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Spectral differences in sky radiance over land and sea and orientation of the littoral amphipod Talitrus saltator Montagu

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SEZIONE III

(Botanica, zoologia, fisiologia e patologia)

Etologia. — *Spectral differences in sky radiance over land and sea and orientation of the littoral amphipod* Talitrus saltator *Montagu.* Nota di GIORGIO FIOCCO (*), ANGELO GUERRINI (**) e LEO PARDI (***), presentata (****) dal Corrisp. L. PARDI.

RIASSUNTO. — Differenze spettrali nella radiazione celeste sul mare e sulla terra sono teoricamente prevedibili sulla base della diversa riflessione della superficie marina e dei vari tipi di superfici terrestri nude o coperte di vegetazione.

Misurazioni effettuate su una spiaggia tirrenica rivelano effettivamente differenze nel colore del cielo sul mare e sulla terra che potrebbero eventualmente rappresentare un meccanismo ausiliario per gli Anfipodi dotati di orientamento solare astronomico.

1. INTRODUCTION

The sandhopper *Talitrus saltators* Montagu, a littoral amphipod commonly found on Italian beaches, may utilize different mechanisms of orientation to recover its habitat, the moist area of the beach, after having been displaced. The main mechanism is astronomical and is controlled by an endogenous rhythm: during the day the animals use the position of the sun to orient, and during the night the position of the moon [1–5]. This assumes that the animals " know " at what bearing with respect to the sun, the coastline is.

Additional mechanisms assist the animals in their choice, and may help to explain the increase of the scattering around the mean preferred direction shown by the animals tested on shores oriented differently from their natural shore or in the inland, compared to the animals tested on their natural shore. For instance, animals collected on a Tyrrhenian shore show the same preferred compass direction (toward the Tyrrhenian sea) either when tested on the Tyrrhenian or the Adriatic coast, but their scattering around the mean direction is greater on the opposite shore (Adriatic). Animals from an Adriatic shore behave in the same way if tested both on the Adriatic and the Tyrrhenian shores. Moreover, in inland localities (such as Turin and Florence) animals of every population usually scatter more than on their natural shore [6–7].

These studies suggest that the characteristics of the sky (color, polarization) may be assisting factors, but no direct experimental evidence exists to support this hypothesis. Studies of the sensitivity and response to artificial light of these amphipods [8] have demonstrated that the phototactic response is predominantly positive with a clear preference for the shorter wavelengths.

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(****) Nella seduta dell'8 gennaio 1983.

Thus the question has been raised whether there are consistent differences in the characteristics of sky radiation over land and sea enabling an observer to obtain orientation.

In this note we consider the effect of surface albedo on the sky radiance and its spectral dependence and present the result of observations showing the existence of definite difference of the sky radiance respectively over land and sea. The experiments have been carried out in areas which represent a typical habitat of the sandhopper. It should be pointed out that the animals activity is predominant in spring and summer: during this period the weather conditions are generally fair, the solar zenith angle is high.

The importance of surface albedo in determining the radiative properties of the atmosphere has been demonstrated, for instance, by Fiocco, Grams and Mugnai [9] who have shown that stratospheric heating rates after the Mt Agung eruption were associated with albedo patterns.

Analysis

Schematically the process is as follows. Direct solar radiation propagating through the Earth's atmosphere in conditions of low turbidity is in part scattered by the atmospheric constituents—molecules, aerosols, clouds—and in

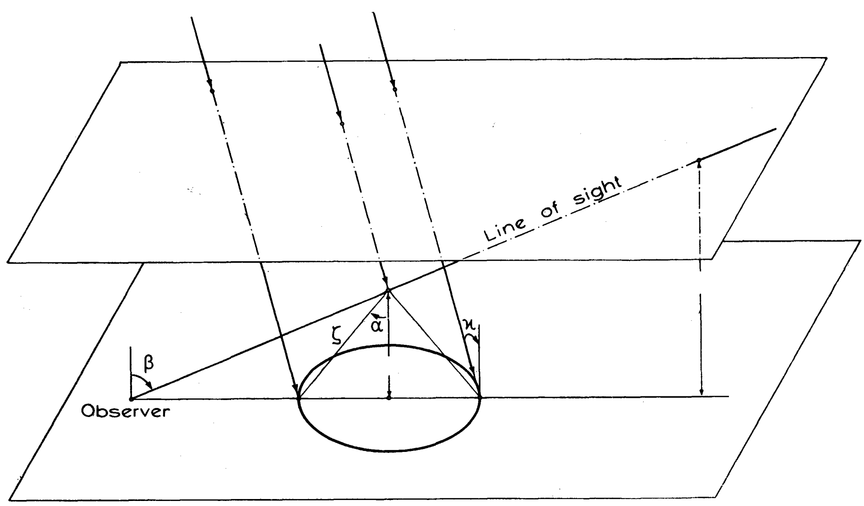

Fig. 1.

part reaches the ground: of the scattered fraction, a portion also reaches the ground as diffuse radiation. The radiation reaching the ground is partially absorbed and partially diffused back into the atmosphere. As a result the diffuse sky radiation consists of a part which is affected by the characteristics of the surface and a part which is not.

We consider a horizontally stratified atmospheric layer extending from the ground to a height H, characterized by a scattering coefficient per unit volume

K and a phase function $\tilde{P}$. Neglecting absorption and multiple scattering, with reference to Fig. 1 the sky radiance observed from the ground at an angle β to to the vertical can be formally obtained by summing the contributions along the line of sight:

$$\text{(1)} \qquad I = \int_0^\tau \sigma \sec\beta \, e^{-\tau' \sec\beta} \, d\tau$$

where τ' and τ are the optical depths from the ground respectively to a height h and to the top of the layer H:

$$\text{(2)} \qquad \tau = \tau' + \tau'' = \int_0^h K \, dz + \int_h^H K \, dz$$

τ'' is the optical depth from h to H. σ is the source function: we separately account for the contributions to σ due to the direct solar radiation (σ_1) and to the diffuse radiation backscattered by the ground (σ_2). We get

$$\text{(3)} \qquad \sigma_1 = \frac{1}{4\pi} \tilde{P} F_\infty e^{-\tau'' \sec\varkappa} \sec\varkappa$$

where F_∞ is the direct solar power flux per unit horizontal surface outside the atmosphere; $\varkappa$ is the solar zenith angle.

The source function for the ground-scattered solar radiation is obtained by accounting for the contributions reaching the scattering volume in h at an angle α from the circular elements at distance ζ. We obtain

$$\text{(4)} \qquad \sigma_2 = \frac{1}{2\pi} \mathscr{A} F_\infty e^{-\tau \sec\varkappa} h \int_{\zeta=h}^{\zeta=\infty} \tilde{P} e^{-\tau' \sec\alpha} \, d\zeta/\zeta^2$$

where $\mathscr{A}$ is the diffuse ground reflectivity, or albedo.

If we assume that $K = \text{constant}$ and $\tilde{P} = 1$ throughout the layer, the integral in the above expression reduces to the exponential integral function $E_2(Kh)$.

Various approximate expressions for I can be obtained; for $\tau \ll 1$ and with the further assumption that $\beta \approx \varkappa$, we obtain the much simplified expression

$$\text{(5)} \qquad I = F_\infty \frac{\sec\beta}{4\pi} \tau (1 + 2\mathscr{A}) .$$

Thus the sky radiances respectively over sea (I_M) and over land (I_T) should be in the ratio

$$\text{(6)} \qquad I_M/I_T = (1 + 2\mathscr{A}_M)/(1 + 2\mathscr{A}_T) .$$

Data on the spectral albedo of various natural surfaces in the spectral region 400–850 nm are reported in the Handbook of Geophysics (MacMillan Co, 1960), the most important source being Krinov. Fig. 2 is a compendium of Krinov's data: reference is made to three classes of surfaces. Fig. 2A refers to water surfaces, Fig. 2B to bare areas and soils, Fig. 2C to vegetation. For the water surfaces the curve in Fig. 2A exhibits a steady decrease with an increase in wave length, from approx 0.15 at 400 mm, to 0.05 at 550 mm, to 0.02 at 850 nm.

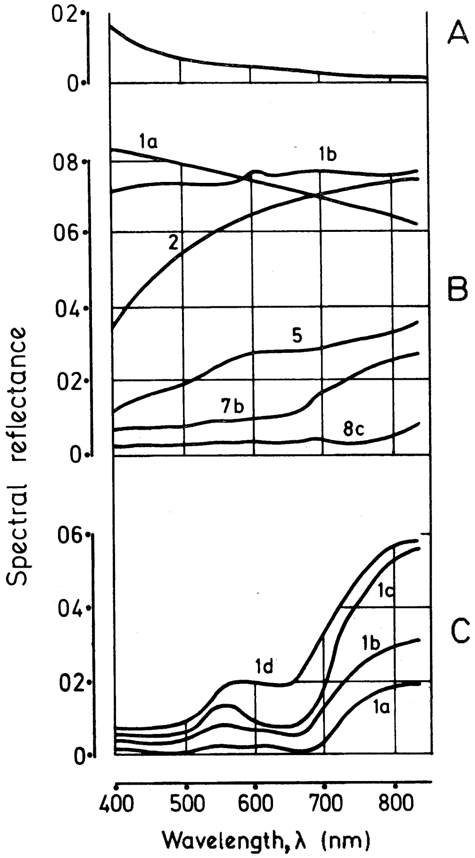

Fig. 2.

For the soil and vegetation typical of Mediterranean summer, the following cases come close:

B5 ; sands, bare areas in the desert some mountain outcrops;

B8c ; black earth sand loam and earth roads;

B7b ; podzol, clay, loam and other soils, paved roads and some buildings;

C1b ; coniferous forests in summer, dry meadows and grass in general, excluding lush grass.

C1c ; deciduous forests in summer and all lush grass.

In all these cases the reflectivity increases with an increase in wavelength, thus showing the opposite trend displayed by the water surfaces.

These spectral reflectivity values have been utilized in calculating the ratio I_M/I_T and the results are shown in Fig. 3; the ratio is always larger that 1 at the shorter wavelength end of the spectrum, whereas it is smaller that 1 at the other end.

Thus an observer on a beach whose visual sensitivity is larger at the shorter wavelengths will see the sky brighter in the direction of the sea, other conditions being equal.

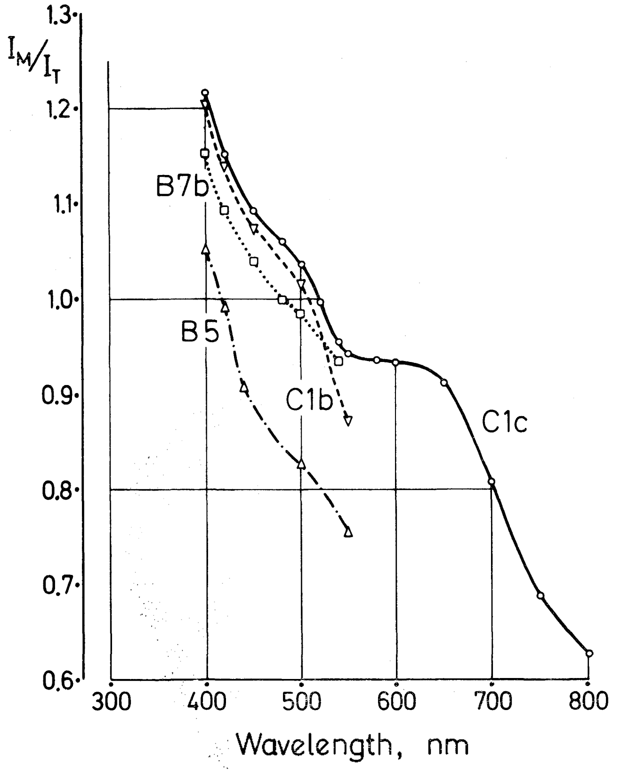

Fig. 3.

The simplicity of exps. 5 and 6 is based on several assumptions: among those we should point out that isotropic scattering ($\tilde{P} = 1$) is rarely obtained in a real atmosphere. Relatively large aerosols scatter predominantly in the forward direction and may determine differences in sky radiance. The effect, however should not be particularly sensitive to wavelength.

It should be considered that most beaches of the Italian peninsula run approximately from North to South: around midday assuming a homogeneous particle distribution the radiances over sea and over land would be symmetrically affected with no consequence on exp. 6. On the other hand the use of exp. 6 may become questionable when the solar azimuth approaches directions orthogonal to the beach line, conditions obtained in the early morning and in the late afternoon, when the contributions of forward scattering may produce large asymmetries.

Measurements

The experiments were based on comparing the diffuse sky radiances over sea and land in the blue-violet region of the spectrum: broad band measurements of atmospheric turbidity were also carried out.

Relative measurements of the spectrally resolved sky radiance were obtained with a lightweight Jobin–Yvon H. 10 scanning monochromator equipped with a chopper and a RCA IP21 photomultiplier. This compact instrument was mounted on a theodolite mount allowing the optical axis to be pointed to the sky with any assigned azimuth and elevation angles. The photomultiplier output was synchronously detected and recorded.

The atmospheric turbidity was measured with a Kipp & Zonen actinometer equipped with a Schott OG1 filter, which is transparent to solar radiation in the wavelength region around $\varkappa = 0.530$ nm.

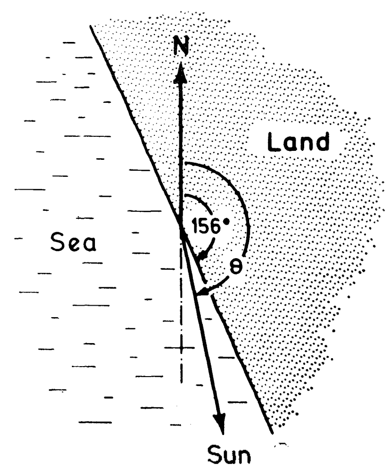

Fig. 4.

The measurements were carried out on the beach at Cerenova, approx. 40 Km NW of Rome. The following procedure was used. Consider in Fig. 4 the straight line Sun-observer and its projection on the horizontal plane; such projection makes an angle θ with the North, and represents the solar azimuth. Also shown is the coast line, which at the location of the experiments is at an angle of approximately 156° with respect to North.

Throughout the measurements the instrumental axis was maintained at the constant elevation of 45°; its azimuth was alternated between the two values $\alpha_1 = \theta + 90°$ and $\alpha_2 = \theta - 20°$ which during most of the day, because of the direction of the coast line, correspond to directions respectively over sea and over land. In the late afternoon, with the solar azimuth going through the orthogonality conditions ($\theta = 246^{\circ}$), such correspondence is reversed.

For each direction a complete scan in the wavelength range 320–480 nm, taking minutes to complete, was carried out.

Thus, values of the sky radiances, I_1 and I_2, respectively referring to azimuthal angles α_1 and α_2, were obtained.

Although the solar azimuth θ varied during the day we were thus assured of comparing portions of the sky under substantially symmetrical conditions as regards solar illumination and scattering phase functions.

According to the effect which we seek to evaluate, the sky radiance depends on the average albedo of the underlying surface, that is on the proportion of land and sea surface which contribute to the diffuse component along the line of sight. When the solar azimuth θ coincides with the coast line, condition which at our site is obtained in the late morning hours, α_1, and α_2 are in directions orthogonal to the beach line and the difference between I_1 and I_2 should be maximum. As θ deviates from such condition, the difference should be smaller, becoming zero when the solar azimuth is orthogonal to the beach line.

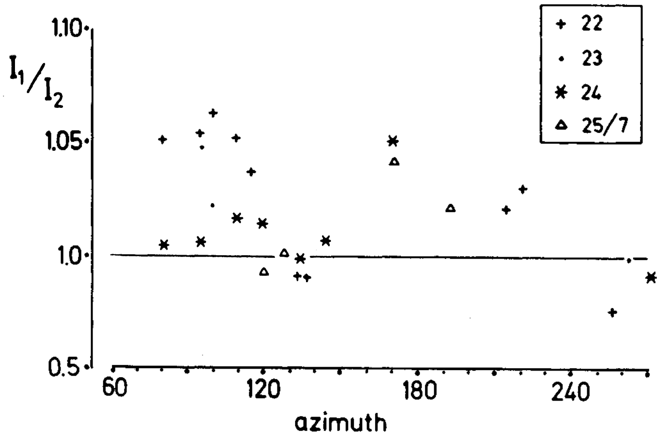

Fig. 5.

The measurements were carried out in the period 22–25 July 1980 and were characterized by fair weather conditions. A total of 170 scans were obtained: of these only 90 were utilized after a preliminary, subjective, choice based on the level of the fluctuations, attributed to the presence of thin clouds in the field of view. After this preliminary selection, the spectral data were digitized at wavelengths corresponding to known maxima and minima in the solar irradiance. Some averaging was carried out to correct the non-simultaneity of the measurement and the ratio I_1/I_2 was obtained.

Fig. 5 shows the ratios I_1/I_2 arranged as a function of the solar azimuth θ, after those values whose standard deviation exceeds 0.03 were excluded. The ratio tends to diminish when orthogonality is approached and actually reverses when $\theta > 246°$. Fig. 6 shows the ratio $\rho = I_M/I_T$ of the brightnesses over land, I_M, and over sea, I_T. This ratio is taken as $\rho = I_1/I_2$ when $\theta > 246°$ and is $\theta = I_2/I_1$ when $\theta > 246°$. All data whose standard deviation is less than 0.06

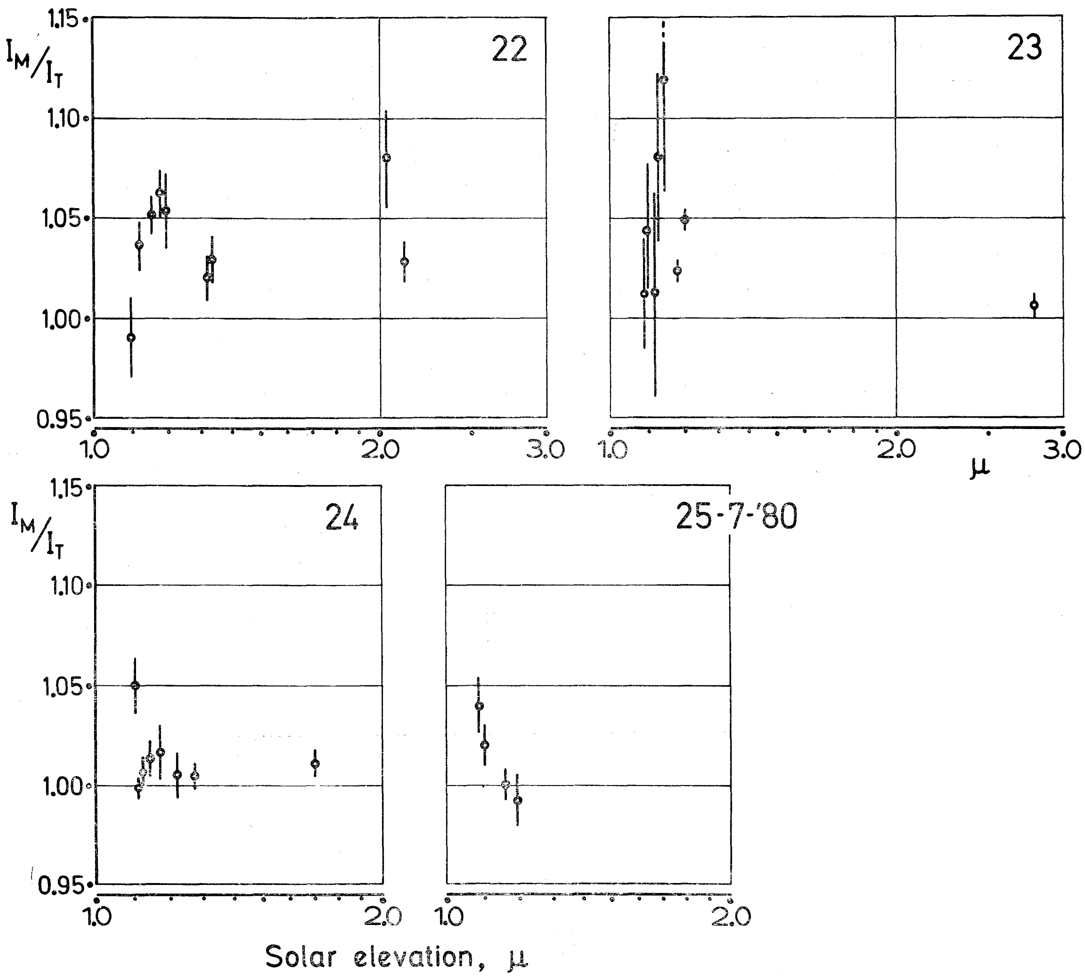

Fig. 6.

are included. The data, separately displayed for the four measurement days, are shown as a function of the solar elevation, $\mu = \sec \varkappa$. In the great majority of the shown cases, within experimental errors, the ratio exceeds unity.

In conclusion it appears that differences in the colour of the sky over sea and over land can be instrumentally detected, and should be considered as providing guidance information to animals for retrieving their habitat.

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