中央氣象局全球預報模式 RRTMG輻射參數化與臭氧參數化方法之影響評估

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Outline

- RRTMG 輻射參數化 & 臭氧參數化方法簡介
- 實驗 & 診斷評估
  - *Experiments：*
    - *Sep. Exp.： 2015/09*
    - *Jan. Exp. ： 2013/01*
    - *Jul. Exp. ： 2015/07*
- 總結

Weather+ Service Observation Climate Forecasts Satellite Earthquakes Marine Radar Astronomy

RRTMG scheme

- *RRTMG : a Rapid Radiative Transfer Model for GCM*

  - Developed at AER (Atmospheric and Enviromental Research Inc.)
  - Utlizes the correlated-k approach to calculate SW / LW fluxes and heating rates.

- RRTMG scheme – Global and Regional Model Applications.

Inc.	System	RRTMG-LW used	RRTMG-SW used
ECMWF	IFS,ERA40	2000/06 ~ v4.84	2007/06
MPI	ECHAM5	2002 ~ v4.84	
NCEP	GFS	2003/08 ~	2010/07 ~
NCEP	CFS	2004 ~	2010/09 ~
NCAR	WRF-ARW	2009/04(WRFv3.1)	2009/04(WRFv3.1)
NCAR	CAM5,CESM1	2010/06/25	2010/06/25

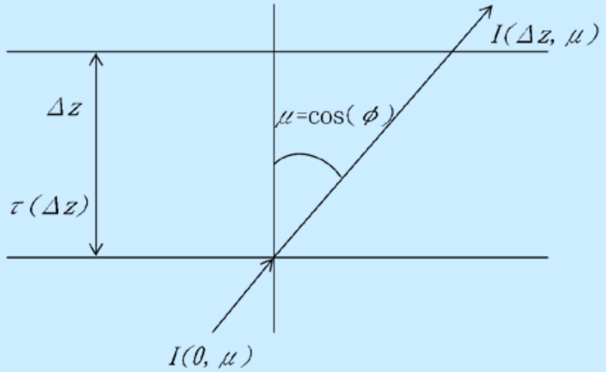
Correlated - K method

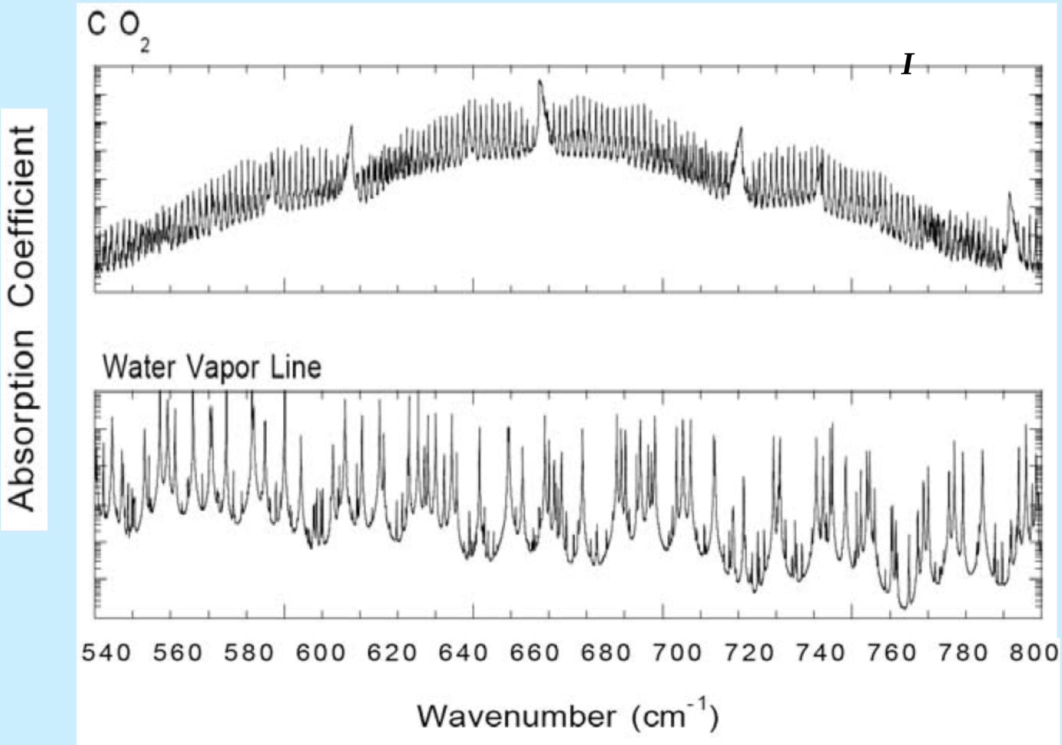
- 輻射在傳送過程中，輻射能量因介質的吸收而衰減，其方程式如下 ：

$$I_v = I_o \cdot e^{-\tau/\mu} = I_o \cdot T_v(\tau/\mu)$$

□ □ □ : $T_v = e^{-\tau/\mu}$

□ □ □ □ : $\tau = \int_{\Delta z} k_{v} \rho_a dz$, k_v : □ □ □ □





- 計算一波段的輻射通量:

如果介質的吸收係數(k)相對應於波數(v)， 變化很大.....

需計算此波段每一條吸收光譜的輻射通量透射率(Tv)加總，才能精確算出此波段的輻射通量

➔非常費時!!

Correlated - K method

- 將輻射通量透射率(T_v) 從 波數(v)的函數，轉成 吸收係數累積機率 (g) 的函數

1) 先將此波段之吸收係數 k 由小到大排序，
再定義每個 k 在此波段的機率分布函數 f(k)，
則可得對 k 積分的輻射通量透射率。

$$T_{\bar{v}}(u) = \int_{\Delta v} e^{-k_v u} \frac{dv}{\Delta v} = \int_0^\infty e^{-ku} f(k)dk, \quad \int_0^\infty f(k)dk = 1$$

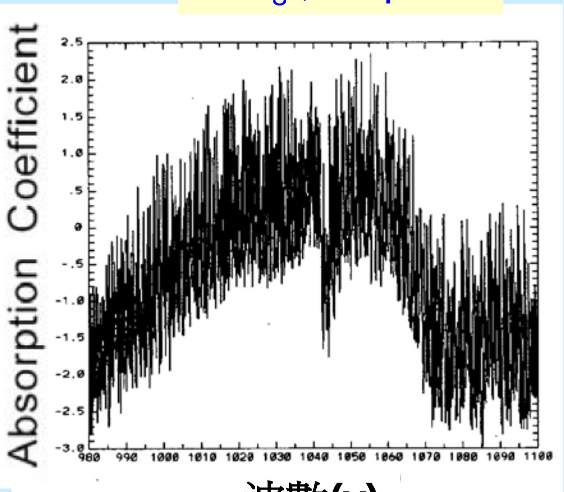
2) 再定義吸收係數 k 的累積機率函數 g(k)，

$$g(k) = \int_0^k f(k)dk, \qquad dg(k) = f(k)dk$$

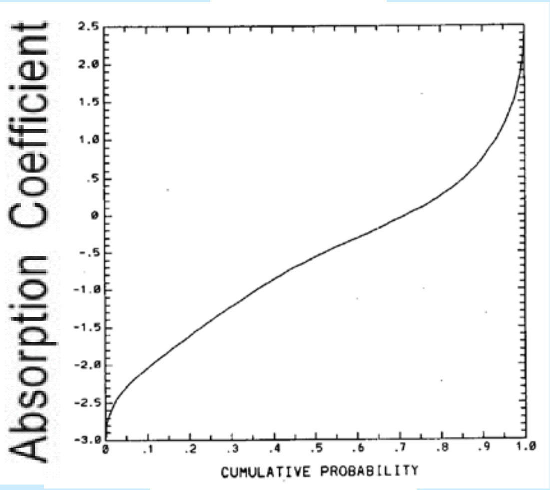
3)可得對 g 積分的輻射通量透射率。

$$T_{\bar{v}}(u) = \int_{\Delta v} e^{-k_v u} \frac{dv}{\Delta v} = \int_0^\infty e^{-ku} f(k)dk = \int_0^\infty e^{-k(g)u} dg \approx \sum_{j=1}^m e^{-k(g_j)u} \Delta g_j$$

O_3 , 9.6μm



波數(v)



累積機率 (g)

Fu-Liou vs. RRTMG

Shortwave Radiative Transfer	
Fu - Liou	**RRTMG**
• Solution of RT equation : Two - streams method, Delta-Eddington approximation	• Solution of RT equation : Two - streams method, Delta-Eddingten approximation
• Spectral intervals : (Correlated – k method) - 11 bands & 38 g-intervals	• Spectral intervals : (Correlated – k method) - 14 bands & 112 g-intervals
• SW absorber : H20, O3, neglect minor gases and aerosols effect.	• SW absorber : H2O, O3, CO2, N2O, CH4, O2, aerosols
• No McICA - (Monte Carlo Independent Column Approximation)	• Includes McICA for sub-grid cloud information
• Cloud overlap assumption - maximum-random	• Cloud overlap assumption - radom / maximum-random
• Water & Ice clouds : (Chou and Suares(1999)	• Water clouds : (Hu and Stamnes , 1993) • Ice clouds : (Fu, 1996)
• Reference : (Fu and Liou, 1993)	• Reference : (Mlawer and Clough , 1997, Hou Y.-T. , 2002)

Fu-Liou vs. RRTMG

Long wave Radiative Transfer	
Fu - Liou	**RRTMG**
● *Solution of RT equation* *Delta – two and four stream approximation*	● *Solution of RT equation* *Two – stream method*
● *Spectral intervals : Correlated – k method* *- 12 bands & 67 g-intervals*	● *Spectral intervals : Correlated – k method* *- 16 bands & 140 g-intervals*
● *LW absorber :* H_2O, O_3, CO_2, CH_4, N_2O, CFC-11, CFC-12	● *LW absorber :* H_2O, CO_2, O_3, CH_4, N_2O, O_2, CO, CFC-11, CFC-12, CFC-22, CCL_4, *aerosols*
● *No McICA - (Monte Carlo Independent Column Approximation)*	● *Includes McICA for sub-grid cloud structure and distribution to interact with radiation*
● *Cloud overlap assumption* *- maximum-random*	● *Cloud overlap assumption* *- radom / maximum-random*
● *Water & Ice clouds :* *(Chou and Suares,1999)*	● *Water clouds : (Hu and Stamnes , 1993)* ● *Ice clouds : (Fu, 1996)*
● *Reference :* *(Fu et al. 1998; Fong , 1998)*	● *Reference :* *(Mlawer et al., 1997, Morcrette et al. 2001)*

Ozone parameterization

- *Based on Cariolle and Deque(1986)*

- *The parameterization assumes that chemical change in ozone can be described by a linear relaxation towards a photochemical equilibrium.*

$$\frac{dO_3}{dt} = C_0 + C_1(O_3 - \overline{O_3}) + C_2(T - \overline{T}) + C_3(O_3^{\uparrow} - \overline{O_3^{\uparrow}}) \quad , \quad C_i : \text{relaxation rates}$$

$$O_3^{\uparrow}(p) = -\int_p^0 \frac{O_3(p')}{g} dp' \quad , \quad T \, , \quad \overline{O_3} \quad , \quad \overline{O_3^{\uparrow}} \; : \; \text{equilibrium values.}$$

- *the relaxation rates are determined from a photochemical model. (NASA 2D Chemistry model)*

Experiments and Evaluation

- **Experiments :** 3 exp. in different seasons for operational request .

- **Sep. Exp. :** 2015/09/04 -2015/09/13
- **Jan. Exp. :** 2013/01/01 – 2013/01/10
- **Jul. Exp. :** 2015/07/01 – 2015/07/10

- 20 cases in each experiment.
- 5-days (120 hours) integration for each case.

(1) Sep. Exp. : 2015/09/04 - 2015/09/13

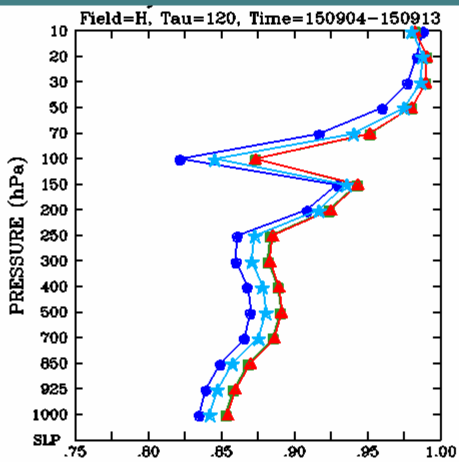
Experiment : .

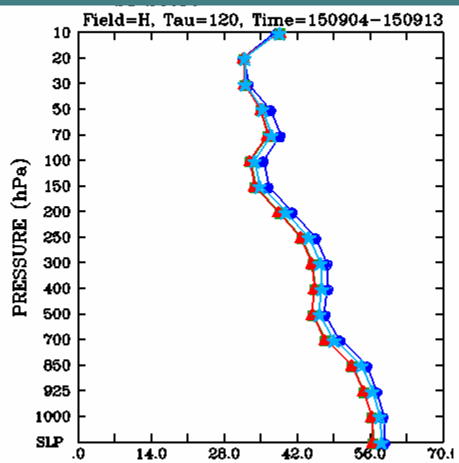
- **Fu-Liou (Ozone - on) : blue line**
- **RTMG + Ozone - on : red line**
- **RRTMG + Ozone - off : sky-blue line**

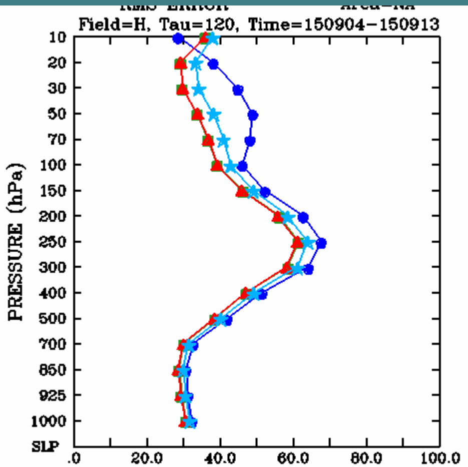
September exp. : 2015/09/04 - 2015/09/13

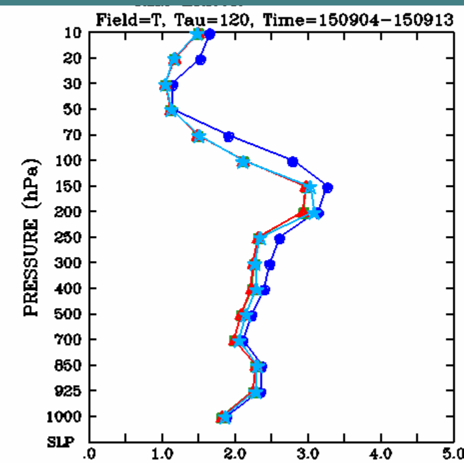
For North Hemisphere :

anomaly correlation -H	S1 – score -H	RMS error - H	RMS error - T

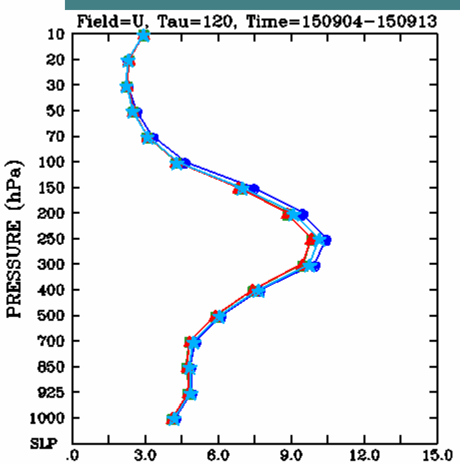


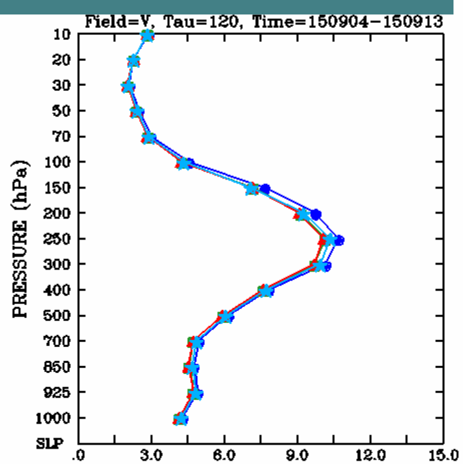






RMS error - U	RMS error - V





Performance of Score :

- *1 st : NECP-RRTMG scheme + Ozone - ON*
- *2 nd : NCEP-RRTMG + Ozone - off*
- *3 rd : Fu-Liou scheme + Ozone –on*

(2) Jan. Exp : 2013/01/01 - 2013/01/10
(3) Jul. Exp : 2015/07/01 - 2015/07/10

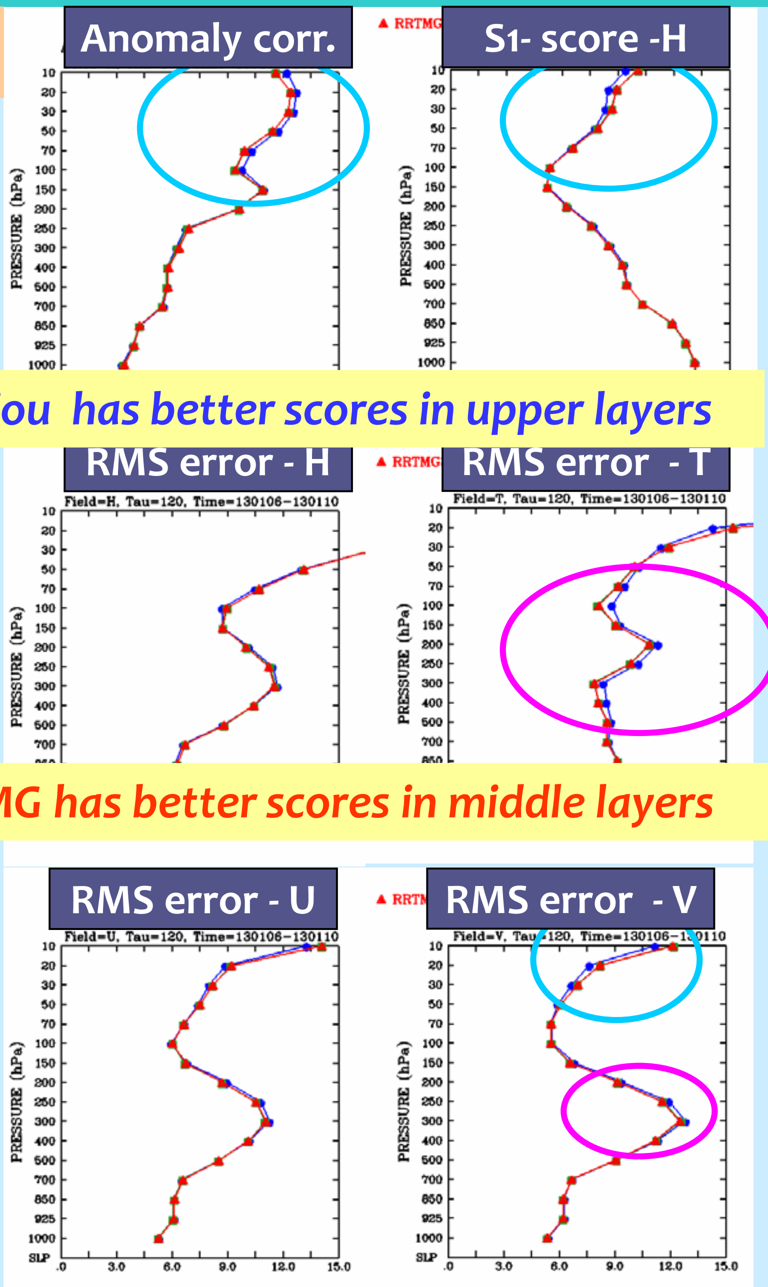
Experiment :

winter /summer cases of North-Hemisphere

- *Fu-Liou scheme : blue line*
- *RRTMG scheme : red line*

Jan . Exp. (winter) : 2013/01/01 – 2013/01/10

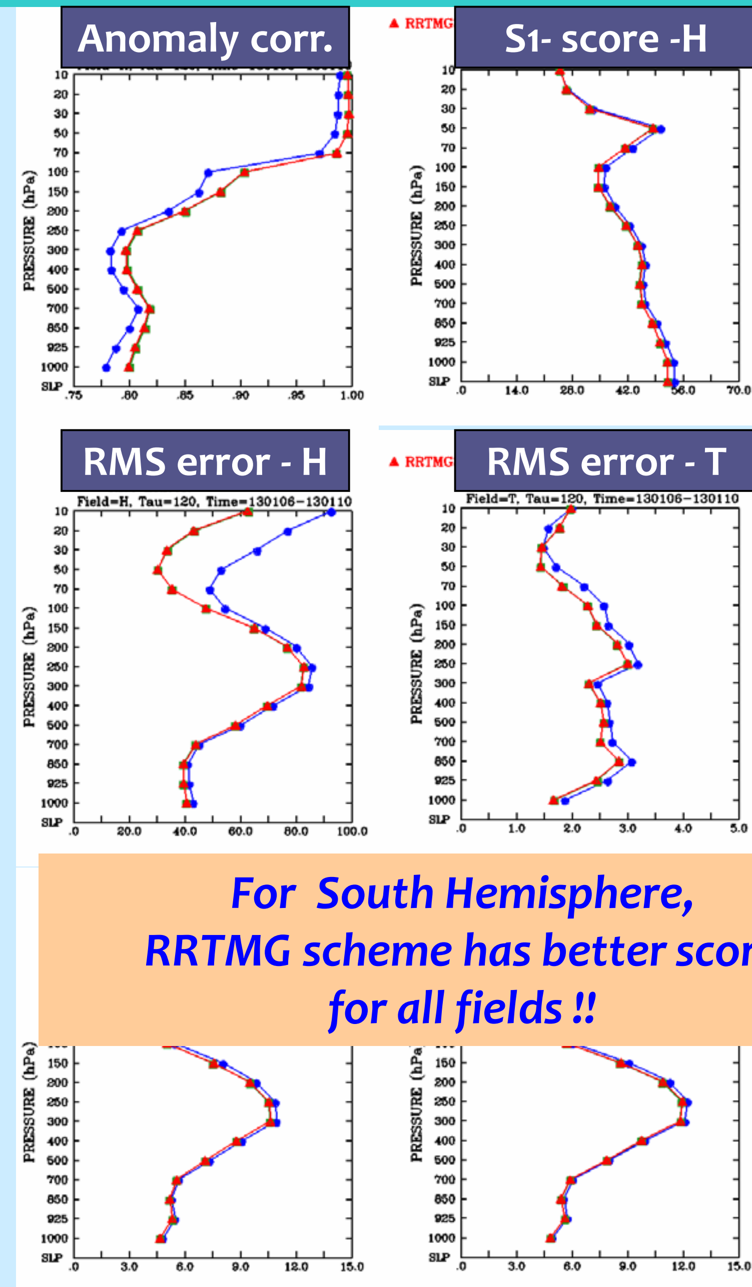
NH



Fu_Liou has better scores in upper layers

RRTMG has better scores in middle layers

SH



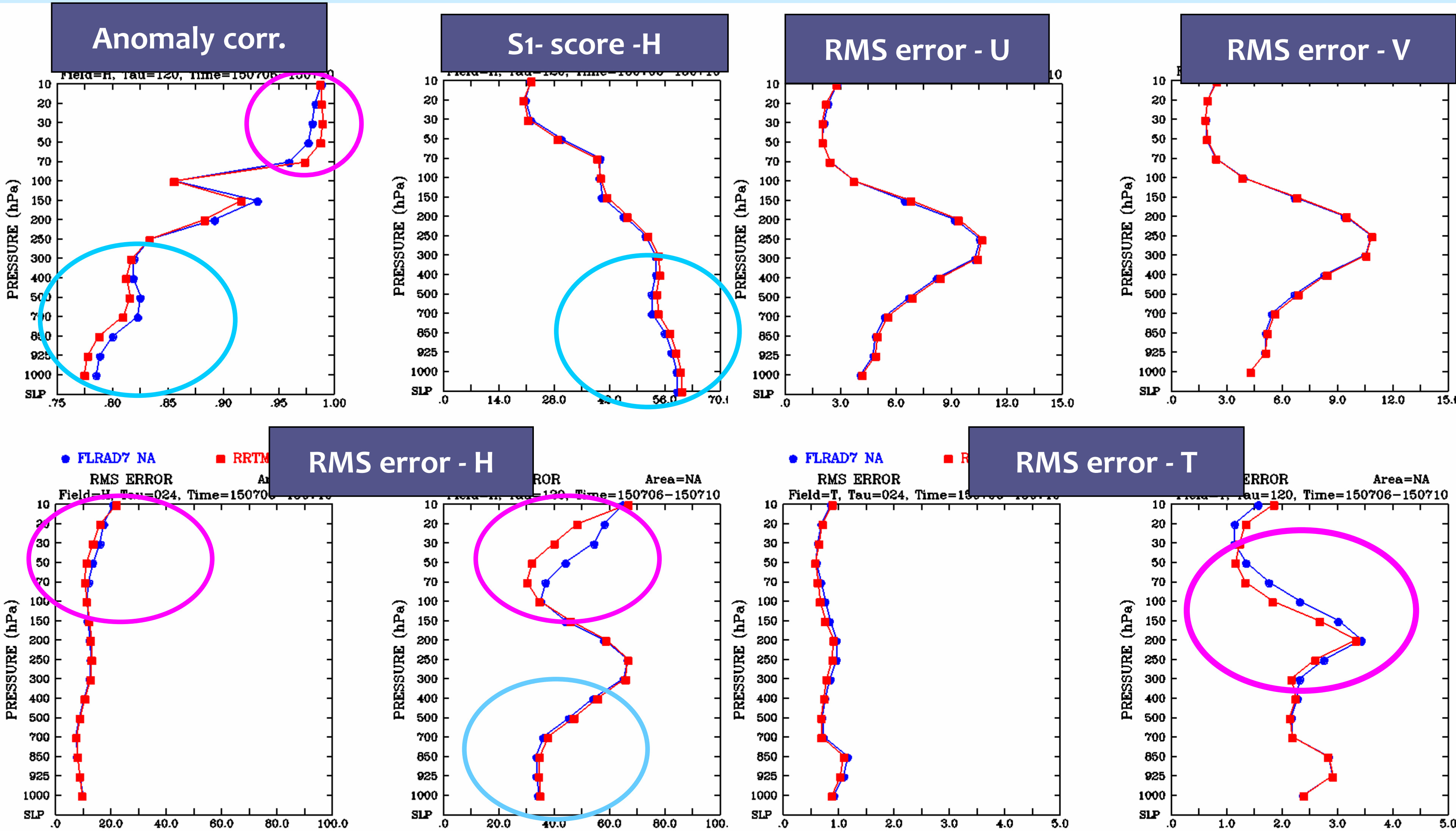
For South Hemisphere,
RRTMG scheme has better score
for all fields !!

July exp (summer) : 2015/07/01 - 2015/07/10

For North Hemisphere :

For lower layers, Fu_Liou scheme is better,

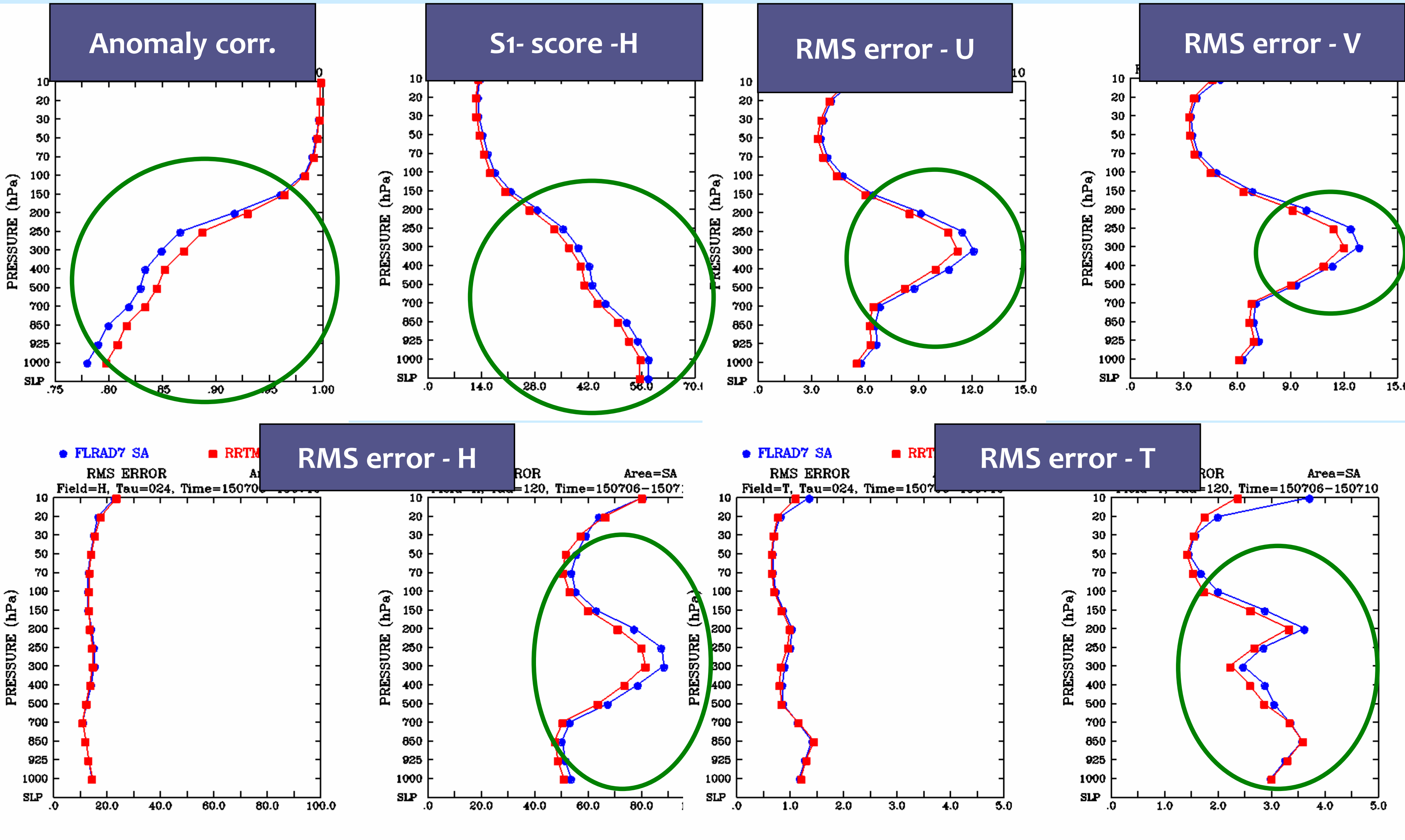
For upper layers, RRTMG is better !!



July exp (summer) : 2015/07/01 - 2015/07/10

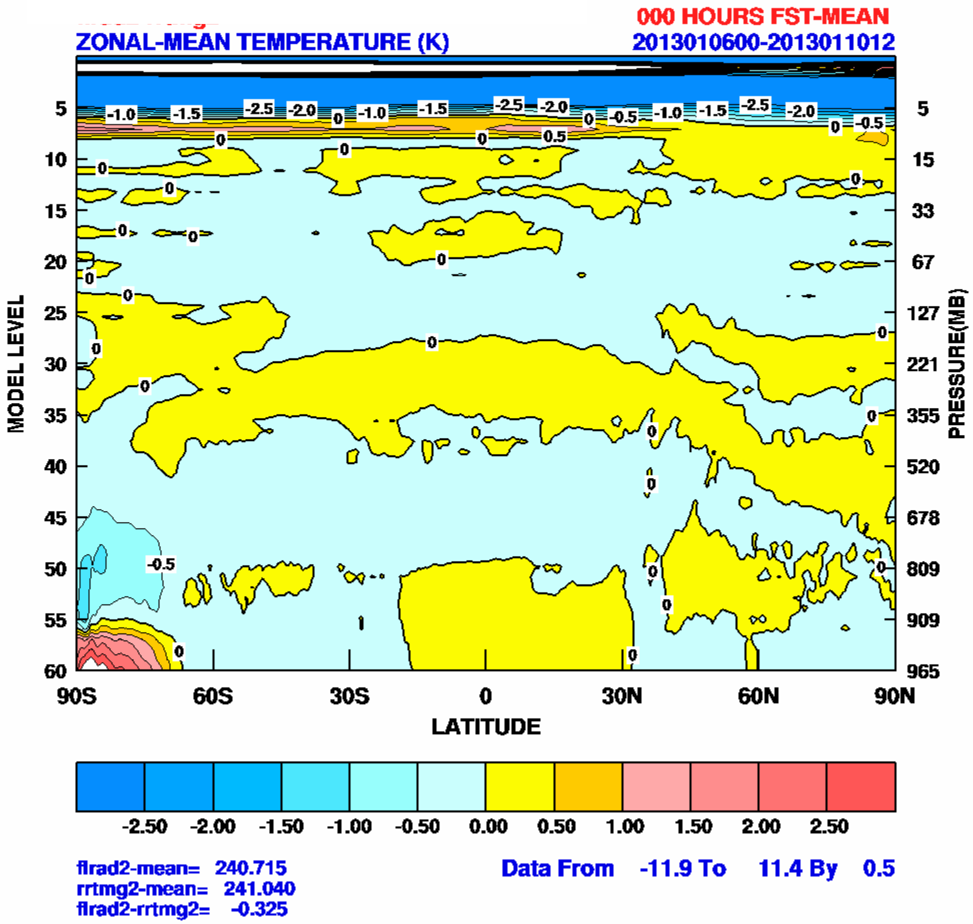
For South Hemisphere :

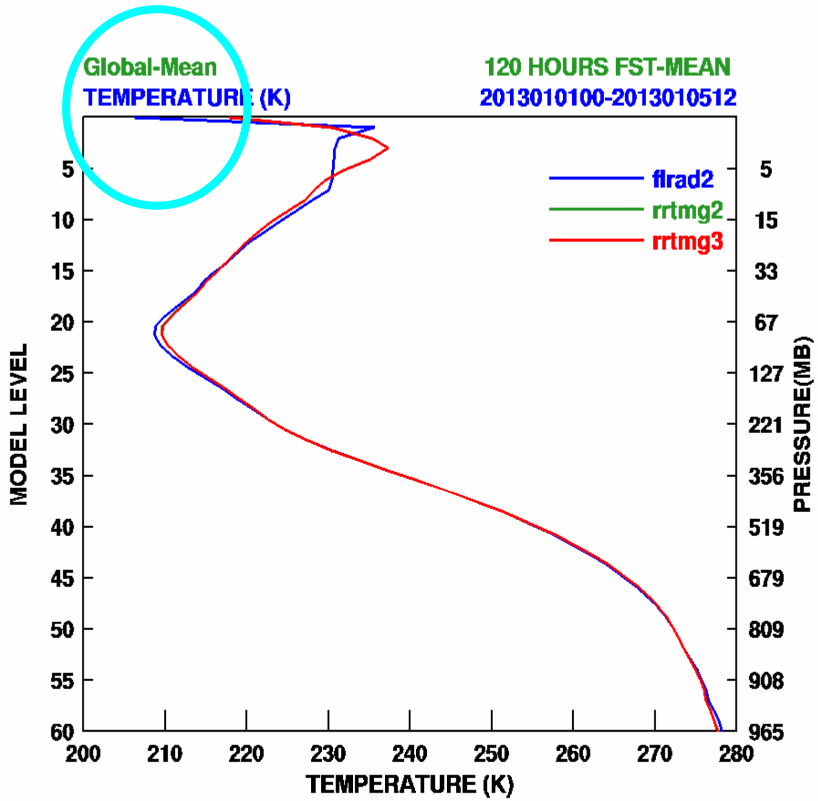
The scores of RRTMG are better !!

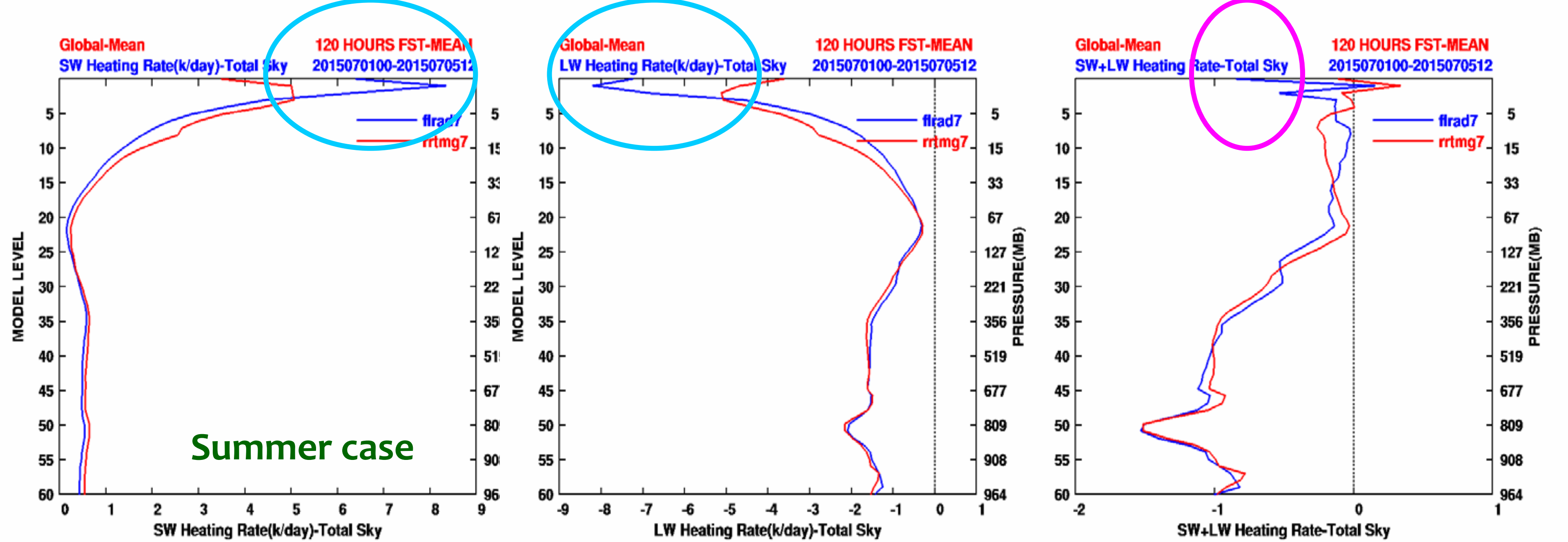


RRTMG scheme improves cold bias at model top

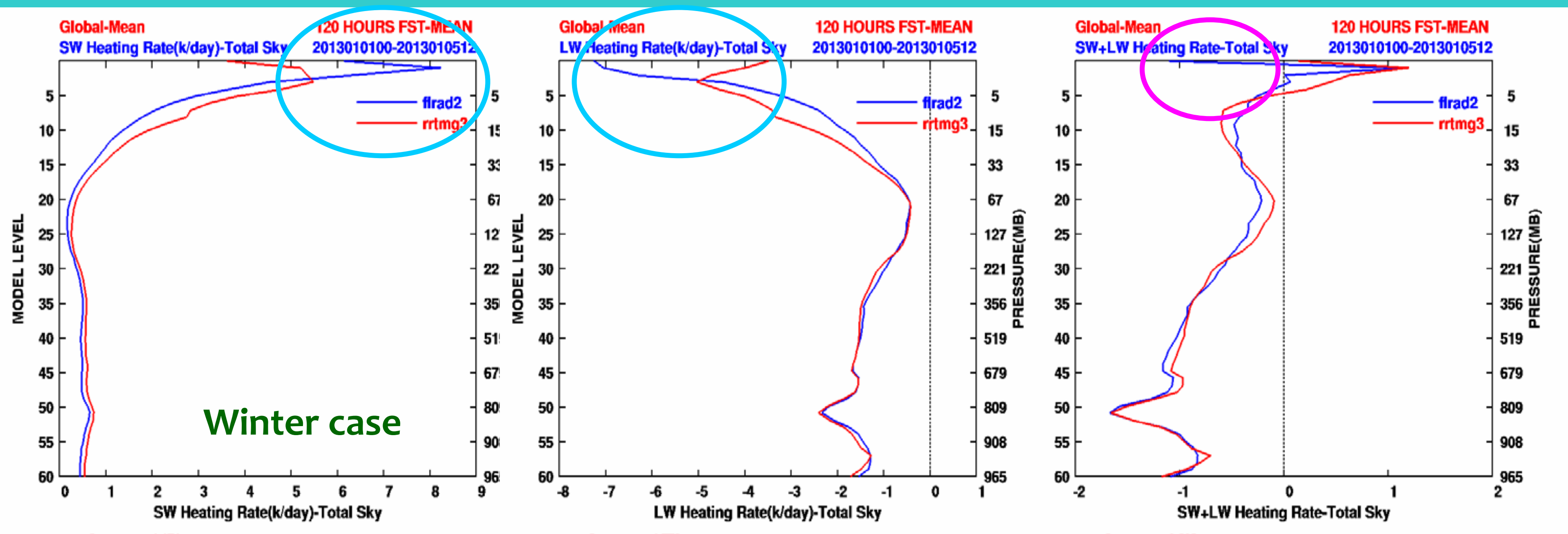
Fu-Liou - RRTMG



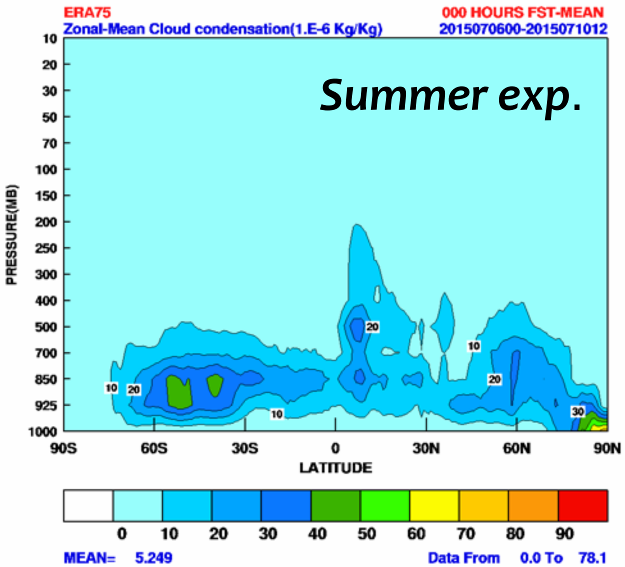


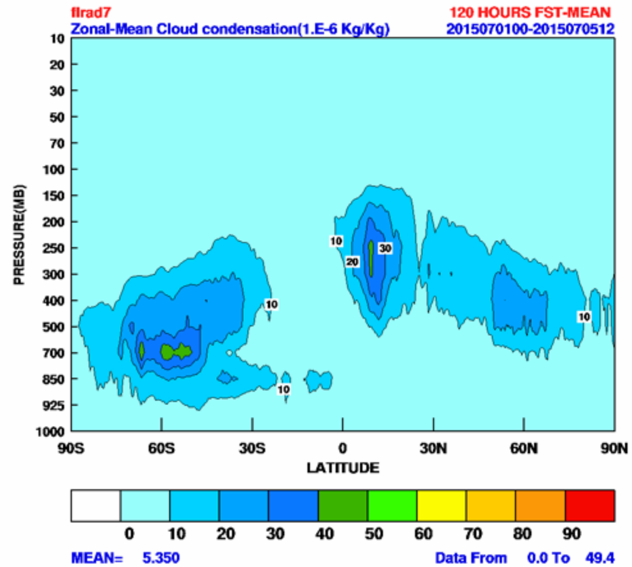


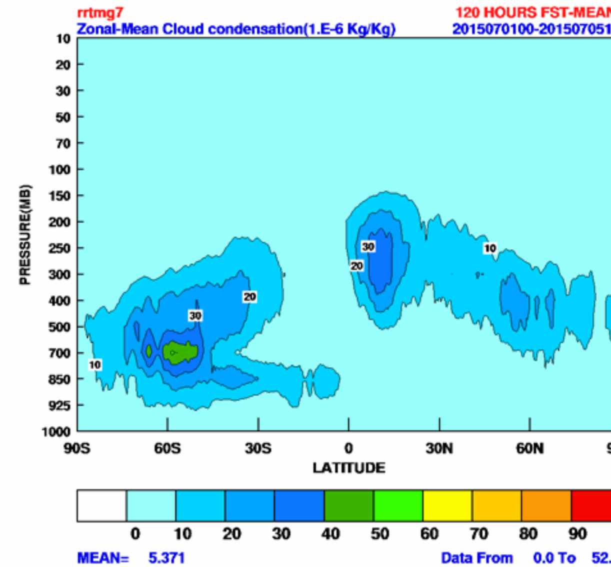
Fu-Liou scheme has large rad. cooling rate at model top => makes cold bias at model top !!



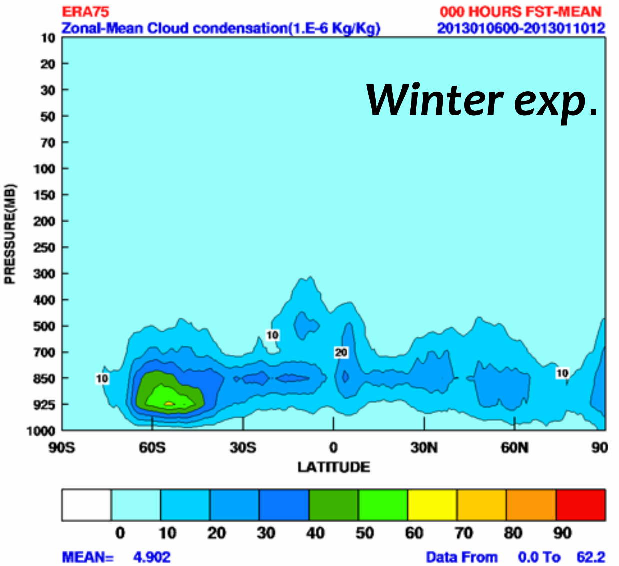
Evaluation by ERA-interm data

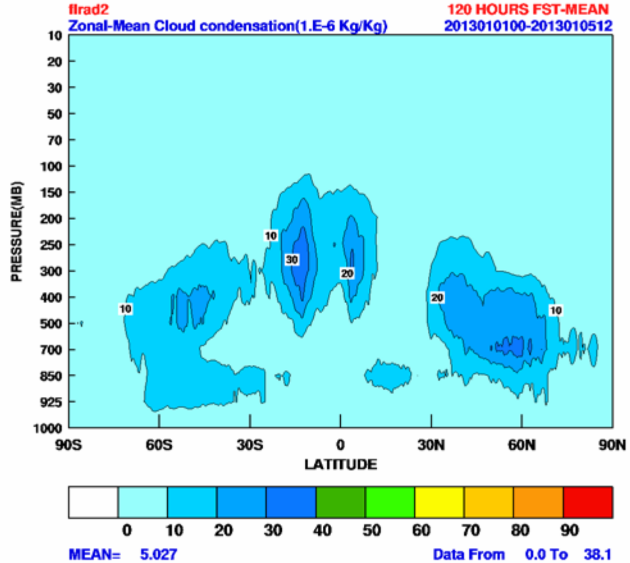


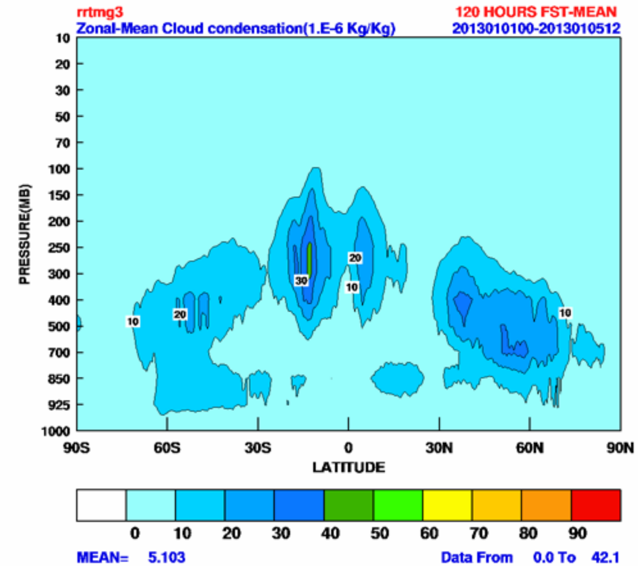




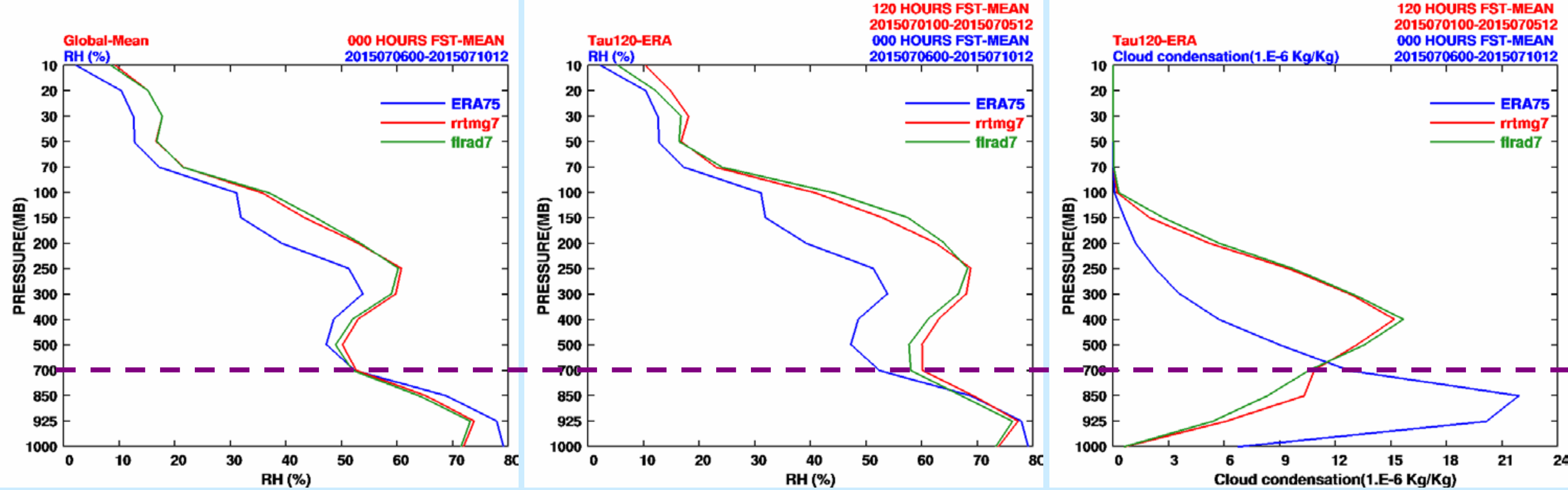
Too less cloud condensation in lower layers !!



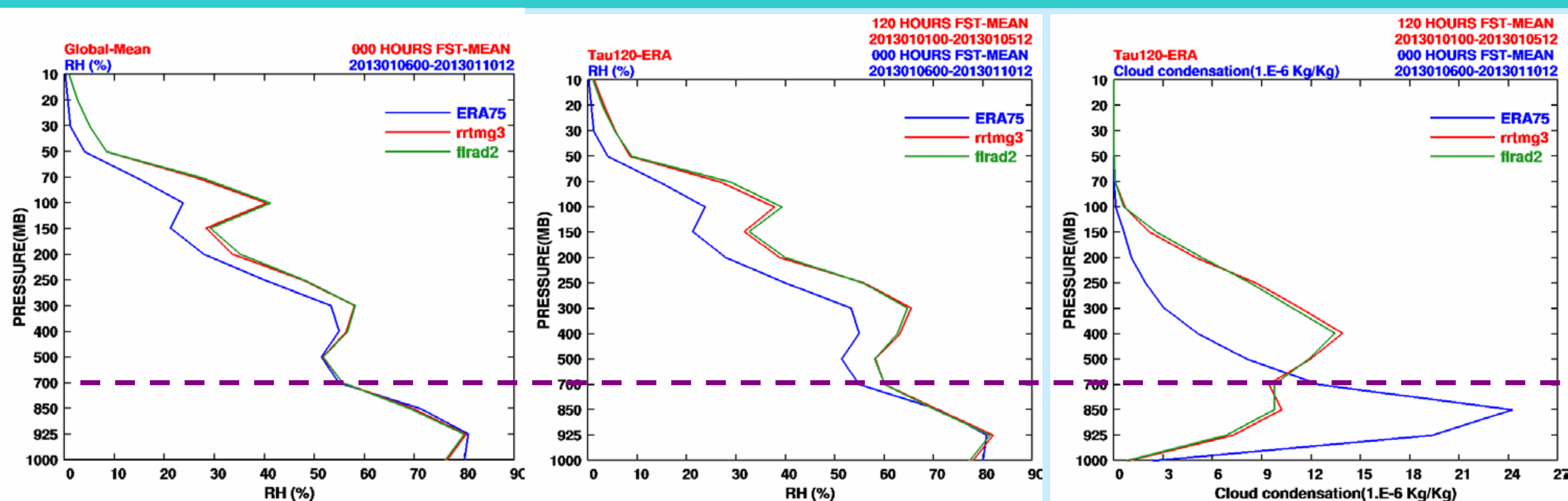


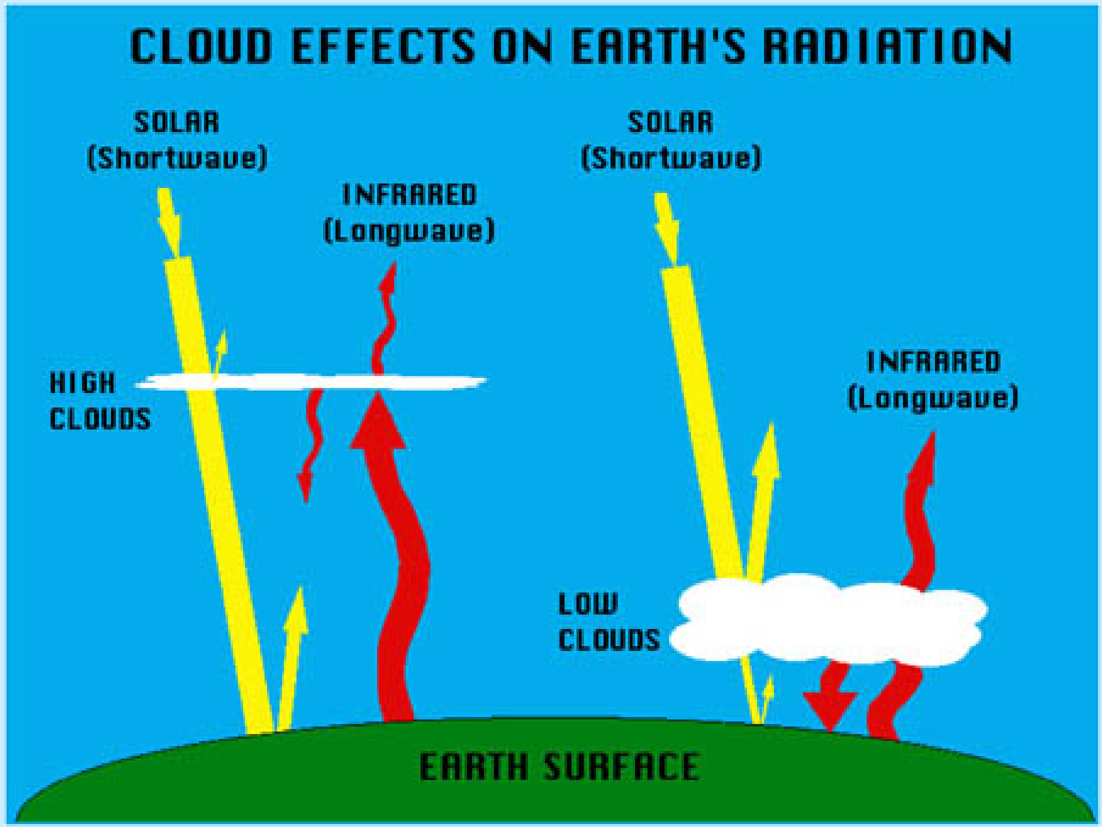


Summer case : CWBGFS model is too wet above 700hpa !!



Winter case : summer is wetter than winter. Cloud is over-estimate above 700hpa, too !!



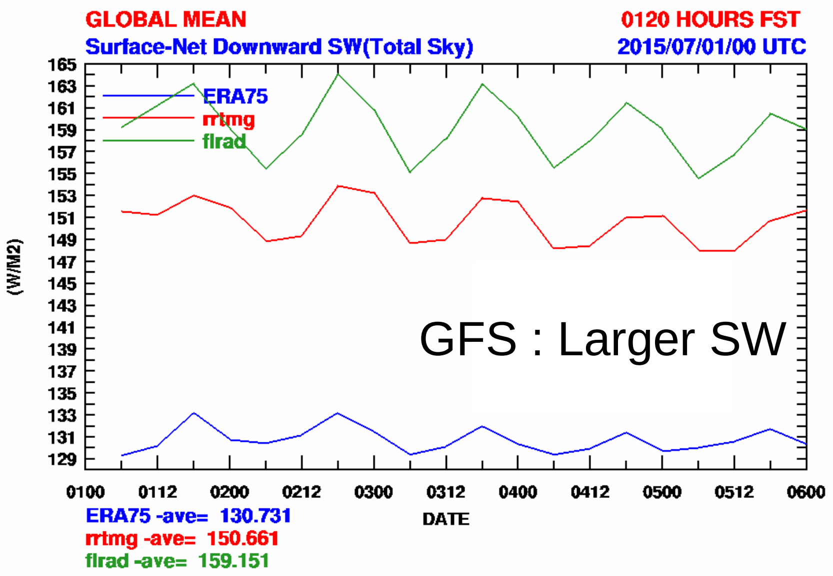


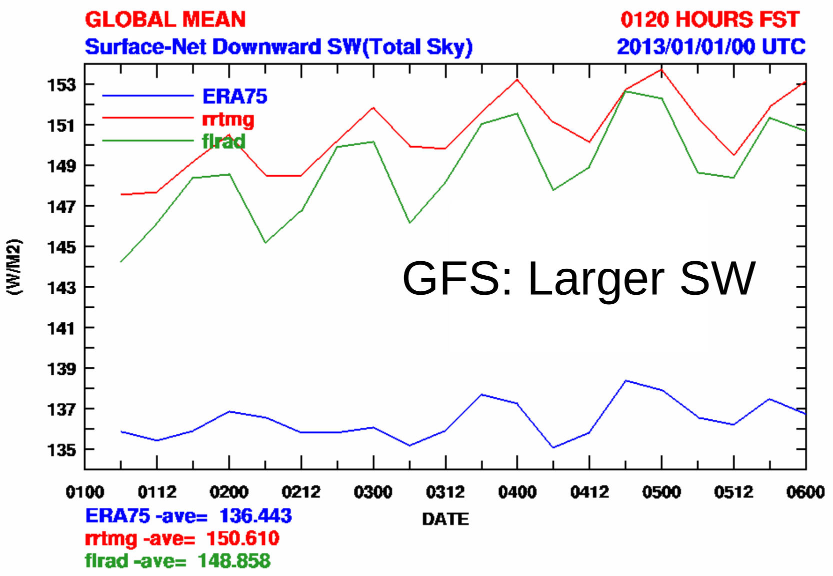
Less low clouds → less reflection of SW → larger downward SW at surface

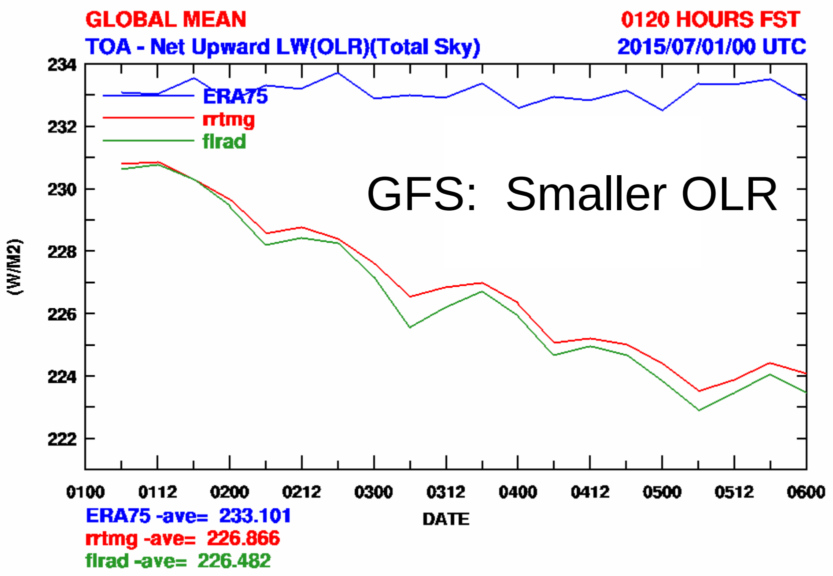
More high clouds → more LW trapped → smaller OLR at TOA

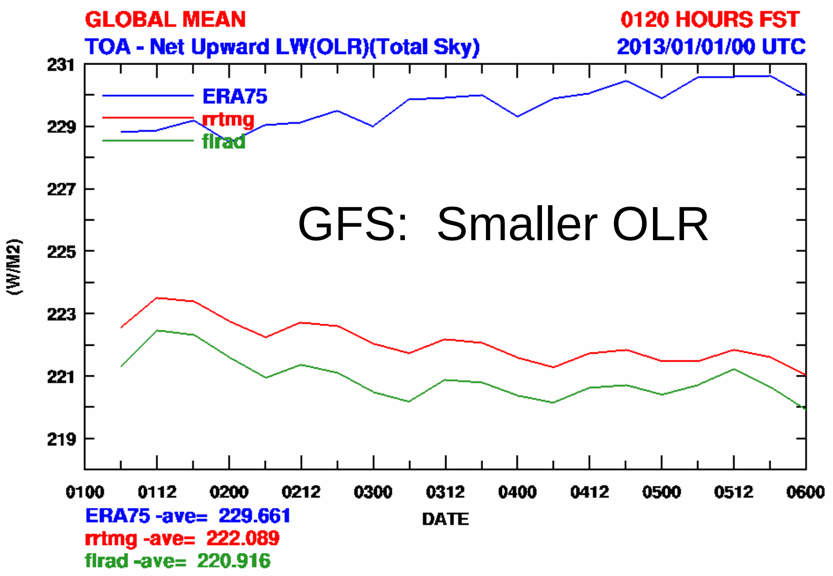
Summer case : 2015/07/01/00 UTC

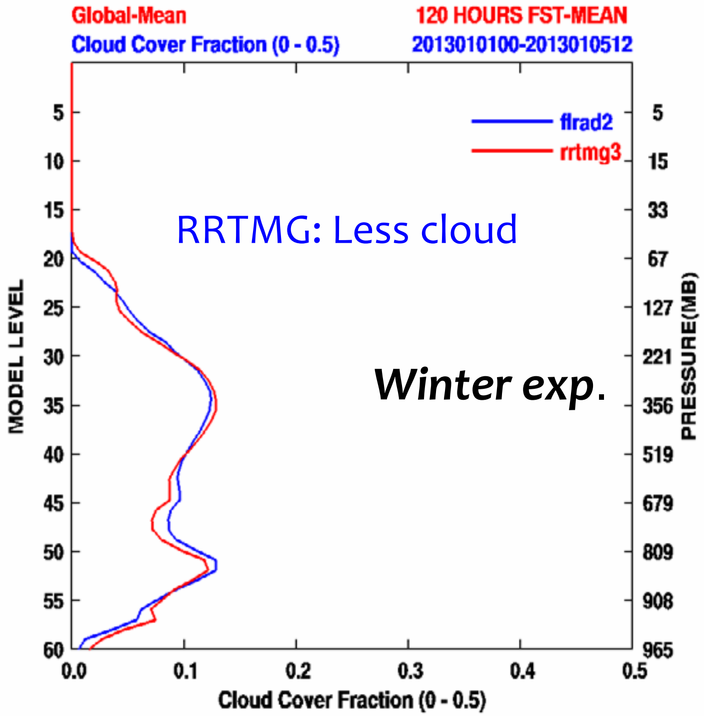
Winter case : 2013/01/01/00 UTC

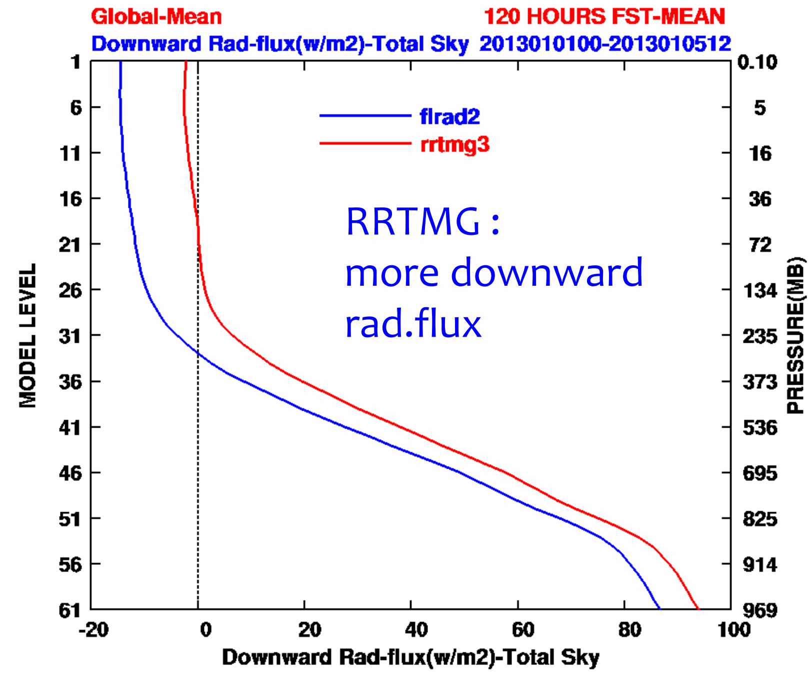


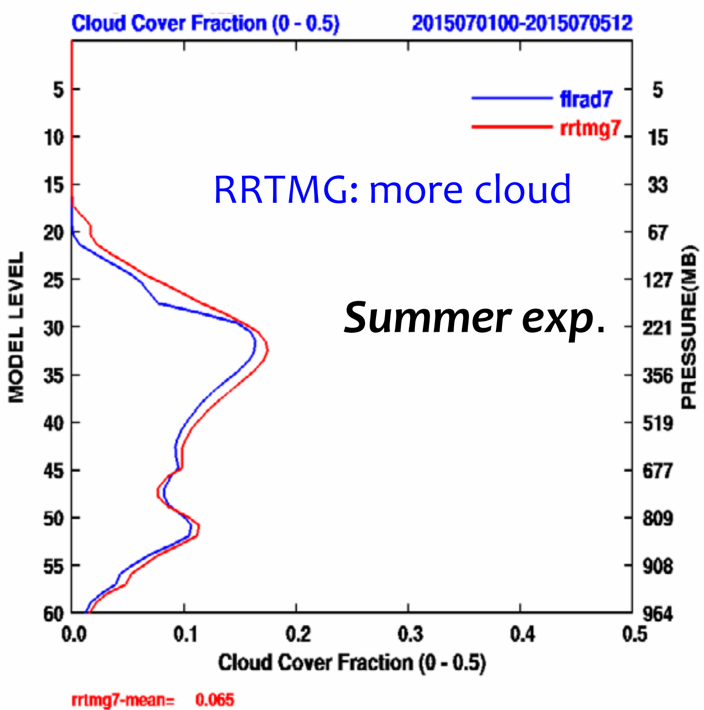


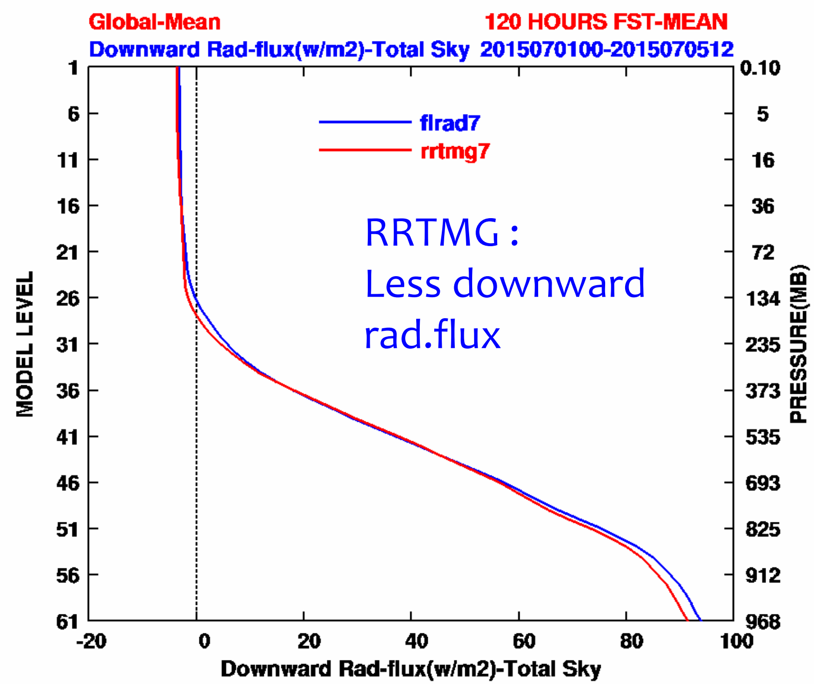





Global-Mean
120 HOURS FST-MEAN
Cloud Cover Fraction (0 - 0.5)
2013010100-2013010512
flrad2
rrtmg3
RRTMG: Less cloud
Winter exp.
MODEL LEVEL
PRESSURE(MB)
Cloud Cover Fraction (0 - 0.5)


Global-Mean
120 HOURS FST-MEAN
Downward Rad-flux(w/m2)-Total Sky
2013010100-2013010512
flrad2
rrtmg3
RRTMG :
more downward
rad.flux
MODEL LEVEL
PRESSURE(MB)
Downward Rad-flux(w/m2)-Total Sky


Cloud Cover Fraction (0 - 0.5)
2015070100-2015070512
flrad7
rrtmg7
RRTMG: more cloud
Summer exp.
MODEL LEVEL
PRESSURE(MB)
Cloud Cover Fraction (0 - 0.5)
rrtmg7-mean= 0.065


Global-Mean
120 HOURS FST-MEAN
Downward Rad-flux(w/m2)-Total Sky
2015070100-2015070512
flrad7
rrtmg7
RRTMG :
Less downward
rad.flux
MODEL LEVEL
PRESSURE(MB)
Downward Rad-flux(w/m2)-Total Sky

Summary & Future work

- *In general, RRTMG package and ozone prognostic scheme have better performance for most cases, especially in south hemisphere.*
- *RRTMG scheme improves the cold bias at model top .*
- *Cloud radiative forcing is one of the most important process in radiation scheme. In the future, we have to continue our efforts to improve model moisture field and cloud, to lead to more proper cloud-radiation process in CWBGFS.*