IMPROVEMENT in GLOBAL DROUGHT WATCH FROM S-NPP VEGETATION HEALTH (VH)

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National Environmental Satellite Data and Information Services (NESDIS)
Center for Satellite Applications and Research (STAR)

JPSS
August 27, 2015
Drought (D) as Natural Disaster

- D. affects the largest number of people
- D. is the most costly
- D. is a part of earth’s climate
- D. occurs every year
- D. does not recognize borders, political & economic differences

<table>
<thead>
<tr>
<th>Disaster Type</th>
<th>Affected</th>
<th>Killed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weather</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought</td>
<td>51</td>
<td>38</td>
</tr>
<tr>
<td>Flood</td>
<td>38</td>
<td>9</td>
</tr>
<tr>
<td>Hurricane etc.</td>
<td>8</td>
<td>27</td>
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<tr>
<td><strong>Geological</strong></td>
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<td></td>
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<tr>
<td>Earthquake</td>
<td>2</td>
<td>18</td>
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<tr>
<td>Volcano</td>
<td>&lt;1</td>
<td>&lt;1</td>
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</tbody>
</table>

Total People Affected: **2.8 billions**

Total People Killed: **3.5 millions**
Drought Disasters during 1980-2008

• No of people affected 1,551,455,112
  India 2002 - 300,000,000

• No of people killed 558,565
  Ethiopia 1983 - 300,000

• Economic damages
  China 1994 $ 13.8 bil
  Australia 1981 $ 6.0 mil
  USA 1988 $ 40-60 bil
  USA 2006-2015 California $ 2.7 bil (21,000 job loss)

http://www.preventionweb.net/english/hazards/statistics/?hid=59
Drought Unique Features

- **Start** unnoticeably
- **Build-up** slowly
- **Develop** cumulatively
- **Impact** cumulative & not immediately observable
- **Mitigation:** When damage is evident it’s too late to mitigate the consequences
- **Drought type:** Meteorological, Agricultural, Hydrological, Socio-Economic
Normalized Difference Vegetation Index & Brightness Temperature
VH Requirements

• Real time NDVI and BT
• Climatology of NDVI and BT
Vegetation Condition (VCI) and Temperature condition (TCI) indices
2012 Global Vegetation Health (VH)
From AVHRR/NOAA-19 Operational Polar Orbiting Satellite

US Drought
Crop losses
Fires

Drought
SE. Europe
S. Ukraine
N. Kazakhstan

Fires
E. Russia

Malaria Risk
Sub Sahara AFRICA
S. AFRICA
W. India

Global Vegetation Health
October 9, 2012
From NOAA-19 Operational polar orbiting satl

2012 - Extreme drought in the USA, southern UKRAINE, northern KAZAKHSTAN,
    - Severe drought in eastern INDIA, Kenya & South America
2011 – Exceptional drought in Texas (USA) and the Horn of AFRICA
2010 - Exceptional drought in RUSSIA and UKRAINE
Eric Luebehusen, Analyst for FAS & WAOB (ELuebehusen@oce.usda.gov)

“the 4km VHI is a very big hit at USDA with senior level staff, economists, and meteorologists. I often get specialized requests for maps of the 4 km VHI “as soon as it’s available”, and the data is used to support our monthly crop yield and production estimates, particularly in the mid-latitudes”
VIIRS versus AVHRR

Channels

Climate data records problems

Normalized Difference Vegetation Index (NDVI)

Brightness Temperature (BT)
NDVI (SMN): AVHRR-VIIRS time series

Regression Coefficients: $Y = a + b \times X$

- $a = -0.0374925$
- $b = 0.703031$

- Mean (a) = -0.0373363
- Mean (b) = 0.702253

Correlation Coefficients: $X = \text{VIIRS-SM:mean_SMN}$, $Y = \text{VHP-SM:SMN}$

- Mean (CC) = 0.939411

Data used: 2012 week 27 to 2013 week 30

- lon: [−180.00, 180.00]
- lat: [−40.00, 40.00]
BT (SMT): AVHRR-VIIRS COR and TSer

Regression Coefficients
\[ Y = a + b \times X \]
- mean(a) = -12.5047
- mean(b) = 1.04711

Correlation Coefficients
- mean(CC) = 0.963497

\[ \text{lon} = [-180.00, 180.00], \text{lat} = [-40.00, 60.00] \]

Data used: 2012 week 35 to 2013 week 47

Nsamples = 8638092
CC = 0.9610
RMSE = 3.51405
Towards NDVI & BT Climatology

Graph 1: NDVI Time Series
- SMN, AVHRR
- SMN, VIIRS
- SMN, VIIRS adjusted

Graph 2: BT Time Series
- SMT, AVHRR
- SMT, VIIRS
- SMT, VIIRS adjusted
CAL/VAL: VH-Biomass & Corn Yield Modeling & Prediction

Pasture biomass vs VCI, MONGOLIA

MONGOLIA
Biomass

Corn yield vs VCI, ZIMBABWE

ZIMBABWE
Corn
CAL/VAL: VH-Crop Losses Prediction: USA, Kansas

Winter Wheat

Sorghum

Corn

Observed & Predicted Yield, USA, Kansas
AVHRR-based VHI & VCI

Insurance Payment

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<tr>
<th>Year</th>
<th>Value</th>
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<tr>
<td>2006</td>
<td>1.4 mln</td>
</tr>
<tr>
<td>2007</td>
<td>3.6 mln</td>
</tr>
<tr>
<td>2008</td>
<td>1.3 mln</td>
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<tr>
<td>2009</td>
<td>1.0 mln</td>
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</tbody>
</table>

Vegetation Health Moisture Condition

VH-based crop condition & Insurance payment (Grivna), UKRAINE

Source: NOAA and "Strahovaia Grupa TAC"
VH-based Drought Stress & % state with pasture & range land in poor & very poor conditions, May 6, 2013

% Poor Pastures

VH-based Drought Stress (NOAA), May 6, 2013 & Percent Winter Wheat Area in Poor and Very Poor Conditions (USDA), May 5, 2013

% Poor Winter Wheat

Low | High
---|---
0 | 3

Winter Wheat (hard, soft & white) major area
Users attending Vegetation Health WEB

WEB page total users from a day of calculation started in Nov 2010

- 2010: 2,459
- 2011: 25,866
- 2012: 38,243
- 2013: 56,176
- 2014: 58,855
- 2015: 66,000

Aug 25: 45,000

VALIDATION: VCI/VIIRS vs VCI/AVHRR
VALIDATION:
TCI VIIRS vs AVHRR
Sep 9, 2014
Vegetation health (VHI)

NOAA-19/AVHRR

S-NPP/VIIRS

VEGETATION HEALTH. August 6, 2015
• Drought affects Global Food Security by reducing agricultural production below consumption.
• Since 2000, this occurred 8 years out of 13.
• Early drought detection and accurate monitoring its area, intensity, duration & impacts is important for mitigation drought consequences.
• Vegetation health (VH) method applied to SNPP/VIIRS data greatly improve drought watch & impact assessment.
• The two images showing similar patterns, indicate much more details of drought/no drought areas along the rivers: at the background of drought (red) no drought (yellow and green) is observed along the rivers (western part of 1 km image).
California Drought from USDM & VHI

California Drought from US Drought Monitor

California Drought from 16 km NOAA-19 Vegetation health index (VHI)

California Drought from 0.5 km S-NPP/VIIRS Vegetation health index
S-NPP/VIIRS Vegetation Health

S-NPP/VIIRS-500m Vegetation health, June 12, USA, California, Central Valley
California Drought Dynamics & Economic Impacts in 2015

Economic Impacts of California Drought

SUMMARY

• VH algorithm requires NDVI & BT:
  (a) Real time (from VIIRS)
  (b) Climatology (from AVHRR)
• VIIRS/VH indices (VHI, VCI & TCI) are validated against AVHRR/VH because AVHRR’s VH are validated against in situ data
• VIIRS/ NDVI & BT are different than AVHRR
• VIIRS/NDVI & BT are adjusted to AVHRR (in order to use climatology)
• The adjustments are stable over time and correlation is strong
• FURTHER Development:
  (a) New climatology from VIIRS
  (b) High resolution VH
  (c) New VH products
BACK UP
Correlation: Yield anomaly (dY) vs VCI, Kansas, USA

Cor. Coeff. vs Growing season:
- Winter Wheat
- Corn
- Sorghum

Yield anomaly (dY) vs VCI for different crops in Kansas, USA.
AVHRR/VH-Crop Yield Correlation
Validation: VCI
Correlation of VIIRS & AVHRR
Jan 7, 2015 & Sep 9, 2014

VCI, Jan. 7 2015 (week 1)
Normalized Histogram

- AVHRR (1)
- VIIRS (2)

Nsamples = 155015
mean1 = 52.8503
mean2 = 52.7104
std1 = 24.4400
std2 = 23.2928
Diffmax = 96.5556
Diffmin = -100.000
mean(diff) = -0.139904
stddev(diff) = 49.0099

VCI, Sep. 9 2014 (week 36)
Normalized Histogram

- AVHRR (1)
- VIIRS (2)

Nsamples = 173313
mean1 = 55.3912
mean2 = 54.4912
std1 = 21.3344
std2 = 23.0444
Diffmax = 96.5980
Diffmin = -81.6950
mean(diff) = -0.899956
stddev(diff) = 23.2617

Y = a + b * X
a = 18.2694
b = 0.651672

VIRS

Samples = 155015
CC = 0.6838
RMSE = 16.9969

VIRS

Samples = 173313
CC = 0.4527
RMSE = 20.5482
Validation: TCI
Correlation of VIIRS & AVHRR
Jan 7, 2015 & Jul 1, 2014

Jan 7, 2015

Figures show scatter plots and normalized histograms for VIIRS and AVHRR data on Jan 7, 2015. The data includes
- Mean values for each channel
- Standard deviation
- Difference max and min
- Mean and stddev of differences

(reqired values)

Jul 1, 2014

Similar figures are shown for Jul 1, 2014 with
- Regression equation: $Y = a + b \cdot X$
- Additional statistics

(reqired values)
Validation: VHI
Correlation of VIIRS & AVHRR
Jan 7, 2015 & Sep 9, 2014

VHI, Jan. 7, 2014 (week 1)
Normalized Histogram

- AVHRR (1)
- VIIRS (2)

Nsamples = 155015
mean1 = 43.7866
mean2 = 43.7382
std1 = 14.7389
std2 = 15.7933
Diffmax = 89.5337
Diffmin = -63.4900
mean(diff) = -0.048475
stddev(diff) = 45.7859

VHI, Sep 9, 2014 (week 36)
Normalized Histogram

- AVHRR (1)
- VIIRS (2)

Nsamples = 173313
mean1 = 46.3055
mean2 = 44.4286
std1 = 13.7028
std2 = 15.3751
Diffmax = 73.2884
Diffmin = -53.7011
mean(diff) = -1.87685
stddev(diff) = 45.6778

Y = a + b * X
a = 21.8202
b = 0.500564

Samples = 155015
CC = 0.4671
RMSE = 13.9643

Y = a + b * X
a = 22.4342
b = 0.474985

Samples = 173313
CC = 0.4233
RMSE = 13.9296
Moisture & Thermal Condition

Vegetation Condition 2015, California (500 m)
Percent Western US under Drought

Drought Area & Intensity by weeks: Western United States, 1982-2014
Days with Drought
World Grain Production-Consumption, 1970-2013

Droughts

2013 - Argentina, Brazil, Australia, USA
2012 – USA
2011 – USA
2010 – Russia, Ukraine, Kazakhstan, Argentina
2007 – Australia, China, Argentina, Brazil
2003 – USA, Europe, Australia, India, China
2002 – USA, India, Australia, S. Africa
2001 - China
1996 – USA, Russia, Argentina, Kazakhstan Australia
1988 – USA

Total World Grain
(Wheat, Corn, Rice)

Every week on Thursday
## 2.5-day VH WEB view (May 4-6, 2015)

### Page Views May 1-6, 2015

<table>
<thead>
<tr>
<th>STAR Vegetation Health Site</th>
<th>Today May 6</th>
<th>Yesterday May 5</th>
<th>This Month May 1-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>132</td>
<td>206</td>
<td>806</td>
</tr>
</tbody>
</table>

### Countries used Vegetation Health WEB during May 4-6, 2015

<table>
<thead>
<tr>
<th>153 Hits</th>
<th>30.60% United States</th>
<th>🇺🇸</th>
</tr>
</thead>
<tbody>
<tr>
<td>81 Hits</td>
<td>16.20% South Africa</td>
<td>🇿🇦</td>
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<tr>
<td>54 Hits</td>
<td>10.80% Switzerland</td>
<td>🇨🇭</td>
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<tr>
<td>41 Hits</td>
<td>8.20% Australia</td>
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<tr>
<td>17 Hits</td>
<td>3.40% Mexico</td>
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<td>16 Hits</td>
<td>3.20% India</td>
<td>🇮🇳</td>
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<tr>
<td>16 Hits</td>
<td>3.20% Armenia</td>
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<td>11 Hits</td>
<td>2.20% France</td>
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<tr>
<td>10 Hits</td>
<td>2.00% Germany</td>
<td>🇩🇪</td>
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<td>9 Hits</td>
<td>1.80% Dominican Republic</td>
<td>🇩🇴</td>
</tr>
<tr>
<td>8 Hits</td>
<td>1.60% United Kingdom</td>
<td>🇬🇧</td>
</tr>
<tr>
<td>7 Hits</td>
<td>1.40% Myanmar</td>
<td>🇬🇲</td>
</tr>
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<td>7 Hits</td>
<td>1.40% Korea, Republic Of</td>
<td>🇰🇷</td>
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<td>7 Hits</td>
<td>1.40% Spain</td>
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<td>6 Hits</td>
<td>1.20% Ukraine</td>
<td>🇺🇦</td>
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<td>5 Hits</td>
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<td>1.00% China</td>
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<td>4 Hits</td>
<td>0.80% Romania</td>
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</table>
VH-Web Visitors

August 24, 2015, by 10 am

Countries during Aug 20-24

<table>
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<tr>
<th>Country</th>
<th>Flag</th>
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</thead>
<tbody>
<tr>
<td>United States</td>
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<td>Germany</td>
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<td>India</td>
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<td>Russian Federation</td>
<td>Russian Federation Flag</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Ukraine Flag</td>
</tr>
</tbody>
</table>
Conclusions

2014 World Population 7.3 bil. Increases with Accelerating Rate; World Grain Production Increases with Decelerating Rate.

Grain supply drops below demands (in the 21st century 8 years out of 15)

Severe Droughts - Reduces Global Grain Production 4-7% every 4-6 years; Moderate Drought – Reduces Grain 1-3% every 2-3 years.

Satellite-based Vegetation Health (VH) Technology Provide Tools for Drought Monitoring & 1-2 Month Advanced Prediction of its Start/End, Area, Intensity, Duration and Impacts.

VH Provide Prediction of Drought-related Crop & Pasture Losses: (a) 1-2 Months in Advance of Harvest, (b) During ENSO years 3-4 months prediction.

Drought Area & Intensity has not Changed during the Period of Strong Global Warming.
ENSO impacts on global vegetation health. Large scale events like El Nino/La Nina can affect many regions of the world. Using the VHI, one can assess which regions of the world are being most affected. Red boxes show regions under significant stress and blue boxes show regions with good vegetation growth conditions. Note the global pattern shifts between El Nino and La Nina. 2 to 4 months advance notice can be provided for the affected regions using VHI information; time enough for planners to take action to mitigate seasonal changes. Courtesy of F. Kogan.

VH-Drought Prediction from ENSO (3-6 months)

1982-83

1988-89
NDVI-based Land Cover Change trend, 1982-2007

Percent Greenness Change during 1982-2007 by Latitudinal Circles

Annual
-20 -10 0 10 20

Summer
-20 -10 0 10 20

Equator
Climate: Percent Land under Drought

- **World**
- **Northern Hemisphere**
- **Southern Hemisphere**

Legend:
- Yellow: Severe-to-Exceptional
- Pink: Extreme-to-Exceptional
- Red: Exceptional

Percent drought area

Years: 1985 to 2010
Percent Drought-affected Grain Crop Area

CHINA

U.S.A.

INDIA
## AVHRR Data for Land Use

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Advanced Very High Resolution Radiometer (AVHRR)</th>
<th>Visible Infrared Imaging Radiometer Suite (VIIRS)</th>
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<tbody>
<tr>
<td>Satellites</td>
<td>NOAA: NOAA-7, 9, 11, 14, 16, 18, 19 S-NPP JPSS</td>
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<tr>
<td>Data Resolution</td>
<td>Spatial - 1, 4 (GAC), 8 &amp; 16 km (GVI); Temporal - 7-day composite</td>
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<tr>
<td>Period</td>
<td>35-year (1981-2015)</td>
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<td></td>
<td>3.5-year (2011-2015)</td>
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<tr>
<td>Coverage</td>
<td>World (75 N to 55 S)</td>
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<tr>
<td>Channels</td>
<td>VIS, NIR, Thermal</td>
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</tr>
</tbody>
</table>
Mega-Drought in Western USA

Figure 1. Vegetation health (from VHI) in August 2005 through 2014.
VALIDATION:
VHI VIIRS vs AVHRR
Sep 9, 2014
Biomass vs VHI, Turkmenistan

Erbent, Turkmenistan, 1982-2009 (Rsq=0.67)

Lekker monitoring site (36°16' N, 63°42' E)  \( R^2=0.885 \), n=35, 1982-2005 Southeastern Turkmenistan.
Winter Wheat Yield
Vinnitsa Obl. UKRAINE

![Graph showing Winter Wheat Yield observed and predicted values from 1997 to 2009. The solid line represents the yield, the dashed line represents the predicted yield, and the correlation coefficient R is 0.839. The graph includes an independent test.]
Winter Wheat Yield
Odessa Obl. UKRAINE

\[ dY = 0.286 - 0.057VH_5 + 0.067VH_6 - 0.041VH_{18} + 0.044VH_{19} \]

Partial CC: -0.57, 0.58, -0.33, 0.38

\[ R = 0.74, \ SE = 0.20 \]
### Vegetation Health data sources

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<td><strong>Coverage</strong></td>
<td>World $(75,\text{N},\text{to},55,\text{S})$</td>
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<tr>
<td><strong>Channels</strong></td>
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<tr>
<td><strong>Indices</strong></td>
<td>NDVI &amp; BT</td>
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