Simple Climate Models

Lecture 4

Two-dimensional (meridional-vertical) models

Reasons for wanting 2-D models

- ♦ augment RCM's to allow for spatial variation
  - include meridional transport of heat, water, etc ...
- ♦ augment EBM's to treat radiation (etc) explicitly
  - include vertical transports of heat, water, etc...
- ♦ need to represent both **latitude** & **altitude**
  - transport both by MMC and turbulence (eddies)
    - (MMC = mean meridional circulation)
- ♦ also : heat & water transport by ocean
  - primarily due to **meridional** circulation

Nature of 2-D models

- ♦ are invariably Statistical-Dynamical
  - include explicit dynamics (buoyancy, friction, etc...) for the **mean flow only**
  - do not resolve eddies : treated statistically
  - but include fluxes due to **eddy correlations**
    - which need to be parameterised (turbulence closure)
- ♦ involve **parameterisation** of eddy fluxes
  - use mixing length & flux-gradient methods
  - diffusivities (etc) $K = U^* L$, flux = $K \times$ gradient
    - U^* = characteristic **amplitude scale** for velocity (fluctuations)
    - L = characteristic **spatial scale** of velocity (fluctuations)

Derivation of (im)balance equations in terms of means and eddy fluxes

2-D Ocean Models

- Will be discussed in detail later by J.M.
- Involve meridional-vertical transports due to
  - **surface forcing** (interaction with the atmosphere)
    - by radiation, heating and freshwater fluxes (and winds ?)
  - and thus **buoyancy forces**
  - balancing **friction**
    - as Rayleigh drag or eddy viscosity
  - **mixing** (lateral & diapycnal) : usually specified
  - and effects of **rotation** (maybe, somehow)
- Examples include...
  - Stocker & Wright
  - Marotzke et al

2-D Atmospheric Models

- Involve meridional-vertical transports due to
  - **radiative forcing** (NB : surface albedo, clouds...)
  - **interaction with the land & ocean**
    - by radiation, heating and freshwater fluxes, & winds
  - **buoyancy forces** (moist convection)
  - **friction**
    - as Rayleigh drag or eddy viscosity (momentum transport)
  - **mixing** (lateral & vertical)
    - needs to be very carefully **parameterised**
  - **rotation** (which is very important)
- Examples include...
  - GISS (Hansen, Stone....)
  - Lawrence Livermore (MacCracken et al)

Meridional processes in the Atmosphere

- Primary balance is between
  - buoyancy forcing (convection), and friction...
- Major features of MMC (existence and extent of Hadley & Ferrel cells) can be obtained from
  - transport of **zonal** (angular, total) **momentum**
    - by both the MMC and by eddies
  - the **thermal wind** equation (buoyancy forcing)
- See review by MacCracken & Ghan (1988)
- Eddy transport of momentum is very important
  (but not absolutely necessary or wholly dominant)

Eddies (and eddy correlations)

- are due to **Baroclinic Instability**
  - see Stone (1997) : [Venice lecture notes]
- lead to eddy viscosity, diffusivity (etc)
  - (Austausch coefficients)
- but cause transport of momentum **up** the gradient of **relative** angular momentum $\Rightarrow$ a problem !
  - “negative viscosity” (Starr, 1968)
- Use parameterisation due to Green(1970) and Branscome (1980,1983)
  - see Stone & Yao, J Atmos Sci, 44, 3769- 3786, 1987
  - based on conservation of potential temperature and **potential vorticity**

Mixing Lengths & Eddy Diffusivities

parameterisation of Stone & Yao (1990)

$$\langle v'\grave{e}' \rangle = 0.6\frac{gd^2N}{\grave{e}f^2}\exp(-z/D)\left|\frac{d\grave{e}}{dy}\right|\left(\frac{d\grave{e}}{dy}\right)$$

where $d = H/(1+\tilde{a})$ and $\tilde{a} = \hat{a}H/\acute{a}f$

Processes included in SDM's

- ♦ Heat fluxes
  - Sensible (dry) & Latent (moist)
- ♦ Moisture fluxes (moving freshwater)
  - Evaporation & Precipitation : E-P
- ♦ Momentum fluxes (zonal winds)
- ♦ Radiation
  - transmission, absorption, albedo, clouds (explicit)....
- ♦ Buoyancy & convection
  - leading to mean meridional circulation

What about Clouds ?

- At several (maybe all) levels
- Must allow for fractional cloud cover
  - to allow for zonal variations
  - and avoid “blinking” instabilities
- usually parameterised in terms of RH
  - as in many GCM’s
  - incorporating type vs. altitude correlation
  - but one could model liquid water explicitly...

Lawrence Livermore SD Climate Model (MacCracken et al)

- 10 deg latitude resolution (18 bands)
- 9 vertical levels (5 in troposphere)
- Stone’s parameterisation for eddy fluxes of heat, moisture, etc
- Prescribed eddy momentum transport (1988)
  - because of the parameterisation problem
- “Bucket” hydrology
- Mixed layer ocean only (prescribed heat flux !)
- Simple (multiple-band) radiation scheme
- Fractional land/sea/ice cover

GISS 2-D SDM
(Hansen, Stone et al)

Utility ?

- Land & sea
- Continents