Aerosols, Precipitation, and Turbulence

Are Turbulence-induced Collisions a potential Buffer?
Preliminary Understanding

• Initially precipitation is delayed or suppressed...
  – Increase Aerosols
  – Increases CCN
  – Increases $N_d$
  – Decreases precipitation due to the effect on collision efficiency.
Complex Relationship

• Meteorology is important
  – Humidity at cloud tops
  – Cloud-type
  – Wind shear
Figure 4 | The deepening effect. The local inhibition of precipitation helps precondition the environment for deeper convection, which then rains more.
Secondary Cloud Formation

• In the presence of moderate wind shear, squall lines and secondary clouds form as a result of downdraft motion’s reinforcement by evaporative cooling.

Precipitation is Delayed


Figure 17. Time evolution of accumulated rain in the PRE-STORM thermodynamic conditions in maritime and continental aerosol cases.
After initial delay...

– Net result is more vigorous convection.
– Increased turbulent energy and dissipation rate.
– Net precipitation efficiency over an area may decrease, but water vapor from a large region can be concentrated locally into strong storms. [Khain et al. 2005]

• Good conditions for turbulent droplet collisions!
Turbulence and Rain-formation

• Turbulent enhancement over a purely gravitational collision kernel is as high as 5 for strong turbulence.
  1. Increased turbulent collision efficiency
  2. Increased droplet clustering
  3. Modified droplet relative motion
1. Increased Turbulent Collision Efficiency

Figure 9. Turbulent collision efficiencies for cross-size collisions. (a) $a_1 = 20 \mu m$, (b) $a_1 = 30 \mu m$ and (c) $a_1 = 50 \mu m$.

2. Increased Droplet Clustering

\[ St = \frac{\tau_p}{\tau_\kappa} \]

\[ \tau_p = \frac{d^2 \rho_p / \rho_{air}}{18 \nu_{air}} \]

\[ \tau_\kappa = \left( \frac{\nu_{air}}{\epsilon} \right)^{1/2} \]

3. Modified Droplet Relative Motion


Turbulence and Rain-formation

• Enhancement is largest for drops of similar sizes
  – Effect of clustering is most pronounced for droplets of similar size (effect of Stokes number)
  – Collision efficiency is also highest for similar sized drops.
Figure 2. (a) The ratio of a typical turbulent collision kernel to a purely gravitational collision kernel (Wang and Grabowski, 2009) for $\varepsilon = 200 \text{ cm}^2 \text{ s}^{-3}$. The ratio on the 45° degree line is undefined owing to the zero value of the gravitational kernel. The ratio is essentially one when droplets are greater than 100 $\mu$m. The constituent parts of the turbulent collision kernel are shown in (b) the droplet relative velocity, (c) the RDF and (d) the collision efficiency.

The flow viscous dissipation rate and terminal velocity are effective in altering the local aerodynamic interaction shape of droplets in the turbulent flow; the center panel shows trajectories of two colliding droplets at the scale of droplets in the turbulent flow; and the right panel is a snapshot of flow vorticity surfaces and the location of the collision kernel, is plotted as a function of the radius ratio of the small droplet.

Figure 1.

Air Turbulence in Warm Rain Initiation 3

This section highlights selected findings obtained using the hybrid DNS approach. Figure 2 shows the enhancement of the collision rate is a product of the geometric collision factor and turbulence, where

\[ \eta_T = \frac{\eta}{\eta_0} \]

\[ \eta = 100 \text{ cm}^2/\text{s}^3 \]

The above-scaling arguments show that a larger acceleration, and therefore this first condition prefers a larger geometric collision kernel and the hydrodynamic-gravitational enhancement factor, \( \gamma \), which favors the two limiting cases of a large ratio of droplet radii, \( \frac{a_2}{a_1} \) close to one. The second condition may be stated as

\[ \frac{a_2}{a_1} \rightarrow 1 \]

\[ \frac{a_2}{a_1} \rightarrow \frac{a_2}{a_1} \]

The right panel of Figure 2 shows the above-scale visualizations from the hybrid simulation approach. The left panel: The net enhancement factor, the ratio of the turbulence enhancement of the collision efficiency, as a function of the radius ratio of the small droplet.


\[ a_1 = 30 \text{ microns} \]
Figure 3. The ratio of a typical turbulent collection kernel to the Hall kernel. The ratio on the 45° degree line is undefined due to the zero value of the Hall kernel. The ratio is essentially one when droplets are above 100 μm. The flow dissipation rate is 400 cm²/s³ and rms velocity is 202 cm/s.

Figure 4 highlights striking differences between the two collection kernels. The intensity of the autoconversion is significantly increased by the turbulent kernel. The time interval for the autoconversion is reduced from about 32.5 min (Hall kernel) to 10.5 min (the turbulent kernel). This twofold reduction factor increases with either the initial number density distribution or an average value of about 0.36, which is within the range of 0.1–0.4 observed standard deviation and the mean droplet radius.

The above turbulent collection kernel is then used in the kinetic collection equation to solve for droplet concentration factors shown in Figure 3 are similar to those reported recently in Pinsky et al. (2006), where ε = 1230 s (or 1250 s) for the turbulent kernel. This twofold reduction factor increases with either the initial number density distribution or an average value of about 0.36, which is within the range of 0.1–0.4 observed standard deviation and the mean droplet radius.

Copyright © 2007 Amer. Meteor. Soc. All rights reserved.

7.6.4 Effects of Aerosol–Cloud Interactions on Precipitation

In summary, it is unclear whether changes in aerosol–cloud interactions arising from changes in the availability of CCN or IN can affect, and possibly intensify, the evolution of individual precipitating cloud systems. Some observational and modelling studies suggest such an effect, but are undermined by alternative interpretations of the observational evidence, and a lack of robustness in the modelling studies. The evidence for systematic effects over larger areas and long time periods is, if anything, more limited and ambiguous.