
Satellite Products and Services Review Board

**The Blended Polar Geo Biomass Burning
Emissions Product (Blended-BBEP) Algorithm
Theoretical Basis Document Standards and
Guidelines**



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TITLE: BLENDED-BBEP DOCUMENT OBJECT

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1. INTRODUCTION

The Blended Polar Geo Biomass Burning Emissions Product (Blended-BBEP) prepares this document based on the standards provided by the SPSRB Common Standards Working Group (CSWG). The emphasis is to assemble a standard SPSRB document from components. The Blended-BBEP provides individual components that are referred to as “document objects (DO)”. These objects have similarities to the code objects of object-oriented programming. There are 98 distinct DOs identified in this document.

The DO concept is intended to be implemented with a document-writing tool that will automatically insert DOs into the appropriate location of a document. This tool is not available at this time. Until this tool has been acquired and validated, projects may choose to write their documents in a traditional manner or may choose to write DOs and insert them manually into their documents.

2. DOCUMENT OBJECT

2.1 Product Requirements

Biomass burned area and emissions over North America have been requested by various users. NWS/NCEP Environmental Model Center is responsible for providing fire weather model guidance to the NWS Incident Meteorologists (IMET) who are deployed at the fire sites. Currently, NCEP NWP models do not account for wild-fire heating or fire burned area impacts on its land surface model component. A 1.3 km fire weather model nest forecast run is planned for FY11, therefore, burned area and fire behavior processes should be incorporated in local area fire weather models. Burned area and fire area information are both needed to initialize the NWP fire weather model. NWS/NCEP is also developing capabilities to provide global aerosol forecasts. The global model needs biomass burning emissions sources (fires) as input. There is a need for timely update of emissions on an hourly basis globally. Information from a network of geostationary satellites will be very useful. NCEP and NESDIS STAR are working towards this development through funding from Joint Center for Satellite Data Assimilation. Moreover, EPA has requested the product for air quality monitoring.

2.2 Product Team

The Blended-BBEP development team consists of members from STAR and OSPO. The roles and contact information for the different product team members are identified in Table 1-1.

Table 1-1 Product Team Members

Team Member	Division	Role	Contact Info
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2.3 Product Development History

The Blended-BBEP is a continuous product of biomass burning emissions, which is used to replace previous operational product. Previously, the Geostationary Operational Environmental Satellite Biomass Burning Emission Products (GBBEP) are produced from GOES-E and GOES-W fire products separately beginning in 2008. In these products, each emission species is stored in an individual ASCII file. Current Blended-BBEP is produced by blending fires detected from GOES-E, GOES-W, MODIS, and AVHRR. The outputs are written in both ASCII and netCDF files which include burned area and all emission species.

2.4 Hardware Description

Blended-BBEP algorithm is running for North America. It requires 300 MB for static inputs, 1.0 MB for near real time input data each day, and 6.0 MB for daily outputs.

2.5 Hardware Overview

GP75 (Operational Server)
 GP78 (Backup Server)
 RedHat Linux oper. system
 IDL environment
 GCTP Package
 HDF Package
 C compiler
 Linux Script
 Pearl
 GRIB2
 NetCDF4

2. 6 Software Description

Tools such as compilers, Perl, or the Gnu utilities are installed and managed by IT system administrators, and therefore, are not included in the table. Tools, such as IDL, GCTP, GRIB2, NetCDF4, and HDF are required by Blended-BBEP.

There are four processing units in Blended-BBEP: (1) the burned-area unit, (2) the fuel-moisture proxy unit, (3) the emission-calculation unit, and (4) the output-generation unit. They are all located at: `/home/oper/BBEP2/`

The burned-area unit performs several important functions.

- It collects fire data (ASCII) detected from both GOES WF-ABBA and HMS in a given period. HMS fires observed from MODIS and AVHRR are matched with GOES pixel footprint.
- By adding climatological diurnal pattern in fire size, the blended fire observations are used to reconstruct diurnal pattern of fire size.

The fuel-moisture proxy unit resides downstream of the burned-area unit. It reads AVHRR VCI data with a global coverage. The subset of North America is extracted and converted from geographic project to Lambert Azimuthal project.

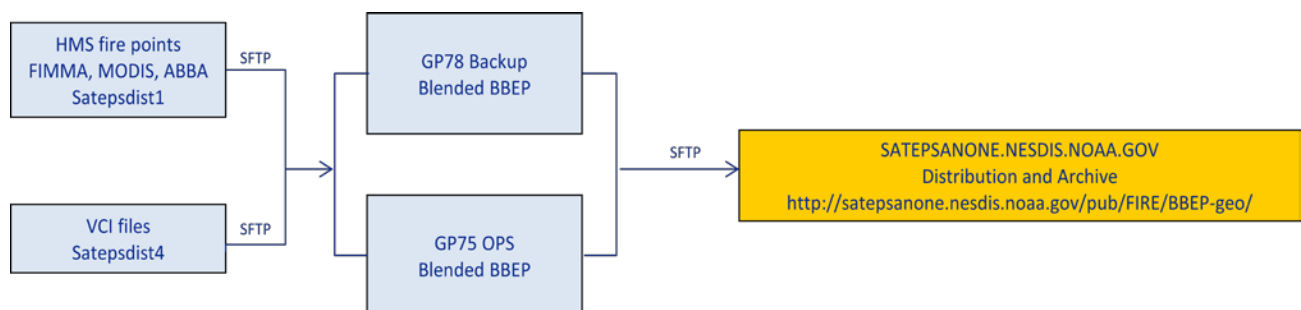
The emission calculation unit produces emissions by combining burned area, fuel loading, fuel moisture proxy, and combustion and emission factors. It traces fire individual pixels over NA, and produces emissions in an ASCII file.

The output-generation unit is to produce output files in IDL and C environments. The burned area and emissions are packed in both ASCII file and netCDF4 file. Six-hour burned area at a spatial resolution of 12km and twelve-hour burned area at a spatial resolution of 1km are written in GRIB2 files, separately. Both the spatial distribution and statistic quality of burned area are presented in two jpg files.

2.7 Software Overview

All low-level processing code in the Blended-BBEP is written in C and Perl compiled languages. Low-level code performs all data processing, scientific computation, read/writing, reformatting, and opening/closing of files. All high-level code is written in Perl. High-level tasks include file management, system management, making system calls, and error trapping from low-level processing. All scheduled processes are initiated as Perl scripts.

2.8 Interfaces Overview



2. 9 User's Interaction

All products are available via the site
<http://satepsanone.nesdis.noaa.gov/pub/FIRE/BBEP-geo/>

2.10 Procedures for Normal Operations

The Blended BBEP code runs 4 times a day at 5, 11, 17 and 23 Z. Each run takes about 4 minutes and the products are loaded, saved and distributed by satepsanone sever via the site <http://satepsanone.nesdis.noaa.gov/pub/FIRE/BBEP-geo/>. The code runs in both the operational and backup servers (GP75 and GP78 respectively) and generates log files and error messages that are sent to the contractor on call.

2. 11 Required SAB Training

No need of SAB training to use this product.

2.12 Internal Tool Limitations

Not applicable.

2. 13 Processing Outline

Biomass burning emissions are modeled using satellite-derived vegetative fuel loading, fuel moisture, and burned area. The emission model developed by Seiler and Crutzen (1980) is used in the Blended-BBEP. The data processing is outlined in Figures 2-1. Briefly, the fuel loading is developed from MODIS data including land cover type, vegetation continuous field, and monthly leaf-area index. The weekly fuel moisture category is retrieved from AVHRR Global Vegetation Index (GVIx) data for the determination of fuel combustion efficiency and emission factor. The burned area is simulated using half-hourly fire sizes obtained from the GOES WF_ABBA fire product. By integrating all these parameters, quantities of various emission species are calculated for each individual fire at an interval of half hour. Finally, the output data are written in ASCII format, NetCDF4, and GRIB2.

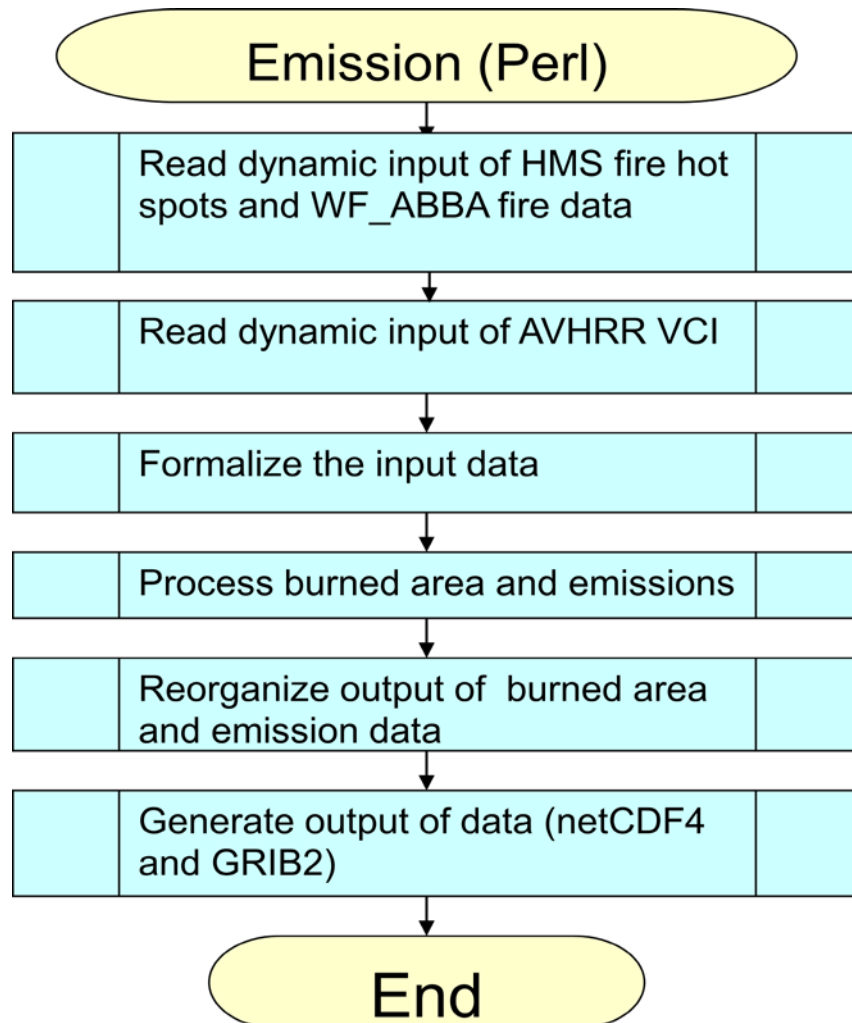


Figure 2-1. Processing of the product of biomass burning emissions.

2.14 Algorithm Input

The primary input of biomass burning emissions product is active fire data from GOES fire product and both MODIS and AVHRR fire hotspot detections. Besides, various static ancillary data are also required.

Fire characteristics are the primary input required for the estimates of biomass burning emissions. These fire data are obtained from GOES-East and GOES-West WF_ABBA fire products and HMS fire hotspots. The main parameters extracted from the WF_ABBA fire product are geolocation (latitude and longitude), instantaneous sub-pixel fire size, pixel

size, ecosystem, time of the fire observation, and assurance of the fire detection. The fire characteristics from HMS are fire locations from AVHRR and MODIS and time of fire observations.

In the Seiler-Crutzen algorithm, ancillary data are listed and briefly described in the followings.

- MODIS-based fuel data: Fuel loading is basically divided into live fuel loading and dead fuel loading. The live fuel loading consists of foliage and branch biomass in forests, shrub biomass, and grass (including crop) biomass. The dead fuel loading is composed of litter and coarse woody detritus. The fuel loading for each pixel was obtained from a MODIS Vegetation Property-based Fuel System (MVPFS). This dataset was primarily calculated from percent vegetation cover in MODIS continuous field product, LAI, and land cover types at a spatial resolution of 1 km. The spatial resolution is aggregated to 2km in the processing because GOES pixel is coarse.
- MODIS land cover type: It contains 16 different land cover types of IGBP schemes at a spatial resolution of 1 km, which is aggregated to 2km. This data were classified using a decision tree algorithm and MODIS bidirection-adjusted references.
- Lookup table for consumption factors: It is a lookup table containing fractions of fuel loadings consumed during fires.
- AVHRR VCI: AVHRR Vegetation Condition Index (VCI) is employed as a surrogate to represent the fuel moisture conditions required for calculating the factors of combustions and emissions. The weekly VCI provided in the NOAA AVHRR product has been demonstrated to be effective in monitoring drought information for various environments (Kogan, 1995). This parameter is derived from a time series of NDVI data (Kogan, 1995; 1997).
- Lookup table for CH₄ emission factors: It is a lookup table containing factors of CH₄ emissions for various fuel types and moisture conditions during fires.
- Lookup table for CO emission factors: It is a lookup table containing factors of CO emissions for various fuel types and moisture conditions during fires.
- Lookup table for N₂O emission factors: It is a lookup table containing factors of N₂O emissions for various fuel types and moisture conditions during fires.
- Lookup table for NH₃ emission factors: It is a lookup table containing factors of NH₃ emissions for various fuel types and moisture conditions during fires.
- Lookup table for NO_x emission factors: It is a lookup table containing factors of NO_x emissions for various fuel types and moisture conditions during fires.
- Lookup table for SO₂ emission factors: It is a lookup table containing factors of SO₂ emissions for various fuel types and moisture conditions during fires.

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- Lookup table for TNMHC emission factors: It is a lookup table containing factors of TNMHC emissions for various fuel types and moisture conditions during fires.

2.15 Physical Description

The Blended-BBEP product is to calculate burned area and emissions (PM_{2.5}, CO, CH₄, CO₂, TNMHC, NH₃, N₂O, NO_x, and SO₂) released from wildfires using active fire detections, fuel loading, combustion factor, and emission factor. Active fires are obtained from the Hazard Mapping System (HMS). The HMS consolidates automated fire detections from Geostationary Operational Environmental Satellite (GOES) Imager, Advanced Very High Resolution Radiometer (AVHRR), and Moderate Resolution Imaging Spectroradiometer (MODIS) over North America. Wildfire from GOES data are detected using the Wildfire Automated Biomass Burning Algorithm (WF_ABBA). Specifically, WF_ABBA v65 detects instantaneous fires in sub-pixels using 3.9 μm and 10.7 μm infrared bands by assuming that the thermal radiance in a pixel (4 km at nadir) is a linear mixture of radiance from a fire target and background. The algorithm not only identifies fire pixels but also calculates sub-pixel fire size for the pixels with high quality detections. Using WF_ABBA v65, fire products are produced from the GOES-E and GOES-W Imager data in an interval of half hour, respectively.

Polar orbiting fire observations are provided by the MODIS instruments on both the NASA Terra and Aqua spacecraft and the AVHRR on NOAA-15/17/18/19 and MetOp. These data provide a nominal spatial resolution of 1 km. Each instrument scans a surface location twice a day in low-middle latitudes. Fire hotspots from AVHRR data are retrieved using FIMMA (Fire Identification, Mapping, and Modeling Algorithm). Basically, it uses mid-infrared band (3.55-3.93 μm) to identify all potential fires, uses thermal band (10.3-11.3 μm) to eliminate clouds, has multiple filters for noise in the data, and uses the difference between brightness temperature in mid-infrared band and thermal band to isolate fires from warm background. Similarly, MODIS fire detection is also based on various spectral thresholds.

The HMS system allows satellite analysts to manually integrate fire data from all the above satellite detections. The analysts inspect fires detected from all instruments, delete detections that appear to be false alarms, and add fires that are undetected in the automated algorithms.

The Blended-BBEP algorithm estimates burned area using active fire observations from MODIS, AVHRR, and GOES for each GOES fire pixel. Specifically, diurnal pattern of fire sizes is simulated using climatological diurnal variation and timely available fire observations. The climatological diurnal variations in fire sizes for various ecosystems are generated using historical WF_ABBA fire size estimates. Although without fire size, the MODIS+AVHRR observations improve the quality of time duration of a fire event in a GOES footprint because some small fires may not be instantaneously detected from GOES. The simulated fire sizes are empirically converted to burned areas using a

conversion factor that was derived by comparing fire size with the burn scars detected from post-fire Landsat ETM+ (Enhanced Thematic Mapper plus) imagery. In the cases there are only MODIS and AVHRR observations, the burned areas are empirically calculated based on the relationship between fire counts and ETM+/TM-based burn scars.

Fuel loading is basically divided into live and dead fuel loadings. The live fuel loading consists of canopy (foliage and branch) biomass in forests, shrub biomass, and grass (including crop) biomass, and the dead fuel loading is composed of litter and coarse woody detritus. To determine the fuel loadings for each pixel at a spatial resolution of 1 km, we developed a MODIS Vegetation Property-based Fuel System (MVPFS) using percent vegetation cover, leaf area index, and land cover types.

Combustion and emission factors are dependent on fuel type and moisture condition. Fuel moisture conditions are derived from time series of AVHRR data, which are then related to moisture category factors for estimating the factors of combustions and emissions.

By integrating burned area, fuel loading, and combustion and emission factors, the Blended-BBEP product is produced every 6 hours by acquiring and blending instantaneous fire observations from GOES-W, GOES-E, MODIS, AVHRR during past 24 hours. The processing is fixed in North America (NA) and produces burned area and emissions of PM_{2.5}, CO, CH₄, CO₂, TNMHC, NH₃, N₂O, NO_x, and SO₂ in every hour. The GBBEP-Geo algorithm runs automatically four times a day through a CRONTAB job and makes them available at an ftp site.

2.16 Mathematical Description

Emissions from biomass burning are controlled by four fundamental parameters. These parameters are burned area, fuel loading (biomass density), the fraction of combustion, and the factor of emissions for trace gases and aerosols. By integrating these parameters, Seiler and Crutzen (1980) have developed a standard formula to model the biomass burning emissions (Figure 2-2):

$$E = ABCF \quad (1)$$

where E represents the emissions from biomass burning (ton); A is the burned area (ha); B is the biomass density (ton/ha); C is the fraction of biomass consumed during a fire event; and F is the factor of the consumed biomass released as trace gases and smoke particulates.

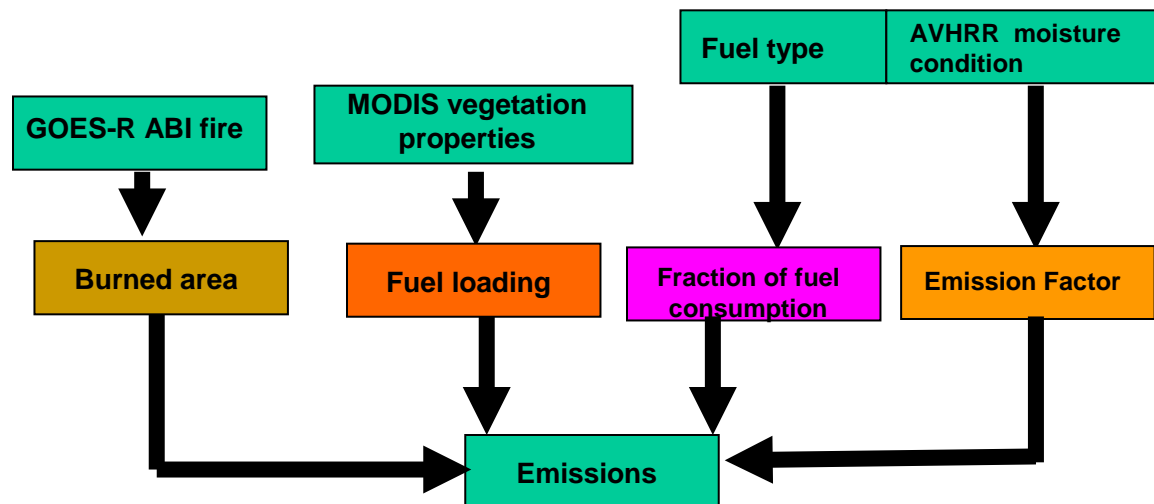


Figure 2-2. Framework in estimating the emissions of biomass burning using the Seiler and Crutzen algorithm.

Model parameterization is most important in this algorithm but it is complex. In the Blended-BBEP, the parameters for the estimates of biomass burning emissions are derived from various MODIS land surface products, AVHRR vegetation index data, and GOES fire data. These parameters may vary with different space and time. The detailed procedure of parameterization is described in the following several sections.

To estimate burned area, active fire observations from multiple satellite instruments are integrated. The general methodology of data processing is summarized in Figure 2-3.

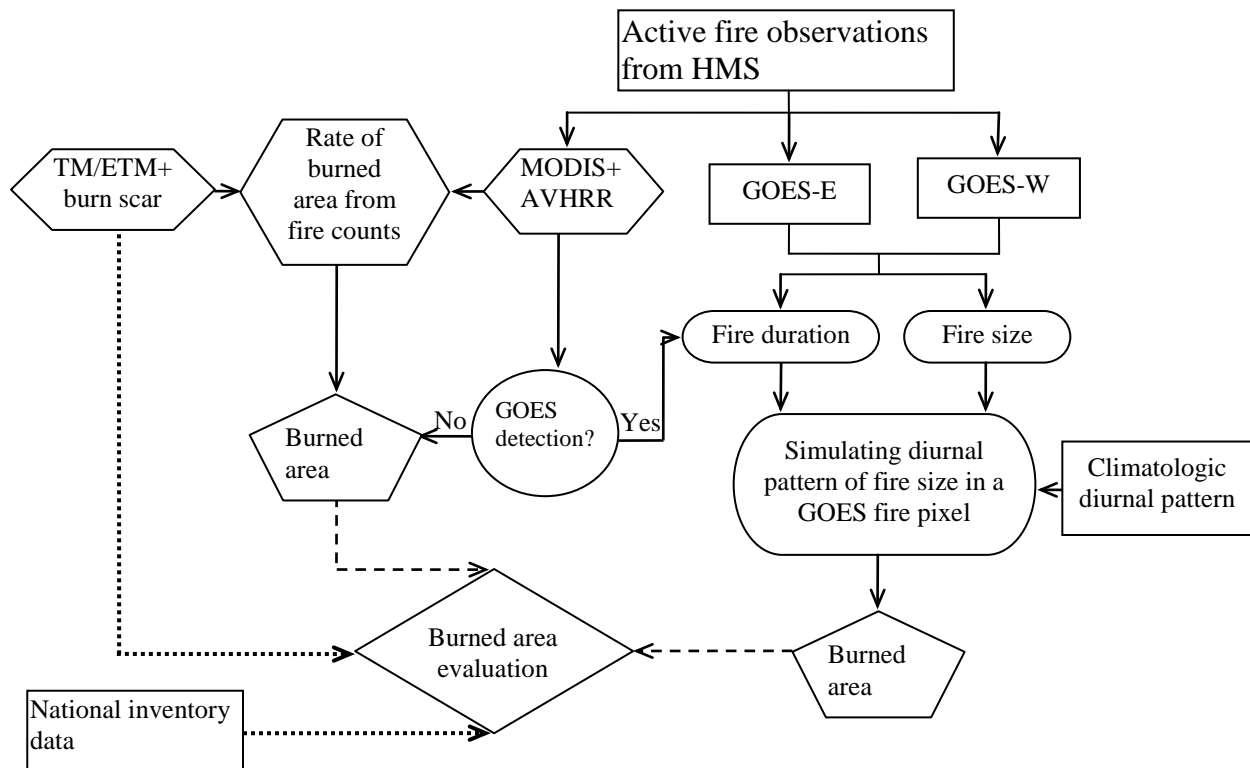


Figure 2-3. Flowchart of integrating various satellite data for the estimates of burned area. MODIS+AVHRR active fires consist of detections from MODIS instruments on both the Terra and Aqua spacecraft and AVHRR on the NOAA-15/17/18.

The Blended-BBEP algorithm established a set of climatologic diurnal variation in fire sizes to simulate the missed detections in temporal patterns. The climatologic diurnal pattern was generated for different land cover types using all half-hourly sub-pixel fire sizes from GOES fire data between 2002 and 2005. For each ecosystem, the fire sizes in each specified half hour were averaged to generate diurnal variations. The averaged values were then fitted using a Fourier model to create a set of representative curves of diurnal sub-pixel fire sizes for forests, savannas, shrublands, grasslands, and croplands, separately.

Combining the climatologic diurnal curves and available fire observations (GOES+MODIS+AVHRR), the Blended-BBEP algorithm simulates diurnal pattern of fire size for individual pixels. Specifically, it is assumed that the curve shape of the diurnal fire size for a specified ecosystem should be similar but the magnitude could be different for various fire pixels. Thus, the climatological diurnal curve for the related ecosystem is shifted to fit available GOES sub-pixel fire sizes in a pixel during previous 24 hours (or previous day). Moreover, it is also assumed that the fire is burning continuously in a given pixel

during the first and last instantaneous observations because fire smokes and clouds could obstacle satellite instruments from detecting fires.

The subpixel fire size in the diurnal curve is then converted to the burned areas using the equation:

$$A = \alpha \int_{t_s}^{t_e} F_t dt \quad (3)$$

where A is the area burned within a specified time period (km^2), F_t is the subpixel fire size (km^2), t_s and t_e represent the starting and ending time of a fire, and α is a coefficient of conversion. The time step is set to half hours in this equation to match the temporal resolution of GOES satellite fire detection.

Fuel loading is basically divided into live and dead fuel loadings. The live fuel loading consists of canopy (foliage and branch) biomass in forests, shrub biomass, and grass (including crop) biomass, and the dead fuel loading is composed of litter and coarse woody detritus. To determine the fuel loadings for each pixel at a spatial resolution of 1 km, a MODIS Vegetation Property-based Fuel System (MVPFS) was developed using percent vegetation cover, leaf area index, and land cover types. Percent vegetation cover, which includes tree cover, percent non-tree vegetation (shrubs, crop, and herbaceous), and percent bare ground, was derived from the MODIS vegetation continuous field (MOD44B) with a spatial resolution of 500 m. Leaf area index (LAI) was obtained from the MODIS LAI product (MOD15A2) at a spatial resolution of 1 km and a temporal resolution of 8 days between 2001 and 2004, which was used to derive maxima monthly LAI. Land-cover data were acquired from the MODIS land-cover product at a 1 km resolution.

Live fuel loading in forest foliage biomass and grass biomass is a function of percent vegetation cover, maxima monthly leaf area index, and land cover types. Specifically, foliage biomass and grass biomass were calculated using the specific leaf area (SLA) and LAI.

Biomass components in forests were calculated using tree allometric models. While the diameter at breast height (DBH) currently could not be directly obtained from satellite data, canopy leaf properties were widely measured from spectral reflectance. Therefore, a foliage-based allometric model was derived.

$$M_c = \delta M_f^\gamma \quad (4)$$

where γ and δ are coefficients, M_c is the oven-dry weight (kg) of the biomass components of trees, and M_f is foliage biomass (kg).

Based on MODIS vegetation properties and tree allometric models, biomass components were calculated.

The total aboveground biomass for shrubs is a function of crown area or vegetation cover. To calculate shrub biomass, a regression model developed in the western US was applied to CONUS.

$$M_s = 1.09 \times 10^5 - 2.161 \times 10^3 V_c + 1.078 \times 10^2 V_c^2 \quad (5)$$

where M_s is the shrub biomass (kg/km^2) and V_c is the percentage of shrub cover. The resultant shrub biomass is high in the eastern US and the northwestern US while it is low in the open shrublands in the southern west US.

To estimate litter and CWD more realistically, we separated percent vegetation cover for different land cover types in a 1-km pixel. The non-forest vegetation within the forest land cover types was assumed to be a mixture between grasses and shrubs because they were not able to be further separated. On the other hand, the trees in the land cover types of non-forests were considered as mixed forests. Thus, the related litter and CWD in each pixel were refined using the following equation:

$$M_{lw} = M_{lwf} V_{cf} + M_{lws} V_{cs} \quad (6)$$

where M_{lw} is litter or CWD density in a pixel (kg/m^2); M_{lwf} and M_{lws} are litter or CWD density (kg/m^2) for forests and non-forest vegetation, separately; V_{cf} and V_{cs} are percent forest cover and non-forest vegetation cover. The calculated litter and CWD are much larger in forests than in non-forest land cover regions. The CWD values are as high as 30 ton/ha in the northern needleleaf forests while the values are very small in the central agriculture areas. The litter displays a similar pattern but the values are relatively low.

Combustion and emission factors are dependent on fuel type and moisture condition. Fuel moisture conditions are determined from a time series of AVHRR Global Vegetation Index (GVIX) data, which are then related to moisture category factors for estimating the factors of combustions and emissions. VCI is employed as a surrogate to represent the fuel moisture conditions required for calculating the factors of combustions and emissions. The weekly VCI provided in the NOAA AVHRR product has been demonstrated to be effective in monitoring drought information for various environments. This parameter is derived from the Normalized Difference Vegetation Index (NDVI):

$$VCI = 100 \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \quad (7)$$

where $NDVI_{\max}$ and $NDVI_{\min}$ in a pixel are the maximum and minimum values in the corresponding week from 1985 to present.

The weekly VCI values ranging from 0 to 100 are equally divided into six different categories which represent fuel moisture conditions of very dry, dry, moderate, moist, wet, and very wet, separately (Figure 2-4). The weekly variation in moisture conditions is used to associate with fuel moisture category factors (mcf).

The factor of combustion is a function of fuel type and moisture category. The combustion factors are calculated from the following model:

$$C_l = (1 - e^{-1})^{mcf} \quad (8)$$

where C_l denotes the fraction of fuel loading consumed for fuel type l which is canopy (foliage and branch), shrub, and grass, separately; and mcf is the moisture category factor. The mcf value in each fuel type is determined using the fuel moisture condition derived from AVHRR VCI data (Table 5), which increases from dry to wet fuel conditions. As a result, C_l varies with the temporal (weekly) AVHRR VCI.

Table 2-3. Moisture category factor (mcf) (from Anderson et al., 2004).

Moisture condition	Canopy	Shrub	Grass	Duff	CWD
Very dry	0.33	0.25	0.125	0.33	0.08
Dry	0.5	0.33	0.25	0.5	0.12
Moderate	1	0.5	1	1	0.15
Moist	2	1	2	2	0.22
Wet	4	2	4	4	0.31
Very wet	5	4	5	5	0.75

The fraction of combustion for litter is assumed to be 100% under various moisture conditions. This may overestimate biomass burning for the crown fires if the litter is not fully burned. However, the value for CWD is calculated using the following formula:

$$C_w = 0.6(0.31 + (0.03 * (0.31 - mcf))) \quad (9)$$

The factor of PM_{2.5} emitted from the burned fuel loading also varies with fuel types and moisture conditions. We adopt the values from the Fire Order Fire Effects Model. Thus, the emission factor for coarse wood is 8.10, 9.15, 11.25 kg/Mg for fuel moisture conditions of dry, moderate, and wet. However, the values of emission factors for litter, canopy, shrub, and grass are currently constant in various moisture conditions, which are 3.95, 10.65, 10.65, and 10.65 kg/Mg, separately.

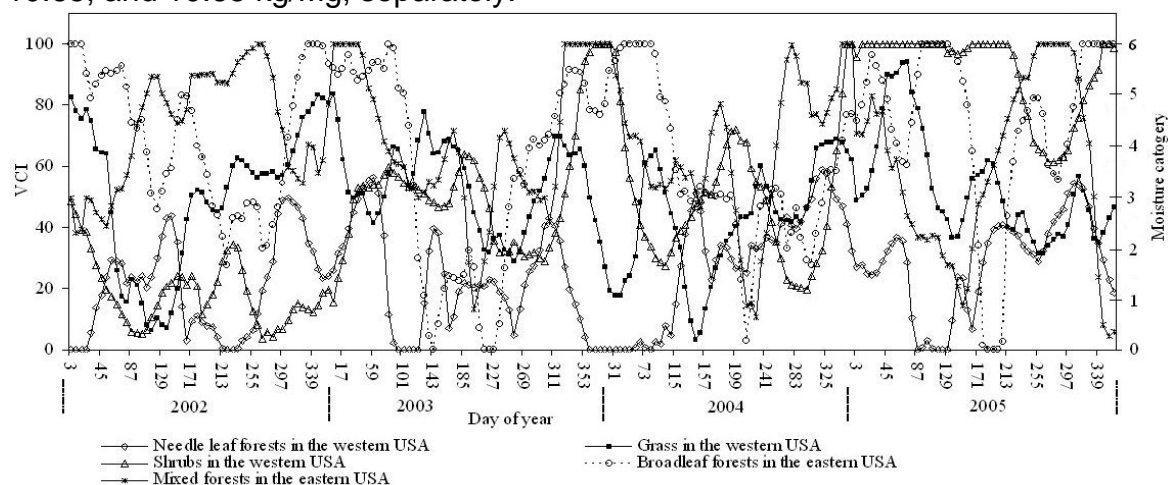


Figure 2-4. Variation in fuel moisture category and VCI from 2002 to 2005. Moisture category is defined as very dry (0-1), dry (1-2), moderate (2-3), moist (3-4), wet (4-5), and very wet (5-6).

2.17 Algorithm Output

The output of biomass burning emissions are hourly emissions of PM_{2.5}, CO, CH₄, CO₂, TNMHC, NH₃, N₂O, NO_x, and SO₂, hourly burned area, fire location(latitude and longitude), ecosystem type, fire pixel size, and fuel loading. These parameters are written in both NetCDF4 and ASCII files. The burned area data are also produced in 12km grid cells and 1km grid cells with a Lambert Conformal projection. Specifically, a netCDF4 file contains hourly biomass burning emissions, burned area, fuel loading, and geolocation. An ASCII file contains the same information as the netCDF4 file. Two GRIB2 files are produced, in which one contains cumulated burned area in a six-hour period in a grid cell format of 12km GRIB2 and another contains cumulated burned area in a twelve-hour period in a grid cell format of 1km GRIB2. Two jpg files are also produced. One is the spatial distribution of burned area and another is the statistics of fire size and burned area for investigating the quality of burned area.

2.18 Sensor Effects

Because the fire detections from GOES, MODIS, and AVHRR data are the primary inputs, satellite sensor data are not directly used in biomass burning emissions. However, some fires are not able to be detected because of weak fire radiance, cloud/smoke effects, and satellite instrument saturation. Besides, false fire detections also happen because of low radiance contrast between fires and background. Detailed fire detection could be found from documents of WF-ABBA and HMS products.

2.19 Error Budget

Primary sources of error in biomass burning emissions are uncertainties in:

- Fire detections and burned area estimates
- Fuel loading is complex
- Biomass combustion rate is a function of burn severity

2.20 Algorithm Performance Assumptions

There are several assumptions in the Blended-BBEP algorithm. These include:

- The inter-annual and seasonal variation in fuel loading is limited during recent years.
- Fires from GOES, MODIS and AVHRR data are accurate.
- Fire size derived from GOES WF-ABBA is reliable.
- Diurnal pattern in fire size is generally stable.

The major limitations in current Blended-BBEP are:

- Fires are not always accurately detected from satellites. For example, fires under forest canopy and clouds are not detectable from satellites.
- Seasonal and inter-annual variation in fuel loading is not taken into consideration.
- Lack of ground truth of biomass burning emissions to validate the emission results

2. 21 Numerical Computation Considerations

No special consideration.

2.22 Programming and Procedural Considerations

The numerical implementation uses Perl to link various parts of calculations, and C to calculate pixel based data and to create netCDF and GRIB2 files, and IDL to generate jpg images. Quality of biomass burning emissions is assessed using the spatial pattern of fire distribution, particularly looking for artifacts or non-physical behaviors (e.g., fires over water) and by monitoring burned area statistics for small, medium, and large fires over different ecosystems

In the implement of biomass burning emissions, the algorithm reads fire data as the dynamic input. The fire hotspots vary in each calculation, which results in the change in computing time. Large number of fires appears during fire season while fires are limited during cold and rainy season. If fire number is larger than 250000 hotspots within a day, the calculation will overflow. Beside, WF_ABBA produces large number of files during a day, which might result in loses of some files if FTP network is too slow.

2. 23 Quality Assessment and Diagnostics

Two burned area images (jpg) are generated using IDL program for visually monitoring the performance of the Blended-BBEP product. One is the spatial distribution of burned area, and the other is the statistic histogram of burned area. These two images provide the basic information of product quality. Specifically,

- Quality of biomass burning emissions is assessed using the spatial pattern of fire distribution, particularly looking for artifacts or non-physical behaviors (e.g., fires over water).
- Monitoring burned area statics for small, medium, and large fires over different ecosystems.
-

2. 24 Exception Handling

Quality has been checked and artifacts removed.

2.25 Potential Improvements

The Blended-BBEP algorithm could be enhanced by updating fuel loadings, fire size diurnal pattern, fitting diurnal variation in fire size, and the allocation of GOES burned area to 1km grid cell.

2.26 Validation

Accurate validation of biomass burning emissions is currently impossible because the direct field measurement is very complex. Alternatively, the parameters of emission calculation were validated, particularly, burned area and fuel loadings.

Quantifying the accuracy of burned area estimates from MODIS+AVHRR+GOES instruments was conducted using both higher spatial resolution remote sensing data (TM/ETM+) and ground-based measurements (NFI ICS-209). Burn scars derived from Landsat TM/ETM+ imagery (30 m) represent the actual burned areas with high quality. National Fire Inventory (NFI) data were also used to validate burned area derived from MODIS+AVHRR+GOES active fires. The NFI data are the burned areas and fire occurrences that are reported from federal, state, and local agencies. The NFI dataset in 2005 contains about 2900 fire events with ground-based measurements including fire location, size, and other information, but these fires only cover parts of fire events over CONUS.

The validation of burned area shows that the burned areas derived from the Blended-BBEP in 2005 are correlated well with TM/ETM+-based burn scars across CONUS. The root mean square error (RMSE) is 14.1 km^2 for all the samples. The linear regression (at 95% confidence) intercept is -0.92 ± 0.64 ($p=0.152$) and the slope is 1.0288 ± 0.0079 ($P<0.00001$). This indicates that the samples of burned area estimates against TM/ETM+-based burn scars are generally distributed along a 1:1 line, which means that there is no significant systematic bias.

The accuracy of the burned-area estimates varies with ecosystems. The burned area is slightly overestimated in forests and savannas with an error of 13% and 30%, separately. However, it is underestimated in shrublands (2.2%), grasslands (8.4%), and croplands (15.7%). These errors are likely associated with the fire energy released from fires. In forests and savannas, large amount of fuel loadings usually causes intense and severe fires, which are easy to be detected from satellites. In contrast, fires are of relatively low intensity in shrublands, grasslands, and croplands where the small amount of fuel loading is available. Thus, the fires with less radiative energy are relatively hard to be continuously observed.

Comparison of satellite-derived burned area to data from national inventory shows that the fire detection rate from multiple satellites is a function of ecosystems and the size of the burned area reported in national inventory data in 2005. The detection rate from

MODIS+AVHRR+GOES is very similar in various ecosystems except for shrublands. Overall, MODIS+AVHRR+GOES detect 40% of small fire events (burned area < 1 km²) in NFI ICS-209 and more than 80% of large fire events (burned areas >10 km²).

The Blended-BBEP estimates of burned areas are matched well with ICS-209 data in 2005. Comparison of the matched fire events shows that the overall accuracy of burned area estimated from the MODIS+AVHRR+GOES is 83%. The satellite estimates are slightly smaller than the inventory data. This result is expected because uncertainties exist in both datasets. As reported by WRAP (2005), the field measurements are difficult in large regions and national inventory data usually contain a certain amount of unburned areas (24% on average) within the fire's perimeter. If the proportion of unburned area is excluded from national inventory data, the difference between these two datasets is much smaller.

This validation also indicates that the burned areas estimated from the Blended-BBEP are overestimated in small fire events and underestimated in large fire events. The error ranges from 17% (overestimates) to -20% (underestimates) for different sizes of burned areas in inventory data. This pattern is identical to the difference between the MODIS+AVHRR+GOES estimates and the TM/ETM+-based burn scars.

Two datasets were obtained to evaluate the estimates of fuel loading (biomass). Forest inventory database produced by National Forest Inventory Analysis (FIA) program in the US Department of Agriculture Forest Service (USFS) is available at plot scales in the US. Since a FIA plot represents one acre (0.004 km²) sample area, the plot-based data are hard to directly compare with the MODIS estimates in a 1 km pixel. Therefore, the average plot biomass in each state of eastern US was adopted. The second dataset is a forest biomass map with a spatial resolution of 30 m in National Forests in California. This dataset was generated by intersecting FIA-derived timber volume estimates with a forest cover map by the Remote Sensing Laboratory for Region 5 of the USFS. The timber volume data were then converted to biomass values using an expansion factor coefficient. This dataset was aggregated from 30 m to 1 km to compare with MODIS estimates in MVPFS.

Comparison of aboveground biomass density indicates that estimates from MODIS data and allometric models match the average of FIA values very well in the eastern US. The root mean square error (RMSE) is 15.6 tons/ha and the coefficient of determination (R^2) is 0.56. However, the aboveground biomass in Iowa was greatly underestimated from the MODIS data. This is likely due to the sparse forests in the 1 km pixels because there are only 0.4% of forest areas in this state. In contrast, the FIA data usually represent plots well covered by forests.

The comparison in California provides assessment at a pixel level. The result reveals that the MODIS estimates are associated with over 63% of the variation in FIA data with a RMSE of 44.3 tons/ha. Similar to the estimates from the regression tree-based model, aboveground biomass were slightly underestimated for the areas where biomass is larger than 250 tons/ha. This discrepancy is likely attributed to either the sparse forests containing in pixels or the saturation of MODIS estimates.

2. 27 Algorithm Overview

The Blended-BBEP algorithm is described in detail in ATBD. Brief description is provided here. The Blended-BBEP product is to calculate burned area and emissions (PM_{2.5}, CO, CH₄, CO₂, TNMHC, NH₃, N₂O, NO_x, and SO₂) released from wildfires using four variables: burned area, fuel loading, combustion factor, and emission factor. The Blended-BBEP algorithm estimates burned area using active fire observations the Hazard Mapping System (HMS). The HMS consolidates automated fire detections GOES Imager, AVHRR, and MODIS data over North America. GOES WF_ABBA not only identifies fire pixels but also calculates sub-pixel fire size for the pixels with high quality detections. Polar orbiting fire observations are provided by the MODIS instruments on both the NASA Terra and Aqua spacecraft and the AVHRR on NOAA-15/17/18. These data provide a nominal spatial resolution of 1 km. Each instrument scans a surface location twice a day in low-middle latitudes. Detections from MODIS and AVHRR data only provide the occurrence of fire hotspots.

Fuel loading is basically divided into live and dead fuel loadings. The live fuel loading consists of canopy (foliage and branch) biomass in forests, shrub biomass, and grass (including crop) biomass, and the dead fuel loading is composed of litter and coarse woody detritus. To determine the fuel loadings for each pixel at a spatial resolution of 1 km, The Blended-BBEP developed a MODIS Vegetation Property-based Fuel System (MVPFS) using percent vegetation cover, leaf area index, and land cover types.

Combustion and emission factors are dependent on fuel type and moisture condition. We determine fuel moisture conditions from time series of AVHRR data, which are then related to moisture category factors for estimating the factors of combustions and emissions.

By integrating burned area, fuel loading, and combustion and emission factors, the Blended-BBEP product is produced every 6 hours by acquiring and blending instantaneous fire observations from GOES-W, GOES-E, MODIS, AVHRR during past 24 hours. The processing is fixed in North America (NA) and produces burned area and emissions of PM_{2.5}, CO, CH₄, CO₂, TNMHC, NH₃, N₂O, NO_x, and SO₂ in every hour. The GBBEP-Geo algorithm runs automatically four times a day through a CRONTAB job and makes them available in the ftp site.

2.28 Satellite Instrument Description

The Blended-BBEP algorithm does not directly use satellite data as inputs. Instead, it employs active fire detections from GOES, MODIS, and AVHRR, fuel loading from MODIS products of vegetation properties, and fuel moisture condition from AVHRR-based vegetation health condition.

2.29 Satellite Instrument Overview

The Blended-BBEP algorithm does not directly use satellite data as inputs

2.30 Satellite Data Preprocessing Overview

The Blended-BBEP is processed based on the steps listed in the Figure 2-5. The processing first reads HMS (MODIS+AVHRR) fire product, GOES WF_ABBA fire data and AVHRR VCI (vegetation condition index). It then simulates burned areas from the active fires, determines fuel moisture condition, calculates emissions by integrating simulated burned area and static inputs (fuel loading and emission factors). Finally, the processing generates output (ASCII, netCDF4, and GRIB2) data of hourly burned area and various emissions in a period of every 6 hours.

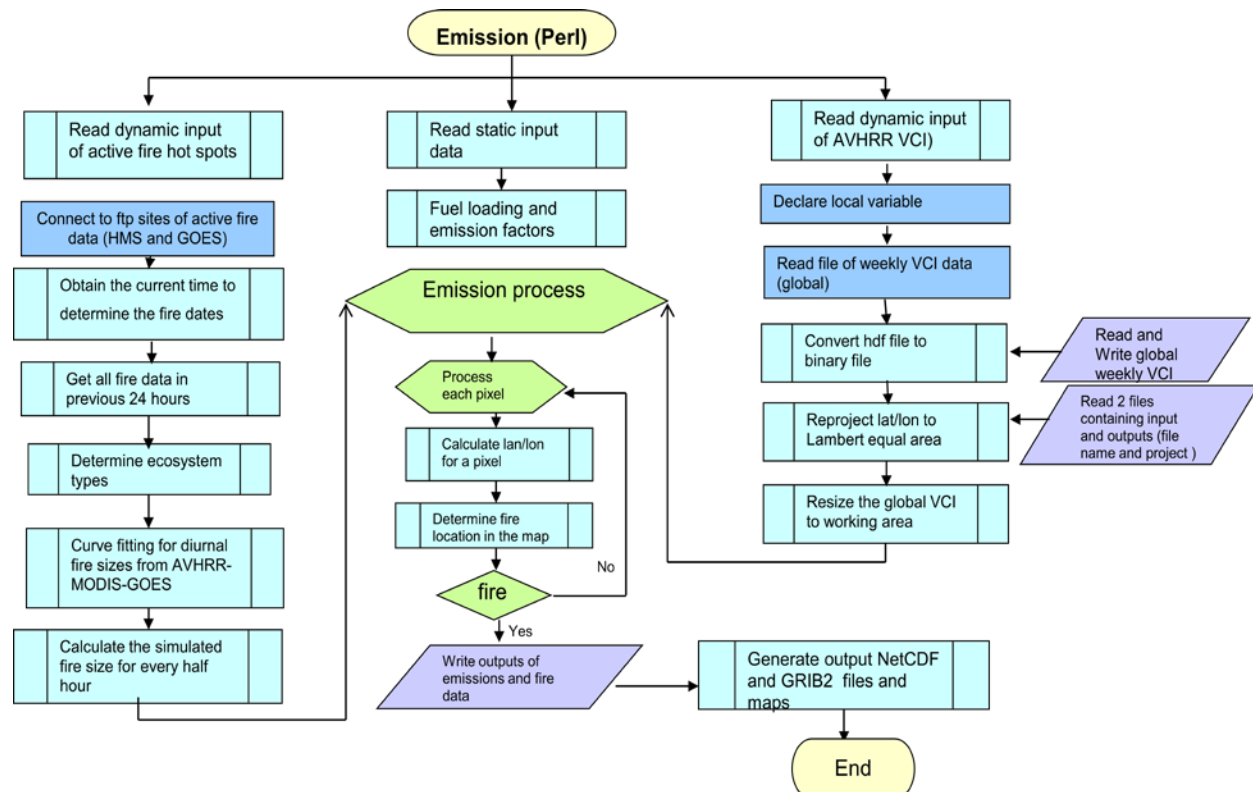


Figure 2-5 Blended-BBEP Processing Flowchart

2.31 Test Data Description

The Blended-BBEP algorithm and code have been tested extensively. The test data are the fire detections from GOES-13 and GOES-15 WF-ABBA and HMS from December 1, 2011 to February 30, 2012. Basically, the code has been running routinely in a local machine before official operation. It has produced hourly biomass burning emissions every six hours (four times a day).

2.32 Ancillary Data Description

The input files containing ancillary data are listed in the followings (Table 2-4).

Table 2-4 Data Flow for Biomass Burning Emissions

File	Input/ Output	Source	Description	State
Lon_lat_east*	Input	Blended-BBEP	GOES-E pixel location	Static
Lon_lat_west*	Input	Blended-BBEP	GOES-W pixel location	Static
fittedfiresizeLST.txt	Input	Blended-BBEP	Climatologic diurnal pattern of fire size	Static
LWmask_lambert_CON1km_NA	Input	Blended-BBEP	1 km land/water mask	Static
LWmask_lambert_CON12km	Input	Blended-BBEP	12 km land/water mask	Static
MVPFS_fuel_ave200234_NA_2km	Input	Blended-BBEP	Fuel loading data	Static
UMD_LC_NA_mosaic_SUB_2km	Input	Blended-BBEP	Land cover	Static
FEPS_moisture_consumption.txt	Input	Blended-BBEP	Moisture-dependent consumption factor	Static
FOFEM_emiss_CO.txt	Input	Blended-BBEP	Emission factor of CO	Static
FOFEM_emiss_CH4.txt	Input	Blended-BBEP	Emission factor of CH4	Static
FOFEM_emiss_TNMHC.txt	Input	Blended-BBEP	Emission factor of TNMHC	Static
FOFEM_emiss_NH3.txt	Input	Blended-BBEP	Emission factor of NH3	Static
FOFEM_emiss_N2O.txt	Input	Blended-BBEP	Emission factor of N2O	Static
FOFEM_emiss_NOX.txt	Input	Blended-BBEP	Emission factor of NOX	Static
FOFEM_emiss_SO2.txt	Input	Blended-BBEP	Emission factor of SO2	Static

		BBEP		
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2.33 Ancillary Data Overview

Various ancillary data are used in the Seiler-Crutzen algorithm for the estimates of biomass burning emissions, which are listed and briefly described in the followings.

Fuel loading is basically divided into live fuel loading and dead fuel loading. The live fuel loading consists of foliage and branch biomass in forests, shrub biomass, and grass (including crop) biomass. The dead fuel loading is composed of litter and coarse woody detritus. The fuel loading for each pixel was obtained from a MODIS Vegetation Property-based Fuel System (MVPFS). This dataset was primarily calculated from percent vegetation cover in MODIS continuous field product, LAI, and land cover types at a spatial resolution of 1 km. In the biomass burning processing, the spatial resolution is reduced to 2km because the GOES pixel size is much coarser.

The land cover type contains 16 different land cover types of IGBP schemes at a spatial resolution of 1 km. This data were classified using a decision tree algorithm and MODIS bidirection-adjusted references.

The latitude and longitude for GOES-E and GOES-W are provided in two separate files. They are "lon_lat_east" and "lon_lat_west". These two files will be updated with the launch of new GOES satellites. The water area is masked to reduce computation time.

The fuel combustion factor is contained in a file named as FEPS_moisture_consumption.txt. The factor varies with fuel moisture condition.

Emission factor varies with emission species. Thus, there are seven ASCII files (lookup table) containing emission factors.

The Blended-BBEP system uses a number of template files. These are all static files that will only change with a new delivery of the system. They are never modified by the scripts and programs that use them. Scripts will only copy these files to a local directory or create soft links to them.

These template files include climatologic diurnal pattern of fire size (fittedfiresizeLST.txt) and reprojection parameters (CONvert_VCI_Y_NA_2km.out and CONvert_VCI_Y_NA.in).

Land/water mask is added in the GRIB2 files. Two type of land/water masks are used, which are at spatial resolutions of 1km and 12km.

2.34 Product Description

The Blended-BBEP produces biomass burning emissions four times a day. In each processing, hourly burned area and emissions (PM2.5, CO, CH4, CO2, TNMHC, NH3, N2O, NOX, and SO2) are produced during last six hours. The hourly outputs are written in one file with NetCDF4 and ASCII formats, separately. The burned area is further convert to

GRIB2 format with a spatial resolution of 1km and 12 km separately. The 1km GRIB2 burned area is a cumulative value during last 12 hours, which covers a spatial region:

upper left center	-179.5076°	64.9978°
upper right center	-14.2080°	65.9894°
low left center	-128.1977°	14.5586°
low right center	-65.0022°	15.0012°

The 12km GRIB2 burned area is a cumulative value during last 6 hours, which covers a spatial region:

upper left center	161.7229°	45.7454°
upper right center	9.1585°	40.4839°
low left center	-138.4411°	-7.9159°
low right center	-50.0185°	-9.8716°

2.35 Product Overview

The Blended-BBEP produces hourly burned area and biomass burning emissions, which is operationally produced every six hour. The products are:

- biomass_burning_yyyymmdd_hh_hh.nc — contains hourly values including burned area, emissions of PM2.5, CO, CH4, CO2, TNMHC, NH3, N2O, NOX, SO2, fire location(latitude and longitude), ecosystem type, fire pixel size, and fuel loading.
- burned_area_yyyymmdd_hh_hh_12km.grib2 --- cumulated burned area (1km grid) within 6 hours
- burned_area_yyyymmdd_hh_hh_1km.grib2 --- cumulated burned area (12km grid) within 12 hours
- burned_area_yyyymmdd_hh_hh_NA.jpg — spatial pattern of burned area
- burned_area_yyyymmdd_hh_hh_QA.jpg — statics of burned area for quality check.
- biomass_burning_yyyymmdd_hh_hh.txt — an ASCII file contains burned area, emissions of PM2.5, CO, CH4, CO2, TNMHC, NH3, N2O, NOX, SO2, fire location(latitude and longitude), ecosystem type, fire pixel size, and fuel loading.

2.36 Archives

Products locally archived in the GP75/GP78 directory /home/oper/BBEP2/OUTPUT/SAVE_OLD. A shorter term archive is available via the Satepsanone site http://satepsanone.nesdis.noaa.gov/pub/FIRE/BBEP-geo/PREVIOUS_DAYS/.

2.37 Archive Format Description

Netcdf, grib2, jpg and ASCII formats.

2.38 Quality Control Output

Currently, the Blended-BBEP does not provide QA flag.

2.39 Product Accuracy

- Validation of burned area using TM/ETM+-burned scars in 2005
- Accuracy: 0.17
- Validation of fuel loading using National Forest data
- Accuracy: 0.13

2.40 Data Preparation

All the static data should be prepared in a related directory. The data files and format are listed in Table 2-4.

2.41 Data Flow

Various levels of the Blended-BBEP data flow are presented here. The data flow includes the external interfaces to the system code which represents the connectivity of the Blended-BBEP system codes, the next lower level of the system design which identifies the main system units, describes their function, and reveals their interrelationships through data flow, and the units detailing sub-unit components.

The relevant external interfaces are shown in Figure 2-6.

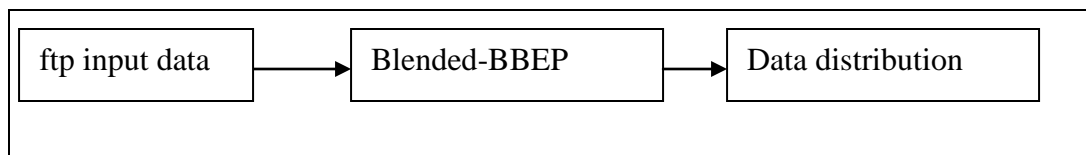


Figure 2-6 External Interfaces

Figure 2-7 shows the context level data flows into and out of the Blended-BBEP system. The collective input and output of all the units are generalized as input and output relative to the Blended-BBEP box in the center of the figure.

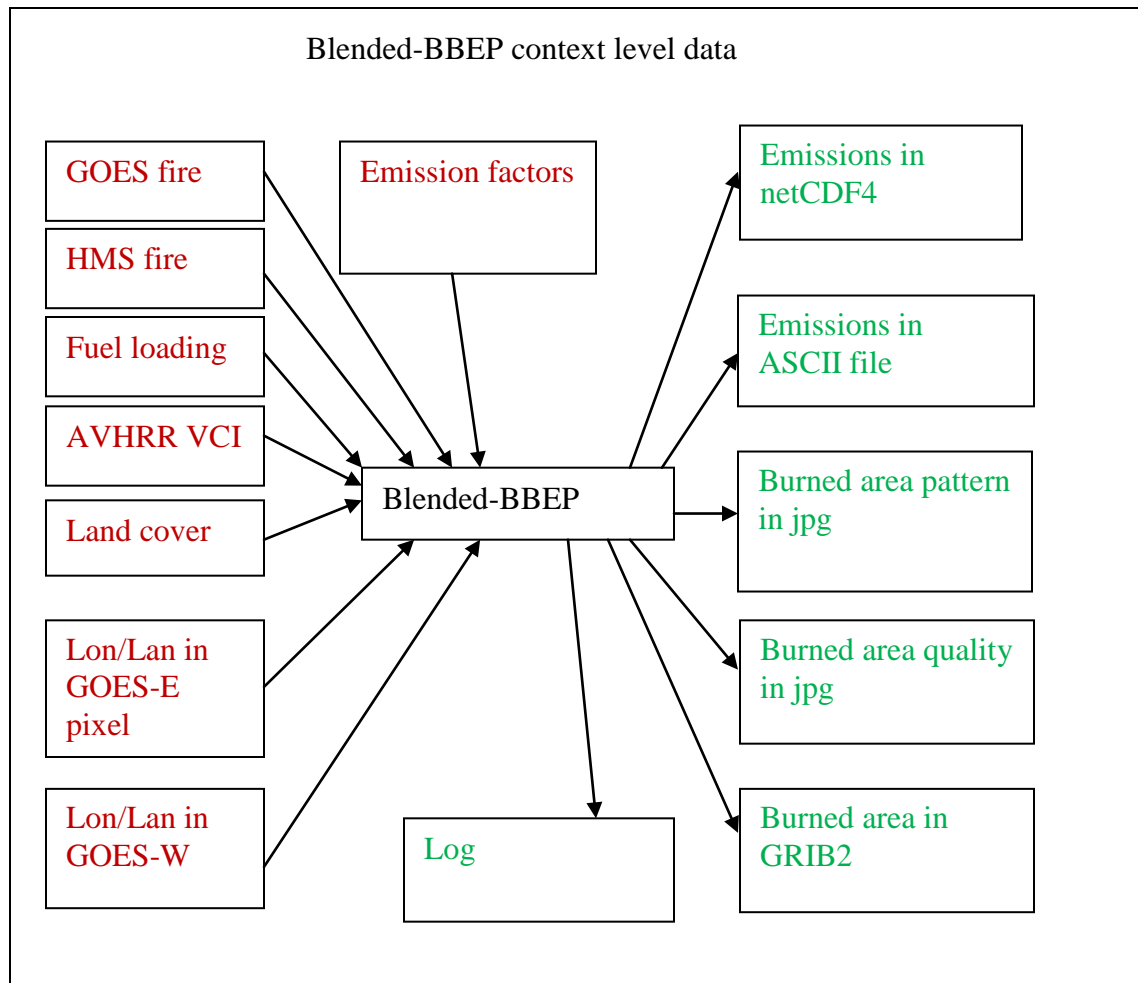


Figure 2-7 Blended-BBEP Context Level Data Flow

The arrows represent only the high-level file-based interfaces to the system, as opposed to other types of interfaces such as the unit return values, program arguments, or shell variables.

The Blended-BBEP system is developed to run on the Linux system. The system level data flow is shown in Figure 2-8.

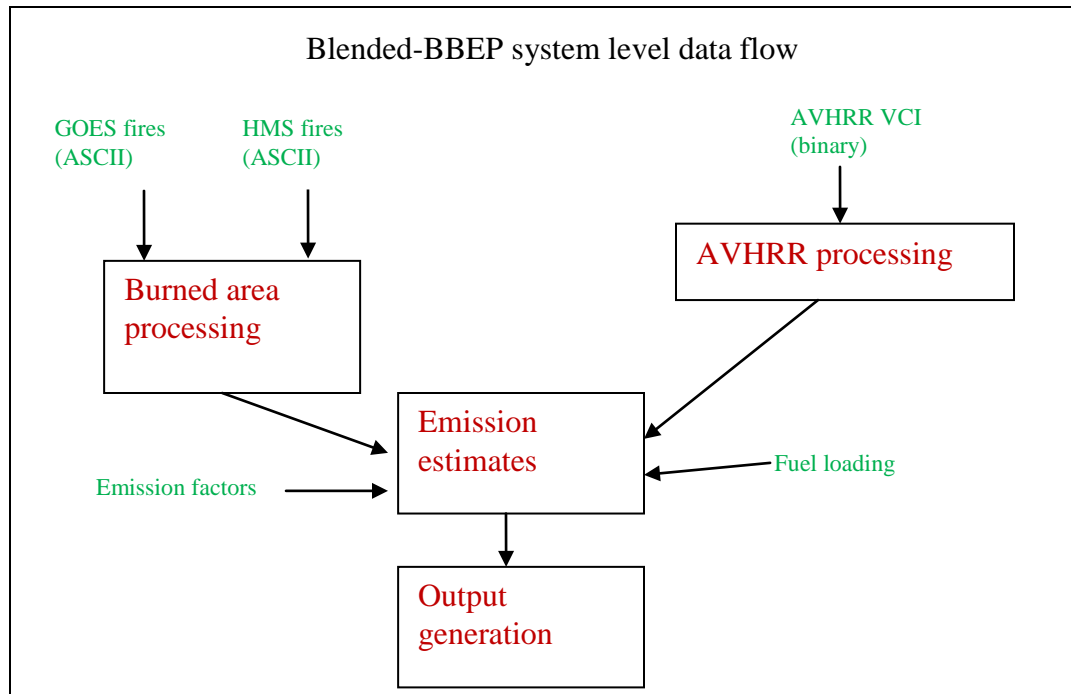


Figure 2-8 Blended-BBEP System Level Data Flow

2.43 Error Correction – Warnings and Messages

A log file contains the warnings and messages when executing the computer codes. Each error message lists the program that produced the error.

2.44 Error Correction - Error Codes

The possible error messages are listed in Table 2-5.

Table 2-5 Blended-BBEP Error Messages

Error Message	Explanation	Action
Error in \$SCRIPT: Can't ftp to GOES fires	The ftp site for GOES fire data is not correct	If this error occurs, check the host name and directory of GOES fire data.
Error in \$SCRIPT:	The login server or passwd is not	If this error occurs, check

Can't login to GOES fire data	correct	the login information
Error in \$SCRIPT: Can't cd the GOES fire directory	The direction of fire data is not correct	If this error occurs, check GOES fire data
Error in \$SCRIPT: Can't get GOES fire list	The direction of fire data is not correct or no fire data available	If this error occurs, check GOES fire data
Error in \$SCRIPT: Can't ftp to HMS fires	The ftp site for HMS fire data is not correct	If this error occurs, check the host name and directory of HMS fire data.
Error in \$SCRIPT: Can't login to HMS fire data	The login server or passwd is not correct	If this error occurs, check the login information
Error in \$SCRIPT: Can't cd the HMS fire directory	The direction of fire data is not correct	If this error occurs, check HMS fire data
Error in \$SCRIPT: GOES-EW_lola.exe does not exist	The file is not exist	If this error occurs, check with development team
Error in \$SCRIPT: Lon_lat_east does not exist	The file is not exist	If this error occurs, check with development team
Error in \$SCRIPT: Lon_lat_west does not exist	The file is not exist	If this error occurs, check with development team
Error in \$SCRIPT: Fire data are not integrated	Data processing error	If this error occurs, check with development team
Error in \$SCRIPT: Can't open file: FittedfiresizeLST.txt	The file of climatologic fire size data is not exist	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: reproj_linux_v2.exe	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: CONvert_VCI_Y_NA.in	The file does not exist or is located in a wrong directory	If this error occurs, check with development team

Error in \$SCRIPT: file does not exist:CONvert_VCI_Y_ NA_2km.out	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: VCI_Y_LA_NA2km.out	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:MVPFS_fuel_ave20 0234_NA_2km	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:UMD_LC_NA_mos aic_SUB_2km	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FEPS_moisture_con sumption.txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: nfd_r_FOFEM_emission.t xt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_CO. txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_CH 4.txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_TN MHC.txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team

Error in \$SCRIPT: file does not exist:FOFEM_emiss_NH 3.txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_N2 O.txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_NO X.txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_SO 2.txt	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:DATA_LA- lanlon_NA_2km	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:\$outfilefit	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:\$outfilevci	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:pgbbep_emis2km.e xe	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not	The file does not exist or is located in a wrong directory	If this error occurs, check with development team

exist:setColorTableForL nes.pro		
Error in \$SCRIPT: : file does not exist:colorbar.pro	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:circle.pro	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:fir_imagedis_ascii_ NA.pro	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:create_netcdf_all.pr o	The file does not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:plot_bar_chart.pro	The file does not exist or is located in a wrong directory	If this error occurs, check with development team

2.45 Menus and Navigation

2.46 Product Access Procedures

All products are updated 4 times a day at 5, 11, 17 and 23 Z and available via the site <http://satepsanone.nesdis.noaa.gov/pub/FIRE/BBEP-geo/>.

2.47 Test Results

The Blended-BBEP has been tested. The outputs are reasonable based the statistic values and spatial patterns.

2.48 Unit Test Plans

Contents: Describe all test plans that were produced during development, including links or references to the artifacts.

Writers: Development Testers

2.49 Input Data Set Description

The Blended-BBEP contains four inputs from satellites. WF_ABBA produces one file in each observation, which consists of half hourly fire data from GOES-W and GOES-E, separately. The file is written as Fyyydddhmm.v65.g11.filt and Fyyydddhmm.v65.g13.filt for GOES11 and GOES13, separately. MODIS and AVHRR fire hotspots are written in the file of "Hmsyyyymmdd.prelim.txt". The vegetation health condition contains in a file of NPR.VGWG.NN.Dyydd.VCII.

2.50 Intermediate Data Set Description

The Blended-BBEP contains a set of intermediate files. The files are listed in the Table 2-6.

Table 2-6. Intermediate files used in the Blended-BBEP.

File	Description
Fyyydddhfitted_burnedarea	Half-hourly burned area
Fyyydddh_day_fire_v65.txt	Combined GOES fire detections in previous 24 hours
Temp1	Combined GOES and HMS fires
Temp2	Blended GOES and HMS fires in GOES pixel footprint
TEMPfile	Timely aggregated GOES and HMS fire detections
Temp_1km	Plain binary file of burned area in 1km grid cells
Temp_12km	Plain binary file of burned area in 12km grid cells
VCI_temp	NA subset of AVHRR VCI
CONvert_VCI_Y_NA.in	Projection information of AVHRR VCI
CONvert_VCI_Y_NA_2km.out	Projection information of re-projected AVHRR VCI
NPR.VGWG.NN.D11.LA_NA	Re-projected NA subset of AVHRR VCI within a standard region
VCI_Y_LA_NA2km.out	Re-projected NA subset of AVHRR VCI
Fyyydddhfitted_burnedarea	Half-hourly burned area
NPR.VGWG.NN.D11.LA_NA	Re-projected NA subset of AVHRR VCI within a standard region
Fyyydddh.out_ascii	Half-hourly biomass burning emissions and fire information
Lc_temp	It contains statistic values of burned area
Burned_area_yyyymmdd_hh_hh	Burned area and lon/lan for generating spatial distribution map
biomass_burning_yyyymmdd_hh_hh	Biomass burning emissions and burned area for generating netCDF file

2.51 Output Data Set Description

The Blended-BBEP produces several files regarding biomass burning emissions and burned area. The files are written in ASCII, NetCDF4, and GRIB2. Details can be found in Table 2-7.

Table 2-7. Output data

File	Description
biomass_burning_yyyymmdd_hh_hh.nc	Output hourly biomass burning emissions in netCDF
burned_area_yyyymmdd_hh_hh_1km.grib2	Output twelve-hour burned area in 1km GRIB2
burned_area_yyyymmdd_hh_hh.grib2	Output six-hour burned area in 12km GRIB2
biomass_burning_yyyymmdd_hh_hh.txt	Six hourly emissions
burned_area_yyyymmdd_hh_hh_NA.jpg	Spatial pattern in burned area in jpg map
burned_area_yyyymmdd_hh_hh_QA.jpg	Statistic data in burned area
Log	Log file

2.52 Internal Product Tools

Because the output files are written in standard formats, special tools are not needed.

2.53 External Product Tools

Because the output files are written in standard formats, special tools are not needed.

2.54 System Control Files

Contents: Describe the process control file

Writers: Development Programmers.

2.55 Look Up Tables

Table 2-8 presents files contain look up tables and parameters for the estimates of biomass burning emissions.

Table 2-8. Files of look up table and static parameters.

File	Description
FEPS_moisture_consumption.txt	Moisture-dependent consumption factor
FOFEM_emiss_CO.txt	Emission factor of CO
FOFEM_emiss_CH4.txt	Emission factor of CH4
FOFEM_emiss_TNMHC.txt	Emission factor of TNMHC
FOFEM_emiss_NH3.txt	Emission factor of NH3
FOFEM_emiss_N2O.txt	Emission factor of N2O
FOFEM_emiss_NOX.txt	Emission factor of NOX
FOFEM_emiss_SO2.txt	Emission factor of SO2
CONvert_VCI_Y_NA.in	Projection information of AVHRR VCI
CONvert_VCI_Y_NA_2km.out	Projection information of re-projected AVHRR VCI

2.56 Operational Scenario

Product Processing: Daily processing occurs through the following sequence of CRON jobs (four times a day—every 6 hours):

```
00 05 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
00 11 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
00 17 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
00 23 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
```

2.57 Operations Documentation

All documents are available in G:\OSDPD\SSD\LIBRARY\LAND\Fire\BLENDED_BBEP:

- Blended_BBEP_Document_Object.doc
- Blended_BBEP_Internal Users_Manual.docx
- Blended_BBEP_Algorithm Theoretical Basis.docx
- Blended_BBEP_EUM.docx
- Blended_BBEP_SMM.docx
- Operational Events Log.docx
- Data flow diagram.pptx
- BBEP_Build_Form.docx

2.58 Maintenance History

All documents are available in G:\OSDPD\SSD\LIBRARY\LAND\Fire\BLENDED_BBEP:

Blended_BBEP_Document_Object.doc
Blended_BBEP_Internal Users_Manual.docx
Blended_BBEP_Algorithm Theoretical Basis.docx
Blended_BBEP_EUM.docx
Blended_BBEP_SMM.docx
Operational Events Log.docx
Data flow diagram.pptx
BBEP_Build_Form.docx

2.59 Storage Requirements - Data

Table 2-9 contains a list of storage requirements for all Blended-BBEP primary and ancillary input data, intermediate data, and output data. These requirements reflect the current build of Blended-BBEP.

Table 2-9. Blended-BBEP Storage Requirements

Storage Item	Size (daily data storage)
Data Product Files	15 MB
Intermediate Files	200 MB
Incoming Blended-BBEP Data	2MB
System Resource Files	350MB
Tools (library/utilities)	100 MB
Total	667 MB

2.60 Storage Requirements - Code

The Blended-BBEP requires a size of 1.5MB for system executable codes and a size of 1.5MB for system scripts.

2.61 Computer Resource Requirements

The Blended-BBEP software was developed and tested to run on RedHat Linux 8.0. Observation of run times shows that for nominal operational processing, the system requires an average of 1 CPUs at any given time to maintain latency.

The running time for Blended-BBEP varies with the amount of wildfire pixels. During the peak fire season, the running time is about 1.0 hours (varying with the number of fire hotspots).

Blended-BBEP requires the following libraries and utilities:
IDL, GRIB2, GCTP, NetCDF4, and HDF packages

To compile on the test machine, the Linux 8.0 C/C++ compiler must be present.

The system was developed using Perl version 5.8.8, but should function with any newer version and standard Perl library modules.

2.62 Communication Needs

Blended-BBEP inputs satellite-derived fire data and vegetation health condition instead of satellite radiance directly. The dynamic inputs are HMS fires from MODIS and AVHRR, and GOES WF_ABBA fires, and VCI from AVHRR.

2.63 Performance Statistics

Two burned area images (jpg) are generated using IDL program for visually monitoring the performance of the Blended-BBEP product. One is the spatial distribution of burned area, and the other is the statistic histogram of burned area. These two images provide the basic information of product quality.

2.64 Operating System

Blended-BBEP will be operated using RedHat Linux 6.0 or higher

2.65 Monitoring

The BBEP is monitored on a daily basis by visual inspection of the product image output, files sizes, log files and error messages that automatically sent to the staff monitoring group whenever errors occur.

2.66 Science Maintenance

Science maintenance is needed to improve the quality of biomass burning estimates. This procedure will be based on the improvement of algorithm and the change of satellite-derived data sets.

2.67 Data Signal Monitoring

The HMS input data is manually quality checked the SAB fire analysis team before being posted in the distribution server.

2.68 Job Monitoring

The Blended_GBBEP system is fully automated from the initial design and no regular maintenance is required. The maintenance contractor is responsible for checking the Blended_GBBEP webpage daily, to make sure the page is updating and that the fires look reasonable. If the Blended_GBBEP jobs fail to run daily, an e-mail alert will be sent to the PAL and to the maintenance staff.

The monitoring requires checking the outputs in an ftp site daily and verifies that the files in there are not empty and that the JPG image with the emission spots is not clear of points.

The processing errors can be found in a log file. If there is problem in processing, an email will sent out to the operator.

2.69 Product Monitoring

The BBEP is monitored on a daily basis by visual inspection of the product image output, files sizes, log files and error messages that automatically sent to the staff monitoring group whenever errors occur.

2.70 Image Display

The BBEP is monitored on a daily basis by visual inspection of the product image output, files sizes, log files and error messages that automatically sent to the staff monitoring group whenever errors occur.

2.71 Library Maintenance

No special requirement is needed.

2.72 Special Maintenance Procedures

No special maintenance procedure required.

2.73 Data Transfer / Communications

The input HMS and VCI files are transferred to GP75 and GP78 via SFTP from satepsdist1 and satepsdit4 respectively. The output products are sent to satepsanone for distribution via the site <http://satepsanone.nesdis.noaa.gov/pub/FIRE/BBEP-geo/>.

2.74 Directory Description

This section describes the location of processing code (scripts and programs) in the delivered version of the Blended-BBEP only. When the system is integrated into the server, it is for the operational integrators to determine where scripts, programs, data, system files, and working directories reside. Blended-BBEP does not assume any path structure for its processing. All Blended-BBEP processing assumes that everything that the given Blended-BBEP application needs is located in the present working directory.

Paths are always shown in italics. Because the system could be installed at any location on a given machine, the highest level directory path of installation for the system is always referred to as “\$BASE”. Therefore, the location of all files and directories is described with respect to this high level directory. Since server will handle all Blended-BBEP files and directories, we only provide the source code and driver scripts directory.

All driver scripts (Perl) for the four processing units are located at:

/home/oper/BBEP2/

Source code is only kept on the test machine. Only executable code is allowed on the production machine. All source code for those languages which are compiled (C/C++) is located at:

/home/oper/BBEP2/code

All the retrieval code is at:

/home/oper/BBEP2/

All the regular Blended-BBEP system code is located at:

/home/oper/BBEP2/

All statistic inputs are located at:

/home/oper/BBEP2/INPUT

The Makefile configuration file provides information on file prefix and suffix structures for the compilation. It is located here:

/home/oper/BBEP2/code/

All output data are located here:

/home/oper/BBEP2/OUTPUT

2.75 Setup Requirements

All items that are required for installation are listed in the following:

Static input data files:

- CONvert_VCI_Y_NA_2km.out
- CONvert_VCI_Y_NA.in
- FEPS_moisture_consumption.txt
- fittedfiresizeLST.txt
- FOFEM_emiss_CH4.txt
- FOFEM_emiss_CO.txt
- FOFEM_emiss_N2O.txt
- FOFEM_emiss_NH3.txt
- FOFEM_emiss_NOX.txt
- FOFEM_emiss_SO2.txt
- FOFEM_emiss_TNMHC.txt
- lon_lat_east
- lon_lat_west
- LWmask_lambert_CON12km
- LWmask_lambert_CON1km_NA
- MVPFS_fuel_ave200234_NA_2km
- nldr_FOFEM_emission.txt
- Static_input
- UMD_LC_NA_mosaic_SUB_2km

Source files:

- biomass_burning_creatNetCdf4.c
- GOES_EW_lola_Cluster.c
- goes_hms1km.c

grib2_burnedarea_lamCON.c
GVI_subset_NA.c
pgbbep_emis2km.c
reproj_v2.c
subsetLA_NA16_2km.c
circle.pro
colorbar.pro
fire_image_NA.pro
map_grid_cxu.pro
plot_bar_chart.pro
setColorTableForLines.pro
tvread.pro

Script files:

bbep-geo.pl
paths.pl

Make files:

biomass_burning_creatNetCdf4.make
GOES_EW_lola_Cluster.make
goes_hms1km.make
grib2_burnedarea_lamCON.make
GVI_subset_NA.make
pgbbep_emis2km.make
reproj_linux_v2.make
subsetLA_NA16_2km.make

2.76 Compilation Procedures

Uses “make -f *.make”.

2.77 Installation Procedures

Code installed according to the SPSRB guidelines.

2.78 Build Procedures

Build form located in G:\OSDPD\SSD\LIBRARY\LAND\Fire\BLENDED_BBEP:

BBEP_Build_Form.docx

2.80 Source Code Description

All items that are required for installation are listed in the following:

/home/oper/BBEP2/bbep-geo.pl

This is the main program to preprocess the Blended-BBEP data. This program links all subroutines to generate biomass burning emissions.

\$BASE/SOURCE/paths.pl

This program contains all directories of data inputs, output, and processing.

/home/oper/BBEP2/code/ GOES_EW_lola.c

This program is to combine all fire detections in a GOES pixel footprint. It reads GOES-E and GOES-W pixel locations, GOES WF_ABBA fire detections, and HMS fire detection. The output is a temporary ASCII file containing fire detection in a GOES pixel.

\$BASE/SOURCE/code/ GVI_subset_NA.c

This program reads AVHRR VCI (binary, 16km) data at a global coverage and extracts the subset of North America. The output is a temporary binary file containing AVHRR VCI over North America with a geographic projection.

/home/oper/BBEP2/code/reproj_v2.c

This program is to re-project AVHRR VCI from geographic projection to Lambert equal area projection. The projection information is included in files of "CONvert_VCI_Y_NA.in" and "CONvert_VCI_Y_NA_2km.out". The former is for input file and the latter is for the output file.

\$BASE/SOURCE/code/subsetLA_NA16_2km.c

This program reads in the re-projected AVHRR VCI data and extracts the subset of entire North America which matches the coverage of fuel loading.

/home/oper/BBEP2/code/pgbbep_emis2km.c

This program is to calculate biomass burning emissions for each GOES fire pixel. It reads in burned area, fuel loading, land cover type, AVHRR VCI, emissions and combustion factors. The static inputs are located in */home/oper/BBEP2/INPUT*. All inputs are stored in the file of "Static_input". The output is the emissions of various species (ASCII).

/home/oper/BBEP2/code/grib2_burnedarea.c

This program is to generate a GRIB2 format for the cumulated burned area for six hours.

/home/oper/BBEP2/ create_netcdf_all.pro

The program is an IDL code. It reads in a temporary file containing burned area, emissions, and other fire information to generate a netCDF file which is the main out put product.

/home/oper/BBEP2/plot_bar_chart.pro

The program reads in statistics of burned area in a six hour period and produces a jpg image of fire histogram.

/home/oper/BBEP2/fire_image_NA.pro

This program is an IDL code. It reads in burned area and produces a spatial pattern map.

/home/oper/BBEP2/setColorTableForLines.pro

/home/oper/BBEP2/map_grid_cxu.pro

/home/oper/BBEP2/circle.pro

/home/oper/BBEP2/colorbar.pro

/home/oper/BBEP2/tvread.pro

Above five IDL codes (*pro) contain color information in support “*fire_image_NA.pro*” to draw burned area map.

2.81 Data Preparation

All the static data should be prepared in the directory “*/home/oper/BBEP2/INPUT*”.

2.82 Problem Diagnosis and Recovery Procedures

Error messages returned from scripts are outlined in Table 2-10. The origins of many of these errors are from low-level sources. Log file contains the standard output of the executable that was run inside the calling scripts. Each error message lists the program that produced the error as \$PROGRAM (main program, subroutine, function), the item as \$ITEM (e.g. variable name or array name) associated with that error, or a file name as file \$FILE.

Table 2-10 Blended-BBEP Error Messages (Low-Level)

Error Message	Explanation	Action
Error in \$SCRIPT: Can't ftp to GOES fires	The ftp site for GOES fire data is not correct	If this error occurs, check the host name and directory of GOES fire data.
Error in \$SCRIPT: Can't login to GOES fire data	The login server or passwd is not correct	If this error occurs, check the login information
Error in \$SCRIPT:	The direction of fire data is	If this error occurs, check

Can't cd the GOES fire directory	not correct	GOES fire data
Error in \$SCRIPT: Can't get GOES fire list	The direction of fire data is not correct or no fire data available	If this error occurs, check GOES fire data
Error in \$SCRIPT: Can't ftp to HMS fires	The ftp site for HMS fire data is not correct	If this error occurs, check the host name and directory of HMS fire data.
Error in \$SCRIPT: Can't login to HMS fire data	The login server or passwd is not correct	If this error occurs, check the login information
Error in \$SCRIPT: Can't cd the HMS fire directory	The direction of fire data is not correct	If this error occurs, check HMS fire data
Error in \$SCRIPT: GOES-EW_lola.exe does not exist	The file is not exist	If this error occurs, check with development team
Error in \$SCRIPT: Lon_lat_east does not exist	The file is not exist	If this error occurs, check with development team
Error in \$SCRIPT: Lon_lat_west does not exist	The file is not exist	If this error occurs, check with development team
Error in \$SCRIPT: Fire data are not integrated	Data processing error	If this error occurs, check with development team
Error in \$SCRIPT: Can't open file: FittedfiresizeLST.txt	The file of climatologic fire size data is not exist	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: reproj_linux_v2.exe	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:CONvert_VCI_Y_NA.in	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:CONvert_VCI_Y_NA_2km.out	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: VCI_Y_LA_NA2km.out	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:MVPFS_fuel_ave20023	The file is not exist or is located in a wrong directory	If this error occurs, check with development team

4_NA_2km		
Error in \$SCRIPT: file does not exist:UMD_LC_NA_mosaic _SUB_2km	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FEPS_moisture_consu mption.txt	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: nfd_r_FOFEM_emission.txt	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_CO.txt	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_CH4.tx t	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_TNMH C.txt	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_NH3.tx t	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_N2O.tx t	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_NOX.t xt	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:FOFEM_emiss_SO2.txt	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:DATA_LA- lanlon_NA_2km	The file is not exist or is located in a wrong directory	If this error occurs, check with development team

Error in \$SCRIPT: file does not exist:\$outfilefit	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:\$outfilevci	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist:pgbbep_emis2km.exe	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: setColorTableForLines.pro	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: : file does not exist: colorbar.pro	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: circle.pro	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: fir_imagedis_ascii_NA.pro	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: create_netcdf_all.pro	The file is not exist or is located in a wrong directory	If this error occurs, check with development team
Error in \$SCRIPT: file does not exist: plot_bar_chart.pro	The file is not exist or is located in a wrong directory	If this error occurs, check with development team

2.83 System Reboot Procedures

The PAL and the responsible contractors are supposed to be notified prior to rebooting procedures.

2.84 Maintenance Utilities

Current and previous output products are available in the satepsanone site
<http://satepsanone.nesdis.noaa.gov/pub/FIRE/BBEP-geo/> save in GP75 and GP78 in the
 directory /home/oper/BBEP2/OUTPUT/SAVE_OLD.

2.85 Distribution Restrictions

No restrictions.

2.86 Product Criticality

Maintenance level: 8x5

2.87 Product Retention Requirements

Six months retention period in the following servers: GP75, GP78 and Satepsanone.

2.88 Program Backup Procedures

Code saved in the CVS repository.

2.89 Data Recovery Procedures

The code runs in both GP75 (operational) and GP78 (backup) machines. They can be used as a recovery resource for each other.

2. 90 Program Recovery Procedures

The code is saved in CVS.

2.91 GUI Procedures

The GUI is available via the Satepsanone site
<http://satepsanone.nesdis.noaa.gov/pub/FIRE/BBEP-geo/>.

2.92 Application Restart Procedures

Run the following cron jobs in both GP75 and GP78:

```
10 05 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
10 11 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
10 17 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
10 23 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
```

2.93 System Restart Procedures

Run the following cron jobs in both GP75 and GP78:

```
10 05 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
10 11 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
10 17 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
10 23 * * * /home/oper/BBEP2/bbep-geo.pl > /home/oper/BBEP2/bbep-geo.log1 2>&1
```

2.94 Application Shutdown Procedures

Make sure the shutdown is done at least 10 minutes off the running times specified above.

2.95 System Shutdown Procedures

Make sure the shutdown is done at least 10 minutes off the running times specified above.

2.96 Granule/collection level metadata

Not applicable.

END OF DOCUMENT