Integrating Geodetic Observations into Hydrological Models

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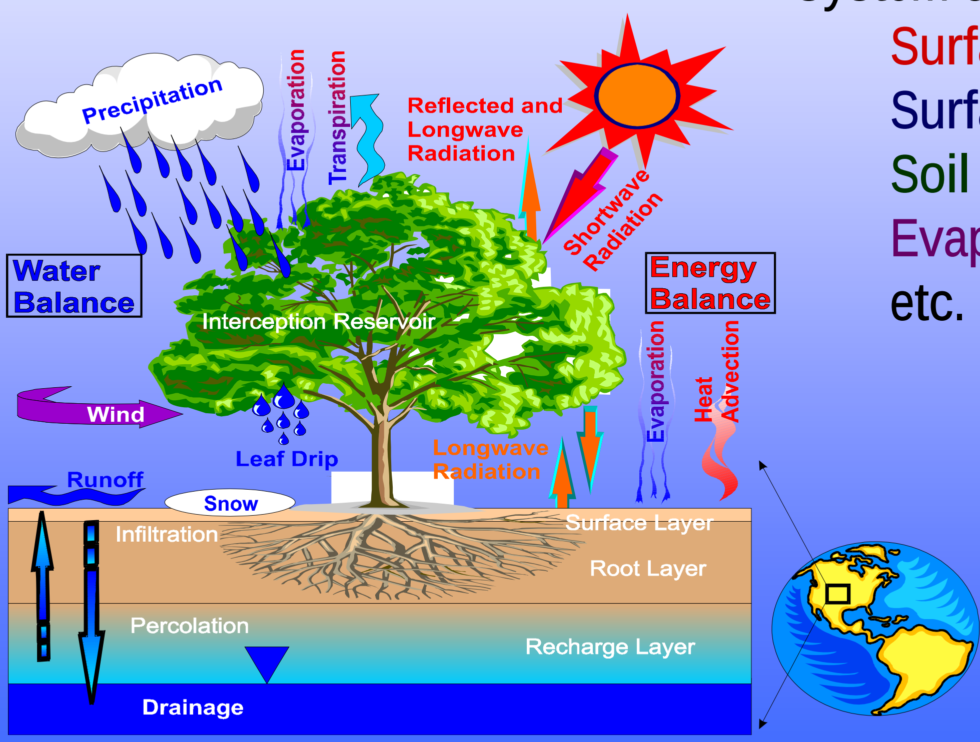
Land Surface (Hydrological) Models

- Simulate the redistribution of water and energy incident on the land surface using physically based equations
- Merge data from diverse sources, including satellites, in a spatially and temporally continuous and consistent manner
- Economical



System of physical equations:

Surface energy conservation equation

Surface water conservation equation

Soil water flow: Richards equation

Evaporation: Penman-Monteith equation

etc.

Advanced processes such as groundwater storage, carbon fluxes, and vegetation dynamics are beginning to be included

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Input and Output Fields

Input Parameters:

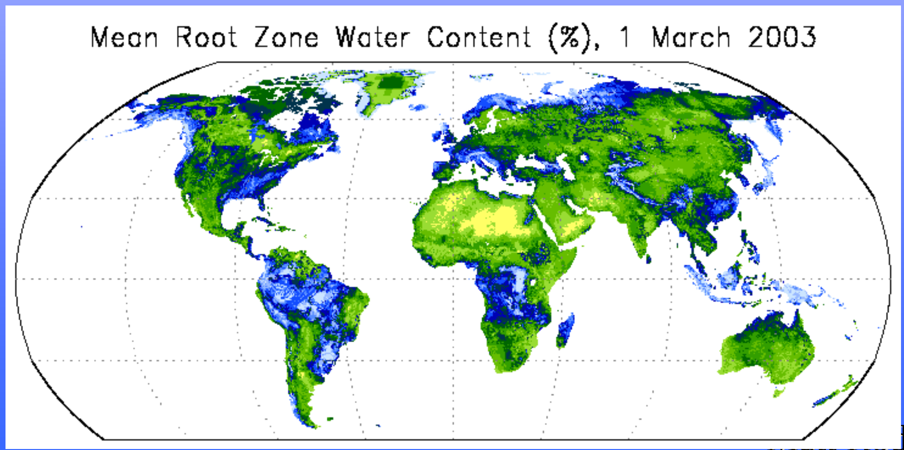
vegetation class
vegetation greenness/LAI
soil type
elevation

Required Forcing Fields:

total precipitation
convective precipitation
downward shortwave radiation
downward longwave radiation
near surface air temperature
near surface specific humidity
near surface U wind
near surface V wind
surface pressure

Summary of Output Fields:

soil moisture in each layer
snow water equivalent
soil temperature in each layer
surface and subsurface runoff
evaporation
transpiration
latent, sensible, and ground heat fluxes
snowmelt
snowfall and rainfall
net shortwave and longwave radiation



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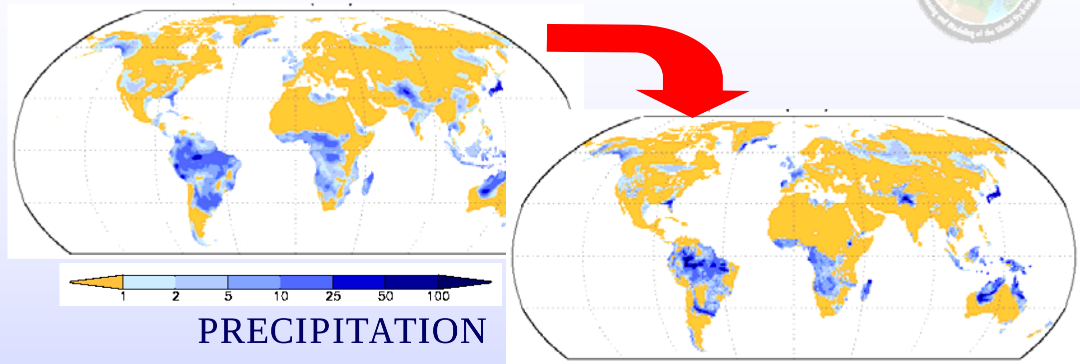
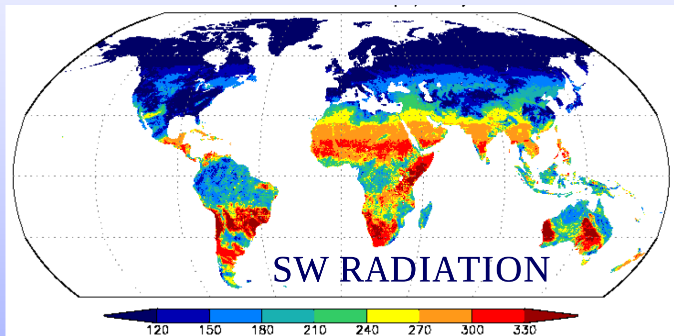
Data Integration Within a Land Surface Model

INTERCOMPARISON and OPTIMAL MERGING of global data fields



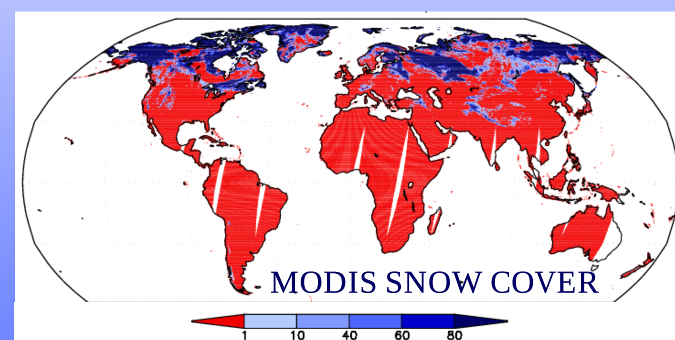
PRECIPITATION



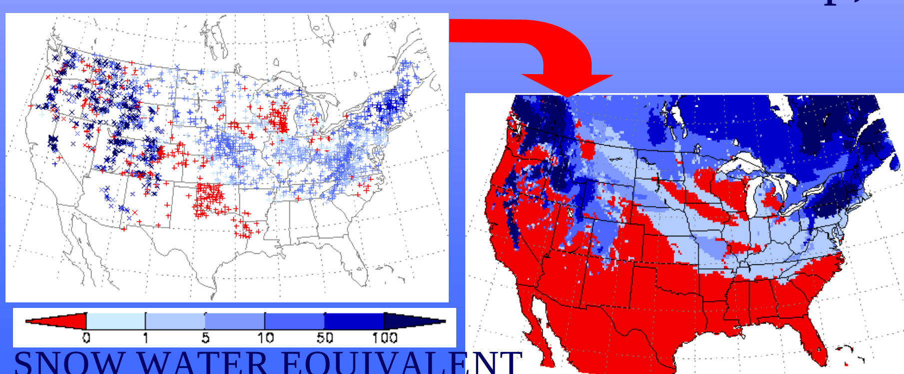
SW RADIATION

Satellite derived meteorological data used as land surface model FORCING

ASSIMILATION of satellite based land surface state fields (snow, soil moisture, surface temp, etc.)



MODIS SNOW COVER



SNOW WATER EQUIVALENT

Ground-based observations used to VALIDATE model output

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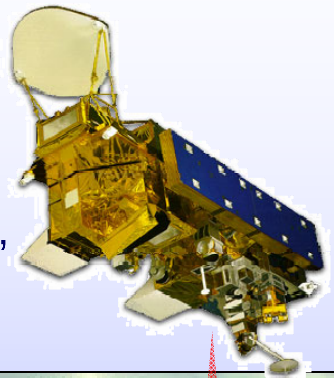
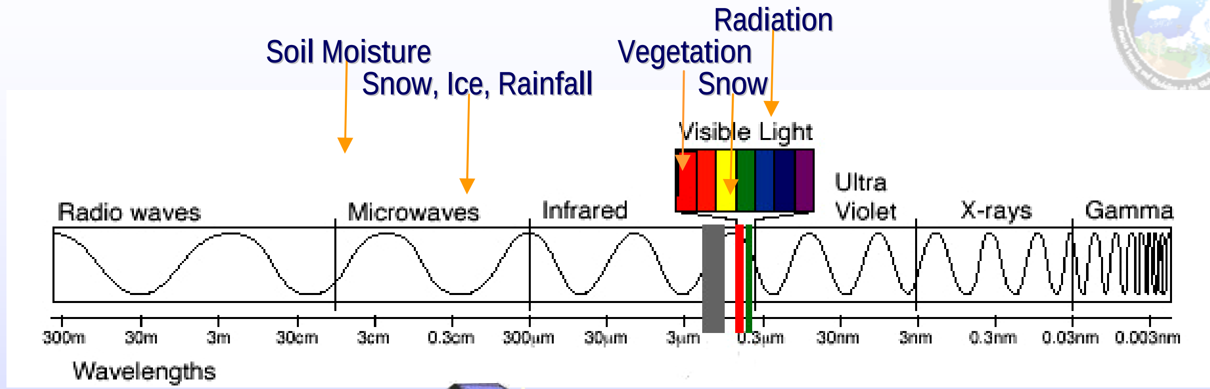
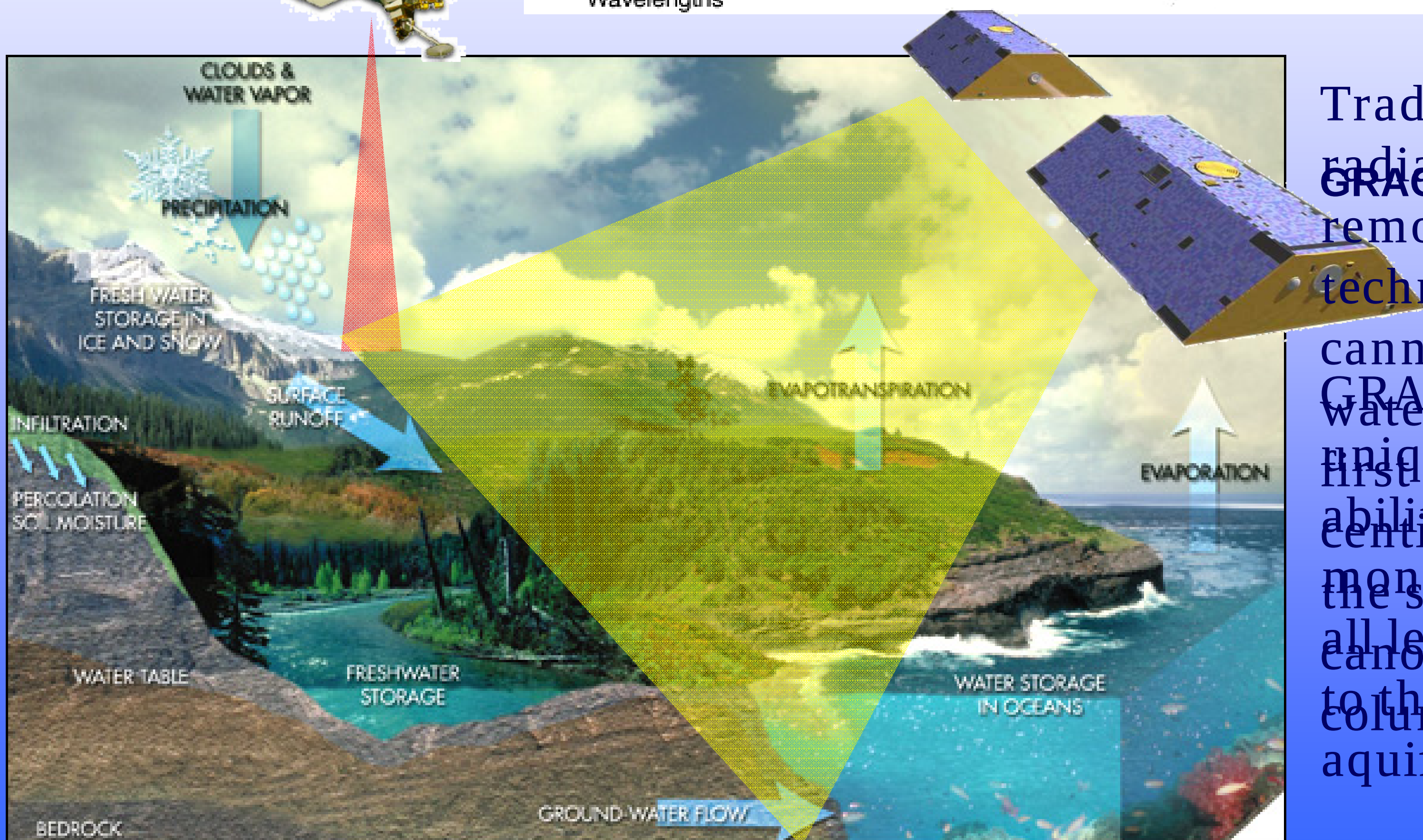
Remote Sensing of the Water Cycle

Aqua:
MODIS,
AMSR-E,
etc.







Traditional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

GRACE

GRACE is unique in its ability to monitor water at all levels, down to the deepest aquifer

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Integration of Geodetic Observations into Hydrological Models

Challenges

- Observed and modeled variables differ
- Spatial resolution of observations is relatively coarse
- Temporal resolution and latency

Key Advantage

- Geodetic observations are not limited to a certain depth of penetration

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Options for Incorporating Geodetic Observations into Hydrological Models

- Parameter Definition

  Example: Elevation data are used to adjust surface temperature and set the infiltration-to-runoff ratio

- Parameter Calibration

  Example: The amplitude of GRACE-derived terrestrial water storage variations can help to tune parameters like porosity and depth of soils, for which reliable maps often don't exist

- Data Assimilation: Model States

  Example: Terrestrial water storage, as derived from GRACE, is merged with the model's own estimate using an optimization algorithm like a Kalman filter

- Data Assimilation: Observed States

  Example: Earth's gravity field or rotation is forward modeled based on mass variations simulated by a fully coupled global model, and the GRACE based gravity field is directly assimilated (same theory as radiance assimilation)

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Assimilation of GRACE TWS Data

• LSMs simulate the terrestrial water cycle, but accuracy is limited by

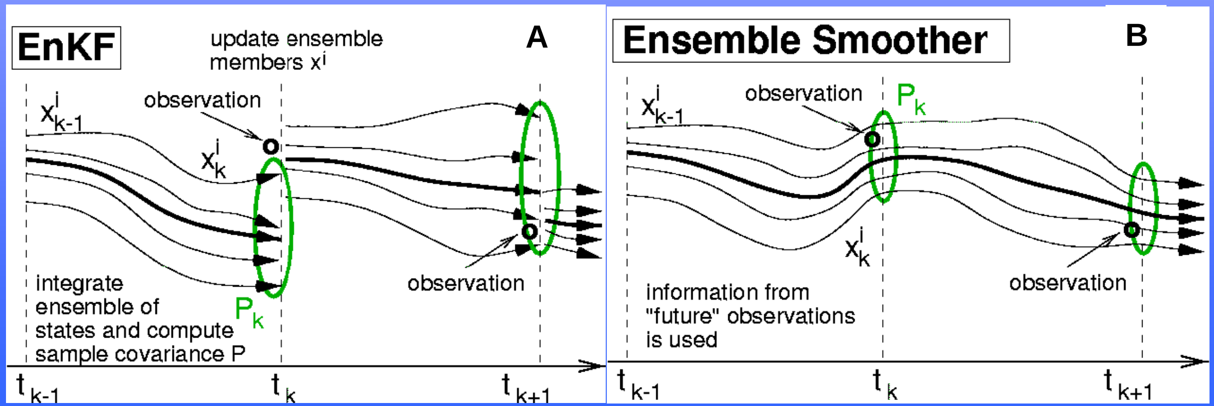
- quality of the input forcing and parameter data
- model developers' understanding of the physics involved
- simplifications necessary to simulate physical processes economically

• Value of GRACE observations for hydrology is limited by

- low spatial and temporal resolutions; product latency
- lack of info on vertical distribution of observed mass changes

• Data assimilation can harness the advantages of each:

- LSMs provide physically consistent, high resolution output; run up to near-real time driven by other data
- GRACE and other observations anchor the results in reality
- DA incorporates error information to ensure optimal blending



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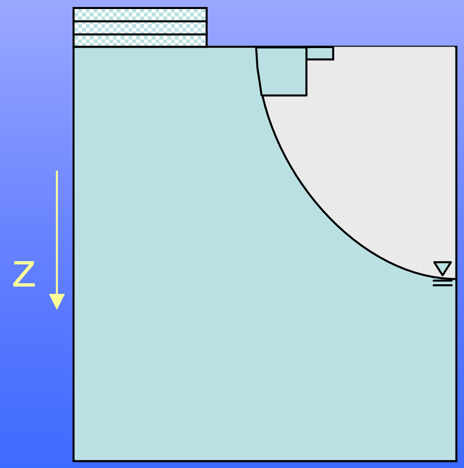
GRACE Data Assimilation Study

- Offline simulations of the Catchment land surface model using GLDAS forcing data
- 10 year spin-up under 2002 forcing
- 20-member ensemble simulations for open loop (OL) and data assimilation (DA)
- Monthly GRACE anomalies: CSR/GFZ/JPL mean, Jan 2003 - May 2006
- Ensemble Kalman smoother DA

Catchment LSM
(Koster et al., 2000):



three snow layers
surface excess
root zone excess
“catchment deficit”

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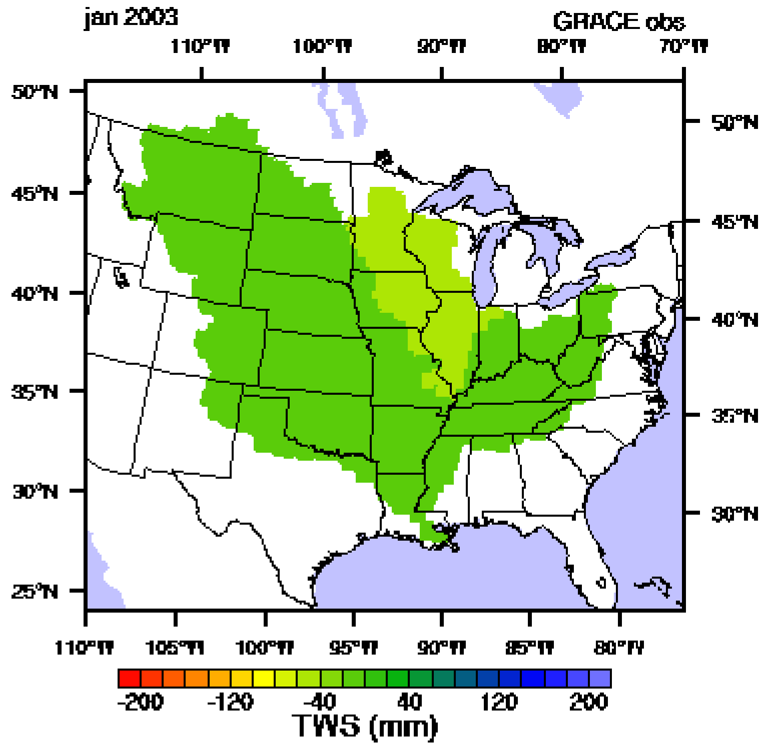
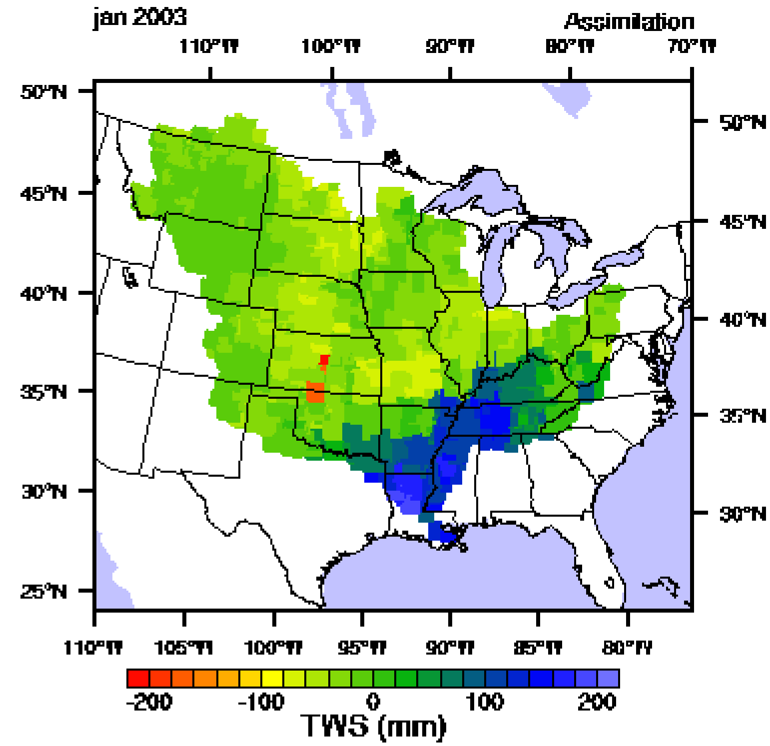
Assimilation of GRACE TWS Data

Results have higher resolution than GRACE alone, better accuracy than model alone.

GRACE TWS anomaly
January 2003 – June 2006



GRACE Assimilating Catchment LSM
TWS anomaly, mm
January 2003 – June 2006



From scales useful for water cycle and climate studies…

To scales needed for water resources and agricultural applications

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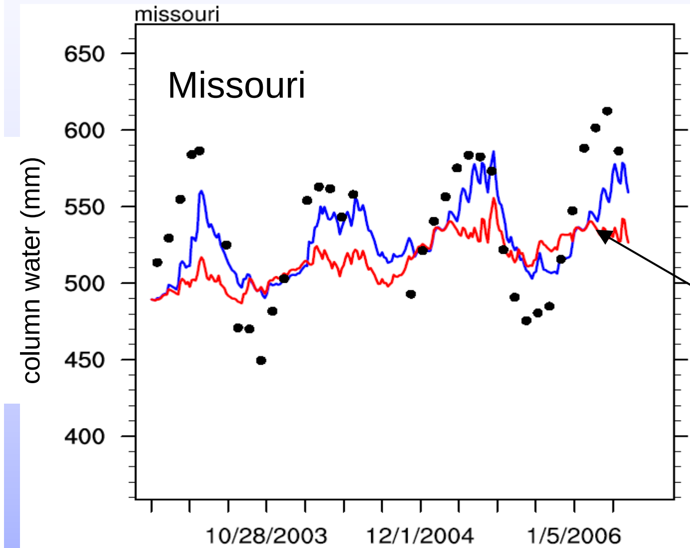
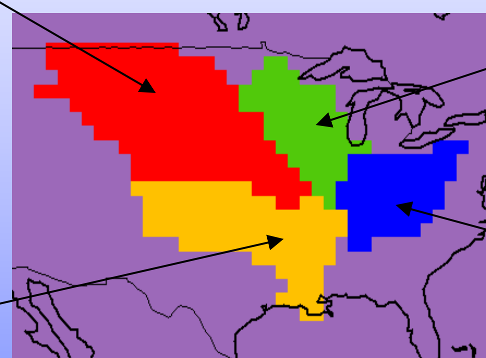
Assimilation of GRACE TWS Data

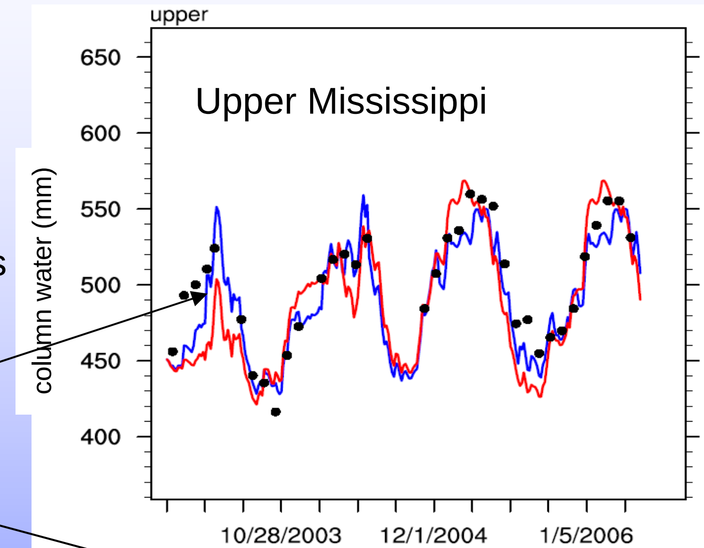
LDAS models produce continuous time series; near-real time capable.

Monthly GRACE data anchor model results in reality



Mississippi River sub-basins

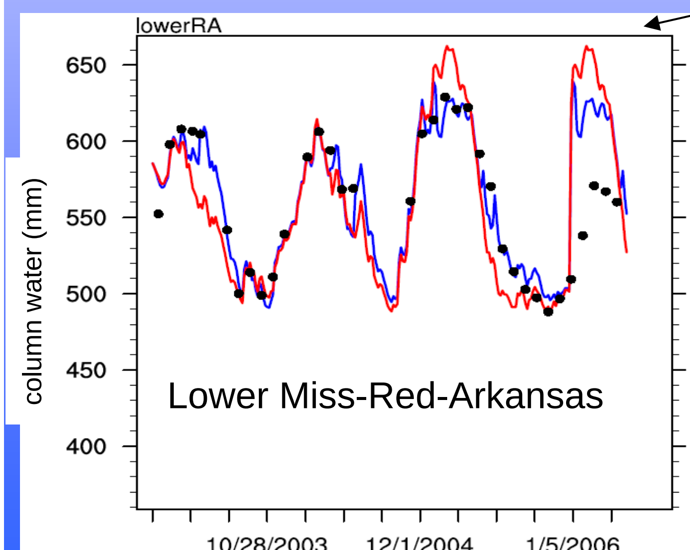




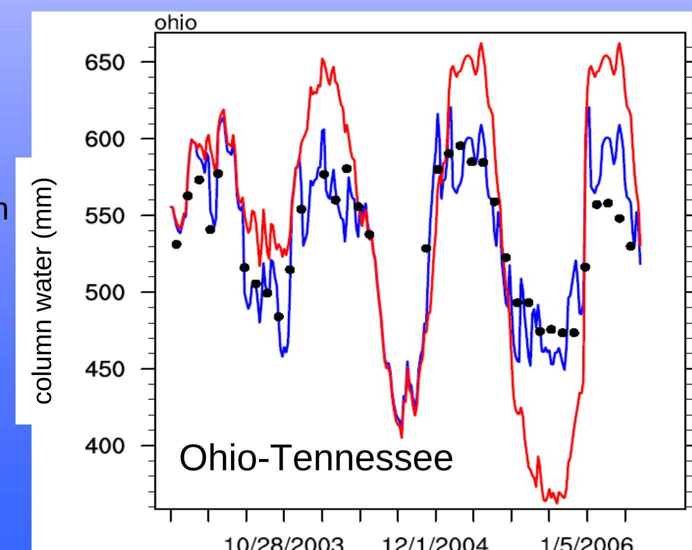
● GRACE Water Storage

Modeled Water Storage (red line)

Model-GRACE Assimilation (blue line)

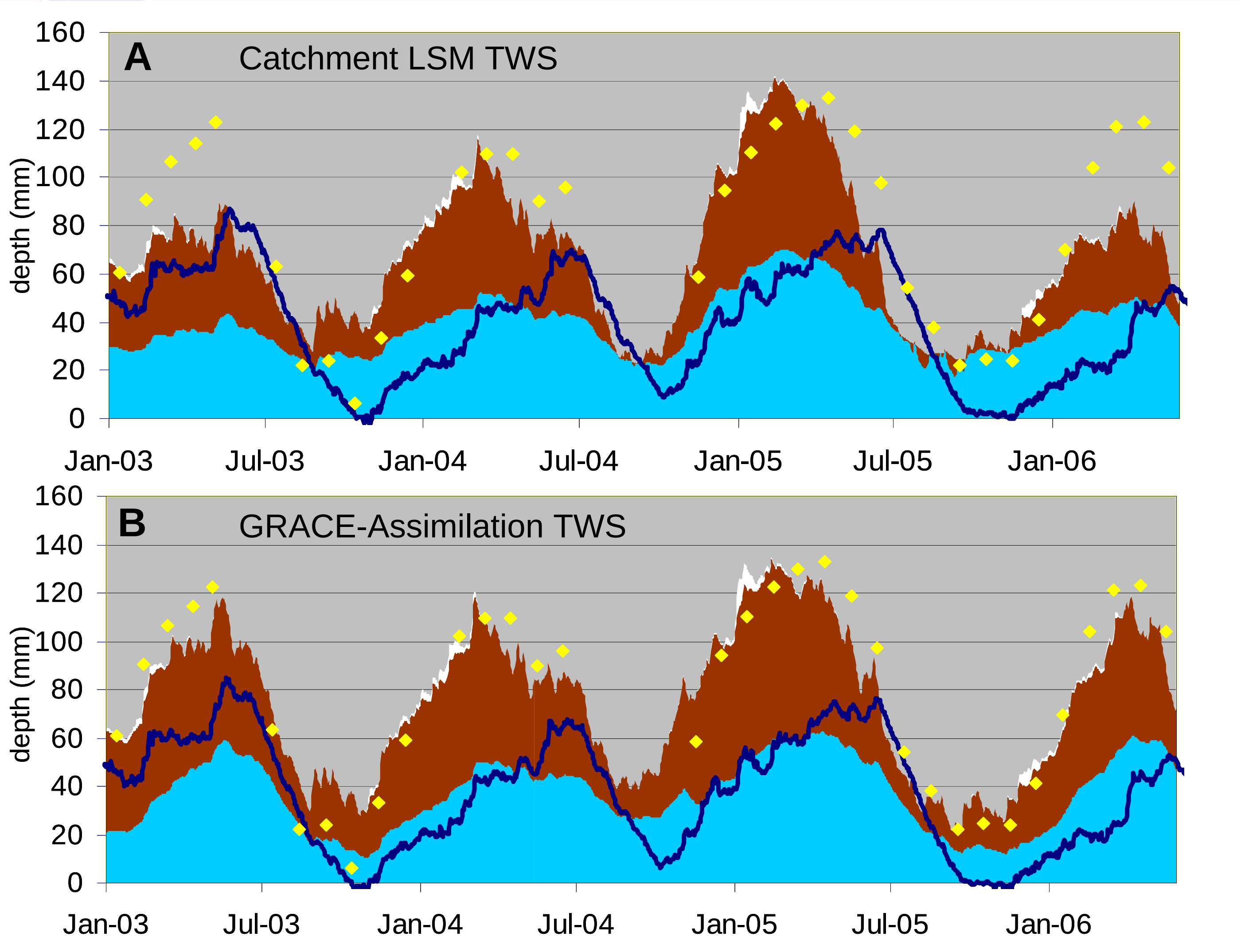


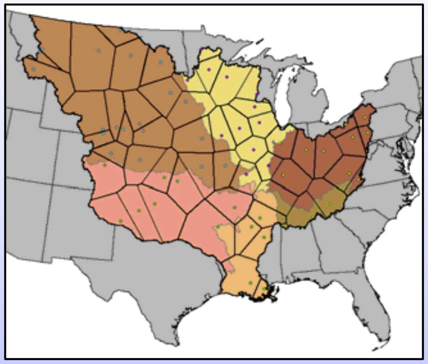
Daily estimates are critical for operational applications

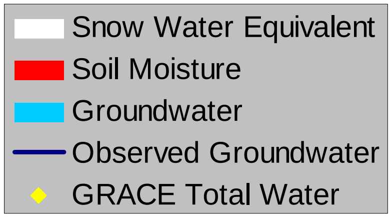


Assimilation of GRACE TWS Data

Models separate snow, soil moisture, and groundwater; GRACE ensures accuracy.







From a global, integrated observation
To application-specific water storage components

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Assimilation of GRACE TWS Data

GRACE data assimilation improves groundwater storage estimates

	OL		GRACE DA		
	r	RMSE	r	RMSE	skill
Mississippi	0.59	23.5	**0.69**	18.7	0.20
Ohio-TN	0.78	62.8	**0.82**	41.1	0.35
Upper Miss.	0.29	42.6	0.29	40.1	0.06
Red-Ark. / L.M.	0.69	30.9	*0.72*	26.5	0.14
Missouri	0.41	24.5	**0.66**	19.7	0.20

OL = open loop (no data assimilation)

r = coefficient of correlation

RMSE = root mean square error (mm H_2O)

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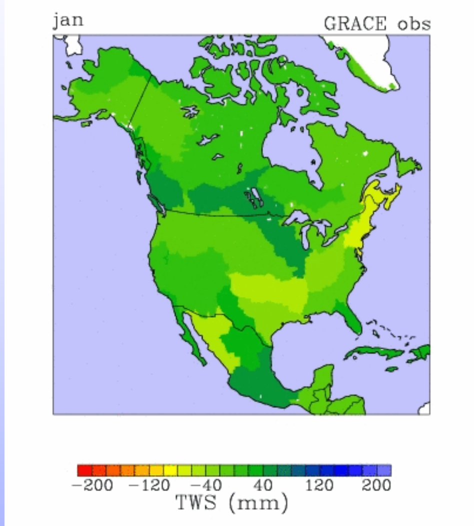
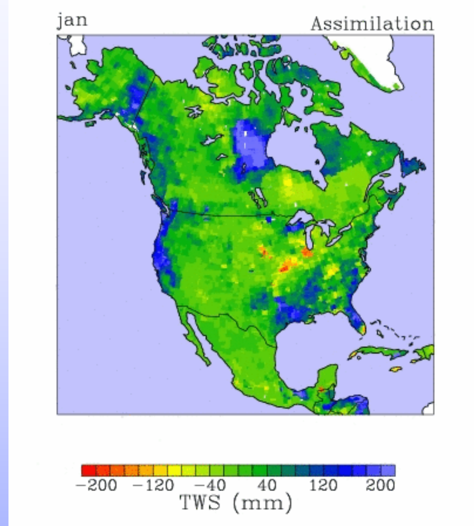
GRACE Data Assimilation: Recent Progress and Applications

Extension to other regions and the globe



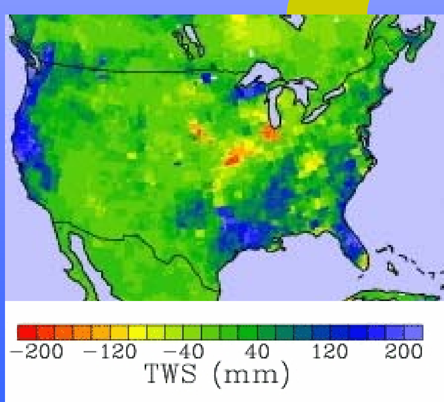
GRACE water storage, mm
January-December 2003 loop

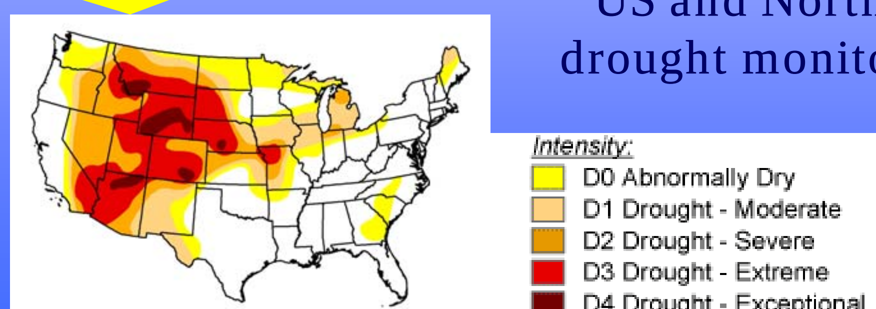


Model assimilated water storage, mm
January-December 2003 loop

Arab Land Data Assimilation System project

US and North American drought monitoring project





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Summary

• Geodetic observations have certain advantages over conventional ground based and remote sensing observations, thus there is potential for them to contribute to hydrology via model integration

• Potential methods for integrating geodetic observations into hydrological models include:

- Parameter definition and calibration
- Data assimilation: model states or observation states

• Data assimilation has already proven valuable for spatially, temporally, and vertically disaggregating GRACE derived terrestrial water storage variations and mitigating the latency issue

• GRACE data assimilation results are now benefitting water resources applications

Backup slides

Integration of Geodetic Observations into Hydrological Models: Challenges

	GRACE	Land Surface Model
Spatial Resolution		
Vertical Stratification		
Temporal Resolution and Latency		

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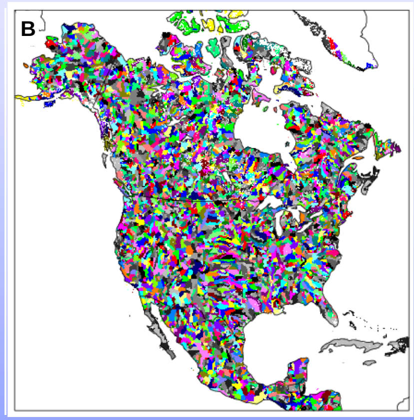
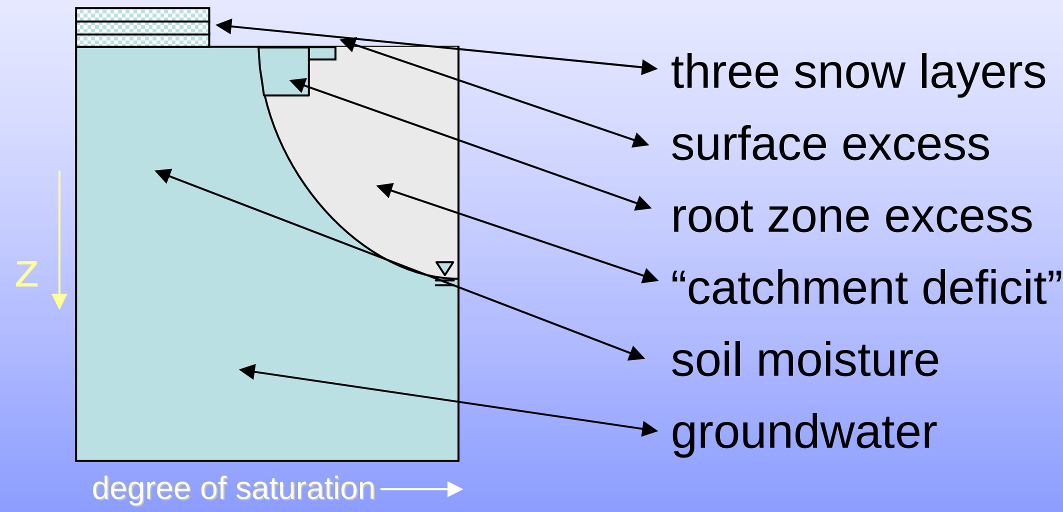
GRACE Data Assimilation

Data assimilation enables information from multiple space and ground based observation systems to be merged in a physically consistent manner, using our knowledge of physical processes as represented in numerical models

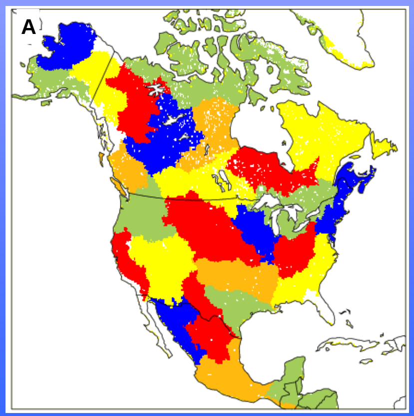
Catchment LSM spatial elements (average size ~2,500 km²)

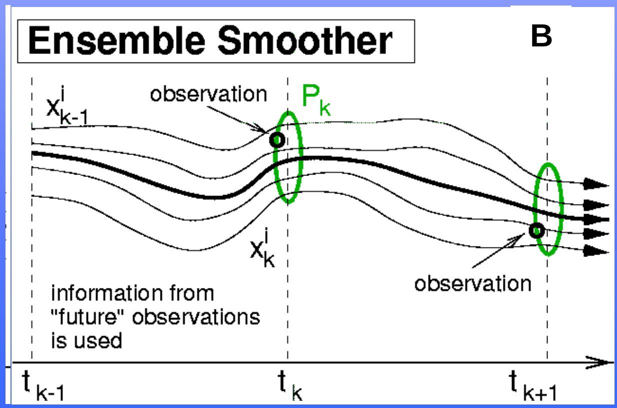


Catchment LSM (Koster et al., 2000)



GRACE observation scale: river basins (200,000 – 1,000,000 km²)





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