Interaction between the boundary-layer and precipitation processes in WRF

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Presentation

- Overview of the YSUPBL
  - Scheme description
  - Off-line experiment : One –D. idealized case
  - NWP experiment in WRF : WRF storm case, CASES97
    (Hong et al. 2004, AMS conference)
  - Tropical precipitation in a seasonal forecast model
    (Byun and Hong 2004, J. Climate)

- Implementation of the YSUPBL on NWP models
  -- Interaction between the boundary-layer and precipitation processes
  (BAMEX Nov. 10^{th}, 2002 case simulation)

The MRFPBL

Known problems and analysis of Stevens (2000)

Based on the Troen and Mahrt (1986)

Too much mixing when wind is strong

Too early development of PBL

Too deep and dry moisture in PBL

Too high PBL height

Explicit representation of the entrainment process

Based on Noh et al. (2003)

Improvement of the K-profile model

for the PLANETARY BOUNDARY LAYER

based on LARGE EDDY SIMULATION DATA

`*Y. Noh*, W.G. Cheon and S.Y. Hong*

S. Raasch

YSUPBL

Generalization and reformulation of the explicit entrainment

$$-\overline{w'\theta'} = K_h\left(\frac{\partial\theta}{\partial z}-\gamma_h\right)-\overline{w'\theta'}_h\left(\frac{z}{h}\right)^3 \quad \text{for } z < h$$

- Alleviate resolution dependency
- Inclusion of moisture, tracers, and hydrometeors
- Conservation of fluxes
- Numerical problem (staggered)

YSUPBL after the MRFPBL

- Implementation of the explicit heat flux at h (N2003)

- Inclusion of moisture effect in cloudy environment
- Mixing of hydrometeors

- Removal of nonlocal mixing for moisture

- Turbulence at PBL top considering large-scale

- Moisture effect in saturated soundings

Experimental test runs

- Offline test : 8 AM – 8PM
  -- High resolution : 10, 30, 50,,,, 2750 (LES model : 138 level)
  -- Low-resolution : 50, 150, 300, 500, 750, 1050, 1400, 1800, 2250, 2750
  (NWP model : 10 level)
- Minnesota thunderstrom : 12Z 11 June 2001 → 24 hr, 10 km, 27 levels
- CASES97 case : 00Z 29 April 1997 -> 24hr, 10 km (243x213), 34 levels
- Heavy rainfall case : 00Z 14 July 2001 -> 24hr, 45 km MM5 and WRF
- Regional climate simulation : JJA 2001 over Asia, and JJ 1993 over US
- Seasonal forecast experiments : Tropical precipitation with YOURS GSM
- **YSUPBL has been running daily in WRF since September 2002**

YSUPBL – development

2000.9-2001.3 — To formulate a theory (LES→ a new conceptual model)

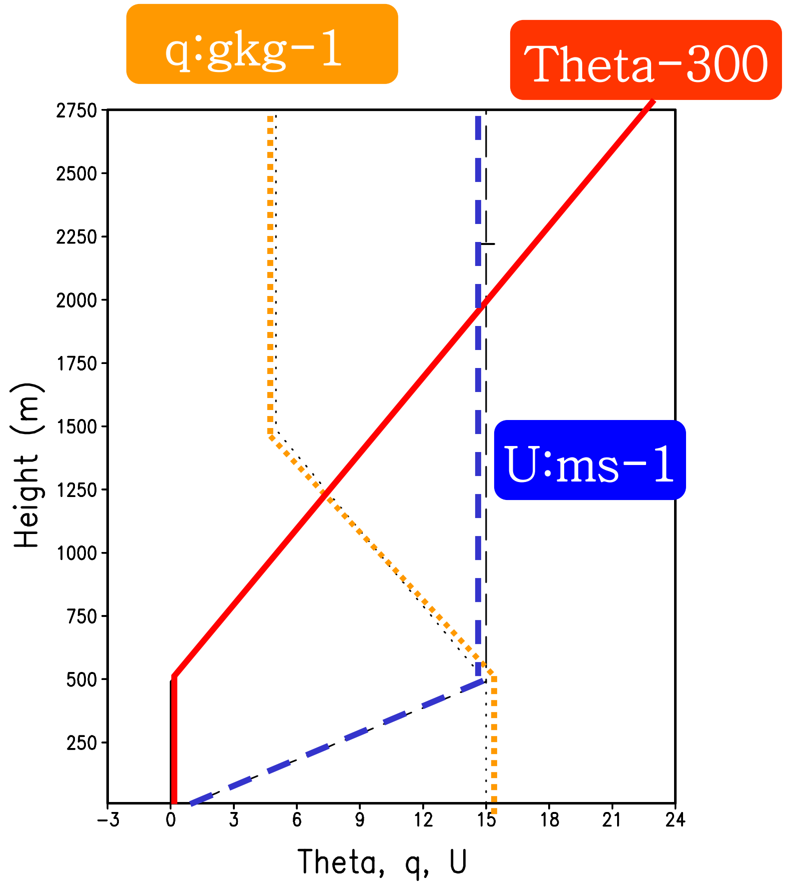
2001.3-2002.7 — To develop a new numerical scheme (PDE → FDE)

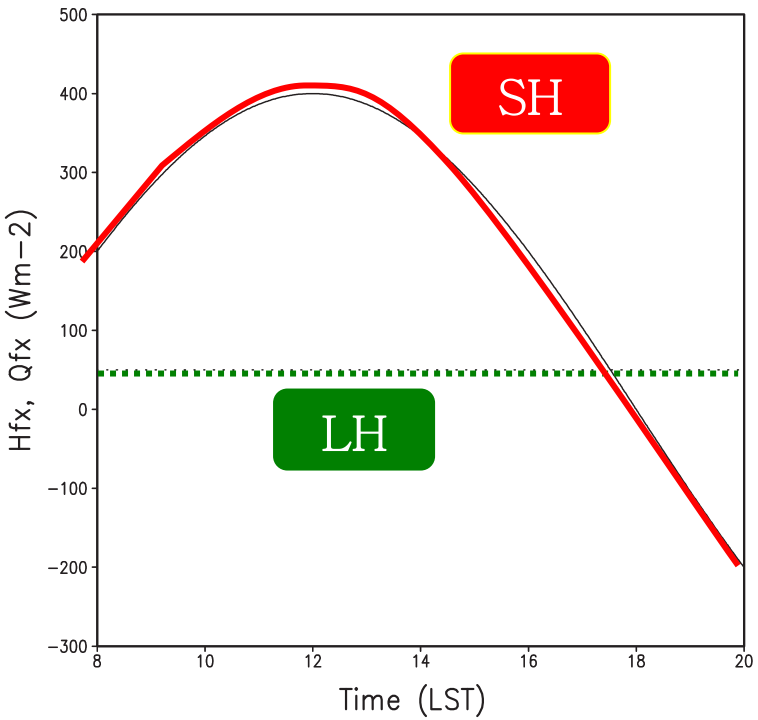
2002.9-2003.6 — To evaluate the scheme and balance with nature (A new scheme)

2003.7-2004.2 — To revised the scheme based on the various evaluations (A revised new scheme)

2005.2 — Further revisions (A finalized new scheme)

Initial & boundary condition

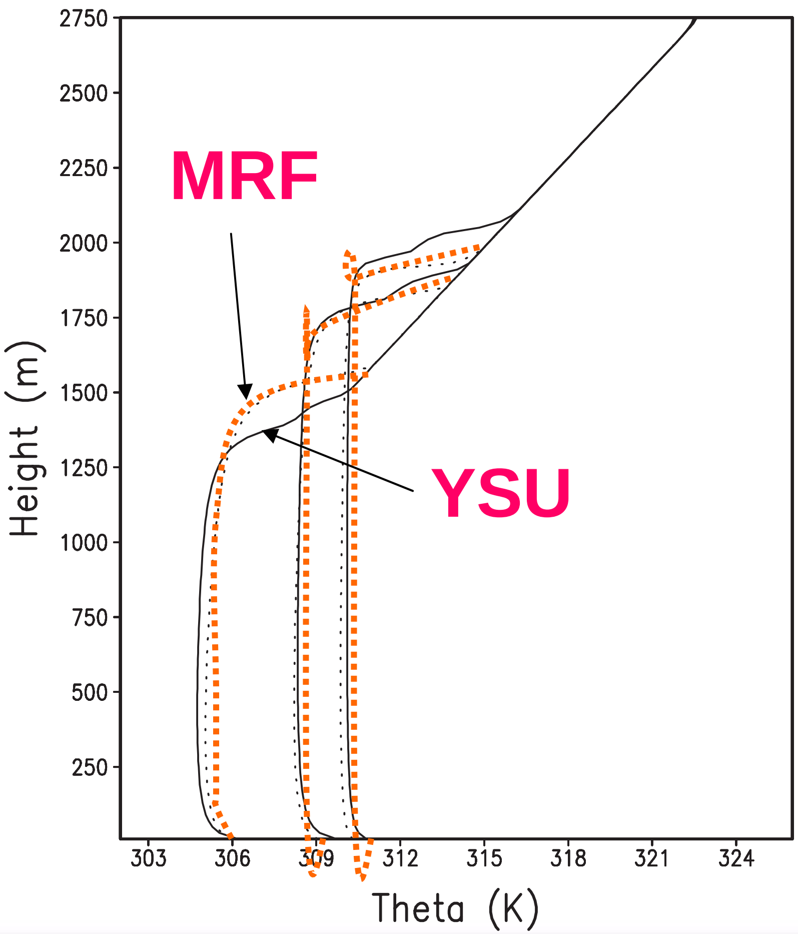




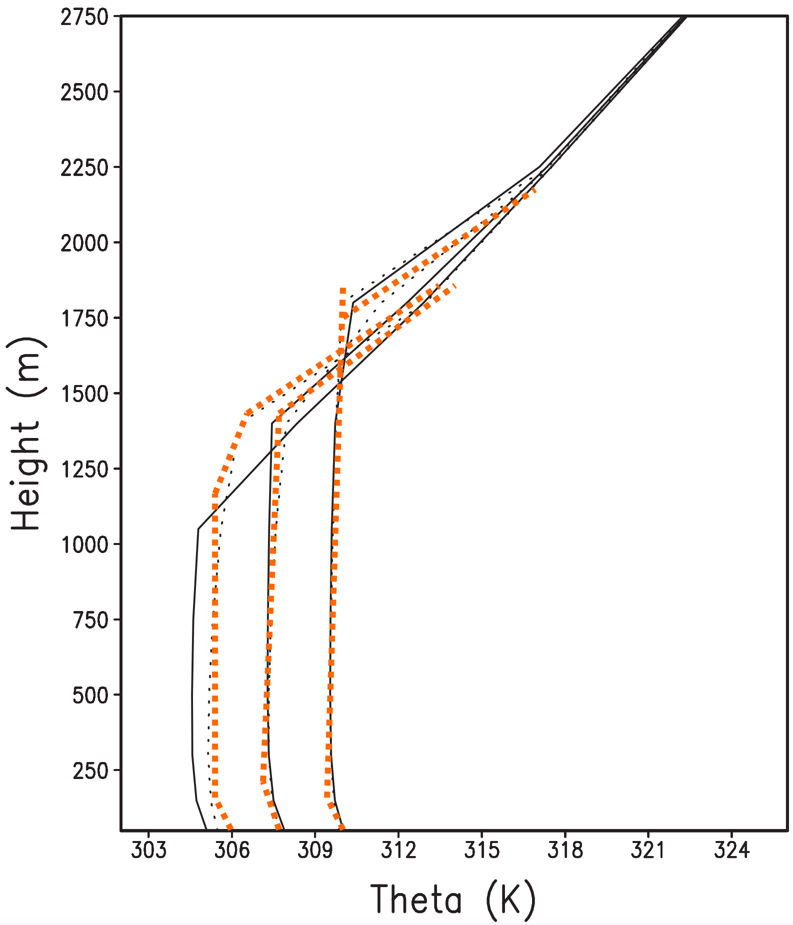
Resolution dependency

Potential Temp

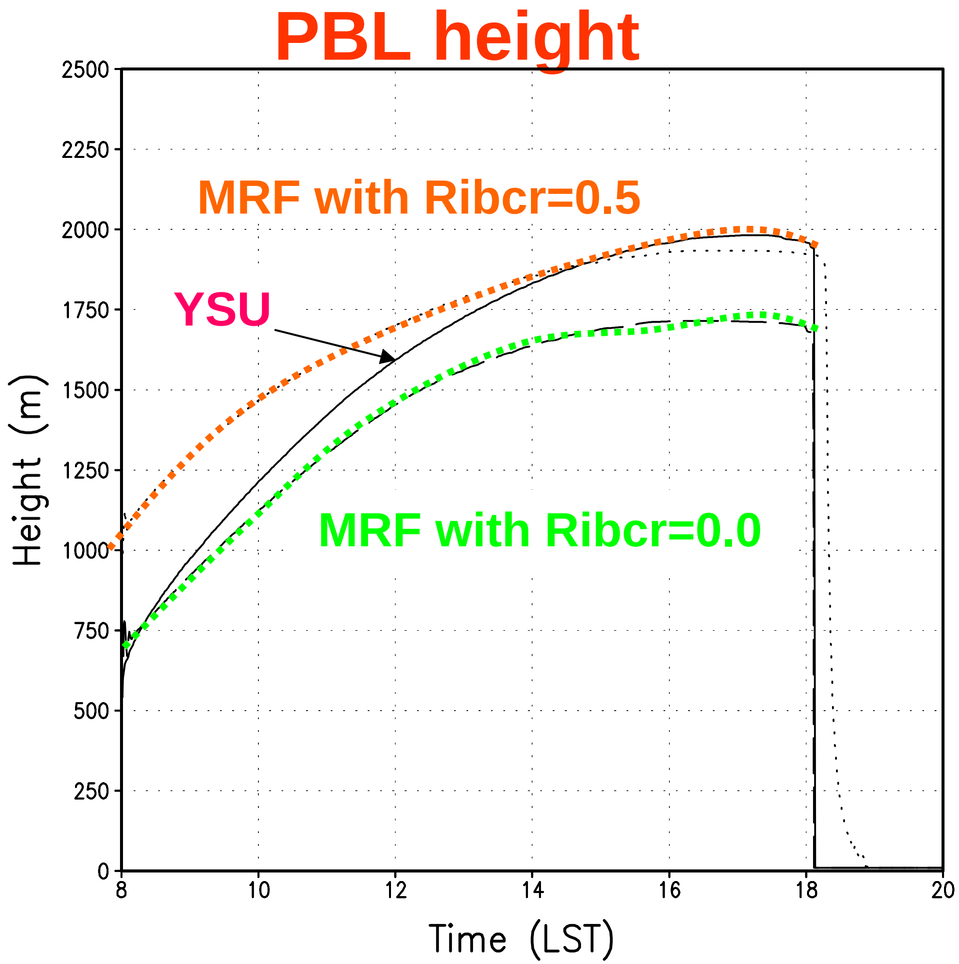
High (138L)



Low(10L)



Behavior of YSUPBL over MRFPBL in Dry convection regime



YSUPBL resolves the morning convection problem in the MRFPBL

YSUPBL increases PBL mixing in thermally induced free convection, whereas the mechanically driven forced convection is weakened

Model setup : BAMEX 2002

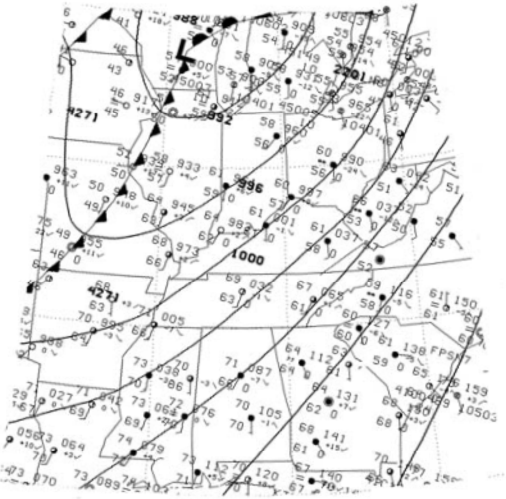
- Cold front (10-11 Nov 2002)
- 4 km grid (cloud-resolving)
- YSU PBL compared to MRF PBL
- WSM6 microphysics
- NOAH land surface
- No cumulus parameterization scheme

Initial time : 12Z 10 November 2002

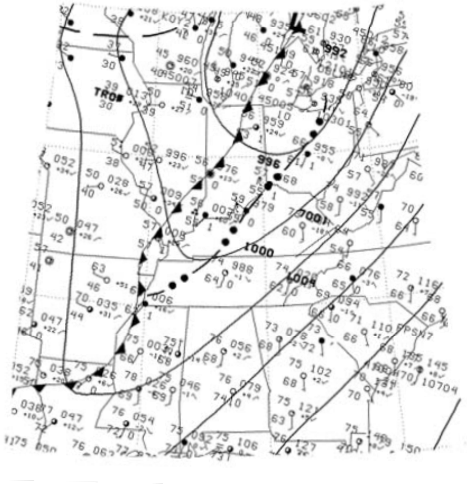
Initial and boundary data : EDAS analyses

Focus : Precipitation response due to the differences
in YSU and MRF PBL

12Z 10 November

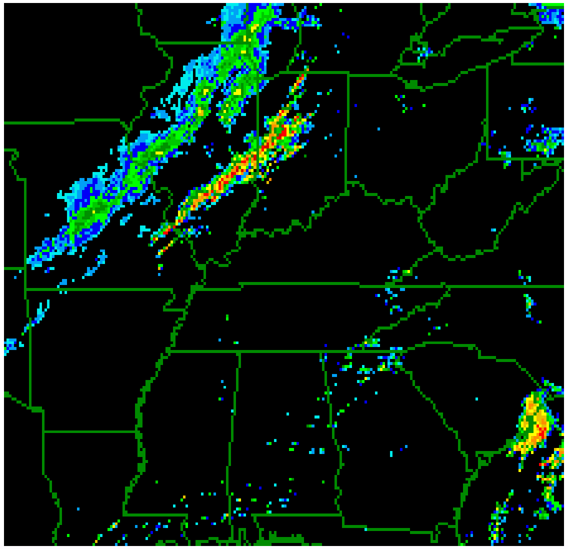


00Z 11 November 2002

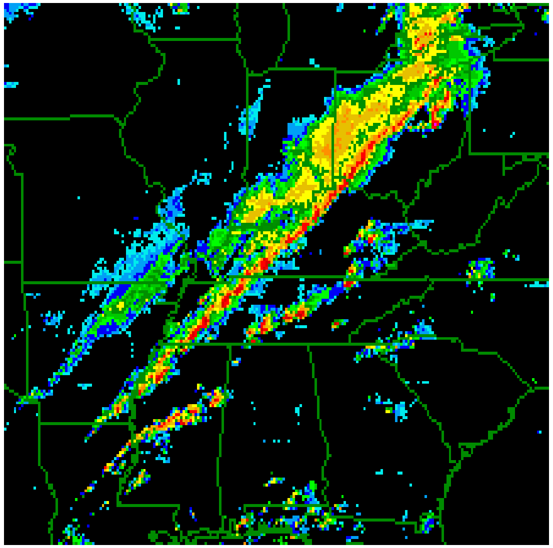


BAMEX (Bow-Echo and Mesoscale convective Vortex Experiment, Davis et al. 2004)

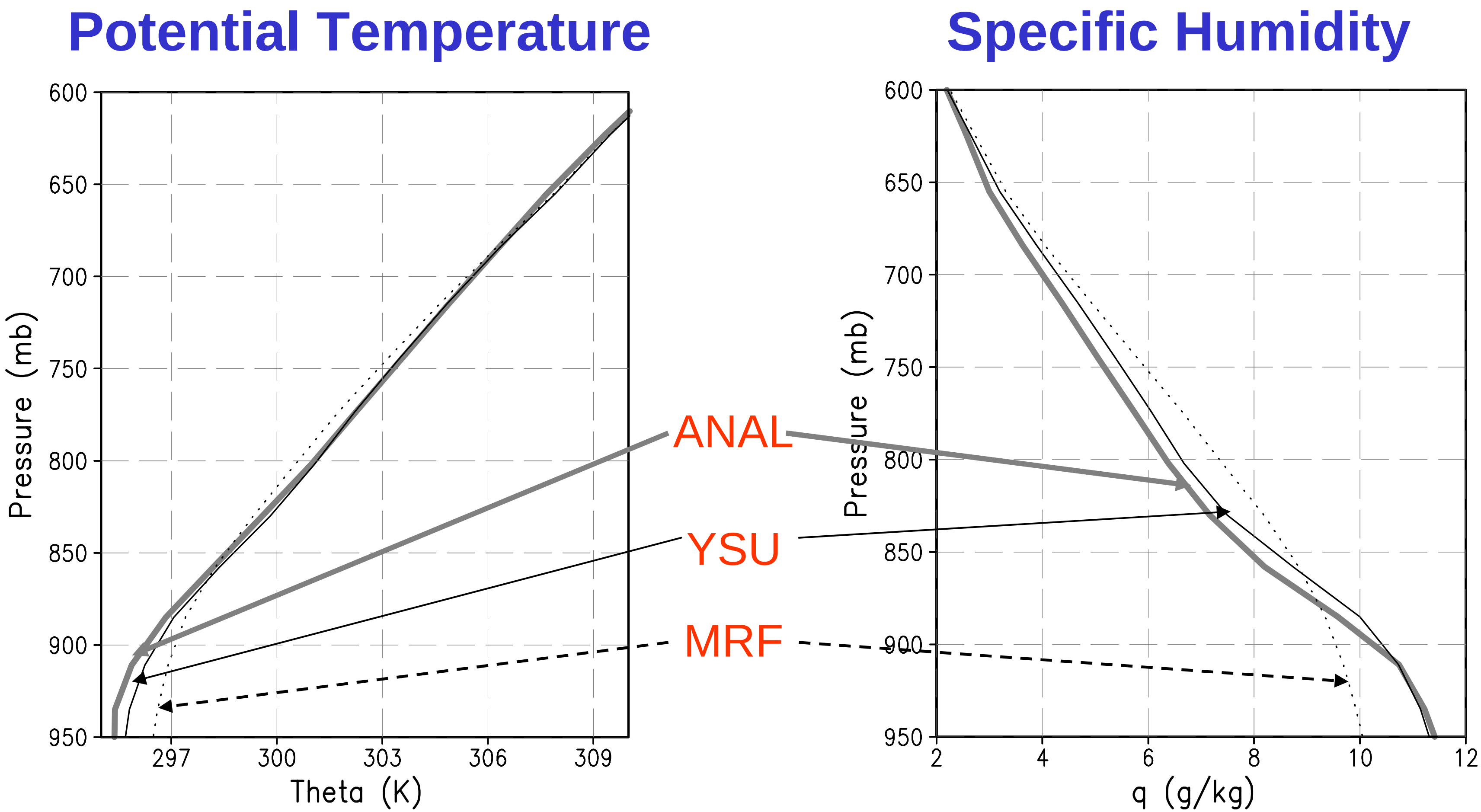
18Z 10 (noon) November



00Z 11 (evening)



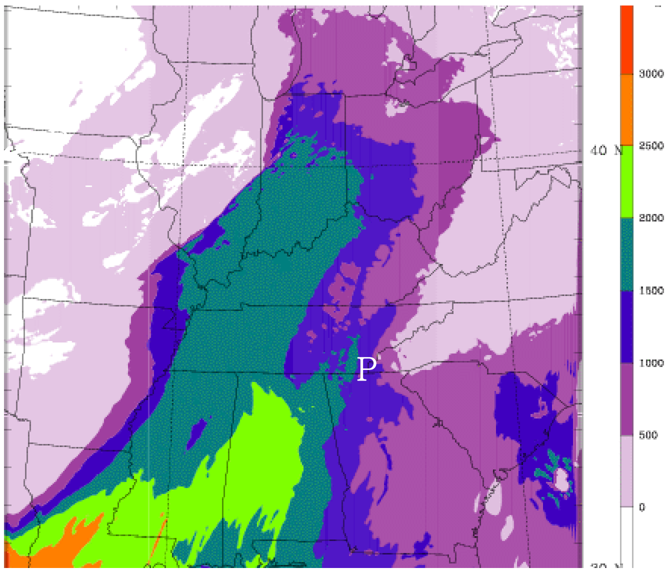
75 tornados in 13 states on the night of Nov. 10th, 2002



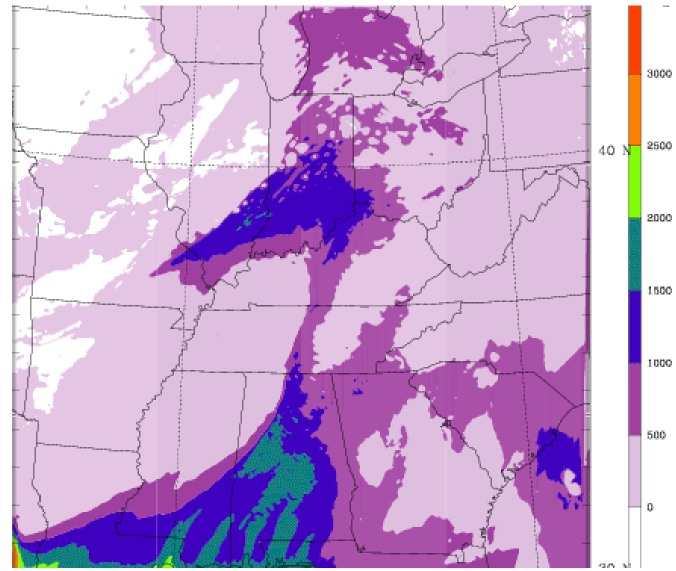
- The PBL with the YSUPBL is cooler and moister below 870 mb, whereas impact is reversed above → closer to the observed
- Impact is more significant for moisture than temperature

Convectively Available Potential Energy (CAPE)

YSU



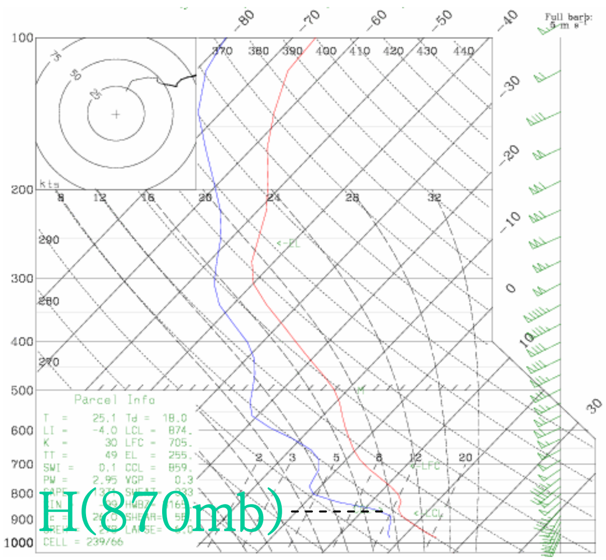
MRF



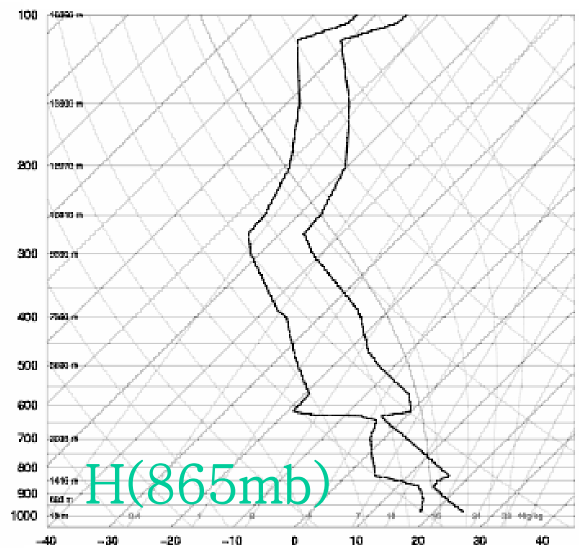
- CAPE is larger with YSU than with MRF, since the PBL is moister and cooler in the YSU

Sounding profile at 18Z in the pre-frontal regions (near Nashville Tennessee)

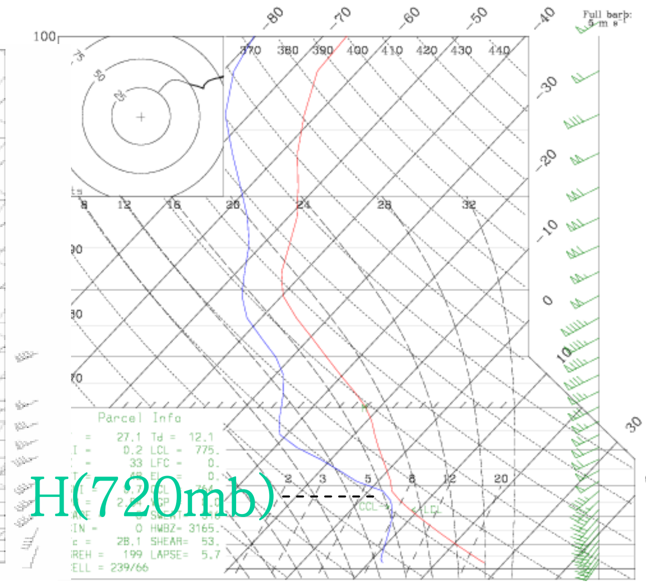
YSU



OBS



MRF

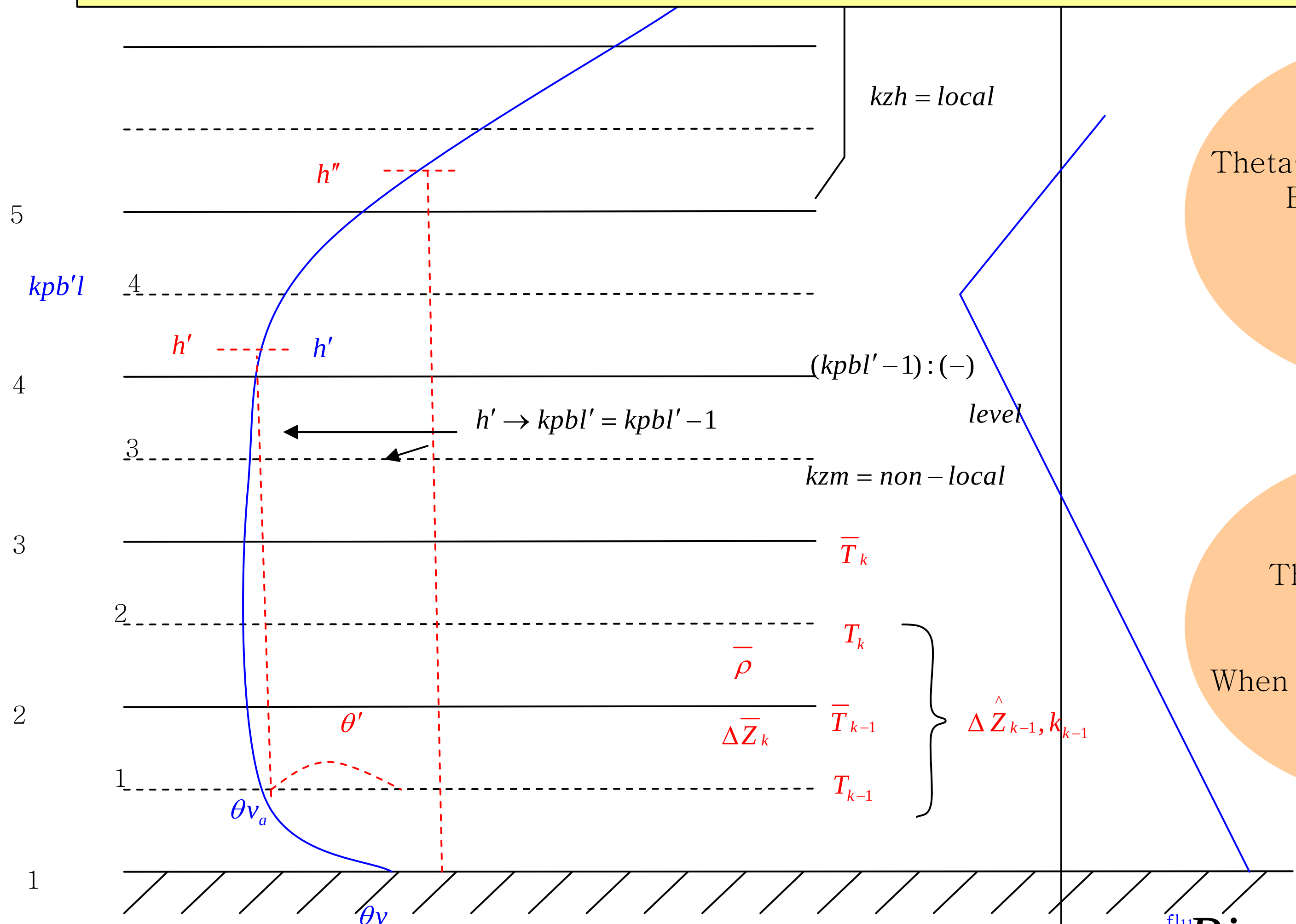


Cooler & moister

Warmer & drier

- PBL structure is better reproduced by YSU than MRF in the pre-frontal region → Improved the inversion above h

MRFPBL (Troen and Mahrt) represents the entrainment implicitly



Theta-prime due to thermal
Excess can be as
large as 2-3 K
In clear sky

Theta-prime due to
BR can be as
large as 3.4 K
When U = 15ms-1, Rbcr=0.5

flux

$$Ri = \frac{g(\theta_v(h) - \theta_s)}{\theta_{va} \, |U(h)|^2} z$$

V is greater than 20 m/sec for this case

Dry convection is easy to explain, but
How can we explain the differences in precipitation ?

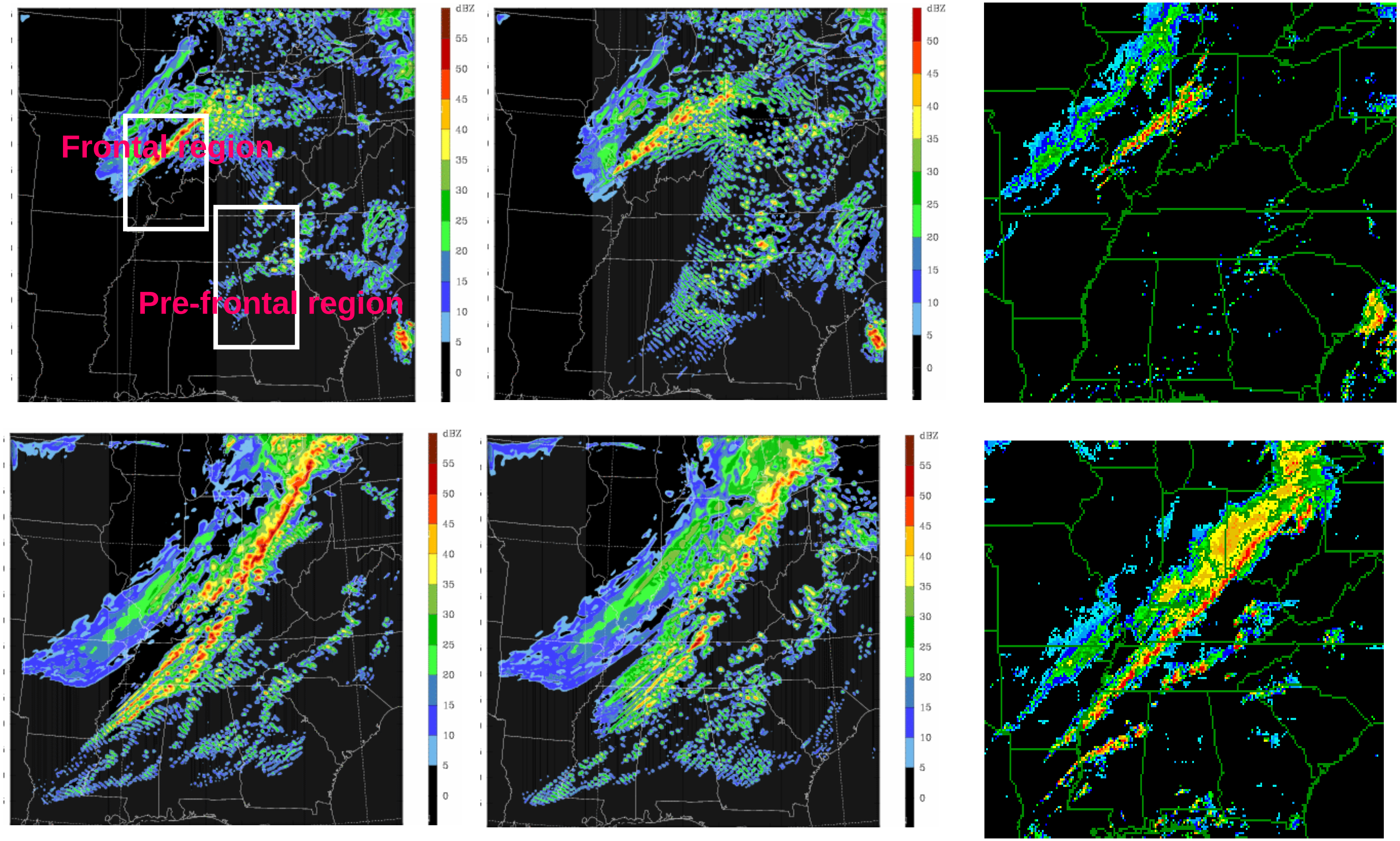
CAPE is not the driving source for precipitation convection
Since CPS is taken out in 4 km resolution !!!

Maximum radar reflectivity (dBz)

YSU MRF OBS

18Z 10 Noon

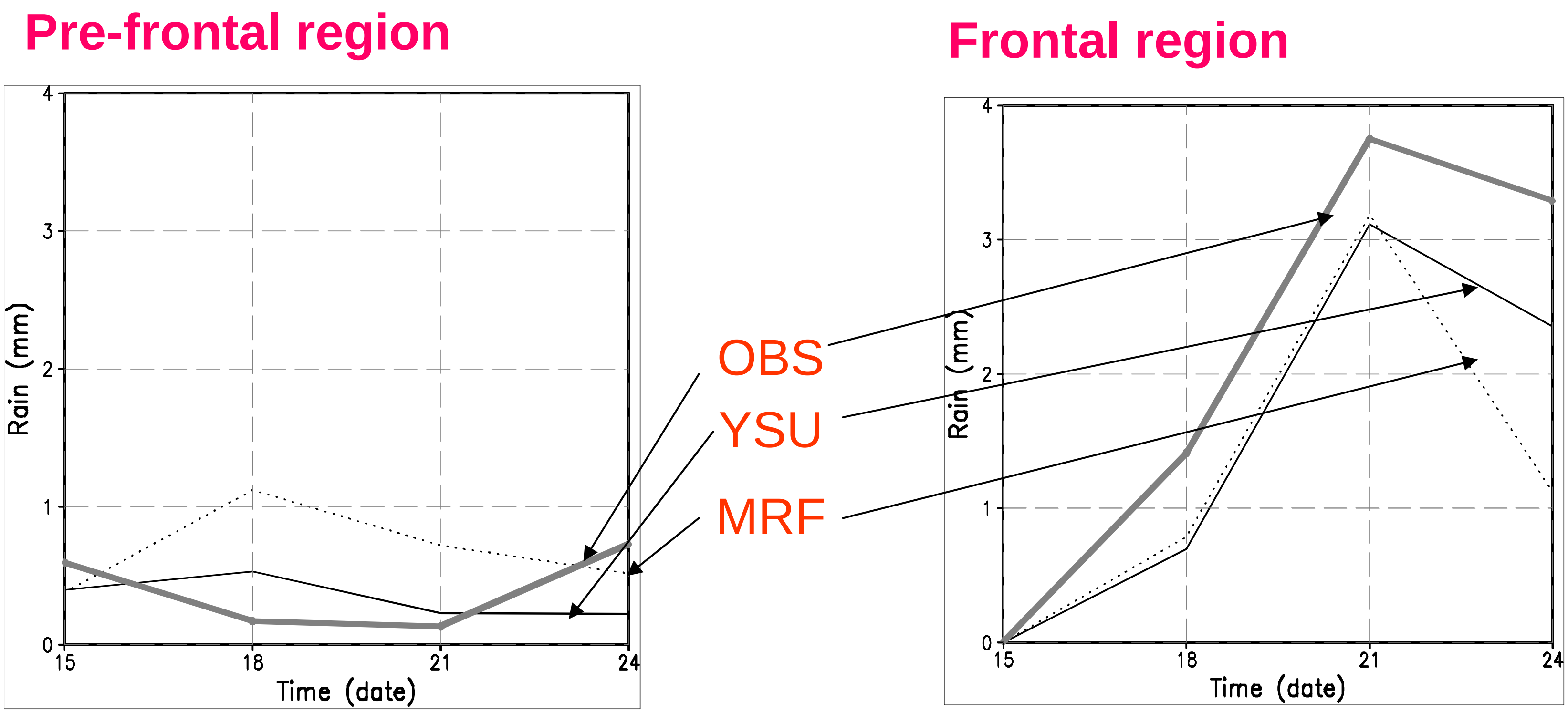
00Z 11 Evening



Weaker mixing within PBL induces widespread precipitation, and weakens the deep convection (Hong and Pan 1996)

Then, how can we explain the opposite precipitation responses ???

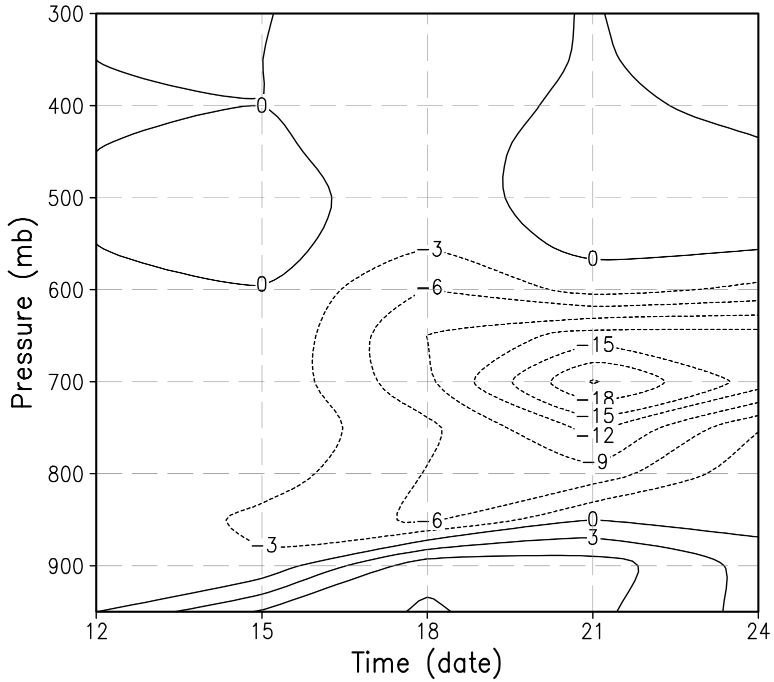
Time series of domain averaged precipitation



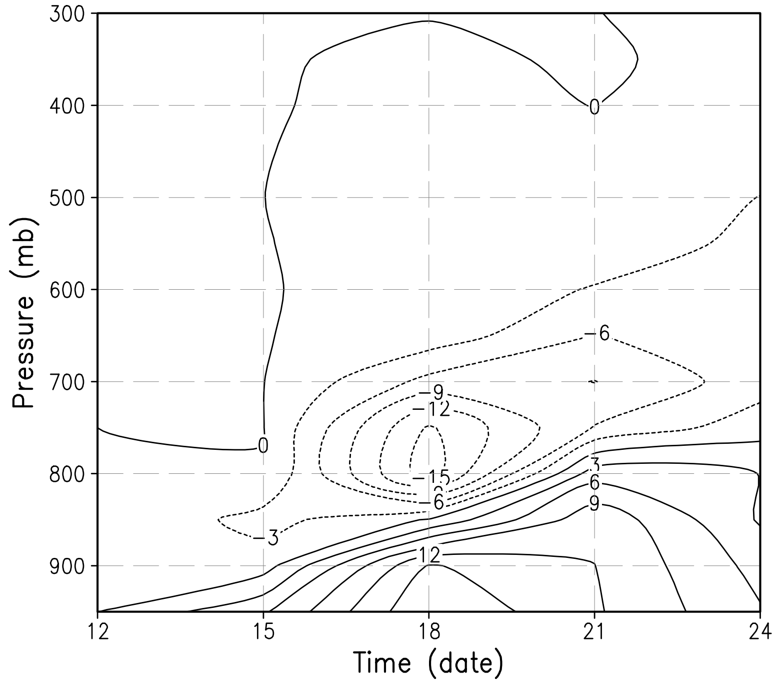
• Why precipitation with the YSU is better than with MRF PBL ?

Time series of domain-averaged relative humidity (YSU-MRF)

Pre-frontal region



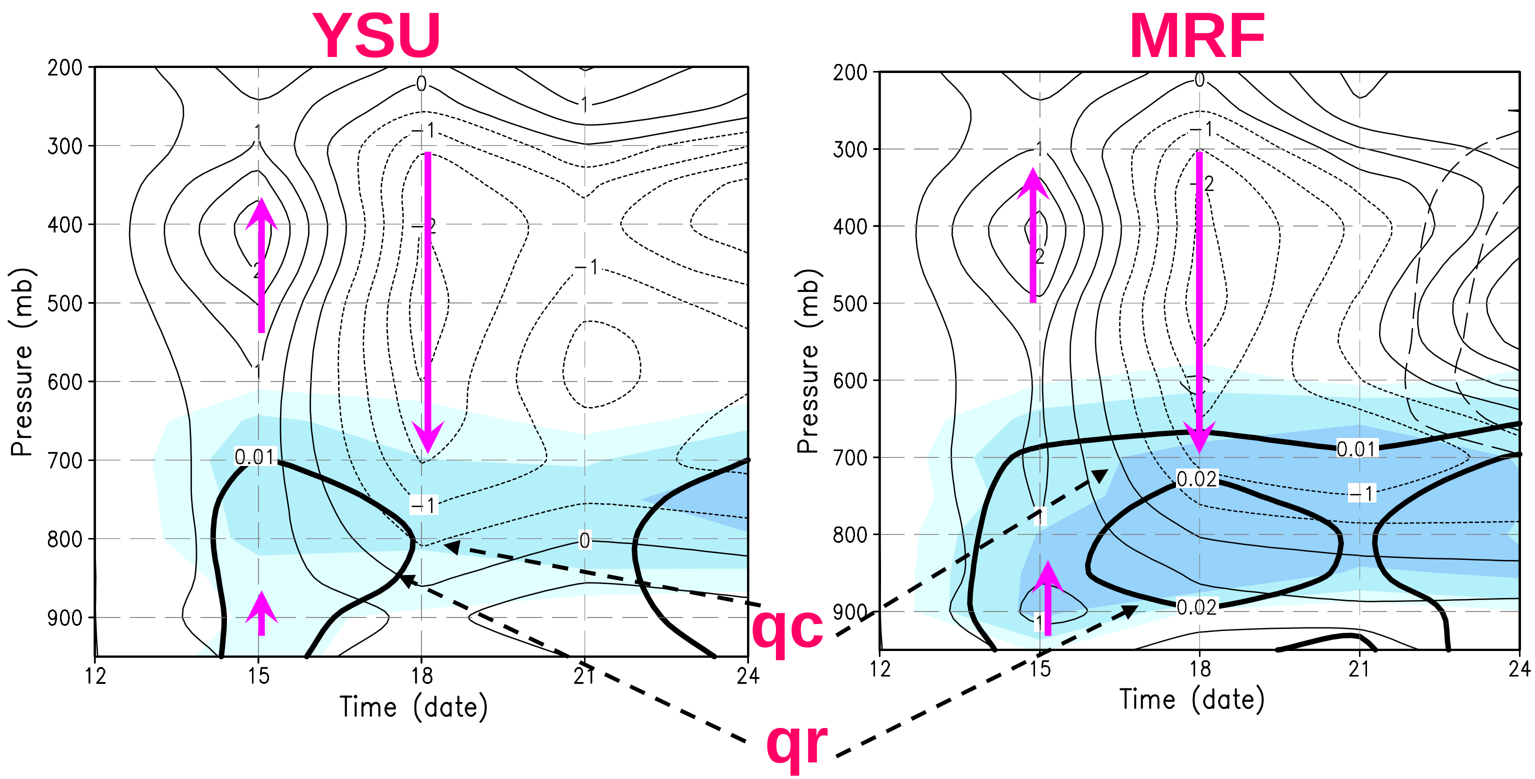
Frontal region



- Moistening within the PBL and drying above due to weaker mixing by the YSUPBL than the MRF
- Temperature differences are opposite signs

Should explain the precip difference

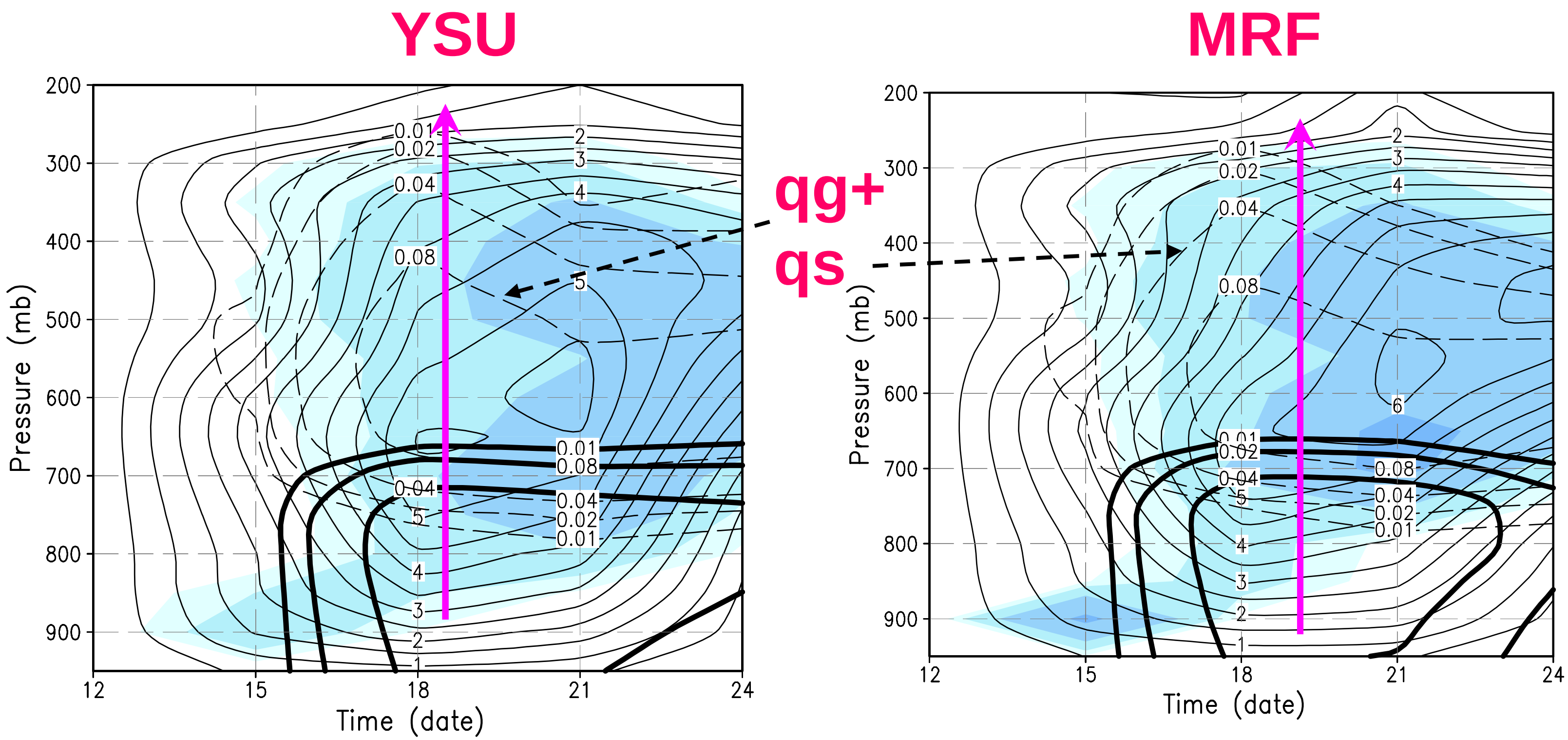
Time series of w, qc, and qr in the pre-frontal region



- Compared to the MRF, YSU PBL induces a less mixing within PBL due to a stronger inversion → less clouds formation below 600 mb despite a larger CAPE → less rain water formation → less precipitation at the surface

- Precipitation is organized by thermal forcing and clouds are shallow

Time series of w, qc, qr, and qg in the frontal region



•Same scenario to the pre-frontal region in terms of PBL structure, but different impact on precipitation due to different synoptic situation
→ Intense precipitation after 21Z due to less evaporation of falling rain drops in moister PBL with YSU PBL

•Precipitation is organized by strong dynamical forcing and clouds are deep

Concluding remarks

Dry convection : The YSUPBL increases boundary layer mixing in the thermally induced free convection regime and decreases it in the mechanically induced forced convection regime, which alleviates the well-known problems in the MRFPBL.

Precipitation convection : In the frontal region, the YSU PBL scheme improves some characteristics, such as a double line of intense convection. It is due to the fact that the YSU PBL scheme remains less diluted by entrainment leaving more fuel for severe convection when the front triggers it. The new scheme does a better job in reproducing the convective inhibition in the pre-frontal region.

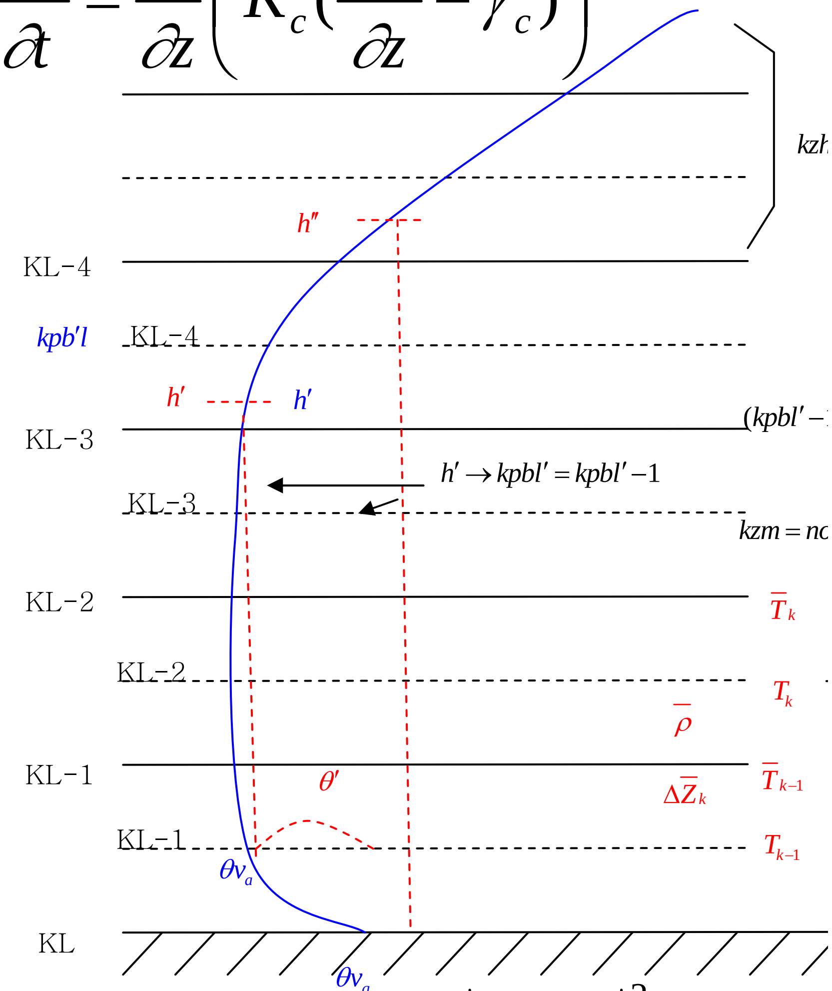
Operational evaluation : Real-time forecasts at NCAR, including hurricane forecasts and has proved itself to be robust and realistic in its behavior in a wide variety of situations since its first inclusion in 2003.

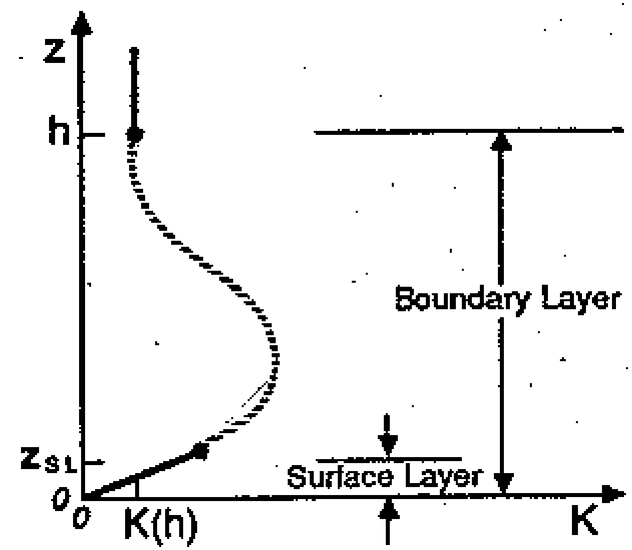
Surface layer	• MM5 Similarity theory • Janjic (Eta)	
Land-Surface layer	• 5-layer soil temperature • Noah LSM • RUC LSM	• CLM
Boundary layer	• Yonsei (YSU) • Mellor-Yamada-Janjic	
Subgrid eddy diffusion	• Constant diffusion • Stress/deformation form (with TKE) • Stress/deformation form (Smagorinsky) • Horizontal Smagorinsky (mesoscale)	

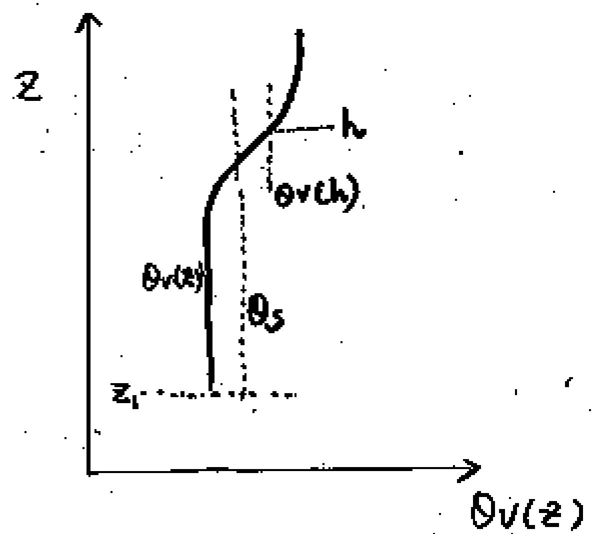
The end

The paper is in press in *Monthly Weather Review*

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(K_c \left(\frac{\partial C}{\partial z} - \gamma_c \right) \right)$$

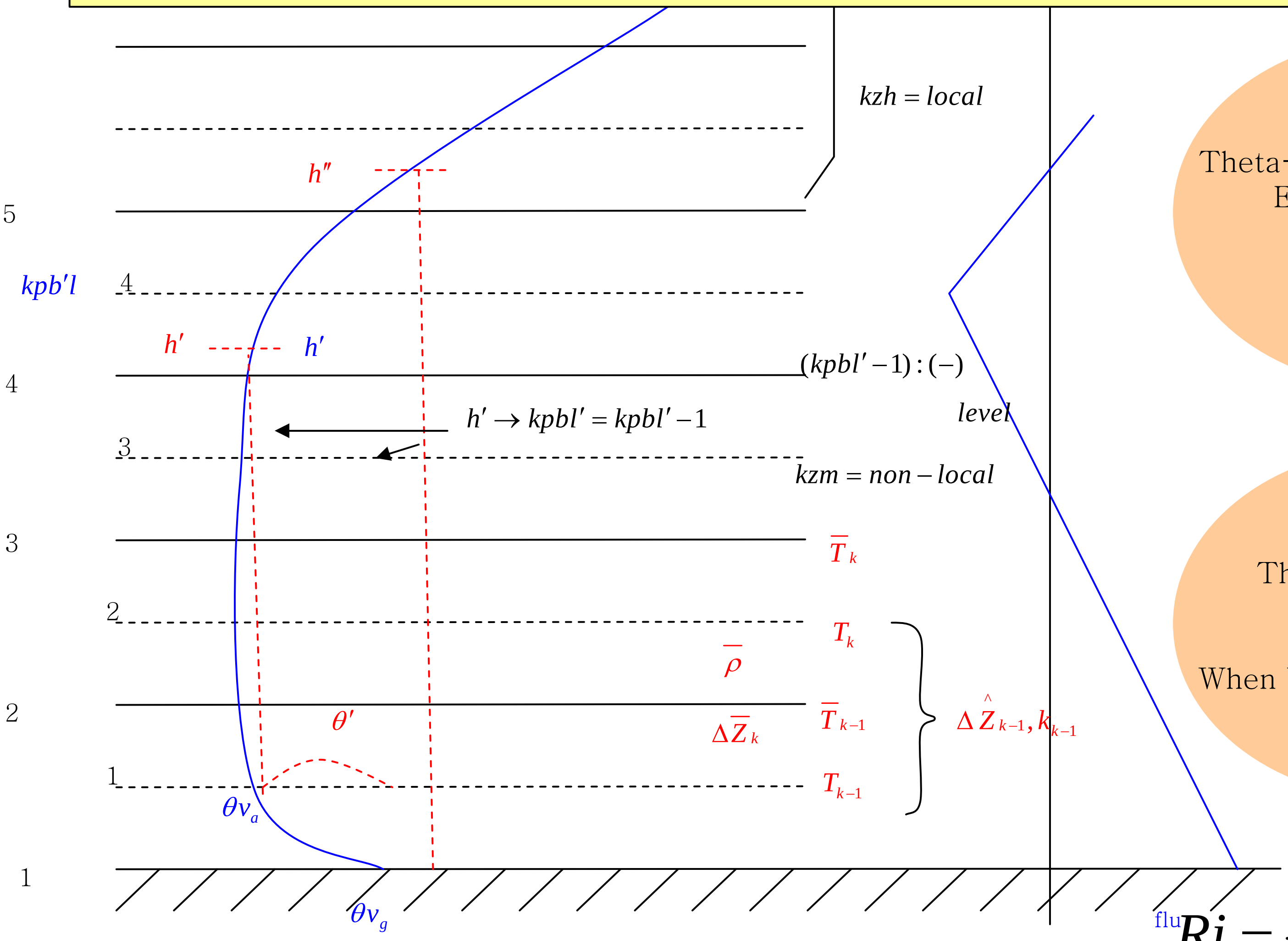






$$h = Rib_{cr} \frac{\theta_{va} \left| U(h) \right|^2}{g(\theta_v(h) - \theta_s)}$$

MRFPBL (Troen and Mahrt) represents the entrainment implicitly



Theta-prime due to thermal
Excess can be as
large as 2-3 K
In clear sky

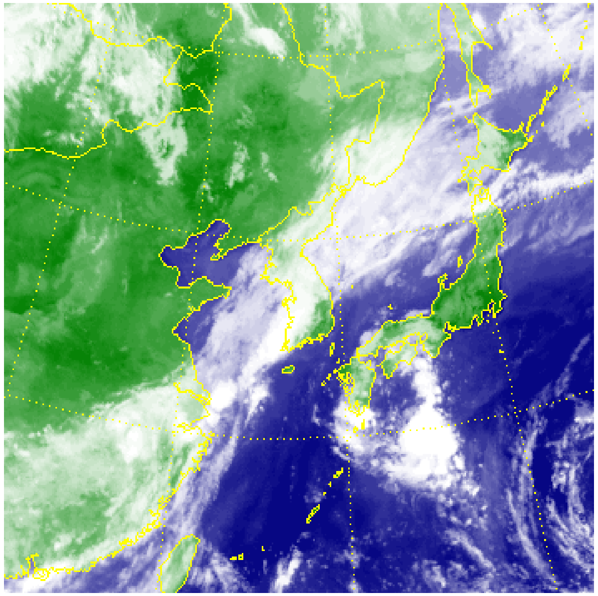
Theta-prime due to
BR can be as
large as 3.4 K
When U = 15ms-1, Rbcr=0.5

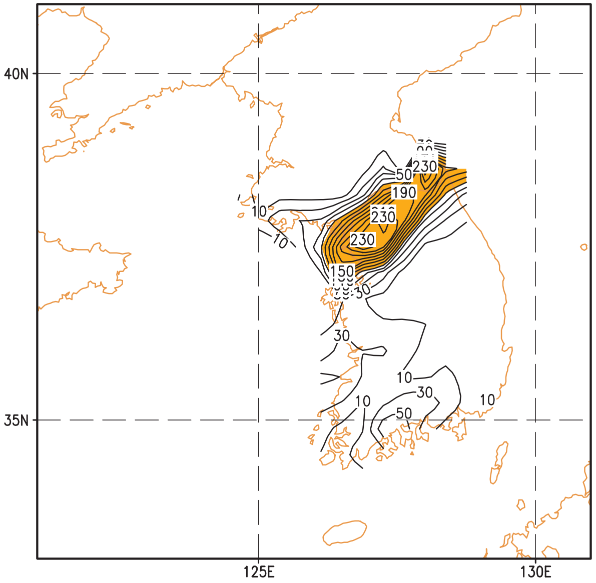
$$Ri = \frac{g(\theta_v(h) - \theta_s)}{\theta_{va}\,|U(h)|^2} z$$

Not in notes

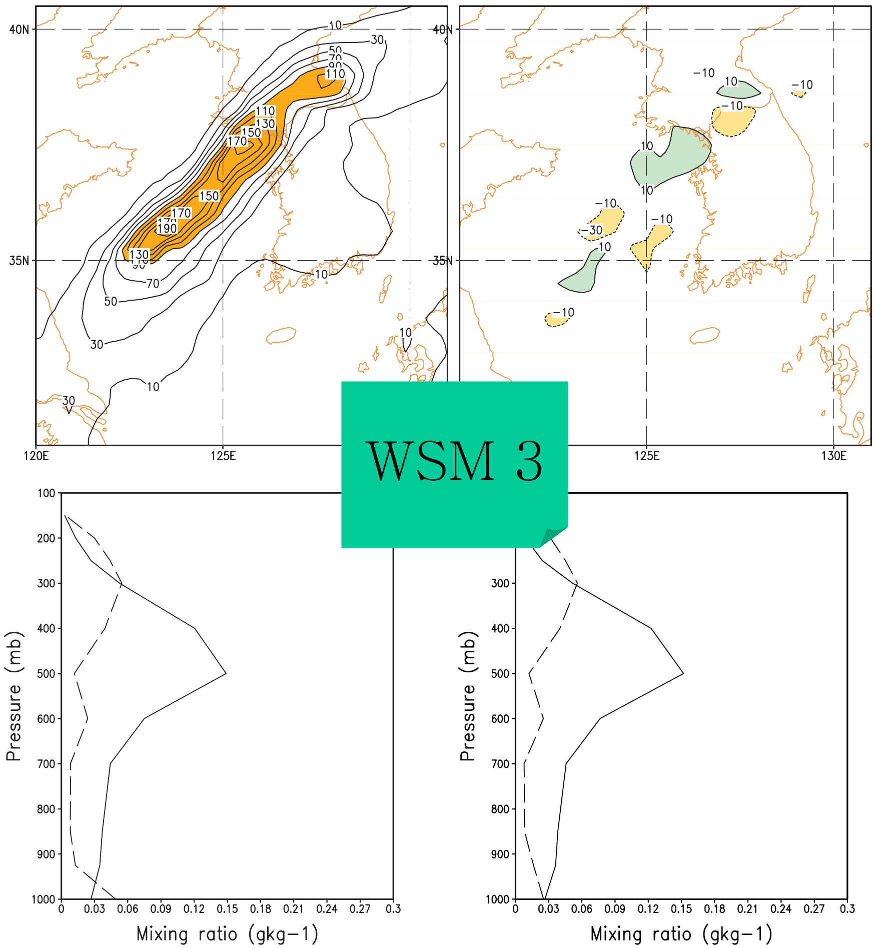
NWP evaluation – heavy rainfall

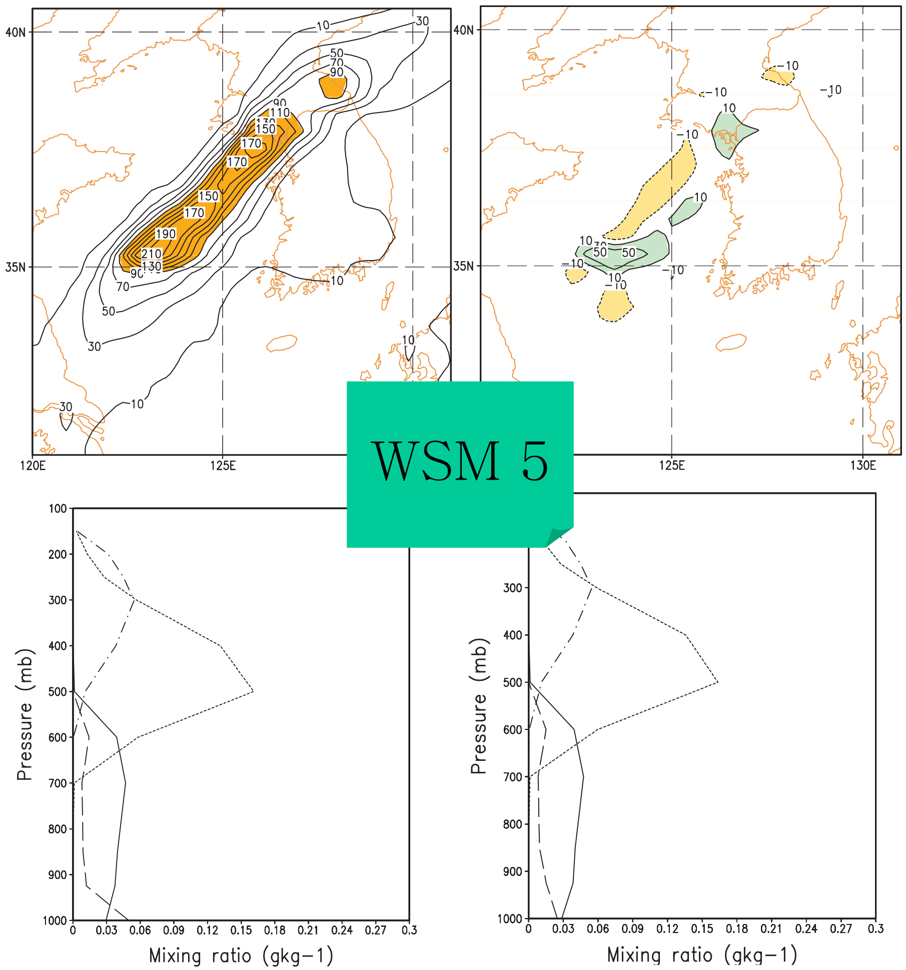
- Heavy rainfall for 14-15 July 2001
- 45 km grid WRF
- YSU PBL compared to MRF PBL





NWP evaluation – heavy rainfall

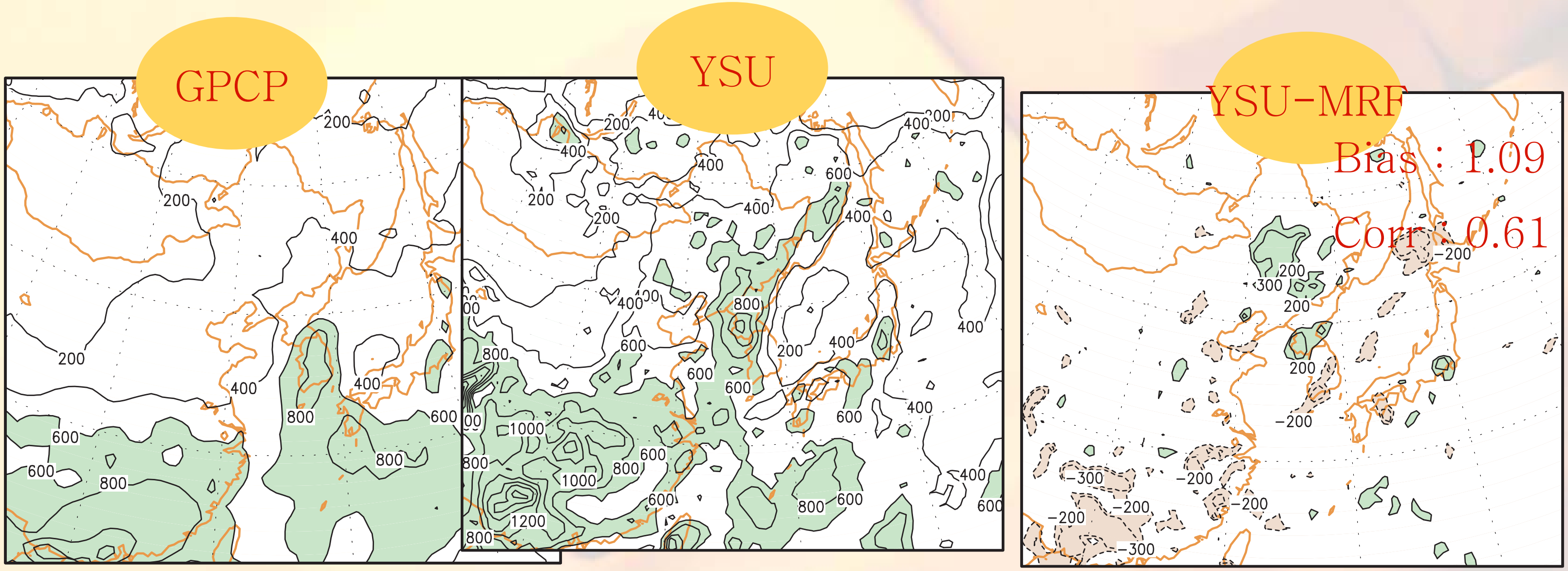




YSU MRF YSU MRF

Regional climate evaluation – RSM

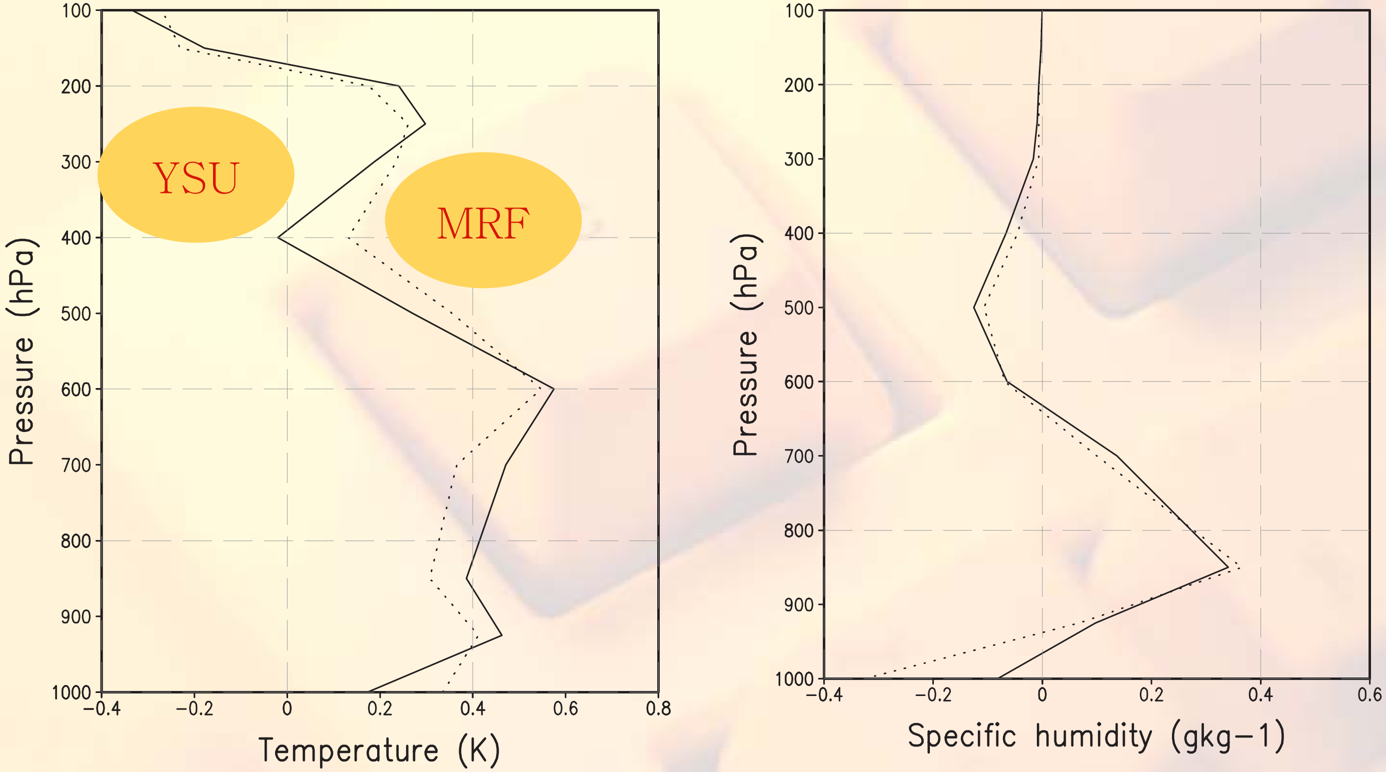
- **YSUPBL evaluation for 2002 summer monsoon**



	MRF	YSU
Bias :	1.09	1.07
Corr :	0.64	0.61

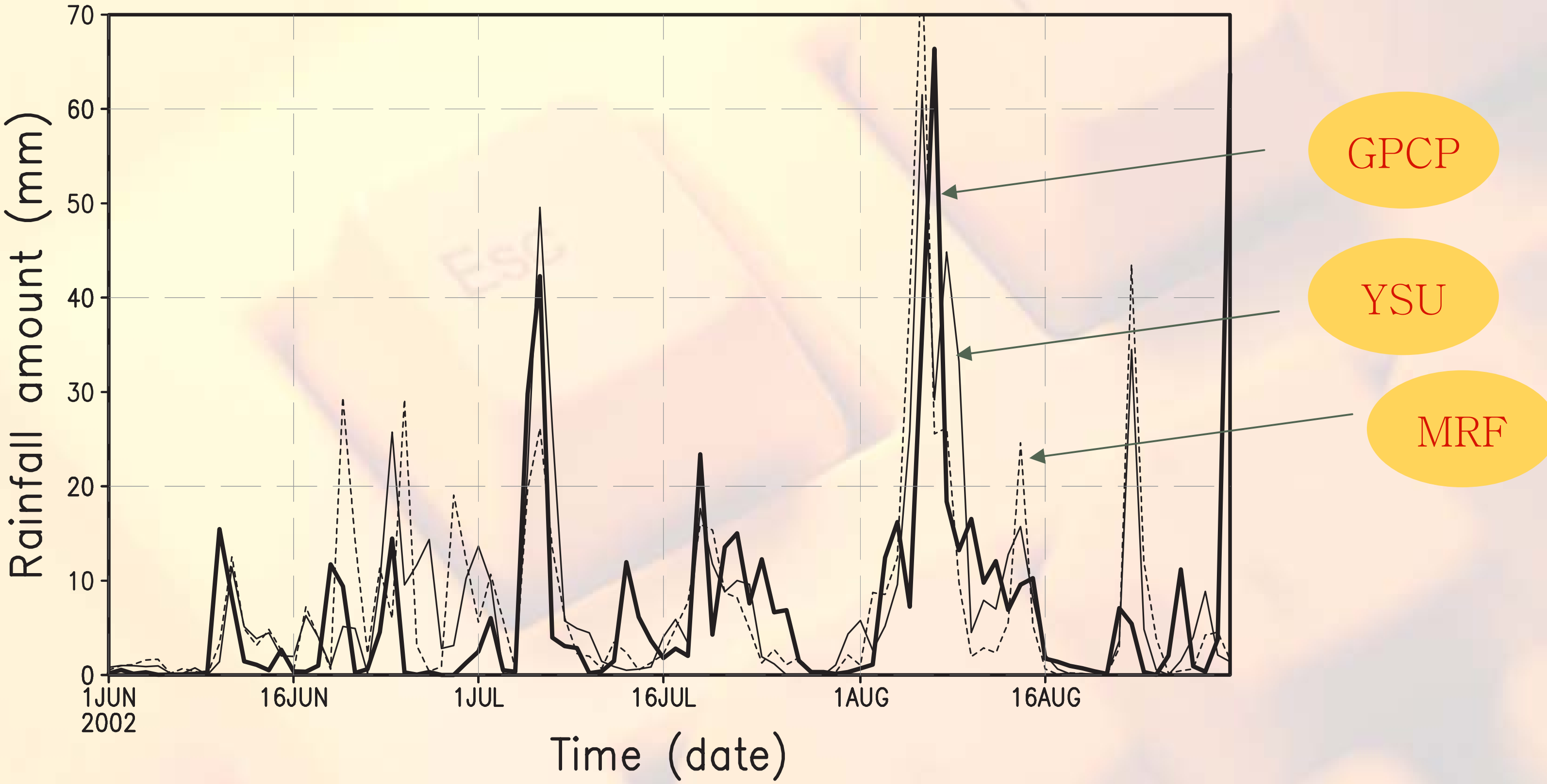
Regional climate evaluation – RSM

Biases (Experiment–RA2)



Regional climate evaluation – RSM

Time series of rainfall over the Korean region



MRF YSU

Corr : 0.42 0.54

Seasonal simulation – Byun and Hong (2004)

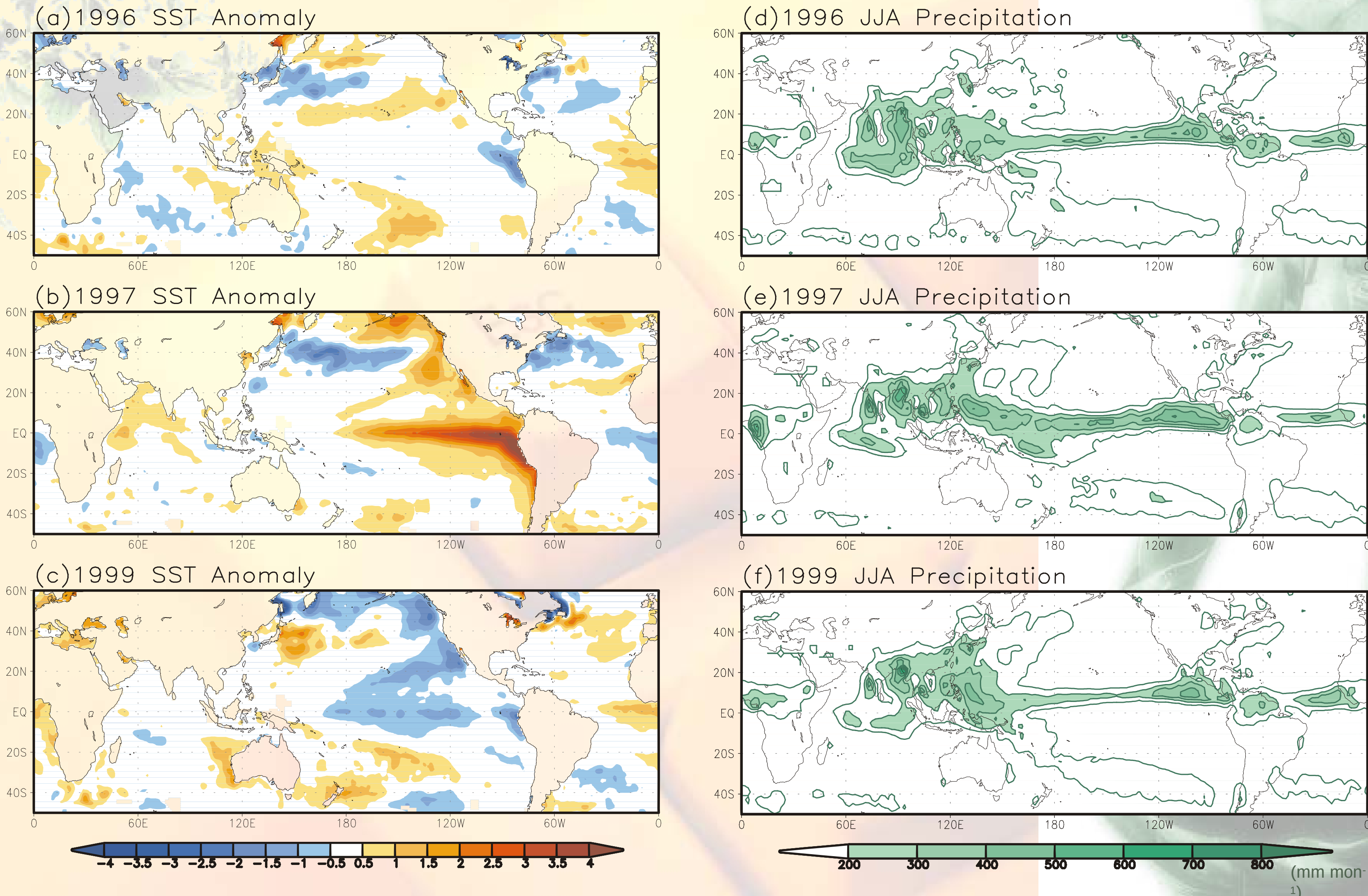
Experiments

Name	PBL scheme	Convection scheme
CNT_S	MRF PBL	SAS
NEW_S	New PBL	SAS
CNT_R	MRF PBL	RAS
NEW_R	New PBL	RAS

Ensemble runs

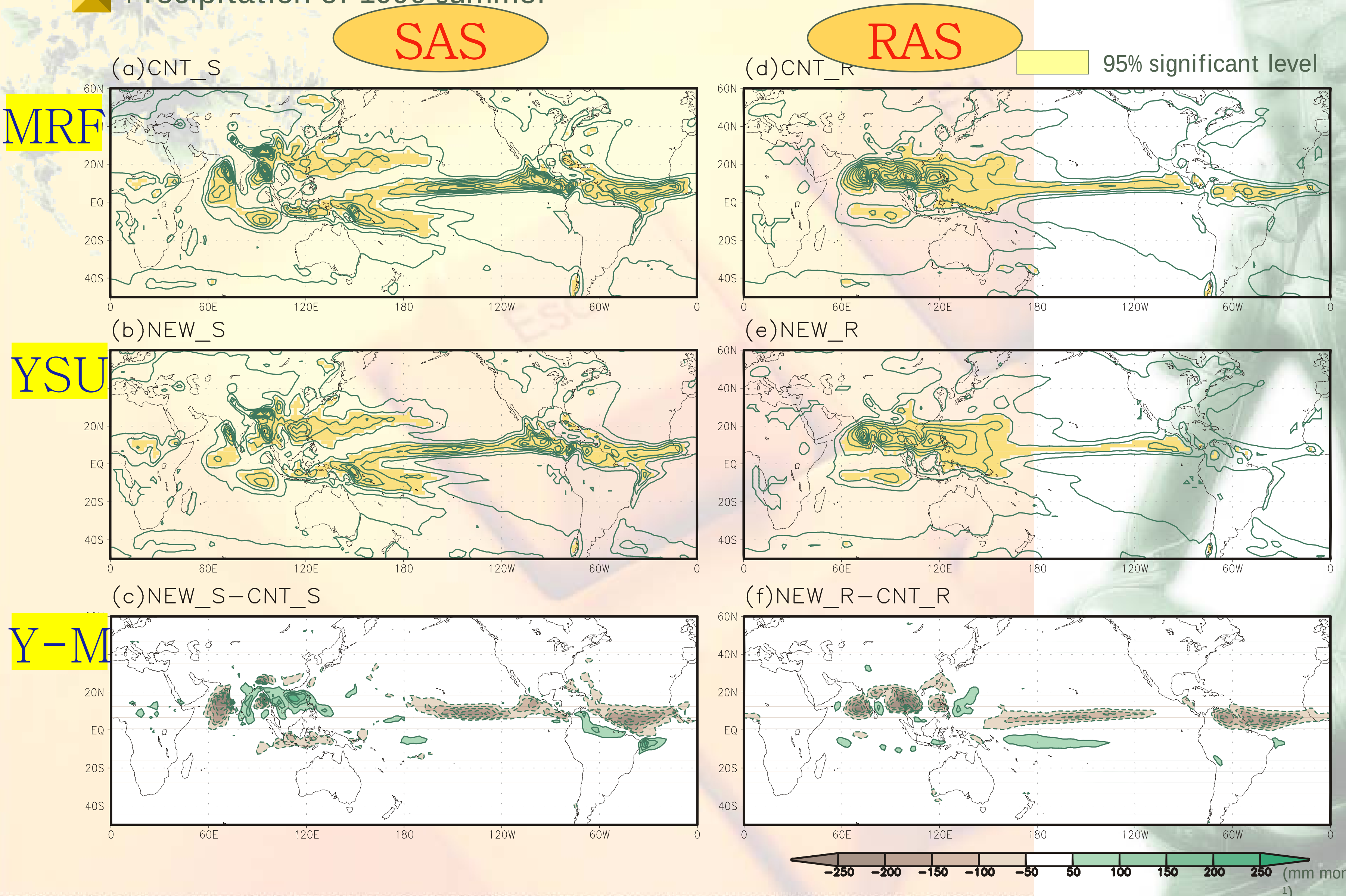
- boreal summer (JJA)
- 10 member ensemble run with NCEP Reanalysis II data
  - LAF : 5.1~10 0000 UTCs
- for three years with different SST conditions
  - 1996 : normal
  - 1997 : El Nino
  - 1999 : La Nina

Experimental Design



Result

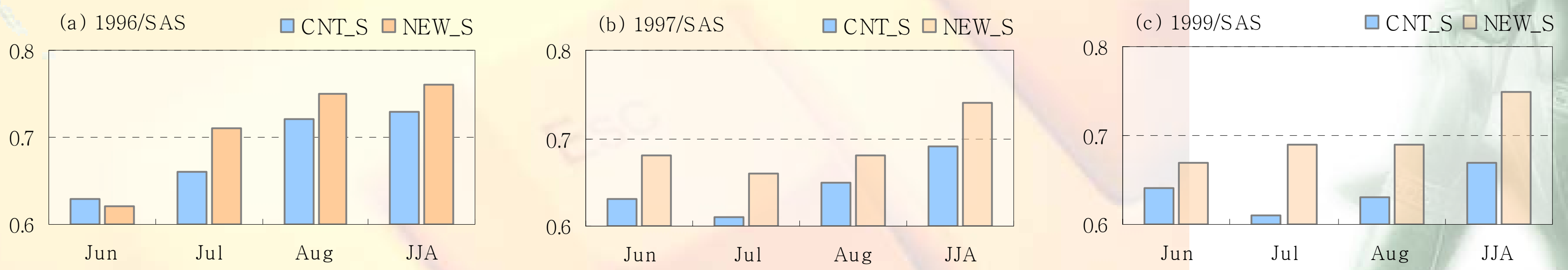
Precipitation of 1996 summer



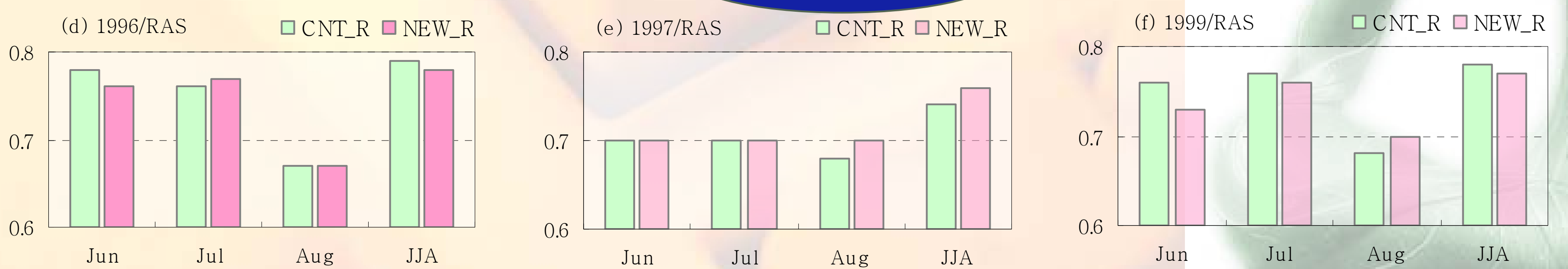
Result

Pattern correlation (50S-60N)

SAS



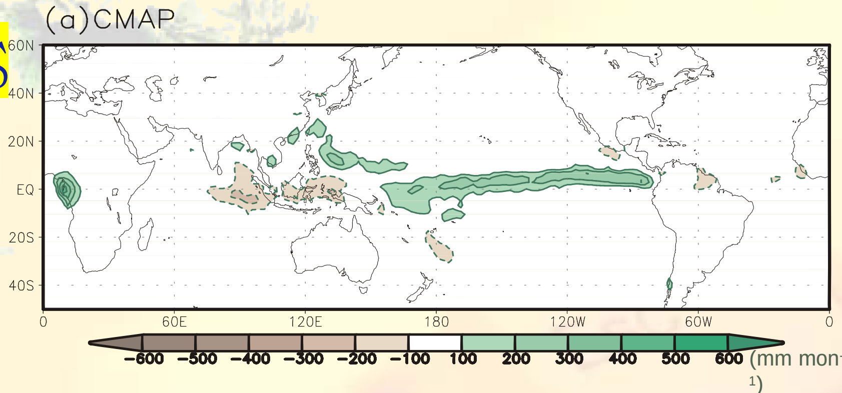
RAS



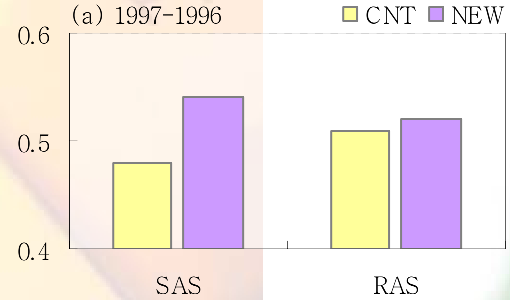
Result

Precipitation anomaly (1997-1996) El Nino

OBS

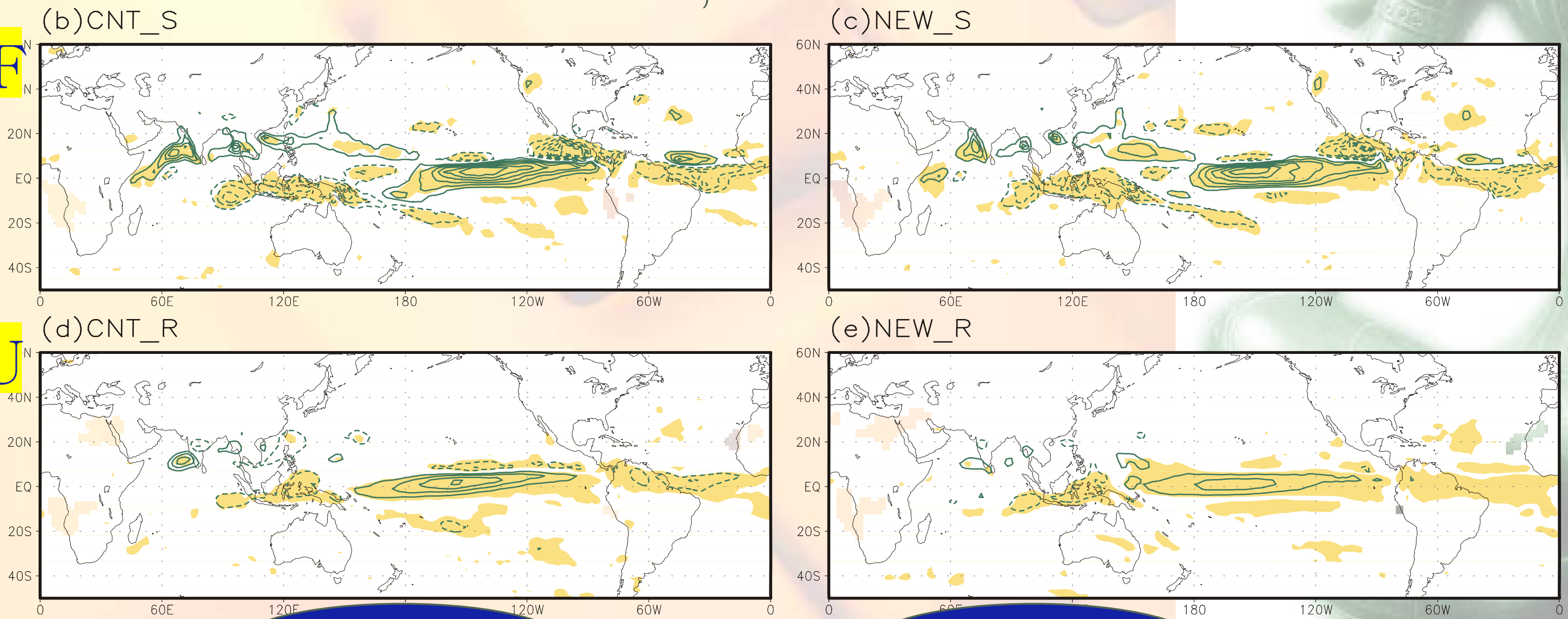


Pattern correlation



MRF

YSU



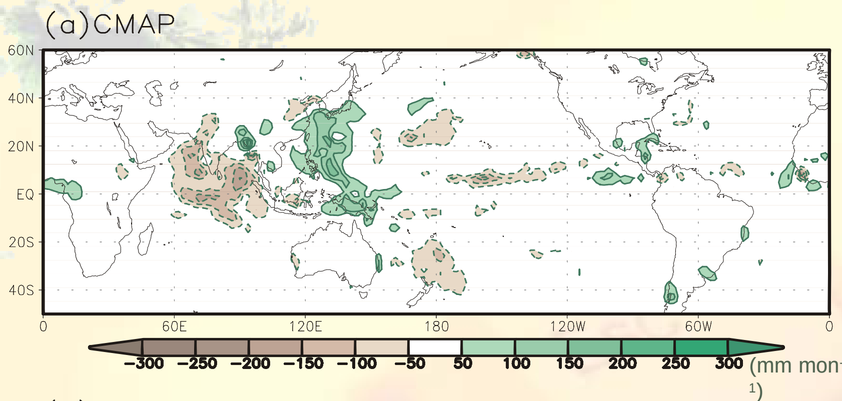
SAS

RAS

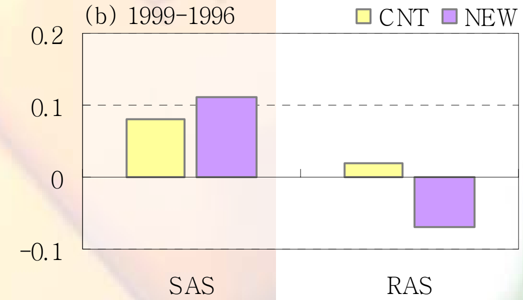
95% significant level

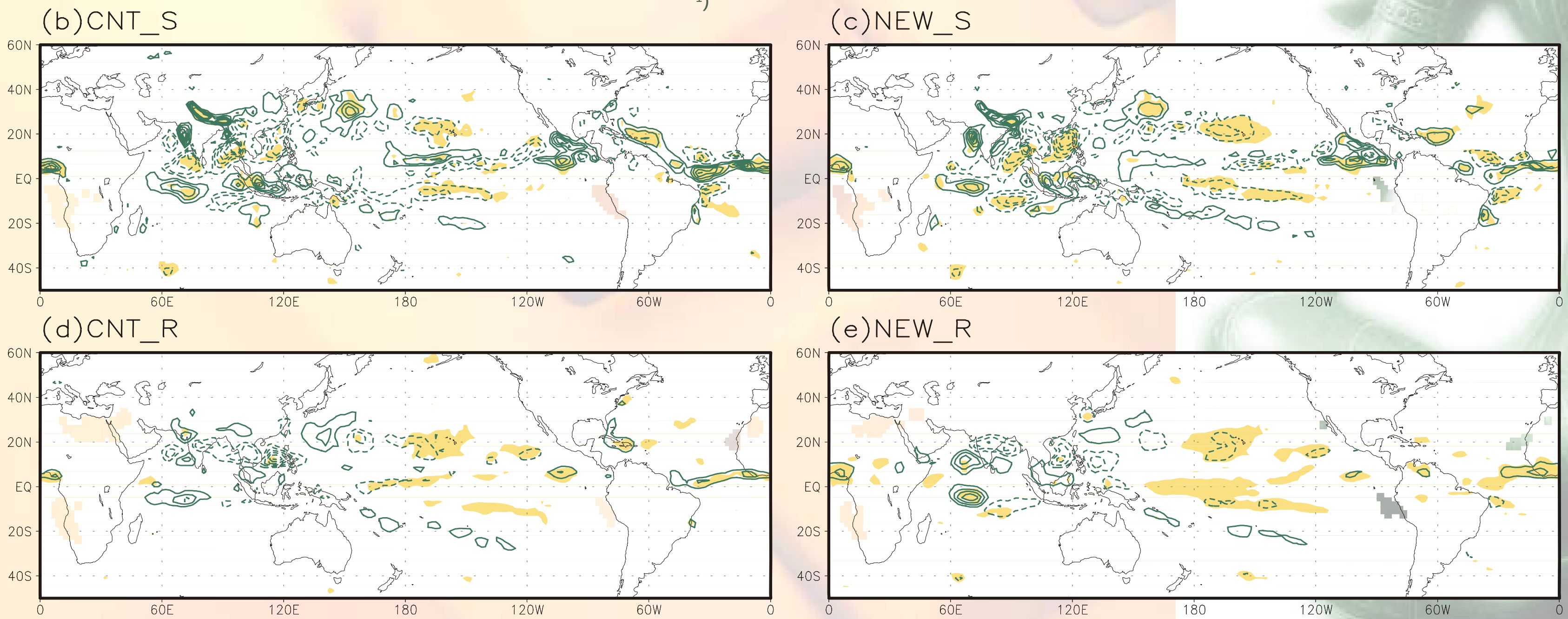
Result

Precipitation anomaly (1999-1996) La Nina



Pattern correlation

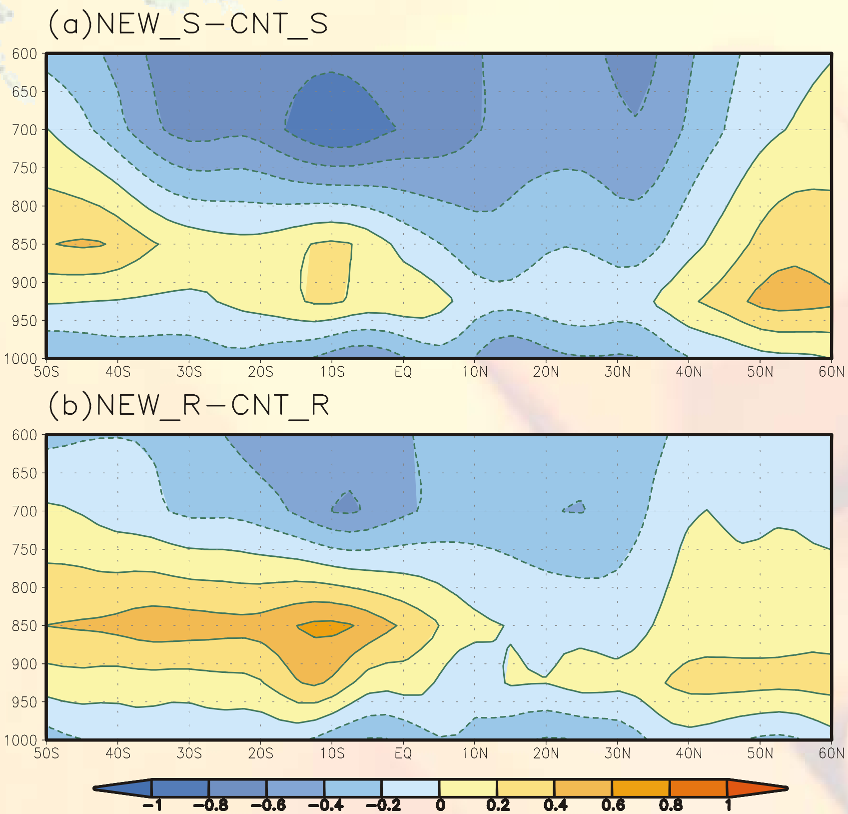




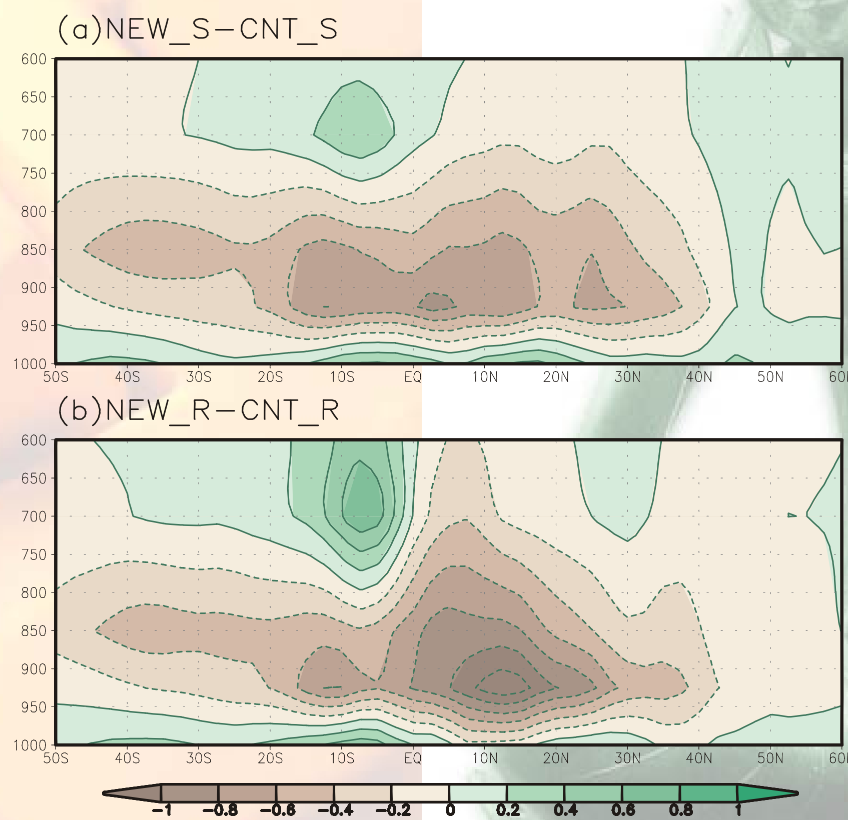
95% significant level

Result

Temperature (K)

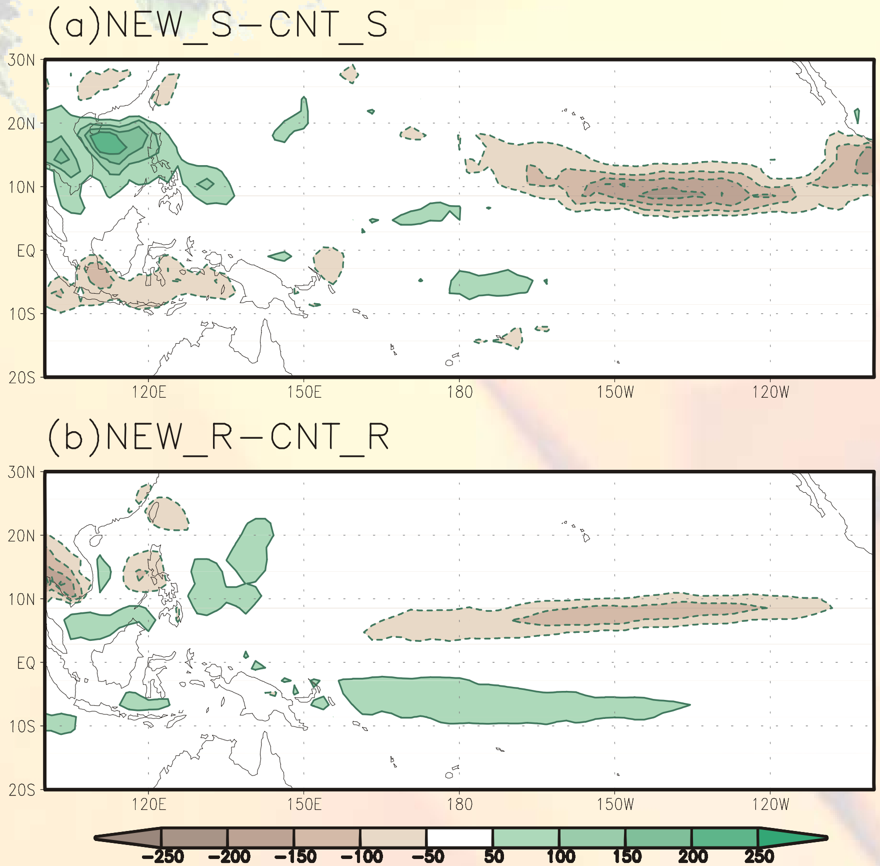


Mixing ratio (g/kg)

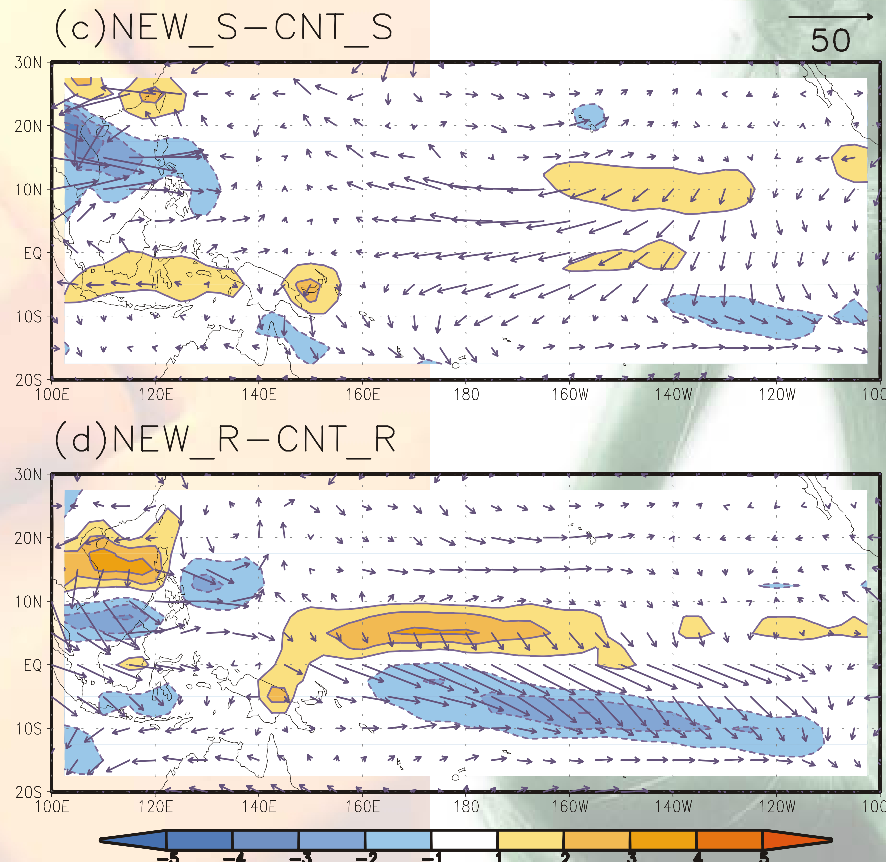


Result

- Convective rainfall (mm mon^{-1})

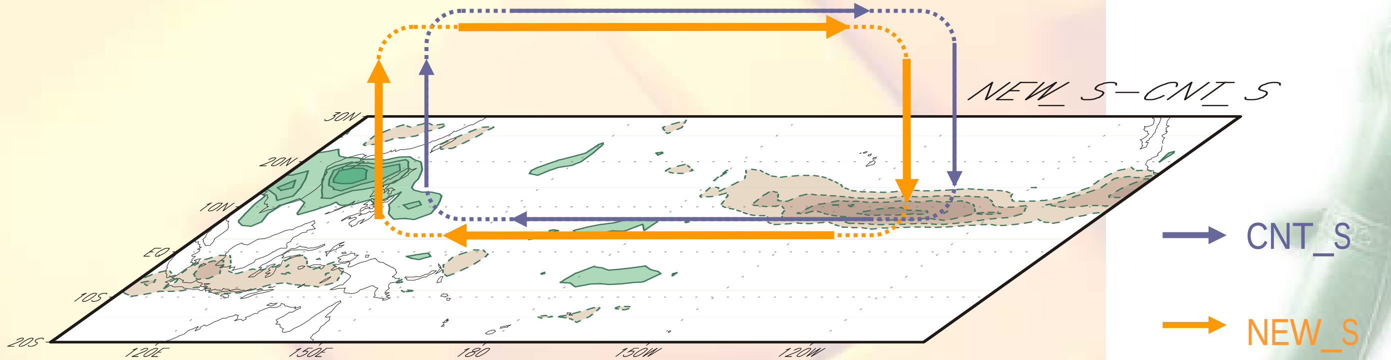


- 850 hPa moisture flux (vector) & divergence (10^{-5} g kg^{-1} s^{-1})



Summary

New PBL +
SAS convection

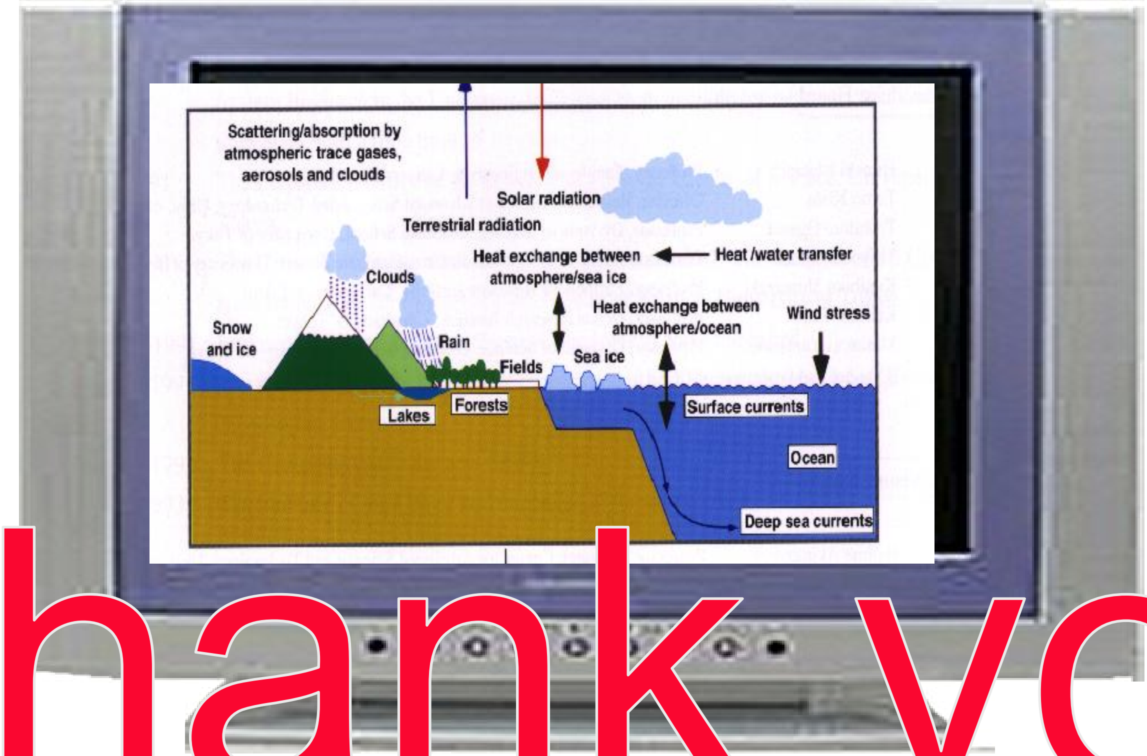


Western Pacific

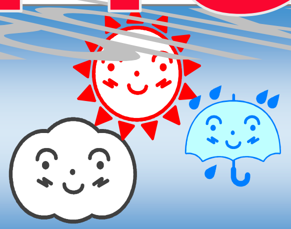
- Increase of tropical rainfall
- Larger low-level moisture advection due to the intensified Walker circulation
  -> More CAPE (More convective activities)
- Lower SLP
  -> Intensifying Walker circulation

Eastern Pacific

- Decrease of tropical rainfall
- Less mixing due to New PBL
  -> Less CAPE (Less convective activities)
- Higher SLP
  -> Intensifying Walker circulation



Thank you



$$\Longrightarrow \frac{DV}{Dt} = -f\mathbf{k}\times\mathbf{V} - \nabla_p\Phi + \alpha$$

- Severe weather
- NWP
- Regional climate
- Seasonal prediction
- Climate mechanism