Sky Colours

Math 309 – Spring 2004

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Overview

- Why the sky is blue
- Colour of sky during sunsets and sunrises
- Polarization of light affecting “blueness”
- Atmospheric effects
- Why the sailor’s adage works (or doesn’t work).

Sky Colour

- Historical Overview
  - John Tyndall (1859)
    - Tyndall Effect: light passing through fluid is scattered by particles in suspension
  - Lord Rayleigh (1871)
    - Rayleigh Scattering: the amount of light scattered by small particles is inversely proportional to the fourth power of wavelength
  - Tyndall and Rayleigh thought that the blue colour of the sky must be due to small particles of dust and droplets of water vapour in the atmosphere

Sky Colour

- Historical Overview (cont.)
  - If scattering is due to atmospheric particulate, there would be more variation of sky colour with humidity or haze conditions than is observed
  - The molecules of oxygen and nitrogen in the air are sufficient to account for the scattering
    - Molecules are able to scatter light because the electromagnetic field of the light waves induces electric dipole moments in the molecules
  - Albert Einstein (1911)
    - Calculated the detailed formula for the scattering of light from molecules

Rayleigh Scattering

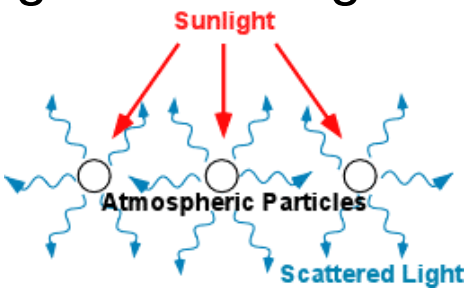
- The probability that a single photon of sunlight will be scattered from its original direction by an air molecule is inversely proportional to the fourth power of the wavelength.
- $I = 1 / \text{wavelength}^4$

Rayleigh Scattering

- The visible spectrum of light spans wavelengths from ~400 nm (violet) to ~700 nm (red)

- The shorter the wavelength the light is, the greater the chances are of being scattered
  - Scattering at 400 nm is 9.4 times as great as that at 700 nm.

Rayleigh Scattering



- Since blue light is scattered much more frequently than red light, when you look at the sky (excluding the sun) you are more likely to see a blue photon of scattered sunlight rather than a red one

Factors affecting sky colour

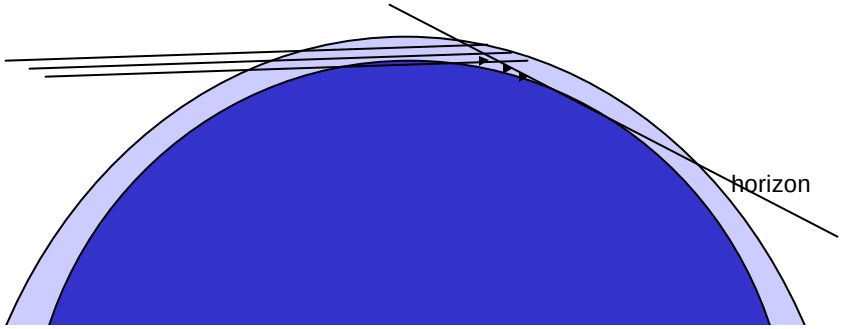
- Time of day
- Atmosphere
  - Polarization
  - Temperature / Time of year
- Atmospheric particulate & geography
  - Water
  - Aerosols
  - Dust & Ash
- Violet light

Sky Colour – Time of Day

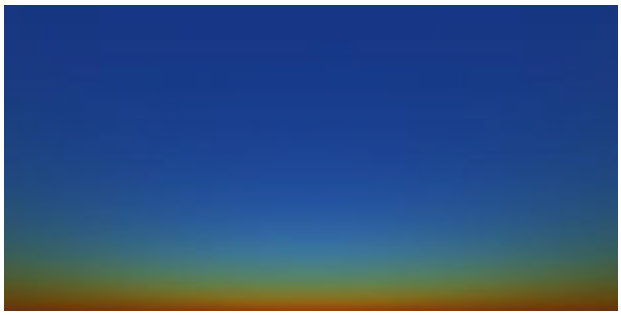
- At night, there is minimal scattering of light in the atmosphere, thus the sky appears black

Sky Colour – Time of Day

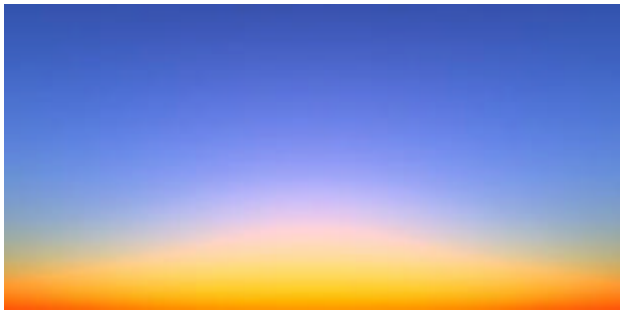
- As the sun approaches the horizon, it's rays begin to be scattered at the periphery of the visible sky



Sky Colour – Time of Day



Sky Colour – Time of Day

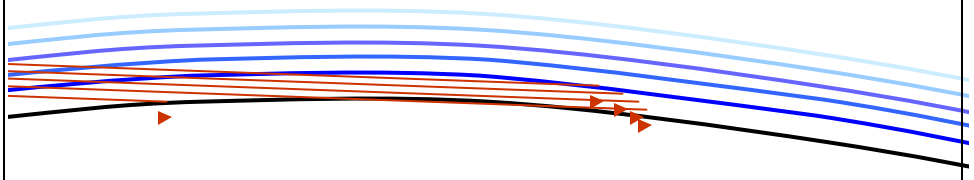


Sky colour simulations from:
http://www.student.seas.gwu.edu/~sylee/sky/sky.html

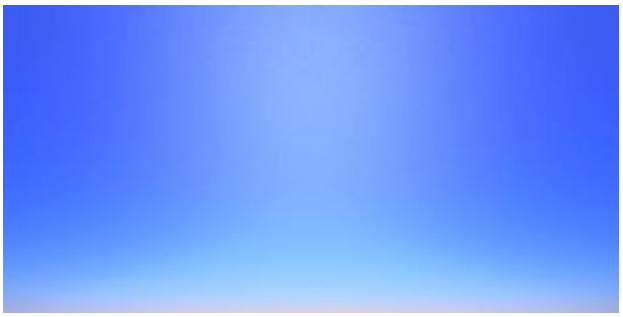
Sky Colour – Time of Day

- When the sun is at or near the horizon, the light that we see has been scattered by much more atmosphere than when the sun is at its zenith
- The light has travelled further through denser atmosphere, which can scatter yellow, orange and red light to a greater degree

Sky Colour – Time of Day



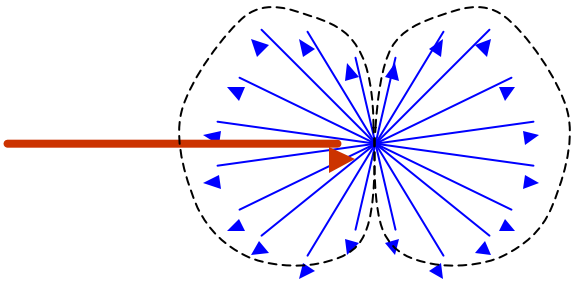
Sky Colour – Time of Day



- As the sun rises, the horizon appears to be much more opaque due to the increased scattering introduced by the additional air masses in the visible range

Sky Colour - Polarization

- Rayleigh scattering is dipolar



Sky Colour - Polarization

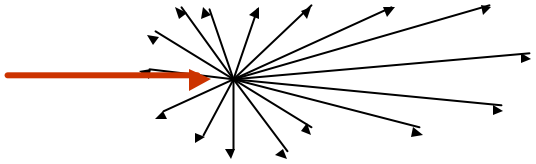
- Due to the dipolar scattering of light, there appears a darker band of blue in the sky 90 degrees away from the sun

Sky Colour – Time of Year

- During winter, the troposphere, the lower, denser layer where the significant amount of scattering occurs, is not as deep as in the summer
- In very cold air (winter), ice crystals and super-cooled water droplets form more easily in the atmosphere

Sky Colour - Particulate

- Mie scattering occurs with atmospheric particles larger than a wavelength
- Unlike Rayleigh scattering, which produces an even scattering, Mei scattering produces an antenna lobe pattern, which is sharper and more intense that larger the particle
- This causes the glare closest to the sun, and also creates the effect of white light emanating from fog banks

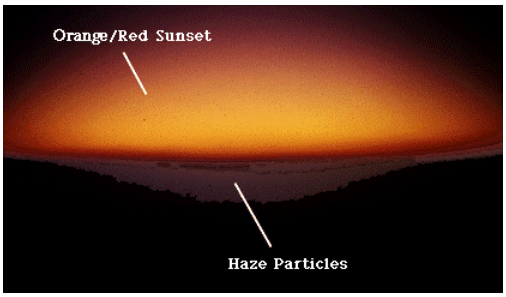


Sky Colour - Particulate

- Water: ice, hot vapour
  - Light is scattered in a much more even and uniform matter
  - This creates the effect of white (or pale blue) sky colour
- Aerosols: create a coloured haze
  - Aerosols from forests react with ozone to create small particles (~200 nm) that scatter more blue light
  - Smog (denser particulate) produces a red haze

Sky Colour - Particulate

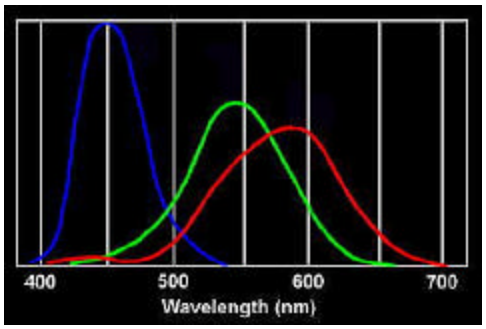
- Atmospheric particulate increases the amount of longer wavelength light scattered (increases the yellow and red colour of the sky).
  - Predominately dust, volcanic ash, and salt



Why Isn't the Sky Violet?

- Since violet light is "shorter" than blue light, it would seem that our sky should be violet in colour
- Some of this violet light is absorbed by the upper atmosphere
- Our eyes are less perceptive to violet light than to blue, green and red light
- Sun's light is yellowish, not evenly distributed across the visible spectrum

Human Perception of Light



- The three types of receptors, or cones, in our eye respond most favourably to blue, green and red light

Human Perception of Light

- The net effect is that the red and green cones are stimulated about equally by the light from the sky, while the blue is stimulated more strongly
- Seeing the sky as a pure blue hue helps us survive, since we are able to distinguish natural colours more clearly

Sailor's Adage

Red sky at night,
Sailor's delight.
Red sky at morning,
Sailor take warning.

Red Sky at morning…

- If you look at a global map of surface pressure, you will see a string of alternating high-pressure and low-pressure areas
  - Low pressure is associated with "bad" weather since low pressure causes air to converge (to try to "fill" the low), and converging air causes upward motion, which in turn produces clouds and precipitation
  - In contrast, air diverges from the center of a high-pressure area. This causes downward motion, which suppresses cloud formation, resulting in "good" weather

Sailor Take Warning

- A temperature inversion (temperature increasing with height) forms at the level of the troposphere where this downward motion is strongest. Vertical motion is inhibited at the level of the inversion; thus dirty air containing suspensions of soot, dust, and other particles (known as aerosols) is trapped near the surface.
- Atmospheric conditions in a high-pressure area are typically cloud free and dirty, and those in a low-pressure area are cloudy and relatively clean (fewer aerosols).

Red Sky at night…

- Sailors in the mid-lattitudes (30 to 60 degrees in either hemisphere) experience westerly winds
- Red sky in the east (morning) indicates that the high pressure zone is east of you – and will continue to move east (bringing your ship a low pressure zone)

Sailors Delight

- Red sky in the west (sunset) indicates that the high pressure zone is west of you – and will continue to move east (bringing your ship a high pressure zone and good weather)

Summary

- Blue sky is due to Rayleigh scattering of light by oxygen and nitrogen molecules
- Density of atmosphere and polarization of light can affect the saturation level
- At sunset and sunrise, longer distance of light travel introduces increased scattering of light of longer wavelengths
- Atmospheric particulate can also lead to increased scattering of light

Sources

- HyperPhysics web site:
  - http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html
- NOAA SRRB web site:
  - http://www.srrb.noaa.gov/highlights/redsky/
- Light & Colour in the Atmosphere:
  - http://www.env.leeds.ac.uk/envi1280/lecture_notes_carslaw2/sld001.htm
- Clear Sky Phenomena
  - http://envsci.rutgers.edu/~veron/ClearSkyNotes.pdf