A mission simulation and evaluation platform for terrestrial hydrology using the NASA Land Information System (LIS)

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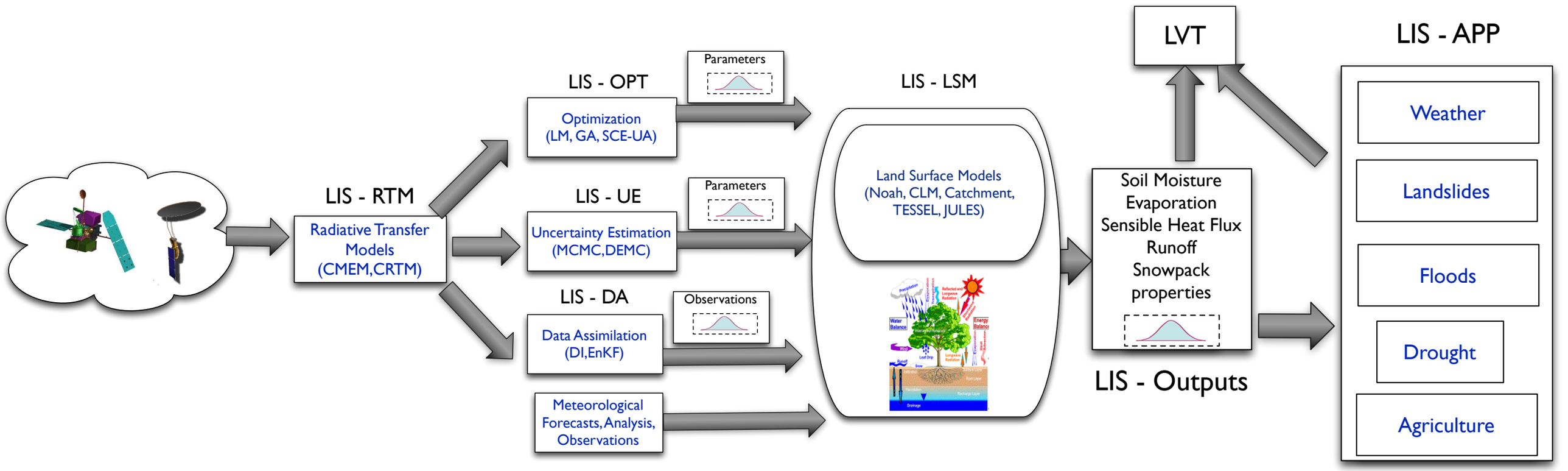
Motivation & Outline

- Extend the state-of-the-art for Observing System Simulation Experiments (OSSEs) in terrestrial hydrology
  - Broader range of computational methods
  - Applications-focused
  - Systematic, standardized evaluation

- Outline: 3 OSSEs
  1. SMAP (Soil Moisture Active Passive mission)
  2. GPM (Global Precipitation Measurement mission)
  3. GRACE-FO and GRACE-2 (Gravity Recovery And Climate Experiment)

Schematic of the Land Information System (LIS) OSSE platform



- End-to-end OSSE platform for terrestrial hydrology that links raw observations, radiative transfer models, data assimilation, uncertainty estimation, physical models, end-use applications and evaluation and verification techniques within a single integrated framework.

1. SMAP OSSE for drought/flood risk estimation

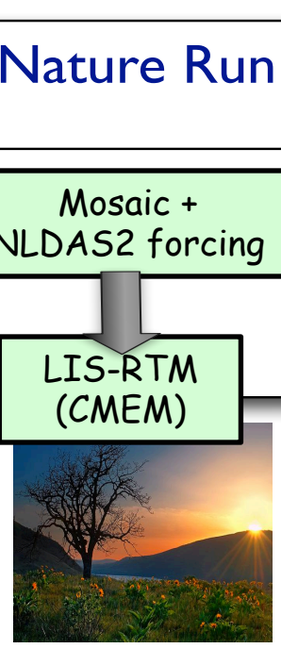
Simulation Domain: Continental U.S.,
35KM Spatial resolution
Time period: 1980-2012.

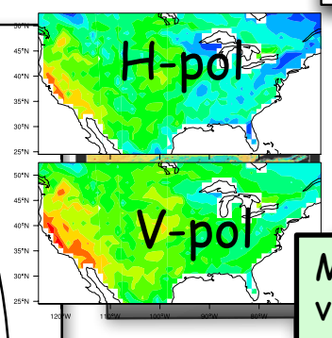
impact of having L-band brightness temperature observations for improving the representation of drought/ flood events

Nature Run

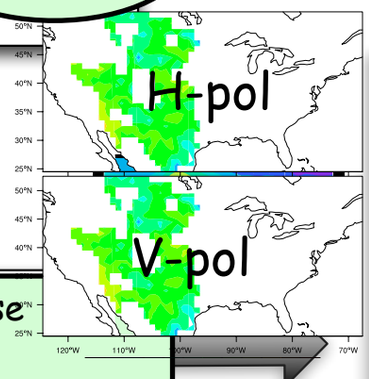
Mosaic + NLDAS2 forcing

LIS-RTM (CMEM)



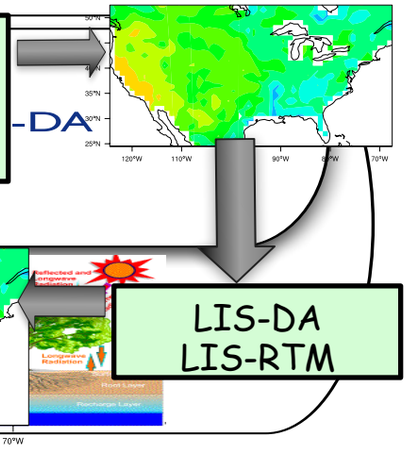


Masking for dense vegetation
rain/snow events
1.3 K gaussian noise
1 observation per day



System Simulation

Noah+ MERRA forcing (open loop; OL)



LIS-DA
LIS-RTM

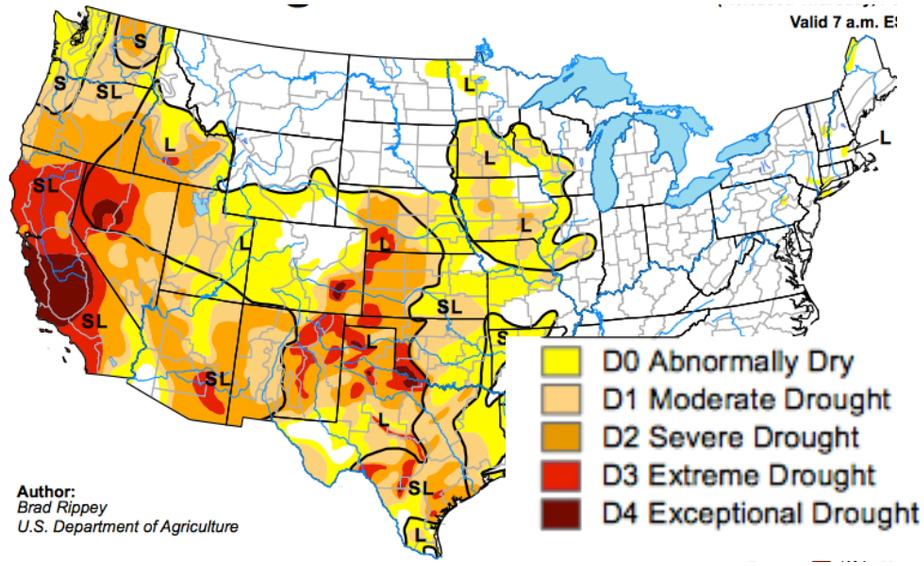
LVT

How much improvements in the drought/flood risk assessments are obtained?
How do these improvements translate to associated cost reductions?

Kumar et al. (2014), "Assessing the impact of L-band observations on drought and flood risk estimation: A decision theoretic approach in an OSSE environment, Journal of Hydrometeorology, Special collection on SMAP applications, in revisions.

Quantifying drought/flood-risk

- Droughts are typically quantified through normalized indices that capture deficits of the water cycle variable (precipitation, soil moisture, streamflow) from average conditions
- A common approach is to use root zone soil moisture percentile-based drought indices
- The U.S. Drought Monitor (USDM) defines drought into 5 categories: D0 – abnormally dry < 30 %tile; D1-extreme drought; <20%, D2 –severe drought<10%, D3-extreme drought<5% and D4-exceptional drought < 2%



- These normalized indices can also be used to quantify wetter than normal conditions (flood risk conditions). F0 (>70%), F1 (>80%), F2(>90%), F3(>95%) and F4 (> 98%)
- Essentially the OSSE examines the contribution of the soil moisture retrievals towards improving the extremes of the soil moisture distribution

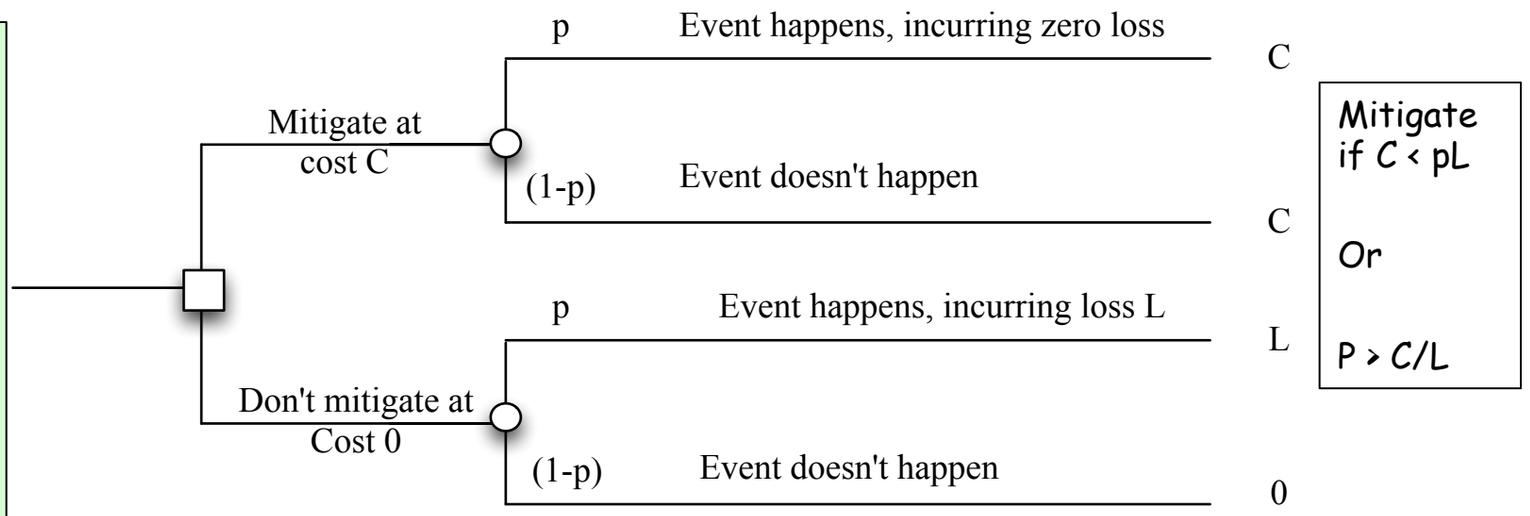
Decision theory model for an economic assessment of the SMAP OSSE

- Statistical decision theory has lots to say about making OSSEs relevant. E.g. : "Commercial decisions are often made, not on the basis of events which are likely to occur, but on the basis of events that are unlikely to occur, but which if they occur, would involve serious financial loss (Palmer, 2002)

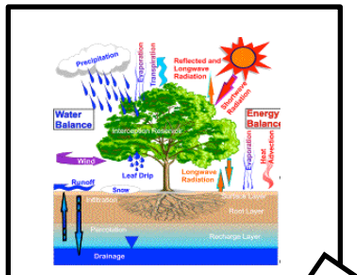
- A simple approach:
  - C – cost of taking action to mitigate event (e.g. drought) regardless of whether event happens or not
  - L – loss if event happens and no-mitigation was taken (C/L < 1)
  - p – probability of the event as assessed by the ensemble

The total cost is computed by summing across the cost/loss incurred for each flood/drought event

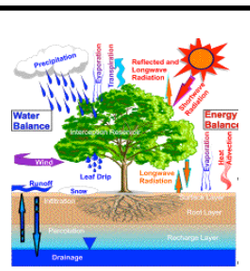
The costs can be computed both from a "deterministic" approach that uses the ensemble mean values in the decision tree or a "probabilistic" approach that diagnoses the probability of the event from the ensemble



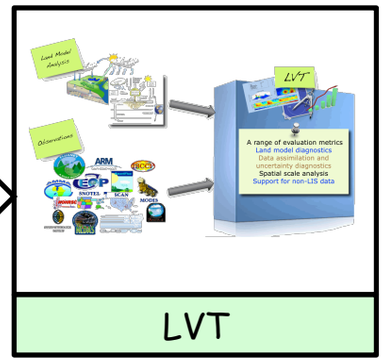
Sequence of decision theory analysis in the SMAP OSSE



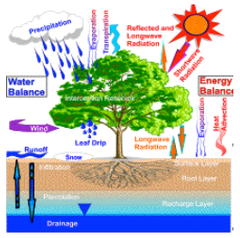
Open loop run (Noah)



Truth run (Mosaic)

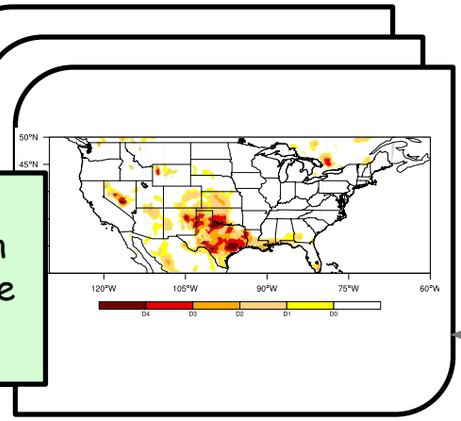


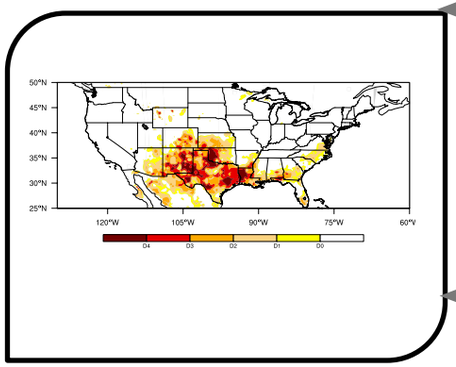
LVT

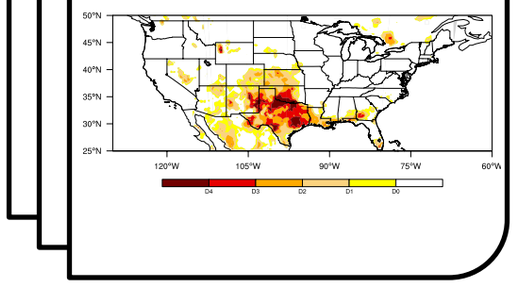


DA run (Noah)

Drought/Flood risk assessments based on root zone soil moisture percentiles







Cost-Loss Model

Cost_OL

Cost_DA

Value of Information (VOI) = (Cost_OL - Cost_DA)/ Cost_OL

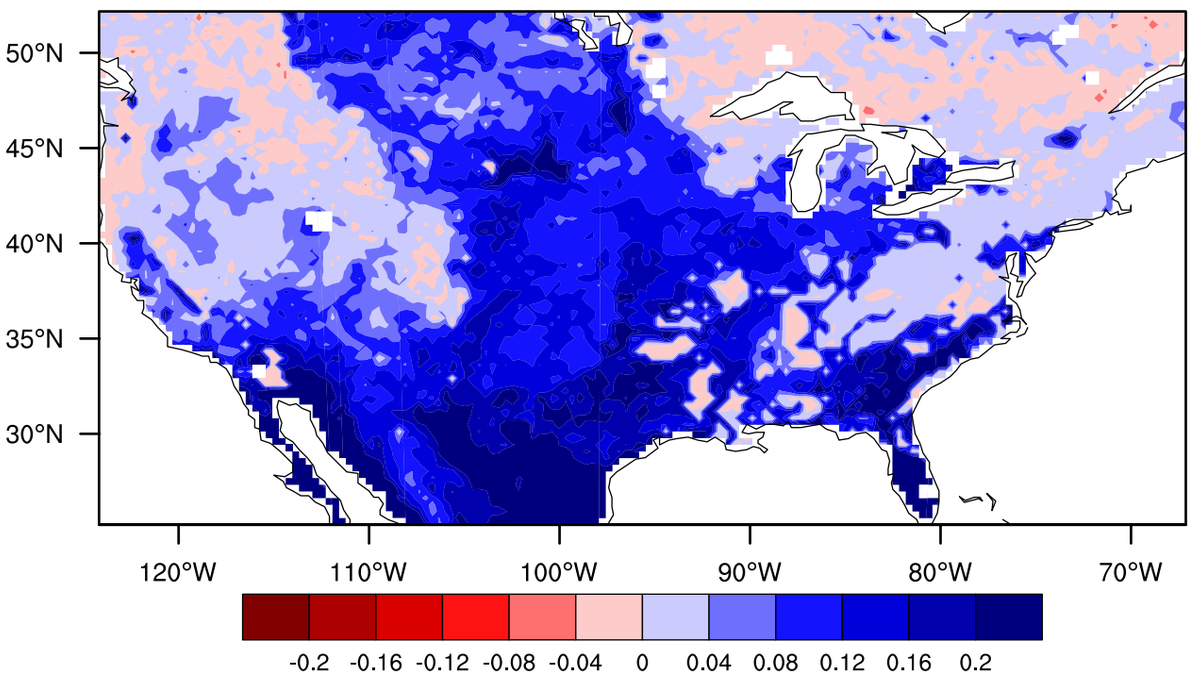
VOI>= 0 => DA helps to reduce associated costs

Improvements in soil moisture fields from SMAP Data Assimilation (DA)

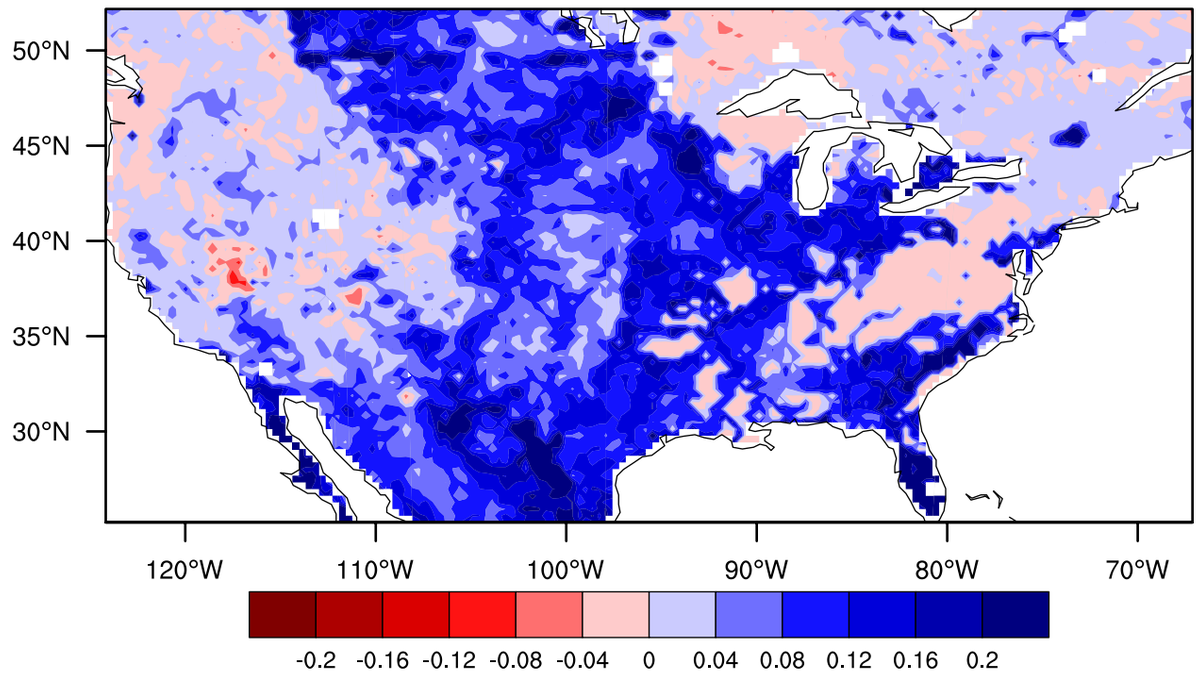
Maps present Anomaly R (DA) – Anomaly R (OL) of surface and root zone soil moisture.

Blue (positive values) indicate improvements
Red (negative values) indicate degradations

Assimilation of L-band Tb provides improvements to both surface and root zone soil moisture fields.



Surface soil moisture



Root zone soil moisture

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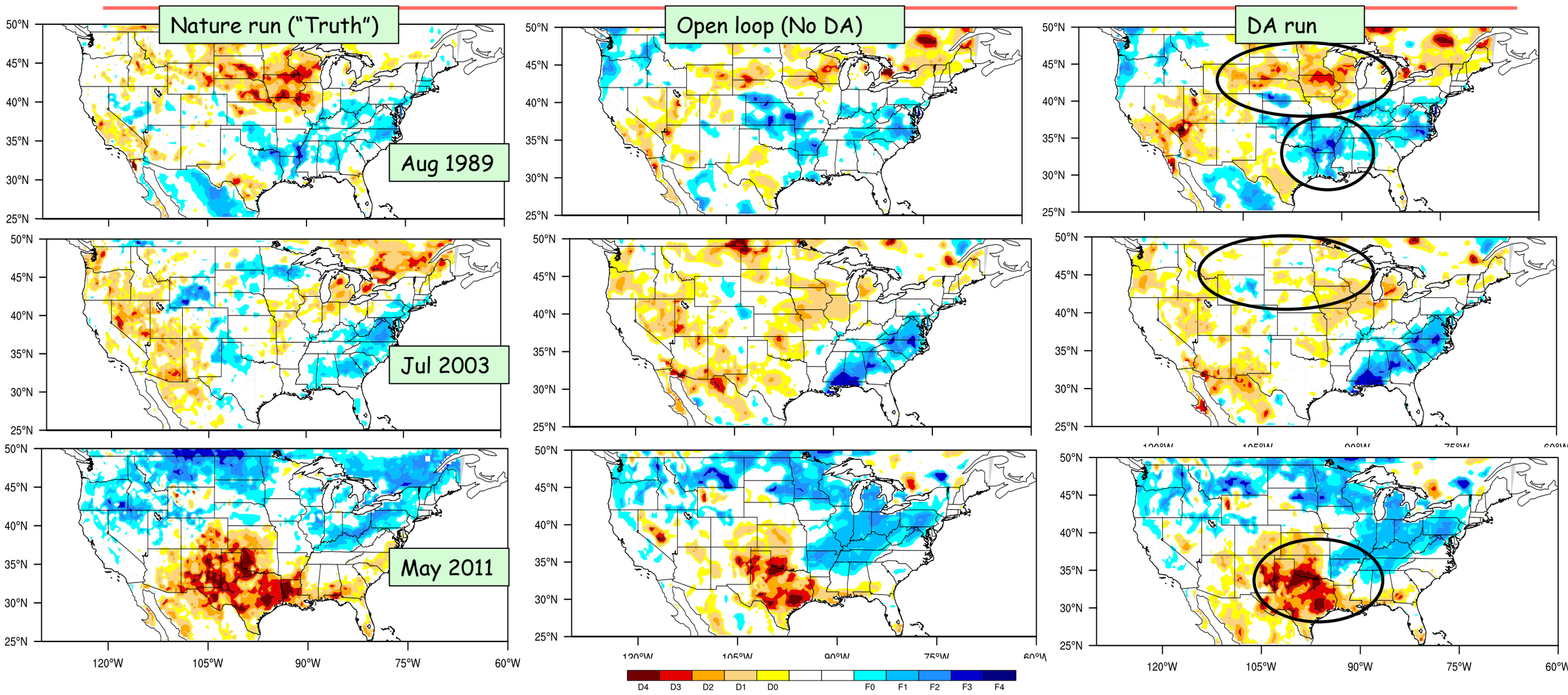
Drought percentile maps with and without SMAP

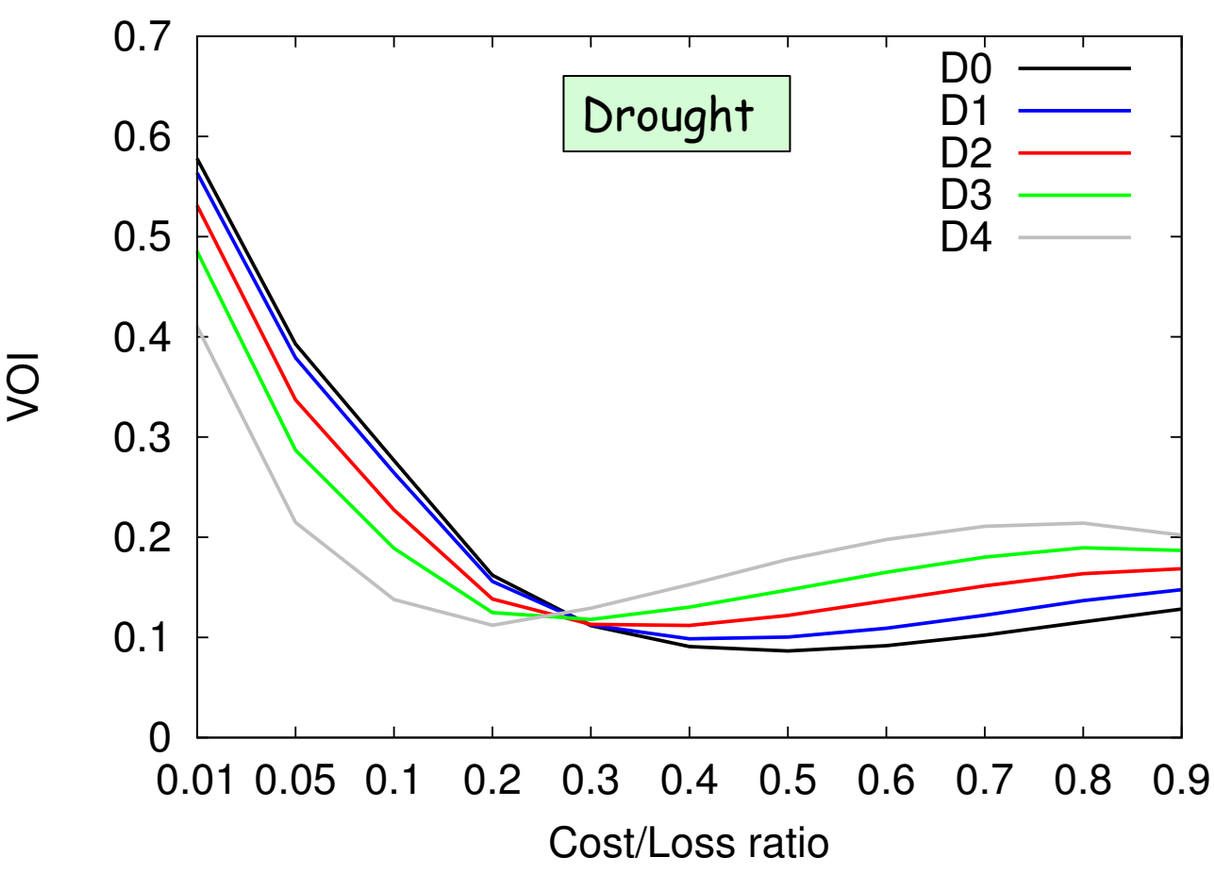


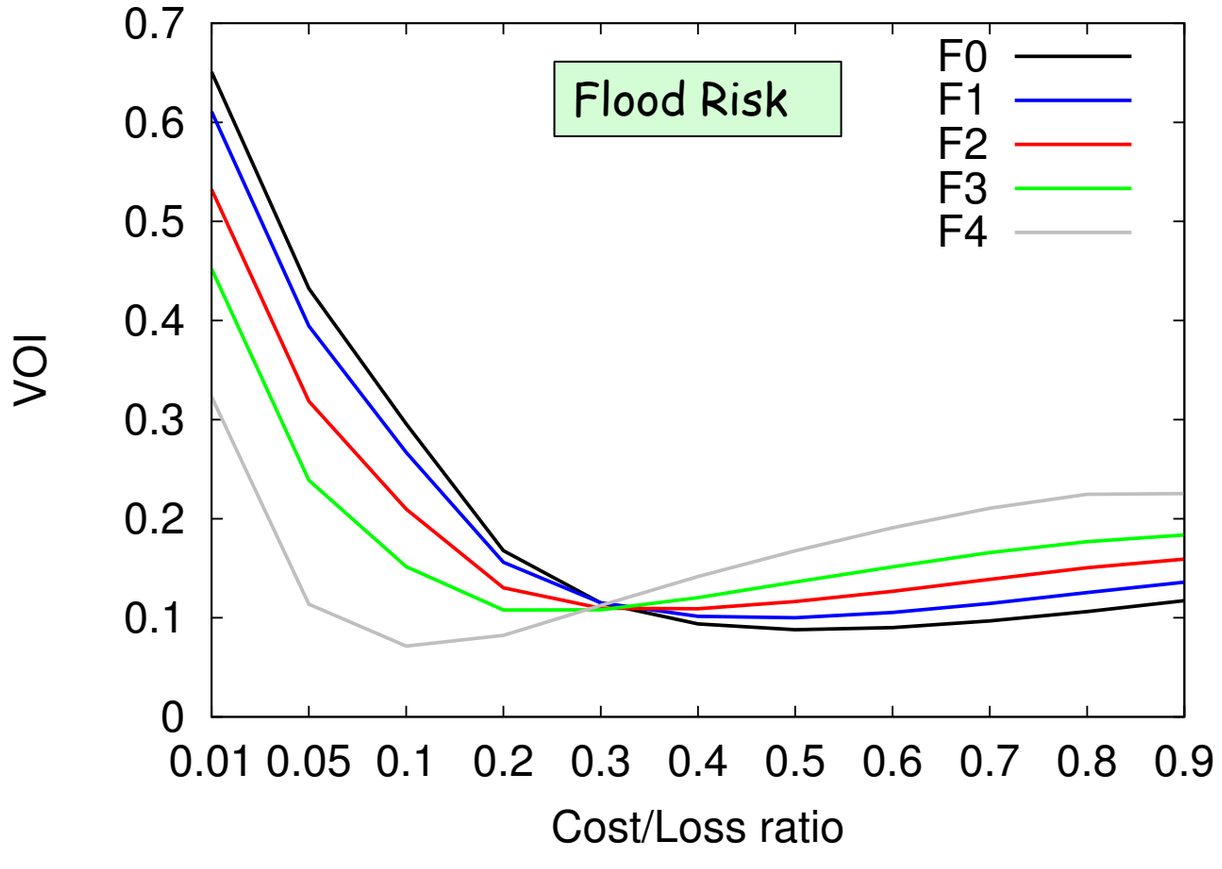
The assimilation of L-band Tb observations aid in improving the representation of drought/flood risk estimates

- Aug 1989 case: DA correctly intensifies the drought over the Midwest, improves flood risk estimation over lower Mississippi
- July 2003 case: DA reduces the severity of drought over the Highplains (that was incorrectly specified in the open loop run)
- May 2011 : DA correctly intensifies the drought over Texas

Value of SMAP information from "probabilistic" estimates

VOI = (Cost_OL – Cost_DA)/Cost_OL





The value of information is calculated for 5 different drought and flood categories (based on the percentile thresholds)

- The value of information from the probabilistic estimates are generally greater than those obtained from the deterministic estimates, as information is lost when summarizing the value of observations based on ensemble mean (used in the deterministic estimate)

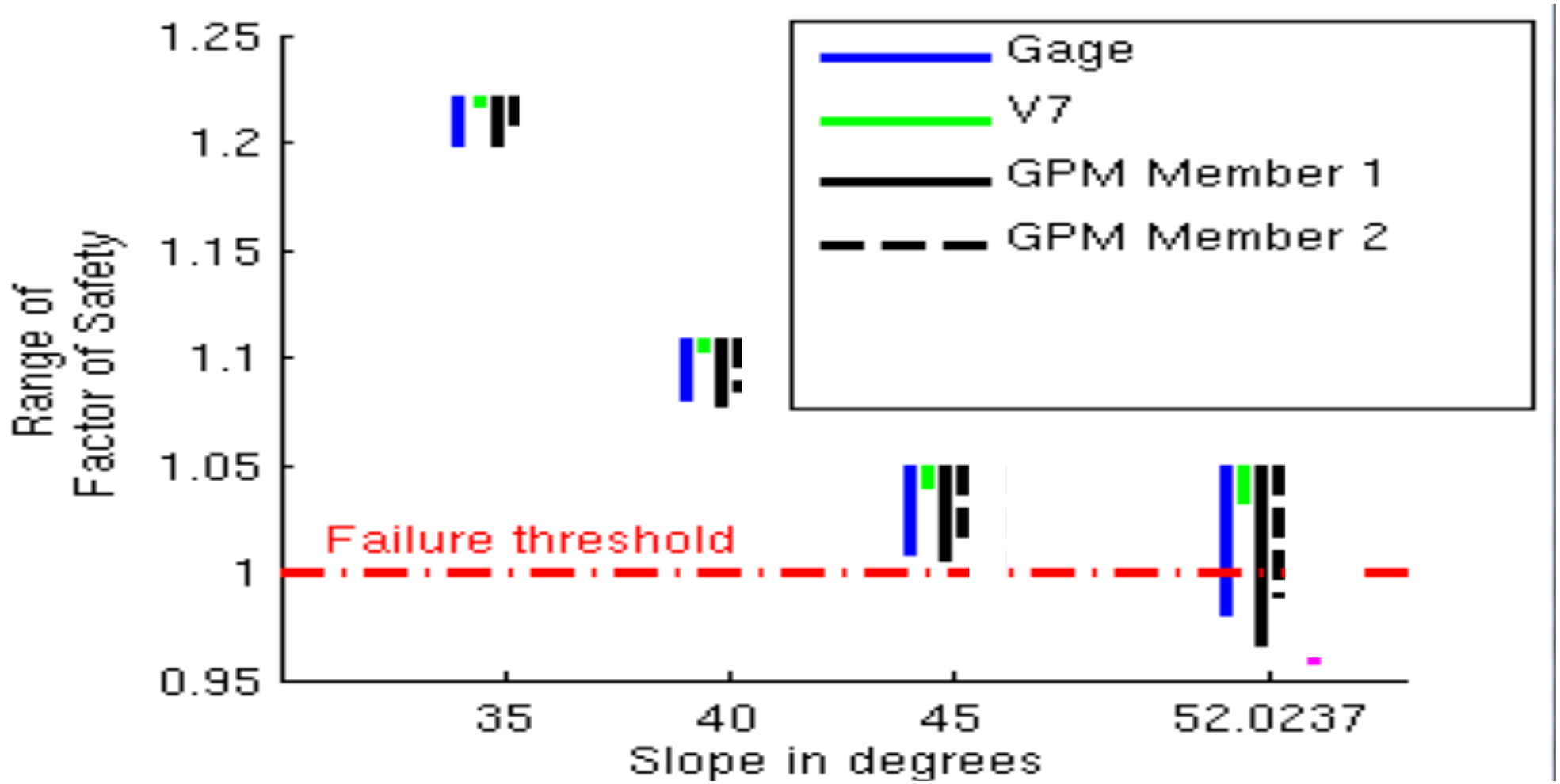
- The contribution to the value of information metric for low C/L ratios are from the improving the probability of detection of drought events through DA and for high C/L ratios are from reducing the false alarm ratio of drought events in the open loop run

2. GPM OSSE for landslide prediction

- Landslides are one of the most pervasive hazards in the world, resulting in more fatalities and economic damage than is generally recognized. An estimated 98% of all landslides are triggered by rainfall.
- Remote sensing information is poised to provide significant inputs to physical landslide modeling approaches in order to estimate these processes over larger areas
- Current physically-based slope-stability models are conducted at very high spatial resolution with in-situ gauge data and few/ no studies use satellite-based rain for local models
- This work considers how satellite-based products from Tropical Rainfall Measuring Mission (TRMM) and simulated data from the GPM mission may prove useful in applying a landslide model over broader regions

TRMM vs. GPM Landslide Forecasts

Range of FoS from Start of simulation to minimum

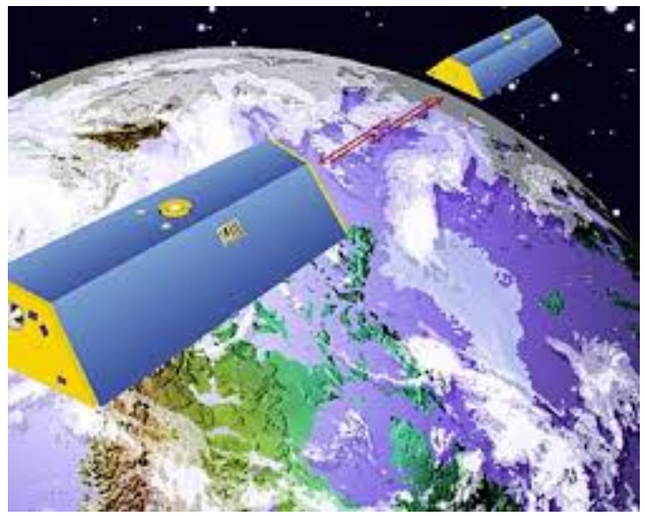


- GPM Ensemble members show improvement for determining decreases FoS over the observed landslide failure region but upper ensemble values overestimate failure

Yatheendradas et al. (2014), ""Evaluation of satellite rainfall for physically-based landslide modeling applications: examples over the Washington State region" J. Hydrometeorology, in prep.

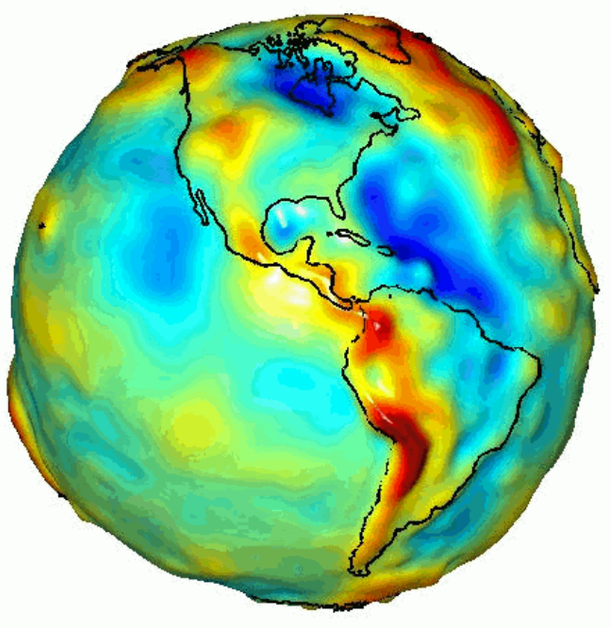
3. GRACE OSSE for the development of future GRACE missions

- GRACE – Gravity Recovery and Climate Experiment (launched in 2002) satellite provides measurements of Earth's gravity field anomalies



- Measurements are NOT derived from electromagnetic waves; GRACE uses a microwave ranging system to measure changes in the speed and distance between two identical spacecrafts ("Tom" and "Jerry") flying in a polar orbit at about 220 km apart, 500 km above earth

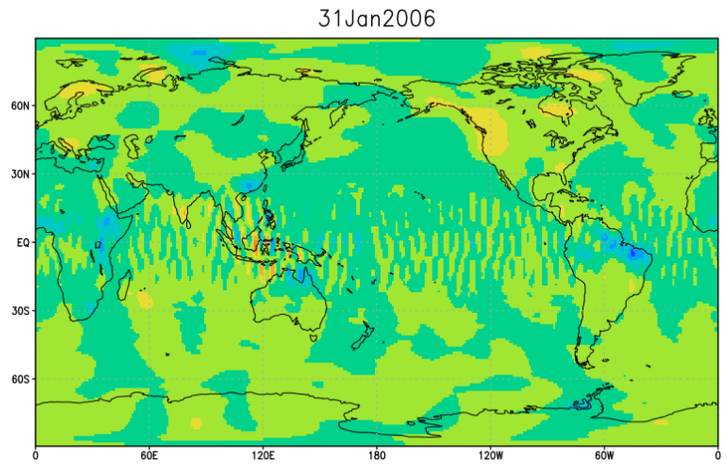
- The twin satellites sense minute variations in Earth's gravitational pull. By combining the data of distance between the satellites and GPS measurements of the position of satellites, a detailed map of Gravity anomalies can be constructed (at a spatial resolution of about 660 km)



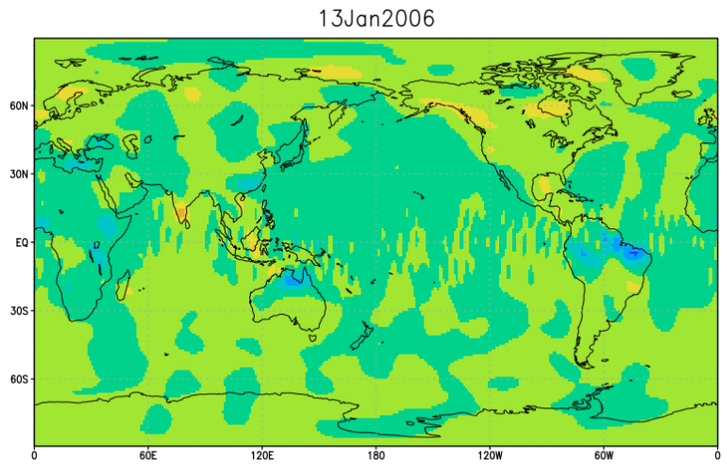
- Through the gravity field measurements, GRACE shows how mass is distributed around the planet and varies over time.

GRACE OSSE

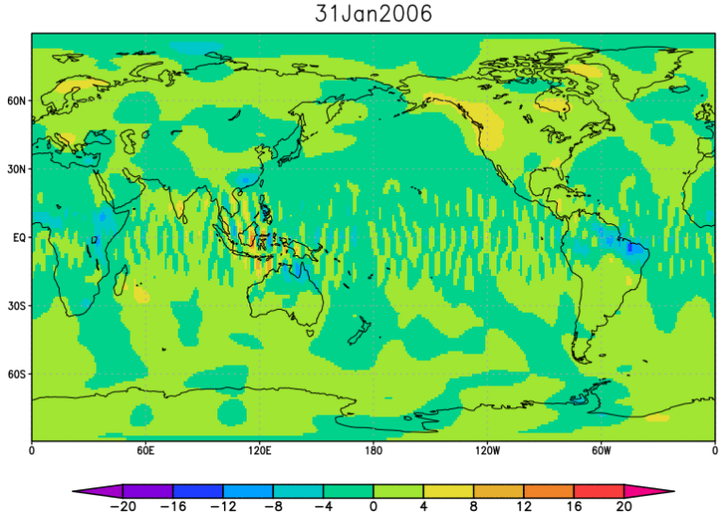
- Conduct OSSEs to examine the science tradeoffs of future GRACE mission configurations.
- A nature run simulation and global estimates of TWS anomalies were generated using the CLSM model and were provided to GRACE SDT



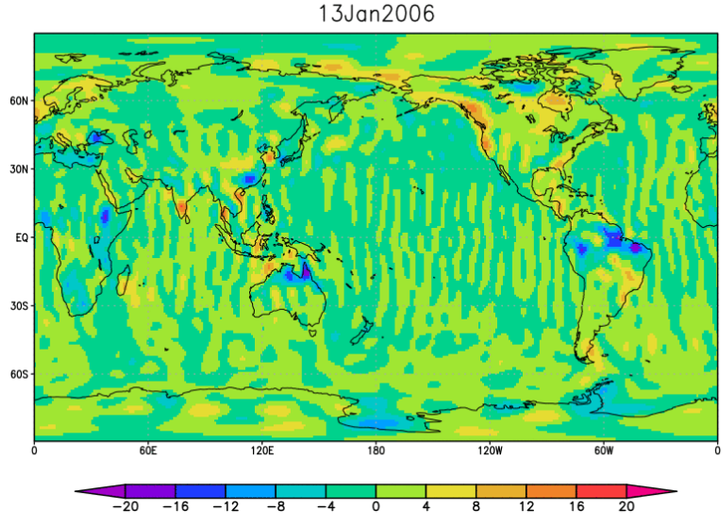
GRACE benchmark



GRACE-2/single pair



GRACE-FO configuration



GRACE-2/two pairs

- Standard configuration: 30-day repeat, 475km altitude, 89 inc.
- GRACE-2 single pair: 13-day repeat, 320km altitude, 90 inc
- GRACE-2 two pairs: 13-day repeat, 320 km alt, 90 inc + 13-day repeat, 290 km, 72 inc.
- Configurations will also examine the impact of spherical harmonics-based data and mass conservation based data
- Working with Scott Luthcke to add the Cold Atom Gravity Gradiometer (CAGG) retrievals to this suite, which is based on the light pulse atom (LPA) interferometry.

Summary

- A comprehensive environment for conducting end-to-end and applications focused OSSEs for terrestrial hydrology has been developed
- The environment has been demonstrated for a number of OSSEs for current and future missions (e.g. SMAP, GPM)
- The GRACE science definition team is employing this environment for the development of future GRACE missions.