# Introducing the Concept of the “Causal Continuum” in Introductory Weather and Climate Courses

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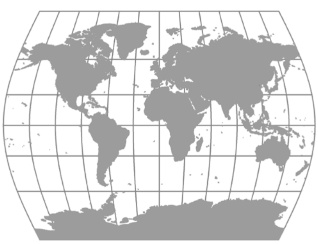

In any introductory meteorology, climatology, Earth science, or physical geography course, students will likely gain a much greater understanding of the weather and/or climate material if their course instruction is effectively rooted within the framework of why weather occurs and why climates exist. Indeed, without an early understanding of why weather even occurs, much of what is taught within an introductory course will likely never be fully grasped or appreciated by students. Along those lines, it should be extremely beneficial to include an explicit discussion of what is here termed the “causal continuum”, in the early portion of such an introductory course. Moreover, the causal continuum should preferably be repeatedly referred to throughout much of the course. I have certainly found this to be beneficial in my own introductory courses.

But what is the “causal continuum”? In terms of weather and climate, it is a term I coined and, if you teach introductory meteorological or climatological material, you most likely already fully understand the concept, though maybe not by this specific name. The causal continuum involves the idea that within the atmosphere’s system of weather and climate – from the initial latitudinal differences in solar radiation receipt through the existence of the atmospheric circulation which serves to balance out the latitudinal energy differences – there is an entire series of continua of “causal steps”, whereby one phenomenon causes another phenomenon, which in turn causes another phenomenon, which then causes another phenomenon, and so on. In other words:

> Radiation differences *cause* temperature differences, which *cause* density differences, which *cause* pressure differences, which *cause* the wind, which *causes* the latitudinal energy differences to balance-out.

More specifically, the radiation differences between the low and high latitudes *cause* the low latitudes to be warmer than the high lati-

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tudes. These temperature differences *cause* the low latitudes to have less dense air than the high latitudes. These density differences *cause* the low latitudes to have lower surface pressures (although ultimately higher pressures aloft) than the high latitudes. These pressure differences *cause* the atmospheric circulation (i.e., the global winds, both at the surface and aloft). The effect of the circulation is to *cause* the initial latitudinal radiation/energy differences to be balanced out such that the low latitudes do not become hotter and hotter and the high latitudes do not become colder and colder.

Virtually everything that happens within Earth's system of weather and climate can ultimately be traced back to this causal continuum. A thorough understanding of how and why weather occurs is unlikely without an understanding of the causal continuum. Most (if not all) basic meteorology, climatology, Earth science, and physical geography textbooks do, in fact, address all of the steps within the causal continuum. The problem with most of these texts, however, is that students must read between the lines to grasp the connections involved within the atmospheric system (i.e., the causal continuum), because all the connections are usually not presented together nor stated as explicitly connected. From personal experience during my own undergraduate years, and from the observation of other classes, the same seems to be true about many courses.

Given that the idea of these connections (i.e., continua) should ideally be made relatively early within the course (prior to students receiving much background information) the typical student may not be able to fully grasp the connections within the causal continuum without them being pointed out explicitly. This can lead to an inefficient learning curve, high levels of frustration (for the students and the instructor), poor course performance, and possibly reduced long-term retention. All of these problems may be reduced by explicitly stating the connections within the context of the causal continuum early in the course. The causal continuum provides the all-important connections between the sometimes seemingly abstract and unrelated (from an introductory students' perspective) meteorological elements such as temperature, pressure, and wind. Once these connections are fully grasped, further understanding of the weather and climate system can proceed much more efficiently. If nothing else, students taking the course for "general education" credit should have much more of a life-long appreciation of the weather if their understanding is rooted within the causal continuum. Additionally, students interested in pursuing meteorology further may have greater success in future courses if they already have an understanding of the concept of the causal continuum.

The initial discussion of atmospheric pressure seems the most likely place to first introduce the causal continuum by name (although a complete explanation of the "final steps" will need to wait until the topic of wind is addressed). This discussion of pressure typically occurs after already covering the topics of radiation and temperature, making it a good time to address the causal continuum – as long as the relationship between temperature and air density has been addressed, even if that includes merely mentioning hot air is less dense than cold air. It is then a straightforward effort to begin putting together the continuum by emphasizing that radiation differences *cause* the temperature differences, the temperature differences *cause* the air density differences, and the density differences *cause* the pressure differences.

It is also important to be able to teach students that radiation differences (the imbalance of energy consisting of a low latitude surplus of radiation/energy and a high latitude deficit of radiation/energy) actually create the mechanism for balancing out the radiation/energy differences via the steps of the causal continuum. Stated in terms of the causal continuum, these latitudinal radiation differences are the *cause* of the temperature differences that are the *cause* of the differences in air density that are the *cause* of the differences in pressure which are the *cause* of the wind which *causes* the initial radiation/energy imbalance to balance. Although other factors do influence temperature, density, pressure, and wind (for example, moisture can directly or indirectly affect each of the components of the continuum), the radiation differences have the greatest overall influence.

Helping students understand the concept of Earth being a self-regulating system allows instructors more of a chance to see the proverbial light bulb appear above a student's head. This can occur once the student grasps the causal connections operating within the Earth-atmosphere system, and aids them in more fully comprehending how and why weather actually occurs.

In addition to helping students understand why weather occurs, by repeatedly referring to the causal continuum throughout much of the remainder of the course, additional meteorological concepts can be illustrated more effectively. For example, any discussion of the varying strength of winds aloft can be tied to the causal continuum. This can include seasonal differences in the strength of the polar jets resulting from the seasonal changes in the "strength" of the causal continuum. That is, the latitudinal radiation differences are greatest in winter and least in summer. The variations in the radiation differences affect the strength of the polar jet stream via all of the steps of the causal continuum (i.e., when the radiation differences are greatest, the temperature differences are greatest, and so on along the continuum). The causal continuum can be used to illustrate the idea that winter weather is usually more active and more variable in the mid-latitudes than summer weather. The existence of monsoons and sea breeze/land breeze circulations can be tied to the causal continuum – with the differential heating and cooling of land and water being the "starting point" for the continuum instead of latitudinal radiation differences *per se*. Even the existence of cyclonic systems can be explained within the context of the causal continuum, since these cyclones serve to transport energy from the "energy rich" low latitudes to the "energy poor" high latitudes via the causal continuum. The various ways of incorporating the causal continuum into meteorological instruction are mostly limited only by the imagination of the instructor.

In closing, as I have observed firsthand from watching my own students, once the causal continuum idea is grasped, a deeper understanding of (and often interest in and appreciation for) weather and climate may be attained. For many students this may translate into a greater desire to further their knowledge of weather and climate by working harder in their course, taking additional atmospheric science courses, or following the weather more closely in their everyday lives.