



**MEaSURES Unified and Coherent Land Surface Temperature and Emissivity  
(LST&E) Earth System Data Record (ESDR):**

**The Combined ASTER and MODIS Emissivity database over Land  
(CAMEL) Users' Guide**

**Technical documentation**

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## **Abstract**

Land Surface Temperature and Emissivity (LST&E) data are essential for a wide variety of studies, from calculating the evapotranspiration of plant canopies to retrieving atmospheric water vapor. LST&E products are generated from data acquired by sensors in Low Earth Orbit (LEO) and by sensors in Geostationary Earth Orbit (GEO). Although these products represent the same measurement, they are produced at different spatial, spectral and temporal resolutions using different algorithms. The different approaches used to retrieve the temperatures and emissivities result in discrepancies and inconsistencies between the different products. Over the past decade NASA has identified the need to develop long-term, consistent, and well calibrated data and products that are valid across multiple missions and satellite sensors. These datasets are referred to as Earth System Data Records (ESDRs) and are optimized to meet specific requirements in addressing science questions. NASA has identified LST&E data as an important ESDR and efforts are currently underway to produce long time series of these data in a NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) project. This document will introduce a new land surface emissivity ESDR for the NASA MEaSUREs project – the Combined ASTER and MODIS Emissivity for Land (CAMEL). CAMEL is developed by combining the MODIS baseline-fit emissivity database (MODBF) produced at the University of Wisconsin-Madison and the ASTER Global Emissivity Dataset (ASTER GEDv4) produced at JPL. The CAMEL ESDR will be produced globally at 5km resolution in mean monthly time-steps and for 13 bands from 3.6-14.3 micron and extended to 417 bands using a Principal Component (PC) regression approach. CAMEL will benefit numerous applications including improved atmospheric retrievals, and radiative transfer simulations.

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## Software version identification

The current version of the software is 1.0

## 2.Introduction

Land Surface Temperature and Emissivity (LST&E) data are critical variables for studying a variety of Earth surface processes and surface-atmosphere interactions such as evapotranspiration, surface energy balance and water vapor retrievals. LST&E have been identified as an important Earth System Data Record (ESDR) by NASA and many other international organizations (NASA Strategic Roadmap Committee #9, 2005, Global Climate Observing System (GCOS), 2003; Climate Change Science Program (CCSP), 2006, and the recently established International Surface Temperature Initiative (Willett et al. 2011).

Accurate knowledge of the LST&E at high spatial (1km) and temporal (hourly) scales is a key requirement for many energy balance models to estimate important surface biophysical variables such as evapotranspiration and plant-available soil moisture (Anderson et al. 2007b; Moran 2003). Currently no single satellite exists that is capable of providing global LST&E products at both high spatial and temporal resolution. LST&E data are also essential for balancing the Earth's surface radiation budget, for example an error of 0.1 in the emissivity will result in climate models having errors of up to  $7 \text{ Wm}^{-2}$  in their upward longwave radiation estimates –a much larger term than the surface radiative forcing ( $\sim 2\text{-}3 \text{ Wm}^{-2}$ ) due to an increase in greenhouse gases (Zhou et al. 2003). LST&E are also utilized in monitoring land-cover / land-use changes (French et al. 2008), and in atmospheric retrieval schemes (Seemann et al. 2003).

LST&E products are currently generated from sensors in Low Earth Orbit (LEO) such as the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on the Terra and Aqua satellites as well as from sensors in Geostationary Earth Orbit (GEO) such as the Geostationary Operational Environmental Satellites (GOES). Sensors in LEO orbits provide global coverage at moderate spatial resolutions ( $\sim 1\text{km}$ ) but more limited temporal coverage (twice-daily), while sensors in GEO orbits provide more frequent measurements (hourly) at lower spatial resolutions ( $\sim 3\text{-}4 \text{ km}$ ) over a geographically restricted area. For example the GOES sensors produce data over North America every 15 minutes and South America every 3 hours.

LST&E products are generated with varying accuracies depending on the input data, including ancillary data such as atmospheric water vapor, as well as algorithmic approaches. For example, certain LST&E MODIS products (MOD11) use a split window algorithm applied to two or more bands in conjunction with an emissivity estimate obtained from a land classification to produce the LST. Conversely, other LST&E MODIS products (MOD21) use a physics based approach involving a radiative transfer model to first correct the data to a surface radiance and then use a model to extract the temperature and emissivities in the spectral bands. This physics based approach is also used with the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Validation of these approaches has shown that they are complementary, with the split-window approach working better over heavily vegetated regions and the physics based approach working better in semi-arid and arid regions.

NASA has recognized this general problem and identified the need to develop long-term, consistent, and calibrated data and products that are valid across multiple missions and satellite sensors. In this project we address this problem for LST&E by generating a set of Earth System Data

Records (ESDRs) that capitalizes on the type of observation (LEO or GEO) and retrieval type (physical-based or split-window). Three ESDRs will be produced; 1) a unified global 1 km resolution land surface temperature (LST) ESDR resampled to daily, 8-day and monthly; 2) a unified N. and S. America 5 km resolution LST-ESDR resampled to hourly spatial resolution for N. America and 3-hourly for S. America and; 3) a unified global 5 km resolution average land surface emissivity (LSE) at monthly temporal resolution (Table 1)). In this document, the LSE ESDR will be described in detail including methodologies, uncertainties and all the technical aspects.

**Table 1. Planned LST&E Earth System Data Records (ESDRs)**

ESDR	Spatial Resolution	Coverage	Temporal Resolution	Time Period
LEO LST-ESDR	1 km	Global	Daily, 8-day and monthly	2000-2017
GEO LST-ESDR	5 km	N. and S. America	N. America-hourly, S. America-3 hourly	2000-2017
<b>LEO LSE Emissivity (CAM5K30EM)</b>	<b>5 km</b>	<b>Global</b>	<b>Monthly</b>	<b>2000-2017</b>
<b>LEO LSE Uncertainty (CAM5K30UC)</b>	<b>5 km</b>	<b>Global</b>	<b>Monthly</b>	<b>2000-2017</b>
<b>LEO LSE Coefficient (CAM5K30CF)</b>	<b>5 km</b>	<b>Global</b>	<b>Monthly</b>	<b>2000-2017</b>

Under the MEaSURES project, a monthly mean unified LEO LSE-ESDR at 5km has been produced by merging two current state-of-the-art emissivity databases, the UW-Madison MODIS Baseline Fit emissivity database (UWBF) (Seemann et al. 2008), and the JPL ASTER Global Emissivity Dataset (GEDv4) (Hulley and Hook 2009) and termed the Combined ASTER and MODIS Emissivity over Land (CAMEL). The CAMEL LSE-ESDR has been further extended to hyperspectral resolution using a Principal Component (PC) regression approach. For the emissivity ESDR products a full set of uncertainty statistics has also been provided.

### **3.Emissivity Hinge-points Methodology**

CAMEL has been produced by combining the University of Wisconsin-Madison MODIS Baseline Fit database (UWBF) and the JPL ASTER Global Emissivity Databset (GEDv4). A limitation of the UWBF database is that emissivity in the thermal infrared region (TIR) region (8-12  $\mu\text{m}$ ) is not well defined because MODIS only has 3 bands in this region (bands 29, 31, 32). This results in imperfect TIR spectral shape in the two quartz doublet regions at 8.5 and 12  $\mu\text{m}$ . The advantages are its moderate spatial resolution (5km), uniform temporal coverage (monthly), and emissivities, which span the entire IR region (3.6-12  $\mu\text{m}$ ). A disadvantage of the ASTER-GED database is that although there are more

bands to more accurately define the spectral shape in the TIR region (5 bands, 8-12  $\mu\text{m}$ ), there are no bands in the mid-wave infrared (MIR) region around 3.8-4.1  $\mu\text{m}$ , which limits its use in models and other atmospheric retrieval schemes. The advantages are its high spatial resolution ( $\sim 100\text{m}$ ) and high accuracy over arid regions. The two databases have been integrated together to capitalize on the unique strengths of each product's characteristics. This involved four steps: 1) ASTER GED v3 emissivities have been adjusted for vegetation and snow cover variations over heterogeneous regions to product ASTER GED v4, 2) ASTER-GED v4 emissivities have been aggregated from 100m resolution to the UWBF 5km resolution, 3) the spectral emissivities have been merged together to generate the CAMEL product at 13 points from 3.6-12  $\mu\text{m}$ , and 4) the 13 hinge-points have been further extended to hyperspectral resolution using a PC-regression approach. We will discuss step 3 and 4 in more details.

The third step involves merging the spectral emissivities from the 5 ASTER bands with the 10 hinge-point bands from the UWBF database. The determination of the CAMEL emissivity by hinge-points are summarized in Table 2 and described below.

#### CAMEL hinge points from 3.6 till 7.6 $\mu\text{m}$

In the ASTER band gap of the short and mid-wave IR region, the CAMEL emissivity from 3.6 till 7.6  $\mu\text{m}$  have been determined by the UWBF values only, also keeping the location of the hinge points.

#### CAMEL hinge points 10.6 and 11.3 $\mu\text{m}$

The 10.6 and 11.3  $\mu\text{m}$  hinge points have been added based on the additional observations from ASTER band 10.6 and 11.3  $\mu\text{m}$ . CAMEL values at these hinge points were determined from the ASTER GED observations only.

#### CAMEL hinge point 8.6 $\mu\text{m}$

Since the spectral response of MODIS band 29 (8.55  $\mu\text{m}$ ) – also UWBF 8.3 and 9.1  $\mu\text{m}$  (see below) - matches closely with ASTER band 11 (8.6  $\mu\text{m}$ ), we used a weighting rule based on uncertainties using a 'combination of states of information' approach (e.g. Tarantola (2005)). In this approach two pieces of information (e.g. two spectral emissivities  $\varepsilon(1, \nu)$  and  $\varepsilon(2, \nu)$ ) can be merged in a probabilistic manner by weighting each input based on its relative uncertainty, i.e.  $\varepsilon(\nu) = [1/(w_1 + w_2)] [w_1 \cdot \varepsilon(1, \nu) + w_2 \cdot \varepsilon(2, \nu)]$ , where  $w$  is a weighting factor based on an uncertainty,  $\sigma$ , as follows:  $w = 1/\sigma$ . To apply this method we used 90% and 10% weights as the corresponding uncertainties for ASTER GED and UWBF on a pixel-by-pixel basis. ASTER band 11 (8.6  $\mu\text{m}$ ) gets the 90% weight for arid and semi-arid regions, while for all the other cases the UWBF hinge-point 6 (8.3  $\mu\text{m}$ ) is weighted by the 90%. To determine the arid, semi-arid region, the ASTER NDVI ( $<0.2$ ) and ASTER 9.1  $\mu\text{m}$  band ( $\leq 0.85$ ) is used. Additionally, over the tropical rainforest region, the MODIS MOD11 emissivity suffers from cloud contamination resulting in the emissivity value at the Restrahen band to be low. To avoid this artifact over that region ( $\pm 20$  degree latitude band where ASTER NDVI is larger than 0.7 and UWBF emissivity at 8.6  $\mu\text{m}$  is less than 0.96) the ASTER 11 (8.6  $\mu\text{m}$ ) is weighted by 90%.

#### CAMEL hinge point 8.3 and 9.3 $\mu\text{m}$

The baseline-fit procedure used in generating UWBF product extends emissivity from MODIS band 29 (8.6  $\mu\text{m}$ ) to inflection points at 8.3  $\mu\text{m}$  and 9.3  $\mu\text{m}$ . The location of these inflection points were maintained, but the UWBF emissivities are improved by replacing the interpolated inflection points with retrieved ASTER emissivities from corresponding bands 10 (8.3  $\mu\text{m}$ ) and 12 (9.1  $\mu\text{m}$ ) and

adjusting them by the emissivity difference between the new CAMEL 8.6  $\mu\text{m}$  and ASTER 8.6  $\mu\text{m}$  band. This significantly improved spectral shape in the Si-O stretching region (8-12  $\mu\text{m}$ ) (Figure 1).

CAMEL hinge point 10.8  $\mu\text{m}$

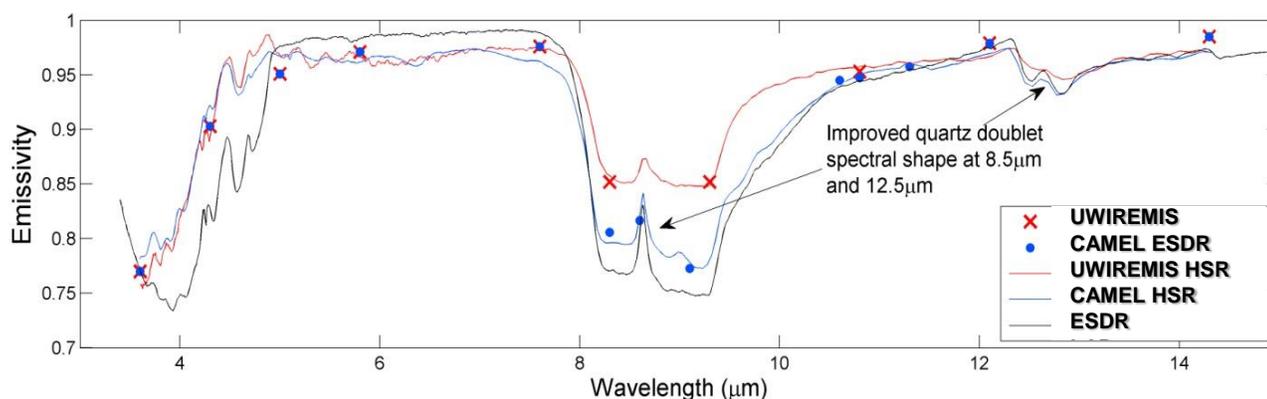
The CAMEL emissivity at the 10.8  $\mu\text{m}$  hinge point has been determined as the linear combination of the ASTER band 10.6  $\mu\text{m}$  and 11.3  $\mu\text{m}$  emissivity.

CAMEL hinge points 12.1 and 14.3  $\mu\text{m}$

The UWBF at 12.1 and 14.3  $\mu\text{m}$  has been adjusted by the difference between the UWBF 12.1  $\mu\text{m}$  and ASTER 11.3  $\mu\text{m}$  emissivity to be consistent with the 10.6-11.3  $\mu\text{m}$  region (mostly ASTER based observation) and to improve the spectral shape in this longwave spectral region.

**Table 2:** Determination of the CAMEL hinge points

CAMEL Hinge Points	Method
3.6 $\mu\text{m}$	= UWBF <sub>3.6</sub>
4.3 $\mu\text{m}$	= UWBF <sub>4.3</sub>
5.0 $\mu\text{m}$	= UWBF <sub>5.0</sub>
5.8 $\mu\text{m}$	= UWBF <sub>5.8</sub>
7.6 $\mu\text{m}$	= UWBF <sub>7.6</sub>
8.3 $\mu\text{m}$	= Adjusted ASTER <sub>8.3</sub> by CAMEL <sub>8.6</sub> - ASTER <sub>8.6</sub>
8.6 $\mu\text{m}$	= Weighted combination of UWBF <sub>8.3</sub> and ASTER <sub>8.6</sub>
9.1 $\mu\text{m}$	= Adjusted ASTER <sub>9.1</sub> by CAMEL <sub>8.6</sub> - ASTER <sub>8.6</sub>
10.6 $\mu\text{m}$	= ASTER <sub>10.6</sub>
10.8 $\mu\text{m}$	= linear interpolation between ASTER <sub>10.6</sub> and ASTER <sub>11.3</sub>
11.3 $\mu\text{m}$	= ASTER <sub>11.3</sub>
12.1 $\mu\text{m}$	= Adjusted UWBF <sub>12.1</sub> based on UWBF <sub>12.1</sub> - ASTER <sub>11.3</sub>
14.3 $\mu\text{m}$	= Adjusted UWBF <sub>14.3</sub> based on UWBF <sub>12.1</sub> - ASTER <sub>11.3</sub>



**Figure 1:** The advantages of combining the ASTER GED and MODIS UW Baseline Fit databases are evident here showing emissivity spectra over the Namib Desert, Namibia. UWBF v4.1 emissivity for Jan 2004 (crosses) and hyperspectral fit (red line), the CAMEL 13 hinge-point emissivity (blue dots)

and hyperspectral fit (blue line), and lab spectra (black) of sand samples collected over the Namib Desert. Note improved spectral shape in CAMEL HSR (blue) in the quartz doublet regions from 8-10 micron, and 12-13 microns.

#### 4.High Spectral Resolution Emissivity Methodology

The MEaSUREs CAMEL database was extended to high spectral resolution (HSR) using a Principal Component (PC) regression analysis similar to the method, which was developed to the UWIREMIS-HSR Algorithm (*Borbis and Ruston (2010)* and *Borbis et al (2014)*). The UWIREMIS-HSR version was designed for data assimilation schemes and radiative transfer models that require accurate high spectral resolution emissivity or as first guess emissivities in retrieval schemes of hyperspectral sounders such as AIRS, IASI, and CrIS. The PC regression approach has been adapted to generate a HSR emissivity of the CAMEL database.

The PCs (eigenvectors) were generated using three sets of selected laboratory measurements (chosen to represent various surface types) and regressed to the CAMEL 13 hinge-points as follows:

$$\vec{e} = \vec{c}U$$

where  $\vec{e}$  is the CAMEL emissivity on 13 hinge points,  $\vec{c}$  is the PCA coefficient vector and  $U$  is the matrix of the PCs of the lab emissivity spectra on the reduced spectral resolution. After calculating the coefficients ( $\vec{c}$ ), the high spectral resolution emissivity values are determined at the same latitude and longitude point by using the high spectral resolution PCs of the laboratory sets. There are two main updates in the CAMEL HSR algorithm from the UWIREMIS HSR algorithm:

- The number of Principal Components (PCs) now varies among 2, 7 and 9, based on the surface scene type and coverage using the 3.6, 10.6 and 11.3  $\mu\text{m}$  CAMEL emissivity, the ASTER NDVI, and fractional snow cover from MODIS Version 5 MOD10 Snow Cover for determination.
- Three sets of laboratory measurements have been created for the PCA regression also based on the surface scene type and coverage: general (55 spectra), arid (including carbonates, 82 spectra) and snow/ice (4 spectra).

The method for determining the number of PCs and version number of the laboratory dataset to use for each pixel is summarized in Table 3.

**Table 3:** Determination of the number of PCs and the version number of laboratory datasets for each pixel.

Tests	Version number of Laboratory dataset	Number of PCs
Carbonate test yes	10 (general_carbonates)	5
Carbonate test no, but $CAMEL_{9,1} \leq 0.85$	8 (general)	9
All the others	8 (general)	7
MOD10 snow fraction $\geq 0.5$	12 (snow/ice)	2

**Carbonate test:**  $(CAMEL_{10.6} - CAMEL_{11.3}) > 0.009$  &  $ASTER\ NDVI < 0.2$  &  $CAMEL_{3.6} < 0.9$

Figure 1 shows an example of applying the PC regression fit to the CAMEL LSE ESDR product at 13 points over the Namib Desert, Namibia. Comparisons of the unified LSE-ESDR with lab emissivity spectra from field sand samples show very good agreement, particularly in the quartz doublet regions at 8.5 and 12.5  $\mu\text{m}$  when compared with the original UWIREMIS HSR fit (UWIREMIS\_hyper). Biases and RMS errors were reduced by 3% and 4% respectively by using the unified LSE-ESDR instead of the original UWIREMIS product.

### 5.MEaSURES CAMEL Emissivity Uncertainty determination

The product uncertainty is estimated by a total emissivity uncertainty that comprises 3 independent components of variability—a temporal, spatial, and algorithm variability. Each measure of uncertainty is provided for all 13 channels and every latitude-longitude point. A quality flag is provided for the total uncertainty as in Table 4.

**Table 4:** Definition of CAMEL emissivity uncertainty quality flag

VALUE	DEFINITION OF 'total uncertainty quality flag'
0	Sea/ no CAMEL data available
1	Good quality
2	Unphysical uncertainty

The total uncertainty is calculated from the components as a root square sum:

$$\sigma_{total} = \sqrt{\sigma_{spatial}^2 + \sigma_{temporal}^2 + \sigma_{algorithm}^2}$$

The spatial uncertainty component is calculated as the standard deviation of the surrounding 5x5 pixel emissivity, which is equivalent to a 0.25x0.25 degree latitude-longitude region. This uncertainty represents the variability of the surrounding landscape (ocean is not included) and is only provided where the CAMEL emissivity quality flag is not zero.

The temporal uncertainty is defined by the standard deviation of the 3 surrounding months (e.g. Oct. uncertainty = standard deviation (Sept., Oct., Nov.)). Even if emissivity values are not available for all 3 months as in the case of the starting or ending month of the CAMEL record, an uncertainty is still reported.

Algorithm uncertainty is estimated by the differences between the two CAMEL emissivity inputs: the ASTER GEDv4 and UWBF products. Table 5 below shows the CAMEL, ASTER, and UWBF channel wavelengths, the method for combing the ASTER and UWBF emissivity to create the CAMEL product, and the method for determining the CAMEL emissivity algorithm uncertainty. Because the spatial and temporal uncertainty components are estimated by a standard deviation rather than a difference, the measure of difference between the ASTER and UWBF products are divided by the square root of 3 after an absolute value is taken. For channels 6-9 and 11-13 where ASTER and UWBF

report emissivities at nearby frequencies, differences between the ASTER and UWBF emissivity are used to define the algorithm variability as are shown in Table 5. Channel 10, at 10.8 micron, uses a linear interpolation between the ASTER channels 4 and 5. Where no ASTER data is available in the shortwave region for CAMEL channel 1 and 2, a variability is estimated from a fractional difference from channel 7. For channels 3 and 4, it is assumed that there is a small variability which is constant across time, space, and channels, and for channel 5 at 7.6 microns it is assumed that there is no variation.

To produce the quality flag and determine which total uncertainty values are flagged as unphysical (i.e. have a 'total\_uncertainty\_quality\_flag'=2), unphysical uncertainties are first flagged in the 3 uncertainty components (though are not provided to users due to file size restraints). Spatial and temporal uncertainties values are flagged unphysical if they are located in the 99.9<sup>th</sup> percentile, while algorithm uncertainty values are determined as unphysical if the ASTER and BF differences prior to having their absolute values taken are in the 0.1<sup>st</sup> or 99.9<sup>th</sup> percentiles. Total uncertainty values are then flagged as unphysical if any of the 3 components are flagged as being unphysical.

**Table 5:** Method of calculating CAMEL algorithm uncertainty

	CAMEL	UWBF	ASTER	CAMEL COMBINING METHOD	ALGORITHM UNCERTAINTY METHOD
1	3.6	Y	-	BF1	$Abs( BF1 * [(BF6 - ASTER2) / BF6] ) / \sqrt{3}$
2	4.3	Y	-	BF2	$Abs( BF2 * [(BF6 - ASTER2) / BF6] ) / \sqrt{3}$
3	5.0	Y	-	BF3	$Abs( 0.01 ) / \sqrt{3}$
4	5.8	Y	-	BF4	$Abs( 0.01 ) / \sqrt{3}$
5	7.6	Y	-	BF5	0 (Minimal variation)
6	8.3	Y	Y	$ASTER 1 + (CAMEL7(BF6, ASTER 2) - ASTER 2)$	$Abs( BF6 - ASTER 1 ) / \sqrt{3}$
7	8.6	S	Y	WeightedMean(BF6, ASTER 2)	$Abs( BF6 - ASTER 2 ) / \sqrt{3}$
8	9.1	S	Y	$ASTER 3 + (CAMEL7(BF6, ASTER 2) - ASTER 2)$	$Abs( BF6 - ASTER 3 ) / \sqrt{3}$
9	10.6	-	Y	ASTER 4 & BF8	$Abs( BF8 - ASTER 4 ) / \sqrt{3}$
10	10.8	Y	-	LinearInterpol(ASTER 4, ASTER 5) & BF8	$Abs( BF8 - [(ASTER4*5 + ASTER5*2) / 7] ) / \sqrt{3}$
11	11.3	-	Y	ASTER5 & BF8	$Abs( BF8 - ASTER 5 ) / \sqrt{3}$
12	12.1	Y	-	BF9 but if ASTER5 > BF9, BF9+ diff(BF9, ASTER 5)*s	$Abs( BF9 - ASTER 5 ) / \sqrt{3}$
13	14.3	Y	-	BF10 but if ASTER 5 > BF9, BF9+ diff(BF9, ASTER 5)*s	$Abs( BF10 - ASTER 5 ) / \sqrt{3}$

## 6.MEaSURES CAMEL data product files

The V001 CAMEL emissivity, uncertainty and PCA coefficients have been processed for the time period of 2003-2015. This section describes the technical information of the three data files. *Please, note that we track a local version in the global attributes of each file as prd\_version=v01r02, which is equivalent of the NASA LP DAAC version V001.*

**a. MEaSURES CAMEL Emissivity Product File**

The CAMEL emissivity is provided in monthly netcdf files with contents (see Table 1) and filename specification as:

Filename: CAM5K30EM\_emis\_YYYYMM\_vXXX.nc

YYYY = year

MM = month

XXX = version number

Size: ~57 MB

Number of files: 154 (between 2003-2015, missing: 2003 Dec, 2010 July)

Total size: ~ 8 GB

Temporal Resolution: monthly

Spatial Resolution: 0.05 degrees

Format: netcdf4 (internally compressed with deflate\_value=5)

Dimensions:

latitude = 3600 [-89.975, 89.975]

longitude = 7200 [-179.975, 179.975]

spectra = 13

**Table 6:** The MEaSURES CAMEL emissivity variables

Name	Type	Dims	Scale Factor	Fill Value	Valid Range	Description
latitude	float32	latitude,	na	na	[-90 90]	<b>Latitude</b> , degrees North at grid-box center
longitude	float32	longitude	na	na	[-180 180]	<b>Longitude</b> , degrees east at grid-box center
bfemis_qflag	int16	latitude, longitude	na	na	[0 4]	<b>UW Baseline Fit Emissivity Quality Flag:</b> 0 = no MOD11 data 1 = baseline fit method was applied 2 = averaged from the 2 adjacent months 3 = 2003 annual average 4 = average over the annual average over all emissivity with latitude < -8
aster_qflag	int16	latitude, longitude	na	na	[0 ]	<b>ASTER GED Quality Flag:</b> 1 = good quality ASTER-GED data 2 = sea or inland water 3 = filled value
camel_qflag	int16	latitude, longitude	na	na	[0 4]	<b>CAMEL Quality Flag:</b> 0 = sea or inland water 1 = good quality of BF and ASTER-GED data 2 = good quality of BF data and filled ASTER-GED data 3 = good quality of ASTER-GED data and filled BF data 4 = both BF and ASTER-GED data are filled values
aster_ndvi	int16	latitude, longitude	0.001	na	[0 1000]	<b>ASTER GED NDVI – vegetation fraction</b>
snow_fraction	int16	latitude, longitude	0.01	na	[0 100]	<b>Snow fraction derived from MODIS MOD10</b>

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camel_emis	int16	latitude longitude, spectra	0.001	-999	[0 1000]	<b>Combined ASTER MODIS Emissivity over Land:</b> Emissivity at 3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 8.6, 9.1, 10.6,10.8, 11.3,12.1, 14.3 microns
------------	-------	-----------------------------------	-------	------	----------	---

**b. MEaSURES CAMEL Emissivity Uncertainty Product File**

The CAMEL emissivity uncertainty is provided in monthly netcdf files congruent to the CAMEL emissivity product with contents (see Table 7) and filename specification as:

Filename: CAM5K30UC\_emis\_uncertainty\_YYYYMM\_vXXX.nc

YYYY = year

MM = month

XXX = version number

Size: ~141 MB

Number of files: 154 (between 2003-2015, missing: 2003 Dec, 2010 July)

Total size: ~ 21.7 GB

Temporal Resolution: monthly

Spatial Resolution: 0.05 degrees

Format: netcdf4 (internally compressed with deflate\_value=5)

Dimensions:

latitude = 3600 [-89.975, 89.975]

longitude = 7200 [-179.975, 179.975]

spectra = 13

**Table 7:** The MEaSURES CAMEL emissivity uncertainty variables

Name	Type	Dims	Scale Factor	Fill value	Valid Range	Description
latitude	float32	latitude	na	na	[-90 90]	Latitude, degrees North at grid-box center
longitude	float32	longitude	na	na	[-180 180]	Longitude, degrees east at grid-box center
wavelength	float32	spectra	na	na	[3.6 14.3]	Channel locations of CAMEL emissivity in [μm]
spatial_uncertainty	uint16	latitude, longitude, spectra	0.001	9999	[0 1000]	<b>Spatial uncertainty of the CAMEL Emissivity database</b>
temporal_uncertainty	uint16	latitude, longitude, spectra	0.001	9999	[0 1000]	<b>Temporal uncertainty of the CAMEL Emissivity database</b>
algorithm_uncertainty	uint16	latitude, longitude, spectra	0.001	9999	[0 1000]	<b>Algorithm uncertainty of the CAMEL Emissivity database</b>
total_uncertainty	uint16	latitude, longitude, spectra	0.001	na	[0 1000]	<b>Total uncertainty of the CAMEL Emissivity database</b>
total_uncertainty_quality_flag	uint8	latitude, longitude, spectra	na	99	[0 2]	<b>Quality flag of the CAMEL uncertainties</b> 0 = Sea, no CAMEL data

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						1 = Good quality data 2 = Unphysical uncertainty
camel_qflag	uint8	latitude, longitude	na	99	[0 4]	<b>CAMEL Quality Flag:</b> 0 = sea or inland water 1 = good quality of BF and ASTER-GED data 2 = good quality of BF data and filled ASTER-GED data 3 = good quality of ASTER-GED data and filled BF data 4 = both BF and ASTER-GED data are filled values

**c. MEaSURES Coefficient Product File**

The CAMEL PCA coefficients are the inputs of CAMEL HSR Emissivity algorithm. The CAMEL PCA coefficients are provided in monthly netcdf files congruent to the CAMEL emissivity product, with contents (see Table 8) and filename specification as:

Filename: CAM5K30CF\_coef\_YYYYMM\_vXXX.nc

YYYY = year

MM = month

XXX = version number

Size: ~137 MB

Number of files: 154 (between 2003-2015, missing: 2003 Dec, 2010 July)

Total size: ~21 GB

Temporal Resolution: monthly

Spatial Resolution: 0.05 degrees

Format: netcdf4 (internally compressed with deflate\_value=5)

Dimensions:

latitude = 3600 [-89.975, 89.975]

longitude = 7200 [-179.975, 179.975]

max\_npcs = 9

mask = 8685101 (can vary by month)

**Table 8:** The MEaSURES CAMEL coefficient variables

Name	Type	Dims	Scale Factor	Fill Value	Valid Range	Description
latitude	Float32	latitude	na	na	[-90 90]	<b>Latitude</b> , degrees North at grid-box center
longitude	Float32	longitude	na	na	[-180 180]	<b>Longitude</b> , degrees east at grid-box center
camel_qflag	int16	latitude, longitude	na	na	[0 4]	<b>CAMEL Quality Flag:</b> 0 = sea or inland water 1 = good quality of BF and ASTER-GED data 2 = good quality of BF data and filled ASTER-GED data 3 = good quality of ASTER-GED data and filled BF data 4 = both BF and ASTER-GED data are filled values

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snow_fraction	int16	Mask	0.01	na	[0 100]	<b>Snow fraction derived from MODIS MOD10</b>
pc_labvs	int16	Mask	na	na	[8 12]	<b>Version number of the Laboratory PCscores datafile</b>
pc_npcs	int16	Mask	na	na	[2 9]	<b>Number of PCs used</b>
pc_coefs	Float32	Max_npcs , mask	na	-999	[-10 10]	<b>CAMEL PCA Coefficients</b> PCA coefficients are dependent of the version of lab PC data and number of PCs used.

To save storage and memory load space in the HSR emissivity algorithm, the values of the snow fraction, the version number of laboratory data, the number of PCA coefficients and the PCA coefficients have been stored only over land pixels when the CAMEL quality flag is larger than zero ( $camel\_qflag > 0$ ). Instead of the 3600x7200 dimensions, the above mentioned variables have been stored in a vector of length 8685101 (for Jan 2007); however the number of land pixels may vary by month. This method reduces the storage place and memory load down to a third of what is required for the original gridded formatting files.

The part of the *read\_CAMEL\_coef.f* Fortran subroutine which converts the land pixels into the 2 dimensional (Lat, lon) matrix is as follows:

---

```

!-----
! Generate the look-up table into the emissivity data
!-----
coef_lut = -1
indexlut = 1
Do i=1,nc_dim(1)
    Do j=1,nc_dim(2)
        If (camel_qflag(j,i) > 0) then
            coef_lut(j,i) = indexlut
            indexlut = indexlut + 1
        End If
    End Do
End Do

! extract coef for a pixel (gridx,gridy):
If (coef_lut(gridx,gridy) > 0) Then
coeff(:) = pcacoefs(1:npcs,coef_lut(gridx,gridy))*pca_sfac + pca_offs
! where npcs is between 1 and 13, pca_sfac is the scale factor and pca_offs is the offset.

```

The part of the *read\_CAMEL\_coef\_V001.m* Matlab subroutine which converts the land pixels into the 2 dimensional (Lat, lon) matrix is as follows:

```
for i=1:max_npcs
  clear coef
  coef=double(squeeze(pc_coefs(i,:)));
  indexlut=1;
  for j=1:Xmax
    for k=1:Ymax
      if camel.camel_qflag(k,j) > 0
        camel.coef(i,k,j) = coef(indexlut);
        if i == 1
          camel.pcnpcs(k,j) = double(pc_npcs(indexlut));
          camel.pclabvs(k,j) =double(pc_labvs(indexlut));
          camel.snowf(k,j) =double( snow_fraction(indexlut));
        end
        indexlut = indexlut + 1;
      end
    end
  end
end
```

## 7. Description of the MEASURES CAMEL High Spectral Resolution Algorithm

The standalone version of the HSR emissivity Algorithm has been developed in MATLAB and Fortran. In this section, you can find technical details about these software packages.

### a. Fortran version

This package contains software to create a Fortran library to calculate the CAMEL High Spectral Resolution emissivity as well as a sample program for users to understand how to run the algorithm. The software runs on version 1.0 (NSA LPDAAC V001/PGE v01r02) CAMEL emissivity coefficients data. Output of the software can be (1) a 5 wavenumber resolution emissivity at 417 wavenumbers (between 698 and 2778) and/or (2) an instrument specific emissivity.

#### Requirements:

Software requirement: netcdf4 library (gcc)

#### Software package contains:

- src\_hsrlib\_V001 - contains fortran algorithm
- lib - will contain the "libhsrremis\_V001.a" after installation
- coef - contains all the laboratory eigenvector and eigenvalues netcdf files
- include - contains the hsremis\_EDR.inc
- data - includes one CAMEL coefficient file for testing purpose
- test - includes a test code (run\_hsrremis.f) to run for one geographical location

#### Install the package:

1. cp /pathname/MEASURES\_CAMEL\_hsrremis\_lib\_delivery\_Jan19\_2017\_V001.tar.gz to desired directory
2. unzip (gzip -d) and untar (tar -xvf) it

The complete list of the package can be found in Appendix 2.

Create the HSR emis library:

1. cd src\_hsrlib\_V001
2. edit hsriremis\_EDR.inc if you run on your own data directory:  
     DATA path\_camel/'../data/'  
     DATA path\_lab/'../coef/'
3. make -f Makefile\_lib clean
4. make -f Makefile\_lib
5. make -f Makefile\_lib install

Test code for the HSR emis library:

1. cd test
2. edit the library links in run\_hsriremis\_online.mk
3. run ./run\_hsriremis\_online.mk (compile code)
4. run ./run\_hsriremis.exe
5. compare results for Namib validation site at IASI frequencies:  
     sdiff Namib\_iasi\_emis.txt.test Namib\_iasi\_emis.txt

**Table 9:** Inputs of the CAMEL HSR Algorithm V001

Inputs	Data type	Valid range	Notes
year	Character (len=4)	['2003', '2015']	
month	Character (len=2)	['01', '12']	
Latitude	Real	[-90, 90]	Latitude of the location in degree
longitude	Real	[-180, 180]	Longitude of the location in degree
First	Logical	[yes, no]	Switch for initialization Set TRUE for the first call and then FALSE
Instr_switch	Logical	[yes, no]	Set to TRUE for hsr emis to be calculated for a certain instrument otherwise set to FALSE
Debug	Logical	[yes, no]	Set to TRUE for more outputting otherwise set to FALSE
nchs	Integer		Set to zero if calculating hsr emis for a certain instrument (if instr_switch = TRUE) otherwise set to the number of channels of the instrument
Instr_wn (optional)	Real [nchs]		central wavenumber of the instrument bands in increasing order

**Table 10:** Outputs of the CAMEL HSR Algorithm V001

Outputs	Data type	Valid Range	Notes
hsrreemis	Real (417)	[0.5, 1]	
Instr_emis (optional)	Real(nchs)	[0.5, 1]	Output only if nchs is not set to zero

Usage:

```
call compute_hsrreemis(
    & cyear,           ! in
    & cmonth,         ! in
    & lat_site,       ! in
    & lon_site,       ! in
```

```

& first,           ! in
& instr_switch,   ! in
& debug,          ! in
& hsriemis,       ! out
& nchs,           ! in
& instr_wn,       ! in, optional
& instr_emis)     ! out, optional

```

The wavenumber of the HSR emissivity is not output, but it can be obtained by the following:

```

Do i=1,numwave
      hsr_wavenum(i) = 698 +(i-1)*5
Enddo

```

Note to run for the whole grid (3600x7200), it is suggested to read the camel\_qflag first and call the compute\_hsriemis.f subroutine for land pixels only (camel\_qflag > 0).

```

call read_CAMEL_coef_qflag(
      & fn_coef,      !in - character (len=300) - name of the coefficient file
      & camel_qflag)!out  int2[7200,3600] - CAMEL quality flag

```

The codes in the CAMEL HSR package:

SUBROUTINE **compute\_hsriemis** : creates library to compute high spectral resolution emissivity spectra from the MEaSURES CAMEL database

SUBROUTINE **init\_hsriemis** (name of the CAMEL coefficient file): initializes variables and reads in the eigenvectors of the laboratory data (calls read\_labpcs for all three laboratory sets).

SUBROUTINE **read\_CAMEL\_coef** (name of the CAMEL coefficient file): reads the 0.05 degree resolution MEaSURES CAMEL (from the netCDF file into memory).

SUBROUTINE **read\_CAMEL\_coef\_qflag** (name of the CAMEL coefficient file): reads the CAMEL quality flag from the 0.05 degree resolution MEaSURES CAMEL Coefficient file into memory.

SUBROUTINE **read\_labpcs** (laboratory data version): read the eigenvectors and eigenvalues of the selected laboratory measurements.

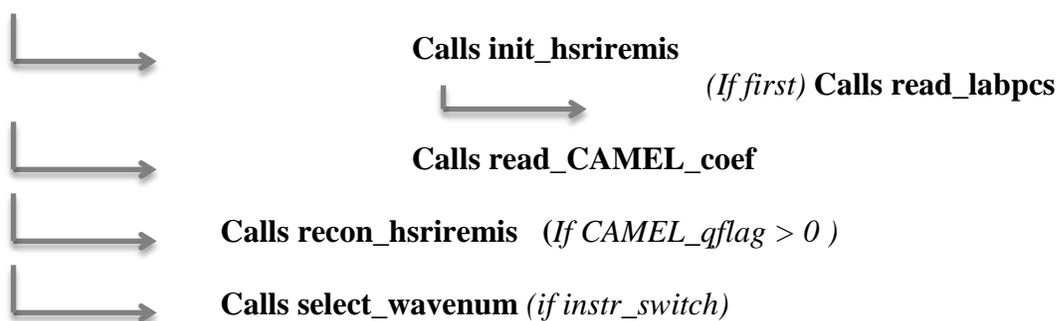
SUBROUTINE **recon\_hsriemis** (number of PCs to use, version number of laboratory set, coefficients(output), hsriemis (output)): creates high spectra resolution emissivities at 417 wavenumbers from the MEaSURES CAMEL emissivity database (at 13 hinge points) and laboratory measurements using principal component analyses.

SUBROUTINE **select\_wavenum hsremis** (number of channels, instr\_wavenum, instr\_emis (output)): is called if instr\_switch is set to TRUE. The subroutine finds the closest wavenumber from the MEaSURES CAMEL HSR emissivity spectra for the instrument frequency and assigns the instrument

emissivity by either choosing the closest spectral point value or bilinear interpolating between the two closest spectral point values.

---

**Compute\_hswiremis**




---

**Figure 2:** Structure of the MEASURES CAMEL HSR Algorithm

**b. Matlab version**

The package contains software to calculate the CAMEL High Spectral Resolution emissivity as well as a sample program for users to understand how to run the algorithm. The software runs on the version 1.0 (V001) CAMEL emissivity coefficients data. The HSR emissivity can be calculated using the CAMEL 13 hinge points emissivity values or the CAMEL Principal Component Analyses coefficients as input.

Install the package:

1. ftp MEASURES\_hswiremis\_algorithm\_matlab\_delivery\_Jan28\_2017\_V001.tar.gz  
from [ftp://ftp.ssec.wisc.edu/pub/ICI/MEASURES\\_hswiremis\\_algorithm/](ftp://ftp.ssec.wisc.edu/pub/ICI/MEASURES_hswiremis_algorithm/)
2. unzip (gzip -d) and untar (tar -xvf) it

Software package contains:

- coef - contains files of laboratory eigenvectors and eigenvalues (Matlab format)
- data - contains MEASURES emissivity and coefficients files for a test month (2007 January)
- outdir -contains an image and a mat-file of the test case result for sanity check

mfiles -contains the MEaSURES HSR algorithm

file structure:

main code: run\_MEASUREs\_hsremis\_test.m

calls: -read\_CAMEL\_coef\_V001.m  
-read\_CAMEL\_emis\_V001.m  
-create\_HSRemis\_fromCAMELcoef\_V001.m  
-create\_HSRemis\_fromCAMELemis\_V001.m

Test run:

1. go to the mfiles directory
2. start matlab
3. run: run\_MEASUREs\_hsremis\_test.m
4. compare the resulting image and mat-file in the output directory with the \*orig.png and \*orig.mat file

## 8. References

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---

**Appendix 1: CAMEL Product CDL Files****a. CAMEL Coefficient Product**

```
netcdf CAMEL_coef_200701_V001 {
dimensions:
    latitude = 3600 ;
    longitude = 7200 ;
    max_npcs = 9 ;
    mask = 8685101 ;
variables:
    float latitude(latitude) ;
        latitude:units = "degrees north" ;
        latitude:long_name = "Latitude; Degrees north at grid-box center" ;
        latitude:comment = "none" ;
        latitude:valid_range = -90.f, 90.f ;
        latitude:coordinates = "latitude" ;
    float longitude(longitude) ;
        longitude:units = "degrees east" ;
        longitude:long_name = "Longitude; Degrees east at grid-box center" ;
        longitude:comment = "none" ;
        longitude:valid_range = -180.f, 180.f ;
        longitude:coordinates = "longitude" ;
    short camel_qflag(latitude, longitude) ;
        camel_qflag:units = "none" ;
        camel_qflag:long_name = "CombinedASTER MODIS Emissivity over Land: Quality
Flag" ;
        camel_qflag:comment = "0 = sea or inland water;1 = good quality of BF and ASTER-
GED data; 2 = good quality of BF data and filled ASTER-GED data;3 = good quality of
ASTER-GED data and filled BF data ; 4 = both BF and ASTER-GED data are
filled values" ;
        camel_qflag:valid_range = 0s, 4s ;
        camel_qflag:coordinates = "latitude longitude" ;
    short snow_fraction(mask) ;
        snow_fraction:units = "none" ;
        snow_fraction:long_name = "Snow fraction derived from MODIS MOD10" ;
        snow_fraction:comment = ;
        snow_fraction:scale_factor = 0.01f ;
        snow_fraction:valid_range = 0s, 100s ;
        snow_fraction:coordinates = "latitude longitude" ;
    short pc_labvs(mask) ;
        pc_labvs:units = "none" ;
        pc_labvs:long_name = "Version number of the Laboratory PCscores datafile" ;
        pc_labvs:comment = "None" ;
        pc_labvs:valid_range = 8s, 12s ;
        pc_labvs:coordinates = "latitude longitude" ;
    short pc_npcs(mask) ;
        pc_npcs:units = "none" ;
```

---

```
pc_npcs:long_name = "NUmber of PCs used" ;
pc_npcs:comment = "None" ;
pc_npcs:valid_range = 2s, 9s ;
pc_npcs:coordinates = "latitude longitude" ;
float pc_coefs(mask, max_npcs) ;
pc_coefs:units = "none" ;
pc_coefs:long_name = "Combined ASTER MODIS Emissivity over Land: PCA
Coefficients" ;
pc_coefs:comment = "PCA coefficients are dependent of the version of lab PC data and
number of PCs used." ;
pc_coefs:_FillValue = -999.f ;
pc_coefs:valid_range = -10.f, 10.f ;
pc_coefs:coordinates = "mask npcs" ;
```

```
// global attributes:
```

```
:institution = "UW-MAD/SSEC/CIMSS, Cooperative Institute for Meteorological
Satellite Studies, Space Science
and Engineering Center, University of Wisconsin, Madison, http://cimss.ssec.wisc.edu/"
;
:creator = "Eva E. Borbas " ;
:contributor = "Glynn C. Hulley " ;
:id = "CAMEL_coef_200701_V001.nc " ;
:Prd_Version = "v01r02" ;
:LP_DAAC_Version = "V001" ;
:date_issued = "2017-01-05" ;
:cdm_data_type = "grid " ;
:featureType = "grid " ;
:spatial_resolution = "0.05 degrees " ;
:spectral_resolution = "3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 8.6, 9.1, 10.6,10.8, 11.3, 12.1, 14.3
micrometer " ;
:source =
"global_emis_inf10_monthFilled_MYD11C3.A2007001.041.nc,ASTER_GEDv4_A20
07001.nc" ;
:title = "NASA MEASUREs: Combined ASTER MODIS Emissivity over Land
(CAMEL) COEF ESDR " ;
:summary = "Monthly Mean Global IR Land Surface Emissivity; " ;
:license = "No restrictions on access or use" ;
:keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Earth
Science Keywords, Version 6.0 " ;
:date_created = "2017-01-12 20:59:29Z" ;
:geospatial_lat_min = -89.9749984741211 ;
:geospatial_lat_max = 89.9749984741211 ;
:geospatial_lat_resolution = "0.05 degree grid " ;
:geospatial_lat_units = "degrees north " ;
:geospatial_lon_min = -179.975006103516 ;
:geospatial_lon_max = 179.975006103516 ;
:geospatial_lon_resolution = "0.05 degree grid " ;
:geospatial_lon_units = "degrees east " ;
:time_coverage_start = "2007-01-01 00:00:00Z" ;
```

```
:time_coverage_end = "2007-02-01 00:00:00Z" ;  
:time_coverage_duration = "P1M " ;  
}
```

**b. CAMEL Emissivity Product**

```
netcdf CAMEL_emis_200701_V001 {
dimensions:
    latitude = 3600 ;
    longitude = 7200 ;
    spectra = 13 ;
variables:
    float latitude(latitude) ;
        latitude:units = "degrees north" ;
        latitude:long_name = "Latitude; Degrees north at grid-box center" ;
        latitude:comment = "none" ;
        latitude:valid_range = -90.f, 90.f ;
        latitude:coordinates = "latitude" ;
    float longitude(longitude) ;
        longitude:units = "degrees east" ;
        longitude:long_name = "Longitude; Degrees east at grid-box center" ;
        longitude:comment = "none" ;
        longitude:valid_range = -180.f, 180.f ;
        longitude:coordinates = "longitude" ;
    short bfemis_qflag(latitude, longitude) ;
        bfemis_qflag:units = "none" ;
        bfemis_qflag:long_name = "UW Baseline Fit Emissivity Quality Flag" ;
        bfemis_qflag:comment = "0 = no MOD11 data;1 = baseline fit method was applied; 2
        = averaged from the 2 adjacent months;3 = 2003 annual average ; 4 = average over the
        annual average over all emis with latitude<-8" ;
        bfemis_qflag:valid_range = 0s, 4s ;
        bfemis_qflag:coordinates = "latitude longitude" ;
    short aster_qflag(latitude, longitude) ;
        aster_qflag:units = "none" ;
        aster_qflag:long_name = "ASTER GED Quality Flag" ;
        aster_qflag:comment = "2 = sea or inland water; 1 = good quality ASTER-GED data; 3
        = filled value" ;
        aster_qflag:valid_range = 0s, 4s ;
        aster_qflag:coordinates = "latitude longitude" ;
    short camel_qflag(latitude, longitude) ;
        camel_qflag:units = "none" ;
        camel_qflag:long_name = "Combined ASTER MODIS Emissivity over Land - Quality
        Flag" ;
        camel_qflag:comment = "0 = sea or inland water;1 = good quality of BF and ASTER-
        GED data; 2 = good quality of BF data and filled ASTER-GED data;3 = good quality of
        ASTER-GED data and filled BF data ; 4 = both BF and ASTER-GED data are filled
        values" ;
        camel_qflag:valid_range = 0s, 4s ;
        camel_qflag:coordinates = "latitude longitude" ;
    short aster_ndvi(latitude, longitude) ;
        aster_ndvi:units = "none" ;
        aster_ndvi:long_name = "ASTER GED NDVI" ;
        aster_ndvi:comment = "none" ;
```

```
aster_ndvi:scale_factor = 0.001f ;
aster_ndvi:valid_range = 0s, 1000s ;
aster_ndvi:coordinates = "latitude longitude" ;
short snow_fraction(latitude, longitude) ;
snow_fraction:units = "none" ;
snow_fraction:long_name = "MODIS MOD10 Snow Fraction" ;
snow_fraction:comment = "none" ;
snow_fraction:scale_factor = 0.01f ;
snow_fraction:valid_range = 0s, 100s ;
snow_fraction:coordinates = "latitude longitude" ;
short camel_emis(latitude, longitude, spectra) ;
camel_emis:units = "none" ;
camel_emis:long_name = "Combined ASTER MODIS Emissivity over Land" ;
camel_emis:comment = "Emissivity at 3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 8.6, 9.1, 10.6,10.8,
11.3,12.1, 14.3 micron" ;
camel_emis:scale_factor = 0.001f ;
camel_emis:_FillValue = -999s ;
camel_emis:valid_range = 0.f, 1000.f ;
camel_emis:coordinates = "latitude longitude spectra" ;
```

```
// global attributes:
```

```
:institution = "UW-MAD/SSEC/CIMSS, Cooperative Institute for Meteorological
Satellite Studies, Space Science and Engineering Center, University of Wisconsin,
Madison, http://cimss.ssec.wisc.edu/" ;
:creator = "Eva E. Borbas " ;
:contributor = "Glynn C. Hulley " ;
:id = "CAMEL_emis_200701_V001.nc " ;
:Prd_Version = "v01r02" ;
:LP_DAAC_Version = "V001" ;
:date_issued = "2017-01-05" ;
:cdm_data_type = "grid " ;
:featureType = "grid " ;
:spatial_resolution = "0.05 degrees " ;
:spectral_resolution = "3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 8.6, 9.1, 10.6,10.8, 11.3, 12.1, 14.3
micrometer " ;
:source =
"global_emis_inf10_monthFilled_MYD11C3.A2007001.041.nc,ASTER_GEDv4_A20
07001.nc" ;
:title = "NASA MEASURES: Combined ASTER MODIS Emissivity over Land
(CAMEL) ESDR " ;
:summary = "Monthly Mean Global IR Land Surface Emissivity;" ;
:license = "No restrictions on access or use" ;
:keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Earth
Science Keywords, Version 6.0 " ;
:date_created = "2017-01-12 20:58:59Z" ;
:geospatial_lat_min = -89.9749984741211 ;
:geospatial_lat_max = 89.9749984741211 ;
:geospatial_lat_resolution = "0.05 degree grid " ;
:geospatial_lat_units = "degrees north " ;
```

```
:geospatial_lon_min = -179.975006103516 ;  
:geospatial_lon_max = 179.975006103516 ;  
:geospatial_lon_resolution = "0.05 degree grid " ;  
:geospatial_lon_units = "degrees east " ;  
:time_coverage_start = "2007-01-01 00:00:00Z" ;  
:time_coverage_end = "2007-02-01 00:00:00Z" ;  
:time_coverage_duration = "P1M " ;  
}
```

**c. CAMEL Uncertainty Product**

```
netcdf CAMEL_emis_uncertainty_200701_V001 {
dimensions:
    latitude = 3600 ;
    longitude = 7200 ;
    spectra = 13 ;
variables:
    double wavenumber(spectra) ;
        wavenumber:units = "none" ;
        wavenumber:scale_factor = 1. ;
        wavenumber:add_offset = 0. ;
    ushort spatial_uncertainty(latitude, longitude, spectra) ;
        spatial_uncertainty:long_name = "Spatial uncertainty of the CAMEL Emissivity
        database" ;
        spatial_uncertainty:units = "none" ;
        spatial_uncertainty:scale_factor = 0.001 ;
        spatial_uncertainty:add_offset = 0. ;
    ushort temporal_uncertainty(latitude, longitude, spectra) ;
        temporal_uncertainty:long_name = "Temporal uncertainty of the CAMEL Emissivity
        database" ;
        temporal_uncertainty:units = "none" ;
        temporal_uncertainty:scale_factor = 0.001 ;
        temporal_uncertainty:add_offset = 0. ;
    ushort algorithm_uncertainty(latitude, longitude, spectra) ;
        algorithm_uncertainty:long_name = "Algorithm uncertainty of the CAMEL Emissivity
        database" ;
        algorithm_uncertainty:units = "none" ;
        algorithm_uncertainty:scale_factor = 0.001 ;
        algorithm_uncertainty:add_offset = 0. ;
    ushort total_uncertainty(latitude, longitude, spectra) ;
        total_uncertainty:long_name = "Total uncertainty of the CAMEL Emissivity database" ;
        total_uncertainty:units = "none" ;
        total_uncertainty:scale_factor = 0.001 ;
        total_uncertainty:add_offset = 0. ;
    ubyte total_uncertainty_quality_flag(latitude, longitude, spectra) ;
        total_uncertainty_quality_flag:long_name = "Quality flag of the CAMEL uncertainties"
        ;
        total_uncertainty_quality_flag:Flag_0 = "0 = Sea, no CAMEL data" ;
        total_uncertainty_quality_flag:Flag_1 = "1 = Good quality data" ;
        total_uncertainty_quality_flag:Flag_2 = "2 = Unphysical uncertainty" ;
        total_uncertainty_quality_flag:units = "none" ;
        total_uncertainty_quality_flag:scale_factor = 1. ;
        total_uncertainty_quality_flag:add_offset = 0. ;
    ubyte camel_qflag(latitude, longitude) ;
        camel_qflag:long_name = "Combined ASTER MODIS Emissivity over Land - Quality
        Flag" ;
        camel_qflag:Flag_0 = "0 = sea or inland water" ;
        camel_qflag:Flag_1 = "1 = good quality of BF and ASTER-GED data" ;
```

```
camel_qflag:Flag_2 = "2 = good quality of BF data and filled ASTER-GED data" ;
camel_qflag:Flag_3 = "3 = good quality of ASTER-GED data and filled BF data" ;
camel_qflag:Flag_4 = "4 = both BF and ASTER-GED data are filled values" ;
camel_qflag:units = "none" ;
camel_qflag:scale_factor = 1. ;
camel_qflag:add_offset = 0. ;
```

```
// global attributes:
```

```
:Title = "NASA MEASURES:Emissivity Uncertainties of the CAMEL database" ;
:Created_by = "Eva Borbas and Michelle Feltz UW/CIMSS/SSEC" ;
:Institution = "UW-MAD/SSEC/CIMSS, Cooperative Institute for Meteorological
Satellite Studies, Space Science and Engineering Center, University of Wisconsin,
Madison, http://cimss.ssec.wisc.edu/" ;
:Creation_date = "21-Dec-2016 23:42:55" ;
:Prd_Version = "v01r02" ;
:LP_DAAC_Version = "V001" ;
:Id = "CAMEL_emis_uncertainty_200701_V001.nc" ;
:cdm_data_type = "grid" ;
:featureType = "grid" ;
:spectral_resolution = "3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 8.6, 9.1, 10.6,10.8, 11.3, 12.1, 14.3
micrometer" ;
:spatial_resolution = "0.05 degrees" ;
:geospatial_lat_min = "-89.975" ;
:geospatial_lat_max = "89.975" ;
:geospatial_lat_resolution = "0.05 degree grid" ;
:geospatial_lat_units = "degrees north" ;
:geospatial_lon_min = "-179.975" ;
:geospatial_lon_max = "179.975" ;
:geospatial_lon_resolution = "0.05 degree grid" ;
:geospatial_lon_units = "degrees east" ;
:time_coverage_start = "2007-01-01 00:00:00Z" ;
:time_coverage_end = "2007-02-01 00:00:00Z" ;
}
```

## Appendix 2: Contents of the CAMEL HSR algorithm Software package

### a. Fortran version

MEASURES CAMEL hsremis lib delivery Jan19 2017 V001.tar.gz package contains:

```
src_hsrlib_v00r06:
  compute_hsrireemis.f
  init_hsrireemis.f
  Makefile_lib
  read_labpcs.f
  read_CAMEL_coef.f
  read_CAMEL_coef_qflag.f
  recon_hsrireemis.f
  select_wavenum.f

test:
  iasi_chans616.txt
  Namib_iasi_emis.txt.test
  run_hsrireemis.f
  run_hsrireemis_online.mk

coef:
  pchsr_v10.2.nc
  pchsr_v12.2.nc
  pchsr_v8.2.nc

data:
  CAMEL_coef_200701_V001.nc

lib:
  empty dir

include:
  empty dir
```

### b. Matlab version

MEASURES hsremis algorithm matlab delivery Jan28 2017 V001.tar.gz package contains:

```
coef:
  pchsr_v10.2.mat
  pchsr_v12.2.mat
  pchsr_v8.2.mat
  pmodast_v10.2.mat
  pmodast_v12.2.mat
  pmodast_v8.2.mat

data:
  CAMEL_coef_200701_V001.nc
  CAMEL_emis_200701_V001.nc

mfiles:
  create_HSRemis_fromCAMELcoef_V001.m
  create_HSRemis_fromCAMELemis_V001.m
  read_CAMEL_coef_V001.m
  read_CAMEL_emis_V001.m
  run_CAMEL_hsremis_test.m

output:
  Namib_CAMEL_HSRemissivity_200701_V001.orig.mat
  Namib_CAMEL_HSRemissivity_200701_V001.orig.png
```