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Satellite Remote Sensing

9.0.1 Radiometers

9.0.2 An Ideal Radiometer

A radiometer is a device used to measure the energy of electromagnetic radiation over some spectral interval. The radiometric model describes the signal given by an instrument as a function of the incident radiation field. As an example consider a radiometric instrument that measures the radiant energy from the hemisphere above an ideal sensor during some time interval Δt. If the sensor area is ΔA then the radiant energy, Q, measured by the instrument is

$$Q = \Delta A \int_{t}^{t+\Delta t} \int_{0}^{\infty} \int_{0}^{2\pi} L_\lambda(\lambda, \boldsymbol{\omega}, t)\, d\Omega\, d\lambda\, dt \qquad (9.1)$$

where $L_\lambda(\lambda, \boldsymbol{\omega}, t)$ is the spectral radiance incident on the sensor from direction $\boldsymbol{\omega}$ at time t. Now consider having a sensor whose response is not uniform with wavelength or alternatively the instrument contains filters to select a portion of the electromagnetic spectrum. The spectral response of the instrument is described by $\phi(\lambda)$ over some wavelength range $[\lambda_1, \lambda_2]$. The integral of $\phi(\lambda)$ is unity. The measured energy is then given by

$$Q = \Delta A \int_{t}^{t+\Delta t} \int_{\lambda_1}^{\lambda_2} \phi(\lambda) \int_{0}^{2\pi} L_\lambda(\lambda, \boldsymbol{\omega}, t)\, d\Omega\, d\lambda\, dt \qquad (9.2)$$

The angular distribution of radiation reaching the sensor is usually concentrated over a small solid angle $\Delta\omega$ which strikes the detector at an incident angle near normal. The pattern of angular response is described by a field-of-view function $\eta(\boldsymbol{\omega})$ whose integral over $\Delta\omega$ is unity. As a first approximation the field-of-view function is the diffraction pattern caused by the apertures within the instrument. Including the field-of-view function gives radiant energy as

$$Q = \Delta A \int_{t}^{t+\Delta t} \int_{\lambda_1}^{\lambda_2} \phi(\lambda) \int_{0}^{\Delta\omega} \eta(\boldsymbol{\omega}) L_\lambda(\lambda, \boldsymbol{\omega}, t)\, d\omega\, d\lambda\, dt \qquad (9.3)$$

It is quite possible for the field-of-view function to be wavelength dependent. Note that the radiometer model expressed through Equation 9.3 is an ideal case and generally too complex to be used as an instrument model within a retrieval scheme.

To simplify this measure of energy it is typical to assume that spectral radiance does not vary over a measuremnt time interval, Δt, or within the field-of-view, $\Delta\omega$.

Furthermore we will use channel to refer to the integrated signal measured by the instrument. The radiant energy for channel x is then

$$Q_x = \Delta A \Delta t \Delta \omega \int_{\lambda_1}^{\lambda_2} \phi(\lambda) L_\lambda(\lambda)\, d\lambda \tag{9.4}$$

We then define the measured radiance in channel x as

$$L_x = \frac{Q_x}{\Delta A \Delta t \Delta \omega} = \int_{\lambda_1}^{\lambda_2} \phi(\lambda) L_\lambda(\lambda)\, d\lambda \tag{9.5}$$

In practice imaging radiometers which measure over a narrow spectral band report a Sun normalised radiance which is formed by dividing the radiance measured in a waveband by the radiance the satellite would measure if viewing a Lambertian surface illuminated by the Sun at zenith angle θ_0 i.e.

$$R_x(\omega_0, \omega_r) = \frac{L_x}{\frac{\cos\theta_0 E_i^0}{\pi}} \tag{9.6}$$

given

$$E_i^0 = \int_{\lambda_1}^{\lambda_2} \phi(\lambda) E_\lambda^0\, d\lambda \tag{9.7}$$

where E_λ^0 is the extraterrestrial solar irradiance at the time of observation. In the limit of a very narrow band, the Sun-normalised radiance is a good approximation to the reflection function defined in Section 3.6.3. A second way to think about Equation 9.6 is to express the formula as

$$R_x(\omega_0, \omega_r) = \frac{\pi L_x}{\cos\theta_0 E_i^0} \tag{9.8}$$

and to assume the observed area is a Lambertian reflector. Then the numerator is the surface exitance and the denominator the solar irradiance onto the surface. Their ratio is the bihemispherical reflectance or albedo. This is why the Sun-normalised radiance times 100 is often described as being in units of percentage albedo. Strictly this terminology is only true for observations of a Lambertian surface.

9.0.3 Characterising a Radiometer

Consider a satellite channel which is insensitive outside the wavelength interval $[\lambda_1, \lambda_2]$. The behaviour of each channel is denoted by its spectral response function ϕ which is usually normalised so that the maximum response is unity. The two principle factors used to designate the spectral characteristics of the channel are the mean wavelength

$$\bar{\lambda} = \frac{\int_{\lambda_1}^{\lambda_2} \lambda \phi(\lambda)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} \phi(\lambda)\, d\lambda} \tag{9.9}$$

and the spectral bandwidth defined by

$$\Delta\lambda = \int_{\lambda_1}^{\lambda_2} \phi(\lambda)\, d\lambda \tag{9.10}$$

Replacing wavelength with wavenumber in these expressions provides the definitions of mean wavenumber and the spectral bandwidth in terms of wavenumbers.

Problem 9.1 Show that if $T(p) = \exp(-\beta p^{\alpha})$, where α and β are constants, and if the height-like variable $\zeta = -\ln(p/p_0$ is used as a vertical co-ordinate the vertical weighting function is

$$K(p) = \alpha\beta p^{\alpha} \exp(-\beta p^{\alpha})$$

Find α and β for an isothermal atmosphere containing an absorber with a small and constant mass mixing ratio x when

1. the absorber is grey with a constant absorption coefficient k,
2. the radiometer is sensitive to a single frequency in the far wings of a Lorentz line.

Find the pressure levels at which the peaks of the weighting functions occur, and also the widths (in terms of pressure) at half maximum weighting functions.

[The roots of $2x = e^{x-1}$ are approximately 2.68 and 0.23]

Additional Reading

Rodgers, C. D., *Inverse Methods for Atmospheric Sounding: Theory and Practice*, World Scientific Pub Co Inc, Singapore, 2000.