Princeton's Flood and Drought Monitors for Africa, and Latin America and the Caribbean

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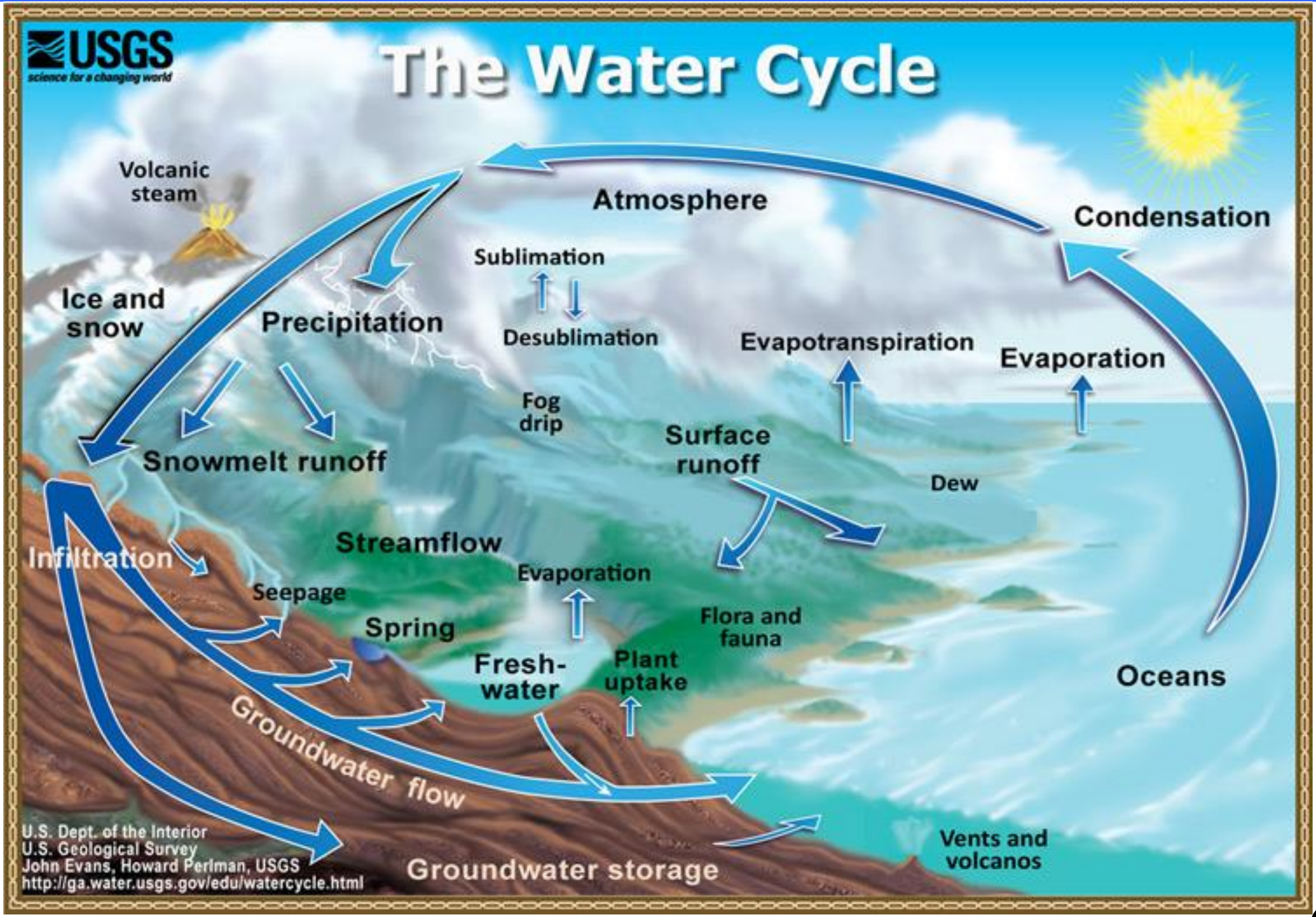
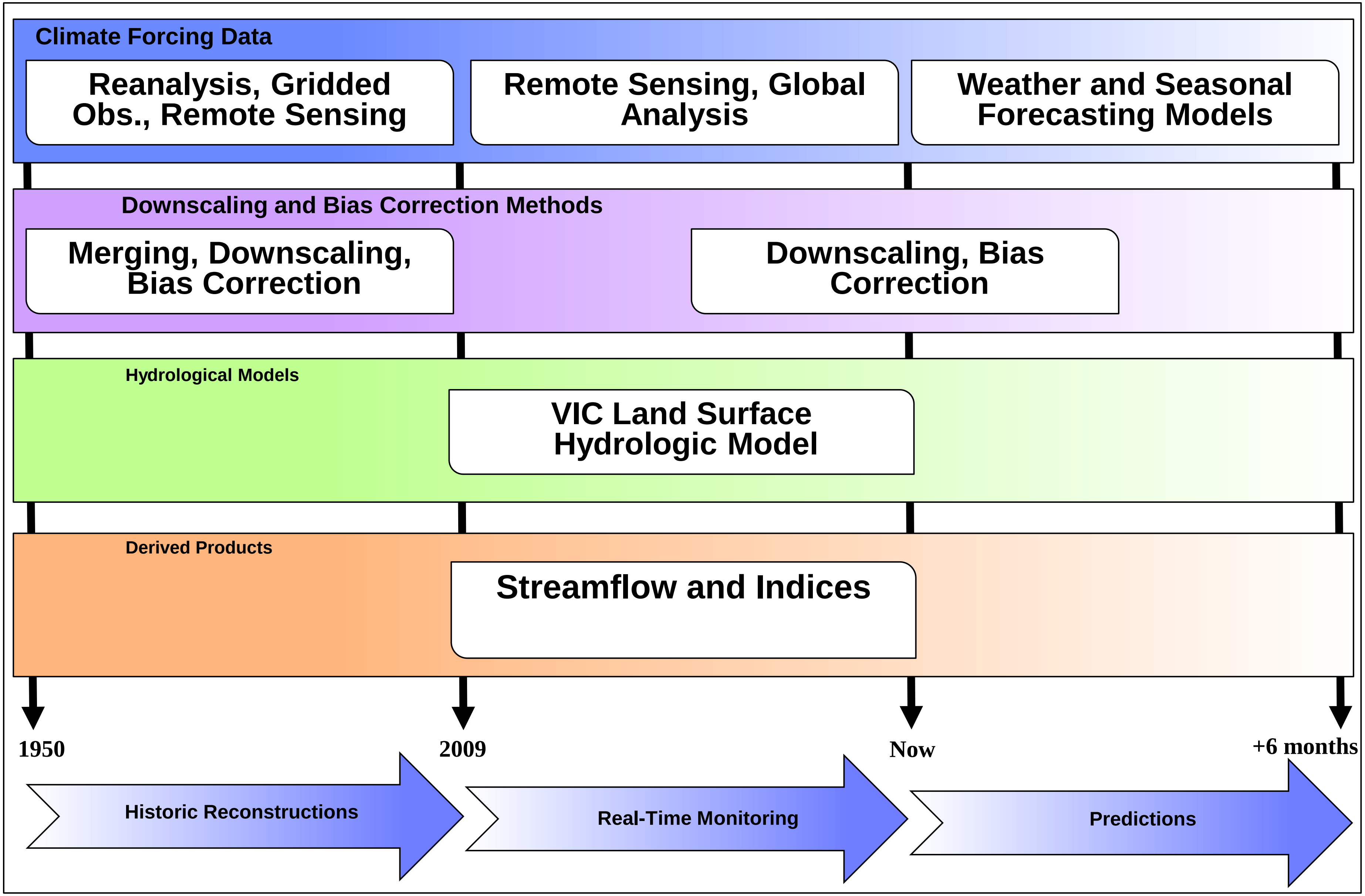
World Bank BBL| June 15th, 2016

Tracking Drought Through the Water Cycle



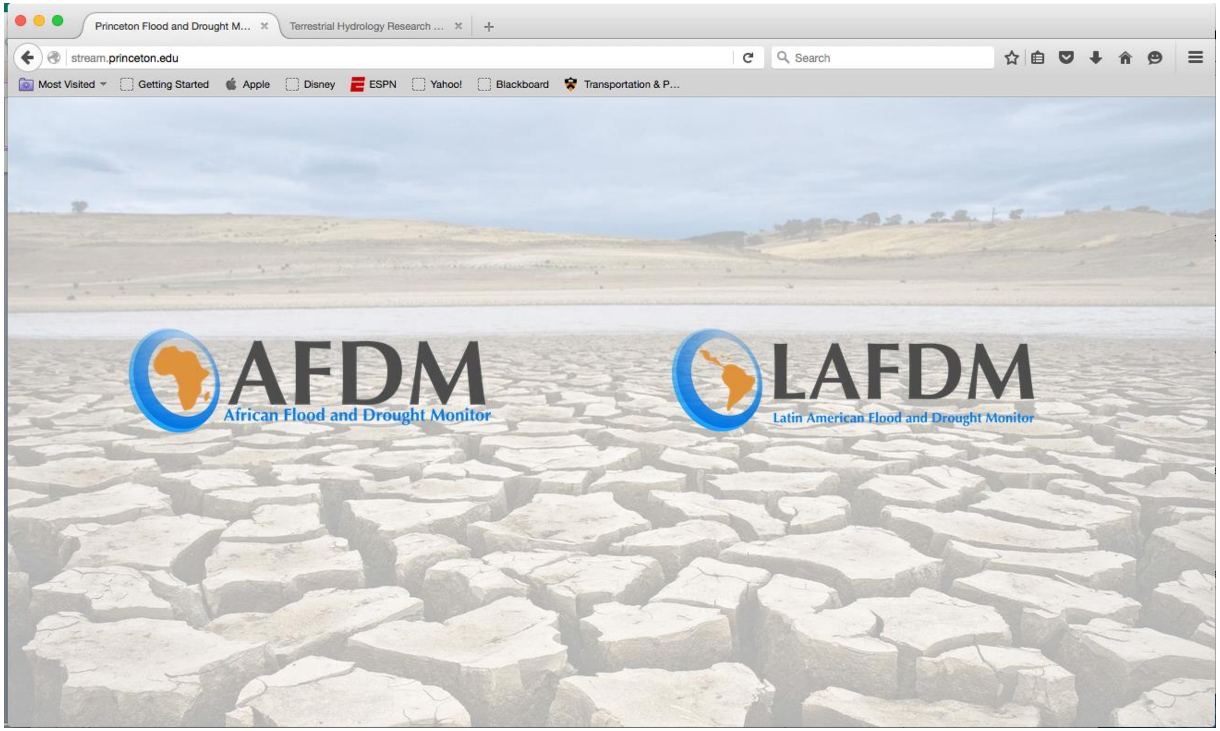


Sheffield et al. (2014), BAMS

THE FLOOD AND DROUGHT MONITOR WEB INTERFACE

Main Portal for Flood and Drought Monitors

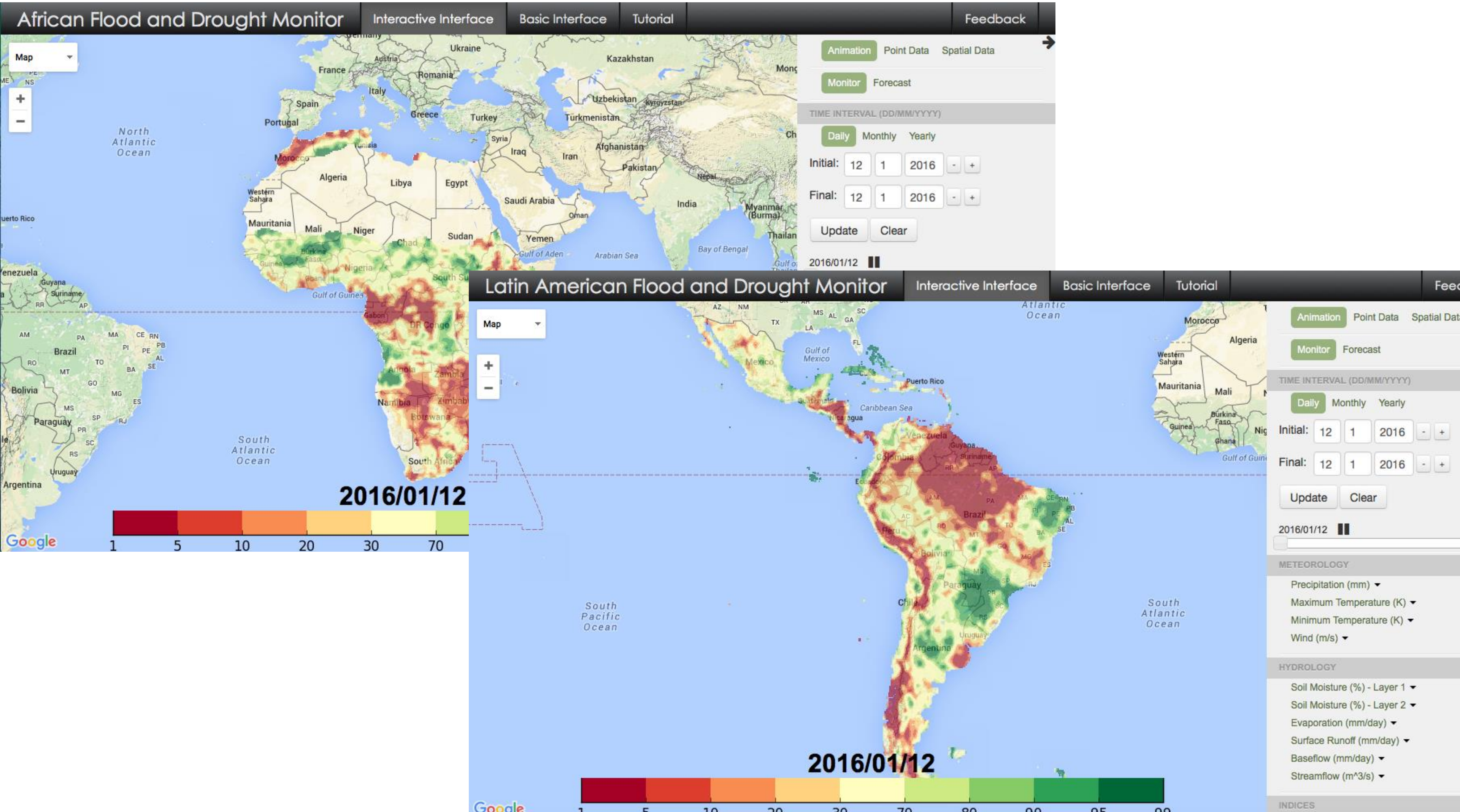
http://stream.princeton.edu



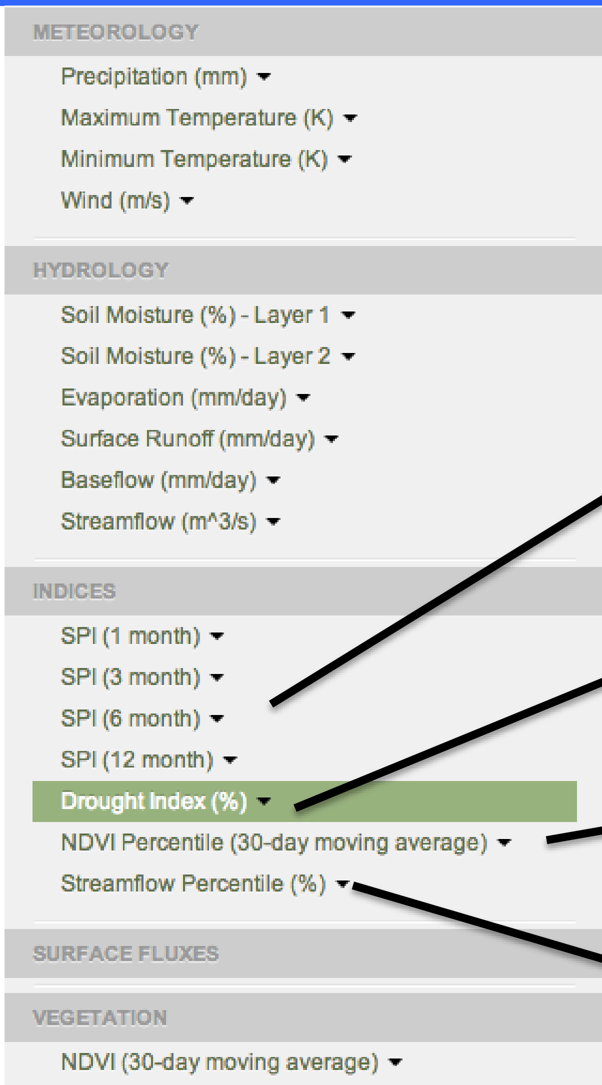
Available in English, French, Spanish, Arabic, Mandarin, and Portuguese (only for LAFDM)

Main Portal for the Latin American Monitor

Web Interfaces



Water Cycle Products and Indices



SPI – The standardized precipitation index is the number of standard deviations that observed cumulative precipitation deviated from the climatological average. Low values indicate meteorological drought.

Drought Index - Measure of the severity of drought; low values indicate drought conditions.

NDVI – Normalized Difference Vegetation Index is a measure of live green vegetation; Changes to low values typically correlate well with drought conditions.

Streamflow Percentiles- Measure of the severity of hydrologic drought; low values indicate drought conditions.

Basic Interface

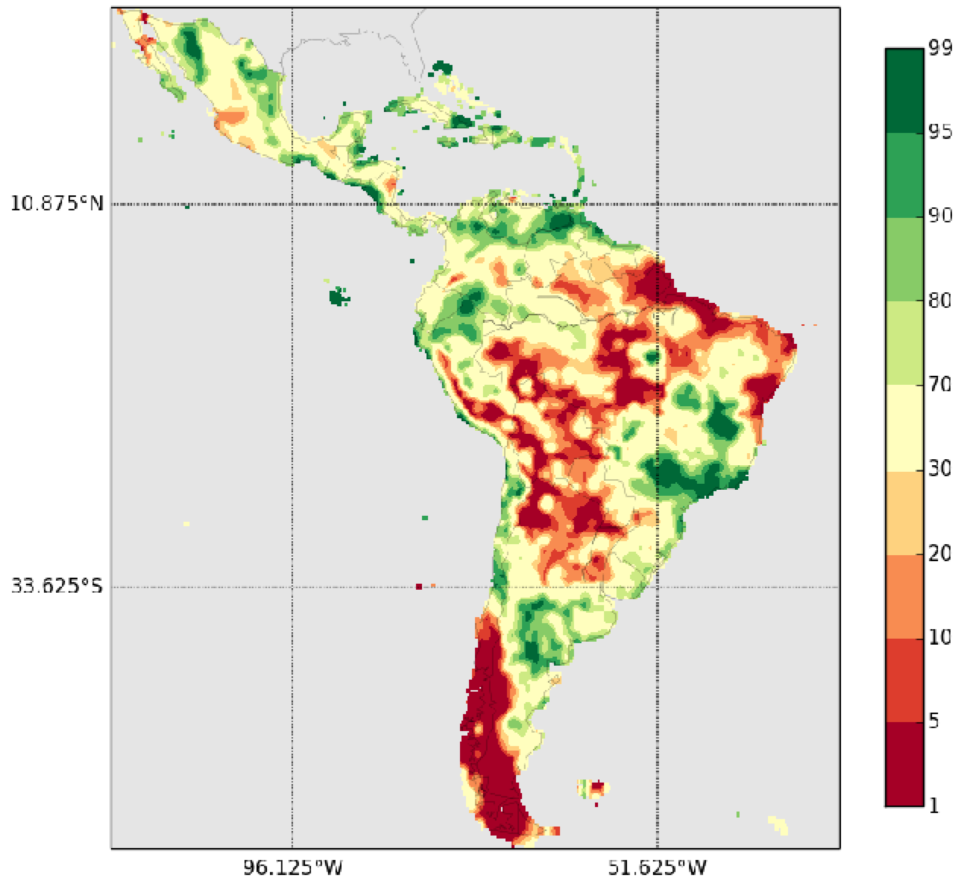
Latin American Flood and Drought Monitor | Interactive Interface | Basic Interface | Tutorial | Feedback

Initial: 11 6 2016 - +

Final: 11 6 2016 - +

Update Clear

2016/06/11



METEOROLOGY

- Precipitation (mm)
- Maximum Temperature (K)
- Minimum Temperature (K)
- Wind (m/s)

HYDROLOGY

- Soil Moisture (%) - Layer 1
- Soil Moisture (%) - Layer 2
- SMAP Soil Moisture (m3/m3)
- Evaporation (mm/day)
- Surface Runoff (mm/day)
- Baseflow (mm/day)
- Streamflow (m^3/s)

INDICES

- SPI (1 month)
- SPI (3 month)
- SPI (6 month)
- SPI (12 month)
- Drought Index (%)
- NDVI Percentile (30-day moving average)
- Streamflow Percentile (%)

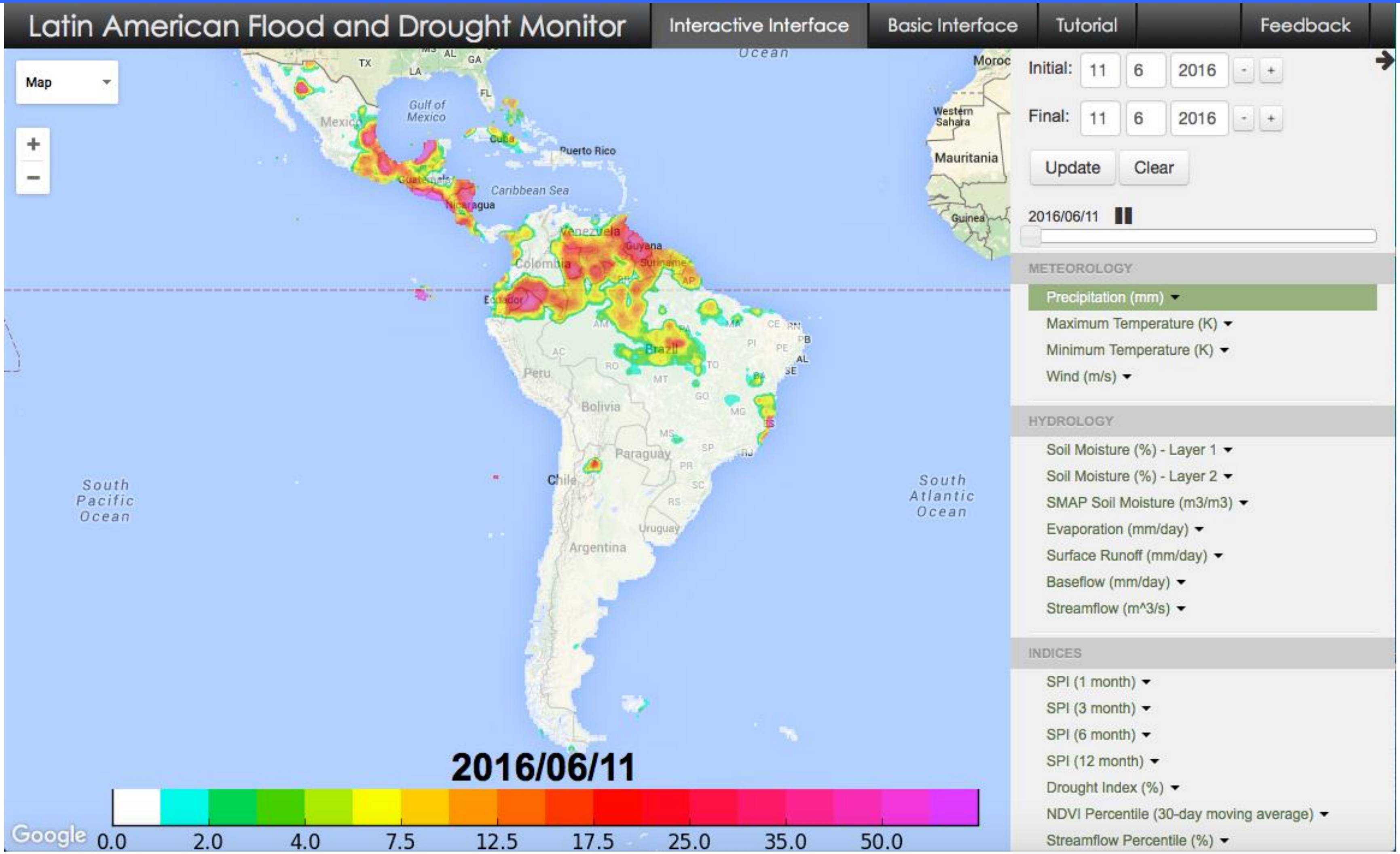
SURFACE FLUXES

- Net Radiation (W/m^2)
- Net Longwave Radiation (W/m^2)
- Net Shortwave Radiation (W/m^2)

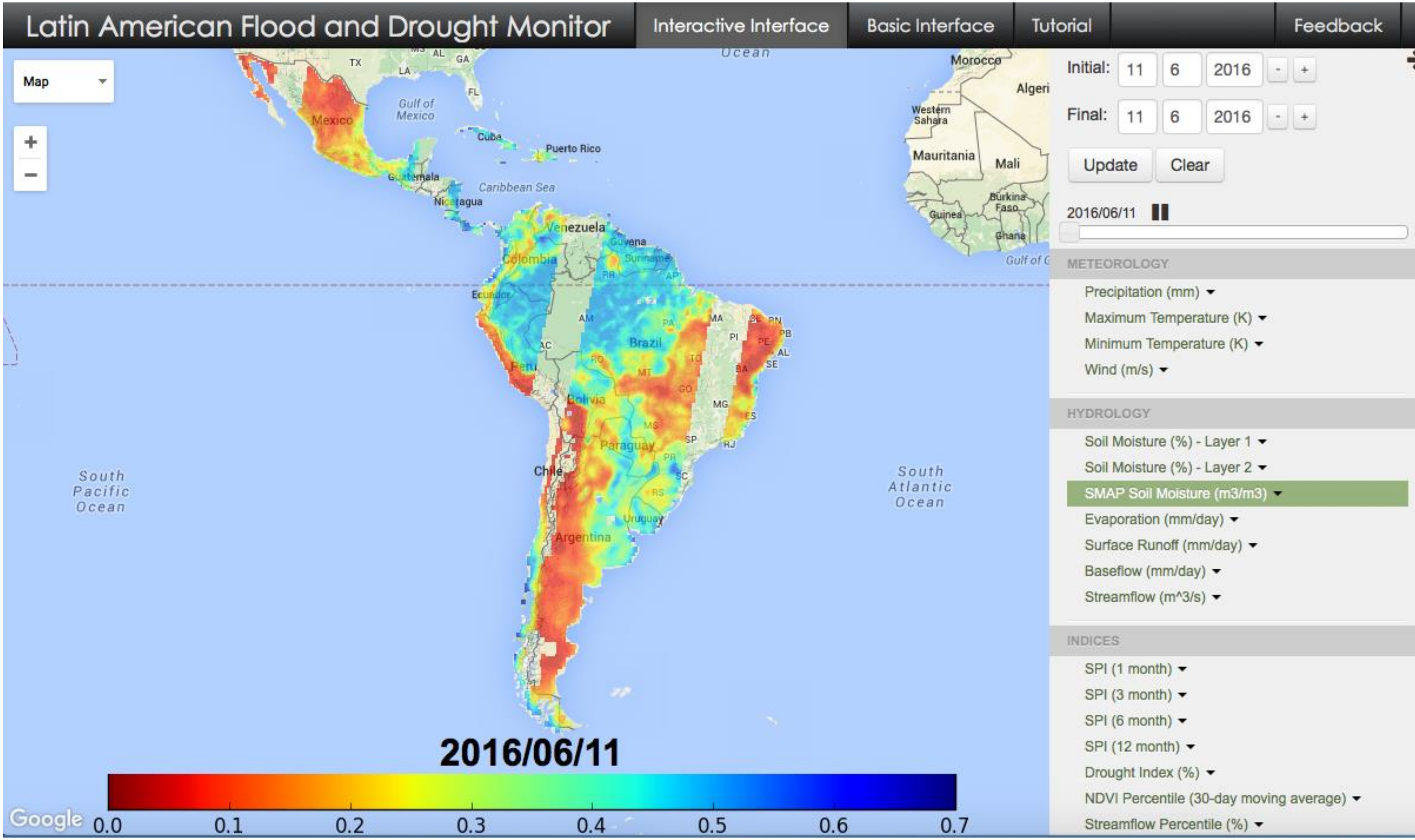
VEGETATION

- NDVI (30-day moving average)

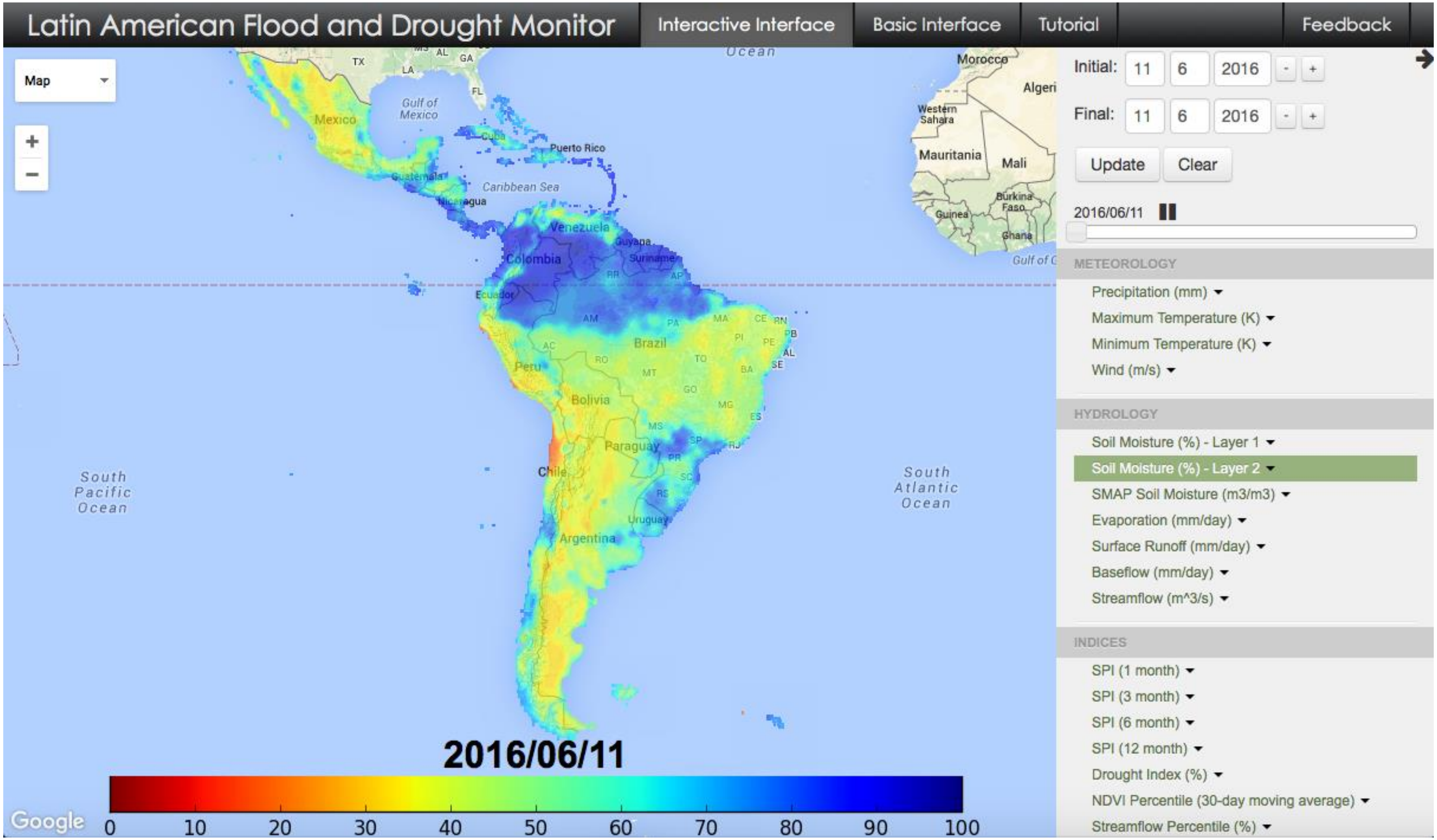
Interface: Precipitation



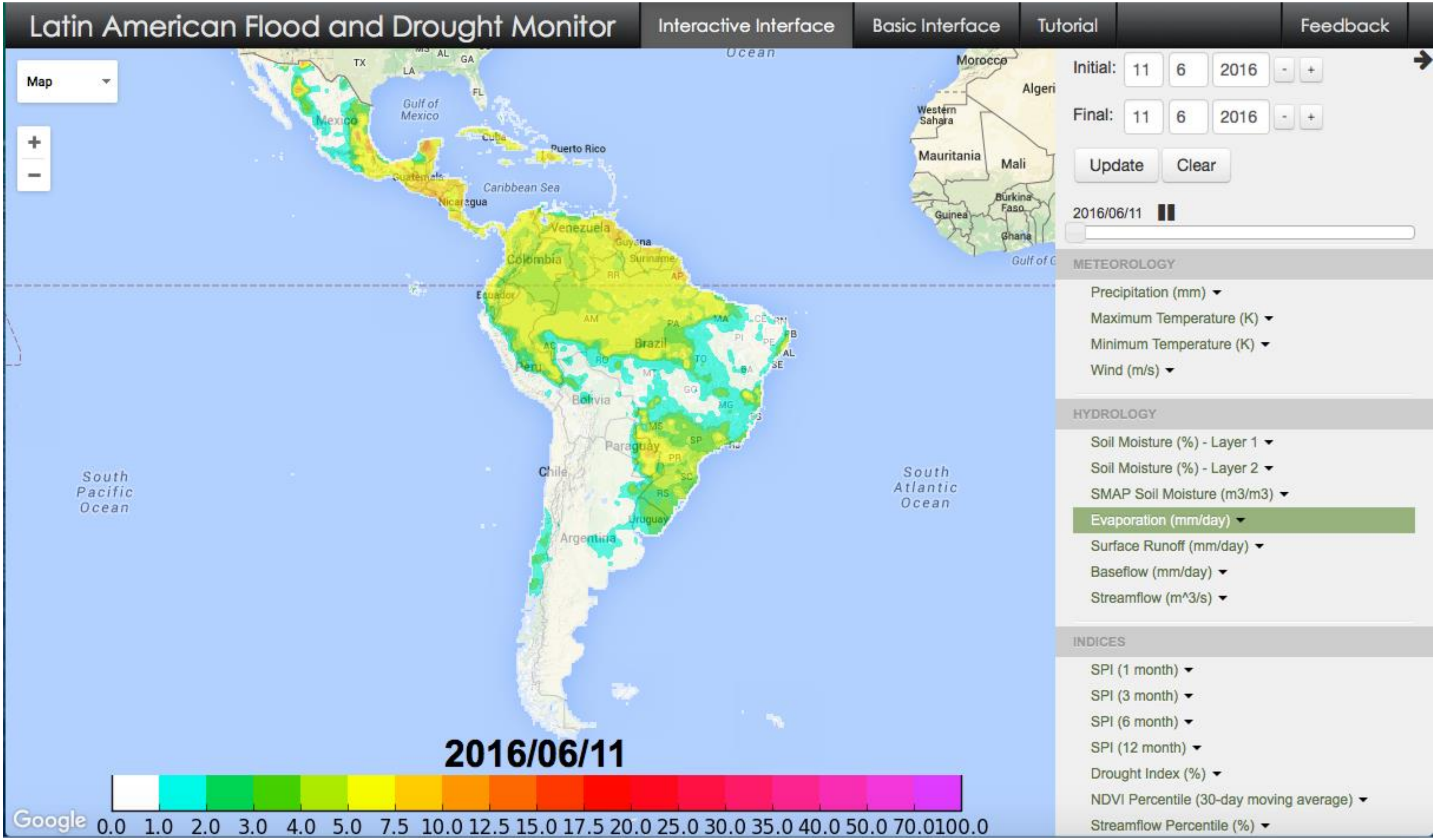
Interface: Soil Moisture (Remote Sensing)



Interface: Soil Moisture (modeled)



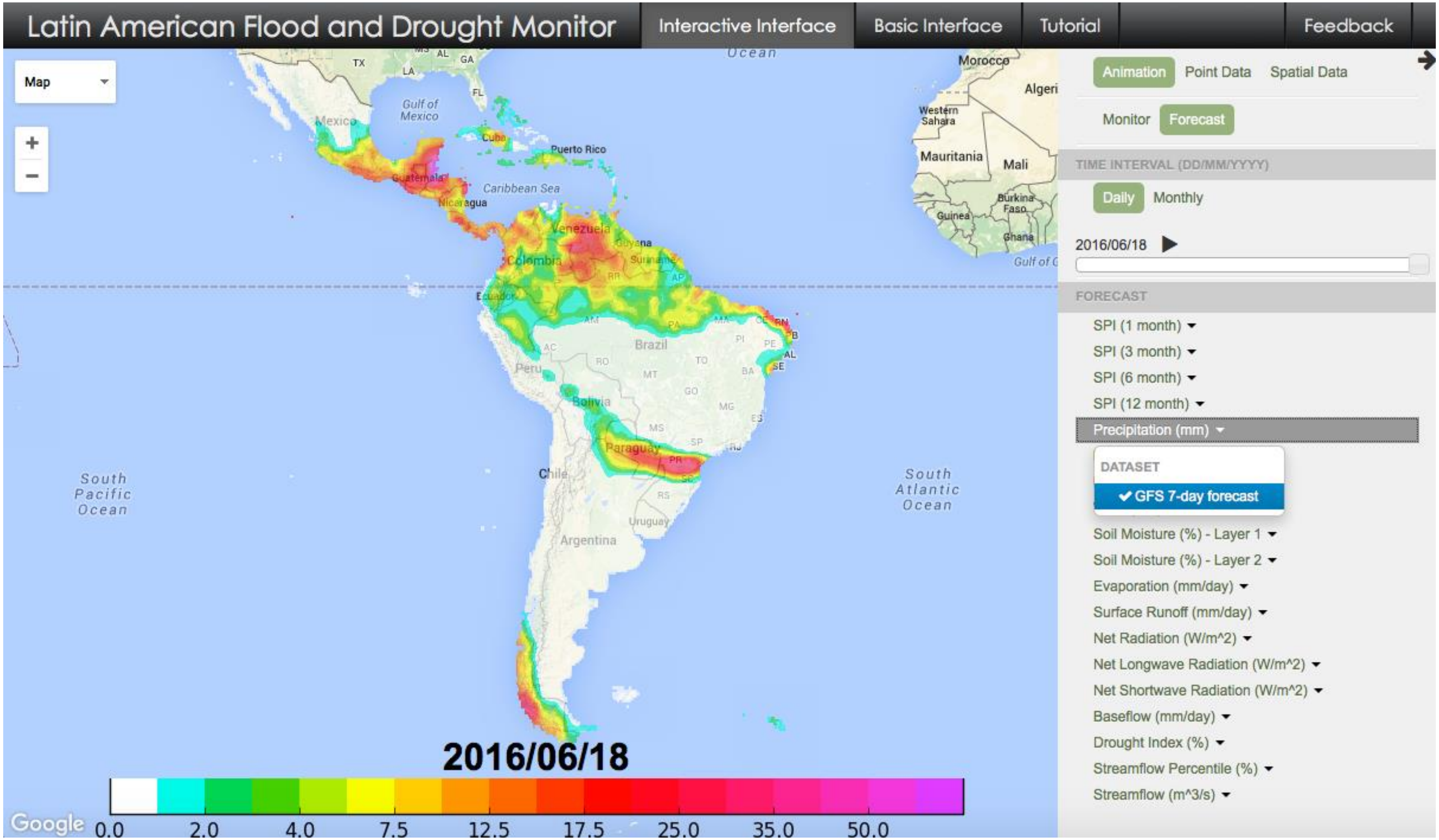
Interface: Evapotranspiration



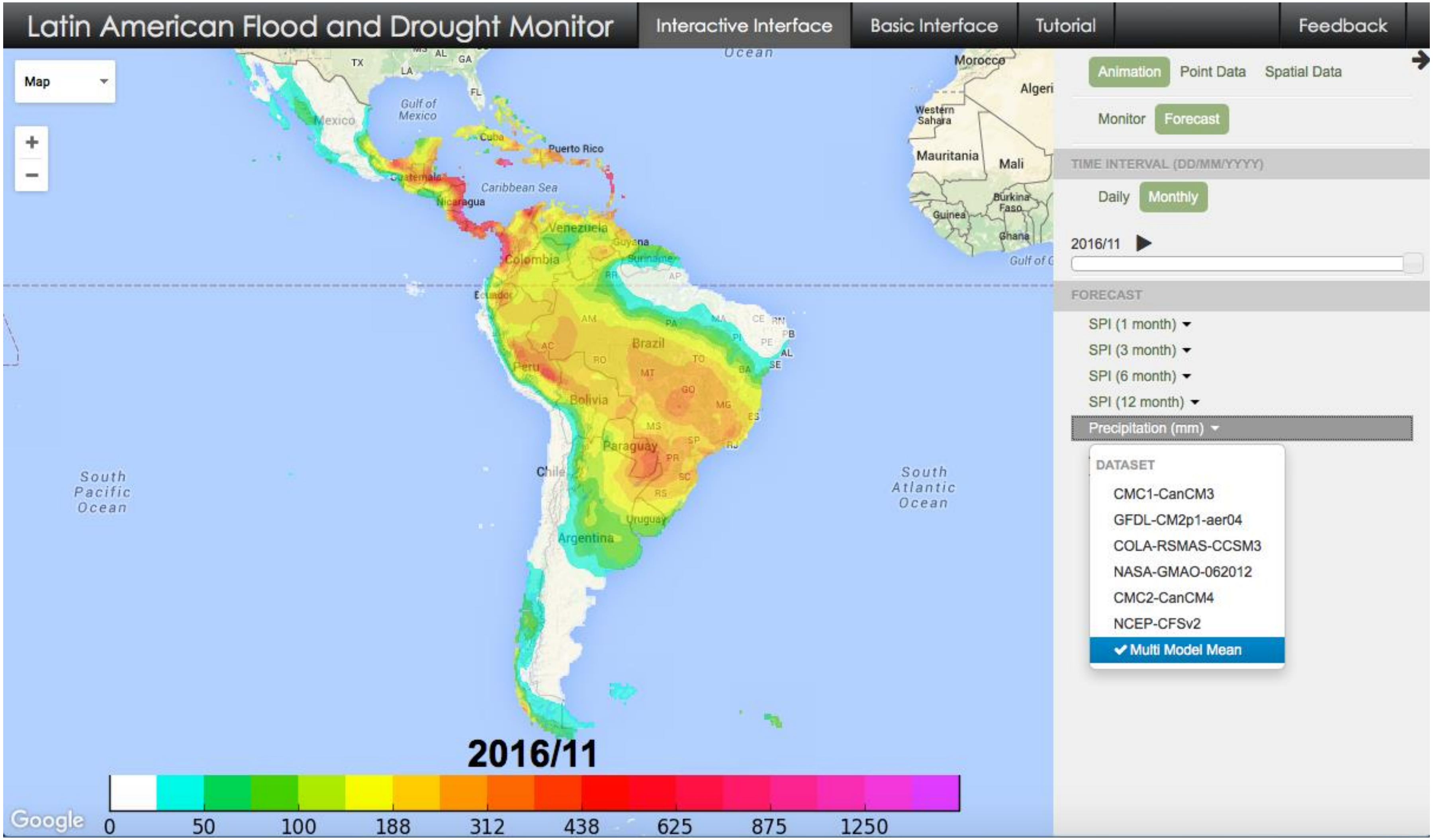
Interface: NDVI (Remote Sensing)

NDVI – Normalized Difference Vegetation Index is a measure of live green vegetation; Changes to low values typically correlate well with drought conditions.

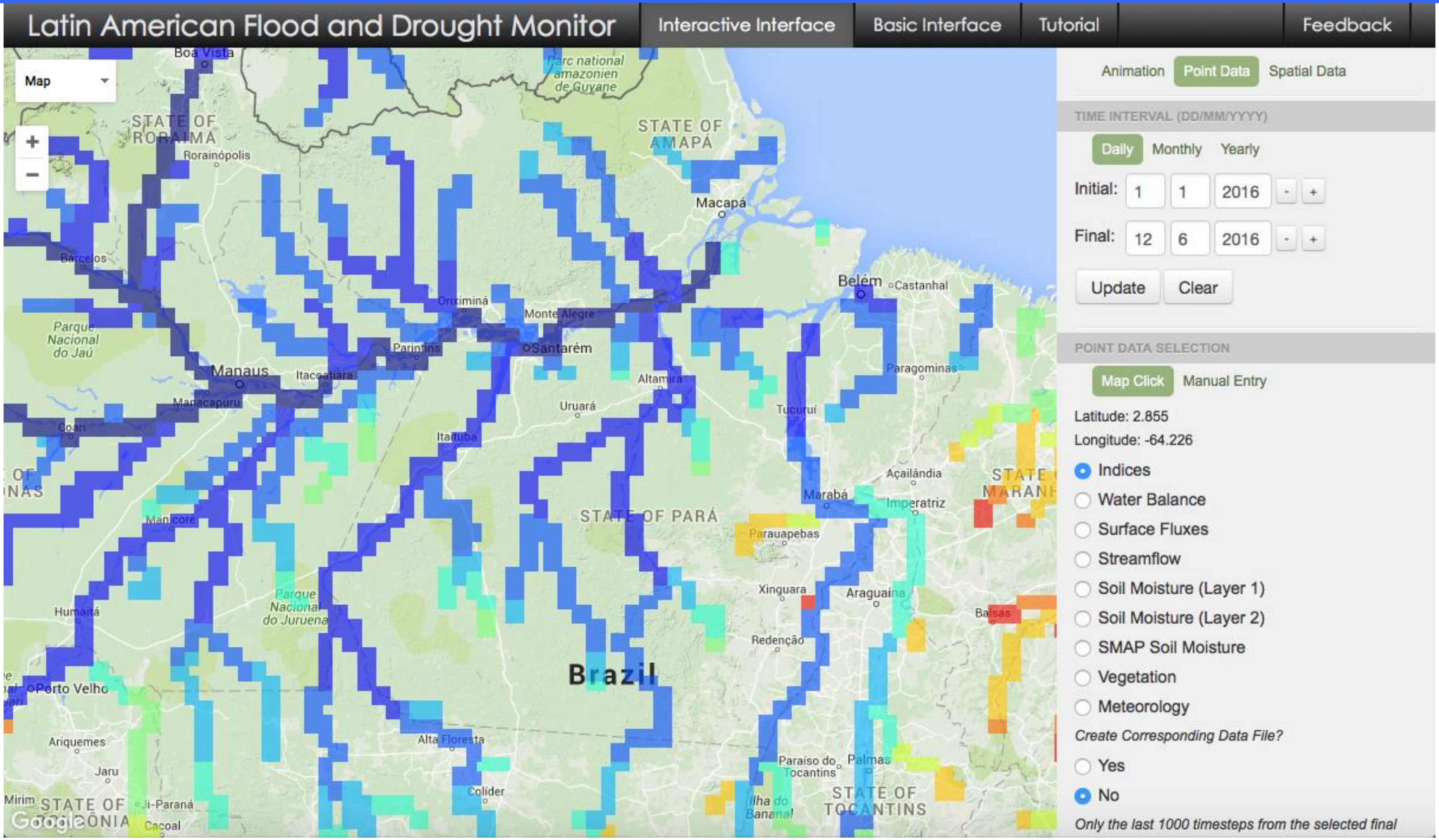
Interface: 7-day Forecast



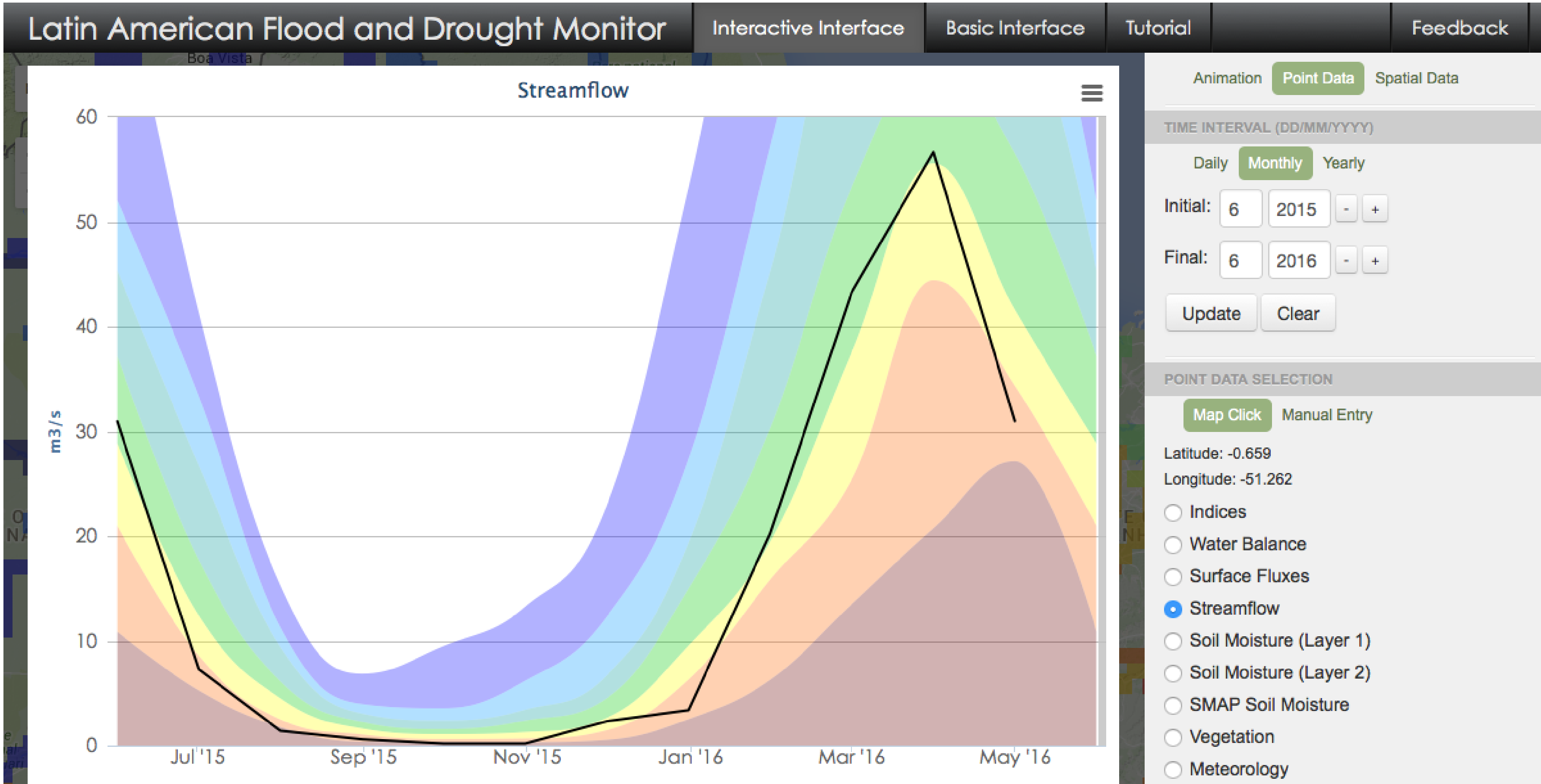
Interface: Seasonal Forecast



Point Data: Map Selection

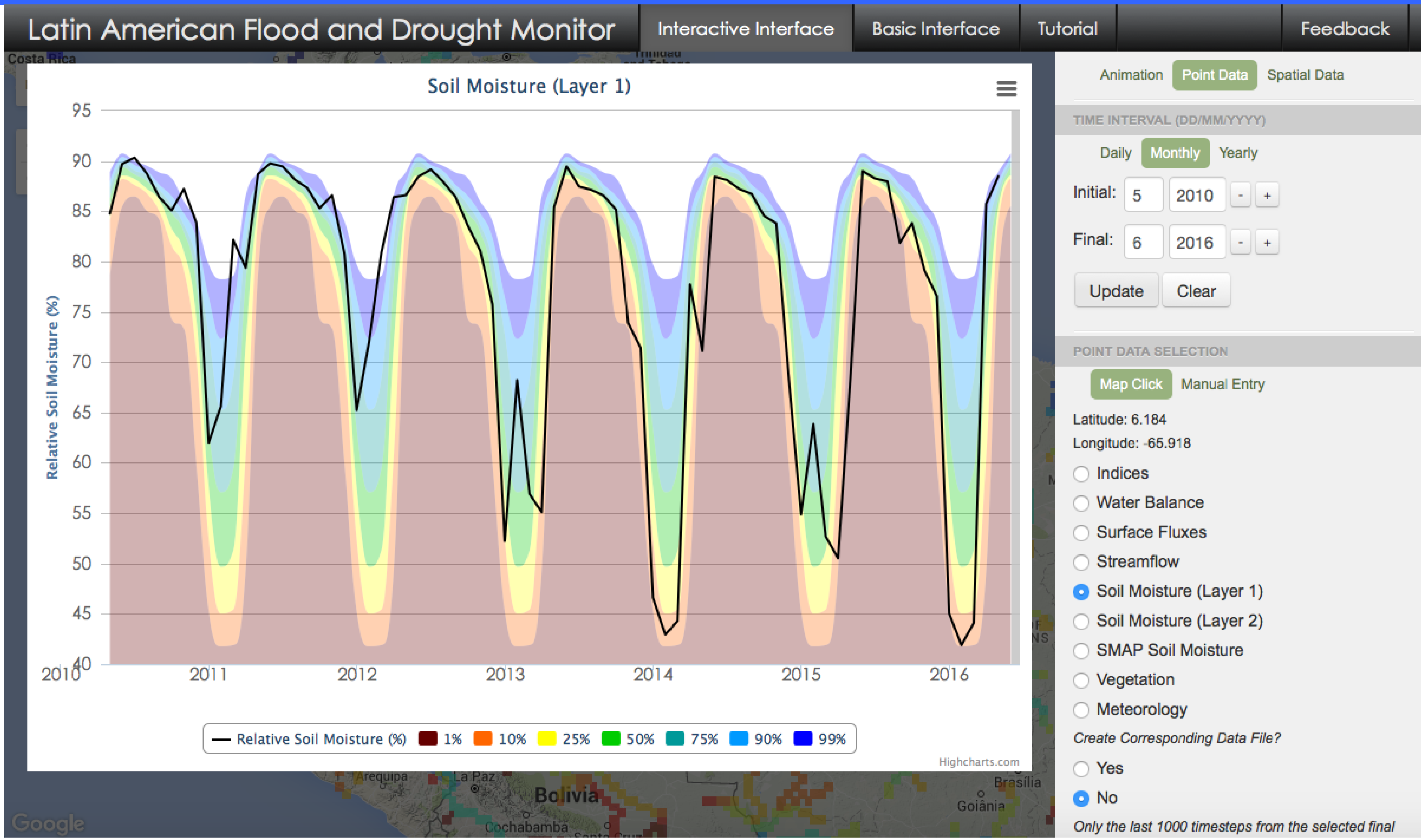


Point Data: Streamflow (Amazon River)



Streamflow Percentiles- Measure of the severity of hydrologic drought; low values indicate drought conditions.

Point Data: Soil Moisture (Venezuela)

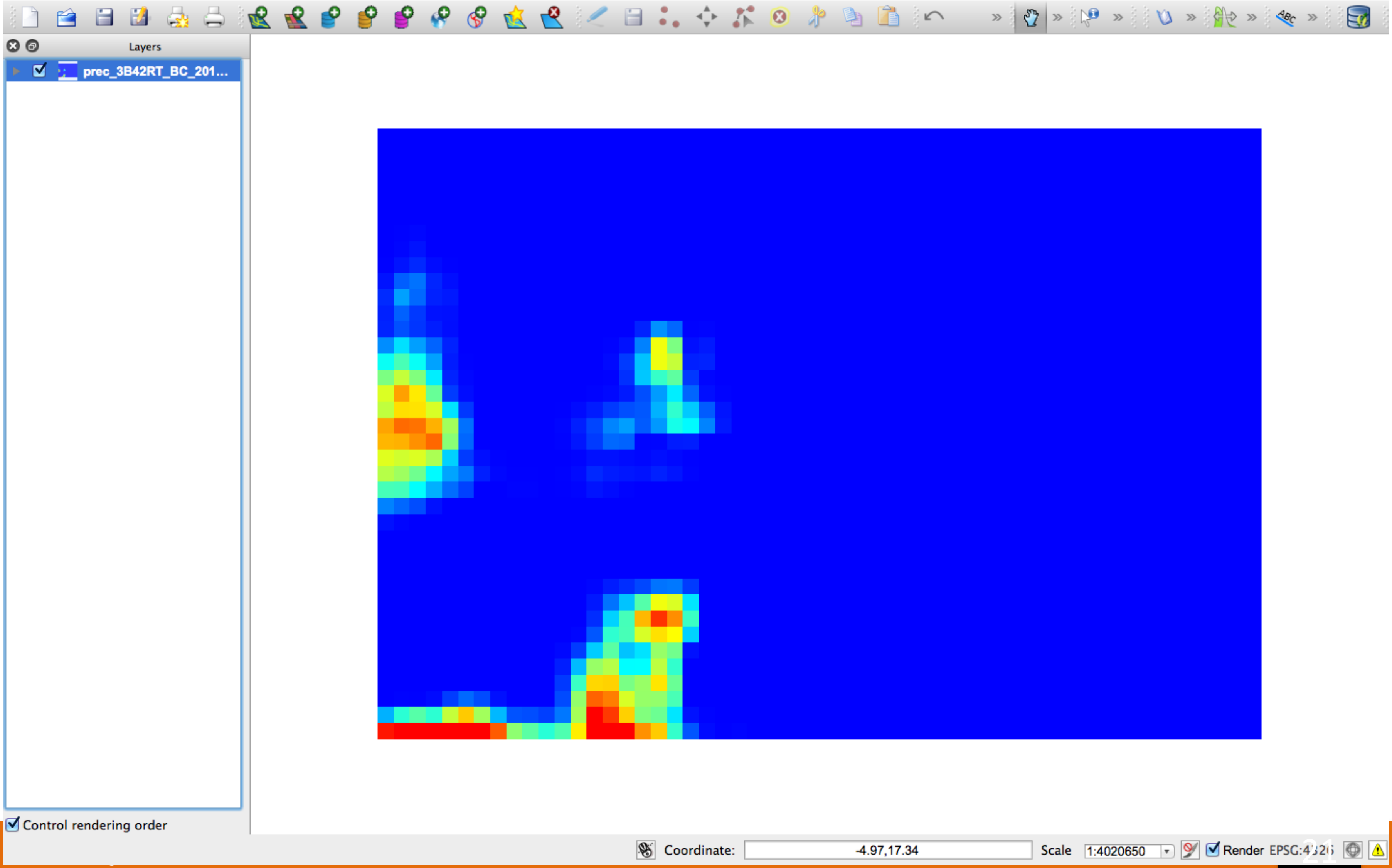


Point Data: Download

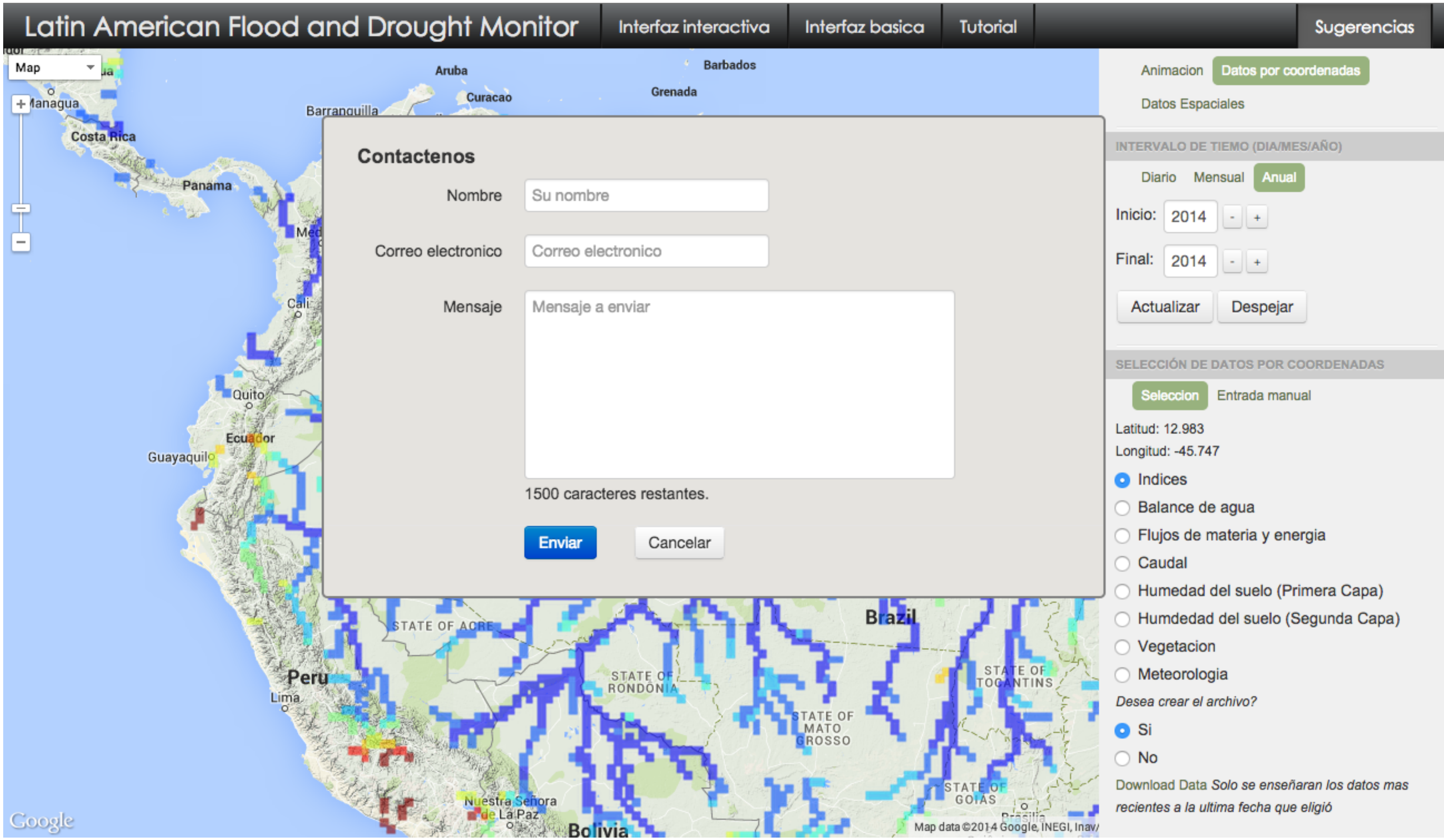
Indices_1951_2014_-4.625_-54.875.txt

year	SPI (3 month	SPI (12 mese	SPI (1 mes)	SPI (6 month	Anomalia (C)	Indice del ca	Indice de veg	Indice de la humedad del suelo (%)
1951	-0.492	-0.854	-0.393	-0.856	-999	42.043	-999	42.605
1952	-0.25	-0.815	-0.067	-0.395	-999	43.668	-999	41.584
1953	-0.11	-0.436	-0.034	-0.237	-999	45.87	-999	41.082
1954	-0.021	-0.042	0.054	-0.06	-999	49.678	-999	52.572
1955	0.494	0.584	0.28	0.595	-999	54.743	-999	57.608
1956	0.548	0.733	0.381	0.664	-999	57.609	-999	59.628
1957	-0.651	0.434	-0.564	-0.414	-999	42.285	-999	38.691
1958	-0.714	-1.087	-0.343	-0.801	-999	44.127	-999	37.901
1959	0.897	0.32	0.537	0.802	-999	58.375	-999	56.906
1960	-0.879	-0.817	-0.546	-1.064	-999	32.59	-999	26.857
1961	0.552	1.003	0.149	0.865	-999	61.429	-999	51.095
1962	-0.18	-0.595	0.047	-0.386	-999	52.049	-999	49.801
1963	-0.121	0.183	-0.215	-0.064	-999	44.332	-999	39.811
1964	-0.35	-0.19	-0.213	-0.219	-999	53.979	-999	51.398
1965	-0.54	-0.78	-0.288	-0.754	-999	45.508	-999	43.474
1966	-0.282	-1.369	-0.099	-0.465	-999	43.775	-999	39.606
1967	-0.238	0.287	-0.19	-0.061	-999	48.41	-999	42.786
1968	0.118	-0.204	0.209	0.049	-999	51.184	-999	54.524
1969	-0.652	-0.241	-0.546	-0.524	-999	42.646	-999	42.432
1970	-0.383	-1.644	-0.084	-0.994	-999	42.091	-999	36.29
1971	0.173	0.213	0.128	0.252	-999	55.126	-999	53.509
1972	-0.43	0.108	-0.273	-0.361	-999	50.802	-999	47.974
1973	0.53	-0.512	0.48	0.11	-999	57.834	-999	63.293
1974	0.727	1.1	0.466	0.912	-999	52.21	-999	60.882
1975	1.106	2.853	0.579	2.066	-999	71.675	-999	72.592
1976	-0.65	-0.141	-0.392	-0.673	-999	46.673	-999	44.431
1977	0.096	-0.845	0.069	-0.238	-999	54.895	-999	52.751
1978	-0.027	0.148	0.018	-0.023	-999	47.593	-999	56.796
1979	-0.035	-0.142	-0.119	-0.04	-999	49.731	-999	47.595
1980	-0.977	-1.197	-0.567	-1.138	-999	32.561	-999	32.888
1981	-1.497	-2.373	-0.906	-2.095	-999	31.942	-999	25.732
1982	-0.447	0.049	-0.283	-0.301	-999	46.935	-999	41.121
1983	-1.32	-2.896	-0.86	-1.989	-999	29.18	-999	27.745
1984	1.534	0.413	0.978	1.631	-999	60.213	-999	62.992
1985	0.131	1.343	0.177	0.268	-999	48.941	-999	50.171
1986	0.523	1.514	0.137	1.07	-999	51.099	-999	56.688
1987	-0.175	-0.297	-0.315	-0.185	-999	47.083	-999	42.983
1988	0.471	-0.156	0.526	0.26	-999	56.705	-999	62.1
1989	1.345	1.758	0.944	1.456	-999	69.78	-999	78.9
1990	-0.458	0.276	-0.453	-0.412	-999	36.636	-999	45.414
1991	0.087	-0.039	0.03	0.126	-999	55.968	-999	56.63
1992	-0.524	-1.048	-0.283	-0.818	-999	40.456	-999	41.031
1993	-0.204	-0.312	-0.054	-0.211	-999	48.685	-999	48.763

Spatial Data: Selection, Download, and GIS



Interface: Feedback



Summary of Monitors’ Capabilities

- Multiple Languages
- Short-Term Forecast (7 days)
- Seasonal Forecast (6 months)
- Standard Precipitation Index (SPI) and Drought Index
- Vegetation Monitoring (NDVI)
- Download point data
- Download spatial data
- Provide feedback

http://stream.princeton.edu

DATA SCIENCE AND HYDROLOGY BEHIND THE FLOOD AND DROUGHT MONITORS

INTRODUCTION

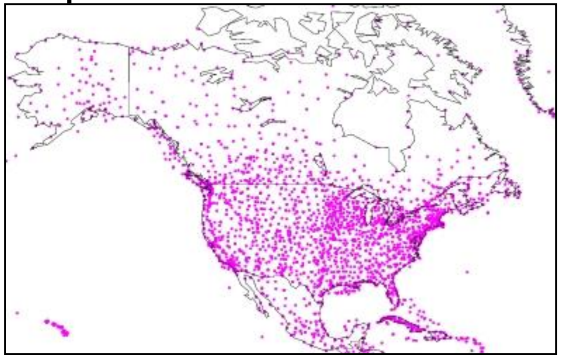
MODELING FRAMEWORK

METEOROLOGICAL DATASETS

DROUGHT PRODUCTS

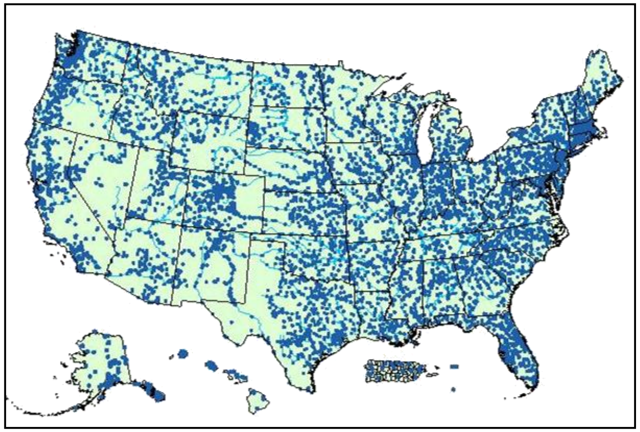
Observing the Water Cycle: Ground Measurements

Precipitation - the best measured



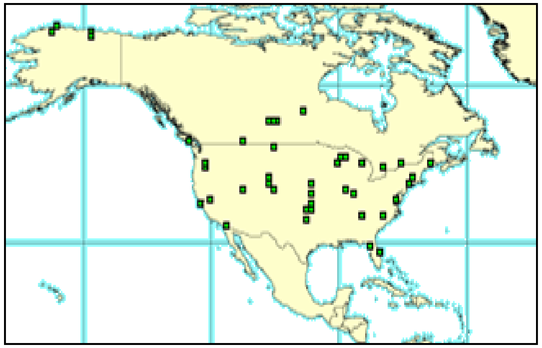
U.S. station density: 1 per 700 km^2

$$Q = P - E - dW/dt$$

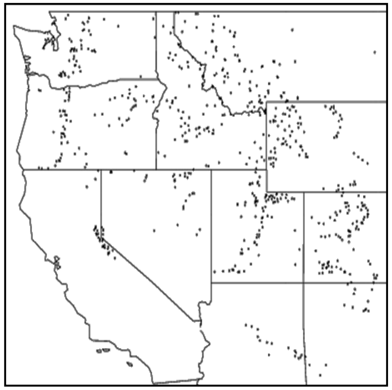


Streamflow measured at roughly 7,000 active gauging stations.

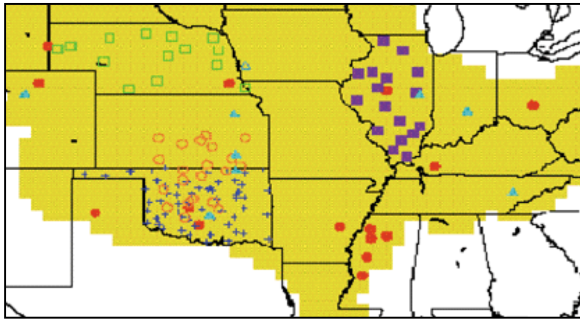
Ameriflux (flux towers) measure E, since mid 1990's



Snow water equivalent at SNOTEL sites



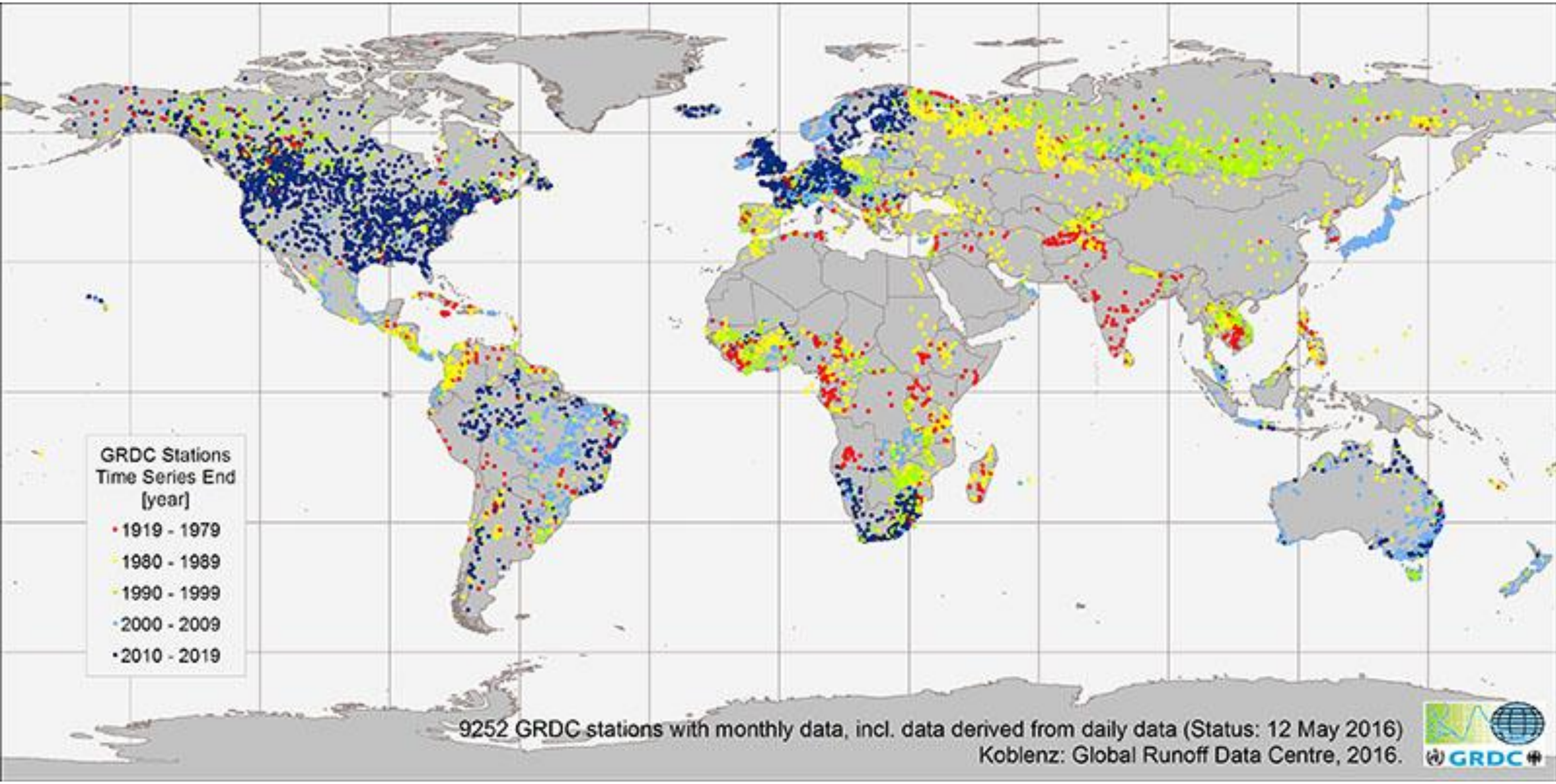
Top 1-m soil moisture measurements



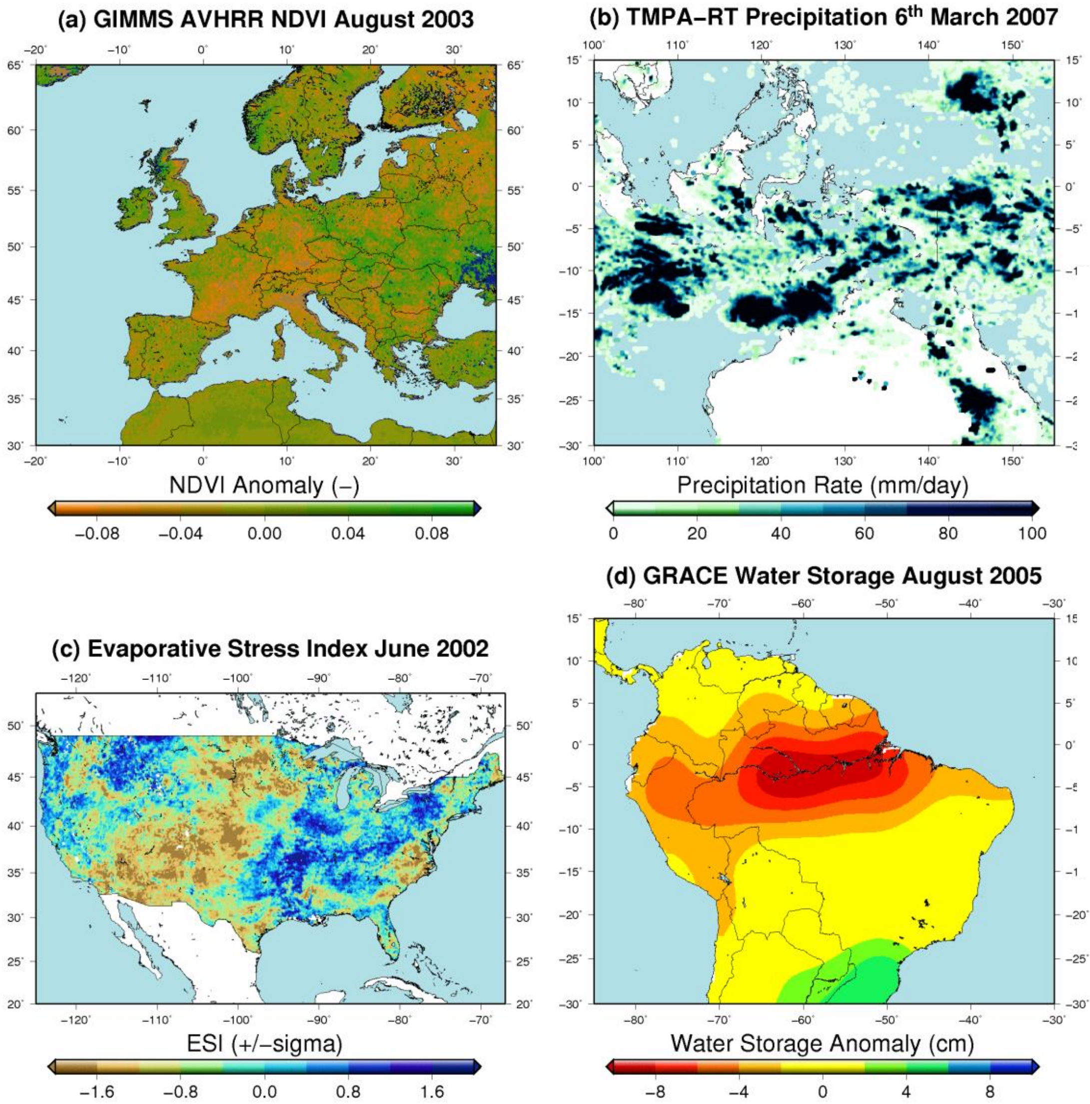
Source: ***A. Robock, Rutgers U.***

Decreasing Station Data in Developing Countries

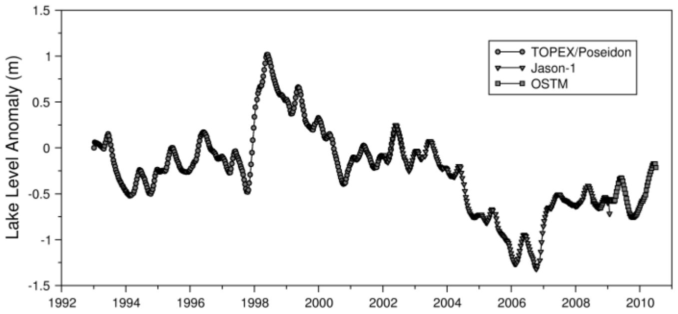
World's River Discharge Data from the Global Runoff Data Center



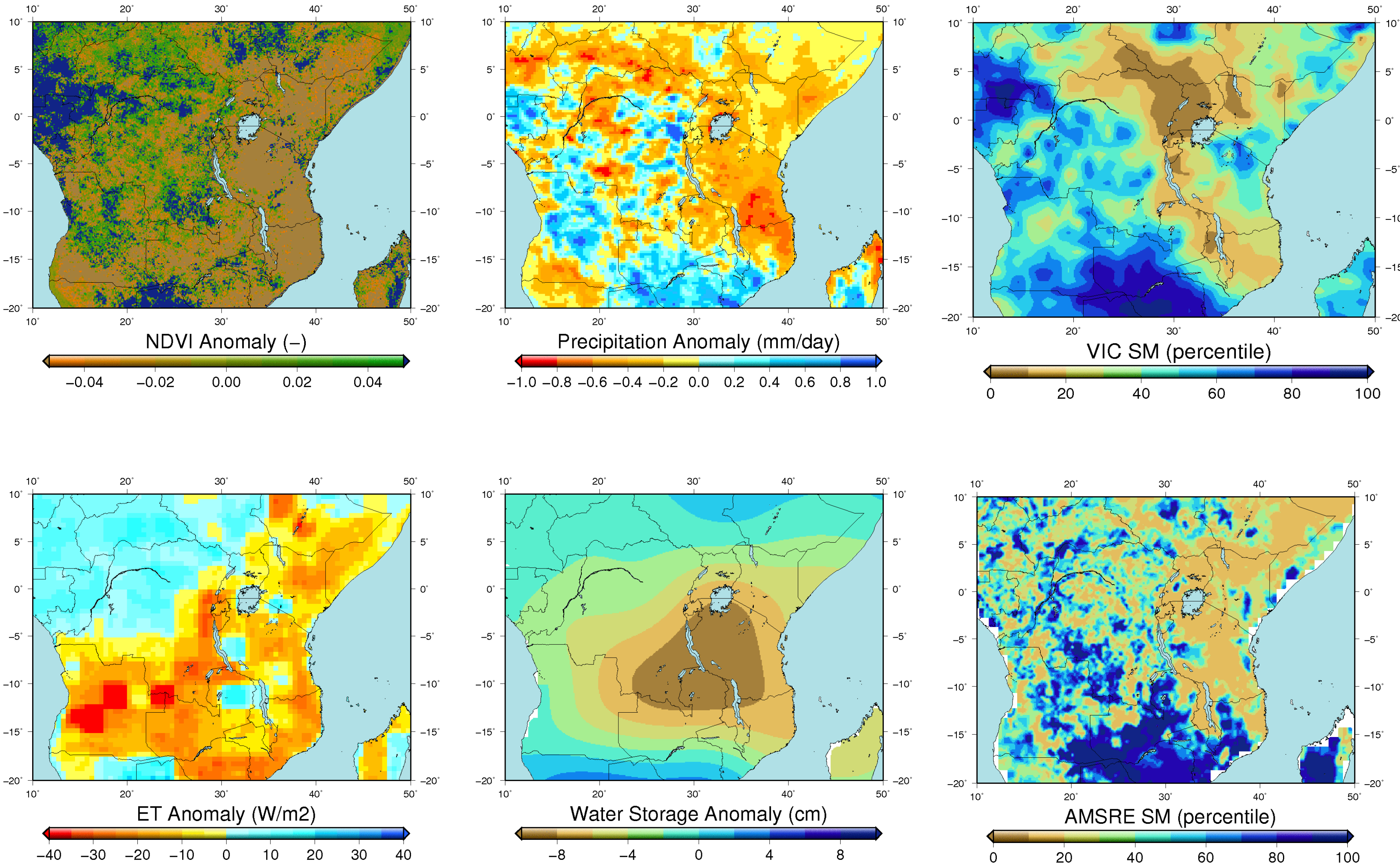
Observing the Water Cycle: Remote Sensing



Satellite Altimetry of Large Water Bodies

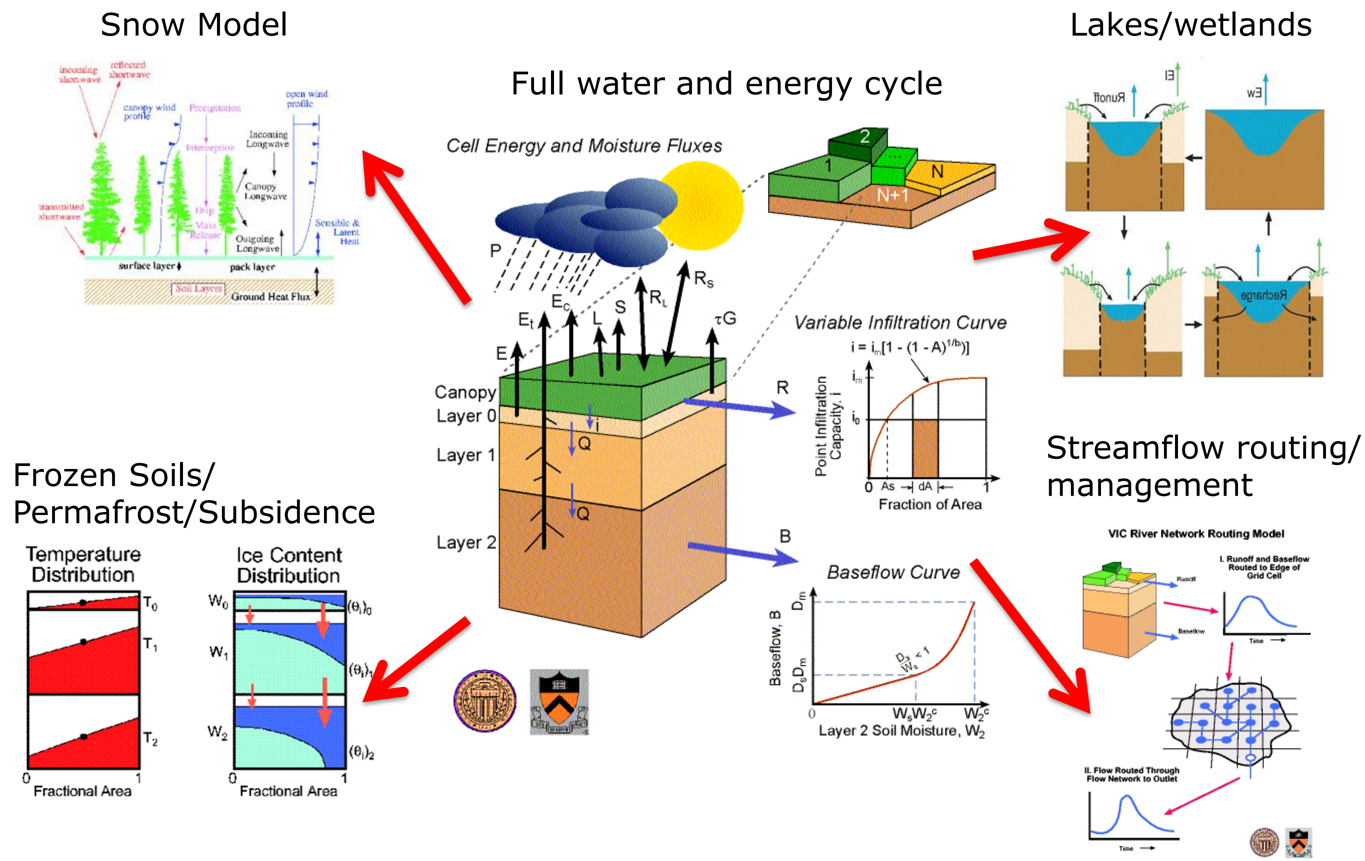


Multi-Sensor View of Single Drought Event

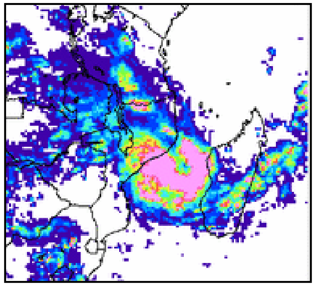


Observing the Water Cycle: Modeling

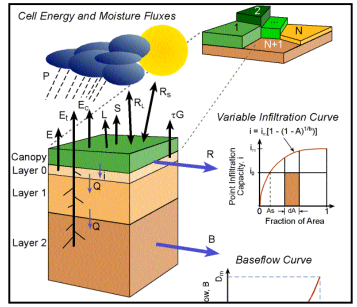
VIC Land Surface Hydrologic Model



Putting it all together: Hydrological and Drought Monitoring System

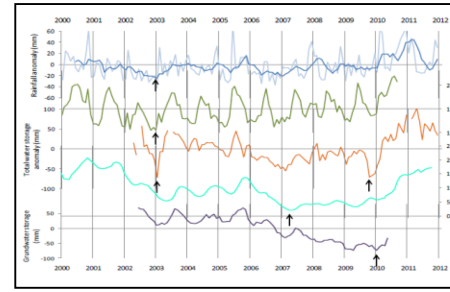


Real-time Weather

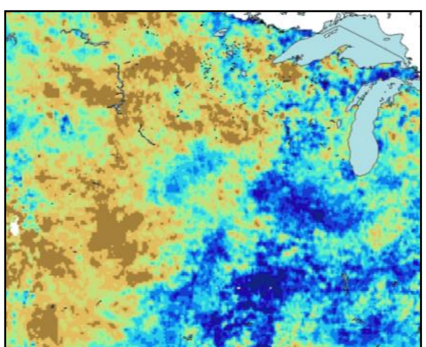


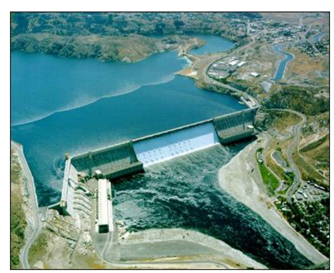
Land surface (hydrology) models

Initial Conditions



Hydrological Variables, Streamflow, Drought Indices

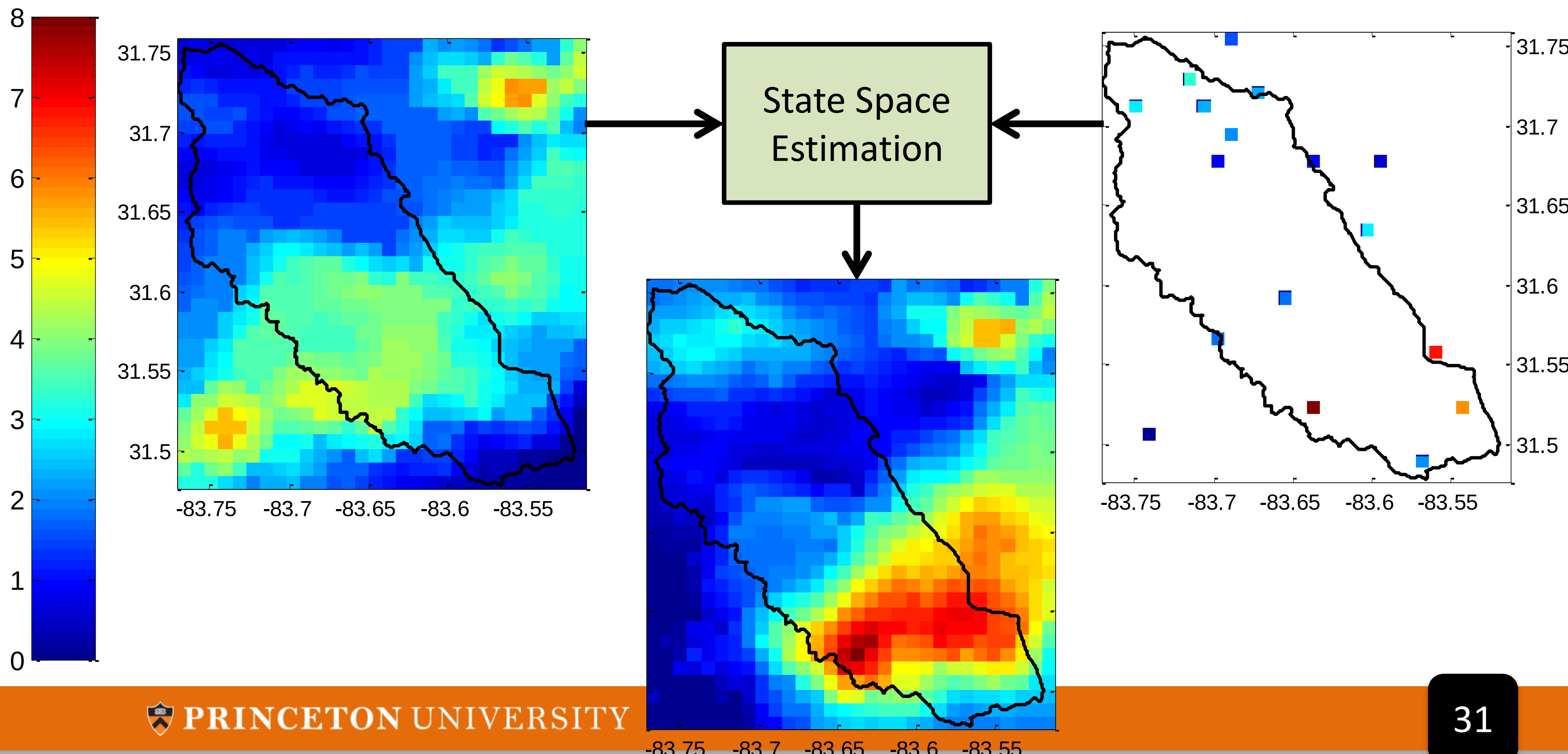




Management/Mitigation

Some Challenges of Large Scale Monitoring

- Validation of remote sensing products, hydrological modeling, drought products
- Assimilation of local measurements (gauge data for precipitation, streamflow, etc)



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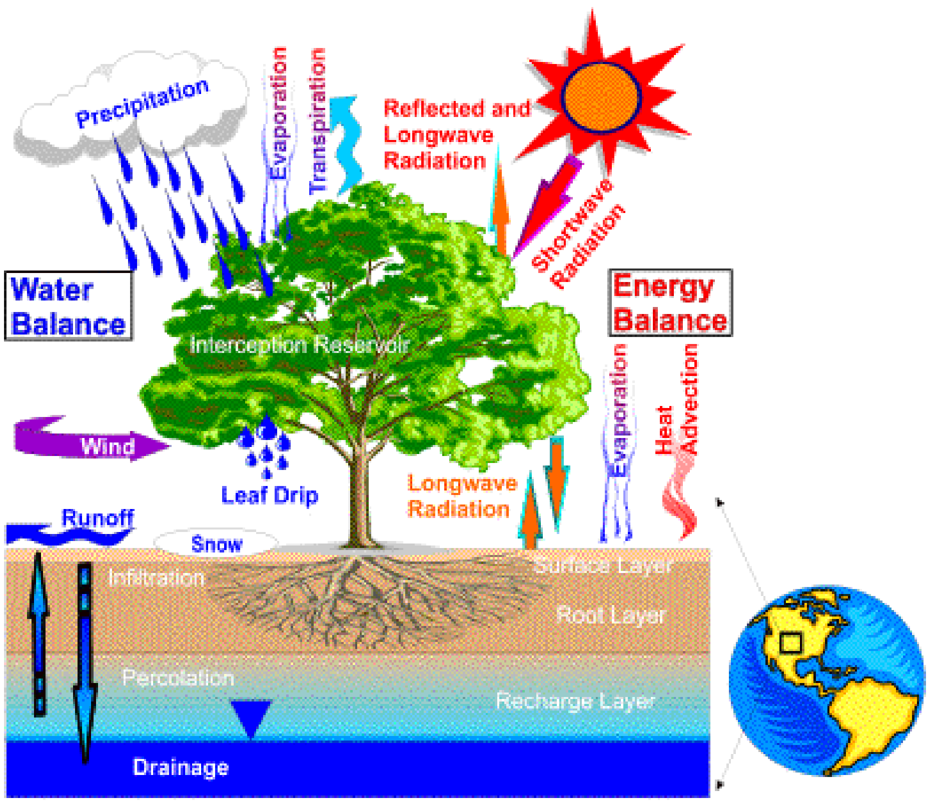
Land Surface Model: Land – Atmosphere Interaction

Land Surface Modeling Concept

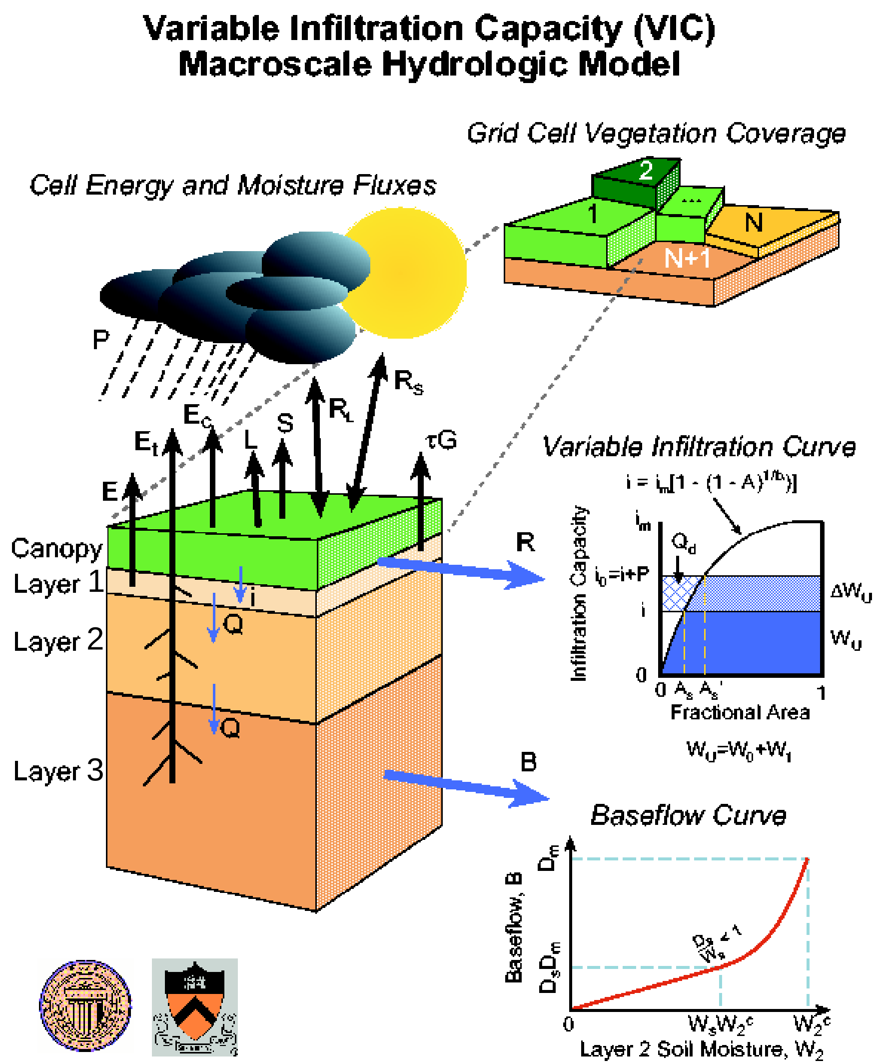


- Model the interaction between the land and atmosphere.
- Processes to account for:
  - **Water balance**
    $\Delta S = P - E - R$
  - **Energy balance**
    $SW\downarrow + LW\downarrow - LW\uparrow - SW\uparrow - SH - LH - G = 0$

<u>Terminology</u>

- ΔS = Change in storage
- P = Precipitation
- E = Evapotranspiration
- R = Runoff
- $LW\uparrow$ = Upward Longwave Radiation
- $LW\downarrow$ = Downward Longwave Radiation
- $SW\downarrow$ = Downward Shortwave Radiation
- $SW\downarrow$ = Upward Shortwave Radiation
- LH = Latent Heat
- SH = Sensible Heat
- G = Ground Heat Storage

Land Surface Model: Variable Infiltration Capacity



1. Each grid cell is modeled independently without horizontal flow.

2. The surface of each grid cell is described by *N+1* land cover tiles.

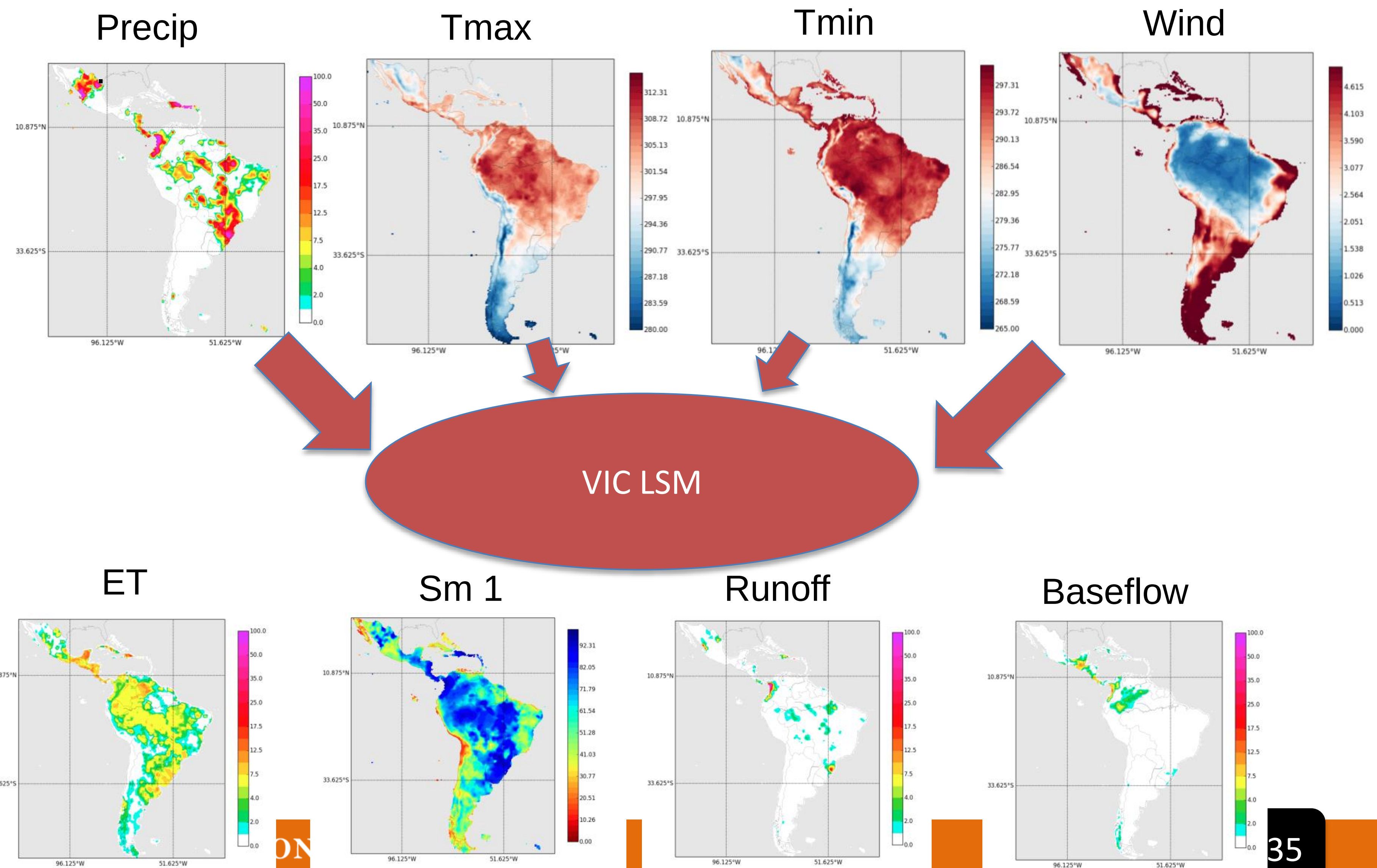
3. Evapotranspiration is calculated for all vegetation tiles in a grid cell and then averaged over the grid cell.

4. The top two soil layers are designed to represent the dynamic response of soil.

5. Baseflow comes from the layer 3.

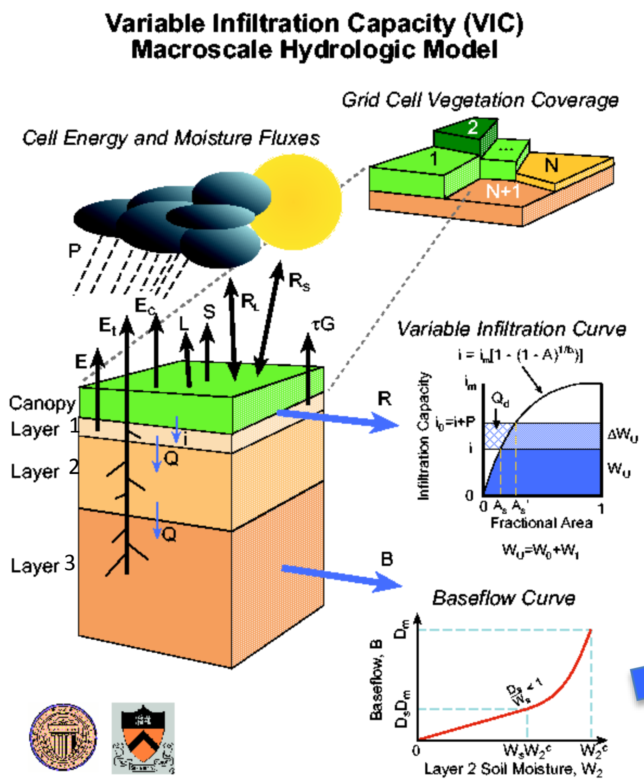
6. The variable infiltration curve parameterizes the spatial variability of infiltration.

Land Surface Model: Example

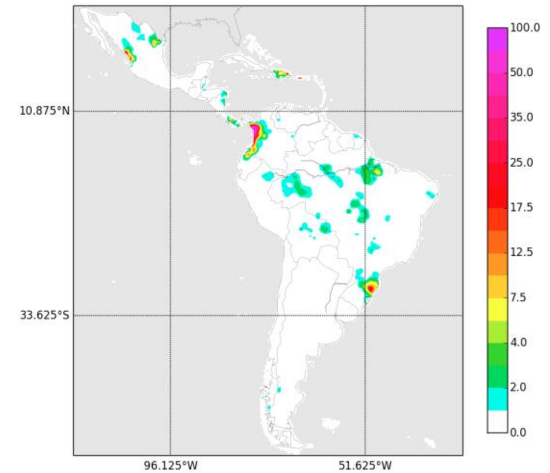


Land Surface Model: Simulate Discharge

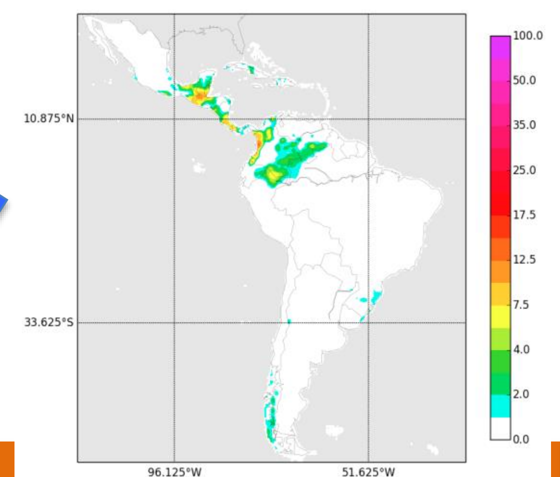
How do we simulate discharge at stream gauges using our land surface model output of baseflow and surface runoff?



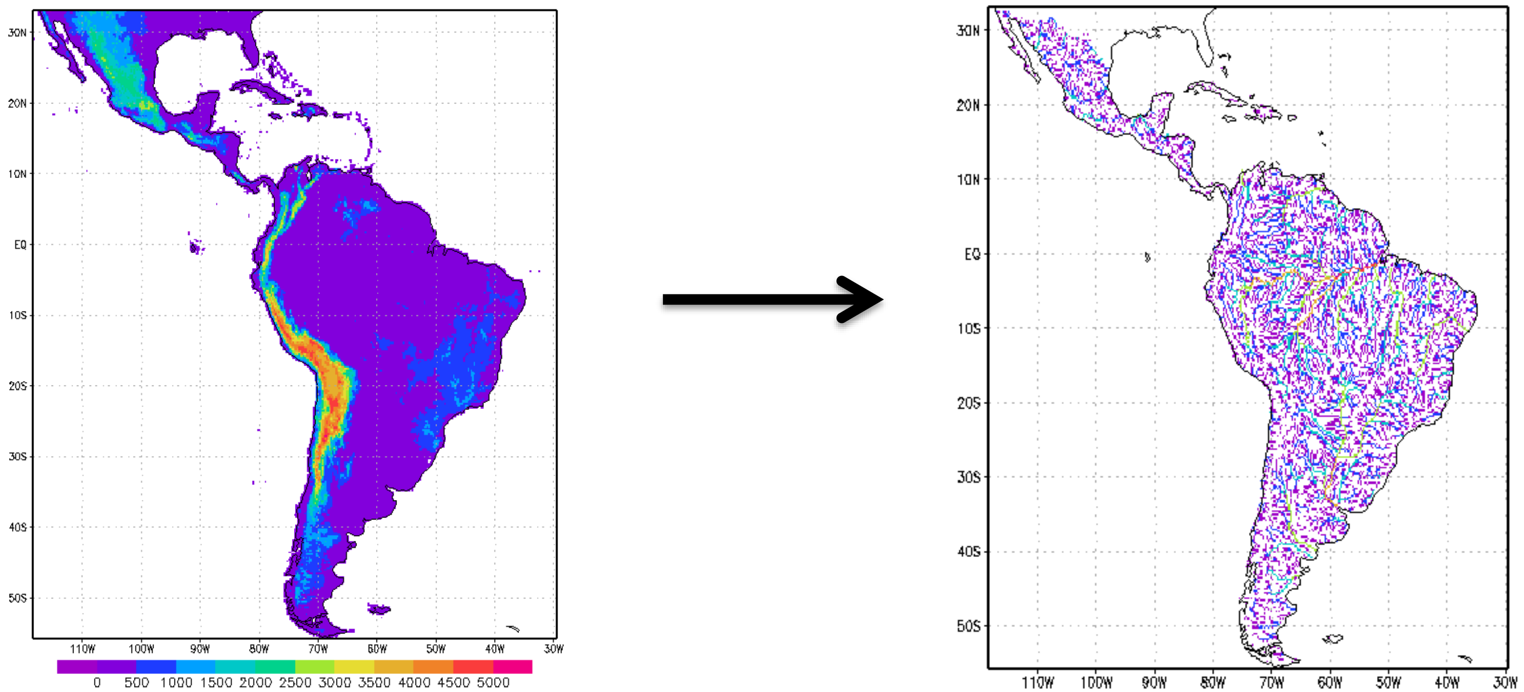
Runoff



Baseflow



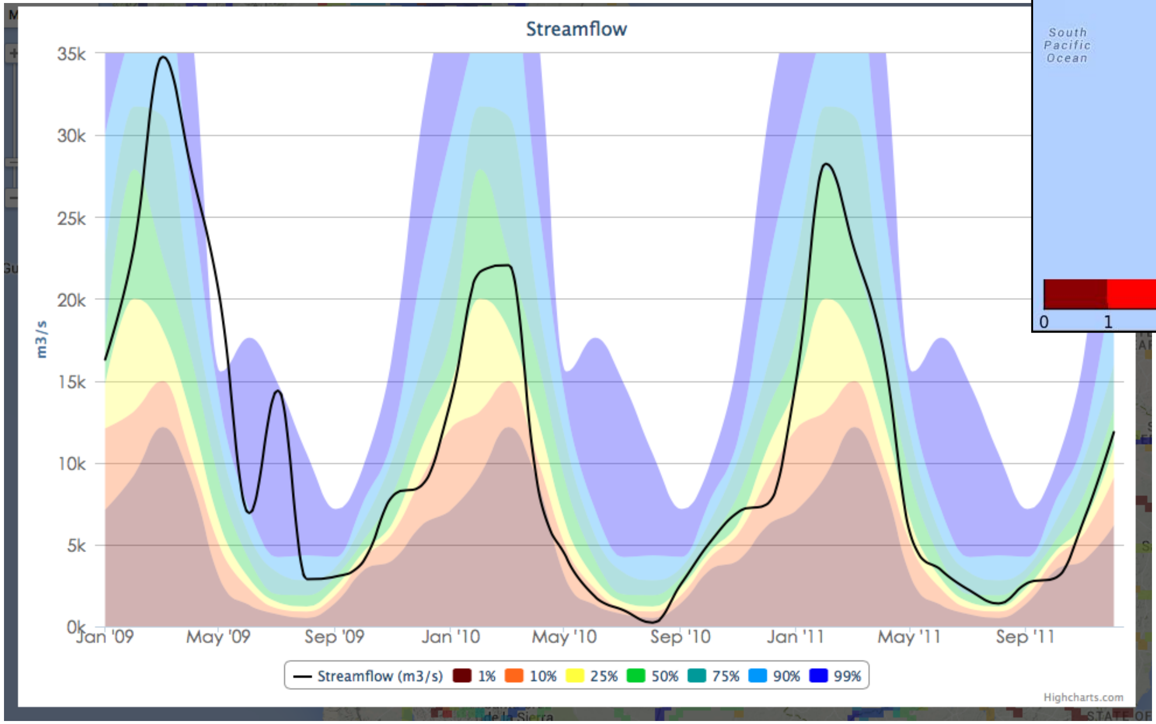
Simulate Discharge

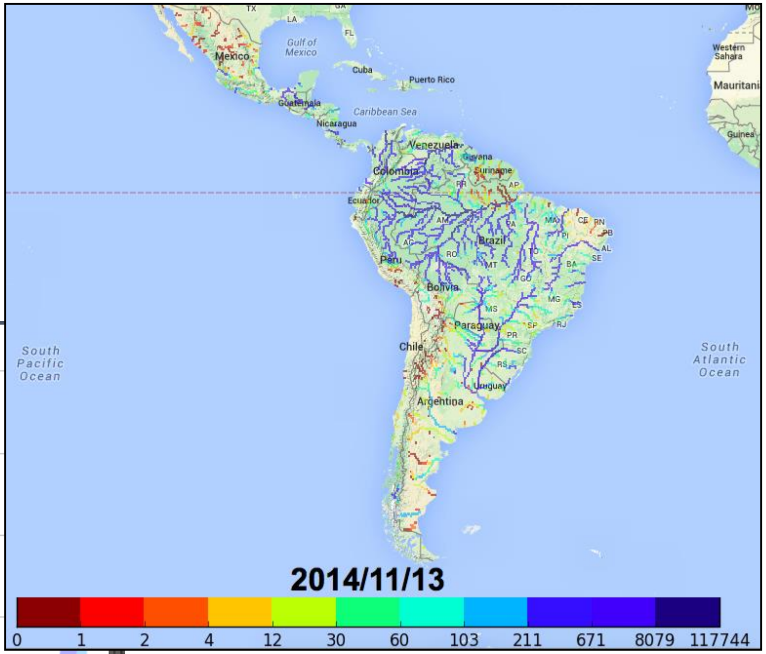


- Use the elevation data to delineate the basins (HydroSHEDS - WWF).
- Determine the path that surface runoff and baseflow from each grid cell follow until reaching the stream gauge.
- For each grid we essentially add up the contributions at that time step from all grid cells.

Simulate Discharge: Routing Model

Ultimately, we produce gridded estimates of discharge that can easily be viewed as time series for a single grid

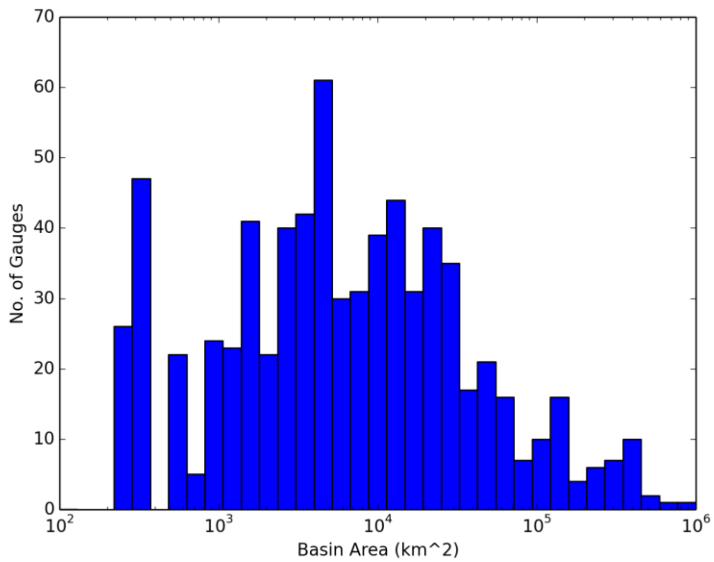




Validation: Grid Cell Runoff Observations

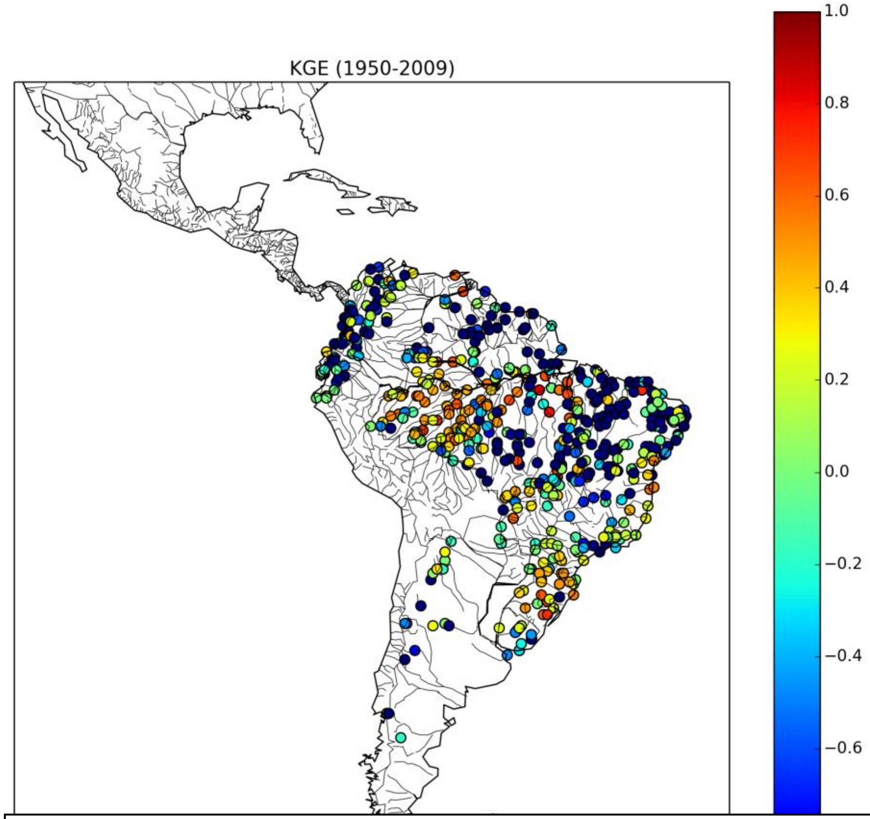
Validate the model against discharge observations

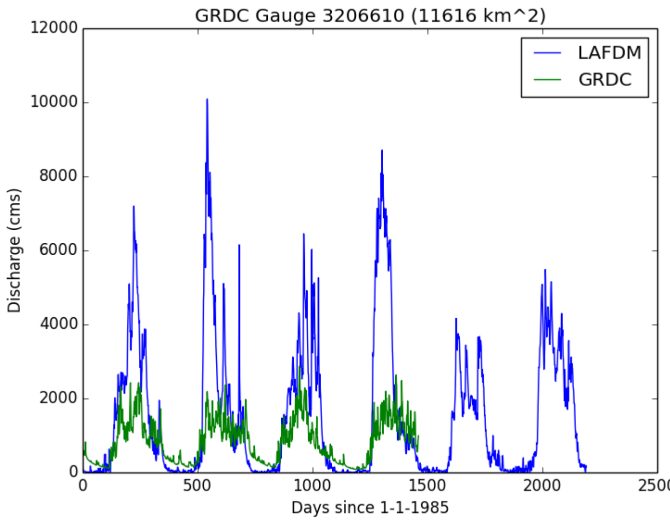
- GRDC (Global Runoff Data Center) database (1950 – 2010)
  - The points represent stream gauges.
  - Each stream gauge has a corresponding catchment.
  - Data is available in both monthly and daily forms

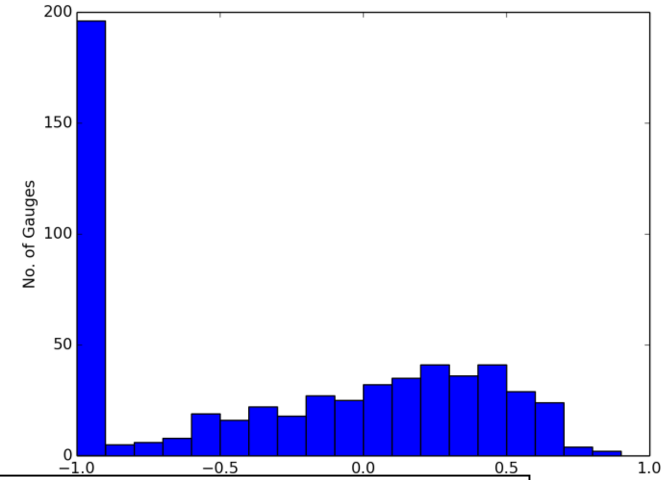


Validation of the Land Surface Model

Kling-Gupta Efficiency:
Measure of the correlation, bias and variability of model, 1 is perfect, <0 means the mean is better







Future calibration may improve the land surface model's ability to reproduce measured discharge. Additional gauges will also be useful.

DATA SCIENCE AND HYDROLOGY BEHIND THE FLOOD AND DROUGHT MONITORS

INTRODUCTION
MODELING FRAMEWORK
METEOROLOGICAL DATA
DROUGHT PRODUCTS

Historical Meteorological Dataset

Reanalysis
High temporal/low spatial resolution
MANY BIASES and SPURIOUS TRENDS

Observations
Generally low temporal/high spatial resolution
BEST ESTIMATE of individual variables

Forcing Dataset
High temporal/high spatial resolution:
CORRECTED, CONSISTENT

NCEP/NCAR Reanalysis
1948-, 3hr, 6hr, daily, T62
P, T, Lw, Sw, q, p, w

CRU
1901-2000, Monthly, 0.5deg
P, T, Tmin, Tmax,

GPCP
1997-, Daily, 1.0deg
P

UW
1979-2000, Daily, 2.0deg
P

TRMM
2002-, 3hr, 0.25deg
P

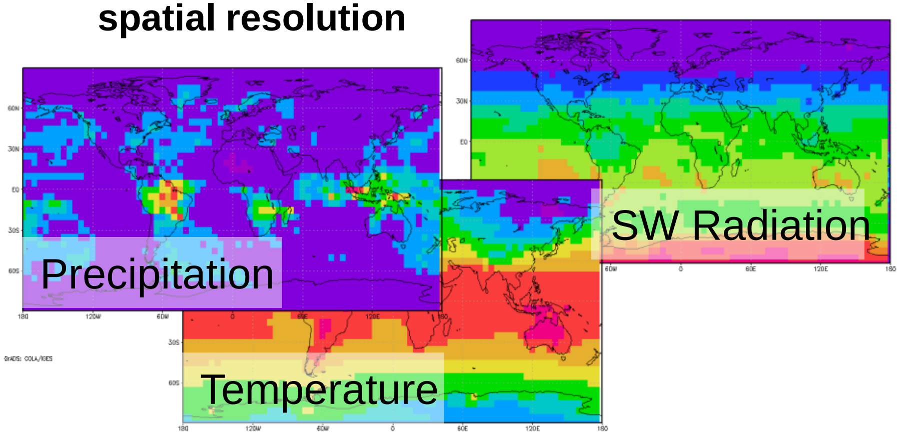
SRB
1985-2000, 3hr, 1.0deg
Lw, Sw

PGF
1948-2008, 3hr, daily, 0.25 deg
P, T, Lw, Sw, q, p, w

Historical Meteorological Dataset

Reanalysis

High temporal/low spatial resolution



Observations

Generally low temporal/high spatial resolution

CRU
190…
P, T…

GPCP
199…
P

UW
197…
P

TRMM
200…
P

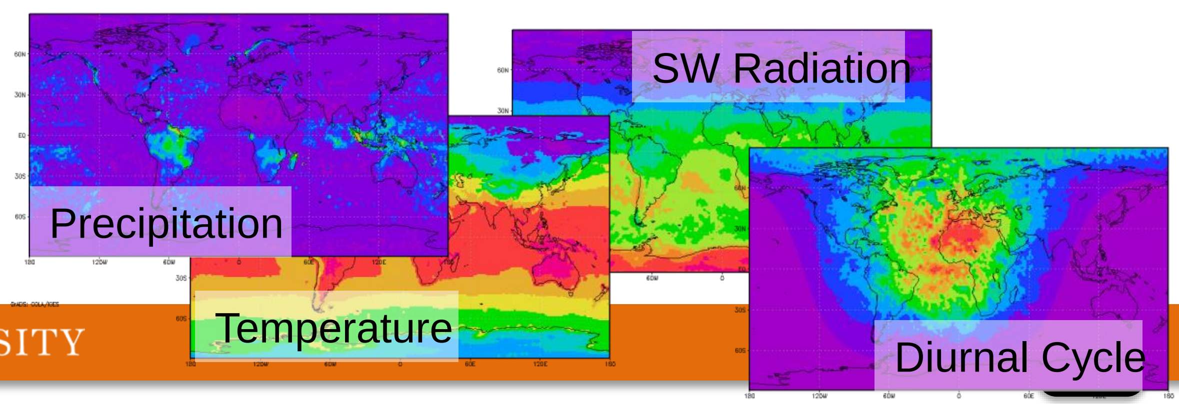
SRB
1985-2000, 3hr, 1.0deg
Lw, Sw

Bias Correct and Downscale

- corrected rainday statistics, gauge undercatch
- removal of biases in monthly P, T, SW, LW
- removal of spurious trends in SW
- adjustment for elevation effects
- downscale in time and space

Global Forcing Dataset

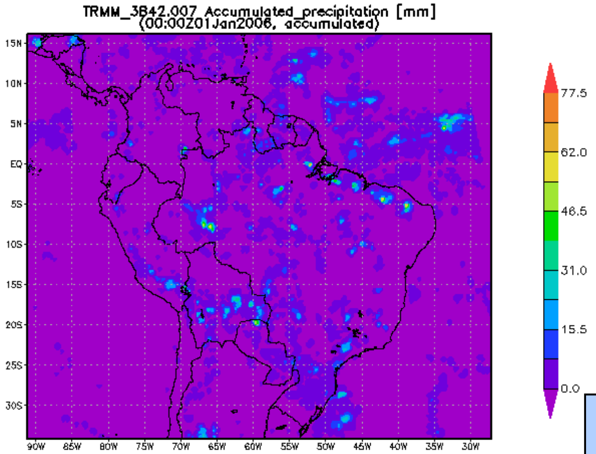
High temporal/high spatial resolution, bias corrected, trend corrected, etc…



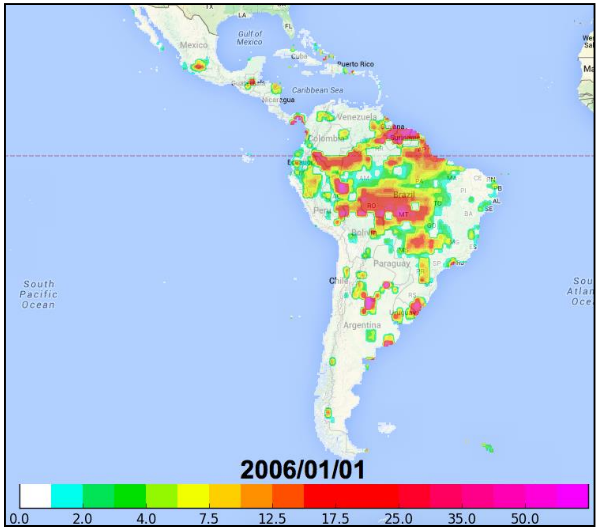
Real-Time Meteorological Data: Satellite Precipitation

Monitor uses TRMM 3B42v7 daily precipitation estimates, bias corrected against the historical climatology

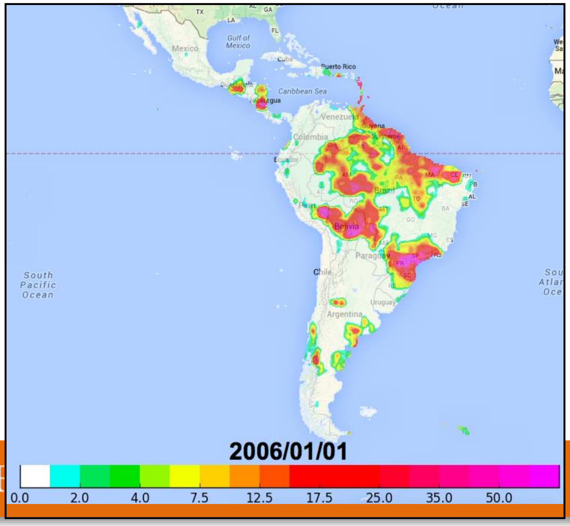
TRMM



PGF

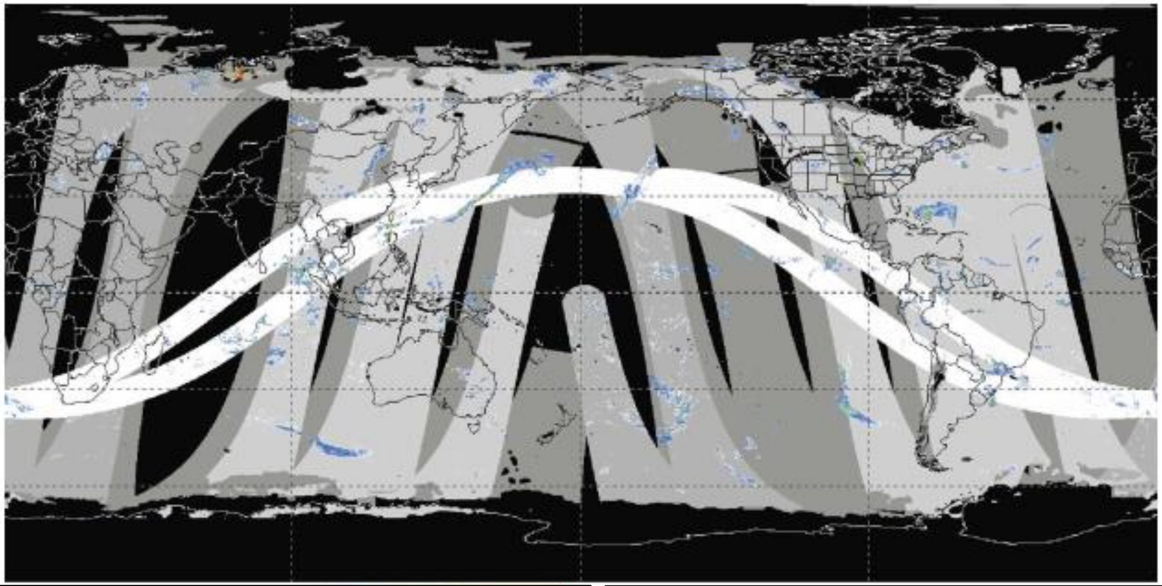


Bias Corrected



Satellite Precipitation - TMPA (Example)

TMPA – TRMM Multi-Satellite Precipitation Analysis



3-hour period centered at 0000 UTC 25 May 2004
- Different Sources:
  - TMI (white)
  - SSM/I (light gray)
  - AMSR-E (medium gray)
  - AMSU-B (dark grey)

A diverse, growing set of <u>input precipitation estimates</u> – various
- periods of record
- regions of coverage
- sensor-specific strengths and limitations

Real-Time Meteorological Data: Weather Model

Global Forecast System

1. Global weather forecasting model at 1 degree spatial resolution
2. Run by NOAA (National Oceanic and Atmospheric Administration) in the US.
3. Run every 6 hours at 00,06,12,18 hours UTC.

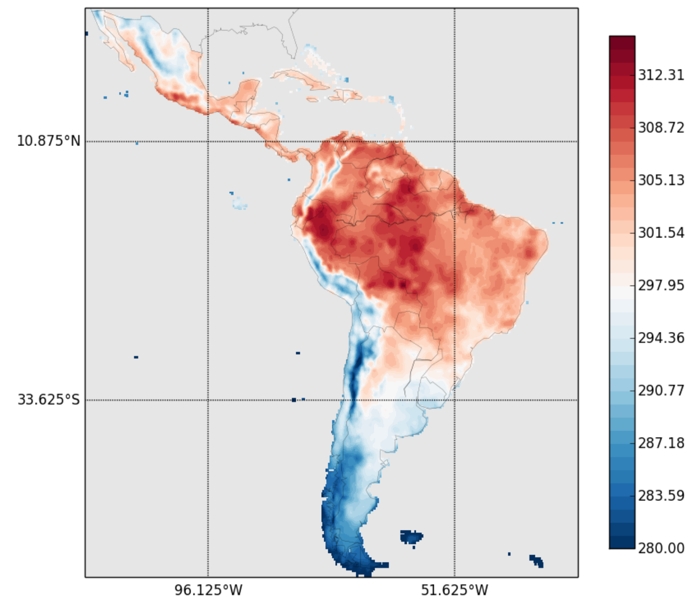
- Initial conditions are necessary at the beginning of each forecast.
  - The Initial conditions come from GDAS (Global Data Assimilation System)
- The observation based initial-conditions are used to find temperature and wind speed data.
- Forecasts of precipitation are used to supplement TRMM observations
- **Used in the drought monitor since 2009**

Real-Time Meteorological Data: Weather Model

How is the weather model data processed in order to use in the land surface model?

1. Initial conditions provide the temperature and wind speed data for 00,06,12,18 hours UTC.
2. The 3 hour forecast since the beginning of the run is also used (e.g. 00 -> 03 hour).
    - *<u>There are 8 values of temperature and wind speed for a day.</u>*
3. The minimum temperature, maximum temperature and mean wind speed are derived from GFS.
4. Use bilinear interpolation to downscale to ¼ degree spatial resolution.

Daily Maximum Temperature



DATA SCIENCE AND HYDROLOGY BEHIND THE FLOOD AND DROUGHT MONITORS

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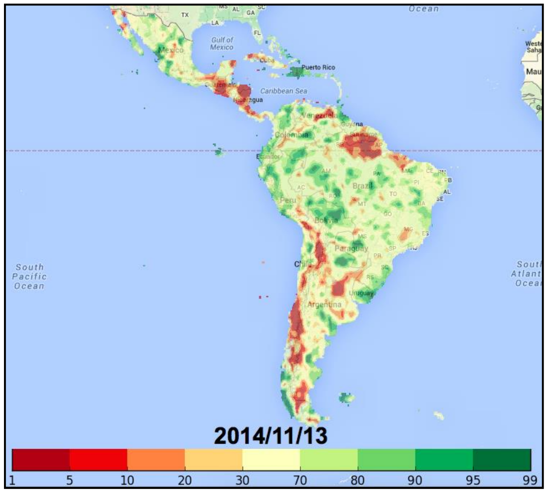
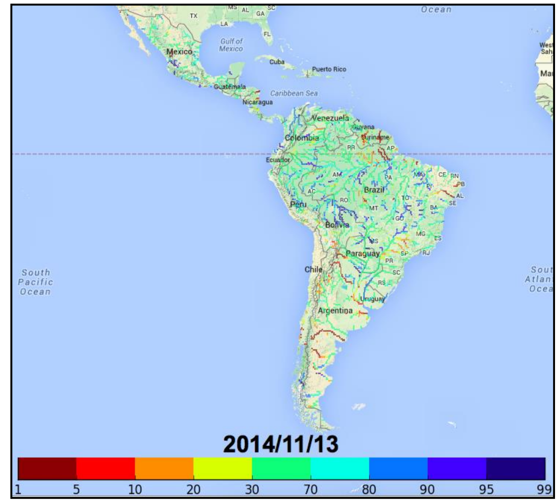
Part 3: Drought Products

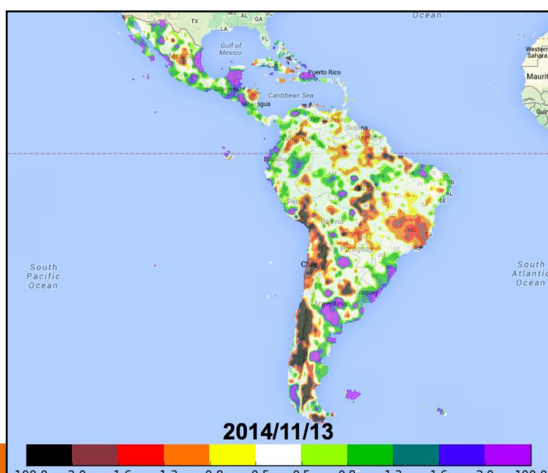
- Drought Index



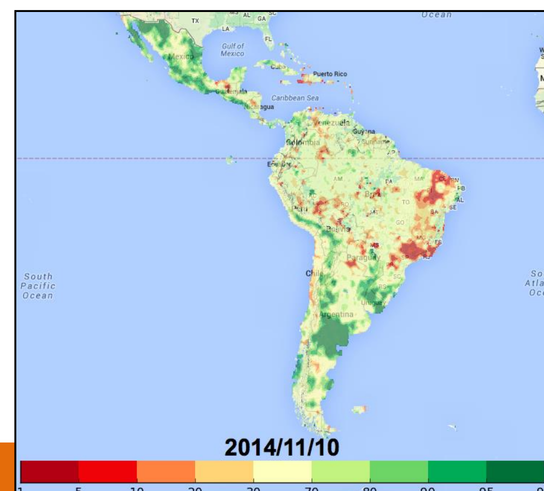
- Simulated Discharge Products



- SPI



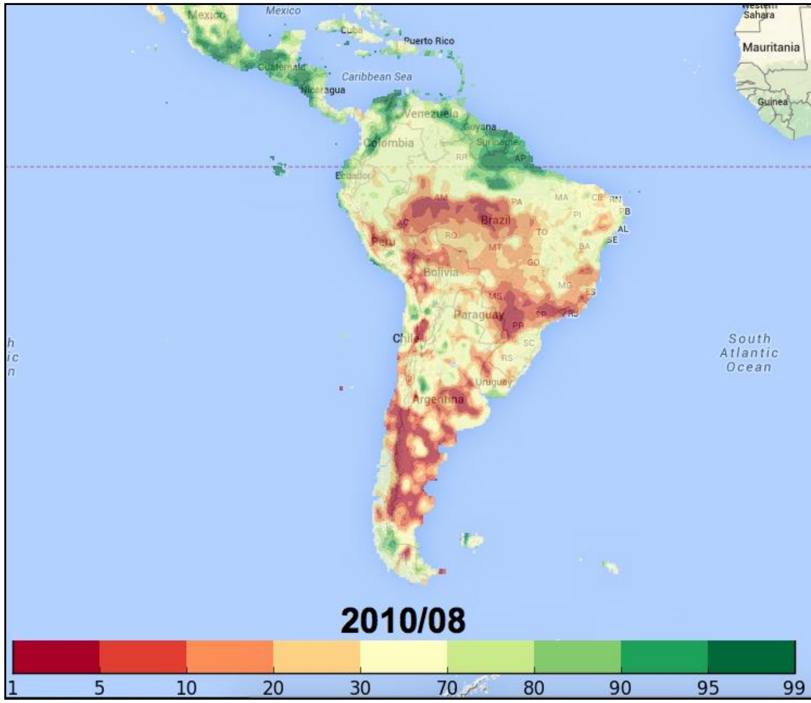
- Vegetation (NDVI) Products



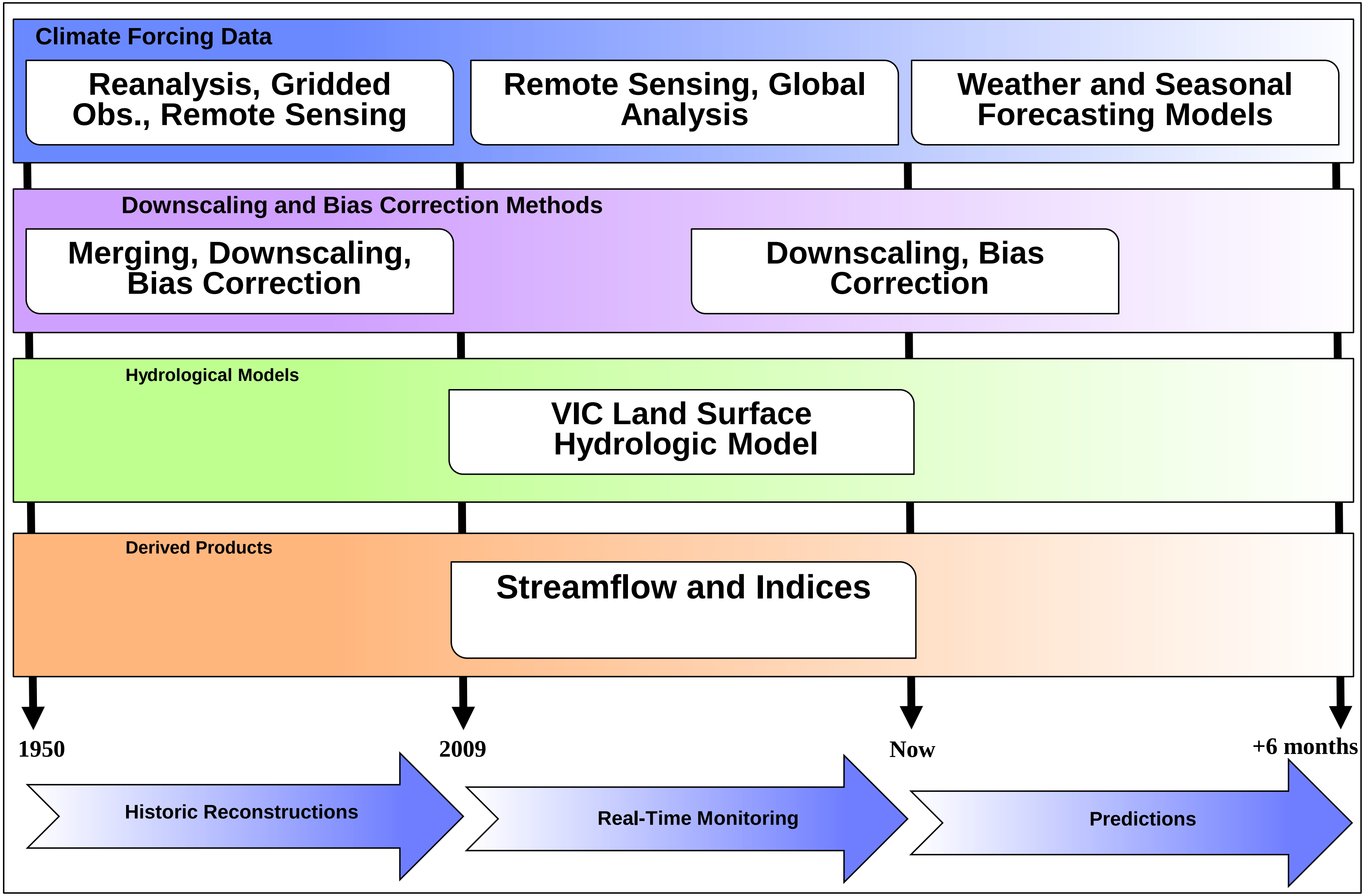
Drought Products: Drought Index

Drought Index - Measure of the severity of drought; low values indicate drought conditions.

Steps to calculate:
1. Calculate the relative soil moisture of the sum of the land surface model output of layers 1 and 2
2. Find the percentile of the day in question by comparing it to the climatology provided by the historical simulations (1950 - 2008).
   - **<u>The index is the resulting percentile</u>**.



- **What historical information do we use?**
  - The VIC land surface model is run between 1950 and 2008.
  - We assume that this time period establishes the climatology to which compare drought conditions.



Sheffield et al. (2014), BAMS

On Modeling Human Impacts

http://thewatercycle7.weebly.com/

On Modeling Human Impacts

- To calculate water scarcity we need information of water demand (domestic, industry, agriculture)
- Hydrological models are moving in that direction
  - PCR-GDEM (Utrecht University, Netherlands) estimates human water demand from socio-economic data (land cover, GDP, population density, electricity use etc.), at monthly time steps and at 0.5 degrees, globally.
  - Inter-Sectoral Impact Model Intercomparison or ISI-MIP (Postdam Institute for Climate Impact Research, International Institute for Applied Systems Analysis)

References

Drought Monitor Framework

Sheffield, J., Wood, E. F., Chaney, N., Guan, K., Sadri, S., Yuan, X., Olang, L., Amani, A., Ali, A., Demuth, S. and L. Ogallo , 2014: A Drought Monitoring and Forecasting System for Sub-Saharan African Water Resources and Food Security, *Bulletin of American Meteorological Society*, http://dx.doi.org/10.1175/BAMS-D-12-00124.1

African Dataset

Chaney, N., Sheffield, J., Villarini, G., and E. F. Wood, 2013: Development of a High-Resolution Gridded Daily Meteorological Dataset over Sub-Saharan Africa: Spatial Analysis of Trends in Climate Extremes, *Journal of Climate*, 27, http://dx.doi.org/10.1175/JCLI-D-13-00423.1

Princeton Global Forcing

Sheffield, J., Goteti, G., and E. F. Wood, 2006: Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling, *Journal of Climate*, 19, http://dx.doi.org/10.1175/JCLI3790.1

Thank you for your attention!
Questions or comments?

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