

Visualizing the Herlofson's nomogram

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Abstract

On 1947, N. Herlofson proposed a modification to the 1884 Heinrich Hertz's Emagram with the goal of getting more precise hand-made weather forecasts providing larger angles between isotherms and adiabats. From that date to nowadays, the Herlofson's Nomogram has been used every day to visualize the results of about 800 radiosonde balloons that, twice a day, are globally released, sounding the atmosphere and reading pressure, altitude, temperature, dew point, and wind velocity. Relevant weather forecasts use such pieces of information to predict rains, thunderstorms, clouds height, fog, etc. However, in spite of its diffusion, non-technical people (e.g., private gliding pilots) do not use the Herlofson's Nomogram because it is confusing and hard to read. The paper attacks this problem presenting an interactive visualization environment that allows for visualizing an Herlofson's Nomogram in an easier way, selecting the right level of detail and inspecting at the same time the sounding row data and the plotted diagram.

Keywords: Information visualization , Herlofson's Nomogram , Weather forecast, Incremental learning.

1 Introduction

While weather forecasts rely on models of increasing complexity (see, e.g., [2, 6, 9]) making short time local forecasts require the usage of local data, like air temperature, humidity, etc. To this aim, hundreds of radiosonde balloons are released across the world, sounding the atmosphere and reading pressure, altitude, temperature, dew point, and wind velocity (see Figure 1.a).

Typically such balloons sound the atmosphere close to main airports (e.g., Rome Fiumicino airport or Kirov airport) in order to provide detailed information useful for local forecasts (rains, thunderstorms, clouds height, fog, etc.) that affect the airport traffic security (an example of such data collected close to the Kirov airport is visible on Figure 1.b). Even if the sounding data is, in principle, quite simple, i.e., few basic values collected at different altitudes, using it for forecasting even simple relevant weather events (e.g., fog, clouds height, ice, etc) requires complex calculation based on the use of physical laws, like the gas law, vapor saturation, heat exchange, temperature gradients, etc. As a simple example, knowing that the air temperature at ground level is 20 °C and that it is warmer than the surrounding air (so it will start to raise and to cool down by adiabatically expanding) and that its relative humidity is 85%, two typical questions for estimating the visibility above a runway are:

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(a) European sites

27199 Kirov Observations at 12Z 20 Jun 2018

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1000.0	-41									
977.0	158	14.8	11.6	81	8.85	290	6	289.9	315.1	291.4
971.0	214	16.2	10.2	68	8.10	283	8	291.8	315.1	293.2
960.0	312	-13.9	-20.9	55	0.76	270	12	262.3	264.5	262.4
925.0	616	-11.7	-17.7	61	1.03	275	23	267.3	270.3	267.5
887.0	957	9.2	3.2	66	5.46	279	28	292.2	308.2	293.2
882.0	1005	8.8	2.8	66	5.35	280	29	292.3	308.0	293.2
850.0	1316	6.4	0.4	65	4.66	280	31	292.8	306.6	293.7
786.0	1952	1.5	-3.1	71	3.89	285	33	294.2	305.9	294.9
777.0	2046	0.8	-3.6	72	3.79	284	33	294.4	305.8	295.1
711.0	2756	-1.4	-15.9	32	1.56	275	33	299.6	304.6	299.9
702.0	2858	-1.7	-17.7	28	1.36	275	33	300.3	304.8	300.6
700.0	2881	-1.5	-18.5	26	1.28	275	33	300.8	305.0	301.0
693.0	3076	-2.5	-23.5	18	0.85	273	32	301.8	304.7	301.9
581.0	4336	-11.9	-28.9	23	0.61	261	27	305.1	307.2	305.2
576.0	4401	-12.3	-29.5	22	0.58	260	27	305.4	307.5	305.5
560.0	4614	-13.4	-31.6	20	0.49	255	31	306.5	308.3	306.6
500.0	5470	-18.1	-40.1	13	0.23	220	51	310.9	311.8	310.9
496.0	5530	-18.3	-40.3	13	0.23	215	51	311.4	312.3	311.4
491.0	5605	-18.5	-40.5	13	0.23	213	50	312.0	312.9	312.1
466.0	5989	-21.4	-42.2	13	0.20	205	47	313.1	313.9	313.1
430.0	6579	-25.9	-44.9	15	0.16	189	48	314.7	315.3	314.7
400.0	7100	-28.1	-41.1	28	0.26	175	49	318.4	319.4	318.4
387.0	7335	-29.7	-40.6	34	0.29	165	45	319.3	320.4	319.4
370.0	7654	-31.9	-39.9	45	0.32	167	50	320.5	321.8	320.6
353.0	7984	-34.5	-41.5	49	0.29	168	55	321.3	322.4	321.4

(b) Sounded data

Figure 1: a) European sites releasing radiosonde balloons twice a day (00 Zulu and 12 Zulu); b) Sounding data close to Kirov airport on 20 June 2018 from ground to 7984 meters.

1. Will that raising air generate a cloud?
2. And if the answer is yes, what is the forecasted cloud base?

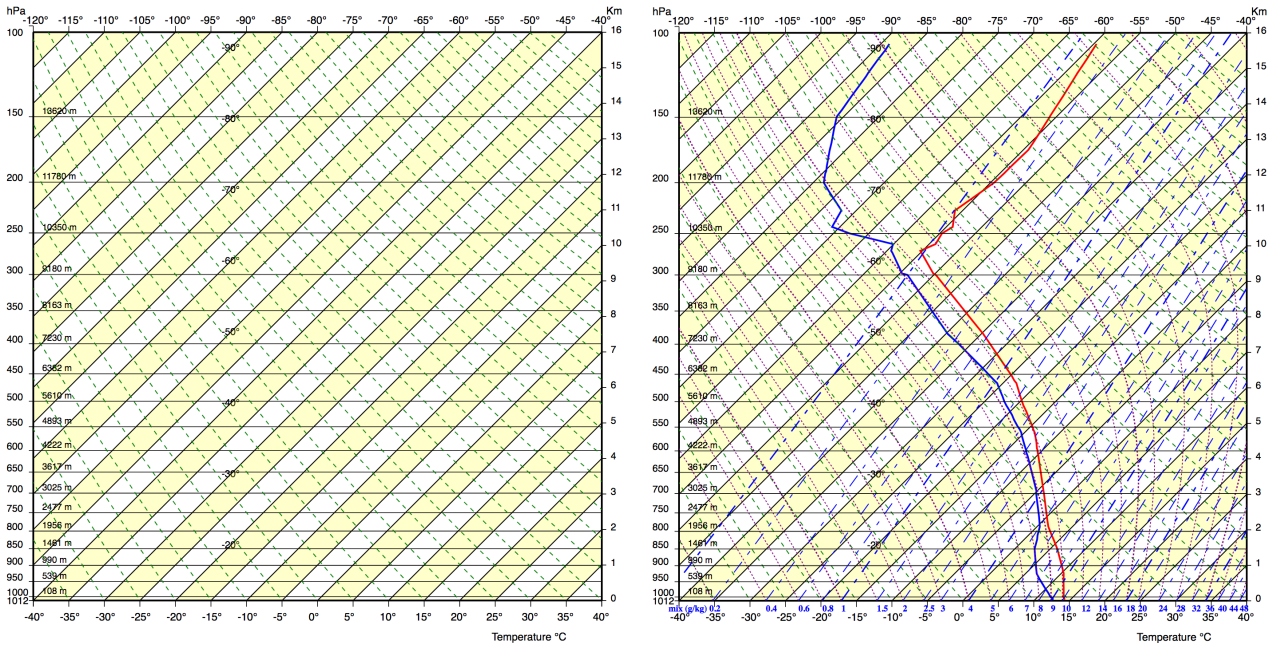
To answer these questions it is required to calculate at which height the temperature of the raising air will be equal to its dew-point (i.e., the altitude at which the vapor condensation generates a cloud). This issue pushed the development of suitable nomograms plotting the relevant physical laws in order to compute *graphically* the required pieces of information that are discovered at the intersection of two lines (the Webster definition of nomogram is: "a graphic representation that consists of several lines marked off to scale and arranged in such a way that by using a straight edge to connect known values on two lines an unknown value can be read at the point of intersection with another line). That was the motivation that pushed N. Herlofson to modify the original Heinrich Hertz's Emagram (diagram resembling an M) bending of 45 the temperature axis with the double benefit of a) increasing the angle between isotherms and adiabats cooling gradients and b) increasing the temperature resolution with the clear advantage of getting a better precision in manually finding a crossing point between these lines (see Figure 2.a), generated using our interactive environment). Nowadays computers analyze sounding data and can easily calculate the required forecasts, without manually drawing lines on a nomogram but the Herlofson proposal is still used to *show* sounding data, in order to increase a pilot or weather expert situational awareness about the actual situation or to do a last minute forecast (this is very common in flight clubs, where the diagrams are widely used by glider pilots to forecast the strength of thermals and the height of the base of the associated cumulus clouds). However, the inherent complexity of the concepts behind the nomogram, its crowded aspects (see Figure 2.a), and its logical distance from the classical Cartesian plane, makes very difficult its comprehension and usage.

The paper attacks this problem presenting an Interactive VisualizAtion enviroNment, namely **IVAN**, that exhibits three main characteristics:

- It is fully configurable, allowing for exploring the nomogram at different levels of complexity;
- It provides clear connection with the sounding procedure;
- It presents a high degree of interactivity, allowing for exploring data details and testing different hypotheses to quickly forecast weather.

IVAN has been informally tested in incremental teaching activities and practical usage, providing encouraging results.

The paper is structured as follows. Section 2 describes related work, Section 3 introduces the main concepts underlying the nomogram, Section 4 describes the prototype, Section 5 provides some feedback about the system, Section 6 concludes the paper.



(a) Isotherms and dry adiabats

(b) Nomogram with all data

Figure 2: a) A simplified version of the Herlofson's nomogram produced by our interactive environment, displaying only isotherms (parallel to the yellow bands) and dry adiabats (green dashed lines). It is easy to grasp that the temperature axis is rotated of 45 degrees and that isotherms exhibit a large angle (around 90°) with dry adiabats; b) A full, crowded version of the Herlofson's nomogram that typically confuses users that are overwhelmed by lines and numbers.

2 Related work

Visualizing information is often a useful means in order to enhance the comprehension of a phenomena under investigation. Among different abstract representations, the very most often used are visual representations of mathematical concepts [13] under the form of diagrams. To this goal, many different plotting libraries exist that allows fast visualization of mathematical diagrams (e.g. Matplotlib, GNUplot). The problem with these environments is the lacking of interaction with the plots, allowing only a static inspection of the plotted results. Our proposal instead aims at providing an environment for effective exploration and interaction with the represented diagram in order to improve learning and exploration capabilities.

Several works in information visualization coped with weather forecast, ranging from very specific solutions (e.g., [10] [8]) to more general approaches that use the weather forecast as an application domain (e.g. [12] [11]). Ferstl et al. [3] propose a new approach for analyzing the temporal growth of the uncertainty in ensembles of weather forecasts which are started from perturbed but similar initial conditions. Lundblad et al. [5] propose a tool for Ship and Weather Information Monitoring (SWIM) visualizing weather data combined with data from ship voyages, with the goal of monitoring a fleet and the weather development along planned routes and provide support for decisions regarding route choice and to evade hazard; while a similar monitoring task is supported by our solution, conversely the reviewed system targets only the monitoring task with no support for learning capabilities. Among the reviewed literature, very few approaches refer to the very specific problem of coping with Herlofson's nomogram and not even a similar diagram for a different problem, to which our solution is targeted. The few available commercial solutions (see, e.g., [1]) are targeting expert users and do not support the configurability features of our proposed approach and their are not targeted towards incremental learning and insights discovery.

3 The Herlofson's Nomogram

This section has the main goal of describing the main characteristics of the Herlofson's nomogram, useful to follow the examples and the features described in Section 4. The first point worth to be discussed is the structure of the two axes, temperature and pressure, depicted on Figure 3.a. The nomogram is indicated as skew-T, log-P

because the temperature axis is rotated of 45° and the pressure axis is logarithmic. Rotating the temperature axis has also the advantage of giving more room for temperature: considering Figure 2.a it is also evident that the management of the temperature range of 160 °C (-120 °C, + 40 °C) is done in an horizontal space able to bear a much narrow interval of 80° without compressing the X scale; a little drawback of this solution, disregarding the unfamiliar feeling of having an equation like $x = constant$ represented by a 45° line, is that the temperature legend must be represented on both the lower and upper edges of the nomogram, because all the isotherms (but the diagonal) intersect only one of the two horizontal edges.

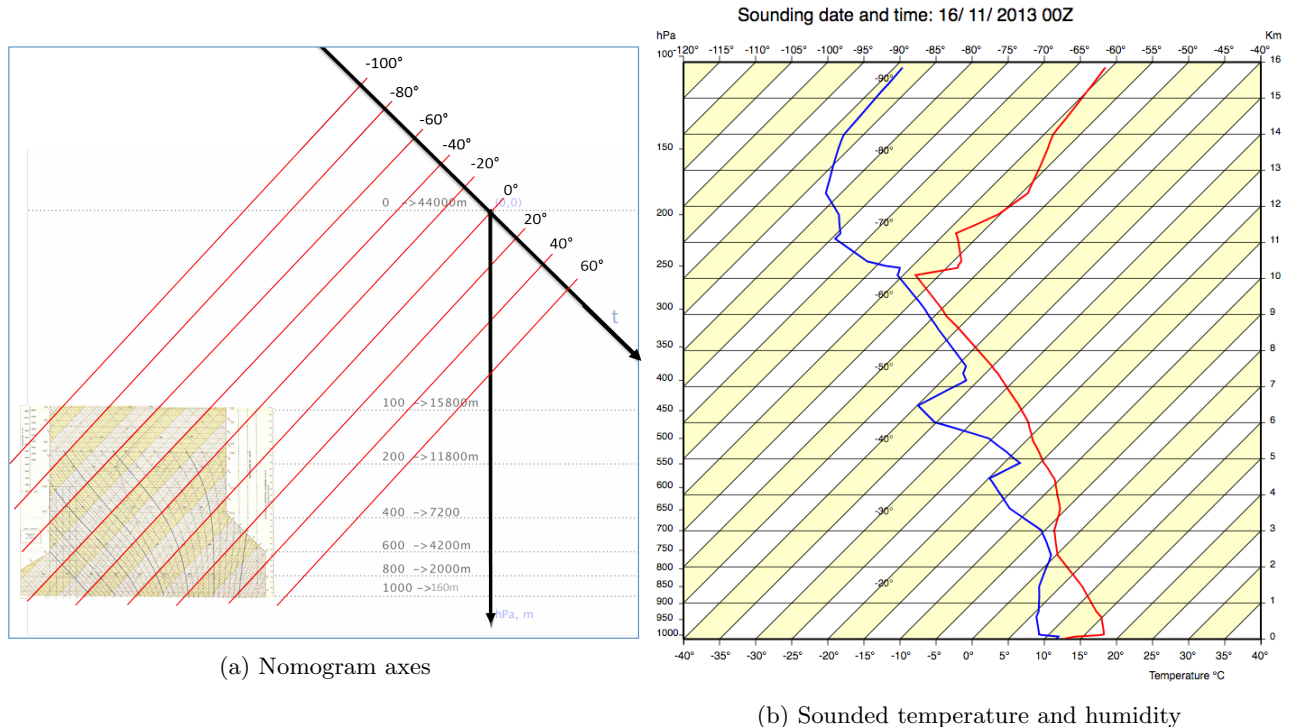


Figure 3: a) The Nomogram skew-T, log-P. The X axis, temperature, is rotated of 45°(skew-T), the Y axis, pressure, has an inverted scale (the higher the pressure, the lower the altitude) and it is logarithmic (log-P), to compensate the non linear relationship between pressure and altitude; the nomogram is very far from the axes origin.

The second aspect worth to be discussed is how to represent the air humidity, collected by the sounding, on a temperature/pressure plane. The chosen solution is to represent *two* temperatures for each sounding point (see Figure 3.b). The first temperature corresponds to the *measured* air temperature during the sounding process, $t_1 = f(p)$, and this tabular function is interpolated by the continuous red line on Figure 3.b. The second temperature corresponds to the *dew-point* temperature computed using the measured pressure and humidity, $t_2 = f(p, humidity)$ and it is interpolated by the continuous blue line. Note that for the physical definition of dew-point $t_2 \leq t_1$. These two status lines are called temperature and humidity curve or state curve and dew-point curve. To discover the effective humidity of a blue point on a nomogram, a second scale is added on the bottom horizontal edge, together with dashed blue iso-humidity lines. Iso-humidity lines, visible in the nomogram on Figure 2.b, represent the *maximum* humidity that can be had, at a certain combination of pressure and temperature, without the water vapor being transformed into water. That adds confusion to the story, because iso-humidity lines are perceived as points with the same humidity while they have the same *maximum* humidity they can bear before condensing. Obviously, given a triple $\langle humidity, pressure, dew - point temperature \rangle$ the maximum bearable humidity coincides with the actual humidity, so iso-humidity lines can be used to read actual humidity *only* at the intersection with the blue dew-point lines.

The above considerations make clear the complexity that exist behind the Herlofson's nomogram and that makes hard its usage, even for the basic task of understanding the meaning and the relationships of what is represented on it.

Having clarified the main issues and technicalities behind the nomogram, we can discuss two typical usage

scenarios.

3.1 Getting a situational awareness about the weather situation

The slope of the red line provides a first rough insight about the air stability: roughly speaking, a left slope of about 40° means that the atmosphere temperature decreases with the altitude more or less as raising air temperature does, and that implies that the strength of thermals will be constant; larger left bending calls for strong thermals, while lower bending corresponds to more stable air and weak thermals. A strong bending on the right (more than 45°) represents a temperature gradient inversion (the air temperature *increases* with the altitude) and that will stop both thermals and cloud degeneration.

Moreover, the distance between the two lines provides an indication of the relative humidity: if the lines are very close that means the actual temperature is only a little bit above the dew-point temperature and that implies an high likelihood of fog, clouds, and veiling of the sky.

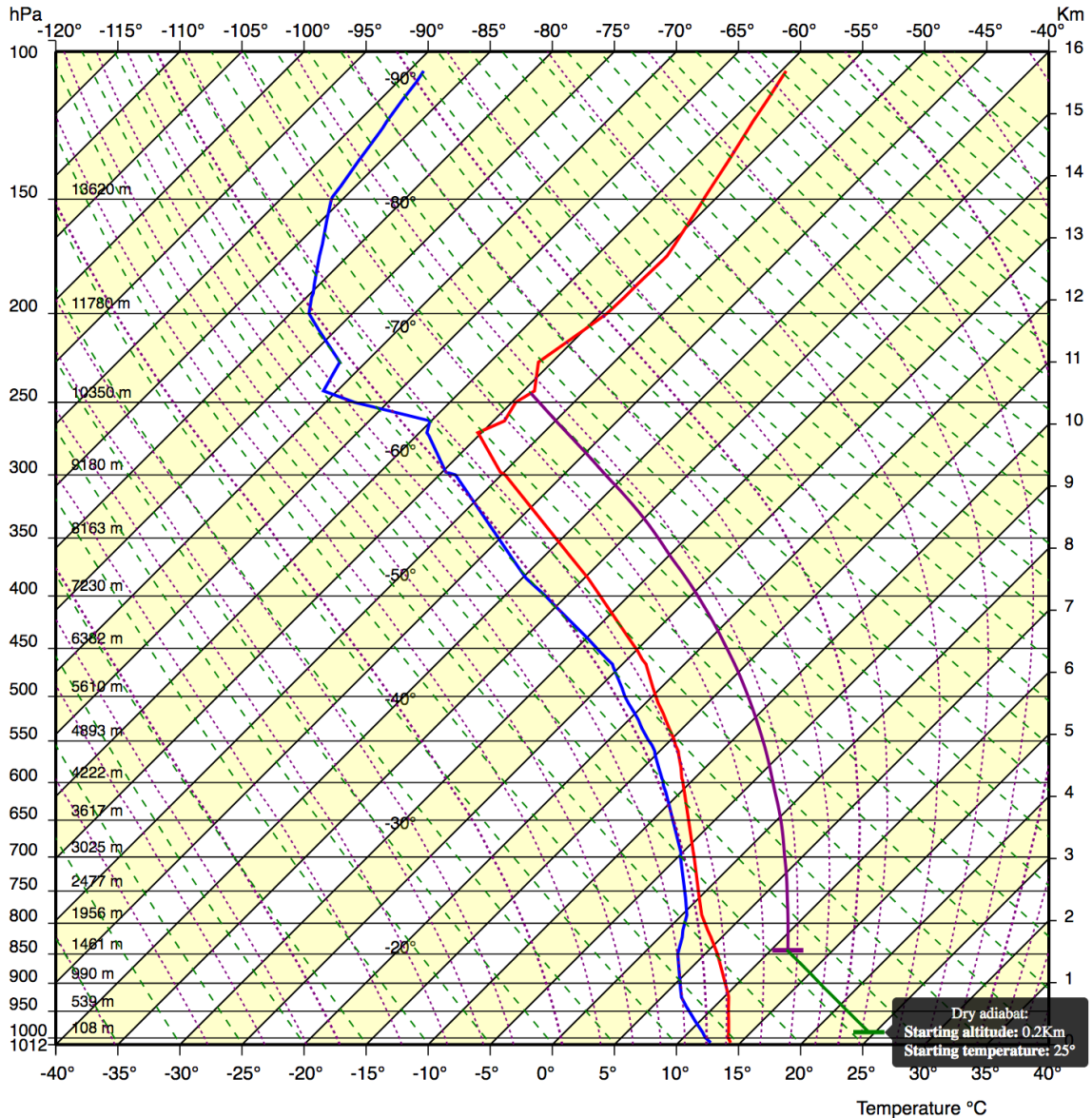


Figure 4: Air warmer than atmosphere rises along a dry adiabat reaching its dew-point; after that it rises along a wet adiabats and generates a dangerous cloud that will likely produce a thunderstorm.

3.2 Forecasting clouds base and cloud evolution

Forecasting, in this case, implies to make some assumptions on the near future (e.g., the temperature of the air close to the ground at 14.00 will be 24 °C) and to use other two nomogram curves: dry and wet adiabats. Such curves describe the cooling of an ascending air with (wet) or without (dry) condensed water (or conversely, the warming of a descending air). Such curves are visible in Figure 2.b, where dashed green curves represent dry adiabats and dashed purple curves represent wet adiabats.

In Figure 4 we see that if the air close to the ground temperature is 25 °C, being warmer than the atmosphere temperature (red line), it climbs cooling along a dry adiabat (thick green line) and about at an altitude of about 1,3 Km and 12,5 °C (the dew-point temperature) the vapor starts to condense generating a cloud (horizontal thick purple segment); after that it continues its climbing and cooling as a cloud along a wet adiabat (thick solid purple line), till crossing the red line at about 10,5 Km and, having the same atmosphere temperature (about -55 °C), it stops. The generated cloud is about 9 Km high (from 1,3 to 10,5 Km) and there is a high risk of thunderstorms.

4 The IVAN system

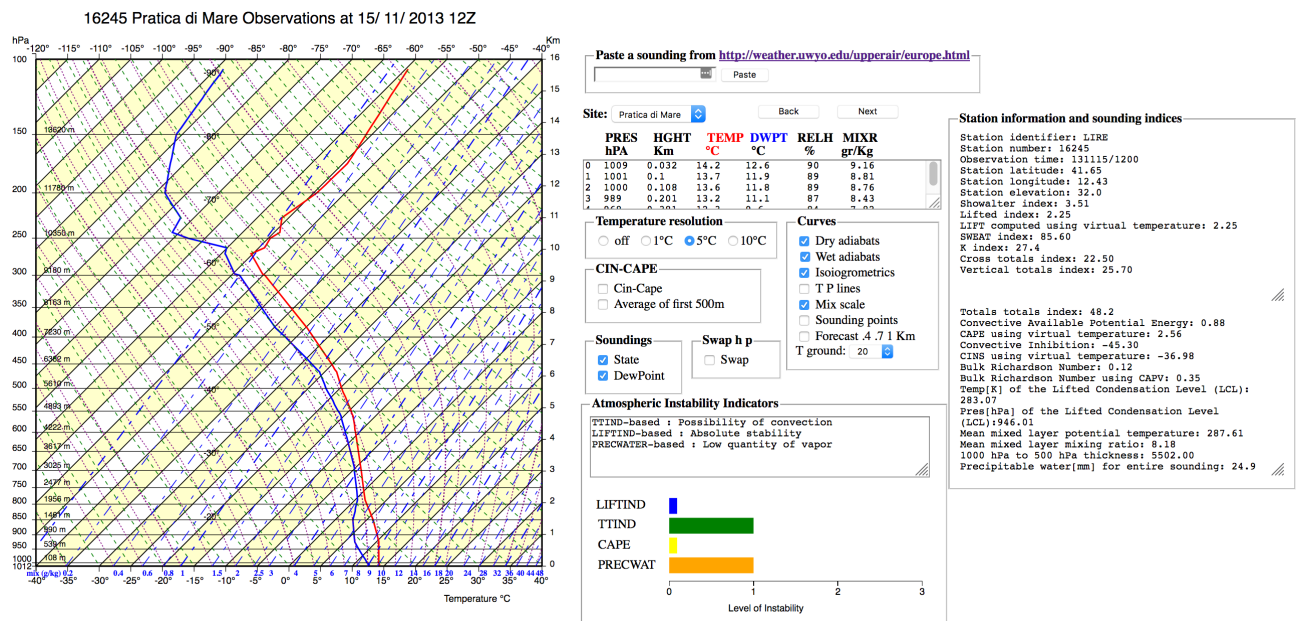


Figure 5: Overview of the IVAN Web application. The left side shows the Herlofson’s nomogram, the central part presents detailed sounding data, configuration commands and the main atmospheric indicators, while right side reports several detailed sounding indices

This section describes the Web application IVAN, presenting its functionalities following an incremental approach, similar to the strategy of incremental learning presented in Section 5. Figure 5 presents an overview of the system, in which all the features of the Herlofson’s nomogram are available. To discuss its concepts along an incremental learning approach strategy, we can initially present the user with these initial pieces of information:

- Step 1: state curve, sounding points, and P, T lines, Figure 6.a. The system is configured to show only the state curve and the T and P axes. Moreover, sounding points are plotted on the curve, making clear that the curve is an interpolation of finite data points, whose numerical values are visible in the upper center part of Figure 5. Mouse overing a sounding point triggers two dashed black lines that make clear how to read the P and the T values on the axes;
- Step 2: Step 1 + dry adiabats, Figure 6.b. The user is presented with the concept of dry adiabats and understands how to evaluate the state curve bending with respect to the dry adiabats gradient, getting the idea that when a dry adiabat cross the status curve the air rising stops;

- Step 3: Step 1 + wet adiabats, Figure 6.c. The user is presented with the concept of wet adiabats and understands how to evaluate the state curve bending with respect to the dry adiabats gradient, getting the idea that when a wet adiabat cross the status curve the raising cloud stops growing;

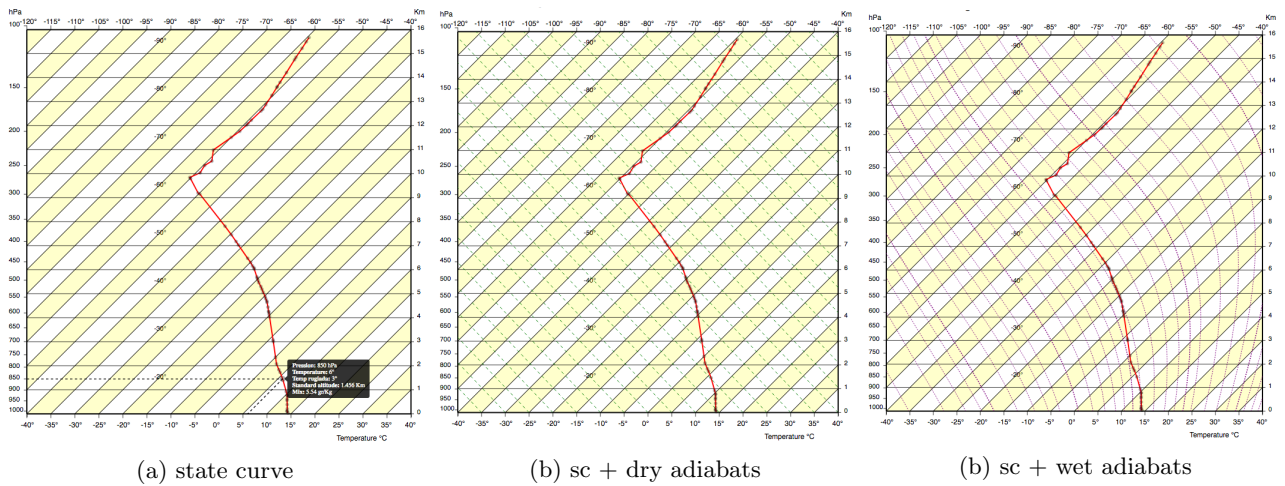


Figure 6: a) Exploring the state curve (sc), sounding points, and making explicit how to read the values of the curve. b) Dealing with dry adiabats. c) Dealing with wet adiabats.

When users are familiar with the basic concepts we move further with other 3 steps:

- Step 4: state curve, dew-point curve, and P T lines, Figure 7.a. The system is configured to show both the state and dew-point curves together with sounding points, making clear that both curves represent temperatures (even the "humidity" curve) and that they refer to two temperature values of the *same* sounding point. Moreover, the distance between the curves is described, explaining the risk of fog or veiling of the sky that can reduce the solar radiation;
- Step 5: ONLY dew-point + mix legend + iso-humidity, Figure 7.b. The user is presented with the definition of iso-humidity and with the second legend on the x axis, and learns how to read the effective humidity values of a sounding point on the dew-point line, using a third projection parallel to iso-humidity lines; to simplify the understanding of this operation we remove all the other lines (isotherms, red line, iso-metric, yellow bands) making easier to read and use the iso-humidity lines.
- Step 6 state curve + iso-humidity, Figure 7.c. The confusing concept of iso-humidity is further clarified, showing, interactively, that two points on the *same* iso-humidity, P1 and P2, have *different* humidity but share the *same* maximum humidity they can bear before condensing.

Now the users have all the basic notions needed to start explorative forecasting activities and we move further with other 3 steps:

- Step 7: state curve, dew-point curve, iso-humidity, and P, T lines, Figure 8.a. The system is configured to show both the state and dew-point curves together with sounding points and iso-humidity, and allows for practicing with calculating the humidity on the state curve that will be useful to make forecast on condensation altitudes. Selecting a sounding point on the state curve triggers selecting its corresponding point on the dew-point curve and locating on the humidity legend the actual humidity value. That further clarifies that the two points correspond to the same sounding point and that they share P, T, humidity and dew-point temperature;
- Step 8: state curve, and P, T lines + dry and wet adiabats, Figure 8.b. Clicking with the mouse the nomogram on the right of the state curve allows for making hypotheses on future evolution of air raising from a specific altitude at a given temperature. In the figure the user is forecasting that the air temperature at 0.9km altitude (e.g., the top of a little mountain) will be of 31 °C. IVAN shows that such a warm air will dry climb (solid green line parallel to dry adiabats) till about 3,4 Km and generates a cloud (so the cloud

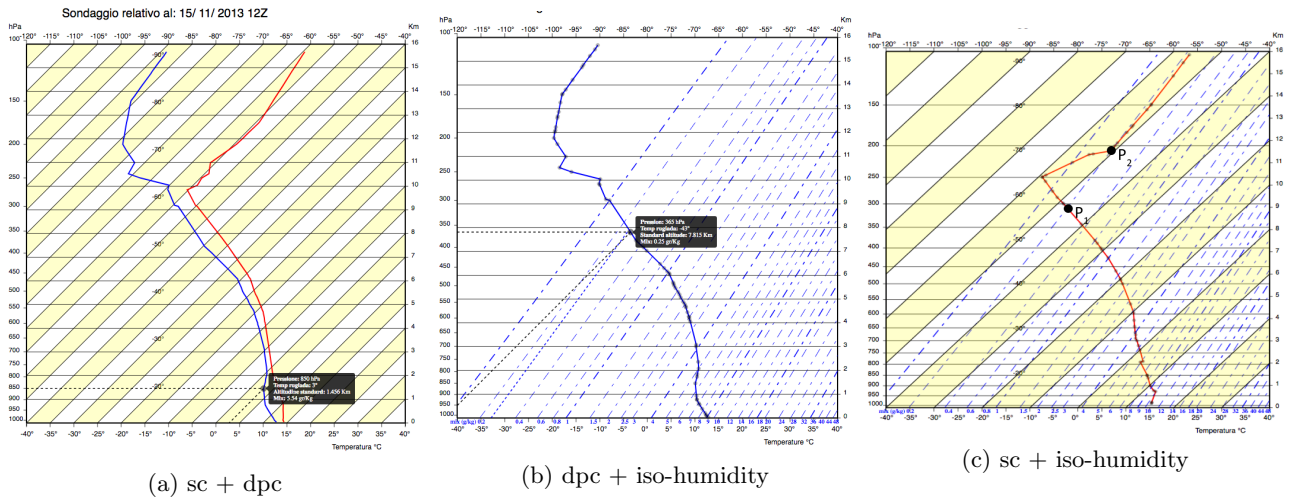


Figure 7: a) Exploring state curve (sc) and dew-point (dpc) curve. b) Carefully introducing the notion of iso-humidity w.r.t. dew-points curve. c) Carefully introducing the notion of iso-humidity with respect to the state curve, better clarifying its meaning.

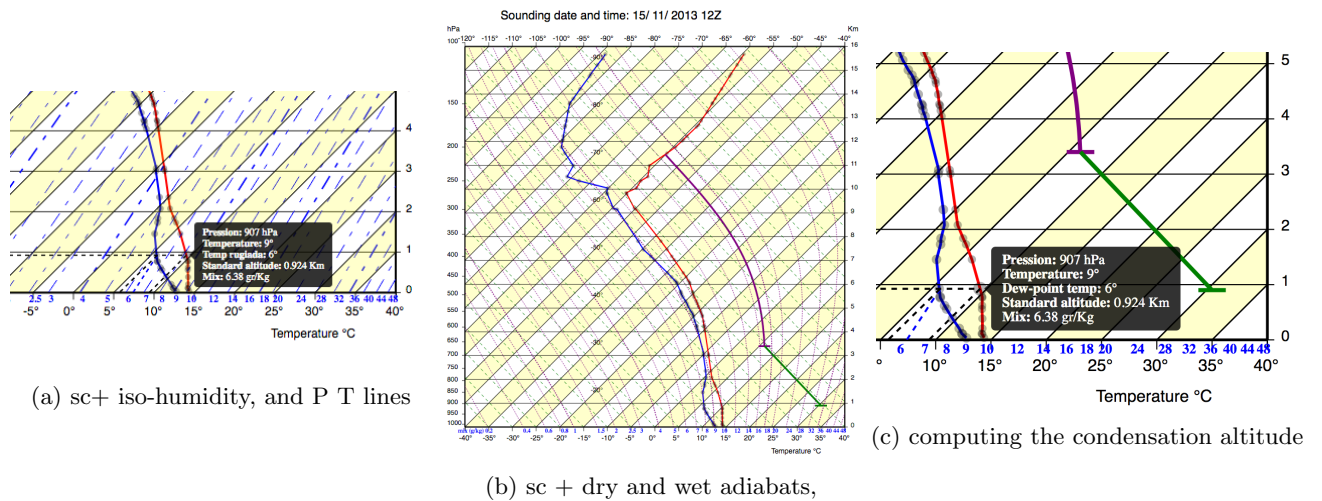


Figure 8: a) Relationship between sounding points and state and dew-point curves; b) Evolution of raising air along dry and wet adiabats. c) Computing condensation altitude.

base will be 3,4 Km). After that the climbing will go for a purple wet-adiabat (parallel to wet-adiabat), generating a high cloud (thunderstorm risk) and stopping against the red state curve around 11,5 Km. The user can test different hypotheses, discovering situations in which the air stops before generating a cloud (blue thermals) and compare different thermals starting from different altitudes (e.g., flat land, hill, mountain).

- Step 9: Step 8 + iso-humidity, Figure 8.c. The goal here is to explain how the condensation altitude can be computed on the nomogram. The user moves from the point he clicked on to the blue curve at the same altitude (0,9 Km) and discovers the humidity (6,8) and the dew-point temperature (6 °C) of the rising air. Under the assumption that the composition of the air depends only on the altitude and not on the location he concludes that the dew-point temperature of the raising air is 6 °C: intersecting the actual dry adiabat with the 6 °C isotherm he forecasts the condensation (and the cloud base) at about 3,4 Km.

5 Evaluation

It is well known that learning is incremental and continuous, in children this is strictly related with the process of brain development (see, e.g., [4]), but this characteristic remains also in adults. The brain will form connections with every experience we have, so that each new learning activity makes one more efficient in learning new information or acquiring new skills. Also, presenting adult learners with incrementally growing difficulties when getting new knowledge or performing new tasks helps them to form positive outcomes about their capabilities, motivate persistence and avoid giving them up. Providing learners opportunities to experience success in incremental steps definitely increases their self-efficacy (see, e.g., [7]). We informally tested these general principles while using the IVAN system to teach to glider pilots the basic principles of the nomogram, that are mandatory to correctly understand the actual weather situation and the main weather forecast (e.g., base of clouds and risk of fog and thunderstorms). More in detail, we divided the learners in two homogeneous groups of four people. The first group was instructed with a traditional approach using paper-based diagrams of the Herlofson' nomogram, while for the second group we adopted the interactive incremental approach implemented by IVAN and described in the previous section. At the end of the teaching period, pilots learning was assessed through a simple multiple choices test. At the end we also administered them a satisfaction questionnaire about the learning experience. On the average people of the second group performed better in the test and gave higher marks as for the quality of their experience. We do not report scores because the number of participants was too little and as a future work we plan to run a formal study involving more users and using a combination of appropriate techniques to evaluate the participants learning.

6 Conclusions

The paper presented an interactive visualization of the Herlofson's nomogram that has the goal of providing a better understanding of the nomogram and its usage. The high degree of interactivity and the possibility of reducing the visualized elements, considering only those relevant for the task at hand, provided the means for teaching the nomogram in an incremental way. Informal experiments of teaching and usage with glider pilots produced interesting results and now we are setting up an e-learning environment based on the IVAN system. The actual version of the prototype is available at <http://awareserver.dis.uniroma1.it:8080/IVAN/>.

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