Biomass Burning and Global Change
Volume 1
Remote Sensing, Modeling and Inventory Development, and Biomass Burning in Africa

edited by Joel S. Levine

The MIT Press
Cambridge, Massachusetts
London, England

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Use of the Earth Observation System in the Space Shuttle Program for Research and Documentation of Global Vegetation Fires: A Case Study from Madagascar

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Madagascar is the world's fourth largest island with an area of about 587 000 km^2 and well known for biodiversity of landscapes, flora, and fauna and for its richness of endemic vegetation. According to White (1983) about 20% of Madagascar's flora is endemic. High landscape diversity is not only the result of topography and distinct climatic differentiation but also of human impacts. In the late Quaternary period, fires seem to have influenced the island's vegetation before the presumable arrival of humans on the island (Burney 1987). Paleo-Indonesians were the first immigrants to the island and practised swidden agriculture and pastoralism in which fire was an inevitable basic tool for clearing land and maintaining secondary grassland vegetation (Battistini and Verin 1972).

The original extent of Madagascar's rain forests has been estimated at 11.2×10^6 ha. Evaluation of historic aerial photographs and modern satellite imagery shows that between 1950 and 1985 ca. 111 000 hectares were deforested annually (Green and Sussman 1990). Today approximately one fourth of the forest formations of the prehuman era is left. Still today fire is the main tool in swidden agriculture and maintenance of secondary formations. No reliable statistical data on the extent of fires in forests, grasslands, and agricultural systems are available. Recent statistics compiled by the Forest Service (Direction des Eaux et Forêts) differentiate between savanna/grassland fires and forest fires. According to these data ca. 95% of all surface burned between 1987 and 1990 was in savanna-type ecosystems, averaging 440 000 ha yr^{-1}.

Study Area

The region of Beforona is in the humid zone of Madagascar and in the center of the fire observations by the STS-60 space shuttle mission. Meteorological data were collected in Beforona village (18°53′20″S, 48°38′30″E) which is in midst of the Terre-Tany project area, a Swiss-Madagascan research cooperation project in which different vegetation types are studied in function of distance (ecological gradient) to the primary forest (Zurbuchen 1993).

The dwellers of this region, the *Betsimisaraka*, are living at the forest edge. The cultural system based on fire cannot be, in this region, denominated as shifting cultivation in the strict sense. Primary forest is generally burned after selective exploitation, but most present burning activities are in secondary vegetation (locally called *savoka*; figure 22.1). The quantities of the dried plant biomass determine intensity and impacts of the fire: Aboveground biomass is ca 150–250 txha^{-1} of the forest already selectively exploited (2 to 5% of observed fires), and 25–50 txha^{-1} in young *savoka*. *Savoka* burning represents 95% of burned biomass in the study zone. Sowing is conducted directly after the fire. Cultivation and weeding follow until harvest between April and June. Harvest residuals are left on the fields for soil protection.

Environmental Consequences of Fire

After three or four fire cultivations on fallow lands the percentage of forest species is reduced drastically (ca. 80% of species are lost). The erosion rate is extremely high on steep and unprotected sites, particularly as a consequence of cyclones and landslides.

Long-term influence of fire has led to the formation of savannas on the ridges and tops of mountains characterized by species like *Pteridium aquilinum*, *Dicranopteris linearis, Sticherus flagellaris*. Degraded lands are occupied by *Imperata cylindrica*.

The emission from forest and grassland burning adds to the pan-African pyrogenic emission load in two ways (Garstang et al. 1995). Westerly zonal transport of air masses originating in the Indian Ocean region consist of maritime air not influenced by pyrogenic emissions. These air masses become affected by fire

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Figure 22.1 Fresh *tavy* (forest conversion burn) in primary mountainous rain forest

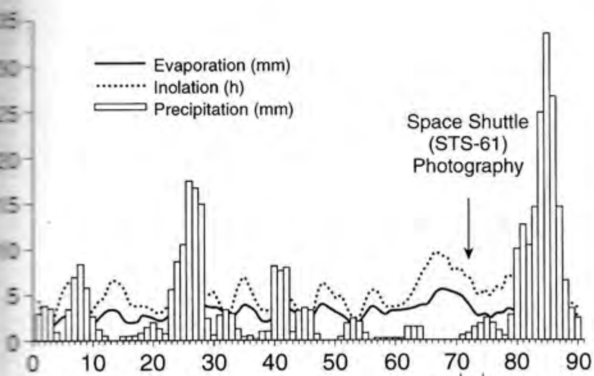

Figure 22.2 Weather observations (3-day average) in Beferona Village, Madagascar, during the period 1 October to 31 December 1993. Photographs were taken from the Space Shuttle STS-61 just before the end of the dry season.

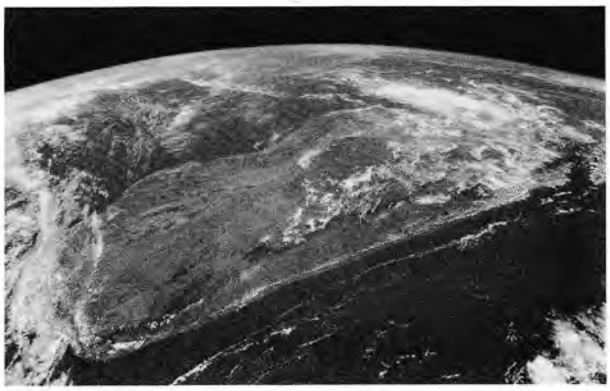

Figure 22.3 View of Madagascar in the morning of 11 December 1993 at 1020 local time (0720 GMT). No burning activities can be observed at this time of day.

Figure 22.4 Close-up of the south-central part of Madagascar on the morning of 8 December 1993 at 0937 local time. Vegetation patterns are clearly visible (dark: mountain rain forest; light: secondary scrub, dry forest, and savanna)

Figure 22.5 Close-up (looking south) of the east coast of Madagascar during afternoon overpass of 9 December 1993 at 1700 (same overpass as in figure 22.7)

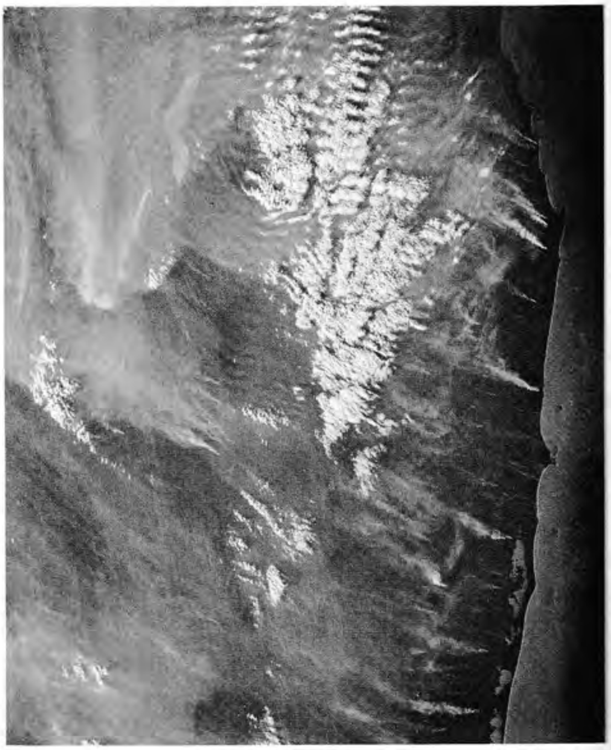

Figure 22.6 Close-up (at nadir) of the east coast of Madagascar during afternoon overpass of 9 December 1993 at 1700 local time (same overpass as in figure 22.7)

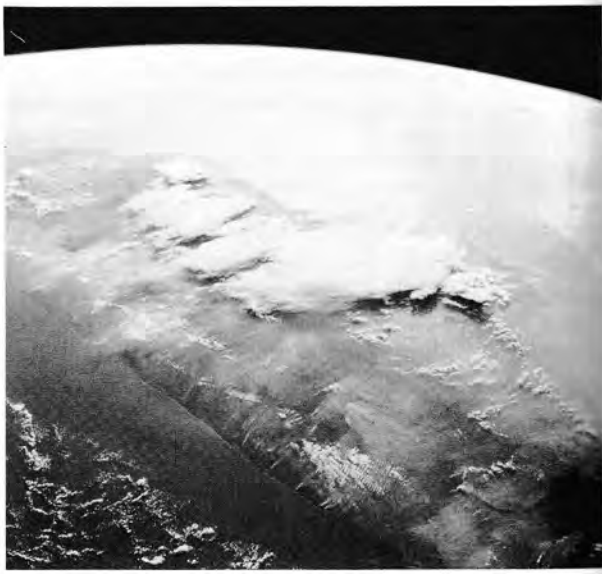

Figure 22.7 Looking south on Madagascar from spacecraft altitude 320 mm asl in the afternoon of 10 December 1993 at 1704 local time

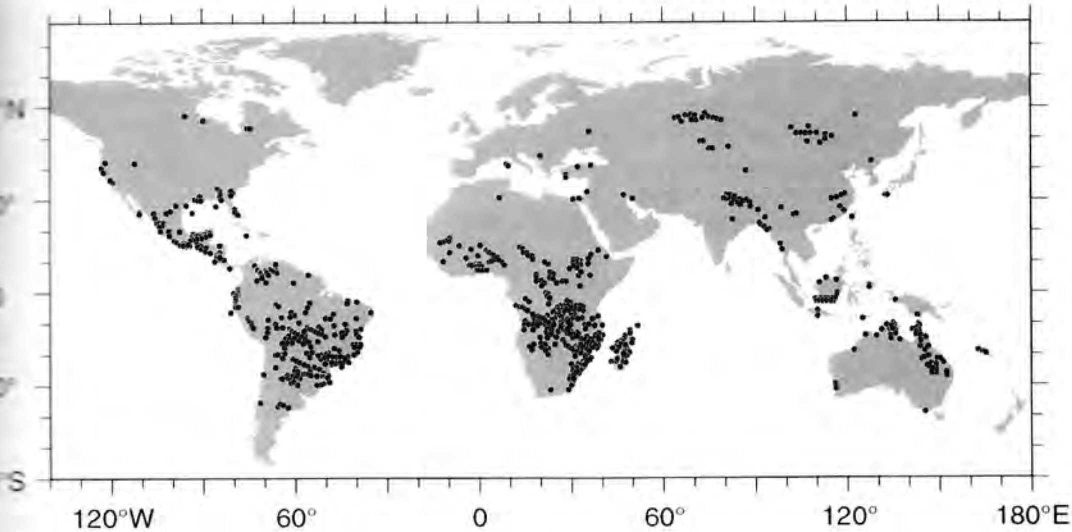

Figure 22.8 Global distribution of fires as seen from manned space flights. Dots are the center points of photographs showing smoke from vegetation fires. Source: Andreae 1993

emissions when crossing Madagascar and entering the continent.

The air masses may also be on recirculation mode, originating in the southern African subcontinent where they were already affected by pyrogenic products. These aged continental fire emissions are then refreshed with Madagascar's emissions and recirculated to the continent.

Documentation of Fire from Space

The use of the history of manned space missions to document vegetation fires has been described earlier (Helfert and Lulla 1990; Wood and Nelson 1991; Andreae 1993, figure 22.8). In this case study 163 orbits of the Space Transportation System 61 (STS-61) mission between 2 and 13 December 1993 were evaluated. STS-61 (Space Shuttle *Endeavor*) nominal altitude was 587 km, inclination 28.5°. The photographs were taken with a NASA-modified Hasselblad 500 EL/M, 70-MM (NASA 1994).

The observation period was at the end of the dry season in Madagascar during which the last cultivation fires had to be performed in order to take advantage of the upcoming rainy season (figure 22.2).

The photographs show a typical diurnal pattern of burning. In the mornings of the overpasses the whole island was completely smoke-free (figures 22.3 and 22.4). In the afternoon hours when fuels become drier and burning efficiency high enough to guarantee a sufficiently hot fire to clear the site, smoke palls were abundant (figures 22.5–22.7). These photographs show the transport patterns of smoke, which is driven west towards the African continent (Mozambique, Tanzania).

Conclusions

Earlier observations of fires from space have proved useful in visualizing regional distribution patterns of fires and trajectories of smoke transport. The STS-61 observations for the first time were closely linked with ground observations in order to explain diurnal patterns of fire occurrence and pyrogenic emissions. Subsequent Space Shuttle missions in which large fire experiments were involved have failed so far. This is mainly due to lack of communication between remote experimental field sites and the NASA facility at Johnson Research Center which coordinates the Earth Observation Programme. Future experiments under the umbrella of IGAC/BIBEX should coordinate with Space Shuttle missions and with the permanently manned space station MIR.

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