Applications of Satellite Observations in Climate Monitoring and Diagnostics at NOAA/CPC

Pingping Xie

NOAA Climate Prediction Center

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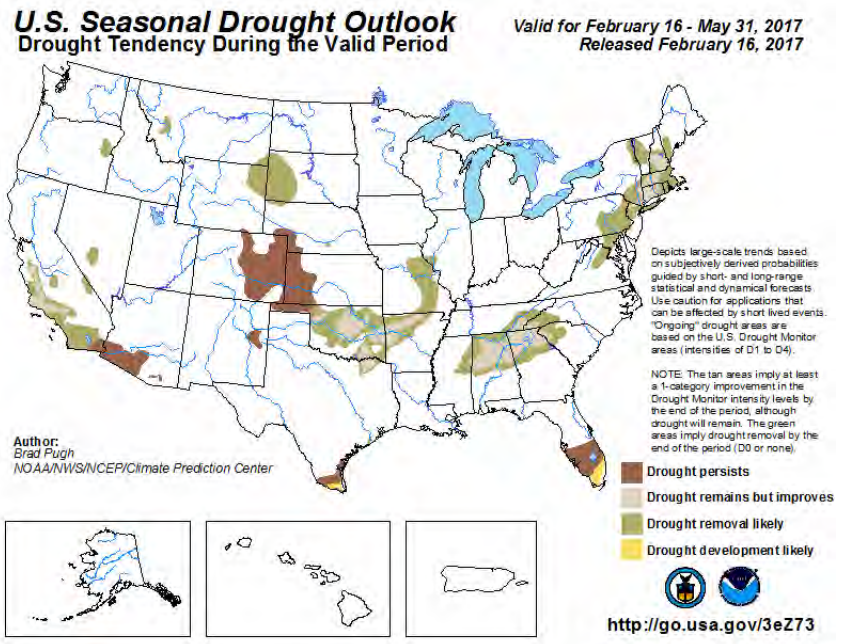
CPC Mission

We deliver climate prediction, monitoring, and diagnostic products for timescales from weeks to years to the Nation and the global community for the protection of life and property and the enhancement of the economy.

Operational Requirements:

- **Deliver national outlook products: temperature, precipitation, drought, hurricanes,..**
- **Span weeks, months, seasons, years**
- **Embrace collaborative forecasting with other NCEP Service Centers, NOAA line offices, other agencies and labs**
- **Ensure real-time, on-time, all the time (since '79)**



Monitoring and Diagnosing Short-Term Climate Variability

- Short-Term Climate Variability
  - *Weeks (MJO) to years (ENSO)*
  - *Accumulated effects of individual weather events*
  - *Affected / modulated by long-term climate changes*
  - *Measured as departure from long-term climatology (30-yr);*
    - *Anomaly from long-term mean*
    - *Ranking (percentiles)*

- Common Basic Requirements for Data Sets to be Used for the Monitoring and documentation of Short-Term Climate Variability
  - *A gridded data set of reasonable time / spatial resolution (or station data at unchanging locations)*
  - *Covering a time period of sufficient length (ideally >=30 yr)*
  - *With appropriate temporal homogeneity*
  - *Updated on a quasi real-time basis*

Climate Applications of Satellite Data

- Monitoring, documenting, and diagnosing climate variability
- Verifying climate forecasts and climate model simulations
- Initial condition for climate models (land surface model)
- *In situ* observations by itself are often insufficient for such applications (sparse networks, poor representativeness et al.)

CPC is a Pioneer in Climate Applications of Satellite Data

- CPC started satellite-based climate monitoring and diagnostics more than 30 years ago when it was called Climate Analysis Center (CAC)
  - *Thanks to the great scientific vision and leadership of Dr. Rasmusson, then the CAC Diagnostics Branch Chief*
  - *As a part of CAC effort to construct in situ and satellite climate database*
  - *Instead of waiting for satellite and in situ data centers to create climate data sets, CAC started the work on its own*

Well Known CAC/CPC In Situ and Satellite Based Climate Data Sets

- Sea Surface temperature (SST)
  - *Reynolds*
- Outgoing Longwave Radiation (OLR)
  - *Janowiak*
- Precipitation
  - *Arkin*
- Surface Air temperature and Precipitation (in situ)
  - *Ropelewski and Halpert*
- The Global Precipitation Climatology Project (GPCP) *was initiated by CAC sponsored by WMO, aiming to creating satellite based global precipitation estimates using IR data from geostationary satellites owned by member countries.*

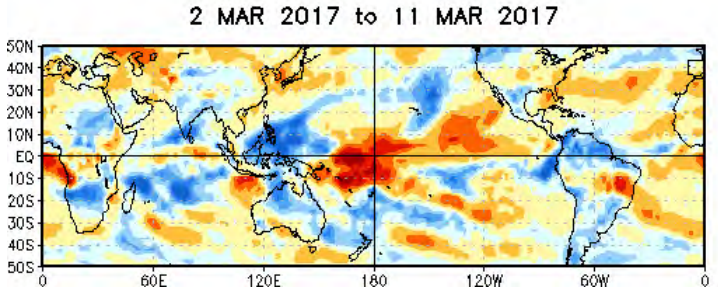
Unique Approach of CPC to Utilize Satellite

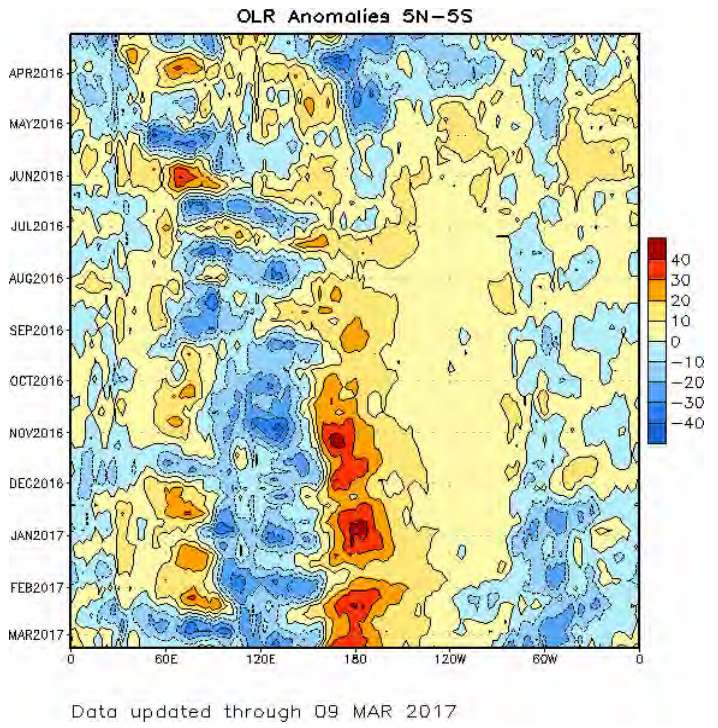
- Satellite data generated by satellite centers are often NOT readily / easily usable for climate applications
  - *Classification of satellite products of geophysical variables*
    - *Level 0: raw satellite data*
    - *Level 1: radiance calibrated / geo-location determined*
    - *Level 2: Geophysical variables retrieved at satellite pixels / orbit time*
    - *Level 3: Gridded fields of geophysical variables at equal time steps*
  - *Often satellite centers consider Level 1 / 2 as their final products, while climate users need Level 3 from all satellites combined into a single data set*

- Two basic types of satellite data applications at CPC
  - *Direct use of satellite data from NESDIS and other satellite agencies*
  - ***Integrating individual satellite data into climate analyses***

Outgoing Longwave Radiation (OLR) Data

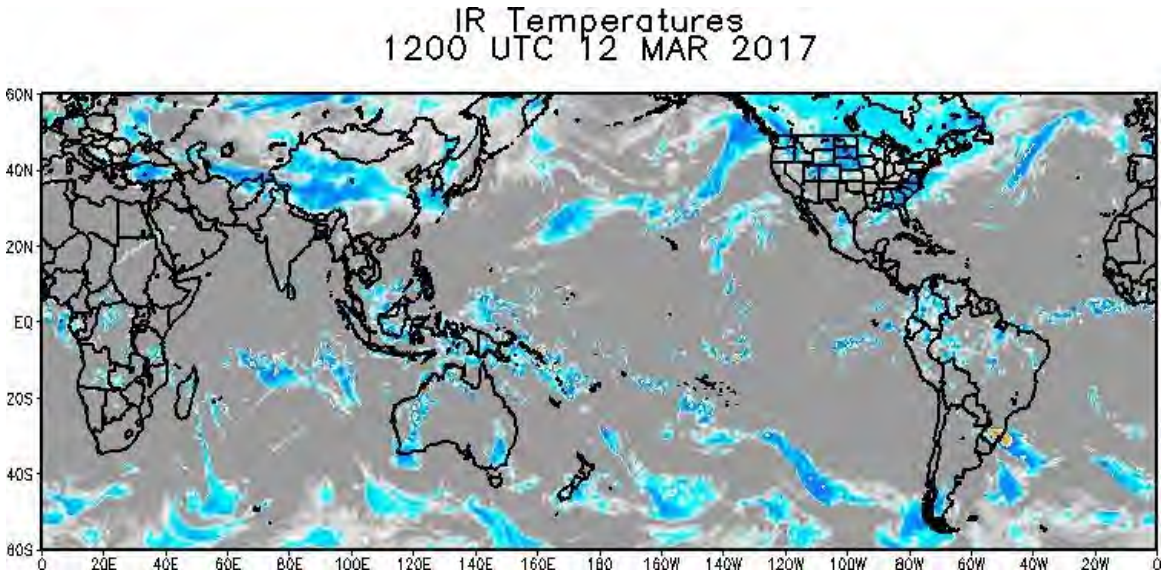
- Satellite measured OLR is important
  - *An index of the intensity of tropical convection and thereby global climate variations*
  - *Relationship to precipitation (may be used to derive quantitative precipitation estimates)*
- CPC integrates OLR retrievals from NOAA/NESDIS into gridded analysis
  - *2.5°lat/lon; monthly / pentad; updated real-time*
  - *A new version is underdevelopment taking advantage of newly available broadband and hyperspectral measurements*
- CPC utilizes OLR data for
  - *Monitoring of ENSO, MJO / sub-seasonal variability*
  - *Global Tropics Hazards Outlook*
  - *Deriving precipitation estimates*





Geostationary IR Temperature

- GEO IR Data
  - *Black Body temperature (TBB)*
  - *Intensity / movements of cloud systems*
- CPC integrates GEO IR data from five satellites into a single grid fields of TBB
  - *Limb correction / inter-satellite calibration*
  - *4kmx4km / 60°S – 60°N*
  - *30-min interval from jan.1, 1998*
- Applications at CPC
  - *Global Tropics Hazards Outlook*
  - *Tropical weather / MJO*
  - *Part of inputs to CMORPH satellite precipitation estimates*

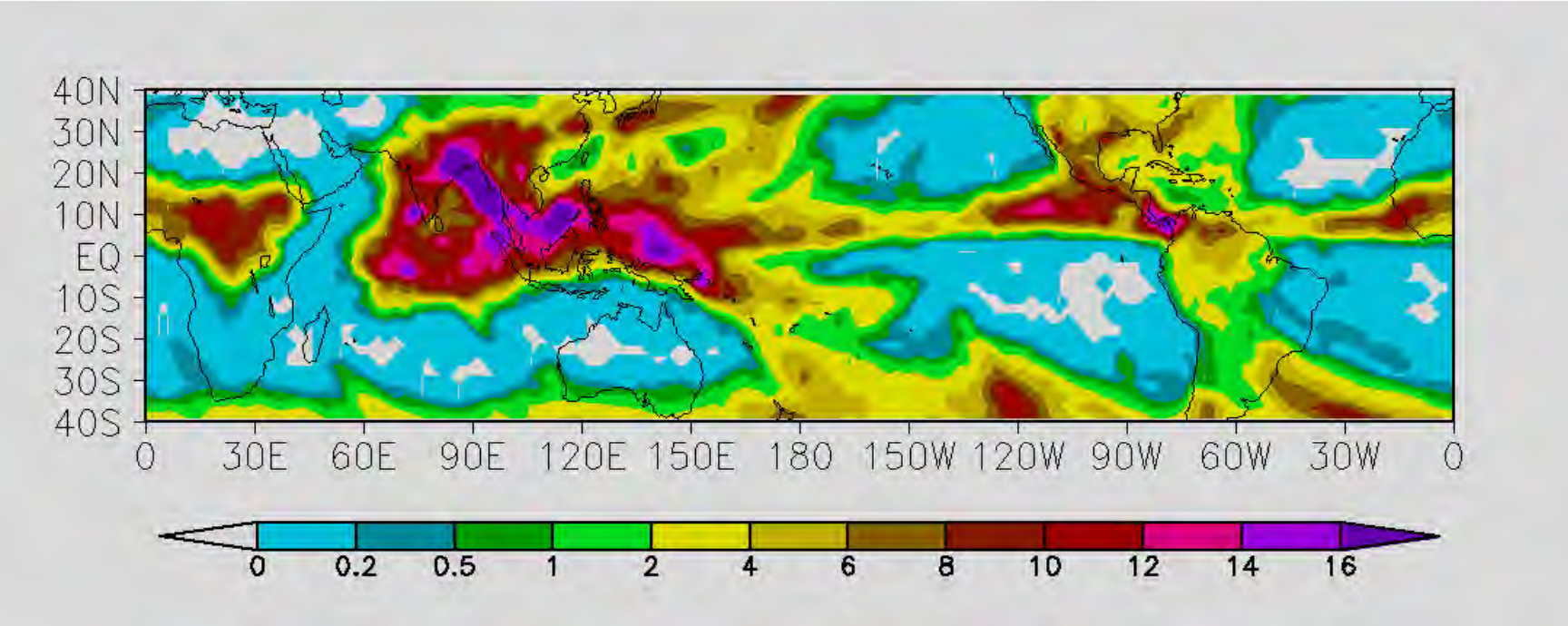


CPC Precipitation Products [1]

- Precipitation information is critical to
  - *Climate Monitoring, climate diagnostics*
  - *Validations of climate prediction, climate model performance*
  - *Forcing climate models (land-surface)*
- Sources of Precipitation Information
  - *In situ measurements (gauge, buoys)*
  - *Remote sensing (Radar / satellite estimates)*
  - *Numerical model simulations (forecasts, reanalyses)*
- Each individual sources has strength and shortcomings
  - *In situ (gauge) :*
    long-term record; point accuracy / sparse network
  - *Remote sensing:*
    broad spatial coverage / compromised accuracy; saturation
  - *Model data:*
    reasonable for cold season / poor for convective rain
- **Blending (fusion) is an effective mean to improve precipitation analyses**

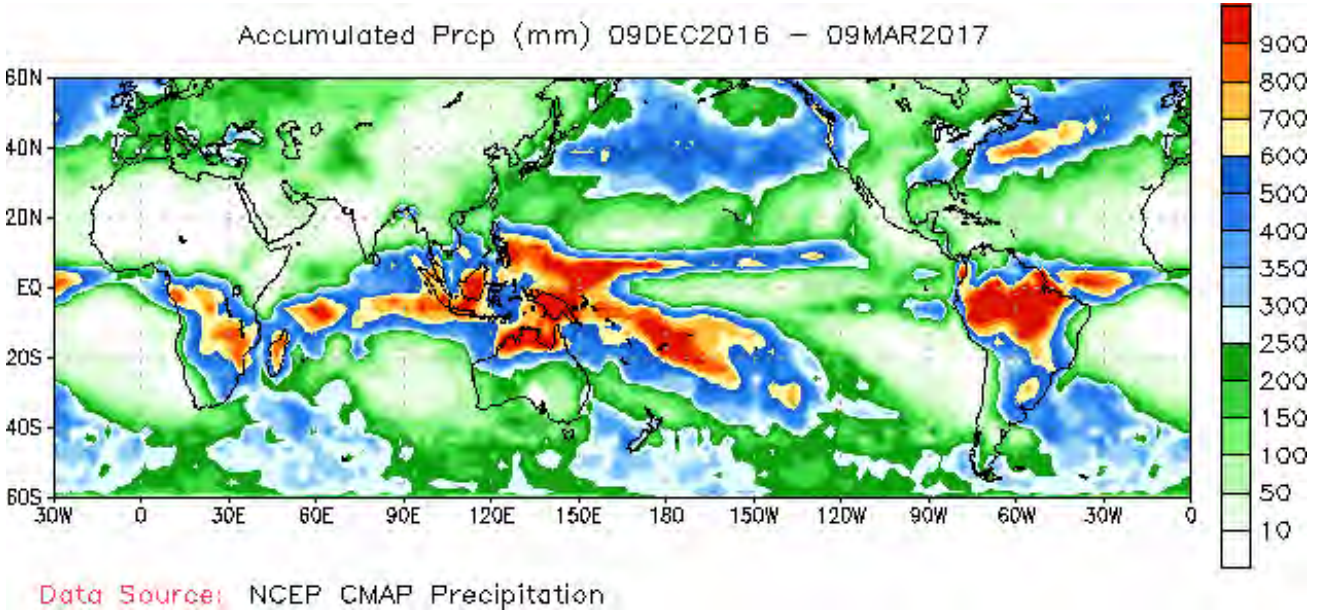
CPC Precipitation Products [2]

- CPC Heritage Precipitation Products
  - ***GOES Precipitation Index (GPI)***
    - *Arkin (1979)*
    - *Very simple technique to estimate tropical precipitation from coverage of cold clouds (<=235°K)*
    - *Enabled monitoring of precipitation over the tropical belt*



CPC Precipitation Products [3]

- CPC Heritage Precipitation Products
  - ***CPC Merged Analysis of Precipitation (CMAP)***
    - *Blending gauge, IR/PMW satellite estimates and reanalysis;*
    - *Monthly / pentad from 1979; 2.5°lat/lon over the entire globe*
    - *Real-time monitoring, diagnostics and forecast verifications of ENSO, MJO, global monsoons*
    - *CMAP 90-day accumulated rainfall for monsoon monitoring*

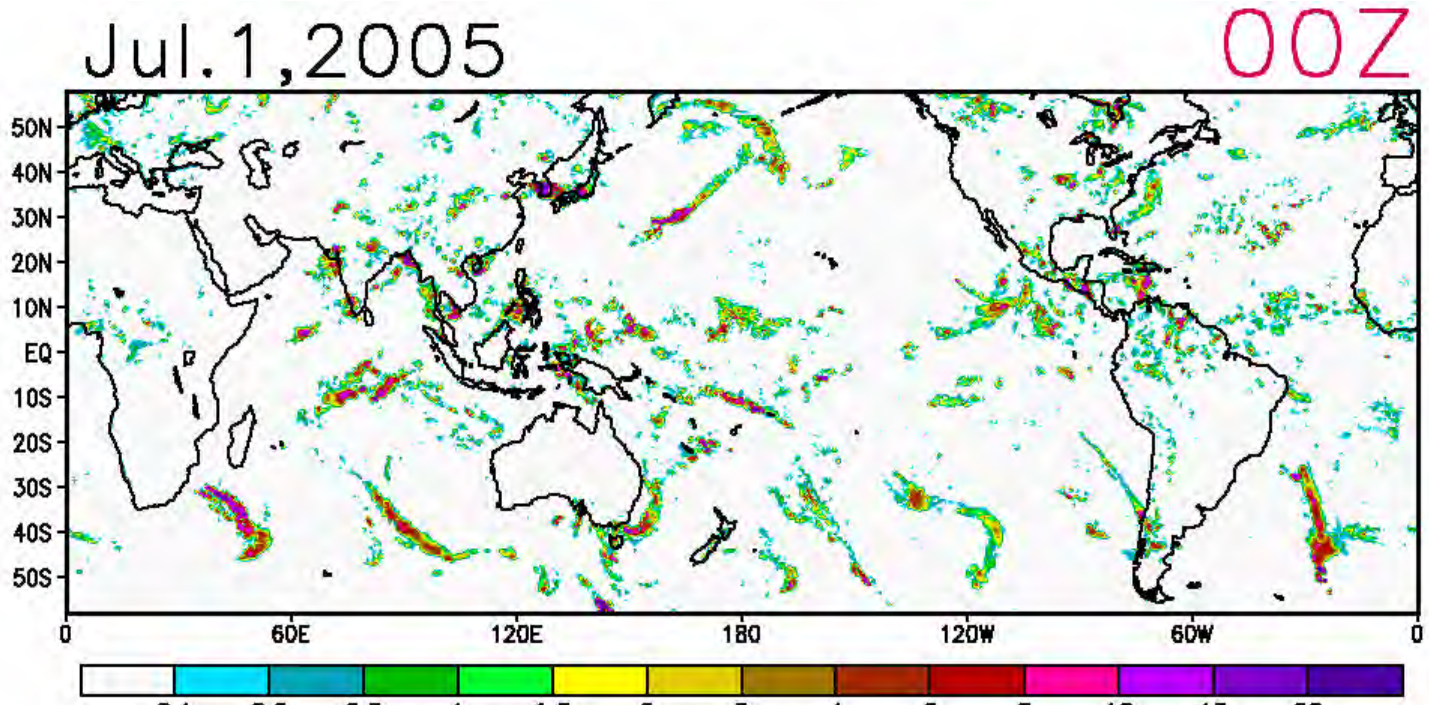


CPC Precipitation Products [4]

- CPC Morphing Technique (CMORPH)
  - ***Motivation:***
    - *Resolution of heritage satellite precipitation products (CMAP/GPCP) too coarse for many application (MJO, extreme events, hydrometeorology et al;*
    - *New satellite data available (PMW from ~10 satellites, IR a2 4kmx4km resolution)*
  - ***Objective:***
    - *Creating satellite-based high-quality, high-resolution global precipitation estimates*
  - ***Strategy:***
    - *Integrating precipitation information from all available satellites*
    - *Defining motion vectors of cloud systems through comparison IR TBB fields from two consecutive observations (30-min apart)*
    - *Propagating low earth orbit (LEO) based passive microwave (PMW) retrievals of instantaneous precipitation rates from their respective observation times to the target analysis time using the motion vector*

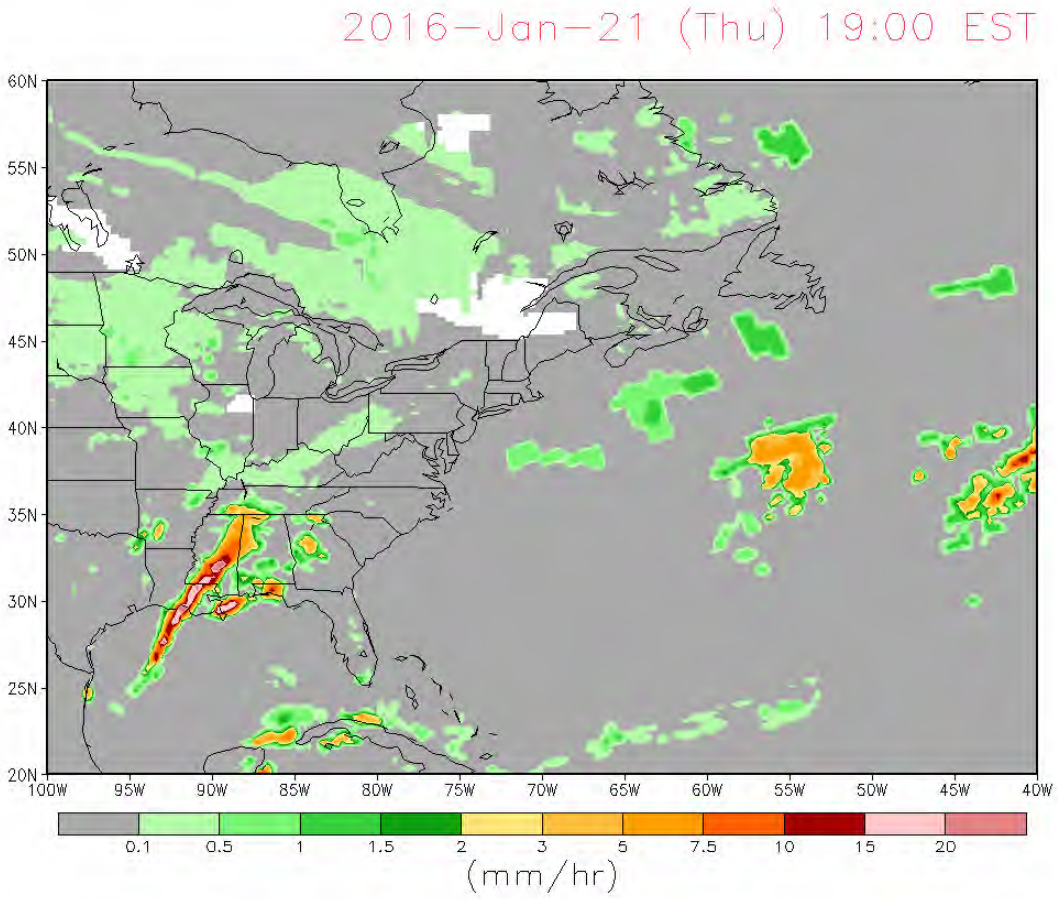
CPC Precipitation Products [5]

- CPC Morphing Technique (CMORPH)
  - *Creating high-quality, high-resolution global precipitation estimates through integrating information from multi-channel measurements from multiple platforms (GEO/LEO)*
  - *Bias corrected against gauge observations over land*
  - *8kmx8km / 60°S-60°N;*
  - *30-min interval / from Jan. 1998 / Real-time (2 / 12 hours)*



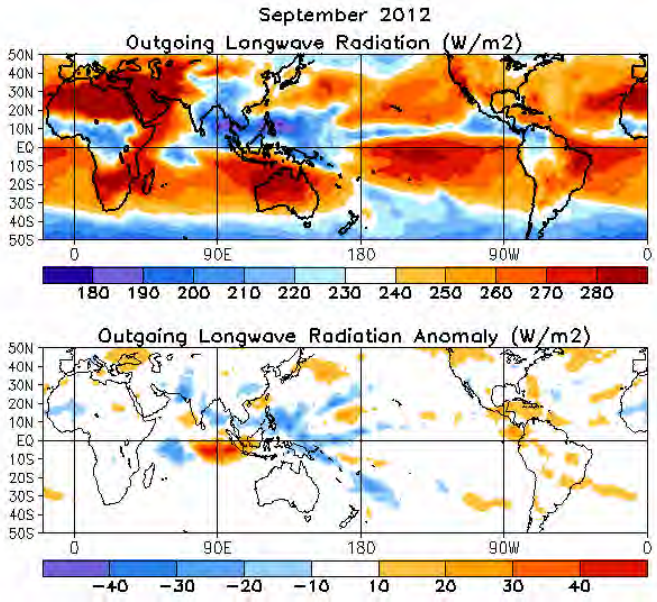
CPC Precipitation Products [6]

- CMORPH Captures Snowstorm



Applications of Satellite data in Monitoring the Atmosphere

Outgoing Longwave Radiation

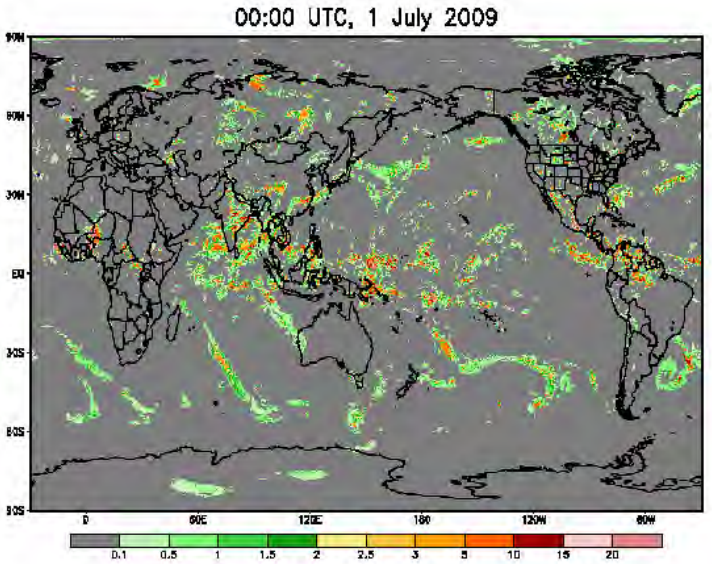


- Retrieved from Advanced Very High Resolution Radiometer (AVHRR) observations from NOAA polar orbiters
- Used as a proxy for atmospheric convection
- Monitoring Applications
  - Climate Variability (e.g. El Niño / La Niña)
  - Monsoons
  - Droughts and Floods

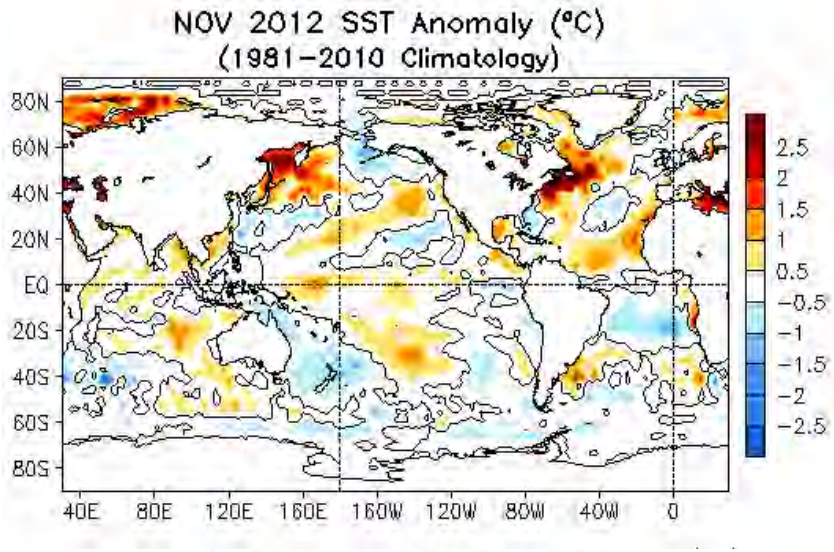
Precipitation

- CPC MORPhing (CMORPH) Technique integrates precipitation information from passive microwave sensors aboard low earth orbiting satellites and infrared observations from geostationary satellites.
  30 min temporal resolution
  1/8 deg horizontal resolution
  Testing pole to pole product (shown here)

- Applications
  - Model Verification
  - Diagnostic studies

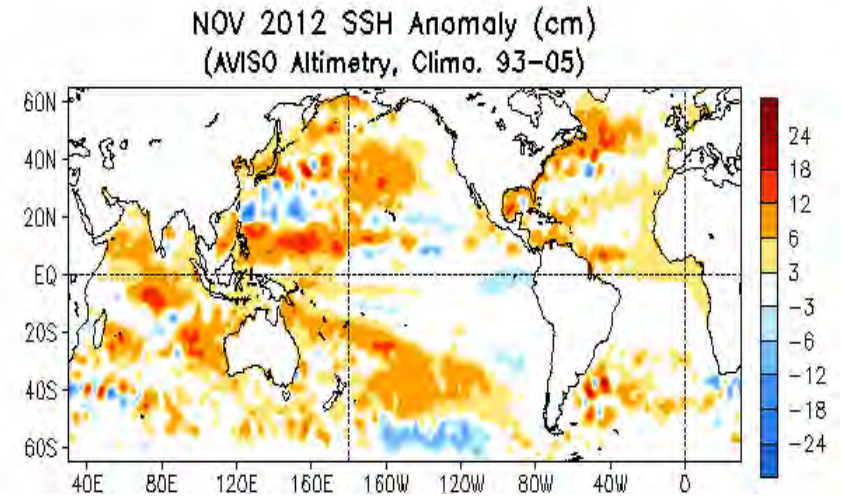


Monitoring the Oceans



Sea Surface Temperature

- Optimal Interpolation (OI) version 2 from NCDC
  - Blended analysis using in situ and satellite obs.
  - Time period: Nov 1981 to present
  - Temporal resolution: weekly
  - Spatial resolution: 1 deg
  - Applications: monitoring ENSO, IOD, PDO, AMO, TAV and trend
- Also used for model verification and diagnostic studies



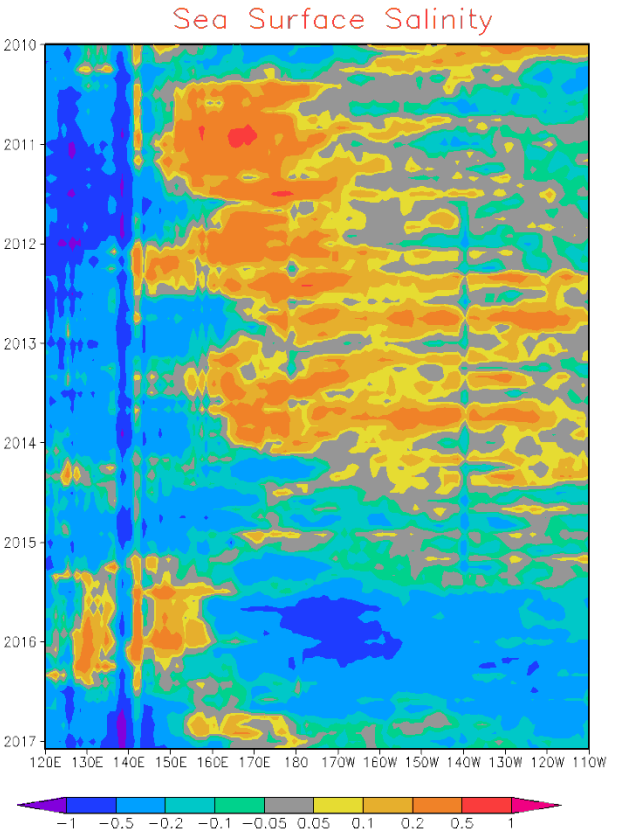
Sea Surface Height

- Gridded Absolute Dynamic Topography
  - Merged analysis using multiple satellite obs.
  - Time period: Oct 92 – present
  - Temporal resolution: daily
  - Spatial resolution: 1/4 deg
  - Applications: monitoring ENSO, IOD, PDO, trend
- Also used for model verification and diagnostic studies

Courtesyy of Y. Xue

Surface Salinity (SSS)

- SSS is an important oceanographic state variable
- Reflection of oceanic fresh water flux, circulations as well as upwelling
- In situ (buoy) measurements not sufficient to resolve fine structures of SSS variations over many global oceanic regions
- A new SSS analysis created at CPC through blending in situ measurements with satellite retrievals (SMOS, Aquarius, SMAP)
  - *1°lat/lon over the entire global ocean*
  - *Monthly time interval from 2010*

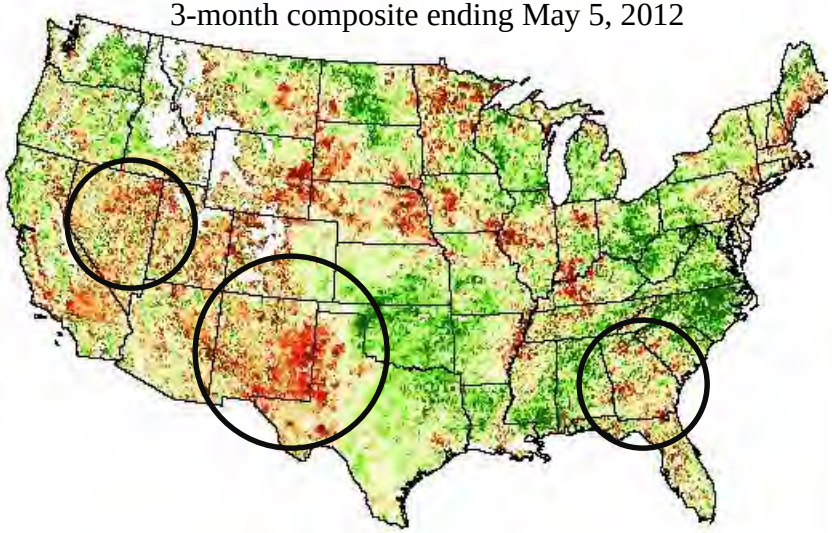


Hovemoller diagram for equatorial SSS anomaly (10°S-10°N)

Monitoring the Land Surface

EVAPORATIVE STRESS INDEX

3-month composite ending May 5, 2012

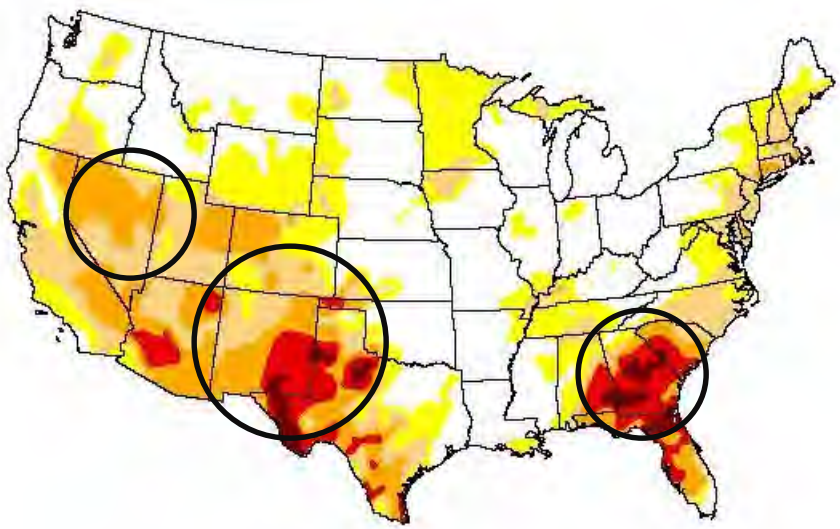


Standardized ET/PET anomalies

< -2σ -1σ 0 +1σ > +2σ

U.S. DROUGHT MONITOR

May 8, 2012



Drought class

D0 D1 D2 D3 D4

Mo (NOAA) and Anderson (USDA) developed the Evaporative Stress Index for drought monitoring using GOES satellite data. The index was developed within a thermal remote sensing energy balance framework.

Advantages:

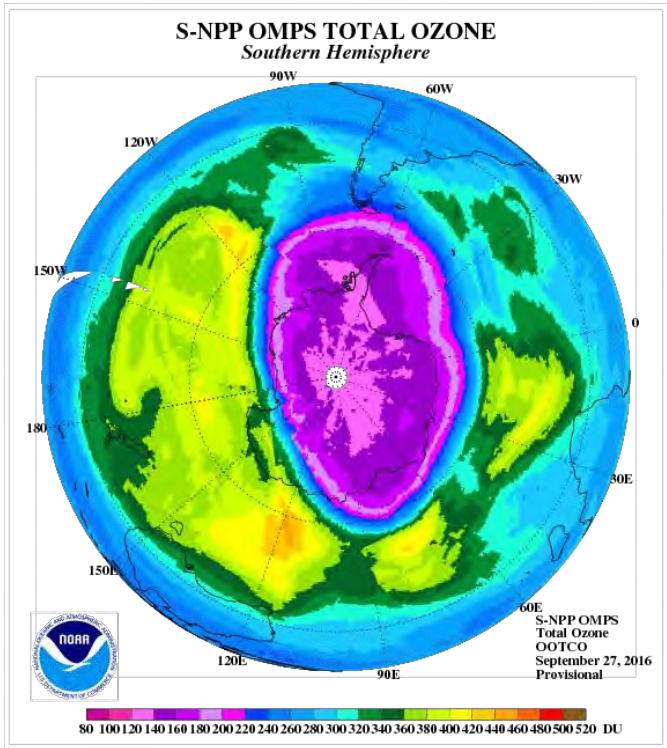
1.A good index for monitoring rapid drought onset

2.Compares well with the U. S. Drought Monitor and the North American Land Data Assimilation System

3.Independent of land models

Courtesy of M. Rosencrans

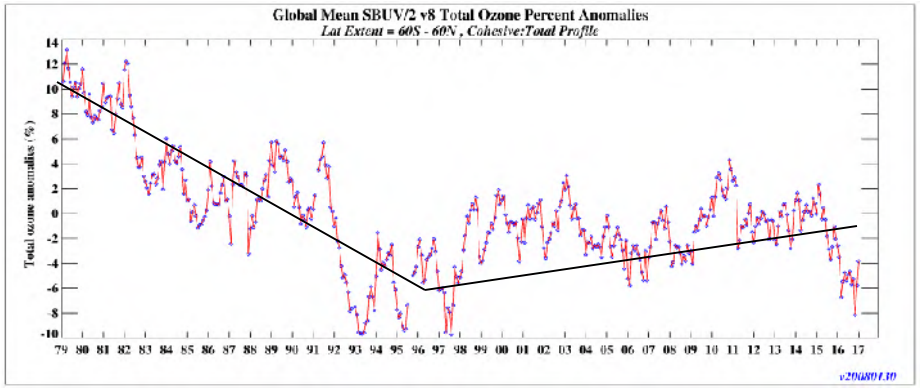
Stratospheric Ozone Monitoring



2016 Antarctic Ozone Hole

- CPC monitors the ozone layer in real-time and historically.
- Ozone observations from the SBUV/2 and OMPS instruments are analyzed daily to monitor short term depletion events such as the “ozone hole” over Antarctica.

TOTAL OZONE ANOMALIES

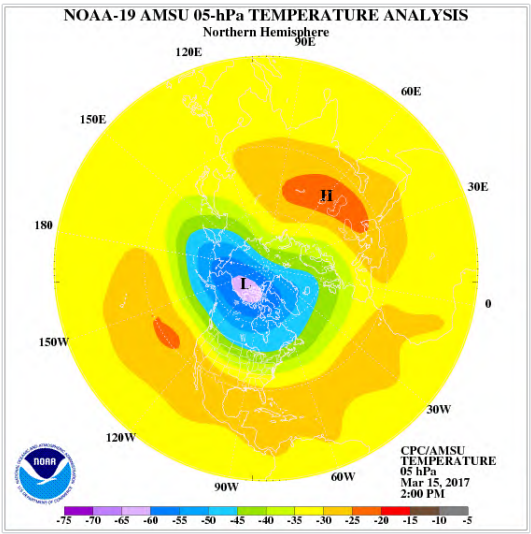


- SBUV and OMPS datasets allow CPC to monitor the global ozone depletion that occurred in the 1980s and early 1990’s and the status of ozone recovery since the mid 1990’s.
- Increased UV radiation at the surface results from ozone depletion. The environment, food supply, and human health communities are concerned about the impacts of increased UV radiation.

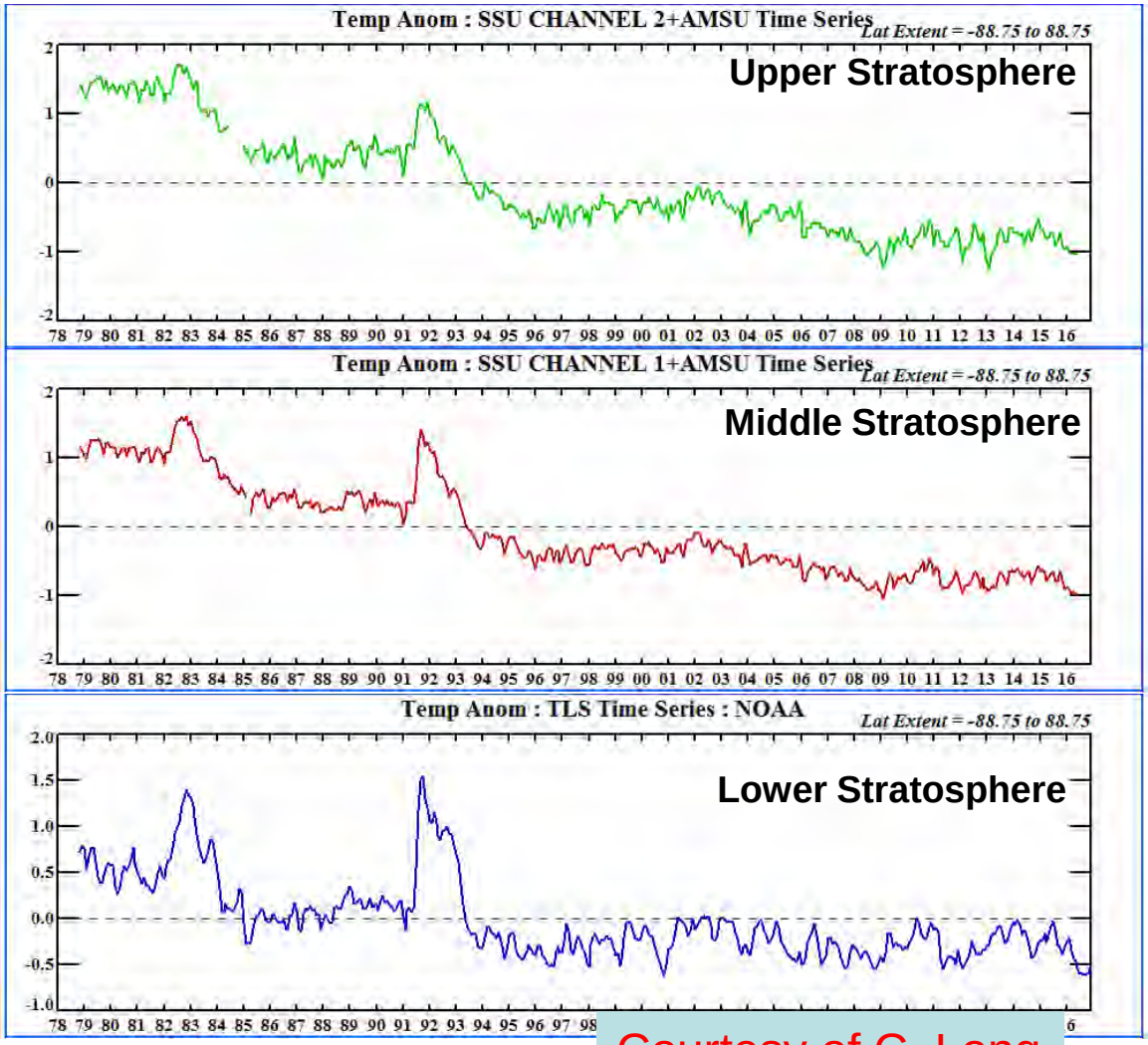
Courtesy of C. Long

Stratospheric Temperature Monitoring

- CPC monitors long term trends of satellite derived temperatures in the stratosphere.
- There is stronger cooling in the upper stratosphere.
- Satellite temperature trends are validated using rocketsondes, lidars, and microwave instruments.



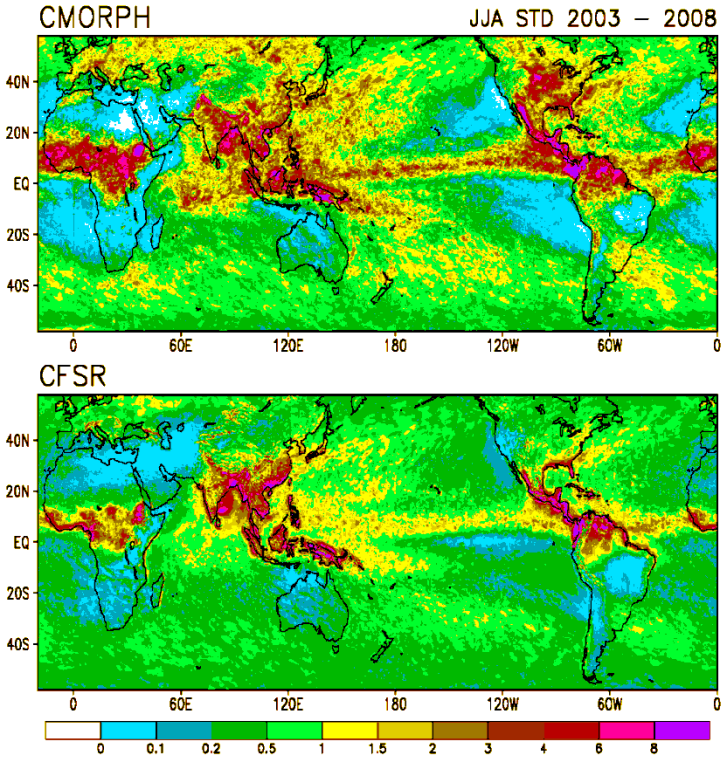
Global Temperature Anomaly Time Series



Courtesy of C. Long

Climate Model Forecast Verification

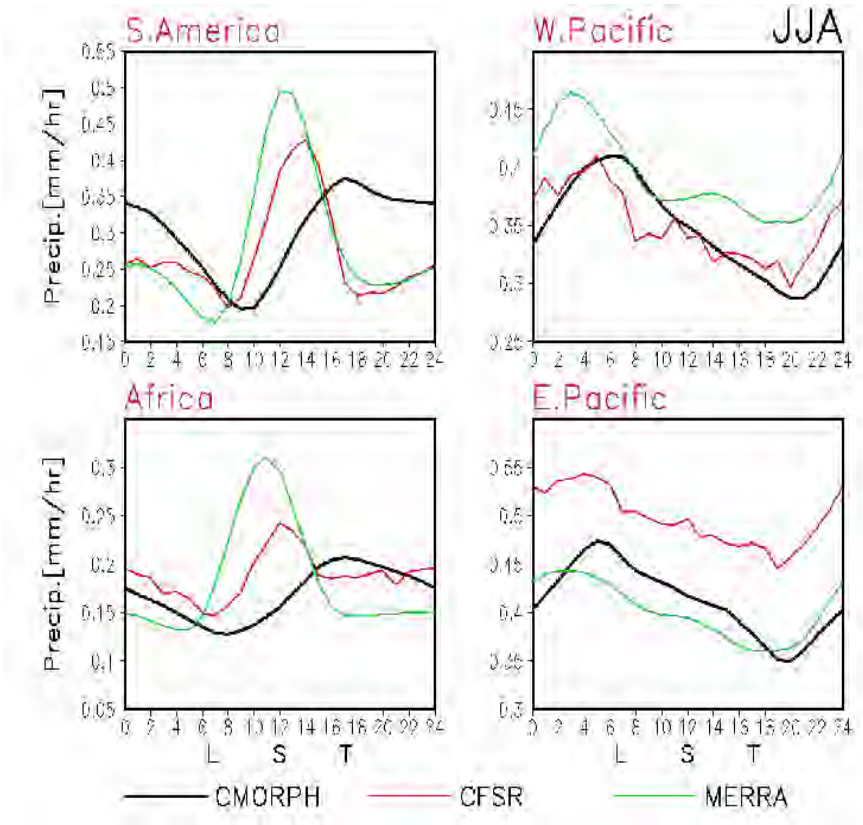
Amplitude of the Diurnal Cycle of Precipitation



STD DEV of 24 HOURLY VALUES

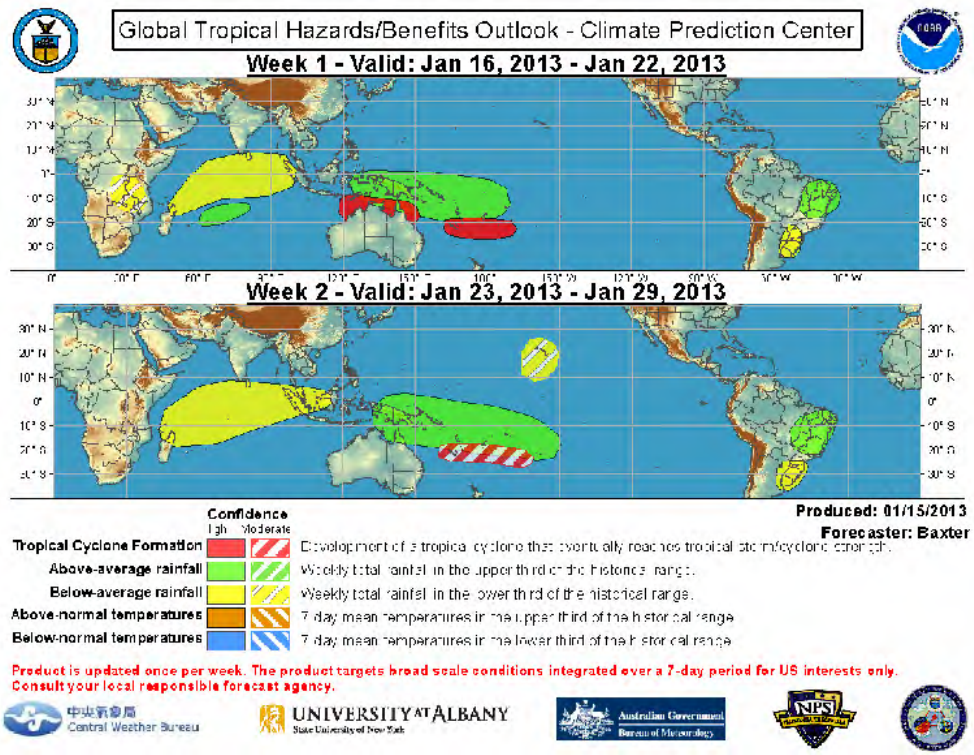
- The spatial distribution is similar, but the amplitude is weaker in CFSR than in obs.

Mean Diurnal Cycle for Selected Regions



- Over land, the reanalyses peak around local noon, earlier than the obs.
- Over oceans the reanalyses capture the phase , but with less amplitude than the obs.

Hazards Outlooks

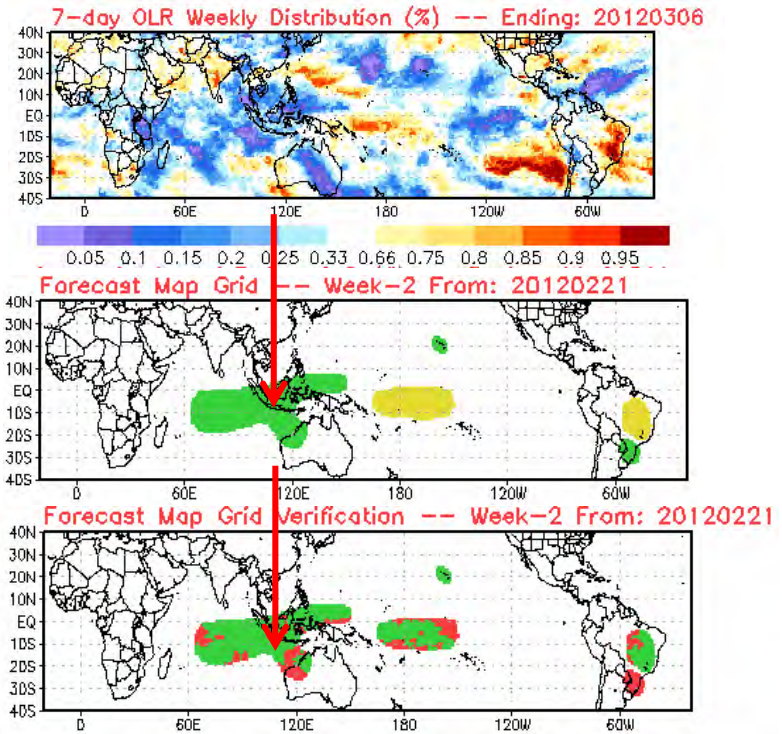


U.S. Hazards Outlook

Satellite derived OLR and precip data contribute to CPC operational hazards outlooks by:

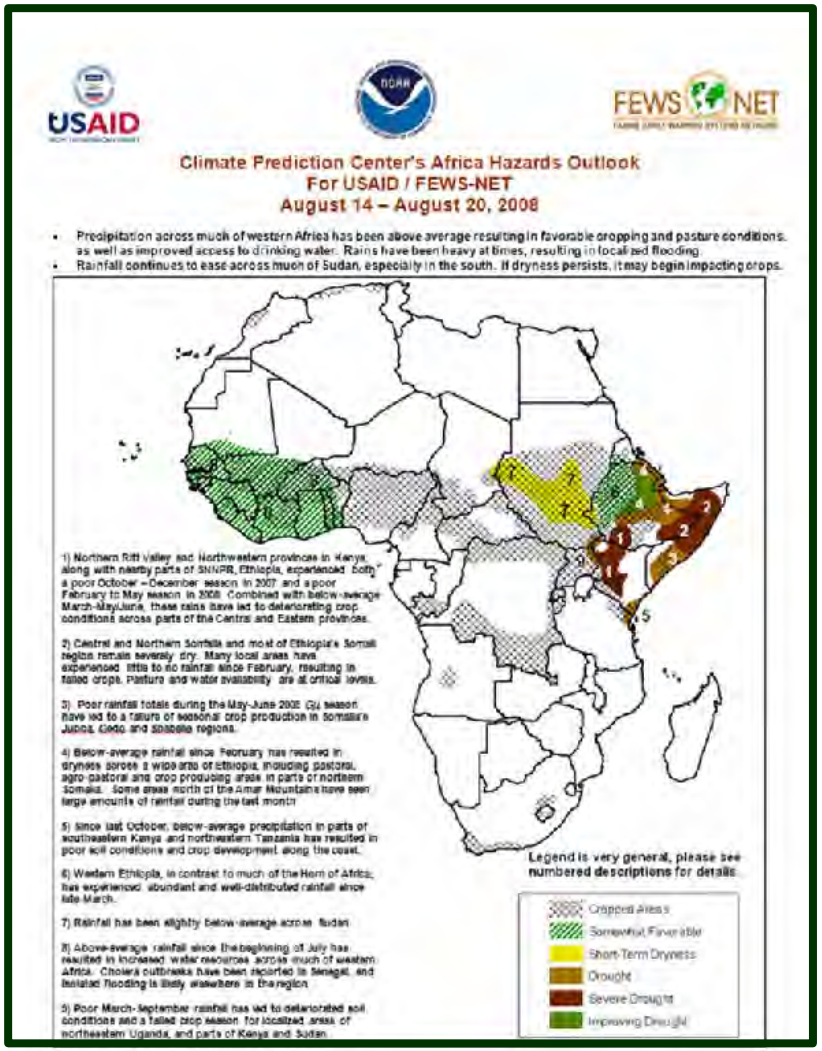
(1) Providing additional monitoring and prediction products to the forecaster

(2) Quantitative evaluation of outlooks



Courtesy of J. Gottschalck

FEWS Applications for Humanitarian Relief



Satellite derived products: precipitation, soil moisture, and numerical model forecasts are analyzed to prepare regional hazard outlooks for food security.

Information is used to assess climate impacts on agriculture and water resources

Drought risk areas are shaded in yellow and brown.

Enables USAID to develop strategies for humanitarian relief in affected areas.

Courtesy of W. Thiaw

Other Data Used for Climate Operations at CPC

- Satellite data is only one source of information used for climate monitoring, climate diagnostics, and climate model verifications
- Other important sources of information for climate operations at CPC include
  - *In situ data*
    - *CAMS (Climate Anomaly Monitoring System)*
    - *Ocean observations*
  - *Numerical model simulations*
    - *Reanalyses*
    - *Land surface model simulations*
- As scientists at CPC, we need to always keep in mind:
  - *What we need to maintain, improve and expand climate operations and services;*
  - *What we have right now and in near future that may help us improve climate operations and services;*
  - *What is the optimal strategy to capitalize new technology achievements into improved climate operations and services.*

Summary

- Satellite data has been indispensable for CPC climate information products;
- CPC is a pioneer in climate applications of satellite observations;
- In addition to using existing satellite products created by satellite centers, CPC also develops satellite-based products suited for applications;
- Well known satellite-based climate products developed by CPC include OLR, precipitation, and ozone;

- A UV Index Forecast is generated daily at NCEP from the GFS. Global forecast grids are generated for each hour out to 5 days at 1 hr freq.
- NWS and EPA jointly inform the public of the dangers of over exposure to the Sun's UV radiation.
  - NWS provides forecasts; EPA distributes the forecasts, UV radiation information, and precautionary steps to prevent over exposure.
- The UV Index forecasts are derived from forecasts of total column ozone, surface albedo (snow cover), clouds and aerosols

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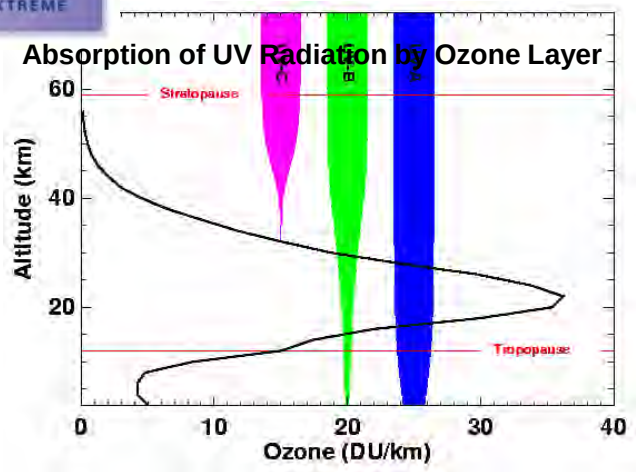

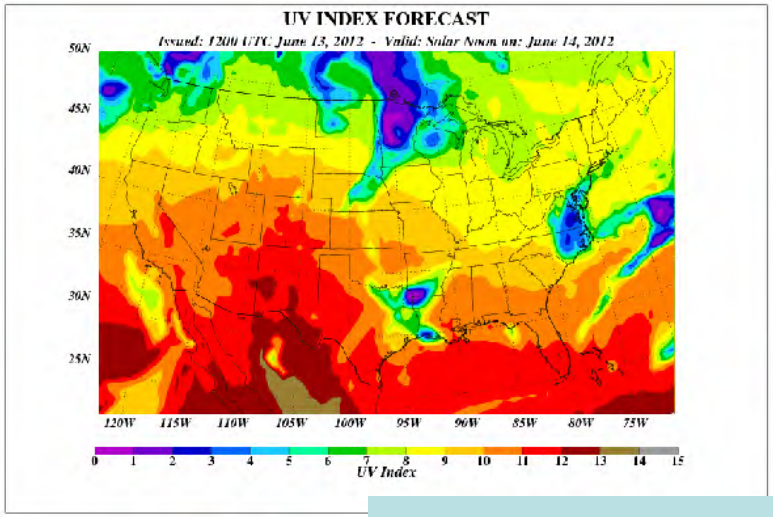

Courtesy of C. Long