Collection 005 Change Summary for the MODIS Land Vegetation Primary Production (17A2/A3) Algorithm

Maosheng Zhao, Steven Running, Faith Ann Heinsch, Ramakrishna Nemani

Summary:

1. Modification of parameters in Biome Property Look-Up Table (BPLUT) to agree with GPP derived from measurements at eddy flux towers and synthesized NPP.
2. Alteration of growth respiration module in the collection 004 to make it is 25% of annual NPP, rather than being dependent on the annual maximum LAI.
3. Replacement of the constant Q_{10} quotient of 2.0 for vegetation maintenance respiration calculation with a variable Q_{10}, which changes with air temperature.
4. Spatially non-linear interpolation of coarse resolution meteorological data into 1-km MODIS pixel level, instead of nearest neighbor sampling, to increase the accuracy of meteorological data input at pixel level.
5. Limitations of the collection 005 comprise two aspects. First, the BPLUT may be subject to change if collection 005 MODIS FPAR/LAI or new version of meteorological data have large changes. Second, 8-day data and annual NPP are subject to incorrect estimates caused by contaminated FPAR/LAI. The in-house reprocessing is required to clean these contaminated inputs, and users are encouraged to obtain the improved annual MODIS NPP from website of the principal investigator or Dr. Running directly.
6. References

1. Retuned BPLUT

At TERRA launch, for the previous versions of MOD17, including Collections 003 and 004, the parameters in BPLUT were tuned based on different remotely sensed and meteorological data sets. Additionally, there were inadequate GPPs from eddy flux towers and no synthesized global NPP data available to calibrate these parameters. Since launch, we have collected GPP from flux towers, and the latest developed global synthesized NPP are now available. Furthermore, several years of accumulated MODIS data make it possible to retune the BPLUT with these ground-based GPP and NPP data. To ensure the BPLUT is appropriate at the global scale, we tuned it at the global level. To speed the tuning process, we (1) reduced the 8-day 1-km MODIS FPAR/LAI to half degree resolution; (2) ran the algorithm to get the annual average total GPP and NPP for each biome; (3) compared MODIS GPP and NPP with the observations; and (4) changed the related parameters if the differences between MODIS GPP and NPP and observations were unacceptable. We reiterated the above procedure until the differences are negligible. The MODIS GPP and NPP estimated with the new BPLUT are comparable with the observations. Fig. 1 illustrates the GPP and NPP validation at flux towers located in North America and with the EMDI NPP data set, respectively.

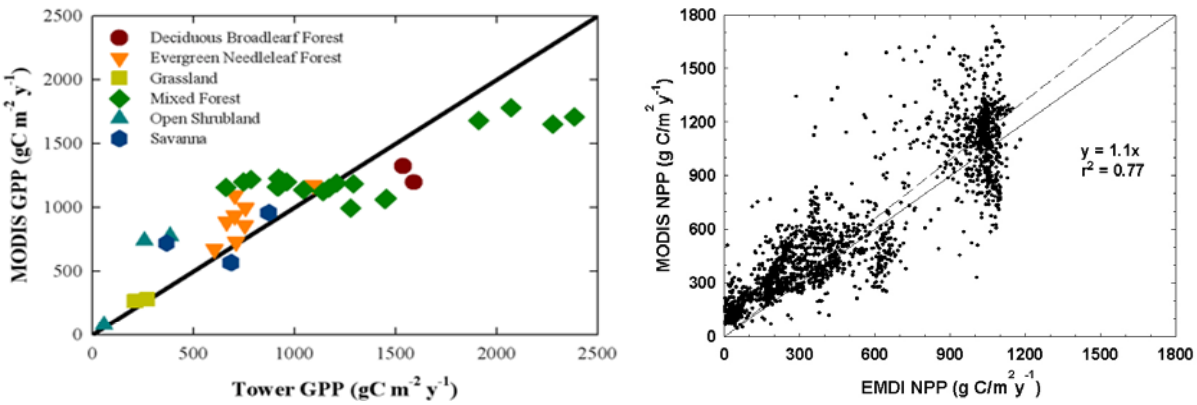

Fig. 1. MODIS GPP and NPP validation with GPP derived from measurements at flux towers (Heinsch et al., 2006) and NPP from EMDI (Ecosystem Model-Data Intercomparison) data set (Zhao et al., 2005).

2. New growth respiration module

The previous MOD17 algorithm calculates vegetation growth respiration by using annual maximum LAI to retrieve the amount of leaf grown within a year, which is subject to practical issues associated with MODIS LAI, though theoretically, it may be reasonable. The annual maximum MODIS LAI, however, has been truncated to 6.8 m^2 m^{-2} in MOD15A2 for forest biome types due to the saturation of reflectance from red and near-infrared channels when LAI is high, leading to the same growth respiration cost for pixels in the same biome with different annual NPP values, or a given pixel with large inter-annual variability in NPP. Because functionally, growth respiration is believed to be the cost associated with organic matter fixed by photosynthesis in a given time interval, and to be proportionally related to NPP, it is assumed to be 25% of annual NPP (Ryan, 1991). We adopt this generally accepted notion in the new growth respiration calculation, and discard that determined by using annual maximum LAI. We evaluated the impact of this change on the performance of the algorithm for capturing the inter-annual variability in NPP, by using multi-year tree ring data over USA (66 sites) as proxy of NPP (Fig. 2), and found that new growth respiration method improves the ability of the algorithm to detect inter-annual variability in NPP.

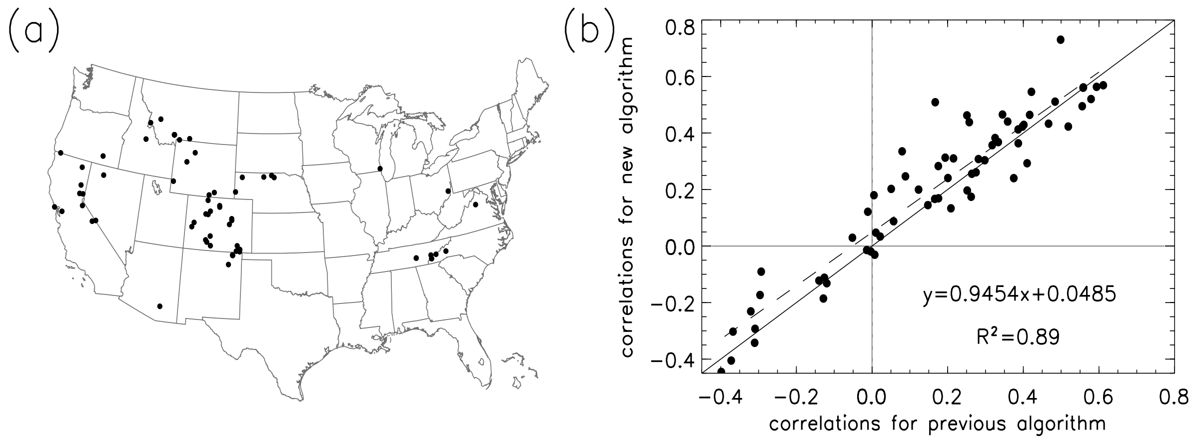

Fig. 2. New growth respiration improves the performance of capture inter-annual variability in NPP, which is shown by the increased correlation between annual NPP and tree ring data relative to the previous algorithm.

3. Changeable vegetation maintenance respiration Q_{10} quotient

Recent studies have shown that Q_{10} is not constant, but varies with temperature (Tjoelker et al., 2001). We replaced 2.0, the constant Q_{10} value used in the previous algorithm in calculation of maintenance respiration, with Equation (1), which is proposed by Tjoelker et al. (2001):

$$Q_{10} = 3.22 - 0.046 * Tavg \qquad (1)$$

4. Non-linearly Spatial interpolation of meteorological data

The previous MOD17 process used a nearest-neighbor sampling method to retrieve daily meteorological inputs for 1-km MODIS pixel. This approach left obvious footprints of the coarse resolution (1.25 by 1.0 degree) meteorological data (Fig. 3). To eliminate these footprints, and improve the accuracy of the meteorological input at the MODIS pixel level, we propose a non-linear scheme to interpolate the four surrounding meteorological cells down to 1-km level. This non-linear formula is more stable than the widely used Inverse Distance Weighting (IDW), because IDW may cause a number to be divided by zero in some situations. Comparison of the meteorological data extracted with the nearest neighbor method and with spatial interpolation to observations from WMO weather stations, we have found that, under most conditions (~70%), our revised method improves the accuracy of meteorological input at the local level. Detailed information on the method and how it improved the accuracy of meteorological inputs are available at Zhao et al. (2005). Fig. 3 shows the NPP images over a portion of Amazon rain forest with meteorological input obtained by the nearest neighbor sampling and non-linearly spatial interpolation, respectively.

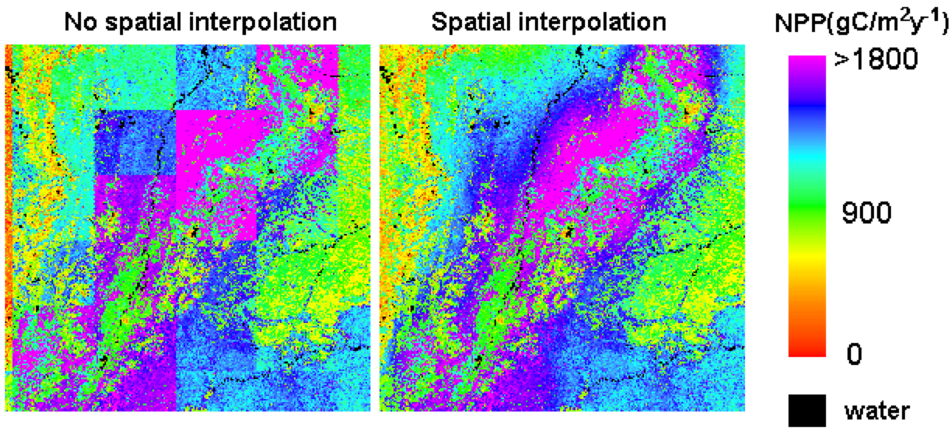

Fig. 3. An example shows how non-linearly spatial interpolation eliminate footprints from coarse spatial resolution of meteorological data. The left panel shows the clear footprints in NPP image when the nearest neighbor sampling method was applied to coarse resolution meteorological data, while the right NPP image has no such footprint due to spatial interpolation (Zhao et al., 2005).

5. Limitations

Unlike other daily, 8- or 16-day composite MODIS products, MOD17 represents the accumulated carbon fixed by terrestrial vegetation in a given time period. In particular, the annual product, MOD17A3, which is the total carbon fixed by vegetation annually, has important implications for human society. Clearly, if there are some errors containing in 8-day product, the annual result will be not reliable and less useful. The input 8-day FPAR/LAI are subject to cloud/aerosol contaminations, and consequently, 8-day and annual MOD17 data contain errors induced by these unreliable FPAR/LAI values. Over regions with excessive cloudiness (e.g, rain forests with high annual NPP), the errors in MOD17 are substantial. Though we have tried our best to refine and improve the MOD17 algorithm, the current official MOD17 process still is unable to resolve these problems in the 8-day and annual MOD17. We now have in-house software to exclude these contaminated FPAR/LAI pixels and temporally fill them with the reliable periods, in order to recalculate and generate an enhanced MOD17 product (Zhao et al., 2005). Fig. 4 illustrates one example on how we masked the contaminated FPAR/LAI, and filled them, to improve the reliability and quality of MOD17 on a site within the Amazonian rain forest. Fig. 5 shows the improved annual global terrestrial NPP for 2003. The users are encouraged to download the improved MOD17 at http://www.ntsg.umt.edu, or contact with the PI, Dr. Running, for the details on improved MOD17 data availability. Additionally, we have found that MODIS NPP is very sensitive the uncertainties in the meteorological data set inputs, especially over tropical region

(Zhao et al., 2006). As with the GPP calculations, the BPLUT is subject to change if the input meteorological data is changed.

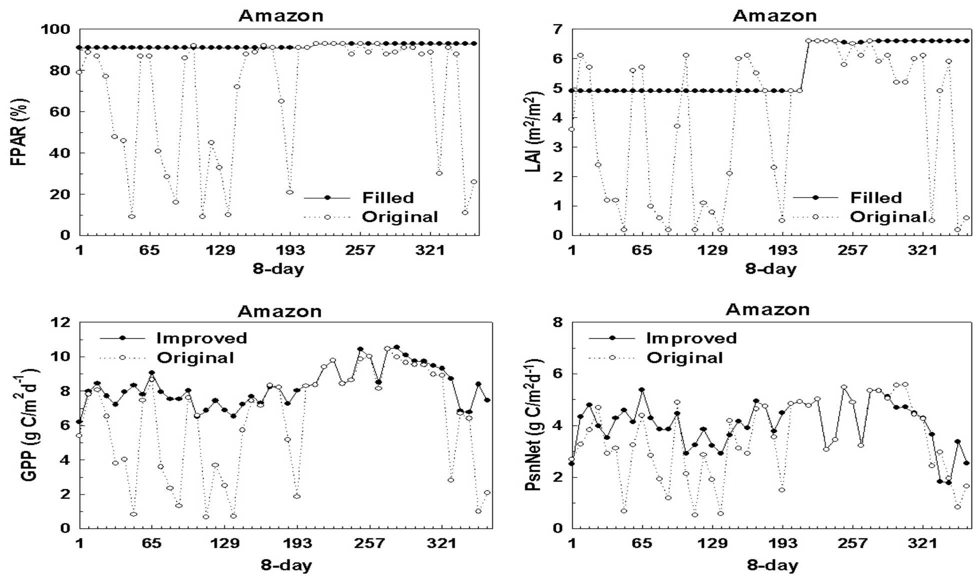

Figure 4. An example on how temporal filling unreliable 8-day FPAR and LAI, and thereafter improved 8-day GPP and PsnNet for one MODIS 1-km pixel located in Amazon basin (lat = -5.0, lon= -65.0). MODIS land cover is evergreen broadleaf forest (EBF). In 2002, the improved annual GPP and NPP are 2759 g C/m^2y^{-1} and 914 g C/m^2y^{-1}, respectively, in comparison to corresponding original annual GPP and NPP of 2252 g C/m^2y^{-1} and 871 g C/m^2y^{-1} (Zhao et al., 2005).

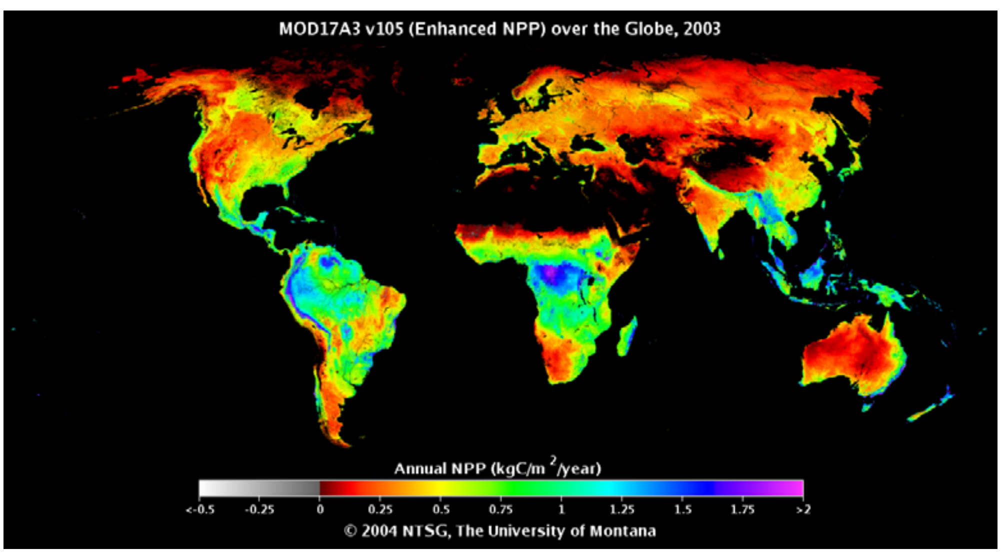

Fig. 5. Improved MODIS 1-km global terrestrial NPP for 2003, which is generated by in-house software (Zhao et al., 2005).

6. References

Algorithm references

Monteith, J.L. (1972). Solar radiation and productivity in tropical ecosystems. *Journal of Applied Ecology*, 9, 747-766.

Monteith, J.L. (1977). Climate and efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society of London*, B281:277-294.

Ryan, MG. 1991. The effects of climate change on plant respiration. *Ecological Applications*, 1: 157-167.

Running, S.W., Thornton, P.E., Nemani, R.R., Glassy, J.M. (2000). Global terrestrial gross and net primary productivity from the earth observing system. In Sala, O., Jackson, R. and H. Mooney (Ed.), *Methods in Ecosystem Science*. (pp44-57). Springer-Verlag New York.

Running, S. W., R. R. Nemani1, F. A. Heinsch, M. Zhao, M. Reeves, and H. Hashimoto, A continuous satellite-derived measure of global terrestrial primary productivity: Future science and applications. *Bioscience*, 56(6), 547-560, 2004.

Tjoelker M. G., J. Oleksyn and P. Reich, 2001, Modelling respiration of vegetation: evidence for a general temperature-dependent Q10. *Global Change Biology*, 7: 223-230.

Heinsch, F. A., M. Reeves and P. Votava et al., *User's Guide, GPP and NPP (MOD 17A2/A3) Products, NASA MODIS Land Algorithm*. Version 2.0, December 2, 2003.

Improvements and sensitivity of the algorithm

Zhao, M., F. A. Heinsch, R. R. Nemani, and S. W. Running. (2005). Improvements of the MODIS terrestrial gross and net primary production global dataset. *Remote Sensing of Environment*, 95: 164–176.

Kang S., S. W. Running, M. Zhao, J. S. Kimball, J. Glassy. (2005). Improving continuity of MODIS terrestrial photosynthesis products using an interpolation schme for cloudy pixels. *International Journal of Remote Sensing*, 26(8):1659-1676.

Zhao, M., S. W. Running, and R. R. Nemani. (2006). Sensitivity of Moderate Resolution Imaging Spectroradiometer (MODIS) terrestrial primary production to the accuracy of meteorological reanalyses. *Journal of Geophysical Research*, 111, G01002, doi:10.1029/2004JG000004.

Validation of the MOD17

Turner, D.P., W. Ritts, W. B. Cohen, S. T. Gower, M. Zhao, S. W. Running, S. C. Wofsy, S. Urbanski, A. L. Dunn, J.W. Munger. (2003). Scaling Gross Primary Production (GPP) over boreal and deciduous forest 2 landscapes in support of MODIS GPP product validation. *Remote Sensing of Environment*, 88: 256–270.

Turner, D.P., W. D. Ritts, W. B. Cohen, T. K. Maeirsperger, S. T. Gower, A. Kirschbaum, S. W. Running, M. Zhao, S. C. Wofsy, A. L. Dunn, B. E. Law, J. C. Campbell, W. C. Oechel, H. J. Kwon, T. P. Meyers, E. E. Small, S. A. Kurc, J. A. Gamon. (2005). Site-level evaluation of satellite-based global terrestrial gross primary production and net primary production monitoring. *Global Change Biology*, 11:666-684.

Turner, D. P., W. D. Ritts, W. B. Cohen, S. T. Gower, S. W. Running, M. Zhao, M. H. Costa, A. Kirschbaum, J. Ham, S. Saleska, D. Ahl. (2006). Evaluation of MODIS NPP and GPP products across multiple biomes. *Remote Sensing of Environment*, in press.

Heinsch, F.A., M. Zhao, S.W. Running, et al. (2006). Evaluation of remote sensing based terrestrial productivity from MODIS using regional tower eddy flux network observations. *IEEE Transactions on Geoscience and Remote Sensing*, in press.

Turner, D. P., W. Ritts, M. Zhao, S. Kurc, A. Dunn, S. Wofsy, E. Small and Steve W. Running. (2006). Assessing interannual variations in MODIS-based estimates of gross primary production. *IEEE Transactions on Geoscience and Remote Sensing*, in press.

Application of the algorithm and the MOD17

Nemani, R. R., C. D. Keeling, H. Hashimoto, W. M. Jolly, S. C. Piper, C. J. Tucker, R. B. Myneni, and S. W. Running. (2003). Climate-driven increases in global terrestrial net primary production from 1982 to 1999. *Science*, 300: 1560-1563.

Running, S. W., R. R. Nemani1, F. A. Heinsch, M. Zhao, M. Reeves, and H. Hashimoto. (2004). A continuous satellite-derived measure of global terrestrial primary productivity: Future science and applications. *Bioscience*, 56(6): 547-560.

Hashimoto, H., R. R. Nemani, M. White, W. Jolly, S. C. Piper, C. D. Keeling, R. B. Myneni and S. W. Running. ENSO induced variability in terrestrial carbon cycling, *Journal of Geophysical Research*, 109: D23110, doi:10.1029/2004JD004959. 2004.

Reeves, M. C., M. Zhao, and S. W. Running. (2006). Applying improved estimates of MODIS productivity to characterize grassland vegetation dynamics. *Rangeland Ecology & Management*, 59:1-10.

Reeves, M. C., M. Zhao and S. W. Running. (2005). Usefulness and limits of MODIS GPP for estimating wheat yield. *International Journal of Remote Sensing*, 27(7):1403-1421.

Kimball, J.S., M. Zhao, K.C. McDonald, and S.W. Running. (2006). Satellite remote sensing of terrestrial net primary production for the pan-arctic basin and Alaska. *Mitigation and Adaptation Strategies for Global Change*, in press.

Kimball, J. S., K. C. Mcdonald, M. Zhao. (2006). Spring thaw and its effect on northern terrestrial vegetation productivity observed from satellite microwave and optical remote sensing. *Earth Interactions*, in press.

Kimball, J. S., M. Zhao, A. D. McGuire, F. A. Heinsch, J. Clein, M. Calef, W. M. Jolly, S. Kang, S. E. Euskirchen, K. C. McDonald, and S. W. Running. (2006). Climate driven increases in boreal and Arctic vegetation productivity: evidence of decreasing stability of the northern high latitude terrestrial carbon reservoir. *Earth Interactions*, in press.