Outline

- Role of Land Surface Models (LSMs)
- Model requirements: physics & parameters, atmospheric forcing, land data sets, initial land states
- Land Data Assimilation
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Land Data Assimilation (LDA)

Motivation:

- **Better initial conditions of land states** for numerical weather prediction (NWP) & seasonal climate model forecasts.
- **Assess model** (physics) **performance** and make improvements by **assimilating real land data** (sets).
- **Application to** regional and global **drought** monitoring and seasonal hydrological prediction.

- ***Observations incorporated into weather, seasonal climate and hydrological models in analysis cycles***, where in each analysis cycle, observations of current (& possibly past) state of a system are combined with results from a weather/climate/hydro model.
- ***Analysis step is considered "best" estimate of the current state of the weather/climate/hydro system***, where the analysis step balances uncertainty in data & in forecast; model then advanced in time & its results becomes the forecast in next analysis cycle.

Land Data Assimilation (LDA)

• Minimization of a "cost function" has the effect of making sure that the analysis does not drift too far away from observations and forecasts that are known to usually be reliable.

1. 3D-Var

$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + (\mathbf{y} - H[\mathbf{x}])^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{y} - H[\mathbf{x}]),$$

where $\mathbf{B}$ denotes the background error covariance, $\mathbf{R}$ the observational error covariance.

$$\nabla J(\mathbf{x}) = 2\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) - 2H\mathbf{R}^{-1}(\mathbf{y} - H[\mathbf{x}])$$

2. 4D-var

$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + \sum_{i=0}^{n}(\mathbf{y}_i - H_i[\mathbf{x}_i])^{\mathrm{T}}\mathbf{R}_i^{-1}(\mathbf{y}_i - H_i[\mathbf{x}_i])$$

provided that H is linear operator (matrix).

Developing Land Data Assimilation Capabilities

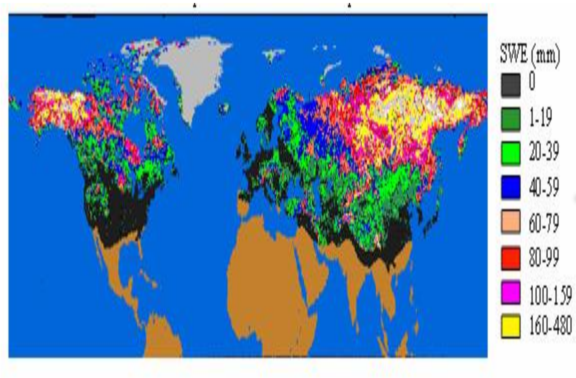
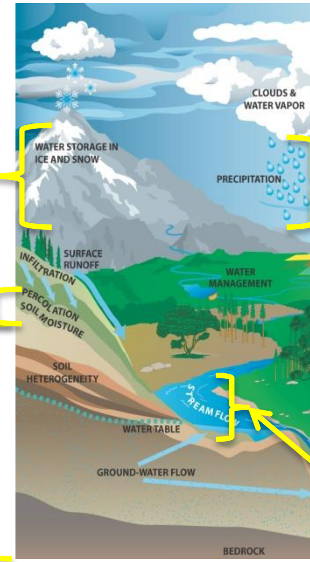


Figure 1: Snow water equivalent (SWE) based on Terra/MODIS and Aqua/AMSR-E. Future observations will be provided by JPSS/VIIRS and DWSS/MIS.



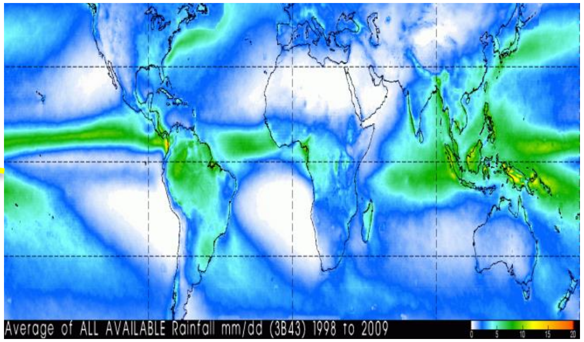


Figure 2: Annual average precipitation from 1998 to 2009 based on TRMM satellite observations. Future observations will be provided by GPM.

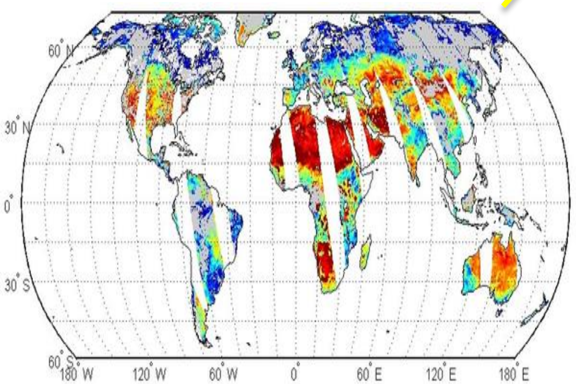


Figure 3: Daily soil moisture based on Aqua/AMSR-E. Future observations will be provided by SMAP.

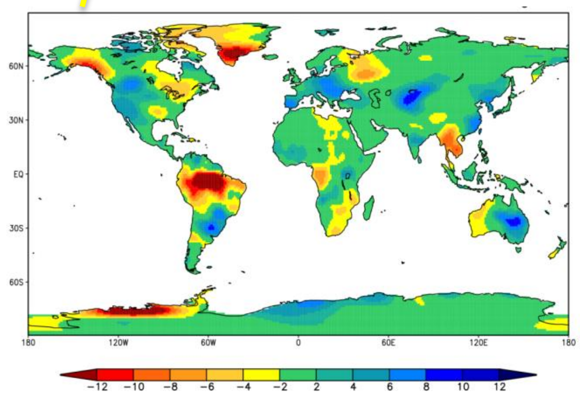


Figure 4: Changes in annual-average terrestrial water storage (the sum of groundwater, soil water, surface water, snow, and ice, as an equivalent height of water in cm) between 2009 and 2010, based on GRACE satellite observations. Future observations will be provided by GRACE-II.

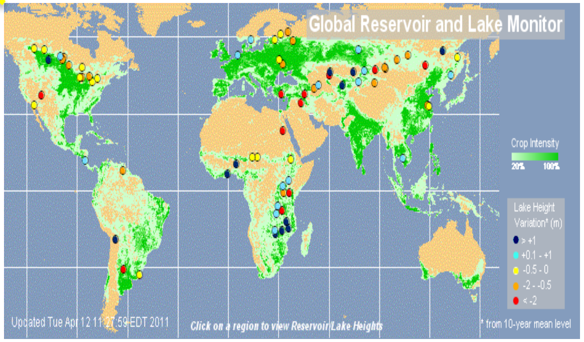


Figure 5: Current lakes and reservoirs monitored by OSTM/Jason-2. Shown are current height variations relative to 10-year average levels. Future observations will be provided by SWOT.

C. Peters-Lidard et al (NASA)

NASA Land Information System (LIS)

Inputs

Topography, Soils (Static)

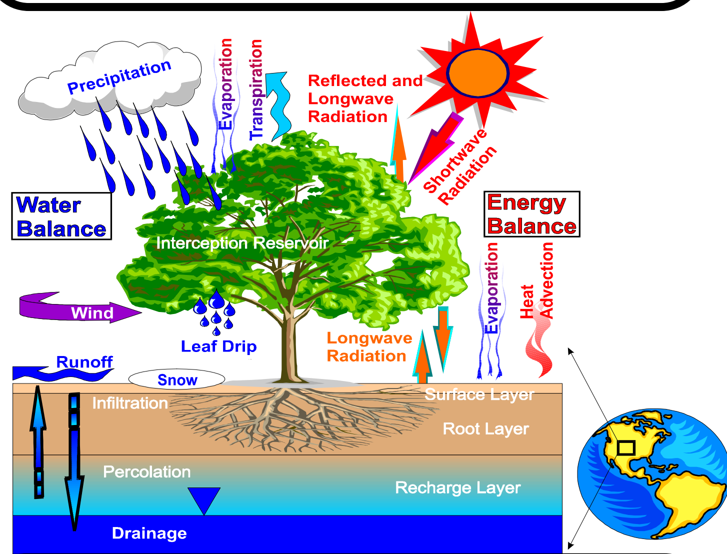
Land Cover, Leaf Area Index (MODIS, AMSR, TRMM, SRTM)

Meteorology: Modeled & Observed (NLDAS, DMIP II, GFS,GLDAS,TRMM GOES, Station)

Observed States (Snow Soil Moisture Temperature)

Physics

Land Surface Models
SAC-HT/SNOW17
Noah, CLM, VIC, Catchment



Data Assimilation Modules (DI, EKF, EnKF)

Outputs

Surface Energy Fluxes (Q_h, Q_{le})

Soil Moisture Evaporation

Surface Water Fluxes (e.g., Runoff)

Surface States (Snowpack)

Applications

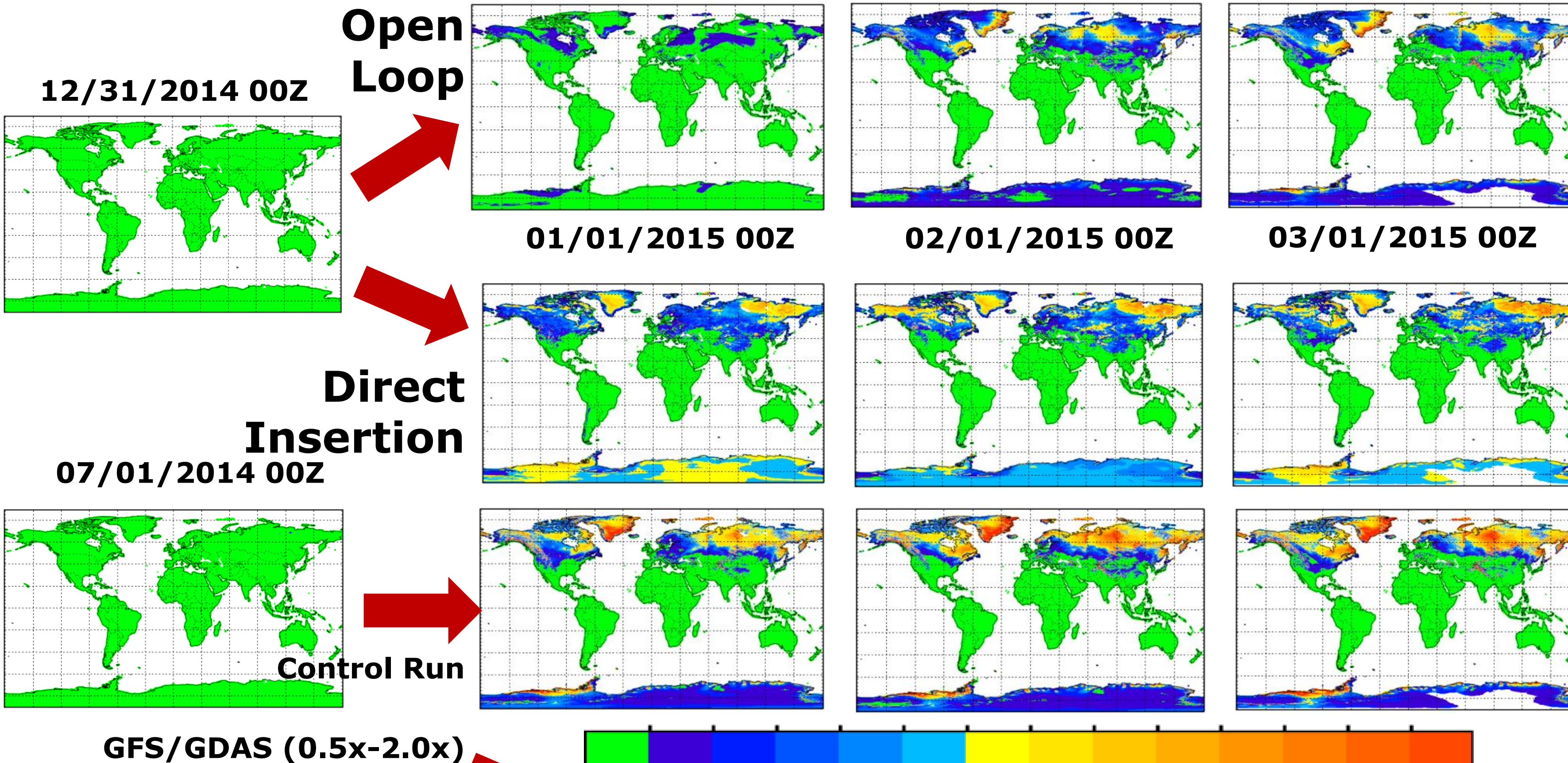
Water Supply & Demand

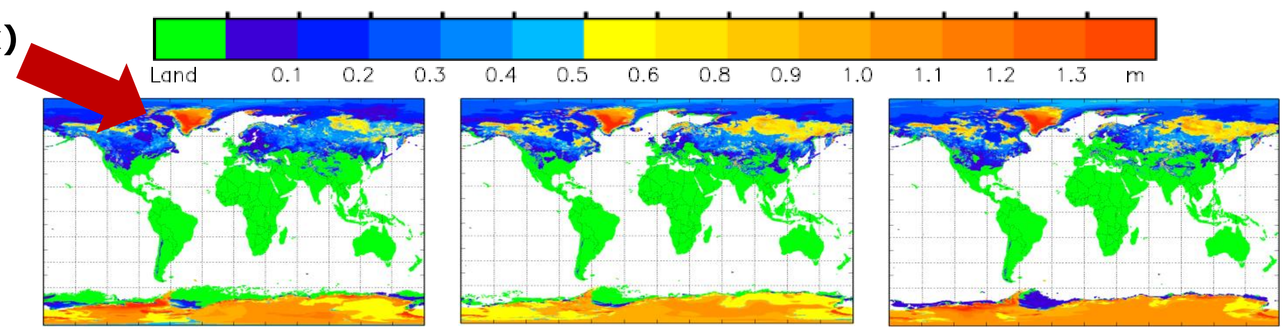
Agriculture Hydro-Electric Power, Water Quality

Improved Short Term & Long Term Predictions

Christa Peters-Lidard et al., NASA/GSFC/HSB

Land data assimilation: AFWA Snow Depth

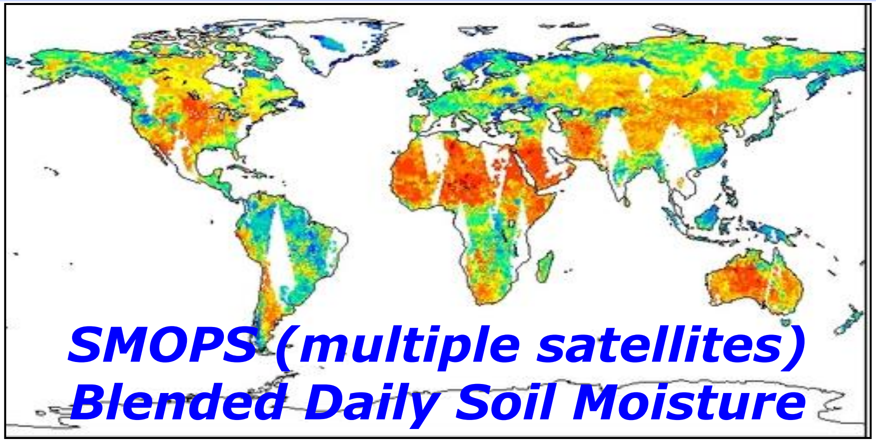


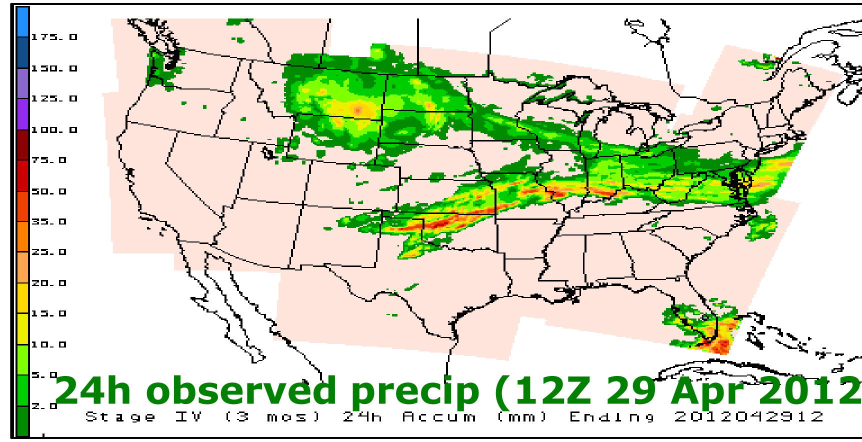


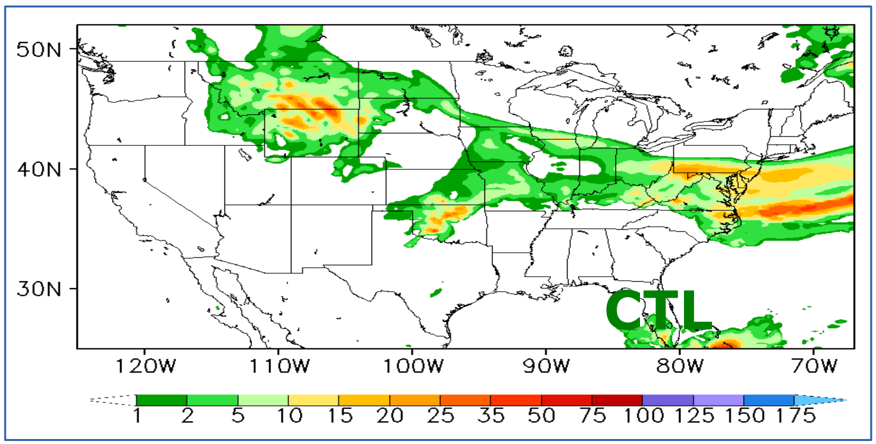
Working on using LIS EnKF to assimilate AFWA snow depth. The successful EnKF applications require accurate error estimates both from satellite observations and from the land model.

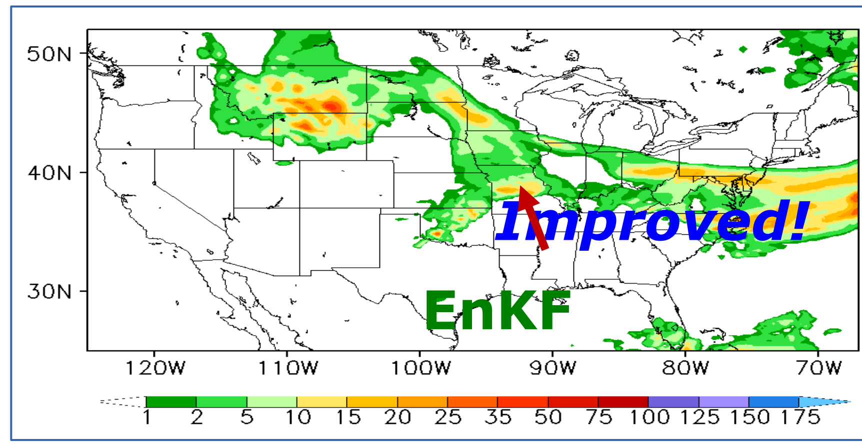
Jiarui Dong, NCEP/EMC

Land data assimilation: Soil Moisture









Forecast hour 60-84, precipitation forecast 24h accum (mm) ending at 12Z 29 Apr 2012

- Noah land model multiple-year grid-wise means & std devs used to scale surface layer soil moisture retrievals before assimilation.
- Testing assimilation of SMOPS in GFS; positive impact on precip.

Weizhong Zheng, NCEP/EMC and Xiwu Zhan, NESDIS/STAR

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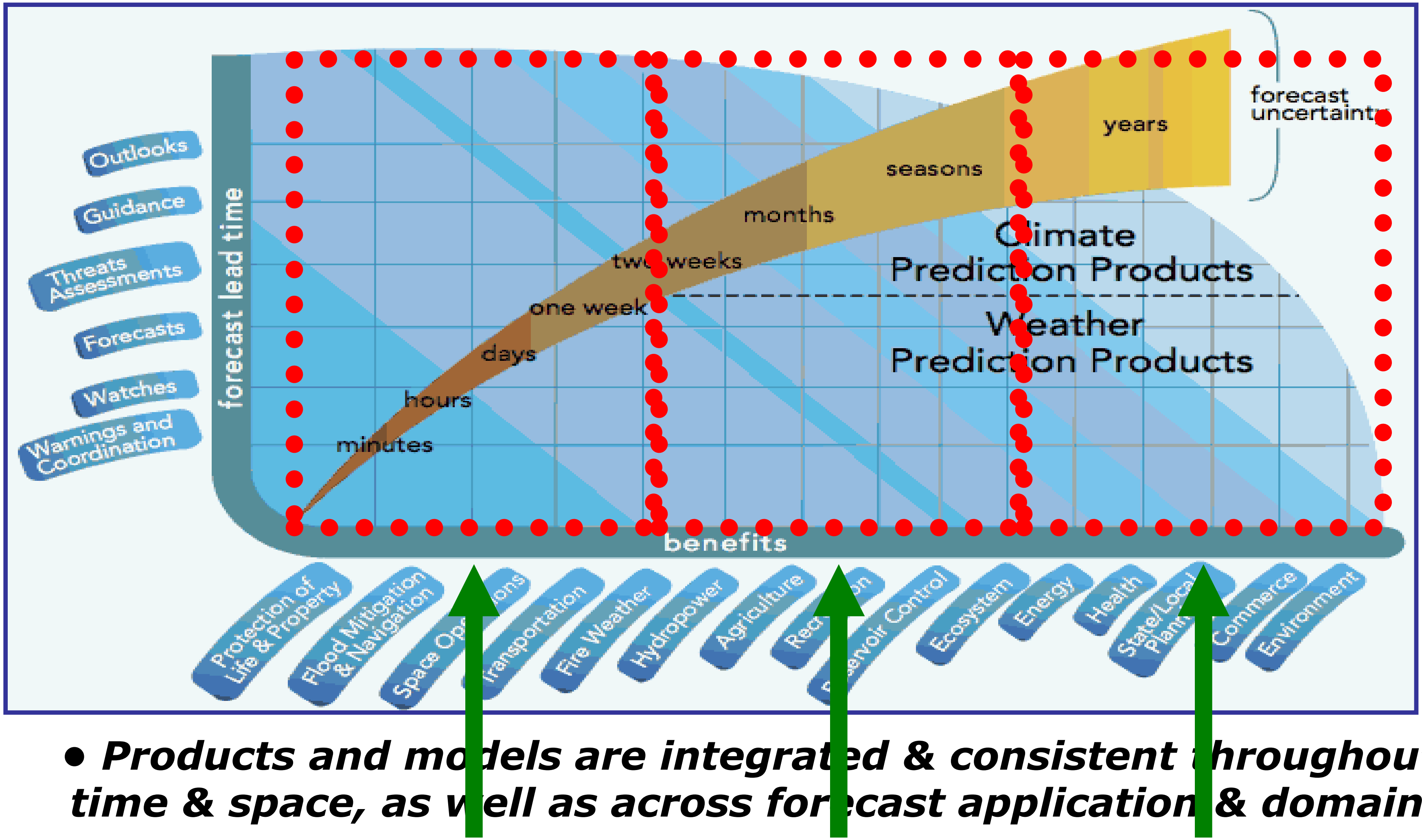
Weather & Climate: a "Seamless Suite"



- ***Products and models are integrated & consistent throughout time & space, as well as across forecast application & domain.***

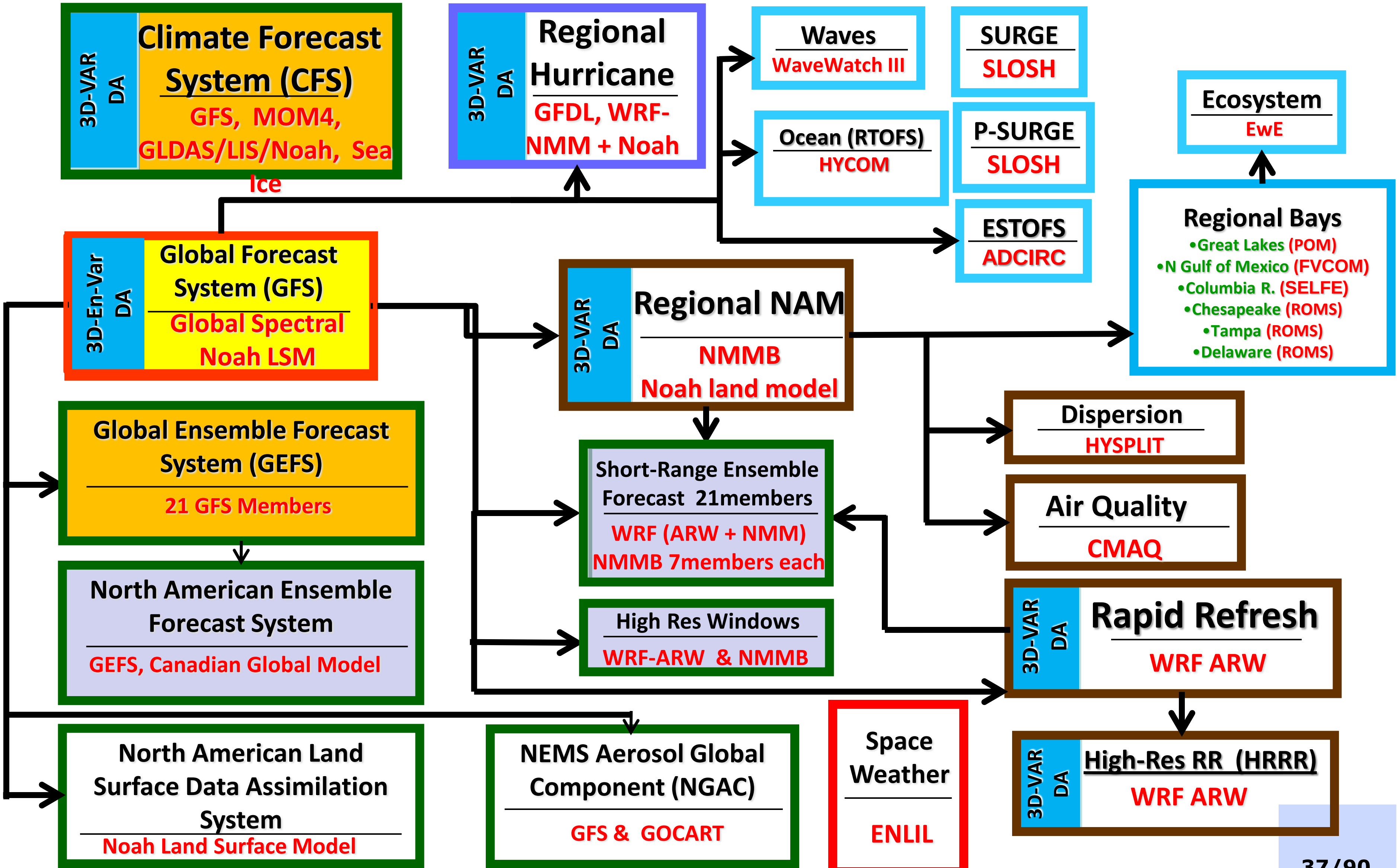
Land modeling example:

Static vegetation, e.g. climatology or realtime observations

Dynamic vegetation, e.g. plant growth

Dynamic ecosystems, e.g. changing land cover

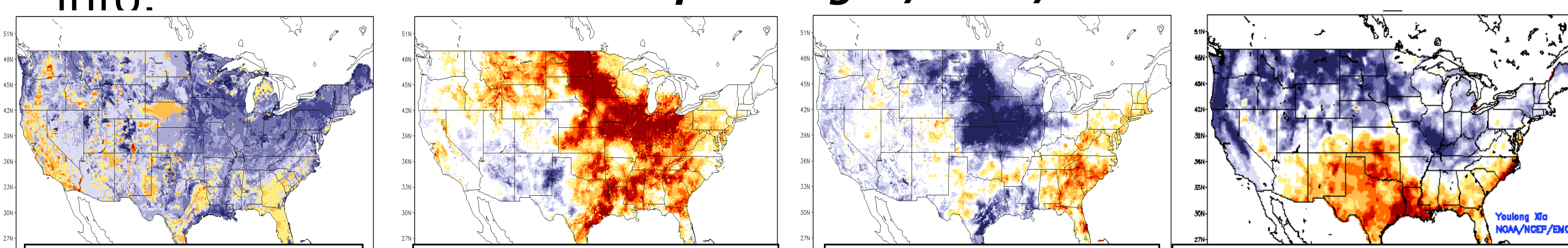
Land Applications for Weather & Climate: NOAA's Operational Numerical Guidance Suite



North American Land Data Assimilation System (NLDAS)

- August 2014: North American LDAS (NLDAS) operational.
- NLDAS: 4 land models run uncoupled, driven by CPC observed precipitation & NCEP NARR/R-CDAS atmospheric forcing.
- Output: 1/8-deg. **land** & **soil states**, **surface fluxes**, **runoff** & **streamflow**; anomalies from 30-yr climatology for drought.
- Future: higher res. (~3-4km), extend to full North American/global domains, improved land data sets/data assimil. (soil moisture, snow), physics upgrades including hydrology, initial land states for weather/climate models; global drought info.

www.emc.ncep.noaa.gov/mmb/nldas



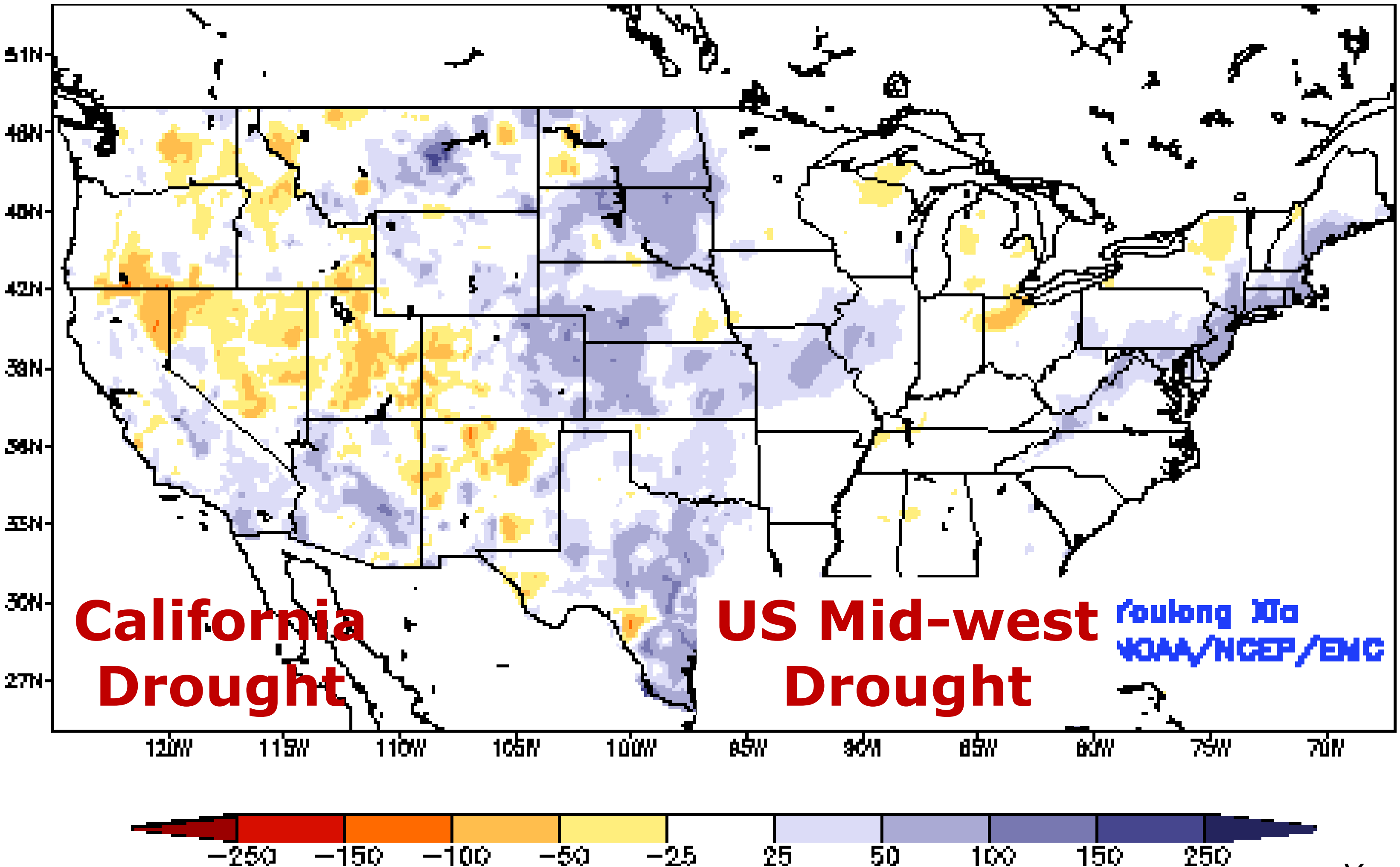
July 30-yr climate | *July 1988 (drought)* | *July 1993 (flood)* | *July 2011 (TX drought)*

NLDAS four-model ensemble soil moisture monthly anomalies

Youlong Xia, NCEP/EMC

NLDAS Soil Moisture Monitoring

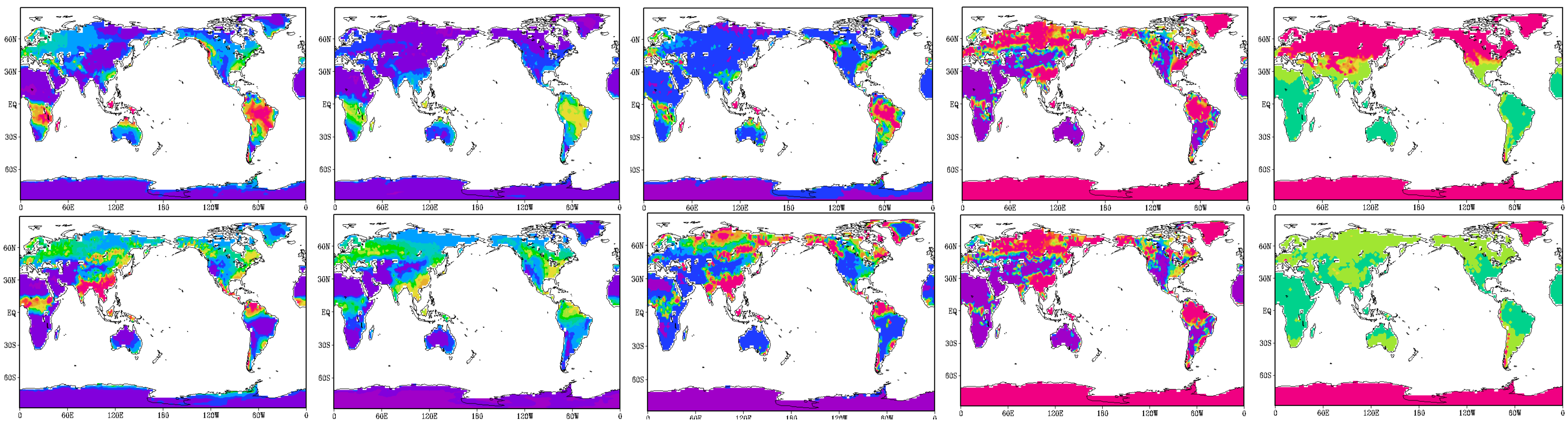
Ensemble mean total column soil moisture anomaly
March 2012 – December 2013



Youlong Xia

Global Land Data Assimilation System (GLDAS)

- Uses **Noah land model** running under NASA Land Information System forced with **Climate Forecast System** (CFS) atmos. data assimil. cycle output, & **"blended" precipitation** (gauge, satellite & model), "semi-coupled" –daily updated land states.
- **Snow** cycled or assimilated (IMS snow cover, AFWA depth).
- GLDAS land "re-runs", with updated forcing, physics, etc.
- 30-year land climatology: energy/water budgets:



Precipitation *Evaporation* *Runoff* *Soil Moisture* Snow

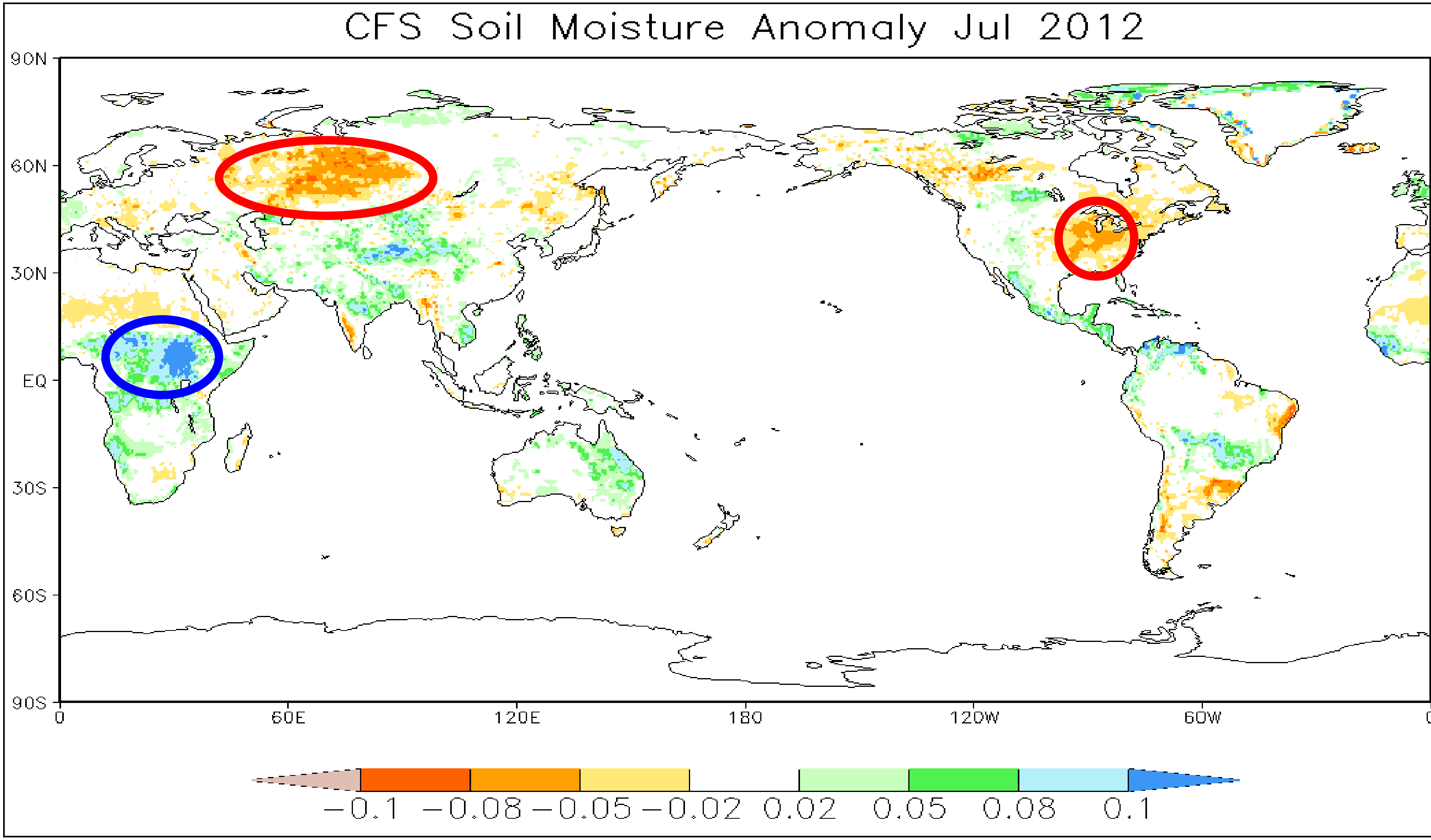
Jan (top), July (bottom) Climatology from 30-year NCEP CFS Reanalysis

(Precip, Evap, Runoff [mm/day]; Soil Moisture, Snow [mm])

Rongqian Yang, Jesse Meng NCEP/EMC

GLDAS CFS Soil Moisture Anomaly: July 2012

- US and Russian droughts, flooding in central Africa.



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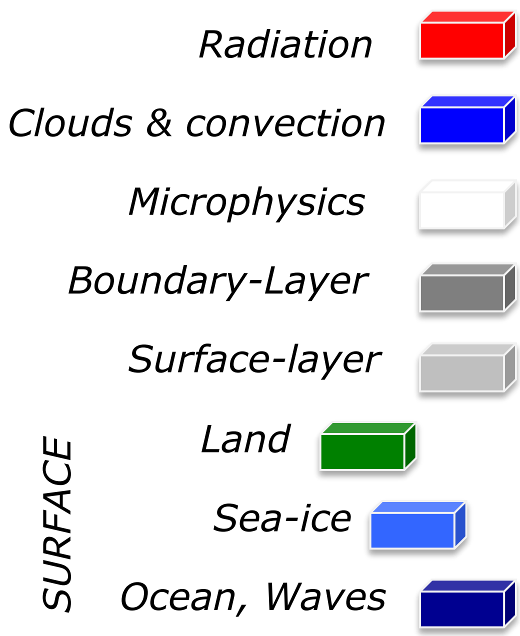
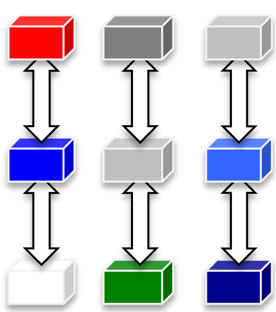
Testing & Validation: Simple-to-More Complex
Hierarchy of Model Parameterization Development

Simulators

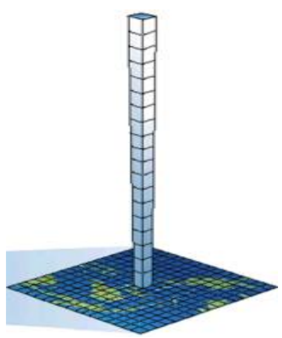


- Simulators: test submodel parameterizations at process level, e.g. radiation-only, land-only, etc.
- Testbed data sets to develop, drive & validate submodels: observations, models, idealized, *with "benchmarks" before adopting changes*.
- Submodel interactions, *with benchmarks*.
- Full columns, *with benchmarks*.
- Limited-area/3-D (convection) *with benchmarks*.
- Regional & global NWP & seasonal climate, *with benchmarks.*
- **More efficient** model development, community engagement, R2O/O2R & computer usage.

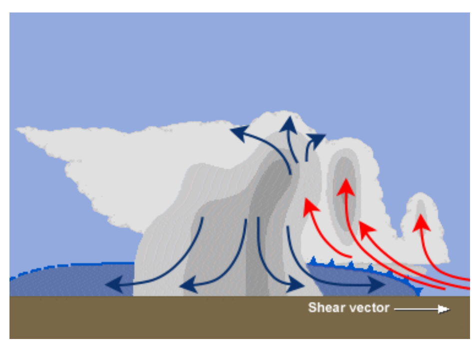
Interaction tests



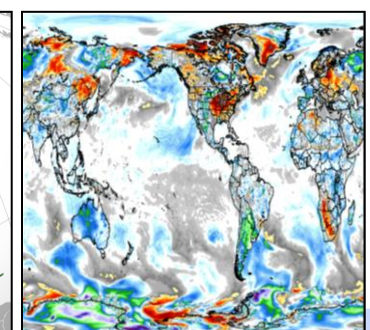
Column tests



Limited-area



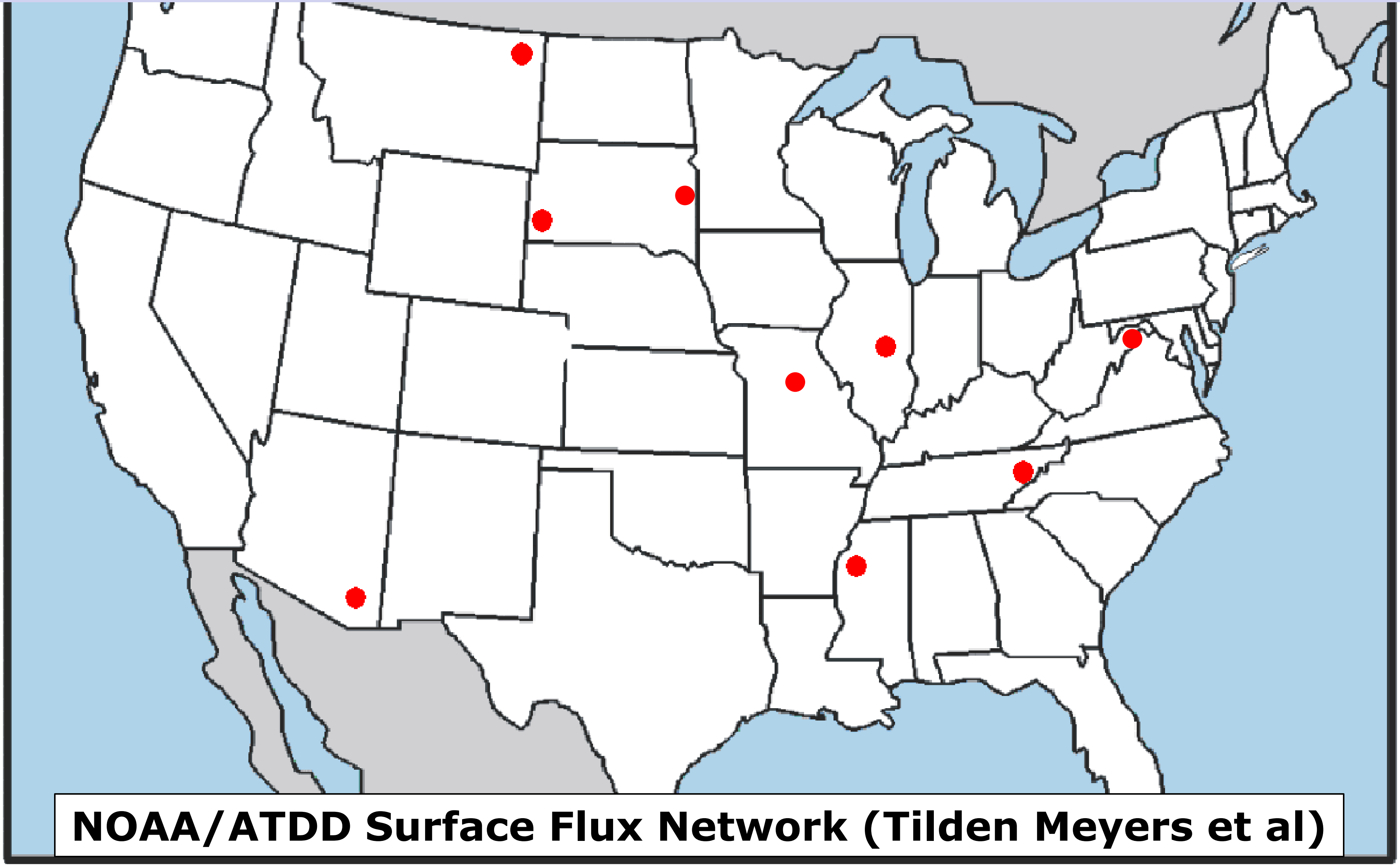
Regional & Global

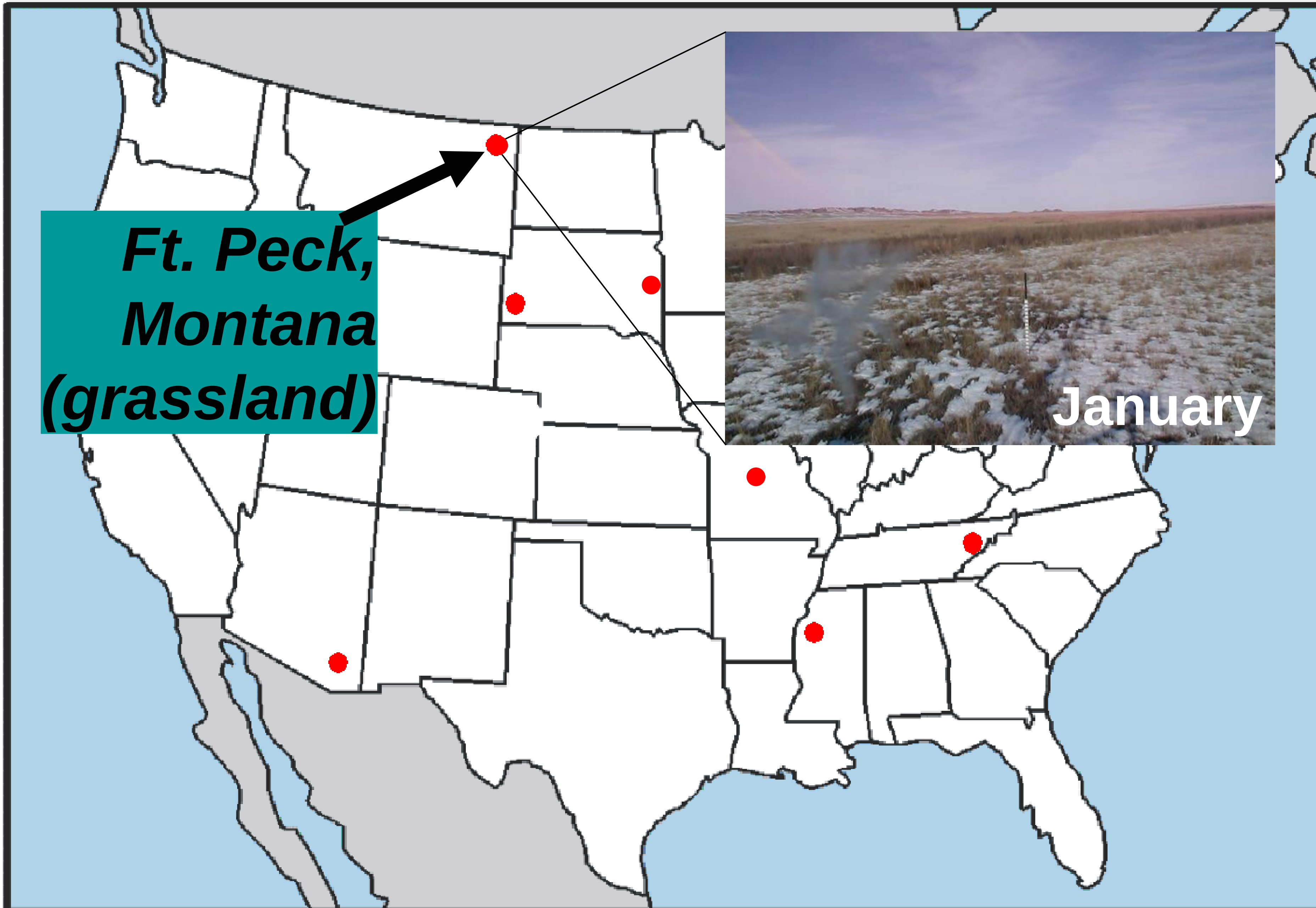


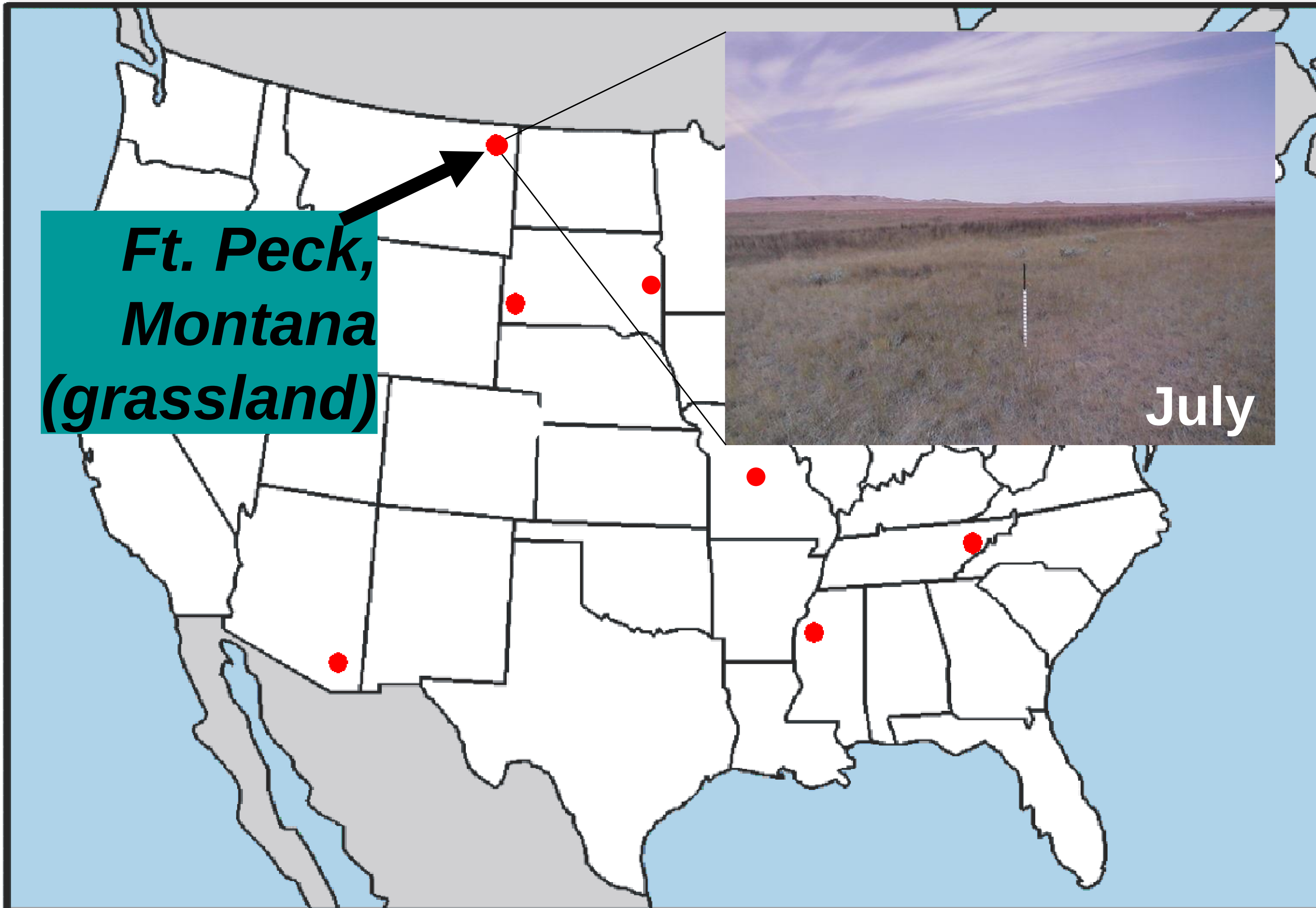
Land Model Testing and Validation

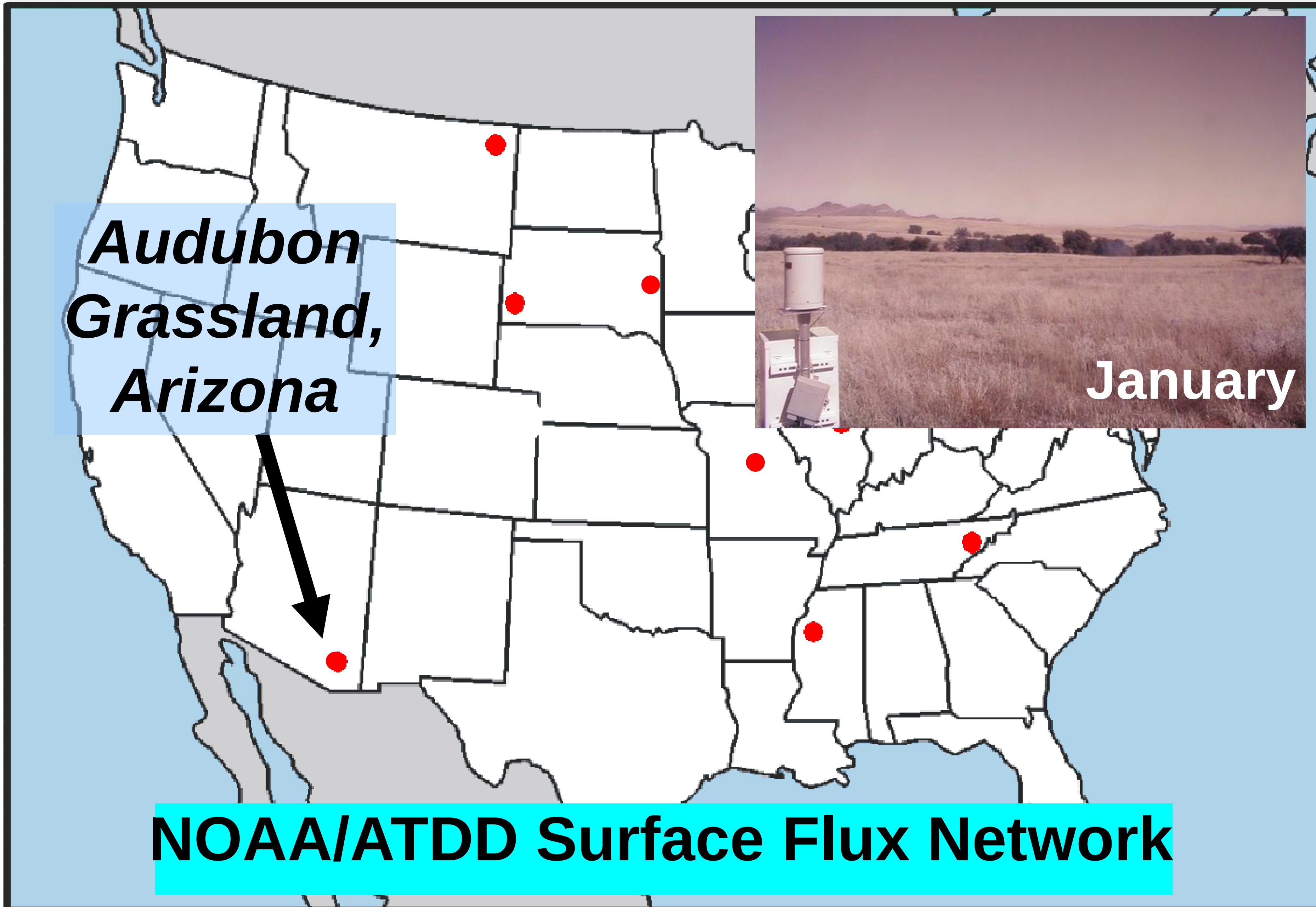
- **Validation** uses near-**surface** observations, e.g. routine weather observations of air temperature, dew point and relative humidity, 10-meter wind, along with upper-air validation, precipitation scores, etc.
- To more fully validate land models, **surface fluxes** and soil states (soil moisture, etc) are also used.
- Monthly diurnal composites to **assess systematic model biases** (averaging out transient atmospheric conditions), and suggest land physics upgrades.

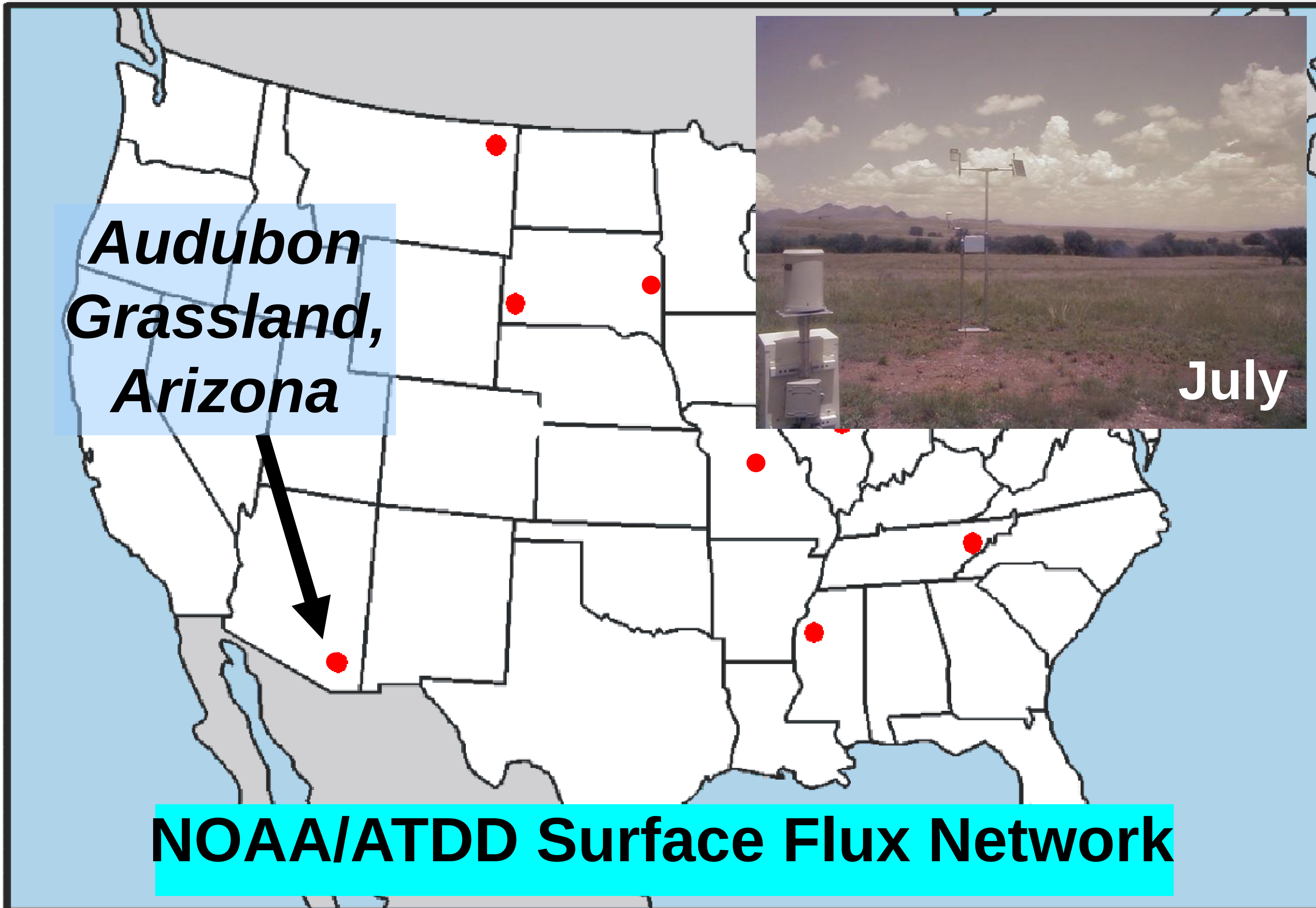
Compare monthly diurnal composites of model output versus observations from flux sites to assess systematic model biases.

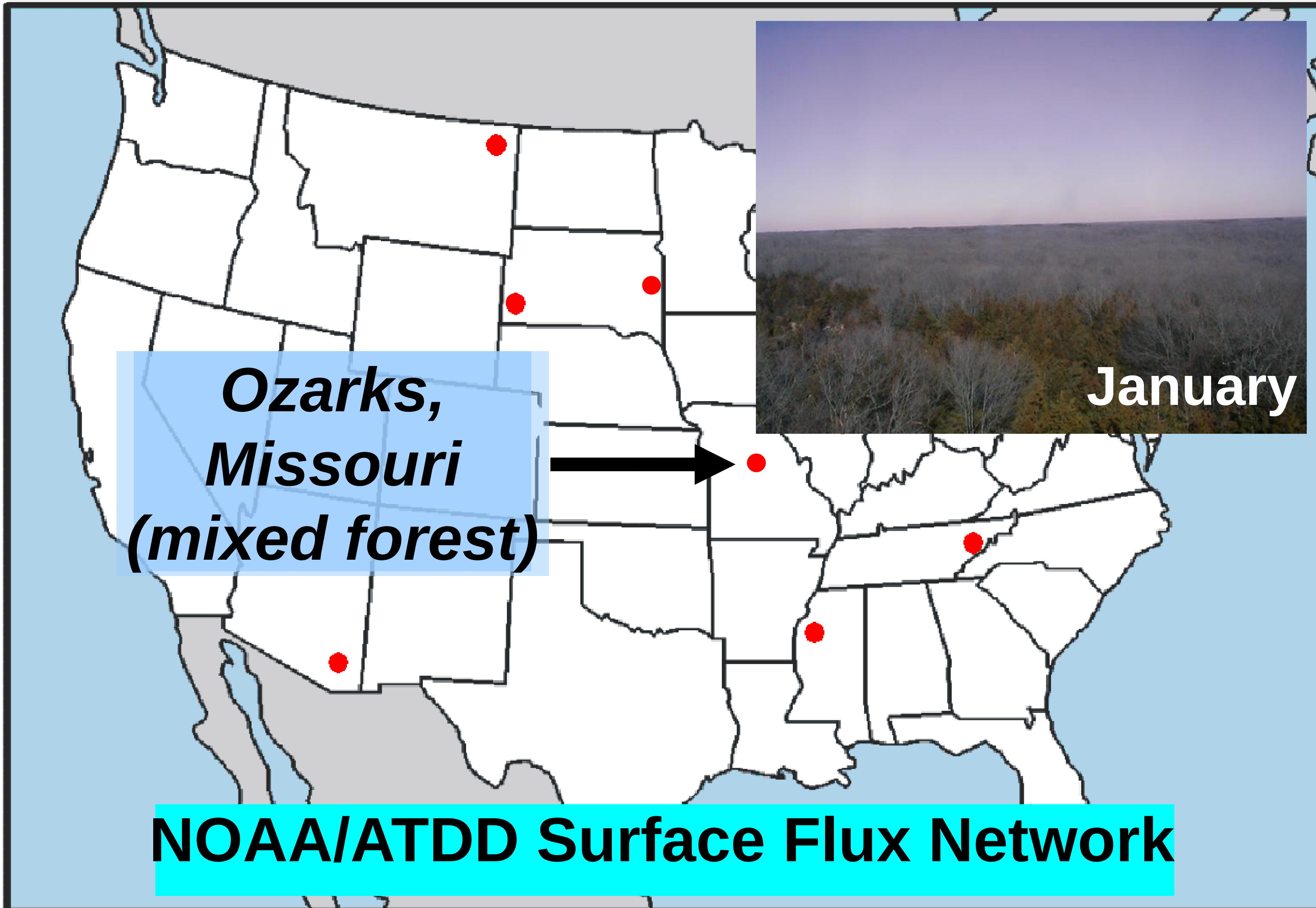


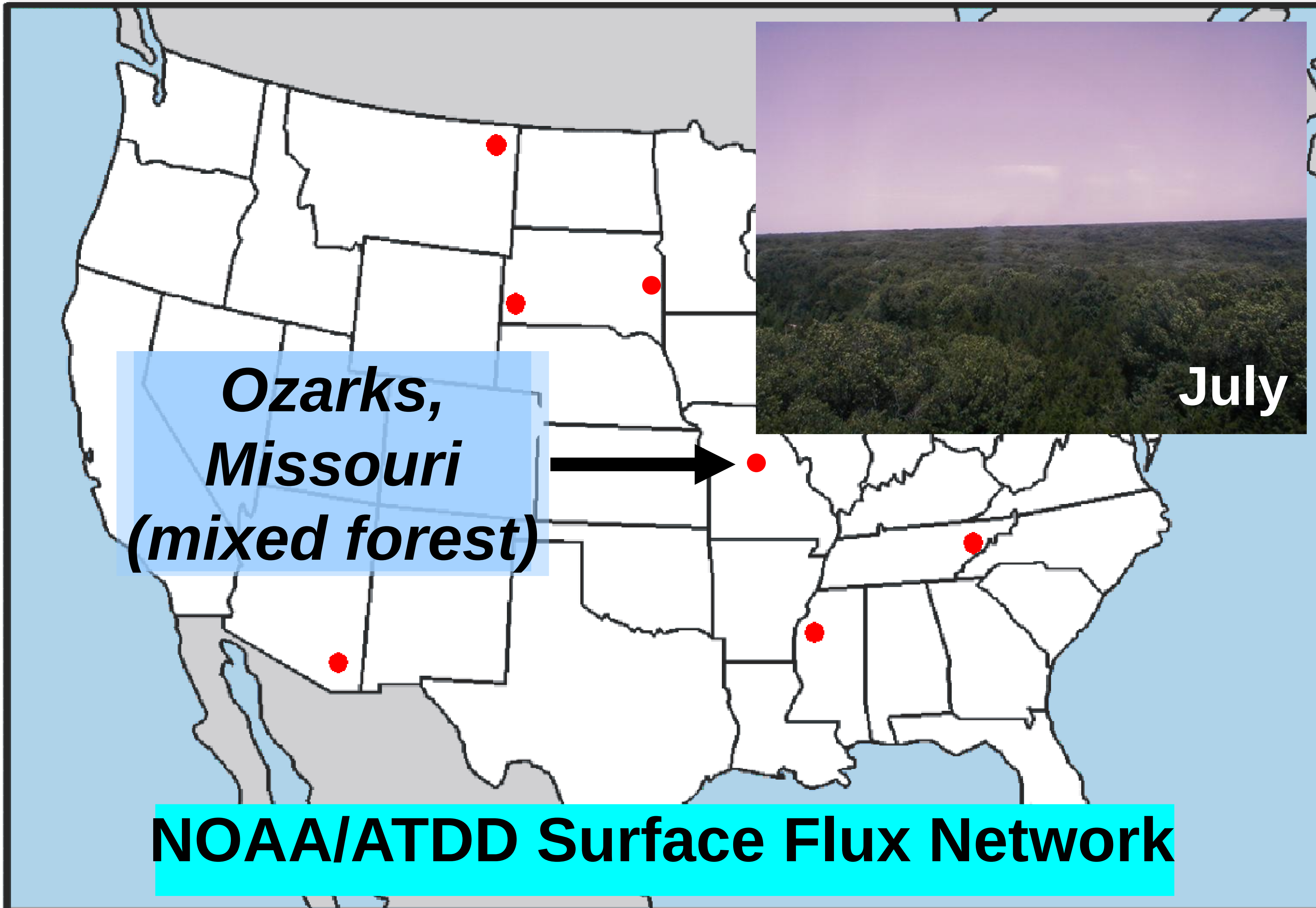

Ft. Peck,
Montana
(grassland)
January

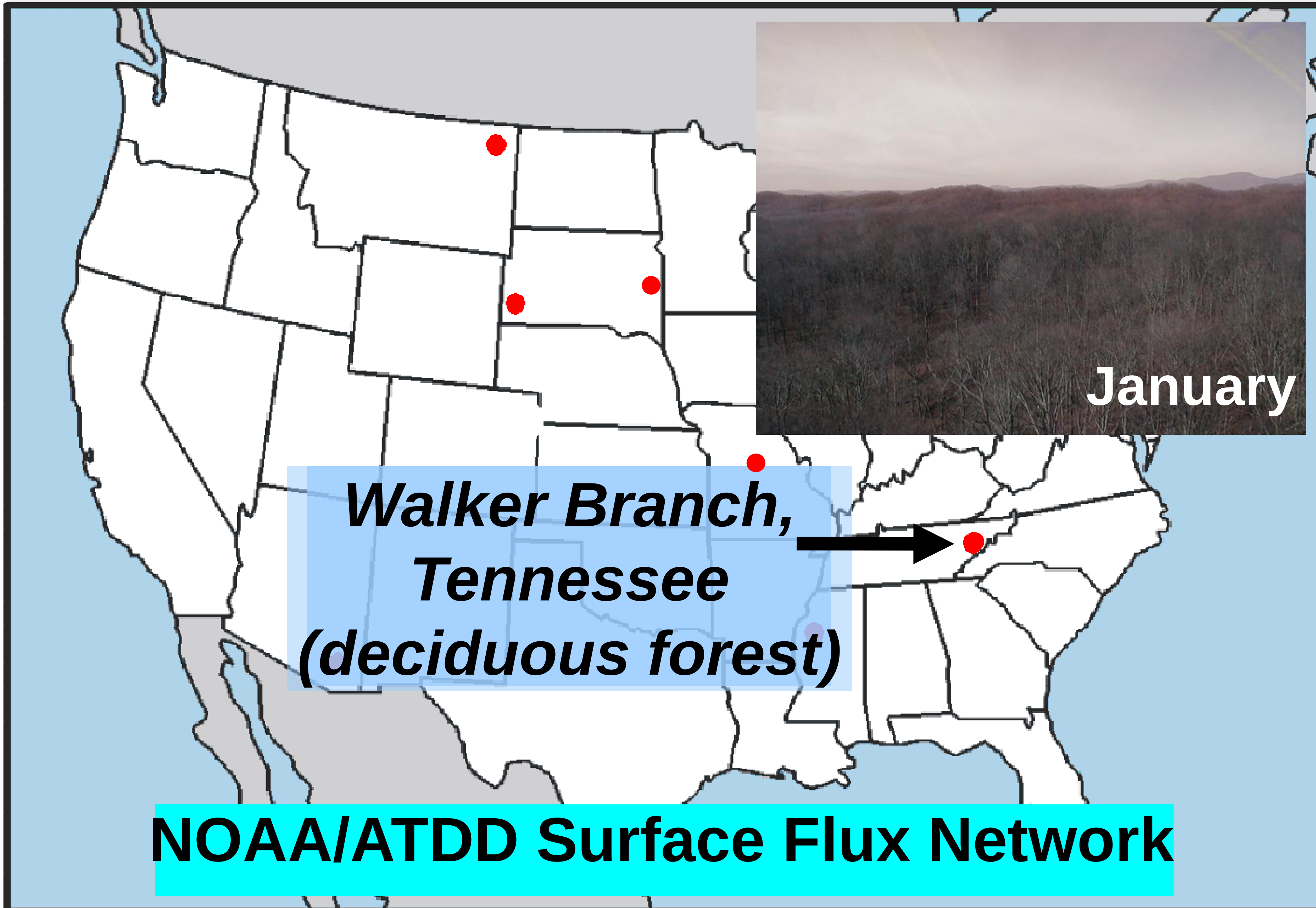

Ft. Peck,
Montana
(grassland)
July

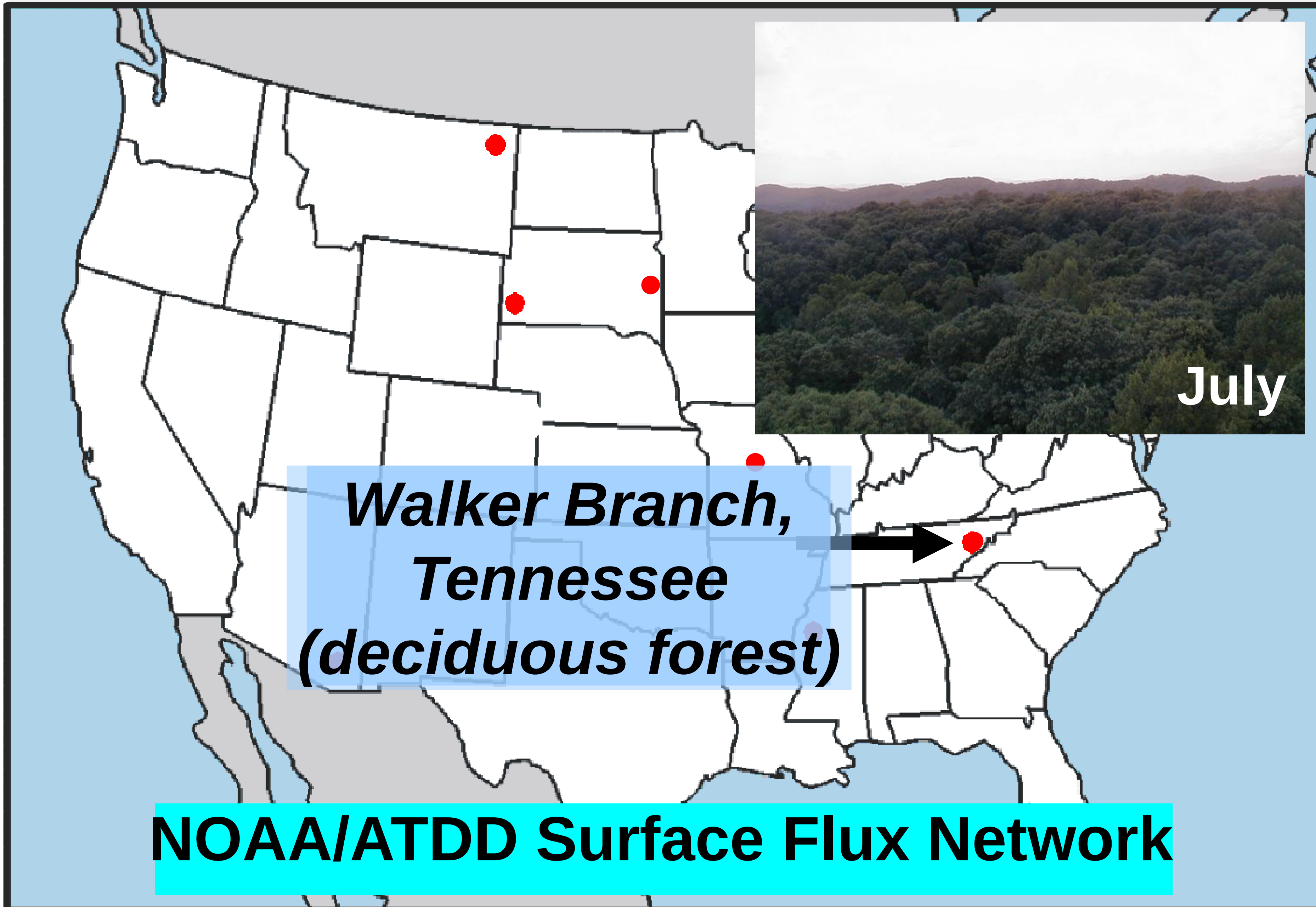

Audubon Grassland, Arizona
January
NOAA/ATDD Surface Flux Network


Audubon
Grassland,
Arizona
NOAA/ATDD Surface Flux Network
July


Ozarks, Missouri (mixed forest)
January
NOAA/ATDD Surface Flux Network


July
Ozarks,
Missouri
(mixed forest)
NOAA/ATDD Surface Flux Network

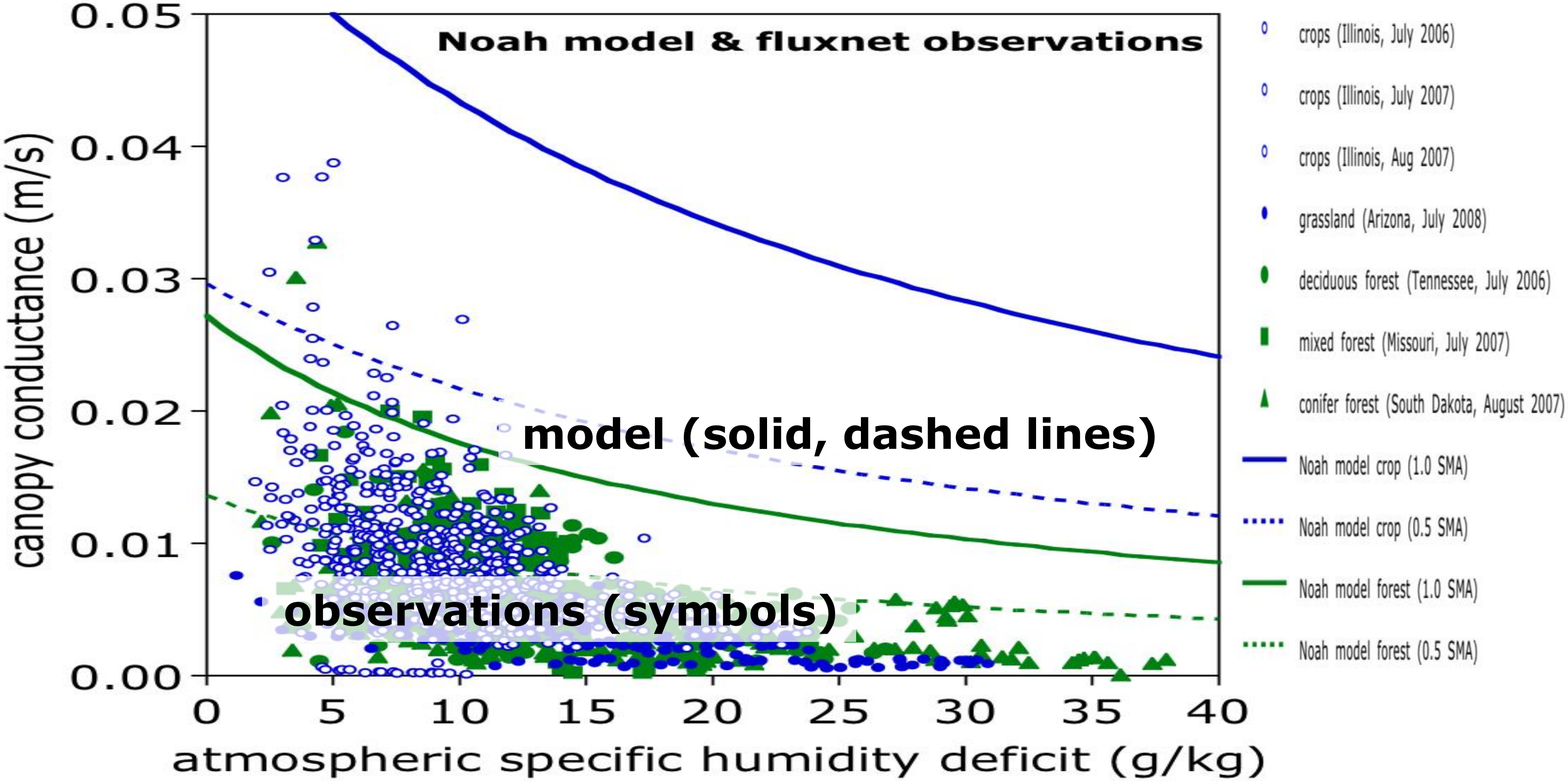

January
Walker Branch, Tennessee (deciduous forest)
NOAA/ATDD Surface Flux Network


July
Walker Branch, Tennessee (deciduous forest)
NOAA/ATDD Surface Flux Network

Testing & Validation: Land Model Canopy Conductance

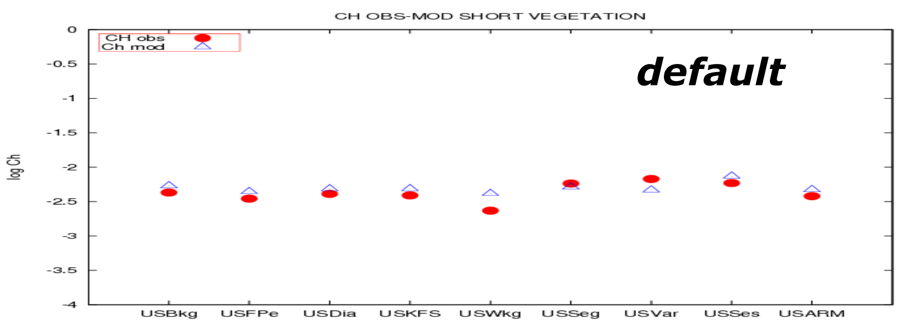
- Use surface fluxes (latent & sensible) to evaluate land-surface physics formulations and parameters, e.g. invert transpiration (Penman-Moneith) formulation to infer canopy conductance.

Action: modify relative humidity effect on canopy conductance.

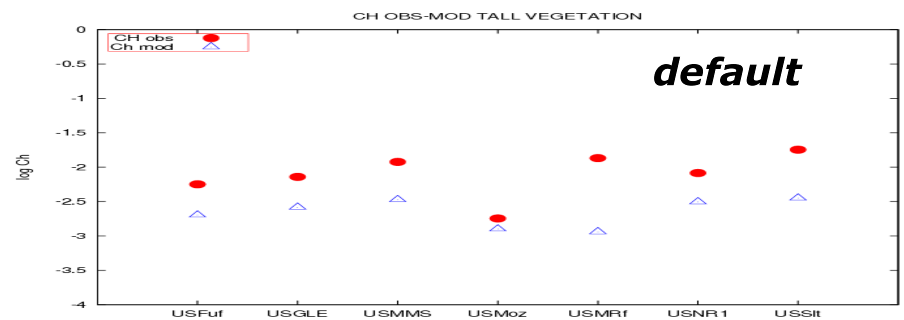


Testing and Validation: Surface-layer Simulator

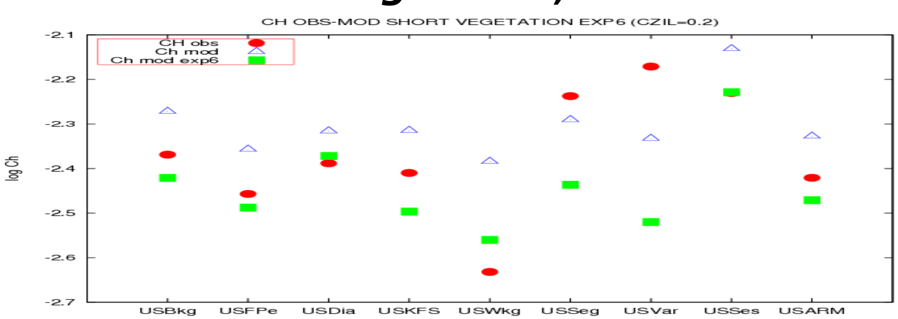
- GOAL: Improve surface turbulence exchange coefficients.
- Surface-layer simulation ("SLS") code simulates surface-layer and schemes from meso-NAM and medium-range GFS.
- Use observations to drive SLS (U,T,q and Tsfc) and compare with inferred Ch, Cd from independent "fluxnet" obs (H, LE, τ).
- Bias in surface exchange coefficient for heat dependent on vegetation height. *Action: adjust thermal roughness parameter.*



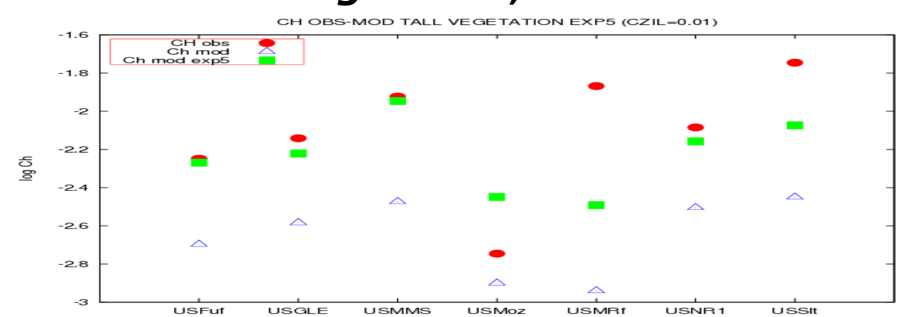
short vegetation, czil=0.1



tall vegetation, czil=0.1



short vegetation, czil=0.2

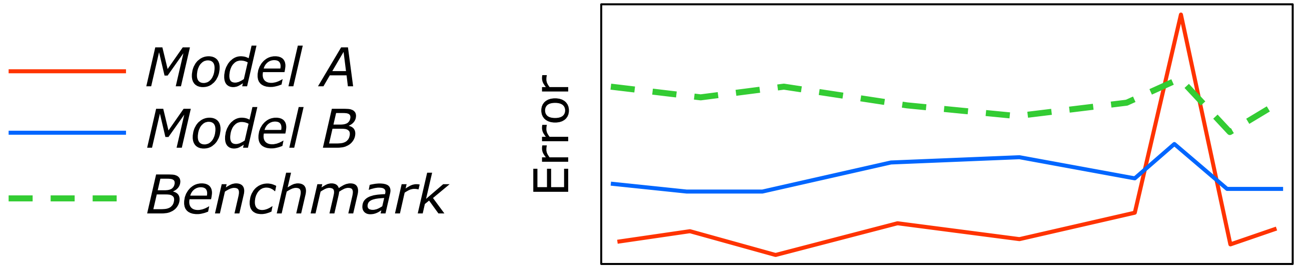


tall vegetation, czil=0.01

Caterina Tassone, NCEP/EMC land team (now WMO)

Testing & Validation: Land Model Benchmarking

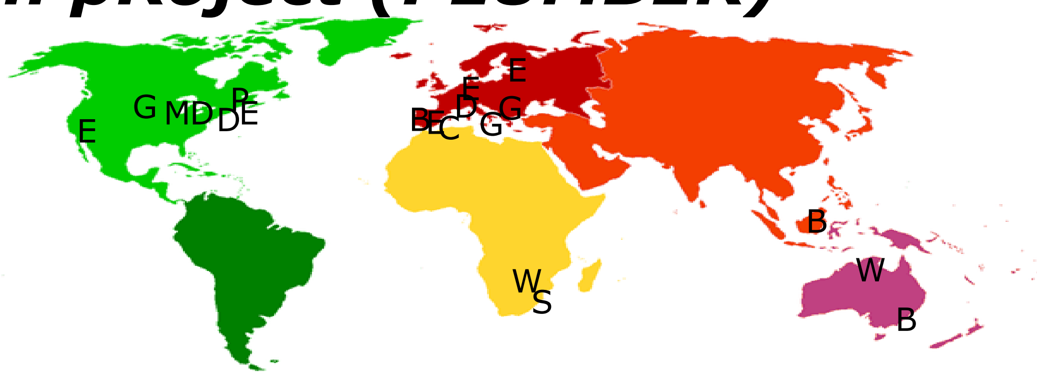
- **Evaluation**: Run model and compare output with observations then ask: ***How good is the model?***
- **Benchmarking**: Decide how good model needs to be, then run model and ask: ***Does model reach the level required?***



Land model should be able to e.g. out-perform empirical models, persistence (for NWP models), climatology (for climate models).

The PALS Land sUrface Model Benchmarking Evaluation pRoject (PLUMBER)

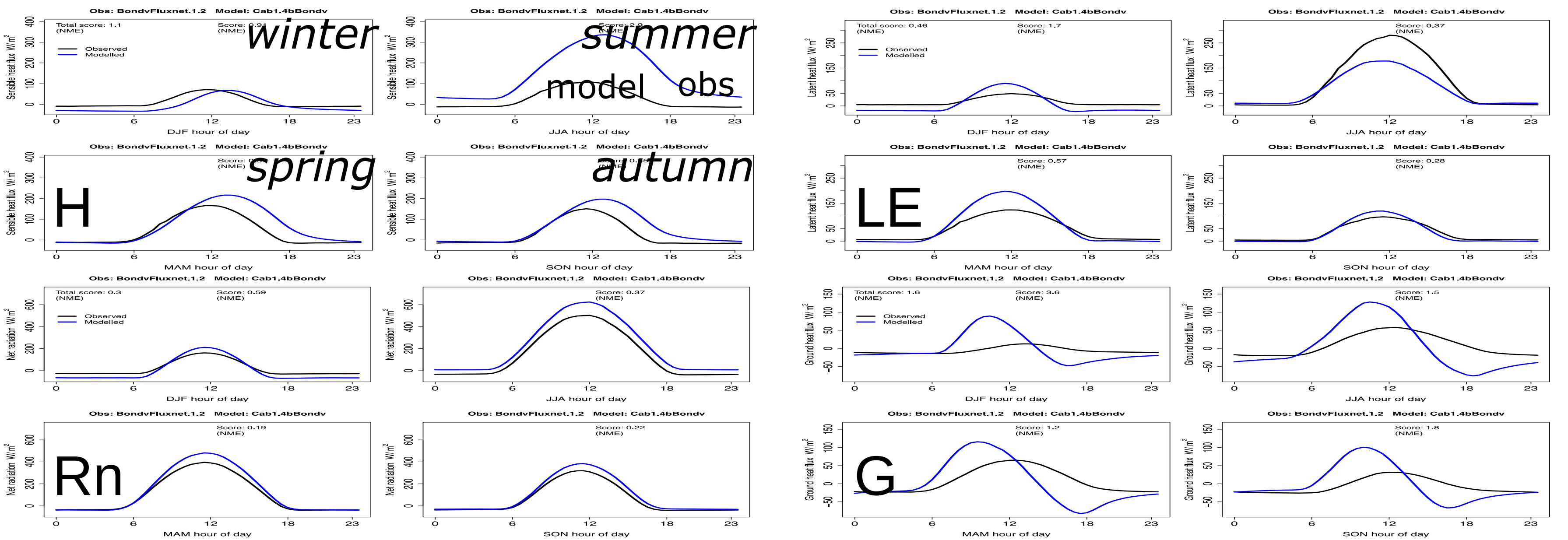
E – Evergreen Needleleaf
B – Evergreen Broadleaf
D – Deciduous Broadleaf
M – Mixed Forest
G - Grassland
C – Cropland
W – Woody Savanna
S – Savanna
P – Permanent Wetlands



Martin Best (UKMO), Gab Abramowitz (UNSW) et al.

Testing & Validation: Land Model Benchmarking

- ***P**rotocol for the **A**nalysis of **L**and **S**urface models (**PALS**)*: www.pals.unsw.edu.au. ***GEWEX/GLASS project.***
- Compare models with empirical/statistical approaches, previous model versions, other land models. Different plots/tables of model validation and benchmarking metrics.
- Community-dependent metrics:climate/weather, carbon, hydro.
- *Identify systematic biases for model development & validation*.



PALS example: CABLE (BOM/Aust.) land model, Bondville, IL, USA (cropland), 1997-2006, avg diurnal cycles.

Martin Best (UKMO), Gab Abramowitz (UNSW) et al.

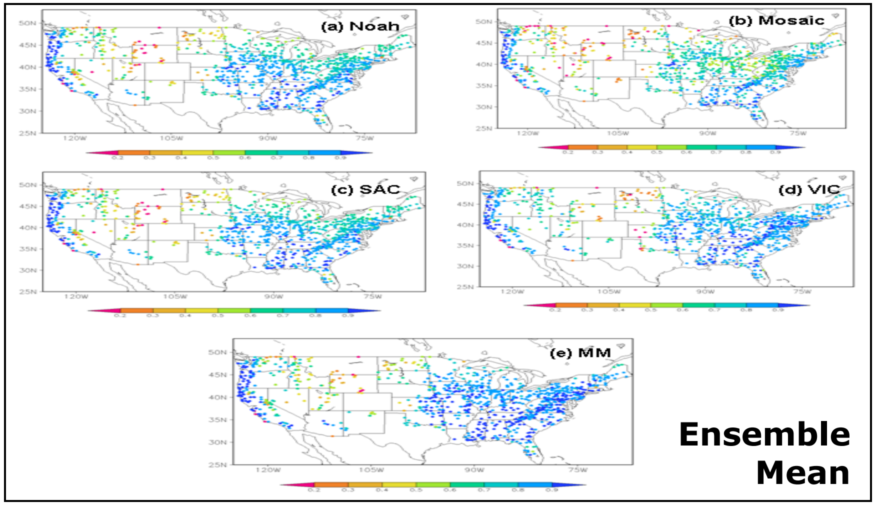
Testing & Validation: "uncoupled" NLDAS

Comprehensive evaluation against *in situ* observations and/or remotely sensed data sets.

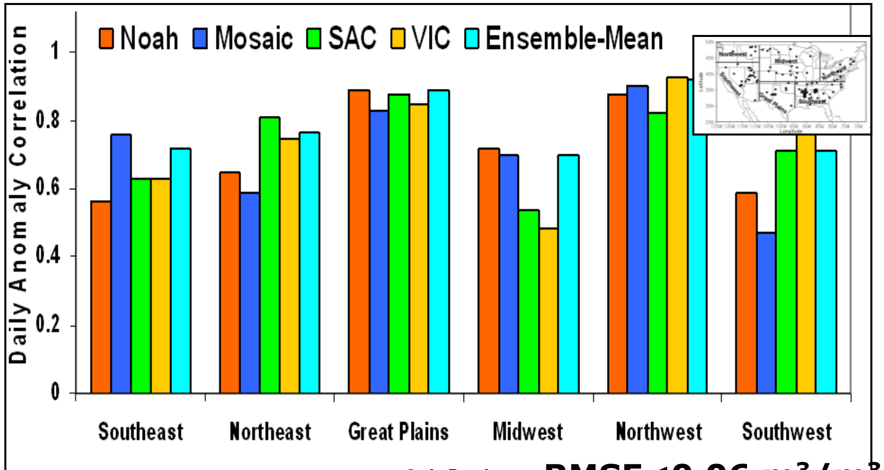
Energy flux validation from tower: net radiation, sensible, latent & ground heat fluxes.

Water budget: evaporation, total runoff/streamflow.

State variables: soil moist., soil/skin temp., snow depth/cover.



Monthly streamflow anomaly correlation (1979-2007 USGS measured streamflow)



Daily top 1m soil moisture anomaly corr. (2002-2009 US SCAN Network)

Youlong Xia (NCEP/EMC land team)

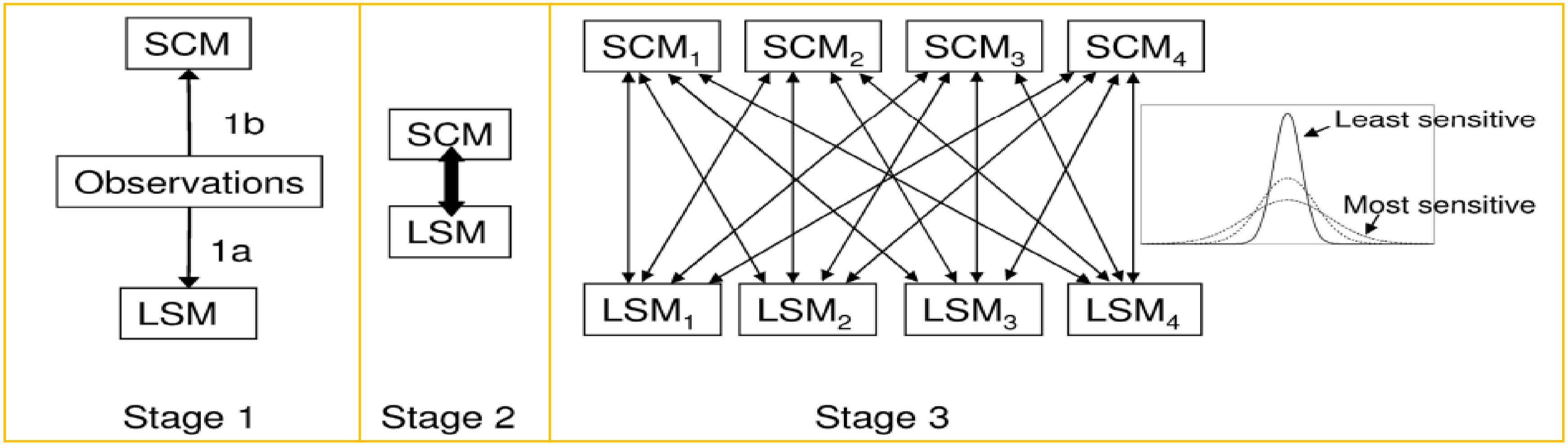
Testing & Validation: Column Model Testing

Diurnal land-atmosphere coupling experiment (DICE)

Objective: Assess impact of land-atmosphere feedbacks.
Stage 1: stand alone land, and single column model (SCM) alone.
Stage 2: Coupled land-SCM.
Stage 3: Sensitivity of LSMs & SCMs to variations in forcing.

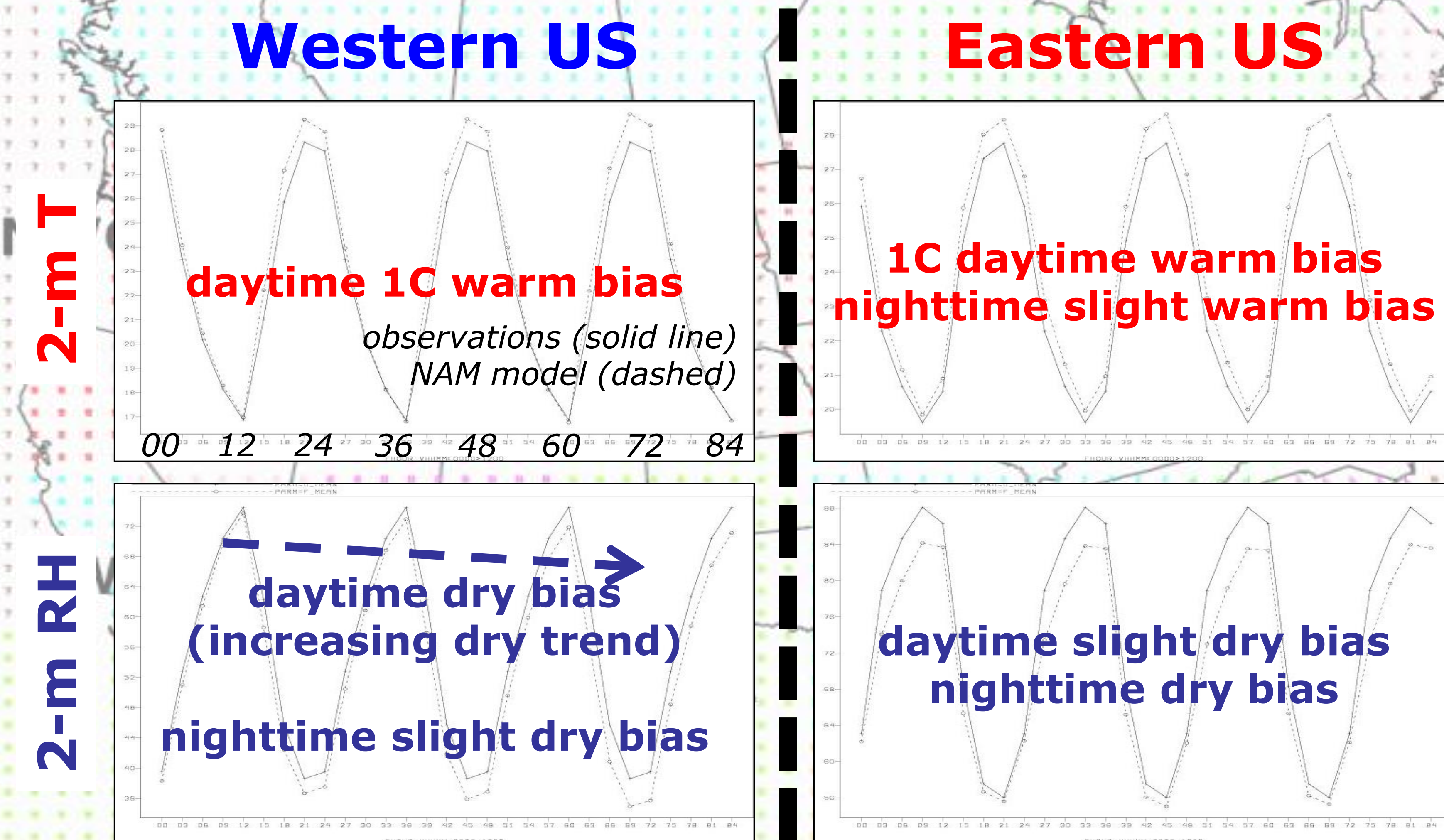
Data Set: CASES-99 field experiment in Kansas, using 3 days: 23-26 Oct 1999, 19UTC-19UTC.

Joint GEWEX GLASS-GASS project –outgrowth of GABLS2 (boundary-layer project). ***Land-atmosphere coupling identified as a important mechanism***. ~10 models participating.



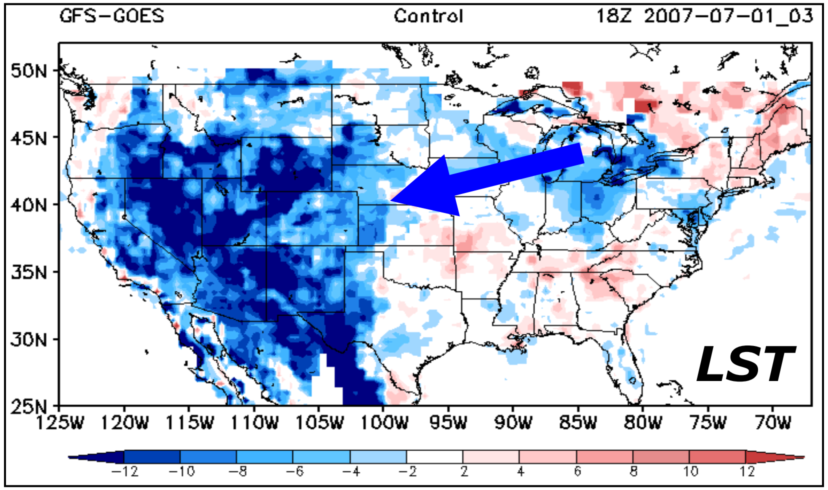
Martin Best and Adrian Lock (UKMO) et al.

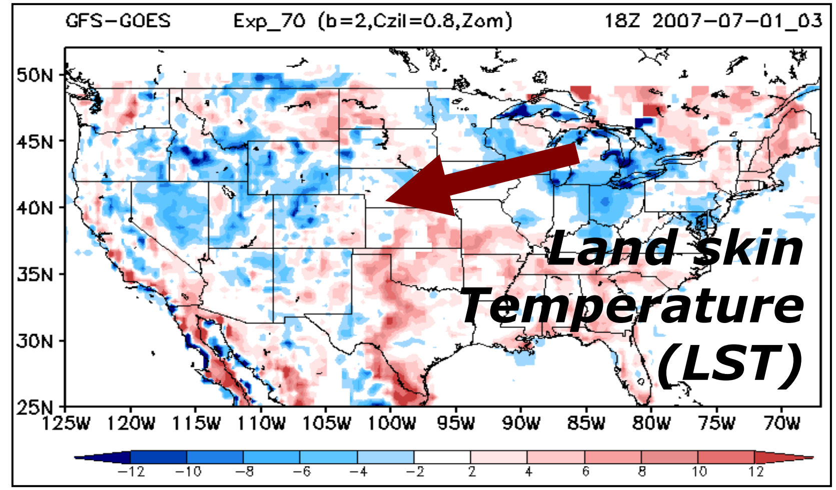
Testing & Validation: NWP model
NCEP North American Mesoscale model, 0-84hr forecast



- **Assess systematic biases using diurnal monthly means.**

Testing & Validation: NCEP GFS Surface-layer formulation modifications ("z0t"): GFS LST Verification with GOES and SURFRAD 3-Day Mean: 1-3 July 2007, Valid 00Z



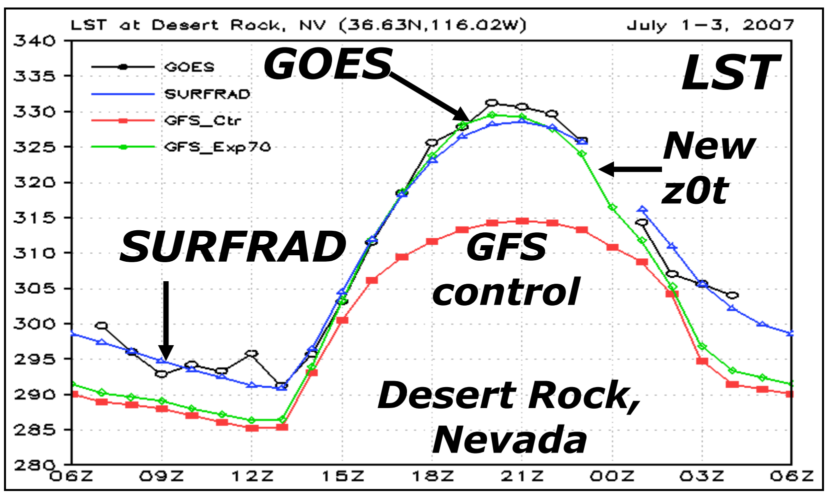


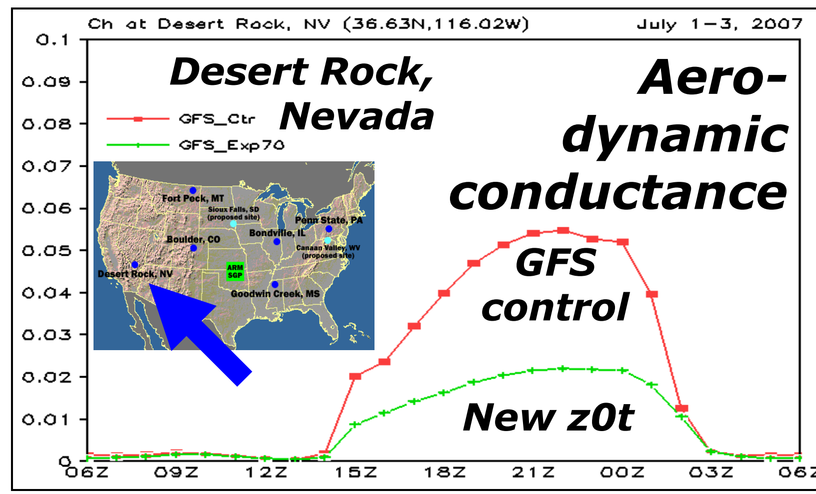
GFS-GOES: Control

Large cold bias (western US).

GFS-GOES: New "z0t"

Daytime significantly improved.





Weizhong Zheng (NCEP/EMC land team)

NCEP michael.ek@noaa.gov

Testing & Validation: Land and related issues

Low-level biases in winds, temperature, and humidity are influenced in part by the land surface via biases in surface fluxes exchanged with the atmospheric model (& effect on precipitation).

Improving the proper partition of surface energy budget between sensible, latent, soil heat flux and outgoing longwave radiation, and effect on water budget, requires:

- Improved vegetation physics/parameters to calculate ET.
- Better soil physics/properties to address surface heterogeneity.
- Improved snow physics (melt/freeze, densification).
- Surface-layer physics, especially nighttime/stable conditions, and interaction with the surface & atmospheric boundary layer.
- Remote sensing of many different initial land states, e.g. near-real-time vegetation; corresponding data assimilation of these land states, e.g. snow, soil moisture, GVF.
- Improved forcing for the land model, especially precipitation and downward radiation; requires enhanced downscaling techniques.

Such validations suggest land model physics upgrades.

Outline

- Role of Land Surface Models (LSMs)
- Model requirements: physics & parameters, atmospheric forcing, land data sets, initial land states
- Land Data Assimilation
- Applications for Weather & Climate
- Testing and Validation
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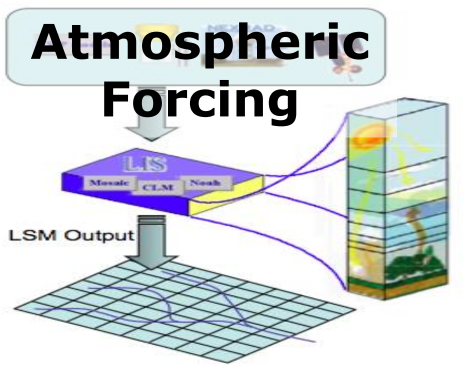
Land Models in Earth Systems

In a more fully-coupled ***Earth System***, this role involves ***Weather & Climate*** connections to:

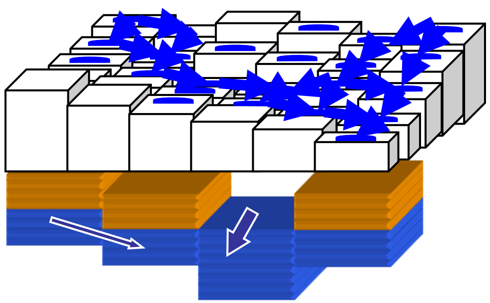
- ***Hydrology***: soil moisture & ground water/water tables, irrigation and groundwater extraction, water quality, streamflow and river discharge to oceans, drought/flood, lakes, and reservoirs/human mgmt.
- ***Biogeochemical cycles***: application to ecosystems, both terrestrial & marine, dynamic vegetation and biomass, carbon budgets, etc.
- ***Air Quality***: interaction with boundary-layer, biogenic emissions, VOC, dust/aerosols, etc.

More constraints, i.e. must close energy and water budgets, and those related to air quality and BGC cycles. *Get the right answers for the right reasons!*

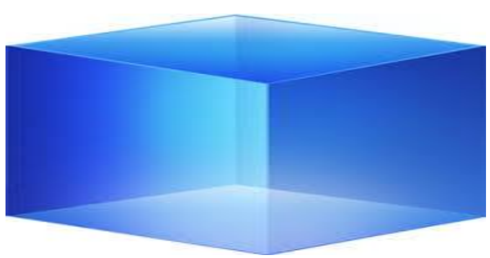
Hydrology: River-routing, Groundwater



Surface flow

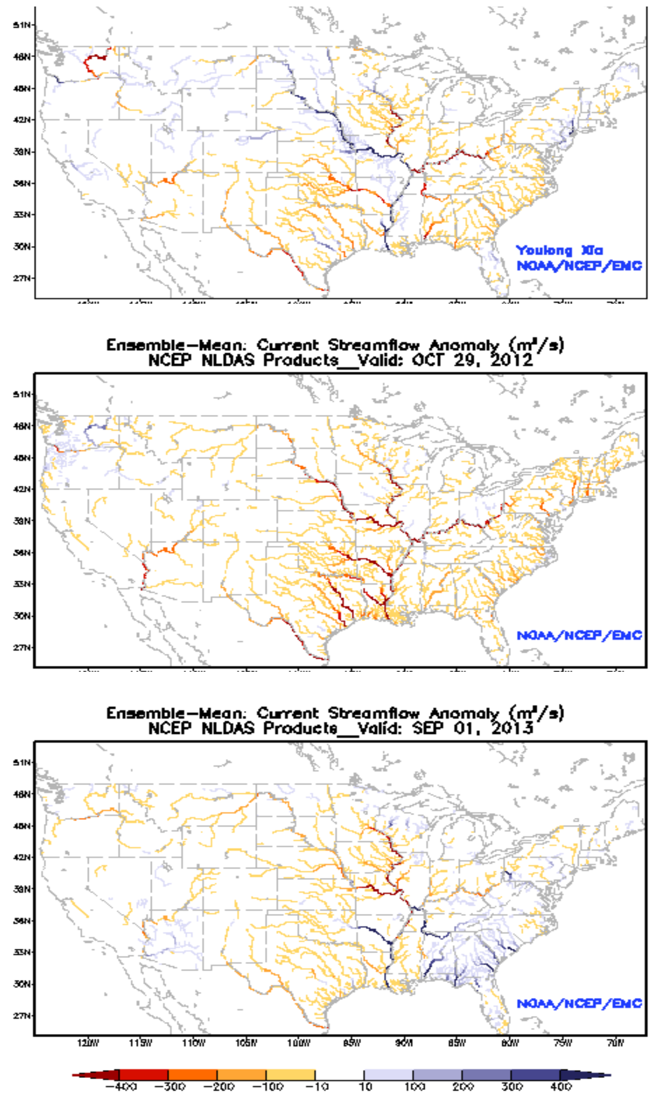


Saturated subsurface flow



Groundwater

Ensemble mean daily streamflow anomaly



Hurricane Irene and Tropical Storm Lee, 20 August – 17 September 2011

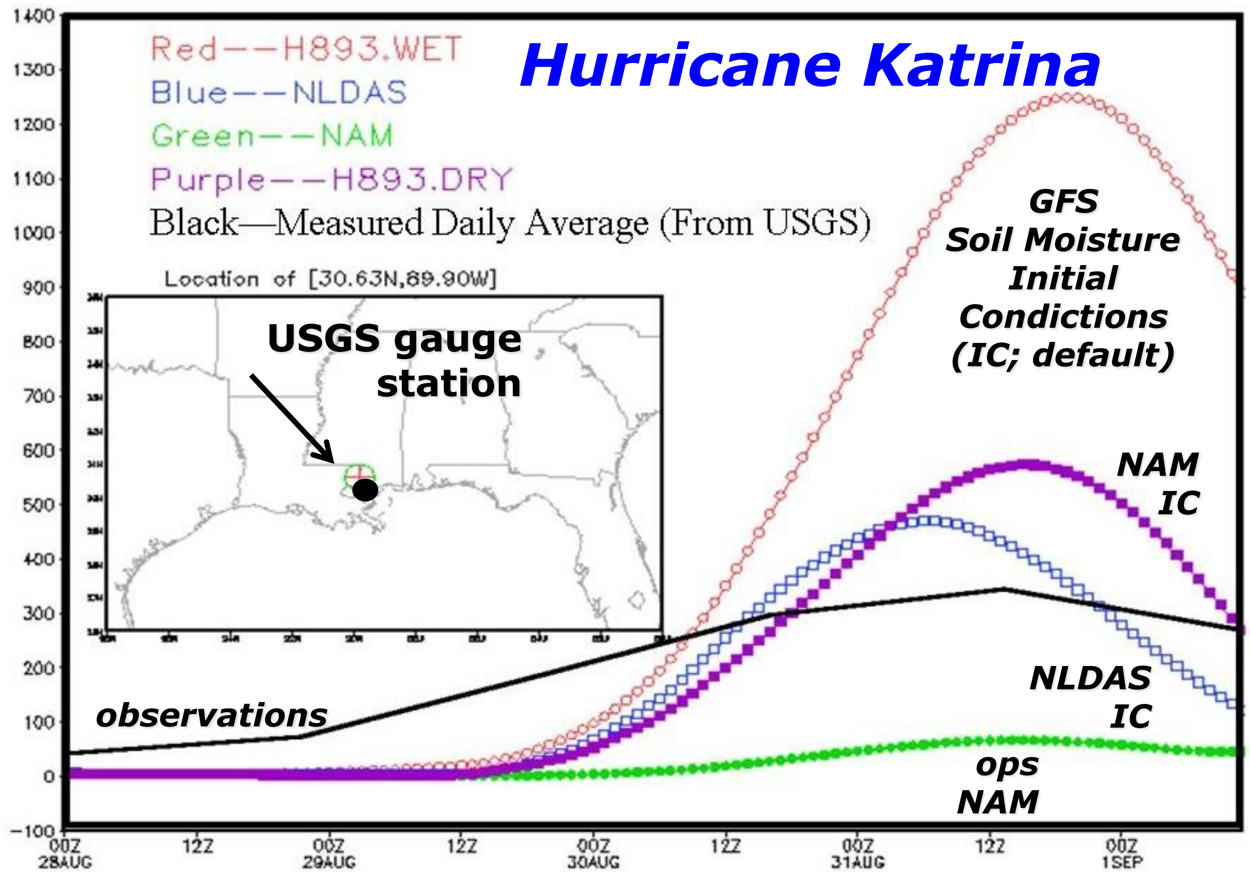
Superstorm Sandy, 29 October – 04 November 2012

Colorado Front Range Flooding, September 2013

Streamflow anomialies: Youlong Xia (NCEP/EMC land team)

Hurricanes and Inland Flooding

- Physical-based Noah model included in (mesoscale) Hurricane Weather Research & Forecasting model, with little degradation in track & intensity & precip.
- **Inland flood forecasting** (right) using Noah runoff & streamflow model.
- Extend to global/climate models: **river discharge to oceans**.

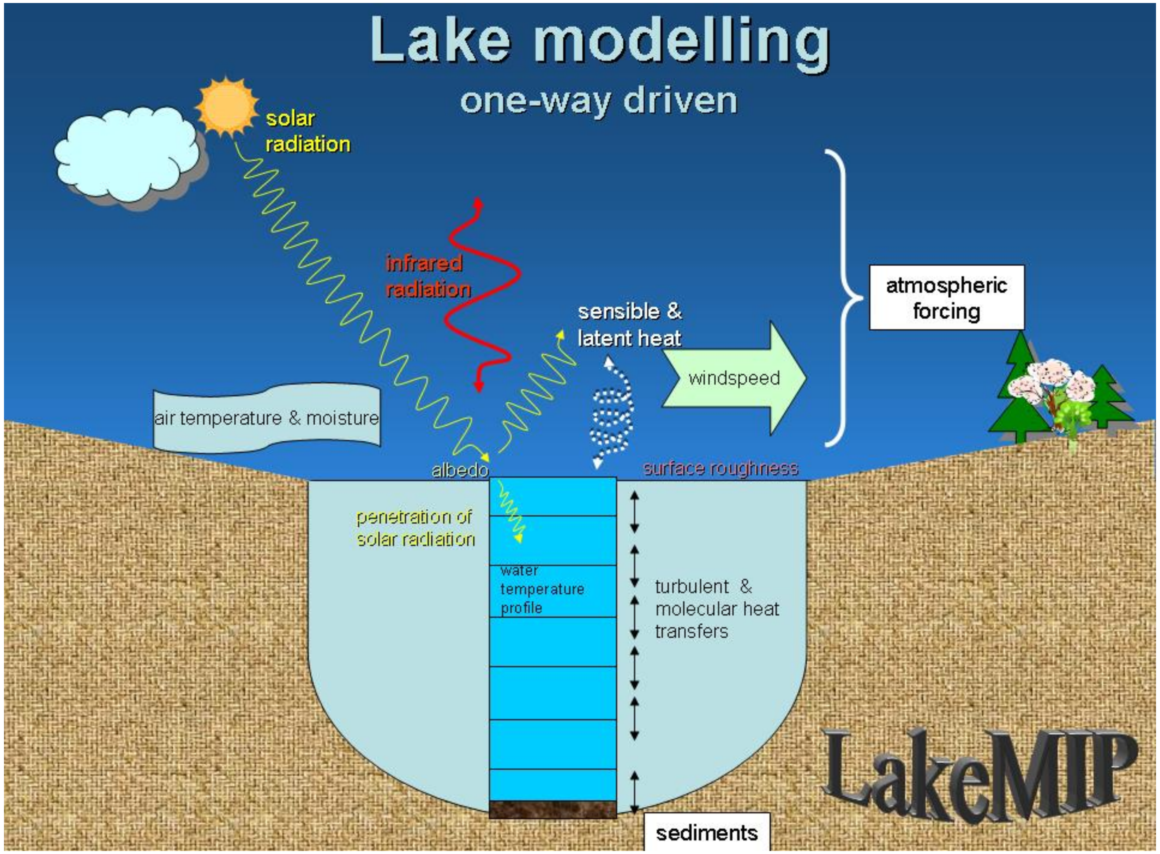


Yihua Wu (NCEP/EMC land team)

Lakes

- ***Thousands*** of lakes on scale of 1-4km not resolved by SST analysis -> greatly influence surface fluxes; explicit vs subgrid.
- Freshwater lake "***FLake***" model *(Dmitrii Mironov, DWD).*

- Two-layer.
- Atmospheric forcing inputs.
- Temperature & energy budget.
- Mixed-layer and thermocline.
- Snow-ice module
- Specified depth/turbidity.
- Used in COSMO, HIRLAM, NAM (regional), and global ECMWF, CMC, UKMO.



Yihua Wu, NCEP/EMC

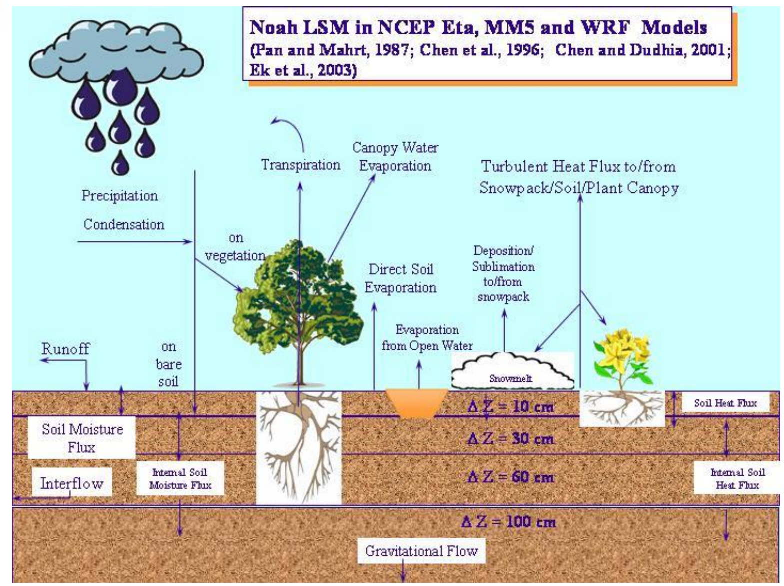
New generation Noah-MP community land model

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D12109, doi:10.1029/2010JD015139, 2011

The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements

Guo-Yue Niu,[1,2] Zong-Liang Yang,[1] Kenneth E. Mitchell,[3] Fei Chen,[4] Michael B. Ek,[3] Michael Barlage,[4] Anil Kumar,[5] Kevin Manning,[4] Dev Niyogi,[6] Enrique Rosero,[1,7] Mukul Tewari,[4] and Youlong Xia[3]

Received 4 October 2010; revised 3 February 2011; accepted 27 March 2011; published 24 June 2011.



Niu et al. (2011)

The community Noah land surface model with multiparameterization options (Noah-MP): 2. Evaluation over global river basins

Zong-Liang Yang,[1] Guo-Yue Niu,[1,2] Kenneth E. Mitchell,[3] Fei Chen,[4] Michael B. Ek,[3] Michael Barlage,[4] Laurent Longuevergne,[5] Kevin Manning,[4] Dev Niyogi,[6] Mukul Tewari,[4] and Youlong Xia[3]

Received 4 October 2010; revised 4 February 2011; accepted 25 March 2011; published 24 June 2011.

- **Noah-MP implemented in WRF, testing in WRF-Hydro (hydrology/groundwater), Regional WRF & NCEP season-al Climate Forecast System (with drought applications)**

Noah-MP is Unique Among Land Models

- ***Multiple parameterizations to treat key hydrology-snow-vegetation processes paradigm in a single land modeling framework.***
- ***In a broad sense,***
  - Multi-physics ≡ Multi-hypothesis
- ***A modular & powerful framework for:***
  - Diagnosing differences
  - Identifying structural errors
  - Improving understanding
  - Enhancing data/model fusion and data assimilation
  - Facilitating ensemble forecasts and **uncertainty quantification**

Noah-MP Physics Options

VEGETATION:

Leaf area index (prescribed; predicted)
Soil moisture stress factor for transpiration (Noah; SSiB; CLM)
Canopy stomatal resistance (Jarvis; Ball-Berry)
Biogeochemical Advances, e.g. nitrogen (in addition to carbon)
Plant growth/Crop modeling

CANOPY:

Radiation transfer (explicit vegetation canopy):
- **Modified 2-stream: Gap = F(3D structure; solar zenith angle) ≤ 1-GVF**
- **Two-stream applied to the entire grid cell: Gap = 0**
- **Two-stream applied to fractional vegetated area: Gap = 1-GVF**

SNOW:

Snow surface albedo (BATS; CLASS)
Frozen soil permeability (Noah; Niu and Yang, 2006) (3-layers)
Supercooled liquid water (Noah; Niu and Yang, 2006)

RUNOFF AND GROUNDWATER:

TOPMODEL with groundwater
TOPMODEL with equilibrium water table (Chen&Kumar, 2001)
Original Noah scheme
BATS surface runoff and free drainage

OTHER:

Partitioning of precipitation to snowfall & rainfall (CLM; Noah)
Turbulent transfer (Noah; NCAR LSM)

More to be added!

Collaborators: Yang, Niu (UAriz), Chen, Barlage et al (NCAR), Ek et al (NCEP/NOAA), and others.

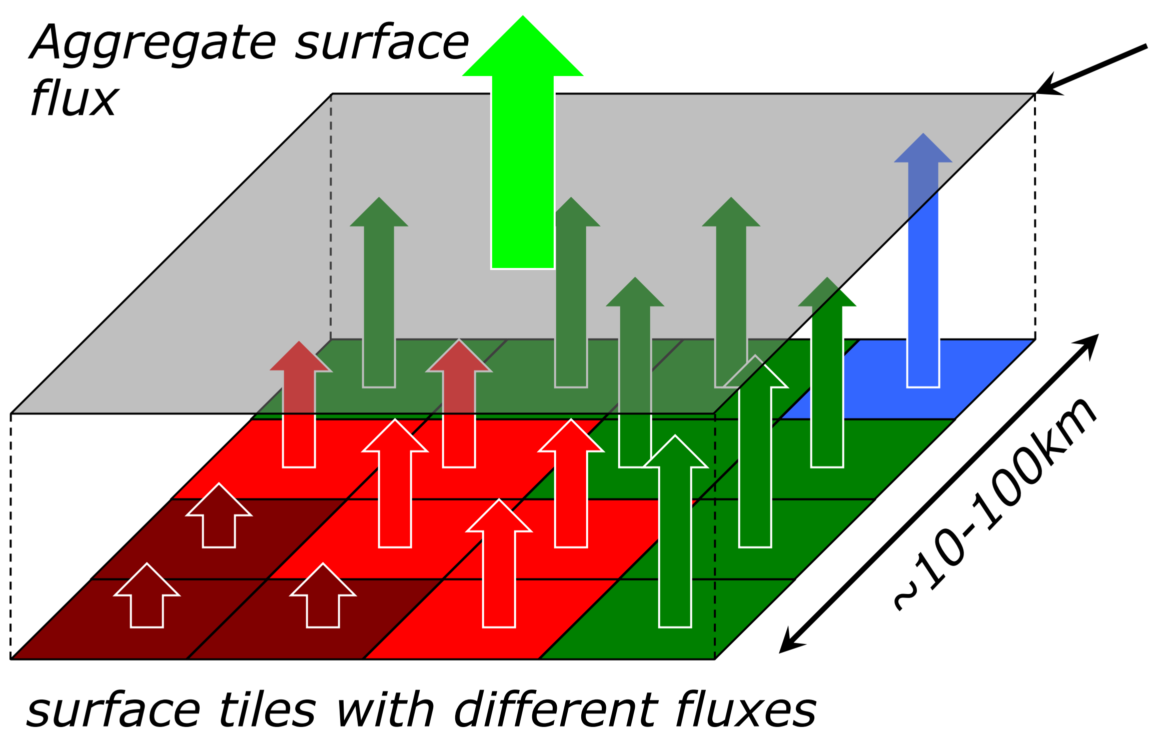
Recet Noah-MP Physics Changes in WRF ver3.8

- Code structure added for spatially-varying soil properties.
- Crop model code added.
- New vegetation options added (LAI – read, specified, predicted; fveg – read, maximum, empirical).
- Glacier option added (consistent with Noah method)
- Surface resistance option added (treating soil/snow evap/sub resistance).
- Fix patchy-snow surface temperature option.

Download offline Noah-MP code at:
https://github.com/NCAR/hrldas-release.git

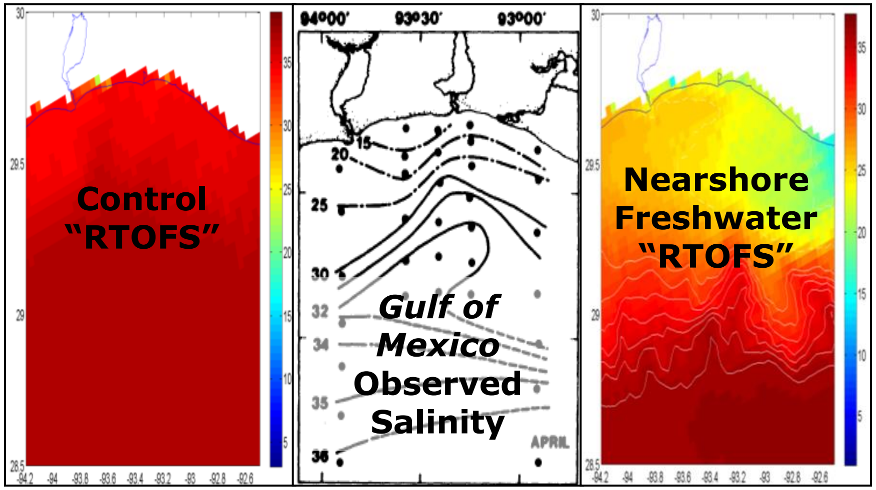
Land Physics: Tiled Land Grid

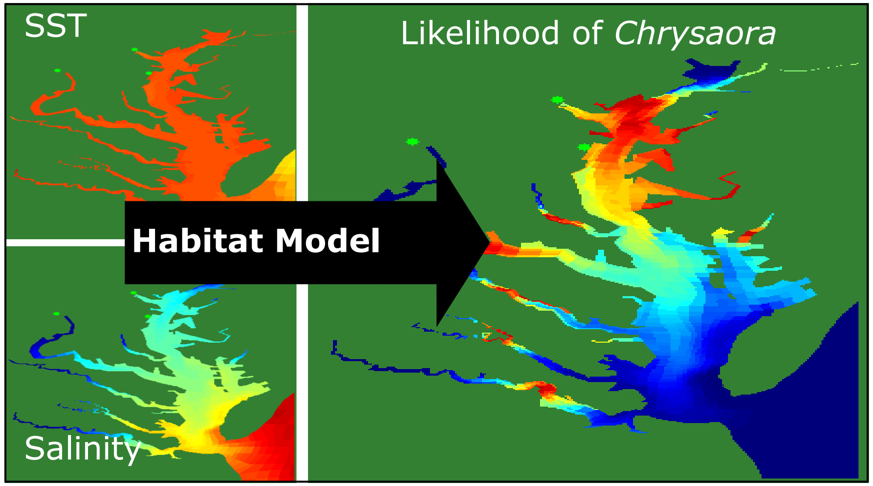
- A land model grid may comprise sub-atmospheric-grid-scale "tiles", e.g. forest, shrubland, grass, crop, water, etc, O(1-4km), with coarser-resolution atmospheric forcing downscaled to land.
- Aggregate flux to "parent" atmospheric model.
- Recent versions of Noah LSM.



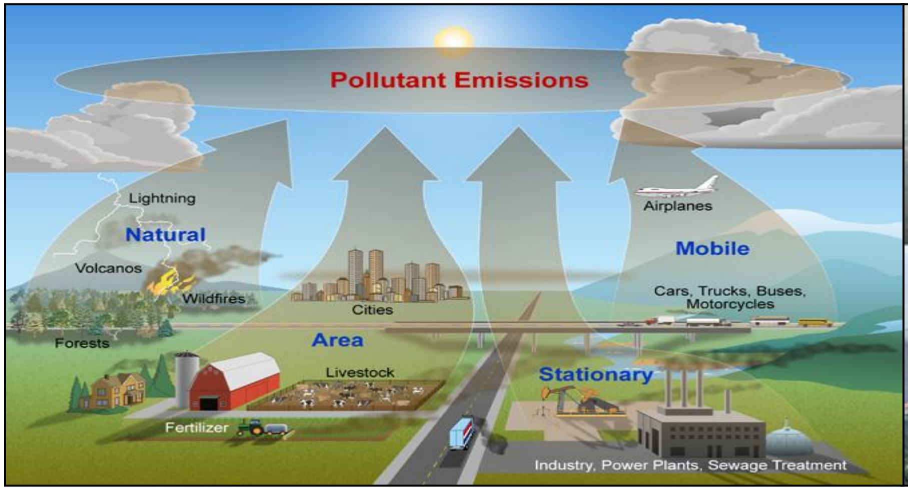
- Boundary-layer issues: when blending height is greater than the lowest atmospheric model level or even the ABL depth, an aggregated flux needs to be re-examined.

Ecosystems, Air Quality



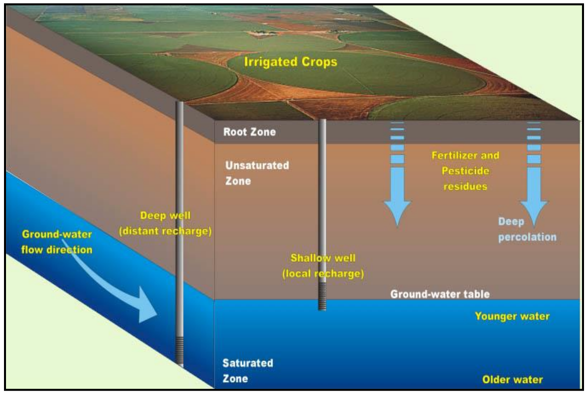


- ***Hydro-Coastal Linkage***
- ***Sea Nettle Forecasting***



- ***Land sources of dust and aerosols, mixed through ABL.***

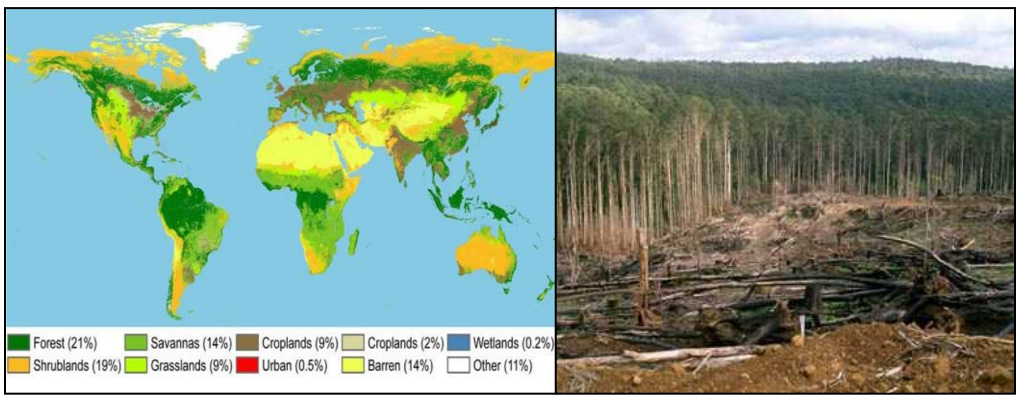
Human Influences/Management



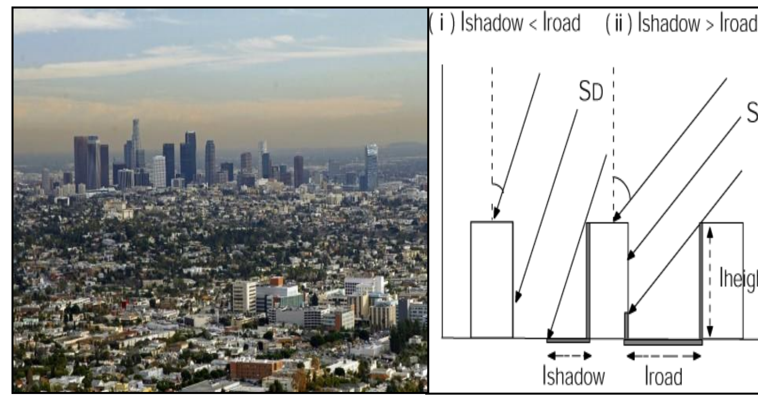
Groundwater Extraction

Irrigation

Reservoirs



Land-cover change/deforestation



Urban areas/model

- Proper initial conditions (e.g. via remote sensing), and improved land model physics parameterizations.

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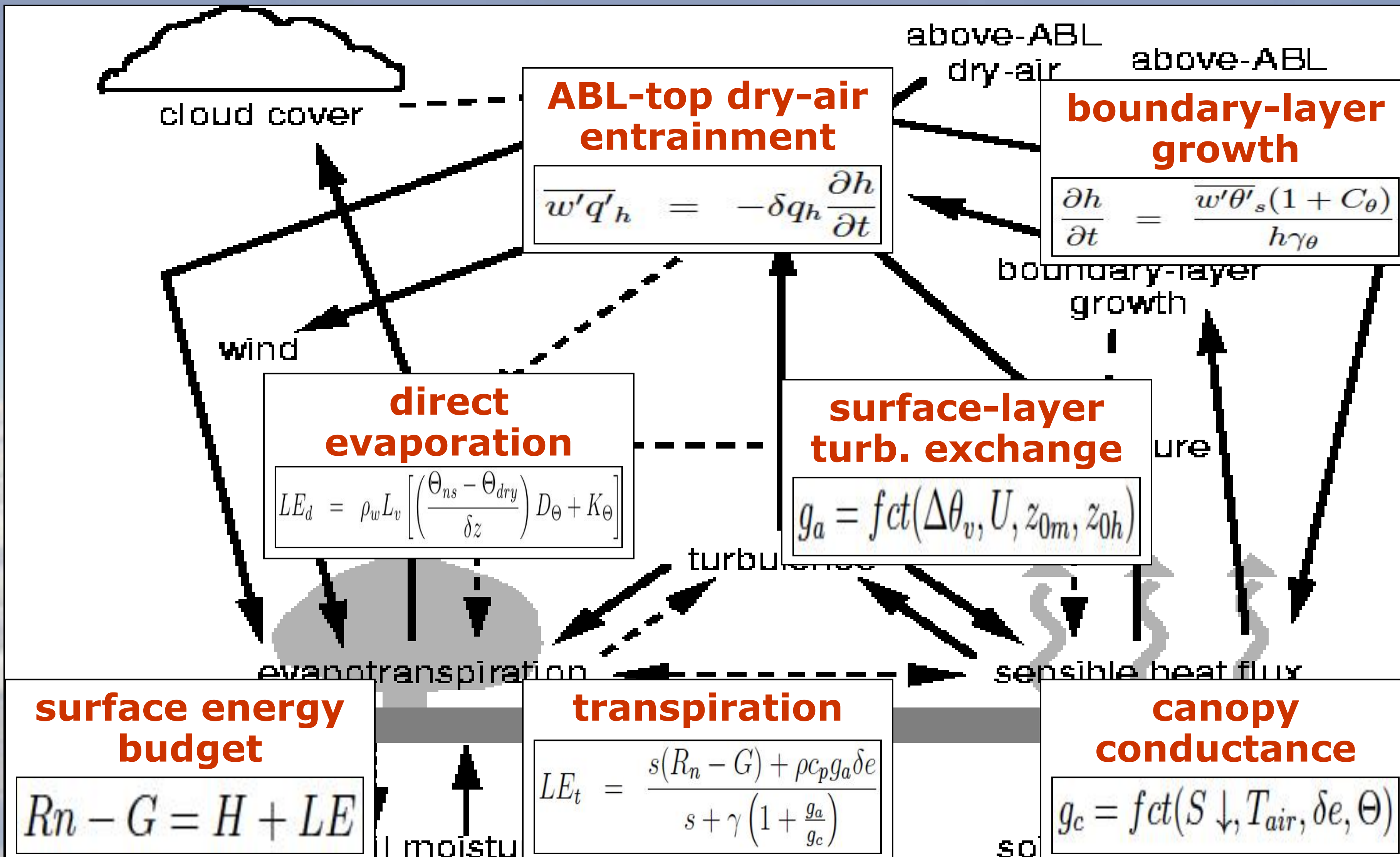
Land-Atmosphere Interaction

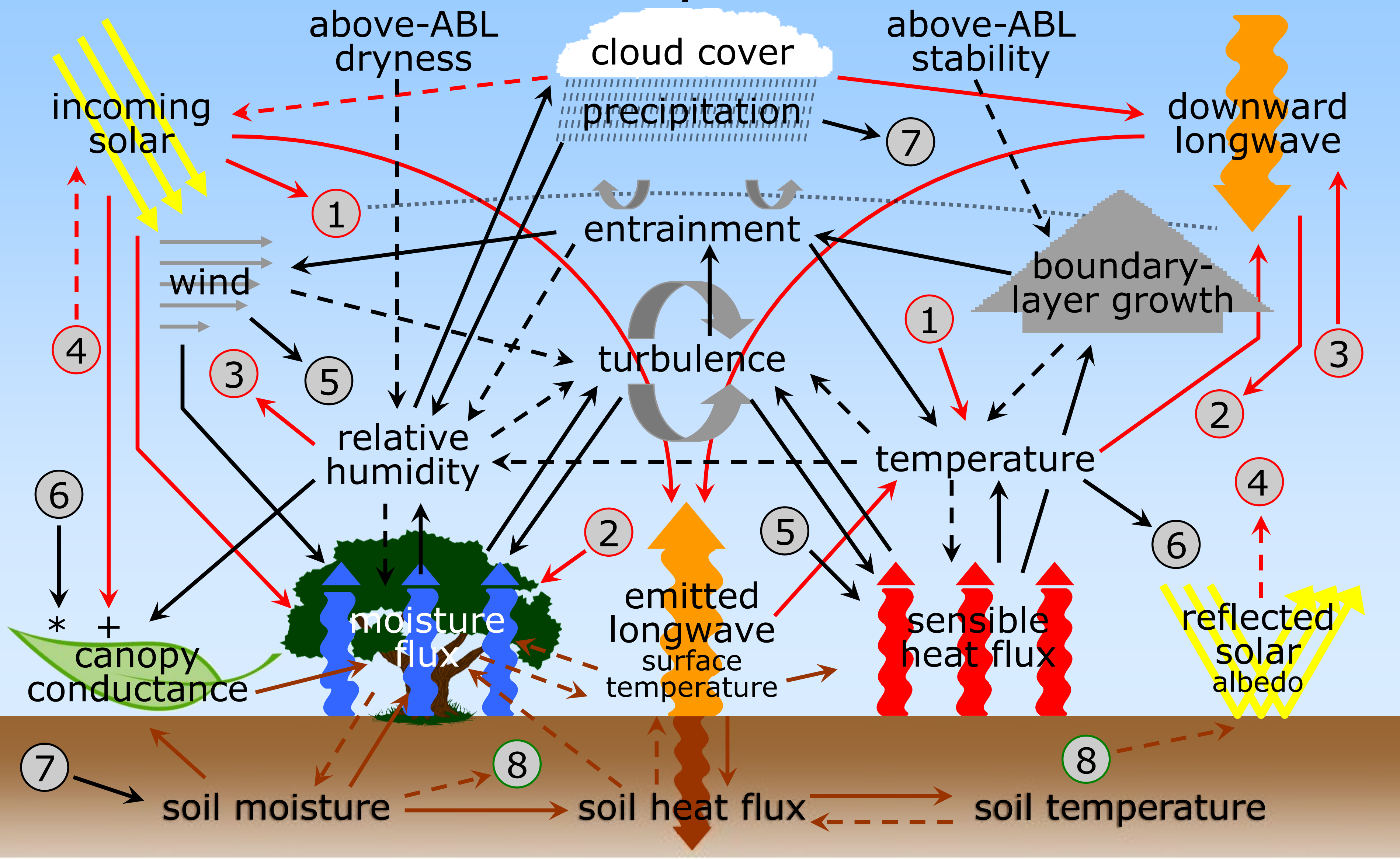
- Many land-surface/atmospheric processes.
- Interactions & feedbacks between the land and atmosphere must be properly represented.
- Global Energy and Water Exchanges (GEWEX) Program / Global Land/Atmosphere System Study (GLASS) project: ***Accurately understand, model, and predict the role of Local Land-Atmosphere Coupling "LoCo" in water and energy cycles in weather and climate models.***
- All land-atmosphere coupling is local…

…initially.

Land-Atmosphere Interactions



Local Land-Atmosphere Interactions

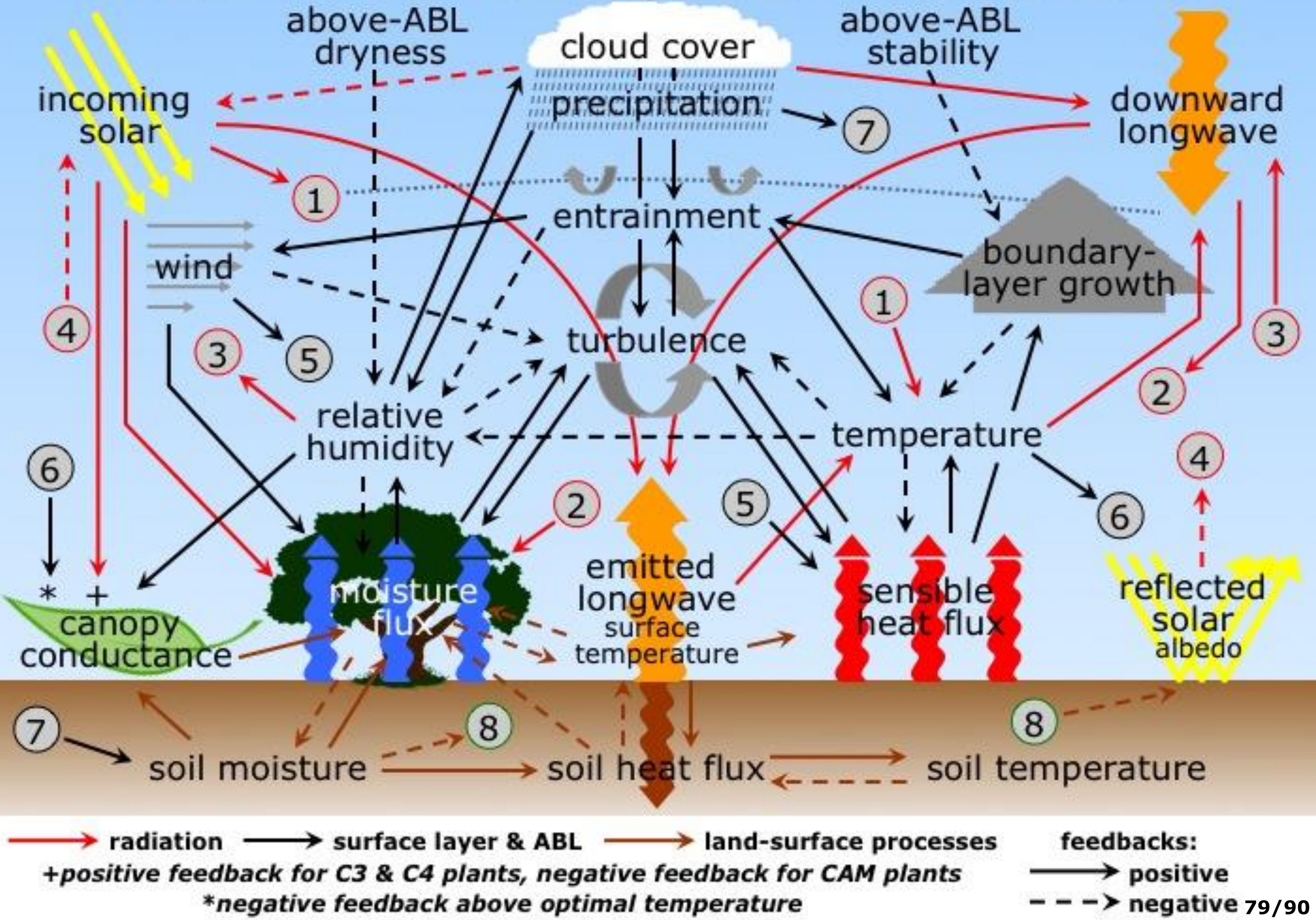


radiation **surface layer & ABL** **land-surface processes** **feedbacks:**

+positive feedback for C3 & C4 plants, negative feedback for CAM plants **positive**

****negative feedback above optimal temperature*** **negative**

Local Land-Atmosphere Interactions



Land-Atmosphere Interactions

Betts et al (1996)

Considered diurnal, seasonal, century time scales,

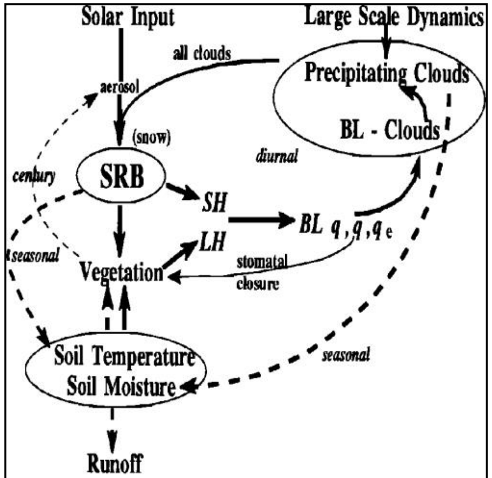


Figure 1. Schematic showing some important land surface-atmosphere interactions on different timescales.

Beljaars (2005)

"We discussed including this in a recent document, but dropped it because it was too confusing."

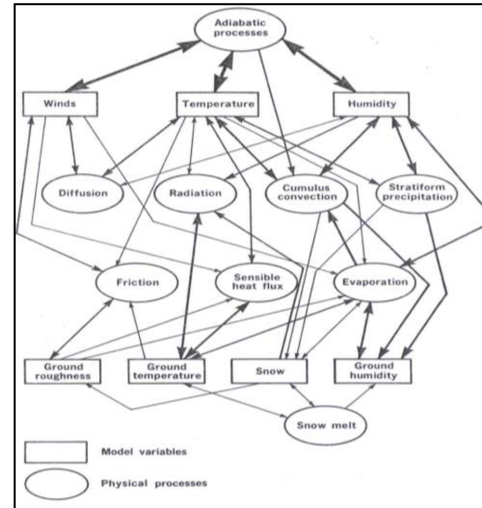
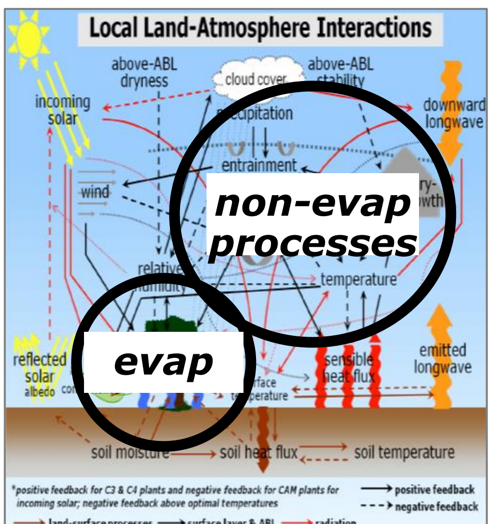


Fig. 1.1 Schematic representation of the processes included in the ECMWF model.

From "GEWEX" Imperatives: Plans for 2013 and Beyond"

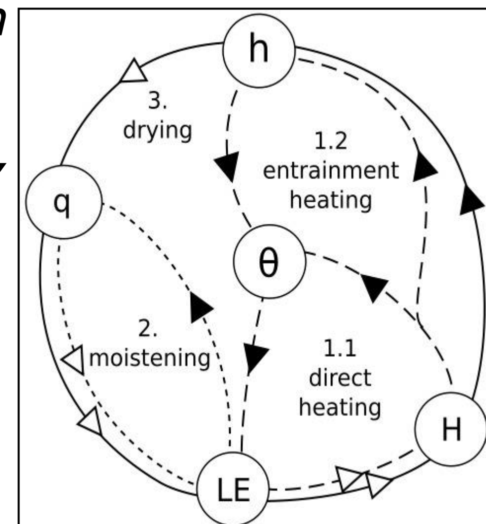
Ek&Holtslag (2004) characterized land and atmospheric processes and feed-backs for typical daytime with focus on soil moisture vs other processes.



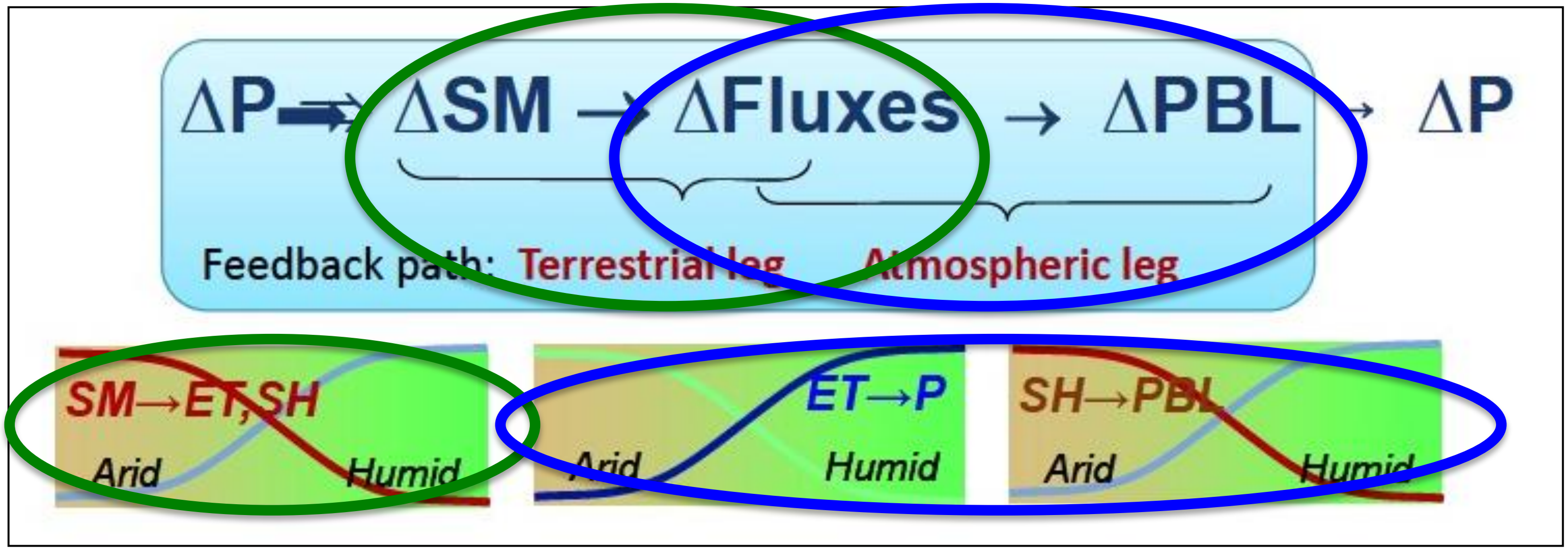
v.Heerwaarden et al (2009)

"Ek & Holtslag is too complicated"

Negative feedback mechanisms and the relationships among variables that regulate evaporation.



Land-Atmosphere Feedbacks stand on 2 legs



- **Terrestrial** – When/where does soil moisture (vegetation, soil, snow, etc.) control the partitioning of net radiation into sensible and latent heat flux (and soil heat flux)?
- **Atmosphere** – When/where do surface fluxes significantly affect boundary-layer growth, clouds and precipitation?

Paul Dirmeyer, George Mason Univ., Joe Santanello, NASA/GSFC

Near-Surface Interactions:

Soil moisture – evapotranspiration relationships

Transpiration:

$$ef_t = \frac{s + \frac{\rho c_p g_a \delta e}{R_n - G}}{s + \gamma\left(1 + \frac{g_a}{g_c}\right)}$$

Penman-Monteith

Evap. fraction change with soil moisture change:

$$\frac{\partial \ln ef_t}{\partial \Theta} = \frac{1}{\delta\Theta_{rz}}\left\{\underbrace{\left[\left(\frac{s+\gamma}{\gamma}\right)\frac{g_c}{g_a} + 1\right]^{-1}}_{=\omega} + \left[\frac{s(R_n - G)}{\rho c_p g_a \delta e} + 1\right]^{-1} \frac{\delta\Theta_{rz}}{\Theta_{ns}} \frac{b\beta G}{(R_n - G)}\right\}$$

Direct evaporation:

$$ef_d = \frac{\rho_w L_v}{R_n - G}\left[\frac{\delta\Theta_{ns}}{\delta z} D_\Theta + K_\Theta\right]$$

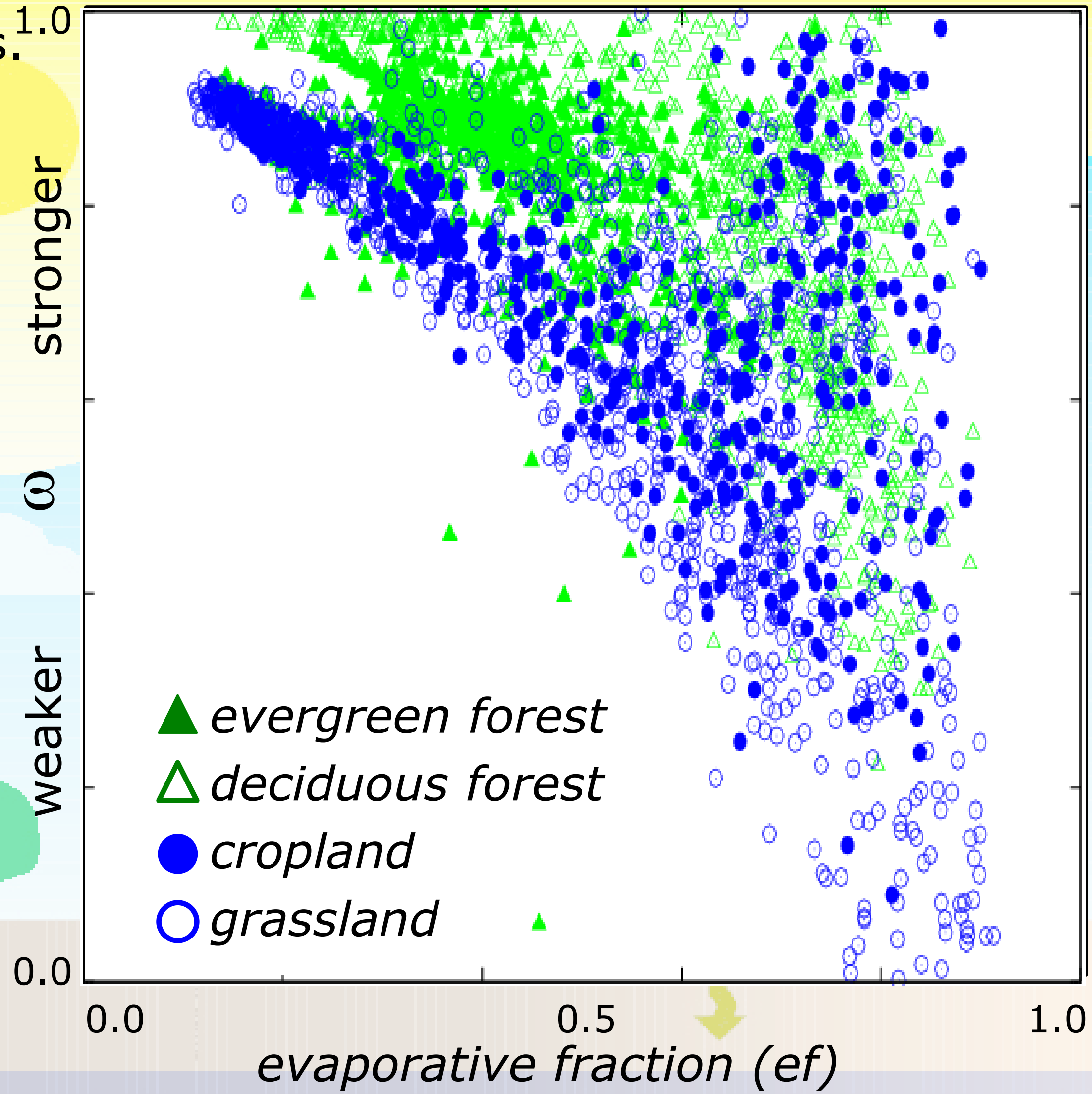
Mahrt & Pan (1983)

Evap. fraction change with soil moisture change:

$$\frac{\partial \ln ef_d}{\partial \Theta} = \frac{1}{\Theta_{ns}}\left\{\frac{[\Theta_{ns} + (\beta + 2)\delta\Theta_{ns}]\, s_\Theta + (2\beta + 3)}{1 + \delta\Theta_{ns}\, s_\Theta} + \frac{b\beta G}{R_n - G}\right\}$$

Near-Surface Interactions:
Evaporative Fraction vs Coupling Parameter

- Evaporative fraction (ef) vs. "ω" (coupling parameter) for JJA mid-day averages (CONUS FluxNet sites; Rn-G>100 Wm-2, H>50, LE>50).
- Higher ef:
  - Stronger land-atmosphere coupling for forests.
  - Weaker land-atmosphere coupling for cropland and grassland.
- Lower ef: strong coupling regardless of vegetation type, due to stronger surface heating and turbulence (larger ga, smaller gc).



Land-Atmosphere Interactions:
Soil moisture/ET role in ABL & cloud development

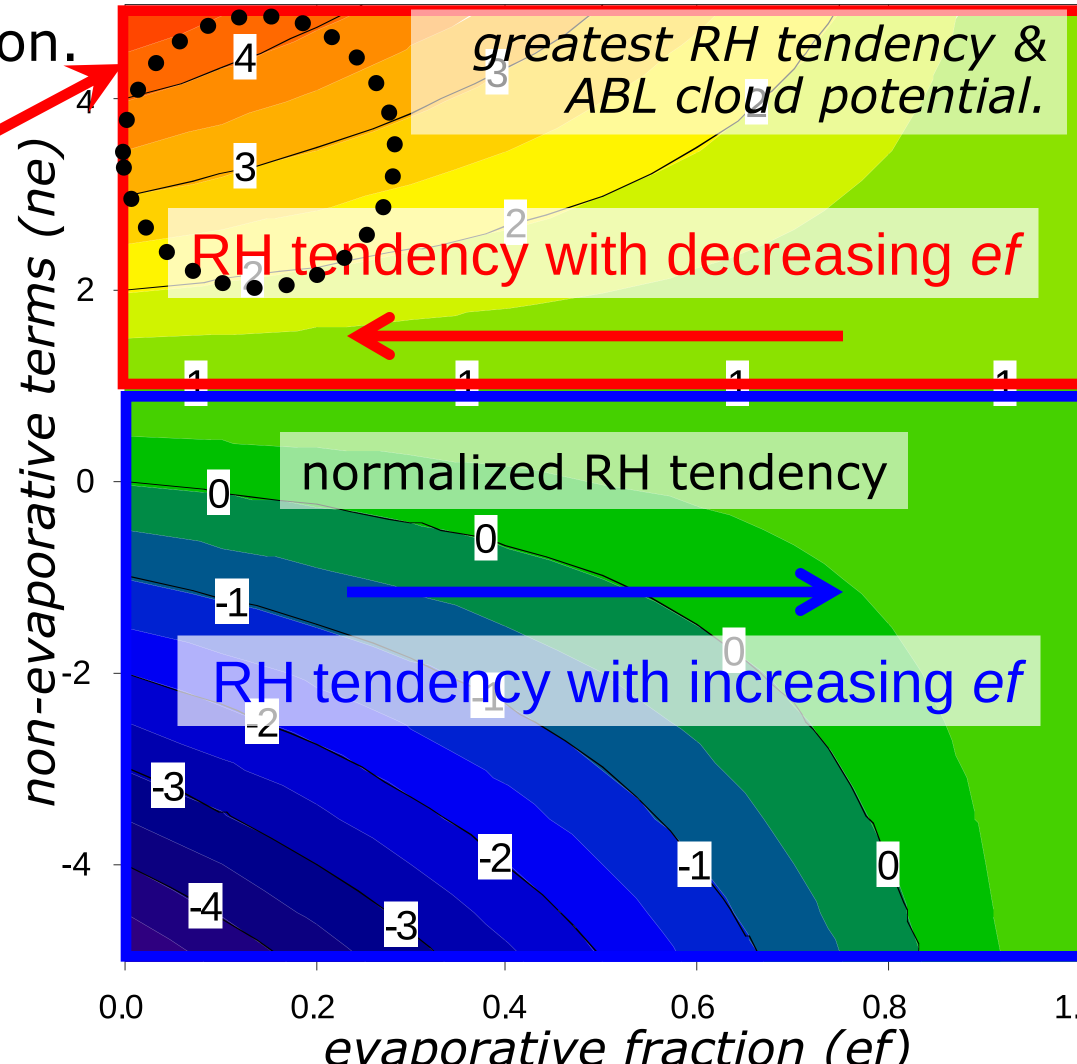
- RH controls cloud initiation.

$$\frac{\partial RH}{\partial t} = \left(\frac{R_n - G}{\rho L_v h q_s}\right)\left[e_f + ne(1 - e_f)\right],$$

$$ne = (1 + C_\theta)\frac{L_v}{c_p}\left[\frac{\Delta q}{h\gamma_\theta} + RH\left(\frac{c_2}{\gamma_\theta} - c_1\right)\right]$$

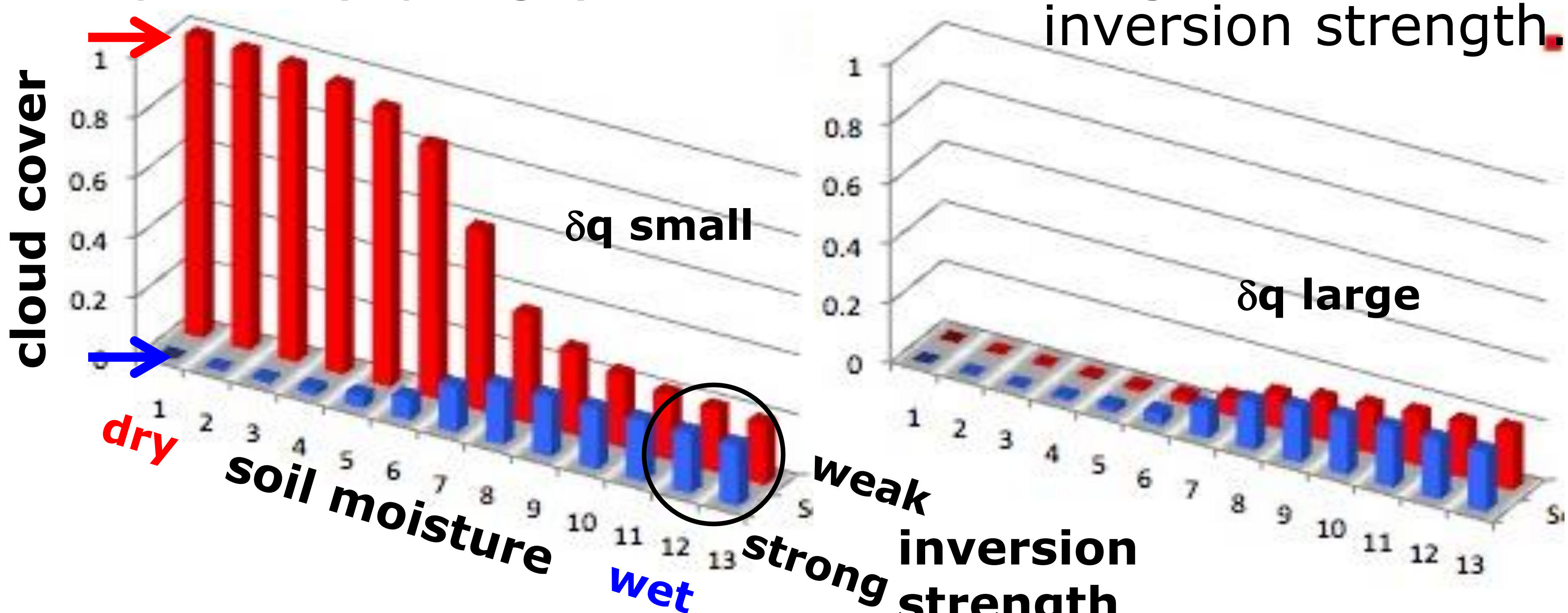
- ABL-growth regime (weaker above-PBL stability & Δq small)

- surface moistening regime (stronger above-PBL stability and/or Δq large)



Land-Atmosphere Interactions:
Soil moisture/ET role in ABL & cloud development

- dry soil/strong inversion -> shallow ABL, no clouds.
- dry soil/weak inversion -> deeper ABL, more clouds.
- moist soil -> shallow ABL, cloud cover similar.
- dry aloft (δq large) -> fewer clouds regardless of inversion strength.



- Sensitivity tests with many single column model runs.

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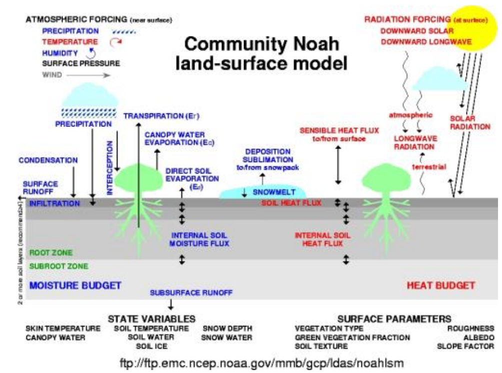
Partners/Projects

- Noah land model development: NCEP/EMC land team, NCAR, U. Ariz., U. Texas/Austin, U. Wash., WRF land & PBL working groups, other national/international partners; freshwater "FLake" community.
- NLDAS/GLDAS drought: Princeton, Univ. Washington, NASA, NWS National Water Center, NCEP Climate Prediction Center).
- Remote sensing/land data sets/data assimil-ation of soil moisture, vegetation, surface temperature, snow: JCSDA, NESDIS, National Ice Center, NASA, AFWA.
- NOAA CPO/MAPP and NWS/NGGPS: support land modeling in NCEP operational systems.
- WCRP/GEWEX: GLASS/land-hydrology, GABLS/boundary-layer, GHP/hydroclimate projects, UKMO, ECMWF, Meteo-France, etc.



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Summary

- Land models provide surface **boundary conditions** for weather and climate models, and then **proper representation of interactions** with atmosphere.
- For weather & climate modeling, land models must have **valid** (scale-aware) **physics** and associated parameters, representative **land data sets** (in some cases **near real-time)**, proper **atmospheric forcing**, and **initial and *cycled* land states**. Longer time scales require more processes (physics).
- Land model **validation** using (near-) **surface observations**, e.g. air temperature, relative humidity, wind, soil moisture, surface fluxes, etc… suggests model **physics improvements**.
- The role of land models is expanding for weather and climate in increasingly more fully-coupled Earth-System Models (atmosphere-ocean-land-sea ice-waves-aerosols) with **connections** between **Weather & Climate** and **Hydrology**, **Ecosystems & Biogeochemical** cycles (e.g. **carbon**), and **Air Quality** communities & models on local as well as large scales.

Thank you!
Obrigado!
¡Gracias!

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