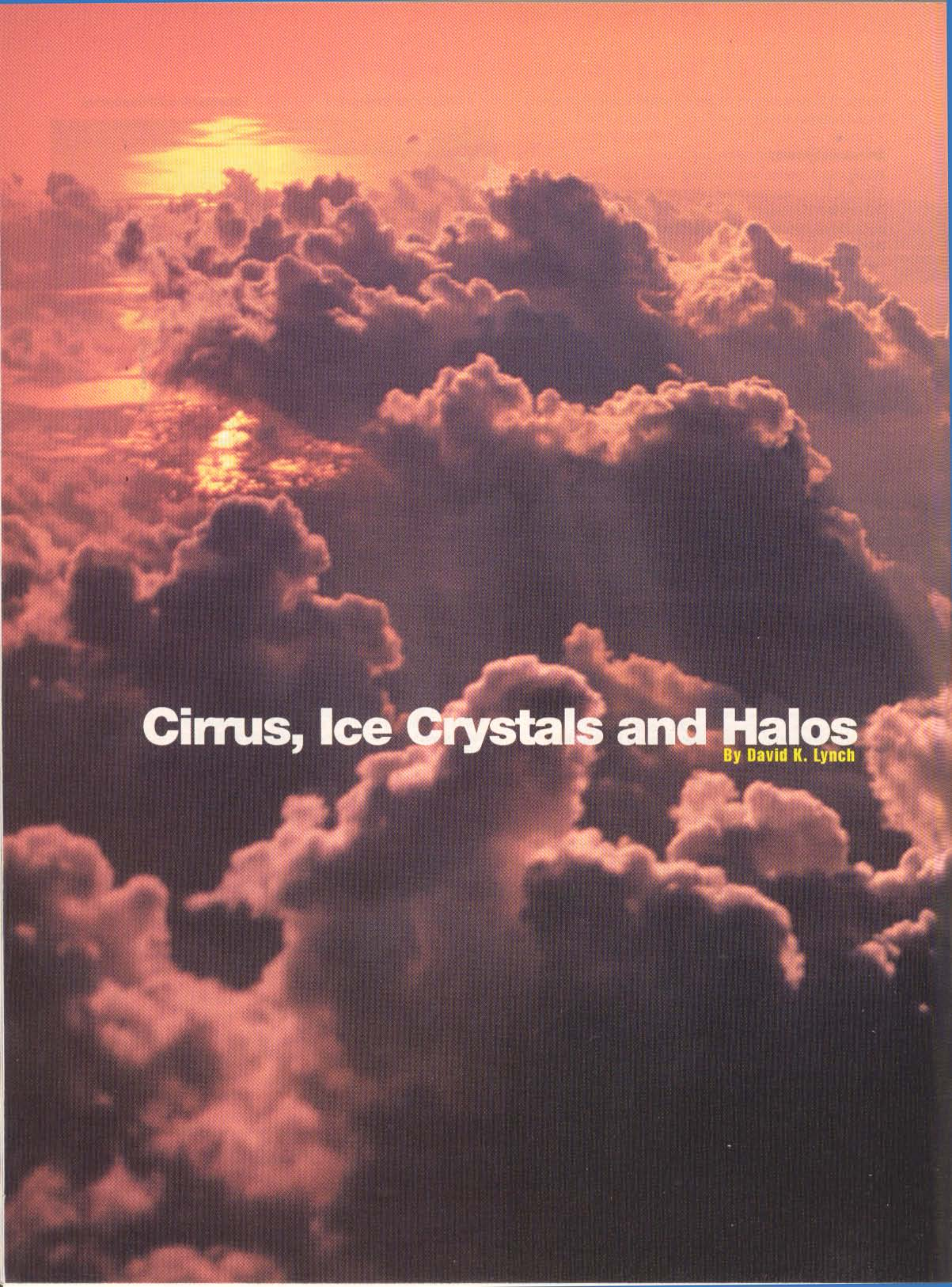
Cirrus, Ice Crystals and Halos

By David K. Lynch



Cirrus, cirrostratus and cirrocumulus clouds are high, usually thin, always cold clouds composed predominantly of ice. Our understanding of ice clouds, including the recognition of ice's presence, is intimately tied to halos. Descartes was probably the first person to suggest that cirrus clouds were composed of ice crystals.

Magnification of ice crystals.

Cirrus clouds are composed primarily of ice.

The historical view of cirrus

The most distinguishing physical property of cirrus (cirrostratus and cirrocumulus) is their composition. Cirrus clouds are made predominantly or wholly of ice, while the vast majority of clouds (both in name and number) are composed of water droplets. The ancients, who surely encountered fog in valleys and mountains, were probably aware that most clouds were composed of water droplets. Yet the presence of ice in cirrus would not have been something experienced in everyday life. Who discovered that cirrus is made of ice? To answer this question, we must trace developments in meteorology back almost 2500 years.

Anaxagoras of Clazomenae (c. 500 - 428 BC) might have deduced that cirrus clouds were made of ice. Using an approach based on measurements and observations, Anaxagoras came to realize that clouds were made of water and that air was colder aloft. He believed that warm moist air convected upwards and that the water vapor cooled, condensed and ultimately froze at great heights to become hail. "Clouds and snow are formed in somewhat the same manner; and hail is formed when, already cooled by its descent earthwards, it is thrust forth from frozen clouds; and it is made round."[1] We don't know if Anaxagoras considered cirrus explicitly, because what little is left of his writings doesn't specify any cloud formation recognizable as cirrus.

Two thousand years passed before any substantial progress was made on cirrus. In 1637 Descartes (1596-1650) published *Discours de la méthode* (1637) in three parts: Dioptrics, Meteorology and Geometry.[2] In Dioptrics he set forth the law of refraction (Snell's law); in Meteorology, he applied the law to rainbows by performing numerical ray traces. Although he almost certainly knew the principle of minimum deviation, nothing in his writings explicitly refers to it.

In the Ninth Discourse on Meteorology, Descartes conjectures that the common 22-degree halo was due to refraction through ice crystals:

"... around the heavenly bodies there sometimes appear certain circles... they are round... and

History of Cloud Classification

- **1802: Lamarck formed first, little-known naming scheme**
- **1803: Luke Howard proposed Latin cloud names based on appearance**
- **1887: Abercrombie and Hildebrandsson classified clouds by height above ground and by appearance (from Howard's naming scheme)**

Cloud Classification

Cirrus (Ci) **Cirrostratus (Cs)** **Cirrocumulus (Cc)**	**High clouds** **5–13 km**
Altostratus (As) **Altocumulus (Ac)**	**Middle clouds** **2–7 km**
Stratus (St) **Stratocumulus (Sc)** **Nimbostratus (Ns)**	**Low clouds** **0–2 km**
Cumulus (Cu) **Cumulonimbus (Cb)**	**Vertical clouds** **> 0 km**

always surround the sun or some other heavenly body... they are colored, which shows that there is refraction. But the circles are never seen where it rains, which shows that they are not caused by the refraction which occurs in drops of water or in hail, but by that which is caused in those small little stars of transparent ice... those that we have observed most often have had their diameters at around 45°... "[3]

Descartes was obviously referring to the common 22°-radius halo whose diameter is about 45°. He recognized that the circles were visible on clear days and were not related in any way to rainbows. There is no evidence that Descartes actually ray-traced an ice crystal. Still, Descartes almost surely recognized the existence of thin clouds when the halos were present and he probably deserves the credit for identifying ice in cirrus.

The work of French physicist Edme Mariotte (1620–1684) included experiments on heat and cold, light, sight, and color. The strength of his work proved to be his ability to recognize the importance of results, confirming them by new and careful experiments, and drawing out their implications. In 1681, Mariotte explained several halos as being due to refraction through crystals.[4] This confirmed Descartes' conjecture and later led Venturi (1794)[5] and Young (1802)[6] to set forth the modern basis of halo theory. Mariotte's framework of geometrical optics is still in place today.[7,8]. Curiously, however, the notion of ice high in the atmosphere and the implication for temperature did not take root in the minds of 17th century meteorologists.

Around 1600, Fludd, Drebbel, Santorio and Galileo were inventing what was to become the thermometer.[9] Which of these inventors should actually be credited with this advance is still subject to uncertainty. The Italians Galileo and Santorio, famous in their lifetimes, were innovators in their respective fields of science. On the other side of the Alps, Fludd, a Welsh Rosicrucian mystic, and Drebbel, a Dutch inventor of mechanical devices, were also working on temperature devices. Based on available evidence, it is difficult to be sure which of them actually invented the instrument; however, it is known that Santorio was the first to actually make use of the thermometer as a scientific instrument.[9] Although the historical record does not tell us the name of the first person to take a thermometer up in the air and record freezing temperatures, such an outcome would surely have been a reasonable expectation and possibly a known fact by the early 17th century.

Thus, by the middle of the 17th century, all the pieces were available: Descartes had optically linked cirrus with ice, even though cirrus had not yet been named or classified as a cloud type. Galileo and Santorio had established the quantitative relation between altitude and temperatures. What was necessary to complete the concept was empirical evidence that cirrus clouds were very high in the atmosphere. This finding was not to come until almost two centuries later, when systematic cloud classifications began.

Modern cloud classification

Jean-Baptist Lamarck (1744–1829), was one of the first to scientifically study the weather. In 1802, he published the first scientific cloud classification based on morphology.[10] Though not intended as a complete system, one of his classes—"nuages en balayures," or "sweep clouds"—referred to what we now call "cirrus." Despite his pioneering efforts, however, Lamarck's French terminology was never adopted.

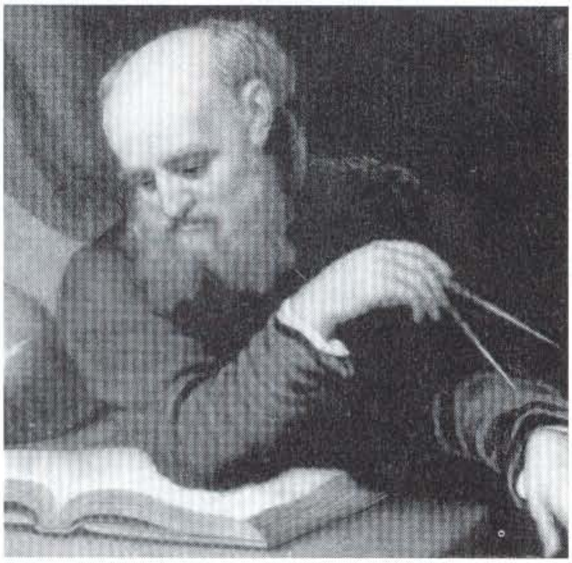
The year after Lamarck's work was published, Luke Howard published a cloud classification[11] using Latin names. He was the first person to use the term "cirrus" to refer to wispy, fibrous clouds. According to Howard, cirrus clouds were "parallel, flexuous, or diverging fibres, extensible by increase in any or all directions." Furthermore, "Clouds in this modification appear to have the least density, the greatest elevation, and the greatest variety of extent and directions."[11]

Both Lamarck and Howard had backgrounds in biology, and it is not surprising that the term "cirrus" was already employed in taxonomy to describe various "dangling" or "prehensile" appendages. If Howard were with us today, he would have the pleasure of knowing that his cloud classification is still in use.

The next advance in the understanding of cirrus clouds came over 50 years later. In 1855, Renou recognized the importance of cloud height, and people began triangulation measurements. Later, Hildebrandsson and Abercrombie (1887) firmly established height as an important classification parameter when they introduced five families of ten cloud genera. Their work was immediately adopted as the standard for cloud classification.

In 1879, Hildebrandsson published an atlas of 16 cloud photographs. A few years, later he and Abercrombie published a more extensive cloud classification,

René Descartes. Photo courtesy of AIP Emilio Segré Visual Archives, Physics Today Collection.



Galileo. Photo courtesy of AIP Emilio Segré Visual Archives, Physics Today Collection.

which stressed cloud vertical height and structures (Abercrombie and Hildebrandsson, 1887). This work became the standard in cloud classification and was closely followed in preparing the C.E.N.[13] Since then, our understanding of the composition, height and temperature of cirrus clouds has not changed significantly. Nor, in general, has our definition of cirrus.

There have, however, been considerable advances in our understanding of cirrus and halos. Modern works on halos can be credited in part to Walter Tape.[8] Tape recently co-authored a paper with Günther P. Können entitled "A general setting for halo theory." This paper puts forth a framework for the systematic treatment of halos due to refraction in preferentially oriented ice wedges, and an atlas is constructed of such halos. Initially, Tape is not constrained either by the interfacial angles, or the orientations of real ice crystals. Instead, he considers "all possible" refraction halos. As a result, no assumptions are made regarding the wedge angle, and only a weak assumption is made regarding the allowable wedge orientations. The atlas is thus a very general collection of refraction halos that includes known halos as a small fraction.[14]

The most up-to-date work on cirrus is reviewed in Lynch *et al.*, (2000).[15] People interested in the recent research on halos and other naked eye optical phenomena, such as rainbow refractometry, should refer to Charles Adler (2000).[16]

The author is not a professional historian and welcomes information from any source that could further refine the results presented here.

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