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MTP 5

METEOROLOGICAL TEMPERATURE PROFILER

PRODUCT INFORMATION

BACKGROUND

There are a number of applications in meteorological and environmental sciences where it is desirable, or indeed necessary, to measure the temperature of the atmosphere. A temperature profile provides the temperature at different heights above the ground.

Most people are aware that as altitude increases the air temperature falls, you experience it when climbing a mountain. Normally this occurs with a typical 'lapse rate' at low altitudes of approximately 6.5 ºC decrease in temperature per 1,000 m increase in altitude and can be influenced by a number of factors. The theoretical value where the only effect considered is the change of atmospheric pressure with altitude is termed the 'Adiabatic' Lapse Rate.

Where we are concerned with environmental issues relating to air quality the most important part of the atmosphere is the 1–3 km nearest to the ground. This is often called the Planetary Boundary Layer (PBL) or Atmospheric Boundary Layer (ABL) and is the lowest level of the Troposphere. Under Adiabatic conditions pollutant gases, aerosols and fine particulates tend to rise into the atmosphere and disperse.

However, there are conditions under which the normal lapse rate does not apply within the PBL. For instance during heavy rain or snow the temperature profile at low altitudes could be isothermal because the temperature at all heights is effectively the temperature of the raindrops or snowflakes.

Of more concern is a temperature inversion, in which there is a layer of air where the temperature rises instead of falling, often by several degrees. The effect of this is to trap the pollutants below the inversion so that the concentration builds up at, or close to ground level, leading to poor air quality events. Once established an inversion can be stable and last for many hours.

If the atmospheric temperature profile can be monitored in real-time it is possible to predict both the development and break-up of inversions within a specific area and action can be taken to minimise the environmental and health impact. Actions can vary from public information broadcasts to restricting or re-routing traffic flows. The greater the density of a conurbation, the greater is the potential health hazard.

Many industries have processes which require the emission of gasses into the atmosphere and these should not take place when an inversion is present. Temperature profiling can help decide when emissions can take place under the least harmful conditions and is also an essential input for accurate plume and dispersion modelling.

The development of a temperature inversion is one of the key parameters in the formation of certain types of fog and is an important input to fog forecasting. At airports the atmospheric stability and air density along the flight path is of great interest for aircraft on the final approach to landing.

It can be seen that for most of the above applications the temperature profile needs to be monitored in real-time at very regular intervals, the temporal evolution of inversions is particularly important.

MEASUREMENT TECHNIQUES

There are several possible methods for measurement of PBL temperature profiles. Historically, tethered balloons were used; where a large instrument package including a temperature sensor could be let out on a winch to several defined heights and then brought down again. Originally the recordings would be by pen on paper graphs, later by electrical transmission down cables to the ground.

In meteorology the most common method in use today is the Radiosonde. The large tethered balloon has been replaced by a small balloon filled with Helium. The balloon is released into the atmosphere lifting a light weight, low-cost instrument package which transmits data back to the ground by radio, including temperature and height information. Because of the launch equipment needed radiosondes are labour intensive and not easily moved to different locations, the instrument packages are often lost and they can only fly in relatively low wind speeds. Radiosondes typically measure a temperature profile at approximately 50 m height resolution from about 150 m to 30 km above the ground, but unless the conditions are windless the profile is not vertical.

Radiosondes and tethered balloons are expensive to operate, cannot be used in built-up areas and normally are launched only once or twice per day when conditions are good. They cannot provide the continuous real-time monitoring of vertical temperature profiles in all weather conditions that are needed for pollution and air quality forecasting.

A few meteorological research sites have towers up to 300 m high with instruments every 25 or 50m, but these are expensive to build and have strong location restrictions. In any case, the majority of inversions over conurbations and industrial complexes occur above 300 m.

The methods described so far all use direct measurement of the atmospheric temperature, newer techniques all use ‘Remote Sensing’ and derive the temperature from other measurements.

Meteorological satellites can provide temperature measurements on a global scale. Unfortunately they cannot measure the lowest 3 km of the atmosphere with sufficient accuracy over the areas that we are interested in here, because of thermal emission from the ground, buildings, structures and traffic. The data is rarely available freely or in real-time and unless the satellite overhead is geo-synchronous measurements are only available when a satellite passes over the area and there is not too much cloud.

A Radio Acoustic Sounding System (RASS) can provide continuous profiling of the temperature from 100 m to approximately 1,000 m. The system is based on a SODAR (Sound Detection and Ranging) unit that propagates acoustic waves upwards into the atmosphere. Waves reflected from the atmosphere (echoes) are picked up by a receiver and from the frequency and amplitude distributions the wind velocity profile with height can be derived. RASS adds to this a radio transmitter and receiver system. The back-scattered radio waves are modulated by the SODAR acoustic waves and a Doppler shift is induced which is a measure of the velocity of the sound, and hence the air temperature. Temperature measurements up to 1,000 m with height resolution of 50 m, and better than ± 0.5 ºC accuracy, are possible in good conditions; depending on the size and power of the system. This is performance comparable to a radiosonde.

The acoustic pulse comes from a powerful sound source, typically at 1-2 KHz, which creates a noise nuisance and a transmitting licence is normally required for the radio source. RASS installations have been widely used in the past, particularly at airports, but are traditionally large, heavy and complex and the lowest levels of the PBL are not usually measurable. Results are dependent upon weather conditions and are affected by water droplets (rain, mist) and/or strong wind. The main concern today is the noise emitted, limiting their use in urban environments.

RADAR (Radio Detection and Ranging) wind profilers can be used with high power RASS units to derive temperature profiles at higher altitudes, but they also suffer operational limitations and are even larger, heavier and are very expensive.

LIDAR (Light Detection and Ranging) systems are based upon the emission of Laser pulses at single or multiple wavelengths and the analysis of the return signal back-scattered by the atmosphere, or the stimulated emission from the atmosphere. LIDAR systems have the capability to measure many atmospheric parameters to high altitudes, in excess of 20 km, including temperature profiles depending upon the configuration. However, they are overly expensive and complex solution to measure just the temperature profile and the performance is highly dependent upon the atmospheric conditions. There are also operational limitations, such as eye-safety issues.

The most promising recent technology for retrieving atmospheric temperature profiles is by ground-based remote sensing using microwave technology. Until recently these instruments have been designed for the scientific user and require considerable knowledge to set up and operate correctly. They do not measure in all weather conditions and the calibration requires the handling of liquid Nitrogen. Data processing usually requires the 'teaching' of a neural network programme about the local conditions and normally the temperature profiles are derived during post-processing, rather than in real-time. Until now they have been designed for measurements up to 10 km and as a consequence provide poor height resolution and accuracy in the PBL.

However, a new generation of passive meteorological temperature profilers using innovative and unique microwave technology and data processing algorithms became commercially available a few years ago. The MTP 5 family of instruments are specifically designed for PBL measurements with all-weather, unattended operation and automatic self-calibration. They require no specialist knowledge to install, maintain and operate or to analyse the data; and emit no radiation or sound.

MTP 5 stands for 'Meteorological Temperature Profiler, 5 mm' and the instrument is produced in the Russian Federation by SKB ATTEX Ltd. of Moscow. ATTEX is a privately owned and financed company developing technologies for Atmospheric Science Instrumentation that primarily originate from research carried out at the Central Aerological Observatory in Dolgoprudny, Moscow.

Kipp & Zonen has an exclusive worldwide Distribution and Co-operation Agreement with ATTEX for the MTP 5 range outside Russia and the CIS.

ABOUT THE MTP 5

The MTP 5 uses a uniquely designed compact, rugged and self-calibrating microwave receiver which is highly sensitive to radiation in the 5 mm wavelength (60 GHz frequency) band. In essence this is 'black-body' thermal radiation from the atmosphere and the intensity varies with the temperature. The incoming radiation from the atmosphere is directed by a reflector into a specially shaped narrow-beam antenna which is coupled to the microwave receiver. The receiver produces a voltage output proportional to the radiation intensity, which is digitised by the on-board electronics along with other system diagnostic information.

The reflector is rotated under microprocessor control in angular steps from horizontal to vertical to produce a scan of the atmosphere with a range up to 1,000 m. The raw data is sent to a PC running the software that controls the instrument, processes the data into height and temperature information and stores the results to the hard disk drive. Measurements are typically performed every 5 minutes and software using specially developed algorithms automatically generates the temperature profile as a graphical display after each measurement. The scanner assembly is protected by a thick Teflon™ window which is effectively self-cleaning as the scanner rotates.

The standard versions for environmental monitoring are small and light (20 kg) and optimised for measurements up to 1,000 m. They typically have 50 m height resolution and temperature measurement accuracy of ± 0.5ºC. For increased safety outdoors and flexibility of power supply choice the instrument operates from 12 Volts DC. Self-calibration is carried out automatically, between the routine measurement scans.

The main benefits are that the instrument has a wide operational range (covering conditions of fog, snow and rain), zero emission of radiation and quiet operation, a high level of quality assurance, automatic calibration, low installation and running costs and operates continuously. The only regular maintenance is to periodically clean the scanner cover. These features make the MTP 5 ideal for network use and for the user who is only interested in the information produced and wishes to treat the instrument as a 'white box'. For experimental and research use the added features of being readily transportable and having a low weight and simple, quick, set-up are an advantage. A specialised version is available for Polar research and a mobile version for mounting on the roof of a vehicle.

The MTP 5-H measures the air temperature profile from the level of the MTP 5 up to 600 m and is used in studies and forecasts of air pollution, atmospheric stability (particularly at airports), climatology, weather conditions and for optimisation of industrial emission releases.

At 5 mm wavelength the absorption by water vapour is very low compared to the Oxygen absorption, thus the measurement is not significantly affected by varying humidity, rain or fog. This means that the performance is unaffected by rain, fog and snow. However, the strong absorption of the 5 mm radiation by Oxygen means that the MTP 5-H cannot 'see' radiation from further away than 700 m.

In order to measure up to 1000 m the MTP 5-HE has the frequency shifted so that the Oxygen absorption is not so strong. However, this results in some interference from water, so that the accuracy is slightly reduced in heavy rain and fog.

THE MTP 5 SYSTEM

MTP 5-H and MTP 5-HE are intended for operation in harsh climates and have a wide operating temperature range and a scanner window that rotates to automatically shed rain and snow.

The complete MTP 5 system consists of 6 components, shown in Figure 1, as follows:

1. MTP 5 Meteorological Temperature Profiler with mounting cradle and straps
2. Ambient Air Temperature Sensor with mounting bracket
3. Power Supply Unit (AC input, 12 VDC output, to power the MTP 5)
4. Cable set (DC Power – 15 m, RS-232 Data – 15 m, Temperature Sensor – 3 m)
5. MTP 5 Windows™ Software (download the latest version from the ATTEX website)
6. Personal Computer with RS-232 serial port (not included in the delivery)

The scanner (rotating reflector with stepping motor and Teflon™ cover), the receiver (antenna and radiometer), the microprocessor controller, and the thermal radiation coming in through the cover are shown in Figure 1. A cylindrical housing provides environmental protection for the internal components.

MTP 5 has no on-board data or programme storage and must be connected to a computer with the software running in order to make measurements. It is advisable to use an uninterruptible power supply (UPS) with the computer and the Power Supply Unit to protect against ‘brown-outs’.

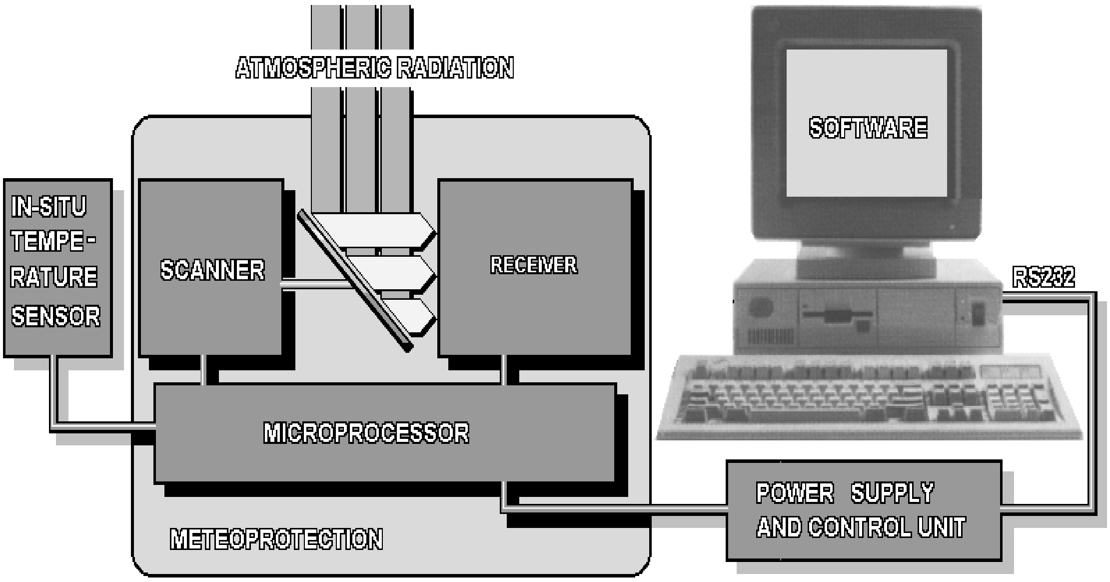


Figure 1: MTP 5 System Schematic

There are only four system connections to be made:

1. RS-232 Data Cable from MTP 5 to computer serial port
2. Ambient Air Temperature Sensor to MTP 5
3. Power Supply Unit DC output to MTP 5
4. Power Supply Unit AC cord to mains outlet (must be grounded for optimum electrical safety of the PSU and interference screening of the MTP 5)

Specially developed Windows™ software provides control of the instrument, processing, storage and visualisation of the data and also quality assurance.

Determination of the temperature profile is based on thermal radiation measurements at a number of elevation angles from 0° to 90°, in a vertical plane. A new temperature profile is calculated and displayed graphically after each scan. Scans are performed at intervals chosen by the user in the software, typically every 5 minutes.

Calibration checks are carried out between scans by comparison of the radiometer readings from the atmosphere in the horizontal direction to the external temperature sensor and to an internal radiometer reference load.

The MTP 5 monitors the internal temperature of the housing and controls it using ventilation fans to provide a suitable environment for the electronics and the stepping motor that rotates the scanner assembly. The microwave radiometer has its own precise temperature control and monitoring to ensure stability of the measurements.

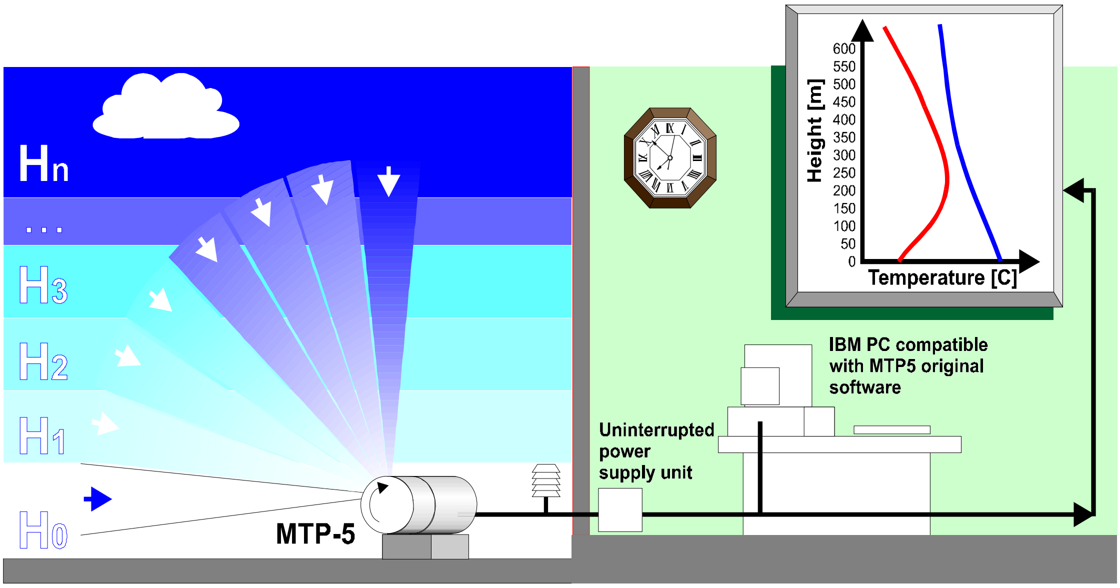


Figure 2: MTP 5 Operation Schematic

The temperature profiles in Figure 2 show a typical 'adiabatic' atmospheric condition (blue line) and a 'temperature inversion' (red line), which may lead to bad air quality by trapping pollutant gasses and particles close to the ground.

For maximum reliability during continuous use it is recommended to use a desk-top computer with a RS-232 serial port. This is normally provided locally by the customer or Kipp & Zonen distributor for ease of support.

OUTLINE SPECIFICATIONS

Figure 3: MTP 5-H/HE showing connectors, air vents and rain shields for forced cooling fans.

Figure 4: MTP 5-H/HE showing securing straps, mounting cradle, scanner and orientation line.

Specifications	MTP 5-H	MTP 5-HE
Altitude range	0 - 600 m	0 - 1000 m
Altitude resolution	50 m	50 m to 120 m depending on height
Measurement interval	180 seconds minimum	180 seconds minimum
Accuracy of adiabatic profile Accuracy of inversion	± 0.2 ˚C ± 0.5 ˚C	± 0.3 ˚C / ± 0.4 ˚C ± 0.8 / ± 1.2 ˚C (0-500 m / > 500 m)
Central measurement frequency	59.6 GHz	56.7 GHz
Receiver sensitivity	0.04 ˚C, 1 second integration	0.1 ˚C, 1 second integration
Scan angles	Intervals from 0 º to 90º	Intervals from 0 º to 90º
Field of view	3˚ conical	
Power requirements, AC / DC power supply	220 VAC / 1A or 110 VAC / 2A 50 - 60 Hz	
Power consumption, MTP 5	12 VDC 120 W max / 60 W nominal	
Ambient temperature range	-40 ˚C to +50 ˚C	
Operating conditions	Rotating scanner sheds precipitation	
Calibration	Self-calibrating relative to ambient air temperature sensor (included) and internal radiometer reference load	
Dimensions (nominal), excluding power supply	25 cm diameter 59 cm length 20 kg weight	

Both MTP 5-H and MTP 5-HE operate from 12-14 VDC provided by the 220 VAC or 110 VAC Power Supply Unit (included). Other suitable 12 VDC sources can be used.

A minimum of 12 VDC is required at the MTP 5, therefore voltage drop in the supply cable must be allowed for.

The MTP 5 is protected against interference through the screen of the DC power cable and this must be grounded at the power supply.

PRINCIPLE OF OPERATION

The technique used in MTP 5 for determination of the air temperature profile is based upon the measurement of thermal radiation from the atmosphere at the centre of the molecular oxygen absorption band, around 5 mm wavelength. This technique can also be referred to as microwave remote sensing.

The atmosphere is a strong radiation source but the changes in radiation caused by variations in temperature are small, so the measurement requires a very sensitive radiometer. The radiometer and the antenna, which limit the field of view, form the receiver. The receiver is the core of MTP 5. At the central measurement frequency of the MTP 5-H, 59.6 GHz, the effective height of the radiating layer (best signal-to-noise ratio) is about 300-400 m. The antenna has a conical field-of-view with an included angle of 3º and is specially designed to have minimal side-lobes.

By definition the effective thickness is equal to the height H_b where optical depth:

$$\tau(H_b) = \frac{1}{\cos Q}\int_0^{Hb} k_f(h)dh = 1 \qquad (1)$$

For the Planetary Atmospheric Boundary Layer (PABL) the absorption can be approximated by $k_f(h)=const=k_f(0)$ and $H_b(h)=\cos Q/k_f(0)\approx \cos Q\times 300m$, where Q is the elevation angle. Remote sensing of the PABL temperature profiles is conducted by measurements of the radio-brightness temperature at different elevation angles from Q=0° up to Q=90°. In this case the optical depth of the contributing radiation layer ranges from 0 to 300 m.

The expression for the radio-brightness temperature T_b has the form:

$$T_b(Q) = \frac{1}{\cos Q}\int_0^{H} T(h)k_f(h,T)\exp[-\frac{1}{\cos Q}\int_0^{h} k_f(h',T)dh']dh = \int_0^{H} T(h)k(h,Q)dh \qquad (2)$$

where k is the kernel; H≈2 km – the upper limit of integration. The layers of the atmosphere higher than 2 km do not influence T_b.

Equation (2) is a type 1 Fredholm equation. When solving (2) for the MTP 5 it is possible to use the Tikhonov method in the form of a generalised variation or an iteration method, with a dedicated algorithm permitting retrieval of the temperature profiles in real time.

The reception of radiation from different elevation angles is achieved by mechanical rotation around the receiver axis of a parabolic reflector that directs the radiation into the antenna and radiometer. Scanning of the reflector is carried out from horizontal up to vertical at pre-set angles, under computer control. The protective Teflon™ cover rotates with the reflector on a large ring bearing assembly, which is gear-driven by a powerful stepping motor, whereby rain and snow are automatically removed.

The radiation received by the antenna is detected, amplified and processed inside the radiometer and then sent to the control electronics inside the MTP 5, where the signal is digitised by the Analogue to Digital Converter (ADC). The digital values represent the total radiation energy measured at each elevation angle from 0° up to 90° and are transmitted to the controlling computer via a RS-232 serial data link.

The digital energy values are processed in the MTP 5 software to calculate the mean radio brightness temperature in Kelvin at each elevation angle. The dedicated algorithm for inverting the angular radiometer measurements into temperature profiles is written specifically for the MTP 5. This calculates the air temperature in ºC for altitudes from 0 m to 600 m with a 50 m height resolution. After signal processing, the graph of the temperature profile is displayed on the computer screen immediately after each scan.

The MTP 5-HE is similar to the MTP 5-H, but operates at 56.7 GHz and with a narrower bandwidth to allow measurements up to 1000 m. This results in a progressive decrease in accuracy and resolution at heights above 500 m. However, the temperature profile is still calculated and displayed at 50 m intervals.

A unique aspect of the MTP 5 is its calibration. As the central frequency of the receiver is in a strong absorption band of molecular oxygen (14dB / km attenuation at 5 mm wavelength), the brightness temperature of the atmosphere when looking in a horizontal direction is in practice equal to the ambient air temperature as measured by the ambient air temperature sensor, which is delivered as part of the system. This provides one calibration temperature for the radiometer. The response of the radiometer is linear over a wide range so only one other calibration temperature is necessary and this is provided by an internal radiometer reference load of high stability.

Calibration is automatically carried between measurement scans and averaged over a period. The software makes a best fit to the data to calculate the linear radiometer response. Each calibration is checked for the quality of the data, if there is too much statistical variation (e.g. thermal noise from the ambient temperature sensor) it is rejected. If the new calculated calibration differs only slightly from the current values it is used, but if the new calibration differs significantly from the current calibration it is rejected until confirmed by several repeated calibrations. All calibration data is recorded in the ‘raw’ data files.

The receiver always looks through the same small part of the scanner cover as it rotates. The scanner rest position is horizontal, so most dirt, rain and snow falls on the unused part of the cover. The auto-calibration will correct for some dirt but the signal is reduced and will eventually result in a noisy and inaccurate measurement. The only regular maintenance is to clean the Teflon™ scanner cover periodically with a cloth and domestic glass cleaner

A range of test and diagnostic facilities are built into the MTP 5 firmware, software and hardware.

LOCATION

The receiver has a narrow field of view that is a cone of 3° and this must be clear of obstructions in a plane from horizontal to vertical, ideally for more than 600 m for the MTP 5-H and more than 1000 m for the MTP 5-HE. Because 1.5° of the view at 0° elevation angle is below horizontal, the MTP 5-H should be at least 15 m above ground level and 25 m for the MTP 5-HE. The edge of the roof of a building is ideal.

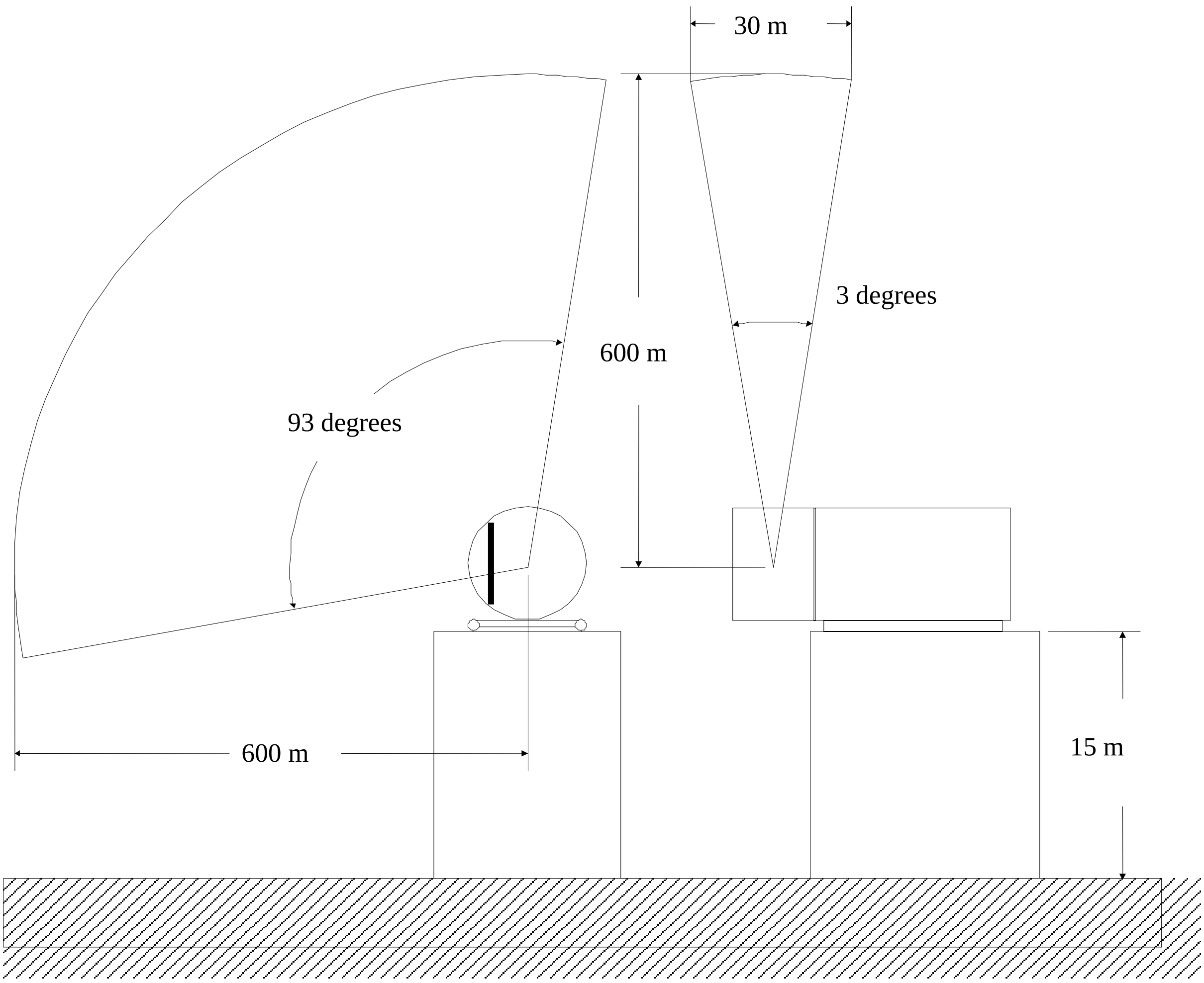


Figure 5: MTP 5-H Installation Height

If it is not possible to mount the MTP 5 sufficiently above the ground it may be possible to offset the horizontal first measurement, with some loss of accuracy.

The power and data cables are 15m long. The Power Supply Unit and any controlling PC are not environmentally protected and must be located indoors.

MTP 5 is not itself affected by the sun being in its field of view, but the column of air directly in line with the sun may be slightly warmer than the surrounding air mass. For the best results the MTP 5 should be oriented with its field of view towards the nearest pole (North in the Northern Hemisphere).

In areas with intense sunshine it may be necessary to mount a reflective heat-shield above the MTP 5 or to place it in a shaded location. If the internal temperature becomes too high no damage will occur, but the instrument will shut down until the temperature drops. The mounting cradle should be securely fixed to the mounting surface to resist strong winds, knocks and vibration.

MTP 5 is a device for measuring air temperature and it will see changes due to exhausts, vents and gas plumes and any bodies within its field of view that are not at the ambient air temperature (e.g. metal structures, buildings, etc). For this reason the MTP 5 should not be mounted looking across building roofs, particularly black asphalt roofs (these make effective black body radiators).

The ambient air temperature sensor has a 3 m cable and should be mounted approximately at the same height as the MTP 5 and in a shaded and sheltered position, so that it truly represents the temperature of the air.

SOFTWARE

An important part of the MTP 5 is its dedicated software running under Windows™. The MTP 5 software is the primary user interface for the system and runs on all platforms from Windows 98 onwards. Connection via a 9-pin serial port with securing screws is recommended for a reliable long-term connection. A desk-top computer is recommended for long-term continuous operation.

The MTP 5 software is a relatively small application, about 4 MB, and includes the operating manual. The latest version of the software can be downloaded from the ATTEX website. It is generic for all versions of the MTP 5 and is configured on start-up by entering a code that is unique to the radiometer of the particular MTP 5. This sets all the necessary operating parameters and characteristics.

MTP 5 will not operate, and no data will be recorded, unless the software is running (it can run minimised).

The MTP 5 software performs several essential functions, including:

Physical location information (site name, longitude, latitude, altitude, etc)
Directory for data storage
Communication, and installation tests
Scan interval (user defined, default is 5 minutes)
Data processing and storage
Display of temperature profile after each scan
Display of historical profiles
Display of trends
Error log file

The software makes a new set of data files each day. These are in readable ASCII text form.

Each scan has 3 data files:

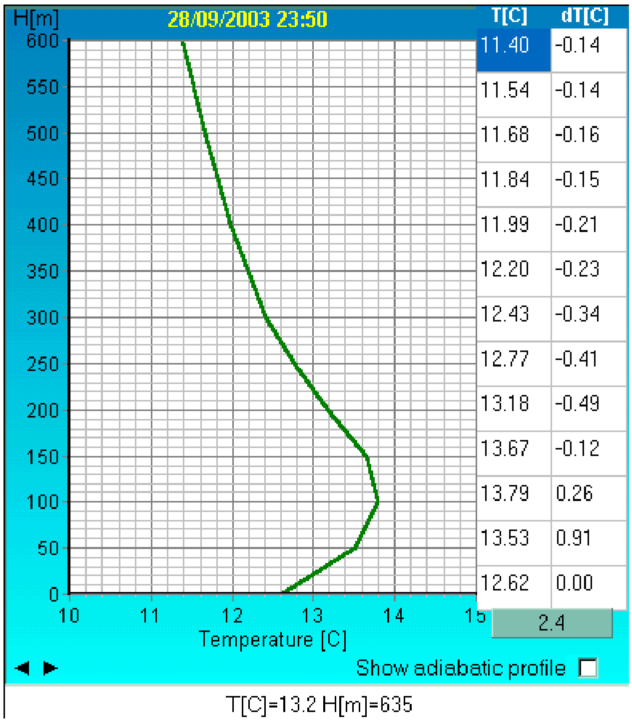
'DATA' contains the digital radiation values at each elevation angle, plus all calibration and internal status data;
'TBR' contains the path averaged radio brightness temperature in Kelvin at each elevation angle, calculated using the current calibration data;
'RESULT' contains the air temperature in ºC at each 50 m height interval.

The 'MtpNews' graphical display software can be used in stand-alone mode on another computer, without connection to an MTP 5, for viewing imported temperature profile data.

Figure 6 shows an example of the main operational software window. A new profile is shown after each scan. The buttons at bottom left allow searching backwards and forwards through the database. In the graph one can see a temperature inversion between 150m and 400m.

Figure 7 shows a temperature map for a complete day. The heights displayed can be turned on or off as desired and there are zoom facilities.

Due to continuing improvements the latest software version may differ from that shown.



T[C]	dT[C]
11.40	-0.14
11.54	-0.14
11.68	-0.16
11.84	-0.15
11.99	-0.21
12.20	-0.23
12.43	-0.34
12.77	-0.41
13.18	-0.49
13.67	-0.12
13.79	0.26
13.53	0.91
12.62	0.00
	2.4

Figure 6: Main Operational Software Window Showing an Inversion

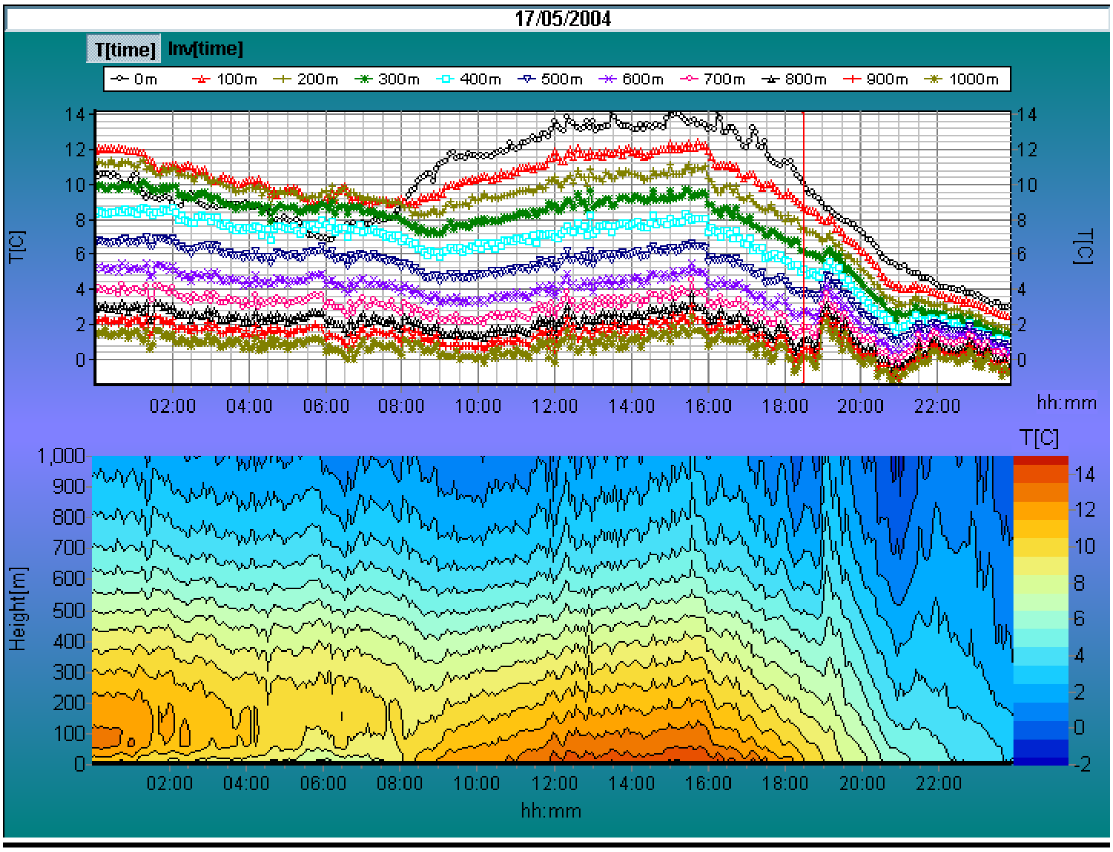


Figure 7: Temperature Map for a Complete Day

MTP 5-P

This is the 'Polar, version of the MTP 5 family. It uses similar measurement technology to MTP 5-H and the same microwave radiometer and electronics. However, it is designed to provide much improved height resolution in the first 100 m above the instrument, typically down to 10 m resolution at low altitudes. This is important for measurements over snow and ice, where temperature gradients can be very steep over small height increments.

To achieve this improved height resolution a much narrower field-of-view is required, 1° or less. A larger capture area is therefore needed in order to maintain the signal-to-noise performance. The receiver comprises a large parabolic dish antenna with the radiometer attached directly to it. There is no separate scanning reflector, the entire receiver assembly is rotated in very small angular steps by a modified Kipp & Zonen 2AP Sun Tracker.

Figure 8: MTP 5-P Polar Version Internal View

The housing of the MTP 5-P is much larger than that of MTP 5-H and MTP 5-HE and is designed for operation in typical Polar conditions, as encountered in the Arctic and Antarctic.

MTP 5-P is 90 x 90 x 90 cm, weighs 100 kg and is AC powered only. Ideally MTP 5-P should be mounted at least 5 m above the ground.

The large Teflon™ cover is fixed and therefore dirt is not compensated for during the auto-calibration and more frequent cleaning is required than with the MTP 5-H and MTP 5-HE.

Please contact Kipp & Zonen for further information regarding the MTP 5-P.