MISMO Workshop
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Results on daily simulation using a cloud resolving model over the tropical Indian Ocean during the MISMO

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Two topics in this presentation

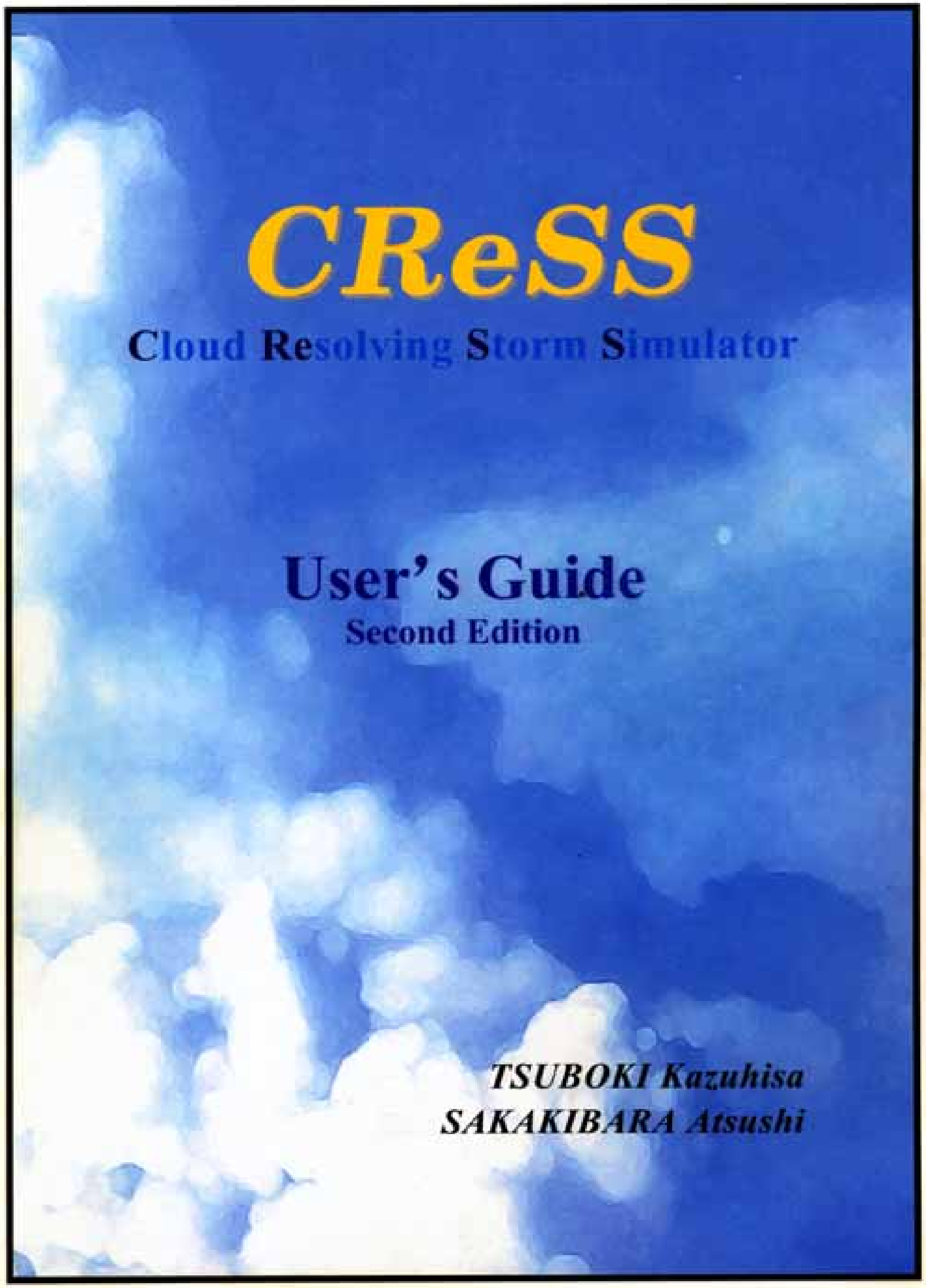
(1) One is the results of daily simulation using the cloud resolving model whose horizontal grid resolution is 5 km.

→ Some problems using the cloud resolving model of 5-km grid resolution applied over the tropical ocean.

(2) The other is the results of the calculation of the PDF (probability density function) of cloud parameters for using the GCM.

→ Collaborative study with GCM researchers.

The Cloud Resolving Storm Simulator (CReSS)



Prof. Tsuboki have developed the CReSS for about 10 years.

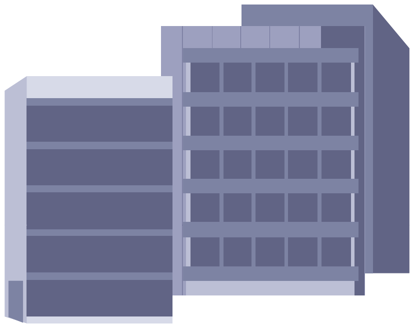
- **The non-hydrostatic and compressible equation system.**
- **Terrain-following coordinate system.**
- **Finite difference method.**
- **Surface processes.**
- **Conformal map projections.**
- **6 categories water substances include cold rain processes.**
- **Parallel processing (Message Passing Interface: MPI and OpenMP).**

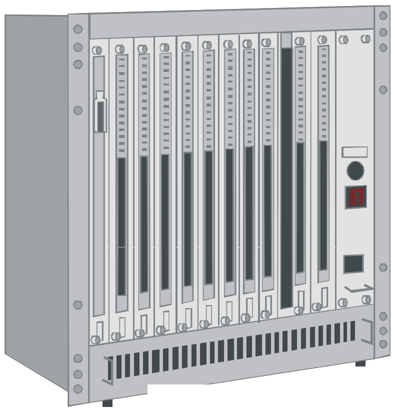
Daily Simulation around Japan Area Using the CReSS

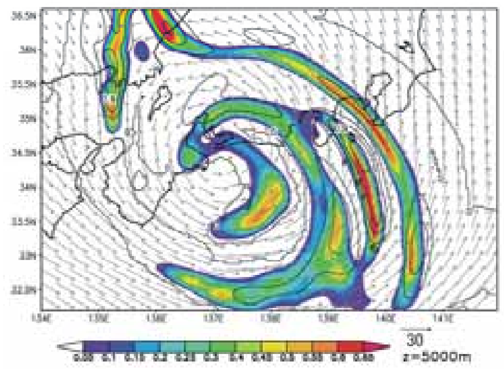
We have examined daily simulation around Japan area using the CReSS since May 2004.

JMA forcast GPV-data (RSM, GSM) from Japan Meteorological Business Support Center.
Initial and boundary condition

Results present in the web-site of our Lab.





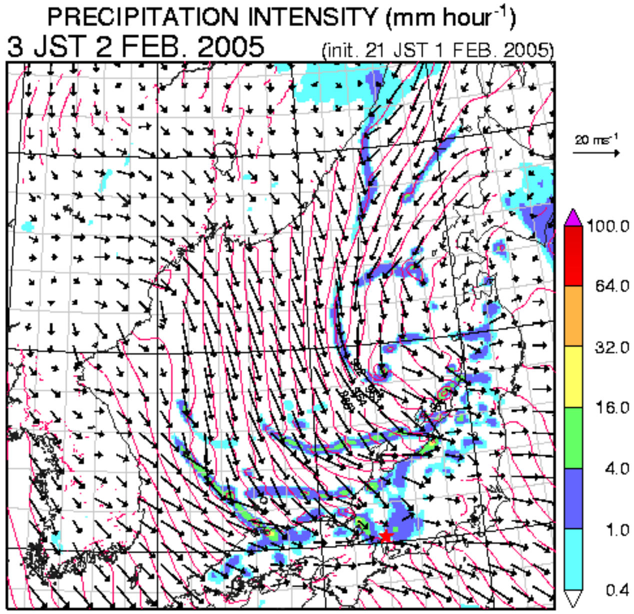


Simulation in our Lab. every day.

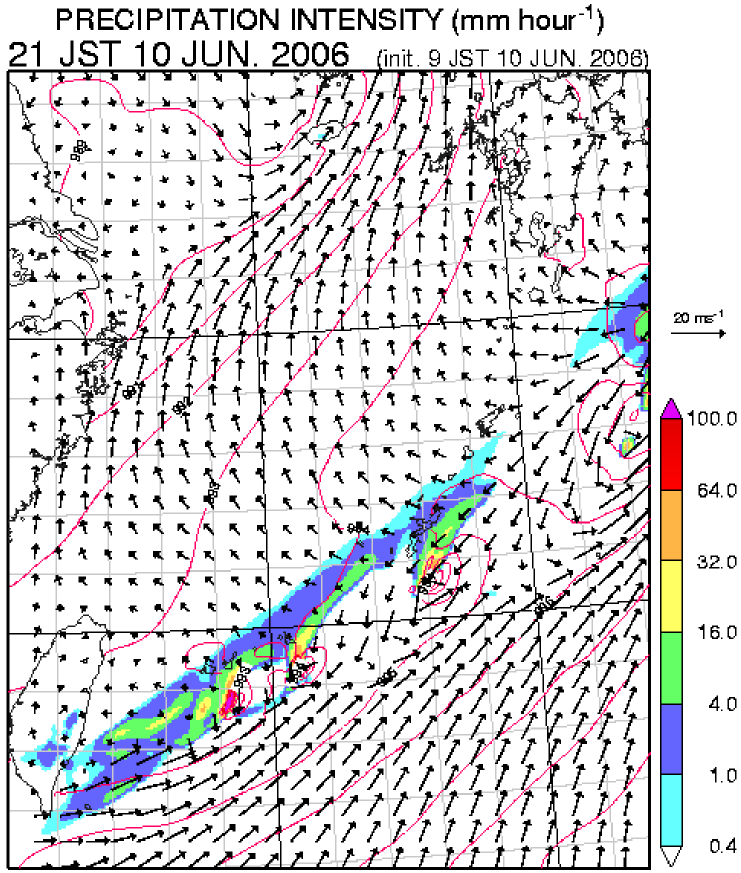
http://www.rain.hyarc.nagoya-u.ac.jp/CReSS/fcst_exp.html

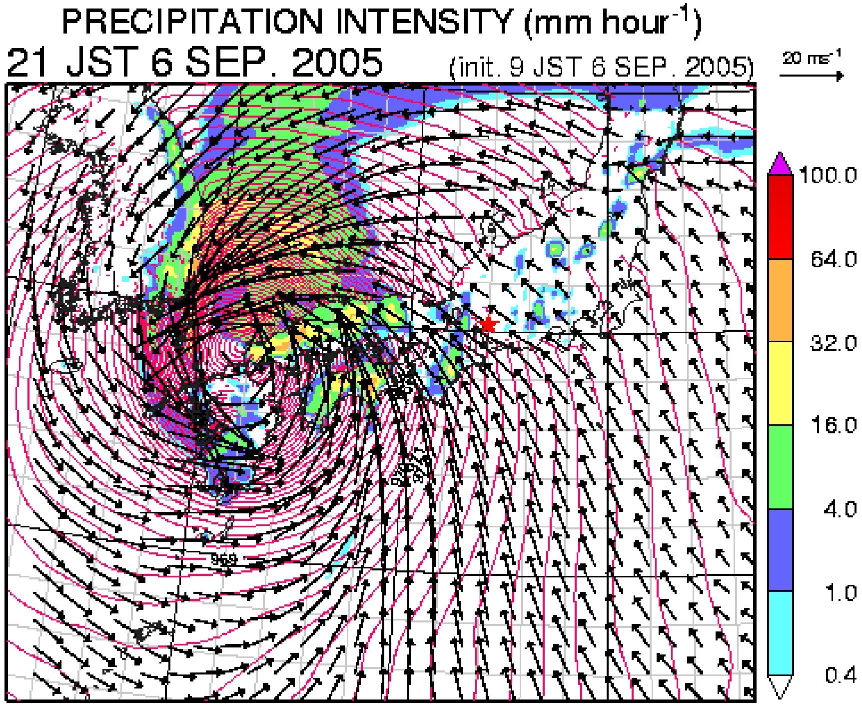
Sample of the Daily Simulations around Japan Area

Heavy snowfall around Nagoya
Feb. 01, 2005



Heavy rainfall at Okinawa by the Baiu front
Jun. 10, 2006





Heavy rainfall around Kyushu by Typhoon T0514
Sep. 06, 2005

Purpose of the Daily Simulation over the Tropical Indian Ocean

- **The weather system around Japan (in the mid-latitude region) should be governed by the synoptic scale.**

→ The predictability of the precipitation system in the CReSS mainly depended on that of the large-scale model (GSM).

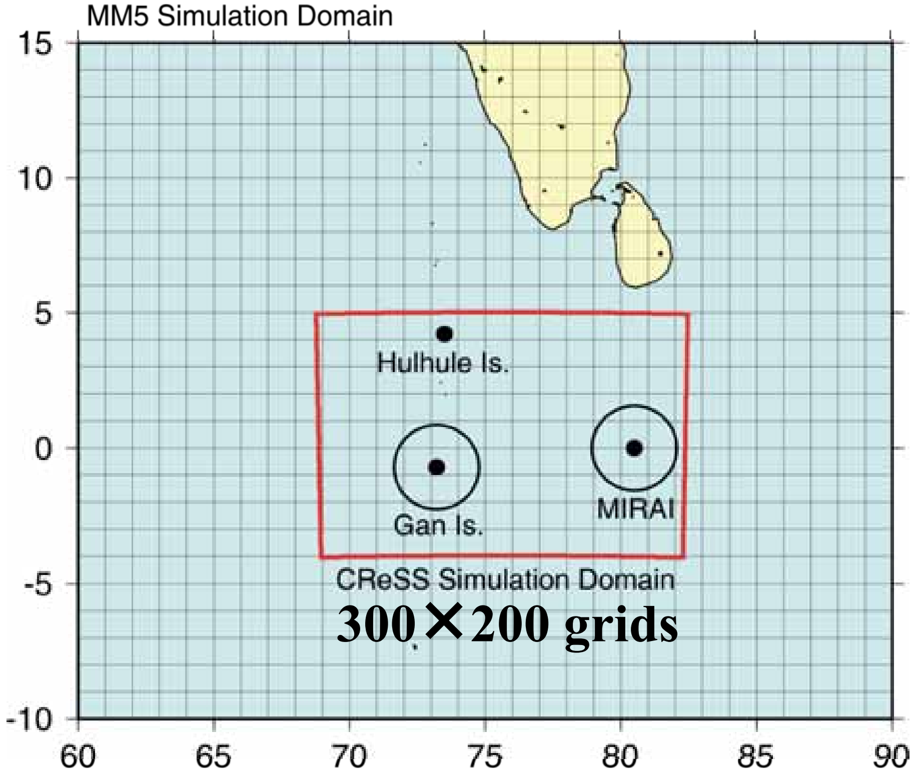
*** Convergence and water vapor fields in the lower troposphere.**

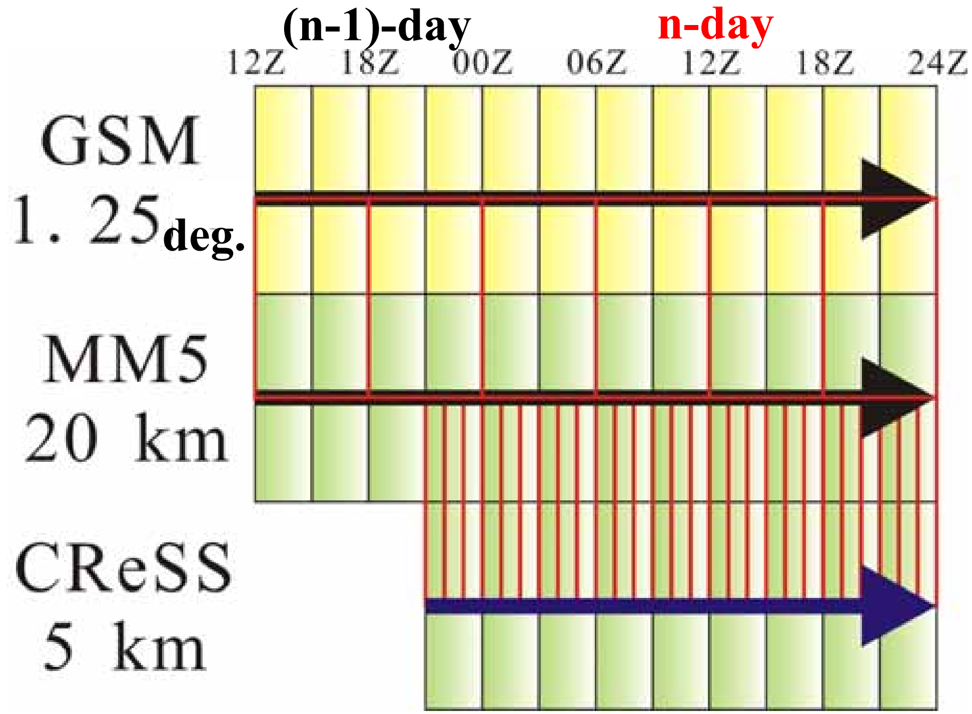
- **How about is the predictability in the tropical region?**

→ It should be difficult because the synoptic scale structure is not predominant.

- **In order to confirm the predictability over the tropical ocean, we tried to examine daily simulations over the tropical Indian Ocean using the CReSS during the MISMO in 2006.**
- **In this study, we show some problems in this simulations.**

Overview of the Daily Simulation





Simulation Period

Oct. 20 – Dec. 03, 2006

Total: 45 days

Finish normally : 21 → 31 days

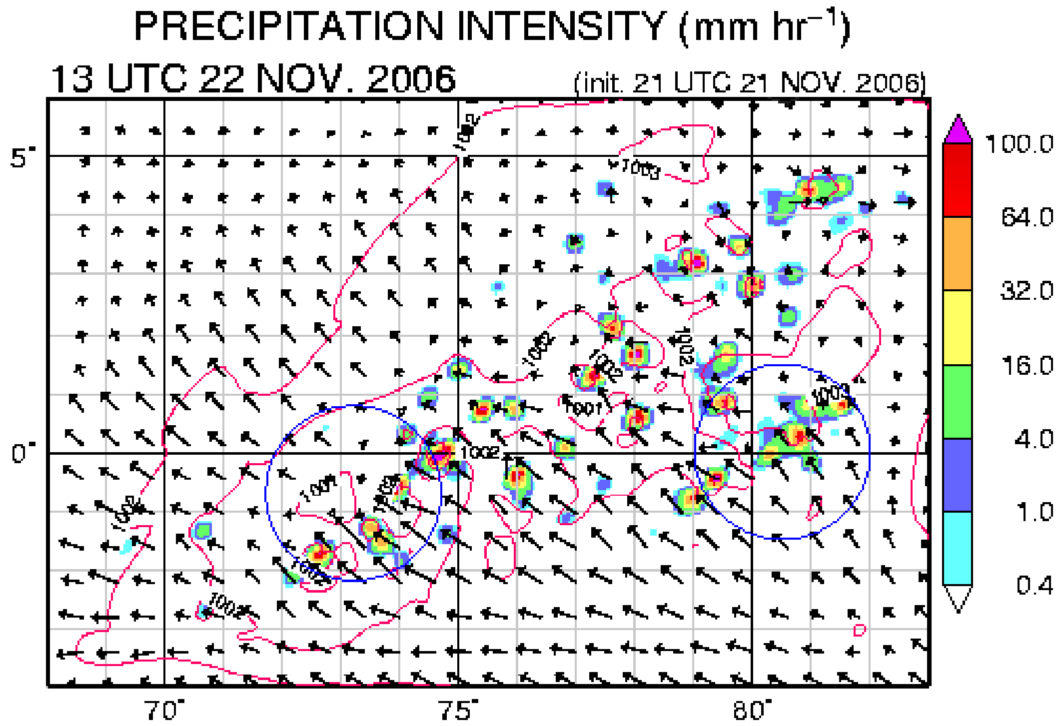
Stop abnormally: 7 → 8 days

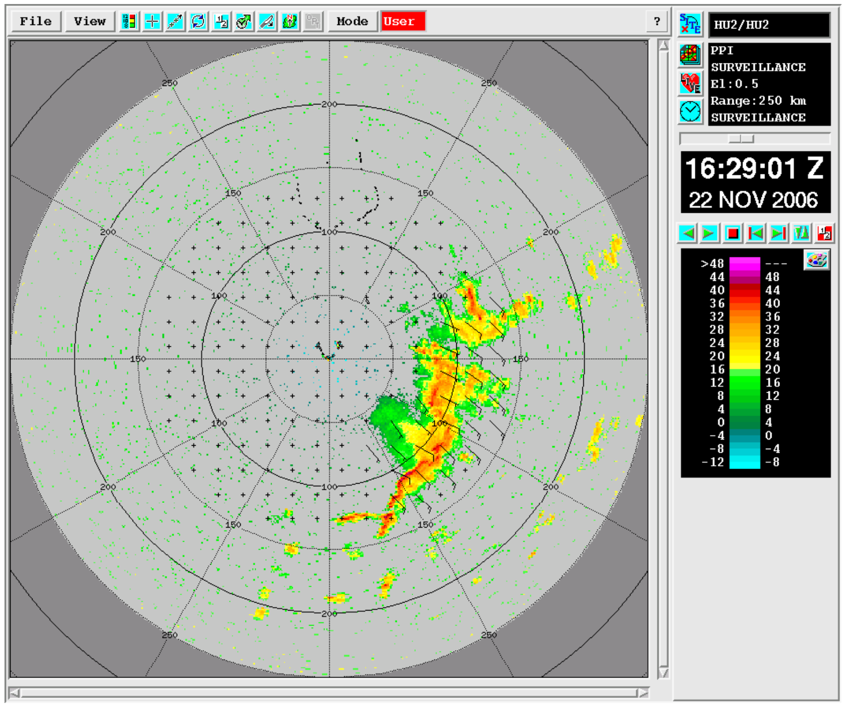
Not Start : 17 → 6 days

- **The GSM-GPV data were made by JMA and provided by Japan Meteorological Business Support Center every day.**
- **These data were used as the initial and boundary conditions of the MM5 simulations.**
- **The results of the MM5 simulations were used as the initial and boundary conditions of the CReSS simulations.**

Sample of the Simulated Precipitation System

Observed around Gan Island on Nov. 22, 2006





Provided by Dr. H. Yamada

*Precipitation cells aligns from SW to NE.

* These locate ahead of the strong southeasterly.

* Simulated time is different from observed one.

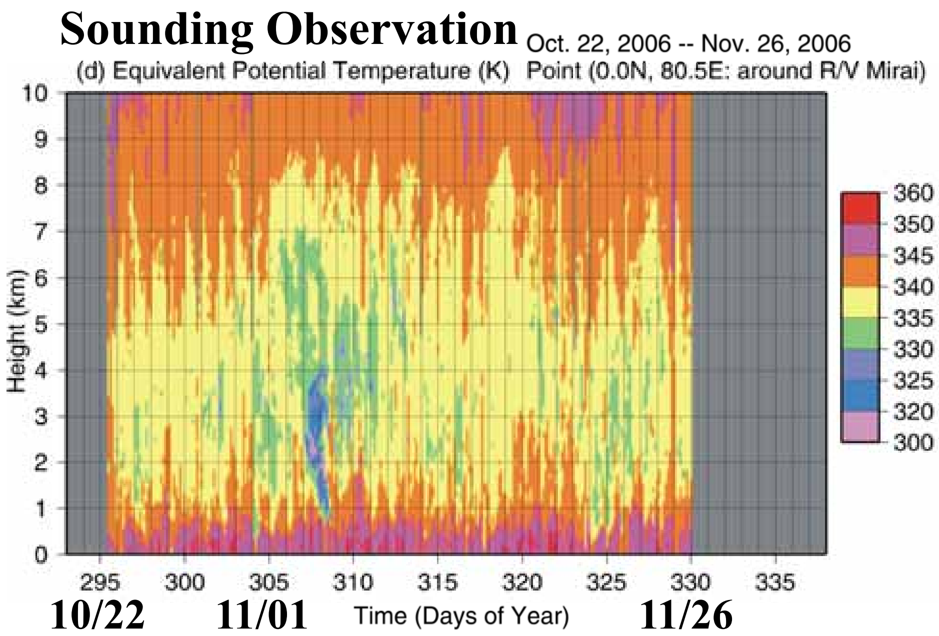
*Doppler radar observation at Gan Is.

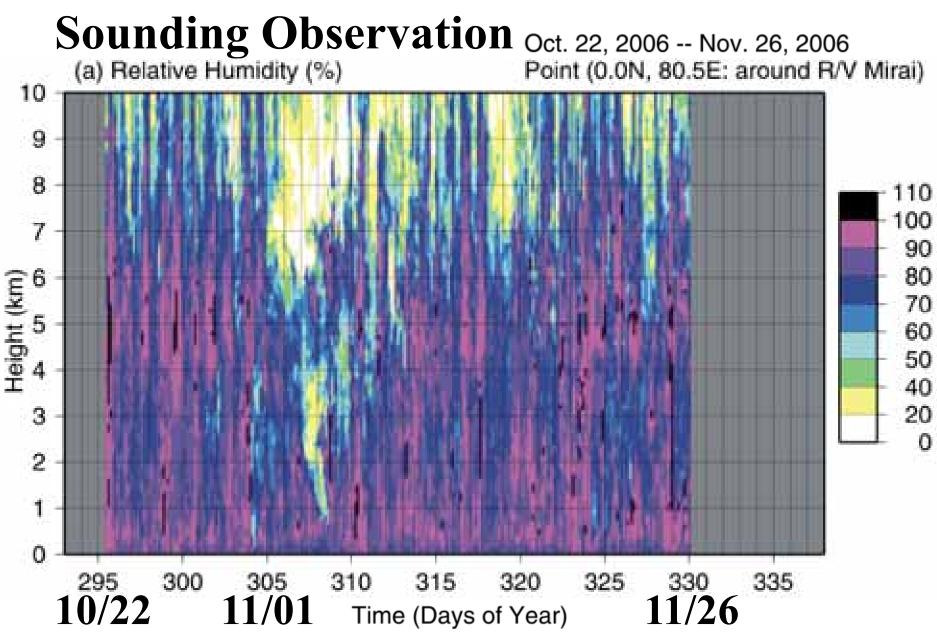
*Line-shaped precipitation system aligns from SSW to NNE.

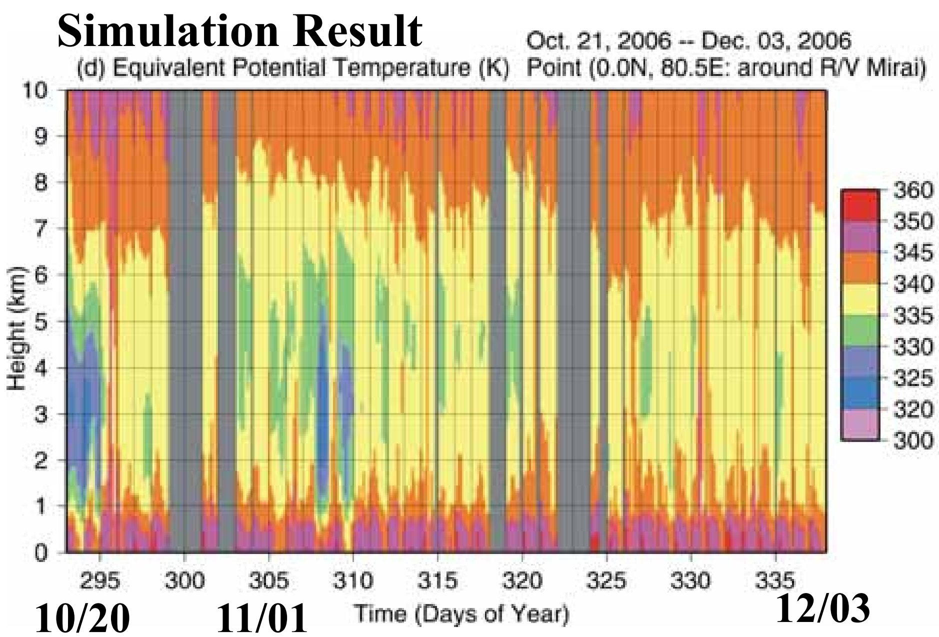
*It moves northwestward.

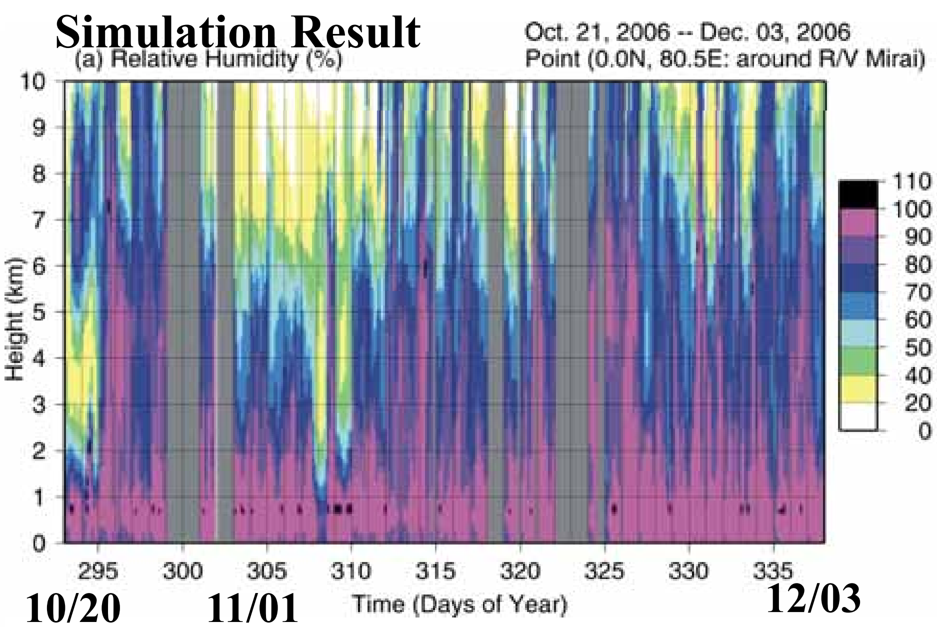
*Southeasterly wind behind the precipitation region.

Time Series of Vertical Profiles of EPT and RH (Sounding vs Model)

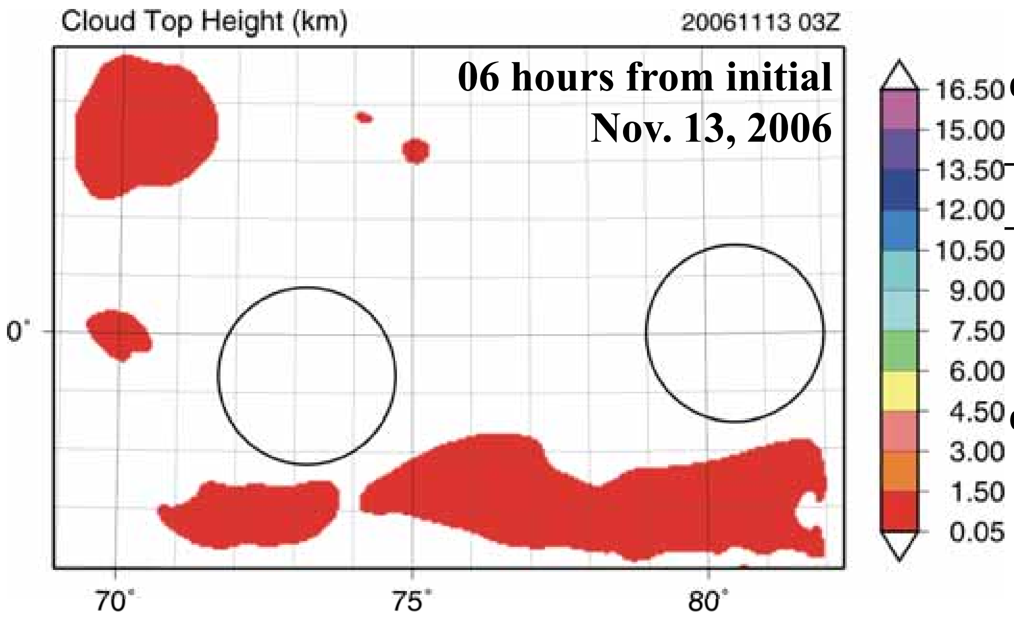




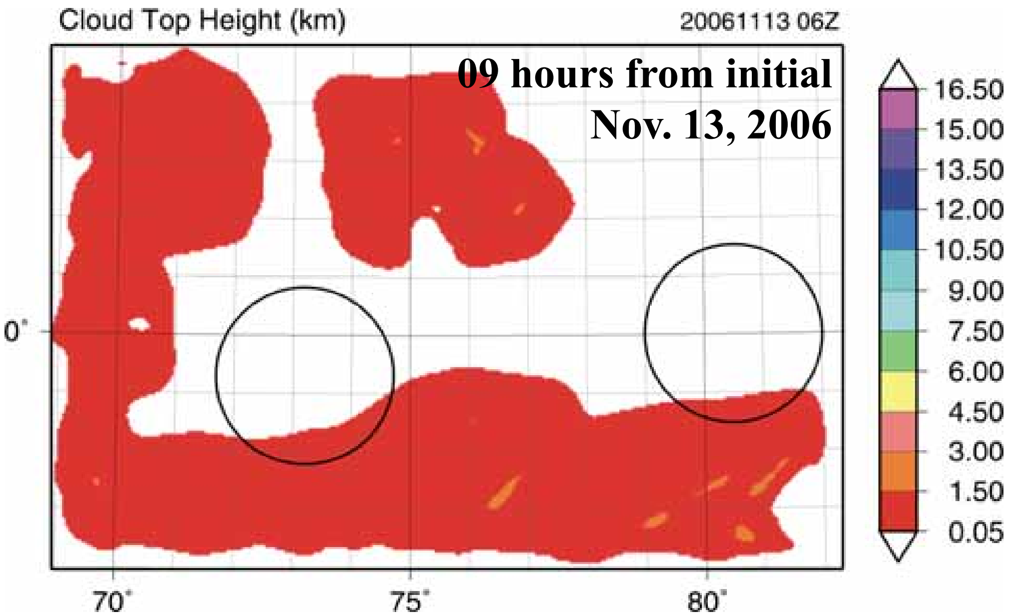




Problem 1: Unrealistic Boundary Layer Clouds



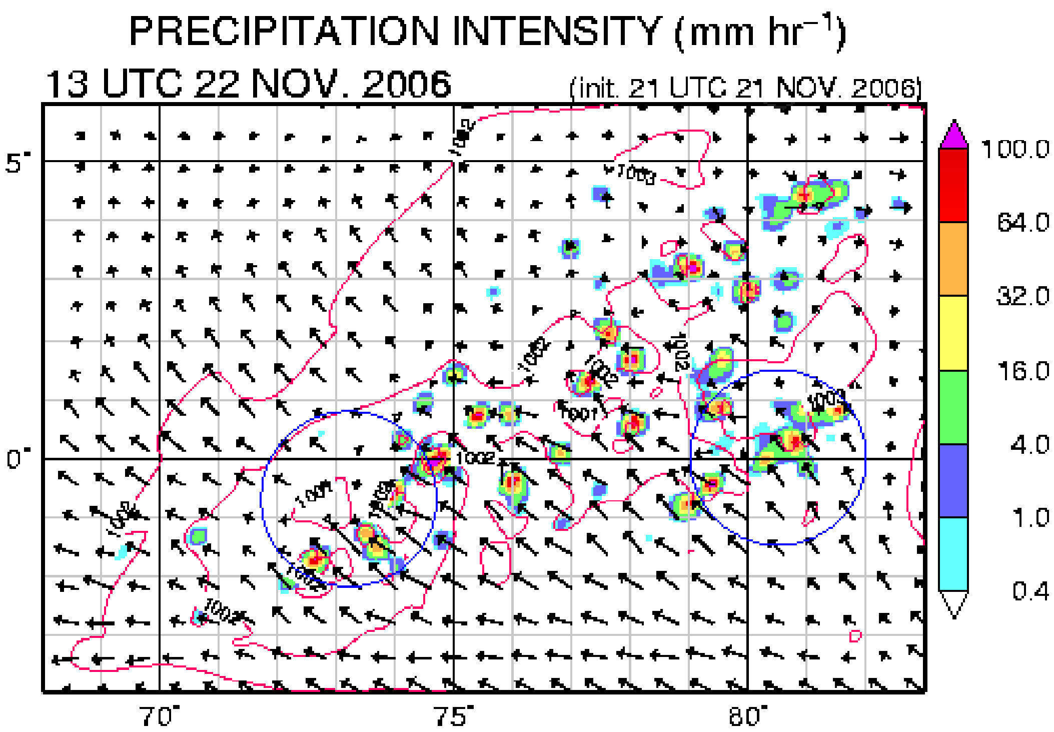
- **Widespread lower clouds**
  → **Unrealistic!!**
  → **Water vapor is imprisoned and condensate in the BL**
- **Shallow cumulus clouds transport water vapor from the BL to the FA.**
  → **We cannot reproduce this process.**

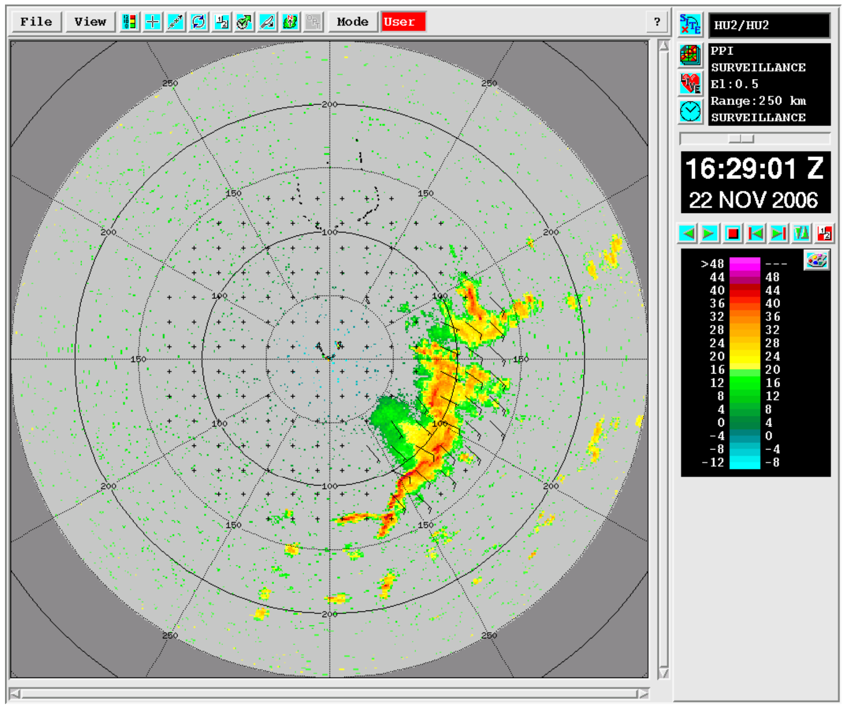


- **We have to introduce the shallow cumulus parameterization or use finer horizontal grid resolution.**

Problem 2: Cellar Precipitation Regions (not Precipitation System)

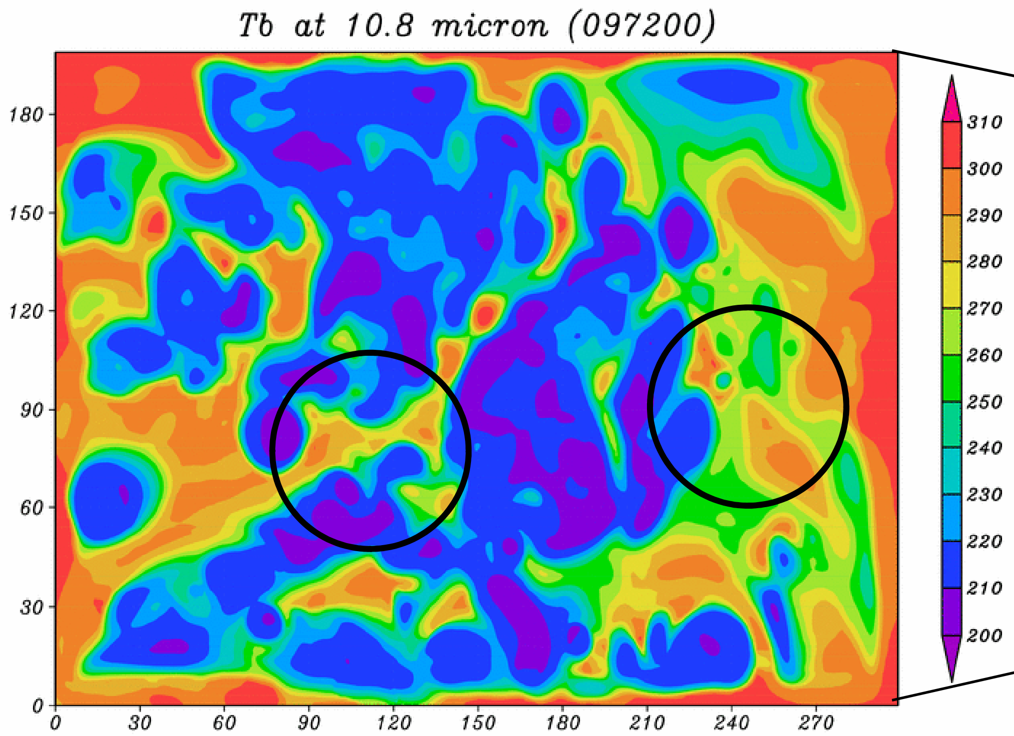
Observed around Gan Island on Nov. 22, 2006





- **Precipitation regions are cellar structure** **(～ 50 km), the structure of the precipitation system is not reproduced.**
- **Perhaps this structure depends on the horizontal grid resolution.**

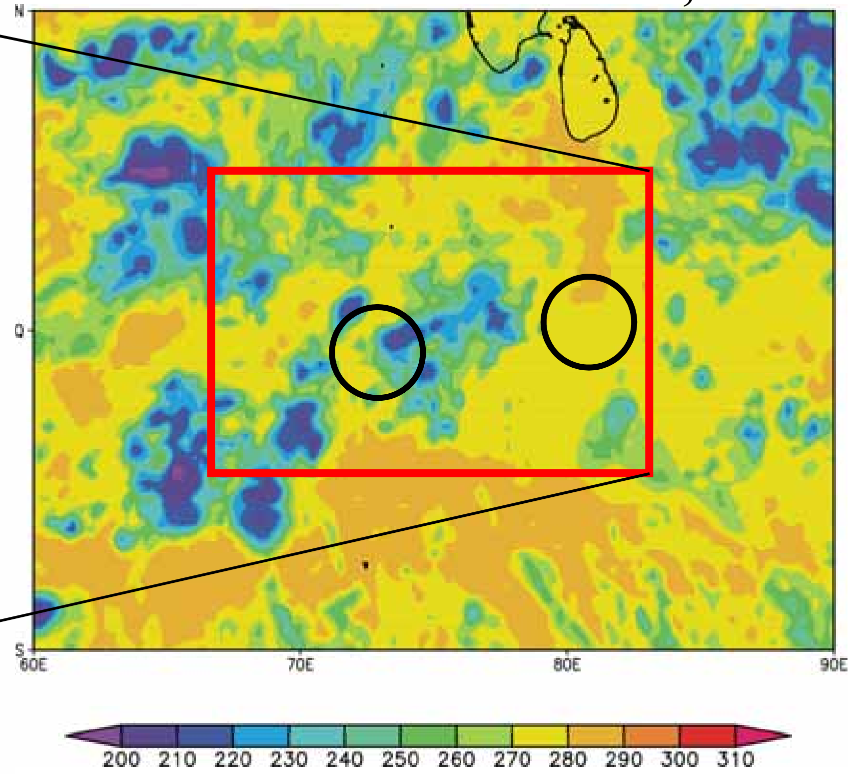
Problem 3: Large Amount of High Cloud Fraction



T_{BB}-IR1 from CReSS + SDSU

by Prof. H. Masunaga

METEOSAT-IR 24Z Nov. 13, 2006



- **Large amount of high cloud fraction in the simulation result.**
- **We cannot find out the course of this result.**
  - *** The horizontal grid resolution?**
  - *** Bulk microphysical processes in the CReSS?**

Summary on the First Topic

- We have carried out the daily simulations using the CReSS over the tropical Indian Ocean during the MISMO in 2006.
- We reproduced the development of deep precipitation cells.
- We needed longer spin-up time (6 to 9 hours) compared with the case on mid-latitude.
- Some problems arose:

  * Unrealistic boundary layer clouds developed,

  → We need to apply the shallow cumulus parameterization and to use finer horizontal grid resolution.

  * Cellar precipitation regions (not precipitation system) developed,

  → We need to use finer horizontal grid resolution.

  * Large amount of high cloud fraction existed.

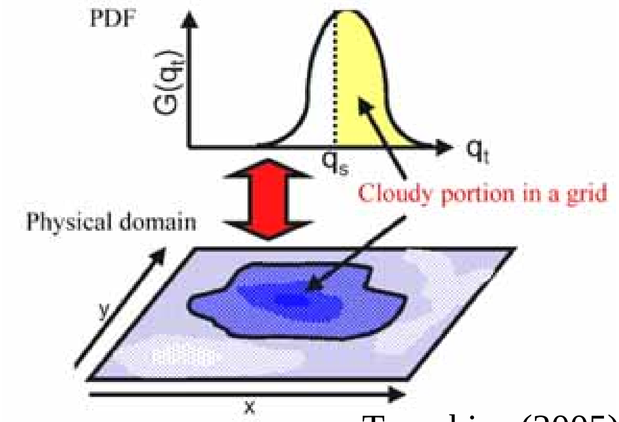
  → We cannot find the course of the results. (microphysiccal parameterization?)

Development of Prognostic Cloud Scheme in GCM

- **Large-scale condensation (LSC)**

✓ Assume a subgrid-scale distribution of q_t' or $s=a_L(q_t'-\alpha_L T_l')$?

✓ Predict condensate amount and cloud fraction?



Tompkins (2005)

"Hybrid" Prognostic Cloud scheme (HPC)

Quasi-reversible operator I_χ:

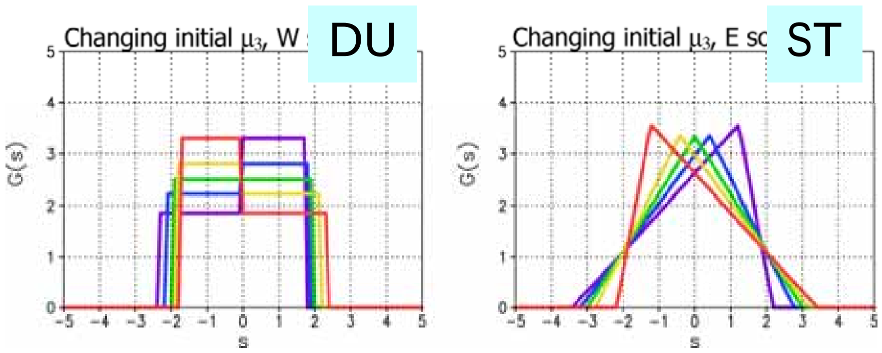
Cloud fraction	$C = I_C(\overline{p}, \overline{T}_l, \overline{q}_t, V, S)$	**PDF variance**	$V = \tilde{I}_V(\overline{p}, \overline{T}_l, \overline{q}_v, \overline{q}_c, C)$
Condensate amount	$\overline{q}_c = I_q(\overline{p}, \overline{T}_l, \overline{q}_t, V, S)$	**PDF skewness**	$S = \tilde{I}_S(\overline{p}, \overline{T}_l, \overline{q}_v, \overline{q}_c, C)$

Prognostic equations for PDF variance & skewness

$$\frac{DV}{Dt} = \left.\frac{\Delta V}{\Delta t}\right|_{\text{conv.}} + \left.\frac{\Delta V}{\Delta t}\right|_{\text{micro.}} + \left.\frac{\Delta V}{\Delta t}\right|_{\text{turb.}} - \varepsilon_V V$$

$$\frac{DS}{Dt} = \left.\frac{\Delta S}{\Delta t}\right|_{\text{conv.}} + \left.\frac{\Delta S}{\Delta t}\right|_{\text{micro.}} + \left.\frac{\Delta S}{\Delta t}\right|_{\text{turb.}} - \varepsilon_S S$$

Basis PDF (varying S)



from Prof. Watanabe (Univ. of Tokyo)

Definition of Parameter S

- **Calculate from mixing ratio of total water (q_t) and liquid water potential temperature (θ_l) (Bougeault 1981)**

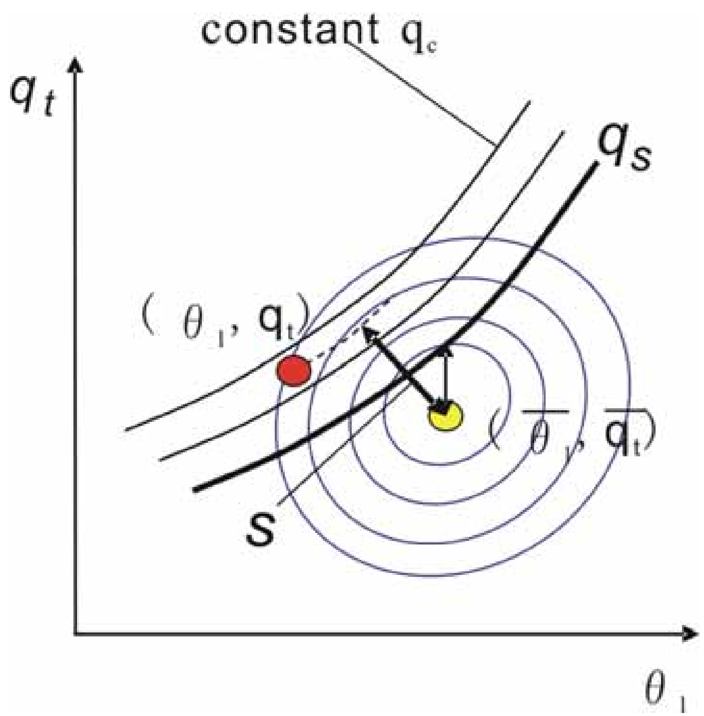
$$s \equiv a_l(q_t' - \alpha_l \theta_l')$$

q_t : Total Water ($q_v + q_c + q_i + q_s$)
θ_l : Liquid water potential temperature

Rain (q_r) and graupel (q_g) are excluded as condensate in GCM.

$$\alpha_l = \frac{L_v q_{vs}}{R_v T^2}$$

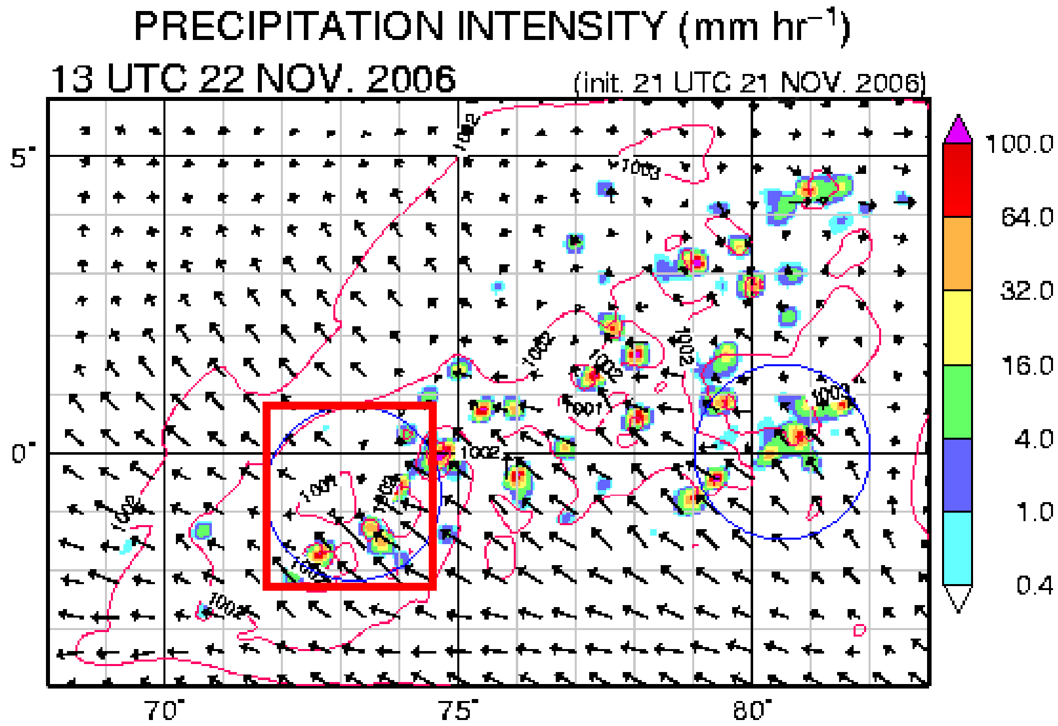
$$a_l = 1/(1 + \frac{L_v}{c_p}\alpha_l)$$

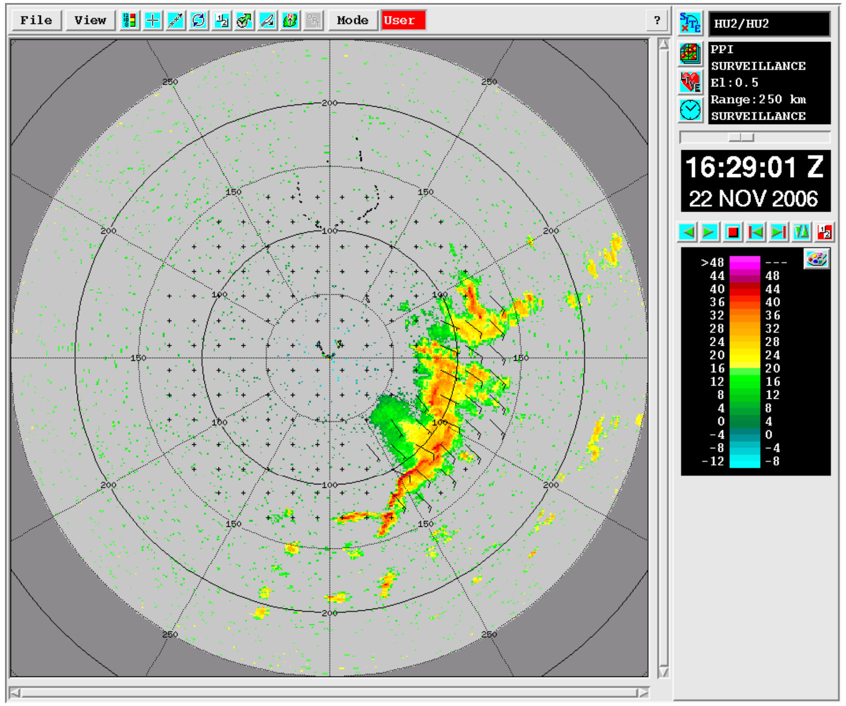


- **In order to confirm the PDF variance and skewness used in the GCM, we have to understand the change of PDF in the various weather system.**
- **We will show a result of the variation of PDF variance and skewness when the precipitation system developed over the tropical ocean during the MISMO.**

Sample of the Precipitation System

Observed around Gan Island on Nov. 22, 2006



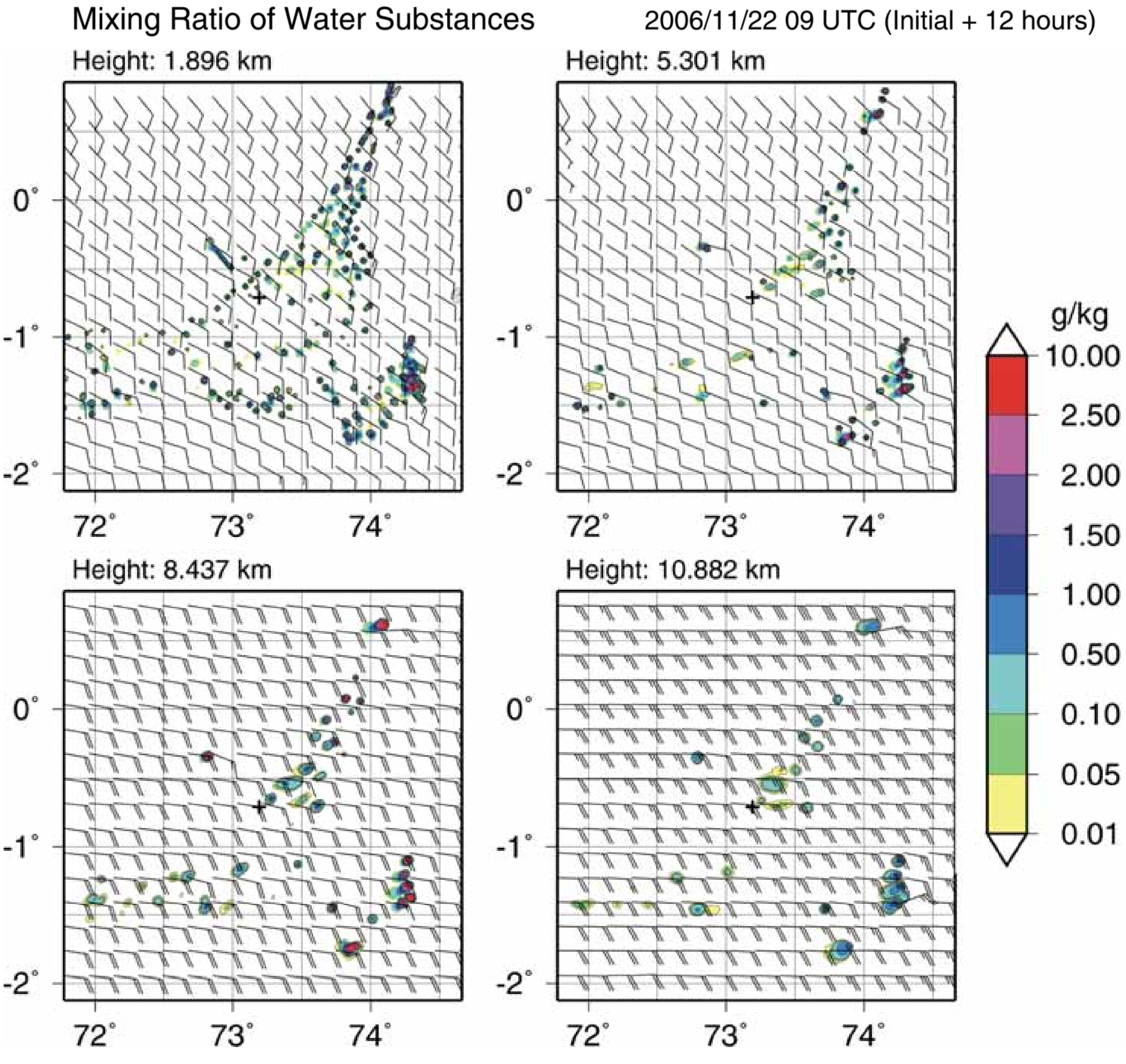


- Down-scaling simulation using 1-km horizontal grid resolution

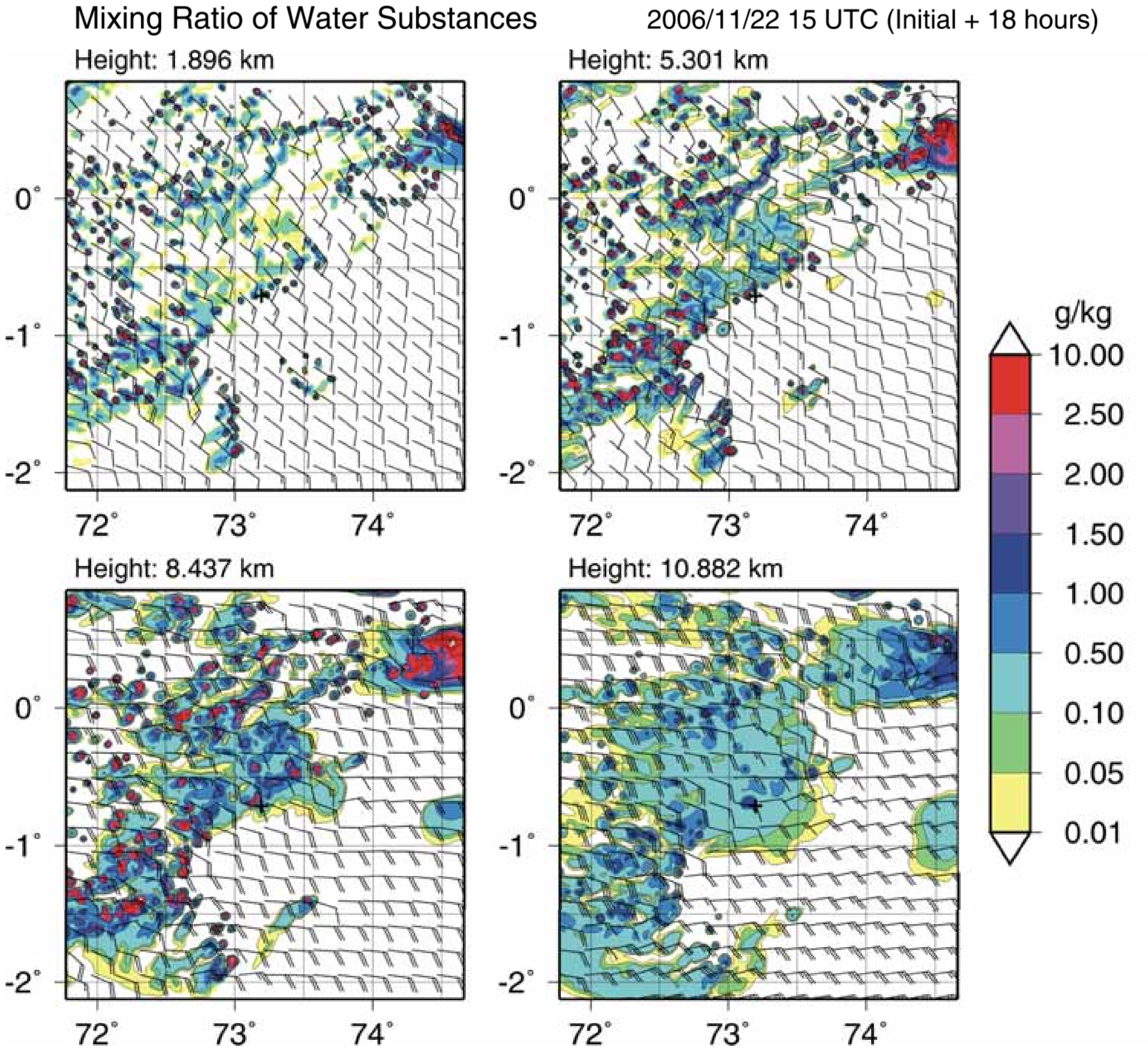
CReSS down-scaling simulation

- Horizontal Grid 1 km
- Domain Size 322×333
- Initial Time 21Z on Nov. 21, 2006
- Initial and Boundary Conditions: 5-km CReSS Simulation Results

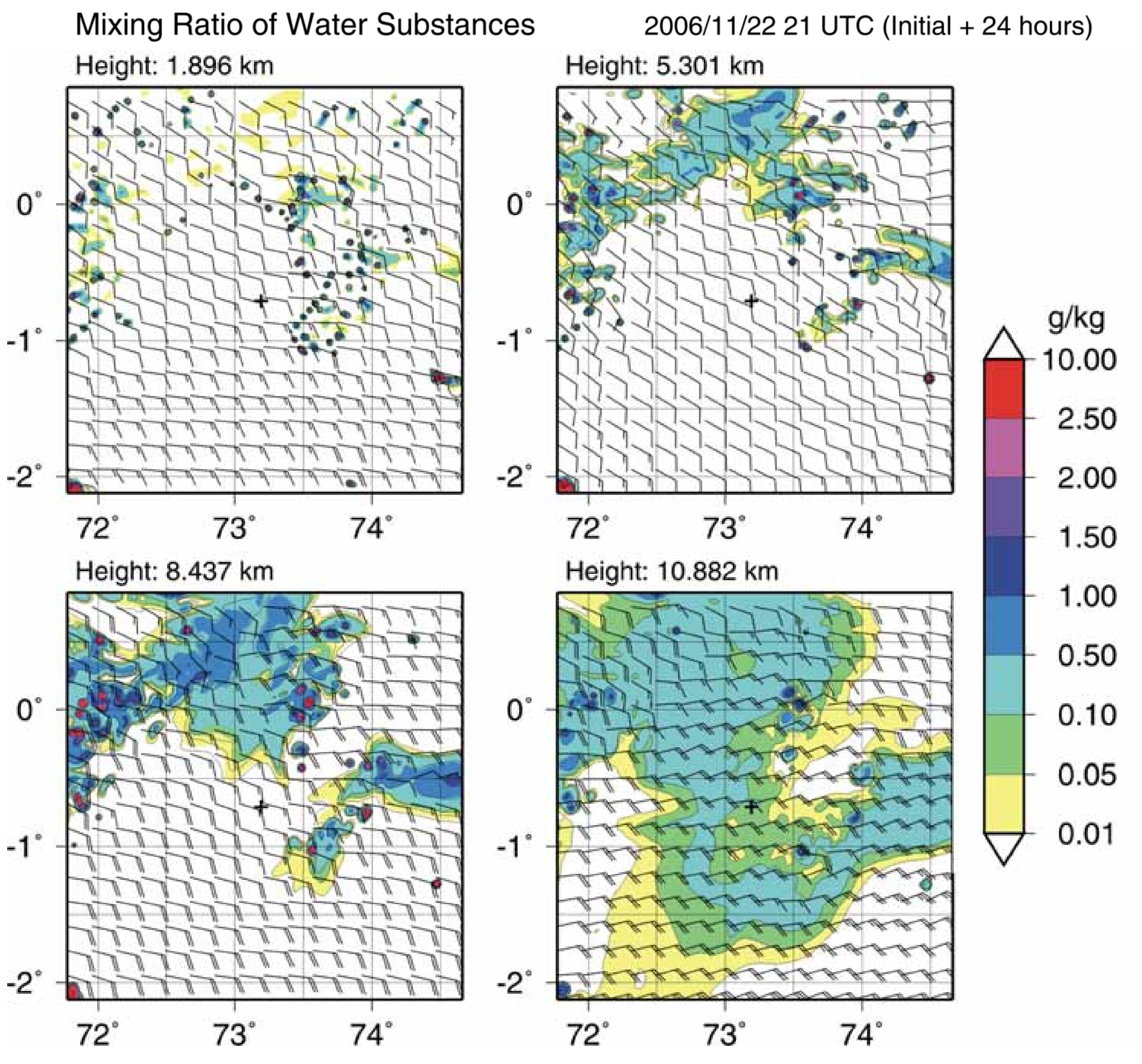
Developing Stage of the Precipitation System (CReSS-1km, 12 h)



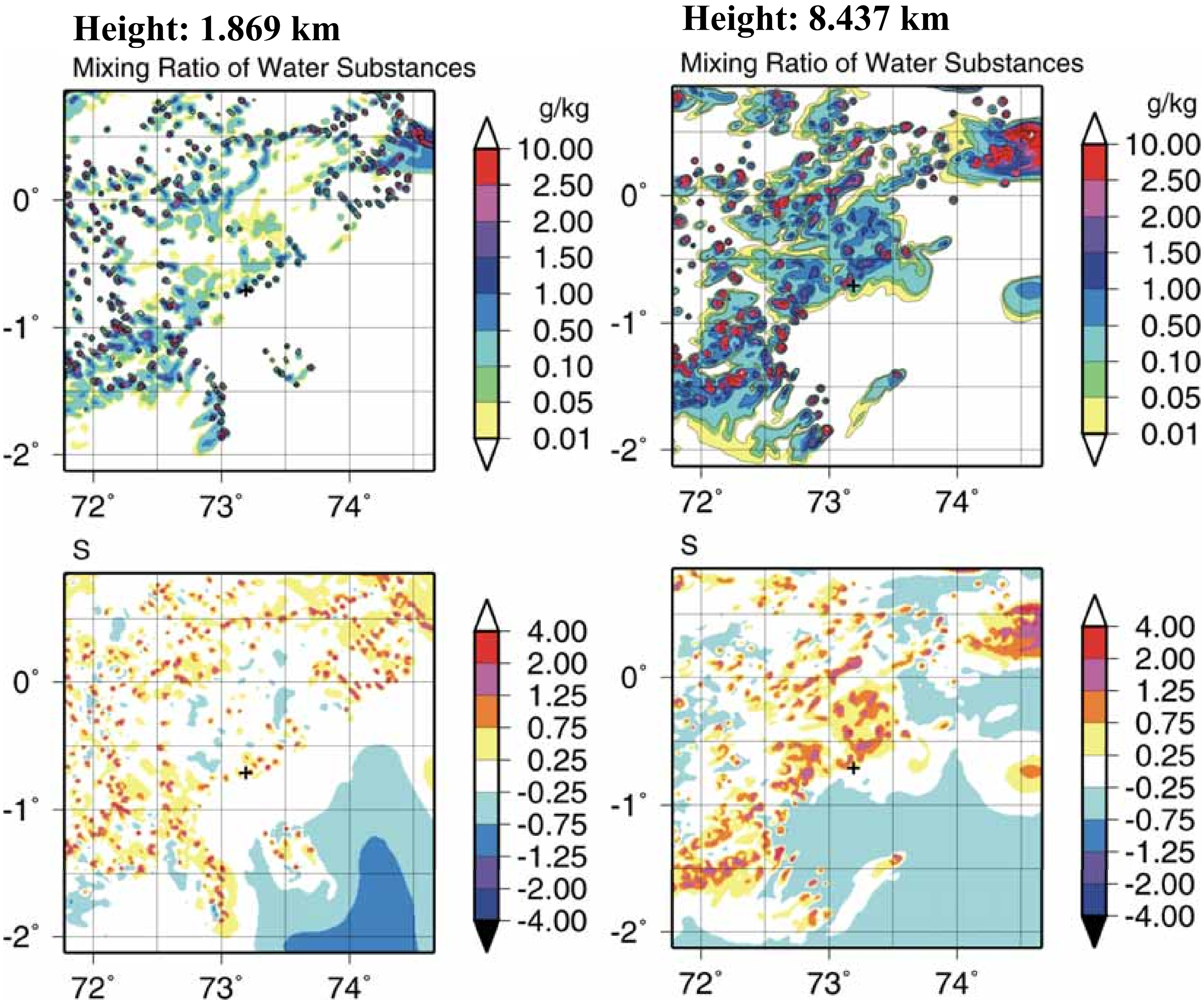
Mature Stage of Precipitation System (CReSS-1km, 18 h)



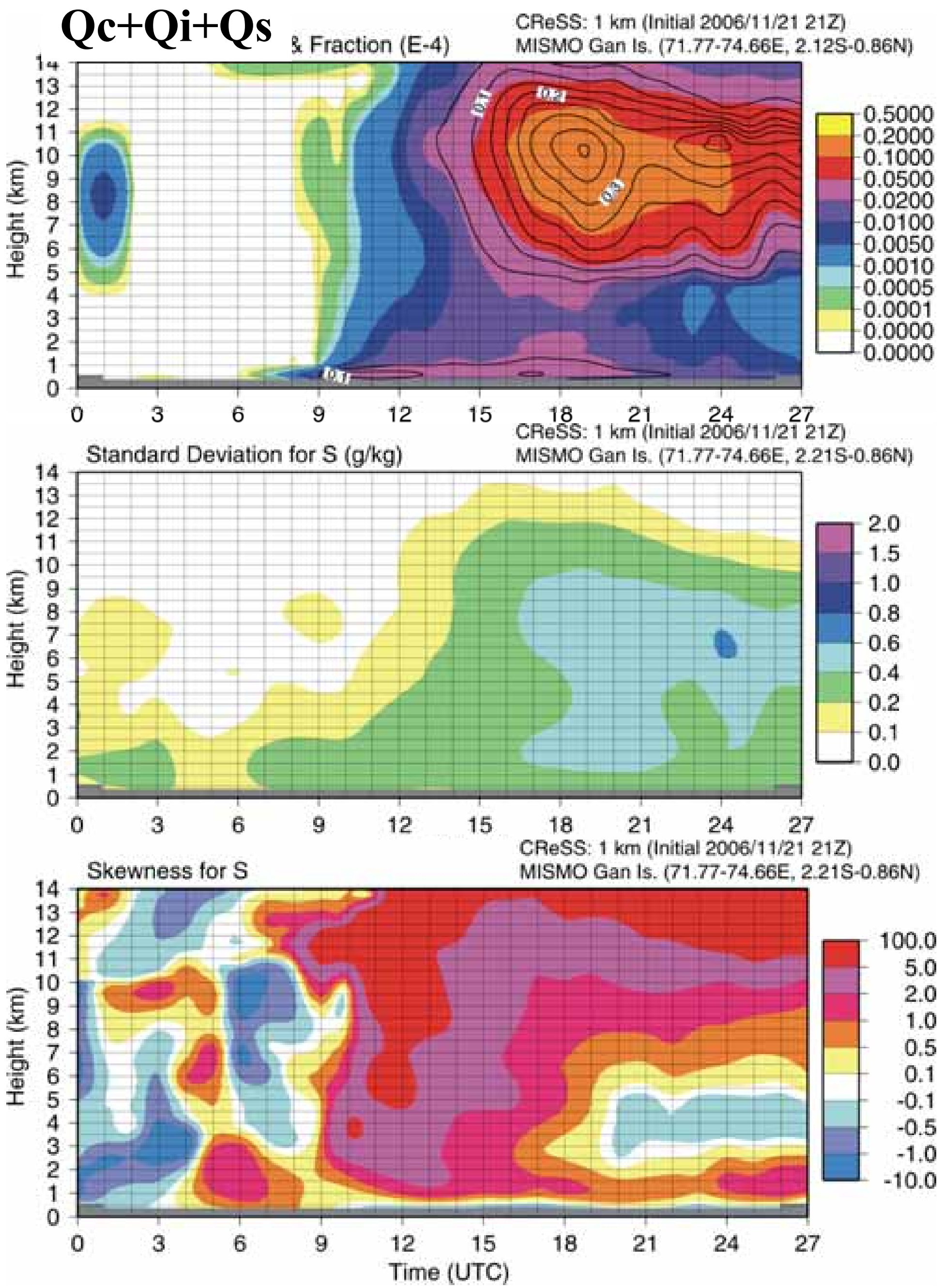
Dissipating Stage of Precipitation System (CReSS-1km, 24 h)



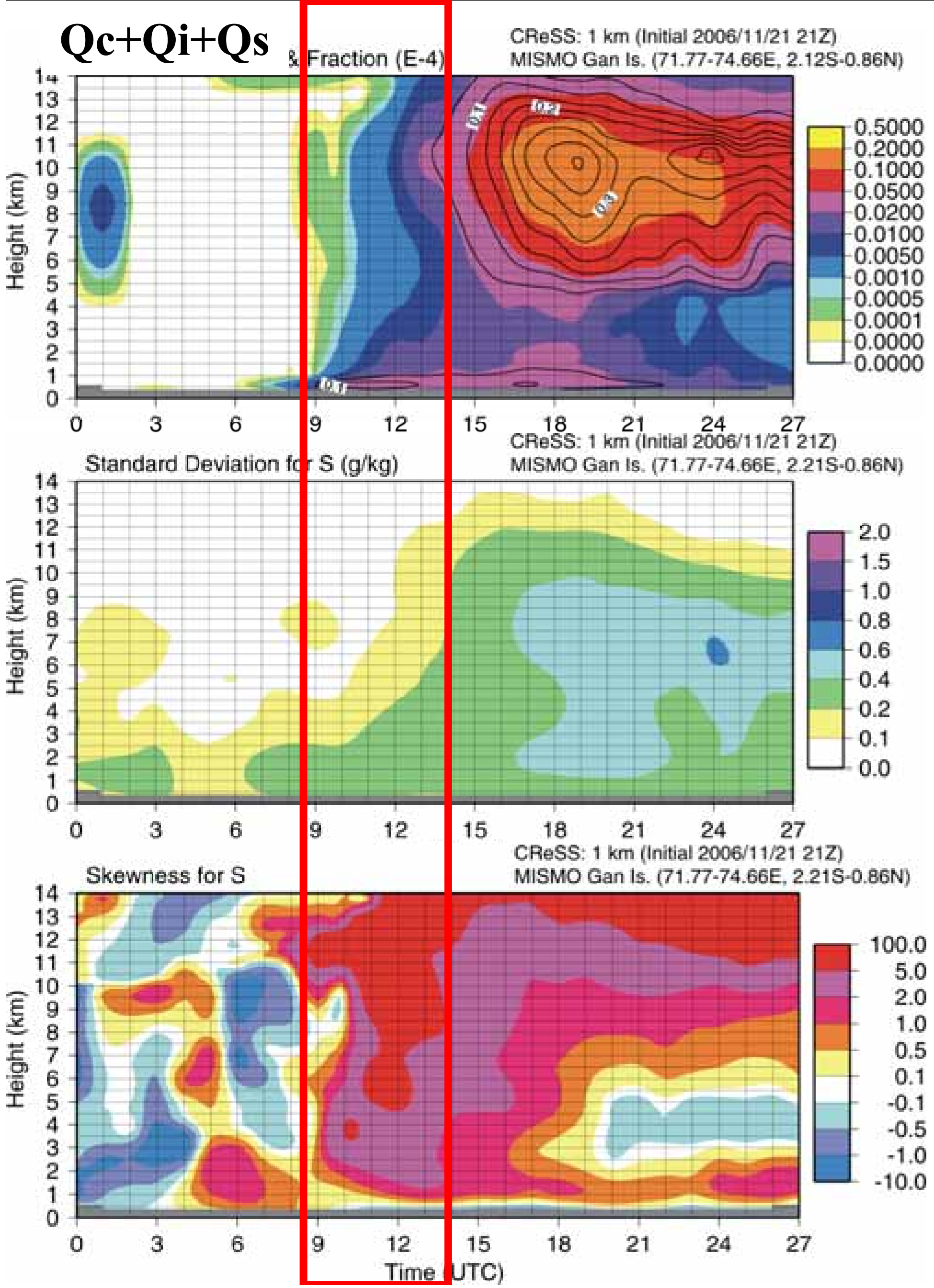
Distribution of S-value (Mature Stage, CReSS-1km, 18 h)



Time Series of Vertical Profiles of Prognostic Parameters



Time Series of Vertical Profiles of Prognostic Parameters



• Developing Stage

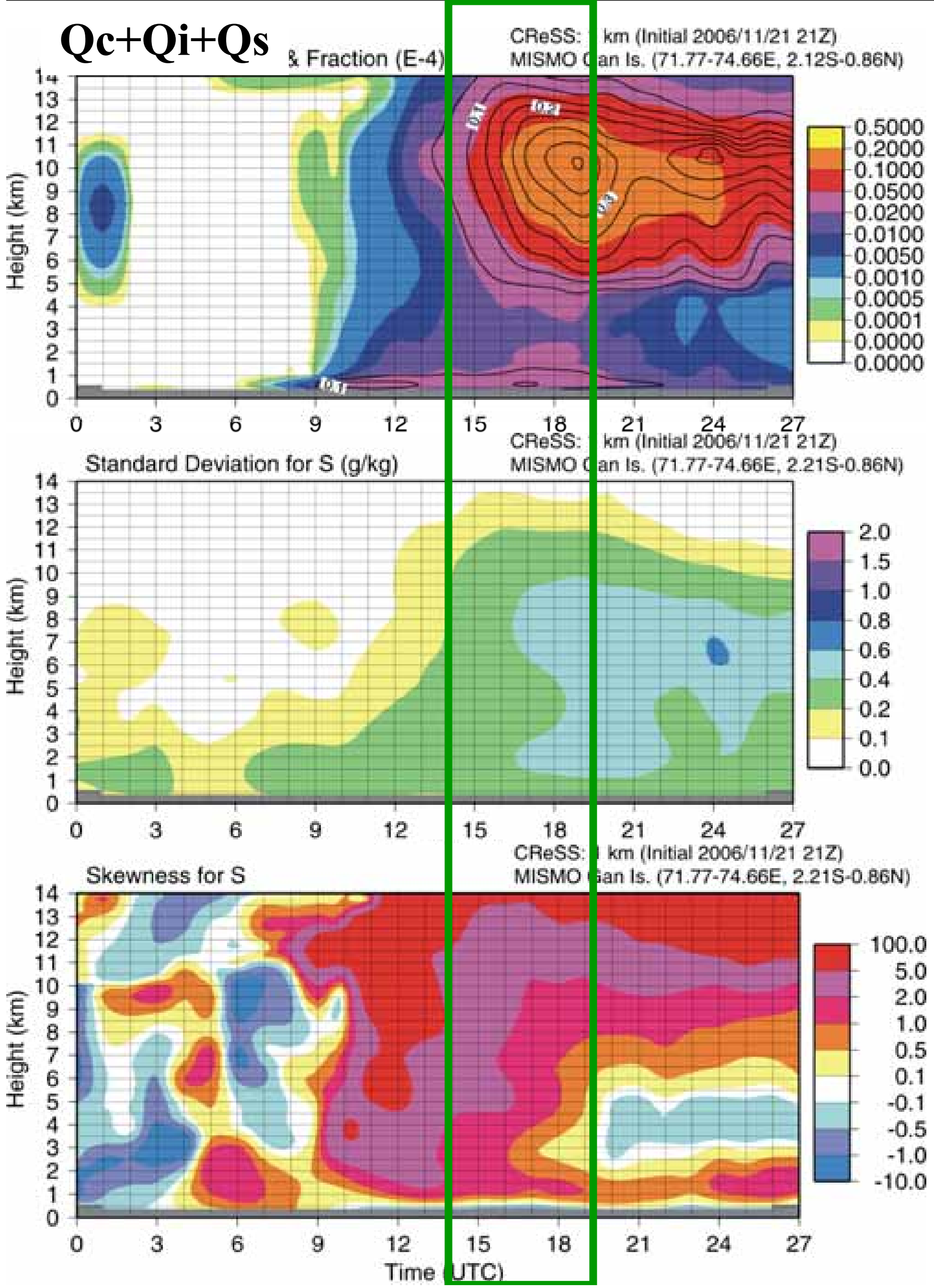
* **Condensate amount**:
increase at all levels
→ vertical transport of water vapor and condensate by convection

* **Cloud fraction**:
increase but not recognized

* **Standard deviation of S**:
increase from lower to upper troposphere

* **Skewness of S**:
large positive valus
→ Mixing ratio of condensate in clouds is quite large

Time Series of Vertical Profiles of Prognostic Parameters



- **Mature Stage**

* **Condensate amount**:
increase above the ML

* **Cloud fraction**:
increase above the ML

→ **Snow amount increase in the stratiform region**

* **Standard deviation of S**:
increase in the whole of the troposphere

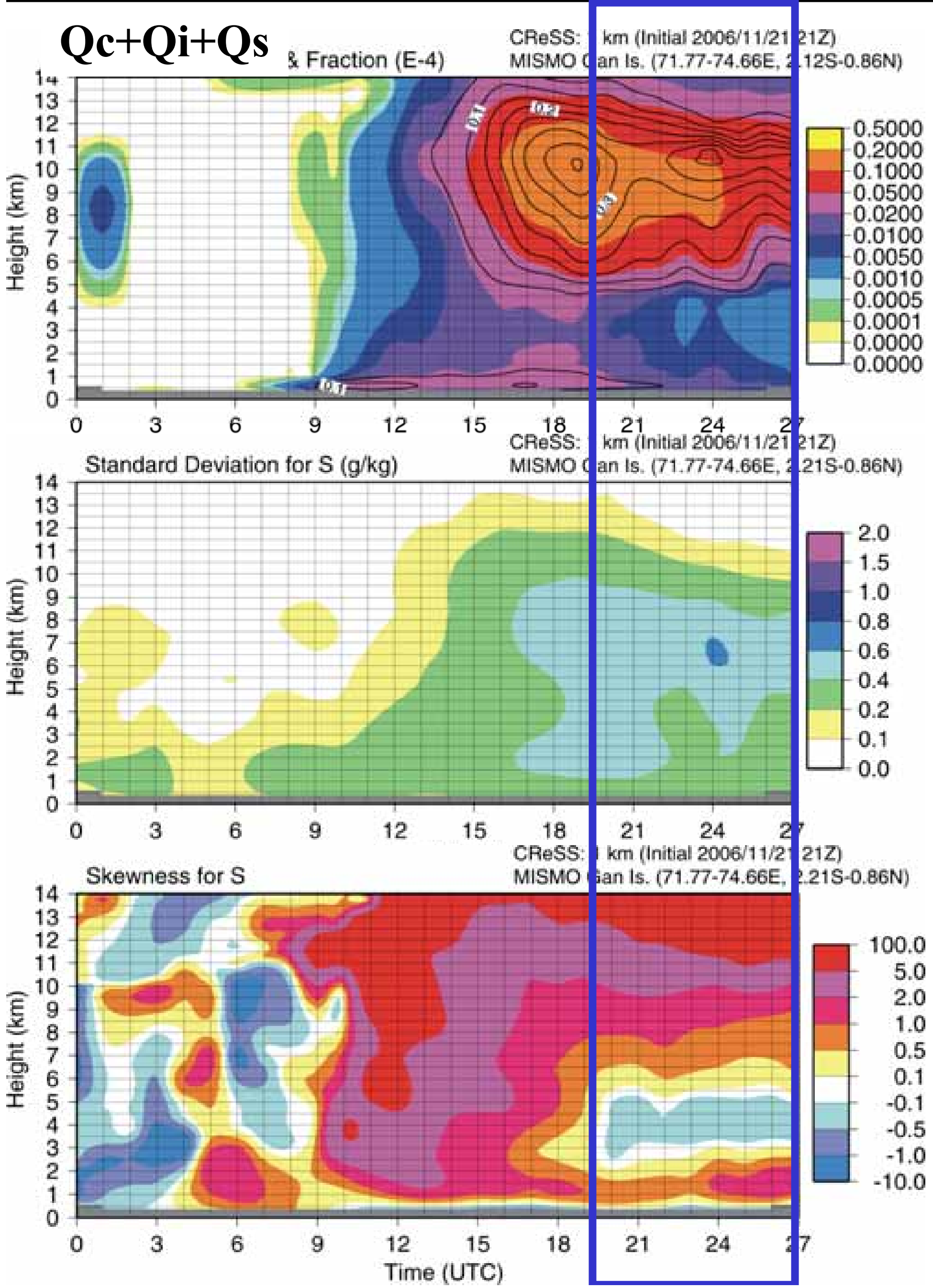
* **Skewness of S**:
decrease in the lower level

→ Lower level moisten, peak values of large mixing ratio in clouds should be masked.

maintain in the upper level

→ **Snow amount increase in the upper stratiform region**

Time Series of Vertical Profiles of Prognostic Parameters



• Dissipating Stage

* **Condensate amount**:
decrease gradually above the ML

* **Cloud fraction**:
decrease gradually above the ML

→ **Small falling velocity of cloud ice and snow**

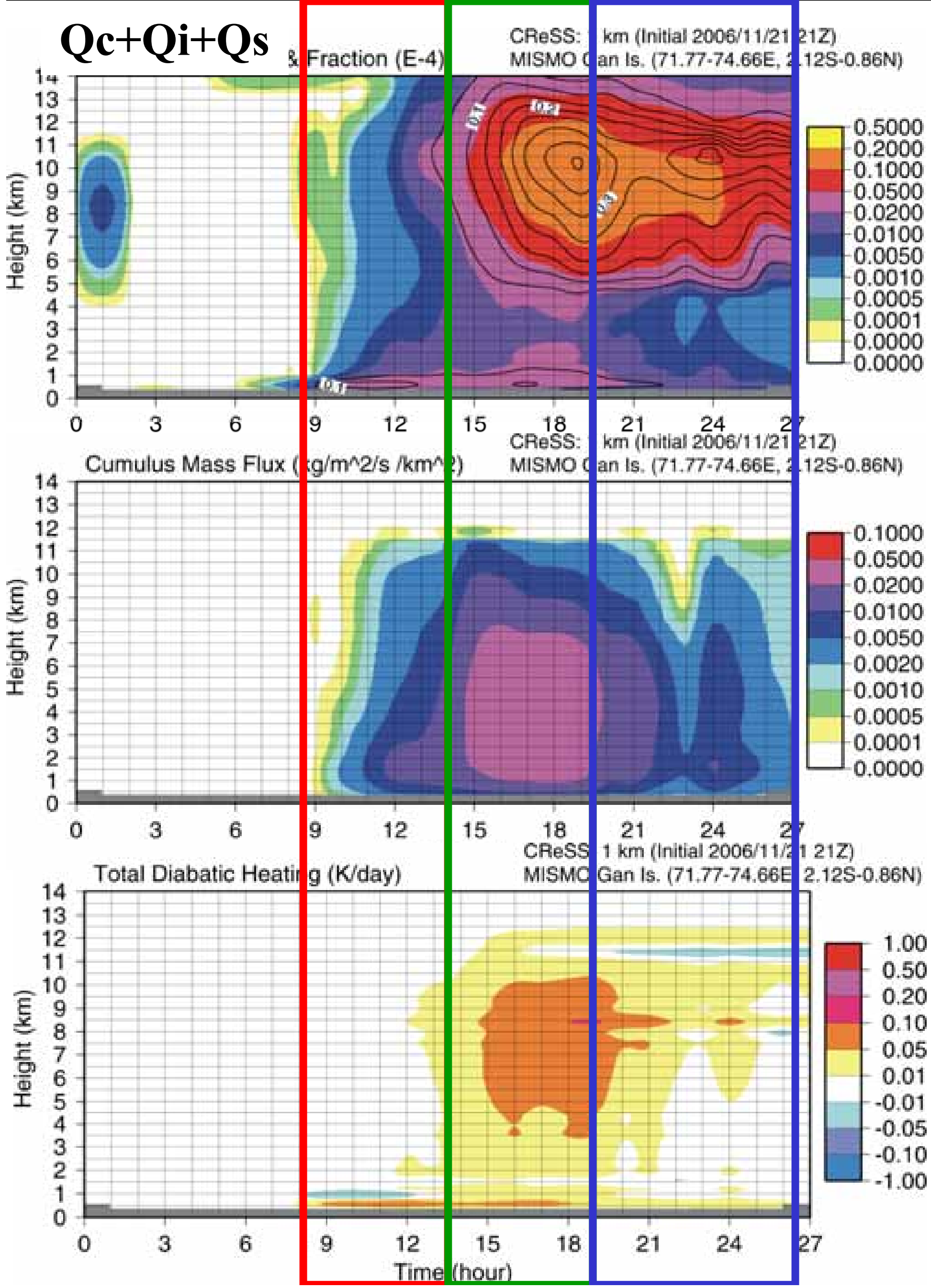
* **Standard deviation of S**:
decrease in the lower level
maintain in the upper level

→ Small falling velocity of cloud ice and snow

* **Skewness of S**:
maintain at all levels
negative value in the lower level

→ Cloud water decrease by the collection of rain or decrease of the development of new cells?

Time Series of Cumulus Mass Flux and Diabatic Heating



- **Cumulus mass flux**

* increases in the whole layer in the developing stage,

* maintains in the mature stage,

* decreases in the dissipating stage.

- **Total diabatic heating**

* increase in the developing and mature stages,

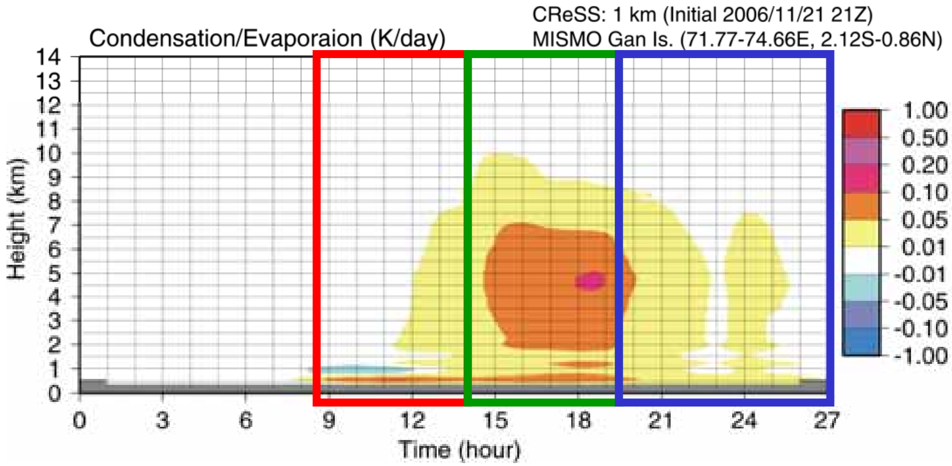
* decrease in the lower layer in the dissipating stage.

→ Separate to each contribution

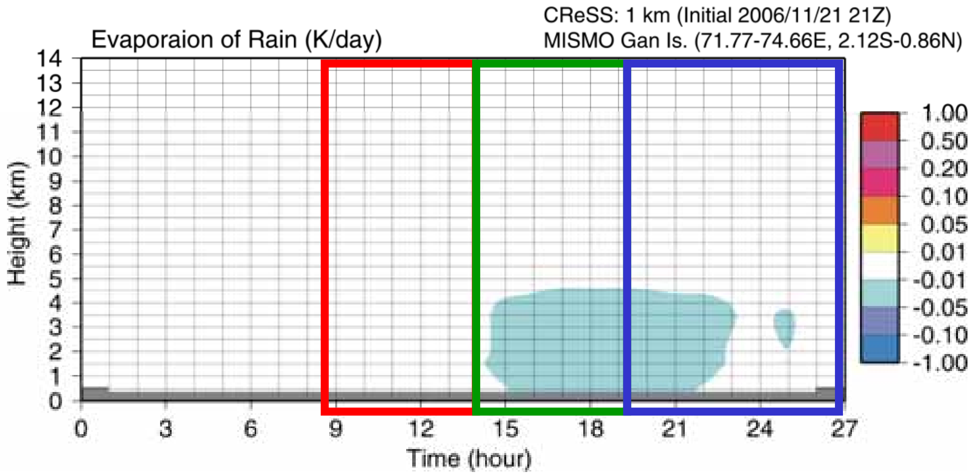
(method by Dr. C. Takahashi)

Factors of Diabatic Heating (1-km)

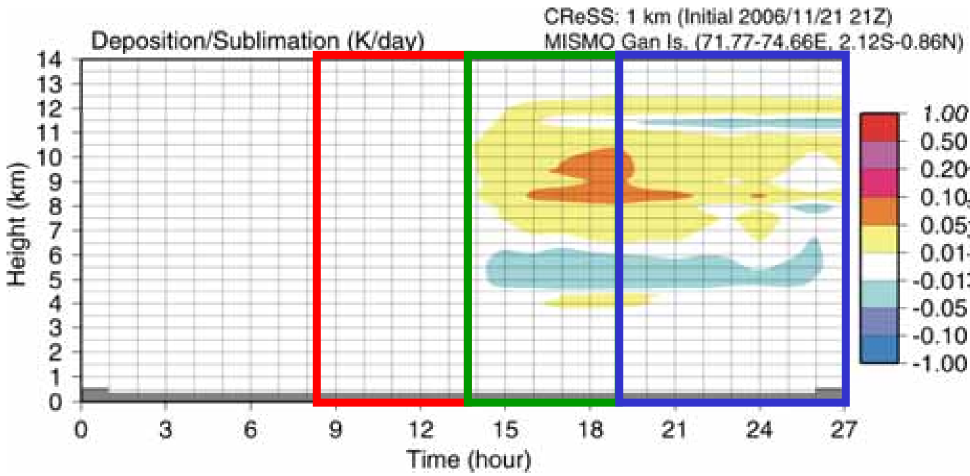
Condensation/Evaporation (Qv-Qc)



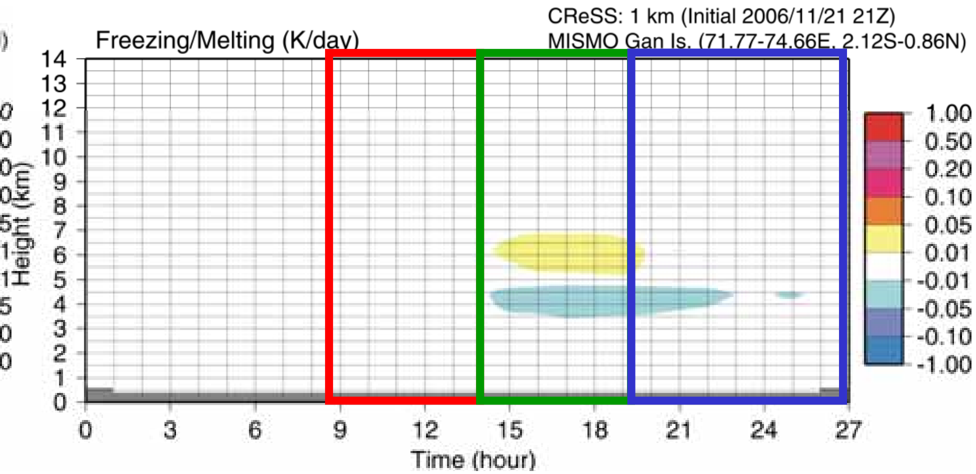
Evaporation of Rain (Qr->Qv)



Deposition/Sublimation (Qv-Qi, Qs, Qg)



Freezing/Melting (Qc, Qr-Qi, Qs, Qg)



Summary on the Second Topic

- We have carried out the simulations using the CReSS in order to show a result of the variation of condensate amount, cloud fraction, PDF variance (standard deviation) and skewness when the precipitation system developed.
- We can show the time series of PDF variance and skewness:

  * Developing stage: Variance increase, Skewness increase:

  → Vertical transport of water vapor and condensate in clouds

  * Mature stage: Variance increase, Skewness decrease in the lower troposphere:

  → Condensate with small fall velocity accumulate in the upper troposphere.

  → Condensate begin to decrease in the lower troposphere.

  * Dessipating stage: Variance decrease gradually,

  → Condensate still exist in the upper troposphere.

Summary on the Second Topic

- **The stages of the precipitation system can be recognized by the cumulus mass flux and total diabatic heating.**
  → Contributions of each diabatic heating profile corresponds to the each stage.

- **Condensate amount, Cloud fraction, PDF parameters of S will be relate to the cumulus mass flux and/or diabatic heating profiles.**
  → We have to accumulate these statistics and find out the relationship among these parameters.
  → Now we are conducting the analyses for 7 days (cases).
- **We will apply the relationship to the Single Column Model (SCM) for the validation of the GCM-LSC parameterization.**