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POLLUTION AND ENVIRONMENTAL CONTROL

CLOUDS AND OROGRAPHIC PRECIPITATION

Computer Practical: Clouds and Orographic Precipitation
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1 Overview

In this computer practical, a single column model of the atmosphere (SCM) is used to demonstrate a number of phenomena, including: the importance of aerosol-cloud interactions; the importance of the warm-rain process; and the importance of desert dust as ice nucleating particles (INP). This model solves equations for how aerosol and cloud particles evolve into precipitation particles. The same equations are used in many weather forecasting models.

2 Model formulation

The one-dimensional model is written in Fortran (like many other models). It has been installed on a computer at the University of Manchester and a web-page has been written so that the model can easily be run. The webpage runs the model and generates an output file, which is a format known as NetCDF. NetCDF is a common data format used in atmospheric and environmental sciences. After the model is run the web page uses a Python script to plot out the results. This process takes around 30 seconds and is largely hidden from the user to make it simple.

The model has prognostic variables for aerosol, cloud, rain, ice, and temperature. Clouds are represented by the values of these variables as a function of height and time. When the cloud is shallow, it tends to not precipitate and stays in the atmosphere indefinitely. However, when the cloud deepens water condenses on the cloud drops to make them large enough to rain. Figure 1 illustrates the main idea behind the model simulations.

3 Running the model

As noted above the model is run from a web-page interface.
A link to the web page is given here:
`http://130.88.66.117/~mccikpc2/scm01.html`
(username and password will be provided in the practical session).

Table 1 describes the parameters that can be modified. Note that a typical cloud drop concentration in the clouds is 100 cm^{-3}. This means if you count the number of cloud drops in 1 cm^3 there would be 100 of them! In the atmosphere cloud drop number concentrations are linked to aerosol particle concentrations since cloud droplets form around these aerosol particles. Generally, aerosol concentrations are higher in more polluted environments. A typical cloud drop concentration in a polluted environment might be 2000 cm^{-3}.
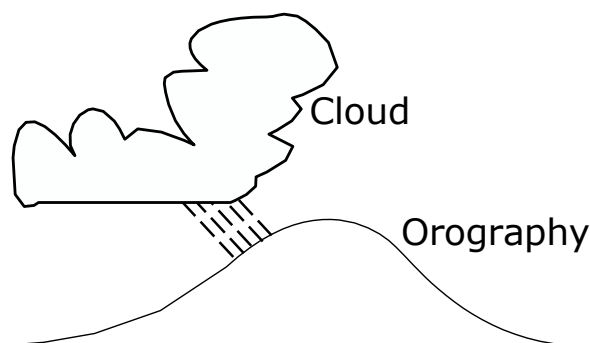

Figure 1: Schematic of the scenario being modelled, where the orography is the Anaga Massif, and clouds become deeper and precipitate as they are lifted over the mountain range.

Table 1: Parameters controlling the behaviour of the model.

Variable	Default value	Description
N_{cloud}	100 cm^{-3}	Initial number concentration of cloud drops
N_{dust}	0 cm^{-3}	Number concentration of desert dust particles
ΔT	2 K	Temperature of cloud base minus temperature of cloud top
$T(K)$	303.15 K	Atmospheric temperature at sea-level
Warm rain	on / off	Whether the simulation includes the warm rain process or not

To run the model all that is required is to:

1. Set the initial number of cloud drops in the cloud (units are per cubic centimetre).

2. Set the number of desert dust particles in the air (units are per cubic centimetre).

3. Set the value of ΔT. This is the temperature difference between the bottom of the cloud and the top of the cloud (which is colder). A positive number should be used.

4. Set the value of the surface temperature, T. This is the atmospheric temperature at sea level (K).

5. Switch the warm rain process on / off.

6. Click `Run Model` and wait for up to 1 minute for the results to appear.

7. Right click on the image and save a copy to your computer (maybe copy into a document and make notes).

4 Experiments

4.1 Changing Cloud Droplet Number

Run the model for the default case by clicking `Run Model` and waiting for 30 seconds. Do not forget to copy the image to your computer and make notes. Look at plot (a). You will notice that the cloud disappears as it rises over the mountain (drawn in red). Why is this?

Look at the rain in plot (c). You will notice that as the cloud disappears the rain appears and falls to the surface. This is because cloud droplets are becoming large enough to collide and coalesce to form rain drops, which is known as the *warm-rain process*. Repeat the simulations for:

- N cloud = 10 /cc (i.e. lower than normal)
- N cloud = 1000 /cc (i.e. higher than normal)
- N cloud = 2000 /cc (i.e. very polluted)

Do not forget to save the images each time.

Question: For the default case where on the mountain does the rain fall? What do you notice as you reduce, and increase the cloud drop number concentration (in terms of where the rain falls)?

4.2 Switching off the Warm Rain Process

In this simulation change all values back to their defaults in Table 1 and then turn off the warm rain process and click `Run Model`. Repeat the simulation with `warm rain` switched off and the number of cloud drops set to 2000 /cc. Do not forget to save your plots and make some notes.

Question: What do you notice about the persistence of the clouds and the rain fall when switching off the warm rain process?

4.3 Cooler surface conditions

Again change all values back to their defaults in Table 1, then set the surface temperature to 280 K, and click `Run Model`. Repeat the simulation with `warm rain` switched off. Looking at plot (d) you should notice that there is now ice in the simulations (N_{ice} is the number of ice crystals in 1 litre of air).

Question: What do you notice in the simulation without warm rain? Is there any rain fall? How can this be?

For the final simulation keep the *warm rain process* turned off and increase the value of N_{dust} to 1000 /cc.

Question: How does increasing the number of dust particles affect the number concentration of ice crystals in the simulations?

4.4 Deeper Cloud

Finally, change all values back to their defaults in Table 1 again. Now change the value of N_{cloud} to 1000 /cc and ΔT to 5 degrees. You will see that the cloud is around 1 km deep now.

Exercise: Compare the two simulations with N_{cloud} = 1000 /cc and ΔT = 2 or 5 degrees. How does the value of ΔT affect the amount of precipitation and why?

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