出國報告（出國類別：實習）

研習多模式系集氣候預報統計降尺度技術

偶合與非偶合氣候模式在北半球冬季的比較

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摘要

若以是否考慮大氣與海洋之間的交互作用來區別，氣候模式主要可分為兩大類，其一為不考慮交互作用的大氣環流模式(Atmospheric General Circulation Models；AGCMs), 另一為考慮兩者有交互作用的大氣海洋偶合模式(Coupled atmosphere-ocean GCMs；CGCMs)。本研究比較了 AGCMs 與 CGCMs 在北半球冬季(12 月至隔年 2 月)於 1982 至 2002 之間的表現，發現 AGCMs 與 CGCMs 表現優劣與否均於聖嬰與南方振盪現象(El Niño-Southern Oscillation； ENSO)的強度有密切相關，而且，兩者表現好的範圍也剛好是 ENSO 影響程度較明顯的地區。另外，當 ENSO 訊號明顯時，兩者的表現均較好，若 ENSO 訊號微弱時，AGCMs 與 CGCMs 之間的差異性較大。

另外，本研究亦評估 CGCMs 在 1 個月與 4 個月不同預報領先時間對 ENSO 與 ENSO Modoki 的掌握能力，發現不論在 1 個月或 4 個月的預報領先時間，CGCMs 掌握 ENSO 的能力均相當好。相對來說，對 ENSO Modoki 的掌握能力在 1 個月預報領先時間略為減弱一些，但在 4 個月預報領先時間其能力就明顯偏弱。

本研究亦發現，AGCMs 對於熱帶強對流區與弱對流區的降水分別有低估與高估的誤差，CGCMs 亦有類似與但較不明顯的誤差。這一個對熱帶降水的誤差評估，在冬季與夏季亦成立。

關鍵詞：氣候模式比較

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一、目的

此行主要目的乃赴韓國亞太經合會氣候中心(Asia Pacific Economic Cooperation ClimatecCenter；APCC)進行「研習多模式系集氣候預報降尺度技術」，以精進專業技能、提升英文能力，有利業務的推動與發展。

天氣預報的可信度一般隨著預報的天數遞減，目前可靠天氣預報日數大約可達7至10日。僅管如此，預報時間更長的季節預報還是有可能的。Palmer and Anderson（1994）提出季節預報可行的原因如下：（1）因爲時間平均的大氣環流要比其在某個特定時間的狀態可預報，（2）因爲有些環流型態要比平均狀態可預報，（3）因爲緩慢而且可預報的下邊界變化（特別是海面溫度）會影響大氣環流的狀態與特性。也就是說，變化相對緩慢的海溫是季節預報的主要根據。海溫是水氣最主要的來源，而水氣凝結釋放出的潛熱是驅動熱帶大氣環流最重要的能量，簡而言之，海溫預報的技術是季節預報優劣最主要的關鍵之一。也因此國際上在約20年前實行以觀測海溫驅動大氣環流模式，並比對其表現的模擬工作計畫（Atmospheric Model Intercomparison Project；AMIP, Gates, 1999）。

過去的研究指出，異常海溫對於季節平均環流與降水異常有顯著影響(Shukla and Wallace 1983; Livezey et al. 1996; Barnett et al. 1997; Kumar and Hoerling 1998)。若以是否考慮大氣與海洋之間的交互作用來區別，氣候模式主要可分爲兩大類，其一爲不考慮交互作用的大氣環流模式(Atmospheric General Circulation Models；AGCMs)，另一爲考慮兩者有交互作用的大氣海洋偶合模式(Coupled atmosphere-ocean GCMs；CGCMs)。由於模式的缺陷以及氣海耦合過程的複雜性，當今的 CGCMs 產出的季節預報海溫其預報技術得分，總體而言，尚略遜於 AGCMs，其原因爲 CGCMs 對熱帶海洋與大陸的氣候場模擬的不是很好(Mechoso et al. 1995)。

AGCMs 方式首先由 Bengtsson et al.(1993)提出，作爲邊界條件的海溫預報乃經由特定的耦合模式或經由統計模式或兩者整合而取得，再用來驅動大氣環流模式，因步驟需經 2 步完成，故此系統又稱二步法(Tier-two)。然而，在真實大氣-海洋系統中，兩者會有交互作用，爲符合真實的環境，CGCMs 系統就在 20 世紀末被開發出來。在 CGCMs

系統中，海溫本身就是預報產品，海溫與大氣兩者會相互影響，此法又稱一步法(Tier-one)。過去的研究中發現，除了聖嬰與南方振盪現象(El Niño-Southern Oscillation；ENSO)影響程度較強的區域之外，AGCMs 似乎比 CGCMs 有較佳的季節預報技術得分。此結果在西北太平洋及東印度洋等熱帶暖池區域更是明顯。照理說，季節平均環流與降水異常也應該是 AGCMs 系統有較佳的結果。然而，實驗事實卻是相反。CGCMs 系統在上述季風海洋與暖池區域較 AGCMs 系統反而有較佳的大氣環流與降水的季節預報技術，暗示在季風盛行區域 AGCMs 是有不足之處。

關於 AGCMs 與 CGCMs 的比較，Wang et al.(2004)分析實際的觀測資料發現，在季風盛行的洋面，海溫會因強降水而有降溫現象，即降水與海溫呈現負相關關係。但此海溫-降水的負相關只有 CGCMs 能成功摸擬，AGCMs 無法成功模擬此現象乃因缺乏大氣的回饋機制。並且，觀測的海溫異常落後於降水異常的現象，突顯了海氣耦合過程對於季風氣候區之季節預報具有關鍵的角色。上述觀測事實也建議季風洋區的降水異常並非單純的只決定於區域海溫邊界條件，而是海氣耦合過程欲達平衡下的產物。

另一方面，此不平衡的肇因也非只侷限於季風區本身，尚可能與遙地驅動力，例如赤道中東太平洋的 ENSO 現象，透過東西沃克環流(walker circulation)而與區域哈德雷環流(Hadley circulation)產生交互作用，進行影響遠地的環流。由於大氣的負回饋機制，即使預報不佳的 AGCMs 也可能產生較佳的降水預報。

在耦合系統架構下，假設區域海溫有了偏差，海氣耦合過程扮演了降低此初始偏差的角色。例如，正海溫偏差有機會促使正降水偏差，而後者透過雲量的增加降低入射的太陽短波導致淨地表通量的負偏差可以修正初始海溫的正偏差，甚或導致額外的冷卻海溫，在某些區域形成負偏差。此一大氣的負回饋機制(介於海溫-熱通量-降水之回饋圈)，在海溫是預設的 AGCMs 系統中是不存在的。因此，雖然海溫存在系統偏差，CGCMs 系統模擬的淨地表通量系統偏差却較 AGCMs 系統小的多。此一機制也解釋了 AGCMs 系統內，海溫-降水之間與觀測不符的正相關關係。過去的研究指出此一大氣負回饋機制對於夏季季風預報相當關鍵。最近的研究進一步指出大氣內部之正回饋機制對冬季西北太平洋海溫異常的維持也可能扮演某種角色(Chikamoto et al. 2009)。這正是當下各個

重要的作業中心正逐步將其預報主力從 AGCMs 系統移往 CGCMs 系統的原因之一。

過去許多研究發現，系集模式(multi-model ensemble, MME)的預報技術通常較單一的 AGCMs 或 CGCMs 模式好(Krishnamurti et al. 2000; Wang et al. 2008)。這是因爲假設模式的參數化及隨機誤差在各模式是獨立、無關的，所以 MME 可藉由平均來減少這些誤差，使預報技術較佳(Wang et al, 2009)。因此，本報告的主要重點在著重在 MME 的預報技術。

由以上說明可知，比較 AGCMs 與 CGCMs 的表現是必要的，但台灣不是世界氣象組織(World Meteorological Organization；WMO) 的會員國，要取得氣候預報資料不易。亞太經合會(Asia Pacific Economic Cooperation；APEC) 爲目前台灣能參與的國際組織，其會員國大約位於環太平洋地區，分別有台灣、日本、韓國、中國大陸、美國、俄羅斯及澳大利亞等 21 國，是亞太地區最重要的世界經濟組織之一。APEC 在 1998 年時便有成立氣候中心的規劃，最終，APEC Climate Center(APCC)在 2005 年於韓國釜山成立，其目的乃提供 APEC 會員國乃至於全世界各地的氣候預報資料，以因應氣候變遷的衝擊。

APCC(http://www.apcc21.net)存有大量的多國氣候預報資料，其科技部門目前由印度籍的 Saji Njarackalazhikam Hameed 博士和 Ashok Karumuri 博士共同領導，Saji 博士爲印度洋偶合(Indian Ocean dipole；IOD，Saji et al., 1997)的專家，而 Ashok 則專精於 ENSO MODOKI(Ashok et. al. 2007)。IOD 仍指熱帶印度洋東西洋面海溫距平的異常現象，最強盛的時期一般發生在北半球秋季，請參閱圖 1。而 ENSO MODOKI 爲赤道中太平洋與兩側異號的海溫異常現象，請參閱圖 2。IOD 與 ENSO MODOKI 是氣候系統兩個重要的自然律動。Saji 與 Ashok 博士在氣候診斷、預報等領域上都享有國際盛名。所以 APCC 是學習氣候模式比較的理想單位。職在韓期間受到兩位學者的指導，專業能力與英文能力均有所提昇。

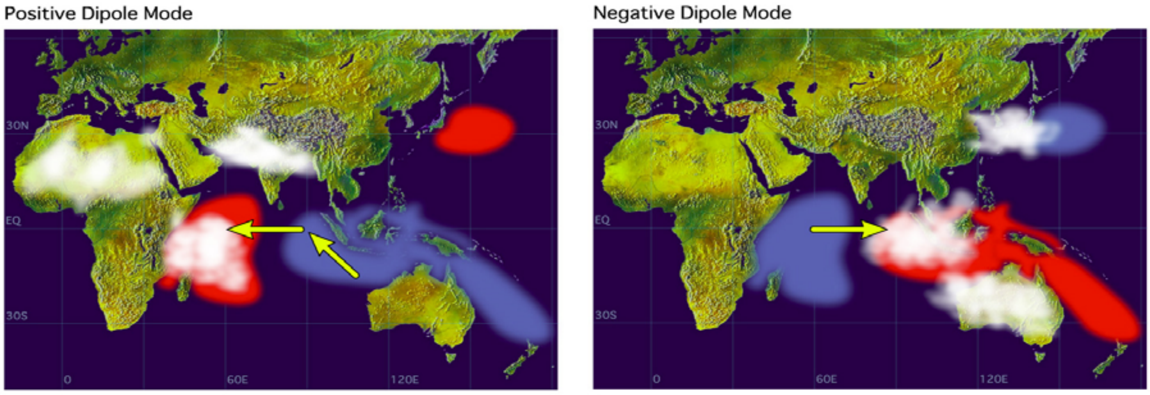

圖 1：印度洋偶合(Indian Ocean dipole；IOD)圖示。IDO 仍指熱帶印度洋東西兩側爲兩極的海溫距平，左圖爲正相位的 IOD，右圖爲負相位。圖片來源：http://www.jamstec.go.jp/frsgc/research/d1/iod/

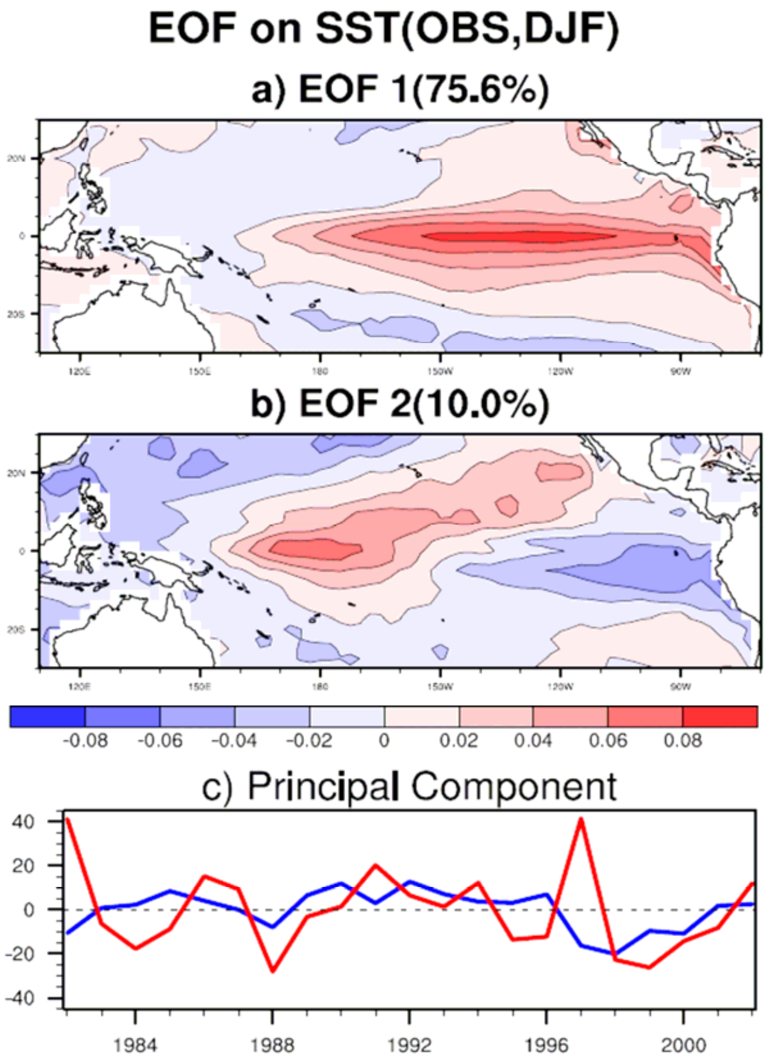

圖 2：ENSO MODOKI 說明。MODOKI 爲日文，意思仍指類似但不一樣。若將熱帶太平洋的海溫進行經驗正交函數分析(Empirical Orthogonal Function, EOF)，第 1 個模爲 ENSO(圖 a)，第 2 個模爲 ENSO MODOKI(圖 b)。其時間系列分別爲紅色線及藍色線(圖 c)。一般來說，傳統的 ENSO 指的是赤道東太平洋海溫的異常現象，而 ENSO MODOKI 爲赤道中太平洋與兩側異號的海溫異常現象。

二、過程

職此次赴韓行程說明如下：

日期	地點與相關工作內容
2009/2/23	台北→韓國釜山
2009/2/24~ 2009/3/6	由 Saji 博士簡介 APCC 環境，並指導職學習 NCAR Command Language(NCL)
2009/3/6~ 2009/7/17	1.由 Ashok 博士指導，評估 CGCMs 在全球與亞洲尺度的預報能力，當時的構想在於若能因此找出一些可用訊號，可藉由統計降尺度，增加其可應用性。 2.經職研究發現，CGCMs 與亞洲氣候的預報能力不佳，無法找出可以訊號，因此，Ashok 博士將研究方向轉向 AGCMs 與 CGCMs 的預報能力比較。 3. 6 月 22 至 24 日，參與於首爾舉行的 University Allied Workshop，發表 Identification of a multi-decadal teleconnection pattern in the extratropical Northern Hemisphere。
2009/7/17~ 2009/8/21	在完成 AGCMs 與 CGCMs 的預報能力比較後，Ashok 博士另指導在職評估模式對風暴路徑(storm track)的掌握能力，然限於時間不足，並無顯著的研究成果。
2009/8/21	韓國釜山→台北

三、心得

職因此難得機會，能赴南韓實習半年，接受 Saji 博士與 Ashok 博士的指導，並有數次英文口頭報告的機會，對於職有莫大的助益，職因此拓展國際觀、擁有更寬闊的視野，英文能力亦能有所進步。特此感謝中央氣象局能提供職此難得的經歷，並藉此感謝職出國期間，課內同仁對職工作及各方面的支援。另外，局內出國實習、進修的機會相對較少，冀望增加類似的出國實習的機會、經費，以培養人材，精進技能。

然而，職亦感氣象局有某些不足之處，如 APCC 共有約 20 個員工，未來更有擴編的計畫。相對來說，氣象局長期預報課可應用的正式職員只有 5 名，工作內容與 APCC 類似甚至更多、更雜，除此之外，長期課更被付與許多煩鎖的例行作業，占據了許多工作時數，大幅降低長期課的研發能力。如今，在氣候變遷的背景之下，氣候領域的研究已成爲國際間重視的議題，由今年年底即將在丹麥哥本哈根舉行的聯合國氣候變遷會議更可了解到，氣候變遷是目前最熱門、須迫切了解的科學議題，也因此各國相繼投入大量人力與經費，成立新的氣候研究中心，冀望能提高氣候預報的能力，以降低氣候變異的衝擊。而今年 8 月初的莫拉克颱風更是血濺濺的實例，說明了氣候變遷已正在進行，在地球村的全球人類正經歷氣候變遷帶來的衝擊，一旦它發生，可能帶來無法估算的人命與財產損失。然而，長期以來國內一直漠視氣象的研究，氣候預報、變遷等領域的研發更不被重視。台灣並不缺乏氣候人才，但缺乏發輝的舞台，只要投入更多的經費，台灣也可以成爲他國取經的氣候研究寶地。氣候研究若能進步，相信可以降低類似莫拉克颱風帶來的損害。

四、建議

本報告指出，影響氣候模式表現的關鍵氣候因子爲 ENSO 現象，當赤道中東太平洋海溫距平較強時，各預報模式均有較高的準確性。另外，模式表現較佳的範圍也剛好是 ENSO 影響程度較明顯地區，此關係可由比較圖 3 與圖 5 或圖 4 與圖 5 得到證實。圖 3 爲 CGCMs 與觀測場在 850 百帕溫度場的時間相關，其值介於±1 之間，相關係數愈高表示模式與觀測愈接近，即表現較佳。由圖 3 中可發現，CGCMs 表現最好的區域主要在熱帶地帶，尤其以西印度洋、中至東太平洋、南美洲及大西洋關係更爲顯著，中緯度的北太平洋亦有訊號；圖 4 與圖 3 有類似的結果。圖 5 爲 Niño3.4 指數(赤道中太平洋在 120°W-170°W，5°S- 5°N 範圍的海溫距平)與觀測場 850 百帕溫度場的相關係數，用來表示 ENSO 影響區域。比圖 3 至圖 5 發現，圖 3 及圖 4 相關係數高的區域，也是圖 5 相關係數高的範圍(不考慮正負值)。

模式表現較佳與 ENSO 影響顯著的區域兩者幾乎重疊的關係不僅在溫度場可被發現，在降水場也是有類似的相關，在圖 6 的 CGCMs 和圖 7 的 AGCMs 中，模式表現較佳的區域集中在熱帶太平洋，尤其在赤道中、東太平洋與台灣鄰近的菲律賓海附近。而這些模式表現較好的區域，也是 ENSO 影響程度較強的範圍(圖 8)。

目前國際間對 ENSO 的影響之了解已相當成熟，國內對 ENSO 與台灣氣候相關的研究亦相當豐富。當吾人在作氣候預報時若可預期未來將有 ENSO 的發展，對於將來的預報便較有信心。但台灣對於 ENSO 現象的反應較熱帶地區或美洲等地較不具一致性，原因乃是台灣位置 ENSO 能量傳遞的下流，而且位於季風最盛行的東亞地區，另外季內振盪等擾動亦會影響台灣氣候，東亞季風區複雜的多重尺度氣候系統使得 ENSO 與台灣氣候關係變得難以掌握。相對來說，與 ENSO 訊號不明顯時，各氣候模式的一致性較差，準確性也較差，此時氣候預報就是個困難的挑戰。關於 CGCMs 及 AGCMs 更多的說明及比較，可參閱本次研習之英文研究報告(如附錄)。

另外，台灣冬季降水主要來源爲鋒面降雨，由圖 6 中 NCEP、SinT 及圖 7 中 NIMR 結果可見在台灣鄰近的東亞沿岸有帶狀的鋒面降雨區，顯示這些模式對於東亞的鋒面掌握能力較佳，當吾人在進行氣候預報時，這些模式的參考比重可考慮較大一些。

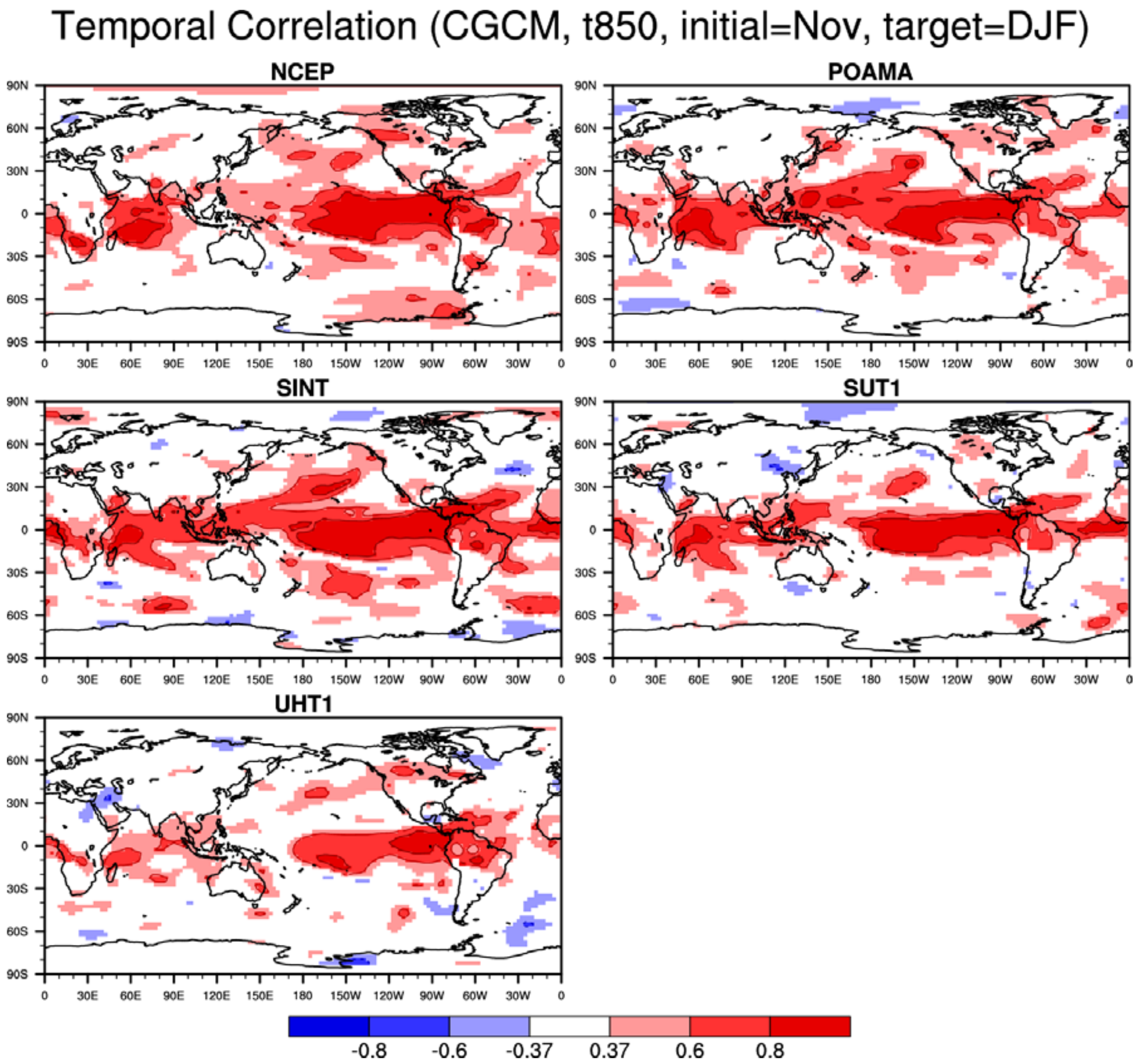

圖 3：CGCMs 與觀測場在 850 百帕溫度場的時間相關，時間為 1982 至 2002 年的 12 月至隔年 2 月，各模式名稱標示在各張小圖的標題。

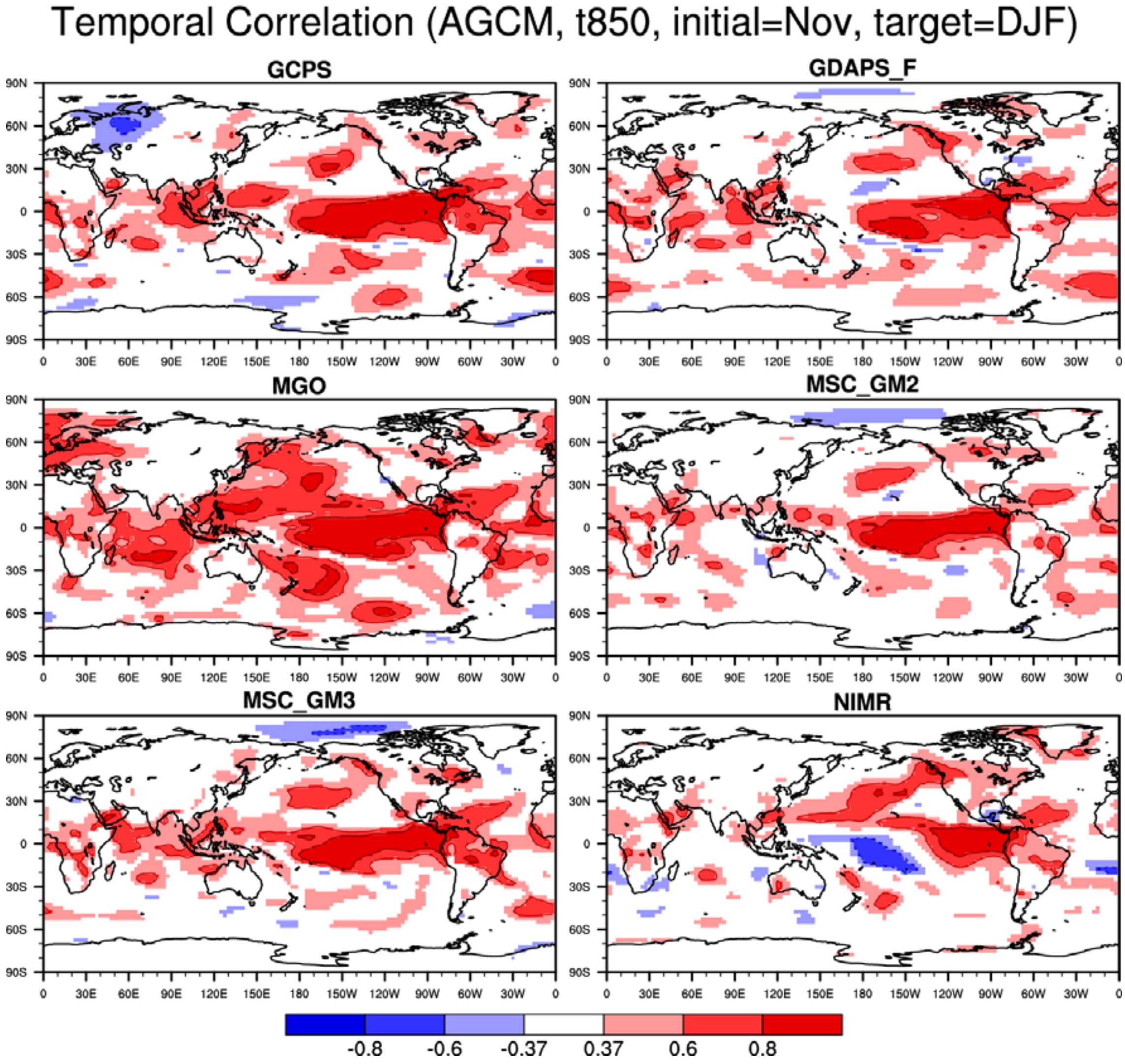

圖 4：同圖 3 但爲 AGCMs。

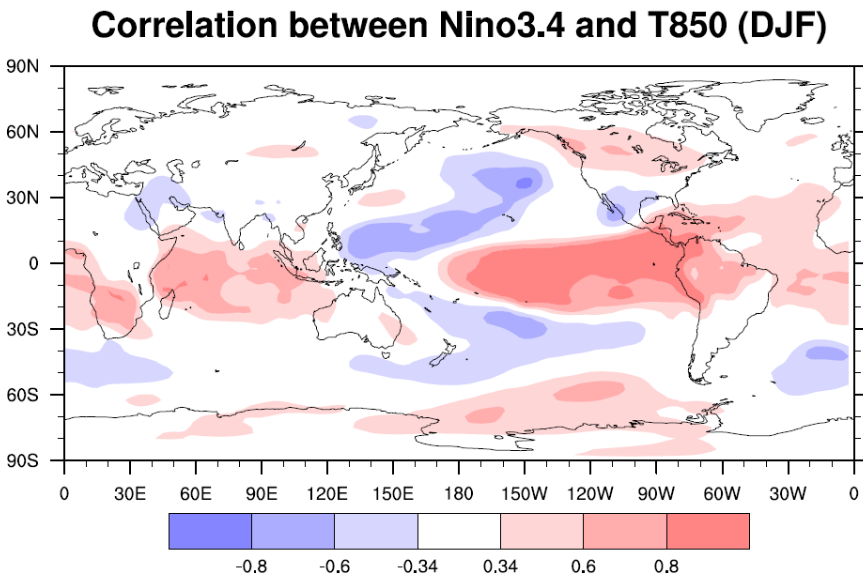

圖 5：Niño3.4 指數與觀測場 850 百帕溫度場的相關係數。

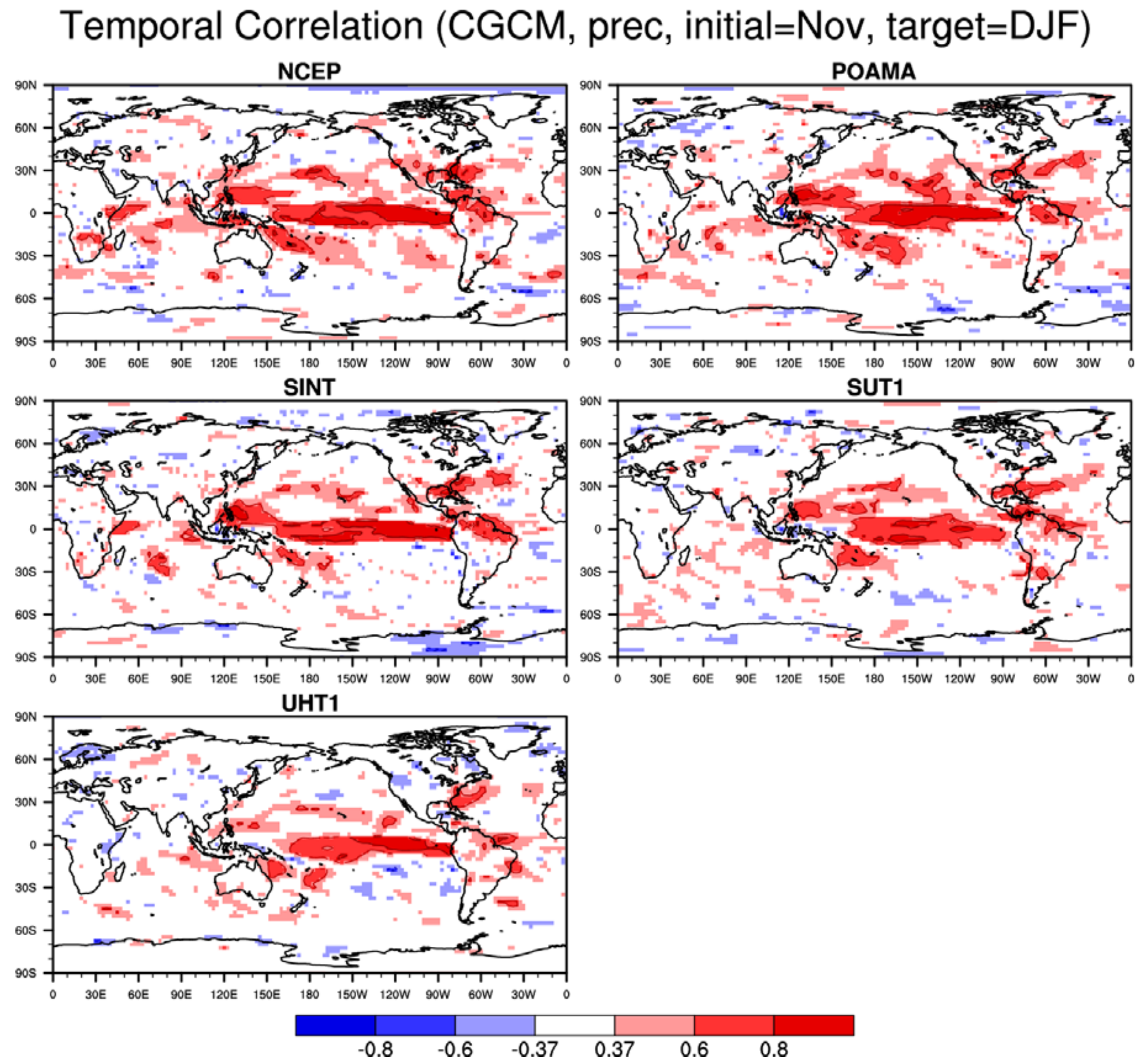

圖 6：CGCMs 與觀測場在降水場的時間相關，時間為 1982 至 2002 年的 12 月至隔年 2 月，各模式名稱標示在各張小圖的標題。

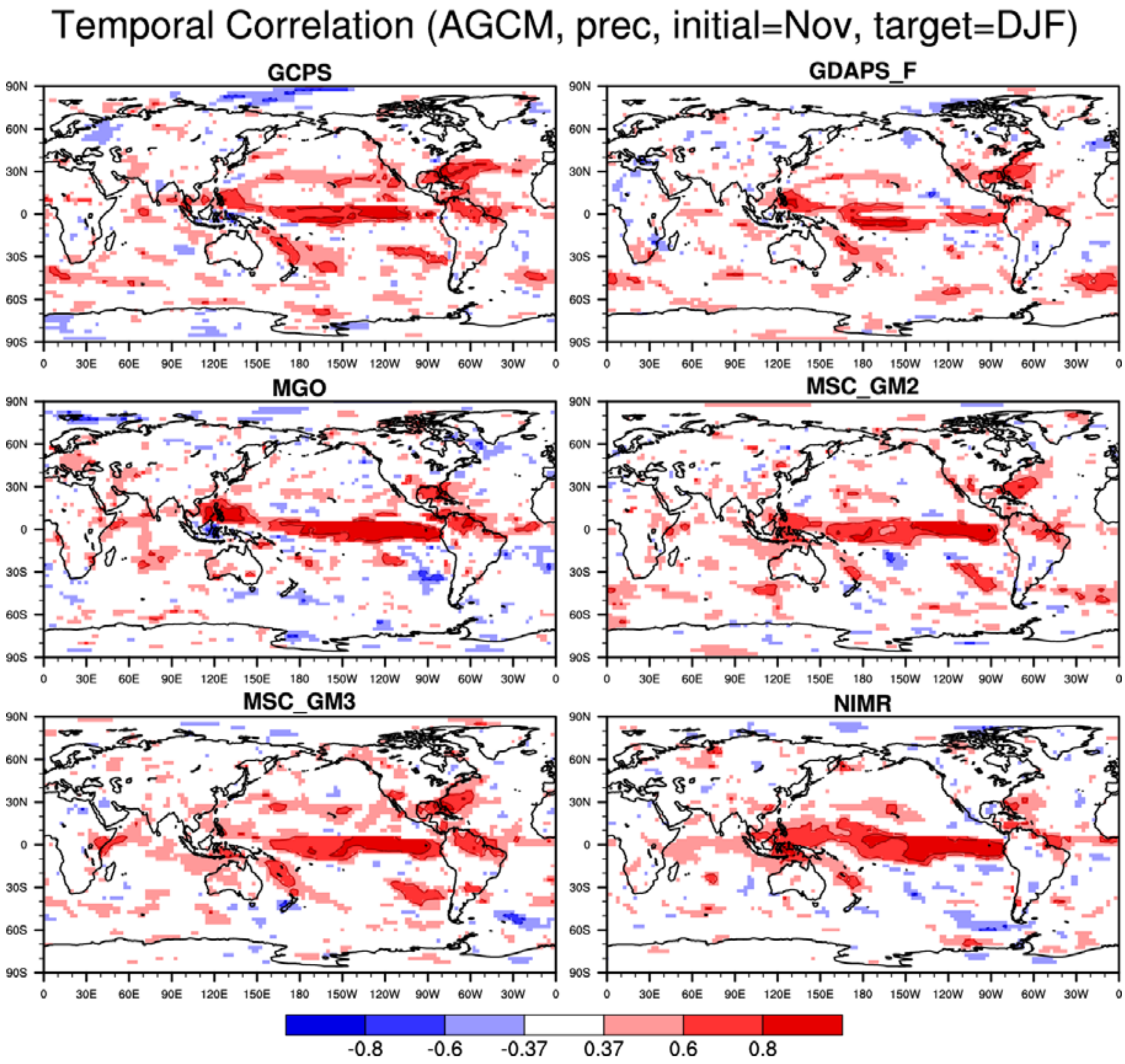

圖 7：同圖 5 但為 AGCMs

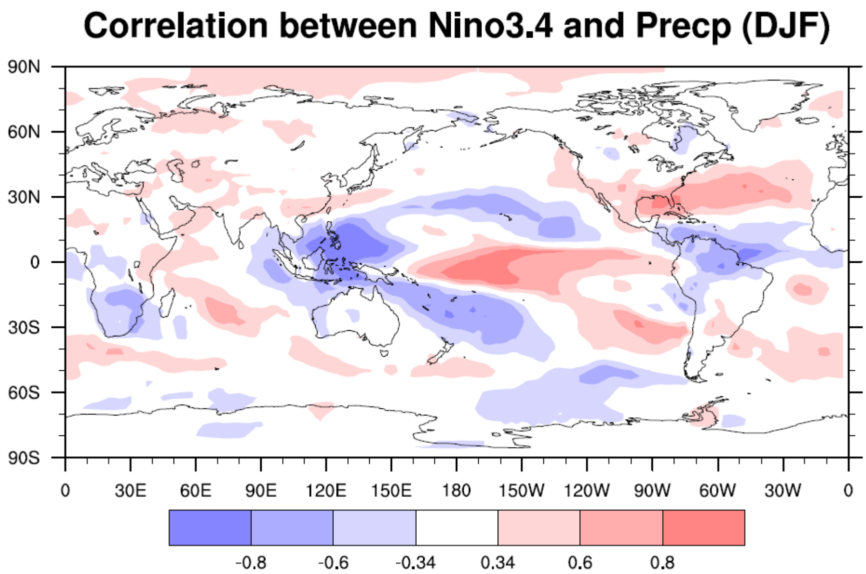

圖 8：Niño3.4 指數與觀測場降水場的相關係數。

降水的模擬一直以來都是氣候模式最困難的挑戰之一，本報告研究不同氣候模式對熱帶降水的表現顯示，對於熱帶強降水區的雨量估算，AGCMs 與 CGCMs 均有低估的現象，而此誤差尤以 AGCMs 明顯，而對於熱帶弱降水區的估算在 AGCMs 與 CGCMs 均有略爲高估的偏差(圖 9)。(上述的現象，不僅在北半球冬季如此，夏季亦有類似的現象，更詳細的內容，請參閱附錄的文件。)因此，吾人在以氣候模式進行氣候預報時，也應將此誤差也考慮進去。可惜的是，APCC 並無存放模式的水氣資料，無法針對此一議題作更深入的研究。

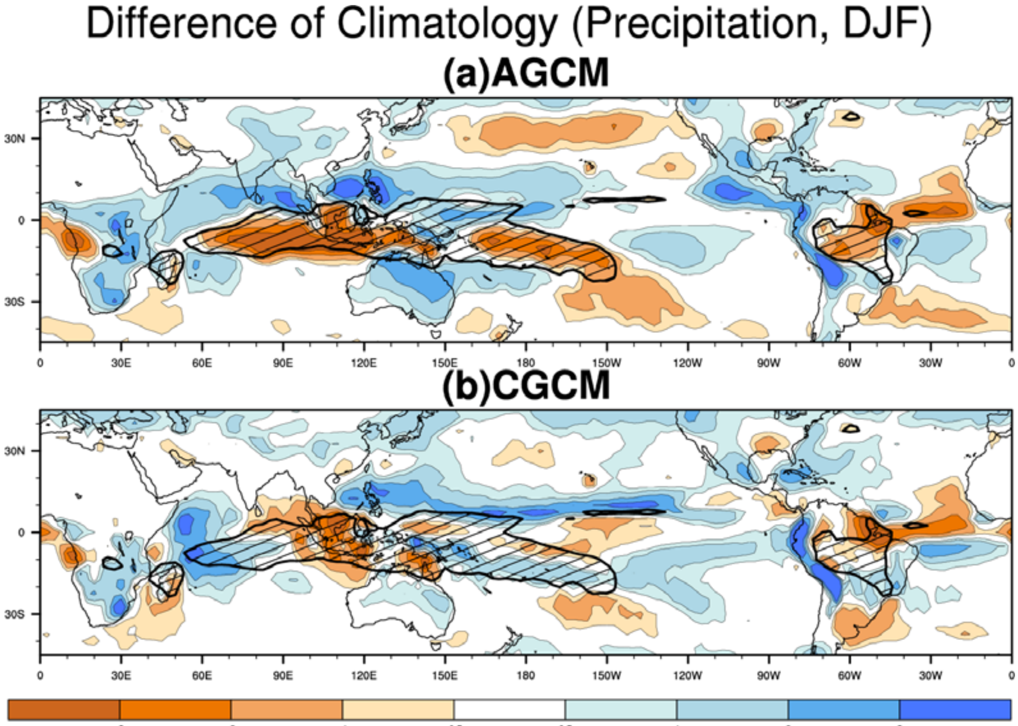

圖 9：模式與觀測降水氣候場的差異，時間爲 1982 至 2002 年的 12 月至隔年 2 月。差值爲觀測減模式，斜線區表觀測場降水平均大於 7mm/day 的區域。(a)、(b)分別爲 AGCMs 與 CGCMs。

總而言之，雖 AGCMs 與 CGCMs 在全球尺度的表現差異不大，但本研究亦指出，對於熱帶降水的估計，CGCMs 的表現略優於 AGCMs，國際間的研究亦指出，發展 CGCMs 是有助於改善氣候預報模式，尤其位於季風最爲盛行的東亞地區更是如此。APCC 的未來方向爲 6 個月以上的氣候預報，此目標亦需由藉由改善 CGCMs 來完成。然而，國內目前尚無發展完整的 CGCMs，發展 CGCMs 或許是中央氣象局未來的重點方向之一。

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附錄：

Compare the performance between AGCMs and CGCMs in the boreal winter

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Abstract

We evaluated the performances between AGCMs hincast and CGCMs hincast in DJF for the period of 1982-2002. The domains of high skill in both of AGCMs and CGCMs almost coincide with the areas that efficient impacts association with ENSO in temperature and precipitation. The close temporal relation between predictability of models and strength of ENSO are also seen. Our result also indicates that in absence of the strong ENSO force, the performance of AGCMs and CGCMs models may become more divergent, thus may decrease the predictability of MME.

The canonical ENSO can be captured very well in one-month or 4-months lead CGCMs, and the capability in capturing the ENSO Modoki are diminish lightly and largely in one-month and 4-months lead CGCMs, respectively. On the other issue, we found that the precipitation in AGCMs almost drier than and moister slightly than observation in tropical convergent and Non-convergent zone, respectively. Similar pattern is also seen in CGCMs MME but with smaller magnitude. This unique dissimilarity can be found not only in boreal winter but also in summer.

Introduce

Climate scientists believe the atmospheric circulations are major forced by sea surface temperature (SST). How to connect both of ocean and atmosphere are most basic and essential problems. There are two new approaches were proposed in sequentially in the past two decades, the first is so-called “two-tier” and the later is “one-tier” prediction. In general, the two-tier and one-tier models also can be called atmospheric general circulation models (AGCMs) and coupled atmosphere-ocean GCMs (CGCMs), respectively.

The two-tier approach was first proposed by Bengtsson et al. (1993) in early 1990s, in which global SST anomalies was first predicted by using coupled models, and the atmospheric models is subsequently forced by the predicted SST to make a future seasonal prediction. The two-tier is one-way systems, which only consider the effect of SST anomalies on atmosphere and ignore the atmospheric feedback. At that time, El Niño-Southern Oscillation (ENSO) was recognized as the major source of the predictability of the tropical and mid-latitude climate variations through ENSO teleconnection, which depends critically on the correct simulations of mean climatology. Nevertheless, the CGCMs had substantial errors in simulating the observed climatology as well as anomalous conditions of the tropical ocean and atmosphere (Mechoso et al. 1995).

However, in real climate systems, not only SST anomalies can force atmospheric circulation, but also the atmospheric feedback also can influence ocean, they are an interactive system. In order to involve the atmospheric feedback, a new method, one-tier approach, was proposed in the end of the twentieth century. After that, many researches found that the low performance of AGCMs forced by observed SST in simulation of the Asian summer monsoon variability is partially attributed to the neglect of atmospheric feedback on SST (Wang et al. 2004). It has been increasingly recognized that the CGCMs are the most promising ultimate tools for seasonal prediction.

Many researches found the multi-model ensemble (MME) prediction skill usually outperform to the predictions made by any single-model component for both two-tier and one-tier systems (Krishnamurti et al. 2000; Wang et al. 2008). The idea behind the MME is that if the model parameterization schemes are independent of each other, the model errors associated with the model parameterization schemes may be random in nature; thus, an average approach may cancel out the model errors contained in individual models (Wang et al, 2009).

In this study, we compared the performances between 6 AGCMs hincast and 5 CGCMs hincast in global scale those datasets archived from Asian-Pacific Economic Cooperation Climate Center (APCC). We mainly focus on the performance of MME and use simple composite method. The arrangement of the article is as follows. Section 2 describes models and observation data. Section 3 present the temporal and spatial similarity of models over global. The performance of models in tropics is shown in section 4. Summary and discussion are presented in section 6.

2. Models and observation data

In this study, we compared the performances between 6 atmospheric GCMs (AGCMs) hincast and 5 coupled atmosphere-ocean GCMs (CGCMs) hincast for the period of 1982-2002. The members of models are listed in Table 1 and 2. We mainly focus on boreal winter season (December to next February, DJF. For example, 1997 DJF represents Dec1997 to Feb1998). For convenience, the resolution of all models was transferred to same dimension in 2.5^0(lat) x 2.5^0(lon) and used simple composite method for MME. The AGCMs hincast have 1-month lead and the CGCMs hincast have 1-month and 4-months lead datasets.

The observed and reanalysis data used for verification are as follows. The observed precipitation data were obtained from Climate Anomaly Monitoring System and OLR Precipitation Index (CAMS OPI, Xie and Arkin, 1998). And the compared SST used NOAA Optimum Interpolation Sea Surface Temperature (OISST, Reynolds et al., 2002). The reference data for circulation come from the reanalysis datasets namely the NCEP/NCAR (Kalnay et al., 1996). The observed data were also transferred to same resolution as models in 2.5^0(lat) x 2.5^0(lon).

3. The temporal and spatial similarity of models over global.

In this section, we evaluated the temporal correlation coefficient (TCC) and pattern anomaly correlation coefficient (ACC) to assess the performance of AGCMs MME and CGCMs MME. TCC and ACC indicate the temporal and spatial similarity between observation and models. Both of scores always ranges from -1.0 to 1.0. If the models are totally same to observation, the scores will equals to 1.0.

3.1 Temporal correlation coefficient

Fig. 1 shows the spatial distribution for 850hPa temperature between observation and MME for 1982-2002 in DJF season obtained from 1-month lead AGCMs, 1-month and 4-months lead CGCMs. The spatial patterns are similar among those MME. The most significant skill appear in tropical eastern Pacific, and higher skill are also seen in whole tropics, the southern Pacific, northern Pacific and northern American. Interestingly, If compute the correlation map of Niño3.4 index (the SST anomalies average over 120°W-170°W and 5°S- 5°N) for 850hPa temperature, significant negative correlation is seen in a horseshoe pattern extending from Maritime continent toward the extratropics in the northeastern and southeastern Pacific, while significant positive coefficient appear in most of tropic and northern American (figure not shown). These regions that high efficient impacts association with ENSO almost coincide with the high skill areas in Fig 1. It indicates that ENSO and its global impacts are the most predictable phenomenon in both of AGCMs and CGCMs.

While the similar high skill pattern among each MME in Fig1, the CGCMs MME have higher skill than the AGCMs MME in tropical Indian Ocean (Fig. 1 a, b) even if the lead time extend to 4-months (Fig. 1c). The CGCMs MME also can capture higher skill in tropical western Pacific warm pool at same lead time (Fig.1 a, b). Compare different lead time in CGCMs MME, the skills decrease slightly while the lead time increase (Fig. 1 b, c). On the other word, mid to high latitude of Asia continent and Australia almost no skill, it points out the remains a major challenge for climate prediction in those areas.

As like in 850hPa temperature, the TCC maps for precipitation are also similar among AGCMs MME and CGCMs MME (Fig. 2). But the high skill area more confined in narrow tropical zone. The most significant sign is seen in tropical Pacific between 10°S to 10°N, and also in tropical South American, tropical Indian Ocean, the East Asian polar front near southern China and Taiwan, Philippine Sea and extending toward Hawaii, Gulf of Mexico and extending toward Atlantic, South Pacific Convergence Zone (SPCZ). Those areas also are high efficient impacts association with ENSO. The high predictable sign attributed from ENSO appear again in precipitation in both of AGCMs and CGCMs MME.

Many researches suggest may require taking into account local monsoon-warm pool ocean interactions in monsoon regions (Wang et al., 2000, 2003). They argue poor skill of AGCMs in monsoon regions is partially attributed to the neglect of atmospheric feedback on SST. Contrasted with our results, the CGCMs MME outperform AGCMs MME slightly in East Asian polar front, tropical South American and SPCZ (Fig. 2a, b), conform those previous studies.

The skill of CGCMs MME for precipitation decreased while the lead time from one-month extend to 4-months, especially in tropical Indian Ocean (Fig. 2b, c), it implies that the precipitation in tropical Indian Ocean is difficult to capture before 4-months. The land regions appear almost no skill except in tropical southern American in both of AGCMs and CGCMs MME, it indicates predictability of precipitation over land is very challenging task in climate prediction.

3.2 Pattern anomaly correlation coefficient

Fig. 3 shows that the ACC for 850hPa temperature between observation and MME in DJF season over global, the MME include one-month lead AGCMs, one-month lead CGCMs and 4-months lead CGCMs. Interestingly, if we define the amplitude of Niño3.4 above 1 as strong ENSO years, we can find ACC of MME also have high skill in these years. For example, in strong El niño years (1982, 1986, 1991, 1997 and 2002) and strong La niña years (1984, 1988, 1998 and 1999), ACC always great than 0.2 (outperform the 95% confidence level). By contrast, in some poor ACC years, like 1983, 1989, 1992 and 1993, the ENSO signals also are weak. In actually, the correlation between the ACC and amplitude of Niño 3.4 are 0.6, 0.73 and 0.68 for one-month lead AGCMs MME, one-month lead CGCMs MME and 4-months lead CGCMs MME, respectively. Similar results also can be seen in precipitation (Fig. 4), ACC almost above 0.6 in strong ENSO year except in 1984(around 0.45) and 2002(around 0.5). The correlation coefficient between ACC and amplitude of Niño 3.4 are 0.76 to 0.79 for precipitation in each MME.

The performance of ACC among 1-month lead AGCMs, one-month lead CGCMs and 4-months lead CGCMs near can’t distinguish between them, except in 2001 for 850hPa temperature (Fig. 3) and in 1985, 1989, 1993 for precipitation (Fig. 4), the ENSO signals also are weak in these years. Furthermore, the remarkable variance of each individual models also in accord with weak ENSO years, like one-month lead AGCM in 1989, 1990 and 4-months lead in 1992 for 850hPa temperature (Fig. 3), and one-month lead CGCM in 1985, 1989 and 4-months lead CGCM in 1983, 1992, 1993, 1995, 2000 for precipitation (Fig. 4). In summary, it implies that in absence of the strong ENSO force, the performance of AGCMs and CGCMs models may become more divergent, thus may decrease the predictability of MME.

4. The performance of models in tropics

In this section, we use 2 approaches to evaluate the performance of models. First, we perform Empirical Orthogonal Function (EOF) analysis on DJF seasonal mean SST over tropical Pacific in CGCMs to assess their capability in capturing the two leading modes. Second, we compare the difference of tropical precipitation between observation and models.

4.1 Tropical Pacific SST

Ashok et al. (2007) identified a phenomenon in the tropical Pacific, apparently distinct and different from the canonical ENSO, which name as ENSO Modoki (Pseudo-ENSO). El Niño Modoki, the positive phase, is characterized by warm SST anomaly in the central tropical Pacific flanked by colder than normal SST anomaly on its eastern and western sides. Follow their approach, an EOF analysis on DJF seasonal mean SST over tropical Pacific (110°E-70°W and 30°S- 30°N) was performed during the period of 1092-2002. The observed first mode accounts for 75.6%, while the second mode accounts for 10% of total variance (figure not show). Unsurprisingly, the first two modes capture the canonical ENSO and ENSO Modoki and totally account for 85.6% of total variance during the DJF. Same analysis also apply to one-month lead and 4-months lead each CGCM individual models and MME. (Not apply to AGCMs, because APCC didn't archive the SST for AGCMs). Then calculate the correlation coefficient between observation and models for empirical orthogonal modes (spatial pattern) and principal components (PCs, temporal series), and list the result to Table 3 and 4.

For one-month lead CGCMs, models can capture the first mode (canonical ENSO) very well, the correlation coefficient for both of spatial pattern and PCs between observation and models almost above 0.9 except in UHT1 (0.82 and 0.86, Table 3). The capability in capturing the second mode (ENSO Modoki) in NCEP, POAMA and SINT diminish a little, and decrease larger in SUT1 and UHT1. Compared with one-month lead, the ability of 4-months CGCM in simulating canonical ENSO just decrease slightly, the skill almost same except in SUT1 (0.94 to 0.83, Table 4). However, notably diminished skill are seen in the capability for catching the second mode in 4-months lead CGCMs, especially in SUT1, its second mode can't capture the ENSO Modoki even if its third mode is a little similar to ENSO Modoki, but its spatial correlation is only 0.42.

4.2 Tropical precipitation

The spatial patterns of climatology are resembling among observation, AGCMs and CGCMs (figure not show). But if computed the different between observation and models, an interesting fact can be found. Fig. 5 shown the difference of precipitation between observation and models for 1982-2002 in DJF, the filled slash regions denote the observed precipitation great then 7mm/day, we defined this areas as convergent zone and the remainder areas as Non-convergent zone over tropics (30°S- 30°N). The precipitation in AGCMs MME almost less than observation in convergent zone, similar pattern is also seen in CGCMs MME but with smaller magnitude (Fig. 5). Furthermore, Fig. 6 shows the difference between observation and MME, each individual model over tropics in convergent and Non-convergent zone. Surprisingly, although the annual variability are similar between AGCMs and CGCMs in convergent zone, the AGCMs MME always drier than CGCMs MME during all of period 1982-2002, while the AGCMs MME always more moist slightly than CGCMs in Non-convergent zone(Fig 6). This unique dissimilarity also almost confirm even if in each individual models. Not only that, same analysis apply to boreal summer season (June to August, JJA), the interesting fact also come into existence in boreal summer season (Fig. 7, 8).

5. Summary and discussion

Previous studies confirm ENSO was recognized as the major source of the predictability of the tropical and mid-latitude climate variations through its teleconnection mechanism (Wang et al, 2009). In this study, we compared the performances between AGCMs hincast and CGCMs hincast in DJF for the period of 1982-2002. Our results confirm this theory again. The domains of high skill in both of AGCMs and CGCMs almost coincide with the areas that efficient impacts association with ENSO in temperature (Fig. 1) and precipitation (Fig. 2). The close temporal relation between predictability of models and strength of ENSO are also seen in the ACC analysis (Fig 3, 4). Our result also indicates that in absence of the strong ENSO force, the performance of AGCMs and CGCMs models may become more divergent, thus may decrease the predictability of MME.

About the predictability of tropical Pacific leading mode, all of one-month lead CGCMs can capture the canonical ENSO very well, and the capability in capturing the ENSO Modoki in NCEP, POAMA and SINT diminish a little, while decrease larger in SUT1 and UHT1 (Table 3). Compared with one-month lead, the ability of 4-months CGCM in simulating canonical ENSO just decrease slightly, but notably diminished skill are seen in the capability for catching the ENSO Modoki (Table 4).

We found that the precipitation in AGCMs almost drier and moister slightly than observation in tropical convergent zone and Non-convergent, respectively. Similar pattern is also seen in CGCMs MME but with smaller magnitude. This unique dissimilarity can be found not only in boreal winter (Fig. 5, 6) but also in summer (Fig. 7, 8). It will deserve to be research advanced using water vapor and heat flux field in the future. If we can figure out what reason make the dissimilarity, it will maybe help us to improve the predictability of tropical precipitation.

One important issue that it not dealt with in this study is the predictability for precipitation in Asian continent. While the whole Asian continent shows near no skill, the narrow high band appears in the East Asian polar front near southern China and Taiwan (Fig. 2). The NCEP model has the most significant skill for East Asian polar front (figure not show), in order to figure out why the NCEP model can capture East Asian polar front well, we had evaluated the performance of several variables, unfortunately, we can’t detect the critical key for this issue until now. But we still not estimate the water vapor or heat flux field, maybe the critical variable hide in these moist and heat field. It maybe is necessary for collecting more variable like water vapor or heat flux field in APCC archive.

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Table 1: Description of AGCMs

Acronym	Organization	Resolution
GCPS	Seoul National University	T63 L21
GDAPS_F	Korea Meteorological Administration	110 km L21
MGO	Voeikov Main Geophysical Observatory	T42 L21
MSC_GM2	Meteorological Service of Canada	Spectral T32 10 sigma levels
MSC_GM3	Meteorological Service of Canada	Spectral T63 32 sigma levels
NIMR	Meteorological Research Institute/KMA	72 x 46(4^0latitude x 5^0longitude) L17

Table 2 : Description of CGCMs

Acronym	Full names	AGCM	OGCM
NCEP	National Center for Environmental Prediction	GFS	MOM3
POAMA	Predictive Ocean-Atmosphere Model for Australia	T47 L17	0.5-1.5^0lat x 2^0lon L31
SINT	Scale INTeraction experiment-FRCGC	T106 L19	2^0cos(lat) x 2^0lon L31
SNU	Seoul National University	SNU T42 L21	MON2.2 $1/3^0$lat x 1^0lon L32
UHT1	University of Hawaii	ECHAM4 T31 L19	UH Ocean 1^0lat x 2^0lon L2

Table 3: The correlation coefficients for empirical orthogonal modes (2nd and 3rd row for 1st and 2nd EOF mode, respectively) and PCs (3rd and 4th row for 1st and 2nd PCs, respectively) in one-month lead CGCMs. The explainable variances also show in 2nd and 3rd row (the first column for observation).

	NCEP	POAMA	SINT	SUT1	UHT1	MME
1st EOF (75.6%)	0.96 (72.8%)	0.95 (63.4%)	0.95 (70.9)	0.94 (66.7%)	0.82 (56.1%)	0.97 (75.6%)
2nd EOF (10.0%)	0.81 (8.7%)	0.83 (13.2%)	0.89 (10.8%)	0.65 (8.4%)	0.51 (14.1%)	0.88 (10%)
1st PCs	0.93	0.93	0.96	0.90	0.86	0.95
2nd PCs	0.75	0.83	0.83	0.74	0.58	0.83

Table 4: As in Table 3, but for 4-months lead.

	NCEP	POAMA	SINT	SUT1	UHT1	MME
1st EOF (75.6%)	0.93 (77.5%)	0.94 (67.9%)	0.94 (75.9)	0.83 (64.2%)	0.77 (77.8%)	0.95 (80.3%)
2nd EOF (10.0%)	0.60 (7%)	0.69 (11.3%)	0.81 (8%)	0.1 (9.4%)	0.45 (10.6%)	0.69 (8.5%)
1st PCs	0.91	0.87	0.94	0.91	0.78	0.94
2nd PCs	0.68	0.70	0.75	0.39	0.59	0.65

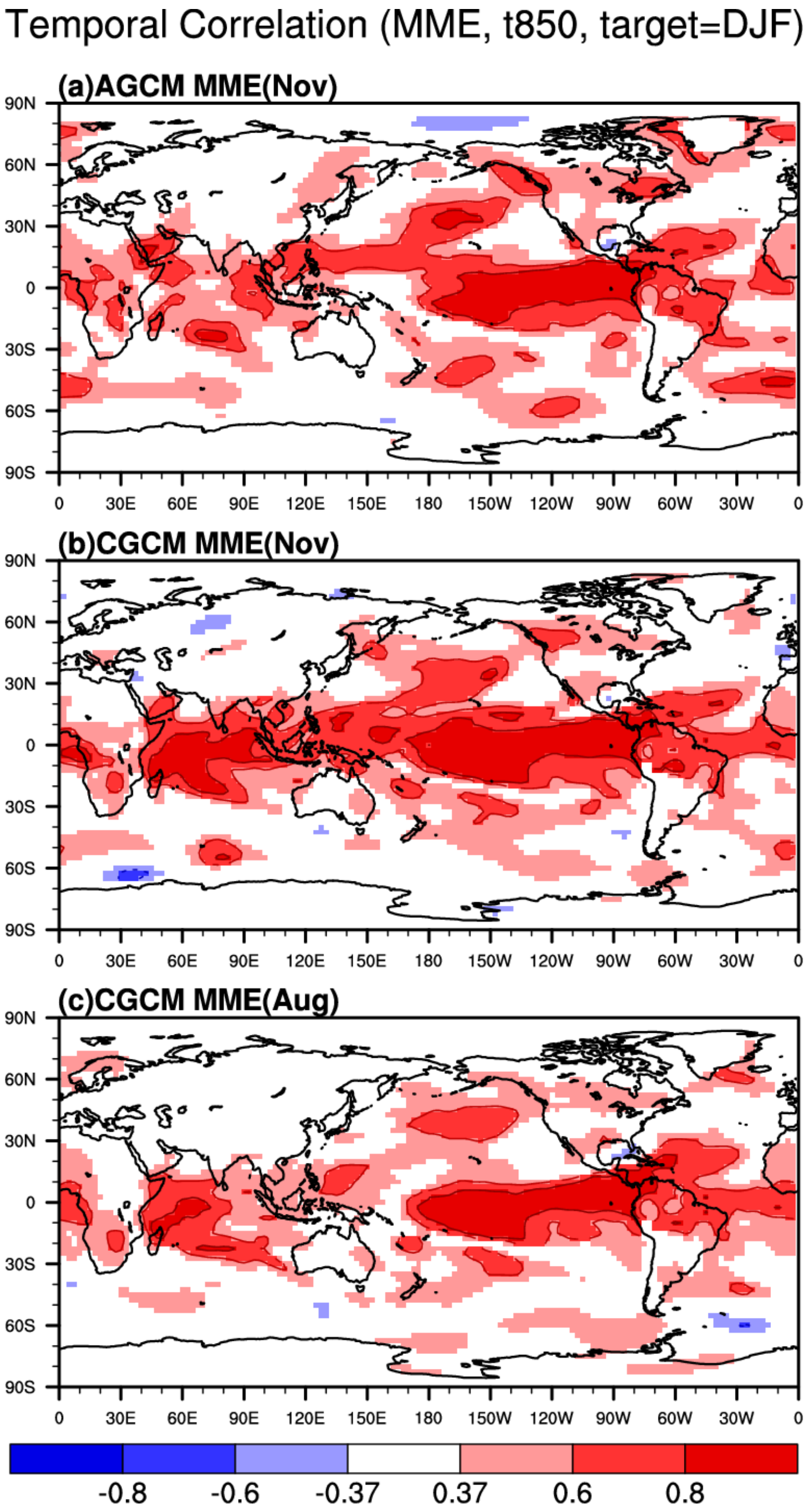

Fig.1: Temporal correlation coefficient for 850hPa temperature between observation and MME for 1982-2002 in DJF season obtained from (a)1-month lead AGCMs, (b)1-month lead CGCMs and (c) 4-months lead CGCMs. The correlations below the 90% confidence level are omitted for clarity.

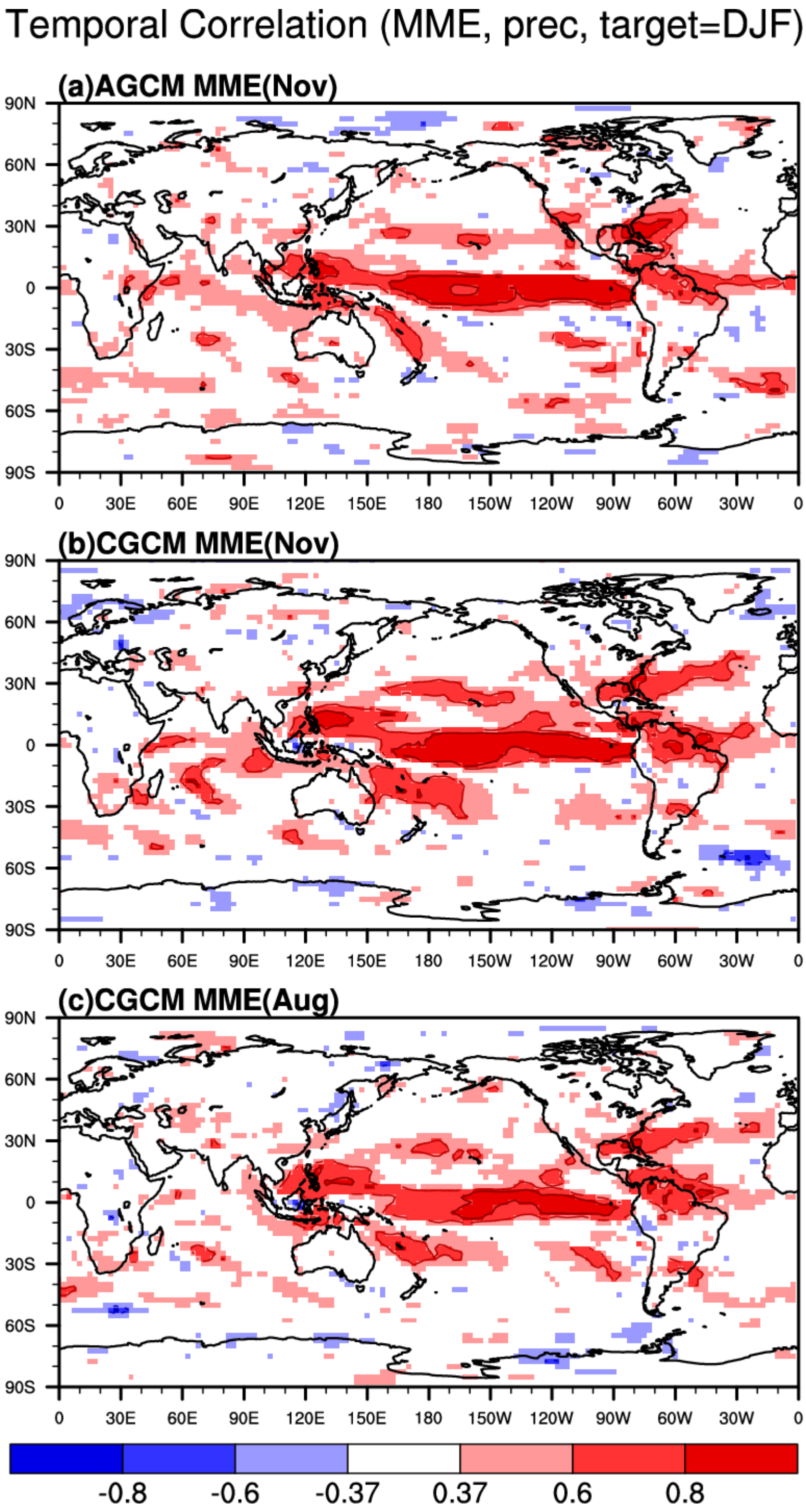

Fig. 2: As in Fig. 1 but for precipitation.

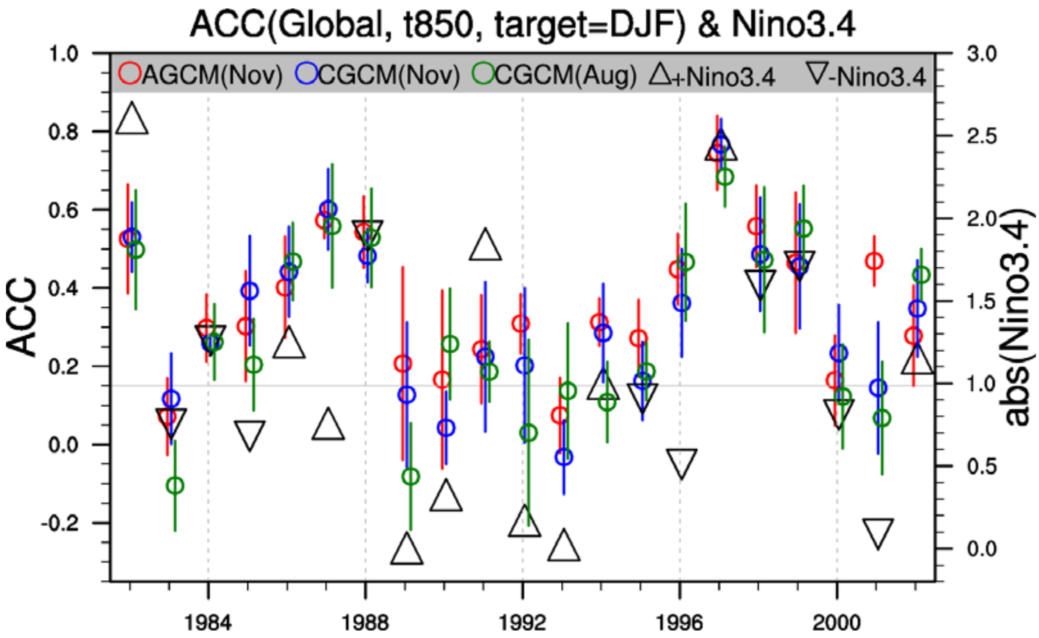

Fig. 3: Time series of ACC in 850hPa temperature between observation and MME in DJF season over global. The red, blue and green open circles indicate MME of 1-month lead AGCMs, 1-month lead CGCMs and 4-months lead CGCM, respectively. The vertical bars represent one standard deviation of each individual model. The black triangles denote the absolute value of Niño3.4 index, upward and downward triangle indicate the positive and negative Niño3.4 index, respectively. The gray horizontal line marks the notable value of ACC (90% confidence level) and Niño3.4 index (amplitude equal to 1).

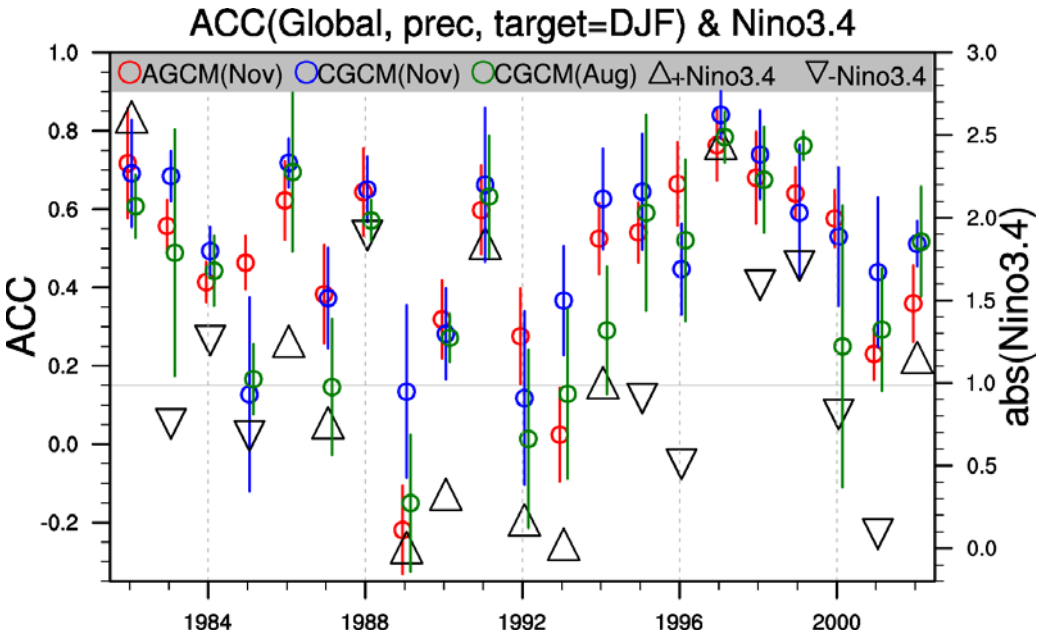

Fig. 4: As in Fig. 3 but for precipitation.

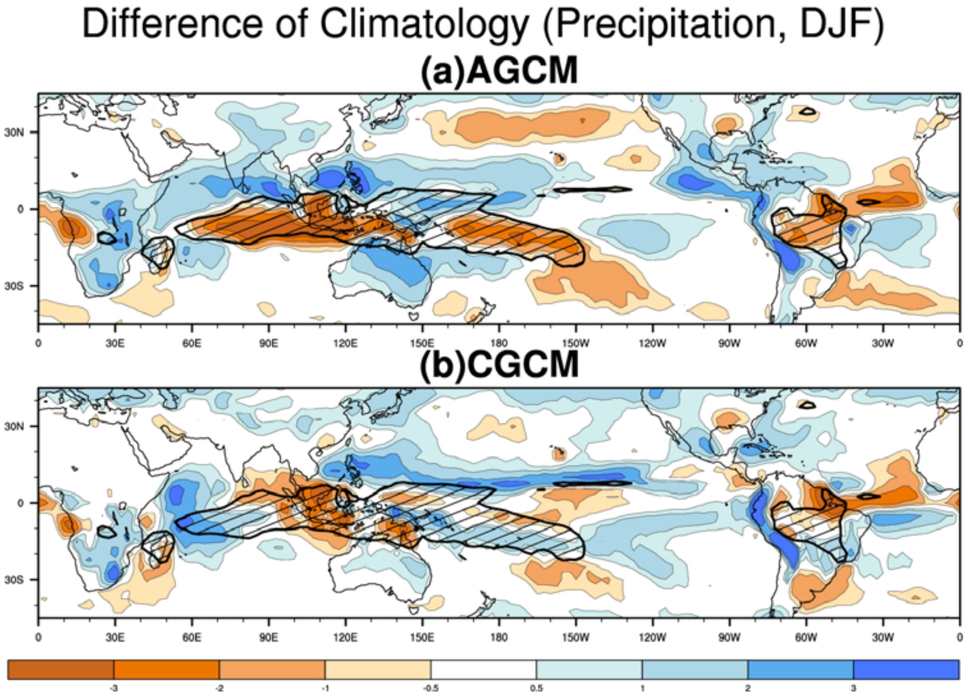

Fig. 5: Difference of climatology for precipitation between observation and MME for 1982-2002 in DJF in one-month lead (a)AGCMs and (b)CGCMs, respectively. The difference is observation minus MME, and the regions with filled slash denote that observed precipitation great then 7mm/day.

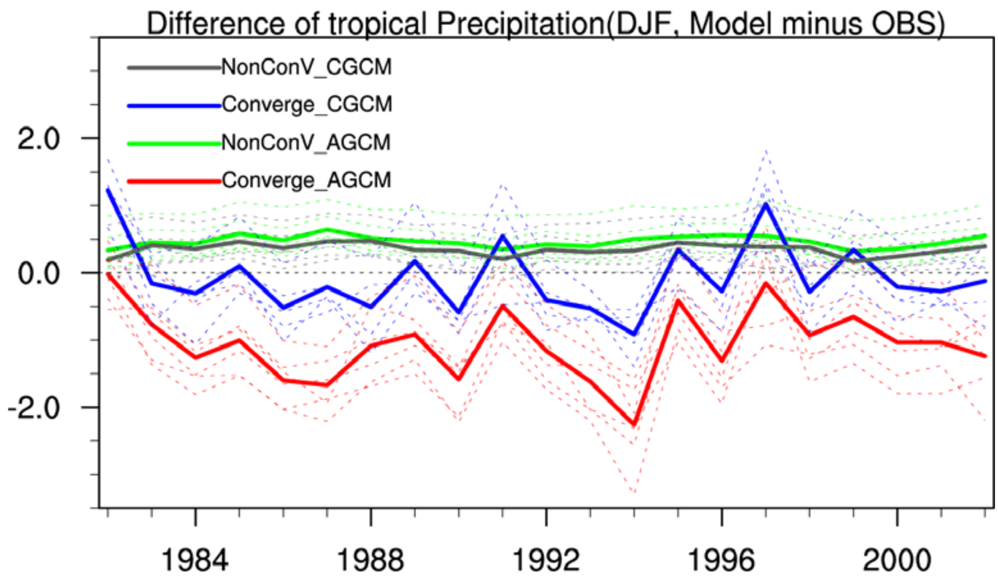

Fig. 6: Difference of seasonal precipitation between observation and models over tropics (30°S- 30°N) during 1982-2002 in DJF. The red and blue thick lines represent the convergent zone (precipitation great than 7mm/day, the slash filled regions in Fig. 5) in one-month lead MME of AGCMs and CGCMs, respectively. The green and grey thick lines represent the Non-convergent zone (the remainder domains from convergence). The individual models are also plotted with thin dashed line.

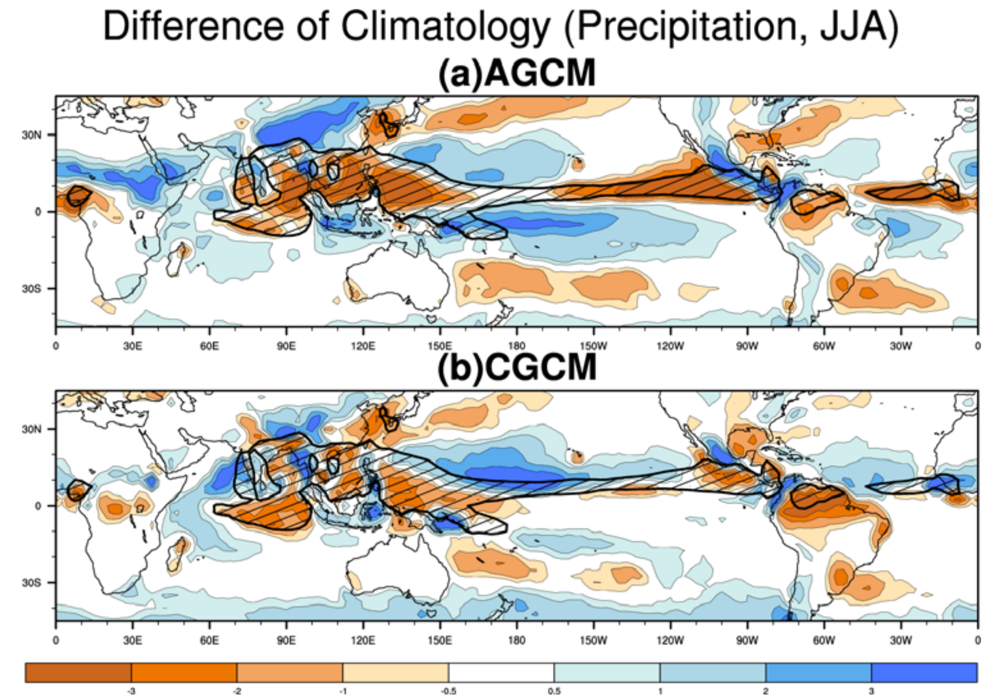

Fig. 7: As in Fig. 5 but for JJA.

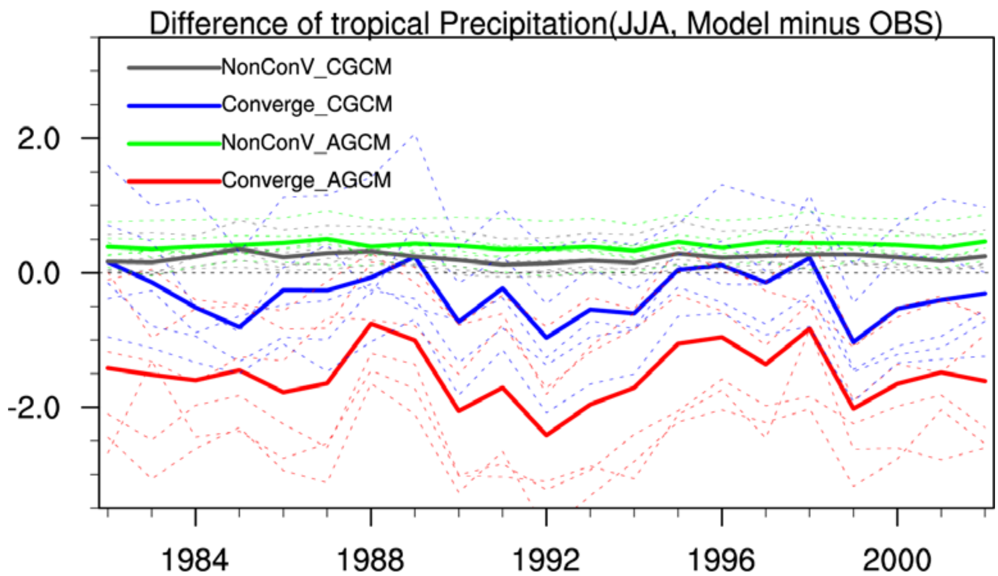

Fig. 8: As in Fig. 6 but for JJA.