Geography Compass 4/9 (2010): 1203–1217, 10.1111/j.1749-8198.2010.00368.x

Exploring the Challenges of Climate Science Literacy: Lessons from Students, Teachers and Lifelong Learners

Lesley-Ann L. Dupigny-Giroux*
Department of Geography, University of Vermont

Abstract

Today more than ever, being climate literate is a critical skill and knowledge area that influences our interaction with the environment around us, our understanding of scientific news and the daily decisions that we make. Yet, the term climate literacy can be misunderstood, as are the terms weather, climate and climate variability. This article surveys the existing literature and highlights six challenges to achieving a climate literate citizenry in both formal and informal or lifelong learning. The lessons learned from high school and undergraduate students, teachers and lifelong learners, many of whom are retired, serve as the threads which are woven into a tapestry of strategies for embedding climate science principles across entire school curricula as well as society at large.

Introduction

Science literacy in general refers to the knowledge, skills and attitudes needed to apply inquiry or problem-based approaches to new situations and decision making. It can be geared towards student learning in science, mathematics and technology, as in the case of the American Association for the Advancement of Science's (AAAS 1993) Benchmarks for Science Literacy, adult or lifelong learners only, or everyone as identified in the AAAS' (1989) Science for All Americans. Over the last decade, geoscience literacy has emerged as a particular area of interest and concern within the larger framework of science literacy. Out of the conversations among federal agencies, funding sources, university educators and scientists, a number of organising frameworks have coalesced around ocean literary (Ocean Literacy, 2005), earth science literacy (Earth Science Literacy Principles, 2009), atmospheric science literacy (Atmospheric Science Literacy, 2008) and climate literacy (2009).

Many of these literacy frameworks were developed primarily for the formal education structure with benchmarks and principles appropriate to elementary and secondary school students. Hoffman and Barstow (2007) reviewed the implementation of these literacy frameworks in the United States and concluded that in general, significant improvements were needed across the United States in Earth System science education. In particular, the incorporation of the atmosphere, weather and climate into state standards was mediocre with 30, twelve and eight states directly, indirectly or failing to address these concepts respectively.

While climate literacy encompasses many of the tenets outlined in the AAAS' (1989) Science for All Americans document, it is a distinct subset of science literacy in a number of ways. Climate science examines the dynamics and interactions among the atmosphere, land and ocean systems at varying spatial and temporal scales, using methods that draw upon statistics, modelling, visualisation and geospatial technologies to name a few. Climate

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

literacy is also concerned with the complexity and interconnectedness of hydrometeorologic patterns (e.g. droughts, cold spells) over space and time, the role that humans exert and the ability to 'act accordingly' having understood the above, as well as the recognition of bias or the change in behaviour due to a deeper appreciation of an issue or concept (Dupigny-Giroux 2008:483). The Essential Principles of Climate Science Literacy (US Global Change Research Program. 2009) were developed through a collaborative process among a number of science agencies, scientists, educators, non-governmental agencies and U.S. governmental agencies including NOAA (National Oceanic and Atmospheric Administration), AAAS and the National Science Foundation (NSF). It states that

> People who are climate science literate know that climate science can inform our decisions that improve quality of life. They have a basic understanding of the climate system, including the natural and human-caused factors that affect it. Climate science literate individuals understand how climate observations and records as well as computer modeling contribute to scientific knowledge about climate. They are aware of the fundamental relationship between climate and human life and the many ways in which climate has always played a role in human health. They have the ability to assess the validity of scientific arguments about climate and to use that information to support their decisions.

Recently, climate literacy has received special notice from both the formal and informal sectors alike, as public attention has been captured by anthropogenic climate change, deadly heat waves in Europe and the impact of El Niño on coastal storms. At the same time, a number of journals have dedicated special issues to the topic of climate literacy and the understanding of weather, climate and climate change concepts. These include the December 2008 issue of *Physical Geography* guest edited by Dupigny-Giroux (2008) and the Special Issue on Climate Change Communication of the *International Journal of Sustainability Communication* guest edited by Maibach (2008). Other complementary publications include the use of mental models to quantify seventh grade students' understanding of the greenhouse effect (Shepardson et al. 2009); the thematic overview of public opinion, perception and understanding of global climate change (Leiserowitz 2007) as a function of their beliefs, motivations, risk perception and other behavioural characteristics (Maibach et al. 2009); a presentation about children's weather misconceptions at the National Association of Research in Science Teaching (Henriques 2000); and the urgency and rationale for reaching informal or lifelong learners (Stephens and Graham 2008).

These studies are important in presenting facets of climate literacy from the viewpoints of certain populations (e.g. children or students) or themes (e.g. climate change). They also highlight key barriers to understanding and knowledge creation such as the role of perception, beliefs, country of origin and the phrasing of survey questions. A recent solicitation from the National Science Foundation's Geoscience Education program highlighted additional obstacles to climate and geoscience literacy including state and local curricular constraints that lead to uneven depth and content coverage (Stevermer et al. 2007); lack of content knowledge among elementary and secondary school teachers (Hoffman and Barstow 2007) and; the difficulties in surmounting student misconceptions and preconceptions in the face of complex Earth processes at varying spatial and temporal scales.

The goal of this article is to synthesise these recurring themes and to combine them with the content analysis of surveys and observations made by the author to deconstruct the major obstacles to achieving a climate literate citizenry and suggest remedial strategies. These qualitative data were acquired over the last decade from Grade 11 high school students, introductory undergraduate classes at the University of Vermont, elementary and secondary school

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

teachers in Vermont and presentations to lifelong learners. The latter are also called informal learners or K-gray (kindergarten to gray) learners, representing anyone who is not part of a formal education structure.

Challenge 1: The Language of the Climate Sciences

Like other natural and physical sciences, the climate sciences use specific vocabulary, terminology and methods (see the American Meteorological Society (AMS, 2000) online Glossary of Meteorology) that are clearly understood by practitioners of the atmospheric sciences, but whose subtleties may not be as transparent to those in other disciplines or to the lay public in general. Hassol (2008:106) refers to such jargon as scientists 'speaking in code'. The first 4–5 weeks of introductory meteorology or climate sciences classes tend to be devoted to the linear acquisition of this vocabulary or terminology, before inquiry-based activities or other learning strategies are used. In much the same way as learning a second or third language, these newly acquired terms and concepts must be placed in their proper context and practised often. Student and teacher comments alike reflect this struggle with new terms:

> … there are many names and concepts that seem foreign to me and hard to remember.
>
> I think for any gender, vocabulary is the most challenging part and being able to remember key terms and explaining them correctly.

The use of metaphors to aid the learning of this vocabulary often leads to the 'bad science' or 'bad meteorology' so eloquently elucidated by Harrington (2008) in his explanation of the origins of commonly held misconceptions in the climate and atmospheric sciences. The processes operating in the greenhouse effect are a common example of the misuse of explanatory terminology leading to misconceptions. Students are often unable to grasp the difference between the shortwave radiation emitted by the Sun that is absorbed by the Earth and re-emitted as longwave radiation, due to the very different temperatures of the two bodies. This is exacerbated by explaining the role of clouds and atmospheric gases such as water vapour and carbon dioxide as 'trapping heat' or 'bouncing back energy', instead of referring to their absorption and re-emission of the terrestrial or longwave radiation. Such language misuse conjures up mental images of a physical lid on the atmosphere below which the 'trapped heat' circulates like water boiling in a pot with its lid in place. Shepardson et al. (2009) present an in-depth look at the construction of such mental models and their origins.

Even more fundamental is the concept of radiation itself. For an atmospheric scientist, radiation refers to the radiant energy emitted by a body such as the sun or the earth. However, the term radiation can conjure up images of nuclear energy or chemotherapy treatments making it critical to define key terms before lecturing or discussing subsequent topics. As climate scientists, we are often unaware of how difficult it is to grasp abstract concepts that cannot be readily visualised by students or which are outside their realm of direct experience. Thus, although the notion of the earth's rotation on its axis while revolving around the Sun giving us the four astronomical seasons is the first tenet of the Climate Literacy Principles (U.S. Global Change Research Program 2009), undergraduate student feedback sheds light on their struggles:

> The Earth's rotation is a harder to grasp, however, because it seems to lack the face-to-face example. The geographical concepts that have comprehensible, smaller versions are not as hard

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

> as astronomical concepts. The concepts that lack imaginable proportion expand into a realm that feels abstract, almost made-up.
>
> I had a very hard time spatially picturing the earth in reference to its orbit around the sun, rotation, and angle position according to the seasons. Geometry has been a struggle of mine since high school and putting an image to angles and degrees is my biggest weakness.

At the root of it all is the fuzzy understanding among non-atmospheric scientists of the differences between weather and climate, the processes involved and the temporal and spatial timescales over which atmospheric events evolve (Dupigny-Giroux 2008). Weather is chaotic, dynamic and non-linear in nature while climate is deterministic. Both are interconnected systems with inherent uncertainties. Feedback loops in the land–ocean–atmosphere can act to enhance observed changes or to suppress them. Local climates which are observed on the order of square centimetres (plant microclimates) or square kilometres (urban microclimates), are in turn influenced by regional and ultimately global climates, but modified by local characteristics such as topography, surface cover and boundary layer dynamics. When these interconnections are not fully understood, weather and climate either become interchangeable concepts or synonymous with only one variable or process such as temperature and precipitation, climate change, the carbon cycle or extreme events such as tornadoes or tsunamis. However, when undergraduate students fully grasp the many interconnected facets of the land–ocean–atmosphere system, they comment that 'I am also more conscious of the fact that learning about climate is not all learning about climate change and there are a lot of different topics that make up climate.'

Challenge 2: The Role of Misconceptions

Climate science misconceptions have been well studied in the past (e.g. Harrington 2008; Hendriques 2000; McCaffrey and Buhr 2008; Shepardson et al. 2009). Among the most prevalent are (i) the Ozone hole causes or exacerbates global warming, (ii) the use of the three-cell model to explain global atmospheric circulation (Harrington 2008), (iii) that seasons result from the Earth–Sun distance changing over the course of the year (McCaffrey and Buhr 2008), (iv) the distinction between weather and climate, the processes involved and scales over which these operate, (v) why clouds exist or that raindrops are tear-shaped (Hendriques 2000) and (vi) urban sprawl, deforestation and canal dredging are evidence of climate change.

Of these, the ozone hole causing global warming misconception is particularly deeply engrained. An example of this was extracted from two assignments given to the introductory physical geography course called Weather, Climate and Landscapes (hereafter referred to as WCL) in Fall 2009. The first was a reflective journaling exercise based on a *Science* article about the new Environmental Protection Agency (EPA) standard for tropospheric ozone levels. Students were then exposed to the concepts of the vertical profile of the atmosphere; the difference between the stratosphere and troposphere; and the absorption of ultraviolet radiation by stratospheric ozone versus the longwave or terrestrial radiation absorbed by tropospheric ozone. On the midterm examination, students were then asked to list two wavelengths that are shorter than visible light, as well as to describe 'two consequences of a thinner ozone shield in the stratosphere'. While over 75% of the class was able to identify ultraviolet, gamma rays or X-rays as shortwave radiation, only 13% (twenty students) correctly identified consequences such as skin cancer and vegetation damage as resulting from a thinner stratospheric ozone shield. The other 87% of student responses included 'global warming', 'global climate change', polar bear mortality

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

and ice cap melting due to stratospheric ozone depletion, an alarming percentage which has remained unchanged over the last 5 years of offering this class.

The root of this ozone hole/global warming misconception is that many perceive stratospheric ozone depletion to be an *actual hole* through which *longwave* radiation is lost to space. Or as one lifelong learner wrote 'The Ozone hole allows in more radiation, acting as a catalyst for climate change.' This is a classic example of a concept that is resistant to instructional remediation (Chi 2005), making it imperative that the misconception be avoided altogether. Hendriques (2000) identifies some possible sources of misconceptions including textbook diagrams, verbal explanations, personal observations and the stories recounted to young children.

Challenge 3: Where in the Curriculum?

One of the most fundamental challenges in creating a climate literate citizenry is the imparting of the fundamental concepts and understandings in such a way that is age-appropriate for a given audience (formal and informal), and which can be built upon through life-long learning experiences. Traditionally, since climatology is one of the pillars of physical geography, weather and climate principles tend to be found in geography, social studies or earth science curricula. However, the timing and scope of this content delivery is far from uniform. In some school districts, neither geography nor earth is taught in the elementary or secondary school curriculum. In other cases, students are exposed to weather at the elementary/primary levels, while others take an earth science or environmental science class in high school only. For many others, an undergraduate geography or meteorology class is their first exposure to climate science basics. With this newly acquired content knowledge, undergraduates in the WCL class spoke about the need to make this material accessible to everyone:

> This class has helped tremendously with the clarification of terms and concepts that should be common knowledge in my eyes.
> Considering the fact that my everyday life consists of weather, climate and landscape, I can't believe I had such little knowledge of the formation of thunderstorms, precipitation, blue skies and every other physical geographical experience I encounter.

Exposure to weather and climate principles in primary and secondary school increased student understanding and comfort level with these concepts at the tertiary level, giving them an advantage over other classmates. They report that:

> I found the composition of the atmosphere and radiation, heat transport and temperature units easiest to understand and absorb quickly. It may have been because I was exposed to this material in my earlier schooling.
> I had little background in the realm of climate prior to taking this class, and I wish that I had a little bit more to fall back on to make up for moments when I struggled.

However, as Dupigny-Giroux (2008:483) noted, 'not everyone will have the benefit of having taken a climate-related class as part of their undergraduate studies', an Advanced Placement (AP) Environmental Science class in their final year of high school or geography/earth science content at the elementary levels. One way to address this challenge is to embed core climate concepts in other science and math classes in an integrated manner that supports the larger framework being taught. Core principles that transcend disciplinary science boundaries include radiation, temperature, motion, pressure difference, gradients and acceleration to name a few. An example of a teacher professional development pro-

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

gram that is testing this transdisciplinary climate content dissemination is the Satellites, Weather and Climate (SWAC) program at the University of Vermont. Participating middle school and high school teachers come from social science, earth science, chemistry, physics and biology backgrounds and are working within a constructivist, problem-based, inquiry-based framework to embed core climate concepts into their respective curricula. SWAC's use of remote sensing to focus on the atmosphere–land–ocean system sets it apart from other atmospheric/climate programs such as EARTHSTORM, COMET (Jackson and Carr 1995), GLOBE, CERES S'COOL (Chambers et al. 2002), Project DataStreme, Project ATMOSPHERE (Ginger et al. 1996) and the Oklahoma Climate Survey's climate training workshops (Shafer et al. 2009).

Apart from teacher professional development, another tenet of the SWAC program is making weather and climate accessible at an early age. Introducing weather and climate concepts in an inquiry-based setting allows educators to capitalise on children's natural curiosity about the environment around them, while drawing upon the Nature of Science literature (see AAAS' Science for all Americans, 1989). We cannot underestimate the early experiences of children in this realm. One student in reflecting upon her fear of tornadoes touching down in her Massachusetts hometown wrote that 'If I had taken Geography 040 [WCL] when I was a child, it would have saved me years of restless nights.' Other undergraduate comments include:

> In second grade Tom Messner spoke to my class, which I have never forgotten, as he explained all about the way the 'weather man' does his job.
> I remember learning a song back in elementary school, 'cumulus, cirrus, nimbus, stratus, those are the clouds that come right at us!
> I remember keeping a cloud journal and memorizing the different types of clouds that exist in our atmosphere. To this day, I remember all the different types of clouds because of my seventh grade teacher.

Challenge 4: The Importance of Learning Styles

There are number of learning style models to summarise the preferences by which we learn and process information. Four commonly used ones are the Myers–Briggs Type Indicator, Kolb's Learning Style Model, Hermann Brain Dominance Instrument and Felder–Silverman Learning Style Model (Felder 1996). The author has used the Kolb's (1984, 1985) Learning Style Model with undergraduate students who display a preference for *concrete experience*, *abstract conceptualisation*, *active experimentation* or *reflective observation*. Educators should be aware of the mixture of learning styles present in their classroom(s) so that the techniques and methods of delivery used address both the preferred styles of students as well as their less preferred styles, allowing them to develop 'mental dexterity' in learning (Felder 1996). This is critically important in cases where one learning preference dominates the student population and goes beyond best practices for science teaching. As Karstens et al. (2009) demonstrate, there are approaches and perspectives that set geoscientists apart in their study of the earth as a system. These include the notion that 'feedback loops function as a threshold concept'; learning in the field leads to 'professional vision'; spatial thinking and the notion some students are spatially challenged; and geoscientists' experiences, approaches and values lead them to problem-solve in a connected, interdisciplinary way. The fact that some students may be spatially challenged will influence their ability to conceptualise many geoscience and climate science phenomena that are two-dimensional and three-dimensional in nature.

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

Reflective journaling exercises assigned in the WCL class revealed that over 50% of the students were concrete experience learners. Such learners rely on feeling-based processing and are often the most creative writers in the class. For them, a visual aid such as a graph or a thematic diagram may be understood when presented in class, but without a direct connection to their senses, does not become internalised and lead to the production of new knowledge. Thus, while an abstract conceptualiser student would intuitively understand the concept of dew point temperatures from a saturation vapour pressure curve diagram, a concrete experience student would prefer to visualise standing in the early morning dew with swirling mist and cool temperatures. Similarly, while numerical- and factual-based evaluations may adequately test the knowledge and understanding of abstract conceptualisers and reflective observers, other forms are also valid for concrete experience learners. As one such student wrote, 'when provided with the chance to explore all of the information we have learned over the semester in essay form I was more than excited.'

This understanding of learning styles has implications for our roles as educators as motivator, expert, coach or non-interventionist. It also has implications for deconstructing observed trends in climate science learning where a linear approach is often used for the explanatory diagrams and constructs taught. As aforementioned, abstract concepts such as radiation and earth–sun relationships can be challenging for students, especially when these foundational concepts are taught at the beginning of many physical geography/earth science classes. In addition in recent years, there seems to be an increasing inability on the part of students to conceptualise processes in three-dimensional space. Three-dimensional processing forms the backbone of many core and applied concepts in the atmospheric sciences, with examples ranging from multilevel ozone and atmospheric stability to global circulation patterns. Finally, there is an increasing reliance by students on animations and simulations (over static black/white or colour diagrams) to explain concepts that involve motion such as convection currents or the Coriolis force. Where such aids are absent, kinesthetic learning allows students to 'act out' the various components of, for example, warm air colliding with cold air to form a cold front, or the development of wind as air moves from areas of high pressure to low pressure.

Challenge 5: Educators Can Make a Difference

> The need for sufficient numbers of highly qualified Earth Science teachers in the K-12 workforce is a problem that has contributed to a lack of awareness of, and interest in, the geosciences among students. Geoscience Education Working Group II (2005:9)

Many US federal funding agencies including NASA, NOAA and the National Science Foundation continue to stress that educators are a critical link in addressing the challenges of climate science literacy. Not only can we stimulate student interest and begin their process of lifelong learning, but in many cases, we as teachers are their first point of contact with weather and climate information. When asked the source of their climate information (see Challenge 6 for more detailed results), many 11th grade students responded with 'my teacher'. Teacher enthusiasm can be contagious and spur students in unforeseen ways. For example, 20% of the Fall 2009 WCL students chose to complete their term projects on the influence of volcanic eruptions and sandstorms on weather and climates, because they had been so struck by the NASA MODIS images of Saharan dust plumes and recent volcanic eruptions shown on the first day of class. Like the 11th grade high

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

school students surveyed in 2009, these WCL undergraduates were previously unaware of volcanic activity as a contributor to climate variations.

As aforementioned, professional development programs assist teachers in acquiring the content knowledge and skills with which to effect change in their classrooms. SWAC participating teachers report being 'more enthusiastic in class' with the newly acquired content, 'thrilled' to use new applications like Google Earth in their classes and using SWAC:

> to design curriculum that is problem based and framed around essential questions and understandings' a design that 'has added relevance, clarity, and organization to my weather unit.' In response to this shift '[s]tudents have appreciated this and have invested more time and energy into their learning.

Such feedback from educators echoes the call made by the Geoscience Education Working Group II (2005:21) that '[g]eoscience teachers need opportunities to gain content-area knowledge so that they have the confidence to make changes in their lessons, going beyond the facts given in textbooks.' The successful implementation of climate and other knowledge is often constrained, however, by the lack of cohesion in the curricula or fragmented resources faced by European teachers (Uherek and Schüepbach 2008), a feeling of personal isolation and lack of preparation to impart climate science (Johnson et al. 2008) and the need to 'teach to the test'. Thus, given that a dedicated semester or year-long course on weather and climate may not be feasible at the primary and secondary school levels, core concepts should be embedded where appropriate in a whole-school manner.

Challenge 6: The Role of Life Experience

The importance of one's life experience surfaced from surveys distributed to lifelong learners and other student groups whenever the author gave a climate-based talk, asking them to comment on the source of their weather, climate and climate change information. Prior to this, elementary and secondary school teachers had been polled about their perceptions of their students' weather and climate knowledge, with responses ranging from watching the news or forecasts on television, the Weather Channel, science classes, folklore and familial knowledge among farming/hunting families. The responses to the actual student and lifelong learner surveys provide insights into which high impact sources could or should be targeted by climate literacy professionals at various levels including the governmental organizations outlined in Niepold et al. (2008) or the U.S. National Climate Service discussed in Shafer (2008). As Arndt and LaDue (2008) have already noted, the approaches and learning needs of lifelong or adult learners differ markedly from school-aged students, and this becomes especially relevant for ongoing decision-making efforts and funding allocations that involve climate science knowledge and literacy in both the short and long terms.

Figures 1–5 summarise the responses to the question 'What is the source of your global warming/climate change knowledge?' among five different populations – 11th grade environmental science high school students (in 2008 and 2009), introductory World Regional Geography undergraduates (2008), Focus the Nation climate teach-in attendees (2008) and staff at the University of Vermont (UVM) (2008). Striking qualitative and quantitative differences emerged across the populations. Student respondents, both high school and undergraduates alike (24–57%), reported that most of their knowledge was gained in previous classes, especially earth science and environmental science courses.

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

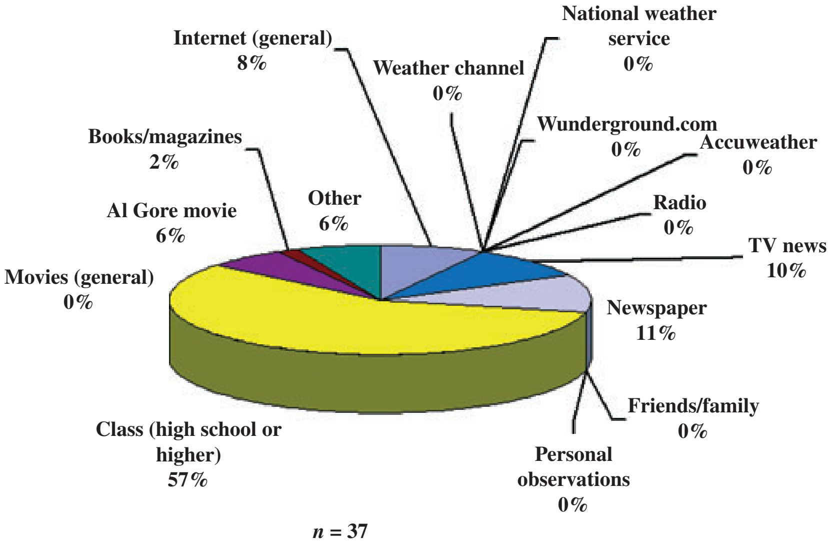

Fig. 1. Survey responses to the question 'What is the source of your global warming/climate change knowledge?' for 11th grade environmental high school students visiting the University of Vermont in May 2008.

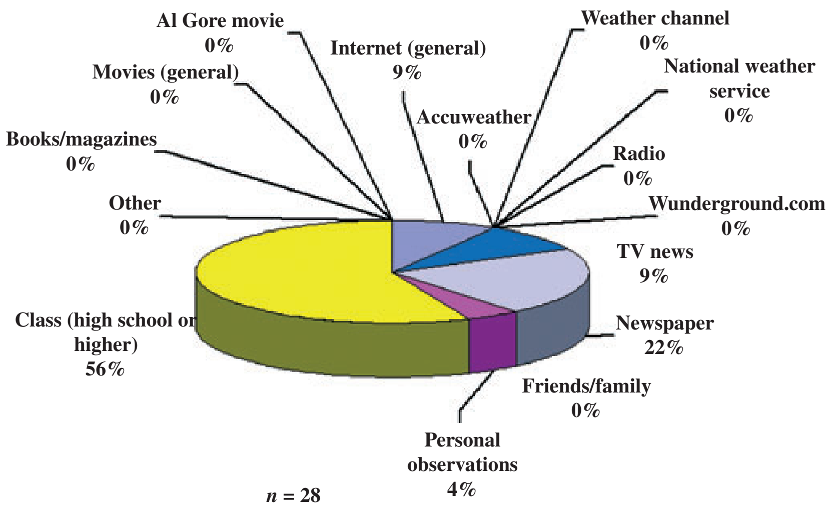

Fig. 2. Survey responses to the question 'What is the source of your global warming/climate change knowledge?' for 11th grade environmental high school students visiting the University of Vermont in May 2009.

This was particularly true for the high school students and Focus the Nation attendees. The two high school student populations were also very similar in terms of relying on the Internet and TV news, with the 2009 group using more newspapers but fewer books/magazines or other materials than their 2008 counterparts. Undergraduate sources resembled those of the high school students, but with more emphasis on the use of newspapers and movies in general. In contrast, the UVM staff poll ranked highest on the use of TV news and other sources such as the National Geographic and Discovery Channels or no existing knowledge. None of these lifelong learners cited previous classes as

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

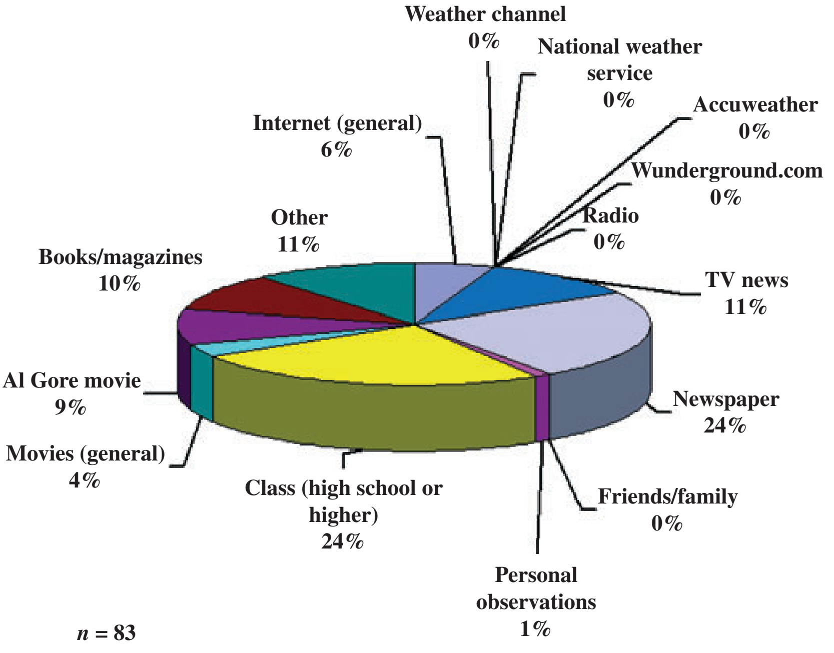

Fig. 3. Survey responses to the question 'What is the source of your global warming/climate change knowledge?' for the World Regional Geography class (introductory human geography) at the University of Vermont in January 2008.

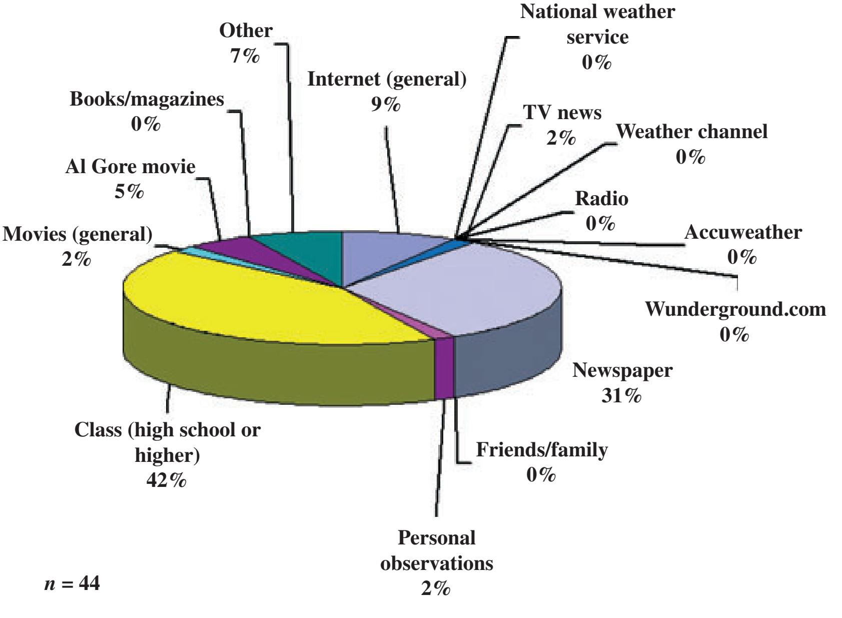

Fig. 4. Survey responses to the question 'What is the source of your global warming/climate change knowledge?' for the Focus the Nation climate teach-in at the University of Vermont in January 2008.

contributing to their knowledge, although they were remarkably similar to the student populations in citing Al Gore's 'An Inconvenient Truth' film and were the only population that depended upon friends and family.

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

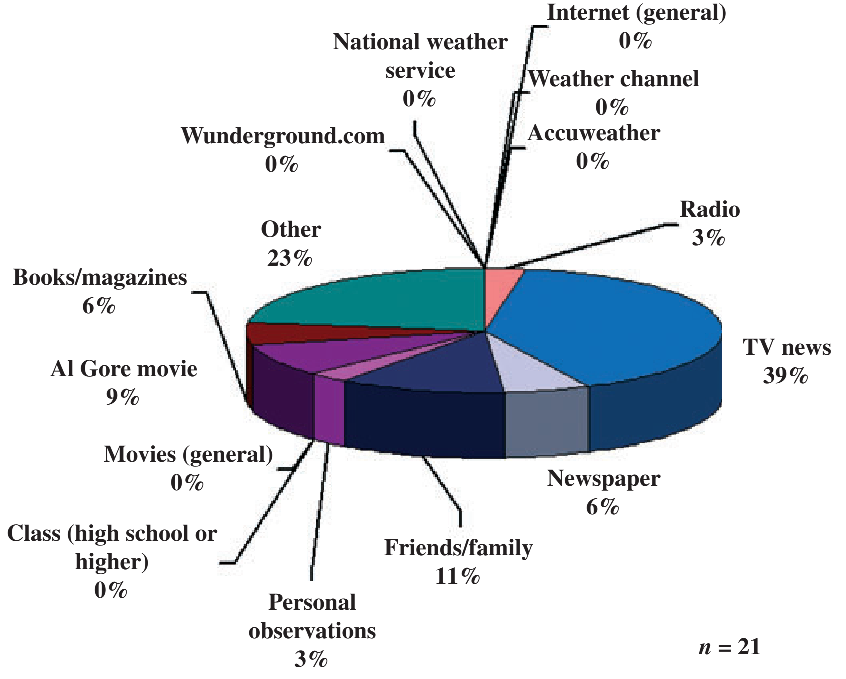

Fig. 5. Survey responses to the question 'What is the source of your global warming/climate change knowledge?' for a University of Vermont staff professional development presentation in March 2008.

The dichotomy between student and lifelong learner knowledge was also echoed in the responses to 'Where do you get weather and climate information?' summarized on Figures 6 and 7. For comparability between the two questions, response categories and colour schemes remain unchanged. For the introductory WCL class, 47% of their information came from the Internet in some form, with the Weather Channel being the

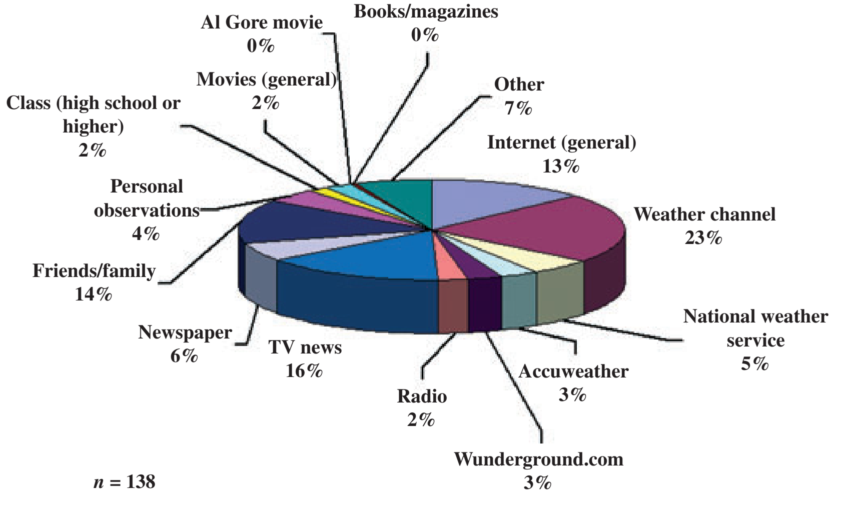

Fig. 6. Survey responses to the question 'What is the source of your weather and climate information?' for the Fall 2009 weather, climate and landscapes class (introductory physical geography) at the University of Vermont.

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

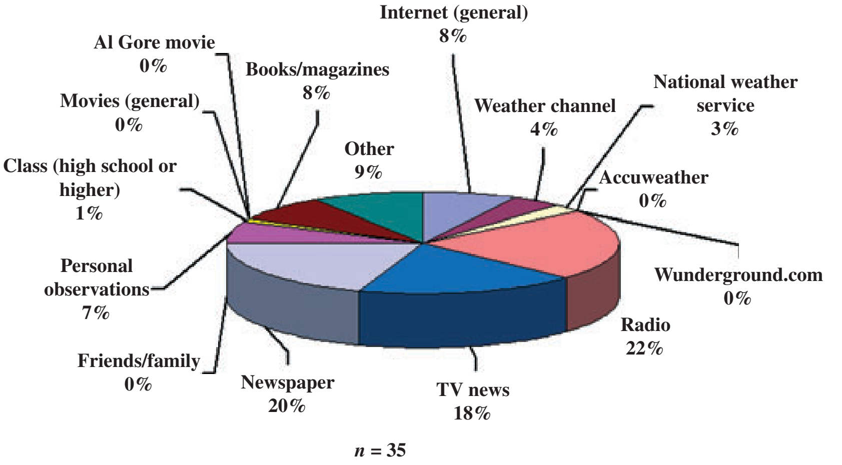

Fig. 7. Survey responses to the question 'What is the source of your weather and climate information?'at the beginning of a 2009 presentation to lifelong learners (aged 50 and older) in central Vermont.

most popular. Previous classes only accounted for 2%, while the role of TV news (16%) and family/friends (14%) (especially their parents) was more dominant. Other sources included the National Geographic and Discovery Channels as well as their cellular telephones. Most of the lifelong learners' information was almost evenly split between the radio (especially National Public Radio), newspapers and TV news. Their use of books/magazines equalled that of the Internet, but with different destinations (e.g. http://www.weather.gov or the Vermont Department of Transportation site) than those frequented by the undergraduates. Finally, other sources used by lifelong learners included watching birds and animals, following flight information, using a weather radio and using GOES (geostationary satellite imagery for weather loops) data.

The foregoing results highlight a number of key points. Firstly they reveal how closely aligned elementary and high school teachers' perceptions of their student knowledge are with reality. Secondly, the influence of family/friends is a consistent theme among lifelong learners, but a recent development in the student population. Third, the importance of self-selection in these small samples cannot be underestimated, especially in the cases of the WCL class, Focus the Nation attendees and lifelong learners all of whom had a pre-existing interest in weather, climate and/or climate change. Fourth, it is interesting to note that some sources such as the National Geographic and Discovery channels are used by almost all populations, while others (e.g. radio and observations of outdoor conditions) are predominantly used by lifelong learners. Finally, Internet usage was highest among the WCL class (47%), absent among the UVM staff, and only 6–9% for all other student groups and lifelong learners, regardless of the survey question posed. These findings about the diffuse avenues used by lifelong or informal learners concur with those outlined in Stephens and Graham (2008), who found that 80% of the US population fell into this category.

The importance of a person's life experience is reflected in his/her ability to appreciate and articulate distinctions between weather and climate, the timescales and processes involved and the role of statistical properties such as trends in atmospheric data. Hence, lifelong learners tend to describe climate as the 'yearly' or 'long-term patterns'/'conditions' 'for a particular location', 'widespread geographical conditions', 'interaction with other regions' and 'impacts plant and animal life'. Undergraduate students who had self-

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

selected into the WCL class also gave similar definitions of climate using phrases such as the 'occurrence of weather over long periods of time. Localized to specific regions as climates vary among places', 'the average weather in an area, sometimes grouped by time of year' or 'the habitual conditions of Earth's atmosphere in a specific region over a longer period of time.' In contrast, high school students tend to think of climate in terms of one meteorological variable only (usually temperature), as synonymous with weather or 'how that area mainly is' with less reference to temporal or spatial scales and interactions.

Concluding Remarks

Achieving climate science literacy will require a connected web of disciplinary, interdisciplinary, multidisciplinary and transdisciplinary approaches. Recent advances have been made in inviting cognitive sciences such as Psychology to enrich the conversation around how beliefs, culture and attitudes shape learning, perceptions and behaviour (Swim et al. 2009). The recognition and elucidation of six major challenges outlined in this article highlight existing obstacles and mitigative strategies for boosting climate literacy in both the formal and informal settings. In the formal arena, continued teacher professional development and support for curricular reform is essential, while providing students with cutting-edge content, skills and inquiry-based experiences within which to apply them. In order to work with students' learning styles and help them begin to conceptualise processes in an integrated or earth systems science way of thinking, core weather and climate concepts should be introduced or incorporated in other classes apart from Geography, Earth Science or Environmental Science. The SWAC program at the University of Vermont has proven the viability of embedding these principles in History and Social Studies curricula, as well as Physics, Chemistry and Biology.

In terms of lifelong learning, suggestions are more numerous because of the various pathways to learning that exist. These include but are not limited to, speaker series, workshops and seminars; programs designed for science museums, planetariums and other galleries; online courses or summer courses; partnering with outdoor agencies and groups such as gardening clubs, hiking clubs, nature protection groups and land trusts; capitalising on local knowledge and personalities including local weather reporters, forecasters, historical societies and tertiary institutions; and working with public radio or public television affiliates to produce segments of global importance, with a local flavour. In that way, a whole-school curricula change would be complemented by the whole-society education suggested by Stephens and Graham (2008) and the Geoscience Education Working Group II (2005) as well.

Acknowledgement

I would like to acknowledge my M.Sc. and Ph.D. advisor Dr. John E. Lewis whose training as both a climatologist and remote sensing specialist inspired me to become likewise and to eventually found the SWAC program. I would also like to thank the many students, teachers (especially SWAC participants) and audience members whose insights and questions have allowed me to become engaged in promoting the scholarship of climate literacy. This research was supported by the National Science Foundation Geoscience Education award 0807787.

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

Short Biography

Dr. Lesley-Ann Dupigny-Giroux is an associate professor in the Geography Department at the University of Vermont, and Vermont State Climatologist. Her teaching responsibilities and research interests climate variability and change, historical climatology, climate literacy, severe weather hazards, drought, remote sensing, Geographic Information Science, and the regional climatology of New England, Brazil and the Caribbean. She obtained her M.Sc. and Ph.D. degrees from McGill University. Her work on drought characterization and mitigation, published in the *Journal of the American Water Resources Association*, has been used by the Vermont Emergency Management in developing a mitigation strategy for the state. Hydrometeorological analyses of drought and severe weather dynamics have appeared in *Weather, International Journal of Remote Sensing*, *Photogrammetric Engineering and Remote Sensing* as well as *Remote Sensing of Environment*. She is also the lead editor of *Historical Climate Variability and Impacts in North America* (published by Springer) the first monograph of its kind in North America to deal with the use of documentary and other ancillary records in the analysis of climate variability and change.

Dr. Dupigny-Giroux served as the director of the Climate Specialty Group of the Association of American Geographers from 2006 to 2008. During her term, she founded the AAG Climate Literacy Initiative, a national and international collaboration devoted to the standardization of information and resources by which to promote a climate literate citizenry at all levels. She is also a founding member of the Climate Literacy Network, made up of groups and individuals interested in promoting both climate literacy and climate action efforts. In order to create a state-of-the-knowledge reference on climate literacy, she served as the guest editor of a special issue of the *Physical Geography* journal (of which she is an Editorial Board member) devoted to many lenses through which Climate Literacy can be understood. Finally in 2008, she was awarded a National Science Foundation (NSF) Geoscience Education grant to work with Vermont teachers on enhancing their professional development around the area of climate content knowledge.

Note

* Corresponding address: Lesley-Ann L. Dupigny-Giroux, PhD, Associate Professor and Vermont State Climatologist, Department of Geography, University of Vermont, 200 Old Mill Building, 94 University Place, Burlington, VT 05405-0114, USA. E-mail: ldupigny@uvm.edu.

References

American Association for the Advancement of Science (AAAS) (1989). *Science for all Americans*. New York, NY: Oxford University Press.

American Association for the Advancement of Science (AAAS) (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

AMS (The American Meteorological Society) (2000). *Glossary of meteorology*, 2nd ed. Lawrence, KS: The Allen Press. [Online]. Retrieved on 13 March 2010 from: http://amsglossary.allenpress.com/glossary/search?id=climate1

Arndt, D. S., and LaDue, D. S. (2008). Applying concepts of adult education to improve weather and climate literacy. *Physical Geography* 29, pp. 487–499.

Atmospheric Science Literacy (2008). [Online] Retrieved on 13 March 2010 from: http://www.eo.ucar.edu/asl/pdfs/ASLbrochureFINAL.pdf.

Chambers, L. H., et al. (2002). The CERES S'COOL Project. *Bulletin of the American Meteorological Society* 84(6), pp. 759–765.

Chi, M. (2005). Commonsense conceptions of emergent processes: why some misconceptions are robust. *Journal of the Learning Sciences* 14, pp. 161–199.

Dupigny-Giroux, L.-A. L. (2008). Introduction – Climate science literacy: a state of the knowledge overview. *Physical Geography* 29, pp. 483–486.

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd

Earth Science Literacy Principles: The Big Ideas and Supporting Concepts of Earth Science (2009). [Online]. Retrieved on 13 March 2010 from: http://earthscienceliteracy.org/es_literacy_22may09.pdf.

Felder, R. M. (1996). Matters of Style. *ASEE Prism* 6(4), pp. 18–23. [Online]. Retrieved on 13 March 2010 from: http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/LS-Prism.htm.

Geoscience Education Working Group II. (2005). Geoscience education and diversity: vision for the future and strategies for success. Arlington, VA: National Science Foundation; [Online]. Retrieved on 13 March 2010 from: http://nsf.gov/geo/adgeo/geoedu/GEWGII_Report_sept_2005.pdf.

Ginger, K. M., et al. (1996). Project ATMOSPHERE 1995 Teacher Enhancement Programs. *Bulletin of the American Meteorological Society* 77(4), pp. 763–769.

Harrington, J. Jr (2008). Misconceptions: barriers to improved climate literacy. *Physical Geography* 29, pp. 575–584.

Hassol, S. J. (2008). Improving how scientists communicate about climate change. *EOS* 89(11), pp. 106–107.

Hendriques, L. (2000). Children's misconceptions about the weather: A review of the literature, presented at the annual meeting of the National Association of Research in Science Teaching, New Orleans, Louisiana, USA, 29 April. [Online]. Retrieved on 13 March 2010 from: http://www.csulb.edu%7Elhenriqu/NARST2000.htm.

Hoffman, M., and Barstow, D. (2007). Revolutionizing Earth System Science Education for the 21st Century, Report and Recommendations from a 50-State Analysis of Earth Science Education Standards. Cambridge, MA: TERC.

Jackson, V. C., and Carr, F. H. (1995). A Mesoscale Meteorology Course for University Faculty. *Bulletin of the American Meteorological Society* 76(11), pp. 2459–2462.

Johnson, R. M., et al. (2008). Lessons learned through our climate change professional development program for middle and high school teachers. *Physical Geography* 29, pp. 500–511.

Karstens, K. A., et al. (2009). How geoscientists think and learn. *EOS, Transactions*. *American Geophysical Union* 90(31), pp. 265–266.

Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. Englewood Cliffs, NJ: Prentice-Hall.

Kolb, D. A. (1985). *Learning style inventory*. Boston, MA: McBer and Company.

Leiserowitz, A. (2007). Global public perception, opinion, and understanding of climate change: Current patterns, trends, and limitations. Thematic paper for: Human Development Report 2007: Climate Change and Human Development – Rising to the Challenge. United Nations Development Program. [Online]. Retrieved on 13 March 2010 from: http://hdr.undp.org/en/reports/global/hdr2007-2008/papers/leiserowitz_anthony.pdf.

Maibach, E. (2008). Editorial, special issue on climate change communication. *International Journal of Sustainability Communication*, June. [Online]. Retrieved on 13 March 2010 from: http://www.ijsc-online-online.org | IJSC 3(2008), pp. 2–4.

Maibach, E., Roser-Renouf, C., and Leiserowitz, A. (2009). Global Warming's Six Americas 2009: An audience segmentation. New Haven, CT: Yale University and George Mason University. Yale Project on Climate Change. [Online]. Retrieved on 13 March 2010 from: http://environment.yale.edu/uploads/6Americas2009.pdf.

McCaffrey, M. S., and Buhr, S. (2008). Clarifying climate confusion: Addressing systemic holes, cognitive gaps and misconceptions through climate literacy. *Physical Geography* 29, pp. 512–528.

Niepold, F., Herring, D., and McConville, D. (2008). The role of narrative and geospatial visualization in fostering climate-literate citizens. *Physical Geography* 29, pp. 529–544.

Ocean Literacy: Essential Principles and Fundamental Concepts of Ocean Sciences (2005). [Online]. Retrieved on 13 March 2010 from: http://www.coexploration.org/oceanliteracy/documents/OceanLitChart.pdf.

Shafer, M. A. (2008). Climate literacy and a National Climate Service. *Physical Geography* 29, pp. 561–574.

Shafer, M. A., James, T. E. and Giuliano, N. (2009). Enhancing climate literacy. 18th Symposium on Education, American Meteorological Society, Phoenix, AZ.

Shepardson, D. P., Choi, S., Niyogi, D. and Charusombat, U. (2009). Seventh grade students' mental models of the greenhouse effect. *Environmental Education Research* 15(5), pp. 549–570.

Stephens, J. C., and Graham, A. C. (2008). Climate science to citizen action: Energizing nonformal climate science education. *EOS* 89(22), pp. 204–205.

Stevermer, A., Geary, E., Hoffman, M., and Barstow, B. (2007). A Status Report on K-12 Earth and Space Science Education in the United States, 2006, TERC Center for Earth and Space Science Education.

Swim, J., et al. (2009). Psychology and Global Climate Change: Addressing a Multi-faceted Phenomenon and Set of Challenges. A Report b the American Psychological Association's Task Force on the Interface Between Psychology and Global Climate Change. [Online]. Retrieved on 13 March 2010 from: http://www.apa.org/science/climate-change.

Uherek, E., and Schüepbach, E. (2008). European efforts in Earth science education. *Physical Geography* 29, pp. 545–560.

US Global Change Research Program. (2009). Climate Literacy: The Essential Principles of Climate Science, A Guide for Individuals and Communities/a jointly published brochure; [Online]. Retrieved on 13 March 2010 from: http://www.globalchange.gov/resources/educators/climate-literacy.

© 2010 The Author
Geography Compass © 2010 Blackwell Publishing Ltd