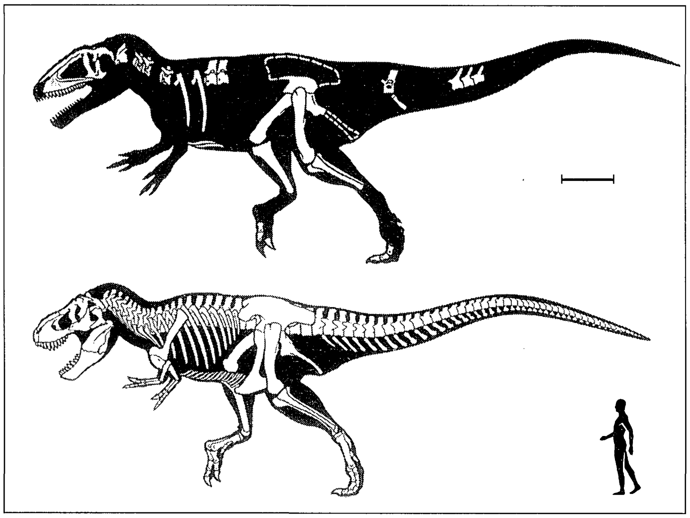
Out of Africa: Meat-Eating Dinosaurs That Challenge *Tyrannosaurus rex*

Philip J. Currie

In recent years, the Kem Kem region of Morocco has been the site of increasing interest by those scientists hoping to get a first good look at dinosaur life on the isolated continent of Africa. An international expedition from the University of Chicago visited this paleontologically rich area in 1995 to see if they could recover better specimens. After several months in the field, enough fossils, data, and information had been gathered to establish a framework within which thousands of teeth and bones could be placed. As the field season wore on, the hope of finding significant dinosaur remains was rapidly dying. But, as often happens, that was when two superb discoveries were made in quick succession. As described by Sereno *et al.* on page 986 of this issue (*1*), the skull of one animal and much of the skeleton of another represent two of the best Cretaceous meat-eating dinosaurs (theropods) ever discovered in Africa and have ended some of the speculation that arose from more than 80 years worth of intriguing but enigmatic fragmentary discoveries.

Sereno and his colleagues describe a new genus and species of coelurosaurian theropod characterized by long, slender limbs suggestive of speed and agility (*1*). The remarkable thing is that the length dimensions of this animal seem to have been as large as those of *Allosaurus* and most other genera of large theropods. Its bones are dwarfed in comparison with the second specimen, however. This skull has been identified as *Carcharodontosaurus saharicus*, a species first recognized in 1927. Incomplete, usually fragmentary remains of this dinosaur have been recovered across northern Africa, leading to speculation about its size and relationships. The new specimen is as long or longer than any skull of *Tyrannosaurus rex*, which has always been referred to as the largest known terrestrial carnivore. At least that was the case until last September when Coria and Salgado announced the discovery of *Giganotosaurus carolinii* in Argentina (*2*). The head of *Giganotosaurus* is significantly longer than that of any known tyrannosaur skull (*3*). However, as Sereno and his colleagues point out, *Tyrannosaurus* is still longer limbed and taller than the apparently heavier *Giganotosaurus* and *Carcharodontosaurus*. Which of the two latter animals was larger remains to be determined. Fortunately, this rather simple problem will be resolved shortly thanks to the discovery of most of the rest of the skull of the Argentinian form in March of this year.



Predator pair. Skeletal silhouette drawings showing the known bones of two of the largest Late Cretaceous predators. *Carcharodontosaurus saharicus* (top), from northern Africa, is based on bones from Morocco and Egypt. *Tyrannosaurus rex* (bottom) is known from several skeletons from western North America. Scale bar equals 1 m; average-height human silhouette, 1.8 m). [Courtesy P. Sereno and C. Abraczinskas]

To a paleontologist, the size of an animal is of less interest than its adaptations, relationships, distribution, behavior, and a host of other characteristics. It is rather interesting that two of the largest theropod specimens ever discovered—Sereno's *Carcharodontosaurus* and *Giganotosaurus* from Argentina—were found within a year of each other. What is even more amazing, however, is the fact that these specimens, found on two different continents, have turned out to be closely related to each other. The shared characteristics cited in the Sereno *et al.* paper are just the tip of the iceberg, and more features are being discovered to strengthen this relation. The Moroccan *Carcharodontosaurus* has a well-preserved brain case, formed of the bones that surrounded the brain. Brain cases are conservative, which makes them excellent tools for studying relationships because they are less susceptible to the rapid evolutionary changes that characterize skeletal structures associated with feeding and locomotion. Brain case studies by the Sereno team on *Carcharodontosaurus* and by Coria and his colleagues on *Giganotosaurus* are revealing unique characteristics. A few additional features are suggestive of the sinraptorids, large theropods from the Jurassic of China.

Such discoveries are changing our rapidly evolving concepts of paleogeography during the Cretaceous. In 1995, Rauhut noted the partitioning of the world by tyrannosaurids, which dominated the northern continents, abelisaurid theropods (such as *Carnotaurus*) that were at the top of the food chain in South America, and carcharodontosaurids, which controlled Africa (*4*). With the recognition of *Giganotosaurus* as a carcharodontosaurid and the discovery of abelisaurids in Africa and southern Europe, it is clear that these families were free to intermix well into the Cretaceous. The coelurosaur reported in the current paper and dromaeosaurid remains reported by Rauhut from the Sudan show that these animals dispersed from the northern continents into Africa during the Late Cretaceous, demonstrating that there were no physical boundaries to prohibit the overlap of tyrannosaurid and carcharodontosaurid predators. It would be interesting to know what was happening in the zone of contact.

When Sereno published his paper on *Afrovenator* in *Science* 2 years ago (*5*), African dinosaur faunas were more poorly known than those of all continents except Antarctica. The discoveries by Sereno's team (*1*) and another report on Moroccan fossils (6) have done much to rectify this situation. At least this is true insofar as the saurischian dinosaurs are concerned. The paucity of African ornithischian dinosaurs continues to be noteworthy. Ornithischians, like the duck-billed hadrosaurs, the armored ankylosaurs, and the horned ceratopsians, were the dominant herbivores of Asia and North America during Late Cretaceous times and apparently were common in some environments in South America. Did the advanced ornithischian lineages fail to get into Africa? Or have the right kinds of paleoenvironments never been sampled? This is a problem that particularly vexes Forster and Krause (State University of New York at Stony Brook), who are part of an international team search-

The author is at the Tyrrell Museum of Palaeontology, Box 7500, Drumheller, Alberta T0J 0Y0, Canada. E-mail: pcurrie@dns.magtech.ab.ca

ing for the answers in Madagascar. It is one of the many problems that can only be resolved by further fieldwork and research. And it is one of the reasons why the discoveries of Late Cretaceous dinosaurs by the Sereno team in northern Africa will continue to attract international attention.

References

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3. ——, unpublished data.
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Stratospheric Control of Climate

Alan Robock

From 1905 to 1952, Charles Greeley Abbott directed the measurement of the solar constant and its relation to sunspots from his office in the tower of the Smithsonian Building, convinced that these solar variations held the clue to weather and climate forecasts (*1*). Since then, the lack of a convincing mechanism has hampered acceptance of such a connection. Now, as reported in this issue, Haigh (*2*) has used a climate model simulation to show a mechanism whereby the stratosphere is changed by the sun, which in turn drives the tropospheric climate.

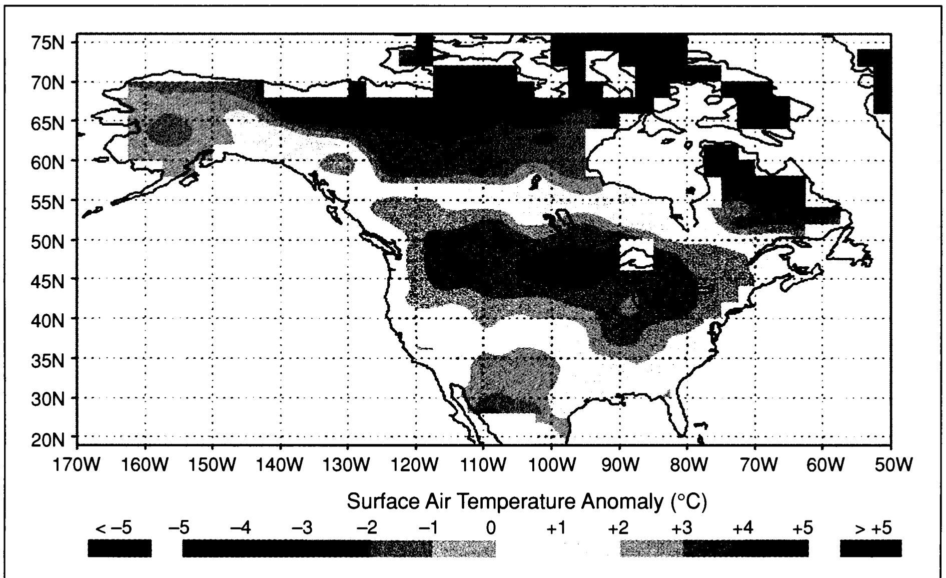
Interest in possible solar-weather variations grew after Eddy (*3*) described the Maunder Minimum in sunspots in the 1600s and suggested that it represented reduced solar insolation and was responsible for the Little Ice Age. He suggested that the envelope of the sunspot number was most representative of the solar influence on climate, but my subsequent work (*4*) showed that the decadal-scale variations produced by climate models that this implied were not representative of recent climate change of the past several centuries. Whereas all these earlier studies emphasized surface climate variations, van Loon and Labitzke, in a long series of observational papers (*5*), found climate variations at the surface and in the upper atmosphere with significant variations related to the sunspot number. They found that some of the signals were stronger when modulated by the quasi-biennial oscillation (QBO) in equatorial stratospheric wind.

Variations of the total solar irradiance over an 11-year sunspot cycle are only about 0.1%, but most of this variation is in the ultraviolet (UV) wavelengths, which are absorbed by the ozone in the stratosphere. Recognizing this, Kodera *et al.* (*6*) and Rind and Balachandran (*7*) used general circulation models (GCMs) of the climate system in which the solar variations in the UV were felt in the stratosphere, producing gradients of heating and inducing a response in the tropospheric circulation with much larger indirect effects than what would be produced by the direct effects of spectrally averaged heating. Still, the results did not correspond closely to the observed solar-related variations, and they had to use unrealistically large solar UV variations to get a significant response.

Now Haigh (*2*) has conducted a simulation that produces realistic tropospheric response to solar variations, by recognizing that stratospheric ozone also varies with the sun and by including ozone variations in her model forcing. In these perpetual January GCM simulations, the stratosphere is heated because there is excess solar UV radiation, and there is more ozone to absorb this radiation. These combined effects produce changes in the tropical Hadley cell and in mid-latitude storm tracks. The resulting changes are still not quite as large as the observed changes, and she has not tested the relation to QBO variations, as this model keeps the stratospheric winds in the easterly phase. More detailed calculations should be done with a climate model that goes through the seasonal cycle and has more resolution in the stratosphere.

These results resemble the recent work of Kodera (*8*) and Graf *et al.* (*9*), which show a large winter dynamic response of the climate system to explosive volcanic eruptions, another response produced by stratospheric heating. In the case of volcanic aerosols, the direct heating of the stratosphere attributable to long-wave absorption by the volcanic aerosols produces a temperature gradient anomaly and a circulation response seen as winter warming of the Northern Hemisphere continents. The Graf *et al.* simulations were also conducted with a perpetual January GCM and are now being repeated with a more detailed GCM going through the entire seasonal cycle.

A large body of work (*10*) suggests that surface temperature and precipitation anomalies can be predicted for months to a year in advance by taking account of the state of the sea surface temperature (SST) patterns in the tropical Pacific Ocean, which are most dramatic during an El Niño. During the large 1982–1983 El Niño, large surface temperature variations over North America, however, have recently been shown to be a result of the circulation anomalies induced by the 1982 El Chichón volcanic eruption, and not the SST-induced changes. By comparing climate



Surface air temperature anomalies over North America for 1982–1983. The observations are obtained from Schemm *et al.* (*17*). The contour interval is 1°C. (A version of this figure that includes observations and simulations for 1982–1983 and 1986–1987 is available on the World Wide Web at http://www.meto.umd.edu/~alan/fig10c.GIF)

The author is in the Department of Meteorology, University of Maryland, College Park, MD 20742, USA. E-mail: alan@atmos.umd.edu