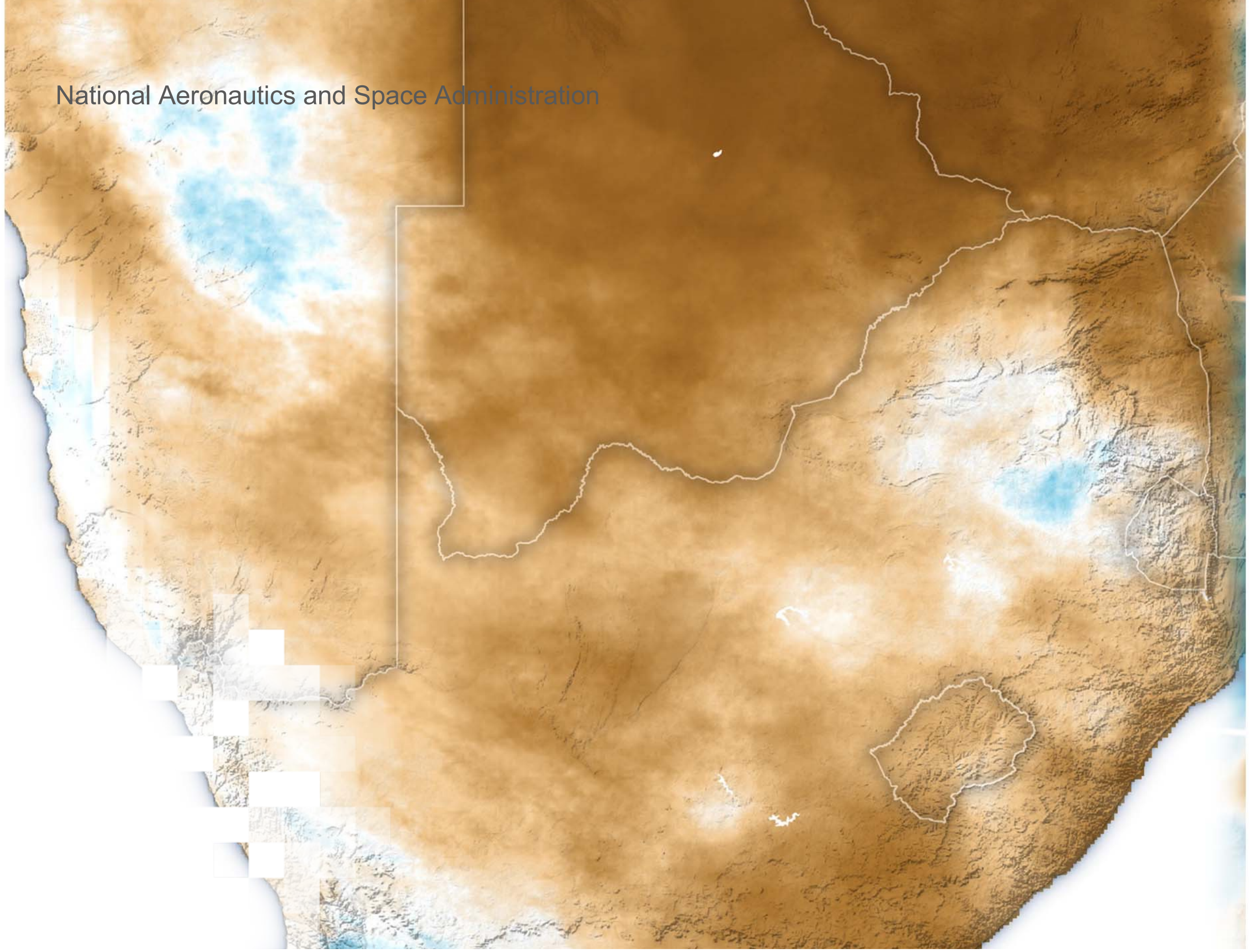
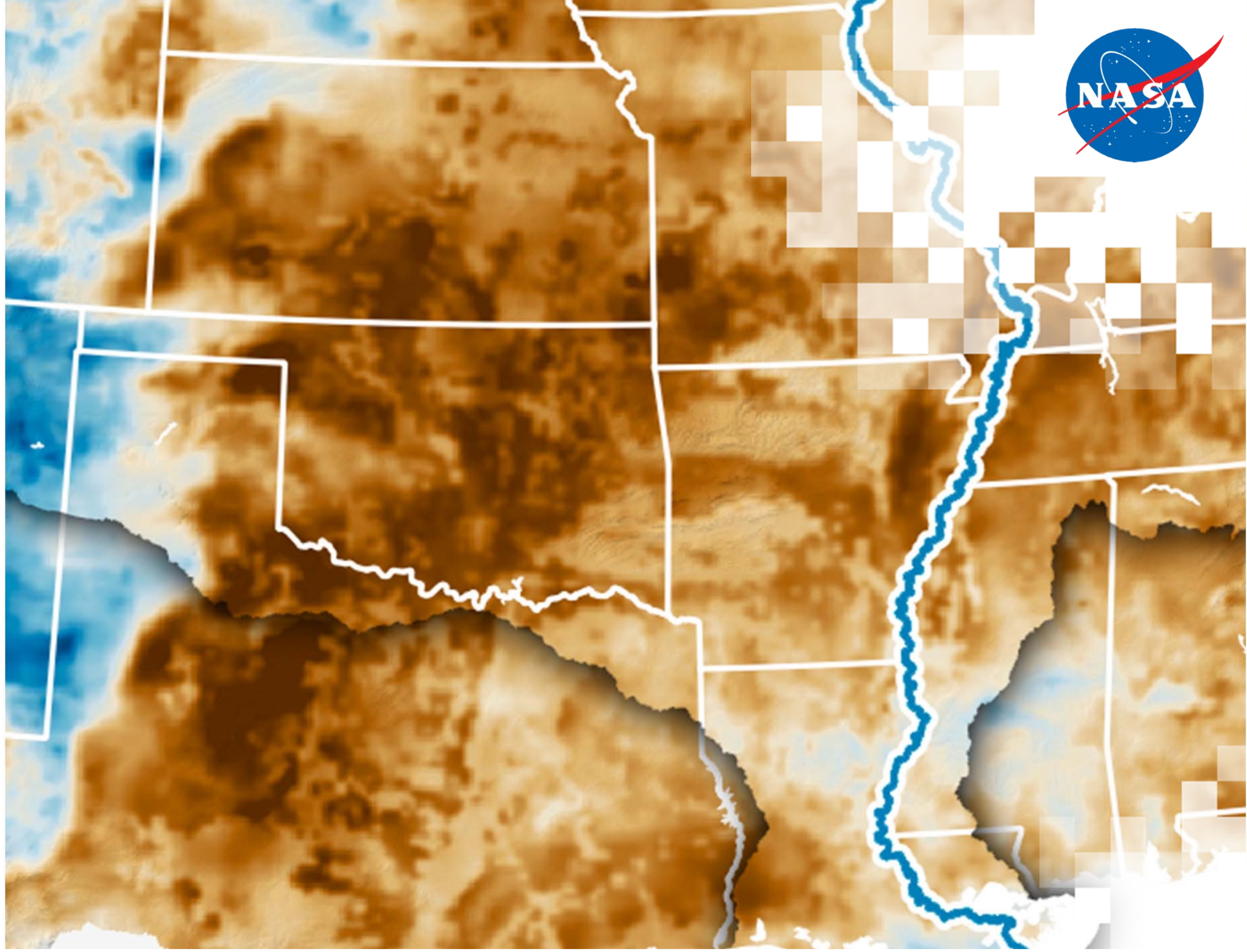




Drought Monitoring, Prediction, and Projection using NASA Earth System Data

Part 2: Drought Prediction using NASA Sub-seasonal to Seasonal (S2S) Predictions

ARSET Host: Amita Mehta
Guest Speaker: Dr. Andrea Molod, NASA Goddard Space Flight Center GMAO

25 July 2024

Training Outline

Part 1
Overview of Drought Monitoring Data and Tools using Earth Observations

July 23, 2024

Part 2
Drought Prediction using NASA Sub-seasonal to Seasonal (S2S) Predictions

July 25, 2024

Part 3
Climate Change Projections and Droughts

July 30, 2024

Part 4
Demonstration of Regional Drought Monitoring Tools

August 1, 2024

Homework

Opens August 1 – Due August 15 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Part 1 Review

Overview of:

- Various types of droughts: meteorological, agricultural, hydrological
- Earth observations for drought monitoring: precipitation, soil moisture, vegetation index, temperature, ground water

Type of Drought	Parameter Indicators (Satellites & Sensors)
Meteorological Drought	Precipitation (GPM IMERG) Temperature (Terra & Aqua MODIS, SNPP& JPSS VIIRS, Landsat TIRS,)
Agricultural Drought	Normalized Difference Vegetation Index (NDVI), Evapotranspiration (Terra & Aqua MODIS, SNPP& JPSS VIIRS, Landsat OLI)
Hydrological Drought	Soil Moisture (SMAP), Ground Water (GRACE-FO)

GPM: Global Precipitation Measurements
IMERG: Integrated Multi-satellitE Retrievals for GPM
MODIS: MODerate-resolution Imaging Spectroradiometer
SMAP: Soil Moisture Active Passive
GRACE: Gravity Recovery and Climate Experiment Follow On (FO)

SNPP: Suomi National Polar Partnership (NSPP
JPSS: Joint Polar Satellite System
VIIRS: Visible Infrared Imaging Radiometer Suite

Part 1 Review

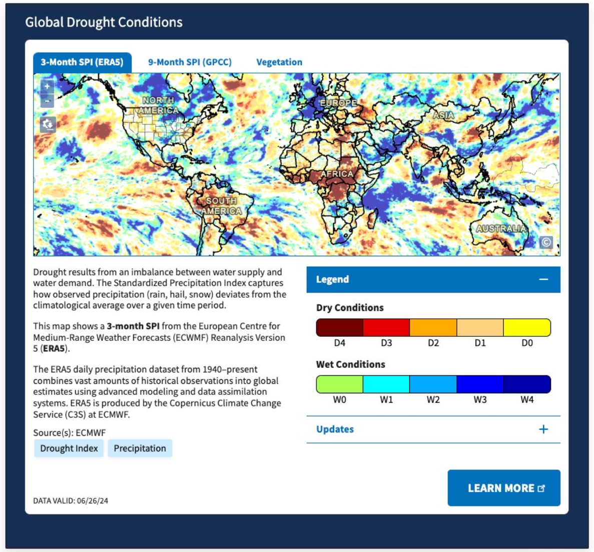
Overview of:

- Drought Indices: Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI) Normalized Difference Vegetation Index (NDVI)
  - The SPI values can be interpreted as the number of standard deviations by which the observed rainfall deviates from the long-term mean.
  - The PDSI is calculated based on precipitation and temperature data and a water balance model.
  - The NDVI is calculated from red and near-infrared wavelengths to detect green vegetation.

Part 1 Review

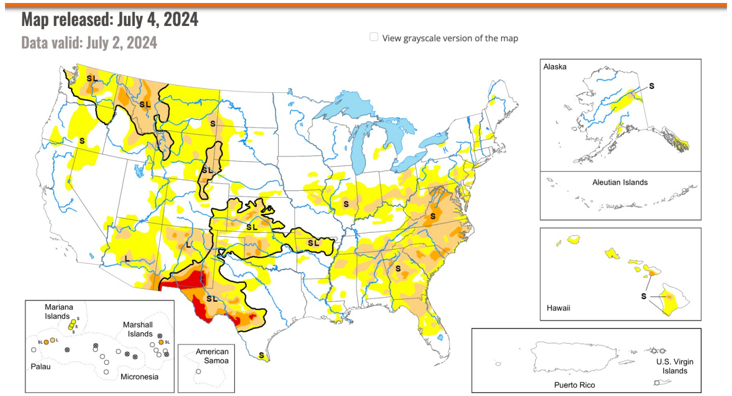
NIDIS Drought.gov

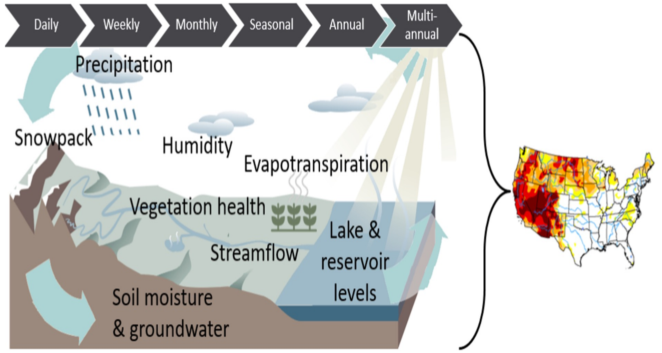
National Integrated Drought Information System



[NIDIS Drought.gov]

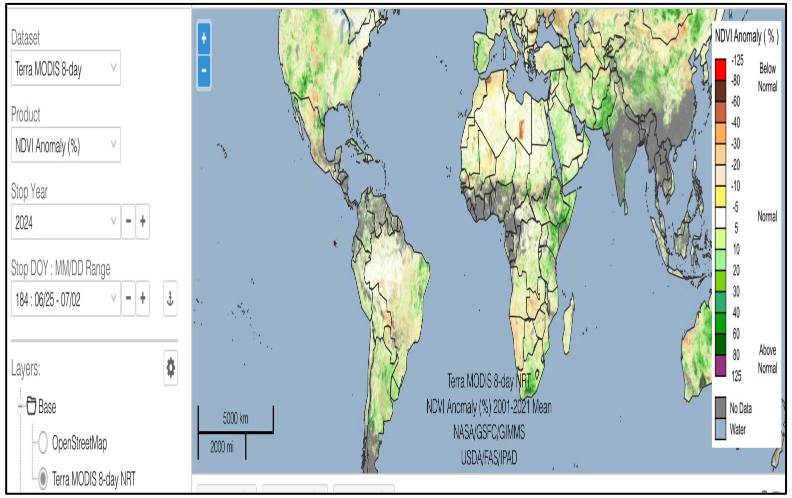
U.S. Drought Monitor





[U.S. Drought Monitor]

GIMMS Global Agricultural Monitoring

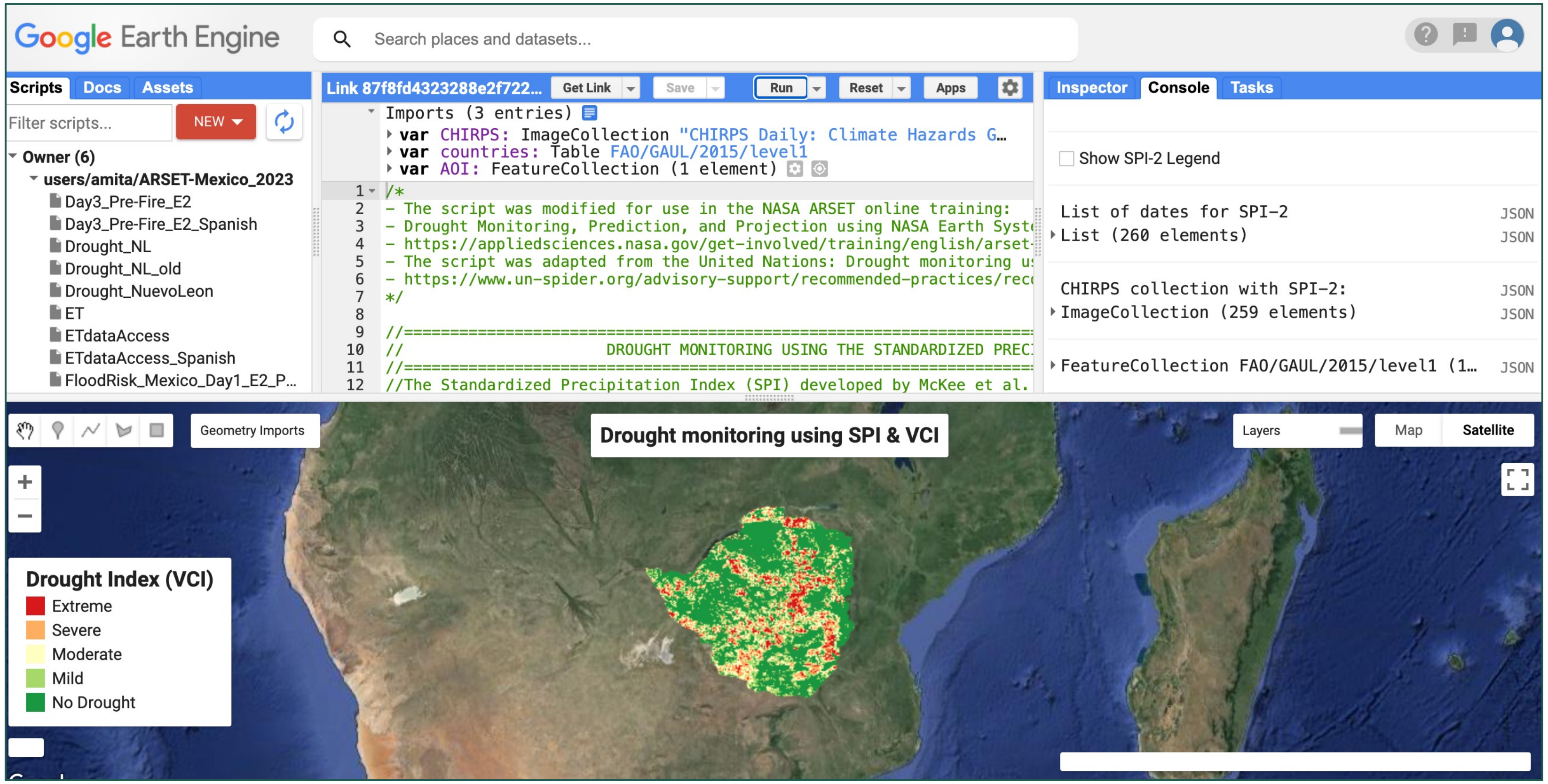


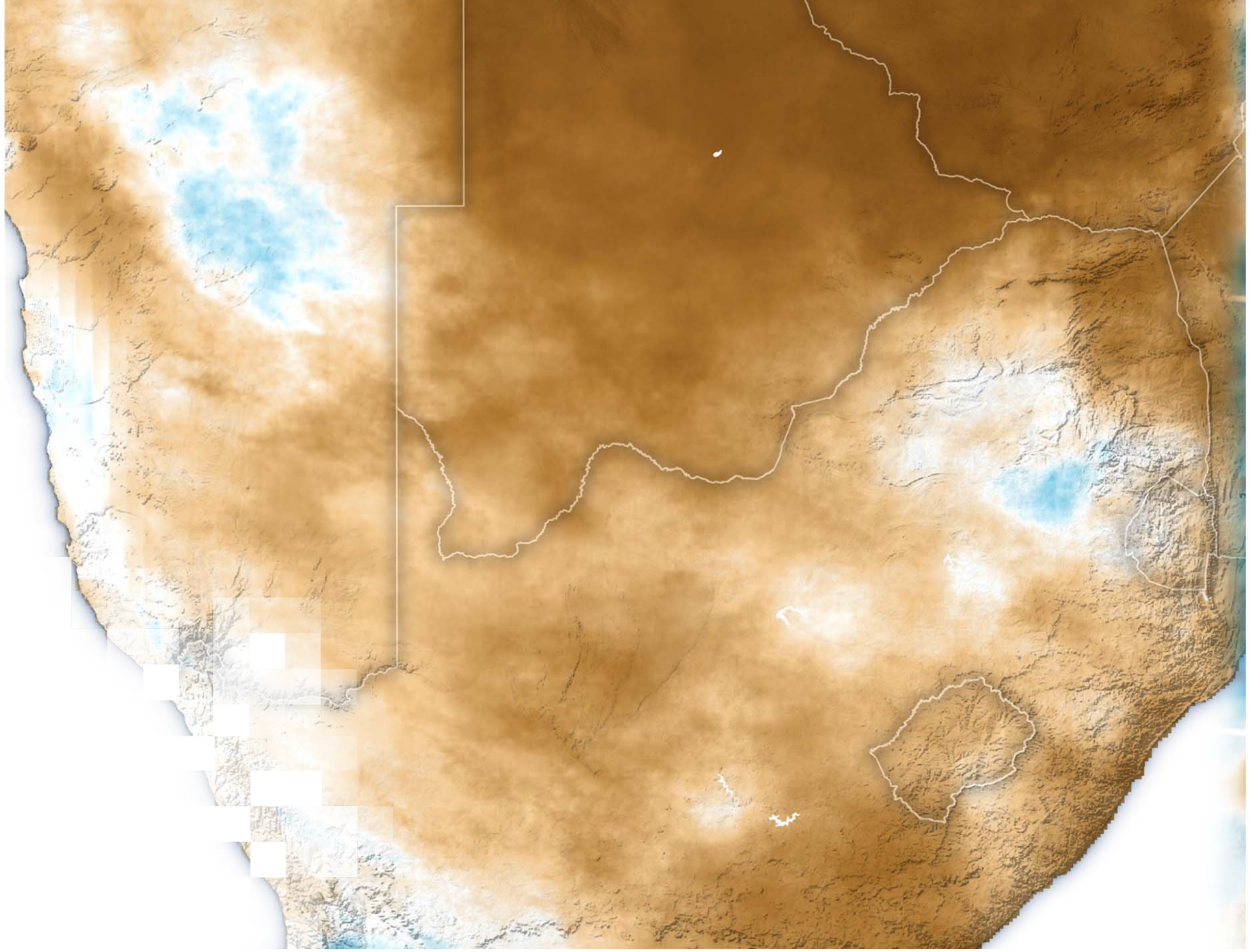
[GIMMS Global Agricultural Monitoring]

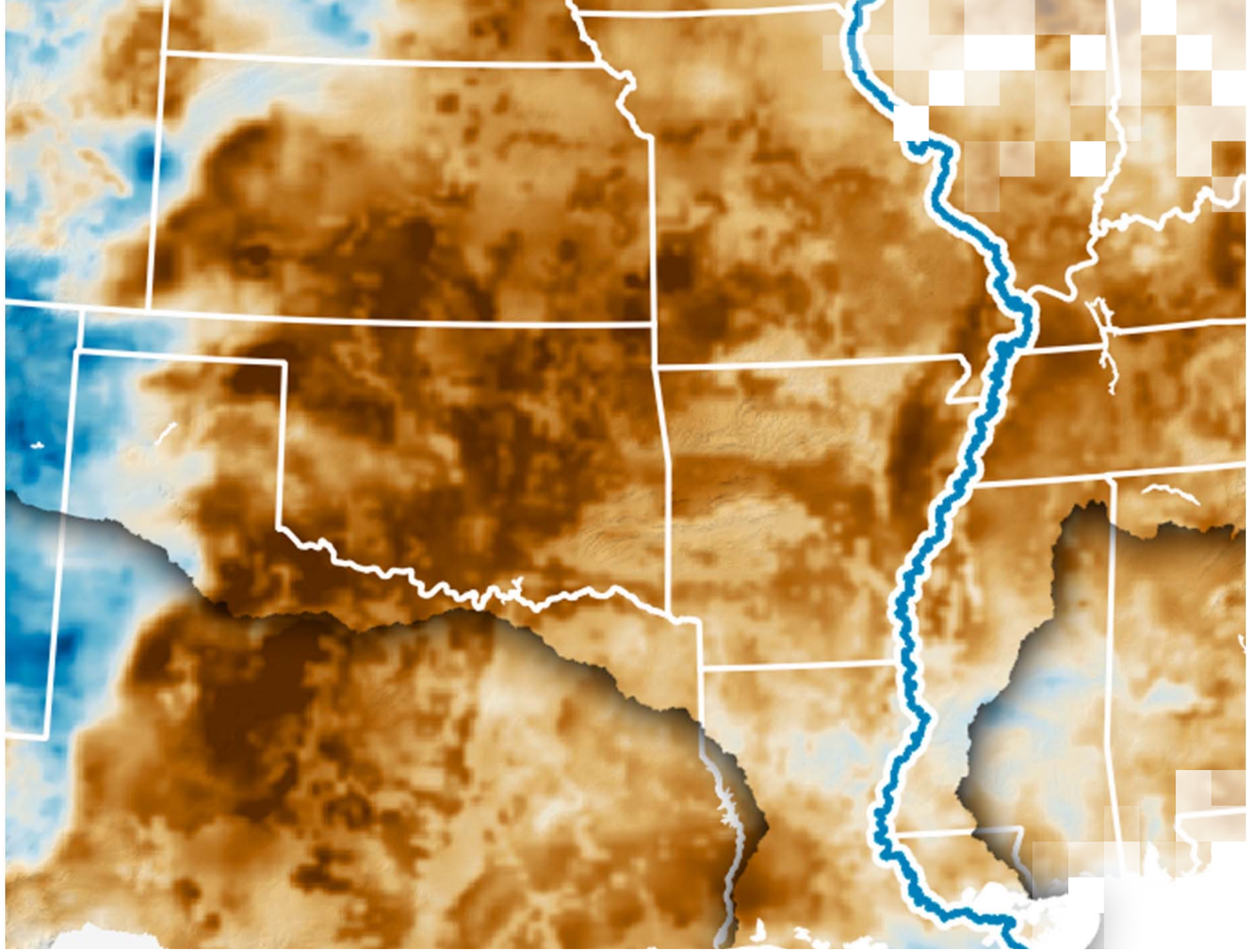
Part 1 Review

Calculations of:

- SPI and VCI as indicators of drought, using Google Earth Engine (GEE)







Drought Monitoring, Prediction, and Projection using NASA Earth System Data

Part 2: Drought Prediction using NASA Sub-seasonal to Seasonal (S2S) Predictions

Part 2 Objectives

By the end of Part 2, participants will be able to:

- Recognize functionality of NASA's sub-seasonal to seasonal (S2S) forecast system and data.
- Assess evolving drought conditions using given S2S temperature and precipitation prediction data for a region of interest.

Part 2 Outline

- Description of NASA's sub-seasonal to seasonal (S2S) forecast system and data
- Demonstration: Analysis of S2S predictions of temperature and precipitation using QGIS

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 2 Instructors

Amita Mehta
ARSET Instructor
NASA 612, UMBC-GESTAR II

Andrea Molod
Guest Instructor
NASA 610.1

NASA’s Sub/Seasonal Prediction System and Products

Andrea Molod, NASA Global Modeling and Assimilation Office (GMAO)

GMAO Seasonal Prediction Development Group and Collaborators: Santha Akella, Lauren Andrews, Nathan Arnold, Donifan Barahona, Anna Borovikov, Jim Carton, Yehui Chang, Richard Cullather, Eric Hackert, Randal Koster, Zhao Li, Young-Kwon Lim, Yuna Lim, Kazumi Nakada, Li Ren, Siegfried Schubert, Priyanka Yadav, Yury Vikhliaev, Bin Zhao

GEOS-S2S

- What is seasonal prediction and how does it differ fundamentally from weather prediction?
- GEOS-S2S forecast user community
- Some information about GEOS-S2S model features, ensemble forecast characteristics
- GEOS-S2S forecast output information
- **Note: GMAO is about (next month) to transition from GEOS-S2S-2 to GEOS-S2S-3, a system with many upgrades, generally improved forecast skill and extensive retrospective forecast suite. Transition to making GEOS-S2S-3 output easily available to users is currently under way.**

Why is NASA Developing and Maintaining a Sub/Seasonal Prediction Project?

GMAO Seasonal Prediction group uses coupled Earth-System models and analyses, in conjunction with satellite and in situ observations, to study and predict phenomena that evolve on sub/seasonal to decadal timescales. A central motivation for maintaining a state-of-the-art system is to investigate the innovative use of NASA satellite data to improve forecast skill.

GEOS-S2S – System History

Each of NASA's Seasonal Prediction Systems, beginning before GEOS, included a coupled model, a "one-way weakly coupled" data assimilation used for reanalysis and/or creating dynamically balanced initial conditions for forecasts, and an ensemble perturbation strategy.

- NASA's "pre-GEOS" seasonal prediction began in late 90's as part of NASA's Seasonal to Interannual Prediction Project (NSIPP, Rienecker et al., 2015)
- GEOS-S2S-1 was released in 2012 (Borovikov et al., 2018)
- GEOS-S2S-2 was released in November 2017 (Molod et al., 2020)
- GEOS-S2S-3 Scheduled for release and near-real time use in August 2024

Challenge/Opportunity for End Users: Seasonal Prediction is Not the Same as Weather Prediction

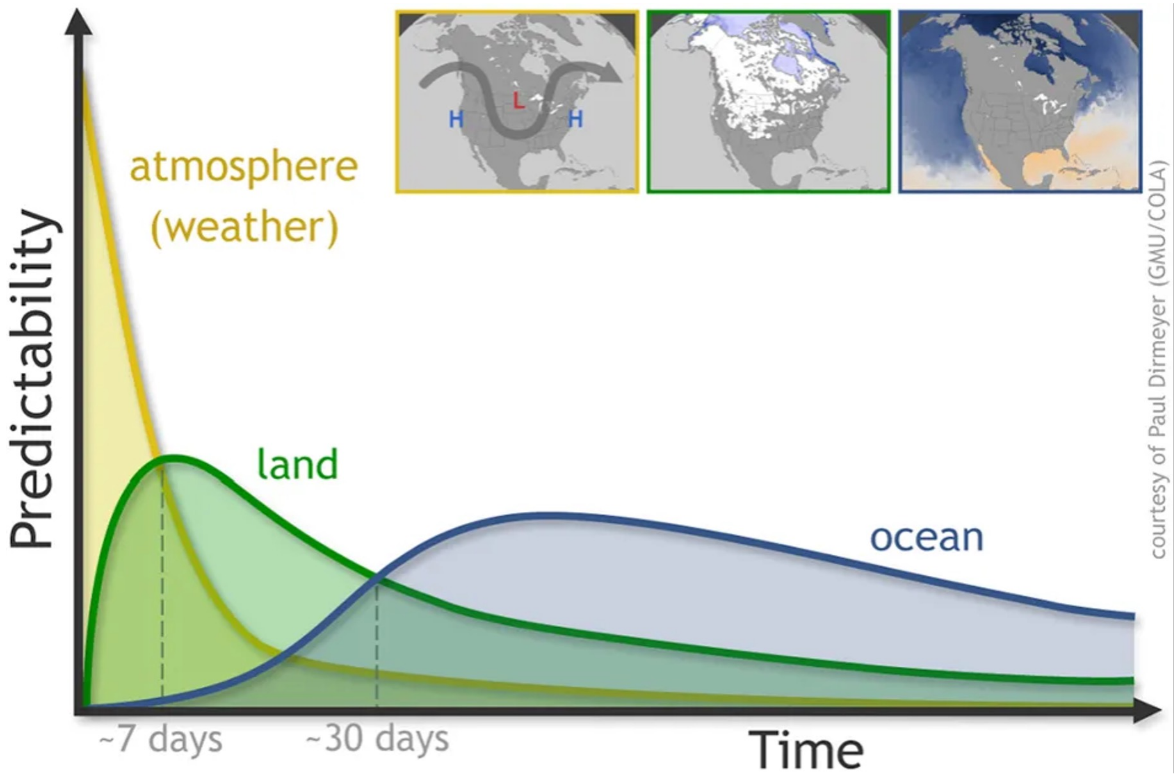
The climate system is a forced dissipative nonlinear dynamical system, and due to its chaotic nature, there is a finite limit of weather predictability. Despite this….

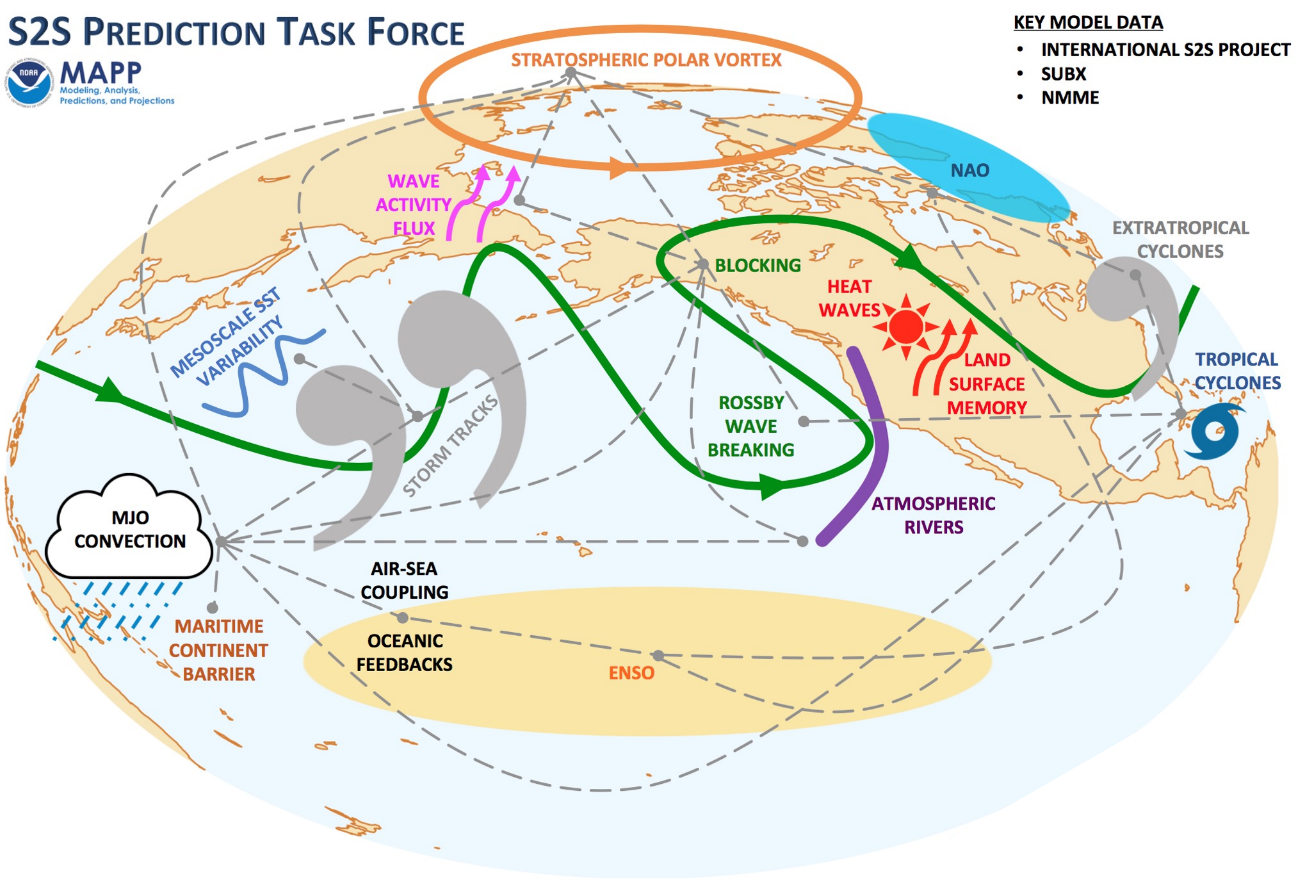
- The tropical flow patterns and rainfall, are so strongly determined by the underlying sea-surface temperature (SST) that they show little sensitivity to changes in the initial conditions. The tropical SST was shown by Seager (1989) to depend on the overlying atmosphere.
- Also, the ocean (and land) evolve more slowly (the ocean takes atmospheric white noise forcing and makes it red) and so extend predictability
- So - it should be possible to predict the large-scale seasonal tropical circulation and rainfall for as long as the ocean temperature can be predicted.

An important element is the signal-to-noise (S/N) ratio, which represents the relative proportion of the climate variability that is potentially predictable. The predictable portion (the signal) depends on SST or other sources of predictability. The remainder of the climate variability is related to fluctuations internal to the atmosphere (the noise), which is generally unpredictable.

Challenge/Opportunity for End Users:
Seasonal Prediction is Not the Same as Weather Prediction

Slowly varying components of the climate system provide sources of predictability.





Sources of predictability at longer lead times: IOD, ENSO, AMM, PDO….

IOD: Indian Ocean Dipole   ENSO: El Nino Southern Oscillation   AMM: Atlantic Meridional Mode   PDO: Pacific Decadal Oscillation

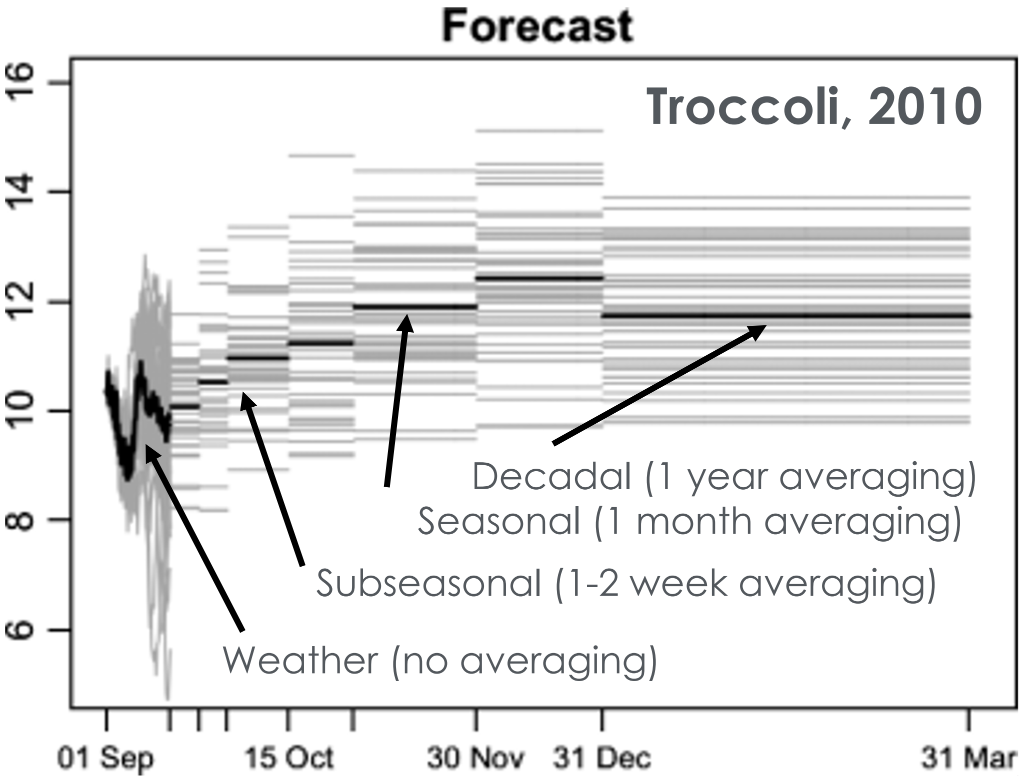
Challenge/Opportunity for End Users: Seasonal Prediction is Not the Same as Weather Prediction

What is predictable at Seasonal Lead Times?

- Time averages (Predictability of Second Kind, Lorenz, 1975)
- Spatial averages
- Probabilistic Measures (PDFs)

Sub/seasonal prediction is fundamentally a statistical endeavor - Ensembles of forecasts are needed to predict probabilities, must assess reliability.

Forecasts require calibration, or removal of mean bias or of mean bias and variance (standardization). For this we need reforecasts. Calibrated forecasts are more "reliable".



The longer the lead time, the longer the period of time average needed. This increases the signal to noise ratio enough to obtain reliable forecasts.

GEOS-S2S-2 – Sub/Seasonal Forecast System: 2017-Present

Contribution to Multi-Model Forecasts and Intercomparisons:

- North American Multi-Model Ensemble (NMME) – multiple fields for seasonal forecasts
- SubX (now SubC) Multi-model Subseasonal Forecast Experiment – multiple fields for subseasonal forecasts (week 3-4)
- APEC Climate Center (APCC) – Busan, Korea – multiple fields for multi-model seasonal forecasts
- International Research Institute for Climate and Society (IRI) – Columbia Univ – El Niño indices
- Atmospheric River Intercomparison Project – vertically integrated moisture transport for use by California water resources management
- Arctic Research Consortium of US (ARCUS) Sea Ice Prediction Network Sea Ice Outlook
- NOAA/NCEP Drought Briefing – Soil Moisture
- NOAA Sea level prediction – Sea surface height

NOTE: All of these data are tailored collections made available through ftp.

GEOS-S2S-2 – Sub/Seasonal Forecast System: 2017-Present

Operational Forecasts using GEOS-S2S as sole source:

- NASA/GSFC Hydrological Sciences Laboratory - drought forecasts for Africa-based FEWSNET program
- Tennessee Valley Authority Water Management System – Water resources forecasting
- Mekong River Basin Water Managers – Water Resources forecasting

Experimental Applications using GEOS-S2S as sole source:

- George Mason University – multiple fields for study of factors controlling dust sources in the U.S.
- NASA Code 613 - soil moisture, precipitation, temperature for landslide prediction
- UK Centre for Ecology and Hydrology – dust, relative humidity for African Meningitis outbreak prediction
- University of Connecticut – surface temperature for ecological forecasting
- Hebrew University of Jerusalem – data to drive a pest population model
- Oak Ridge National Lab (ORNL) – data to drive a pest population model

NOTE: All of these data are tailored collections made available through ftp.

GEOS-S2S/User Engagement

GEOS-S2S Sub/Seasonal Forecasts are produced in near-real time with an extensive and unique list of output fields of use to a wide variety of users. Some examples of potential additional user communities:

- **Health Care Field:**
  - Forecasts of seasonal anomalies of air quality, number of exceedance days, other metrics
  - Spread of disease associated with dust, rainfall, etc…
- **Municipal planning:**
  - Winter snow anomaly forecasts (how many trucks to buy?)
  - Forecasts of rainfall/soil moisture anomalies for water resources management
- **Scientific community:**
  - Predictability studies with large ensemble size (40 ensemble members)

Unique to GEOS-S2S: Why Interactive Aerosol Model?

GEOS-S2S is the only near-real time system running with an interactive aerosol model and a two-moment cloud microphysics that includes the direct, semi-direct and indirect aerosol effect.

Current "production" version (GEOS-S2S-2) and its replacement (GEOS-S2S-3) include:

- The GOCART aerosol module (single moment aerosol microphysics)
- The two-moment cloud microphysics that models the aerosol-cloud interaction
- AOD analysis (AVHRR, MODIS, Aeronet) as part of GEOS-S2S-3's coupled assimilation

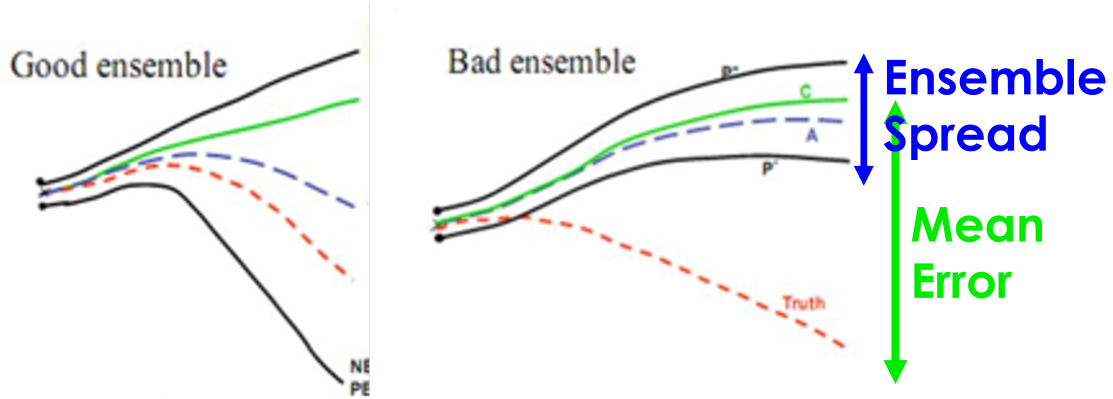
The use of interactive aerosol and aerosol-cloud interaction has been shown to result in:

- Credible sub/seasonal forecasts of air quality (AOD and aerosol-based PM2.5) in some regions not dominated by smoke (Freire et al., 2020).
- Increased skill of AOD but also T2M and cloud water/ice content during "forecasts of opportunity", an example is in the wake of a volcanic emission event (Barahona et al., in preparation)
- Results showed examples of T2M skill increase, separated into benefits due to interactive aerosol and due to aerosol-cloud interactions (Study by Barahona and others).

Ensemble Forecast Strategy: Forecast "Confidence"

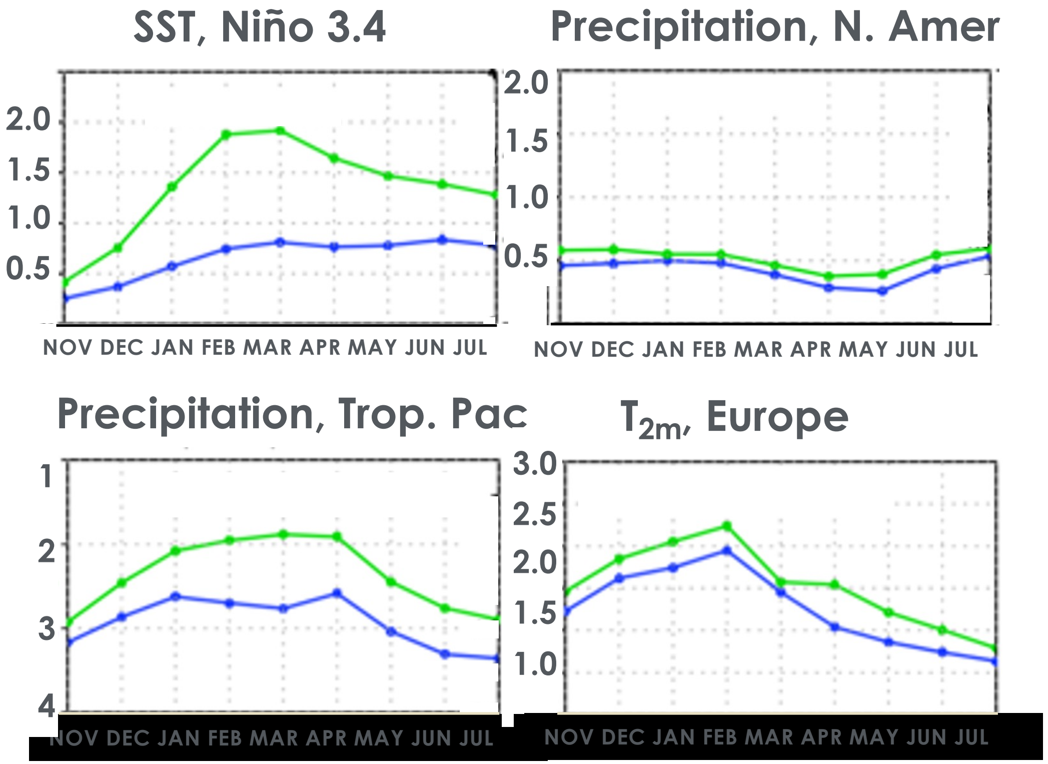
Evaluate "confidence" by comparing:

- Ensemble spread (distance among members)
- Mean Error (mean of error of individual ensemble members)



Kalnay, 2003

GEOS-S2S-2



Spread too low over the ocean "overconfident"

Spread is good over land, confidence matches skill

Forecast Ensemble Strategy

Motivation for Change in Ensemble Strategy:

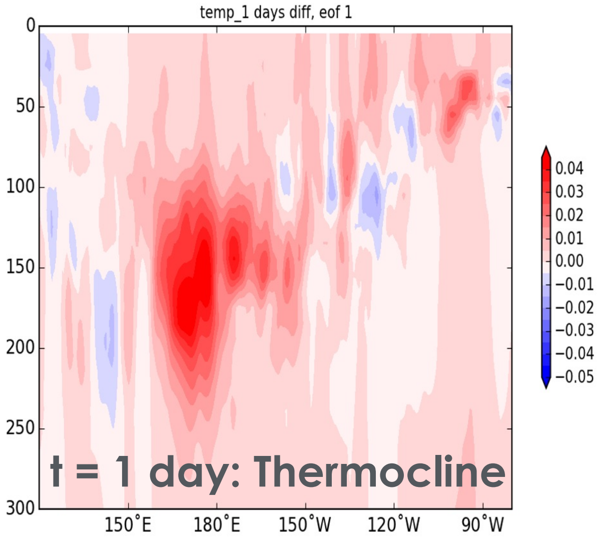
- GEOS-S2S Tropical Pacific SST was found to be “too confident” early in the forecast and “under confident” later (Molod et al., 2020). This prompted the change in the ensemble perturbation strategy.
- Extratropical skill was lower than the best state-of-the-art systems because of the small ensemble size (eg., Scaife et al., 2018). This prompted the change in ensemble size and the new approach to the number of ensembles.
- Little evidence of additional skill from ensemble size beyond a few months. This prompted the sub-sampling strategy for extending selected ensemble members

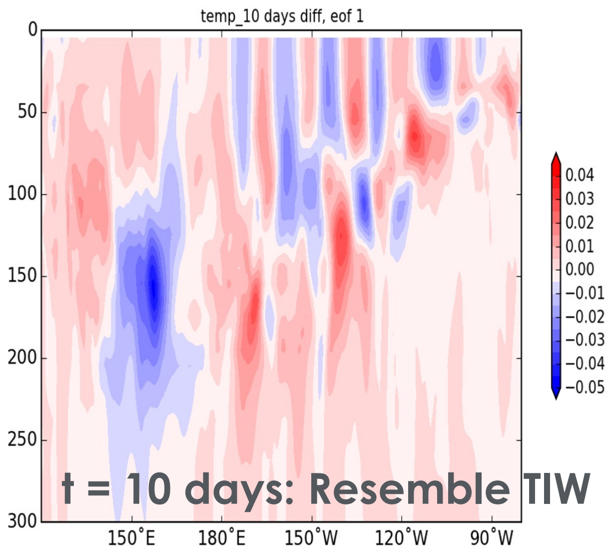
Retained from GEOS-S2S-2: “Lag-Burst” ensemble

Ensemble Forecasts – Perturbation Strategy

- **GEOS-S2S-2**
  - Perturbations are scaled differences in AODAS states, 1-day differences for subseasonal forecasts, 5-day differences for seasonal.
- **GEOS-S2S-3:** "Synchronized Multiple Time-lagged (SMT)"
  - Perturbations for combined forecasts are randomly selected from 1-day through 10-day differences in AODAS states. These spatial structures are closely related to the optimal perturbations that would be obtained from a singular value decomposition of the linear propagator A: $(\Delta\vec{X}\tau(t) \equiv \vec{X}(t+\tau) - \vec{X}(t) \approx A\tau\vec{X}(t))$, and presumably be sampling preferentially those perturbations with the largest growth rates.

Typical structure of SON ocean temperature perturbations, shown as the leading EOF of the Pacific equatorial x-z cross section of temperature averaged between 2°S-2°N.





From: Schubert et al., 2019

GEOS-S2S-3 Sub/Seasonal Prediction Suite

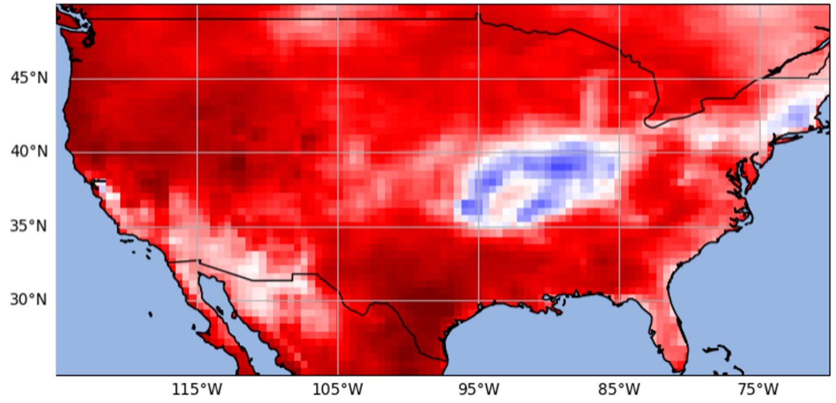
Length of Forecast	9 months
Frequency of forecasts	Every 5 days
Number of Ensembles	40 member lag/burst for first three months, selection of 10 members for remaining 6 months
Frequency of submission	Once per week OR once per month (as needed)
Retrospective Initial Conditions from	"GiOcean" GEOS-S2S-3 AODAS
Retrospective Forecasts	1991-2024
Near-real time Initial Conditions from	"GiOcean-NRT" GEOS-S2S-3 AODAS

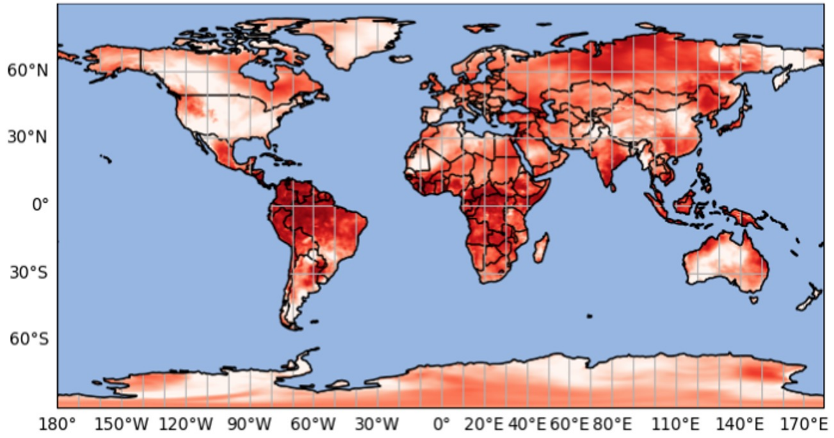
GEOS-S2S-3: Forecast Evaluation Example: T2M "Anomaly Correlation"

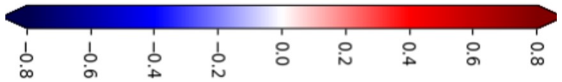
June 1-month lead

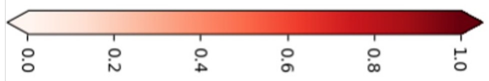
January 1-month lead

GEOS-S2S-2



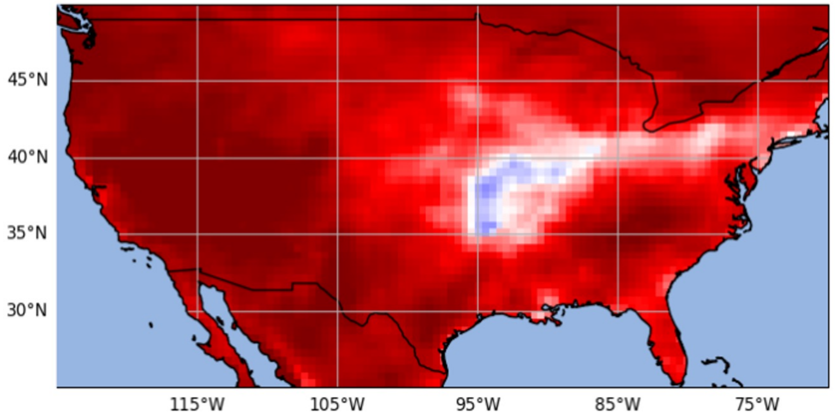


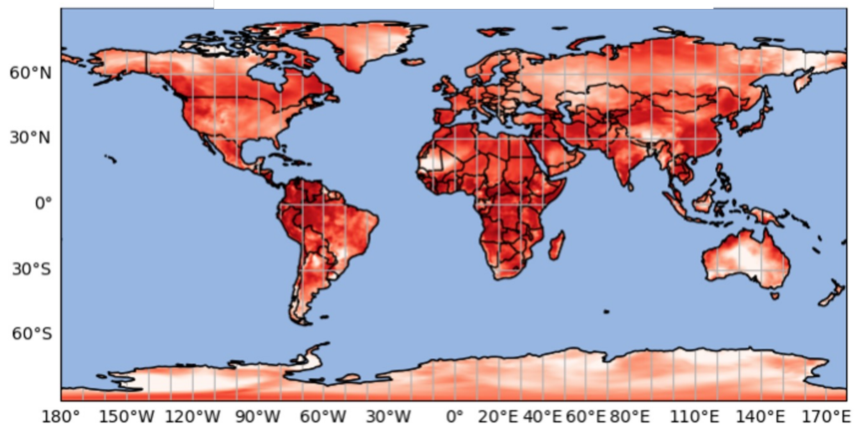




T2M_AC:

GEOS-S2S-3





GEOS-S2S Output

- How output is organized (files, ”collections”, which fields are in which files)
- What are the available “collections”?
- File specification document
- Where to find files staged for users

GEOS-S2S-2 forecast output is available from “retrospective forecasts” from 1981-2020 and from “near-real time” forecasts from 2020 onward.

GEOS-S2S-3 forecast output is available from “retrospective forecasts” from 1991-2024 and from “near-real time” forecasts from 2024 onward.

Data are extensive! Current practice is for users to request that data be staged by sending an email to: andrea.molod@nasa.gov

GMAO Output (Example for GEOS-S2S-3)

"COLLECTIONS" (examples):

'atm_inst_6hr_glo_L720x361_p49'

"Specification" for each collection: (example):

```
atm_inst_6hr_glo_L720x361_p49.frequency:  060000,
atm_inst_6hr_glo_L720x361_p49.resolution: 720 361,
atm_inst_6hr_glo_L720x361_p49.vscale:     100.0,
atm_inst_6hr_glo_L720x361_p49.vunit:     'hPa',
atm_inst_6hr_glo_L720x361_p49.vvars:     'log(PLE)' , 'DYN'          ,
atm_inst_6hr_glo_L720x361_p49.levels:     1000 975 950 925 900 875
850 825 800 775 750 725 700 650 600 550 500 450 400 350 300 250 200
atm_inst_6hr_glo_L720x361_p49.fields:
                    'PHIS'     , 'AGCM'         ,
                    'SLP'      , 'DYN'          ,
                    'U;V'      , 'DYN'          ,
                    'T'        , 'DYN'          ,
                    'PS'       , 'DYN'          ,
                    'ZLE'      , 'DYN'          , 'H'  ,
                    'OMEGA'    , 'DYN'          ,
                    'Q'        , 'MOIST'        , 'QV' ,
                    'QITOT'    , 'AGCM'         , 'QI' ,
                    'QLTOT'    , 'AGCM'         , 'QL' ,
                    'RH2'      , 'MOIST'        , 'RH' ,
                    'O3'       , 'CHEMISTRY'    ,
```

GMAO Output (Complete list for GEOS-S2S-3)

```
COLLECTIONS: 'iau_inst_6hr_glo_L720x361_v72'
             'iau_tavg_1mo_glo_L720x361_p49'
             'atm_inst_6hr_glo_L720x361_p49'
             'sfc_tavg_3hr_glo_L720x361_sfc'
             'sfc_tavg_1hr_glo_L720x361_sfc'
             'mjo_tavg_1dy_glo_L720x361_slv'
             'rad_tavg_1mo_glo_L720x361_p49'
             'mst_tavg_1mo_glo_L720x361_p49'
             'trb_tavg_1mo_glo_L720x361_p49'
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             'tnd_tavg_1mo_glo_L720x361_p49'
             'int_tavg_1dy_glo_L720x361_slv'
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             'ocn_tavg_1mo_glo_L720x361_slv'
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             'aci_tavg_1dy_glo_L360x181_p27'
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             'ice_inst_6hr_glo_T1440x1080_slv'
```

Sample file name from "ensemble 1" for the **sfc_tavg_3hr_glo_L720x361** Collection:

ens1.sfc_tavg_3hr_glo_L720x361_sfc.monthly.202307.nc4

GMAO Output

GEOS-S2S-2:

- File specification document: https://gmao.gsfc.nasa.gov/pubs/docs/Nakada1033.pdf
- ftp access for files that have been staged: https://gmao.gsfc.nasa.gov/gmaoftp/gmaofcst/seasonal/GEOSS2S-2_1/

GEOS-S2S-3:

- File specification document: In preparation
- ftp access for files that have been staged: https://portal.nccs.nasa.gov/datashare/gmao/geos-s2s-3/

GMAO Output

File specification document contains information about the grid, the file naming convention, and for each collection contains an entry listing variable names, descriptions and units. For example:

geosgcm_00zins*: *3d_Daily_Instantaneous_at_00Z

Frequency: *daily value from 00:00 UTC (instantaneous)*
Spatial Grid: *3D, pressure-level, full horizontal resolution*
Dimensions: *longitude=720, latitude=361, level=15, time=1*
Granule Size: *~98 MB*

Note – Forecast only collection.

Name	*Dim*	*Description*	*Units*
H	tzyx	edge heights	m
OMEGA	tzyx	vertical pressure velocity	Pa s-1
PHIS	tyx	surface geopotential height	m+2 s-2
PS	tyx	surface pressure	Pa
QV	tzyx	specific humidity	kg kg-1
SLP	tyx	sea level pressure	Pa
T	tzyx	air temperature	K

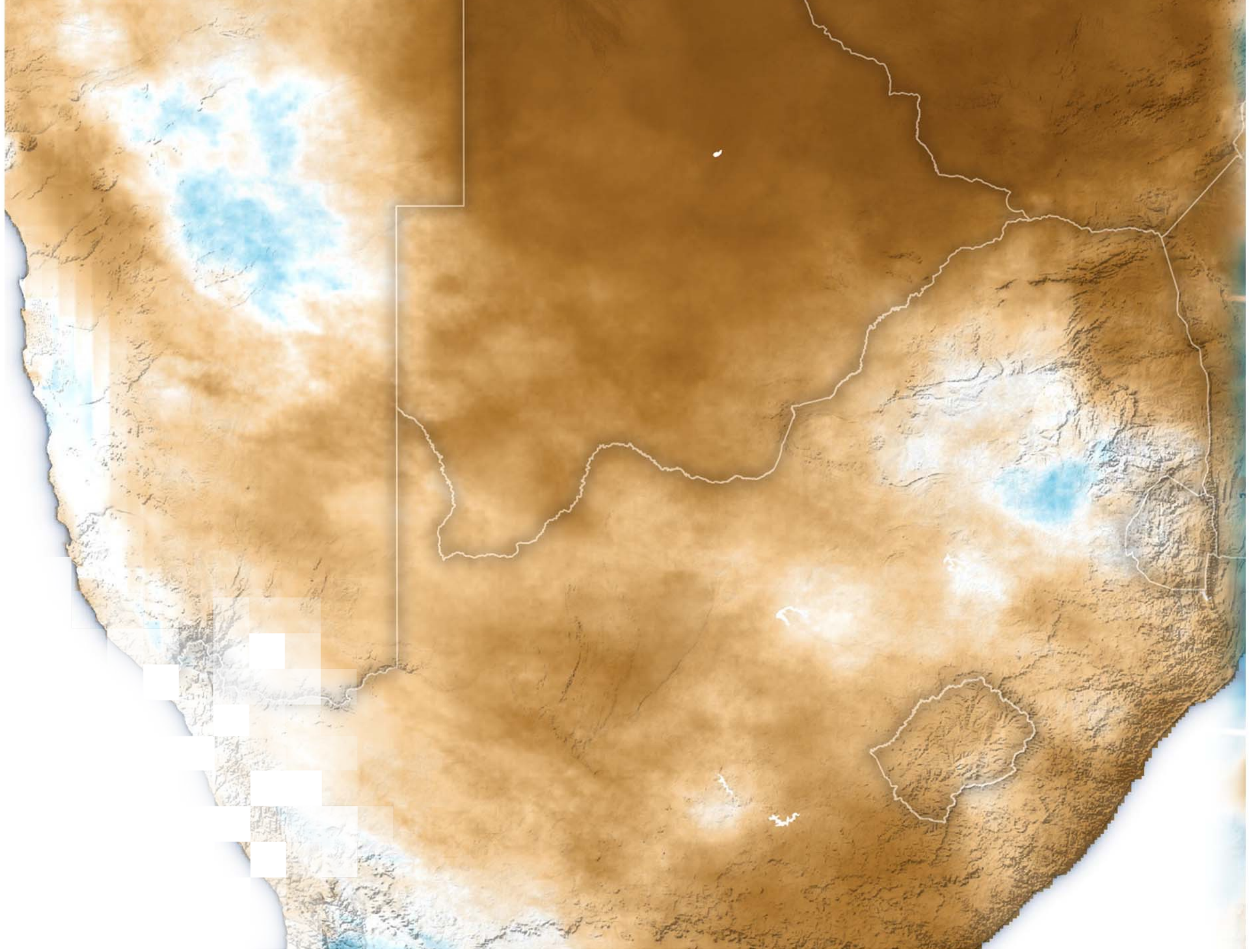
Thank you for your attention

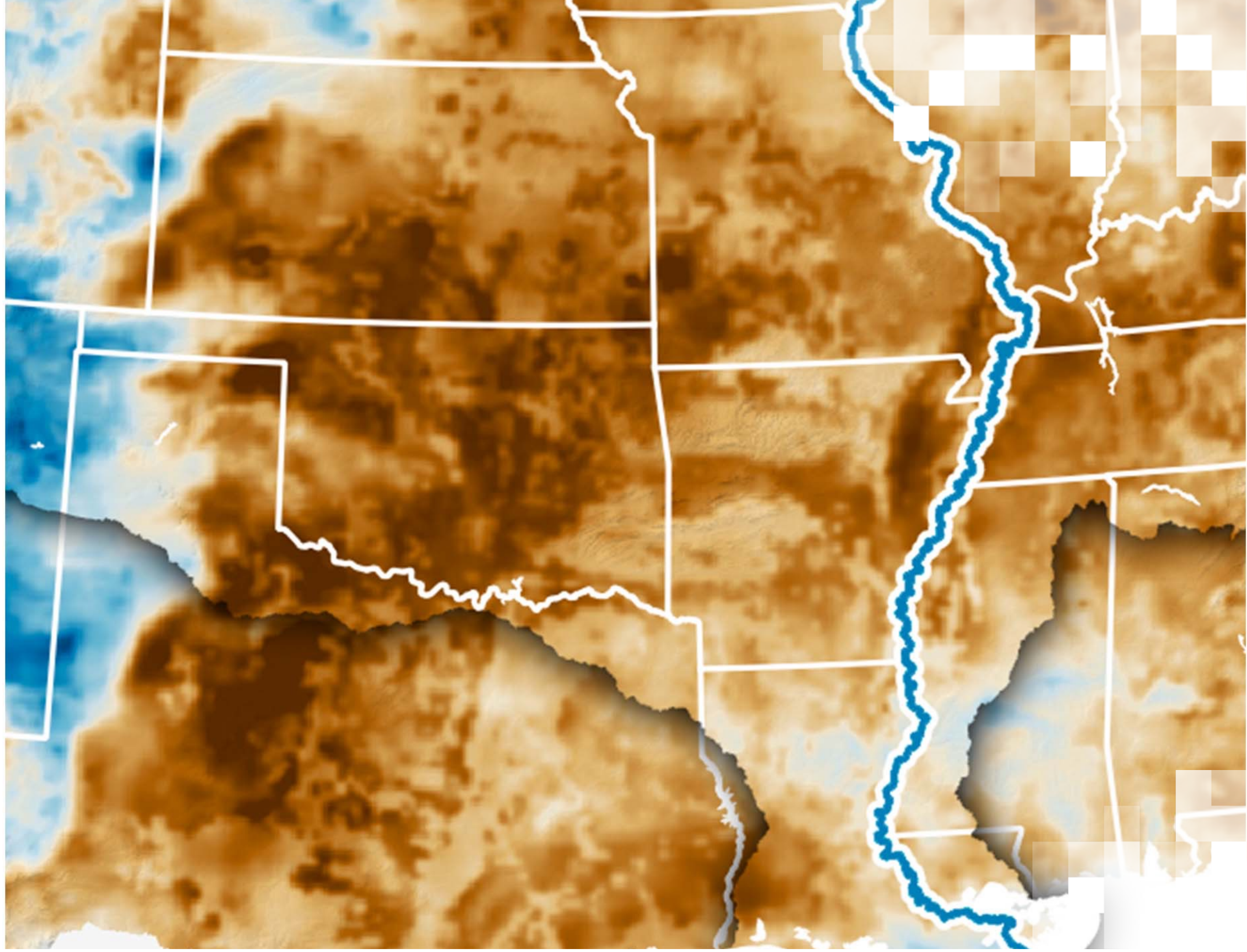
Questions?

- andrea.molod@nasa.gov

GMAO and GEOS-S2S Forecast/Assimilation output availability:

- Assorted- DISC, ftp, dataportal, some TBD – please get in touch!
- GEOS-S2S is “nimble” and can accommodate specialized data requests.





Demonstration:

Access and Analysis of S2S Data for Drought Assessment

Examine S2S Data for Evolving Drought Conditions

- GMAO S2S data for a specific period (historical and present) are available upon request [contact: Dr. Andrea Molod (andrea.m.molod@nasa.gov)].
- There is an ftp site where data staged in response to users' requests are available.
- In this demonstration:
  - We will examine maps of atmospheric anomalies to identify areas of dry/wet and warm/cold conditions.
  - Examine surface temperature and precipitation predictions for next three months based on the most recent forecast made available by Dr. Molod from GMAO S2S data repository.

Summary

- GMAO Seasonal Prediction group
  - Uses coupled Earth-System models and analyses in conjunction with satellite and in situ observations to study and predict phenomena that evolve on sub/seasonal to decadal timescales.
- S2S prediction is not the same as weather prediction
  - Is a statistical approach where ensembles of forecasts are needed to predict probabilities.
- Multiple uses of S2S data
  - Includes drought forecasting & water resources forecasting, studying dust sources in the US, soil moisture, precipitation, temperature for landslide prediction, ecological forecasting, data to drive a pest model.
- Data for users are tailored and distributed from an ftp site.
- Maps of 2-m temperature and precipitation monthly anomaly predictions for 9 months are available form GMAO Atmospheric Anomalies site.
- Examples of ensemble mean predictions of surface temperature and precipitation anomalies were analyzed in QGIS to examine areas of dry/warm conditions in next three months.
- Specific data can be requested by contacting Dr. Andrea Molod (andrea.m.molod@nasa.gov).

Looking Ahead to Part 3

- Overview of NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) for the Coupled Model Intercomparison Project Phase 6 (CMIP6).
- Access and analysis of NEX-GDDP-CMIP-6 climate projections of precipitation and temperature data to assess long-term drought conditions.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens **08/01/2024**
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 08/15/2024**

- **Certificate of Completion:**
  - Attend all four live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Trainers:

- Amita Mehta
  - amita.v.mehta@nasa.gov
- Andrea Molod
  - Andrea.m.molod@nasa.gov

- ARSET Website
- Follow us on Twitter!
  - @NASAARSET
- ARSET YouTube

Visit our Sister Programs:

- DEVELOP
- SERVIR

Resources

- GEOS S2S Forecast System
- Available S2S Data: ftp site.
- GMAO Atmospheric Anomalies.

Thank You!