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Introduction to atmospheric Modeling

The atmospheric component of a model usually distinguishes the Dynamical core (D) from "Physics" (P) such that a general predictive equation for a generic model variable ψ can be written:

$$\frac{\partial \psi}{\partial t} = D(\psi) + P(\psi)$$

Atmosphere Models are based on conservation laws

Conservation of Momentum → "Momentum Eq" or force balance (D)

Conservation of Energy - "Thermodynamic energy equation" (D & P)

Conservation of Mass - "Continuity Eq" (D)

Equation of State - Ideal gas law with correction for moist physics (D & P)

Now the Equations in words only

Horizontal Momentum Eq:

{Horiz. acceleration on Earth following a parcel} = Coriolis force + pressure gradient force + friction

Vertical Momentum Eq

{Vert. acceleration on Earth following a parcel} = pressure gradient force + gravity + friction

note often vertical accel & friction in this eq are ignored in which case we refer to the eq as "hydrostatic balance". Climate models usually make this approx while weather models do not. (Holton p456 says it is a good approx for horizontal length scales above ~10km)

Thermodynamic Energy Eq

{Rate of Temperature Change following parcel} = adiabatic heating + diabatic heating ("Physics")

Equation of state

Ideal gas law with corrections for moist processes

Physics includes: Condensation/evaporation (cloud processes) & short & longwave radiation heating rates

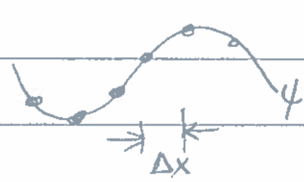
Numerics

HW1 shows Numerics are about trade offs

- computation efficiency & accuracy most broadly but accuracy is also in the eye of the beholder For example, the diffusion you saw in upsteam differencing might be desirable if it mimics some real behavior. Then the term that describes that behavior is not needed because it is a side-effect of the numerics
- Also I hope you see that time & space differencing are both important and neither one can ensure desirable behavior

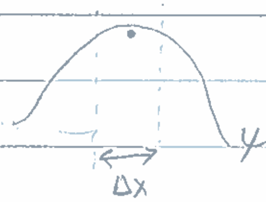
Broadly three kinds of numerics are widely used in atmosphere model

1) standard finite difference (like in HW1)



$\psi_j^n = \psi(j\Delta x, n\Delta t)$

2) Finite Volume ψ_j^n is an average of ψ in interval $(j-\frac{1}{2})\Delta x, (j+\frac{1}{2})\Delta x$



note ψ_j^n is slightly below true ψ at pt that is concave down

3) Spectral ψ_j^n = sum of wave functions

wave functions are sines & cosine on latitude circle & Legendre polynomials on meridions

"T42" or "T85" roughly means 42 or 85 wave crests are resolve in the finest wave see Animation

The time differencing is custom for each one but generally requires two time levels in the past to compute the "new" like leap frog.

Boundary Conditions vs. Initial Conditions

Initial Conditions are the starting point

$T(\theta, \phi, p)$ Temperature

u Zonal (Eastward) wind

v meridional (northward) wind

$PS(\theta, \phi)$ Surface pressure

Boundary Conditions

(From most traditional sense to somewhat surprising)

PHIS(θ, ϕ) Φ_s = gravity * height of topography

Lateral Boundary of T, u, v, PS if not global