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Land Surface Analysis and Reanalysis at the NASA GMAO

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Outline

Introduction

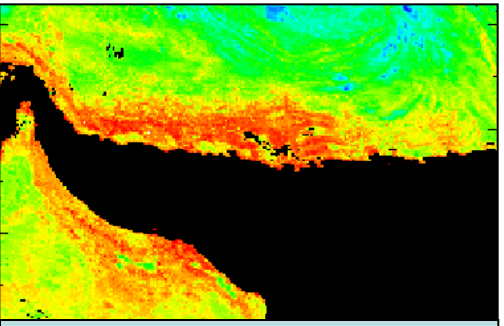
MERRA-Land

- Motivation and data product design
- Validation

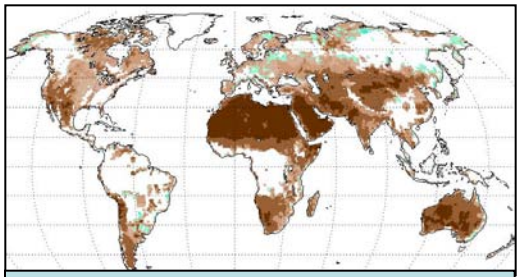
Developments in land surface analysis

- Soil moisture
- Snow

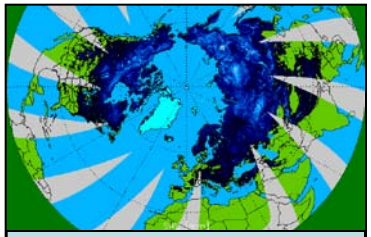
Satellite observations



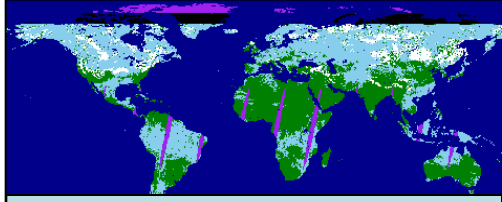
Land surface temperature
(MODIS, AVHRR,GOES,…)



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

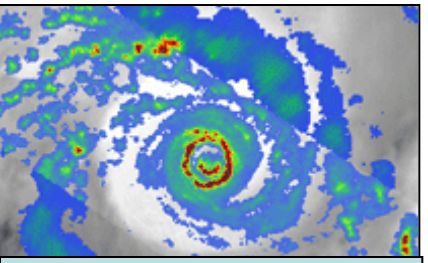


Snow water
equivalent
(AMSR-E, SSM/I,
SCLP)

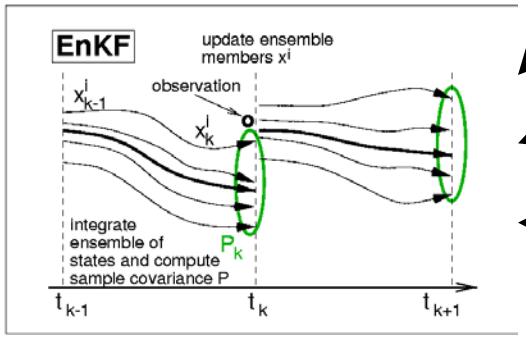


Snow cover fraction
(MODIS, VIIRS)

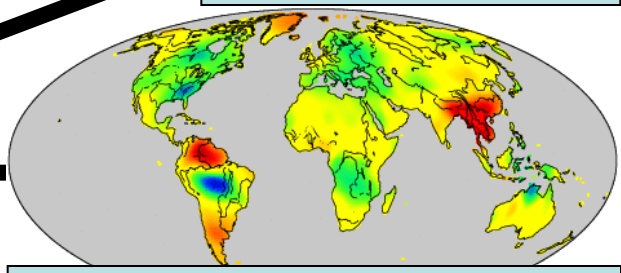
Water surface elevation
(*SWOT*)



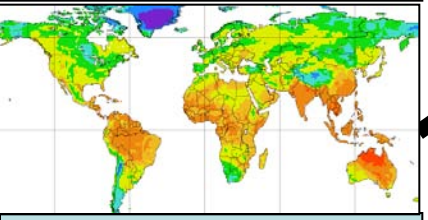
Precipitation
(TRMM, *GPM*)



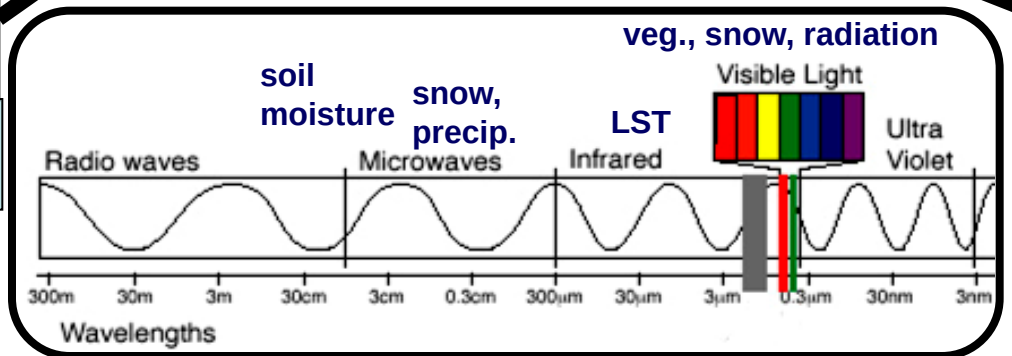
Land data assimilation system



Terrestrial water storage (GRACE)

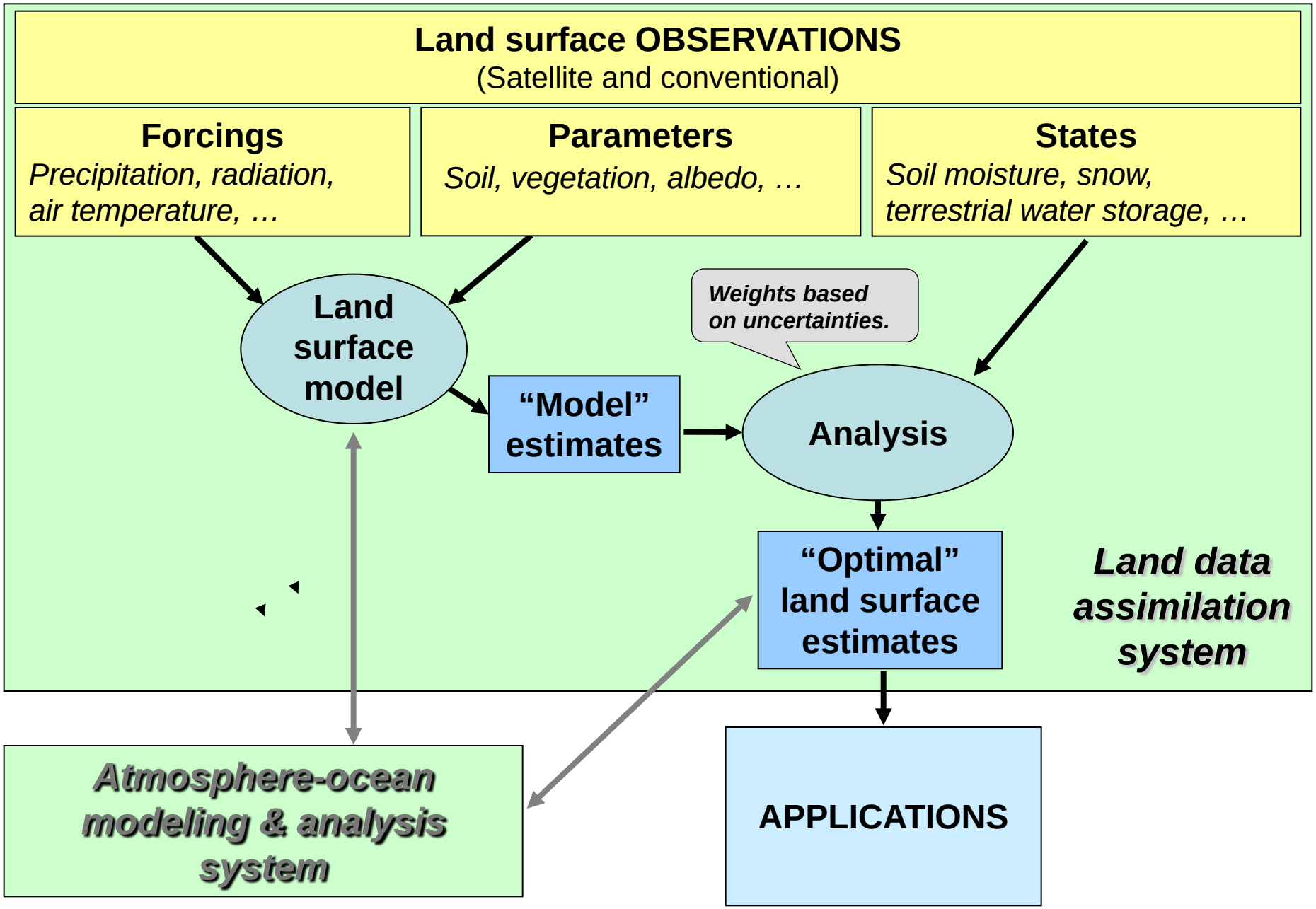


Radiation
(CERES, *CLARREO*)

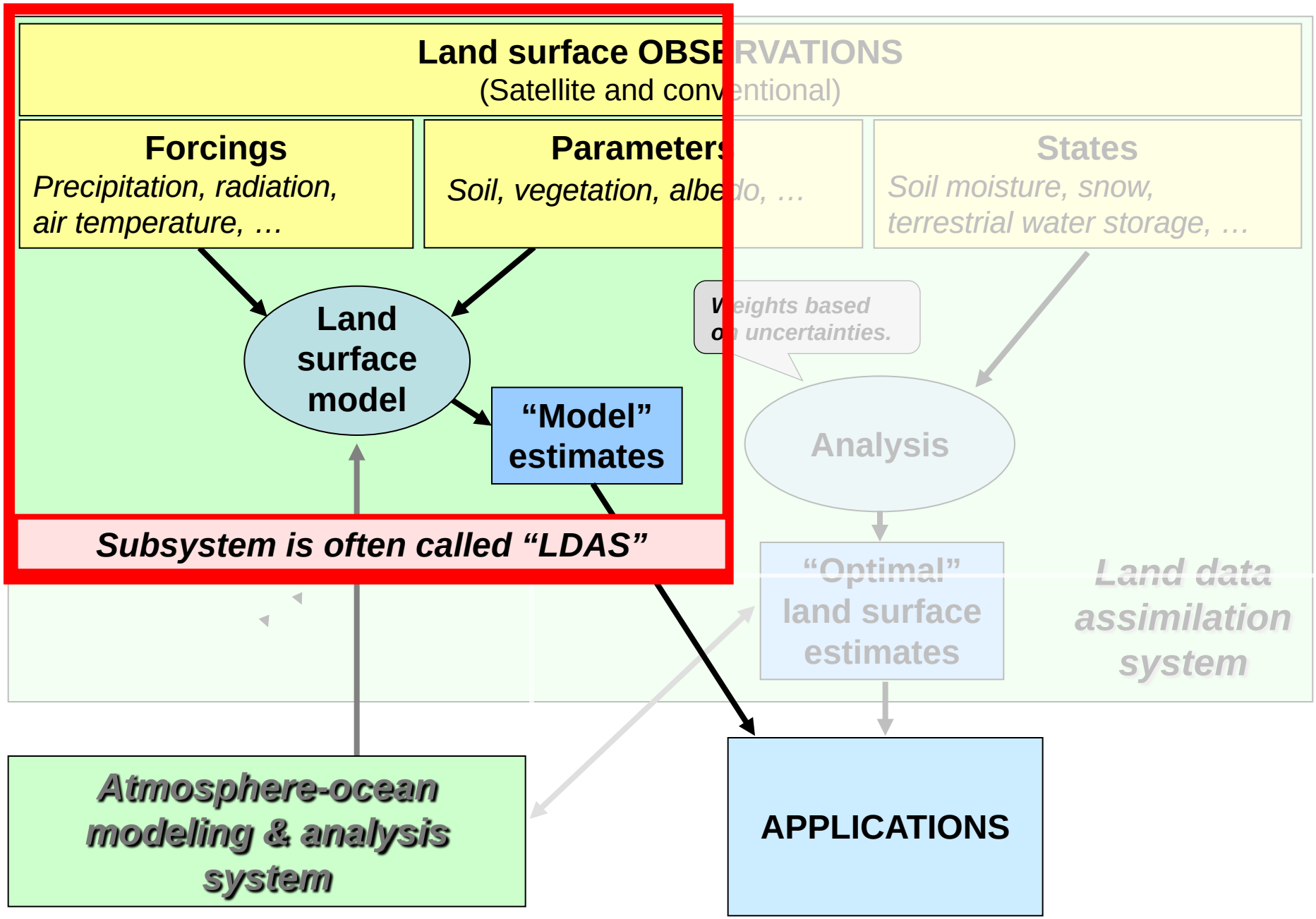


Vegetation/Carbon
(AVHRR, MODIS, *DESDynI, ICESat-II, HyspIRI, LIST, ASCENDS*)

A generic land data assimilation system



A generic land data assimilation system



A generic land data assimilation system

Land surface OBSE
(Satellite and conv

Forcings
Precipitation, radiation, air temperature, …

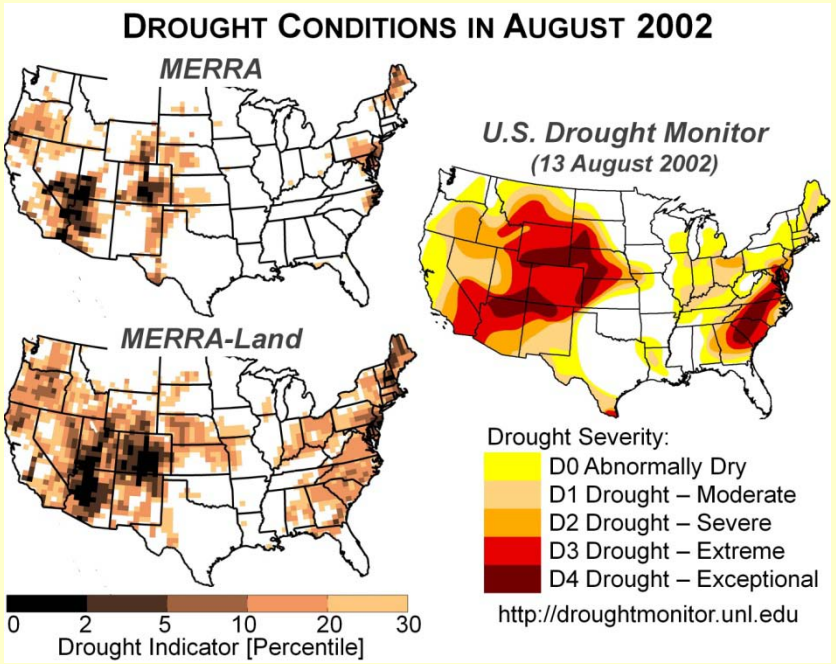
Parameters
Soil, vegetation, albe

Land surface model

"Model" estimates

Subsystem is often called "LDAS"

Example:
The MERRA-Land data product

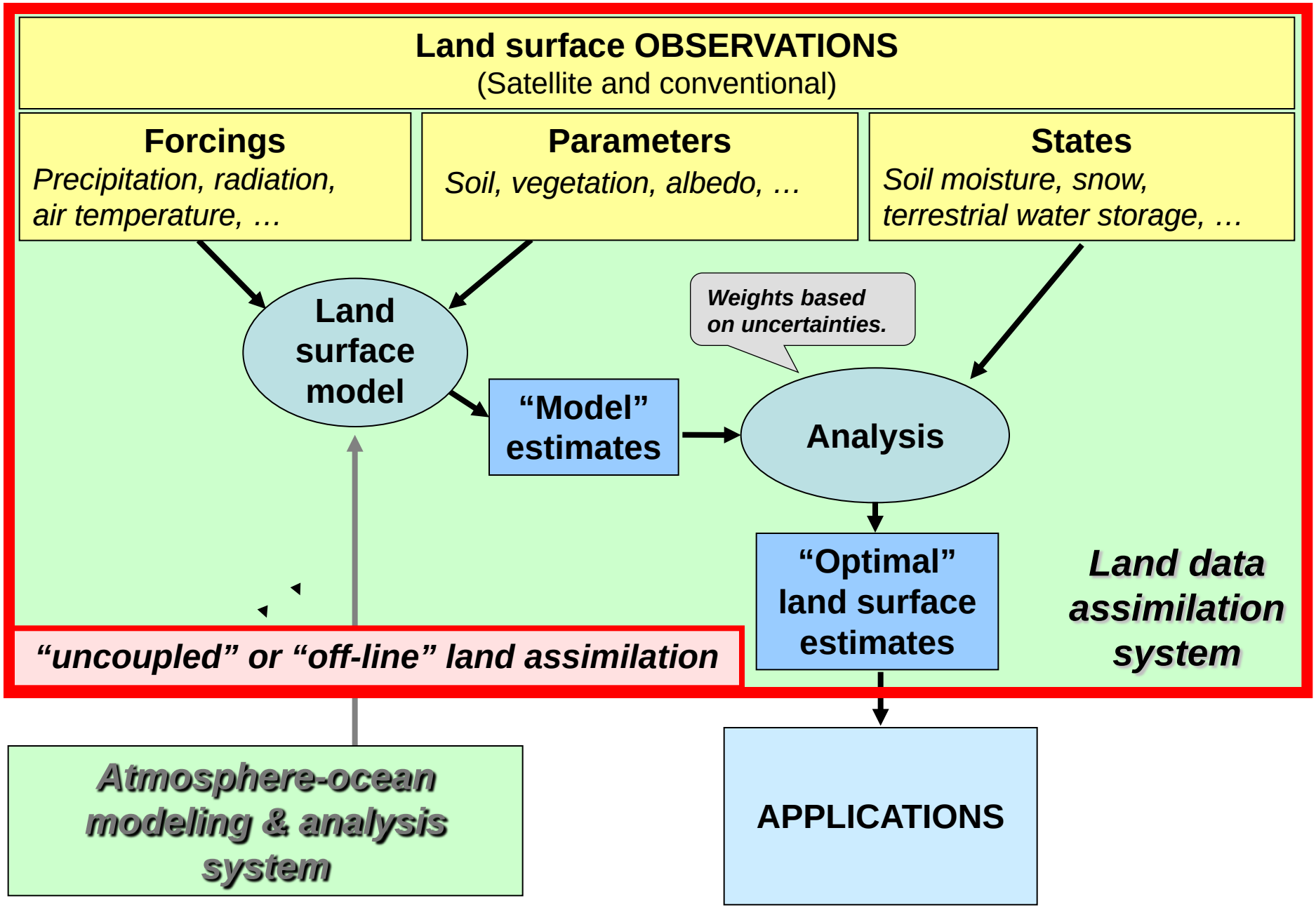


http://gmao.gsfc.nasa.gov/research/merra/merra-land.php

Atmosphere-ocean modeling & analysis system

APPLICATIONS

A generic land data assimilation system



A generic land data assimilation system

Land surface OBSERVATIONS
(Satellite and conventional)

Forcings
Precipitation, radiation, air temperature, …

Parameters
Soil, vegetation, albedo, …

States
Soil moisture, snow, terrestrial water storage, …

Land surface model

Weights based on uncertainties.

"Model" estimates

Analysis

Example: The SMAP Level 4 Surface and Root Zone Soil Moisture (L4_SM) Product

"Optimal" land surface estimates

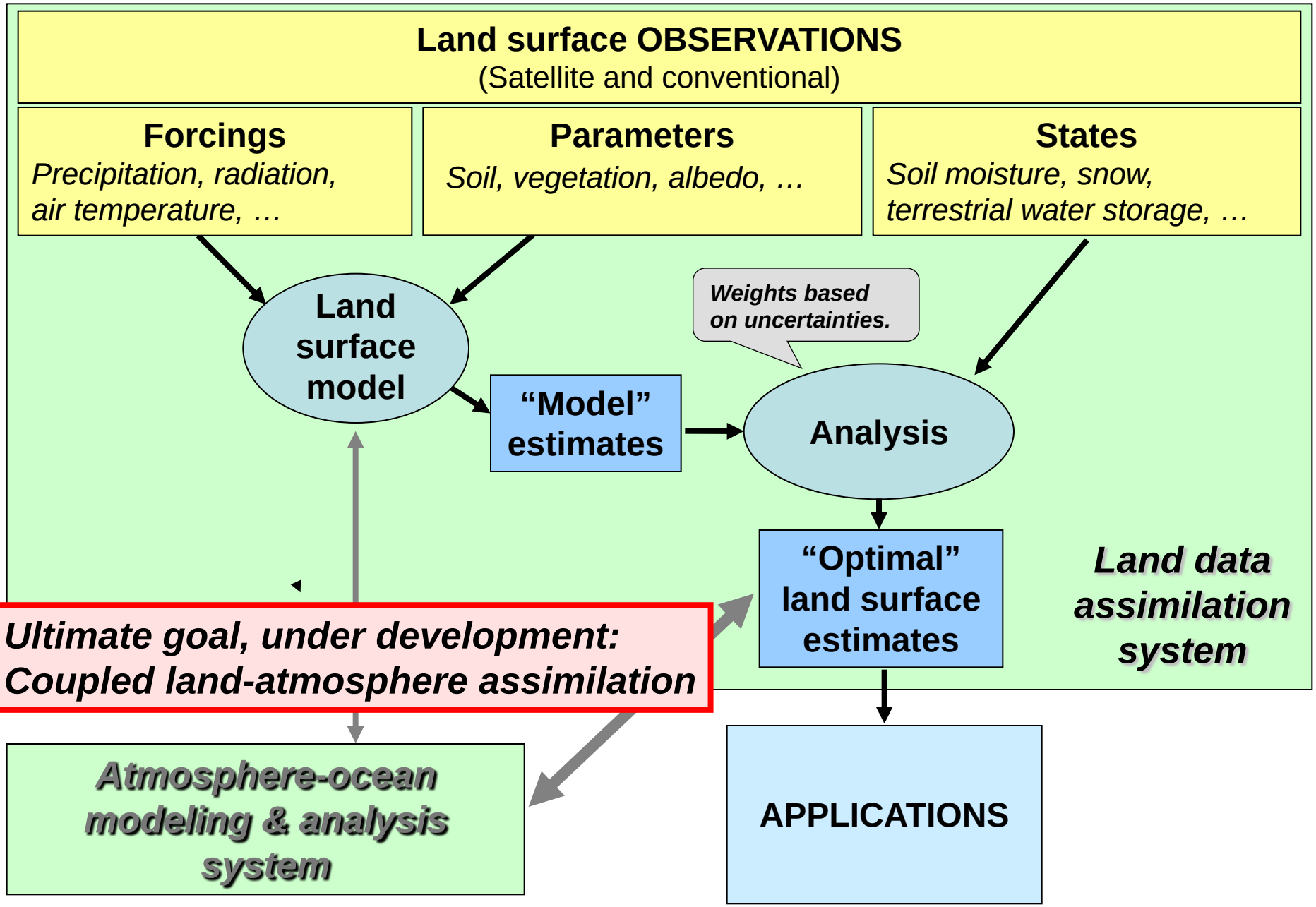
Land data assimilation system

"uncoupled" or "off-line" land assimilation

Atmosphere-ocean modeling & analysis system

APPLICATIONS

A generic land data assimilation system



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MERRA-Land

- Motivation and data product design
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Developments in land surface analysis

- Soil moisture
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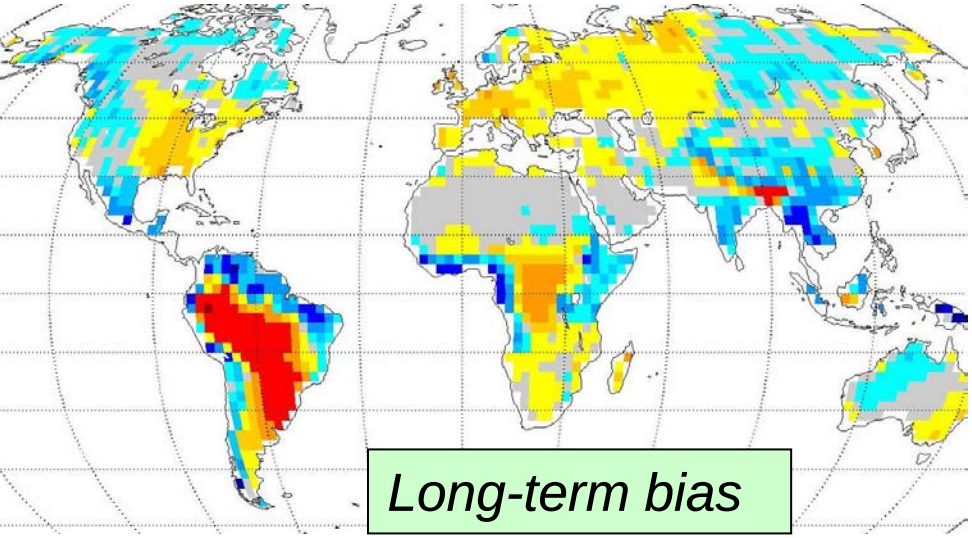
Motivation for MERRA-Land: Precipitation

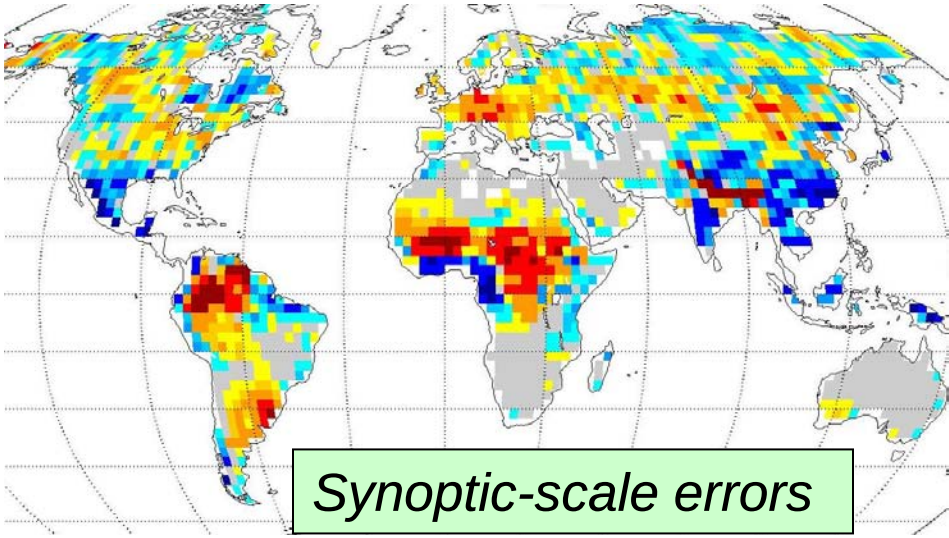
MERRA – GPCPv2.1

1981-2008 *[mean=-0.03 mm/d]*

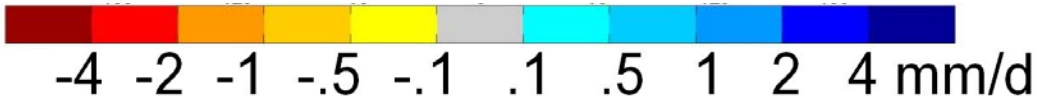


Long-term bias

Aug 1994 *[mean=-0.04 mm/d]*



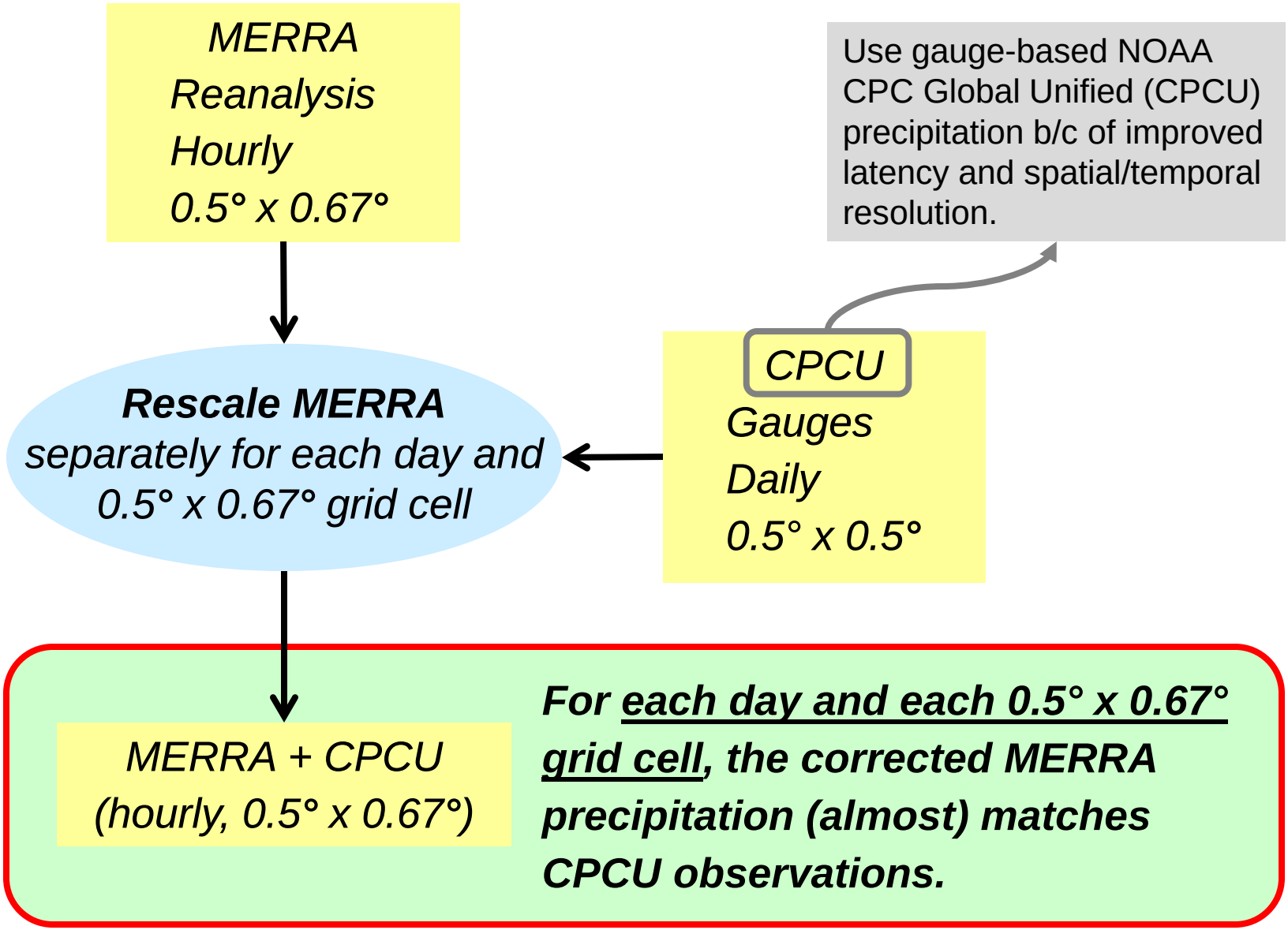
Synoptic-scale errors



→ *Correct MERRA precipitation with gauge-based precipitation observations to the extent possible.*

Reichle et al. J Clim (2011)
doi:10.1175/JCLI-D-10-05033.1

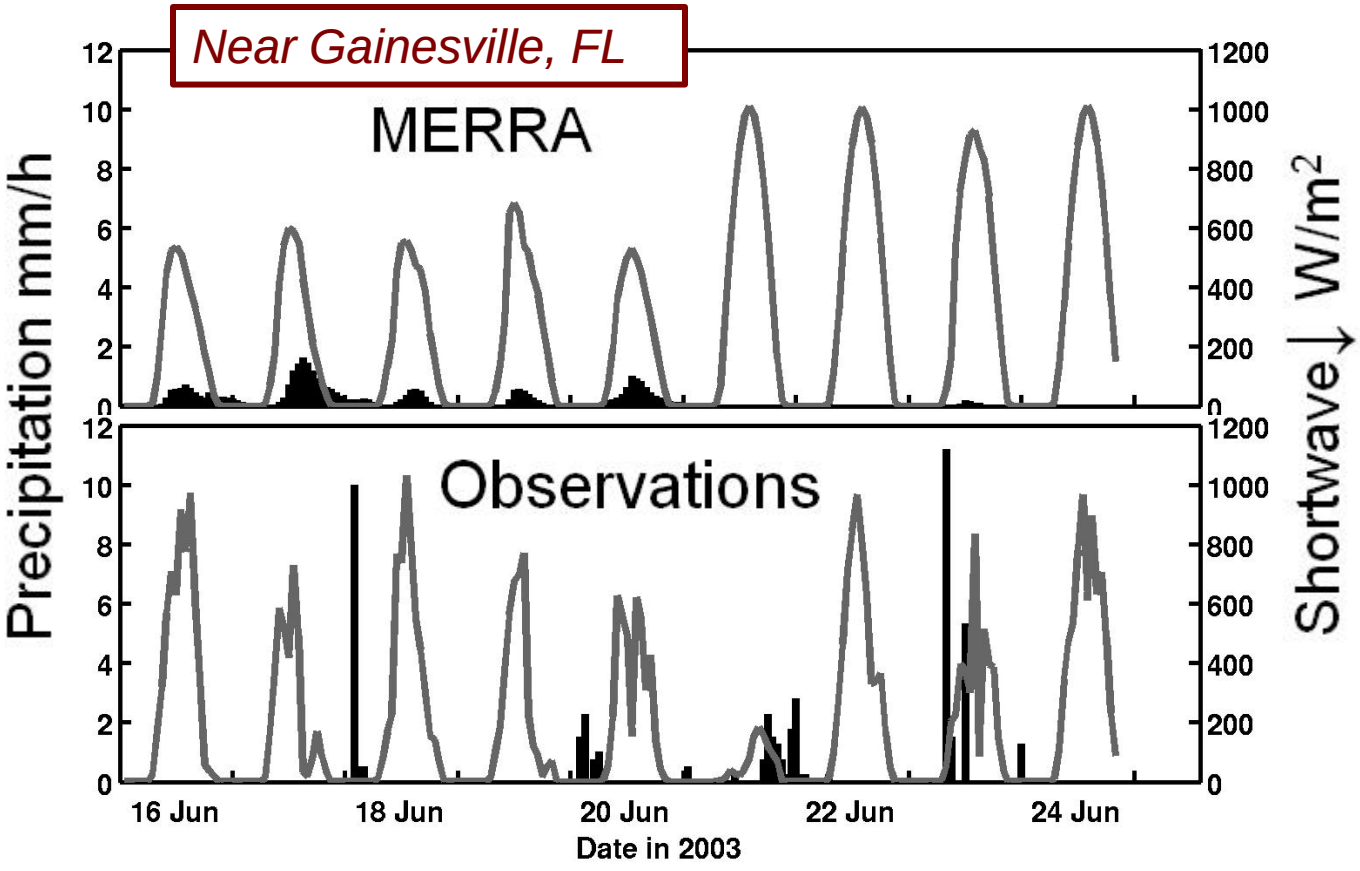
MERRA-Land precipitation corrections



MERRA precipitation and radiation forcing

MERRA precip. has short-term errors in

1. *intensity,*
2. *timing, and*
3. *consistency with SW radiation forcing.*

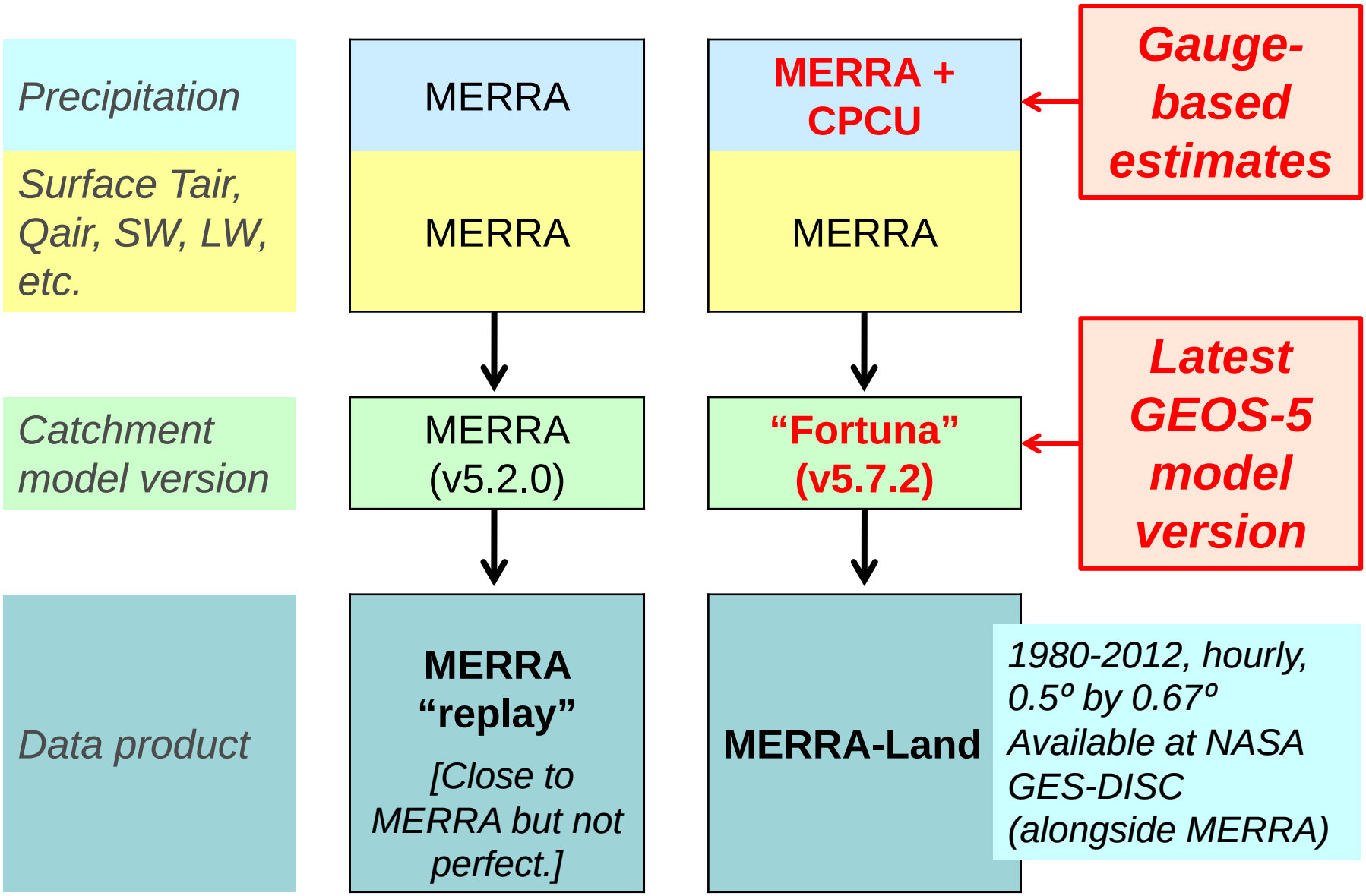


Too much canopy evaporation

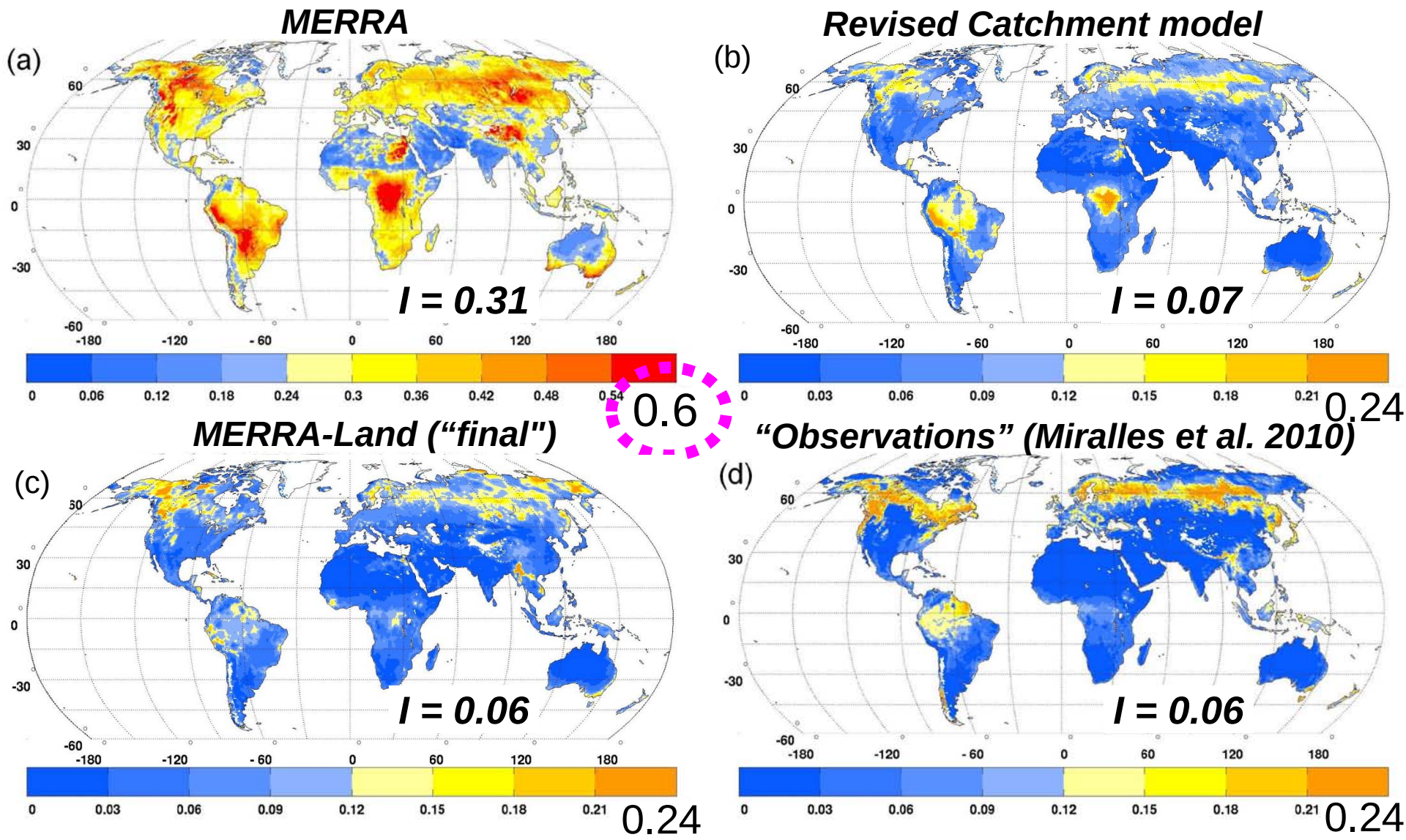
→ not enough water reaches the soil!

Additional fix:
Change Catchment model interception parameters.

Land-only ("off-line") replay



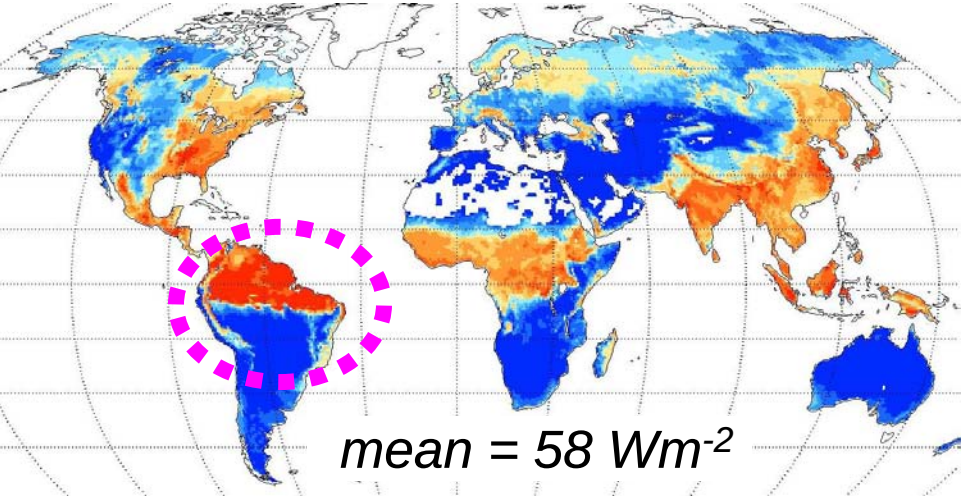
Interception loss frac. = canopy evap. / rainfall (2003-2007)



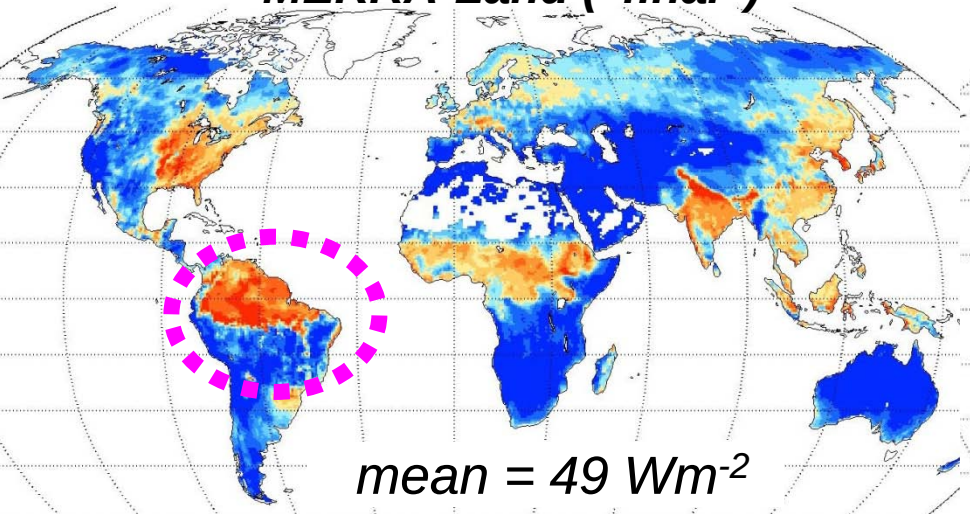
Improvement everywhere from revised interception parameters (b).
Additional improvement from precipitation corrections (c).

Latent heat flux (August 1994)

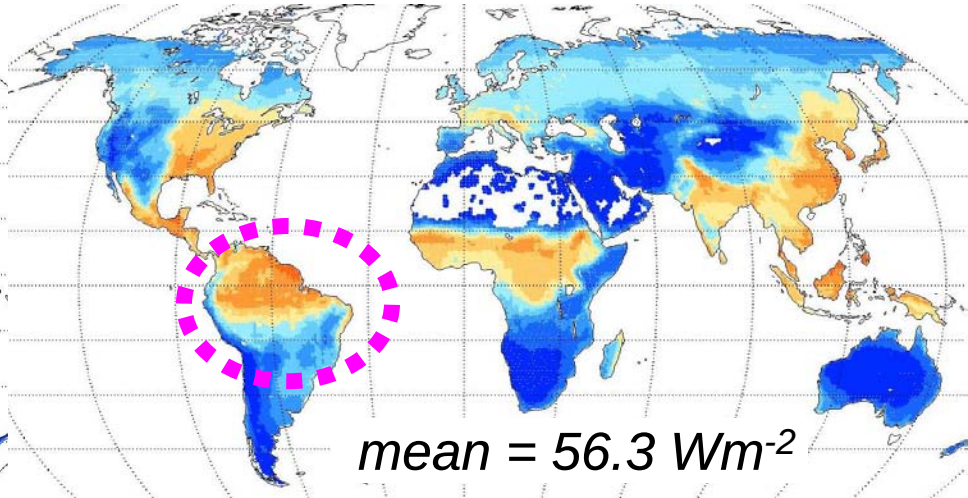
MERRA



MERRA-Land ("final")

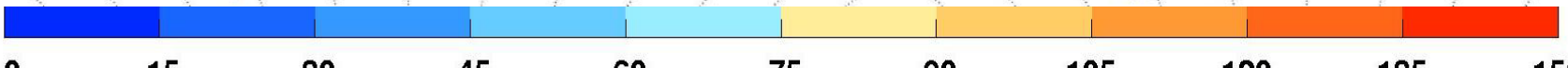


Multi-product average (Jimenez et al. 2011)



MERRA-Land has more realistic LH over Amazon during dry season.

Attributed to revised interception parameters and precipitation corrections.



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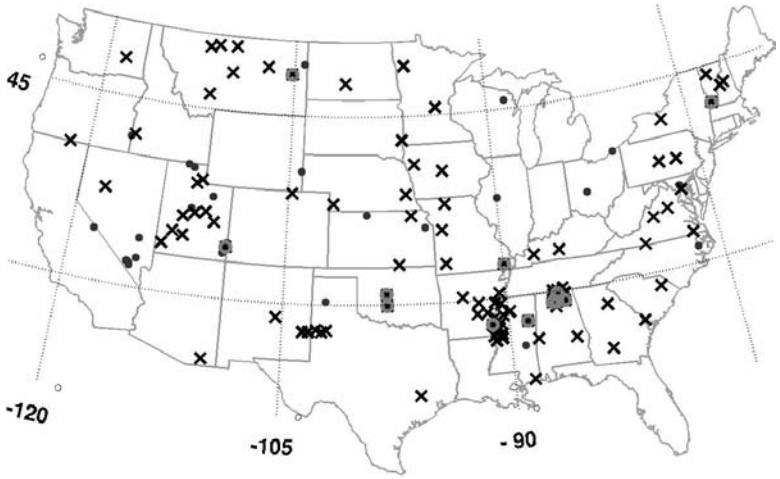
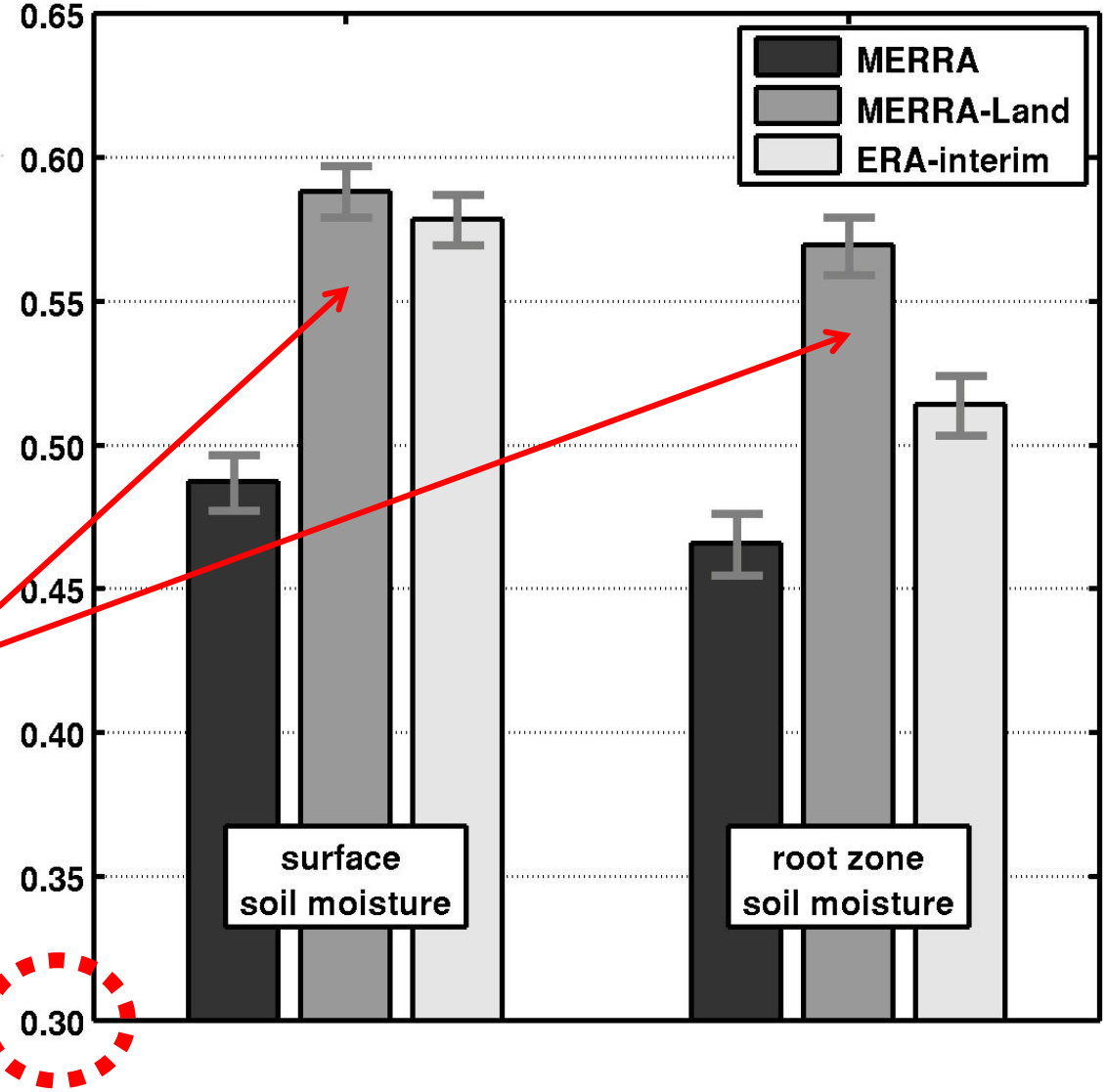
Soil moisture validation (2002-2009)



MERRA-Land has better soil moisture anomalies than MERRA (attributed to precipitation corrections).

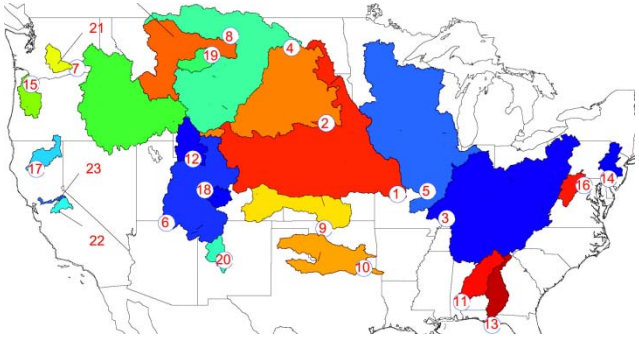
MERRA-Land root zone skill better than ERA-Interim.

***Skill** (pentad anomaly R)*
v. SCAN in situ observations

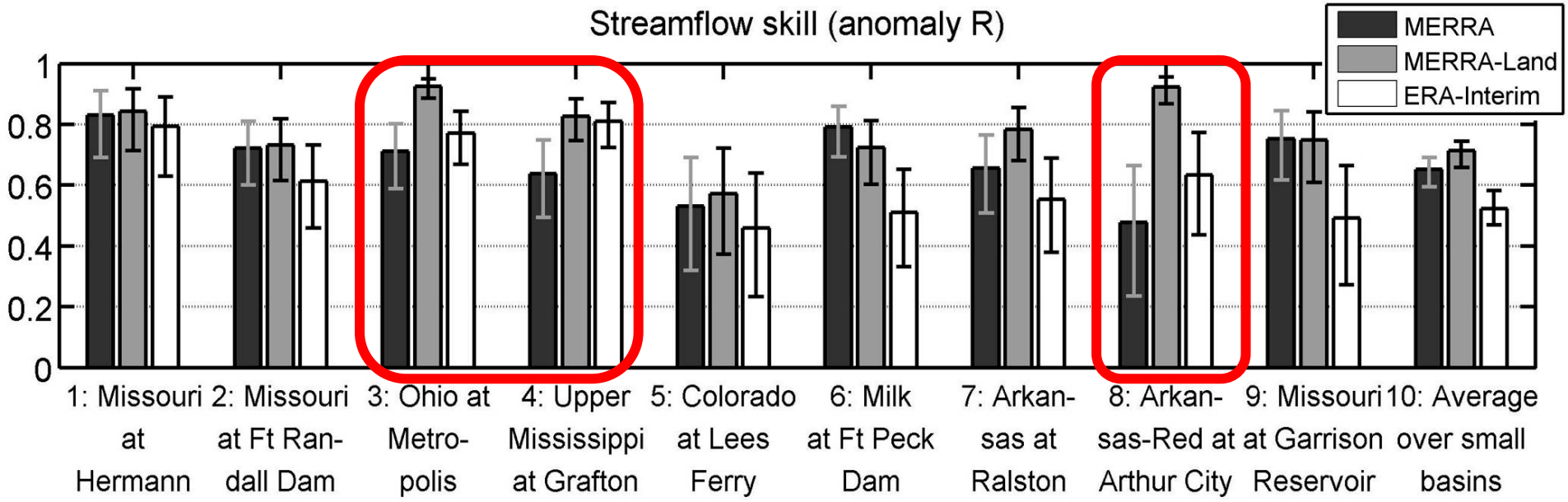


Runoff

Validation against naturalized streamflow observations from 9 "large" and 9 "small" basins (~1989-2009).



NB: Numbering does not match figure below.



Precipitation corrections yield significantly better runoff for 3 basins.

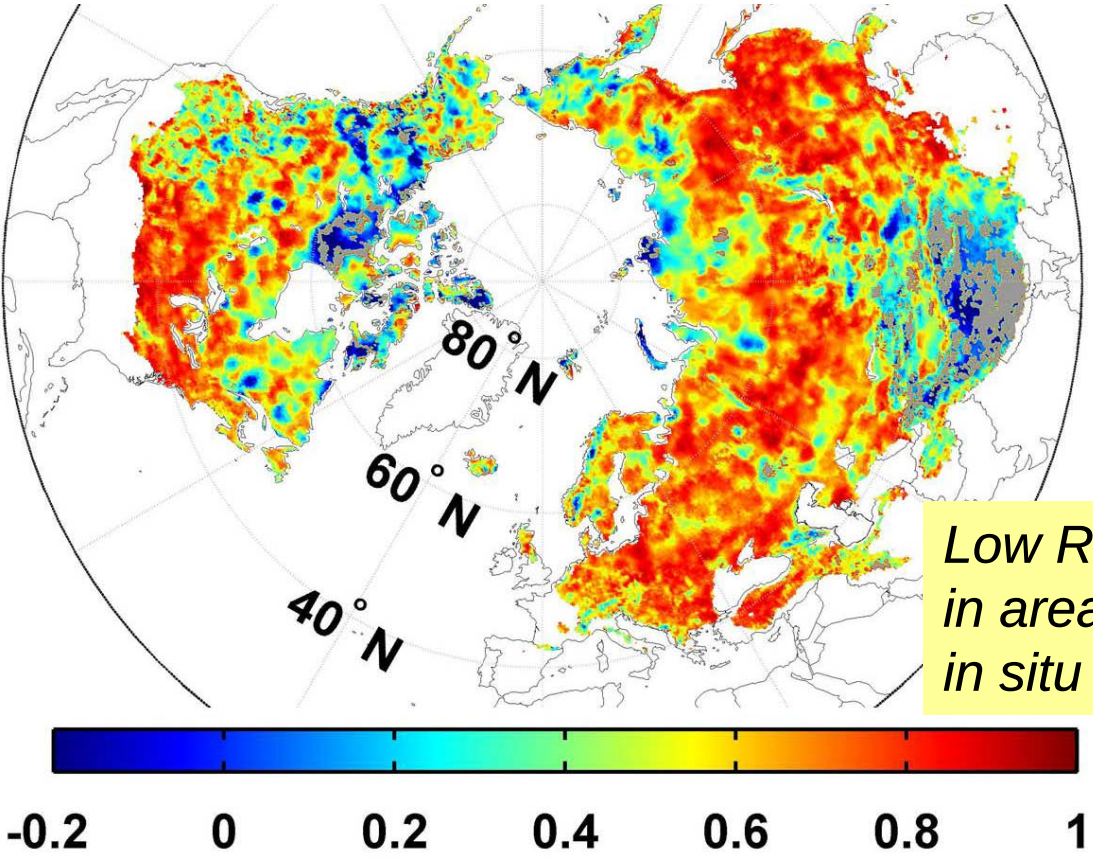
MERRA and MERRA-Land (0.5 deg) better than ERA-Interim ("1.5 deg").

Not shown: In all cases the revised interception parameters yield improved runoff anomalies (albeit not significant).

Snow depth

MERRA-Land v. CMC snow analysis

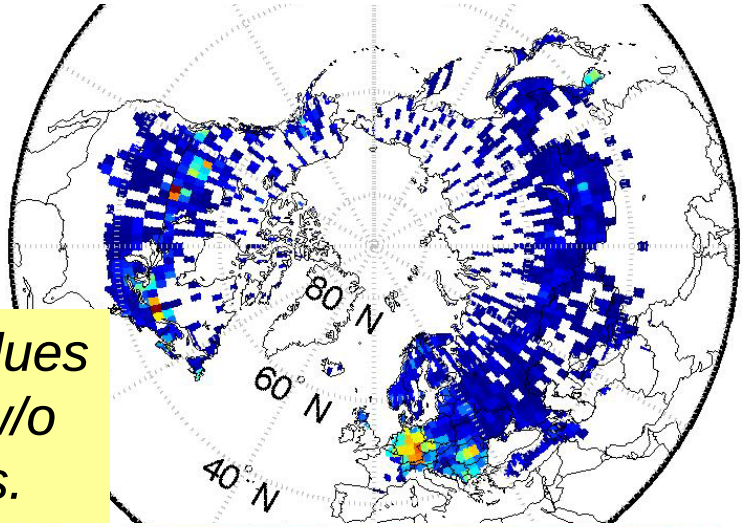
Pentad anomaly R (2002-2009)



*Note: **No** snow analysis in MERRA or MERRA-Land.*

CMC snow analysis

Density [stations/10,000 km²]

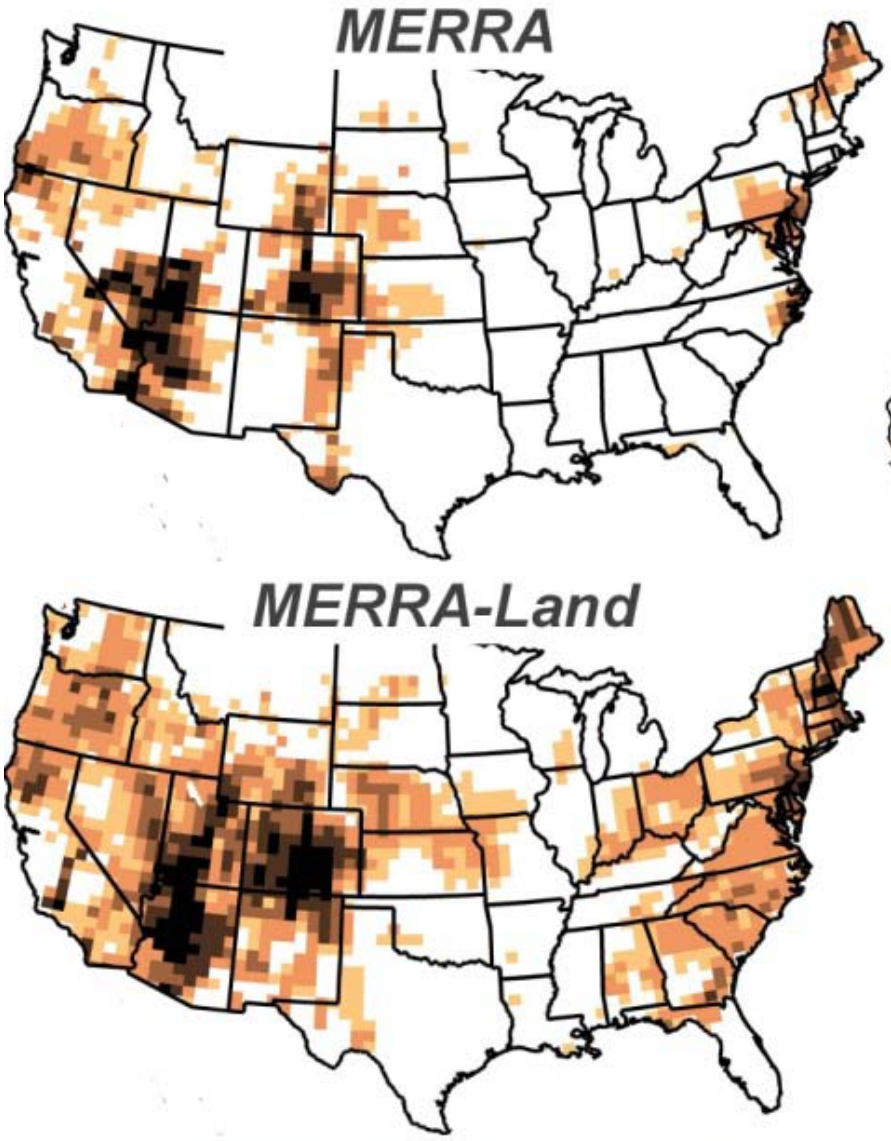


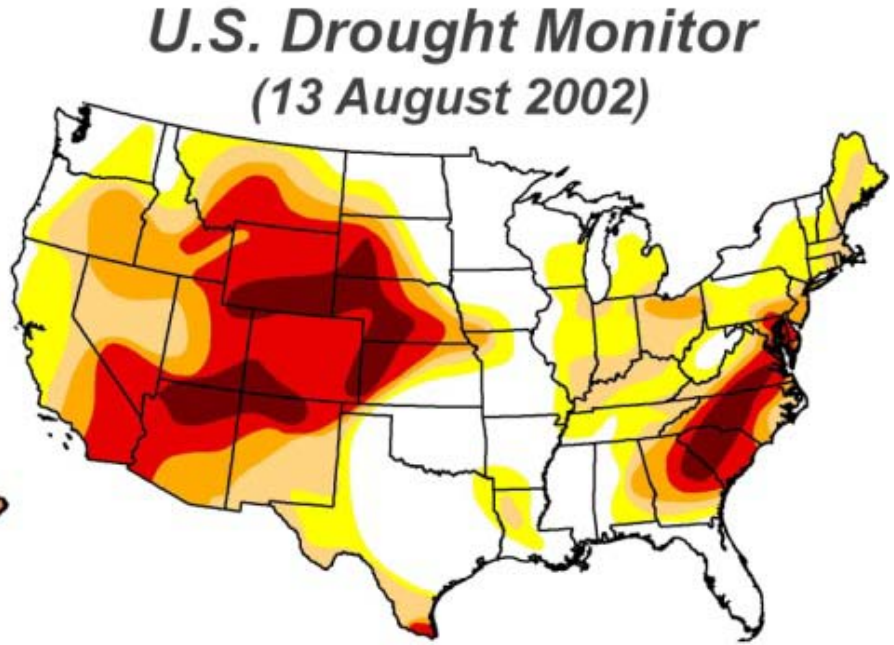
Low R values in areas w/o in situ obs.

NOT SHOWN

- *MERRA and MERRA-Land have similar skill.*
- *Similar results for comparison vs. in situ obs. (583 stations).*
- *Similar results for snow water equivalent (SWE).*
- *Step in 1998/99 in CPCU high-lat avg precip. → step in snow mass.*

Drought Conditions in August 2002





Drought Severity:

- D0 Abnormally Dry
- D1 Drought – Moderate
- D2 Drought – Severe
- D3 Drought – Extreme
- D4 Drought – Exceptional

http://droughtmonitor.unl.edu

http://gmao.gsfc.nasa.gov/merra/merra-land.php

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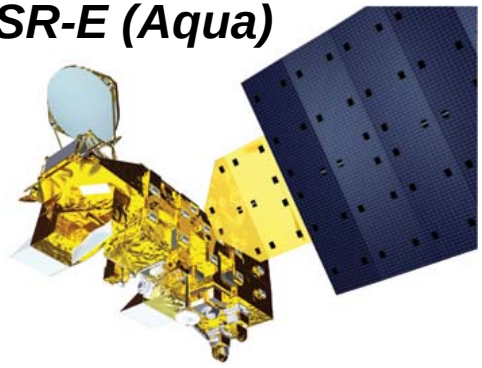
Satellite remote sensing of (surface) soil moisture

AMSR-E (Aqua)

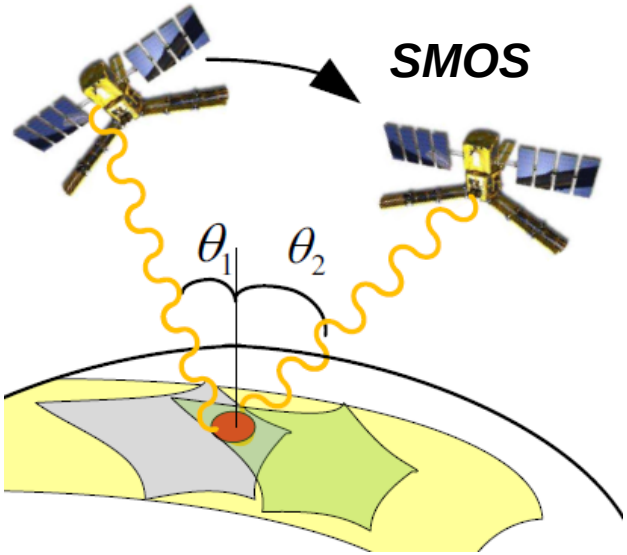


2002-2011
C/X-band passive
40 km resolution

ASCAT (Met-op)

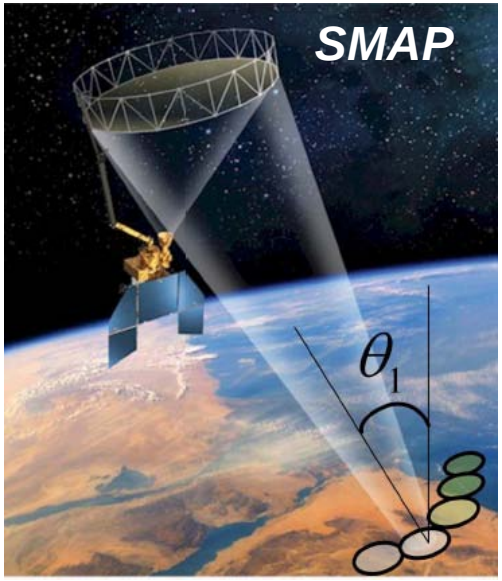
2007-present
C-band active
40 km resolution

SMOS



2009-present
L-band passive
40 km resolution
interferometric &
multi-angular

SMAP



Launch: 2014
L-band active/passive
3-40 km resolution

Frequency band	Sensing depth
C/X-band	1 cm
L-band	5 cm

Soil moisture assimilation

Skill increases significantly through data assimilation.

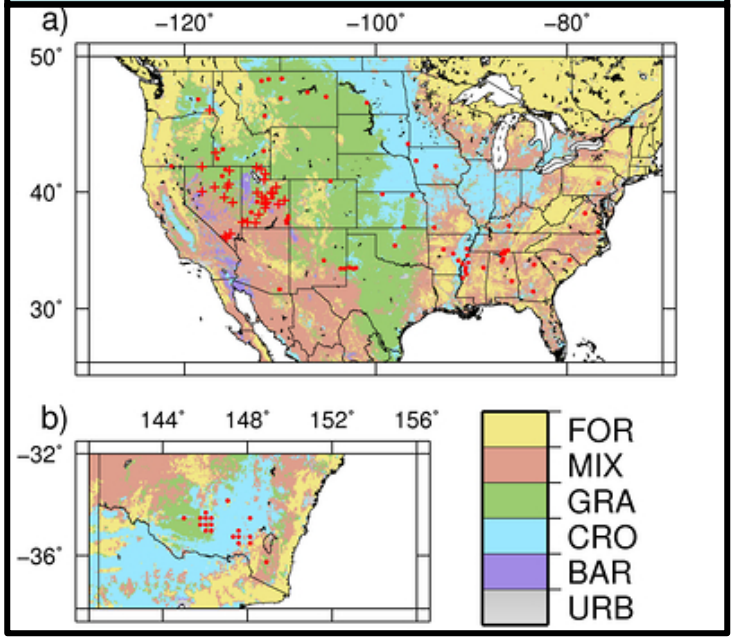
Similar improvements from AMSR-E and ASCAT.

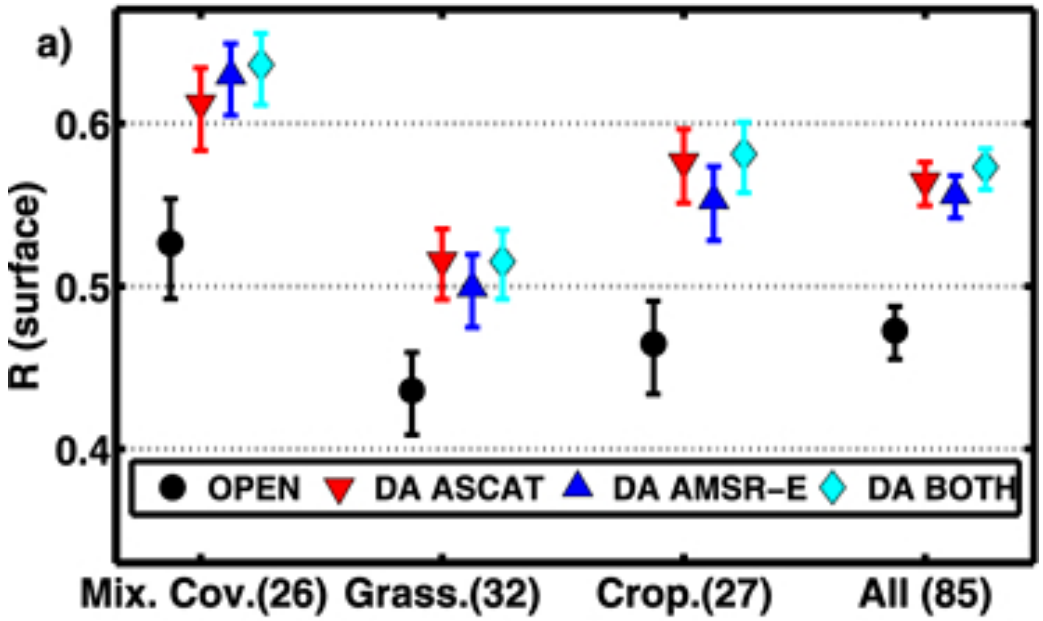
Root-zone *not* observed by satellite. **Improvements** may be critical for applications.

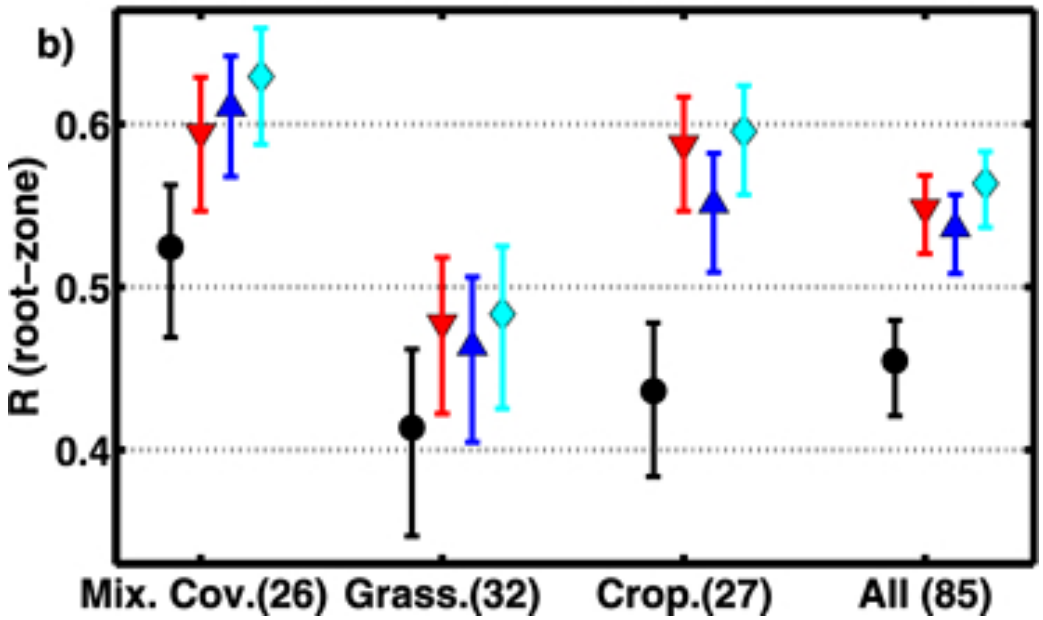
Metric: Anom. time series corr. coeff.

Anomalies ≡ mean seasonal cycle removed

Validated with in situ data

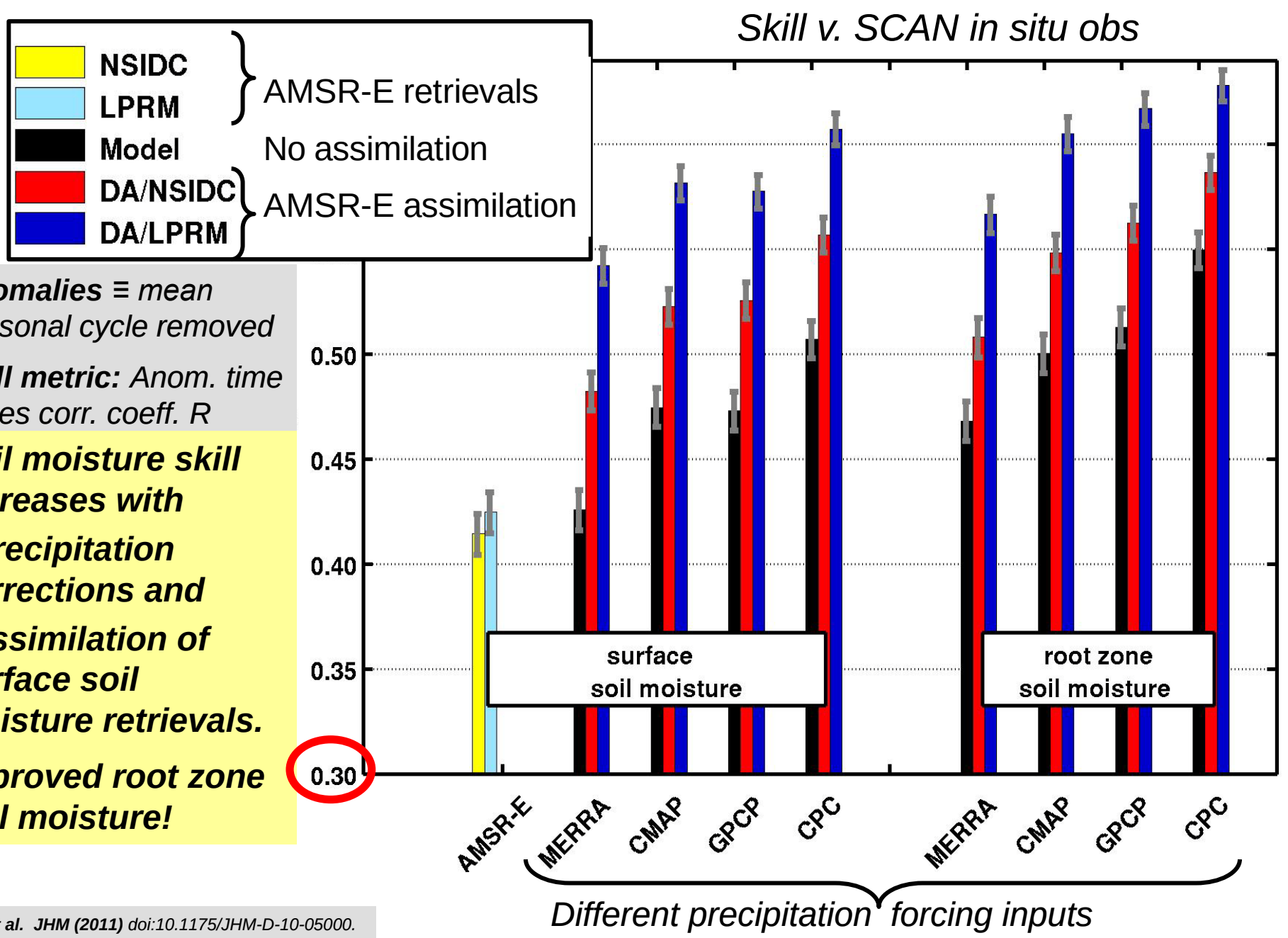






Draper et al. (2012), GRL, doi:10.1029/2011GL050655.

Precipitation corrections v. retrieval assimilation



Anomalies ≡ *mean seasonal cycle removed*

Skill metric: *Anom. time series corr. coeff. R*

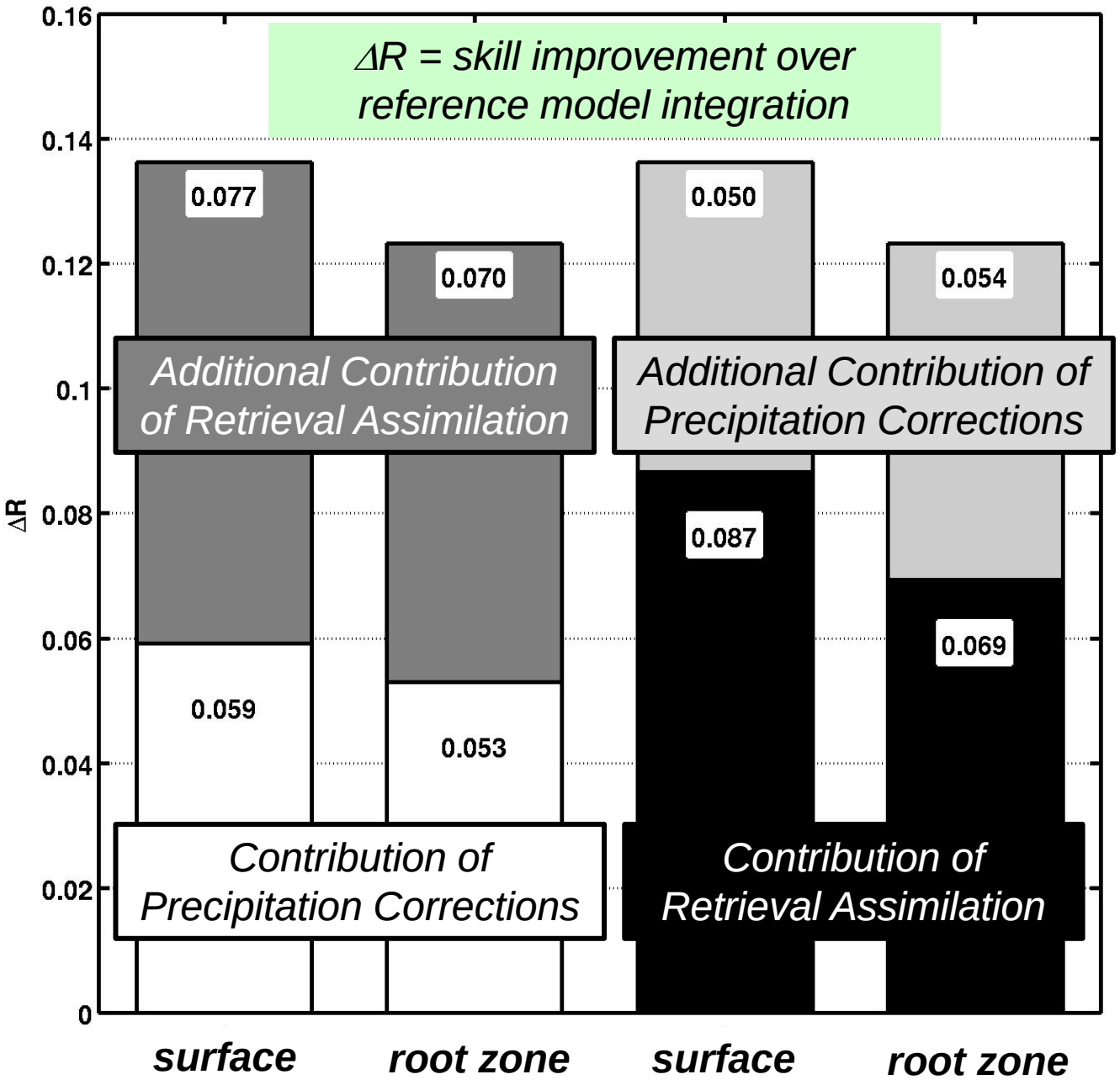
Soil moisture skill increases with

- ***precipitation corrections and***
- ***assimilation of surface soil moisture retrievals.***

Improved root zone soil moisture!

Liu et al. JHM (2011) *doi:10.1175/JHM-D-10-05000.*

Precipitation corrections v. retrieval assimilation



Precipitation corrections and retrieval assimilation contribute approximately:

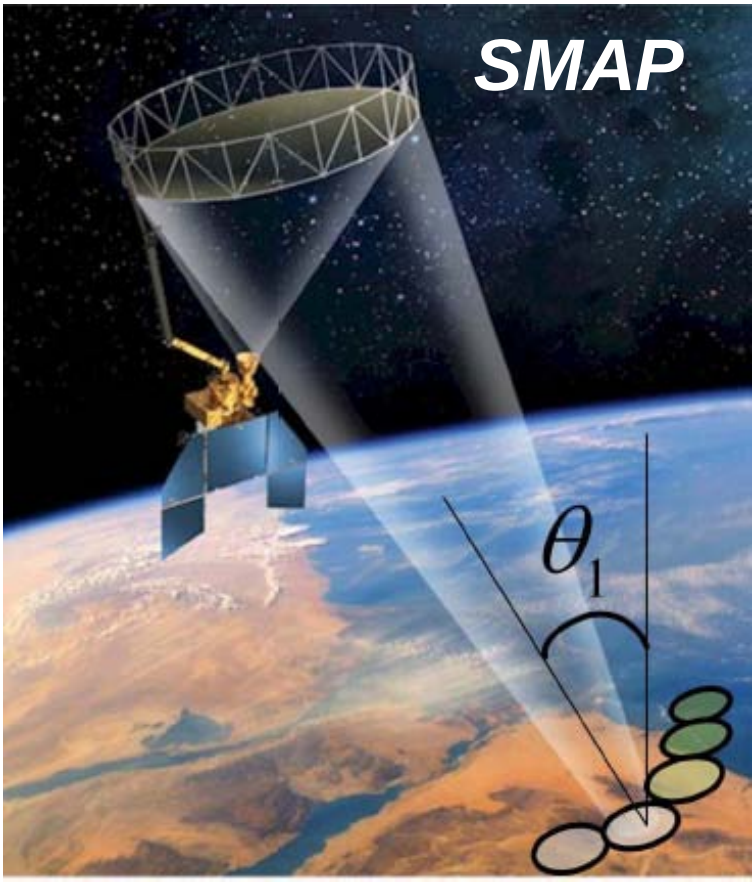
- *evenly and*
- *independently*

to skill improvement.

Results from single sensor per watershed (SCAN data) are consistent with those from distributed CalVal in situ sensors.

Liu et al. JHM (2011)
doi:10.1175/JHM-D-10-05000.

Soil moisture assimilation

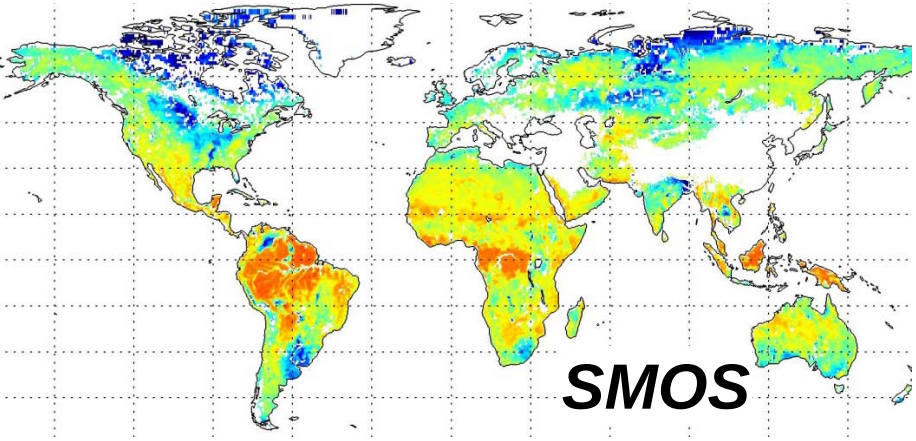


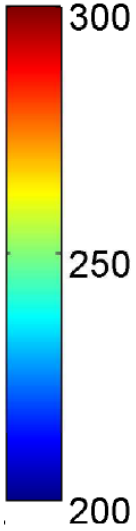
*For the SMAP L4_SM product use **brightness temperature (radiance) assimilation.***

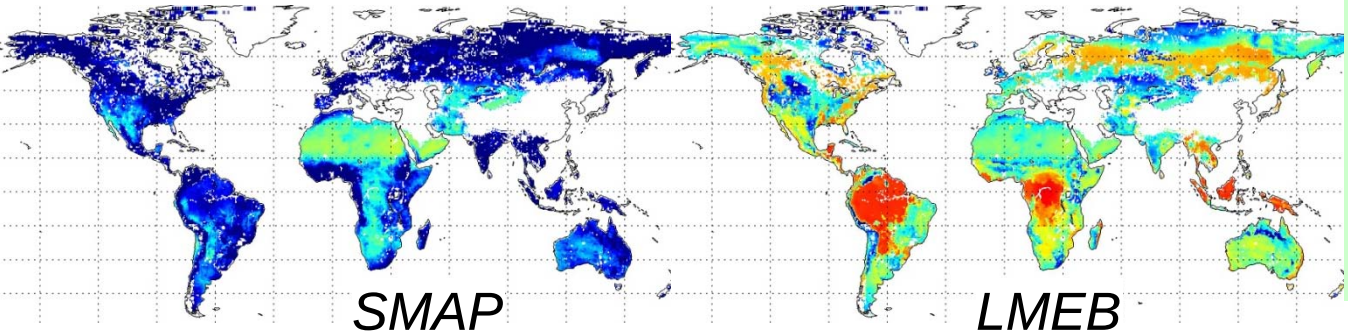
*Need **L-band** radiative transfer model (RTM).*

L-band brightness temp.: SMOS vs. Catchment/RTM

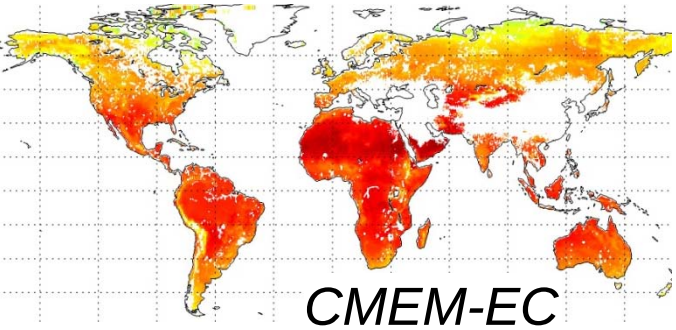
Annual mean [K]







Model



H-pol
42.5 ^{0}

1/1/2011 – 1/1/2012
(validation period)

Literature values for parameters yield strongly biased Tb.

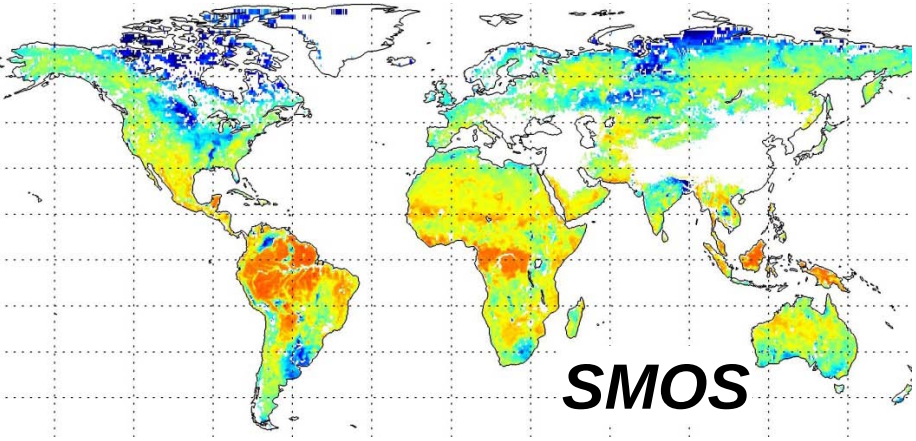
RTM parameters

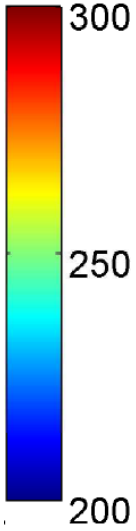
Prescribed:

SMAP Level2 ATBD
LMEB literature
SMOS-monitoring at ECMWF (CMEM-EC)

L-band brightness temp.: SMOS vs. Catchment/RTM

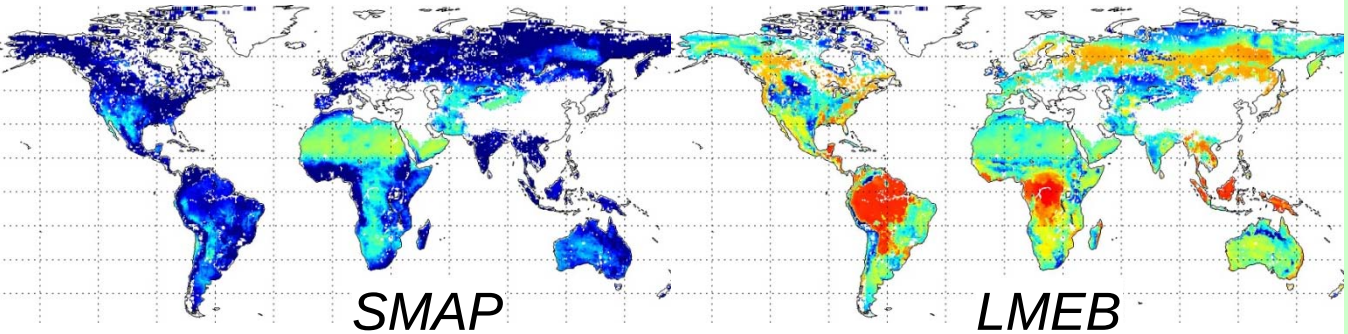
Annual mean [K]



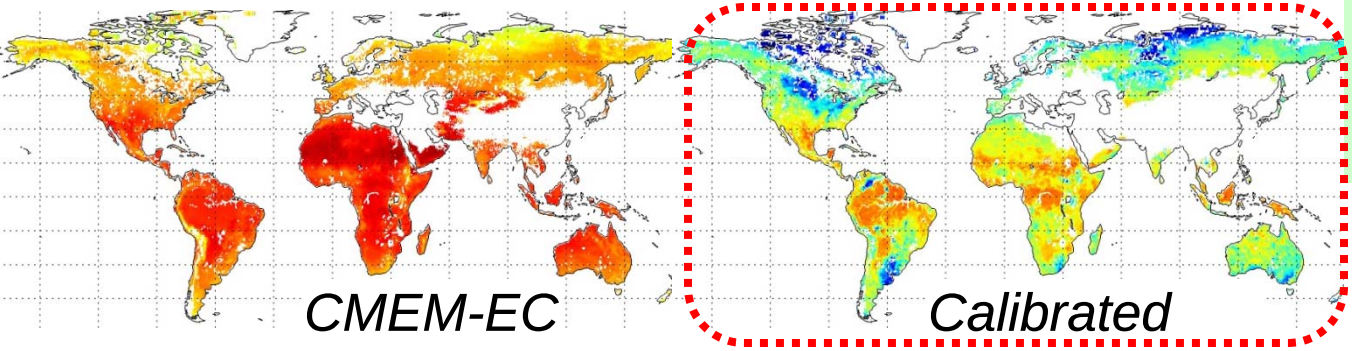


H-pol 42.5 ^{o}	1/1/2011 – 1/1/2012 (validation period)

Calibrated parameters yield mostly unbiased long-term mean Tb.



Model



RTM parameters

Prescribed:

SMAP Level2 ATBD
LMEB literature
SMOS-monitoring at ECMWF (CMEM-EC)

Calibrated:

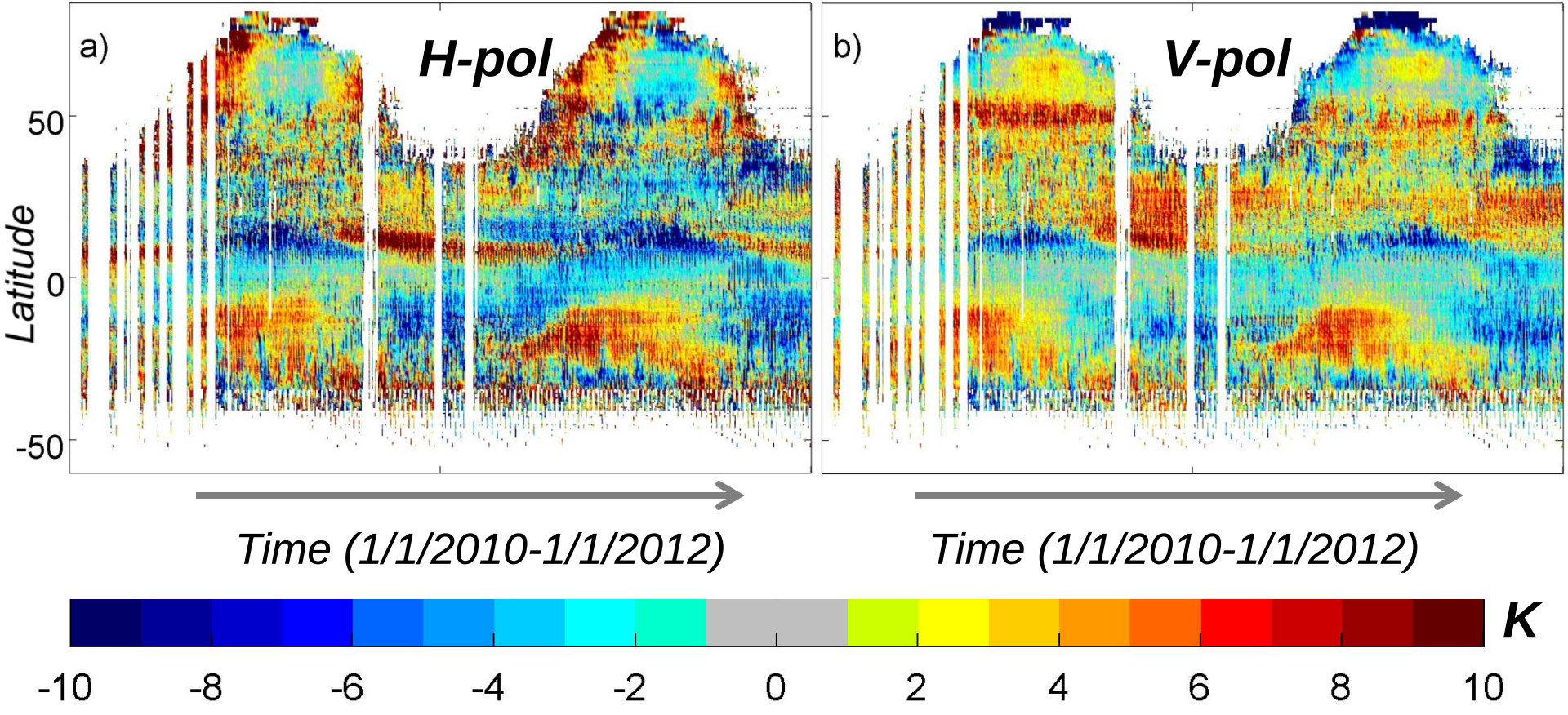
From multi-angular calibration during 1/1/2010 – 1/1/2011

L-band brightness temp.: SMOS vs. Catchment/RTM

Seasonally varying, residual biases after calibration.

Need to address in assimilation system.

RFI in V-pol from Distant-Early-Warning (DEW) Line?
Suppressed in H-pol through calibration?



Bias ≡ SMOS minus Model, average over 6 angles, ascending only

Outline

Introduction

MERRA-Land

- Motivation and data product design
- Validation

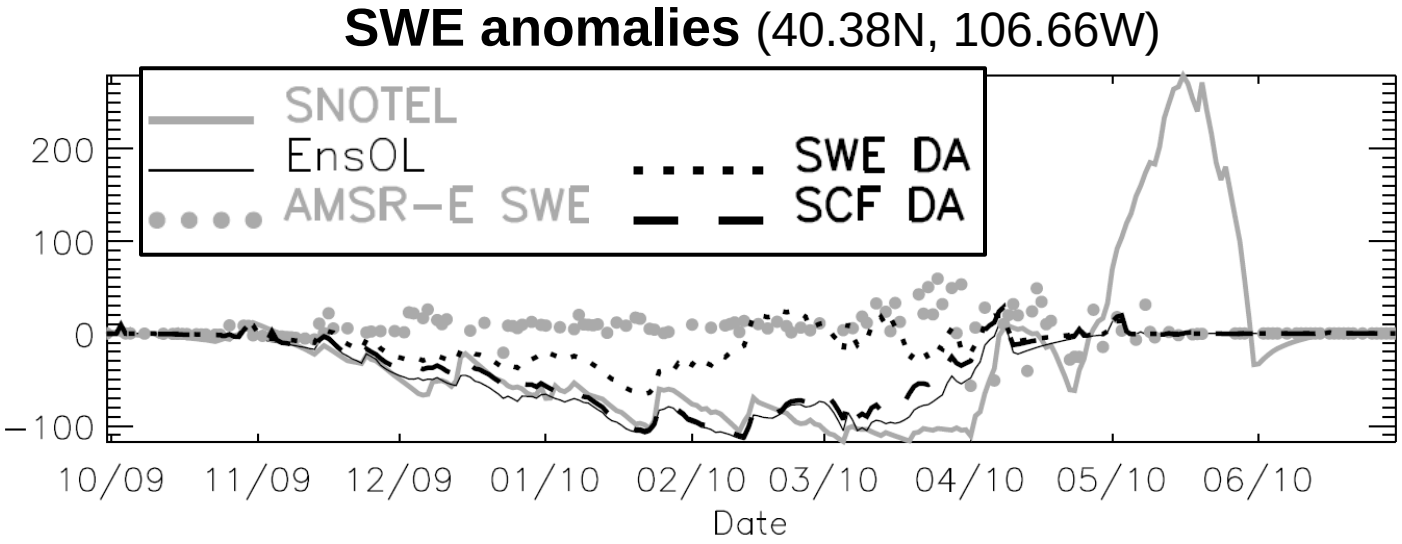
Developments in land surface analysis

- Soil moisture
- Snow

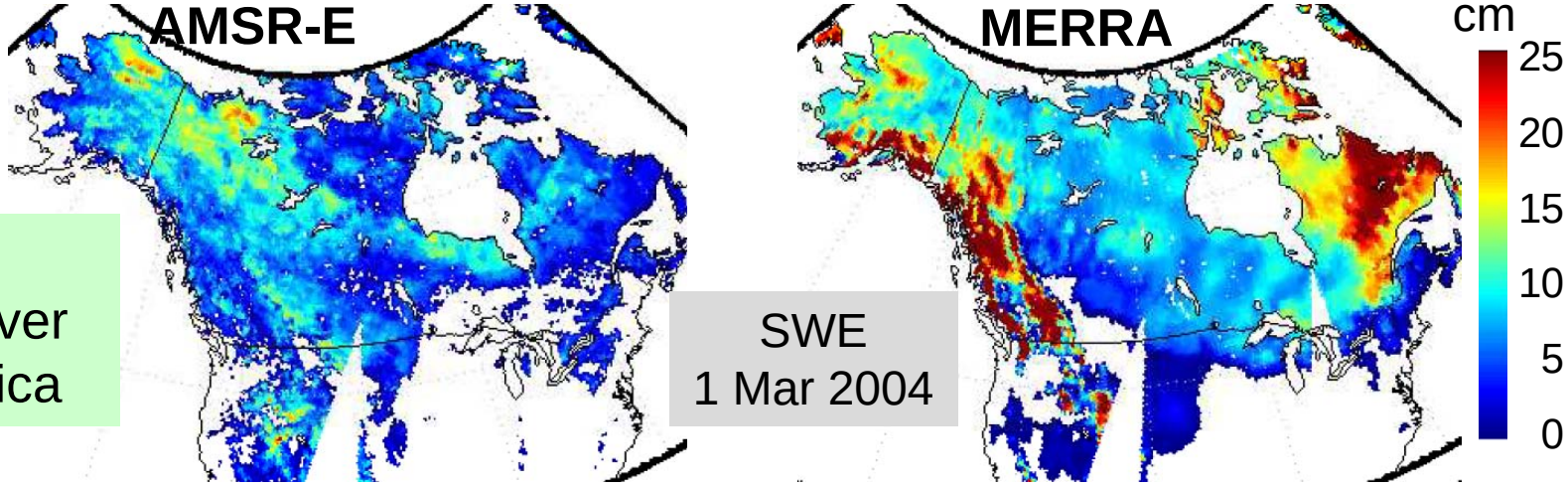
Assimilate AMSR-E snow water equivalent (SWE)?

Example 1: Anomaly time series at SNOTEL site.

De Lannoy et al. WRR (2012)



Example 2: Snapshot over North America



Satellite SWE retrievals not (yet) suitable for assimilation.

Radiance assimilation?

GEOS-5 vs. AMSR-E brightness temp. (18 GHz, V-pol)

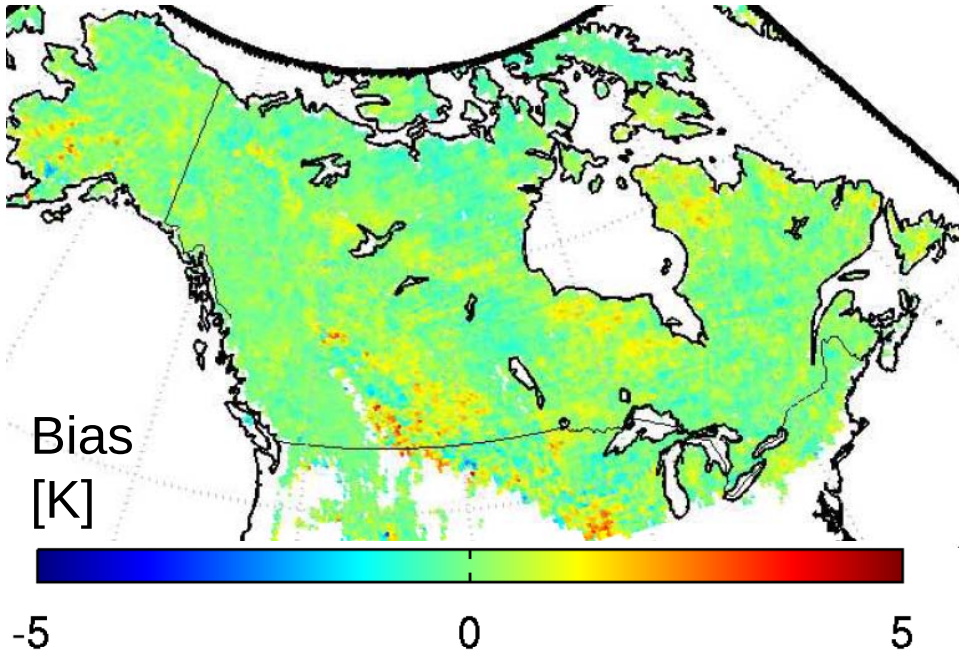
Artificial Neural Network for GEOS-5 global snow model

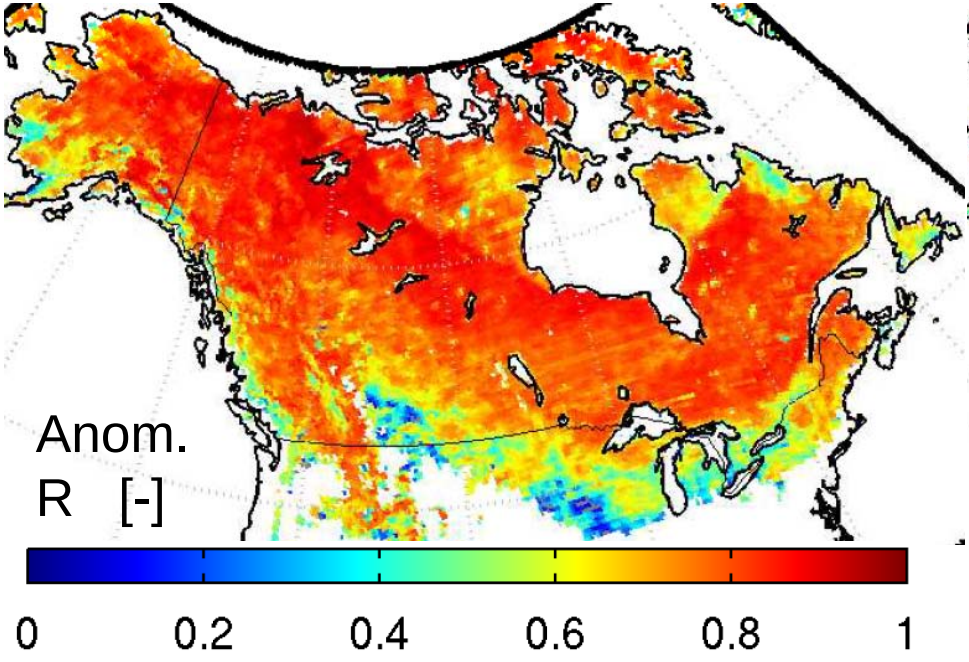
Input: *Snow water equivalent, density, liquid water content, snow/air/soil temperature)*

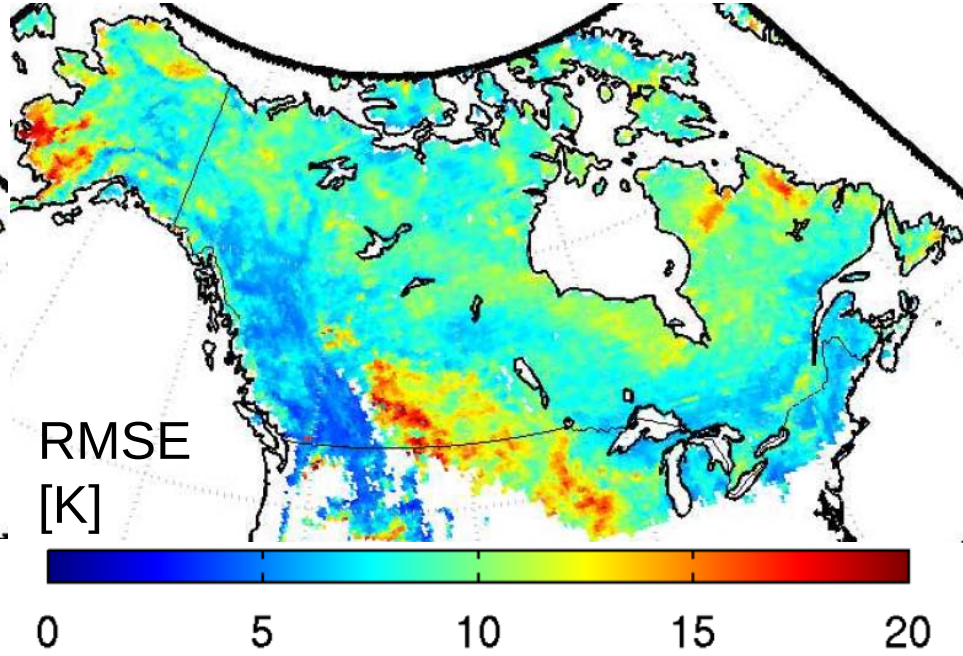
Output: *Tb (H-/V-pol, 10/18/36 GHz)*

Robust forward modeling of AMSR-E Tb using GEOS-5.

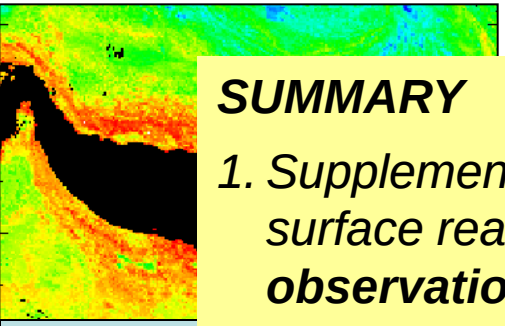
Forman et al. (2012), IEEE/TGARS, submitted.







Satellite observations



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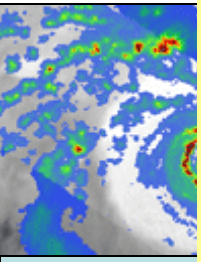

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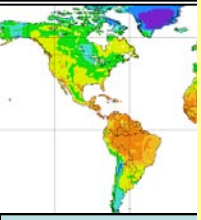

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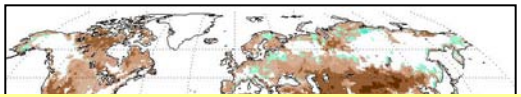

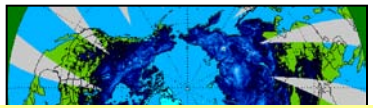

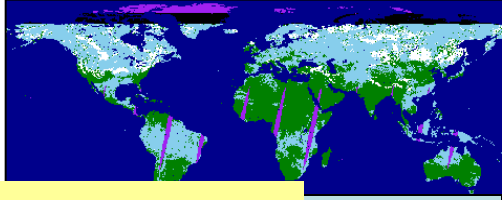

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e elevation
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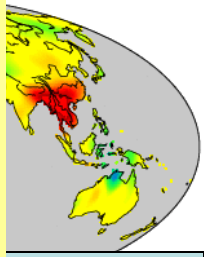


e (GRACE)

Carbon
, *DESDynI,*
IRI, LIST,
S)

SUMMARY

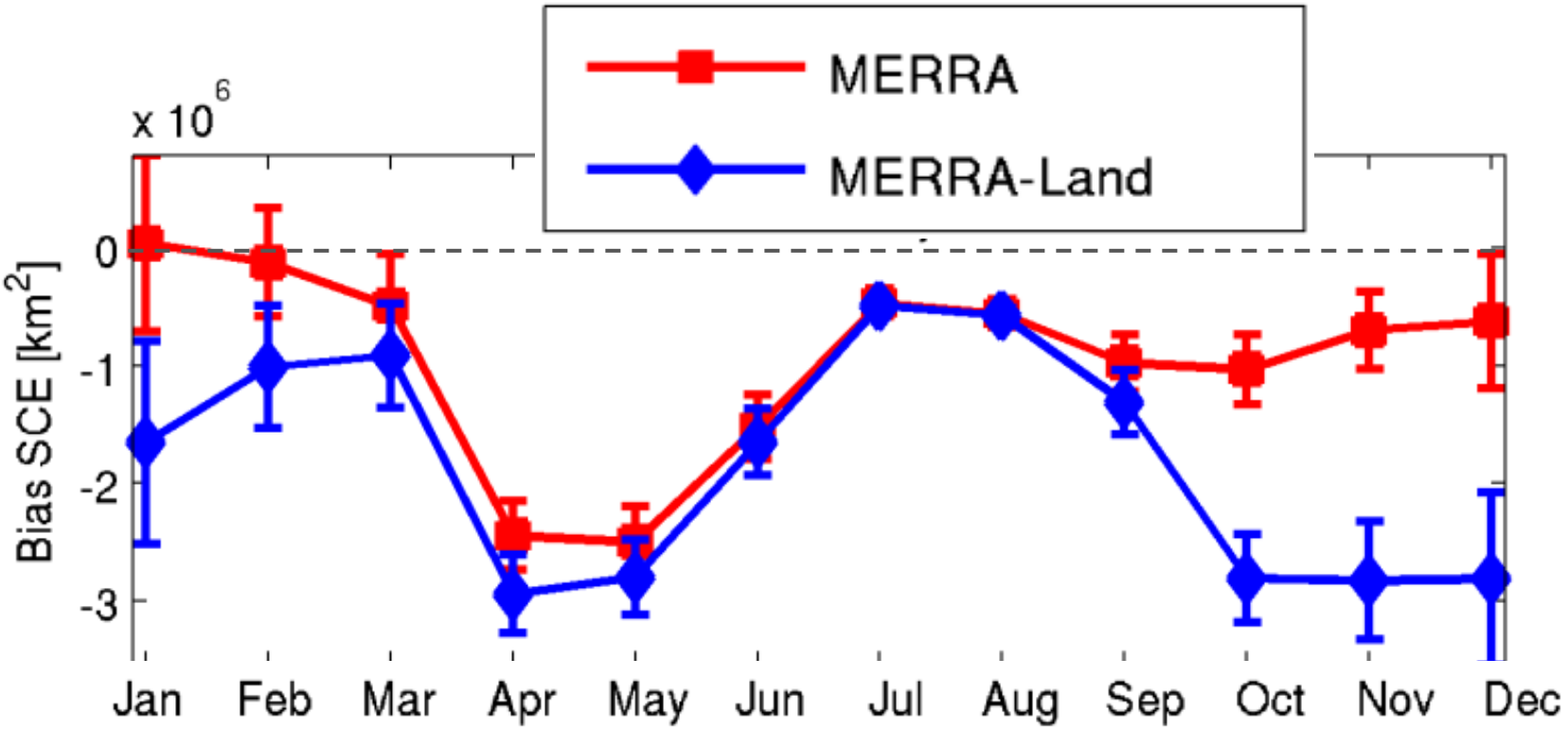
1. *Supplemental **MERRA-Land** data product provides enhanced land surface reanalysis estimates (through use of **precipitation observations** and **land model improvements**).*
2. *Retrieval-based **soil moisture assimilation** can further improve reanalysis. Radiance-based soil moisture analysis for SMOS and SMAP requires careful calibration of radiative transfer model.*
3. ***Snow water equivalent** retrievals not (yet) suitable for assimilation. Developed neural network-based forward operator for radiance assimilation.*
4. *Other topics: Assimilation of **skin temperature, snow cover,** and **terrestrial water storage** not discussed in this presentation.*

OUTLOOK

1. *Focus has been on **univariate, off-line** assimilation. Need **multi-variate** analysis of soil moisture, LST, snow cover, and snow water equivalent.*
2. *We are integrating land and atmospheric assimilation to allow feedbacks in **coupled** land-atmosphere analysis system.*
3. *Assimilate satellite-based **vegetation/carbon** observations.*

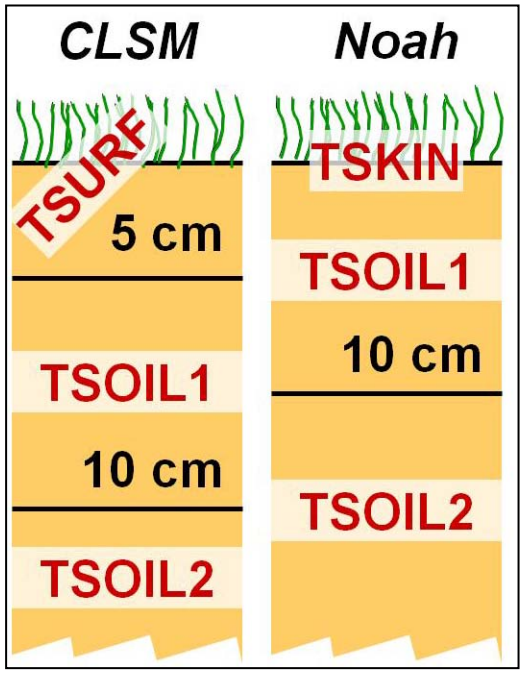
THANK YOU FOR YOUR ATTENTION!

Snow cover extent (SCE) v. MODIS



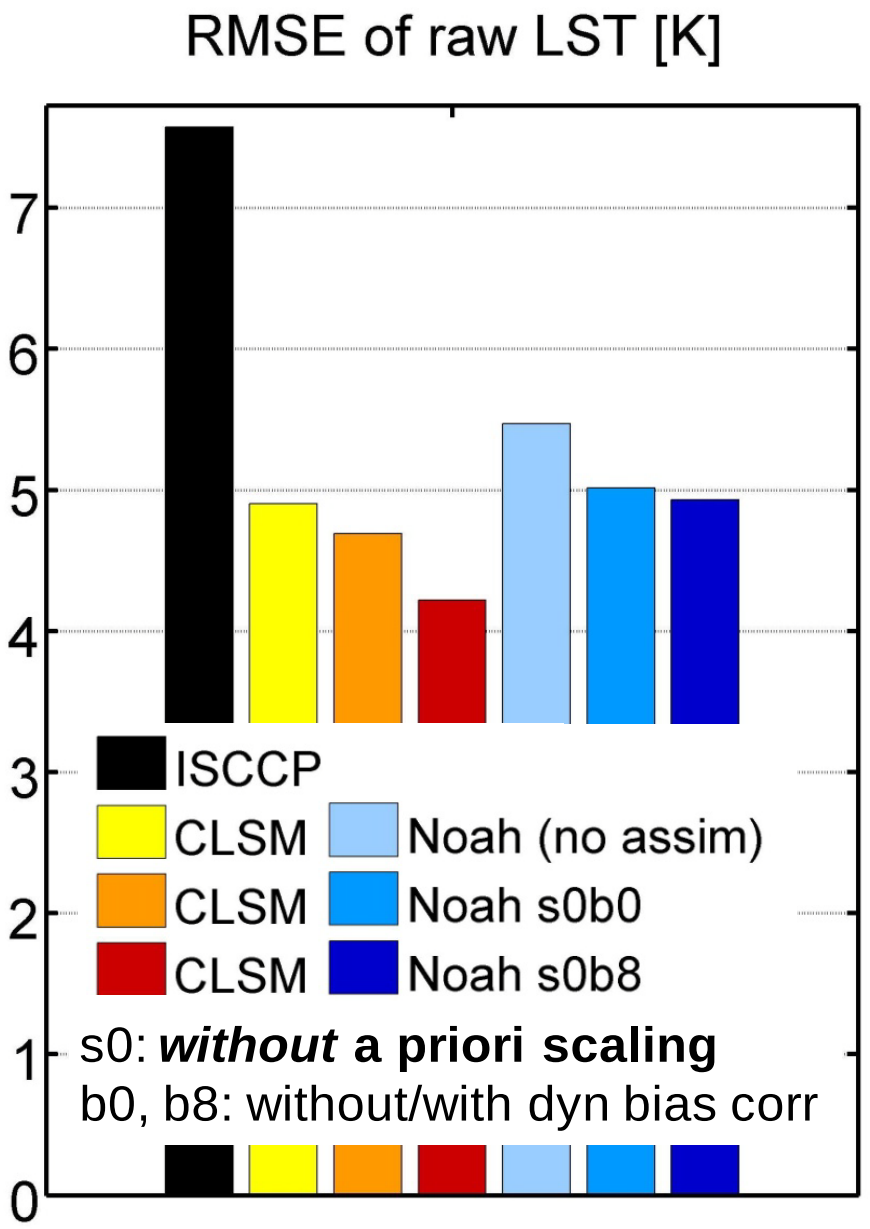
Larger bias in MERRA-Land snow cover extent vs. MODIS (compared to same in MERRA) due to parameter change in snow model (WEMIN).

Land surface temperature (LST) assimilation



Assimilate ISCCP LST retrievals into two off-line land models.

Validate against in situ obs.



"Model" LST better than ISCCP.

Assimilation reduces RMSE (by up to ~0.7 K), increases anomaly R (by up to 0.05).

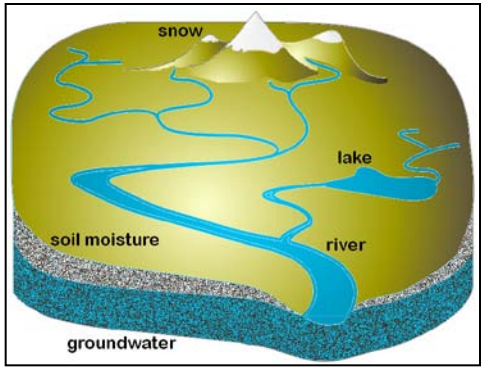
Model formulation impacts assimilation: Dynamic bias correction key for CLSM.

Fluxes can be MUCH worse if bias is not addressed (not shown).

Reichle et al. (2010), JHM, doi:10.1175/2010JHM1262.1.

Assimilation of GRACE terrestrial water storage (TWS)

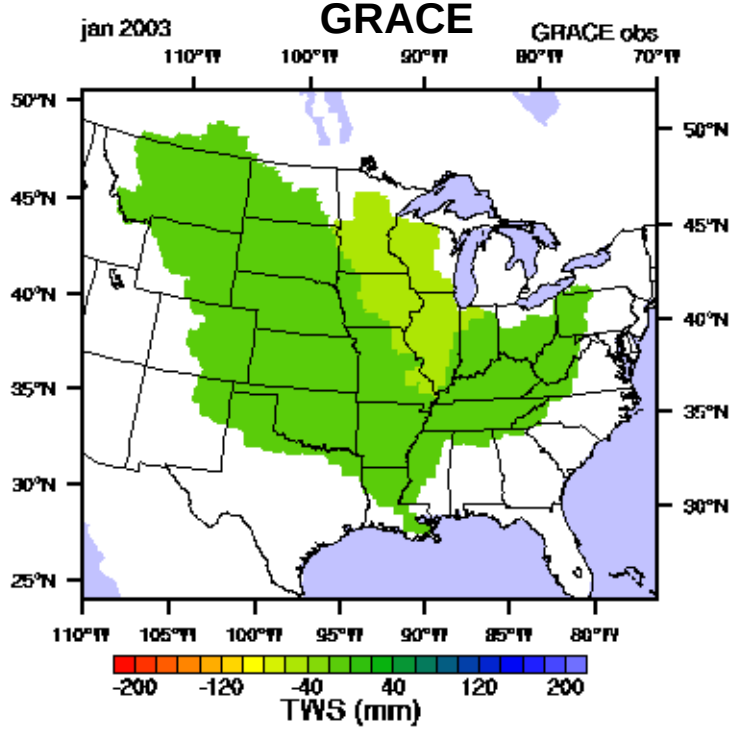
GRACE measures
large-scale TWS
= groundwater
+ soil moisture
+ snow
+ surface water

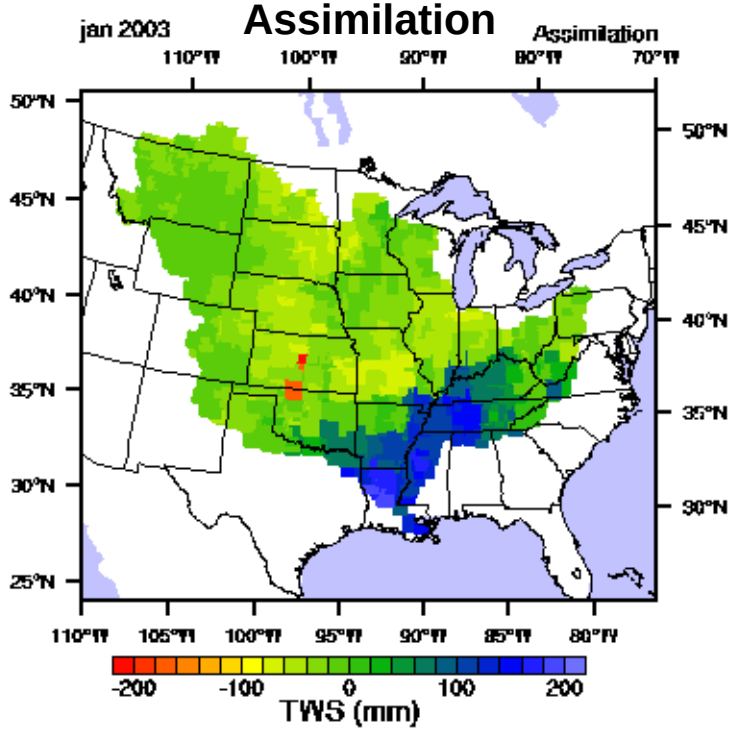


Assimilation yields:

- fine-scale information subject to GRACE basin-scale constraints
- better runoff than model (not shown).

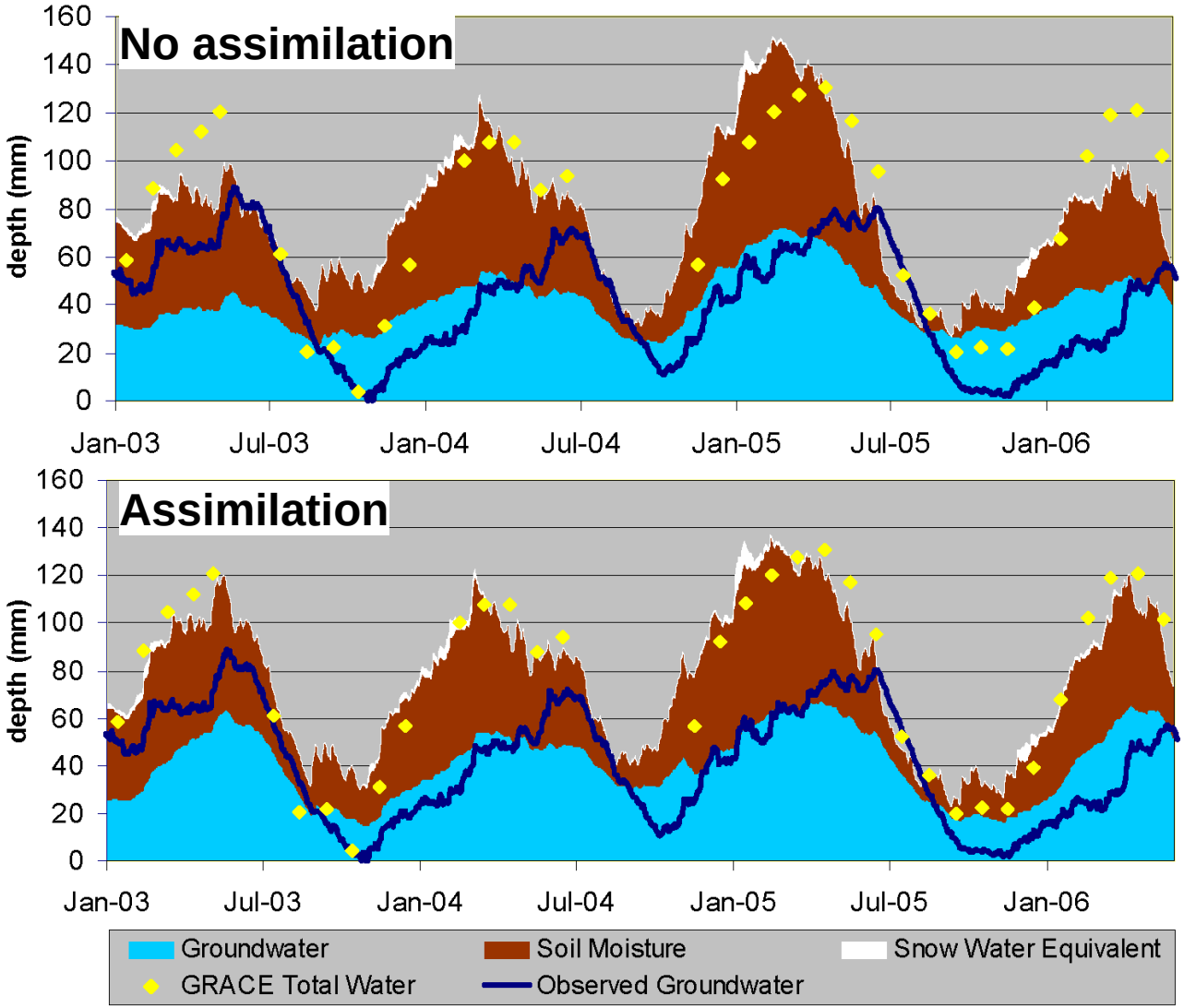
Terrestrial water storage anomaly (Jan. 2003 – Jun. 2006 loop)





Zaitchik et al. (2008) *J. Hydrometeorology*, doi:10.1175/2007JHM951.1

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 et al. (2008) *J. Hydrometeorology*, doi:10.1175/2007JHM951.1