Luke Howard and *The Climate of London*

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The International Association for Urban Climate (IAUC) has recently re-published Luke Howard's *The Climate of London*. While Howard is best known for his work on clouds (e.g. Hamblyn, 2001; Pedgley, 2003), he was also the first to recognize the effect that urban areas have on local climate. Although *The Climate of London* is largely concerned with the weather and climate in general as seen from the vantage point of London, his analysis of temperature records allowed him to detect, describe and analyze the urban heat island phenomenon many decades before others. For this reason, the IAUC's highest recognition for achievement in the field of urban climatology is the Luke Howard Award. To mark the initiation of the award, the IAUC undertook to re-publish the second edition of *The Climate of London* (1833), which consists of three volumes and is a rare book, often cited but rarely accessed (Howard, 2007). In this article, I endeavour to describe *The Climate of London* and its importance. In particular, I focus on Howard's analysis of the urban heat-island phenomenon and place it within the context of modern urban climatology.

Howard was born in London in 1772 into a Quaker household. Although he trained as a pharmacist, he had a passionate interest in climate and weather, a study that he advocates to others in *The Climate of London* as a worthwhile pursuit:

> *Now, in no one department of Natural knowledge is the field less trodden, or the opportunity for a successful exertion of the judgment in establishing general principles greater, than in Meteorology, in its present state. There is no subject on which the learned and the unlearned are more ready to converse, and to hazard an opinion, than on the Weather – and none on which they are more frequently mistaken! This, alone, may serve to show that we are in want of more* **data***, of a greater store of facts, on which to found a Theory that might guide us to more certain conclusions; and facts will certainly multiply together with observers…. So, to become qualified to reason on the variations of our own Climate, we should begin by making ourselves familiar with their extent and progress, as marked by the common instruments, and the common natural indications: for which purpose such a model as the present Volume may be found very serviceable.* (p.xvi)

His observational skills appear to have been honed during his upbringing, which occurred outside London and during which he developed a particular fascination with clouds. The knowledge he acquired was formalized when he returned to London in 1794 and joined other young professionals (many of whom were also Dissenters and thus barred from public office) in attending and organizing science meetings (Figure 1). The Askesian Society, established by his business partner, William Allenby, provided an environment where his weather interests were encouraged and developed. This was a time in London of burgeoning scientific interest driven by gifted 'amateurs'. The societies that were established during this period produced modern professional societies like the Royal Meteorological Society (Ackroyd, 2001).

In 1802, Howard delivered his famous 'Essay on Clouds' to the Askesian Society. This essay was to be re-published several times (and appears in *The Climate of London*) over the next couple of decades (often accompanied by drawings) and was to become his lasting achievement. In the absence of meteorological readings and a means for rapid transmission of weather information, forecasting was based largely on an ability to read the skies and the movements of air currents shown by clouds of different types and elevations. However, before Howard's attempts there was no accepted nomenclature to classify and describe clouds. Thus, forecasting was essentially a learned 'art' not easily communicated to anyone else. Howard's essay on clouds introduced a simple classification of clouds and provided a universal lexicon: cirrus (curl of hair), stratus (layer), cumulus (heap) and nimbus (rain bearing). So effective was his approach that it was quickly adopted and is now universally used to communicate meteorological information on clouds.

Howard continued to work and publish on meteorological topics for most of his life. His personal meteorological observations were published as monthly tables in several publications from 1806 onwards (Table 1). In 1818, the first volume of *The Climate of London* was published and the second volume appeared in 1820. In 1833, a new edition was printed that contained a third volume. This text presented his analysis of the major features of climate: temperature, pressure, wind, precipitation, etc., – the first volume is particularly significant as it contains analyses of the meteorological elements (e.g. temperature and pressure) that make up climate. The foundation for these analyses is his daily observations, compiled

Table 1

Luke Howard's observations 1806–1830.

Years	Location	Originally published†
1806–1809	Plaistow	Athenæum
1810–1811	Stratford & Clapton	Unpublished
1811–1812	Plaistow	Nicholson's Philosophical Journal
1813–1819	Tottenham	Thomson's Annals of Philosophy
1819–1827	Tottenham & Stratford	Annals of Philosophy, Philosophical Magazine and Journal
1828–1830	Stratford	Unpublished

† Howard's original tables were published as a Meteorological Register in a number of journals.

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correspondence on weather-related events and experimental notes gathered over a 25-year period, 1806 to 1830. These data comprise volumes 2 and 3.

Howard published other works – Seven Lectures on Meteorology (1837), A cycle of eighteen years in the seasons of Britain (1842) and Barometrographia (1847) – but *The Climate of London* remains his most comprehensive work. Throughout, he demonstrates a concern for precision both in the use of language and in the practice of making meteorological observations. These characteristics are illustrated in the following passages taken from the re-published work.

Howard on cloud classification:

> *But the principal objection to English, or any other local terms, remains to be stated. They take away from the Nomenclature its present advantage of constituting, as far as it goes, a universal Language, by means of which the intelligent of every country may convey to each other their ideas, without the necessity of translation. And the more this facility of communication can be increased, by our adopting: by consent uniform Modes, Terms, and Measures for our observations, the sooner we shall arrive at a knowledge of the phenomena of the atmosphere in all parts of the globe, and carry the science to some degree of perfection.* (p.xv)

Howard on rainfall measurements at the Royal Society:

> *The average Annual rain of the ten years (from 1820 to 1830, omitting 1826) is 17.615 in. which corrected for the elevation of the gauge gives 23.277 – a quantity falling below the real average of the district by more than two inches. It may be said that probably other causes than such as have been stated, and those peculiar to a great city, contribute to this deficiency. It would be very satisfactory to be able to appreciate the action of such causes, and their annual share of effect – but until an Instrument, which is understood to be that of so respectable a Scientific corporation, and the indications of which they have so long been in the habit of publishing, shall be deemed worthy of daily use when Rain is falling, we shall in vain expect from this quarter the data needful even for the construction of the problem.* (p.68)

Another feature is his use of graphs to analyze and describe his observations (Figure 2).

The urban heat island

The impact of London upon its climate is discovered by Howard when he compares his temperature records against those made by the Royal Society at Somerset House. He concludes that 'the temperature of the city is not to be considered as that of the climate; it partakes too much of an artificial warmth, induced by its structure, by a crowded population, and the consumption of great quantities of fuel in fires' (p.2). His is the first analysis of two related, but distinct issues: the urban 'contamination' of meteorological records and the magnitude and cause of the urban effect.

Howard's analysis is based on temperature records gathered at three different sites outside London (Plaistow, Tottenham and Stratford) and one site (Royal Society) within London (Table 1, Figure 1). The urban effect is examined as the temperature difference between his 'urban' and 'rural' sites ($\Delta T_{u\text{-}r}$, see Figure 3). 'Unfortunately, his exposures varied and were far from standard – at Plaistow, 1809 a village 6.4 km east of London, the thermometer hung beneath a laurel bush, and at Tottenham, where readings were taken between 1813 and 1816, the thermometer was 3 m above the ground on the north wall of a house' (Chandler, 1965, p.147). The exposure of the Royal Society's instrument is unknown.

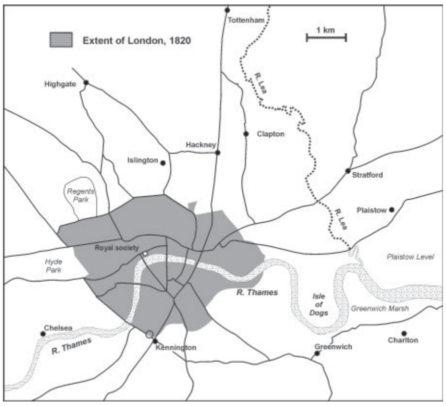

Figure 1. London in the early nineteenth century was 'a built-up area, itself a kaleidoscope of neighbourhoods, set amidst a large and amorphous region' (Schwarz, 2001, p.641). The period of Howard's work (1800–1830) was one of rapid population growth (from about 1 to 1.5 million) resulting from continued in-migration and a fall in the death rate. (This map is based on The Environs of London, Published by Baldwin and Cradock, 47 Paternoster Row, London. Published by the Superintendence of the Society for the Diffusion of Useful knowledge. February 1st, 1832, Drawn and Engraved by H. Waters. Source: http://www.londonancestor.com/maps/).

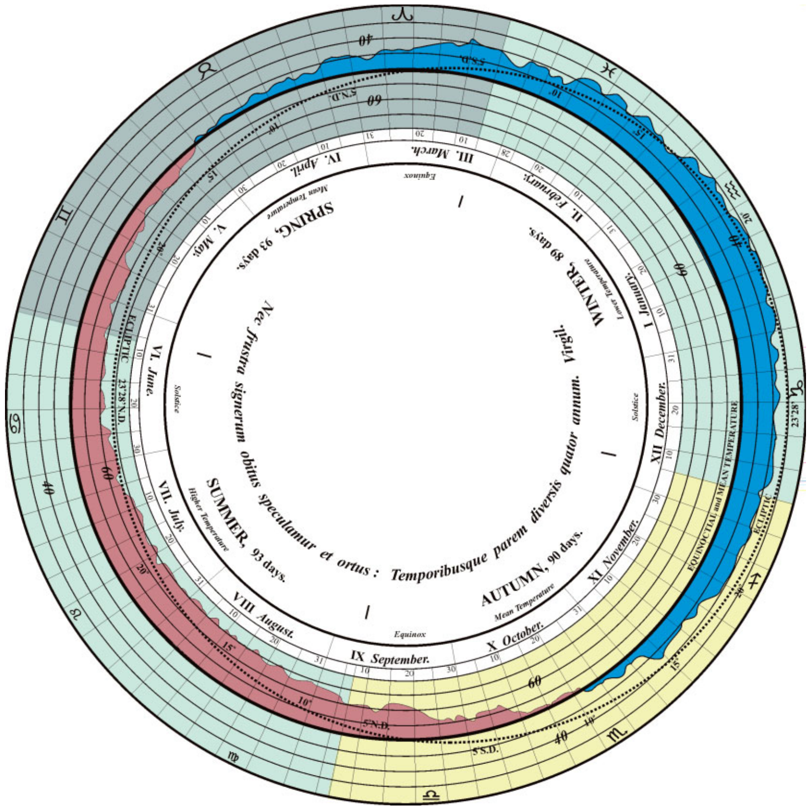

Figure 2. The yearly cycle of temperature. The concentric lines represent a temperature scale graduated at 5º [deg F] intervals – the 40º and 60º lines are marked. The declination of the sun is shown with a dotted line with regular latitude markings. The detailed line outlines warm (red) and cold (blue) areas defined as periods above or below, respectively, the annual average. Finally, the four coloured areas represent the four seasons. Redrawn from Plate 2 in the second edition of The Climate of London.

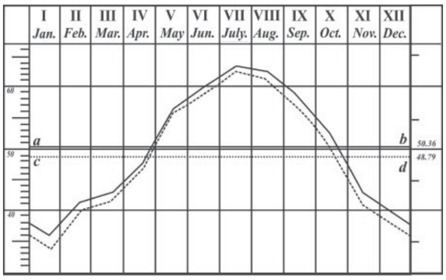

Figure 3. The annual temperature curves for the city (solid) and the countryside (dashed). The labelled horizontal lines represent the means (based on the 30-year period 1797 to 1816) for the city (a–b) and countryside (c–d). Redrawn from Figure 3 in the second edition of The Climate of London.

It is climate, as observed from the vantage point of London, rather than the distinctive urban climate of the metropolis that is of particular interest to Howard. Consequently, part of his analysis is concerned with removing the urban influence:

> *Thus, under the varying circumstances of different Sites, different Instruments, and different Positions of the latter, we find London always warmer than the country, the average excess of its temperature being 1.579° [deg F]. But as the same causes which produce an artificial elevation of temperature in London, must likewise influence, in a smaller degree, the country, the Mean of which for the ten years ending with 1816 is 48.79°, and as the second fractional Figure was uniformly neglected in taking the Monthly means for the Annual average in the Register of the Royal Society, I shall for the present abate a little of the one, and add to the other; and for the purposes of comparison rate the* **Mean of the Latitude and level** *of London at 48.5°, and that of the* **Metropolis itself** *at 50.5°. Future observations with Thermometers previously compared, and a greater degree of care to secure the fractions, may determine these with an accuracy not as yet attained.* (p.3)

The means by which Howard 'discovered' the urban effect have become commonplace. Ideally, the urban effect, measured as $\Delta T_{u\text{-}r}$, would be assessed from a continuous set of observations that begin prior to urban settlement. Over a stable climatic period, the unique contribution of the stable urban area could be identified and extracted. However, most studies are based on comparisons between observations made at existing 'urban' and 'rural' sites. Consequently, the selection of these sites is critically important.

However, Howard is hardly to be criticized for making use of the available records, which were few in number and short in duration. In fact, as the quotes above illustrate, he was aware of degrees of urban influence. It was Lowry (1977) who first formulated the problems inherent in examining the 'urban effect'. He identifies three separate components in any set of measurements: the 'background' climate, the effects of the local climate and the effects of local urbanization. For example, London has a background climate associated with its position in the mid-latitudes and on the western side of Europe. It has a local climate as it is situated within the Thames Basin and, of course, it has its urban influence (Figure 4). The urban area (u) has an effect on its environs (u'). Outside this area may be considered rural (r), where just the background and local effects are present and the urban effect is absent. The problem with establishing the urban effect ($\Delta T_{u\text{-}r}$), is that the shape and extent of the area u' will vary with weather and climate. In Figure 4(a), airflow from one direction carries the urban effect in one direction downwind forming a narrow elliptical area. A site within this zone of influence now has a degree of urban influence. In Figure 4(b), a lengthy sequence of weather events (a climate, in fact) has established a zone of influence around the urban area. Lowry concludes that, in the absence of pre-urban observations, the urban effect may be only estimated.

In the Summary to *The Climate of London*, Howard provides a concise statement of the temporal variation of $\Delta T_{u\text{-}r}$ and hints at its spatial character:

> *The* **Mean Temperature of the Climate** *… is strictly about 48.50° Fahr.: but in the denser parts of the metropolis, the heat is raised, by the effect of the population and fires, to 50.50°; and it must be proportionately affected in the suburban parts. The excess of the Temperature of the city varies through the year, being least in spring, and greatest in winter; and it belongs, in strictness, to the* **nights***; which average three degrees and seven-tenths warmer than in the country; while the heat of the day, …. falls, on a mean of years, about a third of a degree short of that in the open plain.* (p.147)

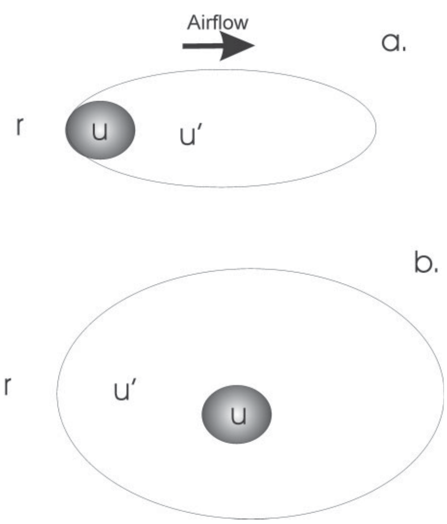

Figure 4. Estimating the urban effect, based on Lowry (1977). See text for details.

Many of the temporal characteristics of the urban effect on air temperature observed by Howard have since been confirmed (Oke, 1982).

Although Howard never took simultaneous measurements at different sites in London and its environs, he correctly deduced that it was an urban phenomenon and that, most likely, its effect lessened in the suburbs. When detailed spatial information became available a century later and was mapped, the urban temperature effect was revealed as a 'pool' of warmer air that occupies the built-up area. Generally, it has been found that the magnitude of this urban heat 'island' increases towards the core of the settlement, where building density is greatest. Where 'natural' features (e.g. parks and rivers) remain they appear as pockets of cooler air within this general pattern. These features can be seen in Figure 5.

Defined in modern terms, Howard is describing (as Figure 5 does also) the urban 'canopy layer' effect on air temperature. The canopy layer may be defined as the air that lies below roof level. The outdoor canopy layer acquires its properties through interaction with the adjacent surfaces (building walls and street surface) and through exchanges of air with indoor (across building openings and gaps) and outdoor (between streets and with the overlying atmosphere) spaces.

Howard's examination of the urban effect consists of a description of its character from which he deduces potential causes. His analysis attempts to account for the elevation of London's temperature to varying degrees throughout the year and his explanation invokes causes, some of which are intuitively 'obvious' and others of which are relatively sophisticated:

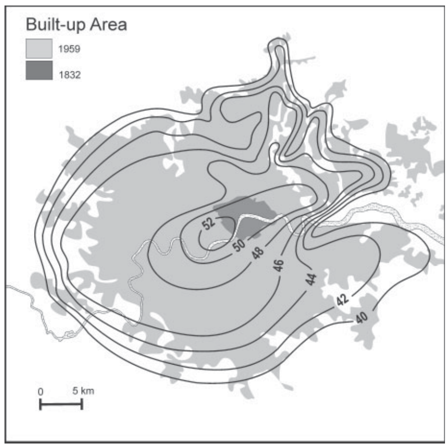

Figure 5. The distribution of the minimum air temperatures (°F) for 14 May 1959. Redrawn from Figure 55 in Chandler (1965). The darkened area shows the extent of London during Howard's time.

That the superior temperature of the bodies of men and animals is capable of elevating, in a small proportion, the Mean heat of a city or populous tract of country in a temperate latitude, is a proposition which will scarcely be disputed. Whoever has passed his hand over the surface of a glass hive, whether in summer or winter, will have perceived, perhaps with surprise, how much the little bodies of the collected multitude of Bees are capable of heating the place that contains them: hence, in warm weather, we see them ventilating the hive with their wings, and occasionally preferring, while unemployed, to lodge, like our citizens, about the entrance.

But the proportion of warmth which is induced in a city by the Population, must be far less considerable than that which emanates from the fires: the greater part of which are kept up for the very purpose of preventing the sensation attending the escape of heat from our bodies. A temperature equal to that of Spring is hence maintained, in the depth of Winter, in the **included** *part of the atmosphere, which, as it escapes from the houses, is continually renewed: another and more considerable portion of heated air is continually poured into the common mass from the chimnies; to which, lastly, we have to add the heat diffused in all directions, from founderies, breweries, steam engines, and other manufacturing and culinary fires. The real matter of surprise, when we contemplate so many sources of heat in a city is, that the effect on the Thermometer is not more considerable.*

To return to the proportions held by the excess of London, it is greater in winter than in summer, and it sinks gradually to its lowest amount as the temperature advances in the spring, all which is consistent with the supposition, that in winter it is principally due to the heat diffused by the fires.

It appears that London does not wholly lose its superiority of temperature, by the extinction of most of the fires in Spring: on the contrary, it is resumed in a large proportion in the Sixth month, and continues through the warm season. It is probable, therefore, that the Sun in summer actually warms the air of the city more than it does that of the country around. Several causes may be supposed to contribute to this: the country presents for the most part a plain surface, which radiates freely to the sky, – the city, in great part, a collection of vertical surfaces, which reflect on each other the heat they respectively acquire: the country is freely swept by the light winds of summer, – the city, from its construction, greatly impedes their passage, except at a certain height above the buildings: the country has an almost inexhaustible store of moisture to supply its evaporation – that of the city is very speedily exhausted, even after heavy rain. When we consider that radiation to the sky, the contact of fresh breezes, and evaporation, are the three principal impediments to the daily accumulation of heat at the surface, we shall perceive that a city like London ought to be more heated by the summer sun than the country around it. (p.9–10).

Discussion

This analysis is relatively complex. In summary, he identifies four causes for the observed differences in air temperature:

1. Anthropogenic sources of heat resulting in atmospheric warming, particularly in winter.
2. The geometry of urban surfaces which 'traps' radiation and obstructs 'free radiation to the sky'.
3. The effect of urban 'roughness' in impeding the passage of 'the light winds of summer'.
4. The availability of moisture for evaporation in the country.

While the first cause is invoked to explain the excess warmth of London in the winter, the latter three are used to explain the fact that 'London does not wholly lose its superiority of temperature, by the extinction of the fires in Spring.'

The causes of the warming effect are explored in greater detail when Howard considers the rates at which the urban area warms and cools relative to the surrounding country:

But this effect is not produced suddenly. For while, in the forenoon, a proportion of the walls are exposed to the sun, the remainder are in shade, and casting a shadow on the intervening ground. These are receiving, however, in the wider streets, the reflected rays from the walls opposed to them; which they return to the former, when visited in their turn by the sun. Hence in the narrow streets, especially those that run East and West, it is generally cooler than in the larger ones, and in the squares. Hence too, in the morning of a hot day, it is sensibly cooler in London than in the country; and in the evening sensibly warmer. For the hottest time in a city, relatively to the hour of the day, must be that, when the second set of vertical surfaces having become heated by the Western sun, the passenger is placed between two skreens, the one reflecting the heat it is receiving, the other radiating that which it has received. Many of my readers must recollect having felt the heat of a Western wall, in passing under it long after sunset. (p.10)

Howard's analysis is readily translated into modern research on the urban effect, which is framed in terms of its energetic basis. Specifically, the energy budget of the urban canopy layer can be expressed as follows,

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S,$$

where each term represents a flow of energy: Q^* is net radiation, Q_F is heat added by anthropogenic activities, Q_H and Q_E are sensible and latent heat exchanges, respectively and ΔQ_S represents energy added to, or taken from, the urban fabric. The net radiation term can be decomposed into shortwave (K) and longwave (L) radiation

$$Q^* = K{\downarrow} - K{\uparrow} + L{\downarrow} - L{\uparrow} = (K^* + L^*),$$

where the arrows represent the directions of the fluxes, to and from the surface and the asterisks represent net fluxes. In Table 2, the suggested causes of the canopy layer urban heat island (UHI) are presented in terms of their effect on these energy budget terms.

Research has shown that the UHI is strongest at night under calm and clear skies. Under these conditions, those terms requiring turbulence (Q_H and Q_E) are at a minimum and there is no solar radiation available. Moreover, with few exceptions, Q_F is generally small in magnitude. In these circumstances, the energy budget is greatly simplified,

$$L^* = \Delta Q_S.$$

This implies that, when the urban temperature effect is greatest, it is primarily a product of cooling driven by loss of longwave radiation to the sky which is offset by the withdrawal of heat from storage. In urban areas, the canopy surfaces (building walls and street surfaces) have a limited 'view' of the sky and consequently longwave cooling (L^*) at night is reduced. In addition, the materials of which the urban fabric is composed are impervious and dense. Such materials are characterized by high thermal conductivity and heat capacities, that allows daytime energy gain to be stored for withdrawal during the night. By comparison, rural surfaces (like pastures) have an almost unimpeded view of the sky and the thermal properties of the underlying soil vary greatly with moisture content. Under these ideal UHI conditions, the magnitude of $\Delta T_{u\text{-}r}$ will depend on the respective sky geometries and thermal properties at both urban and rural sites that will govern the comparative rates of night-time surface cooling.

Conclusion

It is a pity that Howard had no means of recording wind velocity except by direct observation. With detailed wind information he would certainly have examined the correspondence between $\Delta T_{u\text{-}r}$ and wind-speed, to which he alludes. In addition, he had no comparative data to examine rates of evaporation or differences in humidity. His examination of the urban effect was therefore largely limited to temperature (he had little trust in the available urban rainfall

Table 2

Suggested causes of modern canopy layer Urban Heat Island (Oke, 1982).

Energy budget term	Urban feature	Meteorological effect
Increased absorption of solar radiation (K^*).	Canyon geometry	Increased surface area and multiple reflection
Increased long-wave radiation received from the sky ($L\downarrow$).	Air pollution	Greater absorption and re-emission
Decreased long-wave radiation loss from surfaces of buildings and streets ($L\uparrow$).	Canyon geometry	Reduced sky view factor
Heat added by human activities (Q_F).	Buildings & traffic	Direct addition of heat
Increased storage of heat in city fabric (ΔQ_S).	Construction materials	Increased thermal admittance
Decreased latent heat exchange (Q_E).	Construction materials	Increased water-proofing
Decreased sensible and latent heat exchange ($Q_H + Q_E$).	Canyon geometry	Reduced wind speed

data). Howard did not attempt to formalize his analysis by examining the relative magnitudes of the causes he hypothesized (such as the anthropogenic contribution). Moreover, he did not consider the impact of urban construction materials on the thermal properties of the city's surfaces. Despite this, Howard identified virtually all of the factors that are responsible for the UHI – that he did so in 1820, at the very beginning of the scientific study of weather and climate is remarkable. By any measure, 'Luke Howard's account is monumental' (Chandler, 1965, p.147)

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Delicate pileus cloud capping a rapidly rising tower of cumulus congestus, photographed from a height of around 12 000 m over the Malaysian coastline near Penang, about 45 minutes flying time from Singapore, on 14 May 2007 at 1637 local time. Pileus clouds (from the Latin pilleum, *or 'cap') are occasionally formed fleetingly above vigorously growing convective clouds, and result from the rapid lifting of a layer of moist air. The smooth texture of the pileus contrasts with the lumpy, cauliflower-like surface of the cumulus tower. (© Stephen Burt.)*