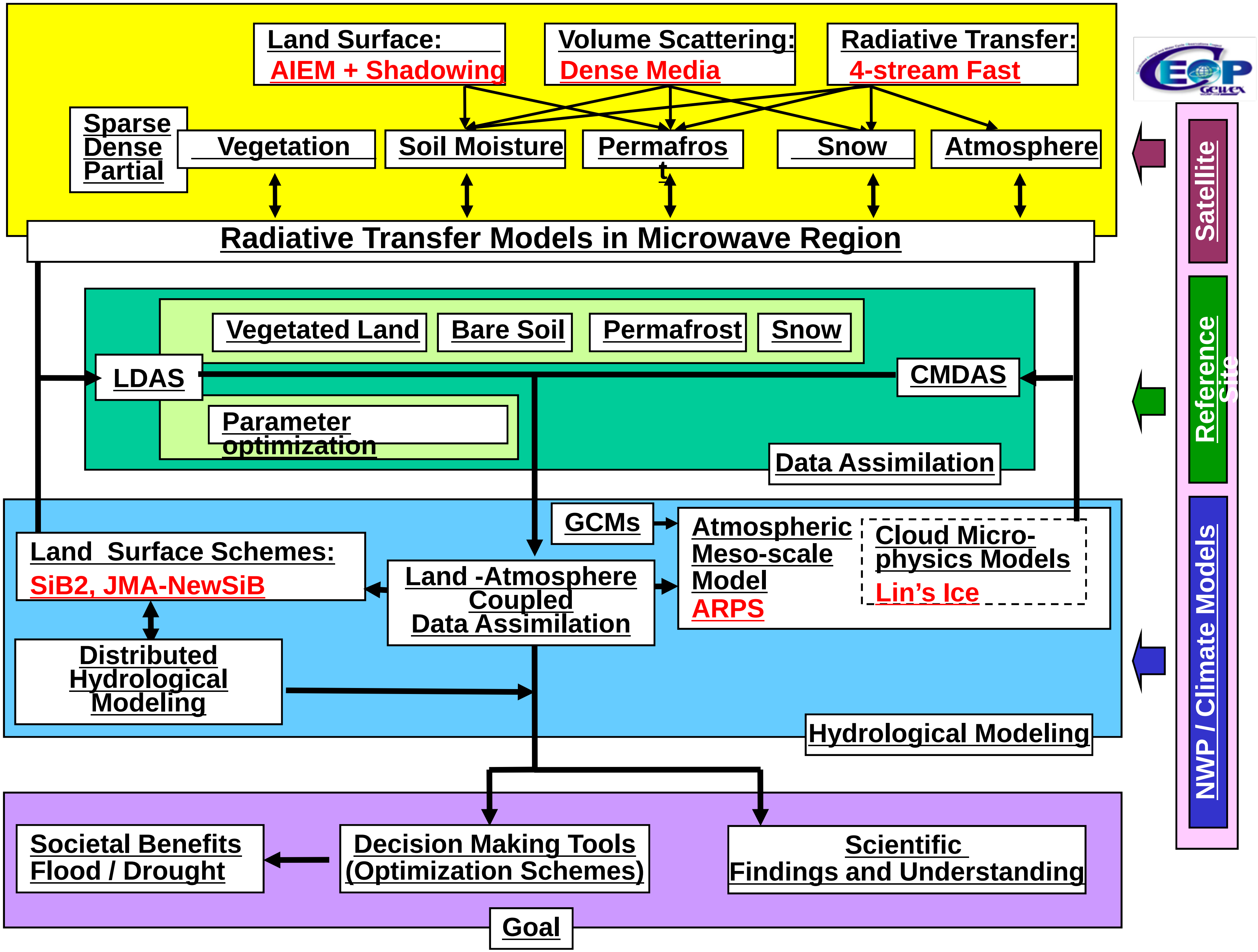
# Development of LDAS Coupled with Atmospheric Models by CEOP

Souhail Boussetta (now at ECMWF) and Toshio Koike (U. Tokyo)

Acknowledgement to

Tobias Graf , Xin Li, Kun Yang, Lu Hui,
Mahadevan Pathmathevan, David Kuria,
Tetsu Ohta, Dawen Yang, Cyrus raza Mirza,
Hiroyuki Tsutsui, Oliver Saveedra, Wang Lei
Katsunori Tamagawa, Hideyuki Fuji



Land Surface:
AIEM + Shadowing
Volume Scattering:
Dense Media
Radiative Transfer:
4-stream Fast
Sparse
Dense
Partial
Vegetation
Soil Moisture
Permafrost
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Radiative Transfer Models in Microwave Region
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LDAS
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Parameter optimization
Data Assimilation
GCMs
Land Surface Schemes:
SiB2, JMA-NewSiB
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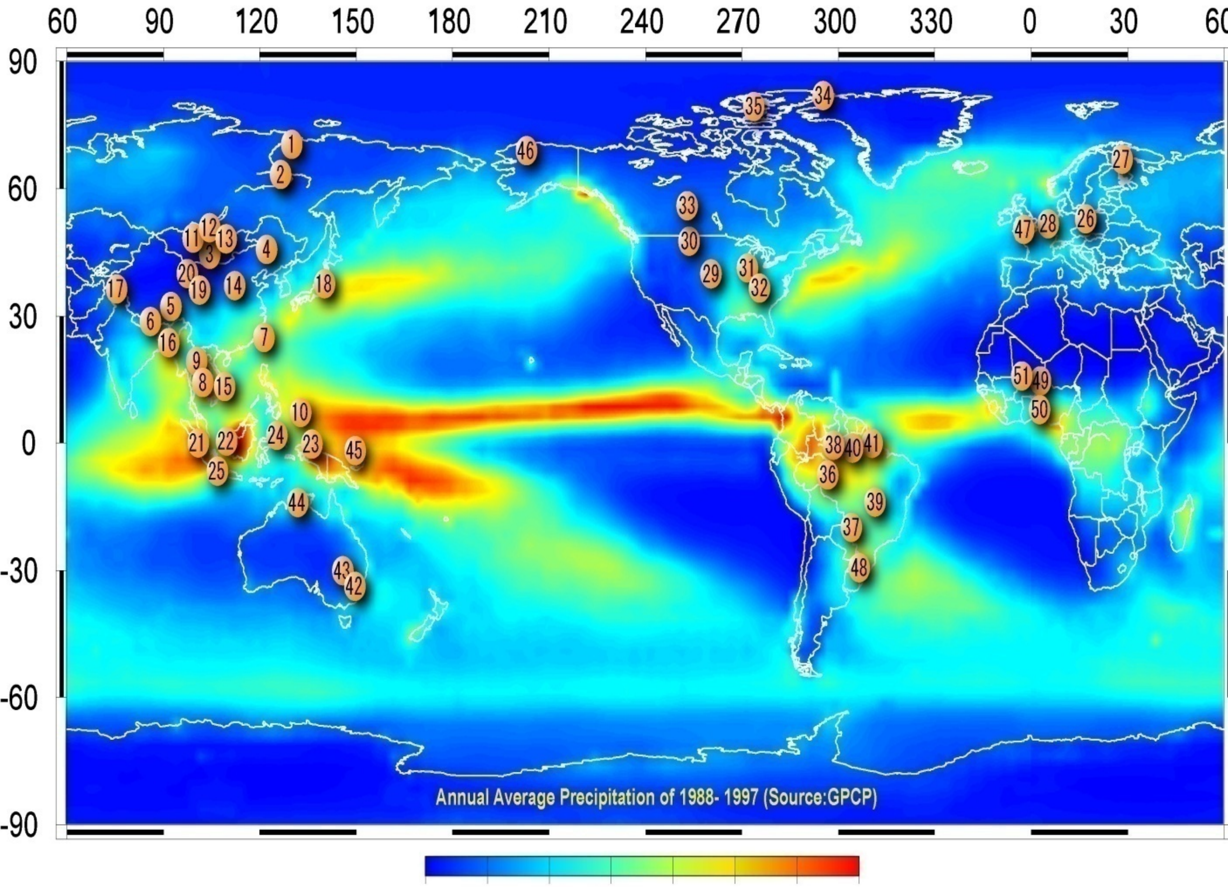
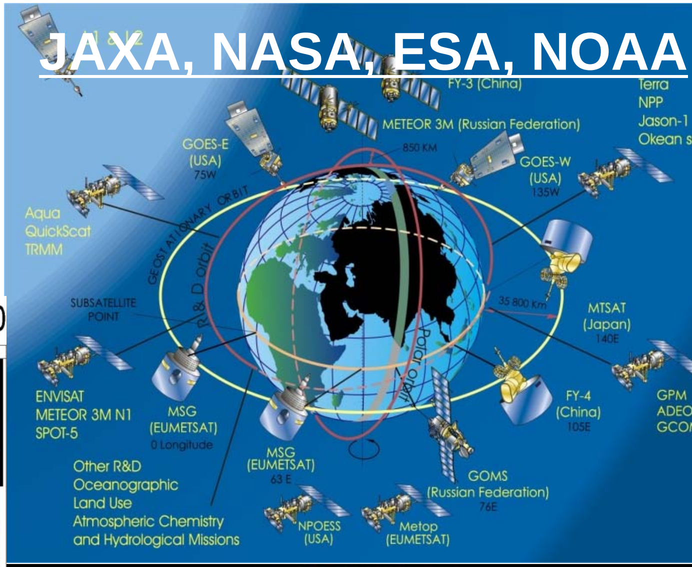
Societal Benefits
Flood / Drought
Decision Making Tools
(Optimization Schemes)
Scientific Findings and Understanding
Goal
Satellite
Reference Site
NWP / Climate Models

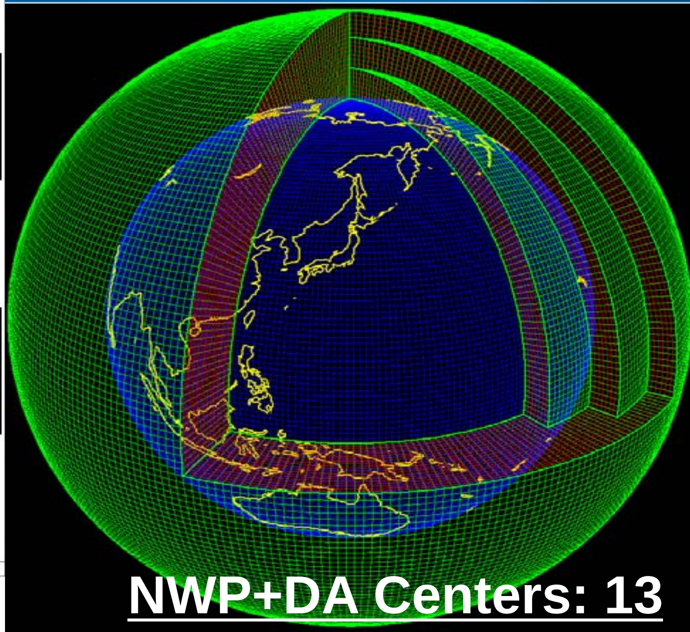
# Coordinated Energy and Water Cycle Observations Project

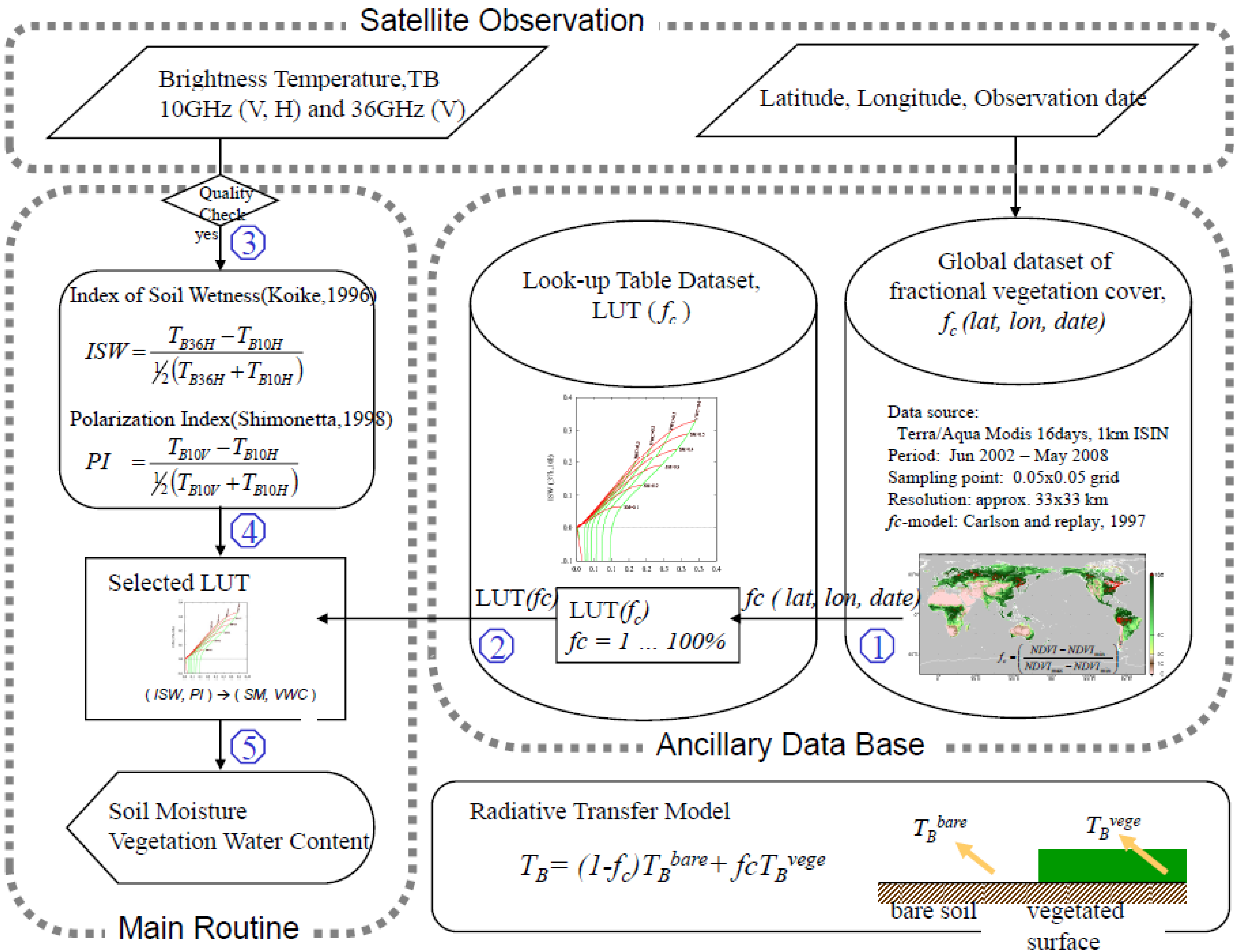
## Convergence of Observations

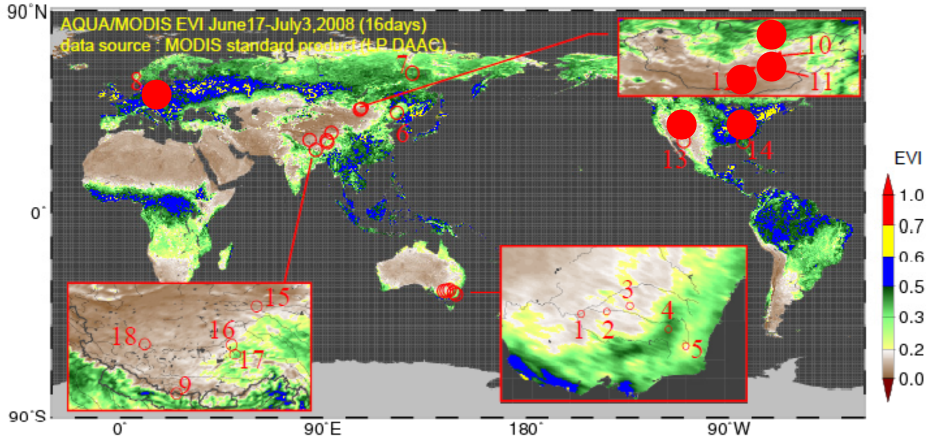
***A Prototype of the Global Water Cycle Observation System of Systems***

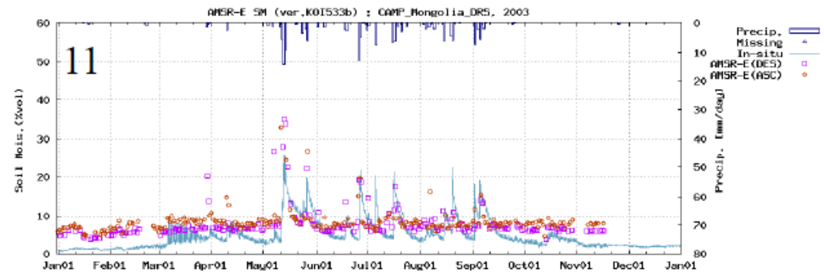


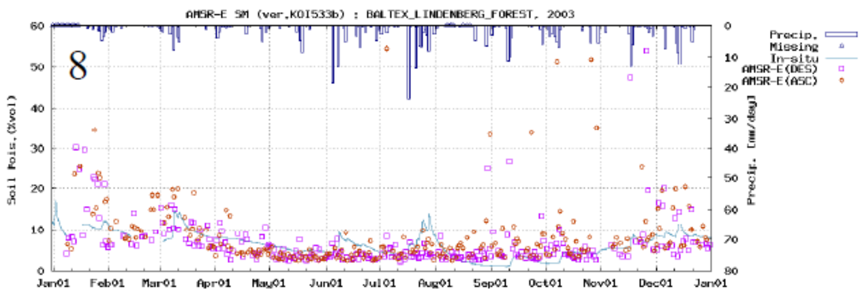



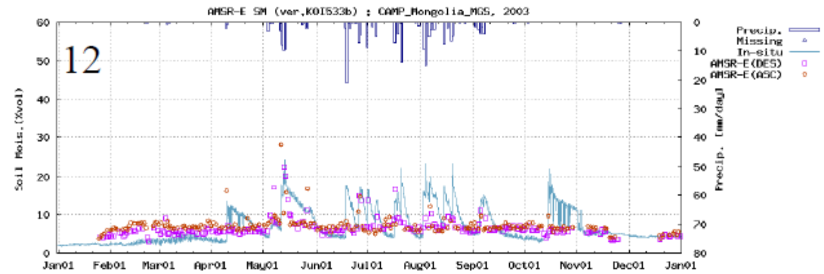



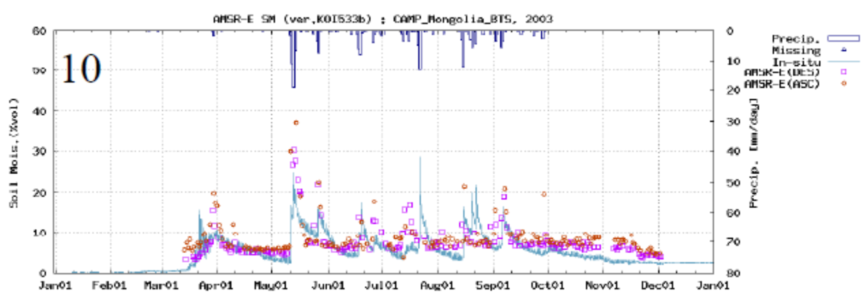

Satellite Observation
Brightness Temperature,TB
10GHz (V, H) and 36GHz (V)
Latitude, Longitude, Observation date
Quality Check
yes
3
Index of Soil Wetness(Koike,1996)
$ISW = \frac{T_{B36H} - T_{B10H}}{\frac{1}{2}(T_{B36H} + T_{B10H})}$
Polarization Index(Shimonetta,1998)
$PI = \frac{T_{B10V} - T_{B10H}}{\frac{1}{2}(T_{B10V} + T_{B10H})}$
4
Selected LUT
( ISW, PI ) → ( SM, VWC )
5
Soil Moisture
Vegetation Water Content
Main Routine
Look-up Table Dataset,
LUT ($f_c$ )
Global dataset of
fractional vegetation cover,
$f_c$ (lat, lon, date)
Data source:
Terra/Aqua Modis 16days, 1km ISIN
Period: Jun 2002 – May 2008
Sampling point: 0.05x0.05 grid
Resolution: approx. 33x33 km
fc-model: Carlson and replay, 1997
LUT(fc)
LUT($f_c$)
fc = 1 ... 100%
fc ( lat, lon, date)
$f_c = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)$
2
1
Ancillary Data Base
Radiative Transfer Model
$T_B = (1-f_c) T_B^{bare} + fc T_B^{vege}$
$T_B^{bare}$
$T_B^{vege}$
bare soil
vegetated surface

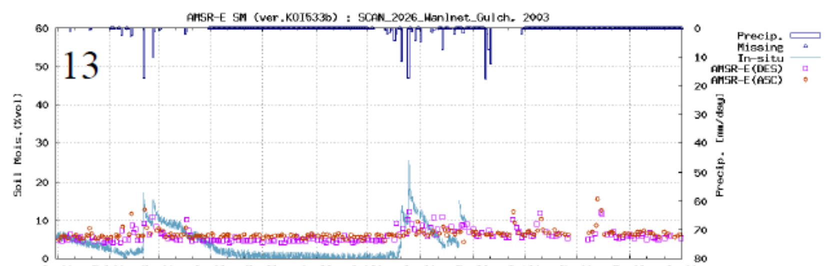


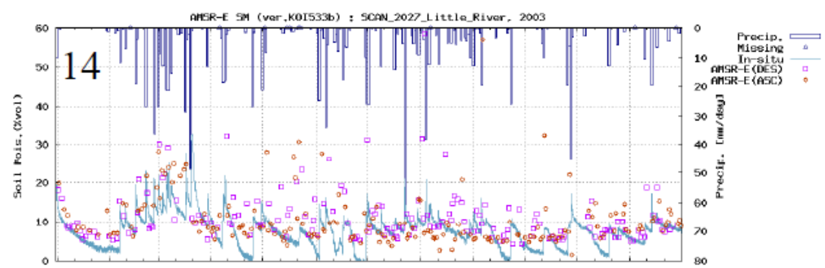



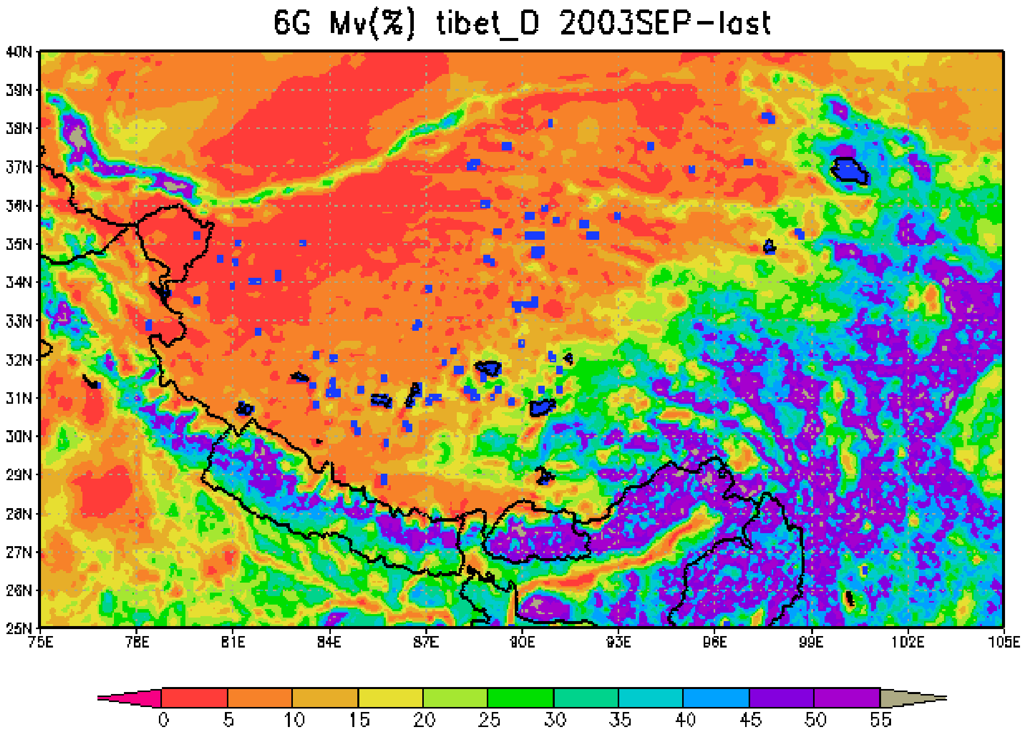



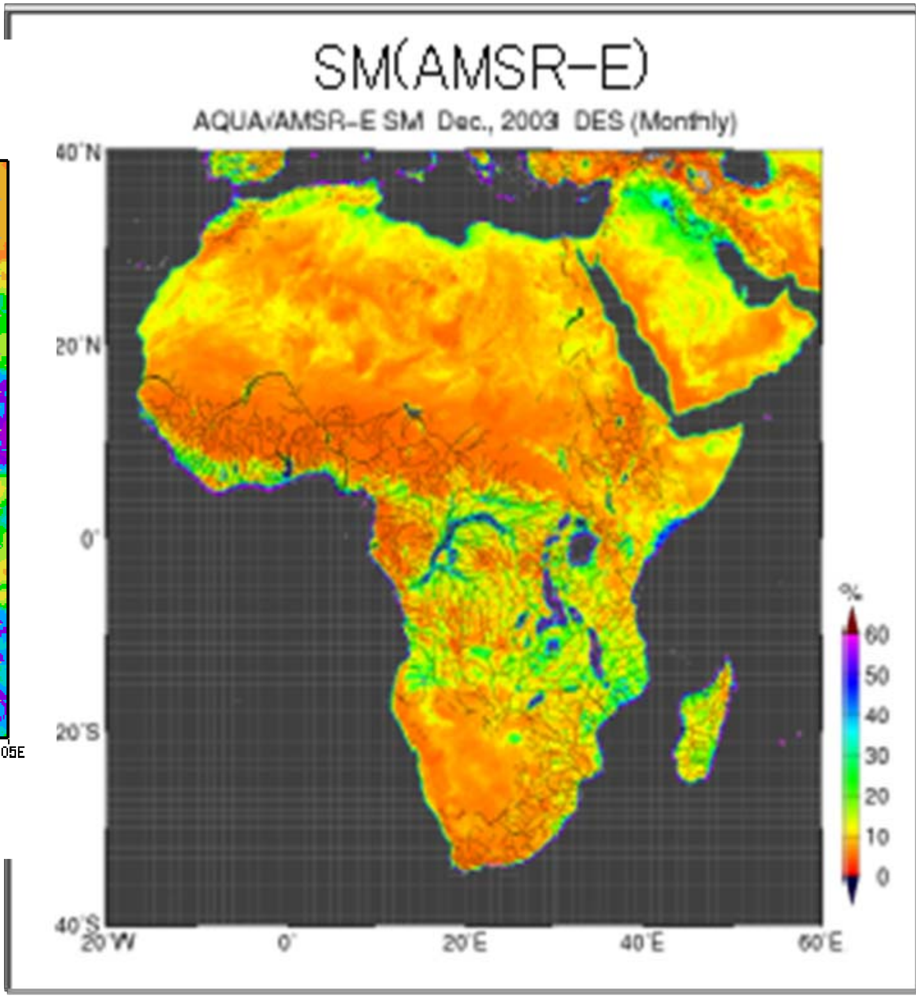




(Lu et al. 2007 and
Tamagawa et al. 2008)

# Seasonal Variation of the Soil Moisture

## Tibetan Plateau Africa

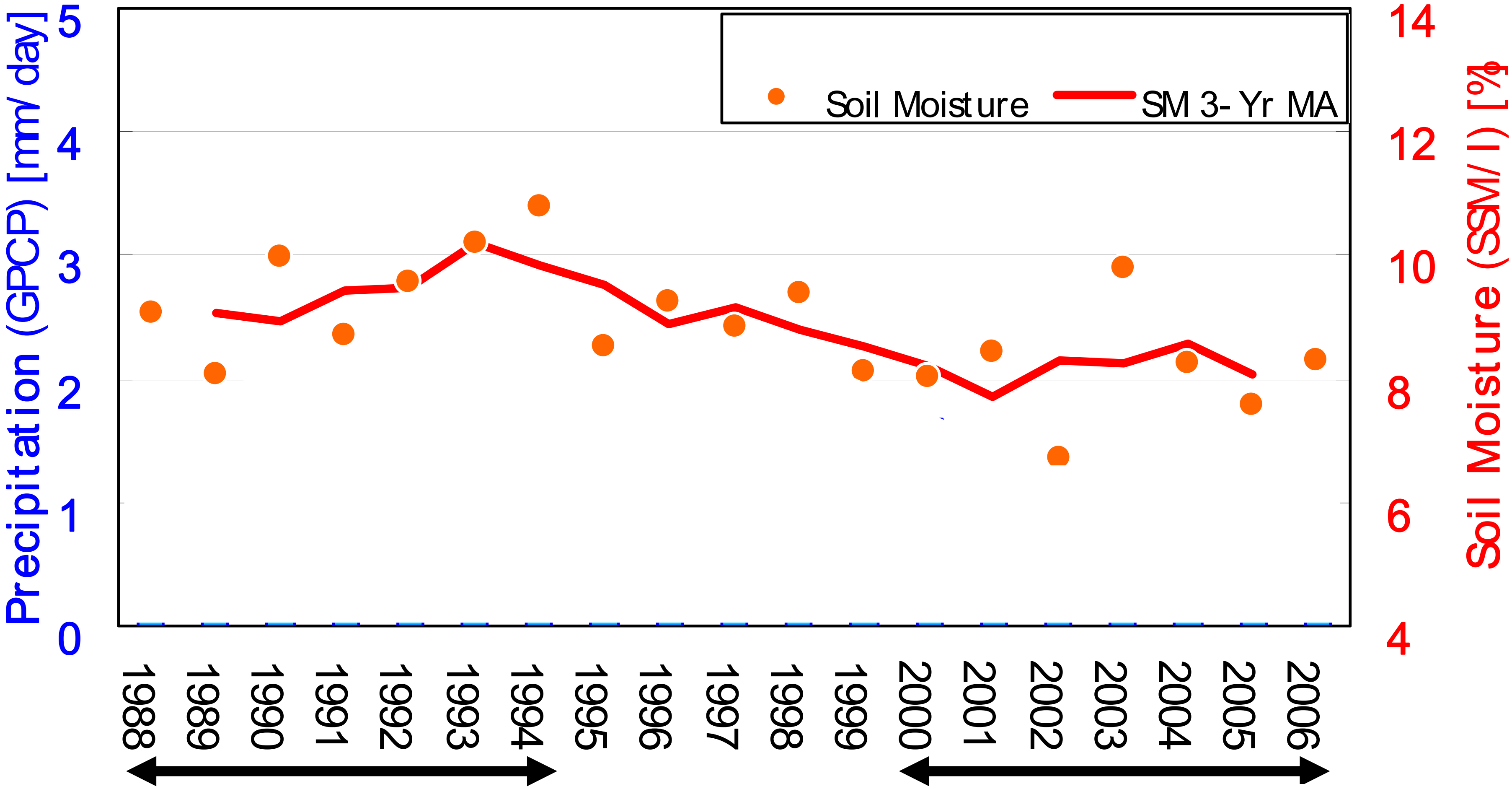


# CEOP Reference Site in Mongolia

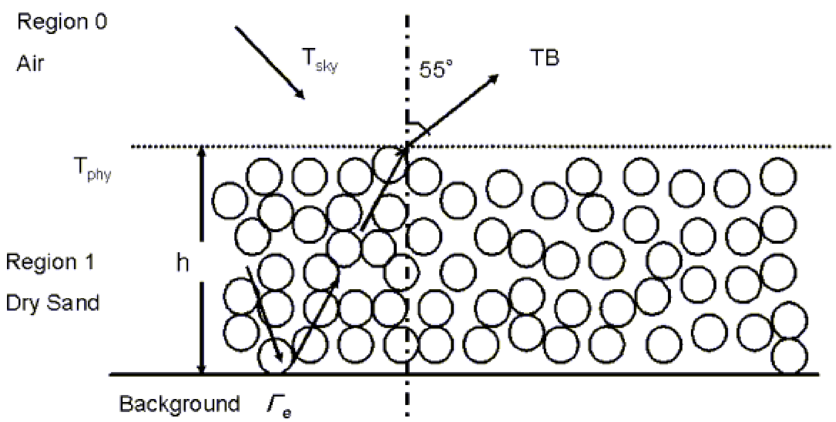
Long Term Application of 2.5 x 2.5 Degrees Area including Validation Sites (JJA Average)

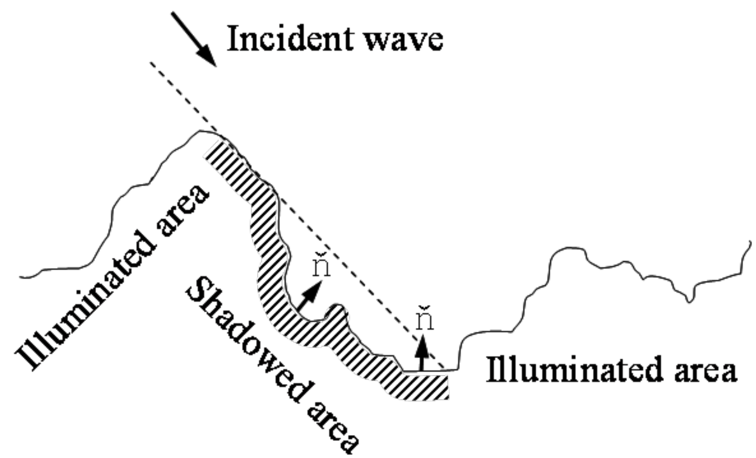
(Satellite data application to climate change)



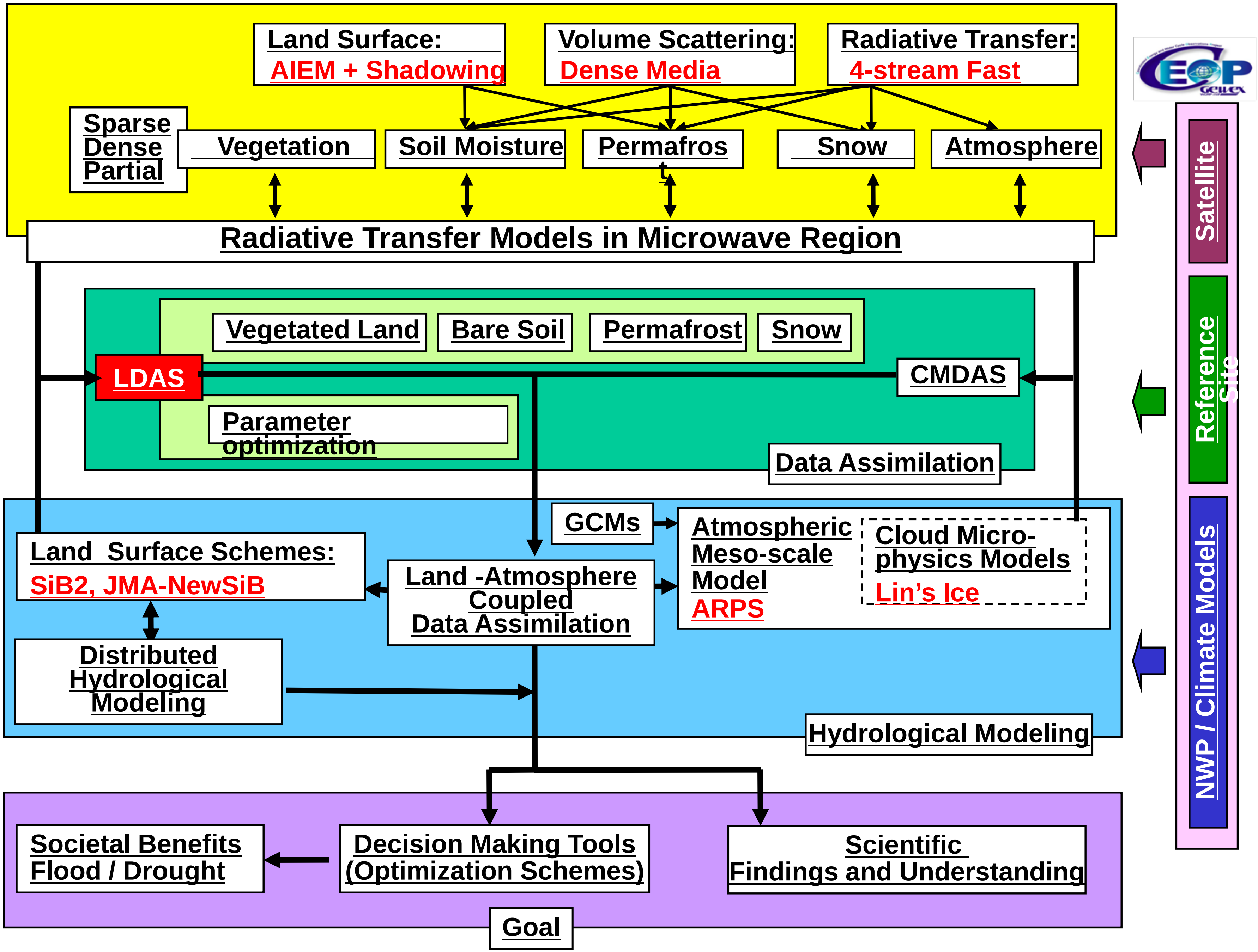

*(Ohta & Koike, 2008)*

# GBHM Experiments


(Kuria et al. 2007)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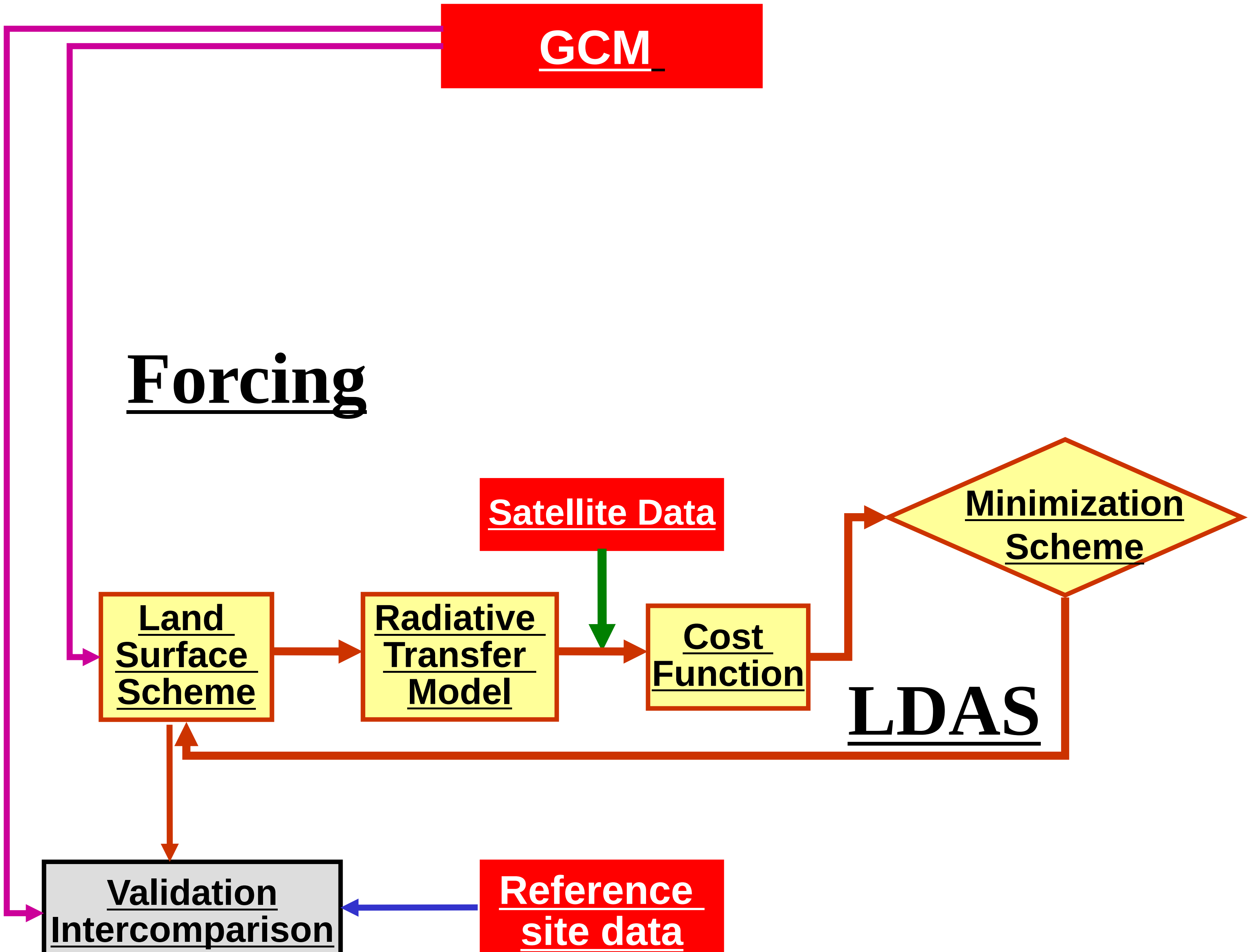
GCM
Forcing
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Minimization Scheme
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Radiative Transfer Model
Cost Function
LDAS
Validation Intercomparison
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# SA method （Boltzmann Annealing)

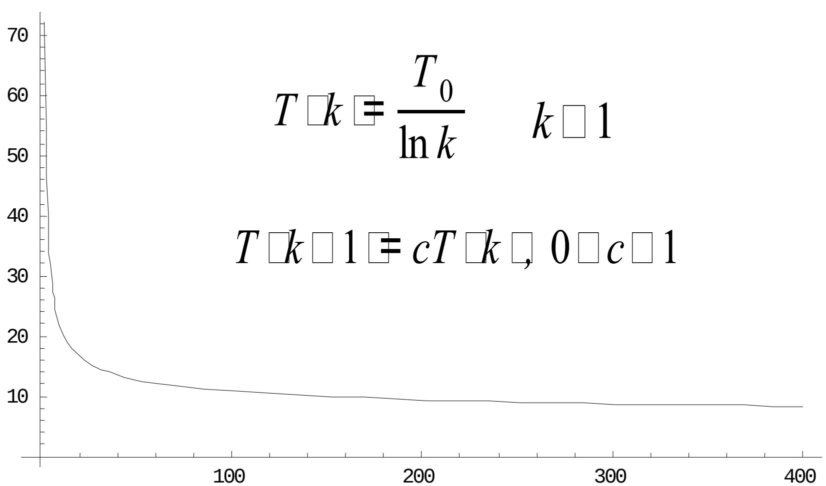
- Boltzmann distribution

$$g(x) = (2\pi T)^{-D/2} \exp[-\Delta x^2/(2T)]$$

- Annealing schedule

$$T(k) = \frac{T_0}{\ln k} \qquad k > 1$$

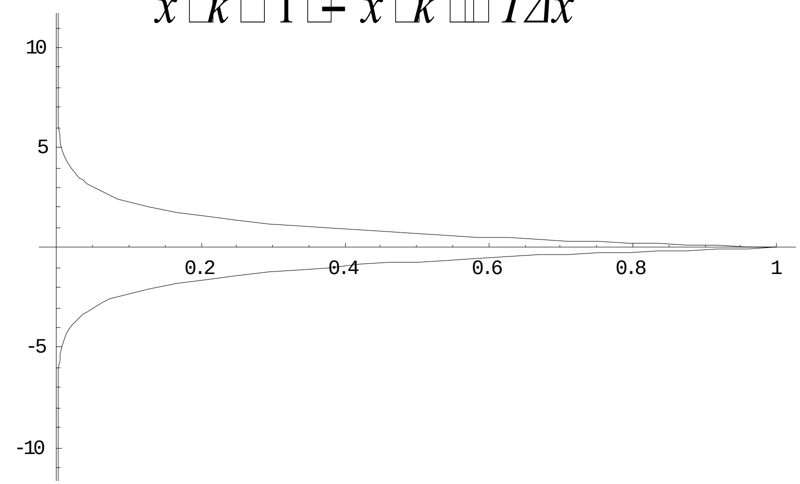
$$T(k+1) = cT(k),\ 0 < c < 1$$



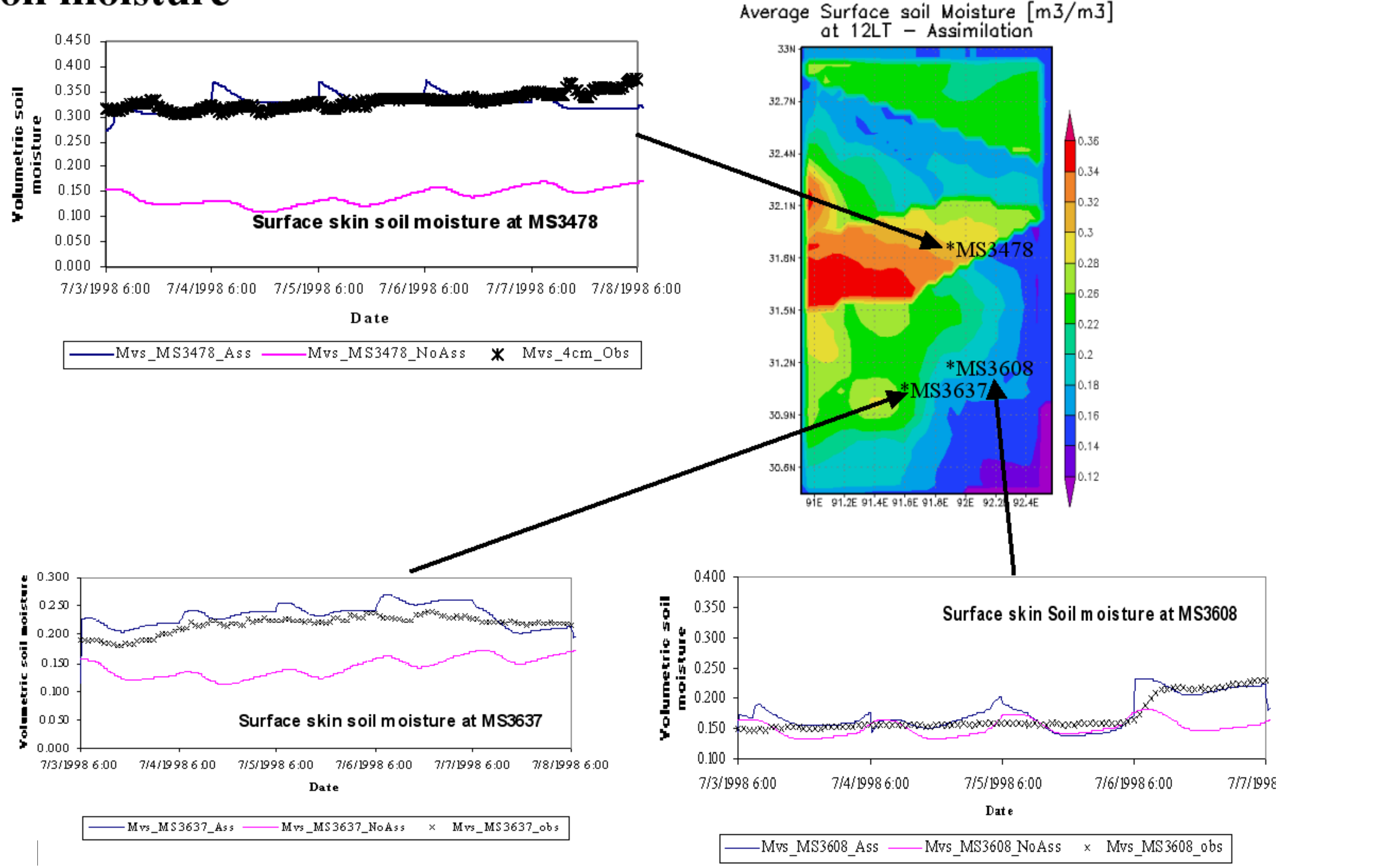

- Generating function of random change

$$\Delta x = \mathrm{sign}\{U[-1,1]\} \times \ln U[0,1],\ \Delta x \in [-\infty, +\infty]$$

$$x(k+1) = x(k) + T\Delta x$$

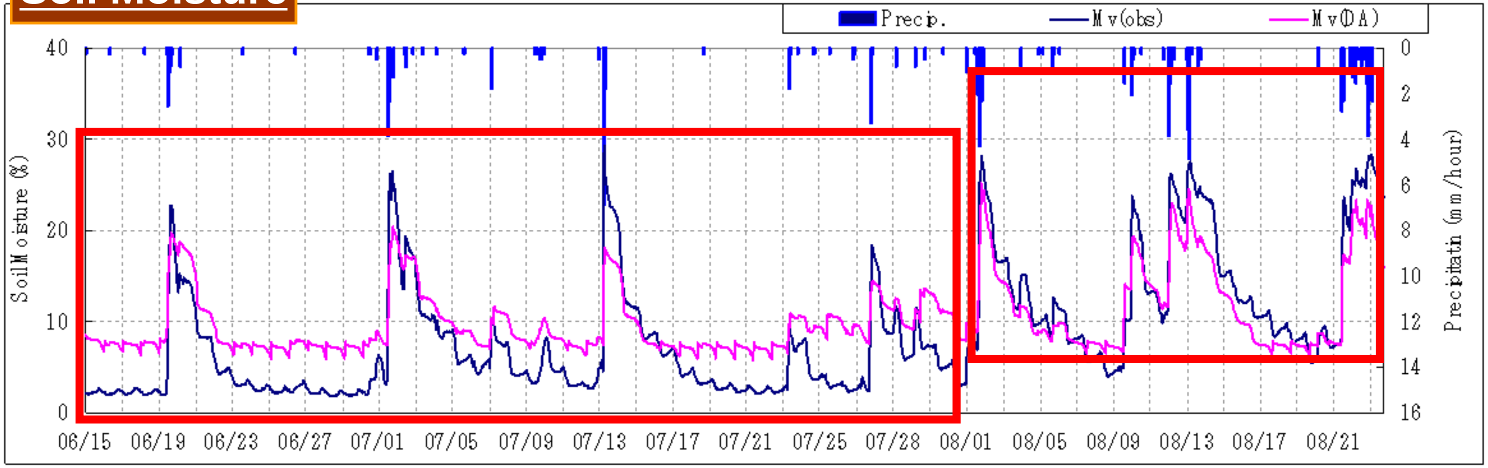


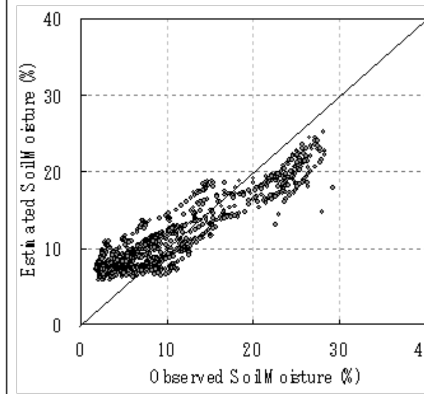
# soil moisture



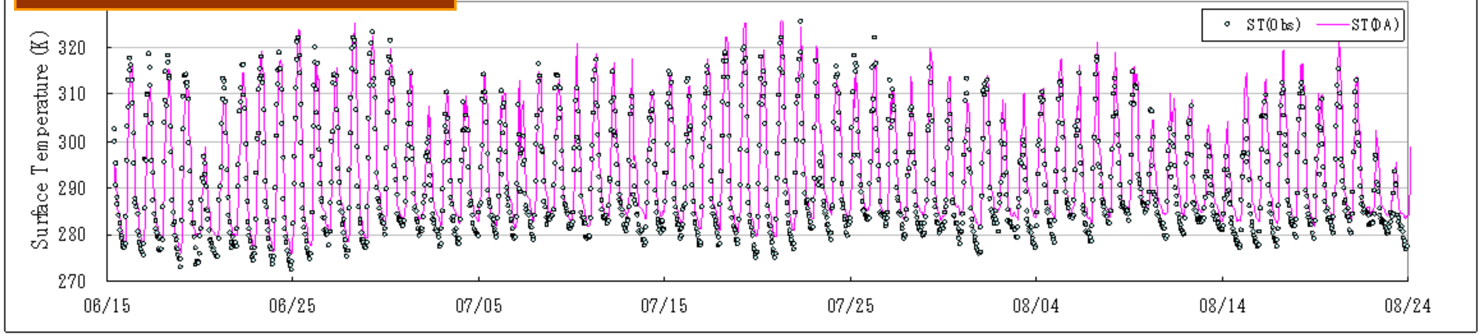

(Boussetta et al. 2005)

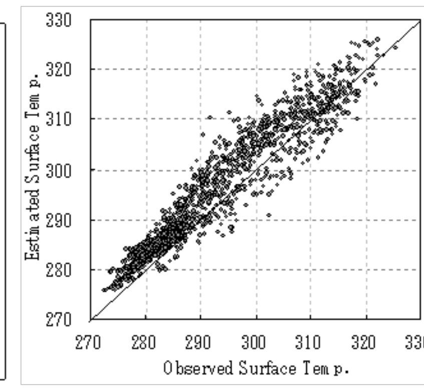
## Soil Moisture




## Surface Temperature



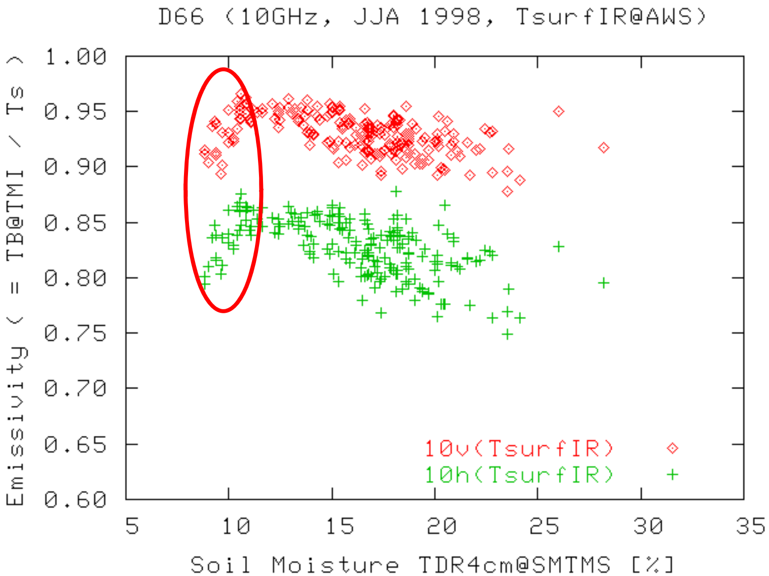

**LDASUT**

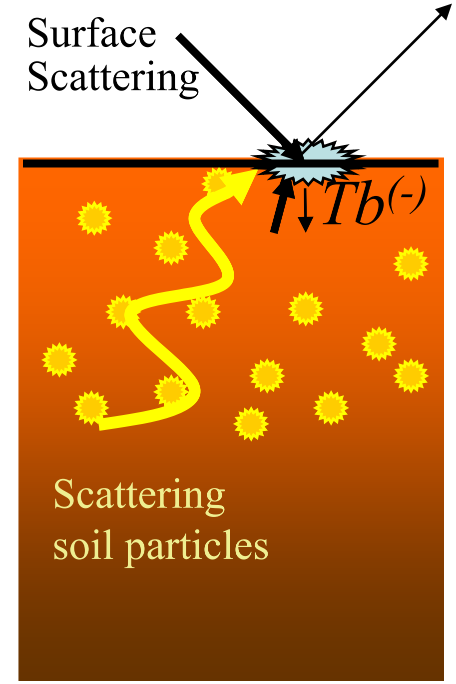
**Good agreement under wet condition**

**Gap under dry condition**

**(Yang et al. 2007)**

# *Radiative Transfer Model for dry soil*



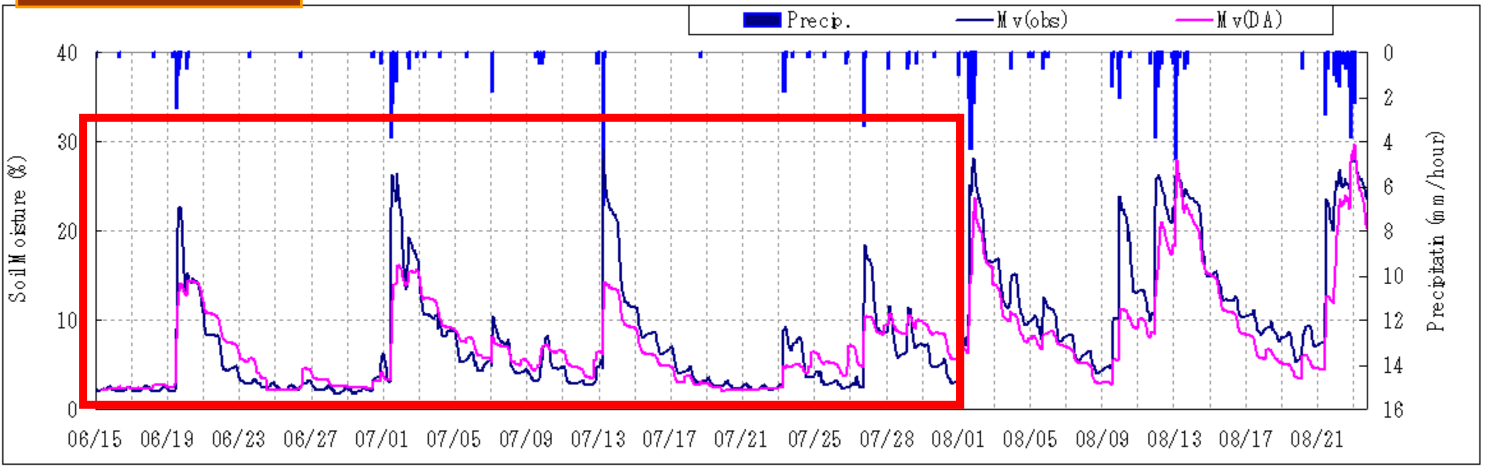



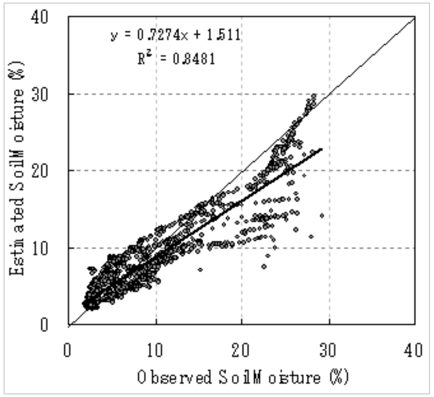

radiative transfer model which can represent the ***scattering effect of soil particles***

$T_{bs}$

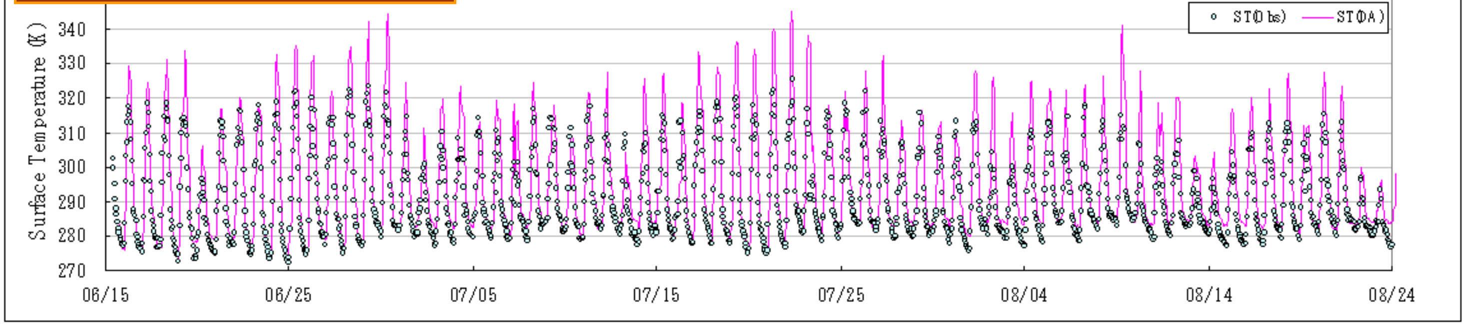
$$T_b = (1-f)(1-\Gamma)T_{bs} + f((1-\Gamma)T_{bs}e^{-\tau_c} + (1-w_c)(1-e^{-\tau_c})T_c + (1-w_c)(1-e^{-\tau_c})T_c\Gamma e^{-\tau_c})$$

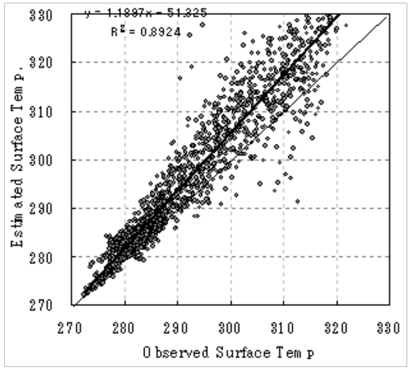
## Soil moisture



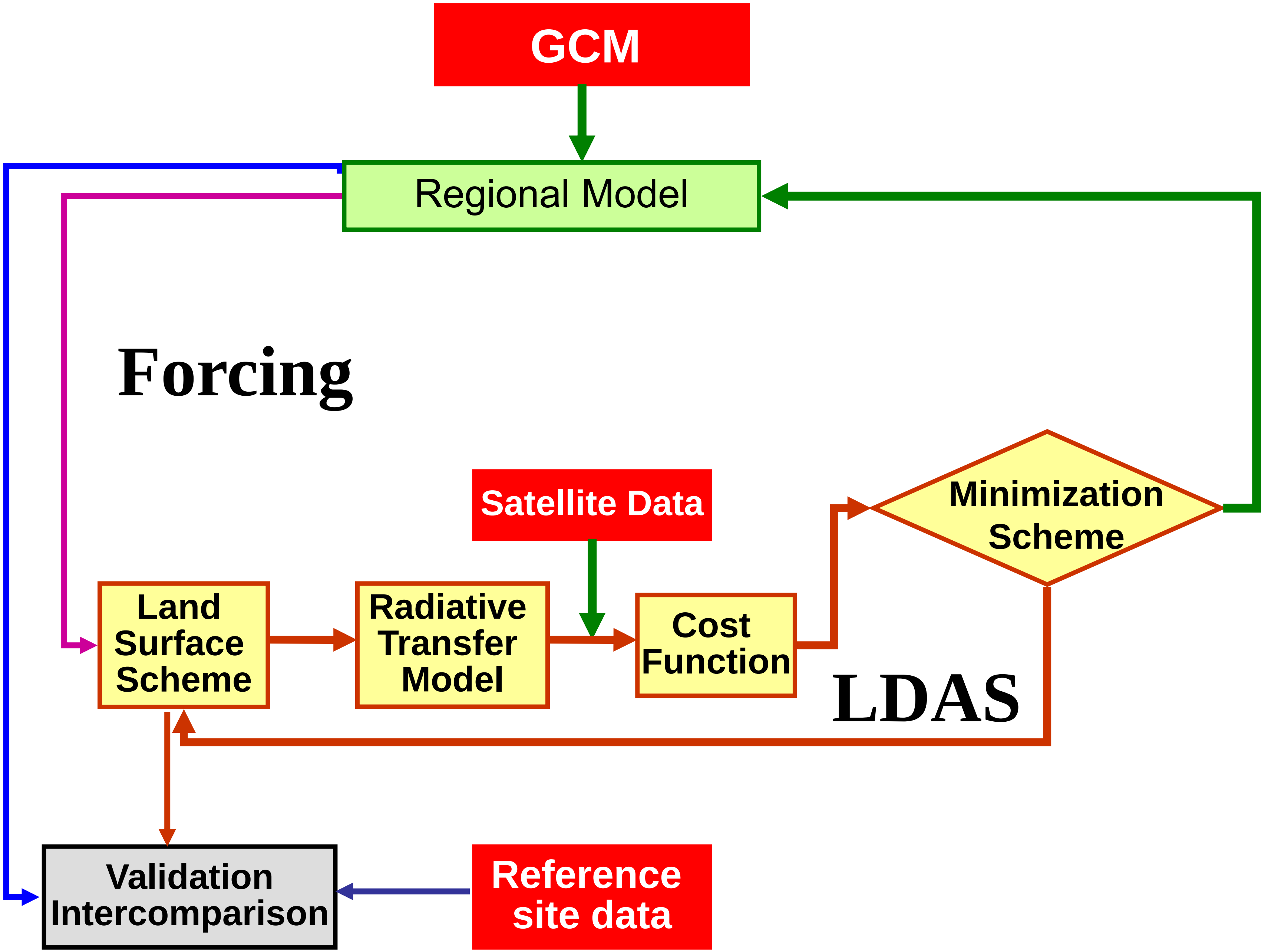




## Surface Temperature

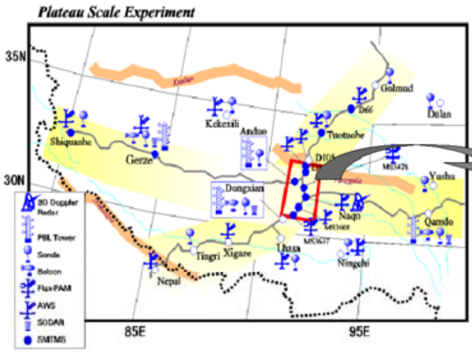


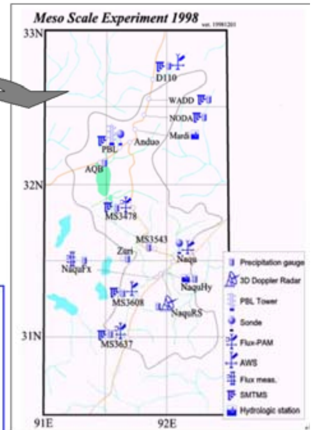




**LDASUT with DMRT (dense media radiative transfer model)**


GCM
Regional Model
Forcing
Satellite Data
Minimization Scheme
Land Surface Scheme
Radiative Transfer Model
Cost Function
LDAS
Validation Intercomparison
Reference site data

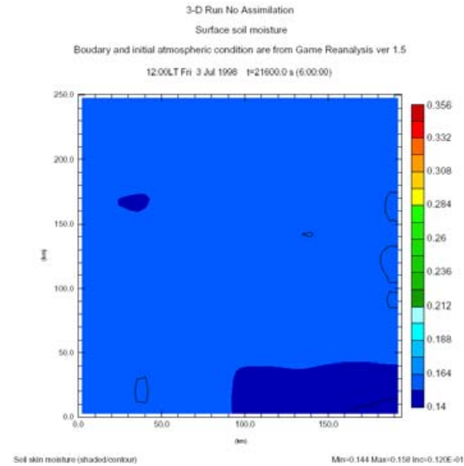
# Coupling Atmospheric Model with Land Data Assimilation System

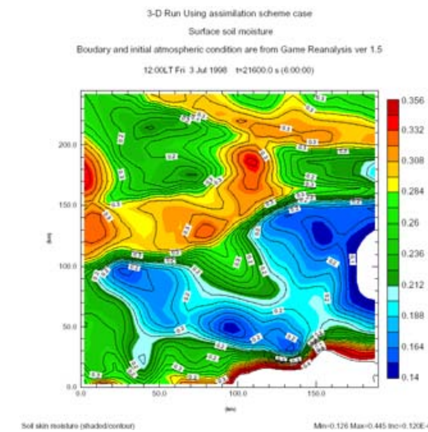


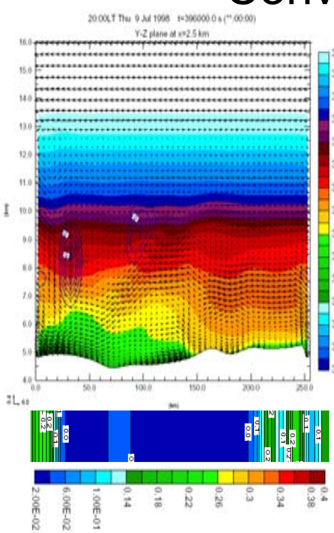

| | |
|---|---|
| Spatial Resolution | = 0.05°*0.05° (1800 Grids) |
| Assimilation Window | = 1Day |
| Initial Conditions | = GAME Reanalysis Ver1.5 |
| Simulation Period | = July 3rd 1998~8th |
| Satellite Data | = TMI (10.35GHz & 19.65GHz |

## Surface Soil moisture Distribution

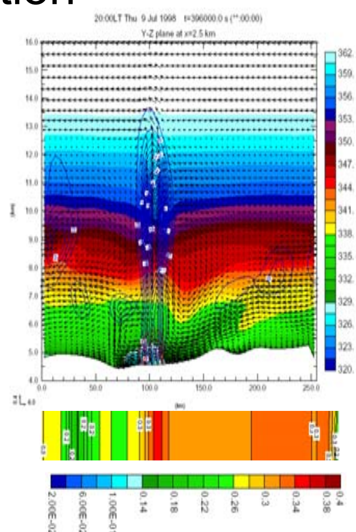



## Convection

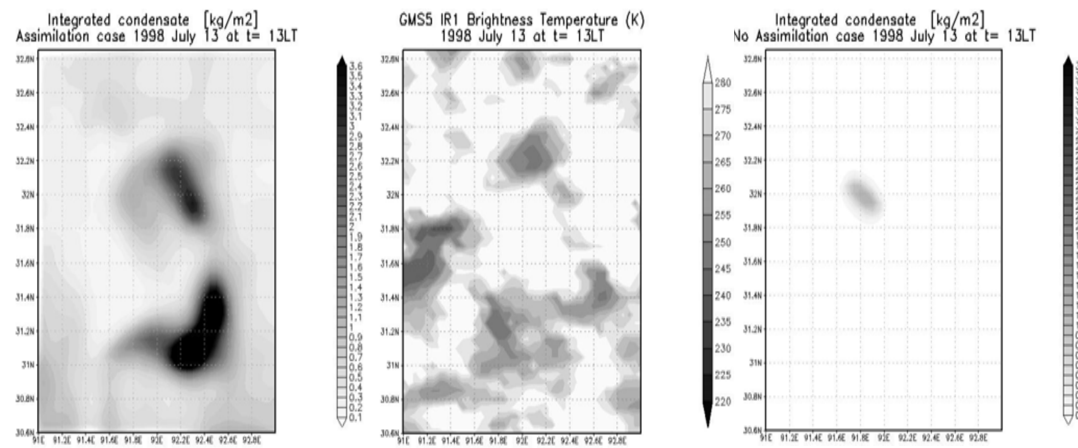


No assimilation case



Assimilation case

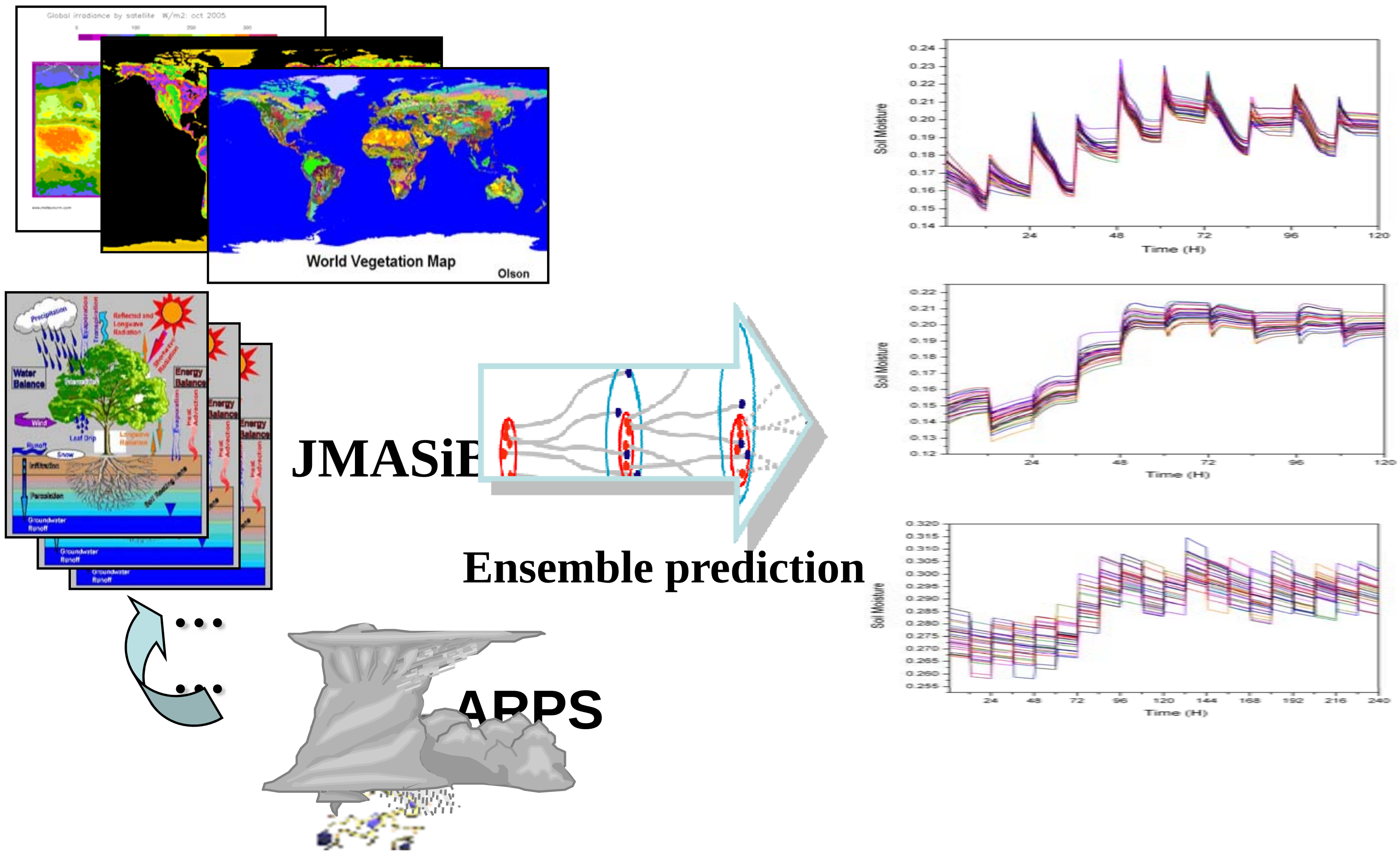
## Cloudiness



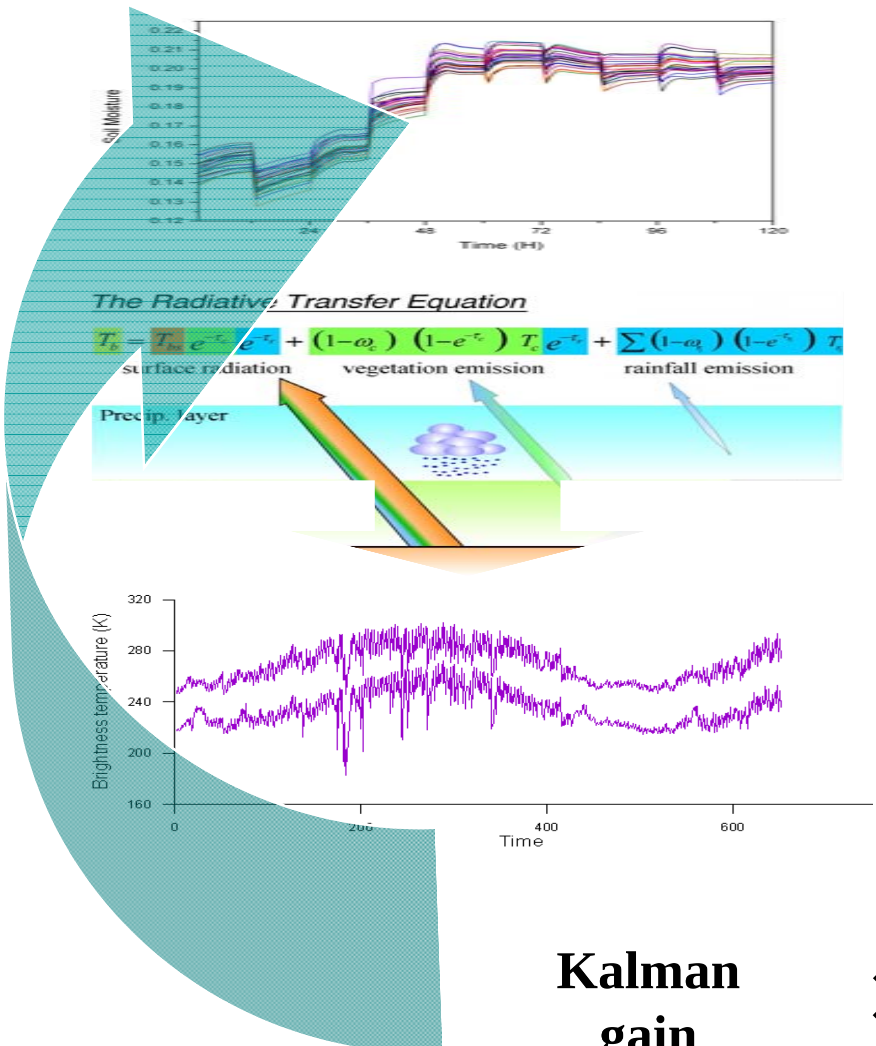

Spatial distribution of the integrated condensate : no-assimilation case (right), assimilation case (left), compared with the spatial distribution of the GMS5 IR1 infrared brightness temperature (middle)

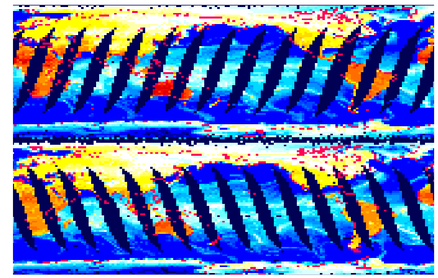
(Boussetta et al. 2007)

# Ensemble Prediction



# Ensemble filtering



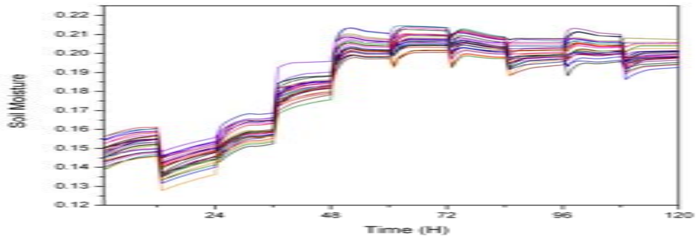




**AMSR-E**

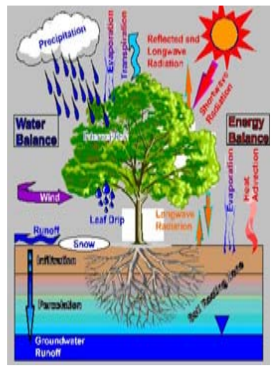
**+**


**Kalman gain** **×** **Innovation vector**

# Atmospheric Prediction

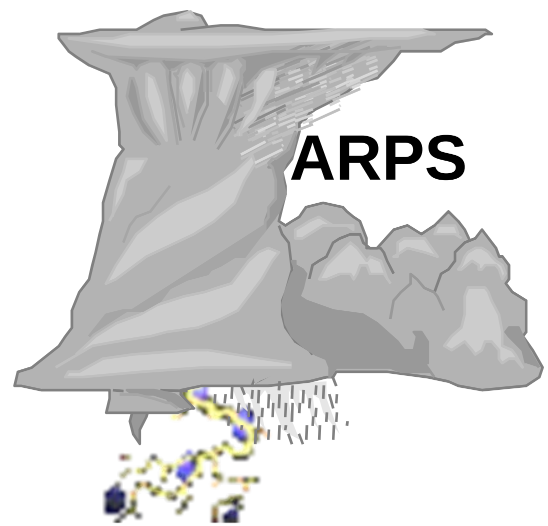



**State**




**fluxes**

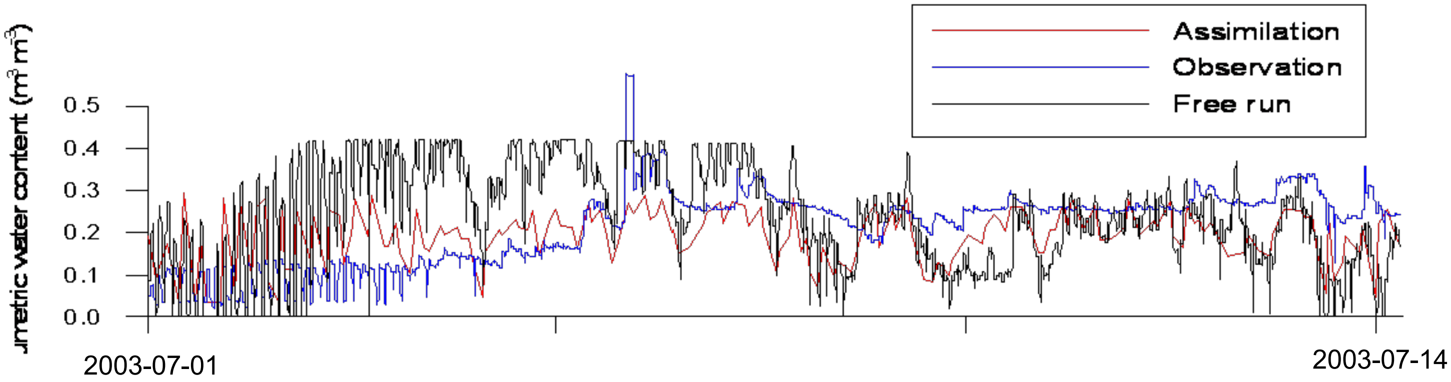
**JMASiB**



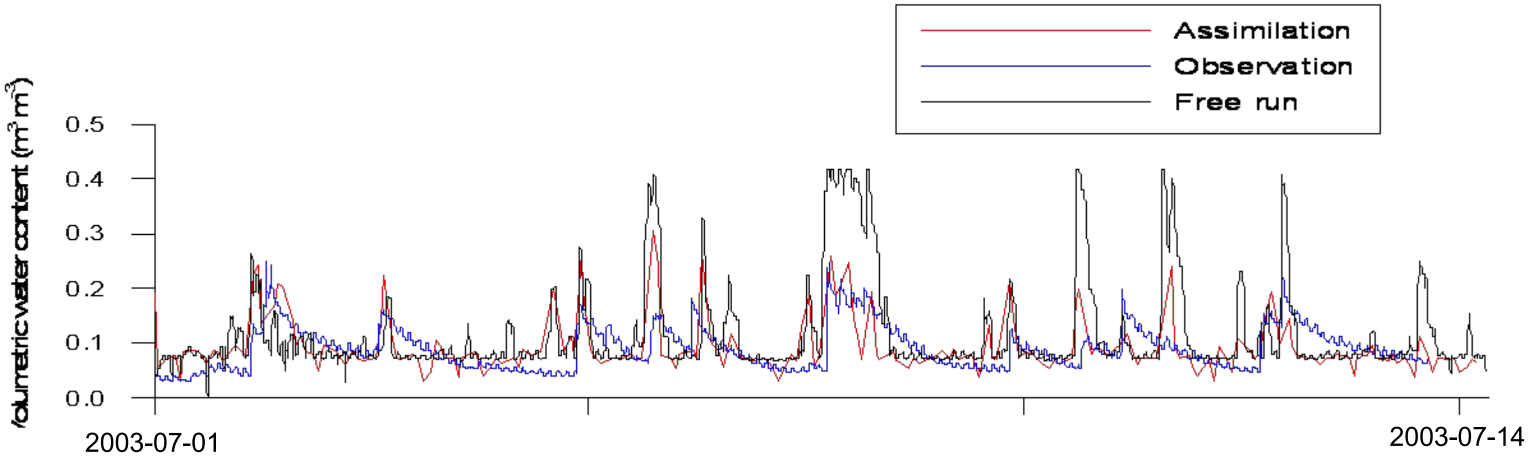
**ARPS**

(Boussetta et al. 2007)

# Surface soil moisture(Tibet)




# Surface Soil moisture (Mongolia)




(Li et al. 2007)

# EnKF vs 4DVAR

- Variational methods
  - Multiple minima
  - Hard to compute error statistics
  - Do not allow for sequential processing of measurement
- Ensemble methods
  - Provide estimate with error statistics
  - Allow for sequential processing of measurement
  - Advantage with nonlinear dynamics

(Evensen G. The parameter estimation problem revisited. Bergen, Norway: Hydro Research Centre, 2005)

# EnKF vs 4DVAR (cont)

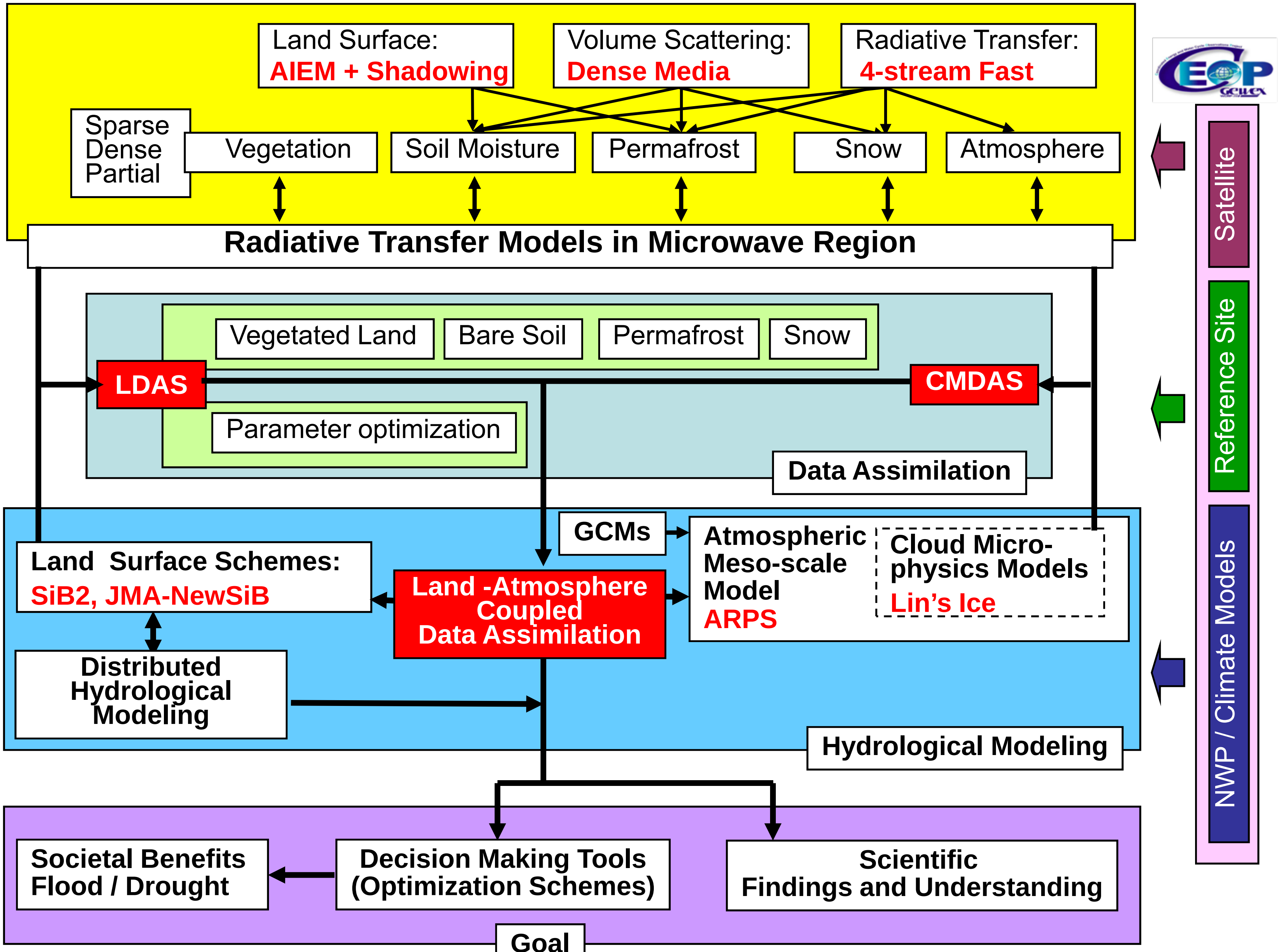
| | 4DVAR | EnKF |
|---|---|---|
| Flow dependent background errors | Yes, within each cycle, but errors are not propagated between cycles | Yes. |
| Nonlinear observation operators | Yes, with non-quadratic cost function | Yes, but results will be treated as Gaussian |

$$J(\delta\underline{\mathbf{x}}) = \tfrac{1}{2}\left(\delta\underline{\mathbf{x}} - \delta\underline{\mathbf{x}}^{b}\right)^{T} \left[\mathbf{B}^{f}_{e}\right]^{-1}_{(\underline{\mathbf{x}})} \left(\delta\underline{\mathbf{x}} - \delta\underline{\mathbf{x}}^{b}\right) + \tfrac{1}{2}\left(\underline{\mathbf{y}} - \underline{\mathbf{y}}^{o}\right)^{T} \mathbf{R}^{-1}\left(\underline{\mathbf{y}} - \underline{\mathbf{y}}^{o}\right)$$

# EnKF vs 4DVAR (cont)

| | 4DVAR | EnKF |
|---|---|---|
| Forecast model | Uses a TLM or PF model that must be specially designed. Model switches are problematic. | Uses full nonlinear forecast model which describes the evolution of atmospheric states. |
| Lateral boundary conditions | Set boundary increments to zero, or treat as control variables | May require a global ensemble |
| Balance | Balance imposed as part of assimilation | Localization removes some balance |

(Dance S, Roulstone I, Lorenc A. A review of the theoretical potential, & limitations of the Ensemble Kalman Filter and 4D-Var. NERC Centres for Atmospheric Science, 2003)



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Scientific
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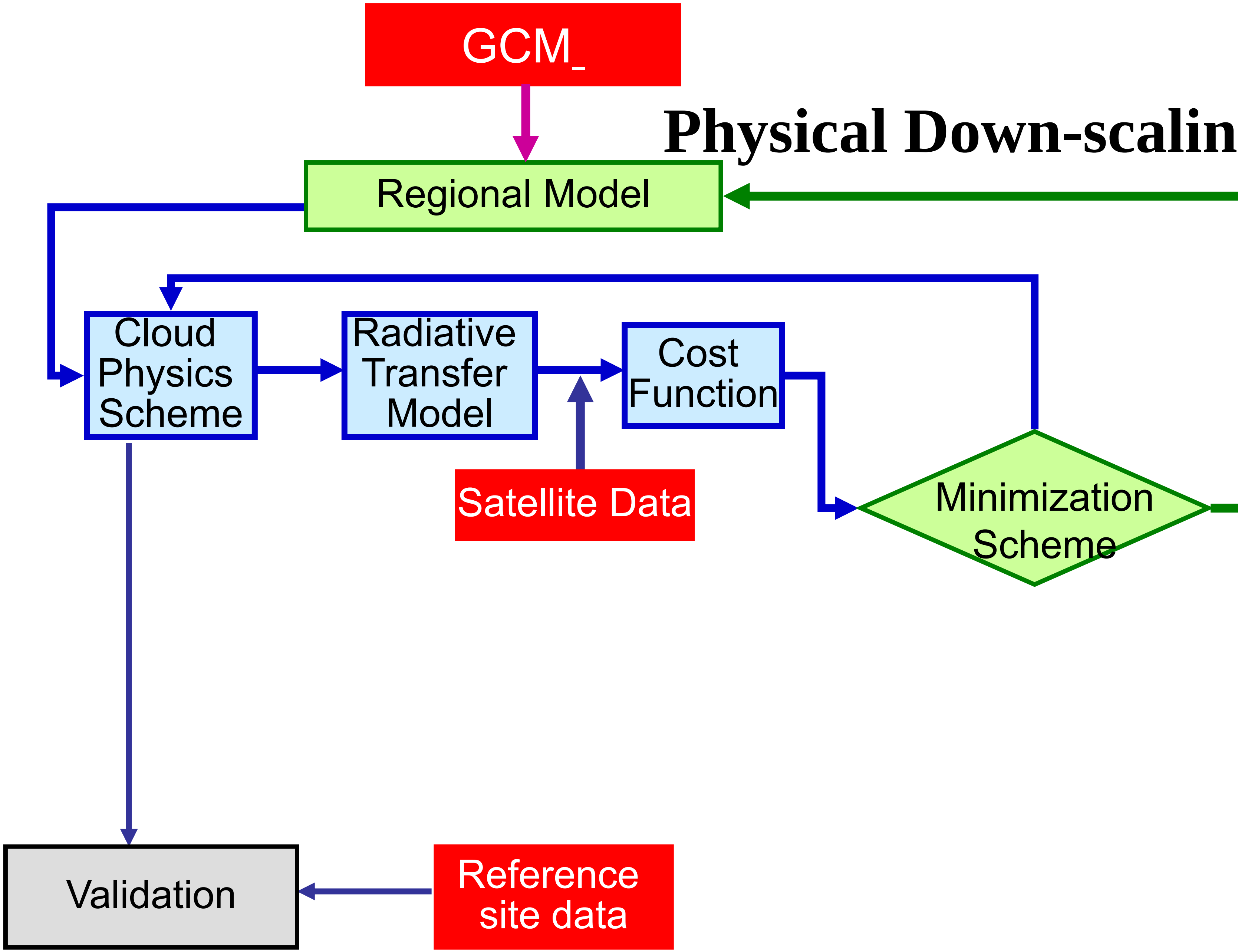
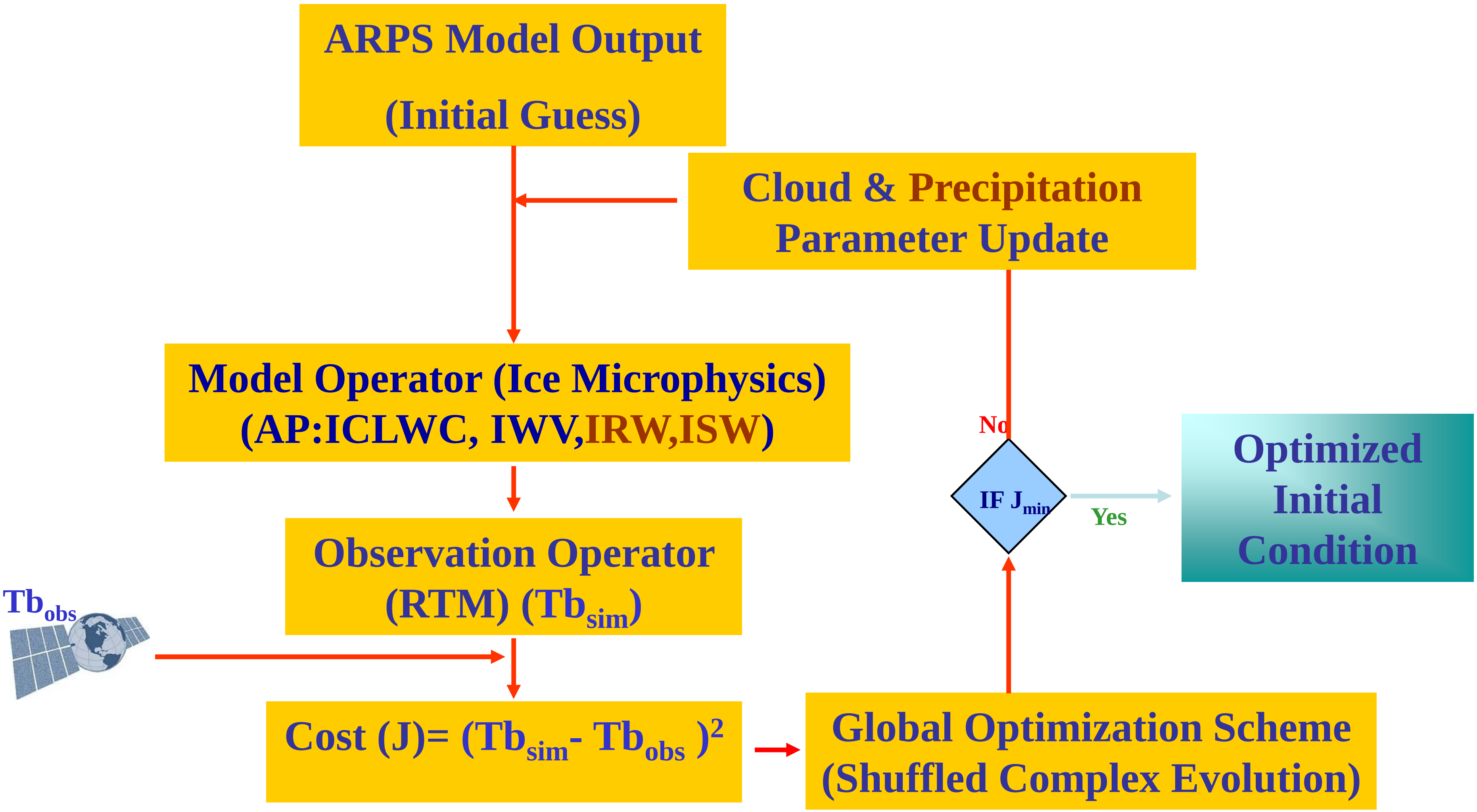
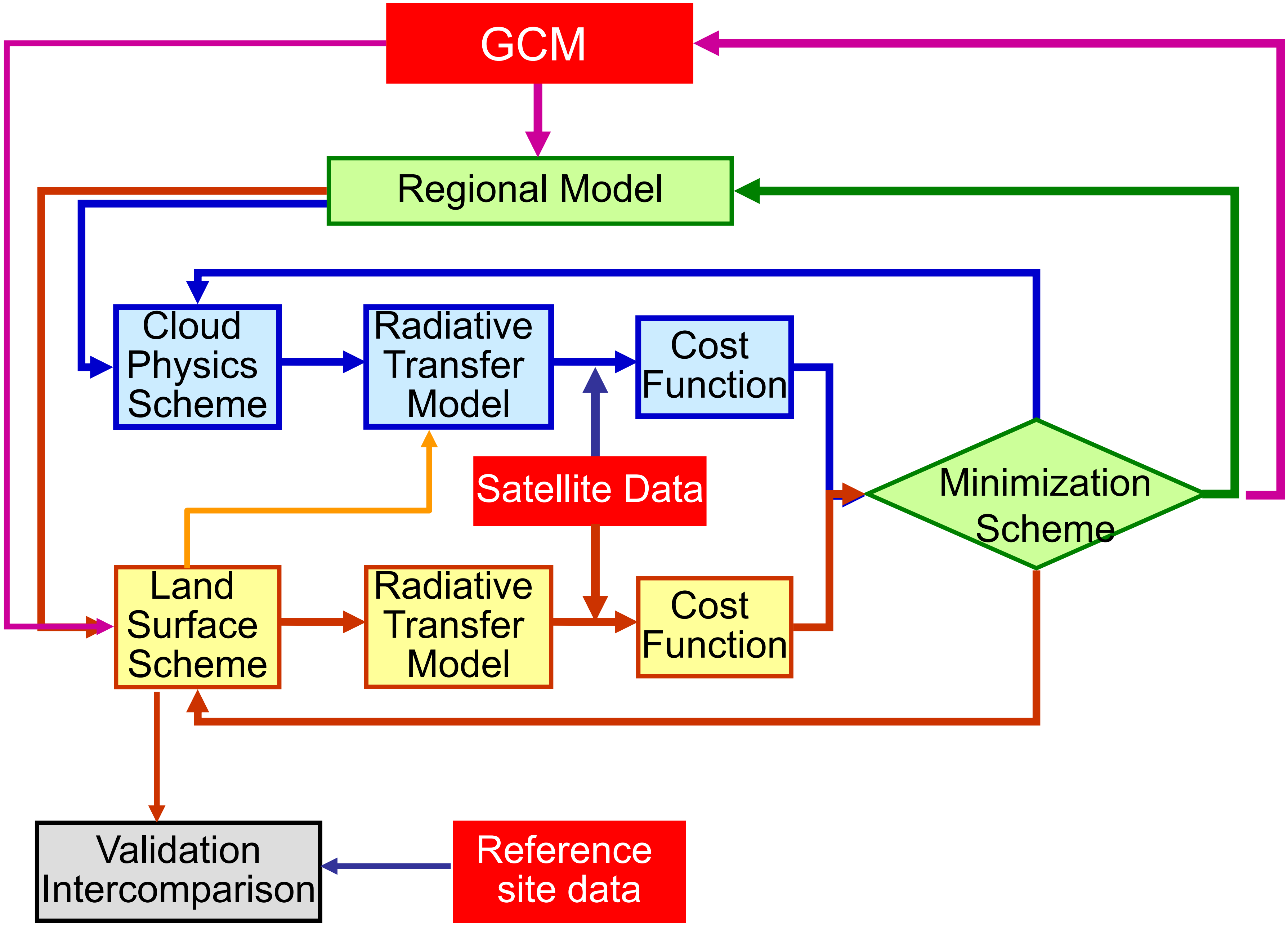
# Physical Down-scaling

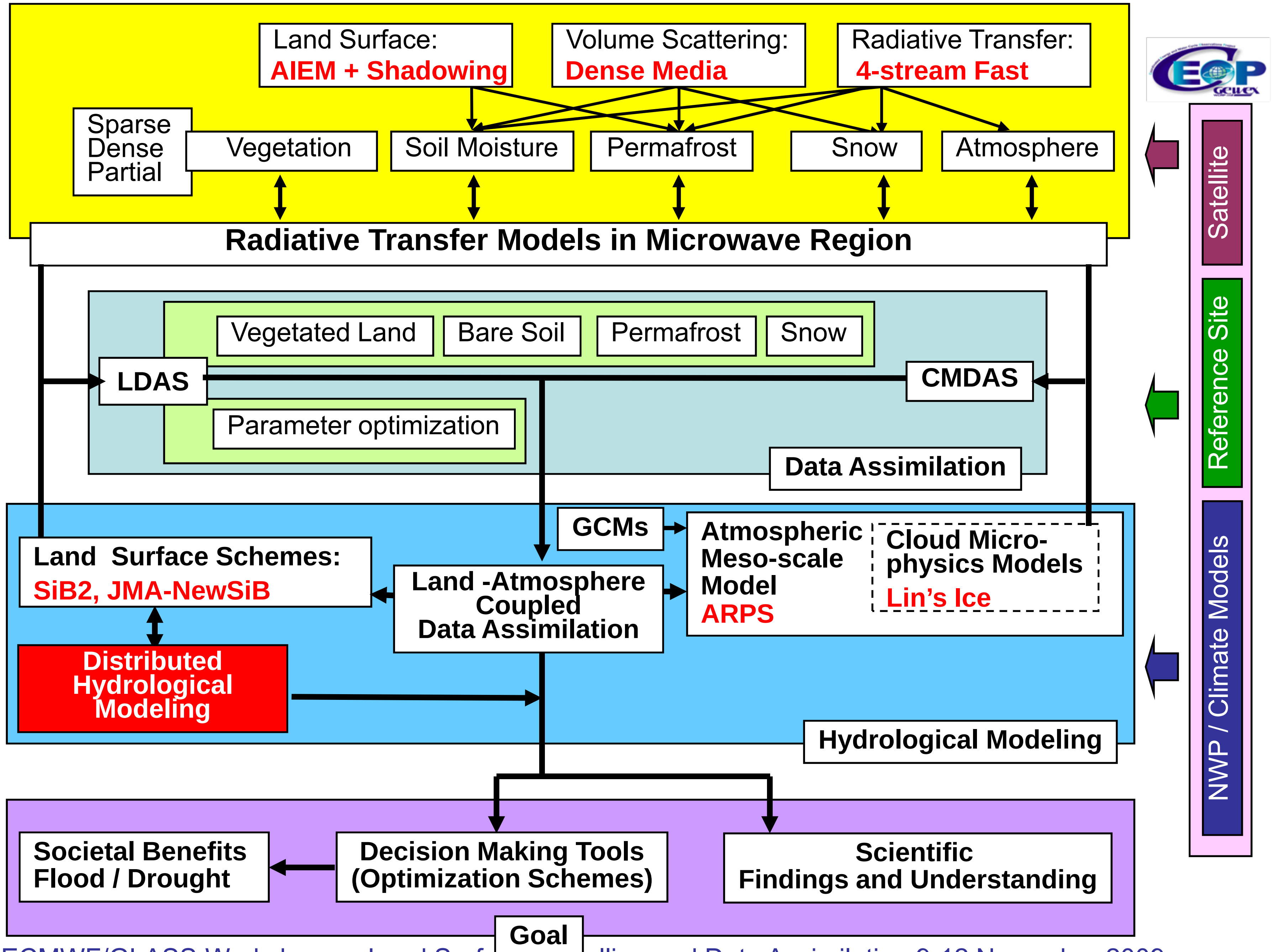


# CMDAS Framework

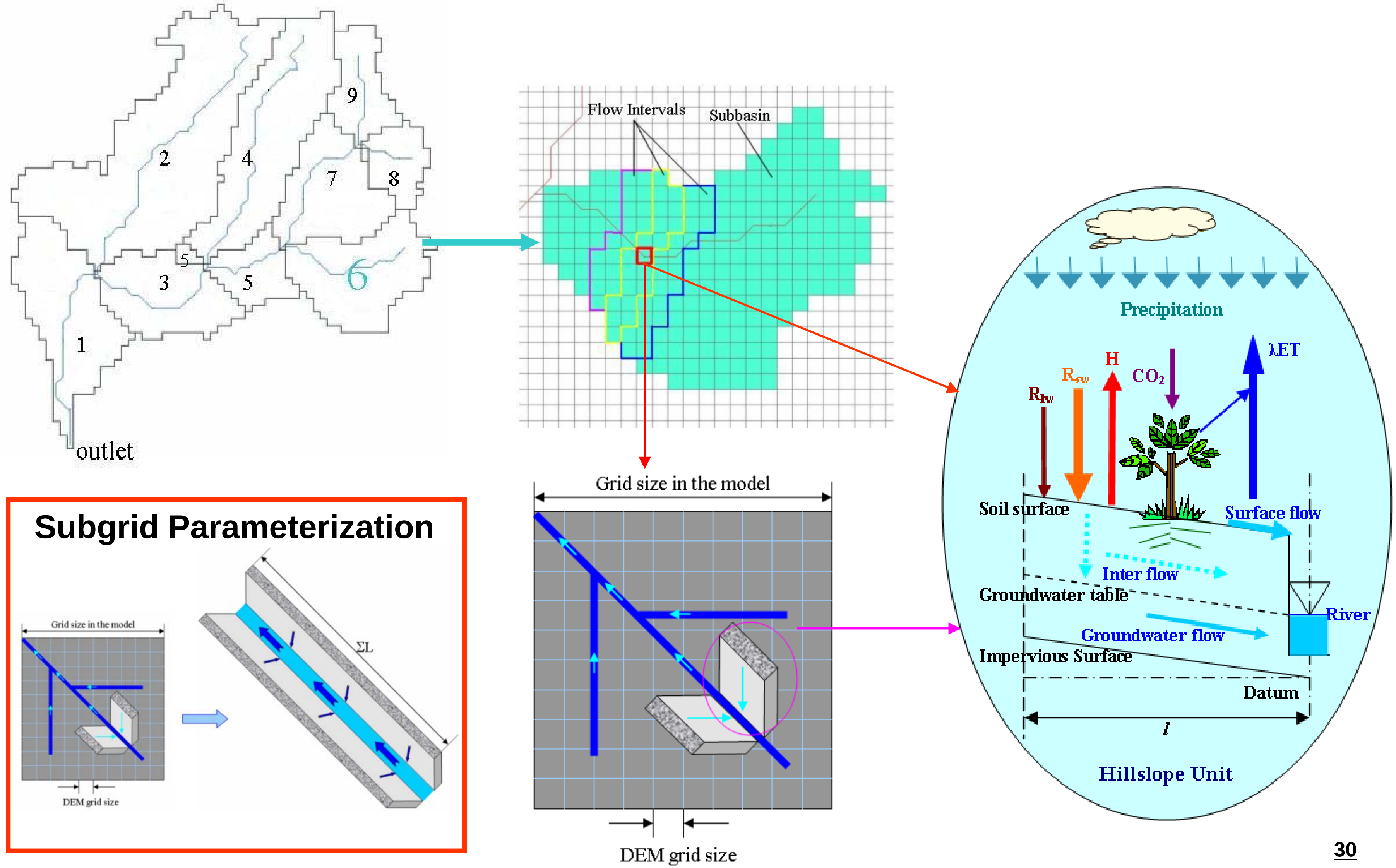



(Mirza et al. 2007)


GCM
Regional Model
Cloud Physics Scheme
Radiative Transfer Model
Cost Function
Satellite Data
Minimization Scheme
Land Surface Scheme
Radiative Transfer Model
Cost Function
Validation Intercomparison
Reference site data

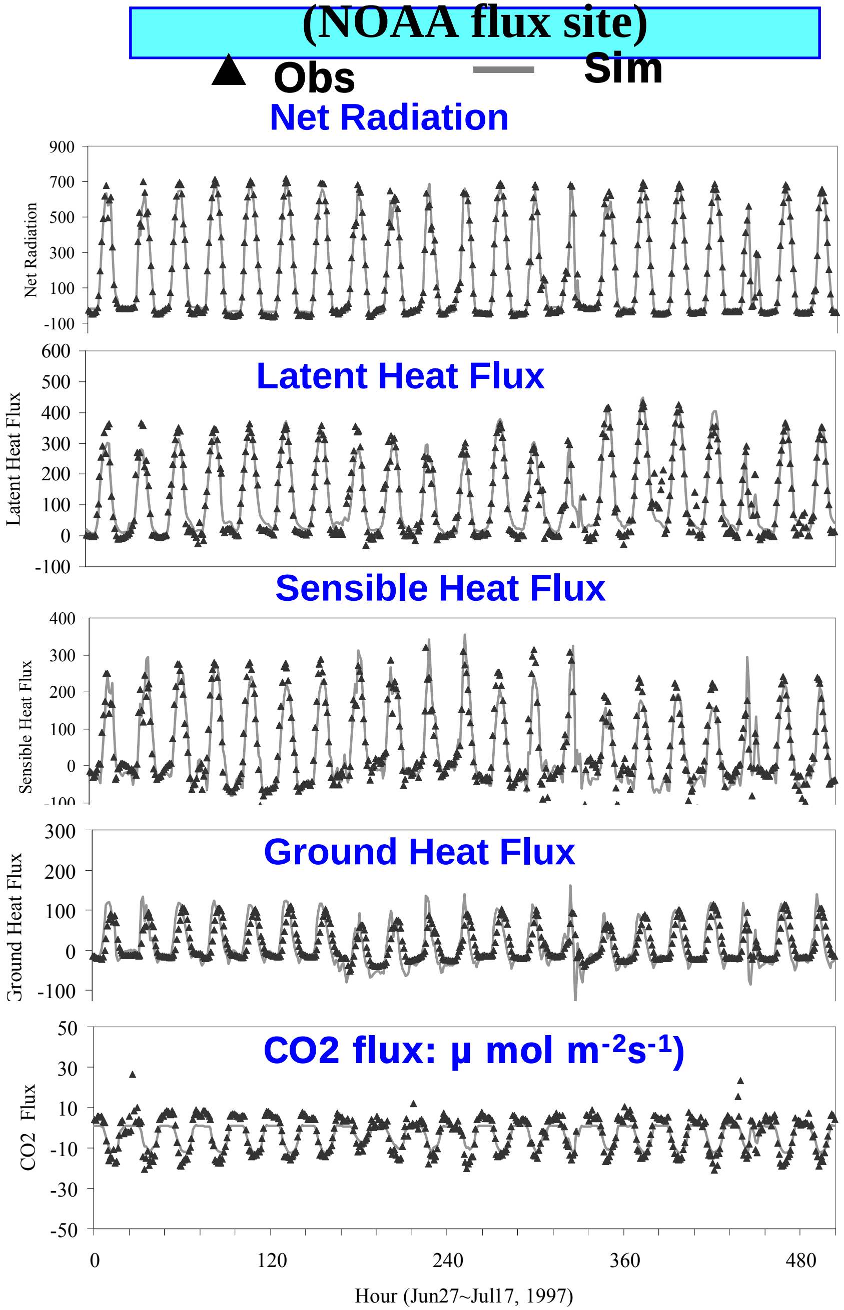

Land Surface:
AIEM + Shadowing
Volume Scattering:
Dense Media
Radiative Transfer:
4-stream Fast
Sparse
Dense
Partial
Vegetation
Soil Moisture
Permafrost
Snow
Atmosphere
Radiative Transfer Models in Microwave Region
Vegetated Land
Bare Soil
Permafrost
Snow
LDAS
CMDAS
Parameter optimization
Data Assimilation
GCMs
Land Surface Schemes:
SiB2, JMA-NewSiB
Land -Atmosphere Coupled Data Assimilation
Atmospheric Meso-scale Model
ARPS
Cloud Micro-physics Models
Lin's Ice
Distributed Hydrological Modeling
Hydrological Modeling
Societal Benefits
Flood / Drought
Decision Making Tools
(Optimization Schemes)
Scientific
Findings and Understanding
Goal
Satellite
Reference Site
NWP / Climate Models

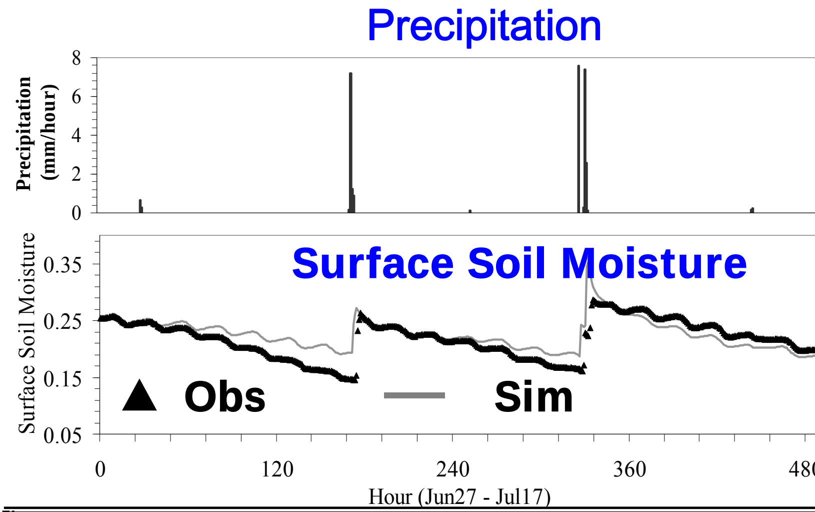
# (Water and Energy Budget-based Distributed Hydrological Model)

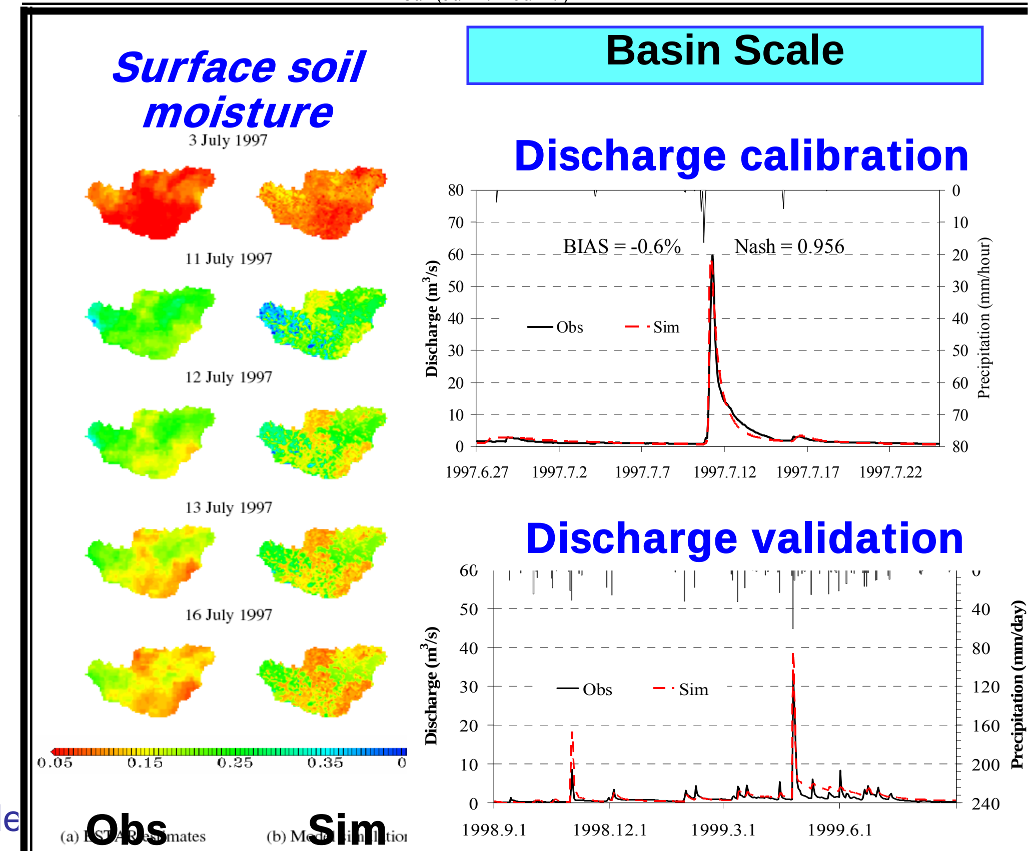


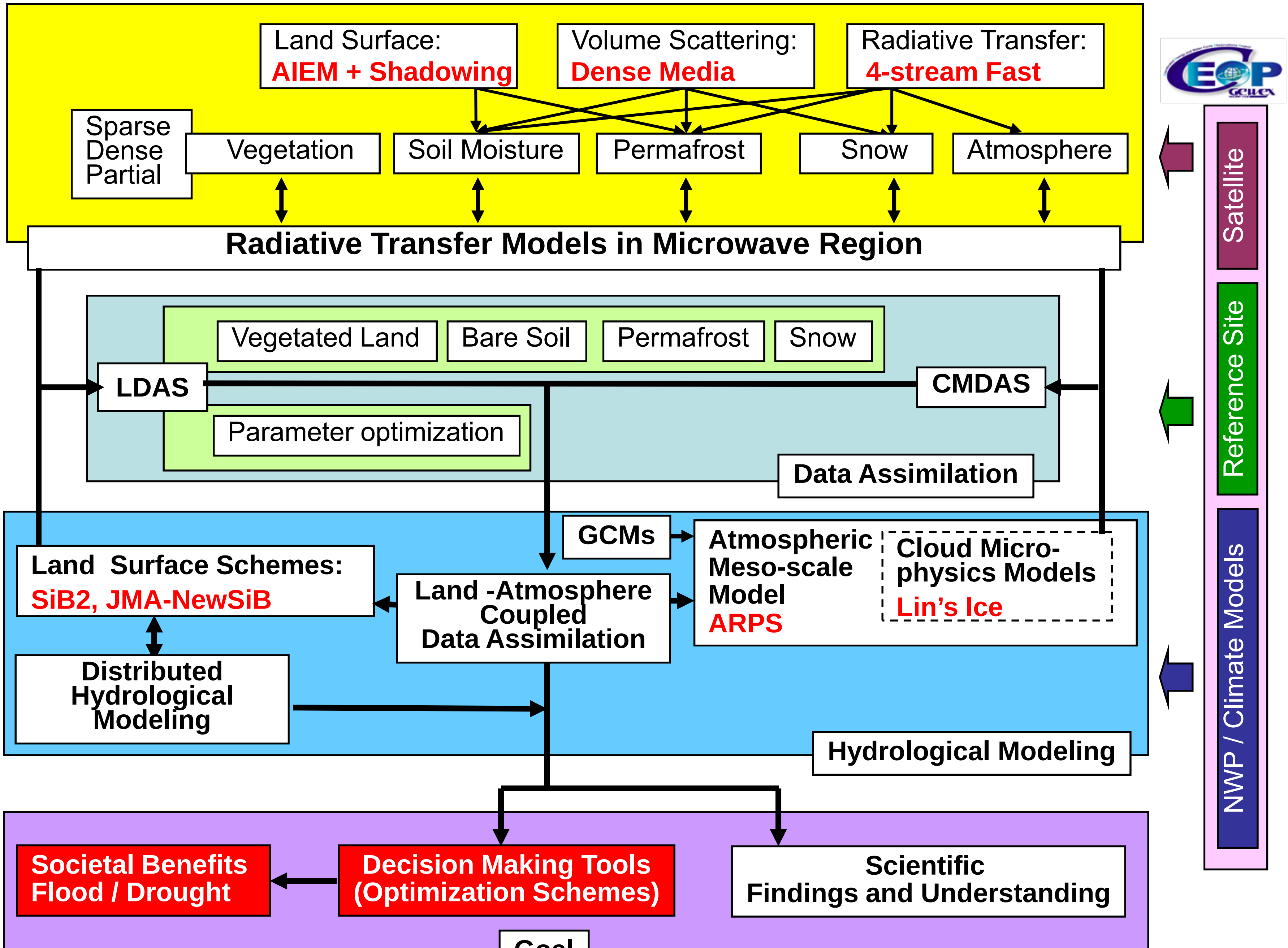
# Validation in Little Washita, USA

(Saveedra et al. 2006 and Lei et al. 2009)




Land Surface:
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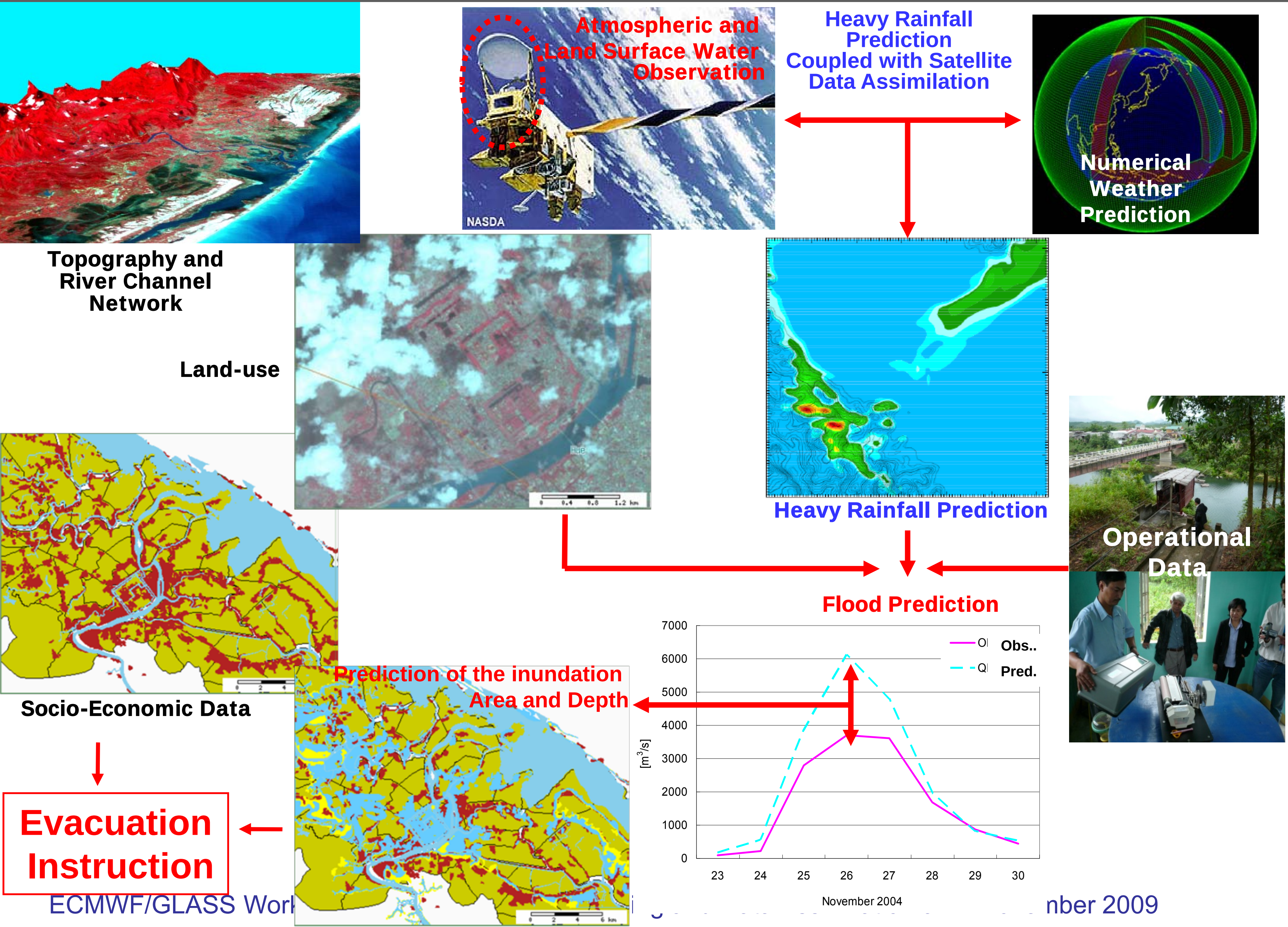
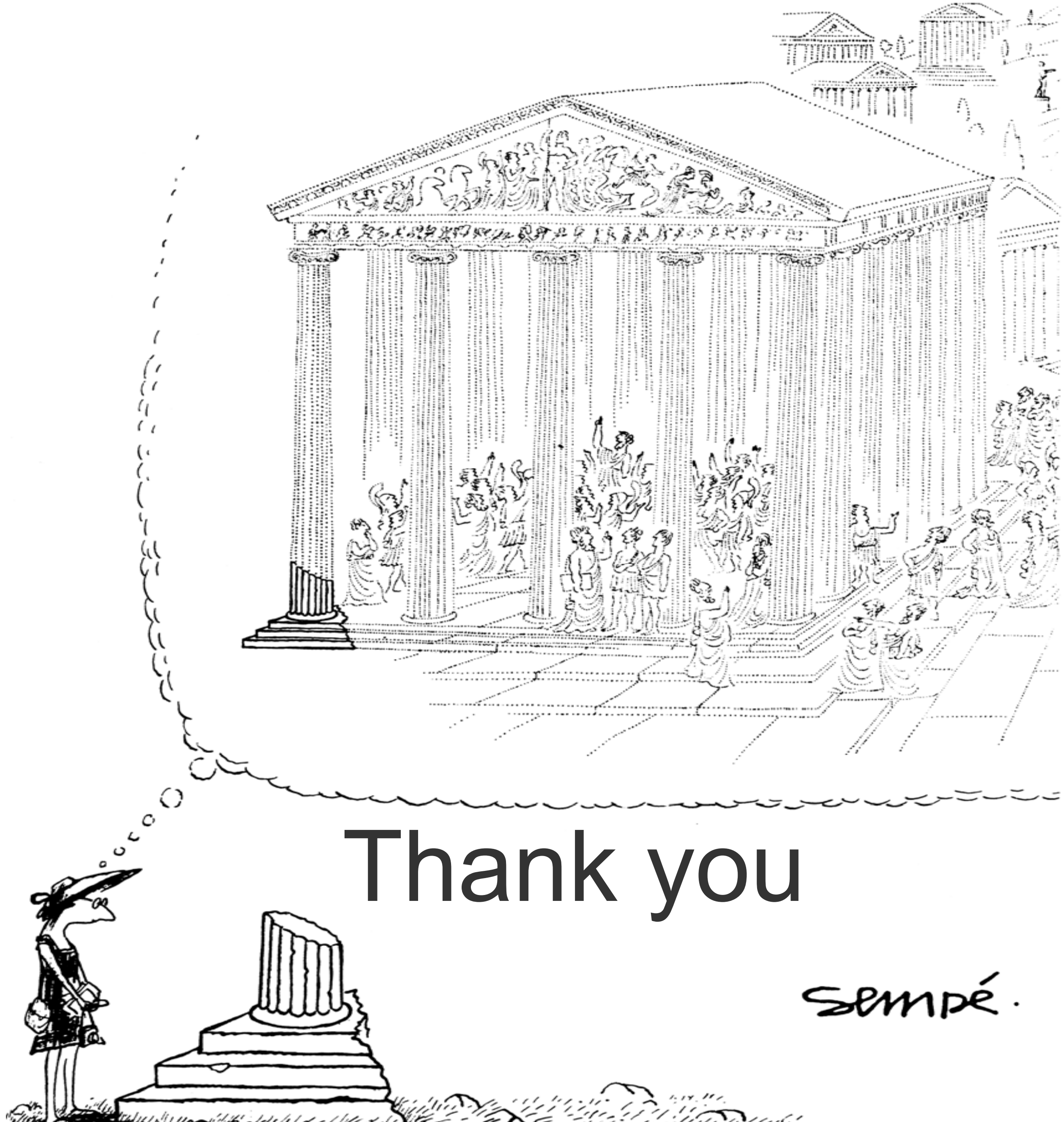
# GEOSS/AWCI-SAFE Flood Prediction System in Vietnam (Huong R.)



# GEOSS Asian Water Cycle Initiative (AWCI)

## 19 Member Countries

## 18 River Basins for Initial Demonstration




# Thank you

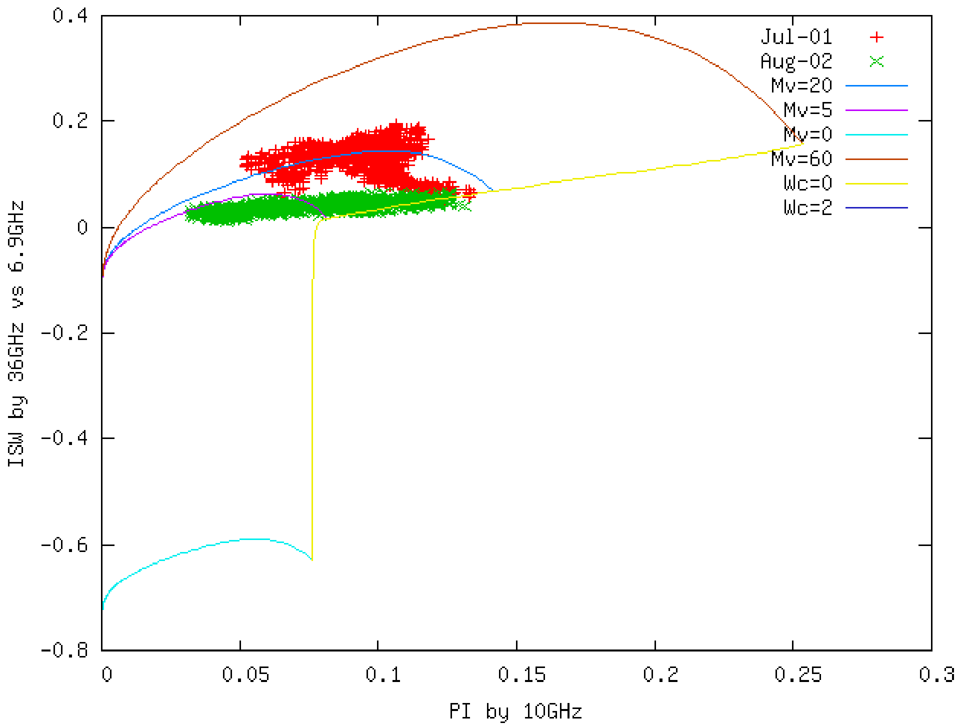
# Look Up Table

- Index of Soil Wetness (ISW)

$$ISW = \frac{T_{b36h} - T_{b6.9h}}{\frac{1}{2}(T_{b36h} + T_{b6.9h})}$$

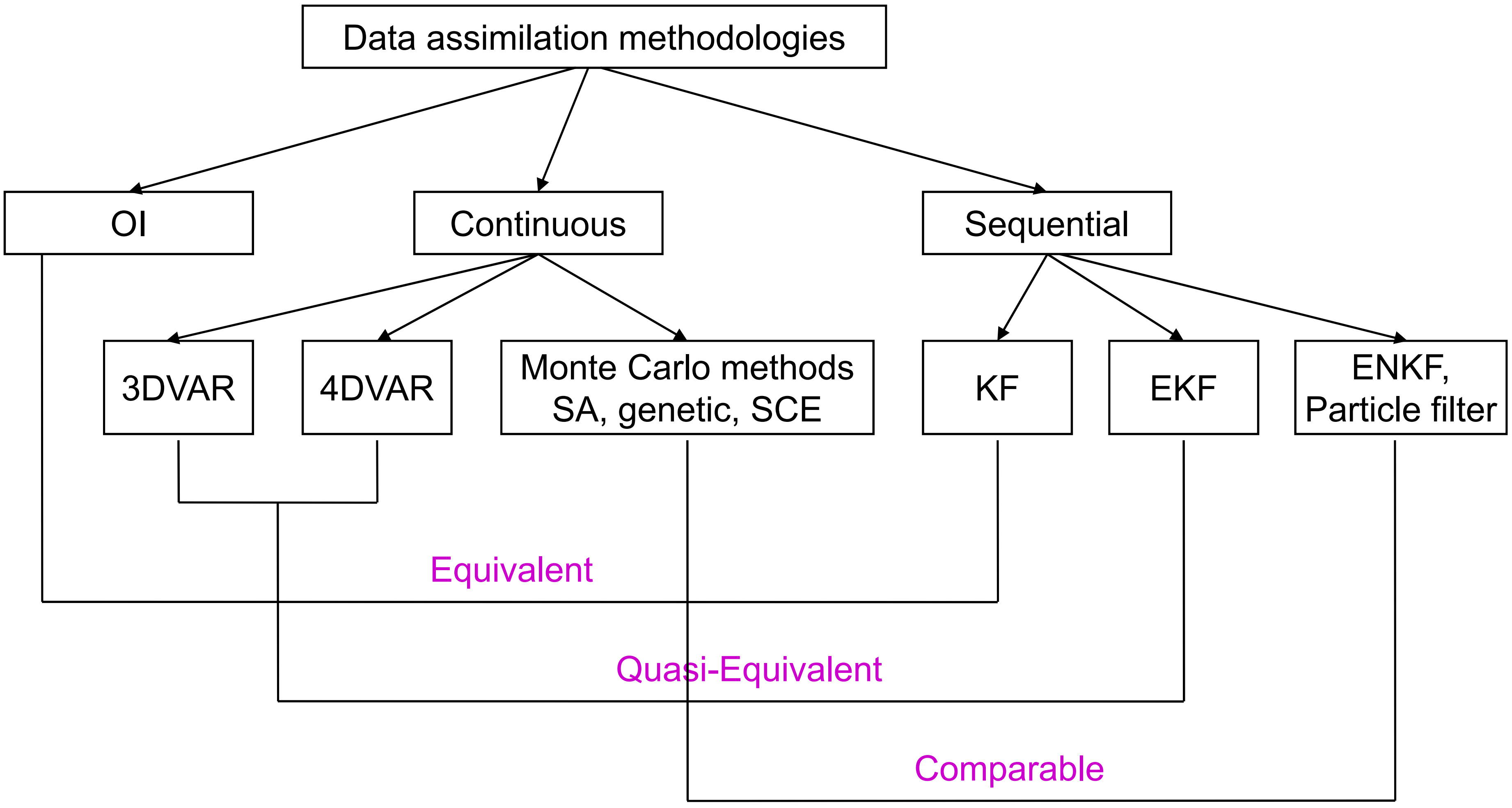
- Polarization Index (PI)

$$PI = \frac{T_{b10v} - T_{b10h}}{\frac{1}{2}(T_{b10v} + T_{b10h})}$$

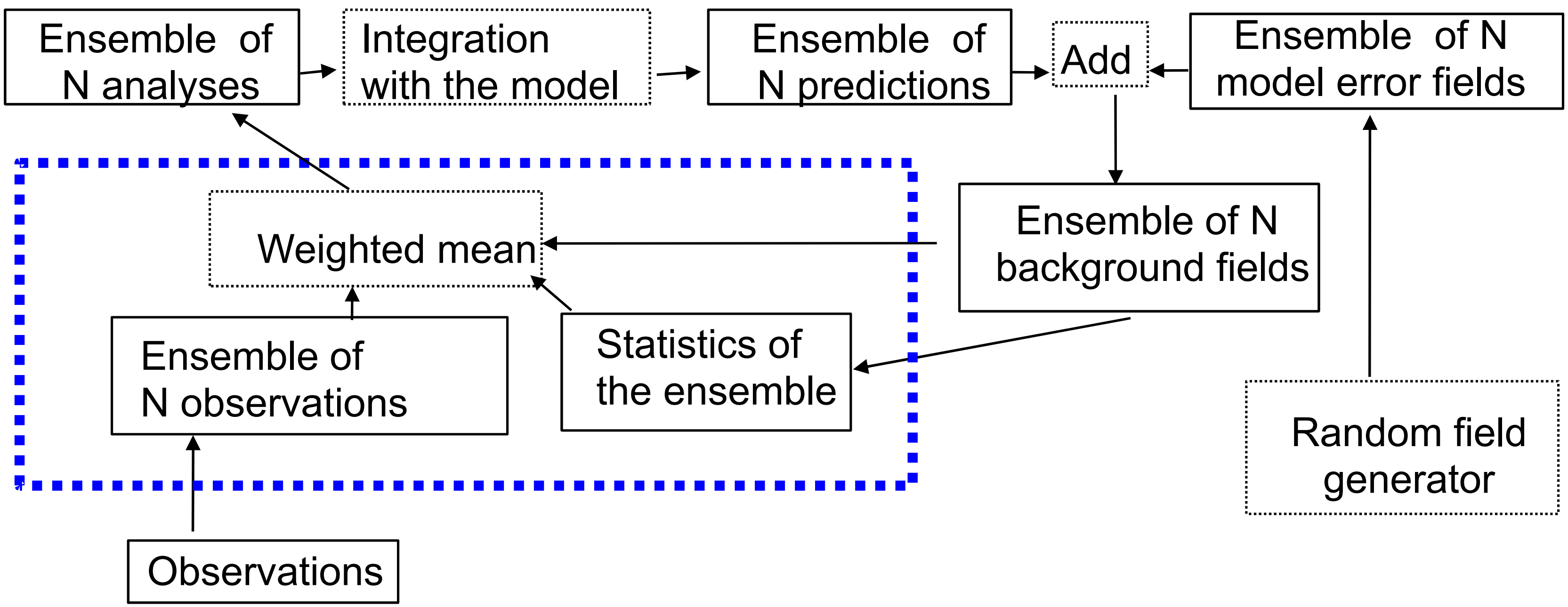



- Changing Mv from 0% to 60%, Wc from 0 to 2 every 0.01, running forward model, making look-up table

# DA Classification

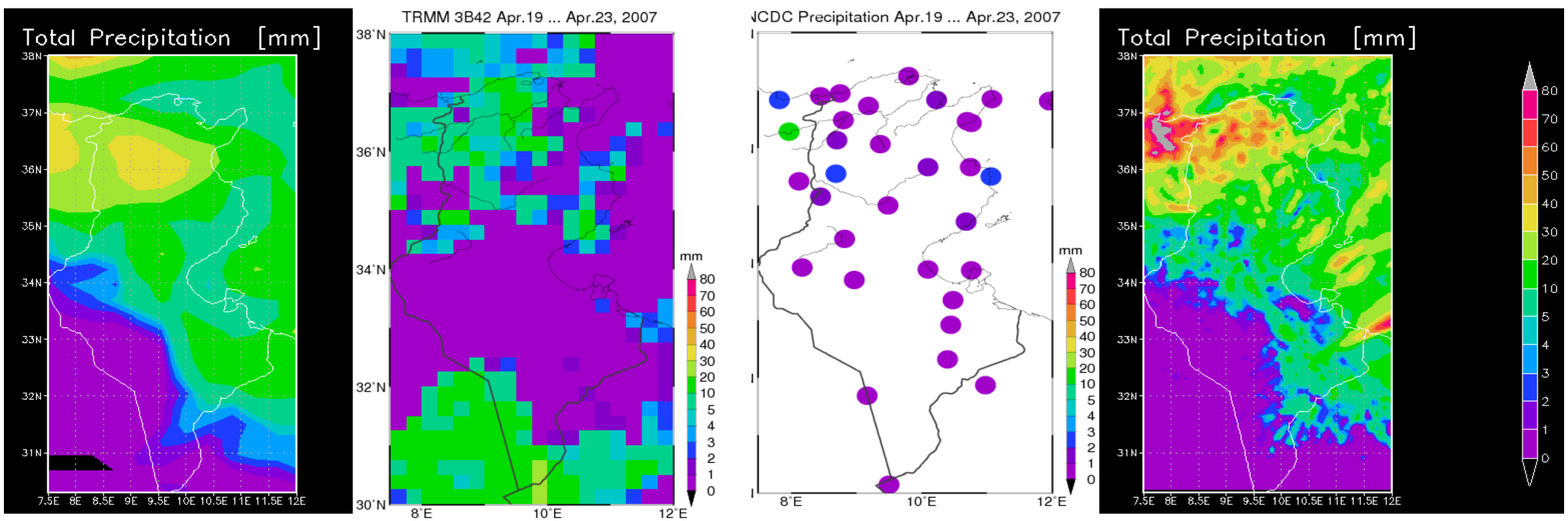


# Ensemble Kalman filter



# Precipitation over Tunisia

Without coupled System | TRMM product | NCDC product | With coupled System




(Boussetta et al. 2009)