Examination Questions & Model Answers

(2009/2010)

PLEASE PREPARE YOUR QUESTIONS AND ANSWERS BY USING THE FOLLOWING GUIDELINES;

1. If using option 2 or 3 use template provided
2. Use Times New Roman 12
3. Enter the Module Code and Title
4. Please do not switch between text/fonts
5. Ensure all technical terms are correct
6. Each question must have the marks it’s worth shown
7. Show marks as e.g. [50 marks] not 50% or 50% of marks
8. Run spell checker
9. If you are setting more than one question then please submit ONE file only
10. Please indicate the 2nd Marker
11. Please indicate if there any special instructions for e.g. if a question is compulsory

Module Code: CEGEG046
Module Title: Principles and Practice of Remote Sensing
Contributor: M. Disney

2nd Marker

P. Lewis

Special Instructions

Question No: 1

Question

1. Outline the main features of the Planck blackbody energy distribution, particularly those pertinent to terrestrial remote sensing. You should use figures to demonstrate your understanding. [70 marks]

2. Calculate Φ, the total energy emitted by a ‘grey’ body at 300K with emissivity ε = 0.88, where ε is independent of wavelength. You may assume that α, the Stefan-Boltzmann constant, is 5.67x10^-8 Wm^-2K^-4. [10 marks]

3. If this object is considered as a flat plane of unit area, rather than a point source, with a surface normal oriented at 45° to a viewer, what is the apparent energy flux emitted towards the viewer? [10 marks]

4. What is the impact on Φ in part b if energy is emitted predominantly at λ < λ_m, the wavelength of peak emittance? [10 marks]

Model Answer:

1. Should provide definition of a blackbody (i.e. an idealised object which absorbs all energy incident on it at and emits it as the maximum possible rate). Should mention that the blackbody energy distribution is described explicitly by the the Planck function which predicts energy, E, as a...
function of wavelength, $E(\lambda)$ for a body at temperature $T$. A very top answer would reproduce the Planck function i.e.

$$E(\lambda) = \frac{2\pi^2 \hbar}{\lambda^5} \frac{1}{e^{\frac{\hbar c}{kT\lambda}} - 1}$$

Where $E$ is energy; $\lambda$ is wavelength (m); $T$ is temperature of blackbody (K); $c$ is speed of light ($3 \times 10^8$ m/s); $\hbar$ is Planck’s constant ($6.63 \times 10^{-34}$ m$^2$ kg s); $k$ is the Boltzmann constant ($1.38 \times 10^{-23}$ JK$^{-1}$).

Should draw the BB curves, ideally in log-log space (log Energy per unit wavelength, $E$ on the y axis and log wavelength on the x axis as below). We see that the curve for 300K is completely contained within the curve for 6000K. The area under the curve (i.e. $\int E(\lambda)d\lambda$) is the total energy emitted i.e. Stefan-Boltzmann’s Law ($M$ (total energy emitted) = $\sigma T^4$). The peak of the curves is found from $dE(\lambda)/d\lambda$ and decreases with $T$ at a constant rate in log-log space, which is described by Wien’s Law, which says that in the log-log space, the $\lambda$ of peak emittance follows a straight line decrease with $T$. Important to note that for $T=5800$K (sun) the peak is at around 550nm i.e. in the visible, and 40% of total lies in range 0.4-0.7µm. For $T=300$K (Earth), the peak is around 10-12µm i.e. in the thermal part of the spectrum. Top answer might mention that Planck function allows us to calculate the energy between two wavelengths, so we can design instrument spectral bands accordingly.

2. $\Phi = \varepsilon \sigma T^n$, where $n = 4$ because $\varepsilon$ is independent of wavelength. So $\Phi = 0.88 \times 5.67 \times 10^{-8} \times 300^4 = 404.2$J.
3. $\Phi_{\text{apparent}} \propto \Phi \times \cos(45) = 285.8$J.
4. In this case, $\Phi \propto T^n$ and as energy is emitted predominantly at $\lambda < \lambda_m$ then $n > 4$, so $\Phi$ would be larger than in 2.

### Question No: 2

**Question**

1. Give two alternate forms of the RADAR equation, describing each of the terms in the equations. Discuss the implications of the forms of these equations for the design and operation of RADAR instruments – you should consider the properties of each term in the equations in your answer. [30 marks]

2. What wavelength would be required in principle to allow a real aperture RADAR system with an antenna length of 5m, at a height of 1km, to resolve two objects separated by 4m along track (in the azimuth direction), at a depression angle $\gamma$ of 65°? [30 marks]

**Model Answer:**
1. So phrased in terms of either the antenna gain (first) or area (second) and related because \( A \) is related \( G \) by \( (A = \frac{\lambda^2 G}{4\pi}) \). The second part of the question should refer to the power of the transmitted signal and the resulting consequences for the instrument SNR, the power requirements in terms of cost and weight, the size of the antenna used (and type), and examples of airborne and spaceborne systems. It should also refer to the scattering cross section i.e. the nature and intensity of the return from the surface as a function of the imaging geometry, as well as the roughness and dielectric properties of the surface. A good answer should highlight the differences in scattering cross section for smooth and rough surfaces, corner reflection, as well as the dielectric properties, giving examples of different surfaces.

\[
P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} = \frac{P_t A^2 \sigma}{4\pi \lambda^4 R^4}
\]

2. Assuming \( Ra = S \lambda / L \), where \( S \) is the slant range and \( L \) is the antenna size (5m) and \( S = \text{height}/\sin \gamma \). So \( \lambda = L Ra / S \) and \( S = 1000/\sin(65) = 1103.4 \). So \( \lambda = 5.4/1103.4 = 0.018 \text{m} = 1.8 \text{cm} \).

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<td><strong>Question</strong></td>
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<tr>
<td>1. Define the terms ‘atmospheric scattering’ and ‘atmospheric absorption’ and describe how these can impact radiance measured at the top of the atmosphere. [70 marks]</td>
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<td>2. Show that for a near-polar orbiting instrument of orbital period 101 minutes, the separation (in km) on the Earth’s surface of successive ground tracks is ( \sim 2810 \text{km} ). If this instrument has a swath width of 170km, what is the approximate repeat time at the equator in days? [30 marks].</td>
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You may assume the Earth’s radius to be constant at \( 6.38 \times 10^6 \text{m} \).

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<td><strong>Either:</strong></td>
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<td>1. Atmospheric scattering results from interactions with gases, dust soot etc. in atmosphere. Largely divided into three broad spectral regions: <strong>Rayleigh scattering</strong>: (particles ( \ll \lambda )) due to dust, soot or some gaseous components (N2, O2). Very strongly inversely wavelength dependent ( (1/\lambda^4) ). Some directional dependence, function of scatter number density and distance. <strong>Mie scattering</strong>: (particles approx. same size as ( \lambda )), e.g. dust, pollen, water vapour. Strongly directional (backscattering), affects longer ( \lambda ) than Rayleigh, BUT weak dependence on ( \lambda ), mostly in the lower portions of the atmosphere where larger particles more abundant, dominates when cloud conditions are overcast i.e. large amount of water vapour (mist, cloud, fog) results in almost totally diffuse illumination. <strong>Non-selective</strong>: (particles ( \gg \lambda )) e.g. water droplets and larger dust particles; all ( \lambda ) affected about equally (hence name), results in fog, mist, clouds etc. appearing white = equal scattering of red, green and blue ( \lambda )s. Atmospheric absorption, caused by gas molecules of various species in atmosphere, but predominantly O3, CO2, H2O. These all attenuate signal in very specific wavelength ranges corresponding to specific vibrational and rotational modes of the species in question. A very good answer would show for e.g.</td>
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2. Earth’s angular rotation = $2\pi/24*60*60 = 7.27 \times 10^{-5}$ rad s$^{-1}$ so in 101 mins = 101 * 60 * 7.27x10$^{-5}$ = 0.441 rads. So given that $l = r \times \theta$, where $\theta = 0.441$ and $r = 6.38x10^{6}$, then $l = 2810.8$km.
Repeat time is then how long to cover whole Earth radius i.e. $2\pi*6.38x10^{6} = 40.09x10^6$m with swaths of 170km width per orbit = $40.09x10^6/17x10^4 = 236$ orbits = $236 \times 101 \times 60 = 14.3x10^5$s so to convert to days just divide by 24*60*60 = 16.6 days.

Question No: 4

Define the following terms using figures and examples wherever appropriate:
1. Atmospheric windows [20 marks]
2. Bidirectional reflectance distribution function (BRDF) [20 marks]
3. Synthetic Aperture Radar (SAR) [20 marks];
4. Angular and radiometric resolution [20 marks]
5. Whiskbroom and pushbroom scanners [20 marks]

Model Answer:
1. Atmospheric windows – places in the bb spectrum of the sun arriving at the top of the atmosphere where transmittance is high (i.e. absorption is low) e.g. see figure above. For a full answer I would expect at least one fig – possibly something like:
And then some examples of the absorption features across the spectrum with approximate wavelength ranges. The easy one would be the very large window from the cm to m range in the microwave part of the spectrum.

2. Bidirectional reflectance distribution function (BRDF) is the ratio of incremental radiance, \( \text{d}L_{\text{e}} \), leaving surface through an infinitesimal solid angle in direction \( \Omega (\theta_v, \phi_v) \), to incremental irradiance, \( \text{d}E_{\text{i}} \), from illumination direction \( \Omega' (\theta_i, \phi_i) \) and would expect equation for this, plus figure showing what it represents schematically i.e. a hemisphere with viewing, illumination solid angles in direction of view/illum vectors.

3. Synthetic Aperture Radar (SAR) - As an imaging side-looking radar moves along its path, it accumulates data; synthetic aperture is the synthesis of a potentially large aperture by moving the sensor rather than physically collecting energy across a physical aperture instantaneously (or having multiple small antennae). The motion of the sensor (or the combination of small antennae) generates (synthesises) the larger antenna size. RADAR returns are then post-processed (combined) to form a single image of higher resolution.

4. Angular resolution is the minimum solid angle (or more generally, view and zenith angular precision) over which a sensor samples. This can sometimes be confused with angular sampling i.e. the number of angular samples over the hemisphere an instrument can collect. I would expect some examples here of multi-angular instruments e.g. MISR (9 angles), CHRIS-PROBA (5), SPOT (2), or pseudo-multi-angle instruments like MODIS, AVRR with wide swaths. Radiometric resolution – the radiometric precision of a digital system is the number of bits per pixel the instrument can store/transmit. For an analogue system this comes down to the sensitivity of the optical medium (film). Would expect examples of bits per pixel & gray levels (2, 4, 8 etc) for a full answer.

5. Whiskbroom scanner – moving mirror either rotates fully, or oscillates across the track i.e. perpendicular to direction of instrument travel. Examples are: Landsat MSS, TM. Pushbroom scanner is a linear array (or multiple array) of sensors aligned perpendicular to the direction of instrument travel which collect data simultaneously in lines along-track. Examples are MISR, SPOT, Ikonos.

Question No: 5

Question

EITHER:
Describe the principles and applications of RADAR interferometry, using figures and examples wherever possible. [100 marks]
OR:
Discuss the options and tradeoffs in sensor design and orbit which might be considered for a system (not necessarily a single sensor or platform) designed for monitoring terrestrial vegetation dynamics at global scales. [100 marks].

Model Answer:
Must discuss the concepts of phase difference to resolve distances, then coherence information and phase unwrapping to produce coherence images and then interferograms. Discuss issues of how phase unwrapping works (coregistration, complex multiplication), and issues that reduce coherence i.e. changes in surface (snow, vegetation etc), time differences between pairs, long baselines, resampling, atmosphere. Examples of acquisition i.e. single pass, repeat pass, missions such as ERS 1, 2, RADARSAT, SRTM etc. and then applications. DEM generation; small topographic variations i.e. deformation, subsidence, volcanoes; ice sheet dynamics.

Note that question refers to a system so there is no reason to restrict answer to one sensor or even one platform. Should consider the temporal, spatial, spectral and angular resolution and sampling at the least (and possibly radiometric as well for excellent answer). Application requires global–scale observations, and temporal variation of vegetation means days to weeks is required for change dynamics. This implies polar orbit, but would accept geostationary as long as it was clearly-justified why such a high repeat time would be needed (only advantage really – capture all dynamics). The temporal sampling means wide swath instruments 1000s of km to provide repeat time of a day or two, eg AVHRR, MODIS, MERIS. Tradeoff is to have spatial resolution not so great that data volumes too high, where this is somewhat flexible, but 100m or greater. Might go for multiple platforms to increase temporal and angular sampling. Related issues regarding spectral properties - must mention vis/NIR channels, and SWIR water absorption channels, plus (possibly) thermal (for water stress, soil temp). Bandwidths not so important, but depends on how much detailed information on pigments is desired. Including RADAR would allow for cloud, and provide information at higher leaf area (if P band for example). LiDAR would also allow for limited spatial estimates of vegetation height and structure. Angular sampling allows directional information to be explored i.e. height, density, structure. Also permits observations at different sun/view angles to be combined by accounting for BRDF.