J14.4 INTEGRATING A REAL-TIME GREEN VEGETATION FRACTION (GVF) INTO THE LAND INFORMATION SYSTEM (LIS)

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1. INTRODUCTION

The greenness of vegetation is a very important input into land surface models when computing parameters such as fluxes, evapotranspiration, and albedo. The Land Information System (LIS) is a highly configurable land surface modeling and data assimilation framework developed by NASA Goddard Space Flight Center and is currently in use at the Air Force Weather Agency (AFWA). LIS uses satellite- and ground based observations and model forecasts to produce estimates of land surface conditions. At AFWA, LIS uses AFWA's unique database of observational and satellite-based meteorological fields and the National Center for Environmental Protection (NCEP) Community Noah land surface model (LSM) version 2.7.1 to produce gridded, global estimates of land surface parameters, such as soil moisture and temperature, surface heat and moisture fluxes, accumulation of precipitation, and snow cover. The parameter used by Noah to measure vegetation greenness is the Green Vegetation Fraction (GVF), or "the fractional area of the vegetation occupying each model grid cell." (Gutman and Ignatov 1998). According to Miller et al. (2006), parameters sensitive to a change in GVF in Noah include upward longwave radiation, latent heat flux, sensible heat flux, and ground heat flux.

2. COMPUTATION OF GVF

Gutman and Ignatov (1998) computed the GVF using the normalized difference vegetation index (NDVI) from the NOAA Advanced Very High Resolution Radiometer (AVHRR). They found that GVF can be computed from NDVI by using the equation

$$f_g = (\mathrm{NDVI} - \mathrm{NDVI_o})/(\mathrm{NDVI_\infty} - \mathrm{NDVI_o}) \qquad (1)$$

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where f_g is the green vegetation fraction, NDVI is the NDVI value from the instrument, $\mathrm{NDVI_o}$ is a constant value representing an NDVI signal for bare soil and $\mathrm{NDVI_\infty}$ is a constant value representing an NDVI signal for dense green vegetation. They computed a monthly climatology of GVF based on 5 years of data using this method, and this climatology is currently used by LIS operationally at AFWA.

Work has been ongoing to compute the GVF based on NDVI data from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Aqua and Terra satellites. This involves using equation (1) to compute the GVF based on NDVI values, however the value of $\mathrm{NDVI_\infty}$ now becomes dependent on land cover. For example, grasslands will never have an NDVI value as high as a broadleaf evergreen forest, and keeping the value constant could underestimate the GVF value in grassland areas. The values of $\mathrm{NDVI_\infty}$ for each vegetation type was found using MODIS NDVI data from 2004. The land cover map uses the International Geosphere-Biosphere Programme (IGBP) scheme, with land cover data from MODIS Terra from the period 1/1/01 to 12/31/01. These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (lpdaac.usgs.gov), and were re-gridded for ease of use by Boston University.

A new GVF value is computed at AFWA using new MODIS-based NDVI data once a day. At AFWA, NDVI is computed from MODIS radiance data over land areas without cloud cover, and stored on a 6 km polar-stereographic grid. If data exist from both Aqua and Terra in one day for a grid point, the higher value of the two is used. A 14-day average GVF is then computed using all of the GVF values available from the current day and the previous 13 days. This is done for gap-filling between daily MODIS swaths, and areas inside swaths where NDVI is not computed due to cloud cover. This averaging also helps to prevent Noah from being shocked with drastic changes.

3. INSERTION INTO LIS

A version of LIS has been modified to read in the real time MODIS-based GVF data instead of the climatology data it currently uses. It will continue to use the climatology data to fill in any gaps where the real time GVF data are not available in the 14 day average (usually due to persistent clouds or snow cover). For this paper, three time periods during the northern fall transition period were chosen to analyze differences in greenness and how much these differences change LIS outputs.

4. ANALYSIS

Previous studies (Miller et al. 2006) have shown that MODIS GVF values tend to be higher than the AVHRR climatological GVF data for almost all vegetation types and all seasons. That also appears to be the case here, at least during the autumn months. Figure 1 shows the 14-day average GVF for September 15, 2010 for the western hemisphere, with AVHRR climatology data used to fill in areas of missing data. These are the data used by LIS in the real time GVF version. Figure 2 is the AVHRR climatology currently used by LIS operationally at AFWA for September 15. Figure 3 is the MODIS real time GVF minus the AVHRR climatological GVF, and Figure 4 is the IGBP land cover map and legend that is used to determine the value of NDVI_∞ in equation (1). The areas with the biggest changes appear to be west of the Missouri River in the United States, showing higher values for the real time GVF data. Some of the biggest areas of increased GVF occur in areas classified as grasslands, which has a NDVI_∞ value that is lower than any other land cover type. The same is seen in the grassland areas just south of the Sahara Desert in Africa (not shown). As mentioned previously, grassland GVF in the climatological dataset may be underestimated due to the constant NDVI_∞ value. Some of the forested areas of Western Canada show less vegetation than climatology. The land cover of these areas is compromised of Evergreen Needleleaf Forest, Mixed Forest, and Croplands. These areas were categorized as experiencing abnormal dryness to extreme drought in September, based on the North American Drought Monitor (Figure 5).

Figures 6, 7, and 8 are the real time GVF, climatological GVF, and difference maps for October 15, 2010. It now appears that the increases of greenness shown in the real time GVF product when compared to climatology are greater than they were in September across North America. Southwestern Canada is also now showing increased vegetation. The Drought monitor still shows drought in this area, but less severe both spatially and in magnitude (Figure 9). The same grassland areas continue to show increased GVF. This difference map may indicate that this year’s transition out of the growing season may be slower than climatology. Central Brazil and Bolivia show some areas with a decrease in real time greenness when compared to climatology. As seen in Figure 10, these areas experienced below normal rainfall in September, and the land type in this area is mostly evergreen broadleaf forest (Figure 4), which has a high NDVI_∞value. Figure 8 also shows that a very small portion of the eastern Brazil coastal area shows increased GVF, this area experienced above average rainfall for the month of September, 2010, as seen in Figure 10.

Finally, Figures 11, 12, and 13 show the real time, climatology, and difference maps for November 15, 2010. The changes across North America appear to have about the same magnitude as in October, however they don’t extend as far north. Central parts of Brazil are still showing reduced greenness, but of smaller magnitude, and the east coast continues to show an increased greenness over climatology. It can be seen in Figure 14 that the low precipitation anomaly in central Brazil has been reduced in many areas in October when compared to September, and an excess of precipitation continues to show up near the east coast which correlates well with placement of the increased greenness when using the real time product, as shown in Figure 13(Deutscher Wetterdienst 2010).

Validation of net longwave radiation flux, and average surface temperature was done using the SURFRAD (Surface Radiation) Network. These data are made available through the NOAA's Earth System Research Laboratory/Global Monitoring Division - Radiation (G-RAD) (Augustine et al. 2000). The network contains 7 stations across the CONUS and is used for evaluating satellite-based estimates and validating model output. Biases and RMSEs for each of these stations are analyzed.

Data for September 13-15 are shown in Table 1, October 13-15 in Table 2, and November 13-15 in Table 3. As expected, larger changes in GVF between the climatology and real time data tend to lead to larger differences in RMSE and bias in net longwave flux and average surface temperature. There does not seem to be a trend on which model performs better overall when looking at these values. In several places the RMSEs seem to be slightly higher for the real time GVF values, yet the biases are slightly smaller in magnitude. Time series plots of these data tend to show the values of LIS using the real time GVF have bigger amplitude than those of the operational version of LIS. In September, the values show that the real time GVF version of LIS performs about as well or slightly worse than the climatological version, when comparing the two parameters. In October, the results seem more mixed. At Goodwin Creek, Bondville, Sioux Falls, and Fort Peck, the biases are generally better using real time GVF, and RMSEs are generally the same or a little worse. Time series show a small lag, where the model values rise and fall slightly ahead of the observations. It also appears that the real time GVF model output data match the observations a little better than the production version of LIS at these locations when the lag is not factored in. The smaller biases may be telling the story of accuracy of the model, while the RMSEs are larger due to the lags. These four stations are all classified as cropland or a cropland/natural vegetation mosaic. At Desert Rock and Boulder, the biases and RMSEs are generally the same or worse when using the real time GVF version. In November, LIS using real time GVF seems to be performing slightly better at most stations. An exception is Desert Rock, where using the real time GVF still seems to perform worse.

5. CONCLUSION

Integrating a real time GVF into LIS at AFWA has shown mixed results on how it affects the performance of the model. There appears to be some strong correlation between precipitation anomalies and the real time GVF when compared to climatology. When integrating this real time GVF into LIS, it appears the real time GVF performance is improving as fall progresses; however analysis over longer time periods, over more seasons, and over more areas is needed to make any strong conclusions. A longer spinup needs to be used as well to validate other parameters, such as soil temperature and moisture, which change slower over time than the surface temperature and flux parameters studied here. GVF is continuously being saved and archived, to enable LIS runs using these data of 6 to 12 months or more in the future in order to permit a more thorough analysis and validation.

6. REFERENCES

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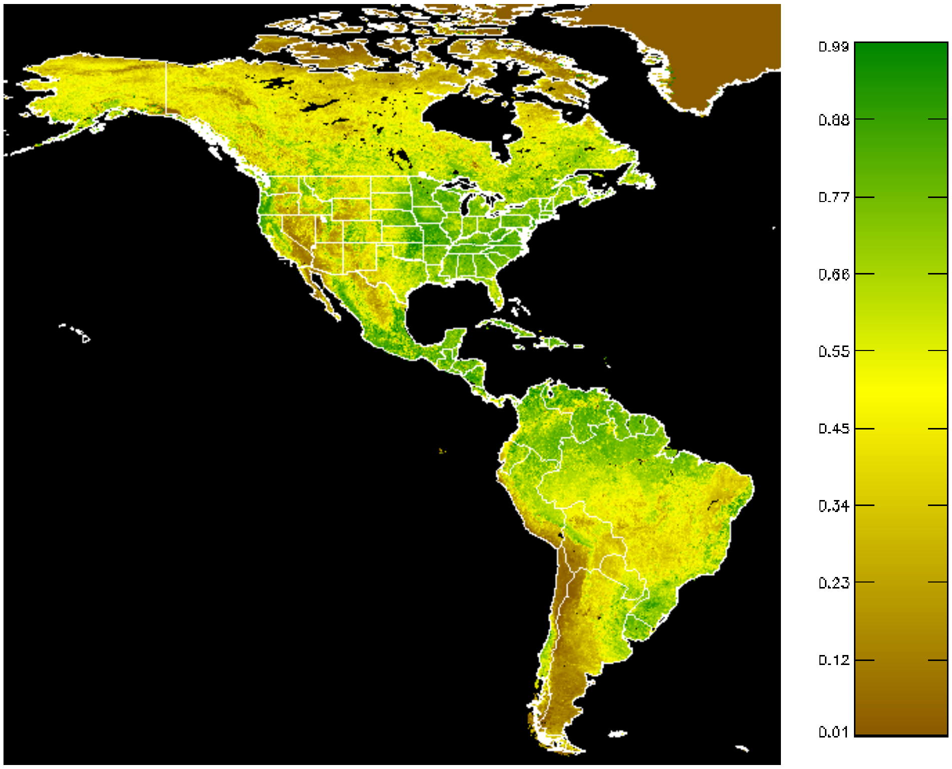

Figure 1. The 14-day average realtime GVF for September 15, 2010, with climatology inserted for areas of missing data.

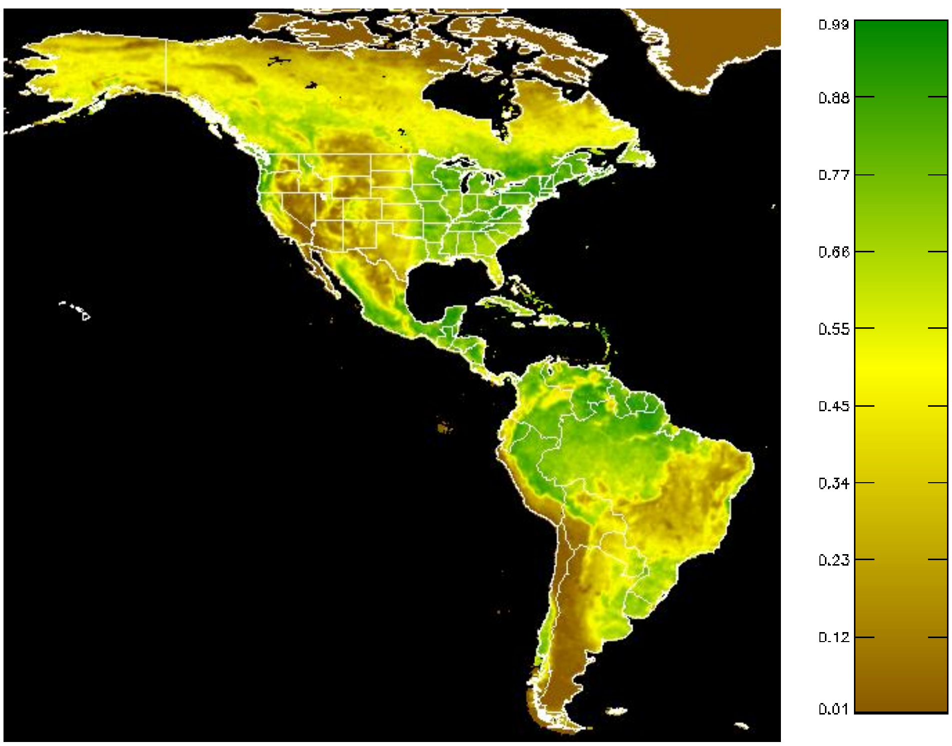

Figure 2. The AVHRR climatology GVF data for September 15, 2010, currently used for LIS in production at AFWA.

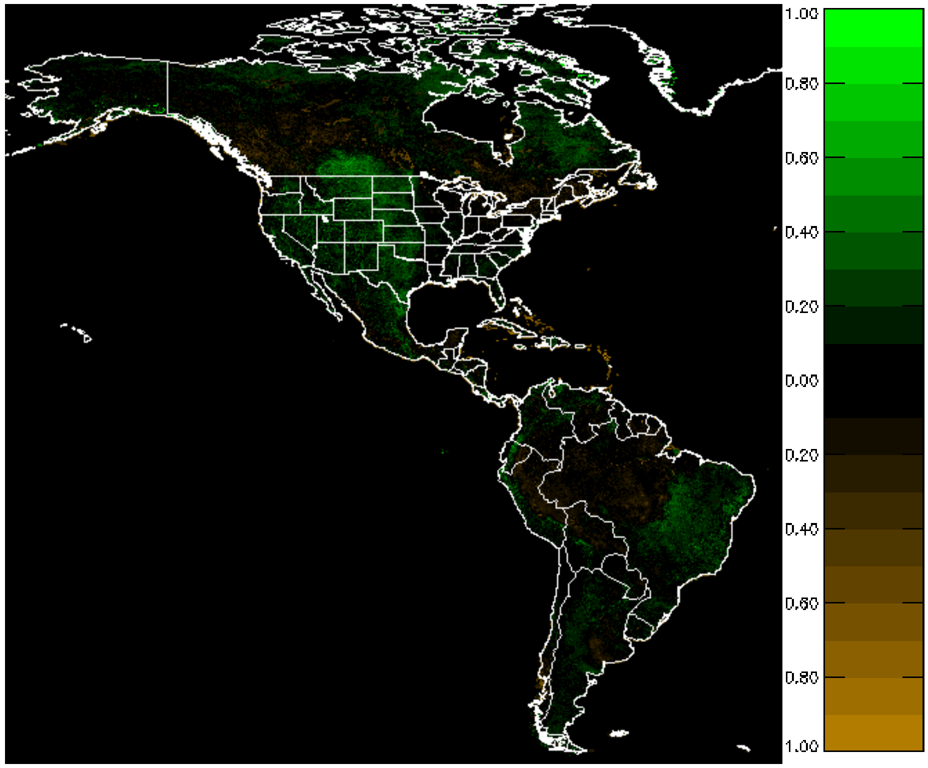

Figure 3. The realtime MODIS-based GVF minus the AVHRR climatology GVF for September 15, 2010.

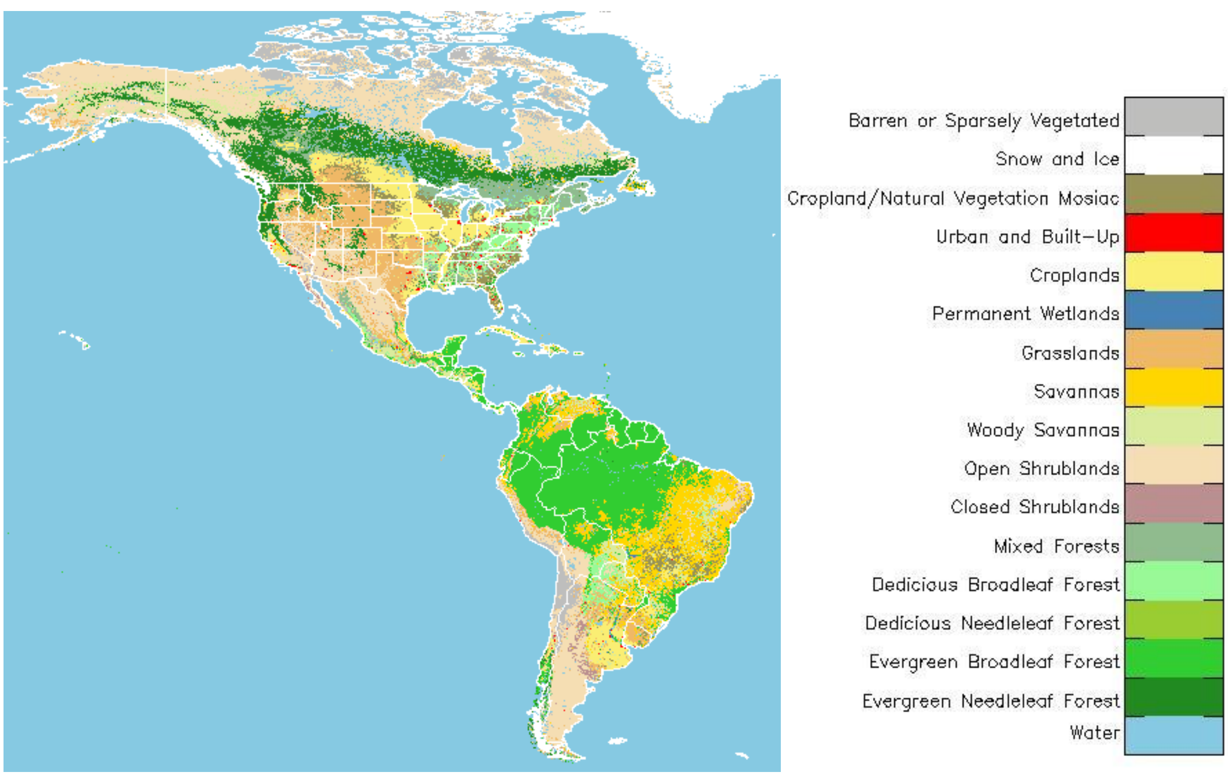

Figure 4. The IGBP scheme MODIS landcover map used by the realtime GVF based algorithm to set the value of NDVI_{∞}

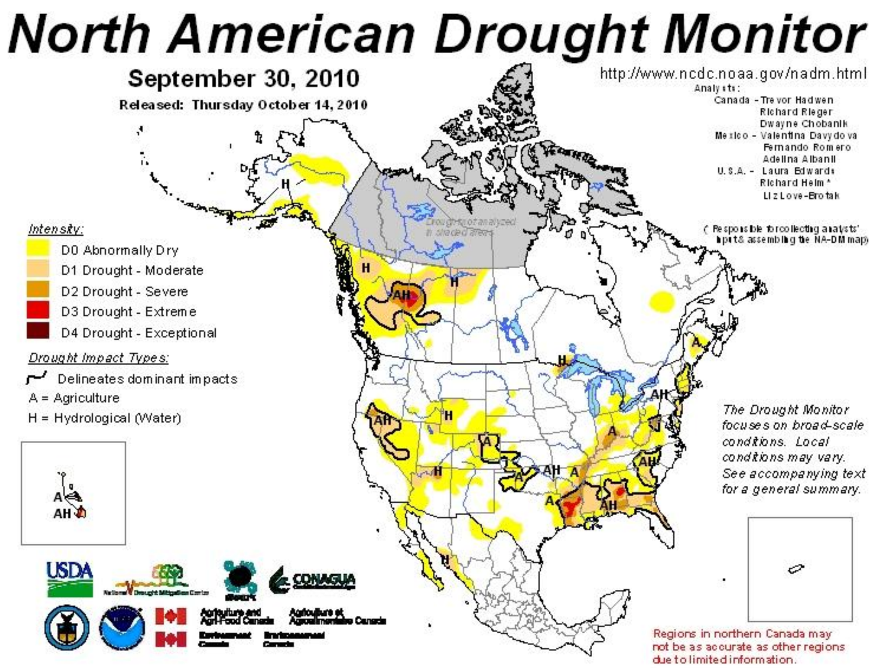

Figure 5. The North American Drought monitor for September, 30 2010.

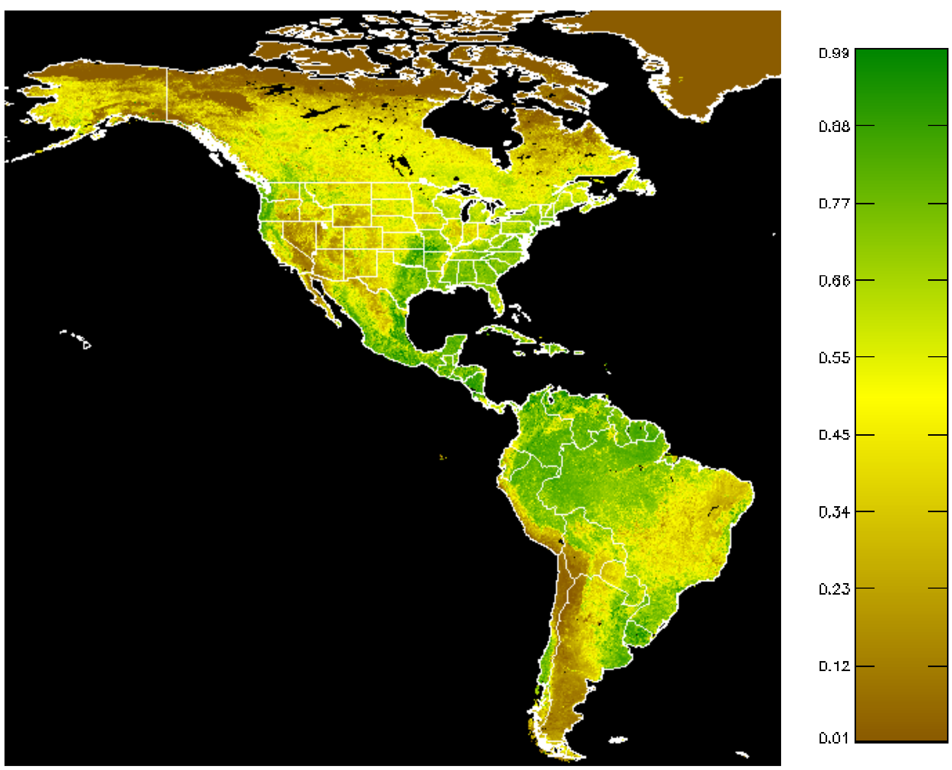

Figure 6. The 14-day average realtime GVF for October 15, 2010, with climatology inserted for areas of missing data.

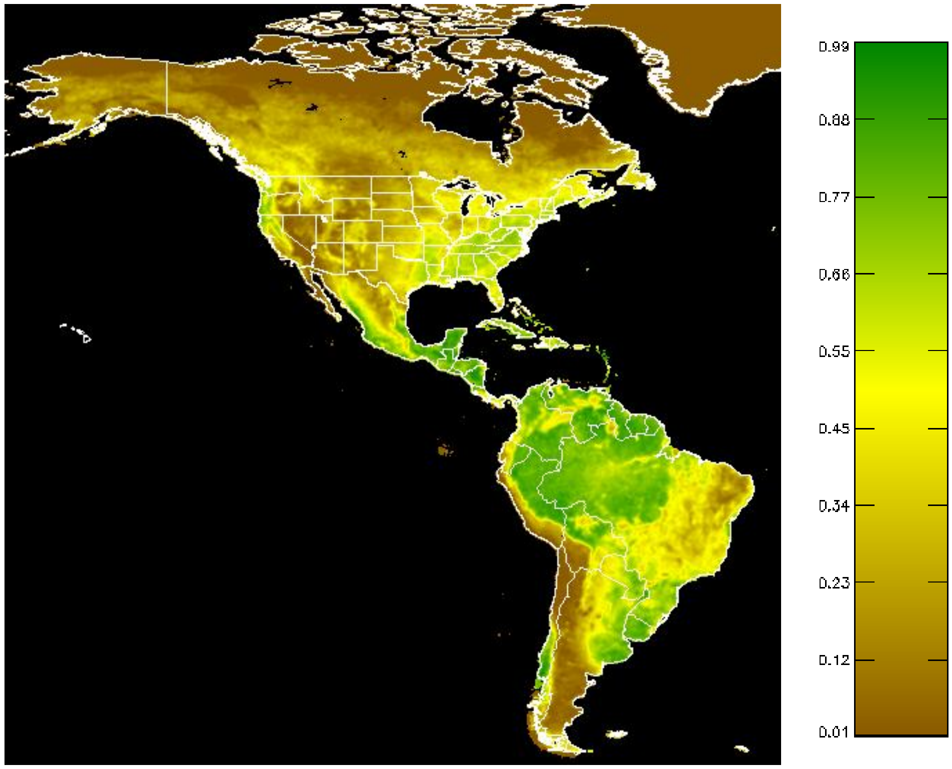

Figure 7. The AVHRR climatology GVF data for October 15, 2010, currently used for LIS in production at AFWA.

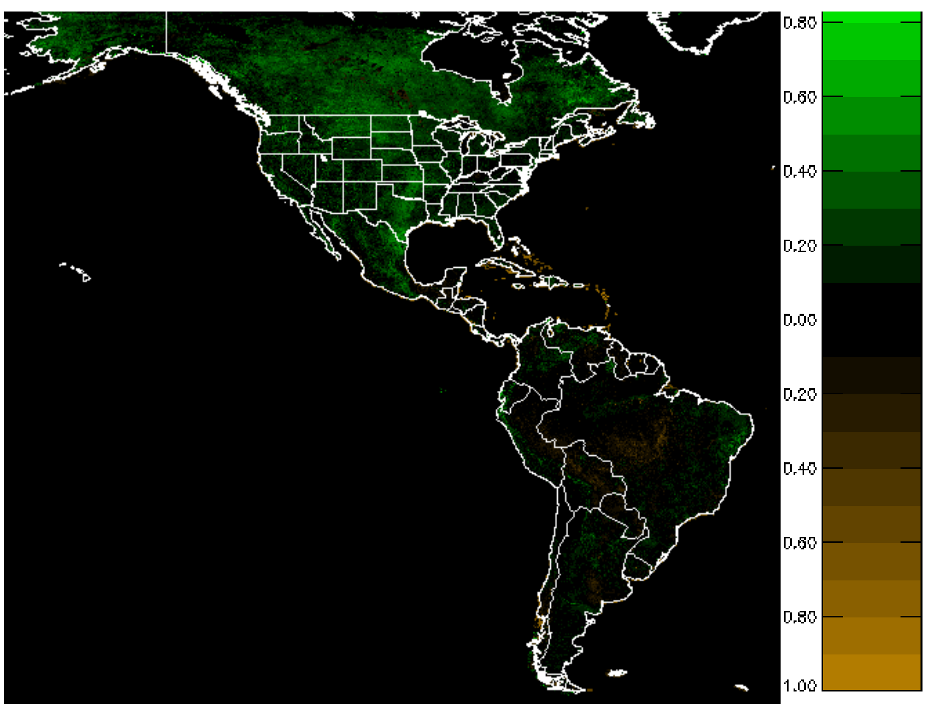

Figure 8. The realtime MODIS-based GVF minus the AVHRR climatology GVF for October 15, 2010.

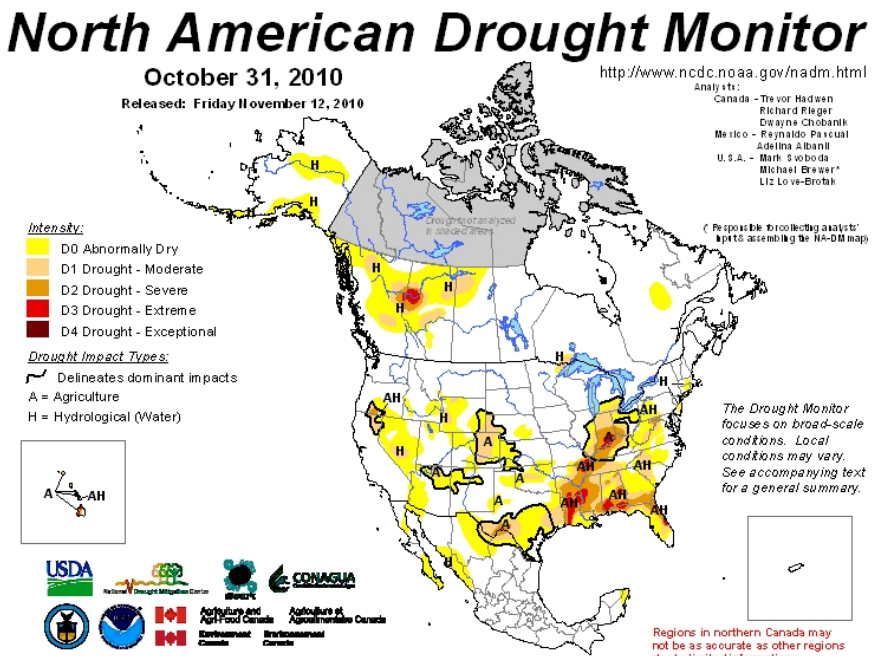

Figure 9. The North American Drought monitor for October, 31 2010.

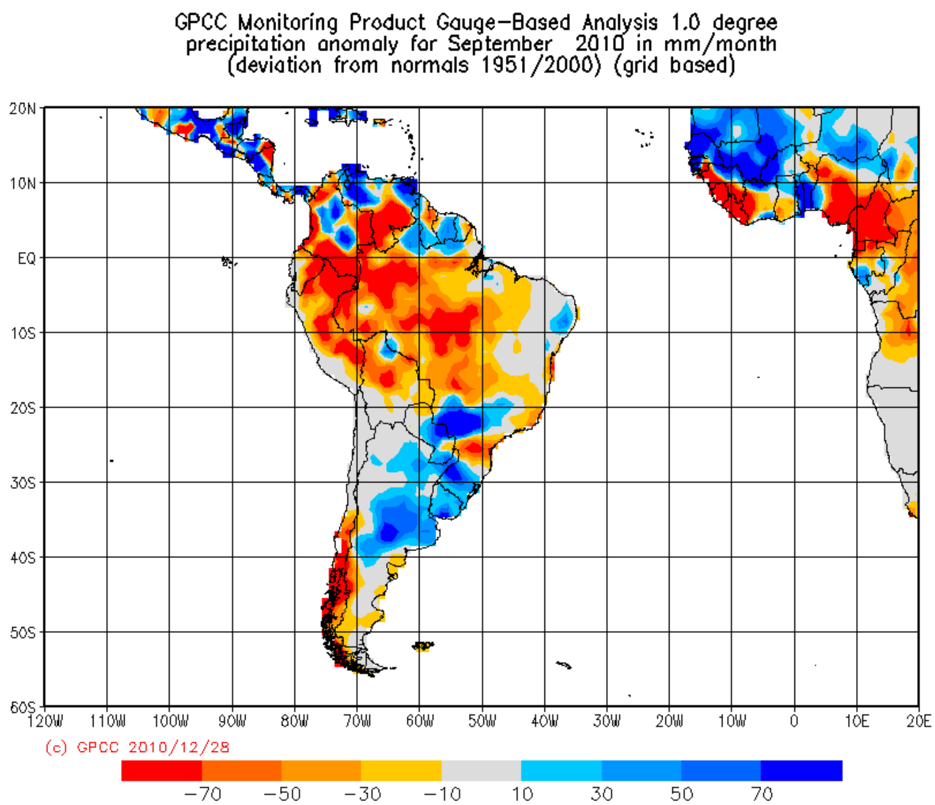

Figure 10. Precipitation anomaly over South America in September, 2010 (Deutscher Wetterdienst 2010)

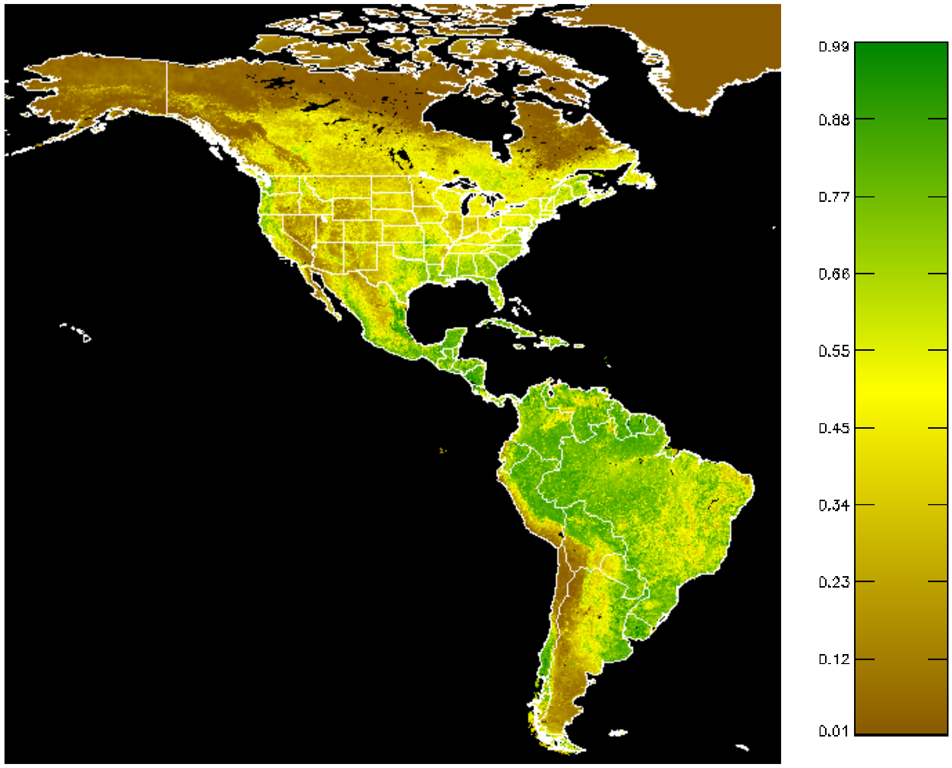

Figure 11. The 14-day average realtime GVF for November 15, 2010, with climatology inserted for areas of missing data.

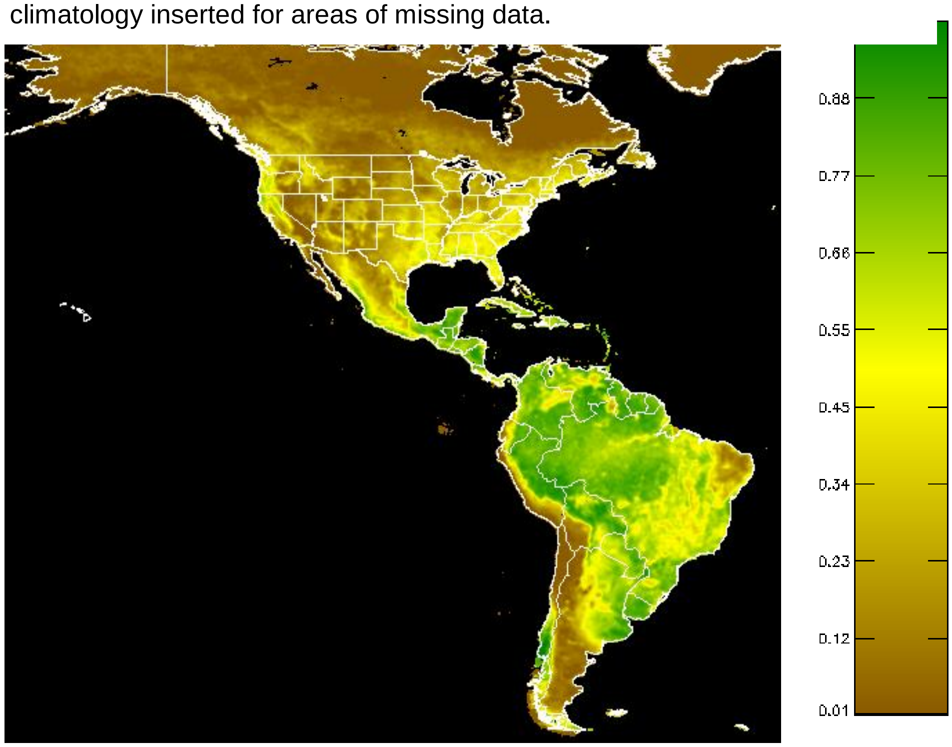

Figure 12. The AVHRR climatology GVF data for November 15, 2010, currently used for LIS in production at AFWA.

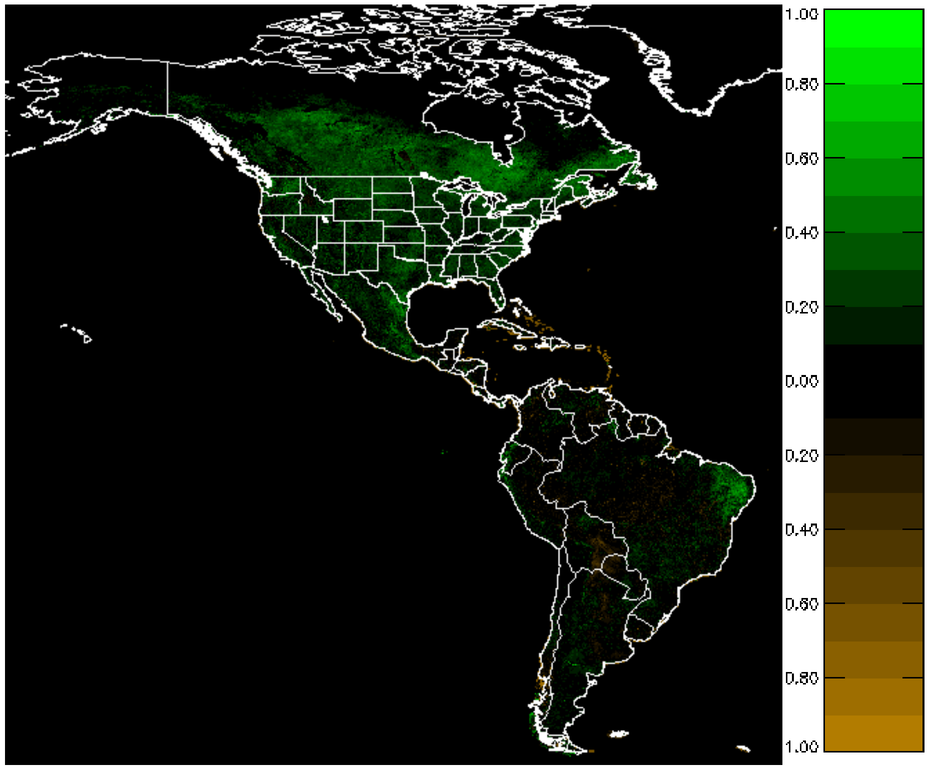

Figure 13. The realtime MODIS-based GVF minus the AVHRR climatology GVF for November 15, 2010.

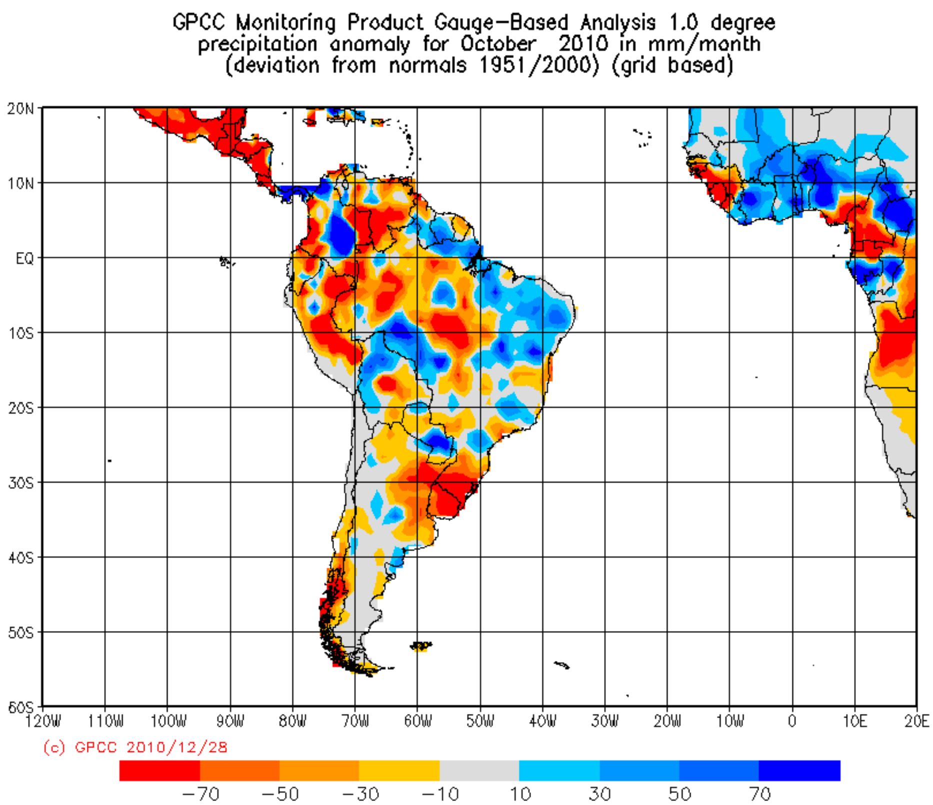

Figure 14. Precipitation anomaly over South America in October, 2010 (Deutscher Wetterdienst 2010)

	LWNET RMSE Test	LWNET RMSE Prod	LWNET Bias Test	LWNET Bias Prod	AVGT RMSE Test	AVGT RMSE Prod	AVGT Bias Test	AVGT Bias Prod	GVF Test	GVF Prod
Goodwin Creek, MS	47.30	45.28	-22.22	-23.47	7.228	6.773	0.2098	0.4515	0.85	0.71
Desert Rock, NV	43.53	41.40	22.48	20.26	6.441	6.019	-3.855	-3.466	0.12	0.01
Boulder, CO	40.98	37.35	11.06	9.805	7.114	6.166	-3.100	-2.796	0.71	0.47
Bondville, IL	27.02	27.26	-18.34	-18.26	4.180	4.252	0.1063	0.1021	0.65	0.66
Penn State, PA	28.21	28.26	-16.32	-16.44	3.837	3.823	0.07166	0.09249	0.82	0.82
Sioux Falls, SD	31.95	32.40	-14.12	-15.01	4.104	4.054	-0.3436	-0.1894	0.88	0.77
Fort Peck, MT	34.58	34.94	-24.58	-26.88	3.656	3.024	-0.4458	-0.008266	0.39	0.15

Table 1. Biases and RMSEs of net longwave flux and average surface temperature for the time period of 03Z on September 13, 2010 to 00Z on September 16, 2010 when comparing LIS running operationally (prod) at AFWA and LIS using a realtime GVF(Test). Validation is against SURFRAD data.

	LWNET RMSE Test	LWNET RMSE Prod	LWNET Bias Test	LWNET Bias Prod	AVGT RMSE Test	AVGT RMSE Prod	AVGT Bias Test	AVGT Bias Prod	GVF Test	GVF Prod
Goodwin Creek, MS	41.08	38.31	-17.64	-19.05	6.604	5.927	0.2473	0.5306	0.79	0.57
Desert Rock, NV	19.20	17.64	11.03	9.472	4.026	3.751	-1.981	-1.714	0.11	0.01
Boulder, CO	32.03	30.23	10.73	9.362	5.827	5.260	-3.109	-2.801	0.59	0.36
Bondville, IL	22.89	22.29	-10.74	-12.28	4.424	4.337	1.565	1.865	0.34	0.25
Penn State, PA	21.17	21.22	-2.357	-2.707	2.644	2.643	0.1960	0.2669	0.70	0.66
Sioux Falls, SD	20.54	19.25	-4.121	-7.333	4.787	4.410	0.3611	0.9944	0.49	0.29
Fort Peck, MT	27.13	26.77	-7.092	-10.34	5.901	5.870	2.638	3.267	0.34	0.09

Table 2. Biases and RMSEs of net longwave flux and average surface temperature for the time period of 03Z on October 13, 2010 to 00Z on October 16, 2010 when comparing LIS running operationally (prod) at AFWA and LIS using a realtime GVF(Test). Validation is against SURFRAD data.

	LWNET RMSE Test	LWNET RMSE Prod	LWNET Bias Test	LWNET Bias Prod	AVGT RMSE Test	AVGT RMSE Prod	AVGT Bias Test	AVGT Bias Prod	GVF Test	GVF Prod
Goodwin Creek, MS	34.13	34.44	-22.76	-24.75	4.127	3.626	0.5525	0.9608	0.62	0.40
Desert Rock, NV	20.09	19.49	4.831	3.244	4.008	3.782	-2.090	-1.761	0.12	0.01
Boulder, CO	23.55	23.20	-1.592	-3.538	3.336	2.971	0.3860	0.8277	0.53	0.27
Bondville, IL	29.87	30.77	-15.58	-17.55	3.202	3.069	0.5803	0.9845	0.29	0.12
Penn State, PA	24.16	25.16	-13.47	-15.25	5.188	5.265	2.544	2.919	0.56	0.39
Sioux Falls, SD	29.30	29.89	-23.42	-24.14	2.860	2.833	1.431	1.602	0.35	0.20
Fort Peck, MT	45.55	47.48	-37.05	-39.39	3.203	3.051	-0.1099	0.4234	0.32	0.05

Table 3. Biases and RMSEs of net longwave flux and average surface temperature for the time period of 03Z on November 13, 2010 to 00Z on November 16, 2010 when comparing LIS running operationally (prod) at AFWA and LIS using a realtime GVF (Test). Validation is against SURFRAD data.