Seasonal distribution of African savanna fires

**Donald R. Cahoon, Jr[*], Brian J. Stocks[†],
Joel S. Levine[*], Wesley R. Cofer III[*]
& Katherine P. O'Neill[‡]**

Reprinted from Nature • Vol 359 • 29 October 1992

Seasonal distribution of African savanna fires

**Donald R. Cahoon, Jr*, Brian J. Stocks†,
Joel S. Levine*, Wesley R. Cofer III*
& Katherine P. O'Neill‡**

* Atmospheric Sciences Division, National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia 23681, USA
† Great Lakes Forestry Centre, Forestry Canada, Ontario Region, 1219 Queen Street East, Sault Ste Marie, Ontario, P6A 5M7 Canada
‡ College of William and Mary, Department of Geology, Williamsburg, Virginia 23186, USA

SAVANNAS consist of a continuous layer of grass interspersed with scattered trees or shrubs, and cover ~10 million square kilometres of tropical Africa[1,2]. African savanna fires, almost all resulting from human activities, may produce as much as a third of the total global emissions from biomass burning[3]. Little is known, however, about the frequency and location of these fires, and the area burned each year[4]. Emissions from African savanna burning are known to be transported over the mid-Atlantic, south Pacific and Indian oceans[5,6]; but to study fully the transport of

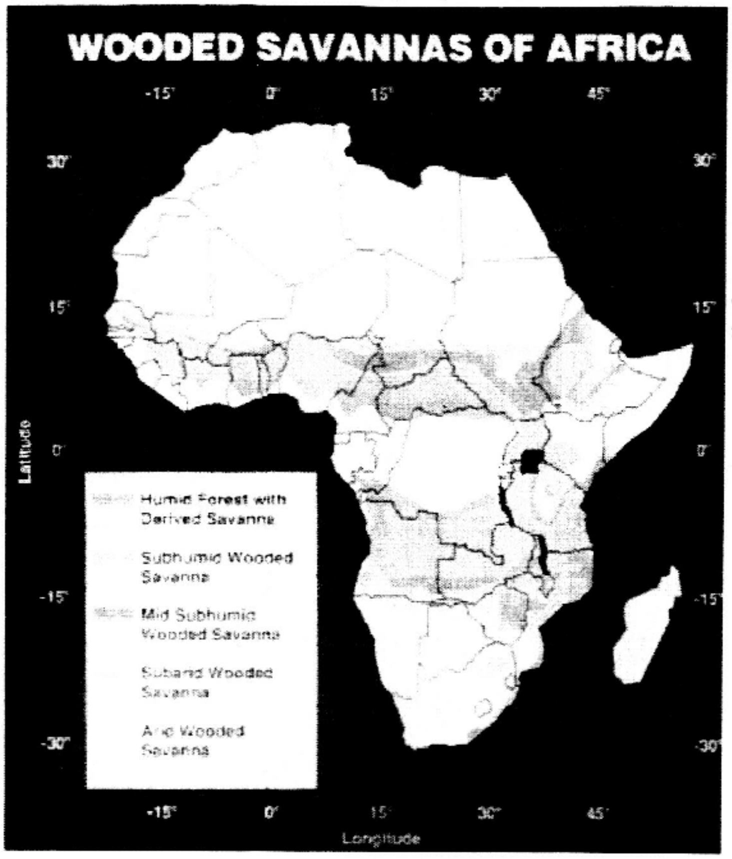
regional savanna burning and the seasonality of the atmospheric circulation must be considered simultaneously. Here we describe the temporal and spatial distribution of savanna fires over the entire African continent, as determined from night-time satellite imagery. We find that, contrary to expectations, most fires are left to burn uncontrolled, so that there is no strong diurnal cycle in the fire frequency. The knowledge gained from this study regarding the distribution and variability of fires will aid monitoring of the climatically important trace gases emitted from burning biomass.

The night-time low-light satellite imagery used here was acquired by the Defense Meteorological Satellite Program (DMSP) Block 5 satellites during 1986 and 1987. The satellites provide imagery primarily for use in weather forecasting, in snow and ice boundary observation, and in cloud studies[7,8]. But night-time imaging of the Earth also records man-made and natural lighting such as cities, fires, lightning and auroras8. We used local midnight imagery to observe light sources on the Earth's surface in the region of Africa shown in Fig. 1. The upwelling terrestrial light is measured in the 0.4-1.1 micro-m range at a resolution of 2.7 km. One problem with the use of DMSP imagery is that variations in intensity cannot be quantitatively interpreted, as the images are archived in photographic form, rather than in digital form, and calibration after processing is impossible. Even so, because of the high contrast between the background and the light sources, the light sources can easily be distinguished qualitatively and mapped. Cities are isolated and removed, as their location does not vary from month to month, leaving only the time-varying light sources. Throughout the study years, visible imagery was obtained for every fourth day on average. Although these images are not spread out evenly, the temporal distribution through most months is good. We produced mosaic images showing light from the time-varying sources averaged over each month. We also examined the daily spatial distribution of fires for each month to check that each mosaic is representative of the actual burning throughout the month.

Analysis of monthly DMSP imagery during 1986 and 1987 indicates that January is the peak season for African savanna burning north of the Equator. The January precipitation analysis shows nearly all of the savannas north of the Equator receiving less than 25 mm of precipitation. The Northern Hemisphere savannas burn extensively during this time of year and have been widely studied on the regional scale[9-11]. In the January DMSP composite images (Fig. 2a), a wide band of fires can be seen stretching across the savannas south of the Sahara desert. The 'speckled' light sources represent the locations of active fires sweeping across the continent. The northern edge of this active fire band has been reported previously[8]. The majority of these fires are initiated by human activities.[5,6]

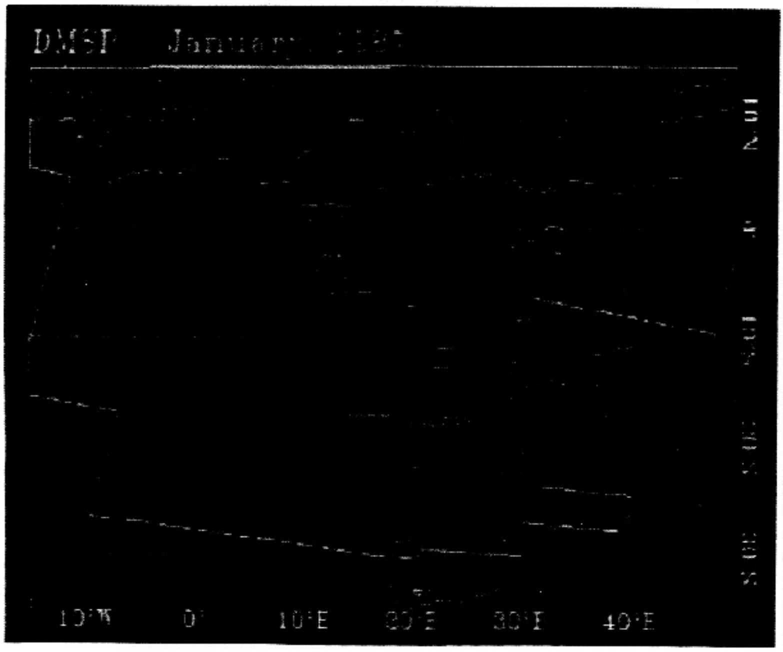
During the first half of the year, the dry season shifts from the Northern Hemisphere to the Southern Hemisphere. In February and March, precipitation increases gradually from south to north across the Northern Hemisphere African savannas, and there is a noticeable drop in the frequency of fire activity. By April, few lights exist across the entire African continent except in populated and industrial areas, and savanna burning in both hemispheres is at a minimum. From March to June, drier conditions spread over the Southern Hemisphere savannas from Namibia eastward towards the interior of southern Africa, and fire activity increases rapidly over the interior southern Africa savannas. By May, burning activity is widespread in Angola, Zambia, southern Zaire and Zimbabwe. In June, burning is at a peak in southern Zaire (Fig. 2b and c) with a sinusoidal pattern defining the northern edge of the fires. This pattern follows the ecosystem boundary between subhumid forest and the equatorial topical rainforest in north and central Zaire, and also appeared in 1979 DMSP imagery. Some fire activity is also apparent in eastern Africa in the nation of Tanzania, but little activity is identifiable in Mozambique to the south.

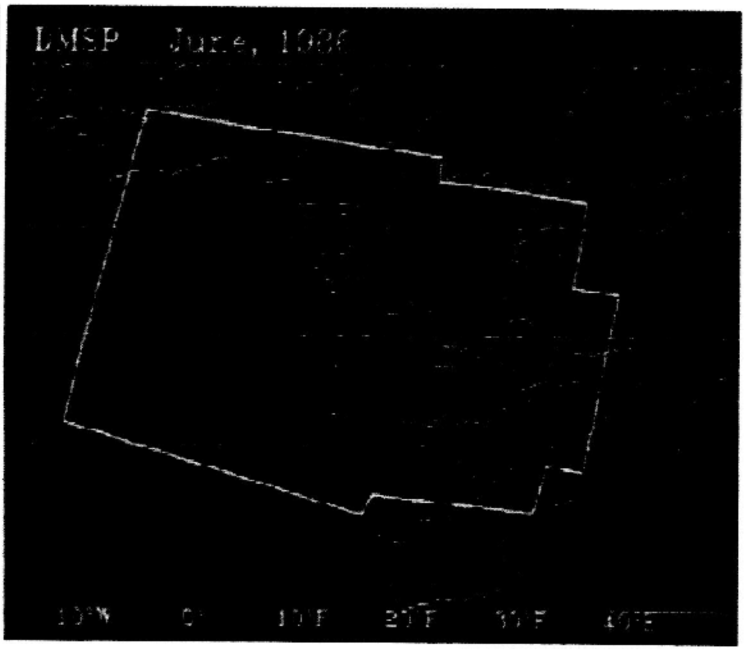
From July to October, savanna burning increases in the eastern countries and wanes in some western and interior nations south of the Equator. During July and August, the fire activity slowly drops off in Zaire due to increasing precipitation, there is little change in fire activity over Angola, and fires increase in Tanzania. Through the months of August and September, drier conditions extend to the eastern coast of southern Africa, and fire activity increases in Tanzania and Mozambique (Fig. 2d). In 1987 burning activity in Angola dropped off substantially by September, but in 1986 it required a few more weeks because



precipitation increased more slowly in that region. In October, the greatest fire activity across the southern African savannas occurs in the southeastern nations. During October, moist conditions return to most of the interior nations south of the Equator,

FIG. 1 A gradual transition of the savannas, influenced primarily by precipitation, takes place outward from the tropical rain forest of equatorial Africa, with wooded humid savannas giving way to savanna grasslands, semi-arid grasslands, and desert, respectively.





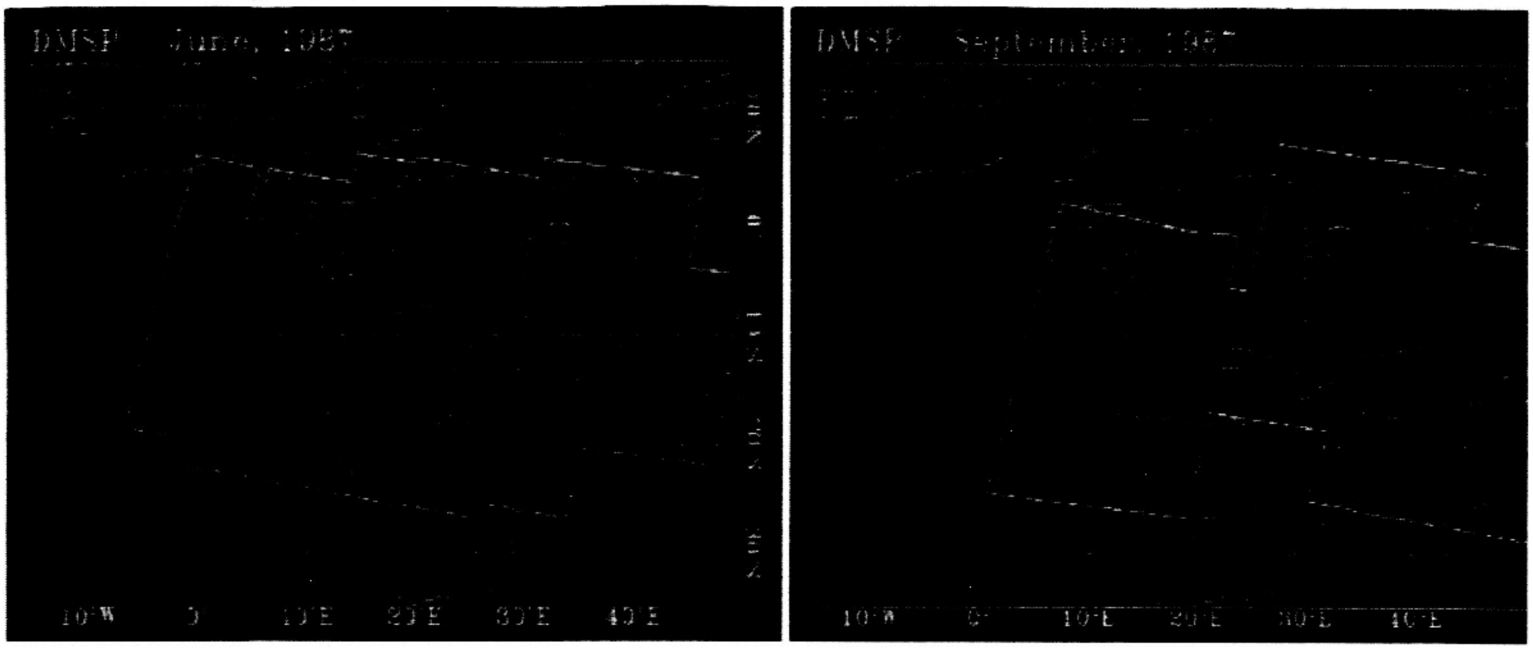


FIG. 2 Monthly DMSP mosaics for 1987. Each scene shows red 'dots' on a black background with a superimposed white outlined map of Africa. The red dots map the locations of low-level light emitted from fires. The yellow polygon outline delineates the out boundary of the available clear-sky satellite coverage used to produce the mosaic.

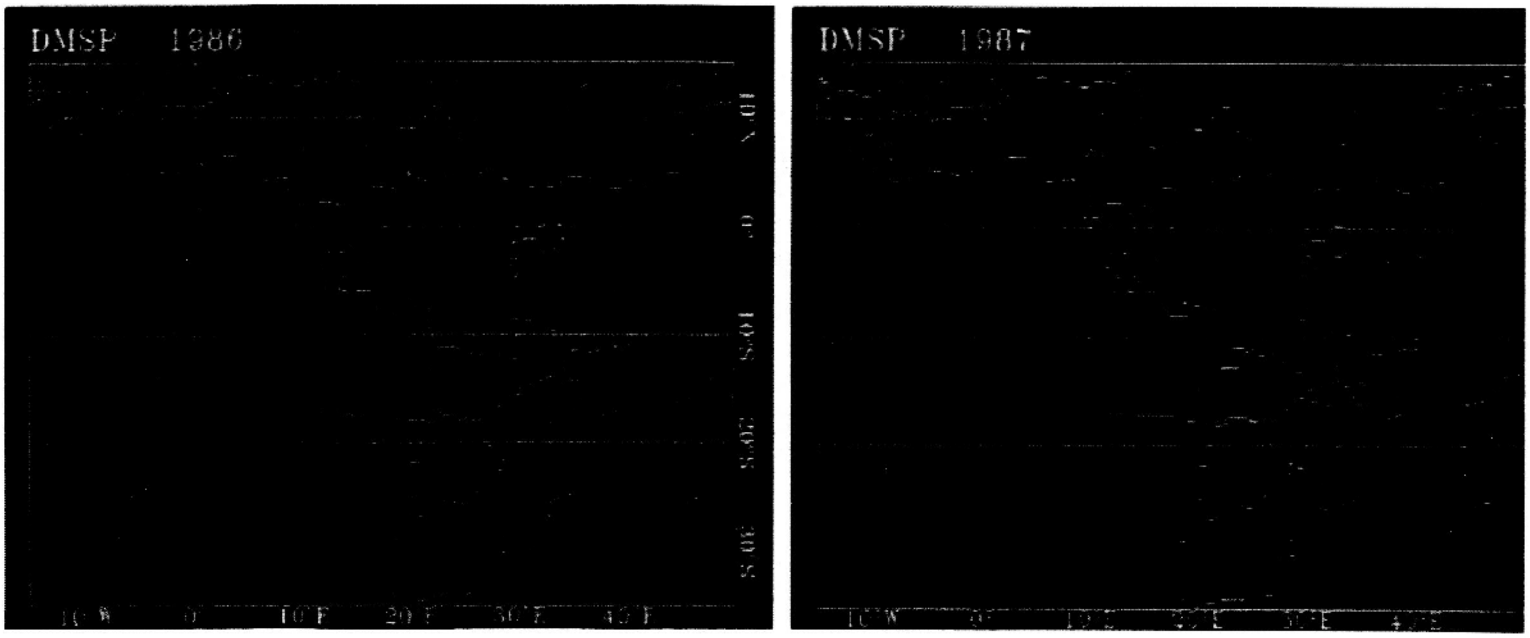


FIG 3 1986 and 1987 DMSP mosaic, consisting of all the monthly mosaics and showing the distribution of fire activity across all of the African savanna regions.

---

and dry conditions remain along a path from the coast of Namibia to Lake Malawi in the east. Fire activity seems most widespread in Tanzania, and i s decreasing in neighbouring countries. This observation is consistent with results from the 1984 measurement of air pollution from satellites (MAPS) shuttle experiment which flew in early October and measured the highest middle tropospheric carbon monoxide year, the fires are most frequent during the dry period when the herbaceous material has completely withered.

It is readily apparent that to study African savanna burning thoroughly, an extensive portion of the African continent must be examined and, for remote concentrations over the southeast African nations[12]. Photographs taken during the 1984 MAPS shuttle flight also showed many active fires burning in Mozambique[3,12].

Satellite coverage was scarce or unavailable for the remaining months in the year, so that the demise of the Southern Hemisphere African savanna burning cycle and onset of the Northern Hemisphere African savanna burning cycle could not be analysed. November 1986 imagery was available (but limited) and showed no fire activity in the west and central nations in the southern African continent. From the actual and mean precipitation patterns and the previous observations, it is expected that fire activity south of the Equator will continue along the east coast nations into November but will cease by December. At the same time, fire activity will return to the interior African savannas north of the Equator first, and spread to the far west later in December. Hence, the annual burning cycle of the African savannas continues.

All of the monthly composites for each year were combined (Fig. 3) to illustrate the extremity of savanna burning in Africa. From the annual mosaics it is immediately obvious that a large percentage of African savanna is affected annually by fire and that the overall patterns are the same. The regions that show the highest fire frequency are southern Zaire, Angola, northern Mozambique, southern Tanzania, eastern Central African Republic and southwestern Sudan. In areas such as southern Zaire (in June) where the fire frequency is extremely high, the burned areas are more likely to be homogeneous in coverage. The spatial distribution of Northern Hemisphere African fires is consistent with the work of Goldammer[13] (based on the spatial extent of the northern savannas). From our multiyear study (including some 1979 DMSP imagery), the examination of the mean[14] and actual precipitation patterns, the knowledge that the burning is the result of enhancing agricultural productivity and is tied to a seasonal cycle, and the consistency with the MAPS mission data and photography, it seems that the overall tire distribution does not vary much from year to year. This can probably be attributed to the distribution of the human population, which, in an agricultural society, is not likely to shift rapidly on a year-to- year basis. Any interannual variability is most probably attributable to variations in the precipitation patterns.

Two other observations are made from the DMSP imagery. There is a great deal of fire activity well into the night, and the night-time frequency and distribution of fires resemble those mapped during the daytime in some regional studies. Once the fires are started, in most cases they are left to burn uncontrolled, and as the satellite imagery shows, fire frequency may not be as strongly diurnal as is commonly sensing investigations, a substantial volume of imagery must be acquired. Because of the extent of the savannas and the difficulty of working with such a volume of satellite imagery, the continental distribution of African burning has remained largely unstudied. Previous remote sensing investigations of African savanna fires have been regional in scope, not recognizing the shifting distribution of the fires such as the eastward progression of fire activity across the Southern Hemisphere savannas, or establishing its relations'hip with atmospheric circulation. Emission estimates from savanna burning have been based largely on statistical reports, which contain a great deal of uncertainty. Knowledge of the temporal and spatial variability of the African savanna fires, as shown here, can greatly reduce the extent of satellite coverage required to determine and monitor the total area burned throughout the year. The reduction in required satellite coverage makes it feasible to monitor and estimate the extent of the burned savanna, and, from the area estimates, the atmospheric trace gas emissions can be derived.

The transport of African savanna fire emissions depends on time, geographical location, altitude and winds. Given the expected geographical location of the fires in the Southern Hemisphere, fire emissions are more likely to be transported towards the mid-Atlantic Ocean. Emissions from savanna fires that burn in September and October around Tanzania are more likely to be transported westward towards the Atlantic Ocean rather than the Indian Ocean. Emissions from Northern Hemisphere fires are almost always transported to the west, but cross-hemispheric transport largely depends on the time of year. The wind flow also varies with altitude, and emissions at higher altitudes are more likely to be transported to the west by the trade winds. Atmospheric instability is a primary mechanism for carrying savanna fire emissions to higher altitudes, but under some atmospheric conditions, large and intense fires can inject the emissions to higher altitudes as well. Knowledge of the savanna fire location relative to the wind flow and zones of instability is extremely important in evaluating savanna fire emission export off the African continent.

Savanna burning predates the presence of humans in Africa, the result of lightning-initiated fires, but human population pressures have greatly increased its extent and frequency[13]. With the increase in fires comes the increased environmental and climatic impact of trace gas cycling and photochemistry, greenhouse gas production, acid rain deposition, and the influence of believed. The DMSP imagery occasionally shows random fires in the rainy areas. Although random burning may take place throughout the

fire-produced aerosols on tropical cloud behaviour. Only through the combined knowledge of the distribution of African savanna fires, fire emission estimates and atmospheric circulation can we further our understanding of how the fire emissions affect both the biosphere and the atmosphere. As a step towards that understanding, this study demonstrates the spatial and temporal (seasonal and daily) shifts in African savanna burning and should help satellite coverage to be tailored to maximize its efficiency for estimating burned savanna.

Received 11 March; accepted 25 September 1992.

1. ***Delmas, R. A., Loudjani, P., Podaire, A. & Menaut, J in Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications (ed. Levine, J. S.) 126-132 (MIT Press, Cambridge, Massachvssetts, 1991).***
2. ***Phillips. J. Proc. 4th Ann. Tall Timbers Fire Ecol Conf, Tallahassee 7-1 09 (Tall Timbers Research Station, Tallahassee, Florida, 1976).***
3. ***Andrea, M. 0. in Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications (ed. Levine, J. S.) 3-21 (MIT Press, Cambridge, Massachusetts 1991).***
4. ***Brustet, J. M. et al in Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications (ed. Levine, J. S.) 47-52 (MIT Press. Cambridge. Massachusetts. 1991).***
5. ***Levine, J. S. Global Biomass Burning: Atmospheric, Climate, and Biospheric Implications (ed. Levine, J. S.) (MIT Press, Cambridge, Massachusetts, 1991).***
6. ***Crutzen, P. J., & Andreae, M. 0. Science 250, 1669-1678 (1990).***

7. Sullivan, W. T. III Int J. Remote Sensing 10(1), 1-5(1989).
8. Croft, T. A. Scient Am, 86-98 (July, 1978).
9. Frederiksen. P., Langass. S. & Mbaye, M. in Fire in the Tropical Biota: Ecosystem Processes and Global Challenges (ed. Goldammer, J G.) 401-416 (Springer, Berlin 1990).
10. Malingreau, J. P. in Fire in the Tropical Biota: Ecosystem Processes and Global Challenges (ed. Goldammer, J. G.) 338-370 (Spinger, Berlin, 1990).
11. Menaut, I, Abbadie, L., Lavenu, F., Loudjani, P. & Podaire, A. in Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications (ed. Levine. J S.) 133-142 (MIT Press, Cambridge, Massachusetts, 1991).
12. Reichle, H. G. Jr et al. J geophys. Res, 95,9845-9856 (1990).
13. Goldammer, J. G. in Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications (ea. Levine, J. S.) 83-91 (MIT Press, Cambridge, Massachusetts. 1991).
14. Shea. D. J. Natn. Center Atmos. Res. Tech. Note 269+STR (1988).

Last Updated: 10/01/2002 12:44:43
Web Curator: P. Kay Costulis (p.k.costulis@larc.nasa.gov)
Responsible NASA Official: Dr. Joel S. Levine, Atmospheric Sciences Competency

Feedback on Langley Products and Services