

# Turning to Meteorology for Teaching and Learning Resources — Part 1

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## ***Introduction***

Who am I? I prepare information for all walks of life. My work is always a good talking point. My results can be “short of the mark”. Nevertheless, I willingly have my results published for all to see, daily. I am a weather forecaster. As a member of a service industry, a weather forecaster needs to have a thick skin, a well-developed sense of humour and be prepared to withstand the occasional scathing attack from stakeholders and the mass media. Weather is one of the most natural phenomena. The quote, "Everybody talks about the weather, but nobody does anything about it," attributed to Mark Twain, echoes the public attitude to this perfectly natural, yet often confounding raft of phenomena, called weather. In her book, Katherine Anderson (c2005) showed that although weather forecasting has always been a high-risk activity, the outcomes are worthwhile.

Can you imagine how meteorology can link and integrate educative ideas and resources to the secondary school curriculum? This article introduces some teaching and learning ideas and resources through meteorology. I write this article largely from the point of view of a weather forecaster. Because weather is not straightforward, yet is topical on a daily as well as monthly and annual basis, it can be put to good effect as a stimulus context for student interest in and across several areas of the curriculum. The following material provides an outline of several meteorology related contexts that could be used for this purpose from Level 6 of the *Mathematics, Science, and Humanities — Geography* domains for Victorian Essential Learning Standards or VELS (HREF1) through to various related VCE studies (HREF2).

A quick inspection of the Level 6 VELS indicates there are several collective ideas, which can link meteorology to the curriculum. To this end, I have collected links between the curriculum and meteorology into some rough bundles, some linked through commonality and others through meteorology's unique ability to highlight a certain aspect of the curriculum. The collective keywords in the context of this article are:

***Collaboration*** (*working together, teams*);

***Communication*** (*getting the message across effectively*);

***Conceptual Models*** (*physical processes simplified by isolating the model from the fluid*);

***Critical Thinking*** (*thinking logically, in a balanced manner and making distinctions*);

***Dynamics*** (*motion described by Newton's Laws*);

***Fluids*** (*matter which has special properties and can flow but cannot be treated as a solitary solid*);

***Geography*** (*study of the earth*);

***History*** (*study of the past particularly people of the past*);

*Ideas* (springboards for stimulation acting; this article contains meteorological ideas aimed at stimulating teaching and learning activities);

*Integration of Disciplines*, (mutually supporting links between disciplines);

*Issues; Nature* (the natural world);

*Process* (methodology, scheme or procedure for achieving an outcome);

*Probability & Statistics* (the arm of mathematics dealing with chance and likelihood);

*Radiation* (the science of electromagnetic radiation);

*Scaling* (the study of how magnitude and dimension of components of physical processes relate to each other);

*Service* (the ethic of providing a service to a community);

*Thermodynamics* (study of thermal properties of matter).

One may also inquire how meteorology relates to the other physical sciences. The three fundamental input disciplines into Meteorology are chemistry, dynamics and radiation. Mathematics and computing help the three fundamental disciplines “converse” with Meteorology. Oceanography and Meteorology share their fluid behaviour (and are linked through common theories of dynamics and thermodynamics) as well as their global scale physical coupling and teleconnections, as demonstrated by the mechanism contributing to large effects such as El Niño. Meteorology links also to atmospheric physics, weather forecasting, pollution modelling, and climatology.

Meteorology also relates to many other disciplines and areas of interest, including, economics, risk management, as well as tradition disciplines such as aeronautics, agriculture, fishing, transport, recreation, medicine, geography, politics and history. It is enriching for the student to research the historical context that accompanied progress in meteorology, just as in any other discipline. Finding out about people involved with Meteorology through biographies and autobiographies brings the science alive. Meteorology infiltrates many other disciplines and thus can assist the student in integrating subject matter across the curriculum.

Meteorology has many unsolved problems. Visit the Clay Mathematics Institute Millennium Problems websites ([HREF3](#)) to see one of the big yet-to-be-solved problems associated with fluid mechanics and the boundary layer of the atmosphere. Rather than reject a problem out of hand, should we consider whether there might be other ways to look at the problem? How we can “manage” a useful solution, even if it is not exact?

Tackling, complex issues and real problems, even if only to make a start in formulation, or develop a partial solution under certain conditions, can be rewarding for the student, providing there is sufficient scope for achievement. If approached as a challenge, the student can test his or her understanding. It becomes useful when one puts a fence around a problem and realises it is not practical to solve it with the available resources at that time. Distraction from the curriculum would not be useful and this needs to be balanced against the stimulation derived from tackling difficult problems.

## **Background**

We cannot proceed without saying something more about the essential weather forecaster. Weather forecasting is an extraordinary data-management job. It seems that it takes more computing power to prepare *numerical weather prediction* guidance for tomorrow's weather forecast, than it took to place a human on the moon! Very few professionals would make as many decisions in the day's work as the weather forecaster. Much of the decision-making is experience-based. So strangely, it is often difficult for even the most able forecaster to explain exactly how he or she arrived at the detail of a forecast.

We must bear in mind that, like the oceans, the atmosphere is a fluid. As a fluid, air has rather special physical properties. For example, we are used to applying Newton's laws to solids. When it comes to a fluid, we have to look at the force per unit volume (often just abbreviated to "force" in the context of meteorology). Fluids tend not to have "holes" or "lumping effects" due to *continuity*. The equations of motion for the atmosphere are known, but turn out to be non-deterministic (non-linear) and the fact that we find ourselves with less-than-ideal starting conditions (observations); there are no exact solutions to these equations of motion. Complex interactions and feedback mechanisms make the system intractable. Students may feel uncomfortable with the fact that there can be no exact solution, a matter that could be explained better to the public as well. There is a need for aligning the public's expectations of weather forecasts with the reality.

Meteorology exposes one to the different "behaviour" of weather elements. For example, the Bureau of Meteorology's Monthly Rainfall Review used to have a prime description of rainfall: "Rainfall, unlike other meteorological elements such as temperature and pressure, is non-continuous in time and space. As a result the statistical description of rainfall occurrence is quite complex". Compare the continuous weather elements (such as temperature and pressure) to the ephemeral nature of clouds, for example. One of the outstanding problems of numerical weather prediction modelling is how to represent most closely the behaviour of clouds. We have to learn how to manage the best solution available to us at the time, under the prevailing circumstances, since extracting an exact solution for our forecast problem is impossible.

We also endeavour to reflect upon the use of our language. Weather forecasts use the term "tends to be" in preference to "is". Rather than attributing causation, the forecaster may prefer to resort to saying, "X is associated with Y". This is a little like real-life in fact, when things **are** complex. We could also attempt to make a distinction between the terms "accuracy" and "precision". The theory of measurement can assist here. The observation may have certain precision associated with it, the forecast for tomorrow's weather, less precision, the outlook for Day 7 less, and the Seasonal Climate Outlook far less precision. These differing time-scales have corresponding differing levels in the confidence placed on them by the weather forecaster. The greater the extension into the future of the prognosis, the less precise it is: so we have less confidence in the "forecast". The rounding of an observed temperature to the nearest 0.2 °C may be acceptable, the forecasting of temperature to within 2° twenty-four hours ahead may be acceptable (5° or

more is deemed a major error), but what about seven days hence? How does the Seasonal Climate Outlook of a couple of months ahead compare?

Despite the vagaries of weather forecasting, associated resources can be a useful source of data, information and stimulation. The teacher has to be aware that meteorology could become a confusing distraction and thus a negative experience for the student.

Meteorology involves non-deterministic problems, a large variety of units, and resorts to some non-intuitive solutions to problems. Furthermore, because Meteorology defers to many other disciplines, the student of Meteorology has to become well versed in a number of different nomenclatures. So, where possible, the teacher is advised to provide careful explanations, simple examples, and use technology to assist in demonstrating the atmospheric processes.

### ***The weather forecasting process – curriculum connections***

Firstly, looking over the flow of information with which the forecaster deals every operational shift, let us see what some of the forecasting processes are:

- Assimilation of observations and data;
- Analysis;
- Numerical Weather Prediction guidance comparison and assimilation;
- Applying meteorological knowledge skills and understanding;
- Application of forecast “conceptual models”;
- Distillation of information;
- Decision-making;
- Synthesis - formulation of forecast policy;
- Preparation of forecast products;
- Preparation of warnings;
- Weather watch – monitoring observations and diagnostics;
- Amendment of forecasts and warnings;
- Forecast verification; and
- Research.

Note that observations flow dynamically into this scheme.

Forecasters prepare the following groupings of *Basic Products* (which are free to the community because of the perceived “for the public’s good”): weather forecasts and weather warnings. These groups are categorised into forecasting regimes of: “Public and Marine” (aimed at the public at large and for ocean going craft and the fishing industry), “Aviation” (tailored for the Australian aviation industry to international standards) and “Severe Weather” (aimed at disaster mitigation).

Once these products have been prepared, they may be transmitted almost immediately to the client or they can be stored temporarily for scheduled transmission. Furthermore, the forecasts and warnings may be reconstituted into other ensembles of products automatically and disseminated to the public by such systems as text-to-speech telephone messages, faxes that can include graphics or, that which may be presented on the Bureau’s web-page (HREF4). Basic products can also be manipulated to suit clients who

wish to have “value-added” information: the service is tailored specifically for that client and an agreed charge is paid for the extra work involved in presenting the data to the client’s specifications.

Routine forecast products are scheduled, but may require amendment at any time. Extra products such as warnings may have to be prepared at very short notice. The forecast verification enables experiential learning to consolidate experience and skill in the forecaster’s mind and improve the forecast service. Research can improve forecasts and the service to the community, as well as the forecaster’s own ability. Despite this long list of daunting tasks, weather forecasting, a rather specialised job, is one of the most satisfying jobs. Dr John Zillman (Director of Meteorology 1978 – 2003) said in his farewell article in the *Australian Meteorological and Oceanographic Society (AMOS) Bulletin* vol 16 on page 80, “Training completed, I was off to Sydney as Information Officer and to Brisbane as Duty Forecaster (the most enjoyable and satisfying years of my professional career!) ...”

The skill of estimation, extrapolation, interpolation and assigning probabilities or likelihoods to events reinforces the theory, and serves as an excellent reality check. These days when technology becomes more and more like the proverbial “black box”: the student really needs to develop a healthy interest in checking his or her answers against Nature. Meteorology has many non-intuitive aspects, which add to the intrigue. A good reference on the intrigues of the atmosphere is Craig Bohren’s book, *Clouds in a Glass of Beer* (c1987). One example is the fact that moist air is actually less dense than dry air. A quick check of the average molecular weight of the two samples will confirm this for you. This fact is important in appreciating how cloud forms, how precipitation comes about and how convection works. The release of latent heat and the transport of energy about the atmosphere is one of the fundamental driving forces of atmospheric dynamics.

An interesting program on ABC Radio’s *Science Show* recently described how face recognition demonstrates pattern recognition. (Refer to the ABC Radio link in the References.) The pattern involves recognising all-important “information” in the changes in detail, beyond the “mean” pattern. The weather forecaster has to analyse a chart by hand about once every three hours. This task is often an excellent opportunity for the forecaster to reflect on the current situation, and glean an enormous amount of information from each chart. The forecaster notes the changes in the many plots of observations. Each plotted observation may display many elements of weather. Similarly, the principle applies when interpreting satellite images or radar images. Data visualisation enables the forecaster to recognise the changes in detail (for example, looped images of Mean Sea Level Pressure (MSLP) charts can assist tracking system translation, the growth and decay. To study the structure of the disturbance in isolation, one moves the image’s origin to the centre of a disturbance on each frame, and then the loop of images is reconstituted.

During the 1990s, the Bureau went from a text-based observations and numerical weather prediction display to a *graphics*-based system. The forecasters have the ability to animate the data for visualisation purposes. The Bureau is now investing in techniques to prepare

forecasts for its clients in graphical format. As Yogi Berra said, “The future isn’t what it used to be!”

Weather forecasting is a balance between the team effort and the individual’s thinking processes and experience. On one hand, we encourage forecasters to make distinctions, think consistently and logically, and critically, yet on the other hand, the job is far too great for one individual. The virtue of the team effort is that forecasters share the workload, forecasters learn for each other’s experience: collaboration is going to win the day in the end. The Bureau of Meteorology is charged with preparing and disseminating weather forecasts and warnings to the Australian community.

Some researchers attempt to estimate the monetary worth of weather forecasting. The non-pecuniary benefits to the community include the flow-on from disaster mitigation and improvement in the quality of life (through enjoyment of sport and recreation). Tailored weather forecasts serve different communities within Australia too. Thus, different client-oriented weather products tend to use different units. This fact of life is an opportunity for students to practise their skills of converting between units, and applying dimensional checks. Dimensional checks are another approach to seeing how “real” one’s solution is. It may be that too many units will not be instructive, and teachers may balk at this approach if the hurdle is too great for the student. Meteorology and weather forecasting are rich in units!

### ***Scales of motion in the atmosphere***

I first met the idea of scaling when studying physics in the late 1960s, in a diagram showing the relationship between thickness of an elephant’s leg (compared to that of a giraffe) and the loading on the “column”. The unifying rule is the greater the load on the “column”, the greater the cross-sectional area of the “column”. Load is proportional to  $r^2$ . (Hence,  **$\log_{10}(\text{Load}) = \text{Constant} + 2 \times \log_{10}(r)$** ). To extend one’s repertoire of examples in scaling, I recommend Bak’s intriguing book, *How Nature Works: The Science of Self-Organized Criticality*, which explores (amongst other examples) the magnitude of earthquakes and their frequency. Earthquakes behave in a similar manner to the relationship between characteristic time and size scales of atmospheric motion.

In terms of magnitude of numbers and logarithms, when one considers the atmospheric phenomena in order of their size and their longevity on a diagram where the  $x$ -axis is  $\log_{10}$  (Characteristic distance in metres) against the  $y$ -axis being  $\log_{10}$  (Characteristic lifespan in seconds) the surprising result is depicted in Figure 1.

Various types of forecasts interact with their characteristic scales of motion. On the national scale, the National Meteorology and Oceanographic Centre takes hemispheric analyses and applies them to national forecasting guidance products such as the synoptic scale Mean Sea Level Pressure analysis map. The national guidance provides a setting for the various Regional Forecast Centres (located in Capital Cities): the Regional Office forecast policy is set in terms of the Public and Marine forecasts. From there, the Aviation Forecaster applies the office policy using his or her autonomy over individual aerodrome forecasts. The time-scales involved in Public and Marine forecasting tends to

be from about 12 hours to 24 hours; Aviation forecasting time scales are of the order of 6 hours; in Severe Weather forecasting, the time-scales are about 1-2 hours. Looking at the scales of forecast from the Regional scale to the Aviation or Severe Weather scales, the forecaster has to apply an increasingly intense attention to detail. Aviation forecasters derive most satisfaction from their relative autonomy over their forecasting.

Why are scales of motion important in meteorology? If you were to shoot a missile between Melbourne and Hobart, say, you may notice some error in your aim. Firing a missile over some distance during a considerable time-lapse may be of sufficiently large enough scale to cause the projectile to land somewhere off the line of action. Compare this action to throwing a basketball from one end of the court to the other: we expect no perceptible error, because the scale of motion is so much smaller than the missile example. Similarly, large-scale phenomena such as High Pressure systems (Highs) and Low Pressure systems (Lows) persist longer than short-lived, small-scale phenomena such as thunderstorms, or a willy-willy. Scales of motion assist the student to make appropriate simplification of the physical processes.

A popular misconception about the Coriolis Force demonstrates one favourite application of such interpretation of scales. The Coriolis Force is a force that acts on a body, causing it to tend to accelerate towards the left of its motion in the Southern Hemisphere, and is due to the earth's rotating frame of reference.

The web-based Coriolis Wind applet at Weather Wise shows how this force works and demonstrates its relationship to the Geostrophic Wind, a conceptual model of balanced flow (discussed below). A scale-appropriate use of the Coriolis Force explains rotations of Highs and Lows. Water running down the plughole, tornadoes, dust devils and willy-willies are too small for the relatively large-scale Coriolis Force to be evident. Although the Coriolis Force is at work in these examples, it is not evident because the other forces at play are far, far greater in magnitude (relative scale).

When forecasts are verified, it is found that for the public weather and marine forecasts, which tend to extend out to of the order of twenty-four hours or more, the statistics wash out evidence of the smaller events, which are often not so important in day-to-day affairs. In the realms of Aviation Forecasting and Severe Weather Forecasting, critical events can last from minutes to hours, say, and are relatively small in scale. These events, such as individual thunderstorms, can have devastating effects on select (unfortunate) portions of the populus. The effects of a thunderstorm on aircraft in flight or worse still, attempting to take off or land, could be fatal. So, the forecast verification has to be tuned to this scale of operation.

Numerical weather prediction guidance does not pick up such small-scale events either, because the time-response for a numerical weather prediction model to react is often too long, and because of the inadequate spatial distribution of data, which the model assimilates. Furthermore, the numerical weather prediction model grid resolution is generally is far too coarse to capture such events.

[NOTE: Further discussion of Meteorology as a resource for classroom mathematics, with Examples, will appear in Part 2 of this article, along with References.]

## Turning to Meteorology for Teaching and Learning Resources — Part 2

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### ***Conceptual models***

Conceptual models assist in the understanding of an isolated aspect of a physical process in the atmosphere without regard to the *continuity* of the fluid. In the atmosphere “everything is connected to everything else”. When employing a conceptual model, the weather forecaster makes no pretence of portraying the real atmosphere: the idea of the model is to assist the student appreciating and understanding one process at a time. Boundaries are put around the realism and technical veracity of the model. Some examples will demonstrate this.

### **Conceptual-model Example 1 Parcel of air**

It is useful to construct an idealistic “parcel of air” which is small enough so that the weather elements such as temperature, pressure and moisture content do not vary (significantly) throughout the parcel. We can imagine the cylindrical parcel’s axis is vertical. Such a “parcel” is similar to a plastic bag. When the parcel ascends, it expands and cools, and the parcel tends to stretch length-ways along its axis. When it descends, it tends to compress, warm and squash into a “fatter, squatter” parcel in the vertical. This conceptual parcel helps us understand qualitatively such processes as convection, vorticity, advection of meteorological properties with the wind, and helps explain what happens when air moves up against and passes over mountains. When the wind blows, certain thermodynamic properties of the air remain constant. For example, potential temperature is just one such conservative element. If a parcel descends from a height to 1000 hPa level - in the vicinity of the surface - without any condensation of water vapour and without any input or output of energy, the parcel undergoes compression and tends to warm. The temperature that the parcel assumes at 1000 hPa is called the parcel’s potential temperature, ( $\theta$ ). The parcel is useful in visualising these ideas. The leap in faith comes when we move from the behaviour of a parcel of air to a large complex atmospheric system. Strangely, certain correspondences do hold quite well (such as vorticity) but are beyond the scope of this article.

### **Conceptual-model Example 2: Balanced flow - the Geostrophic Wind model**

For example,  $\mathbf{V}_g$ , the Geostrophic Wind is an extremely simple model, which provides an astounding insight into the way in which the surface pressure pattern is related to wind speed and direction. The Geostrophic Wind is a horizontal wind where the horizontal Pressure Gradient Force,  $\mathbf{P}$ , is equal in magnitude but opposite to the Coriolis Force,  $\mathbf{C}$ , (that is  $P = C$ ). (N.B. Here  $\mathbf{C}$  is the approximation for the Coriolis Force’s horizontal component when applied to the horizontal wind: refer to Figure 2.)

Note that the horizontal pressure gradient is the change in atmospheric pressure over a horizontal distance. The vertical pressure gradient is the change in atmospheric pressure over a vertical distance (in the  $\mathbf{k}$  direction, where  $\mathbf{i}$ ,  $\mathbf{j}$ ,  $\mathbf{k}$  are 3-D vectors — we take  $\mathbf{k}$  as the unit vector in the vertical direction, and  $\mathbf{i}$  and  $\mathbf{j}$  unit vectors can be thought as the east and north directions respectively). The Geostrophic Wind,  $\mathbf{V}_g$ , is a wind vector, a different “entity” from  $\mathbf{P}$  and  $\mathbf{C}$ . We ignore friction, setting the frictional force as a zero vector  $\mathbf{F} = \mathbf{0}$ .

Due to the Earth’s rotation,  $C$  is a constant multiple of  $V$ , written as  $C = fV$  where  $f$ , the Coriolis Parameter is given by  $f = 2 \times \Omega \sin(\Phi)$ , and depends on latitude,  $\Phi$ .

In the Southern Hemisphere  $\Phi < 0$  (by convention) and  $\Omega$ , the rate of rotation of the Earth, is taken as a constant, and has the value  $\frac{2\pi}{24 \times 60 \times 60}$  radians per second or,  $\Omega = 7.292 \times 10^{-5} \text{ rad s}^{-1}$ . At  $43^\circ$  South,  $f \approx -10^{-4} \text{ s}^{-1}$ . What does  $f$  equal when  $\Phi = 0^\circ$  (at Equator) or, when  $\Phi = -90^\circ$  (South Pole)?

$\mathbf{C}$  always acts perpendicular to the **Left** of  $\mathbf{V}$  in the Southern Hemisphere (plan view).

Clearly,  $C = 0$  if either  $V = 0$  or  $\Phi = 0$

These ideas can be neatly summarised using the notion of vector cross-product where

$$\mathbf{C} = -f \mathbf{k} \times \mathbf{V}$$

Summary of Geostrophic Flow:

- Friction is ignored:  $\mathbf{F} = \mathbf{0}$
- Flow is parallel to straight parallel isobars
- $\mathbf{C}$  balances  $\mathbf{P}$
- In the Southern Hemisphere, the low-pressure systems are always to the right of  $\mathbf{V}_g$
- $V_g = \frac{1}{\rho f} \frac{\partial p}{\partial n} V_g$  where  $\frac{\partial p}{\partial n}$  represents the change in pressure ( $p$ ) across the horizontal distance (ideally) normal to the isobars and, where  $\rho \approx 1.2 \text{ kg m}^{-3}$  near the surface
- $V_g \propto \frac{1}{\text{isobar spacing}}$

The smaller the isobar spacing, the larger the Geostrophic Wind. The Geostrophic Wind equation is diagnostic, that is, it is not predictive. The use of the Geostrophic Wind relationship is not appropriate:

- for small-scale motions, where  $\mathbf{C}$  will be negligible (for example flow out of bathtubs);
- within the boundary layer as  $\mathbf{F}$  can be significant;
- for highly curved flow where we resort to the Gradient Wind Equation; or

- in the tropics,  $\mathbf{C}$  is negligible as  $f$  is small and the pressure gradient is “slack” - hence “cross-isobar flow” is more common in the tropics where local effects dominate the wind patterns.

How is the Geostrophic Wind, associated with weather? Deviations of actual winds (observed winds) from the theoretical Geostrophic Wind are associated with vertical motion and accelerations.  $\mathbf{V}_{ag}$  is the *ageostrophic* wind: that is, the wind component that is not geostrophic. The web-based Weather Wise applet (below) shows how to calculate the Geostrophic Winds across the globe.

### Conceptual-model Example 3: Balanced flow — The Gradient Wind model

The Gradient Wind model is an extension of the Geostrophic Wind approximation. It includes the effect of trajectory’s curvature in balance with the horizontal Pressure Gradient Force and the Coriolis Force. It excludes Friction, so that  $\mathbf{F} = \mathbf{0}$ . The Gradient Wind,  $\mathbf{V}_{gr}$ , is a horizontal wind that more closely approximates the observed Gradient Level Winds (generally measured at approximately 3,000 feet above sea level — intended to be above the boundary layer).

The Gradient Wind,  $\mathbf{V}_{gr}$ , is such that  $\mathbf{P}$ ,  $\mathbf{C}$  and  $\mathbf{C}_e$  are all in balance in the horizontal plane.  $\mathbf{C}_e$  the centrifugal force, which is due to the curvature of the trajectory of the air parcel in the horizontal plane, depends on the *radius of curvature*,  $R$ , and the *speed of the parcel* around the curve,  $V$ :

$$C_e = \frac{V^2}{|R|} \text{ where } R > 0 \text{ for anticyclonic flow and } R < 0 \text{ for cyclonic flow (another}$$

universal convention). Here,  $\mathbf{V}_{gr}$ , the Gradient Wind is a velocity vector, while  $\mathbf{P}$ ,  $\mathbf{C}$  and  $\mathbf{C}_e$  are force vectors.  $\mathbf{C}$  depends on  $\mathbf{V}_{gr}$ , and  $\mathbf{C}_e$  depends on  $V_{gr}$ .

Figures 3 and 4 show the vector balance for southern hemisphere high (H) and low (L) pressure systems. The Gradient Wind equation is:

$$V_{gr} = \frac{-f \pm \sqrt{f^2 - \frac{4}{R} \cdot \frac{1}{\rho} \cdot \frac{\partial p_h}{\partial n}}}{\left(\frac{2}{R}\right)}$$

Implications of the Gradient Wind Equation:

- There is a limit to anticyclonic pressure gradient;
- There is limit to the radius of curvature for a High; and
- There is no such limit to the radius of curvature for a Low.

In the southern hemisphere plan view, flow around a high-pressure system is anticyclonic, and flows anticlockwise: around a low-pressure system, flow is cyclonic and flows clockwise.

**Questions:**

1. Having investigated the Geostrophic Wind model, which is greater, vertical pressure gradient or the horizontal pressure gradient? Another surprise!

2. The contention is, in comparison to the Geostrophic Wind, “The Gradient Wind is slow around a Low, but it flies around a High”. Is this true? One would not expect the outcome, I strongly suspect.

The Gradient Wind model boils down to solving a quadratic equation (well within the grasp of Secondary students). Participants of weather workshops have, without formal training in Meteorology, successfully applied the Geostrophic Wind and the Gradient Level Wind models to actual plotted synoptic charts. If one were to assume that 1° of latitude is worth approximately 111 km across the ground (along a line of longitude) on a Mean Sea Level Pressure (MSLP) analysis chart using a Lambert Conformal projection, this is sufficiently accurate for the above exercises. Use a map downloaded from the Bureau’s website to demonstrate the Geostrophic and Gradient Wind models. The source of greatest error is generally from estimating the radius of curvature ( $R$ ), of the isobars.

### ***Transformations***

When changing from one frame of reference to another, such as from one coordinate system in a “fixed” frame of reference to another accelerating frame of reference, with the appropriate transformations, Newton’s Laws of Motion still prevail: so-called “apparent” forces can easily be reconciled.

In the Conceptual Models section, we discussed in effect the transformations needed when changing our frame of reference to another (accelerating) frame of reference. Newton’s Laws allow the two frames of reference to be easily reconciled through a transformation. The Centrifugal and the Coriolis Forces are manifestations of such change of frame of reference. In the above simplified examples, the calculations are reduced to algebra well within the grasp of the secondary school student.

In meteorology, changing from the coordinate system anchored on the ground (such as a surface observing site) to looking at the world from the point of view of the flow of air, the mathematical transformation, which reconciles different frames of reference, is called “advection”. Advection has a physical interpretation that can be useful in forecasting. Firstly, imagine leaning over a bridge that straddles a bubbling brook. You notice a leaf is hurrying down the stream like a small white-water raft, following the flow between stones, boulders, and the banks. If you picture yourself sitting on that leaf, how would the world appear? The origin fixed to the surface of the earth sees the world in a Eulerian manner, with the flow streaming past him or her. Following the flow with the origin fixed to the leaf, one sees the world from a Lagrangian point of view. The link between the two points of view, the advection term, represents the flow that the fixed station experiences: the flow transports atmospheric properties such as temperature, moisture content, instability, etc., to that station. The use of advection or transport ideas is a basic approach to anticipating changes at that station in the future.

One further note on the Eulerian point of view: if the horizontal distance does not exceed about 60 km, the “flat-earth” theory holds well for all practical purposes. (Fortunately, we generally do not need resort to spherical coordinates for tackling problems close to our Eulerian origin!)

### Transformation Example 1

Most of the public are generally aware how the Mean Sea Level Pressure (MSLP) analysis map that they see in their newspaper or on television relates to weather. Many people are not aware that the weather forecasting effort depends not only on these “surface charts” (where  $z = 0$ ) but also upon so-called “upper air charts” which depict observed winds, temperatures and moisture content. These “upper air charts” belong to the *troposphere*, the region between the *tropopause* (at an altitude of  $\sim 12$  km) and the surface. The *troposphere* is where most of the weather occurs. Numerical weather prediction depends on data from various standard pressure levels within the troposphere. We note that atmospheric pressure decreases with height. The upper charts are often analysed in “heights”, technically known as geopotential heights. For the sake of this exercise, we can take a geopotential metre as being essentially equivalent to the SI metre. On the constant pressure surface Highs and Lows, ridges and troughs, behave just as they do on a MSLP pattern. This is the correct interpretation: but this is not intuitive. Lines joining points of equal height on a constant pressure surface ( $p = \text{constant}$ ) are isohypes, and are analogous to the topographic contours we encounter when enjoying an orienteering exercise over and about hilly terrain. This strong analogy is commonly employed in interpreting the MSLP map ( $z = 0$ ) and the constant pressure level map ( $p = \text{constant}$ ). The most frequently used standard pressure levels used for the constant pressure charts with their typical heights above seal level are:

- 850 hPa ( $\sim 5,000$  feet)
- 700 hPa ( $\sim 10,000$  feet)
- 600 hPa ( $\sim 15,000$  feet - transport aircraft flights)
- 500 hPa ( $\sim 18,500$  feet - notionally halfway up the troposphere)
- 300 hPa ( $\sim 30,000$  feet - interstate aircraft flights - polar front jet stream)
- 250 hPa ( $\sim 35,000$  feet - jet streams, polar front and the subtropical and international aircraft flights)
- 200 hPa ( $\sim 40,000$  feet - subtropical jet stream and international aircraft flights)

The International Civil Aviation Organization (ICAO) Standard Atmosphere gives a rough conversion between pressure levels and height in feet. Note that the Aviation Industry worldwide insists on using feet or hundreds of feet for height. Figure 5 shows the transformation from  $(x, y, z)$  coordinates to  $(x, y, p)$  coordinates graphically.

### Transformation Example 2

The aerological diagram, (Skew T – Log P diagram) is craftily designed so that atmospheric thermodynamic processes can be analysed. Typically, we estimate thermodynamic stability by using the temperature and dew point temperature (a measure of moisture content) traces that are derived from a *sonde flight*: a balloon is released with instruments and the on-board transmitter sends back readings at various pressure levels. The aerological diagram has pressure lines, temperature lines and mixing ratio lines (a

measure of moisture content). The way these lines are oriented allows the forecaster to compare the observed environment with theoretical lapse rate lines (lines where air parcels have the same potential temperature,  $\theta$  or  $\theta_{\text{moist}}$ ). Areas bounded by the temperature trace and the parcel trajectory, are proportional to the amount of available potential energy. This idea of representing thermodynamic diagrams in this manner was pioneered by J Willard Gibbs, an American thermodynamicist and mathematician.

Using the aerological diagram, one can convert dew point temperature to relative humidity at constant pressure. Access to other representations of aerological or thermodynamic diagrams is via the American Meteorological Society Glossary. The aerological diagram is central to understanding the structure and severity of thunderstorms and other convection.

The International Civil Aviation Organization (ICAO) provides the international benchmark used for analysing the thermodynamic state of the troposphere. Aircraft set their altimeter reference reading using the ICAO equivalent for the Mean Sea Level Pressure, to ensure aircraft fly on separate pressure levels, and ICAO pressure readings at airports assist pilots landing safely. Using the ICAO Standard Atmosphere, one can approximate the pressure and temperature to the height of the *tropopause*. The ICAO atmosphere is based on the International Standard Atmosphere (ISA), (see the below).

This article provides a glimpse of meteorological ideas and resources that could be employed in teaching and learning in the secondary school. Meteorology links not only ideas and resources to mathematics, computing, geography and science especially it assists in integrating ideas and resources across the curricula. With this in mind, Australian Meteorological and Oceanographic Society (AMOS) is preparing teaching and learning resources based on meteorology and weather forecasting, (HREF5).

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<http://www.amos.org.au/> Australian Meteorological and Oceanographic Society — an independent Australian society that supports and fosters interest in meteorology, oceanography and other related sciences, by providing a forum for people with a common interest, and by publishing relevant material: Follow the links from *Education to School Level Links* — accessed 29/06/07

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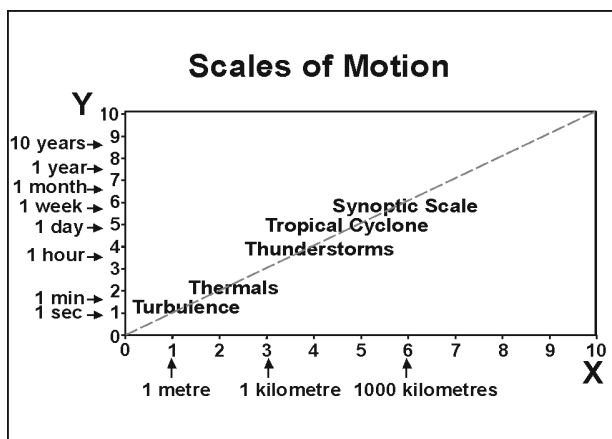


Figure 1 Scales of atmospheric motion

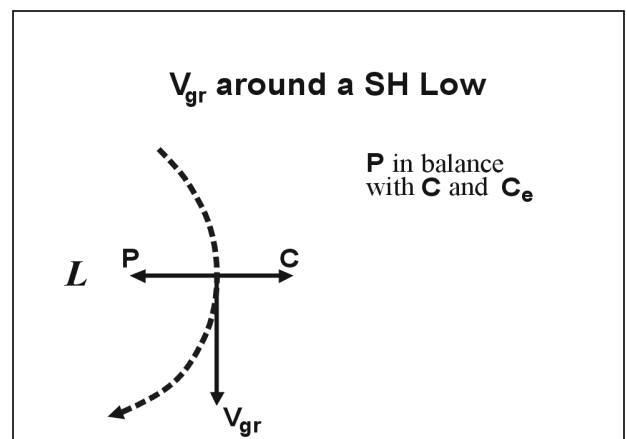


Figure 4 The Gradient Wind around a southern hemisphere Low pressure system

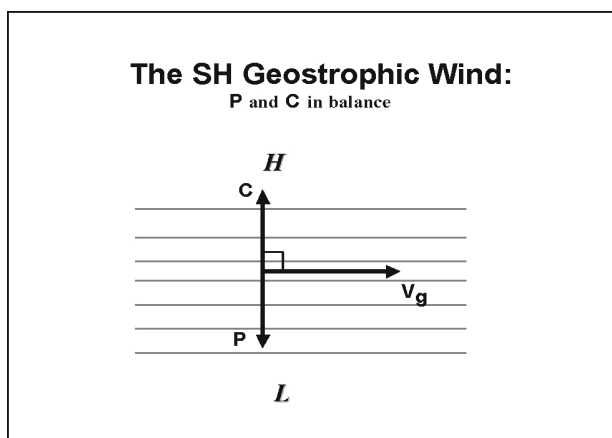


Figure 2 The Coriolis Force and the Geostrophic

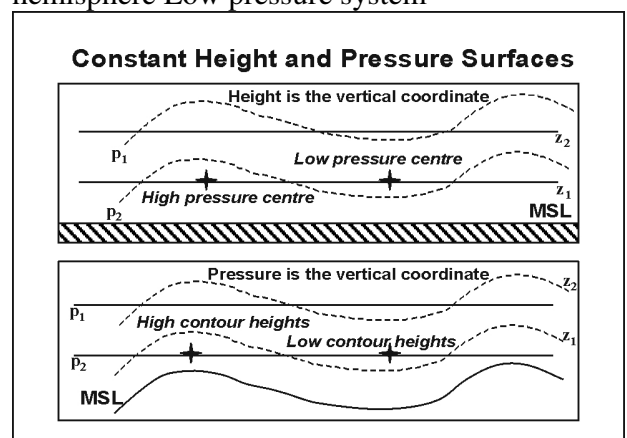


Figure 5 Constant height and constant pressure

Wind

levels

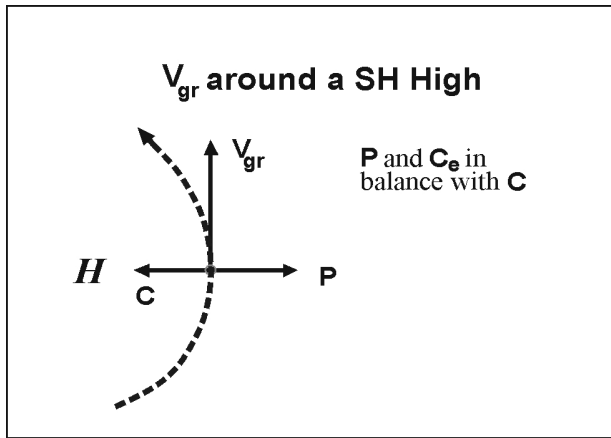


Figure 3 The Gradient Wind around a southern hemisphere High pressure system

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