Using MODIS and CERES Data to Improve Energy Balance Snowmelt Modeling

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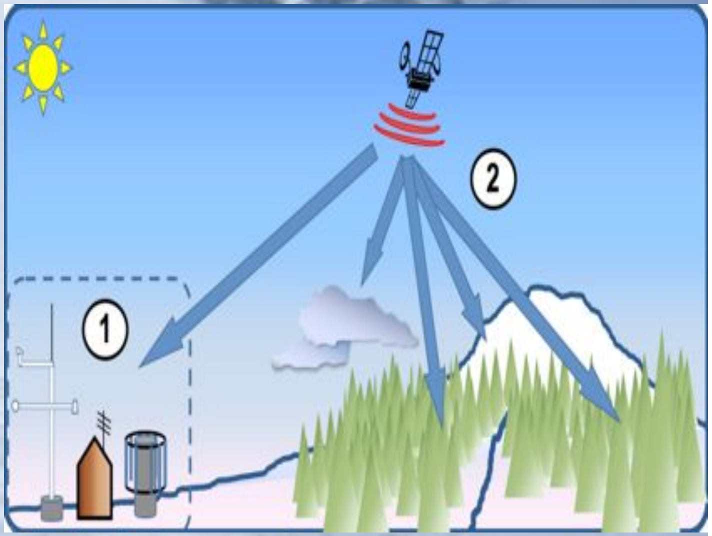
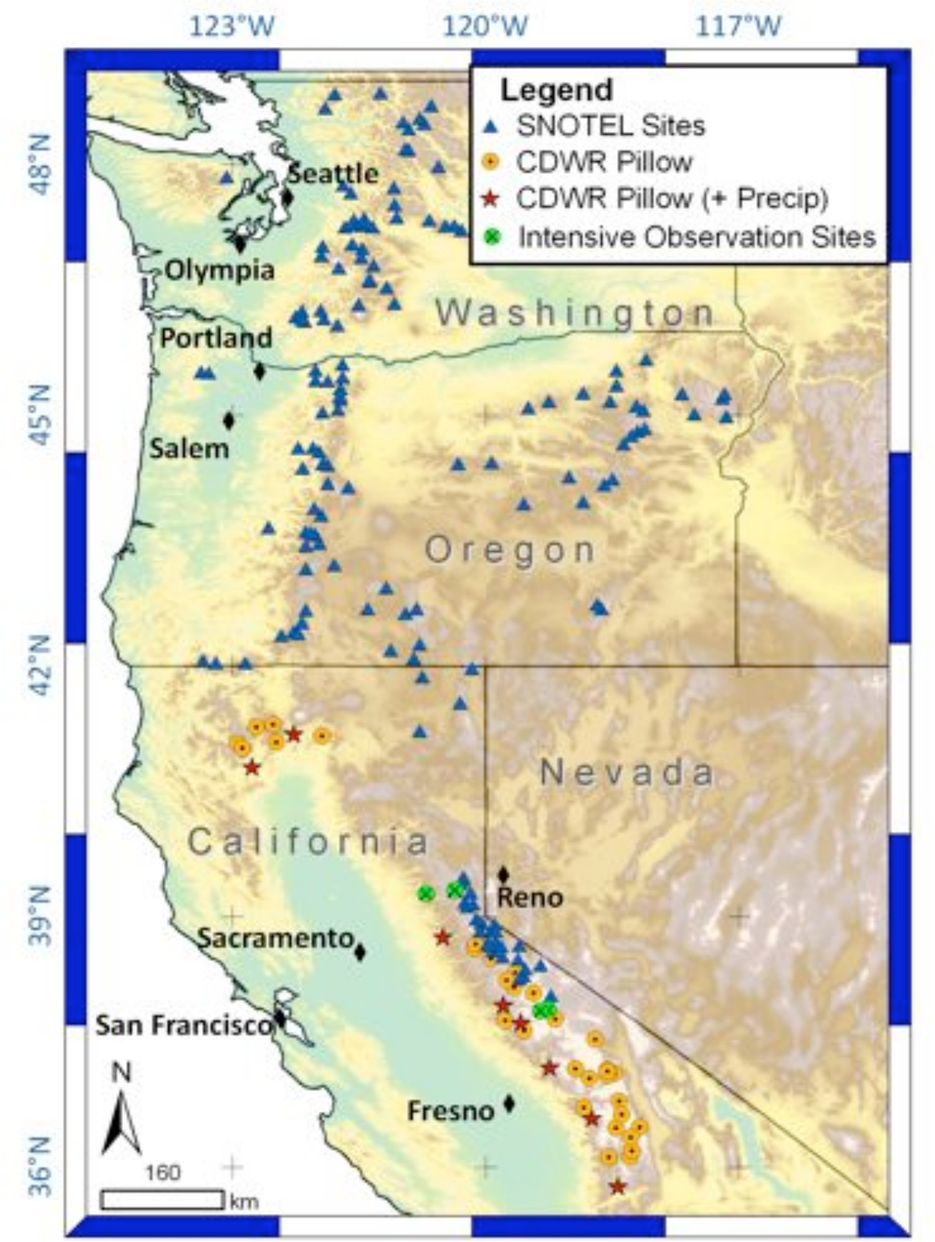


MODIS Science Team Meeting
Atmosphere Team Breakout
U. Maryland Conference Center
College Park, MD, May 18-19, 2011

UNIVERSITY of WASHINGTON

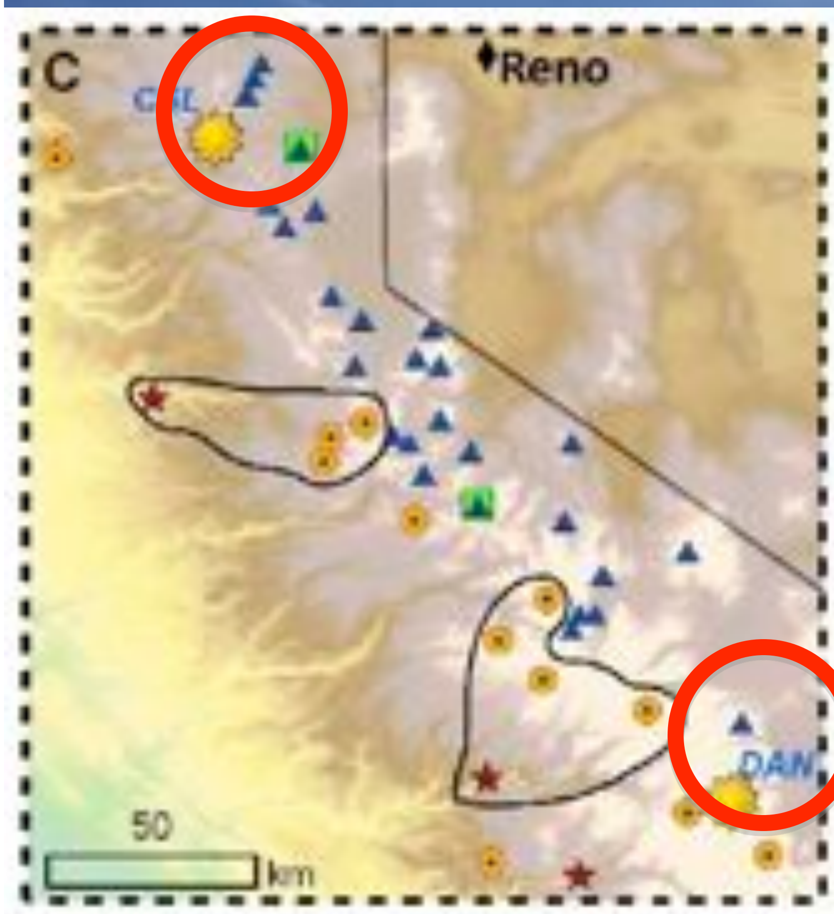
UNIVERSITY OF MARYLAND



At Issue

Snowmelt supplies as much as *75% of surface water in basins* of the western United States. Global *Climate Model simulations* show continued *loss of snowpack* as much as 70% by mid-21st century.

Intensive observation sites



CSL: Central Sierra Snow Lab

2 m temperature
Relative humidity
Precipitation } **10 min**
Wind speed
Incoming SW
Snow water equiv **daily**

DAN: Dana Meadows
2 m temperature
Relative humidity } **hourly**
Wind speed
Incoming and net SW
Snow water equivalent **daily**
(No precipitation)

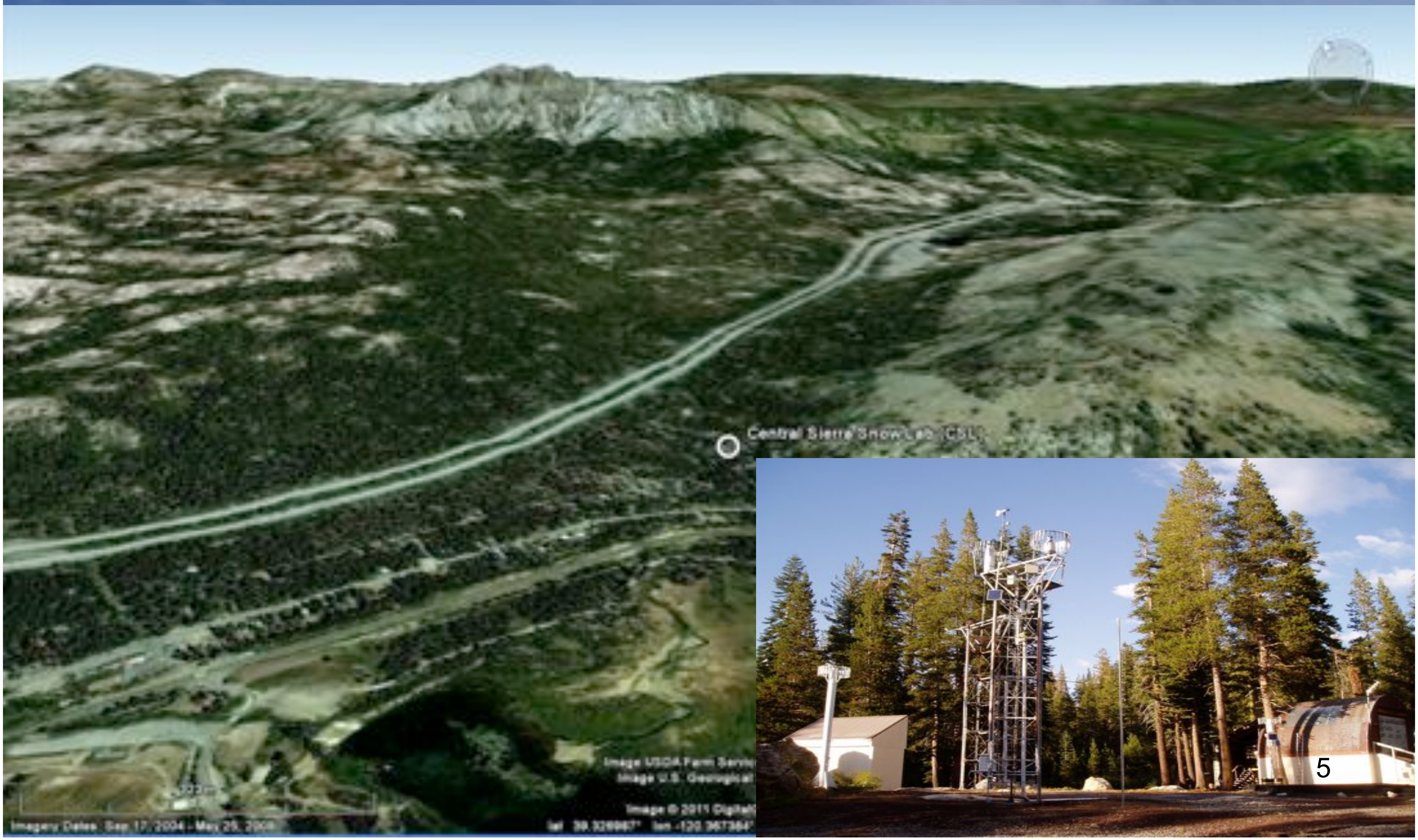
The *greatest potential sources of error* in simulating snowmelt rates and timing are *inaccurate shortwave and longwave radiative* inputs.

Objective of Project

Evaluate benefit of high resolution radiative fluxes from satellites, *primarily* Terra and Aqua *for snowmelt modeling in complex terrain.*

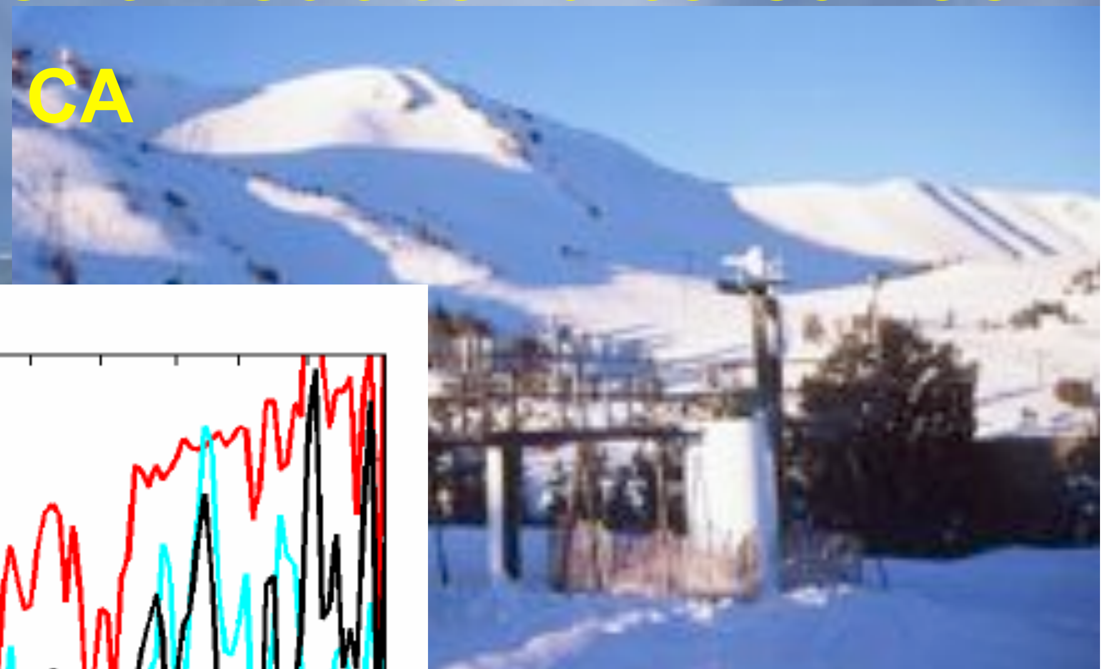
Central Sierra Snow Lab

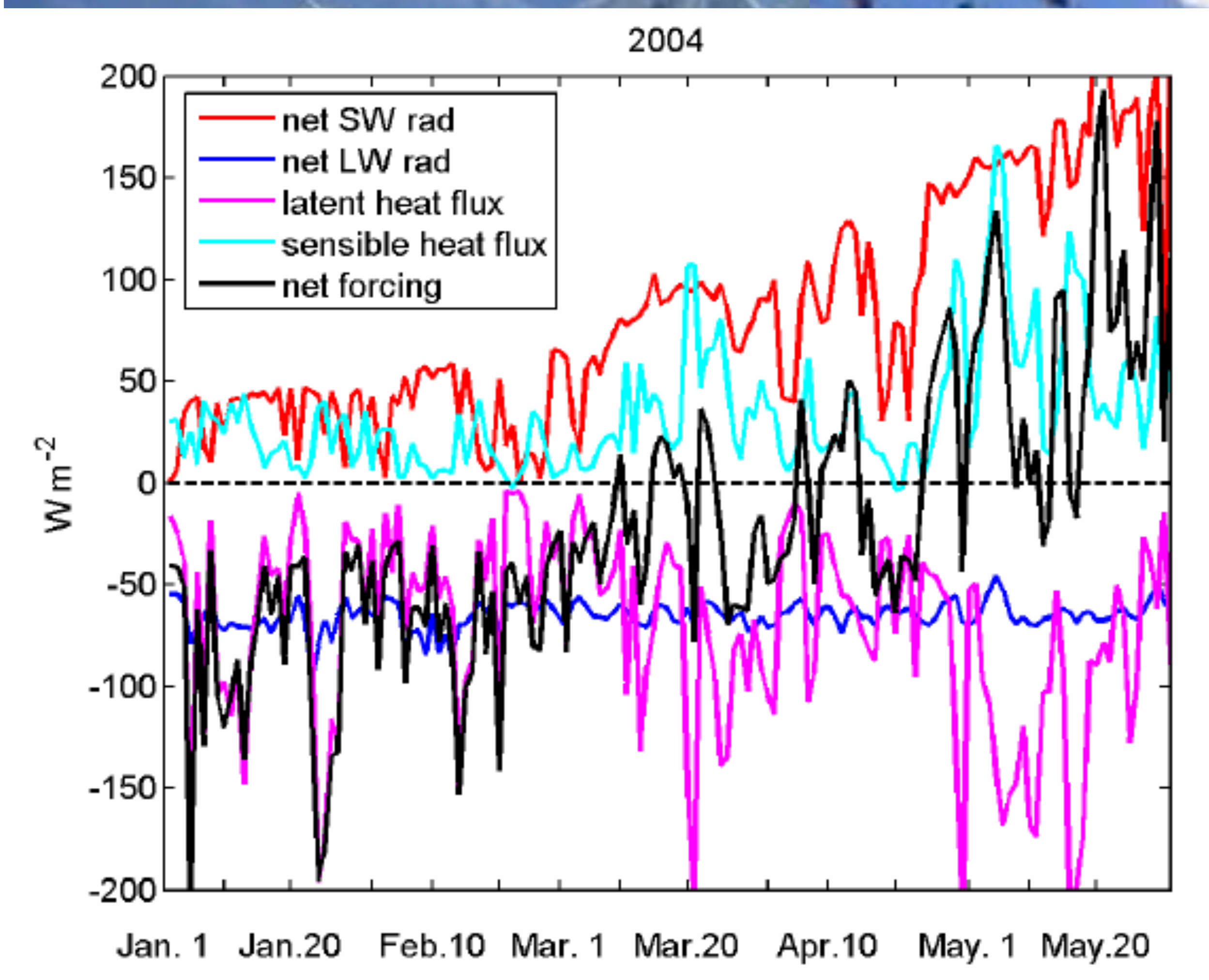
N



Sensible and Latent Heat tend to cancel

Mammoth Mountain, CA



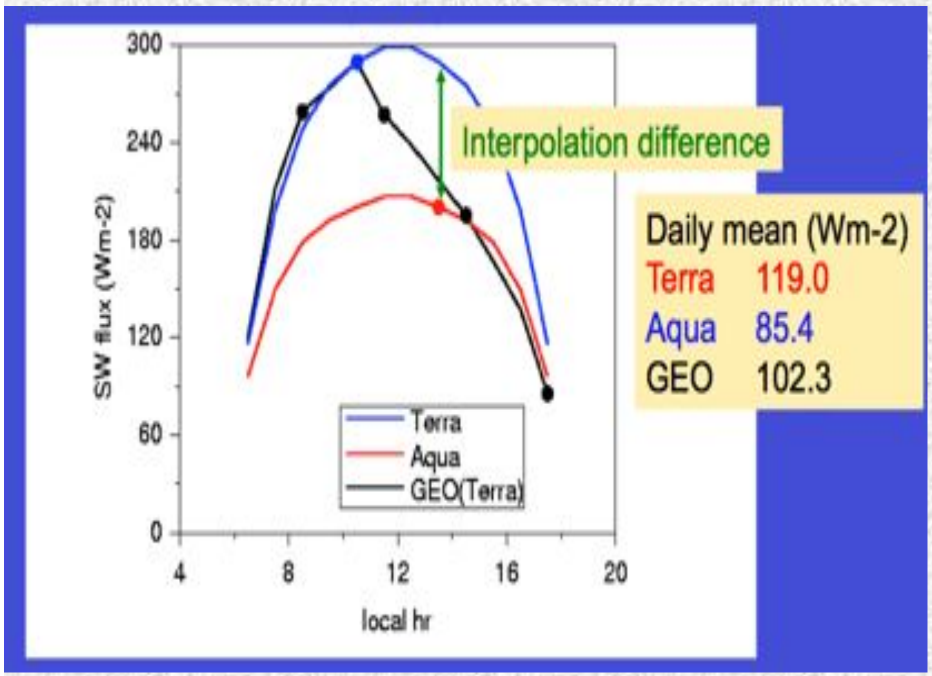


30 W/m^2 ~ 8 mm/day melt

Current methods use observations or parameterizations. Replace parameterization with:

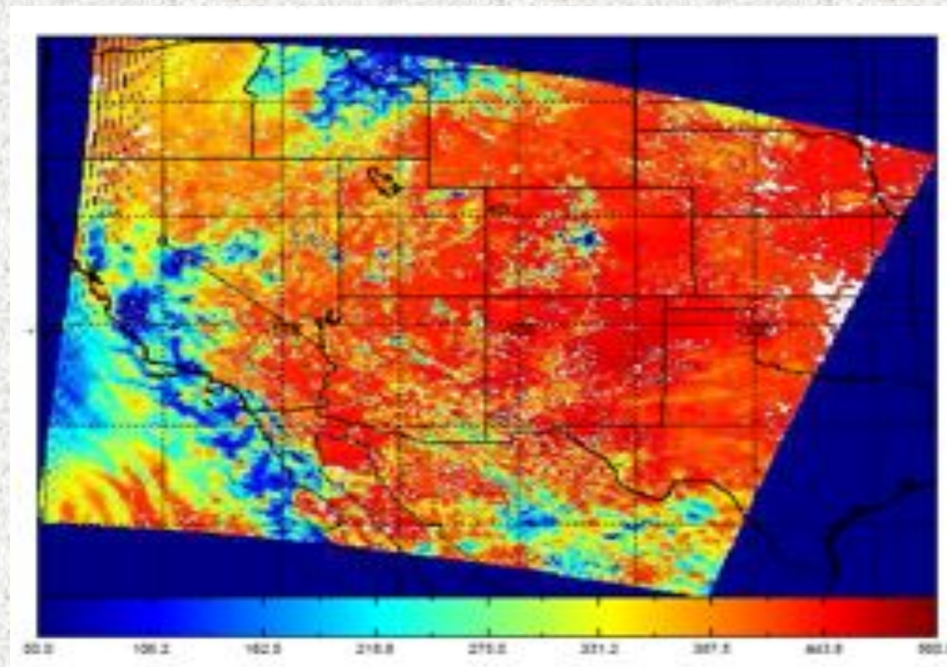
- **CERES SYN: Good temporal variability, 1°spatial**
- **MODIS: High spatial resolution (5 km), twice/day**

CERES temporal interpolation



Courtesy of David Doelling

MODIS spatial field (SW)

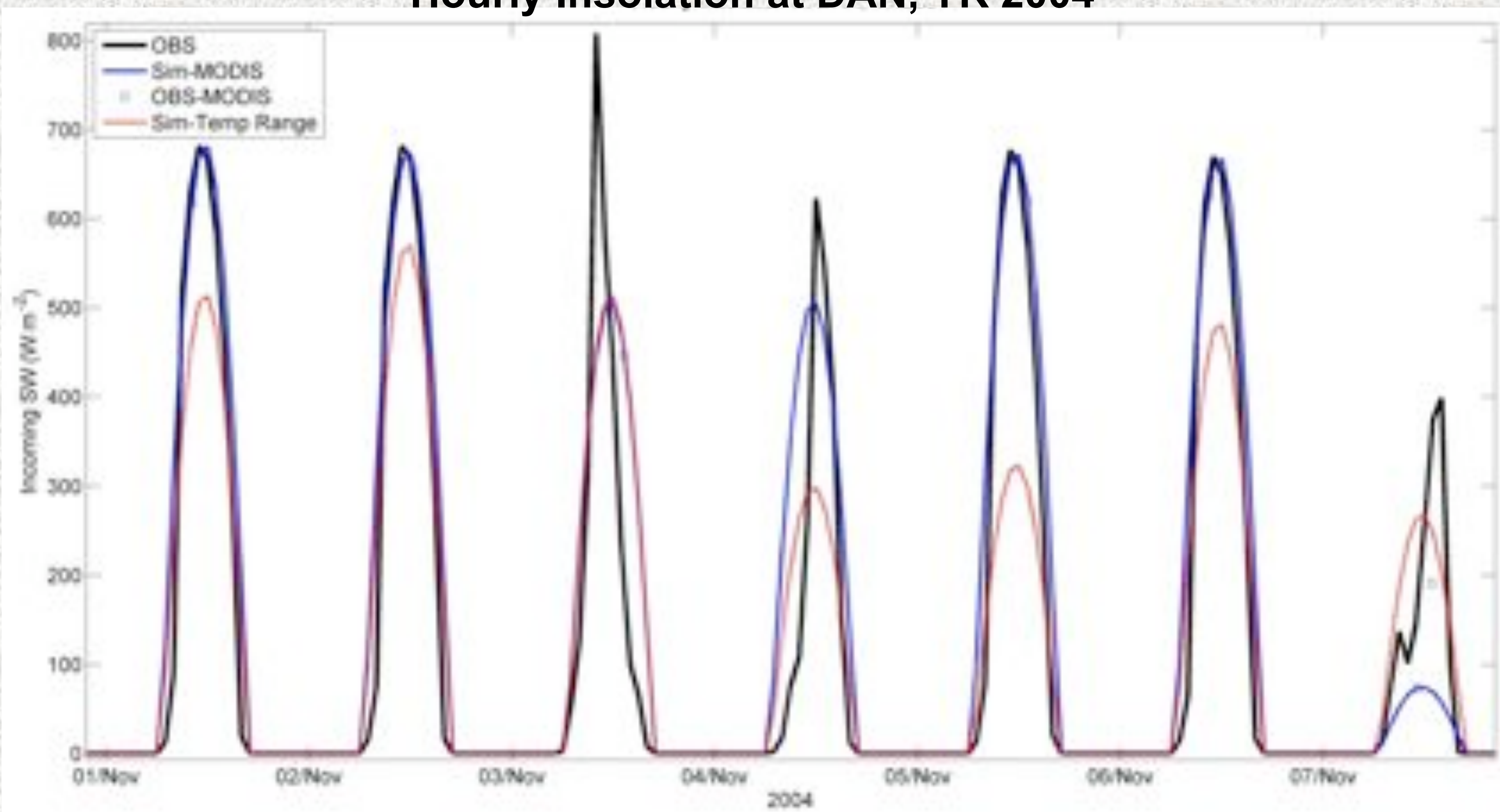


Wang and Pinker, 2009. JGR, 114, D20201

Sample SW downwelling flux comparisons

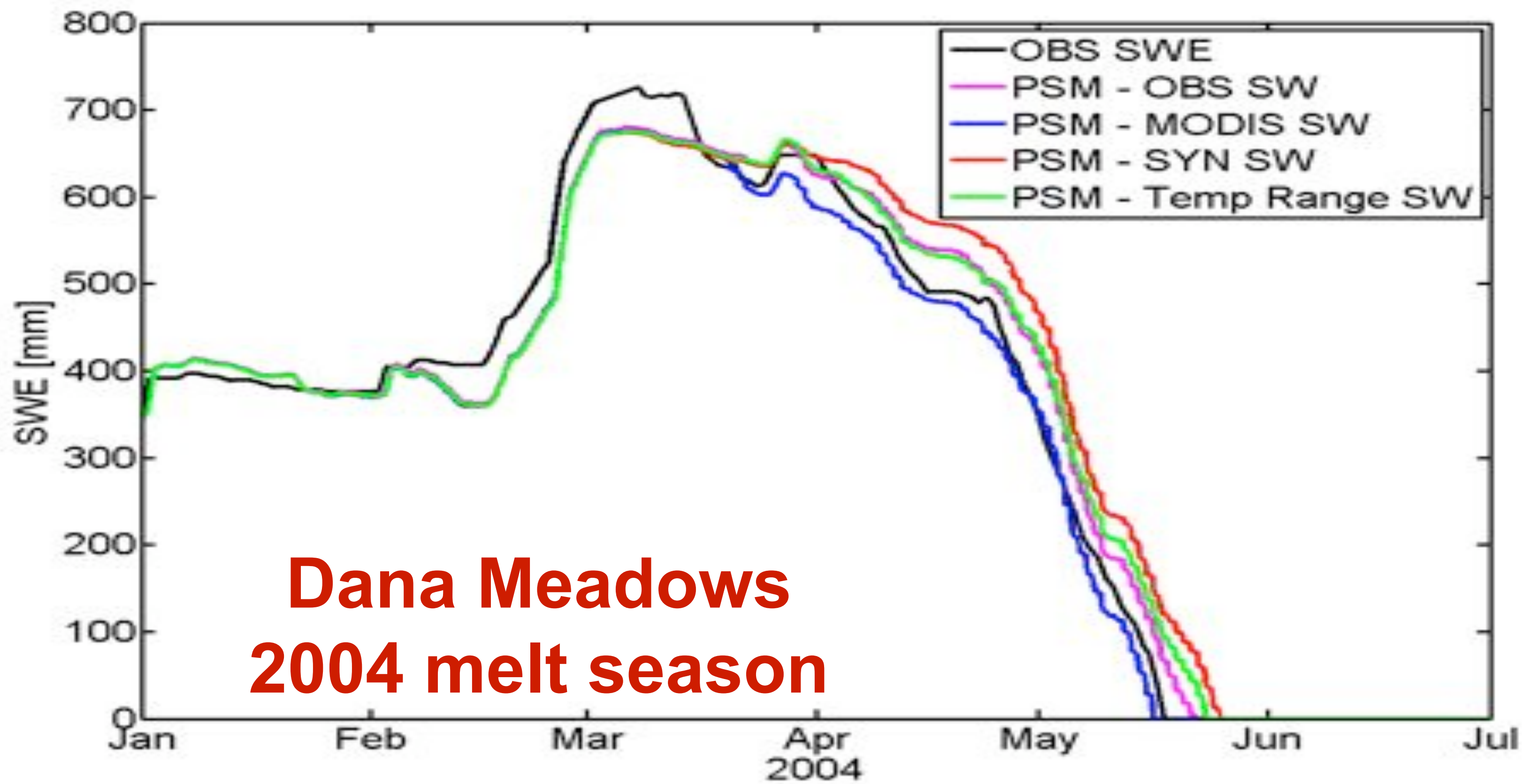
MODIS (5-km), November 2004, Dana Meadows, CA

Hourly Insolation at DAN, YR 2004



OBS **Sim-MODIS** o **OBS MODIS** --- **Sim-temp range**

Early modeling results

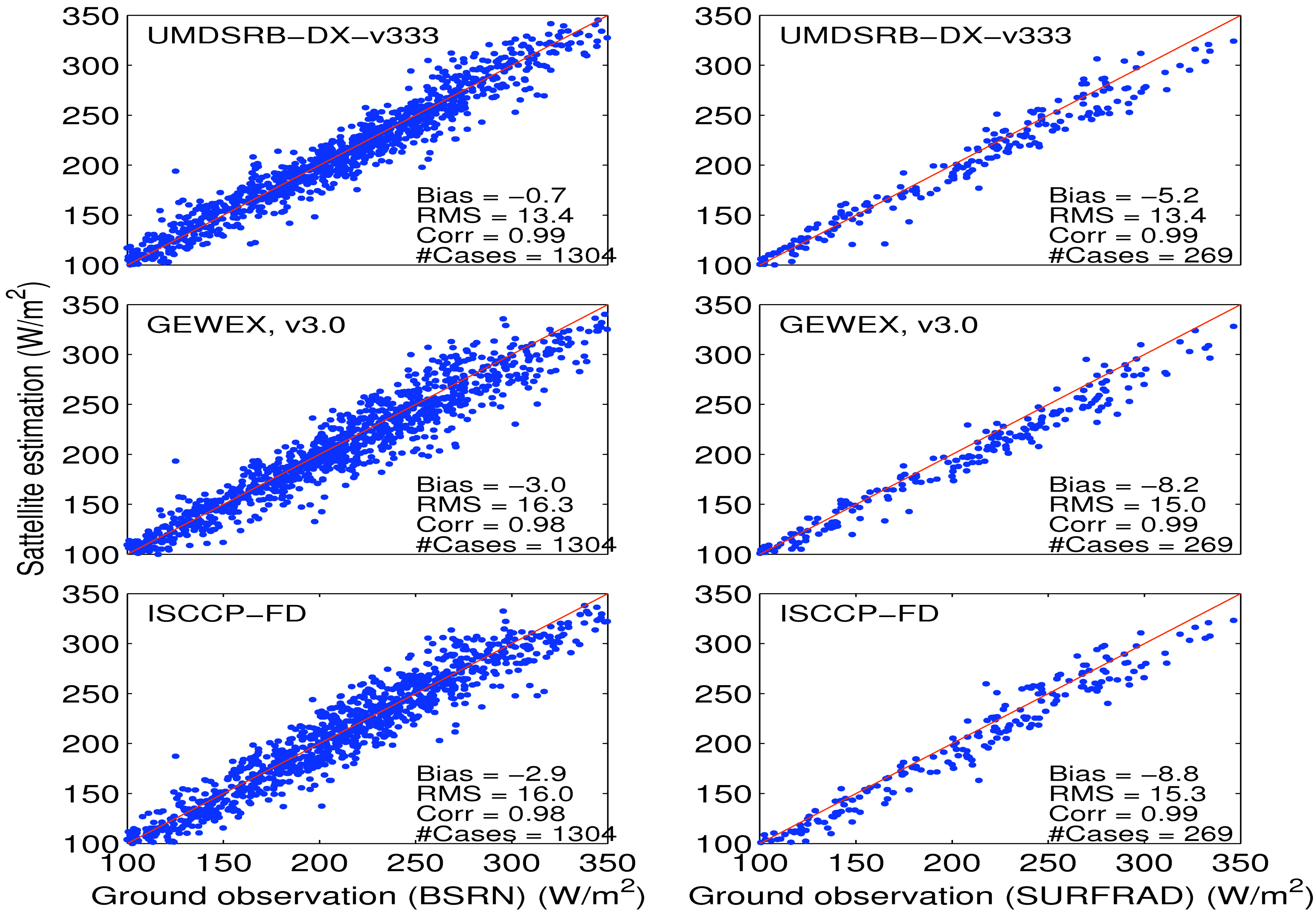


Distributed Hydrology Soil Vegetation Model (DHSVM) (Wigmosta et al. 1994)

Run as Point Snow Model - re-coded to just one grid cell for testing purposes

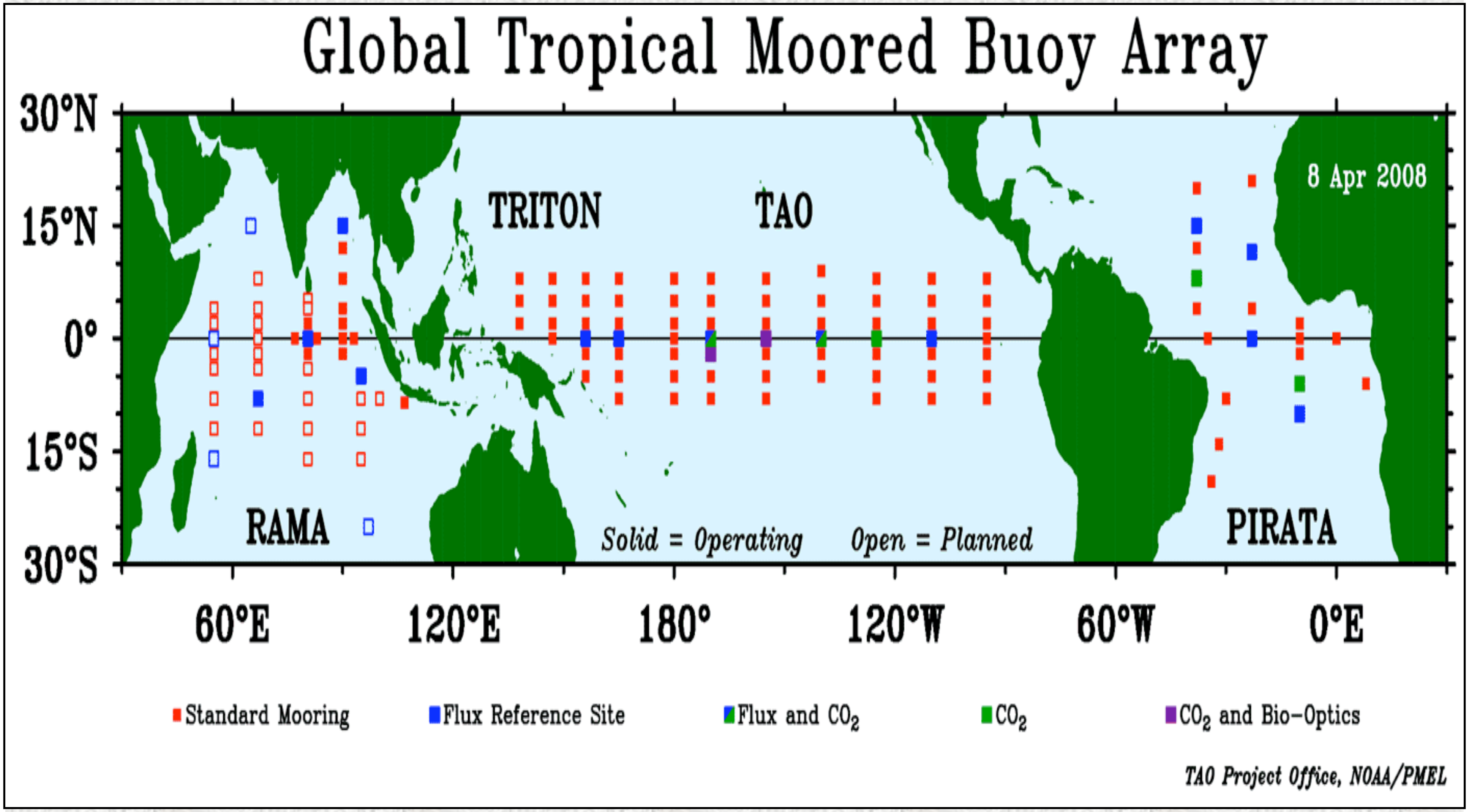
Motivation to use MODIS

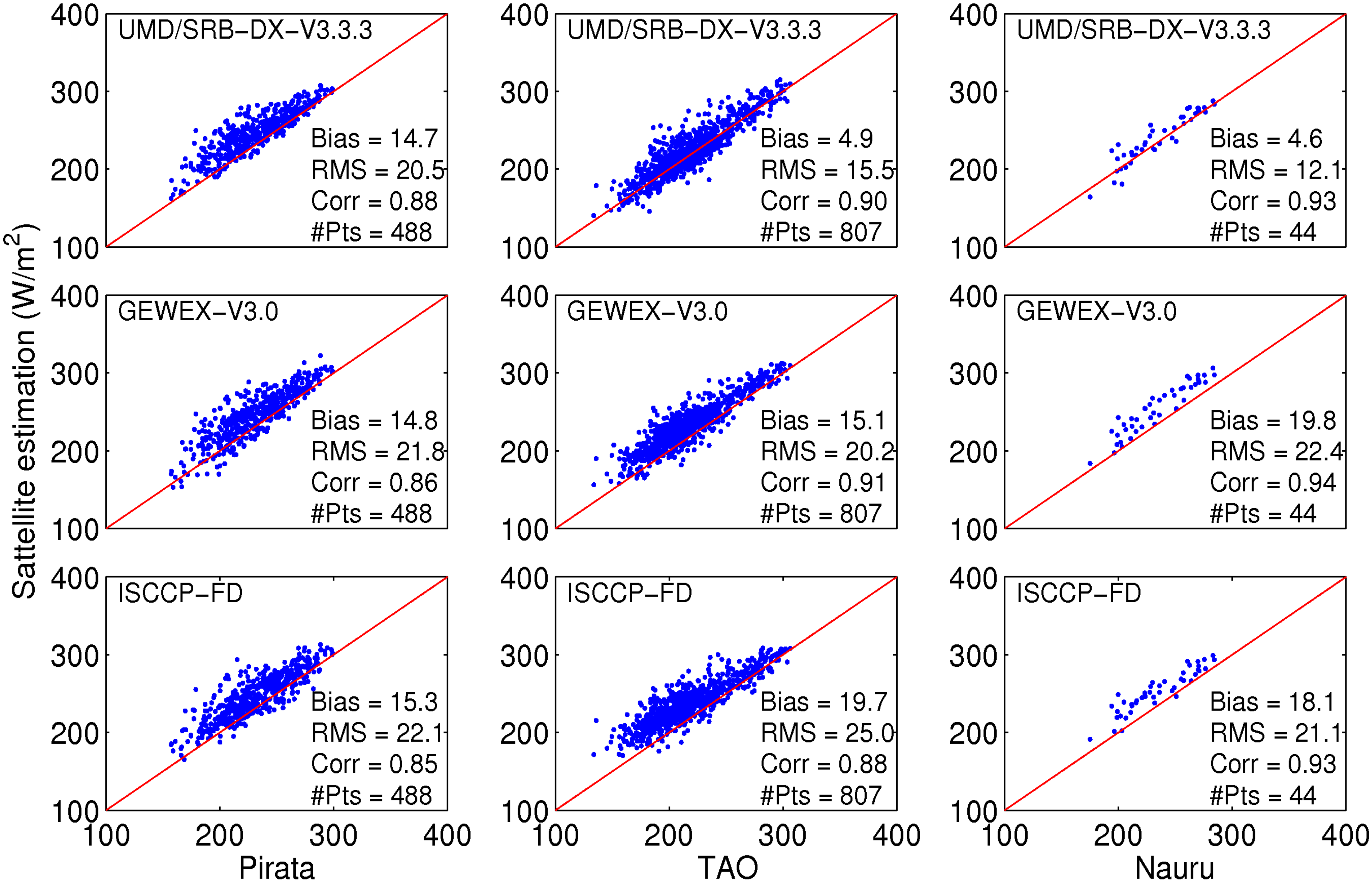
- All *national and international* climate research programs require information on ***radiative fluxes*** *(GEWEX)*
- Most *global estimates* based on *ISCCP* data
- Evaluation done against BSRN network



Monthly means 2003-2005-30 BSRN sites

Oceanographers ***demand*** validation over oceans





Evaluation of monthly mean surface SW from several satellite modelsagainst buoy observations for for 2000/01-2005/12

- Wang, H., and R. T. Pinker, 2009. Shortwave radiative fluxes from MODIS: **Model development** and implementation. JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 114, D20201.

- Pinker, RT; Wang, HM; Grodsky, SA, 2009. How good are **ocean buoy** observations of radiative fluxes? GEOPHYSICAL RESEARCH LETTERS, 36, L10811.

- Niu, X., R. T. Pinker, and M. F. Cronin, 2010. Radiative fluxes at **high latitudes**. GEOPHYSICAL RESEARCH LETTERS, 37, L20811, doi:10.1029/2010GL044606, 2010

Updated parameterization schemes

Water cloud: Edwards and Slingo (1996), based on MIE theory; optical properties represented in terms of liquid water path and effective cloud droplet radius

Ice cloud: Chou et al (2002), bulk optical properties given as a function of the effective particle size of a mixture of ice habits, the ice water amount, and spectral band

Aerosol Model: Optical Properties of Aerosols and clouds (OPAC) (Hess et al., 1998), the single scattering properties and vertical profiles of Continental, Desert, Maritime, Arctic and Antarctic aerosols

Water vapor absorption: Tarasova and Fomin (2000), based on k-distributed method, using more extensive spectroscopic database and incorporating the water vapor continuum model

Statistical cloud layer thickness model: Wang et al., 2000, cloud layer thickness given as a function of cloud top pressure, latitude and month of year for land and ocean separately

Level-3 MODIS Atmosphere Daily Global Product (MOD08_D3, MYD08_D3) Collection 005

Input parameters: Optical Depth Land And Ocean, Cloud Top Pressure Day, Cloud Optical Thickness Liquid, Cloud Optical Thickness Ice, Cloud Effective Radius Liquid, Cloud Effective Radius Ice, Cloud Effective Radius Undetermined, Cloud Fraction Liquid, Cloud Fraction Ice, Cloud Fraction Undetermined, Cloud Optical Thickness Undetermined, Total Ozone, Atmospheric.

Statistics sorted into 1^0 x 1^0 cells on an equal-angle global grid (360x180 cells).

Clouds with undetermined phase - treated as water clouds

Since the atmospheric water vapor was retrieved only when at *least 9 out of 25 Field of Views* (FOV) were cloud free, precipitable water from the National Centers for Environmental Prediction (NCEP) Reanalysis Data is used for conditions with large cloud fraction.

Missing aerosol optical depths were filled with ***MISR*** observations

Spectral surface albedo from The Filled Land Surface Albedo Product, generated by MODIS Atmosphere team from MOD43B3 (Moody el al., 2005).

Monthly mean sea ice extent data at 1^0 longitude/latitude grid cells based on Special Sensor Microwave/Imager (SSM/I) were taken from NOAA/NESDIS National Climate Data Center (NCDC).

Surface albedo of ice over oceans at visible and near-infrared was given as 0.77 and 0.33 respectively.

Snow and ice coverage data used in the first version of UMD_MODIS

- **Snow coverage:**
  - MODIS daily global snow cover data at 0.25 °
- **Sea ice concentration**:
  - Monthly mean sea ice extent at 1° grid cells based on the Special Sensor Microwave/Imager were used which are taken from NOAA/NESDIS National Climate Data Center (NCDC)

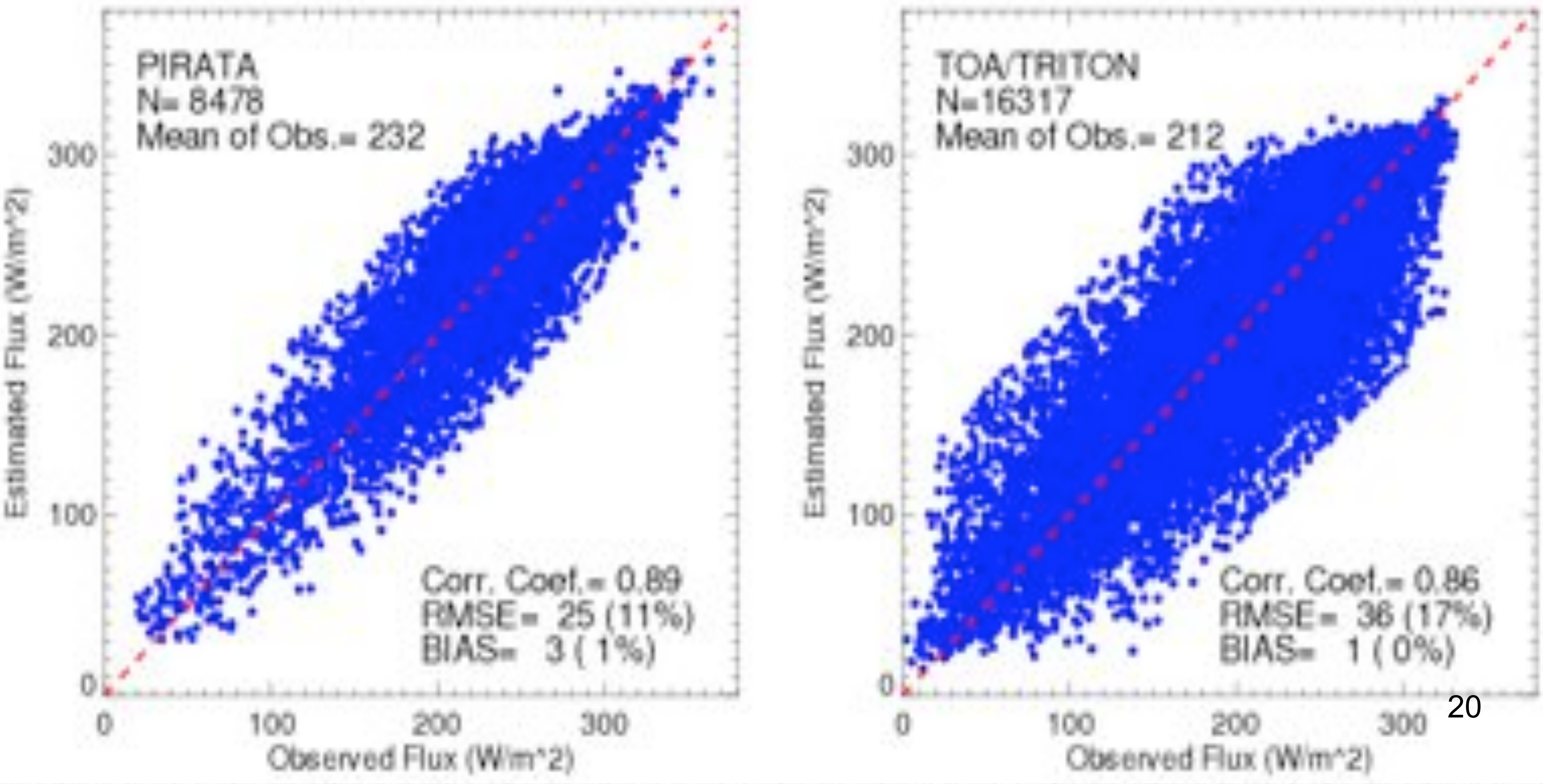
For Snow

Spectral reflectance assumed as 0.9 for visible spectrum and 0.6 for near-infrared (NIR) spectrum

For sea ice:

- Spectral reflectance assumed as 0.73 for the visible spectrum and 0.33 for NIR spectrum

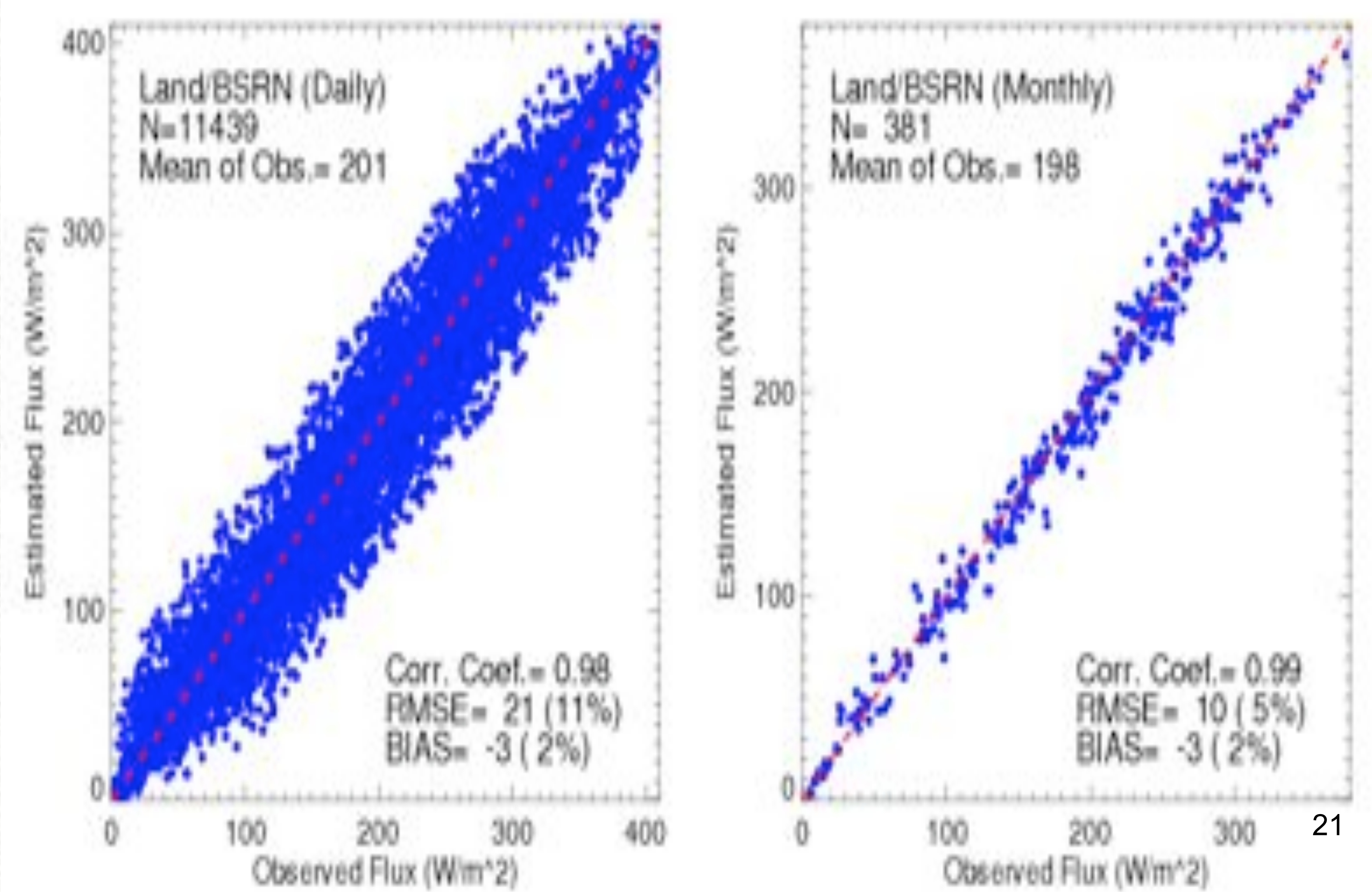
Daily mean surface SW flux estimated by UMD/ SRB_MODIS against PIRATA and TAO/TRITON buoys over the Atlantic and Pacific Oceans, January 2003-December 2005



Daily and monthly mean SW flux estimated by UMD/ SRB_MODIS against BSRN measurements over land

January, 2003-December, 2005)

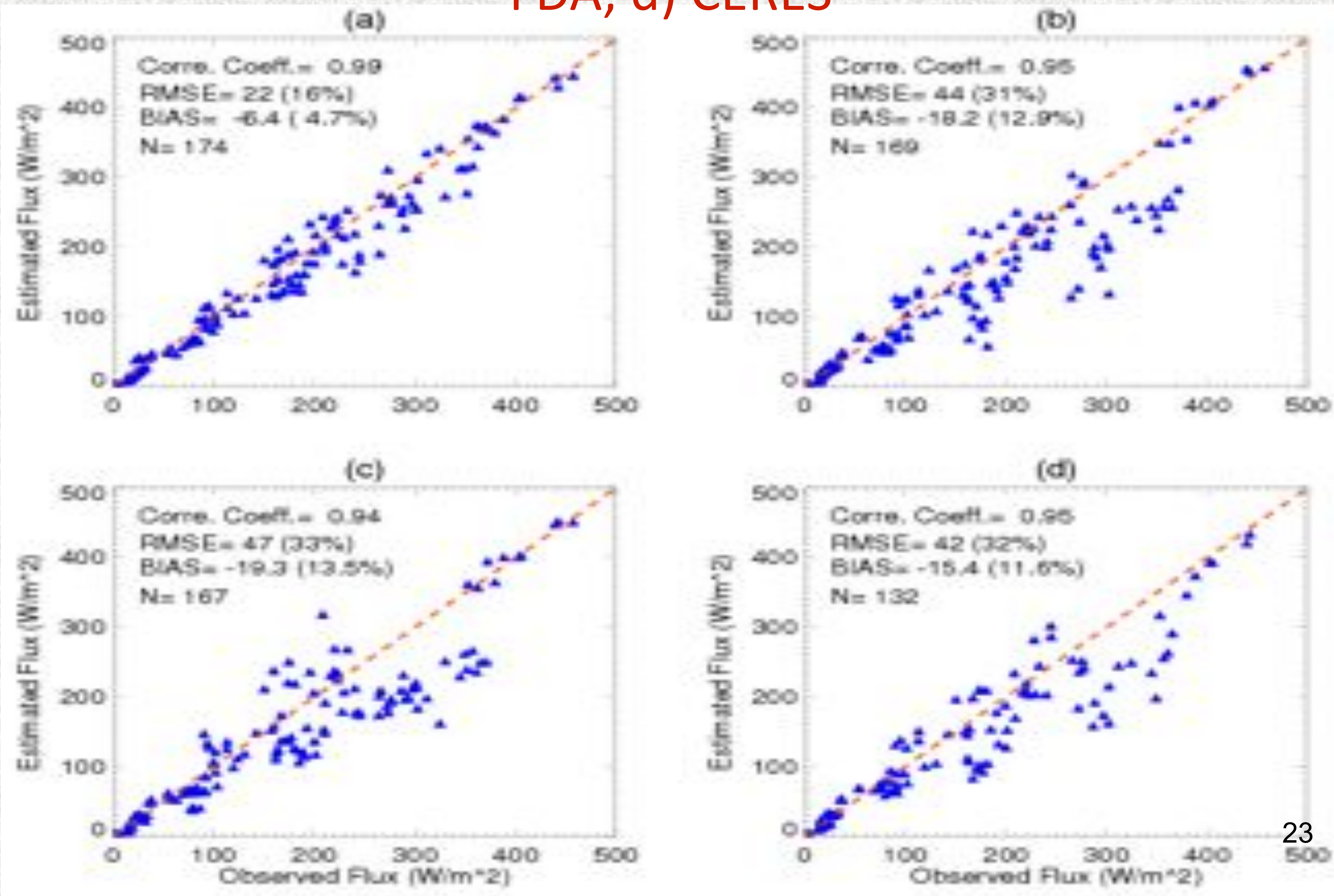
Cases eliminated: 1.6% (Daily)

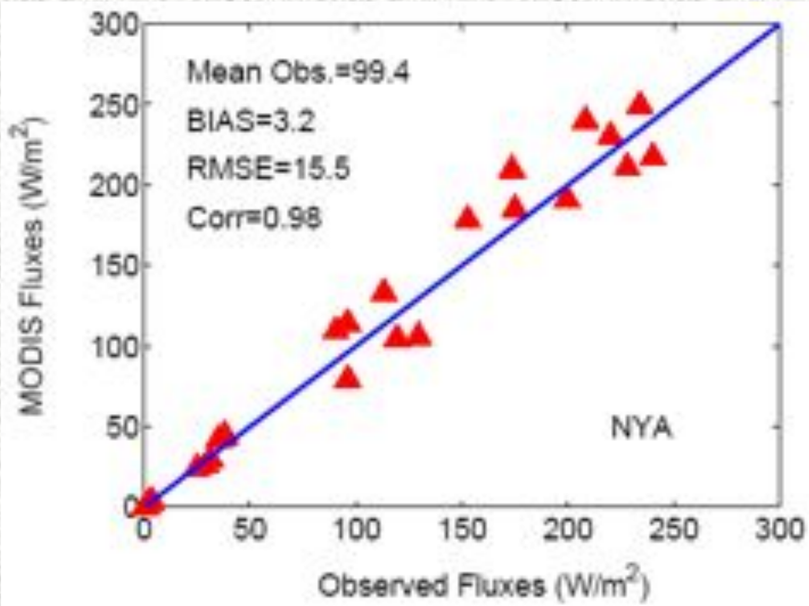


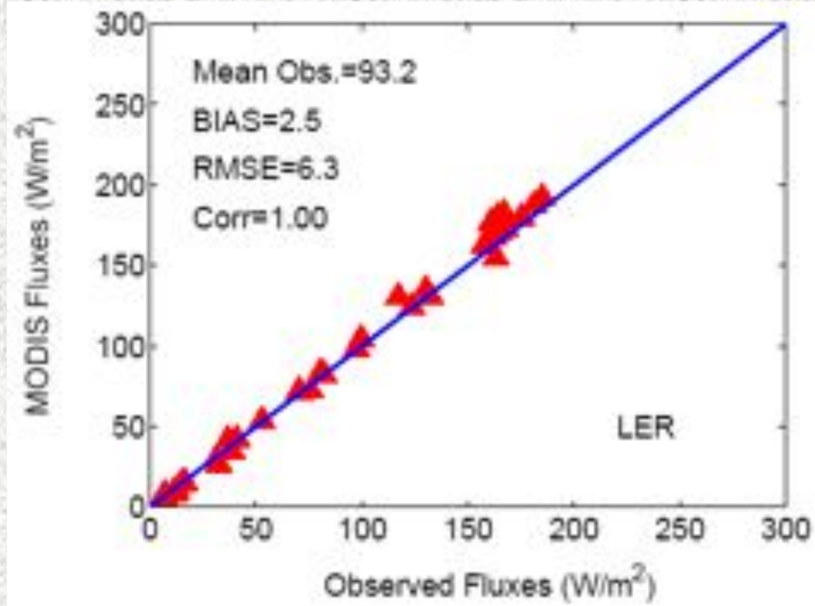
Information on BSRN sites at High Latitudes

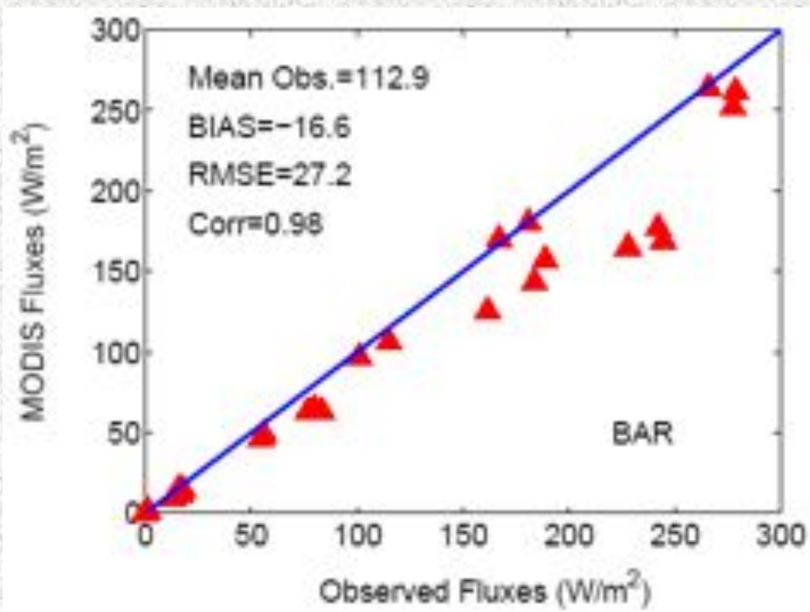
BSRN Site	Abbrev.	Latitude	Longitude
NY-Alesund, Spilsbergen	NYA	78.93^0N	11.95^0E
Barrow, Alaska	BAR	71.32^0N	156.61^0W
George von Neumayer, Antarctica	GVN	70.65^0S	8.25^0W
Syowa, Cosmonaut Sea	SYO	69.01^0S	39.59^0E
South Pole, Antarctica	SPO	89.98^0S	24.80^0W

Monthly mean SW over High Latitude: **BAR**,NYA,GVN, SPO, SYO during (2003-2006) a) MODIS; b) GEWEX-LaRC; c) ISCCP-FDA; d) CERES







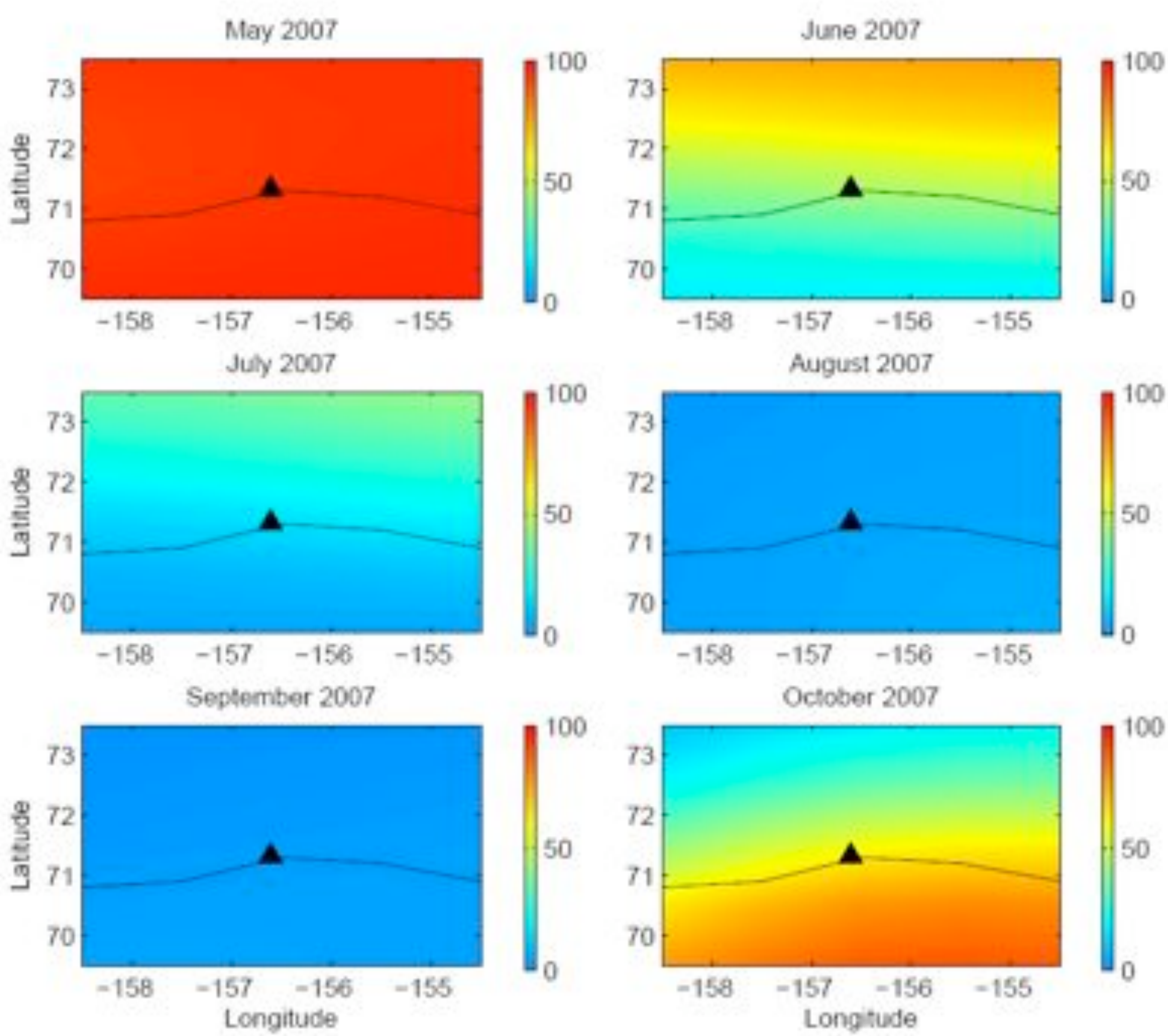


NYA

LER

Monthly means MODIS

BAR



Monthly mean of snow/ice coverage around Barrow site for May, June, July, August, September, and October 2007 (National Snow and Ice Data Center).

Updates on snow and ice coverage data

- Snow coverage:
  – Higher resolution snow cover at 0.05° at a daily scale (MOD10C1 from Terra, MYD10C1 from Aqua) and at a monthly scale (MOD10CM from Terra, MYD10CM from Aqua)

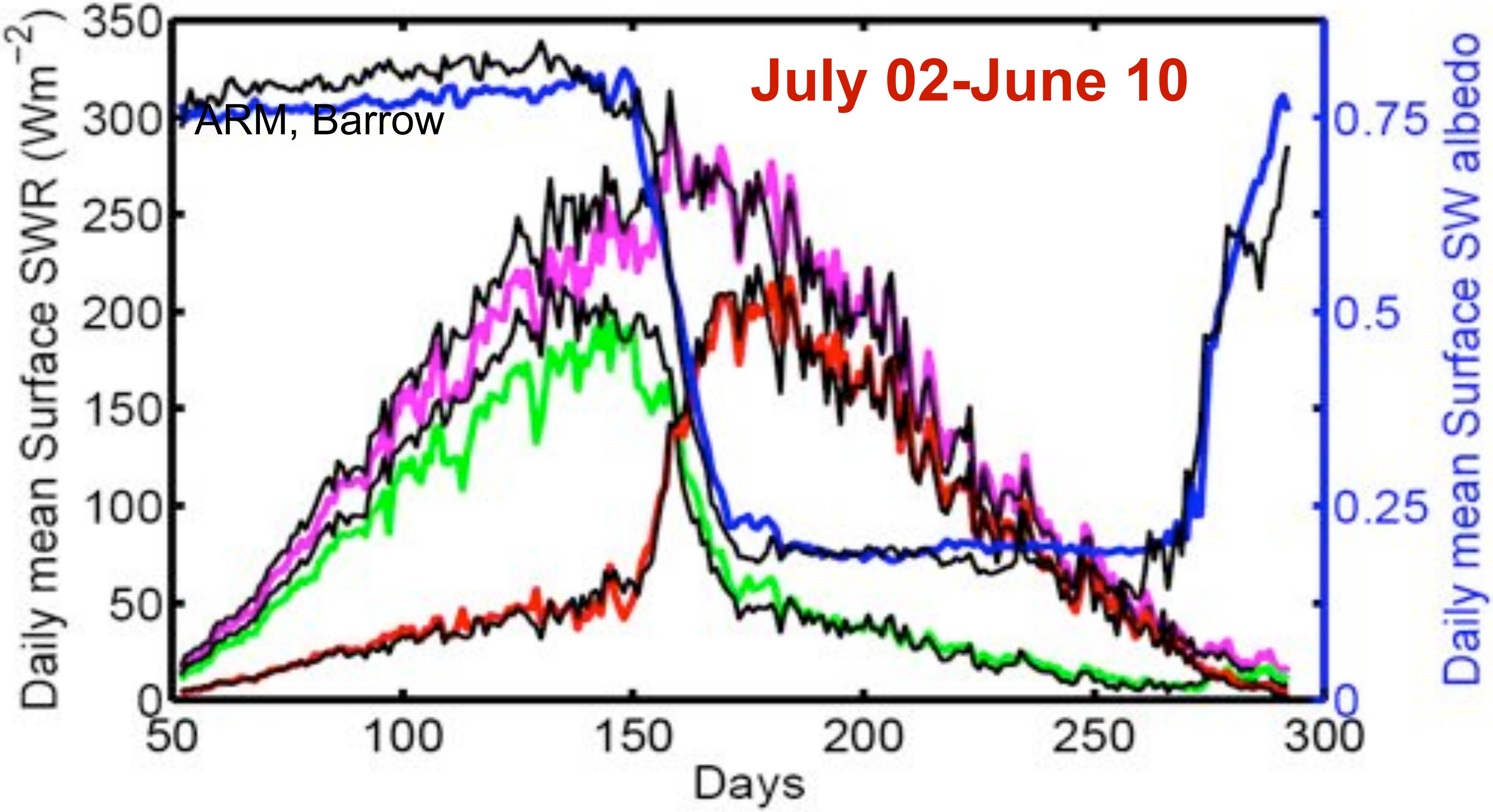
- Sea ice concentration:
  – Higher resolution (25 km) sea ice concentrations at both daily and monthly scales (fill the daily missing values), derived from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) and the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) radiances based NASA team algorithm (Cavalieri et al. 1996 and updated 2008

MODIS Filled Albedo Map Snow Statistic data

The data are availble at website:
http://modis-atmos.gsfc.nasa.gov/ALBEDO/acquiring.html
For instance, the mean values of Northen Hemisphere five-year(2000-04) spectral white-sky surface reflectance in the presense of snow aggregated by IGBP classification (Moody et al. 2007):

Ecosystem	White-sky snow albedo by wavelength (μm)									
	0.47	0.55	0.69	0.86	1.24	1.64	2.13	0.3–0.7	0.7–5.0	0.3–5.0
Evergreen needle forest	0.36	0.36	0.33	0.40	0.24	0.09	0.05	0.31	0.24	0.27
Evergreen broad forest	0.49	0.49	0.47	0.50	0.31	0.11	0.06	0.44	0.33	0.38
Deciduous needle forest	0.43	0.42	0.41	0.42	0.26	0.12	0.07	0.39	0.27	0.33
Deciduous broad forest	0.43	0.43	0.41	0.46	0.26	0.10	0.06	0.35	0.27	0.31
Mixed forest	0.39	0.39	0.37	0.43	0.25	0.10	0.05	0.32	0.25	0.29
Closed shrubs	0.48	0.48	0.46	0.47	0.29	0.11	0.06	0.42	0.30	0.36
Open shrubs	0.73	0.72	0.70	0.67	0.37	0.12	0.06	0.68	0.44	0.56
Woody savanna	0.47	0.46	0.44	0.47	0.28	0.11	0.06	0.44	0.30	0.37
Savanna	0.59	0.59	0.58	0.59	0.31	0.11	0.05	0.57	0.39	0.47
Grassland	0.72	0.72	0.71	0.70	0.39	0.12	0.06	0.70	0.48	0.59
Wetland	0.69	0.70	0.69	0.67	0.32	0.01	0.04	0.66	0.44	0.55
Cropland	0.76	0.76	0.76	0.74	0.40	0.11	0.05	0.69	0.47	0.58
Urban	0.54	0.54	0.53	0.55	0.30	0.11	0.06	0.50	0.34	0.42
Crop mosaic	0.65	0.66	0.64	0.65	0.36	0.11	0.06	0.59	0.41	0.50
Permanent snow	0.95	0.94	0.92	0.84	0.45	0.12	0.05	0.89	0.57	0.74
Barren/desert	0.87	0.87	0.85	0.80	0.42	0.12	0.06	0.78	0.51	0.65

Time series of 8 year average daily mean radiative parameters from UMD_MODIS magenta: downward SWR; green: upward SWR; red: net SWR; blue: surface albedo; black measured



Niu, X. and R. T. Pinker, 2011. IJRS, in press.

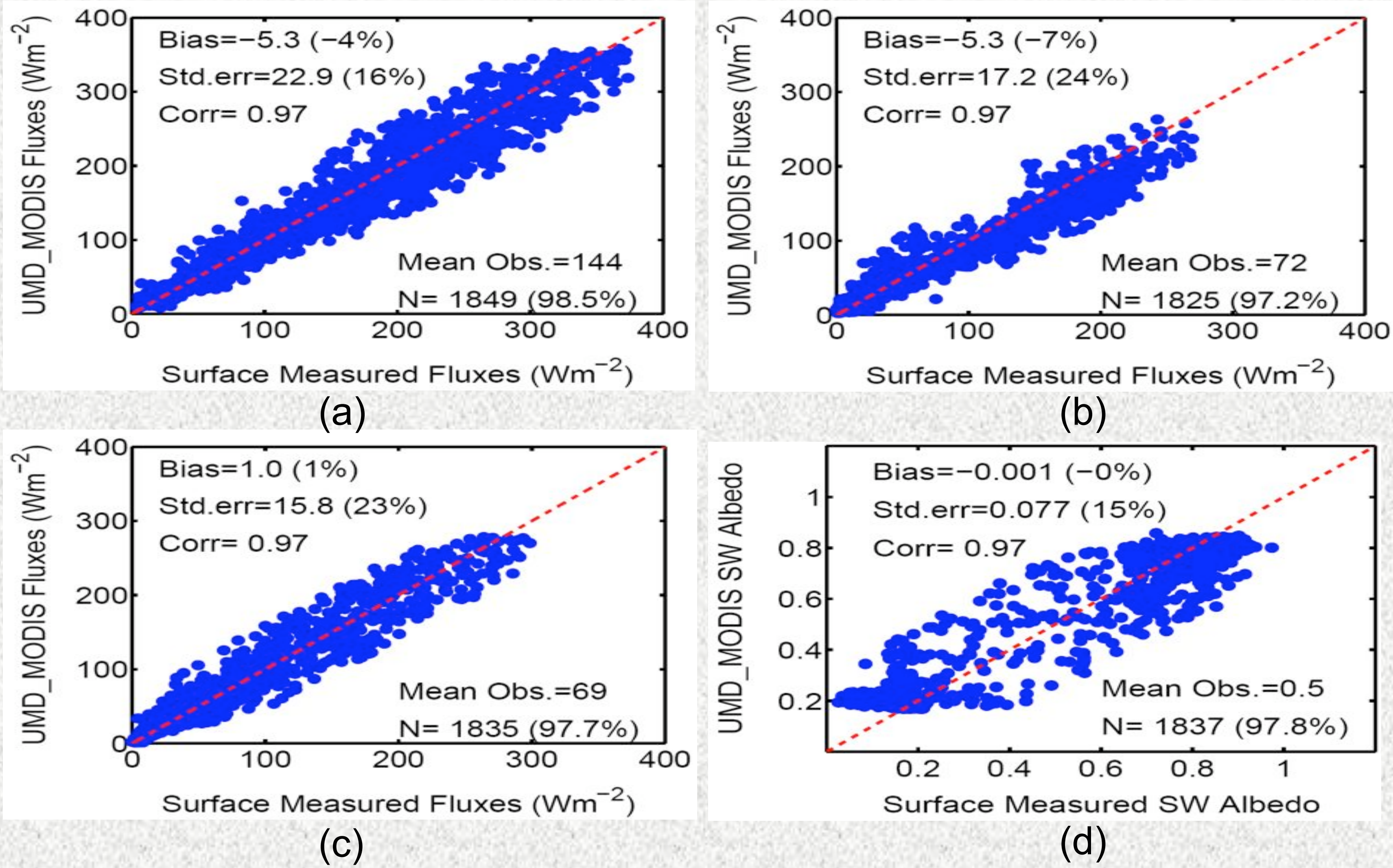
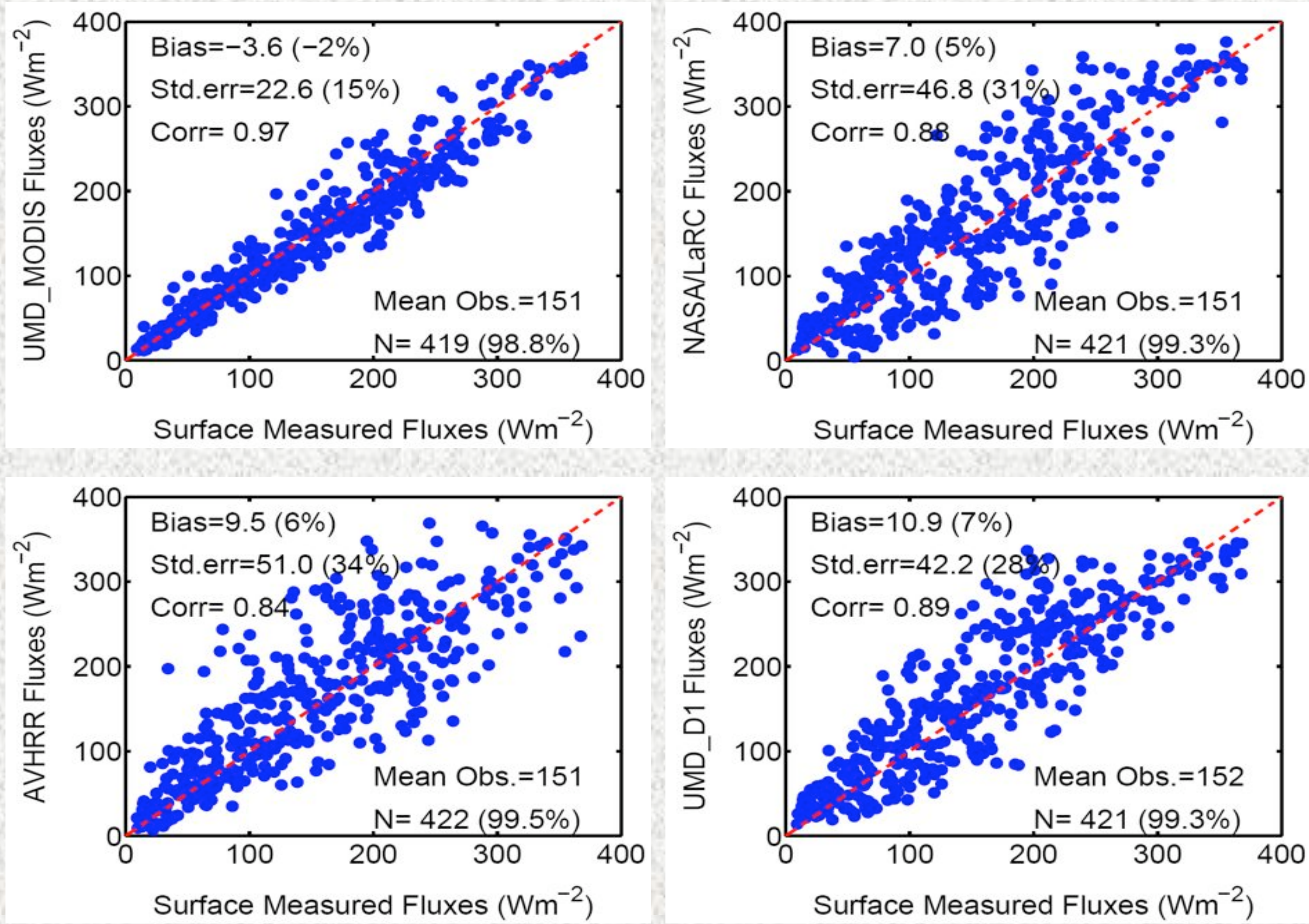
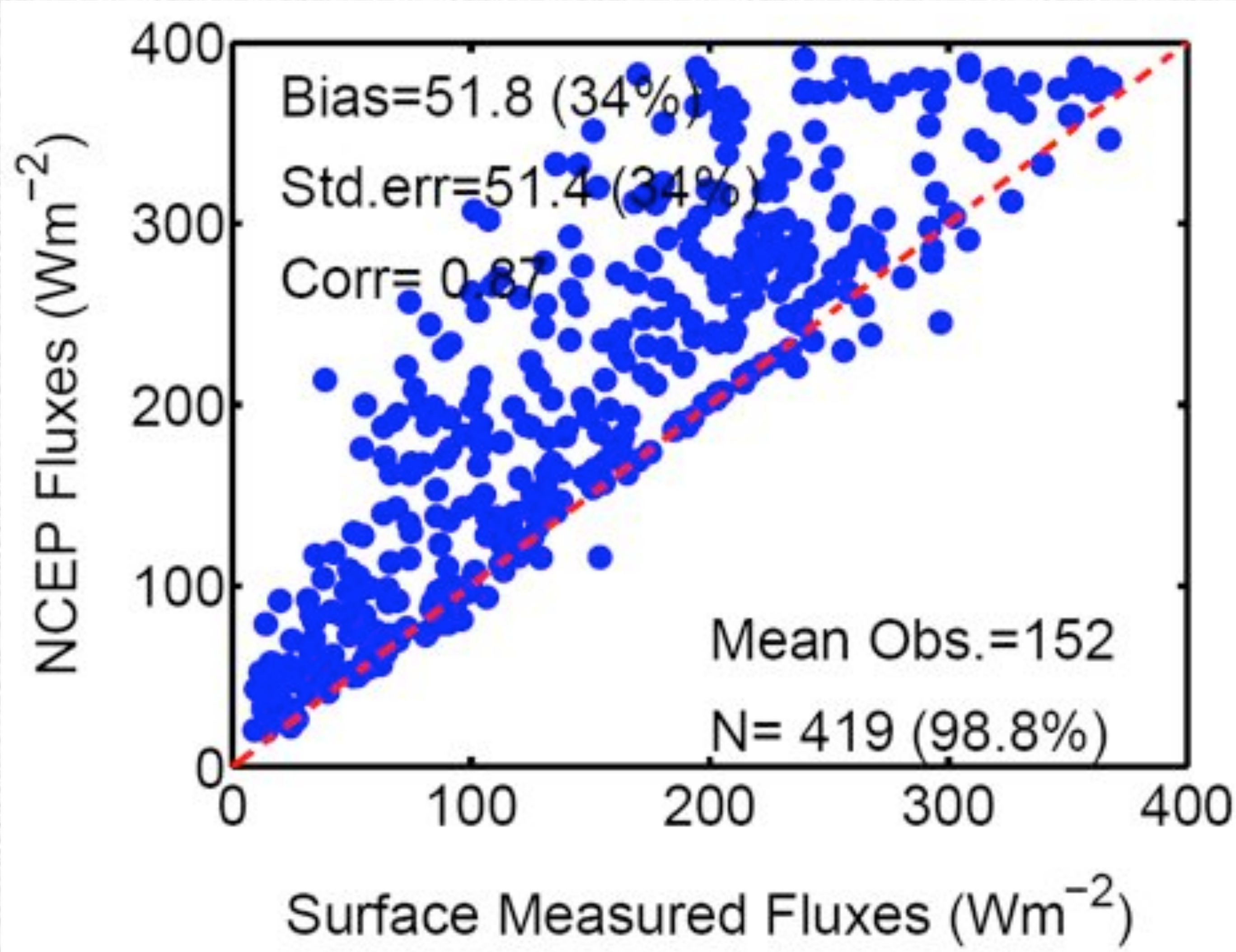


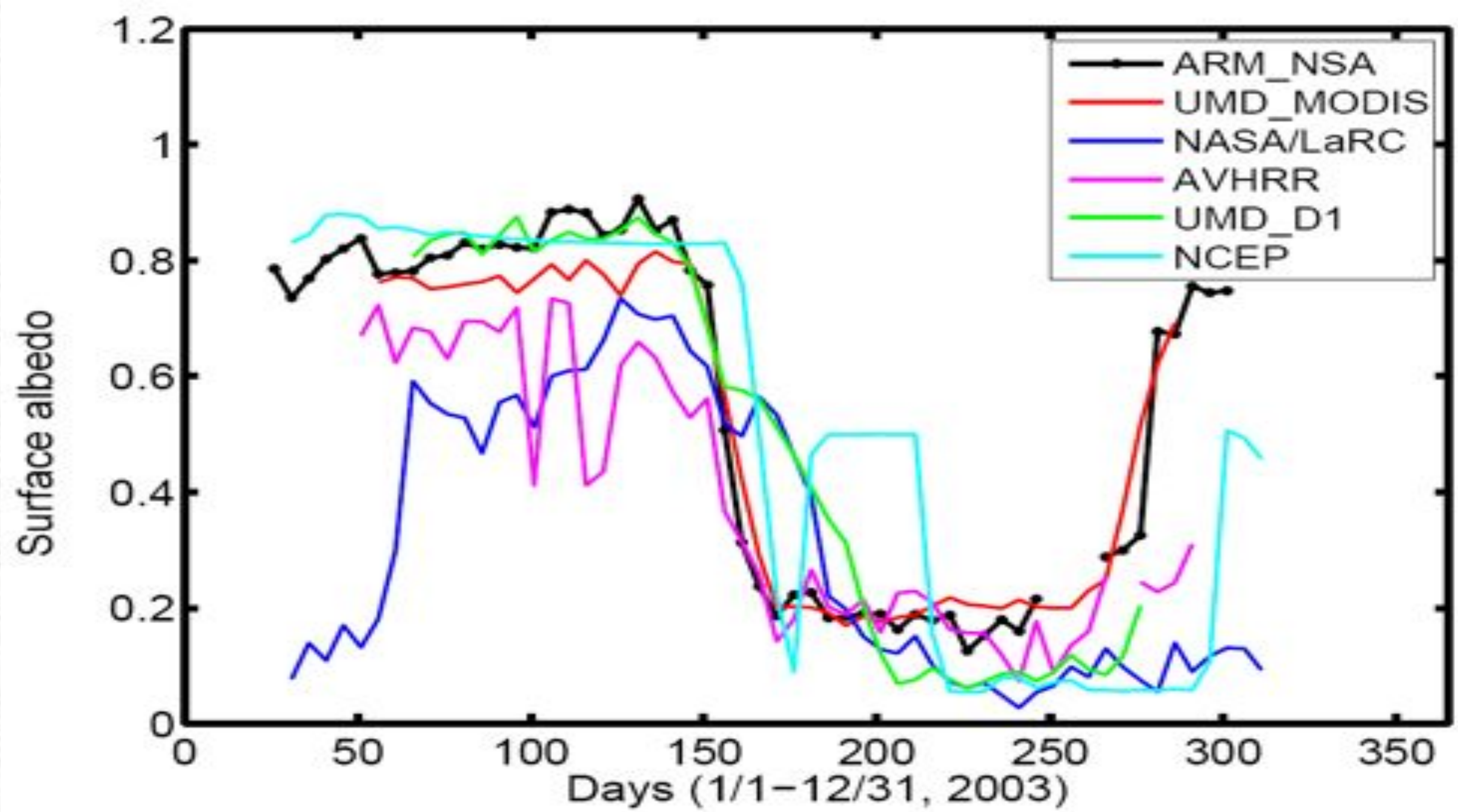
Figure 3. Evaluations of daily mean surface parameters from UMD_MODIS against surface measurements at Barrow from ARM_NSA for period of July 2002 to June 2010: (a) downward SWR; (b) upward SWR; (c) net SWR; (d): surface albedo.



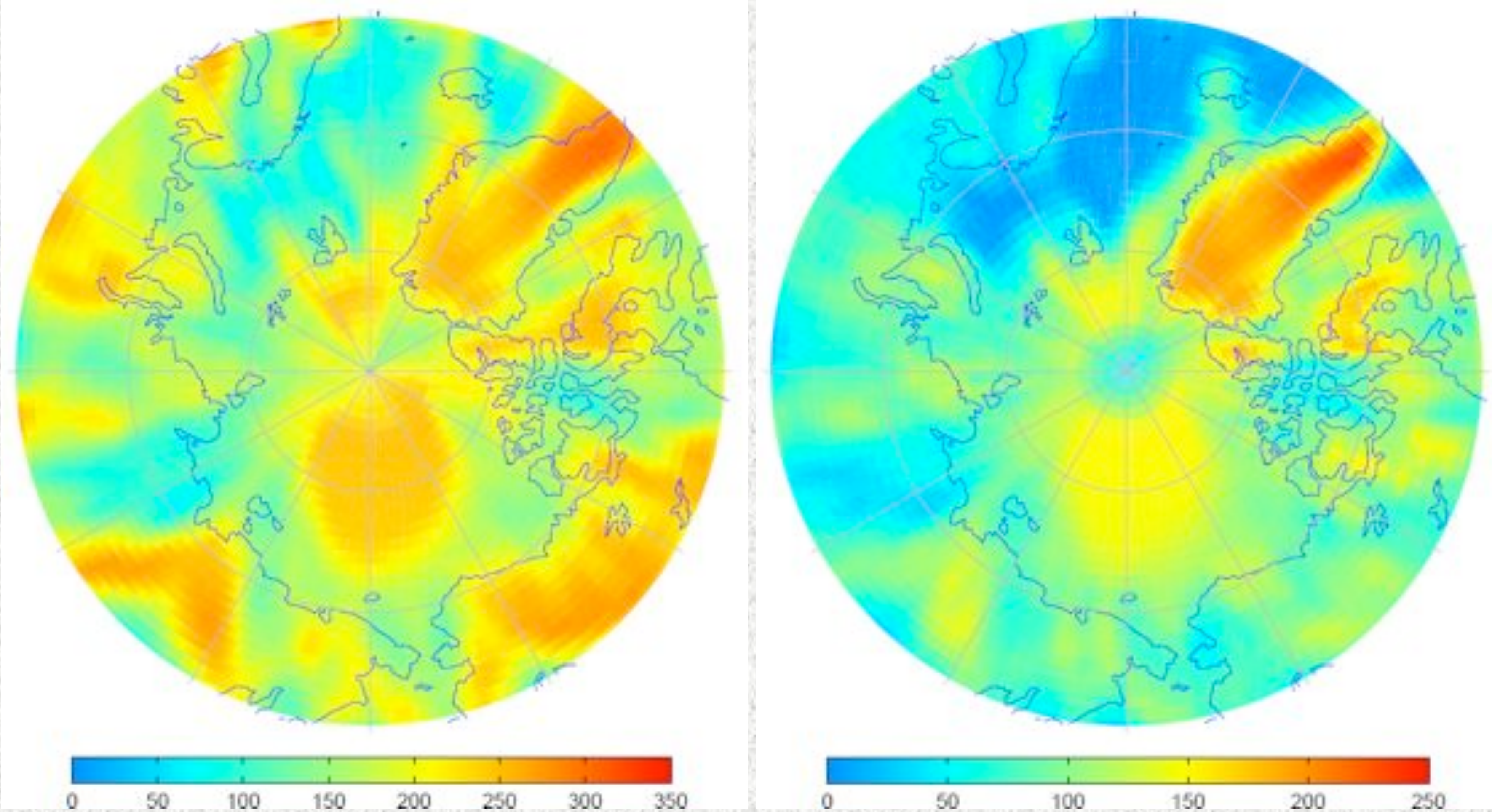
Evaluations of daily averaged SW (Wm^{-2}) from satellite estimates (UMD_MODIS, NASA/LaRC, AVHRR, and UMD_D1) against surface measurements at ARM_NSA site for (2003-04).



Evaluations of daily averaged surface downward SWR (Wm^{-2}) from NCEP Reanalysis against surface measurements at ARM_NSA site for 2 years (2003-04).

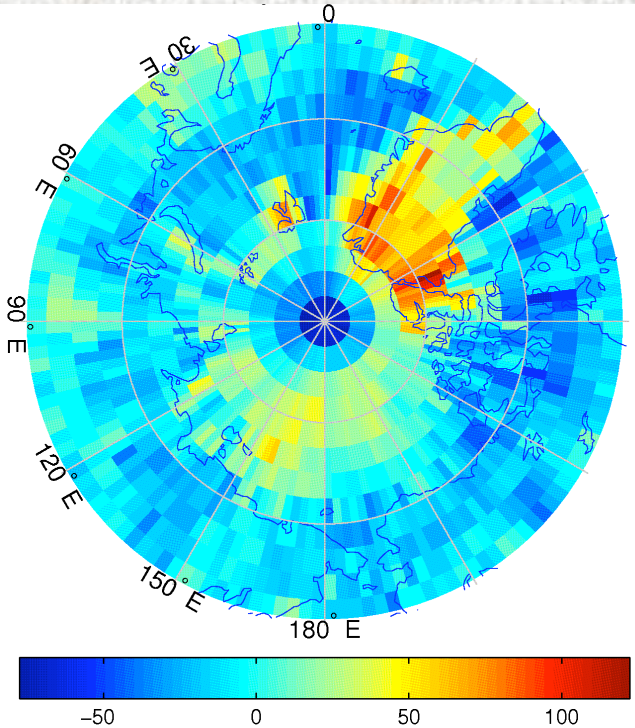


Time series of daily mean surface albedo derived from UMD_MODIS (red line), NASA/LaRC (blue line), AVHRR (magenta line), UMD_D1 (green line), and NCEP (cyan line) against surface observations (black line) at ARM_NSA site for period of January 1 to December 31 2003.

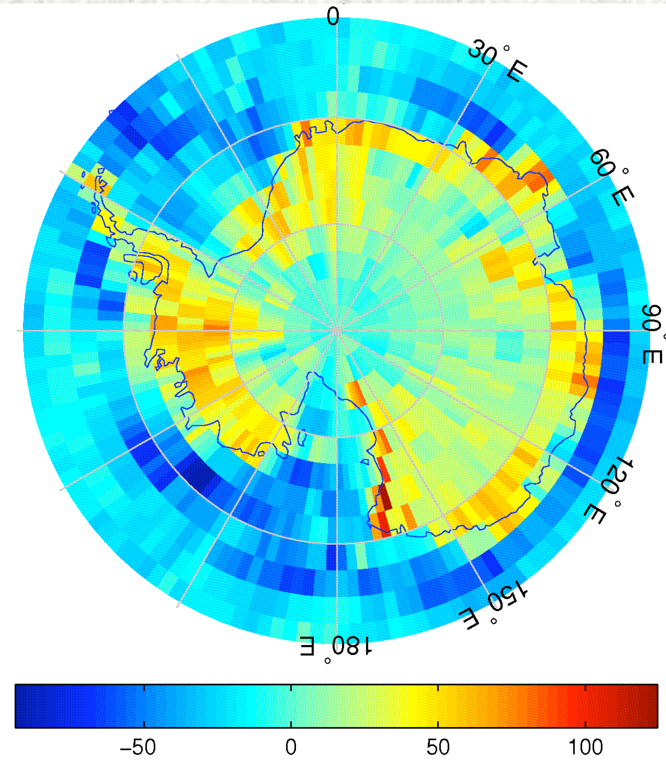


Daily mean surface downward (Left) and upward (Right) SWR (Wm^{-2}) estimated from UMD_MODIS (1°) over the Arctic regions (60°N-90°N) for May 1, 2007.

2005/07



2005/01



Difference between MODIS and ISCCP-FD Monthly Means

Methods to calculate the Solar Input into Polar Ice-ocean system

Solar input to the ice-ocean system calculated as:

$$F(t) = F_s(t) - F_s(t)\overline{\alpha}(t)$$

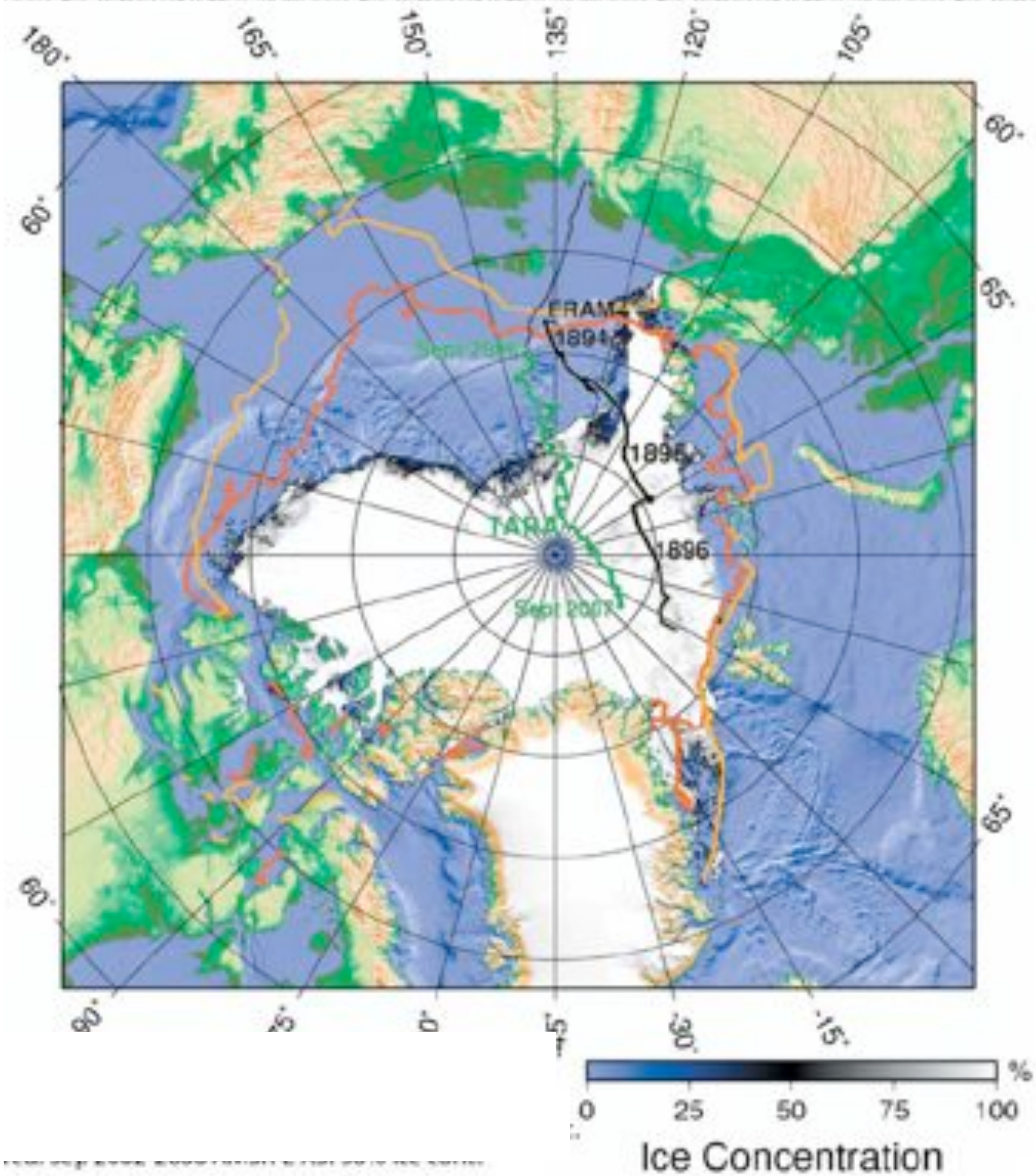
F	:	the solar input to ice-ocean system
Fs	:	the surface solar irradiance
$\overline{\alpha}$	:	the areally averaged albedo

The areally averaged surface albedo calculated as:

$$\overline{\alpha}(t) = \alpha_{ice}(t)A_{ice}(t) + \alpha_{ocean}A_{ocean}(t)$$

α_{ice}	:	the albedo of sea ice
α_{ocean}	:	the albedo of ocean (~0.07)
A_{ice}	:	ice cover fraction
A_{ocean}	:	open water fraction

Perovich et al. (2007)

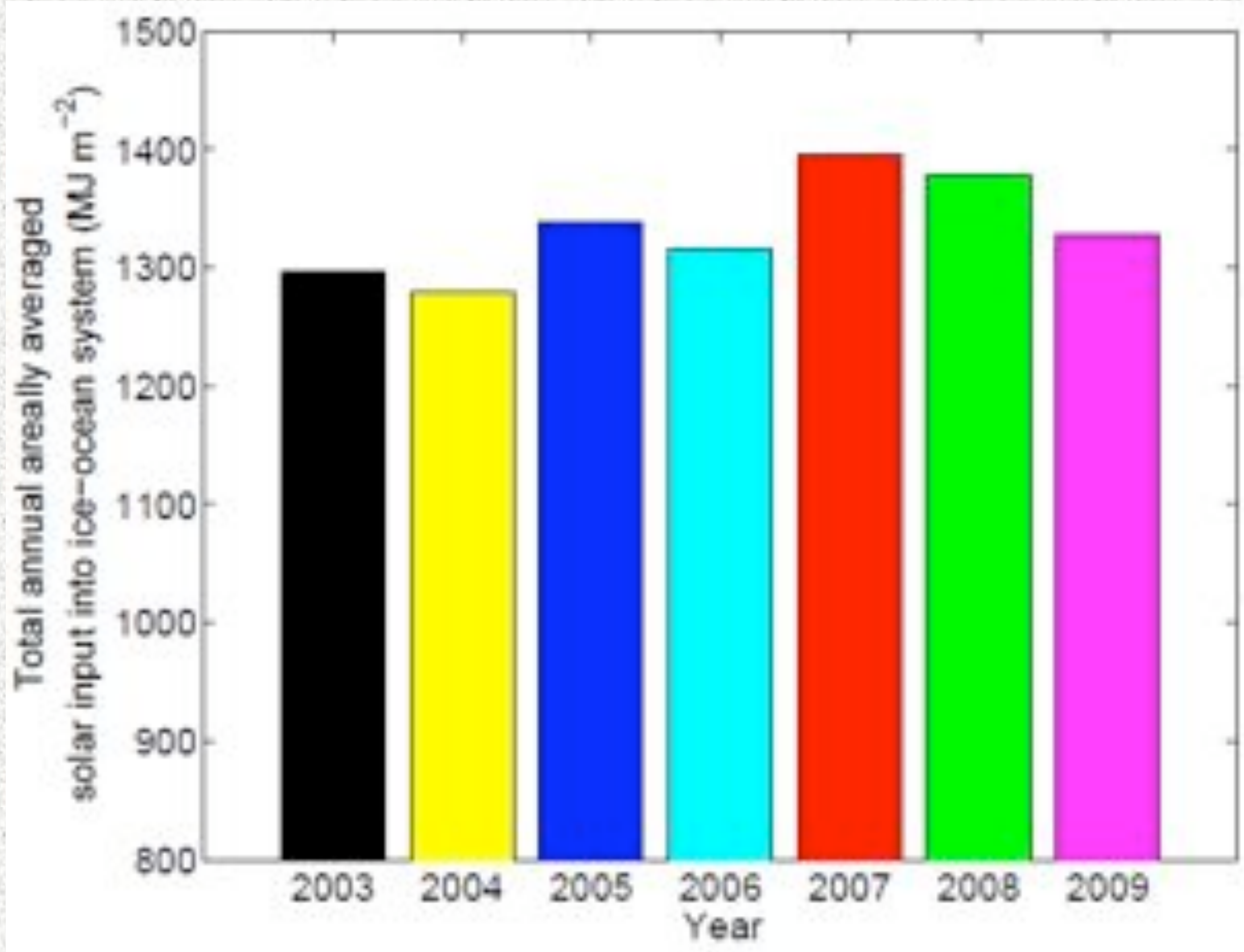


AMSR-E ASI
2007-09-17
Sea Ice
Minimum

Orange: Sept. 1979-1981

Red: Sept. 2002-2008

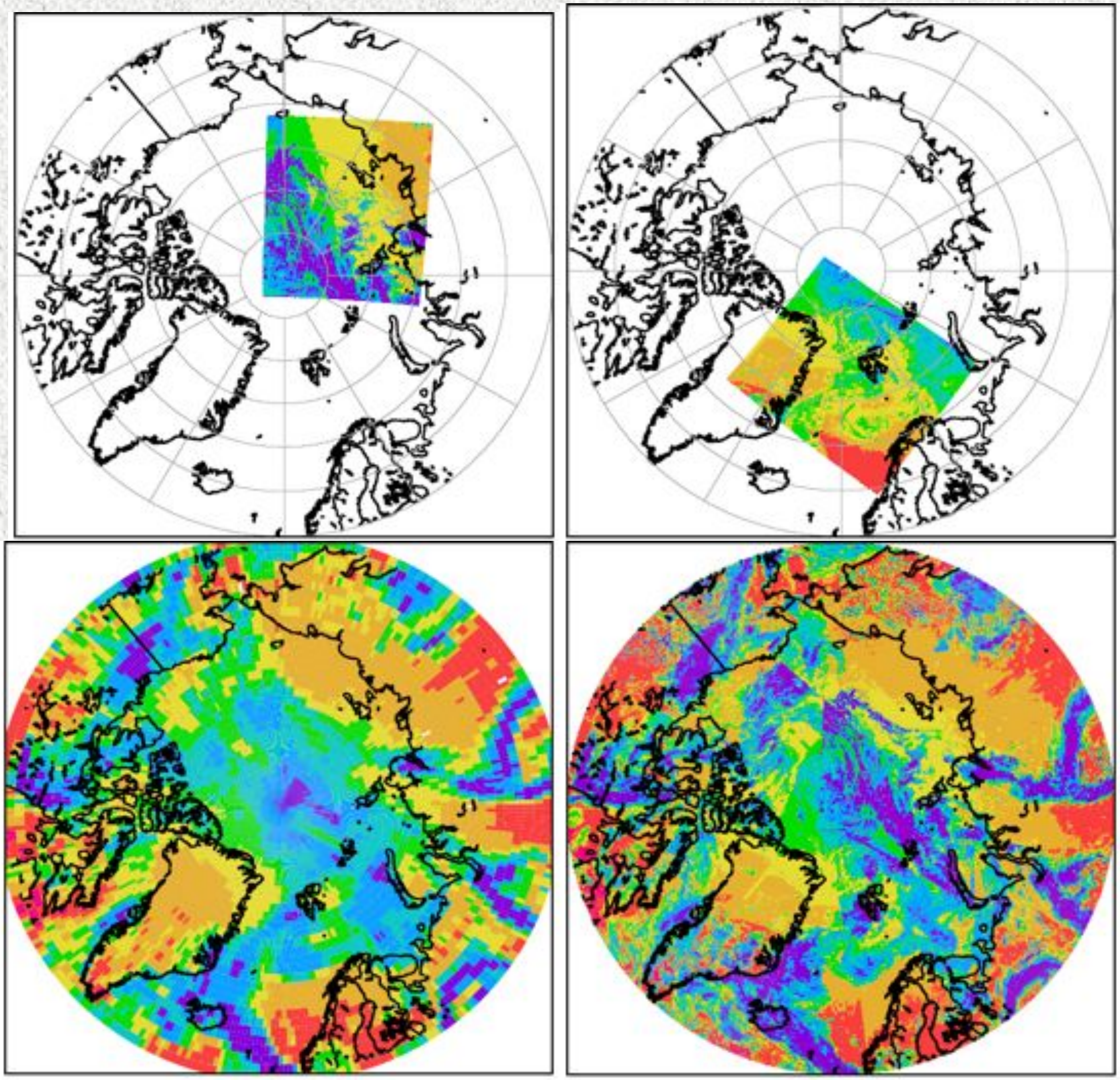
Solar input into Arctic ice-ocean system



Total annual areally averaged solar input into ice-ocean system (60°N-90°N)

Issues with MODIS 5 km swaths

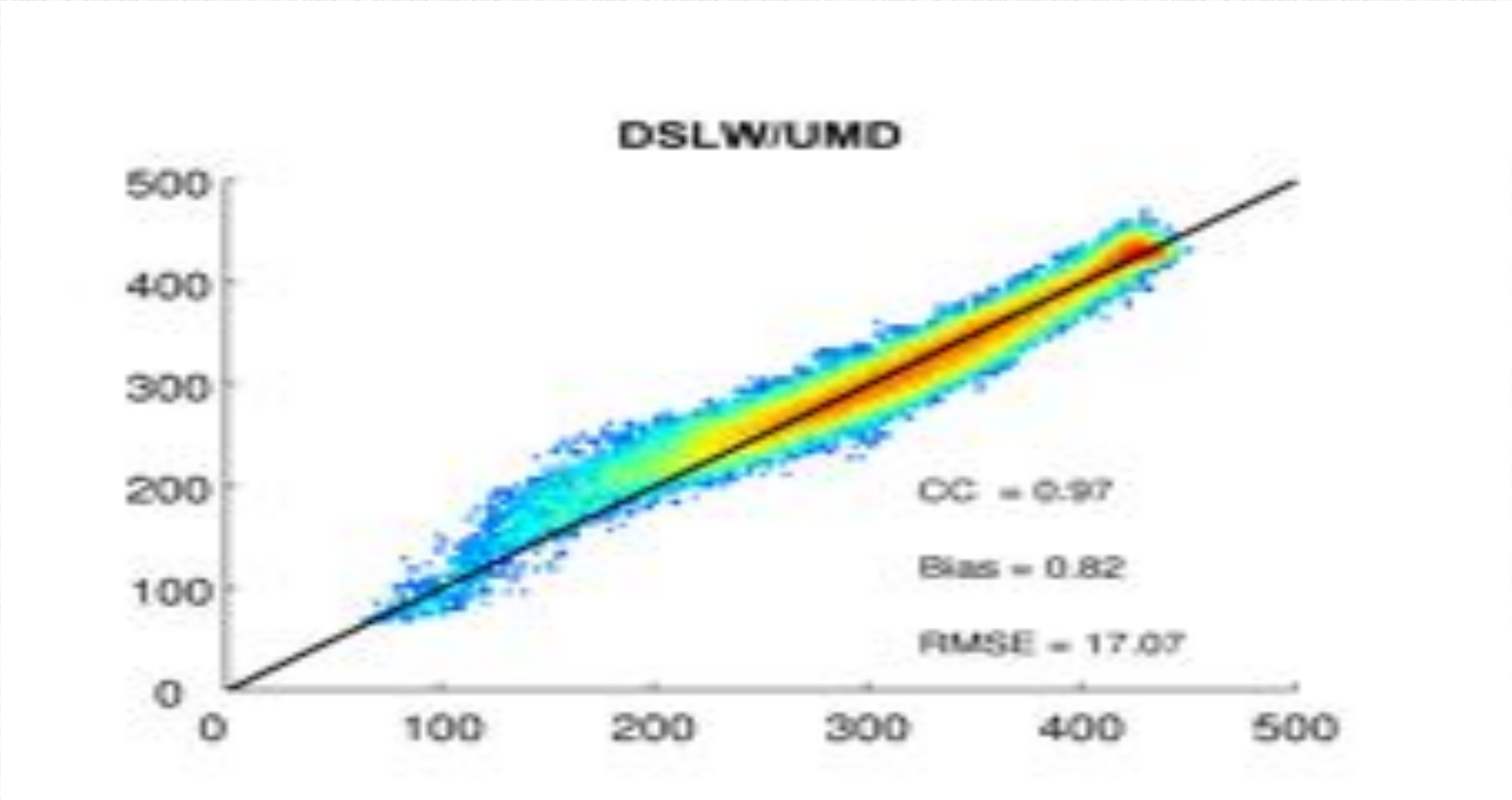
UTC 04:35



“Stitched” map of SW fluxes using 28 orbits overpass around 10:30 am (Local Time) on July 1st 2005)

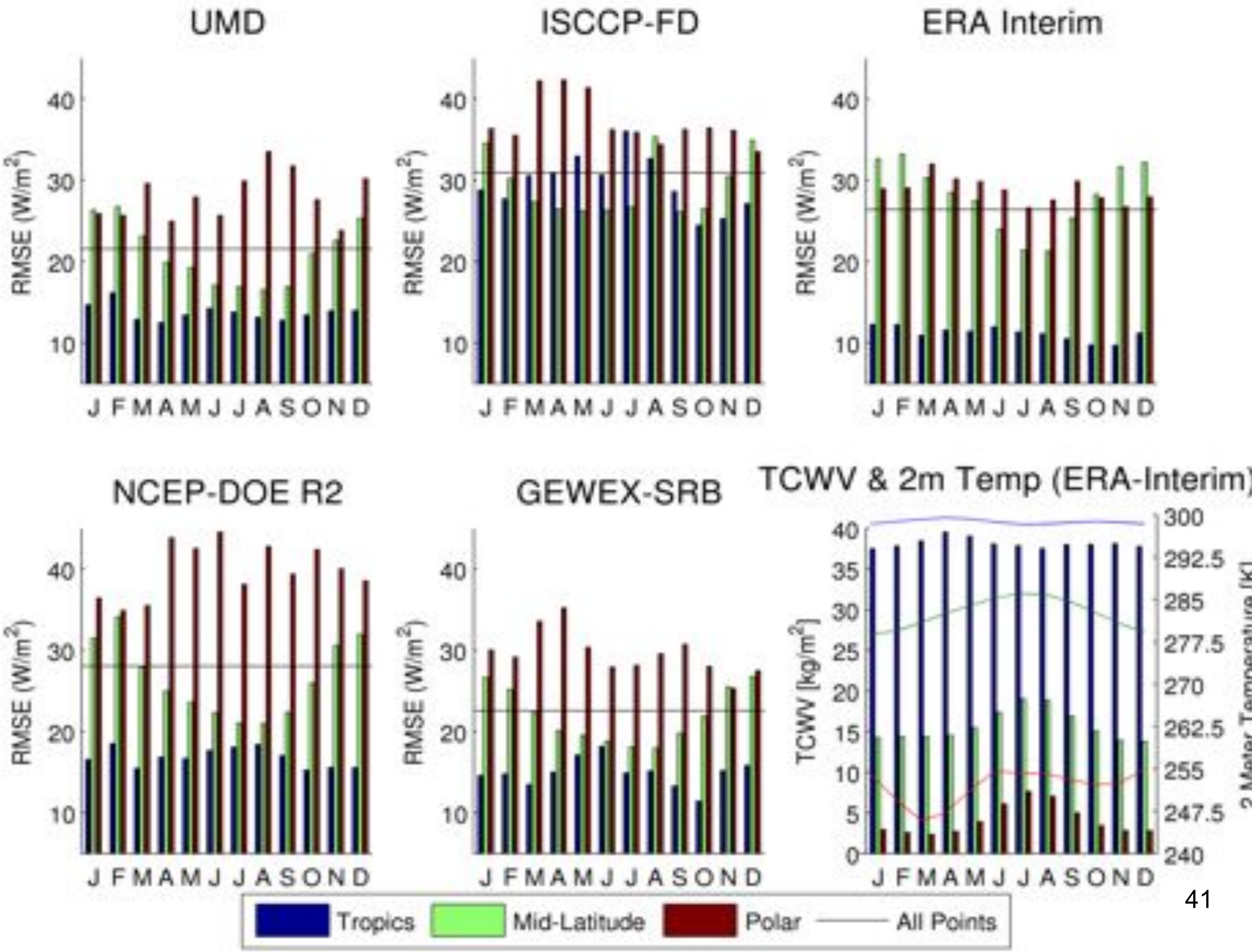
Surface instantaneous downward SW fluxes at 1^0 resolution Available for 2003-2006

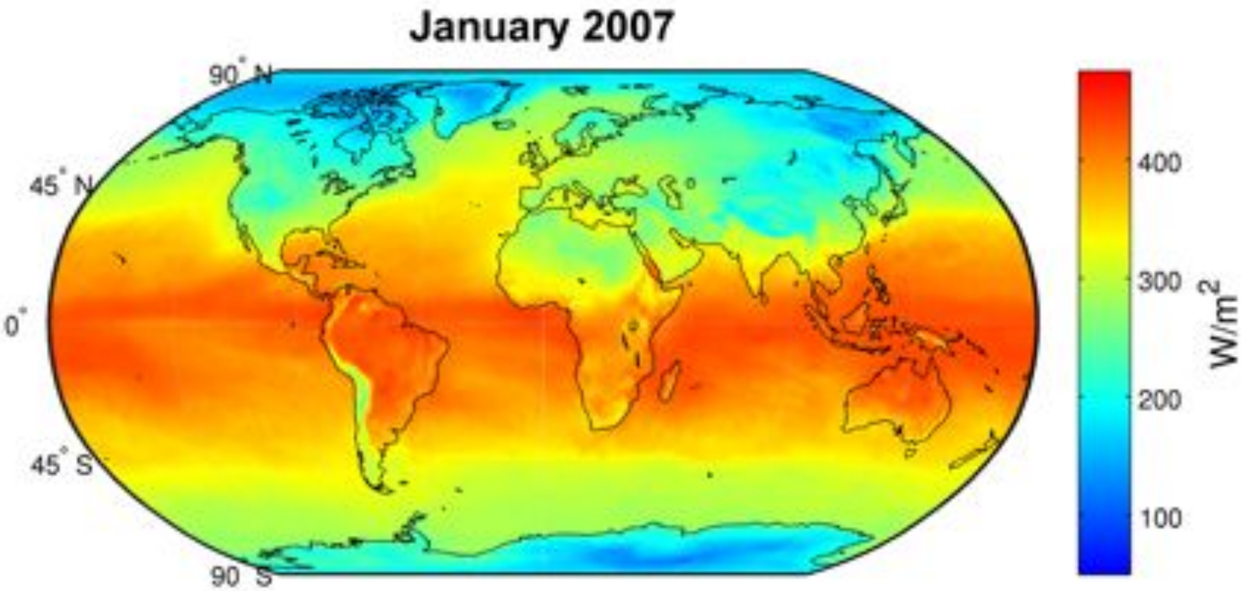
Longwave Fluxes



Satellite based estimates of daily DSLW from versus BSRN ground stations (18) for 2003-2007 (bias and rms W m^{-2}).

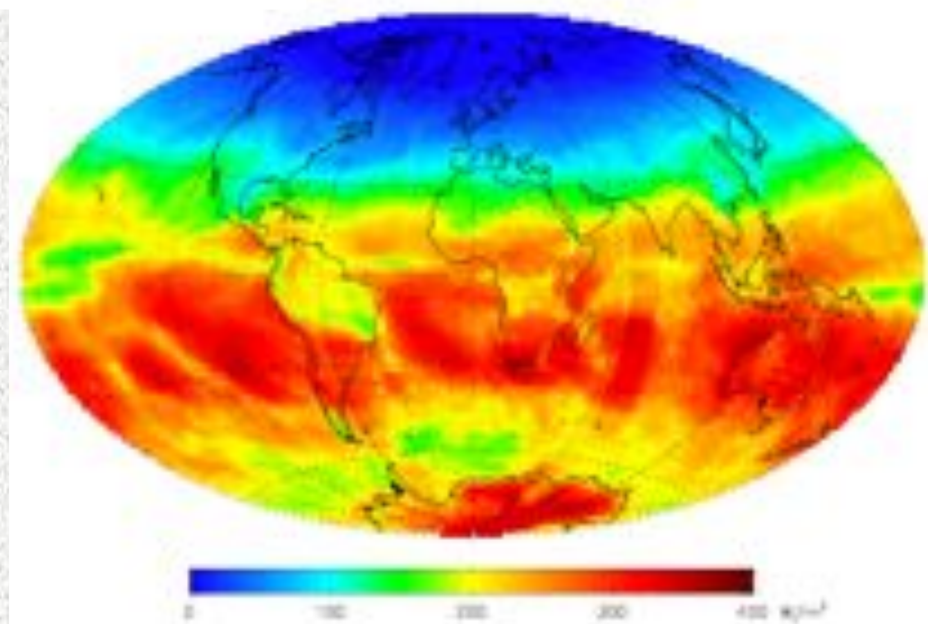
Nussbaumer, E. A., and R. T. Pinker, 2010. Estimating surface longwave radiative fluxes at global scale. *QJRMS,* In review.


UMD
ISCCP-FD
ERA Interim
NCEP-DOE R2
GEWEX-SRB
TCWV & 2m Temp (ERA-Interim)
RMSE (W/m2)
TCWV [kg/m2]
2 Meter Temperature [K]
J F M A M J J A S O N D
Tropics
Mid-Latitude
Polar
All Points



Surface LW from MODIS at 1^0

Available for about
10 years
At daily time scale
at 1^0 resolution

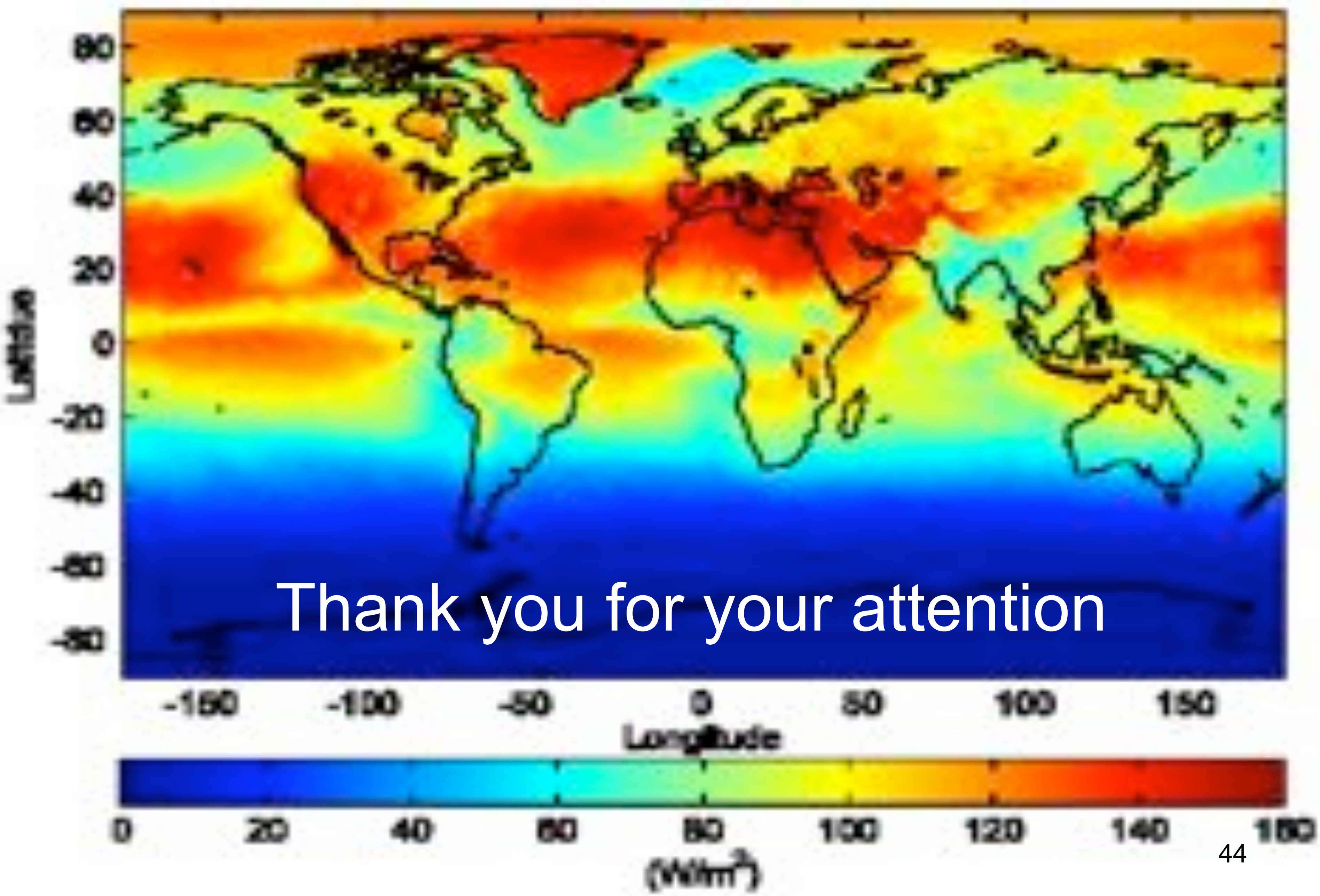


Surface SW from MODIS at 1^0

Summary

1. Surface radiative fluxes from MODIS very promising
2. The *high resolution* observations from MODIS open new possibilities for *scientific investigations*
3. The MODIS product could be used to calibrate longer time series from independent satellites *(like ISCCP)*
4. Updates of *MODIS products* could potentially result in *improved radiative fluxes.*

July mean PAR from MODIS averaged over 2003-2005



Thank you for your attention

The bars for each model represent the average value of RMSE (W/m^2) for each month for the combined years of 2003-2004.

The comparison is broken down into latitudinal regions: Tropical (blue), Mid-Latitude (green), and Polar (red). The black line is the mean RMSE of all ground stations for the entire period.

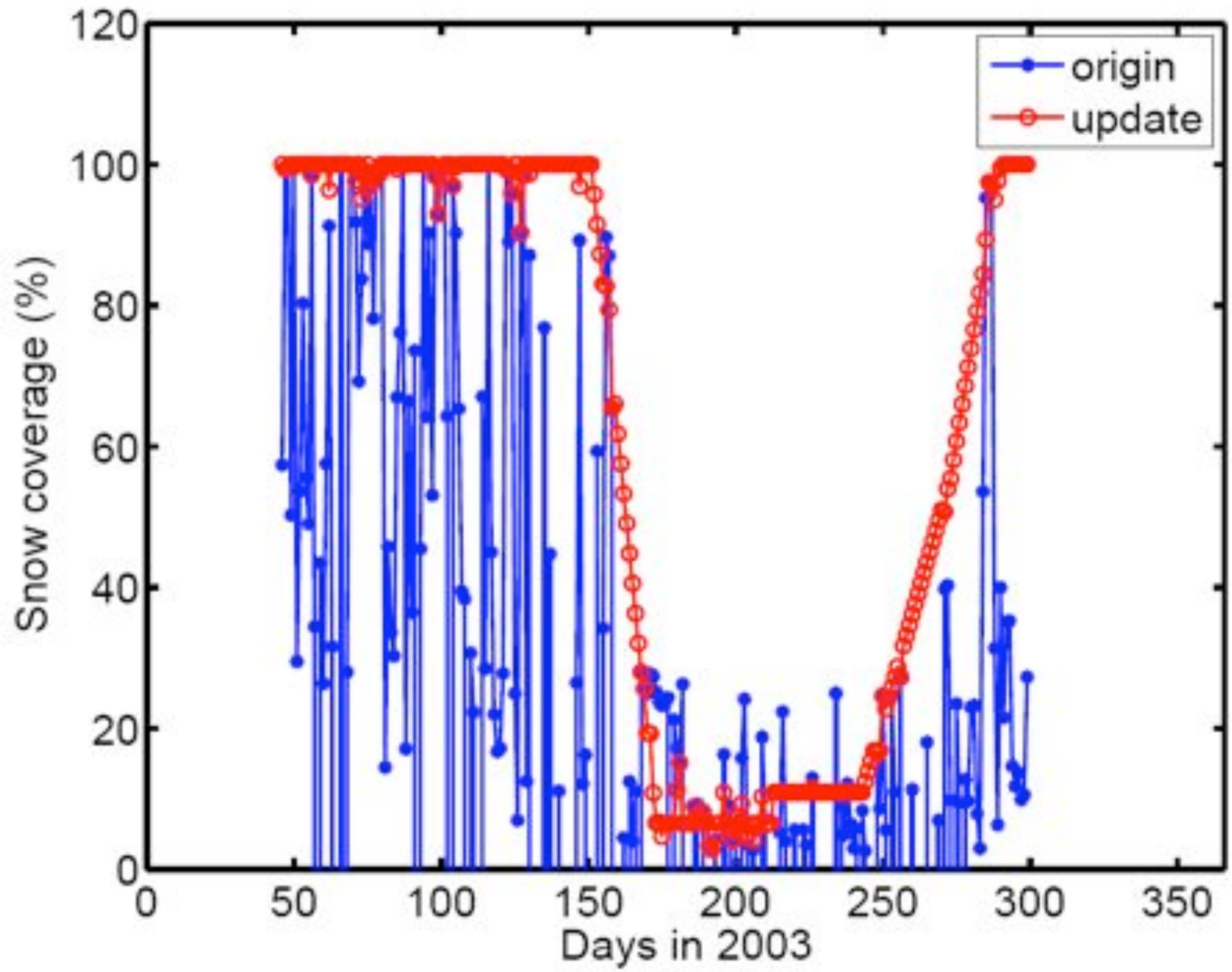
The last graph depicts the averaged total column water vapor (kg/m^2) derived from ERA Interim reanalysis broke down by month and region. The lines correspond to 2-meter surface temperature from ERA Interim reanalysis. The blue line represents the Tropical, green the Mid-Latitudes, and the red corresponds to the Polar Regions.

Evaluation of MODIS fluxes

January 1, 2003-December 31, 2005

- Tropical Atmosphere Ocean (TAO) Triangle Trans-Ocean Buoy Network (TRITON) Array: 33 buoys
- Pilot Research Moored Array in the Atlantic (PIRATA): 10 buoys
- Baseline Surface Radiation Network (BSRN): 18 sites over land
- **Observations of "opportunity"**

Updates on snow and ice coverage data



Fill the missing values in the daily snow cover or sea ice concentration by using the monthly mean values

Daily snow coverage data at Barrow, Alaska.

Topographic Effects

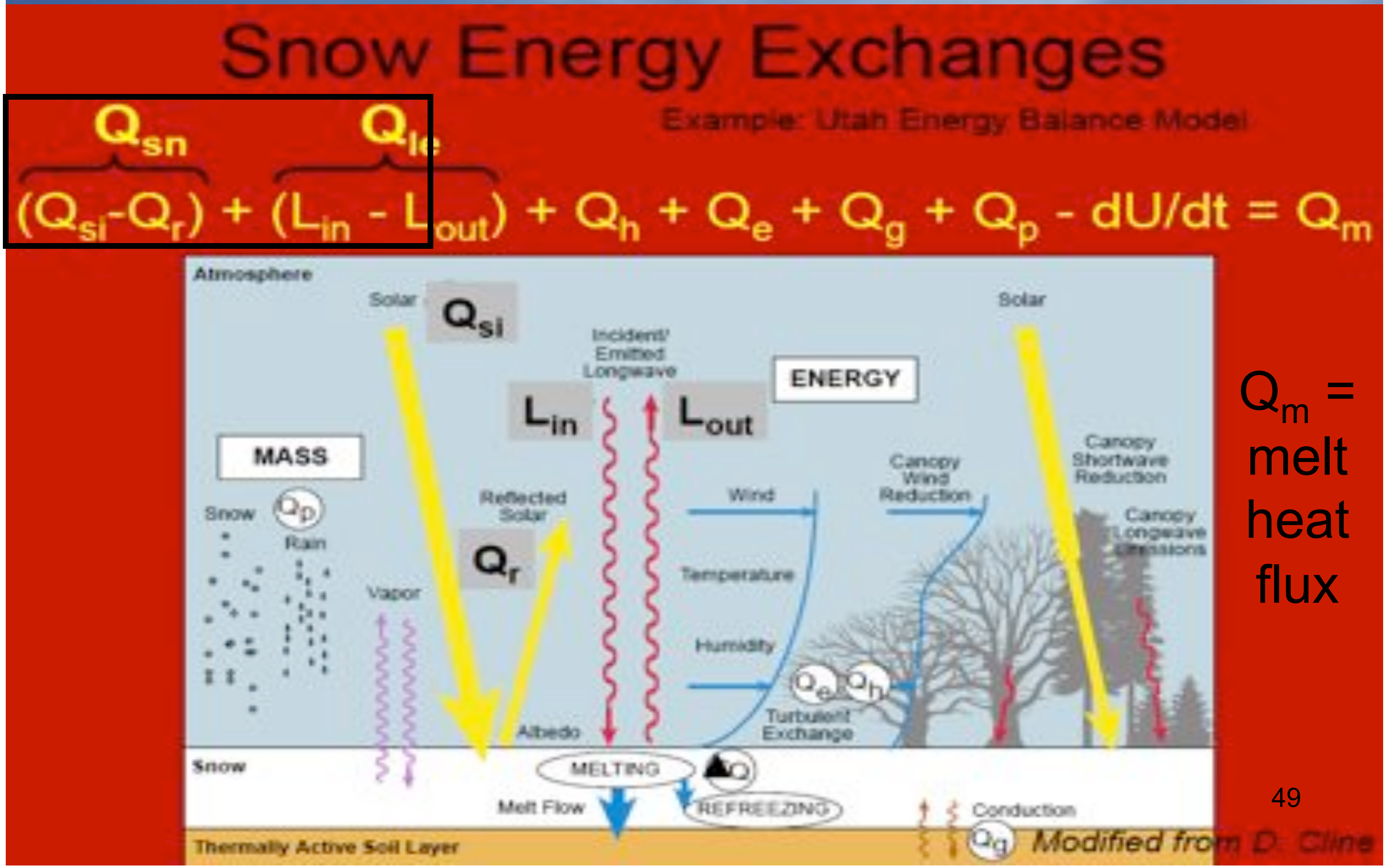
Accounting for topographic effects **on SW radiation is critical for accurate modeling of snowmelt in complex terrain.**

The *snowmelt models* to be used contain *procedures* to adjust estimated or explicitly provided surface fluxes for terrain slope and aspect.

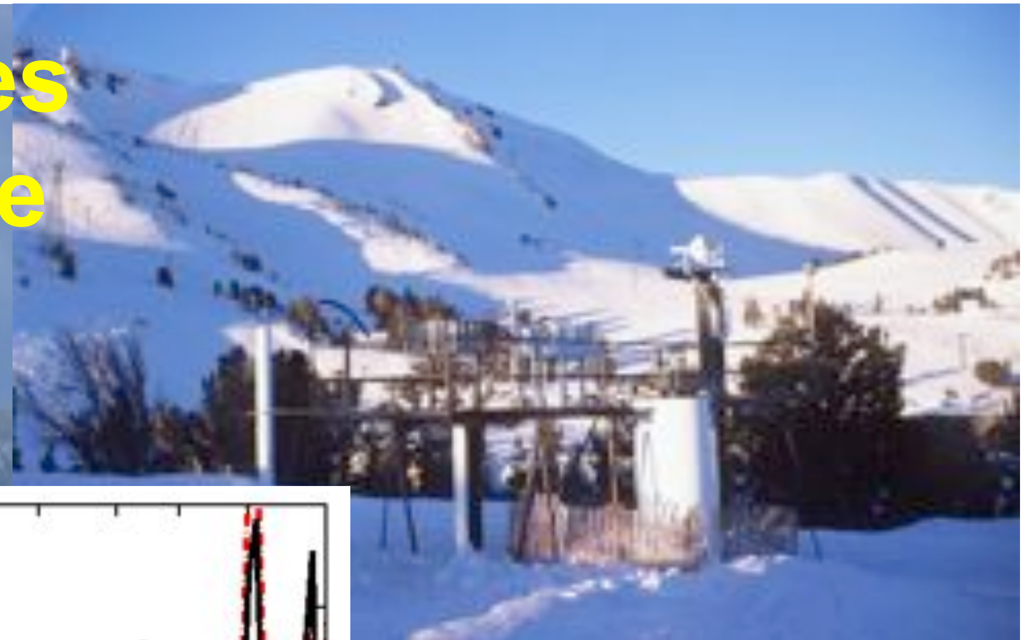
Plan: **use the method from the *Distributed Hydrology Soil Vegetation Model* (DHSVM) which creates monthly maps of terrain shadowing, to correct for the effect of nearby mountains on SW radiation.**

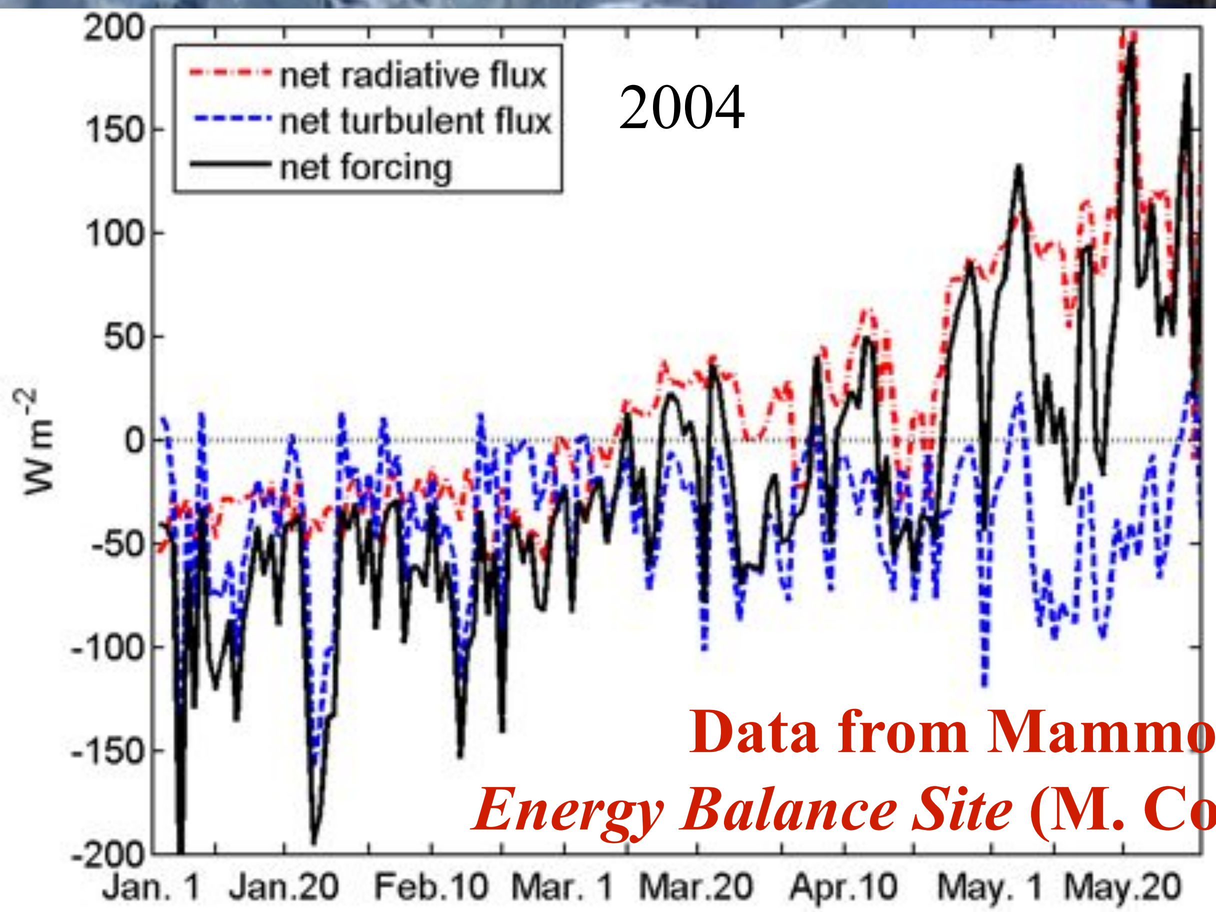
SW is divided into *direct* and *diffuse* components. Diffuse is distributed *uniformly* over the landscape, while direct **can be blocked by the surrounding *topographical features.***

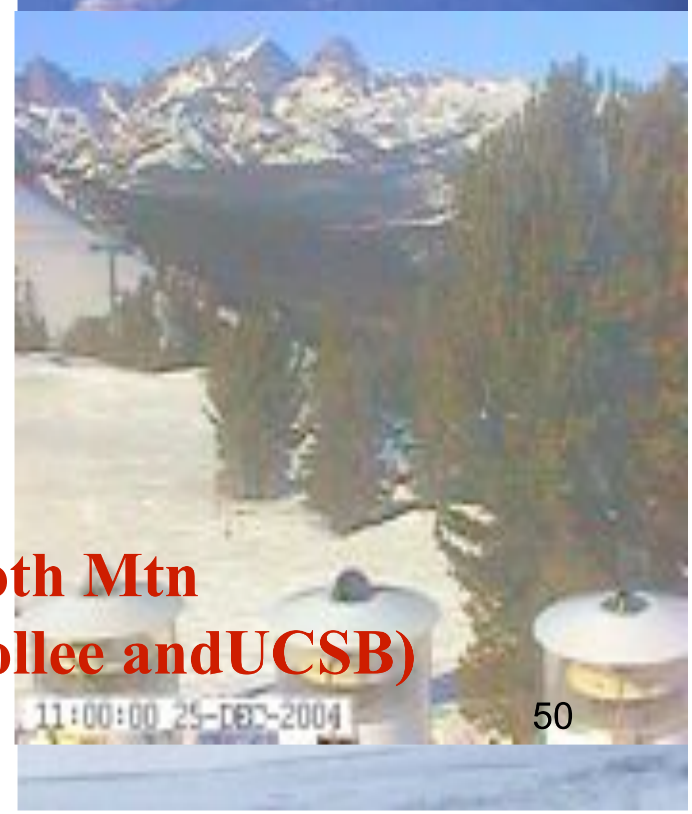
Energy balance modeling



Radiation dominates the energy balance Sierra Nevada

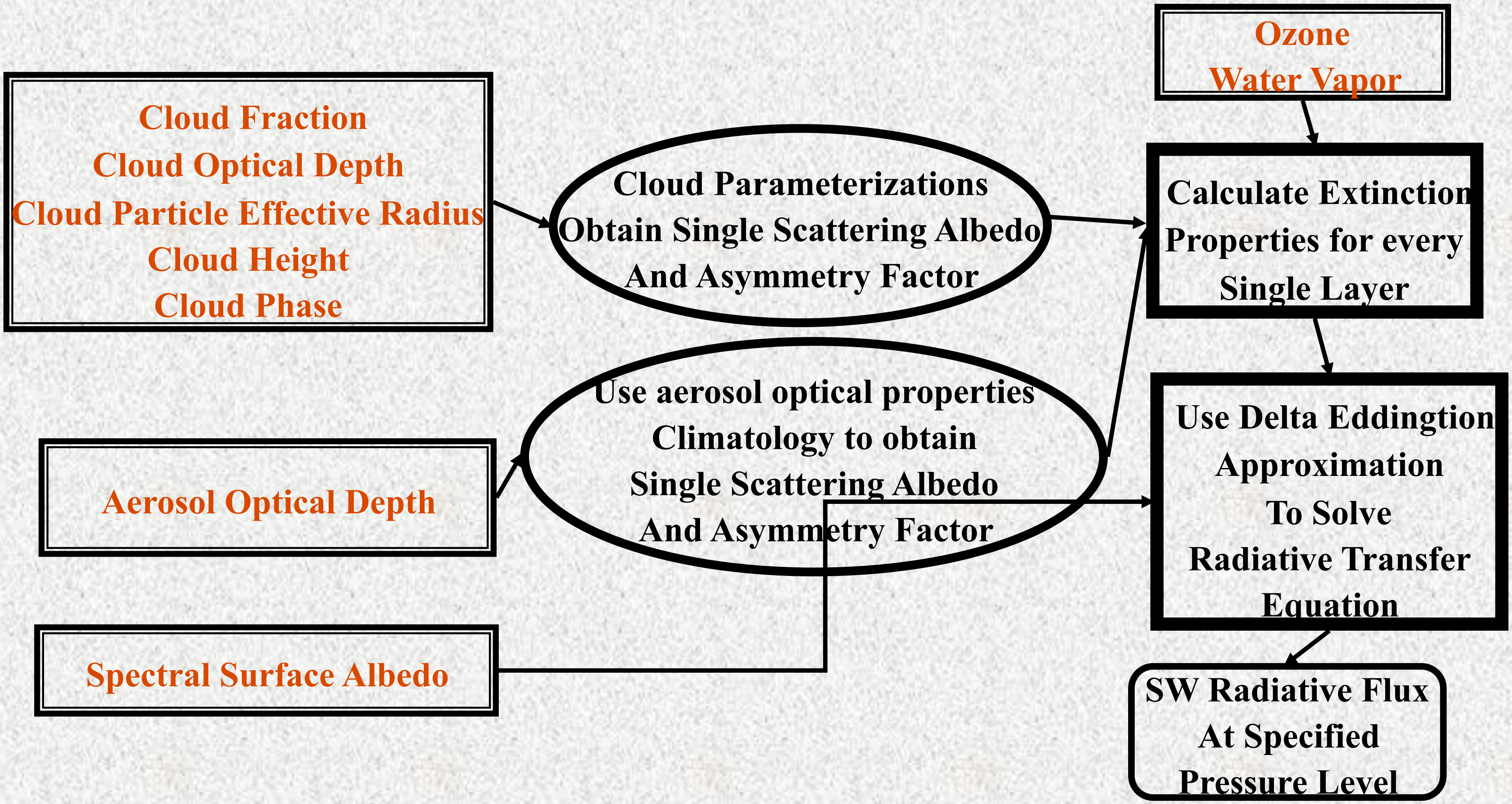






Data from Mammoth Mtn
***Energy Balance Site* (M. Collee andUCSB)**

Flowchart of New Inference Scheme



Changes in Solar Input to Polar Ice-ocean system

The areally averaged solar input to the ice-ocean system can be calculated as:

$$F(t) = F_s(t)\overline{\alpha}(t)$$

$$\overline{\alpha}(t) = \alpha_{ice}(t)A_{ice}(t) + \alpha_{ocean}A_{ocean}(t)$$

F : the solar input to ice-ocean system

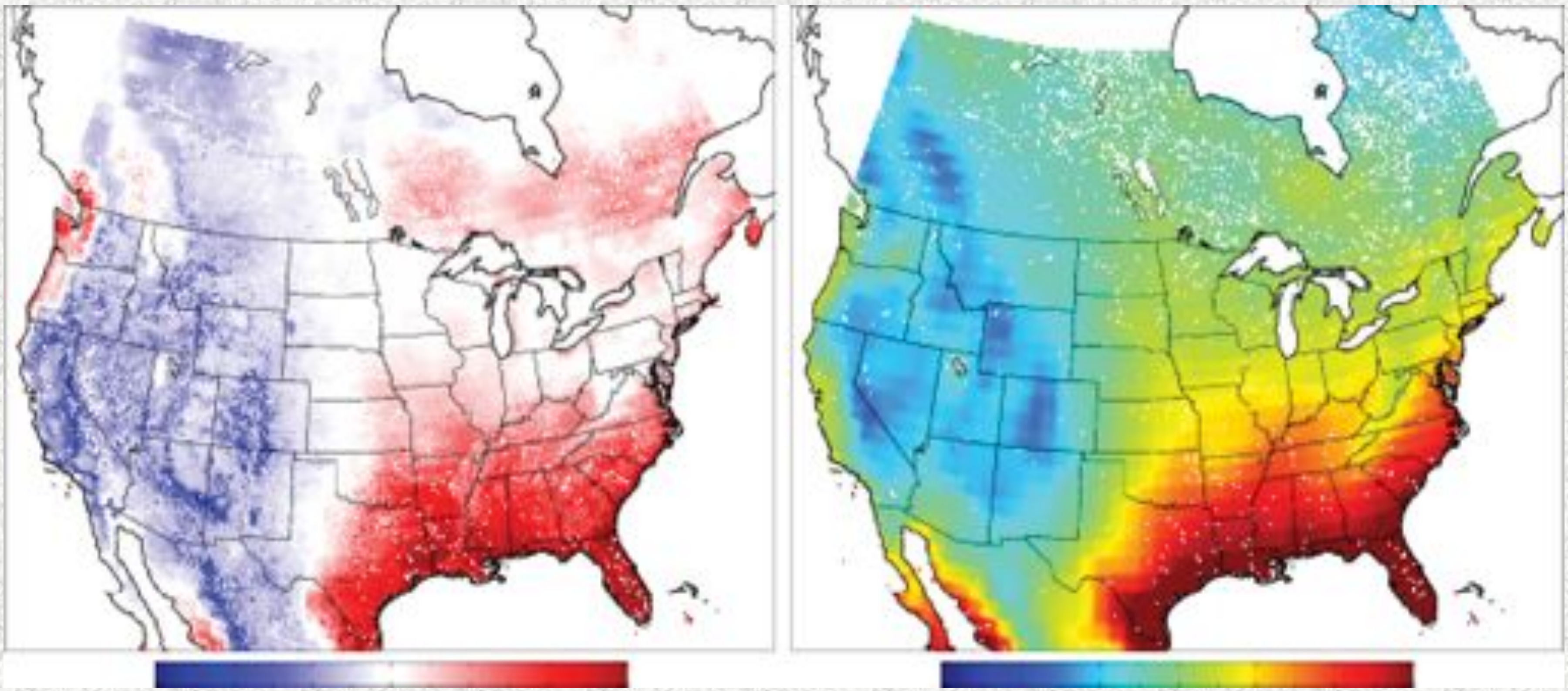
Fs : the surface solar irradiance

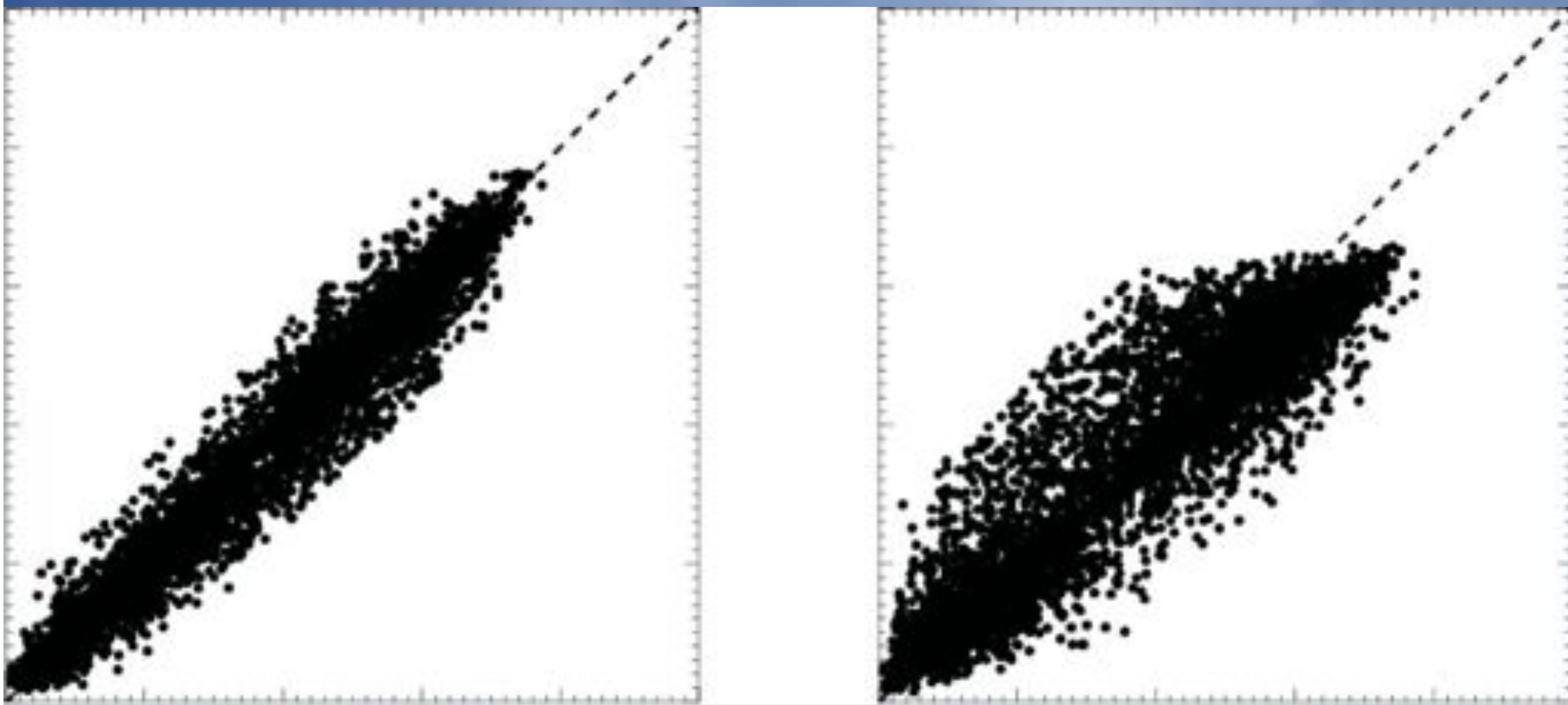
$\overline{\alpha}$: the areally averaged albedo

α_{ocean} : the albedo of ocean (~0.07)

Perovich et al. (2007)

(a) Difference between annual total NPP of the two runs (sensitivity minus control),
(b) the corresponding distribution of average precipitable water in the growing days (GPP . 0)
as derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) for the same
time period. Both figures are the average for years 2003–2005.





f daily mean surface downward shortwave (SW) values from (a) Global Modelling and Assimilation Office (GMAO) and (b) University of Maryland Shortwave Radiation Budget Moderate Resolution Imaging Spectroradiometer (UMD/SRB_MODIS) models against ground measurements at six Surface Radiation Network (SURFRAD) sites for 2003–2005. Pinker,. , Zhao,, Wang, and Wood (2010) 'Impact of satellite based PAR on estimates of terrestrial net primary productivity', International Journal of Remote Sensing, 31: 19, 5221 -5237

At Issue:

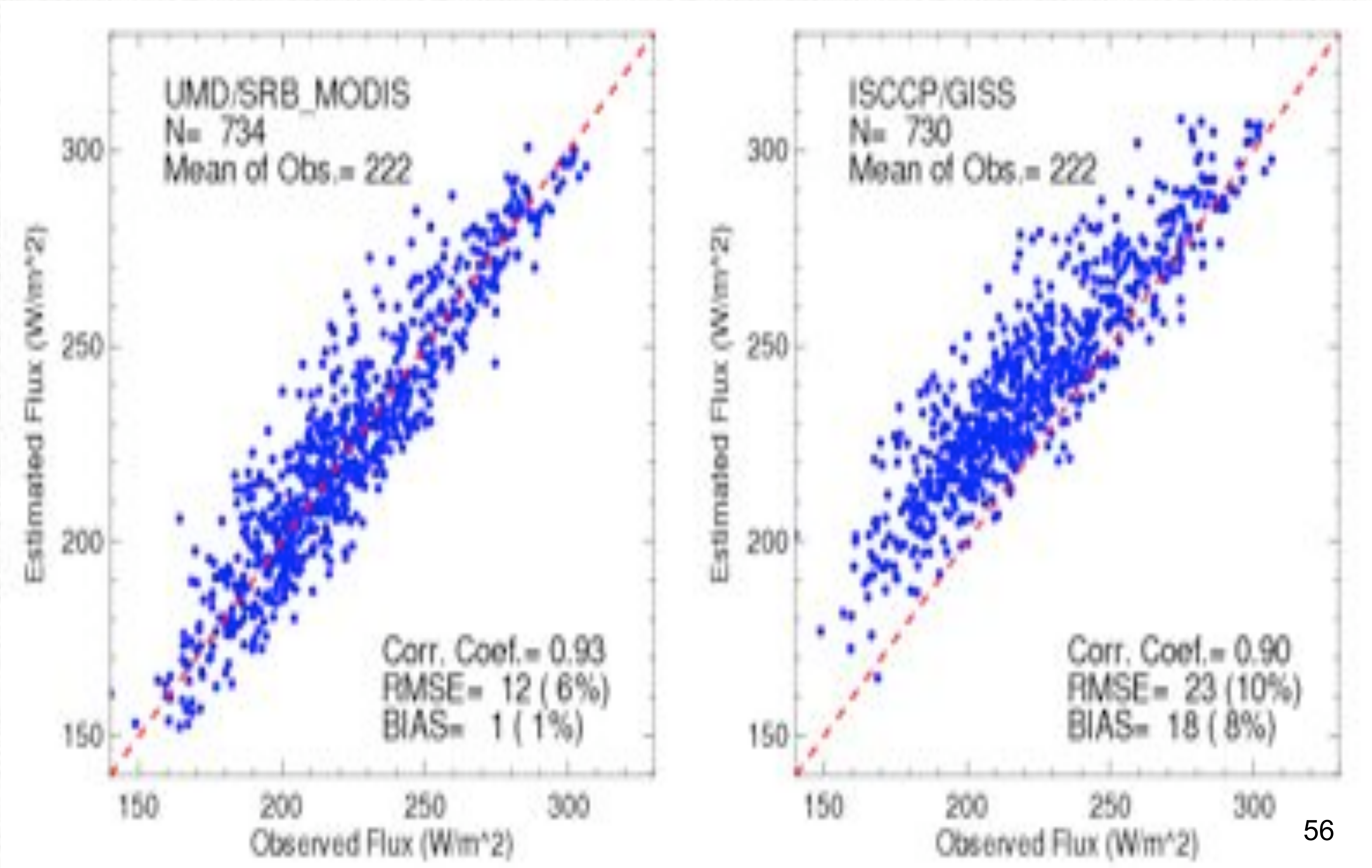
- Snowmelt supplies as much as *75% of surface water in basins* of the western United States.
- Future global *climate model simulations* show continued *loss of snowpack* as much as 70% by mid-21st century.
- The *greatest potential sources of error* in simulating snowmelt rates and timing are *inaccurate shortwave and longwave radiative* inputs.

<u>Objective of Project</u>

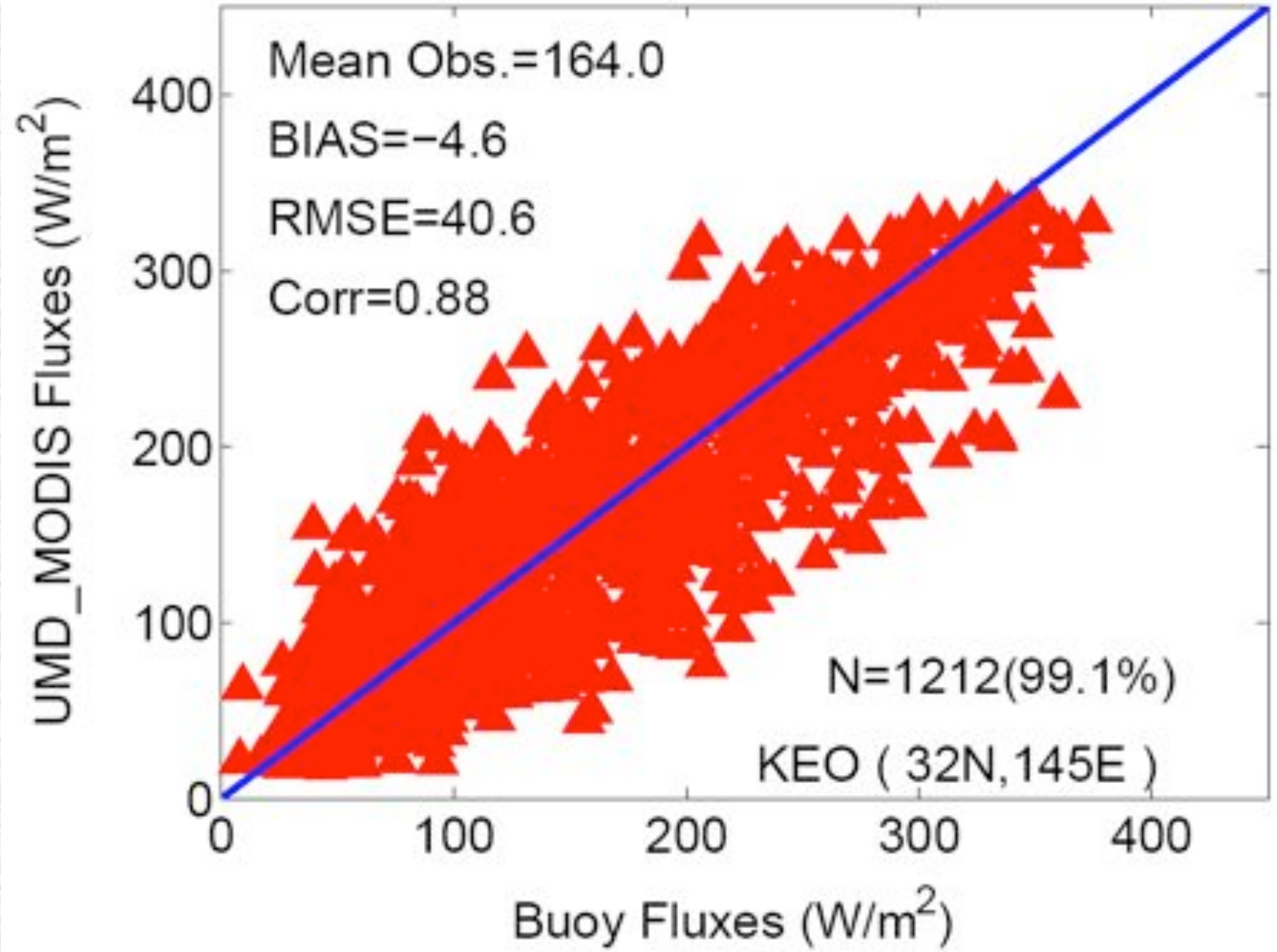
Evaluate benefit of high resolution radiative fluxes from satellites, primarily Terra and Aqua *for snowmelt modeling in complex terrain.*

Monthly mean surface SW flux estimated by UMD/SRB_MODIS and ISCCP-FD against PIRATA and TAO/TRITON buoys

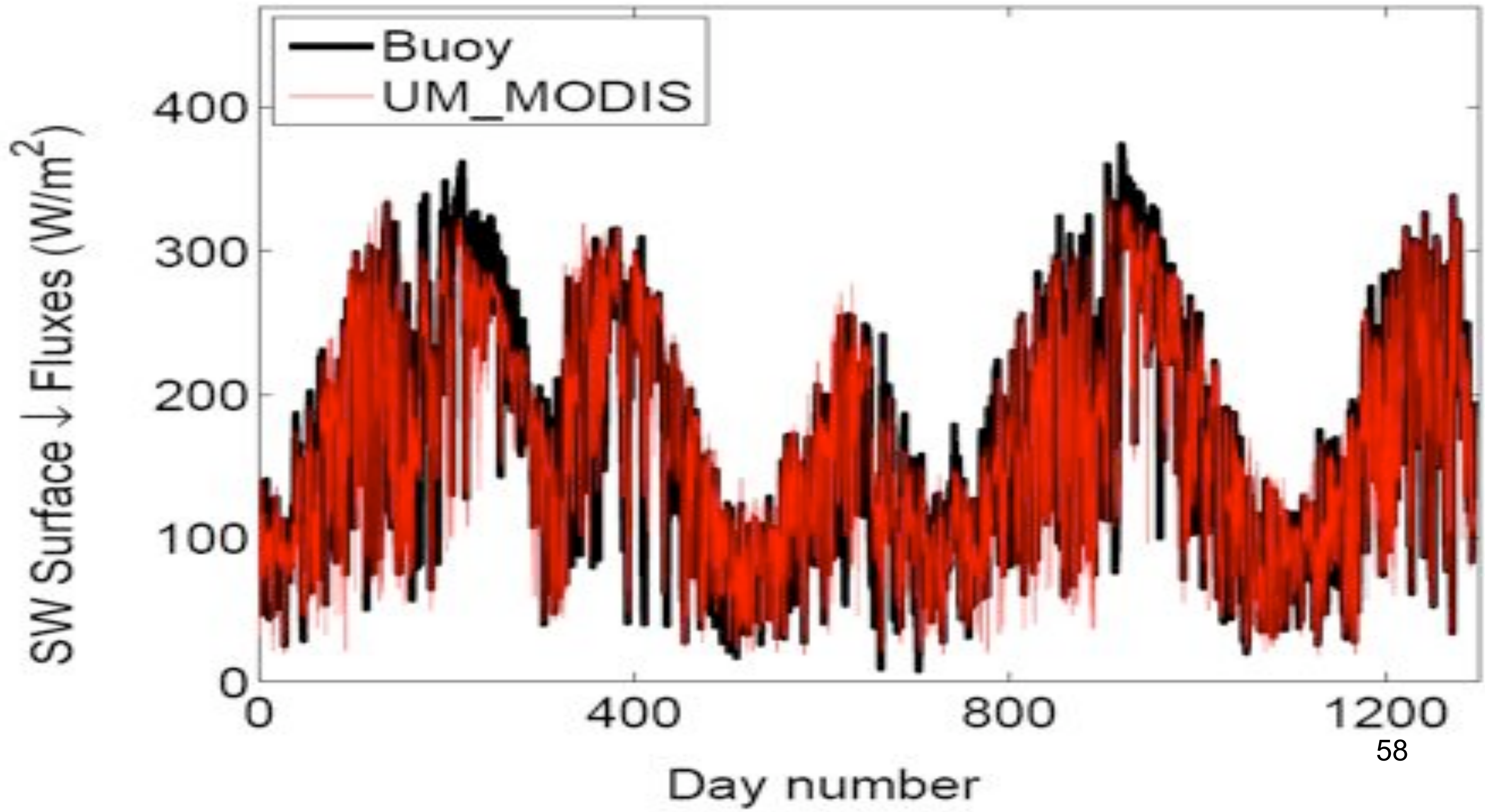
Cases eliminated: 1.3% (UMD/SRB_MODIS; 1.9% (ISCCP-FD)



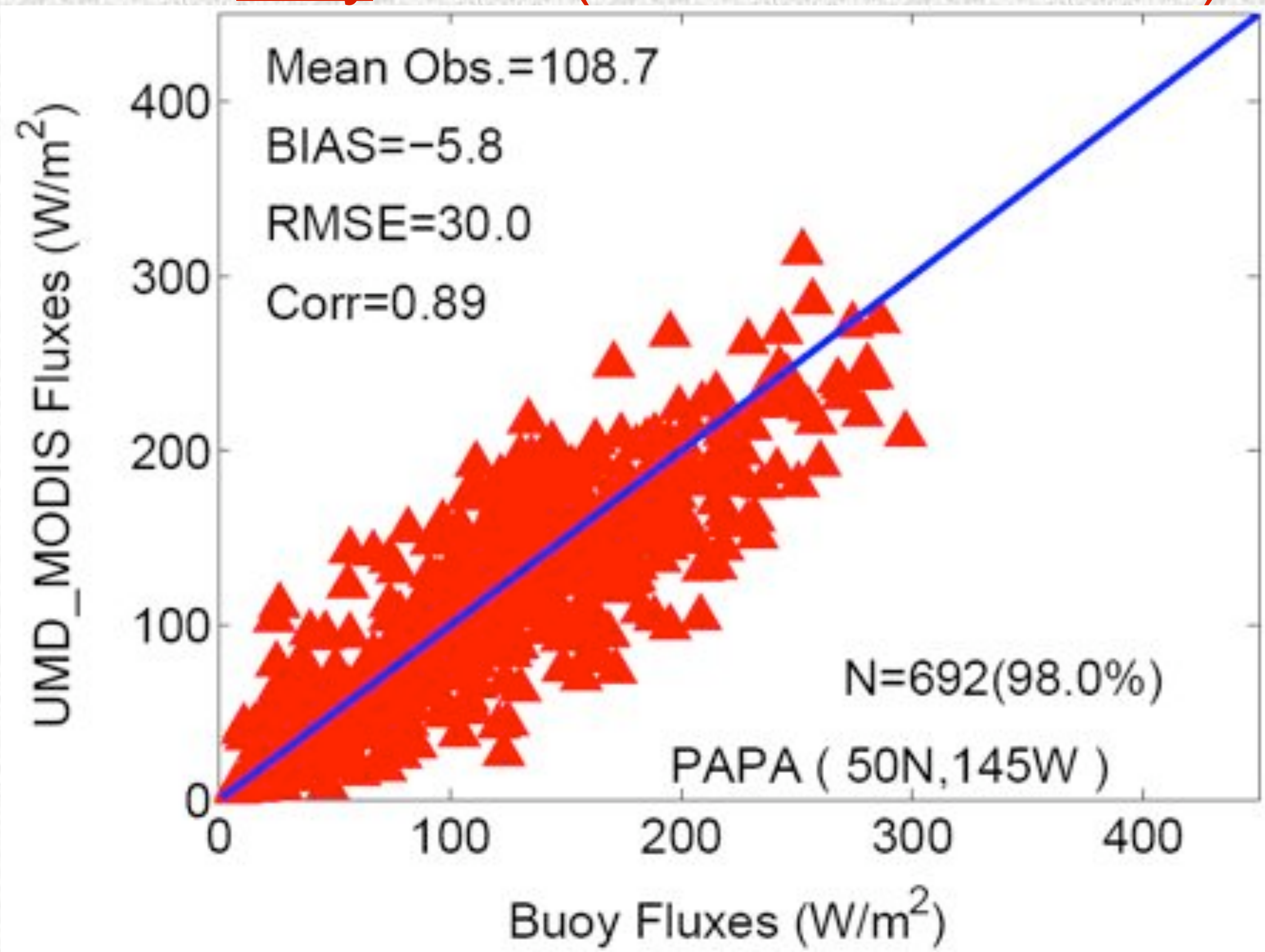
Evaluations at KEO buoy (32^0N, 145^0E) for period (May 1~ Nov. 9, 2005; May 27, 2006 ~ Apr. 16, 2007; Sep. 26, 2007 ~ June 29, 2009; Sep. 6 ~ 18, 2009) at daily scale (eliminate 3-SD data)



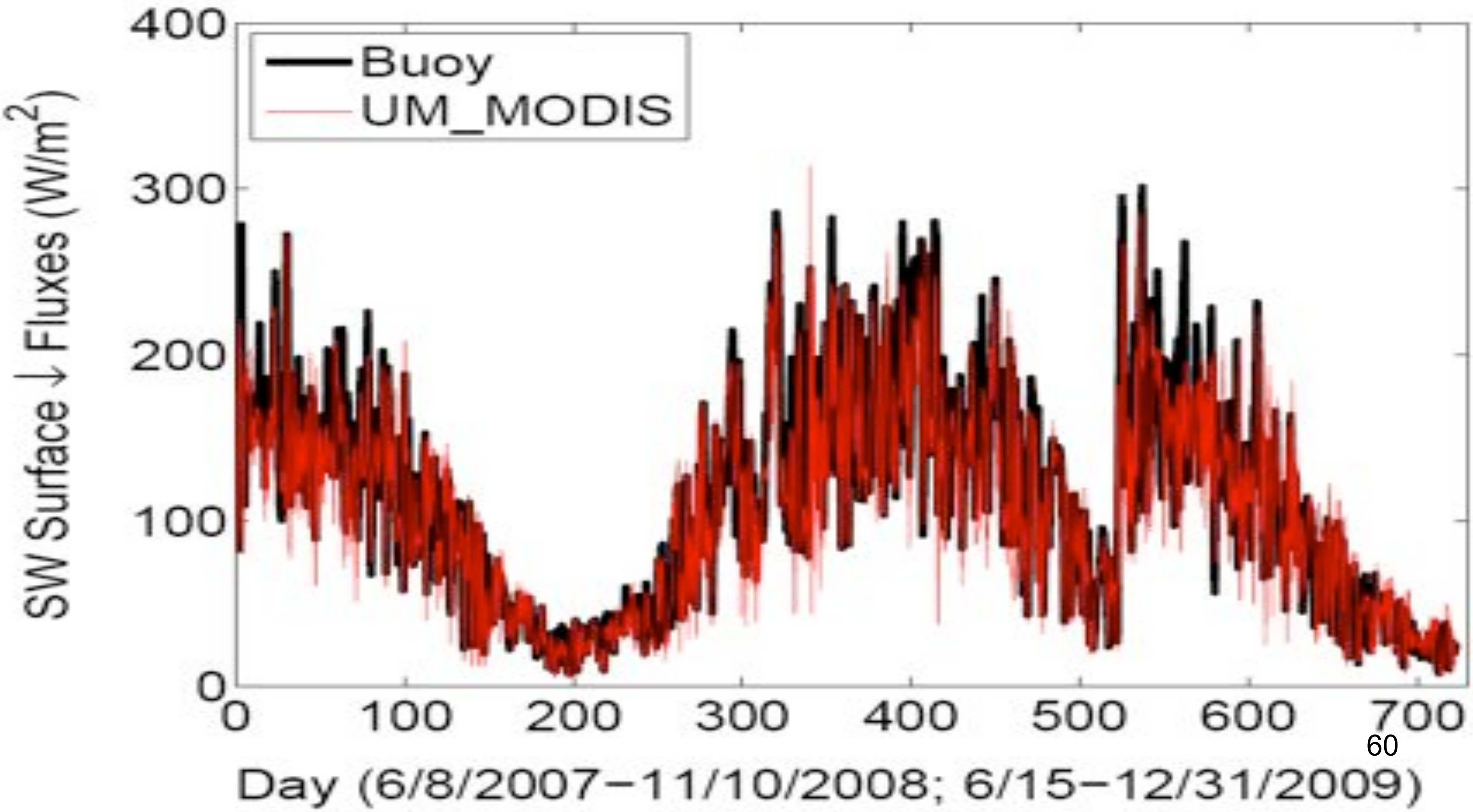
Time series of daily averaged SW fluxes at KEO buoy (32^0N, 145^0E) (May 1~ Nov. 9, 2005; May 27, 2006 ~ Apr. 16, 2007; Sep. 26, 2007 ~ June 29, 2009; Sep. 6 ~ 18, 2009)



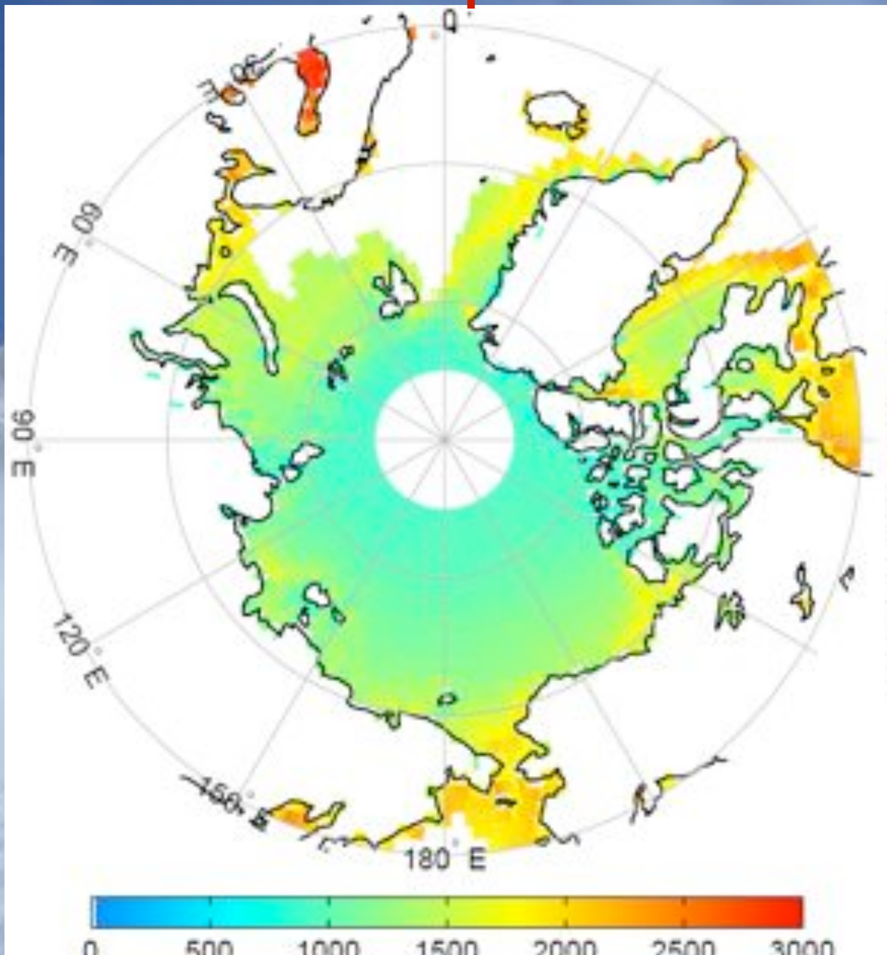
Evaluations at PAPA buoy (50^0N, 145^0W) for period (June 8 , 2007 ~ Nov. 10, 2008; June 15 ~ Dec. 31, 2009) at daily scale (eliminate 3-SD data)

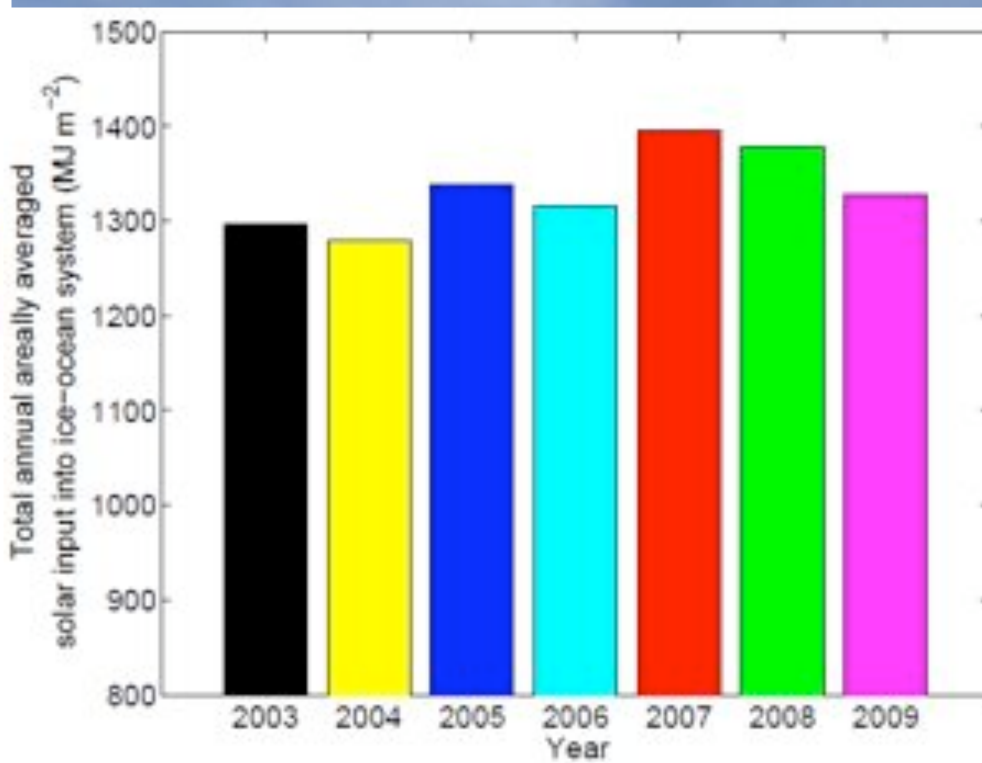


Time series of daily averaged SW fluxes at PAPA buoy (50^0N, 145^0W) (June 8 , 2007 ~ Nov. 10, 2008; June 15 ~ Dec. 31, 2009)



Solar input into Arctic ice-ocean system





Mean total annual solar heat input to Arctic (60°N-90°N) ice-ocean system averaged over 2003-2009 (Apr. – Sep.) (units are in MJ m^{-2}).

Total annual areally averaged solar input into ice-ocean system (60°N-90°N)