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USING A LIGHT WEIGHT MODEL TO MONITOR A VARIETY OF GRAIN CROPS IN AFRICA

Eric J. Wolvovsky*
Wyle Information Systems and NOAA / Climate Prediction Center, Camp Springs, Maryland

1. INTRODUCTION

The United States Agency for International Development's (USAID) project at the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center is dependant on timely, global-reaching information for its daily operations. This sector of the USAID program monitors food security from a meteorological perspective, with its goal to both alert and provide supporting information to decision makers regarding humanitarian emergency situations. Frequently, these emergency situations occur because of insufficient food production. However, it is difficult to provide early warning without sufficient and accurate data. The task of monitoring the impact of weather on food security is made difficult when a humanitarian situation occurs outside of the detailed, discontinuous realm of meteorological data coverage. In response, a regional crop model has been developed to provide decision makers with a continuous suite of crop monitoring products.

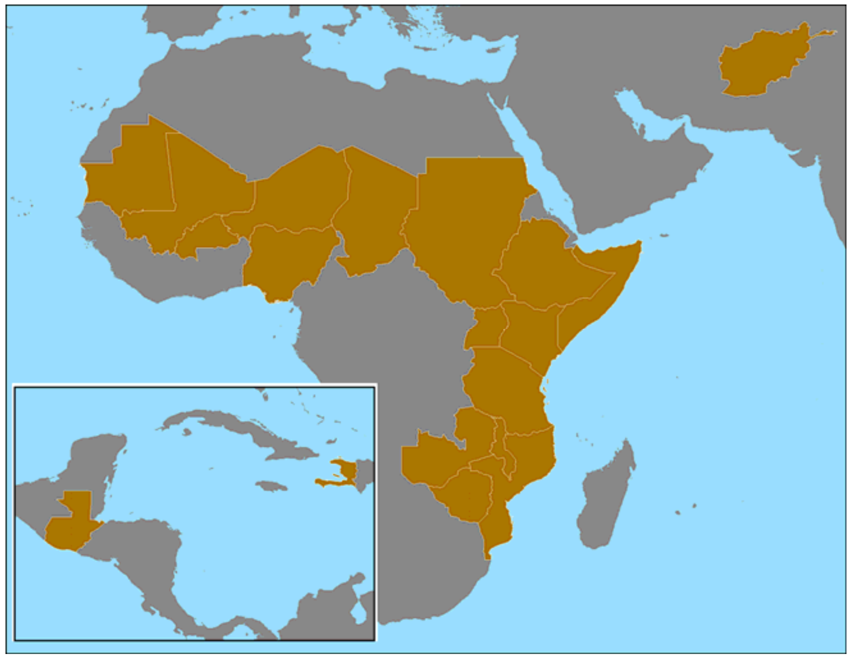


Figure 1: Countries part of the FEWS-NET and MFEWS programs are mainly in Africa. There are also countries in Central Asia and Latin America.

USAID does not only need meteorological data, but also requires a way to analyze how these meteorological factors impact crop development. A newly developed model now addresses these requirements. The model combines total rainfall, moisture distribution, and the impacts of temperature on those moisture requirements, in high resolution output that is easy to interpret. The Temperature and Rainfall Analysis of Crop Conditions (TRACC) was developed to address these issues. The additional challenge of limited data availability in Africa requires the use of reanalysis and remote sensing.

There are two programs within USAID focusing on food security that have operations at NOAA's Climate Prediction Center (CPC); *the Famine Early Warning System Network (FEWS-NET), and the Mesoamerican Food Security Early Warning System (MFEWS). The FEWS-NET and MFEWS programs (See Figure 1), encompass much of sub-Saharan Africa as well as Afghanistan, Guatemala and Haiti. The partnership between CPC and USAID began over the Africa region, which continues to be the core of these projects.

The meteorological connection with crop growing conditions has been understood since ancient times. Proper temperature, rainfall and moisture distribution are critical for plant growth, particularly grains. Grains' importance is due to its role as most people's staple food. This means that sufficient production of grains is critical to maintaining food security in the developing world. USAID monitors fluctuations in the availability of grains to be prepared if food requirements are not met. Due to the nature of the FEWS-NET and MFEWS programs it is critical to identify small areas with insufficient food availability, thus a high resolution product was also needed.

2. Methodology

TRACC was developed utilizing temperature, rainfall totals, rainfall distribution and hours of daylight in an effort to monitor crop conditions. With real time data availability

* Corresponding author address: Eric Wolvovsky, Climate Prediction Center, 5200 Auth Road #811-D, Camp Springs, MD 20746, eric.wolvovsky@noaa.gov

in Africa being scarce, the model employs satellite rainfall estimation and temperature reanalysis data, at a resolution of 0.1 degrees. TRACC relies primarily on the Blaney-Criddle Formula, which relates the above inputs to crop moisture needs.

2.1 Determining Moisture Requirements

Temperature is a key component of determining moisture availability for plants. Moisture loss is not limited to evaporation before the plant can absorb water, but also the plant's ability to retain water. Each plant's moisture requirements depend on: the amount of water the plant's root system absorbs; and the plants evaporation vulnerability. Plant development correlates with the number of hours of daylight as additional hours of daylight increase the rate of evaporation. (Dunne, 1978)

The Blaney-Criddle Formula relates these characteristics in the following equation (Dunne, 1978):

$$E = K \sum_{i=1}^{n} T_{ai} d_i$$

E is seasonal moisture required (cm)
K is crop coefficient (cm/^{o}F)
T_{ai} is mean monthly temperature (^{o}F)
d_i is monthly fraction of annual daylight hours
n is number of months

Although this formula does use a somewhat awkward combination of metric and imperial units, it is the standard for measuring moisture requirements for irrigated crops. For the purpose of the model, temperature is converted from Kelvin to Fahrenheit. The Blaney-Criddle Formula was adopted by the US Soil Conservation Service in 1970, (Dunne, 1978) and the Food and Agriculture Organization (FAO) branch of the United Nations. (Brouwer, 1986)

For the temperature input the NCEP/NCAR reanalysis data is used (see Figure 2). Despite its coarseness at 2.5 degree resolution, the output is still applicable. Moisture requirements do not have a precipitation-like signature, and instead are more uniform across large areas.

The other two variables, K and d_i, are both related to the loss of water due to consumption, and water expelled from the plant. K, or the crop coefficient, is a number that determines the amount of moisture in millimeters used by the plant for every degree (F) during a given month. This value determines the quantity of moisture needed to sustain the plant and to compensate for moisture loss due to evaporation. The value of K is different for different

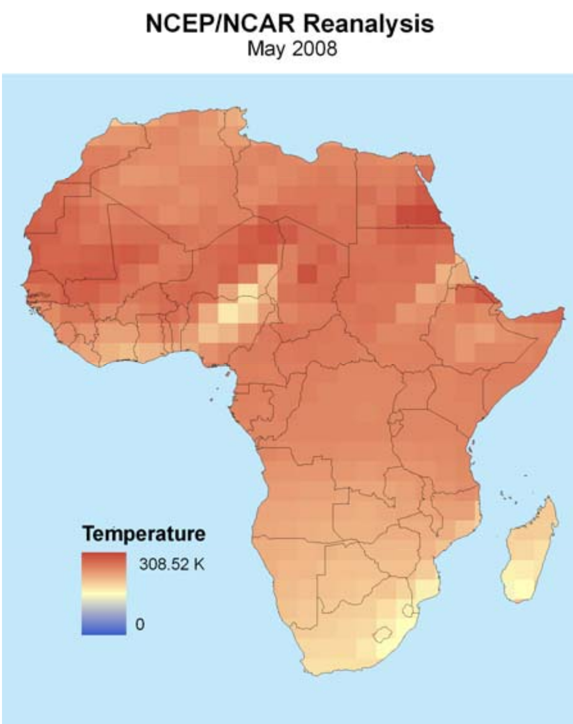


Figure 2: A sample of May 2008 surface temperatures. Note the coarseness of the data. This will not be an issue due to moisture requirements having a weaker gradient than precipitation.

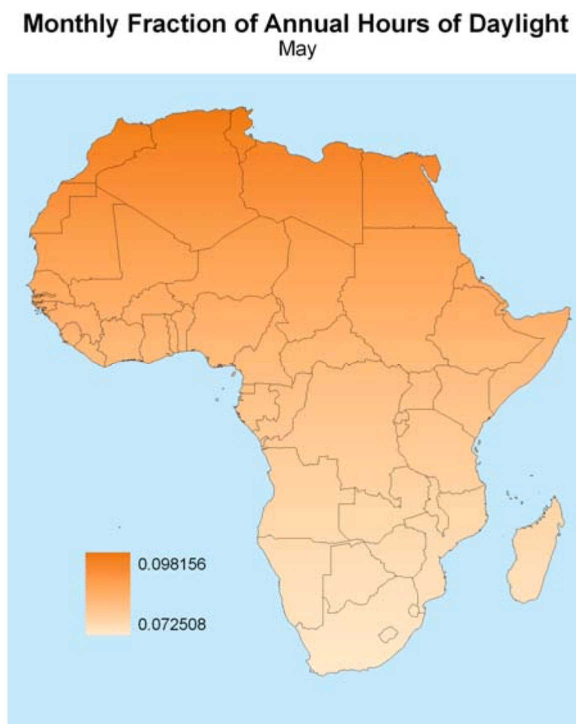
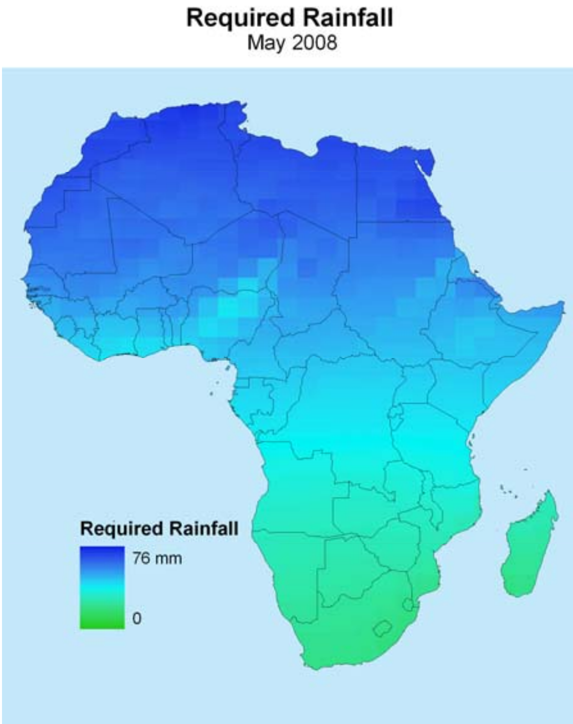


Figure 3: The fraction of monthly daylight hours to annual daylight hours for May. Note the smooth transition across the continent. Higher values indicate more hours of daylight relative to a year.



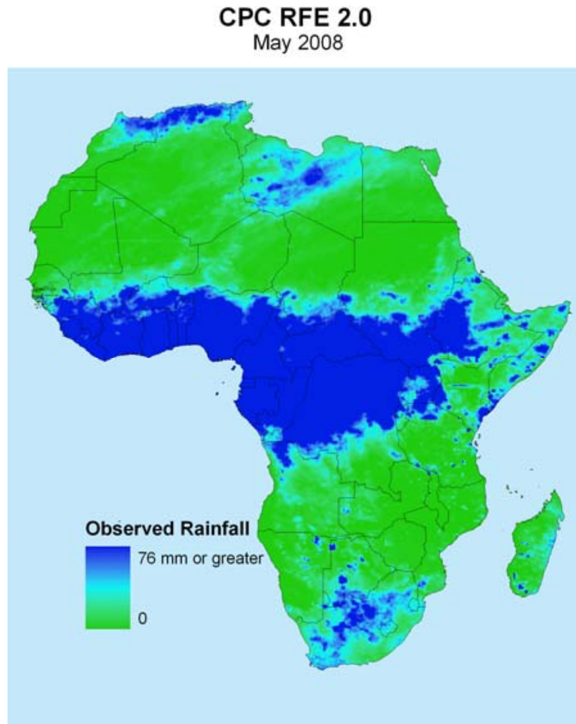


Figure 4: Using the data from Figures 1 and 2, required rainfall for maize during May 2008 was calculated. Note the general influence of the fractional hours of daylight increasing required moisture south to north, and the localized influence of temperatures, such as in Nigeria and Niger.

Figure 5: Satellite estimated rainfall for May 2008. Notice the rainfall pattern does not provide sufficient rainfall in the south, despite a lower threshold for rainfall, shown in Figure 4, as compared to central Africa.

kinds of crops, but generally is in the range of 1.5 – 2.0 cm/^{o}F. These values were developed from studies in the western United States.

The last variable d_i, is a ratio comparing the number of daylight hours each month to the total number of daylight hours during the year (see Figure 3).

2.2 Assessing Rainfall Availability

After using the Blaney-Criddle Formula to calculate moisture requirements across the continent (see Figure 4), it becomes necessary to compare these requirements with observed precipitation totals. Minimal rain gauge data is available in real time from Africa, and a merged satellite-gauge product has been applied in place of rain gauge interpolation. The RFE 2.0 was developed for the FEWS-NET project. Non-technical staff within FEWS-NET have become accustomed to applying this method of rainfall estimation. By incorporating it into TRACC, USAID will have a thorough understanding of one of the key inputs.

The RFE 2.0 is used to determine if the moisture requirements of crops have been met (see Figure 5). This is done using percentages. The reason for using percentages instead of anomalies is people and plants living in different locations are accustomed to the precipitation climatology of that region. Thus an area that is extremely wet, such as southern Nigeria, has no negative impacts from a seasonal deficit of 200 mm. That same deficit in Mauritania would trigger a humanitarian disaster. Percentages are classified using the following rubric:

Classification	Percent of Required Rainfall
Failure	Less than 50%
Poor	51 – 75%
Below Average	76 – 125 %
Average	126 – 175%
Good	176 – 225%
Excellent	Greater than 225%

Notice that the required moisture is skewed, resulting in the “Average” classification requiring 126% - 175% of the required moisture. This is necessary because the Blaney-Criddle Formula was initially intended to be used for irrigated crops. Irrigation is a more efficient and reliable method for supplying water to a plant’s root system. Additional rainfall is needed to ensure sufficient water is

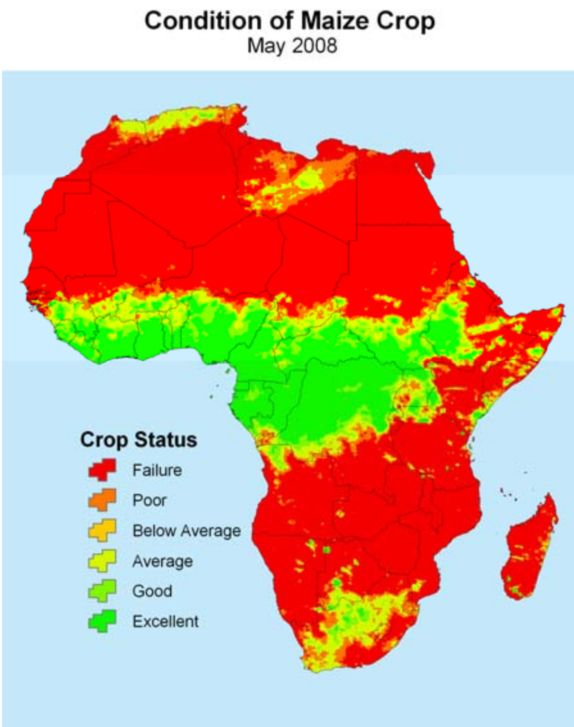


Figure 6: May 2008 after calculating the Blaney-Criddle Formula, and applying the classification scheme.

received by crops due to wind, leaves, soil and other obstacles preventing rain water from directly accessing a plants root system, (see Figure 6).

In the May 2008 example, after calculating the classification values (Figure 6), the spatial pattern is based primarily on the precipitation signature. Comparing the rainfall in South Africa and Algeria (Figure 5), rainfall totals are roughly the same, however because of heat and more hours of daylight in Algeria, more rainfall would be required to produce similar crop conditions to those in South Africa. (Figure 6)

2.3 Factoring in Rainfall Distribution

Moisture requirements are only part of what must be monitored. A balanced temporal rainfall distribution is also needed for crops to remain healthy. For this reason an adjustment is made in locations that do not meet a minimum ratio of monthly to seasonal rainfall. For every month this minimum ratio is not met the TRACC reduces the classification by one level.

$$\frac{R_m}{R_s} > \frac{1}{n} - 0.05$$

R_m Rainfall for one month of the growing season
R_s Rainfall for the entire growing season
n number of months in the growing season

Each month of the growing season is tested with this metric. The second term on the right side of the equation provides some leeway in the rainfall distribution. It would be unreasonable to expect moisture during a three month period would divide into three months at exactly 1/3 for each month. This method of measuring rainfall on a monthly basis against the rest of the season captures excessive rainfall only when it is so excessive that it eclipses the rest of the season. Consistent, season-long, excessive and insufficient rainfall will not be captured by this test.

The right side of this equation is constant, other than the number of months. Thus it is possible to view the required distribution in the following table:

Number of Months	Minimum Ratio of Month to Season Rainfall
2	0.45
3	0.28
4	0.20
5	0.15
6	0.116
7	0.092
8	0.075

For example, a three month season with below sufficient rainfall for each month, but still distributed its rainfall evenly throughout the season, would not have its classification reduced with this test. It is likely that the initial analysis would provide low classification values for this kind of season. However, if rainfall was average for the first month of the season, but lighter during the second and third months, the imbalance of the rainfall during the season may not meet the 0.28 month to season ratio requirement, and that area would be penalized by two classification levels.

2.4 Masking out Irrelevant Areas

This analysis is conducted over the entire African continent, because the input data is in a gridded format. While this results in producing data across Africa, the vast majority of the continent does not have active crops throughout the year. If the areas without active crops are not masked out it is difficult to determine which locations have crops growing, and which do not. This mask is from an analysis conducted by the Food and Agriculture Organization's Global Information and Early Warning Service, a branch of the United Nations (see Figure 7).

3. GRAPHICS AND DATA DISTRIBUTION

The three most crucial aspects of data dissemination are: 1. the information provides increased knowledge, 2.

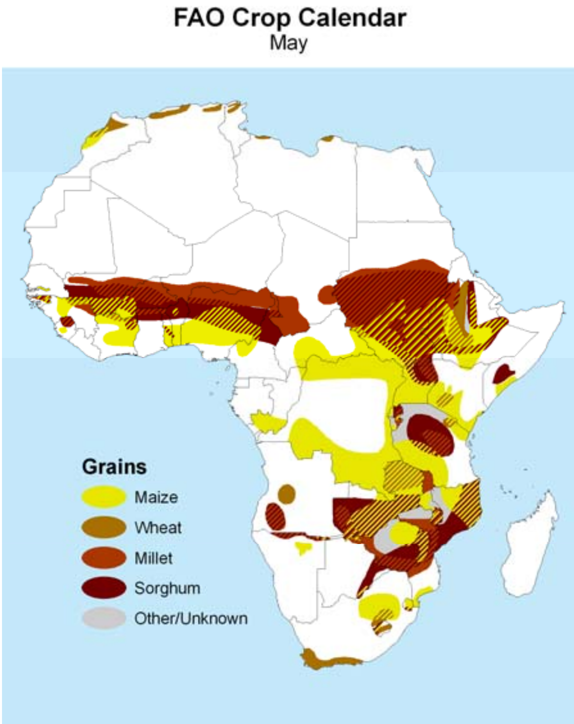


Figure 7: Data from the Food and Agriculture Organization is used to mask out regions that do not have active cropping seasons.

reaches the appropriate user, and 3. is in a format the user can interact with. The target audience needs to be identified to determine what information should be disseminated. For the USAID-funded project at the Climate Prediction Center, there are three primary customers: 1. USAID and partner organizations, including decision makers and environmental scientists; 2. International humanitarian agencies; and 3. Local ground-based field personnel.

Geographic Information Systems (GIS) is rapidly becoming the vehicle through which spatial analyses are conducted and distributed. Binary, while still maintaining its status as a format that programmers use, prevents data from being accessible to the average user. Meanwhile, graphics software prevents interaction with the data. GIS combines both of these aspects and allows users, in different fields, such as meteorology, agriculture and humanitarian aid to interact with a common data format, and still manage to view the data spatially. The output of TRACC data will be distributed in Raster format. This allows users at USAID, and other organizations, to directly download and manage the data as well as apply it. Future plans include the distribution of static images for users that do not have access to GIS software, that do not wish to interact with the data and users with low bandwidth connections.

4. PRIMARY APPLICATIONS

Historically CPC has provided data, usually in the form of satellite estimated rainfall, model output and other relatively raw data to USAID initiatives. TRACC brings CPC beyond just a producer and translator of data, but also demonstrates the potential CPC has at developing regional analyses for specific crops. Furthermore, with easy access to GIS raster layers and graphics, individuals working in Washington and worldwide can rapidly transmit and apply the model output.

TRACCs primary use is expected to be as an input into the weekly weather hazards analysis lead by CPC in Africa. This analysis is done on behalf of USAID to support FEWS-NETs, and other humanitarian operations. Although this analysis relies on crop observations conducted in Africa, it makes heavy use of model and satellite inputs to fill in the gaps between locations where observations are available.

Currently partners at the United States Geological Survey produce the Water Requirements Satisfaction Index (WRSI), another crop monitoring model. The WRSI focuses on rainfall thresholds and soil saturation, a substantial difference from TRACC. The WRSI is the only such product that currently exists for FEWS-NET. By adding a second model, which is based on different premises, it becomes possible to observe a “convergence of evidence” when both models produce output that are similar to one another. At these times an analyst would have stronger confidence in the model output. If the models diverge then the specific situation would determine which model to favor based on each models strengths and weaknesses.

The final application is more open ended. The data is provided to the public allowing for use by individuals, and other humanitarian organizations, as well as use by other governments.

5. LOOKING AHEAD

TRACC has several opportunities for improvement. The most critical are: 1. developing a way to have the product generate output more frequently than once per month, 2. moving beyond Africa, and 3. a method of verification.

The reason for the monthly temporal resolution is the NCEP/NCAR Reanalysis data. While the NCEP/NCAR is a reliable product, it processes only once per month. Currently, there is no other real-time, or near real-time dataset with a proven track record available over the African continent. However, the temporal resolution for the RFE 2.0 precipitation data allows daily processing. The main method being considered is evaluating past anomalies during the current season, and applying them to the coming month. This method uses climatology as a regression line, and assumes the average deviation from that line, during the past, will continue. For example, if the average temperature anomaly during the current season is 2^{o}C, TRACC will assume that season long anomaly will continue during the coming month. As observed data becomes available, it replaces estimated data in the model. There are drawbacks to this method, needing further evaluation.

The second challenge facing TRACC is the limitation to Africa. Currently there are three FEWS-NET and MFEWS countries not located in Africa: Afghanistan, Guatemala and Haiti. Afghanistan's crops primarily depend on snow melt from higher elevations, rather than rainfall. Reservoirs play a major role in the cultivation of Afghan fields. Observing rain and snowfall is more effective than attempting to correlate crop conditions with temperature and rainfall. Guatemala and Haiti, however, do cultivate rain fed crops and, due to factors unique to Central America and the Caribbean, the RFE 2.0 is not processed in this region. If TRACC is expanded beyond Africa, a different satellite precipitation product is needed.

The last, and possibly biggest, challenge is validation. Unlike rainfall or temperature products that can be compared with ground observations, a product like TRACC produces output that is somewhat subjective. Even more subjective, however, would be observations of the ground conditions. While the difference between 'Poor' and 'Good' is easy to determine, the difference between 'Good' and 'Excellent' is not. Any verification with a product like TRACC will ultimately be based on its ability to capture general patterns in crop conditions as well as its ability to build confidence over time with the people who are regularly exposed to the product.

With a product as young as TRACC there are many future options. Like all crop analysis products, the verification of TRACC will not involve heavy statistics due to the subjective nature of crop monitoring products.

6. SUMMARY

USAID's FEWS-NET, and MFEWS programs require meteorological data evaluated with regard to crop conditions to support humanitarian activities over a large part of the world. This is the basis for creating the Temperature and Rainfall Analysis of Crop Conditions, or TRACC, as a supplement to existing activities. The nature of the new monitoring product incorporates existing methodologies, but applies them to remote sensing techniques in an effort to compensate for existing shortfalls in global weather and crop data availability. User needs can be addressed from a more comprehensive perspective by distributing the data in a GIS, and a graphical format. Concurrently research continues in an effort to improve on the ability for FEWS-NET and MFEWS to monitor humanitarian conditions.

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