Evapotranspiration and Drought Monitoring Using GOES-R Products for NIDIS

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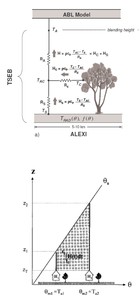
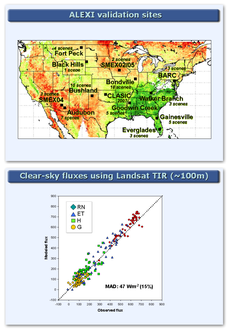
Atmosphere-Land-Exchange-Inversion Model (ALEXI)

ALEXI is a two-source energy balance model which was initially developed to address issues dealing with the monitoring of surface fluxes from a satellite-based platform (Anderson et al., 1997). Flux partitioning within ALEXI is driven by time changes in surface brightness temperature (11 micron channel), where the amplitude of the diurnal surface temperature wave has been found to be a good indicator of surface flux partitioning.

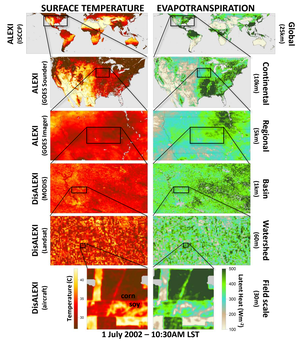
The implementation of ALEXI on a regional-scale (spatial resolution of 10^2 km^2 using the GOES Sounder) across the continental United States allows for a unique opportunity to quantify heat and moisture fluxes from the land surface. Soil moisture conditions yield a distinctive thermal signature (increased sensible heat flux and decreased latent heat flux); moisture deficiencies in the root-zone lead to vegetation stress and elevated canopy temperature; while depletion of water from the soil surface layer causes the soil component of the scene to heat up rapidly (Anderson et al., 2005). The ALEXI algorithm has been vigorously validated with EC flux observations across the CONUS with an average flux MAD of around 15%. Finally, well established disaggregation techniques have been developed to use high resolution TIR sensors (e.g., MODIS, ASTER, Landsat) to provide a fully scalable surface flux monitoring system from the global scale (~0.25 deg) to the field scale (~50 m)



(a) ALEXI surface component and (b) ALEXI Atmospheric boundary layer (ABL) component.



Validation sites for ALEXI clear-sky fluxes (top) and modeled vs. observed clear sky fluxes using Landsat TIR to disaggregate GOES fluxes to the tower footprint scale (bottom).



Multi-scale ET maps for 1 July 2002 produced with ALEXI/DisALEXI using surface temperature data from aircraft (30-m resolution), Landsat (60-m), MODIS (1-km), GOES Imager (5-km) and GOES Sounder (10-km).

Implement ALEXI over Europe and Africa using MSG products as a proxy for GOES-R

Building on prior work, we propose to use our ALEXI modeling system to demonstrate the utility of GOES-R baseline and option 2 products for routine mapping of ET and drought. Prior to launch, GOES-R proxy data will be used, generated with Meteosat-SEVERI data over Europe and Africa. Key tasks to be accomplished include the following:

1) Implement the ALEXI model at 3-km over a European domain using LSA SAF SEVIRI products;
   ✓ Completed
2) Build a climatological database of ALEXI model simulations from 2007-present;
   ✓ Completed
3) Evaluate ALEXI flux estimates in comparison with ground-based observations;
   In Progress
4) Generate 3-km ESI maps over archival period;
   In Progress
5) Evaluate ESI in comparison with standard drought indices and historical drought records;
   In Progress
6) Adapt ALEXI-NESDIS system to ingest GOES-R products as they come on-line.
7) Demonstrate a 2-km GOES-R prototype system over NIDIS pilot study regions in the U.S.

With the launch of GOES-R, our capabilities for ET and drought monitoring will be significantly enhanced due to substantial improvements in spatiotemporal resolution, radiometric accuracy, and cloud-clearing capabilities. In particular the increase in spatial resolution (2 km) will significantly improve utility to the drought community and action agencies served by NIDIS, who are demanding drought information at increasingly higher spatial resolution to support decision making at the sub-county scale.

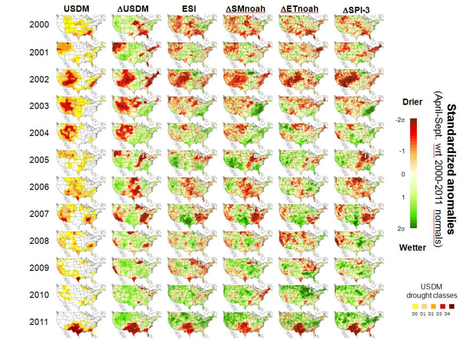
GOES-R products that will be used in post-launch will include Land Surface Temperature (LST), downward Shortwave and Longwave Radiation (SWR and LWR), Vegetation Index (VI) and Green Vegetation Fraction (GVF), and the GOES-R Cloud Mask products.

ALEXI Evaporative Stress Index (ESI) – A Remote Sensing-based Drought Early Warning and Monitoring Tool

The ALEXI Evaporative Stress Index (ESI) represents temporal anomalies in the ratio of actual evapotranspiration (ET) to potential ET (PET).

Advantages over precipitation- or model-based drought indices:

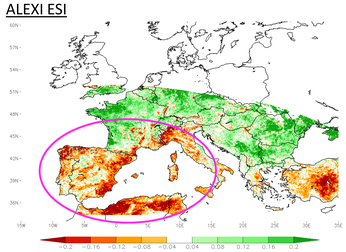
- ESI does not use rainfall data, therefore it provides an independent check on precipitation-based drought indicators and may be more robust in regions with minimal ground-based meteorological infrastructure.
- Time-differential land surface temperature measurements from geostationary imagery in the thermal infrared (TIR) atmospheric window channel (~10.7 micron) are combined with shortwave information about vegetation cover fraction to directly diagnose evaporative fluxes at 3-10 km spatial resolution.
- TIR LST is a valuable metric for constraining estimates of ET because varying soil moisture conditions yield a distinctive thermal signature: soil surface temperature increases with decreasing water content in the upper few centimeters of the soil profile, while moisture deficiencies in the root zone lead to vegetation stress and elevated canopy temperatures.
- ALEXI ESI inherently includes non-precipitation related moisture signals (such as irrigation; vegetation rooted to groundwater; lateral flows) that need to be modeled a priori in prognostic LSM schemes



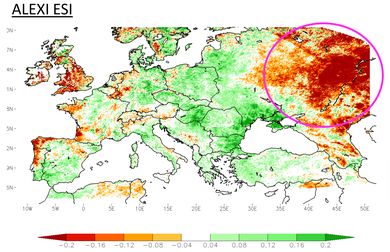
Seasonal (26-week) anomalies in USDM, ESI, Noah SM, Noah ET and SPI-3 for 2000-2011.

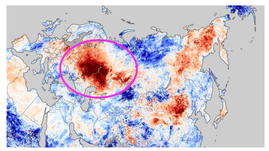
ALEXI ESI using MSG as a GOES-R Proxy – Europe (2008-2011)

2008 Drought over Catalonia Region of Spain and Northern Africa (April - May)

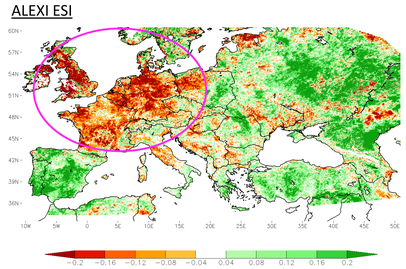


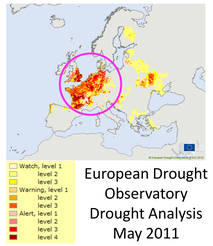
2010 Drought over Russia (July – August)





2011 Drought over England, France and Germany (May)



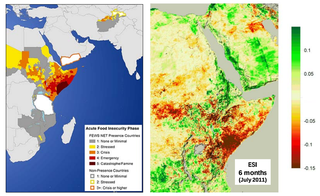


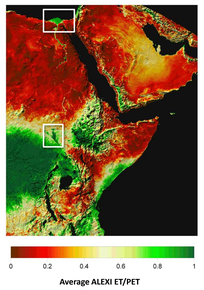
European Drought Observatory Drought Analysis May 2011

- Qualitatively, ALEXI ESI captures the most significant drought events during the initial analysis period (2008-2011).
- ALEXI ESI is currently being quantitatively compared with several standard drought products over Europe including: Standardized Precipitation Index, Palmer Drought Severity Index, Vegetation Health Index, NDVI/EVI Anomalies and analyses from the European Drought Observatory.

ALEXI Evapotranspiration – Monitoring Water Resources

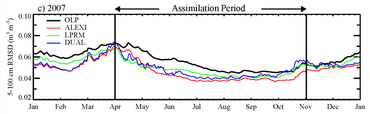
- As water security and freshwater availability becomes an increasingly important issue, routine monitoring of evapotranspiration over the Americas - and eventually the globe – will be critical.
- ALEXI is a unique remote sensing-based algorithm which can retrieve evaporative fluxes from future GOES-R sensors at high resolutions (2 km) without any knowledge of accumulated precipitation or antecedent soil moisture conditions.
- ALEXI ESI inherently includes non-precipitation related moisture signals (such as irrigation, wetlands, vegetation rooted to groundwater, lateral flows) that need to be modeled a priori in prognostic LSMs



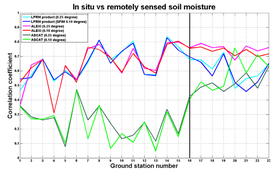


ALEXI Soil Moisture – A Numerical Weather Prediction Tool

- An additional asset of ALEXI with future GOES-R products is the potential for a high-resolution thermal soil moisture proxy.
- Flux outputs from ALEXI allow for the calculation of a fraction of potential evapotranspiration (f_{PET}) for each pixel for the total system (surface + root-zone). ALEXI f_{PET} can be related to soil moisture in the surface and root-zone layers as a function of the observed fraction of vegetation cover.
- ALEXI retrievals over low vegetation cover are sensing soil moisture conditions in the first few centimeters of the soil profile, while retrievals over dense vegetation cover are sensing soil moisture conditions in the root-zone layers. Under mixed cover pixels, a composite observation of surface and root-zone soil moisture is assumed, based on the following weighting function.



Example of improvement in root-zone SM predictions from assimilating ALEXI into the Noah LSM over the CONUS (Hain et al. 2012).



ALEXI soil moisture estimates show higher correlation with observations (Spain, France) than do microwave products (LPRM, ASCAT) (Image Credit to R. Parinussa - VU University Amsterdam).