibly it was included in Newton’s spectrum for mystical reasons.

Blue
The sky appears blue because the amount of scattering of light is proportional to its energy. Light scattered by air particles makes the atmosphere a luminous blue.

Cyan
Cyan - Not one of Newton’s colours. This has become significant as the colour of a printing ink primary.

Green
Why is grass green? Plants use red and blue light to manufacture sugars. We see the reflected unused green light.

Yellow
The yellowing of paper is countered by ‘optical brightening agents’ - chemicals which fluoresce UV into blue light.

Orange
The conversion of electrical to optical energy at only two orange wavelengths makes low pressure sodium vapour streetlights extremely efficient. However it does mean the only colours visible are shades of orange.

Red
Red promotes strong emotional responses world-wide. Used internationally to signify danger. Walls painted red have been shown to increase workplace tension.

Infrared
Not strictly light as infrared is not energetic enough to be detected by the eye.

3.1.7. Colour Temperature

Many sources are like the Sun and emit a continuous spectrum "colours" (or near continuous) of light. For example, if a prism is used with a tungsten lamp exactly the same colours will be seen as in sunlight. This is because the mechanism for generating the light is thermal in nature i.e. heating of a substance to a temperature such that it gives off visible light. It should be noted that all things, including ourselves, emit thermally generated electromagnetic radiation, "light", as a consequence of their temperature. However, the exact spectral distribution is directly related to the temperature. A cool object like a human emits mostly in the Infrared part of the spectrum (beyond the range of our eyes), whereas something hot like the Sun or the tungsten wire of an electric light bulb (~3000 °C) emit with a peak closer to the visible part of the spectrum. The exact spectral distribution dictates the apparent colour of the emitting source and so often a source of light is assigned a "colour temperature". The colour temperature of a source is as the name describes, the temperature that most closely correlates with the apparent colour of the source (its spectral distribution) referenced to a standard source called a Planckian radiator or "black body".

To illustrate this principle look at a hot poker as it is heated in a fire, as it gets hotter it glows from red to bluish white as the colour temperature increases. It should be noted that the "colour temperature" is simply a descriptor for the source and unless the source is itself similar to a black body (the sun and tungsten lamp are like black bodies) it does not necessarily relate to the actual temperature of the source, simply its spectral distribution. For example the sky has a blue bias and will be assigned a relatively high colour temperature, but it is not actually hot! For monochromatic sources such as Lasers and LEDs the concept has no meaning and thus it only applies to broad emitters, the sky and daylight can reasonably be assigned a colour temperature, the hotter the temperature, the bluer the colour.

3.2. The Optical Radiation Measurement Group (ORM)

Within our group, the Optical Radiation Measurement Group, we establish and maintain the primary scales for optical radiation and in particular the traceability to fundamental constants, for the measurement unit of light, the *candela.*

In addition to establishing the primary scales and ensuring their comparability with other countries through comparisons we provide calibration and consultancy services to UK industry and undertake research in support of many applications ranging from health and security to climate change.

Our range of capabilities are second to none in the world and include:

Reflectance and Transmittance:- colour, clarity of beer, energy efficient coatings…

Characterisation of all types of sources:- Lamps, lasers, LEDs, TV screens….

Detector characterisation: - cameras, power meters, light-meters …

Some of our research activities include:

Studies of climate change and remote sensing from space

Sensory metrology – how to ascribe a number and measure perceived "quality" or "naturalness" of something

Measurements and interactions of individual photons of light

and of course the "Worlds Bluest sky"

3.3. Light measurement

The efficiency and ease with which we see objects depends on the level of light present. It is therefore important to develop a scientific system to measure light levels. This helps to determine how much light falls on the objects we see, and also aids the development and comparison of the myriad number of artificial light sources available today. Achieving a specified lighting level is important in safety and regulation, ensuring that there is the recommended level of lighting in a laboratory or classroom, adequate illumination of road signs and the correct brightness levels for emergency lighting. It is also important in many leisure activities - television, photography and sports lighting to name a few.

Vision is one of the most important of our five senses. It is chiefly through sight that we understand our environment and gain instant knowledge which informs our actions and movements. Our ability to perform certain tasks is greatly dependent on how well we can perceive them. Unconsciously our perception of the visual scene greatly affects our moods, emotions and sense of well-being.

3.3.1. Why the candela?

The S.I. (International System of Units) base unit chosen to underpin measurements of light is the 'candela'.

The power of optical radiation is measured in watts. However the eye cannot see all colours, or wavelengths, of light equally well and thus another unit is needed to assess the visual effect of optical radiation - this unit is the candela. The eye is most sensitive to light in the yellow-green region of the spectrum, close to the colour, which corresponds to the peak output of sunlight reaching the Earth's surface. It is less sensitive to red and blue light. A special function, known as the $V(\lambda)$ function, has been agreed internationally to describe the way in which the eye responds to different colours of light.

The shape of the $V(\lambda)$ function, the eye's approximate response as a function of the wavelength of light, affects how we perceive different types of light source. For example, a 60 W tungsten bulb, a normal household bulb, consumes more than six times the electrical power of a 9 W compact fluorescent lamp but they are both perceived as producing approximately equal amounts of light, giving out roughly the same number of candelas. This is because a lot of the power used by a tungsten bulb is given out in the infrared part of the spectrum where the eye has no response. The light given out by the fluorescent lamp corresponds more closely to the peak sensitivity of the eye.

The current international definition of the candela specifies the intensity of radiation at a particular wavelength, the nominal peak of the response of the human eye.

Whilst this definition or realisation of the candela is convenient for some situations particularly for standardisation, it is of little value unless it can be used for real measurements of real sources like a tungsten lamp. This is known as dissemination. The ways the candela has been realised historically and the way it is currently realised are described below.

3.3.2. Current realisation of the candela

The candela was re-defined in 1979 in terms of the watt because the use of a blackbody (as required by previous definition) was experimentally difficult and the temperature at which the experiments were carried out was far below that of modern light sources.

Radiometry is the system of concepts and terminology used to describe light and its interaction with matter. Radiometers are instruments that can measure light and they were used in the radiometric realisation of the candela at NPL, which was successfully completed in 1985. This method, which utilises our ability to measure optical radiation very accurately, was based on the NPL cryogenic absolute radiometer, an instrument capable of measuring optical power (in watts) in a laser beam to an accuracy of better than 0.01%. The measured laser beam was used to calibrate a photometer, a detector with a filter to mimic the response of the eye, which was then used to measure the luminous intensity (in candelas) emitted by a tungsten lamp source with an accuracy of 0.1%. Other types of lamp could also be measured either directly, using the photometer, or by comparison with the tungsten lamps. This was by no means a simple experiment and many subsidiary measurements were necessary to accurately establish the candela.

3.3.3. The V(λ) Function

The V(λ) function (Figure 4) describes the ability of visible light to produce a visual response. It is a definition of the relative sensitivity of the eye to different wavelengths, or colours, of light. It was established in 1924 through extensive experimental work at several laboratories, including NPL, and was defined on the data obtained from observers matching the brightness of different colours. The function has a maximum at the peak of the sensitivity of the eye, a wavelength of 555 nm, or yellowish-green.

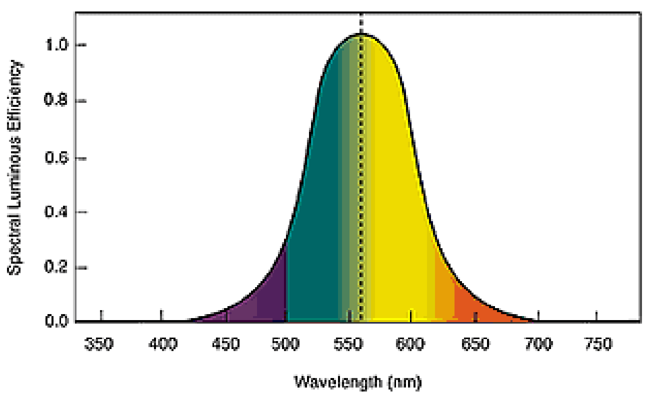


Figure 4: V(λ) function.

The V(λ) function represents a mean of over 200 different people's eye response covering a wide range of ages, 18 to 60, and both sexes. Actual eye response varies from person to person and changes with age as the lens of the eye yellows. This means a standard person doesn't really exist - if one did it would probably be a woman in her late twenties. It follows, therefore, that real people see life in slightly different ways.

4. 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.

When we look near the Sun (but not directly at it, as this is harmful) the area of the sky beyond the aurora is pale bluish white. This light has taken a more direct path through the atmosphere to our eyes. Looking away from the Sun in the opposite direction we see the light which has been scattered a greater amount (or through a bigger angle), and it will appear significantly bluer - the bluest part of the sky.

In the absence of an atmosphere (e.g. on the moon) the sky would be black as only light that came directly from the Sun would be present.

Clouds appear white as the water droplets they contain scatter all the different colours of light by the same amount. During the summer when a high-pressure region sits over the country, the air is often calm and levels of pollution can build up. This causes the daytime skies to become 'milkier' as dust and other pollutants scatter the sunlight in the same manner as the cloud droplets. The 'ideal' blue sky may be present in winter as there is very little pollution and dust; this is an aspect that may be measured.

Figure 5: Photograph of sunrise over the Amazon Jungle (courtesy of Heather Pegrum).

5. Why are sunsets red?

As the Sun sets or rises (Figure 5), 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. As this process takes place, the sky changes from blue to red, exhibiting each of the colours of the spectrum, (violet, indigo, blue, green, yellow, orange and red) for varying amounts of time. If you look closely there is even a moment each evening when the sky has a greenish tinge.

Many other environmental factors affect the colour of the sky. Volcanic eruptions cause lots of dust to be blasted into the upper atmosphere; this leads to spectacular red sunsets. Additionally, surrounding land colour may play a part in perceived sky colour.

6. 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 (like a prism, see Section 3.1.6), 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 this 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. The measurements made with the spectrometer allow sky colour, brightness and sky clarity to be determined. Sky clarity and “brightness” is affected by environmental factors such aerosols, particles and pollutant content in the air. In addition, all Anya's blue sky photographs were taken under defined criteria, so that they too can be calibrated and traced back to NPL standards.

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.

6.1. What do these experiments hope to achieve?

NPL became involved in this project, to provide Anya 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), www.npl.co.uk/reference, so we can confidently determine where in the world has the best blue sky holiday destination! (At least on the day of the measurement).

7. The Blue Sky Explorer and Destinations

Anya travelled to the 25 destinations listed in Table 1. At each destination 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.

Location	Country	Latitude (North +ve)	Longitude (East -ve)	Time zone	10am LST occurs at Hr min	
Antananarivo	Madagascar	-18	-48	3 noDST	9	48
Cape Town	South Africa	-38	-18	2 (no DST)	10	48
Victoria Falls	Zambia	-17	-26	2(no DST)	10	16
Tokyo	Japan	25	-141	9 (no DST)	9	36
Phnom Penh	Cambodia	13.5	105.8	7 (no DST)	9	57
Koh Samui	Thailand	9.4	-100	7 (no DST)	10	20
Denarau island	Fiji	-17	179	12 (noDST)	10	04
Bay of Islands	New Zealand	-35	-174	12 (DST off)	10	24
Uluru	Australia	-25	-132	9.5 (no DST)	10	42
St Lucia	Caribbean	14	61	-4	10	4.2
Karumba	Maldives	3	-72	5 (no DST)	10	12
Reykjavik	Iceland	64	22	0 (no DST)	11	28
Mont Blanc	France	46	-7	2 (DST on)	11	32
Castel Dinas Bran	Wales	52	5	1	11	20
Rock, Cornwall	England	50	5	1	11	20
Edinburgh	Scotland	56	3	1	11	12
Dublin	Ireland	53	6	1	11	24
Amalfi Coast	Italy	40.5	-14.5	2 (DST on)	11	02
Marrakech	Morocco	32	8	0 (no DST)	10	32
Pyramids of Giza	Egypt	30	-31	2 (DST from 28Apr)	10:56	56
Macchu Picchu	Peru	-13	72	-5	9	48
Juneau	Alaska	61.2	141	-8 (DST on)	11	24
Rio de Janeiro	Brazil	-23	43	-3 (DST off)	9	52
San Francisco	N America	38	120	-7 (DST on)	11	00
Long Beach	N America	34	118	-7 (DST on)	10	52

Table 1: Locations and LST for each measurement.

To ensure that the different destinations were measured in a consistent way, the measurements were made at 10 am local solar time (shown in Table 1). This was chosen, as skies tend to be clearer in the morning than afternoon and a noon Sun would present high scatter issues for the measurements.

The local solar time, is the apparent solar time as indicated by the sun on a sundial. The solar noon is when the sun appears highest in the sky, compared to its positions during the rest of the day. For Anya to make measurements at 10 am local solar time, she had to take them at the times indicated in Table 1, which is the mean solar time (as indicated by clocks).

8. The Spectrometer

Anya took various pieces of equipment (Figure 6) 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 6: Pictures of the equipment provided by NPL.

The spectrometer used for the project is a Hamamatsu mini-spectrometer TM series C10083MD with 1024 pixels, the spectral range of the spectrometer ranges from 320 to 1000 nm. The light to be measured is guided into the entrance port of the spectrometer through an optical fibre, a collimating mirror directs the beam onto the grating, and light transmitted by the grating is focused onto the built-in array sensor by a focusing mirror. The spectrum measured with the sensor is outputted via a USB port to a PC for data acquisition. The array sensor is similar in concept to that used in a photocopier.

8.1. NPL Tests

Before the equipment was packed up to be taken around the world, the equipment underwent some initial testing at NPL.

8.1.1. Spectrometer Responsivity

To determine how efficiently the spectrometer measures light, (its responsivity) it was used to measure a standard lamp, which has a known light output. The standard lamp was measured on various NPL facilities to determine its output, and to provide measurements that are traceable to SI. Further details on this process can be found on the NPL website (www.npl.co.uk/optical_radiation/). The spectrometer responsivity is then taken into account when analysing the results from each destination.

To check that this response does not change while travelling around the world, a calibration source was provided to the blue sky explorer. The procedure simply required the explorer to position a LED torch at a fixed distance from the spectrometer and made a measurement with the spectrometer. This process was identical to that used at NPL (although using a lower power light source) and is also analogous to the calibration procedure used historically.

8.1.2. Wavelength Accuracy

The wavelength measured by the spectrometer may not equal the true wavelength passing through the spectrometer. In photodiode array spectrometers this difference is mainly because of misalignment of the grating. To study the wavelength accuracy mercury and argon spectral lamps, in addition to a He-Ne laser, were used. These light sources emit light at particular (very well defined) wavelengths. By measuring these sources with the spectrometer, the wavelength error can be determined. The wavelength accuracy of the spectrometer was determined at NPL and found to be within ±1 nm, which is good result for this application.

8.1.3. Stray Light

Stray light can be defined as any undesired light that is measured instantaneously with the desired light. There are many sources of stray light, some of them are due to disorder or random roughness in the grating grooves, others may be due to higher diffraction orders, and others are attributed to scattered light from the inside surface of the spectrometer walls. All of these sources are easy to avoid or even correct in ordinary mechanical spectrometers through the use of a mask.

But the problem in the photodiode array spectrometers is that they detect all light diffracted from the grating at the same time, this in turn makes each pixel detect stray light and also re-scatter it back, increasing the effect of the undesired signal.

For the spectrometer that was used, the stray light contribution to the light measured was small enough to have little or no effect on the final result.

8.2. Experiments performed

Anya took a series of measurements at each location, following a detailed procedure that was given to her by the NPL (See Appendix A – Measurement Procedures).

8.2.1. Calibration Procedure

A calibration procedure for the explorer to carry out in the “comfort” of their hotel room, to maintain the calibration of the spectrometer, was required.

The procedure simply required the explorer to position a LED torch at a fixed distance from the spectrometer (distance defined using the calibration mat provided - Figure 7) and making a measurement with the spectrometer.

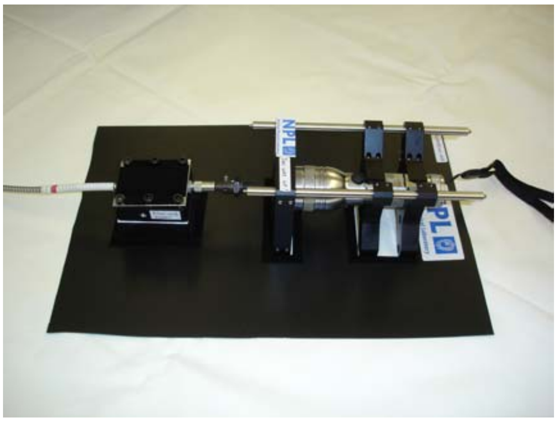


Figure 7: Calibration equipment.

8.2.2. Test procedure for "Sky Brightness":

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 (Figure 8), 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).

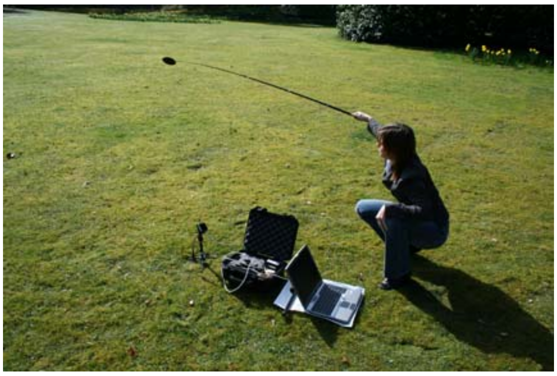


Figure 8: Picture of 'solar-direct' measurement demonstration.

These measurements allow the sky clarity to be determined since the greater the amount of particles in the air, the greater the increase in the scattering of sunlight and so the sky brightness will be higher. (Although appearing quirky this is a standard test used in particular for validation of satellite measurements). It may be possible for these measurements made by the explorer to be correlated with real satellite data as well.

The above test also gives sky brightness in its own right in the same way as a lightmeter as the response level of the spectrometer had been previously calibrated.

8.2.3. Test procedure for "Blue Sky":

The spectrometer was attached to the tripod and aligned to look directly overhead at the sky, using a lens on the end of the fibre (Figure 9). Anya took one measurement of the sky with the spectrometer, in this orientation. This measurement looks through the least amount of atmosphere, so should have the least additional scattering, giving the best blue.

Figure 9: Pictures of the fibre and lens being set-up to take the 'Blue Sky' measurements.

The fibre was then pointed in the opposite direction to that of the sun and is tilted to a 45° angle from the horizon and another measurement was taken. This region of the sky should have a good-sized region of even blue colour, making it easier to measure at the different locations.

8.3. Analysis of Spectrometer Results

All of the data was stored on the computer before being emailed to NPL to analyse and assign a colorimetric value to the reading i.e. a colour to the sky. The following sections show how each set of data was analysed and the results.

8.3.1. Calibration Results

At every destination Anya performed the calibration procedure. Each of these measurements has been compared to an initial measurement that was conducted at NPL before the journey began. The results are plotted in Figure 10. The results from these measurements suggest that there was no drift associated with the instrument, and the measurements taken were within the stability expected from the torch.

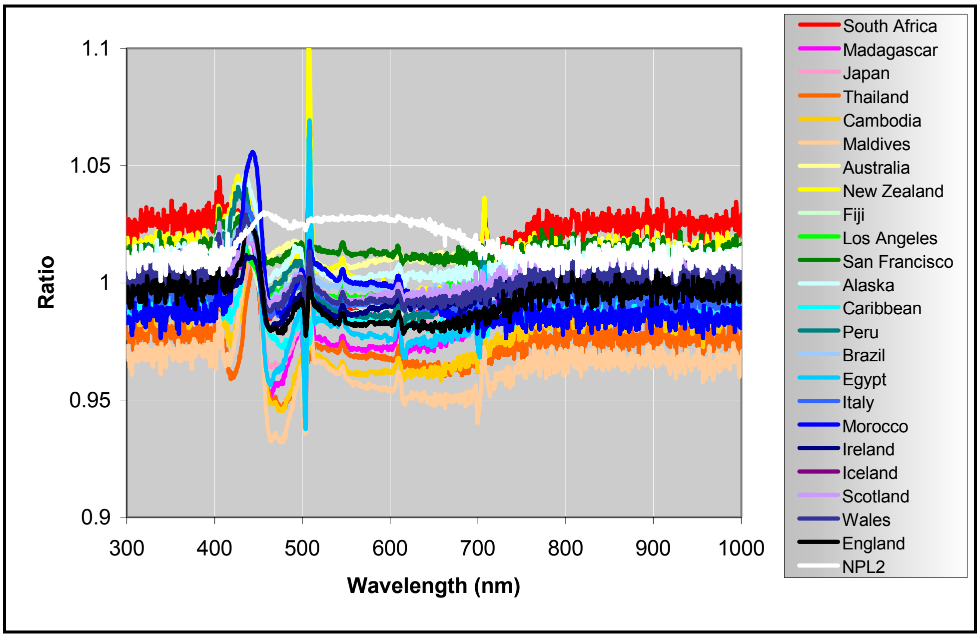


Figure 10: Results from the Calibration measurements.

8.3.2. Sky Clarity/Brightness

There were two measurements taken at each location that are used to determine the sky brightness, which were taken when the diffuser was attached the end of the fibre. One measurement was taken of the 'solar direct' (with an area of sky blocked with the shader) and the other measurements was 'solar shaded' (when the shader was used to create a shadow over the end of the diffuser).

To determine the sky brightness, the ratio of these two measurements was calculated (taking into account the integration time for each measurement). 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 11.

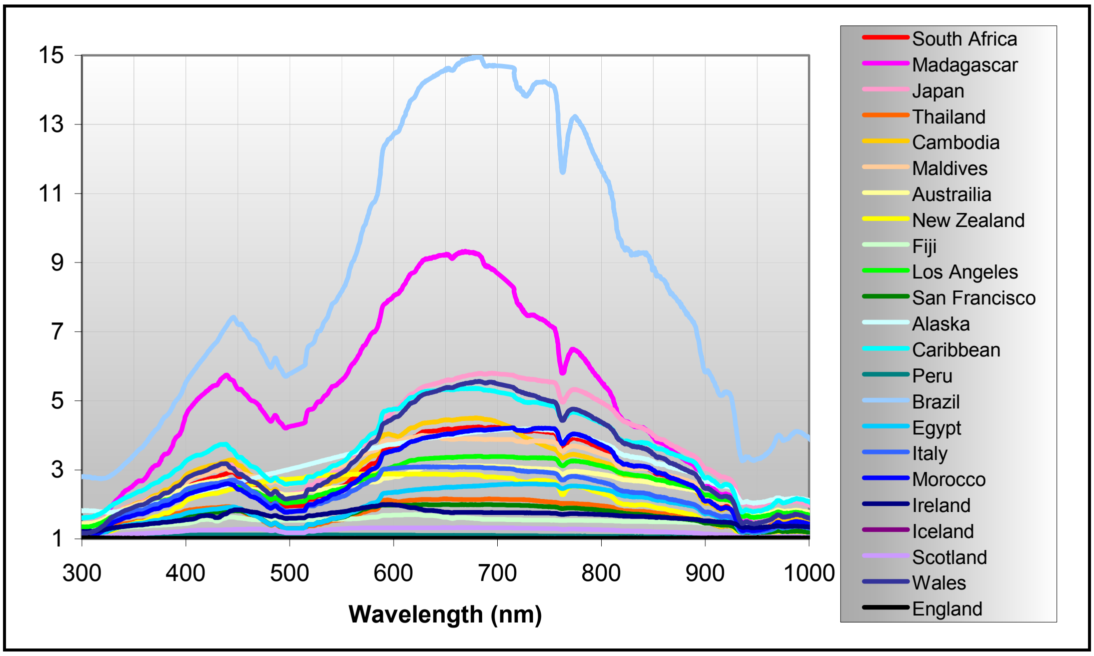


Figure 11: Sky Clarity results - the clearest sky has the highest values.

8.3.3. 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. 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.

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 graphs in Figure 12, show the spectral power distributions (i.e. the intensity of the different wavelength or colour) for two destinations (*A* and *B*). Shorter wavelengths are blue and longer are red. As can be seen in the graph below, destination *A* has more blue light than red in comparison to destination *B*, which has a lot of red light, therefore destination *A* has the bluer sky.

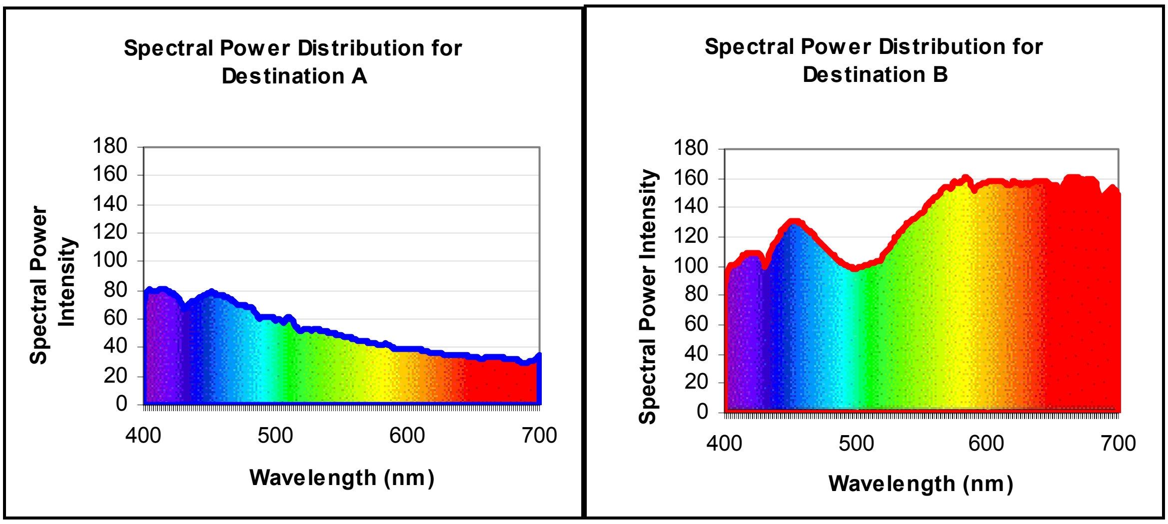


Figure 12: Spectral power distributions of two example destinations.

The spectral power distribution for each destination can then be used to calculate and assign "colorimetric coordinates", so the best blue sky can be determined.

8.3.4. Colorimetric coordinates

As we indicated earlier in Section 3, the colour perceived by a person, an observer, relates to the three colour detection system of the eye. An observer can match a colour stimulus with an additive mixture of three primaries. Therefore any colour stimulus (an illuminated object) can be specified by the amounts of the primaries that an observer would use to match the stimulus. The CIE 'standard observer' (see Section 3.1) resulted from experiments where observers were asked to match monochromatic wavelengths of light with mixtures of three primaries (x, y, Z). The standard observer is a table showing how much of each primary would be used (by an average observer) to match each wavelength (colour) of light. This is illustrated in Figure 13. The values on the 'standard observer' table are called the colour matching functions.

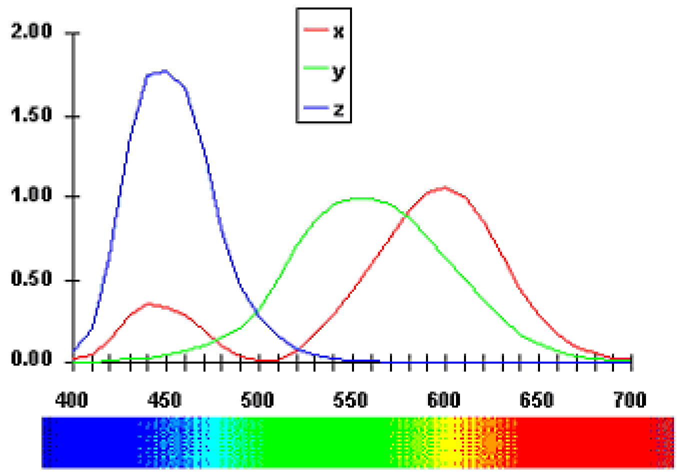


Figure 13: CIE 1931-2°- standard observer – tristimulus values of the spectral colours.

To assign colorimetric coordinates for any given object requires the multiplication of its spectral power distribution at each wavelength, times the weighting factor from the colour matching functions. The coordinates can be represented in a two-dimensional plot. Only two of the coordinates are required and by convention *x* and *y* are always used. A plot of this type is referred to as a chromaticity diagram.

The spectral power distribution from each of the destinations was used with the standard CIE x,y,z, colour matching functions, and the corresponding x and y colour coordinates calculated. These are all plotted on the chromaticity diagram in Figure 14.

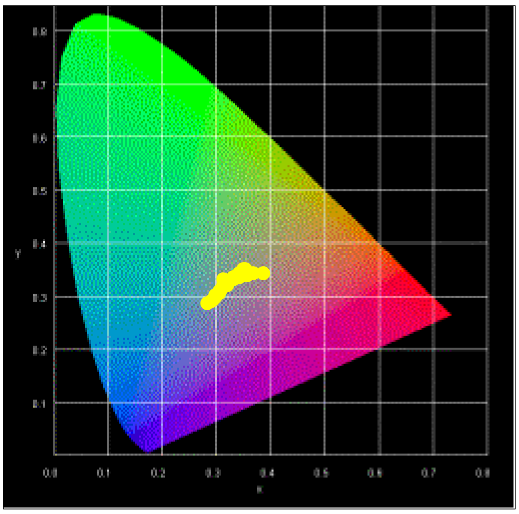


Figure 14: Chromaticity diagram - showing the coordinates of all the destinations.

The destination, which is closet to the bluest part of the chromaticity diagram, is the one that has the Best Blue Sky. The reason that they are not over the bluest part of the diagram is due to the fact that the light from the sky is not just blue light (as would be from a blue LED for example, but the light is made from lots of colours, as could be seen in the spectral power distribution plots (see Section 8.3.3). However the destination with the most blue light compared to other colours, therefore has coordinates that are closest to the blue part of the diagram.

8.3.5. Results

Figure 15, is a small section of the chromaticity diagram that contains the results from all the destinations where measurements were taken.

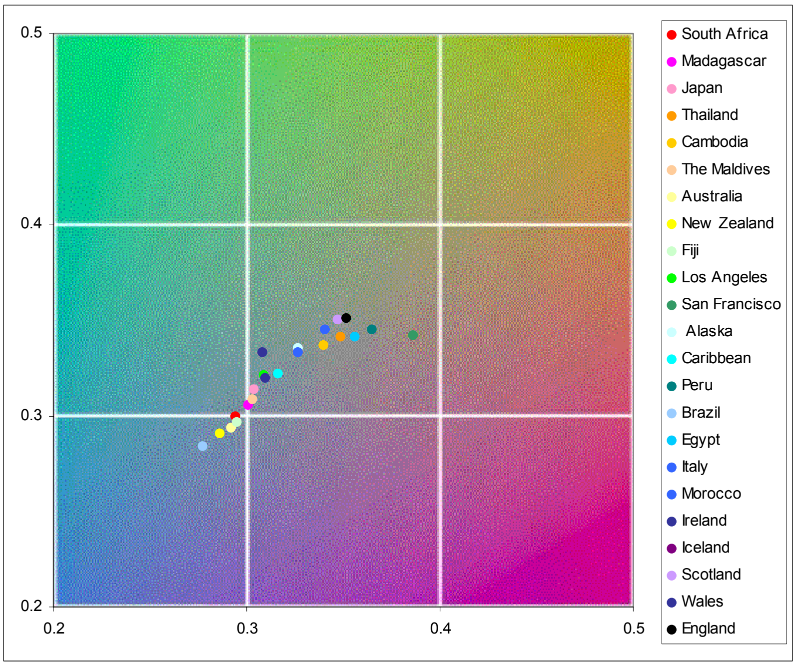


Figure 15: Extract from the chromaticity diagram to show the coordinates of all the destinations.

The results from the spectrometer show that the Best Blue Sky ranking took the following order (Table 2). Please note that no measurements were taken at the destinations shaded in grey.

Ranking	Best Blue Sky
1	Brazil
2	New Zealand
3	Australia
4	Fiji
5	South Africa
6	Madagascar
7	The Maldives
8	Japan
9	Wales
10	Los Angeles
11	Caribbean
12	Ireland
13	Morocco

Ranking	Best Blue Sky
14	Alaska
15	Cambodia
16	Italy
17	Thailand
18	Scotland
19	Egypt
20	England
21	Peru
22	San Francisco
23	Iceland
24	France
25	Zambia

Table 2: Best Blue Sky Ranking.

Therefore Expedia's Best Blue Sky was found to be Rio de Janeiro in Brazil, (Figure 16**).**

Figure 16: Picture of Anya taking measurements in Brazil.

9. Photography

9.1. Background

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 take a picture the camera has to work out things like auto focussing and determining the best exposure for a given scene. After the picture has been taken a lot of complicated processing is also required inside the camera so that the images that are taken and displayed are a true representation of the initial object. One subtle issue is the white balance of the image. Your brain automatically adjusts how we perceive colours, so that the same object in a scene, viewed under different lighting conditions (e.g. sunlight, fluorescent light) will always appear the same colour, even though different colour information is reaching the brain. The camera has to guess what the lighting in the image is in order to correctly determine the image colours. It also has to apply a common set of settings to the whole image, which in a complex scene can sometimes cause variations.

Due to all this hidden complexity it is not possible to 'calibrate' a digital camera as easily as with the spectrometer. In order to know how the camera is behaving we need to take a picture of a known coloured object. Anya did this by placing a business card sized colour test chart on the ground, illuminated by the sun and taking a picture of it. As the colour of the card had been previously measured at NPL, we could understand how the camera was behaving at the different locations. More specifically by analysing how the camera recorded the colours in the chart an examination of the colour of the sunlight and quality of the camera exposure could be made. In general the camera was found to have taken very well exposed and balanced images.

9.2. Test photos

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. For most of the images a standard 50mm lens was used so that all the images had the same field of view. For all these pictures the camera was set to 'full automatic' so that it decided on the camera settings and processing needed to deliver the best image. This avoided the problem of having to determine settings that would produce good photographs at all the locations. The use of a colour test chart allowed us to remove any variations that the camera may have introduced.

1. **Photograph of the NPL test card** (Figure 17). The test card was placed on the ground so it was illuminated by the sunlight. Anya then stood so that the sun was in front of her, and pointed the camera directly downwards to take the photograph. The camera was set with a 50 mm focal length.

Figure 17: Picture of the NPL test card taken in Madagascar.

2. **Photograph of the sky overhead** (Figure 18). Anya had to lie on her back and take a photograph of the sky directly overhead. The camera was set with a 50 mm focal length.

Figure 18: Picture of the 'sky overhead' taken in Madagascar.

3. **Photograph of the horizon** (Figure 19). Anya had to stand with her back to the sun, change the focal length to the widest field of view (around 22 mm), and took a photograph of the horizon with a good section of the sky in the photo.

Figure 19: Horizon test picture taken in Madagascar.

4. **Photograph with the fisheye lens** (Figure 20). Anya had to lie on her back and take a picture looking straight up at the sky with the fisheye lens, which can capture a much larger area of the sky.

Figure 20: Picture taken with the fisheye lens in Madagascar.

9.3. Analysis and Results

The first part of the analysis was to determine the quality of the camera exposure and colour balance as mentioned above. The results showed the camera had performed very well. If this was not the case, it would have been possible to use the data from the colour test-chart to 'correct' the images, but this was found to be unnecessary.

The first way the images were processed involved looking at the picture of the horizon and analysing how the colour of the sky varied at different heights above the horizon. High in the sky opposite the sun is the location where the bluest part of the sky is expected to lie. At the horizon the sky is generally a milky white colour due to lots of haze and scattering. At increasing heights above the horizon the colour of the sky is expected to darken and turn a deeper, more saturated blue colour.

For each location a slice was taken through the image starting at the horizon. Some averaging was performed, to reduce the effect of pixel noise and then the sky colour data was extracted using Adobe Photoshop image processing software. The results for all the locations are plotted in Figure 21. The axes of the plot are special 'colour' co-ordinates, the y-axis ("Lightness") gives an indication of the sky brightness and the x-axis ("Chroma") gives a measure of the colourfulness. All the locations give curves that start at top left (at the horizon) with a very bright, but largely uncoloured appearance, then they all curve down to the bottom right (higher up in the sky) where the sky is a darker, but more colourful blue.

The ‘bluest’ sky could be considered the one that lies furthest to the right in the plot, i.e. the most colourful one. Several of the locations exhibit sharp kinks, these are due to clouds in the picture. From this plot the following relative ranking of the locations can be produced (Table 3).

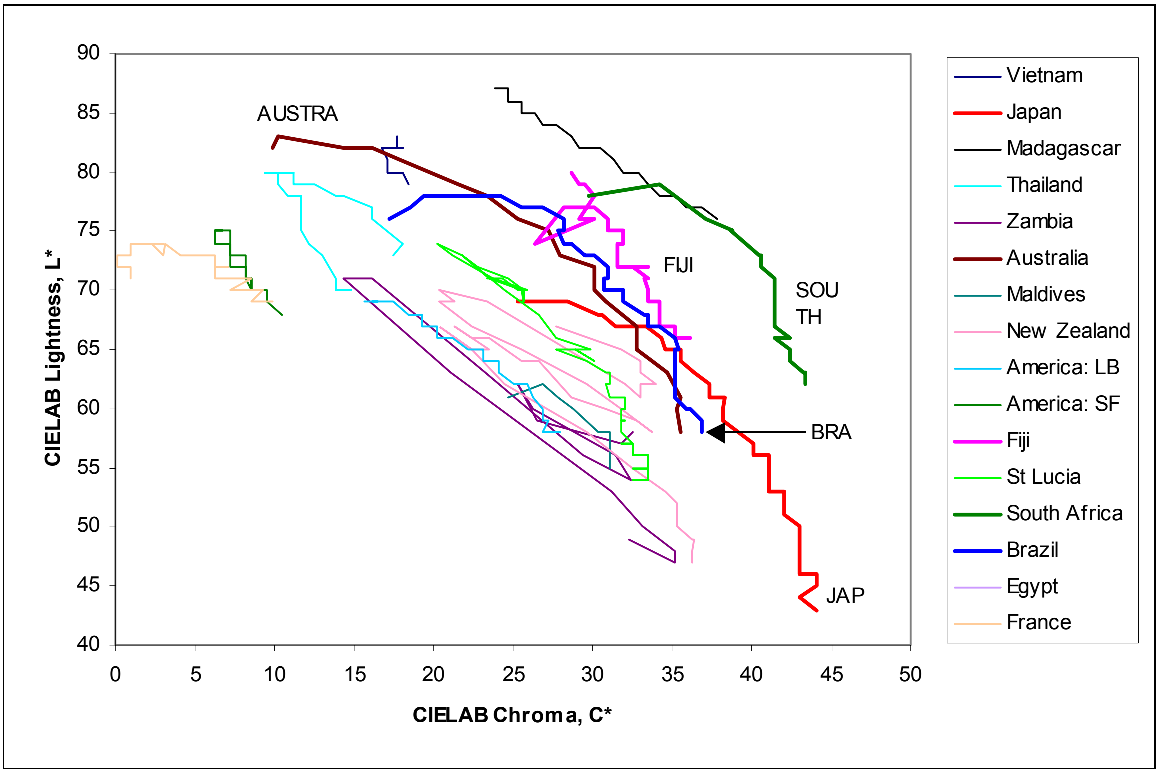


Figure 21: Colorimetric analysis of photographic images.

Ranking	Destination
1	Japan
2	Brazil
3	Australia
4	Fiji
5	South Africa

Table 3: Ranking of locations based on the analysis of the horizon pictures.

Next a check of the photographs of the sky directly overhead was taken to allow a comparison with the spectrometer data of the same part of the sky. In this case the results were as follows.

In this analysis there is too little difference to discriminate between Fiji and Brazil and so we have ranked both as 1 (Table 4). It is also worth noting that in this analysis

Zambia enters the top five. (Unfortunately for Zambia there was no spectrometer data available and so this could not be ranked using this method).

Ranking	Destination
1	Fiji
1	Brazil
3	New Zealand
4	Madagascar
5	Zambia

Table 4: Ranking of locations based on the analysis of the sky overhead pictures.

9.4. Conclusion

Although modern digital cameras perform a lot of complex data processing on the images they take, the results can be repeatedly good and well exposed. This allowed the colour of the sky at the different locations to be measured well by the camera and when viewing similar scenes give a similar 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.

The camera identifies the same top sites as the spectrometer; except that there is some variation between final rankings dependent on what part of the sky is imaged (as is to be expected). However, we believe that the high ranking of Brazil as number 2 in the "Horizon" based analysis and number 1 in the "overhead" analysis is consistent with that of the spectrometer based approach for both colour and sky clarity. Since this latter method also provides well defined colour coordinates we have chosen to use this data for our selection.

10. Summary

The summary of the spectrometer based results is shown in Figure 22. 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!

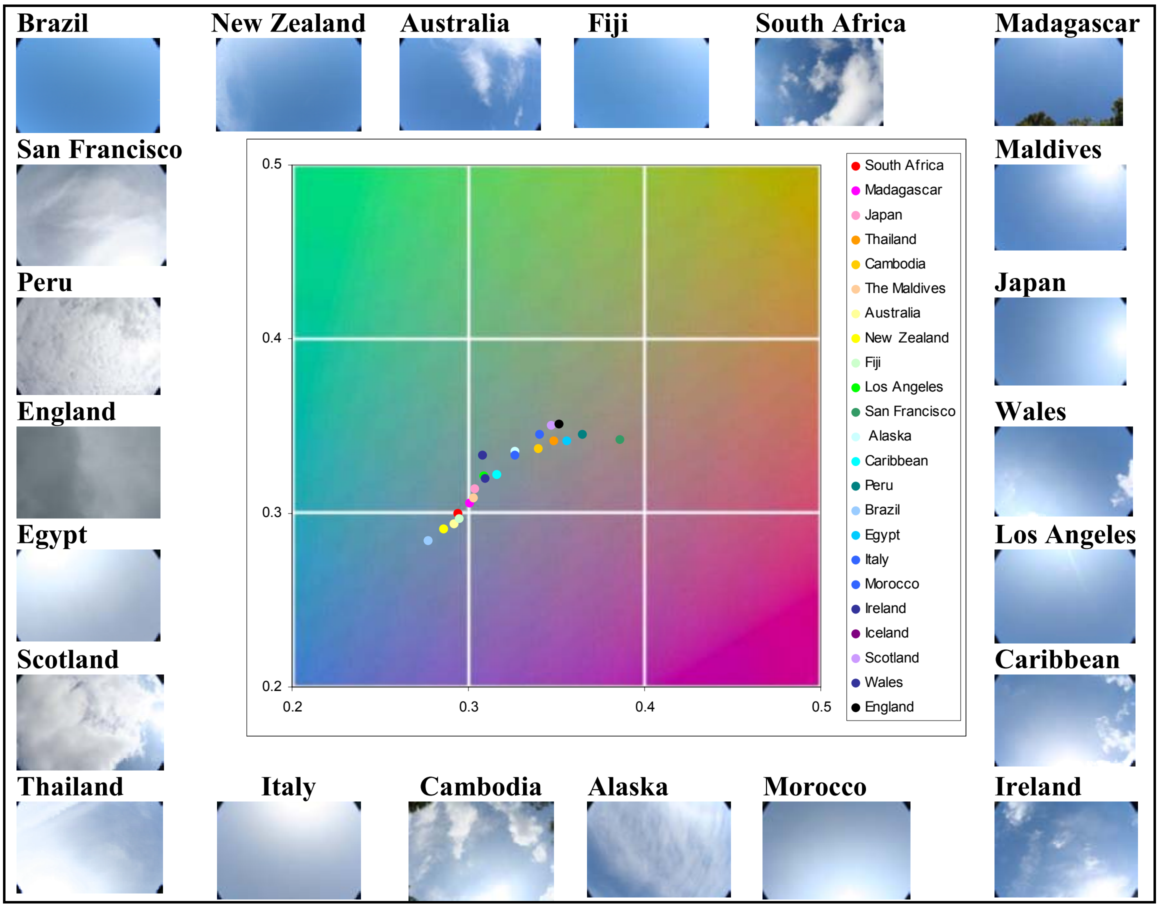


Figure 22: Summary of the spectrometer results.

11. 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 23.

Directly Overhead | Fish Eye Picture | Horizon Picture

Figure 23: Test pictures from Brazil.

12. Appendix A – Measurement Procedures

Information and Measurement Procedures from NPL

EXPEDIA BLUE SKIES RESEARCH METHODOLOGY

Research rules:

- A similar size area of sky will be measured at each location. This will be determined by the measurement protocol and the physical design/selection of the optical components e.g. lens focal length aperture.
- In order to keep consistency, the area of sky measured must be geographically similar in position to the Sun and background environment, made at the same local solar time and at a similar position at each location e.g. near a coast, away from built up areas and major cities. Solar time relates to 'local noon' when the sun is due south, this varies with time zone, longitude and also due to the Earth's elliptical orbit.
- The Expedia explorer should lie on the ground and take images of each sky at a 90-degree angle to ensure the angle of the sun is at the same place each time, using the same focal length of the lens.
- All measurements will be made traceable to NPL to ensure that the colorimetric and radiometric based quantities that are measured are robust, and compliant with international standards. This allows the selected blue sky to have assigned to it a reproducible numeric classification. For more details on the measurement of colour see http://www.npl.co.uk/publications/colour/index.html

Photography

Test concept: to obtain consistent, reproducible high-quality photographs of the sky and surrounding environs for visual assessment, and publication purposes which allow quantitative and qualitative assessment of the sky appearance.

Given the relatively small discrimination available in a camera in terms of "blueness" due to potential saturation effects, it is recommended that the you take a number of defined images to allow appropriate colorimetry to be made of the digital image. Before setting off, NPL will have performed a calibration of the camera against primary colour standards. The calibration will be monitored throughout the trip by the use of a test target supplied by NPL. The test chart has a series of "standard colours" upon it.

Test procedure: To ensure that the different sites are measured in a consistent way the following outline procedure will be adopted.

- No flash photography, this should not be an issue.

- The camera should be set to save the pictures as 'raw' files; this provides extra information about the camera settings used, allowing for extra analysis. For instance f-number, exposure time and possible information about the 'white setting' the camera used

- All measurements will be made at 10 am local solar time, this is chosen, as skies tend to be clearer in the morning than afternoon and a noon Sun would present high scatter issues. The local time that the measurements are to be made is provided later in this document.

- You should set the focal length of the supplied lens to its longest setting (around 50 mm). Place the NPL calibration test card on the ground so it is illuminated by the sunlight. Then standing so the sun is in front of them, point the camera vertically down and take a photograph of the card.

- Following this, you will then lie on your back and take a photograph directly up at the sky (again at 90 degrees to the horizontal) without changing the focal length of the lens and allowing the camera to carry out all other actions automatically. The 50 mm focal length should allow some directionality to the measurement and minimise scatter from other sources.

- As a second photograph you should stand with your back to the Sun, change the focal length to allow the widest field of view (around 22 mm) and take a photograph of the horizon (including a good section of sky) to ensure that a range of colours, hues and intensities are captured.

- Attach the ‘fish-eye’ lens to the camera (take care not to get any dirt into the camera) and whilst standing take a photo of the whole sky. The shot can be aligned by ensuring that the same amount of horizon is visible around the edge of the camera frame. If a volunteer is available another shot could be taken with them shading the fish-eye lens from the sun, but covering as little amount of the sky as possible whilst doing so.

- Make sure that every evening the photos taken that day are downloaded to the laptop and saved in a separate directory. Make a brief note in Notepad/Word about where each of the shots were taken, the type of shot and the direction faced. This will help in the analysis.

- As the raw data takes up a lot of space, it is recommended that the photos from each day are compressed before sending.

- You use the pop up window to download the photos.

- Keep the camera on 'the green box'.... full auto and we should be OK.

Make sure you recharge the camera battery regularly!!

Test equipment:

Canon EOS 350D with standard lens.
Fish eye lens.
NPL colour test chart.

SKY COLOUR

Test concept: This test is a visual check to determine the exact hue of each sky location.

Test procedure: Using a pantone reference book, the overall sky colour is compared to determine the closest colour match. Record that pantone reference number.

Test equipment: Pantone reference book using coated paper (non-coated paper is more likely to deteriorate particularly in high salt content atmospheres).

Spectrometer Tests

Tests using the spectrometer will help to determine the 'blueness' of the sky more accurately. If the sun is obscured or there are no large areas of blue sky present, then these experiments cannot be performed.

Test procedure sky clarity and "brightness":

The spectrometer has a diffuser attached to its entrance port and it is aligned to point directly at the Sun (using a tripod). The explorer extends a Sun shader (in effect a black telescopic rod with a small black disk attached to one end). The explorer sits out of the field of view of the spectrometer and holds the solar blocking disc in the air to block the light from a small patch of sky, and a measurement is then taken by the spectrometer. The Explorer then holds 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 is taken.

These measurements allow the sky clarity to be determined since the greater the amount of particles in the air, the greater the increase in the scattering of sunlight and so the sky brightness will be higher. (Although appearing quirky this is a standard test used in particular for validation of satellite measurements). It may be possible for these measurements made by the explorer to be correlated with real satellite data as well.

The above test also gives sky brightness in its own right in the same way as a lightmeter as the response level of the spectroscope has been previously calibrated.

Test procedure blue sky:

The spectrometer is attached to the tripod and aligned to look directly overhead at the sky, using a lens on the end of the fibre. The explorer takes a reading of the sky with the spectrometer. This measurement looks through the least amount of atmosphere, so should have the least additional scattering, giving the best blue. Unfortunately near the equator, the sun may be close which could interfere with the measurement. The fibre will then be pointed in the opposite direction to that of the sun and is tilted to a 45° angle from the horizon and another measurement will be taken. This region of the sky should have a good sized region of even blue colour, making it easier to measure at the different locations.

All of the data will then be stored on the computer before dispatch to NPL who will then analyse and assign a colorimetric value to the reading i.e. a colour to the sky.

Calibration

In addition to the above, a calibration procedure for the explorer to carry out in the "comfort " of their hotel room, to maintain the calibration of the spectrometer, is required.

The procedure simply requires the explorer to position a LED torch at a fixed distance from the spectrometer (distance defined using the calibration mat provided) and making a measurement with the spectrometer.

Background information:

This process is identical to that used at NPL (although using a lower power light source) and is also analogous to the calibration procedure used historically. The base unit of light is called the candela and is based on visibility of a "standard candle" by a human observer (hence the name), this was later replaced by electrical lamps.

Test equipment:

- Lap top computer
- Spectrometer with 1m fibre optic cable attached (Keep the fibre attached to the spectrometer) (NPL supplied)
- USB cable for connecting the laptop to the spectrometer.
- Sun shader (NPL supplied) – extended rod with small black disk on the end.
- Diffuser and lens for the end of the optical fibre
- Small tripod
- Fibre-end holder (this is firmly attached to the other end of the optical fibre and must not be removed).
- Black plastic template for spectrometer calibration.
- Small spirit level
- LED torch in mount with diffuser (you will not need to remove the torch from the mount during usage and battery changing).
- Spare batteries for the torch.

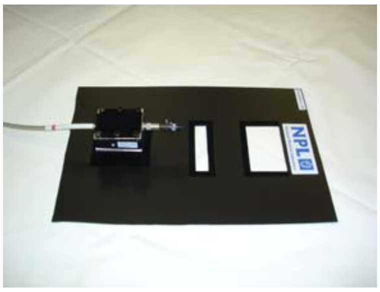
The following pages show the detailed procedures to be followed by the explorer for carrying out the experiments with the spectrometer.

Calibration Procedure

The calibration procedure should be performed daily in the evenings. It must be performed inside in a darkened room (close any curtains and turn off the room lights if possible).

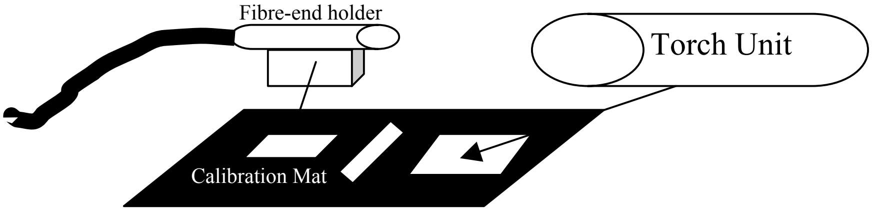
1. Remove the black plastic calibration template from the box and place on a level table.

2. Remove the fibre-end holder from the box and place in the space on the calibration mat.



3. Carefully remove the lens from the end of the fibre and place carefully within the circular storage box. Carefully attach the small diffuser to the end of the fibre.

4. Remove the torch unit from the box and place in the double space on the calibration mat.



5. Connect the USB cable from the spectrometer to the computer.

6. Turn on the computer and open the Blue-sky program.

7. Follow the instructions on the screen.

8. Click 'Calibrate'

Computer instruction:

Please put fibre and torch in holders (you will have already done this). Switch on torch and wait 2 minutes, then click ok.

Computer information:

Please wait, taking measurements…
Calibration complete, click ok.

9. Click 'Exit'

10. Turn the torch off. (Please ensure the battery is replaced after the 12th location).

11. The computer can then be closed down.

12. Unplug the USB from the computer.

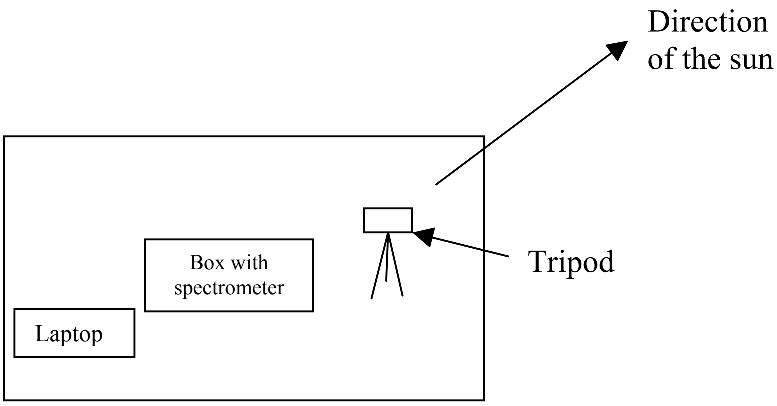
13. Replace the lens on the fibre and diffuser into the box.

14. Replace the equipment back into the box.

Blue Sky Measurement Procedure

The blue-sky measurements should be made at 10 am local solar time (a list of local times will be provided) Ensure that you have all equipment with you and set-up before the required local time, so that measurements can be made as close to required time as possible.

Find a reasonably open and flat location such that you can get the equipment set-up and it is not as risk of damage. Also ensure that you have a relatively unobstructed sky view, i.e. away from buildings and trees. The figure below shows an aerial view of an example layout of the equipment. The laptop and the box containing the spectrometer should not be placed on the sunward side of the tripod, in this way they will not get in the way of the spectrometer.



Aerial view of measurement set-up

1. Remove the tripod from the box. Pull out the legs and slide the top of the legs to the base and secure by screwing into the bottom. (This should ensure that the tripod is stable).


2. Remove the top plate from the top of the tripod and using the one pence piece that has been supplied, attach it firmly to the bottom of the fibre-end holder. Reattach to the tripod, rotating so that the fibre end is pointing in the right direction and tighten the knobs to secure it in place.

3. Remove the extendable rod from its container and pull the thinnest section out and attach the black metal disk. Then fully extend the rod and lay on the floor ready to be used.
4. Connect the spectrometer to the PC with the USB cable. Positioning the laptop on the ground, to one side of the tripod will help.

5. Turn on the computer and open the Blue-sky program.

6. Follow the instructions on the screen.

7. Click on the 'Blue Sky' button

Computer instruction:

Please point fibre at the sun. Diffuser in place and sun blocker over a patch of sky.

- Carefully remove the lens from the end of the fibre and place carefully within the circular storage box.
- Carefully attach the small diffuser to the end of the fibre.

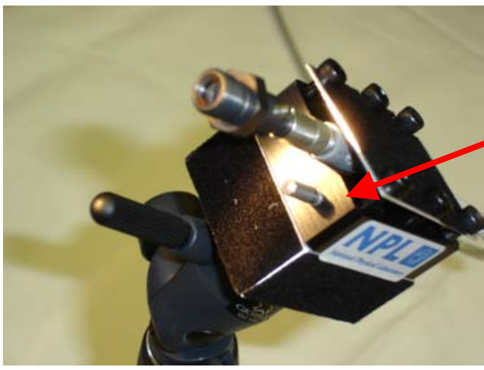
NOTE: Avoid touching the end of the fibre with anything!


Lens and the diffuser


Lens attached to the fibre

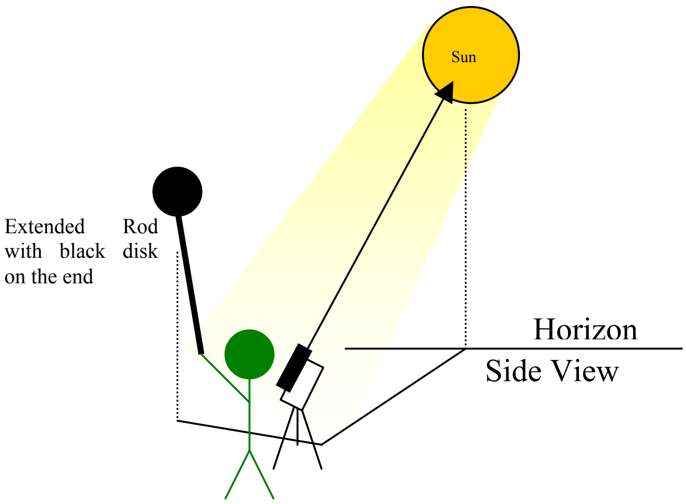

Diffuser attached to the fibre

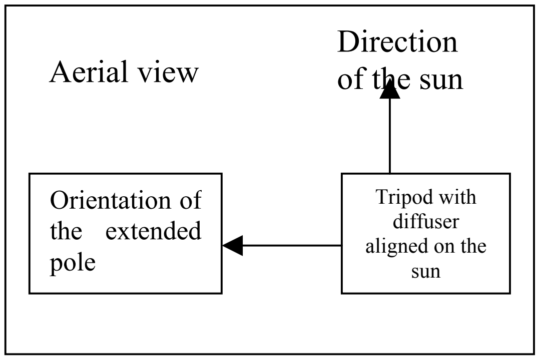
By moving the tripod and tilting the top section of the tripod align the diffuser so that it is directly looking at the sun. (To help with the alignment, there is a small metal rod that sticks out from the fibre-end holder. When the diffuser is looking directly at the sun, the small metal rod will not cast a shadow.


Minimise the shadow

Move the mount until the shadow disappears

- Pick up the extended rod, which should have the disk attached to the end of it. Stand just behind and to one side of the tripod, so that the diffuser cannot see you
- Position the rod so that is it approximately 90 degrees from the direction of the sun, and blocks a small patch of the sky from the sensor.





8. Click ‘Ok’ on the computer.

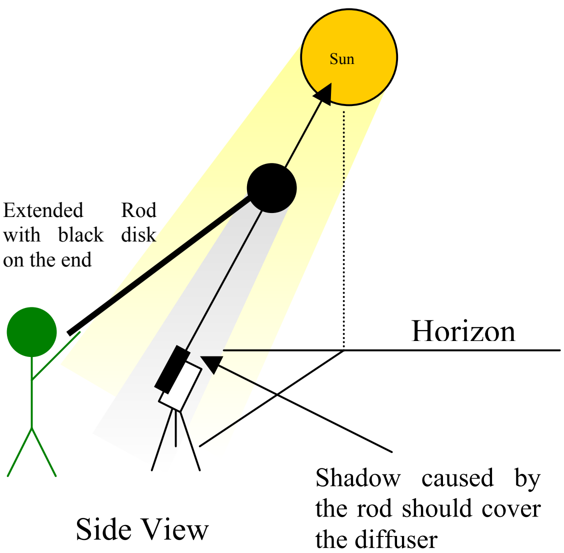
Computer information:

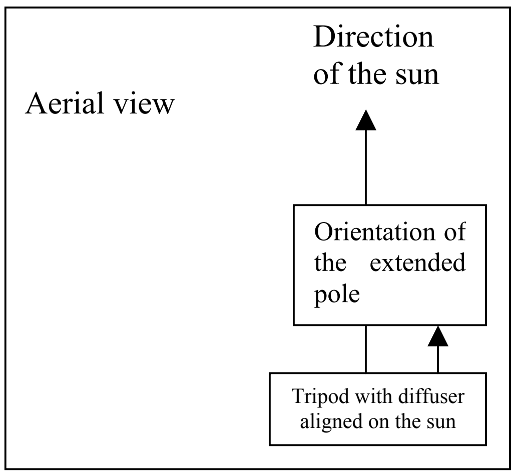
Please wait, taking measurement.

Computer instruction:

Please point fibre at the sun.
Diffuser in place and sun blocker over the sun.

- Check the diffuser is still pointed towards the Sun.
- The extended pole should be moved so that the shadow cast by the disk on the end of the rod covers the diffuser.





9. Click 'Ok on the computer

Computer information:

Please wait, taking measurements

Computer instruction:

Please point fibre at sky overhead (Straight up) - Lens in place.

- Remove the diffuser from the end of the fibre and place carefully within the circular box.
- Attach the lens to the end of the fibre.
- Rotating and tilting the top section of the tripod point the lens straight up so that it is looking at the sky. Placing the small circular spirit level on the top surface of the fibre-end holder can help get the lens aligned by getting the bubble centred in the circle.

10. Click 'Ok' on the computer.

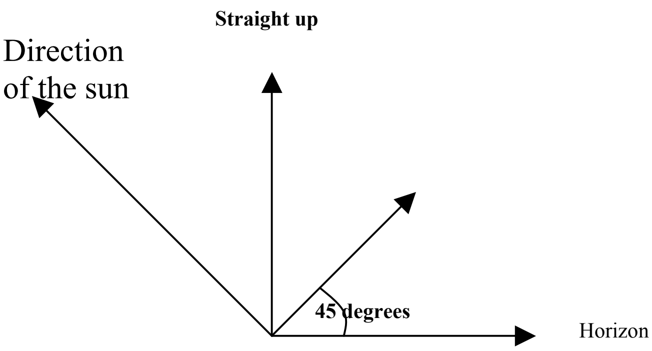
Computer information:

Please wait, taking measurements

Computer instruction:

Please point fibre at the sky. (Away from sun and 45 deg. Up from horizon) – Lens in Place.

- Ensure that the small metal angle indicator on the side of the fibre-end holder is free swinging (loosen if necessary), tilt the block until the metal indictor is aligned with the scratch mark that indicates that the fibre is pointing up at 45 deg elevation.



11. Click 'Ok' on the computer.

Computer information:

Please wait, taking measurements

Measurements complete

12. Click 'Exit'

13. The computer can then be closed down.

14. Unplug the USB from the computer.

15. Replace the cover on the fibre lens.

16. Replace the equipment back into the box.

Glossary

90 degrees	At right angles to.
Altitude	The height of a thing above a reference level, especially above sea level or above the earth's surface. See Synonyms at elevation. A high location or area.
Azimuth	The horizontal angular distance from a reference direction, usually the northern point of the horizon, to the point where a vertical circle through a celestial body intersects the horizon, usually measured clockwise. Sometimes the southern point is used as the reference direction, and the measurement is made clockwise through 360°. The horizontal angle of the observer's bearing in surveying, measured clockwise from a referent direction, as from the north, or from a referent celestial body, usually Polaris.
Calibration	Process by which instruments are measured against a known scale**.** An absolute calibration is the process whereby these scales are directly related to fundamental physical constants.
Colour Temperature	The equivalent temperature of a black body such that it would have the same spectral power distribution (or effective colour).
DST	Daylight saving time also called British Summer Time in the UK.
GMT	Greenwich mean time
GPS	Global position system. A constellation of around 20 satellites that allow people to determine their location anywhere on the Earth's surface to within 20m. Small units for use in cars are now becoming common.
LST	Local Sidereal Time - Sidereal time is the hour angle of the vernal equinox, the ascending node of the ecliptic on the celestial equator. The daily motion of this point provides a measure of the rotation of the Earth with respect to the stars, rather than the Sun. Local mean sidereal time is computed from the current Greenwich Mean Sideral Time plus an input offset in longitude (converted to a sidereal offset by the ratio 1.00273790935 of the mean solar day to the mean sidereal day.) Applying the equation of equinoxes, or nutation of the mean pole of the Earth from mean to true position, yields local apparent sidereal time. Astronomers use local sidereal time because it corresponds to the coordinate right ascension of a celestial body that is presently on the local meridian.
Latitude	The angular distance north or south of the earth's equator, measured in degrees along a meridian, as on a map or globe. A region of the Earth considered in relation to its distance from the equator: temperate latitudes.
Longitude	Angular distance on the Earth's surface, measured east or west from the prime meridian at Greenwich, England, to the meridian passing through a position, expressed in degrees (or hours), minutes, and seconds.
Meridian	An imaginary great circle on the Earth's surface passing through the North and South geographic poles. All points on the same meridian have the same longitude. Either half of such a great circle

	from pole to pole. Astronomy. A great circle passing through the two poles of the celestial sphere and the zenith of a given observer.
Occult	To conceal or cause to disappear from view. Astronomy. To conceal by occultation: The moon occulted Mars. Hidden; concealed. Not accompanied by readily detectable signs or symptoms.
Spectrometer	An instrument used for measuring wavelengths of light spectraA spectroscope equipped with scales for measuring wavelengths or indexes of refraction.
Spectrum	The colour image presented when white light is resolved into its constituent colours: red, orange, yellow, green, blue, indigo, violet, for example in a rainbow
Stray Light	the scientific term for light, that gets measured, which does not follow the intended route. It can come from light reflecting off surfaces or being scattered.
Zenith	The point on the celestial sphere that is directly above the observer. The upper region of the sky. The highest point above the observer's horizon attained by a celestial body

Contents of NPL box

Item	**Serial Number**	**Value**
Black Box		£50
Ocean Optics optical fibre	QP400-1-SRBX	£126
Hamamatsu VIS C10083MD NIR Spectrometer	30694101	£2,500
Ocean Optic 74-UV lens with cap		$159
Fibre-end holder		£20
Small LED torch		£20
Torch and diffuser mount		£100
Giotto camera tripod (small)		£35
Ocean Optics CC-3 Diffuser		$99
1 pence piece		£0.01
Small spirit level		£5
2 batteries CR123A 3V		£10
1 metre USB cable		£7
Gretamacbeth mini colour checker		£5
Black aluminium disk (10 cm in diameter)		£5
Sheet of black plastic – labelled calibration mat		£1
Fishing Rod (cut up to suit application)		£14

Location Information

Location	Country	Latitude (North +ve)	Longitude (East -ve)	Time zone	10am LST Hr	min
Antananarivo	Madagascar	-18	-48	3 noDST	9	48
Cape Town	South Africa	-38	-18	2 (no DST)	10	48
Victoria Falls	Zambia	-17	-26	2(no DST)	10	16
Tokyo	Japan	25	-141	9 (no DST)	9	36
Phnom Penh	Cambodia	13.5	105.8	7 (no DST)	9	57
Koh Samui	Thailand	9.4	-100	7 (no DST)	10	20
Denarau island	Fiji	-17	179	12 (noDST)	10	04
Bay of Islands	New Zealand	-35	-174	12 (DST off)	10	24
Uluru	Australia	-25	-132	9.5 (no DST)	10	42
St Lucia	Caribbean	14	61	-4	10	4.2
Karumba	Maldives	3	-72	5 (no DST)	10	12
Reykjavik	Iceland	64	22	0 (no DST)	11	28
Mont Blanc	France	46	-7	2 (DST on)	11	32
Castel Dinas Bran	Wales	52	5	1	11	20
Rock, Cornwall	UK	50	5	1	11	20
Edinburgh	Scotland	56	3	1	11	12
Dublin	Ireland	53	6	1	11	24
Amalfi Coast	Italy	40.5	-14.5	2 (DST on)	11	02
Marrakech	Morocco	32	8	0 (no DST)	10	32
Pyramids of Giza	Egypt	30	-31	2 (DST from 28Apr)	10:56	56
Macchu Picchu	Peru	-13	72	-5	9	48
Juneau	Alaska	61.2	141	-8 (DST on)	11	24
Rio de Janeiro	Brazil	-23	43	-3 (DST off)	9	52
San Francisco	N America	38	120	-7 (DST on)	11	00
Long Beach	N America	34	118	-7 (DST on)	10	52

Final points:

Any problems or queries, don't hesitate to contact us:

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Note keeping

While on your travels, please keep notes of the measurements that are made at each of locations. For example:

Time for camera shots, other photographs and directions?

From the Team at NPL we wish you well and Happy Travelling!

From Left to Right: Nigel Fox, Laura Crane, Heather Pegrum, Peter Woolliams, Magdalena Chapman, Ruth Montgomery and Saber Salim.