Atmosphere-Land Coupled Data Assimilation by Using Satellite Microwave Radiometers

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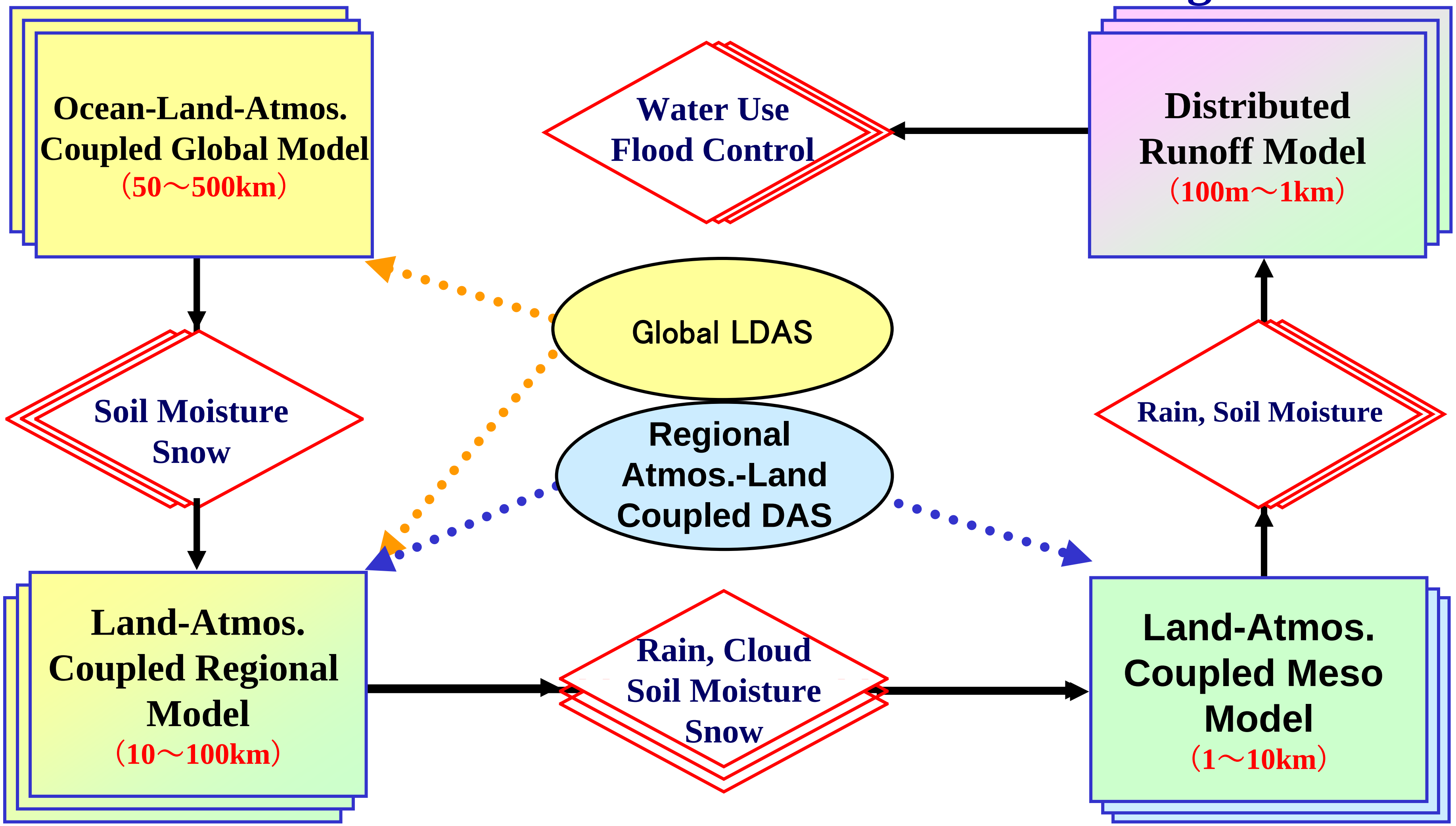
The 3rd WCRP International Conference on Reanalysis
Tokyo, Jan. 28 – Feb. 1, 2008

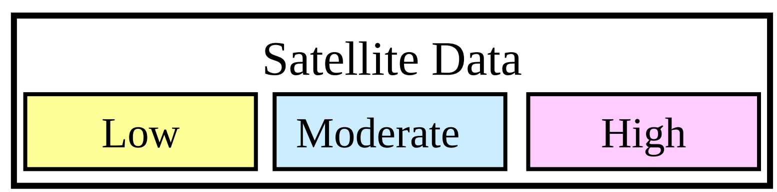
Global ⇔ Regional-Meso ⇔ River Basin

Satellite Data Assimilation and Down-scaling

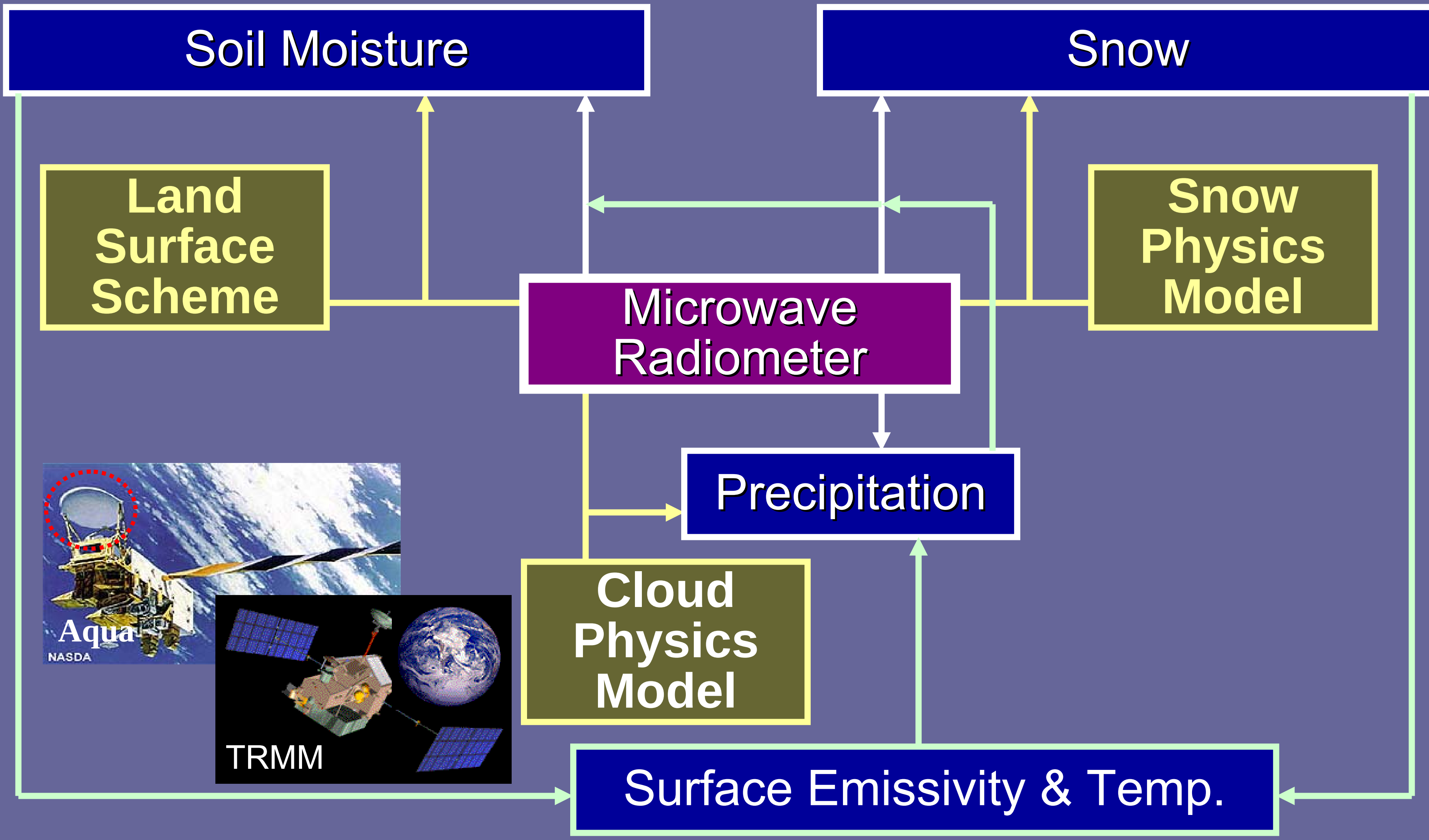


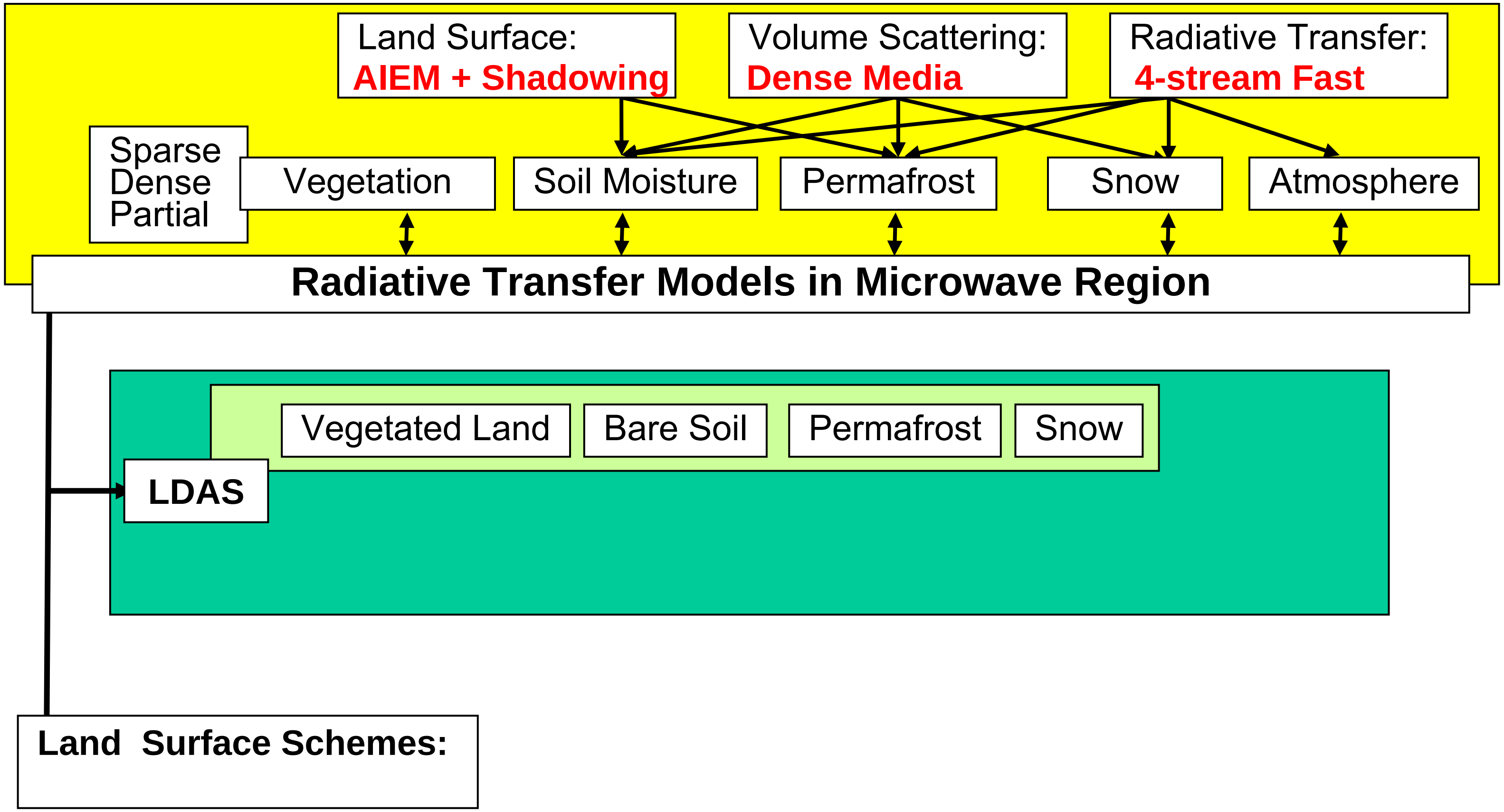
Short Forecasting：Initial Condition

Long-term Forecasting: Boundary Condition



Microwave Remote Sensing




Land Surface:
AIEM + Shadowing
Volume Scattering:
Dense Media
Radiative Transfer:
4-stream Fast
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Partial
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Soil Moisture
Permafrost
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Vegetated Land
Bare Soil
Permafrost
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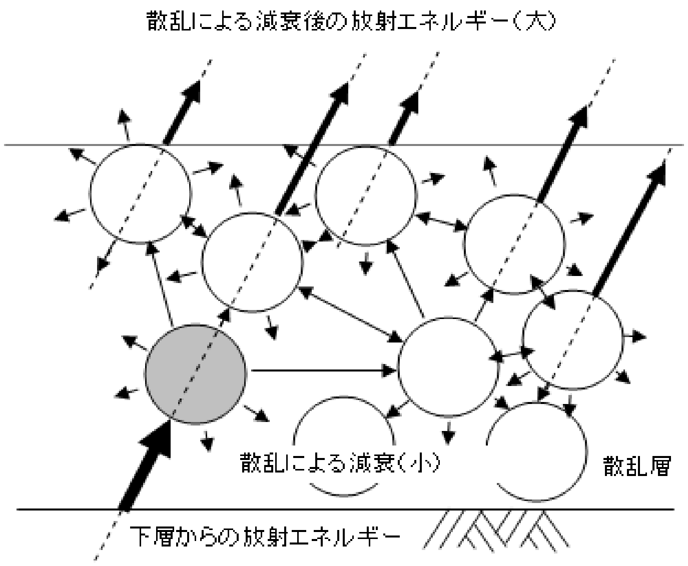
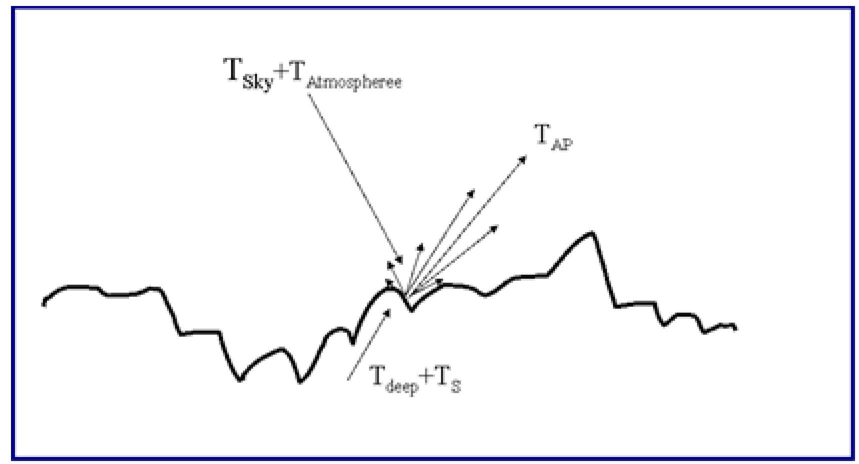
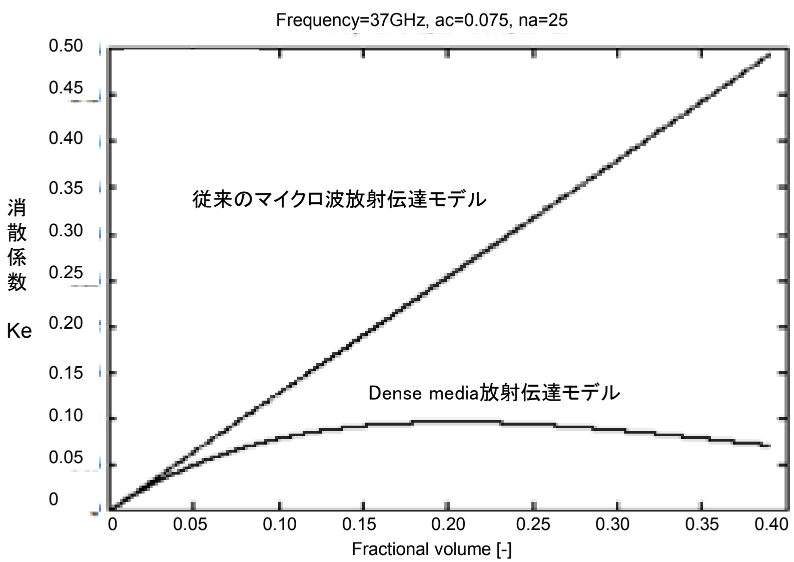
LDAS
Land Surface Schemes:

Application of DMRT & Surface Models to Soil







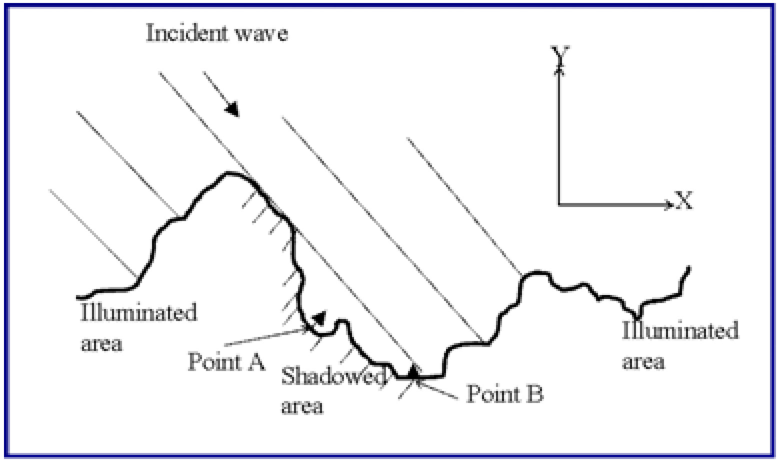
Qh (Wang and Choudhury, 1981)

AIEM (Chen et al., 2003)

Qp (Shi et al., 2005)

Introduction of the Shadowing Effect

Sancer, 1969



$$S(\theta_s,\theta_i)=\begin{cases}\dfrac{1}{1+\Lambda(\mu_s)} & \theta_s\ge\theta_i\\ \dfrac{1}{1+\Lambda(\mu_i)} & \theta_s\le\theta_i\\ \dfrac{1}{\Lambda(\mu_s)+\Lambda(\mu_i)+1} & otherwise\end{cases}$$

where $\mu=\cot\theta$

$$\Lambda(\mu)=\frac{1}{2}\left[\sqrt{\frac{2}{\pi}}\frac{s}{\mu}e^{-\mu^2/2s^2}-erfc\left(\frac{\mu}{\sqrt{2}s}\right)\right]$$

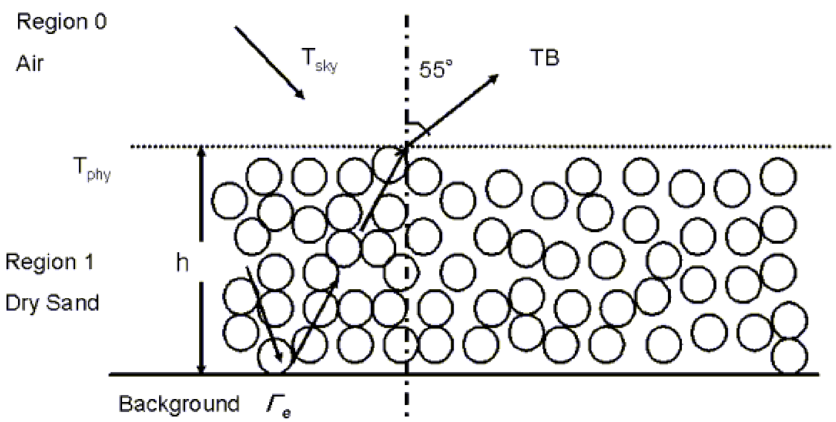
$$R_p^e=r_p\cdot\exp\left[-\left(2\cdot k\sigma\cdot\cos\theta\right)^2\right]\cdot S(\theta,\theta)$$

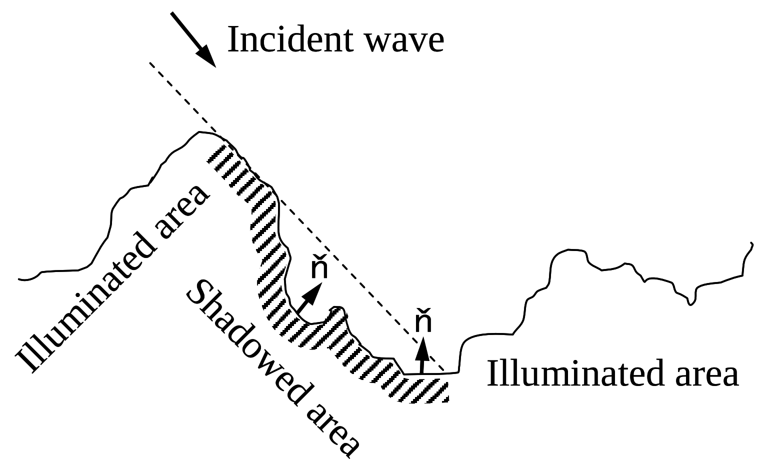
$$+\frac{1}{4\pi\cos\theta}\times\int_0^{2\pi}\int_0^{\pi/2}\left[\sigma_{pp}\left(\theta,\theta_j,\phi_j\right)\cdot S(\theta,\theta_j)+\sigma_{pq}\left(\theta,\theta_j,\phi_j\right)\cdot S(\theta,\theta_j)\right]\times\sin\theta_j\cdot d\theta_j\cdot d\phi_j$$

AIEM using the Discrete Ordinate Method (DOM), 4-stream

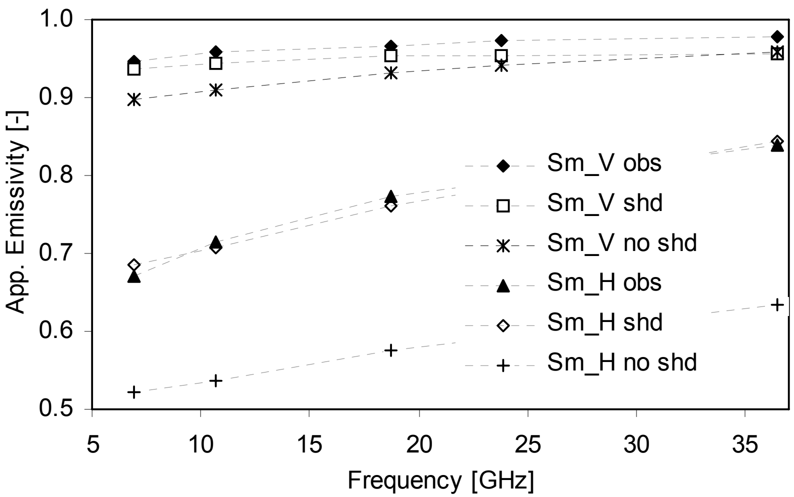

18.7/23.8/36.5/89GHz
6.9/10.7/18.7GHz

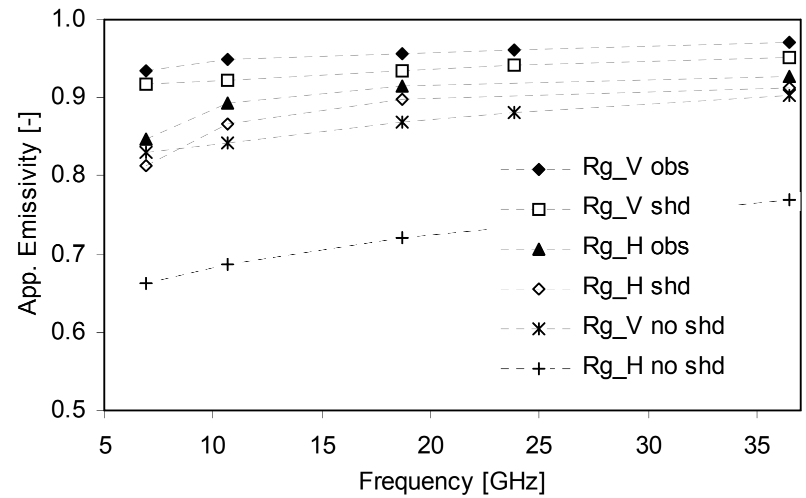
GBHM Experiments

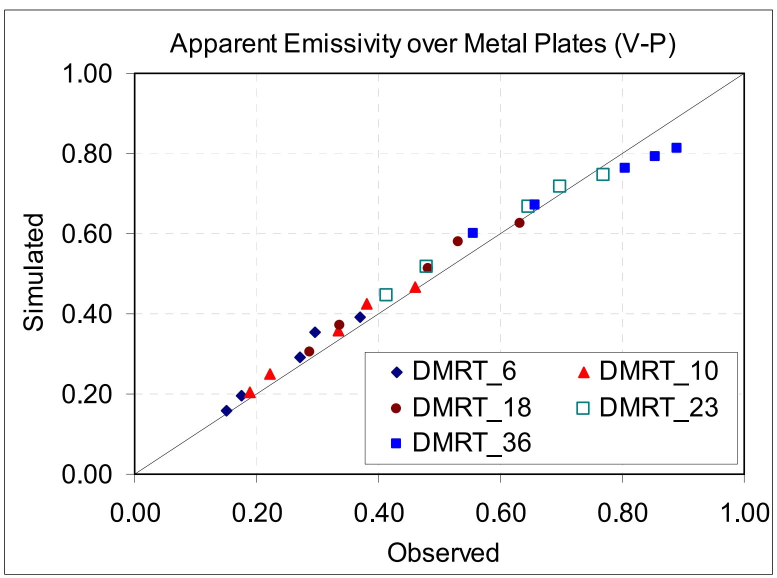


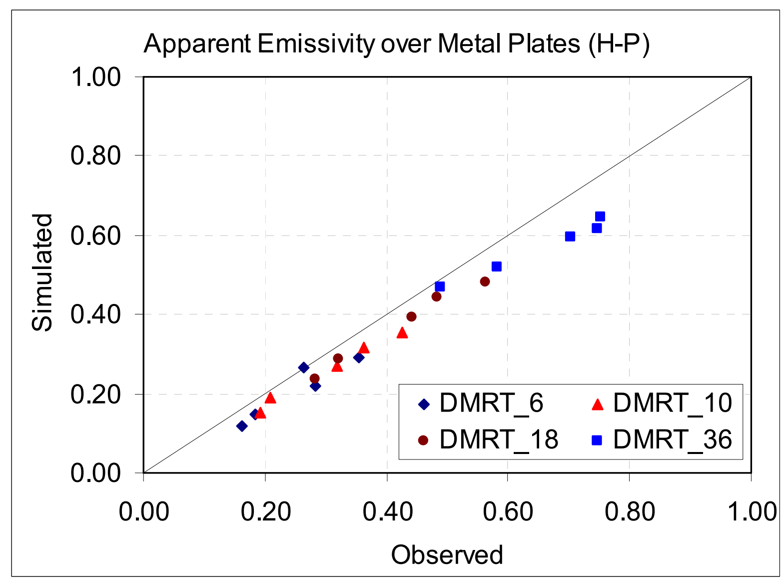


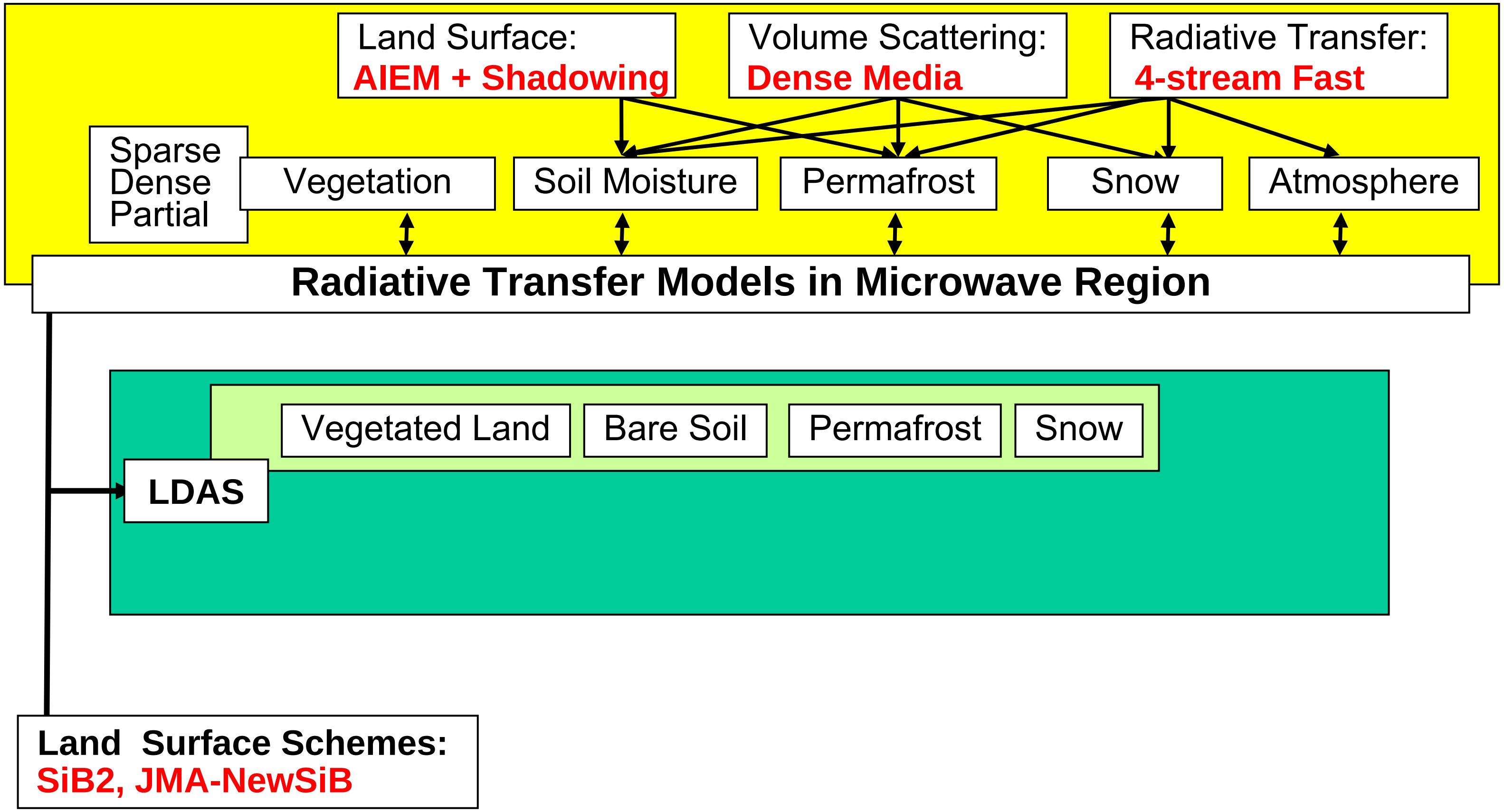
DMRT + AIEM Model +Shadowing Effect: Validation in Tokyo







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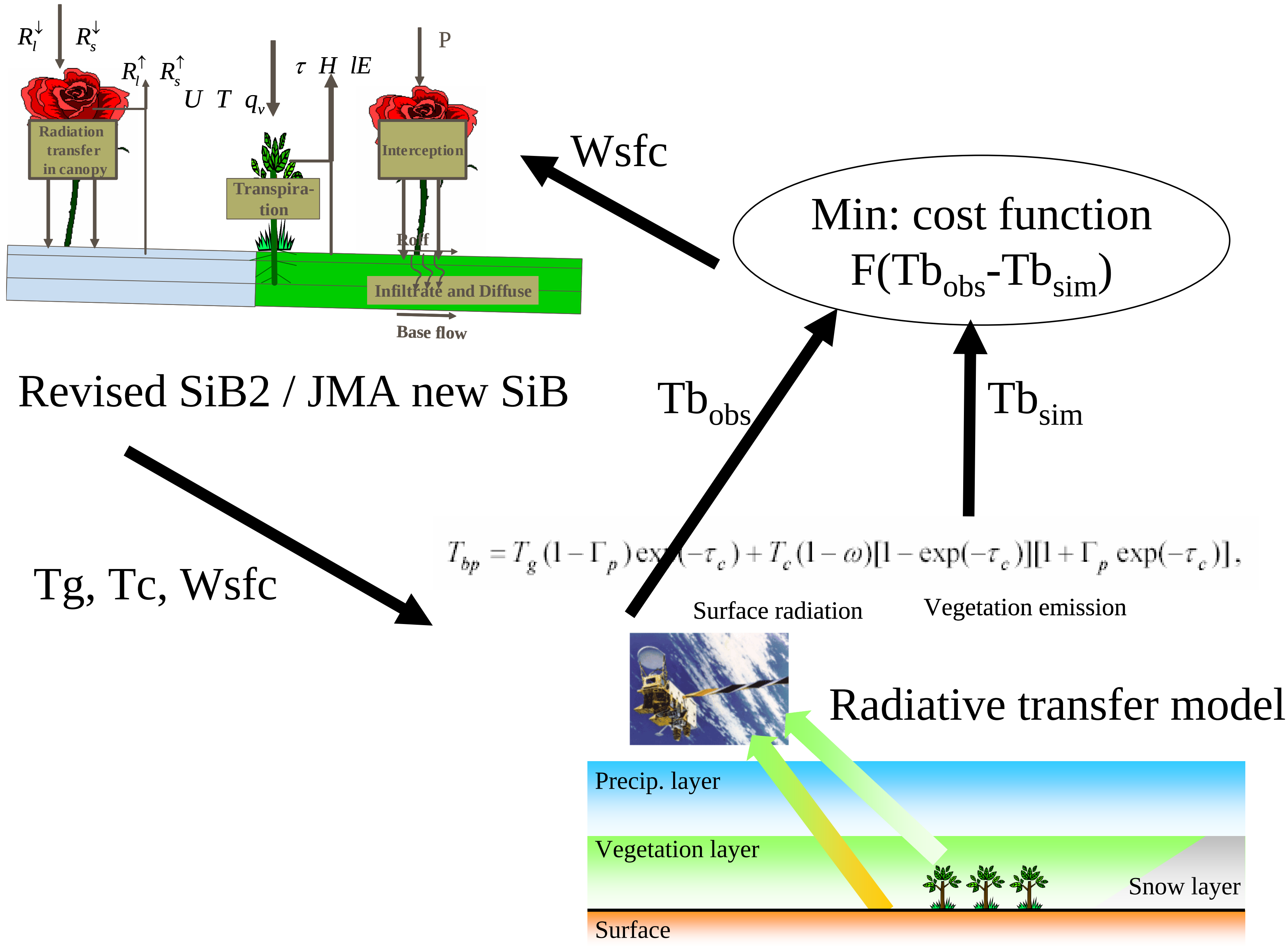
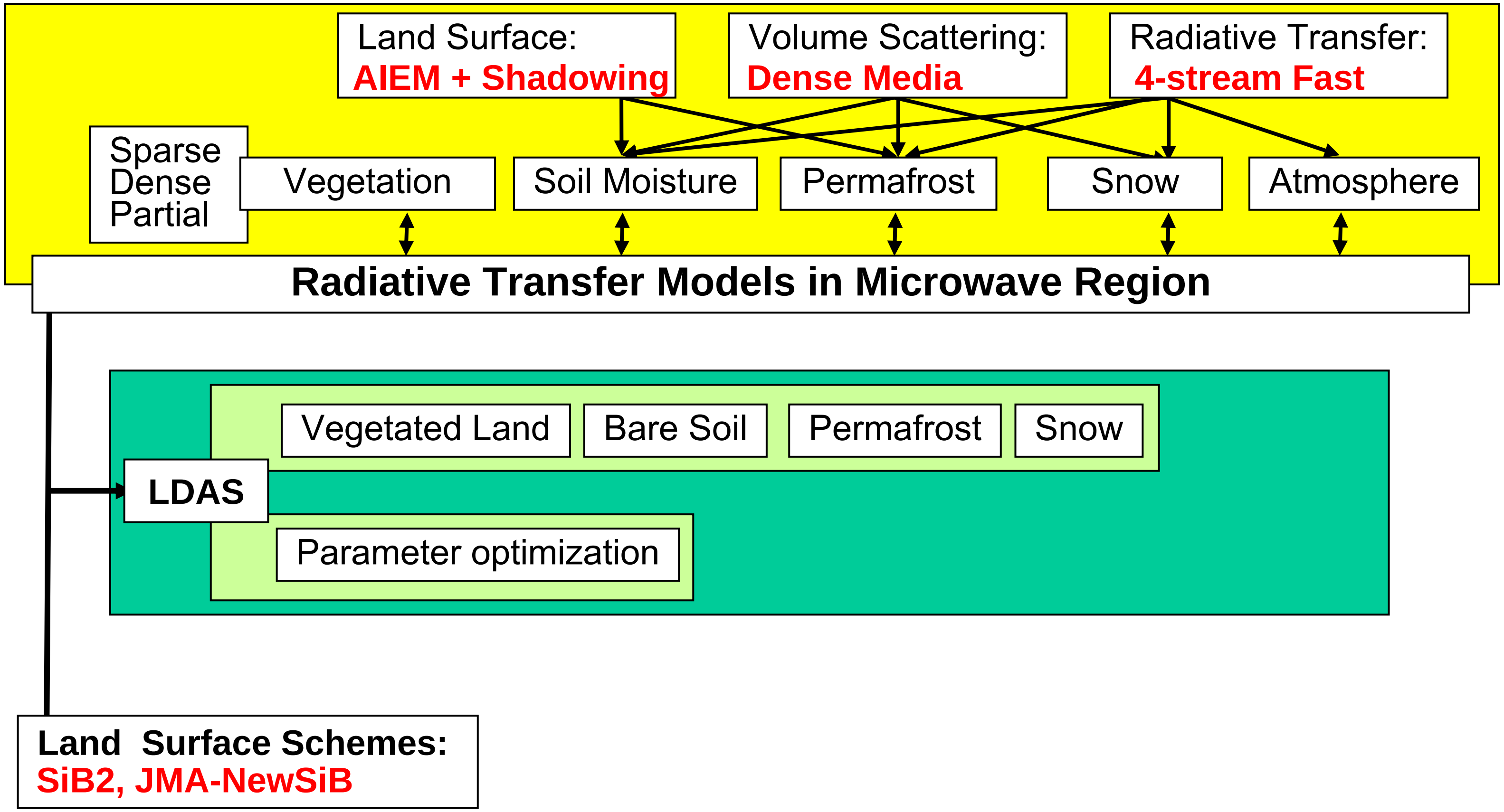


$R_l^{\downarrow}$ $R_s^{\downarrow}$
$R_l^{\uparrow}$ $R_s^{\uparrow}$
U T q_v
τ H lE
P
Radiation transfer in canopy
Transpira-tion
Interception
Roff
Infiltrate and Diffuse
Base flow
Revised SiB2 / JMA new SiB
Wsfc
Min: cost function
$F(Tb_{obs}-Tb_{sim})$
Tb_{obs}
Tb_{sim}
Tg, Tc, Wsfc
$T_{bp} = T_g(1-\Gamma_p)\exp(-\tau_c) + T_c(1-\omega)[1-\exp(-\tau_c)][1+\Gamma_p\exp(-\tau_c)]$,
Surface radiation
Vegetation emission
Radiative transfer model
Precip. layer
Vegetation layer
Snow layer
Surface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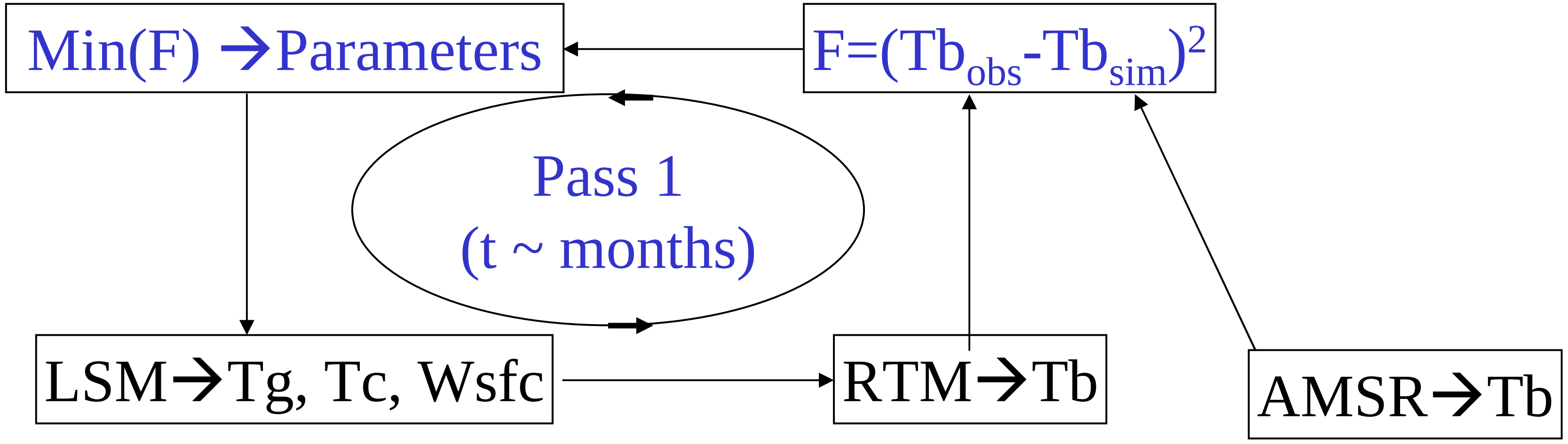
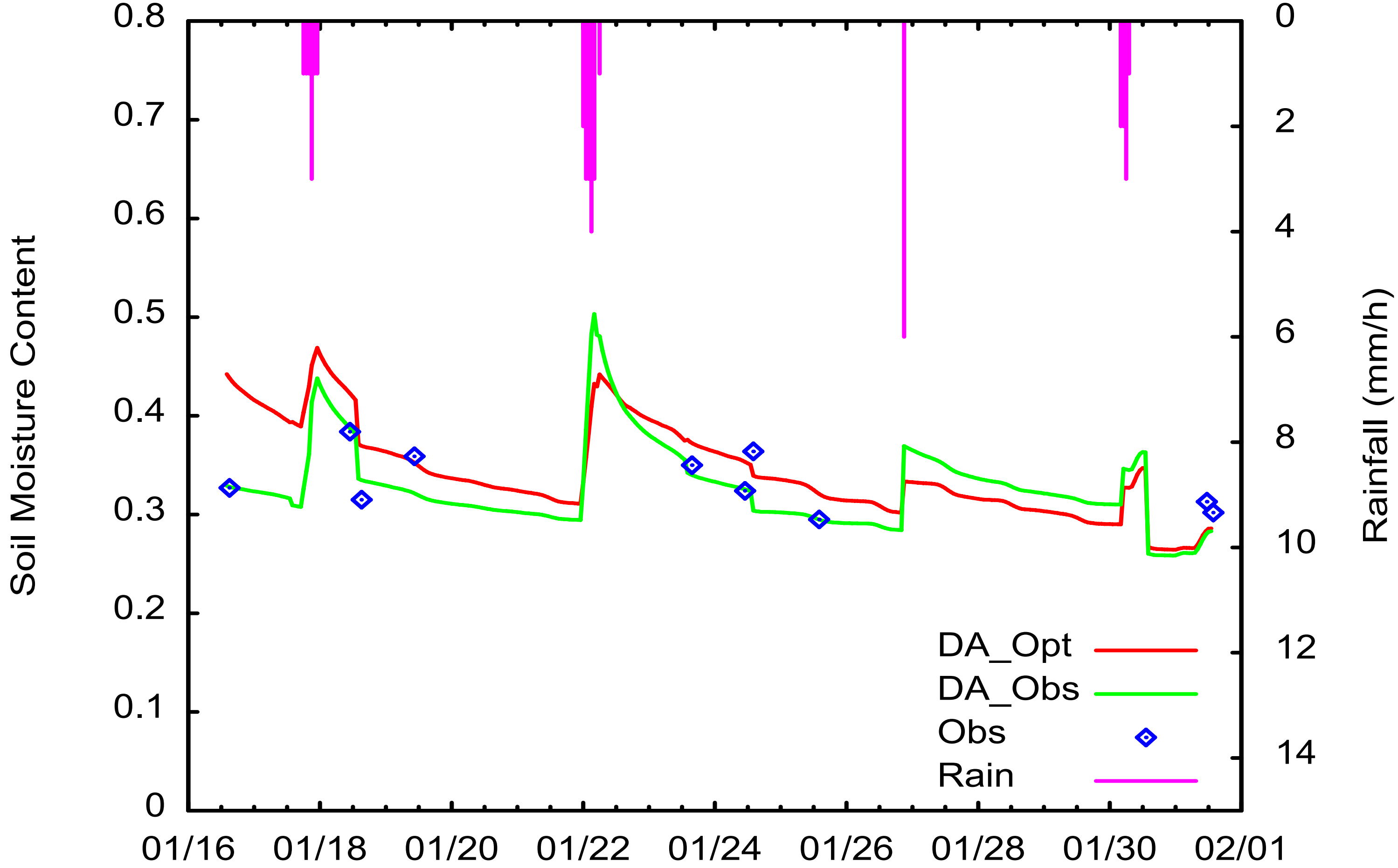
Parameter Optimization



(Yang, Koike et al.,2007)

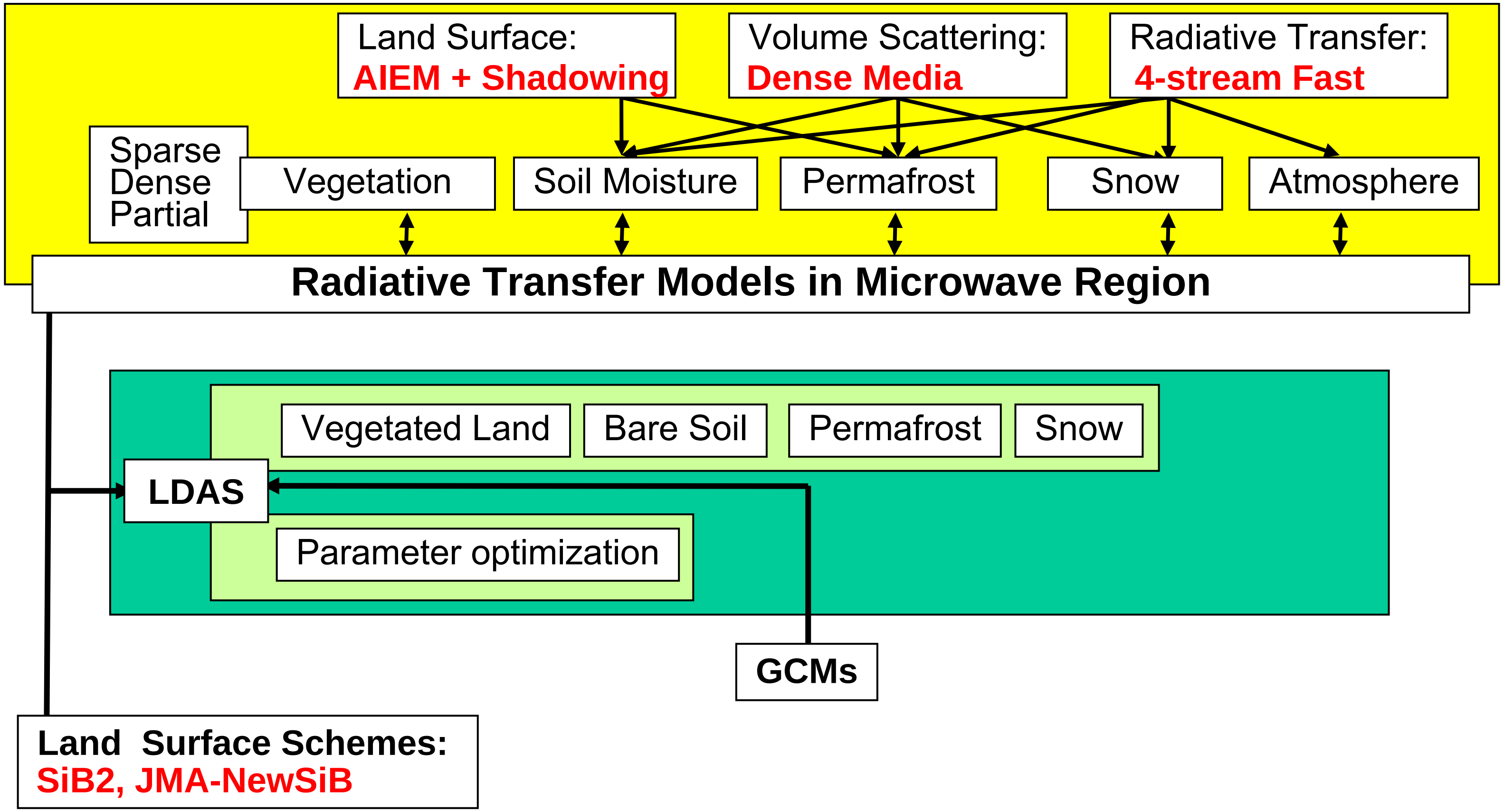
Parameter Optimization in Tanashi Exp.-- without vegetation effect



Good estimation of soil moisture

Optimized parameters in Mongolia

	A3	C2	E4	G6	H7	Used
sand(%)	46	40	42	46	39	60
clay(%)	18	20	20	20	19	20
bulk density (g/cm3)	1.40	1.52	1.51	1.46	1.53	1.258
rms h (cm)	0.38	0.40	0.25	0.25	0.20	0.34
Correlation l (cm)	0.44	0.49	0.33	0.33	0.34	0.72



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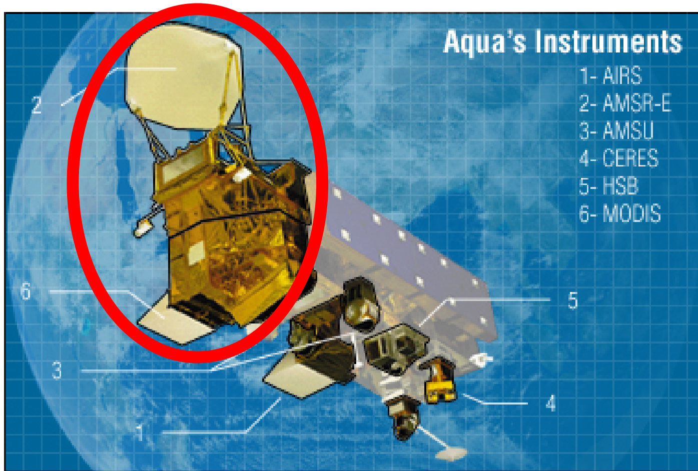
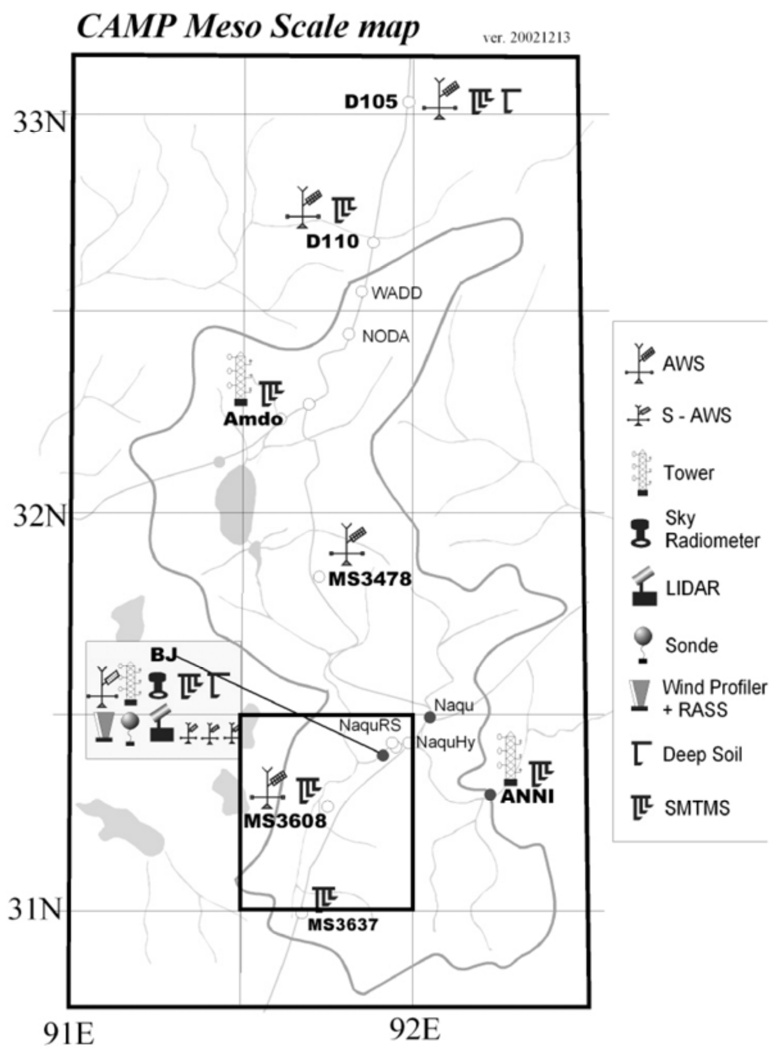
Input Data→ High Applicability in Any Region

- LDAS-UT grid size: 0.5 degree
- Forcing
  – GPCP precipitation: 1 degree
  – ISCCP radiation: 2.5 degree
  – NCEP reanalysis: 1.5 degree
- Leaf area index: MODIS
- Microwave Tb: AMSR-E



(Yang, Koike et al.,2007)

First application: A case at CEOP Tibet site



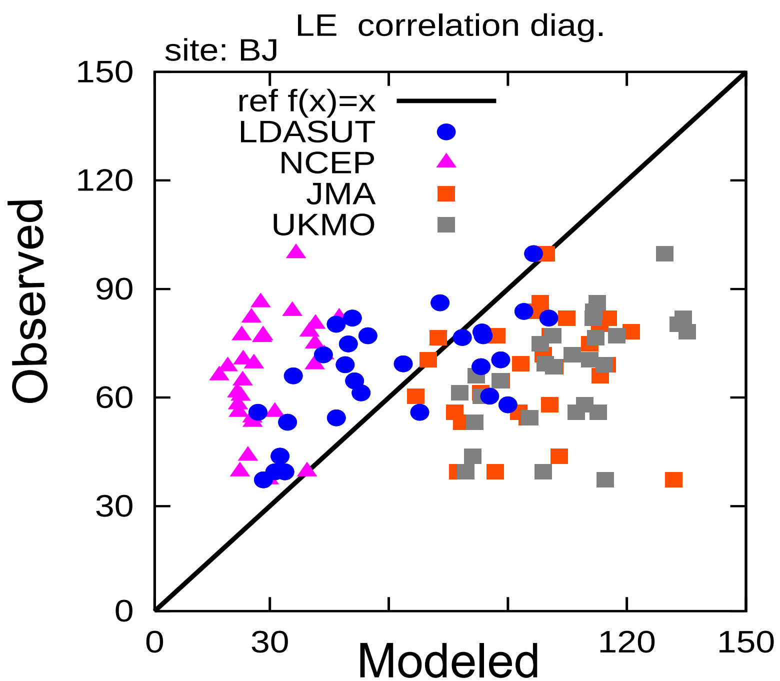
Items	Station (depth)
Precipitation	BJ
Radiation	BJ
Surface temperature	BJ, MS3608 S-AWS1, S-AWS3
Near-surface soil moisture	BJ, MS3608 (4cm) S-AWS1, S-AWS3 (0-5 cm) SSMTMS (0-3 cm)
Turbulent fluxes	BJ (3m, 20m)

(Yang, Koike et al.,2007)

LDASUT- GCMs

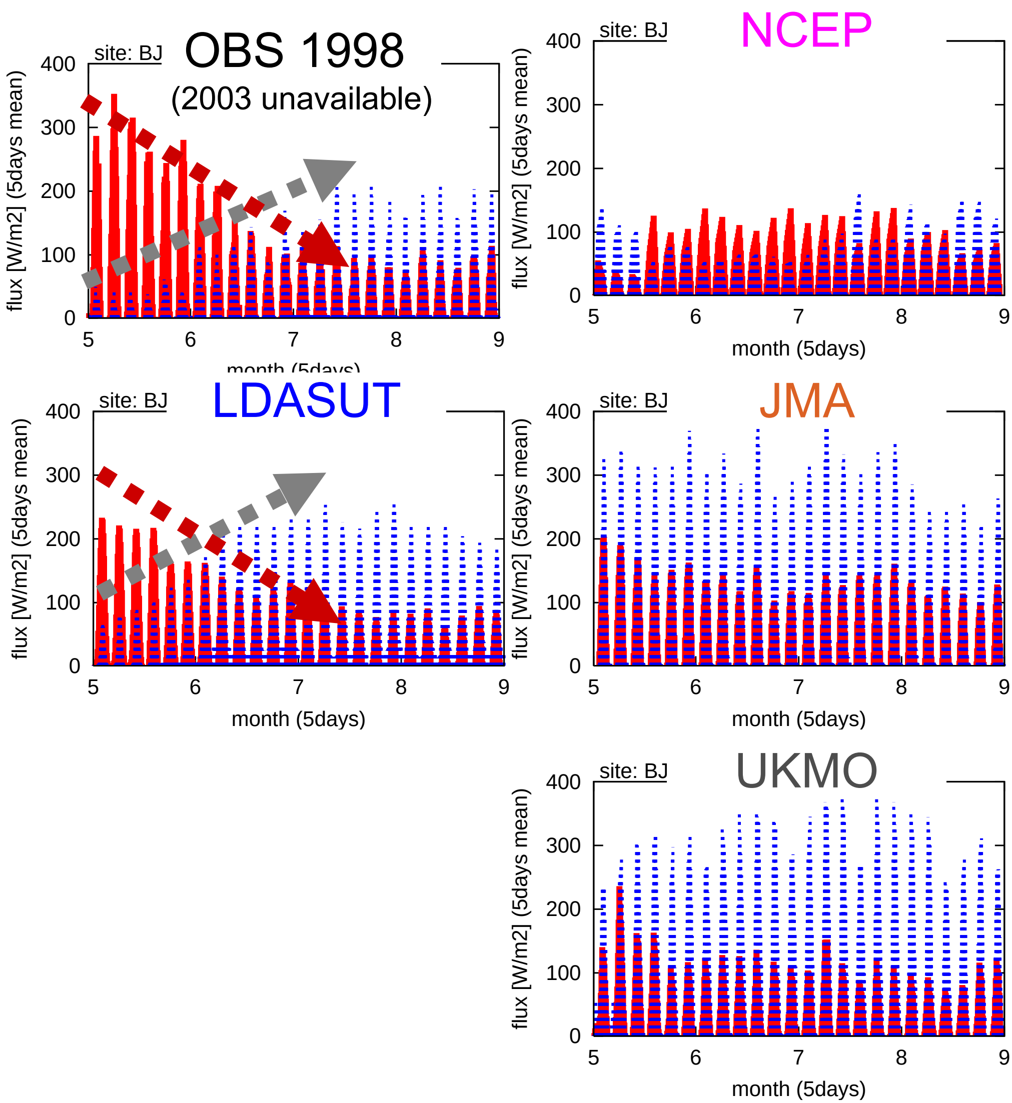
LE daily-mean (June)

	H RMSE [W/㎡]	LE RMSE [W/㎡]
LDASUT	32.0	42.5
NCEP	40.2	68.4
JMA	32.3	79.8
UKMO	35.3	80.1



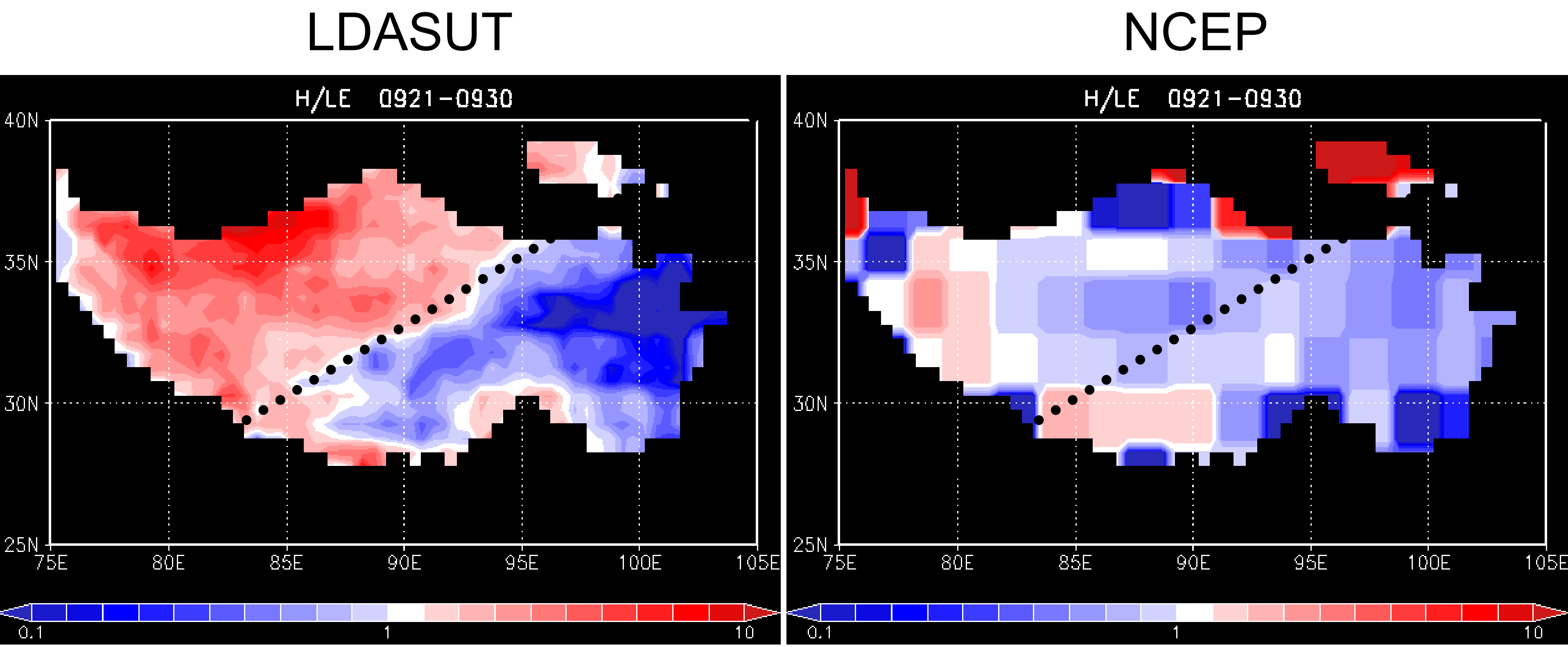
Seasonal variation (May - September)

Sensible(H) —
Latent(LE) —



(Yang, Koike et al.,2007)

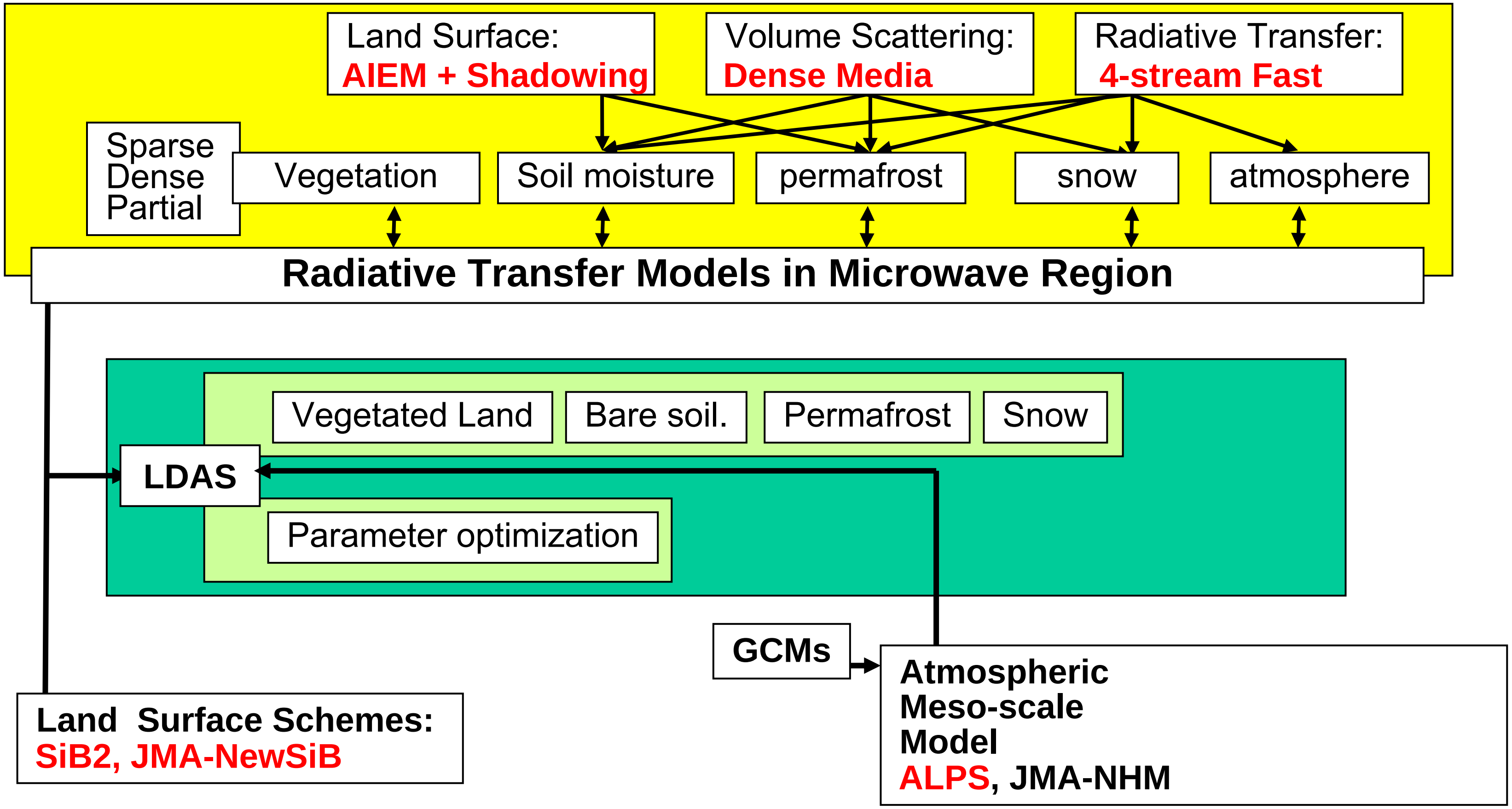
Seasonality of distributed Bowen Ratio: Sensible Heat Flux/Latent Heat Flux



LDAS Seasonality: May~Mid June, H > lE; Mid June~Aug; lE>H

LDAS Regionality: H is dominant in N.W. TP, lE is dominant in S.E. TP

(Yang, Koike et al.,2007)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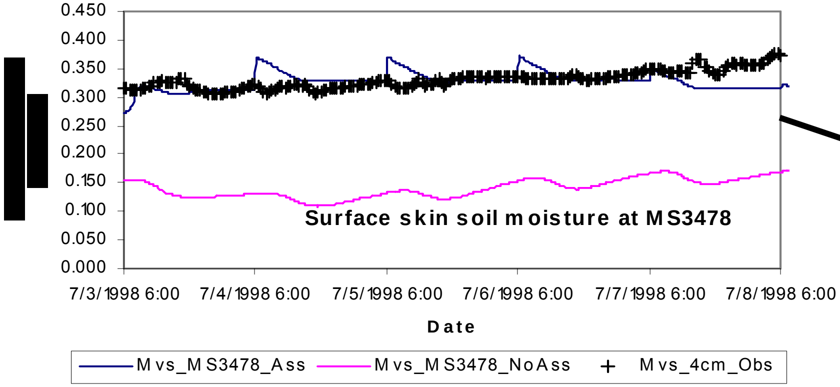
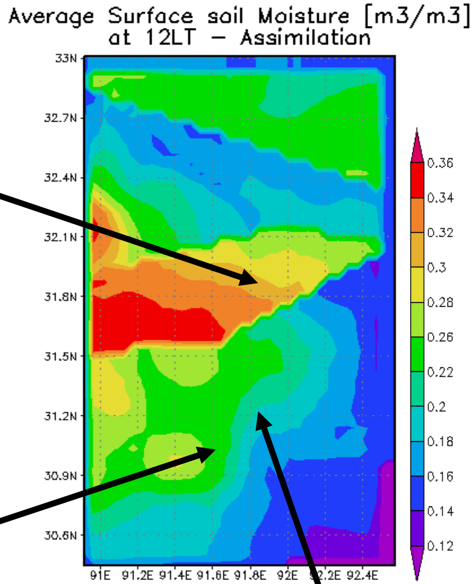
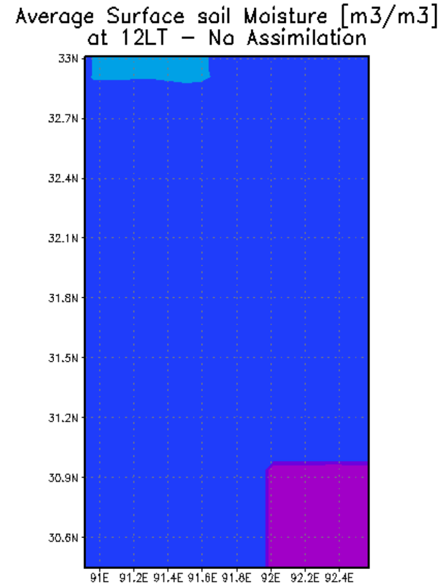
soil moisture

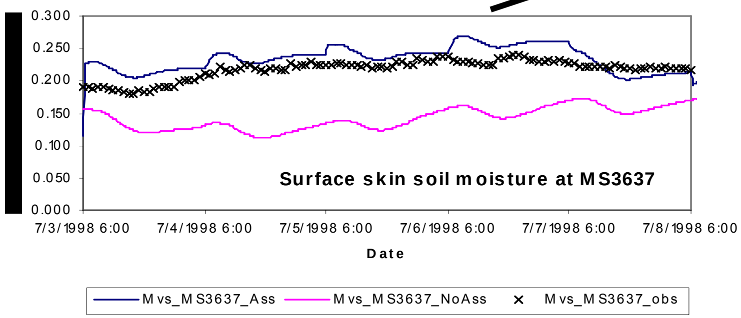


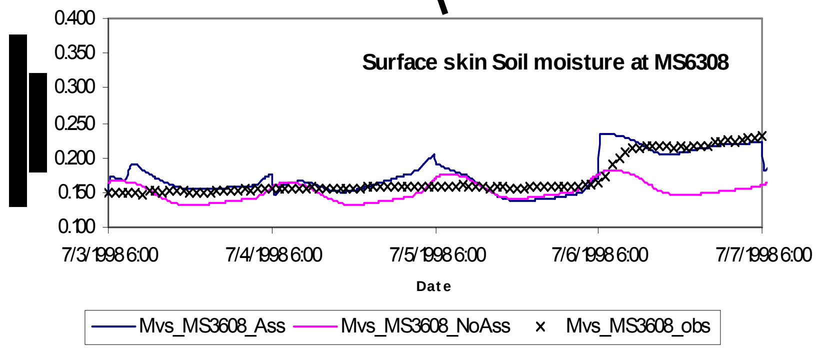
Assimilation



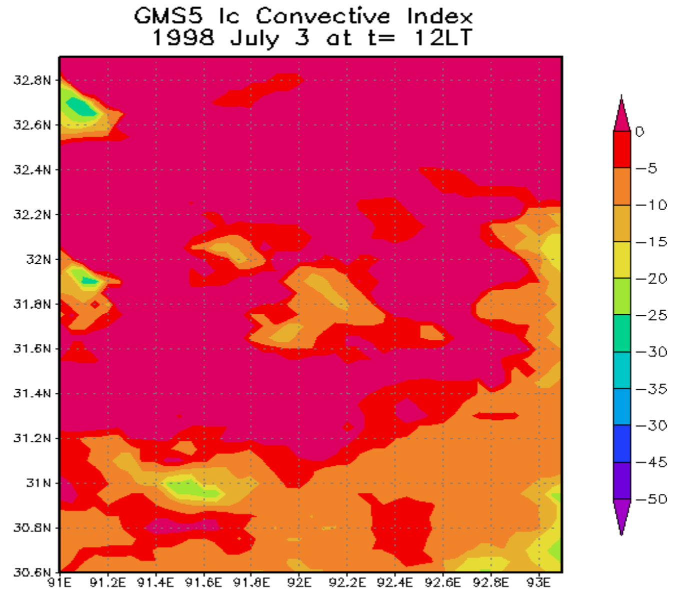
No Assimilation



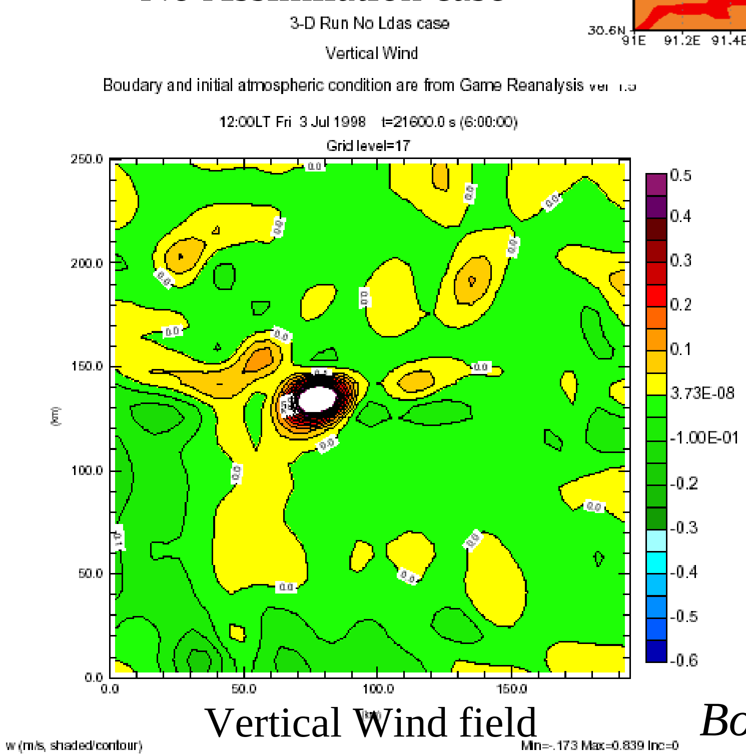




Boussetta & Koike, 2007



No Assimilation case

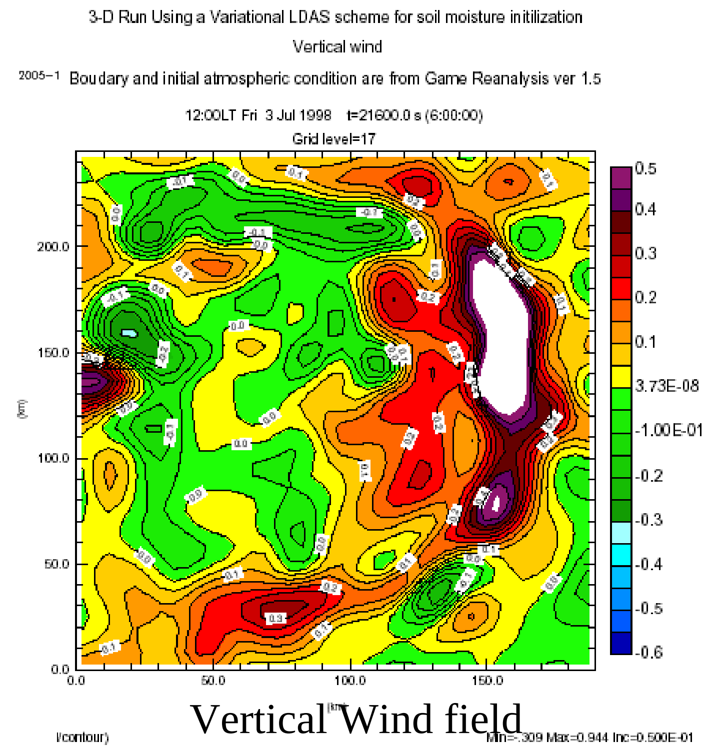


Vertical Wind field

GMS IR1-based convective Index

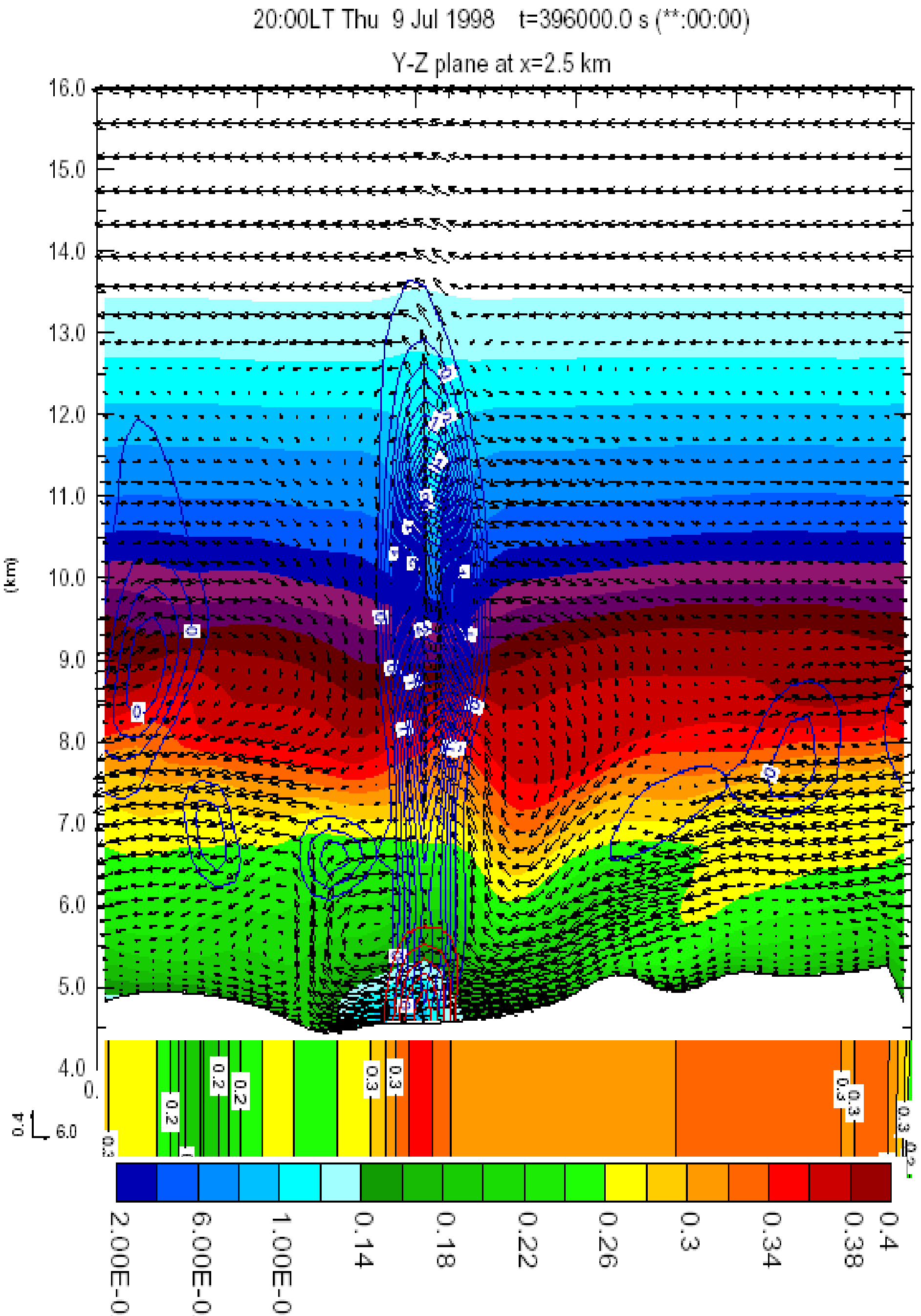
Boussetta & Koike, 2007

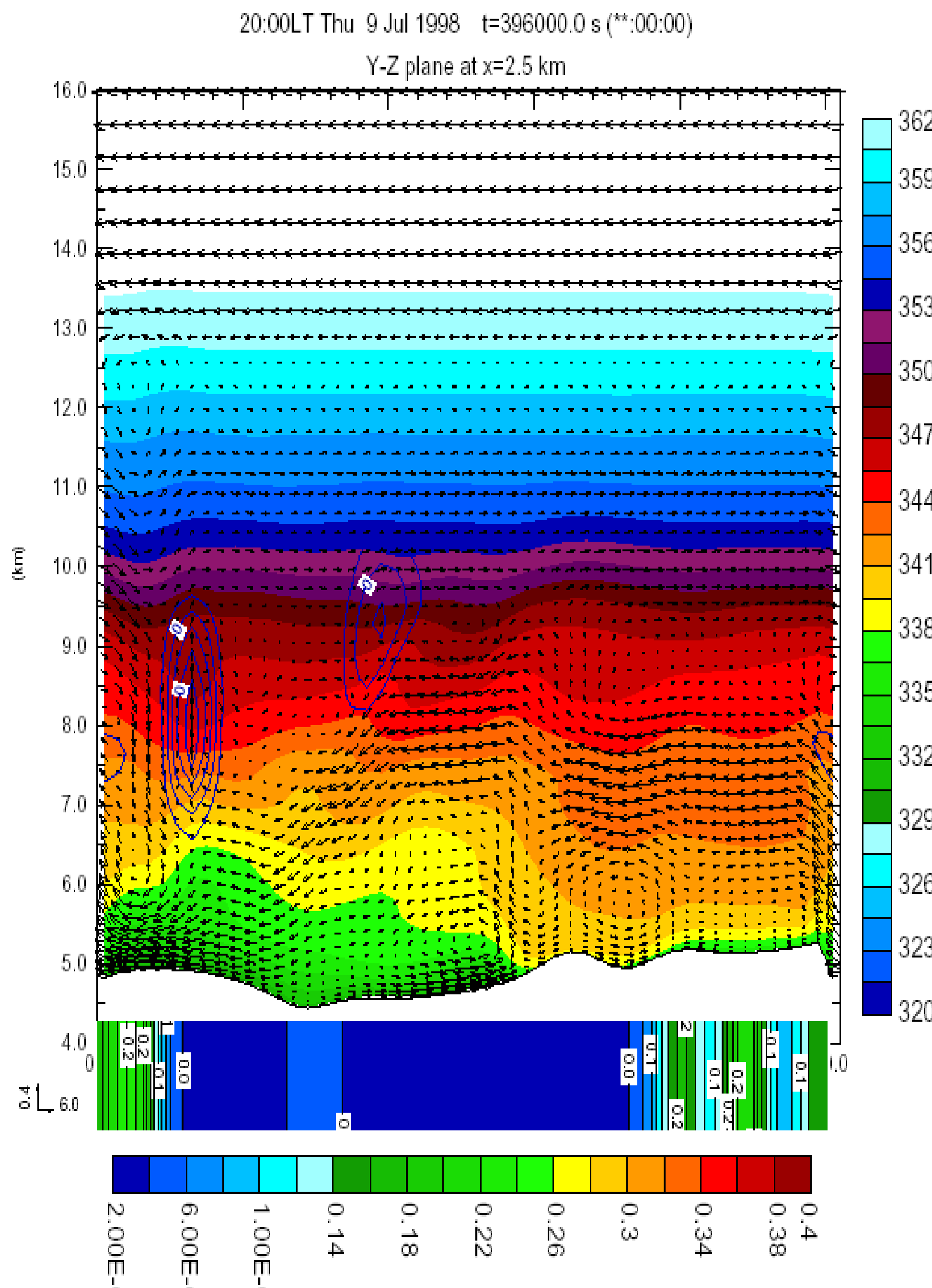
Assimilation case

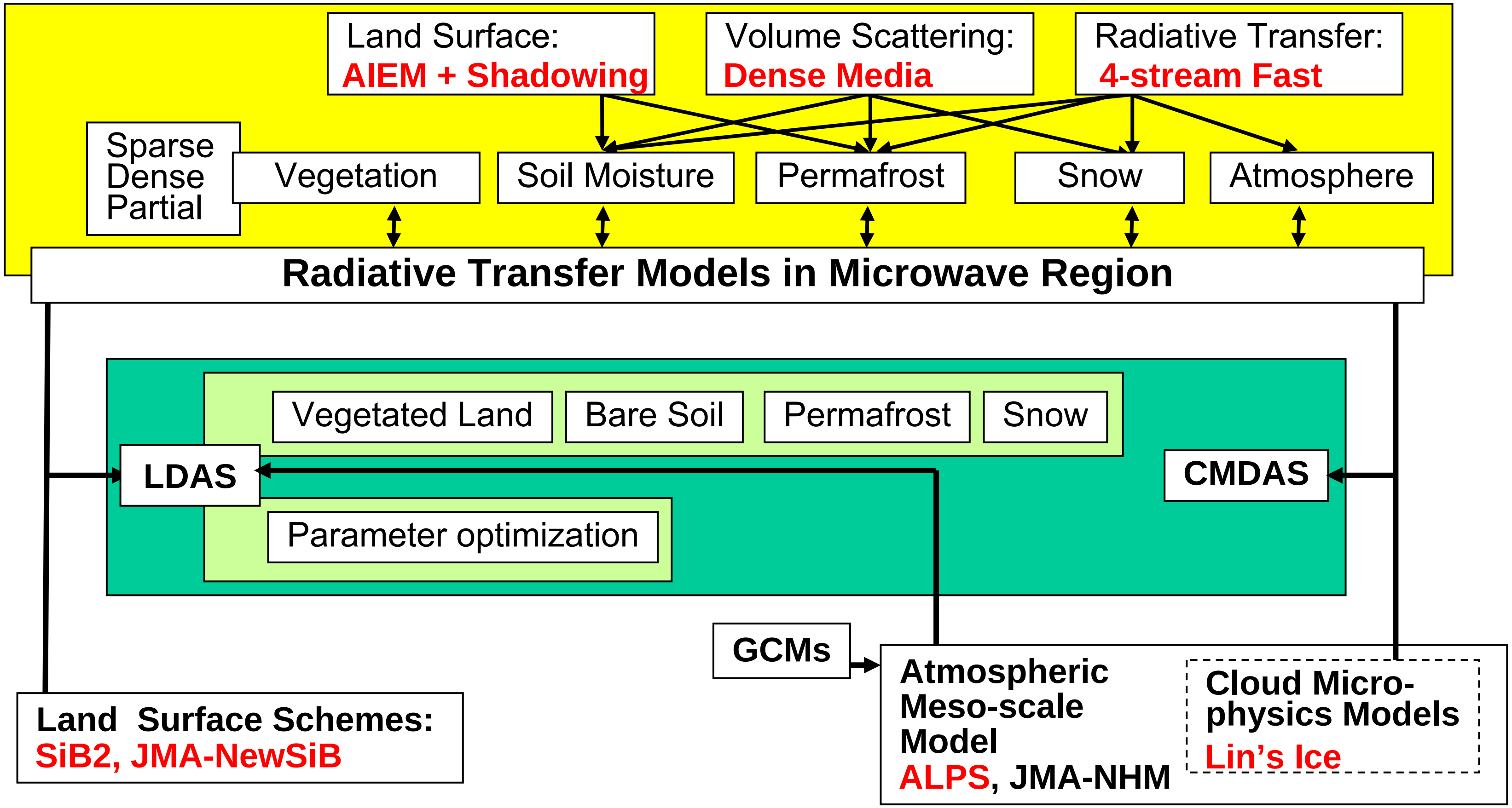


Vertical Wind field

L-A DAS *Boussetta & Koike, 2005* Only Regional Model







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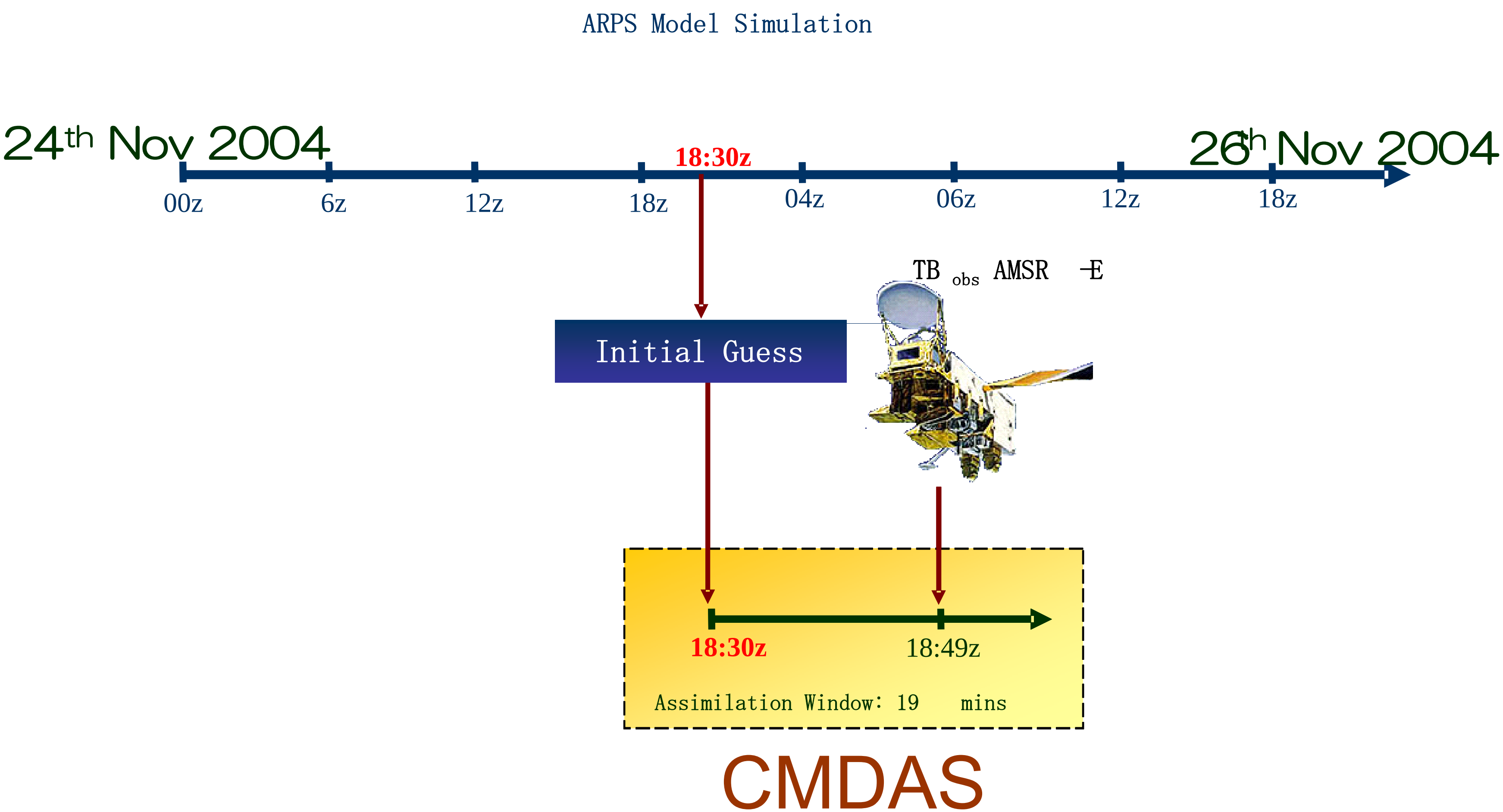
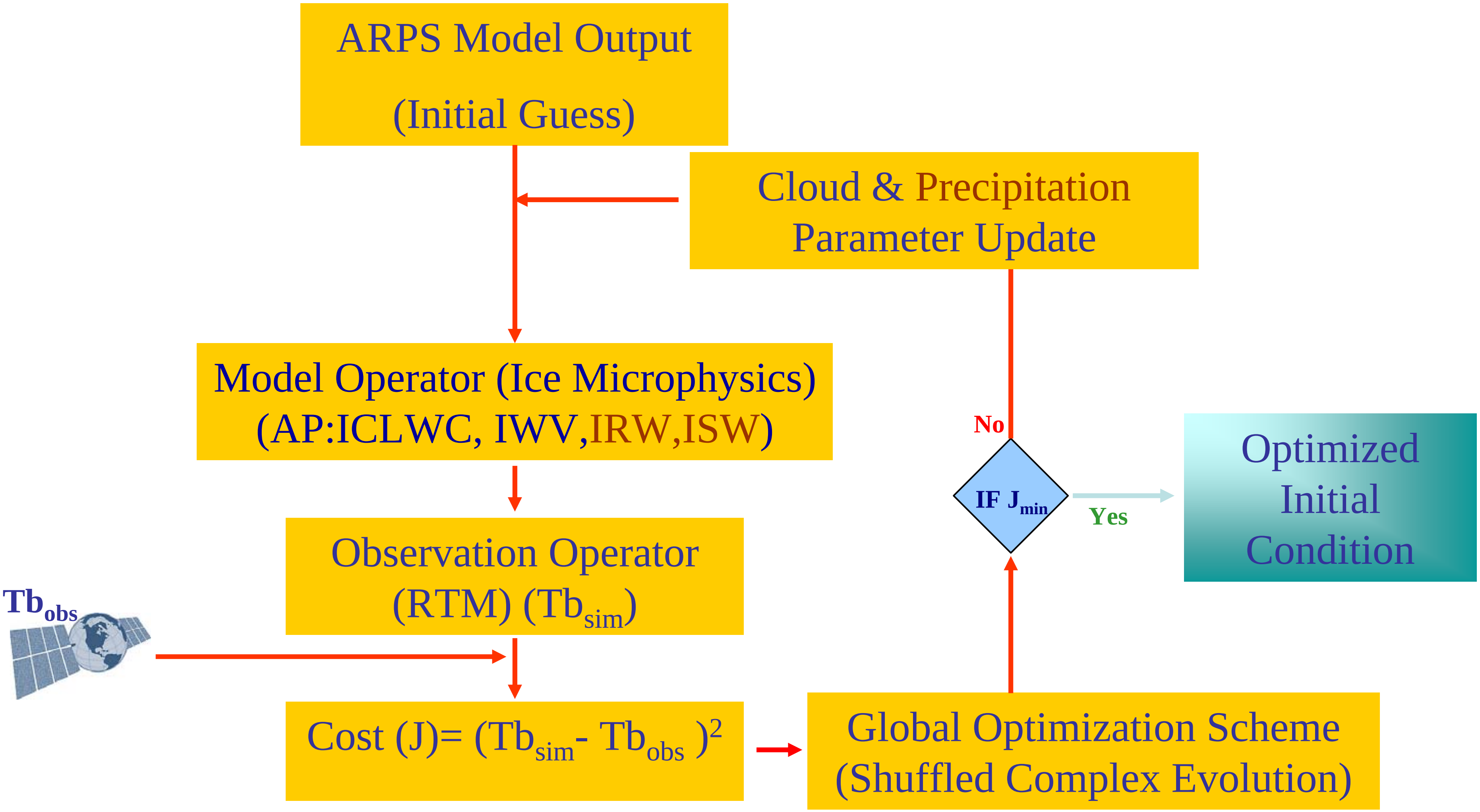
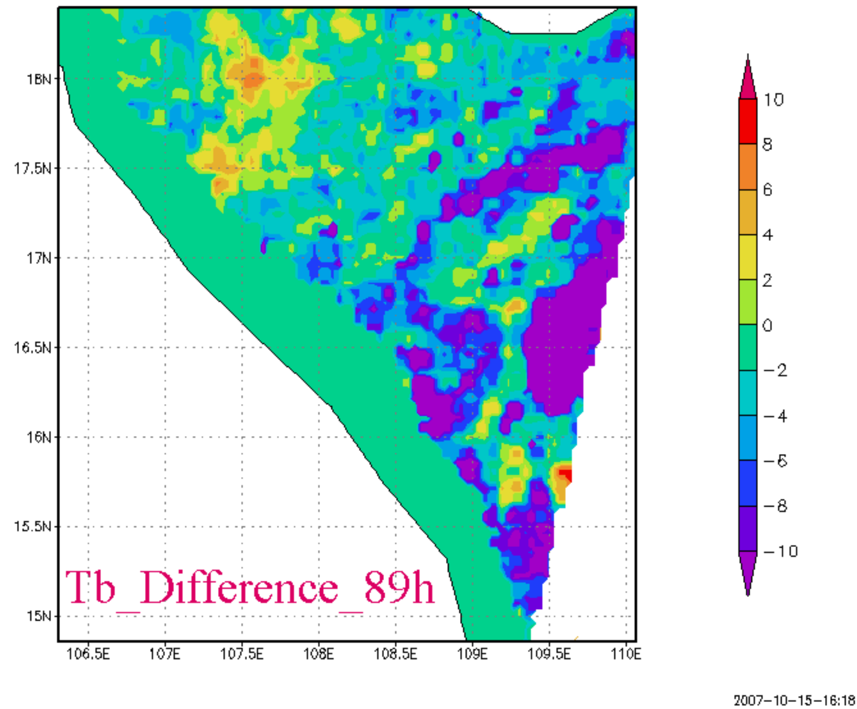
Practical Approach

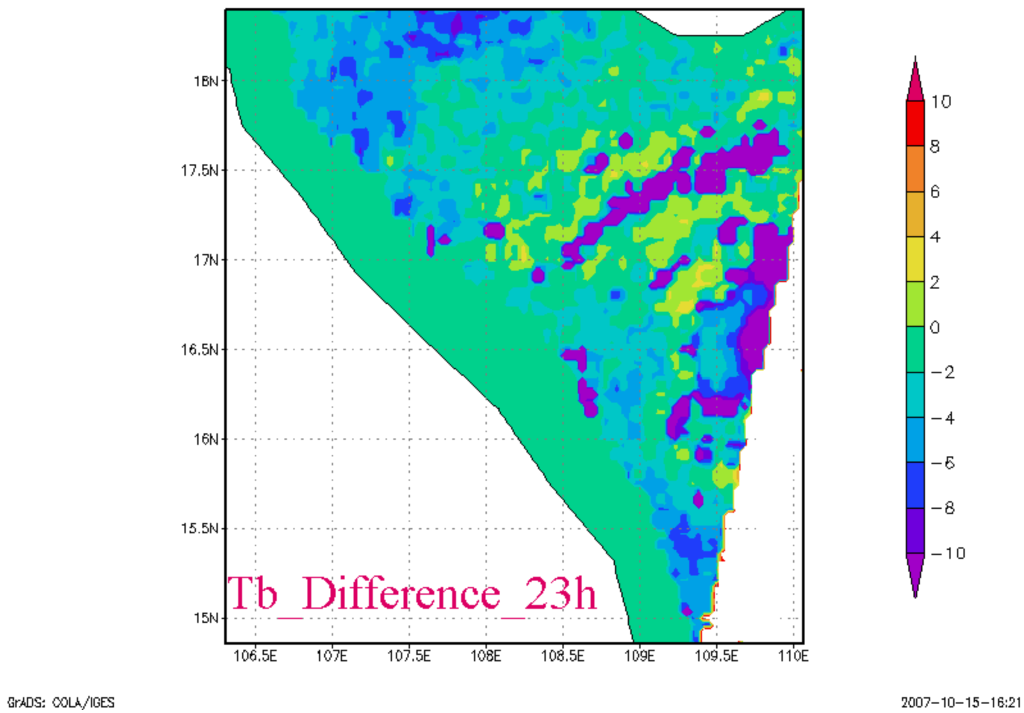


CMDAS Framework

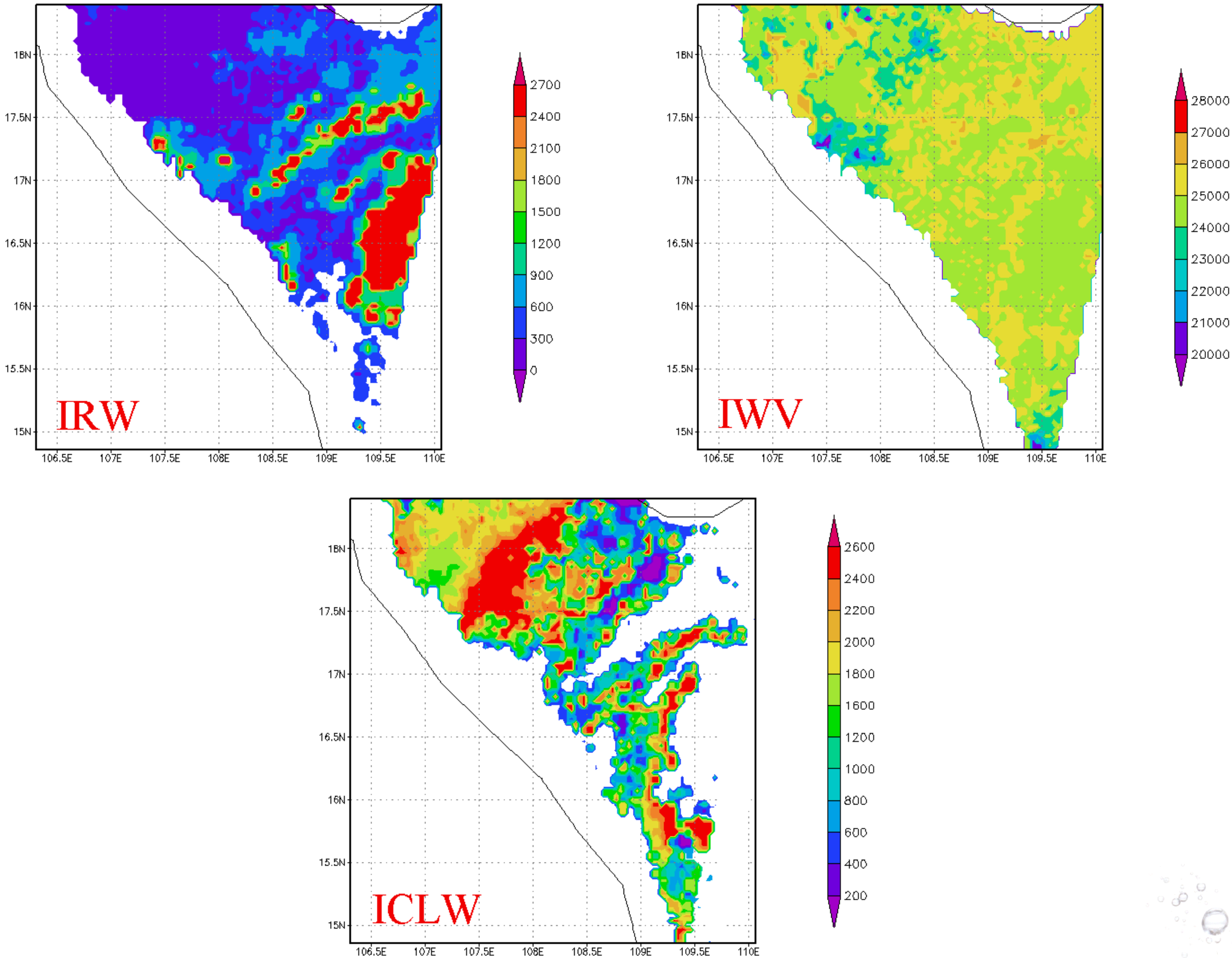


CMD





24th Nov 2004


IRW
IWV
ICLW
18N
17.5N
17N
16.5N
16N
15.5N
15N
106.5E
107E
107.5E
108E
108.5E
109E
109.5E
110E
2700
2400
2100
1800
1500
1200
900
600
300
0
28000
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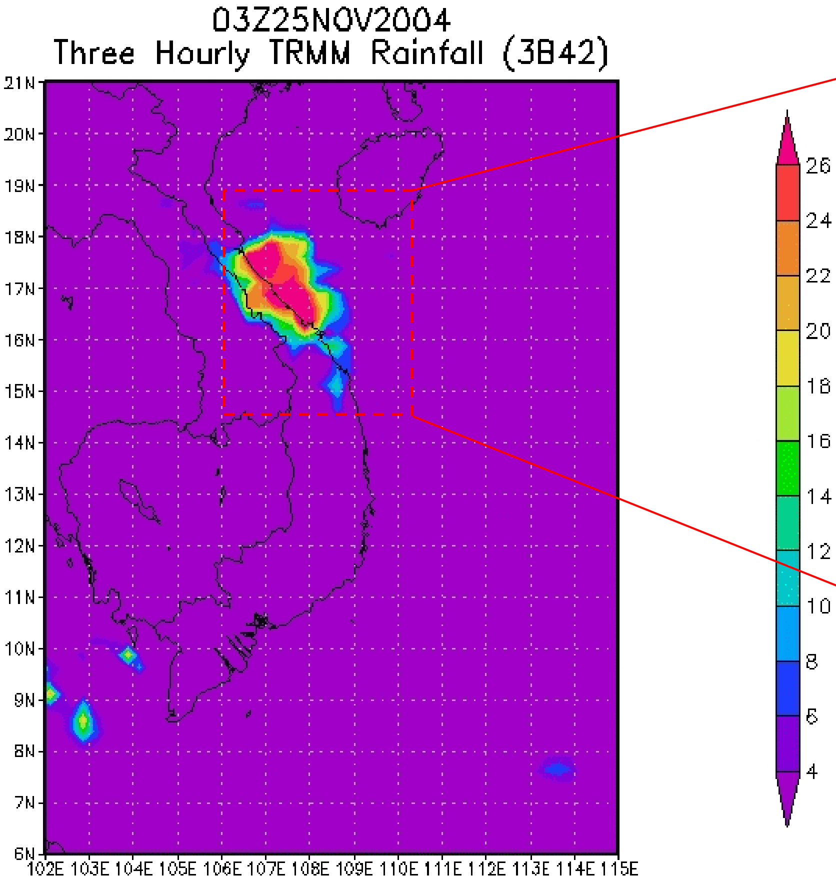
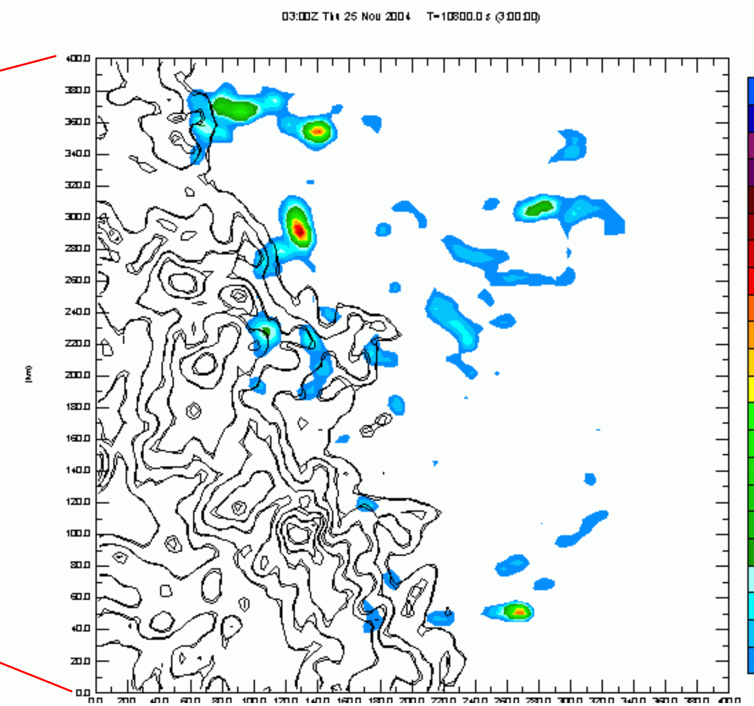
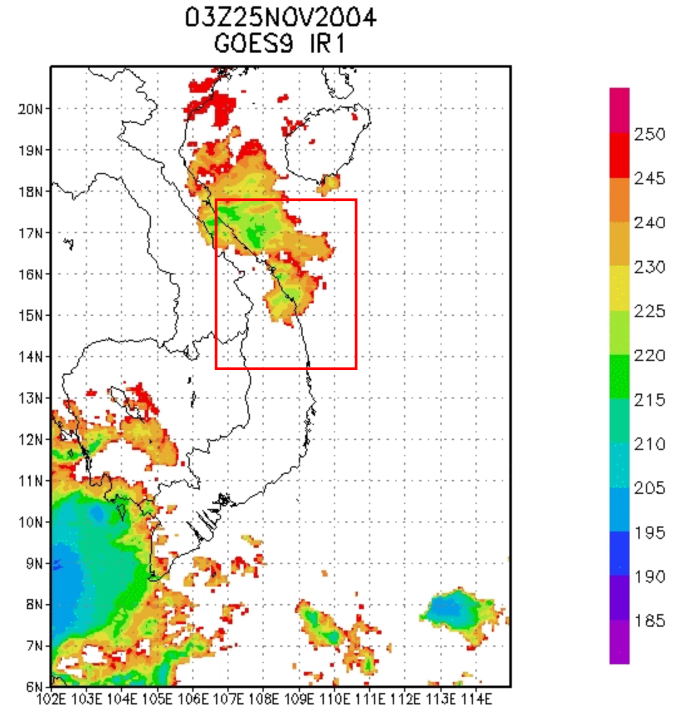
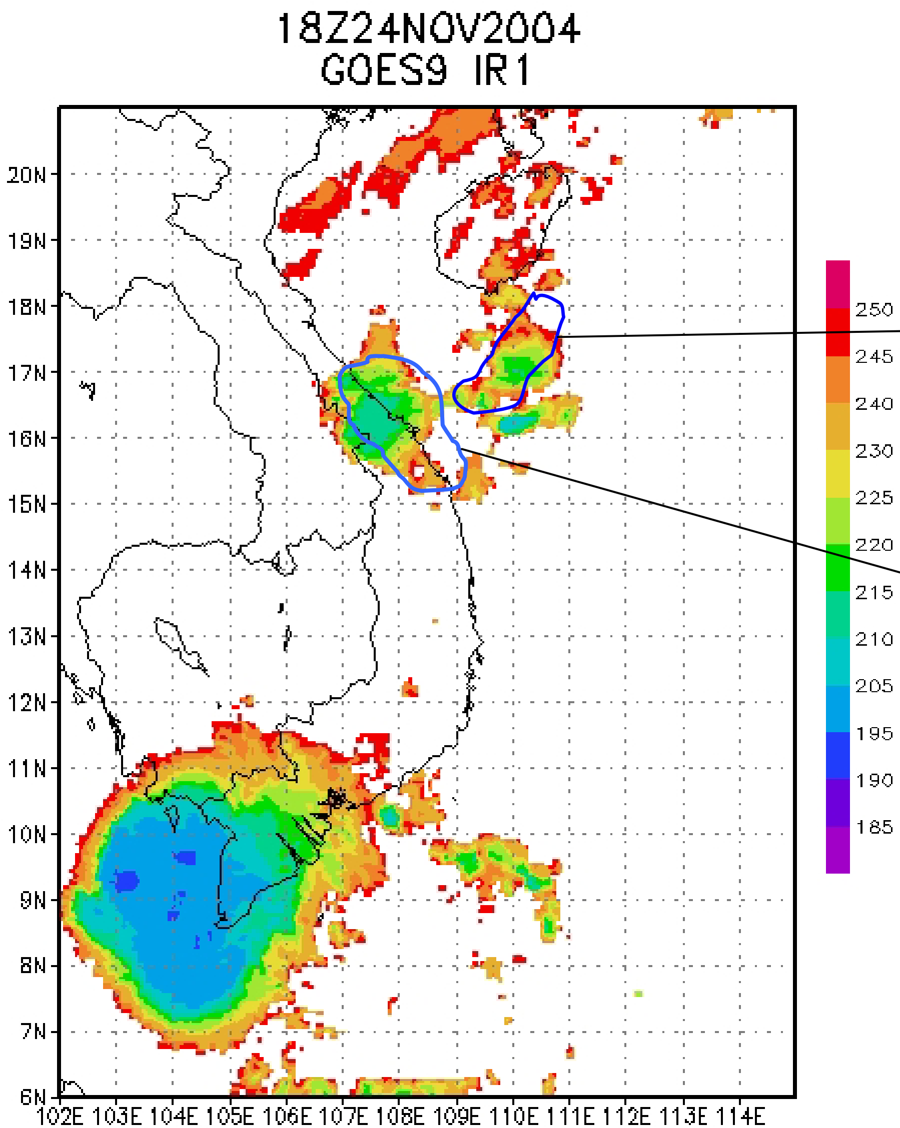


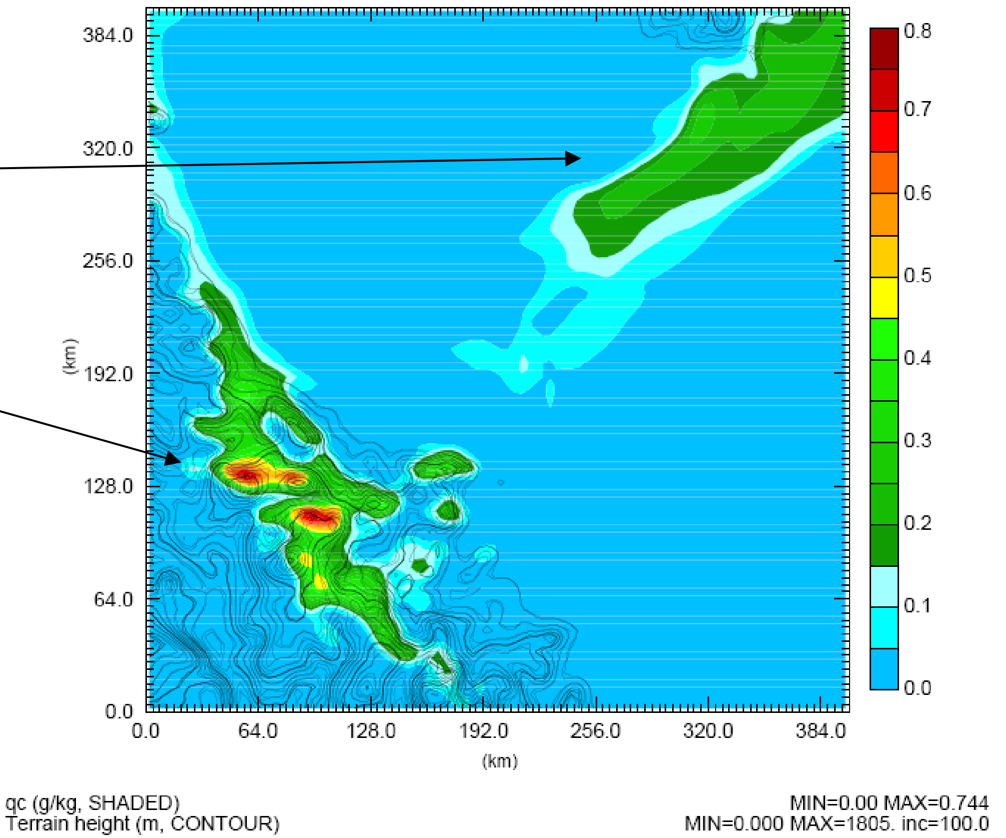




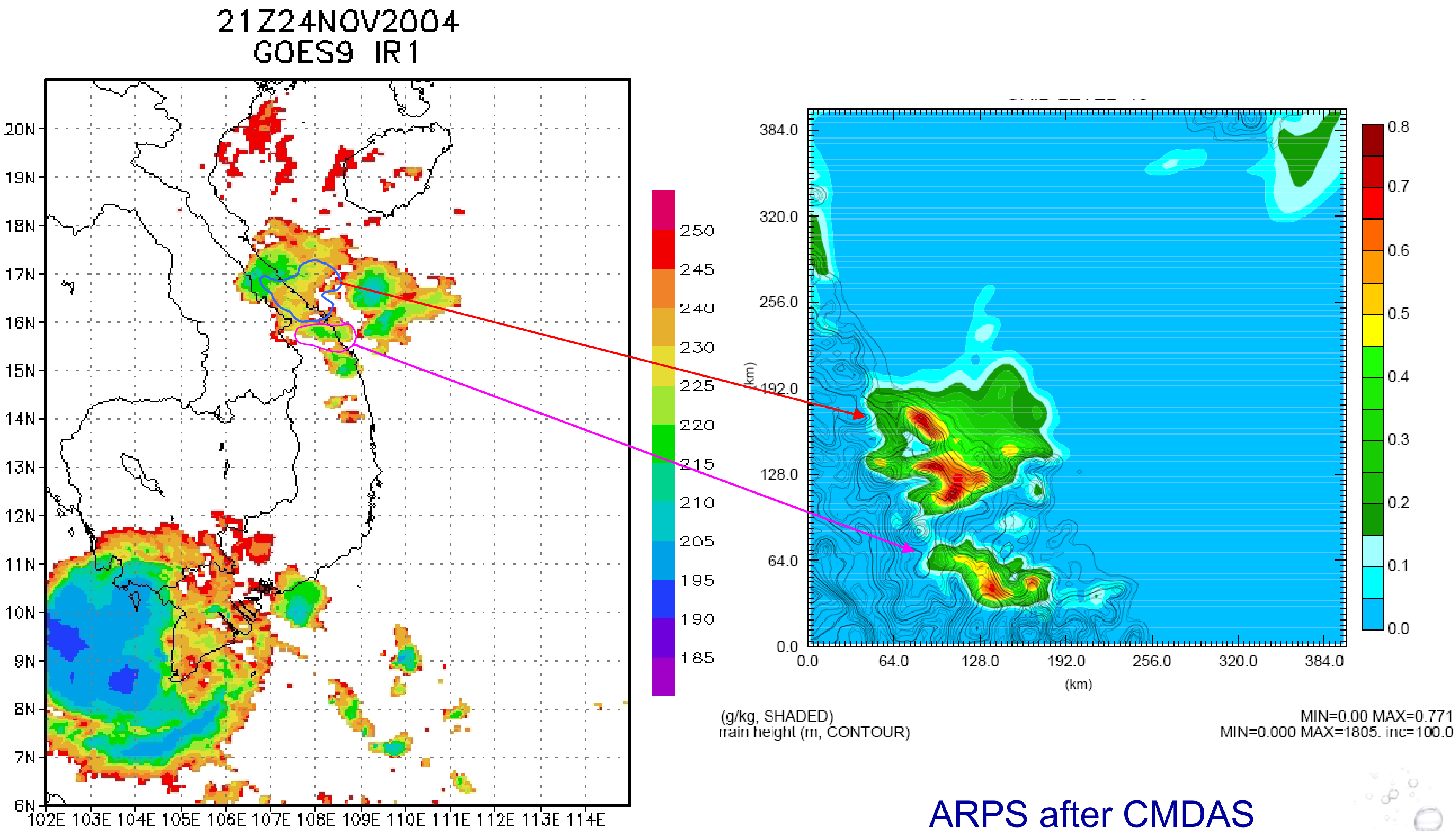
ARPS Before CMDAS



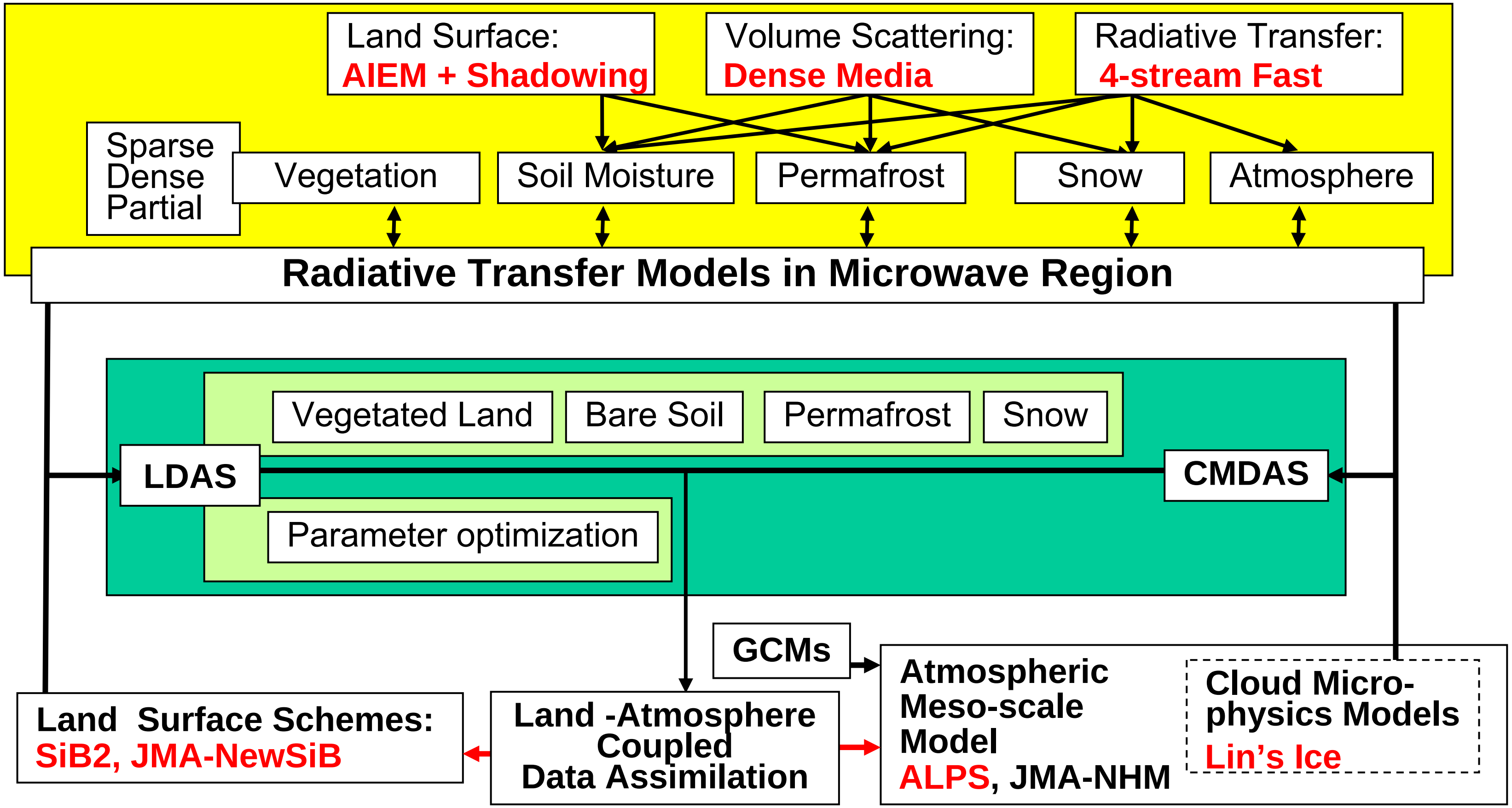
18:30z 24th Nov 2004 (ARPS)



ARPS after CMDAS



ARPS after CMDAS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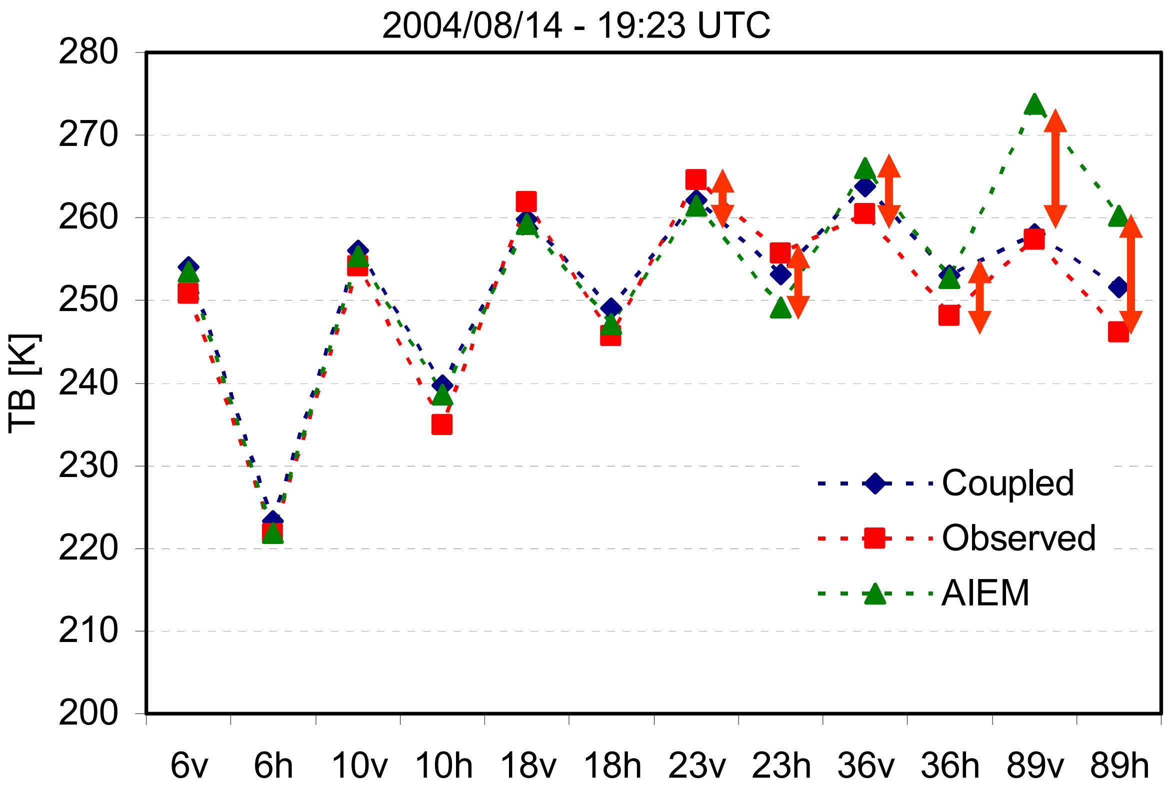
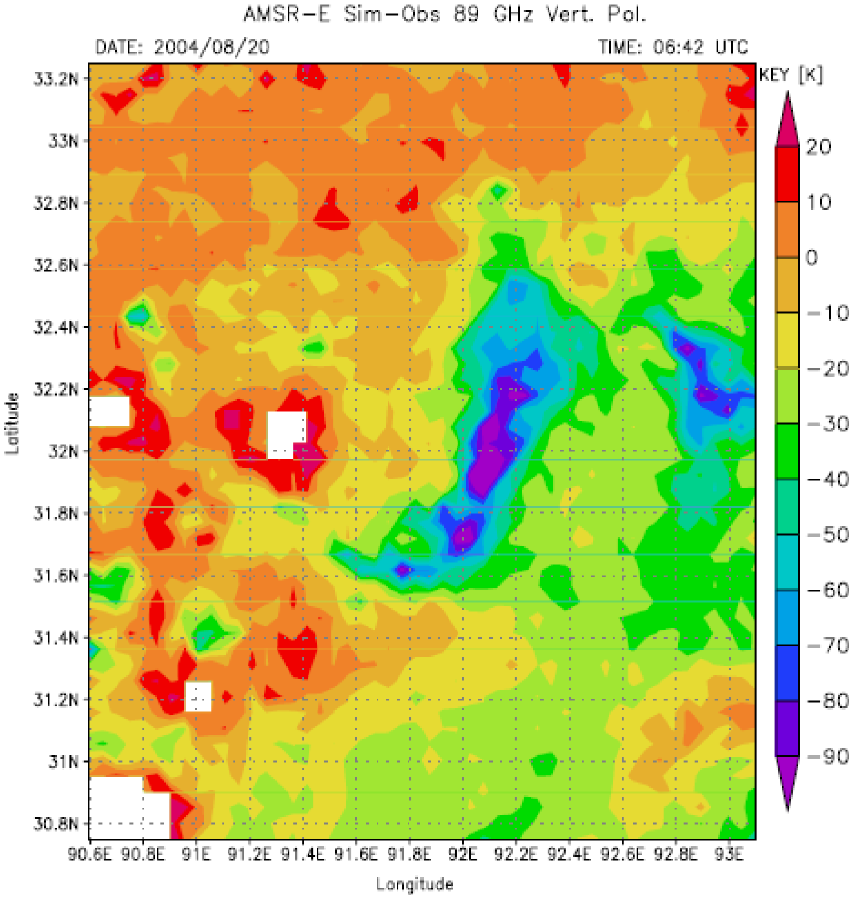
Data Assimilation

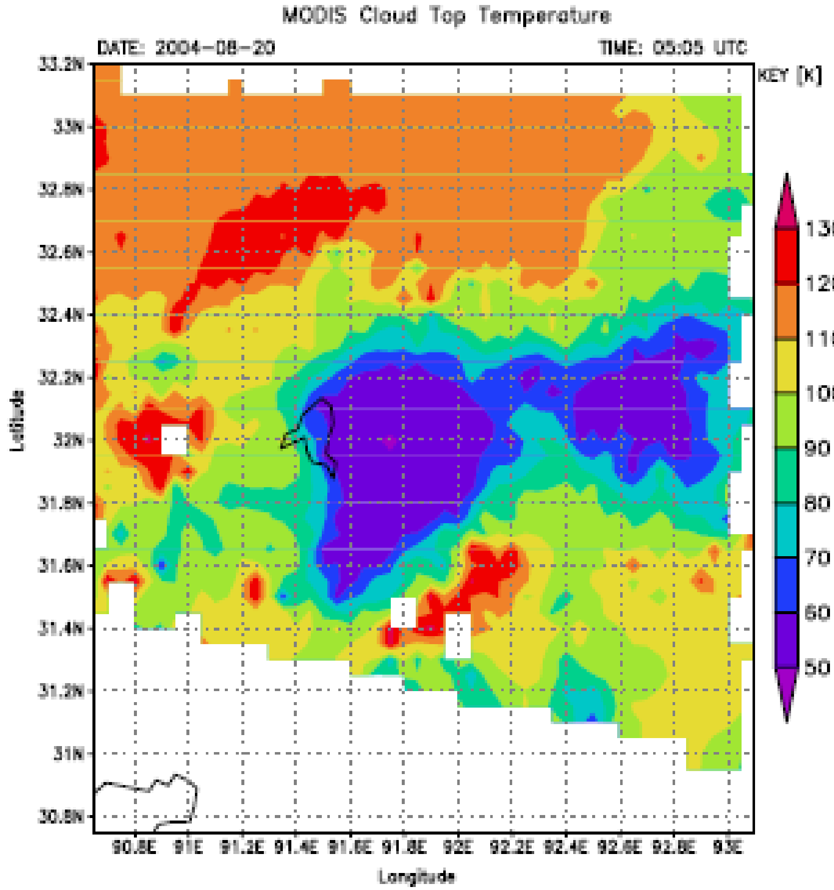
Coupled Soil Atmosphere RTM



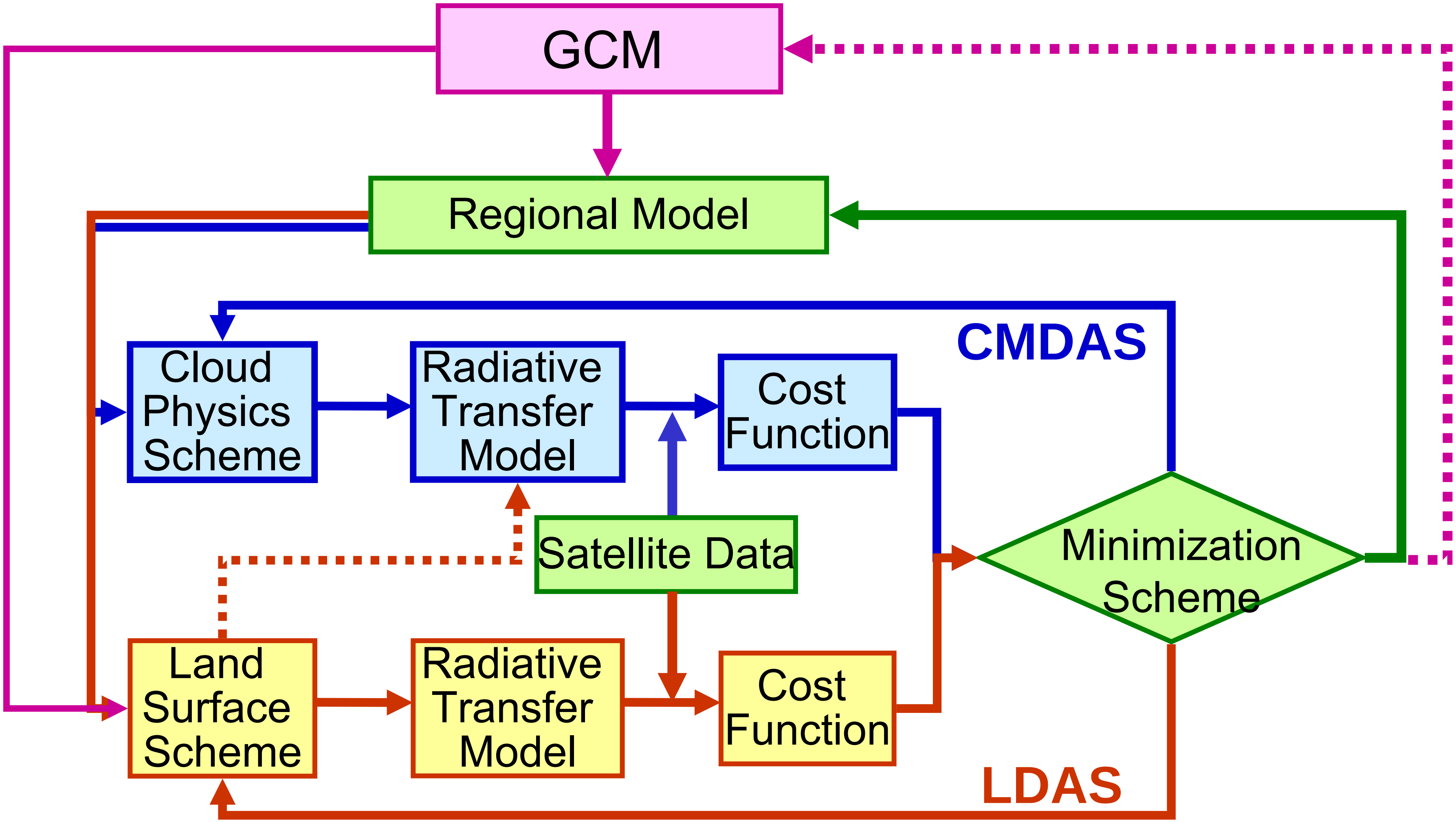
By coupling AIEM with atmosphere RTM we get better agreement. For wetter cases AIEM is sufficient.

Effect of Atmosphere



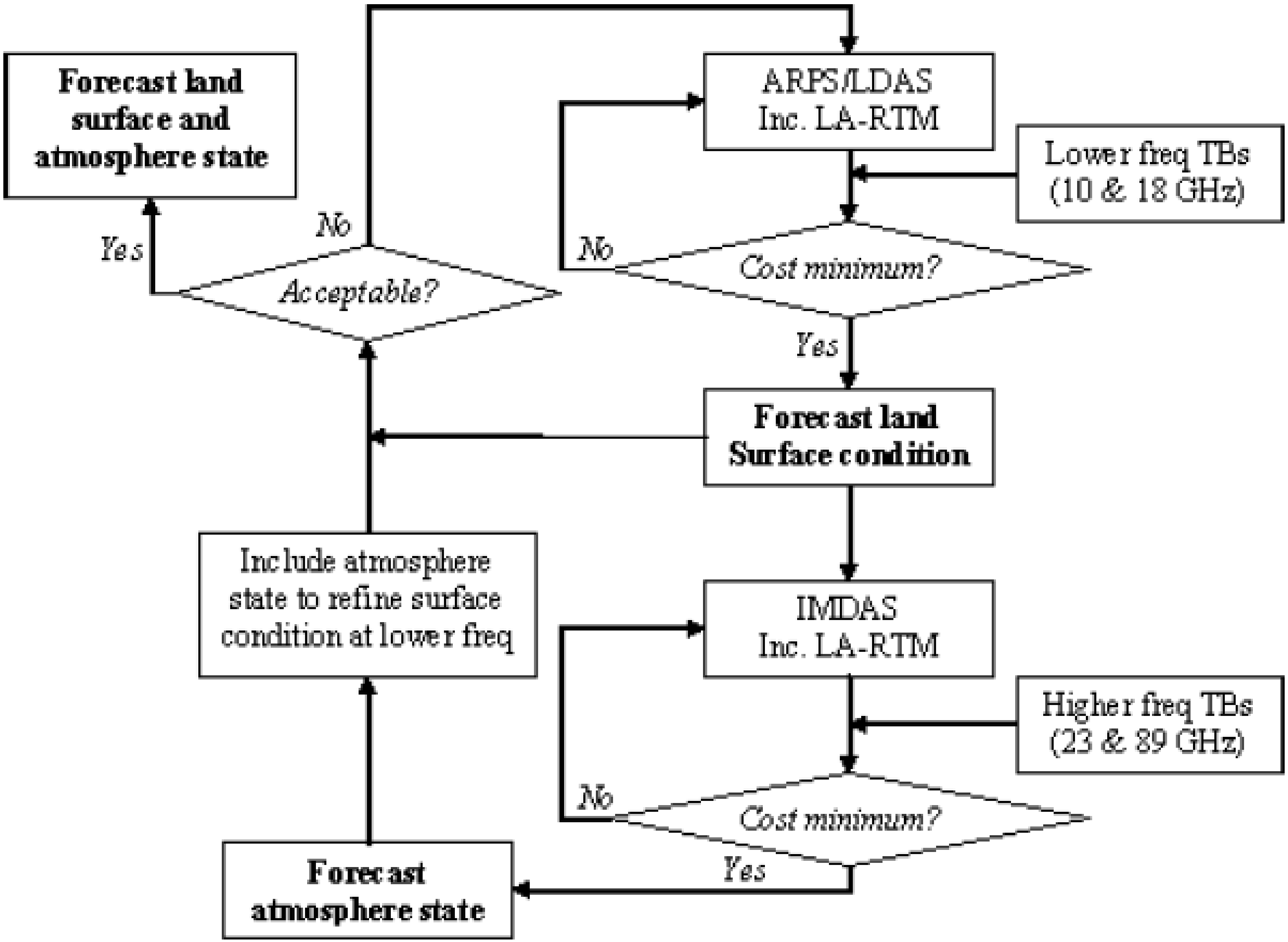


Atmospheric effect derived from AMSR-E vs. MODIS Cloud Top Temperature

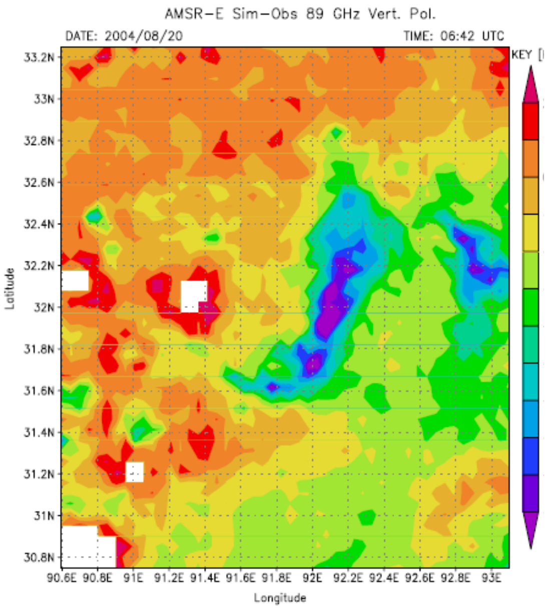


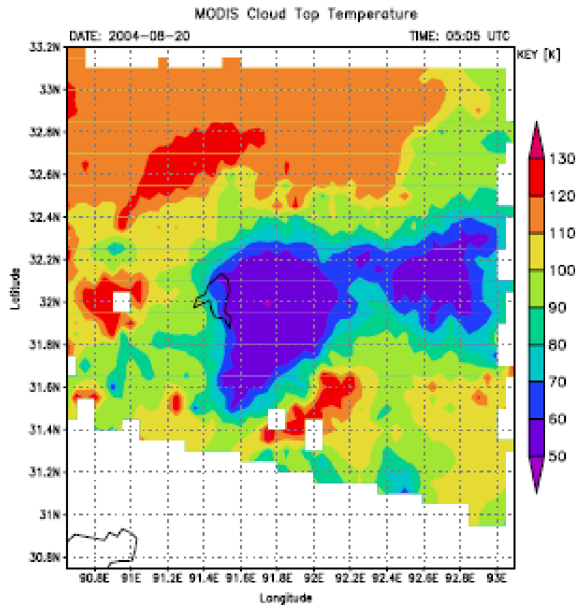
GCM
Regional Model
CMDAS
Cloud Physics Scheme
Radiative Transfer Model
Cost Function
Satellite Data
Minimization Scheme
Land Surface Scheme
Radiative Transfer Model
Cost Function
LDAS

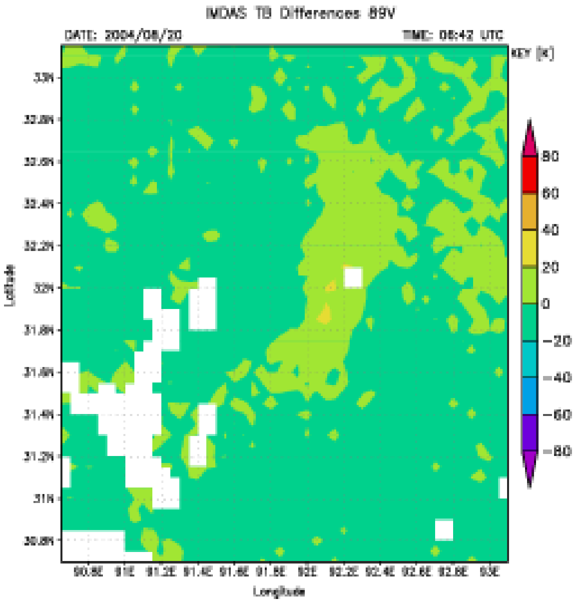
Atmosphere-Land Coupled Data Assimilation System



Tb Error



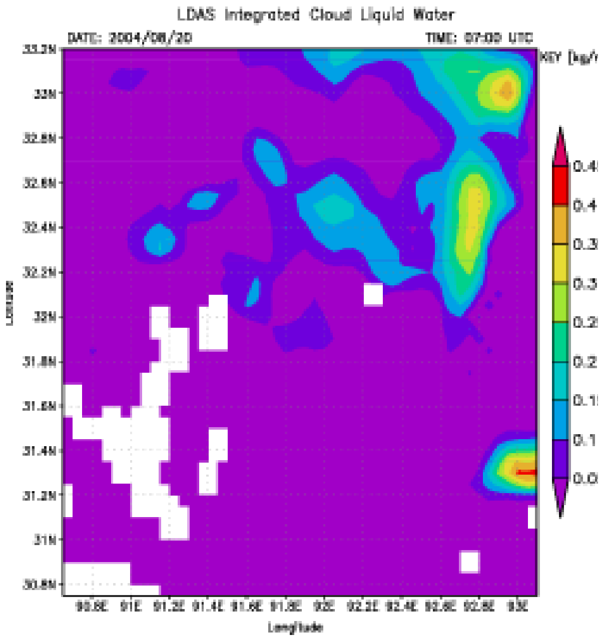




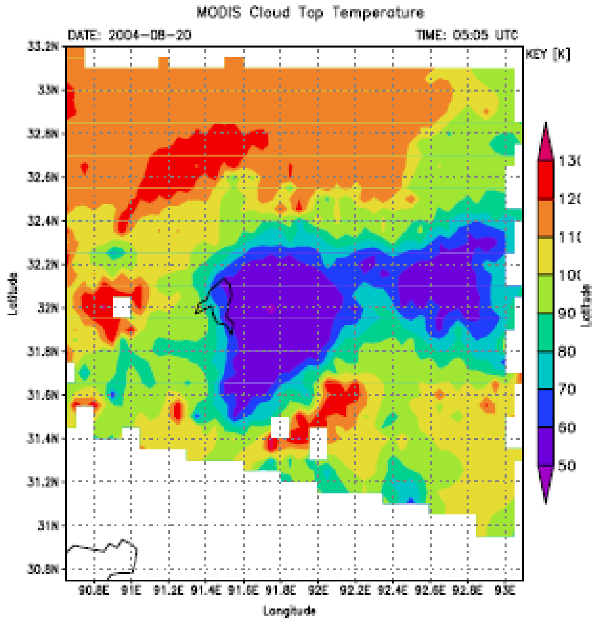
LDAS only **MODIS/IR** **A-L Coupled DAS**

Atmospheric effect derived from AMSR-E vs. MODIS Cloud Top Temperature

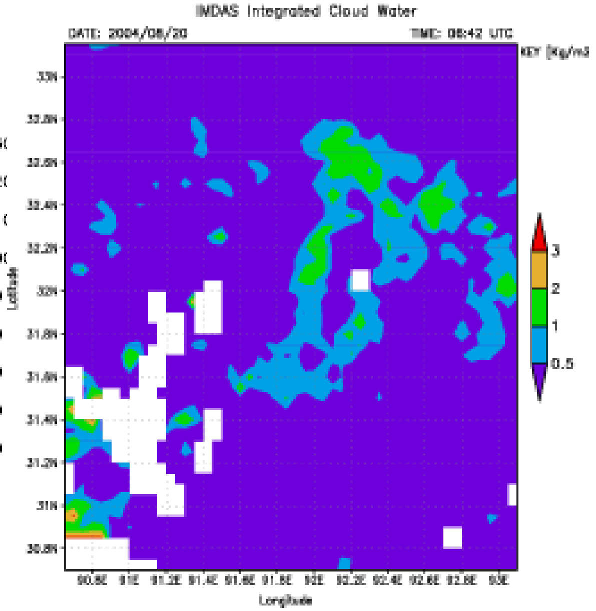
Integrated Cloud Liquid Water



LDAS only



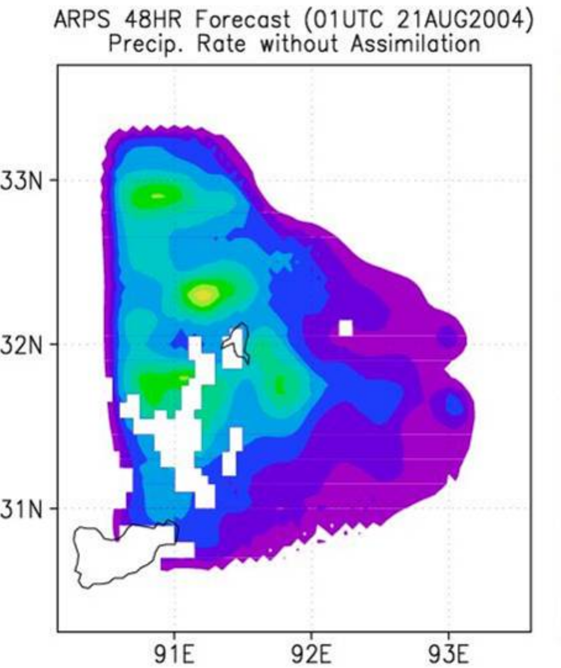
MODIS/IR

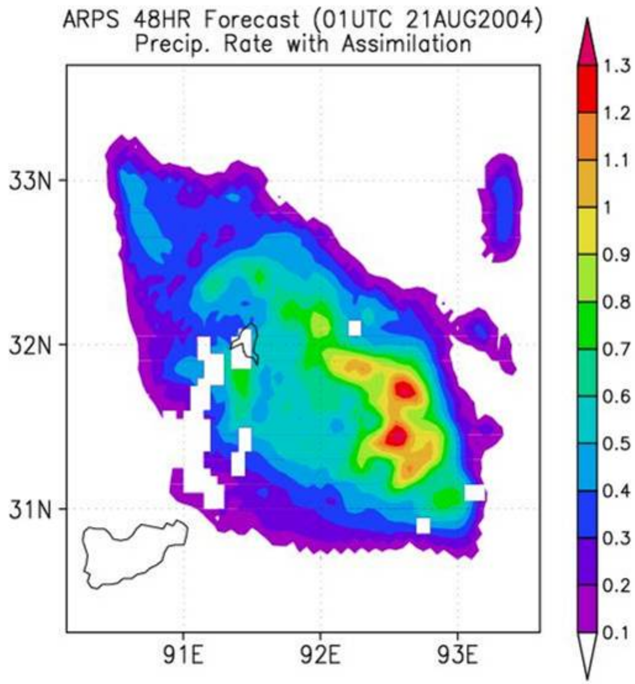


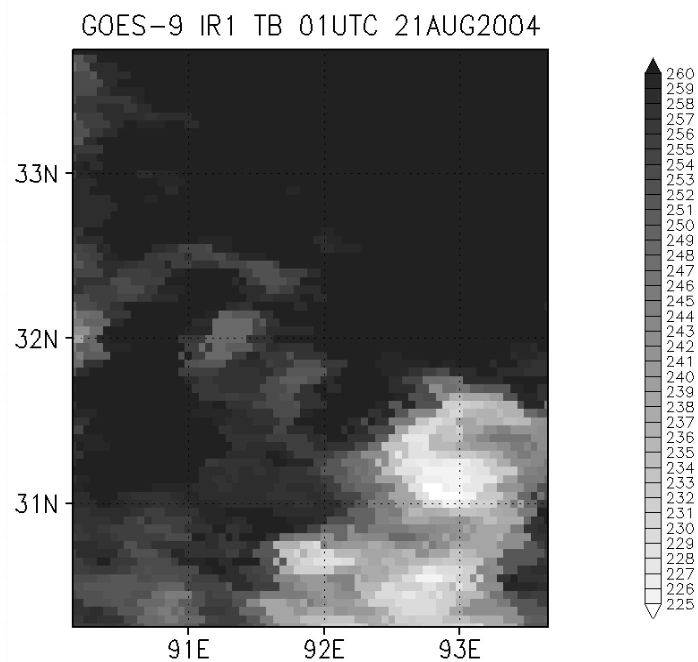
A-L Coupled DAS

Atmospheric effect derived from AMSR-E vs. MODIS Cloud Top Temperature

24 hour Prediction of Rainfall over the Tibetan Plateau



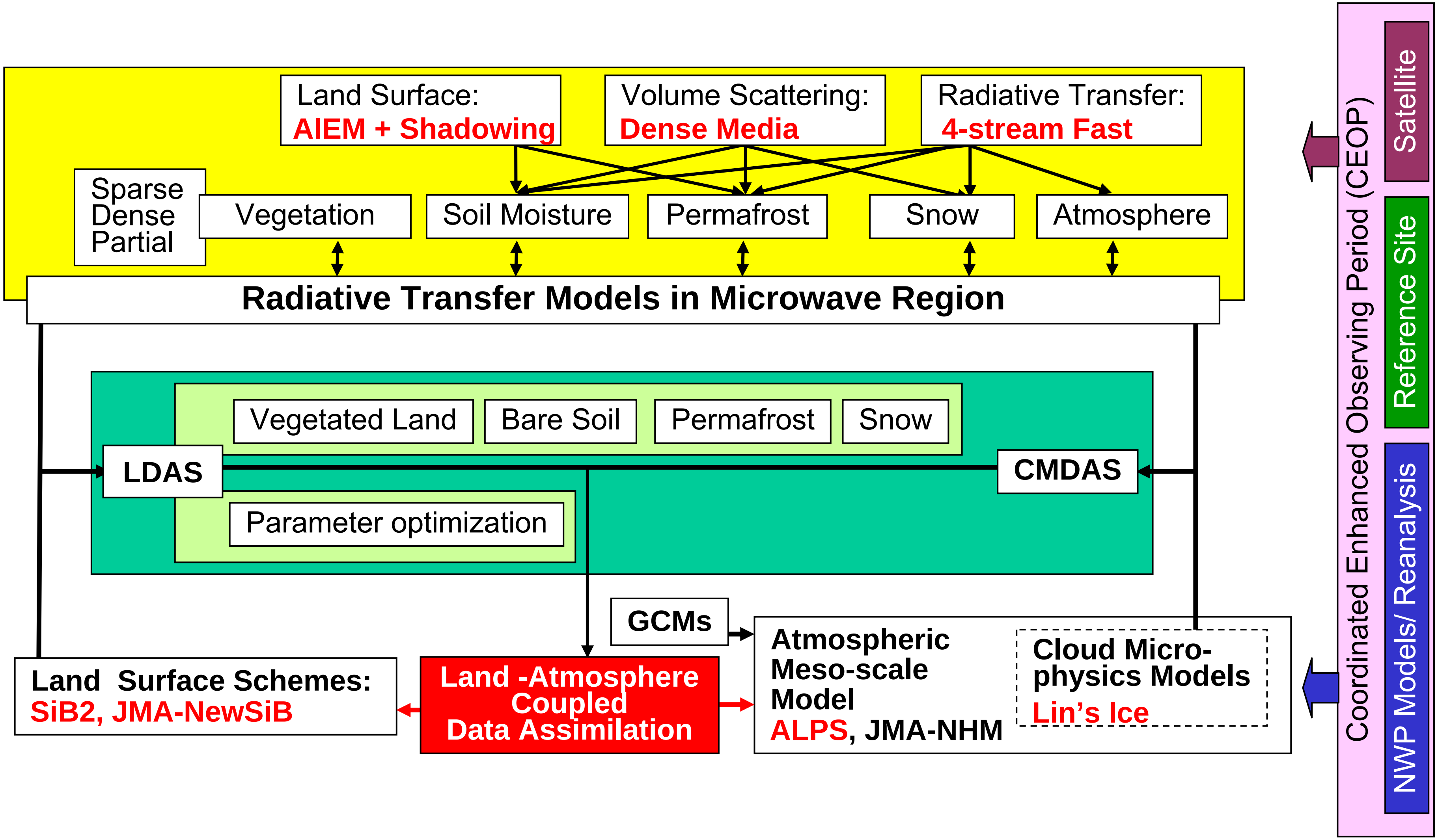




Only Nesting

Prediction with
the A-L Coupled
Data Assimilation
As an Initial Condition

GOES IR



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
GCMs
Atmospheric Meso-scale Model
ALPS, JMA-NHM
Cloud Micro-physics Models
Lin's Ice
Land Surface Schemes:
SiB2, JMA-NewSiB
Land -Atmosphere Coupled Data Assimilation
Coordinated Enhanced Observing Period (CEOP)
Satellite
Reference Site
NWP Models/ Reanalysis

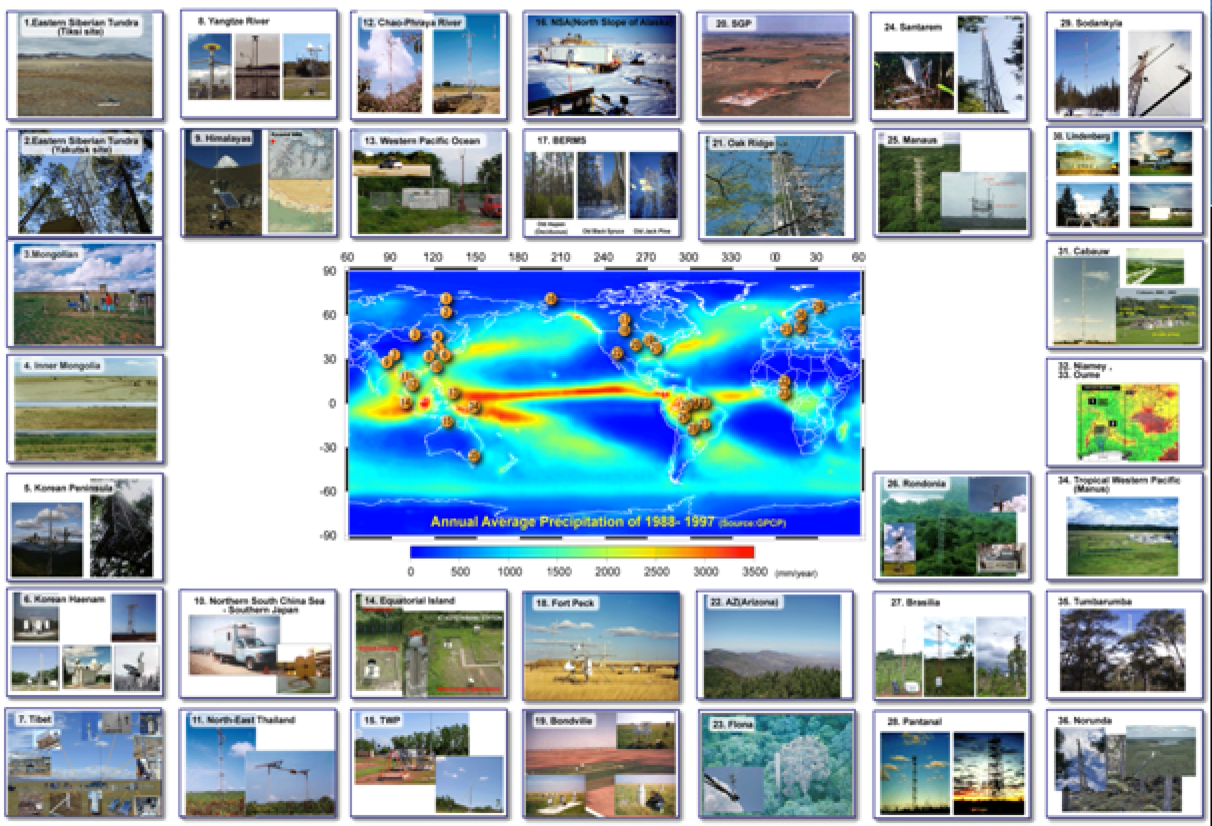
Coordinated Enhanced Observing P

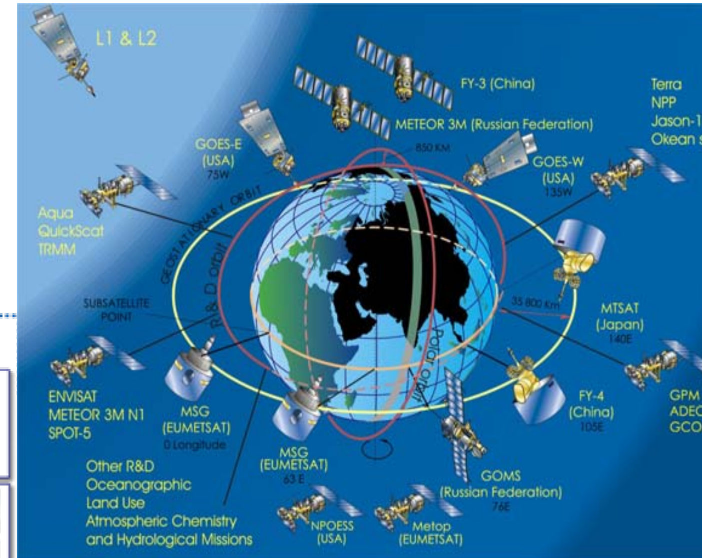
Three Unique Capabilities

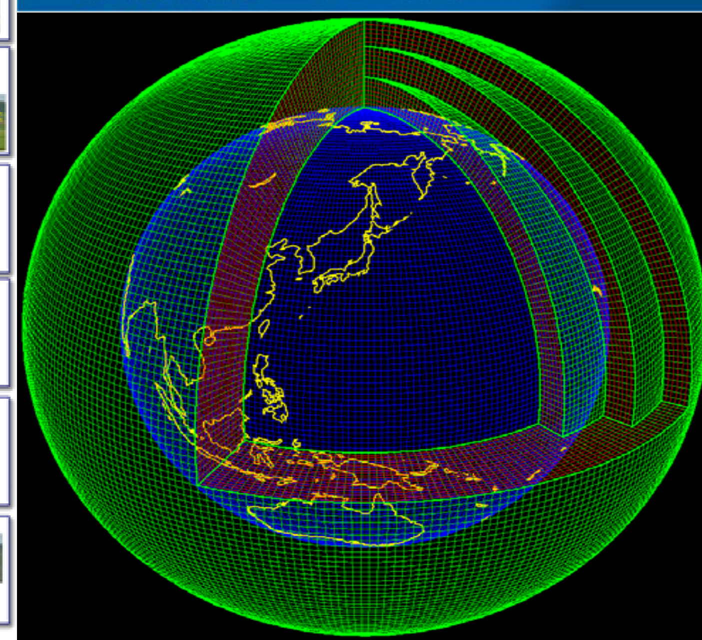
Convergence of Observations

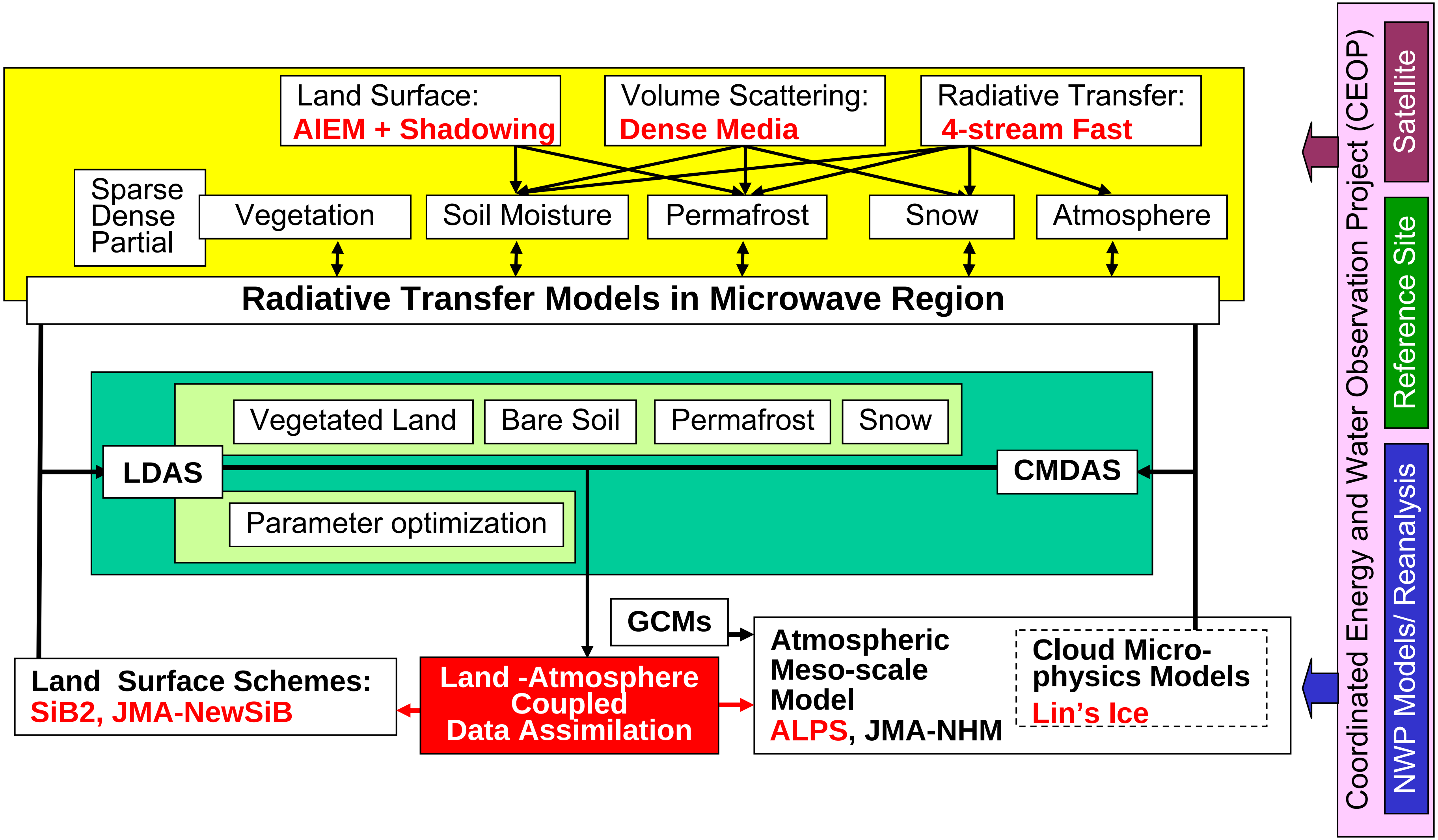
A Prototype of the Global Water Cycle Observation System of Systems

International Cooperation for the Global Coverage








Land Surface:
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Satellite
Reference Site
NWP Models/ Reanalysis


GBMR
1125944


18.7/23.8/36.5/89GHz
GBMR
1125029

Microwave radiative transfer model for snow

Dielectric constant (Ice: ε_{ice})

Dielectric constant (Air: ε_{air})

Snow density (ρ_{snow})

Frequency (f)

Snow grain size (r)

Dense media radiative transfer model

(Tsang,1992)

Eextinction coefficient *ke*

$$K_e = \sqrt{k^2 + \frac{3K^2}{D(K)} \sum_{sl=1}^{L} f_{sl} y_{sl} \cdot \left(1 + i\frac{2K^3}{3D(K)}\left[a_{sl}^3 y_{sl} + \sum_{sj=1}^{L} y_{sj} a_{sj}^3 n_{sj} 8\pi^3 H_{sjsl}\right]\right)}$$

$$D(K) = 1 - \sum_{sl=1}^{L} f_{sl} y_{sl}(K) \qquad y_{sl}(K) = \frac{k_{sl}^2 - k^2}{3K^2 + (k_{sl}^2 - k^2)}$$

albedo ω

$$\omega = \frac{2|Ko|^4}{Ke|D(Ko)|^2} \sum_{sl=1}^{L} f_{sl} y_{sl}(Ko) \cdot \left(a_{sl}^3 y_{sl}^*(Ko) + \sum_{sj=1}^{L} y_{sj}^*(Ko) a_{sj}^3 n_{sj} 8\pi^3 H_{sjsl}\right)$$

$$Ko = \sqrt{k^2 + \frac{3K_o^2}{D(Ko)} \sum_{sl=1}^{L} f_{sl} y_{sl}(Ko)}$$

4-stream fast radiative transfer model

(Liu,1998)

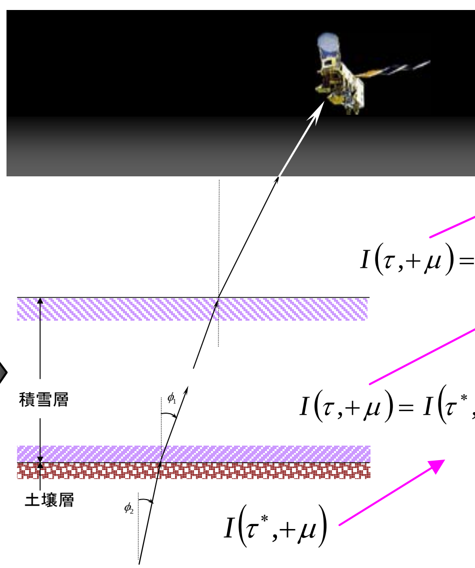
Temperature (t_{snow}・t_{soil})

Snow depth(d)

Soil moisture (m_v)

Soil density (ρ_{soil})

Dielectric constant (Soil: ε_{soil})



Brightness temparature

$$I(\tau,-\mu) = I(0,-\mu)e^{-\tau/\mu} + \sum_{j=-n}^{n} L_j W_j(-\mu)\left(e^{-k_j\tau} - e^{-\tau/\mu}\right) + Z_0\left(1 - e^{-\tau/\mu}\right) - B_1\left[\tau - \mu\left(1 - e^{-\tau/\mu}\right)\right]$$

$$I(\tau,+\mu) = I(\tau^*,+\mu)e^{-(\tau^*-\tau)/\mu} + \sum_{j=-n}^{n} L_j W_j(\mu)\left(e^{-k_j\tau} - e^{-\left[k_j\tau^* + (\tau^*-\tau)/\mu\right]}\right) + Z_0\left(1 - e^{-(\tau^*-\tau)/\mu}\right) - B_1\left[(\tau^* - \tau) - \mu\left(1 - e^{-(\tau^*-\tau)/\mu}\right)\right]$$

$$I(\tau,+\mu) = I(\tau^*,+\mu)e^{-(\tau^*-\tau)/\mu} + \sum_{j=-n}^{n} L_j W_j(\mu)\left(e^{-k_j\tau} - e^{-\left[k_j\tau^* + (\tau^*-\tau)/\mu\right]}\right) + Z_0\left(1 - e^{-(\tau^*-\tau)/\mu}\right) - B_1\left[(\tau^* - \tau) - \mu\left(1 - e^{-(\tau^*-\tau)/\mu}\right)\right]$$

$$I(\tau^*,+\mu)$$

Models

- Model Operator - JMA New-SiB:
  - Assuming Bare Soil => Khatassy (open Field)
  - Simple grain growth model
  - Model Run from: Nov. 15 to March 15
    Assimilation was initialized using Model Start in October
- Observation Operatore - RTM:
  - MEMLS
    = Microwave Emission Model for Layered Snowpacks
    - Linear conversion between grain size and correlation length
  - Dry Soil, but actually Frozen Soil
  - No Effect of Vegetation
  - No Atmospheric Correction

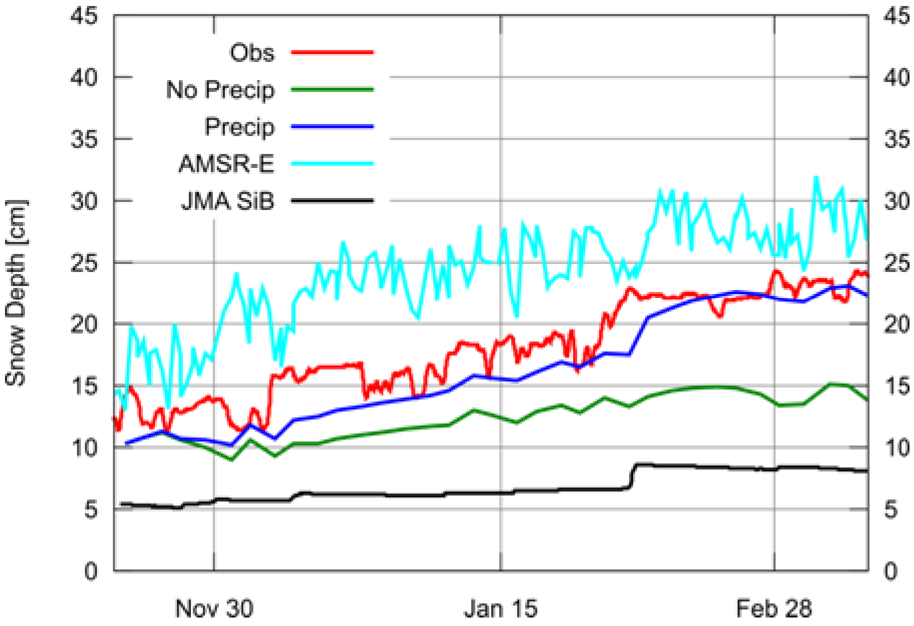
Simple Grain Growth Model

- Rachel Jordan, 1991:
- Dry Snow – Kinetic Growth:

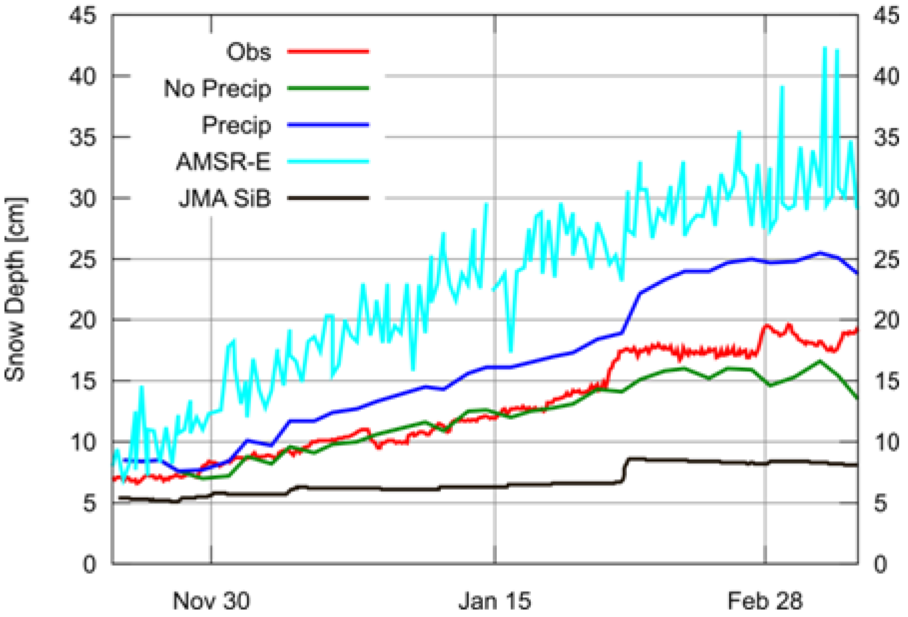
$$\frac{\delta d}{\delta t}=\frac{g_1|U_v|}{d}=\frac{g_1}{d}D_{EOS}\left(\frac{1000}{P_a}\right)\left(\frac{T}{273.15}\right)^6 C_{kT}\left|\frac{\delta T}{\delta t}\right|$$

- Wet Snow
  - θ < 0.09: $\frac{\delta d}{\delta t}=\frac{g_2}{d}(\theta_l+0.05)$
  - 0.09: $\frac{\delta d}{\delta t}=0.14\frac{g_2}{d}$
- Basic features
  - Temperature Gradient - dr/dt increases
  - High Temperature - dr/dt increases
  - large Grain Size - dr/dt decreases
  - Wetness - dr/dt increases
- Does not consider Equitemperature, but small anyway compared to Kinetic Grain Growth

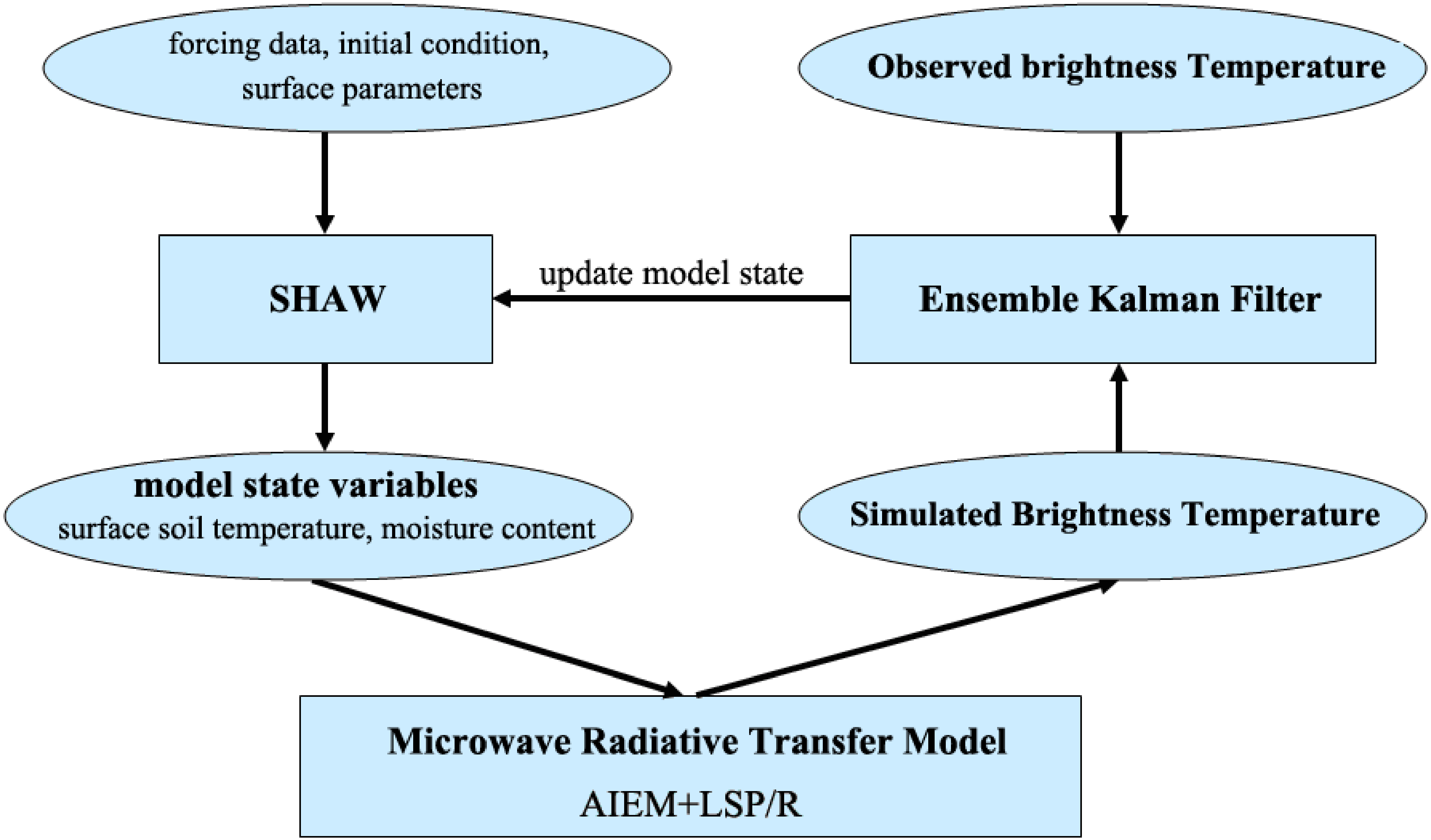
Validation of Snow-LDAS in Yakutsk



2003-2004



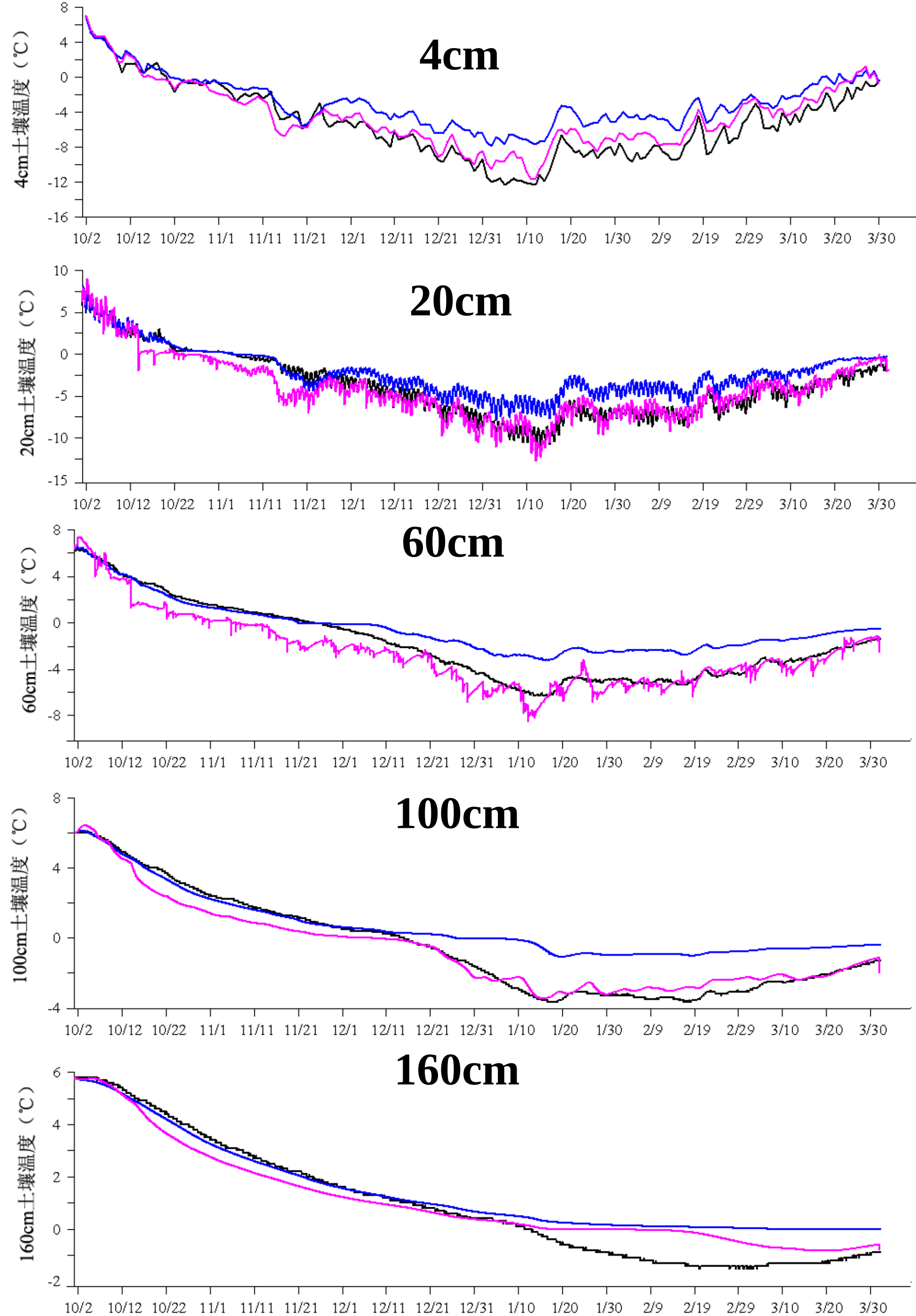
2004-2005



Soil Surface Frozen/Thawed Status Detection by Using SSM/I and the Active Layer Data Assimilation System

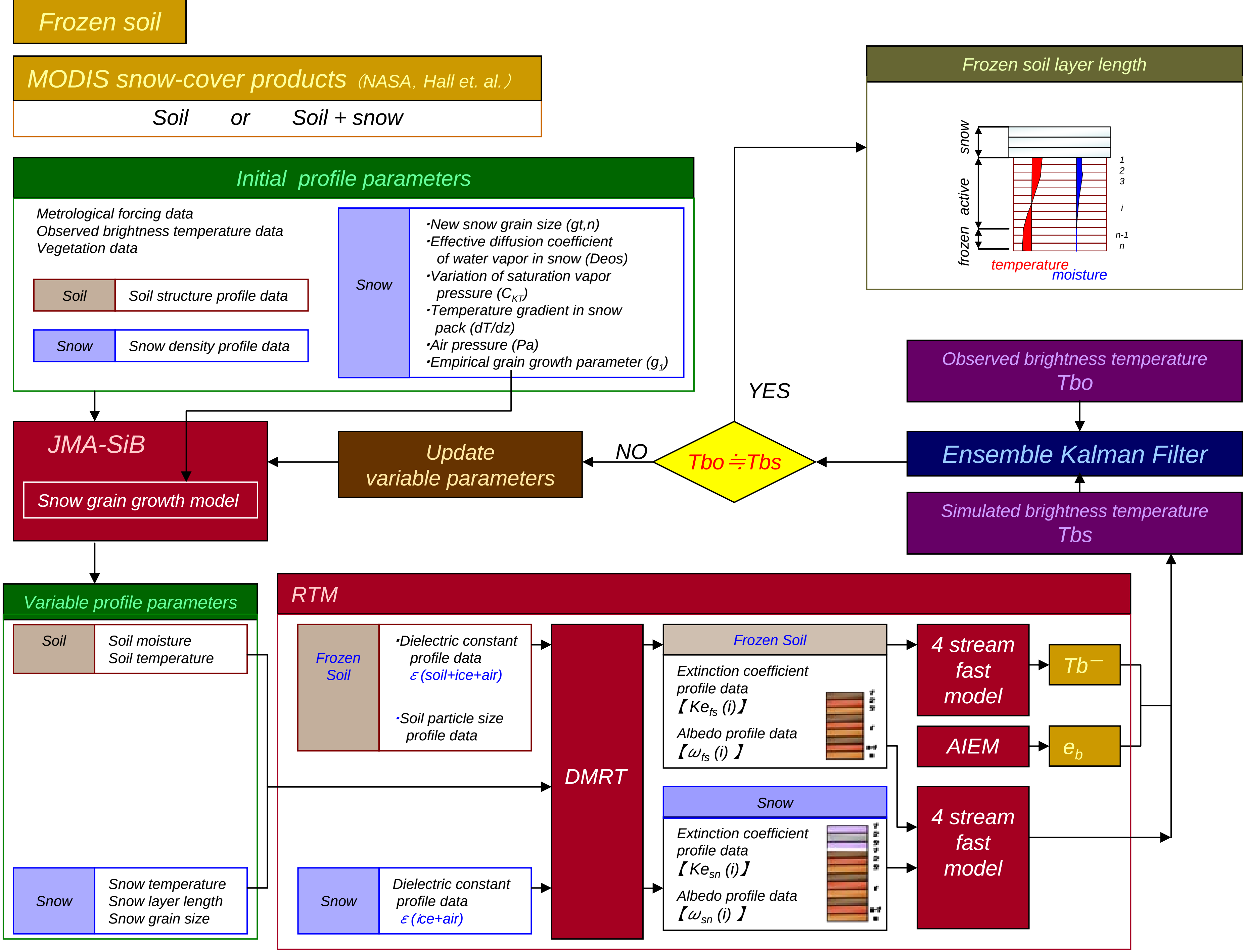
Dr. Rui Jin

Assimilation Result of the soil tem.



After assimilating SSM/I 19GHz brightness temperature, the RMSE of soil temperature in winter decrease 0.76K.

By Dr. Rui Jin


Frozen soil
MODIS snow-cover products (NASA, Hall et. al.)
Soil or Soil + snow
Initial profile parameters
Metrological forcing data
Observed brightness temperature data
Vegetation data
Soil
Soil structure profile data
Snow
Snow density profile data
Snow
·New snow grain size (gt,n)
·Effective diffusion coefficient of water vapor in snow (Deos)
·Variation of saturation vapor pressure (C_{KT})
·Temperature gradient in snow pack (dT/dz)
·Air pressure (Pa)
·Empirical grain growth parameter (g_1)
Frozen soil layer length
snow
active
frozen
1
2
3
i
n-1
n
temperature
moisture
YES
Observed brightness temperature Tbo
JMA-SiB
Snow grain growth model
Update variable parameters
NO
Tbo≒Tbs
Ensemble Kalman Filter
Simulated brightness temperature Tbs
Variable profile parameters
Soil
Soil moisture
Soil temperature
Snow
Snow temperature
Snow layer length
Snow grain size
RTM
Frozen Soil
·Dielectric constant profile data
ε (soil+ice+air)
·Soil particle size profile data
Snow
Dielectric constant profile data
ε (ice+air)
DMRT
Frozen Soil
Extinction coefficient profile data
【Ke_{fs} (i)】
Albedo profile data
【ω_{fs} (i) 】
Snow
Extinction coefficient profile data
【Ke_{sn} (i)】
Albedo profile data
【ω_{sn} (i) 】
4 stream fast model
AIEM
4 stream fast model
Tb^{-}
e_b