The Global Land Data Assimilation System (GLDAS): Results and New Directions

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LDAS Heritage

North American LDAS

- NOAA/GAPP and NASA/LSHP 1998-2001
- NOAA/NCEP, GSFC/HSB, and 6 other institutions
- Spin-offs: GLDAS, NLDAS-E
- Mitchell et al., *J. Geophys. Res.,* 2004

Global LDAS

- NASA/IDS 2000-03; THP discretionary funding 2004-05
- GSFC/HSB and NOAA/NCEP
- Spin-offs: LIS, NEWS/Product Integration
- Rodell et al., *Bull. Amer. Meteor. Soc.,* 2004

Land Information System (LIS)

- NASA/HPCC 2002-05
- Software adopted by all other GSFC LDAS projects
- Kumar, Peters-Lidard, et al., *Environ. Model. Soft.,* 2005

"Integration of Energy and Water Cycle Research Products in a Global Land Surface Modeling and Assimilation System"

- NEWS 2005-10 (PI: M. Rodell)

NEWS "Integration" Project Overview

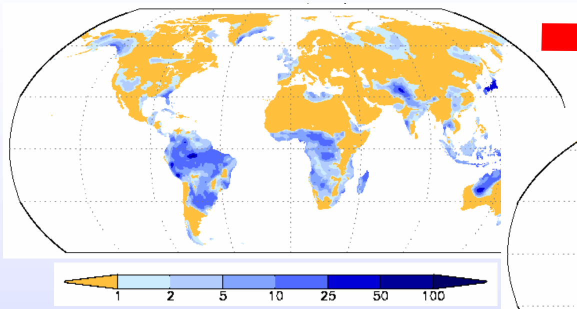
Hypothesis: **Large scale land surface processes cannot be skillfully represented and described without a comprehensive approach, which integrates the best water and energy cycle observations as data for parameterizing, forcing, constraining, and evaluating sophisticated land surface models (LSMs).**

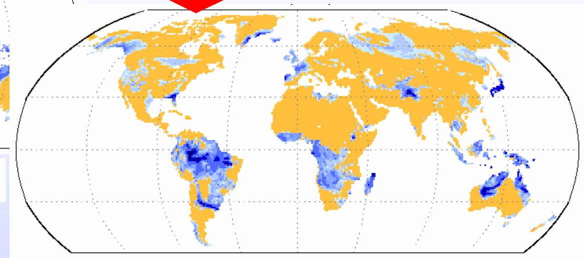
Objectives:

- Implement mature assimilation capabilities within LIS, including schemes for AMSR soil moisture (e.g., Zhan et al., 2004) and snow water equivalent (e.g., Sun et al., 2004), MODIS snow cover (e.g., Rodell and Houser, 2004), and geostationary satellite IR surface temperature (e.g., Bosilovich et al., 2004; Radakovich et al., 2001)
- Incorporate new data products as parameters and forcing
- Utilize a runoff routing scheme
- Include subgrid precipitation variability
- Assess impacts/interactions of each new dataset and capability
- Produce long term, global LSM analyses and associated uncertainty assessments, using multiple configurations with each of the linked LSMs
- Based on these, characterize regional, seasonal to interannual variability in the stocks and fluxes of the water and energy cycles

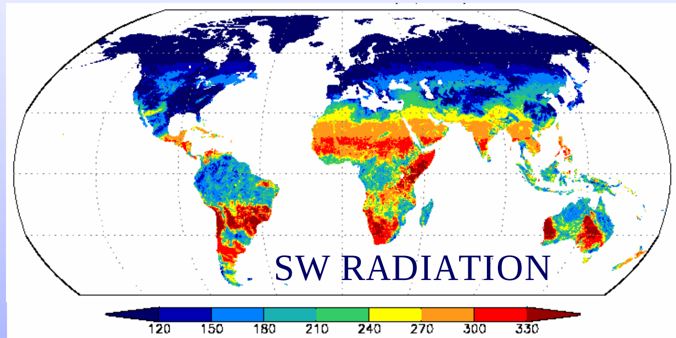
Data Integration

INTERCOMPARISON and OPTIMAL MERGING of global data fields



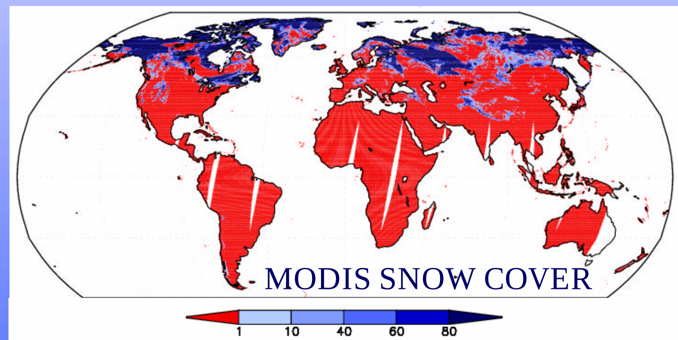


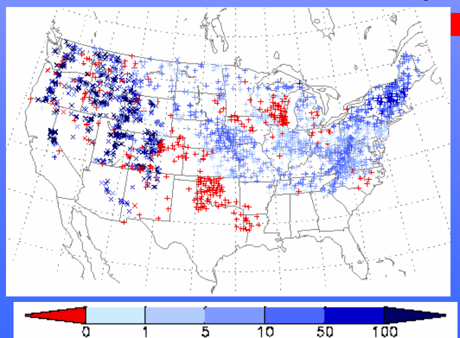
PRECIPITATION

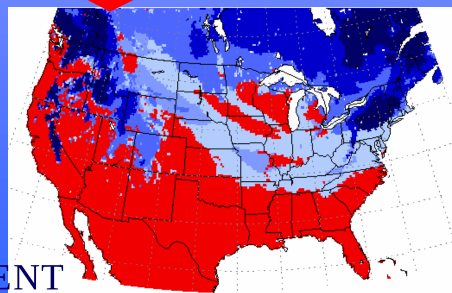


Satellite data products used to PARAMETERIZE and FORCE sophisticated land surface models

ASSIMILATION of satellite based land surface state fields (snow, soil moisture, surface temp, etc.)







SNOW WATER EQUIVALENT

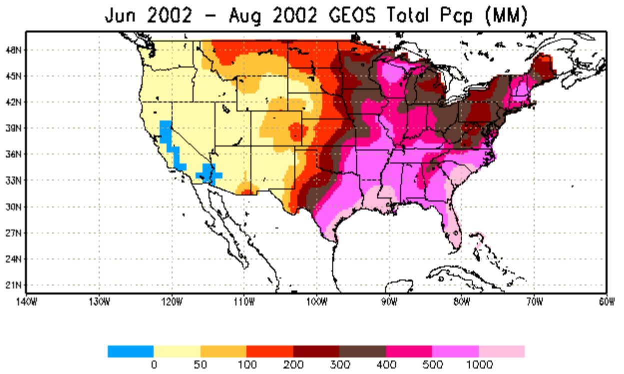
Ground-based observations (e.g., CEOP) used to EVALUATE model output

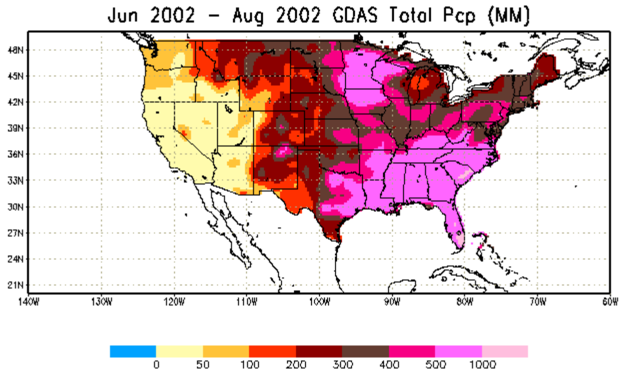
GLDAS Data Archive

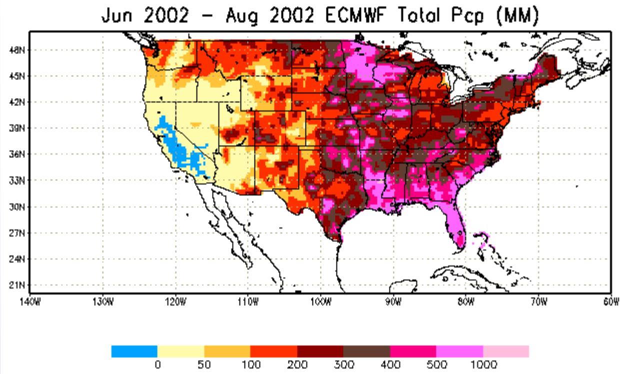
Type of Data	Source	Original Spatial Resolution	Time Period	Near Real-Time
Modeled Forcing	NASA Goddard Earth Observing System (GEOS)	1.0°	12/2000 – present	✝
	NOAA Global Data Assimilation System (GDAS)	~ 0.7°	1/1999 – present	✝
	ECMWF forecasts and analyses	~ 39 km	10/2001 – present	✝
	Berg et al. (2002) bias corrected ECMWF reanalysis	0.5°	1/1979 – 12/1993	
	Berg et al. (2002) bias corrected NCEP/NCAR reanalysis	0.5°	1/1985 – 12/1993	
Observation-Based SW and LW Radiation Forcing	Derived at NASA/GSFC using U.S. Air Force Weather Agency cloud and snow analyses	0.25°	3/2001 – present	✝
Observation-Based Precipitation Forcing	U.S. Naval Research Laboratory	0.25°	4/2001 – present	✝
	NASA/GSFC Mesoscale Atmospheric Processes Branch	0.25°	3/2002 – present	✝
	NOAA Climate Prediction Center	2.5°	1/1979 - present	
Observation-Based Snow Cover	Derived at NASA/GSFC using Terra-MODIS satellite observations	0.125°	11/2000 - present	
Observation-Based Leaf Area Index	Boston University Department of Geography	16 km	7/1982 – 5/2001	
Observation-Based Surface Temperature	Television Infrared Observation Satellites (TIROS) Operational Vertical Sounder (TOVS)	~ 15 km	1/1998 – 12/1998	
Vegetation Class	University of Maryland, AVHRR-derived	1 km	static	
	Boston University, MODIS-derived	1 km	static	
Soils	USDA Agricultural Research Service	5’	static	
Elevation	GTOPO30 digital elevation model	30”	static	

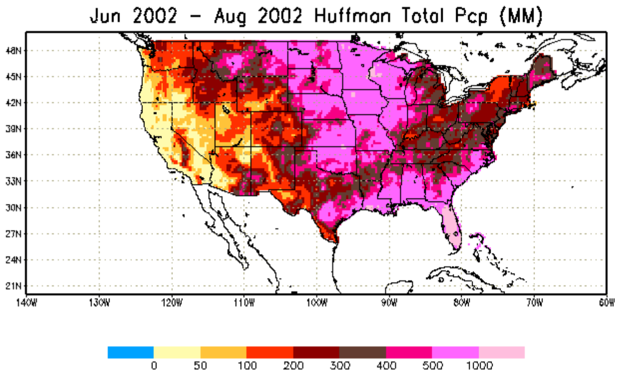
Output includes 0.25 ° and 1 ° global, 1979-present simulations with 3 LSMs: CLM2, Mosaic, and Noah 2.7.1 *(contact Matthew.Rodell@nasa.gov)*

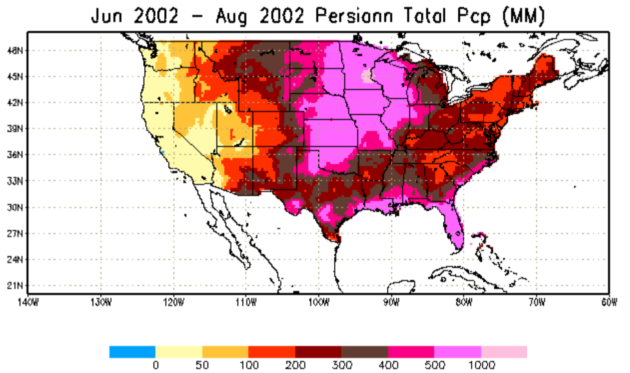
Intercomparison of Data Fields: Precipitation

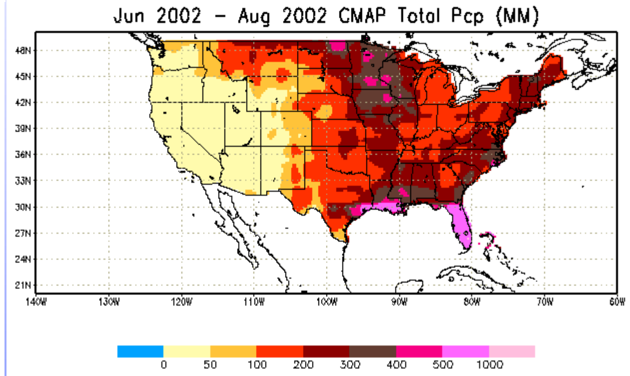


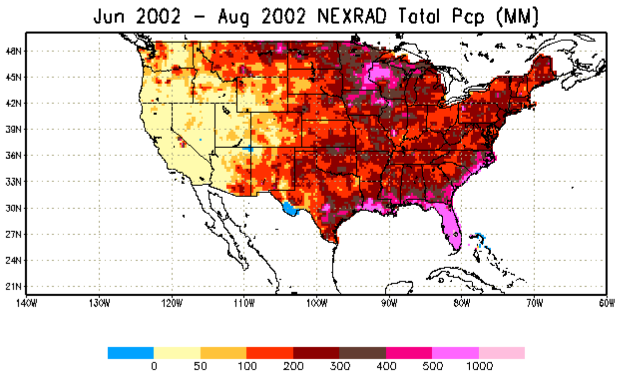




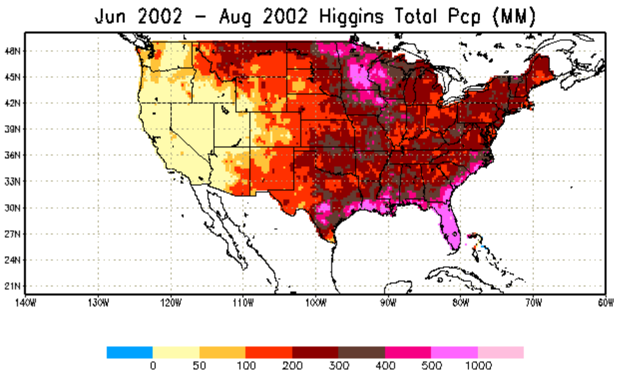






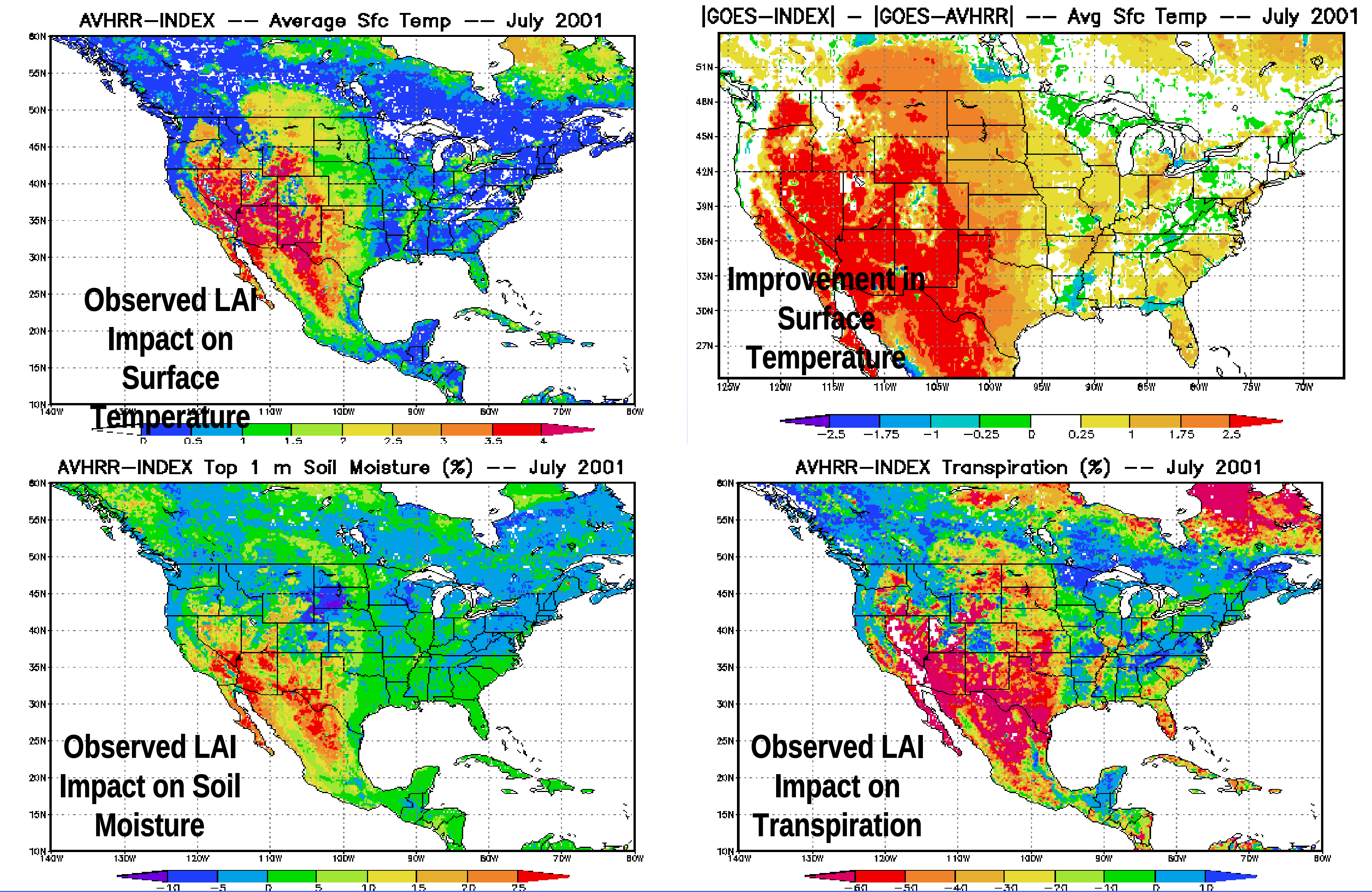


Accumulated Precipitation, JJA 2002



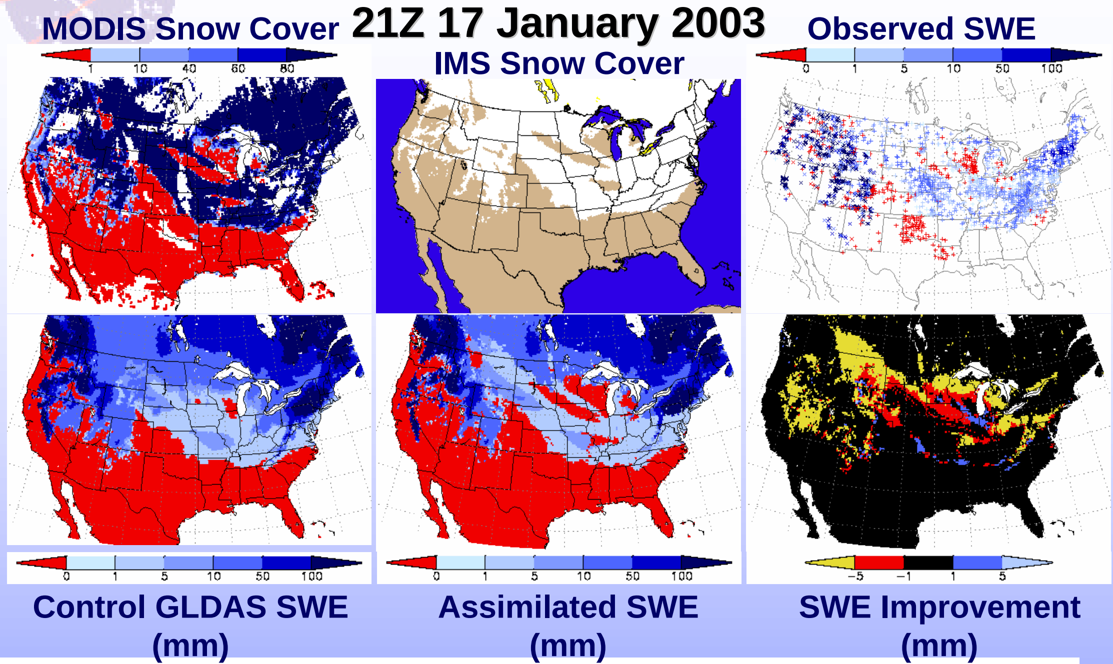
Gottschalck, J., J. Meng, M. Rodell, and P. Houser, Analysis of multiple precipitation products and preliminary assessment of their impact on Global Land Data Assimilation System (GLDAS) land surface states, J. Hydromet., in press, 2005.

Parameterization: Leaf Area Index

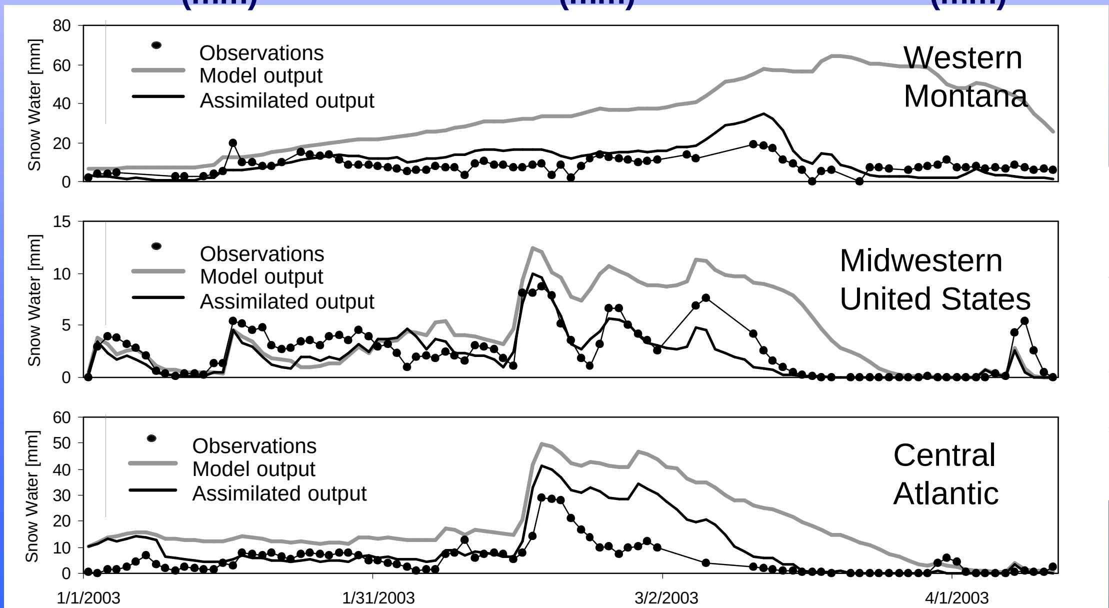


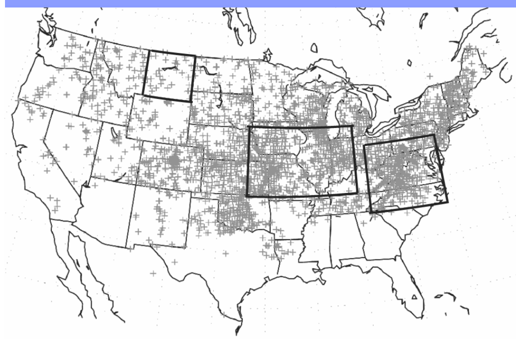
Gottschalck, J., M. Rodell, P. Houser, U. Jambor, J. Meng, K. Arsenault, and B. Cosgrove, Impact of remotely sensed leaf area index as part of the Global Land Data Assimilation System, J. Hydromet., submitted, 2005.

Data Assimilation: Snow



- MODIS snow cover fields used to update GLDAS simulations
- Models fill spatial and temporal gaps in data
- Assimilated output agrees more closely with independently derived snow fields (top left) and time series (bottom left)
- Assimilated output contains more information (snow water equivalent) than MODIS (snow cover) alone

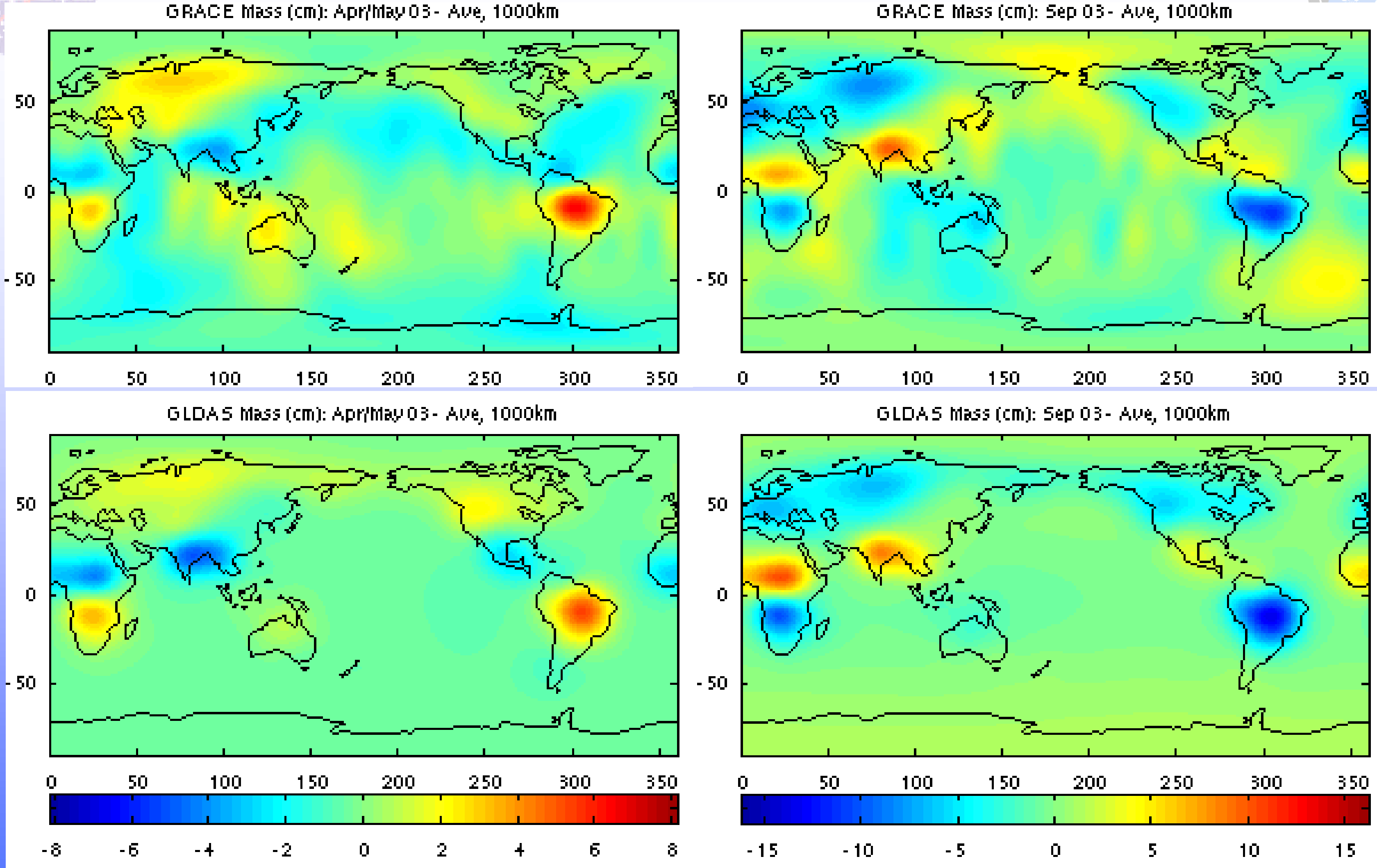




Locations of averaging regions and Cooperative Network snow observation sites

Rodell, M., and P. R. Houser, Updating a land surface model with MODIS derived snow cover, J. Hydromet., 5 (6), 1064-1075, 2004.

Output Evaluation: Global Observations



Terrestrial water storage from GRACE (top), and 2m column soil moisture plus snow water equivalent from Noah (bottom), April/May (left) and September (right), 2003 (1000 km smoothing)

Sensitivity of Land Surface Simulations to Model Physics, Parameters, and Forcing

- CEOP site characteristics and met data are control inputs
- CEOP surface observations used for evaluation
- What are the impacts and relative importance of inputs:
  - Parameters: elevation, soil, land cover,
  - Forcing: precipitation, radiation,
  - Land surface models: Noah 2.7.1, CLM2, Mosaic;
- to outputs:
  - Evapotranspiration (ET),
  - Sensible heat flux (Qh),
  - Soil moisture (SM)?
- Is reality within the expected range of possible outcomes from a reasonable set of configurations?

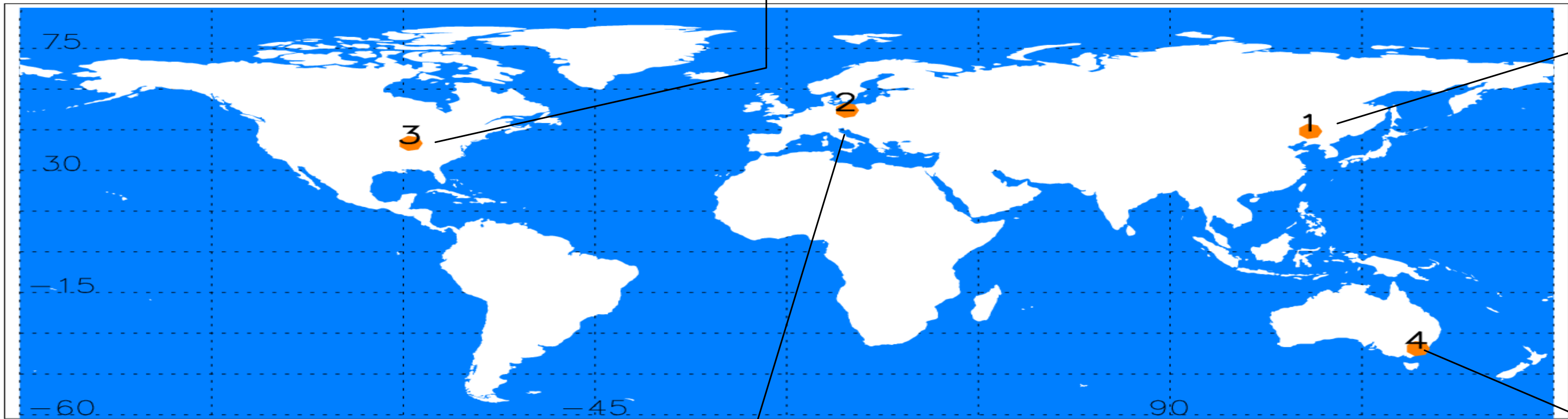
Kato, H., M. Rodell, F. Beyrich, H. Cleugh, E. van Gorsel, H. Liu, and T. P. Meyers, Sensitivity of Land Surface Simulations to Model Physics, Parameters, and Forcings, at Four CEOP Sites, J. Meteor. Soc. Japan, submitted, 2006.

Bondville

(40° 0'22.356"N,
88° 17'25.476"W)

Tongyu

(44º25’N,
122º52’E)

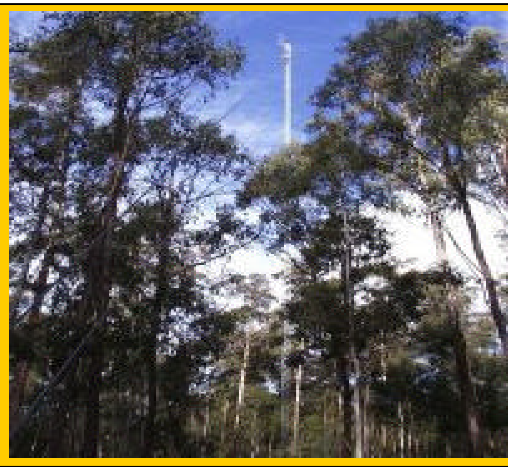


Lindenberg

(52 ° 10'01" N,
14 ° 07'27" E)

Tumbarumba

(35°39’20.6’’S,
148 ° 09’07.5”E)



GLDAS/CEOP Sensitivity Study Inputs

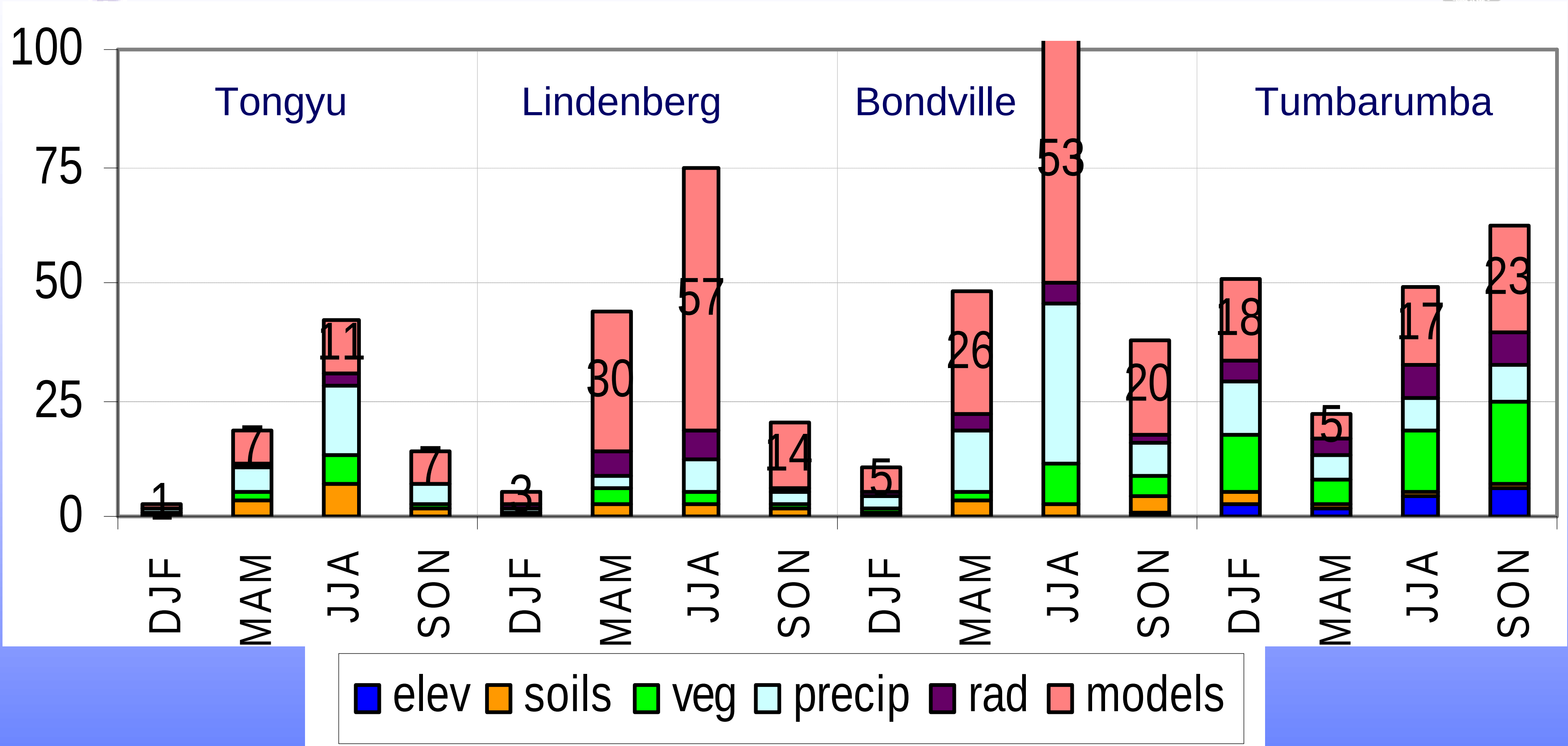
- Precipitation: Observations, disaggregated CMAP, and GDAS
- Radiation: Observations, AGRMET, and GDAS
- Elevation, Land cover, Soils:

Site Name	Elev.	Land cover	Sand	Clay	Zobler	USDA
Lindenberg	73 *68*	Grassland *Cropland*	74 *48*	26 *20*	Coarse-med-fine *organic*	sandy clay loam *loam*
Tongyu-Cropland	184 *146*	Cropland *Woody Grassland*	60 *38*	35 *32*	Coarse-med-fine *medium-fine*	sandy clay *clay loam*
Bondville	216 *213*	Cropland *(Grassland)*	8 *34*	27 *25*	organic *organic*	silty loam/silt *loam*
Tumbarumba	1200 *914*	Evergreen Broadleaf forest *Cropland**	33.5 *59*	32.5 *23*	Medium-fine *Coarse-med-fine*	clay loam *sandy clay loam*

Model parameters based on station observations (control; normal font) and the *GLDAS standard (experimental; italics).*

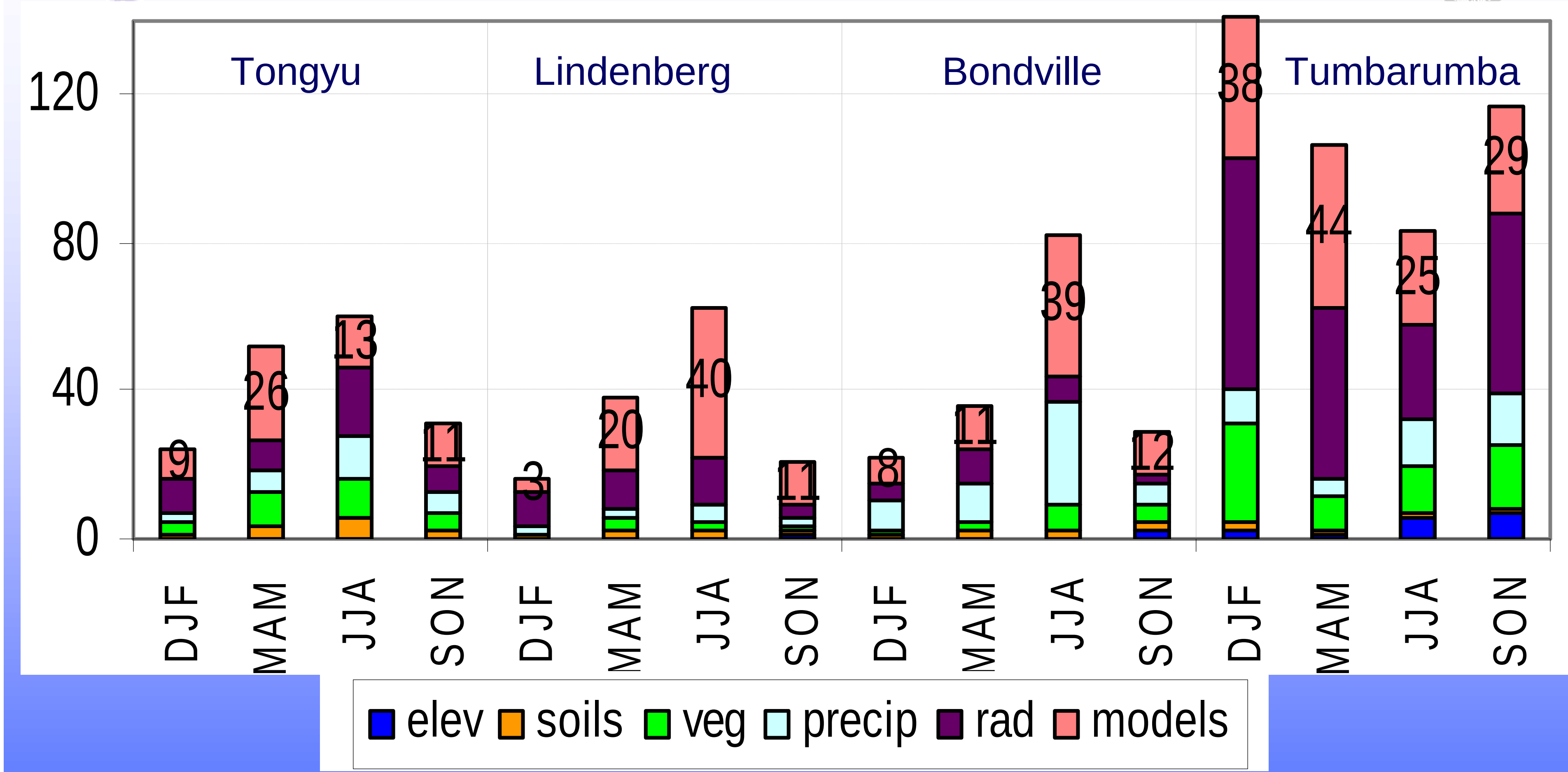
- Used GLDAS standard data for other parameters (soil color, slope, porosity, albedo, greenness, LAI, SAI, etc.)

Sensitivity of Evapotranspiration by Season



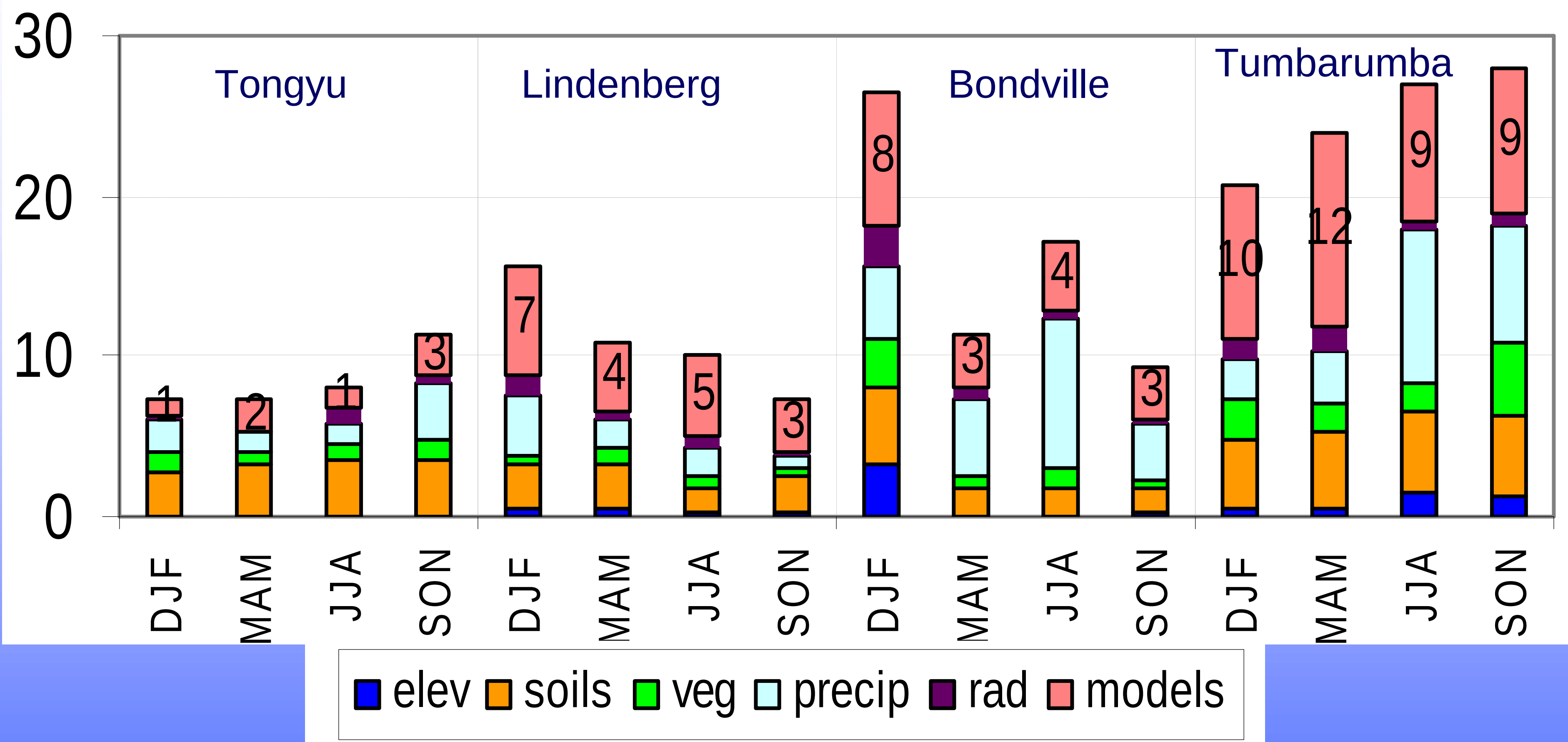
Evapotranspiration (mm/month) most sensitive to LSM, followed by precipitation, then land cover and radiation

Sensitivity of Sensible Heat Flux by Season



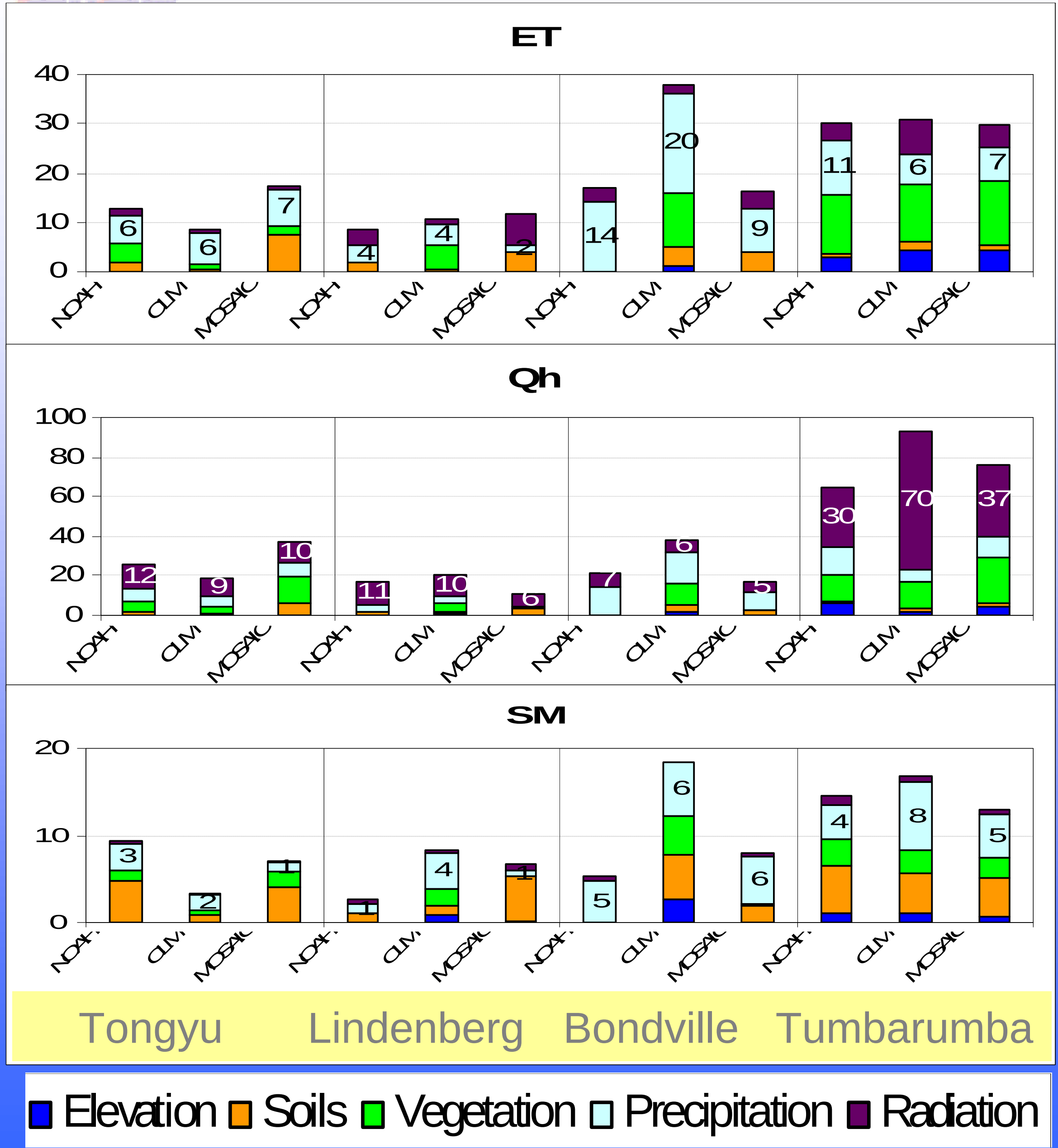
Sensible heat flux (W/m^2) most sensitive to LSM, followed by radiation, then precipitation and land cover

Sensitivity of Soil Moisture by Season



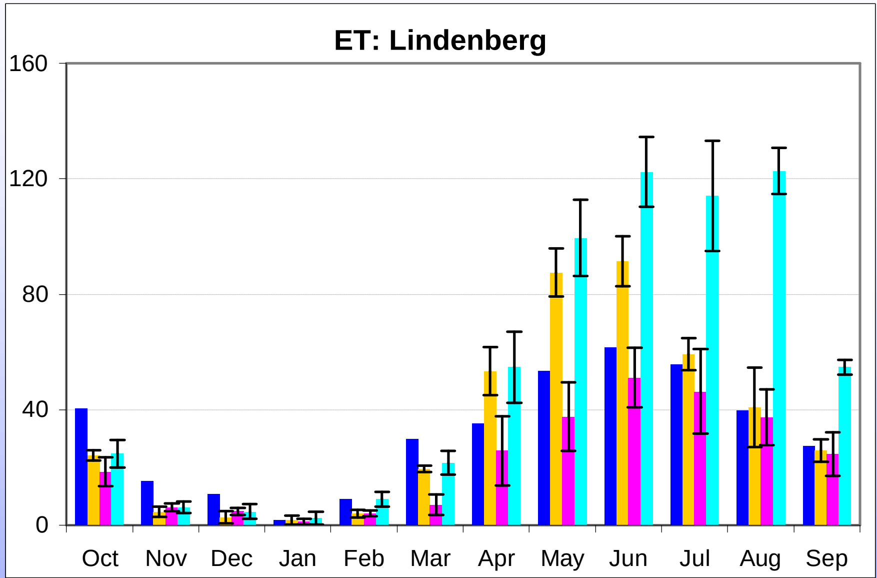
Top layer soil moisture (% volumetric) most sensitive to LSM, followed by precipitation, then soils and land cover

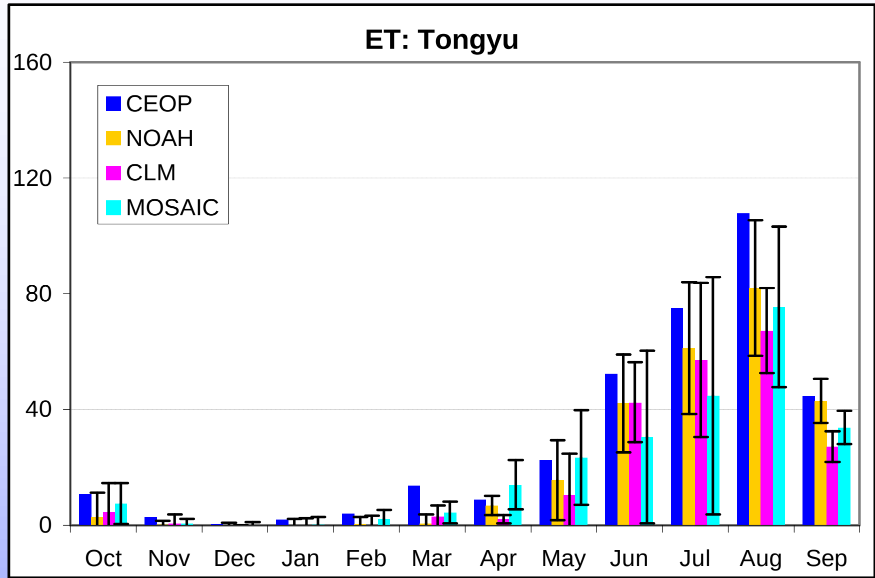
Sensitivity by Land Surface Model

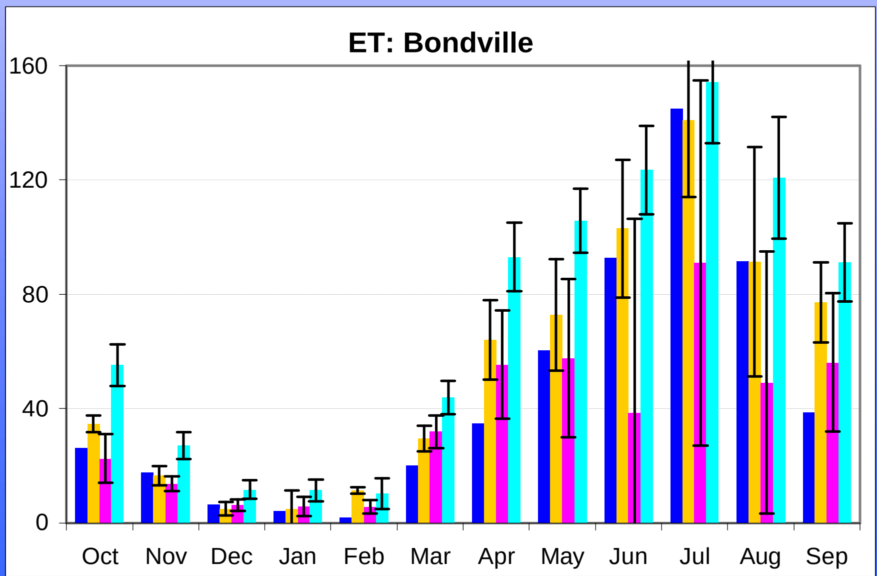


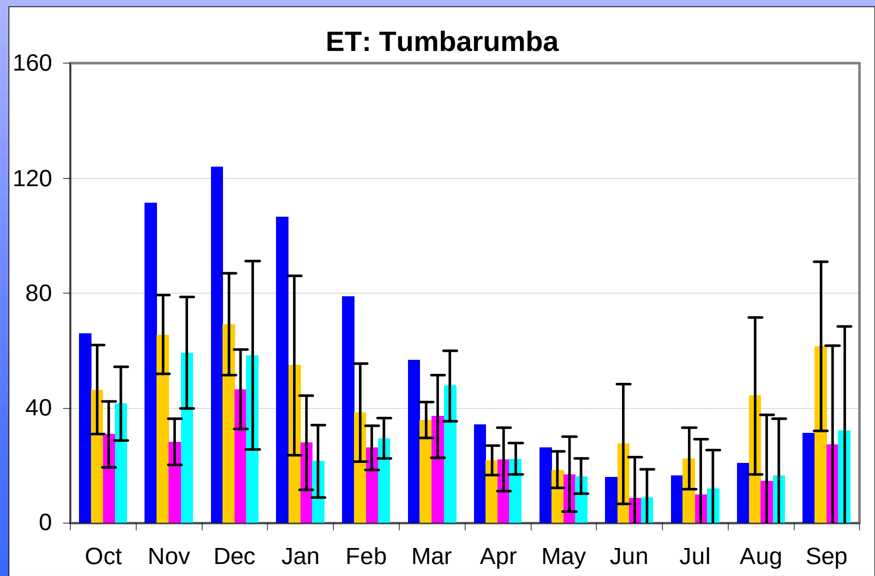
- Noah: Typical sensitivities. Land cover change between grassland and cropland has no effect. Soil type did not change at Bondville.
- CLM: Sensitive to change between grassland cropland. More sensitive to elevation than other models.
- Mosaic: More sensitive to soils than other models. Radiation more important than precipitation at Lindenberg.

Range of Expected Outputs, ET (mm/month)

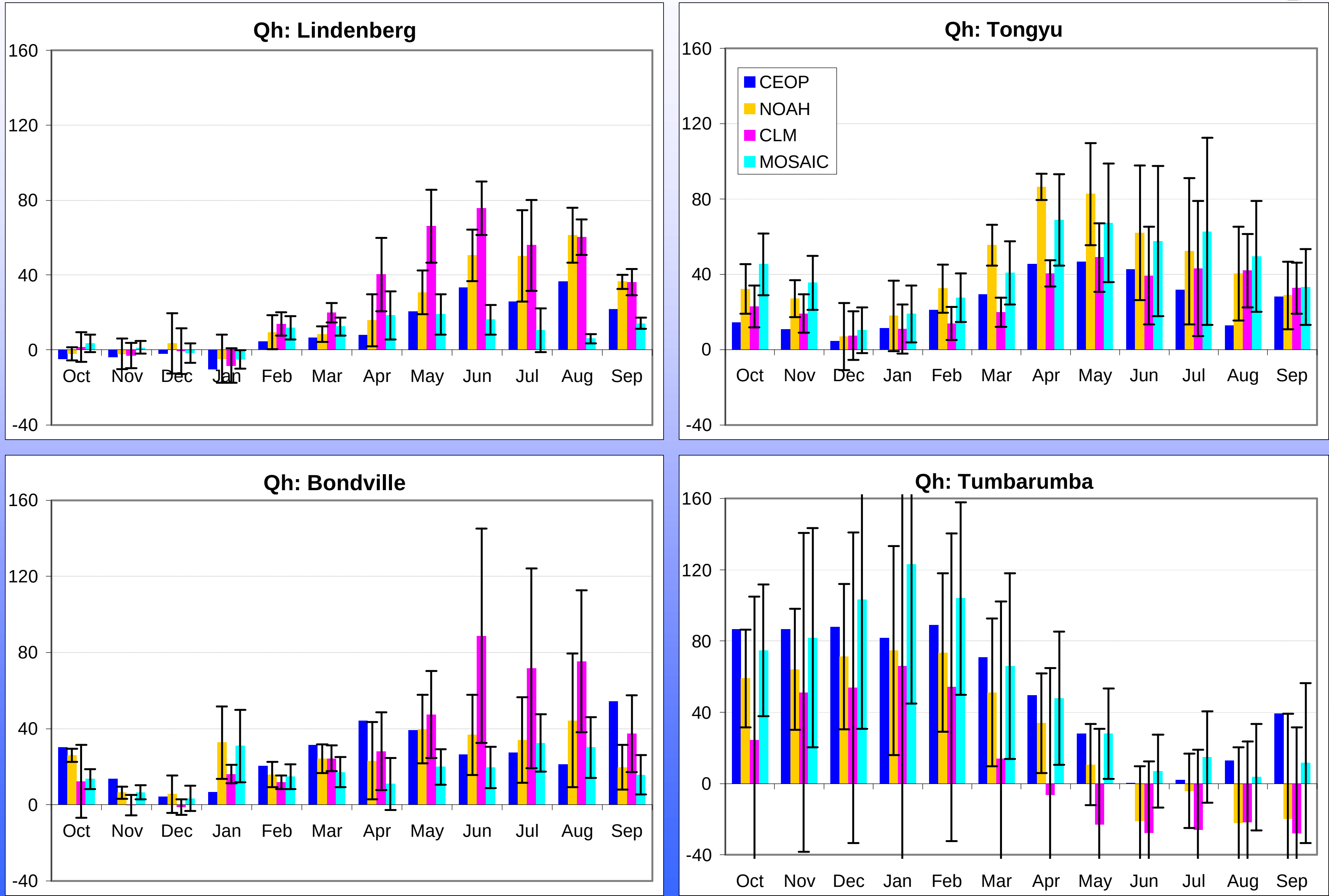




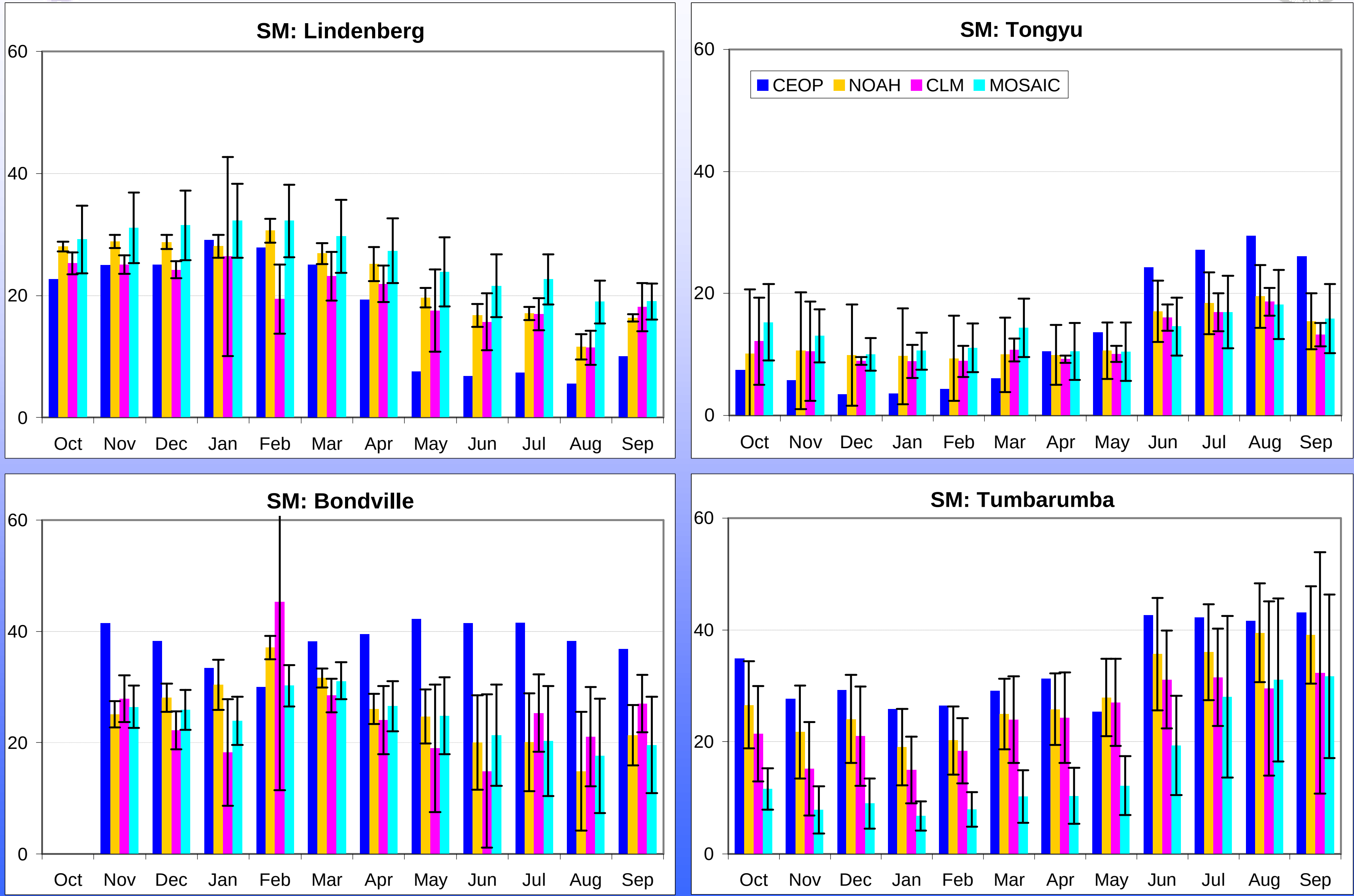




Range of Expected Outputs, Qh (W/m²)



Range of Expected Outputs, SM (% volumetric)

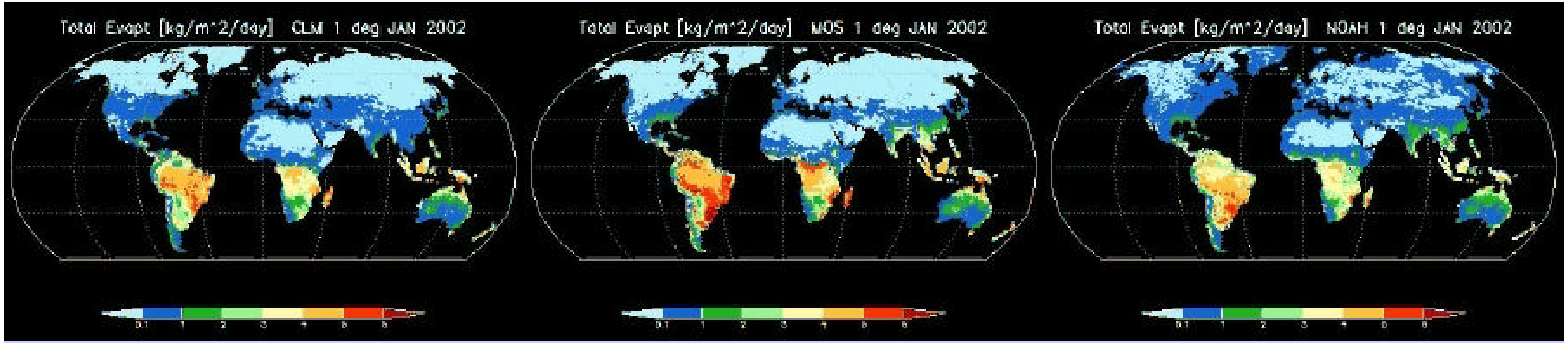


GLDAS/CEOP Sensitivity Study: Discussion

- **Output ET, Qh, and SM most sensitive to choice of LSM (Noah, CLM, Mosaic) despite identical forcing and parameters**
- ET very sensitive to precip, followed by land cover and radiation
- Qh very sensitive to radiation, followed by precip and land cover
- SM very sensitive to precip, followed by soils and land cover
- Water vs. energy limited shifts sensitivity b/t precip and rad
- Larger uncertainty in forcing during wet season, which leads to larger range of outputs
- **Potential for achieving accurate simulation of reality (*in situ* data) by adjusting/refining inputs alone is fair to poor**

∴ Continued improvement and calibration of LSMs is essential

GLDAS Output



Monthly mean evapotranspiration, 2002-04, from simulations with CLM2, Mosaic, and Noah 2.7.1 LSMs. [Color bars range from 0.1 to 8 mm/day]

- 0.25° and 1° gridded, global, 1979-present simulations with 3 LSMs: CLM2, Mosaic, and Noah 2.7.1 (contact Matthew.Rodell@nasa.gov)
- CEOP MOLTS (3 models, EOP1-4) available from UCAR
- We advise against using old GLDAS/Mosaic 0.25° MOLTS

Sensitivity by Season

ET

Qh

SM

ET	Site	Elevation	Soils	Land cover	Precipitation	Radiation	Models
DJF	Tongyu	0.01	0.37	0.06	1.48	0.06	0.95
	Lindenberg	0.02	0.58	0.04	1.03	1.15	2.52
	Bondville	0.23	1.08	0.19	3.23	0.67	4.79
	Tumbarumba	2.97	2.27	12.73	11.15	4.10	17.78
MAM	Tongyu	0.04	3.51	1.36	5.56	0.52	7.31
	Lindenberg	0.17	2.46	3.19	2.61	5.24	30.21
	Bondville	0.23	2.93	2.47	12.56	4.05	26.07
	Tumbarumba	1.59	1.11	5.13	5.47	3.33	5.36
JJA	Tongyu	0.13	7.06	5.93	15.25	2.74	10.79
	Lindenberg	0.15	2.83	2.29	6.57	6.33	56.51
	Bondville	0.11	2.94	8.02	34.60	4.03	53.16
	Tumbarumba	4.57	0.38	13.44	7.36	6.40	16.83
SON	Tongyu	0.08	1.50	1.27	3.98	0.49	6.67
	Lindenberg	0.16	1.22	1.40	2.12	1.36	14.07
	Bondville	1.01	3.26	4.07	7.46	1.63	20.23
	Tumbarumba	5.98	1.08	17.59	7.68	6.75	22.90
Qh	Site	Elevation	Soils	Land cover	Precipitation	Radiation	Models
DJF	Tongyu	0.21	0.66	3.28	3.02	8.75	8.63
	Lindenberg	0.17	1.00	0.04	2.60	8.85	3.32
	Bondville	0.43	1.06	0.47	8.44	4.15	7.98
	Tumbarumba	2.24	1.96	26.81	9.27	62.96	37.82
MAM	Tongyu	0.12	3.48	9.63	4.77	8.34	25.79
	Lindenberg	0.32	2.39	3.07	2.42	10.55	19.88
	Bondville	0.20	2.45	2.38	10.28	9.45	10.89
	Tumbarumba	1.26	1.06	9.19	4.97	46.44	44.01
JJA	Tongyu	0.14	5.33	10.31	11.96	18.82	13.25
	Lindenberg	0.21	2.05	1.83	5.13	12.89	40.34
	Bondville	0.07	2.38	6.47	27.72	7.03	38.80
	Tumbarumba	6.21	0.45	12.85	13.27	25.22	25.16
SON	Tongyu	0.17	1.69	5.46	5.79	6.68	11.30
	Lindenberg	0.93	1.17	1.29	2.13	4.08	10.69
	Bondville	1.85	3.11	4.35	5.94	2.36	11.65
	Tumbarumba	7.06	1.08	17.42	14.15	48.03	29.32
SM	Site	Elevation	Soils	Land cover	Precipitation	Radiation	Models
DJF	Tongyu	0.01	2.84	1.08	2.11	0.13	1.25
	Lindenberg	0.57	2.83	0.40	3.67	1.27	6.81
	Bondville	3.26	4.70	3.24	4.55	2.40	8.23
	Tumbarumba	0.50	4.25	2.66	2.33	1.25	9.76
MAM	Tongyu	0.02	3.16	0.91	1.14	0.11	1.98
	Lindenberg	0.57	2.62	1.06	1.75	0.58	4.29
	Bondville	0.09	1.71	0.64	4.88	0.75	3.22
	Tumbarumba	0.52	4.73	1.84	3.14	1.70	11.92
JJA	Tongyu	0.04	3.49	1.04	1.34	0.81	1.34
	Lindenberg	0.13	1.74	0.76	1.61	0.78	5.03
	Bondville	0.01	1.64	1.40	9.24	0.54	4.42
	Tumbarumba	1.48	5.13	1.71	9.45	0.61	8.71
SON	Tongyu	0.05	3.43	1.40	3.53	0.30	2.65
	Lindenberg	0.16	2.31	0.59	0.79	0.29	3.16
	Bondville	0.15	1.67	0.55	3.34	0.38	3.32
	Tumbarumba	1.32	5.07	4.50	7.27	0.86	8.94

low	low-mid	mid-low	mid	mid-high	high

Sensitivity by Land Surface Model

ET

ET	Model	Elevation	Soils	Land cover	Precipitation	Radiation
Tongyu	NOAH	0.06	1.76	3.67	5.87	1.31
	CLM	0.04	0.34	0.94	6.45	0.80
	MOSAIC	0.09	7.23	1.86	7.38	0.74
Lindenberg	NOAH	0.11	1.50	0	3.71	3.09
	CLM	0.18	0.14	5.17	3.97	1.26
	MOSAIC	0.09	3.68	0.03	1.57	6.22
Bondville	NOAH	0.02	0	0	14.19	2.63
	CLM	1.11	3.89	11.00	20.22	1.57
	MOSAIC	0.05	3.76	0.07	8.99	3.58
Tumbarumba	NOAH	2.87	0.61	11.98	11.20	3.58
	CLM	4.31	1.71	11.82	5.82	7.10
	MOSAIC	4.15	1.31	12.86	6.72	4.75

Qh

Qh	Model	Elevation	Soils	Land cover	Precipitation	Radiation
Tongyu	NOAH	0.14	1.68	4.87	6.50	12.22
	CLM	0.18	0.69	3.65	5.15	9.30
	MOSAIC	0.15	6.00	12.98	7.50	10.43
Lindenberg	NOAH	0.12	1.43	0	3.88	11.13
	CLM	1.01	0.43	4.65	3.76	10.33
	MOSAIC	0.10	3.10	0.02	1.57	5.82
Bondville	NOAH	0.07	0	0	14.01	7.10
	CLM	1.82	3.92	10.19	16.32	5.60
	MOSAIC	0.03	2.84	0.06	8.95	4.54
Tumbarumba	NOAH	6.24	0.74	12.96	14.71	29.93
	CLM	1.66	1.55	13.17	6.21	70.41
	MOSAIC	4.69	1.12	23.58	10.31	36.64

SM

SM	Model	Elevation	Soils	Land cover	Precipitation	Radiation
Tongyu	NOAH	0.03	4.69	1.28	3.02	0.32
	CLM	0.02	0.93	0.40	1.92	0.38
	MOSAIC	0.04	4.07	1.65	1.17	0.32
Lindenberg	NOAH	0.04	1.01	0	1.03	0.37
	CLM	0.83	1.04	2.09	4.06	1.16
	MOSAIC	0.20	5.08	0.01	0.77	0.66
Bondville	NOAH	0.04	0	0	4.80	0.53
	CLM	2.57	5.27	4.33	6.15	1.84
	MOSAIC	0.02	2.01	0.04	5.55	0.68
Tumbarumba	NOAH	1.04	5.47	3.09	3.91	0.73
	CLM	1.06	4.58	2.67	7.79	1.97
	MOSAIC	0.78	4.34	2.28	4.94	0.62