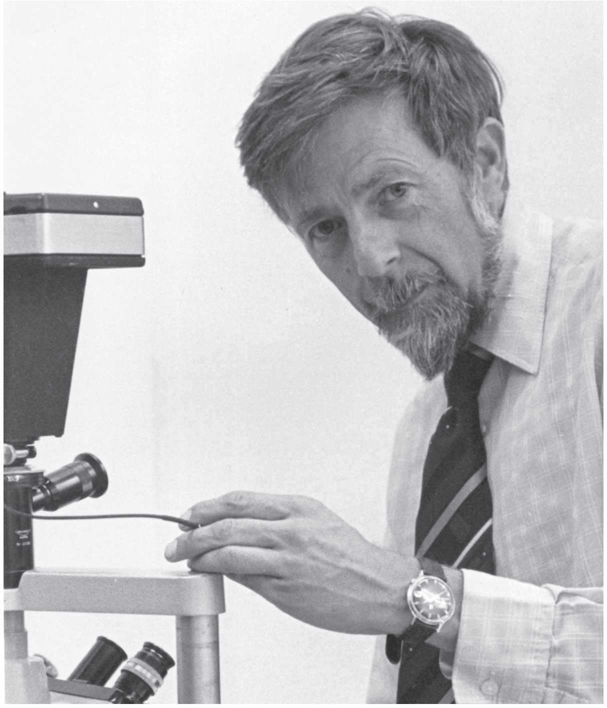
THE IMPACT OF JOHN HALLETT ON THE FIELD OF WEATHER MODIFICATION

ANDREW DETWILER

University of North Dakota, Department of Atmospheric Sciences

South Dakota School of Mines and Technology,
Department of Physics, and Atmospheric and Environmental Sciences Program

John Hallett was born in Bristol, England on December 2, 1929 and died in Reno, NV, on November 5, 2018. A wonderful obituary published by his family in the Reno Gazette Journal can be found on legacy.com. (https://www.legacy.com/obituaries/rgj/obituary.aspx?n=john-hallett&pid=190700992&fhid=15274) Many personal aspects of his remarkable life are surveyed there. During his professional career he conducted laboratory and field research that shed new light on important processes in atmospheric physics, including cloud physics, aircraft icing, and atmospheric electricity. He mentored a new generation of atmospheric physical scientists through their graduate education and research training for a short time at the University of California – Los Angeles and for almost 50 years at the University of Nevada - Reno. In addition, some of his professional accomplishments were summarized in a presentation by a group of his former students at the 2019 International Union of Geodesy and Geophysics meeting in Montreal (https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/normal#!abstractdetails/0000791180) Here we will review the impact of his work on the field of weather modification.



In the 1950's, while John was pursuing his graduate education in atmospheric physics, one of the big issues in this new field was the need to develop a scientific understanding of precipitation growth and how it might be modified by cloud seeding. The discovery of the effects of cloud seeding with dry ice and silver iodide by the General Electric (GE) Research Laboratory in 1947 led to the rapid appearance of new groups experimenting with cloud seeding in many countries around the world who made a wide range of optimistic claims for their successes in enhancing precipitation, reducing hail damage, and having other beneficial impacts. Irving Langmuir, the leader of the research group at GE that had made the initial discoveries, was fond of saying that "it will be easier to make the weather we want than it will be to predict natural weather". Many scientists of the day did not accept this claim, but the scientific knowledge needed to test it was not yet developed enough to test it. So, it was natural that a bright young graduate student working in atmospheric physics at this time might be interested in working in this area.

John Hallett's early research during his graduate school years focused on ice crystal growth. He worked under Basil John ("BJ") Mason at Imperial College in London. One of his first publications was based on laboratory observations of ice crystal growth (Hallett and Mason, 1958). He started in the laboratory but soon was also making field observations in England and elsewhere. After coming to the US in the early 1960's to take a faculty position at the University of California in Los Angeles (UCLA) he was invited to join one of the famous winter expeditions to Yellowstone Park led by Vincent Schaefer to do experimental cloud physics near the hot geyser pools in the Old Faithful geyser area. Here researchers could work on the ground at temperatures characteristic of the mid- and upper troposphere. In the mid-1960's he left UCLA to help found the Desert Research Institute (DRI) in Reno, NV, which developed a strong research program in atmospheric physics and cloud seeding. He also became a faculty member in the physics department at the University of Nevada – Reno.

By the early 1970's, Hallett was immersed in both laboratory studies on the nucleation and growth of ice crystals and in field studies concerned with cloud seeding, including the Florida Area Cumulus Experiment (FACE). In 1974 he and Stanley Mossop solved one of the great mysteries of the day, the not uncommon observation in natural clouds of ice crystal concentrations orders of magnitude higher than would be expected based on measured ice nuclei concentrations. (See Hallett and Mossop, 1974.) Beginning as early as the 1940's several mechanisms had been proposed to explain this puzzle but field observations and laboratory work had not been able to quantify any of them. In a well-controlled laboratory experiment Hallett and Mossop demonstrated that in a specific set of conditions high concentrations of ice particles can develop due to rime splintering. This was an important advance in understanding precipitation development in mixed-phase clouds. During FACE John studied both the effects of seeding clouds with ice nucleants (Sax *et al.,* 1979) and the rapid glaciation of towering cumuli in non-seeded clouds. (Hallett *et al.,* 1978). Prior to these studies many had considered primary ice nucleation on aerosol particles to be the only, or at least the most important mechanism leading to the formation of ice hydrometeors. As a result of the Hallett-Mossop work, along with further studies by them and others, many aspects of a rime-splintering process for ice multiplication were scientifically explored. This well-defined mechanism for "secondary ice production" or "ice multiplication" is now often referred to as the "Hallett-Mossop process". For cloud seeding operators it became increasingly important to consider the impact of natural so-called "secondary" ice production processes in precipitation formation, and whether the addition of more primary ice nuclei could have any beneficial effect on precipitation development in a particular set of conditions.

Observations were fundamental to John Hallett's research, both in the laboratory and in the field. He studied ice crystal growth in the laboratory and in the field from his student days (Hallett and Mason, 1958) well into the next century (Bailey and Hallett, 2009; Bailey and Hallett 2010). When suitable observing equipment could not be acquired off-the-shelf, he invented new instruments. His airborne Formvar replicator provided unique data on hydrometeor shapes, sizes, and concentrations during FACE and later projects. By the 1980's he furthered his research into mixed-phase cloud microphysics, important both in precipitation development and in electrical charge separation in thunderstorms. This interest became stronger after a DRI research flight in mixed phase clouds crashed due to excessive aircraft icing. All aboard were lost. This was a flight that John was supposed to be on, but it took off without him after he was delayed in getting from the campus to the airport. The loss led him to focus even more on understanding mixed-phase conditions in clouds and their role in precipitation formation and also in aviation. His instruments tended to be rugged and based on simple physical principles. The "T-probe" for cloud water and ice observations (Vidaurre *et al.,* 2011), the airborne "cloud scope" (Meyer and Hallett, 2001), and the "hot plate" precipitation rate sensor co-invented with Roy Rasmussen (Rasmussen *et al.,* 2011) are three examples of instruments he invented to make better observations of mixed-phase precipitation processes.

Bob Black, a colleague in the NOAA hurricane reconnaissance operation, collaborated with John on an extensive analysis of microphysical conditions in hurricanes collected by cloud microphysical research instrumentation installed. on hurricane patrol aircraft. (Hallett and Black, 1986). These observations showed that individual developing convective elements in hurricane rain bands rapidly glaciate at relatively high temperatures due to ingestion of ice from neighboring more mature convective elements. These observations cast doubt on the basic premise of Project Stormfury, the NOAA effort to explore the possibility of modifying tropical cyclone development using cloud seeding (Gentry, 1969). The Hallett and Black observations suggested that hurricanes naturally glaciate so rapidly that adding ice nucleants would have negligible effects on precipitation development and storm evolution.

Roy Rasmussen notes that John exuded infectious enthusiasm and creativity. "If you weren't excited about his research when you met him, you were after talking to him for a few minutes." Many members of the atmospheric physics community visited John and toured his lab while he delivered his impromptu one-on-one lectures.

John Hallett became skeptical of the standard assumption made by many cloud seeding operators that adding ice nuclei to a cloud or storm will almost always accelerate the development of precipitation. A theme of his work was that natural precipitation-forming processes can be very efficient. John was not dogmatic in his skepticism, but genuinely interested in better understanding of mixed phase hydrometeor processes in clouds that cloud seeding operators attempt to modify. I feel that John would have been excited to engage in a discussion of recent results from well-executed winter orographic cloud seeding field programs like the Snowy Mountain Project in Australia (Manton *et al.,* 2017), the Wyoming Precipitation Enhancement Pilot Project (Rasmussen *et al.,* 2018), and the Seeded and Natural Orographic Wintertime clouds: the Idaho Experiment (SNOWIE, French *et al.,* 2018) in the US. While this work showed that experimental dispersal of ice nucleating materials can lead to enhanced precipitation formation in some situations encountered in these projects, in other situations effects of such seeding have been difficult to discern. This is in part because "natural" ice formation can be so effective in some circumstances that effects of higher concentrations of primary ice nuclei are masked.

We who work in weather modification have benefited greatly from the insights into cloud microphysical processes developed by John Hallett and his collaborators as well as the many tools he has left to us to continue making observations and gain further insights. We need to continue this research and develop new observing technology to better focus our efforts to beneficially modify natural precipitation processes.

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