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D.A. Bunskoek, A.C.A.P. van Lammeren and A.J. Feijt

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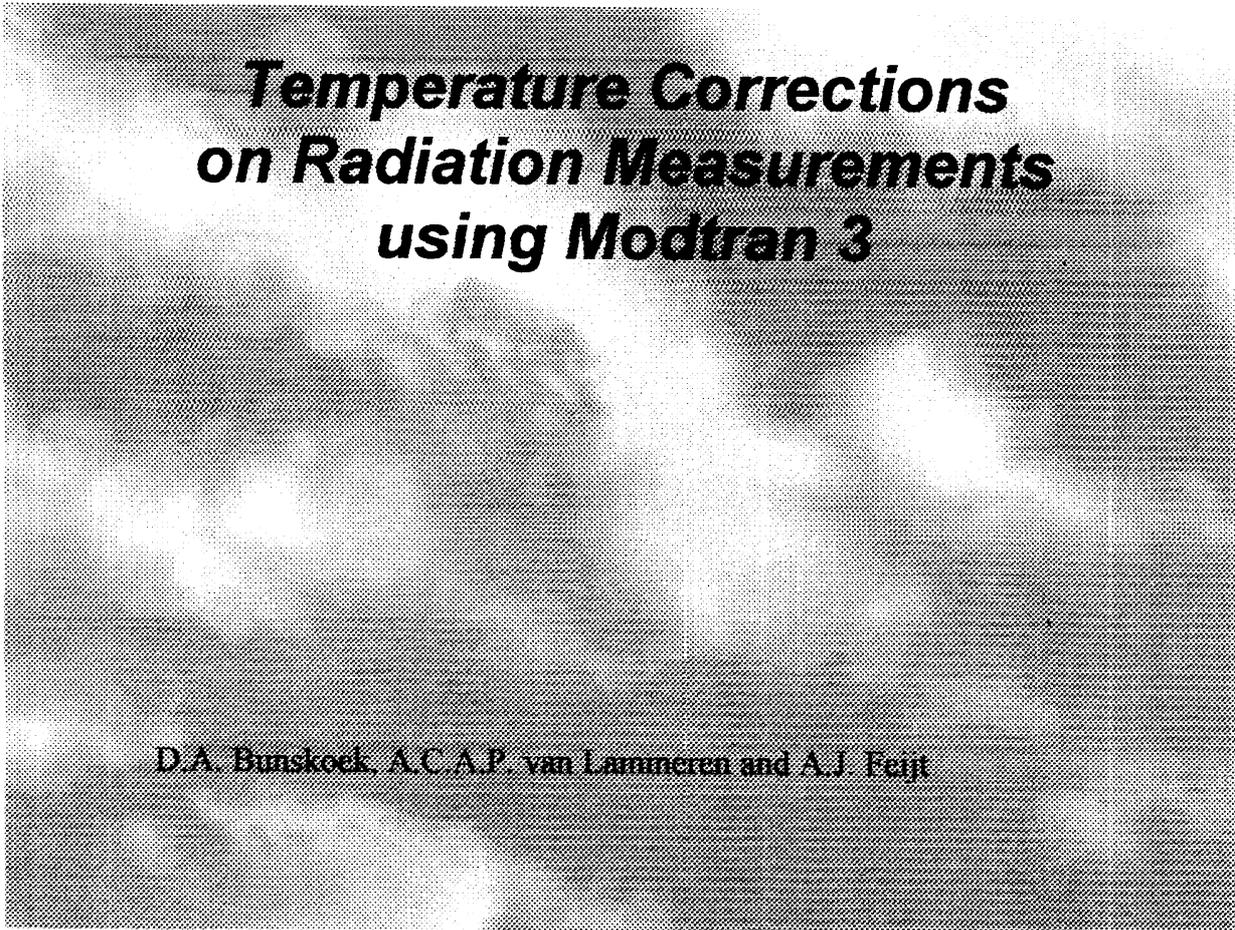
Temperature Corrections on Radiation Measurements using Modtran 3

D.A. Bunskoek, A.C.A.P. van Lammeren and A.J. Feijt

Abstract

Temperature Corrections on Radiation Measurements using Modtran 3

Temperatures obtained from radiation measurements on clouds need to be corrected for the radiative properties of the atmopsheric layer between the clouds and the sensor.
This can be done using the radiative transport model Modtran 3.
In order to simplify and automate the use of this model, an interface has been developed.
This interface uses radiosonde data to parameterize the atmosphere, and calculates a correction table for radiation measurements.
A number of cases were analysed.

It was concluded, that using this correction, a better cloud description is obtained, because of a more accurate estimate of the cloud base and top temperatures and hence the cloud base height.

Furthermore, it is now possible to use Modtran 3 routinely for temperature corrections on radiation measurements.

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1. Introduction

Weather and climate models which are used to predict and/or describe the weather rely on several parameters; for example pressure, temperature and relative humidity. The parameterization of clouds is one of the weakest components of current weather and climate models, although clouds play a very important role in our present climate. The fact that clouds are not properly parameterized is among other reasons due to our limited knowledge of clouds and their interaction with radiation.

Two important cloud parameters are the base and the top temperature. By measuring the radiance from a cloud in the so called 'atmospheric window', a wavelength interval from 8 to 11 μm, one can determine these temperatures.

Because clouds behave very much like blackbodies in the atmospheric window, one can use Planck's law to calculate the cloud temperature from the measured radiance. However, there is always an atmospheric layer between the sensor and the cloud. This layer influences the radiative measurements. In order to derive the correct temperature from the radiative measurements a correction has to be made. To determine the radiative properties of the part of the atmosphere between the sensor and the cloud, the radiative transport model Modtran 3 is used. Modtran 3 has to be 'fed' with parameters like pressure, temperature and relative humidity at several heights in the atmosphere, which are obtained from radiosondes.

This study contributes to two projects which aim for clarification of the relationship between the micro and macro properties of clouds and radiative transfer. These two projects are : the Tropospheric Energy Budget Experiment (TEBEX) and the Clouds and Radiation (CLARA) project. They are described concisely on the following pages.

1.1. TEBEX : Tropospheric Energy Budget Experiment

1.1.1. Introduction

The tropospheric energy budget is determined both by radiative transfer of energy and by transfer of energy and water due to air motions and precipitation. These transport processes are highly variable in time and space, mainly due to the presence of clouds, variability in landsurface properties and to small scale turbulence and convection.

For an adequate diagnosis of the tropospheric energy budget, data are needed both on the large scale flow properties and on small scale processes. Such data are scarce. Available global data sets suffer from a lack of detail, whereas experimental data with sufficient detail are generally only available for specific sites and short observational periods.

1.1.2. Observations

The observations of TEBEX started in the autumn of 1994 and were concluded on the last day of 1996. The experiment was conducted by KNMI in co-operation with the Royal Air Force, RIVM (National Institute of Public Health and the Environment), AUW (Agricultural University Wageningen) and UA (University of Amsterdam). The experiment was supported by the National Research Program for Global Air Pollution and Climate. In view of future operational applicability it was decided to primarily use commercially available instrumentation in TEBEX.
The TEBEX observations include :

- a Cloud Detection System (CDS), which is shown in figure 1.1.
- a main observing site at the Cabauw 200 metres mast experimental facility.
- a secondary observing site in a forest near Garderen equiped with a 36 metres mast.
- operational weather observations from synoptic stations on the TEBEX area.

1.1.3. Overview of TEBEX instrumentation

Table 1.1 - Overview of TEBEX instrumentation

| Instrument	Location	Properties
Cloud lidar	CDS	wavelength 911 nm, max range 4 km
	Cabauw	wavelength 911 nm, max range 7 km
IR-radiometer	CDS	spectral range 9,6 ... 11,5 μm
Pyranometer	CDS	spectral range 0,3 ... 4 μm
Meteorological tower	Cabauw	Vertical profiles of temperature, humidity, wind and visibility up to 200 m
	Garderen	Vertical profiles of temperature, humidity and wind up to 36 m
Windprofiler/RASS	Cabauw	1290 Mhz profiler.
Sonic and IFM	Cabauw	Measurement of turbulent fluxes of heat, water vapour, CO_2 and
	Garderen	momentum.
Shortwave and longwave radiometers	Cabauw	Measurement of the components of the radiation budget (shortwave and
	Garderen	longwave) and net radiation
Heat flux plates	Cabauw	measurement of the soil heat flux.
Pressure sensors	Cabauw	measurement of the water table depth.
Thermometer needles	Cabauw	measurement of the soil temperatures at different depths.
NOAA/AVHRR	space	5 spectral channels: 2-4 times a day.
Meteosat	space	3 spectral channels: every half hour.
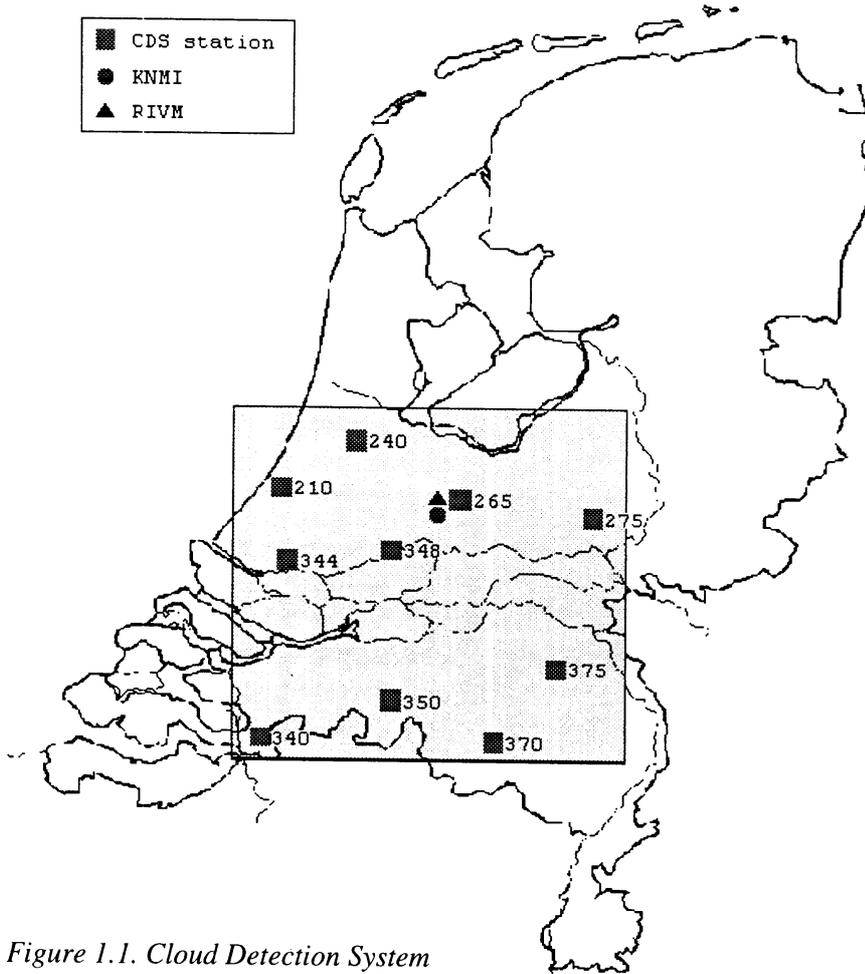
Figure 1.1. Cloud Detection System

1.2. CLARA : Clouds and Radiation

1.2.1. Introduction

The CLARA-project focuses on microphysics, its relation with the macro properties of clouds and its importance for routine observations of clouds by satellite and groundbased remote sensing. The information from the field campaigns are used to improve routine retrieval methods and to test detailed models for clouds and radiative transfer. These case studies will further serve as a testbed for parameterizations, that will be included in general circulation models.

Advanced groundbased remote sensing techniques like radar and lidar, as well as satellites play a crucial role in the monitoring of clouds. The algorithms which are used to derive physical parameters from these measurements are based on several crude assumptions about the micro-physical properties of the cloud and the relation between these properties and the measured (macro-physical) properties. This project offers the opportunity for validation of the different remote sensing techniques with in situ measurements.

1.2.2. Objectives

- To produce a validated data set on clouds and cloud-radiation interaction. This campaign-data set is composed of many cloud parameters derived from the different instruments, specified in table 1.2.

Table 1.2 - Cloud parameters and the instruments they are obtained with

Cloud parameter	Instrument
Base height	lidar ceilometers, atmospheric radar, RIVM-lidar
Top height	atmospheric radar, NOAA/AVHRR; For thin clouds the RIVM-lidar system and the lidar ceilometers are also able to observe the cloud top.
Base temperature	IR-radiometers
Top temperature	NOAA/AVHRR, Meteosat
Size distribution	lidar ceilometers, atmospheric radar, lidar, NOAA/AVHRR
Droplet size distribution	FSSP on aircraft and in cloud chamber
Vertical velocity in the clouds	atmospheric radar
Optical depth	RIVM-lidar, NOAA/AVHRR, lidar ceilometers
Liquid water content	FSSP on aircraft, microwave radiometer, atmospheric radar, NOAA/AVHRR

- To validate and calibrate the retrieval algorithms of various groundbased and satellite remote sensing instruments. This will improve the quality of the KNMI Cloud Detection System.

- To validate cloud- and radiative transfer models and parameterizations of clouds and radiation which are developed at KNMI.

1.2.3. CLARA instruments used in this study

Two satellite based instruments and one groundbased instrument were used in this study, which are

- *AVHRR (Advanced Very High Resolution Radiometer) aboard
  NOAA (National Oceanic and Atmospheric Administration)
  POES (Polar Orbiting Environmental Satellite)*

Sensor height	833 km
Temporal resolution	6 hours
Spatial resolution	1,1 × 1,1 km subsatellite
Channel 1	0,58 ... 0,68 μm
Channel 2	0,73 ... 1,1 μm
Channel 3	3,6 ... 3,9 μm
Channel 4	10,3 ... 11,3 μm
Channel 5	11,5 ... 12,5 μm

- *METEOSAT*

Sensor height	35.800 km
Temporal resolution	30 minutes
Spatial resolution	5 × 9 km subsatellite
Channel 1	0,5 ... 0,9 μm
Channel 2	5,7 ... 7,1 μm
Channel 3	10,5 ... 12,5 μm

- *Heimann infrared radiometer (groundbased)*

Sensor height	95 metres
Temporal resolution	10 seconds
Channel	9,6 ... 11,5 μm

The spectral response functions of these instruments, as used in this study, can be seen in figure 2.3., page 12.

2. Background

2.1. Atmospheric Radiation

The main components of the atmosphere are O_2 and N_2, which take in over 99% of the total volume of the atmosphere.

These gases mainly absorb at wavelengths in the ultra-violet (UV) region, except for the O_2-A and O_2-B intervals (around 760 and 690 nm, respectively).

Changes in the pressure and temperature profile of the atmosphere change the shape of the molecular absorption intervals. The temperature has an influence on the 'strength' of the absorption intervals due to population changes in the molecular energy levels. Pressure changes affect the width of the absorption intervals, because the decay time is dependent on pressure.

Besides molecules, the atmosphere contains small particles like dust, water droplets, particles formed by fotochemical reactions and particles originating from volcanic explosions.

Blackbodies

A so-called blackbody absorbs all incoming energy; and it radiates the same amount of energy.

The total amount of emitted radiation per square meter of a blackbody can be described by the Stefan-Boltzmann law :

$$E_b = \sigma \cdot T^4$$

(2.1)

E_b = emitted radiation $\qquad$ [W m^{-2}]

σ = emission coefficient $\qquad$ [5,67·10^{-8} W m^{-2} K^{-4}]

T = temperature $\qquad$ [K]

The amount of energy that is radiated by a blackbody at wavelength λ is given by Planck's law :

$$E_{\lambda b} = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

(2.2)

$E_{\lambda b}$ = radiated energy $\qquad$ [W m^{-2} m^{-1}]

h = Planck constant $\qquad$ [6,63·10^{-34} Js]

c = speed of light $\qquad$ [3,00·10^8 m s^{-1}]

λ = wavelength $\qquad$ [m]

k = Boltzmann constant $\qquad$ [1,38·10^{-23} J K^{-1}]

The spectrum of electromagnetic radiation is categorised according to wavelength as follows :

0,001 μm	...	0,4 μm	:	ultra-violet
0,4 μm	...	0,76 μm	:	visible light
0,76 μm	...	4 μm	:	near infrared
4 μm	...	25 μm	:	thermal infrared
25 μm	...	1000 μm	:	far infrared

It is important to note that 99% of the solar energy is located in the wavelength interval from 0,2 μm to 4 μm. This can also be seen from a different point of view. Because the surface temperature of the sun is about 6000 K, it can be seen as a blackbody at that temperature. The earth and clouds radiate at an average temperature of 288 K. Because of this large temperature difference the spectral emission of the sun and that of the earth and clouds can very well be measured separately, as shown in figure 2.1.
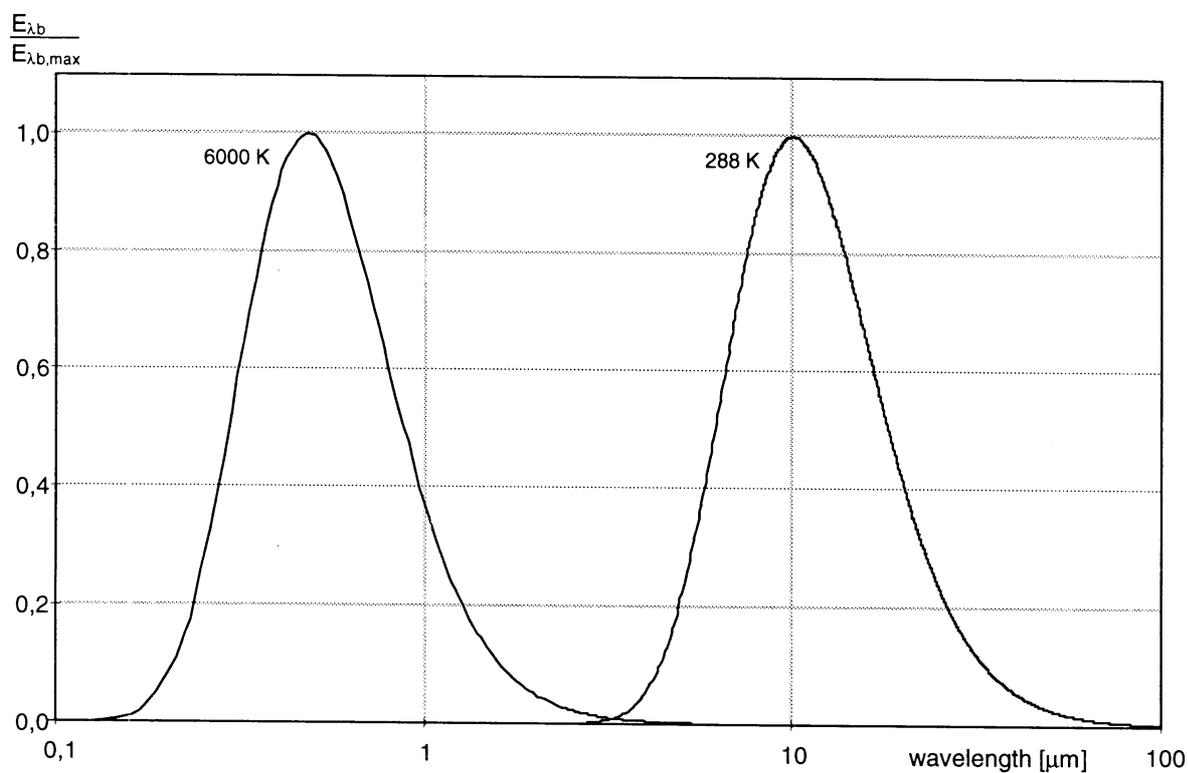

Figure 2.1 - Peak-normalised spectral emission of blackbodies at 6000 and 288 K

Absorption

Energy can be absorbed in different ways, e.g. by :

increase of rotational energy of a molecule	($\lambda \approx 0,1 \dots 10$ mm)
increase of vibrational energy of atoms along their connecting line	($\lambda \approx 1 \dots 40$ μm)
changes in electron configuration	($\lambda \approx 0,1 \dots 1$ μm)

Absorption is determined by the use of an absorption coefficient. This absorption coefficient is defined as the fraction of incoming energy that is absorbed, and can thus be represented by the following equation :

$$\alpha = \frac{E_{abs}}{E_{in}} \qquad (2.3)$$

Because a blackbody absorbs all incoming energy its absorption coefficient $\alpha = 1$
The absorption of radiation in the atmosphere takes place as follows :

ultra-violet (UV)	ionisation/division of molecules and absorption by O_2 and O_3
O_2, O_3	$\lambda < 0,24$ μm
O_3	$\lambda\ 0,24 \dots 0,32$ μm
infrared (IR)	absorption by O_3, H_2O and CO_2
O_3	strong narrow absorption interval at 9,7 μm
H_2O	$\lambda < 4$ μm
	$\lambda\ 5 \dots 8$ μm
	$\lambda > 11$ μm (rapidly increasing)
CO_2	$\lambda\ 13 \dots 17$ μm

This means, that almost all of the longwave radiation is absorbed by the atmosphere, except for the radiation in the interval from 8 to 11 μm; the so-called 'atmospheric window'.

The above mentioned absorption can be observed by comparing radiative calculations from Modtran 3 which simulate measurements at a cloud with and without an atmosphere. An example case of such calculations is shown below.

Example

In this example a blackbody of 17,3 °C at 0 m describes the cloud. This irrealistic cloud height is used in order to determine the influence of the entire atmosphere, and not just the part of the atmosphere that is situated between the cloud and the sensor.
The results from simulated satellite based measurements with and without September 1st 1996 15:00 atmosphere are shown in figure 2.2.
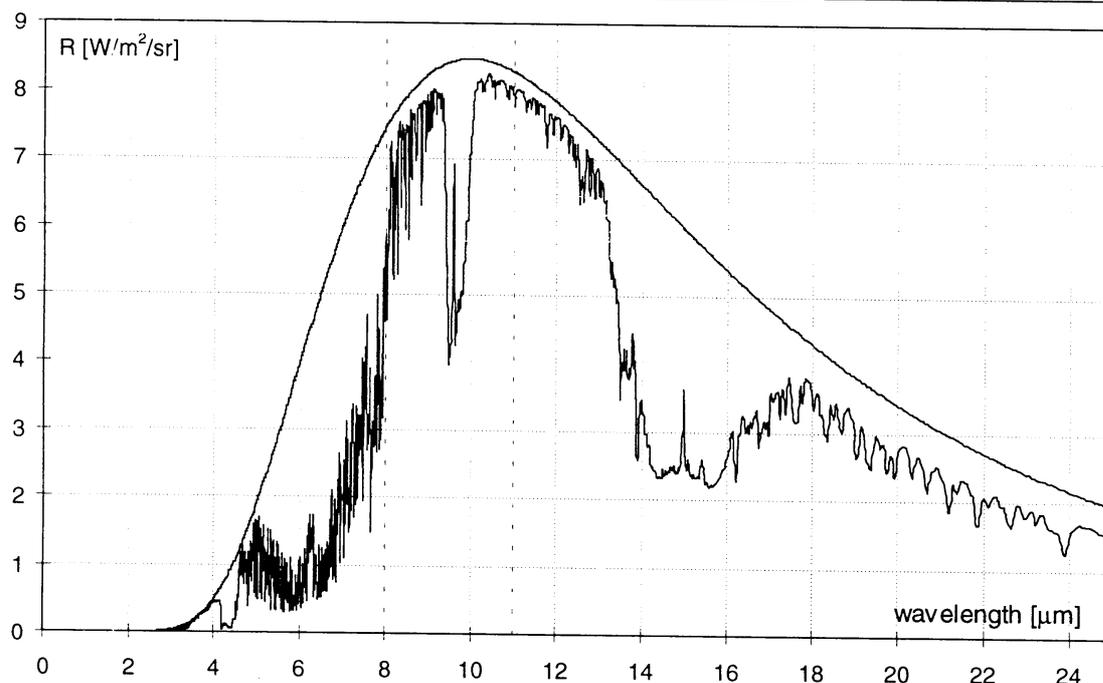
Figure 2.2 - Radiance calculations (satellite based) with and without September 1st, 1996, 15:00 atmosphere, performed by Modtran 3

The O_3 absorption peak at 9,7 μm is prominently visible in figure 2.2, as well as the absorption intervals from CO_2 and H_2O, at 13 to 17 μm and 5 to 8 μm, respectively.
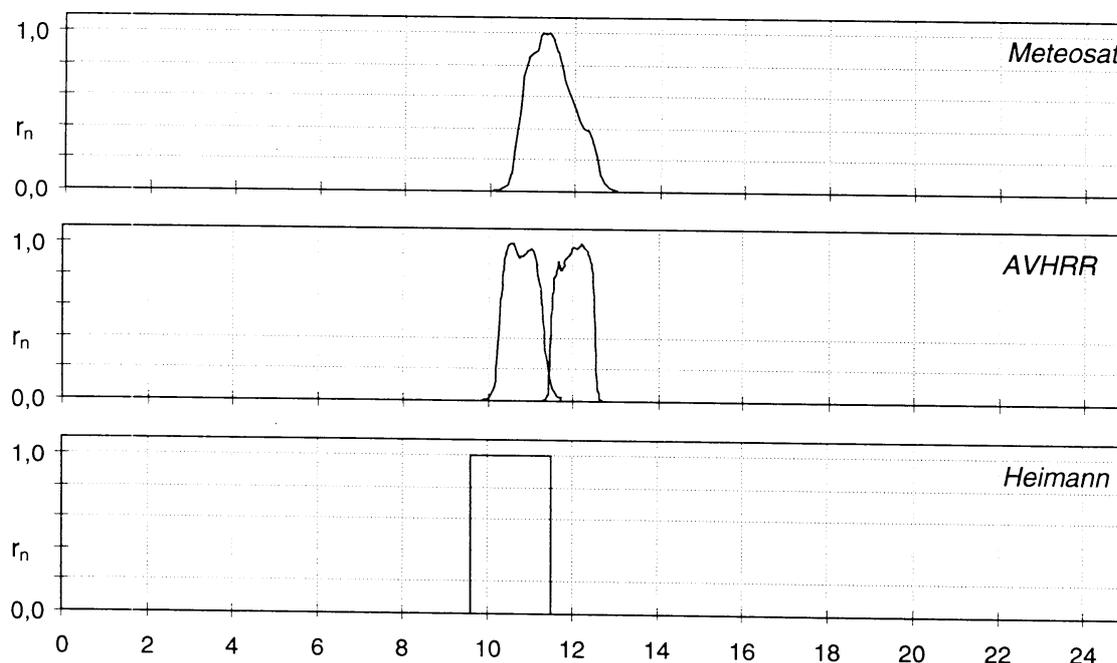
Figure 2.3 - Spectral response functions used in this study

Figure 2.3 in combination with figure 2.2 shows that the largest influence of the absorption on measurements from the Heimann IR radiometer is caused by the O_3 absorption peak.

The AVHRR channel 5 spectral response function has its peak at about 12,2 μm, and therefore the absorption by water is most likely to influence these measurements.

Measurements from Meteosat and AVHRR channel 4 are influenced the least.

2.2. Modtran 3

2.2.1. Introduction

The Modtran code has been developed by the US Air Force Geophysics Laboratory (AFGL) starting in 1972. It has been written in the FORTRAN style of the seventies

The version used in this study is Modtran 3 v 1.5.

2.2.2. Specifications

Modtran 3 calculates:

- atmospheric transmittance

- atmospheric background radiance

- single scattered solar and lunar radiance

- multiple scattered solar and thermal radiance

- direct solar irradiance

Modtran includes molecular absorption as well as scattering. It operates at moderately high spectral resolution (1 cm^{-1} = 1 wave per cm) in the range of 0 to 50.000 cm^{-1} in steps of 1 cm^{-1} (0,2 μm to infinity)

The code consists of several default profiles that determine the spectral behaviour of molecular species (0 ... 100 km), like absorption and refraction.
Also, several representative atmospheric, aerosol, cloud and rain models are incorporated in the code.
A climatology can be chosen by selecting one out of six reference atmospheres, which all define density and mixing ratios of H_2O, O_3, CH_4, CO and NO_2, as well as temperature and pressure as a function of height.
All three of these properties can also be specified by the user.

The AFGL radiative transfer code, while perhaps conceptually and scientifically elegant, is not user-friendly, modular, or an example of state-of-the-art programming; mainly due to the open evolution. There is also a lack of documentation; both within the source code and in its backup reports.

3. Realisation

3.1. Operation of Modtran 3

The interface to the radiative transport model Modtran 3 is specified by non-interactive input and output, which is discussed below.

3.1.1. Input

The file that is required to specify calculation parameters like wavelength interval, viewing angle and the atmospheric parametrization is called *tape5*, pointing out the similarity with the computer tape used to enter data in the early days of computing.

An example of such a file is given below.

```
t   7    2     1    0    0    0    2    2    2    2    1    1    1 286.800      .00
f   0f   0   355.000
    0    1    0             0              .000
   61    0    0-- 10 Jun 1996 --   0
        0.004 1.021E+03 2.868E+02 9.500E+01 3.700E-01 2.300E-03AAH22222222222
        0.076 1.013E+03 2.865E+02 8.300E+01 3.700E-01 2.300E-03AAH22222222222
        0.144 1.005E+03 2.878E+02 7.900E+01 3.700E-01 2.300E-03AAH22222222222
        0.210 9.968E+02 2.888E+02 7.500E+01 3.700E-01 2.300E-03AAH22222222222
        0.275 9.893E+02 2.886E+02 7.300E+01 3.700E-01 2.300E-03AAH22222222222
        0.335 9.823E+02 2.885E+02 7.200E+01 3.700E-01 2.300E-03AAH22222222222
        0.395 9.754E+02 2.881E+02 7.000E+01 3.700E-01 2.300E-03AAH22222222222

       (radiosonde profile partly skipped)

        6.252 4.699E+02 2.555E+02 3.100E+01 3.700E-01 2.300E-03AAH22222222222
        7.493 3.970E+02 2.461E+02 3.800E+01 3.700E-01 2.300E-03AAH22222222222
        8.938 3.234E+02 2.339E+02 2.900E+01 3.700E-01 2.300E-03AAH22222222222
       10.688 2.486E+02 2.204E+02 2.200E+01 3.700E-01 2.300E-03AAH22222222222
       12.779 1.786E+02 2.154E+02 7.000E+00 3.700E-01 2.300E-03AAH22222222222
       15.236 1.212E+02 2.161E+02 1.000E+00 3.700E-01 2.300E-03AAH22222222222
       18.194 7.580E+01 2.166E+02 1.000E+00 3.700E-01 2.300E-03AAH22222222222
       30.000                                                   2222222222222
       35.000                                                   2222222222222
       40.000                                                   2222222222222
       45.000                                                   2222222222222
       50.000                                                   2222222222222
       50.000      0.004  180.000      .000      .000      .000    0
         769        990        1         2
    0
```

Figure 3.1 - Example of tape5 for Meteosat temperature correction (6:00 - June 10th, 1996)

This *tape5*, that is used for the purpose of temperature corrections, can roughly be divided into three parts, hereafter called the *front*, *profile* and *back*, respectively.

Each part consists of one or more so-called cards, whose arrangement is shown in Appendix A.

The front part of tape5

The *front*, made up by the first four lines in figure 3.1, consists of *card1*, *card1a*, *card2* and *card2c*, which, among other things, take care of the following :

card1 tells Modtran 3 to read in a new model atmosphere, that the output should be 'short' and that the boundary temperature is 286,8 K.

card1a sets the CO_2 mixing ratio to a value of 355 ppmv (1995 value).

card2 turns off the aerosol attenuation in the calculation.

card2c sets the number of atmospheric levels that have to be read in to 61, and defines the format of these lines to be the strict Lowtran format.

The profile part of tape5

The *profile* part consists of data obtained from radiosonde measurements. Modtran allows the user to specify a maximum of 61 lines, that should describe the entire atmosphere. Because a file containing radiosonde data consists of more than 61 lines, an appropriate selection of lines needs to be made. To obtain the most reliable atmopsheric parameterization, one should use a large line density at the bottom of the atmosphere, because it has the largest influence on radiative measurements. This large influence is caused by the relatively large amount of particles in the lower atmosphere (relatively high pressure and humidity in comparison to the top of the atmosphere, visualized in figure 3.2)
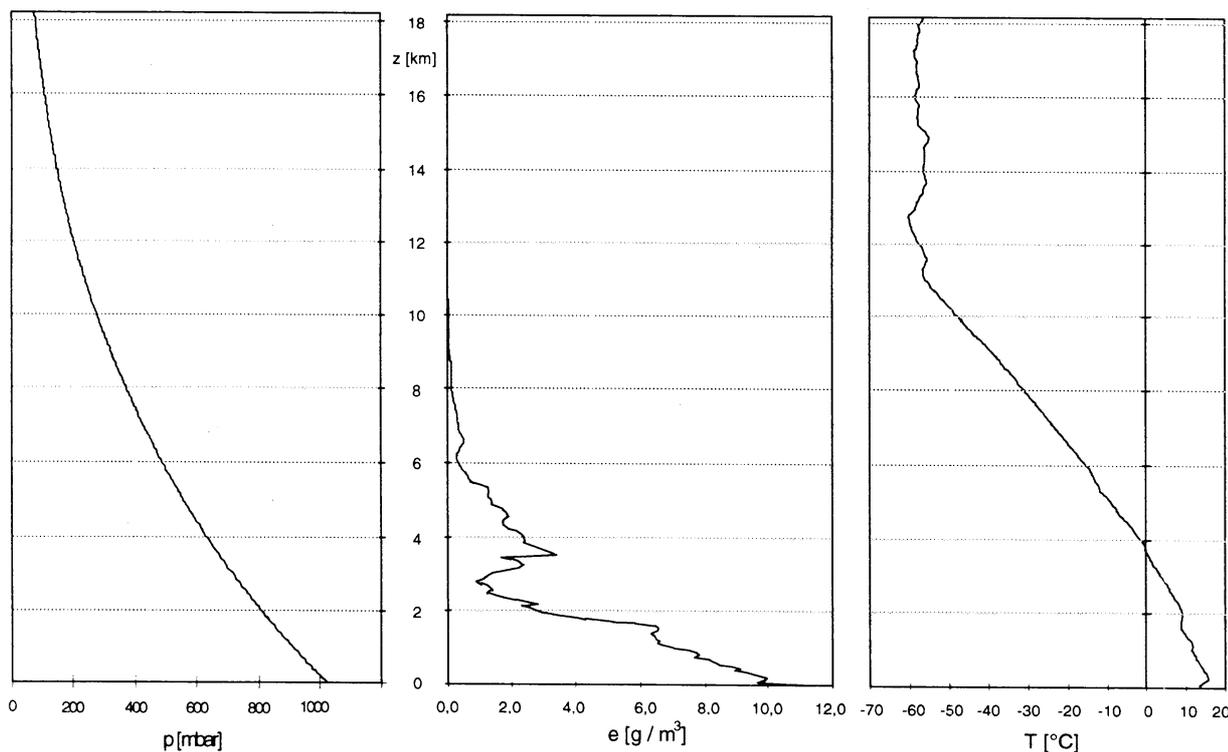

Figure 3.2 - Pressure, humidity and temperature profile obtained from radiosonde measurements (6:00 - June 10th, 1996 Atmosphere)

It was chosen to spread the profile lines logarithmically throughout the atmosphere. This has been found to give the best estimate of the radiative properties of the atmosphere. The profiles used to specify the June 10th, 6:00 atmosphere in Modtran 3 are depicted in figure 3.3.[1]
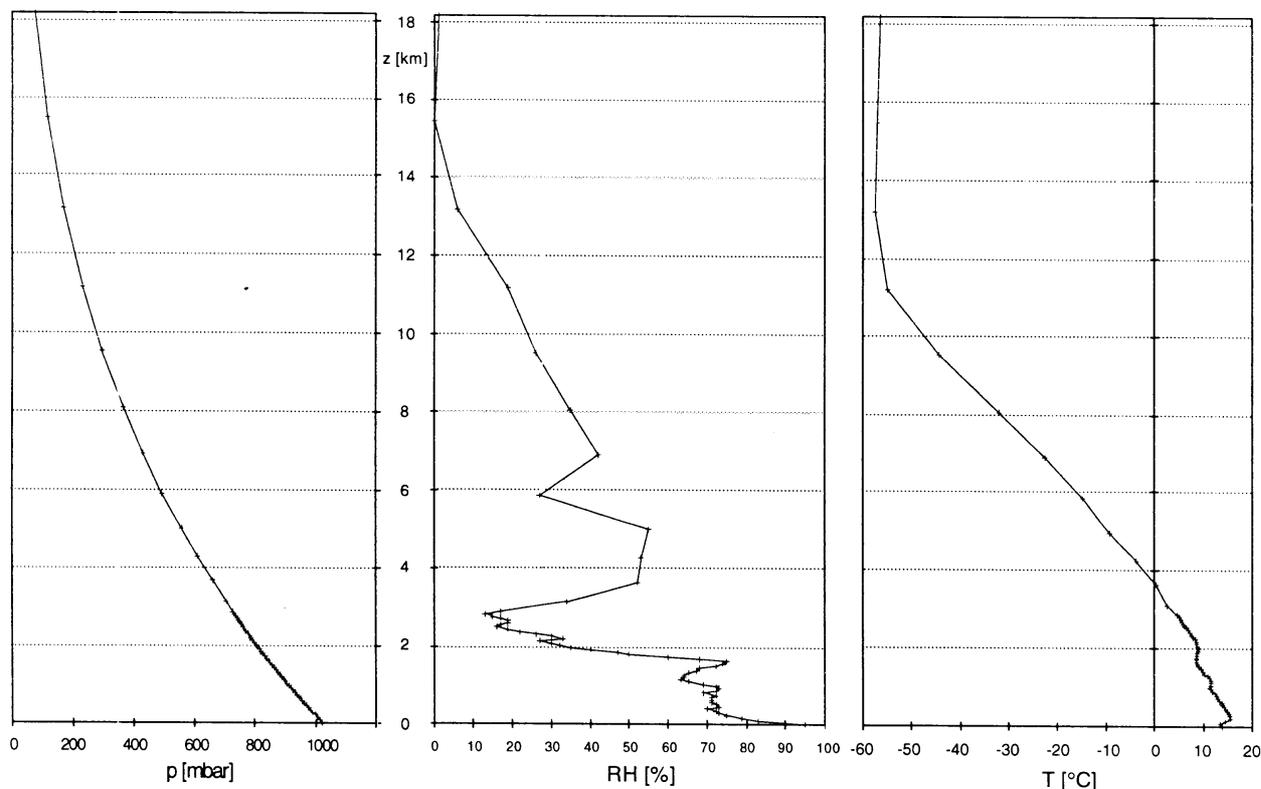
Figure 3.3 - Logarithmically spread profile points describing the atmosphere in Modtran 3

In order to spread the profile lines logarithmically throughout the atmosphere, the lines near the earth surface should be very close to eachother. However, the radiosonde measurements do not provide enough measurements near the earth surface to make the spread entirely logarithmical. It was chosen to select the next point from the radiosonde measurements, when no measurement near the logarithmical height value was available.

Therefore, the first part of these profiles (i.e. the nearest to the earth surface) is described by subsequent points from the radiosonde file, so in fact no logarithmical spread has taken place in this part. In the part where the logarithmical spread is taking place, it was chosen to average the values for the relative humidity and the temperature, to provide an accurate description of the atmosphere.

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[1] Note that instead of the absolute humidity, the relative humidity is shown. This was chosen because the relative humidity can be obtained directly from radiosonde measurements and is used as is in the further course of this report

The back part of tape5

The *back* part of *tape5* consists of *card3*, *card4* and *card5*.

card3   determines the geometrical path along which the calculation has to be made; in this case from 50 km to 4 m.

card4   defines the spectral range of the calculation; in this case from 769 to 990 cm^{-1}, in steps of 1 cm^{-1}.

card5   tells Modtran 3 to stop.

3.1.2. Output

After performing the requested calculations, Modtran 3 writes the output to three output files, called *tape6*, *tape7* and *tape8*.

tape6   contains the complete output of the Modtran 3 model, as well as the input as it was interpreted by the code, which can be useful for tracing errors.

tape7   consists of a header followed by the spectral data. This spectral data can be used for further processing of the results.

tape8   can contain three kinds of spectral data, dependent on the type of calculation that is performed.

3.2. Program description

3.2.1. Introduction

The program *create* and its subprograms were written in ANSI-C release 5.3 on a Silicon Graphics INDY workstation running UNIX operating system.

It provides an interface for Modtran 3, that simplifies the use of this radiative transfer model for cloud temperature corrections on groundbased and satellite based measurements. It also makes automation of these corrections possible, which is useful for processing large amounts of data.

A program flow diagram from the main program *create* is shown on pages 19 to 21.

3.2.2. Description

A description of the activities of the modules which are depicted in the program flow diagram is shown below. For a more detailed description see Appendix B.

create	creates the Modtran 3 input file, and uses Modtran 3 to calculate the temperature corrections while iterating through the specified atmosphere.
check_file	checks important files for existence and integrity.
build_frnt	builds the front of *tape5*.
build_prof	builds the profile part of *tape5*.
build_back	builds the back part of *tape5*.
set_date	sets several date dependent parameters in *tape5*.
set_height	sets height from the beginning or the end of the Modtran 3 calculation.
progress	shows the progress of *create*.
filter	applies a filter to the output spectral radiances in *tape6*, thus obtaining the integrated radiance.
analyse	analyses the create output file *mod-file* to obtain a temperature correction table.

(Figure 3.4)

3.2.3. Program flow diagram

(Figure 3.4 continued)

Execute
analyse

tvr-file

Print analysed output
to screen
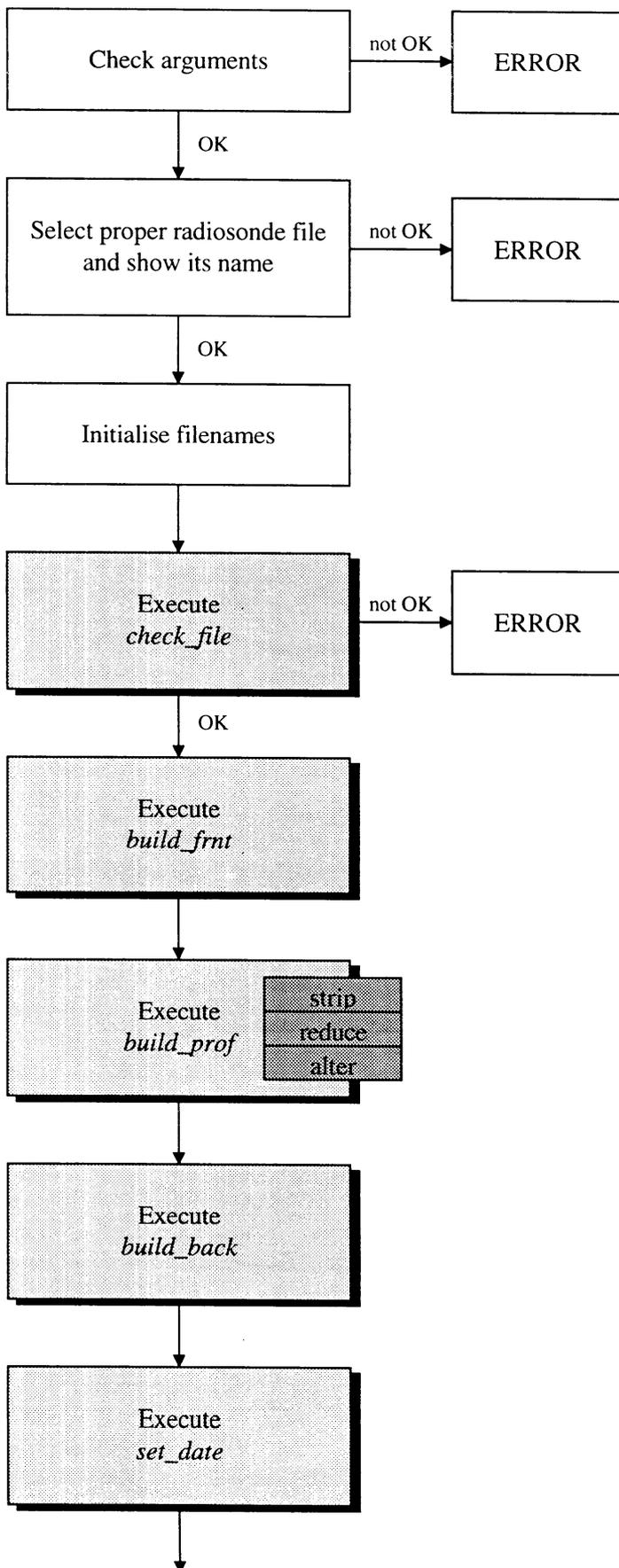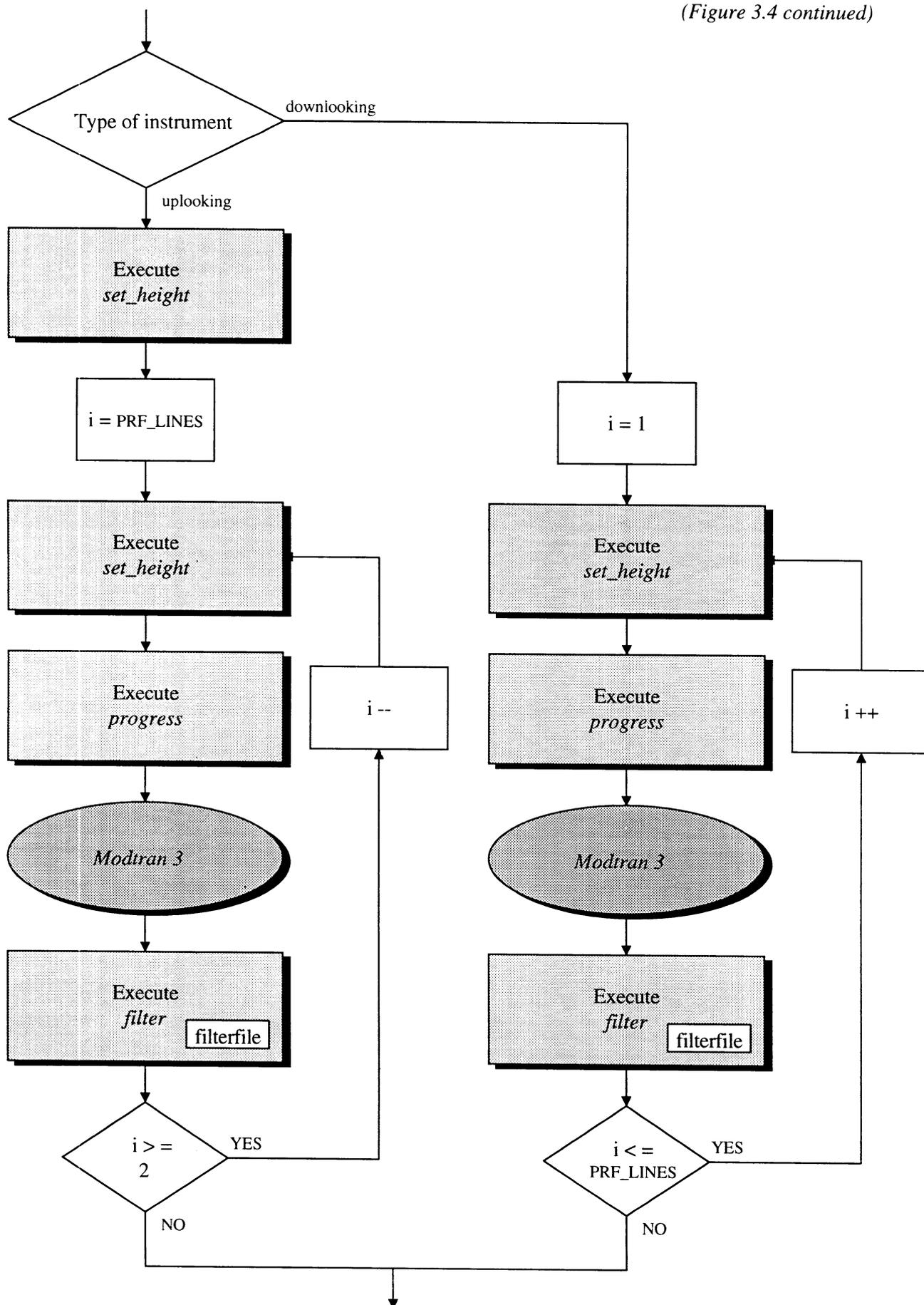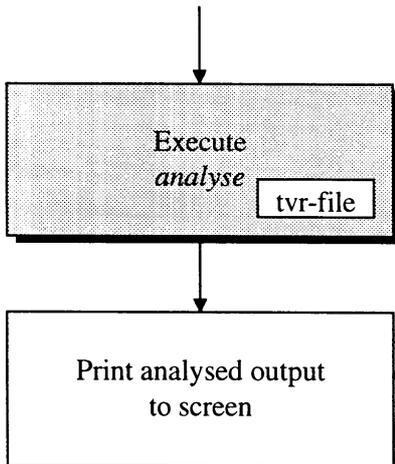
3.2.4. Output

The output of the main program 'create' consists of two files whose filenames are the same as the radiosondefile name, except for the extensions. The extensions of the output files are ".mod" and ".ana". The first extension indicates that the file results from a Modtran 3 calculation, while the second indicates that we are dealing with the results of an analysis. This last file is printed to the screen at the end of the program, as indicated in the flow diagram above.

The first file, further indicated as the mod-file, consists of a table containing radiosonde parameters and the filtered radiance.
An example of a part of such a file is shown below in table 3.1.

z [km]	p [mbar]	$T_{radiosonde}$ [K]	RH [%]	$R_{filtered}$ [W m^{-2} sr^{-1}]
0.004	1021	286.9	95	10.042
0.076	1013	286.6	83	10.007
0.144	1005	287.8	79	10.150
0.210	996.8	288.8	75	10.273
0.275	989.3	288.7	73	10.261
0.335	982.3	288.5	72	10.232
0.395	975.4	288.2	70	10.196
(file partly skipped)				
6.252	469.9	255.6	31	5.942
7.493	397.0	246.2	38	4.921
8.938	323.4	234.0	29	3.767
10.688	248.6	220.4	22	2.702
12.779	178.6	215.4	7	2.367
15.236	121.2	216.1	1	2.412
18.194	75.8	216.7	1	2.451

Table 3.1 - Example of the structure of the mod-file from Meteosat, 6:00, June 10th 1996

The file with the ".ana" extension, further indicated as the ana-file, contains the same values as the mod-file. Besides that, it contains an extra column, in which the temperatures corresponding to the filtered radiances are shown. This temperature is the temperature that the instrument will measure if there is a cloud boundary at the height specified in the first column.

An example of a part of an ana-file is shown below in table 3.2.

z[km]	p[mbar]	RH[%]	$T_{corrected}^{2)}$ [°C]	$T_{measured}$ [°C]	$R_{filtered}$ [W m^{-2} sr^{-1}]
0.004	1021	95	13.7	12.3	10.042
0.076	1013	83	13.4	12.1	10.007
0.144	1005	79	14.6	13.0	10.150
0.210	996.8	75	15.6	13.8	10.273
0.275	989.3	73	15.5	13.7	10.261
0.335	982.3	72	15.3	13.5	10.232
0.395	975.4	70	15.0	13.3	10.196
(file partly skipped)					
6.252	469.9	31	-17.6	-17.7	5.942
7.493	397.0	38	-27.0	-27.1	4.921
8.938	323.4	29	-39.2	-39.2	3.767
10.688	248.6	22	-52.8	-52.8	2.702
12.779	178.6	7	-57.8	-57.8	2.367
15.236	121.2	1	-57.1	-57.1	2.412
18.194	75.8	1	-56.5	-56.5	2.451

Table 3.2 - Example of the structure of the ana-file from Meteosat, 15:00, June 10th 1996

---

[2] Note that $T_{radiosonde}$ from table 3.1 and $T_{corrected}$ from table 3.2 have the same values except for their units.

3.3. How to implement a new instrument

To implement a new instrument, the following steps need to be taken :
• creating the directories where the software should be located.
• compiling the sourcecode, using a new initialisation file[3].

In the initialisation file "ini.h", which is used while compiling, the user can specify several properties of the instrument and of the way the correction calculation will take place.

```
#define INSTRUMENT       "uplooking"
#define SENSOR_HEIGHT    95      /* in metres */
#define ZENITH_ANGLE     0       /* aberration from viewing line */

#define PRF_LINES        61      /* no. of lines from radiosonde profile */
#define STD_LINES        0       /* no. of lines from standard atmosphere */

#define MIN_WAVENR       870     /* in cm-1 */
#define MAX_WAVENR       1042
#define STEP_WAVENR      1

#define FILTER           "heim_ir_block.fil"
#define TEMP_VS_RAD      "kt1585.tvr"

#define MOD_PATH         "/sd3/usr/people/bunskoek/modtran3"
#define ORG_PATH         "/sd3/usr/people/bunskoek/modtran3/heimann"
#define DAT_PATH         "/sd3/usr/people/bunskoek/modtran3/radiosondes"
#define FIL_PATH         "/sd3/usr/people/bunskoek/modtran3/heimann/Filters"
#define TVR_PATH         "/sd3/usr/people/bunskoek/modtran3/heimann/T_vs_rad"
#define OUT_PATH         "/sd3/usr/people/bunskoek/modtran3/heimann/Output"
```

Figure 3.5 - Example initialisation file for Heimann IR radiometer

The first parameters describe the instrument geometry.

INSTRUMENT   type of instrument; uplooking or downlooking.
SENSOR_HEIGHT   distance from the instrument to the surface of the earth in metres.
ZENITH_ANGLE   angle between the viewing direction of the instrument and a vector perpendicular to the earth surface in degrees.

The next two parameters define how the atmospheric profile used in the calculations needs to be built.

PRF_LINES[4]   number of lines from the radiosonde file that have to be used as input for Modtran 3.
STD_LINES[4]   number of standard profile lines that have to be inserted after the lines from the radiosonde profile, to make sure that the entire atmosphere is defined from the object to the instrument (in case of satellite measurements).

---

[3] It is important to enter the correct DESTINATION directory in *makefile* before compiling the source using the new *ini.h*.

[4] (PRF_LINES + STD_LINES) cannot be bigger than 61 in the version of Modtran 3 (v 1.5) used in this study.

The following parameters are used to define the wavelength interval in which the amount of radiation has to be calculated.

MIN_WAVENR	minimum wavenumber [cm^{-1}]
MAX_WAVENR	maximum wavenumber [cm^{-1}]
STEP_WAVENR	step size [cm^{-1}]

With the last part of the initialisation file the important files and directories are defined.

FILTER	name of the filter file (file needs to be located in *FIL_PATH*)
TEMP_VS_RAD	name of the file containing the parameters for converting the filtered radiance to the measured temperature (file needs to be located in *TVR_PATH*)

MOD_PATH	path of Modtran 3.
ORG_PATH	original path, indicating het location of 'create' and its subprograms.
DAT_PATH	path in which the radiosonde files are located, sorted by day.
FIL_PATH	location of the filter files.
TVR_PATH	path in which the files containing temperature versus radiance tables are located.
OUT_PATH	path where output files (mod-file and ana-file) should be written to.

Usually, only the spectral response characteristics of the instrument are known. To obtain the temperature versus radiance table needed in the *create* run an utility was written. This utility called *bb_rad* calculates the spectral blackbody radiance at several temperatures and applies the instrument response filter to these radiances, thus creating a temperature versus radiance table.

4.   Results

4.1.   Introduction

In order to test the temperature corrections, two testcases were analysed.

The cloud covers for which the temperature corrections are performed had to be well defined, in order to avoid uncertainty in this part of the analysis. This meant looking for an optically thick stable cloud deck which is measured by various instruments to be able to intercompare the several outcomes.

In practice this meant analysing data from the CLARA measurement campaigns, because many instruments were available during these campaigns.

The two test cases that were chosen are :

* April 19th, 1996, 6:00 UTC.
* September 1st, 1996, 14:45 to 15:15 UTC.

4.2.   April 19th, 1996, 6:00 UTC

4.2.1.   Introduction

This particular testcase is interesting for the CLARA project because of the stable cloud cover. The low altitude of this cloud cover made it suitable for aircraft measurements, thus producing in situ measurements of this water cloud.

The lidar (light detection and ranging) measurements are shown in fgure 4.1.
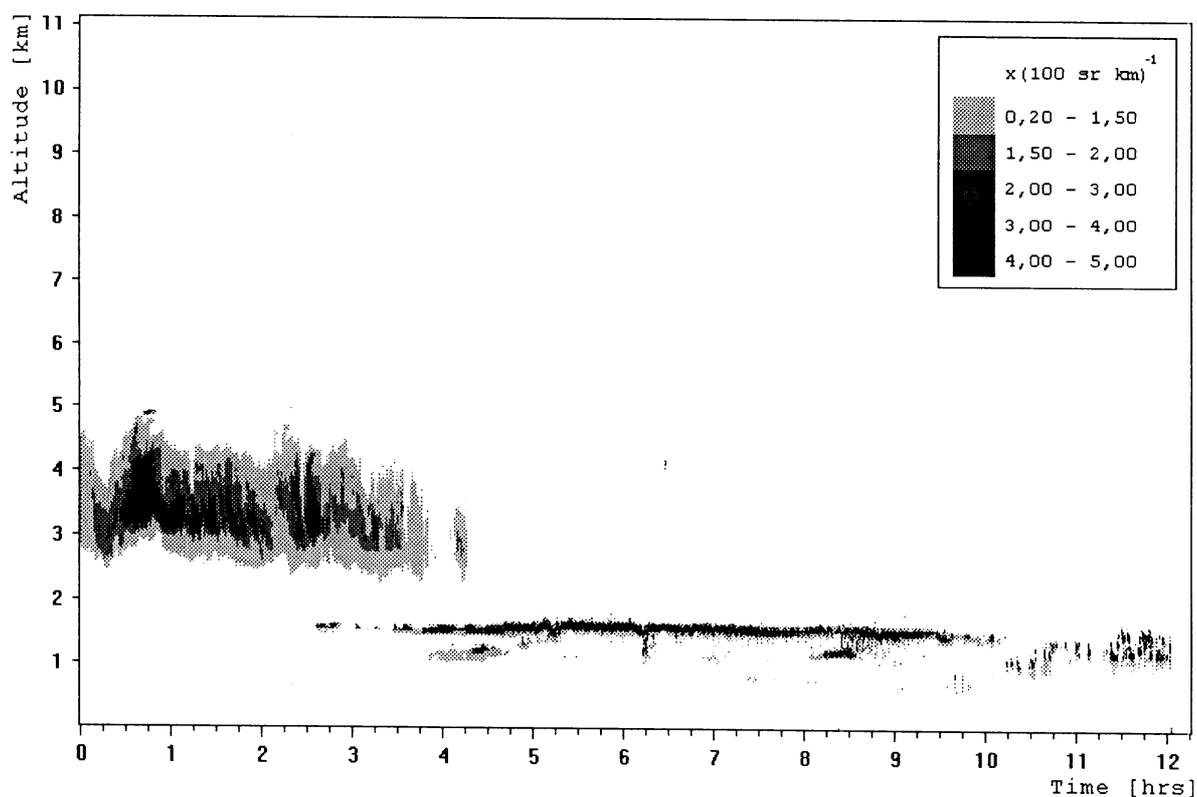
Figure 4.1 - Range corrected lidar return, KNMI-ESA lidar (Delft), April 19th, 1996

From the lidar data the cloud base height and top height of the stationary cloud deck are determined.

Cloud base height	1500 ± 100 m.
Cloud top height	1700 ± 100 m.

4.2.2. Temperature corrections

Satellite based measurements

In figure 4.2 the different temperature profiles are plotted as they would be measured (if there were a cloud at that specific altitude) by the different satellite based instruments. The radiosonde temperature profile is also plotted. So, from figure 4.2 the correction for these satellite based measurements can be derived. The corrections are obtained using *create* (see section 3.2).
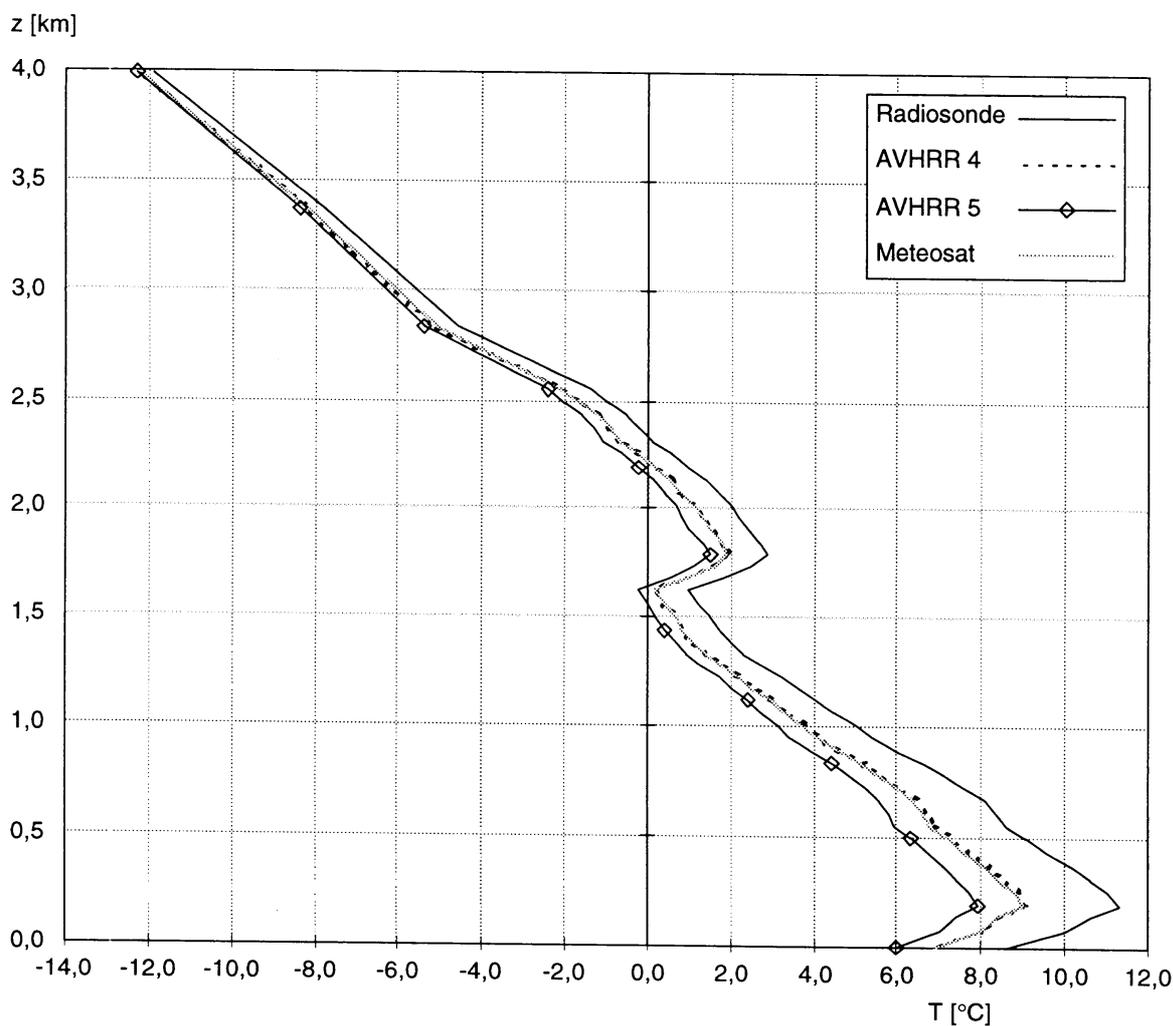
Figure 4.2 - Temperature correction plot for satellite based instruments;
Delft, April 19th, 1996, 6:00 UTC

Discussion

In figure 4.3 an inversion layer can be seen at about 1700 metres. In an inversion layer the temperature increases with height. This hampers the rising of thermals, which can result in the formation of clouds at that altitude.

The largest temperature correction is calculated for the AVHRR channel 5. At an altitude of 1700 metres (cloud top in lidar analysis), the correction is 1,3 °C.

The corrections that are needed for the AVHRR channel 4 and Meteosat measurements are almost equal. The correction is 0,8 °C at 1700 metres for AVHRR channel 4, while the correction for Meteosat is slightly higher; 0,9 °C. The similarity in these corrections is caused by the small influence of absorption in both measurement channels (see also figure 2.2 and 2.3, page 12).

Groundbased measurement

The typical brightness temperature of the cloud base that was measured using the Heimann radiometer is about 2 °C for this particular testcase. The temperature correction that has to be performed on this measurement, can be derived from figure 4.4. The real cloud base temperature (= the radiosonde temperature) according to *create* is 1,5 °C at 1502 metres, which is also the cloud base height, as measured by the lidar.
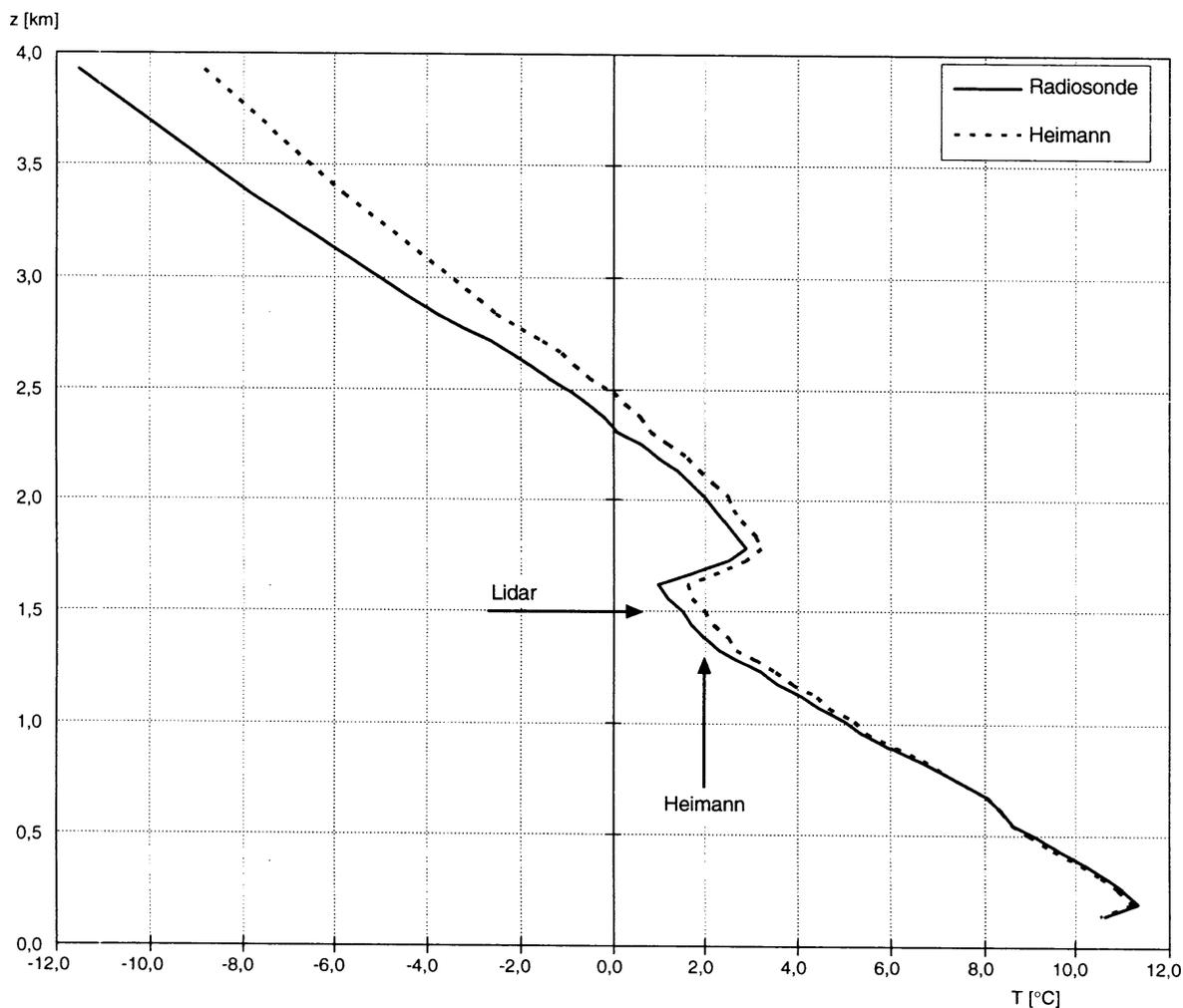
Figure 4.4 - Heimann temperature correction; Delft, April 19th, 1996, 6:00

Discussion

The lidar analysis and the corrected temperature plot both put the cloud base at an altitude of about 1500 metres, which is an indication that using this temperature correction plot helps enabling an intercomparison of the Heimann IR radiometer and the lidar system.

When no correction is made, one obtains a different cloud base altitude from the radiosonde measurements. In this particular case, looking up the uncorrected temperature of 2 °C in the radiosonde data would result in a cloud base altitude of 1383 m. This is a difference of more than 100 m.

4.3. September 1st, 1996, 14:45 to 15:15 UTC

4.3.1. Introduction

The interest in this particular testcase is mainly because of the CLARA project. There was convection in the cloud cover around 15:00 UTC which was well visible in radar measurements. This is the main reason why this day was picked as a collective study object for the contributing parties in CLARA. One of the analyses that has been made was a temperature histogram produced from cloudy pixels measurements using the AVHRR channel 4. The analysis is interesting for this study because it enables the verification of temperature corrections for this particular (and the other) satellite based instrument.

A lidar analysis of this testcase is depicted in figure 4.5.
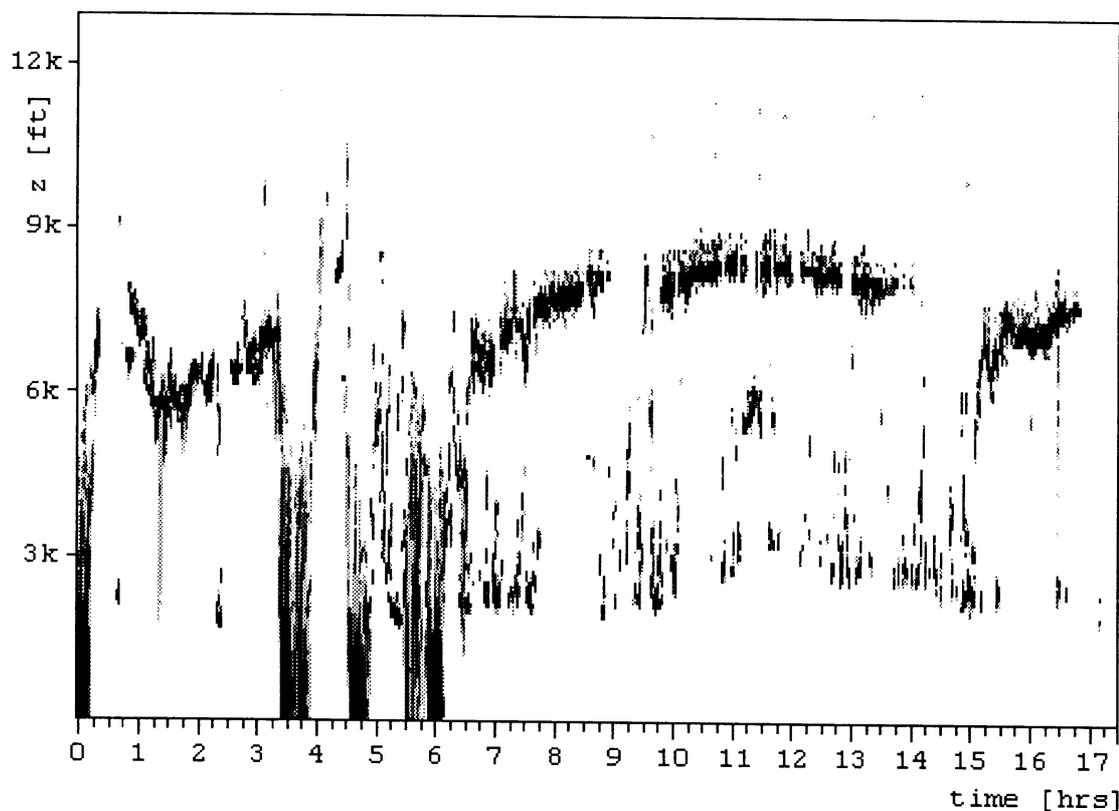
Figure 4.5 - Range corrected lidar return, KNMI-ESA lidar (Delft), September 1st, 1996

Because the AVHRR channel 4 measurement closest to 15:00 is at 13:22 it was chosen to produce a temperature histogram of this measurement.

Figure 4.6 shows that a cloud cover temperature of 267,5 K (-5,7 °C) can be used when one wants to define the cloud top temperature.
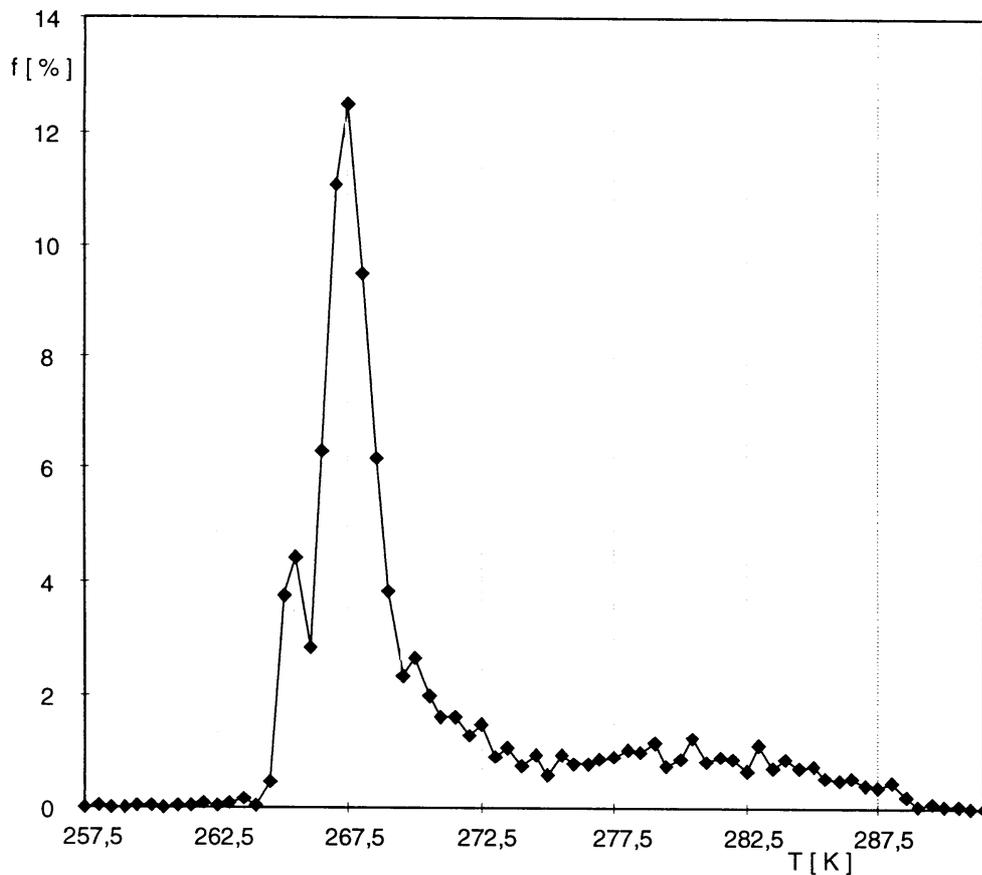
Figure 4.6 - Temperature histogram of AVHRR 4 measurements;
        TEBEX area; September 1st, 1996, 13:22 UTC

Channel 1 of the AVHRR provides an overview of the cloud distribution, as can be seen in figure 4.7.
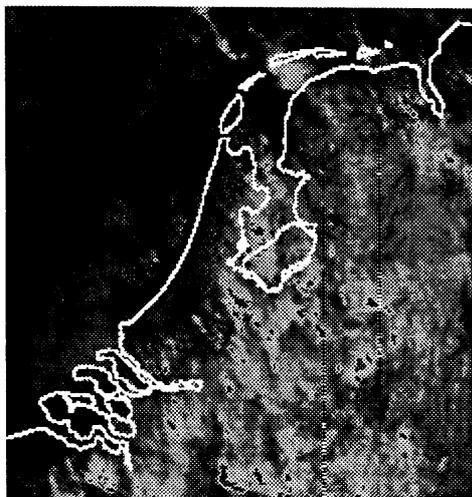
Figure 4.7 - AVHRR channel 1 measurements over the Netherlands; 13:22 UTC

4.3.2. Temperature corrections

The temperature correction on AVHRR channel 4 measurements was executed with two different atmospheres (at 12:00 and 15:00) because the AVHRR measurement is in between these radiosonde measurements describing the atmosphere.

The outcome of this analysis is shown in figure 4.8 and 4.9.
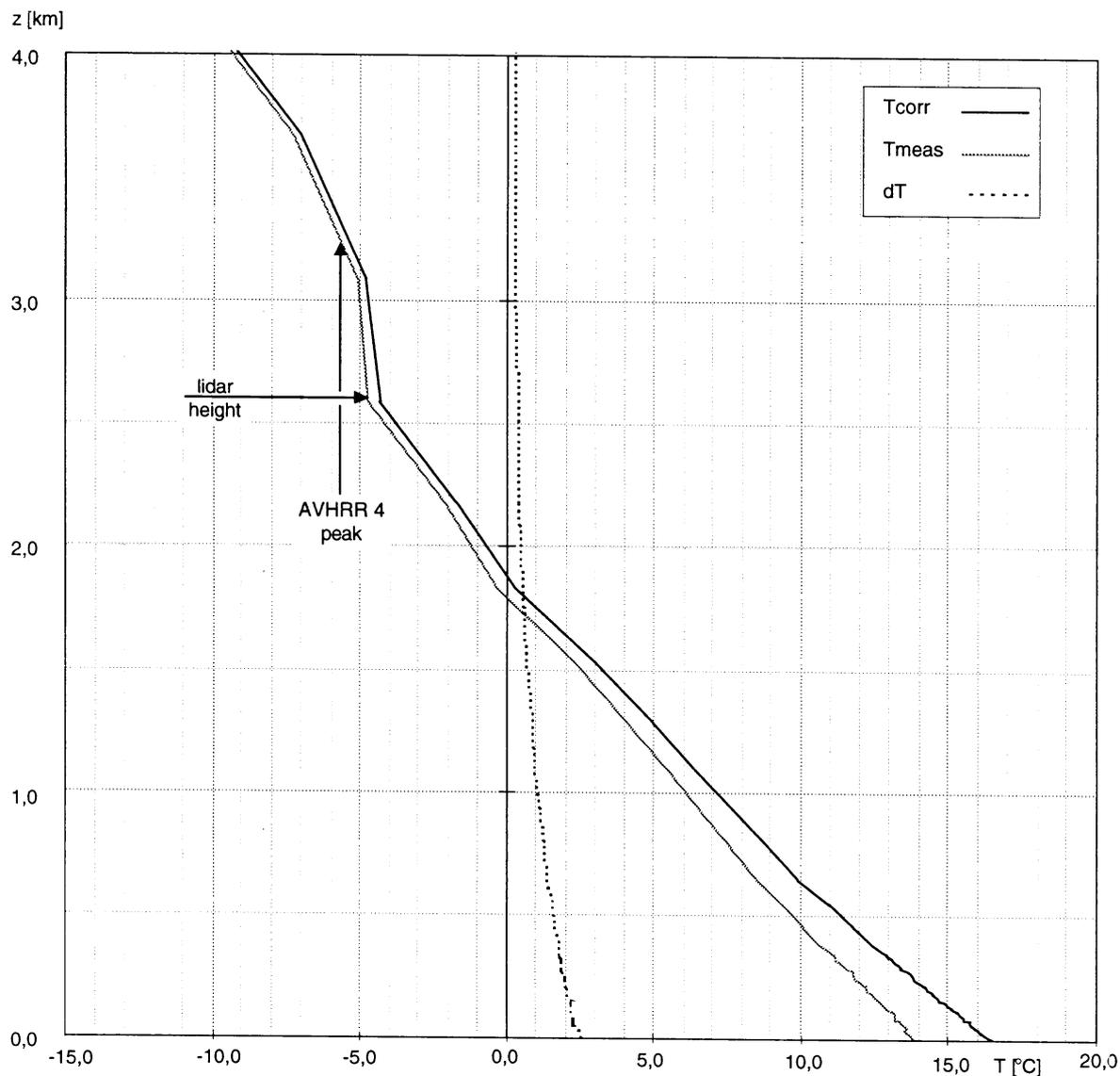
Figure 4.8 - AVHRR channel 4 temperature corrections; Delft, September 1st, 1996, 12:00 UTC

T_{meas} = measured temperature

T_{corr} = corrected temperature (= radiosonde temperature)

dT = difference between T_{meas} and T_{corr}

z [km]

Tcorr ————
Tmeas ....
dT - - - - -

lidar
height

AVHRR 4
peak

-15,0   -10,0   -5,0   0,0   5,0   10,0   15,0   T [°C]   20,0
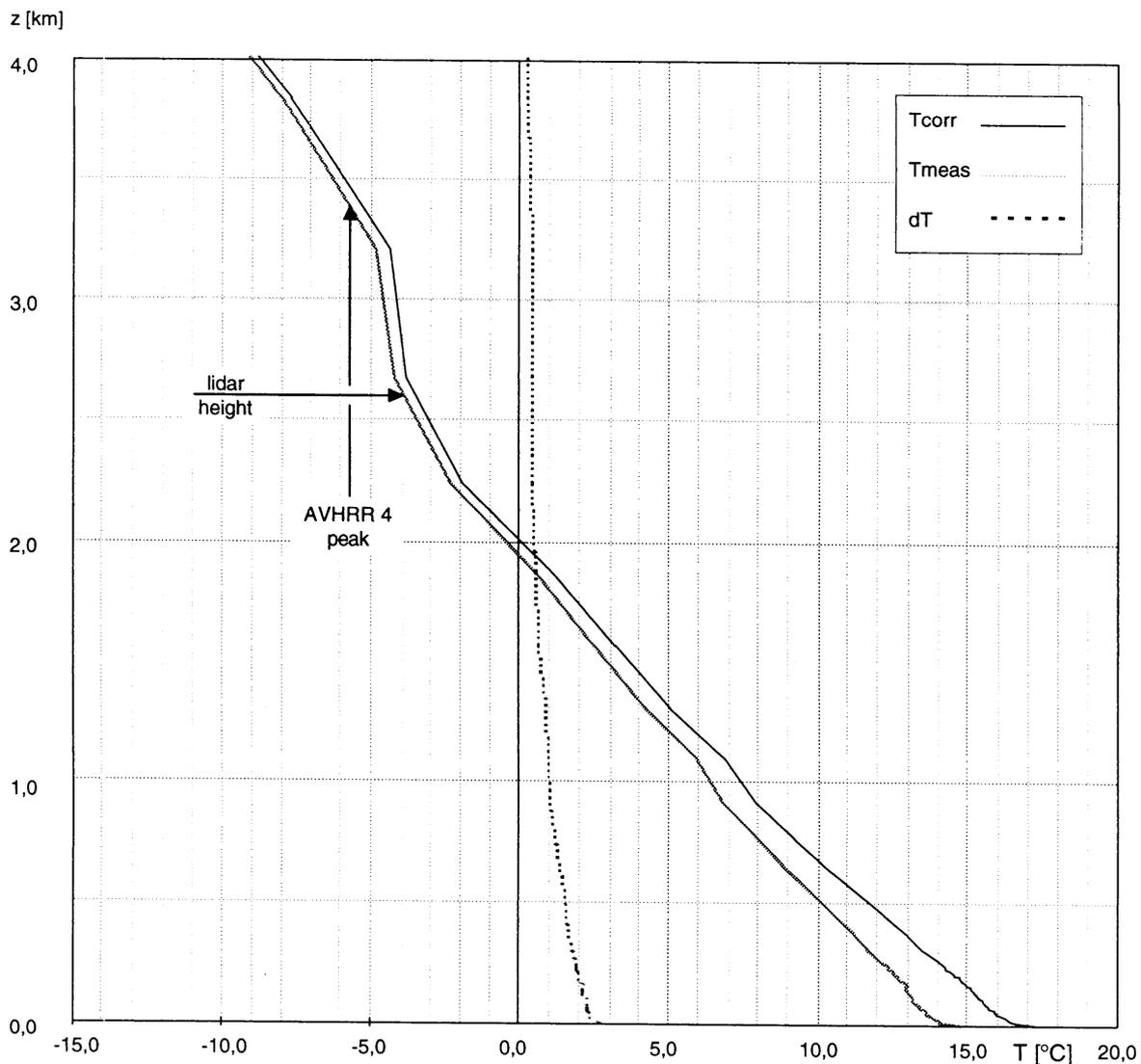
Figure 4.9 - AVHRR channel 4 temperature corrections; Delft, September 1st, 1996, 15:00 UTC

Discussion

The cloud top height derived from the lidar analysis in figure 4.5 is 8,6 kft, which is equal to 2,6 km. Correcting the cloud top temperature of -5,7 °C results in a temperature of -5,4 °C at 12:00 and in a temperature of -5,3 °C at 15:00. The corresponding cloud top heights are 3,2 and 3,4 km, respectively. The temperature corrections are small and the temperature does not vary strongly with height (about 1 °C between 2,6 and 3,2 km), so it is hard to make an accurate estimate of the cloud top height using this method.

The difference between the cloud top height obtained from the lidar analysis and the cloud top heights derived from the radiosonde profiles could also be due to the inability of the lidar system to penetrate optically dense clouds.

Furthermore, it could be caused by the fact that the radiosonde measurements in Delft do not represent the typical atmosphere of the whole TEBEX area.

4.4. Conclusions

The cloud base and top temperatures which are derived from radiation measurements can be corrected for the influence of the atmosphere using this interface for the radiative transport model Modtran 3.

Combining lidar measurements and temperature corrected Heimann measurements gives information on the optical properties of the cloud in the infrared.

Combining this with the cloud base and top temperatures yields a more accurate cloud description.

Acronymes and Symbols

AFGL   : Air Force Geophysics Laboratory
ANSI   : American National Standards Institute
AUW   : Agricultural University Wageningen
AVHRR   : Advanced Very High Resolution Radiometer
CDS   : Cloud Detection System
CLARA   : Clouds and Radiation
FSSP   : Forward Scattering Spectrometer Probe
IFM   : Infrared Fluctuation Meter
IR   : Infrared
KNMI   : Royal Netherlands Meteorological Institute
NOAA   : National Oceanic and Atmospheric Administration
POES   : Polar Orbiting Environmental Satellite
ppmv   : Parts Per Million Volume
RASS   : Radar Acoustic Sounding System
RH   : Relative Humidity
RIVM   : National Institute of Public Health and the Environment
TEBEX   : Tropospheric Energy Budget Experiment
UA   : University of Amsterdam
UTC   : Universal Time Coordinated
UV   : Ultra-violet

c	: speed of light	$[3,00 \cdot 10^{8} \text{ m s}^{-1}]$
E_b	: emitted radiation per square metre of a blackbody	$[\text{W m}^{-2}]$
$E_{\lambda b}$	: energy radiated by a blackbody at wavelength λ	$[\text{W m}^{-2} \text{ m}^{-1}]$
f	: fraction	$[\%]$
h	: Planck constant	$[6,63 \cdot 10^{-34} \text{ J s}]$
k	: Boltzmann constant	$[1,38 \cdot 10^{-23} \text{ J K}^{-1}]$
p	: pressure	$[\text{mbar}]$
R	: radiance	$[\text{W m}^{-2} \text{ sr}^{-1}]$
r_n	: normalised response	
T	: temperature	$[\text{K}] \text{ or } [°\text{C}]$
z	: altitude	$[\text{m}] \text{ or } [\text{km}]$
λ	: wavelength	$[\text{m}] \text{ or } [\mu\text{m}]$
σ	: emission coefficient	$[5,67 \cdot 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}]$

References

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Appendices

A - Structure of Modtran 3 Input

B - Program Description

Appendix A - Structure of Modtran 3 Input

CARD1   *Sets basic calculation parameters*

MODTRN   *Model choice*
T = Modtran
F = Lowtran

MODEL   *Selection of geographical/seasonal model atmosphere*
0 = if meteorological data are specified (horizontal path only)
1 = Tropical
2 = Midlatitude Summer
3 = Midlatitude Winter
4 = Subarctic Summer
5 = Subarctic Winter
6 = 1976 US Standard
7 = if a new model atmosphere has to be read in (radiosonde data)

ITYPE   *Path type*
1 = Horizontal
2 = Slant
3 = Slant to space

IEMSCT   *Execution mode*
0 = Transmittance mode
1 = Thermal radiance mode
2 = Radiance mode with single scattered solar/lunar radiance
3 = Calculation of direct solar/lunar irradiance

IMULT   *Multiple scattering*
0 = No
1 = Yes

M1, M2, M3, M4, M5, M6, MDEF   *Atmospheric constituence specification*
T,P H_2O O_3 CH_4 N_2O CO
0 = Reset to default value = value from **MODEL**
1...6 = Model number (see **MODEL**)
MDEF = 1, Use default profiles for CO_2, O_2, NO, SO_2, NO_2, NH_3, HNO_3

IM   *Atmospheric profile definition*
0 = Normal operation, **MODEL** data set (or rerun)
1 = User input data (radiosonde data) (first run)

NOPRT   *Output files specification*
-1 = Normal tape6, tape7 and tape8
0 = Normal tape6 and tape7   Short tape8
1 = Normal tape7   Short tape6 and tape8

TBOUND   *Boundary temperature [K] (if **IEMSCT** = 1, 2)*

SALB   *Surface albedo (0.0 .. 1.0) of earth at average frequency of calculation*
If left blank, blackbody is assumed

CARD1A   *Controls DISORT multiple scattering algorithm*

LDISORT   *(requires that IMULT = 1)*
T = Activate DISORT multiple scattering algorithm
F = Continue with original Isaacs two-stream

ISTRM   *Number of streams to be used by DISORT*
2 = Better use Isaacs model
4 = 4 streams
8 = recommended at this time
16 = 16 streams

LSUN1   *Solar irradiance specification*
T = Read 1 cm_{-1} solar irradiance from the file "sun2" (requires **ISUN**)
F = Use default solar irradiance as embedded in Modtran Block Data

ISUN   *ISUN resolution scanning function (>3 cm^{-1})*
Values less than 5 cm-1 are not recommended

CO2MIX   *Replacement CO_2 mixing ratio (default = 330 ppmv)*
1995 value = 335...360 ppmv

CARD2   *Aerosol/Cloud/Rain definition*

IHAZE   *Aerosol model for boundary layer (0-2 km)*
0 = No aerosol attenuation included in the calculation
1 = Rural extinction, default **VIS** = 23 km
2 = Rural, **VIS** = 5 km
3 = Navy Maritime, sets own **VIS**
4 = Maritime, **VIS** = 23 km (Lowtran model)
5 = Urban, **VIS** = 5 km
6 = Tropospheric, **VIS** = 50 km
7 = User defined, reads **CARD2D, 2D1, 2D2**
8 = Fog1 (Advective fog), **VIS** = 0.2 km
9 = Fog2 (Radiative fog), **VIS** = 0.5 km
10 = Desert, sets own **VIS** from **WSS**

ISEASN   *Seasonal tropo/stratospherical aerosol profile*
0 = Season determined by value of **MODEL**
        Spring-Summer = 0, 1, 2, 4, 6, 7
        Fall-Winter = 3, 5
1 = Spring-Summer
2 = Fall-Winter

IVULCN   *Stratospherical aerosol profile, type of extinction*
0,1 = Background stratospheric profile and extinction
2 = Moderate volcanic profile, Aged volcanic extinction
3 = High volcanic, Fresh volcanic
4 = High volcanic, Aged volcanic
5 = Moderate volcanic, Fresh volcanic
6 = Moderate volcanic, Background stratospheric
7 = High volcanic, Background stratospheric
8 = Extreme volcanic, Fresh volcanic

ICSTL   *Air mass character, only used when IHAZE = 3*
1...10 = Open ocean...Strong continental influence

ICLD   *Cloud and rain models*
0 = No clouds or rain
1 = Cumulus cloud, base 0.66 km, top 3.0 km
2 = Altostratus, 2.4-3.0
3 = Stratus, 0.33-1.0
4 = Stratus/Strato Cumulus, 0.66-2.0
5 = Nimbostratus, 0.16-0.66
6 = 2.0 mm/h at 0 km, 0.22 mm/h at 1.5 km
7 = 5.0, 0.2 at 2.0
8 = 12.5, 0.2 at 2.0
9 = 25.0, 0.2 at 3.0
10 = 75.0, 0.2 at 3.5
11 = User defined, reads cards 2D, 2D1, 2D2
18 = Standard Cirrus model
19 = Sub-visual Cirrus model
20 = NOAA Cirrus model (Lowtran6 model)

IVSA   *Army vertical structure algorithm for aerosols in boundary layer*
0 = No
1 = Yes

VIS   *Surface visual range [km], overriding default from IHAZE*
0 = Use default by **IHAZE**

WSS   *Wind speed [m/s], used when IHAZE = 3, 10*

WHH   *24 hour average wind speed [m/s], only used when IHAZE = 3*

RAINRT   *Rain rate [mm/hr]*

GNDALT   *Ground altitude above sea level [km]*
Modifies aerosol profiles below 6 km altitude

CARD3   *Geometrical path specification*

H1   *Initial altitude [km]*
Observer altitude for **IEMSCT = 1, 2**

H2   *Final altitude [km]*

ANGLE   *Initial zenith angle as measured from H1 [deg]*
Observer zenith angle for **IEMSCT = 1, 2**

RANGE   *Path length [km]*

BETA   *Earth centre angle subtended by H1 and H2 [deg]*

RO   *Radius of the earth [km]*

LEN   *Path length from H1 to H2*
0 = Short path (default)
1 = long path through the tangent height

CARD3x   *Geometrical path for direct irradiance (alternate to Card3 for IEMSCT = 3)*

H1   *Observer altitude [km]*

H2   *Tangent height of path to sun or moon [km]*

ANGLE   *Apparent solar/lunar zenith angle at H1 [deg]*

IDAY   *Day of the year*

RO   *Radius of the earth [km]*

ISOURC   *Extraterrestrial source*
0 = Sun
1 = Moon

ANGLEM   *Angle formed by sun, moon and earth [deg]*
required if **ISOURC = 1**

CARD3A1   *Optional card for solar/lunar irradiation (IEMSCT = 2)*

> **IPARM**   *Solar/lunar geometry for CARD3A2*
> 0 = Observer latitude/longitude, Source latitude/longitude
> 1 = Observer latitude/longitude, Time
> 2 = Azimuth, Zenith
>
> **IPH**   *Aerosol phase function*
> 0 = Henyey-Greenstein (**CARD3A2**)
> 1 = User defined (**CARD3B**)
> 2 = MIE-generated (Lowtran)
>
> **IDAY**   *Day of the year (default = 93)*
>
> **ISOURC**   *Extraterrestrial source*
> 0 = Sun
> 1 = Moon

CARD3A2   *Optional card for solar/lunar irradiation (IEMSCT = 2)*

> **PARM1**   *Observer latitude [deg]*
> -90...90
>
> **PARM2**   *Observer longitude [deg]*
> 0...360 = West of Greenwich
>
> **PARM3**
> If **IPARM** = 0 : **PARM3** = *Source latitude [deg]*
> If **IPARM** = 1,2 : **PARM3** Not required
>
> **PARM4**
> If **IPARM** = 0 : **PARM4** = *Source longitude [deg]*
> If **IPARM** = 1,2 : **PARM4** Not required
>
> **TIME**   *Greenwich time [decimal hrs]*
>
> **PSIPO**   *Path azimuth angle [deg], used when IPARM = 0, 1*
>
> **ANGLEM**   *Angle formed by sun, moon and earth [deg]*
> required if **ISOURC** = 1
>
> **G**   *Henyey-Greenstein asymmetry factor, used when IPH = 0*
> -1 = Complete backscattering
> 0 = Isotropic/symmetric scattering
> 1 = Complete forward scattering

CARD4   *Spectral Range specification*

V1   *Minimum wavenumber [cm^{-1}]*

V2   *Maximum wavenumber [cm^{-1}]*

DV   *Frequency increment [cm^{-1}], must be multiple of 5 for Lowtran*

FWHM   *Full Width Half Maximum of triangular slit function*
(used only in Modtran)

CARD2A   *Optional card for cirrus (**ICLD** = 18, 19, 20)*

    CTHIK   *Cirrus thickness [km]*
    0 = Use thickness statistics
    >0 = User defined thickness

    CALT   *Cirrus base altitude [km]*
    0 = Use calculated value
    > 0 = User defined value

    CEXT   *Extinction coefficient [km^{-1}] at 0.55 μm*
    0 = Use 0.14 · **CTHIK**
    > 0 = User defined extinction coefficient

    ISEED   *Random number initializing flag*
    0 = Use default mean values for cirrus
    > 0 = Initial value of seed for random number generator

CARD2BD   *Optional card for Army VSA (**IVSA** = 1)*

    ZCVSA   *Cloud ceiling height [km], 0.0 for default*

    ZTVSA   *Cloud thickness [km], 0.0 for default*

    ZINVSA   *Height of the inversion or boundary layer [km], 0.0 for default*

CARD2C   *Optional card for user profiles (**MODEL** = 0, 7)*

    ML   *Number of atmospheric levels (<62)*

    IRD1   *Read **CARD2C2***
    0 = No, 1 = Yes

    IRD2   *Read **CARD2C3***
    0 = No, 1 = Yes

    TITLE   *Title of new model atmosphere*

    PROF_FORMAT   *Format of **CARD2C1...3***
    0 = Strict Lowtran format
    1 = Own format

Lowtran format :

```
      0.000 9.800E+02 2.830E+02 2.415E+17 3.500E+02 1.024E+12AABABBBBBBBBBB
  7.532E+12 3.773E+12 4.136E+13 2.095E-01 0.000E+00 3.438E+05 8.968E+09
0.000E+00
  0.000E+00
      0.890 9.120E+02 2.800E+02 1.967E+17 3.500E+02 1.069E+12AABABBBBBBBBBB
  7.083E+12 3.416E+12 3.880E+13 2.095E-01 0.000E+00 3.694E+05 7.131E+09
0.000E+00
  0.000E+00
      1.480 8.490E+02 2.760E+02 1.570E+17 3.500E+02 1.109E+12AABABBBBBBBBBB
  6.688E+12 3.101E+12 3.654E+13 2.095E-01 0.000E+00 3.923E+05 5.503E+09
0.000E+00
  0.000E+00
      2.060 7.900E+02 2.740E+02 1.202E+17 3.500E+02 1.133E+12AABABBBBBBBBBB
  6.268E+12 2.789E+12 3.415E+13 2.095E-01 0.000E+00 4.084E+05 4.004E+09
0.000E+00
  0.000E+00
```

Own format :

First a list of the necessary quantities, then the format specification

HELP CARD2C1   *Optional card for layer data and H_2O,CO_2,O_3 (MODEL=0, 7)*

ZMLD	*Altitude of layer boundary [km]*
JCHAR(1), **P**	*Unit ([mbar]=A, [atm]=B, [torr]=C, MODEL=1-6), Pressure*
JCHAR(2), **T**	*Temperature unit ([K]=A, [°C]=B, MODEL=1-6), Temperature*
JCHAR(3), **WMOL**(1)	*Unit, Value H_2O*
JCHAR(4), **WMOL**(2)	*Unit, Value CO_2*
JCHAR(5), **WMOL**(3)	*Unit, Value O_3*
MODEL=1-6	
JCHAR(J), J=6-14	*Units for resp.: N_2O, CO, CH_4, O_2, NO, SO_2, NO_2, NH_3, HNO_3*

Units:	vol. mix	[ppmv]	= A
	num. dens	[cm^{-3}]	= B
	mass mix	[g/kg]	= C
	mass dens	[g/m^3]	= D
	part.pressure	[mbar]	= E
(H_2O)	dew point	[K]	= F
(H_2O)	dew point	[°C]	= G
(H_2O)	rel.humidity	[%]	= H
	user defined		= I

HELP CARD2C2   *Optional card for additional molecular data (MODEL=0, 7)*

WMOL(J), J=4-12   *Values for resp.: N_2O, CO, CH_4, O_2, NO, SO_2, NO_2, NH_3, HNO_3*

HELP CARD2C3   *Optional card for cloud/rain/aerosol (IRD2=1)*

AHAZE, EQLWCZ	*Aerosol extinction at 0.55μm [km-1], Equivalent liquid water content [g/m3]* (Only one of these options is allowed)
RRATZ	*Rain rate [mm/h]*
IHA1, ICLD1, IVUL1	*Corresponds to IHAZE, ICLD, IVULCN (CARD2)* (Only one of these options is allowed)
ISEA1	*Corresponds to ISEASN (CARD2)*
ICHR1	*Aerosol region boundary; 0 = Same region. 1 = Boundary*

CARD2C1 — *Optional card for layer data and H_2O, CO_2, O_3 (MODEL=0, 7)*

JCHAR(1-14)	ZMLD	T	P	H₂O	CO₂	O₃	
AA66D666666666	.0	288.15	.10133E+03	0	0	.20000E-03	RIVM O3 profile
AA66D666666666	1.0	281.65	.89814E+02	0	0	.20000E-03	
AA66D666666666	1.5	278.40	.84470E+02	0	0	.10300E-03	
AA66D666666666	2.0	275.15	.79386E+02	0	0	.53400E-04	
AA66D666666666	2.5	271.90	.74555E+02	0	0	.54400E-04	i=5
AA66D666666666	3.0	268.66	.69965E+02	0	0	.55400E-04	
AA66D666666666	3.5	265.41	.65608E+02	0	0	.56300E-04	
AA66D666666666	4.0	262.17	.61475E+02	0	0	.57200E-04	
AA66D666666666	5.0	255.68	.53842E+02	0	0	.58900E-04	
AA66D666666666	6.0	249.19	.46999E+02	0	0	.61600E-04	i=10
AA66D666666666	7.0	242.70	.40880E+02	0	0	.67000E-04	
AA66D666666666	8.0	236.22	.35425E+02	0	0	.70500E-04	
AA66D666666666	9.0	236.22	.30640E+02	0	0	.76800E-04	
AA66D666666666	10.0	223.25	.26393E+02	0	0	.80400E-04	
AA66D666666666	11.0	218.25	.22599E+02	0	0	.98200E-04	i=15
AA66D666666666	12.0	216.65	.19306E+02	0	0	.10700E-03	
AA66D666666666	13.0	216.65	.16484E+02	0	0	.13400E-03	
AA66D666666666	14.0	216.65	.14075E+02	0	0	.16100E-03	
AA66D666666666	15.0	216.65	.12018E+02	0	0	.17000E-03	
AA66D666666666	16.0	216.65	.10263E+02	0	0	.18800E-03	i=20
AA66D666666666	17.0	216.65	.87644E+01	0	0	.21400E-03	
AA66D666666666	18.0	216.65	.74850E+01	0	0	.25000E-03	
AA66D666666666	19.0	216.65	.63927E+01	0	0	.28600E-03	
AA66D666666666	20.0	216.65	.54601E+01	0	0	.30400E-03	
AA66D666666666	21.0	216.65	.46638E+01	0	0	.32100E-03	i=25
AA66D666666666	23.0	216.65	.34031E+01	0	0	.30400E-03	
AA66D666666666	24.0	216.65	.29072E+01	0	0	.28600E-03	
AA66D666666666	25.0	221.55	.24881E+01	0	0	.26800E-03	
AA66D666666666	30.0	226.51	.11629E+01	0	0	.17900E-03	
AA66D666666666	35.0	236.51	.55769E+00	0	0	.82200E-04	i=30
AA66D666666666	40.0	250.35	.27756E+00	0	0	.36600E-04	
AA66D666666666	45.0	264.16	.14356E+00	0	0	.11600E-04	
AA66D666666666	60.0	247.02	.20747E-01	0	0	.53400E-06	

CARD2C2 — *Optional card for additional molecular data (MODEL=0, 7)*

ZMLD, N_2O, CO, CH_4, O_2, NO, SO_2, NO_2, NH_3, HNO_3

CARD2C3 — *Optional card for cloud/rain/aerosol (IRD2=1)*

ZMLD, AHAZE, EQLWCZ, RRATZ, IHA1, CLD1, IVUL1, ISEA1, ICHR1

CARD2D — *Optional card for aerosols (IHAZE=7, ICLD=11 (CARD2))*

IREG(1-4)
1 = Read aerosol data for altitude region
0 = Use default data for altitude region

CARD2D1 — *Optional card aerosol equiv. liquid water content*

AWCCON — *Conversion factor from elwc to extinction coeff. [$kg.gm.m^{-3}$]*

TITLE — *Title for an aerosol or cloud region*

CARD2D2   *Optional card aerosol extincion (normalized at 0.55μm)*

VX	EXTC	ABSC	ASYM	
.2000	.93700	.13780	.0000	RIVM aerosols region 1
.3000	.94090	.13385	.0000	
.3371	.97240	.11810	.0000	
.55001	.00000	.09055	.0000	
.6943	.97244	.07480	.0000	
1.0600	.97244	.07480	.0000	
1.5360	.97244	.07480	.0000	
2.0000	.97244	.07480	.0000	
2.2500	.97244	.07480	.0000	
2.5000	.97244	.07480	.0000	
-1	.00000	.00000	.0000	
.2000	.93700	.13780	.0000	RIVM aerosols region 2
.3000	.94090	.13385	.0000	
.3371	.97240	.11810	.0000	
.5500	1.00000	.09055	.0000	
.6943	.97244	.07480	.0000	
1.0600	.97244	.07480	.0000	
1.5360	.97244	.07480	.0000	
2.0000	.97244	.07480	.0000	
2.2500	.97244	.07480	.0000	
2.5000	.97244	.07480	.0000	
-1	.00000	.00000	.0000	

VX	*Wavelenght [μm]*
EXTC	*Extinction coefficient*
ABSC	*Absorption coefficient*
ASYM	*Asymmetry parameter*

CARD3B1   *Optional card for user-defined phase function (IPH=1)*

NANGLS   *Number (< 50) of angles for user-defined phase functions*

CARD3B2   *Optional card for user-defined phase function (IPH=1) (1 to NANGLS)*

ANGLE	*Scattering angle [decimal deg]*
PHAR1	*User defined phase function at ANGLE, region 1*
PHAR2	*User defined phase function at ANGLE, region 2*
PHAR3	*User defined phase function at ANGLE, region 3*
PHAR4	*User defined phase function at ANGLE, region 4*

CARD5   *Recycle program*

IRPT   *Card number from where to recycle the program*
0 = Stop
1, 3, 4 = Alternatives

Appendix B - Program Description

create   creates the Modtran 3 input file *tape5*.
performs iterations of radiative calculations through the atmosphere using Modtran 3.
saves the results.
prints results to screen.

calls :   check_file
build_frnt
build_prof
build_back
set_date
set_height
progress
filter
analyse

input :   yy = year
ddd = daynumber
hh = hour

output :   mod-file
ana-file (also printed to screen)

check_file   checks the integrity of the radiosonde file.
checks the existence of mod-file and ana-file.

input :   location and name of radiosonde file
location and name of mod-file
location and name of ana-file

build_frnt   builds the front of tape5

input :   the standard file *front*

output :   first part of tape5

build_prof   builds the profile part of tape5.

calls :   strip   strips the header and footer from the radiosonde file
reduce   reduces the number of lines from the radiosonde file to PRF_LINES
alter   alters the lay-out

input :   radiosonde filename

output :   profile part of tape5

build_back   builds the back part of tape5

input :   the standard file *back*

output :   back part of tape5

set_date   edits date dependent parameters in tape5 using the specified date.

           input :   yy
                       ddd
                       location of tape5

set_height   sets one of the heights in tape5, using the linenumber from the profile.
copies the characteristic values of the profile to mod-file if necessary.

           input :   position [min / max]
                       line number
                       location of tape5
                       location and name of mod-file

           output :   first four columns of mod-file containing radiosonde parameters (line by line).

progress   shows the progress

           input :   stepnumber
                       total number of steps

           output :   progress indicator

filter   filters spectral radiances from Modtran output file *tape6* using a filterfile (*.fil*).
writes the integrated radiance to mod-file

           input :   location and name of filterfile
                       location of tape6
                       location and name of mod-file

           output :   column containing (filtered) integrated radiances in mod-file (line by line).

analyse   analyses a mod-file, by looking up the temperatures corresponding to the (filtered)
integrated radiances in a tvr-file (*.tvr*).

           input :   location and name of tvr-file
                       location and name of mod-file

           output :   ana-file