Tropical Westerlies Over Pangean Sand Seas

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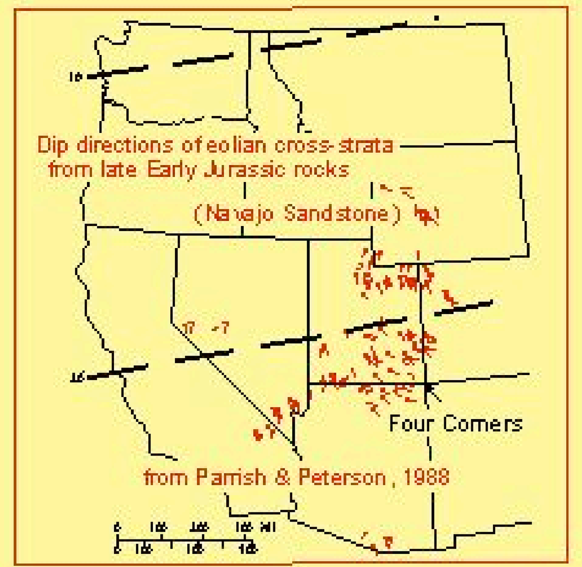
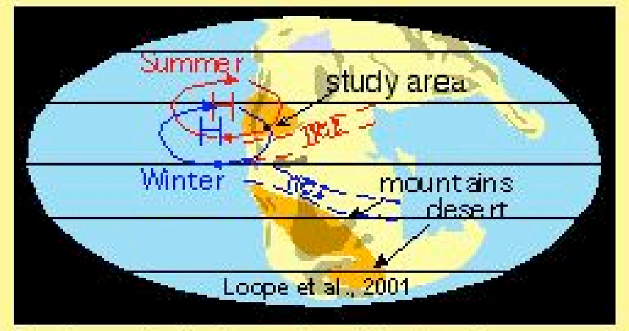
Abstract

Cross-equatorial, westerly winds are key features of tropical circulation in monsoonal regions. Although prominent in numerical climate models of Pangea (the supercontinent straddling Earth's equator, Late Paleozoic through Early Mesozoic), such flow has not been confirmed previously by geologic evidence. Wind-blown sandstones that span 100 million years of Earth history are widely exposed in southwestern USA. If recent paleomagnetic data from the Colorado Plateau are used to correct Mesozoic paleogeographic maps, the Plateau is placed about 10° further south than previously assumed, and the prevailing northwesterly surface winds recorded by dune-deposited sandstones are explicable as cross-equatorial westerlies—the hallmark of modern monsoon circulation. Permian through Early Jurassic dunes were driven by northwesterlies produced by a steep pressure gradient spanning the supercontinent during December-January-February. Although winds are light in most modern, near-equatorial settings, the East African Jet accounts for more than half of the cross-equatorial flow in June-July-August. The thicknesses of annual depositional cycles within the Navajo Sandstone indicate that the near-equatorial, northwesterly winds that drove these particular dunes were stronger than the modern East African Jet. The Early Jurassic dunes that deposited the thick cycles were positioned west of the dominant (southern hemisphere) thermal low, and against highlands to the west --a setting very similar to the East African Jet. The mountains along the western coast of Pangea not only enhanced wind strength, but also cast a rain shadow that allowed active dunes to extend very close to the paleoequator.



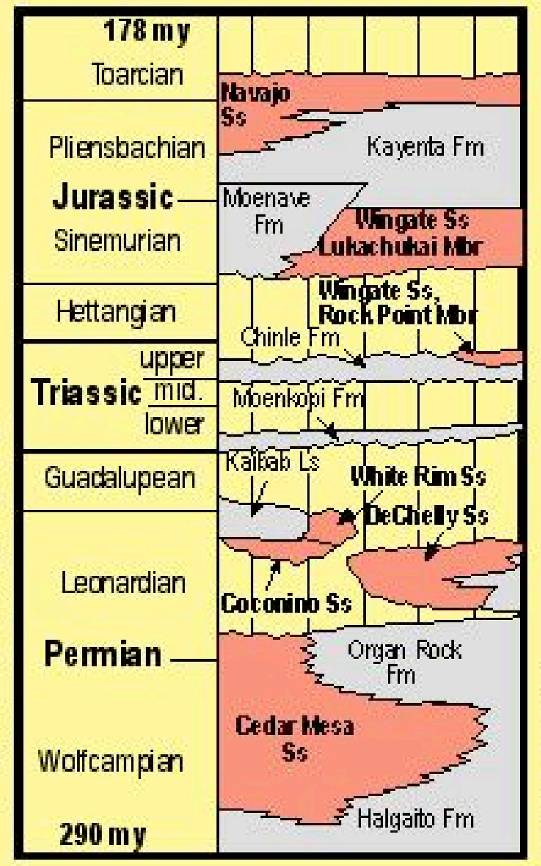


Previous studies have placed the Four Corners area at about 18°N during the Early Jurassic. Winds from the NW drove dunes southeastward. These winds were interpreted as mid-latitude westerlies, related to the anticyclone along the western margin of Pangea. Paleomagnetic data from Colorado Plateau rocks, however, place the Four Corners 10° farther south. The aim of this poster is to show that in this new paleogeographic context, the northwesterly winds can be understood as cross-equatorial, tropical westerlies.

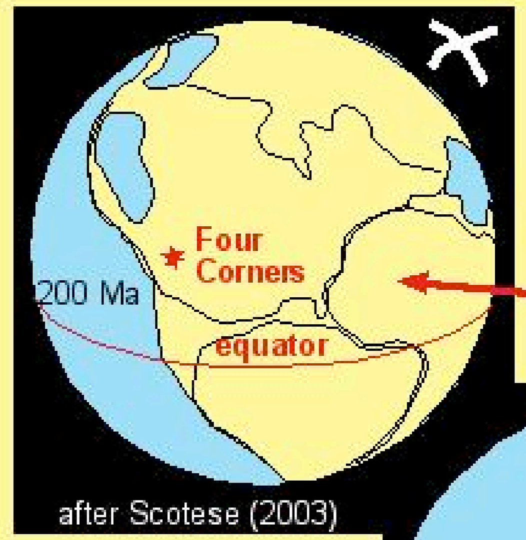
Evidence for heavy rainfall events recorded in Navajo cross-strata suggest a tropical setting

Rain-soaked lee slopes leave distinctive features in the sediment record. The modern slump above (Grand Desierto, Mexico) is underlain by a thrust fault and has a recognized toe. Ancient slumps can be recognized in the Navajo Sandstone. In some exposures, slumps are evenly spaced and have been interpreted as products of monsoon rains (Loope et al. 2001). Given the low latitude (less than 20°N, and possibly less than 10°), precipitation events are most likley during summer. Arrows mark thrust faults generated by slumping. Red lines show position of deflation surfaces that truncate slump masses.

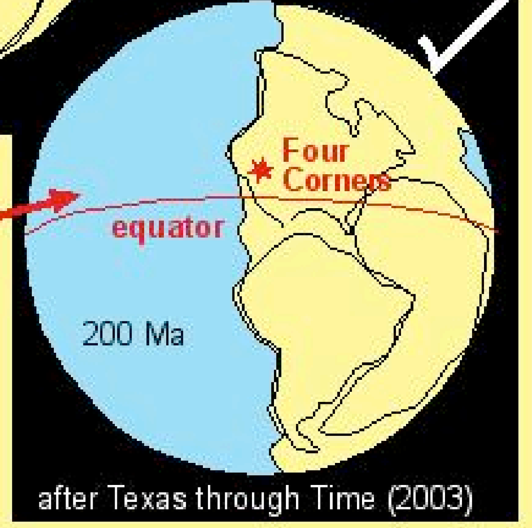
For the eolian units of the Plateau shown here in red, tropical westerlies were dominant for all but the DeChelly and part of the Coconino (after Blakey et al. (1988).



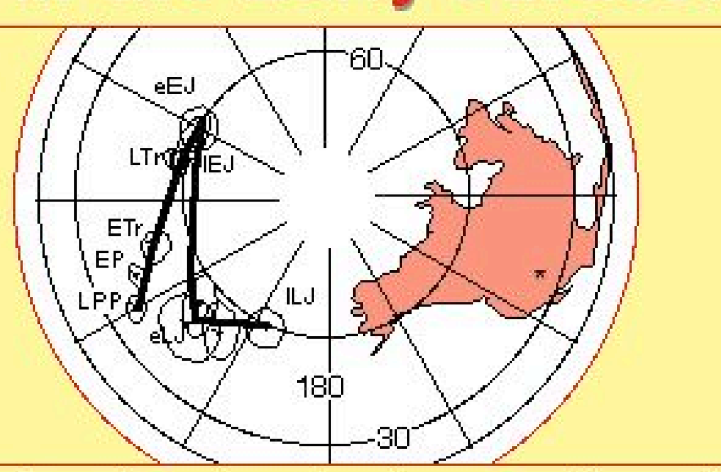
Where did the equator cross Pangea in the Early Jurassic?



In this reconstruction, Four Corners (common point of UT, AZ, CO, NM) is about 18° N of the equator.



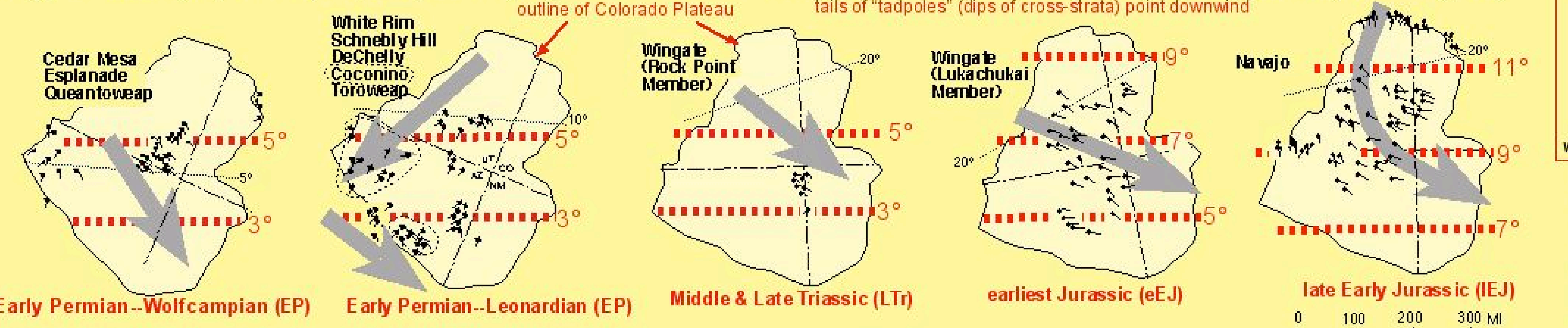
In this reconstruction, Four Corners is less than 10° N of the equator--a position that fits our new hypothesis for atmospheric circulation.



Two decades of paleomagnetic work on the Colorado Plateau by two independent research teams has shown that the Plateau lay at a low latitude at this time. The polar wander curve above summarizes the conclusions of Steiner, 1983, 2003; May & Butler, 1986; Bazard & Butler, 1991).

Dip directions of eolian sandtones provide key evidence:
Northwesterly winds that persisted for 100 million years make sense only at near-equatorial latitudes.

Using paleolatitudes (red) from the paleopoles (above right), the Four Corners moves only from 4°N to 9°N from Early Permian to Early Jurassic (100 million years).



The small amount of northward migration is corroborated by paleowind directions recorded by dip directions of eolian cross-strata.

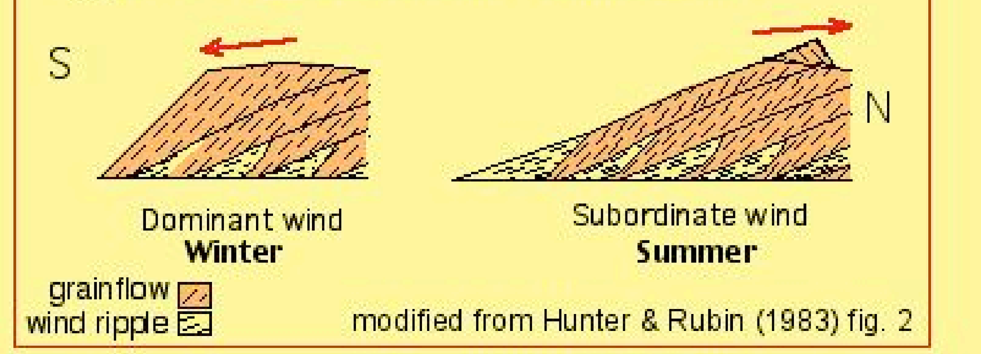
Northwesterly winds dominate from Early Permian to Early Jurassic.

Wind strength near the equator

Annual Cycles of Dune Migration

White Rim Ss along Green River, Wingate Ss on skyline

At several localities in southern Utah and northern Arizona, the lower part of the Navajo Sandstone contains depositional cycles involving large wedges of wind ripple laminae that intertongue with grainflow cross-strata. Hunter and Rubin (1983) referred to these as *compound cyclic crossbeds*. They interpreted the cyclicity as the product of fluctuating air flow: annual shifts in the dominant (dune-driving) wind direction led to erosion of the lee face and deposition of a wind-ripple-dominated wedge that was over-run by grainflow strata when the dominant wind resumed.



These large Jurassic dunes migrated about 1 meter per year. According to Hunter and Rubin (1983), 40 m-high dunes migrate about 1 meter per year if the annual mean wind velocity is 6 m/sec. The windiest nonpolar arid or semiarid modern region is coastal Patagonia, where the yearly mean wind speed is 9 m/sec. If our tropical westerly hypothesis presented here is correct, the dominant Jurassic winds blew for only three or four months per year (December-January). This suggests that the Jurassic winds were quite strong-- much stronger than any near-equatorial winds today.

References

Bazard, D.R. and Butler, R.F., 1991, Paleomagnetism of the Chinle and Kayenta Formations, New Mexico and Arizona: *J. Geophys. Res.*, 96, 9847-9871

Blakey, R.C., Peterson, F. and Kocurek, G., 1988, Synthesis of late Paleozoic and Mesozoic aeolian deposits of the Western Interior of the United States: *Sed. Geol.*, 56, 3-125.

Buckle, C., 1996, Weather and Climate in Africa. Addison, Wesley, Longman Ltd. 312 pp.

Chandler, M., Rind, D. and Ruedy, R., 1992, Pangaean climate during the Early Jurassic: GCM simulations and the sedimentary record of paleoclimate: *Bull. Geol. Soc. Amer.*, 104, 543-559.

Findlater, J., 1969, Interhemispheric transport of air in the lower troposphere over the western Indian Ocean: *Quart. J. Royal Meteor. Soc.*, 95, 400-403.

Hunter R.E. and Rubin, D.M., 1983, Interpreting cyclic cross-bedding, with an example from the Navajo Sandstone: in *Aeolian Sediments and Processes*, (eds Brookfield M.E. and Ahlbrandt, T.S.) (Elsevier, Amsterdam) 429-454.

Loope, D.B., Rowe, C.M. and Joeckel, R.M., 2001, Annual monsoon rains recorded by Jurassic dunes: *Nature*, 412, 64-66.

Loope, D.B., Steiner, M.B., Rowe, C.M., and Lancaster, N., *in press*, Tropical westerlies over Pangean sand seas: *Sedimentology*.

May, S.R. and Butler, R.F., 1986, North American Jurassic apparent polar wander—implications for plate motions, paleogeography and Cordilleran tectonics: *J. Geophys. Res.*, 91, 11,519-11,544.

Parrish, J.T., 1993, Climate of the supercontinent Pangaea: *J. Geology*, 101, 215-233.

Parrish J.T. and Peterson, F., 1988, Wind directions predicted from global circulation models and wind directions determined from aeolian sandstones of the western United States: *Sed. Geol.*, 56, 261-282.

Scotese, C.R., 2003, PALEOMAP, Earth History, Jurassic. (April, 2003)

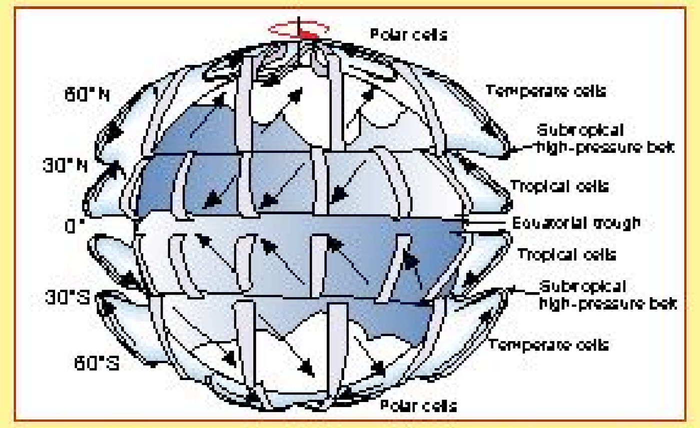
Steiner, M.B., 1983, Mesozoic apparent polar wander and plate motions of North America, in Reynolds, M.W., and Dolly, E.D. (eds.) *Mesozoic Paleogeography of the West-Central United States*: Rocky Mountain Paleogeography Symposium 2, Rocky Mtn. Section, SEPM, 1-11.

Steiner, M.B. and Lucas, S.G., 2000, Paleomagnetism of the Late Triassic Petrified Forest Formation, Chinle Group, western United States: Further evidence of "large" rotation of the Colorado Plateau: *J. Geophys. Res.*, 105, 25,791-25,808.

Steiner, M.B., 2003, A cratonic middle Jurassic paleopole: Callovian-Oxfordian pole stillstand (J-2 cusp), rotation of the Colorado Plateau, and Jurassic North American apparent polar wander. Tectonics, 22 (3), Art. No. 1020.

Texas Through Time, 2003, University of Texas Institute for Geophysics
http://www.ig.utexas.edu/people/staff/ian/
http://www.ig.utexas.edu/research/projects/plates/200.htm

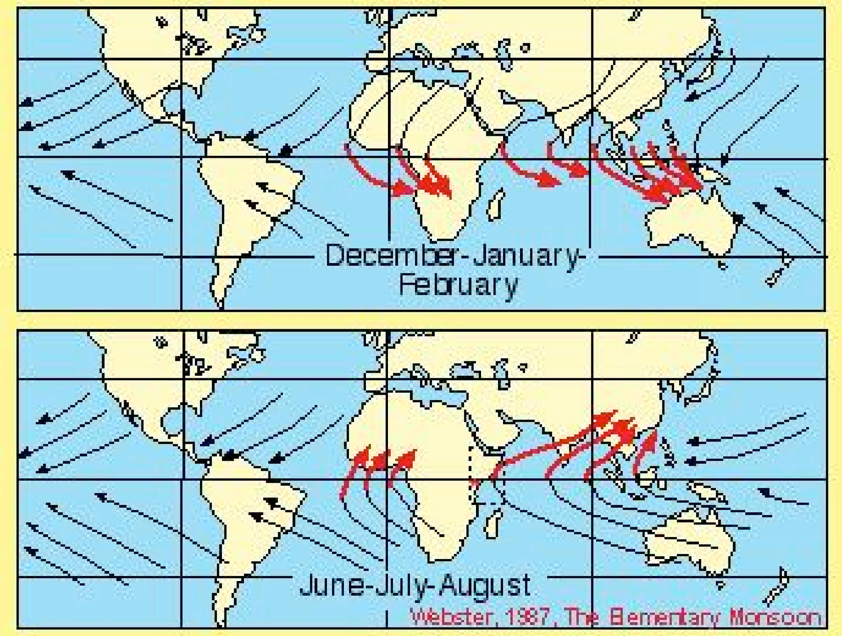
Webster, P.J., 1987, The elementary monsoon: in *Monsoons* (ed. Fein, J.S. & Stephens, P.L.) (John Wiley & Sons, New York) 3-32.

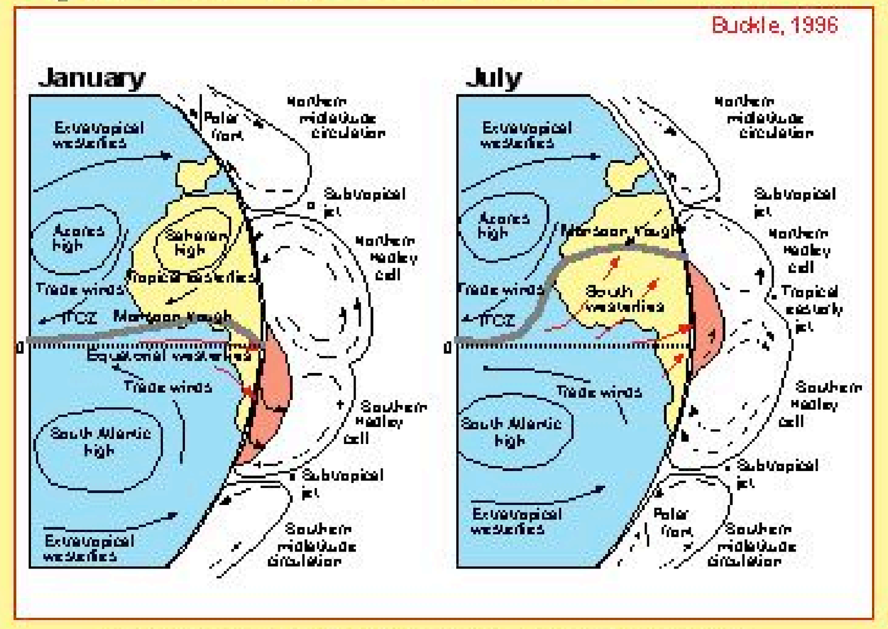


The diagram above is useful for visualizing the major wind systems of the western hemisphere. In the eastern hemisphere, however, the presence of large continents (Africa and Asia) in near-equatorial positions produces monsoonal surface winds quite different in direction from any shown above.

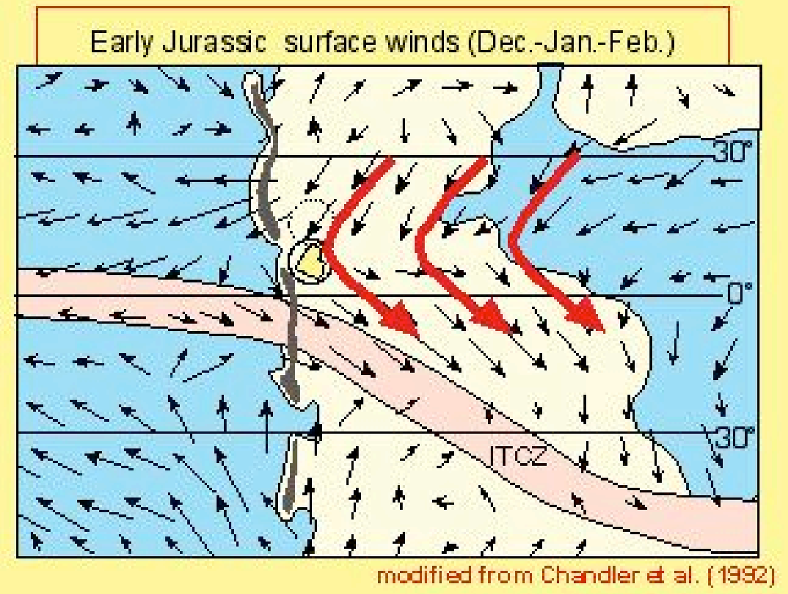
The red arrows on the map at right show cross-equatorial, tropical westerlies. When deep thermal lows develop over large continental areas in the summer hemisphere, they generate a steep pressure gradient. As trade winds in the winter hemisphere approach the equator, and the Coriolis force (which is zero at the equator) weakens, the air is drawn across the equator by the pressure differential. These winds flow at low level in a direction opposite to the trades, and are sometimes called the anti-trades.

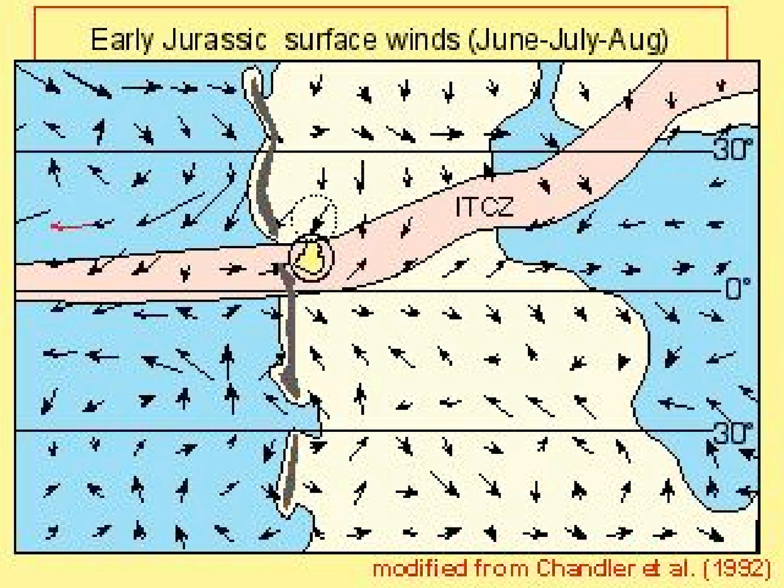
Modern and Ancient Tropical Westerlies





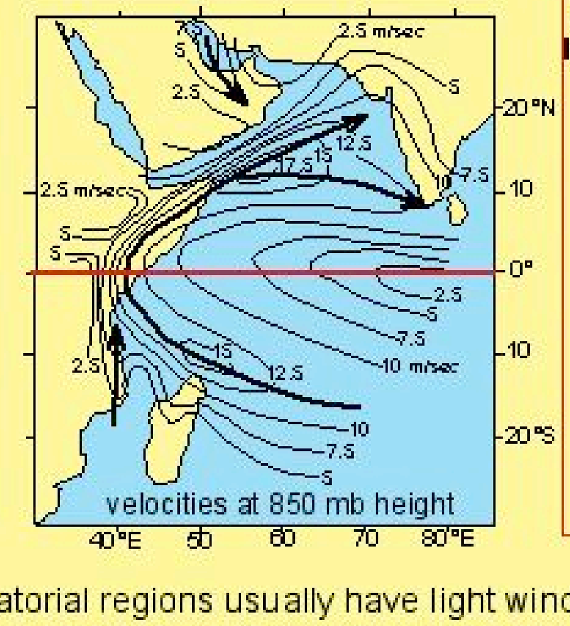
As shown above in red, tropical westerlies are low-level air flows.

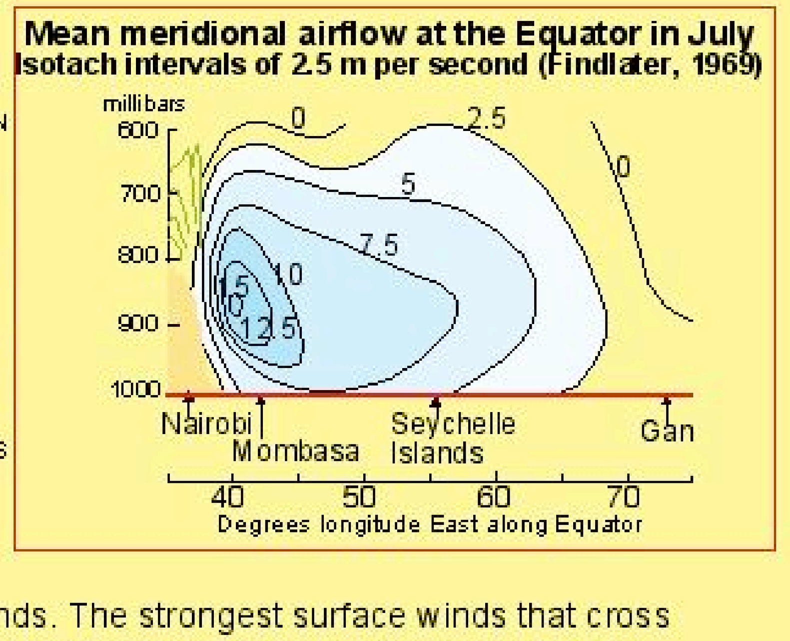


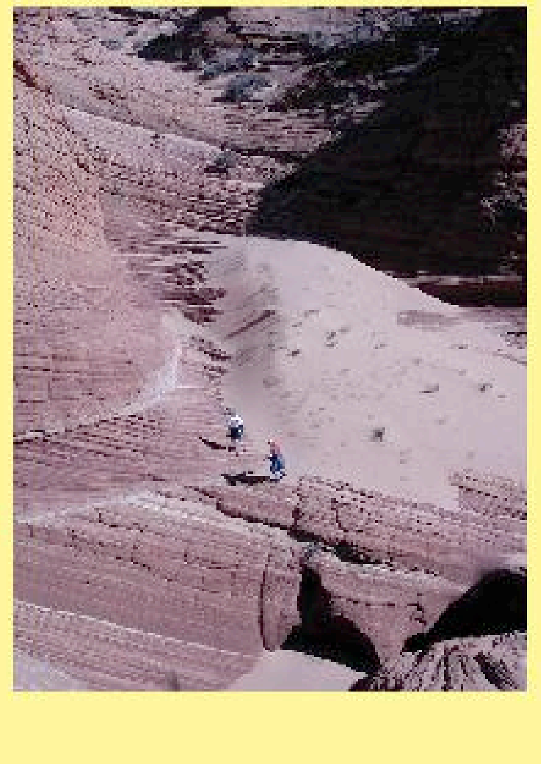


The Jurassic global climate model by Chandler et al. (1992) shows cross-equatorial westerlies in western Pangea. In the above maps, we have shifted the position of the Colorado Plateau 10° southward to conform to modern paleomagnetic information. This southward shift puts the Plateau in the belt of tropical westerlies during December, January, and February and thus brings agreement with the dip of cross-strata within the Navajo Sandstone. During June, July, and August the Plateau lies within the Intertropical Convergence Zone. Such a position helps to explain the evidence of heavy rain events (slumped and brecciated cross-strata). On map to left, red arrows show northeasterlies (trades) turning at about 10° N to become cross-equatorial westerlies.

Navajo Ss, Coyote Buttes South, Paria Plateau







Equatorial regions usually have light winds. The strongest surface winds that cross the equator today blow near the east coast of Africa. Only over a small part of the Earth's surface (for June, July, and August only) do mean velocities attain 6 m/sec.