Image-based measurement of clear sky radiation distribution from 0 to 5000 meters above sea level

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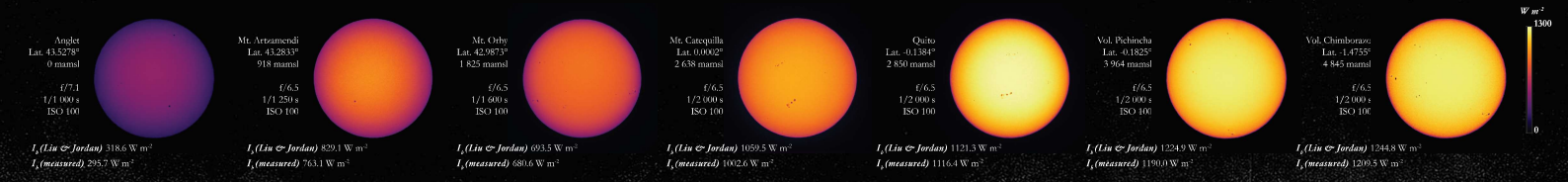

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has imposed on itself as a working principle to accompany the simulations with measurements likely to corroborate the results [1]. In [2], the comparison between measurements and finite element simulation was used to estimate several material properties for the study of historic urban districts. The measurement also allowed setting the initial conditions of the scene's radiative environment, based on imaging data collected in every direction (angle of 4π sr) [3]. The observations are carried out under meteorological conditions similar to those we are able to simulate, i.e., in the absence of wind, in clear, dry weather. However, this measurement could not be used in its integrity. Some portions of the sky images were saturated by the presence of the sun and had to be replaced by a theoretical sky model [4].

To be able to integrate the sky into the simulation, it is thus necessary to overcome the limitation of measuring the sun. Liu [5] proposes a theoretical model to calculate the value of direct solar radiation, which has been validated by measurements up to 2000 mamsl. Another method to estimate direct radiation is to deduce it from measurements of global and diffuse sky radiation [6].

The sun was photographed for the first time in 1845 by the French physicists Léon Foucault and Hippolyte Fizeau using a complex system. This operation has long been limited by the shutter speed, which had to be higher than what the devices of the time allowed. Today, new technologies and the development of special filters for astronomy make solar photography more accessible.

Outside the area occupied by the sun, photography of the sky in HDR (High Dynamic Range) does not cause any particular problem. The measured irradiance values can be compared with the reference values of the theoretical model [5]. In addition, the measurement by photography contains information on the color of the sky, which varies as the altitude increases. This phenomenon was noted in 1789 by Horace-Bénédict de Saussure during his first ascent of the Mont-Blanc, for which he painted a palette of blue shades that represented the colors of the sky, called cyanometer, and then by Alexander von Humboldt in 1802, during his ascent of Chimborazo. These works made it possible to evaluate the transmittance and the composition of the atmosphere according to the altitude.

We measured the clear sky and the sun at seven different altitudes, in the Pyrenees (Anglet beach - 0 mamsl, Artzamendi peak - 918 mamsl, Orhy peak - 1825 mamsl) and in the Andes (mount Catequilla - 2638 mamsl, Quito - 2850 mamsl, Pichincha volcano - 3964 mamsl, Chimborazo volcano - 4845 mamsl). The measurements, made with a photographic camera and filters, are compared to the values obtained from theoretical models. The images were used to compose a digital cyanometer, studied on the HSB (Hue, Saturation, and Brightness) color space. The combination of direct and diffuse radiation measurements, in a single image, can be used as input for urban physics radiative simulations i.e. raytracing lighting simulations or thermal simulation using the finite element method.

COLORS OF THE SKIES

The photograph offers information on the color of the sky, which changes according to atmospheric conditions. From photographs of the sky taken at different altitudes, it is possible to compose a color chart in the manner of Saussure's and Humboldt's cyanometer, which was composed using one of the first synthetic paints: Prussian blue. On each recomposed image of the sky (see previous image), we extract a sample of 5x5 pixels around the zenith. To study the variations obtained according to the altitudes, we refer to the color space HSB that allows qualifying respectively the hue, the saturation, and the brightness of the color.

The results show that the hue is almost constant on all the measurement points up to 2000 mamsl and is around 200, i.e. around the blue color, before tending slightly to violet at higher altitudes while the brightness of the sky decreases. From 3000 mamsl, the saturation of the color increases quite strongly. On the mountains, the sky is indeed darker and of a purer color, because the atmospheric layer is thinner and the sun's rays are less diffused. In space, there is no atmosphere and the backdrop for astronomical observations is in total darkness.

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