P1.83 CHALLENGING CLOUD PHYSICISTS

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1. INTRODUCTION

Cloud Physics deals with the evolution of the particles in a cloud, coupled to an environment described by its dynamics. The main issue is to understand the explanation of the formation of precipitation, being it snow, ice particles or rain. The question discussed here is about the main components that are not or not well enough understood and require extensive studies to produce a reasonably complete picture of the formation of precipitation. This is not only important per se, it is also an important input into climate and climate change models.

The forecasting of precipitation from convective systems is difficult – as any forecaster knows. It is not better for climate models, which have little if any skill in the assessment of precipitation. This is illustrated by attempts at ECMWF to deal with precipitation with the help of stochastic/statistical methods - which are easier to manage und are supposed to produce smaller errors.

This may be the point also to comment on "averaging" and "resolution". To use statistics without any constraints of Physics, is deplorable and should not be tolerated. It is also ludicrous to have to run a NASA aircraft and measure particle concentration over more than 20 km in order to get "significant" results for possible precipitation processes. This only produces results which are statistically significant and physically dumb. There are other examples. Even a radar with a 1^o resolution is averaging over all particles in the beam volume, be they important in terms of precipitation or be they particles rejected in the precipitation processes.

What aspects are crucial and worthy of accelerated treatment? I would list two issues about the physics of particles: Ice nucleation and electrification. On dynamics I would list the complete lack of understanding of the turbulence in updrafts.

Nucleation has always been an issue in cloud physics. Remember that in the early nineteen fifties condensation nuclei were all particles activated by the large supersaturations (400-500%) in Aitken or Pollack counters. It was the pioneering work of Wieland (1956) that allowed counting of particles at supersaturations down to 0.1 %. For ice nuclei there has been no critical assessment about the conditions or range of conditions under which the count should be made and what instruments would be best suitable. What fraction of water molecules are deposited on nuclei as "water" and what fraction as "ice". What are the properties of nucleating surfaces? It is also disturbing to see that cloud physics has lost its once leading role in nucleation to surface physics, where quantum mechanical approaches have produced major insights. There is no question that intensive thinking and sorting will lead to major advances.

Electrification has always excited meteorologists. There are barely any issues of the Austrian journal "Meteorologische Zeitschrift" of the late nineteenth Century without any articles on charging. The main usage of electrical effects nowadays is to explain events which have no other explanation yet. I venture to say that most textbooks and lectures even give wrong explanations about the sign of charge generation! Elster and Geitel (1885) assumed that a small droplet would collide with a large droplet in the aft-part of the large particle. This was violently criticized by Simpson (1909) who pointed out that the small droplet would hit the large droplet in the front hemisphere – and then bounce off. This was acknowledged later by Elster and Geitel (1913). It turns out, that this was wrong and that the small drop, in order to separate, would have to hit in the front part near the equator – to be carried around (by inertia) in to the aft sphere, where separation could take place (Whelpdale and List, 1971; List and Freire, 1992). This is the only configuration where physical collision could occur without coalescence. Electrically this situation can lead to the following ambiguities: oppositely charged droplets can repel each other, without a physical collision by bouncing off an air cushion. A charge transfer could still take place by corona discharge (kissing drops). One other fact has to be taken into account: two oppositely charged droplets can coalesce once they get close enough, so that polarization charges lead to attraction. There is no question that this type of charging is rare [Dr. Bell in Hong Kong did not find electrical activities in warm clouds, i.e. clouds without ice (Personal communication, ~ 1980)].

In icing wind tunnels the author did not find any charge separation involving hailstones, unless they were dry and were colliding with ice particles (crystals). Thus, the main events would occur during the growth of graupel in a cloud also containing ice crystals. Note that graupel, by definition, grow with dry surfaces. Corresponding experiments were performed by Berdeklis and List (2001). The results have been parameterized and are available for modeling of charge separation in clouds. Thus, a first step for exploring the consequences are possible.

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2. CLOUD MODELS AND TURBULENCE

Unfortunately, cloud modeling has not evolved any further from its state 35 years ago; no new ideas have been developed. The past achievements have been remarkable in their days because they explained concepts. Two examples depicting the structure of storms in terms of flow tubes (Fig. 1) and “streamlines” (Fig. 2).

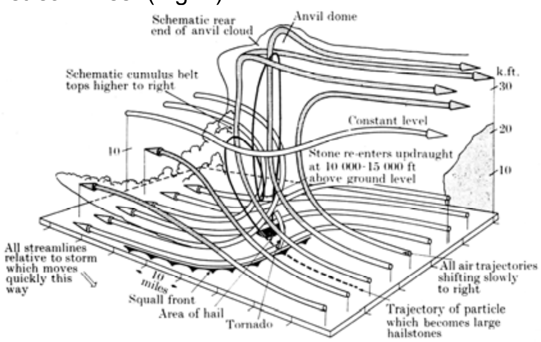

Fig. 1. 3-dimensional storm model by Browning and Ludlam.

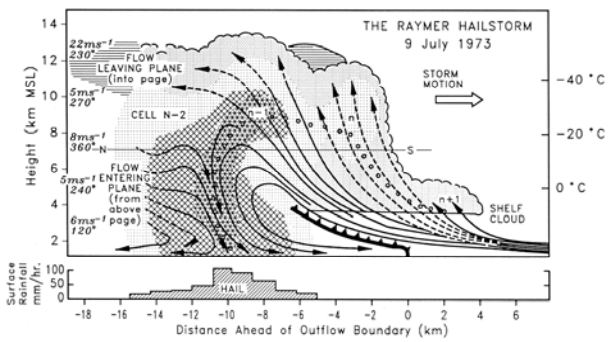

Fig. 2. 2-dimensional storm model by Browning and Ludlam.

These models are very sophisticated and beautiful - idealizing the flow of air and the movement of hailstones through the storm. The models of a typical, isolated Colorado hailstorm, show the basic flow in coherent and logical fashion, while continuity and “laminarity” are maintained at all times. But are the spaghetti-like flow tubes and the hail conveyer belts real? My answer is NO.

Have we forgotten the bubbles and plumes introduced by Scorer and Ronne (1956) and Scorer (1957), followed by the experiments with thermals by Turner (1963). Yang (1968) did experiments in water tanks with simulated cloud bases, decreasing densities and flocculation in my Toronto lab. After building an acoustic radar with turbulence measuring capabilities (List et al, 1972), Melling and List (1980) studied the atmospheric boundary layer with its thermals. The picture resulting from this work in the lab and the BL clearly show the turbulence in thermals and plumes with eddy sizes comparable to the horizontal dimension of the convective elements. [The tank-experiments were carried out because there were no computers available to numerically recreate them.] Unfortunately the lessons of those laboratory simulations were lost.

The message is clear: THE STANDARD CONCEPT OF LAMINAR FLOW IN STORMS NEEDS TO BE REPLACED BY TURBULENT UPDRAFTS. New concepts need to be approached with turbulence elements, i.e. large eddies of sizes up to the diameter of the updraft. We have to address real turbulence, not their mathematical description, at the same time realizing that flow is orderly, even with turbulence [see airflow from stationary satellites with their often regular whirls, which in standard Meteorology are described by Navier-Stokes equations, and the occasional singularities]. An example from the laboratory: the inflow into an open wind tunnel is normally laminar before the fan imparts the forward momentum to the flow and makes it quite turbulent. Convective clouds are similar. Just assume that the region where momentum is injected into a cloud is the region of release of latent heat. That is the driving force for the updraft in convective clouds. It creates turbulence which can be visualized as vortex streets in wakes.

Spheres start to shed doughnut-shaped ring vortices at relatively low Reynolds numbers, Re. With increasing Re they are replaced by “half”-doughnuts, detached on one side, alternating with vortices shed on the opposite side (not exactly). It can be assumed that updrafts consist of such vortex streets, with the vortex axes horizontal. This would make the eddies amenable to treatment by Navier-Stokes equations.

There is considerable literature on wakes available in mechanical and chemical engineering. One can also go back to the “old times” of water tank experiments and measure. Systematic measurements of turbulence of scales of o.1000 m (and down) in convective clouds may give the necessary answers – if they allow visualization of the actual eddies/vortices.

Such observations will be very relevant to understand the packaging of precipitation particles in high-resolution Doppler spectra measured by an upward pointing radar.

Fig. 3 shows packages of hailstones in a squall line (Thompson and List (1996). As the air flows by, soundings are translated into distance and vertical scans were carried out every ~160 m. The scans by the Environment Canada King City Doppler radar are given by the heavy white squares, triangles and circles. The hail was mostly observed below the 0^oC level. No hail had been located above the -17^oC level. Note that three packages are on top of each other at ~8.3 km (distance reflects time as air moves over the radar site). The particle spectra changed from 1 to 2 to 3 peaks over distances of ~200 m. With the data of the King City Doppler radar of Environment Canada, 21km away, the interpretation is that the hail was

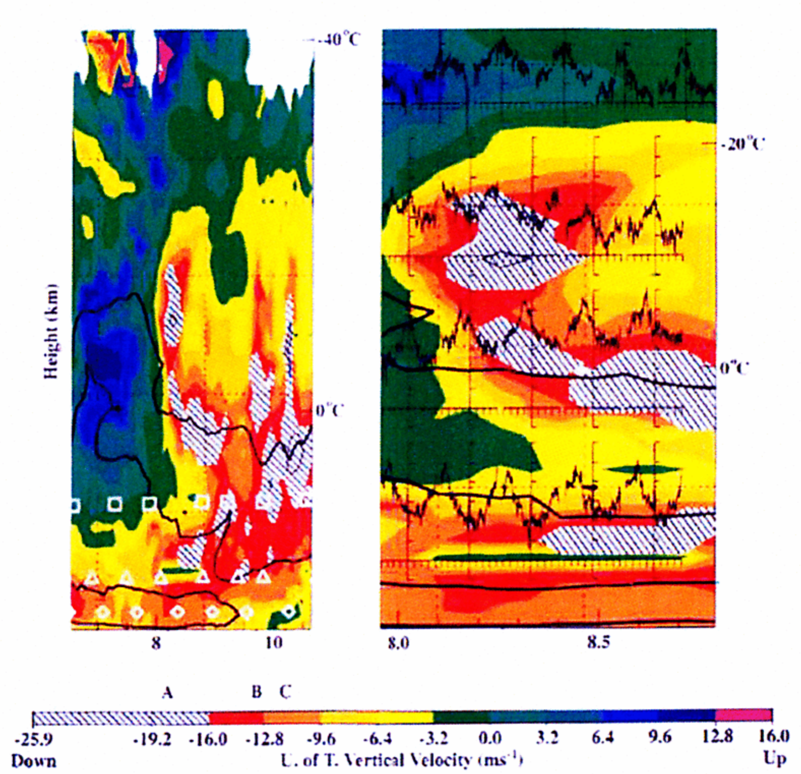

Fig. 3. Vertical Doppler scans as squall line storm moved over radar site, while 1 cm hail fell on radar. Length scale in terms of storm passing over site; hatched area shows hail regions. Right hand side: stretched area from 8 – 8.7 km, with power spectra measured every ~ 160 m by vertical scan centered about the eastern edge of the main updraft. Each spectrum from -16 to 16 m/s and -30 to 40 dBZ [(m s^{-1})$^{-1}$] vertically. Black contours show 0 dBZ and 30 dBZ respectively. The origins of the power spectrum axes (0 m/s, -20 dBZ (m/s)$^{-1}$) are positioned with respect to the data at the locations where each spectrum was measured; 0^{o}C level at 3.7 km. Based on Thomson and List, (1996).

often falling in sheets with thickness of 100-200 m. Amazingly Farley and Orville (1999) found in their numerical simulations that hail fell in tongues (Fig. 4). Their calculations were based on a 2-D model with 30 m resolution.

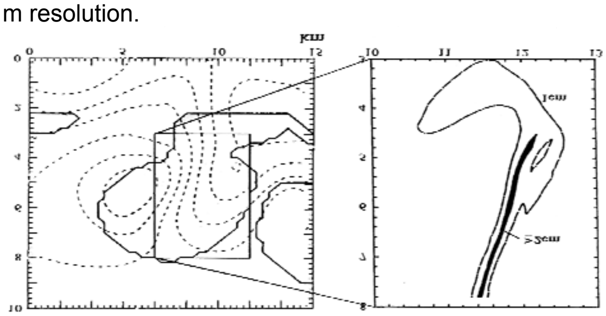

***Fig 4.** Farley Hail tongue in Cloud Model by Farley and Orville (1999), starting with 6 mm hail; 2-D model with 30 m resolution*

The lack of modeling capability manifests itself in missing efforts to use available experimental data to produce meaningful depictions of hail clouds.

3. LONG-TERM ISSUE AND PROPOSAL OF A MAJOR CLOUD PHYSICS PROJECT

There is a big success story in Cloud Physics: the book *"AEROSOL POLLUTION IMPACT ON PRECIPITATION",* Eds. Z. Levin and W.R. Cotton, Springer, 2009, pp 386. It is a comprehensive study of everything that is known about the aerosol, its measurement and evolution, and its influence on precipitation. A good number of top scientists in the field have either contributed by writing or by reviewing. The book is of importance for the understanding of the behavior of the atmosphere and its reaction to pollution. It may also have an impact on Climate Change Models.

Should we not continue and try reach for the next higher goal? There is a great opportunity to parallel aerosol pollution with another investigation: ***"THE FUNDAMENTALS OF PRECIPITATION".*** The contents could contain the evolution from weather-active nuclei to snow, rain and hail. It could also address measurement methods and systems, followed by results of laboratory and field experiments, theories and numerical models of clouds and cloud systems. The key problems could be identified now by a group of leaders and the suggestions in this paper could be assessed, together with other proposals, followed by an approach to the cloud physics community. Maybe the proposals could then be bundled for a combined funding application. Within 5 to 10 years sufficient advances are possible to produce and continuously update the state of the art of Precipitation Physics. That is not only a goal within itself, it is also a goal beneficial to understanding and forecasting Severe Storms, tornadoes and hurricanes; it would also be beneficial for Climate and Climate Change modeling.

It is not an easy undertaking considering that the skill in forecasting precipitation from convective clouds is low due to the inherent complexities and difficulties. It will not be easier in climate models either. Normal climate models are working with a 1^{o} grid. Who believes in the validity of climate and precipitation projections for nested 30x30 km or 10x10 km grids, sizes comparable to that of electoral ridings?

The postulate by the author (List, 2010) that shedding by hailstones is the main source of rain, also in the tropics, would help and simplify the understanding of precipitation [What opportunities for attack!]. However, an adequate dynamic model would have to include multiple and interacting particle types, such as raindrops, graupel, small hail, hail and frozen drops and cloud droplets (see Joe, 1982).

In recent years the study of aerosol has flourished, the main application being radiation – not their weather active properties. This disregards that the effect the aerosol is small, with an average effect on global temperature being normally < 1^{o}C. The weather-active aerosol, however, is key to the precipitation process. Remember ***no precipitation means desert, precipitation means life***. That difference is 100x more important then the aerosol's *radiation* effect! Yet most of the climate change modelers rather hang on to their comfortable funding than admit their severe lack of skills in making climate change projections in terms of precipitation. This dishonesty is the real "Climategate".

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