交通部中央氣象局委託研究計畫成果報告

評估及更新中央氣象局全球模式之非對流降水物理過程（3）

Improvement and Upgrade of Cloud Parameterization in the Global Forecast System at the Central Weather Bureau

計畫類別：☐國內　☑國外

計畫編號：MOTC-CWB-95-3M-03

執行期間：95 年 1 月 1 日至 95 年 12 月 31 日

計畫主持人：李瑞麟

執行單位：Real One Connection

中華民國 95 年 12 月

Final Report

Improvement and Upgrade of Cloud Parameterization in the Global Forecast System at the Central Weather Bureau (3)

Project number: MOTC-CWB-95-3M-03

Principle Investigator: Dr. Jui-Lin F. Li

November 2006

SUMMARY

The goal of this project is to improve the weather forecast skill and capability of climate simulation of the global forecast system (GFS) at Central Weather Bureau (CWB). NCEP prognostic cloud scheme (PCW) and NCEP simplified Arakawa-Shubert scheme (SAS) and SAS with momentum friction (SASM) convective scheme are implemented and evaluated against operational moist package (OPS) with the GFS. The evaluations were conducted through a single column model (SCM) of the GFS forced by the large-scale conditions from the observed ARM, TOGA COARE and GATE column environment as well as with the full-coupled version of the GFS forced by annual cycle SSTs.

We have conducted a five days forecast to examine the forecast biases with the PCW and OPS versions of the GFS. With the PCW only, the temperature biases have been reduced (improved) with decreased model cloud fractions possibly associated with less simulated high cloud fraction and weaker radiative cooling/warming in the upper/mid-lower troposphere. Note that, however, one critical upgrade for the direct couple between the PCW and radiation package has not completed yet in this version. Thus, the PCW cloud water (rather than diagnostic by relative humidity only) has not been incorporated properly for determining model cloud fraction in the radiation scheme. The revision of the interplay between the PCW cloud scheme and the radiation scheme has been undergoing.

Model with the SAS (and PCW), on the other hand, produced too strong convections with little model clouds presented, the model produces very weak vertical gradient of longwave and shortwave radiative forcing with SAS version. Detail diagnostic analysis to unveil these issues is under going.

We will continue on upgrading/evaluating the coupling between the convection (SAS), cloud (PCW) and radiation schemes in GFS.

1. Background

It is important to represent convective cumulus cloud and stable clouds and their interplay with radiation realistically in GCMs. Particularly, the stable cloud (and its fraction) is a critical element for the radiation through the link between the convective tower and anvils. We have implemented the NCEP prognostic cloud scheme (PCW) and Arakawa-Shubert scheme (SAS) schemes (both with and without momentumn effect) in the CWB CFS.

We have conducted experiments with a single column model (SCM) mode as well as full-coupled mode for short term weather forecast and long term climate simulations.

1. SCM version:
    - With the PCW only, the simulated total precipitation rates are realistic forced by the observed large-scale forcing from field experiments from ARM sites and TOGA COARE and GATE. The stratiform precipitation was underestimated with overestimated convective precipitation.
    - With the PCW and SAS, the simulated cumulus precipitation rates are excessively strong. The simulated fields of humidity and temperature exhibited fairly large biases when forced by the observed large-scale forcing from field experiments from ARM sites and TOGA COARE and GATE.
    - With the PCW and SAS, but with reduced cumulus updraft: The simulated precipitation rates are realistic when the updraft is reduced to a factor of $\sim 10^{-2}$. The simulated fields of humidity and temperature biases are comparable to the observed large-scale fields (Figures not shown). Note that, the interactions between the model radiation and PCW has not been upgraded in this version.

2. Full coupled 3-D with PCW and/or SAS schemes:

- Typhoon forecast experiments with full-coupled version with PCW and SAS: The model failed to maintain Typhoon intensity and structure after 48 hours.
- With the SAS and PCW, both the climate (perpetual run for 150 days) and multi-year runs forced by annual cycle SSTs exhibited significant systematic biases in particular for the radiation related fields such as longwave/short wave heating vertical structures.

In general, model with the SAS and PCW produces too strong convections (with delay) and weaker grid-scale precipitation (and very little large-scale clouds). With little model clouds presented in radiation, the model produces very weak vertical gradient of longwave and shortwave radiative heating producing an imbalance between convection and radiation. In order to understand the deficiencies and isolate the effects from SAS, we have conducted detail budget diagnostic study with PCW to unveil these issues focus mainly on the interaction between radiation and cloud processes.

2. Cloud scheme: a brief overview for the PCW scheme

In the current cloud scheme, supersaturation is simply removed through the condensation of excessive water vapor. The saturated water vapor is condensed to liquid water and the latent heat is released to the local vertical adjacent layer. The condensed water falls to the layer beneath and re-evaporates until relative humidity there reaches 100%. Such that, the treatment of the clouds is over simplified and offers no direct coupling to the convective process. A prognostic cloud water (PCW) scheme (Zhao and Carr, 1998) of the Eta model at the NCEP is implemented and evaluated in the GFS at CWB. In a summary of this scheme:

- Cloud water and cloud ice are prognostically calculated in both stratiform and convective precipitation parameterizations. The predictive variable (either the cloud water or ice mixing ratio depending on the temperatures) to represent cloud properties.
- A link between convective core and the stable cloud system is directly coupled.
- Evaporation and horizontal advection of cloud are allowed.
- Precipitation is diagnostically calculated directly from the cloud water/ice mixing ratio. Both frozen and liquid precipitation can be prognostically produced, enabling this scheme to predict precipitation type.
- This scheme allows part of the condensed water/ice to fall as precipitation and the rest to stay in the atmosphere as nonprecipitating clouds and advect with the air.
- The large-scale condensation method based on relative humidity, changes of temperature, moisture, and pressure that is more thermodynamically and hydrologically consistent with the model.
- More realistic ice-phased clouds calculations of condensation/deposition and precipitation, as well as latent heating release.

The interface between the PCW and radiation scheme, however, needs to be upgraded. In particular, the cloud fraction from cloud scheme has to be modified for the use of the radiation.

Reference

李瑞麟，2005: 評估及更新中央氣象局全球模式之非對流降水物理過程。中央氣象局委託計畫研究報告。

汪鳳如, 馮欽賜 and 李瑞麟, 2006: 氣象局全球模式之網格尺度降水參數化的更新評估測試. Conference 2006.

Klinker, E., and P. D. Sardeshmuk, 1987: The diagnosis of systematic errors in numerical weather prediction models. *Workshop Proc. Diabatic Forcing, Reading*, United Kingdom, ECMWF, 209-244.

Liou, Chi-Sann, Jen-Her Chen, Chuen-Teyr Terng, Feng-Ju Wang, Chin-Tzu Fong, Thomas E. Rosmond, Hong-Chi Kuo, Chih-Hui Shiao, and Ming-Dean Cheng, 1997: The second-generation global forecast system at the central weather bureau in Taiwan. *Weather and Forecasting*, 3, 653-663.

Pudykiewicz, J.,R. Benoit, and J. Mailhot, 1992: Inclusion and verifyication of a predictive cloud-water scheme in a regional numerical weather prediction model. *Mon. Wea. Rev.*, 120, 612-626.

Zhao, Qingyun and F. H. Carr, 1997: A Prognostic Cloud Scheme for Operational NWP Models. *Mon. Wea. Rev.*,125, 1931-1953.

3. The GFS simulations with the SAS and PCW schemes: some issues

With the revised version of the GFS (with the PCW and SAS schemes) the simulated convective heating/moistening rates are stronger (particularly with the SAS) than the GFS operational model simulation (OPS) shown in figures 1 and 2. The model with SAS simulated convective heating/drying rates are 2~3 factors stronger than the OPS with the total precipitation rates of 2.9 to 3.2 mm/day (not shown). These are consistent with those results from the SCM runs. The enhanced total precipitation rates are also consistent with stronger surface latent heat fluxes (not shown).

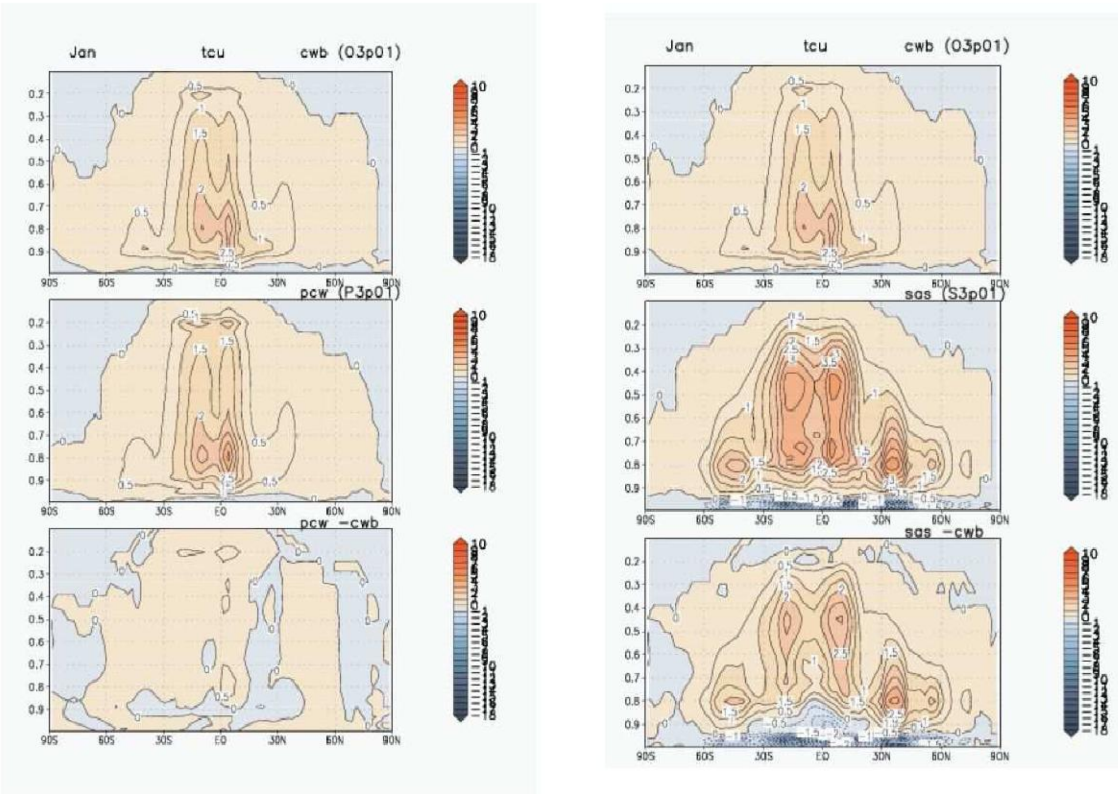

Fig. 1 The zonally average vertical cross section of convective heating rates with CWB OPS (left and right upper panels), PCW (left/middle panels) and SAS (right/middle panels). The difference is at bottom panels.

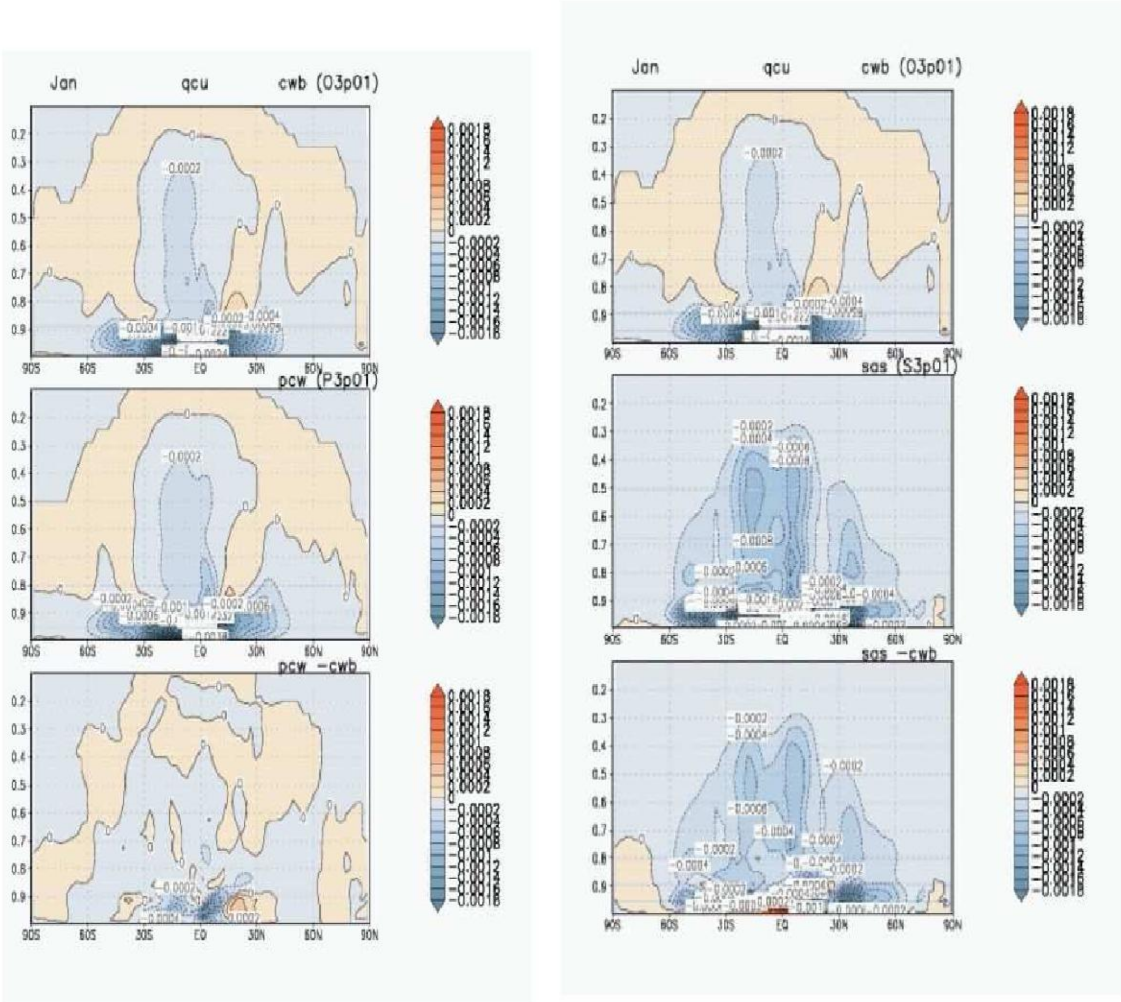

Fig. 2 The zonally average vertical cross section of convective moistening rates with CWB OPS (left and right upper panels), PCW (left/middle panels) and SAS (right/middle panels). The difference is at bottom panels.

We found that the model simulated too strong cumulus updraft and precipitation with SAS. In order to identify the causes of these deficiencies, we have conducted sensitivity tests by tuning physical parameters with SCM and full-coupled version including:

- Rain re-evaporation efficiency,
- Entrainment rate,
- Strength of the cloud updraft/downdraft mass fluxes etc.

We found that, the model with the cumulus updraft with a factor of 0.01~0.05 produced more realistic precipitation rates in the SCM. The efforts are still on going for a best set of the parameters for the use in the full couple mode. Another critical issue we have is that, with SAS scheme, the model produces smaller amount of cloudiness with little vertical gradient of shortwave and longwave cloud radiative heating. This might imply an inbalance between the convection-radiation. We found that with the SAS, the model delayed the convection and produced less cloudiness in upper troposphere resulting in weaker cloud radiative effects (less greenhouse effect in the mid and low troposphere and less longwave radiative cooling in the upper troposphere). It is possible that the convective-radiative imbalance caused by little cloud fraction initially might cause the delay the convection and the accumulate CAPE release as excessive precipitation; the imbalance between the SAS convective heating/moistening and radiative effects. In order to identify the problems, we conducted five days forecast to examine the impact from the cloud radiation with the PCW.

4. Evaluation of the PCW scheme in the GFS

Detailed diagnostic study with the revised GFS has been conducted using a version of T179 (540x270) with 30 vertical levels (Liou et al. 1997). The GFS was initialized at 12z, 1st, April 2006. The model then launched 120 hours forecast at 12z and 6 hours forecast for 00, 06 and 18Z, respectively, for three months. The experiments were conducted with the operational version (OPS) and with the PCW cloud scheme (PCW).

(a)

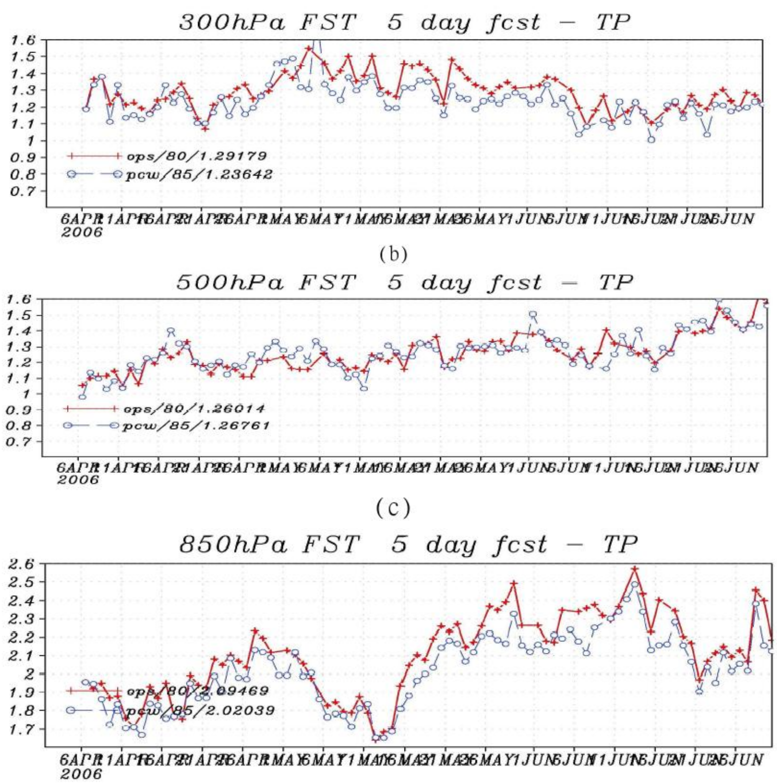

Figure 3 Five day forecast bias between OPS and PCW for period of 1st April to 30th June 2006 for tropical belt (30S-30N) at (a) 300 hpa, (b) 500 hPa and (c) 850 hPa height. The red (solid line) is for OPS and the blue (dashed line) is for PCW.

a. Results

1. Forecast Score

We examined the ACH from the 5 days forecast for Northern and Southern H. and tropical belt, respectively. The ACH definition is followed the method of Chen et al. (1989). The forecast score is defined as perfect if the ACH is one. It is found that the PCW (汪鳳如 2006) has better score in most cases than OPS for temperature (T), zonal wind (U) in tropical belt at 300, 500 and 850 hPa, respectively.

(a)

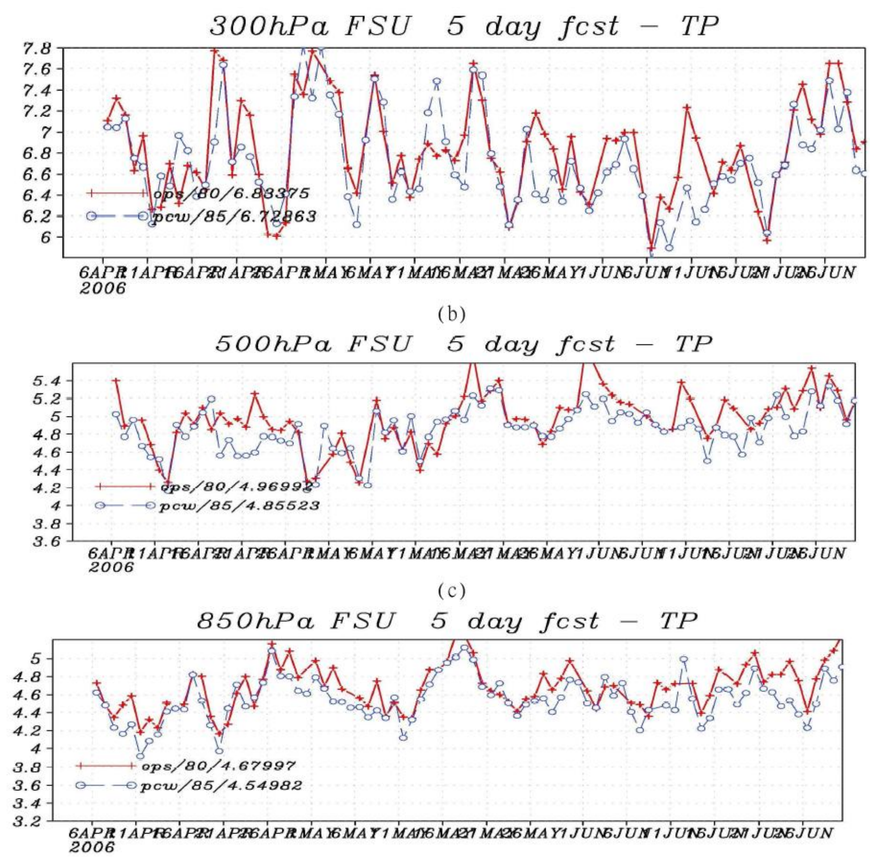

Figure 4 Five day forecast standard deviation for period od 1st April to 30th June 2006 for tropical belt (3oS-30N) for (a) 300 hpa, (b) 500 hPa and (c) 850 hPa zonal wind (U). The red (solid line) is for OPS and the blue (dashed line) is for PCW.

2. Systematic Biases

Figure 5 is the five days forecast systematic bias (the difference between the forecast and analysis) of temperature fields for the OPS (upper panel) and PCW (lower panel) version, respectively. It is evidence that the cold biases have been reduced from the OPS (~-1.5 K at 100 hPa and warm biases below 150 hPa ~1 K) to the version of the PCW (~-1 K at 100 hPa and ~0.5 K at and below 150 hPa), respectively. In general, the PCW version improves the five day forecast skill by reducing the forecast biases (~50%) in deep Tropics (30S~30N).

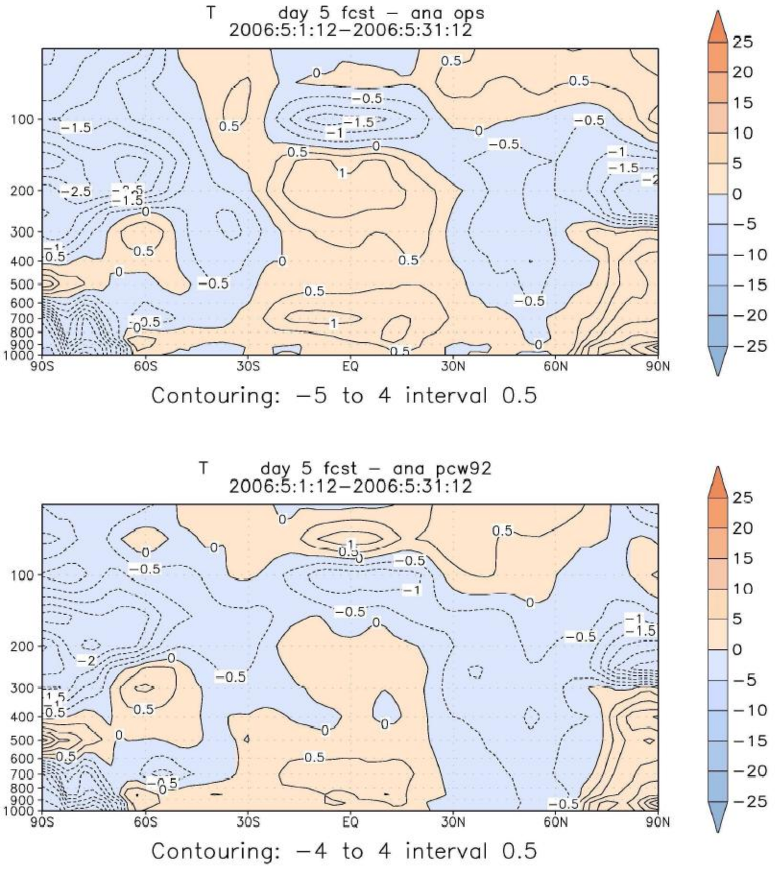

Figure 5. Zonal average of five day forecast bias for May 2006 with (upper) OPS and (lower) PCW versions. We apply budget analysis following Klinker and Sardeshmuk (1987) to identify the sources of the biases.

We examined the cloud fraction changes with the PCW. It is shown that the cloud fractions are reduced with the PCW resulting in the reduction for both longwave and shortwave raditive heating shown in Fig. 6 – 8. The differences are basically from the reduction of the model cloud fractions seen by model longwave and shortwave radiation schemes.

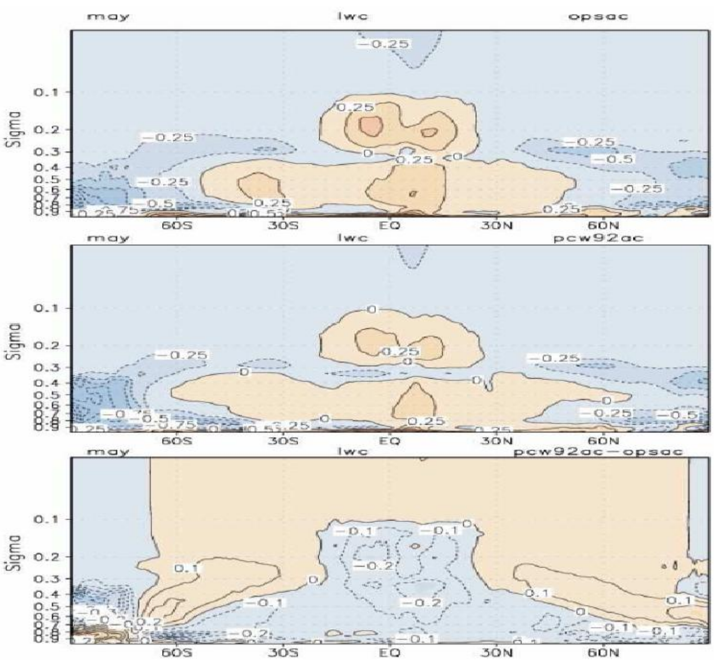

Figure 6. Zonal average cloud fraction seen by model longwave radiation for May 2006 with (upper) OPS, (middle) PCW versions and PCW-OPS (lower).

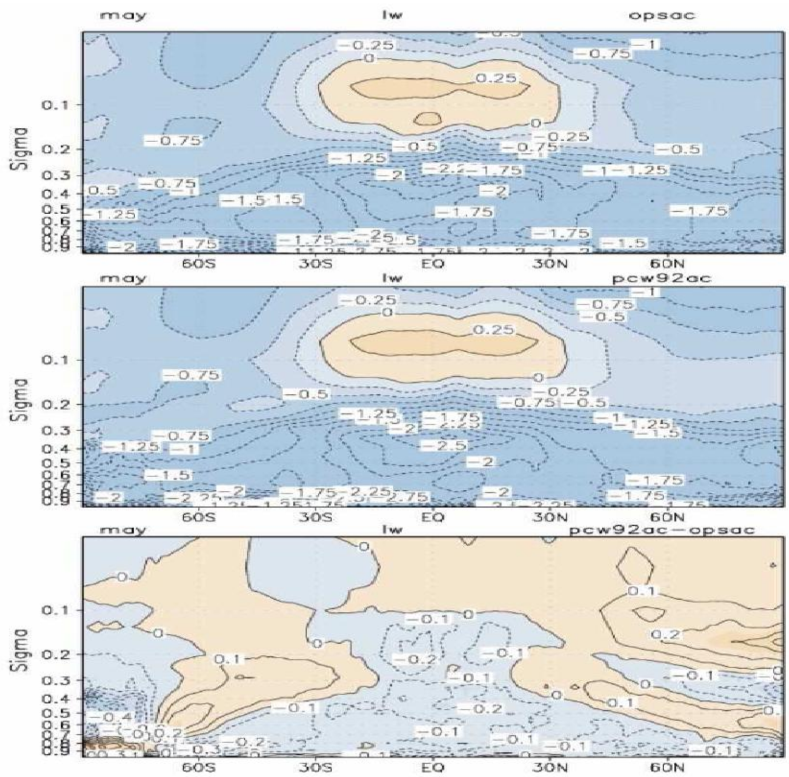

Figure 7. Zonal average longwave radiative heating rates for May 2006 with (upper) OPS, (middle) PCW versions and PCW-OPS (lower).

.

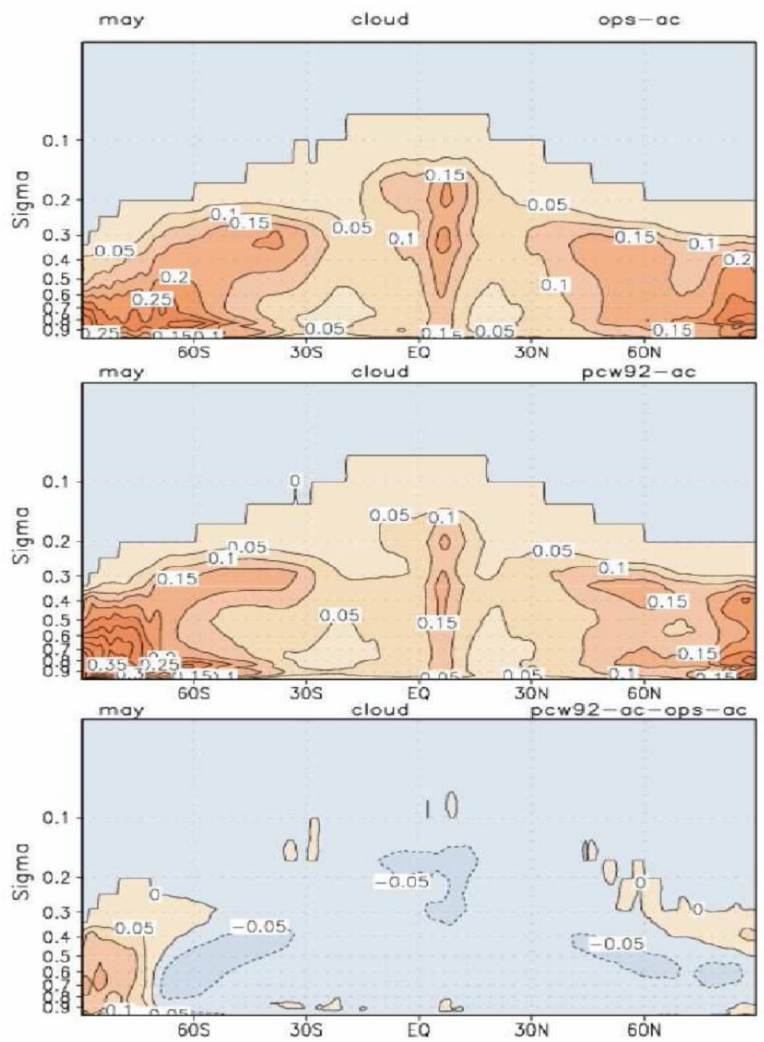

Figure 8. Zonal average total loud fraction seen by model radiation for May 2006 with (upper) OPS, (middle) PCW versions and PCW-OPS (lower).

3. Budget analysis

Following the method of Klinker and Sardeshmuk (1987), we use diabatic budgets to identify the sources of the forecast biases discussed in the previous sections. For temperature forecast field we take average with 30 days of 24 hours forecast for the OPB and PCW versions shown in the figure 9.

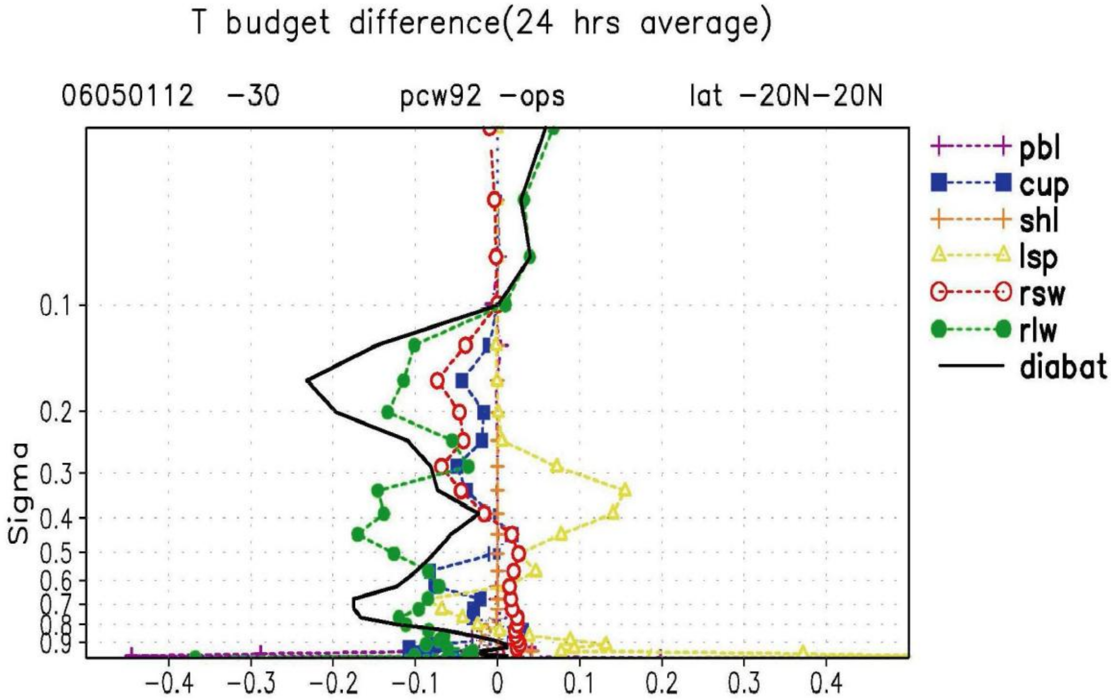

Figure 9. The vertical diabatic budget differences at tropical belt (20S~20N) between the PCW and OPS versions from 24 hours forecast in May 2006.

Figure 9 shows the diabatic temperature budget differences between the PCW and OPS. It is clear that the warming above 100 hPa is contributed mainly from the longwave radiation with PCW consistent with the decreased cloud fraction seen by the longwave radiation (Fig. 6). This alleviates the degrees of cold biases with the OPS. The question is that if the cloud fractions with the PCW are realistically represented for the radiation or not.

From above, we conclude that, with the PCW, the radiative effects play the major role on the reduction of the systematic biases with the PCW. With the PCW, model produces less cloud amount and therefore less cloud top radiative cooling and greenhouse warming in the mid-low troposphere. This alleviates temperature biases mainly in the tropical troposphere. We found that much lower upper cloud fraction than the OPS simulated by the PCW produce less longwave radiative cooling resulting in warmer upper troposphere than that with the OPS simulated. The shortwave heating effects are also responsible for the temperature biases with the associated cloud fraction changes. Less high clouds produces less shortwave heating relatively. We conclude that the reduction of the model temperature forecast biases is mainly due to less cloud amount simulated by the PCW.

5. Discussion

We have examined the temperature forecast biases with the PCW and OPS versions of the GFS. It is noted that the excessive high cloud has been found with the OPS version producing cold/warm biases in the upper/mid-lower troposphere; i.e., from excessive cloud top radiative cooling and less greenhouse warming in the upper and mid troposphere, respectively. Note that, up to date, the link between the PCW and radiation in the GFS has not been upgraded fully. The interaction/link between the PCW and radiation the model produces less high cloud fractions. This might be due to the detrained cloud waters generated by the PCW has not been linked properly to the radiation in the GFS. In other word, the improved forecast could be due to the smaller high cloud fraction reducing radiative cooling/warming in the upper/mid-lower troposphere relative to the OPS version of the GFS. In other words, we do not know weather the lower simulated high cloudiness is caused by RH critical values currently used by the OPS for determining the cloud fraction and/or the inconsistency between the convective and cloud schemes cloud properties and/or radiation scheme.

In our future work, we will continue on utilizing the SCM version of GFS with PCW and SAS schemes with upgrading interactive radiation scheme to look into in more detail on cloud-radiation interaction to identify the cause responsible for the current deficiencies found so far.