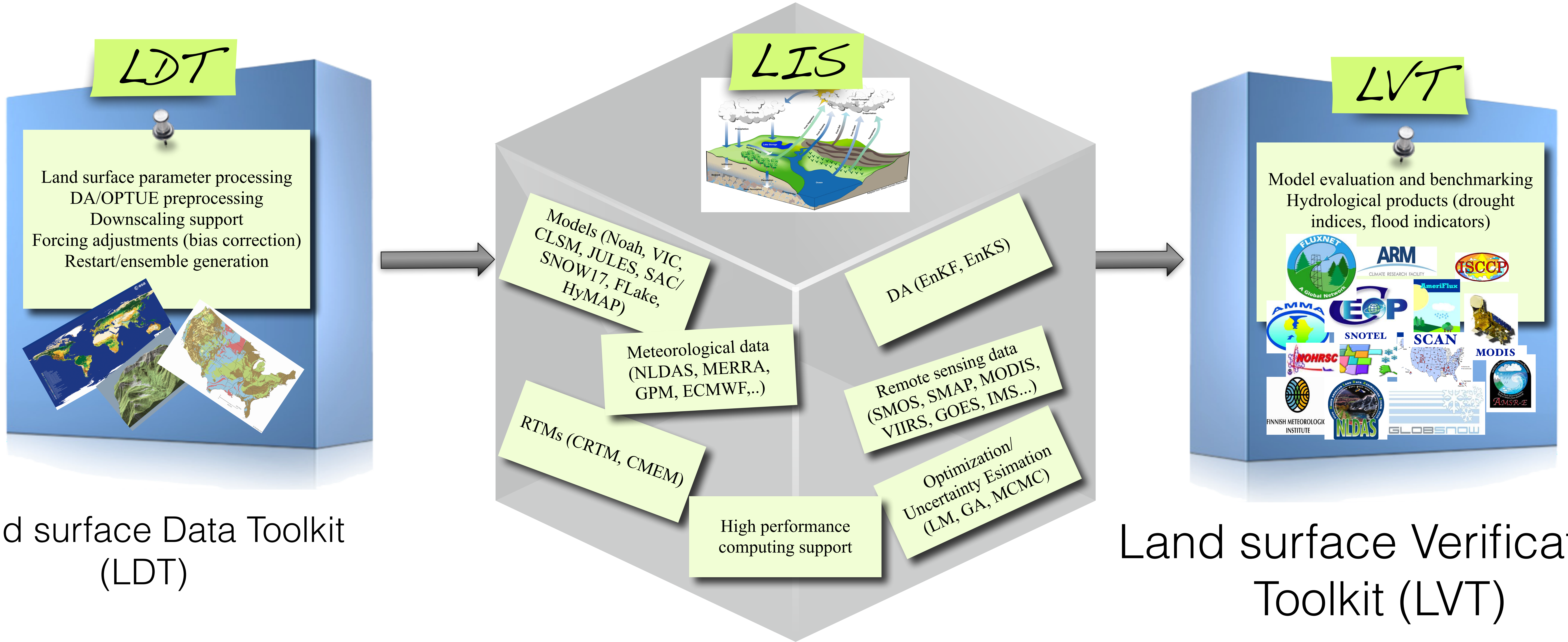
Introduction to Land surface Verification Toolkit (LVT)

Sujay V. Kumar

Science Applications International Corporation/NASA Hydrological Sciences Laboratory



Land surface Data Toolkit (LDT)

Land Information System (LIS)

Land surface Verification Toolkit (LVT)

The LIS modeling suite

Motivation

Entekhabi et al., *BAMS* (1999)

An Agenda for Land Surface Hydrology Research and a Call for the Second International Hydrological Decade

Dara Entekhabi,* Ghassem R. Asrar,+ Alan K. Betts,# Keith J. Beven,& Rafael L. Bras,* Christopher J. Duffy,@ Thomas Dunne,** Randal D. Koster,++ Dennis P. Lettenmaier,## Dennis B. McLaughlin,* William J. Shuttleworth,&& Martinus T. van Genuchten,@@ Ming-Ying Wei,+ and Eric F. Wood***

ABSTRACT

Hydrologic research at the interface between the atmosphere and land surface is undergoing a dramatic change in focus, driven by new societal priorities, emerging technologies, and better understanding of the earth system. In this paper an agenda for land surface hydrology research is proposed in order to open the debate for more comprehensive

Need formal evaluation procedures to improve the "observability" of LSM processes

van den Hurk et al., *BAMS* (2011)

ACCELERATION OF LAND SURFACE MODEL DEVELOPMENT OVER A DECADE OF GLASS

BY BART VAN DEN HURK, MARTIN BEST, PAUL DIRMEYER, ANDY PITMAN, JAN POLCHER, AND JOE SANTANELLO

The Global Land Atmosphere System Study has ushered in an era in which LSMs for numerical weather and climate prediction now incorporate complex vegetation responses, detailed hydrology, dynamic snowpack evolution, urban processes, and more.

Need a general benchmarking framework capable of capturing useful modes of variability of LSMs through a range of performance metrics is necessary for further advancing the performance and predictability of models

- Quantitative measures of fidelity of model simulations are essential for improving the usage and acceptability of model forecasts for real-world applications

- Characterization of accuracy and uncertainty in model predictions - to be used as a benchmark for future model enhancements

Model-Data-Fusion (MDF)

Williams et al., *Biogeosciences* (2009)

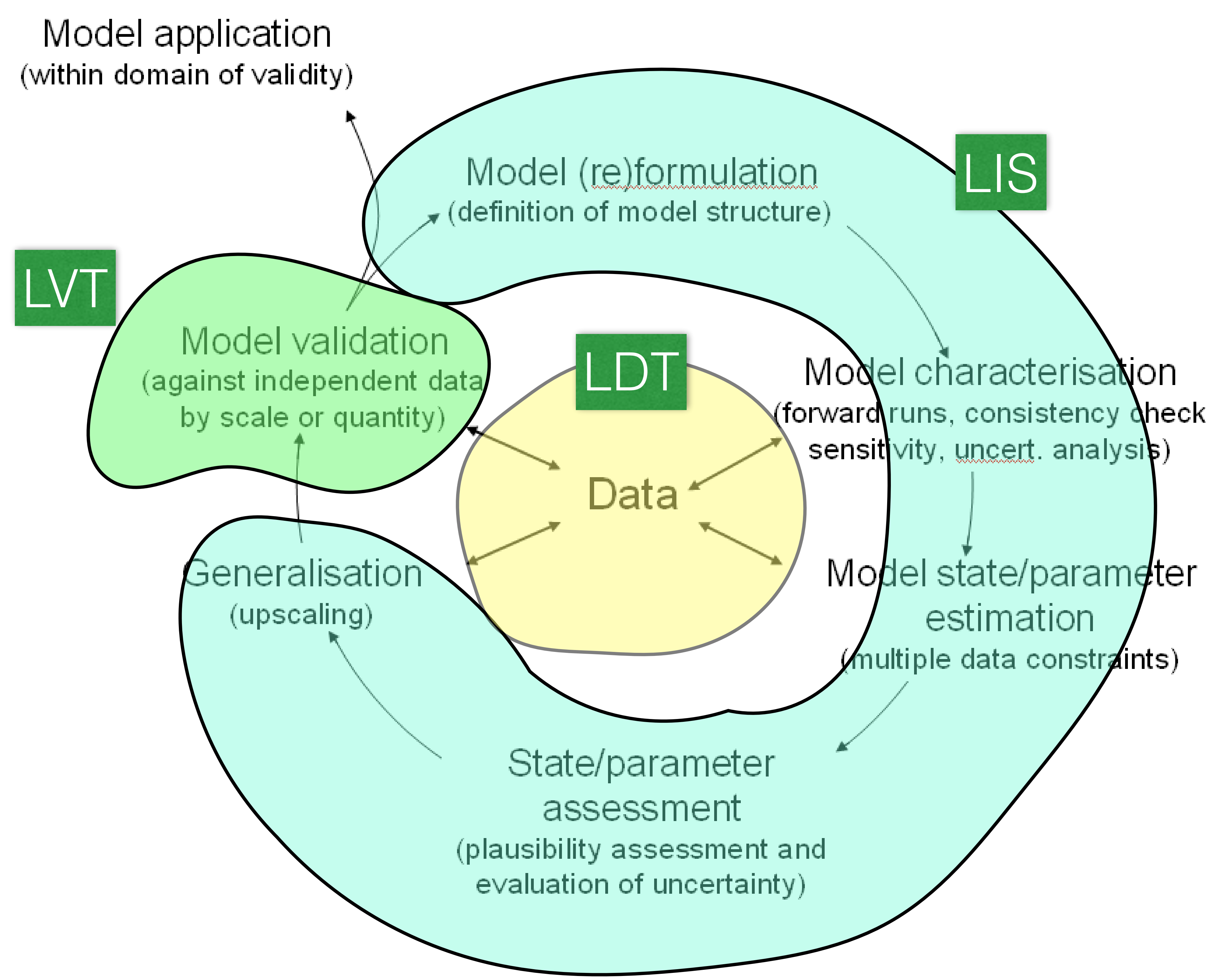
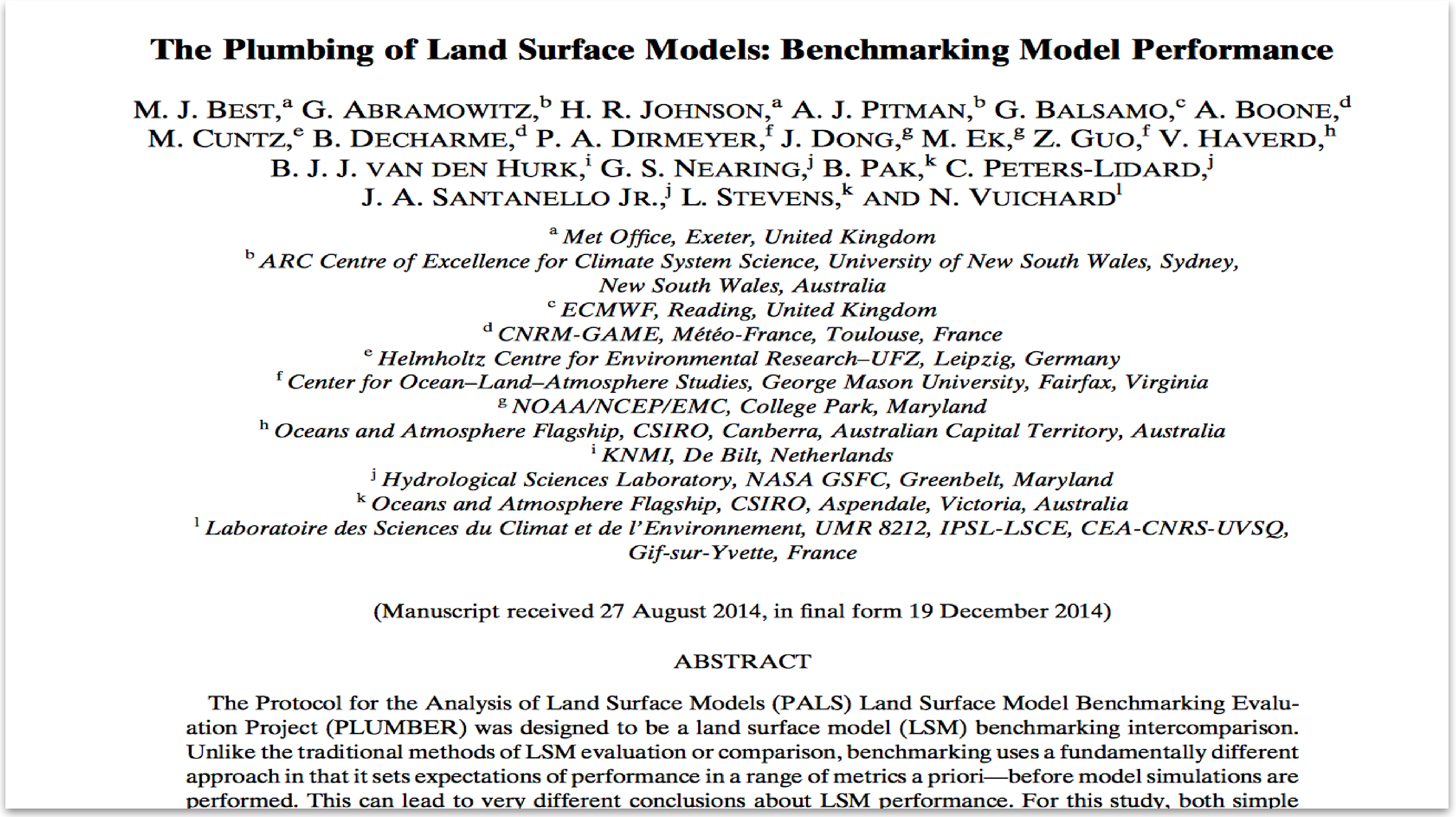


Fig. 1. The multi-stage process for model-data fusion: a conceptual diagram showing the main steps (and the iterative nature of these steps) involved in a comprehensive data-model fusion.

- MDF - the paradigm for combining information from models and data
- Use the information from data to help to formulation, characterization and evaluation of models in a structured manner
- MDF and Benchmarking are two of the core themes of the GEWEX GLASS community
- A comprehensive evaluation and benchmarking framework is essential for enabling the MDF concept

Definitions

LVT functions both as a **verification** and **benchmarking** environment



The Plumbing of Land Surface Models: Benchmarking Model Performance

M. J. Best,[a] G. Abramowitz,[b] H. R. Johnson,[a] A. J. Pitman,[b] G. Balsamo,[c] A. Boone,[d] M. Cuntz,[e] B. Decharme,[d] P. A. Dirmeyer,[f] J. Dong,[g] M. Ek,[g] Z. Guo,[f] V. Haverd,[h] B. J. J. van den Hurk,[i] G. S. Nearing,[j] B. Pak,[k] C. Peters-Lidard,[j] J. A. Santanello Jr.,[j] L. Stevens,[k] and N. Vuichard[l]

[a] Met Office, Exeter, United Kingdom
[b] ARC Centre of Excellence for Climate System Science, University of New South Wales, Sydney, New South Wales, Australia
[c] ECMWF, Reading, United Kingdom
[d] CNRM-GAME, Météo-France, Toulouse, France
[e] Helmholtz Centre for Environmental Research–UFZ, Leipzig, Germany
[f] Center for Ocean–Land–Atmosphere Studies, George Mason University, Fairfax, Virginia
[g] NOAA/NCEP/EMC, College Park, Maryland
[h] Oceans and Atmosphere Flagship, CSIRO, Canberra, Australian Capital Territory, Australia
[i] KNMI, De Bilt, Netherlands
[j] Hydrological Sciences Laboratory, NASA GSFC, Greenbelt, Maryland
[k] Oceans and Atmosphere Flagship, CSIRO, Aspendale, Victoria, Australia
[l] Laboratoire des Sciences du Climat et de l'Environnement, UMR 8212, IPSL-LSCE, CEA-CNRS-UVSQ, Gif-sur-Yvette, France

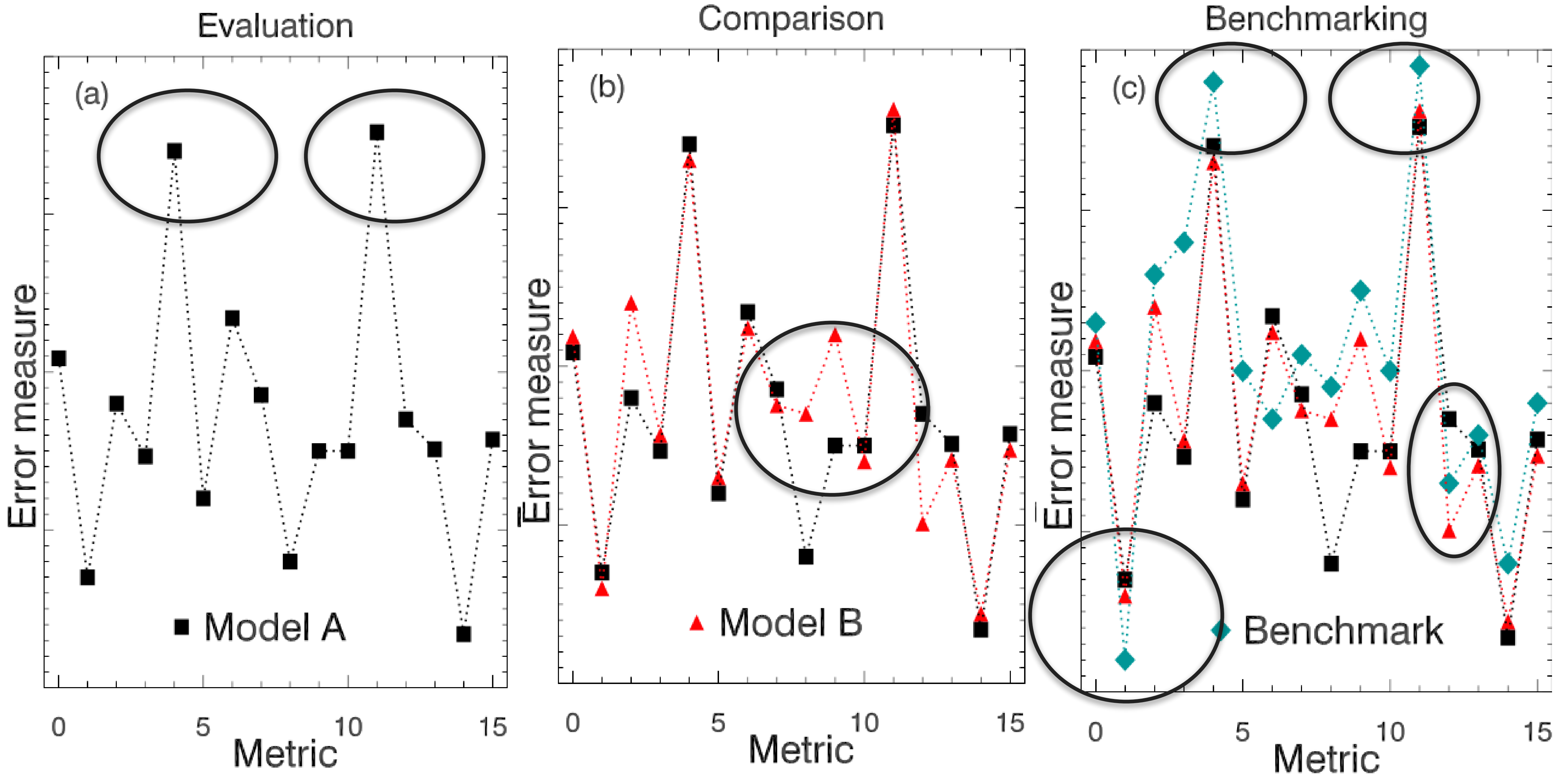
(Manuscript received 27 August 2014, in final form 19 December 2014)

ABSTRACT

The Protocol for the Analysis of Land Surface Models (PALS) Land Surface Model Benchmarking Evaluation Project (PLUMBER) was designed to be a land surface model (LSM) benchmarking intercomparison. Unlike the traditional methods of LSM evaluation or comparison, benchmarking uses a fundamentally different approach in that it sets expectations of performance in a range of metrics a priori—before model simulations are performed. This can lead to very different conclusions about LSM performance. For this study, both simple

ver·i·fi·ca·tion
/ˌverəfəˈkāSH(ə)n/
noun
the process of establishing the truth, accuracy, or validity of something.
"the verification of official documents"
synonyms: confirmation, substantiation, proof, corroboration, support, attestation, validation, authentication, endorsement

bench·mark
/ˈben(t)SHmärk/
verb
gerund or present participle: **benchmarking**
evaluate or check (something) by comparison with a standard.
"we are **benchmarking** our performance **against** external criteria"



- **Evaluation** - model outputs are compared to observations to derive an error measure
- **Comparison** - model is not just compared to observations, but also to other models
- **Benchmarking** - performance expectation defined a priori

source: Best et al. (2015)

Comparisons (MIPs ..)

- Identifies metrics for which one model performs better than another, or where errors in multiple models are systematic
- Indicates where performance improvements are possible/not possible relative to other models
- Too much reliance on model comparisons - models may end up being developed too similar to each other

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ALMIP AMMA Land Surface Model Intercomparison Project

ILAMB THE INTERNATIONAL LAND MODEL BENCHMARKING PROJECT

C-LAMP is the **Carbon-Land Model intercomparison Project**

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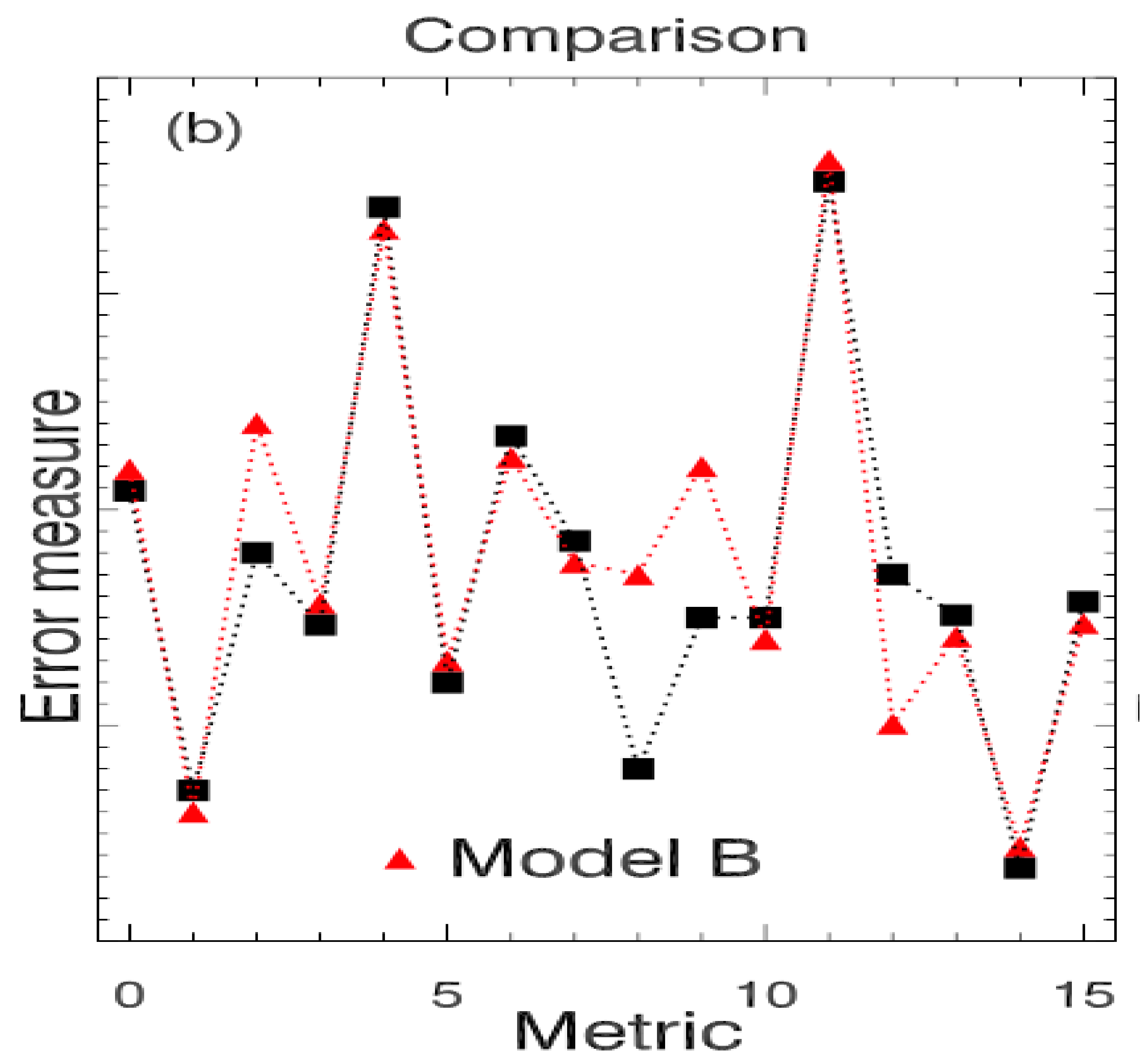


Benchmarking

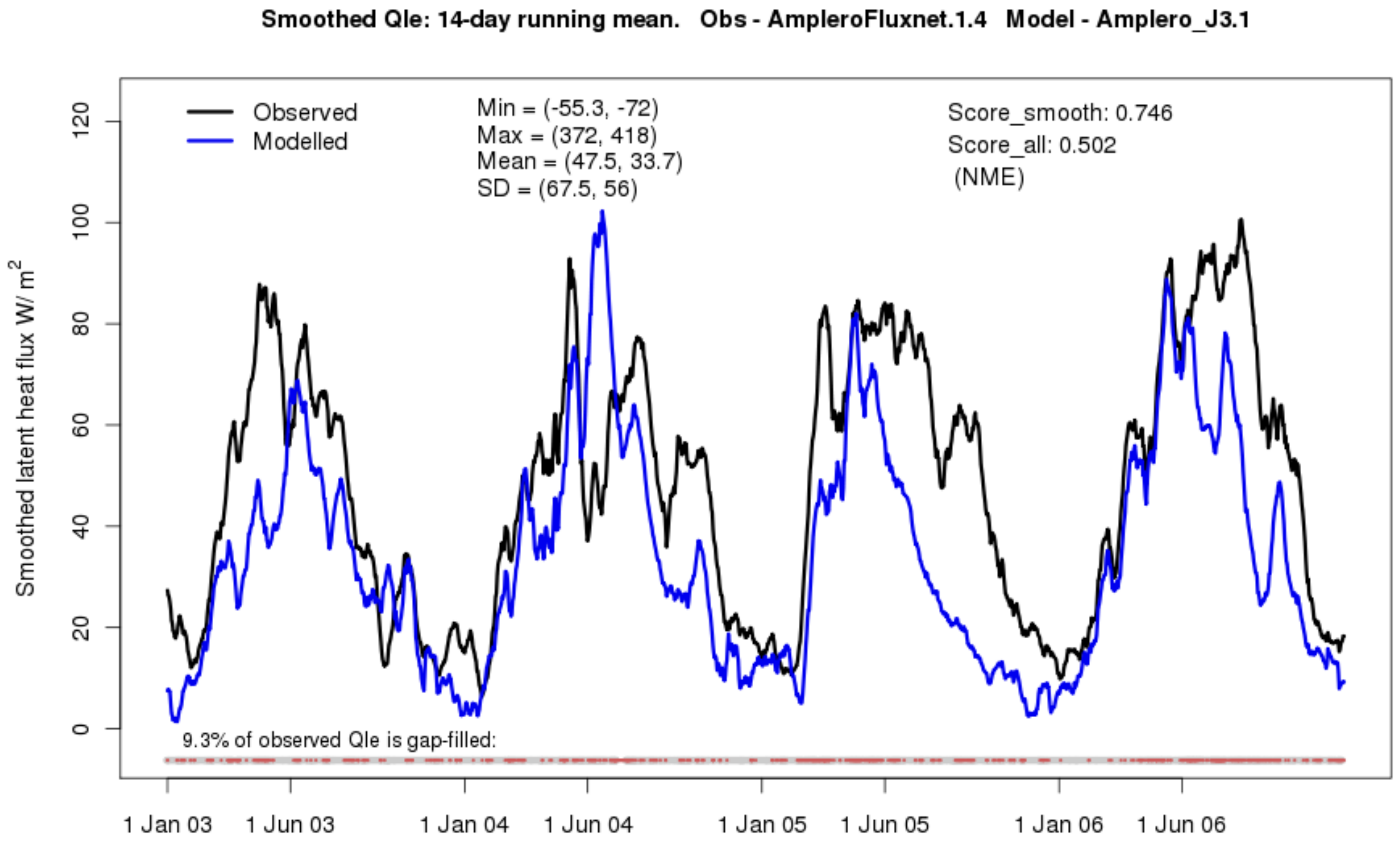
- Simply comparing models and observations – canonical "evaluation" – can't tell us whether any of the models are doing a good job

- Benchmarking involves defining expectations of performance in any metric of interest *a priori* – **before** running model. Options include:

  - previous model version (weak – both models could be poor)

  - fit for a particular application (stronger / useful – can tell us if a model is "good enough")

  - effectively utilizes available information (strong – can give us an objective definition of whether a model is "good") - defines a priori expectations based on the complexity of the model and the amount of information given to it.



- We would typically accept this as a good simulation (good correlation visually)

- Benchmarking will reveal that this is in fact a poor simulation

source: Gab Abramowitz

Benchmarking example

- How well should we expect a LSM to predict latent heat (Qle) flux at Amplero site?

    1. Take several (19) flux tower sites other than Amplero

    2. Train a linear regression between downward shortwave radiation and Qle

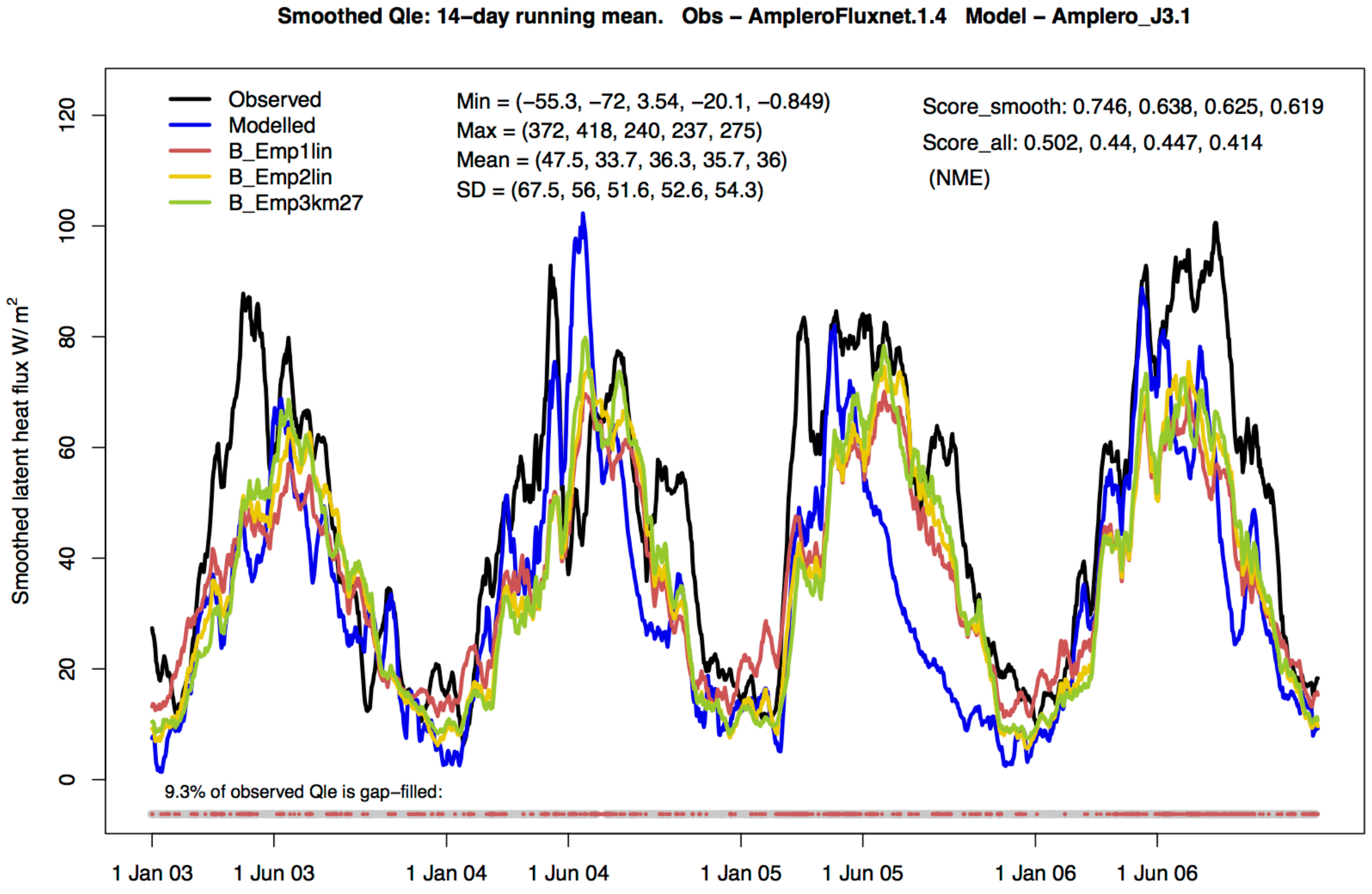
    3. Use these regression parameters to predict Qle at Amplero using site meteorology

- This will tell us:

    - The extent to which Qle is predictable from SWdown alone.

    - How predictable Qle is at Amplero site - is it unusually difficult?

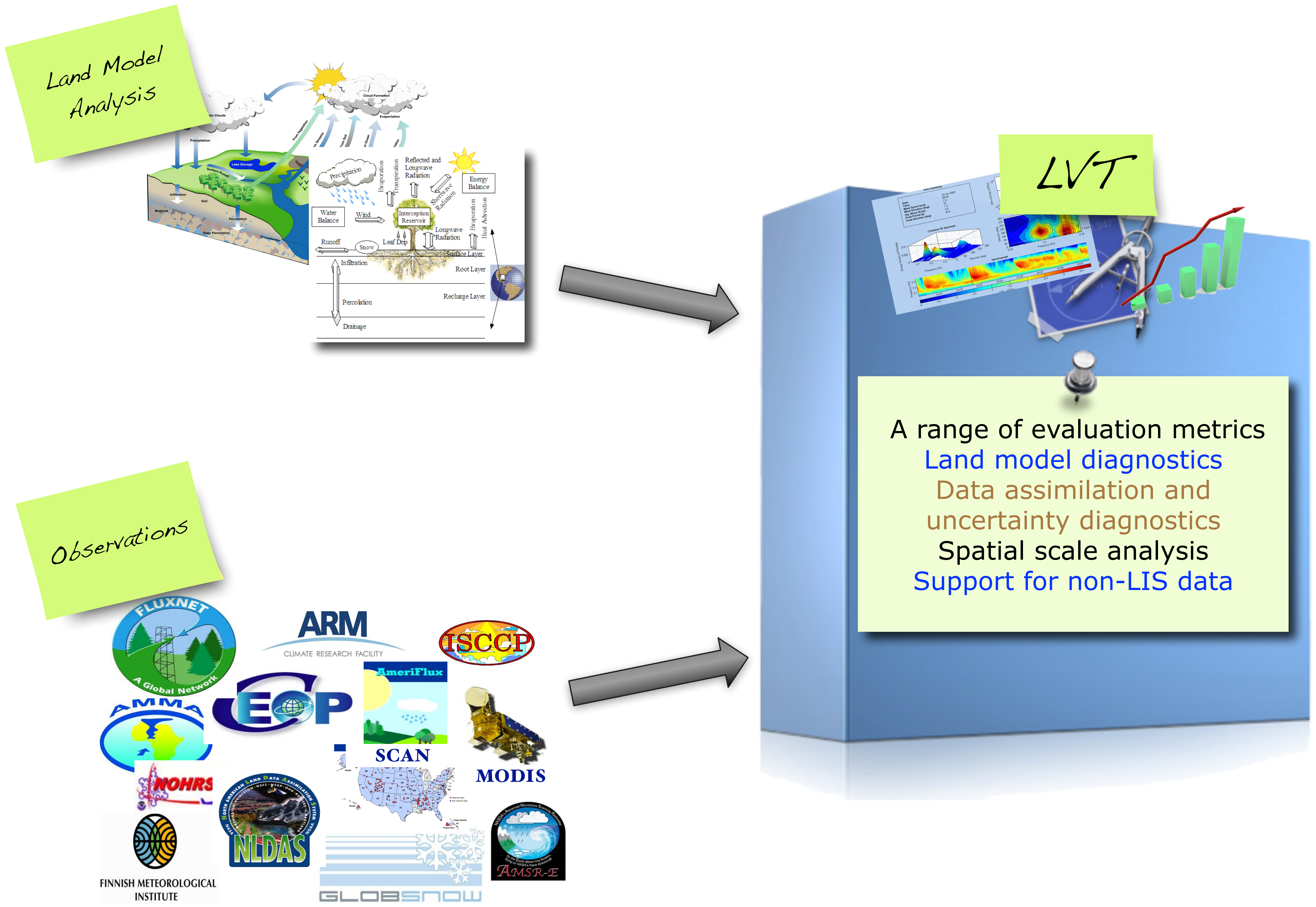
Even the 1-variable regression beats the model!



source: Gab Abramowitz

LVT - original structure

- LIS was/is being used in many different configurations (557, NCEP, NOHRSC, CRREL, NRL, NLDAS, GLDAS, FLDAS, MSFC, NU-WRF, ICBA, …)
- LIS outputs being produced in many different formats (grib, NetCDF, binary), different resolutions, map projections, modes (tile, grid, ensembles)
- The typical next step is to compare the model outputs to reference datasets for evaluation
- LVT was originally designed to bridge this gap - by having a framework that allows the comparison of **LIS output against other datasets**



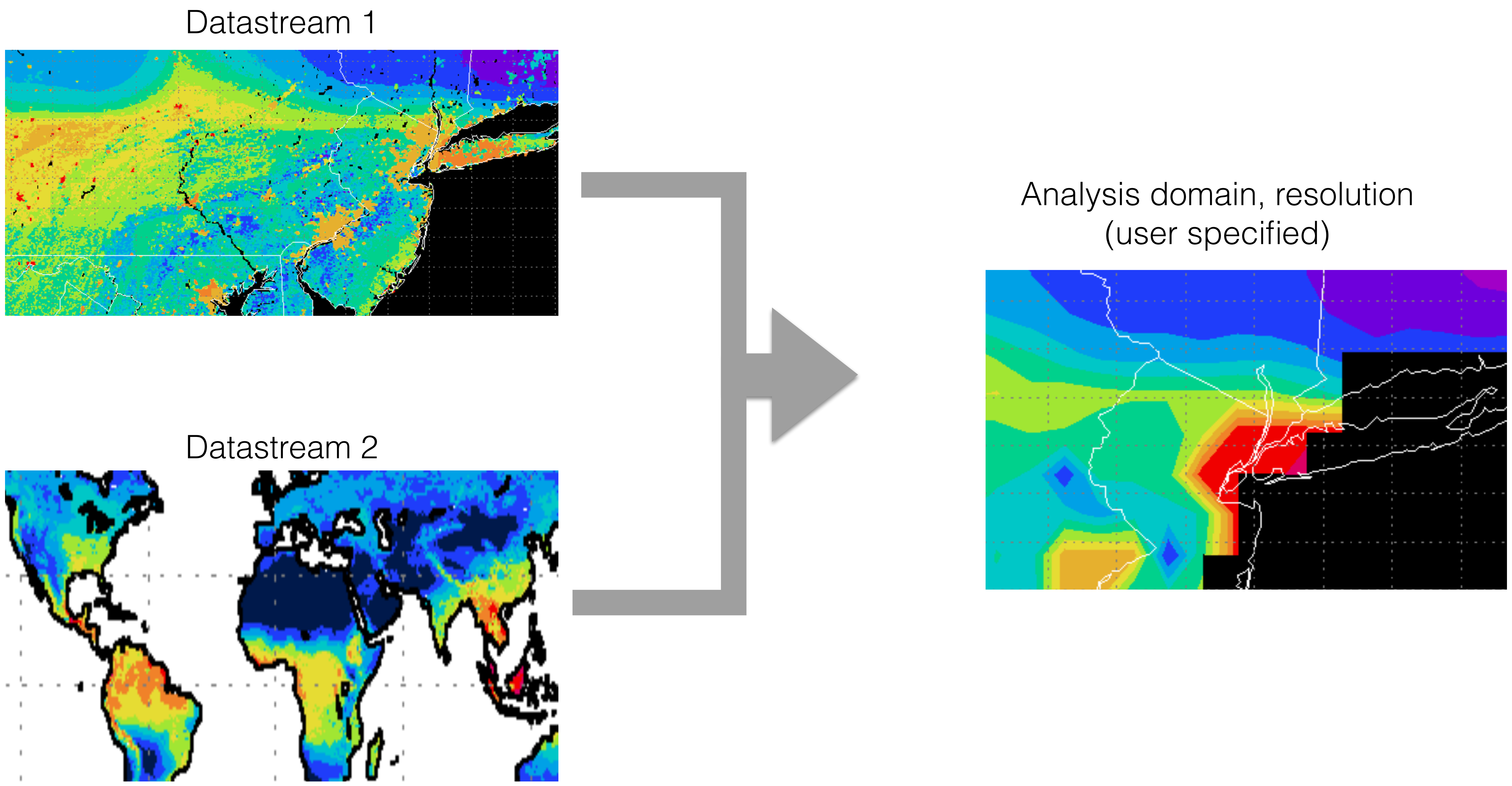
- **Includes support for a range of in-situ, remote sensing and model/ renalysis products**
- **Supports the analysis of outputs from various LIS subsystems (LIS-DA, LIS-OPT/UE)**
- **Includes the capability to generate end-user oriented hydrological products (drought/flood percentiles, indicators)**
- **Very LIS-reliant, non-LIS datasets require pre-processing to make them “LIS-like”**

LVT - current structure

- Redesigned to handle **any two land relevant datasets** (need not be a LIS output)
- In addition to all other existing capabilities, some initial benchmarking capabilities have been developed
- The supported datasets in LVT can be used to develop benchmarks using simple (regression) to more complex (ANN-ish) methods

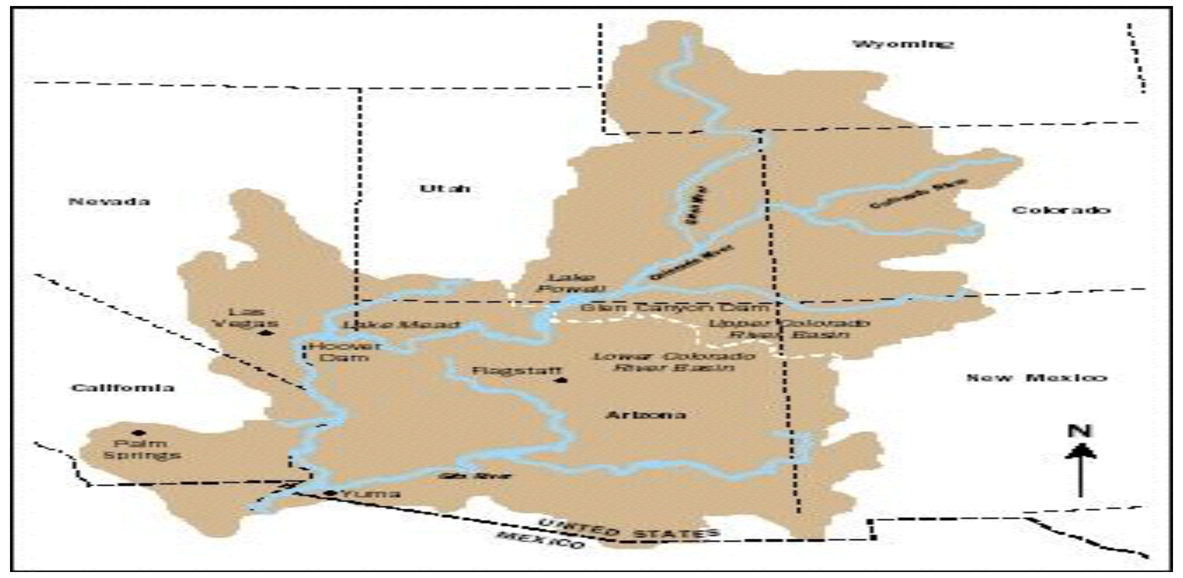
General capabilities

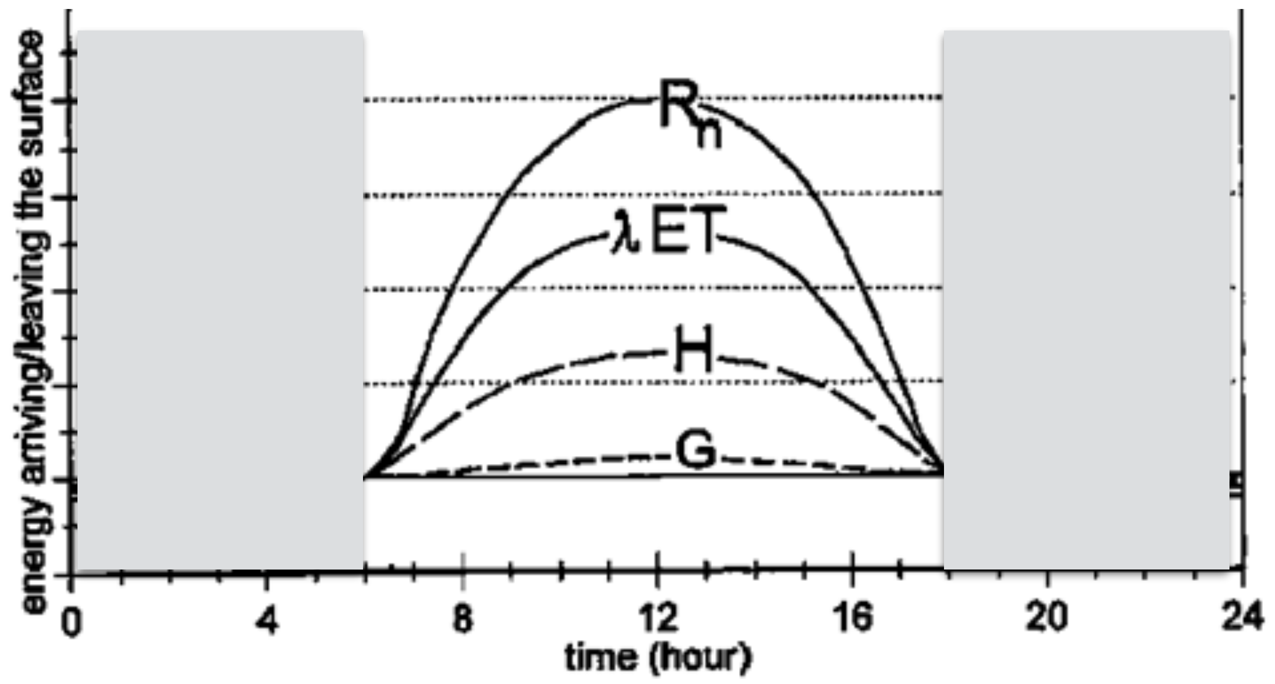
- Reconciles the differences in spatial and temporal resolutions between the two datastreams being compared, by bringing them to a common (user specified space and time domain)

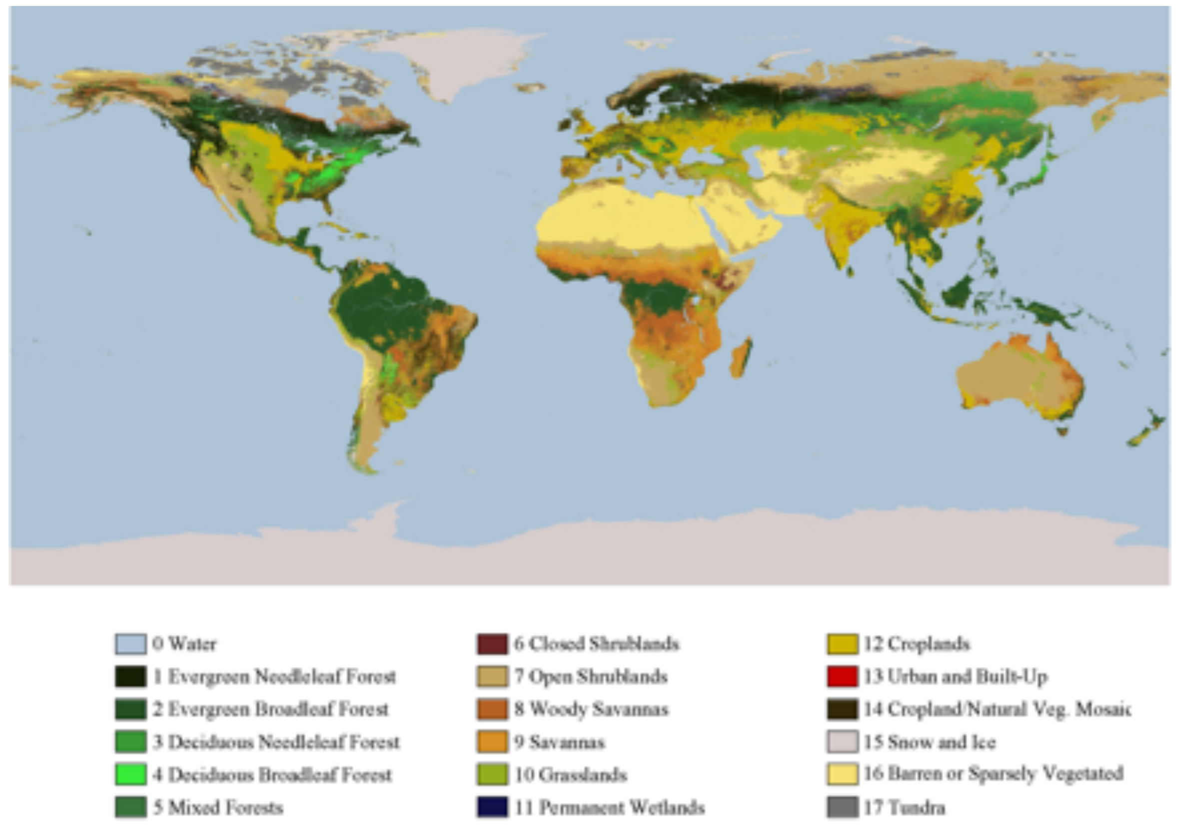


General capabilities

- ☆ Emphasis on supporting datasets natively, as much as possible - Users can download the data by themselves and employ them in LVT
    - ☆ E.g. ARM-CART (NetCDF), AGRMET (Grib), SCAN in-situ (ASCII) …
    - ☆ A reader/processor needs to be built for each dataset
- Many options for masking/stratification of metrics
    - Data count based mask
    - External static mask
    - External time varying mask
    - Variable-based stratification (e.g. day-night stratification using SWdown)
    - External data based stratification (e.g. landcover, soils, elevation)







RMSE for Evergreen Needleleaf Forest

RMSE for Evergreen Broadleaf Forest

RMSE for Deciduous Needleleaf Forest

RMSE for Deciduous Broadleaf Forest

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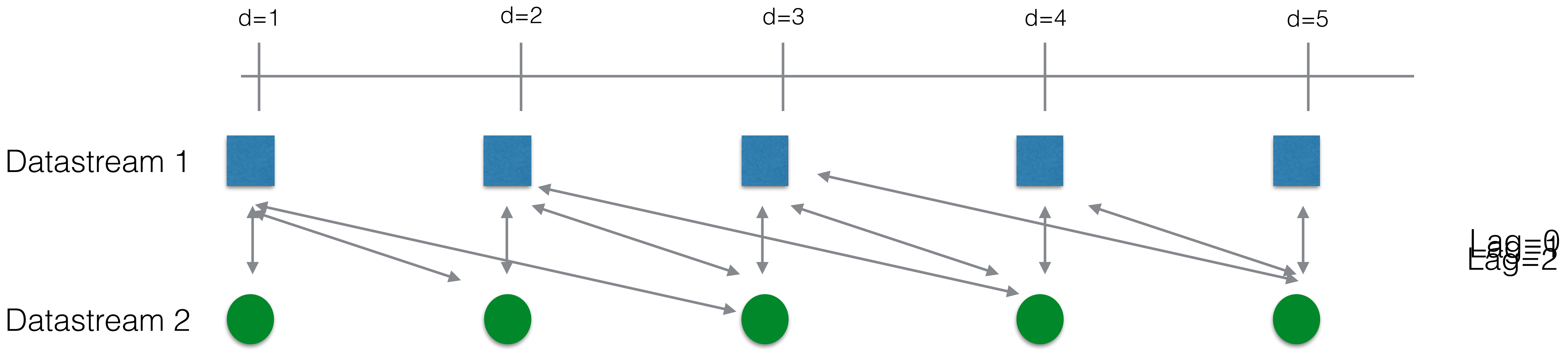
General capabilities

- ⭐ Analysis outputs provided in both gridded (NetCDF/binary) and ASCII formats

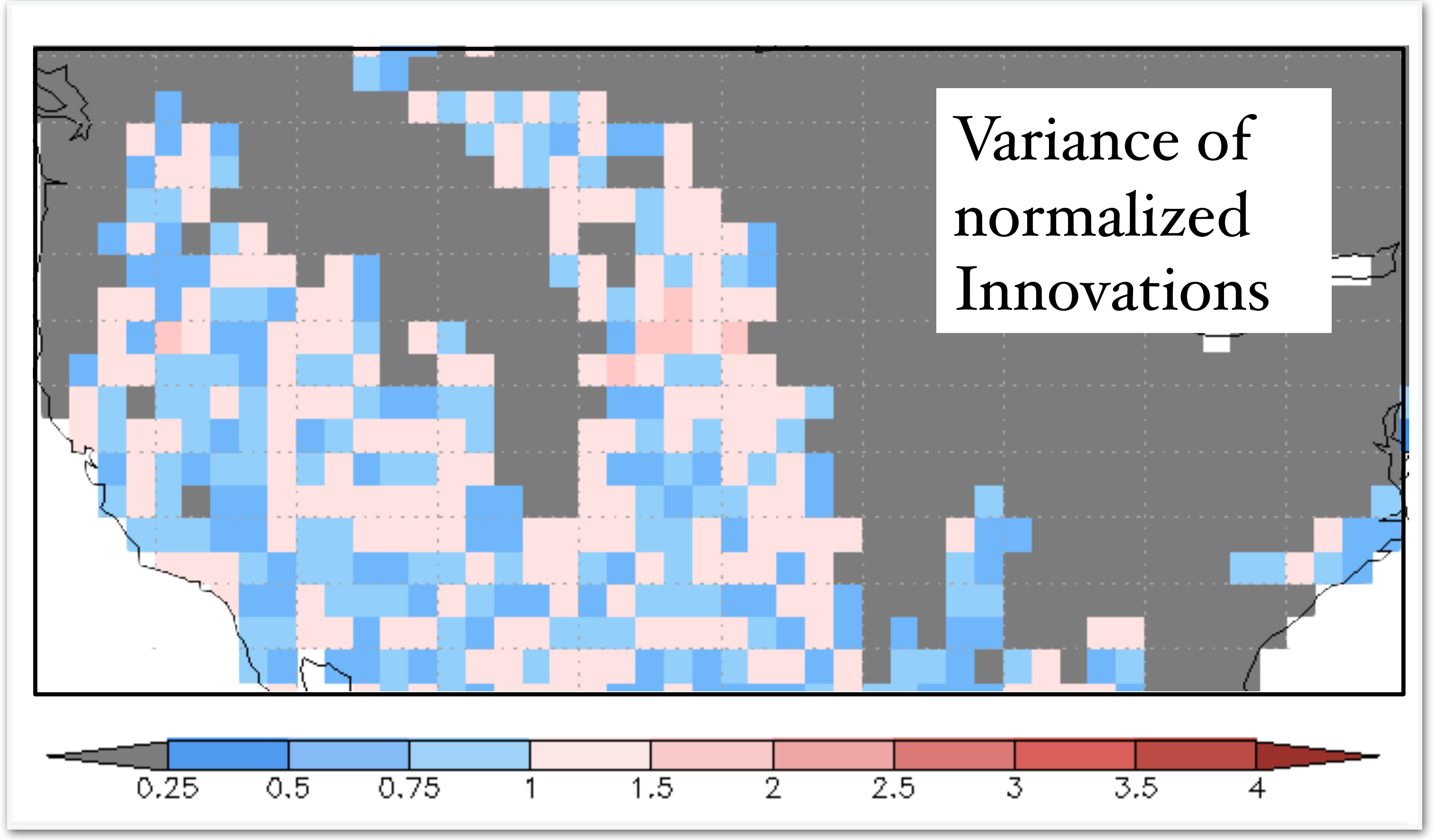
- ⭐ Time-lagged computations



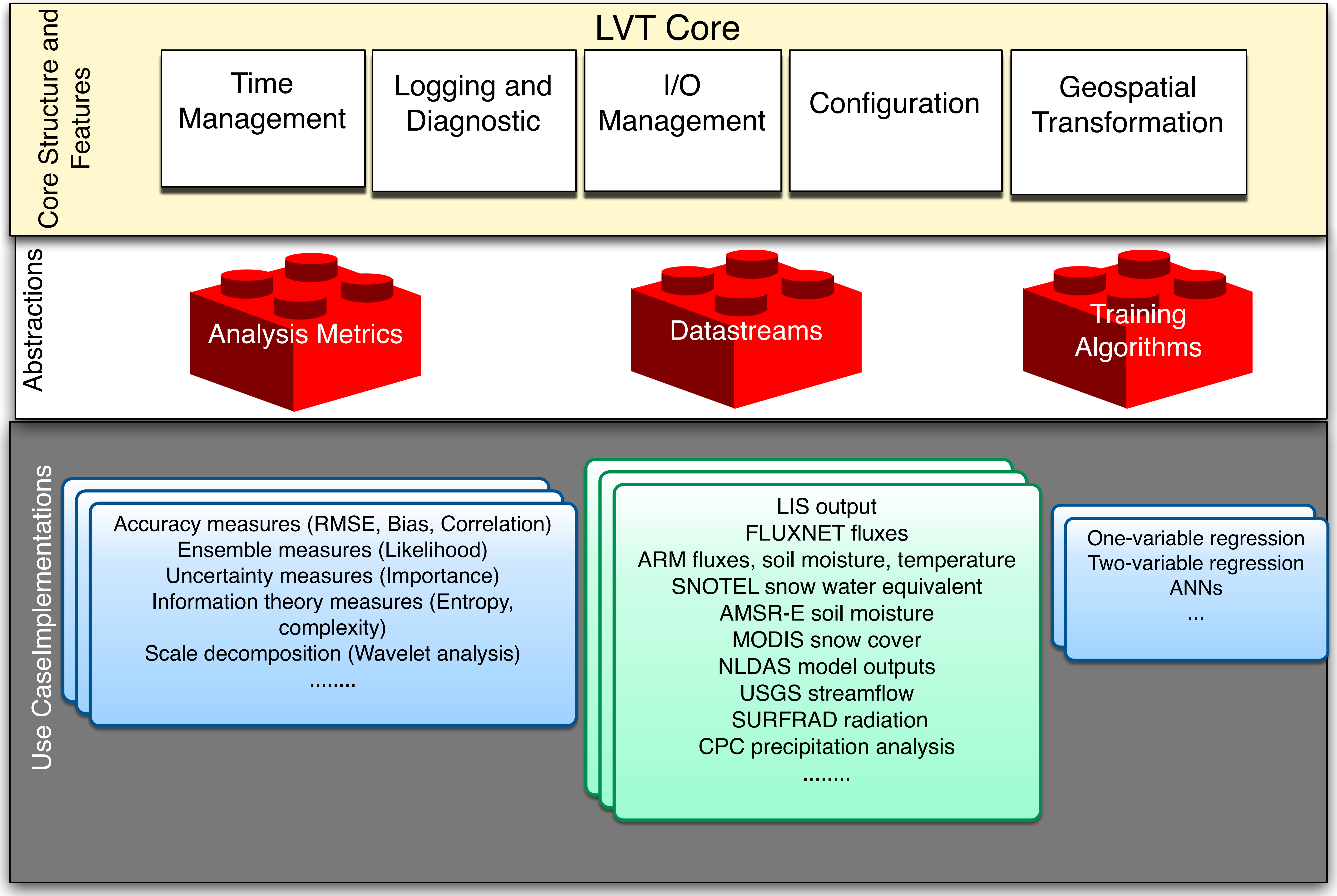
- ⭐ Supports water-year (flexible year specification)
  - ⭐ User specifies the starting month of the year specification
- ⭐ Smoothing support (limited)
  - ⭐ Uses a moving window average for the computation of analysis metrics
- ⭐ Computes confidence intervals (currently CIs in the spatial domain is supported; It will be extended to include temporal CIs)

General capabilities

- Spatial averaging modes for analysis metric can be computed on a pixel-by-pixel basis or at basin averaged basis
  - Pixel-by-pixel - each pixel in datastream 1 is compared to a pixel in datastream 2
  - Basin-averaged - datastream 1 and 2 values are averaged to the basin scale and then compared using the analysis metric
- Computes derived variables
  - e.g. Bowen ratio can be computed through LVT (and used for analysis) if both Qle and Qh are present, A column averaged, weighted root zone soil moisture if individual soil moisture layer values are present
  - Energy/Water/Evaporation balance values
- Analysis metric computations are performed
  - Across the entire analysis period
  - At specified temporal intervals
  - Average seasonal/diurnal cycles (if specified by the user)
- Supports outputs from all LIS computational subsystems
  - Data assimilation diagnostics from the LIS-DA output

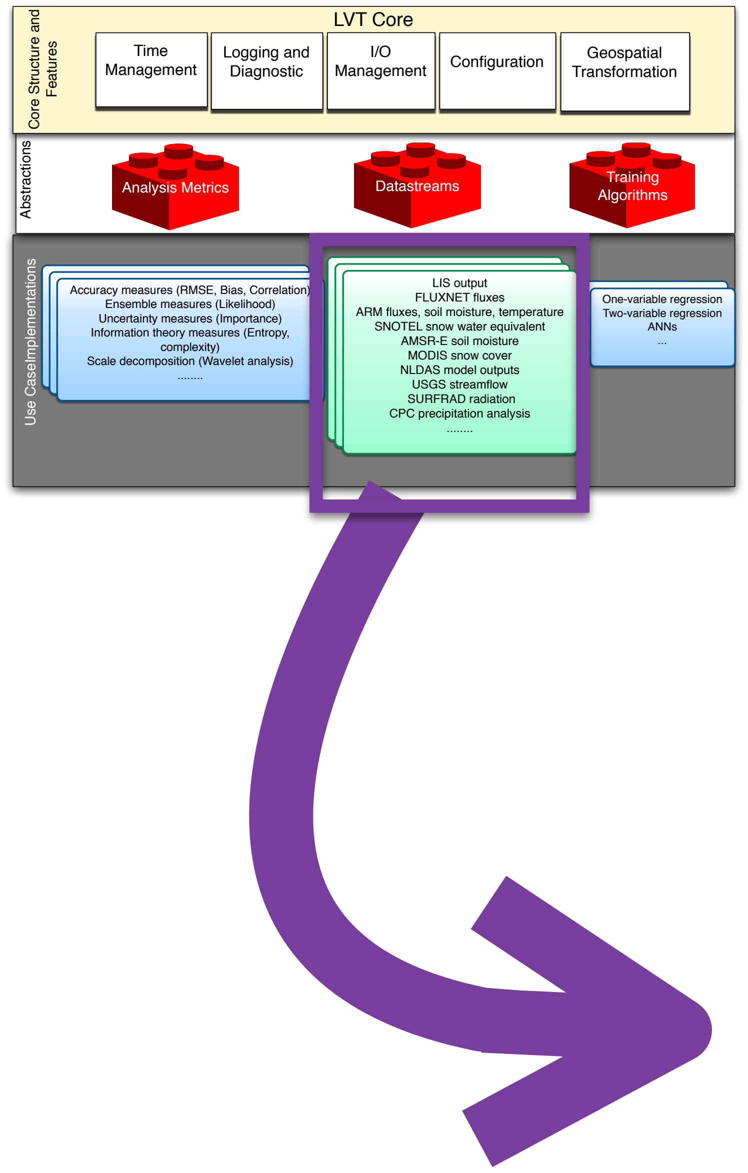


Software architecture



- 3-layer architecture
- Specified as an object oriented framework with plugins defined for
  - Analysis metrics
  - Datastreams
  - Training algorithms
- Analysis instances are enabled by a config file (no external scripting required)

Supported data streams



In-situ

- ☑ Ameriflux fluxes
- ☑ ARM fluxes, soil moisture, soil temperature
- ☑ ARS soil moisture
- ☑ CEOP fluxes, soil moisture, soil temperature
- ☑ CPC precipitation
- ☑ FLUXNET fluxes
- ☑ FMI SWE
- ☑ GHCN snow depth
- ☑ GLERL lake fluxes, temperature
- ☑ ISMN soil moisture
- ☑ NASMD soil moisture
- ☑ PBOH2O soil moisture, snow depth
- ☑ SCAN soil moisture
- ☑ SMOSREX soil moisture
- ☑ SNODEP snow depth metobs
- ☑ SNOTEL SWE
- ☑ SURFRAD radiation
- ☑ USGS streamflow
- ☑ USGS groundwater
- ☑ ..

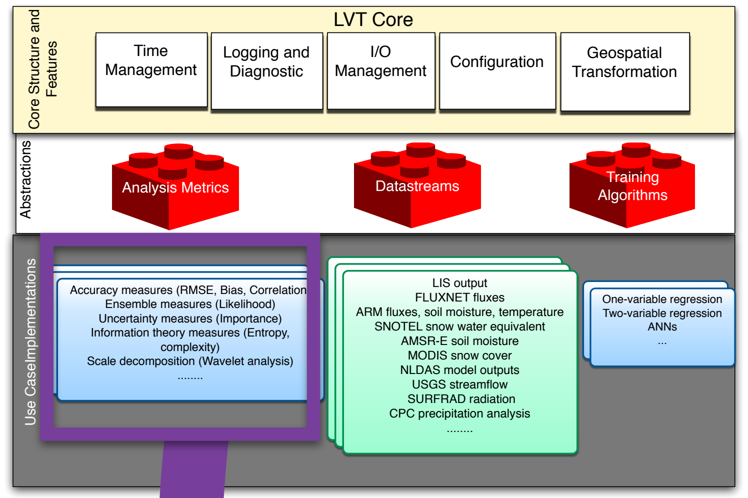
Satellite/Remote Sensing

- ☑ ALEXI
- ☑ AMSR-E SWE/snowdepth
- ☑ LPRM AMSR-E soil moisture
- ☑ ESA CCI soil moisture
- ☑ GIMMS NDVI
- ☑ GlobSnow SWE
- ☑ GRACE TWS
- ☑ ISCCP LST
- ☑ MOD10A1 snow cover
- ☑ MOD16A2 ET
- ☑ MODIS LST
- ☑ SMOPS soil moisture
- ☑ SMOS L1 Tb
- ☑ SMOS L2 soil moisture
- ☑ UW ET
- ☑ …

Model/Reanalysis

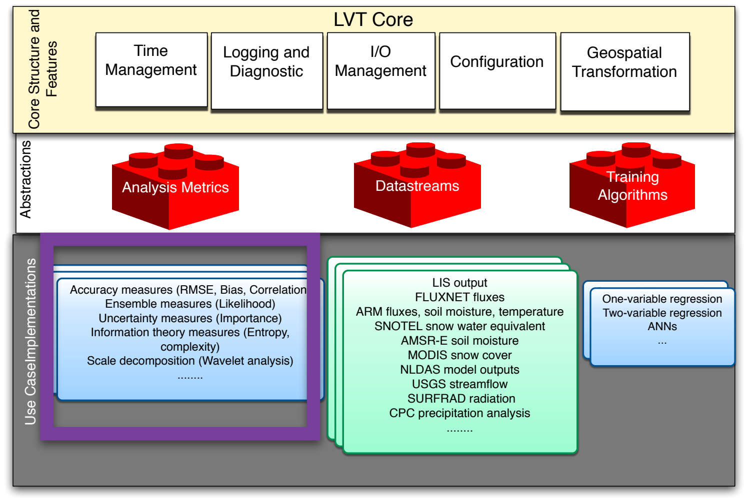
- ☑ AGRMET
- ☑ GLDAS2
- ☑ NLDAS2
- ☑ LIS outputs
- ☑ MERRA2
- ☑ SNODAS
- ☑ CMC
- ☑ GL6 JULES
- ☑ ERA interim Land
- ☑ MERRA Land
- ☑ COAMPS
- ☑ ….

Supported analysis metrics



Metric class	Examples
Diagnostics	Mean, Standard deviation, Anomaly, Tendency, Min, Max, Sum, Maxtime, Mintime
Accuracy	ACC, Bias, CSI, ETS, FAR, FBIAS, MAE, NSE, PODY, PODN, POFD, Correlation, Anomaly Correlation, Tendency Correlation, unbiased RMSE
Indicators	SPI, SRI, SSWI, SSGI, percentiles, probabilistic percentiles
Ensemble	Mean, Likelihood, Spread, Cross correlation, ME
Information theory	Metric entropy, Information gain, Effective complexity, Fluctuation complexity
Scale decomposition	Discrete wavelet transforms
Spatial similarity	Hausdorff norm

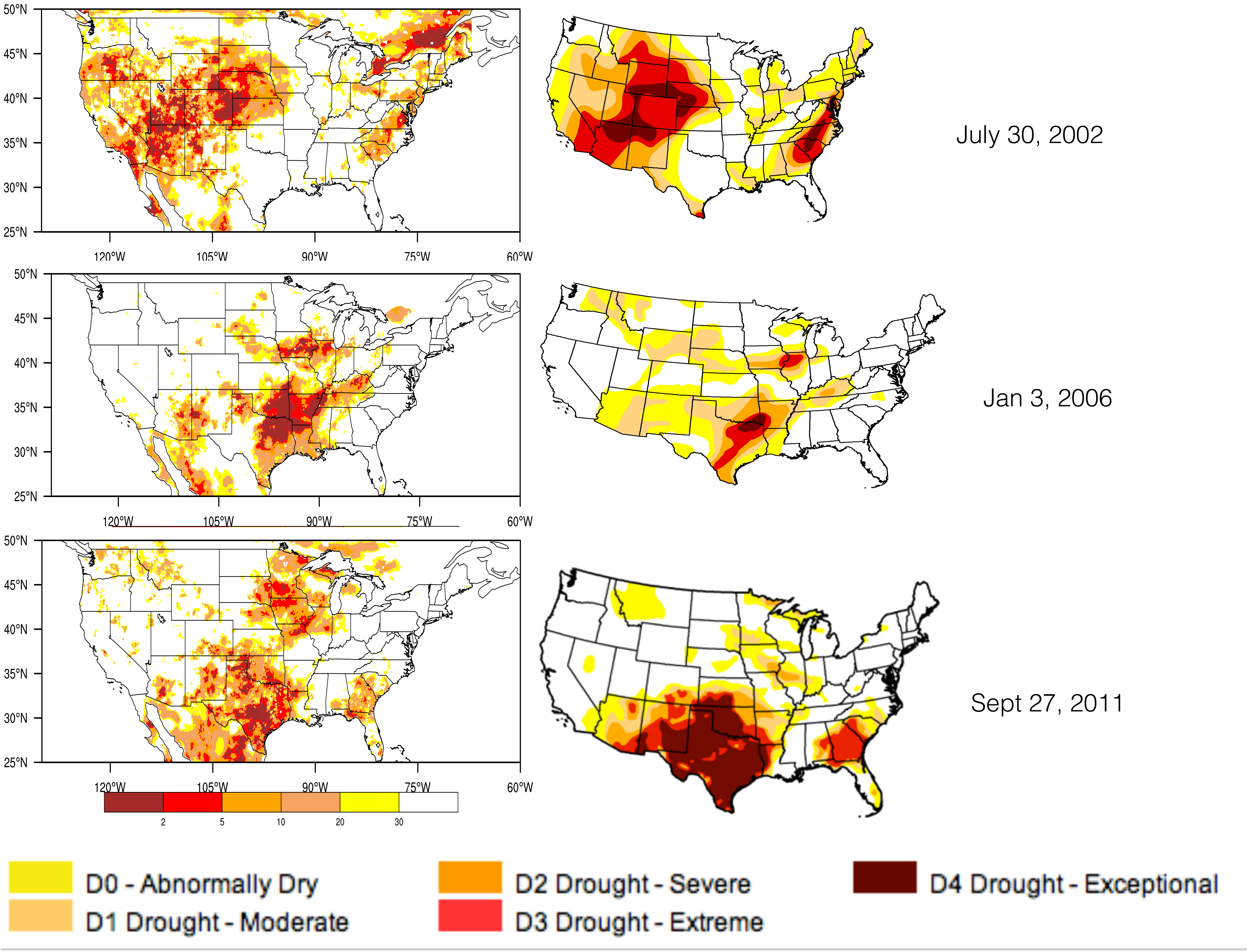
Examples of indicators



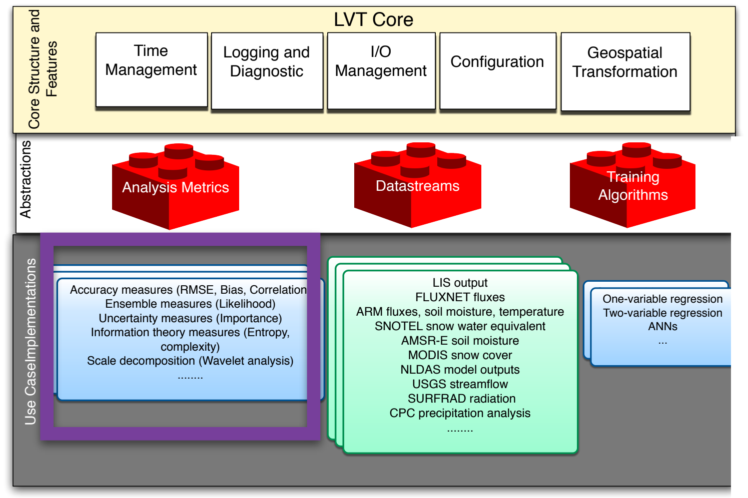
- A suite of common, normalized indicators has been developed
  - SPI, SRI, SSWI, SSGI, percentiles
- These indicators are computed as deviations from long term (fitted/ computed) distributions

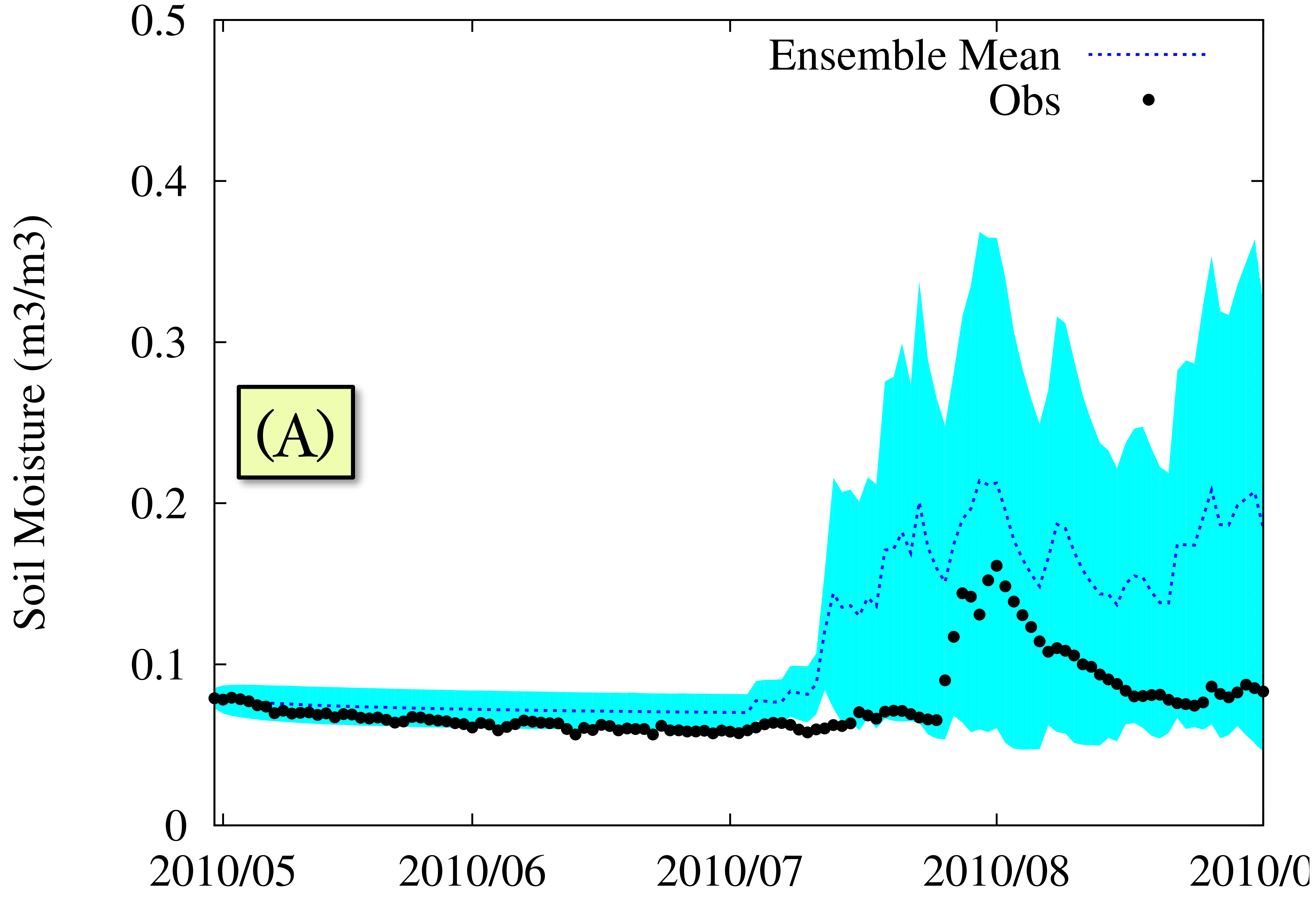
Root zone soil moisture based drought percentiles generated by LVT from a LIS simulation

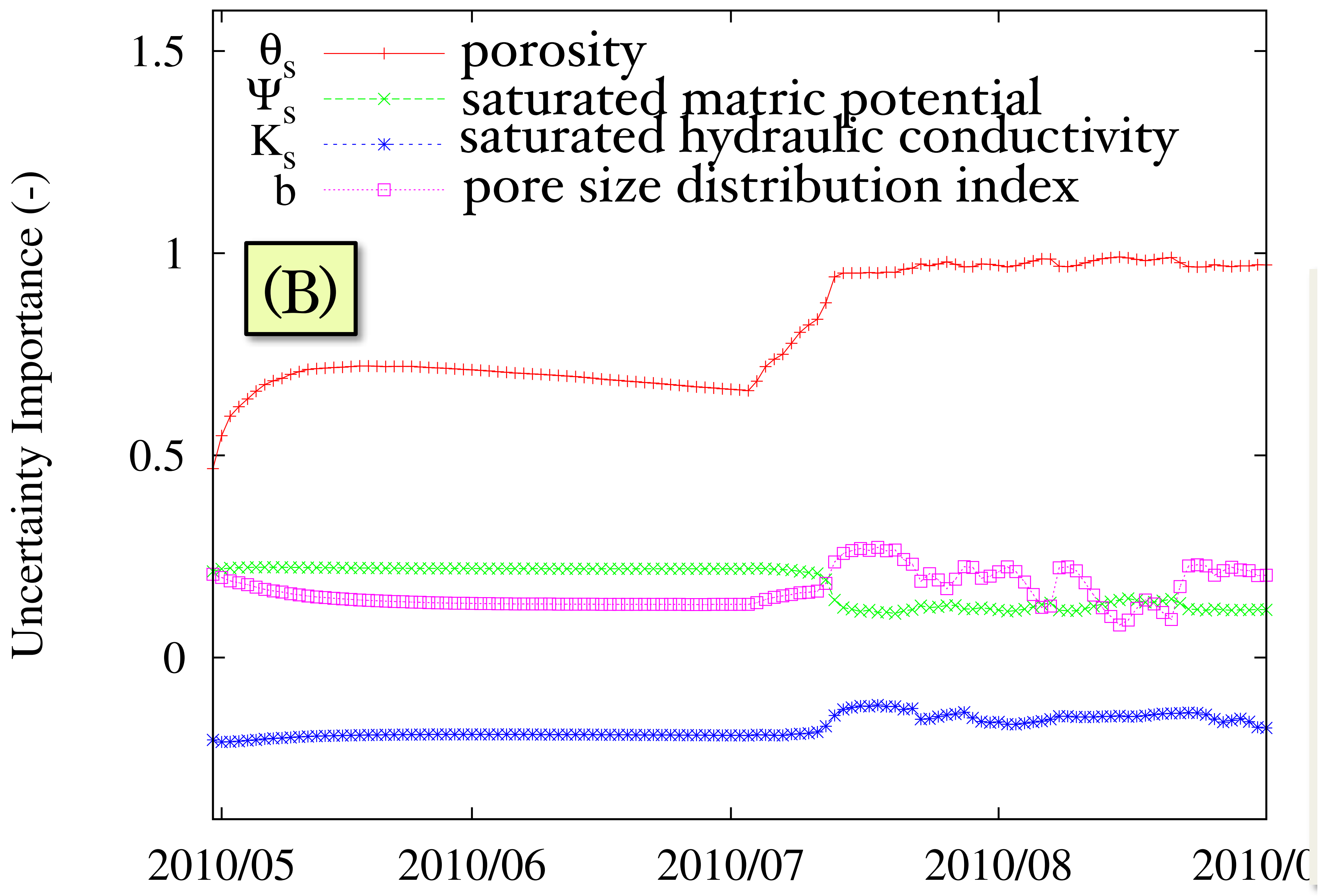
U.S. Drought Monitor estimate



Examples of ensemble analysis

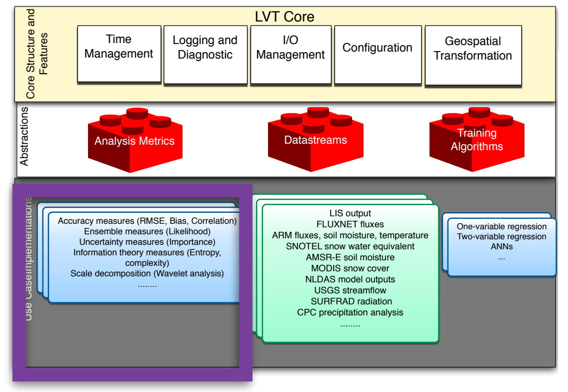




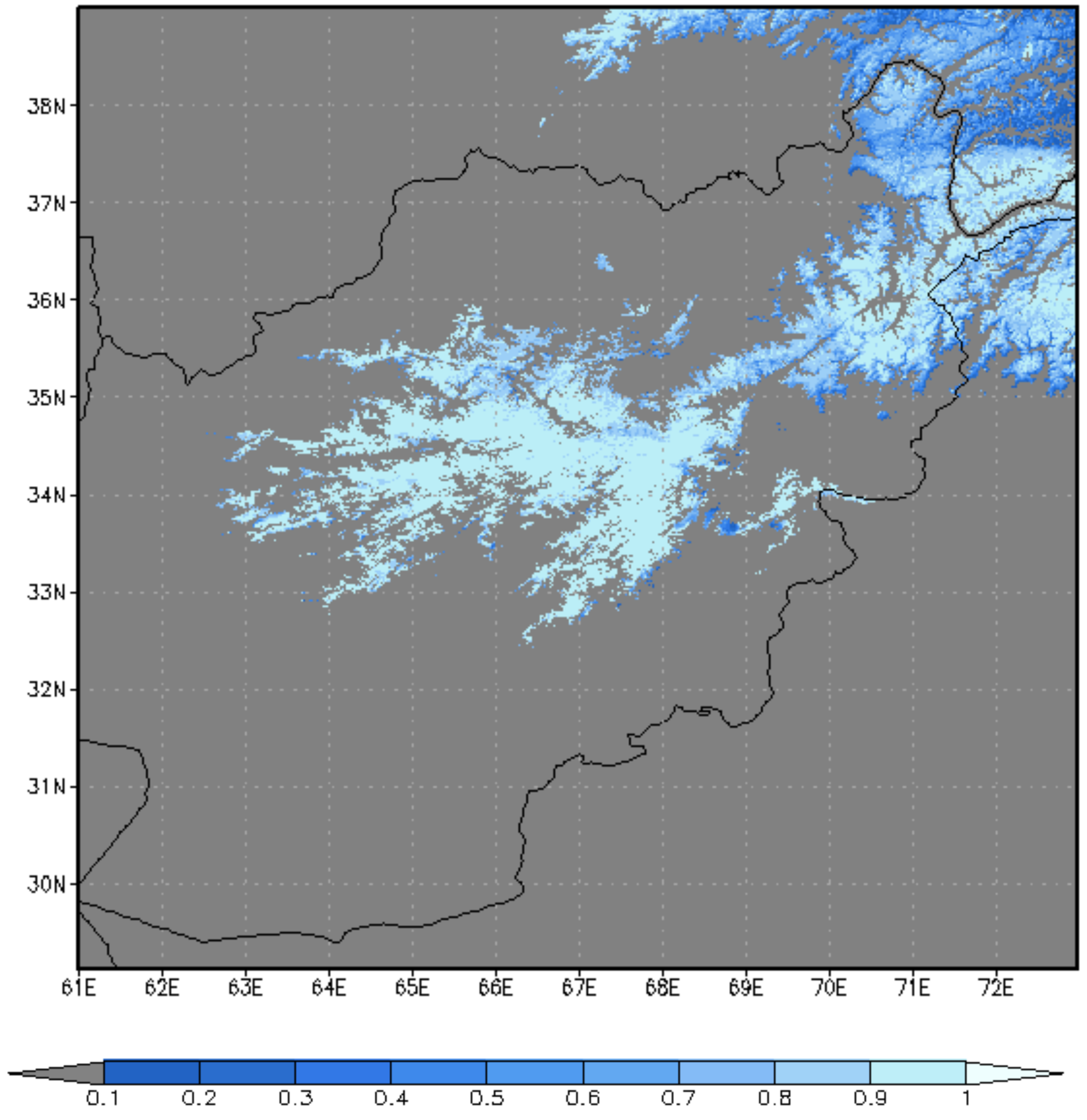


- Uncertainty importance: An assessment of the relative contribution of each parameter to the ensemble spread (cross correlation between the simulated variable and the parameter, across the ensemble)
- Can be used to guide parameter optimization/uncertainty estimation studies

Scale decomposition features

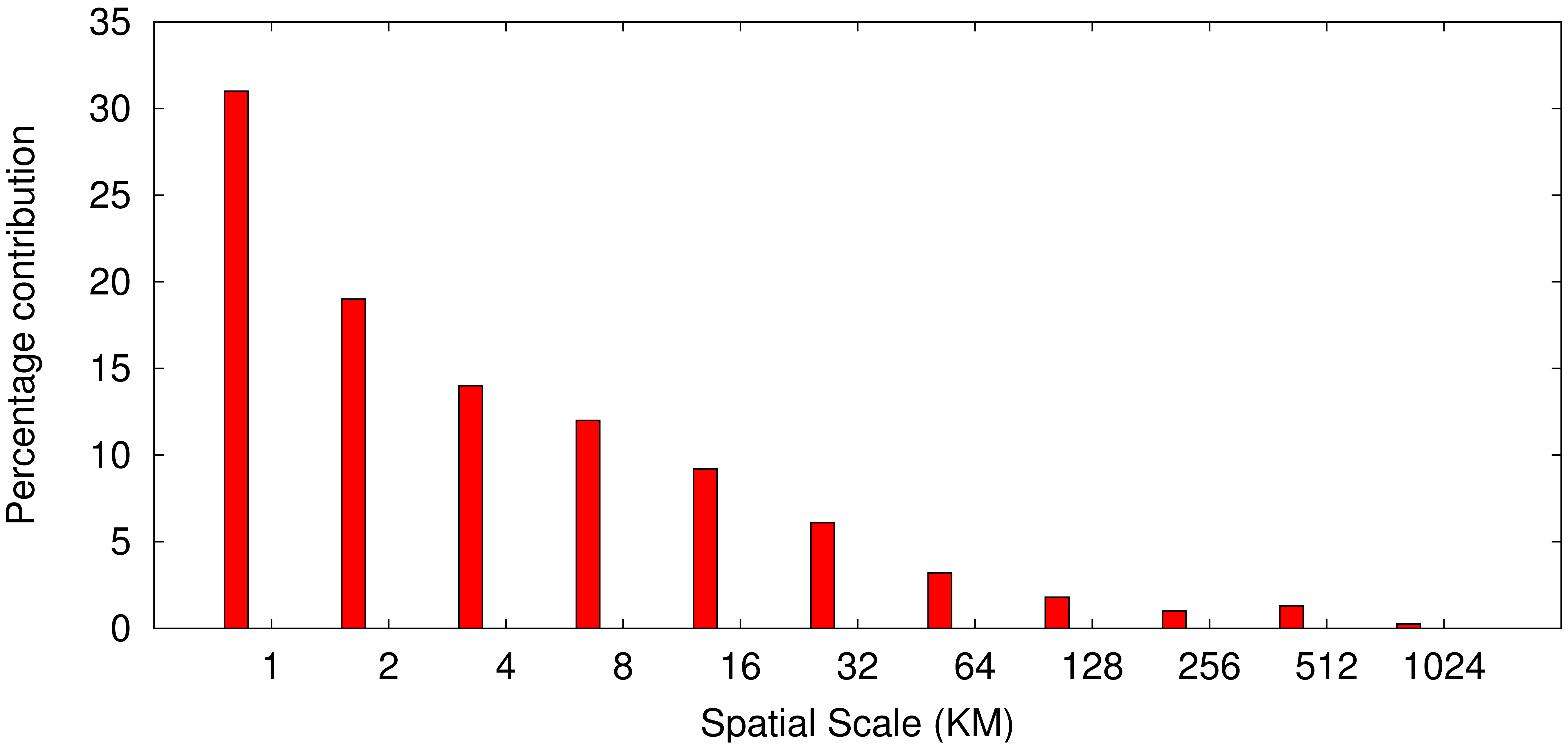


Probability of detection of snow cover (1 km)

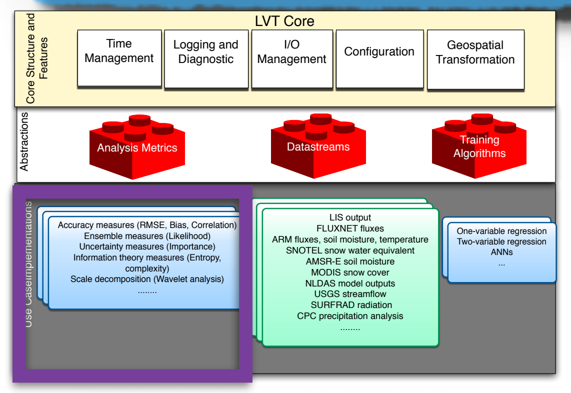


How much of this improvement will be obtained at coarser spatial resolutions where the topography is not well resolved?

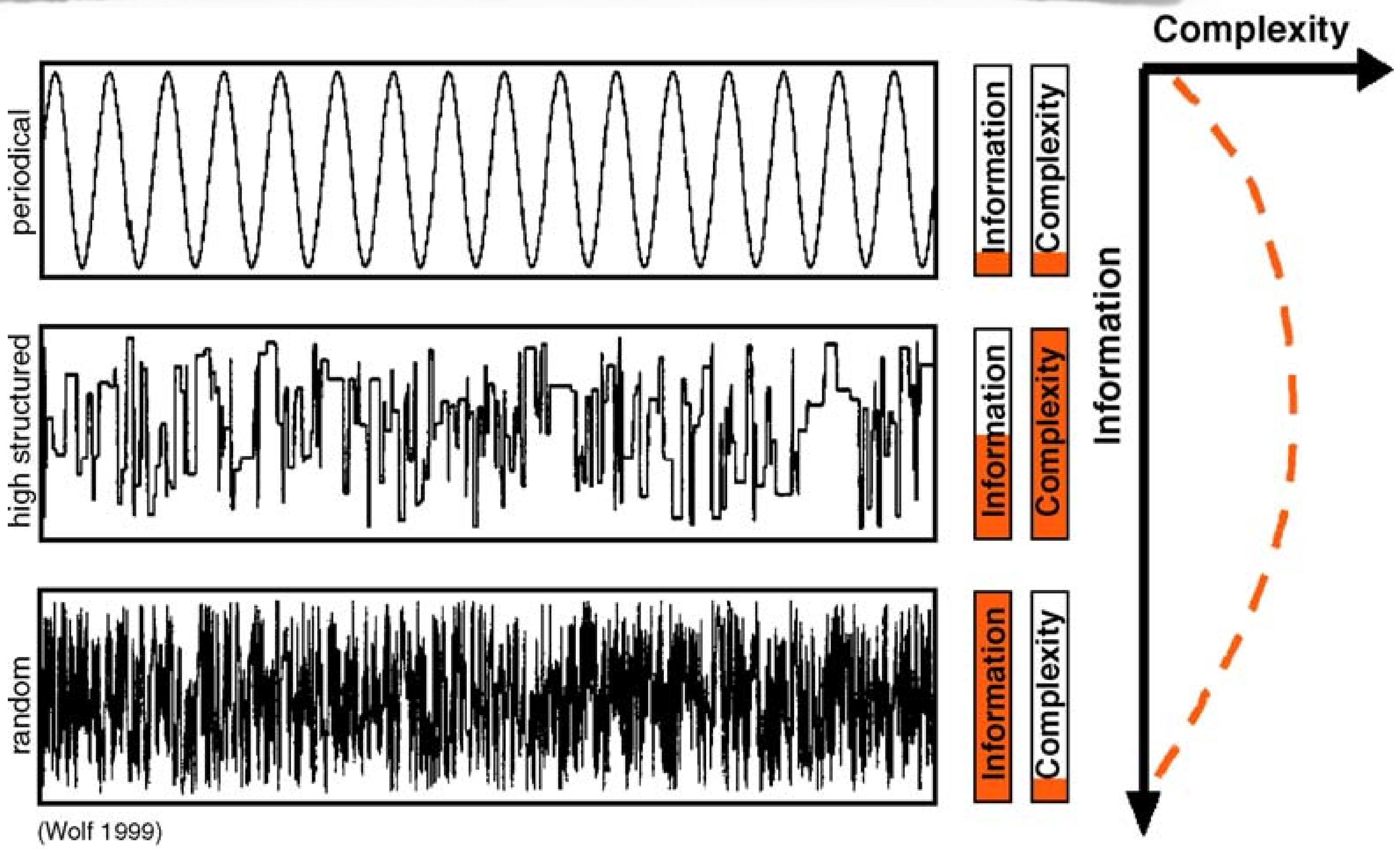
Discrete wavelet transform



Information theory metrics



Time series analysis designed to detect patterns

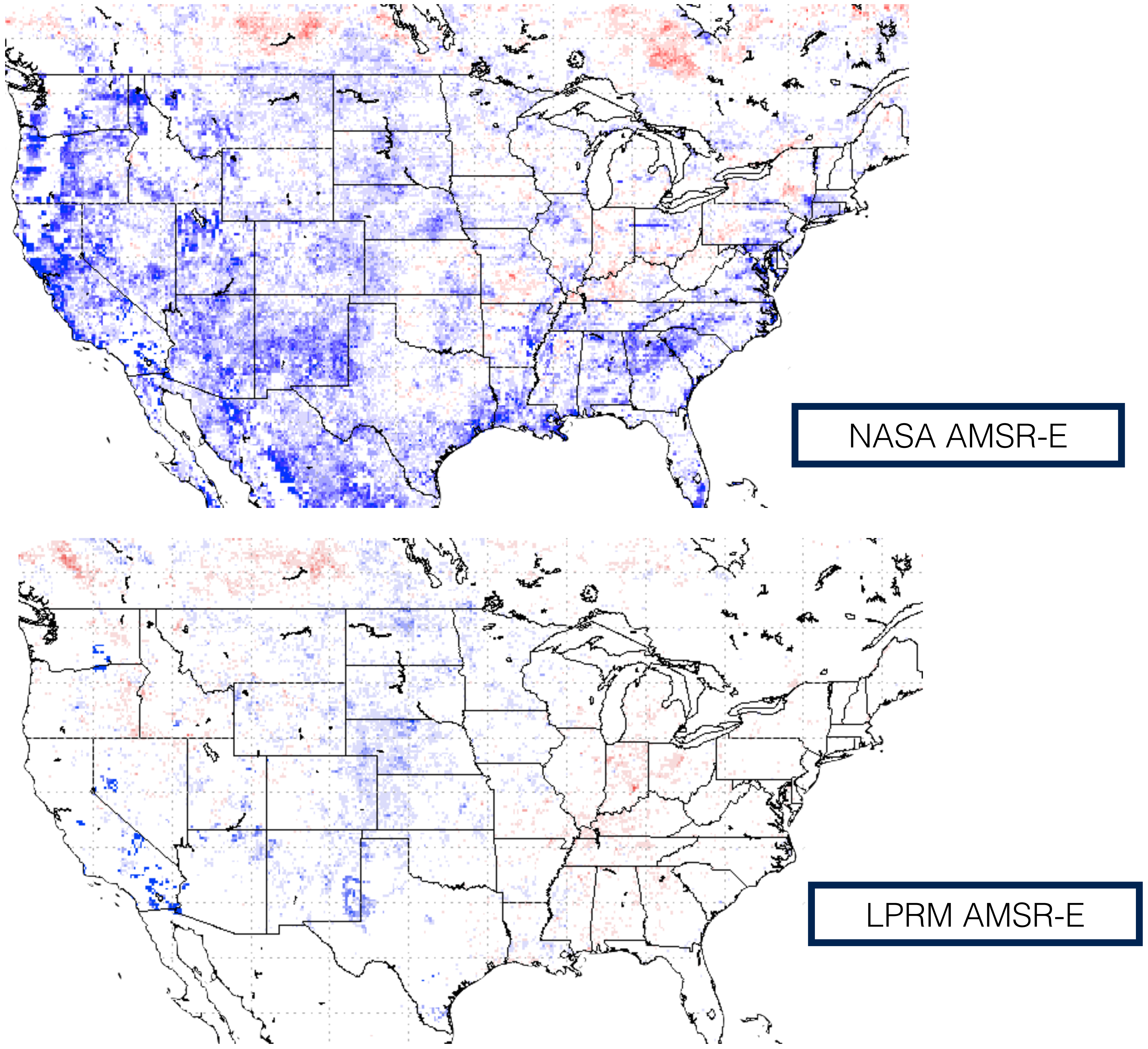


(Wolf 1999)

intuitive relationship between information and complexity

from Pachepsky et al. (2006)

Change in metric entropy through the assimilation of AMSR-E soil moisture retrievals



Benchmarking

- LVT provides two capabilities related to benchmarking:
  - Develop a benchmark dataset by training any two of the supported datasets
  - Compare the model runs to the benchmark dataset
- Training algorithms available
  - One-variable regression
  - Two-variable regression
  - ANN (coming soon..)

Ongoing work

- Currently LVT works only in a serial mode. Multi-processor capabilities are being added.
- Spectral/cross-spectral analysis (along Weedon et al., JHM 2015)
- Expand the suite of indicators (e.g. multi-variable based)