# Meteorological phenomena in Western classical orchestral music

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## Introduction

Depictions of the weather are common throughout the arts. For example, there has been much discussion of meteorological phenomena in the work of painters such as Monet and Constable (e.g. Thornes, 1999; Baker and Thornes, 2006). Weather has also featured prominently in ballet: William Forsythe reportedly spent a lot of time outdoors, observing cloud formations and light changes, as inspiration for his work *Three Atmospheric Studies* (Siegmund, 2005). Such meteorological influences were discussed at a four-day conference on *The seasons in poetry, music and art*, held in Vienna in the early 1980s (Wiesmann, 1985).

Despite these clear influences in other areas of the arts, there has been very little study of meteorological inspiration in Western classical music. As music lovers know, the hint of a distant storm from a few timpani rolls can be as evocative as the crepuscular waves portrayed by Constable. The ability of music both directly to mimic the sounds of the weather and indirectly to imply its subtler moods perhaps gives this medium more scope for dramatic expression than the visual arts and literature, which unavoidably are limited to more literal interpretations.

This article is a study of the representation of meteorological phenomena in classical orchestral music, from the Baroque to the contemporary, which has been compiled over many years from a wide variety of sources (principally orchestral performances, literature, recordings, and discussions with professional and amateur musicians). We interpret 'meteorological phenomena' widely, and include optical atmospheric effects, since these are reported by meteorological observers when seen. Sunrise and sunset are defined as daily astronomical phenomena, and pieces depicting them are included only if other types of weather are represented in the same piece of music.

Vocal music has been excluded for a number of reasons. First, this restriction reduces the number of works discussed: inclusion of more musical genres would produce a much longer list. Second, words in a piece of music also lead to a fundamental change in character, since the music then becomes more specifically associated with the words than is possible with a purely instrumental piece. Orchestral sections of vocal pieces, such as operas, and pieces that include voices but not words, have been included. Finally, the use in orchestral music of a core group of instruments, which has changed relatively little since the Baroque era, enables common themes to be identified in the use of orchestration (i.e. different instruments or combinations of instruments) to represent varying weather conditions.

## Explicit and implicit references to weather in music

The form of allusion to meteorological phenomena can vary. Explicit references can be defined as occurring in pieces following a well-defined 'programme' representing particular scenes or events, specified by the composer. Indeed, programme music has itself been described as having been inspired by nature (Jones, 1990). A notable example is the *Alpine Symphony* by Richard Strauss, which describes a day when hikers climb a mountain, from the beginning of their journey at daybreak, ascending via various landscapes and natural phenomena to encounter a sudden thunderstorm at the summit, and finishing with their descent shortly before night falls. The different sections of the (continuous) piece of music, each lasting a couple of minutes, are closely specified within the orchestral score and form the titles of the different tracks of the recordings. Meteorological phenomena are well represented in the *Alpine Symphony*, both in the individual sections and in the chosen instrumentation: special instruments are added to the percussion section to add greater atmosphere (pun intended!) to the storm scenes. The instruments used to represent different meteorological events will be discussed in more detail later in this article.

Another form of music which can explicitly refer to weather is the 'tone poem'. This is similar to programmatic music, but the image intended is often referred to in the title of the piece without defining a sequence of events as clearly as programme music. An example of a tone poem is *Out of the Mist* by Elkington, a twentieth-century British (female) composer. Operatic interludes that have become successful as standalone orchestral pieces often include explicit references to weather because of the association of one tune or theme with a particular part of the plot. Storms seem especially popular, which could be related to their use as a dramatic device to mark a transition or to evoke some inner turbulence of a major character. Examples of musical storms can be found in Benjamin Britten's *Four Sea Interludes* from the opera Peter Grimes, and The Royal Hunt and Storm from Berlioz's opera *The Trojans*, which describes a sudden summer rainstorm during which lovers out hunting take shelter in a cave to the accompaniment of plucking violins and violas mimicking raindrops, whilst the storm symbolizes their emotional turmoil (Kemp, 1988).

More subtle is the implicit evocation of weather, often as part of a scene or landscape. The intended scene is sometimes referred to in the title of the music, or it can be mentioned by the composer either at the time of writing or subsequently. The impressionistic music championed by Debussy fits into this category, as do some of the tone poems by the Finnish composer Sibelius. His *Night Ride and Sunrise* does not appear specifically to recognize meteorological or optical phenomena in its title or musical score, but Sibelius subsequently described being inspired by seeing the aurora from a sleigh ride in northern Finland (Grimley, 2004). An example of the title summing up all that is needed is the exuberant Troika from the *Lieutenant Kije Suite* by Prokofiev. The Troika is a type of Russian sled, and this title is just enough to conjure up images of a sleigh ride through thick snow in crisp winter woods. Part of the appeal of this implicit



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form of reference is that it is up to the listener to generate a mental picture based on the music. Sometimes composers use implicit references to depict climate, rather than weather. For example, several composers were inspired by the seasons and wrote eponymous pieces evoking this theme rather than any specific meteorological phenomena. For example, the subtitle of Tchaikovsky's First Symphony is *Winter Daydreams*. However, 'season' or 'climate' music can also include explicit meteorological references, as in the most well-known set of concertos by Vivaldi.

Another form of implicit reference is that sometimes the meteorological links are made only after critiques or reviews are published. One well-known example, away from weather, is the Moonlight Sonata by Beethoven, which was known simply as Opus 27 no. 2 until the moonlight analogy was introduced some time later (Sobel, 2005). Another oblique reference is contained in Sibelius' tone poem *Tapiola*. This piece was intended by the composer to be a portrait of the mythical spirit of the Finnish forest, but it has been described more recently as including a storm (Anderson, 2004; Grimley, 2004) and as a representation of the weather changing with the seasons (Murtomäki, 1996).

All the classical orchestral pieces that we have identified as referring to weather in some way are listed in Table 1. In the next section the meteorological representations will be analyzed.

## Types of weather represented in music

Figure 1(a) summarizes the frequencies with which the different types of weather are depicted in our sample of classical orchestral music. We include the aurorae, which are noted when seen at meteorological observatories (Shanklin *et al.*, 2009). We also include 'fair weather', for which a definition can be borrowed from atmospheric electricity terminology (Reiter, 1992), referring to a relatively clear sky with no hydrometeors. More than one type of weather can be counted for each piece and Table 1 shows which categories have been specified by the composer, are clearly identifiable from the musical score, or have been widely discussed in subsequent studies. Note that the categories are not all independent: for example storms involve rain, and therefore this sort of analysis is principally descriptive.

Clearly the most popular type of weather to be represented in music is the storm, presumably because of the use of storms by composers as an allegory for emotional turbulence. In Figure 1(a) a distinction is made between the frontal storm, characterized by strong winds and heavy rain, and the convective storm, involving thunder and lightning. Sub-selection of storm types is possible because of the relatively large sample size and the detail with which the musical storms were specified. Six out of the eight frontal storms represented are defined as storms at sea, with two linked to Shakespeare's play *The Tempest* which begins in this way. The two other storms can be identified as frontal storms based on the climates represented. Bax associated a poem describing an autumnal storm in the Chilterns with his *November Woods* (Foreman, 2006) and Sibelius' *Tapiola* is set in the high-latitude forests of northern Finland, where thunderstorms are rare (<0.5 lightning flashes $km^{-2}yr^{-1}$ (Mach *et al.*, 2007)). All of the convective storms can be identified as occurring over land, except for the *Thunder and Lightning Polka* which is the only non-programmatic thunderstorm and possibly the only light-hearted representation of a storm. Only one storm, in Rossini's *William Tell Overture,* was of unclear type. We believe it is more likely to be convective, as the storm in the Swiss William Tell legend (on which the opera is based) occurs over Lake Lucerne, well within the central European land mass (Porter and Prince, 2008). The *William Tell* storm has therefore been counted as convective in Figure 1(a).

Wind is the second most popular weather phenomenon pictured in music. It is presumably well-represented because it can have a variety of characters, from a gentle breeze rustling the trees, as in the beginning of the third movement of Berlioz's *Symphonie Fantastique* (Berlioz, 1830), to a full-blown (again pun intended!) Antarctic gale, as in Vaughan Williams' *Sinfonia Antarctica*. The *Alpine Symphony* features a 'calm before the storm' section, which has been classified here in the wind category, although strictly it is the absence of wind.

Sunshine is relatively unpopular with composers, but some of the clearest musical representations of it are inspired by the Mediterranean landscape. The best example is the *Helios Overture* by Nielsen, a musical picture of a (sunny) day over an Aegean island (although Nielsen later explained that the day also included rain, readily identified in the recording from the plucked string instruments (Fanning, 1996)). Similarly, the *Dyptique méditerranéen* by French composer Vincent d'Indy reflects the 'Indian summer' of his final years by the Mediterranean (Thomson, 2010). The sonnets that Vivaldi chose to illustrate his *Four Seasons* also conjure up the torpor of an Italian summer's day: *In the torrid heat of the blazing sun, man and beast alike languish, even the pine trees scorch* (Anderson, 2009).

Interestingly, but perhaps unsurprisingly, almost all the pieces in Table 1 depicting frontal storms are in minor keys and all the pieces depicting fair weather are in major keys. The corresponding key analysis for the other weather categories in Table 1 is generally inconclusive, with a mixture of major and minor keys being used. (Here, in the case of multi-movement pieces, we take the main key of the relevant movement rather than the overall key of the piece.) It might even be wondered whether many (or even all) depictions of frontal storms are in the *same* minor key, because it has been suggested that each major and minor key has a particular unique meaning (Steblin, 2005). For example, C major is supposed to represent simplicity, C minor is longing, D major is triumph, E flat major is love and F minor is depression. However, this is found not to be the case here, with G minor, E minor,

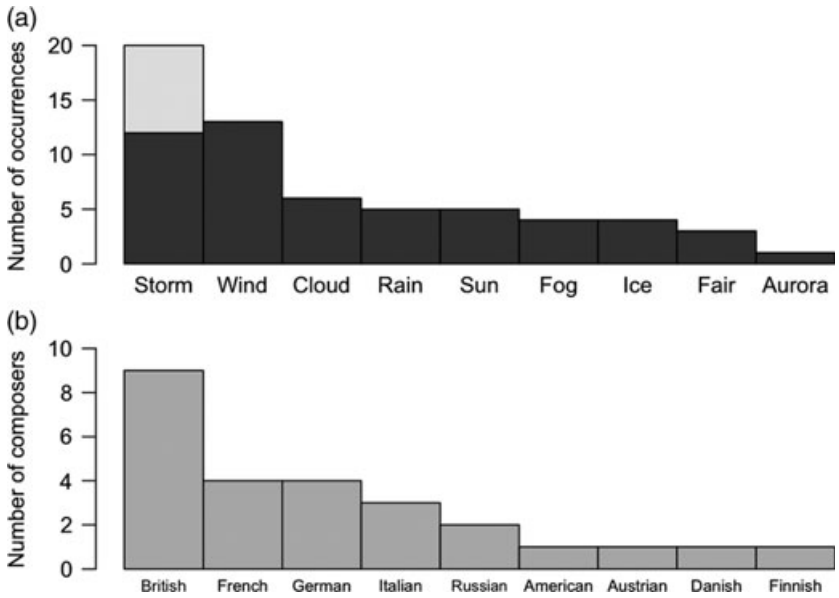


*Figure 1. (a) Types of weather represented in each named piece or section of a piece. 'Storm' is separated into two types: frontal in light grey and convective (thunderstorm) in dark grey. (b) Nationality of composers representing weather in their music.*

**Table 1**

*Orchestral pieces identified as containing references to the weather, in the format name of piece/subsection.*

| *Composer (nationality)* | *Title* | *Year of publication* | *Storm (frontal)* | *Thunder-storm* | *Rain* | *Fog/mist* | *Cloud* | *Sun* | *Wind* | *Snow /ice* | *Aurora* | *Fair weather* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bax (UK) | November Woods | 1917 | x | — | — | — | — | — | — | — | — | — |
| Beethoven (German) | Symphony no. 6 | 1808 | — | x | — | — | — | — | — | — | — | — |
| Berlioz (French) | Symphonie Fantastique | 1830 | — | x | — | — | — | — | x | — | — | — |
| | The Trojans/Royal Hunt and Storm | 1863 | — | x | x | — | | — | — | — | — | — |
| Brian (UK) | Symphony no. 1 | 1927 | — | — | — | — | — | x | — | — | — | — |
| | Symphony no. 10 | 1954 | — | x | — | — | — | — | x | — | — | — |
| Bridge (UK) | The Sea/Seascape | 1911 | — | — | — | — | — | — | x | — | — | x |
| | The Sea/Moonlight | | — | — | — | — | x | — | — | — | — | x |
| | The Sea/Storm | | x | — | — | — | — | — | — | — | — | — |
| Britten (UK) | Four Sea Interludes/ Storm | 1945 | x | — | — | — | — | — | — | — | — | — |
| Debussy (French) | Nocturnes/Nuages | 1899 | — | — | — | — | x | — | — | — | — | — |
| | La Mer/Dialogues of wind and sea | 1905 | — | — | — | — | — | — | x | — | — | — |
| D'Indy (French) | Diptyque méditerranéen | 1926 | — | — | — | — | — | x | — | — | — | x |
| | Jour d'été à la montagne | 1906 | — | x | — | — | x | x | — | — | — | — |
| Elkington (UK) | Out of the Mist | 1921 | — | — | — | x | — | — | — | — | — | — |
| Grofe (USA) | Grand Canyon Suite/ Cloudburst | 1931 | — | x | x | — | — | — | x | — | — | — |
| Henze (German) | Symphony no. 6 | 1969 | — | x | — | — | — | — | — | — | — | — |
| Maxwell Davies (UK) | Antarctic Symphony | 2000 | — | — | — | — | — | — | — | x | — | — |
| Mendelssohn (German) | Fingal's Cave | 1830 | x | — | — | — | — | — | — | — | — | — |
| Nielsen (Danish) | Aladdin's Dream and Dance of the Morning Mist | 1919 | — | — | — | x | — | — | — | — | — | — |
| | Helios Overture | 1903 | — | — | x | — | — | x | — | — | — | — |
| Prokofiev (Russian) | Lieutenant Kije Suite/ Troika | 1934 | — | — | — | — | — | — | — | x | — | — |
| Ravel (French) | Daphnis and Chloe | 1912 | — | — | — | — | — | — | x | — | — | — |
| | La Valse | 1919 | — | — | — | — | x | — | — | — | — | — |
| Rossini (Italian) | William Tell Overture | 1829 | x? | x? | — | — | — | — | — | — | — | — |
| Sibelius (Finnish) | Tapiola | 1926 | x | — | — | — | — | — | — | — | — | — |
| | Night Ride and Sunrise | 1908 | — | — | — | — | — | — | — | — | x | — |
| | Incidental music to the Tempest | 1926 | x | — | — | — | — | — | — | — | — | — |
| Strauss J. (Austrian) | Thunder and Lightning Polka | 1868 | — | x | — | — | — | — | — | — | — | — |
| Strauss R. (German) | Alpine Symphony/ Rising mists | 1915 | — | — | — | x | — | — | — | — | — | — |
| | Alpine Symphony/The sun gradually dims | | — | — | — | — | x | — | — | — | — | — |
| | Alpine Symphony/Calm before the storm | | — | — | — | — | — | — | x | — | — | — |
| | Alpine Symphony/ Thunderstorm, descent | | — | x | — | — | — | — | x | — | — | — |
| | Don Quixote/Ride through the air | 1898 | — | — | — | — | — | — | x | — | — | — |
| Tchaikovsky (Russian) | The Tempest | 1873 | x | — | — | — | — | — | — | — | — | — |
| | Symphony no. 1 | 1866 | — | — | — | x | — | — | — | — | — | — |

*(Continued)*

**Table 1** ***(Continued)***

| *Composer (nationality)* | *Title* | *Year of publication* | *Storm (frontal)* | *Thunder-storm* | *Rain* | *Fog/mist* | *Cloud* | *Sun* | *Wind* | *Snow /ice* | *Aurora* | *Fair weather* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tippett (UK) | Symphony no. 4 | 1977 | — | — | — | — | — | — | x | — | — | — |
| Vaughan Williams (UK) | Sinfonia Antarctica | 1953 | — | — | — | — | — | — | x | x | — | — |
| Vivaldi (Italian) | The Four Seasons/ Spring | 1723 | — | x | — | — | x | — | — | — | — | x |
| | The Four Seasons/ Summer | | — | x | x | — | — | x | x | — | — | — |
| | The Four Seasons/ Winter | | — | — | x | — | — | — | x | x | — | — |
| | The storm at sea | 1725 | x | — | — | — | — | — | — | — | — | — |

?: it is uncertain whether the storm represented was frontal or convective.

E flat minor, B minor and F minor all being used to depict frontal storms.

We note that the earlier composers, from the Baroque and Classical periods (Vivaldi excluded) did not seem to represent weather very much, and therefore these composers are largely missing from Table 1. We have no rigorous explanation for this observation, but it is not difficult to speculate that it could be caused simply by the relative rarity of written records from that time. Baroque and Classical period composers may simply have been inspired more by the impressive contemporaneous human achievements (e.g. architecture) than by nature. Alternatively, because early composers lived in a period that is now known as the Little Ice Age, because it was relatively cold, the weather might not have been particularly changeable or inspiring. Early music might still have been influenced by the climate in subtler ways, though. For example, it has been hypothesized that the superior tonal qualities of Antonio Stradivari's violins were caused by reduced tree-growth rates associated with the relatively cold climate (Burckle and Grissino-Mayer, 2003). Later, the growth of the Romanticism movement meant nature became more common as an artistic inspiration; this is discussed later in this article.

## Composers and their environments

Figure 1(b) shows a breakdown of the nationality of composers choosing to depict meteorological events. This appears to support the stereotypical assumption that people from the UK are more enthusiastic about the weather than their colleagues overseas, although this effect could be due to sampling bias, given that the authors of this paper are both from the UK. Composers could be expected to portray the landscape and weather with which they are most familiar: for example, three of the seven composers depicting frontal storms are from the UK, whereas no well-known composer from these islands has dealt with a thunderstorm to our knowledge. The only representation of the aurora in this selection of music comes from Finland, the north of which is well within the auroral zone. Composers from the central European land-mass are responsible for all the musical thunderstorms identified. Composers occasionally choose to depict weather substantially removed from their usual environment: Vaughan Williams' *Sinfonia Antarctica* was written at a time when the British were captivated by polar expeditions, and later inspired a similar piece by Peter Maxwell Davies. The contrast between Copenhagen and the sunny Aegean was clearly a creative inspiration to Nielsen. Other than Russians, eastern European composers do not feature in Figure 1(b), but some would if we included non-orchestral music (e.g. Chopin, for his *Winter Wind* Étude and *Raindrop* Prelude).

The most prolific representations of weather in music are by Richard Strauss, who chose to depict meteorological phenomena five times across two major tone poems (Table 1). Strauss was known to be a nature lover and his compositional output was apparently heavily influenced by the weather. He needed both sunshine and the Alpine landscape to inspire him (Schweisheimer, 1961), but did not seem to depict sunshine in any of his work.

Several other composers (Berlioz, Schubert, Wagner, Puccini and Stravinsky to name a few) were also dependent on fair weather for their best output. Wagner, for example, referred to *bad-weather unemployment* and wrote: *This is awful weather. My work has been put aside for two days, and the brain is stubbornly declining its services* (Schweisheimer, 1961). Also, Chopin famously visited Majorca, in 1838, for the purpose of finding some winter warmth.

Many composers claimed that they needed it to be sunny and summery to produce their best work, and complained that winds such as the Foehn and Scirocco had a detrimental effect, although Tchaikovsky was unusual in preferring autumnal weather. As Schweisheimer says, *Musicians who suffer from the occasional depression, vague pain and nervous tension often associate their condition with a nervous exhaustion or with being over-worked. A look at the barometer would probably bring them closer to the truth*. There is no clear link between the preferred weather conditions of any composers and the atmospheric phenomena they represented musically.

## Instrumentation used to represent weather

The use of mimicry is common in music to imitate directly many of the sounds of the natural world, so it is unsurprising that several of the pieces indicated in Table 1 attempt to copy the sounds of the weather. This section describes the evolution of meteorological mimicry from the Baroque period, through to specialized instruments specifically designed to copy the sounds of wind and thunder.

### *Weather in the music of Vivaldi*

Direct imitation was more difficult before the larger symphony orchestra developed during the eighteenth and nineteenth centuries, so earlier pieces had in some ways to use cleverer techniques. This might explain why there is only one composer identified who clearly represented weather in the Baroque-period orchestra, namely Antonio Vivaldi. His concertos arguably contained much more colour and dynamic range than those of his mid-Baroque predecessors, so were perhaps better-placed to depict a wider range of weather types than had hitherto been possible. His four violin concertos, *The Four Seasons*, are a classic example of programme music. Each concerto was published with a corresponding sonnet, three of which clearly mention weather. For example, in *Summer* the rapidity of the notes increases during the first movement to depict an impending transition from a gentle breeze under *the blazing sun* to the *harsh, menacing gusts* of the *fierce north wind* (Anderson, 2009). After a lull during the second movement, the storm finally arrives in the final movement and *furious*

*thunder irradiates the heavens*. Similarly, in *The Storm at Sea* (sometimes translated as *The Raging of the Sea*), the tension and unease associated with the storm are depicted using various musical devices, such as repetition, key changes and interruption of the melody.

## Convective and frontal storms

Beethoven was probably the first composer to imitate directly the sounds of the weather in an orchestra, in the *Pastoral Symphony*. Low string instruments playing the same repeated rapid notes (a technique known as tremolando) are used from the very first bar of the fourth movement to suggest the rumbling of thunder, and the tune played by the upper string instruments creates a sense of tension. The thunderstorm gets closer and the cellos and double basses get louder until, when the storm is close by, they break into rapid scales, perhaps to suggest driving rain, whilst the higher string instruments join the tremolando. The other instruments, including the timpani (large, low-pitched drums), then join in to add to the effect.

Beethoven's storm was clearly an important influence for subsequent composers, with many other musical thunderstorms following a similar pattern, so much so that Hopkins (1982) wrote:

> *Confronted with the task of writing storm music, any composer is forced to accept that musical clichés are almost unavoidable. There is no better way of imitating thunder than to use drums; a howling wind does make a chromatic wail; torrential rain does not fall in slow motion.*

Richard Strauss in some ways follows the 'musical clichés' in the Alpine Symphony, yet still manages to make the storm sound fresh and original. The rumble of thunder is heard as the storm approaches, culminating in an effective representation of the storm overhead, a bass drum thunderclap at the same time as a shrieking piccolo (a small, more high-pitched flute), conjuring up images of a lightning strike that is a little too close for comfort.

The frontal type of storm is less frequently represented in music and, as it does not usually feature thunder and lightning, direct mimicry is used less often in favour of more original instrumentation. Hopkins (1982) praises Britten's storm scene in *Four Sea Interludes from Peter Grimes* for not including the predictable tremolando strings and rumbling timpani. Novel effects are used to represent the wind and rain: for example the side-drum could indicate something that has broken loose and is banging against a window-frame (Hopkins, 1982). Towards the end of the piece, a brief improvement in the weather can be clearly heard before the storm returns with a vengeance.

## Wind and thunder machines

As orchestral capabilities grew throughout the nineteenth century, special bespoke instruments were devised specifically to mimic the weather. Two examples from the percussion family are shown in Figure 2. The wind machine is a silk-covered drum that is rotated by revolving a handle against a bar to produce a whooshing or howling sound. It is used by Vaughan Williams in his *Sinfonia Antarctica* and a calmer example can be found in *Flight through the Air* from the tone poem *Don Quixote* by Richard Strauss. The thunder sheet is a suspended sheet of metal, up to around five metres long (Blades, 1970), that can be hit with a drum stick to produce an appropriate rumble. The thunder machine (not shown) is a large rotating drum with balls inside, called for in the musical score for Strauss's *Alpine Symphony*.

Some organs have a storm-effects stop (*pédale d'effets d'orage*) which sounds two low-frequency pipes that, when combined, mimic a storm. Both the *Alpine Symphony* and *Sinfonia Antarctica* are scored for organ, although we are not aware of any orchestral pieces specifically requesting the organ 'thunder stop', as orchestral composers rarely specified organ stops this carefully. Interestingly, though, there was a fashion in early nineteenth-century France to compose programmatic organ works, *depicting the human condition before and after the final judgement of the Last Trump: thunder effects, diminished chords and fanfares [were] used liberally* (Brooks, 1999). During this period, thunder effects were sometimes improvised by placing a plank across the lowest octave of pedals. Research 150 years later justified this approach by measuring the broad acoustic spectrum of thunder (Few *et al.*, 1967).

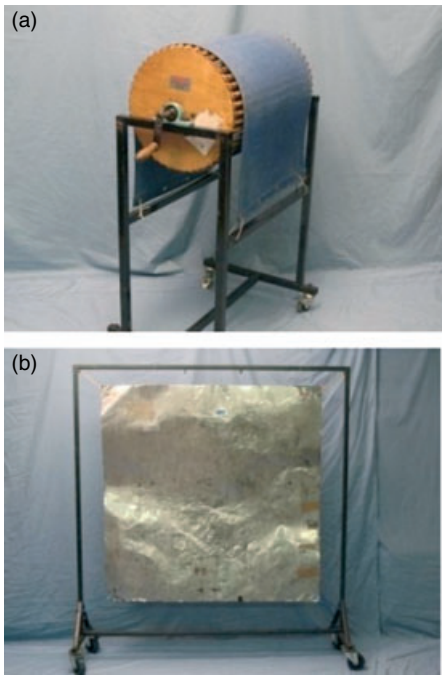


*Figure 2. Percussion instruments specifically designed to represent weather: (a) wind machine, (b) small thunder sheet. (Photographs by Mike Perry of Bell Percussion Ltd.)*

Instruments with no musical purpose other than meteorological mimicry can form even more explicit references than the most carefully specified programme music discussed earlier. According to Scholes (1992), these sorts of instruments are used only *in passages of a meteorological intention*. One example is in Ravel's ballet suite from *Daphnis and Chloe,* which uses a wind machine evocatively. However, the unambiguous soundscape provided by these instruments can also remove the need for composers to explain themselves. Contrary to Scholes' interpretation, this can lead to more abstract representations of atmospheric effects in twentieth century music. For example, the 1969 *6th Symphony* by Hans Werner Henze uses two thunder sheets, one large and one small, as one of many novel sound effects in a complex and challenging piece, which does not seem to have been meteorologically inspired (Henderson, 1972).

## Conclusions

The influence of the natural world on composers and other artists is well known and has been discussed elsewhere in its broad context, for instance within Romanticism, which arose in music, art and literature in the eighteenth and nineteenth centuries (e.g. Runciman, 1918). The influence of the Impressionist movement in art on composers such as Debussy has also been discussed. One important difference between Impressionist art and music is that, unlike Monet's paintings, which are known to be accurate representations of the atmosphere, (Baker and Thornes, 2006), it may be impossible to show that the atmosphere is depicted 'accurately' in sound, despite Debussy's *keen artist's eye* in his descriptions of *the slow, solemn motion of the clouds* (Blakeman, 2003).

We believe that specific meteorological influences in classical orchestral music have not hitherto been identified and catalogued. In this article we have presented a list of orchestral pieces featuring atmospheric phenomena and have provided a basic classification of the conditions pictured. Composers are generally influenced by their own environment in the type of weather they choose to represent, with British composers perhaps having a disproportionate interest in picturing

the UK's variable weather patterns and stormy coastline (though sampling bias cannot be ruled out). The few exceptions to this rule usually represent a completely different type of weather to the composer's 'home' environment. One way to test this hypothesis would be to see if weather depicted in music changes when composers move to a different climate. Unfortunately the most well-known and prolific émigré composers, such as Dvorak and Stravinsky, who moved to the USA from Czechoslovakia and Russia, respectively, did not tend to picture weather directly in their music, so there is no obvious example available.

Different types of weather references within orchestral pieces have been discussed, from explicit mimicry using traditional and non-traditional orchestral instruments through to the vaguest suggestions. The instruments used to represent atmospheric phenomena have also been mentioned, with some predictable patterns identified. Away from the obvious use of mimicry, some of the more inventive instrumentation used was through necessity, whether it be the small Baroque-style orchestra used in Vivaldi's day, or the modest pit orchestra that limited some of the choices made by Benjamin Britten in his operatic interludes for *Peter Grimes*. It is certainly clear that the world of classical orchestral music has been made more interesting and exciting by the inspiration of weather itself, in addition to the broader and more well-known influence of geographical landscape.

We close by remarking that, although we have tried to make the coverage of this article as comprehensive as possible, any study on this topic will inevitably be subjective. We have attempted to reduce sampling bias by discussing our list of musical pieces with colleagues and by adding their suggestions. Nevertheless, we must add the disclaimer that the pieces we have included might still not be fully representative. We welcome correspondence, through the *Weather* letters pages, from any readers who have their own thoughts about the representation of meteorological phenomena in music, and might even consider a subsequent article if enough new material is identified.

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# Diurnal pressure variation: the atmospheric tide

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Those of us who live near the coast are familiar with the tide, that regular ebb and flow of the sea, more strictly called the 'ocean tide'. At most locations it is a phenomenon with a semidiurnal oscillation, though the vertical displacement of the sea varies greatly from place to place. On some coasts in the Mediterranean, for instance, the difference between high and low water may be as little as 0.1 metres on a neap tide while on others, such as the Bay of St. Malo off northwest France, the difference can exceed 14 metres on a spring tide. Influences on the tide are many and complex, but are dominated by the gravitational effect of the sun and moon and their position in relation to the Earth, which incidentally allows a high degree of predictability.

In the atmosphere, elements of the weather such as temperature and humidity also display diurnal variations and, in a similar manner to the ocean tide, there exists an atmospheric tide with air pressure showing an underlying variation. The components which combine to cause this variation are also complex and not fully understood, but the solar component, referred to as radiational forcing (Pugh, 1987), is dominant. The maxima and minima occur at approximately the same local time each day and, as with the ocean tide, studies show the height of the atmospheric tide varies with location, from about 0.3 millibars in polar regions to 3.0 millibars in the tropics. It is the intention of this short paper to demonstrate, rather than explain, the components; readers seeking more information on atmospheric and ocean tides are directed to the works of Pugh (1987), Chapman and Lindzen (1970) and Haurwitz and Cowley (1973) where the subject is covered in detail.

In the upper atmosphere the diurnal heating cycle gives rise to diurnal pressure waves, but the dynamic structure of the atmosphere causes the semidiurnal harmonic to be dominant (Pugh, 1987). More specifically, as Cooper (1982) has noted, the atmospheric tide is largely due to the absorption of ultra violet (UV) radiation by ozone. The effect of diurnal pressure variation is most noticeable in the tropics where incoming solar radiation is greatest but, as dynamic forcing is weak in these regions, absolute surface pressure changes are small: an observation at a tropical station taken at the same time each day has an average difference of ~0.7 millibars from one day to the next, though the barograph trace will show a semidiurnal, approximately sinusoidal, trace with a range of 3 millibars or so over the course of 24 hours.

By way of contrast, mid-latitude surface pressure changes are dominated by dynamic forcing associated with the polar front jet, which causes much greater shorter-term changes. In the Channel Islands, for instance, an observation taken at the same time each day has an average difference of nearly 6 millibars from one day to the next, whilst 10 millibars or more is quite common and a difference of more than 20 millibars is far from rare. As a result, a barograph trace in mid-latitudes is often irregular and usually masks any underlying diurnal cycle. By comparing a mid-latitude station with two stations in the tropics, the similarities and differences can be shown.

While recovering and digitizing old surface pressure data for Jersey Airport, a complete set of three-hourly surface pressure readings was compiled (Le Blancq, 2010). The database starts in 1961 when sea-level pressure was calculated using a mercury Kew pattern barometer, but the period used here covers 40 years from 1971 to 2010 when precision aneroid barometers (PAB) were in use. In accordance with aviation requirements, the PABs were cross-checked daily and calibrated regularly, so we have confidence in the accuracy of the readings.

By averaging observations over a long period, the irregular short-term, (i.e. non-periodic) variations are removed, allowing underlying longer-term variations to emerge. The three-hourly surface pressure observations from three stations were used in the following analysis:

1. Panjim (Goa) 15°N 74°E: a tropical station on the west coast of India, with data from synoptic reports for 12 months in 2007/2008 and no missing data.
2. Malé (Maldive Islands) 4°N 74°E: a station close to the equator, with data from synoptic reports for 2008 (80% data availability).