VIIRS Land Surface Temperature and Emissivity Continuity

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MODAPS and LSIPS Team

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(c) 2018 California Institute of Technology. Government sponsorship acknowledged.
Outline

1. Algorithm and product status
2. Validation
3. VIIRS-MODIS Continuity
4. New Science
<table>
<thead>
<tr>
<th>Proposed development/refinement</th>
<th>Product(s)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implement new L2 and L3 gridded LST&amp;E algorithms (2014-2018)</td>
<td>MxD21 VNP21</td>
<td>Complete In processing at MODAPS/LSIPS</td>
</tr>
<tr>
<td>Produce L3 Climate Modeling Grid (CMG) products</td>
<td>MxD21C1-C3 VNP21C1-C3</td>
<td>On schedule for MODIS C6.1</td>
</tr>
<tr>
<td>Improve atmospheric correction</td>
<td>MxD21 VNP21</td>
<td>On schedule for MODIS C6.1</td>
</tr>
<tr>
<td>• Replace MERRA2 with GEOS5</td>
<td></td>
<td></td>
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<tr>
<td>• Higher resolution and latency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produce emissivity product for midwave IR bands</td>
<td>MxD21 VNP21</td>
<td></td>
</tr>
<tr>
<td>• Critical for sounding community (e.g. CLIMCAPS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Continuity of MEaSUREs LST&amp;E</td>
<td></td>
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</tr>
<tr>
<td>Reduce overall number of MODIS LST products (currently 10)</td>
<td>MxD21 MxD11</td>
<td></td>
</tr>
</tbody>
</table>
## VNP21 Product Suite

<table>
<thead>
<tr>
<th>Earth Science Data Type (ESDT)</th>
<th>Product Level</th>
<th>Data Dimension</th>
<th>Spatial Resolution</th>
<th>Temporal Resolution</th>
<th>Map Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>VNP21</td>
<td>L2</td>
<td>3232 lines by 3200 pixels</td>
<td>750m at nadir Swath, Twice-daily</td>
<td>None, (lat, lon tagged)</td>
<td></td>
</tr>
<tr>
<td>VNP21A1D/VNP21A1N</td>
<td>L3</td>
<td>1200 rows by 1200 columns</td>
<td>1 km Day and Night</td>
<td>Sinusoidal</td>
<td></td>
</tr>
<tr>
<td>VNP21A2</td>
<td>L3</td>
<td>1200 rows by 1200 columns</td>
<td>1 km Eight day</td>
<td>Sinusoidal</td>
<td></td>
</tr>
<tr>
<td>VNP21C1</td>
<td>L3</td>
<td>3600 by 7200 global</td>
<td>0.05 deg Daily</td>
<td>Climate Modeling Grid</td>
<td></td>
</tr>
<tr>
<td>VNP21C2</td>
<td>L3</td>
<td>3600 by 7200 global</td>
<td>0.05 deg Eight day</td>
<td>Climate Modeling Grid</td>
<td></td>
</tr>
<tr>
<td>VNP21C3</td>
<td>L3</td>
<td>3600 by 7200 global</td>
<td>0.05 deg Monthly</td>
<td>Climate Modeling Grid</td>
<td></td>
</tr>
</tbody>
</table>

VNP21A1/A2 Daily (left) and 8-day (right) Daytime Land Surface Temperature (LST) h08v05
Climate Modeling Grid (CMG) Products

VNP21C1 LST_Day 2018-230
Climate Modeling Grid (CMG) Products

VNP21C1 Emis14 Day 2018-230

8.55 micron
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Stage-1 Validation Sites: California

- Algodones Dunes
- Tahoe
- Redwood NP
- Algodones Dunes
Bias = 0.1 K
RMSE = 0.6 K
N = 47

Redwood NP
LST Validation Jan/Aug 2018

Bias = 0.5 K
RMSE = 0.5 K
N = 11

VNP21 LST [K]

In situ LST [K]

Day
Night

Tahoe
Algodones Dunes

LST Validation Jan/Aug 2018

Bias = 0.2 K
RMSE = 1.6 K
N = 41

SVA = 65°
PWV = 4.5 cm
Smoke from wildfires

VNP21 LST [K]

350
340
330
320
310
300
290
280
270

In situ LST [K]

270 280 290 300 310 320 330 340 350

Day
Night
Outline

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LST continuity VIIRS/MODIS Aqua

- 54 scenes CONUS
- JFM, ASO 2012
- SNO’s

Graph showing bias (RMSE) for TES and Split-Window (SW):
- TES: 0.38 (0.89) K
- SW: 1.96 (2.63) K

Counts

LST Difference (VIIRS minus MODIS) [K]

Hulley et al. 2018
Emissivity Continuity

Grassland, TX

Reduced grassland cover due to low winter rainfall 2013

Hulley et al. 2018
Outline

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• Split-window approaches, e.g. MYD11 assume **fixed emissivity** over different land classes, e.g. Urban emissivity = 0.97 (green)

• MYD21 physically retrieves the emissivity state of land surface
San Fernando Valley Turf Removal Program 2014

1.5 °C temperature rise since turf removal program started in 2014

AFTER: Photo from the same vantage point after the project is completed. Turf has been replaced with California Friendly plants.
Annual average days with nighttime LST > 20°C

MODIS Aqua LST 2002-2018

Annual average nighttime days > 20°C

(b) Anaheim

$r^2 = 0.93$

$p = 0.00$

Trend: 0.6 ± 0.21 days/yr

Hulley et al. 2018
Summary

1. MxD21 and VNP21 algorithms implemented at MODAPS and Land-SIPS and in reprocessing
2. MxD21/VNP21 uncertainties at ~1 K level for LST and ~1.5% for emissivity
3. MXD21/VNP21 continuity demonstrated at the ~0.5 K level
4. Urgent user need to reduce overall number of MODIS LST products (currently 10 product types including MxD11 and MxD21)
<table>
<thead>
<tr>
<th>VNP21</th>
<th>Land Surface Temperature and Emissivity (LST&amp;E) Product Status</th>
</tr>
</thead>
</table>
| **Status** | • Undergoing final science test at LSIPS.  
• Once complete, review by LDOPE, science team, and LPDAAC  
• Reprocessing to begin after review.  
• Note: VNP21 LST&E algorithm is identical to MxD21 LST&E algorithm. (Hulley et al. 2017, NASA’s MODIS and VIIRS Land Surface Temperature and Emissivity Products: A Long-Term and Consistent Earth System Data Record) |
| **Documentation** | Complete; ATBD and User Guide  
https://viirsland.gsfc.nasa.gov/Products/NASA/LSTESDR.html |
| **LST&E Products** | • Daily 5-min L2 Swath 1km  
• Daily L3 Global 1km  
• 8-day L3 Global 1km |
| **Validation Status** | Stage 1: https://lpvs.gsfc.nasa.gov/LSTE/LSTE_home.html  
±1 K accuracy demonstrated over U.S. sites (Islam et al. 2017) |
| **Future plans** | 1. Produce Climate Modeling Grid (CMG) products  
• VNP21C1 – Daily 0.05 deg gridded LST&E  
• VNP21C2 – 8-day 0.05 deg gridded LST&E  
• VNP21C3 – Monthly 0.05 deg gridded LST&E  
2. Produce Emissivity products for mid-IR bands M12, M13  
• Ensure continuation of LST&E MEaSUREs products (JPL)  
• Used by atmospheric sounding community as first guess in air temperature/water vapor retrievals |
Land Cover Change Detection

MOD21 Band 29 (8.55 µm) Emissivity, Jornada Experimental Range

Normalized Emissivity

Normalized NDVI

2001 2002 2003 2004 2005 2006

Overgrazing Recovery

Overgrazing

Recovery

Normalized Emissivity

Normalized NDVI

2001 2002 2003 2004 2005 2006

Overgrazing

Recovery

Normalized Emissivity

Normalized NDVI
Cryosphere Studies

MOD21 Band 32 (12 µm) Emissivity, Greenland, August 2004

Extreme Melt Zones

Incipient Melt Zones

Hulley et al. 2014
MODIS Heat Vulnerability Index (HVI)

NASA LCLUC
ECOSTRESS Applications project

Hulley and Shivers, 2018
Heat advisories and mitigation

Heat mitigation

Identify optimal locations for cooling centers

Advise on realistic health advisories

<table>
<thead>
<tr>
<th>Date of Release</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 01</td>
<td>Air Quality Advisory: Air is unhealthy in Santa Clarita Valley</td>
</tr>
<tr>
<td>July 30</td>
<td>Air Quality Advisory: Air is unhealthy in Antelope Valley and Santa Clarita Valley</td>
</tr>
<tr>
<td>July 30</td>
<td>Heat Alert: High temperatures forecast for Pomona area and San Fernando Valley</td>
</tr>
<tr>
<td>July 29</td>
<td>Air Quality Advisory: Air is unhealthy in parts of LA County</td>
</tr>
<tr>
<td>July 28</td>
<td>Air Quality Advisory: Air Quality is unhealthy in parts of LA County</td>
</tr>
<tr>
<td>July 27</td>
<td>Air Quality Advisory: Air is unhealthy in parts of LA County</td>
</tr>
<tr>
<td>July 26</td>
<td>Air Quality Advisory: Air is unhealthy in parts of LA County</td>
</tr>
</tbody>
</table>
Outline

1. Algorithm and product updates
2. Validation
3. Product unification (MOD11+MOD21)
4. Continuity
LST Uncertainty Model

Hulley et al. 2012

\[ \delta LST_{MODIS} = a_o + a_1 TCW + a_2 SVA + a_3 TCW \cdot SVA + a_4 TCW^2 + a_5 SVA^2 \] (10)

- \( a_i \): Regression coefficients dependent on surface type (gray, bare, transition)
- \( SVA \): Sensor view angle
- \( TCW \): Total column water estimate (cm), e.g. from MOD07, NCEP

Combined LST is weighted mean:

\[
\overline{LST} = \frac{1}{(w_1 + w_2)} (w_1 \cdot LST_1 + w_2 \cdot LST_2)
\] (1)

\[
w = \frac{1}{\delta^2}
\]
MODIS LST Validation Summary

- MOD11 larger uncertainty over bare regions (3-5 K)
- MOD11 more stable over graybodies (higher precision)
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MODIS Aqua/VIIRS Matchups for 2012 over Contiguous US:

Winter (Jan, Feb): 24 granules
Summer (Aug, Sep): 30 granules

Observation Criteria:
1. Time: <10 min
2. Angular separation: <2°
3. View angles < 10°
LST&E Validation Sites (Stage 1)

Temperature-based and Radiance-based validation methods
Uncertainty Analysis

Hulley et al. 2012

\[ \delta LST_{MODIS} = a_0 + a_1 TCW + a_2 SVA + a_3 TCW \cdot SVA + a_4 TCW^2 + a_5 SVA^2 \]  \hspace{1cm} (10)

- \( a_i \) = regression coefficients dependent on surface type (gray, bare, transition)
- \( SVA \) = sensor view angle
- \( TCW \) = total column water estimate (cm), e.g. from MERRA2, NCEP
Uncertainty Analysis

Estimated Uncertainty [K] vs. LST error [K]

- Red circles: Day
- Blue circles: Night

Note: Arrows indicate trend direction.