2.11 Atmospheric Effects

大气影响

Atmospheric effects have several impacts on the solar radiation at the Earth's surface. The major effects for photovoltaic applications are:

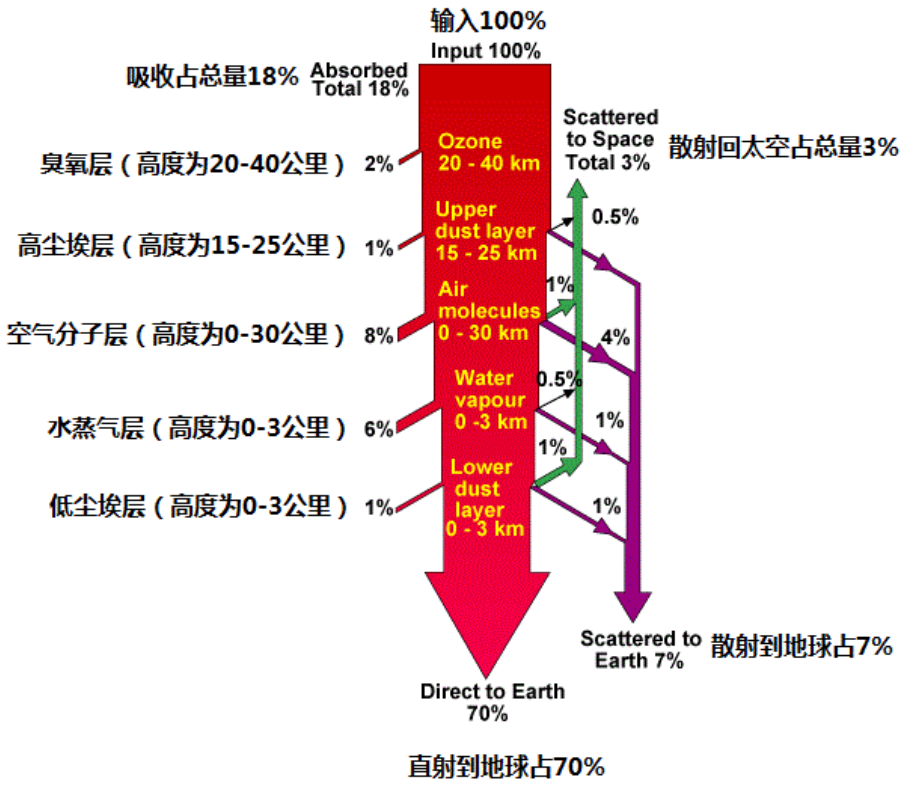
- a reduction in the power of the solar radiation due to absorption, scattering and reflection in the atmosphere;
- a change in the spectral content of the solar radiation due to greater absorption or scattering of some wavelengths;
- the introduction of a diffuse or indirect component into the solar radiation; and
- local variations in the atmosphere (such as water vapour, clouds and pollution) which have additional effects on the incident power, spectrum and directionality.

大气在很多方面影响着地球表面的太阳辐射。对于光伏应用来说，其主要影响包括：

- 因为大气的吸收、散射和反射导致太阳辐射的功率下降
- 因为大气对于某些波长强烈吸收或散射导致太阳辐射的光谱成分发生变化
- 大气导致的散射和间接的太阳辐射以及
- 局部地区的大气变化（如水蒸气、云层和大气污染）导致入射能量、光谱成分和方向的额外改变

These effects are summarised in the figure below.

以上影响在下图中概括列出。



Typical clear sky absorption and scattering of incident sunlight[1].

在典型的晴空条件下大气对入射的阳光的吸收和散射 [1]。

Absorption in the Atmosphere

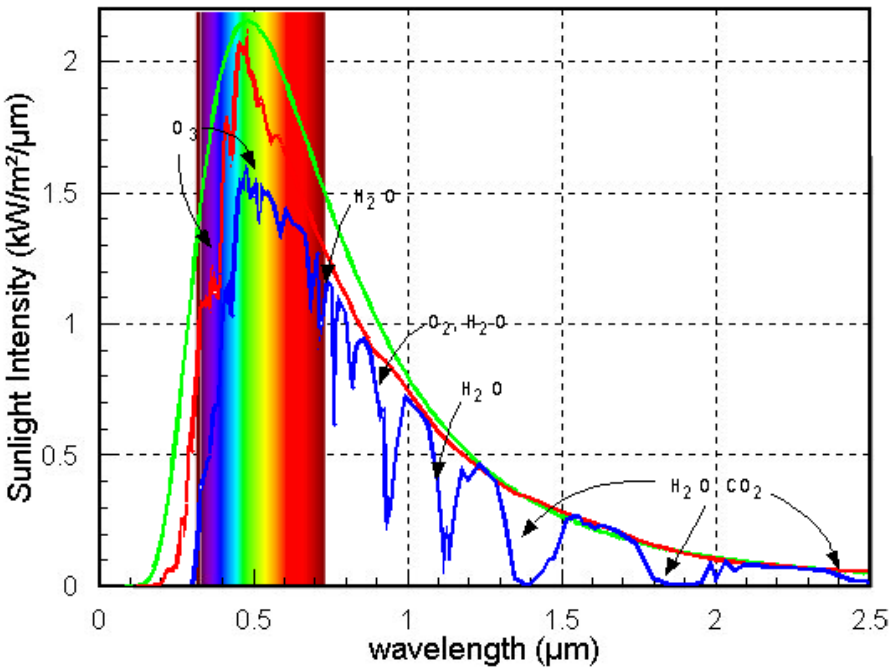
大气的吸收作用

As solar radiation passes through the atmosphere, gasses, dust and aerosols absorb the incident photons. Specific gasses, notably ozone (O_3), carbon dioxide (CO_2), and water vapour (H_2O), have very high absorption of photons that have energies close to the bond energies of these atmospheric gases. This absorption yields deep troughs in the spectral radiation curve. For example, much of the far infrared light above 2 µm is absorbed by water vapour and carbon dioxide. Similarly, most of the ultraviolet light below 0.3 µm is absorbed by ozone (but not enough to completely prevent sunburn!).

当太阳辐射穿过大气时，气体、尘埃以及气溶胶都会吸收入射的光子。某些特定气体，众所周知的臭氧，二氧化碳和水蒸气会强烈吸收能量与其分子键能量相似的光子。它们对太阳辐射的吸收，导致了光谱辐射曲线中的凹槽。举例来说，水蒸气和二氧化碳吸收大多数波长超过 2 微米的远红外光。同样，臭氧吸收大多数波长小于 0.3 微米的紫外线（但这并不足以彻底防止晒伤！）。

While the absorption by specific gasses in the atmosphere change the spectral content of the terrestrial solar radiation, they have a relatively minor impact on the overall power. Instead, the major factor reducing the power from solar radiation is the absorption and scattering of light due to air molecules and dust. This absorption process does not produce the deep troughs in the spectral irradiance, but rather causes a power reduction dependant on the path length through the atmosphere. When the sun is overhead, the absorption due to these atmospheric elements causes a relatively uniform reduction across the visible spectrum, so the incident light appears white. However, for longer path lengths, higher energy (lower wavelength) light is more effectively absorbed and scattered. Hence in the morning and evening the sun appears much redder and has a lower intensity than in the middle of the day.

尽管大气中的一些气体对光线的吸收会导致地球表面的太阳辐射的光谱成分发生变化，然而，这一变化对于总功率的影响很小。相反，大气中的空气分子和尘埃对太阳辐射的吸收才会显著减少入射功率。这一吸收过程并不会使得光谱辐射曲线出现凹槽，但它会导致功率降低，降低的程度取决于阳光穿过大气层的路径的长度。当太阳在头顶正上方时，这些大气成分对阳光的吸收导致了光谱中可见光区域的相对均匀的较少，因此入射的太阳光呈现白色。然而，当路径变长时，高能量（短波长）的光线更有效地被吸收和散射。因此，早晨和傍晚的太阳会更红并且其辐射强度也比中午时低。



☑ Show AM0

显示大气层外的阳光强度

☑ Show AM 1.5

显示当光线通过大气的实际距离为大气垂直厚度1.5倍时的阳光强度

☑ Show blackbody at 6000K

显示6000开尔文的黑体辐射的强度

☑ Show visible wavelengths

显示可见光部分

☑ Show absorption notes

显示吸收该波长的大气成分

A comparison of solar radiation outside the Earth's atmosphere with the amount of solar radiation reaching the Earth itself. The human eye has evolved to the point where sensitivity is greatest at the most intense wavelengths[2].

地球大气层外的太阳辐射和到达地球本身的太阳辐射的比较。人眼通过进化，具有对于强度最强的波长的敏感度最高的特点。

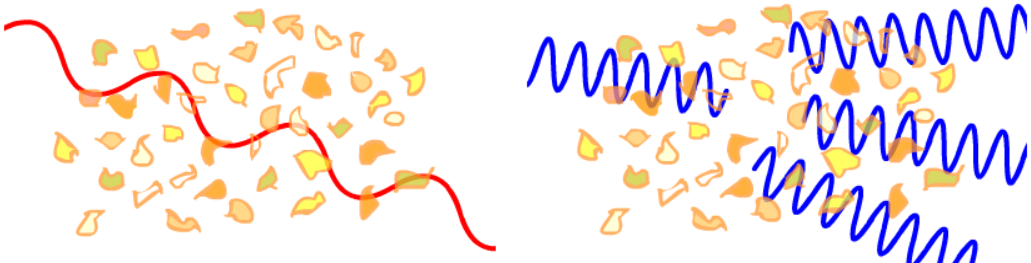
Direct and Diffuse Radiation Due to Scattering of Incident Light

大气对入射光线的散射导致的直接辐射和间接辐射

Light is absorbed as it passes through the atmosphere and at the same time it is subject to scattering. One of the mechanisms for light scattering in the atmosphere is known as Rayleigh scattering which is caused by molecules in the atmosphere. Rayleigh scattering is particularly effective for short wavelength light (that is blue light) since it has a λ^{-4} dependence. In addition to Rayleigh scattering, aerosols and dust particles contribute to the scattering of incident light known as Mie scattering.

当光线穿过大气时，它既会被吸收，同时也会被散射。大气中光线散射的一个机制被称为瑞利散射，它是由大气中的分子造成的。瑞利散射对于短波长的光（比如蓝光）

的散射效果显著，因为散射强度与波长的 4 次方成反比。除了瑞利散射之外，气溶胶和尘埃也会导致光线散射，这种散射被称为米氏散射。



Red light has a wavelength larger than most particles and is unaffected.
红光的波长比大多数颗粒的尺寸长，其传播路径不受影响。

Blue light has a wavelength similar to the size of particles in the atmosphere and so is scattered.
蓝光的波长与大气中的颗粒的尺寸比较接近，因此容易受到散射。

Scattered light is undirected, and so it appears to be coming from any region of the sky. This light is called "diffuse" light. Since diffuse light is primarily "blue" light, the light that comes from regions of the sky other than where the sun is, appears blue. In the absence of scattering in the atmosphere, the sky would appear black, and the sun would appear as a disk light source. On a clear day, about 10% of the total incident solar radiation is diffuse.

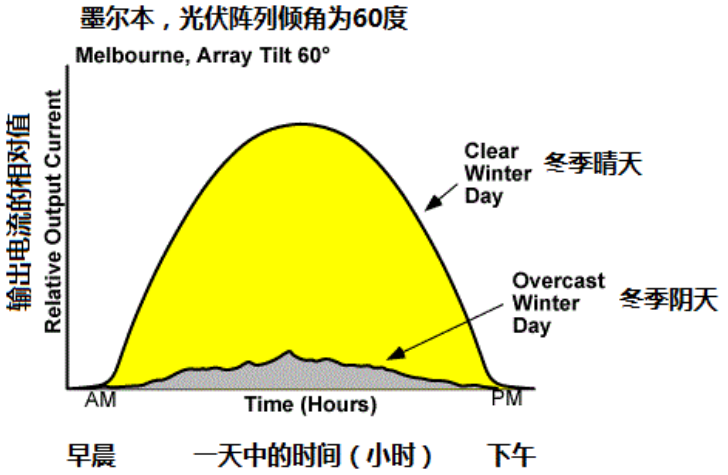
散射光没有确定的方向，因此它看起来来自于天空的任何区域。这种光被称为漫射光。因为散射光主要是蓝光，所以除了太阳所在区域之外，天空的其他区域都呈现处蓝色。如果没有大气的散射作用，天空看起来就是黑色的，而太阳看起来就像一个圆盘状的光源。在天气晴朗的时候，漫射光的能量大约占太阳入射总能量的 10%。

Effect of clouds and other local variations in the atmosphere

云层和其他大气局部差异的影响

The final effect of the atmosphere on incident solar radiation is due to local variations in the atmosphere. Depending on the type of cloud cover, the incident power is severely reduced. An example of heavy cloud cover is shown below.

大气对入射太阳辐射的另一个影响来源是大气局部差异。基于云层的类型，入射功率会显著下降。以下是一个浓密云层对功率影响的例子。



Relative output current from a photovoltaic array on a sunny and a cloudy winter's day in Melbourne with an array tilt angle of 60°[3].

冬季一个位于墨尔本的倾角为 60 度的光伏阵列晴朗和多云天气下的相对输出电流的比较。

参考文献

1. Hu C, White RM. Solar Cells: From Basic to Advanced Systems. New York: McGraw-Hill; 1983.

2. Sekuler R, Blake R. Perception. New York: Alfred A. Knopf Inc; 1985.

3. Mack M. Solar Power for Telecommunications. The Telecommunication Journal of Australia. 1979;29:20-44.