AN OVERVIEW OF THE MICROPHYSICAL STRUCTURE OF A HURRICANE

Cloud Physics

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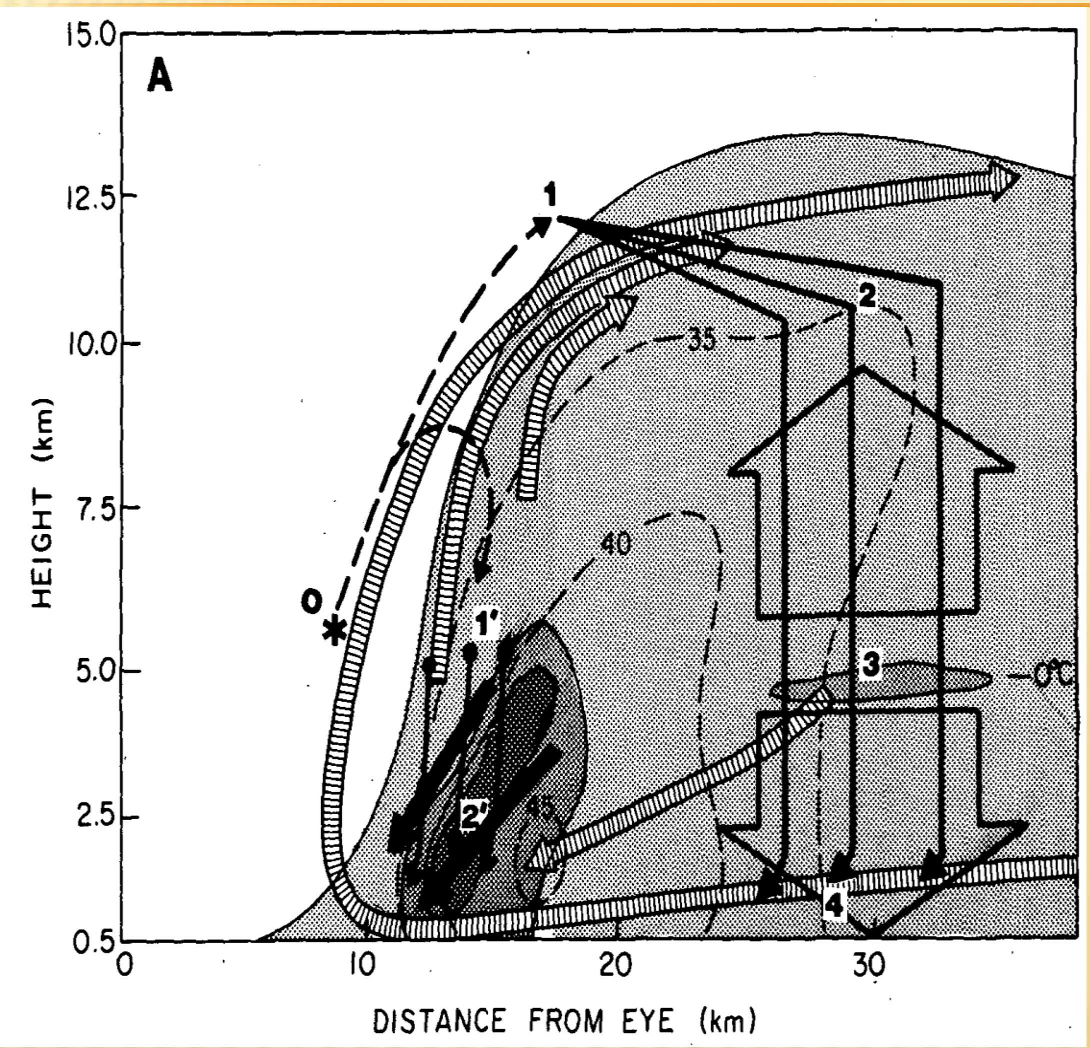
11/29/07

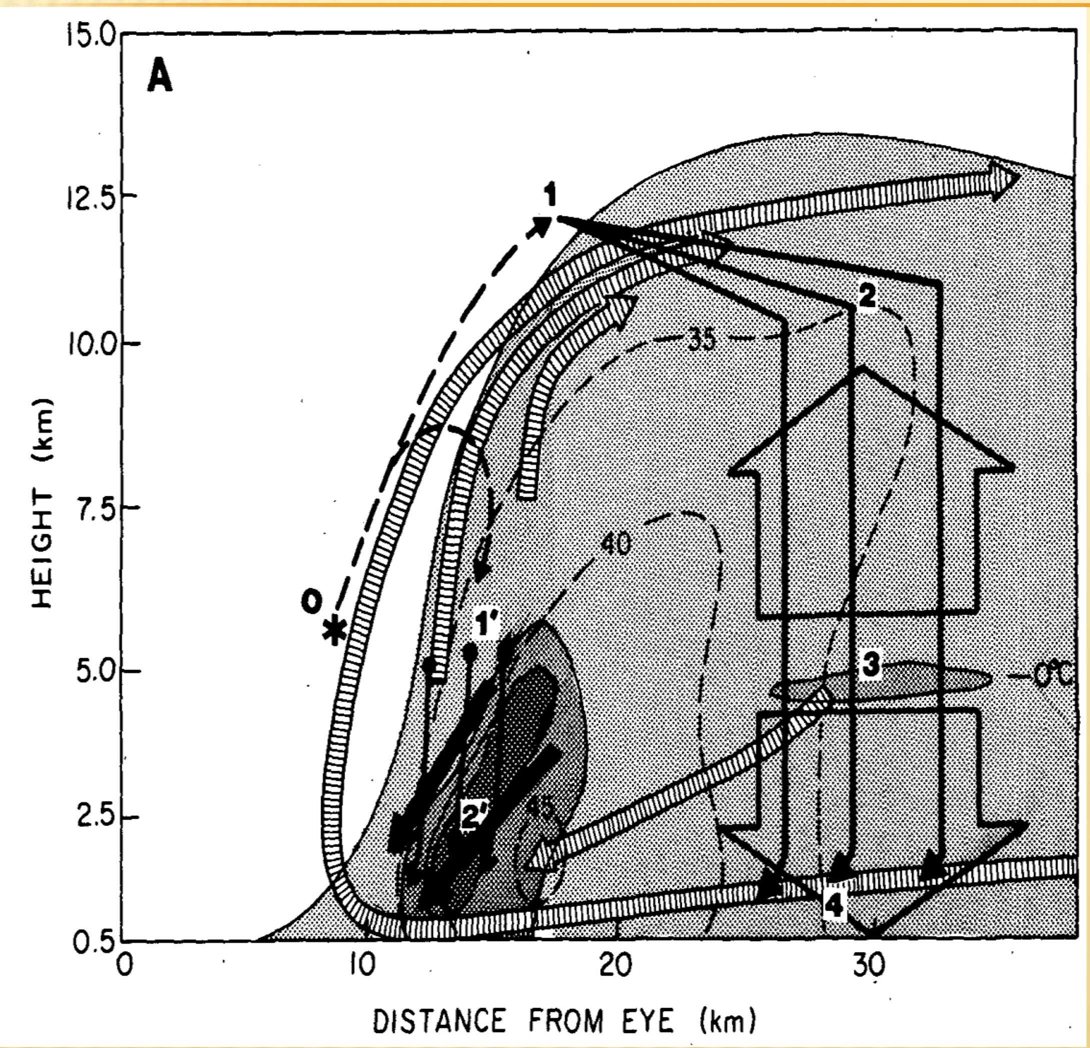
STRUCTURAL OVERVIEW



Marks and Houze (1987): Diagram of the structure of a hurricane. Wind speeds are in m/s.

- Hurricane can be decomposed of primary and secondary circulations
- Primary circulation is in azimuthal direction: rotation around the storm
- Secondary circulation in radial and vertical directions: in, up, and out!
- Ascending portion of secondary circulation slopes radially outward with height

STRUCTURAL OVERVIEW

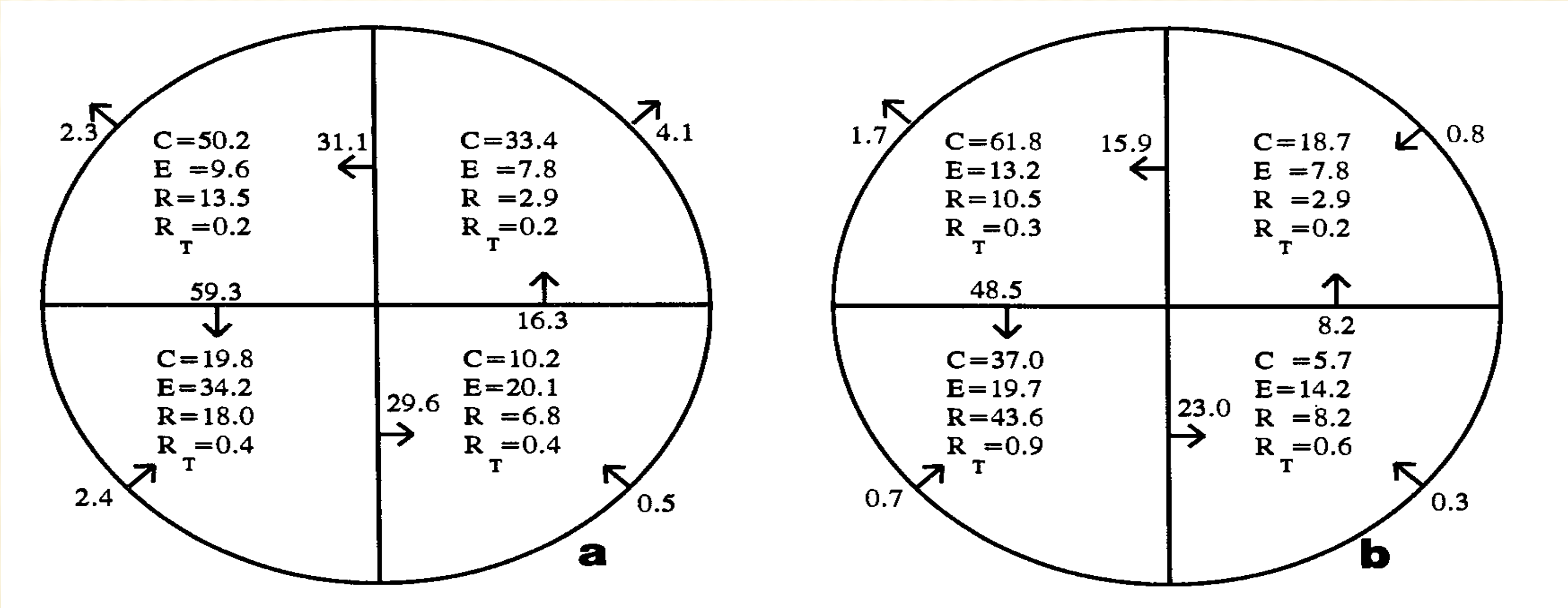


Marks and Houze (1987): Diagram of the structure of a hurricane. Wind speeds are in m/s.

- Can classify precipitation by two regimes: convective and non-convective
- Convective Precipitation:
  1. Associated with secondary circulation
  2. Characterized by strong vertical motions
  3. Hydrometeors **fall** out
- Non-convective Precipitation:
  1. has weak updrafts and downdrafts
  2. mainly made up of stratiform rainbands
  3. Particles **settle** out

HURRICANE WATER BUDGET

- Example of hurricane water budget
- Two methods used:
  1. Doppler derived wind data and radar reflectivity
  2. Doppler derived wind data and microphysical model
- Distinct inter-quadrant differences: sectors act as sinks and sources

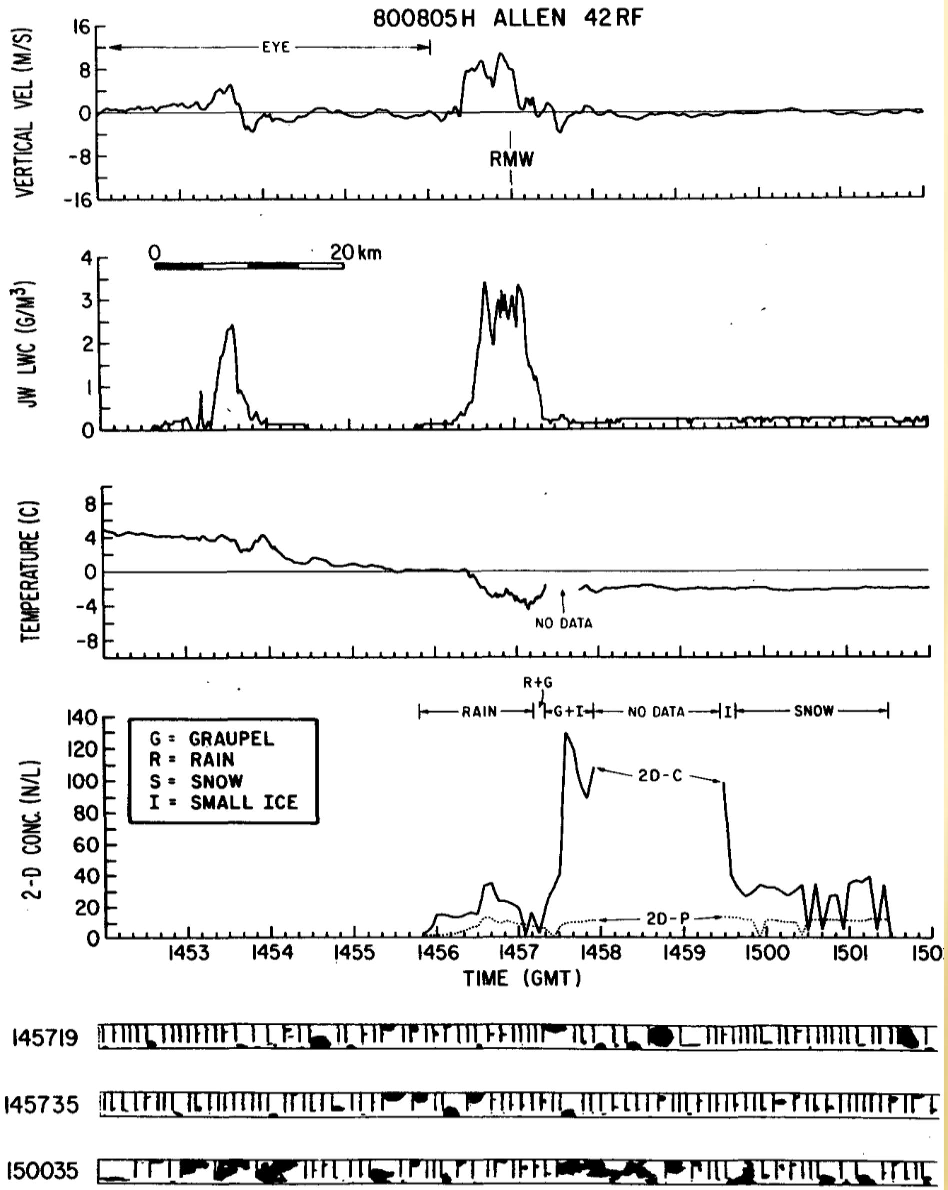


Gamache et. al. (1993): Bulk water budget for Hurricane Norbert (1984) involving two methods. C → condensation, E → evaporation, R → rainfall falling through the bottom, R_T: rainfall falling through top. Advective quantities given for into quadrant, out of quadrant, and out of storm. Units in 10^9 kg/s.

PARTICLE GROWTH BACKGROUND

- Primary ice nucleation not always dominant process
- Secondary ice nucleation predominates at warmer temperatures
- Hallet-Mossop Secondary Ice Nucleation: shedding of smaller ice particles from larger ice particles as the larger one attempts to freeze onto a substrate
- Predominates at temperatures from -3ºC to -8ºC
- Responsible fore large concentration of smaller particles in downdrafts
- Updrafts are source of condensate for these particles
- Hydrometeors in updrafts either grow via diffusional processes or collision/coalescence if liquid or riming in the presence of supercooled water if glaciated

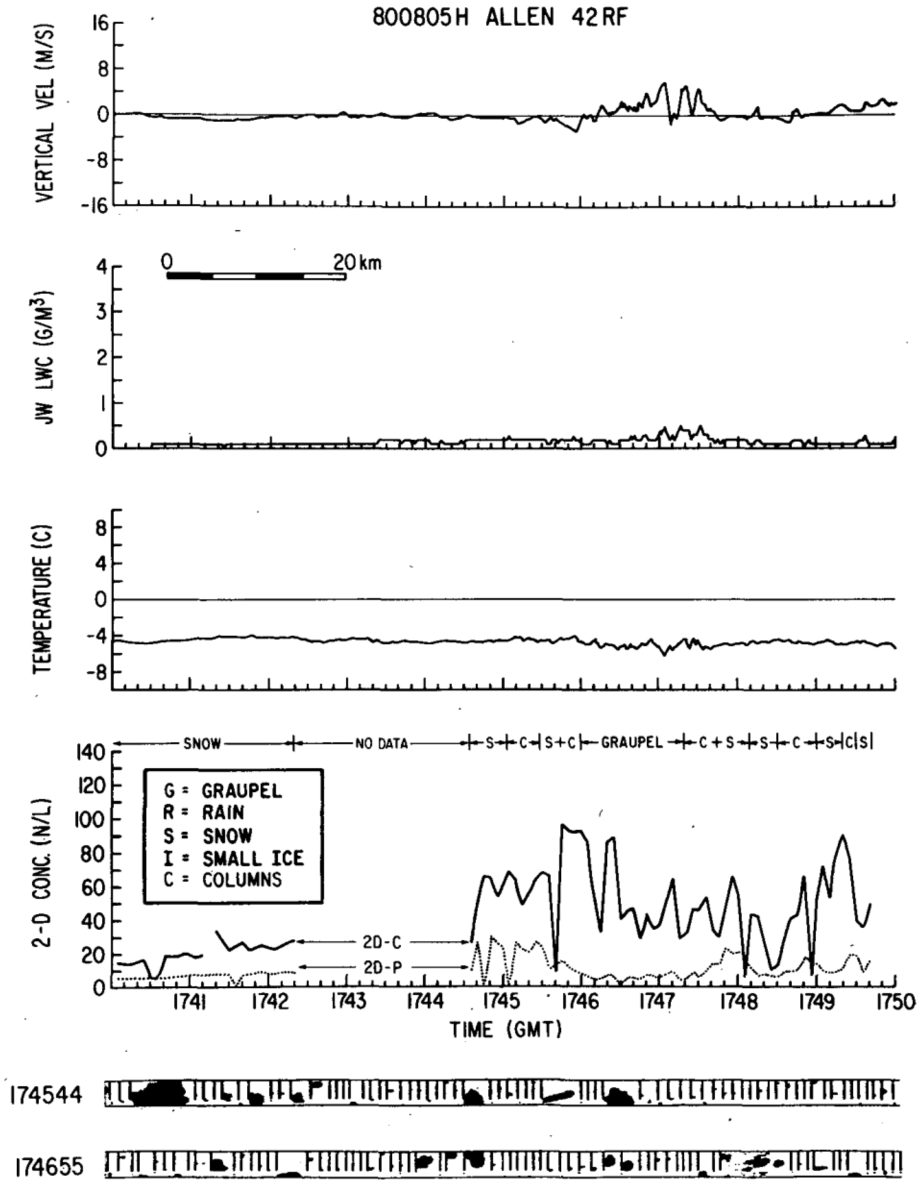
PROPERTIES OF AREAS OF CONVECTIVE MOTIONS



- Pass through eyewall of Hurricane Allen (1980)
- Remnants of old eye present
- Higher liquid water contents in updrafts
- Temperatures inside of eye greater than outside
- Rain shifts to frozen precipitation outside of the eye
- Updrafts mainly rain, location adjacent to downdrafts indicates role as source of condensate
- Downdrafts have spike in concentrations of smaller particles
- Hydrometeors in downdraft are frozen primarily mixture of ice particles and aggregates of snowflakes

Black and Hallett (1986): Strong side pass of the eye of Hurricane Allen (1980) at 6 km. (a) Vertical Velocity (m/s) (b) Liquid water content (g/m^3) (c) Temperature (ºC) (d) Hydrometeor particle concentration (L^{-1}) for 2DC probe (diameter range of 0.05 to 1.6 mm in intervals of 0.05 mm) and 2DP probe (diameter range of 0.2 mm to 6.4 mm in intervals of 0.2 mm) with phase (e) Images of particles taken at various times

PROPERTIES OF AREAS OF NON-CONVECTIVE MOTIONS

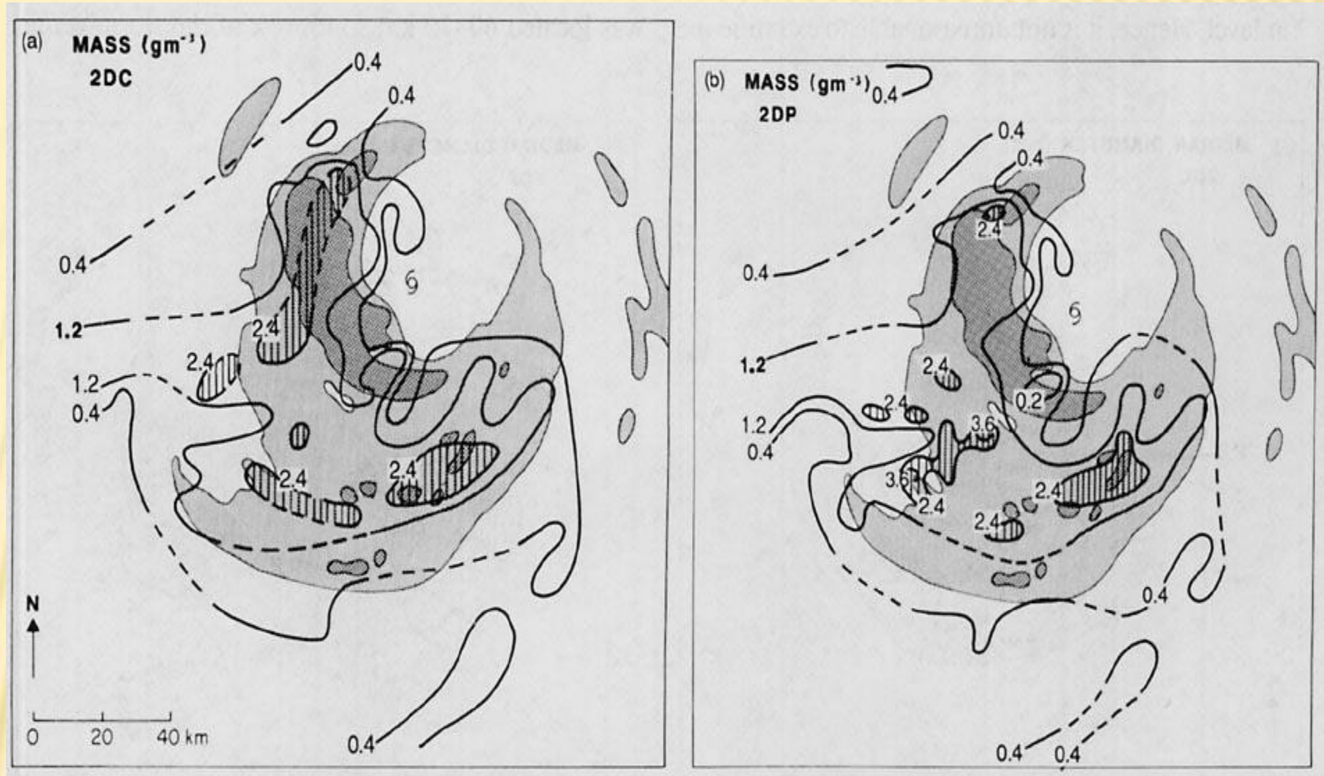


- Pass through rainband of Hurricane Allen (1980)
- More uniform vertical motions
- Low liquid water contents
- Constant temperature around -4ºC
- Changes in liquid water content and particle concentrations occur only in areas of vertical motions
- Particles mainly aggregates of snow, graupel, and columns

Black and Hallett (1986): Pass through rainband of Hurricane Allen (1980) at 6 km. Same as data as figure from previous page.

PROPERTIES OF HYDROMETEORS AT UPPER LEVELS

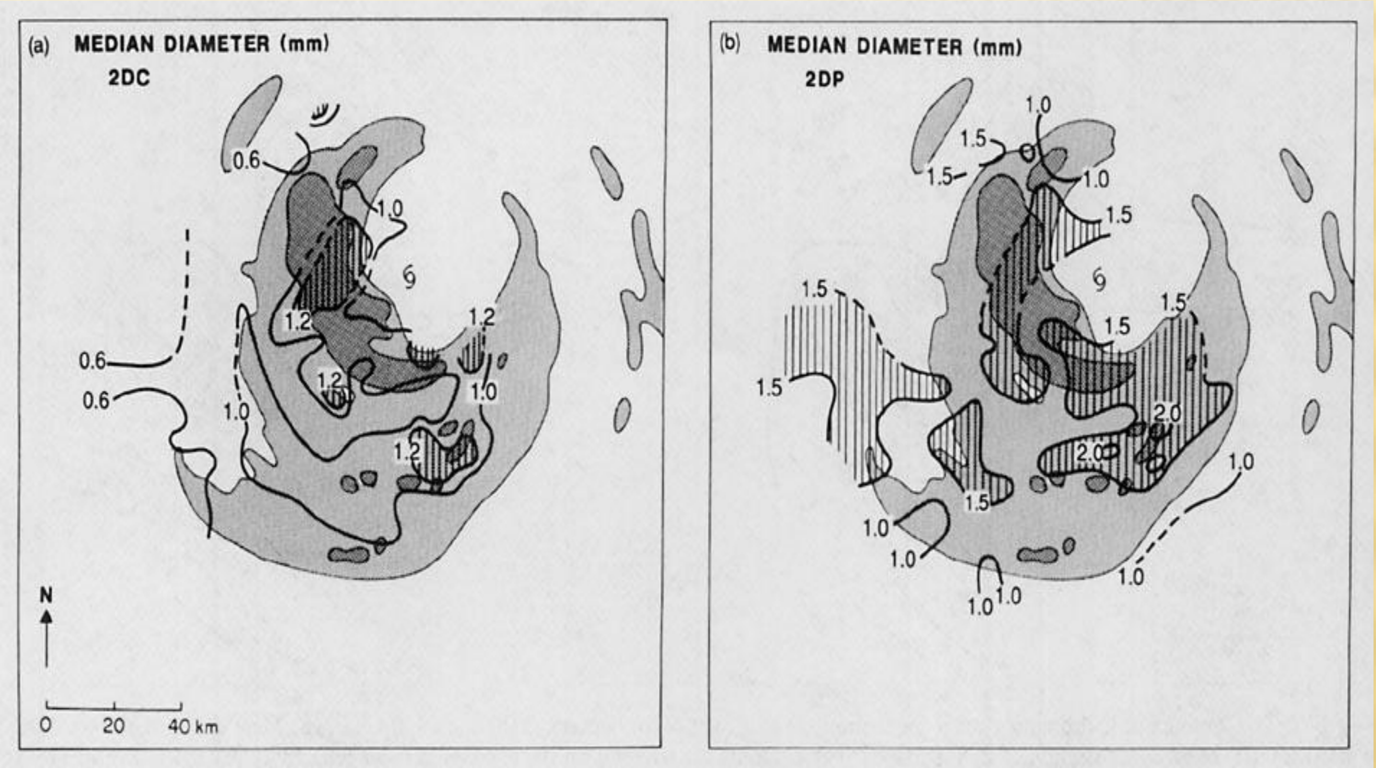
- Observations taken at six km
- More mass in areas of higher reflectivity
- Areas of higher reflectivity are found in eyewall and stratiform region
- Similar masses means particle sizes in range covered by both



Houze et. al. (1992): Contours of hydrometeor mass concentration (g/m^3) overlaying radar reflectivities at a height of 6 km from 0020 to 0420 UTC. (a) Mass of 2DC particles (diameter range of 0.05 to 1.6 mm in intervals of 0.05 mm) (b) Mass of 2DP particles (diameter range of 0.2 mm to 6.4 mm in intervals of 0.2 mm)

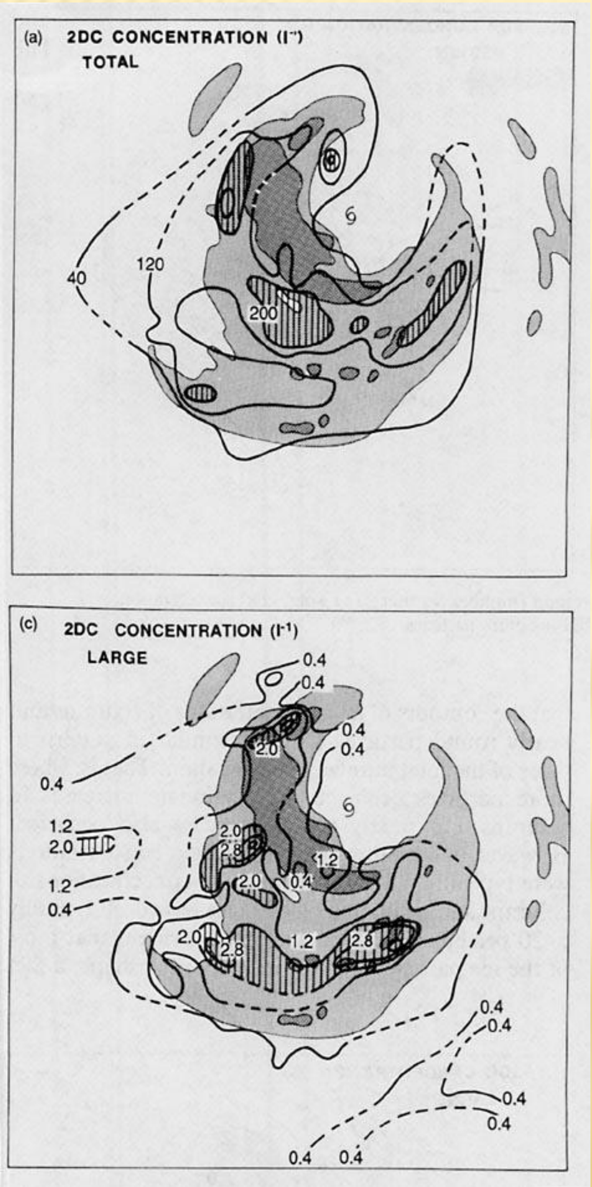
PROPERTIES OF HYDROMETEORS AT UPPER LEVELS (CONT.)

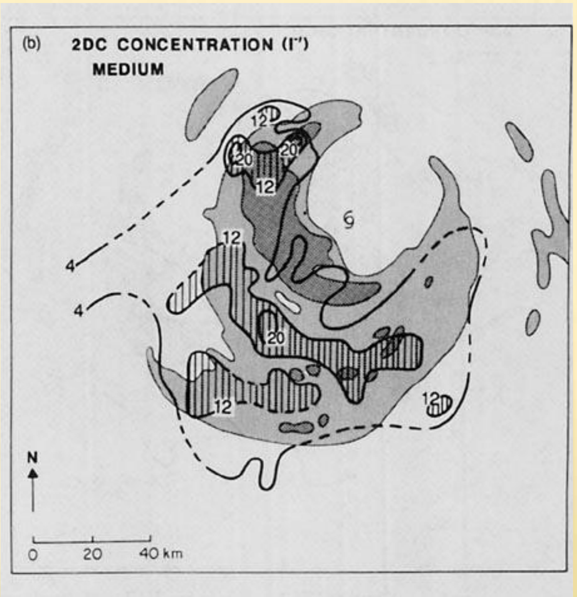
- Larger median diameters found in areas of larger reflectivity
- More mass translates to larger particles



Houze et. al. (1992): Contours of median hydrometeor size (mm) overlaying radar reflectivities at a height of 6 km from 0020 to 0420 UTC. (a) Mass of 2DC particles (diameter range of 0.05 to 1.6 mm in intervals of 0.05 mm) (b) Mass of 2DP particles (diameter range of 0.2 mm to 6.4 mm in intervals of 0.2 mm)

PROPERTIES OF HYDROMETEORS AT UPPER LEVELS (CONT.)



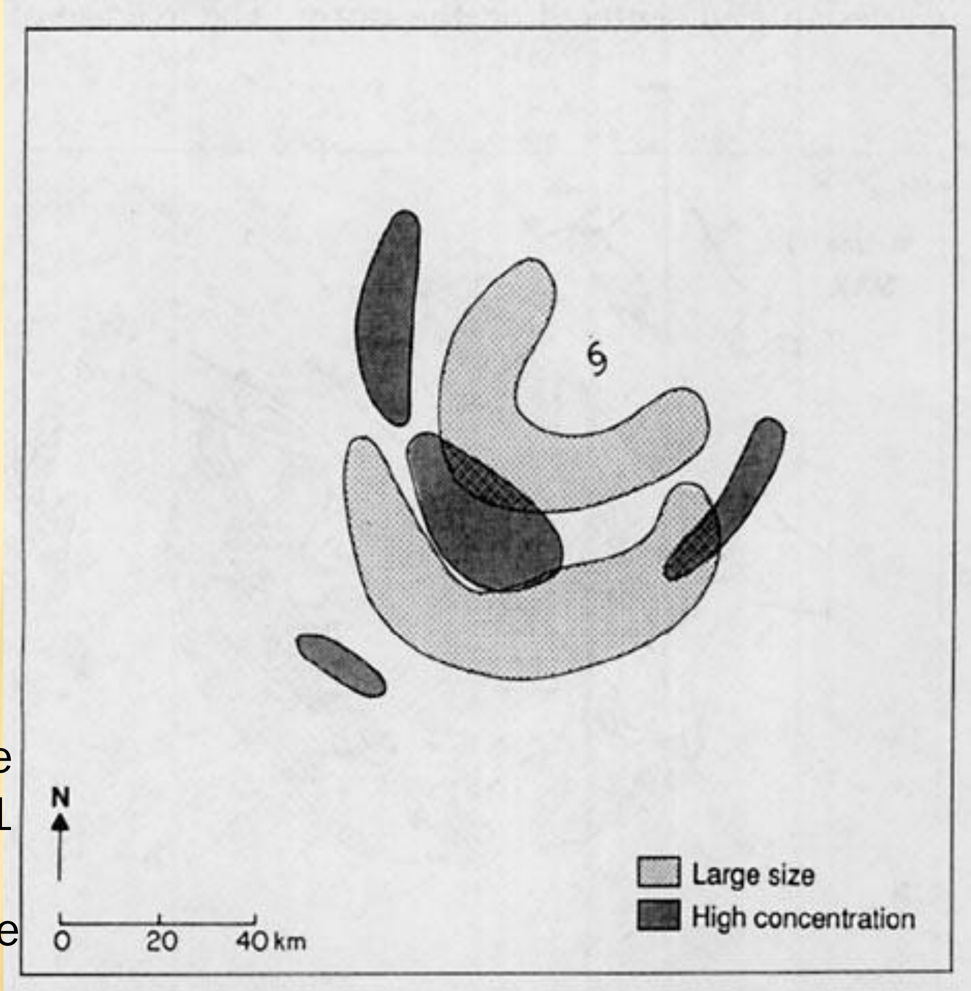


Houze et. al. (1992): Contours of 2DC hydrometeor concentration (L^{-1}) overlaying radar reflectivities at a height of 6 km from 0020 to 0420 UTC. (a) Mass of 2DC particles (diameter range of 0.05 to 1.6 mm in intervals of 0.05 mm) (b) Mass of 2DP particles (diameter range of 0.2 mm to 6.4 mm in intervals of 0.2 mm)

- 2DC particles consistently more numerous than 2DP (next page)
- Peak concentrations displaced 10 to 20 km outside of eyewall and 60 to 70 km southwest of the eyewall
- Large hydrometeor concentrations maximums found upwind of total particle concentration maximums

PROPERTIES OF HYDROMETEORS AT UPPER LEVELS (CONT.)

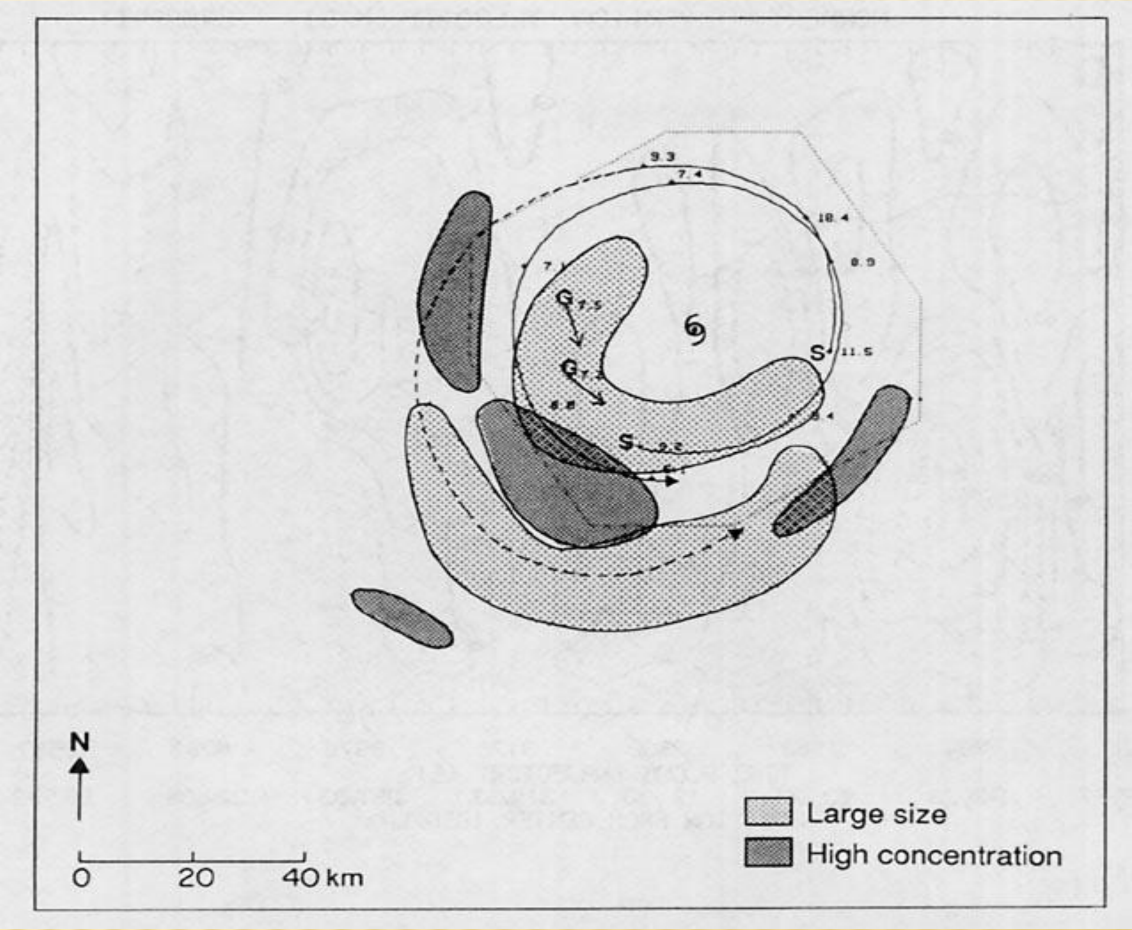
- Large numbers of small hydrometeors in areas other than eyewall/stratiform regions due to secondary ice nucleation
- Small concentrations of large particles found in eyewall and over rainband indicative of particles originating from updrafts
- Large particles exist in these regions because:
    1. Updrafts sloping up and over downdrafts in eyewall. Only particles modified by updrafts can reach this height.
    2. Advection of aggregates of snow from eyewall to these regions is responsible for distribution. Snowfall at a rate of 1 m/s, much slower than 3-6 m/s of graupel. Smaller fall speeds give it the opportunity to circulate around the storm longer.



Houze et. al. (1992): Distribution of large sizes and high concentrations within Hurricane Norbert (1984). Based off of particle distributions from 2DP and 2DC probe.

UPPER LEVEL HYDROMETEOR TRAJECTORIES

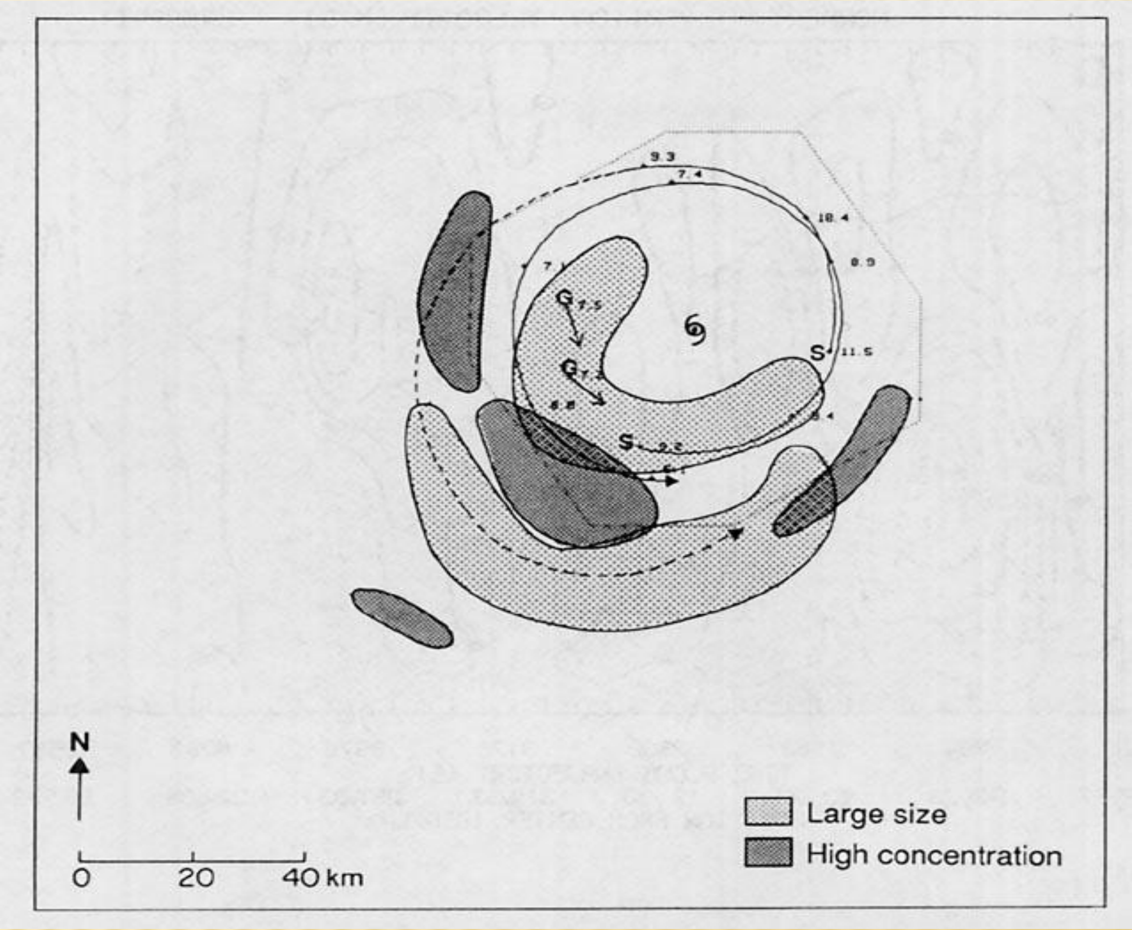
- Typical upper level hydrometeor trajectories given
- All trajectories begin at top of updraft core in eyewall and end when particle falls through 6 km
- 3 different trajectories examined:
  1. Graupel particles – Fall speeds on the order of 3-6 m/s causes them to fall out rapidly. Responsible for area of large particles surrounding the eye. Associated precipitation drag and latent cooling associated with falling particle responsible for creation/maintenance of convective downdraft



Houze et. al. (1992): Doppler derived horizontal projections of ice particle trajectories above altitude of 6 km. Arrows are indicative of where particles drop below 6 km. Snow particles are represented by the letter S while graupel particles are represented by the letter G. Lightly shaded areas represent areas of large particle size. Darker shaded regions represent areas of high particle concentration.

UPPER LEVEL HYDROMETEOR TRAJECTORIES

- 3 different trajectories examined (cont.):
  2. Aggregated Snow Particle I – Trajectory begins at 9.2 km. “Seeds” eyewall rather than being advected outside it because altitude not high enough.
  3. Aggregated Snow Hydrometeor II – Trajectory begins at 11.6 km. Advected by primary secondary circulation in manner that follows path of stratiform rainband. Source of hydrometeors for stratiform region. Not low enough in altitude to collect particles in high concentration region.



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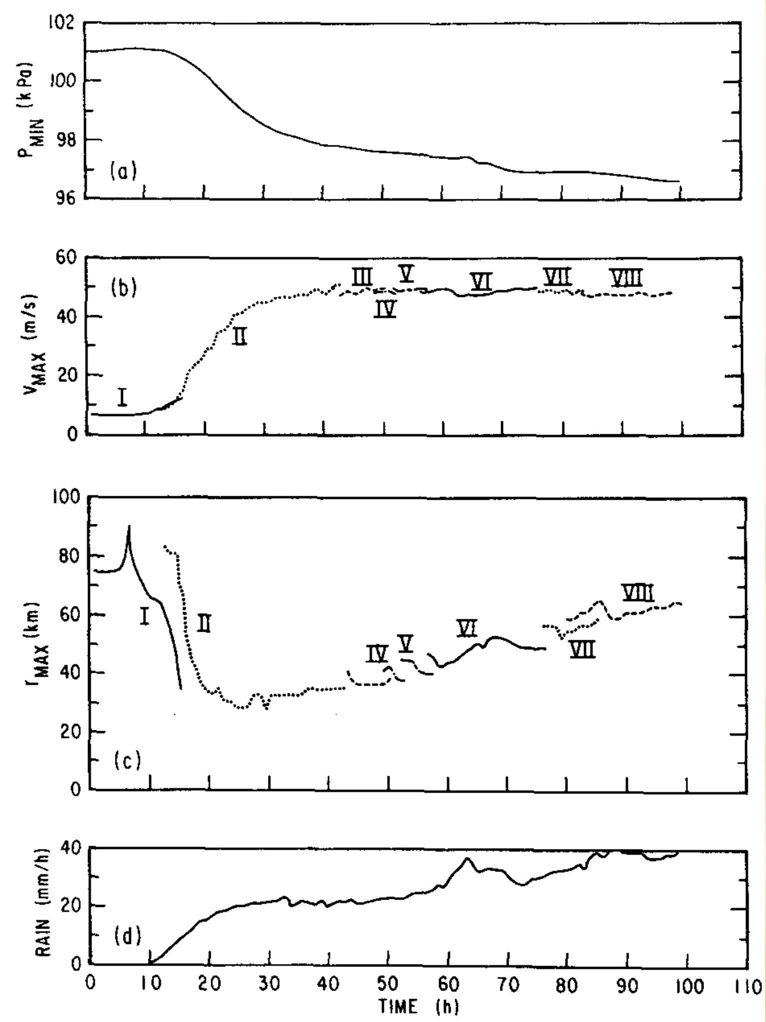
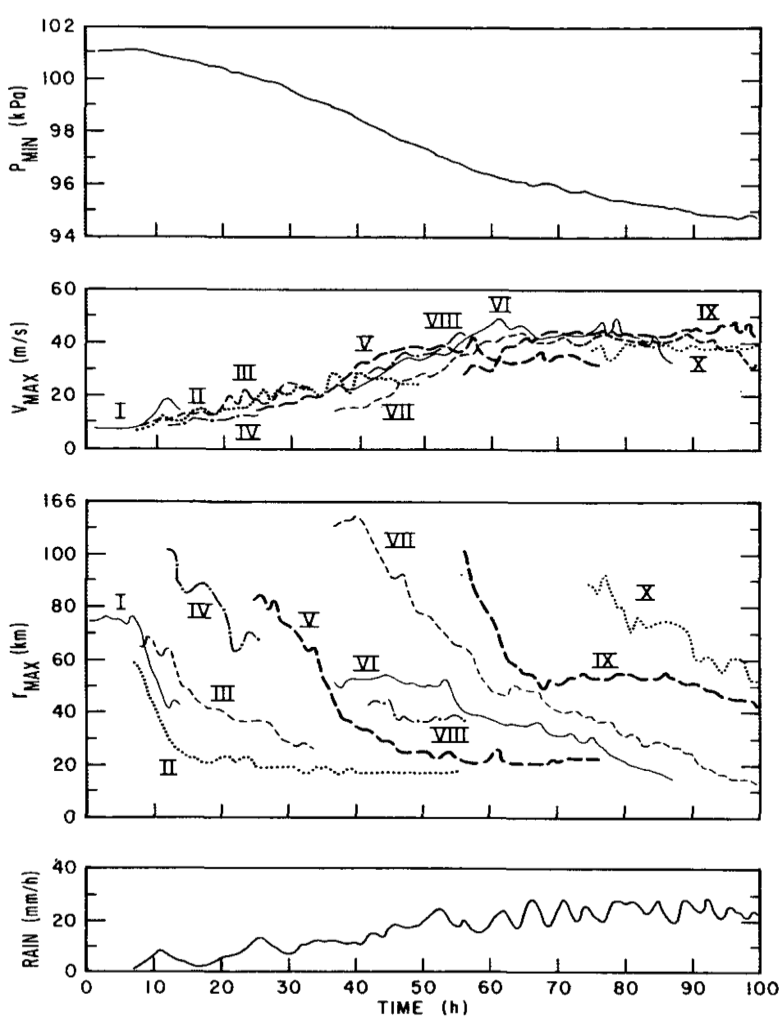
IMPORTANCE OF ICE MICROPHYSICS ON STORM EVOLUTION



Willoughby et. al. (1984): Results from nonhydrostatic, axisymmetric model run excluding ice microphysics and using a moist sounding. (a) Minimum Pressure (kPa) (b) Maximum velocity (m/s) (c) Radius of maximum winds (km) (d) Rainfall rate (mm/hr)

- Willoughby et. al. (1984) used nonhydrostatic, axisymmetric model to prove importance of ice microphysics in storm evolution

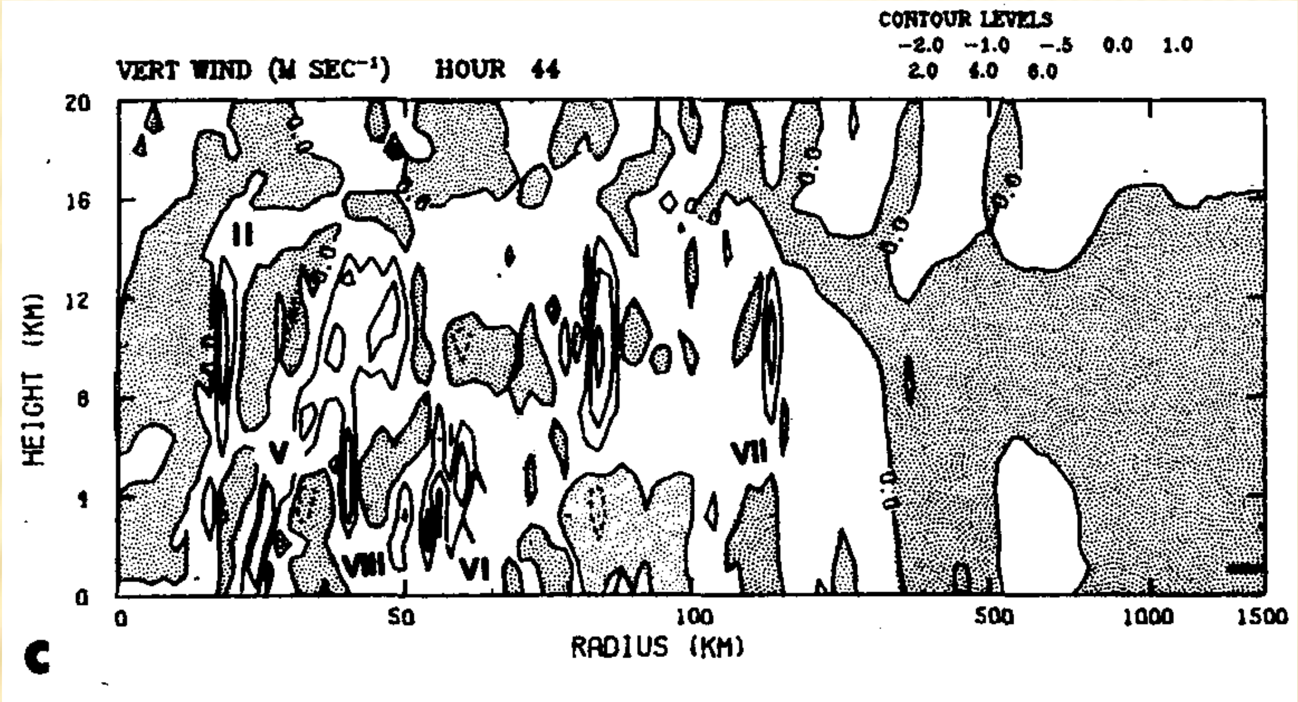


Willoughby et. al. (1984): Same as figure to the left except using ice microphysics and moist sounding

IMPORTANCE OF ICE MICROPHYSICS ON STORM EVOLUTION (CONT.)

- Inclusion of ice microphysics resulted in several significant differences:
    1. Minimum pressure dropped more steadily
    2. Lower final minimum pressure
    3. Higher maximum wind velocity
    4. Rain rates lower by 25%
- These dissimilarities result from more realistic convective ring structure
- Significant structural differences include:
    1. Shallow inflow layer caused by larger frictional inflow
    2. Smaller vertical extent of clouds due to efficient collection by snow
    3. Updrafts narrower and more vertical in structure
    4. More downdrafts initiated at melting level due to latent cooling of frozen species
- Lord and Lord (1984) studied four different microphysical parameterizations. They determined that realistic microphysical conversion processes helps develop realistic convective ring structure. Conversion processes more important than thermodynamic input or vertical sorting.

IMPORTANCE OF ICE MICROPHYSICS ON STORM EVOLUTION (CONT.)



Willoughby et. al. 1984: Radius-height profile of vertical velocity for nonhydrostatic, axisymmetric model with ice microphysics at hour 44. Units are in m/s.

CONCLUDING REMARKS

- Ice microphysics play crucial role in evolution of storm
- Physical and dynamic properties of hurricanes are interdependent
- More observations needs to be taken to better understand those processes most important in hurricanes
- More research needs to be done to come up with more realistic cloud physics schemes in models

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