



Reply to Magnani et al.: Linking large-scale chlorophyll fluorescence observations with cropland gross primary production

The derivation of the first global maps of sun-induced chlorophyll fluorescence (SIF) from Greenhouse Gases Observing Satellite (GOSAT) data in 2011 (1, 2), and later from Global Ozone Monitoring Experiment-2 (GOME-2) (3), was perceived as a milestone in the fields of vegetation remote sensing and carbon modeling. As stated by Magnani et al. (4), space-borne SIF measurements are intrinsically related to photosynthetic activity and therefore have the potential to trigger a new era in the monitoring of vegetation functioning. In fact, the first results from the analysis of the GOSAT and GOME-2 global SIF datasets are confirming the expected link between SIF and the gross primary productivity (GPP) of terrestrial ecosystems (e.g., ref. 2). In particular, our specific study on the potential of SIF observations to monitor crop photosynthesis (5) empirically demonstrates a strong linear relationship between SIF and GPP for croplands and grasslands at 0.5° and monthly scales.

We appreciate the positive feedback from Magnani et al. (4), and agree with their comment that process-based models should be used to exploit the full potential of SIF data to characterize photosynthetic processes. We are indeed fully aware of the generally complex relationships between top-of-canopy SIF and photosynthesis, as we note in our report, for example, in the statement “despite the complicated photosynthesis–SIF relationships and the convolution of the signal with canopy structure...” (5). We would like to clarify, however, that we do not base our analysis “on the assumption of a constant ratio between photosynthetic and fluorescence light use efficiencies,” as stated by Magnani et al. (4), but simply speculate on such an assumption (which we actually expect to hold, especially for well-irrigated and fertilized crops) to partly explain our empirical findings. Nevertheless, we do not discard that the observed linear relationship between cropland SIF and GPP may be highly driven by the fact that our SIF measurements provide a very good proxy for the photosynthetically active radiation absorbed by the green component of the canopy, which is in turn

close to GPP for healthy, highly efficient crops. Spatial scaling issues are likely to occur in our comparisons between 0.5° data and flux tower GPP estimates, but the reported large GPP differences between croplands and grasslands are actually shown by the flux tower data, and can therefore not be attributed to spatial scaling, as suggested by Magnani et al.

We would like to point out that the SIF retrievals used in this study have been obtained from space-borne instruments that were not originally intended for (and not optimal for) measurement of SIF. Considering the coarse-resolution of available data, the many assumptions to be taken at the global level, and the technical limitations to the use of such data in process-based models, we are convinced that an empirical approach to extract statistical relationships between SIF and GPP best fits our global crop productivity study (5). We feel that our results provide strong validation for proposals for dedicated satellite missions to measure SIF and share the hope of Magnani et al. that this initial demonstration will pave the way for more refined studies.

Luis Guanter^{a,1}, Yongguang Zhang^a, Martin Jung^b, Joanna Joiner^c, Maximilian Voigt^a, Joseph A. Berry^d, Christian Frankenberg^e, Alfredo R. Huete^f, Pablo Zarco-Tejada^g, Jung-Eun Lee^h, M. Susan Moranⁱ, Guillermo Ponce-Campos^j, Christian Beer^k, Gustavo Camps-Valls^k, Nina Buchmann^l, Damiano Gianelle^m, Katja Klumppⁿ, Alessandro Cescatti^o, John M. Baker^p, and Timothy J. Griffis^q
^aInstitute for Space Sciences, Freie Universität Berlin, 12165 Berlin, Germany; ^bDepartment for Biogeochemical Systems, Max Planck Institute for Biogeochemistry, 07745 Jena, Germany; ^cLaboratory for Atmospheric Chemistry and Dynamics, National Aeronautics and Space Administration Goddard Space Flight Center, Greenbelt, MD 20771; ^dDepartment of Global Ecology, Carnegie Institution for Science, Stanford, CA 94305; ^eJet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

91109; ^fPlant Functional Biology and Climate Change Cluster, University of Technology Sydney, Sydney, 2007, Australia; ^gInstituto de Agricultura Sostenible, Consejo Superior de Investigaciones Científicas, 14004 Córdoba, Spain; ^hGeological Sciences, Brown University, Providence, RI 02912; ⁱSouthwest Watershed Research, Agricultural Research Service, US Department of Agriculture, Tucson, AZ 85719; ^jDepartment of Applied Environmental Science and Bolin Centre for Climate Research, Stockholm University, 10691 Stockholm, Sweden; ^kImage Processing Laboratory, Universitat de València, 46980 València, Spain; ^lAgricultural Sciences, Eidgenössische Technische Hochschule Zurich, 8092 Zurich, Switzerland; ^mSustainable Agro-ecosystems and Bioresources Department, Research and Innovation Centre, Fondazione Edmund Mach, 38010 San Michele all'Adige, Italy; ⁿGrassland Ecosystem Research Unit, Institut National de la Recherche Agronomique, 63122 Clermont-Ferrand, France; ^oInstitute for Environment and Sustainability, Joint Research Centre, European Commission, 20127 Ispra, Italy; ^pSoil and Water Management Research, Agricultural Research Service, US Department of Agriculture, St. Paul, MN 55108; and ^qDepartment of Soil, Water, and Climate, University of Minnesota, St. Paul, MN 55108

- 1 Joiner J, et al. (2011) First observations of global and seasonal terrestrial chlorophyll fluorescence from space. *Biogeosciences* 8(3):637–651.
- 2 Frankenberg C, et al. (2011) New global observations of the terrestrial carbon cycle from GOSAT: Patterns of plant fluorescence with gross primary productivity. *Geophys Res Lett* 38(17):L17706.
- 3 Joiner J, et al. (2013) Global monitoring of terrestrial chlorophyll fluorescence from moderate spectral resolution near-infrared satellite measurements: Methodology, simulations, and application to GOME-2. *Atmos Meas Tech* 6(10):2803–2823.
- 4 Magnani F, et al. (2014) Let's exploit available knowledge on vegetation fluorescence. *Proc Natl Acad Sci USA*, 10.1073/pnas.1406600111.
- 5 Guanter L, et al. (2014) Global and time-resolved monitoring of crop photosynthesis with chlorophyll fluorescence. *Proc Natl Acad Sci USA* 111(14):E1327–E1333.

Author contributions: L.G., Y.Z., M.J., J.J., M.V., J.A.B., C.F., A.R.H., P.Z.-T., J.-E.L., M.S.M., G.P.-C., C.B., G.C.-V., N.B., D.G., K.K., A.C., J.M.B., and T.J.G. wrote the paper.

The authors declare no conflict of interest.

¹To whom correspondence should be addressed. E-mail: luis.guanter@www.fu-berlin.de.