cultivated pasta wheat and is a potential source of genetic variation that could affect nutritional crop content (*9*). The authors identify the gene for this trait as *NAM-B1* and demonstrate that it encodes a member of the NAC transcription factor family whose members are widely distributed plant-specific transcription factors (*10*).

Uauy *et al*. show that the wheat genome contains three *NAM* genes, and transcript analysis reveals a parallel increase in expression of all these genes in flag leaves (the uppermost leaf on a stem) at grain maturity. Abrogating expression of these *NAM* genes by RNA interference transgenesis results in delayed whole-plant senescence and a >30% reduction of grain zinc, iron, and protein content, suggesting a quantitative contribution from each *NAM* gene. This delay in senescence and decrease in grain nutrients is associated with increased residual nitrogen, zinc, and iron in the flag leaf, thereby demonstrating a role for *NAM* genes in nutrient redistribution to the developing grain during leaf senescence. By establishing a direct link between senescence and nutrient distribution, Uauy *et al*. provide new insight into homeostatic mechanisms of grain nutrient acquisition.

Like all good science, these studies provoke more questions. What are the signals that mobilize iron from vacuoles to distant sites along the developing plant vasculature? If there a specific set of transcripts—a "transcriptome"—regulated by the *NAM* genes that defines nutrient redistribution to the grain? Is so, what are the proteins they encode and how do they function? Understanding the regulation of vacuolar iron content could result in new approaches to iron enrichment in seeds. The cloning of *NAM-B1* illustrates the utility of defining quantitative trait loci that can permit breeding for nutritional traits on the basis of mechanistic insight.

Political and spiritual leader Mahatma Gandhi considered hunger the greatest violence against children. These elegant new studies reinforce the inherent value of basic science for improving the lives of those youngest among us who remain without a voice in this world.

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ATMOSPHERE

Global Change in the Upper Atmosphere

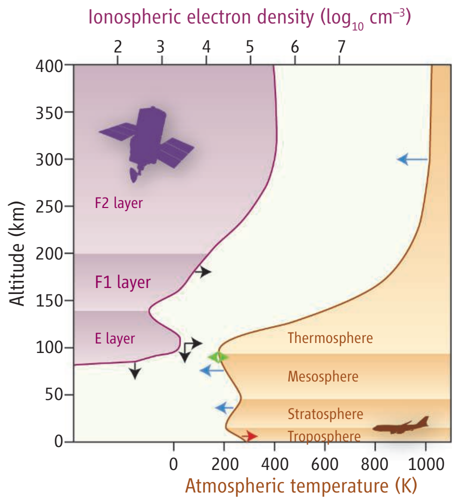
The upper atmosphere is cooling and contracting as a result of rising greenhouse gas concentrations. These changes are likely to affect the orbital lifetimes of satellites.

J. Laštovička, R. A. Akmaev, G. Beig, J. Bremer, J. T. Emmert

Life on Earth is affected more directly by climate change near the surface than in the upper atmosphere. However, as the story of Earth's ozone layer illustrates, changes higher up in the atmosphere can also be important. In 1989, Roble and Dickinson (*1*) predicted that rising greenhouse gas concentrations should affect atmospheric climate in the highest reaches of the atmosphere. Since then, upper atmospheric data have been combed for evidence of long-term trends. A coherent pattern is now beginning to emerge.

The upper atmosphere consists of the mesosphere (~50 to 90 km) and thermosphere (~90 to 800 km) (see the figure). The ionized part of the upper atmosphere, the ionosphere (~60 to 1000 km), is embedded within these regions. The thermosphere is the operating environment of many satellites. The drag exerted by the thermosphere is proportional to the ambient density. Therefore, satellite trajectories and orbital lifetimes are sensitive to long-term trends in atmospheric density at their flight altitude (although their active lifetime is at present mostly determined by the lifetime of their energy sources, by instrument failures, and by the capacity of satellite operation centers). Changes in the ionosphere affect the propagation of radio waves and hence the performance of the Global Positioning System (GPS) and other space-based navigational systems.

The increase in global surface air temperature during the 20th century has been attributed mainly to the increasing atmospheric concentrations of greenhouse gases. In the upper atmosphere, the radiative effects of greenhouse gases, particularly CO_2, become more pronounced and produce a cooling rather than a warming effect (*2*, *3*). This effect is demonstrated by the CO_2–dominated atmosphere of Venus, where the troposphere is more than twice as warm as Earth's and the



Structure and trends in Earth's atmosphere. Atmospheric layers (orange, right) are defined by the temperature profile. Ionospheric layers (purple, left) are defined by the electron density profile (shown here at midnight at the equator). Arrows denote the direction of observed changes in the past 3 to 4 decades: Red, warming; blue, cooling; green, no temperature change; black, changes in maximum electron density (horizontal) and the height of ionospheric layers (vertical). Most spacecraft fly at altitudes above 300 km. The aircraft and satellite shown are not to scale.

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thermosphere is 4 to 5 times as cold (*4*). The cooling should cause the upper atmosphere to contract; we may thus expect a substantial decline in thermospheric density, as well as a downward displacement of ionospheric layers (*5*).

The primary quantity directly affected by the changing concentration of greenhouse gases is temperature. The first comprehensive review of temperature trends at heights of about 50 to 100 km (*6*) reveals, after slight updating, the following trends: (i) moderate negative trends of about 2 to 3 K per decade at heights of 50 to 70 km, with the largest magnitude in the tropics; (ii) slightly larger cooling trends at heights of 70 to 80 km in the low and middle latitudes; (iii) essentially zero temperature trends between 80 and 100 km. Modeling studies agree reasonably well with the observed vertical and latitudinal structure of the thermal response (*3*).

Over the past three decades, the global temperature at Earth's surface has increased by 0.2 to 0.4ºC, compared with a 5 to 10ºC decrease in the lower and middle mesosphere. Summer-winter differences of mid-latitude land-surface temperatures are comparable in magnitude to the seasonal and 11-year solar cycle variability of mid-latitude mesospheric temperatures. Thus, the signal-to-noise ratio of the trends is much higher in the mesosphere than at Earth's surface.

No direct information on thermospheric temperature trends is available. However, estimated ion temperatures (*7*) at heights near 350 km reveal a negative trend of about –17 K per decade (*8*). Because ion temperature is strongly coupled to thermospheric temperature, these trends are qualitatively consistent with the expected thermospheric cooling.

Temperature directly affects atmospheric density. At altitudes between about 200 and 800 km, atmospheric drag causes measurable decay of the orbits of satellites and space debris. Routine satellite tracking data have been used to derive long-term changes in thermospheric density. The results (*9*, *10*) indicate that thermospheric density has declined during the past several decades at an overall rate of 2 to 3% per decade; these density trends increase with height (*9*). This behavior is qualitatively consistent with model predictions (*2*). Model simulations also show that, in addition to the effects of greenhouse gas increases, the impact of long-term changes in stratospheric ozone and water vapor on atmospheric density may extend well into the thermosphere (*11*).

Thermal contraction of the upper atmosphere should result in a downward displacement of ionospheric layers (*5*). Laštovička and Bremer (*12*) reviewed long-term trends in the lower ionosphere and found a positive trend in electron density at fixed heights, consistent with downward displacement. The maximum electron density of the E-layer and the F1-layer increased slightly (see the figure), and the height of the electron density maximum of the E-region decreased slightly (*13*), in qualitative agreement with model predictions (*2*). These ionospheric trends accelerated after 1980, providing support for their anthropogenic origin (*14*).

The trends described above form a consistent pattern of global change in the upper atmosphere at heights above 50 km (see arrows in the figure). The upper atmosphere is generally cooling and contracting, and related changes in chemical composition are affecting the ionosphere. The dominant driver of these trends is increasing greenhouse forcing, although there may be contributions from anthropogenic changes of the ozone layer and long-term increase of geomagnetic activity throughout the 20th century. Thus, the anthropogenic emissions of greenhouse gases influence the atmosphere at nearly all altitudes between ground and space, affecting not only life on the surface but also the space-based technological systems on which we increasingly rely.

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PALEOECOLOGY

Life's Complexity Cast in Stone

Wolfgang Kiessling

The fossil record shows that since the end of the Paleozoic era, the structure of marine communities has become more complex.

There is no doubt that the complexity of life has increased through the ages, both in the structure of individual organisms and in the ecological structure of communities (*1*, *2*). But to trace the complexity of living systems, we need objective measurements. Species diversity is often regarded as a rough proxy of complexity in local communities, because the more species coexist in a community, the more ecological interactions between species and complex food webs are to be expected (*3*). However, a comprehensive picture cannot emerge when the diversity information is reduced to single numbers such as species richness or measures of how evenly species are distributed in a community. Communities with the same number of species and identical evenness values may still differ substantially in their ecological complexity.

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On page 1289 of this issue, Wagner *et al.* (*4*) explore the shape of relative abundance distributions in ancient marine communities to track the evolution of ecological complexity through the past 540 million years. They separate communities whose abundance distributions simply suggest superior access to resources versus those that succeed in their own smaller niche (see the figure). In simple abundance distributions, the relative abundances of species drop rather steadily, which implies that few factors—such as the preemption of resources by dominant species—structure the community. Complex distributions are essentially those in which the dominant taxa add ecological opportunities, and complex niche partitioning is suggested by similar abundances for many species. The big surprise in their analysis is a major difference between Paleozoic (older than 250 million years) and younger communities. In older assemblages, complex and simple distributions are