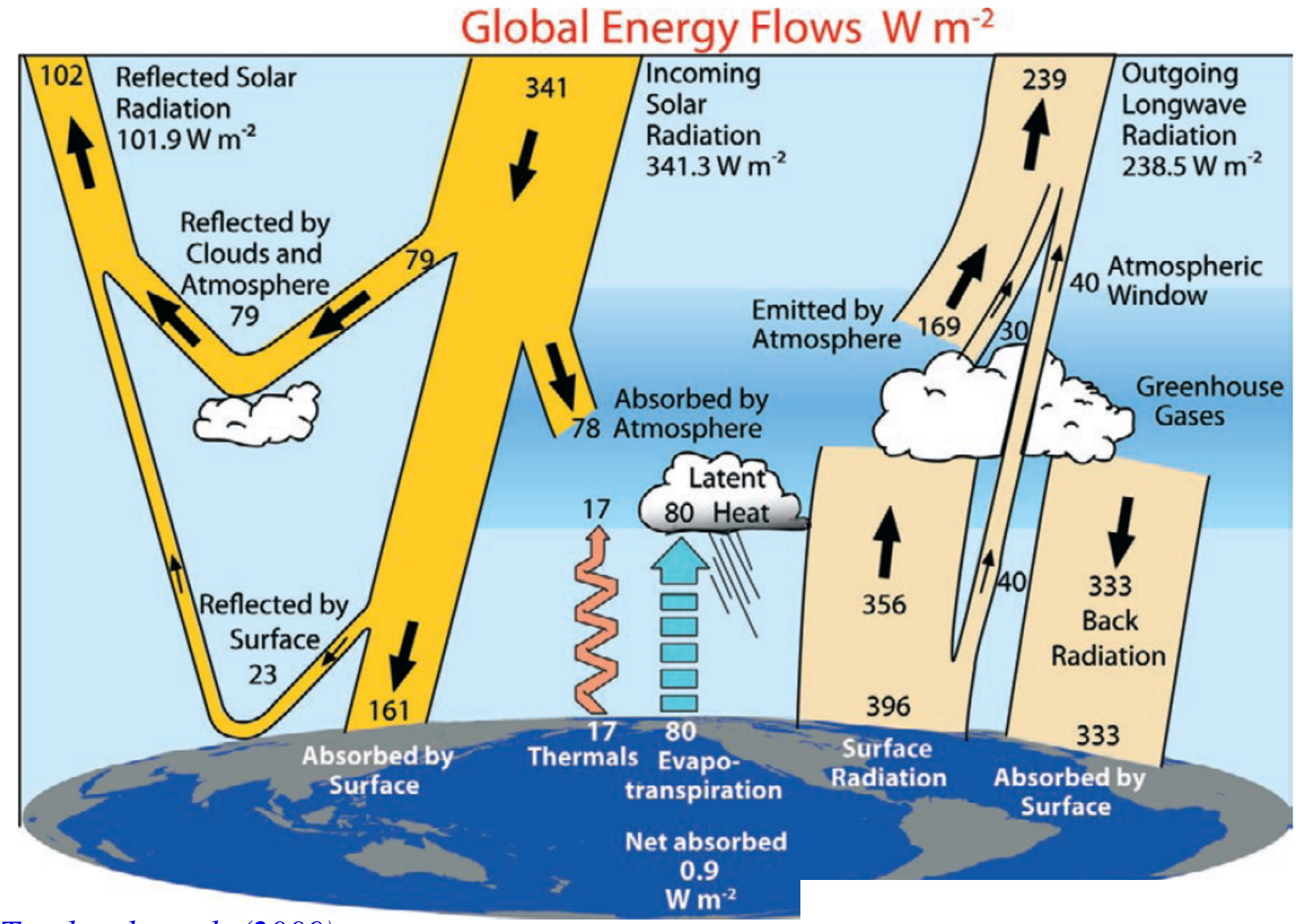
Producing Incident Shortwave Radiation and Photosynthetically Active Radiation Products Over Land Surfaces from MODIS Data

Drs. Dongdong Wang, Tao He
Yi Zhang, Meredith Brown
Prof. Shunlin Liang
University of Maryland
June 8 2016



Trenberth et al. (2009)

Need for high spatial resolution products

- Current global radiation products have coarse spatial resolution (>1°) primarily for atmospheric modeling, and do not account for many local features, such as urbanization.
- Land applications require the high spatial resolution (~1km) but the reasonable temporal resolution (e.g., daily):
  - Ecosystem modeling (say, MOD17 NPP product) requires high-resolution products of PAR(1km);
  - Hydrological modeling (ET, MOD16) at 1km;
  - Other applications (e.g., drought monitoring, clean renewable solar energy).

Incident shortwave radiation and PAR products

Current global incident **shortwave radiation** satellite products

Insolation products	Spatial resolution	Temporal resolution	Temporal range
ISCCP	280km	3-hour	1983-2008
GEWEX-SRB	1°	3-hour	1983-2007
CERES	1°	3-hour	1997-present

WMO requirements for surface downward shortwave irradiance

	Uncertainty goal (Wm^{-2})	Uncertainty threshold (Wm^{-2})	Horizontal resolution goal (km)	Horizontal resolution Threshold (km)
Global NWP	1	20	10	100
Agricultural Meteorology	N/A	N/A	1	20
Climate-AOPC	5	10	25	100

Accuracy of current data sets of incident shortwave radiation

R^2, Bias, Relative Bias of Satellite Products, STD and Relative STD of the Differences Between Observed and Satellite Surface Downwelling Shortwave Irradiance (Wm^{-2}) at All Sites From 2000–2002

Sites	GEWEX-SRB(AllSky2000-2002)			ISCCP-FD (AllSky2000-2002)			CERES-FSW(AllSky2000-2002)		
	R^2	Bias[a] (%)[b]	STD (%)	R^2	Bias (%)	STD (%)	R^2	Bias (%)	STD (%)
North America									
Bondville	0.91	-6.7(-2.1%)	78.0(25%)	0.89	-12.5(-4%)	83.7(27%)	0.85	14.0(2.7%)	103.2(20%)
Boulder	0.84	-13.5(-4.0%)	107.4(32%)	0.85	-1.9(-0.6%)	106.7(32%)	0.64	9.0(1.5%)	157.0(26%)
Desert_Rock	0.94	-14.2(-3.4%)	74.8(18%)	0.96	-16.2(-3.9%)	62.2(15%)	0.87	20.3(2.9%)	82.0(12%)
Fort_Peck	0.92	-14.6(-5.0%)	70.2(24%)	0.88	-6.5(-2.2%)	84.1(29%)	0.88	18.9(3.8%)	87.9(18%)
Goodwin	0.95	-0.6(-0.2%)	62.5(19%)	0.88	-1.3(-0.4%)	94.5(28%)	0.89	33.9(6.1%)	87.2(16%)
Penn_State	0.92	-0.6(-0.2%)	69.4(24%)	0.90	2.0(0.7%)	78.6(27%)	0.87	37.9(7.8%)	98.7(20%)
Mean	0.91	-8.4(-2.5%)	77.1(24%)	0.89	-6.1(-1.7%)	85.0(26%)	0.83	22.3(4.1%)	102.7(19%)
Tibetan Plateau									
Amdo	0.84	-1.8(-0.5%)	116.9(31%)	0.80	-20.6(-5.4%)	128.5(34%)	0.35	46.5(6.7%)	165.9(24%)
D66	0.87	15.9(4.8%)	88.8(27%)	0.88	24.7(7.5%)	87.7(27%)	0.57	74.9(13.0%)	124.7(22%)
D110	0.85	-44.6(-10%)	131.0(30%)	0.87	-52(-12.1%)	122.8(29%)	0.21	-58.7(-6.8%)	273.9(32%)
Naqu	0.83	-18.0(-4.7%)	125.2(32%)	0.84	-25.9(-6.7%)	121.7(31%)	0.25	10.0(1.4%)	220.6(31%)
Toutouhe	0.86	-18.5(-4.9%)	107.3(29%)	0.86	-15.1(-4.0%)	110.7(30%)	0.36	40.3(6.0%)	189.0(28%)
Mean	0.85	-13.4(-3.1%)	113.8(30%)	0.85	-18.0(-4.1%)	114.4(30%)	0.35	22.6(4.1%)	194.8(27%)
Southeast Asia									
Sukothai	0.80	-90.2(-22%)	153.8(38%)	0.83	-38.9(-9.7%)	138.1(34%)	0.40	-118.8(-15%)	204.9(26%)
TakEgat	0.71	8.2(2.6%)	147.1(47%)	0.77	77.1(24.6%)	141.6(45%)	0.42	107.0(19%)	161.3(28%)
Kogma	0.74	45.8(14.7%)	139.6(45%)	0.77	69.4(23.0%)	137.6(46%)	0.46	125.1(22%)	170.0(30%)
Bukit	0.72	43.4(12.8%)	122.5(36%)	0.68	108.7(32%)	146.1(43%)	0.44	107.5(20%)	161.5(30%)
Palangkaraya	0.79	20.5(5.3%)	113.9(29%)	0.78	65.6(17.1%)	123.0(32%)	0.64	130.7(24%)	110.4(20%)
Sakaerat	0.80	19.0(5.2%)	116.7(32%)	0.81	71.6(19.4%)	119.3(32%)	0.48	83.8(13.5%)	157.0(25%)
Mean	0.76	7.8(3.1%)	132.3(38%)	0.77	58.9(17.7%)	134.3(39%)	0.47	72.6(13.9%)	160.9(27%)

Gui, S., S. Liang, K. Wang, and L. Li, (2010), Validation of Three Satellite-Estimated Land Surface Downward Shortwave Radiation Datasets, *IEEE Geoscience and Remote Sensing Letters*,7(4):776-780

Objective and major tasks

Objective: to produce global high-resolution (5km, 3-hours) incident shortwave radiation and PAR over land surfaces from Terra/Aqua MODIS and a series of geostationary satellite data.

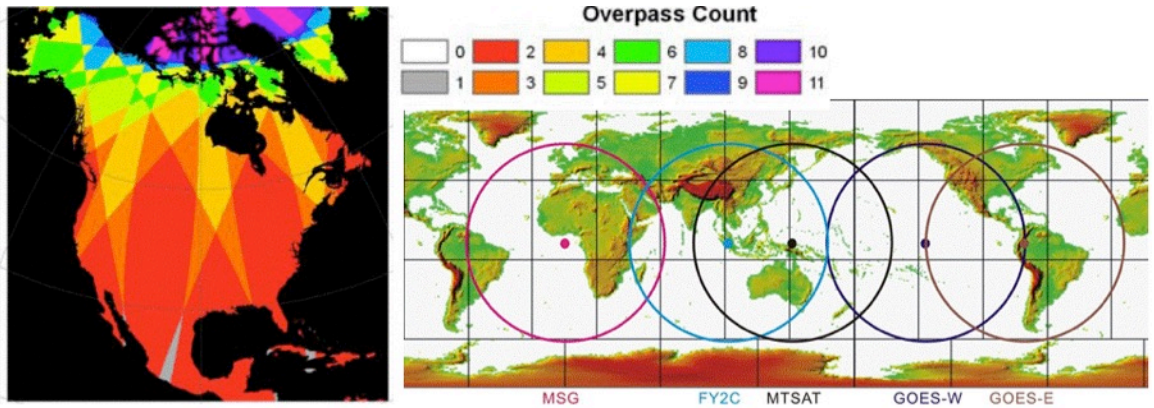
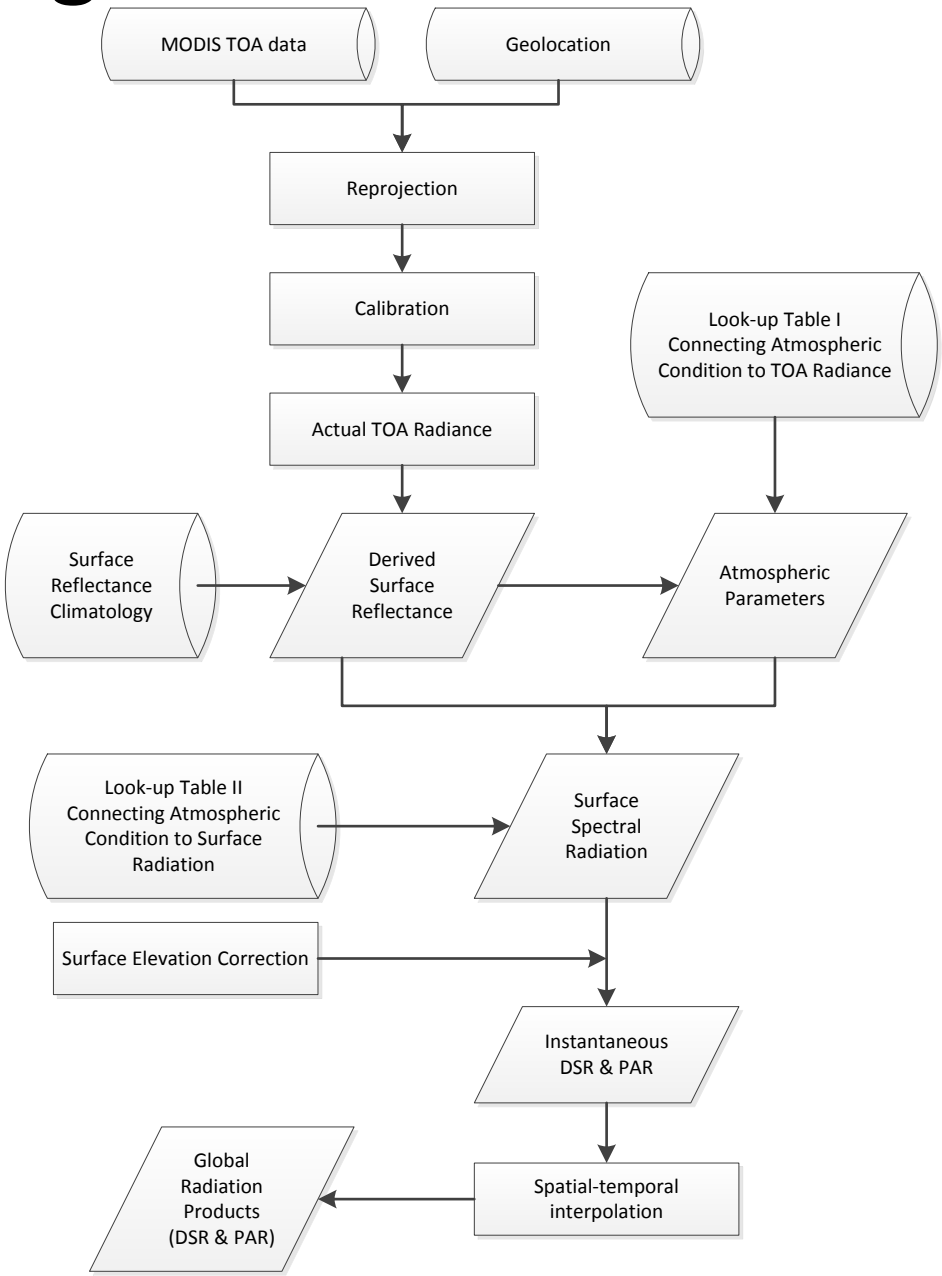


Figure. Daytime MODIS overpass counts from both Terra and Aqua and coverage of the current geostationary satellites.

Major tasks:

1. ATBD improvement and code delivery
2. Evaluation of sensor radiometric calibration
3. Algorithm validation
4. Product quality assessment
5. Product validation
6. Outreach and product advertisement

Algorithms for retrieving PAR and insolation

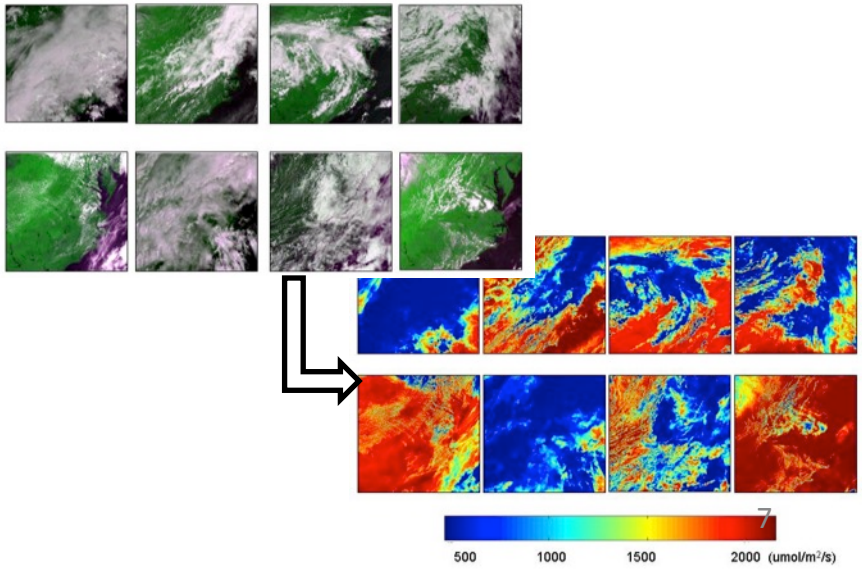


Fast, robust and **mature** LUT based approach.

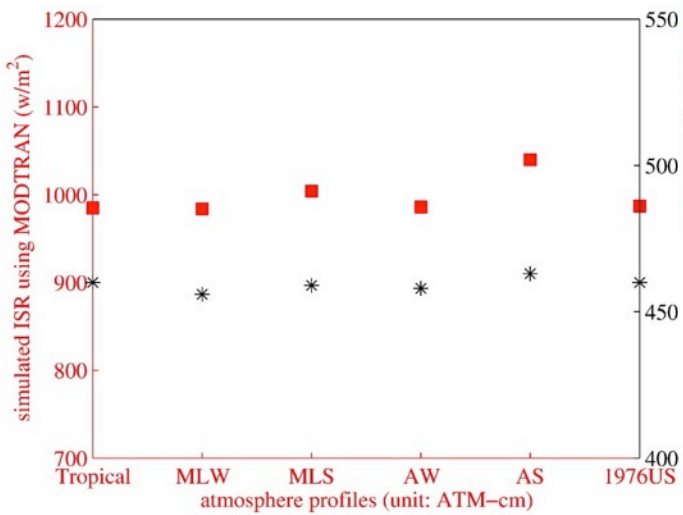
The basic procedure is composed of two steps:

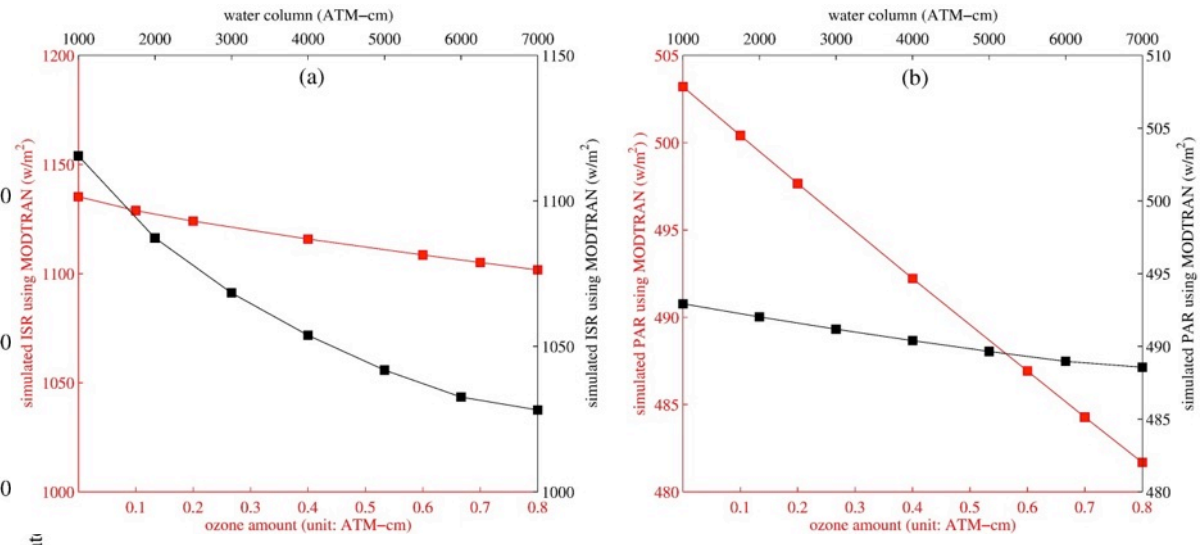
(1) determination of atmospheric parameters by matching observed radiance with modeled ones from the first LUT;

(2) calculation of incident PAR from the determined surface reflectance and TOA radiance/reflectance using the second LUT.



Sensitivity study of the algorithm

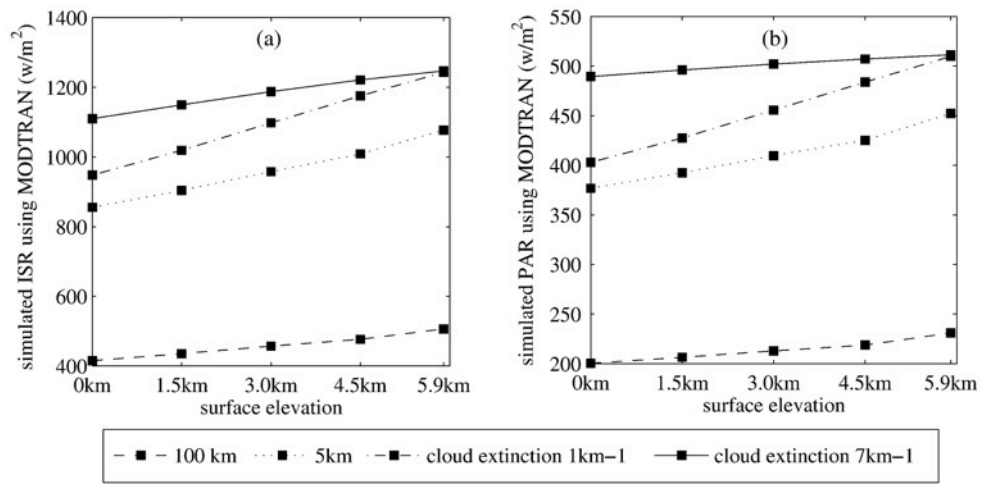




Water vapor and ozone concentration

Atmosphere profile

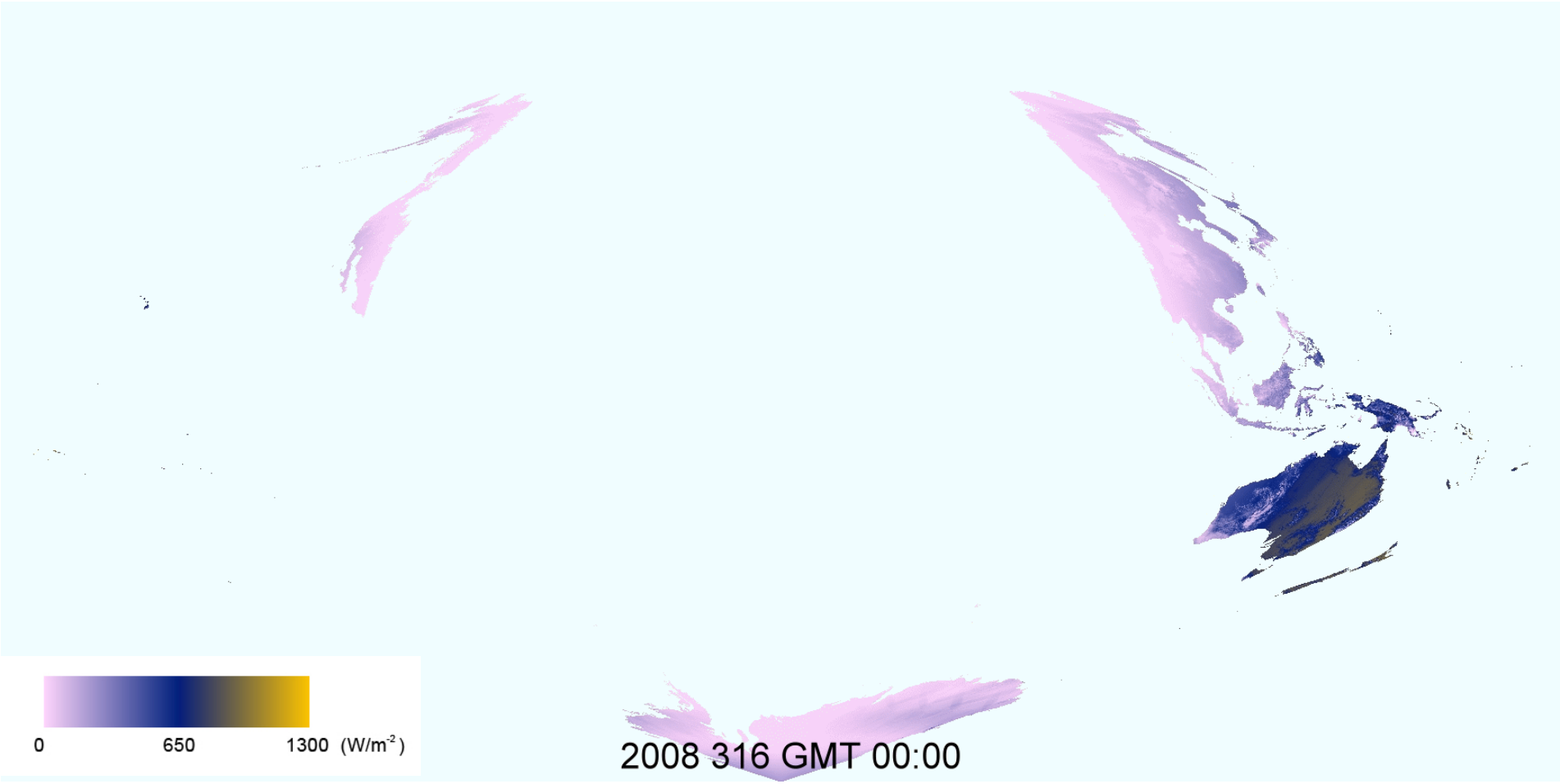
Tropical, MLW, MLS, AW, AS, and 1976US represent the tropical, mid-latitude winter, mid-latitude summer, Arctic winter, Arctic summer, and 1976 US standard atmosphere profiles, respectively.



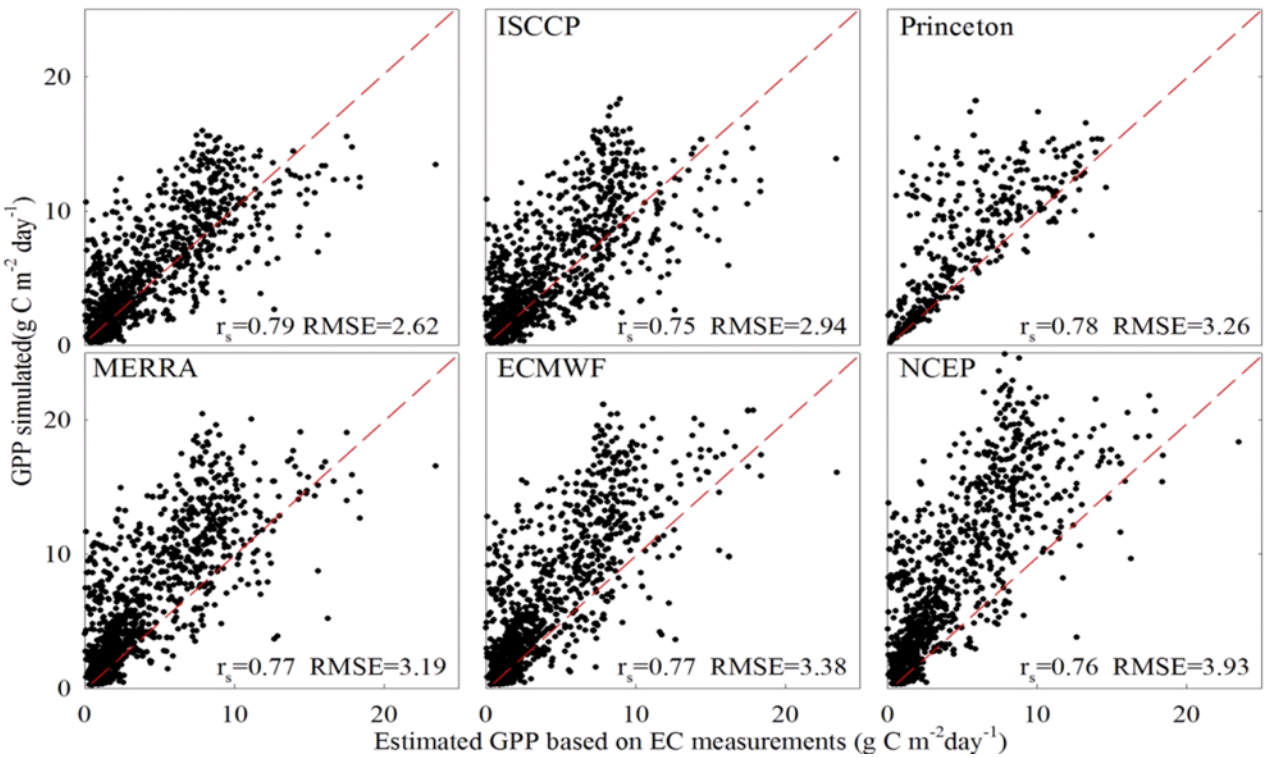
Elevation

Zhang et al., RSE, 2014

Mapping global surface radiation



Improvement in estimating gross primary productivity (GPP) with the new PAR data

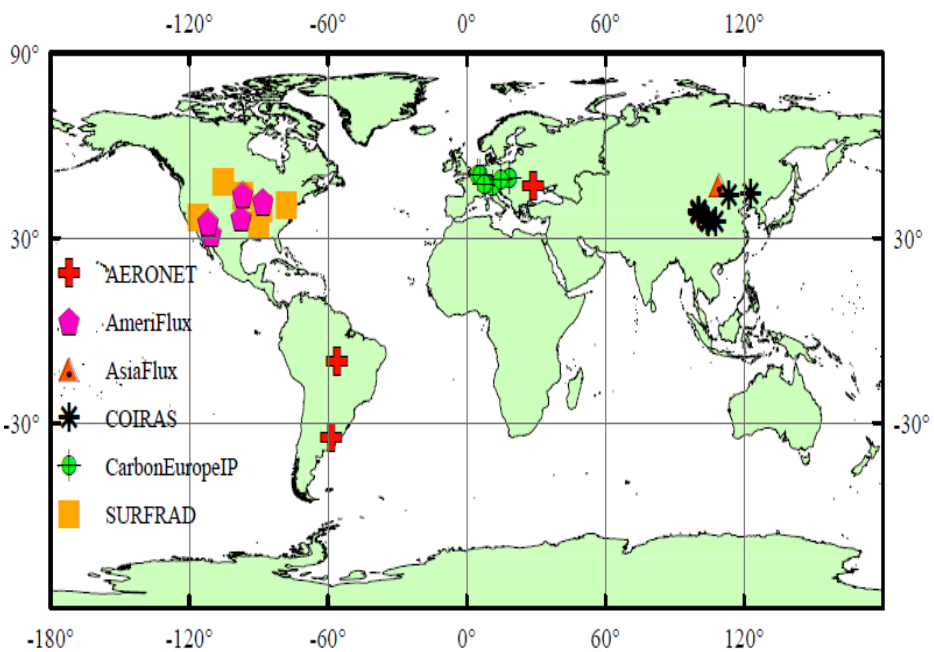


- 6 radiation products
- Same model for calculating GPP
- in-situ measurements at 12 sites in China
- New PAR product produces the best GPP values

Cai, W., W. Yuan, S. Liang, et al., (2014), Improved Estimations of Gross Primary Production Using Satellite-derived Photosynthetically Active Radiation, *Journal of Geophysical Research – Biogeosciences*, *119*, 2013JG002456

Data validation using global flux networks

- Instantaneous
- Daily
- Monthly

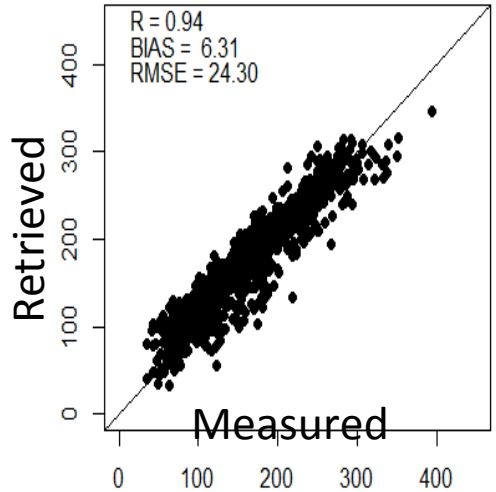


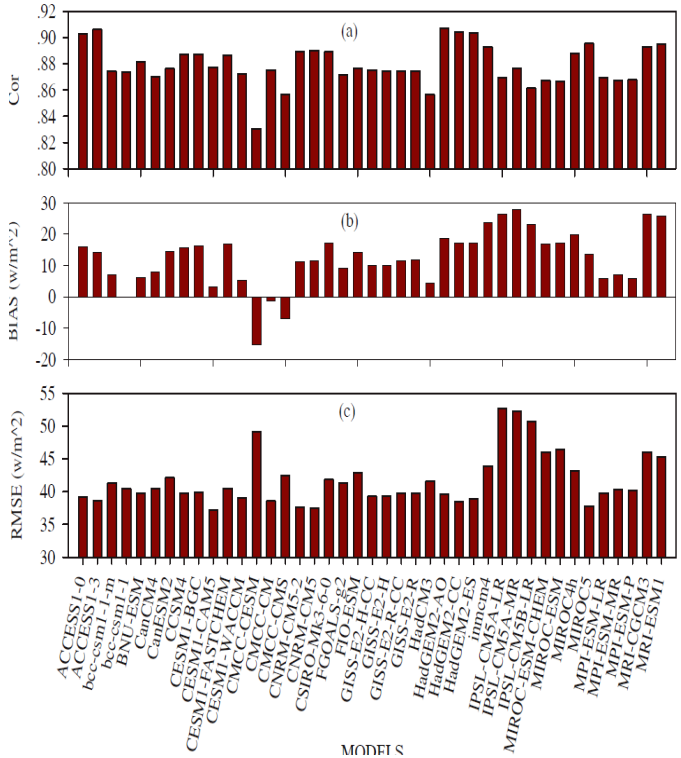
Site	DSSR			PAR		
	R^2	BIAS	RMSE	R^2	BIAS	RMSE
Bondville	0.86	20	100	0.86	4.6	45
FortPeck	0.82	5.5	111	0.82	1.6	46
Goodwin Creek	0.92	1.7	86	0.91	4.2	38
Penn State	0.87	12	100	0.86	9.4	44
Sioux Falls	0.86	14	102	0.86	2.4	43
Boulder	0.77	-8.7	140	0.78	-7.6	58
Desert Rock	0.88	-55	119	0.89	-30	51
ARM-SGP Main	0.9	-7.73	93	0.88	16	45
Audubon Research Ranch	0.86	-42	120	0.87	24	56
Brookings	0.83	-9	114	0.84	33	55
Fermi_Agricultural	0.77	55	145	0.78	2	61
Flagstaff Managed Forest	0.78	-26	150	0.77	-19	68
Flagstaff UnManaged Forest	0.86	-24	110	0.88	-4	44
Neustift	0.8	-48	140	0.83	-5	48
Lonzee	0.6	2	131	0.74	9	48
Vielsalm	0.75	12	107	0.79	22	47
Laegeren	0.77	-41	146	0.83	-4	49
Oensingen2 crop	0.77	-10	129	0.86	-9	47
Bily Kriz-Beskidy	0.77	17	121	0.83	24	48
Bily Kriz grassland	0.79	-3	119	0.82	25	49
CZECHWET	0.88	-17	84	0.86	11	41
Moldova	0.89	34	97	0.85	7	47
Alta_Floresta	0.87	2	108			
CEILAP-BA	0.82	-23	123			
Kherlenbayan	0.9	31	94			
Arou	0.83	-23	119		/	
Changwu	0.82	24	111			
Dayekou	0.84	-20	133			
Dingxi	0.85	16	101			
Dongsu	0.85	-44	115	0.82	-5	48
Tongyu	0.81	-8	106			
Yingke	0.85	-31	117		/	
Yuzhong	0.8	-22	131			
Zhangye	0.87	-6	93			
Total	0.83	-6.5	115	0.84	5	49

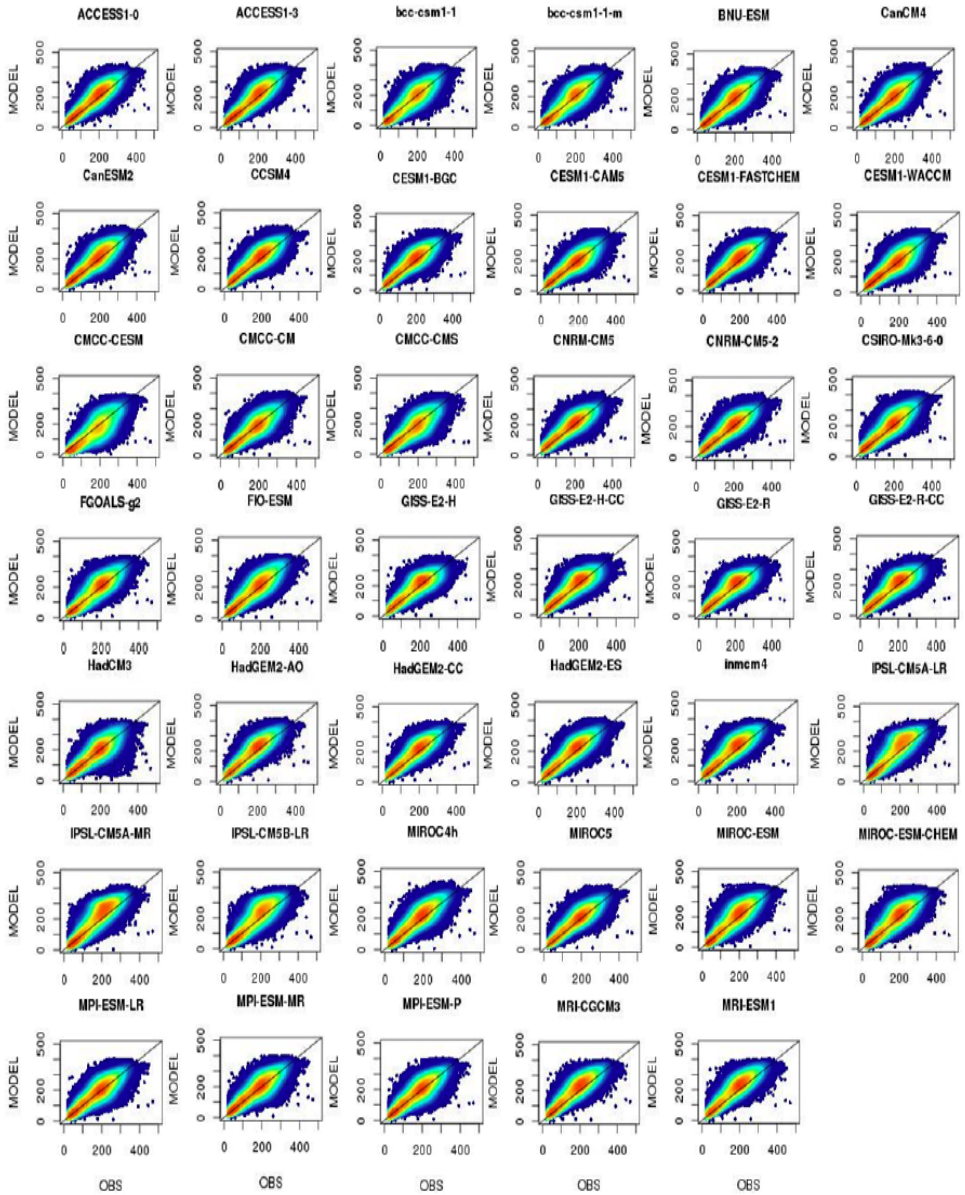
Comparison with existing products

Site	Retrieved DSSR			ISCCP-FD			CERES-MODIS-CALIPSO-CloudSat (CCCM)					
							Model B			Enhanced		
	R2	Bias	RMSE	R2	Bias	RMSE	R2	Bias	RMSE	R2	Bias	RMSE
Bondville	0.87	14.68	104.97	0.71	-7.06	149.88	0.84	12.9	119.5	0.82	-0.5	126.16
FortPeck	0.84	10.51	102.75	0.69	9.61	150.37	0.81	5.3	112.40	0.80	2.3	115.02
Goodwin Creek	0.91	-6.29	99.54	0.64	12.61	184.11	0.69	14.3	172.0	0.66	-3.8	179.35
Penn State	0.85	18.17	109.3	0.7	5.92	152.88	0.87	6.9	107.0	0.86	-8.6	111.18
Sioux Falls	0.81	11.52	114.41	0.65	37.83	168.85	0.62	-11.4	167.4	0.58	-37.8	178.77
Boulder	0.81	-12.8	126.38	0.72	6.49	154.96	0.34	-12.0	249.3	0.47	-43.0	214.41
DesertRock	0.92	-52.4	112.94	0.87	-42.4	125.27	0.52	-24.2	198.0	0.49	-26.6	206.38

Comparison with model results

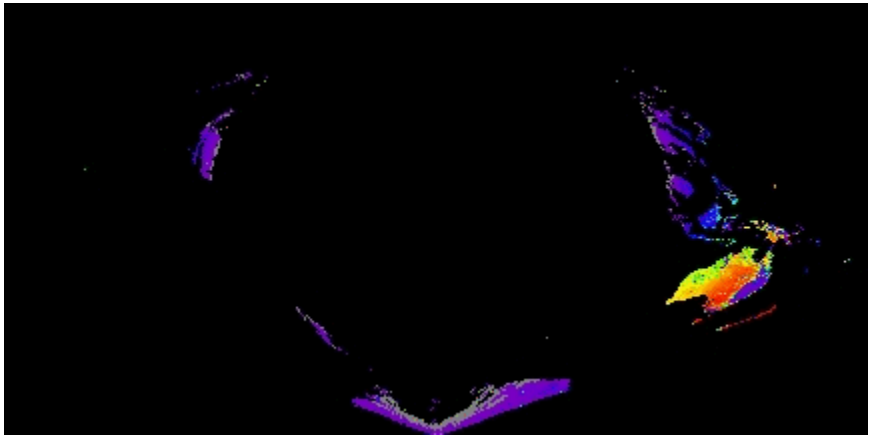






Implementation at MODAPS

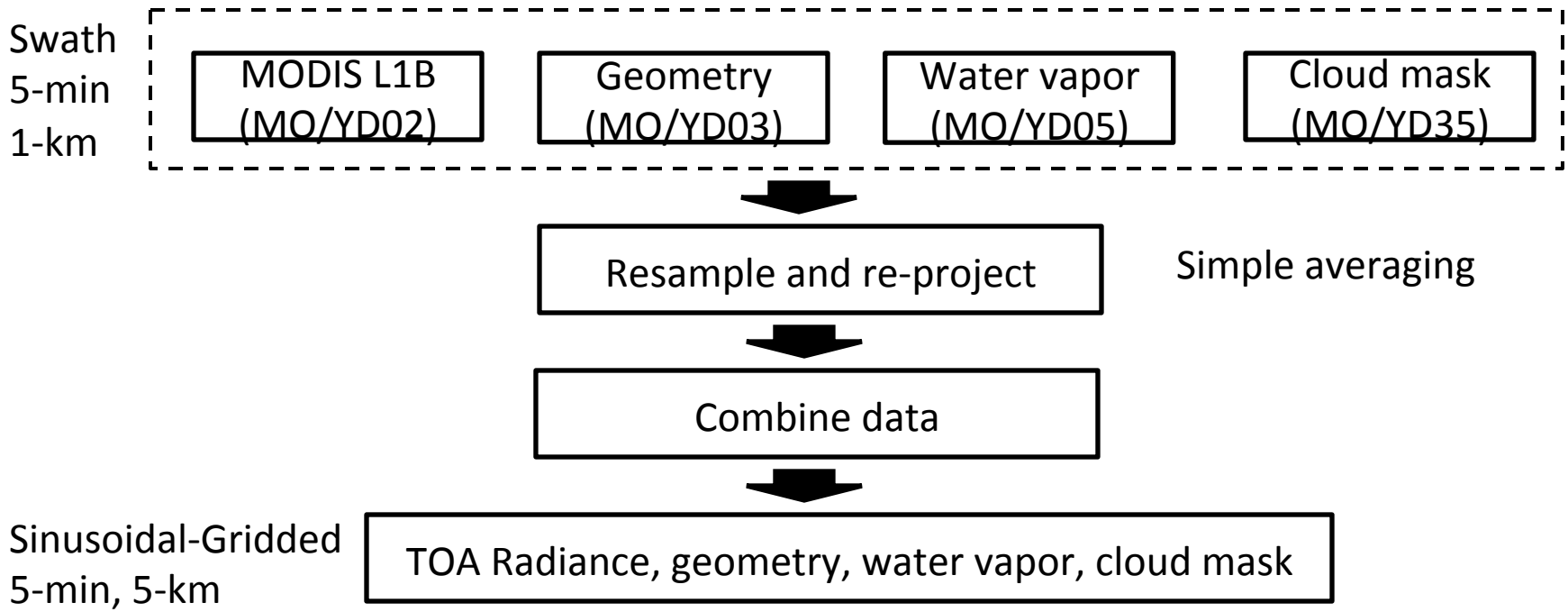
- Delivered and tested at MODAPS
- Refined the codes to fit the tile-driven structure
- Data product
  - Official products:
    - Tiled products MCD18A1 for 5km DSR and MCD18A2 for 5km PAR in SIN projection
    - Global 0.05° products MCD18C1 for DSR and MCD18C2 for PAR in Lat/Long projection
  - Temporal resolution: instantaneous, 3-hourly, and daily



3-hourly DSR (MCD18C1)
on Jan. 1st, 2010

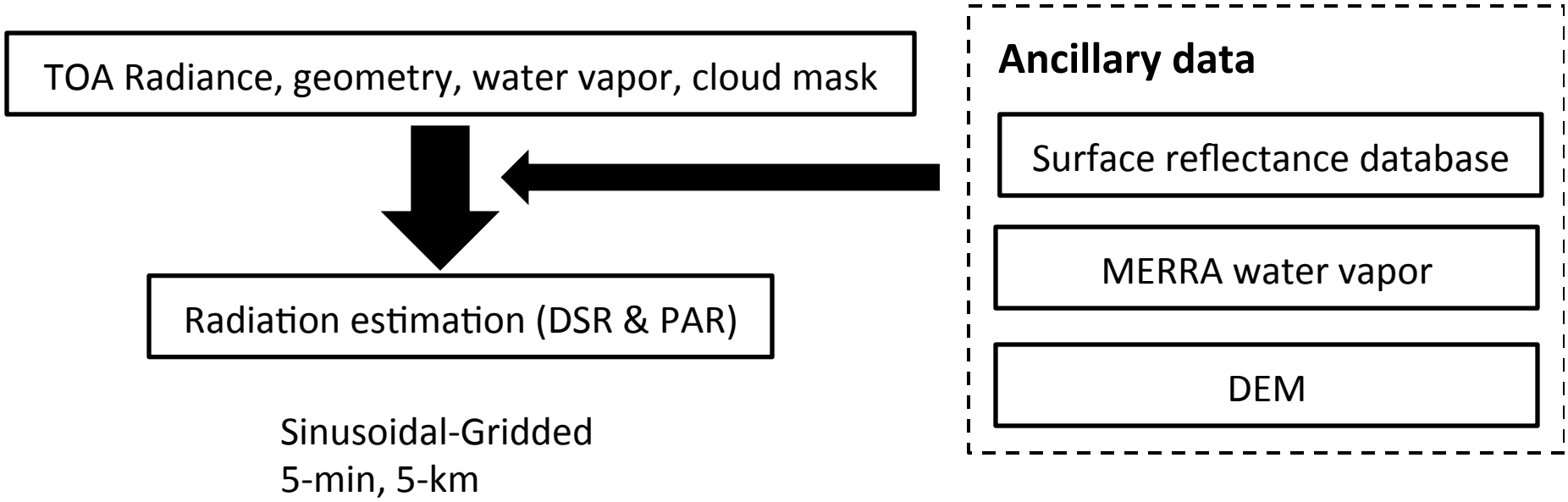
Major modules and I/O (1)

- Pre-processing of MODIS L1B
  - Extract MODIS blue band L1B, geometry, water vapor, and cloud mask
  - Re-project swath into 5-km gridded data



Major modules and I/O (2)

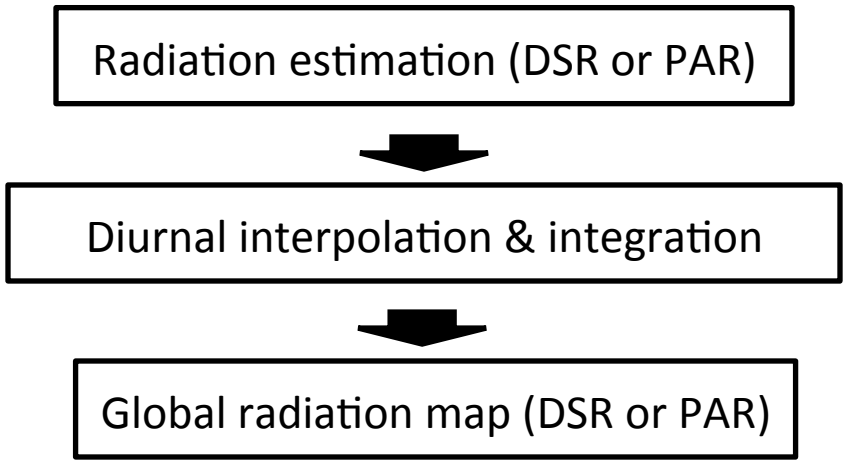
- Instantaneous radiation estimation
  - Estimate DSR and PAR from the 5-min gridded data



Major modules and I/O (3)

- Producing 3-hour and daily global maps
  - Integrate and interpolate 5-min data into 3-hour and daily total values
  - Generate global maps for both sinusoidal and lat/long projections at 5-km and 0.05° resolutions, respectively

Sinusoidal-Gridded
5-min, 5-km



Daily and 3-hourly
1. Sinusoidal 5-km
2. Lat/long 0.05°

Publications in 2015

- Wang, D., Liang, S., He, T., & Shi, Q. (2015). Estimating clear-sky all-wave net radiation from combined visible and shortwave infrared (VSWIR) and thermal infrared (TIR) remote sensing data. *Remote Sensing of Environment*, 167, 31-39, doi:10.1016/j.rse.2015.03.022.
- He, T., Liang, S., Wang, D., & Shi, Q. (2015). Estimation of high-resolution land surface net shortwave radiation from AVIRIS data: Algorithm development and preliminary results. *Remote Sensing of Environment*, 167, 20-30, doi:10.1016/j.rse.2015.03.021.
- Wang, D., Liang, S., He, T., & Shi, Q. (2015). Estimation of daily surface shortwave net radiation from the combined MODIS data. *IEEE Transactions on Geoscience and Remote Sensing*, 53(10), 5519-5529, doi: 10.1109/tgrs.2015.2424716.
- Wang, D., Liang, S., He, T., Cao, Y., & Jiang, B. (2015). Daily surface shortwave net radiation estimation from FengYun-3 MERSI data. *Remote Sensing, 7*, 6224-6239, doi:10.3390/rs70506224.

Summary

- We are closely working with MODAPS team on operational data production.
  - Codes using MODIS data are delivered and tested.
- We have investigated several related issues and explored new methods for further improvement:
  - New optimization method;
  - Temporal scaling of daily SSNR;
  - Improved parameterization;
  - Artificial neural network.