

# Computer Practical: Parcel Modelling

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## 1 Overview

In this computer practical, you will use a model to calculate the condensation of water onto aerosol particles to form cloud droplets. The principles are the same as in previous weeks in that you are solving a set of ordinary differential equations.

## 2 Model formulation

This model calculates the properties of an air parcel that moves through to locations where the pressure changes. The change in pressure is responsible for changes to temperature, which then results in changes to the phase of water. The model solves several coupled equations as below:

$$e_0 = 610.7 \exp\left(\frac{L_v}{R_v} \left[\frac{1}{273.15} - \frac{1}{T}\right]\right) \quad (1)$$

$$e_v = e_0 \exp\left(\frac{2\sigma_w}{R_v T \rho_l r_i}\right) \quad (2)$$

$$\frac{dP}{dt} = -\rho_a g w \quad (3)$$

$$\frac{dT}{dt} = \frac{R_a T}{c_p P} \frac{dP}{dt} + \frac{L_v}{c_p} \frac{dw_l}{dt} \quad (4)$$

$$\frac{dm_i}{dt} = 4\pi r_i D_v \left(w_{v,\infty} \rho_a - \frac{e_v(T)}{R_v T}\right) \quad (5)$$

$$\frac{dw_l}{dt} = \sum_i^N N_i \frac{dm_i}{dt} \quad (6)$$

$$\frac{dw_{v,\infty}}{dt} = -\frac{dw_l}{dt} \quad (7)$$

where  $e_0$ ,  $e_v$  are the equilibrium vapour pressure over a flat and curved surface respectively;  $L_v$  is the latent heat of vaporisation,  $R_v$ ,  $R_a$  are the specific gas constants for water vapour and air respectively;  $T$  is temperature;  $\sigma_w$  is the surface tension of water;  $\rho_l$ ,  $\rho_a$  are the densities of liquid water and air respectively;  $r_i$  is the radius of an aerosol / drop;  $P$  is pressure;  $g$  is gravity;  $c_p$  is the specific heat capacity of air;  $m_i$  is the mass of a single aerosol particle / drop;  $w_{v,\infty}$  is the mass of water vapour in the parcel;  $N_i$  is the number of aerosol / drops in the parcel;  $w$  is the vertical wind, and  $D_v$  is a constant.

These are the equations that the FORTRAN model will solve for us.

## 3 Aerosol size distributions

In the atmosphere, aerosol particle size distributions tend to be distributed according to a log-normal distribution. There are 3 parameters that describe the shape of a log-normal distribution:  $N$ ,  $\bar{D}$ ,  $\sigma_g$  and we will use these variables as part of our initial conditions. In the atmosphere, aerosol particles tend to come in 3 of these modes: the nucleation mode, the accumulation mode, and the coarse mode, so there will be 3 modes in the input file and water will condense onto these aerosol particles to form a cloud. However, the idea with the Marine Cloud Brightening geoengineering scheme is that adding sea salt aerosol particles to the background aerosol will alter the properties of the clouds making them more reflective. This is the idea we will explore in the practical today.

The parcel model is written in FORTRAN and solves for the movement of an adiabatic parcel of air along a vertical coordinate in the atmosphere. The model generates an output file in a format known as NetCDF. NetCDF

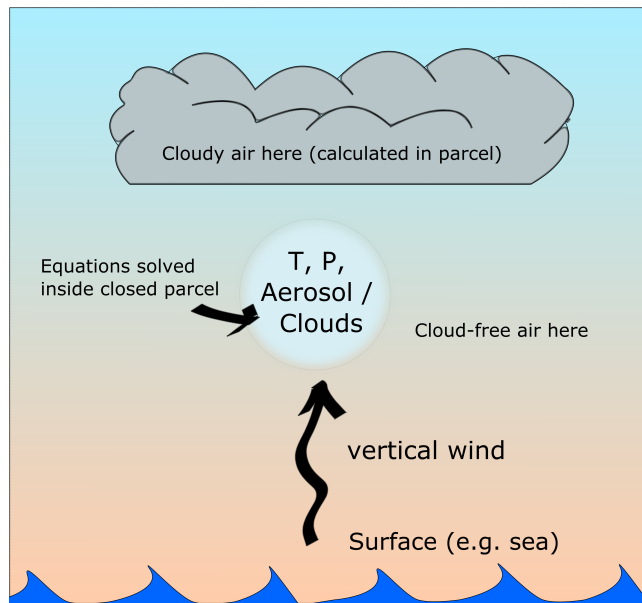


Figure 1: Schematic of the scenario being modelled. The model variables are within the small parcel of air shown. However, if we assume the air surrounding the parcel has similar properties to the parcel we can use the model to predict the properties of the atmosphere along a vertical coordinate.

is a common data format used in atmospheric and environmental sciences. This file can then be read in and plotted using a Python script. Figure 1 illustrates the main idea behind the model simulations that you will run today.

## 4 Downloading and compiling the code

Log into the server computer with an SSH window. Also, log into the server computer with an SFTP window. Space the windows out on your screen so that you can easily move between them.

If you have not done this already, download the code you will be using today from GitHub by typing the following:

```
git clone https://github.com/EnvModelling/bin-microphysics-model
```

this should download the code to your working directory.

In order to access the files you will need to change the working directory to where the files are. Type the following:

```
cd bin-
```

followed by the `tab` key and the command should auto-complete. Then press the `enter` key.

Type `ls` followed by the `enter` key. The screen should list the files in this directory.

Finally, type `make` followed by the `enter` key. This will compile the FORTRAN code into machine code that the computer can run.

## 5 Viewing and Editing the code

We will use the `nano` text editor to view some files. The file that takes input data is called `namelist.in`. To see what variables we can change, type:

```
nano -l namelist.in
```

the `-l` means to show line numbers. The code can be edited in the text editor and saved by typing `Ctrl-X` at the same time and pressing `Y` to save the file. The important lines are lines 9-14 and 57-62 of this file.

Table 1: Parameters that you will change, which control the behaviour of the model.

Variable	Default value	Description
winit	0.3	the speed that the parcel moves along the vertical in the atmosphere ( $\text{m s}^{-1}$ )
tinit	290	the initial temperature in kelvin.
pinit	100000	the initial pressure (Pa).
rhinit	0.65	the initial relative humidity (fraction).
n_aer1	46.64e6, 153.42e6, 166.77e6, 0e6, 0e6, 0.e6	number in each mode ( $\text{m}^{-3}$ ).
d_aer1	18e-9, 39e-9, 154.e-9, 1e-6, 1e-6, 1000.e-9	diameter in each mode (m).
sig_aer1	0.348, 0.354, 0.465, 0.3, 0.3, 0.5	$\ln \sigma_g$ for each mode (width).

On lines 9-14 the vertical wind, temperature, pressure and humidity (related to the water vapour pressure) are defined.

On lines 57-62 the variables `naer1`, `d_aer1`, and `sig_aer` have  $3 \times 2$  elements. These are 3 aerosol modes for each chemical component. For example background aerosol has 3 modes and the sea-salt aerosol has 3 modes.

## 6 Running the model

After the code has been compiled (see Section 4), the procedure for running the model is to type:

1. Edit the file `namelist.in` to configure the model.
2. Type `./run.sh` at the command line, followed by `enter` to run the model.

Table 1 describes the parameters in `namelist.in` that can be modified, although obviously you can hack any part of the code if you want to. Not that if you do change any FORTRAN code you will need to type `make` again to compile the code to the machine executable.

## 7 Experiments

FOR ALL EXPERIMENTS: I STRONGLY SUGGEST YOU OPEN UP A WORD OR POWERPOINT DOCUMENT AND INSERT THE FIGURES AND MAKE SOME NOTES AS YOU GO. YOU COULD BE ASKED QUESTIONS ABOUT THEM IN THE ASSESSMENT.

### 7.1 Temperature lapse rate of the parcel

The first simulation to do is a standard simulation where we use the background aerosol with the parcel starting at the ground and rising through the atmosphere at  $0.3 \text{ m s}^{-1}$  to a height of 1200 m. This is the default case, so we just need to type:

```
./run.sh
```

at the command line, followed by `enter`. The code will take a short while to run and an output file will be created. Check that the file is there by typing `ls /tmp/<username>/` where `<username>` is your username.

**Exercise:** To plot the results of this simulation you will need to run a Python script. Type the following, pressing `enter` after each line

```
python3 python/example_plot_bmm2.py
```

after a short while Python will put a file in the `ls /tmp/<username>/` directory. To download it, go to your SFTP window and type:

```
get /tmp/<username>/vertical.png
```

followed by `enter`, where `<username>` is your username. This should be a plot of the the properties of the parcel in the vertical. It will be discussed in the practical.

**Exercise:** From the top right plot try to estimate how fast temperature decreases with height up to 800m altitude. The rate of increase is a property of dry air that rises adiabatically. It cools at a known rate.

**Exercise:** What happens to the rate of cooling above 800m? Why?

Make a note of the mixing ratio of liquid water in the cloud at the top. This is the mass of liquid water in the parcel of air. Also make a note of the height that the cloud drops form.

## 7.2 Effect of vertical wind-speed

The speed that the air cools is very important to the properties of the cloud that is formed. We will edit the `namelist.in` file on line 9 by changing the value of `winit`.

Do simulations for  $10\times$  less than the default value and  $10\times$  more than the default. i.e. set `winit=0.03` and `winit=3.0`.

You should type:

```
nano -l namelist.in
```

then make the change, followed by `Ctrl-X` to exit, then type `Y` followed by `Enter`.

Run the model by typing:

```
./run.sh
```

each time you run the simulation, follow the steps in Section 7.1 to plot the model results and download to your computer.

**Exercise:** How does the lapse rate look between 0 and 800m on these new simulations?

**Exercise:** Look at both the liquid water mixing ratio (top left) and the CDNC (Cloud Drop Number Concentration) for these plots. What effect does changing the vertical wind speed have? Why?

**Exercise:** Approximately what height does the cloud start to form in these simulations? Why?

You should be in the `bin-microphysics-model` directory.

## 7.3 Increasing humidity (water vapour)

Let's return to the initial default state of the model by typing:

```
git reset --hard
```

Edit line 14 of `namelist.in` by typing:

```
nano -l namelist.in
```

and changing to `rhinit=0.95` and exit / save the file in the usual way.

Run the model and generate the output file and plot in the usual way. Download it using SFTP.

**Exercise:** How did increasing the initial humidity change the result? Why?

## 7.4 Adding sea-salt aerosol

From the main model directory `bin-microphysics-model` return to the default: `git reset --hard`.

Finally we will add some sea salt aerosol and run the simulations to investigate the effect. The simulations you should run are as follows.

1. Change the 3rd mode in the sea salt number concentration to  $1000 \times 10^6$  on line 58 by setting line 58 to `0e6, 0e6, 1000.e6, .` Run the simulation, make the plot, and download the image.
2. Do not change back to the default, and narrow the 3rd mode in the sea salt width  $\ln \sigma_g$  to 0.01 on line 62 by setting line 62 to `0.3, 0.3, 0.01, .` Run the simulation, make the plot, and download the image.
3. Do not change back to the default, and reduce the 3rd mode in the sea salt number concentration to  $100 \times 10^6$  on line 58 by setting line 58 to `0e6, 0e6, 100.e6, .` Run the simulation, make the plot, and download the image.

**Exercise:** What do you notice the effect of narrowing the sea-salt distribution is?

**Exercise:** What do you notice the effect of reducing the sea-salt number concentration to  $100 \times 10^6$  vs the default simulation in Section 7.1 is?

## 7.5 Bonus: Ice Formation

From the main model directory `bin-microphysics-model` return to the default: `git reset --hard`.

Change line 28 so that the cloud top height is 12000 m (`z_ctop=12000, .`). Do the simulation and the plot. We will discuss the output in the practical.