Examination Questions & Model Answers

(Academic year 2013-2014)

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

Module Code: GEOGG141
Module Title: Principles and Practice of Remote Sensing
Contributor: M. Disney 2nd Marker P. Lewis

Special Instructions

Question No: 1

EITHER

i) Describe the importance of the Planck blackbody energy distribution to remote sensing. You should make clear the key features of the distribution, using figures where appropriate. [50%]

ii) What is the theoretical total emissive power M of the Earth (in Wm\(^{-2}\)) with a surface temperature of 300K? At what wavelength does the peak of this emitted power occur? [20%]

iii) Show that around 84% of the total power of a blackbody at 5770K lies in the visible-SWIR region i.e. \(\lambda = 400-2500\) nm (0.4 to 2.5 \(\mu\text{m}\)). [30%]

You may assume \(\sigma\), the Stefan-Boltzmann constant = 5.7\(\times\)10\(^{-8}\) Wm\(^{-2}\)K\(^{-4}\) and Wien’s displacement constant, \(k = 2897\) \(\mu\text{mK}\). 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:
\[ \lambda T (\mu mK \times 10^3) \quad F_0, \lambda (\lambda T) \]

<table>
<thead>
<tr>
<th>( \lambda T )</th>
<th>( F_0, \lambda )</th>
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<tr>
<td>2</td>
<td>0.067</td>
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<tr>
<td>3</td>
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<td>4</td>
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<td>14</td>
<td>0.963</td>
</tr>
<tr>
<td>16</td>
<td>0.974</td>
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OR

i) Derive an expression relating the orbital period \( T \), of a satellite in a stable orbit, to its altitude above the Earth’s surface, \( h \). Your answer should show all working for any derivations required and you should define all terms. [50%]

ii) Use this expression to determine the altitude of a geostationary satellite. [20%]

iii) Give ONE advantage and ONE disadvantage of a geostationary orbit for environmental applications. [20%]

iv) Why is the altitude of a low-earth orbit sensor typically not stable over time? [10%]

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:

EITHER:

i) Figure should be drawn something like this with correctly labelled axes and at the very least the linear shift of lambda max and the correct location:
about 10μm for Earth (300K), with total going from 0.1 to over 100 for Sun, and 3 to < 100 for Earth. Three points from Planck are: allows us to predict shape so we known energy between any two wavelengths so we know signal for EO measurement; integral gives us total energy output of a BB which is Stefan-Boltzman Law – good answer gives the Planck equation and SB (\( M = \sigma T^4 \)); differential gives us the wavelength at which emittance is a maximum, \( \lambda_{\text{max}} \) which is Wien’s displacement law i.e. \( \lambda_{\text{max}} = k/T \) where \( k = 2897 \) μmK. In log-log space \( \lambda_{\text{max}} \) increases inversely with reducing T in linear fashion as in diagram.

ii) \( M = \sigma T^4 = 5.7 \times 10^{-8} \times 300^4 = 461.7 \) Wm\(^{-2} \). \( \lambda_{\text{max}} = k/T \) where \( k = 2897 \) μmK so \( \lambda_{\text{max}} = 2897/300 \) (in μm) = 9.66 μm.

iii) Need total energy from 0.4-2.5 μm, so do for 0 to 0.4 and then 0 to 2.5 and subtract first. For 0-0.4, \( \lambda T \) is \( 0.4 \times 5770 = 2.308 \) μmK x \( 10^3 \) so interpolate between 2 and 3 i.e. \( (2.308-2)/(3-2) \times (0.273-0.067) + 0.067 = 0.130 \). For 2.5, \( \lambda T \) is \( 2.5 \times 5770 = 14.4 \) μmK x \( 10^3 \) so interpolate between 14 & 16 i.e. \( (14.4-14)/(16-14) \times (0.974-0.963) + 0.963 = 0.965 \). So final answer is difference i.e. \( 0.965 - 0.130 = 0.835 = 84\% \).

OR

i) In stable orbit the gravitational force \( F_g = G M_E m_s / R_{SE}^2 \) = centripetal force \( F_g = m_s v_s^2 / R_{SE} \) where \( G \) is universal gravitational constant (\( 6.67 \times 10^{-11} \) Nm\(^2\)kg\(^{-2} \)); \( M_E \) is Earth mass (5.983×10\(^{24}\) 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 (=ω\( _s \)R\(_{SE} \)) where \( \omega_s \) is the satellite angular velocity, rad s\(^{-1} \) = 2π/T for orbital period T). So for stable orbit \( G M_E / (R_{SE}^3) = (2\pi/T)^2 \).

ii) Rearrange so \( h = [T^2 G M_E / 4\pi^2]^{1/3} - R_{SE} \), where T = 24x60x60 = 86.4x10\(^3\) s, so \( h = 35.88 \times 10^3 \) km.

iii) Altitude varies for two reasons – first, wobble up and down due to varying gravitational field strength of Earth due to variations in density; second, due to gradual degradation of orbit due to drag of atmosphere. Good answer would mention atmospheric drag varies with solar activity & how to deal with (boost or crash).
Module Code: GEOGG141

Module Title: Principles and Practice of Remote Sensing

Contributor: M. Disney

2nd Marker: P. Lewis

Special Instructions

Question No: 2

Question

a) Define the following terms and briefly detail their relevance to remote sensing:

i) Grey body (10)
ii) Radiance, L (10)
iii) BRDF (10)
iv) Atmospheric window (10)
v) Temporal sampling (10)

b) Describe the key features of the bidirectional reflectance distribution function (BRDF) of a vegetated surface, using figures where appropriate (50)

Model Answer:

i) Grey body: a so-called black body with emittance < 1 i.e. \( M = E \times \sigma \times T^4 \) where \( E \) is emittance.

ii) Radiance – flux per unit projected area per unit solid angle leaving a source or reference surface \( L = d^2 P / dA_{proj} d\Omega \), where \( dA_{proj} = dA \cos \theta \) and \( \theta \) is the angle between the outward surface normal of the area element \( dA \) and the direction of observation, \( \Omega \). Relevance is this is usually the measured at-surface signal we obtain via remote sensing.

iii) BRDF – Bi-Directional Reflectance Distribution Function of area \( \delta A \) defined as: ratio of incremental radiance, \( dL_e \), leaving surface through an infinitesimal solid angle in direction \( \Omega(\theta, \phi) \), to incremental irradiance, \( dE_i \), from illumination direction \( \Omega'(\theta_i, \phi_i) \) [sr\(^{-1}\)]. In practice this is defined over finite area and lam as well i.e. units are [sr\(^{-1}\)um\(^{-1}\)]

iv) Atmospheric window – part of the EM spectrum where the Earth’s atmosphere is transparent to radiation. Good answer would give examples of windows in the visible & SWIR, & microwave (RADAR). Best answer would indicate that opacity of atmosphere between windows is due to absorption by gases eg O2, O3, CO2 and water vapour. For surface remote sensing we have to look in the atmospheric windows as only region where signal can escape to be measured.

v) Repeat time – time taken for an orbiting sensor to return to the same point on the Earth’s surface.

b) Need to define the BRDF first as ratio of incremental radiance, \( dL_e \), leaving surface through an infinitesimal solid angle in direction \( \Omega(\theta, \phi) \), to incremental irradiance, \( dE_i \), from illumination direction
\( \Omega^*(\theta_i, \phi_i) [\text{sr}^{-1}] \). In practice this is defined over finite area and \( \lambda \) as well i.e. units are \([\text{sr}^{-1}\text{um}^{-1}]\). Good answer would give the equation. Then need to explain that BRDF varies with view and sun angle and vegetation structure. General principle is an upward bowl-shape for dense homogeneous veg, volume scattering as a fn of path length through the canopy. Good answer would show this behaviour on angular plot and explain the origin. For shadow-dominated (sparse, clumped) canopies BRDF more like a downward bowl-shape. In this case we might expect hot-spot i.e. peak of reflectance where sun angle and view angle coincide due to minimised shadowing – again, angular plot and the explanation for good answer. Best answer would give some examples of applications, and sensors from which BRDF derived (MODIS being the obvious case).
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Special Instructions

Question No: 3

EITHER

i) Outline the advantages of airborne and spaceborne LIDAR measurements for estimating forest biomass and structure. [50%]

ii) Sketch examples of a small footprint full-waveform lidar return that might be expected over a conifer tree crown: a) on a flat surface; b) on a sloping surface. You can assume that all of the footprint strikes the crown and that the vertical bin size of the lidar returns is << than the canopy height and that the footprint. [30%]

iii) Briefly describe how terrestrial lidar can be used to estimate forest canopy parameters. [20%]

OR:

i) Describe TWO advantages and TWO disadvantages of RADAR observations over optical. You should include figures and examples where appropriate. [40%]

ii) The RADAR equation can be stated in terms of received power, $P_r$ at a RADAR antenna as:

$$P_r = \frac{P_i G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

Define the various terms in the equation and outline the various physical principles that determine the form of the equation. [40%]

iii) Define what is meant by SAR interferometry, giving one example applications of it in practice. [20%]

Model Answer:

LIDAR question

i) Key is to mention direct measurement of canopy height and structure. A good answer should discriminate between discrete return and waveform systems. Biomass can be derived from height (and crown size) via allometric relationships. Structure eg vertical crown profiles can tell us about gap fraction (LAI and interception) and forest age and type. Limits of coverage to airborne; spaceborne difficult (and now non-existent following demise of IceSAT/GLAS). Excellent answer should provide reference to literature of eg forestry applications, limitations of height and coverage and difficulty of defining what height we mean.

ii) Anything along the lines of:
b) Small-footprint (<1m).

Key points are: a) pick up shape of canopy and hard ground return, slower increase in return due to canopy shape and prominent ground; waveform should vaguely correspond to crown shape; b) should mention the spreading of the ground return and convolution with canopy return.

iii) Measurement of height and/or structure are the key here. For the first, can be related to biomass via allometric equations allowing most direct estimate of standing biomass from EO. Lack of global coverage so only ICESAT from space, but increasing amounts of airborne surveys. Still suffers problems where very dense & few gaps BUT is direct. A good answer would cover most of this and give some examples of where it has been applied (eg the Saatchi et al. map of global tropics biomass; forest inventory and mapping – very big application). Best answer would mention both the height AND structure information. This is used for eg habitat mapping AND changes eg for deforestation, degradation and even changes in soil height (peat depth). Need some key examples for either/both cases and ideally something on limitations.

RADAR question

i) 10 marks for each. AD – any two of: all-weather; night/day operation; penetration of atmosphere due to high transmission in microwave; info. independ. of optical eg on soil moisture, roughness or biomass due to penetration of dense canopies at eg P band; ability to use phase info for interferometry; DISAD – any two of eg: requirement for power (weight, cost); coherent scattering (interference, speckle); difficulty of interpreting values; problem of building RT models due to coherence. Other things considered in both cases IF sensible/justifiable.

ii) Terms are: \( P_t \) = transmitter power (W); \( G \) is gain (a good answer would mention this assumes transmitting and receiving antennae same i.e. bi-static \( G^2 \)); \( \lambda \) =wavelength (m); \( \sigma \) =radar scattering cross section; \( R \) = range (m). Form arises via considering power output by transmitted, spreading outward per unit solid angle (area of a sphere, in both out and return directions hence \( (4\pi)R^2 \)). The scattering cross section arises out of considering the projected area of the target in both the incident and scattered directions as well as the scattering properties of the surface (i.e. gain of target) in both directions.

iii) Has to define SAR and interferometry as use of phase difference to resolve distances. Needs to cover requirement for 2 or more observations either by repeat pass or large antennae. Good answer would then mention coherence information and phase unwrapping to produce coherence images and then interferograms. Applications include: DEM generation; small topographic variations i.e. deformation.
subsidence, volcanoes; ice sheet dynamics; even forest height. A v. good answer would refer to a specific example rather than general area (e.g., refer to sensor, date, location, literature etc).
Module Code: GEOGG141  
Module Title: Principles and Practice of Remote Sensing  
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2nd Marker: P. Lewis  

Special Instructions

Question No: 4

Question

i) Outline THREE types of scattering that occur in the Earth’s atmosphere, giving any possible wavelength and directional dependencies of each scattering type. [30%]

ii) Describe how the effects of atmospheric scattering on remote sensing data can be accounted for. [50%]

iii) Briefly outline the pre-processing stages of radiometric calibration and geometric correction that are typically applied to remotely sensed data in converting from raw DN to at-sensor radiance. [20%]

OR:
You are asked to provide an outline proposal for a new satellite remote sensing system platform (or platforms) to quantify the loss of rainforest to oil-palm plantations across the tropics, which typically are of several to many hectares in size. It is key that the system be able to observe a given region more than once during a given year in order to monitor intra-annual changes. Your proposal should carefully consider the mission requirements, and describe the resulting trade-offs that may be required in sensor type(s), wavelength(s), spatial resolution and orbit. [100%]

Model Answer:

i) 10 marks for each. **Rayleigh scattering**: (particles $<< \lambda$) 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. **Mie scattering**: (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. **Non-selective**: (particles $>> \lambda$) 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.

ii) Either empirical method such as empirical line correction which requires identifying very dark (eg clear deep water, dense veg) and bright stable targets, dust/desert then assuming $L = \text{gain} \times \text{DN} + \text{offset}$, where offset is atmospheric path radiance. Requires a priori knowledge of ground, and assumes Lambertian surface (no angular effects), large homogeneous areas (ignores adjacency
effects) and stability i.e. stays same over time. Also is per-band i.e. assumes same scattering across whole image. So, ok for narrow swath instruments (eg IKONOS, Landsat) but not for wider swath airborne or moderate res. satellite. Another method would be using full radiative transfer model of the atmosphere such as MODTRAN or 6S. Big advantage is it does the job properly accounting for gaseous absorption, aerosols etc. and can be done per pixel. Down side is slow(er) and requires, ideally, info. on atmospheric properties (aerosol optical depth, ozone and water concentrations, types of aerosol etc). The 6S model is used for operational MODIS products. A third method would be to use multi-angle data as per MISR to actually include the atmosphere in any retrieval process as you get multiple path length estimates and so can solve for the atmospheric radiance.

iii) Radiometric calibration - account for sensor response and non-linearities, either done pre-flight and then with checks over time against stable targets, and/or using on-board calibration eg via blackbody heaters; geometric correction – accounting for sensor and surface movement by camera modelling and resampling. Good answers would provide a little bit of detail on each method chosen.

OR

Scope for many types of system. A competent answer would initially consider the specific issue of what is special about oil-palm plantations e.g. the regularity of size and shape. Suited to higher-resolution data (10s – 100m) i.e. doesn’t need to be global so could go for several smaller, faster platforms. Not limited to current systems and in fact should move beyond this. MUST consider the constraints – tropical, sub-annual sampling (so a few observations a year would suffice). ‘Tropical’ should immediately suggest optical may be limited so either need several platforms, or even better, a RADAR instrument eg a C or X-band RADAR. We also need to get change, and not just loss, so perhaps a higher resolution optical + RADAR system or even a constellation. Wavelengths would need to be eg optical vis-NIR for veg properties. Doesn’t require spectral detail, more temporal. A good answer would highlight what’s currently available and so make clear why the proposed system would be better.
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<td>2nd Marker</td>
<td>P. Lewis</td>
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**Special Instructions**

**Question No:** 5

**Question**

i) Describe the three key components of a radiative transfer (RT) model for vegetation in the shortwave domain (400-2500 nm). [60%]

ii) Outline TWO assumptions we might make to allow a solution for RT in vegetation. Make clear what the implications of these assumptions might be on the resulting solution. [30%].

iii) Define what is meant by a spherical leaf angle distribution, and outline why this distribution is often used in practice. [10%].

**Model Answer:**

i) Full answer MUST include canopy architecture description (depth, size of leaves, orientation), leaf reflectance and trans properties, and soil. A good answer would expand on each of these points; an excellent answer would give assumptions associated with providing solutions and pros/cons of approaches.

ii) Any two of: i) description of 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) description of leaf scattering – simplest Lambertian case, or more complex couple leaf-canopy RT model; iii) description of soil scattering – again, v. simple Lambertian case, or more complex rough soil models (eg Ciernewski, Hapke etc).

iii) Leaf projection as if all leaves can be pasted on to the surface of a sphere. Results in preferentially ecrecotphile leaves. Key reason for using is g(l) is then 1 and constant, so can use to solve attenuation term of RT equation. Makes it easy to calculate G(omega) = 0.5 i.e. I = Io *exp(-0.5L/mu)
### Module Code: GEOGG141

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<tr>
<td>Contributor:</td>
<td>P. Groves, 2nd Marker, D. Backes</td>
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**Special Instructions**

**Question No:** 6

**Question**

a) What are the three segments of GPS and what are their functions? Show how they interact with each other using a diagram. [24 marks]

b) How does stand-alone GNSS user equipment determine its position in real time? Your answer should include a diagram showing the satellite and user positions and consider the following:
   - What do the satellites transmit?
   - What do the receivers measure?
   - How is this used to determine position?
   - How many signals are required and why?
   - Explain the main concepts and include a diagram showing satellite and user positions. [32 marks]

c) What are the main sources of GNSS error and their causes? [24 marks]

d) Explain how double-differenced positioning eliminates the effects of satellite and receiver clock and phase biases. [8 marks]

e) Explain the three ways in which implementations of differential carrier-phase positioning may differ? [12 marks]

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**Model Answer:**

Part (a) Marks are allocated as follows with partial answers earning partial marks:

- 4 marks for stating that the three segments are the space segment (or satellites); control (or ground) segment, and user segment.
- 4 marks for stating that the space segment broadcasts the GPS signals that are used for navigation.
- 8 marks for stating that the control or ground segment comprises a network of monitor stations that monitor the signals from the satellites, a control centre that determines the satellite positions, calibrates their clocks and then generates commands, and a network of uplink stations that uploads the commands to the satellites.
- 4 marks for stating that the user equipment determines the user’s position solution using the signals from the space segment.
- 4 marks for a diagram similar to the following:
Part b) Marks are allocated as follows with partial answers earning partial marks:

- 4 marks for stating that the satellites transmit known ranging codes or pseudo-random-noise (PRN) codes to the user.
- 4 marks for stating that the satellites also transmit ephemeris data, from which their positions and velocities may be determined and satellite clock corrections.
- 4 marks for stating that the receivers measure the time of arrival of the signals from the satellites.
- 4 marks for stating that the receivers determine pseudo-ranges by differencing the measured time of arrival with the time of transmission obtained from the signal modulation, and then multiplying by the speed of light. Pseudo-range is range perturbed by timing offsets.
- 8 marks for stating that to the 3D position and receiver clock offset is determined by solving simultaneous equations of the form
  \[ \rho = \sqrt{(r_{\text{sat}} - r_{\text{user}})^2 + (r_{\text{sat}} - r_{\text{user}}) + \delta \rho_{\text{clock}}} \]

  where \( \rho \) is the measured pseudo-range, \( r_{\text{sat}} \) is the known satellite position, \( r_{\text{user}} \) is the user position to be determined and \( \delta \rho_{\text{clock}} \) is the receiver clock offset to be determined. The clock offset is needed because receiver clocks are not synchronised. Alternatively, positioning may be explained in terms of the intersection of the surfaces of spheres (or hyperspheres).
- 4 marks for stating that at least four satellites must be tracked to provide sufficient measurements to determine the 3D position and receiver clock offset.
- 4 marks for a diagram similar to either of the following:
Part c) Each of the following points is worth 4 marks:
- The ephemeris error results from the difference between the true position of the satellite and the positions calculated from the information broadcast by the satellite.
- The satellite clock error results from the time offset of the satellite clock from the relevant GNSS system time. Corrections are broadcast by the satellite, but are not completely accurate.
- The ionosphere propagation delay results from refraction of the signal in the ionosphere.
- The troposphere propagation delay results from refraction of the signal in the troposphere.
- Multipath and non-line-of-sight errors result from reflection of the signal by buildings, vehicles, the ground, water etc.
- Tracking errors result from thermal noise, radio frequency noise and delays in the receiver’s response to motion.

Part d) Each of the following points is worth 4 marks:
- Double-differenced measurements are differenced across both satellites and receivers, combining 4 measurements in total.
- Differencing across satellites eliminates receiver clock and phase biases, while differencing across receivers eliminates satellite clock and phase biases.

Part e) Each of the following points is worth 4 marks:
- Positioning may be real-time, using a data-link, or post-processed, in which case measurements are stored for processing later.
- Positioning may be static, where the rover is stationary, combining data from many epochs, or kinematic, where the rover is moving, requiring a ‘new’ position every epoch.
- A single base-station may be used, usually owned by the operator of the rover or a network of reference stations may be used, with data supplied by a survey provider. (Virtual reference station and precise point positioning (PPP) are types of network approach).
Heights may be expressed with respect to the surface of an ellipsoid in a specified datum such as ETRF89; alternatively, they may be expressed with respect to a land datum such as Ordnance Datum Newlyn, Ordnance Datum Belfast or IGN69; depths are usually expressed with respect to Chart Datum.

Write an essay that explains:

- what the different concepts of height mean;
- what the different height and depth datums are;
- how these differ from concepts such as the geoid and mean sea level;
- when each type of height would be used;
- how transformations can be carried out between the different datums.

Model Answer:
Could potentially structure the answer around a diagram such as this:
Key points are:

Ellipsoidal heights – mathematical, not physical. Used in satellite systems, and hence in data acquisition. Gravity related heights – used in engineering, topography, etc.

Difference between ellipsoid and the geoid. The latter is the theoretical surface for a land datum, but in practice not realised due to errors in national levelling campaigns. MSL differs from the geoid due to permanent currents, changes in salinity, air pressure, and so on. Each national system also starts from a different datum point, and so realises a different equipotential surface – so even with perfect levelling the datums would be different.

Chart Datum is with respect to a conservatively low tidal level etc.

Connection from satellite (ellipsoidal) system would be via a datum model such as OSGM02.

Chart Datum may be related at ports to the land datum via a local levelling link (not always available) and hence via OSGM02 to the ellipsoidal heights. Otherwise, VORF is a continuous link between ellipsoid and Chart Datum.