Examination Questions & Model Answers

(2011/2012)

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

1. Use Times New Roman 12
2. Enter the Module Code and Title
3. Please do not switch between text/fonts
4. Ensure all technical terms are correct
5. Each question must have the marks it’s worth shown
6. Show marks as e.g. [50 marks] not 50% or 50% of marks
7. Each question should be out of 100 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

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Question

i) Describe the importance of the Planck blackbody energy distribution in deciding on how a remote sensing instrument should be designed. You should use figures in your answer. (50)

ii) What is the theoretical emissive power of the sun (in Wm\(^{-2}\)), with a surface temperature is 5770K? How does the actual power differ from this in practice and why? (10)

iii) Show that around 86% of the total power of a blackbody at 5770K lies in the visible-SWIR region i.e. \(\lambda = 380-2500\text{nm}\) (0.38 to 2.5\(\mu\text{m}\)). (40)

You may assume \(\sigma\), the Stefan-Boltmann constant = \(5.7 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}\). Values of the integral of the Planck energy distribution from 0 to \(\lambda\) as a function of \(\lambda T\), \(F_0\Rightarrow\lambda\), for blackbodies at various temperatures T are as follows:
\[
\lambda T (\mu mK \times 10^3) & \quad F_{0, \lambda} (\lambda T) \\
2 & 0.067 \\
3 & 0.273 \\
4 & 0.481 \\
5 & 0.634 \\
6 & 0.738 \\
8 & 0.856 \\
10 & 0.914 \\
12 & 0.945 \\
14 & 0.963 \\
16 & 0.974 \\
18 & 0.981 \\
\]

Model Answer:
i) Allows us to predict energy distribution per unit wavelength for object at any T, i.e. allows us to calculate our signal between \( \lambda \) limits. Answer should show fig of blackbody curve, ideally of both sun (\( \sim 6000K \)) and Earth (\( \sim 300K \)). Need to get y-axis units right – to show both curves on same plot either need log linear plot:

![Log linear plot](image1.png)

or could log-log:

![Log-log plot](image2.png)

Salient points to note are \( \lambda_{\text{max}} \) i.e. \( \lambda \) of peak emitted energy (given by Wien’s Law, \( = k/T \) where \( k = \mu2897mK \)). Also, area under curve gives total (see part ii), according to Stefan-Boltzman Law (\( M = \sigma T^4 \)). Excellent answer would give Planck equation, define all terms and indicate relationship to SB (integrate) and Wien (differentiate).

\[
E(\lambda) = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}
\]
ii) $M = \sigma T^4 = 5.7 \times 10^{-8} \times 5770^4 = 63.2 \text{MWm}^{-2}$. Actual power is lower than this, because sun is not a perfect blackbody i.e. emissivity < 1, so would be given by something like $\varepsilon \times 5.7 \times 10^{-8} \times 5770^4$.

iii) Need total energy from 0 to 2500nm, and then subtract energy shorter than 380nm. First, for total, $\lambda T$ is $2.5 \times 5770 = 14.425 \mu\text{mK} \times 10^3$ so interpolate between 14 and 16 i.e.

$\frac{(14.425-14)}{(16-14)} \times (0.974-0.963) + 0.963 = 0.965$

Now do same for 0 to 380nm so $\lambda T = 0.38 \times 5770 = 2.193 \mu\text{mK} \times 10^3$ so interpolate between 2 and 3 i.e.

$\frac{(2.193-2)}{(3-2)} \times (0.273-0.067) + 0.067 = 0.107$

So final answer is $0.965 - 0.107 = 0.858 = 86\%$
Module Code: GEOGG141

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Special Instructions

Question No: 2

Question

i) Explain the following terms:
Temporal sampling (10)
IFOV (10)
SAR (10)
Atmospheric correction (10)
‘Whiskbroom scanner (10)

ii) A real aperture RADAR instrument at an altitude of 500m is being used to provide image data over fields and urban areas. The instrument has an aperture of 1.5m, operates at a wavelength of 0.01m and has a pulse length of $0.04 \times 10^{-6}$ m. The mission requires identifying objects at a horizontal distance of 2km from the flight track that are > 10m size in the across track (range) direction, separated by > 10m in the along track (azimuth) direction. Can the instrument resolve these objects? You may assume $c$, the speed of light to be $3 \times 10^8$ ms$^{-1}$. (50)

Model Answer:

i) Temporal sampling: frequency with which a sensor is able to observe a particular point on the ground (e.g. several times a day for MODIS, 16 days for Landsat etc).

IFOV – instantaneous field of view i.e. smallest visible region by a single detector element at a given instant in time (not same as pixel size), but equates to ground resolution element (GRE).

SAR – synthetic aperture radar. Method of synthesising a larger aperture by using motion of platform, and using pulses sent out, which are recombined with phase information maintained.

Atmospheric correction – the process of subtracting the atmospheric path radiance from a signal passing down and up through the atmosphere from a sensor to target and back. Required to go from TOA radiance to surface reflectance, and is done through modelling and/or measurement of the path radiance.

Whiskbroom scanner: Whiskbroom scanning involves scanning of a single element of a detector across the direction of travel of the instrument. This can be achieved either by a back-and-forth scan via an oscillating mirror (e.g. Landsat MSS, TM) or a rotating scanning mirror (e.g. MODIS).
ii) Need range and azimuth resolutions. Half marks for either alone. Range resolution is $Tc/2\cos\gamma$ where $\gamma$ is the depression angle is $\tan^{-1}(.5/2) = 14.04^\circ$. So $R_r = (0.04 \times 10^{-6} \times 3 \times 10^8)/(2 \cos 14.4) = 6.2\text{m}$. So yes, can resolve in the range direction. Along track (az) resolution is $0.7S\lambda/L = 0.7 \times 2000 \times 0.01/1.5 = 9.33$, so yes, can resolve theoretically in this direction too. So overall, yes.
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Question No: 3

Question

EITHER

i) Outline the advantages and disadvantages of LIDAR measurements for ecosystem science applications. (80)

ii) Given the possibilities of LIDAR, briefly discuss why there is (currently) no extant or planned spaceborne LIDAR system. (20)

OR

Describe how RADAR interferometry can be used to measure very small changes in surface displacement using figures and example applications where possible. Your answer should highlight any factors which will limit the accuracy of interferometric measurements. (100)

Model Answer:

i) Lidar provides much more direct estimate of radiation interaction with vegetation structure and biophysical properties (water, pigment). Waveform system gives this distance-resolved. Must discuss distance resolved signal, possible applications over forest (height, biomass), land surface, DEM generation and topographic mapping. A good answer would also discuss potential of ground based TLS of Echidna/SAlca type fir characterising up through canopy – gap fraction, LAI, woody v green material. Many ALS systems now in operation. Used widely in forestry applications, primarily for height and then through allometry to biomass and/or C stocks, but also for mapping (DEM, geomorphology etc). Drawbacks are power requirements, wavelength limitations (eye-safe), limited coverage. Difficulties are magnified for spaceborne system – signal, power, how to get coverage – either a string of very narrow spots or you’d have to scan which is even more difficult. Even with spots, footprints of 50m or more are very prone to topography issues – slope makes it hard to get at top of canopy, so either need smaller footprints, or dual wavelength, or both. ICESAT was up, now dead, and DesDYNI cancelled – expensive and technology limitations are main reasons. Can do similar things for eg biomass with P-band radar, with caveats.

ii) Must outline how interferometry works i.e. the concepts of phase difference to resolve distances, baselines, coherence information and phase unwrapping to produce coherence images and then interferograms. Discuss issues of how phase unwrapping works (coregistration, complex multiplication).
Good answer would include options such as single pass, repeat pass, and mention missions. Applications would include ice sheet dynamics, subsidence and landslides, DEMs. Limitations would include decoherence due to water vapour, surface changes, stable baseline positions etc.
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Question No: 4

Question

EITHER:

i) Describe the key spectral features of vegetation reflectance across the 400-2500nm wavelength range. You should use figures wherever possible. (30)

ii) Outline the ‘building blocks’ that might be required to construct a radiative transfer model of vegetation scattering in the optical domain. Your answer should highlight key assumptions and limitations of a particular approach. (70)

OR

You are asked to provide a proposal for a possible satellite remote sensing system (platform or platforms) that is aimed at providing estimates of forest extent and type (structure) on regional (100s km) scales, at least twice a year for 10 years. Your answer should carefully consider the mission requirement, and outline the resulting trade-offs that may be required in sensor type, wavelength, spatial resolution and orbit. (100)

Model Answer:

i) Good answer MUST include fig. Split into: visible (400-700nm) - chlor. pigments, low reflectance across, higher in the green, all < 10%; NIR (700-1100nm) much higher, due to leaf internal structure (air/cell size/spacing); SWIR (1100-2500) gradually declining with potentially strong abs features at 1400 and 2100 due to water. Could show individual pigments including chlor absorption as for the prospect model.

ii)

Require description of: i) canopy architecture i.e. depth, leaf area density – simplest case Beer’s Law plane parallel medium (1D), attenuation, but a good answer would suggest limitations of this and then issue of finite leaf size and orientation, and how these might be overcome; ii) leaf scattering – simplest Lambertian case, or more complex couple leaf-canopy RT model; iii) soil scattering – again, v. simple Lambertian case, or more complex rough soil models (eg Ciernewski, Hapke etc). More generally, a complete answer would indicate the problems of calculating single and multiple scattering, and briefly how these may be addressed.

Scope for many types of system. Not limited to current systems and in fact should move beyond this. Extent
requires resolution of order of 100s of m to km, not nec. wide swath – perhaps Landsat size as temporal sampling not so limiting (once a month perhaps enough). Type (structure) is much more important so in potical would at the very least require multi-angle eg via multi-cameras, and would like to combine with RADAR (L or P-band ideally) or, even better, LIDAR, giving spots of 20-50m footprint, waveform data over narrow swaths. To get coverage could have 2 (or more) of them perhaps? And dual wavelength even better (for a very good answer). Wavelengths would need to be, optical 400-2500 for veg properties. A good answer would highlight what’s currently available and so make clear why the proposed system would be better.
### Question 5

**Question**

i) Derive an expression relating the altitude, $h$, of a satellite in a stable low Earth orbit, to the orbital period, $T$. Your answer should show all working for any derivations required. (60)

ii) Use this expression to calculate the orbital period of a near polar orbiting platform, at an altitude of 705km. (10)

iii) If the platform carries an imager with a swath of 2100km, what is the repeat time of the instrument at the equator, in days? (10)

iv) What happens to this repeat time away from the equator and why? Briefly describe how this property can be exploited. (20)

You may assume $M_E$, the Earth’s mass, to be $5.983 \times 10^{24}$ kg; the universal gravitational constant $G$ to be $6.67 \times 10^{-11}$ Nm$^2$kg$^{-2}$; and the radius of the Earth to be $6.38 \times 10^6$ m.

### Model Answer

i) In stable orbit the gravitational force $F_g = GM_E m_s / R_{SE}^2 = $ centripetal force $F_c = m_s v_s^2 / R_{SE}$ where $G$ is universal gravitational constant ($6.67 \times 10^{-11}$ Nm$^2$kg$^{-2}$); $M_E$ is Earth mass ($5.983 \times 10^{24}$ kg); $m_s$ is satellite mass (unknown) and $R_{SE}$ is distance from Earth centre to satellite i.e. $6.38 \times 10^6 + h$ where $h$ is satellite altitude; $v_s$ is linear speed of satellite (=\(\omega R_{SE}\) where $\omega$ is the satellite angular velocity, rad s$^{-1} = 2\pi/T$ for orbital period $T$). So for stable orbit $GM_E (R_{SE} + h)^3 = (2\pi/T)^2$.

ii) $T = 2\pi [(R_{SE} + h)^3 / GM_E]^{1/2}$ so $T = 2\pi [(6.38 \times 10^6 + 705 \times 10^3)^3 / GM_E]^{1/2} = 5931s = 98.9$ mins.

iii) Repeat time is time taken to return to the same sub-satellite point on the Earth’s surface. Total circumf of Earth = $2\pi \times 6.38 \times 10^6$ and we cover 2100km per orbit, so require $2\pi \times 6.38 \times 10^6 / 2100 \times 10^3 = 19.09$ orbits, and at 98.9 mins this is $\approx 1888$ mins = 1.311 days.

iv) Orbits converge towards the poles, so repeat time reduces the further towards the pole you get. The overlapping swaths provide increased multi-angle sampling eg for sampling BRDF. A full answer should give an example eg MODIS BRDF product.
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**Special Instructions**

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**Question**

**Model Answer:**