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Review of FEWS NET biophysical monitoring requirements

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Abstract
The Famine Early Warning System Network (FEWS NET) provides monitoring and early warning support to decision makers responsible for responding to famine and food insecurity. FEWS NET transforms satellite remote sensing data into rainfall and vegetation information that can be used by these decision makers. The National Aeronautics and Space Administration has recently funded activities to enhance remote sensing inputs to FEWS NET. To elicit Earth observation requirements, a professional review questionnaire was disseminated to FEWS NET expert end-users; it focused upon operational requirements to determine additional useful remote sensing data and, subsequently, to assess whether such data would be beneficial as FEWS NET biophysical supplementary inputs. The review was completed by over 40 experts from around the world. Reviewers were asked to evaluate the relative importance of environmental variables and spatio-temporal requirements for Earth science data products, in particular for rainfall and vegetation products. The results showed that spatio-temporal resolution requirements are complex and need to vary according to place, time, and hazard; that high resolution remote sensing products continue to be in demand; and that rainfall and vegetation products are valued as data that provide actionable food security information.

Keywords: applied remote sensing, requirements definition, Earth observations, early warning

1. Introduction

The Famine Early Warning System Network (FEWS NET) was created in 1985 by the United States Agency for International Development (USAID) to improve their emergency response capabilities in Africa, including disseminating information and increasing food security (Brown 2008). The goal of 'early warning' (USAID 2007) is the timely and effective delivery of information that allows affected individuals to take action to avoid and/or reduce their risk, as well as to prepare for effective response (Buchanan-Smith and Davies 1995). Key elements of a successful early warning system include accurate forecasts of the human consequences of an event when predicting its location, time, and severity; and dissemination of warnings in time for populations at risk to take appropriate action (Davies *et al* 1991). FEWS NET provides early warning information to USAID through a suite of data products that support decision making on how to anticipate and respond to episodes of food insecurity so that the human and financial toll of the disaster can be reduced.

Monitoring information, including Earth science remotely sensed data and ground-based meteorological, crop, and rangeland conditions, strengthens the abilities of FEWS NET to manage the risk of food insecurity. FEWS NET's representatives work to create consensus about a particular country's food security situation. When a crisis is building, a wide variety of actors must both understand and agree about the nature of the problem and, more importantly, the solution. These actors include local, regional, and national government officials from the executive branch, health departments, meteorological departments, and others; non-profit organizations that are active in the affected area, as well as international aid organizations such as the World Food Programme; and key analysts who work on food security. Due to the complexity associated with this diverse group of participants and the overwhelming need for consensus, in this situation remote sensing derived data takes on a new role: it is viewed as politically neutral and easy to understand, making it one of the most important and earliest sources of information on an emerging food insecurity problem. Therefore, remote sensing information is critical to FEWS NET's ability to move from discussion of an impending threat to a decision that food aid is actually needed in a particular area (Brown 2008). Furthermore, when a biophysical hazard such as a drought occurs, remotely sensed data becomes a vital input because it enables decisions to be made about the number of people needing assistance, the geographic area affected, and the need for non-food assistance, such as vaccinations, maternal and child health programmes, and water delivery.

Over the past two decades, there have been several evolutionary shifts in how FEWS NET has used and perceived remotely sensed data. In the mid-1980s, when the early warning system was first established, social scientists dominated the project and were very sceptical about the utility of the newly emerging remote sensing datasets (Tucker *et al* 1985). By the late 1980s, as remote sensing scientific research became available and there was a personnel shift within FEWS NET, vegetation index imagery became the premier data product (Hielkema *et al* 1986, Hutchinson 1991); a great deal of weight was given to its ability to estimate crop conditions over large areas from afar, and to their implications for food production, and ultimately food security. Although the utility of the normalized difference vegetation index (NDVI) was probably oversold (Buchanan-Smith and Davies 1995) by some, its acceptance by food security analysts was due to its low cost, synoptic coverage of large areas, and most importantly, timely access, a compelling characteristic for early warning purposes. In the late 1990s, with the advent of the tropical rainfall measuring mission (TRMM) rainfall datasets significantly improved by blending observations from multiple instruments with station data. As a result, rainfall became more reliable than NDVI in estimating growing conditions. Since 2000, datasets like gridded rainfall and derived water balance products have been extensively used; how well these products address the requirements of food security analysts and decision makers, however, has not been well defined. While the importance of food prices, wage labour markets, and other socio-economic datasets is widely recognized (Torry 1988), they are still too few in number, difficult to access, and only provide glimpses of the true situation on the ground. Consequently, timely remote sensing products continue to be essential for the food security analyses of FEWS NET. They provide valuable context for food security decision making which remains a social, political, and economic phenomenon. An illustrative example was the late start of rains in certain parts of the Sahel in 2006. This was a food security issue as a factor lurking throughout the season, despite the good rainfall totals that were experienced later. There was concern that an abbreviated growing period due to late onset of rains would lead to crop production shortfalls in those parts of the Sahel with fragile food security. Remotely sensed data alerted food security analysts well before any such impacts would be evident in crop production reporting many months later. Although agricultural production was ultimately above average, early detection of the late start allowed FEWS NET to focus attention on potential trouble spots throughout the growing season.

Continued improvement in Earth science data will be useful to both increase the functionality of FEWS NET and address new institutional needs. Since the individuals who actually provide this type of data are generally not those who define the underlying requirements, such as data precision or the optimal resolution in the spatial and temporal domains, a review was initiated to gather expert end-user's Earth science remote sensing requirements necessary to enhance FEWS NET functionality. A questionnaire served as the instrument for eliciting inputs from FEWS NET professionals.

1.1. FEWS NET and biophysical remote sensing data

FEWS NET uses an integrated approach to continually evolve and improve its capacity for vulnerability assessment and early warning of food insecurity in support of humanitarian response programmes. FEWS NET field and Washington offices gather and assess a wide variety of early warning, food access and availability, and vulnerability data and information to determine the food security status of a region. By building networks and through hands-on training, FEWS NET representatives work to improve the human and institutional food security assessment and early warning capacity of country and regional partners/networks. Representatives and remote sensing specialists based in the field also work to develop, test, and implement new applied tools and methods for early warning, as well as food security and vulnerability assessment.

Almost all FEWS NET field offices produce monthly food security situation reports for each country. Alert reports are also prepared when the USAID determines that food security status in a country or area is a problem, based upon the FEWS NET watch, warning, and emergency criteria. FEWS NET interprets the food security significance of biophysical and climate data based on year-to-year variations to help understand food production, threats to pastoral resources, wild food availability, and ultimately the agricultural economy as a whole (Brown 2008). This information is integrated with socio-economic monitoring data (Verdin *et al* 2005). FEWS NET relies upon vegetation, temperature, and rainfall data derived from remote sensing, atmospheric models, and local measurements (when available) to identify abnormally wet and/or dry periods. Presently, FEWS NET early warning is characterized by a weekly weather hazards assessment process that includes members of the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), US Geological Survey (USGS), US Department of Agriculture (USDA), USAID, and a variety of technical specialists in Africa, Central America, and Afghanistan.

1.2. FEWS NET current and planned datasets

FEWS NET uses extensive data types to summarize current climatic situations, including gridded rainfall data and vegetation data derived from satellite imagery. Rainfall images drive a variety of models that allow investigation of the direct effect of rainfall amount on crop production. Vegetation index data derived from satellite imagery can provide insights into vegetative cover response to rainfall. Because vegetation and rainfall images measure different parameters, both types of satellite observations are needed for hazard identification.

FEWS NET's agricultural monitoring is global; therefore, the temporal requirements for any given parameter are driven by the more sensitive time points in a crop's development—at any given time, a crop of some regional importance will be entering a critical time period in some part of the world. Additionally, although early crop development is often most critical, mid-season development, such as grain-fill in rain-fed maize, may often make dramatic swings in yield based on mid-season precipitation. So from an agricultural perspective, FEWS NET is multifactorial; it uses remotely sensed data from a variety of products as needed throughout the different points of the growing season for each region (Central America, Haiti, Afghanistan, and in three regions of Africa).

Examples of new or improved Earth science products that are being considered as enhancements for FEWS NET decision-making capabilities include more accurate and higher resolution vegetation and rainfall datasets, and new temperature, precipitable water, and humidity data. Accuracy estimates and projections of these datasets 1, 2, and 3 months into the future will help food security analysts provide additional information to decision makers regarding future food aid needs. These new datasets will be available to FEWS NET personnel and all interested persons by the end of 2009.

2. Design and administration of professional review

FEWS NET expert end-users and experts in Earth science information content answered a fact-finding professional review, in the form of an online questionnaire, to quantify FEWS NET satellite remote sensing requirements. The end-users included FEWS NET and USGS field personnel associated with country and regional offices. The Earth science information content providers included members of a network of experts in areas including hazards, meteorology, and agriculture.

Three broad sections of user requirements were addressed in the questionnaire. The general requirements section included identification and ranking of environmental variables and the spatio-temporal properties needed in those variables. The rainfall requirements section covered particular needs associated with both measured and predicted rainfall. The vegetation requirements section focused on vegetation monitoring and proposed predictions of vegetation status. The rainfall estimate being evaluated was NOAA's Rainfall Estimate (RFE) (Love *et al* 2004). Vegetation estimates being evaluated were NDVI (Tucker 1979) from the global inventory modelling and mapping studies advanced very high resolution radiometer (GIMMS AVHRR) NDVIg 8 km dataset (Tucker *et al* 2005), 1 km data from SPOT Vegetation (Maisongrande *et al* 2004), and 500 m data from the moderate resolution imaging spectroradiometer (MODIS) (Huete *et al* 2002).

The questionnaire also addressed the usefulness of specific FEWS NET decision support elements. This portion of the questionnaire established a baseline for future activities that will involve measuring the effect of the proposed FEWS NET enhancements.

The review questionnaire was made available in June 2007, and responses were accepted through July 2007. Individuals identified as instrumental in the process of collecting biophysical data and converting it into information products that support food security decision making were invited to participate in the questionnaire review. Because of their familiarity with both the data products and the decision-making process, it was believed that these individuals would provide the most insight into the collective professional judgement of the FEWS NET community. In total, 63 reviewers were invited to participate. Of the invitees, 35 were personnel who worked more directly with the end-user; that is, they were either from FEWS NET field offices or other aligned entities in regions where food security is closely monitored; and 28 were part of the information support infrastructure in the United States. Complete responses were provided by 43 participants. Of these respondents, 20 were field personnel: 5 working in Central America/Haiti and 15 working in Africa. The remaining 23 respondents were US government and contractor personnel from the 5 associated FEWS NET agencies. Forty-four per cent of the reviewers had between 6 and 10 years of FEWS NET-related experience and almost 35% had over 10 years of experience. The reviewers had a variety of educational backgrounds: 32% had an agriculture degree and 21% had a degree in remote sensing science. Most respondents had either on-the-job training or some formal training in meteorology, remote sensing, or geographic information systems.

The goal of the questionnaire was to elicit information for enhancing FEWS NET via a suite of satellite-based standardized products specific for climate monitoring. However, because the users were familiar with both the strengths and weaknesses of different kinds of remote sensing datasets and of the currently available dataset selection, respondents tended to express their requirements more in terms of what they knew was possible rather than in terms of what was actually required. Therefore, although the questions were designed to elicit the most candid responses possible, the responses to more specific questions often tended to be based upon knowledge of existing sensor options. In particular, the reviewers' collective affinity toward higher spatial resolution might bias toward users with more stringent needs.

3. Questionnaire response results

Overall, rainfall data was regarded as an essential component of famine early warning. A clear majority of respondents felt

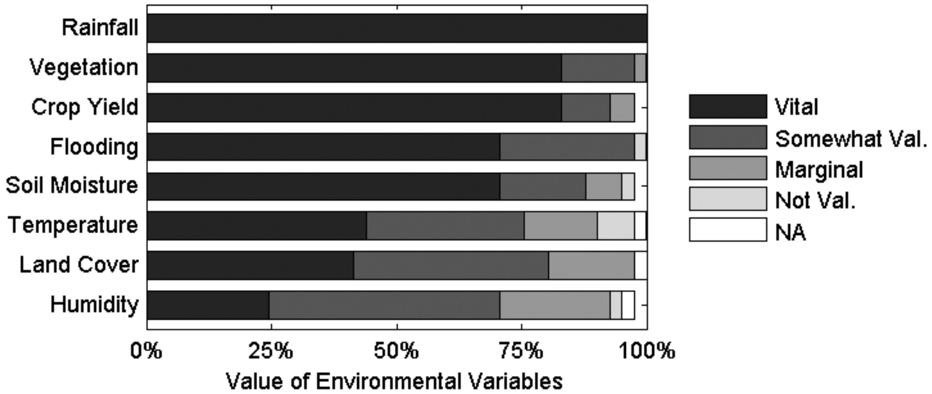

Figure 1. FEWS NET reviewers' ratings of the value of environmental variables.

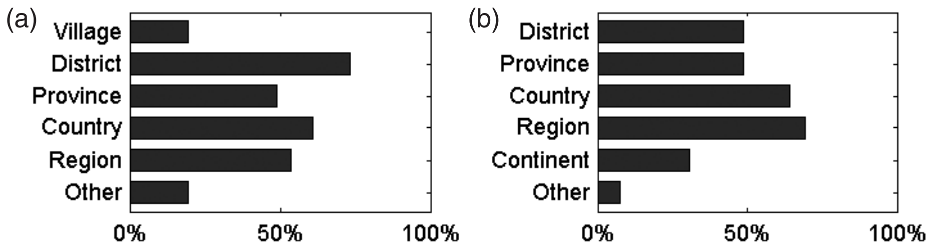

Figure 2. FEWS NET reviewers' identification of spatial qualities considered necessary for their analysis or decision making. Note that reviewers were allowed to select multiple options as 'necessary', so total response is greater than 100%. (a) Spatial resolution. (b) Spatial extent.

that data on crop yield estimates, vegetation, soil moisture, and flooding were vital as well. However, less than half of the group saw temperature, land cover, and humidity data as vital for early warning analysis (figure 1). When asked to cite the drivers for the requirements of FEWS NET analyses, the professional reviewers expressed concerns associated with the great diversity of food security-related challenges and logistical constraints. They specifically referred to issues related to both slow-onset concerns, such as drought, as well as extreme events, such as cyclones and flooding. They also described varying climate regimes (e.g., too much rain, not enough rain, cyclones) requiring different environmental data to assess the impact of climate on food production and food security. Early warning or forecasts of diseases like malaria and Rift Valley fever were also cited as drivers. The available digital infrastructure also placed limits on the size of the datasets analysed and distributed.

Figure 1 summarizes the respondents' opinions regarding the value of various environmental variables.

3.1. Spatial requirements

Responses regarding spatial resolution are shown in figure 2(a). If requirements analyses for output are properly defined, they should be traceable to input requirements for environmental variables. This review approached the problem of bounding spatial requirements by asking respondents to identify labels for the spatial scale of their principal analytical tasks. These labels from small to large included village, district, province, country, and region. The review did not define these scale labels in terms of linear or area units; instead, the respondents were asked to provide a written response for the spatial resolution that they associated with scale labels chosen. For analysis scale, the dominant responses were 'District' and 'Country'. Notably, among respondents who specified a quantitative spatial resolution, the most frequent resolution associated with 'District' scale analysis was 250 m. These responses indicate that the spatial resolutions of current operational monitoring sensors are sufficient, since 250 m (MODIS) systems provide this level of detail.

While reviewers indicated that spatial resolution for general observations were sufficient, when asked about specific parameters, they expressed concern about rainfall. Rainfall is critical to FEWS NET's representatives. Reviewers expressed a need for higher spatial and temporal resolution data related to rainfall because their work covers areas with diverse livelihoods and complex topography. Topography variations do not give a true image of actual ground conditions and makes generalization of information difficult even at the district level. The available rain gauge data is limited, especially in pastoral areas. Therefore, dissatisfaction with current 8 km resolution products was expressed by some; specifically, that this resolution was too coarse to capture important variations. High resolution satellite rainfall imagery would improve the information quality requested, enable better analysis of food security hazards, and provide a higher confidence in the information and areas not covered by rain gauge data.

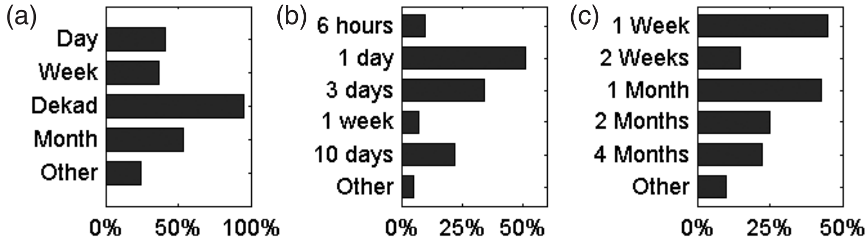

Figure 3. FEWS NET reviewers' identification of temporal qualities considered necessary for their analysis or decision making. (a) Temporal frequency. (b) Latency. (c) Prediction timescale.

Additionally, Central America would benefit from higher spatial resolution products. The current 0.25° or 0.1° rainfall products are not suitable for detecting the rainfall variability, which can be significant within the span of a single 10 km pixel.

Having data at multiple resolutions was expressed as important, because analyses are often conducted at highly variable resolutions; that is, from continental scale to sub-district scale. Consequently, as FEWS NET's ability to process variations in livelihood zones improves, the necessity of finer spatial scale increases.

Questions regarding vegetation revealed that the desired resolutions were between 250 m and 1 km. In this case, rainfall spatial resolution needs were less stringent; resolutions between 2 and 5 km were sufficient.

If connecting resolution with scale labels is a representative constraint, it is possible that some planned products will not meet all FEWS NET requirements. Spatial resolution needs to vary according to place, time, and hazard. Furthermore, as previously mentioned, perception of spatial resolution needed for analysis may be skewed by knowledge of the available sensor resolutions. In general, the findings presented in this paper represent the collective tendency of the reviewing professionals. Additionally, due to interpretation challenges, the spatial resolution finding may be biased toward users with more stringent needs.

Responses on spatial extent (figure 2(b)) were straightforward: over half indicated a need for regional or at least country coverage.

3.2. Temporal requirements

Responses regarding temporal requirements overwhelmingly indicated that the traditional 10 day or dekadal time step (figure 3(a)) was most desired. Even though the dekad was clearly favoured, over half the respondents did say that monthly inputs were important and over 40% considered even daily data important.

For latency, data delivery within 1 day of acquisition was considered important both by environment monitoring experts and FEWS NET representatives (figure 3(b)).

The final temporal consideration was prediction time interval. Respondents stated that predictions looking both 1 week and 1 month into the future would be of particular interest (figure 3(c)).

Each section of the questionnaire asked the reviewers for general comments about their requirements. Overall, responses indicated that the requirements depended upon the particular application. Data requirements for flood monitoring are obviously dependent on high temporal frequency/short latency data, such as rainfall, rainfall forecasts, stream flow, and runoff anomalies. Vegetation/crop monitoring and modelling are not as time-sensitive and can use data with longer periods of both latency and frequency. Spatial requirements are also variable by region. Again, an increasing need for much finer scale monitoring capabilities was expressed, whether for vegetation and rainfall monitoring over small areas or for cropped area delineations for small localized fields.

3.3. Results for rainfall value and accuracy

To evaluate specific environmental variables, the questionnaire asked the value of rainfall estimates at various prediction timescales up through 4-month forecasts. The reviewers' responses are summarized in figure 4(a). Almost all respondents identified a rainfall monitoring product as 'vital', and a majority thought a 1-month forecast to be essential. Beyond 1 month, the information became less relevant; however, a majority of respondents still saw 2- and 4-month forecasts as either valuable or somewhat valuable.

The questionnaire asked reviewers, both directly and indirectly, to comment on the required quality of rainfall estimates. The direct approach asked reviewers what they believed to be the required absolute rainfall estimation accuracy for a dekadal time step. The indirect approach asked reviewers what levels of anomaly (either in absolute or per cent terms) they believed to be significant for decision making.

For rainfall estimate accuracy questions (figure 4(b)), a clear majority of respondents perceived that rainfall monitoring should be accurate to within 10 mm per dekad. For 1-month forecasts, reviewers who selected an accuracy level were nearly evenly split between 10 mm per dekad and 50 mm per dekad. For 2-month forecasts, the largest group supported a 50 mm per dekad requirement. At 4 months out, the response became somewhat diffuse, although there was a trend toward relaxing the absolute requirement. For all the predicted time intervals, a noteworthy segment of respondents (from 22% to 27%) reported being unsure of whether the prediction was necessary for their analysis.

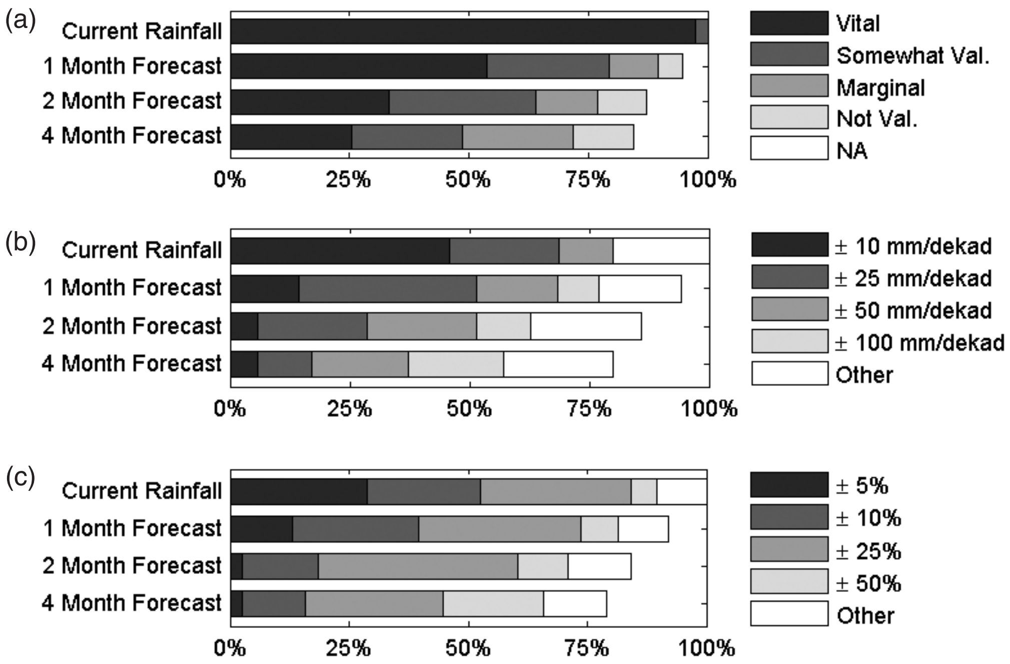

Figure 4. Breakdown of how respondents value various rainfall estimates from current (near real-time observed) through 4-month forecasts. (a) Value of rainfall product. (b) Minimum significance threshold, absolute. (c) Minimum significance threshold, relative.

Answers to questions related to absolute anomalies (figure 4(b)) revealed that for rainfall, most thought that a 10 mm per dekad anomaly for monitoring would be significant; most also thought that a 25 mm per dekad anomaly would be significant for a 1-month forecast. For a 2-month forecast, threshold of significance was basically split between 25 mm per dekad and 50 mm per dekad; at a 4-month forecast, the dominant responses were 50 mm per dekad and 100 mm per dekad. The data show that improving existing rainfall estimation/prediction performance is required as forecasting time increases. This response could impact future data requirements.

For relative rainfall anomalies (figure 4(c)), the predominant response for minimum level of threshold of significance was 25% at every estimate prediction time; interestingly, this requirement diminished as the forecast time extended.

3.4. Results for vegetation value and accuracy

The reviewers' response regarding the value of vegetation monitoring is summarized in figure 5(a). Reviewers were asked to consider both existing monitoring products as well as vegetation forecasting products under development. The responses were strongly supportive of both monitoring (>70%) and 1-month forecasts (>50%), and having estimates at those times was indicated to be 'vital'. At 2 months and 4 months, most reviewers considered vegetation forecasts as 'somewhat valuable'. Overall, the reviewers' responses revealed that vegetation was not valued as highly as rainfall, and some responders were not sure how vegetation product forecasts related to their analysis or decision making.

The questionnaire asked reviewers to consider product quality in relationship to their perception of both required accuracy and thresholds of significance. For vegetation monitoring, it was challenging to word the questions because vegetation as monitored through remote sensing indices is scaled in a variety of ways. Therefore, the questionnaire asked reviewers to consider a common vegetation index scale (-1 to 1) resulting directly from the NDVI formula (NDVI $=$ [NIR $-$ red]/[NIR $+$ red]).

In general, the respondents' view of vegetation accuracy was not as well defined as their view of rainfall accuracy. For many, the role of vegetation products for analysis and/or decision making was not necessarily clear. However, a trend in the group's response was still discernible: dominant selection of 0.02 NDVI for monitoring, 0.05 NDVI for 1-month forecasts, and 0.10 NDVI for 2- and 4-month forecasts.

As with rainfall, reviewers found that the absolute thresholds for vegetation anomalies were more lenient than their stated accuracy requirements. The most frequent selection for significance threshold was 0.02 NDVI for monitoring, but only 0.10 NDVI for 1- and 2-month forecasts, and 0.20 NDVI for 4-month forecasts (figure 5(b)). For relative vegetation anomalies for monitoring and 1-month forecasts, most reviewers identified 10% as a minimum threshold for significance; for 2- and 4-month forecasts, most respondents identified 25% as a minimum threshold for significance (figure 5(c)).

Overall, reviewers appreciated that vegetation required a longer temporal time step because vegetation responds more slowly to rainfall, and consequently the need for quick answers is reduced. Conversely, higher spatial resolution of vegetation was desirable and useful. Higher spatial resolution vegetation maps are also beneficial for small cropping field and mixed land uses.

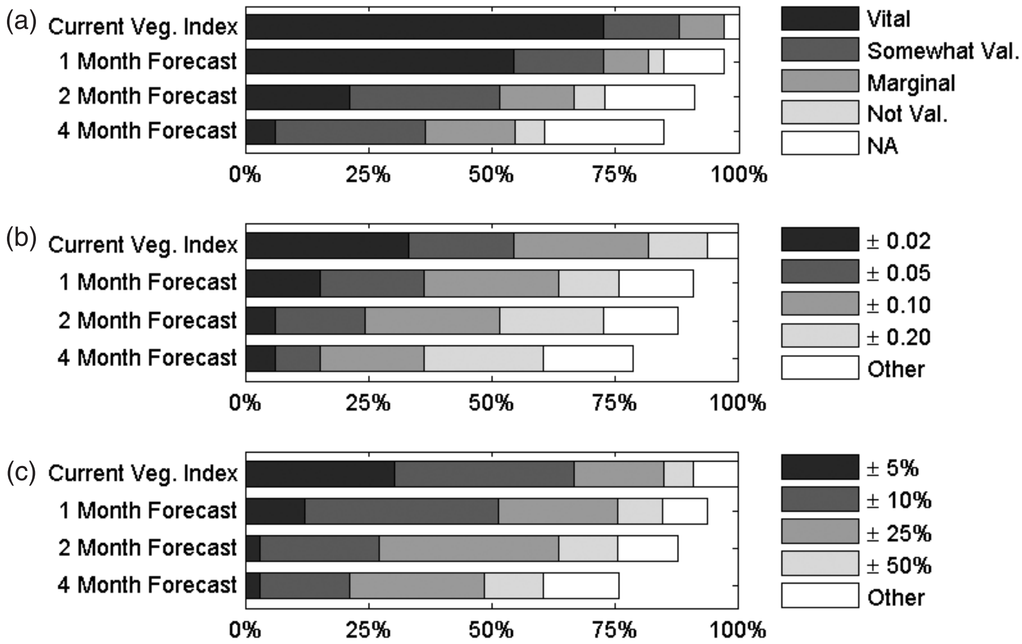

Figure 5. Breakdown of how respondents value various vegetation index estimates from current (near real-time observed) through 4-month forecasts. (a) Value of veg. index product. (b) Minimum significance threshold, absolute. (c) Minimum significance threshold, relative.

3.5. Requirements summary

The reviewers unanimously agreed that rainfall is an essential component of famine early warning. Furthermore, a clear majority of respondents felt that crop yield estimates and vegetation were also vital.

The net results of the review's requirements portion are presented in table 1. The stated requirements numbers have been inferred from the multiple choice items and accompanying comments. In some categories, multiple requirements were stated to satisfy needs arising from multiple drivers. Tables 2 and 3 provide the specific requirements for satellite rainfall and vegetation remote sensing for FEWS NET. Information from these tables can be used to derive and identify areas where improvement can be made and/or where further research is required.

Table 1. FEWS NET general requirements as inferred from review.

Property	User requirement	Drivers
Spatial resolution	250 m–1 km	Need to capture variations to support district level analysis
Spatial extent	2000–4000 km across	Need to capture synoptic views at country and regional scales
Temporal frequency	Dekad (primary)	Established operational practice; need to capture variations from typical phenology (dekadal data satisfies those with 'Monthly' needs as well)
	Daily (secondary)	Need to capture sudden-onset hazards such as flooding
Latency	⩽1 day	Need to quickly address sudden-onset hazards
Prediction timescale	1 week and 1 month	Need to analyse and prepare for both faster and more slowly evolving hazards

4. Discussion

By using this requirements seeking questionnaire technique, information useful to FEWS NET professionals was obtained. Overall, it was determined that rainfall and vegetation remote sensing data provide actionable food security information for FEWS NET. Key areas where decisions were influenced by the data products were identified as follows.

- Flooding—likelihood, duration, and intensity.
- Crop—start of season, progress, spatial and temporal distribution, and projected performance.
- Drought—rainfall shortfalls, duration, spatial spread, and intensity.
- Disease—water- and vector-borne disease due to flooding or excess collection of water.

When temporal requirements for satellite data were being specified, respondents clearly stated that the type of hazard influences the frequency of the data requirement. For example, FEWS NET works particularly well in areas that are highly vulnerable to extreme events, such as cyclones and floods; in these situations, near real-time and daily information is required to provide enough time for reaction (Vorosmarty *et al* 2000). On the other hand, droughts are slow-onset disasters that occur more frequently; therefore, constant monitoring is important to capture these types of events (Husak *et al* 2007). Higher resolution products for both rainfall and vegetation were also of interest to FEWS NET's partners and representatives so that sub-pixel variations could be captured.

Table 2. FEWS NET rainfall requirements as inferred from review.

Property		User requirement	Drivers
Spatial resolution	Rainfall	2–5 km	Somewhat relaxed because of convolving effects of topography, soils, etc
Rainfall absolute accuracy (assuming dekadal time step)	Current	10 mm per dekad	Response
	1-month forecast	30 mm per dekad	Short-range planning
	2-month forecast	50 mm per dekad	Medium-range planning
	4-month forecast	70 mm per dekad	Medium- to long-range planning
Rainfall anomaly relative accuracy (assuming dekadal time step)	Current	15%	Response
	1-month forecast	20%	Short-range planning
	2-month forecast	25%	Medium-range planning
	4-month forecast	30%	Medium- to long-range planning

Table 3. FEWS NET vegetation requirements as inferred from review.

Property		User requirement	Drivers
Spatial resolution	Vegetation	250 m–1 km	Need to capture variations to support district level analysis
Vegetation absolute accuracy (assuming dekadal time step for index scaled from −1 to 1)	Current	0.05	Response
	1-month forecast	0.10	Short-range planning
	2-month forecast	0.15	Medium-range planning
	4-month forecast	0.20	Medium- to long-range planning
Vegetation anomaly relative accuracy (assuming dekadal time step)	Current	10%	Response
	1-month forecast	15%	Short-range planning
	2-month forecast	20%	Medium-range planning
	4-month forecast	25%	Medium- to long-range planning

As multiple reviewers commented, spatial resolution requirements are complex. Spatial resolution needs vary according to place, time, and hazard. Perception of spatial resolution need for analysis may be skewed by knowledge of the sensor resolutions currently available. Given the potential pitfalls, it is important to ascertain some indication of spatial resolution requirements/needs for early warning systems. In general, the findings in this study are meant to represent the central tendency among the participants. In this case, because of the challenges of interpretation, the spatial resolution finding may be biased toward users with more stringent needs.

The responses from the review made it apparent that both absolute and relative anomaly products are required and are of equal importance for appropriate interpretation and decision making regarding biophysical hazards. Additionally, data products are required at varying resolutions (both spatial and temporal) and with short latency period. Therefore, although higher resolution products are needed, multiple resolutions are also useful for the same product. For example, MODIS data at 250, 1000, and 5000 m would all be useful because the lower resolution products can be downloaded and viewed with ease; however, higher resolution imagery is also critical for sub-regional analysis. Furthermore, compared to currently available AVHRR datasets, MODIS data is known to have much higher accuracy and precision in capturing land surface conditions (Brown *et al* 2006).

Some users were interested in receiving new products in addition to those associated with rainfall and vegetation. There was an expressed interest for products that capture moisture and convectively available potential energy status, persistence, and transports.

The review also asked FEWS NET data users how decision makers use remote sensing data products. The goal of FEWS NET is to provide actionable, accurate, and defendable policy information to decision makers. A critical segment of decision makers are at the local and national governments in the region of interest. FEWS NET primarily transforms satellite remote sensing data into information that can be used by these decision makers through the local and regional representatives who have direct interaction with the data. The review targeted these representatives. Figure 6 summarizes how often respondents access selected data products that have been targeted for enhancement. The products include the RFE, the standardized precipitation index (SPI), and NDVI and can be accessed through the Africa Data Dissemination Service portal, found at http://earlywarning.usgs.gov (Verdin *et al* 2005).

The results show that users predominantly use the site to download and view products to analyse prevailing climatic conditions. The reported usage is consistent with the group's assessment of temporal requirements. These products are incorporated into presentations and monthly reports and then used to inform decision makers. At the country level, the information has contributed to an increased ability to make intelligent decisions regarding food security.

Agrometeorological analyses that are carried out for decision makers are based primarily on rainfall estimates and water balance products that are offered through FEWS NET. While these products are usually obtained via e-mail, they are sometimes acquired directly from the website. These analyses are considered important by management and by other important stakeholders. In some cases, the NOAA RFE and

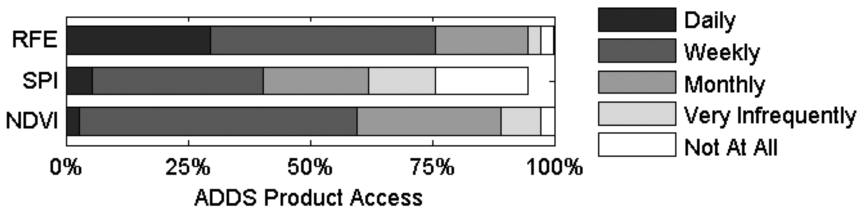

Figure 6. Reported frequency of selected data accessed through the Africa Data Dissemination Service data portal.

Table 4. FEWS NET DSS requirement/NASA input match.

Element	NASA inputs	Met/unmet requirements (as planned)
General	Rainfall and vegetation index products (as listed below)	MET: daily, dekadal, and monthly time step MET: continental coverage UNCERTAIN: latency is expected to be 1–3 days; 1-day latency is a goal, but achievement will be dependent on inputs MET: predictions at 1, 2, and 4 months (perceived requirement of 1-week forecasts not currently addressed) NOTE: product accuracy will be addressed through verification and validation as project is implemented
Rainfall	SPI based on TRMM 3B42-RT	MET: new precipitation products are planned for delivery at 0.05° (∼5 km) versus end-user perceived requirement of 2–5 km
Vegetation	Standardized vegetation index based on MODIS climate model grid release 5	UNMET: new vegetation products are planned for delivery only at 5 km versus end-user perceived requirement of at least 1 km

other products have been used as the basis for identifying problematic areas for field assessments.

For example, one reviewer explained how the amount of rainfall affected the 2006 growing season in a West African country and consequently had a significant impact upon crop production in the region. Rainfall was significantly less than normal during several dekads in July and August of that year. This caused cereal crop failures and resulted in production that met only 30% of the region's mean supply need. These crop failures rippled through the regional economy and resulted in a rise in cereal prices in affected areas. The country's famine/food security monitoring system was able to use the rainfall and price analysis provided by FEWS NET to show how the drought impacted food security in the region.

5. Conclusions

The questionnaire proved to be a useful tool that was able to derive essential FEWS NET user requirements. Table 4 links enhancements offered for FEWS NET with the perceived requirements drawn from this FEWS NET professional review. Requirements have been labelled as follows, based upon current FEWS NET enhancement plans: MET: the requirements should be met; UNCERTAIN: unclear as to whether these requirements will be met; UNMET: the requirements will not be met.

In summary, this questionnaire analysis has led to key findings regarding currently planned FEWS NET enhancements. The focus of NASA-funded work on rainfall and vegetation is well placed. The early warning professionals participating in the review for FEWS NET almost unanimously affirmed rainfall as a vital input. The value placed on vegetation was also quite substantial; approximately 75% of review respondents viewed vegetation as a vital input for analysis and decision making.

Spatial coverage and temporal frequency of planned FEWS NET enhancements are generally sufficient to meet early warning needs in Africa. For the most time-critical analyses that are essential from FEWS NET, the suggested enhancement (1-day latency) may not be timely enough. Meeting the latency requirement is a project goal; however, its achievement is not assured given current inputs and resources. FEWS NET reviewers were interested in the planned 1-month predicted timescale but also wanted 1-week predicted timescale for biophysical parameters.

The review found that many users would like product resolution to be higher than is currently planned. Although the dominant label 'District' was viewed as the most important spatial scale of analysis, when quantifying the spatial resolution for that scale of analysis, FEWS NET reviewer comments reflected an interest in finer resolution. This opinion would limit use of current systems (such as AVHRR, MODIS, and TRMM). Therefore, if these FEWS NET review comments (that suggest resolution and scale labels need to be connected) are valid, some planned products may fall short of FEWS NET requirements.

Limitations associated with this review included the following: small number of responses, participants limited to FEWS NET community, and lack of longitudinal information. It would have been interesting to apply this same questionnaire to a broader community—one that included those partners with whom FEWS NET works. Examples include individuals (affiliated with the country that has food security issues) that are in the government and/or in influential non-profit organizations. Although this would gather interesting information that could be compared to that which is presented here, it would extend the results beyond the actual requirements and scope of FEWS NET and its partners. A key goal of the review was to elicit the requirements for the specific work of FEWS NET. All the survey participants were either from FEWS NET field offices or FEWS NET-related agencies, and ultimately are the individuals who are most likely to make and influence decisions that would affect the US government's effort towards famine mitigation. Therefore, although the respondents were small in number, their opinions carry significant weight.

To date, the questionnaire responses have already influenced FEWS NET operations. First, there is a willingness to invest in higher resolution and better quality rainfall and vegetation data. Second, through a transformation of its website portal, data analysis is provided at the same time that data is presented. Third, higher spatial resolution products, made possible by continued improvements in satellite technology and computing power, will be available. By involving the producers of biophysical data and information in the monitoring and response to food security in this requirements seeking approach, FEWS NET has motivated improvement in the quantitative type of information required to identify food security problems as early as possible. With continued personnel support and/or base funding, further improvements in the data used by FEWS NET and its analysts to address food security issues can be achieved.

This review clearly demonstrated that there are specific spatial and temporal resolutions for rainfall and vegetation that are required to make informed food security decisions; however, there are still diverse opinions about the addition of higher spatial and temporal resolutions for enhancing current remotely sensed data products used in food security analysis. Future work that examines these types of products will certainly benefit not only by expanding of the number of people included in the study, but also by focusing upon understanding which products are most useful and which formats optimize product impact. Understanding the needs of people outside of the FEWS NET community would enable an increased use of this technology; in turn, this would both improve overall consensus on food security crises conditions and build capability to manage food security on a local level, two primary FEWS NET goals.

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