Examination / Tentamen
Introduction to Earth Observation (AE2–E02)
Faculty of Aerospace Engineering
Delft University of Technology

5 July 2007, 14:00–17:00

VERSION with ANSWERS

Please read these instructions first:

This exam contains 11 questions. Please write your name and 7-digit student ID clearly on each page and number your pages. This is a closed-book exam. You are not allowed to have any books, hand-outs, or notes on your table. Use of a pocket calculator is allowed.

S.v.p. eerst deze instructies lezen:

Dit tentamen bestaat uit 11 vragen. Schrijf uw naam en 7-cijferig studienummer boven elke pagina en nummer uw pagina's. Dit is een gesloten-boek tentamen. Het is niet toegestaan boeken, hand-outs of notities op uw tafel te hebben. Gebruik van een zakrekenmachine is toegestaan.

Question 1 (10pt)

Describe the difference between a reference system and a -reference frame.

Vraag 1 (10pt)

Beschrijf het verschil tussen een referentiesysteem en een referentiestelsel.

ANSWER:(see lecture 3, slides 3–4) The main point here is that a reference system is the definition of **how** the system should be created, whereas the reference frame is the actual **realization** of this definition.

For example, a celestial reference system can be defined as being fixed to the stars, but the implementation of this (the reference frame) depends on which stars are chosen and which orientation is made, i.e., if the x-axis points at a particular star. For example, the International Celestrial Reference Frame (ICRF) consists of over 608 points (star locations in an equatorial system, J2000 epoch) used to create the ICRS, an approximation to an inertial reference system.

Reference systems, as a mathematical construct, **do not change**, but **reference frames can change** as measurement techniques improve or new observations are added.

A **reference system** is the complete specification of how a celestial coordinate system is to be formed. It defines the origin and fundamental planes (or axes) of the coordinate system. It also specifies all of the constants, models, and algorithms used to transform between observable quantities and reference data that conform to the system. A **reference frame** consists of a set of identifiable fiducial points on the sky along with their coordinates, which serves as the practical realization of a reference system.

Question 2 (7/7pt)

Consider a spin-scan imaging sensor onboard a geostationary satellite.

a) Describe the image formation process of this sensor.

b) Give an estimate of the percentage of the time the sensor is actually collecting information about the Earth's surface.

Vraag 2 (7/7pt)

Beschouw een *spin-scan* beeldvormende sensor, aan boord van een geostationaire satelliet.

a) Beschrijf hoe een beeld wordt gevormd met deze sensor.

b) Geef een schatting van hoeveel procent van de tijd de sensor werkelijk informatie over aardoppervlak opneemt.

ANSWER:(see Rees fig 6.7)

a) (fig. 6.7 Rees) scanning is performed line by line, lines are running east-west, movement within a line is caused by rotation of entire satellite around a vertical (north-south) axis. A mechanical device (e.g. a mirror) points the system to the next line after each revolution.

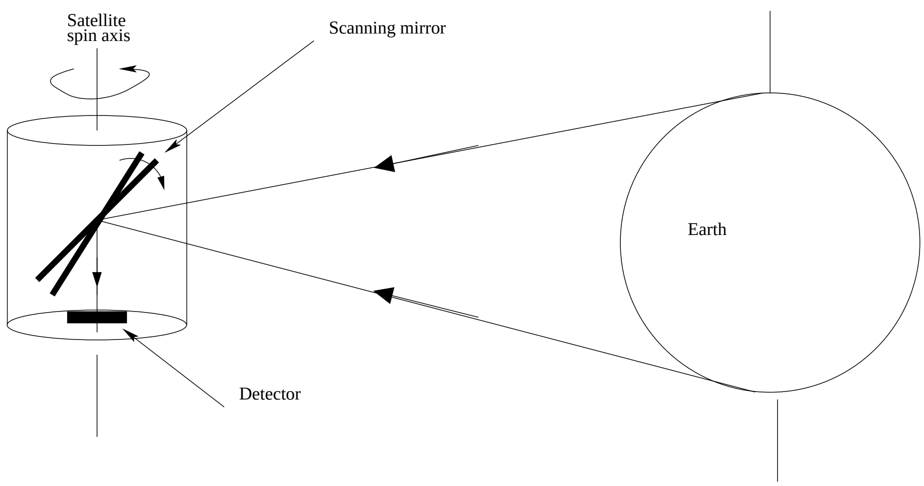


Figure 1: Rees fig 6.7 page 141.

b) While the satellite rotates, most of the time the sensor is pointing into outer space. The distance between the sensor and the earth is $R \approx 42000$km, (altitude geostationary satellite is approx. 35.786 km, say 36.000 km above earth, plus the radius of earth, R_e, say 6370 km, is approx. 42000 km). The circumference corresponding to that radius is $2\pi R = 264000$ km and at most $2R_e \approx 2 \cdot 6370 \approx 12740$ km on this circumference is covered with 'earth', if the spin-scan imager is pointing at equatorial latitudes. That is approx. 12740/264000= 4–5% of time (this answer is precise enough.)

Question 3 (5/5/5pt)

a) Explain why we need the concept of the solid angle in many radiative equations.

b) What is the unit of the solid angle?

c) Suppose we have a flat, horizontal terrain. If we consider the visible open hemisphere in terms of its solid angle, how much of these units does it cover?

Vraag 3 (5/5/5pt)

a) Leg uit waarom we het begrip 'ruimtehoek' *(solid angle)* nodig hebben in stralingsvergelijkingen.

b) Wat is de eenheid van de ruimtehoek?

c) Gegeven een vlak horizontaal terrein. Wanneer we de zichtbare hemel beschouwen in termen van haar ruimtehoek, hoeveel van deze eenheden bestrijkt deze?

ANSWER: (Rees, p.19-21, lecture 10 sheets)

a) Rees, p.20 top line: "It is clear that we will [also] need to be able to describe radiation distributed over a range of directions in space." To express the radiant intensity, I, we need to know how much radiant flux (in [W] or [J/s]) is coming from a particular area in the sky. This means that we need an expression for a part of a sphere, as seen from the inside. As this sphere has an infinite radius, square meters are not desirable as a unit. Therefore we need an angular parameter, similar to a cone. Note however, that the area projected at the inside of the sphere does not necessarily have to be a circle. We also need it for the radiance L, which is the radiant intensity per unit projected source See Rees, p.19–21 and lecture sheets lecture 10

b) The unit of the solid angle is the steradian (in Dutch *steradiaal*), abbreviated as [sr]. Note that mathematically, the solid angle is a dimensionless unit, as it is defined as $\Omega = \frac{A}{R^2}$, where A is a surface area on a sphere [m^2] and R^2 is the sphere's radius squared [m^2], and therefore $\frac{[m^2]}{[m^2]} = [\cdot]$, similar to angular units as [rad] or [degree]. (Note that a 'unit' is the magnitude of a 'dimension', relative to an arbitrary standard. There may be more units for one dimension, e.g. meters and feet for the dimension distance. Thus 'solid angle' is a 'dimension' with the unit 'steradian')

c) The visible open hemisphere covers a solid angle of $\Omega = 2\pi$ sr. 'sr' is the correct abbreviation of the unit steradian. (The solid angle is defined as a surface element of a sphere, divided by the sphere's radius R squared, i.e., solid angle $\Omega = A/R^2$. As a full sphere has surface $A = 4\pi R^2$, a semi-sphere or hemisphere has $2\pi R^2$, and the corresponding solid angle, Ω, is $\frac{2\pi R^2}{R^2} = 2\pi$. One could also derive the answer by integrating $\sin\theta d\theta d\phi$ over the hemisphere, that is $\theta = [0, \pi/2]$ and $\phi = [0, 2\pi]$.)

Question 4 (3/3/3/3/3pt)

State whether the following statements are **True** or **False**. You must justify your answer with a short explanation (the right answer with a wrong explanation will be marked incorrect, and vice versa).

a) A reference system can have more than one coordinate system.

b) Most of the Earth's magnetic field is generated by what's called the External Field, which is generated from ionized particles in the Earth's atmosphere.

c) The geoid is the level surface that approximates mean sea level best.

d) The International Terrestrial Reference Frame (ITRF) is a reference frame that is fixed with respect to the stars.

e) Coordinated Universal Time (UTC) is kept to within one second of Universal Time (UT1) by subtracting one leap second from UT1 every four years.

Vraag 4 (3/3/3/3/3pt)

Zijn de volgende beweringen **Goed** of **Fout**? Licht uw antwoord toe met een korte uitleg (een goed antwoord met een verkeerde uitleg wordt fout gerekend en vice versa).

a) Een referentie systeem kan meer dan een coördinaat-systeem hebben.

b) Het grootste gedeelte van het magneetveld van de Aarde wordt gegenereerd door wat een Extern Veld genoemd wordt, wat gegenereerd wordt door geïoniseerde deeltjes in de atmosfeer van de Aarde.

c) De geoïde is het niveau-oppervlak dat gemiddeld zeeniveau het beste benadert.

d) Het International Terrestrial Reference Frame (ITRF) is een referentiestelsel dat vast staat ten opzichte van de sterren.

e) Coordinated Universal Time (UTC) wordt binnen een seconde van Universal Time (UT1) gehouden door elke vier jaar een schrikkelseconde af te trekken.

ANSWERS:

a) True, examples include Cartesian, spherical, ellipsoidal, etc. (lecture 3, slide 4)

b) False, the core generates roughly 97 % of the Earth's magnetic field, while the external field only contributes around 1-2 %. (lecture 6, slide 10)

c) True, diff max 2.0 m, RMS diff 0.3 m. ((lecture 4, slide 38)

d) False, as the name suggest, the ITRF is a terrestrial frame, meaning that it is fixed w.r.t. the Earth. (lecture 3, slide 7-14)

e) False, leap seconds are used to keep the two time scales within one second, but it is not always on four year intervals. (Moreover, leap seconds are generally added and can potentially be subtracted as well). (lecture 3, slides 38-39)

Question 5 (5/5/5/5pt)

The resolution of an optical imaging system is limited by diffraction effects, and by the size of the detector projected on the Earth's surface.

a) What is the projected size of the detector onto the Earth's surface if the detector size equals $10\,\mu$m, the height of the orbit is 800 km, and the focal length of the objective lens equals 4 m?

b) What is over-sampling? Is it beneficial?

c) With a laser profiler, footprints of subsequent measurements may or may not overlap, depending on several factors. Which are these factors and what role do they play?

d) Should the overlap mentioned in c) be avoided? Compare this answer with b) and give an explanation.

Vraag 5 (5/5/5/5pt)

De resolutie van een beeldvormend optisch systeem wordt beperkt door diffractie-effecten en door de grootte van de detector geprojecteerd op het aardoppervlak.

a) Wat is de geprojecteerde grootte van de detector op het aardoppervlak voor een detector grootte van $10\,\mu$m bij een vlieghoogte van 800 km en een lens met een brandpuntsafstand van 4 m?

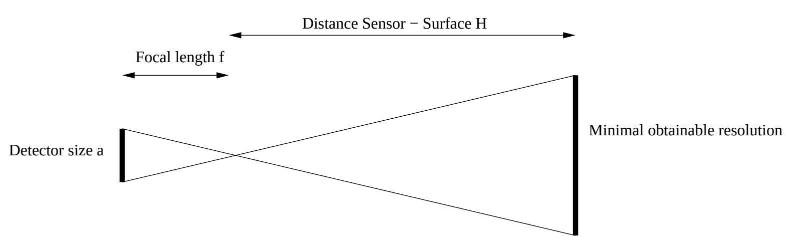
b) Wat is over-sampling? Is dit zinvol?

c) Bij metingen met een laser profiler kunnen de footprints van opeenvolgende metingen al dan niet overlappen, afhankelijk van diverse factoren. Welke zijn deze factoren en welke rol spelen zij?

d) Dient de overlap, vermeld in c), vermeden te worden? Vergelijk het antwoord met b) en geef een verklaring.

ANSWER: (Reference: Rees, p.141-142, and discussed during lecture)

a) Detector size $a = 1\text{e}{-6}$ m; Distance sensor-surface $H = 800000$ m; Focal length $f = 4$ m. The minimal obtainable spatial resolution is the size of the detector area projected onto the Earth's surface. That is $a\,H/f$ is $10\,\mu\text{m} \times 800\text{km}/4\text{m} = 2\text{m}$ (Rees, page 141-142, and discussed during lecture)



b) oversampling occurs when the distance between different measurement (as defined, in a pushbroom system, by the projections of neighboring sensors in the terrain) is smaller than the result of diffraction effects. This is **not necessarily** beneficial, since it does not lead to additional information . Neighbouring measurements will be correlated (but this could be simply eliminated by downsampling). Sometimes over-sampling can be beneficial, to be able to compensate for specific effects. For example, radar systems usually apply oversampling to compensate for spectral effects related to the motion of the sensor.

c) These factors are (i) pulse repetition frequency p, (ii) platform velocity v, and (iii) angular beamwidth $\Delta\theta$ or linear footprint size $H\Delta\theta$. Overlap occurs when v/p (the distance between measurements) is less than the footprint size, i.e.,

$$v/p < H\Delta\theta.$$

d) Overlap yields independent measurements of the same distance, which can be used to reduce noise (by averaging). The difference with question b). is that the surface to be measured is much larger than the footprint, whereas in b). we are looking for objects much smaller than the footprint (every pixel may be different).

Question 6 (5/5pt)

Signals can be described both in the time domain as well as in the frequency domain. The Fourier transform translates between the two domains. In fig. 2, four frequency domain representations of signals are shown.

a) Copy (sketches) of these four signals on your answer sheet and sketch the corresponding time domain signals. Make sure the relative scales between the four signals are comparable.

b) What is the general equation for these signals in the time domain?

Vraag 6 (5/5pt)

Signalen kunnen zowel in het tijdsdomein als in het frequentiedomein worden beschreven. De Fourier transformatie vertaalt tussen de twee domeinen. In fig. 2 worden vier frequentiedomein representaties van signalen gegeven.

a) Maak (schets) een kopie van deze signalen op uw antwoordpapier en schets de corresponderende signalen in het tijdsdomein. Zorg er voor dat de vier schetsen relatief ten op zichte van elkaar op schaal zijn.

b) Wat is de algemene formule voor dit type signalen in het tijdsdomein?

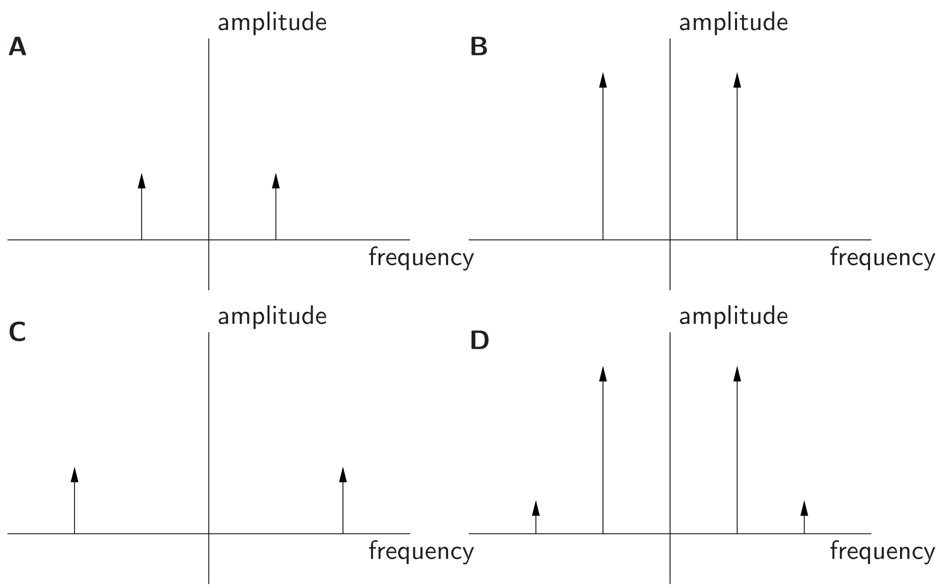


Figure 2: Four different signals represented in the frequency domain. Scales are identical for all plots.

ANSWER: (Ref. Rees, Chap 2, and sheets lecture 7.) These are all real valued signals of the general form

$$
\begin{aligned}
x(t) &= A\cos(2\pi f_0 t + \phi) \\
&= \{Ae^{j\phi}e^{j2\pi f_0 t}\} \\
&= \{Xe^{j2\pi f_0 t}\}
\end{aligned}
$$

where X is the amplitude of the signal, and f_0 the frequency.

a) The first signal (A) is a cosine function (continuous in time) and serves as reference. In (B) the amplitude of the cosine function should be larger. In (C) the amplitude should be the samen as in (A), but the wavelength should be smaller (higher frequency). Finally, in (D), there should be a high amplitude, long wavelength cosine, with a smaller wavelength, smaller amplitude cosine superposed on it. (It will be regarded as correct as long as the sketch shows two superposed signals, of which one has a smaller wavelength and a smaller amplitude.)

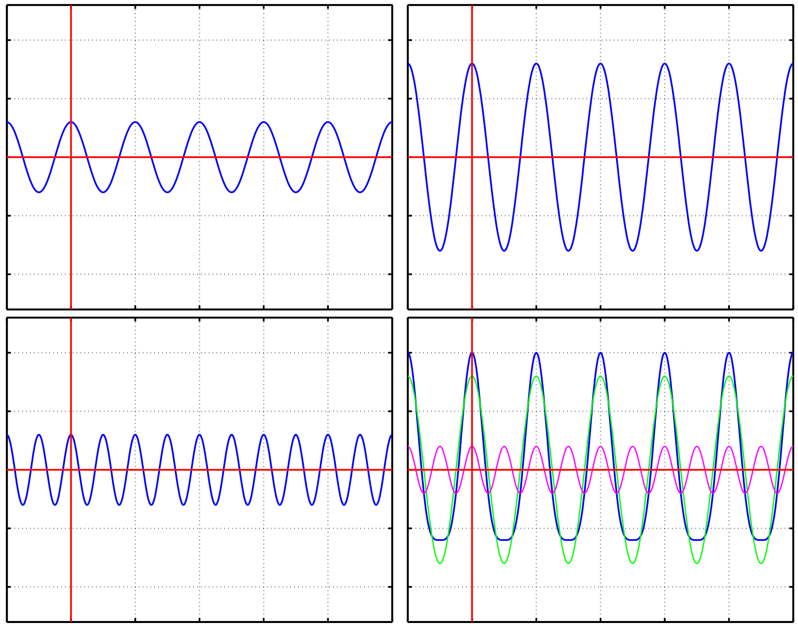


Figure 3: The same four different signals represented in the time domain. Scales are identical for all plots.

b) The generic equation is given above, but at this level a simple $\cos$ or $\sin$ equation is considered correct as well, as long as it includes an amplitude and a frequency factor. (See lecture on sinusoids). The student needs to show that the length of the arrows in the sketches is the amplitude A (in fact, this is already stated in the sketch, (y-axis)), and the frequency is related to the time axis as $2\pi ft$. Thus the equation should be $A\cos(2\pi ft)$, but $A\sin(2\pi ft)$ or $A\sin(2\pi ft + \phi)$will be considered correct as well.

Question 7 (10pt)

The normal gravity field is a spherical ellipsoid of constant potential designed to closely approximate the geoid. Below is a table of computed values of the normal gravity field for a range of latitudes and longitudes. Using this table, determine the value of the normal gravity field at the lat/lon location (35 N, 12 W).

latitude	longitude	normal gravity (m/s^2)
0 N	15 W	9.794
15 N	25 E	9.810
35 S	57 E	9.821
72 S	120 W	9.836

Vraag 7 (10pt)

Het normaalzwaartekrachtveld is een omwentelingsellipsoïde met een constante potentiaal welke een goede benadering is van de geoïde. De onderstaande tabel geeft de berekende waarden weer van het normaalzwaartekrachtveld voor een serie van lengte- en breedtegraden. Bepaal de waarde van de normaalzwaartekracht op breedte- en lengtegraad (35 NB, 12 WL) door gebruik te maken van deze tabel.

Breedte	Lengte	normaalzwaartekracht (m/s^2)
0 NB	15 WL	9.794
15 NB	25 OL	9.810
35 ZB	57 OL	9.821
72 ZB	120 WL	9.836

ANSWER:(lecture 4, slides 45-48) The normal gravity field is an ellipsoid with a surface of constant potential (i.e., gravity). As such, it has no dependency on longitude, and is symmetric about the equator (i.e., odd zonals = 0). This makes the answer 9.821, since it is at the same latitude as point (35S, 57E).

Question 8 (10/10/5pt)

Planck's law, describing the spectral radiance L_f as a function of various parameters is given in

$$L_f = \frac{2hf^3}{c^2\left(e^{hf/kT}-1\right)}$$

a) Using the relations $L_f = \left|\frac{\partial L}{\partial f}\right|$ and $L_\lambda = \left|\frac{\partial L}{\partial \lambda}\right|$, derive the equivalent expression for the spectral radiance L_λ, as function of the wavelength λ.

b) Considering a black body at room temperature and the fact that $\exp(x) \approx 1+x$ for $|x| \ll 1$, for which wavelengths does the equation derived in a) reduce to a linear line on a loglog plot of λ against L_λ?

c) What is the commonly used name for this particular approximation of Planck's law?

Vraag 8 (10/10/5pt)

De wet van Planck, die de spectrale radiantie L_f uitdrukt als functie van verschillende variabelen, is gegeven als

$$L_f = \frac{2hf^3}{c^2\left(e^{hf/kT}-1\right)}$$

a) Gegeven de relaties $L_f = \left|\frac{\partial L}{\partial f}\right|$ en $L_\lambda = \left|\frac{\partial L}{\partial \lambda}\right|$, leid de equivalente uitdrukking af van de spectrale radiantie L_λ, als functie van de golflengte λ.

b) Gegeven een zwart lichaam (*black body*) op kamertemperatuur, en de relatie $\exp(x) \approx 1+x$ voor $|x| \ll 1$. Voor welke golflengten reduceert de vergelijking afgeleid in a) tot een lineaire lijn in een loglog plot van λ versus L_λ?

c) What is de gebruikelijke naam voor deze approximatie van de wet van Planck?

h	Planck constant	6.6261×10^{-34} J s
c	Speed of light *in vacuo*	2.9979×10^{8} m s^{-1}
k	Boltzmann constant	1.3807×10^{-23} J K^{-1}

ANSWER: (Rees, p. 22-23.)

a) To answer this question, one needs to know the basic relation between frequency f and wavelength λ, which is $c = f\lambda$. The relations given in a). can be used to connect the two expressions:

$$\begin{aligned}
\frac{L_\lambda}{L_f} &= \left|\frac{\partial f}{\partial \lambda}\right| \Leftrightarrow \\
L_\lambda &= \left|\frac{\partial f}{\partial \lambda}\right| L_f, \quad \text{with} \quad f = c/\lambda \quad \text{thus} \quad \partial f = \frac{-c}{\lambda^2}\partial\lambda \\
&= \frac{c}{\lambda^2} L_f \\
&= \frac{c}{\lambda^2}\frac{2h(c/\lambda)^3}{c^2\left(e^{h(c/\lambda)/kT}-1\right)} \\
L_\lambda &= \frac{2hc^2}{\lambda^5\left(e^{hc/\lambda kT}-1\right)}
\end{aligned}$$

b) Room temperature, say $T = 300$ K.

$$\begin{aligned}
\exp(hc/\lambda kT) &\approx 1 + hc/\lambda kT \quad \text{if} \\
|hc/\lambda kT| &\ll 1 \Leftrightarrow \lambda \gg hc/kT \\
\lambda \gg {\sim}5 \times 10^{-5}\,\text{m, or} &\quad {\sim}50\,\mu\text{m}
\end{aligned}$$

(In practice "$\gg$" means, wavelengths at least one order of magnitude largere than this value.) For $\lambda \gg 50\,\mu$m, we find

$$L_\lambda = \frac{2ckT}{\lambda^4} \quad \text{or} \quad \log L_\lambda = 2ckT \cdot -4\log\lambda$$

which is a linear line on a loglog plot.

c) This approximation, valid for these large wavelengths, is known as the *Rayleigh-Jeans approximation*.

Question 9 (15pt)

You have been tasked with designing a single-satellite mission to observe the weather patterns of the Amazon basin in South America. The goal of the mission will be to send weather images and other climate data to a receiving ground station every 30 minutes. Describe the general orbit characteristics needed for such a mission.

The following information may or may not be useful for your calculations.

- From Kepler's third law, we can derive the following expression for the orbital period of a satellite around the sphere

$$T = \frac{2\pi r^{\frac{3}{2}}}{\mu^{\frac{1}{2}}}$$

where $\mu = 3.986 \times 10^5 \; km^3 \; s^{-2}$.

Vraag 9 (15pt)

U heeft de opdracht om een missie met één satelliet te onwerpen om het weerpatroon boven het stroomgebied van de Amazone in Zuid-Amerika waar te nemen. Het doel van de missie is om de weerbeelden en andere klimatologische data iedere 30 min. naar een grondstation te verzenden. Beschrijf de algemene baankarakteristiek voor zo'n missie.

De volgende informatie kan nuttig zijn voor uw berekeningen.

- Uit de derde wet van Kepler kunnen we de volgende uitdrukking afleiden voor de baanperiode voor een satelliet rond de bol

$$T = \frac{2\pi r^{\frac{3}{2}}}{\mu^{\frac{1}{2}}}$$

waarin $\mu = 3.986 \times 10^5 \; km^3 \; s^{-2}$.

ANSWER: (lecture 2, slide 14) Since the data is needed every 30 minutes, and the average LEO orbit time is approx. 90 mins, this eliminates most standard orbit configurations. One solution is to place the satellite in a geo-stationary orbit over Brasil. Since the satellite will be at roughly 36000 km altitude at the equator, the entire Amazon should be visible, and the satellite will never move w.r.t. the Earth since it is geostationary, ensuring continuous monitoring (i.e., the 30 min requirement is met)

Question 10 (4/4/4/4/4pt)

In fig. 4, a table from the recent (Feb. 2007) IPCC report on climate change is shown. This table lists the latest information on the rate of sea level rise, firstly as expected by modeling the various contributions, and secondly as observed. Two different time epochs are shown. The bottom row shows the difference between the observed and the modelled rates. How would you interpret this table? Comment on

a) the source that most dramatically increases in terms of sea level rise rates,

b) the changes in velocity for both epochs,

c) differences between the expected ('sum of individual climate contributions to sea level rise') rates and observed rates for both epochs. Discuss their significance. What can be deduced from these differences?

d) the 'error bars' for the observed rates at both time intervals,

e) what these numbers mean for the current quality of earth observation data? Which source of sea level rise requires most attention from future earth observation missions?

Vraag 10 (4/4/4/4/4pt)

In fig. 4 wordt een tabel uit het recente IPCC rapport (feb. 2007) over klimaatverandering getoond. Deze tabel toont de meest recente informatie over de snelheid van zeespiegelstijging, allereerst zoals verwacht door de verschillende bijdragen te modelleren, en daaarnaast zoals gemeten. Twee verschillende tijd-epoches worden getoond. De onderste rij toont het verschil tussen de feitelijk waargenomen en de gemodelleerde snelheden. Hoe zou u deze tabel interpreteren? Geef uw commentaar op

a) de bijdrage die het meest toegenomen is in termen van de snelheid van zeespiegelstijging,

b) de veranderingen in snelheid voor beide epoches,

c) de verschillen tussen de verwachte ('sum of individual climate contributions to sea level rise') snelheden en de waargenomen snelheden voor beide epoches. Bespreek hun significantie. Wat kan worden gededuceerd uit deze verschillen?

d) de foutmarges van de waargenomen snelheden bij beide epoches,

e) wat deze getallen betekenen voor de huidige kwaliteit van aardobservatie (in deze context). Welke bijdrage in zeespiegelstijging verdient de meeste aandacht in toekomstige aardobservatiemissies?

Summary for Policymakers IPCC WGI Fourth Assessment Report

Table SPM-0. Observed rate of sea level rise and estimated contributions from different sources. {5.5, Table 5.3} [Numbers to be converted to mm per year]

Source of sea level rise	Rate of sea level rise (m per century) 1961 – 2003	1993 – 2003
Thermal expansion	0.042 ± 0.012	0.16 ± 0.05
Glaciers and ice caps	0.050 ± 0.018	0.077 ± 0.022
Greenland ice sheets	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheets	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	0.11 ± 0.05	0.28 ± 0.07
Observed total sea level rise	0.18 ± 0.05[a]	0.31 ± 0.07[a]
Difference (Observed minus sum of estimated climate contributions)	0.07 ± 0.07	0.03 ± 0.10

Note:
[a] Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry

Figure 4: Table from the February 2007 IPCC report (WGI Fourth Assessment Report, Summary for Policymakers)

ANSWER: (Lecture sheets lecture 1)

a) The source that most significantly increases the sea level rise rate is the **Greenland ice sheet**, increasing with a factor of 4 in the last decade with respect to the period 1961-2003—from 0.05 ± 0.12 to 0.21 ± 0.07. Second is the increase of thermal expansion, with a factor of about 3.8, from 0.042 ± 0.012 to 0.16 ± 0.05 in the same interval.

b) The velocity **increases** both for the modeled sources as well as for the measured rates—there is an **acceleration**. As the first epoch (1961-2003) also covers the second one (1993-2003)—which has higher rates—it can be deduced that the actual rates in the period 1961-1993 should be lower. They are biased because of the larger rates in the period 1993-2003. This resembles a hockey-stick model, only here for a much more limited period than conventionally used.

c) These differences **have decreased** for the most recent epoch (1993-2003). In the period 1961-2003, considering the error margins, there was a significant difference between modeled and observed (0.11 ± 0.05 versus 0.18 ± 0.05) For the period 1993-2003, the differences are not really significant anymore (0.28 ± 0.07 versus 0.31 ± 0.07). From this we could deduce that modelling capabilities have dramatically improved—the expectations are closer to the measurements.

d) The error margins for the most modern observatios are larger than for the 'old' data. This is counter-intuitive. This is likely not related to the precision of the earth observation methods, but to the larger time interval considered. For a velocity estimate, the precision will increase if—for equal quality measurements—a longer time interval is considered.

e) For the quality of the earth observation this table suggests that the quality is sufficient, i.e., it fits very well with our current understanding of the physical models. Future missions should focus on the Antarctic ice sheet, as this has both a significant contribution (0.28 mm/y) but also a large uncertainty (0.35 mm/y)

Question 11 (7/7pt)

Consider a multi-spectral passive imaging satellite sensor with four spectral bands: near-infrared, red, green, blue.

a) Make a sketch illustrating atmospheric scattering, where three different cases are distinguished.

b) What is the influence on the images? Is it the same for all bands?

Vraag 11(7/7pt)

Beschouw een multi-spectrale passieve satellietsensor met 4 banden: nabij-IR, rood, groen, blauw.

a) Maak een schets die atmosferische verstrooiing illustreert, waarbij 3 gevallen onderscheiden worden.

b) Hoe wordt het beeld hierdoor beinvloed? Is dat hetzelfde in alle 4 banden?

ANSWER:(Rees Figure 6.10)

a) Rees Figure 6.10, cases B, E and F (between sun and earth, between earth and sensor, and between sun and sensor: skylight). These are the solid lines in the sketch below.

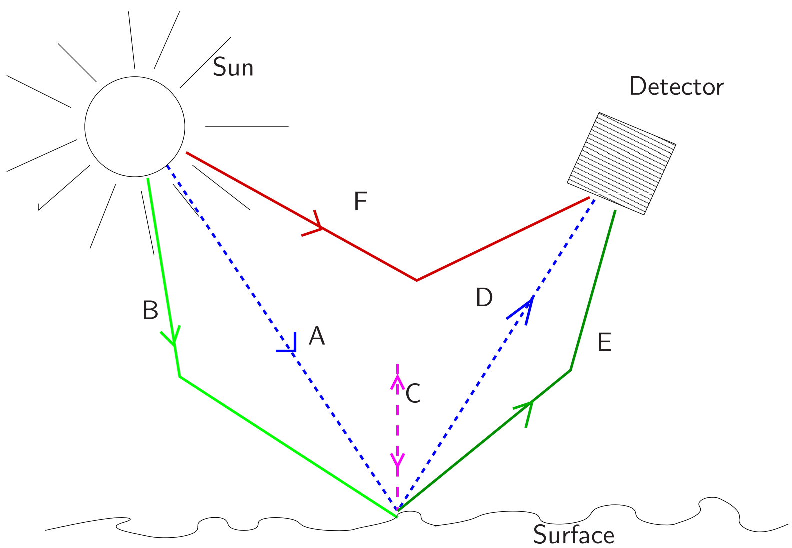


Figure 5: After Rees, fig. 6.10. The various contribtions a detector could sense. (A): direct illumination by the Sun, and (D) direct radiation of surface to detector. (B) is indirect illumination of the surface by radiation scattered from the atmosphere. (C) represents radiation from the surface scattered to the atmossphere. Part of this radiation will be scattered again by the atmosphere and radiated onto the surface. (E) is radiation from the surface which reaches the detector due to the fact that it is scattered by the atmosphere. Finally, (F) is radiation from the Sun that reaches the detector due to the fact that it is scattered by the atmosphere.

b) (B) gives some illumination in shadow areas (this might be useful). (E) causes blurring and loss of contrast. (F) gives an additive effect. With a clear "blue" sky, all these have a (small) effect on the blue band only. In case of dust, smoke and humidity the effect is much larger and affects all bands (haze).