Regional Fuel Load Modeled for Two Contrasting Years in Central and Southern Africa

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Introduction

The spatially and temporally explicit distribution of available fuels is mandatory to characterize and quantify the pyrogenic emissions over the region of southern Africa (see Korontzi *et al.*, this poster session). This study focuses on characterizing and quantifying the available fuel types and their loads using a new Net Primary Productivity model based on Light Use Efficiency approach over a given growing year (from Sept. 1 to Aug. 31), with a 15-day time step.

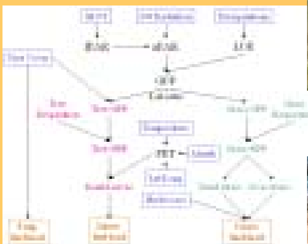
The objectives of the study are:

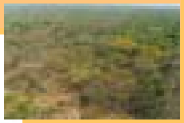
1. To present the Net Primary Production model with the fuel allocation
2. To conduct a sensitivity analysis of the model based on the 1999-2000 growing year
3. To compare the 1991-1992 and 1999-2000 growing years.

Please note that the dry season field campaigns of SAFARI2000 and its ancestor SAFARI92 were conducted following two climatically contrasting years (1991-1992 was abnormally dry whereas 1999-2000 was very wet).

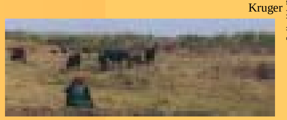
Inputs origins

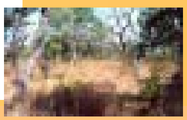
• Tree Cover map 1km² pixel size resolution: Geography Department of the University of Maryland (Hansen et al. 2000).
• Temporal change in NDVI 8 km² pixel size resolution: Global Inventory Mapping and Modeling (GIMMS)
•Monthly mean temperature and monthly cumulated precipitation 0.5 deg pixel resolution: interpolation over the Southern Africa using climate station data extracted from NCDC
•Total short wave incoming radiation 2.5 x 2.0 pixel size resolution: compilation on a 15-days basis - DAO
•Herbivory information was provided by Peter de Leeuw





Fuel Load Model Organization





Model description

Step 1: identification of the leaf out time step of grass layer from the Normalized Difference Vegetation Index (NDVI) time series. Leaf out occurs when the NDVI records its maximum increase relative to the previous time step.
Then within each time step,
Step 2: Light-Use Efficiency (LUE) calculation based on site-level modeling and field data along the Kalahari Transect (Caylor *et al*. this poster session). Calculation involves the Tree Cover (TC) layer and the precipitation from the previous and current months (30% and 70% weights, respectively).
Step 3: The absorbed Photosynthetically Active Radiation (aPAR) is obtained from the total incoming shortwave radiation (also named incident Photosynthetically Active Radiation) multiplied by the fraction of Photosynthetically Active Radiation (fPAR). This fPAR is estimated from the NDVI.
Step 4: Gross Primary Production (GPP) is calculated as the product of LUE with aPAR.
Step 5: The GPP is partitioned between tree and grass components based on the ratio of tree leaf area to grass leaf area (LA ratio). LA ratio has been developed as a function of TC using field data. If current time step is before the NDVI-detected leaf out the GPP is totally assigned to tree component otherwise it is partitioned according to LA ratio.
Step 6: The Net primary Production (NPP) is calculated by subtracting respiration from GPP. Three distinct sources of respiration are taken into account namely the leaf canopy respiration (dark respiration), the non-leaf maintenance respiration (function of biomass), and the synthesis respiration to create new tissue. Each of these three respirations is calculated separately for tree and grass components using various parameters extracted from literature. For each component, total respiration is then removed from GPP to produce NPP (NPPgrass and NPPtree).
Step 7: the dying material is subtracted from NPPgrass and NPPtree loads during the current time step. This transfer from live to dead material (namely dead grass and litter for dead tree leaves) is based on the index of water availability. This index is assessed by calculating first the Potential Evapo-Transpiration (PET) based on the classic Thornthwaite method (Rosenberg et al. 1983) and then by calculating the ratio of Precipitation to PET. When the index is equal or greater than 1 (Precipitation ≥ PET) there is no material death and the NPP of the current time step is added to the previous time step. When the index is less than 1, death is proportional to (1-index) divided by a given factor. Since trees are assumed to be more resistant to water stress on a short term period at least, the tree factor is higher than the grass one (so death is less important), and there is a cumulative effect of water stress through time up to the total death of all living material in case of prolonged drought period as it is usually occurring near the end of the dry season.
Step 8: Grass fuel loads (live and dead) are also affected by grazing where data of herbivory are available. For a given location, the amount of grass depleted by grazing is set constant over the year according to the number of LiveStock Units (LSU), which corresponds with the conversion of the different herbivore types into standard LSU. Grazing removes preferentially live grass but can also reduced dead grass if there is not enough food.
Step 9: the final step synthesizes the different components with the live tree leaves which are not considered as fuel since Southern African fires are mainly surface fires, and the different fuel types with their available quantity: Litter as dead tree leaves, Dead grass, Live grass, Small diameter twigs. This fuel type is not part of the NPP model but has been extracted from empirical relationships based on field measurements relating the twig load to the TC. The available twig load is set constant over the year.

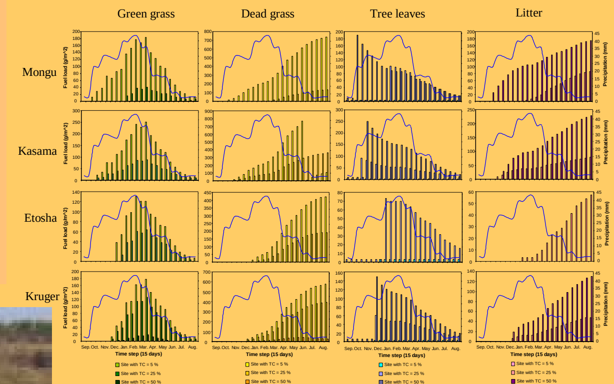
Simulation

The model offers two running options. Figure A presents outputs from the "complete run" option to cover the overall southern African region, while the "pixel run" can be used to focus on specific area. The sensitivity analysis is computed from the "pixel run" option by selection of 6 regions to be representative of Southern Africa. Both options are used to compare and contrast 1991-1992 and 1999-2000 from both general and specific points of view.

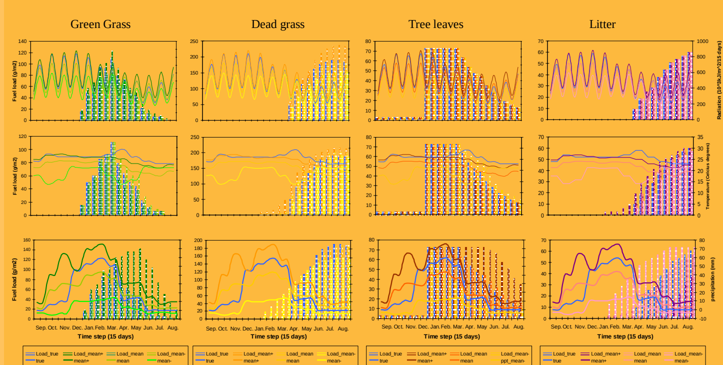
Standing dead grass load in August 2000 (end of season 99_00)

Figure A

1. How Does the model work?

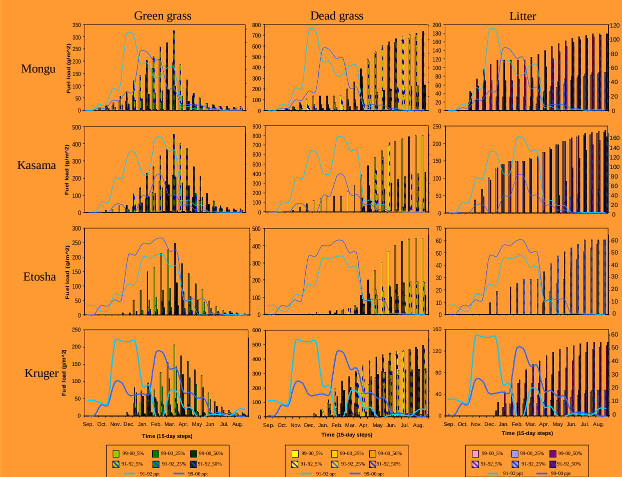


When all 1999-2000 climatic variables are set constant and are equal to the monthly mean values over all of southern Africa:
•Differences among sites within a region result from the varying TC and trends seem to reflect reality: the higher the TC, the lower the grass load (live and dead), and the higher the tree leaves loads (live and dead). When grass growth does not start synchronic, it is delayed in the higher TC sites. Grass death starts at least 15 days after the growth start.
•Differences among regions are due to differences in NDVI reflecting the effect of aridity gradients: Kasama, on the moist end of the gradient (latitude and longitude), experiences the heaviest productivity whereas Etosha and Kruger, on the arid end of the gradient (longitude and latitude, respectively), has the lowest productivity. Net primary productivity starts later in arid regions than in more humid regions.



The main hypothesis is that the model should be most sensitive to precipitation. To test this hypothesis, Etosha, as the most arid region, has been selected and sensitivity analysis has been performed on 99-00 climatic data. Results are presented for the forested site with 33% TC.
Precipitation is confirmed to be the most influencing climatic variable on fuel productivity. High precipitation levels sustain longer green grass production , maintain tree leaves alive, delay grass and tree leave death up to six months.
Temperature slightly influences productivity, with cooler temperature towards the end of the rainy season favoring green grass production and delaying tree leave death up to 3 months when 5ºC cooler (from 25 to 20 ºC).
Radiation fluctuation during the year does not affect the grass nor the tree productivity.

3. Comparison of 91-92 and 99-00 fuel productions



The two years present temporal and spatial contrasts:
•Spatially, 99-00 was the wettest year for the most arid region (Etosha), whereas it was the driest year for the most humid region (Kasama).
•Temporally, for regions such as Mongu and Kruger, 91-92 was particularly wet in the first half of the rainy season (Nov.-Jan.), whereas 99-00 was wet during the second half of the rainy season (Feb.-Apr.). The rainy season extended towards its end in 99-00 in most regions, which resulted in a potential late fire season beginning (mid- June 2000). On the contrary, the starting date for fire season in 91-92 could have been as early as beginning of May in arid regions.

If 250g/m² is assumed to be the minimum total fuel load to sustain fire spread (Hély *et al*. 2000), fuel loads present spatio-temporal variability as a consequence of the difference between the two years precipitation patterns that could sometimes compromise fire spread for some regions:

•Mongu presents same patterns for both 91-92 and 99-00 fire seasons with potential fire season starting in June and heavy enough total fuel to spread fire along the total TC gradient.

•Kasama presents same patterns as Mongu with fire season starting in June but fuel loads differ between years and inside each fire season:
- For the entire 1992 fire season available grass load for fire spread in low TC sites is below the minimum threshold, whereas total fuel load is important enough to sustain fire spread. At the regional scale, Kasama could be a "forest fire region".
- During the 2000 fire season, total fuel loads are above the minimum threshold for all TC sites.

•Etosha presents different potential fire season starts (May for 1992 and June for 2000). However, fuel load availability is below 250g/m² all over the TC gradient in 1992 which should have resulted in almost no fire that year. In 2000, on the contrary, due to high precipitation level for the region, total fuel load is high above the threshold for fire spread, so fire should be numerous.

•Kruger presents similar patterns to Etosha with fire season starting early in May with total fuel load high enough to spread fire all over the TC gradient and for both entire fire seasons.

Discussion and perspectives

- This new fuel load production model, based on a Net Primary Productivity model, seems to simulate efficiently the vegetation growth during the year. It would be valuable to implement the model to simulate productivity over several year to catch the effect of inter-annual variability and to avoid the reset action that occurs at the beginning of Sept., when some grass and litter fuel should be still on the ground. This multi-year product could increase insights on the effect of climate change over savanna ecosystems.
- The sensitivity analysis has showed for a particular site that precipitation is the driving climatic data for vegetation productivity. The next step will examine whether this trend exists all over southern Africa. Efforts will focus on the different sources for precipitation data (higher resolution ground data and/or remote sensed data) to select the best one in order to provide as input for the model the most accurate rain data.
- Herbivory should be implemented with up to date data sets where available and decomposers such as termites should be included where data are available.
- The lack of data on fine woody production in the tropical ecosystems forced us to develop a basic twig load production based on a regional empirical relationship involving the TC percentage but these loads reflect multi-year production. This should be improved in next stages.