GOES-R3 Periodic Reporting

Reporting Period: July 2018 – December 2018 (1st half of FY18 funding cycle)

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Project Title: Upgrading the GOES ET and Drought (GET-D) Product System for GOES-16 and 17
Project Number: 488

Executive Summary

Evapotranspiration (ET) is one of the main components of the global and regional hydrological or water cycle. The latent heat from evapotranspiration is also one of the most important components of the energy cycle because it is the largest energy source for the atmosphere and thus is significant for weather and climate formation. Remote sensing data products of ET have been generated from both polar and geostationary satellite sensors. NOAA has launched a new generation of geostationary satellites, namely GOES-16 and 17. Based on the Atmosphere-Land Exchange Inversion (ALEXI) model, NOAA-NESDIS has developed an operational GOES ET and Drought (GET-D) product system using thermal observations of the Baseline Images on GOES-13 and GOES-15 and is updating the GET-D product system with observations from the Advanced Baseline Imagers (ABI) on GOES-16 and 17. This project will upgrade GET-D system using GOES 16 and 17 ABI observations to 2 km spatial resolution covering CONUS domain. Major updates will involve in modules processing GOES inputs, as well as ancillary data at higher spatial resolution (2 km). The science basis, changes in software architecture of the current GET-D product system and validation of the new ET data product will be carried and documented.

The GET-D software system is based on the science of the Atmosphere-Land Exchange Inversion model (ALEXI) that computes principle surface energy fluxes, including ET, based on satellite observations of solar insolation, vegetation fraction and land surface temperature. A simple evaporative stress index (ESI), which represents the anomaly in the ratio of ALEXI-based daily ET over the daily potential ET (pET) has been proven to be a reliable drought index. Anderson et al. (2007; 2011) has demonstrated that ALEXI ESI over the continental US (CONUS) shows good correspondence with standard drought metrics and antecedent precipitation, but can be generated at significantly higher spatial resolution. The weekly ESI maps has been routinely used by the National Integrated Drought Information System (NIDIS) (see https://www.drought.gov/drought/data-gallery/evaporative-stress-index-esi-contiguous-us).

In the first half of FY18 funding cycle, we started the project from around July 2018 and have ingested GOES 16 observations into current GET-D system configuration and successfully generated ET maps at 8 km resolution over the North America domain. GET-D is then upgraded to 4 km spatial resolution using GOES-16 observations with the available 4 km scale ancillary data for the ALEXI model, which serves as an experimental ET product from GOES-16. The 4 km ET product was successfully generated and validated using visual comparison and preliminary evaluation against remotely sensed vegetation data product. Lastly, we have started to upgrade GET-D system to 2 km spatial resolution using the GOES-16 2 km thermal infrared observations. This effort includes the detailed software system design with upgraded high resolution of GOES-16 observations and preparation of the major ancillary data sets for the ALEXI model as the core of the GET-D system. Details of this project, major milestones and timelines, and current status and accomplishments are provided in this semi-annual report.

Overall Status: Green

	Green [1] (Controlled)	Yellow [2] (Caution)	Red [3] (Critical)	Deviation Summary[4]
Budget	☒	☐	☐	None
Schedule	☒	☐	☐	None
Scope	☒	☐	☐	None

[1] *Project is within budget, scope and on schedule.*
[2] *Project has deviated slightly from the plan but should recover*
[3] *Project has fallen significantly behind schedule, is forecast to be significantly over budget, and/or has taken on tasks that are out of scope.*
4Details of deviations provided in subsequent section of report

Progress toward FY18 Milestones

Proposed Work and Milestones

To continuously meet the users' data needs within and outside NOAA, the GET-D algorithms and software have to be upgraded with the following major tasks, major schedule (modified from the original proposal because of the later start of the project) and major milestones:

1. July - Dec 2018: Test, validate and streamline the retrievals of solar insolation, vegetation fraction and land surface temperature from the new Advanced Baseline Imager (ABI) as input for the ALEXI model.
   Milestone 1: Dec 2018, GET-D ET products based on ABI observations are generated, preliminarily validation.
2. Jan – June 2019: Evaluate the daily estimates of ET from GET-D using the ABI observations against in situ ET measurements and the climatology of ET of previous years.
   Milestone 2: June 2019, GET-D ET products from GOES-16 ABI data reaches validated maturity
3. Apr – Sept 2019: Generate and evaluate the new GET-D ESI from ABI data against the major drought indicators.
   Milestone 3: Sept 2019, GET-D ESI product reaches validated maturity and science paper(s) prepared
4. Oct – Dec 2019: Standardize and deliver GET-D products to users for their evaluation and feedbacks
   Milestone 4: Dec 2019, GET-D products and software system passes algorithm readiness review for STAR operation
5. Jan – Mar 2020, Make the upgraded GET-D product system operational at STAR and document the upgraded GET-D based on ABI observations for user and system maintenance review
   Milestone 5: Jun 2020, STAR GET-D system and website become operational for GOES-16/17 and documents and journal papers reviewed and submitted
6. Jan – Jun 2020, submit and execute SPSRB FY19 project plan for upgrading GET-D system at OSPO collaborating with OSPO GET-D IPT members
   Milestone 6: Jun 2020, Plan for upgrading GET-D system at OSPO for ABI observations of both GOES-16/17 reviewed and submitted to SPSRB for OSPO operations

Specific or detailed tasks for upgrading the GOES-13/15-based GET-D system to high spatial resolution using both GOES-16 and GOES 17 ABI observations include:

1. Archive GOES-16 and 17 Bands 2, 7, and 13 observations and pre-process the data for the use in the ALEXI model;
2. Pre-process meteorological data, vegetation cover data and surface snow cover data sets for the use in the ALEXI model at 2km scale;
3. Pre-process ancillary data for the use in the ALEXI model at 2km scale;
4. Conduct the ALEXI model at 2km resolution with the pre-processed GOES observations and all ancillary data sets;
5. Unit test and system test of the upgraded GET-D software;
6. Validation of ET and drought maps against independent data sets, including in situ measurements and standard drought indices;
7. Document and publish findings of the above investigations.

Sub-tasks regarding GOES-16 and GOES-17 data and ancillary data sets processing are described below.

1. ** GOES ABI process
   - Reads in the NetCDF GOES data and writes the data into GOES hourly band data in binary format for GET-D processing;
   - Generate the clear sky surface radiance and cloud mask for GOES EAST and WEST hourly band data;
   - Using MET data and TRAD to do the atmospheric correction to get surface temperature;
   - Combine the GOES EAST and WEST data into the GET-D domain.
2. Meteorological data process
   - Automatically download Climate Forecast System (CFS) forcing files in GRIB2 format;
   - Extract the meteorological variables required in GET-D;
   - Extract and Convert CFS 3 hourly GRIB2 variables into 24 hour data in common grid in binary format;
   - Extract forcing from the common grid to the GET-D domain at local time for each pixel.
3. ** GSIP data process
   - Extract the GSIP insolation data from GSIP EAST and WEST into GET-D domain for 24 hours in UTP time;
   - Merge the GSIP insolation data into GET-D domain with local 24 hours.
   - Note: As GSIP is no longer producing the GOES-East product since GOES-13 was turned off on January 8 at around 1530Z, and GOES-16 data will not be incorporated into this dataset at this time, alternatives will be explored and tested.
4. Vegetation index data process
   - Mosaic EVI granule inputs to global EVI map in binary format;
   - Resample global EVI to the GET-D domain at 2km resolution;
   - Convert the EVI to LAI.
5. Snow data process
   - Automatically download IMS snow;
   - Remap IMS Snow polar stereographic grid to GET-D's pixel-level latitude-longitude grid;

- Extract global snow map to the GET-D domain.

6. Ancillary data process

Static ancillary data listed in the table below should be processed to the new GET-D system.

File name	Description	Modules used
CFS_landcover_2012.dat	Land cover of CFS data	CFS processing
landmask_UMD.1gd4r	UMD land mask data	CFS processing
region_lc.dat	Land cover mask for the NA domain	CFS processing
landmask_goes_east_v2.dat	Land mask of GOES EAST data	GOES processing
landmask_goes_west_v2.dat	Land mask of GOES WEST data	GOES processing
landmask_UMD.1gd4r	UMD land mask data	GOES processing
view_angle.dat	GOES view angle	GOES processing
**CHAN_DIFF_NEG_DIFF_SMOOTH MAX_TB11_SMOOTH VIS_ALBEDO_SMTH	Climatology data used for GOES EAST cloud masking	GOES processing
**CHAN_DIFF_POS_DIFF_SMOOTH SUNRISE	Climatology data used for GOES WEST cloud masking	GOES processing
na8km_dummy.dat	Dummy file used to replace the missing hourly insolation data.	GSIP processing
**VIIRS_global_GVF_climatology.h5	Climatology data used for VIIRS GVF	VIIRS VI processing
EVI_b0.dat	Parameter used for linear regression	VIIRS VI processing
EVI_b1.dat	Parameter used for linear regression	VIIRS VI processing
imslon_24km.dat	LON index file used to remap the snow mask	snow mask processing
imslat_24km.dat	LAT index file used to remap the snow mask	snow mask processing
** region_adeadl.dat region_adeadn.dat region_adeadv.dat region_aleafl.dat region_aleafn.dat region_aleafv.dat region_xl.dat	Surface parameters in NA domain.	ET/ESI data processing
FINAL_RS_CORR_NAMR_WARM_T5T21.dat	Soil reflectance	ET/ESI processing
**alexi_insol15_smth_2017[ddd].dat alexi_insol55_smth_2017[ddd].dat	Climatology insolation data ddd – day of the year, range from 001 to 365	ET/ESI processing
** Tasks need extra time and effort to make it work for the upgraded 2km GET-D system		

Progresses toward the FY18 Major Milestones:

1. Milestone 1: Dec 2018, GET-D ET products based on ABI observations are generated, preliminarily validation. → Completed.
2. Milestone 2: June 2019, GET-D ET products from GOES-16 ABI data reaches validated maturity. → On schedule

Accomplishments during current reporting period

1. Integration of GOES-16 into current GET-D system

GOES-16 observations have been successfully integrated and tested in current GET-D system. Figure 1 shows the λET (W/m2) retrieval over North America domain at 8km using GOES-16 observations.

2. ET transition product at 4km resolution

GET-D system has been upgraded to a transition system which generates ET product at 4km resolution over CONUS domain. Figure 2 shows the λET (W/m2) composite (July 10 to 24, 2017) comparison over CONUS domain between operational 8km product and 4km transition product using GOES-16. Two examples of regional comparison are shown in Figure 3 over Middle Mississippi River Basin and in Figure 4 for Oklahoma Region. The comparison clearly illustrated that ET maps at higher resolution provides more spatial details.

The transition product is further compared with VIIRS EVI products. The spatial correlation between λET from GET-D at 4km and VIIRS EVI over the period from July 10 to 24, 2017 is shown in Figure 5. The correlation coefficient between those two products averaged over CONUS is 0.790 (Figure 6, left). The mean correlation coefficient over Oklahoma region can be as high as 0.895 (Figure 6, right). The transition system with the integration of GOES 16 observations is proved successful.

3. Upgrade GET-D to 2km resolution over CONUS

1) Domain set up for updated GET-D system

- Domain Projection : EquidistantCylindrical
- Domain East Longtitude : -66.75
- Domain West Longtitude : -124.99
- Domain Long resolution : 0.02
- Domain North Latitude : 49.83
- Domain South Latitude : 24.83
- Domain Lat resolution : 0.02
- Domain output col num : 2912
- Domain output row num : 1250

2) Generate local Land mask and land cover at 2km over CONUS

Maps of land mask and land cover server as a basic static ancillary data for GET-D system. A local land mask and land cover map are created for the upgraded GET-D system. Figure 7 shows the land cover map.

3) CFS forcing process

Listed in the table below are the meteorological variables extracted from CFS forcing and pre-processed for use in GET-D. The original CFS 3 hourly GRIB2 variables are extracted and processed into GET-D domain at 2km resolution at local time. Figure 8 shows the maps of surface air temperature and wind speed as examples.

File name	Description	Notes
pot_profile.bin	Morning potential temperature at each height level	Used for atmospheric correction for GOES radiance data
temp_profile.bin	Morning temperature at each height level	Used to compute the potential temperature in the morning for ALEXI model
pressure_profile.bin	Morning temperature at each height level	Used to compute the potential temperature in the morning for ALEXI model
spfh_profile.bin	Specific humidity at each height level	Used to compute the potential temperature in the morning for ALEXI model
height_profile.bin	Height levels from the surface	Used to compute the potential temperature in the morning for ALEXI model
psfc_series.bin	Surface pressure at 24 hours UTC	Used to extract the two morning pressures for ALEXI model inputs
q2_series.bin	Surface specific humidity at 24 hours UTC	Used to extract the two morning air humidity for ALEXI model inputs
t2_series.bin	Surface air temperature at 24 hours UTC	Used to extract the two morning air temperature for ALEXI model inputs
wind_surface.bin	Surface wind speed at 24 hours UTC	Used to extract the two morning wind speed for ALEXI model inputs
lwdn.bin	Surface long wave down radiation at 24 hours UTC	Used to extract the two morning long wave down radiation for ALEXI model inputs

4) SNOW process

IMS snow product is pre-processed and remapped from polar stereographic grid to GET-D's pixel-level latitude-longitude grid over CONUS. Figure 9 shows the processed snow mask ready to be integrated in ALEXI model.

5) Ancillary data of surface parameters

Surface parameters are land cover dependent. The look up table is shown in the table below. The static ancillary data of surface parameters are created at the upgraded GET-D domain. Figure 10 shows examples of processed "adeadn", "adeadv", "aleafv" and "adeadl" maps.

Total landcover number: 14

Class	aleafv	aleafn	aleafl	adeadv	adeadn	adeadl	rs	hmin(m)	hmax(m)	xl(m)	MODIS	Peren	fcmin	Desc
1	-99.99	-99.99	-99.99	-99.99	-99.99	-99.99	-9999	-99.99	-99.99	-99.99	-9999	-9999	-9999	Water
2	0.89	0.60	0.95	0.84	0.61	0.95	100	5.0	15.0	0.05	0	0	-9999	Evergreen_Needleleaf_Forest
3	0.87	0.40	0.95	0.84	0.61	0.95	150	5.0	15.0	0.10	0	0	-9999	Evergreen_Broadleaf_Forest
4	0.89	0.60	0.95	0.84	0.61	0.95	100	5.0	10.0	0.05	0	0	-9999	Deciduous_Needleleaf_Forest
5	0.86	0.37	0.95	0.84	0.61	0.95	150	5.0	10.0	0.10	0	0	-9999	Deciduous_Broadleaf_Forest
6	0.88	0.51	0.95	0.84	0.61	0.95	125	1.0	2.5	0.05	0	0	-9999	Mixed_Cover
7	0.87	0.49	0.95	0.78	0.53	0.95	150	1.0	2.5	0.05	0	0	-9999	Woodland
8	0.85	0.36	0.95	0.58	0.26	0.95	70	1.0	2.5	0.05	0	0	-9999	Wooded_Grassland
9	0.85	0.37	0.95	0.72	0.44	0.95	40.00	1.0	1.0	0.02	0	0	-9999	Closed_Shrubland
10	0.83	0.35	0.95	0.77	0.52	0.95	40	1.0	1.0	0.02	0	0	-9999	Open_Shrubland
11	0.82	0.28	0.95	0.42	0.04	0.95	40	1.0	1.0	0.02	0	0	-9999	Grassland
12	0.83	0.35	0.95	0.49	0.13	0.95	40	0.1	0.6	0.05	0	0	-9999	Cropland
13	0.82	0.57	0.95	0.92	0.80	0.95	40	0.2	0.2	0.02	0	0	-9999	Bare_Ground
14	0.84	0.37	0.95	0.58	0.26	0.95	100	6.0	6.0	0.02	0	0	-9999	Urban_and_Built-Up

Plans for Next Reporting Period

2. Jan – June 2019: Evaluate the daily estimates of ET from GET-D using the ABI observations against in situ ET measurements and the climatology of ET of previous years.

   Milestone 2: June 2019, GET-D ET products from GOES-16 ABI data reaches validated maturity. → On schedule

Additional Information

1. Interaction with operational partners:

Users from NWS-NCEP EMC (ET user) and NWS-NCEP CPC (ESI user) and National Integrated Drought Information System (NIDIS) are informed for the upgrade of GET-D system

2. Conference/workshop participation:

An Evapotranspiration Data Product from NOAA GOES-16 and 17, Satya Kalluri, L. Fang, M. A. Schull, X. Zhan, C. Hain, and M. C. Anderson, American Meteorological Society 99th Annual Meeting, Phoenix, Jan. 2019 (Presented by Mitch Schull)

3. Outside project publicity:

OSPO project lead of GET-D, Hanjun Ding, is informed of the GET-D upgrade by this project.

4. Journal articles:

One manuscript is in preparation for a special issue of *Remote Sensing* journal.

Key Graphics

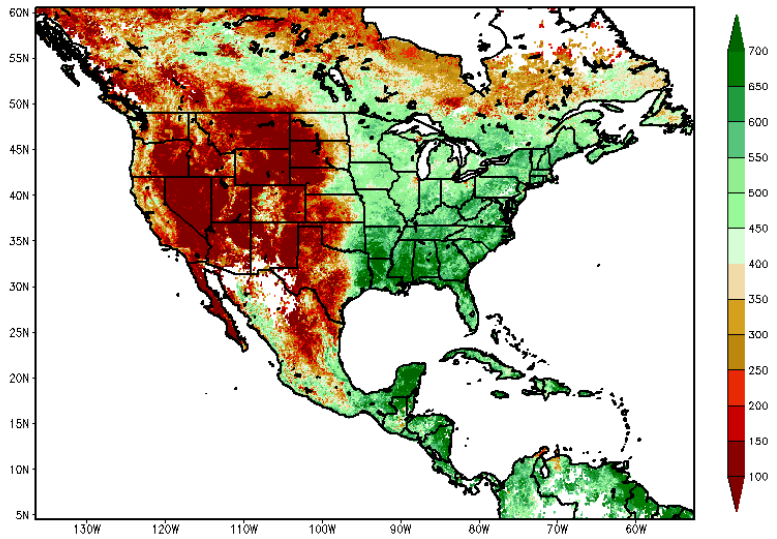

Figure 1. λET over North America at 8km using GOES 16 observations

λET over CONUS at 8km

λET over CONUS at 4km

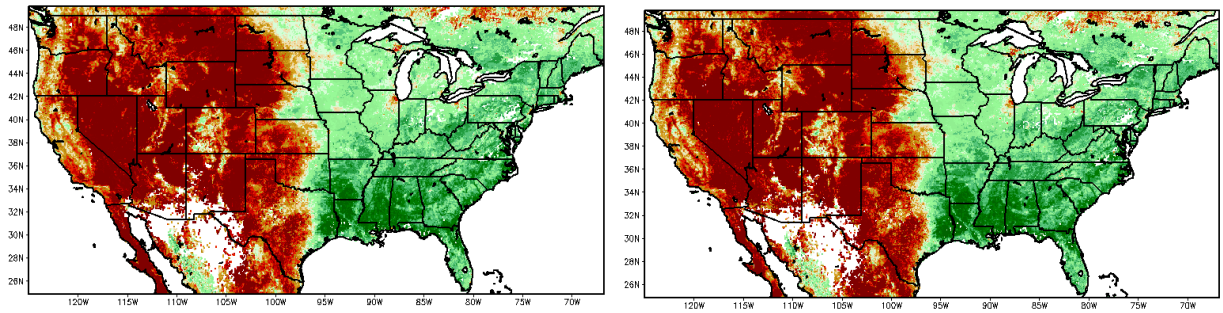

Figure 2 λET (W/m2) retrieval comparison between operational 8km product and upgraded 4km product; Composites of July 10 – 24, 2017

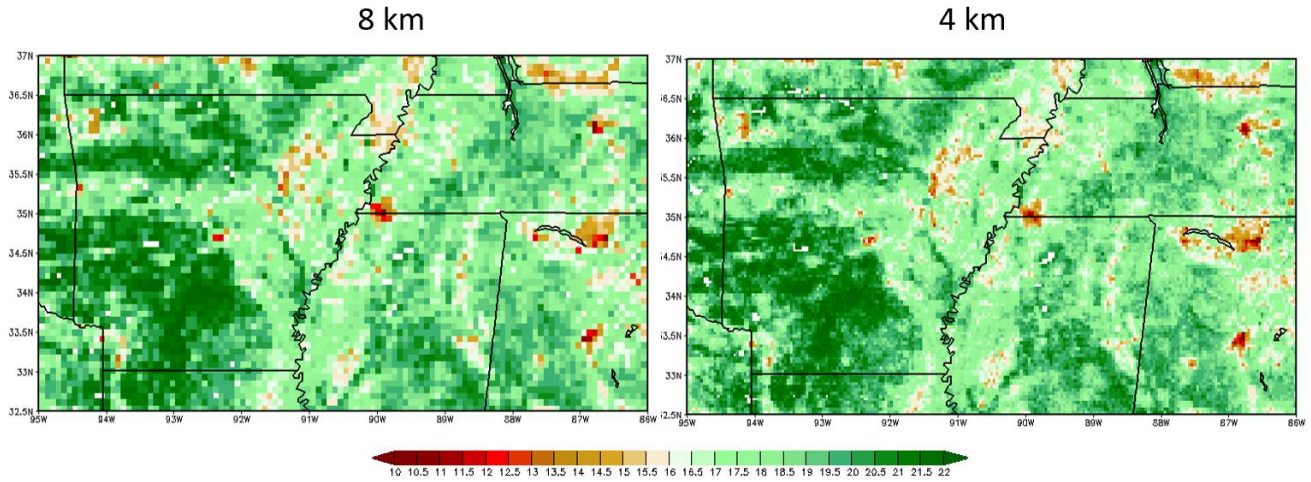

Figure 3 Comparison of ET (mm/day) from GET-D using GOES 16 Observation between 8km and 4km over Middle Mississippi River Basin (2 weeks: July 10-24, 2018)

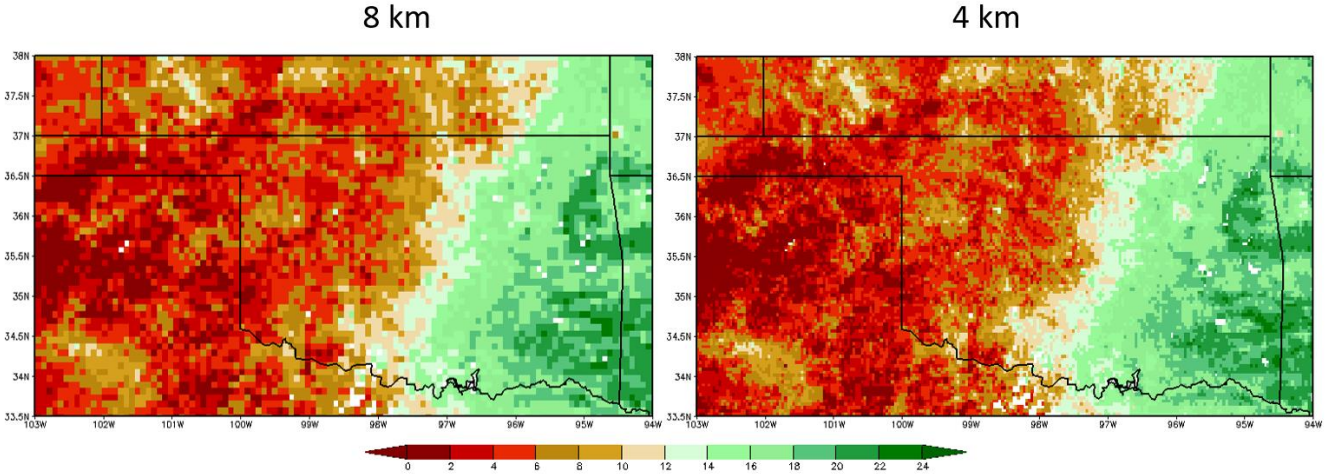

Figure 4 Comparison of ET (mm/day) from GET-D using GOES 16 Observation between 8km and 4km over Oklahoma region (2 weeks: July 10-26, 2018)

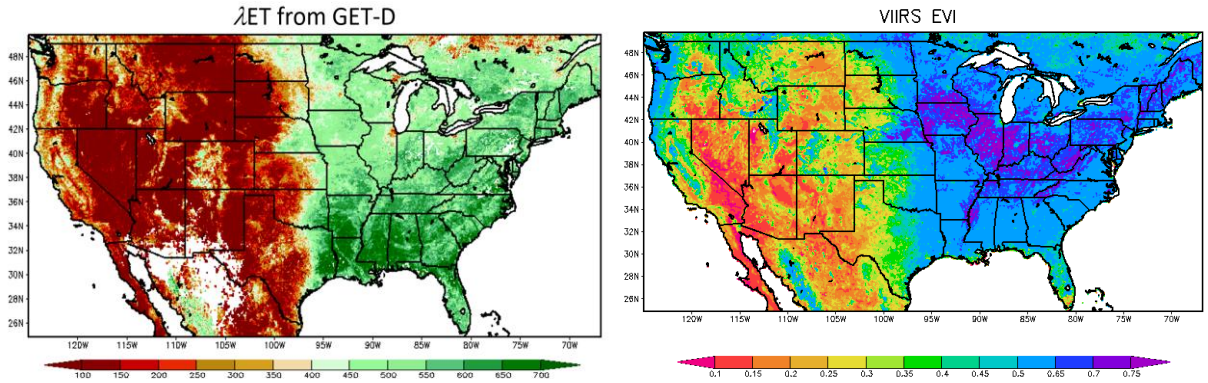

Figure 5. Comparison between λET (W/m2) from GET-D transition product and VIIRS EVI product (July 10-24, 2017)

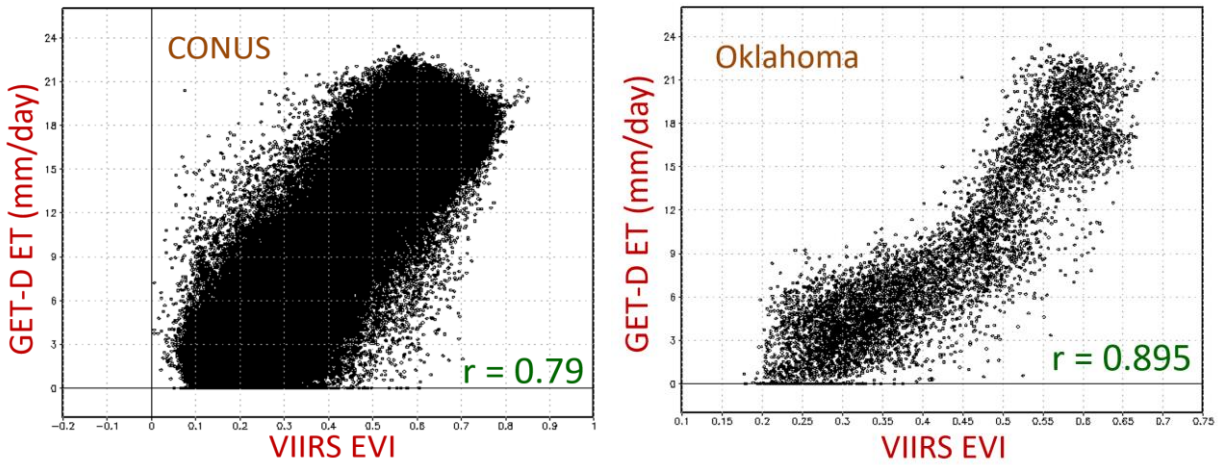

Figure 6 Correlation coefficients between λET (W/m2) from GET-D transition product and VIIRS EVI product averaged over CONUS domain (left) and Oklahoma region (right) (July 10-24, 2017)

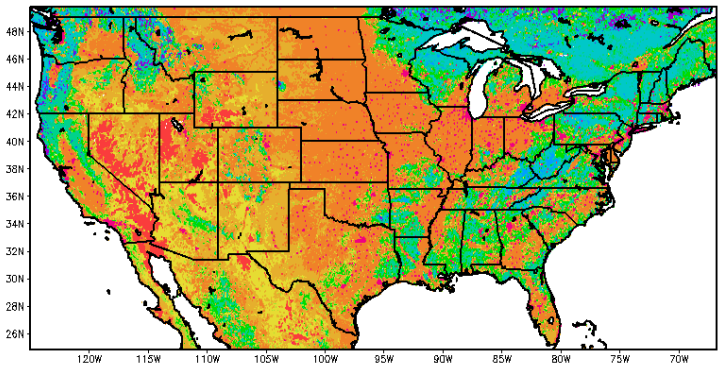

Figure7 land cover at GET-D 2km domain

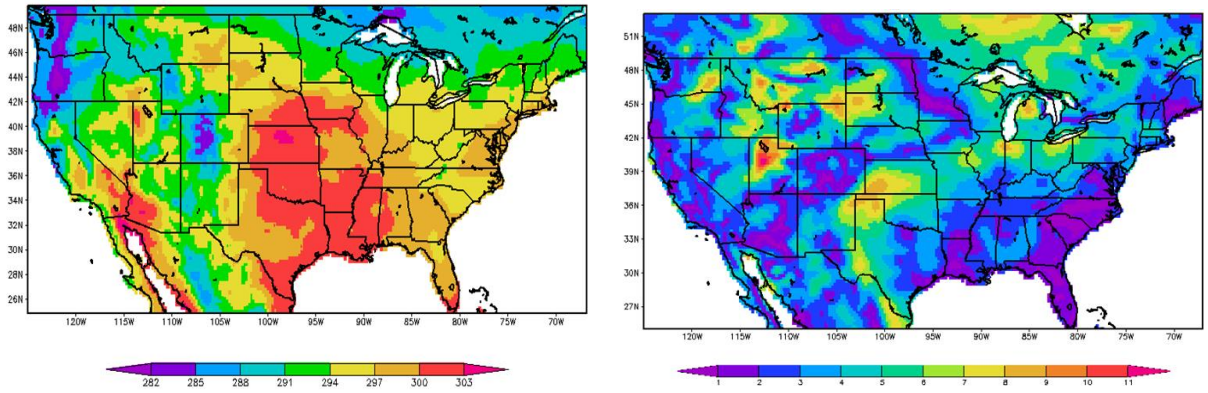

Figure 8 Example of processed CFS forcing variables at upgraded GET-D domain for surface air temperature (left) and wind speed (right)

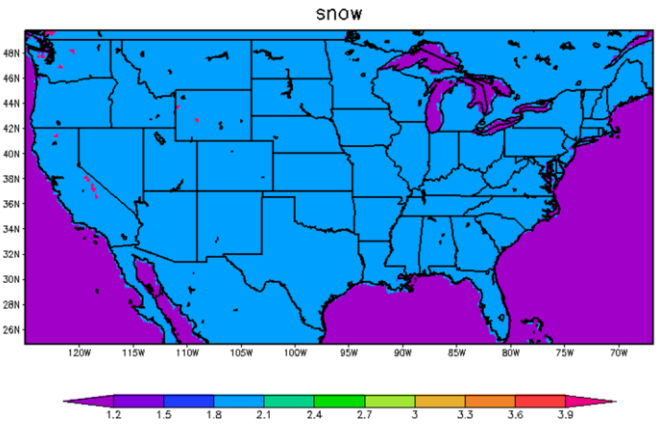

Figure 9 Processed IMS snow mask at GET-D domain

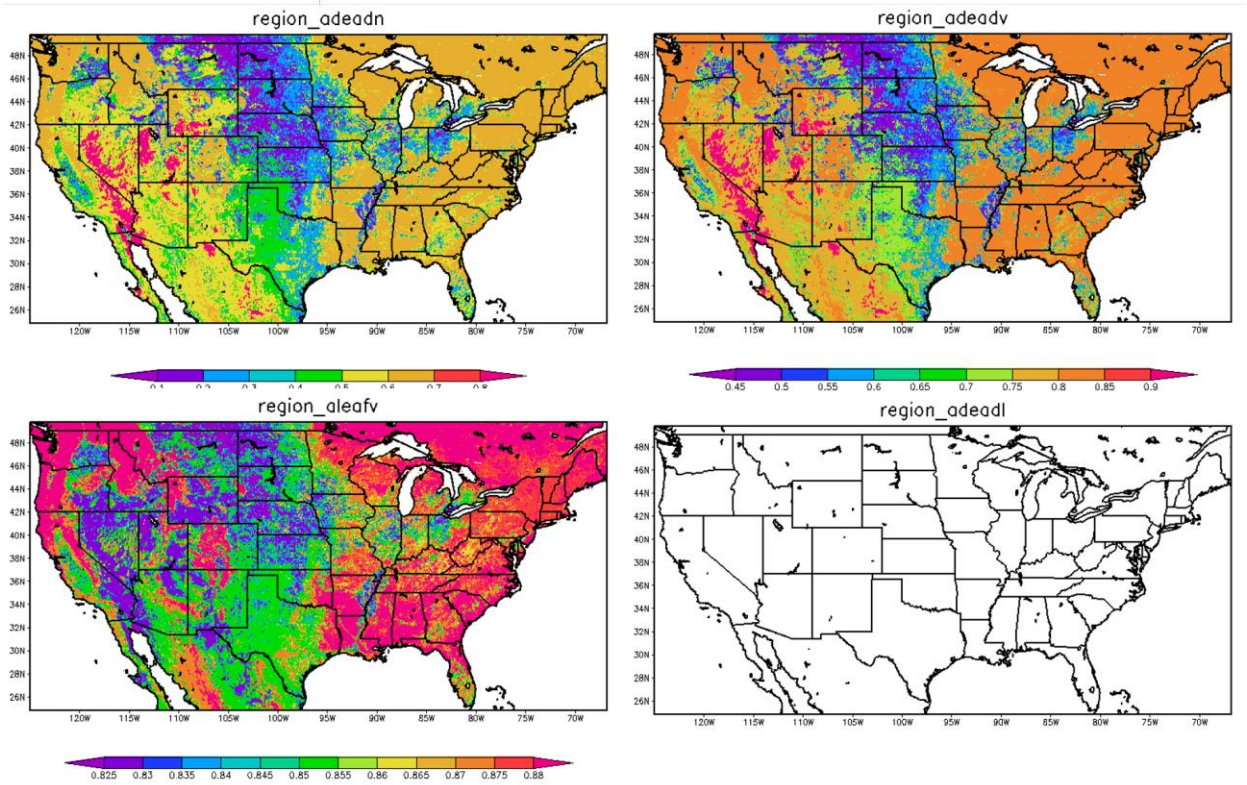

Figure 10 Processed surface parameters of “adeadn”, “adeadv”, “aleafv” and “adeadl” at GET-D domain