There is a relationship between the scale of atmospheric vertical motions and the character of the precipitation they produce. A traditional classification of precip is:

1. Widespread stratiform precip. associated with broad regions of ascent (nimbostratus).

The distinction between these two is not black and white, for example:

• There can be fine scale structures in “stratiform” precip.
• Large regions of stratiform precip. are very frequently associated with nearby convection (MCSs).
On radar, convective cells are deep, vigorous, and generally associated with strong horizontal gradients and large values of reflectivity. Stratiform regions tend to look rather uniform in the horizontal but often have a bright band structure in the vertical we previously discussed.

Convective or stratiform?

Reflectivity at $z = 1$ km

Reflectivity at $z = 6$ km
Convective or stratiform? Vertical cross sections taken through the system…

Reflectivity at 1700 UTC

Reflectivity at 1715 UTC
Convective or stratiform?
Last example, from P-3 tail radar (same date) …

OK, one more… (R&Y Fig. 12.3).
The beam for $r < 20$ km is passing through the stratiform precip. but at 20 km intersects the bright band. Beyond 20 km, the beam is above the 0 °C line and the bright band. When scanned over all azimuth angles, the angled radar beam intersecting with the BB produces the circular BB signal seen on radar.
• OK, so despite the simple classifications in R&Y Ch12, it’s not always easy to tell convective from stratiform.

• They are fundamentally different, however, and great efforts have been made to develop methods to objectively classify convective and stratiform regions from radar data — usually involve horizontal gradients of reflectivity (e.g. c and s will have different Z-R, so may need to separate to obtain total system rainfall).

Whether precipitation is convective or stratiform can be defined in terms of their vertical velocity. The vertical velocities in stratiform precip. are small compared to the fall velocity of ice:

$$|w| < V_{ice},$$

where $V_{ice}$ is the terminal fall speed of ice or snow, $\sim 1-3 \text{ m s}^{-1}$.

• While it is possible for shallow stratiform clouds to produce precipitation, only deeper nimbostratus that reach well above the 0 °C level will produce robust precip.
1. precip begins as ice particles (in situ or external source).
2. particles fall and grow by vapor deposition; supersaturation maintained by gentle uvv.
3. particles aggregate as they near the melting level
4. particles melt as they pass through 0 °C line.

A particle initially at 10 km, will be able to undergo vapor deposition for ~1.7 h before reaching a melting level (4 km).

1. w=1-10 m s\(^{-1}\), much larger than fall speed of ice.
2. Time available for precip growth is much shorter than for stratiform (30 min).
3. Precip. particles originate at cloud base.
4. Carried upward until \( w < V_t \) and then fall.
Microphysical character of stratiform precipitation

Pristine ice habits vary as function of temperature (cf. R&Y Fig. 9.6).

Max. in aggregates largely overlaps max. in dendrites. Implies that aggregation mode is dendrites sticking together.

These microphysical data imply a gentle ascent — required to produce supersaturation needed for the vapor grown habits — but not too strong of ascent, so particles can fall and produce the profile of aggregates.
Whence cometh the large scale ascent pattern in stratiform precip.?

- Topographic forcing on the windward side of a mountain range \((w = \nu_H \cdot \nabla h)\).

- Ascent associated with the warm advection region of a baroclinic wave.

- Gentle ascent associated with upper part of the convective eyewall in a hurricane that slopes outward with height.

- Ascent associated with deep convection (MCS), usually from an ensemble of decaying convective elements that are still weakly positively buoyant. The distribution of heating in an MCS sets up an organized mesoscale circulation — part of it being a robust region of weak ascent conducive to the production of stratiform precip.
Either deep or shallow convection is often inextricably linked to the formation and maintenance of stratiform precip. Why?

Microphysical consideration that we glossed over previously, namely: What is the source for the ice particles at the cloud top?????

- Ice phase particles can nucleate under gentle ascent, but growth of just-nucleated crystals is quite slow — they’re likely to be advected out of the cloud before they can grow large enough to become precipitable.

- It’s clearly preferable that the particle at cloud top be already of appreciable size.

- Convection is the most obvious mechanism to produce lots of precipitation-sized ice particles quickly. Convection can act as a major source of ice particle, seeding the supersaturated region of ascent.
Two main ways convection is able to provide a source for ice particles:

1. Convection occurs over a shallow layer in the upper portion of the cloud, and the ice particles fall into the nimbostratus;
2. Ice particles produced in nearby convection are detrained or advected into the stratiform region, where they fall and grow.

1. Shallow convection embedded above nimbostratus

- convective cells form in the shallow layer of potential instability.
- vigorous growth of ice particles, which then fall out, often subject to shear.

Called the seeder-feeder process (Bergeron 1950; Hobbs et al. 1980; Rutledge and Hobbs 1983)
2. Adjacent deep convection

Special cases:
1. No cell regeneration → get a simple temporal transition from convective cells to nimbostratus (stratiform).
2. Assume steady-state convective region and shear with height. Then the labeled ice particles (3,2,1) can be thought of as trajectory locations.

Ice particles advect into nimbostratus region, and grow by vapor deposition as they fall. This case assumes no shear — convective elements move to the east (right) and decay.
Continuous/nimbostratus/stratiform rain can be considered a steady-state process, variable with height but not in time.

Convective/showery precip. can be considered to vary in time but be constant in height at a given time.

For the convective case, consider the equation for growth by accretion:

\[
\frac{dR}{dt} = \frac{EM}{4\rho_l}u(R),
\]

where E is the collection efficiency, R is drop radius, M is LWC, and u(R) is terminal fall speed of a drop of radius R.

Assume a simple fall speed law, \( u = k_3r \), substitute, and rearrange to get

\[
\frac{dR}{R} = \frac{EMk_3}{4\rho_0} \rightarrow R(t) = R(0)e^{at}, \text{ where } a = \frac{EMk_3}{4\rho_0}.
\]
Assume only accretion with no coalescence of raindrops. Then # of raindrops in interval $dR_0$ in the initial DSD is the same as # in the interval $dR$, i.e.

$$n(R, t)dR = n_0(R_0)dR_0.$$  

Substituting for $R_0$ and $dR/dR_0$ results in

$$N(R, t) = e^{-at}n_0(Re^{-at}).$$

Captures the movement of the rain drop distribution toward larger sizes. Most appropriate in early stages of convection, when rain drop coalescence is of minor importance.

For stratiform precip, assume the number flux of raindrops is constant with height — otherwise the DSD would vary with time. Therefore,

$$n(R, h)u(R)dR = n_0(R_0)u(R_0)dR_0.$$  

Again $u = k_3r$ and realize that $R = R_0 + h\frac{EM}{4\rho_l}$. 

Simplifies to

\[ n(R, h) = \left(1 - \frac{h \bar{EM}}{R \rho_l}ight)n_0 \left(R - h \frac{\bar{EM}}{4\rho_l}\right). \]

Conclusion from this crude approximation is that convective precipitation develops roughly exponentially (in time), while stratiform is more linear (in height here) in nature.