Dynamics of Moist Convective Systems

Grading:

Term Paper: 40%
Homework: 10%
Midterms: 50%

Suggested Reading:

- *Cloud Dynamics, Robert A. Houze Jr., AP, 1993*
- *Atmospheric Convection, K. A. Emanuel, OUP, 1994*
- *Storm and Cloud Dynamics, Cotton and Anthes, AP 1982*
- *Atmosphere-Ocean Dynamics, Gill. AP 1982*
- *Handbook of Weather, Climate and Water, Potter/Colman, JWS, 2002*
- *Mesoscale Meteorology in Middle Latitudes, Markowski and Richardson, 2010*
- *Journal articles to be assigned.*
Syllabus

(I) Introduction: What is a Moist Convective System?
   a. Some Examples
      i. Thunderstorm Definition and Structure
      ii. Supercell Definition and Structure
      iii. MCS definition and structure
      iv. MCC definition and Structure
      v. TC definition and Structure
   b. What do they all have in Common?
      i. Energy Source
         1. Role for Latent Heating (up moist) if a “moist convective system”
         2. Surface energy fluxes (latent, sensible, KE)
         3. Some role of radiation, usually radiative cooling
         4. Usually some role of secondary role of potential energy, i.e. baroclinity
      ii. Compensating, warming subsidence (down dry)
         1. Deep vertical trajectories over small area?
         2. Shallow vertical trajectories over large area?
      iii. Steady or progressive?
         1. Progressive system will exhaust energy supply (local thunderstorm)
         2. Steady system may be fueled externally (TC, ocean)
      iv. The “system” is the contains both the “up-moist” and “down dry” components
      v. Multiples scales of motion
     vi. Scale interaction Processes
        1. Top Down
        2. Bottom Up
   (II) Governing Equations for Deep Convection
      a. Averaging, Equation of State
      b. Entropy, Enthalpy Conservation
      c. Moisture Conservation
      d. Momentum Conservation
      e. Mass Conservation, Compressible Closure
      f. Microphysics Prediction
   (III) Conservation
      a. Energetics, energy conservation, energy conversion
      b. Vorticity conservation, enstrophy
      c. Potential vorticity conservation, Ertel PV
   (IV) Principal Balance
      a. Static Balance
      b. Dynamic Balance
   (V) Wave Oscillations relative to Balance
      a. Gravity Waves
      b. Inertial Waves
      c. Geostrophic or Inertial Adjustment
   (VI) External Scale Interaction
      a. Top Down
         i. GW forcing
         ii. QG forcing
         iii. PV superposition
         iv. Outflow Resistance
         v. C-SI (1) (Emanuel, Seaman, Wolf)
         vi. IAKE, anvil interaction
      b. Bottom-Up
         i. The Cumulus Ensemble
            1. Convective heating, Q1, Q2, Q_R (Yanai, Esbensen and Chu)
            2. Convective Vorticity transport, Z
3. Convection PV forcing
4. Approaches to Cumulus parameterization
   a. Equilibrium
      i. Kuo
      ii. Ooyama
      iii. Arakawa-Schubert
   b. Non Equilibrium
      i. Kreitzberg
      ii. Kain-Fristch
   c. Adjustment
      i. Kurihara
      ii. Betts
      iii. Grell

ii. Jetstream Formations
iii. Cyclogenesis

(VII) Internal Scale Interaction
a. Thunderstorm
   i. Precipitation Structure
   ii. Density Current
   iii. Roll vortices in PBL
   iv. Shear Line
      1. Shear line vortices
      2. Shear line tornado
   v. Mesocyclone (supercell)
      1. Precipitation effects
      2. Hail
      3. Tornado
      4. Miso vortices
b. MCS
   i. Precipitation structure
      1. Anvil
      2. Convective line
   ii. Convective Heating
   iii. Convective momentum transport
   iv. MCV
c. Tropical cyclone
   i. Basic mature structure
   ii. WISHE
      1. Air-sea interaction
      2. Emulsion layer/sea spray
   iii. Thermodynamic equilibrium (Carnot cycle)
      1. Carnot Cycle
      2. Large scale lifting
      3. baroclinity
   iv. Dynamics equilibrium
      1. Angular Mom transport
      2. PBL, mixing
         a. Angular mom loss
         b. Vorticity gain
   v. Eye and Eye Wall
      1. Vortex ring
      2. Vorticity Skirt/Beta Effect
         a. Beta effect
         b. Gyroscopic alignment
         c. merger
      3. Vortex Rossby Waves
         a. Inner core
         b. Outside core
vi. Rain Bands
   1. Rainband structure
      a. Mesoscale structure
b. Shallow
  c. Vorticity max

2. Dynamics behind the structures
   a. Outward propagating GW
   b. Inwardly moving GW
   c. Anvil induced instability
   d. Tap low level vorticity

vii. Genesis
   1. Bottom up
      a. Role of convection
         i. Thermal
         ii. Momentum
         iii. PV, VHT
      b. Adjustment process
         i. Momentum/vorticity
         ii. Conv heating
         iii. Sorting
      c. Eye wall and eye formation
         i. Angular momentum vs vorticity budget
         ii. Beta Effect, vorticity skirt
         iii. Gyroscopic tilting

2. Top Down
   a. Shear
   b. Baroclinity
   c. QG lifting/convergence
   d. Marsupial Pouch

viii. Eye Wall Replacement
   1. Beta skirts interactions
   2. Formation of secondary merger maxima

d. Supercell Tornado
   i. Genesis from mesocyclone
      1. Top down
         a. Secondary vortex center and vortex growth
         b. Vortex structure
            i. Dynamic balance
            ii. Flow separation
            iii. Swirl ratio
               1. Single vortex
               2. Multiple vortices
            iv. Friction
         c. Vortex substructure
            i. Vortons
            ii. Vortex rings
            iii. Gyroscopic alignment
            iv. Beta effect
            v. Vortex Rossby waves
            vi. Surface/friction
         d. Origins of vortex rings
            i. Precipitation induced downdrafts
               1. Loading
               2. Centrifugal force
               3. Evaporation
               4. Melting
            ii. Shear induced vortex breakdown
         e. Environment conditioning
            i. Neutrality
            ii. Palinstrophy

2. Bottom up
   a. Formation of shear line
   b. Vortex rollup
   c. Connection into supercell