Space Weather - Terrestrial Weather
Fruitful Analogies

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Space meteorology is a late offspring of its terrestrial forbear. Lightning, floods, and droughts killed humans in Paleolithic times, but the first casualties from space storms—disrupted telegraph service—occurred only in Victorian times. Not until the advent of long-distance wire and wireless communication, distributed power grids, and satellites did humankind become vulnerable to space weather. Attempts to forecast terrestrial weather probably started already when the instinct to foresee danger first acquired a human brain and could point to omens and sky signs. But attempts to predict space weather could not begin until its dangers became manifest and associated sun signs had been identified. By this time—around 1900—government supported forecasting services already existed for terrestrial weather based on the concept of eastward migrating storm systems and enabled, coincidentally, by the telegraph, the first commodity vulnerable to space weather. Since then, through a long course of research and application, terrestrial meteorology has vastly improved the art of forecasting, and its offspring, space meteorology, has been following nearly the same course benefiting from its progenitor's experience.

Terrestrial weather forecasting has proceeded through a series of ages: a pre-instrument age (sky signs, e.g., solar halo) led to an instrumented but local (barometer) age then to synoptic weather maps (isobars) then to the concept of organized storm systems (traveling cyclonic depressions) then to air masses and weather fronts (the polar-front model) then to objective forecasts (empirically based algebraic algorithms) then to numerical forecasts (physics-based numerical codes) and finally to the same augmented with satellite imagery. Space weather forecasting has been proceeding through roughly analogous ages: a pre-satellite age (sun signs, e.g., solar flares) followed by local satellite measurements (magnetometer measuring IMF Bz) followed by synoptic charts of the sun (magnetograms) followed by the concept of organized storm systems (coronal mass ejection from the sun and substorms within the magnetosphere) followed by models of these phenomena (magnetic clouds and the Hones model) followed by empirically based algebraic algorithms (e.g., the Wang-Sheeley model for solar wind speed and the Burton equation for Dst) followed by physics-based numerical codes (the MFM and global MHD simulation codes) followed by the same augmented with coronal imagery (halo CMEs). Despite the analogies, in the case of space weather the state of the art is still relatively primitive and mostly pre-operational.

The analogy we have been pursuing works in part because terrestrial weather and space weather refer to phenomena manifested in fluid media that occupy complementary volumes of space and in part because in many respects these phenomena are similar or analogous. Take for example weather elements. In the troposphere these are wind, pressure, temperature, precipitation, and the state of the sky. The analogs to these for space weather are solar wind speed and ram pressure, IMF Bz, energetic particle intensity, and auroras. To the general circulation of the atmosphere there corresponds magnetospheric convection. To weather fronts correspond stream interfaces; to air masses, solar wind streams. Tropospheric storms can be extratropical, tropical, or air-mass. Space storms can be CIR, CME, or background substorms. Deterministic chaos which absolutely limits the range of weather forecasts in the troposphere has its space weather analog in the sun-to-earth turbulence in the solar wind which absolutely limits deterministic forecasts of disturbance levels beyond about one hour.

There are differences, too, which will always keep the two fields as separate disciplines, starting with the hugely different volumes, pressures, and speeds that characterize their domains. Beyond this, where tropospheric meteorologists use the Navier-Stokes equation on a rotating sphere, their space-weather counterparts use equations of continuum mechanics based on MHD coupled with the neutral atmosphere in the ionosphere and with kinetic particle drifts in the magnetosphere. Perhaps the biggest difference relates to the means by which their motions are driven. In the troposphere a steady input of solar radiation distributed inhomogeneously over the earth leads to instabilities that drive the general circulation of the atmosphere and its inherent weather systems. In the magnetosphere weather results from a non-steady solar wind. That is weather is directly driven.

We close by returning to the theme of analogies, this time relating to institutional infrastructure. Terrestrial and space weather are supported by programs within NSF and NASA and they achieve their payoff to society through operational forecasting offices within NOAA and DoD. We mention, in particular, the National Space Weather Program administered by NSF and NASA's Living with a Star program. Forecasting offices within NOAA reside in the National Centers of Environmental Prediction, which dispenses forecasting services to space weather customers through the Space Environment Center.