When reprocessing time series of data from different satellite sensors to produce a consistent time series, there are two options: 1) applying the most advanced algorithms to the older, lower quality data or 2) degrading the most recent, higher quality data to match the standards of the old data set. For example, most recent data have generally been degraded spatially to simulate the broader point spread function of older sensors and therefore improve the consistency of the time series [6].

VII. Land-Cover Change Applications

Much of the science related to land-cover change has been previously driven by data availability. With the increasing number of sensors, science is now driving the need for improved data sets. The increasing availability of consistent, high-frequency data sets and a better understanding of the relationship between the physical measurements and biophysical processes as well as the relationship between sensors are essential for continued analyses of land-cover change and the impacts on other earth system processes.

Consistent, long-term data sets will allow more robust estimates of the broad spatial and temporal trends related to interannual to interdecadal climate changes. Understanding the scaling relationship between various data sets will provide a basis to relate human and natural drivers to fine scale changes in land-cover characteristics. Multisensor fusion will permit longer-term studies and analyses at scales more relevant to the socio-economic factors shaping many of the changes detected. It is often the interactions between broad and fine scale processes that lead to the nonlinear trajectories in land-cover change.

References

[1] E. F. Lambin, H. J. Geist, and E. Lepers, "Dynamics of land-use and land-cover change in tropical regions," *Annu. Rev. Environ. Resources*, vol. 28, pp. 205–241, 2003.

[2] M. Linderman, P. Rowhani, D. Benz, S. Serneels, and E. F. Lambin, "Land-cover change and vegetation dynamics across Africa," *J. Geophys. Res.—Atmos.*, vol. 110 (D12), no. D12104, 2005.

[3] E. Lepers, E. F. Lambin, A. C. Janetos, R. DeFries, F. Achard, N. Ramankutty, and R. J. Scholes, "A synthesis of rapid land-cover change information for the 1981–2000 period," *Bioscience*, vol. 55, no. 2, pp. 115–124, 2005.

[4] R. DeFries *et al.*, "Mapping the land surface for global atmosphere-biosphere models: Toward continuous distributions of vegetation's functional properties," *J. Geophys. Res.—Atmos.*, vol. 100, no. D10, pp. 20867–20 882, 1995.

[5] S. D. Prince, E. B. De Colstoun, and L. L. Kravitz, "Evidence from rain-use efficiencies does not indicate extensive Sahelian desertification," *Glob. Change Biol.*, vol. 4, no. 4, pp. 359–374, 1998.

[6] M. E. Brown, J. E. Pinzon, J. T. Morisette, K. Didan, and C. J. Tucker, "Evaluation of the consistency of long-term NDVI time series derived from AVHRR, SPOT-Vegetation, SeaWiFS, MODIS, and Landsat ETM+ Sensors," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 7, pp. 1787–1793, Jul. 2006.

[7] R. Fensholt and I. Sandholt, Evaluating MODIS, SPOT-Vegetation, and MERIS vegetation indices using *in situ* measurements in a semiarid environment, in *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 7, pp. 1774–1786, Jul. 2006.

[8] A. R. Huete, H.-J. Kim, Y. Yin, and T. Miura, "Vegetation index scaling dependencies and uncertainties in heterogeneous environments," in *Proc. IGARSS*, 2005, pp. 5029–5032.

[9] J. R. G. Townshend, C. O. Justice, C. Gurney, and J. McManus, "The impact of misregistration on change detection," *IEEE Trans. Geosci. Remote Sens.*, vol. 30, no. 5, pp. 1054–1060, Sep. 1992.

[10] P. Mayaux and E. F. Lambin, "Tropical forest area measured from global land-cover classifications: Inverse calibration models based on spatial textures," *Remote Sens. Environ.*, vol. 57, pp. 29–43, 1997.

The Utility of Satellite Fire Product Accuracy Information—Perspectives and Recommendations From the Southern Africa Fire Network

D. P. Roy, S. N. Trigg, R. Bhima, B. H. Brockett, O. P. Dube, P. Frost, N. Govender, T. Landmann, J. Le Roux, T. Lepono, J. Macuacua, C. Mbow, K. L. Mhwandangara, B. Mosepele, O. Mutanga, G. Neo-Mahupeleng, M. Norman, and S. Virgilo

***Abstract*—This correspondence gives Southern Africa Fire Network (SAFNet) perspectives on the utility of satellite fire product accuracy information, drawing on two main sources: insights gained during SAFNet's six years of working together, and relevant findings from a SAFNet focus group study that explored factors that promote and constrain the use of the MODIS fire products. In giving this perspective, we comment on the approach and findings of recent fire product validation articles, including the two contained in this special issue. We recommend five ways that validation activities might be made more relevant to users and better connect producers of remotely sensed products to users in order to communicate satellite fire product accuracy information more effectively.**

***Index Terms*—Fire management, product uptake, qualitative survey, SAFnet, users.**

I. Introduction

Activities to validate remotely sensed products are often justified—at least in part—by noting that the resulting accuracy information may help users decide if they can use the product for a particular application and to help explain the accuracy of the application findings.

Manuscript received August 1, 2005; revised December 16, 2005.

D. P. Roy is with the Geographic Information Science Center of Excellence, South Dakota State University, Brookings, SD 57007 USA (e-mail: david.roy@sdstate.edu).

S. N. Trigg is with the Department of Geography, University of Maryland, College Park, MD 20742 USA (e-mail: trigg@umd.edu).

R. Bhima is with the Department of National Parks and Wildlife, Lilongwe 3, Malawi.

B. H. Brockett is with the North West Parks and Tourism Board, Pilanesberg National Park, Mogwase 0314, South Africa.

O. P. Dube is with the University of Botswana, Gabarone, Botswana.

P. Frost is with the CSIR-Satellite Applications Centre, Pretoria 0001, South Africa.

N. Govender is with the Scientific Services, Kruger National Park, Skukuza 1350, South Africa.

T. Landmann is with the UN FAO GLCN Land Cover Topic Centre at IAO, 50131 Florence, Italy.

J. Le Roux is with the Research and Planning Directorate Scientific Services, Ministry of Environment and Tourism, P/Bag 13306, Windhoek, Namibia.

T. Lepono is with the Maloti Drakensberg Transfrontier Project, Maseru 100, Lesotho, South Africa.

J. Macuacua is with the National Directorate of Forest and Wildlife for Maputo, Ministry of Agriculture Building, Praca Dos Herlos, Mozambique.

C. Mbow is with the Institut des Sciences de l'Environnement, Université Cheikh Anta Diop de Dakar, Dakar Fann BP 5005, Senegal.

K. L. Mhwandangara is with the Geospatial Solutions, Belvedere, Harare, Zimbabwe.

B. Mosepele is with the Conservation International Botswana, Maun, Botswana.

O. Mutanga is with the Department of Geography, University of Kwazulu Natal, Pietermaritzburg 3209, South Africa.

G. Neo-Mahupeleng is with the African Wildlife Foundation, Kasane, Botswana.

M. Norman is with the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Proder-Mozambique, Beira, Mozambique.

S. Virgilo is with the Ministry of Urban Affairs and Environment, Rua Luanda-Sul, 302 Luanda, Angola.

Digital Object Identifier 10.1109/TGRS.2006.871200

But to what extent are such statements confirmed by the experiences of people who use satellite derived products in their work?

This correspondence provides feedback on the usefulness and applicability of satellite fire product accuracy information, and makes recommendations on how to improve its relevance, from the perspective of members of the Southern Africa Fire Network (SAFNet).

II. SAFNet

The SAFNet is an open network of scientists, managers and communicators who use fire information to support their resource management and environmental assessment activities. SAFNet's goal is to achieve more effective and appropriate fire management policies and practices in southern Africa through the use of remote sensing and other geospatial information technologies [1]. In the last six years of working together, SAFNet has held annual meetings to develop this goal and to coordinate a number of projects, including the development of a protocol to validate the MODIS burned area product in southern Africa [2]. Recently, SAFNet hosted two focus group discussions [3] at the Fifth annual SAFNet meeting [4] to document perspectives held by southern African resource managers and brokers of satellite data with diverse experiences and affiliations (government, nongovernment organizations, industry, and academic). The focus group participants were asked to identify and discuss factors that promote or constrain the use of the MODIS active fire [5] and burned area [6] products, for actual and potential applications in the region. Transcripts of the focus group discussions were analyzed and the results grouped into recurrent themes [7]. Focus group findings relevant to this correspondence are described below, interwoven with insights gained from our six years of working together.

III. Synthesis

Of the factors that determine the choice and use of satellite fire products, the provision of product accuracy information is considered to exert relatively weak control. The focus group participants did express needs for fire products to represent reality accurately and to include accuracy information; however, discussion on the quantitative specifics of what constitutes an acceptable level of accuracy was not well developed. This lack of specificity mirrors difficulties with defining accuracy requirements found in other applications. For example, the degree that the atmospheric modeling community defined fire product accuracy requirements for modeling emissions was also recently described as "not well developed" [8]. Since user requirements of satellite fire products are often not articulated in terms of numerical thresholds of acceptable accuracy, quantitative accuracy information may exert only a weak control on whether a product is used for a particular purpose.

For many SAFNet members, it is inherently perplexing to translate even conventional quantitative accuracy information [9] into decisions on whether a product is useful for a particular application. This may be because accuracy information is incomprehensible to some users, due to a lack of familiarity with the relevant theory, or because the information is not presented with sufficient clarity. More fundamentally, accuracy information may not sufficiently capture the information users need to determine whether a product is "good enough" for a particular application.

Rather than rely on product accuracy information, the focus group participants noted that many users may decide whether to adopt a product based on their exposure to example products or cases studies, and on the degree that the incidence and extent of fires recorded in the fire products are verified or refuted through their experiences using them.

IV. Recommendations to Make Satellite Fire Product Accuracy Information as Useful as Possible to Users

Although the provision of satellite fire product accuracy information may exert only a weak control on product use, this in no way dismisses the need to document product accuracy. It does however indicate a need to maximize the relevance of fire product accuracy information to users. We suggest that this can be achieved in the following ways.

A. Provide a Complementary Qualitative Summary of Product Accuracy That Can be Understood by Users With Little or No Experience in Remote Sensing or Statistics

The SAFNet supports the provision of conventional error-matrix-based metrics of product accuracy [9]. They recognize that these metrics may both help numerate/science users understand if the product is useful and help them explain the accuracy of their application findings. As already stated, such accuracy information will not be comprehensible to all users; certainly, the more complex an accuracy metric, the smaller the population that will be able to comprehend it.

Furthermore, some users will benefit from qualitative product information that complements and explains quantitative accuracy information, especially those users who are not remote sensing practitioners, or who do not have a numerate/science background. Qualitative information could also usefully include nontechnical disclaimers that explain that the product is not necessarily a true representation of reality, or that the product should not be used in a court of law. Disclaimers may also be useful in helping to educate non-remote sensing experts on ways fire products can be used appropriately, and, perhaps, which uses are inappropriate.

B. Describe Product Accuracy in Terms of Physical Characteristics That Can be Observed and Preferably Measured on the Ground

Users desire product accuracy information defined in terms of physical characteristics that can be related directly to their applications. For fire products, these include characteristics such as the average or maximum fire temperature, the size of the fire and area burned, and the degree of combustion completeness. The importance of defining accuracy in terms of something that is physically observable becomes apparent if we recognize that many users do not understand what is detected by a 1-km MODIS active fire detection, as illustrated in the following focus group exchange:

— "*But what is [detected] ...? Is it the heat, or the area*?"
— "*Often it's not 400 [separate active] fires, it's 400 spots* [1 km *pixels*], *and they're hot and they've been picked up [detected]*."

Similarly, the exact definition of what constitutes a detected burned area is often unclear, even to producers of burned area products [10].

Many non-remote sensing scientists will struggle to understand reported fire product accuracy when it is defined in terms of another remotely sensed product. This is a fundamental problem. For example, [11] and [12] define MODIS 1-km-active fire detection accuracy in terms of the correspondence with contemporaneous ASTER active fire detections. Here, users of the resulting accuracy metrics need to understand what constitutes an ASTER fire detection, as well as the technical remote sensing specifics of the satellite data. For example, [11] define what constitutes a "valid detection" in a manner that requires an understanding of the MODIS sensing geometry, noting that while this definition may help developers of algorithms and sensors, it may not necessarily be useful to the broader user community. Similarly, burned area product accuracy is commonly defined in terms of burned area reference data that is derived from higher spatial resolution satellite data [2], [13]. Again, this can make the resulting accuracy information less easy to interpret, particularly if what constitutes a "burned" high spatial resolution satellite pixel is not defined in a physical or comprehensible manner.

C. Describe Product Accuracy Close to the Scale of the Intended Application

The scale at which product accuracy is reported becomes more relevant as it approaches the application scale. For example, [13] reports burned area product accuracy at resolutions of 0.25°, 0.5°, and 1°, as these scales are of interest to atmospheric modelers. However, these reporting scales are less relevant to most SAFNet members, who are interested in accuracy figures that relate to the local to regional scales of land management. Moreover, accuracy statistics vary as a function of scale [14]. Arguably, it may be useful to report accuracy at both the scale at which the product was generated, as well as at a range of coarser scales that may be of interest to different users.

D. Describe Product Accuracy in Both a Spatially and Temporally Specific Manner

Validation activities that assess product accuracy within individual reference data sets provide accuracy information that pertain only to the time and location at which the particular reference data were sensed. However, the detection accuracy of satellite fire products changes with environmental and remote sensing factors that also vary in space and time [5], [6], [10]. Therefore, accuracy assessments made using a limited number of individual reference data sets may not represent the range of error that a product contains. For example, in southern Africa, fire characteristics vary both spatially, from arid savanna systems to moist woodland, and seasonally, with changes in moisture and greenness. Similarly, cloud persistence and seasonality vary considerably, yet clouds preclude active fire detection and reduce the ability to map burned areas [6]. As such, it would be helpful to describe fire product accuracy over a sufficient range of space and time to ensure the resulting metrics encapsulate variations in cloud and other environmental parameters that affect detection accuracy. We note that statistically rigorous sampling strategies have yet to be defined for collecting independent fire product reference data at regional to global scales [2], [13]. This and validation resource constraints, reduce the likelihood that sufficient reference data will be available. However, fire product accuracy information may be more useful if described in terms of ecosystem type and fire season, rather than on a regional and annual basis.

E. Make Accuracy Information More Comprehensible and Relevant to Users by Involving Them in Validation Activities and/or by Making Validation Data Sets Available to Them

Users may understand product accuracy more easily if they are involved in the validation process and/or can access product samples and corresponding validation data sets. For example, a guiding principle of the Global Observations of Forest Cover/Global Observation of Landcover Dynamics (GOFC/GOLD) initiative is that the user community plays an active role in assessing satellite products and testing pre-operational algorithms. From this principle, SAFNet developed a consensus protocol used to validate the MODIS burned area product at southern African Landsat scenes distributed to capture a range in burned area characteristics at locations where SAFNet members have existing fire projects [2]. Involving users is less meaningful for both retrospective validation [13] and approaches which locate reference data without regard to the location of the user's projects. In all cases, however, it is possible to make validation data sets available to users.

V. Conclusion

This SAFNet perspective on the limited degree that accuracy information determines satellite fire product uptake suggests that accuracy information needs to be made more relevant to users. This need is most likely true for many types of users, including those who are not working in southern Africa and the atmospheric emissions user community. These needs are particularly pertinent given the increasing recognition of the need to develop validation protocols to increase the quality, consistency, and economy of validating satellite products at regional to global scales [15].

Satellite product accuracy information should ideally meet the needs of users who possess varying knowledge of remote sensing and statistics, work in different applications, and work at different spatial and temporal scales. Delivering such information will require both increased resources for validating products and an improved understanding of the accuracy metrics that are required for different applications. To help meet these challenges, we have described five ways that the accuracy information delivered with fire products can be made more relevant and comprehensible to users.

References

[1] SAFNet web site. [Online]. Available: http://safnet.umd.edu/index.asp

[2] D. P. Roy, P. Frost, C. Justice, T. Landmann, J. Le Roux, K. Gumbo, S. Makungwa, K. Dunham, R. Du Toit, K. Mhwandagara, A. Zacarias, B. Tacheba, O. Dube, J. Pereira, P. Mushove, J. Morisette, S. S. Vannan, and D. Davies, "The Southern Africa Fire Network (SAFNet) regional burned area product validation protocol," *Int. J. Remote Sens.*, vol. 26, pp. 4265–4292, 2005.

[3] R. A. Krueger, *Focus Groups; A Practical Guide for Applied Research*. Thousand Oaks, CA: Sage, 1994.

[4] UNEP, Division of Early Warning and Assessment (DEWA), Africa Programme, 5th Southern Africa Fire Network (SAFNet) Meeting Toward Meeting Fire Management Challenges in Southern Africa, Nairobi, Kenya, Aug. 9–13, 2004.

[5] L. Giglio, J. Descloitres, C. O. Justice, and Y. J. Kaufman, "An enhanced contextual fire detection algorithm for MODIS," *Remote Sens. Environ.*, vol. 87, pp. 273–382, 2003.

[6] D. P. Roy, Y. Jin, P. E. Lewis, and C. O. Justice, "Prototyping a global algorithm for systematic fire-affected area mapping using MODIS time series data," *Remote Sens. Environ.*, vol. 97, pp. 137–162, 2005.

[7] S. N. Trigg and D. P. Roy, "A focus group study of factors that promote and constrain the use of satellite-derived fire products by resource managers in southern Africa," *Int. J. Environ. Management*, to be published.

[8] "News from research: Joint GOFC/GOLD fire and IGBP-IGAC/BIBEX workshop improving global estimates of atmospheric emissions from biomass burning," *Int. Forest Fire News (IFFN)*, no. 28, pp. 105–111, 2003.

[9] G. Foody, "Status of land cover classification accuracy assessment," *Remote Sens. Environ.*, vol. 80, pp. 185–201, 2002.

[10] D. P. Roy and T. Landmann, "Characterizing the surface heterogeneity of fire effects using multi-temporal reflective wavelength data," *Int. J. Remote Sens.*, vol. 26, pp. 4197–4218, 2005.

[11] I. Csiszar, J. Morisette, and L. Giglio, "Validation of active fire detection from moderate resolution sensors: The MODIS example in Northern Eurasia," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 7, pp. 1757–1764, Jul. 2006.

[12] J. T. Morisette, L. Giglio, I. Csiszar, and C. O. Justice, "Validation of MODIS active fire product over southern Africa with ASTER data," *Int. J. Remote Sens.*, vol. 26, pp. 4239–4264, 2005.

[13] L. Boschetti, P. A. Brivio, H. Eva, J. Gallego, A. Baraldi, and J.-M. Gregoire, "A sampling method for the retrospective validation of global burned area products," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 7, pp. 1765–1773, Jul. 2006.

[14] S. Openshaw, *The Modified Areal Unit Problem*. Norwich, U.K.: GeoBooks, 1984.

[15] C. O. Justice, A. Belward, J. Morisette, P. Lewis, J. Privette, and F. Baret, "Developments in the 'validation' of satellite sensor products for the study of the land surface," *Int. J. Remote Sens.*, vol. 21, pp. 3383–3390, 2000.