Your SCIPER:

Date: 18 March 2025

Location: GC A3 30

ENV-421 Sustainability, climate and energy first evaluation
Duration: 45 minutes, 14:15 – 15:00

Material allowed: 1 Din A4 page of notes (back and front) and calculator
Not allowed: phones, tablets, connected watches or computers

This exam is worth 20 % of your overall grade.

Instructions:

- Put your Sciper number on each page. If you need replacement pages, ask the supervision team.
- For multiple choice questions, the number of correct choices per question can vary between one and all options. Only by selecting all correct answers leads to the point attribution.
- The number of points is indicated for each question.
- For open questions to be answered with text, respect the line limit. We will not take into account information that goes beyond the line limit.
- For figure interpretation, make sure to explicitly refer to any elaboration that you make to a figure (e.g. when you draw on it) on the exam sheet, and make any elaboration very visible.

The sum of all points obtained through the series of questions (maximum of 40 points) will be rescaled on a maximum grade of 6.0.

Example: 30 points on a maximum of 40 points will lead to a grade of: 1 + (30/40) x 5 = 4.75.

The final grade will be rounded to the nearest quarter of point.

Your SCIPER:

1. Earth's climate

1.1 Which of the following "spheres" are specific spheres of the Earth's climate system? ***One point.***

- ☐ Atmosphere
- ☐ Hydrosphere
- ☐ Stratosphere
- ☐ Lithosphere
- ☐ Pedosphere
- ☐ Biosphere

1.2 Which component of the Earth' system below has the highest albedo? ***One point.***

- ☐ Oceans
- ☐ Forests
- ☐ Snow and ice
- ☐ Sandy desert
- ☐ Grassland

1.3 Which main trace gases are responsible for the longwave absorption bands of the Earth's infrared spectrum below, measured from space? *Write the chemical formula in the rectangles.* ***Three points.***

- Below 8 µm: ☐
- Between ~9.5 and 10 µm: ☐
- Between ~13 and ~17 µm: ☐

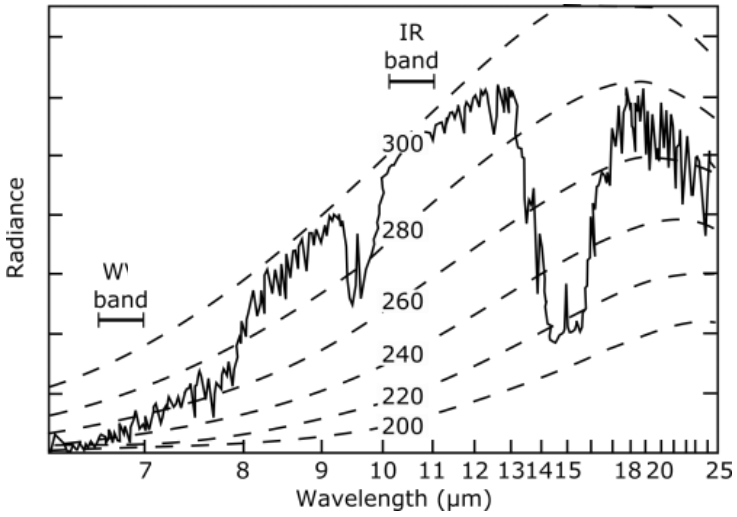


Figure 1: Nimbus 4 satellite measurement of the Earth's infrared spectrum. Observations over the tropical Pacific ocean in April 1970. Source: Hanel and Conrath, Nature, 1970.

Your SCIPER:

1.4 Which of the following atmospheric processes involve a breakdown of molecules due to solar radiation? ***One Point.***

- ☐ Photodissociation
- ☐ Hydrolysis
- ☐ Photolysis
- ☐ Oxidation
- ☐ Photoionization

1.5 Which molecules among those listed below are NOT considered as greenhouse gases? ***One Point.***

- ☐ Ozone (O_3)
- ☐ Carbon monoxide (CO)
- ☐ Nitrous oxide (N_2O)
- ☐ Molecular hydrogen (H_2)
- ☐ Trichlorofluoromethane CFC-11 (CCl_3F)
- ☐ Argon (Ar)

1.6 Explain why the molecules that you selected above are not considered as greenhouse gases. *Two lines maximum.* ***One Point.***

…… ……

1.6 The map below shows the average global distribution of net downward *(taking into account albedo)* shortwave radiation (in $W.m^{-2}$) at the Earth' surface <u>for the month of July</u>.

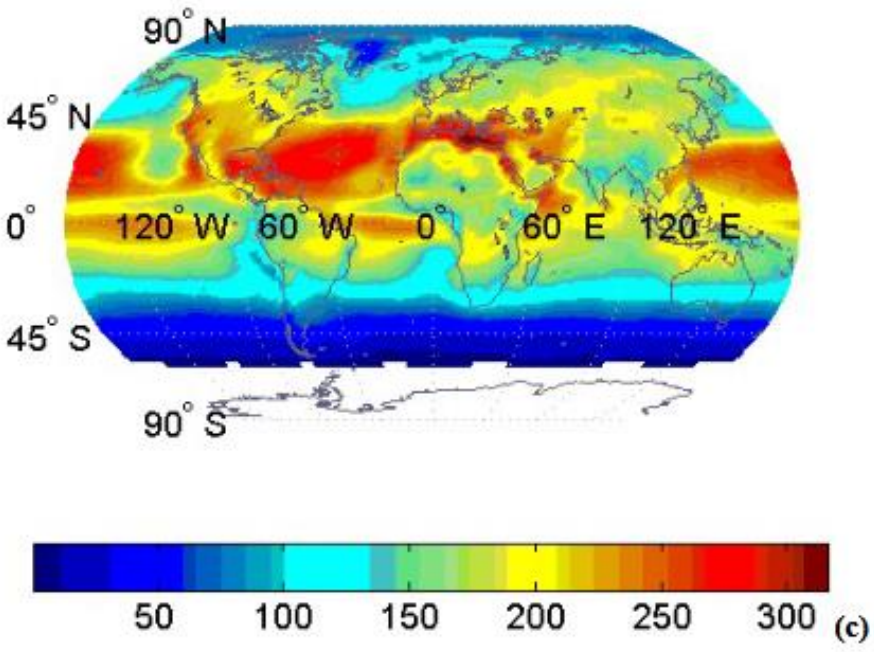


Figure 2: Long-term (1984-1997) average global distribution of net downward (or absorbed) shortwave radiation (in W.m-2) at the Earth' surface for the month of July. Source: Hatzianastassiou et al., Atmos. Chem. Phys. 2005.

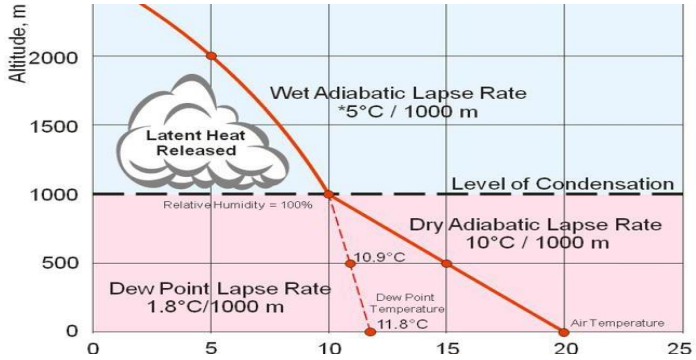
Your SCIPER:

Surround and number on the map four regional anomalies (relatively strong or weak radiation) that you consider important. Explain in two lines maximum for each anomaly what are its main causes. ***0.5 Point for a correct anomaly and 0.5 Point for a good argument. Four points maximum.***

	Feature	Main causes
1		…… ……
2		…… ……
3		…… ……
4		…… ……

1.7 We consider an air parcel with a mass of 1 kg at the Earth' surface, having a temperature *T* of 15°C, with a relative humidity *RH* of 50% and including 6 g of water vapor. When the air parcel rises, at which altitude will condensation begin? ***Two Points.***

Use the different lapse rate values indicated in the following graph.



Reminder: the dew point temperature can be derived from the following equation:

$$T_d \approx T - \frac{(100 - RH)}{5}$$

Answer:

1.8 What will be the temperature of the air parcel after condensation? ***Two Points.***

Reminder:

Energy *Q* released by condensation: $Q = L_v \times m_{\text{condensed water}}$
where $L_v = 2.5 \times 10^6\ \text{J/kg}$

Temperature change: $\Delta T = \frac{Q}{c_p \times m_{\text{air}}}$

where c_p is the heat capacity of air: 1.005 kJ/kg-K
And m_{air} is the mass of the air parcel

Your SCIPER:

- Answer:

1.9 If the phenomena addressed here become more intense in the Tropics under warmer conditions, indicate what would be the sign of the lapse rate feedback. Explain why in a maximum of three lines. ***0.5 Point for the correct sign. 1.5 Points for the correct explanation.***

Sign of the lapse rate feedback (+ or -)	Explanation
	…… …… ……

1.10 What is the effective radiative forcing of carbon dioxide, calculated between 1750 and 2019? ***One Point.***

- □ ~1.0 $W.m^{-2}$
- □ ~1.5 $W.m^{-2}$
- □ ~2.0 $W.m^{-2}$
- □ ~2.5 $W.m^{-2}$
- □ ~3.0 $W.m^{-2}$

1.11 Why the Earth System Sensitivity (ESS) is calculated as being larger than a Transient Climate Response (TCR) by climate models? Answer with five lines maximum. ***One Point.***

……
……
……
……
……

Your SCIPER:

2. Energy systems

2.1 A combined cycle plant consists of a Brayton cycle and a Rankine cycle. The Brayton cycle operates between 1600 K and 600 K and achieves an actual efficiency equal to 80% of its Carnot efficiency. The Rankine cycle operates between 500 K and 300 K, whose actual efficiency is 70% of its Carnot efficiency. Determine the overall plant efficiency. ***One Point.***

- ☐ 50%
- ☐ 64%
- ☐ 72%
- ☐ 80%

2.2 A city with an annual electricity demand of 40 GWh plans to supply 20% of its demand via wind turbines. How many wind turbines with a rated capacity of 2 MW, with a capacity factor of 23% must the city install to reach its target? ***One Point.***

- ☐ 1 Turbine
- ☐ 2 Turbines
- ☐ 4 Turbines
- ☐ 8 Turbines

2.3 A household has an annual electricity demand of 5,000 kWh. PV panels with a conversion efficiency of 25% are available, and they operate with an annual capacity factor of 15% under an irradiation of 1,000 W/m². Determine the minimum roof area that must be covered by PV panels to meet the household's energy demand. ***One Point.***

- ☐ 10.5 m²
- ☐ 15.2 m²
- ☐ 20.8 m²
- ☐ 25.3 m²

2.4 A heat pump provides space heating for a building. With an outdoor ambient temperature of 0°C, the system operates at 50% of the Carnot COP. Calculate the effective COP when the indoor target temperature is set to 20°C, and then when it is reduced to 18°C. Determine the percentage improvement in COP achieved by lowering the indoor temperature. ***One Point.***

- ☐ Effective COPs of 7.33 and 8.08; improvement ≈ 10.2%
- ☐ Effective COPs of 7.33 and 8.50; improvement ≈ 16.0%
- ☐ Effective COPs of 7.00 and 8.08; improvement ≈ 15.8%
- ☐ Effective COPs of 7.33 and 7.80; improvement ≈ 6.4%

2.5 Which processes are involved in a typical heat pump cycle? ***One Point.***

- ☐ Evaporation
- ☐ Compression
- ☐ Condensation
- ☐ Expansion
- ☐ Combustion

Your SCIPER:

2.6 Which statements accurately characterize Carnot efficiency in heat engines? ***One Point.***

- ☐ It represents the maximum theoretical efficiency for a given temperature difference.
- ☐ It is independent of the working fluid used.
- ☐ It can be achieved in practical systems with current technology.
- ☐ It depends solely on the temperatures of the heat source and sink.

2.7 In an open Brayton cycle (as used in jet engines), which components are present? ***One Point.***

- ☐ Compressor
- ☐ Combustor
- ☐ Turbine
- ☐ Condenser

2.8 What is the typical electrical efficiency range of the power cycle for modern nuclear power plants? ***One Point.***

- ☐ 10%-20%
- ☐ 30%-40%
- ☐ 50%-60%
- ☐ 70%-80%

2.9 In wind turbine operation, what does the “cut-out” speed refer to? ***One Point.***

- ☐ The minimum wind speed required for power generation
- ☐ The wind speed at which maximum power is achieved
- ☐ The wind speed above which the turbine shuts down to prevent damage
- ☐ The average wind speed during nighttime

2.10 Which statement best reflects the impact of the second law of thermodynamics on energy conversion processes? ***One Point.***

- ☐ It limits the maximum achievable efficiency of all energy conversion systems
- ☐ It applies only to renewable energy systems
- ☐ It has no effect on fossil fuel combustion
- ☐ It is relevant solely to nuclear reactions

Your SCIPER:

2.11 Define the concepts of *primary*, *secondary*, final *energy* and *end-uses* within the context of energy system modeling. M*aximum of 1 sentence per definition.* ***One Point per correct definition.***

	Energy	Definition
1	Primary	…… ……
2	Secondary	…… ……
3	Final	…… ……
4	End-Uses	…… ……

2.12 For each of the following renewable energy sources, provide one example of a natural factor that influences its seasonal variability or availability. Explain how this factor affects the resource. ***One Point per correct factor + One Point per correct explanation.***

	Resource	Factor	Explanation
1	PV	……	…… …… …… ……
2	Wind Turbine	……	…… …… …… ……
3	Hydropower	……	…… …… …… ……