Title
The next dimension: extending the time axis of global NPPestimates

ISBN
2908885166

Authors
Malmstrom, C. M.
Randerson, James T.
Thompson, M. V.
et al.

Publication Date
1995-08-30

THE NEXT DIMENSION: EXTENDING THE TIME AXIS OF GLOBAL NPP ESTIMATES

C. M. MALMSTRÖM*†, J. T. RANDERSON*†,

M.V. THOMPSON*, H. A. MOONEY*, and C. B. FIELD†

*Department of Biological Sciences
Stanford University
Stanford, CA 94305 USA

†Carnegie Institution of Washington
Department of Plant Biology
290 Panama St.
Stanford, CA 94305 USA

ABSTRACT:

Models of terrestrial productivity are now sufficiently mature to allow investigation of interannual variation in productivity at the global scale. The CASA model is a light-use efficiency model of NPP coupled with a Century-type model of soil organic matter processes. This paper describes the results of driving the CASA model with multiyear sets of AVHRR NDVI and climate variables to generate NPP estimates for the period 1982-1990. Temporal variation in productivity varied with vegetation class, as expected, with forested classes showing a smaller CV than non-forested classes. In all classes, except tundra, precipitation varied more than productivity. At the global level, an increasing trend in NPP was evident. The vegetation classes experiencing the greatest relative increase in NPP during this time period were the high-latitude systems.

KEY WORDS: NPP, Interannual variation, CASA model

1 - INTRODUCTION

Recently the development of global-scale data sets of NPP drivers has permitted the modelling of interannual variation in terrestrial productivity at the global scale. For example, Dai and Fung (1993) used a multidecadal record of temperature and precipitation data in conjunction with simple climate-based models of NPP and heterotrophic respiration to estimate interannual variation in global carbon fluxes from 1940 to 1988. Using more detailed mechanistic models, Maisongrande *et al.* (1995) estimated variation in global NPP from 1986-1991 by driving the TURC model with six years of AVHRR data and invariant mean climate data. In this paper, we discuss the results of driving the CASA model with multiyear sets of both AVHRR NDVI and climate variables, over the period 1982-1990.

2 - METHODS

2.1 The CASA Model

The CASA model is a light-use efficiency model of net primary productivity coupled with a Century-type model of soil organic matter processes. CASA runs at the monthly time step, at the 1° x 1° scale. In CASA, the NPP at each point at each time step is calculated as:

$$NPP(x,t) = IPAR(x,t) \cdot \mathcal{E}(x,t) \quad (1)$$

where IPAR is intercepted photosynthetically active radiation and $\mathcal{E}$ is light-use efficiency.
These terms can be further broken down such that:

$$IPAR(x,t) = SolarRadiation(x,t) \cdot 0.5 \cdot FPAR(x,t) \quad (2)$$

where SolarRadiation as MJ total solar insolation is multiplied by 0.5 to get MJ PAR, FPAR(x,t) is derived from NDVI(x,t), and

$$\mathcal{E}(x,t) = \mathcal{E}* \cdot T_1(x,t) \cdot T_2(x) \cdot W(x,t) \quad (3)$$

where $\varepsilon*$ is the maximum light use efficiency for the globe in g C MJ^{-1}, T_1 & T_2 are scalars that reflect temperature constraints on productivity, and W is a scalar that reflects the effects of soil moisture availability. T_1 reduces ε when mean air temperature is less than an optimum temperature, defined for each grid cell as T_{opt}, the temperature at the month of maximum NDVI. T_2 reduces ε to the degree that T_{opt} departs from 20°C, to reflect the incomplete nature of physiological compensation for non-optimal temperatures. The forms of the scalar functions were derived from current understanding of mechanistic controls on plant growth; for further information, see Field *et al.* (1995). W, the soil moisture constraint, is a nonlinear function of soil moisture, which is based on a one-layer bucket model with a non-linear drying factor. For a more detailed discussion of model structure, see Potter *et al.* (1993).

2.2 Input Data Sets for Multiyear Runs

The multiyear results we discuss here are based on runs using FASIR NDVI from Los *et al.* (1995). The solar radiation fields used were from Bishop and Rossow (1991). Temperature fields were constructed by adding anomalies from Hansen and Lebedeff (1987) to mean temperature fields from Leemans and Cramer (1990). Precipitation fields were constructed by adding anomalies from Fung (personal communication) to mean precipitation fields from Leemans and Cramer (1990). The soil texture map used was from Zobler (1986), and the vegetation classification was from DeFries *et al.*(1994).

3 - RESULTS & DISCUSSION

3.1 Variation in NPP among vegetation classes

The year-to-year variation in NPP differs among vegetation classes, as one would expect. The mean coefficient of variation of annual NPP for each of the SiB vegetation classes can be seen in Figure 1. As is evident, the mean coefficient of variation is greater in the non-forested classes than in the forested ones (grouped to the left). This is consistent with ecological expectations. The CV of non-forested regions should be greater for two reasons. First, these regions have a lower mean annual productivity. Second, it is the great temporal variation in resource availability that helps maintain the non-forested structure of many of these systems.

A more controversial expectation is that NPP would be less variable than precipitation over time, for two reasons. One, the diversity of species in some communities may allow production to remain more constant than precipitation, as species' contributions to community production shift with climate variation, with dry years favoring more drought-resistant species than wet years, for example. Two, in deeply-rooted perennial systems and in those with much waterholding capacity, variation in precipitation may translate into much smaller variation in the availability of moisture to vegetation, depending on the time-scale of the precipitation change. The idea that NPP should vary less than precipitation has been challenged in regards to arid and semi-arid grasslands by Le Houérou *et al.*(1988) and by Lauenroth and Sala (1992), who found that in the cases they examined, the CV of precipitation was generally less than the CV of annual forage production. Annual forage production, however, is not always synonymous with above-ground NPP. Lauenroth and Sala's calculations of aboveground NPP result in a CV for that variable of 22%, which is in fact smaller than the CV of both forage production (44%) and precipitation (31%). Similarly, Tilman and El Haddi's (1992) study of variation in aboveground NPP and precipitation from 1982-1990 in grasslands at Cedar Creek, MN, USA, showed that precipitation was more variable over that time period (CV = ~32%) than NPP (CV = ~18%). The generality of the relationship between variability in production and in precipitation is likely to be function of both the production variable measured and the length and nature of the period of study. CASA's estimates agree with the contention that in most cases the CV of NPP is less than that of precipitation, at least for the period 1982-1990. In Figure 1, the mean CV of precipitation is higher than the mean CV of NPP for all vegetation classes, except the tundra.

3.2 Trends in NPP

3.2.1 ***Global trends***. CASA's estimates of global NPP from 1982-1990 are plotted in Figure 2. As a light-use efficiency model driven by satellite data, CASA's estimates are sensitive to the nature of the NDVI input used. In addition to NPP estimates based on FASIR NDVI, Figure 2 also shows the estimates that result when CASA is driven by FAS NDVI and by PRE NDVI. The FASIR NDVI product is a composited NDVI data set which has been smoothed with a Fourier adjustment to remove noise (FA), corrected for solar zenith angle

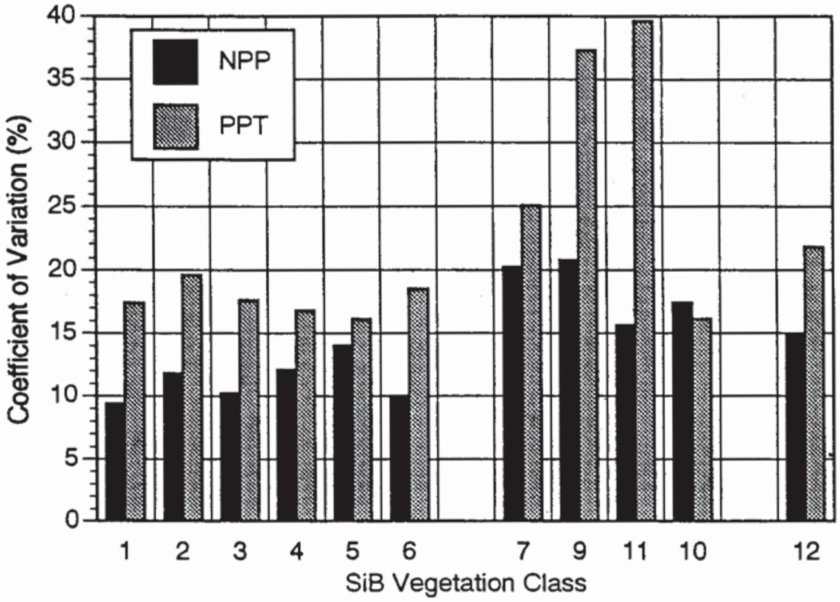

Figure 1. Temporal variation in annual NPP (CASA estimates from FASIR NDVI) and annual precipitation. Vegetation classes as follows: 1 = Broadlf. Ev. Forest, 2 = Broadlf. Decid. Forest, 3 = Mixed Forest, 4 = Ev. Needlelf. Forest, 5 = Decid. Needlelf. Forest, 6 = Trees w/groundcover, 7 = Per. Grasslands, 9 = Shrubs & Soil, 11 = Desert, 10 = Tundra, 12 = Agriculture.

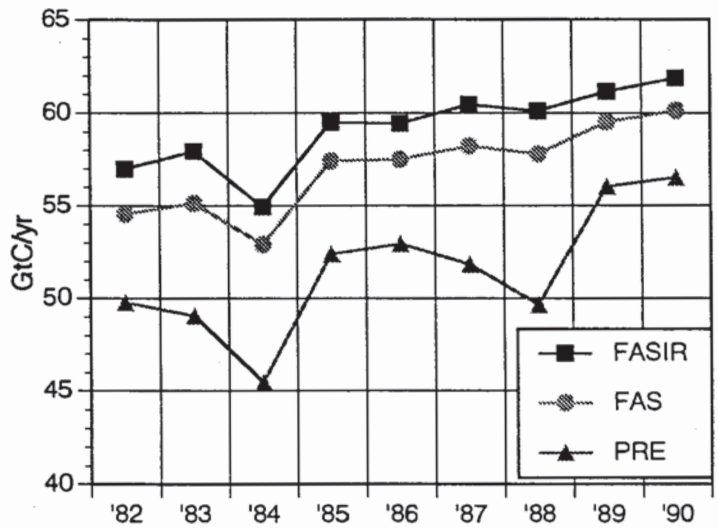

Figure 2. Global NPP as estimated by CASA, as a function of NDVI input. For description of NDVI sets, see text.

(S), and adjusted with a winter boreal forest interpolation (I) and a tropical rainforest reconstruction (R) to reduce the effects of clouds (for details, see Los *et al.*, 1995). FAS NDVI is the FASIR product before the boreal forest interpolation and the tropical rainforest reconstruction have been applied. The PRE NDVI is the same FASIR NDVI before any of the FASIR corrections have been made.

What is important to note is that no matter which NDVI driver set is used, CASA's estimates show an increase in global NPP from 1982 to 1990. For FASIR, for example, total global NPP rises from 56.96 GtC yr^{-1} in 1982 to 61.86 GtC yr^{-1} in 1990. The slopes of lines fitted to the temporal course of the NPP totals provide estimates of the per year increase in total NPP from 1982-1990. The FASIR NDVI results in the most conservative estimate, an increase of 0.676 GtC yr^{-1}, or 1.2% yr^{-1} (with the increase given as a percentage of the 1982 total). With the other NDVI products, the estimate of the increase is somewhat larger: 0.769 GtC yr^{-1}, or 1.4% yr^{-1}, for FAS, and 0.928 GtC yr^{-1}, or 1.9% $^{-1}$, for PRE.

This trend may be due in part to fluctuations in temperature and precipitation, to increases in atmospheric carbon dioxide levels, to changes in land-use, or to fertilization effects of N deposition. Most of the Earth's ecosystems experienced a rise in air temperature over the 1980's (Dai and Fung, 1993), which would in particular be expected to increase productivity in the temperature-limited high-latitude systems.

One estimate of the potential effect of rising CO_2 levels on production is made by Luo and Mooney (1995). Using an instantaneous derivative of the Farquhar photosynthesis model, they estimate that a 1-ppm change in CO_2 levels at 357 ppm would lead to an increase of between 0.113 % to 0.248% in photosynthetic carbon uptake. Between 1982 and 1990, carbon dioxide concentrations measured at Mauna Loa Observatory rose 12.99 ppm, from 340.96 ppm to 353.95 ppm (Keeling and Whorf, 1991). If it is assumed that gross primary productivity (GPP) equals twice NPP and if the FASIR-based CASA estimates of NPP are used, Luo and Mooney would predict an increase in global GPP of between 0.205 GtC $yr^{-1}$and 0.456 GtC yr^{-1} due to increases in atmospheric CO_2 levels. To translate this response into changes in global NPP, assumptions about the response of autotrophic respiration are required. In the extreme case in which autotrophic respiration remained unchanged, the CO_2-induced increase in NPP would equal the CO_2-induced increase in GPP, and would thus be somewhat smaller than the increase in NPP estimated by CASA. In other words, an increase in global GPP in response to rising CO_2 levels, as modelled by Luo and Mooney, is not large enough by itself to explain the increase in NPP estimated by CASA. It is most likely that the trend observed is the result of interactions of several variables, and it is the task of models like CASA to examine these interactions in more detail.

3.2.2 ***Vegetation Class Trends.*** If the trends are examined by vegetation class, increases are evident in all classes except perennial grasses and the two desert classes. Analysis shows the absolute increases to be largest for the broadleaf evergreen forest (0.253 GtC yr^{-1} or 1.4% yr^{-1}), broadleaf trees with groundcover (0.173 GtC yr^{-1} or 1.0% yr^{-1}), and agricultural regions (0.0930 GtC yr^{-1} or 1.2% yr^{-1}). The vegetation classes showing the largest relative increases are high-latitude systems: the deciduous needleleaf forests (0.0352 GtC yr^{-1} or 2.6% yr^{-1}), the evergreen needleleaf forests (0.0697 GtC yr^{-1} or 2.4% yr^{-1}) and the tundra (0.0135 GtC yr^{-1} or 1.8% yr^{-1}).

The increases in the annual NPP for these high latitude systems are somewhat larger than the increases Dai and Fung (1993) estimate would be due solely to changes in temperature and precipitation; for the latitudes 50° - 70°N, Dai and Fung estimate an increase of 0.03 GtC yr^{-1} for the period 1970-1988. Because CASA is driven by NDVI, the CASA estimates include effects of changes in resource availability and land use (as relected in changes in NDVI) that are not considered in the Dai and Fung approach, leading us to expect the estimates from the two approaches to differ somewhat. If temperature increases in high latitudes increase nitrogen availability, for example, the Dai and Fung approach will likely underestimate the NPP response, but it may be captured in an NDVI-based estimate. The CASA estimates are somewhat lower than the 0.085-0.12 GtC yr^{-1} estimates of Kauppi *et al.* (1992) for 1971-1990, but include more than the European forests these investigators considered.

3.3 Conclusions

Models of terrestrial productivity are now sufficiently mature to allow the investigation of interannual variation in productivity at the global scale. Estimates by the CASA model of terrestrial NPP from 1982-1990 suggest that total global NPP rose during that time period. Analysis by vegetation class shows that high-latitude systems experienced the greatest relative increase in annual NPP, and that the rate of increase was greater than that predicted by Dai and Fung's simple model of increases driven by climate variables alone.

4 - ACKNOWLEDGEMENTS

This research was supported by the NASA EOS IDS Program and by a DOE Graduate Fellowship for Global Change to CMM.

4 - REFERENCES

Bishop J. K. B. and W. B. Rossow, 1991. Spatial and temporal variability of global surface irradiance. Journal of Geophysical Research 96(C9):16839-16858.

Dai A. and I. Y. Fung, 1993. Can climate variability contribute to the "missing" CO2 sink? Global Biogeochemical Cycles 7(3):599-609.

DeFries R. S. and J. R. G. Townshend, 1994. NDVI-derived land cover classifications at a global scale. International Journal of Remote Sensing 15(17): 3567-3586.

Field C B, J. T. Randerson, and C. M. Malmström, 1995. Global net primary productivity: combining ecology and remote sensing. Remote Sensing of Environment 51:74-88.

Hansen J. and S. Lebedeff, 1987. Global trends of surface air temperatures. Journal of Geophysical Research 92(D11)13345-13372.

Kauppi P. E., K. Mielikainen, and K. Kuusela, 1992. Biomass and carbon budget of European forests, 1971 to 1990. Science 256:70-74.

Keeling C. D. and T. P. Whorf, 1991. Atmospheric CO2--Modern Record: Mauna Loa. In T. A. Boden, R. J. Sepanski, and F. W. Stoss (eds.) Trends 91: A Compendium of Data on Global Change. CDIAC, Oak Ridge, TN, USA. ORNL/CDIAC Publication number 46.

Lauenroth W. K. and O. E. Sala, 1992. Long-term forage production of North American shortgrass steppe. Ecological Applications 2(4):397-403.

Leemans, R. and W. P. Cramer, 1990. The IIASA database for mean monthly values of temperature, precipitation and cloudiness of a global terrestrial grid, WP-41, International Institute for Applied Aystems Analysis, Laxenburg working Paper, 22pp., IIASA, Laxenburg, Austria.

Le Houérou H. N., R. L. Bingham, and W. Skerbek, 1988. Relationship between the variability of primary production and the variability of annual precipitation in world arid lands. Journal of Arid Environments 15:1-18.

Los S. O., C. O. Justice, and C. J. Tucker, 1994. A global 1 ° x 1° NDVI data set for climate studies derived from the GIMMS continental NDVI data. International Journal of Remote Sensing 15(17):3493-3518.

Luo Y. and H. A. Mooney, 1995. Stimulation of global photosynthetic carbon uptake by increase in atmospheric carbon dioxide concentration: Prediction with a biochemically based model. In G. W. Koch and H. A. Mooney (eds.) Terrestrial Ecosystem Response to Elevated CO2. Academic Press, San Diego. (In press).

Maisongrande P., A. Ruimy, G. Dedieu, and B. Saugier, 1995. Monitoring seasonal and interannual variations of gross primary productivity, net primary productivity and net ecosystem productivity using a diagnostic model and remotely-sensed data. Tellus 47B:178-190.

Potter C. S., J. T. Randerson, C. B. Field, P. A. Matson, P. M. Vitousek, H. A. Mooney, and S. A. Klooster, 1993. Terrestrial ecosystem production: a process model based on global satellite and surface data. Global Biogeochemical Cycles 7:8-11-841.

Tilman D. and A. El Haddi, 1992. Drought and biodiversity in grasslands. Oecologia 89:257-264.

Zobler L., 1986. A world soil file for global climate modeling, NASA Technical Memo. 87802, 32 pp.