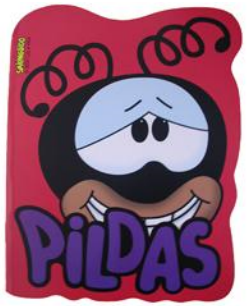
GEWEX/GLASS Panel Meeting, Oct 2016

Project for the Intercomparison of Land Data Assimilation Systems (PILDAS)



PILDAS-1 Update

Rolf Reichle (NASA/GSFC), Sujay Kumar (NASA/GSFC), Qing Liu (NASA/GSFC), Mahdi Navari (NASA/GSFC), Wade Crow (USDA) and Patricia de Rosnay (ECMWF)

PILDAS objectives

- Enable better **communication** among developers of land data assimilation systems (LDAS).
- Develop and test a **framework for LDAS comparison** and evaluation.
- Compare land assimilation **methods**.
- Conduct sensitivity studies of **assimilation input parameters** (such as model and observation errors).
- Provide **guidance and priorities for future** land assimilation research and applications.
- Ultimately, produce **enhanced global data sets** of land surface fields.
- Experiment designed as an extension of the Kumar et al. (2009) heritage study.

PILDAS-1 confirmed participants

Institution	POC	Land model	DA method
ECMWF	P. de Rosnay, G. Balsamo	HTESSEL	EKF
Environment Canada	S. Belair, M. Carrera, B. Bilodeau	ISBA	EnKF
Ghent University	V. Pauwels, N. Verhoest	Toplats	(tbd)
Meteo-France	J.-F. Mahfouf	ISBA	EKF
Monash University	J. Walker	(tbd)	(tbd)
NASA/GMAO	R. Reichle, Q. Liu	Catchment	EnKF
NASA/Hydrological Sciences Lab	S. Kumar, M. Navari	LIS models (Noah, Mosaic, CLM, Catchment, VIC, TESSEL, ...)	EnKF
NOAA/NCEP	M. Ek	Noah	EnKF
Norwegian Institute for Air Research (NILU)	W. Lahoz, T. Svendby	ISBA	EKF, EnKF
USDA/ARS Hydrology and Remote Sensing Lab	W. Crow	(tbd)	EnKF
CAREERI / Chinese Academy of Sciences	X. Han	CLM4	EnKF

PILDAS-1 overview

The **first experiment** (PILDAS-1) will focus on

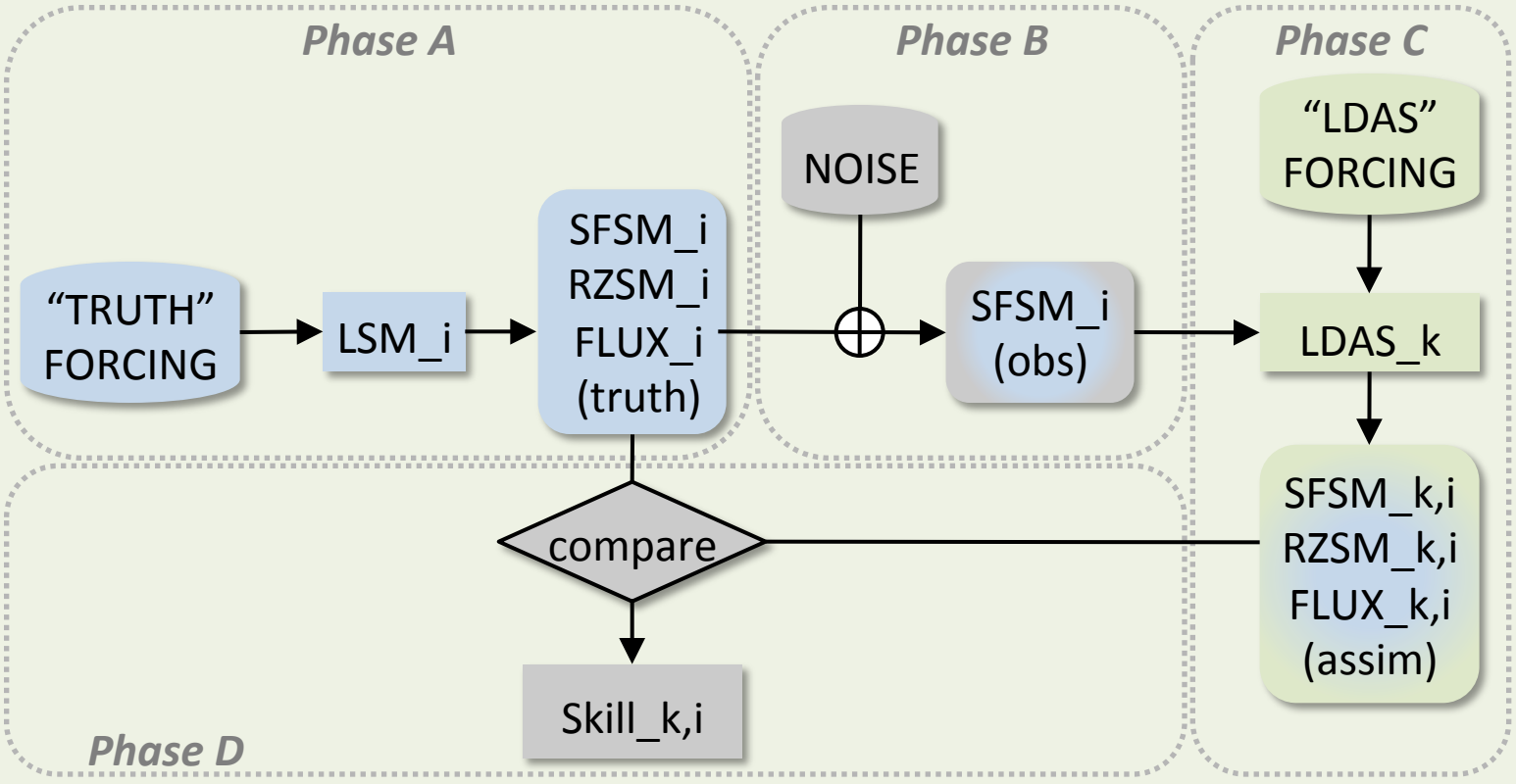
- systems targeted for weather and seasonal forecasting at operational centers and research institutions,
- **soil moisture retrieval assimilation**, and
- development of a framework for LDAS comparison.

PILDAS-1 will use

- various assimilation approaches (EnKF, EKF, …),
- multiple **"off-line"** land models (not coupled to atmosphere), &
- **synthetic observations**.

Future experiments will assimilate satellite observations (SMOS, SMAP)and use coupled land-atmosphere modeling and assimilation systems.

PILDAS-1 Flowchart



Phase A: Generate truth for i=1:N_T land models (participants).

Phase B: Generate i=1:N_T sets of synthetic observations (core).

Phase C: Generate N_A open loop and $N_A \cdot N_T$ assim. runs (participants).

Phase D: Analyze results (all).

PILDAS-1 logistics

“Core group”:

- Disseminates LDAS input data (forcing, synthetic obs).
- Collects and post-processes LDAS output.
- Coordinates analysis of results and publications.

“Participants”:

- Generate synthetic truth data and LDAS output.
- Contribute to analysis of results.

PILDAS-1 Phase C (1)

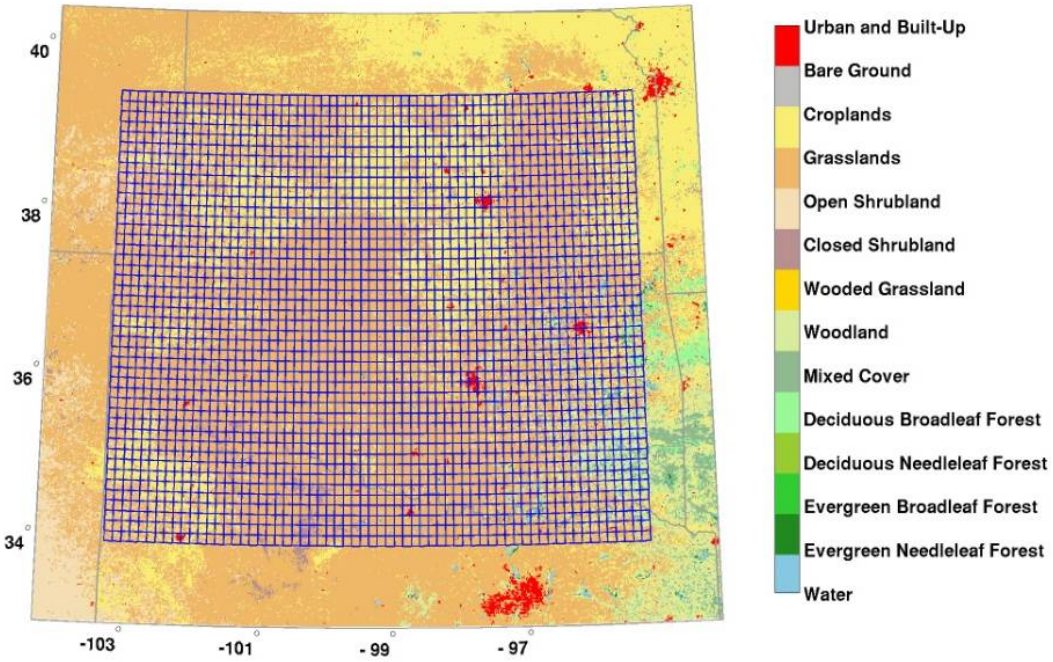
- Participants **should** assimilate all N_T sets of synthetic observations at least once into their default LDAS.
- Participants **may** additionally use LDAS variants (different model, different assimilation method, different assimilation parameters,…).
- Participants **choose** assimilation algorithm and assimilation parameters.
- LDAS output **should** include assimilation diagnostics (O-F, increments, error standard deviations, …).

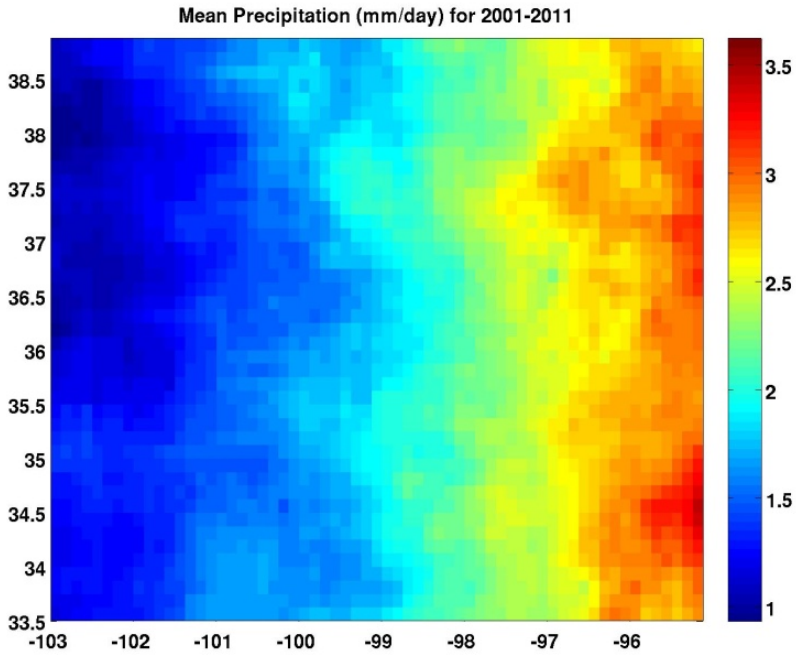
Output of assimilation diagnostics is more complicated when participants choose to run the assimilation system on their native modeling/assimilation grid.

PILDAS-1 Experiment Setup

Experiment setup:

- Domain: 33.5°-39°N, 103°-95°W
- Exchange grid: 0.125 deg lat/lon
- Duration: 2001-2011





Annual mean precipitation [mm/d]

Forcing data is provided and LDAS output is expected on the **exchange grid**.

Participating systems may run on their **native modeling/assimilation grids**.

Participating systems use **native model parameters** (land cover, soil texture, vegetation…).

PILDAS-1 Phase A (1)

Core group provides hourly forcing data sets ("nc4" files) on 0.125° exchange grid for 1996-2011:

- Truth forcing derived from hourly NLDAS-2 at 0.125°
- LDAS forcing derived from hourly MERRA at 0.5°-by-0.67°

Unlike MERRA, NLDAS-2 includes observations-based corrections of precipitation and shortwave radiation.

Forcing datasets have been constructed.

Variable Name	Description	Units
lon	Longitude	degrees east
lat	Latitude	degrees north
time	Time since 2001-03-01 00:30:00	minutes
PRECTOT	Total precipitation	kg m-2 s-1
PRECCON	Convective precipitation	kg m-2 s-1
T2M	air temperature at 2m above displacement height	K
Q2M	specific humidity at 2m above displacement height	kg kg-1
U10M	northward wind at 10m above displacement height	m s-1
V10M	eastward wind at 10m above displacement height	m s-1
PSURF	surface pressure	Pa
SWDN	surface downward shortwave radiation	W m-2
LWDN	surface downward longwave radiation	W m-2

PILDAS-1 Phase A (2)

Participants generate **truth integrations**. Daily average output on the exchange grid ("nc4" files) should include the following land surface states and fluxes:

Variable Name	Description	Units
lon	Longitude	degrees east
lat	Latitude	degrees north
time	Time since 2001-03-01 00:30:00	minutes
PRECTOT	Total precipitation	kg m-2 s-1
PRECSNO	Snowfall	kg m-2 s-1
LAI	Leaf area index	m2 m-2
SFMC	Top soil layer soil moisture content	m3 m-3
RZMC	Root zone soil moisture content	m3 m-3
PRMC	Total profile soil moisture content	m3 m-3
NTMC	Soil moisture profile (N_{sm} native layers)	m3 m-3
TSURF	Mean land surface temperature (incl. snow)	K
TPSNOW	Top snow layer temperature	K
TSOIL	Soil temperature profile (N_{st} native layers)	K
SNOMAS	Snow mass	kg m-2
SNODP	Snow depth	m
ASNOW	Snow cover area fraction	m2 m-2

Table continues on next slide...

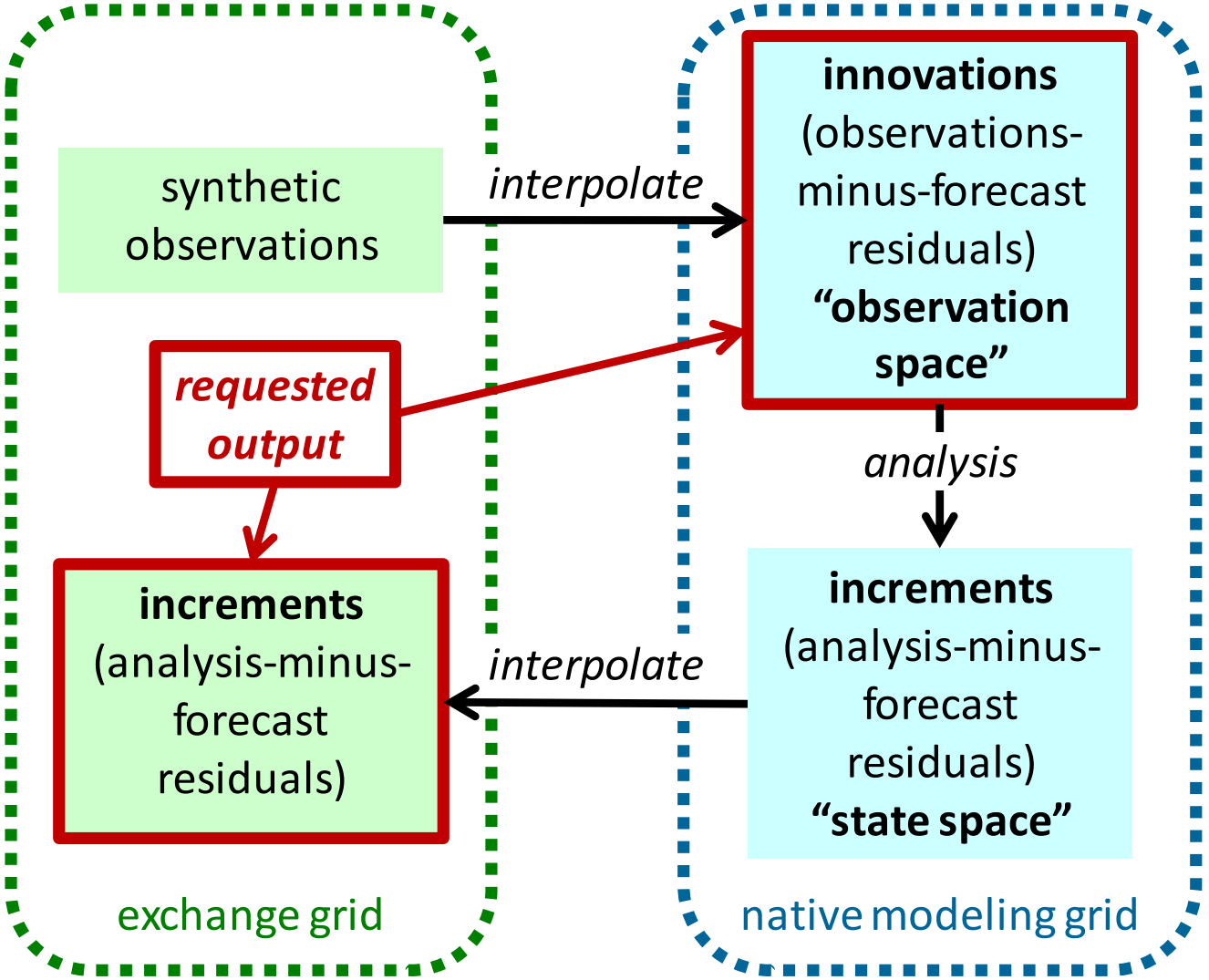
PILDAS-1 Phase A (3)

Output list (continued):

Variable Name	Description	Units
QINFIL	Soil water infiltration rate	kg m-2 s-1
RUNOFF	Overland runoff	kg m-2 s-1
BASEFLOW	Baseflow	kg m-2 s-1
SMLAND	Snowmelt over land	kg m-2 s-1
EVLAND	Evaporation from land	kg m-2 s-1
LHLAND	Latent heat flux from land	W m-2
SHLAND	Sensible heat flux from land	W m-2
GHLAND	Downward heat flux into top soil layer	W m-2
LWLAND	Net downward longwave flux over land	W m-2
SWLAND	Net downward shortwave flux over land	W m-2
TWLAND	Total water stored in land reservoirs	kg m-2
TELAND	Energy stored in all land reservoirs	J m-2
WCHANGE	Total land water change per unit time	kg m-2 s-1
ECHANGE	Total land energy change per unit time	W m-2

Each “truth” experiment will generate ~0.5 GB of data (11 years, exchange grid).

PILDAS-1 Phase C (2)



innovations

$\Delta y = y^o - Hx^-$

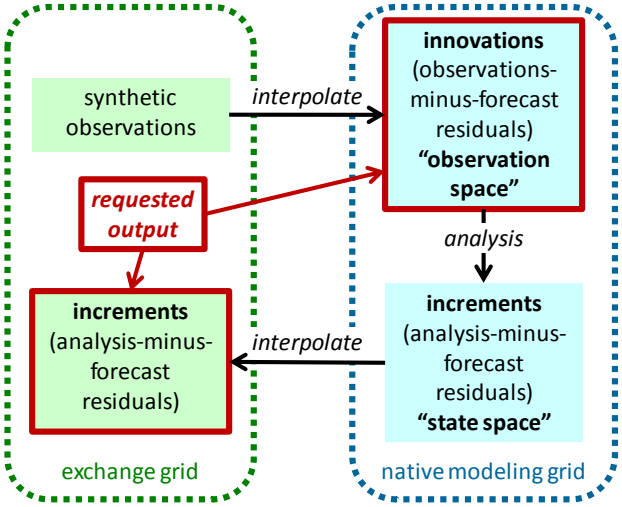
$\Delta x = K \Delta y$

(K=Kalman gain)

increments

$\Delta x = x^+ - x^-$

PILDAS-1 Phase C (3)



"innovations" output on native model grid (a.k.a. "O-F", "O-A")

Variable Name	Description	Units
lon	Longitude	degrees east
lat	Latitude	degrees north
Time	Time since 2001-03-01 00:30:00	minutes
SFMC_OS_OBS	Observed top soil layer soil moisture content	m3 m-3
SFMC_OS_FCST	Model forecast top soil layer soil moisture content	m3 m-3
SFMC_OS_ANA	Analysis top soil layer soil moisture content	m3 m-3
SFMC_OS_OBS_STD	Observation error standard deviation of SFMC	m3 m-3
SFMC_OS_FCST_STD	Model error standard deviation of SFMC	m3 m-3
SFMC_OS_ANA_STD	Analysis error standard deviation of SFMC	m3 m-3

PILDAS-1 Phase C (4)

"increments" output on exchange grid

Variable Name	Description	Units
Lon	Longitude	degrees east
Lat	Latitude	degrees north
Time	Time since 2001-03-01 00:30:00	minutes
SFMC_FCST	Model forecast top soil layer soil moisture content	m3 m-3
RZMC_FCST	Model forecast root zone soil moisture content	m3 m-3
PRMC_FCST	Model forecast total profile soil moisture content	m3 m-3
NTMC_FCST	Model forecast soil moisture profile (N_{sm} native layers)	m3 m-3
SFMC_ANA	Analysis top soil layer soil moisture content	m3 m-3
RZMC_ANA	Analysis root zone soil moisture content	m3 m-3
PRMC_ANA	Analysis total profile soil moisture content	m3 m-3
NTMC_ANA	Analysis soil moisture profile (N_{sm} native layers)	m3 m-3
SFMC_FCST_STD	Model error standard deviation of SFMC	m3 m-3
RZMC_FCST_STD	Model error standard deviation of RZMC	m3 m-3
PRMC_FCST_STD	Model error standard deviation of PRMC	m3 m-3
NTMC_FCST_STD	Model error standard deviation of NTMC (N_{sm})	m3 m-3
SFMC_ANA_STD	Analysis error standard deviation of SFMC	m3 m-3
RZMC_ANA_STD	Analysis error standard deviation of RZMC	m3 m-3
PRMC_ANA_STD	Analysis error standard deviation of PRMC	m3 m-3
NTMC_ANA_STD	Analysis error standard deviation of NTMC (N_{sm})	m3 m-3

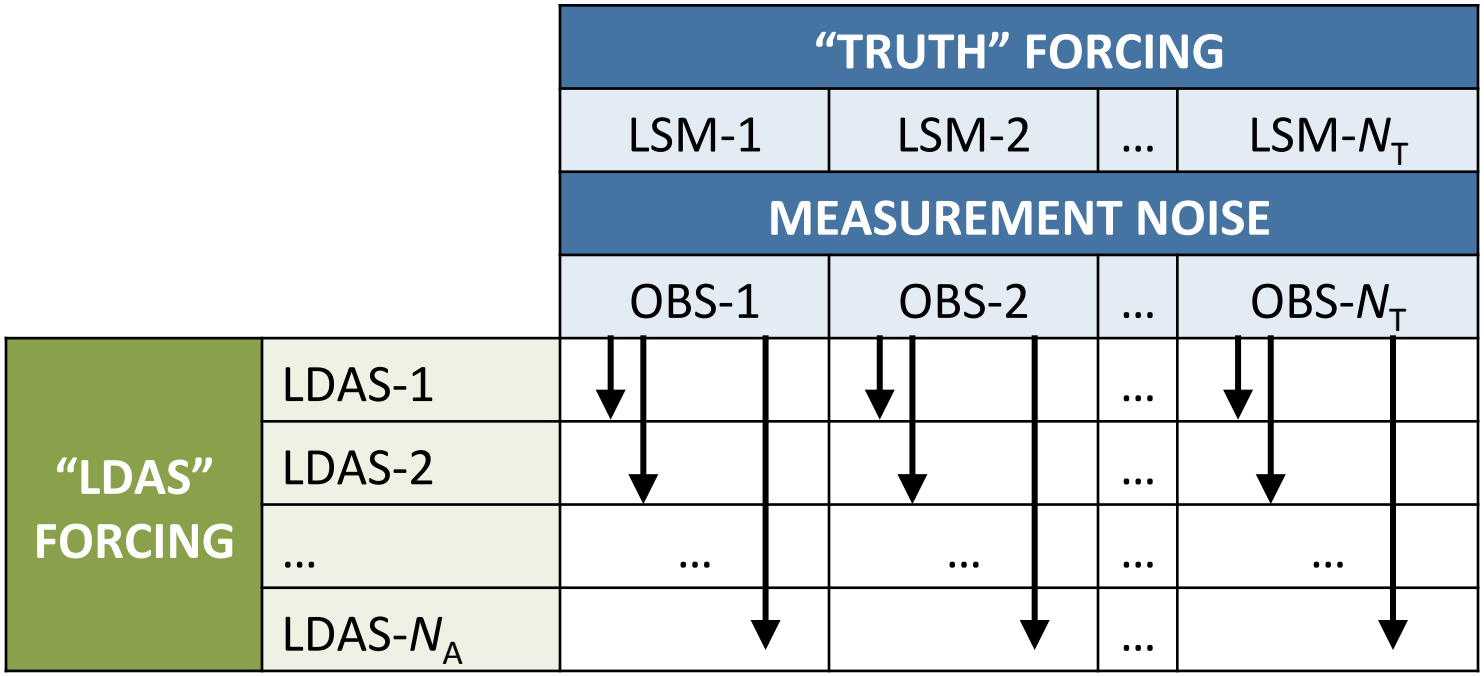
Each assimilation experiment will generate ~1 GB of data (11 years).

PILDAS-1 Phase D

Phase D:

- Core group computes skill metrics, including
  - "Normalized Information Contribution (Improvement from DA normalized by maximum possible improvement)" (Kumar et al. 2009)
  - "Vertical Coupling Strength" (Kumar et al. 2009)
  - Assimilation diagnostics (O-F mean, O-F variance etc.)

PILDAS-1 Experiment Design



Assimilate N_T sets of synthetic obs. into N_A assimilation systems.

N_T = # truth integrations (no more than # participants)

N_A = # assimilation systems (possibly $N_A >> N_T$)

➔ N_A open loop (no assimilation) integrations

➔ $N_T \cdot N_A$ assimilation integrations

PILDAS-1 Dry-Run

Implementation of the experiment plan reveals where refinements are needed.

Started with Dry-Run with just two groups/systems:

NASA GEOS-5 LDAS (Catchment + EnKF) [GSFC/GMAO, Reichle, Liu]

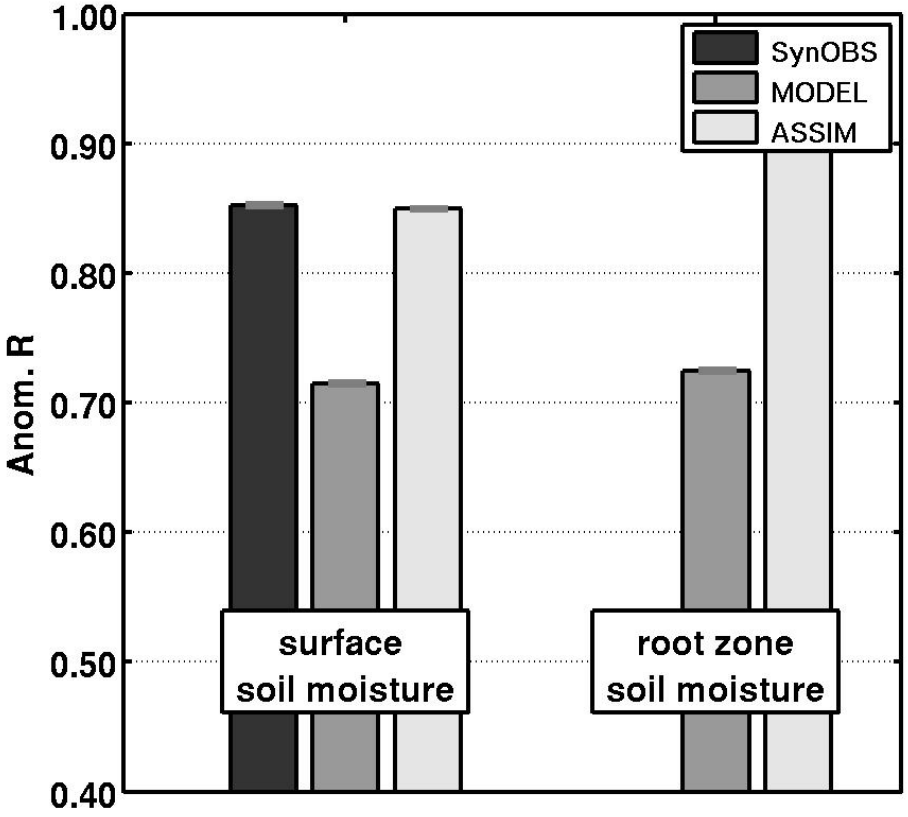
NASA LIS/Noah (incl. ~GEOS-5 EnKF) [GSFC/HSL, Kumar, Navari]

Status as of last panel meeting

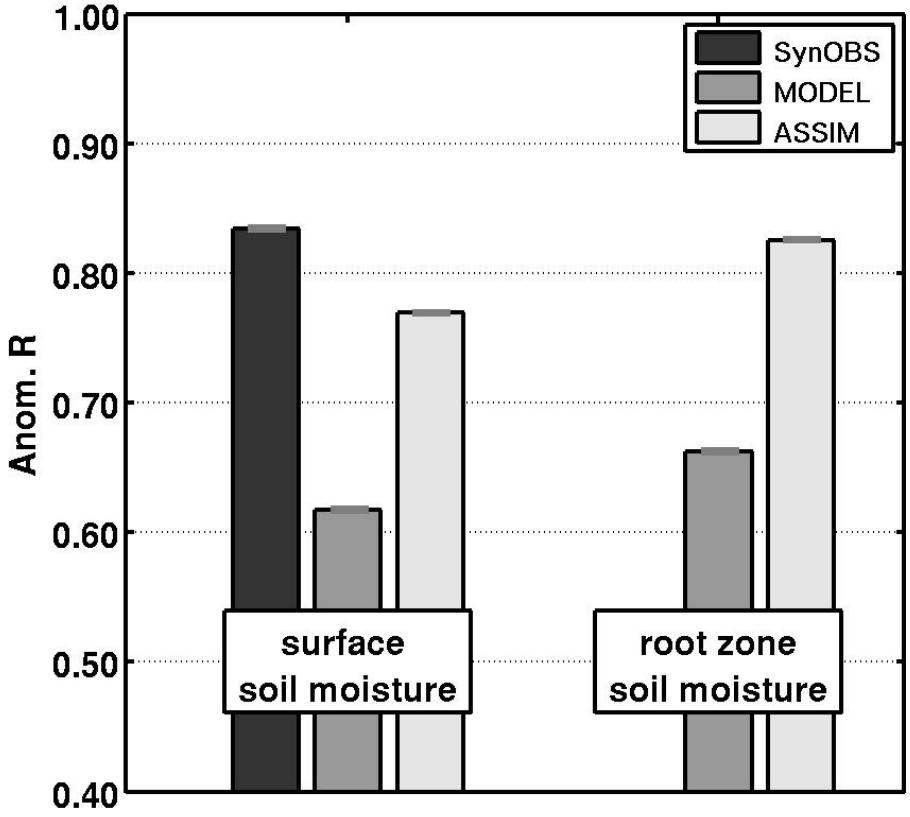
		"TRUTH" FORCING (NLDAS-2)			
		GEOS-5 Catchment	LIS/Noah	…	LSM-N_T
		MEASUREMENT NOISE			
		OBS-1: ***Done***	OBS-2: ***Done***	…	OBS-N_T
"LDAS" FORCING (MERRA)	LDAS-1: GEOS-5/EnKF	***Done***	***Done***	…	
	LDAS-2: LIS/EnKF/Noah-MP	*In progress*	*In progress*	…	
	…	…	…	…	…
	LDAS-N_A			…	

PILDAS-1 Dry-Run (Anomaly R)

LDAS-1 + OBS-1
(vs. Truth-1)
"GEOS-5 **identical** twin exp."



LDAS-1 + OBS-2
(vs. Truth-2)
"GEOS-5 **fraternal** twin exp.



LDAS-1	*= GEOS-5/EnKF*	*+ MERRA forcing*
Truth-1, OBS-1	*= GEOS-5/Catchment*	*+ NLDAS forcing*
Truth-2, OBS-2	*= LIS/Noah*	*+ NLDAS forcing*

PILDAS-1 Dry-Run

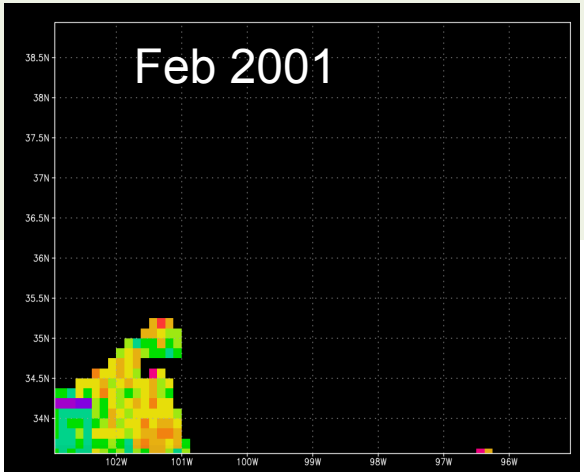
"Dry-Run" extended to four groups/systems:

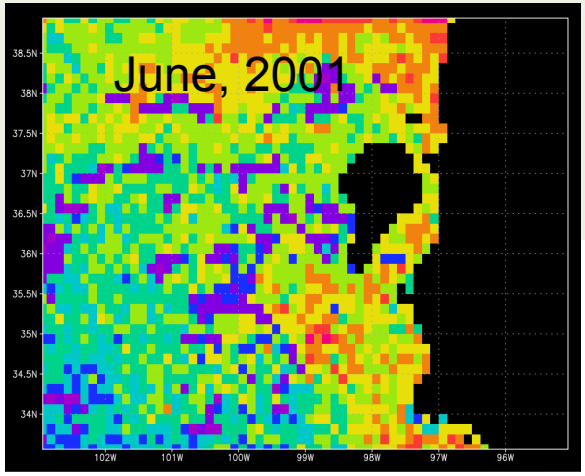
NASA GEOS-5 LDAS	(Catchment + G5-EnKF)	[GSFC/GMAO, Reichle, Liu]
NASA LIS	(Noah-MP + G5-EnKF)	[GSFC/HSL, Kumar, Navari]
USDA/FAS	(2-layer Palmer + EnKF)	[USDA + GSFC/HSL, Crow, Bolten]
ECMWF	(H-TESSEL + EKF)	[ECMWF, De Rosnay]

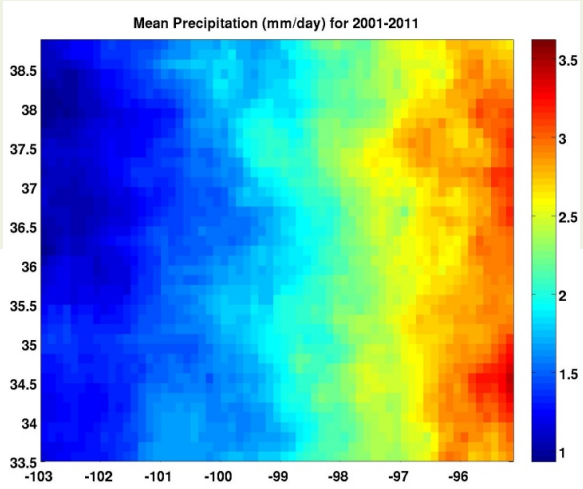
		"TRUTH" FORCING (NLDAS-2)			
		Catchment	LIS/Noah-MP	2-layer Palmer	H-TESSEL
		MEASUREMENT NOISE			
		OBS-1: ***Done***	OBS-2: ***Done***	OBS-3: ***~Spring 2017***	OBS-4: ***~Spring 2017***
"LDAS" FORCING (MERRA)	LDAS-1: G5-EnKF	***Done***	***Done***	*Spring 2017*	*Spring 2017*
	LDAS-2: LIS/G5-EnKF	*In progress*	***Done***	*Spring 2017*	*Spring 2017*
	LDAS-3: USDA-EnKF	*Spring 2017*	*Spring 2017*	*Spring 2017*	*Spring 2017*
	LDAS-4: ECMWF-EKF	*Spring 2017*	*Spring 2017*	*Spring 2017*	*Spring 2017*

LIS experiment details:

- Land Surface Model: NoahMP3.6
- DA scheme : EnKF (NASA-GMAO)
- Ensemble Structure: 20 ensemble members was generated using NASA-GMAO perturbation algorithm
- Bias correction: PILDAS observations can be scaled to the model's climatology prior to data assimilation process through CDF matching (Reichle and Koster 2004).
- Observation screening (High vegetation density (Green veg. fraction >0.7, Snow, Frozen soil and Precipitation)





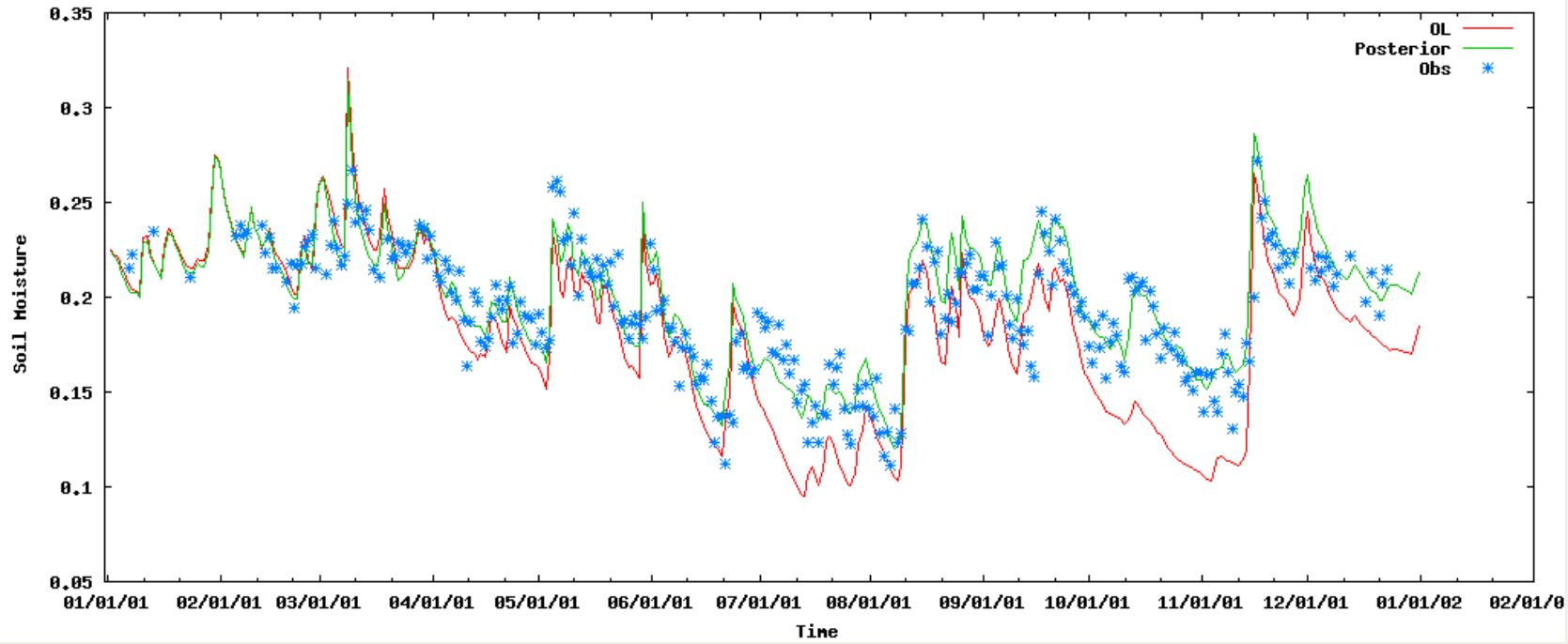


Data assimilation

Measurement error standard deviation

Gaussian noise with an error standard deviation of 0.03 ($m^3\ m^{-3}$)

Result for sample grid cell



PILDAS-1 timeline

Good news:

- PILDAS-1 forcing data & two sets of synthetics observations ready.
- Many PILDAS-1 subroutines/tools developed and integrated into GEOS-5 LDAS.
- LIS has been updated to work for PILDAS (forcing and the ingest of synthetic observations).
- Dry-run with two groups/systems (GEOS-5, LIS) now close to being completed.
- The test runs with LIS required minimal changes to the PILDAS experiment protocol.
- ECMWF off-line LDAS now ready. USDA plans to use an anticipated hire for supporting PILDAS.

Not so good news:

- PILDAS is an unfunded activity. Funded projects take priority.
- PILDAS configuration requires the specification of several components (truth, open loop forcings, support for PILDAS observations, observation screening, development of PILDAS assimilation instance, support for PILDAS specified model outputs and DA diagnostics) – more complicated than other GLASS efforts (GSWP, ALMIP, ..)

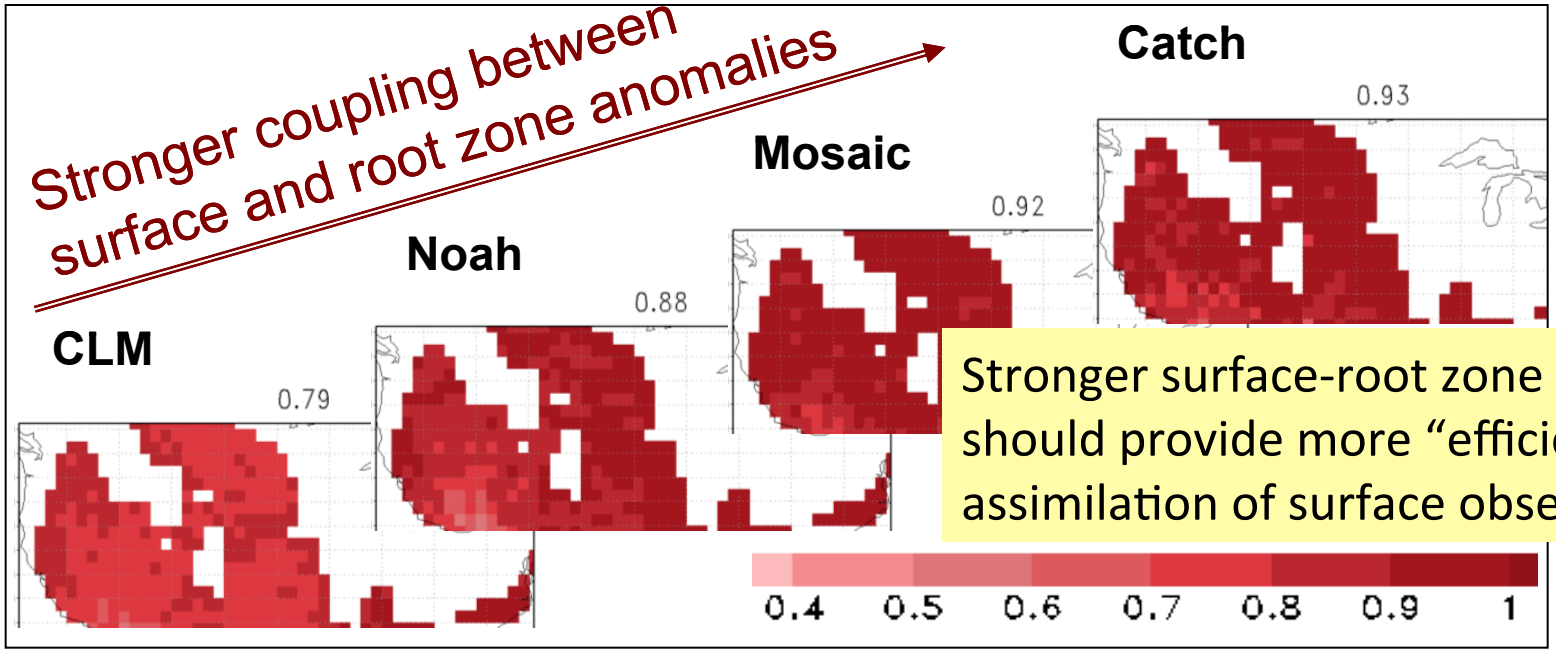
Thank you for your attention!

Any questions?

Heritage pilot study (Kumar et al. 2009)

- How does land model formulation impact assimilation estimates of root zone soil moisture?
- Synthetic soil moisture assimlation with multiple land models but only one assimilation method (EnKF) and only one institution (NASA/GSFC).

		Synthetic observations from			
		Catch	Mos	Noa	CLM
Model	Catch	0.71	0.54	0.36	0.38
	Mos	0.55	0.69	0.31	0.33
	Noa	0.43	0.43	0.36	0.26
	CLM	0.11	0.21	0.10	0.45

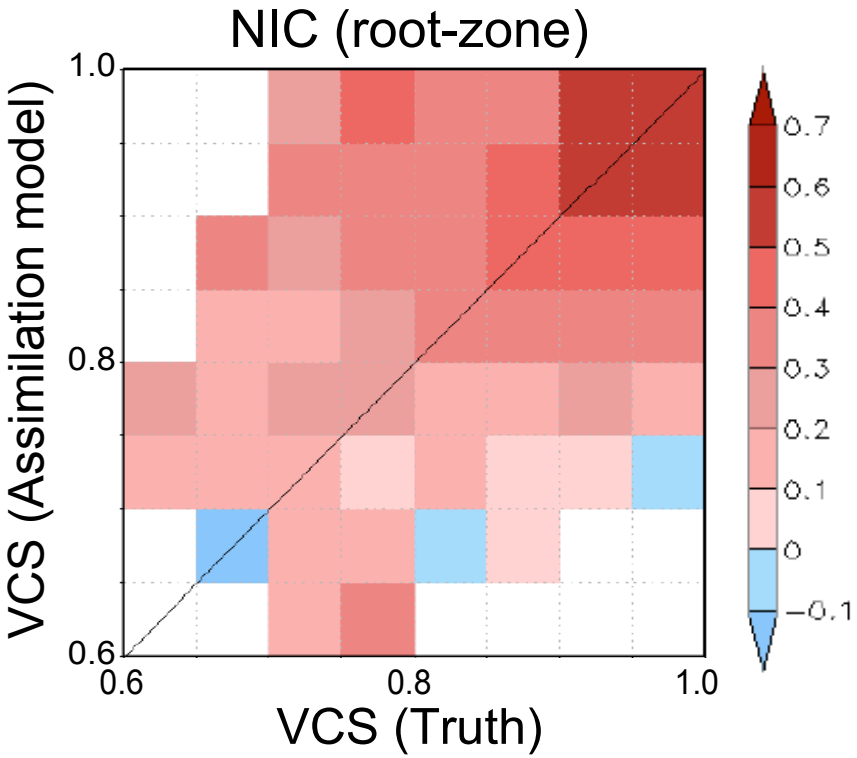


Stronger surface-root zone coupling should provide more "efficient" assimilation of surface observations.

Kumar et al. (2009) Water Resour. Res., doi:10.1175/2009JHM1134.1.

Heritage pilot study (Kumar et al. 2009)

Bin spatially distributed results of all fraternal twin experiments according to vertical coupling strength (VCS):



VCS = vertical coupling strength
NIC = Normalized ROOT ZONE soil moisture improvement from assim. of surface soil moisture

Key findings:

- Identical twin experiments overestimate the skill contributed by the assimilation.
- Stronger coupling between surface and root zone (VCS) leads to more efficient assimilation.
- If assimilation system is properly set up, the skill improvement depends only weakly on the land model.
- It is prudent to overestimate VCS in the assimilation model.

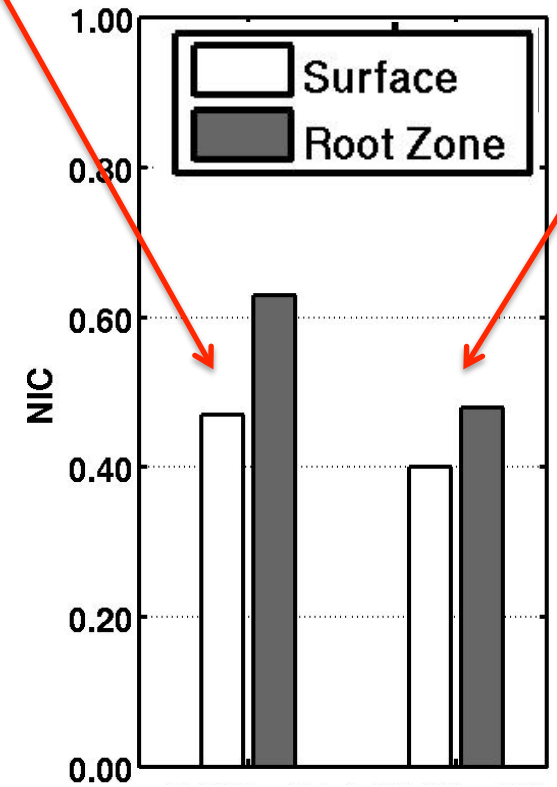
PILDAS-1 Dry-Run (NIC)

LDAS-1 + OBS-1
(vs. Truth-1)
"GEOS-5 **identical** twin exp."

LDAS-1 + OBS-2
(vs. Truth-2)
"GEOS-5 **fraternal** twin exp.

Normalized Information Contribution:

$$NIC = \frac{R_{assim} - R_{model}}{1 - R_{model}}$$



PILDAS-1 will provide an N_A by N_T matrix of such skill graphs.

A variety of performance metrics will be analyzed.

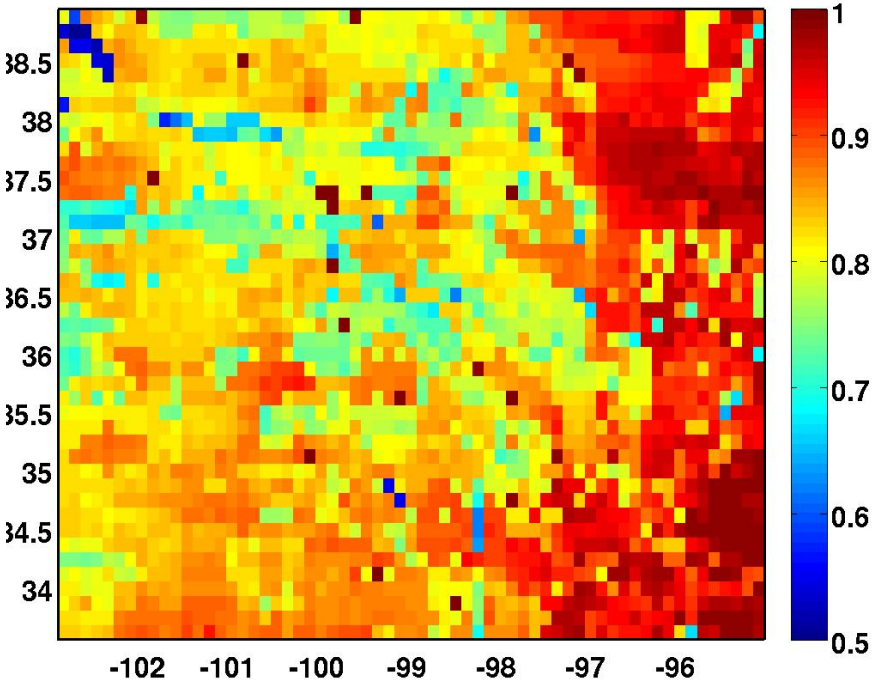
LDAS-1	*= GEOS-5/EnKF*	*+ MERRA forcing*
Truth-1, OBS-1	*= GEOS-5/Catchment*	*+ NLDAS forcing*
Truth-2, OBS-2	*= LIS/Noah*	*+ NLDAS forcing*

PILDAS-1 Dry-Run (VCS)

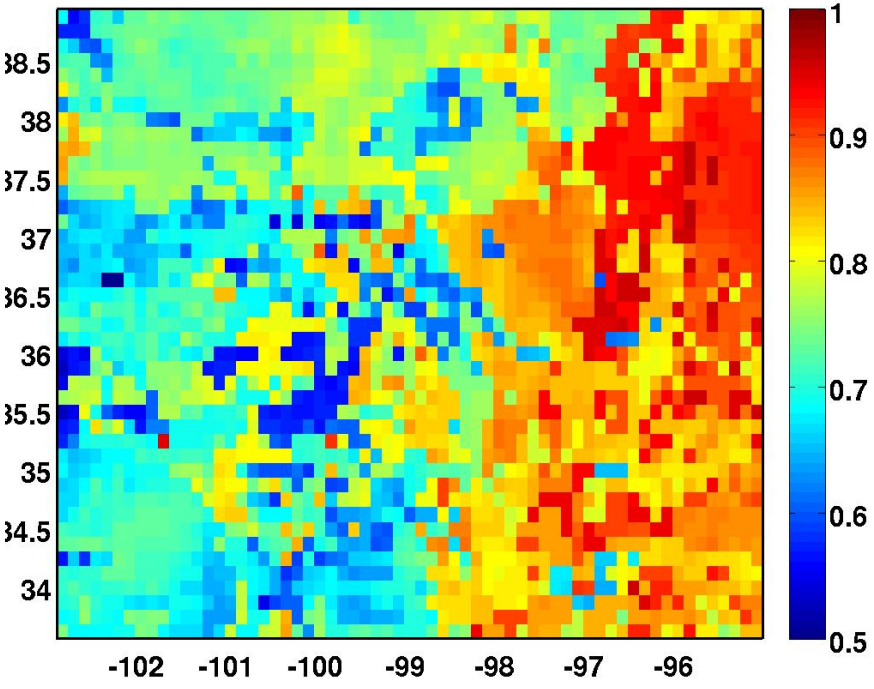
Vertical Coupling Strength (VCS)

- Anomaly time series correlation coeff. betw. surface and root-zone soil moisture.
- Indicates strength of connection between surface and root-zone.

GEOS-5/Catchment + NLDAS
(Truth-1: avg=0.88)



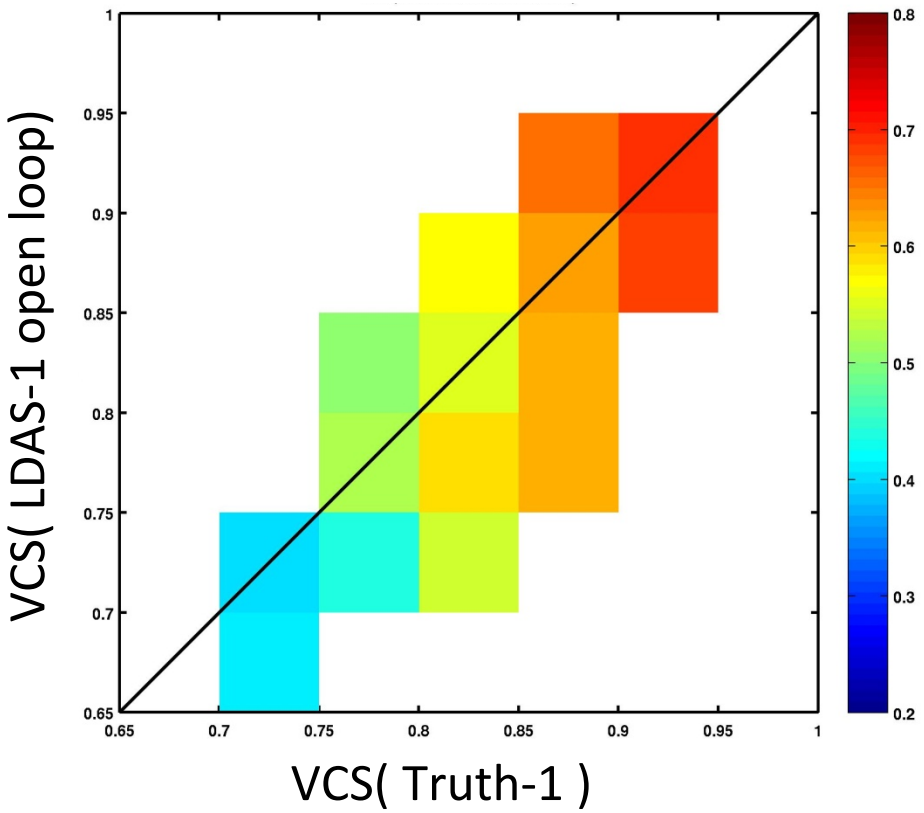
LIS/Noah + NLDAS
(Truth-2: avg=0.77)



PILDAS-1 Dry-Run (VCS, cont'd)

LDAS-1 + OBS-1
(vs. Truth-1)
"GEOS-5 **identical** twin exp."

NIC(root zone soil moisture)



LDAS-1 + OBS-2
(vs. Truth-2)
"GEOS-5 **fraternal** twin exp.

NIC(root zone soil moisture)