At the US Air Force Academy we teach introductory atmospheric physics classes and introductory space physics classes to junior-level meteorology majors and other interested students. Both classes have the same math and physics prerequisites and have foundations in thermodynamics and classical mechanics. Despite these similarities, our students typically perceive the space physics class to be significantly more challenging. Some of this perception arises from a lack of familiarity with space environment processes compared to terrestrial environment processes. Students experience terrestrial weather firsthand for most of their lives but rarely interact with plasmas. Additionally, much of the forcing in the space environment is driven by electric and magnetic forces on plasmas. Descriptions of these behaviors take students into what they perceive as uncharted territory. Further, the impacts of space weather disturbances are daunting to novices. This paper presents a summary of the material we present in our second space environment lesson of the semester. In this lesson of our space environment course we compare and contrast what students know about terrestrial weather and environment with what they will learn about space weather and space environment.

What are the spheres of influence for terrestrial and space weather?

The main energy input to terrestrial weather is solar electromagnetic (EM) radiation, while the energy input for space weather comes not only from EM radiation but from solar particles as well. Terrestrial weather is generally confined to the troposphere, but some effects extend into the stratosphere and mesosphere. Space weather occurs, for the most part, above these regions. Space weather influences are felt in the thermosphere (the Earth's hot but tenuous, upper atmosphere), in the magnetosphere (where the Earth's magnetic field dominates plasma behavior) and in the interplanetary medium (an extension of the Sun's atmosphere where the Sun's magnetic field dominates the plasma behavior). We can take this analogy a bit further. In meteorology we often refer to the mixed or homogenous region below 100 km and the stratified or heterogeneous region above 100 km. The behavior of gasses in these regions is quite different, but both regions are gravitationally bound to the Earth. Likewise, in space weather we can think of the Sun and interplanetary medium as having plasma characteristics quite unique from the Earth's thermosphere-ionosphere-magnetosphere system. Despite the differences, these space environment systems are all linked by plasmas and electric currents.

How do terrestrial weather and space weather energy sources/sinks compare?

Terrestrial weather is driven by the Sun's nearly constant blackbody radiative emission in the ultraviolet, visible and infrared portions of the spectrum. In contrast there are three major solar emissions that energize space weather: two forms of particles and the highly variable non-blackbody radiative emissions. The two particle populations consist of high-energy (relativistic) ions, and low-energy ions (typically with supersonic speeds). The former is usually associated with impulsive events on the Sun. The latter has both quasi-steady and impulsive elements. Non-blackbody emissions from the Sun are primarily in the X-ray, extreme ultraviolet and radio portions of the spectra. Radiative output from these spectral regions may vary by as much as 2 to 3 orders of magnitude in the course of a day. We can also compare the large-scale energy sinks for terrestrial and space environment systems. The ocean acts as a huge reservoir of thermal energy for terrestrial weather. The magnetosphere and ionosphere-thermosphere systems act as similar, but shorter-term, reservoirs of electro-mechanical energy for the space environment system.

What are the controlling forces in terrestrial and space weather and the special force balance situations that simplify our understanding of physical situations?

The terrestrial environment is dominated by pressure gradient, gravitation and apparent coriolis forces in the free troposphere. In the space environment pressure gradient and electromagnetic forces are all pervasive. The gravitational force plays a large role in some locations but is rather unimportant in other realms. As a simple example, in meteorology we often refer to the idealized case of vertical hydrostatic-equilibrium. In hydrostatic-equilibrium, gravity is balanced by the vertical pressure gradient force. In the space environment we can draw an analogy to hydromagnetic-equilibrium in which case the magnetic force on a plasma is balanced by the local pressure gradient. We can also note the balanced forces such as those involved in the geostrophic wind have analogies in the plasma environment. Steady state plasma drifts can arise from the interaction of ionized particles under the control of steady, crossed magnetic and electric fields.

How do the impacts of space weather and terrestrial weather compare?

Societal impacts of terrestrial weather and weather disturbances have to do with human safety and comfort, agricultural productivity and influence on infrastructure (highways, shipping, power lines, *etc*). For the most part we can easily identify the human endeavors disrupted when the weather goes bad. Space weather disturbances are more often manifest in technology disruptions. Power grid failures, satellite command and control glitches, global communication, and navigation outages are the realm of space weather disturbances. There is, however, a human component in space weather safety. Astronauts on-orbit and flight crews making frequent transits of the polar regions are subject to enough radiation risk that they use dosimeters to measure radiation dose while on-orbit or enroute. To date the average human has probably been at most inconvenienced by space weather disturbances. However, the growing reliance on geosynchronous satellite communication networks and precision location by GPS satellites are areas where human lives may hang in the balance during unforecasted or prolonged space weather disturbances.

Are there storm scales for space weather as there are for terrestrial weather?

Yes. Many students are familiar with Saffir-Simpson scale of 0-5 for hurricane intensity and the Fujita 0-5 tornado intensity scale. Similar scales have been developed for levels of geomagnetic disturbance (G1-G5), radio blackout levels (R1-R5) and solar radiation enhancement (S1-S5).

In terrestrial weather we often hear of terms like the “Heat Index” and “Air Quality Index”. Are there similar measures in space weather?

Yes. There are global indices (Kp index and *aa* index) that relate the degree of global geomagnetic disturbance. There are also indices that measure the disturbance in global or regional current systems (Dst index and AE index) and the level of satellite radio signal loss due to electron density changes in the ionosphere (S4 index) .

How do the space environment and the terrestrial environment compare?

The terrestrial atmosphere is a collisionally-dominated high-density neutral gas. For the most part this gas is gravitationally bound to the Earth. Densities range from 1 kg/m^3 at the Earth surface to 10^{-9} kg/m^3 near 150 km altitude. Density in the Earth’s upper atmosphere near 500 km is on the order of 10^{-12} kg /m^3 while interplanetary solar wind density is on the order of 10^{-26} kg/m^3. The interplanetary regime, in which space weather occurs, is typically a non-collisional plasma which has achieved escape velocity from the Sun. Collisional influence is sometimes replaced by magnetic influence. A unique characteristic of the space environment is the presence of a small but important ionized component of the upper atmosphere. About one particle in

10,000 is ionized in the upper atmosphere. While this may seem insignificant, the electric and magnetic forces on such a weakly ionized plasma are extraordinarily important and drive interactions at the many different speeds including the speed of light.

Meteorologists often measure and/or forecast air currents like the jet stream, monsoonal flow or a sea breeze. Space weather scientists are just as concerned about electrical currents in and around the Earth's protective magnetic covering and in the Earth's upper atmosphere. Knowing the magnitude and direction of current flow can be as useful to a space weather forecaster as knowing the magnitude and direction of the jet stream is to a terrestrial weather forecaster.

The GOES and POES satellite are used for remote sensing in terrestrial weather. What instruments are used for space weather remote sensing?

Both the GOES and POES satellites carry space weather sensors as well as terrestrial weather sensors. The Defense Meteorological Satellite Program satellites also carry space weather sensors in addition to their terrestrial weather instrument packages. Additionally, there is a suite of high-frequency, high-latitude radars used for sensing activity in the auroral zone. There are also unique space weather sensor packages positioned at the L1 point between the Sun and the Earth.

What scale sizes are involved in terrestrial weather and space weather processes?

Meteorologists often refer to hemispheric, synoptic, mesoscale and local weather scales, with scales lengths of 10^4 km, 10^3 km, $5x10^2$ km, and 10 km, respectively. The processes of space weather play out on scales as large 10^8 km (1 astronomical unit). The near-Earth space environment is typically considered to be 10-100 Earth radii, corresponding to 10^6-10^7 km. Auroral displays occur over roughly 10^3 km, but can have small-scale features on the order of 1 km. Local thermospheric depletions that affect GPS signals may have sizes from 10^{-2} to 10^2 m.

Are there important time scales or seasons for space weather?

Perhaps the most notable long-term variation (which also has links to terrestrial weather) is the 22-year solar cycle. This is the period during which the Sun's magnetic dipole field performs a 360° rotation. The 11-year cycle of sunspots and other phenomena is really just a half cycle of solar variation. Imposed upon these long-term variations are influences of the Sun's equatorial 27-day rotation cycle. It is often the case that high or low levels of geomagnetic activity in the near-Earth space environment have a 27-day periodicity. We also know that the Earth's dipole tilt can allow space weather disturbances to be more effective. Statistically more and larger geomagnetic storms occur during the equinoxes. Additionally, there are short-time scales associated with specific features on the Sun or in its atmosphere. Impulses of enhanced radiation can reach the Earth in 8 minutes after a solar flare; the often-associated plasma expulsion takes two to three days to reach and disturb the Earth's magnetic field. Once energy has reached the magnetosphere and ionosphere these regions exhibit entirely new sets of time scales due to the differing plasma characteristics in each region

In terrestrial weather we often hear about disturbance phenomena such as hurricane's and tornadoes. Are there similar features in space weather?

Yes. Disturbances in different regimes are evident in terrestrial weather and in space weather. For example, in the tropical regime we have hurricanes and cyclones. In mid-latitudes we have Nor'easters, ice storms, and tornadoes. From polar regions we have cold air outbreaks. By analogy, in the solar wind there are huge magnetized bubbles of plasma called coronal mass ejections that launch from the Sun into interplanetary space. The Sun can send us sudden bursts of energetic particles that can blind satellite sensors or destroy a satellite's ability to make power in solar cells. There are also streams of high-speed solar wind that, through a series of processes, energize electrons in the magnetosphere and cause them to flow toward Earth in an organized manner. Some of these electrons attach themselves to satellites and cause electrical malfunctions. Other electrons slam into the Earth's upper atmosphere and create auroral displays.

Some space scientists speak about convection in the near-Earth environment. How is this similar to or different from the lower atmosphere's convection?

The vertical convection systems associated with surface absorption of short wave solar EM radiation generates convection cells similar to those found in the convective layer of the Sun, so similar convection forms exist in both regions. In contrast convection in the magnetosphere is not driven by thermal instabilities but rather by the motion of highly conducting solar wind plasma across the relatively stationary magnetic field lines of the Earth. Because the magnetosphere and ionosphere are linked by plasma and currents the motion of plasma in the magnetosphere drives a plasma motion in the high latitude ionosphere which is usually referred to as convection.

What are some the marked differences between terrestrial and space weather?

In addition to those differences previously mentioned, we can consider the existence of the Van Allen radiation belts to be to be a unique feature of space weather. These belts of high-energy charged particles owe their existence to the Earth's magnetic field and the interaction of high-energy cosmic rays with the neutral component of the upper atmosphere. The upper atmosphere's influence on radio wave propagation, again due to the weakly ionized component above 80 km, is another significant departure from meteorology. Currently space weather predictability is also a significant difference. The physics behind most terrestrial weather phenomena is well enough understood to be formalized by mathematical equations. Both our lack of physical understanding and the inability to convert this understanding to equations covering many different grid sizes still present a formidable barrier to high-fidelity space weather forecasting.