United States Group on Earth Observations (USGEO) /
Canadian Group on Earth Observations (CGEO)
Workshop on Water and Ice

30 October 2008

High Resolution Land Data Assimilation Supported by NASA/GSFC and the Land Information System (LIS)

Christa Peters-Lidard[1]
Rolf Reichle[2], Matt Rodell[1], Sujay Kumar[1], and many others …

Christa.Peters@nasa.gov
301-614-5811

1 − Code 614.3: *Hydrological Sciences Branch*, NASA-GSFC
2 − Code 610.1: *Global Modeling and Assimilation Office*, NASA-GSFC

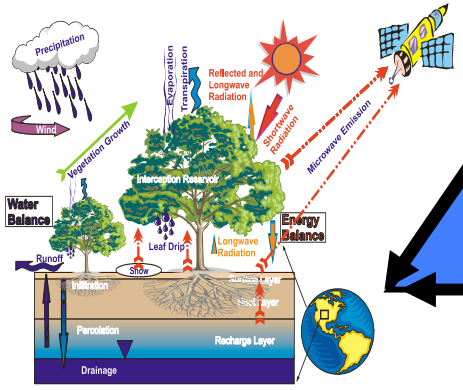
Outline

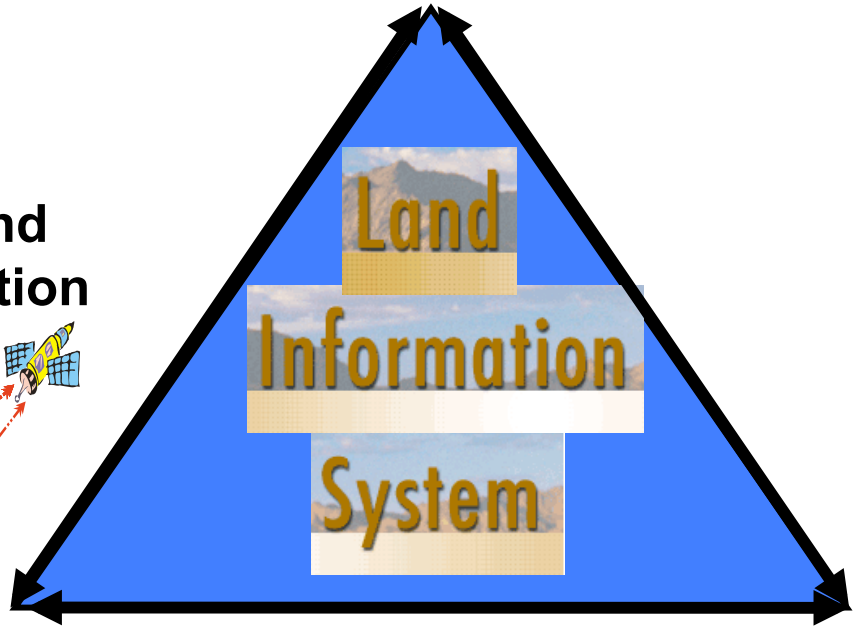
- *Land data assimilation systems*
  - Goals and concept
- *Examples*
  - Soil moisture
  - Terrestrial water storage
  - Snow cover
  - Irrigation
- *Summary and future plans*

LDAS Integrate Observations, Models and Applications to Maximize Impact

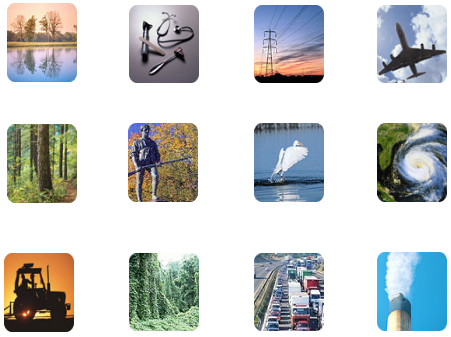
1. Observations

2. Modeling and Data Assimilation



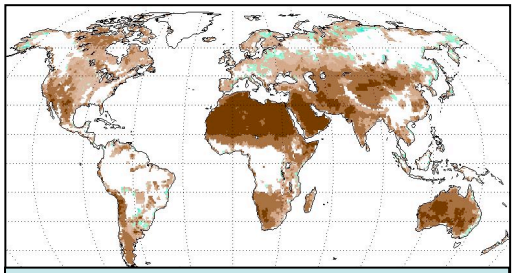


3. Applications

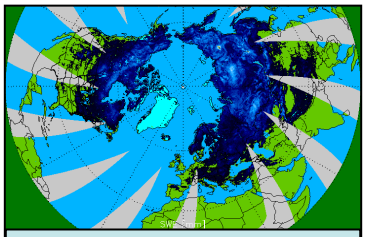


Motivation: Observations

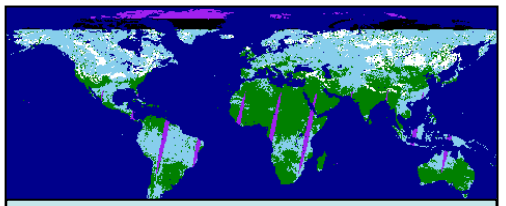
Vegetation/Carbon
(AVHRR, MODIS, *DESDynI, ICESat-II, HyspIRI, LIST, ASCENDS*)



Surface soil moisture
(SMMR, TRMM, AMSR-E, *SMOS, Aquarius, SMAP*)

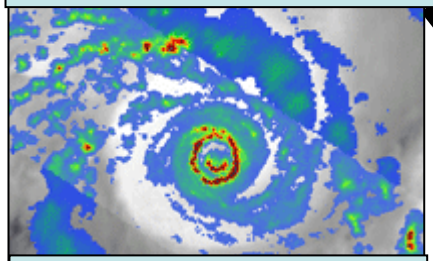


Snow water equivalent
(AMSR-E, SSM/I, *SCLP*)

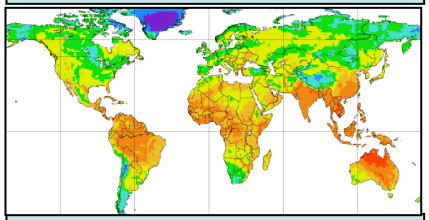


Snow cover fraction
(MODIS, *VIIRS, MIS*)

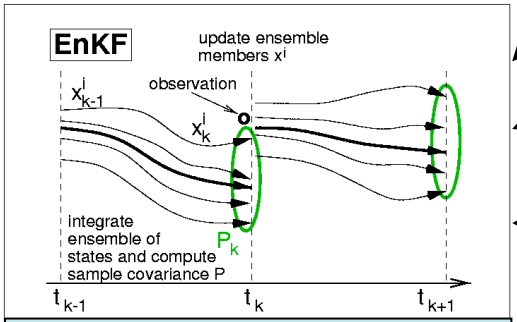
Water surface elevation
(*SWOT*)



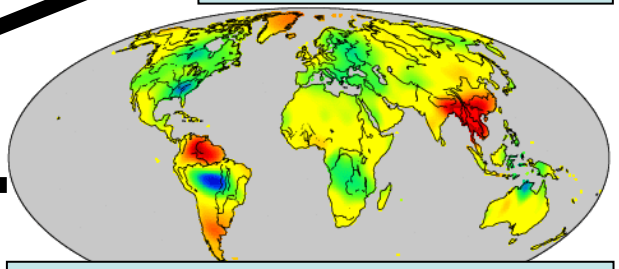
Precipitation
(TRMM, *GPM*)



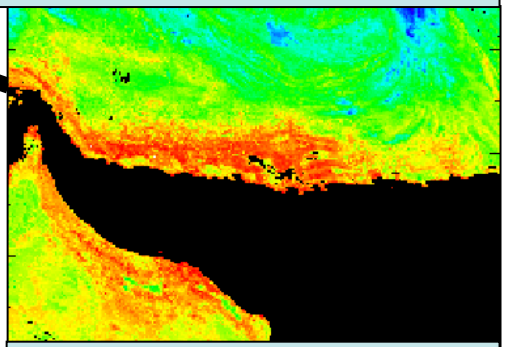
Radiation
(CERES, *CLARREO*)



Ensemble-based land data assimilation system



Terrestrial water storage (GRACE)



Land surface temperature
(MODIS, AVHRR,GOES,…)

Land surface data for research and applications:
Comprehensive view of land surface water/energy/carbon cycle.
Learn about processes, characterize errors, improve models.
Enhance weather and climate forecast skill.
Develop improved flood prediction and drought monitoring capability.
…

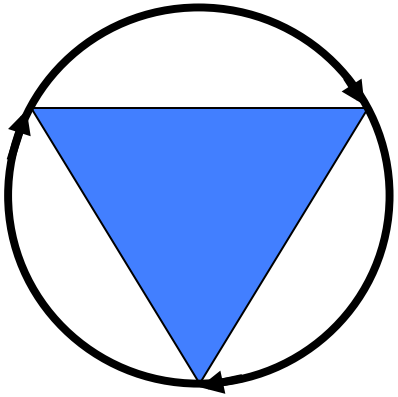
Land data assimilation at NASA/GSFC

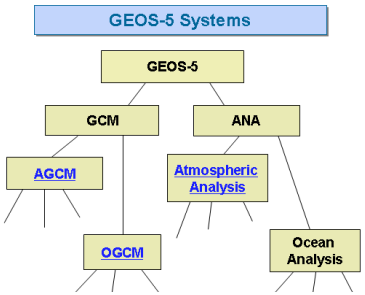
Land Information System (LIS)
Lead: Christa Peters-Lidard (614.3)

- **Award-winning, modular, high-performance software**
- Multiple land surface models
- GEOS-5 land assimilation modules
- Used and co-developed by NOAA/NCEP, AFWA, JCSDA, and many others

Global Land Data Assimilation System (GLDAS)
Lead: Matt Rodell (614.3)

- **Project for land assimilation research and applications**
- Data archive at GES-DISC
- Uses LIS software
- Contributes to GEOS-5 seasonal forecast initialization

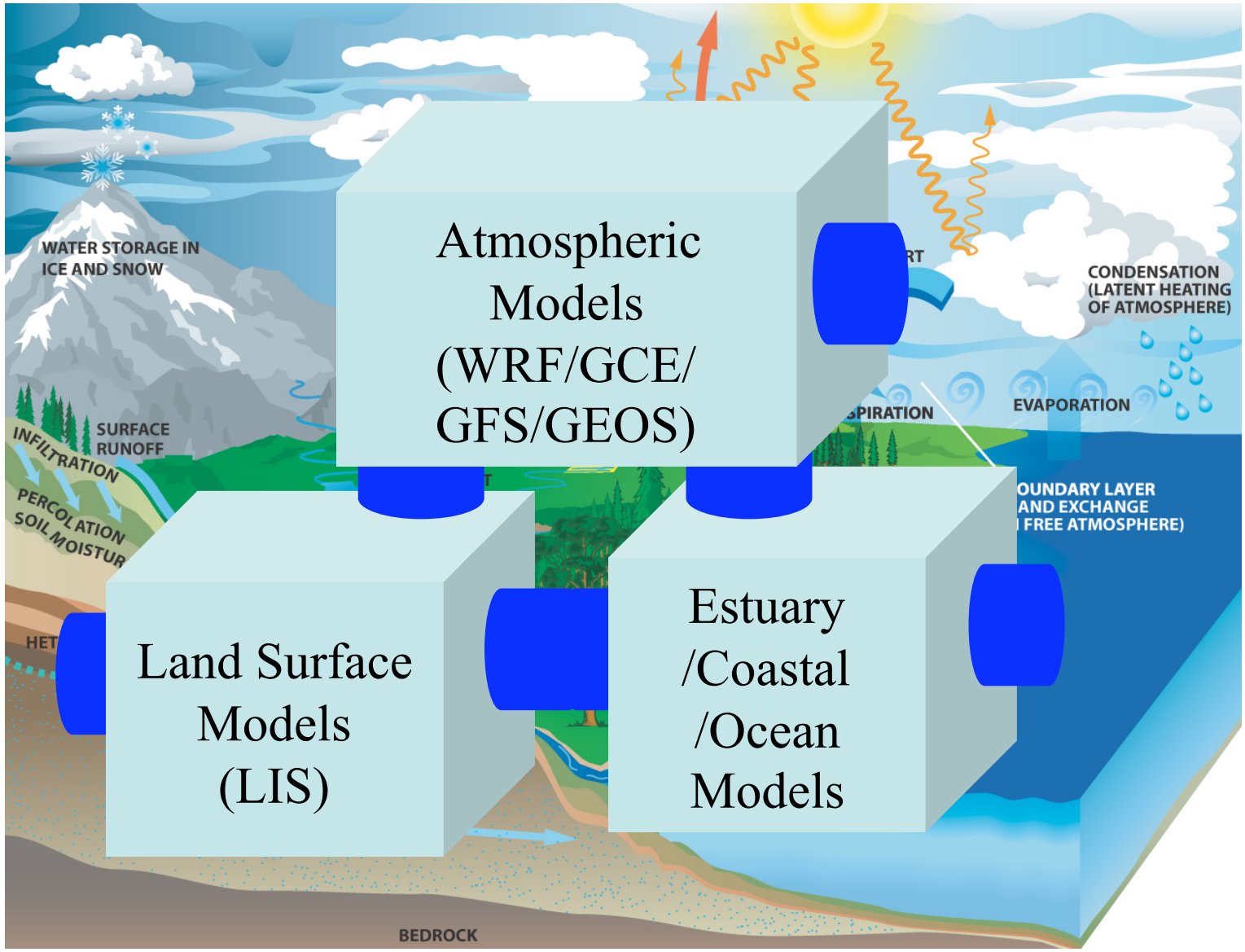




GEOS-5 ($ by NASA Modeling, Analysis & Prediction Program)
Lead (for land assimilation): Rolf Reichle (610.1)

- Comprehensive atmos./ocean/land modeling & assimilation system
- Quasi-operational weather and seasonal forecasts
- MERRA reanalysis
- Development of **ensemble-based land assimilation**

LIS Vision: Land Component for Earth System Models



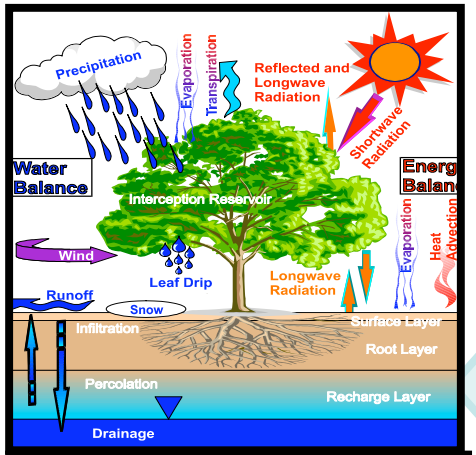
LIS Supports Uncoupled or Coupled LDAS

Uncoupled or Analysis Mode

Station Data

Global, Regional Forecasts and (Re-)Analyses

Satellite Products

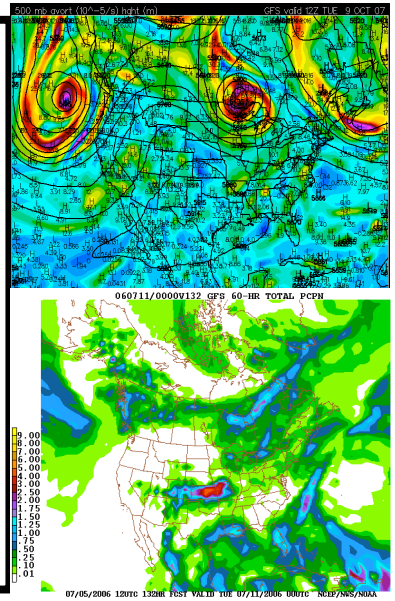


Land Sfc Models (Noah, Catchment, CLM, TESSEL, SSiB)

ESMF

Coupled or Forecast Mode

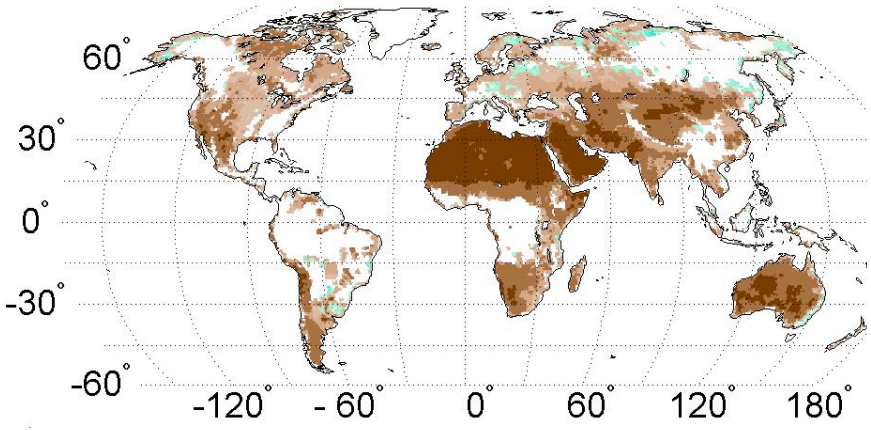
WRF/ GFS/ GCE

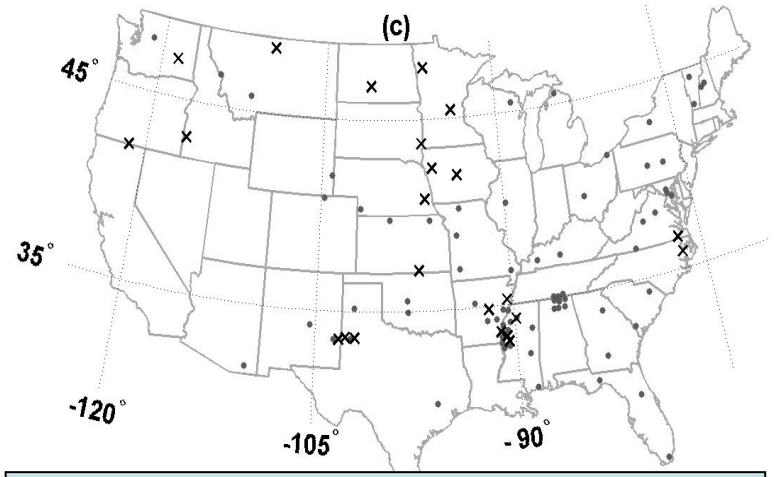


LSM Initial Conditions

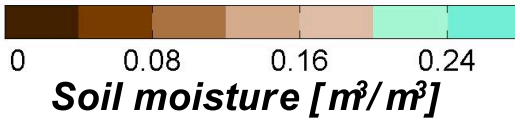
Kumar, S. V., C. D. Peters-Lidard, J. L. Eastman and W.-K. Tao, 2008. An integrated high-resolution hydrometeorological modeling testbed using LIS and WRF. *Environmental Modelling & Software,* Vol. **23**, 169-181.

Soil moisture assimilation





Assimilate AMSR-E surface soil moisture (2002-06) into NASA Catchment model



Validate with USDA SCAN stations (only 23 of 103 suitable for validation)

Skill
(anomaly time series correlation coeff. with in situ data with 95% confidence interval)

	N	Satellite	Model	Assim.
Surface soil moisture	23	**.38±.02**	**.43±.02**	**.50±.02**
Root zone soil moisture	22	**n/a**	**.40±.02**	**.46±.02**

- **Assimilation product agrees better with ground data than satellite or model alone.**
- Modest increase may be close to maximum possible with *imperfect* in situ data.
- Use data assimilation for generation of SMAP "Level 4" product.

Reichle et al. (2007) *J Geophys Res*, doi:10.1029/2006JD008033.

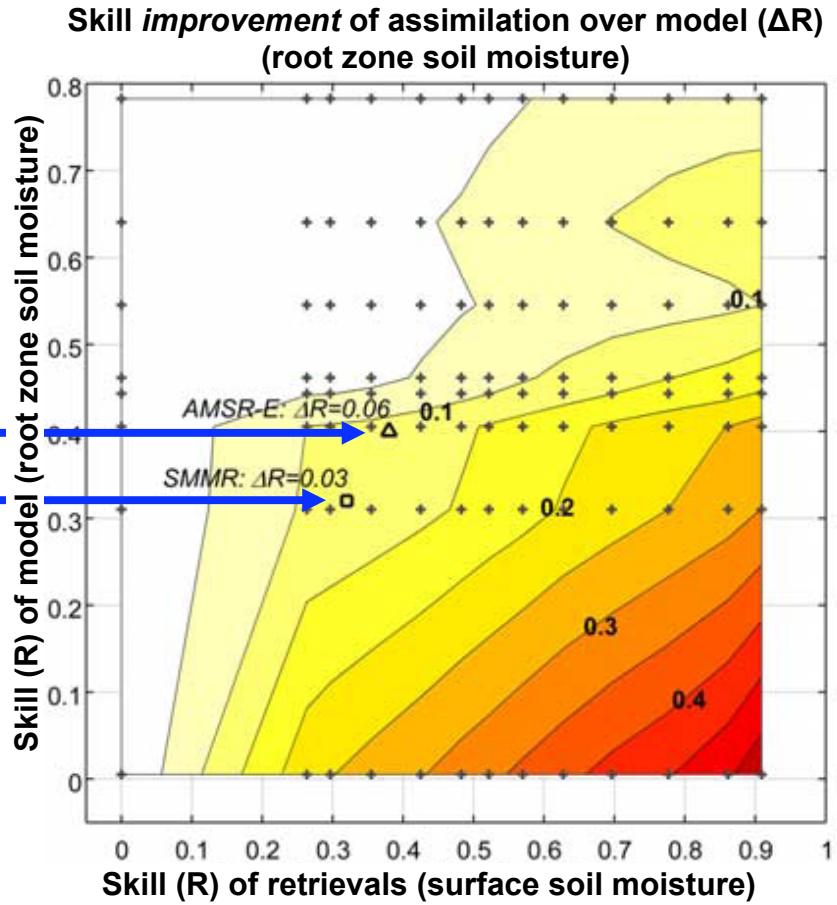
Soil-Moisture-Active-Passive (SMAP) mission design

Q: How uncertain can retrievals be and still add useful information in the assimilation system?
A: Synthetic data assimilation experiments.

Skill measured in terms of R (=anomaly time series correlation coefficient against synthetic truth).

Each plus sign indicates result of one 19-year assimilation integration over Red-Arkansas domain.

AMSR-E (Δ): *ΔR=0.06*
SMMR (□): *ΔR=0.03*



Results
- Assimilation of (even poor) soil moisture retrievals adds skill (relative to model product).
- Published AMSR-E and SMMR assimilation products consistent with expected skill levels.

Reichle et al. (2008) *Geophys Res Lett*, doi:10.1029/2007GL031986.

Multi-model soil moisture assimilation

Goddard Space Flight Center
Land Information System

How does land model formulation impact assimilation estimates of root zone soil moisture?

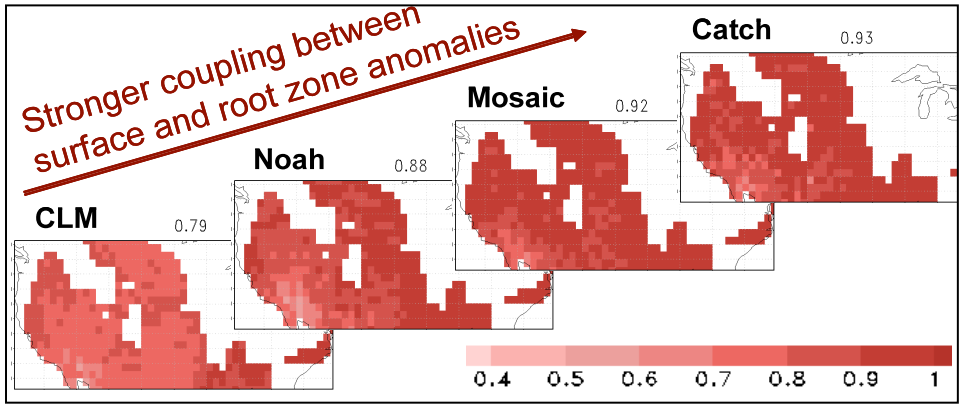
Normalized ROOT ZONE soil moisture improvement from assimilation of surface soil moisture

		Synthetic observations from				Avg
		Catch	Mos	Noa	CLM	
Model	Catch	0.71	0.54	0.36	0.38	**0.50**
	Mos	0.55	0.69	0.31	0.33	**0.47**
	Noa	0.43	0.43	0.36	0.26	**0.37**
	CLM	0.11	0.21	0.10	0.45	**0.22**
Avg		**0.45**	**0.47**	**0.28**	**0.36**	**0.39**

Catchment and Mosaic work better for assimilation than Noah or CLM.

Catchment or MOSAIC "truth" easier to estimate than Noah or CLM "truth".

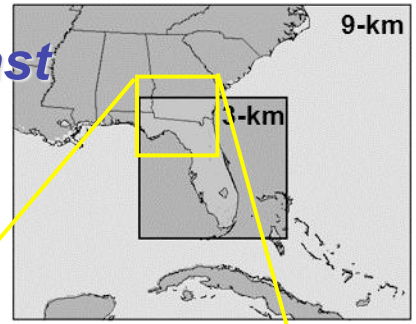
Stronger coupling between surface and root zone provides more "efficient" assimilation of surface observations.



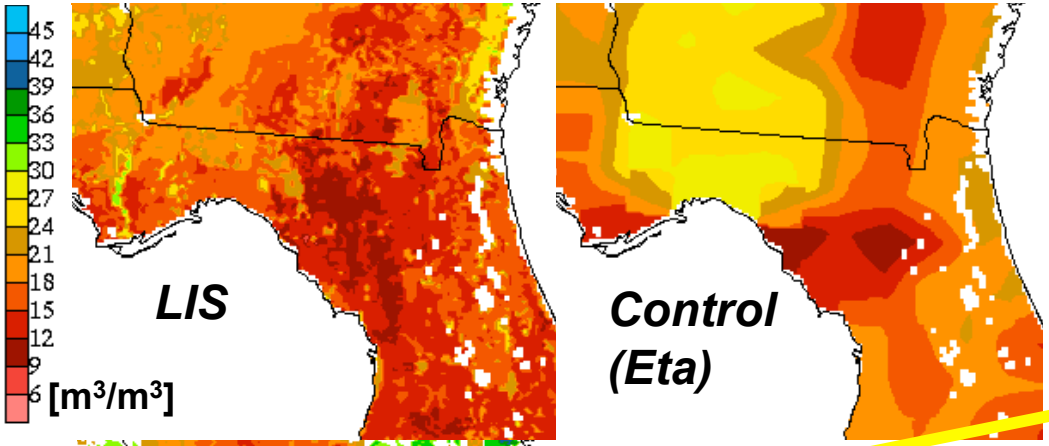
Kumar et al. (2008) *Water Resourc. Res.*, in preparation.

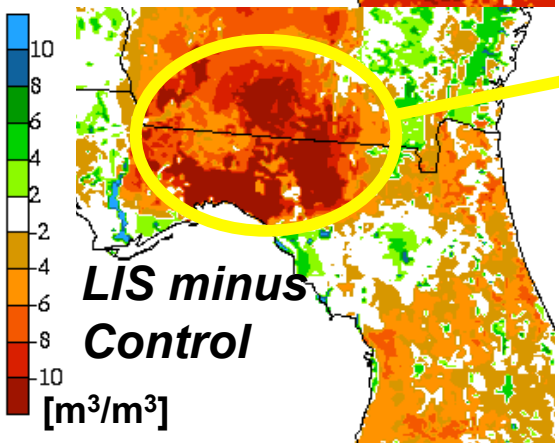
Impact of soil moisture on LIS/WRF sea-breeze forecast

MSFC/GSFC collaboration:
Impact of land initial condition on short-term weather forecast



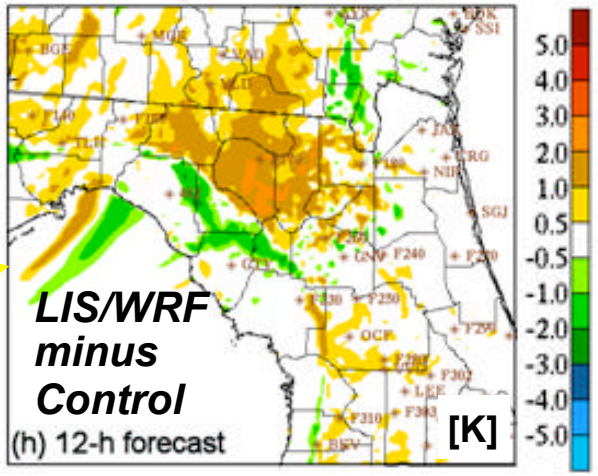
0-10cm soil moisture initial condition (6 May 2004 12z)





12-h forecast

12-hour forecast: 2m air temp. difference (valid 7 May 2004 0z)

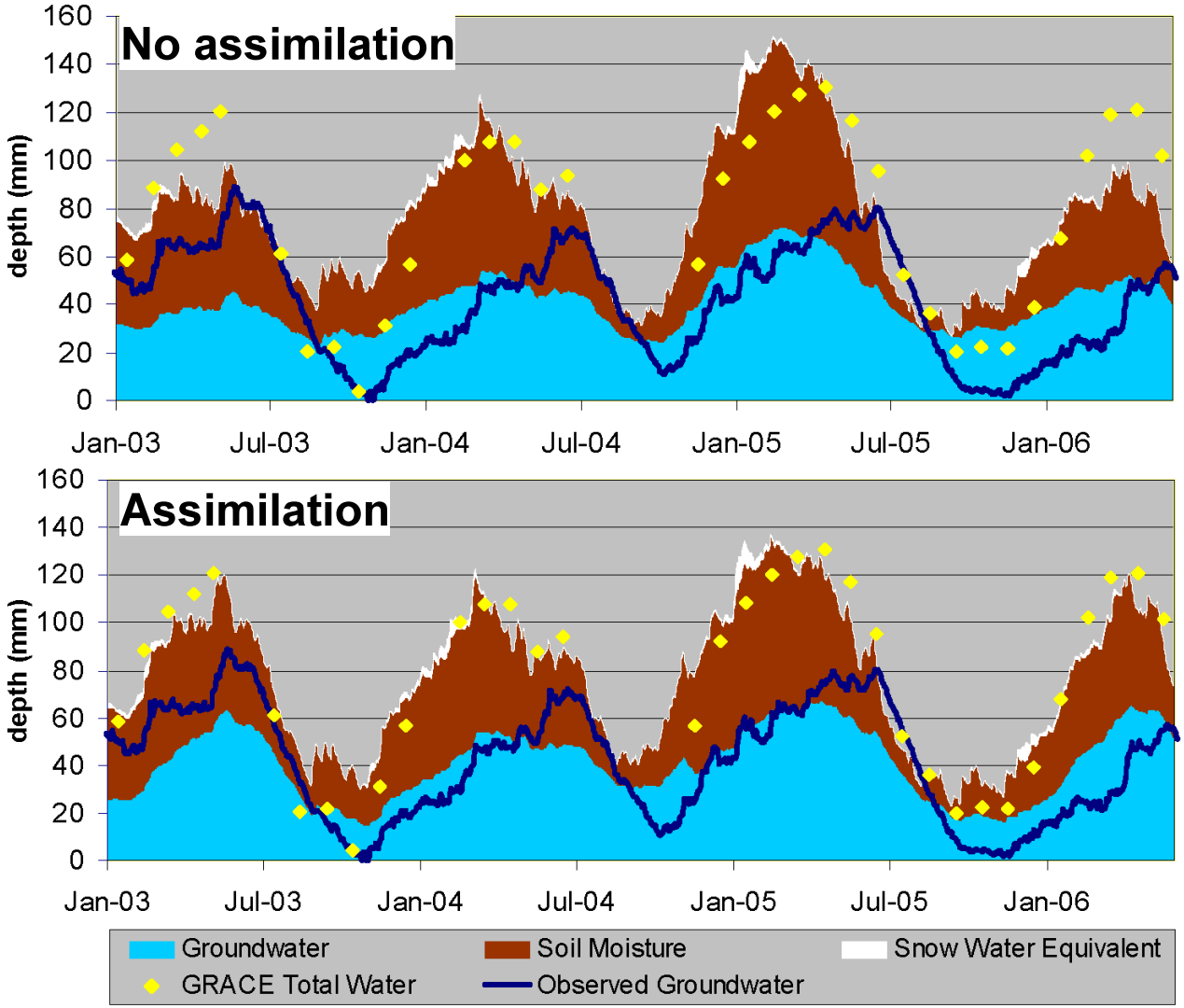


- More detail in LIS initial condition (as expected)
- LIS/WRF drier over Northern FL & Southern GA
- Difference in 12-h forecast of 2m air temp. (sea breeze)
- LIS/WRF better than control (independent validation)

Goddard Space Flight Center
Land Information System

Case et al. (2008) *J. Hydrometeorol.*, doi: 10.1175/2008JHM990.1, in press.

Assimilation of GRACE terrestrial water storage (TWS)



Validation against observed groundwater:

RMSE = 23.5 mm

R^2 = 0.35

RMSE = 18.5 mm

R^2 = 0.49

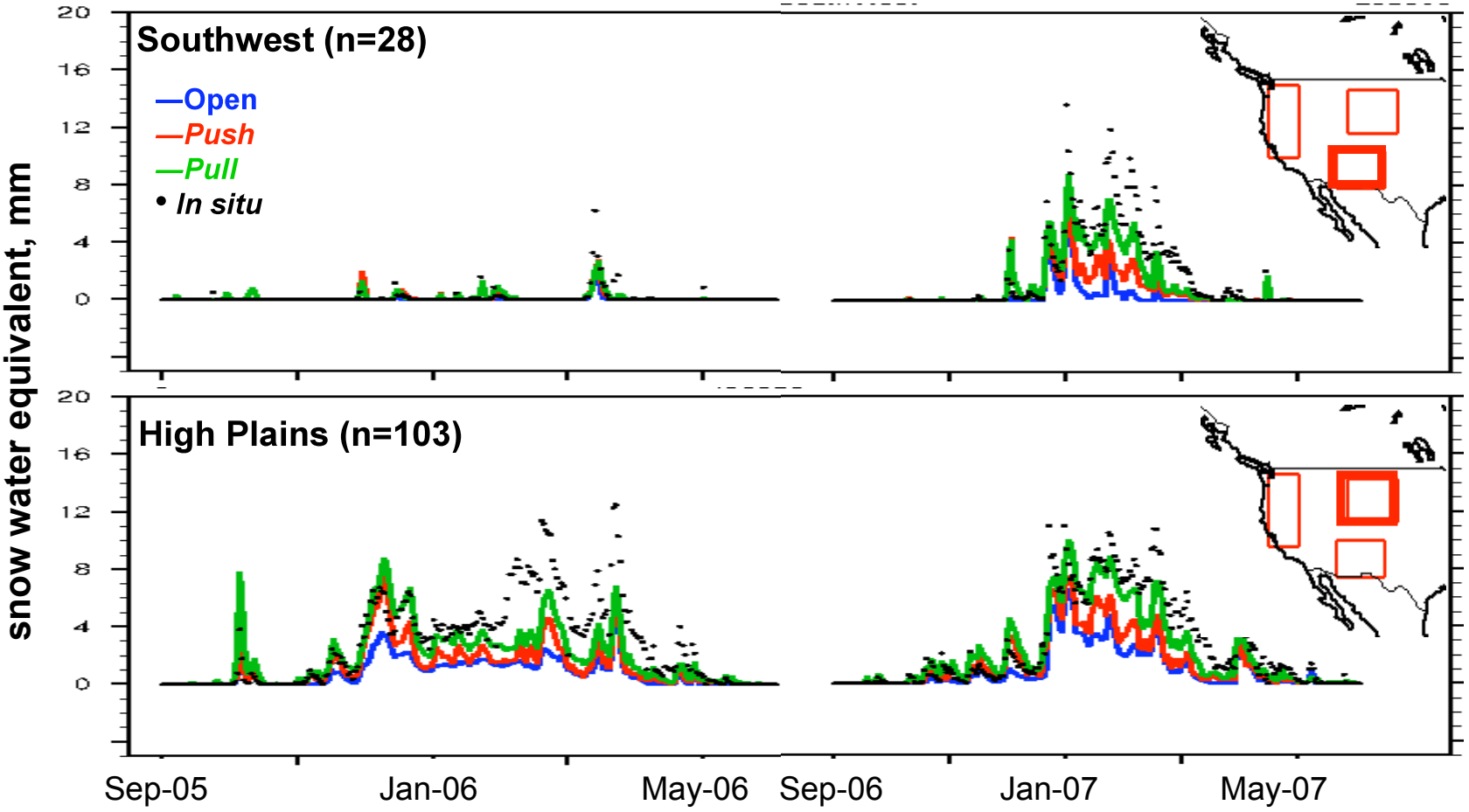
Assimilation disaggregates GRACE data into snow, soil moisture, and groundwater.

Assimilation estimates of groundwater better than model estimates.

Zaitchik, Rodell, and Reichle (2008) *J. Hydrometeorol.*, doi:10.1175/2007JHM951.1

Advanced rule-based MODIS snow cover assimilation

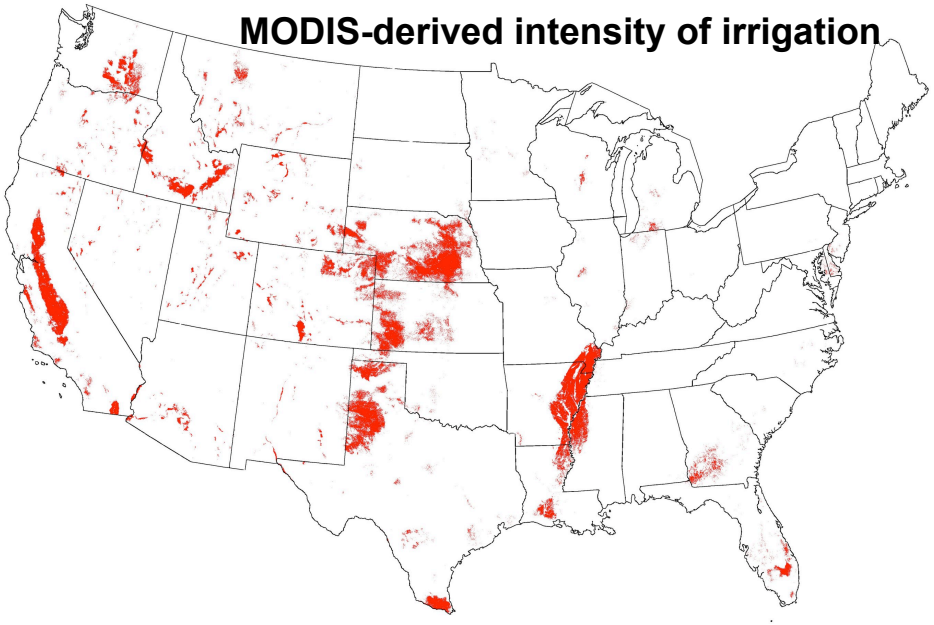
Forward-looking “pull” algorithm (smoother):
- Assess MODIS snow cover 24-72 hours ahead
- Adjust air temperature (rain v. snowfall, snow melting v. frozen)



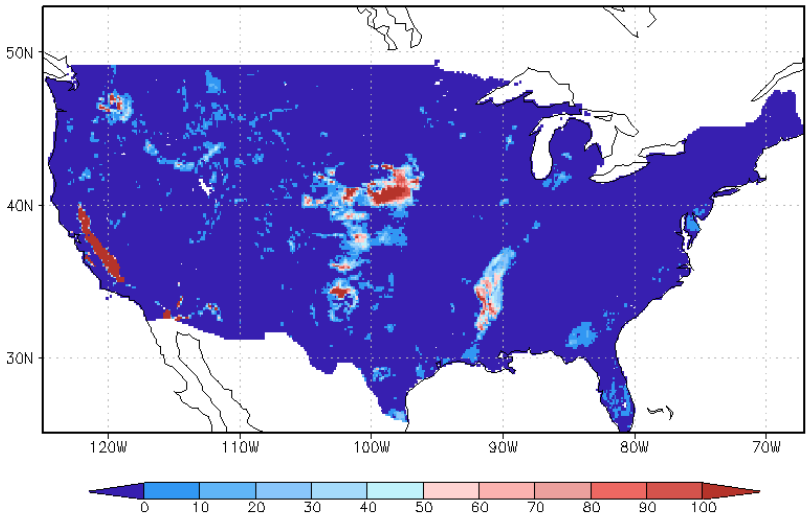
Zaitchik and Rodell, J. Hydromet., doi:10.1175/2008JHM1042.1, in press.

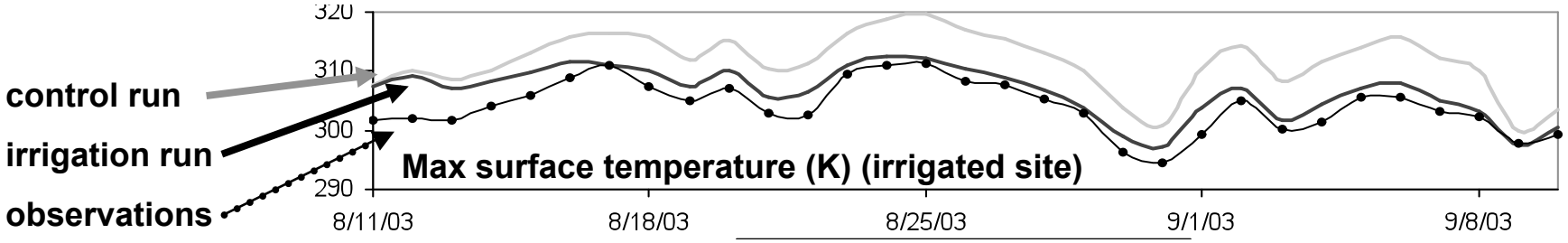
Simulating irrigation based on MODIS observations

MODIS-derived intensity of irrigation



Difference (%) in evapotranspiration between irrigation and control runs, Aug-Sep 2003





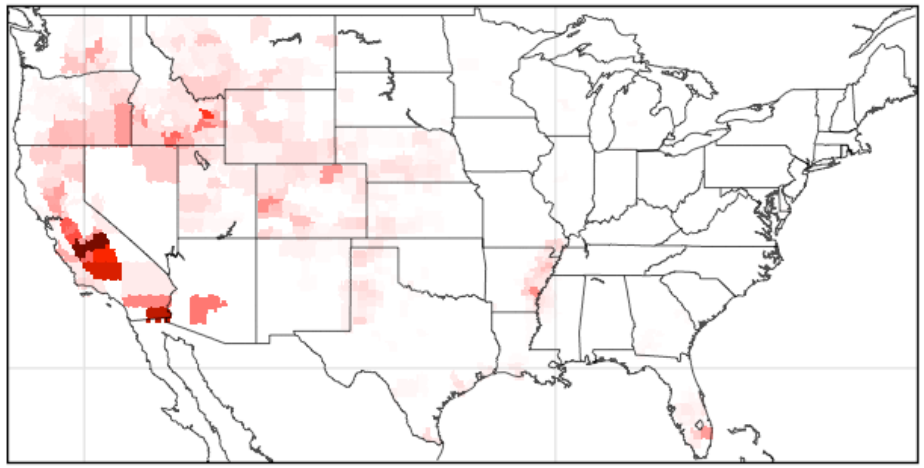
Innovative algorithm models irrigation based on MODIS data, crop type, time of year, soil dryness, and common irrigation practices → improved model fluxes.

Ozdogan and Gutman (2008) *Remote Sens Environ*
Ozdogan, Rodell, and Kato (2008) *J Hydrometeorol,* in preparation

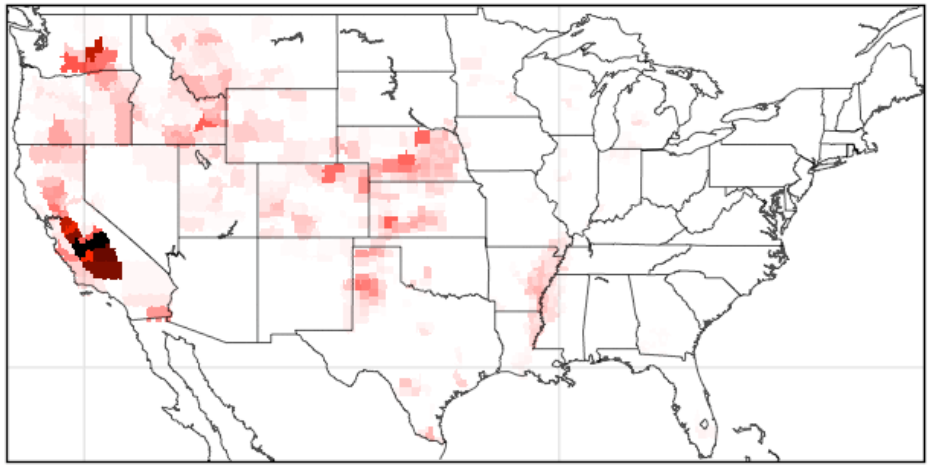
Simulating irrigation based on MODIS observations

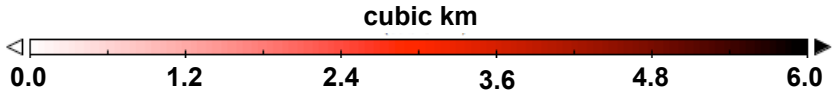
2003 county irrigation totals

Reported by USGS



Modeled in this study

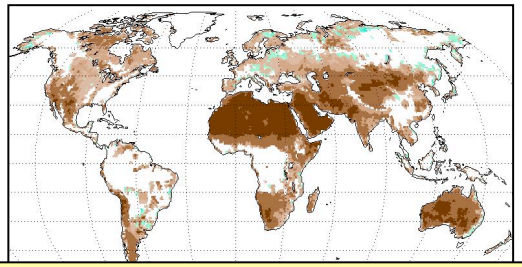


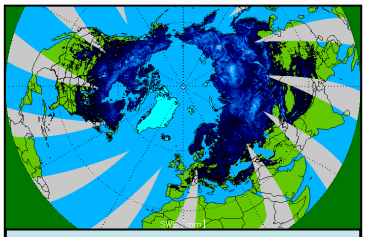


Ozdogan, Rodell, and Kato (2008), *J Hydrometeorol,* in preparation

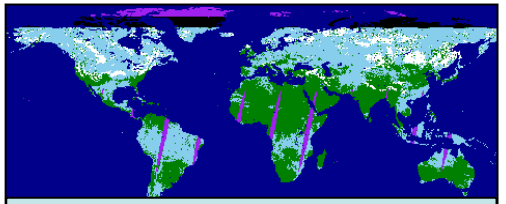
Land data assimilation

Vegetation/Carbon
(AVHRR, MODIS, *DESDynI, ICESat-II, Hys… ASCEN…*

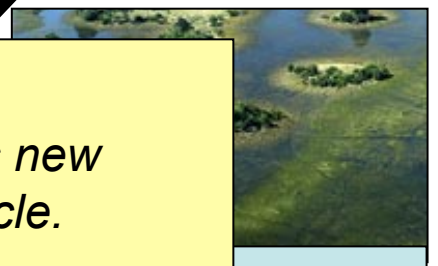




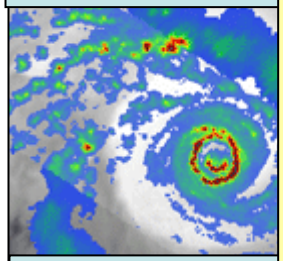
Snow water…



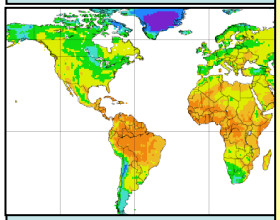
Snow cover fraction
(MODIS, *VIIRS, MIS*)



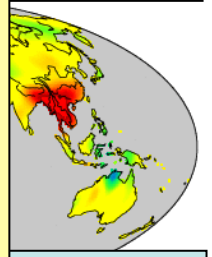
…e elevation
…*OT*)



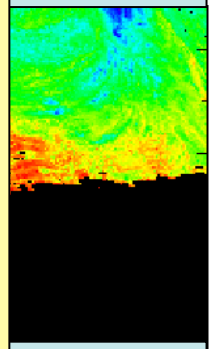
Precipitati…
(TRMM, *GI…*



Radiatio…
(CERES, *CLA…*



…e (GRACE)



…mperature
(MODIS, AVHRR,GOES,…)

Land surface …
Investigate land…
Learn about pr…
Enhance weath…
Develop improv…
…

SUMMARY

- *Abundance of land surface satellite observations offers new perspectives on the global water, energy, and carbon cycle.*
- *Assimilation products better than model or satellite data.*
- *Obs. can be extrapolated and downscaled (space & time).*
- *Key applications: forecast initialization, monitoring of current conditions (e.g. drought), process understanding, ...*

PLANS

- *Prepare for new NASA sensors that offer high-res. precipitation, soil moisture, snow, water surface elevation, …*
- *Assimilation system contributes to mission design & products.*
- *As land surface models evolve, model parameters will become model states (e.g. dynamic vegetation models – 614.4 & GISS).*
- *Multi-variate **"Integrated Earth System Analysis"** (atmosphere + ocean + land)*

References

•Case JL, Crosson WL, Kumar SV, Lapenta WM, Peters-Lidard CD (2008) Impacts of High-Resolution Land Surface Initialization on Regional Sensible Weather Forecasts from the WRF Model. *J Hydrometeorol*, doi:10.1175/2008JHM990.1, in press.

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