PERSPECTIVES: CLIMATE VARIABILITY

The Rains May Be A-Comin'

David E. Black

Reconstructions of long-term climate change often focus on individual climate factors such as surface temperature (*1*, *2*). More comprehensive long-term climate records exist for some climate systems, such as the El Niño–Southern Oscillation and the North Atlantic Oscillation (*3*–*6*), but not for others, including the Southwest Asian monsoon.

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Anderson *et al.* now provide much-needed insights into the decadal- and centennial-scale variability of the Asian monsoon. On page 596 of this issue (*7*), they present a 1000-year sediment record of variations in the southwest monsoon winds from the Oman Margin in the Arabian Sea.

The Southwest Asian monsoon is one of the most important climate systems on Earth, affecting nearly half of the world's population in any given year (see the first figure). Through seasonal reversal in winds and hence moisture transport, it supplies much-needed precipitation during the summer months to the populations of India, Bangladesh, China, and other countries of southern Asia (see the second figure).

Over millions of years, changes in the monsoon are controlled by the tectonic uplift of the Tibetan Plateau, which changes the thermal contrast between the Indian Ocean and the southern Asian mainland (*8*). On time scales of thousands to hundreds of thousands of years, monsoon variability is controlled by insolation changes related to variations in Earth's orbit around the Sun (*9*, *10*).

Over periods of decades to centuries, monsoon variability is less well understood. Yet these are the time scales that are most relevant to humans. It is this shorter-term variability that Anderson *et al.* address. Their record provides new insights into the history of the Southwest Asian monsoon on subcentury to century time scales.

The authors reveal several distinctive trends in monsoon strength between 1000 and 1986 A.D. Particularly interesting is an increase in monsoon intensity from 1600 A.D. through the present. This time period spans the Little Ice Age (~1550 to 1850 A.D.), when the Northern Hemisphere experienced a cold spell, and also covers the last century, during which anthropogenic effects may have begun to influence global climate.

The minimum in monsoon strength shortly after 1600 A.D. coincides with the Maunder Minimum, a period of reduced solar activity (*11*). It appears to represent the weakest monsoon of the last 10,000 years (*9*, *10*). This observation might suggest that insolation variability is an important forcing mechanism even on submillennial time scales. However, the authors point to the link between a weakened southwest monsoon and cooler conditions in the North Atlantic and Eurasia (*12*). They suggest that large-scale regional cooling during the Little Ice Age affected the monsoon, and caution against interpreting the minimum solely in terms of insolation effects on the region of the Tibetan Plateau.

A small boat navigates the Mekong River during the monsoon; Can Tho, Vietnam.

The monsoon does not appear to have been stronger during the earlier part of the record, the so-called Medieval Warm Period (~1000 to 1350 A.D.), than during the 20th century. Still, the monsoon is more intense during this time than in the beginning of the Little Ice Age. Several terrestrial pollen records from China and Tibet indicate stronger precipitation during the Medieval Warm Period, thought to be a result of enhanced monsoonal activity (*13*).

Anderson *et al.* argue that northern hemispheric temperature variability controls the Southwest Asian monsoon on multidecadal to centennial time scales. This argument has critical implications in the face of global warming. Their monsoon record broadly resembles reconstructed Northern Hemisphere temperature changes (*2*), including a pronounced increase in monsoon intensity during the past century.

Temperature is clearly an important influence on monsoon variability. But does the monsoon respond through teleconnections to hemispheric temperature change, or is it driven by local, direct forcing mechanisms such as insolation or greenhouse gases? The question remains unanswered for now. As the authors note, despite its relatively high resolution, their record does not have sufficient temporal resolution to discriminate between these forcing possibilities.

Variations in other parts of Earth's climate system have led to the rise and fall of civilizations; changes related to water supplies have particularly strong effects (*14*). Anderson *et al.* note the societal impact of previous excursions in the monsoon system, including a decrease in the Southwest Asian monsoon that led to widespread famine in the late 19th century. A much-increased monsoon caused by global warming would have equally serious consequences. Too much rain results in severe flooding and soil erosion, strongly affecting the population of this region.

Anthropogenic climate change is expected to occur on multidecadal to centennial time scales. Whatever these anthropogenic effects may be, they will be superimposed on a climatic system that also responds to natural forcing factors (*15*). To differentiate between anthropogenic and background climate change for any climate system, we must first characterize its natural variability. In providing a new

Region affected by the Southwest Asian monsoon. Map from http://earthobservatory.nasa.gov/Newsroom/BlueMarble/; area affected by the monsoon after (*16*).

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baseline for a major component of the global climate system, Anderson *et al.* have taken a large step toward this goal.

References

1. J. T. Overpeck *et al.*, *Science* **278**, 1251 (1997).
2. M. E. Mann, R. S. Bradley, M. K. Hughes, *Geophys. Res. Let.* **26**, 759 (1999).
3. J. E. Cole, R. B. Dunbar, T. R. McClanahan, N. A. Muthiga, *Science* **287**, 617 (2000).
4. A. C. Clement, R. Seager, M. A. Cane, *Paleoceanography* **15**, 731 (2000).
5. J. W. Hurrell, *Science* **269**, 676 (1995).
6. P. D. Jones, T. J. Osborn, K. R. Briffa, *Science* **292**, 662 (2001).
7. D. M. Anderson, J. T. Overpeck, A. K. Gupta, *Science* **297**, 596 (2002).
8. W. L. Prell, D. Murray, S. C. Clemens, D. M. Anderson, in *Synthesis of Results from Scientific Drilling in the Indian Ocean*, Geophysical Monograph 70, R. A. Duncan *et al.*, Eds. (American Geophysical Union, Washington, DC, 1992), pp. 447–469.
9. M. A. Altabet, R. Francoise, D. M. Murray, W. L. Prell, *Nature* **373**, 506 (1995).
10. S. C. Clemens, D. W. Murray, W. L. Prell, *Science* **274**, 943 (1996).
11. J. A. Eddy, *Science* **192**, 1189 (1976).
12. F. Sirocko, D. Garbe-Schomberg, A. McIntyre, B. Molfino, *Science* **272**, 526 (1996).
13. K. B. Liu, Z. J. Yao, L. G. Thompson, *Geology* **26**, 135 (1998).
14. D. A. Hodell, J. H. Curtis, M. Brenner, *Nature* **375**, 391 (1995).
15. R. S. Bradley, P. D. Jones, Eds., *Climate Since A.D. 1500* (Routledge, New York, 1995).
16. C. S. Ramage, *Monsoon Meteorology*, International Geophysical Series (Academic Press, New York, 1971), vol. 15.

PERSPECTIVES: CELL BIOLOGY

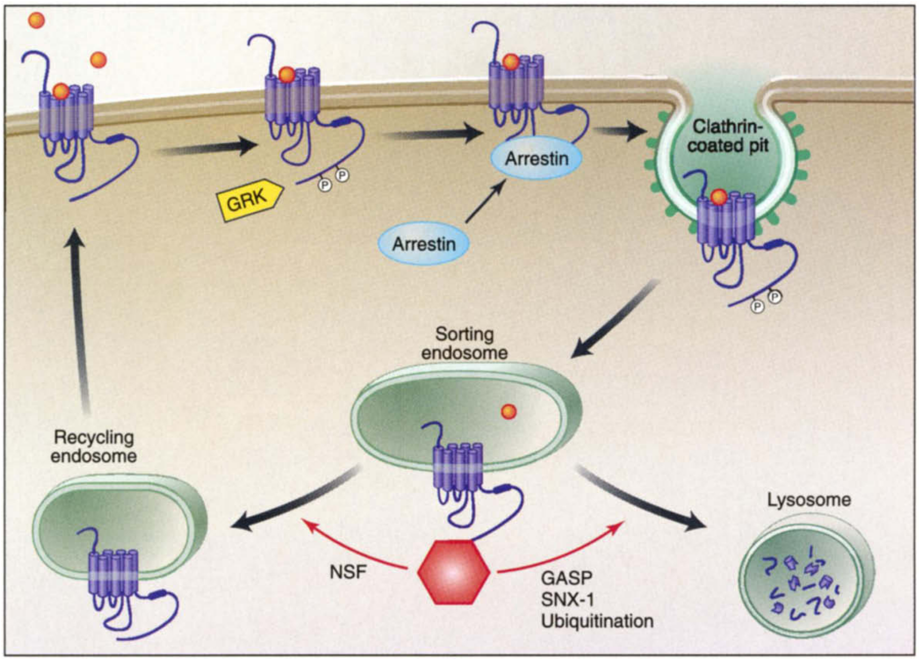
A Last GASP for GPCRs?

John A. Gray and Bryan L. Roth

One of the largest gene families in the human genome is that encoding the G protein–coupled receptors (GPCRs). These plasma membrane receptors, with their trademark seven-transmembrane helices, bind to and transduce signals for a huge variety of ligands including neurotransmitters, odorants, hormones, and other small molecules. GPCRs also mediate the actions of certain medications used to treat disorders as diverse as cardiovascular disease (*1*), drug dependency (*2*), and mental illness (*2*). Prolonged exposure of GPCRs to their endogenous (natural) or exogenous ligands (agonists) induces compensatory decrements in receptor sensitivity (desensitization) and receptor number (down-regulation). A prominent feature of the regulation of GPCR activity after ligand binding is the rapid internalization of these receptors and their sorting to intracellular endocytic compartments (*3*). Internalized GPCRs suffer one of two fates: Either they are rapidly recycled back to the plasma membrane (recycling pathway), or they are targeted to lysosomes for proteolysis (degradative pathway). Several recent studies, including a report on page 615 of this issue by Whistler *et al.* (*4*), identify GPCR-interacting proteins that specify the preferential sorting of GPCRs for either recycling or degradation (see the figure).

What structural motifs must interacting proteins recognize in order to determine the fate of internalized GPCRs? A number of recent studies have described sequences in the cytoplasmic domains of GPCRs, particularly in the carboxyl terminus, that are important for recognition by interacting proteins. For instance, swapping the carboxyl termini of protease-activated receptor–1 (PAR-1), a receptor that is targeted to lysosomes, and the substance P receptor, a GPCR that is recycled rapidly to the plasma membrane, results in a "swap" of the sorting pathways (*5*). Thus, PAR-1 with a substance P receptor carboxyl terminus is recycled to the plasma membrane, whereas the substance P GPCR with a PAR-1 carboxyl terminus undergoes degradation in lysosomes. Studies have also revealed the importance of amino acid residues at the distal carboxyl terminus of GPCRs for mediating receptor recycling, and have identified potential interacting proteins involved in this process. Most notably, interaction of the β_2 adrenergic receptor with NSF-1 (*N*-ethylmaleimide–sensitive factor)—a protein important for intracellular membrane trafficking and release of vesicles from the plasma membrane—regulates recycling of this GPCR (*6*).

New work, including that by Whistler *et al.* (*4*), reveals the identity of several interacting proteins that target GPCRs for lysosomal degradation. Whistler and colleagues have identified a protein they call GASP (GPCR-associated sorting protein) that turns out to be a key player in the lysosomal sorting of δ-opioid receptor (DOR) and probably of other GPCRs. They disclose that disrupting the interaction between GASP and DOR (a GPCR that is normally preferentially sorted to lysosomes) blocks lysosomal sorting and promotes recycling of internalized DORs to the cell surface. Importantly, GASP has a high affinity for the carboxyl terminus of GPCRs that are normally targeted to the degradative pathway, but a low affinity for GPCRs that prefer the recycling pathway. The authors also found that a dominant-negative form of GASP blocked the lysosomal targeting of DOR or of a mutant β_2 adrenergic receptor. Taken together, these findings identify nor-



Getting sorted. After activation by their ligands (orange), GPCRs (blue) become desensitized and are then internalized into endocytic compartments in the cell [see (*3*) for a review]. Within the endosomes, a sorting decision is made either to recycle the receptor to the plasma membrane (resensitization) or to transfer the receptor to lysosomes for degradation (down-regulation). New studies have identified interacting proteins (pink), such as GASP (*4*) and SNX-1 (*7*), that interact with the carboxyl terminus of GPCRs and contribute to this sorting decision. GRK, G protein–coupled receptor kinase.

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