Veðurstofa Íslands
Report

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The energy budget model Ebba

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THE ENERGY BUDGET MODEL EBBA[1]

1 SUMMARY

This report contains a description of an energy budget model nicknamed Ebba, which was originally developed by E. Vowinckel and S. Orvig at McGill University around 1970. The main goal is to make the model operational and work efficiently with the data available. In this process it was necessary to change completely the way Ebba functioned before. The demonstration of Ebba consists of two steps: First, we compare calculations of the downward short-wave (SW) radiation with measurements, conducted using automatic stations. This provides valuable reassurance whether or not the model is working properly. Finally, we calculate the latent and sensible heat fluxes for a particular period, where available measurements from expeditions on a research vessel can be used for comparison.

The report begins with an introduction to the concept of climate modelling and defines two types of one-dimensional models. Next, the model Ebba is briefly described, focusing in its structure and flow. Finally, Ebba is demonstrated using an extensive database available at the Icelandic Meteorological Office.

2 INTRODUCTION

Models used for simulating the physical processes in the atmosphere are of various types depending on the nature of the problem in hand. There are three modelling methods available: General Circulation Models, single-column models and Semiprognistic models.

In the following chapter, we will define these types of models and associate one of those types to Ebba. We will also briefly describe the function of Ebba.

2.1 Climate modeling [Randall et al. 1996]

The purpose of any parameterization is to compute certain tendencies due to the particular process represented by the parameterization. These tendencies can be associated with systematic erroneous in the calculations between each time step and/or physical processes responding to the parameterization. Modelling of the atmosphere offers an excellent opportunity to conduct such experiments and deepen or insight into the relative roles of individual climate processes. Models of the climate system can take many forms ranging from simple one-dimensional energy balance models to complex three-dimensional time-dependent circulation models of the atmosphere and ocean, called General Circulation Models (GCMs). The simpler

[1] Ebba is not an acrynom. It is a chosen nickname given by the authors.

mechanistic models are primarily aimed for parameterization tests, while the more complex models are oriented toward the detailed simulation of observed phenomena.

Testing parameterizations that have been developed for use in GCMs has at least 3 main disadvantages:

1. The results produced by a climate model are big and complicated and depend on all aspects of the model, so that it can be very difficult to attribute particular deficiencies of the results to particular aspects of the model's formulation.
2. Climate simulation are computationally expensive and time consuming so that only limited number of runs can be made.
3. Individual weather systems simulated by climate models do not represent particular weather systems in particular places at particular times in the real world, so only statistical comparisons with observations are possible.

One-dimensional models provide the most convenient and efficient way to conduct parameterization tests. In this approach a parameterization or suite of parameterizations is exercised in the framework of a single isolated atmospheric column, which can be thought of as a single column taken from a GCM. A GCM can be considered to be a collection of such columns, arranged to cover the entire earth and interact with each other through a set of rules known as large-scale dynamics. In a GCM, neighbouring grid columns provide information that is needed to determine what will happen within the grid column in question. In the single-column approach, there are no neighbouring grid columns, so all information that is needed and would otherwise be obtained from such columns is provided instead from observations. In some cases idealised data may be supplied in place of real observations. The data requirement for this parameterization method is therefore extremely demanding, introducing difficulties and complications. There are however two important advantages associated with these kinds of models:

1. It's possible to isolate the parameterization being tested from all other components of the model.
2. The test is computationally very inexpensive compared to running a full large-scale model.

There are two approaches that involve testing parameterizations outside the GCMs, and predictably both have advantages and disadvantages. They are semiprognostic tests and single-column modelling.

2.1.1 Single-column modelling

The second approach for testing climate model parameterizations outside of GCMs, called single-column modelling, is similar to the semiprognostic test. The key difference between single-column modelling and the semiprognostic test is that in a single-column modelling the results obtained for one observation time are used to predict new values of the prognostic variables, which are then provided as input for the next observation time. Though single-column modelling is data demanding, this difference makes single-column modelling far less data demanding compared to semiprognostic tests. A problem with single-column modelling is that the time-averaged total tendencies have to be about right. A second problem is that although feedback's that work inside a single-column are active in single-column modelling, other feedback's involving the large-scale circulation, cannot be included. As a result, problems with the parameterization that involve such large-scale feedback's can not be detected using single-column modelling.

2.1.2 Semiprognostic test

In a semiprognostic test, observations are used to prescribe both the state of the atmospheric column and tendencies due to all processes except those associated with the parameterization to be tested. A semiprognostic test can be applied at a sequence of observation times, and we can think of these as being separated by time steps. Because observations are used to specify the state of the atmosphere at each observation time, errors in the computed tendencies at the previous observation time have no effect. Semiprognistic models therefore have no feedback from one time step to the next. This is both an advantage and a disadvantage. It is an advantage because it means that the time-averaged tendencies can be very wrong, introducing systematic erroneous reproduced between each time step and can therefore be easily isolated. The lack of feedback from one time step to the next is also a drawback because parameterizations can have deficiencies that arise directly from such feedback's; problems of this type cannot be detected with semiprognostic tests. A further difficulty with semiprognostic tests is that the data requirements are very demanding, because observational data needs to be available for each time step. It is necessary to assemble a complete picture of the large-scale circulation and the various physical processes, not necessarily being tested, in order to perform semiprognostic tests.

2.2 The model

An energy budget program, nicknamed Ebba, is a one-dimensional semiprognostic model. The purpose of the program is to use it for 1-hour time step calculations of all energy fluxes in the atmosphere, between the atmosphere and the surface, and in the ground and water. The program also allows the complete water budget to be calculated. By choosing right values for particular parameters and altering the physical processes used in the program, it is possible to imitate the behaviour of the energy fluxes on the Northern Atlantic Sea surface. The sea surface in interest extends over a wide area where limited or no observations are undertaken. It is therefore important to make use of observations conducted by synoptic and automatic stations to fulfil the data requirement of the SCM. By using scattered grid points and interpolating between them, it is possible to achieve a picture of the physical processes and energy budget over large areas.

It is our aim to make Ebba a useful tool in energy budget research in the Northern Atlantic Sea. This will be achieved by thoroughly examining the physical processes and developing appropriate approximations to be used for parameterization with Ebba. It is also important to find ways to use the extensive data available in The Icelandic Meteorological Office.

At this stage Ebba has been simplified substantially by using only sections of the subroutines needed for energy budget calculations above water surface. Parts of the model that take into account different surface types and photosynthesis are still available in the original version but needs to be added to the new version if necessary in the future. The present structure of the model is depicted in figure 1.

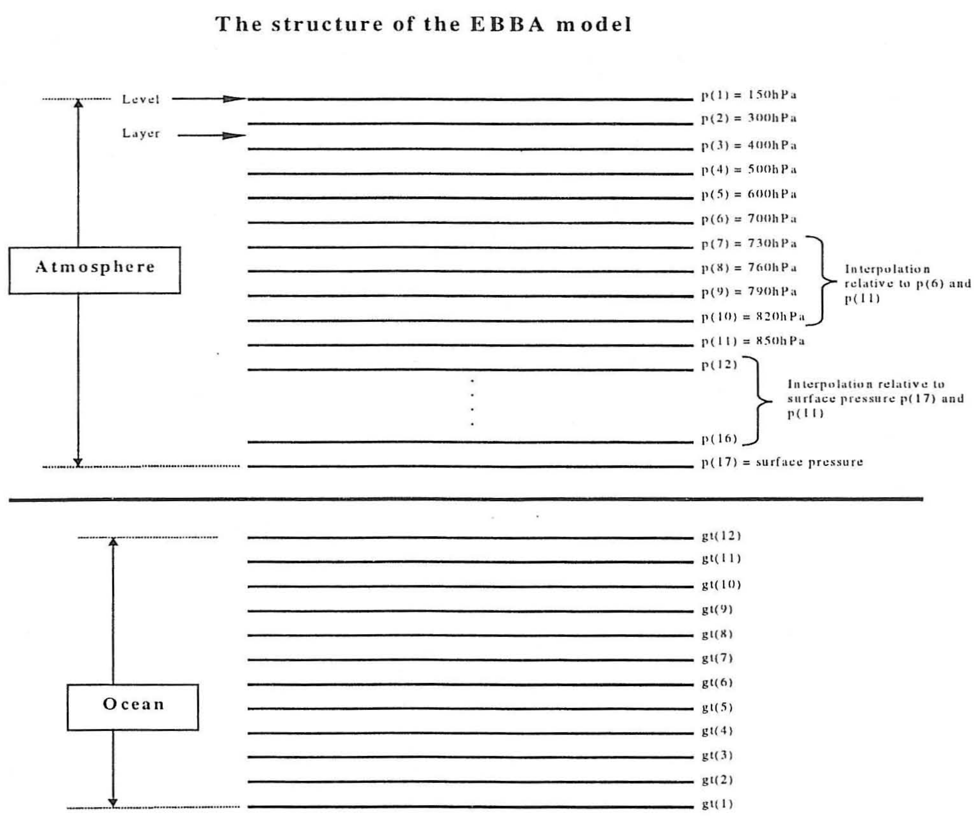

Figure 1 *The structure of the models atmosphere and ocean. The atmosphere and ocean are divided into layers, which are confined by levels. See Appendix II for definition of parameters.*

3 MODEL DESCRIPTION

Ebba is divided into a main program, *ebba.f*, and its subroutines. In the following we will only comment on the structure of *ebba.f*, leaving more detailed description on the subroutines in the appendix.

3.1 Ebba

Ebba is the main program, which controls the flow of the program (See figure 2). Doing so it calls the subroutines in appropriate order. There are three loops that control the operation, the station, day and hour loops. After each hour and day, Ebba writes the result to output files.

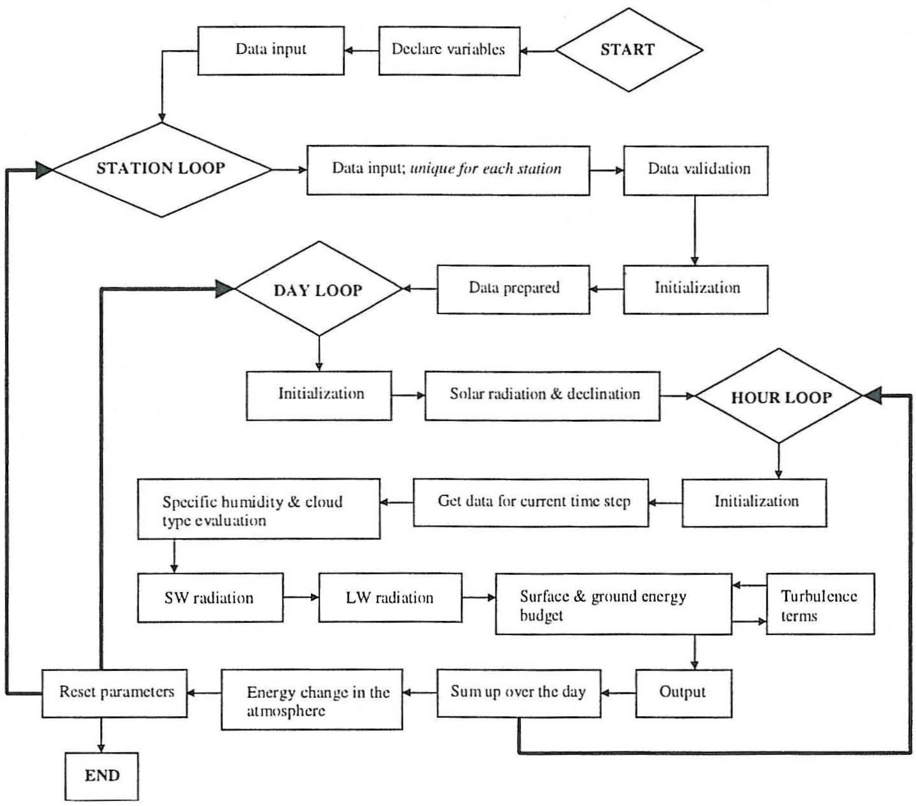

Figure 2 *The flow of the model where each step is described briefly.*

Ebba begins with a module declaring allocatable variables. With the allocatable statement it's possible to declare variables without specifying there size until later in the program. This is convenient since the size of the variables depend on the length of period chosen in the SQL command. To be able to run the program efficiently, the ability to run many calculations for many different time intervals in a fast manner is essential. The main program Ebba begins immediately after the module. The program begins by declaring the module and the parameters used in the calculations. The program then asks for the number of days to calculate.

```
print *, 'Enter number of days: '
```

```
30      read *, nr_days
        print *, 'Enter number of stations: '
31      read *, nr_st
        size1 = 8*nr_days*nr_st !number of 3 hourly values
        size2 = 2*(size1-1)+size1 !number of 1 hourly values
        size3 = 6*2*nr_days !number of 12 hourly radiosonde values
```

The number of 1 hourly *size2*, 3 hourly *size1* and 12 hourly *size3* values for each parameter is then calculated using the number of days, *nr_days*. After *size1*, *size2* and *size3* have been determined, it's possible to declare the allocatable variables. Next Ebba reads necessary data that only needs to be read once during the entire running time. This data determines the initial conditions of the planets orbit and the layer structure and dimensions of the model. Before entering the station loop the subroutine Kondra is called. When Kondra is called the first time, it reads the transmission table for long-wave (LW) radiation [Kondratiev & Niilisk 1961], which will then be ready for use the next time Kondra is called in Doris for the LW calculations.

3.1.1 Station loop

When Ebba enters the station loop, it reads data for the first station. At present we are only interested in a single station. This data includes synoptic and radiosonde data for that station and is extracted from the database. The calculations rely heavily on this data and it is crucial to handle it correctly in each time step. Furthermore, data from the database is not flawless, which demands additional precautions. Some elements in a column might not have values or maybe contain some kind of null character. To ensure the calculations can operate smoothly throughout the code, its necessary to check the whole data and replace dummy values with suitable values. This is done before the calculations commence by calling the subroutines Dummy_check_int and Dummy_check_real. After initialization, calculations can start. Before entering the day loop, Ebba calls the subroutines Convert_units, Initial_earth and Erika3. Convert_units converts the data from the database to preferable units. Initial_earth calculates the hour angle using the GMT time zone and longitudinal position of the station. It also estimates the sidereal time distance from perihelion. Erika3 constructs 1 hourly data from 3 hourly synoptic observations by interpolation.

3.1.1.1 Day loop

After initialization, the first call is made to Helena. Helena calculates the amount of solar radiation reaching the top of the earth's atmosphere at any given day. Furthermore, Helena calculates the earth's orbital progress for each day and takes into account the eccentricity of the orbit. After the hour loop has been executed, the program calls the subroutine Carmen before exiting the day loop. Carmen obtains daily energy change in the atmosphere.

3.1.1.1.1 Hour loop

The first hour begins at 3am. This is because each day in the database is defined from 1am to 24pm and the 3 hourly data begins at 3am. The parameter *fh* is given the value 3 before the day loop. When the first day is over, *fh* is given the value 1 so that each day after the first day begins at 1am. The *if* statement at the beginning checks if the number of time steps that have been executed, *ho*, has exceeded the length of the 1 hourly arrays. If so the program can stop execution in a clean manner. The hour loop begins with initialization. Then the program calls the subroutines: Hour_step, Monika, Ulrika, Doris and Birgit. Finally the hour values of various parameters are written to file. Before executing the next hour, energy parameters of interest are summed up for later representation of daily values.

4 THE DATA

As mentioned before, semiprognostic models like Ebba are extremely data demanding. The model is on the macroscopic scale, which makes synoptic observations a suitable input for its purpose. Ebba's time scale is 1 hour, which means that in order to execute the program efficiently we must be able to extract the necessary data for each hour to be calculated. All the data we need is located in The Icelandic Meteorological Office database, readily accessible through the SQL database language.

The synoptic observations are conducted in 3 hourly intervals every day of the year. Since the time step of the model is 1 hour, the data must be linearly interpolated (See section 7.7). The only problem that remains with the synoptic data is the character '/', used frequently in the synoptic cloud code system when uncertainty with either amount or height of certain clouds remain. The situation causing this uncertainty is usually visual obstruction due to fog or low-level clouds. For the calculations demonstrated in this report, it was decided to use the value 5 in place for '/' when it referred to cloud amount and the value 3 when it referred to cloud height. We therefore assume the presence of medium and high level clouds when it's cloudy. Whether this is justified or not is unclear, but it should be kept in mind when we compare calculations and measurements of the SW radiation at the surface.

It should also be noted that the synoptic data begins each day at 3am, the radiosonde at 12 noon and the radiation measurements at 1am. This is important when interpreting and comparing the results of the calculations with measurements.

We also use SW radiation measurements at the surface from an automatic station situated in Korpa, just outside of Reykjavík. These measurements are used for comparison with SW radiation calculations in the model (See chapter 5.1). The SW radiation measurements are conducted at a 10-minute interval. The total amount of downward energy is measured in unit's $kJ/(m^2 \cdot 10min)$.

The output data files are specially formatted so that Ebba can use it unaltered. The only thing that must be taken care of, before execution of Ebba can take place, is the elimination of the character '/' if present.

5 EBBA DEMONSTRATED

In this section we introduce and represent results based on two experiments. The former experiment deals with the downward SW radiation at the surface and the latter one with latent and sensible heat fluxes. These parameters offer valuable comparison with measurements conducted on land (in the case of SW radiation) and at sea (in the case of latent and sensible heat). However, it should be noted that the sensible and latent heat fluxes are not measured directly, but rather calculated from temperature and pressure measurements using approximations based on bulk coefficients [Jakobsson & Björnsson 1992].

5.1 Downward SW radiation at the surface

The SW radiation comparisons that follow are composed of two summer months: May and June of the year 1998. The obvious reason for this choice is due to the solar height, which is at its maximum in the North Hemisphere approximately in June 21st at the solar solstice. Since the model does not take into account the spherical shape of the earth and the deflection of solar rays through the atmosphere, the SW radiation at the surface for the winter months will only incorporate higher relative errors. The deflection effect for the summer months is irrelevant, especially when comparing average daily values and when solar declination is high. The effect clouds have on the SW radiation is included in the daily average plots. For clarity we show only the total cloud cover amount, which is only one part of many factors that effect SW radiation. Different cloud types, water vapour and aerosol in the atmosphere are also taken into account in the model.

As mentioned before, the radiation measurements are conducted in Korpa, near Reykjavík. The synoptic station number 1 in Reykjavík was therefore chosen for the synoptic observation data used in the calculations. The only available radiosonde is conducted in Keflavík.

It should be kept in mind that the station in Korpa represents SW radiation in a confined point on the surface, whereas the model averages the fluxes to the extent the synoptic and radiosonde measurement apply. Therefore, we can expect abrupt fluctuations in the measurements compared to the model calculations, which as we will see is the case.

In addition to daily average plots, it is also valuable to compare the SW radiation for clear sky days. In this case the model, if considered acceptable, should agree to measurements within a few percents. However, since the model does not take into account solar activity and uses only the average sun temperature for a black body approximation, we can expect even more substantial errors.

5.1.1 May 1998

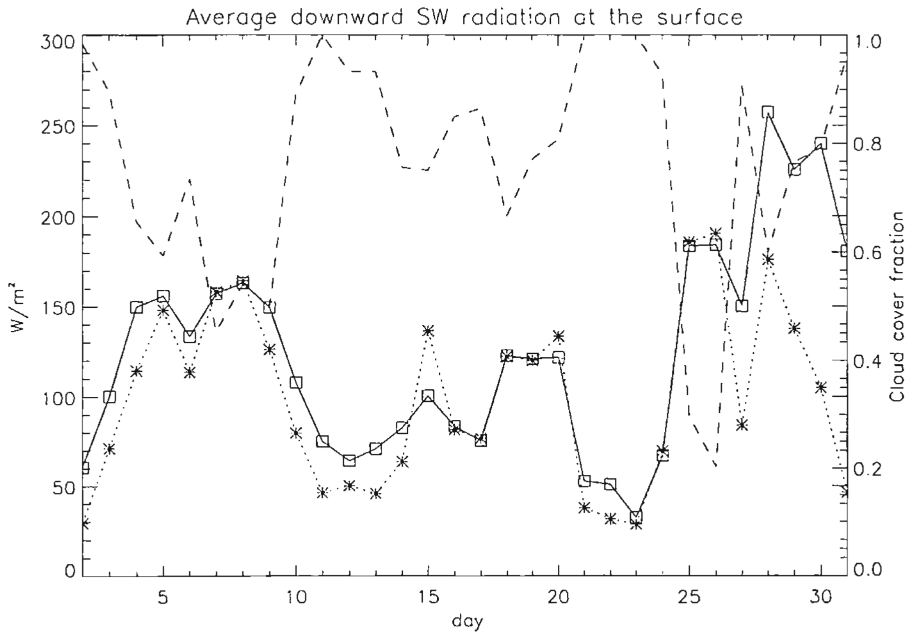

Figure 3 *Daily averaged downward SW radiation at the surface as measured and calculated in May 1998. Model calculations: solid line with square symbols; Measurements: dotted line with asterisk symbols; Cloud cover: dashed line.*

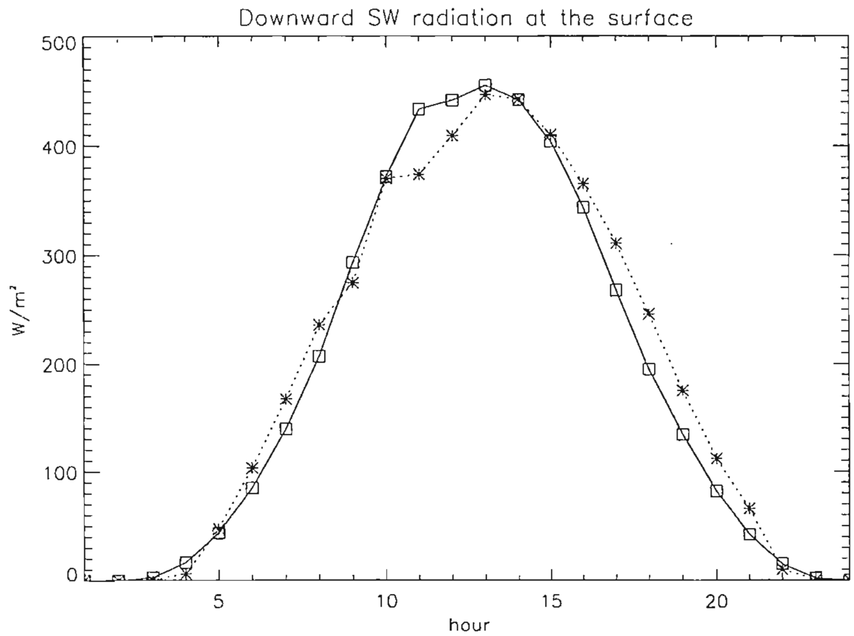

Figure 4 *Hourly values of downward SW radiation at the surface for clear sky on the 26th. For line and symbol conventions, see figure 3.*

The model and measurements seem to agree rather well up to the 27th, where the difference becomes substantial the last days of the month (See figure 3). This shows that under certain cloudy conditions the model fails in SW calculations and apparently over estimates the radiation. As we expect, the correlation is good for clear days, as figure 3 depicts for days 25 and 26. It is however of more concern that the average daily SW radiation seems to be to low for clear sky conditions, both for the calculations and the model. This is also evident in June (See section 5.1.2). This has not been resolved yet. Despite this problem, the daily averages show similar fluctuations tendencies, which is promising.

Figure 4 shows further the good correlation on day 26 between measurements and calculations. For cloudy conditions, we chose day 22 (See figure 5). It becomes evident that fluctuations in the measurements are far more abrupt than in the calculations as expected for reasons discussed above.

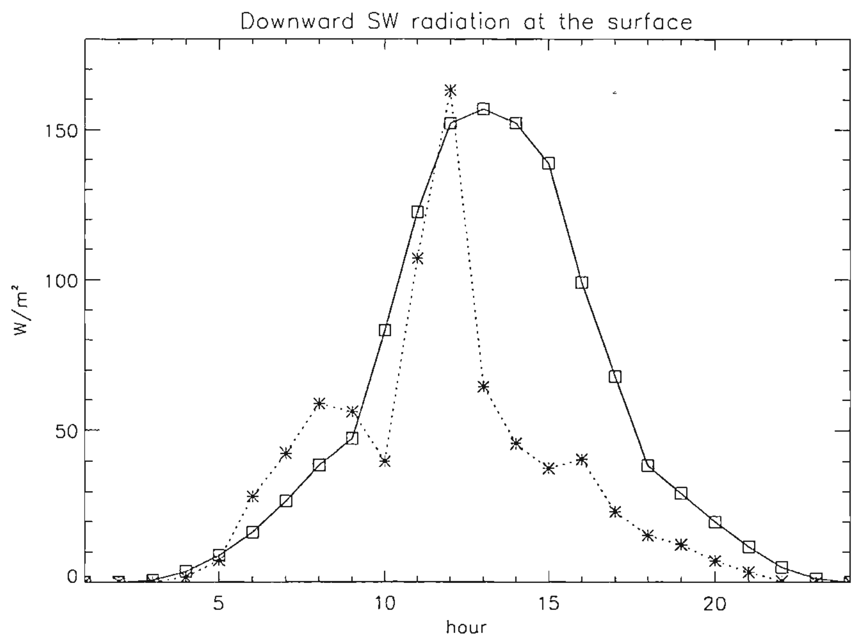

Figure 5 *Hourly values of downward SW radiation at the surface for cloudy sky on the 22nd. For line and symbol conventions, see figure 3.*

5.1.2 June 1998

Once again we see in figure 6 that when its partially cloudy the relative error can get quite high. This could be due to the localization of the measurements as discussed above. The measurements depend on the horizontal distribution of the clouds, which the model does not take into account. In other words, a cloud cover of 50% does not mean necessarily that the SW station will only measure 50% of the clear sky radiation. In the model however, this is the case. Like figure 5, figure 7 confirms this aspect by showing how much the measurements can fluctuate compared to the calculations.

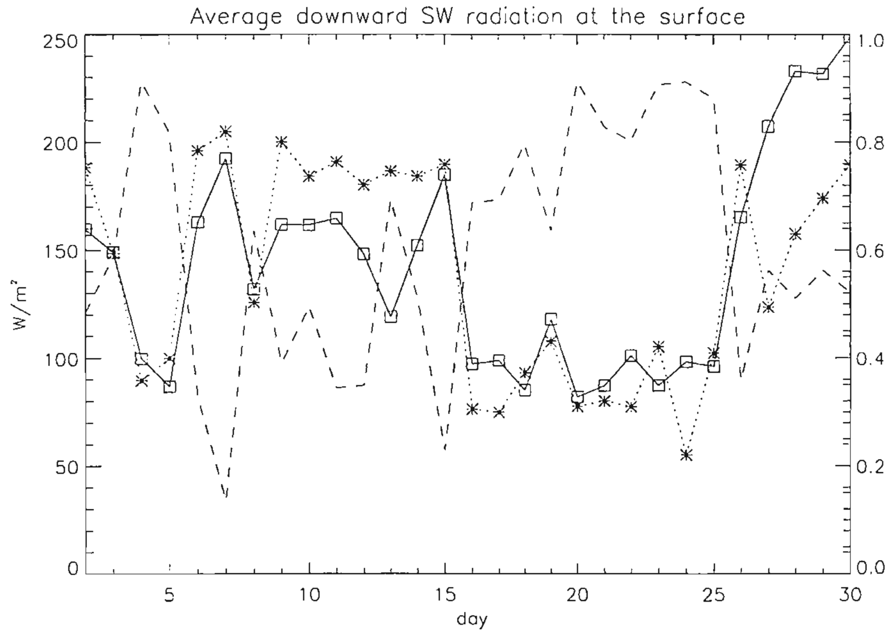

Figure 6 *Daily averaged downward SW radiation at the surface as measured and calculated in June 1998. For line and symbol conventions, see figure 3.*

Figure 6 shows also that the relatively clear skies in days 7 and 15 give an acceptable correlation between measurements and calculations. Figure 8 depicts further the comparison for day 7 and figure 9 shows a comparison for the cloudy day 20.

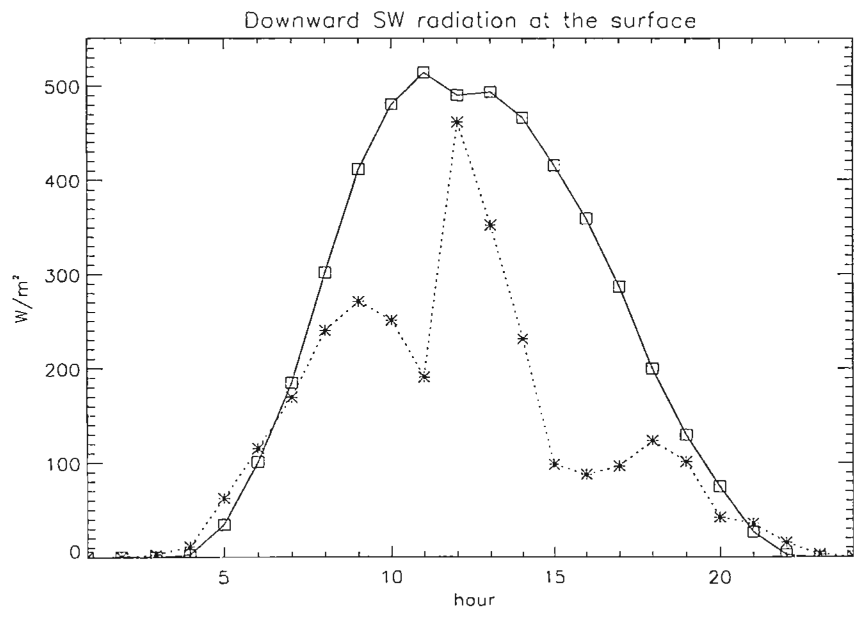

Figure 7 *Hourly values of downward SW radiation at the surface for partially cloudy sky on the 27^{th}. For line and symbol conventions, see figure 3.*

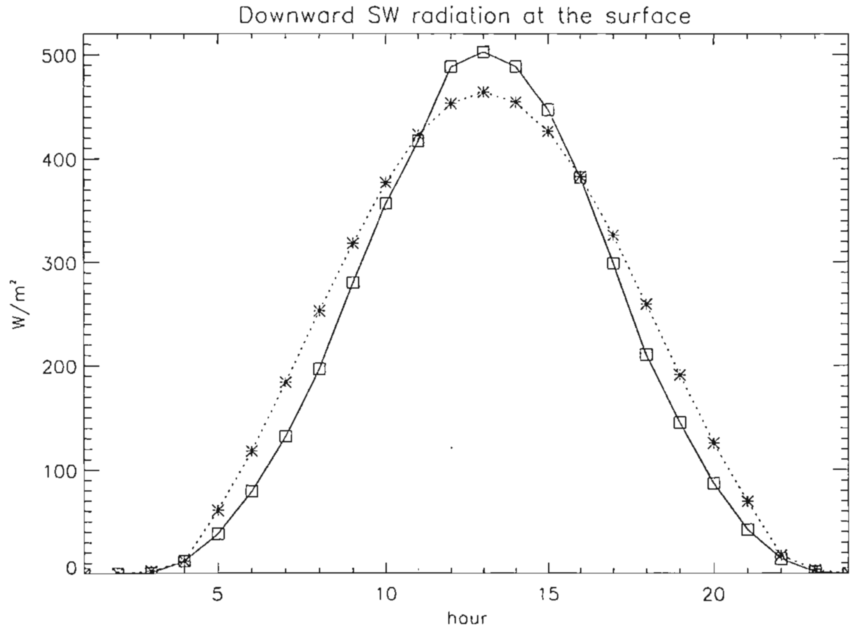

Figure 8 *Hourly values of downward SW radiation at the surface for clear sky on the 7th. For line and symbol conventions, see figure 3.*

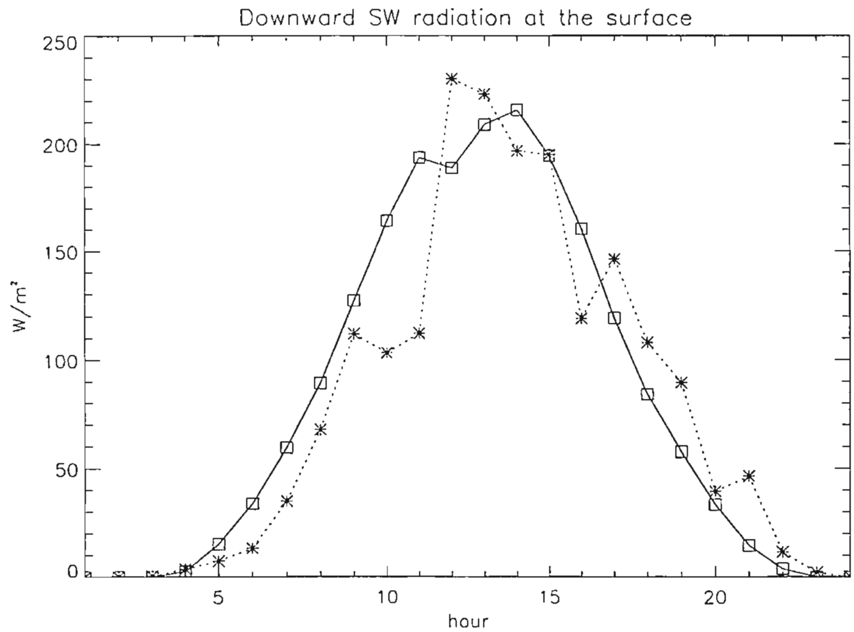

Figure 9 *Hourly values of downward SW radiation at the surface for cloudy sky on the 20th. For line and symbol conventions, see figure 3.*

5.2 Latent and sensible heat

The calculations of latent and sensible heat in the model are based on [Malkus 1962], where constant bulk coefficients are assumed. The only available data to compare with the model comes from measurements conducted on the research vessel Bjarni

Sæmundsson. However, these fluxes are not directly measured but are instead calculated using similar approximations based on bulk coefficients described in [Jakobsson & Björnsson 1992]. In addition, these estimations of the fluxes are based on different data: the model uses synoptic and radiosonde data from Keflavík, whereas the calculations from [Jakobsson & Björnsson 1992] are based on Bjarni Sæmundsson expeditions. This comparison only serves as a first time validation of the models output. Due to different data origin and in light of the scattered nature of the measurements in space and time, we can not expect close correlation, but still some common features should appear.

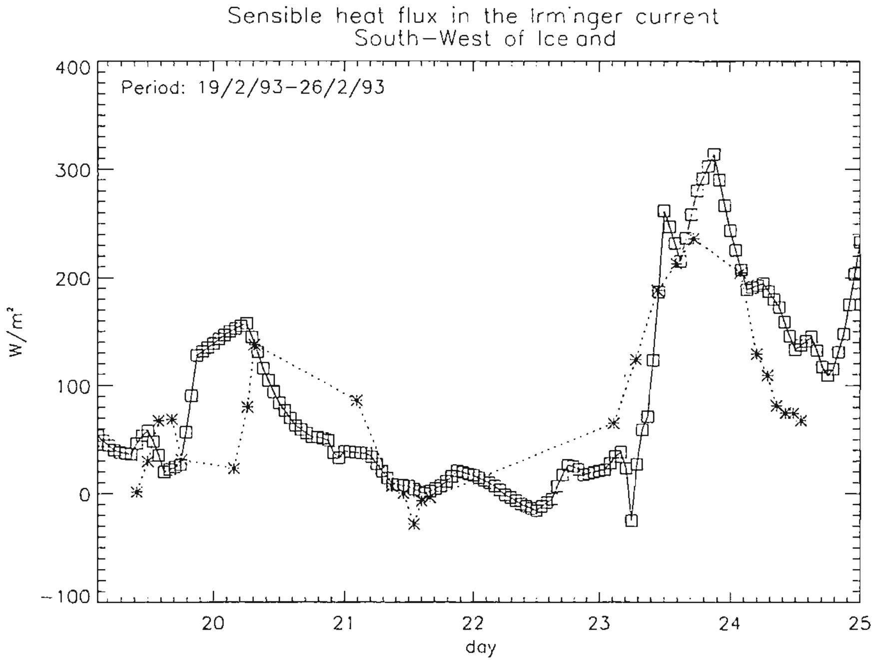

Figure 10 *Sensible heat in the Irminger Current from 19th to 24th February 1993. Average sea temperature profile assumed constant at 5.2°C down to 50 meters depth. For line and symbol conventions, see figure 3.*

In order to make this comparison as reasonable as possible, we chose measurements from the vessel conducted southeast of Iceland in the Irminger Current. The data is confined to the period 19th to 24th February 1993. From the data it was evident that changes in the sea temperature profile down to 50 meters are insignificant over this course of time and nearly constant with height. In the model calculations we assume the constant temperature of 5.2°C in each water layer consistent with the average measured value.

Identical features are apparent in figure 10 and figure 11 indicating that the model is working correctly.

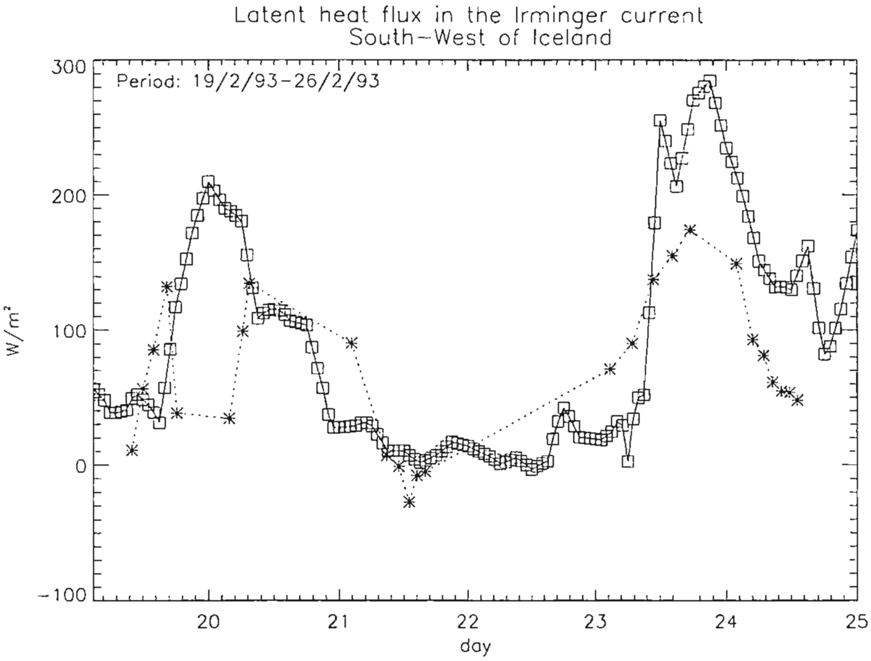

Figure 11 *Latent heat in the Irminger Current from 19^{th} to 24^{th} February 1993. Average sea temperature profile assumed constant at 5.2°C down to 50 meters depth. For line and symbol conventions, see figure 3.*

6 CONCLUSION

This project has been an attempt to awake a 26-year-old energy budget model. Many methods, both physical and technical, used in the model are obsolete today. However, due to simplicity and a fairly acceptable documentation included with the model, it offers endless possibilities of refinements. The main obstacle in bringing Ebba back to life was to integrate it with the database available at The Icelandic Meteorological Office. Therefore, this is not just an attempt to make Ebba functional again, but also a step forward in interpreting the vast data collected by the institution. Using one-dimensional models like Ebba are ideal for this purpose, offering a powerful and efficient way to examine physical processes incorporated in the data. In addition, automatic stations dispersed over a wide area, conduct measurements at time steps down to 10 minutes. These stations provide similar data conducted at manned synoptic stations, accept for cloud evaluation and therefore offer an ideal source of data for models like Ebba.

APPENDIX I

7 DESCRIPTION OF SUBROUTINES

7.1 Birgit

Determines the surface type and calls the appropriate subroutines for surface energy budget. At present only water surface type is assumed for clarity. Therefore, after intializing Birgit calls only Tina2, where the energy budget for a water surface is calculated. Other surface types will be added later if needed.

7.2 Carmen [Vowinckel & Orvig 1972]

This subroutine calculates the energy change in the atmosphere caused by the processes calculated in the energy budget. This is equivalent to the advection required if the temperature of the atmosphere were to remain constant.

The first part splits the turbulent term's *qe* and *qs* into positive and negative terms. A new term *ew* is calculated, is the water budget term of the atmosphere, or rather the heat equivalent to the precipitation minus evaporation. This is then the heat equivalent to the part of precipitation which must be supplied from atmospheric storage or advection. In the case of precipitation being zero, the term is negative. This means that water vapour goes into storage or is exported. Next follows the splitting of *ew* into positive and negative components. *she* is the sum of the heating terms and *sco* is the sum of the cooling terms. The net energy change is then given by *er*. The components of *dfl* are determined from the source *dfl* extracts the energy and radiates to the surface. The details are described in [Vowinckel & Orvig 1971]. Only two fractions are obtained: *rer* the fraction of *dfl* originating from *er* (therefore, either from storage or advection) and the fraction *rsa* originating from SW absorption in the atmosphere. The fractional contributions of the *er* and *saa* terms to the total gain term of the atmosphere, *she*, are determined and then multiplied by *dfl*.

7.3 Check

Checks for consistency in the synoptic cloud code.

7.4 Convert_units

This subroutine is used to convert specific parameters to appropriate units.

7.5 Doris [Vowinckel & Orvig 1972]

Calculates the LW radiation budget. H_2O and CO_2 contents are estimated for each layer. In estimating the content, both substances are weighted by the mean pressure of the layer divided by the surface pressure, to allow for pressure broadening of the absorption lines.

The first calculation is of the upward component of the LW radiation, proceeding downwards from the reference layer. The number of levels used in the calculations is determined by the parameter *lu*. The upward flux is equal to σT^4 of the reference level. Since the cloud amount *c(x)* is given for the lower level of the layer, the cloud amount summation has to start with *c(l+1)*, namely for the lower end of the layer. *sumf* is the total black body radiation from the level of the cloudy part of the sky, which is visible from the reference level. The contributions of the layers to the radiation are determined at the reference level. *a45* and *a48* sum up the water and carbon dioxide between the reference level and the level being calculated. Using the table of transmission functions [Kondratiev & Niilisk 1961], with *a45* and *a48*, a new transmission function *a50* is obtained and added to the previous value. *a50* is then used to obtain the increment to the old *ufl*, which originates from this layer, using the *t4* difference of the levels.

The next step is the incorporation of the cloud radiation from the lower boundary of the layer considered. By definition in Monika, the clouds cannot lie on the ground, but can only start at level 16. The cloud amount visible from the reference level is then given by the clouds at the base of one layer below the present calculations, minus the clouds already considered under *sumc*. The radiation originating from these clouds, *cy*, is added to *sumf*, and the cloud amount to *sumc*. After incrementing the summation term for the transmission function, the radiation for the next level is calculated.

The actual *uf* for the reference level is obtained by the sum of *sumf*, which contains all radiation originating from clouds and the clear sky component *ufl* multiplied with the fraction of the surface visible from the transmission from the reference level.

For the downward LW radiation calculations, the numbering of all arrays must be inverted. The subsequent calculation follows exactly the same pattern as for the upward component. The only difference lies in the final *df* value. For *uf* the final level is the surface, but in the *df* it is a black body at the uppermost level. It should be noted that it is assumed that the atmosphere actually ends at 150mb, i.e. no *df* passes through 150mb. Since this is not quite correct, it means that the energy budget of the atmosphere and of its highest layer is to negative. This inaccuracy is numerically insignificant when compared to the inaccuracies caused by the uncertainties of the cloud amount and can therefore be disregarded.

7.6 Dummy_check

The subroutine Dummy_check finds dummy values in vectors and replaces them with appropriate values, which are usable in the calculations. When data is extracted from the database, some elements of a column do not have a value or are empty. In these cases the SQL statement replaces the empty element with an optional dummy value distinguishable from other data. The dummy value can be read in different ways into the arrays depending on the type and format of the arrays. The value chosen for the dummy in this case is 9999. When a real type array with the format fx.2, where x is some integer, then the dummy value will have the format 99.99. However, if the format is fx.0, then the dummy value will be 9999. Since the formats used for the data from the database are fx.0 and fx.2, there are only to cases we have to consider namely 9999 and 99.99. The subroutine Dummy_check_int checks for 9999 and Dummy_check_real checks for 99.99.

7.6.1 Dummy_check_int

The format type the values of the arrays have is fx.0, where x is some integer value. Therefore the dummy value has the form 9999.. The subroutine begins by checking if the first element is a dummy value.

```
if (array(1)==9999.) then
        do i=2,size
                if(array(i)/=9999.) then
                        do j=1,i-1
                                array(j) = array(i)
                        end do
                        exit
                end if
        end do
end if
```

If the first value is a dummy value, the do loop checks for adjacent dummy values. The values of the first element and adjacent elements with the dummy value are assigned the value of the first element that is not a dummy value.

In a similar way, the last element is checked and replaced by acceptable values if necessary.

```
if (array(size)==9999.) then
        do i=1,size
                if(array(size-i)/=9999.) then
                        do j=0,i-1
                                array(size-j) = array(size-i)
                        end do
                        exit
                end if
        end do
end if
```

The last value and adjacent dummy values, if present, are replaced by the first non-dummy value descending from the last value.

The next step is to check the intermediate values of the array.

```
do i=2,size-1
        if (array(i)==9999.) then
                do j=1,size-i
                        if (array(i+j)/=9999.) then
                                do m=0,j-1
                                        array(i+m) = (array(i-1+m)+array(i+j))/2
                                end do
                                exit
                        end if
                end do
        end if
end do
```

The do loop checks every element of the array except the first and last, since they have been checked earlier. When a dummy value is found in the *i-th* position, another do loop checks for adjacent dummy values. If the number of dummy values are *j*, then the first dummy value *array(i)* is set to the average value of the first elements outside of the dummy gap, that is *array(i) =1/2·[array(i-1)+ array(i+j)]*. The next dummy value *array(i+1)* is found in the same way, but now using *array(i)* instead of *array(i-1)* in the formula.

7.6.2 Dummy_check_real

Dummy_check_real is nearly identical to Dummy_check_int except that the arrays have the format fx.2. This causes the dummy value 9999 to be read 99.99 into the arrays. Therefore, Dummy_check_real goes through the same routine as Dummy_check_int, but instead of checking for dummy values of the form 9999. it checks for 99.99.

7.7 Erika3

Erika3 constructs 1 hourly data from 3 hourly synoptic observations by interpolation. The time step of the model is 1 hour, so we must interpolate the 3 hourly data. The model expects only 12 hourly radiosonde data, so we do not need to interpolate that. Erika3 begins by calling Check, which checks cloud information for consistency. The interpolation factors are then determined. We can now construct 1 hourly arrays.

```
        do i=1,size1-1
                do k=0,2
                ar_1h(3*(i-1)+1+k) = aint(ar_3h(i)+k*dar(i))
man_1h(3*(i-1)+1+k) = aint(man_3h(i)+k*dman(i))
                dagur_1h(3*(i-1)+1+k) = aint(dagur_3h(i)+k*ddagur(i))
                klst_1h(3*(i-1)+1+k) = aint(klst_3h(i)+k*dklst(i))
                tt_1h(3*(i-1)+1+k) = tt_3h(i)+k*dtt(i)
```

```
td_1h(3*(i-1)+1+k) = td_3h(i)+k*dtd(i)
ff_1h(3*(i-1)+1+k) = ff_3h(i)+k*dff(i)
n_nr_1h(3*(i-1)+1+k) = n_nr_3h(i)+k*dn_nr(i)
nh_1h(3*(i-1)+1+k) = nh_3h(i)+k*dnh(i)
h_1h(3*(i-1)+1+k) = h_3h(i)+k*dh(i)
cl_1h(3*(i-1)+1+k) = cl_3h(i)+k*dcl(i)
cm_1h(3*(i-1)+1+k) = cm_3h(i)+k*dcm(i)
ch_1h(3*(i-1)+1+k) = ch_3h(i)+k*dch(i)
rrr_1h(3*(i-1)+1+k) = rrr_3h(i)+k*drrr(i)
ppp_sjo_1h(3*(i-1)+1+k) = ppp_sjo_3h(i)+k*dppp_sjo(i)
end do
```

For each adjacent elements in the 3 hourly arrays there are two intermediate 1 hourly values. The last values must be treated separately.

```
ar_1h(size2) = ar_3h(size1)
man_1h(size2) = man_3h(size1)
dagur_1h(size2) = dagur_3h(size1)
klst_1h(size2) = klst_3h(size1)
tt_1h(size2) = tt_3h(size1)
td_1h(size2) = td_3h(size1)
ff_1h(size2) = ff_3h(size1)
n_nr_1h(size2) = n_nr_3h(size1)
nh_1h(size2) = nh_3h(size1)
h_1h(size2) = h_3h(size1)
cl_1h(size2) = cl_3h(size1)
cm_1h(size2) = cm_3h(size1)
ch_1h(size2) = ch_3h(size1)
rrr_1h(size2) = rrr_3h(size1)
ppp_sjo_1h(size2) = ppp_sjo_3h(size1)
```

We have now constructed 1 hourly arrays, which will be used throughout the program. This simplifies the evaluation of the program time step in the subroutine Hour_step.

7.8 Helena

Calculates the solar constant, used for SW radiation calculation in Ulrika, and solar declination. Takes into account the eccentricity of the orbit by daily correction of the earth's distance from the sun.

7.9 Hour_step

Hour_step feeds the parameters used in the energy budget calculations with appropriate data each hour. The data consists of synoptic observations and radiosonde measurements extracted from the database. New synoptic data is read in every hour, but the radiosonde is read four times a day at the 12th and 24th hours. For the first hour, in this case the 3rd hour, the radiosonde for the 12th hour is read.

7.10 Initial_earth

In Initial_earth the stations hour angle (=*lh*) is calculated, at the initial time location, using the GMT (=*gmt*) time and the longitude of the station (=*flo*). *lh* is an angle measured in degrees defined in the interval [0,360), where *lh=0* at apparent noon and *lh=180* at apparent midnight[2]. We will use *gmt* and *flo* to find *lh*. *flo* is measured in degrees. We assume *180>flo>0* from the GMT meridian to the west[3]. *gmt* is in dimensions time with unit's hours. Its therefore necessary to transform *gmt* to degrees such that 360>*gmt>0* in an anti-clockwise sense. When *24>gmt>12* the hour angle of *gmt* is between 0 and 180. When *12>gmt>1* the hour angle is between 180 and 360.

```
if (gmt>=12) then
gmt_d = anint((gmt-12.)/12.*180.)
else
gmt_d = 180*anint(gmt/12.+1.)
end if
```

gmt_d is the hour angle of *gmt* in unit's degrees. Now we can use *gmt_d* and *flo* to calculate the hour angle relative to the station. There are two situations we have to take into account.

1. If $gmt\_d \geq flo$ then $gmt\_d = flo + lh$
2. If $gmt\_d < flo$ then $gmt\_d = flo + lh - 360$

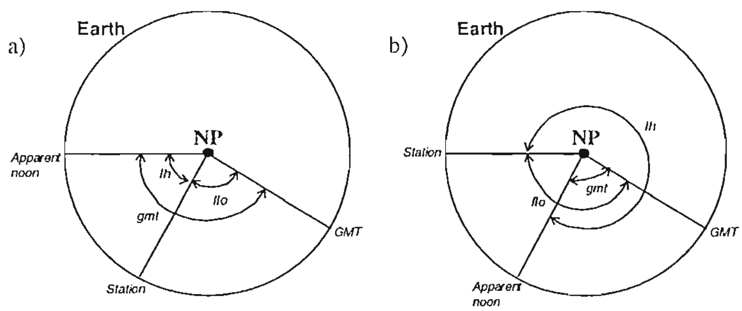

Figure 12 *a) A view of the earth's Northern Hemisphere shows the relative timezone configuration depicted for the case 1, as described above. b) same as in a) but for the case 1. (NP: North pole).*

The code goes as follows

```
if (gmt_d>=anint(flo)) then
lh = gmt_d-anint(flo)
else
lh = gmt_d-anint(flo)+360
end if
```

[2] Obviously the hour angle, can equivalently by defined with dimension time in unit hours, so that $lh \in [0,24)$.

[3] In the case of Iceland this is always true.

Initial_earth ends by calculating the number of days the earth is from perihelion, *ti*. Perihelion is approximately in 3rd of January. Let *man_3h* and *dagur_3h* be the initial month and day and *av_year* is the average number of days per year. Then *ti* becomes

```
ti = man_3h/12.*(av_year-3.) + real(dagur_3h)
```

7.11 Kondra

Kondra is used for LW radiation calculations. When Kondra is called the first time in Ebba, before the station loop is entered, the values of the transmission function are read in a matrix. The transmission function is assumed to be a function of H_2O and CO_2 contents only. When Kondra is called later in Doris, after the H_2O and CO_2 contents have been calculated, the appropriate element of the transmission matrix is found.

7.12 Leda [Vowinckel & Orvig 1972]

The subroutine adjusts the surface temperature toward energy budget equilibrium. At the first call *xrx* is still zero and the temperature is adjusted by 1°, *xn*, the given by the sign of the budget imbalance *rb*. After intializing *i* and *zz*, Leda ends by incrementing the surface temperature *tg* by *xn*. In later calls, *xn* is changed by the same amount and sign as long as the *rb* value of the previous call retains the same sign as the present value of *rb*. If not, the *xn* step is decreased by a factor 10 and depending on which value is smaller, the sign of *rb* or *xrx* is attributed to *xn* and the *zz* value adjusted.

7.13 Lore

Obtains the surface albedo α. In the original version of Ebba, different surface types where considered. Therefore, the surface albedo had to be determined for each type of surface. At present Lore simply gives the albedo a value without any calculations. The average annual albedo in the North Atlantic Sea is approximately $\alpha = 0.30$ and will be used for now.

7.14 Monika [Vowinckel & Orvig 1972]

Prepares a sounding suitable for radiation calculation by using the surface and radiosonde observation data. Monika begins by intializing parameters to zero value for the beginning of a new hour. Values of pressure, temperature and dew point for all levels are calculated by linear interpolation between the main isobaric levels, where observational data is available. Monika then considers cloud cover based on synoptic observations. Due to the high absorption coefficient for the interaction of LW radiation with water vapour, it is important to construct a detailed moisture profile near the surface. Information about the nearest surface layers can therefore have significant effect on the results of the energy budget calculations. When comparing calculations for different stations it is essential they have comparable level structures near the surface and observational data quality. If clouds are present, Monika starts by finding the appropriate base level for the low clouds. Depletion of SW radiation, travelling through a layer of cloud, is estimated with the parameter *chh*, which is the product of the thickness[4] of the layer and the cloud amount in the layer. For estimating the vertical distribution of the lower clouds, where no data is available, three parameters are used as indicators:

1. Cloud type as observed and reported in the synoptic code.
2. Precipitation.
3. Dew point depression.

This determines how high the lower cloud extends from the base, with the amount observed or reported. In cases with full overcast of low clouds, clouds above the base level can only be generated under the following conditions:

1. Convective clouds are reported.
2. Precipitation is reported.
3. Low dew point depressions are reported.

Monika finally calculates the specific humidity for each of the 17 levels by using the calculated dew point profile.

We summarise the operation of Monika as follows:

1. Construct a proper sounding from the radiosonde.
2. Construct a proper cloud distribution.
3. Obtain specific humidity for each level.

7.15 Sh

Calculates the specific humidity. The specific humidity is given by

$$q = \frac{\rho_v}{\rho} = \frac{m_v}{m} = \frac{m_v}{m_d + m_v} = \frac{1}{\frac{m_d}{m_v} + 1}$$

Equation 1

where ρ_v and m_v are the density and mass of water vapour, ρ is the total density and m_d is the mass of dry air. Using the equation of state for dry air and water vapour, it can be shown that

[4] Thickness of a layer is defined as the difference of the pressures at the levels below and above it.

$$\frac{m_d}{m_v} = \frac{p_d}{\varepsilon e}$$
Equation 2

where $\varepsilon = M_v / M_d \approx 0.622$ is the ratio of molar weights. Inserting Equation 2 into Equation 1 and using Dalton's law for partial pressures, $p = p_d + e$, we get

$$q = \frac{\varepsilon e}{p - (1 - \varepsilon) e}$$
Equation 3

where p, p_d and e are the total, dry air and water vapour pressures. The model uses the specific humidity in unit's g/kg. We obviously then have the relationship $shh = 1000q$, where *shh* is the specific humidity in units g/kg.

7.16 Tina2 [Vowinckel & Orvig 1972]

Calculates the energy budget for a water surface. Apart from the diameter of the water body, Tina uses the layer thickness, *tah*, and absorption, *taw*. The subroutine starts with the calculation of the surface budget terms. Contrary to land conditions, no adjustment of surface temperature or adjustment to available energy is necessary before all budget terms can be calculated. This is a result of the large amounts of stored energy and its ready availability.

The water surface temperature, *gt(12)*, is used for Vera, as well as for the calculation of the upward fluxes. The leaf area index, *bla*, determines whether or not vegetation is present on top of the water surface. If $bla \leq 50$, then no vegetation is considered and if $bla > 50$, vegetation is assumed and the surface is called a swamp.

Tina begins by calculating the surface energy budget and calls Vera for latent, *qe*, and sensible, *qs*, fluxes. Vegetation needs also to by considered if present. Next the calculation of the temperature change in each layer, caused by the absorption of SW radiation. The tables of absorption factors and layer thickness are used. The program permits the condition that the water is too shallow to absorb all radiation. The number of water layers determines this. If this number is less than 12, the SW radiation not absorbed in the water layers above is incorporated into the lowest water layer. The portion of energy that might go into the ground, below the water, by convection is considered insignificant.

In the next part of the program, a basic turbulence or conductivity is assumed for the water. The thermal conductivity is very small and is surpassed by other influences. However, for very stable and calm conditions in summer, this is the only transport present, in which case should not be neglected.

Stability due to thermal mixing and dynamic mixing due to wind is also considered. Winds with velocity less than 0.1 m/s are regarded as ineffective in the mixing. The first approximation of the mixing depth is based on long duration and infinite fetch of the wind. Next a reduction has to be applied for smaller water bodies. A linear relationship of mixing depth to water body size is assumed. Once the mixing depth is established, the lowest layer affected is determined.

7.17 Ulrika [Vowinckel & Orvig 1972]

Calculates the SW radiation terms in the energy budget. Moisture content in the layers are calculated, where the content is taken as the average of the specific humidity at the upper and lower level boundaries, adjusted for the thickness of the layer. When Ulrike is first called, the calculations begin at the hour angle *lh* determined by the subroutine Initial_earth. For each later hours, *lh* is incremented in Ulrike by one hour (=15°). The calculation of the hourly value is based on the summation of results from separate calculations for each 12 minute interval (=3°). Then the solar elevation is calculated for the given hour angle. Ozone concentration is assumed constant above the 300-mb level, which is used to estimate the solar radiation that reaches that level, *s300*. This is only approximately valid, as no scattering is taken into consideration. The next loop determines the SW absorption for each layer of the radiosonde. Both absorption and depletion factors are based on the equations given by [Bailey 1965]. This calculation begins at the top layer and progresses downwards. As a first step, the total absorption factor between the base of the layer and the top of the atmosphere is calculated, *ab1*, as a function of solar elevation, air mass and water vapour content. The depletion from scattering by water vapour, *de1*, and by dry air, *de2*, are combined into a depletion value *dev*. The parameter *sr* determines the number of full hours of the day with the sun above the horizon. The actual absorption for each layer is then obtained, where the cloud amount in each layer is considered. This is obtained by multiplying the clear sky value $s300 \cdot su(m)$ by $1+chh(m) \cdot 7 \cdot 10^{-5}$. The factor $7 \cdot 10^{-5}$ is based on results in [Korb 1959]. The details of the use of these results are described in [Vowinckel and Orvig 1969]. The atmospheric absorption is also summed up to give the total actual absorption *saa*. The SW radiation reaching the surface without cloud depletion is then obtained from absorption and clear sky depletion, *sy*. When considering the scattering influence of clouds, *ci* must be treated independently. The cloud amount, where only Ci·albedo is effective, is given by *cin*. The total of non-Ci cloud amount is therefore *fn-cin*. For these non-Ci clouds, the albedo depletion is a function of both cloud thickness and atmospheric water vapour content. The total cloud depletion factor *fac* has essentially the same form as described in [Vowinckel and Orvig 1969]. The SW radiation reaching the ground under actual cloud conditions, *sgc*, is then obtained by $sy \cdot fac$.

Finally, the dust depletion is considered, which is based on [Robinson 1962] and on the assumption that the dust content is indicated by the horizontal visibility. The first specification, *x1*, is that absorption by dust takes place below the clouds, in the near-surface layers (*x1=1* for clear sky conditions). Next, a limit is put on the dust absorption, which is defined as 6.5% with air mass 1 and unlimited visibility. With lower solar elevations the value becomes very large, so we define an upper limit of 30% of *sgc*. The absorption is distributed evenly through the lowest four layers of the atmosphere. Then the dust scattering is calculated in a similar manner. The total dust depletion becomes as high as 40% of *sgc* under the most extreme conditions. Ulrike ends with the definition of the mid-hour solar elevation, *sinai*.

7.18 Vera [Vowinckel & Orvig 1972]

Vera calculates the turbulent terms. It starts with the conversion of air temperature, *tdz*, and dew point, *tx*, at the surface into the specific humidity. The vapour pressure for the surface is calculated for ice when surface temperatures are less than –5°C. The procedure uses subroutine E for the determination of vapour pressure and the function Sh for the calculation of specific humidities *txsh* and *tdsh*.

After the determination of the vertical temperature gradient *gr*, a drag coefficient *cx* is determined from *f*. For stable conditions a factor *fac* is determined, being the gradient as a fraction. This factor is used to reduce the exchange coefficient, a constant value being reached with a temperature gradient of 10° between air and ground. In the case of instability a new factor *cy* is determined, which is linearly related to the temperature gradient, which can be derived from air mass transformation. The final factor *cdf* is then obtained for unstable conditions by a comparison of *cx* and *cy*, where the greater value is chosen.

Next follows the calculation of the sensible heat flux *xs* and the latent heat flux *xe*. The equations, as well as the constants are based on formula given by [Malkus 1962]. The factor 1.25 in *xs* was obtained from references given by [Munn 1966] for the relation of *qe* to *qs*.

APPENDIX II

8 PARAMETERS

In the following list of parameters used in the model, each parameter is described as accurately as possible. Some parameters are not used in the current version but none the less included here. We will use E, L, T and θ to denote the dimensions of energy, length, time and temperature.

1. *lh* = sun's hour angle relative to the station,

Measured in degrees. *lh* has value zero at apparent noon and at apparent midnight its value is 180°. Thus, the angle is defined positive from east to west. Used in Ulrika.

2. *size1, size2, size3*, parameters determining the size of the arrays containing 3 hourly synoptic, 1 hourly synoptic and 12 hourly radiosonde data.

To determine *size2* from *size1* we note that between every 3 hour intervals, there are two 1 hourly values. We have that *size1-1* is the number of intervals in a 3 hourly array. Then we have

$$size2 = 2(size1 - 1) + size1$$

Equation 4

The number of 12 hourly radiosonde values, *size3*, is found using *nr_days*. There are 2 sets of 12 hourly radiosonde measurement per day available in the database.

3. $nlx = nl - 1$, number of layers above surface in the atmosphere considered in radiation calculations.

Used in Doris and Ulrika.

4. *nl* = number of levels above surface in the atmosphere considered in radiation calculations.

Used in Doris and Ulrika.

5. $sa = (sa_1, sa_2, \ldots, sa_{16})$, SW radiation absorbed in different layers in the atmosphere.

$[sa] = E \cdot L^{-2}$, with units cal and cm. Used in Ulrika.

6. $p = (p_1, p_2, \ldots, p_{17})$, pressure at different levels in the atmosphere,

with units mb. P_{17} (=PS) is the surface pressure. Used in Birgit, Doris, Erika3, Monika, Sh and Ulrika.

7. ***ppp_sjo_3h***, 3 hourly values of pressure at sea level.

With units mb.

8. $shh = 10^3 \cdot q = 10^3 \cdot \frac{m_v}{m_{tot}} = 10^3 \cdot \frac{m_v}{m_d + m_v}$

where q is the specific humidity, m_v is the mass of water vapour and m_d the mass of dry air. *shh* is therefore a measure of q where m_v has unit's g and m_d has unit's kg. Calculated in subroutine Sh from the water vapour pressure and total pressure. Used in Doris, Monika, Sh and Ulrika.

9. *fut* = sun's declination,

Measured in degrees. Used in Helena and Ulrika.

10. *s15* = solar constant,

[*s15*] = $E \cdot T^{-1} \cdot L^{-2}$, with units cal, min and cm. Used in Helena and Ulrika.

11. *sr* = approximate number of hours of daylight. Number of hours the sun is above the horizon.

12. *saa* = total SW radiation absorbed in the atmosphere.

[*sa*] = $E \cdot L^{-2}$, with units cal and cm. Used in Carmen and Ulrika.

13. *sga* = SW radiation at the surface under actual cloud conditions. *sga* has various meanings through the execution of the program. In Ulrike, *sga* is the total downward SW radiation as measured by an instrument. After Ulrike has been exited, *sga* means the total downward SW radiation absorbed in the ground.

[*sga*] = $E \cdot L^{-2}$, with units cal and cm. *sga* has various meanings; in the program Ulrike it is the radiation as measured by an instrument, and after statement no. 40 it means solar radiation absorbed in the ground. Used in Birgit, Tina2 and Ulrika.

14. *v* = visibility due to dust depletion.

v = 1, means perfect visibility. Used in Erika3 and Ulrika.

15. *ho* = hour of the day.

Used in Erika3 and Monika.

16. *s300* = solar radiation at 300 mb, the top of the atmosphere.

[*s300*]=EL^{-2} with units cal and cm^2. Used in Ulrika.

17. *br* = station latitude

Measured in degrees. Used in Ulrika.

18. *sgc* = SW radiation reaching the surface under actual cloud conditions, before depletion by dust or pollution.

[*sgc*] = EL^{-2} with units cal and cm^2. Used in Ulrika.

19. *lu* = parameter determining the number of layers for which LW calculations are done. Used in Doris.

20. *df* = downward LW radiation flux for surface (17) and different layers in the atmosphere.

[*df*]= EL^{-2} with units cal and cm^2. Used in Birgit and Doris.

21. *uf* = upward LW radiation flux for surface (17) and different layers in the atmosphere.

[*uf*]=EL^{-2} with units cal and cm^2. Used in Doris.

22. *qe* = latent heat flux.

[*qe*] = EL^{-2} with unit's cal and cm^2. Used in Birgit, Carmen and Tina.

23. *qs* = sensible heat flux.

[*qs*] = EL^{-2} with units cal and cm^2. Used in Birgit, Carmen and Tina.

24. *fg* = ground heat flux.

[*fg*] = EL^{-2} with units cal and cm^2. Used in Birgit, Gaia, Gwen and Tina.

25. *rlu* = LW radiation flux upward from the surface.

$[rlu] = EL^{-2}$ with units cal and cm^2. Used in Birgit, Carmen, Ebba and Tina.

26. ***tt_3h*** = 3 hourly synoptic surface temperature values for *tg* (ground surface layer), *tv* (vegetation surface layer), *tx* (surface layer) and t_{17}.

With units °C.

27. ***td_3h*** = 3 hourly synoptic surface dew point values for td_{17}.

With units °C.

28. *nstn* = a dummy gives instructions when the initial values in Erika3 should be read.

Initial values in Erika3 are only read once in the beginning of the calculations. When *nstn* = 1 then initial values are read.

29. *ff* = wind speed at the surface.

$[ff] = L{\cdot}T^{-1}$, with units m and s. ***ff_3h*** and ***ff_1h*** are 3 and 1 hourly synoptic values for the wind speed *ff* at the surface.

30. *n_nr* = 1 hourly synoptic values for total cloud amount.

Measured in octa (*0-8*). ***n_nr_3h*** and ***n_nr_1h*** are 3 and 1 hourly synoptic values for total cloud amount. Used in Check, Erika3, Monika and Ulrika.

31. *nh* = low level cloud amount.

Measured in octa. ***nh_3h***, ***nh_1h*** are 3 and 1 hourly synoptic values for low level cloud amount.
Used in Check, Erika3, Monika and Ulrika.

32. $\boldsymbol{c} = (c_1, c_2, \ldots, c_{17})$, cloud amount (*nh* or *n_nr*) for each level.

33. ***cl_3h***, ***cm_3h***, ***ch_3h***, 3 hourly synoptic values for cloud types, low, medium and high (synoptic code).

Used in Check, Erika3 and Monika.

34. *h* = height of the low level clouds.

Measured in synoptic code 0-9, but converted in mb for use in model. ***h_3h, h_1h*** are 3 hourly and 1 hourly values for height of the low level clouds *h*. Used in Check, Erika3 and Monika.

35. *nlw* = Number of levels (water layers) below surface (max 12 levels). If no water surface is present, the value for NLW indicates the percent of coniferous forest.

36. ***gt*** = $(gt_1, gt_2, \ldots, gt_{12})$, temperature profile at levels below surface.

$[gt_i] = \theta$, with units °C. The thickness of each layer between the levels is determined by ***tah***.

37. *xx* = Heat of vaporization.

38. *bla* = leaf area index for the area or vegetation type under consideration.

39. *eis* = Ice thickness on the water surface, [cm].

40. ***tah*** = $(tah_1, tah_2, \ldots, tah_{12})$, height interval of levels in water.

$[tah_i] = L$, with units cm. Thickness of 12 layers if they are water.

41. ***taw*** = $(taw_1, taw_2, \ldots, taw_{12})$, fraction of *sga* absorbed in different water layers.

42. *dia* = Diameter of the water body, [km].

43. *ltg* = ?

44. *sue* = ?

45. *ti* = sidereal time distance from perihelion (days from 3. January),

$[ti]$ =T and units days. Used in Helena.

46. *a* = semi-major axis of orbit (mean orbital radius),

$[a]$ = L, with units km. Used in Helena.

47. *ag* = *77°*, orbital angle of equinoxes,

$[ag]$ = 1, measured in degrees from perihelion. In January 3rd, the earth is at perihelion. In March 21st, the ecliptic intersects the celestial equator the first time measured from perihelion. Assuming there are 28 days in Febuary, the total amount of days from perihelion to the first equinoxes are 78. Therefore, *ag=(78/365)360=77° degrees*. Changes in *ag* in the course of decades are negligible. Since we are only interested in timescales spaning only months or years, *ag* is kept constant throughout the calculations. Used in Helena.

48. *ra* = radius of the sun,

[*ra*] = L, with units km. Used in Helena.

49. *tsun* = temperature of the sun,

[*tsun*] = θ, with units K. Used in Helena.

50. *exc* = eccentricity of earth´s orbit,

[*exc*] = 1. Used in Helena.

51. *flo* = longitude of the station,

[*flo*] = 1, measured in degrees. *flo* is positive if east of *gmt* and negative if west of *gmt*, that is $-180^\circ \leq fot \leq 180^\circ$. Used in Hour_angle.

52. ***fp1*** = $(fp1_1, fp1_2,...,fp1_5)$, ***fp2*** = $(fp2_1, fp2_2,...,fp2_5)$ = Fraction of total water withdrawal from ground originating in different layers, 1 = vegetated, 2 = bare.

53. gmt = Greenwich mean time

54. ***eta*** = $(eta_1, eta_2,...,eta_5)$ = albedo correction for snow depth.

55. ***tabh*** = $(tabh_1, tabh_2,...,tabh_{10})$ = conversion of cloud height from code to mb. Conversion table, relating cloud base heights from the synoptic code to a pressure height. A conversion factor of 1mb = 8m was used.

56. ***tapt*** = $(tapt_1, tapt_2,...,tapt_{10})$ = temperature influence on photosynthesis after dewet.

57. ***tar*** = $(tar_1, tar_2,...,tar_{11})$ = temperature influence on respiration.

58. *tap*(**21,11**) = photosynthesis in units (after dewet) dependent on G SGA.

59. *conw, cond* = wet and dry conductivity of soil, [cal/cm, sec, deg].

60. *sph* = heat capacity of natural soil, [cal/cm^3, deg].

61. *du* = time (fraction of hour) before the surface water has run off from the area [hr].

62. *to5* = albedo of litter, fraction.

63. *for* = area index for vegetation without leaves.

64. *fe* = fraction of area which is covered by rock or concrete.

65. *blam* = maximum leaf area index for the area or vegetation type under consideration, in unit areas.

66. ***bw(5), gw(5)*** = soil water terms (maximum water holding capacity of 5 layers in the ground), BW = Potential, GW = Actual, [cm].

67. *pmi* = temperature at which growth of vegetation starts, [°C]. Minimum temperature below which photosynthesis and growth stops.

68. *lper* = length of vegetation period, [days].

69. *topt* = optimum growth temperature of the plants considered, [?].

70. *storo* = water storage in snow on ground, [cm].

71. *sn* = snowdepth on ground in, [cm].

72. *nday* = number of times the day loop is executed.

73. *ind* = directs the program either to hourly calculations, if IND=0, or to statement 100 if separate calculations for day and night are required.

74. *lwr* = parameter instructing printout. If *lwr* = *1*, hourly values are printed, otherwise daily values.

75. *zea* = *0*, means ceres is used, i.e. *pho* is calculated and available.

76. ***t*** $=(t_1, t_2, \ldots, t_{17})$, temperature for corresponding level,

$[t_i] = \theta$, with units °C. Used in Birgit, Doris, Erika3, Gwen and Monika.

77. ***td*** $= (td_1, td_2, \ldots, td_{17})$, dew point for corresponding level,

$[t] = \theta$, with units °C. Used in Birgit, Erika3 and Monika.

78. *rrr* = precipitation,

[*rrr*] = L, with units cm. Used in Erika3, Inge and Monika.

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