ENV 407 - Atmospheric Processes: from Clouds to Global Scales

SSIE-1 - 2022-23

Written EXAM

January 23, 2023

Part of Prof. A.Nenes

Total credit on this part of the exam: 100 marks

Time: 1 hour

Questions are in English, answer in English or French

HINT:	**If you get stuck on a question, move on to the next one. Return to the problematic question afterwards.**

Nom, prénom : ……………………………………..…….   No. Sciper: ………………….

1. (1 point) The frost point temperature for any substance is (greater than, less than, equal to) the dew point temperature. Why? Provide a sketch to illustrate your points.

2. (1 point) Does your answer to Question 2 above apply to any substance that can exist as a solid, liquid and vapor? Justify your answer, using what you qualitatively know about enthalpy of phase change.

3. (1 point) The enthalpy of a water cloud is

$$dH = \left(m_d c_{pd} + m_v c_{pv} + m_l c_l\right) dT + L_{lv} \, dm_v$$

where the subscripts d, v, and l refer to dry air, water vapor and liquid water, respectively. Which terms in the parentheses are usually neglected and why?

4. (1 point) During the isobaric cooling of saturated air, the temperature decrease of the air is directly proportional to the amount of cooling (True, False)

5. (1 point) The saturated adiabatic lapse rate is (less than, greater than, equal to) the dry adiabatic lapse rate. Say why.

Nom, prénom : ……………………………………….   No. Sciper: ………………….

6. (2 points) You look at your local weather station and note that at the current temperature (0 degrees Celcius) the relative humidity is 43%. The weather prediction says that the temperature is expected to drop to -10.5 degrees Celcius overnight. Assuming that there is no loss in water vapor from the airmass surrounding you, do you expect fog to form during this period? And if so, will it be a liquid or an ice fog (assuming that equilibrium thermodynamics always govern). You can use the data from the table provided on the last page to support your calculations.

7. (2 points) Observations of particle size distributions in the atmosphere are often described in terms of "modes", where the number distribution function peaks at certain sizes.

a) How many of these "modes" are typically found in the atmosphere? Name them if you can, as well provide their characteristic size ranges.

b) Which of these modes and aerosol particle types are thought to contribute to the concentration of cloud condensation nuclei (CCN) and which to the ice nuclei (IN)? What makes some particles a good CCN and what a good INP?

8. (2 points) Explain the main components of the Köhler curve (you don't need to use equations, only sketch on a graph the phenomena that are acting), and why it has a peak at the critical supersaturation. In your explanation, assume the CCN has a dry diameter d.

Nom, prénom : ……………………………………….   No. Sciper: ………………….

‿endix D — Saturation Pressures over Pure Liquid Water and Pure Ice as a Function of Temperature

liquid ice

T (°C)	P_V^* (hPa)	$P_{V,i}^*$ (hPa)	T	P_V^*	$P_{V,i}^*$	T	P_V^*	T	P_V^*
-50	0.0635	0.0393	-24	0.8826	0.6983	1	6.565	26	33.606
-49	0.0712	0.0445	-23	0.9647	0.7708	2	7.054	27	35.646
-48	0.0797	0.0502	-22	1.0536	0.8501	3	7.574	28	37.793
-47	0.0892	0.0567	-21	1.1498	0.9366	4	8.128	29	40.052
-46	0.0996	0.0639	-20	1.2538	1.032	5	8.718	30	42.427
-45	0.1111	0.0720	-19	1.3661	1.135	6	9.345	31	44.924
-44	0.1230	0.0810	-18	1.4874	1.248	7	10.012	32	47.548
-43	0.1379	0.0910	-17	1.6183	1.371	8	10.720	33	50.303
-42	0.1533	0.1021	-16	1.7594	1.505	9	11.473	34	53.197
-41	0.1704	0.1145	-15	1.9114	1.651	10	12.271	35	56.233
-40	0.1891	0.1283	-14	2.0751	1.810	11	13.118	36	59.418
-39	0.2097	0.1436	-13	2.2512	1.983	12	14.016	37	62.759
-38	0.2322	0.1606	-12	2.4405	2.171	13	14.967	38	66.260
-37	0.2570	0.1794	-11	2.6438	2.375	14	15.975	39	69.930

Appendix D Saturation Pressures over Pure Liquid Water and Pure Ice as a Function of Temperature

T (°C)	P_V^* (hPa)	$P_{V,i}^*$ (hPa)	T	P_V^*	$P_{V,i}^*$	T	P_V^*	T	P_V^*
-36	0.2841	0.2002	-10	2.8622	2.597	15	17.042	40	73.773
-35	0.3138	0.2232	-9	3.0965	2.837	16	18.171	41	77.798
-34	0.3463	0.2487	-8	3.3478	3.097	17	19.365	42	82.011
-33	0.3817	0.2768	-7	3.6171	3.379	18	20.628	43	86.419
-32	0.4204	0.3078	-6	3.9055	3.684	19	21.962	44	91.029
-31	0.4627	0.3420	-5	4.2142	4.014	20	23.371	45	95.850
-30	0.5087	0.3797	-4	4.5444	4.371	21	24.858	46	100.89
-29	0.5588	0.4212	-3	4.8974	4.756	22	26.428	47	106.15
-28	0.6133	0.4668	-2	5.2745	5.173	23	28.083	48	111.65
-27	0.6726	0.5169	-1	5.6772	5.622	24	29.829	49	117.40
-26	0.7369	0.5719	0	6.1070	6.106	25	31.668	50	123.39
-25	0.8068	0.6322							

Atmospheric Processes
Final exam - Large-scale dynamics of the mid-latitudes
23 Jan. 2023

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I. Geostrophic wind and thermal wind balance
For the following questions, draw a figure to support your explanation. You do not need to write down any equations.

1. Explain what the geostrophic balance is. Draw a schematic of the forces at play to explain why the air around a low pressure system spins in the counter-clockwise direction in the Northern Hemisphere.

2. Explain why we have a westerly jet stream (i.e. a maximum of westerly wind speed just below the tropopause) in the mid-latitudes.

II. Extratropical cyclones

1. What is the main source of energy for extratropical cyclones ?

2. Why are extratropical cyclones more frequent and intense in winter than in summer ?

3. Explain the role of extratropical cyclones in the atmospheric energy cycle.

III. Weather analysis
Analysis of the lower troposphere

1. Based on Figure 1 and 2, identify the extratropical cyclone which dominates the weather over Europe. Mark on Figure 1 the centre of the low pressure system with a "L" and indicate the position of the fronts that you identify on Figure 1. Indicate the types of fronts (remember that they are rotating counter-clockwise around the low pressure centre).

2. Which stage of the Norwegian Cyclone Model (perturbation, mature or occluded) correspond to this extratropical cyclone and why?

3. Where do you expect the strongest surface winds? Indicate it on Figure 1 and explain why you chose this location.

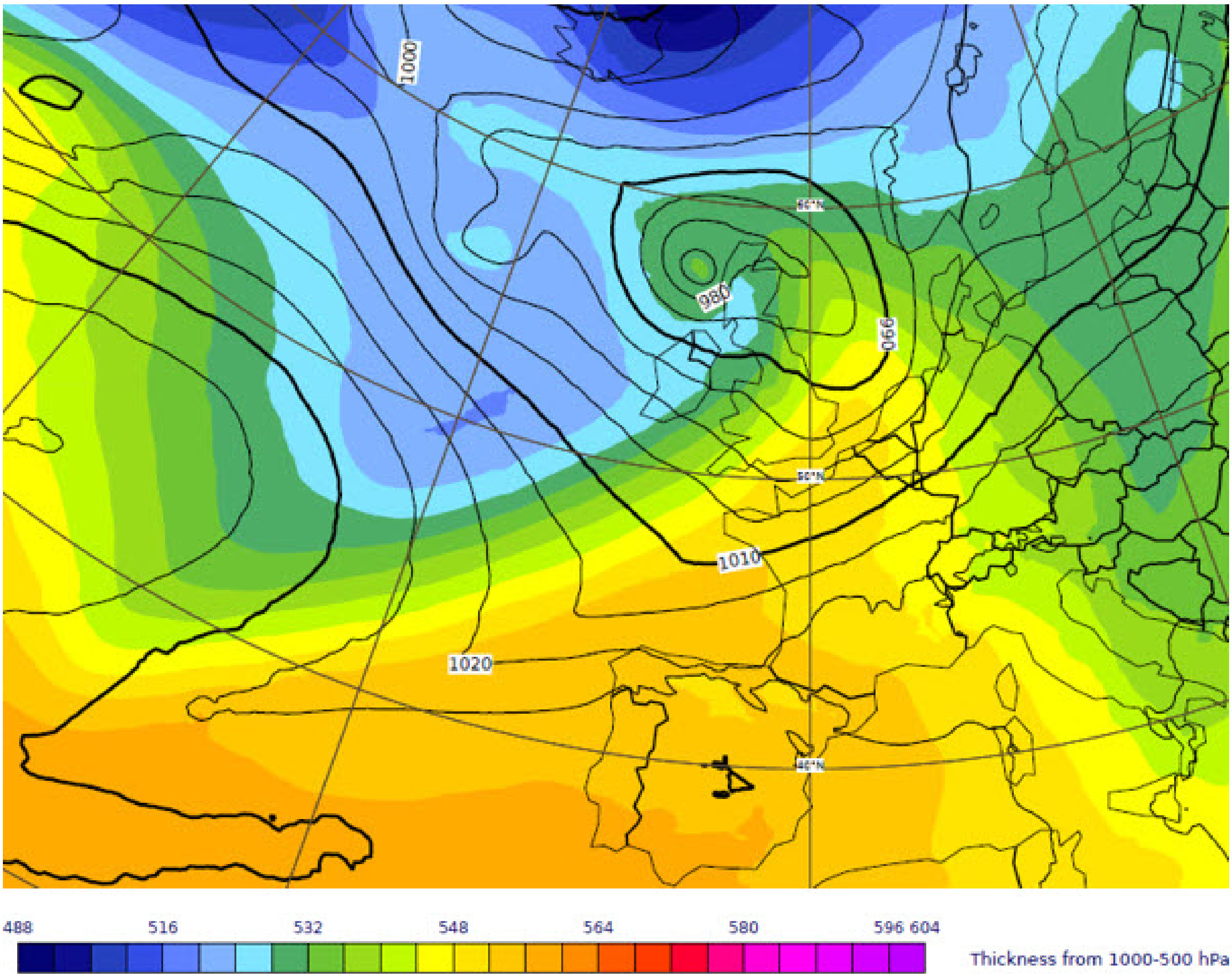

Figure 1: Mean sea level pressure (black contours, labels in hectopascal), and 500 hPa to 1000 hPa thickness (colour filled) on 14 January 2023 at 12 UTC. The 500 hPa to 1000 hPa thickness is directly proportional to the average virtual temperature between these two levels. Source: IFS analysis

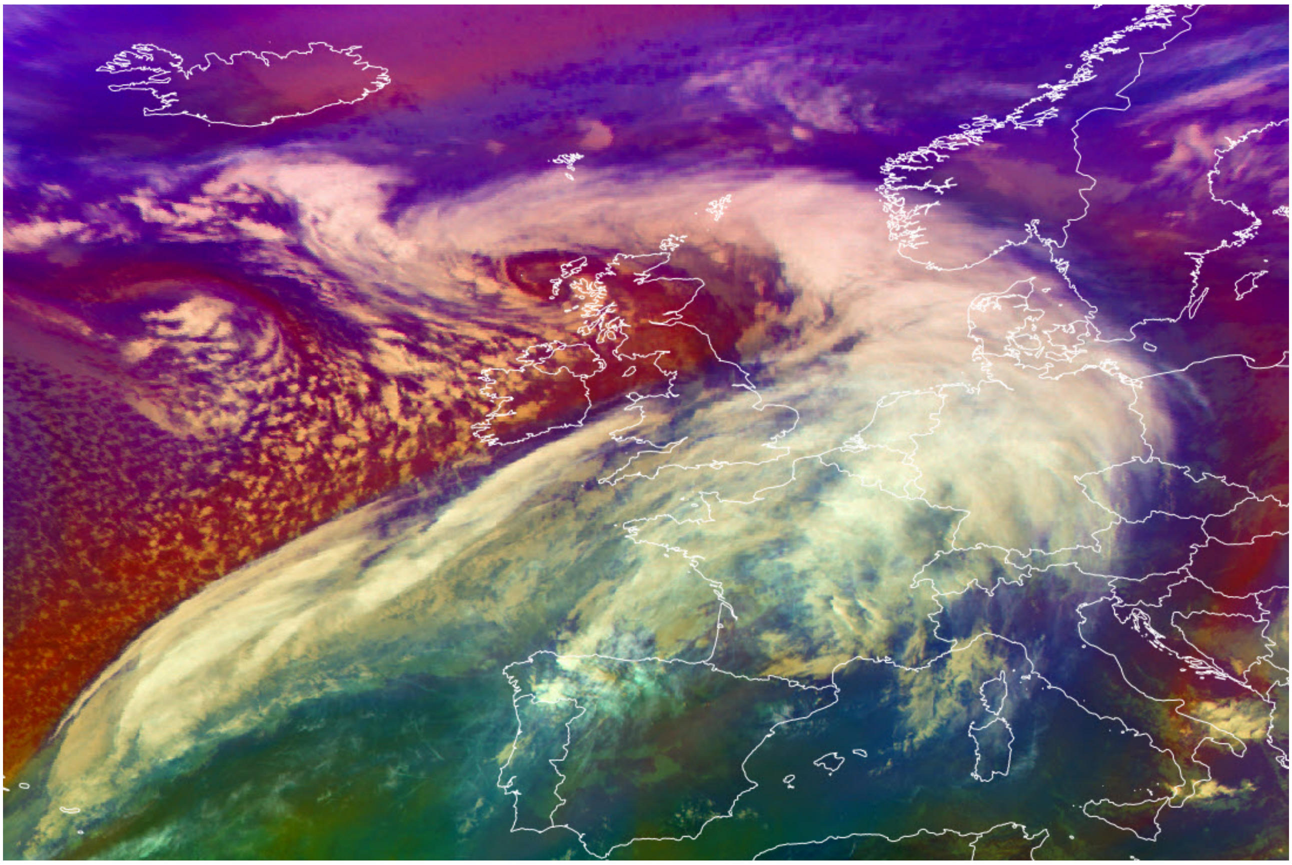

Figure 2: Satellite image over Europe on 14 January 2023 at 12 UTC. Be aware that the latitude lines are straight, as opposed to Figure 1. Source: Eumetsat Airmass RGB product

Analysis of the upper troposphere

1. Looking at the portion of the jet stream on Figure 3, draw on the map the direction of the air flow (with arrows/streamlines).

2. Mark the position of the jet streak (with a "J") and the axis of the trough (with a dashed line) that are directly to the west of Europe.

3. Where is the low pressure system you identified on Figure 1 located with respect to the axis of the trough (i.e. ahead or behind)? Where is it located with respect to the jet streak (right or left entrance/exit)? Are these locations favourable for the formation or intensification of a low pressure system (i.e. cyclogenetic)? Why is it so?

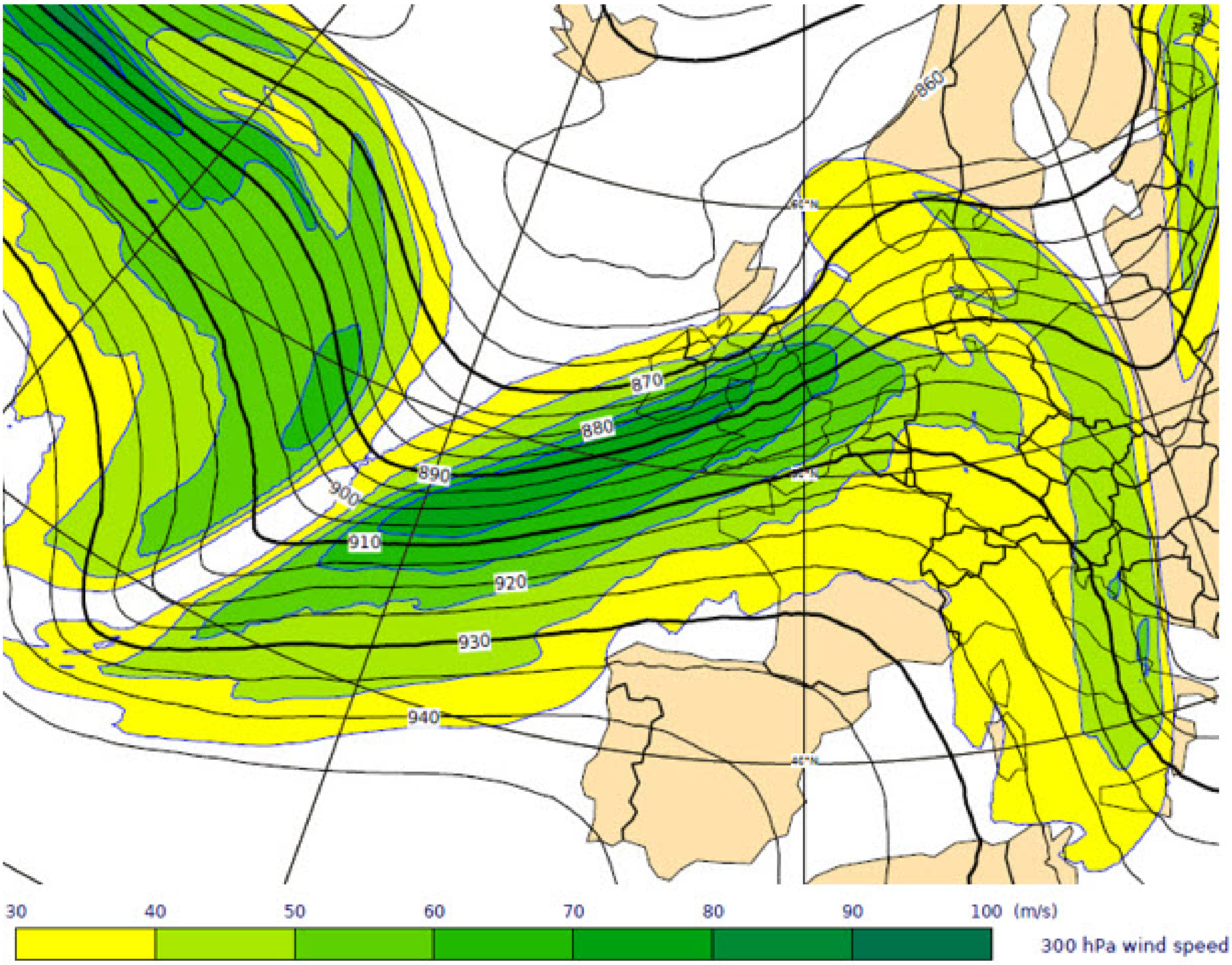

Figure 3: Geopotential height (black contours, labels in decametre) and wind speed (colour filled) at 300 hPa on 14 January 2023 at 12 UTC. Source: IFS analysis.

Time series during the frontal passage

1. Look at the evolution of wind, pressure, and temperature on Figure 4 at the Chasseral (mountain peak in the Jura, 1606 m above sea level). Indicate on the figure the period where the cold front you analysed on Figure 1 passes over Switzerland.

2. Explain why one could expect the rapid change in temperature, wind direction and pressure during the frontal passage on Figure 4. Base your explanation on the pressure and temperature fields of Figure 1. Assume that the cold front moves from west to east and reaches Switzerland in the same configuration as shown on Figure 1. Finally, assume that the mean sea level pressure field is representative of the altitude of the Chasseral.

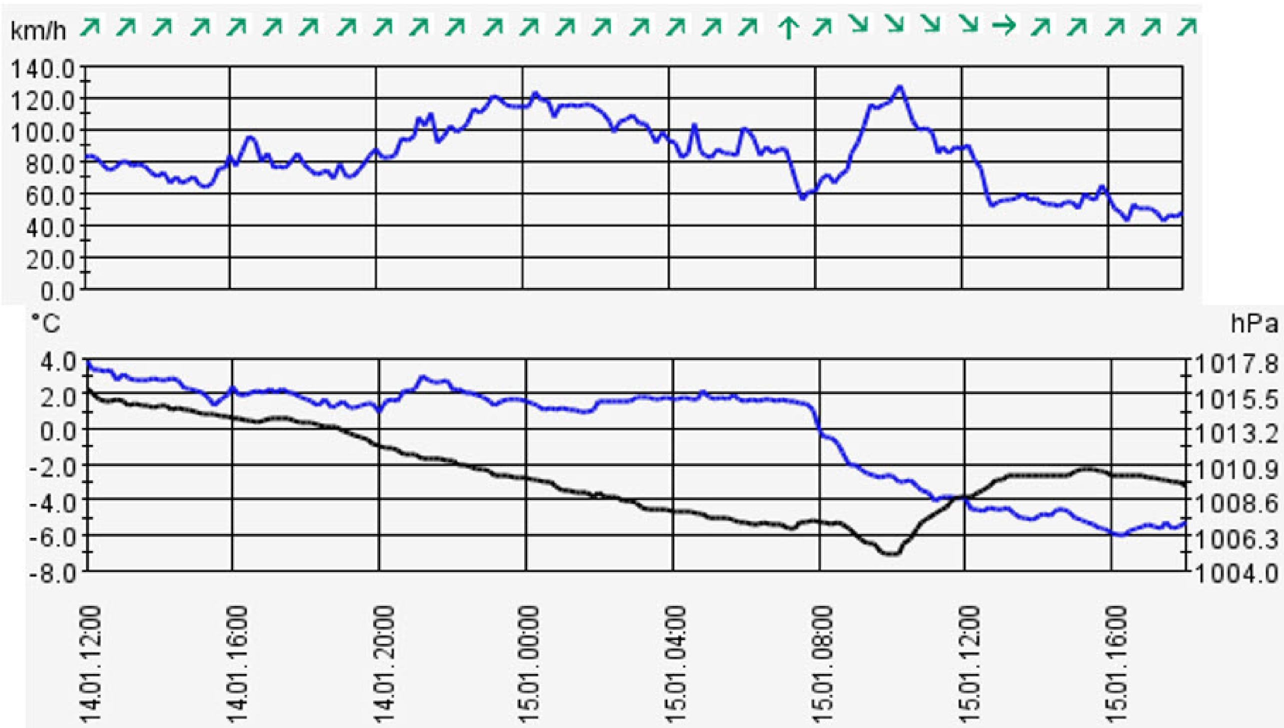

Figure 4: Time series of (top panel) wind direction (arrows) and gusts (blue line), and (bottom panel) air temperature (blue line) and mean sea level pressure (black line) from 14 January 2023 at 12 UTC to 15 January 17 UTC on the Chasseral (1606 m above sea level

Atmospheric Processes
Final exam - 23 Jan. 2023

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I. Microphysics

1. What is the main mechanism contributing to the growth of raindrops?

2. What are the main mechanisms contributing to the decrease of raindrops?

3. What is the raindrop size distribution (DSD)?

4. Explain the Wegener-Bergeron-Findeisen process

II. Numerical modeling

1. Explain the difference between a Eulerian and a Lagrangian grid (or mesh).

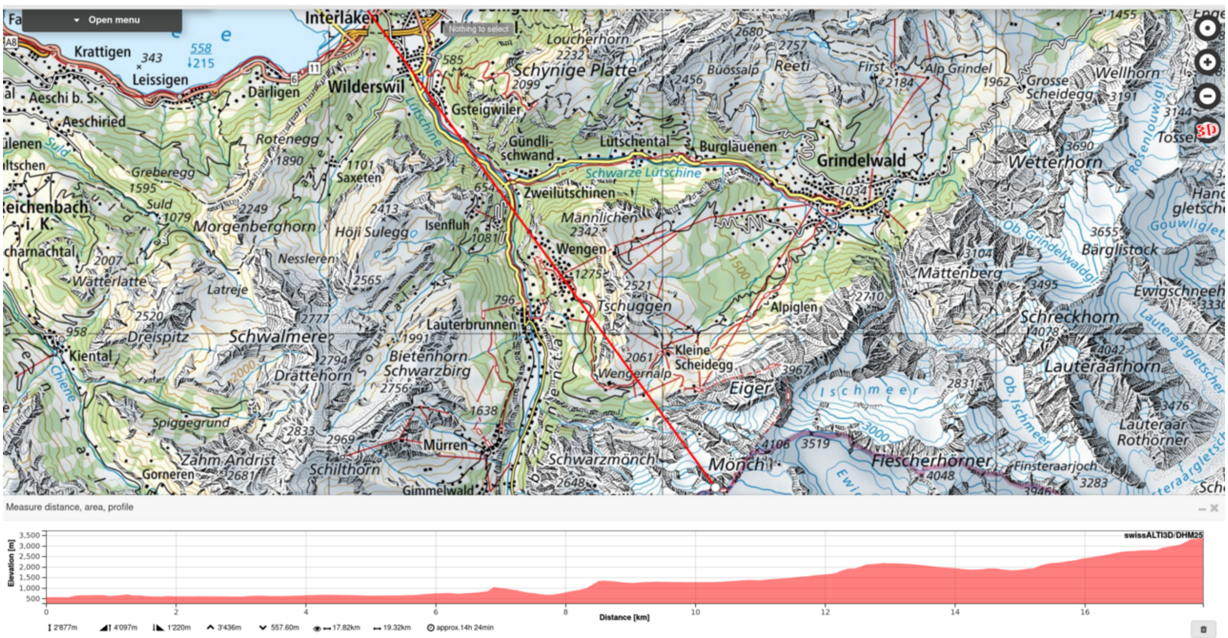
2. For a given numerical model, why is its effective resolution coarser than its grid increment?

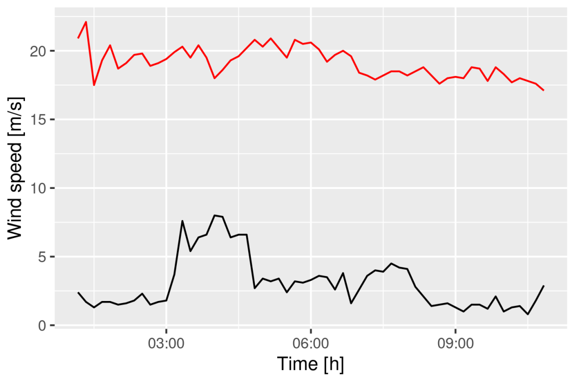
3. What is the added value of ensemble predictions compared to deterministic predictions?

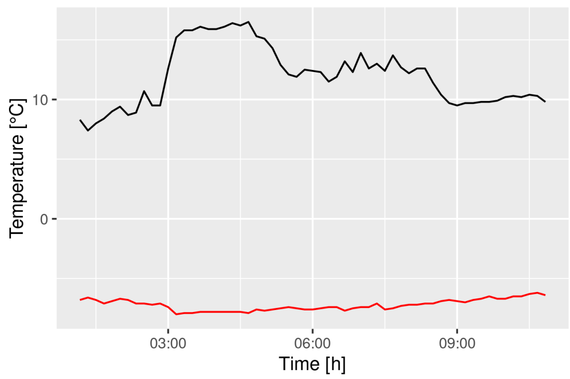
III. Mountain meteorology

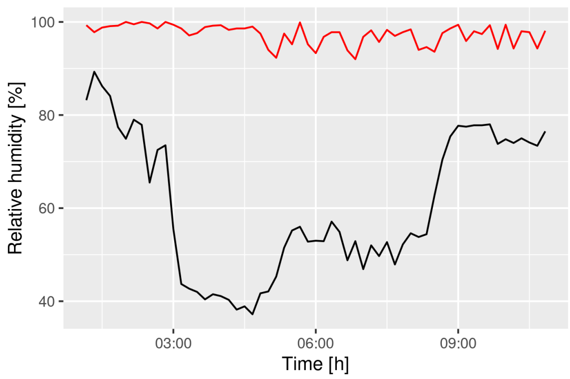
1. Draw (schematically) the wind circulation in a mountain valley during (a) day and (b) night.

2. Let's consider the wind speed, temperature and relative humidity at Interlaken and Jungfraujoch in the Berner Oberland (see map and cross section below).







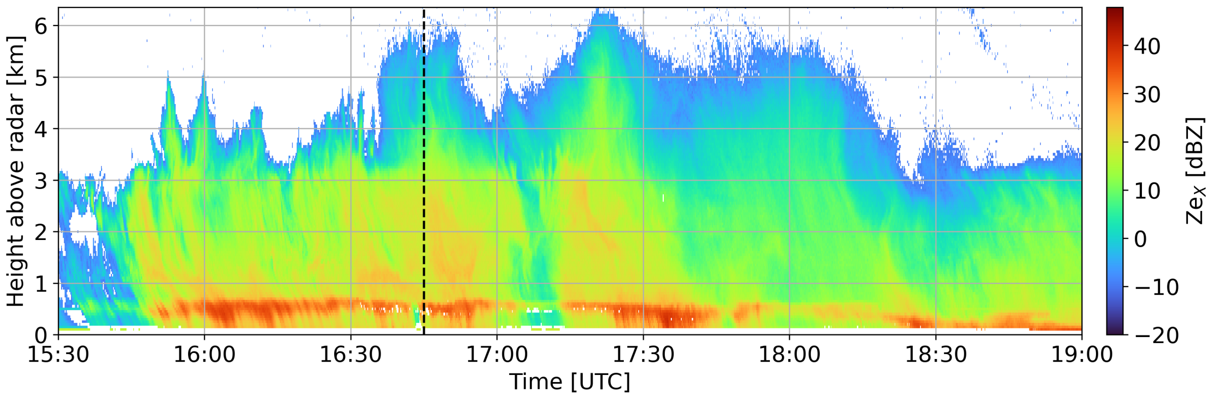


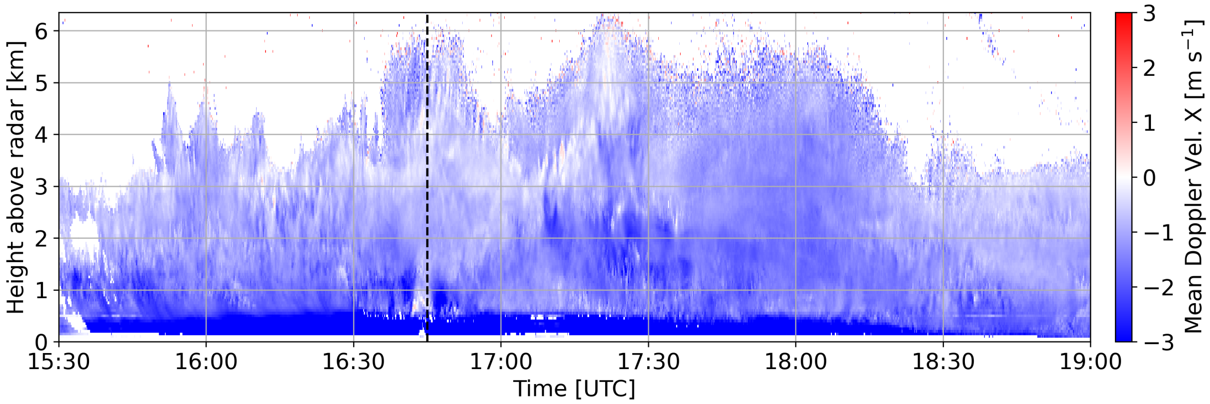
(a) Estimate (roughly) the temperature difference between Interlaken ($\sim$ 560 m alt) and JFJ ($\sim$ 3560 m alt) from 03:00 to 05:00, and comment this value with respect to dry and moist adiabatic lapse rates.

(b) What is the phenomenon occurring during this period (and more generally until 09:00)?

IV. Radar and microphysics

1. We consider, below, the time series of vertical profiles of reflectivity and vertical velocity collected by an X-band (10 GHz) radar.

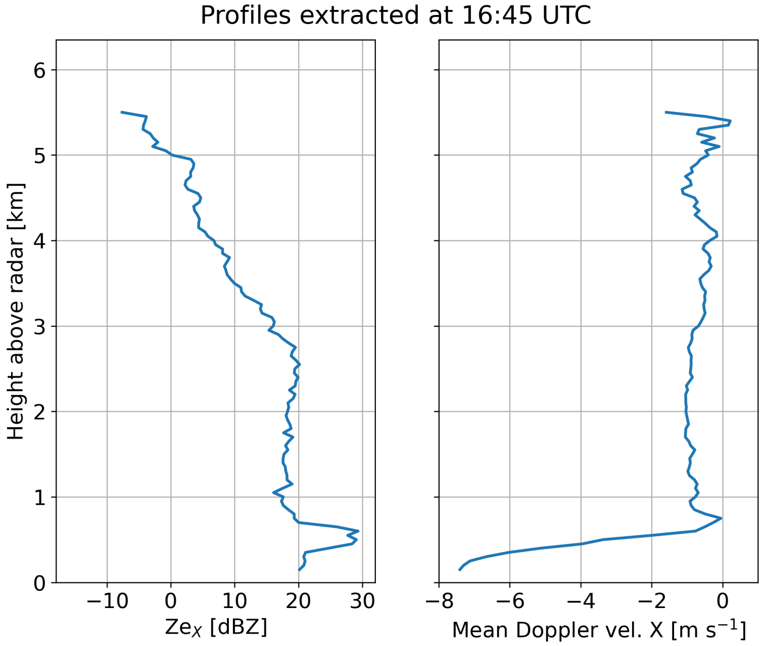




Describe the main feature that is visible at low levels in both reflectivity and vertical velocity across almost the entire event.

2. Identify a region (time + altitude) in which a seeder-feeder mechanism is likely.

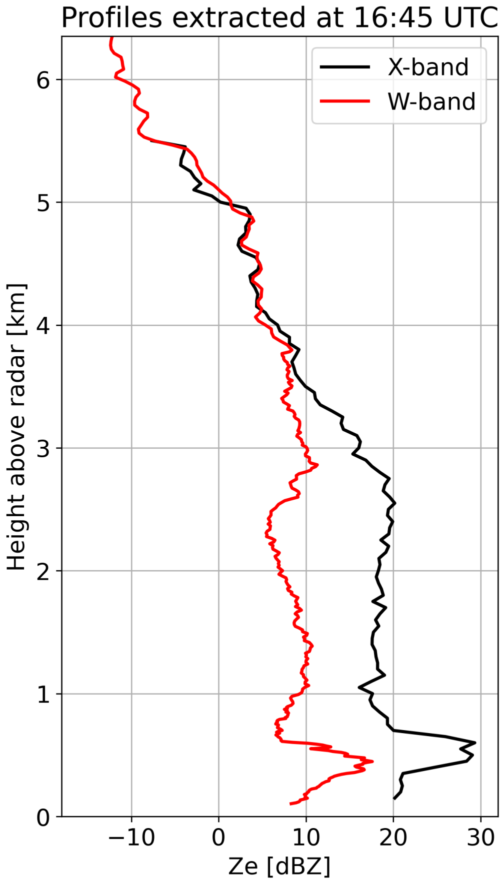
3. We now focus on the time step at 16:45 UTC (dashed line in the plots above). The vertical profiles of reflectivity and of mean velocity have been extracted.



(a) Identify the freezing level altitude.

(b) Which microphysical processes could explain the measured profiles of reflectivity and vertical velocity between 2.5 and 5 km of altitude?

4. Adding the measurements from a colocated radar working at W-band (arounfd 95 GHz), we obtain the profiles below.



Are different scattering regimes occurring?