Boundary layer and cloud exercise: a stratocumulus to cumulus transition case

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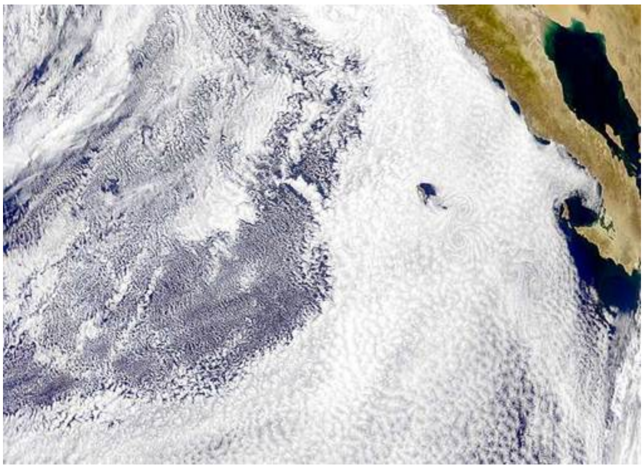

Figure 1: Satellite image of the cloudiness in the North East Pacific: the solid stratocumulus decks close to the coast are replaced by shallow cumuli as the airmasses are advected equatorward by the trade winds.

Introduction

For this exercise, we use an idealized case of the transition from a well-mixed stratocumulus topped marine boundary layer to the broken, shallow convective cloud regime in the trade wind regions.

We want to explore the factors playing a role in the cloud break up, and the timescale on which this breakup happens. Each question will address a different aspect or process involved in the development of the transition:

- Inversion strength
- Large-scale subsidence
- Autoconversion (rain formation)
- Rain evaporation

1 The role of the inversion strength on the timescale of the transition

Large-Eddy Simulation (LES) of the transition case shows that the timescale of the transition is mostly controlled by the strength of the inversion capping the boundary layer at the initial time. A slow transition can become a fast transition by just changing the inversion strength at the initial time. In our control case, the transition starts to be visible during the second day. (To see a figure of the control case, view the file `cloud.ps` in the `BL-CLOUD` directory.)

I **Do you have to increase or decrease the inversion strength for a more rapid transition?**

By "inversion strength" we mean the difference in virtual potential temperature $\theta_v = \theta(1+0.61q_v)$ between the free-troposphere and the cloud layer (where θ is the potential temperature and q_v is the water vapor mixing ratio).

- Revisit the "cheat sheet" for a refresher on how to modify profiles in the netcdf input file `in_trans.nc`. Remember to keep a copy of the original input file, as you will need it later!
- To change the θ_v jump at cloud top modify either the temperature (hence implicitly the potential temperature θ) or the vapor mixing ratio q_v in the free-troposphere
- Do this by adding or subtracting a constant dT or dq between cloud top and approximately 700hPa (which corresponds to model levels 106-119). Tip: dT or dq should not be bigger than 6K and 3 g/kg respectively.
- Run the SCM with the modified input file. Your namelist is `nam_trans` and the executable `master1c.exe` can both be found in the local metview directory for this exercise `BL-CLOUD`.
- Generate output figures with `ncl`:
  - Open a terminal window
  - Change into your metview directory `/home/ectrain/$USER_ID/metview/BL-CLOUD`
  - Modify the input and output filenames (lines 18 and 21) in the ncl script `plot_trans.ncl` (you should give each run a different output name so you can compare figures afterwards)
  - run the script by typing: `ncl plot_trans.ncl`
  - the output .ps file is similar to cloud.ps and shows the time evolution of the cloud fraction, liquid water mixing ratio, rain water mixing ratio (top), integrated liquid water path and surface precipitation rate (bottom), as well as vertical profiles of virtual potential temperature, total water mixing ratio and relative humidity at different times shown in the legend.
  - another ncl script that might be useful during this exercise is `comparison_profiles_trans.ncl`. This script compares the profiles of virtual potential temperature and total water mixing ratio of two simulations at hours 0, 36 and 72. To use it change the names of the input files in lines 17 and 18 and the name of the output .ps file in line 20. And then run the script by typing: `ncl comparison_profiles_trans.ncl`. The full lines correspond to the first initial file, the dashed lines to the second.

II **How much do you have to change the transition strength (in *Kelvin* or g/kg) to get the cloud to transition from stratocumulus to cumulus in half a day?**

III **(GROUP) What is more effective, a change in temperature or in moisture? Why?**

IV **(GROUP) Why does the cloud break up earlier/later when you modify the inversion strength?**

2 The role of large-scale subsidence

The large-scale subsidence associated with the descending branch of the Hadley cell plays an important role in creating and maintaining strong inversions capping the boundary layer in the maritime stratocumulus regions.

I **Modify the large-scale subsidence such that the cloud top height remains constant throughout the three days!** The namelist parameter `RDIVFACT` multiplies the subsidence rate, i.e. a factor of 2 would double the strength of the subsidence.

II **Modify the large-scale subsidence such that the cloud top rises very quickly!** Aim for a cloud top at 800hPa by the end of day three.

III **(GROUP) In the steady-state case (from point I):**

- Which processes have to balance to maintain the quasi-steady state?
- How does the rate of subsidence compare with the rate of entrainment at cloud top?
- What can you learn from the thermodynamic profiles about the mixing state within the boundary layer?

IV **(GROUP) In the rapid development case (from point II):**

- How does the balance between the subsidence and entrainment compare to the steady-state case?
- How does this impact the mixing state of the boundary layer?
- What are the consequences for the cloud evolution?

3 Precipitation formation

The IFS has a bulk microphysics scheme. Cloud liquid, ice, rain and snow are separate prognostic variables. The processes that convert water from one species into another (i.e. sources and sinks) must be parametrized (Fig. 2, left). The growth of cloud droplets via collision/coalesence into rain drops is described by an autoconversion scheme. The rate of autoconversion depends on the spectrum of droplet sizes - bigger droplets are more effective at collecting smaller droplets (Fig. 2, right). The diagnosed droplet size in the model depends on the amount of cloud liquid water and the number of cloud particles (dependent on the number of cloud condensation nuclei). More cloud liquid present and fewer cloud particles will both lead to faster production of falling drizzle/rain size drops.

The autoconversion parameterization in the IFS is based on work by Khairoutdinov and Kogan (2000). The rate of autoconversion is:

$$M_{aut} = 1350 q_l^{2.47} N_c^{-1.79} \qquad (1)$$

where q_l is the cloud liquid water content and N_c the droplet number concentration. The IFS currently assumes that clouds are homogeneous within a grid box and the droplet number concentration is assumed to be a constant $100 cm^{-3}$ over ocean.

I **How does a change in the autoconversion rate impact the transition from stratocumulus to cumulus?**

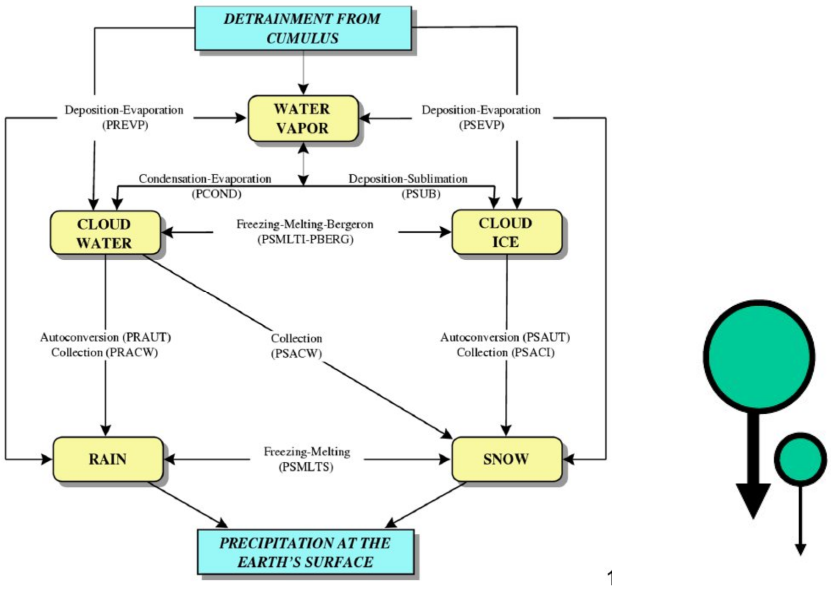

Figure 2: (Left) Schematic illustrating water species predicted in the IFS, and the processes converting water from one species to another. (Right) Schematic of a larger drop falling faster and collecting a smaller drop.

- The namelist parameter `RAUTOFACT` multiplies the autoconversion rate given in the equation above.
- Save the SCM output from your modified runs under a new name.
- Use the ncl script to generate figures.

II **(GROUP) What is the impact on cloud liquid water contents (cloud water path), and precipitation?**

4 Precipitation Evaporation

Precipitation produced in the cloud will partially evaporate below cloud base if the air is sub-saturated.

I **What is the impact of an increase/decrease of the evaporation of rain beneath cloud base on the boundary layer properties and clouds in the transition case?**

- You can vary the evaporation rate by changing the namelist parameter REVAPFACT, which multiplies the evaporation rate in the model for both large-scale and convective precipitation.

II **(GROUP) Explain the relationship between evaporation and decoupling.**

III **(GROUP) What type of problem might a model experience when aiming to represent the transition between stratocumulus and trade cumulus if it produces too much precipitation, and if little of that precipitation evaporates before reaching the surface?**