Estimation of Radiation Budget using Geostationary Satellites

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Back ground

- Radiation budget in climate change

Analysis algorithm

- Cloud analysis “CAPCOM”
- Radiation analysis “EXAM SYSTEM” (SW,PAR,UVA,UVB)

Global analysis

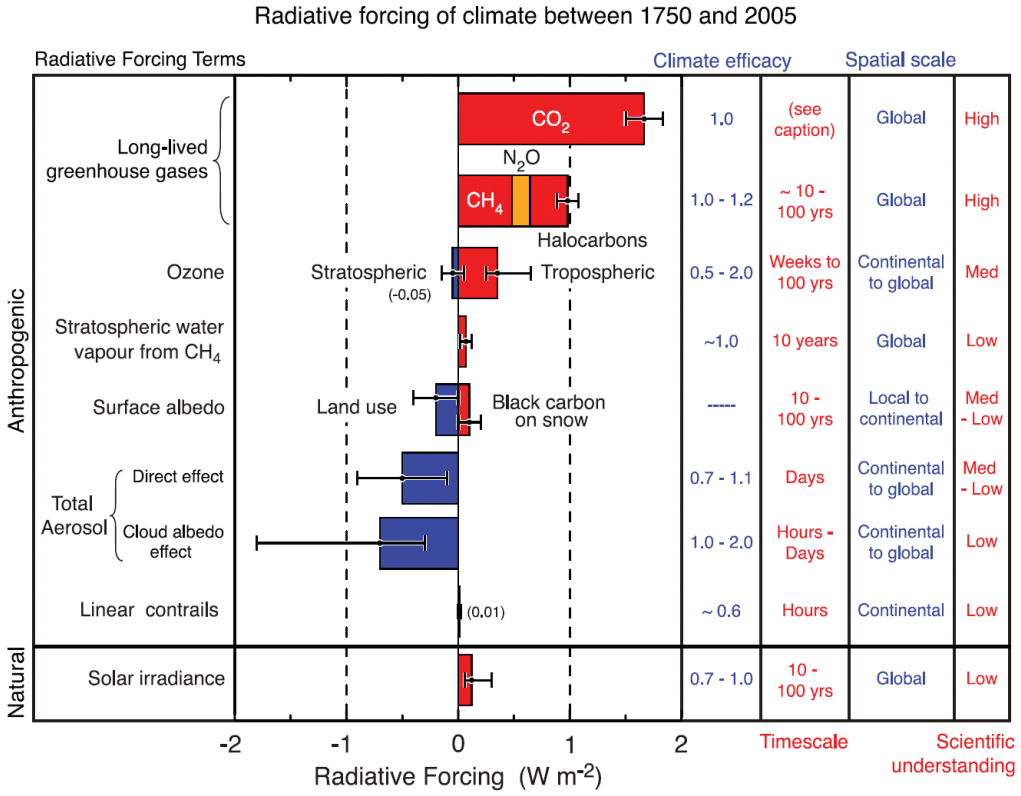
- Five geostationary satellites
- SW radiation budget analysis

Validation of GCM surface SW radiation

- Comparison of downward SW radiation between EXAM SYS and SPRINTERS

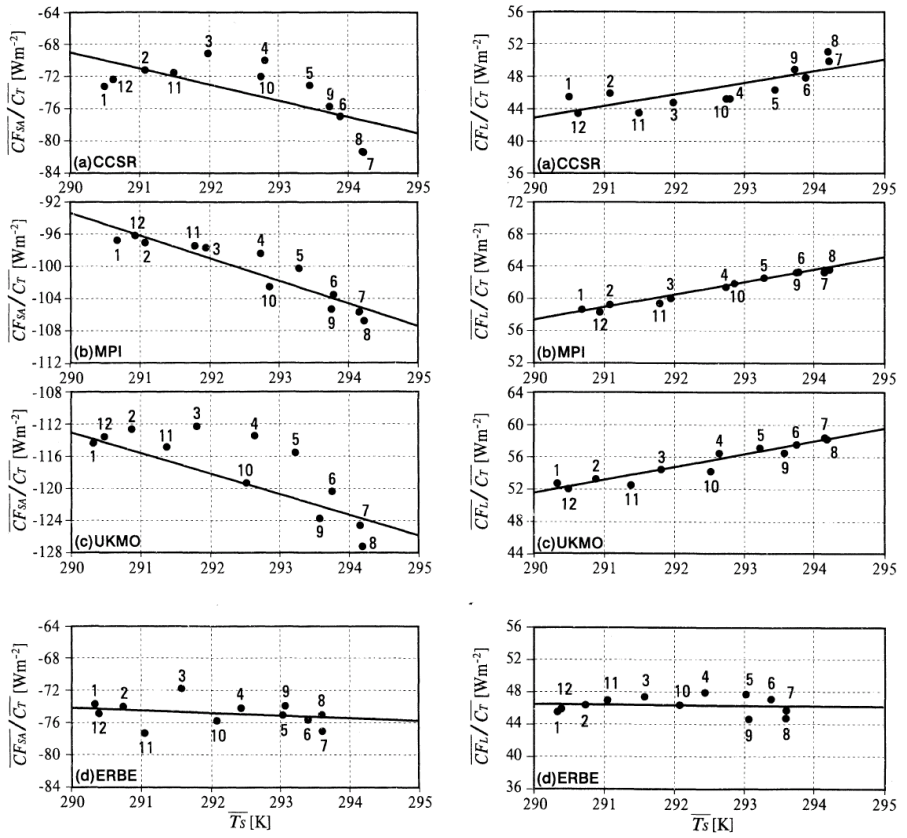
Application to Photo-voltaic power generation

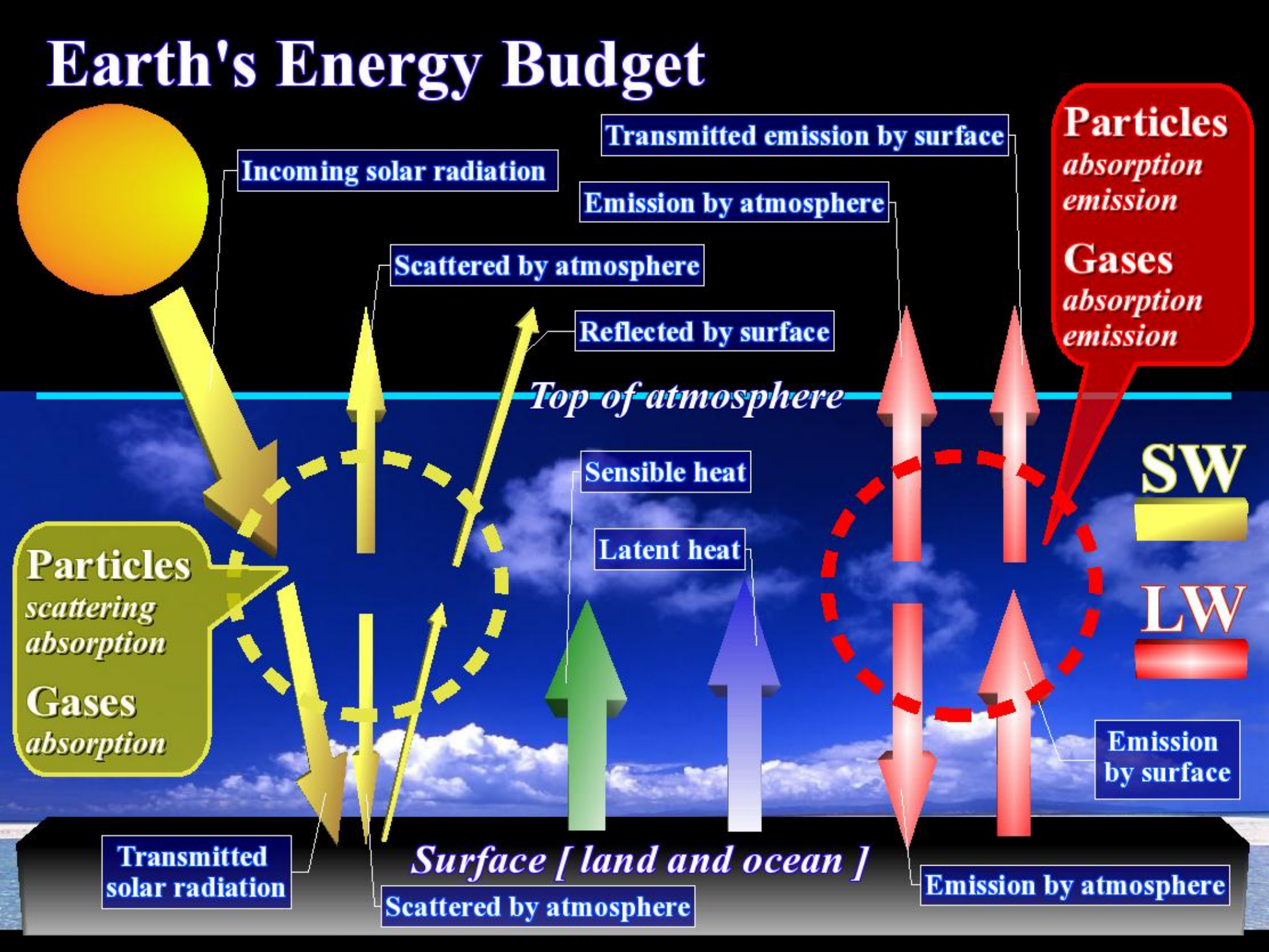
- Monitoring of PV power system
- SW Navigation for solar car



IPCC Forth Assessment Report: Working group 1 [IPCC AR4, 2007]
The influence of the greenhouse gases are clarified but the effect of aerosol and cloud has big uncertainty. CO2 has the strong heating effect, and effect of the albedo of the cloud and the aerosol has cooling.

Influence of cloud feedback on annual variation of global mean surface temperature [Tsushima and Manabe, 2001]
The climate models and the obsevation based analysis shows the different cloud feedback sensitivity




Earth's Energy Budget
Incoming solar radiation
Transmitted emission by surface
Emission by atmosphere
Scattered by atmosphere
Reflected by surface
Particles
absorption
emission
Gases
absorption
emission
Top of atmosphere
Sensible heat
Latent heat
SW
LW
Particles
scattering
absorption
Gases
absorption
Emission
by surface
Transmitted
solar radiation
Surface [land and ocean]
Scattered by atmosphere
Emission by atmosphere

Analysis algorithm

Analysis algorithm

CAPCOM

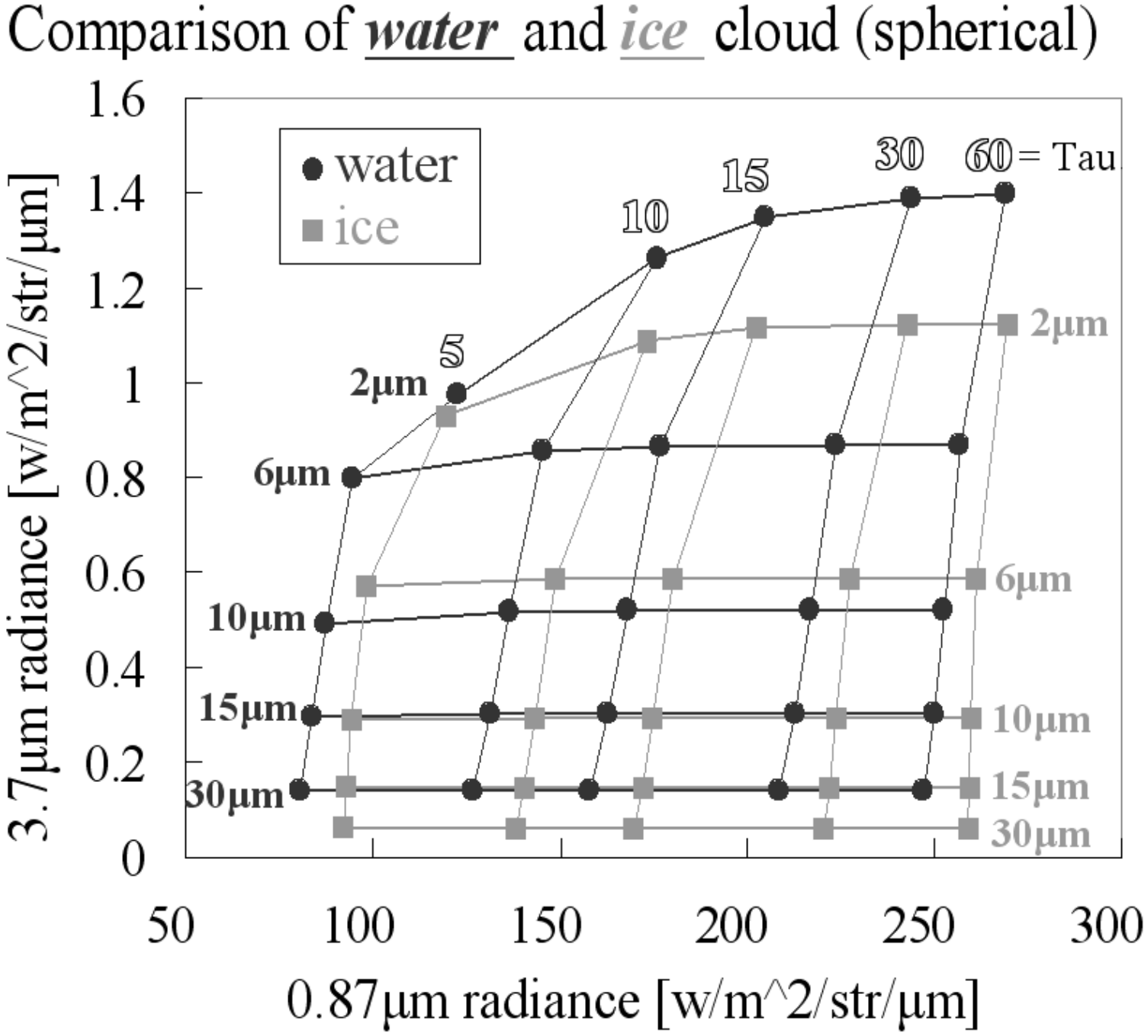
Comprehensive Analysis Program for Cloud optical Measurement

Satellite base cloud optical properties analysis algorithm
Water cloud and Ice cloud optical properties are available
ADEOS-II/GLI standard product algorithm

EXAM SYSTEM

Extreme speed and approximation module Multiple-drive system

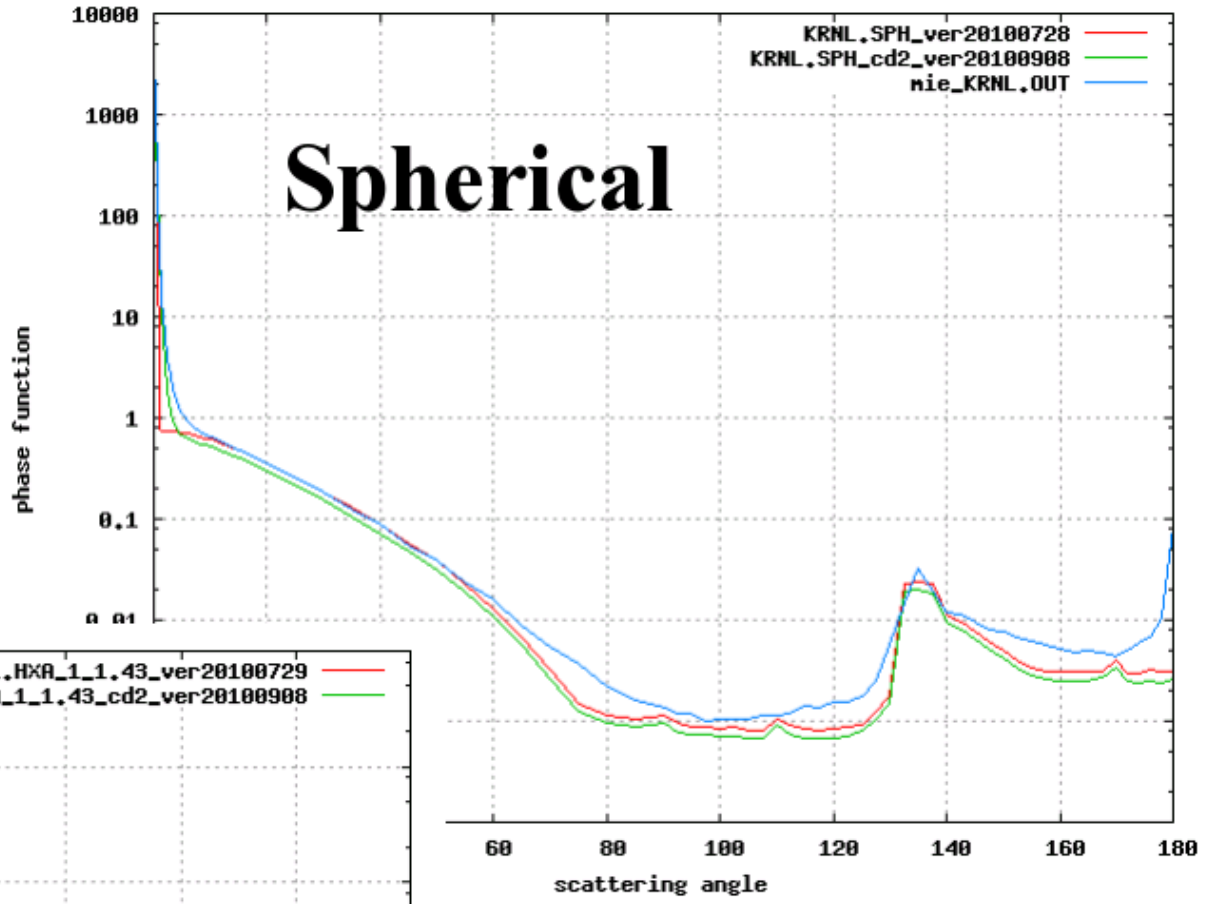
High speed RB solver by function approximation by NN based on RSTAR
TOA and Surface radiation fluxes (SW, PAR, UVA, UVB) are available
Semi-real time analysis become by high-speed NN radiation solver

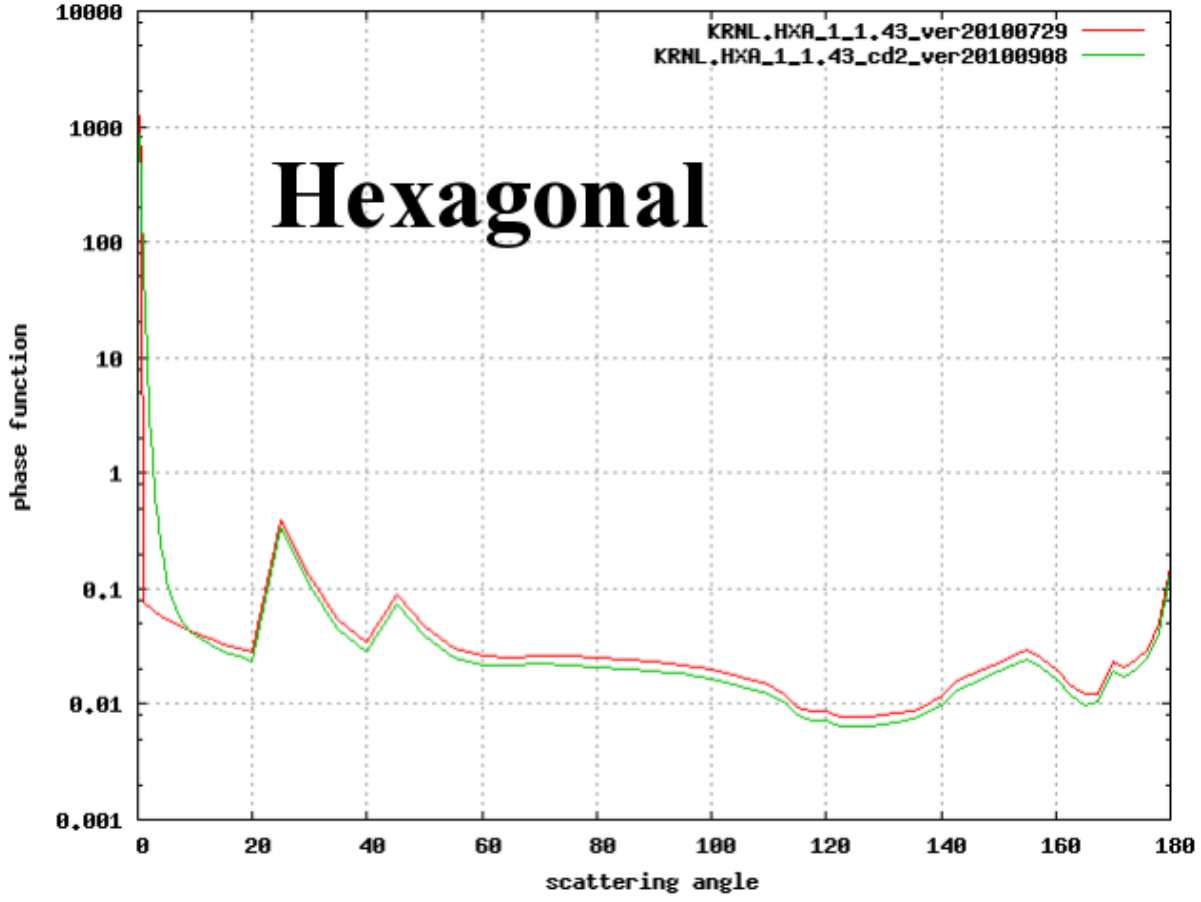


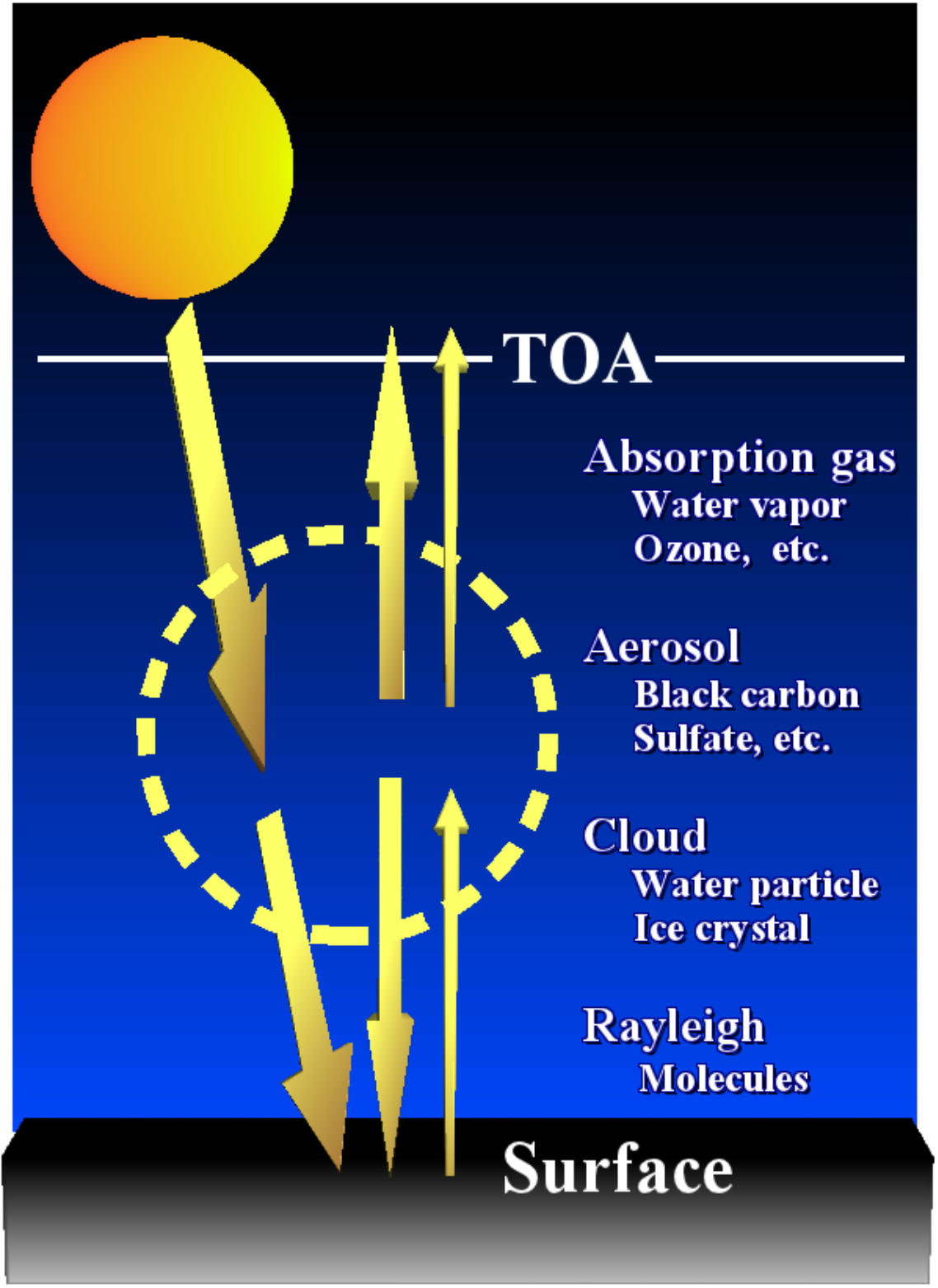
Cloud optical thickness estimation from GMS-5/SVISSR [Takenaka et al. 2009]

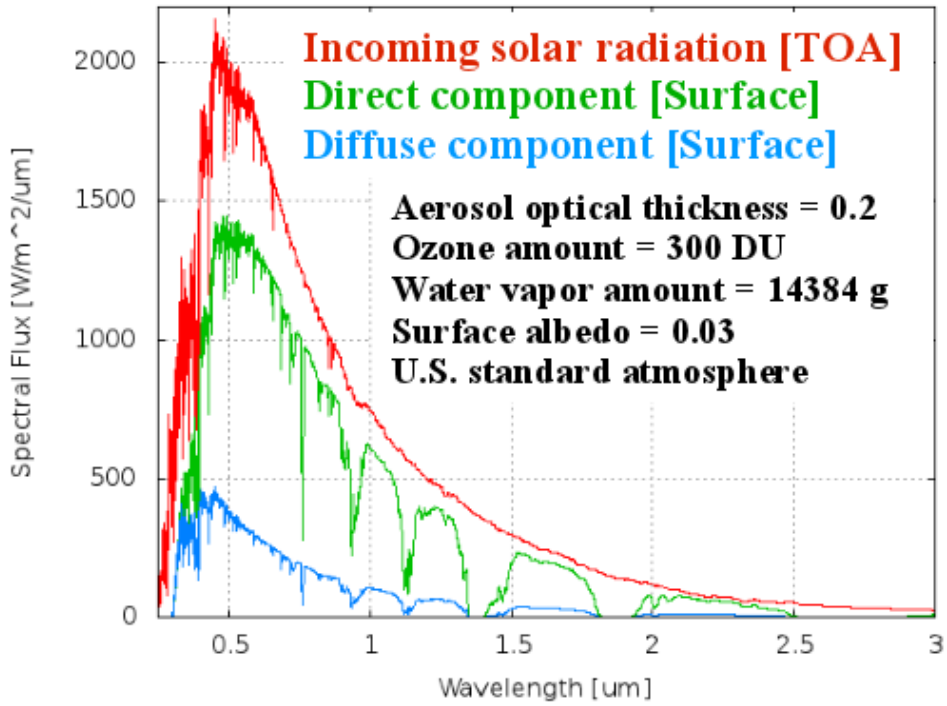
Mie theory

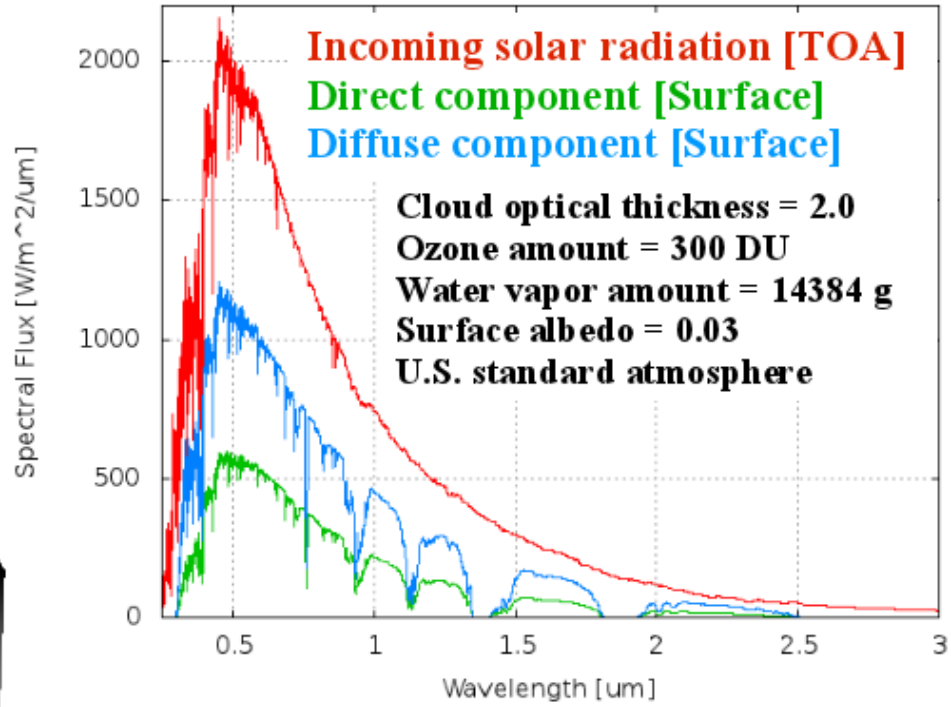
FDTD Finite Difference Time Domain method





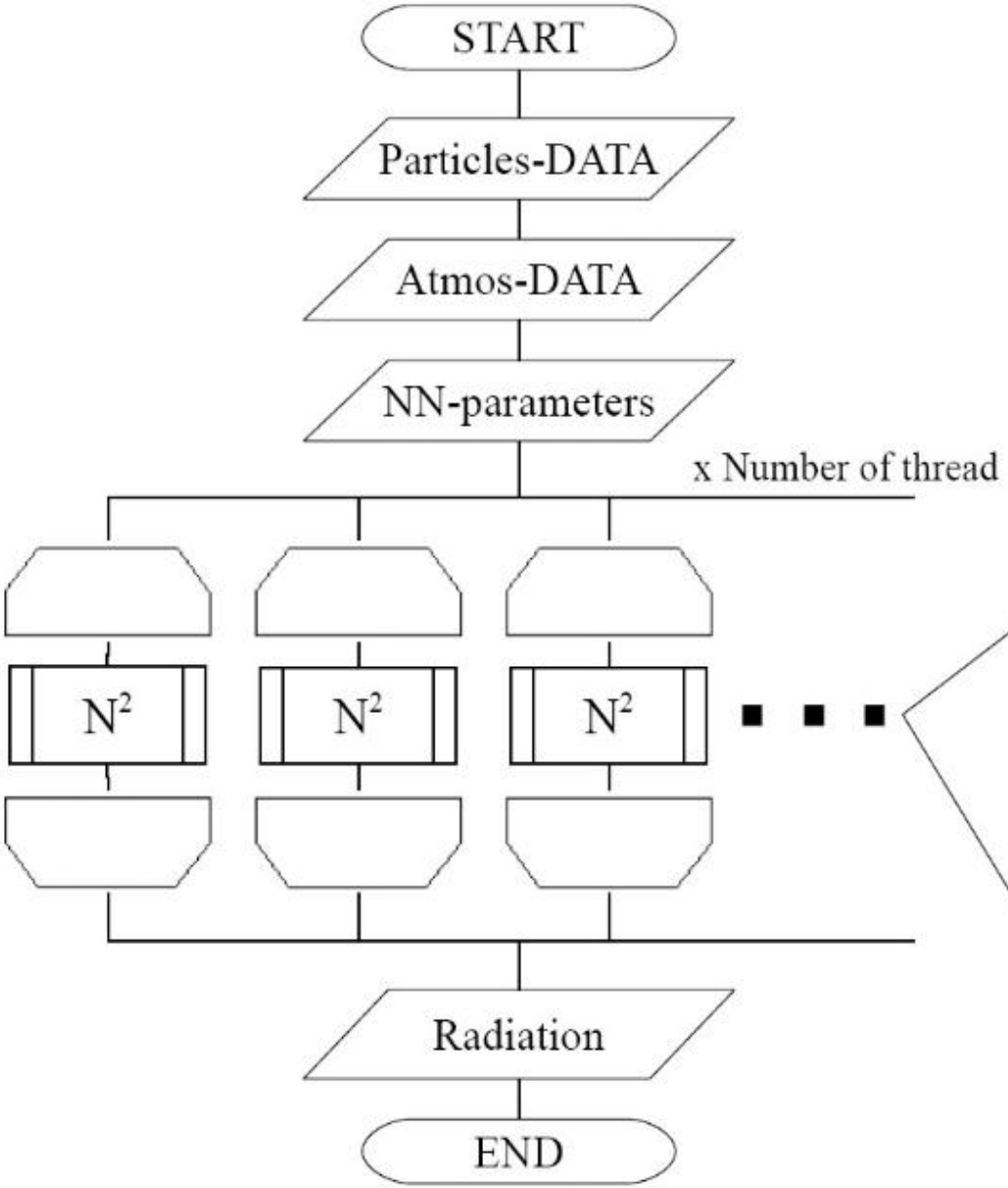

TOA
Absorption gas
Water vapor
Ozone, etc.
Aerosol
Black carbon
Sulfate, etc.
Cloud
Water particle
Ice crystal
Rayleigh
Molecules
Surface


Incoming solar radiation [TOA]
Direct component [Surface]
Diffuse component [Surface]
Aerosol optical thickness = 0.2
Ozone amount = 300 DU
Water vapor amount = 14384 g
Surface albedo = 0.03
U.S. standard atmosphere
Spectral Flux [W/m^2/um]
Wavelength [um]
0
500
1000
1500
2000
0.5
1
1.5
2
2.5
3


Incoming solar radiation [TOA]
Direct component [Surface]
Diffuse component [Surface]
Cloud optical thickness = 2.0
Ozone amount = 300 DU
Water vapor amount = 14384 g
Surface albedo = 0.03
U.S. standard atmosphere
Spectral Flux [W/m^2/um]
Wavelength [um]
0
500
1000
1500
2000
0.5
1
1.5
2
2.5
3

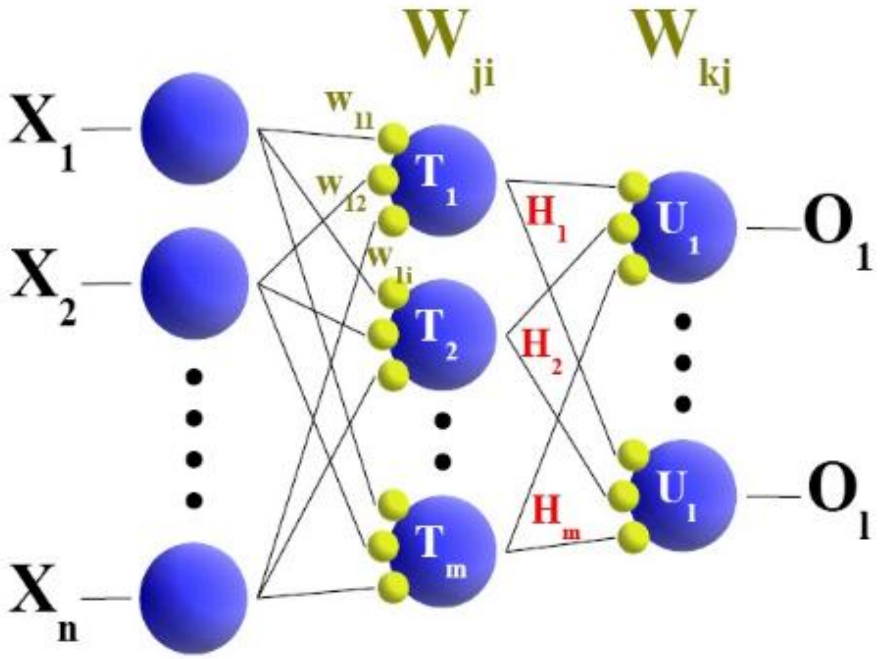
EXAM SYSTEM

Extreme speed and
Approximation module
Multiple-drive System



Neuro-link Network solver

Version 5.0



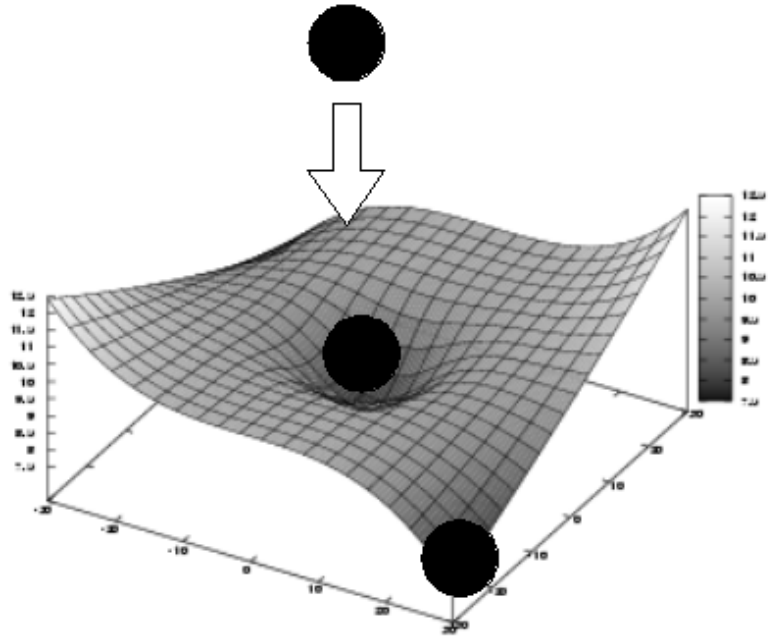
N Layer Feed-Forward Network

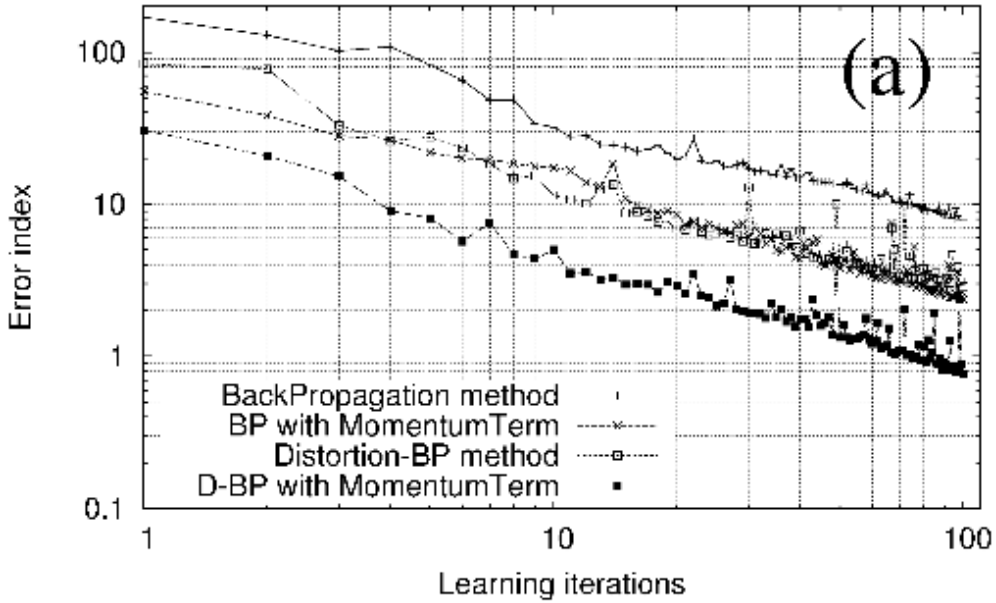
- **Dimension limit free**
- **High speed computation**

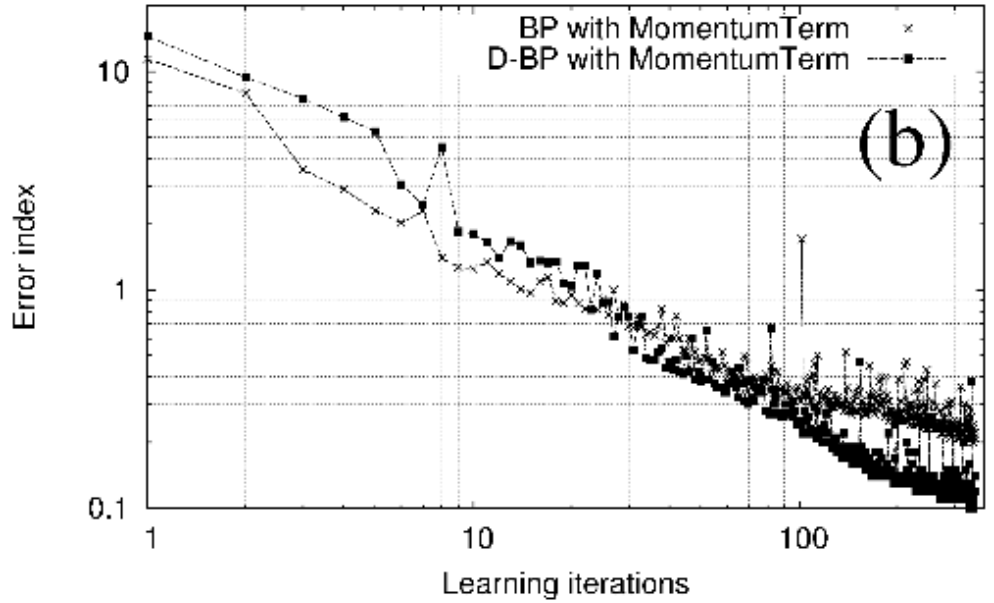
Improved learning algorithm "Distortion-BP"

$$\Delta W^{(s+1)} = -\eta \left.\frac{\partial E}{\partial W}\right|_{W=W^{(s)}} + \alpha \Delta W^{(s)}$$

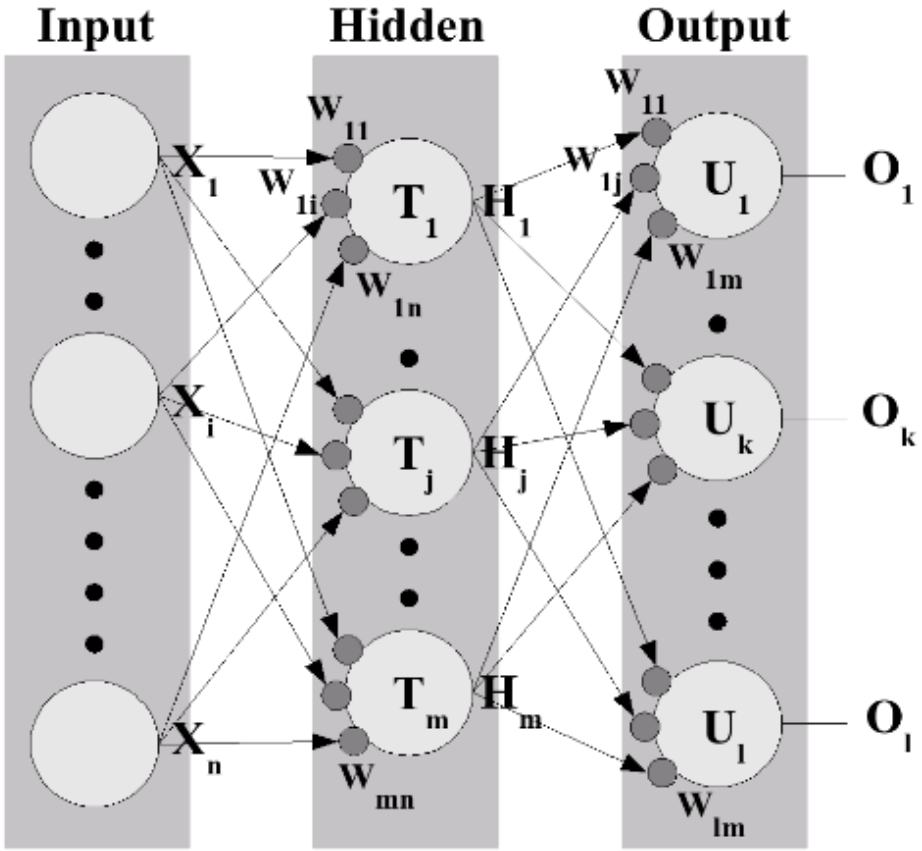
$$\Delta V^{(s+1)} = -\zeta \left.\frac{\partial E}{\partial V}\right|_{V=V^{(s)}} + \beta \Delta V^{(s)}$$







Three layer network

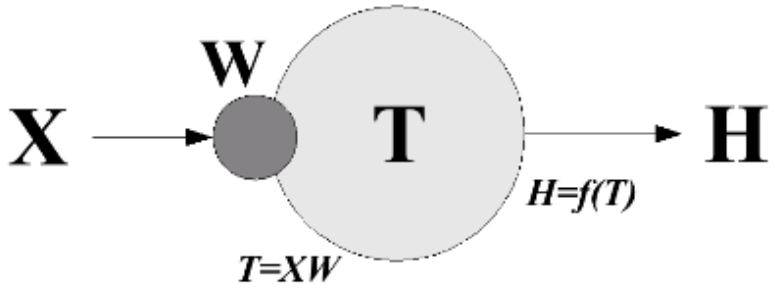


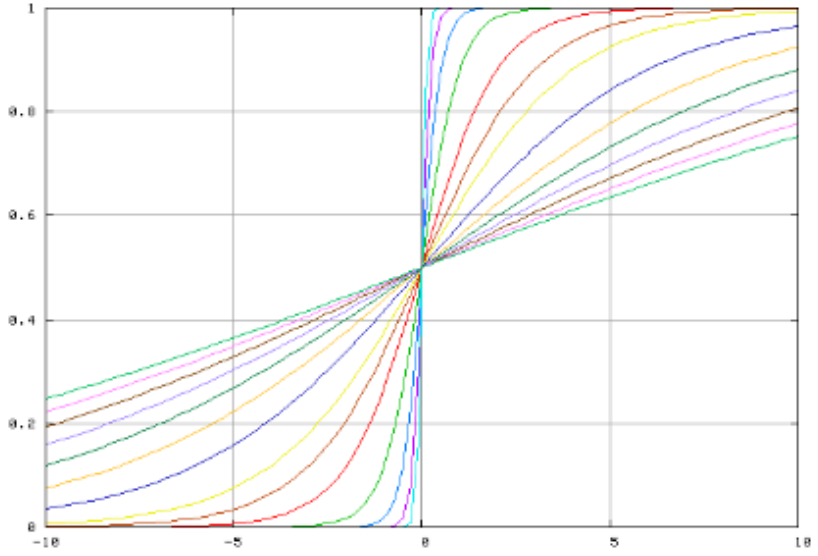
$$T_j = \sum_{i=0}^{n} X_i W_{ji} \qquad f(T) = \frac{1}{1+e^{-\frac{T}{a}}}$$

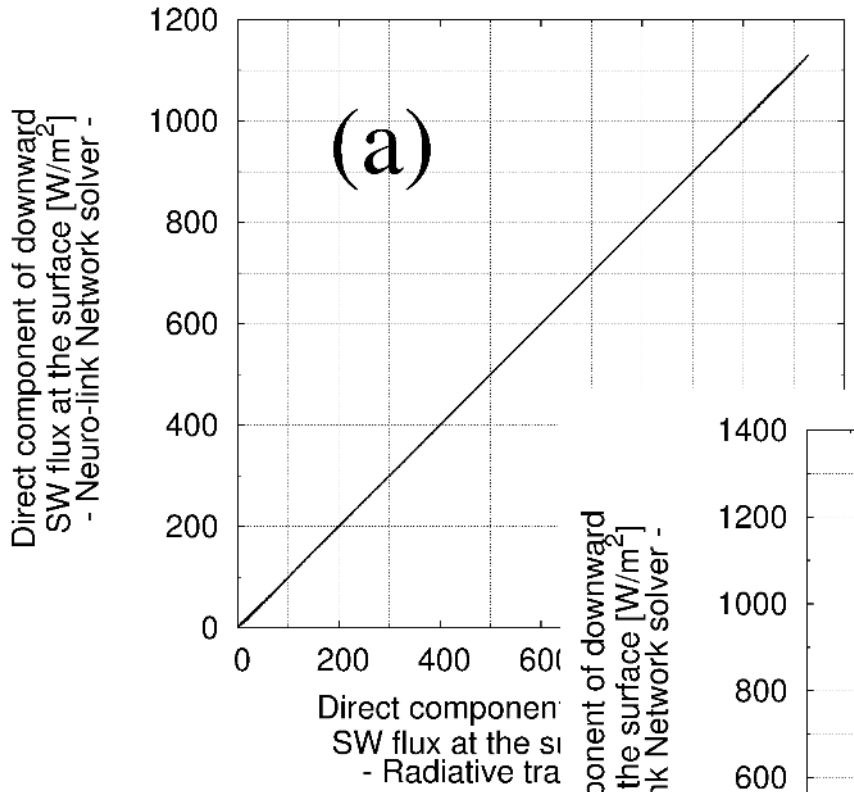
$$H_j = f(T_j, V_j)$$

$$U_k = \sum_{j=0}^{m} H_j W_{kj}$$

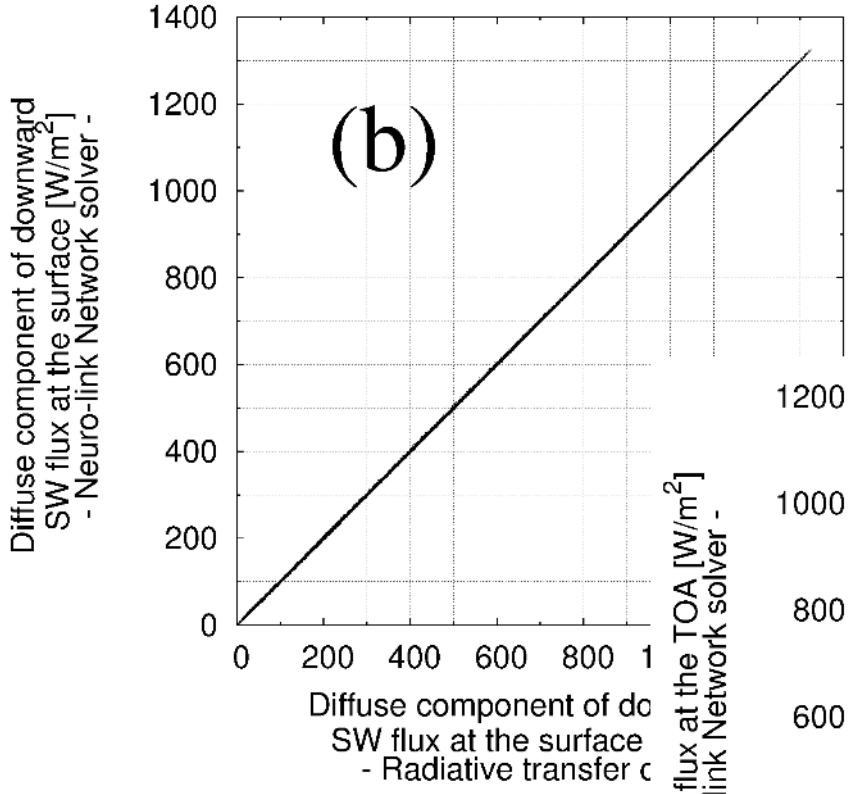
$$O_k = f(U_k, V_k)$$



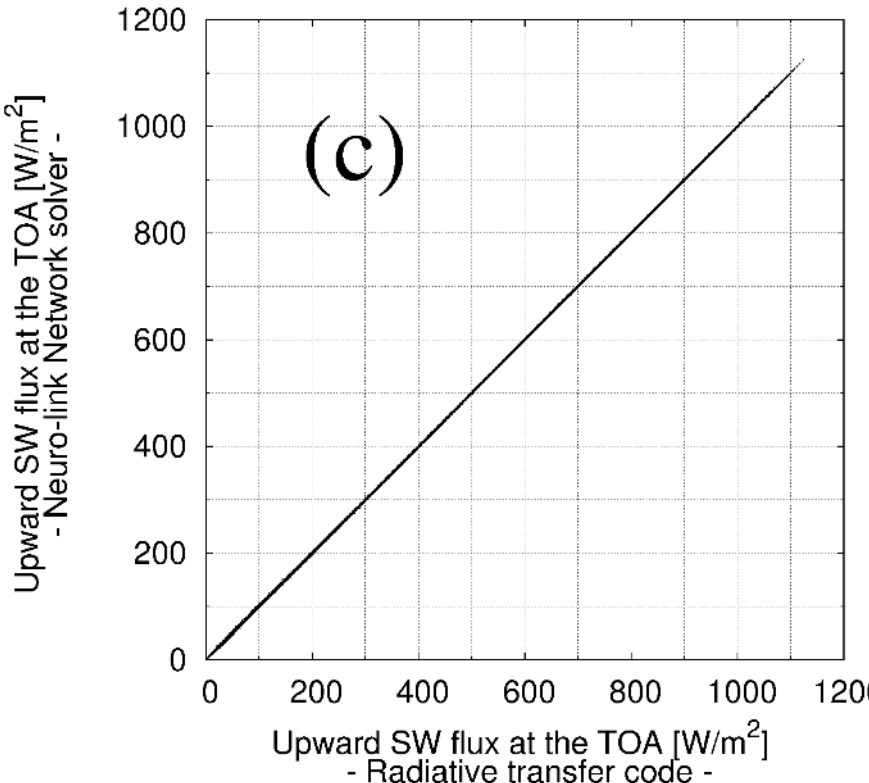




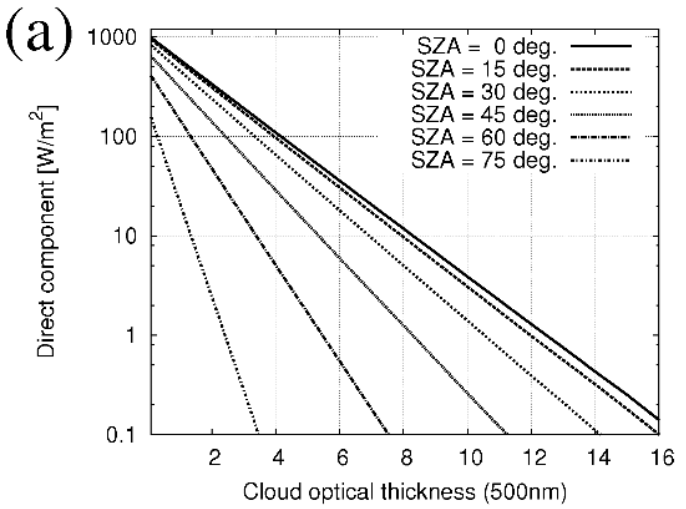
Direct component

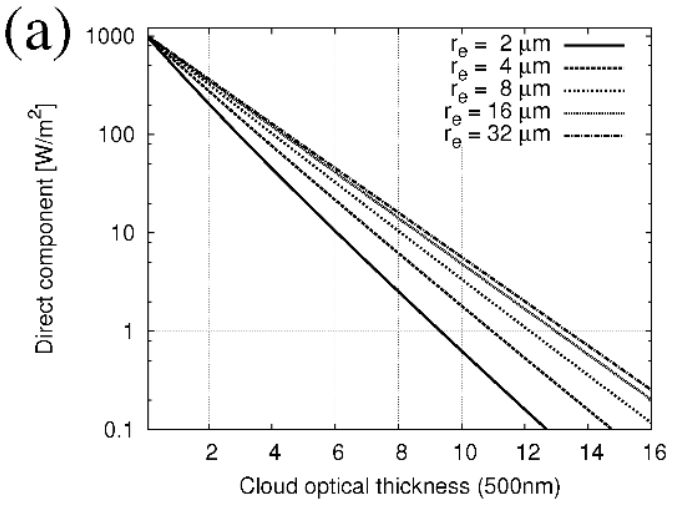


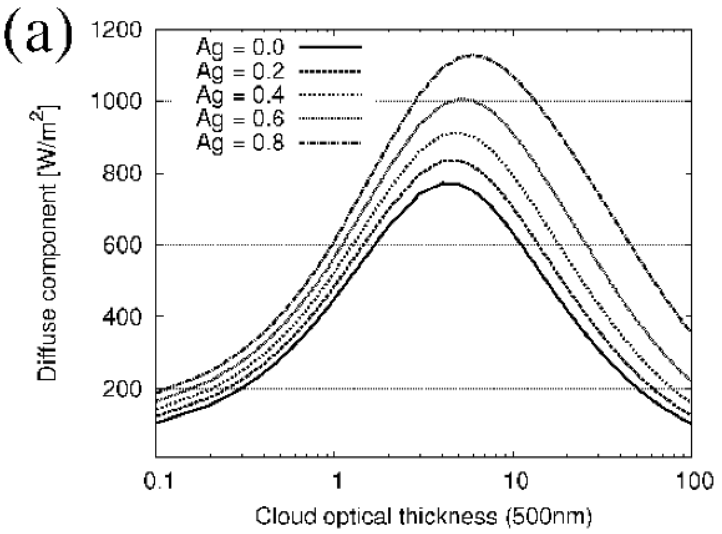
Upward TOA

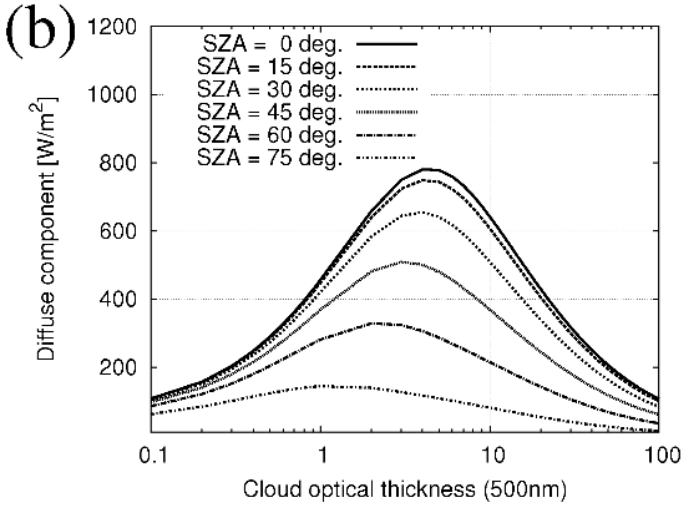


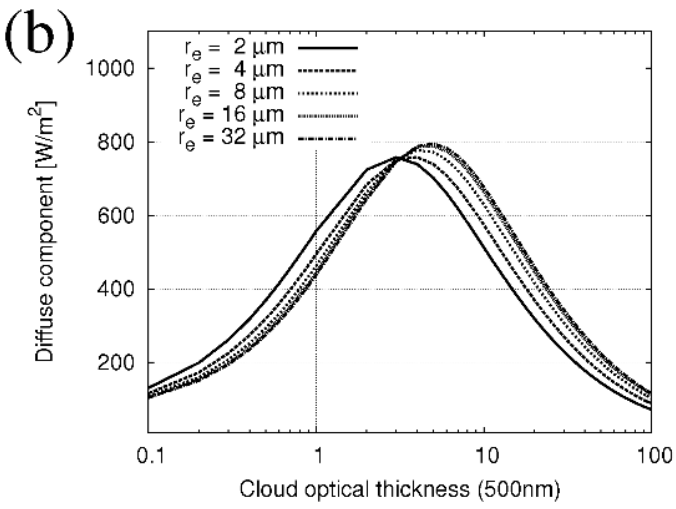
Diffuse component

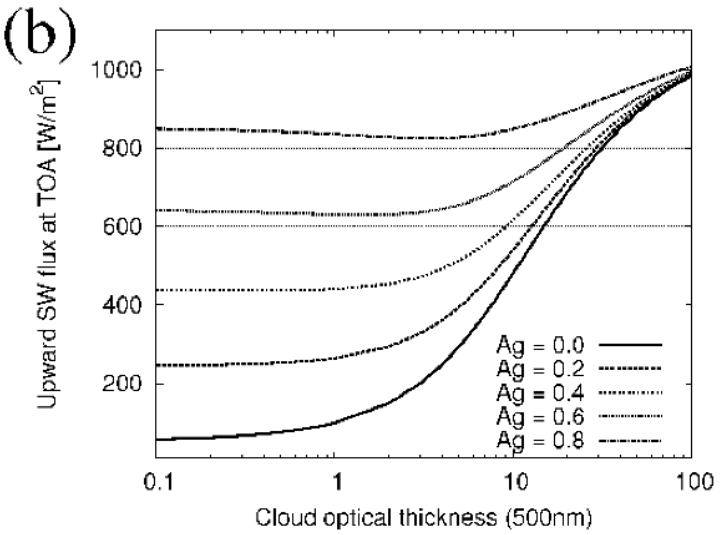

(a)
Direct component [W/m^2]
Cloud optical thickness (500nm)
SZA = 0 deg.
SZA = 15 deg.
SZA = 30 deg.
SZA = 45 deg.
SZA = 60 deg.
SZA = 75 deg.

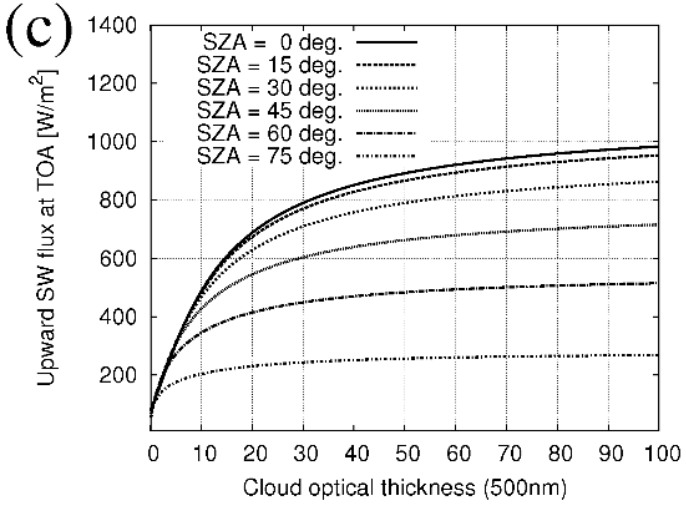

(a)
Direct component [W/m^2]
Cloud optical thickness (500nm)
r_e = 2 μm
r_e = 4 μm
r_e = 8 μm
r_e = 16 μm
r_e = 32 μm

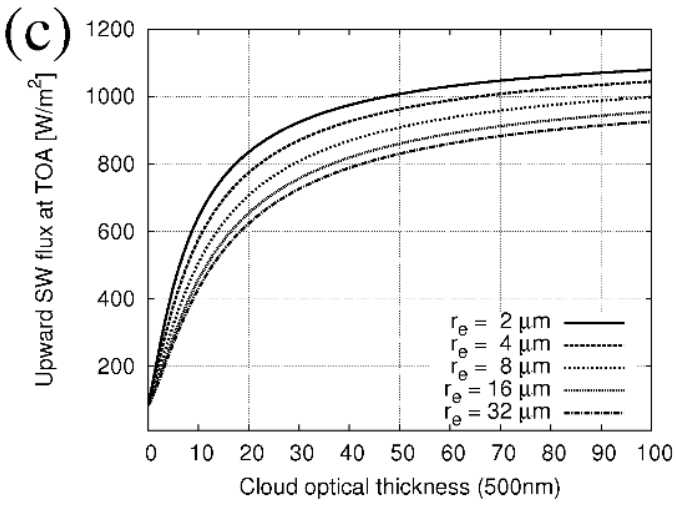

(a)
Diffuse component [W/m^2]
Cloud optical thickness (500nm)
Ag = 0.0
Ag = 0.2
Ag = 0.4
Ag = 0.6
Ag = 0.8

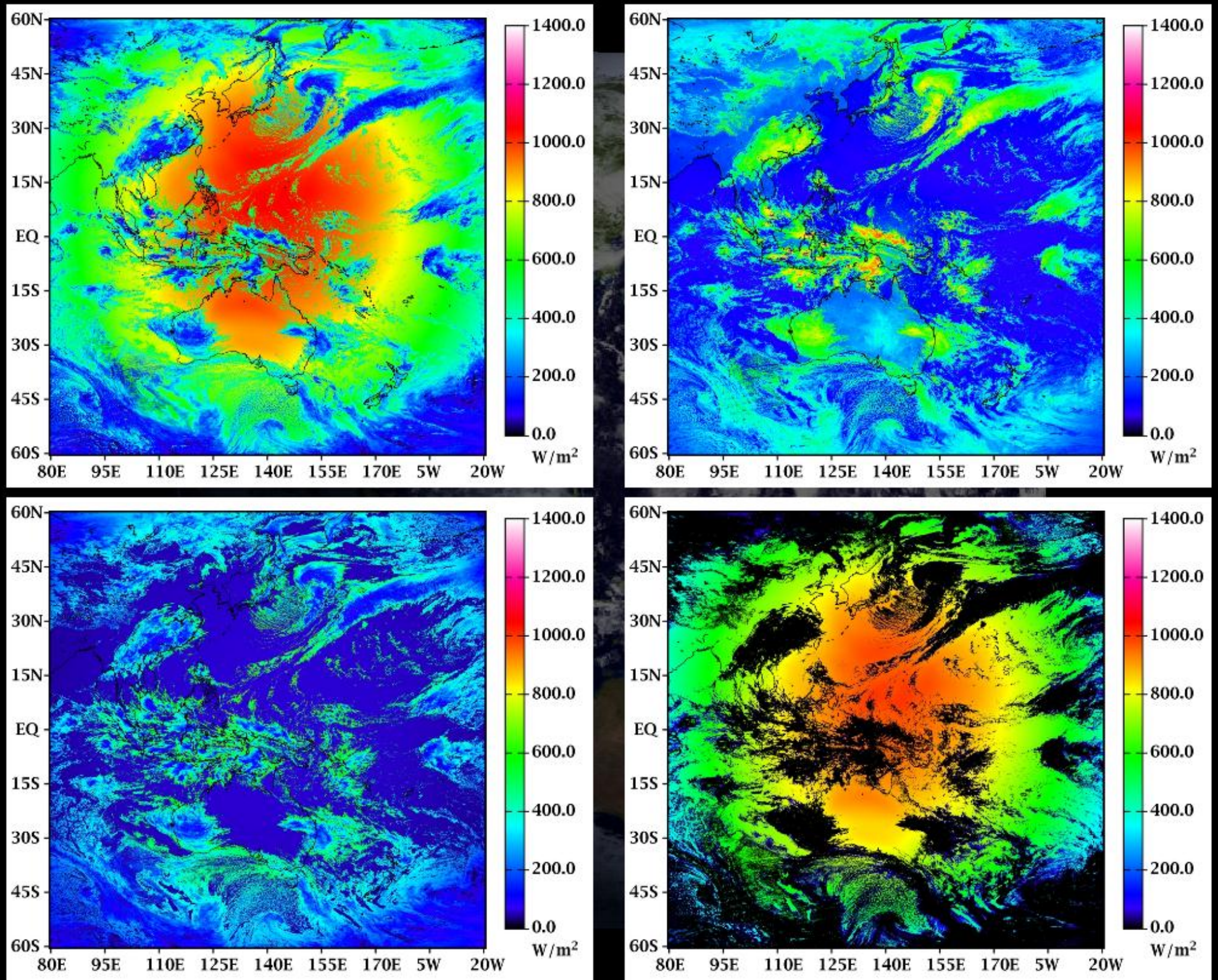

(b)
Diffuse component [W/m^2]
Cloud optical thickness (500nm)
SZA = 0 deg.
SZA = 15 deg.
SZA = 30 deg.
SZA = 45 deg.
SZA = 60 deg.
SZA = 75 deg.


(b)
Diffuse component [W/m^2]
Cloud optical thickness (500nm)
r_e = 2 μm
r_e = 4 μm
r_e = 8 μm
r_e = 16 μm
r_e = 32 μm


(b)
Upward SW flux at TOA [W/m^2]
Cloud optical thickness (500nm)
Ag = 0.0
Ag = 0.2
Ag = 0.4
Ag = 0.6
Ag = 0.8

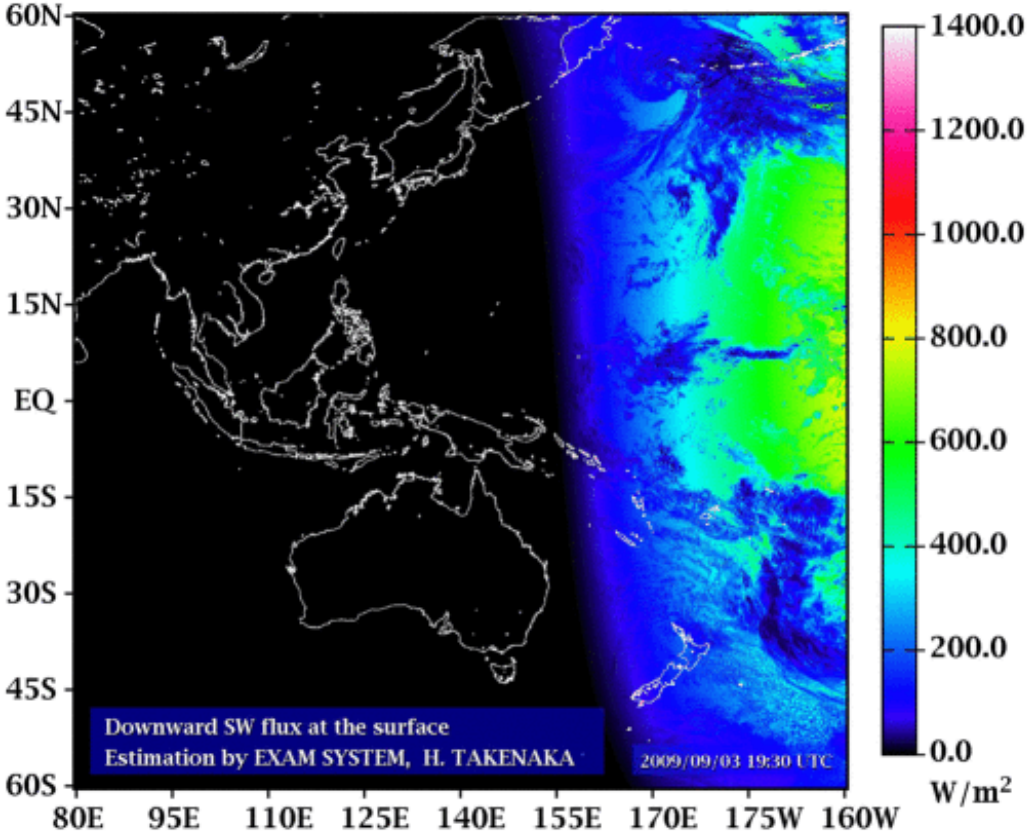

(c)
Upward SW flux at TOA [W/m^2]
Cloud optical thickness (500nm)
SZA = 0 deg.
SZA = 15 deg.
SZA = 30 deg.
SZA = 45 deg.
SZA = 60 deg.
SZA = 75 deg.


(c)
Upward SW flux at TOA [W/m^2]
Cloud optical thickness (500nm)
r_e = 2 μm
r_e = 4 μm
r_e = 8 μm
r_e = 16 μm
r_e = 32 μm

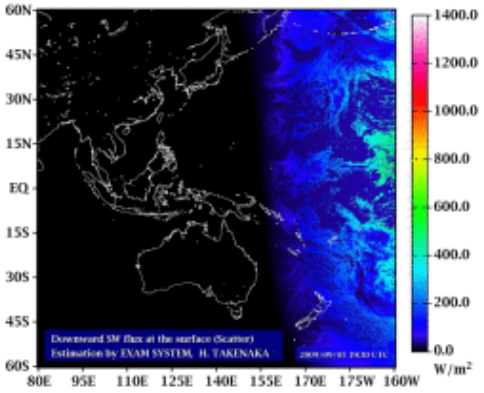

60N
45N
30N
15N
EQ
15S
30S
45S
60S
80E
95E
110E
125E
140E
155E
170E
5W
20W
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
W/m²

Atmospheric radiation budget product samples

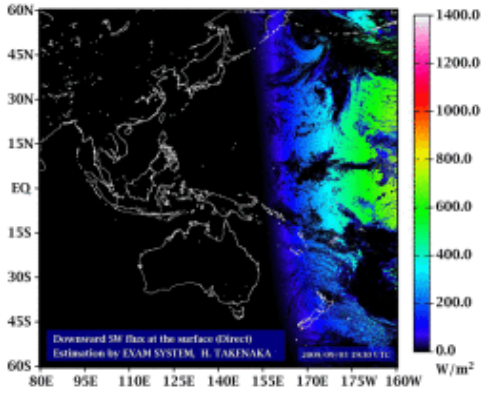
Downward SW flux at the surface



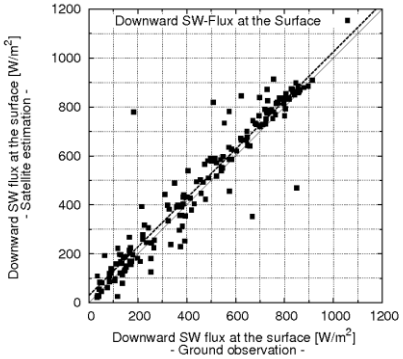
Diffuse SW

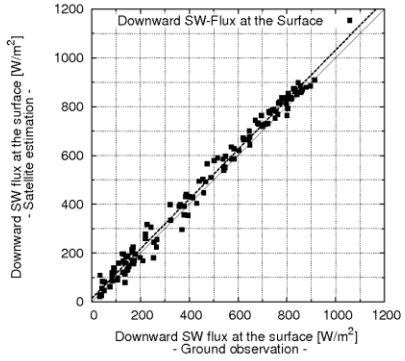


Direct SW

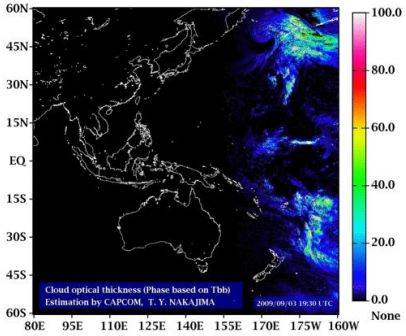


Ground validation of SW flux

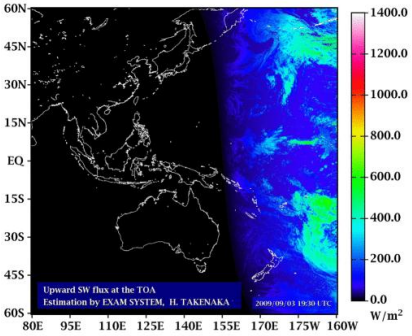




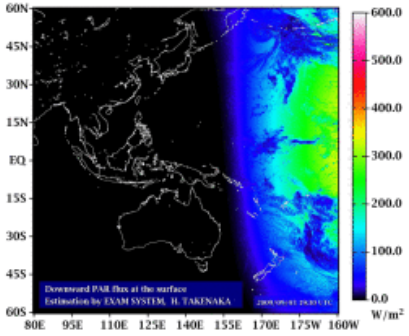
Cloud optical thickness



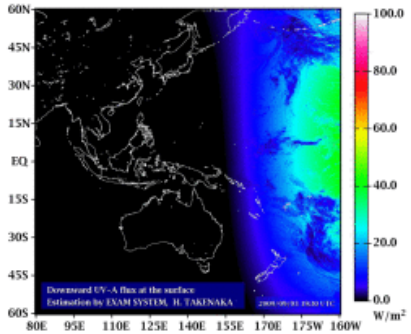
Upward SW flux at the TOA



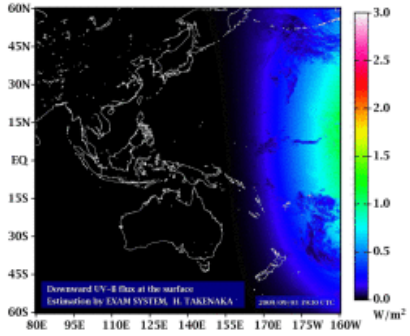
Downward PAR flux at the sfc



Downward UVA flux at the sfc



Downward UVB flux at the sfc



Atmospheric radiation and Weather observation network

"SKYNET"

Atmospheric parameters

swflux_down, swflux_up, lwflux_down, temperature, relative_humidity, pressure, absorption_coeff, scattering_coeff, precipitable_water, liquid_water, wind_speed, wind_direction

Air sampling data

OPC, SO2 and O3

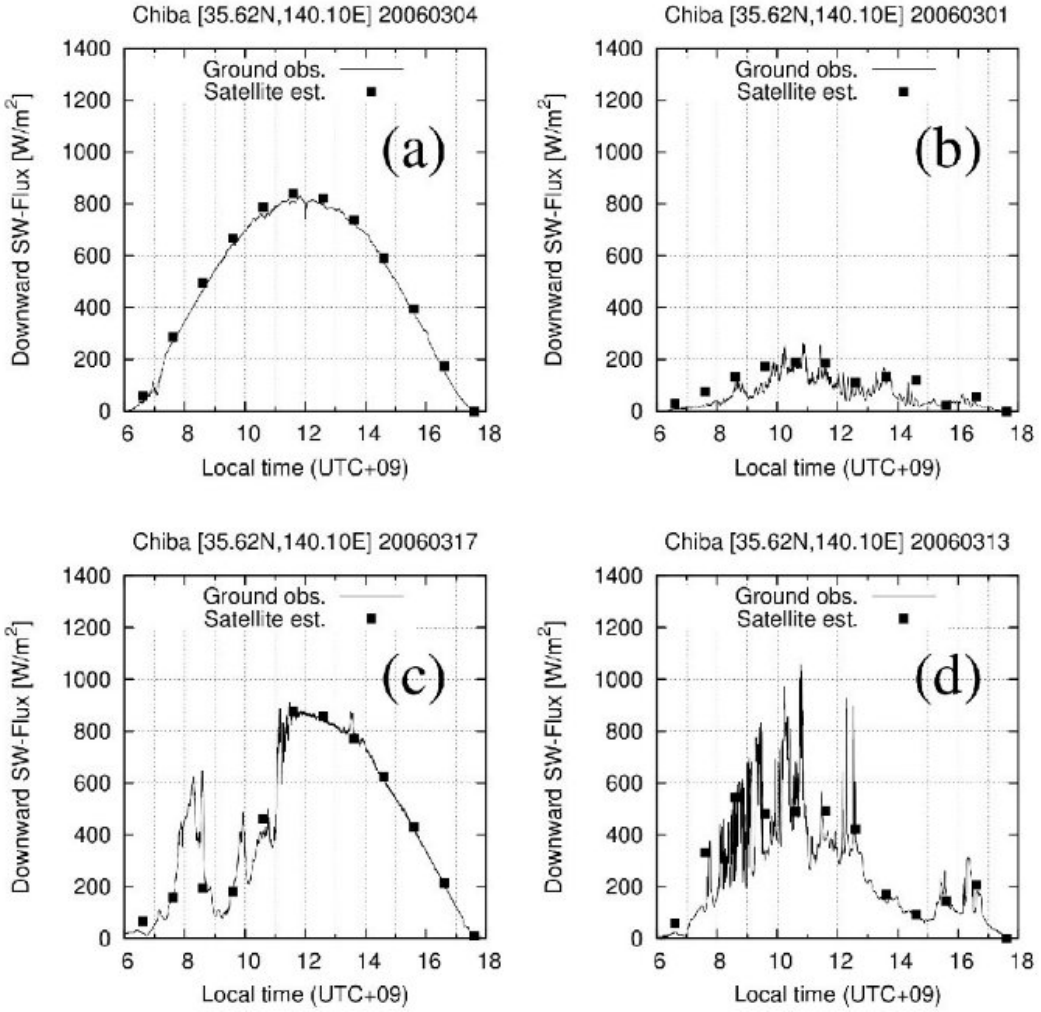
etc..

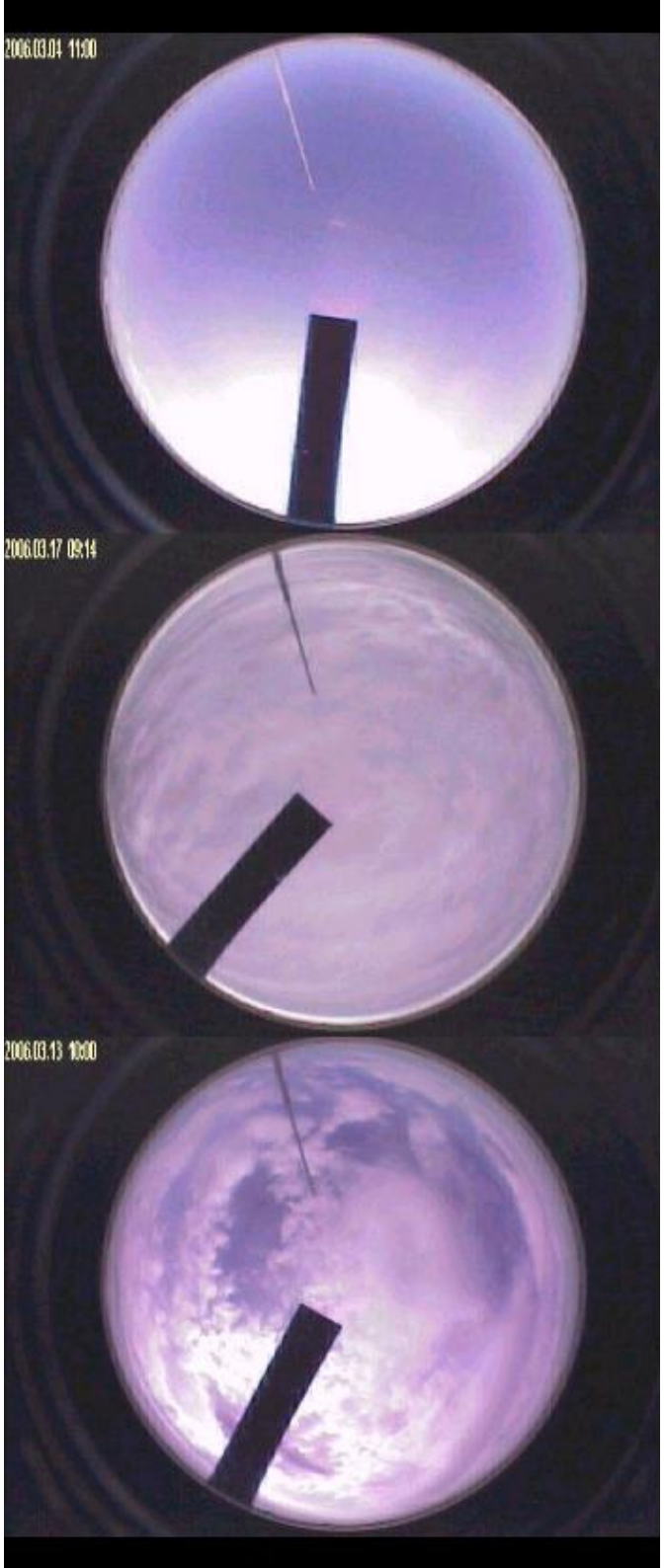
CERES

Atmospheric Radiation Division Science Team

SKYNET site validation

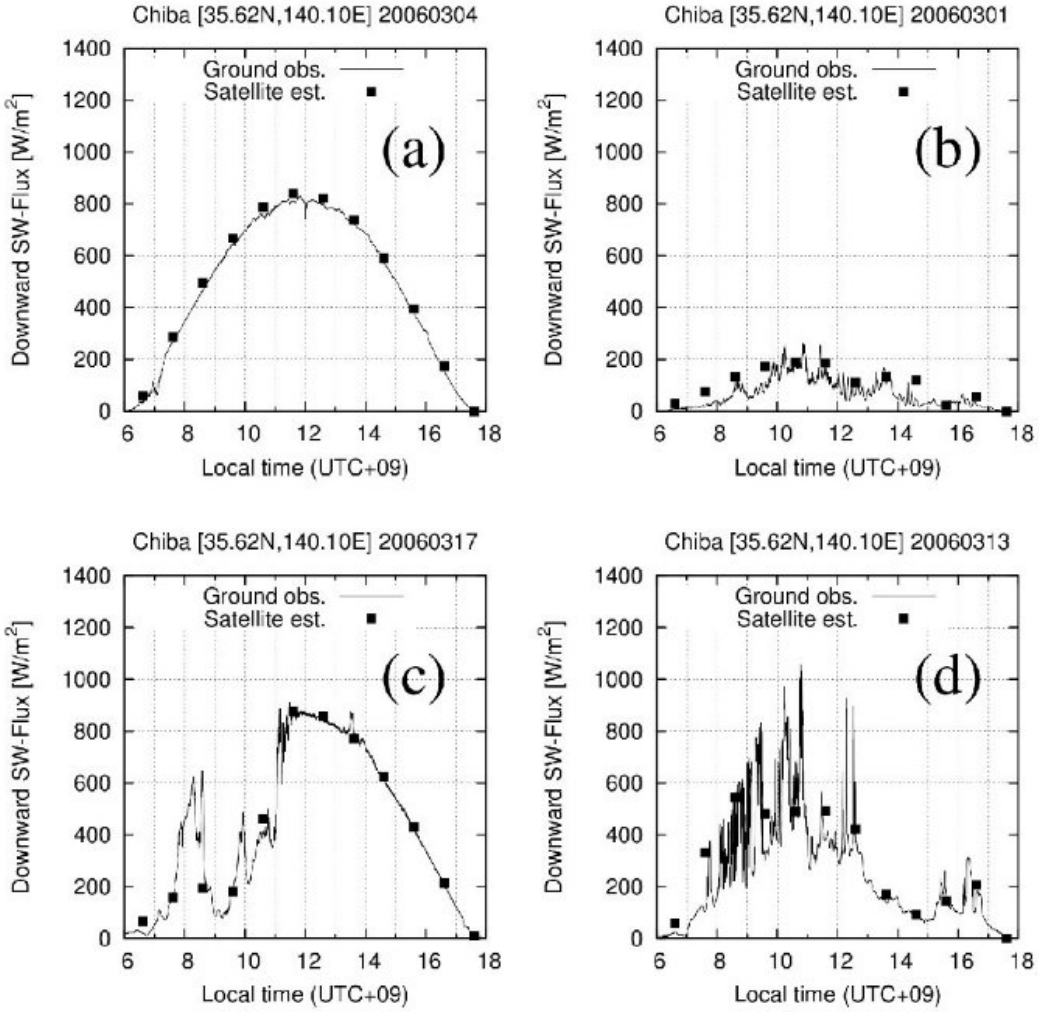
Validation of downward Shortwave flux at the surface, SKYNET/Chiba site

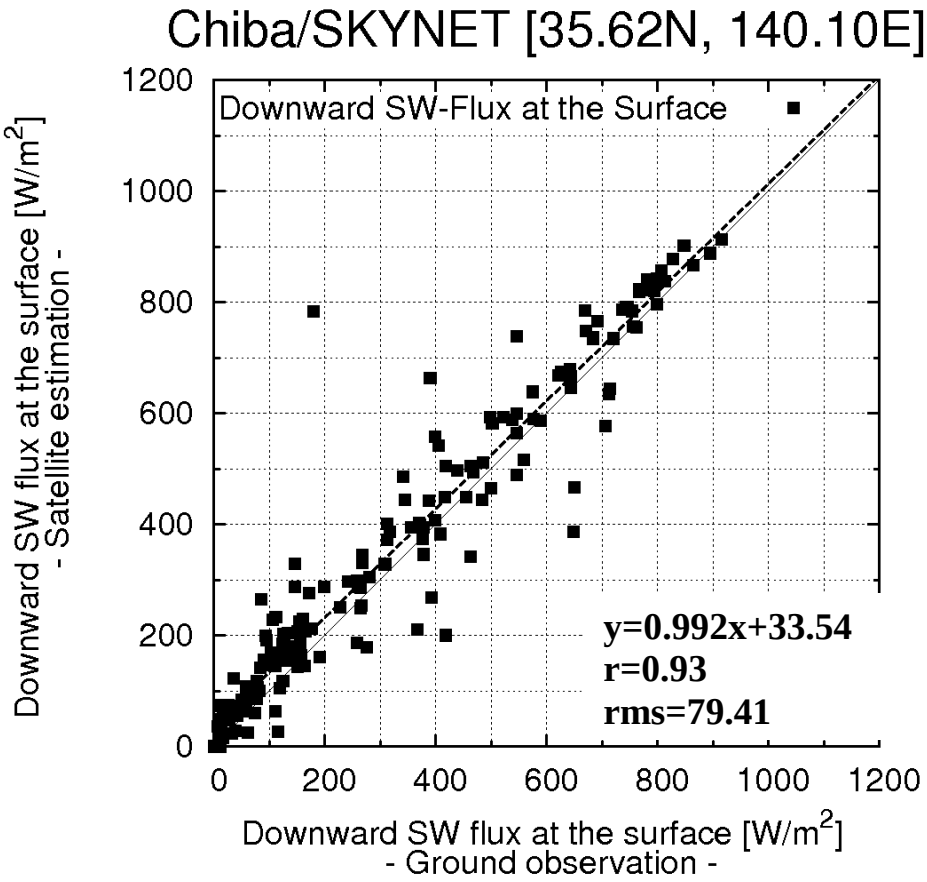




SKYNETsite validation

Validation of downward Shortwave flux at the surface, SKYNET/Chiba site



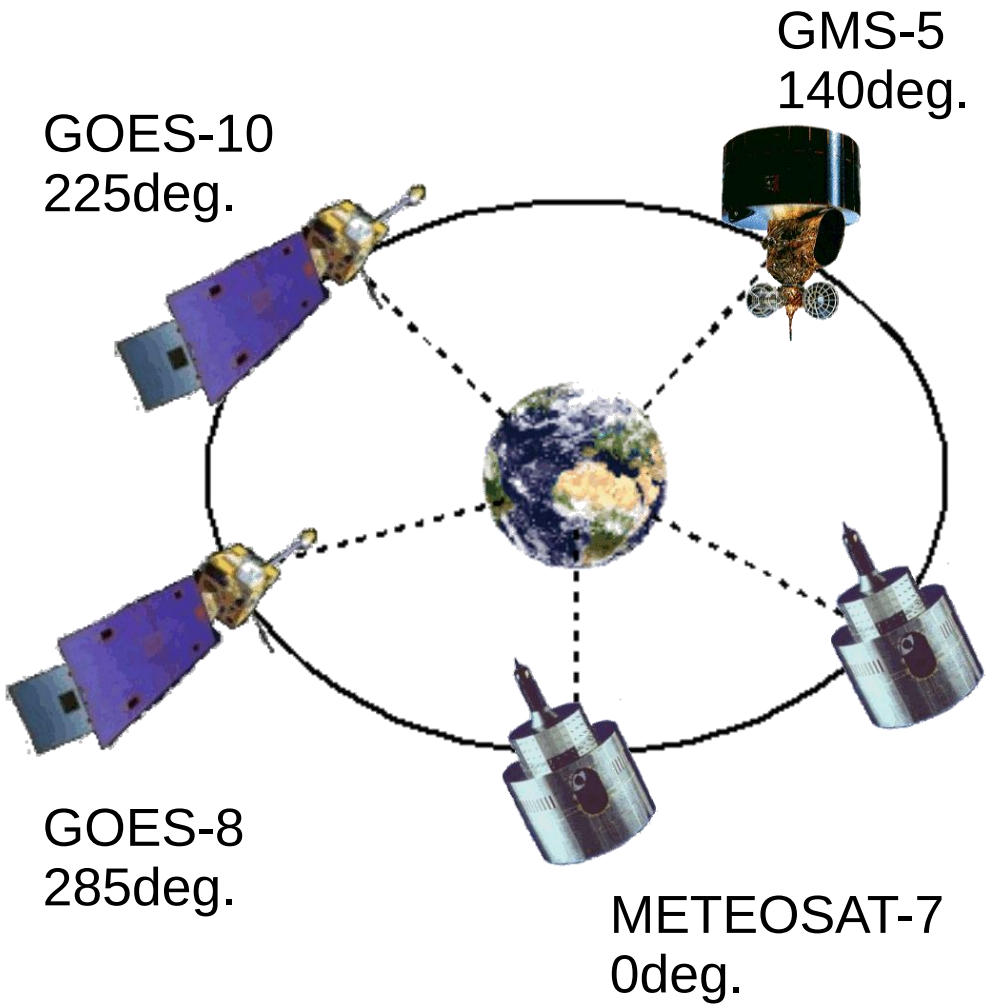


SKYNET chiba
2006/03

Global analysis

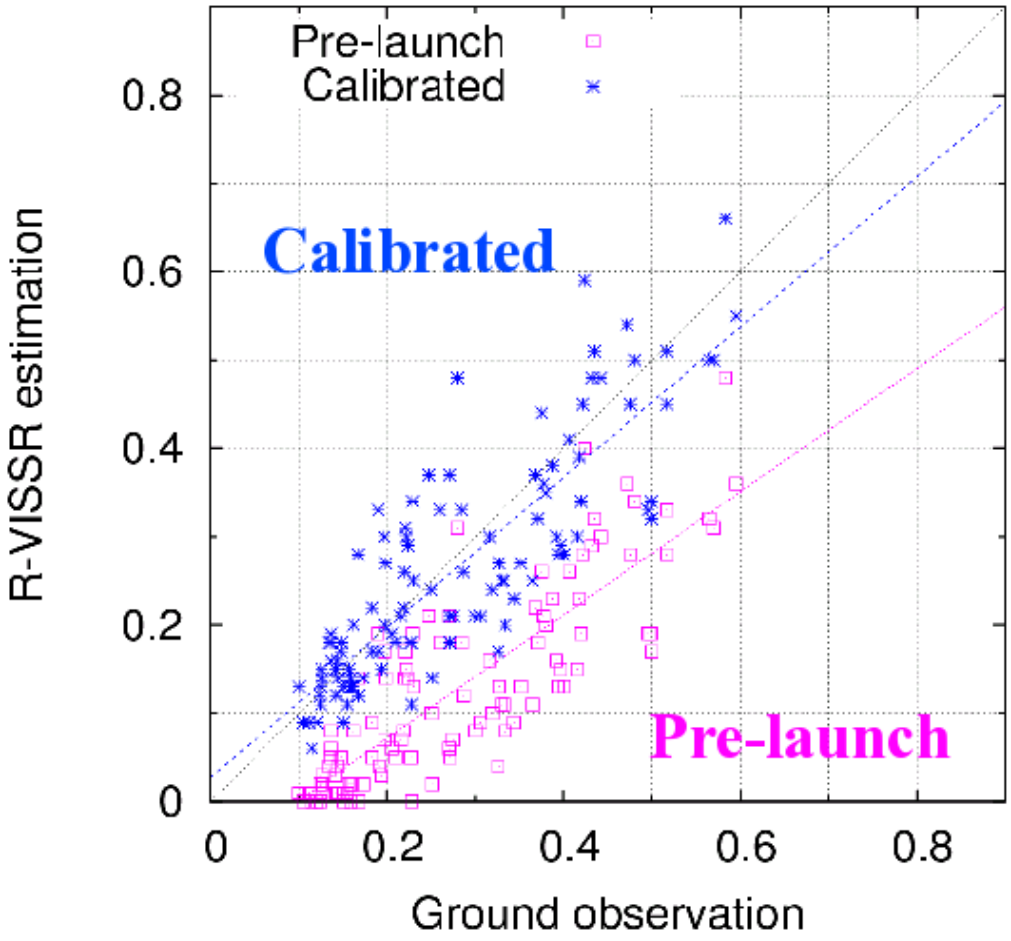
Estimation of SW radiation budget using five geostationary satellites

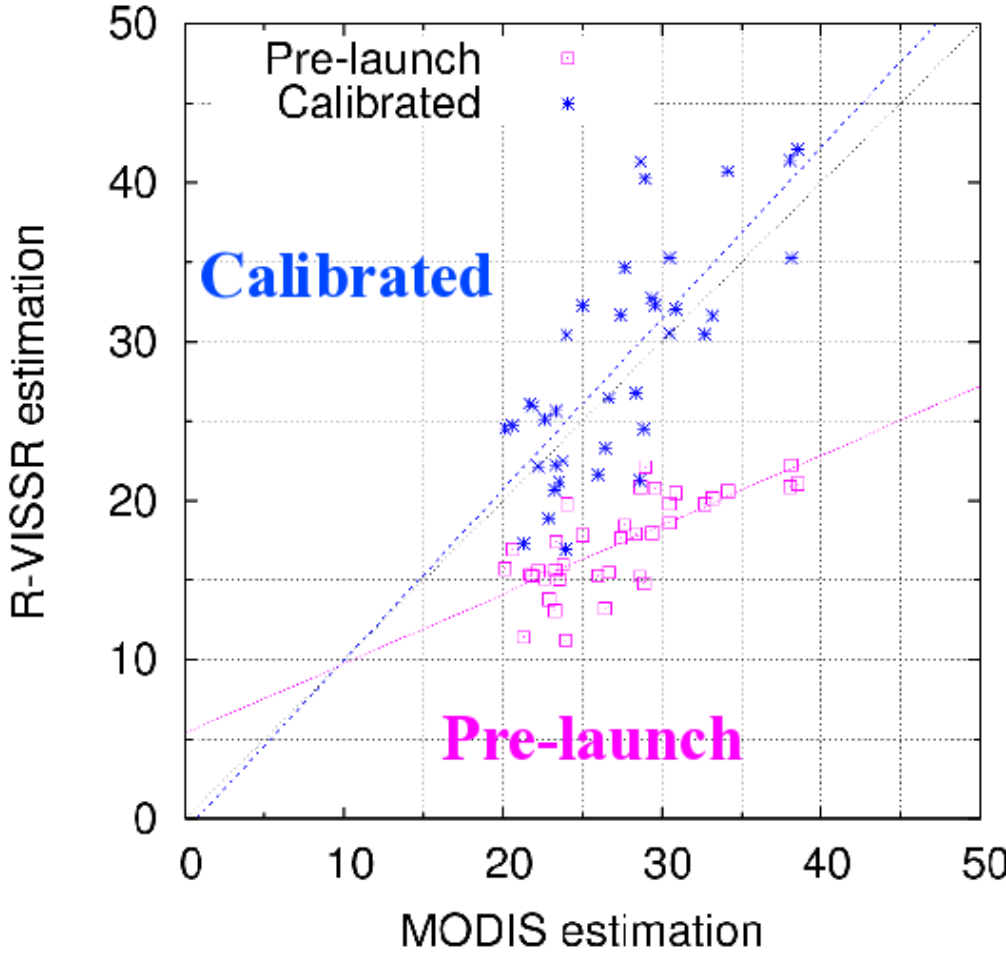
- **Calibration scheme**
- **Analysis algorithm**



GOES-8
GOES-10
GMS-5
METEOSAT-7
METEOSAT-5

APEX-E2 (2001/04)

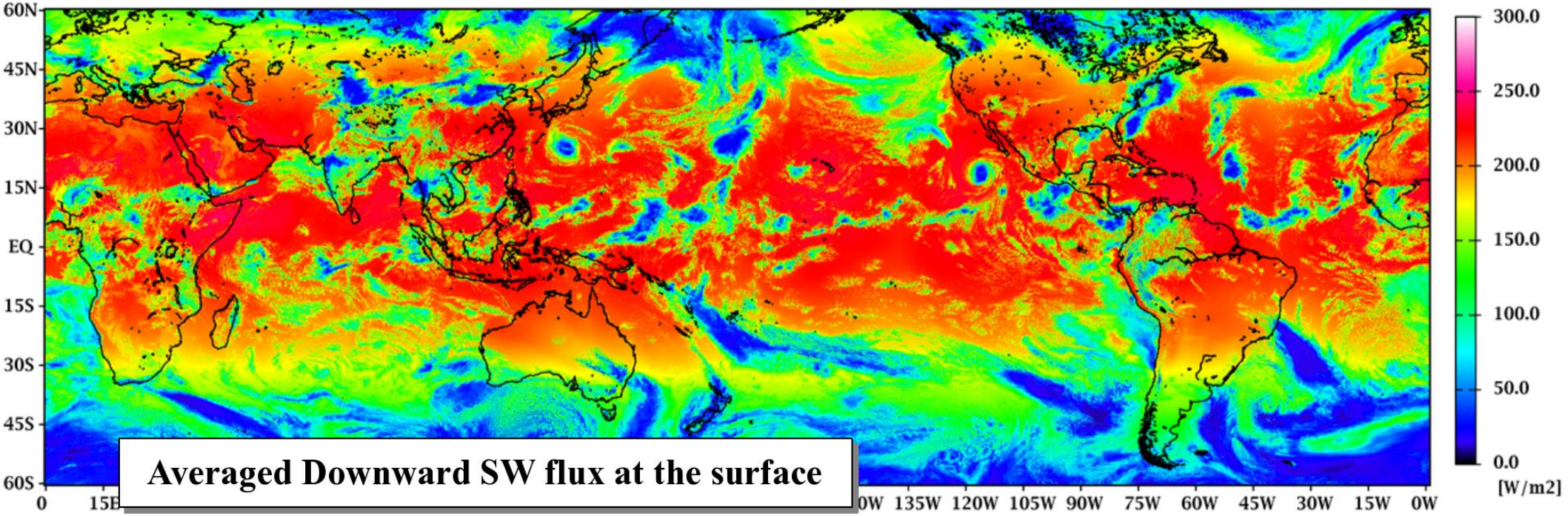




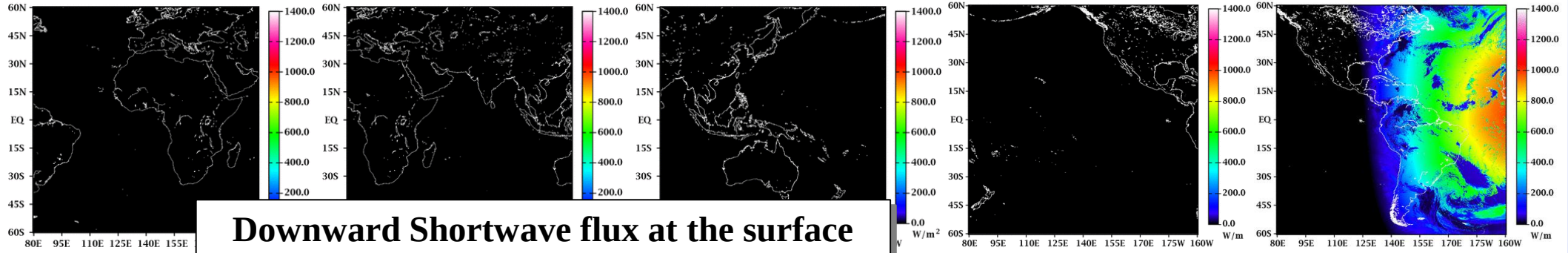
Aerosol
optical thickness

Cloud
optical thickness

2002/09/02 - 03

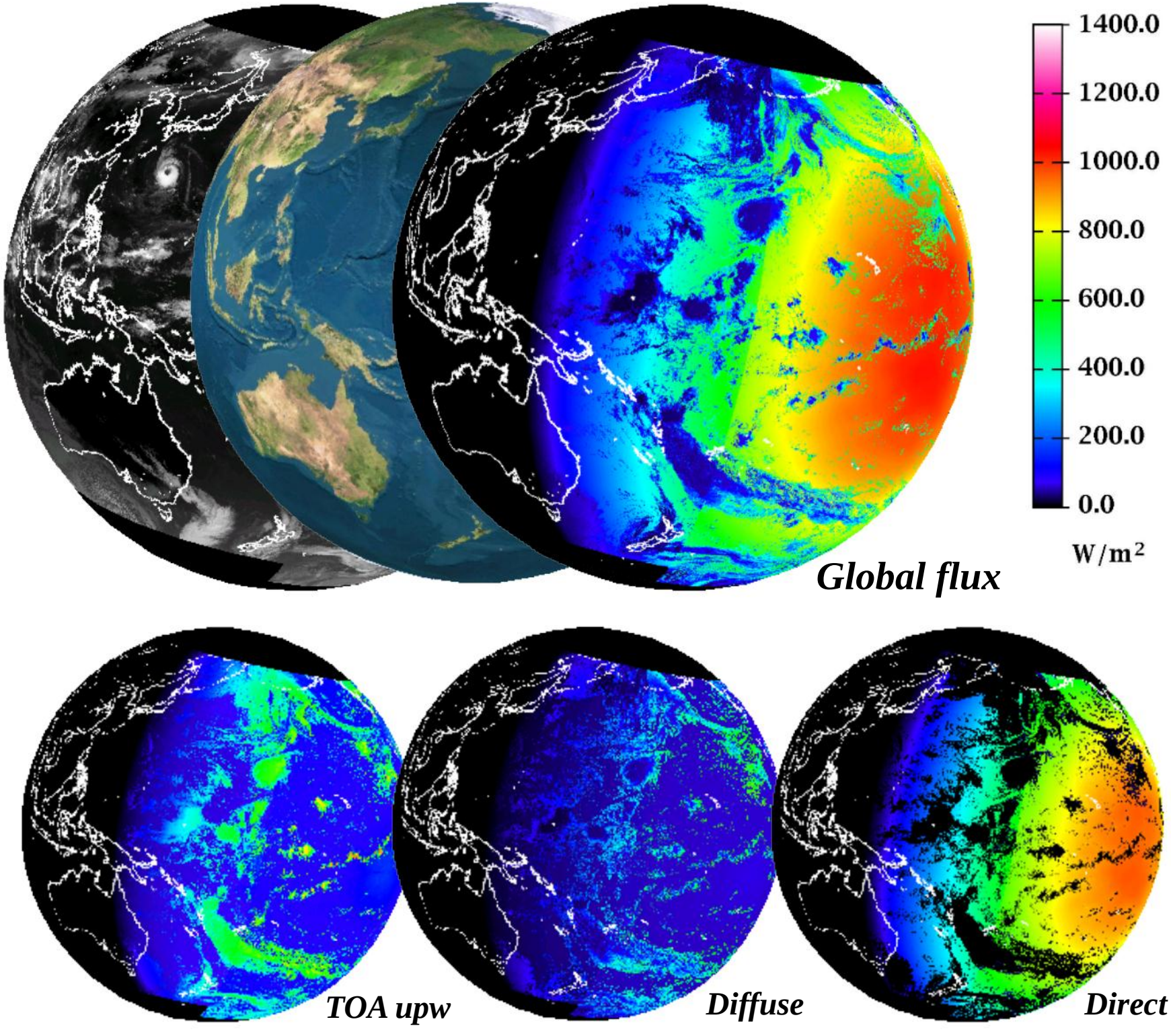


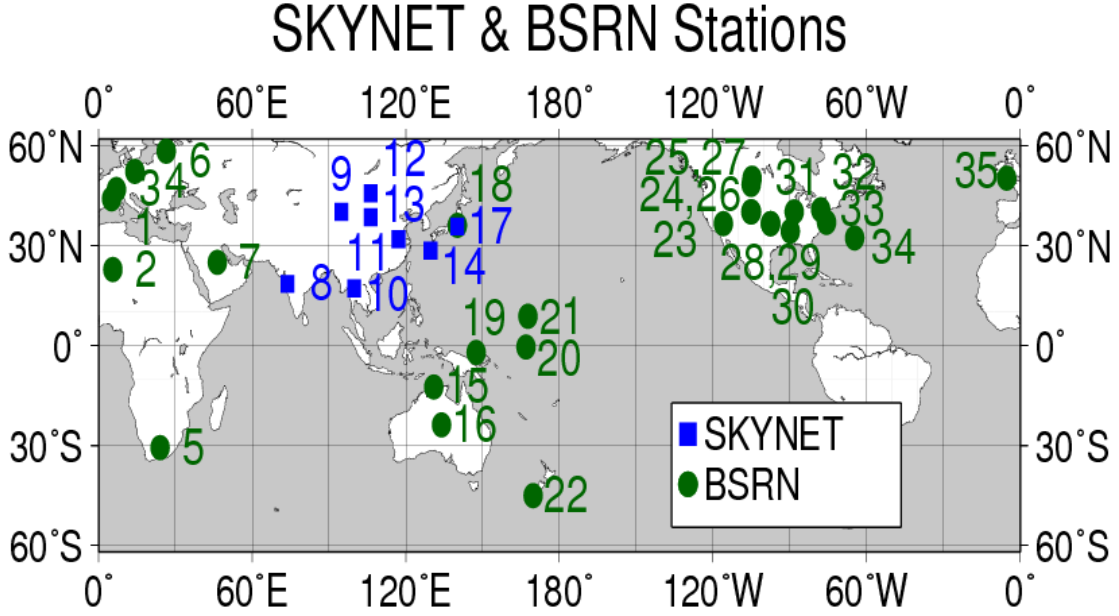
Averaged Downward SW flux at the surface

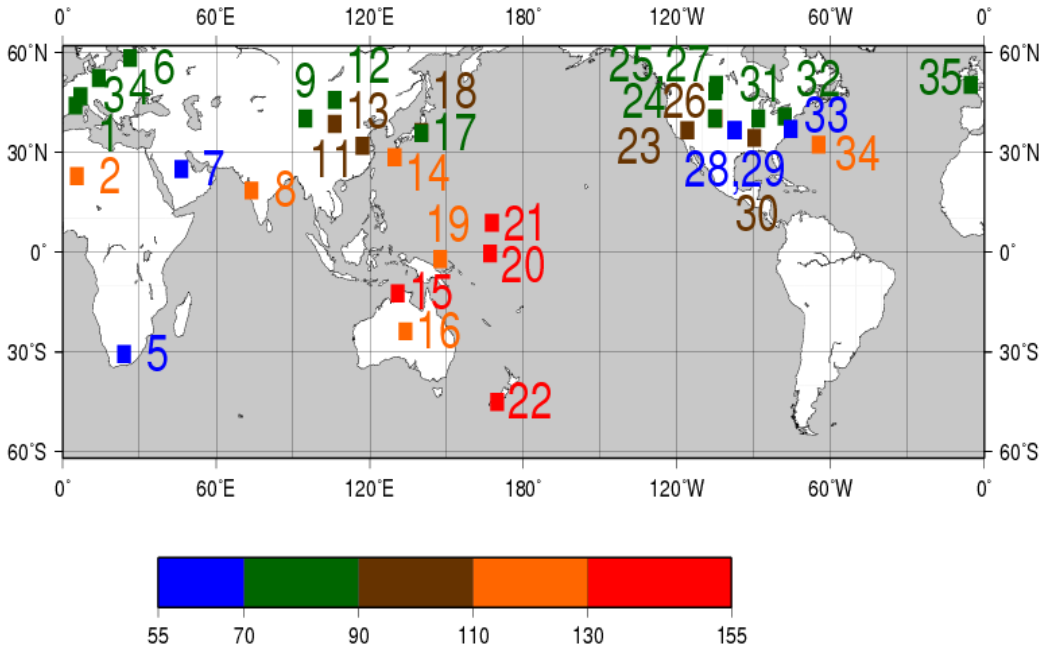


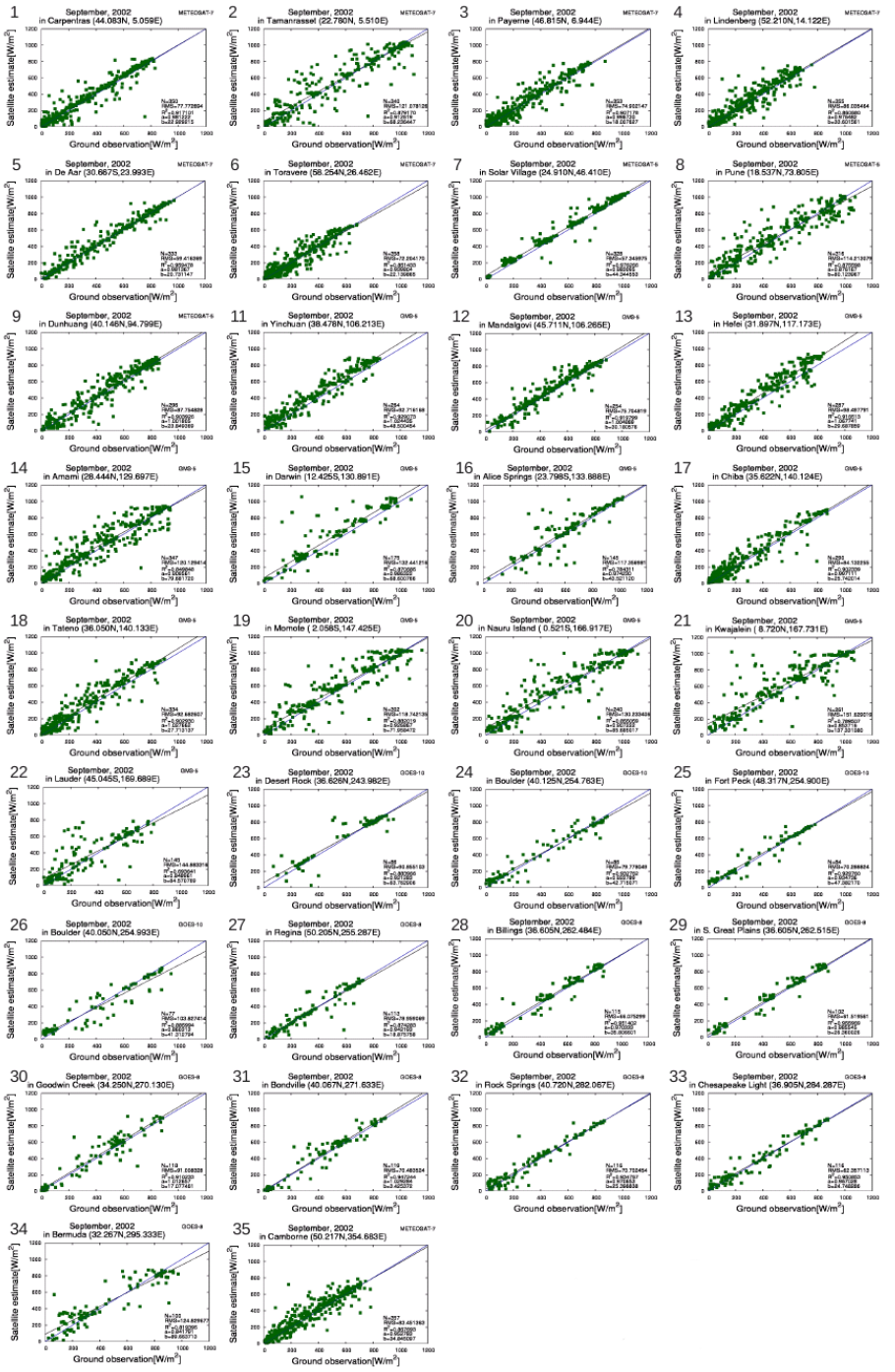
Downward Shortwave flux at the surface

METEOSAT-7	METEOSAT-5	GMS-5	GOES-10	GOES-8
0 deg.	63 deg.	140 deg.	225 deg.	285 deg.

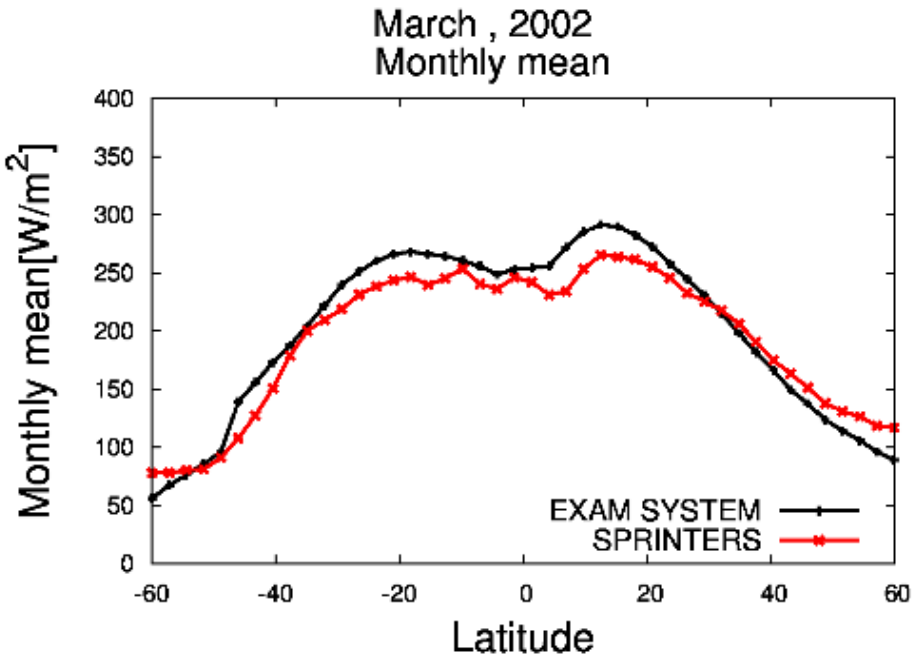

1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
W/m²
Global flux
TOA upw
Diffuse
Direct


SKYNET & BSRN Stations
0°
60°E
120°E
180°
120°W
60°W
0°
60°N
30°N
0°
30°S
60°S
SKYNET
BSRN

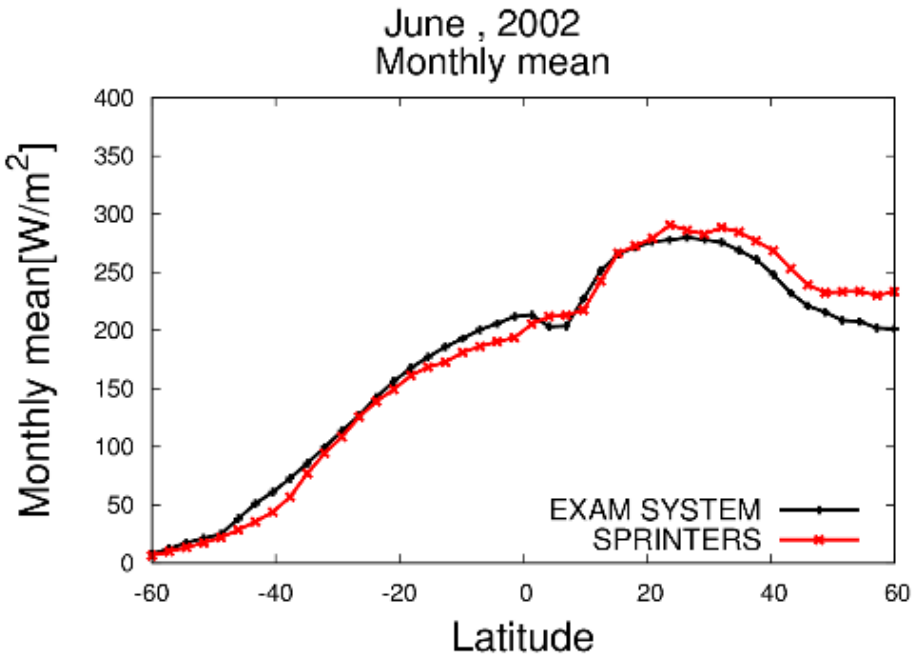

Root Mean Square(RMS)
55
70
90
110
130
155

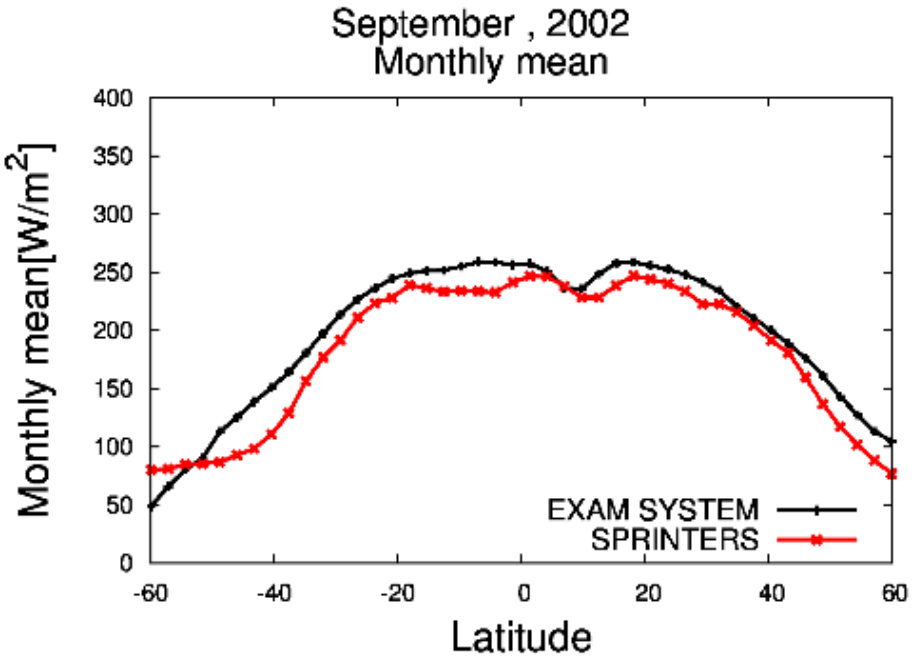

Satellite estimate[W/m²]
Ground observation[W/m²]

Validation of GCM surface SW radiation

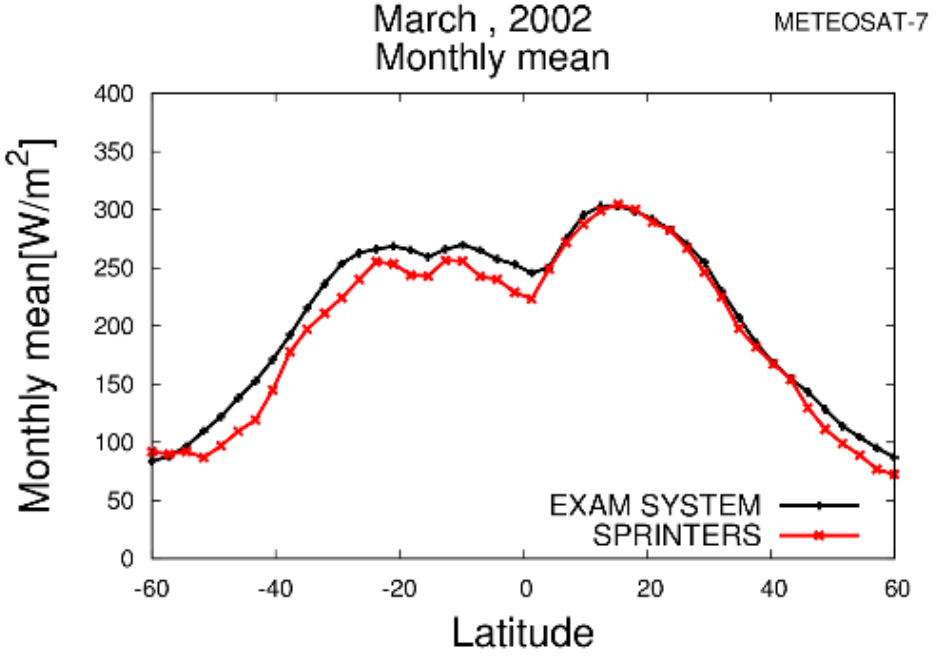


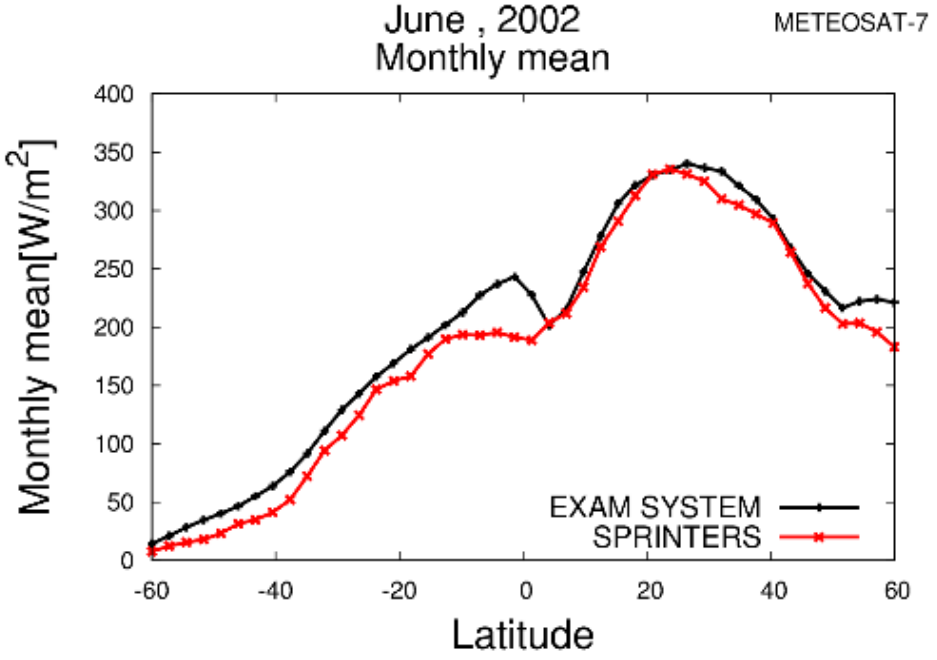
Global Zonal mean

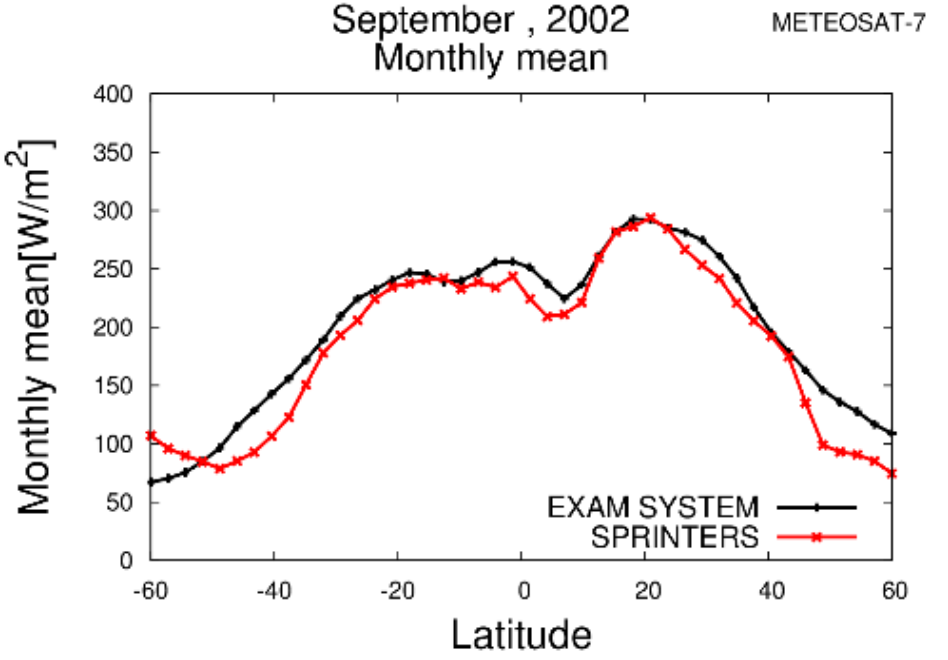




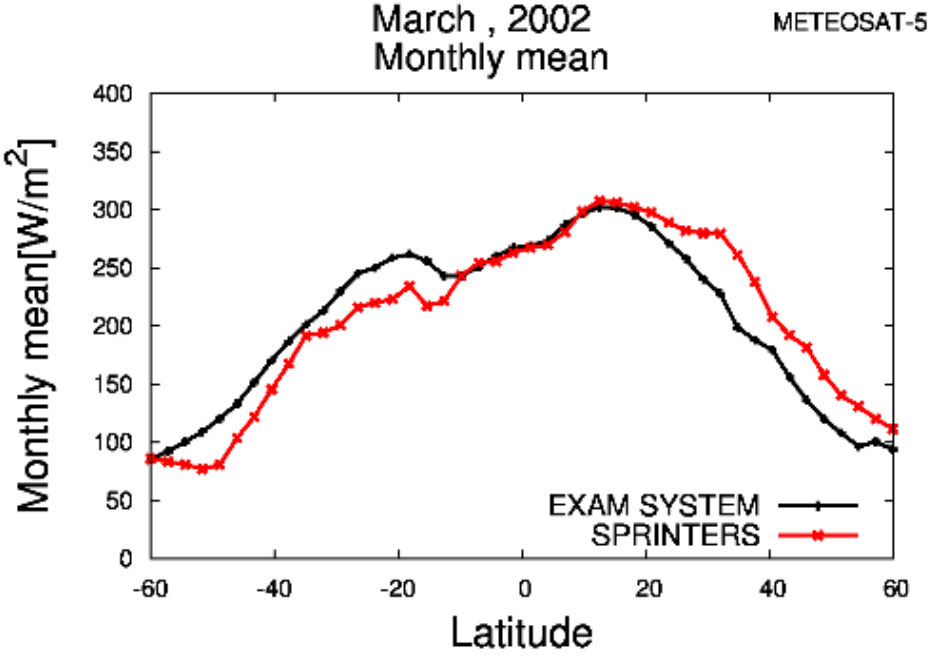
METEOSAT-7
Zonal mean

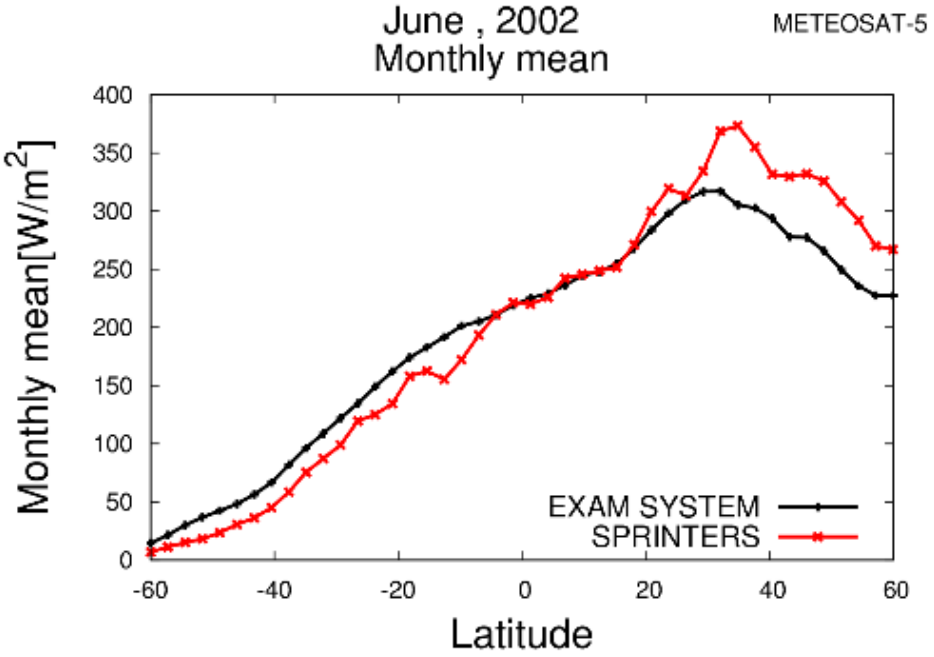


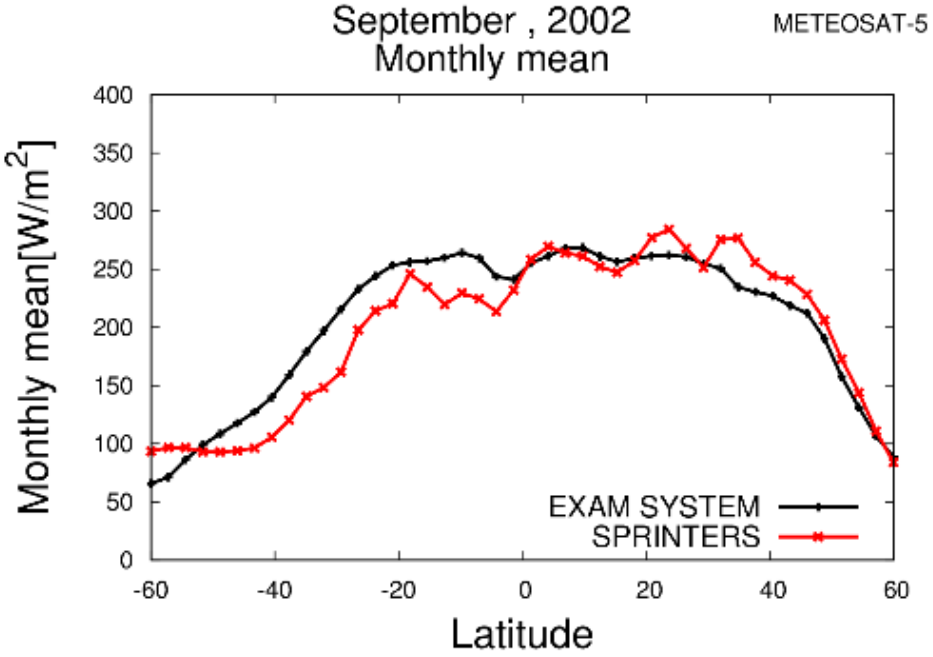




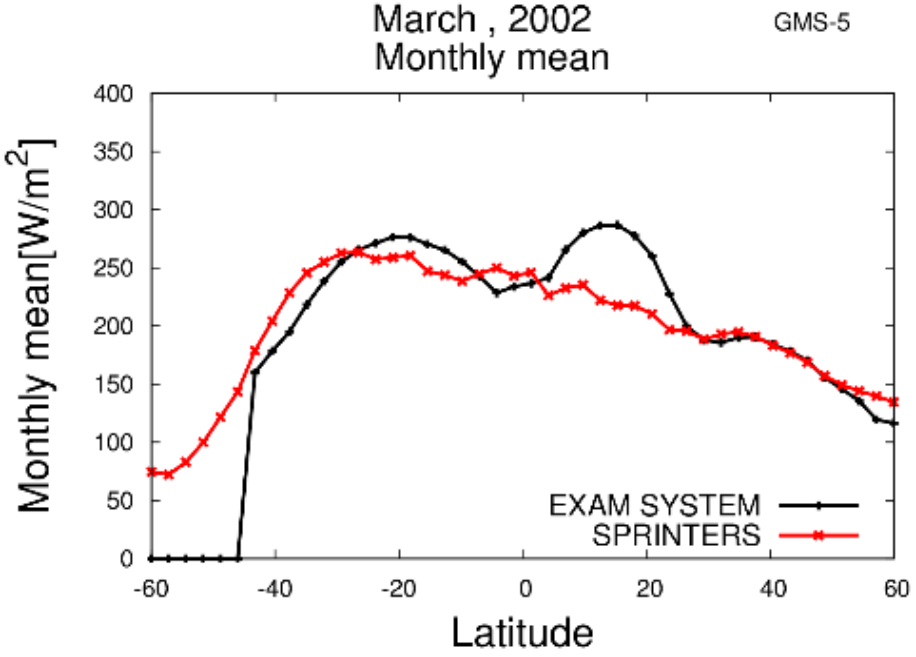
METEOSAT-5
Zonal mean

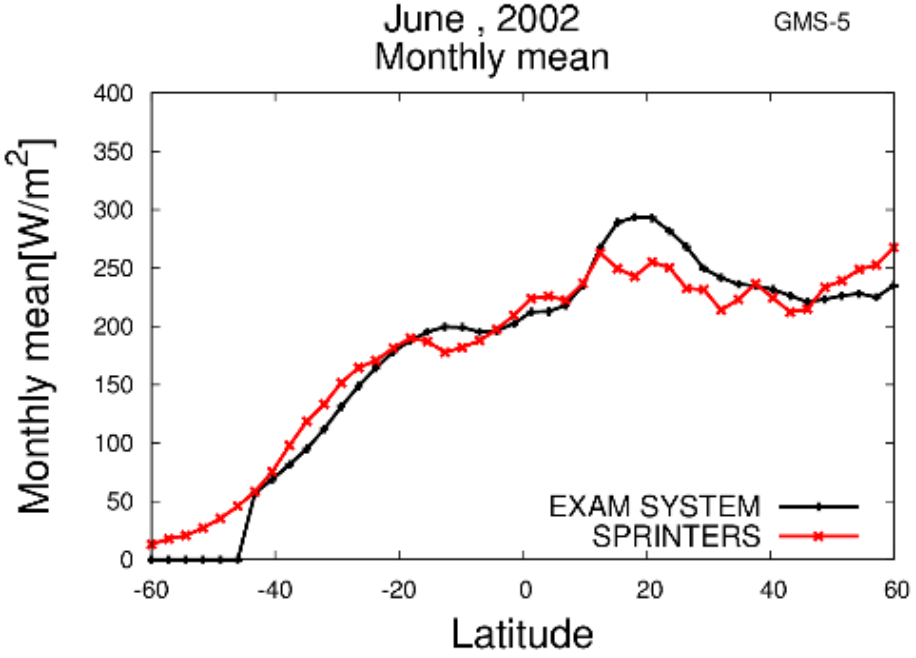


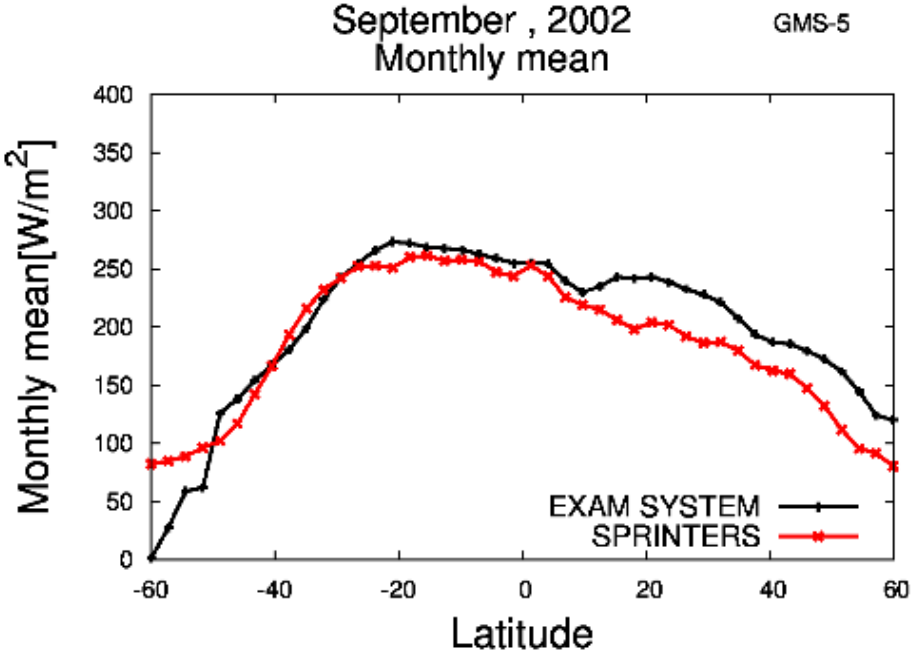




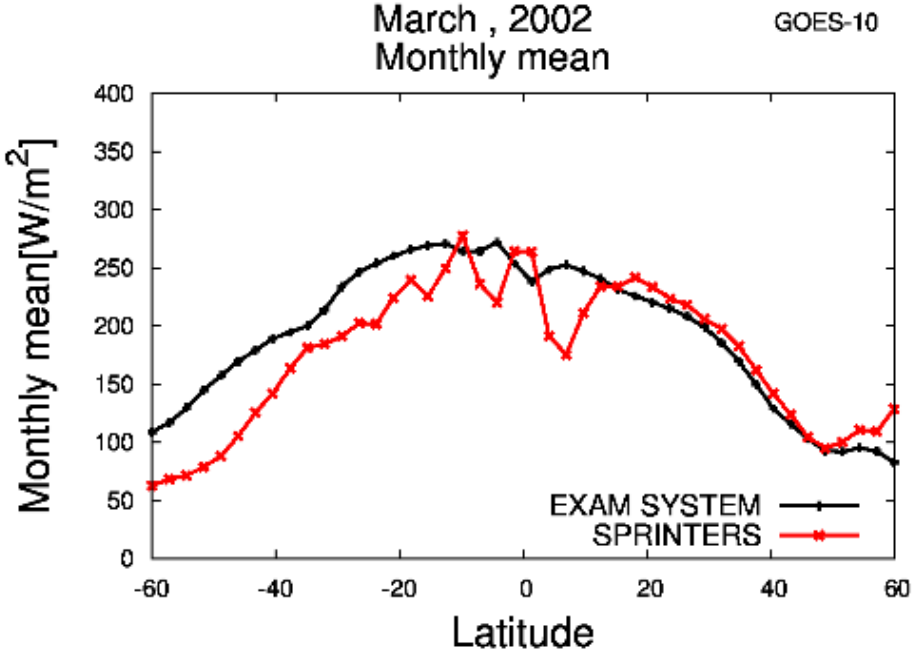
GMS-5
Zonal mean

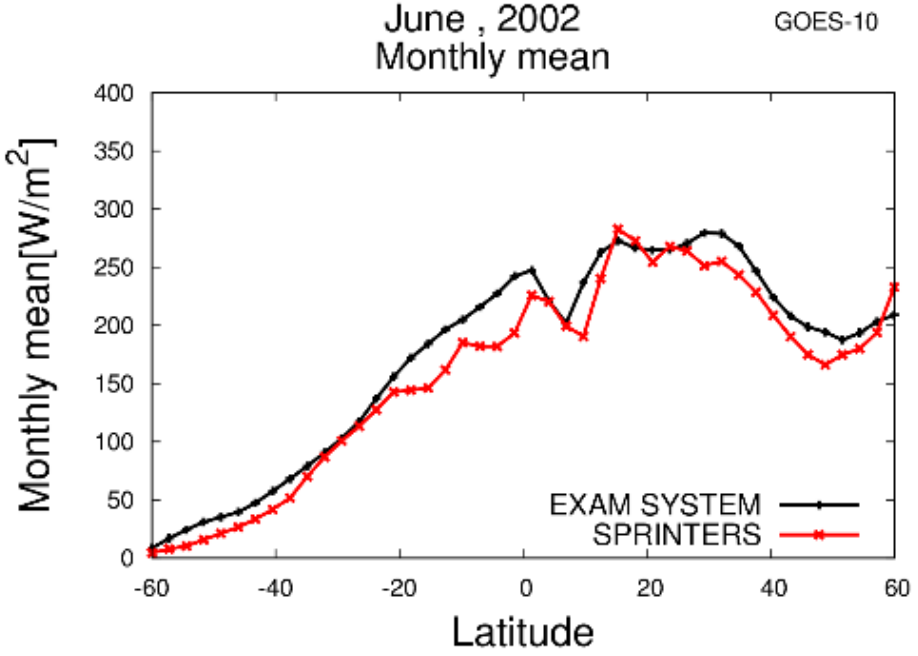


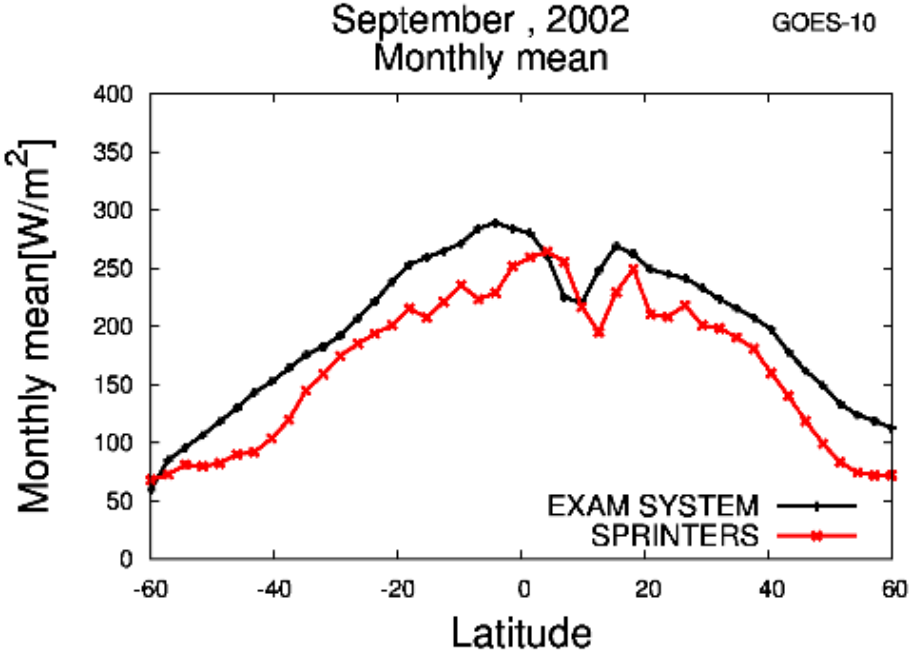




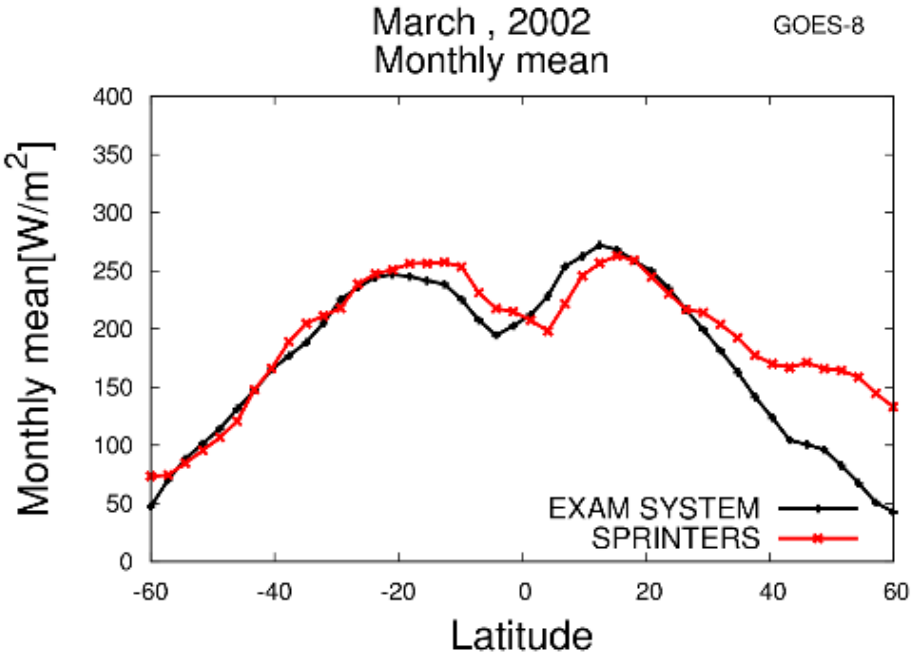
GOES-10
Zonal mean

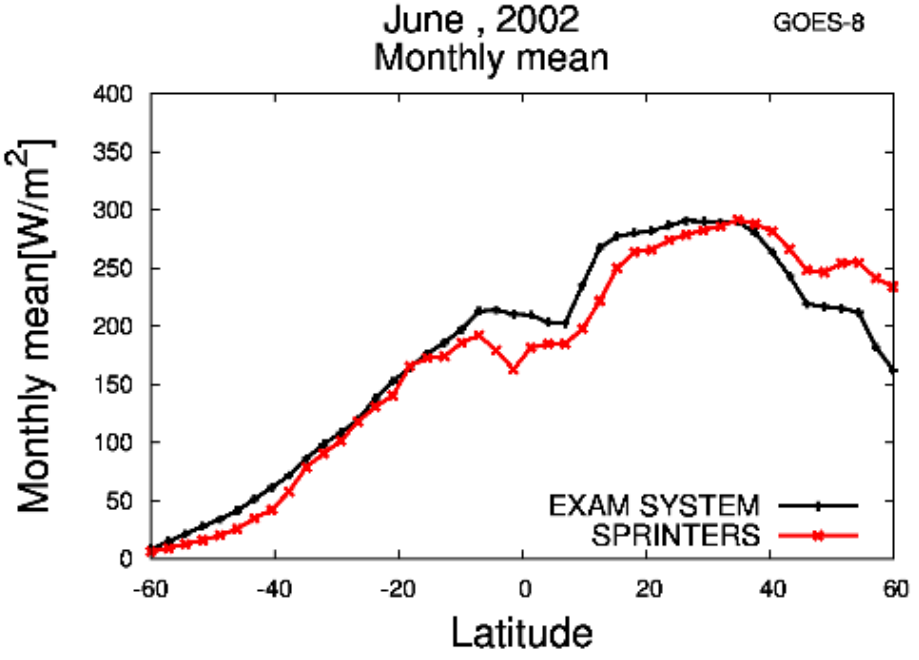


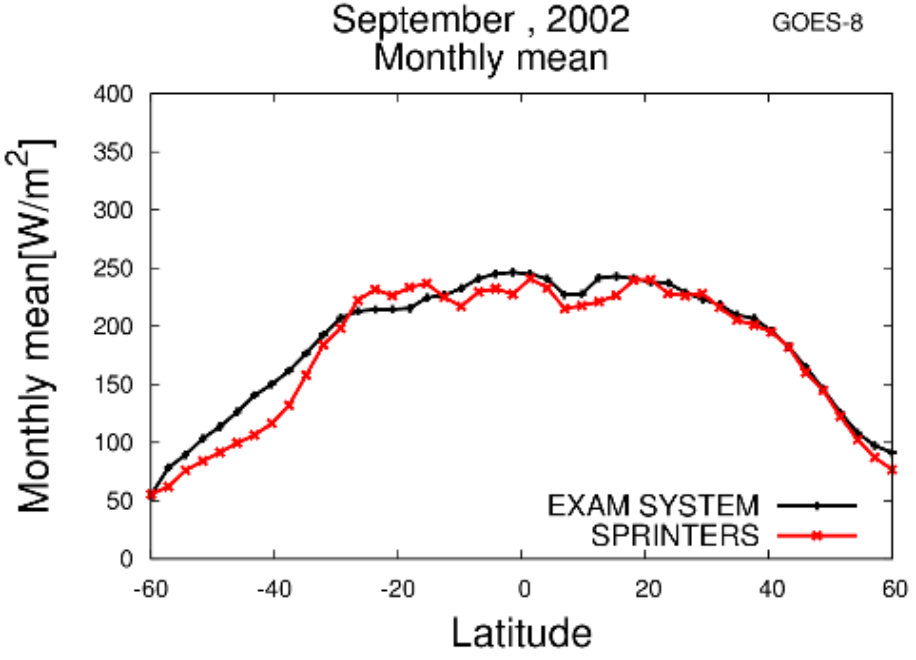




GOES-8
Zonal mean

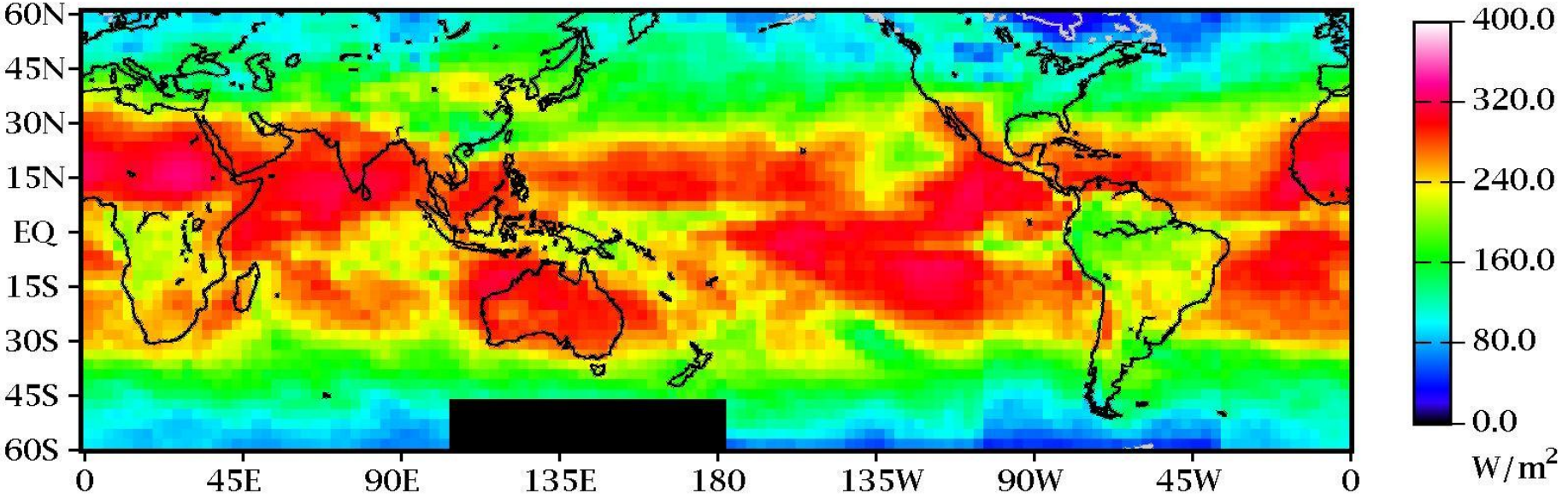




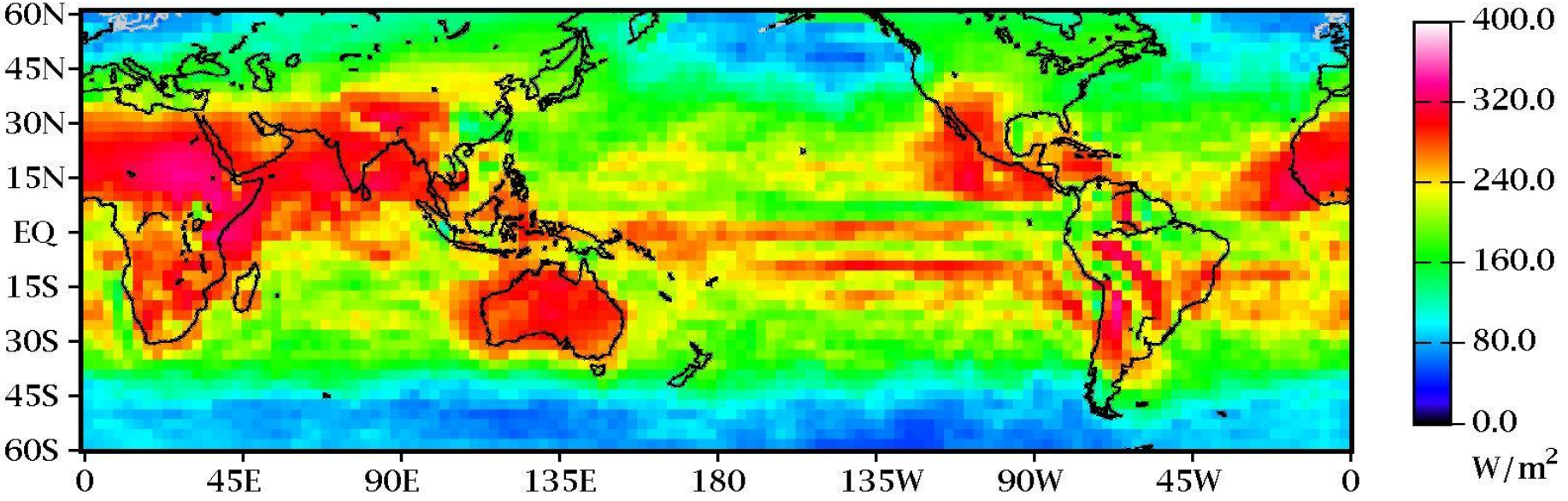


March, 2002

EXAM SYSTEM

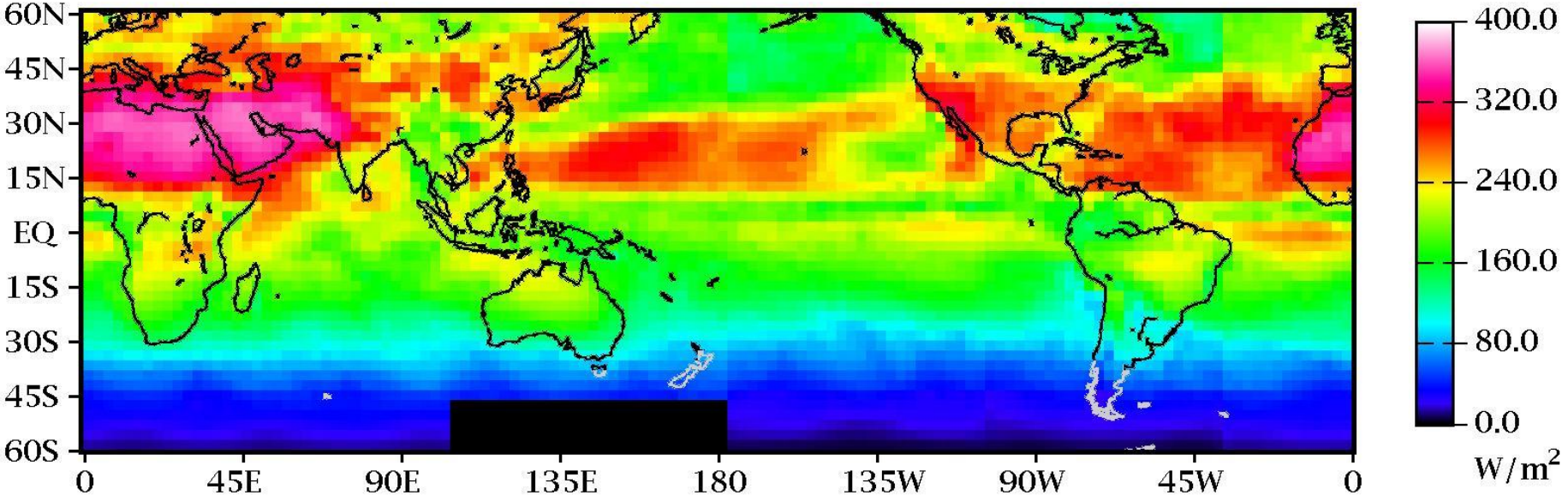


SPRINTERS

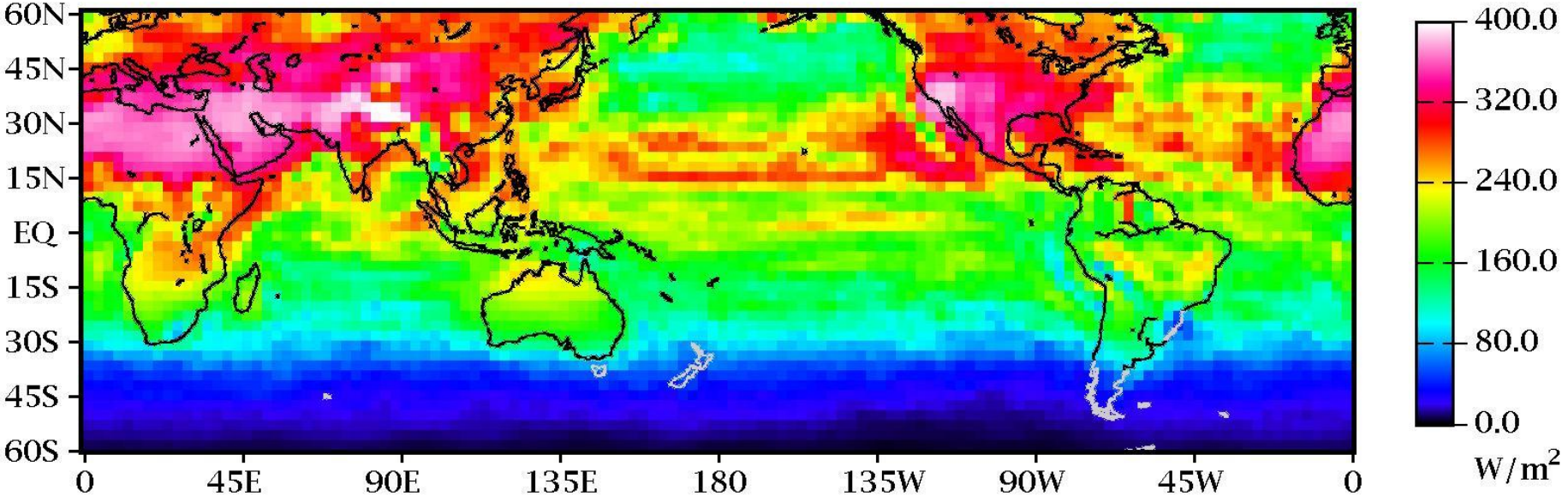


June, 2002

EXAM SYSTEM

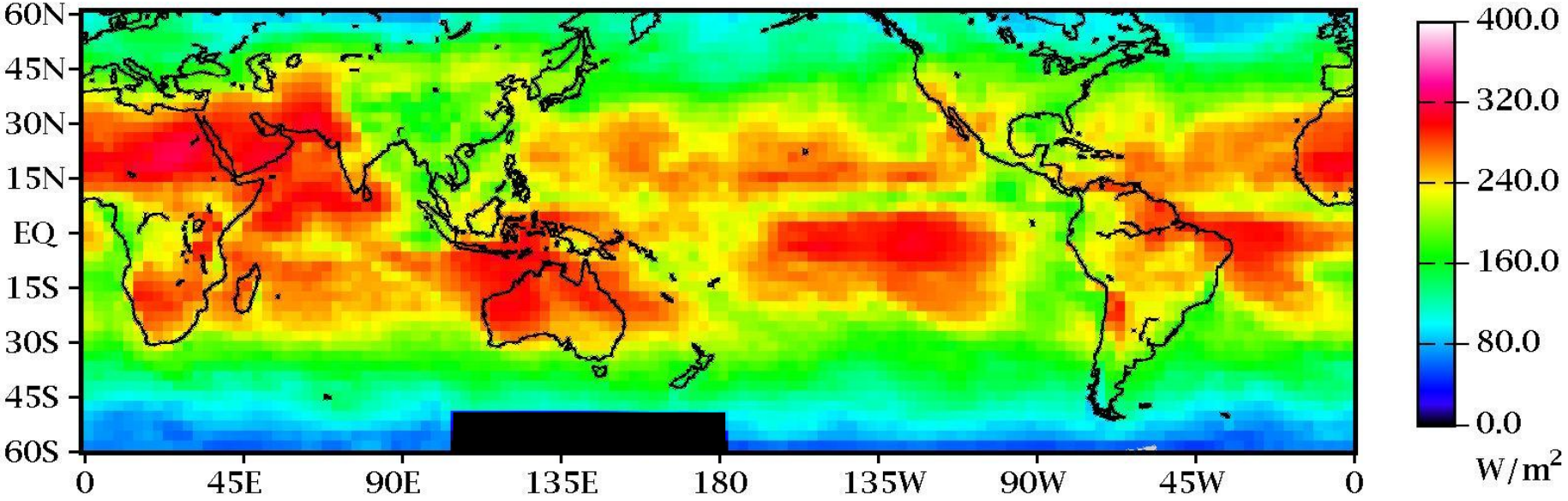


SPRINTERS

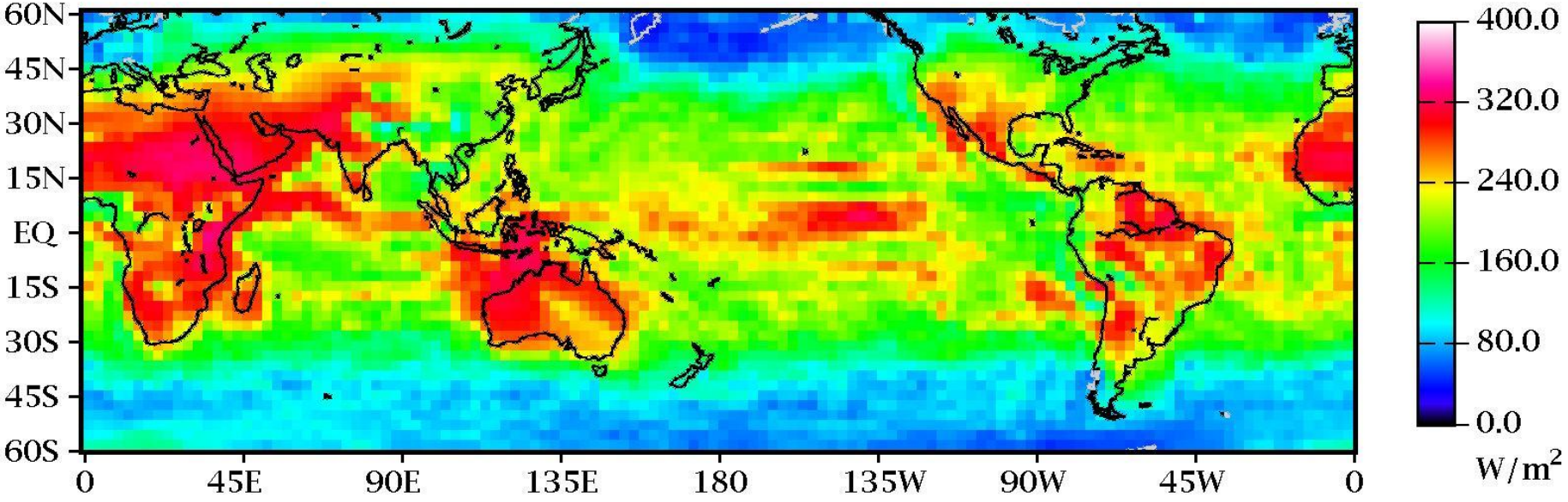


September, 2002

EXAM SYSTEM

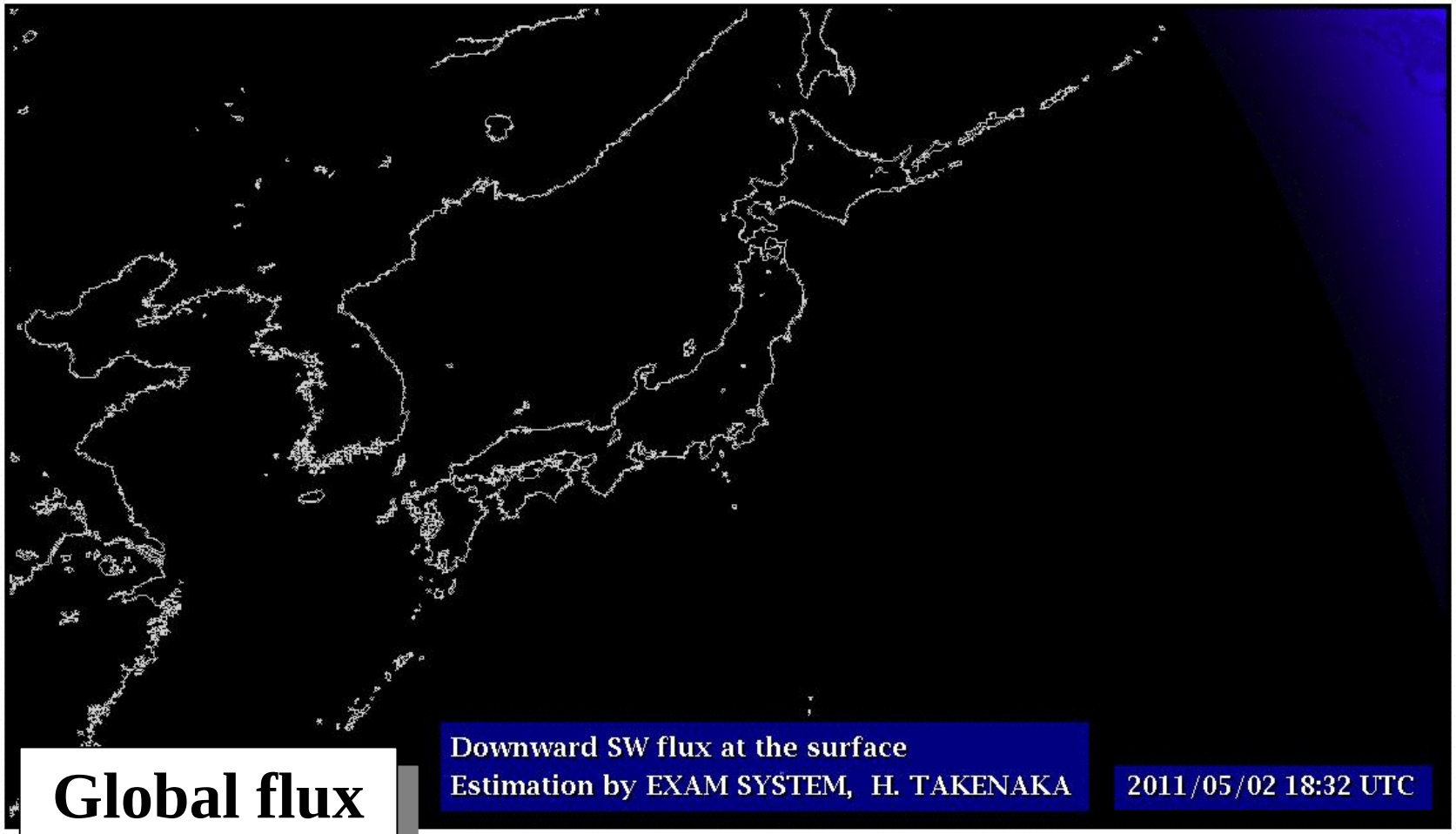


SPRINTERS

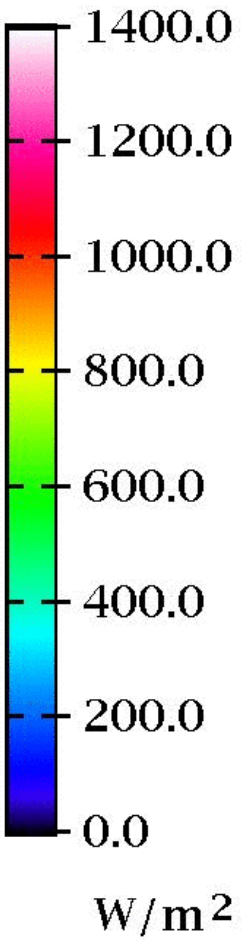


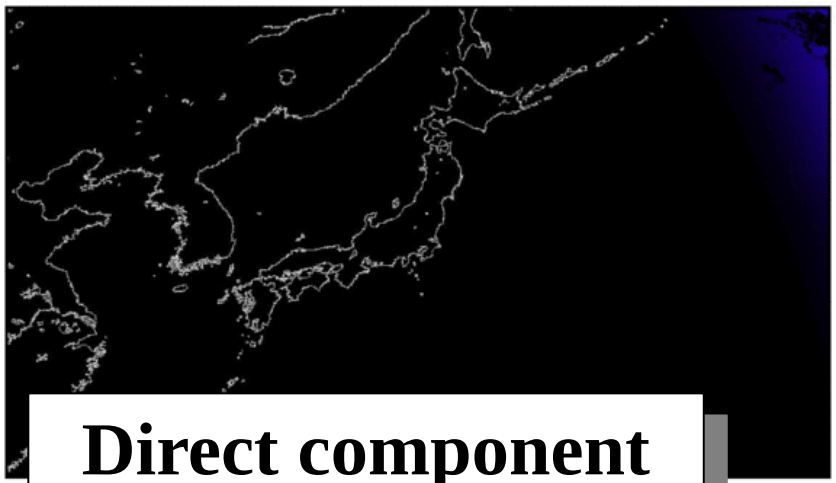
Application to PV power generation


LP PYRA 03 S=7.20 mV/(kW/m²) CE
S/N. 10009357

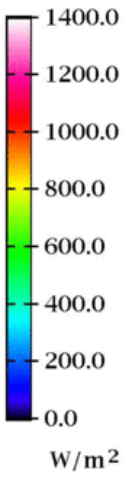


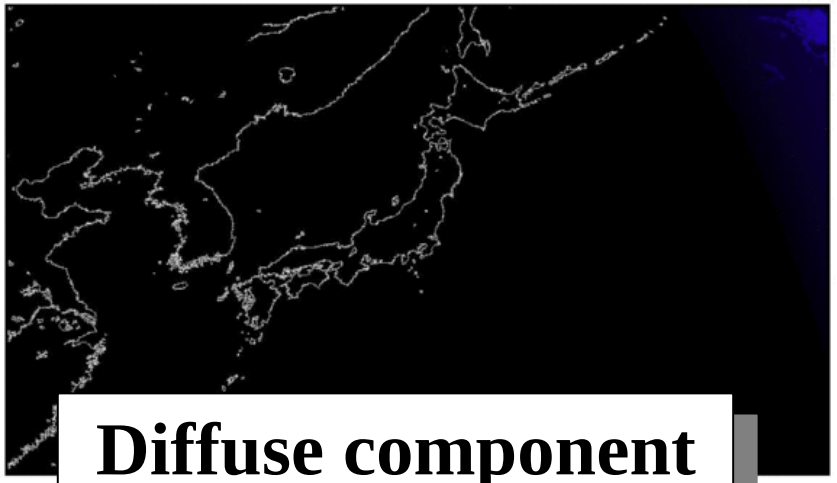
Global flux



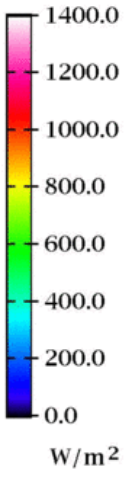


Direct component

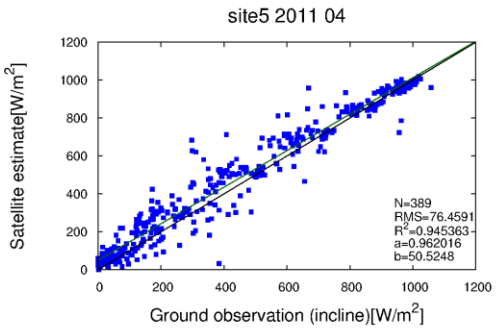


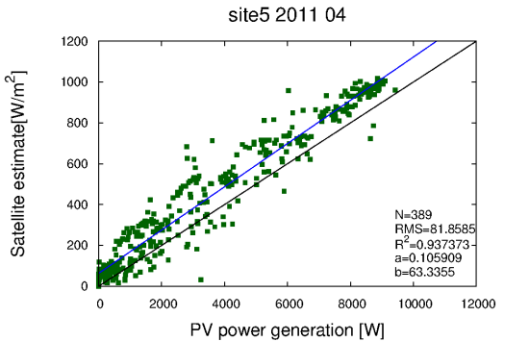


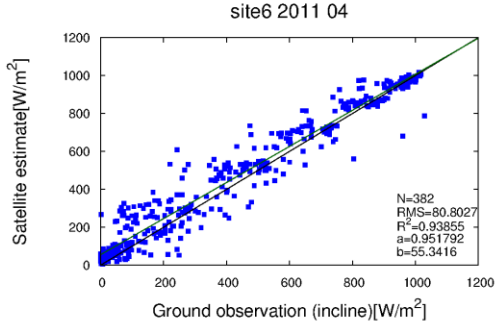
Diffuse component

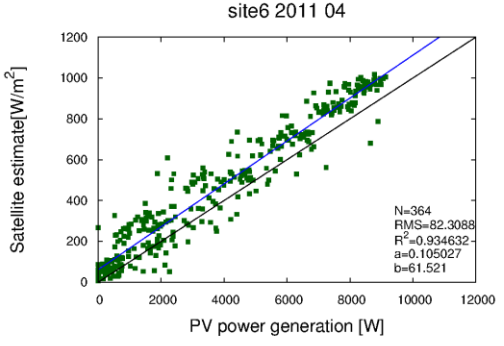


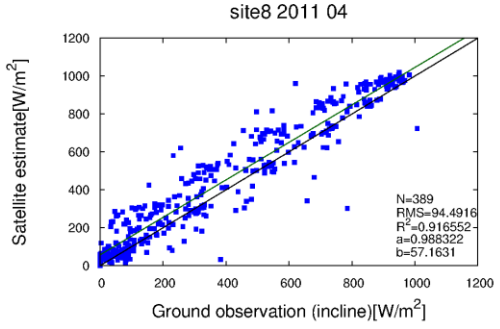
Instantaneous

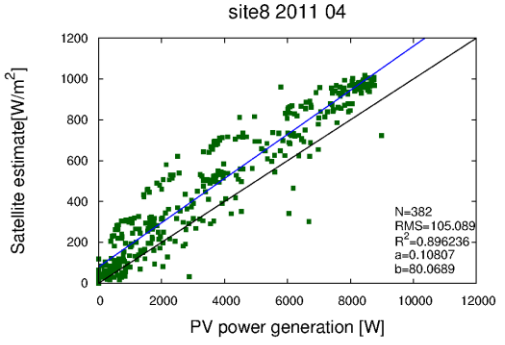


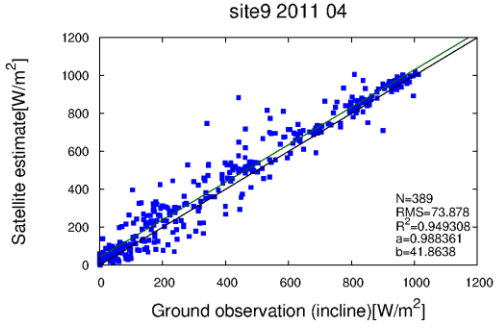


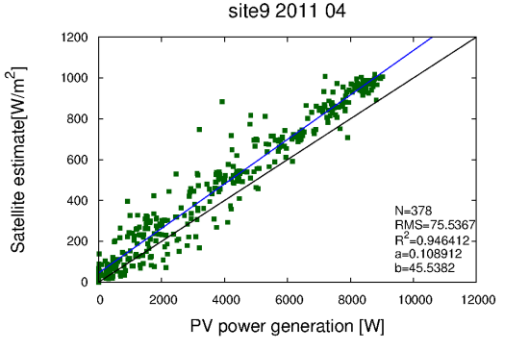




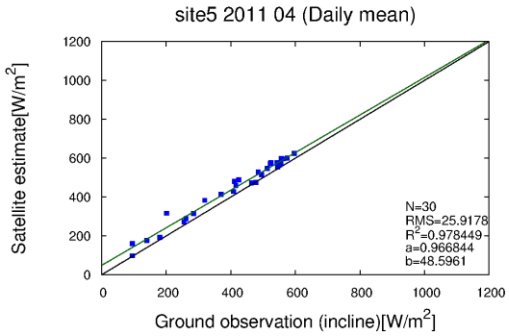


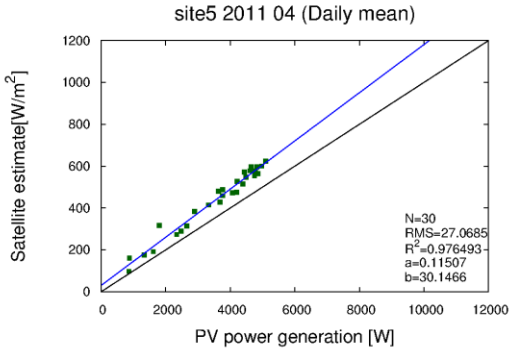


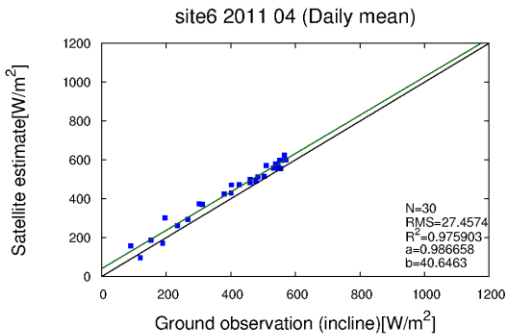


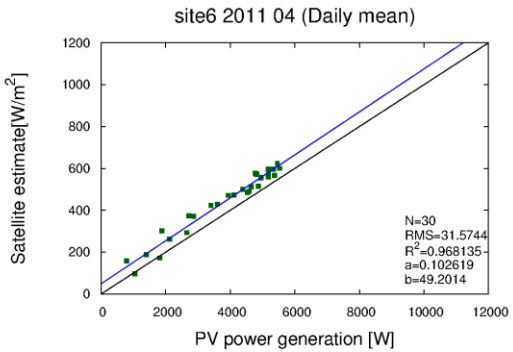


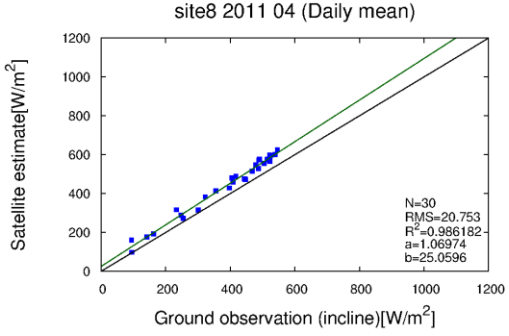
Daytime mean

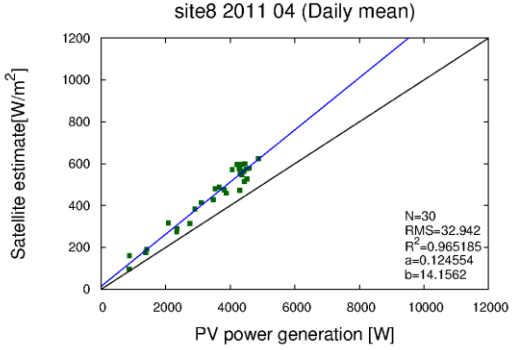


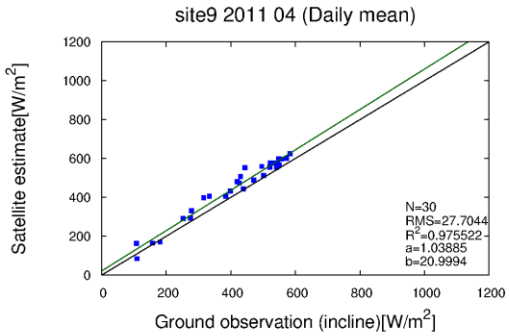


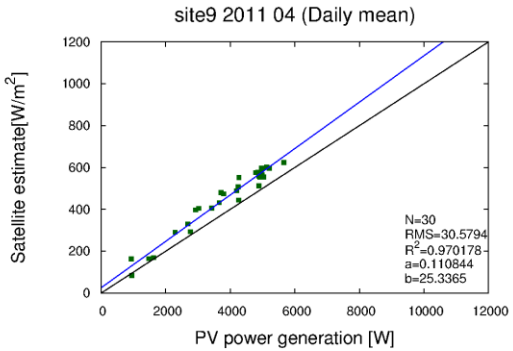


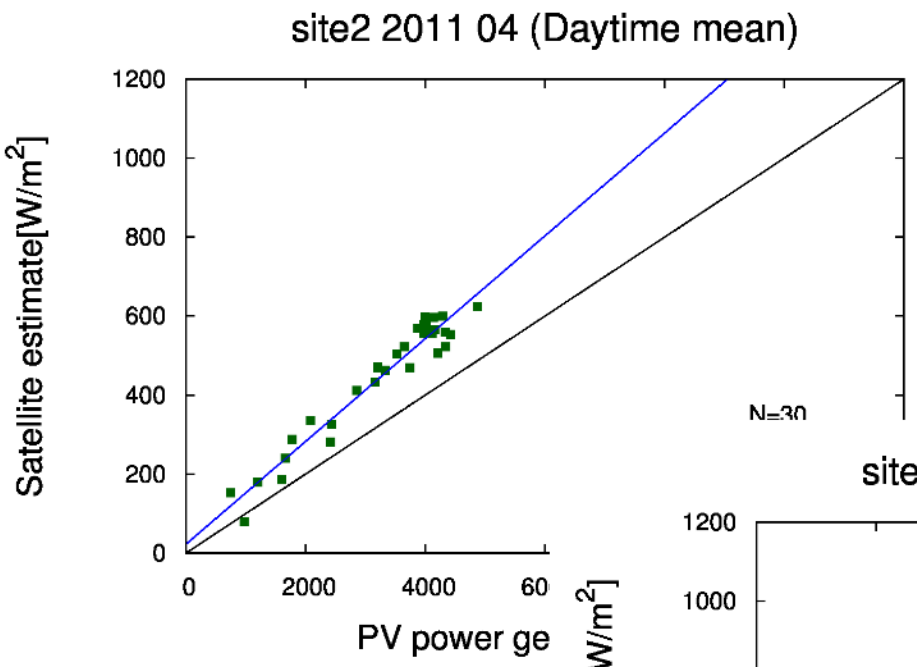




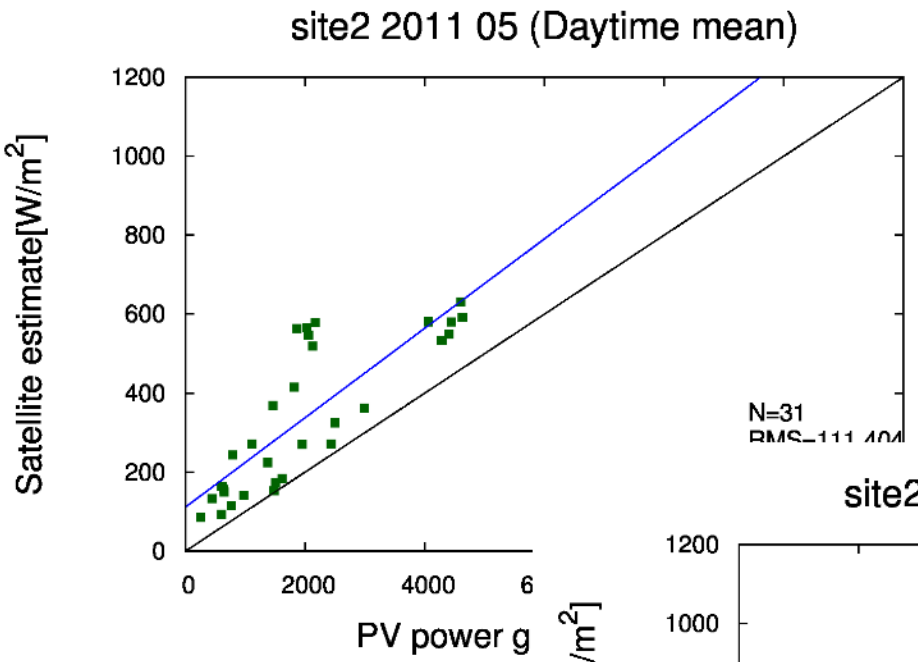




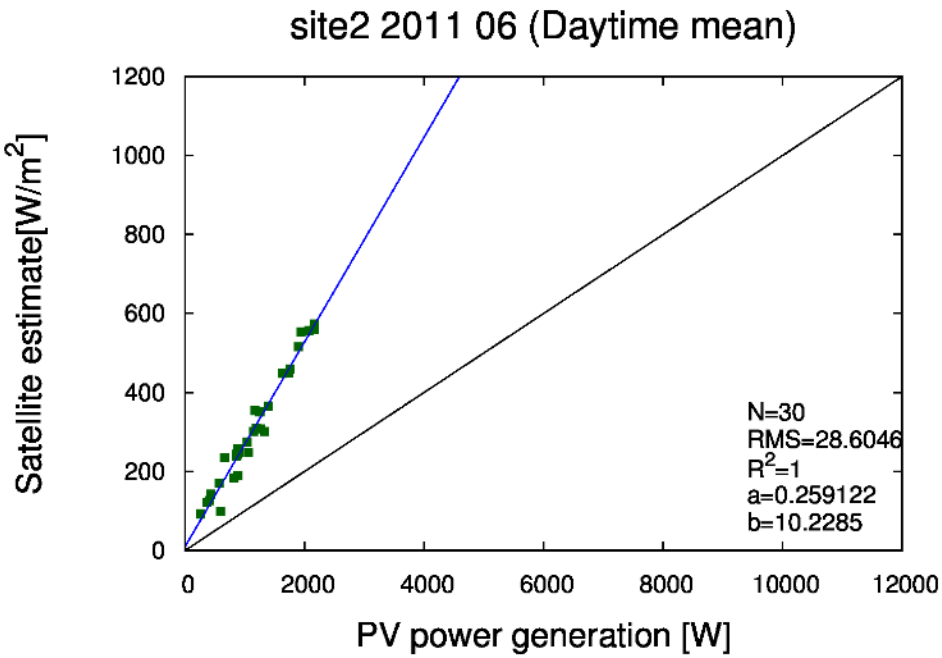




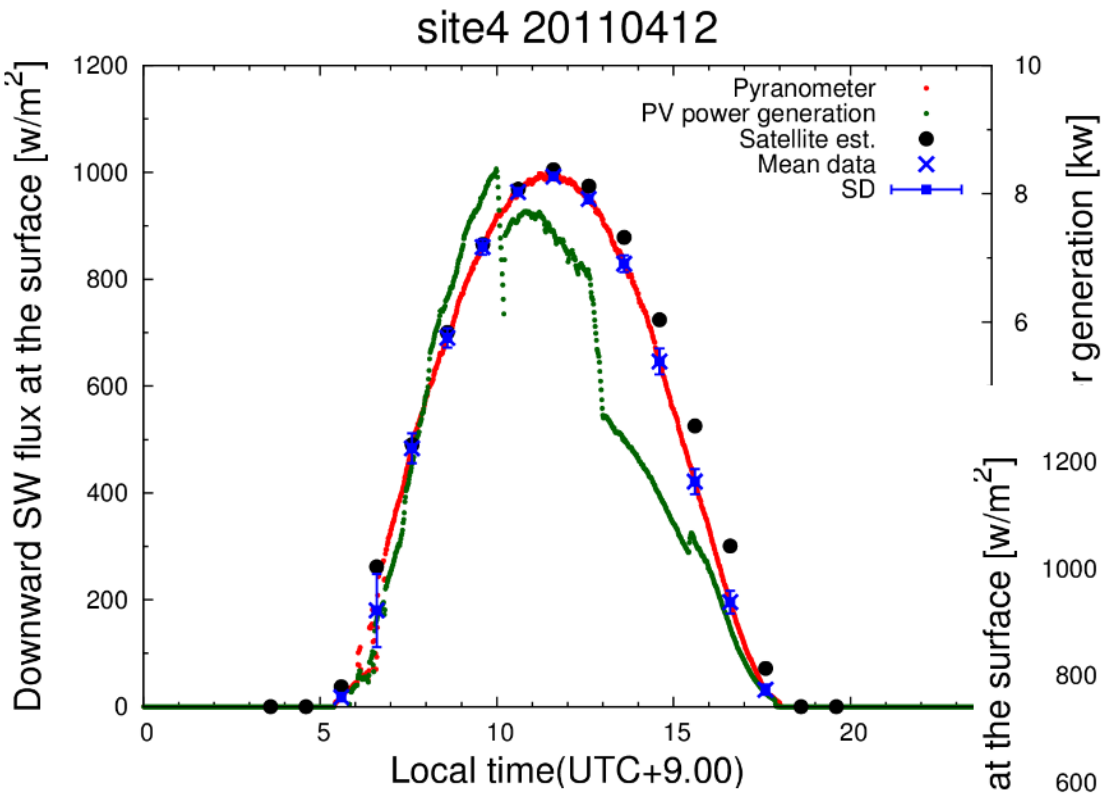
April, 2011

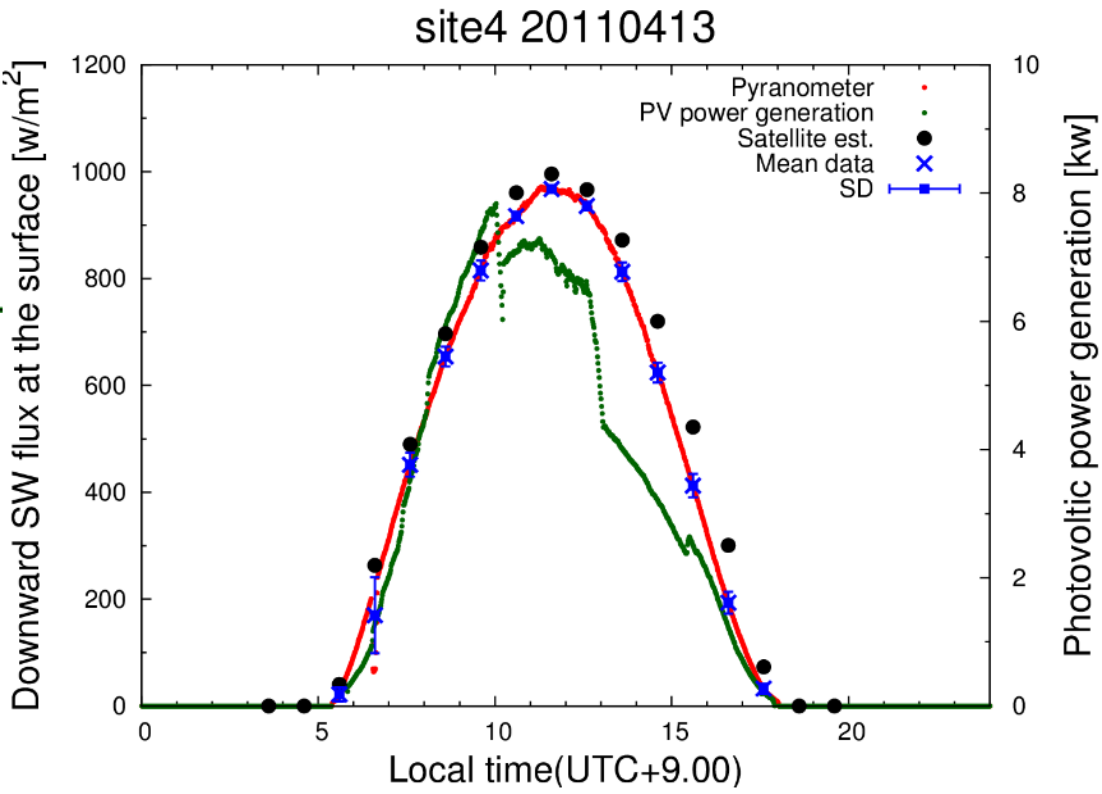


May, 2011

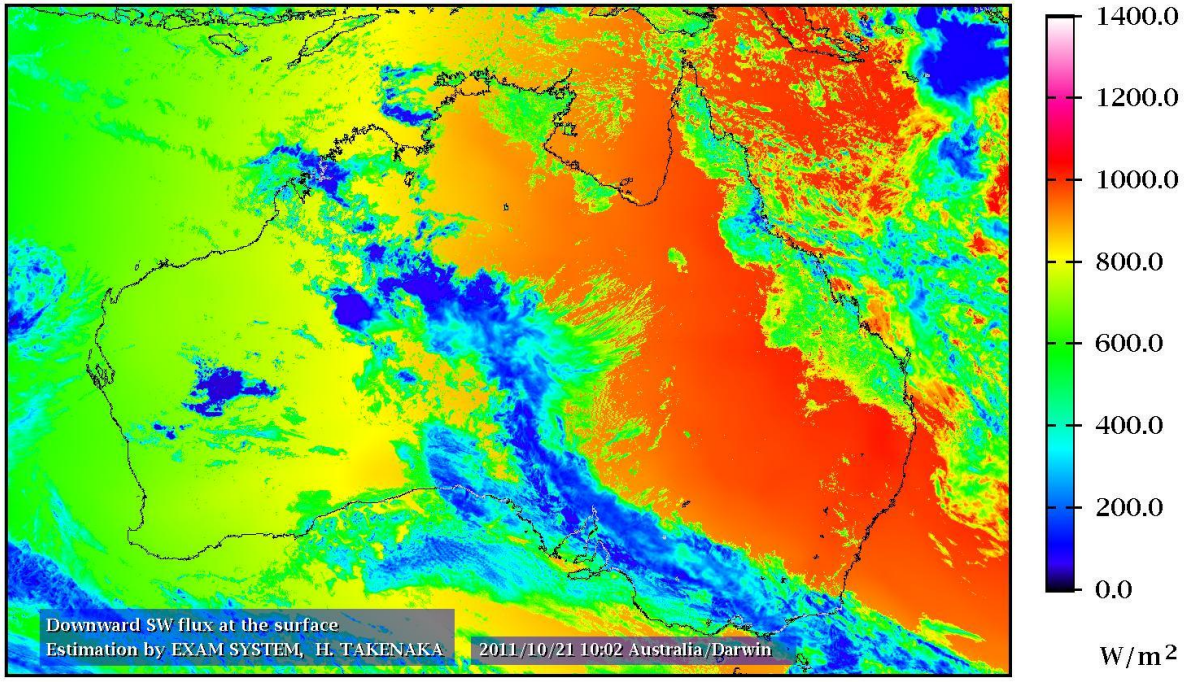


June, 2011


site4 20110412
Pyranometer
PV power generation
Satellite est.
Mean data
SD
Downward SW flux at the surface [w/m2]
r generation [kw]
Local time(UTC+9.00)
0
200
400
600
800
1000
1200
0
5
10
15
20
6
8
10


site4 20110413
Pyranometer
PV power generation
Satellite est.
Mean data
SD
Downward SW flux at the surface [w/m2]
Photovoltic power generation [kw]
Local time(UTC+9.00)
0
200
400
600
800
1000
1200
0
5
10
15
20
0
2
4
6
8
10

World Solar Challenge (WSC)



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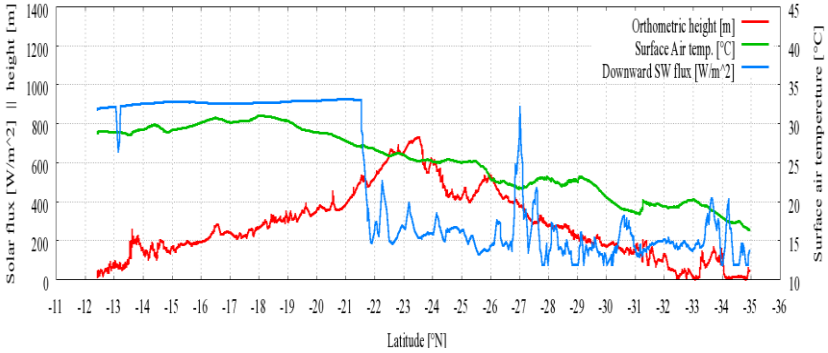

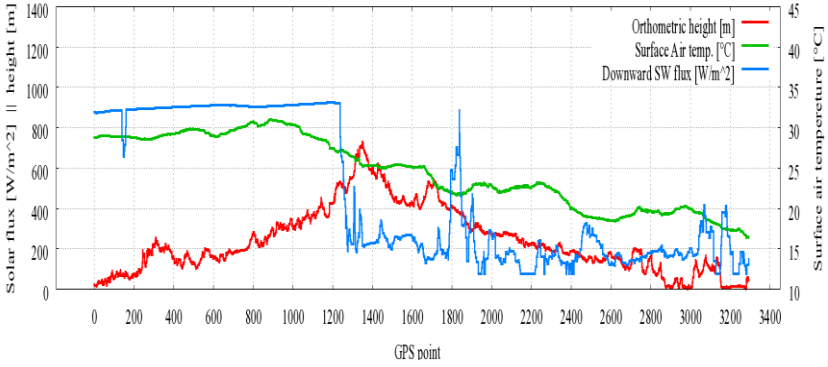

Conclusion

Estimation of SW radiation using five geostationary satellites
- **Global SW flux product is available.**
- **SW, PAR, UVA, UVB flux at the surface and TOA.**

Validation of GCM surface downward SW flux
- **“SPRINTERS” and “EXAM SYS” indicated same trend**
- **(this is zonal mean, therefor planetary surface solar flux is same)**

=> TOA and surface net radiaiton

Application of PV power generation
- **We try to evaluate correspondence relation**
- **between satellite estimate SW flux and PV power**

=> Good relation is found, We have possibility of monitoring of PV power generation in global scale.