The Useful Pursuit of Shadows

The study of clouds has profoundly influenced science and human culture and stands poised to lead climate science forward again

Graeme L. Stephens

On a December evening in 1802, Luke Howard, a London pharmacist and amateur meteorologist, aired his ideas about the classification of clouds. These ideas were presented to a small gathering of young science-minded intellectuals who called themselves The Askesian Society. Howard's lecture on that evening was titled "On the Modification of Clouds" and opened as follows:

> My talk this evening concerns itself with what may strike some as an uncharacteristically impractical subject: it is concerned with the modification of clouds. Since the increased attention which has been given to meteorology, the studies of various appearances of water suspended in the atmosphere has become an interesting and even necessary branch of that pursuit. If clouds were the mere result of condensation of vapour in the masses of the atmosphere which they occupy, if their variations were produced by the movements of the atmosphere alone, then indeed might the study be deemed a useless pursuit of shadows.…

This was a historic lecture for many reasons. Most importantly, it heralded the beginning of meteorology, a previously unrecognized area of natural science. This lecture was published the following year as an essay and appeared in subsequent publications over a span of almost 20 years. It is a remarkable testimony that Howard's classification, with minor changes, remains in use today by practicing meteorologists. His classification was a revelation, bringing a sense of order and understanding to a subject that had lacked coordinated thought—let alone any documented theories as to how pressure, temperature, rainfall and clouds might be related. Perhaps even more impressive than Howard's classification of clouds, or "modifications" as he referred to them, was his intuition, inspired by the earlier ideas of his close acquaintance John Dalton that clouds must be considered as "subjects of grave theory and practical research … governed by … fixed laws.…" Howard's ideas about the physics of clouds were generally sound despite the poor understanding of the physics of air and water vapor in his time.

By contrast, for the past 50 years the modern science of meteorology has fixated on the ever-expanding capability of computer technology and the numerical prediction of the movements of *invisible* air. To the nonmeteorologist this must appear most odd. Clouds, after all, are the most visible manifestation of weather in all its forms, and their prediction should be more than an object of curiosity. However, even the task of numerically integrating forward in time the Navier-Stokes equations governing the behavior of invisible air turned out to be substantially more complex than was originally conceived.

Today, 200 years after Howard's lecture, we enter a period when we return in earnest to pursuing the subject of shadows. Although the focus on weather prediction remains, we now embrace more fully the broader problem of predicting the evolving, moist atmosphere as foretold some 30 years ago by Edward N. Lorenz:

> The previous generation was greatly concerned with the dynamics of pressure systems and talked about highs and lows. Today we have not lost interest in these systems but we tend to look upon them as circulation systems. This change in attitude has led to a deeper understanding of their dynamics. Perhaps the next generation will be talking about the dynamics of water systems.

Concerns about inadvertent climate change and our desire to predict changes associated with the build up of greenhouse gases in the atmosphere return the subject of clouds to the forefront of the atmospheric and climate sciences. The endless, compensating flows of water between the earth and sky fundamentally govern how the climate of Earth evolves and how it will change in the future. There can be no credible climate prediction without a proper quantitative account of the atmospheric water systems that nurture the

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Figure 1. Clouds were first described systematically by Luke Howard, a London pharmacist and amateur meteorologist, in an 1802 address to the Askesian Society. Howard's Linnean cloud-classification system remains largely intact today, and its development thus marks the birth of the science of meteorology. During the last half of the 20th century, however, atmospheric science fixated on the numerical modeling of the movement of *invisible* air masses, only very recently returning to the daunting but crucial subject of water transport in the atmosphere. Meanwhile, the practice of classifying clouds by type has largely disappeared from mainstream research in the atmosphere. The author argues that as effective as modern modeling and imaging techniques may be, something is lost when clouds become only data. These ethereal assemblages of water vapor still hold the potential to inspire quantitative science to new heights. (Maynard Dixon's 1926 *Mesas in Shadow* courtesy of the Brigham Young University Museum of Art.)

planetary water cycle. Yet as we focus anew on the physics of water within the giant circulating eddies of air, it is sobering to realize that our current ability to measure the amounts within these massive systems is rudimentary.

The Classification of Clouds

In the 18th century, scientists seemed to be preoccupied with naming and classifying objects of nature. The language used to describe the natural world at that time was evolving and rapidly becoming standardized. Before Howard, however, attempts to standardize the nomenclature for clouds had failed. The underlying reason for this failure can be drawn from a stanza taken from Percy Bysshe Shelley's famous poem "The Cloud":

> I am the daughter of Earth and Water,
> And the nursling of the Sky;
> I pass through the pores of the ocean and
> shores;
> I change, but I cannot die.

Not only does Shelley express a deep appreciation of the intimate role of clouds in what is now known as the water cycle, but he also conveys one of the truly complex properties of clouds that thwarted early attempts at classification—their ability to mutate rapidly from one form to another in a smooth, fluid continuum within an evolving chaotic world of vapor. How could any classification, which by its nature suggests permanence, capture a sense of endless mutability? Howard's contribution made a leap forward by proposing that the myriad of cloud forms we see in the sky are characterized by a fixed yet small number of basic cloud types that evolve into hybrid forms as they transform from one type to another. In his essay, Howard notes:

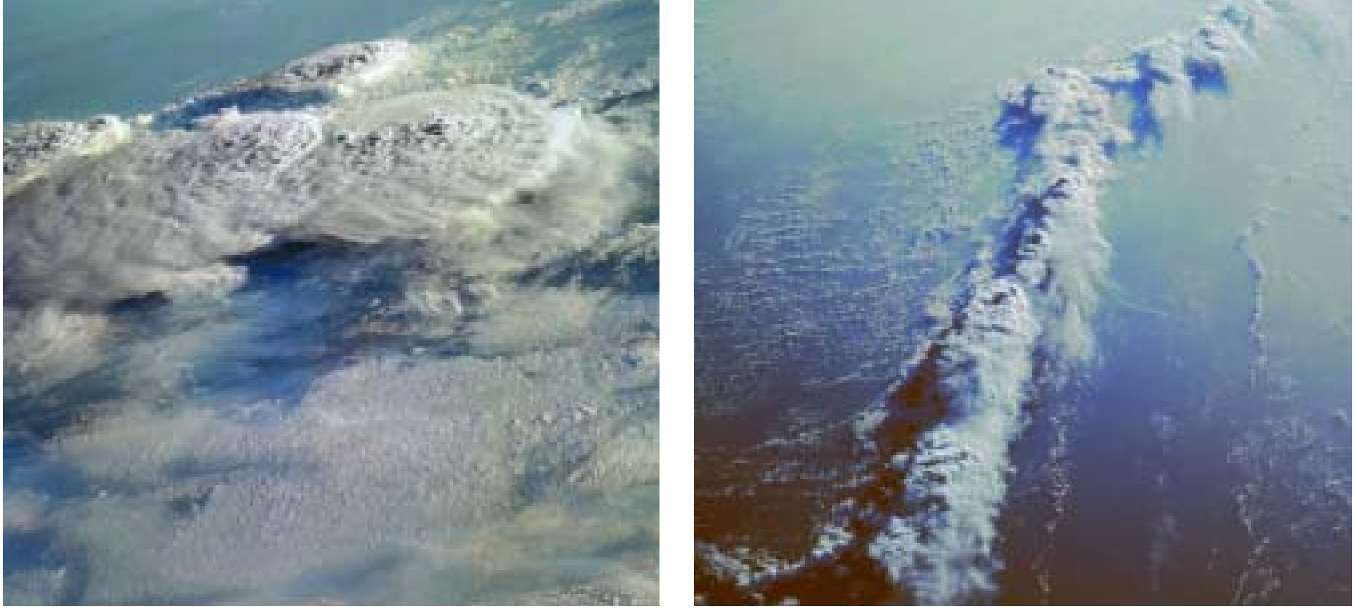

Figure 2. Cloud systems display their structure well when viewed from space. At left, cumulonimbi have organized into supercell thunderstorms observed over Canada during the Space Shuttle mission STS064 in September 1994. The image shows the bubbling up of cumulonimbi and the spewing out of layers of high anvil clouds. The outflow of air associated with individual cumulonimbus or clusters of cumulonimbi often affect neighboring cumulonimbi, organizing them into a squall line. The photograph at right shows such a squall line observed over the Atlantic Ocean from the Shuttle during mission STS51G in June 1985. These squall lines are often massive, extending thousands of kilometers. (Photographs courtesy of NASA.)

> There are three simple and distinct modifications in any one of which the aggregate of minute drops called a cloud may be formed, increase to its greatest extent and finally decrease and disappear … but the same aggregate which has been formed in one modification, upon a change in attendant circumstances, may pass into another.…

The organizational model Howard adopted for cloud classification was based on the system introduced by Swedish botanist Carl von Linne. The Linnean system employs a binomial nomenclature designated by a pair of Latin names; one defines the cloud genus, and the second indicates cloud species. The names Howard chose for his three major types of clouds conveyed a sense of their outward characteristics:

• *Cirrus* (from Latin for "fiber" or "hair"): "Parallel, flexuous or diverging fibres, extensive in any or in all directions."
• *Cumulus* (from the Latin for "heap" or "pile"): "Convex or conical heaps, increasing upwards from a horizontal base."
• *Stratus* (adapted from the Latin stratum for "layer" or "sheet"): "A widely extended continuous horizontal sheet, increasing from below upwards."

Howard then added cloud types that were aggregates of these three major formations. Notable in this addition was the rain cloud.

• (*Cumulo- Cirro-* or *Stratus-*) *Nimbus* (from the Latin for "cloud"), which Howard considered to be a rainy combination of the three major types—"The rain cloud. A cloud or system of clouds from which rain is falling.…"

His intermediate types also included:

• *Cirro-Cumulus:* "Small, well defined roundish masses, in close horizontal arrangement or contact."
• *Cirro-Stratus:* "Horizontal or slightly inclined masses attenuated towards a part or the whole of their circumference, bent downward, or undulated, separate or in groups consisting of small clouds having these characteristics."
• *Cumulo-Stratus:* "The cirro-stratus blended with the cumulus, and either appearing intermixed with the heaps of the latter or superadding a wide spread structure to its base."

This classification scheme, although simple, granted the naming of clouds a sense of freedom. Howard also made one notable observation about clouds that has only recently been used as an organizational principle in cloud research. He realized that clouds could be thought of as "systems"—a concept brought clearly to view by technological advances that deliver global images of clouds from space. These views demonstrate systems of clouds organized on scales far grander than Howard could ever have imagined *(see Figure 2)*.

During the middle and latter part of the 19th century, Howard's classification underwent refinement and reorganization. These refinements included the introduction of different species of the same genus, such as *cumulus humilis*, *cumulus congestus* and *cumulus fractus*. There were also a number of attempts to modify this simple classification over the years, but the naming of clouds given to us by Howard has remained largely intact.

In an 1817 lecture Howard added cloud height in association with cloud types. But it was almost 40 years later, in 1855, when the French scientist Emilien Renou added the classification of middle level altostratus and altocumulus clouds, that attention returned to the use of altitude as a way of grouping Howard's cloud types. This grouping provided a tinge of irony to the history of cloud classification. The idea that clouds should be grouped according to altitude was proposed more than 50 years earlier, in 1802, by Jean-Baptiste Lamarck. Lamarck, too, was French, and his proposal was part of a broader cloud classification scheme introduced at the same time and in competition with the Howard system. Lamarck's scheme was considered too clumsy, lacked a universal appeal and was discarded entirely in favor of Howard's contemporary and more elegant approach.

The first true change to Howard's names for clouds was the replacement of cumulo-stratus with "stratocumulus." This addition was suggested by the German meteorologist Ludwig Kaemtz in 1840, and his inversion of the terms moved this cloud from the cumulus genus to the stratus genus. Other attempts to change the naming of clouds occurred throughout the 19th century. Finally, in 1887 two eminent scientists, Hugo Hildebrand Hildebrandsson and Ralph Abercromby, consolidated the naming of clouds by producing a list of 10 cloud types based on Howard's scheme, cirrus, cirro-stratus, cirro-cumulus, strato-cumulus, cumulus, cumulo-nimbus, nimbus and status plus the addition of two mid-level cloud types: altocumulus and alto-stratus. In 1890, Hildebrandsson and Abercromby produced a cloud directory with photographs and formed a cloud committee as part of the International Meteorological Conference in 1891. The naming of clouds together with the grouping of clouds in terms of altitude was officially adopted at the Paris Conference in 1896, the International Year of the Cloud, some 32 years after the death of Howard. There the *International Cloud Atlas* was launched, and the same 10 cloud genera that are found in the current version of this Atlas, with minor rearrangements, were pronounced and widely accepted by the meteorological community. The present-day classification adopted by the World Meteorological Organization is as follows:

High Clouds (bases > 6 kilometers)
1. Cirrus (Howard, 1803)
2. Cirrocumulus (Howard, 1803)
3. Cirrostratus (Howard, 1803)

Middle Clouds (bases 2 – 6 kilometers)
4. Altocumulus (Renou, 1870)
5. Altostratus (Renou, 1870)
6. Nimbostratus (International Commission for the study of Clouds, 1930)

Low Clouds (bases < 2 kilometers)
7. Stratocumulus (Kaemtz, 1841)
8. Stratus (Howard, 1803)
9. Cumulus (Howard, 1803)

And the final cloud type extending through all ranges of altitudes
10. Cumulonimbus (Weilbach, 1880)

National Gallery, London / Corbis

Figure 3. Clouds have inspired artists and poets for millennia, but John Constable was among the first to paint them in a way that accurately depicts light and shadow, as shown here in *Weymouth Bay*. Constable was most likely familiar with Luke Howard's classification system and made notes about weather conditions on the backs of his canvases.

Clouds, Philosophy and Art

In the 423 B.C. comedic play *Clouds,* Aristophanes wrote through the voice of Socrates that "clouds are the goddess of the idle man," by which he meant that they are the contemplative subjects of the great philosophers and the thinking man. Throughout the ages, clouds have been considered the testing ground for new philosophical ideas of nature. The property that challenged Howard and his classification—their mobility—inspired philosophers and artists. The philosophical man believed that if clouds could be convincingly and rationally explained, then so could anything else in nature, for clouds represented the most extreme manifestations of the ungraspable. The French Jesuit philosopher of the 17th century, René Descartes, wrote:

> Since one must turn his eyes toward heaven to look at them, we think of them … as the throne of God…. That makes me hope that if I can explain their nature … one will easily believe that it is possible in some manner to find the causes of everything wonderful about Earth.

Clouds also preoccupied the cultural pursuits of artists, poets and playwrights throughout the ages. Ancient biblical paintings, for example, commonly portray clouds as resting places for angels and saints. Clouds perhaps first became serious elements of landscape art with the Dutch school of the 17th century, although the ever-changing forms and patterns of clouds were an apparent source of confusion for these artists. Rubens (1577–1640) is considered to be one of the greatest of all land-

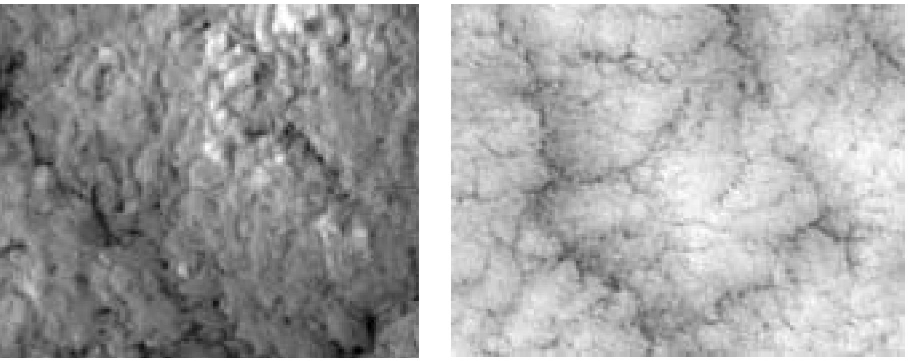

Figure 4. Model *(left)* versus reality *(right)*: Shown here are bird's-eye views of stratocumulus clouds—one derived from a simulation and the other observed from the Multi-angle Imaging Spectral Radiometer on a NASA research satellite. The simulated image uses the output of a detailed cloud model to calculate the amount of visible wavelength sunlight reflected by the cloud. (Simulation courtesy of H. W. Barker, Meteorological Service of Canada.)

scape painters, but his prodigious power for recording natural details and his ability to evoke moods and atmosphere in his paintings did not extend to the sky and clouds. His skies are scarcely recognizable in any meteorological context. The Dutch masters Cuyp, Hobbema, Koninck and notably van Ruisdal also filled their skies with brightly lit three-dimensional clouds, but, as critiqued by John Constable, an icon of English landscape art, the balance of light and the construction of shadows in relation to this light is often wrong.

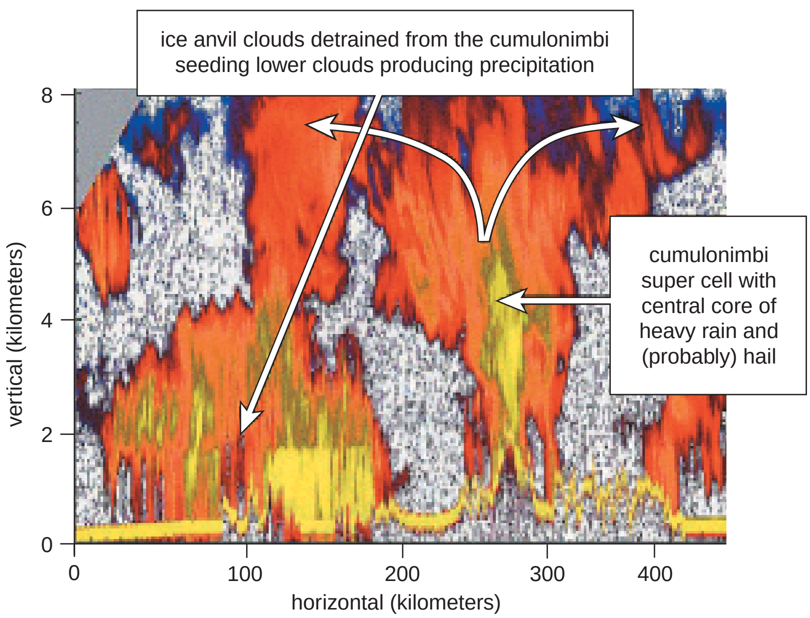

Figure 5. Image derived from airborne millimeter-wave radar is one example of the modern imaging of clouds. The image represents a vertical slice and shows profiles of radiation reflected by small volumes of cloudy air. (The color scale indicates reflection strength, with yellow strongest, orange-red moderate and blue weakest; the speckled regions are clear air.) Shown are a cluster of cumulonimbi and associated clouds that formed over a mountain range (the surface topography is indicated by the lower yellow contour). The scale of these cloud systems is enormous, stretching over hundreds of kilometers and reaching above 10 kilometers in height. An expert can infer much from such an image about the cloud system and the processes taking place, but the clouds under study are rarely classified according to the traditional World Meteorological Organization classification.

The classification of clouds by Howard appeared just at the time attitudes about painting nature were changing and Romanticism was taking hold. The Romantic period of Britain arguably produced more great poets and landscape artists than any other period, and the subject of clouds seemed to preoccupy their works, at least during the first part of the 19th century. John Ruskin, the most famous art critic of the 19th century, wrote, "[I]f a general and characteristic name were needed for modern landscape art, none better could be invented than 'the service of clouds.'"

Notable in this Romantic period were the paintings of Joseph Turner and Constable, and the poetry of Shelley. Turner's art portrays light and color of the sky and is especially notable for the colors used in his sunsets and depictions of storms. Turner's art was intuitive, reflecting his ability to convey the atmosphere from memory. Constable, on the other hand, was a keen observer of meteorology and possessed an affinity to science. In a remarkable series of cloudscapes he referred to as "noble clouds and effects of light," Constable was perhaps the first landscape artist to create a balance of the position of the Sun with lighting of the clouds and the underlying landscape. Etched notes on the backs of his canvases provided information about the weather at the time with occasional reference to past or subsequent weather. This pictorial weather diary provided John Thornes, currently with the University of Birmingham, with a way of dating the cloudscapes of Constable, placing them in the summers of 1821 and 1822.

Whether Howard's blueprint for organizing and studying clouds influenced the great Romantic works of his time has been a topic of some debate and presumably will never be known. It is clear, though, that Constable was aware of Howard's work, for he owned a copy of Thomas Forster's *Researches about Atmospheric Phenomena,* published in 1817. This publication included Howard's essay "On the Modification of Clouds" largely in its original form. It is also apparent from Constable's own handwritten annotations on that publication that the artist possessed a good knowledge of meteorology. It is entirely reasonable to suppose that Constable became aware of Howard's classification of clouds as part of his search for a greater understanding of his subjects, for he wrote "we see nothing truly 'till we understand it."

Although we might debate the extent of Howard's influence on the art of his time, there is no debate about his profound influence on the pursuits of Johann Wolfgang von Goethe. Goethe was a documented admirer of Howard's work. This admiration led to a series of poems "In Honour of Howard," in which Goethe set out to transform Howard's essay into a sequence of lyrical passages describing the three major families of clouds plus the

Stephen J. Krasemann / Photo Researchers Inc.

Figure 6. Atmospheric science has turned its attention back to the subject of clouds in recent years, as concerns about climate change have grown. The ability to model the cycle of water—from vapor to clouds to precipitation—is crucial in understanding how natural and anthropogenic forces might influence climate. As yet, the ability to model and observe this water cycle remains rudimentary. Here, water suspended in air in the form of small ice crystals that form cirrus clouds moves rapidly eastward in the jet stream over Montana.

combination introduced as Nimbus. For Goethe, the power and simplicity of Howard's scheme and his expression of the physical processes responsible for cloud shapes seemed to shed new light and provide the "missing threads" to his own studies on the shapes and forms of nature.

The poetry of Shelley provides another remarkable example of the preoccupation of Romanticism with the sky and clouds. F. H. Ludlam suggests that Shelley conveys an advanced understanding of meteorology in his "Ode to the West Wind." Others argue that "The Cloud" provides a vivid and fluid primer for Howard's classification in which each of the cloud types flow in verse. For example, Thornes assigns the following cloud types to Shelley's verse:

Nimbus

I wield the flail of the lashing hail,
And whiten the green plains under,
And then again I dissolve it in rain,
And laugh as I pass in thunder.

Cumulus

I bear light shade for the leaves when laid
In their noon day dreams.

Stratus

From my wings are shaken the dews that awaken
The sweet buds every one,

Cirrus

That orbed maiden with fire laden
Whom mortals call the Moon,
Glides glimmering o'er my fleece-like floor
By midnight breezes strewn;

Cirrocumulus

When I widen the rent in my wind-built tent
Till the calm rivers, lakes, and seas,
Like strips of the sky fallen through me on high,
Are each paved with the moon and these.

Cirrostratus

I bind the Sun's throne with a burning zone,
And the Moon's with a girdle of pearl;

Whether the motivation for this famous poem stemmed from the work of Howard is, however, not at all obvious. With Thornes, some argue that the poem clearly draws its inspiration from Howard. Others observe that Shelley was a keen

Figure 7. "Hot Towers and Cumulus Fields," a painting by the author, reminds us that the art and science of clouds have seldom been far separated. When viewed from both standpoints, both practices stand to gain.

student of Greek literature, and Stella P. Revard, English professor emerita from Southern Illinois University, has suggested that the similarity of his verse to portions of Aristophanes' play "Clouds" is more than coincidental.

Clouds in the Era of Modern Meteorology

It seems ironic that the focus of modern meteorology has largely relegated the study of clouds to a minor subdiscipline. After all, it was the study of clouds that first breathed life into the new science. The modern era of meteorology, with its focus on quantitative numerical weather prediction and forecast analysis, is broadly considered to have grown from the imperatives of World War II. Also, shortly after the war a number of leading meteorologists suggested that upper-level observations were becoming plentiful enough to evaluate day-by-day transport properties of the atmosphere. There was hope that these observations could provide an initial state from which numerical models applied using the newly available computational machines might produce digital weather forecasts. The challenges thus raised occupied the meteorological research community then and for decades to follow.

Numerical weather prediction certainly has proved to be a much more complicated problem than Vilhelm Bjerknes, Lewis Fry Richardson and other giants of meteorology originally imagined in the first half of the 20th century. Today, we understand that the atmosphere evolves as a chaotic, dynamic system, and the prediction of its trajectories is still limited by imperfect knowledge of the state of the atmosphere at some initial time. As a result, we now witness a shift in interest toward the predictability of atmospheric water systems and away from the use of abstract measures of forecast skill that convey little sense of weather, even to the practicing meteorologist.

The study of clouds during the early period of the modern era largely grew from a desire to modify precipitation. "Weather modification" or "cloud seeding" in those days was based on a very simple idea—that clouds could be seeded with microscopic particles to promote the formation of ice crystals that, on melting, would accelerate the growth of precipitation. Research between the 1950s and '80s concentrated on the microscopic details of how droplets and ice crystals grow and interact to form much larger precipitation particles. Laboratory cloud physics flourished, instruments to measure micron-sized cloud particles were invented, and much was learned.

Weather-modification results, however, were largely discouraging, and the scientific debate over the viability of weather modification continues today. One problem with these early ideas was that they overlooked the important role of air motions around and within clouds in determining amounts and organization of precipitation. Spurred on in part by the lack of general success of weather modification and aided by the increasing accessibility and capability of computers, the field of cloud dynamics grew in the 1970s with the emergence of the earliest forms of cloud models that coupled, albeit crudely at first, dynamic motions and microphysics.

Today our ability to describe clouds over areas of a few tens to a few hundreds of kilometers with these detailed cloud models is impressive *(see Figure 4)*. Yet as we attempt to extend these models to the larger scales inherent in Lorenz's vision, shortcuts are needed; our ability to model these water systems on this scale and ultimately test these models with observations begins to vanish.

Our methods for observing clouds have also advanced beyond reliance on the human observer. The cloud research community now observes clouds with combinations of satellite-borne radiometers, which detect the amount of sunlight scattered by clouds or the amount of infrared radiation emitted by clouds over a wide range of the electromagnetic spectrum. These measurements can be combined with information obtained from sophisticated radar and laser systems, which provide exquisite information on the vertical structures of clouds and potentially the all-important information about how much water and ice exists in clouds. With the impending launch of a cloud radar in space, we are entering an era when determining the water content of the massive circulation systems of our planet may soon be possible.

The Alliance of Art and Science

Whether an artist, poet, meteorologist or layperson, each of us appreciates the marvels of the atmosphere. Through the ages, it has served as a medium linking art and science. Art historian Barbara Novak, emerita professor at Barnard College and Columbia University, for example, writes, "The sky is a finely tuned paradigm of the alliance between art and science." Many believe that art and science, if coordinated in some way, might expose wider vistas of natural truth. After all, the aim of artist and scientist alike is to communicate a new and valuable way of regarding the natural world around us. Goethe was adamant that art and science are inseparable, complementary aspects of the human consciousness, and it certainly seems that the atmosphere is the ideal medium to juxtapose these aspects of our consciousness. L. C. W. Bonacina certainly recognized the value in this alliance and introduced the term "landscape meteorology" to represent the association between art and the atmosphere and the surrounding landscape.

Constable also believed that art might serve science. "Painting is a science and should be pursued as an inquiry into the laws of nature," Constable claimed in a lecture at the Royal Institute. "Why, then, may not landscape painting be considered a branch of natural philosophy?" he earnestly posed. In this spirit, Hans Neuberger has surveyed more than 12,000 paintings created between 1400 and 1967 in an attempt to chronicle climate changes over that period and found a tendency toward cloudiness and darkness during the Little Ice Age (approximately 1560–1850).

The science of clouds, however, has moved beyond the simple naming and classification of their types. Clouds are generally represented in both cloud models and the larger-scale predictive models of weather and climate as abstract fields of water mass. These fields bear little direct resemblance to the descriptive classification of Howard, and, sadly, there is little effort to make them so. Advanced methods of observation also consider clouds with scant regard for type, yet the more routine human observing practices continue today using the principles rooted deeply in Howard's original classification.

The modern era of modeling and observing clouds seems to have diverged from the more traditional observing and recording practices laid down by Howard two centuries ago. This systematic evolution towards the abstract divorces the modern science of clouds from its rich culture, and we are left to ponder whether the path of modern science has lost a source of creativity and inspiration.

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