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Innovative Measurement Tool towards Urban Environmental Awareness

Weather parameters

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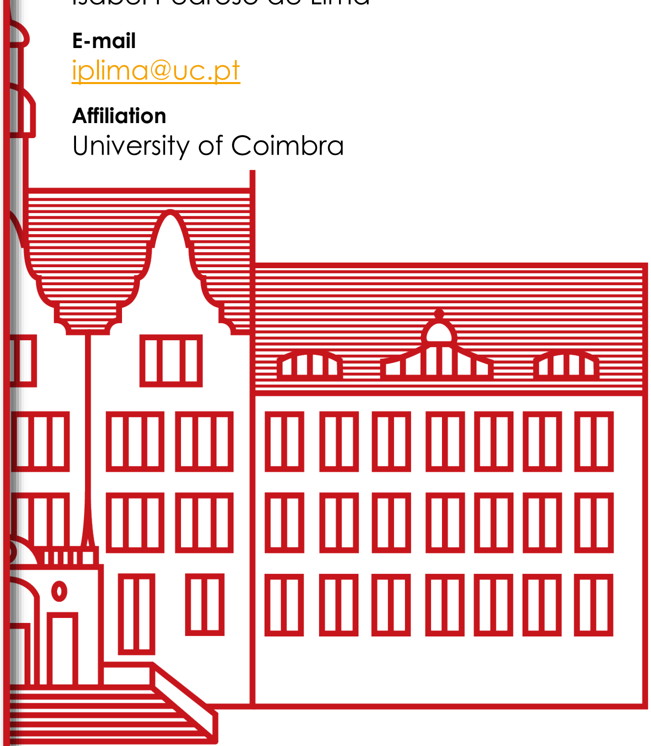

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1.1 Introduction

What is the weather? What defines the weather? As a basic definition, **weather** is the state of the atmosphere, more precisely, in its lowest layer, the troposphere. But is the weather the level of precipitation, or the temperature of the air?

In fact, weather is made up of multiple parameters, including air temperature, atmospheric (barometric) pressure, humidity, precipitation, solar radiation or wind. Each of these factors can be measured to define typical weather patterns and to determine the quality of local atmospheric conditions. However, the impacts of weather elements do not remain solely in the atmosphere. Weather elements form a chain reaction.

For example, temperature, pressure and humidity (moisture) can interact to form clouds. These clouds, in turn, can reduce solar radiation available for plants; or they can increase precipitation, which can runoff into a body of water and, in case of intense/extreme events, perhaps lead to flooding. Similarly, lack of precipitation affects weather conditions but it also affects soil moisture and water levels, and can lead to the development of drought conditions.

High temperatures, in addition to heating the air, can also increase the heat transfer to local bodies of water and increase evaporation or have an impact on aquatic life/ecology and water pollution. High temperatures can also affect energy balances and consumption, or affect the thermal comfort in cities. Ultimately, it can affect human health or put lives at risk.

Wind speed and direction can be indicative of a front moving into the area, or it can create waves and encourage a stratified water column to mix, in a water body.

Thus, overall, the environmental conditions produced by different weather parameters have an impact on the quality of the surrounding ecosystem.

Monitoring the weather provides an environmental baseline, and it can also provide valuable information that can be used to explain or predict weather events and keep an eye on the quality of human comfort conditions or recreational safety, for example.

1.2 Atmospheric conditions and the weather

The Atmosphere

Regarding the scale of the Earth's atmosphere and the atmospheric processes and conditions, our perception is naturally biassed by the (relatively small) human lifetime scale and a usually surface-based viewpoint. There are in fact two very different scales in the atmosphere, the horizontal and the vertical. Horizontally, the atmosphere is much larger than we can perceive from a point on the Earth's surface, of the order of magnitude of tens of thousands of kilometres. Vertically, by contrast, the scale of the atmosphere is much smaller (smaller than the radius of the Earth), but it very much influences the conditions in which we live. Since much of the material of the atmosphere is squeezed into a shallow layer overlying the surface of the Earth, the distribution of e.g. temperature, humidity and other properties are strongly anisotropic, in the sense that their gross vertical and horizontal distributions are very different; for example, vertical gradients are larger.

Immediately overlying the Earth's surface is a region dominated by turbulent interaction with the surface (the planetary boundary layer); its depth varies greatly with time and location. The layer of the atmosphere that is closer to the Earth's surface, the troposphere, is the most relevant to the (surface) weather.

Meteorology is the study of everything above the Earth's surface, namely the study of the physical nature of the troposphere, focussing on the dynamic aspects of this nature and variability. On the other hand, climatology covers the typical and average aspects. However, most significant physical structures and behaviour of the lower atmosphere have their own meteorological and climatological aspects, which frequently overlap. Thus, there is often some confusion, which is also due to the explosion of interest in climate change and the variable nature of climate.

As the atmospheric activity affects the safety of humanity, occasionally even disastrously (e.g. floods, droughts), forecasting atmospheric behaviour is important, in particular the component affecting the Earth's surface conditions.

The Sun has a direct and important influence on the atmosphere and is ultimately responsible for the weather. Solar energy, much of it in the form of visible sunlight, pours continuously on to the Earth, affecting both the surface and overlying air. The atmosphere is solar-powered, i.e., the Sun can be considered as the prime driver of all atmospheric activity. The diurnal variations of radiative fluxes and their variation with latitude influences, in particular, air temperature.

Sunlight rays are absorbed differently by land and water surfaces (equal amounts of solar radiation heat the ground more quickly than they do water). Differential warming, in turn, causes variations in the temperature and pressure of overlying air masses.

As an air mass increases its temperature, it becomes lighter and rises higher into the atmosphere. As an air mass cools, it becomes heavier and sinks. The cooling of air masses with high water vapour content can trigger precipitation.

Pressure differences between masses of air generate winds, which tend to blow from high-pressure areas to areas of low pressure. Fast-moving, upper atmosphere winds known as *jet streams* help move weather systems around the world.

Weather systems

Large weather systems called *cyclones* rotate counter clockwise in the Northern Hemisphere (clockwise in the Southern Hemisphere); they are also called "lows," because their centres are low-pressure areas. Clouds and precipitation are usually associated with these systems. Anticyclones, or "highs," rotate in the opposite direction and are high-pressure areas - usually bringing clearer skies and more stable weather.

The boundary between two air masses is called a *weather front*; here, wind, temperature, and humidity change abruptly, producing atmospheric instability. Such instability leads to the development of storms, bringing rain or snow and sometimes thunder and lightning too.

The weather you experience is influenced by many factors, including your location's latitude, elevation, proximity to water bodies. The degree of urban development, which creates "urban heat islands," and the amount of snow cover, which chills an overlying air mass, also play important roles in some areas.

The next time you watch a weather report on television, think about the many factors that influence our weather, many hundreds of kilometres away, that help make the weather what it is at a given location and time.

1.3 Standard weather parameters

Standard weather parameters include:

- Temperature: Immediate Temperature | Interval Values of Temperature
- Humidity: Instantaneous Relative Humidity | Interval Values of Relative Humidity | Absolute Humidity
- Dew point: Instantaneous Dew Point | Interval Values of Dew Point
- Atmospheric Pressure and Density: Pressure Adjusted to Sea Level | Surface Pressure | Pressure at Higher Altitudes | Air Density
- Wind: Instantaneous Wind Speed | Instantaneous Wind Direction | Horizontal Wind Components | Vertical Wind Component | Interval Wind Speed | Interval Wind Gusts | Interval Wind Direction
- Clouds: Amount of Cloud Cover | Ceiling Height | Cloud Base
- Precipitation: Accumulated Precipitation | Precipitation Type | Precipitation Probability | Hail | Supercooled Liquid Water | Rainfall | Snowfall | Sleet
- Evaporation: Accumulated Evaporation
- Snow and Frost: Frost Depth | Soil Frost | Amount of Snow Melt | Amount of Fresh Snow | Snow Depth | Snow Water Equivalent | Snow Density | Snowfall Probability
- Radiation: Instantaneous fluxes: Clear Sky Radiation | Diffuse Radiation | Direct Radiation | Global Radiation
- Accumulated energy: Accumulated Energy (Direct, Diffuse or Global Radiation) | Clear Sky Radiation
- Other Meteorological Parameters: Geopotential Height | Water Vapor Mixing Ratio | Layer Thickness

Revisiting briefly some concepts:

Solar Radiation

Solar radiation is radiant (electromagnetic) energy from the sun. It provides light and heat for the Earth and energy for photosynthesis. This radiant energy is necessary for the metabolism of the environment and its inhabitants. The three relevant bands, or ranges, along the solar radiation spectrum are ultraviolet, visible, and infrared. Of the light that reaches the Earth's surface, infrared radiation makes up about 50% of it, while visible light provides roughly 42%. Ultraviolet radiation makes up just over 8% of the total solar radiation. Each of these bands has a different impact on the environment.

Sunlight is responsible for warming the Earth, oceans and the atmosphere through infrared radiation. Both water and land reflect back some of that radiation to warm the atmosphere or other objects in contact with the surface. The darker the object or surface, the faster it will absorb light and heat.

Wind Speed and Direction

At a given location, winds are very variable in direction and over time, which is associated with atmospheric turbulence. Horizontal wind direction is indicated by vanes. However, small, light and aerodynamically optimized vanes are needed to register the rapidly varying directions of wind. The meteorological convention is to describe the direction of a horizontal wind by the direction from which it is blowing. Usually, only the horizontal component of wind is appraised because the flattened shape of the atmosphere ensures that the horizontal wind speeds are usually more than 100 times larger than vertical ones, and almost always more than 10 times larger.

In routine observations, ten-minute averages, together with maximum speeds in gusts, are used to define wind speeds near the surface. The strength of wind near the surface, and its effect over land, can be categorized by the Beaufort scale.

Air Temperature

Air temperature is indirectly dependent on solar radiation. While air itself does not absorb infrared radiation, it receives heat from the Earth's surface. This effect occurs through heat transfer by conduction and convection.

Earth absorbs infrared radiation and converts it to thermal energy. As the surface absorbs heat from the Sun, it becomes warmer than the surrounding atmosphere. The heat is then transferred by conduction (contact) from the warmer Earth to the cooler atmosphere. Air itself is a poor conductor of heat, so convection, or the rise and fall of warm and cool air, warms the rest of the atmosphere that is not in contact with the surface. As the warmer air rises, cooler air sinks to the surface, where it continues in the convection process.

Earth's surface also reflects some infrared radiation back into the air. This reflected radiation can be trapped and absorbed by gases in the atmosphere, or re-radiated back to the Earth. This process is called the *greenhouse effect*. Without the greenhouse effect, the Earth's average surface temperature would be about -18°C instead of the current +18°C.

Water Temperature

Infrared light from the Sun is absorbed by bodies of water and converted to heat energy. This low energy radiation excites electrons and warms the top layer of water. Nearly all infrared radiation (about 90%) is absorbed within the first meter of the water column, near the surface. This heat is then transferred to greater depths through movement from wind and convection. While heat is slowly transferred throughout the water column, it often does not reach all the way to the bottom. This is due to water column stratification.

In the ocean and many lakes, water can stratify, or form distinct layers of water. These layers are distinguished by their temperatures, densities and often different concentrations of dissolved substances (such as salt or oxygen). The different water strata are separated by steep temperature gradients known as thermoclines. Even with convection and wind, it is difficult for most of the Sun's heat to cross these barriers. Instead, the lowest strata of water will remain at low temperatures, while the surface water temperature will fluctuate both diurnally (daily) and seasonally.

1.4 Climatic/meteorological observations

How do we observe the atmospheric conditions?

Whereas people can make themselves aware of a wide range of meteorological conditions, their often weak and ambiguous senses reaction severely limits the quality and quantity of our observations. Thus, atmospheric data must be as unambiguous and definite as possible, which can be provided by mechanical aids (i.e. observational instruments). The more common systematic measurements of atmospheric variables include, e.g., temperature, humidity, wind, pressure, precipitation. Of the many other types of observations that could be mentioned, the most relevant concern solar and terrestrial radiation.

Today, advances in science and technology allow us to gather detailed observations using a host of modern measuring instruments, providing a variety of innovative instruments and sensors that are changing conventional instrument-based measurement approaches.

Different observation networks are currently securing a whelm of data of different nature and spatial and temporal resolution are recorded. They include surface, upper air and satellite networks:

The surface network: The conventional monitoring network is composed of ground stations that cover the measurement of standard weather parameters (Figure 1.1).

Figure 1.1. Views of meteorological stations from monitoring networks showing several measuring devices.

Weather stations typically have different instruments, for example: thermometer for measuring air and sea surface temperature; barometer for measuring atmospheric pressure; hygrometer for measuring humidity; anemometer for measuring wind speed; pyranometer for measuring solar radiation; rain gauge for measuring liquid precipitation over a period of time; psychrometer for measuring humidity by taking both a wet-bulb and a dry-bulb temperature reading; wind sock for measuring general wind speed and wind direction; wind vane, also called a weather vane or a weathercock, for showing which way the wind is blowing (Figure 1.2).

Figure 1.2. Examples of instruments deployed at meteorological station. From left to right: anemometer, grass thermometer, rain gauge, and sheltered, thermometer for maxima and minima temperature (in horizontal position) and psychrometer (in vertical position).

The stations of the surface network are scattered across the continents. Each country maintains its own network(s). As far as is possible, the observations are made in sites that are standard in construction and exposure, but are nevertheless representative of the surrounding terrain. However, selected sites vary considerably in altitude, therefore, parameters such as station pressure need to be correct. No attempt is made to correct air temperature for stations' altitude. All instruments used should be designed to conform to international standards, and operated by staff trained to operate them in a consistent and adequate manner. This guarantees that atmospheric data observed across the world are comparable.

In surface networks, conventional analogue instruments are being replaced, to allow for digital (continuously) recording and data transmission (Figure 1.3). Networks of weather radars are as yet very incomplete and limited. At some stations air quality measurements might also be undertaken.

The upper air network: Observations of wind, temperature, relative humidity and pressure are made by radiosondes (free-flying balloons released from the upper-air stations of the synoptic network). While in flight, the data are sent by radio to the ground station, and the sonde's position is monitored by automatically tracking radar. Although these data sampling intervals, in space and time, are much greater in the upper-air network than in the surface network, the fact that the atmospheric structure is much smoother and larger in scale aloft than it is near the surface justifies the interest in this type of data acquisition. The surface heterogeneities generate significantly smaller and more transient structures, especially over land.

Figure 1.3. Examples of automatic weather stations.

The satellite network: the first meteorological satellite was launched in 1960. Since then they have multiplied and developed considerably. Meteorological satellites are platforms for electromagnetic scanning of the atmosphere from above (i.e., *top-side* observations). The scanning can be passive or active. In passive scanning, satellites merely make use of existing radiation emitted or reflected from the atmosphere, without adding to it. The radiometers used are sensitive to one or more wavelength bands, for example, in the visible and infrared ranges. Radiometers that are sensitive in the far infrared are independent of solar radiation and respond instead to the terrestrial radiation emitted continuously by the Earth´s surface and atmosphere. This radiation increases in intensity as the temperature of the emitting materials rise; thus, the resulting imaging has a brightness scale that corresponds to a temperature scale in the original panorama. The brightness scale can be replaced by an arbitrary colour scale for easy of subsequent analysis by eye. Radiosondes are currently under active development, which opens new perspectives in this field. Revisiting times and imagery spatial resolution, as well as the multi-spectral and hyperspectral resolution of the sensors have been increasing much in the last few years. At present, satellites are providing complementary data for characterizing the weather; the data spatial and temporal resolutions depend on the source. For more insight, check images (https://www.ipma.pt/en/espaco/msg/index.jsp) obtained by the SEVIRI sensor on-board the satellite Meteosat Geostationary European Second Generation (MSG).

The World Meteorological Organization (WMO, https://public.wmo.int/en) coordinates the worldwide efforts that are prerequisite for the production of accurate and timely weather forecasts. Currently, there are well over 10 000 manned and automatic surface weather stations, 1000 upper-air stations, 7000 ships, 100 moored and 1000 drifting buoys, hundreds of weather radars and 3000 specially equipped commercial aircrafts that measure key parameters of the atmosphere, land and ocean surface every day. Additionally, there are some 30 meteorological and 200 research satellites in the global network for meteorological, hydrological and other geophysical observations.

Short term monitoring campaigns are also useful to collect data of high temporal and spatial resolution, using eventually a suite of available sensors that are in general different from the sensors used in fixed deployed measuring stations, and which operation does not also follow established standards.

Many **sensors** are currently in use to assess weather parameters, including sensors that are used for measurements that are not carried out within conventional monitoring networks. Technology developments have been directed to this field of environmental monitoring, broadening and improving the range of spatial, temporal and intensity resolutions of instrumentation, in relation to past approaches. This is boosting the need to truly understand how the different sensors work and their response to input signals, as comparison of data from different origins can be easily biased by intrinsic instrumentation and installation features.

Understanding the different origin and resolution of atmospheric data is crucial for correctly interpreting and using data collected by different sensors and types of network.

What do we observe: the weather, the climate?

The relation between weather and climate is that between instantaneous and mean conditions of the atmosphere: "**weather is what you get, climate is what you expect**".

But people often confuse climate and weather - the two really are quite different. For a particular location, weather describes the condition of the atmosphere over a short period of time e.g. from day to day or week to week, while climate describes average (weather) conditions over a longer period of time.

By stepping outside, you might experience many facets of weather. Humidity, air temperature and pressure, wind speed and direction, cloud cover and type, and the amount and form of precipitation are all atmospheric characteristics of the momentary conditions we call weather.

Information about weather parameters can serve different purposes. The intrinsic large temporal and spatial variability in weather processes demands to maintain the continuous operation of dedicated monitoring networks and data collection and analyses.

The data is used to study the climate, its variations and extremes, and its influences on a variety of activities including human health, safety and welfare to support evidence-based decision-making on how to best adapt to a changing climate. Local (ground) data collection and analysis is crucial due to the diversity of environmental conditions found over land, and problems, which requires a case-by-case assessment and decision. Almost all our activities are influenced by weather, climate and water.

Atmospheric data interpretation

In general, the atmospheric data interpretation depends on the scale of climate analysis, which should consider the spatial representativeness of the meteorological stations used.

At a **regional (mesoclimatic) scale**, in which the main climatic differentiation factors are determined by the thermal, hygrometric and dynamic characteristics of the air masses, meteorological stations at a similar altitude and distance from the sea, spaced about 10 km apart, might represent the regional climate satisfactorily; however, this happens despite the spatial contrasts of climatic variables that they inevitably present, but that are mitigated by the parameters of central tendency that characterize the climate.

At the **scale of the local climate (topo/micro climate)**, in which the determining factors of spatial differentiation of climatic variables are linked to the characteristics of the geographic space (e.g., the type of land occupation, altitude and topography), the spatial representativeness of each of the weather stations is heavily restricted. This means that, at this scale of analysis, a given conventional weather station of the surface network is very likely not representative of the climate of a given urban area, or of the urban agglomeration, as a whole.

Thus, one way to deal with this lack of knowledge and that could be important to assess climate issues at the street and neighbourhood scale, for example, is to collect complementary point data in a non-conventional way, often using sensors, many of them operated manually. However, such data, which could be useful to qualitatively assess the impact of different urban features on the urban local climate, is often not obtained by standard instruments and is not operated following standard procedures. Quite commonly, the response times of these sensors are unknown and not respected by the user. This means that, although valuing the contribution that these data might have to raise our awareness of a number of local urban issues, we should not confound the type of information in these data with the information provided by standard meteorological stations. The uncertainty in the data is unquantifiable, and can easily introduce an unquantifiable bias in analysis results. For scientific and technical assessments, or whenever quantitative studies are needed, a sounder and more trustful data collection programme should be established. Nevertheless, the easiness of *ad hoc* data collection allows us for a rapid appraisal, on site, of the main features of the urban environment that seem to dominate the local climate, and this can be quite important to contribute, e.g., to identify problems and/or problem areas within the city (e.g., hotspots, secondary urban heat islands), and find suitable measures to mitigate those problems.

Measurements carried out using non-conventional instruments installed in vehicles (e.g. cars, bikes) are sometimes also considered. This scheme allows one to obtain information on a large number of points (sometimes called dynamic data) and draw detailed maps and profiles that illustrate the spatial variation in the measured weather parameters. This approach could be useful to differentiate between urban areas, suburbs and rural areas and establish types of heat islands for different urban spaces and distinct weather conditions. Disadvantages of this approach include: I) the data obtained by this measuring scheme is not comparable to the data from the conventional network (or other static data), unless the data series undergo non-trivial transformations; II) to guarantee simultaneous measurements, a set of different measuring instruments needs to be used and instrumental errors can easily distort results. To lessen this problems, two-way trajectory measurements could be considered, using the average value of the measurements in graphing profiles; instead of using the real data, it is also possible to use the differences between the temperature observed in each point and the lowest temperature recorded in a given survey trajectory, which diminishes instrumental errors. Nevertheless, the most serious drawback is that this observation system can only be applied to some weather parameters, such as air temperature and humidity; it cannot be applied to precipitation or wind, due to the variability in these processes.

Another path, which also allows for a more comprehensive insight at the urban scale, are remote sensing data obtained by sensors installed in aerial vehicles (AV, drones) and satellites. Whereas sometimes AV flights are heavily restricted over urban areas, or even not allowed, nowadays imagery from satellites are accessible at spatial scales of interest to assess the variability of relevant atmospheric and urban surface conditions. One example regards temperature, which can be appraised from Land Surface Temperature (LST) imaging, for example, from Landsat-8 satellite. The remote sensors capture the radiant temperature of the urban surfaces, which allows a detailed analysis of the temperature spatial distribution and its relation with urban variables. The information on each satellite imagery refers to a specific date that corresponds to the revisit times of the satellite. But the broad spatial coverage of the data is unbeatable, in comparison with other ground-based data types. It can be used, for example, for inspecting differences between the inner city and the surrounding rural area, or for identifying temperature variability across the city.

Thus, depending on the study, one should be able to identify which data are available (from which sources, which spatial and temporal resolutions, which record lengths), their comparability, and how different data sets can be used complementary to better characterise the study area.

About measuring and processing weather data

Weather data collection may vary significantly according to the nature and objective of the study/activity. It concerns, for example: I) the type of variable, the temporal and spatial resolution required, the length of the available record; II) the specific equipment to use, or available, and its ability (or not) for the continuous recording, over time, of a given variable; III) the opportunity to collect static or dynamic data, and analysis tools available. Weather data collection, processing and analysis should be tied to the goal of the particular case study.

Thus, the following should be kept in mind:

- Before collecting data, including *in situ*, make sure that you identify the type of data needed for a specific investigation/study and that you adequately plan the field work.
- Atmospheric fields are extremely variable in time and space, thus, be aware of the representativeness of the data, in particular if acquired during field's measurement campaigns. For the assessment of variations in space of a given variable, make sure that the measurements are conducted within a short period and that the atmospheric conditions (the weather) are not varying significantly during the record period.
- When conducting field measurements, take care about the limitations of the sensors used. Instantaneous single measurements should be avoided. At each point, collect data over a lapse of time and use the average value as a reference value. The duration of the time interval and number of registered values depend on the aim of the study. Do not forget that temperature sensors should be shaded; readings should not be taken when the sensor is exposed directly to incident solar radiation.
- Take note of the exact location (use GPS, if available) and time of the measurements, so that you can interpret the data.
- Make sure, whenever possible, to compare your data with data collected at a nearby weather station from a monitoring network. You could also compare measurements obtained using different sensors, to appreciate similarity and differences in measurement outcomes, in terms of precision, response times, etc.
- Weather stations from measuring networks may offer you the possibility to understand the variation in the data, for example, at the daily, seasonal, annual or larger scales. For example, in relation to heat stress assessments, historic temperature and humidity records will allow you to better appraise the related risk (in statistical terms).
- Long enough data sets will allow you to characterise the climate at the station site. For characterising the urban climate or the regional climate, you need adequate spatial information, which often implies having data for a representative number of points.
- Crude instrumentation and circumstantial observations will not allow one to draw a broad picture of the dominant factors when one refers to atmospheric conditions at the urban scale, ultimately at stake for assessing the urban environment. However, field campaigns might contribute to better understanding the high variability in the measured parameters, and the need to deepen the holistic understanding of the urban environment, as a whole.

1.5 The urban climate

The World Meteorological Organization (WMO) defines **urban climate** as "local climate which differs from that in neighbouring rural areas, as a result of urban development". That means air temperature, precipitation, concentration of air pollutants, noise and wind speed often differ from the surrounding areas. For example, cities usually have a higher air temperature than the surrounding area and hence are in the focus of climatic spatial planning. In times of climate change, the climatic differences between the city and the surrounding regions might result in increasing heat stress on population and infrastructures during the warm(er) seasons.

The climate of a site may be regarded as the integration of a series of controls, differing in scale. In sequence these are: the regional climate, determined by synoptic factors; the modifying effects of the local orography; and the self-induced modifications of the buildings and building groups themselves. In addition, in discussing urban climates, we have nevertheless to distinguish between I) the modification of the climate by the accumulation of buildings (change of topography) and II) the modification of the climate by urban air pollution.

The growing rate of pollutants emitted into the atmosphere by anthropic activities, combined with the influence of topography change, leads to an accumulation of trace substances in the air over cities and, frequently, to the formation of haze. This haze dome, which builds up over densely populated areas, is concentrated or dispersed according to rate of emissions, the effective emission level above the ground, the wind profile, the vertical temperature profile and relief. The characteristics of the haze dome affect the quality of the urban environment.

Thus, all these different factors and effects are important for discussing the urban environment from different perspectives, in particular due to the chain reactions involved.

Some examples of influences of urbanization on urban conditions, namely regarding wind, radiation, visibility, temperature, precipitation and air humidity, are:

Wind

Wind is the basic parameter of urban climate, as a whole. It helps to control pollution concentrations, temperature, fog frequency, evaporation rates and humidity, cloud amount and precipitation. All of these determine the urban environment.

Part of the difficulty in studying wind in urban areas lies in the very complex patterns of airflow in these areas. On the one hand, the whole wind profile and turbulence spectrum changes as air moves across cities; and, on the other hand, there is a rapid increase with height in the time and length of trajectory required for the wind to adjust itself to the change in surface roughness at the urban-rural boundary. Wind speed near the ground (e.g., at 1.5 m above the ground) might differ considerably from the wind speed value measured at 10 m height in meteorological stations.

It is frequently assumed that all winds are reduced in speed in urban areas, although sometimes the opposite is observed. Studies have shown that in urban areas strong winds' speeds are decreased, but light winds' speeds are higher. This might be due to frictional retardation dominating at high speeds, but the relatively enhanced urban turbulence at low speeds may transport greater momentum toward the surface.

Radiation

The pattern of radiation exchanges in urban areas is complex. Short wave radiation is scattered and absorbed by pollution particles of the haze hood, while surface receipts are highly differentiated by the varied geometry, aspect and albedo of city fabrics. Backscatter of the solar beam by pollution aerosols can result in a loss of as much as one fifth in the short wave radiation) received by the earth-atmosphere system. In highly polluted areas, absorption by gases and aerosols can probably result in heating rates in excess of a few couple °C per day, which could not be compensated by stronger infrared cooling. In consequence, there could be a loss, beneath polluted city atmospheres, of visible radiation and ultra-violet radiation. The expectation is that any change in the levels of pollution will lead to changes in the character of radiation exchanges in towns.

Visibility

Ultra-violet radiation plays an important role in photochemical processes involving hydrocarbons and other air pollutants which lead to irritant smog. In general, fogs are both directly and indirectly related to levels of air pollution in cities but the pattern of fog frequencies is not simple; visibility is usually different in city centres and in the suburbs, which could result from warmer but more polluted central areas as compared with the cooler, windier and more humid fringe areas of the city where housing densities are lower and there are more open spaces. For these same reasons, fogs tend to form and disperse earlier in suburban areas than in central areas.

Temperature

The generally higher temperatures inside towns have been noted for a long time. The heat exchange mechanisms leading to the excess heat of towns (the "urban heat island", UHI) in comparison to surrounding (rural) areas are usually influenced by four main contributory factors: I) changes in the thermal characteristics (albedo, heat conductivity and thermal capacity) of the surface following the substitution of farms and fields by buildings and roads; II) changes in the airflow patterns with a reduced diffusion of heat from streets and courtyards; III) changes in evaporation rates and heat losses; and iv) the heat added by humans and human activities. These factors seem to be of differing importance in different cities so that the character of temporal variations (in particular with respect to UHI) also varies, for example, between warmer and colder seasons. The heat island effect is also the main cause for the formation of an *urban circulation system*. The urban structure and construction features can also lead to the development of secondary heat islands (i.e., hotspots) within the city.

Precipitation

Regarding precipitation in towns, the main difficulty is to separate the purely urban controls from the much stronger influences of synoptic climatology and topography within the built-up area.

Three main factors may be the cause of urban-induced changes in precipitation. These are: I) additional condensation nuclei of a particular type; II) increased turbulence because of increased surface roughness; and III) thermal convection resulting from higher temperatures. Presumably because of these influences, a number of cities have been noted to have more rain days, more thunderstorms and more total precipitation than the country areas around them. Only towns above a certain size may affect rainfall amounts. Moreover, it is not necessarily to be expected a coincidence between the area of any change and the limits of the built-up area.

Air humidity

The effects of urbanisation upon atmospheric humidity are hard to assess, and often small in magnitude. But this is not a universal pattern. Proximity to water bodies and green areas can impact importantly on this weather parameter, at the local scale. Urbanization can also induce phenomena such as the *urban dryness island* referring to conditions where lower humidity values are observed in cities relative to more rural locations.

1.6 Understanding and interpreting weather data

The assessment of different urban environmental issues requires insight on local conditions. Often, these are related to weather parameters. For this purpose, exploratory measurements could be carried out. For example, for the better understanding of the risk of heat stress at the street or neighbourhood level based on the Heat Index, air temperature and humidity needs to be assessed at different locations using portable weather stations. Local measurements are key to gain insight into the potential usefulness of different heat adaptive measures, namely green-blue solutions.

While conducting the field survey, you can try to do sketchy maps of the air temperature and/or the Heat Index (or other relevant indicator). This would allow you to confirm (or not) that your planned measurement grid would be suitable for your particular study; while still on location, you could easily collect more data, if needed. You can use the IMPETUS Data Collection App, if applicable to your survey, and/or upload your project in the ClimateScan platform.

However, bear in mind that the weather data that are collected on a given day might not represent well the "typical" (i.e. normal, in statistical terms) local conditions. Remember the difference between the weather and the climate! Thus, you might bias conclusions of your survey regarding the need of adaptive measures implementation if you rely only on circumstantial (single) observations.

In addition to occasional weather variables' measurements conducted across a given study area, whereby you intend to appraise, for example, the spatial variation found for those variables along a given street or neighbourhood, you might like to assess the weather data obtained at a nearby (ground) weather station (e.g., air temperature, relative humidity, wind speed, and global radiation) from a monitoring network for a broader insight and characterization of the weather conditions. Identify the existence of such weather station(s), at a short distance from the study area; annotate the coordinates (including the altitude) and name of the weather station(s).

The sample graphs in Figure 1.4 illustrate the type of data that you could access via the web interface with automatic stations; the data are usually access free. These types of records and graphs will illustrate, e.g., the type of daily variation that you could expect for temperature and air humidity, and for other atmospheric data. Similarly, you can assess seasonal variations in pertinent weather parameters. This could be important for better understanding, for example, the risk of heat stress potentially affecting the area. For climatological studies – that focus on the long-term evolution of atmospheric conditions (years to centuries) - the existence of long data series is required.

You are recommended to make similar graphs for visual interface with the data relevant to your study area. If needed, explore the website of the World Meteorological Organization (WMO) for getting acquainted with the graphical representation of weather and climate data.

There are different web platforms around the world that generically allow users to access weather data or see the evolution of climatological scenarios resulting from numerical modelling of processes applied to the climate parameters for a selected area and/or time interval. Often some platforms provide data through a map service, allow users to perform data download operations and map geoclimatic units.

Figure 1.4. Example of an interface with weather data measured at an automatic weather station. The data were measured on August 5, 2018, at the weather station ICOIMBRA14, Portugal, coordinates 40° 11' 6"N, 8° 24' 46,8"W (https://www.wunderground.com/dashboard/pws/ICOIMBRA14/graph/2018-08-5/2018-08-5/daily).

The material in this module pursued different objectives with respect to contributing to increasing your awareness, curiosity and knowledge on different atmospheric related processes and phenomena, and on the interaction between weather parameters and the urban environment. Namely, you should:

- Be aware of the difference between the weather and the climate.
- Get acquainted with atmospheric parameters.
- Learn about atmospheric observation standards, instruments and networks.
- Appreciate the differences between data collected using standard methods and equipment, and non-professional sensors' data, i.e., between crude instrumentation and circumstantial observations.
- Understand the graphical representation of weather and climate data, at different temporal and spatial scales.
- Comprehend that liveability of cities results from a complex realm of nonlinear processes, including atmospheric processes, which full understanding is still in progress.

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