出國報告（出國類別：其他）

出席「航空氣象現代化作業系統汰換及更新計畫協調會議」出國報告書

服務機關：交通部民用航空局飛航服務總臺

姓名職稱：莊清堯 課長

派赴國家：美國

出國期間：民國 112 年 9 月 16 日~民國 112 年 9 月 22 日

報告日期：民國 112 年 11 月 22 日

提要表

系統識別號：	C11202168
視訊辦理：	否
相關專案：	無
計畫名稱：	航空氣象現代化作業系統汰換及更新計畫協調會議
報告名稱：	出席「航空氣象現代化作業系統汰換及更新計畫協調會議」出國報告書
計畫主辦機關：	交通部民用航空局
出國人員：	姓名：莊清堯；服務機關：交通部民用航空局飛航服務總臺；服務單位：飛航業務室；職稱：課長；官職等：薦任(派)；E-MAIL 信箱：聯絡人：ufvejuan@anws.gov.tw
前往地區：	美國
參訪機關：	美國國家大氣科學研究中心
出國類別：	其他
出國期間：	民國 112 年 09 月 16 日 至 民國 112 年 09 月 22 日
報告日期：	民國 112 年 11 月 22 日
關鍵詞：	協調會議，美國國家大氣科學研究中心，NCAR，航空氣象預報演算法，MPAS，航空氣象現代化作業系統汰換及更新計畫，AOAWS-RU
報告書頁數：	25 頁
報告內容摘要：	為因應科技日新月異及精進飛航安全與服務品質，以達成亞太地區飛航服務提供領先者之組織目標，民航局自 110 年起至 113 年推動「航空氣象現代化作業系統汰換及更新計畫(The Advanced Operational Aviation Weather System Renewal and Update，AOAWS-RU)」，主要目的係為引進美國大氣研究大學聯盟之國家大

出國人員：

姓名	服務機關	服務單位	職稱	官職等	E-MAIL 信箱
莊清堯	交通部民用航空局飛航服務總臺	飛航業務室	課長	薦任(派)	聯絡人：ufvejuan@anws.gov.tw

	氣科學研究中心(NCAR)所發展之最新航空氣象預報演算法，使我國之航空氣象預報品質更上一層樓，另為打造符合國際民航組織 (ICAO) 系統廣泛資訊管理（ System Wide Information Management；SWIM）之航空氣象系統架構，期望透過本計畫取得最新飛航服務規劃。 爰為有效管理及瞭解美方今年度工作執行情形，奉派於 112 年 9 月 16 日至 22 日赴美國科羅拉多州博德市（Boulder）之美國國家大氣科學研究中心參加業務協調會議，並藉機了解目前國際間航空氣象資訊服務之發展趨勢，作為規劃未來航空氣象作業之參考。
電子全文檔：	C11202168_01.pdf
附件檔：	
限閱與否：	否
專責人員姓名：	A15060000HA0
專責人員電話：	

目　錄

壹、目的

為提昇臺北飛航情報區(以下簡稱本區)之航空氣象服務品質，提供符合民航業者需求之航空氣象產品，交通部民用航空局(以下簡稱民航局)自 86 年 7 月起推動航空氣象現代化計畫，與美國大氣研究大學聯盟(The University Corporation for Atmospheric Research，UCAR)合作建置航空氣象現代化作業系統(Advanced Operational Aviation Weather System，AOAWS)，並於 91 年 7 月完成建置。然而，隨著氣象科技日新月異發展，為持續引進新一代航空氣象預報及資料整合技術，並持續增強 AOAWS 系統預報產品，達成產品高度客製化服務，民航局復自 95 年至 99 年及 100 年至 103 年間分別進行為期5年及4年之「航空氣象現代化作業系統強化及支援計畫」(The Advanced Operational Aviation Weather System Enhancement and Support，AOAWS-ES)與「航空氣象現代化作業系統氣象技術增強計畫」(Technical Enhancement for the Advanced Operational Aviation Weather System，AOAWS-TE)，歷經三階段共 14 年之航空氣象現代化計畫，已提升本區航空氣象預報準確率和優化飛航服務品質，並與國際發展緊密接軌，並與歐美先進國家並駕齊驅。

為因應科技日新月異及精進飛航安全與服務品質，以達成亞太地區飛航服務提供領先者之組織目標，民航局自 110 年起至 113 年推動「航空氣象現代化作業系統汰換及更新計畫(The Advanced Operational Aviation Weather System Renewal and Update，AOAWS-RU)」，主要目的係為引進美國大氣研究大學聯盟之國家大氣科學研究中心(NCAR)所發展之最新航空氣象預報演算法，使我國之航空氣象預報品質更上一層樓，另為打造符合國際民航組織 (ICAO) 系統廣泛資訊管理（System Wide Information Management；SWIM）之航空氣象系統架構，期望透過本計畫取得最新飛航服務規劃。

為有效管理及瞭解美方今年度工作執行情形，於 9 月 16 日至 22 日赴美國科羅拉多州博德市（Boulder）之美國國家大氣科學研究中心（National Center of Atmosphere Research，NCAR）參加業務協調會議，並藉機了解目前國際間航空氣象資訊服務之發展趨勢，作為規劃未來航空氣象作業之參考。

貳、過程

為了解美方於 AOAWS-RU 計畫期間之工作進度，計畫期間安排每年赴美進行業務協調會議，惟 110 及 111 年受新冠肺炎(COVID-19)疫情影響，皆改以視訊會議方式辦理，而本次出國計畫執行係推動計畫後，首次赴美參加實體會議，會議分別於 9 月 18 日至 9 月 20 日三天進行，由美方專案主持人許榮祥博士主持，分別就工作進度、協調議題及跨尺度天氣預報模式(MPAS)發展近況進行討論，詳細行程如下表：

日期	時間	美方參與人員	我方參與人員	討論內容
9/18	0910 - 1000	Dr.許榮祥 Gary Cunning Ken Stone James Pinto Gregory Meymaris Jason Craig Jim Cowie	莊清堯	Status updates from product development
	1010-1200	Dr.許榮祥 Gary Cunning Ken Stone James Pinto Gregory Meymaris Jason Craig Arnaud Dumont Jim Cowie	莊清堯	General discussion
	1330-1400	Wiebke Deierling	莊清堯	Status update from GTG/GTGN
9/19	0900-1100	Dr.許榮祥 Gary Cunning Ken Stone	莊清堯 許依萍(視訊) 楊川德(視訊)	Project coordination meeting with Taiwan participants

<table>
<tr><td></td><td></td><td>James Pinto
Gregory Meymaris
Jason Craig
Arnaud Dumont
Jim Cowie Arnaud
Arnaud Dumont</td><td>藍嘉偉(視訊)</td><td></td></tr>
<tr><td rowspan="2">9/20</td><td>0900-
1000</td><td rowspan="2">Dr.許榮祥
Arnaud Dumont
James Pinto</td><td rowspan="2">莊清堯
許依萍(視訊)
楊川德(視訊)
藍嘉偉(視訊)</td><td>MPAS development update by MMM</td></tr>
<tr><td>1000-
1200</td><td>AOAWS preparation for WRF to MPAS transitioning to be discussed with MMM and CWA</td></tr>
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叁、會議內容及結論摘要

一、 **112 年工作進度報告**

本次會議由美方各工作負責人員進行相關工作進度報告，並針對有關工作之後續配合事項進行確認。相關重要工作成果說明如下：

(一) 工作項目 **1 -** 更新飛行中積冰診斷**(TCIP)**及預報**(TFIP)**產品

目前民航局所使用的是由美方經由過去 AOAWS 計畫所發展的 TCIP 及 TFIP v1.x 版本。基於中央氣象署已將決定性天氣研究與預報模式(WRF-D)之解析度升級至 3 公里，因此透過 AOAWS-RU 計畫，進行演算法調整。除使其使用新模式解析度資料，並就因應模式之雲微物理參數化強化部分進行研究，且納入日本向日葵(Himawari-8/9)衛星資料及中央氣象署新雷達資料進行計算。後續再透過天氣個案研究方式，持續微調演算結果，使演算結果符合臺灣地區氣候特性。

依據 AOAWS-RU 計畫，TCIP2 及 TFIP2(即 TCIP 及 TFIP 2.0 版本)將於 112 年 10 月底完成發展，112 年度目前工作成果如下：

1. 完成飛行中積冰診斷及預報產品回饋準備工作，並交由民航局(總臺)進行意見回饋。
2. 確認 TCIP 及 TFIP 產品演算法可順利使用日本向日葵 9 號衛星資料，且無需調整系統規格文件。
3. 經 CIP 測試及評估作業，初步個案研究結果顯示，臺灣地區積冰發生可偵測率較美國地區低約 10%，積冰嚴重程度與美國相似，皆有過度預報情況。
4. 在民航局測試環境安裝完成 TCIP 及 TFIP 程序，並完成測試。
5. 新增 Domain 1 之 TCIP 及 TFIP 程序，並調整相關文件
6. 使用於美國執行之模式資料完成 TCIP 之基線(Baseline)評估工作。
7. 美方已於 9 月 1 日提交測試及評估報告。

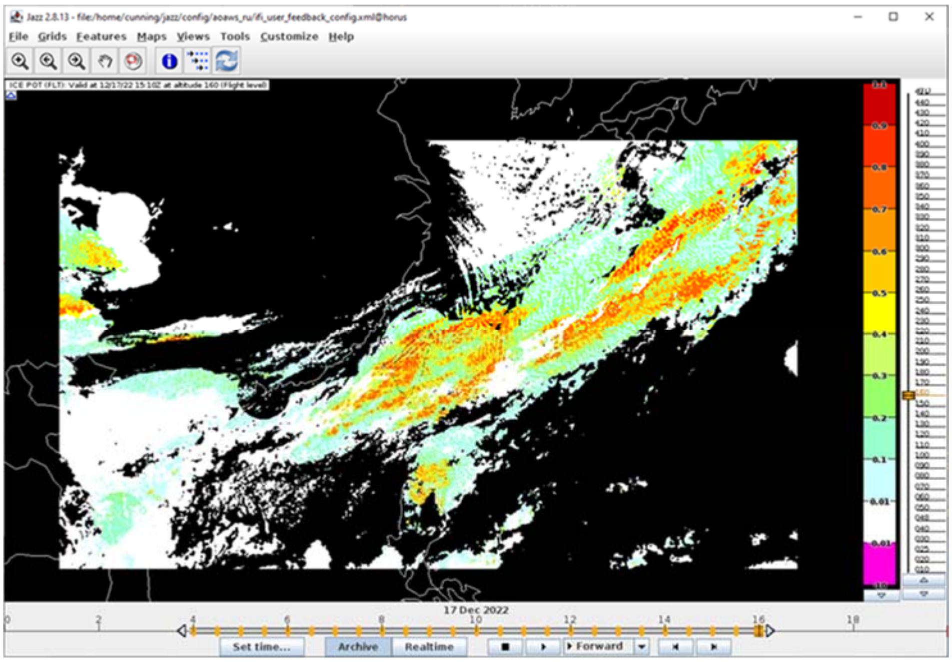


圖 1、積冰產品成果

(二) **工作項目 2 - 升級亂流圖形化指引至第 4 版(GTG4)，並建置亂流圖形化指引臨近預報(GTGN)**

亂流圖形化指引(GTG)係由美方開發並提供予民用航空預測亂流規模之重要演算法產品，目前民航局所使用版本為 GTG 2.5 版，並評估每個網格點之輸出資料(如風、溫度等)，以確定亂流發生的可能性。經計算與亂流相關的幾個指標後，再由不同的檢查方式確認輸出資料正確性，最終結果則是使用輸出資料集合平均值。而 GTG 輸出是以 $m^{2/3}\ s^{-1}$(EDR)為單位。EDR 為國際民用航空組織(ICAO)所要求報告亂流之度量標準，亦為大氣亂流強度指標，其與飛機的 G loading 成比例，故 EDR 可用以表示航空相關亂流強度的等級分類(例如輕度、中度或重度等)。

而 GTG4 為 GTG 預報演算法之第四個版本，GTG4 納入不同的亂流形態，包括晴空亂流(CAT)、山岳波亂流(MWT)、對流誘導亂流(CIT)和低層邊界層亂流(LLT)，因此可彌補目前民航局版本所缺少海拔低於 10,000 英呎之低層亂流預報及山岳波與低層邊界層亂流預報，並加入比目前版本更為新進之亂流診斷方式，進行資料驗證，確保演算結果品質。

另外，亦將 GTG4 輸出結果用以發展臺灣地區之 GTGN(GTG-Nowcasting)版本，並納入國際航空運輸協會(IATA)之渦流消散資料及 NCAR 亂流偵測演算法(NTDA)進行運算，使原本以模式資料為主的 GTG 資料升級為具即時預報功能之 GTGN 版本。

112 年度目前工作成果如下：

1. 整合 GTG4 演算法之建置、安裝及運作程序，開始使用即時資料進行演算法運算，並於 6 月底提供民航局相關程序安裝文件，並持續評估演算法運作效能。
2. 持續進行校準工作，包含使用實地觀測資料(EDR)及 NCAR 亂流偵測演算產品(NTDA)進行機率分布函數、亂流診斷對應及統計評估等工作。
3. 完成國際航空運輸協會(IATA)之渦流消散資料及機場天氣觀測資料格式轉換程序，轉換後之資料納入演算法使用。
4. 持續蒐集亂流個案，作為個案研究及使用回饋調查之用。
5. 以民航局提供之機場天氣觀測資料進行 GTGN 演算，並進行 925hPa 及 850hPa 之結果診斷。

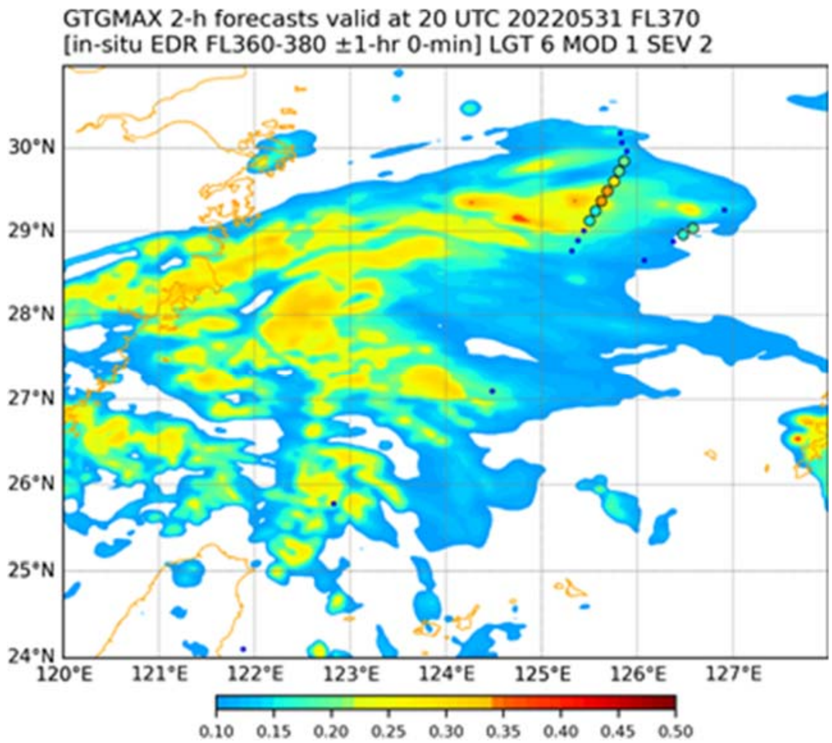


圖 2、GTG4 發展成果

(三) 工作項目 3 - 更新 NCAR 亂流偵測演算法(NTDA)

NTDA 演算係使用雷達觀測資料中之回波場、徑向速度場及波譜寬度等資料，經過資料品質管制，並處理渦流消散率(EDR)。目前民航局之 NTDA 版本業納入中央氣象署之五分山、七股、墾丁及花蓮等 S 波段雷達資料。

為增加現有 NTDA 所使用雷達資料涵蓋率，本計畫納入中央氣象署於樹林、南屯及林園等地建置之 C 波段降雨雷達，以及空軍氣象聯隊於綠島、臺中及澎湖等地建置之 C 波段雙偏極化氣象雷達，並因應中央氣象署雷達汰換現有 S 波段雷達，調整相關資料處理程序，並強化消除人工射頻(RFI)干擾及提升資料處理技術。

112 年度目前工作成果如下：

1. 接收並測試中央氣象署汰新後之墾丁及花蓮雷達資料，並重新評估雷達資料於演算法之應用。另因中央氣象署汰新後之七股雷達資料格式與其他雷達資料相差較大，正進行是否納入演算法之評估作業。
2. 持續配合其他演算法產品進行資料整合及緩解產品本身雜訊問題。
3. 發展演算法之建置、安裝及運作程序，並於民航局之測試環境，以即時資料進行運算。

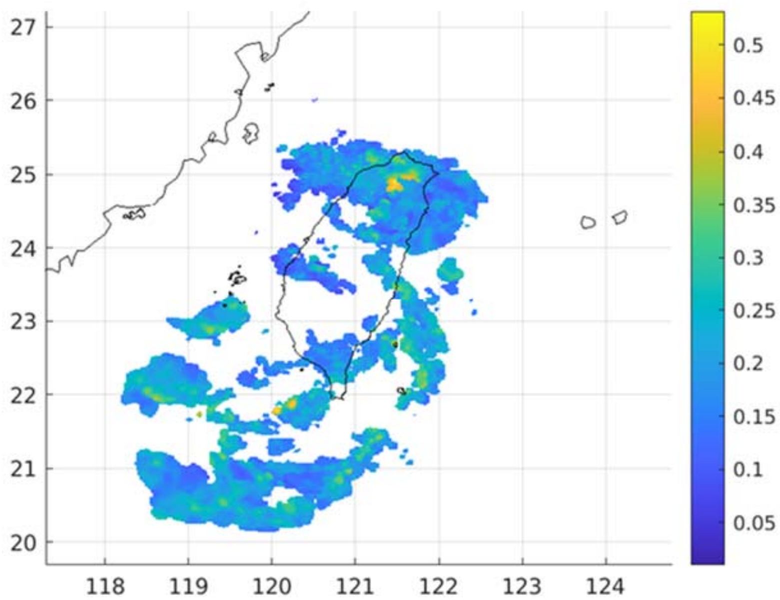


圖 3、NTDA 發展成果

(四) 工作項目 4 - 更新雲頂高預測產品(CTH/CDO)

使用靜態之衛星雲圖來描述對流雲是具有挑戰性的，因為衛星儀器只能看到對流雲頂和穹頂外部，無法看到雲內部。因此雲頂高度(CTH)和對流診斷海(CDO)產品，為美方近年發展在跨洋區域內為航空提供策略性輔助的工具。為進一步瞭解對流雲結構特徵，而於本計畫引入對流診斷海洋(CDO)產品。

CTH 演算法結果主要用以描述雲高度，飛行員用以估計在距離風暴距離和/或知道是否可以安全地飛越天氣系統雲層。CDO 算法則是用以檢測與強上升氣流/下沉氣流相關的對流危害區域。

112 年度目前工作成果如下：

1. 完成 CTH/CDO 演算法程式初步整合，並納入程式碼儲存庫，且於民航局測試環境進行演算法安裝及執行。
2. 持續進行演算法驗證工作，以確認民航局測試環境之產品與美國所得產品相同。

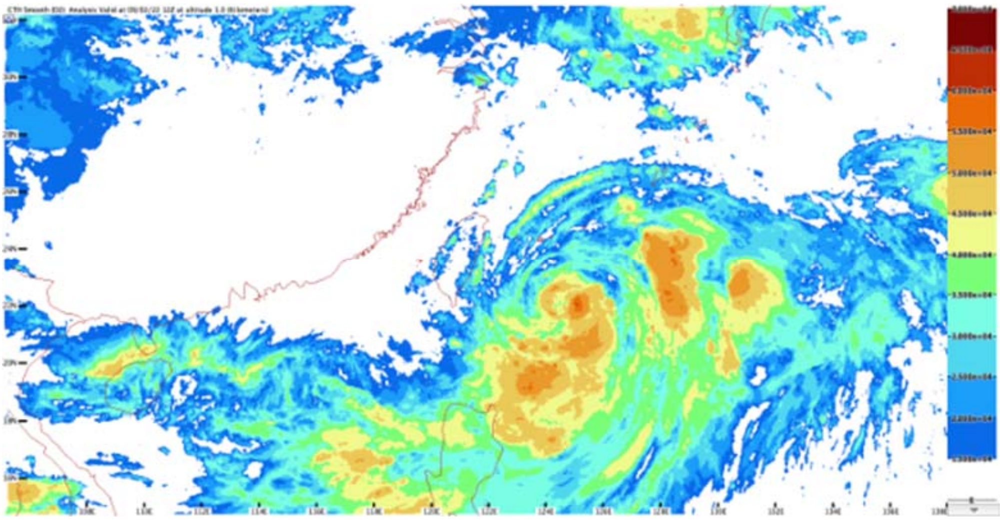


圖 4、軒嵐諾颱風期間 CTH 產品

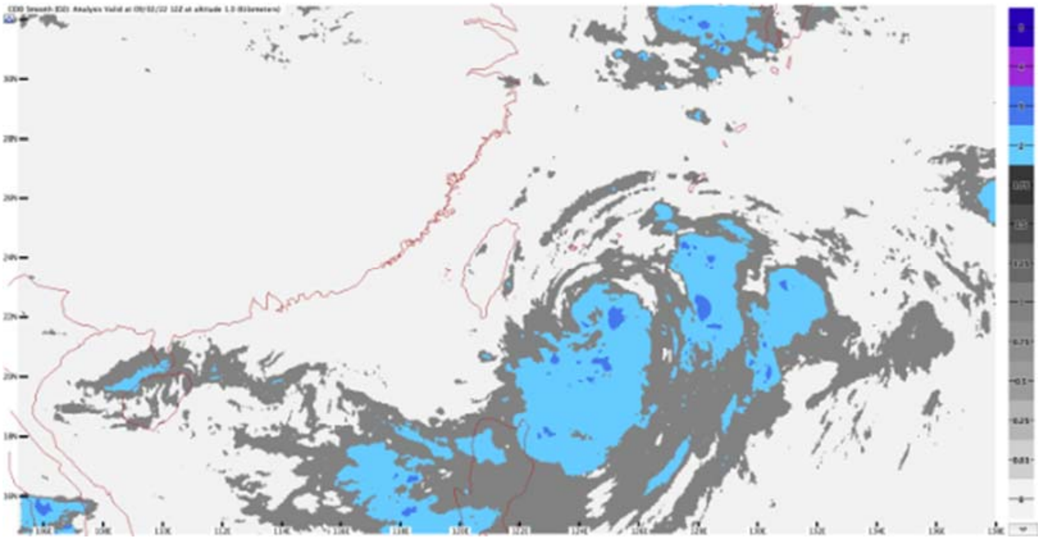


圖 5、軒嵐諾颱風期間 CDO 產品(本圖資訊不納入閃電資料運算)

(五) 工作項目 5 - 更新機場雲冪與能見度預測產品(C&V)

目前民航局所使用之 Model Output Statics(MOS)輸出之機場天氣預報資訊，係亦由美方於過去 AOAWS 計畫期間開發完成，該演算法可提供個別機場單一時間或於時間序內天氣預報資料，此演算方式係採模式資料輸出結果，配合近 60 天之天氣統計情況與實際天氣進行校準後，得到預報結果。在 2019 年，美方對於校準算法進行改進，強化低於目視條件下之天氣情況預報準確度。爰透過本計畫將目前演算法進行調整，並將原本適用於單一機場之預報結果升級為以網格點方式呈現，提升產品可用性。

MOS Forecast Time History for station RCTP:

Time	Wind Direction	Wind Speed	Visibility	Ceiling	Temperature	Dew Point	Pressure	Model Run Time
UTC	Degrees	Knots	Km	Feet	Degrees Deg C	Degrees Deg C	hPa	UTC
2023/11/16 03:00:00	340	10	10	1150	23	21	1023	2023/11/15 18:00:00
2023/11/16 04:00:00	340	10	10	1400	23	21	1023	2023/11/15 18:00:00
2023/11/16 05:00:00	340	10	10	1800	22	20	1022	2023/11/15 18:00:00
2023/11/16 06:00:00	350	10	9.5	1500	22	20	1022	2023/11/15 18:00:00
2023/11/16 07:00:00	210	15	9.5	2450	21	19	1022	2023/11/15 18:00:00
2023/11/16 08:00:00	180	15	10	2350	21	18	1023	2023/11/15 18:00:00
2023/11/16 09:00:00	160	15	10	3750	21	17	1023	2023/11/15 18:00:00
2023/11/16 10:00:00	140	10	9.5	4100	19	17	1023	2023/11/15 18:00:00
2023/11/16 11:00:00	120	10	9.5	4900	19	16	1024	2023/11/15 18:00:00
2023/11/16 12:00:00	090	15	9	4300	19	16	1024	2023/11/15 12:00:00
2023/11/16 13:00:00	050	15	9.5	5450	19	13	1024	2023/11/15 18:00:00
2023/11/16 14:00:00	030	15	10	4850	18	11	1025	2023/11/15 18:00:00
2023/11/16 15:00:00	020	15	10	5750	18	11	1025	2023/11/15 18:00:00
2023/11/16 16:00:00	020	15	10	6200	17	10	1024	2023/11/15 18:00:00
2023/11/16 17:00:00	010	15	9.5	6600	17	10	1023	2023/11/15 18:00:00
2023/11/16 18:00:00	010	15	9.5	6700	17	9	1023	2023/11/15 18:00:00
2023/11/16 19:00:00	020	15	10	> 10000	17	9	1024	2023/11/15 18:00:00
2023/11/16 20:00:00	020	15	10	> 10000	17	9	1024	2023/11/15 18:00:00

圖 6、目前 MOS 輸出產品畫面

112 年度目前工作成果如下：

1. 以季統計資料驗證並評估 C&V 演算法效能。
2. 修正產品輸出之網格資料內偶而出現的圓形偽影情況。
3. 交付 112 年 1 月 1 日至 3 月 31 日與 112 年 4 月 1 日至 6 月 30 日之系統驗證結果報告。
4. 於民航局測試環境安裝更新後之 C&V 演算法程式及設定，以作為後續系統使用即時資料時之用，另安裝資料校準作業所需之程序。

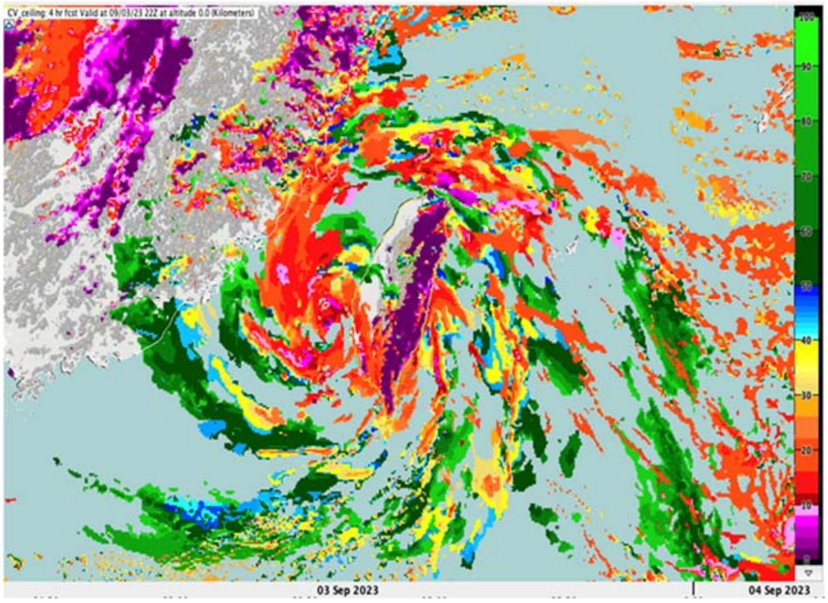


圖 7、網格化之雲冪預報產品

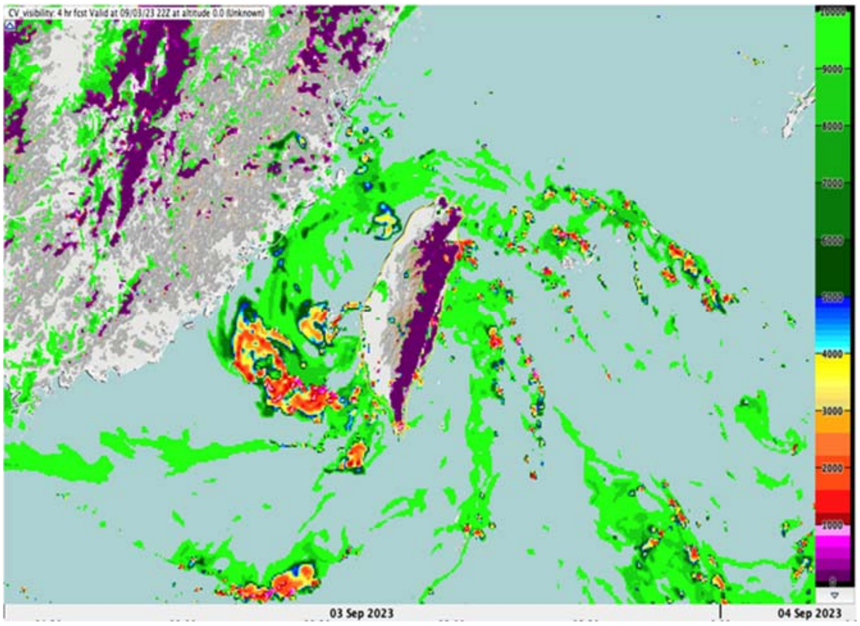


圖 8、網格化後之能見度預報產品

(六) 工作項目 **6 -** 發展 **0-8** 小時的風暴預報能力**(ASPIRE)**

目前民航局業經由 AOAWS 過去計畫取得美方發展之雷雨辨識、路徑追蹤及即時預報(Thunderstorm Identification, Tracking and Nowcasting, TITAN)演算程序，該程序係使用中央氣象署提供之三維雷達合成資料，再由程序自動辨識風暴範圍，並以一小時外延法來產生風暴短期追蹤預報資料(如圖 9)。

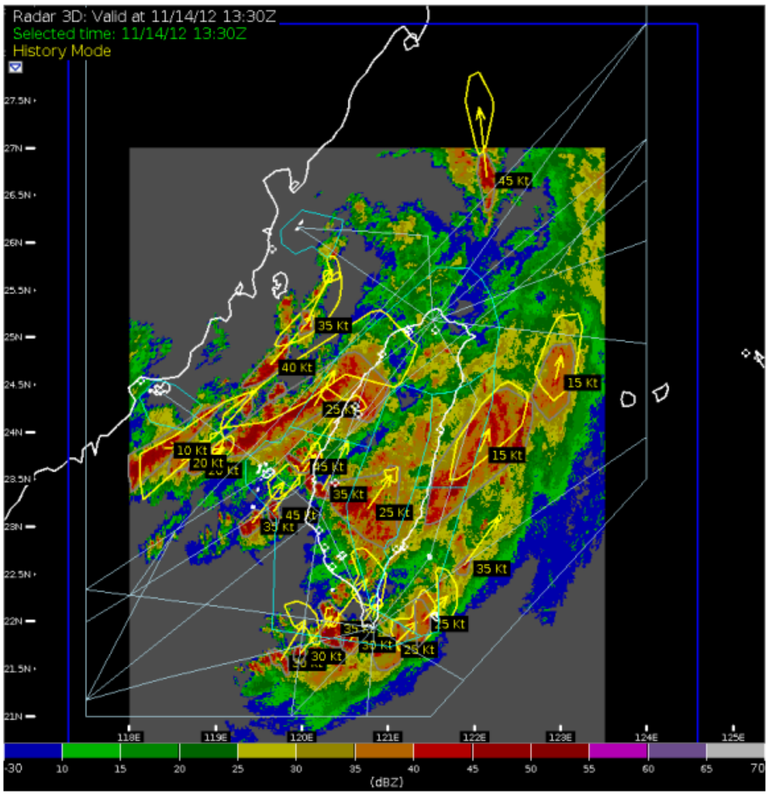


圖 9、TITAN 產品圖

為持續精進風暴短期預報之掌握度，透過本計畫與美方共同研究、開發外推和混合技術，使用中央氣象署提供高更新頻率之模式預報資料，發展提供短期(0 至 8 小時)反射率和回波頂高預報演算法。

本演算法為了於最短時間內產生風暴位置和強度之短期預報，而將目前 TITAN 的外推與模式預報資料結合起來，並以稱為 CoSPA(Consolidated Storm Prediction of Aviation(即目前計畫引入之 ASPIRE)之複雜混合算法，以產生 0 至 8 小時風暴預測結果。期望未來此產品可做為雷雨天氣即時預報及流量管理之參考工具。

112 年度目前工作成果如下：

1. 於民航局測試環境完成 ASPIRE 第 1.2 版發展，並開始進行實際運作。另持續進行演算法之校準、相位校正及混合模組之修改。
2. 開始進行每小時內插輸出作業(每 20 分鐘輸出更新資料一次)，並於 ASPIRE 第 2.0 版本進行實作。
3. 使用 111 年 6 月 17 日至同年月 21 日之個案進行使用回饋意見蒐集。

4. 開發演算法安裝程序、自動檢查機制及即時監控頁面。

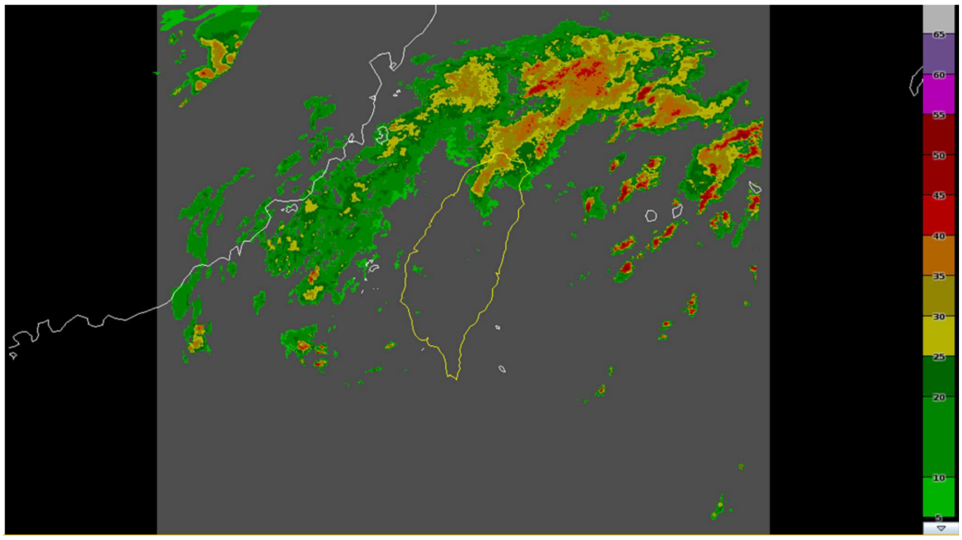


圖 10、ASPIRE 產品

(七) 工作項目 **7 –** 專案管理、行政作業及相關文件準備

112 年度目前工作成果如下：

1. 持續進行民航局測試環境安裝及測試工作之相關協調作業。
2. 依據民航局所提供之積冰產品使用回饋意見、測試環境及使用即時資料部分，進行協調及解決問題之討論。
3. 協調 NCAR 人員預計於 112 年 10 月下半月訪問臺灣事宜，屆時將進行 CTH/CDO、C&V 及 ASPIRE 等演算法產品展示及討論使用回饋意見。
4. 協調 NTDA 演算法使用之中央氣象署新雷達資料及資料解讀與應用問題。

二、 協調會議討論事項

由於本次出國計畫係 AOAWS-RU 計畫推動以來首次實際赴美執行，因此討論議題較多，爰分別於 9 月 18 日及 9 月 19 日進行討論，討論議題及內容摘要如下：

(一) 積冰演算法於最終交付後之驗證方式

新版積冰演算法將於 112 年年底完成發展，屆時 NCAR 將交付相關程式碼及文件，為確保交付版本於民航局環境運作與美國發展版本一致，爰請美方規劃驗證方式。

美方初步規劃將於 NCAR 和民航局測試環境更新最終版本原始碼及應用程式，並同時於 NCAR 及民航局測試環境更新驗證用套件，該套件可用於比對臺灣及美國所產製之積冰預報產品差異，即可了解交付與臺灣運作版本是否存在差異。

(二) ICAO 第三號附約(ANNEX3)第 81 次修正(AMD81)所涉及的新一代世界區域預報系統(WAFS)資料內容變更及資料提供方式

由於 ICAO 規劃於 ICAO ANNEX3 第 81 次修正版本發布時，公布 WAFS 資料內容及供應方式調整資訊，由於我方目前取得資料較為零散，且相關時程需要確認，因此請美方提供相關資訊。

美方提供資訊如下：

1. 新一代 WAFS 將於 2023 年 11 月上線，不過通常會有新舊系統平行運作時間，供目前資料使用人進行調整。
2. 現行資料內容之改變說明如下:
   (1) 網格點預報資料：將由現行特定氣壓高度之預報場資料調整為每 1000 呎即有預報場資料，即資料垂直方向之解析度增加；資料水平方向之解析度自 1.25 度提升至 0.25 度；預報長度時間自原本 36 小時提升至 48 小時，其中第 6 至 24 小時改為提供每小時預報資料，其餘時間維持提供現行每 3 小時預報資料。
   (2) 非網格預報資料：由目前氣象數據的二進制通用表示格式(BUFR)資料格式調整為 ICAO 氣象資訊交換(IWXXM)格式。
   (3) 顯著天氣預報圖檔資料：目前世界區域預報中心(WAFC)提供有全球 13 個選定區域之高層(FL250 至 FL630)及 4 個選定區域之中層(FL100 至 FL450)

之顯著天氣預報圖，未來將調整為僅 3 個中高層區域中層至高層(FL100 至 FL600)之顯著天氣圖。

3. 有關資料提供部分，將逐漸由現行透過網站或以"wget"程序取得資料的方式，調整為透過應用程式介面(API)和高級訊息佇列協定(AMQP)提供資料。
4. 現行非網格資料及顯著天氣預報圖資料將提供服務到 2027 年。

(三) 由於民航局刻正進行新一代低空風切警報系統汰換規劃，因此請 NCAR 就「X 波段雷達與光達組合及 C 波段雷達與光達組合之效能差異，以及兩種組合的各自優勢?」以及「以 X 波段雷達與光達組合及 C 波段雷達與光達組合，在美國哪種組合居多?」進行說明。

美方說明機場以「X 波段雷達與光達組合」或「C 波段雷達與光達組合」偵測低空風切，主要還是依據機場特性及天氣條件決定，如雷達設置位置與機場間距離，或雨衰影響程度等等，並未有何者性能較好的差異情況。但就目前所知，國際間以 C 波段雷達與光達作為低空風切偵測組合，並未多於 X 波段雷達與光達之組合，其原因在於 X 波段雷達天線本身及設置所需用地較小，所以安裝上明顯容易許多。

就目前 NCAR 所掌握資訊，暫時無法確認哪種組合較為適合用於臺灣機場之低空風切偵測。目前民航局已經委託專業氣象團隊進行新一代低空風切警報系統評估工作，且相關工作將進行至 113 年 10 月底，工作內容包含新一代低空風切警報系統組合方式、掃描策略及站點選址等等，美方表示可以在 AOAWS-RU 計畫下的諮詢工作項目下提供民航局後續所需諮詢資訊，如協助提供系統建議規格及就民航局所委託團隊所做評估內容，提供技術諮詢及建議等工作，惟 NCAR 請民航局需要留意這部分的諮詢工作比例，避免占用大部分諮詢工作項目費用。

(四) 目前 ICAO ASBU 氣象模組最新發展情況以及美國推動系統廣泛資訊管理(SWIM)情況與計畫

美方說明目前 ICAO ASBU 仍依原定期程推動，爰尚無進一步發展情況。另目前美國已將航空流量管理所需數據，通過 SWIM 概念提供給用戶，並已開始提供資料與其他地區，而使用飛航訊息管理系統(AMHS)之用戶則處於替換舊資料路由系統之過渡期。同時 SWIM 入口網站正在建置中，未來 SWIM 用戶將透過入口網站進行註

冊，以訂閱後續資料之路徑來源，用戶可依作業需求而同時擁有多個資料來源。ICAO 建議可直接洽目前商業外包系統，如 SOLACE，使用其以爪哇(JAVA)程式語言建構之資訊服務，向資料訂閱用戶提供資料。美國目前亦使用 SOLACE 提供資料予用戶，但對於 NCAR 來說，並不清楚美國是如何透過 SOLACE 提供符合 SWIM 概念之完整服務。

職表示目前民航局也已經完成 SOLACE 軟硬體購置，後續也將規劃透過 SOLACE 進行航空所需資料交換，美方表示 SOLACE 可視為 SWIM 架構的實現，如果民航局建置了符合 SOLACE 架構的服務，其應該才可稱為符合 SWIM 政策。因此仍需要確認 SOLACE 是否提供註冊及允許用戶訂閱資料部分，才能夠確保提供完整的 SWIM 服務。

另因為 SWIM 是新的 ICAO 服務標準，需要留意透過其提供之服務，需能夠使用戶透過檢索並取得數據。為此在美國透過 CSS-Wx 程序完整實現 SWIM 所需要的服務，其允許用戶得以取得更為細緻資料，如請求特定區域中單一模型輸出或特定 METARs 等高級服務。

圖 11、9 月 18 日會議

(五) **113 年 AOAWS-RU 計畫效益評估報告討論**

由於 AOAWS-RU 計畫執行至 113 年年底暫告一段落，為使我方了解計畫期間發展之演算法效益，爰業與美方協調於計畫結束前交付效益評估報告。本議題則是與美方討論該報告內容初步構想，目前規劃該報告將包含「新舊版本演算法差異效益」、「演算法轉移至臺灣地區運作後，與美國本土運作版[本是否存在差異」以及「演算法於臺灣地區運作後，如何確保效能穩定」等三部分。為此，美方由本計畫發展之 TCIP/TFIP、GTG/GTGN、NTDA、CTH/CDO、C&V 及 ASPIRE 等演算法負責人員進行說明及討論，以下為各演算法討論內容摘要：

1. TCIP/TFIP：由於目前臺灣已經具有 TCIP/TFIP v,1.x 版本，所以在比較新舊版本演算法效能上相對比較容易，積冰演算法發展團隊已完成相關驗證方法，並已用在目前計畫之積冰演算法發展說明資料。該方法主要以探空資料作為實際觀測資料，透過訂定當地可能引發結冰的門檻值(如足以引發積冰之相對溼度門檻值)，再分別與新舊版本之 TCIP/TFIP 結果進行比較，即可得知效能差異。但考量到探空資料僅為單點資料，並無法表示全部天空之大氣條件，因此需要蒐集鄰近地區同時間所發布之探空資料，並進行完整分析。評估此方法可用再確認新舊版本演算法效能差異及分別運作於臺灣及美國版之演算法效能比較。
2. GTG4/GTGN：由於目前民航局所使用的 GTG 版本為 v.2.5，其運算結果為 0 至 1 的數值，再以數值大小訂定亂流強度，此與本計畫升級的 GTG4 將結果直接以 EDR 數值輸出不同，因此在比較新舊版本差異上將比較困難，因此在新舊版本差異比較上，目前規劃採說明新版演算法所增加之分析技術及功能資訊。另建議就 GTG4 之效能驗證部分，美方計劃與 IATA EDR 觀測資料進行比對，再透過 PODy 及 PODn 資料，可得到大致之驗證結果。由臺灣地區所得之 PODy 及 PODn 資料換算為 ROC 曲線即可與美國地區之運作進行比較，亦可得到演算法與兩地運作之效能比較。
3. NTDA：NTDA 演算法於本計劃中重要工作為納入中央氣象署降雨雷達(樹林、南屯及林園)以及空軍氣象雷達(澎湖、臺中及綠島)，並調整資料處理程序以因應中央氣象署七股、花蓮及墾丁雷達汰新後之新資料格式。此外，強化雷達資

料品質控管程序也是本演算法重點工作之一。但新版演算法計算方式與目前民航局版本相近，因此預期新舊版本效能應該差距不大。因此在後續效益評估報告中，NTDA 演算法將以展示更大的雷達涵蓋率及比較新舊版本之資料管控程序對於預報結果差異進行說明。至於在比較透過本計劃轉換至臺灣之新 NTDA 版本與美國本土版本之效能比較部分，因為 NTDA 運算結果可視為觀測資料，且臺美兩地天氣條件及雷達資料存在差異性，故建議不進行此部分之比較。

4. CTH/CDO：目前台灣已有 CTH 舊版資料，但無 CDO 資料，因此美方規劃利用比較新舊版本資料，並以實際衛星雲圖資料及降水觀測資料進行驗證。
5. C&V：由於本計劃之 C&V 預報產品已為網格化資料，如需比較現行民航局版本之 MOS 資料，規劃可由目前 C&V 產品挑選特定網格點進行比對，後續需要由進一步討論將目前運作中資料提供給美方之方式。
6. ASPIRE：經過討論，考量到目前臺灣使用之 TITAN 與 ASPIRE 演算原理不太一樣，因此不建議採用直接比對。後續規劃以氣象數值模式之雷達回波場預報及實際雷達觀測資料進行比對，並進行效益評估。

至於在本計畫與美方合作發展之劇烈天氣演算法轉移至臺灣運作後，美方亦將提供驗證程序(如 Jupyter Notebook)或程式給臺灣，並將相關說明、操作及設定方式內容納入最終技術文件中，未來如臺灣面臨演算法所需之資料來源或格式改變時，可透過該程序進行驗證，確認其對於演算法影響程度，並可透過諮詢管道向 NCAR 討論，確保演算法效能。

(六) AOAWS-RU 計畫結束後，未來天氣預報演算法維運方式討論

目前飛航服務總臺將現有使用中之 AOAWS 天氣預報演算法，以委託資訊廠商維護方式，維持其正常運作。惟在面臨所需資料來源或資料格式等重大改變時(如日本 MTSAT2 於 106 年退役，後續改為向日葵 8 號及向日葵 9 號衛星提供衛星雲圖資料，另中央氣象署近年汰新所屬七股、花蓮及墾丁雷達設備)，所涉及資料程序調整及效能驗證作業，仍需由受託之資訊廠商轉請美方提供技術諮詢與支援。為確保本計畫所發展之天氣預報演算法持續保持穩定效能，爰於本次會議與美方討論計畫後之合作方式。

美方表示本計畫結束前會由演算法開發團隊提供驗證程序及程式給臺灣，未來如面臨資料相關之重大變更時，可先行進行評估及驗證作業。若有進一步需要因應調整需求，考量 NCAR 屬於半政府單位，無法直接與臺灣民航局進行合約簽訂，爰建議仍採透過美國在台協會(AIT)及駐美國台北經濟文化辦事處(TECRO)雙方於現有 AOAWS 協議下簽訂執行計畫或比照目前由臺灣民航局委託民間資訊公司辦理系統維護案模式，由民間資訊公司轉洽美方提供協助方式辦理。

(七) 目前美國發展中之最新天氣預報演算法

美國聯邦航空總署(FAA)為發展更為先進及準確之天氣預報演算法，並提供與美國本土作業單位使用，確保飛航安全。因此投入為數不小的資源予 NCAR 等研發單位進行發展，而 AOAWS 計畫自以往以來即將美國發展完成且納入作業的天氣演算法引入臺灣使用，並由美方協助進行調整，使其符合臺灣作業環境及天氣條件。

另考量目前 AI 人工智慧已為熱門議題，各類工作領域逐漸嘗試與 AI 進行接軌，爰於本次會議詢問目前 NCAR 刻正發展中之其他天氣演算法及是否納入 AI 技術，美方回復目前發展中的天氣演算法如下：

1. High Ice Water Content(HIWC)天氣演算法：經近年研究發現飛機發動機吸入大量冰晶，進而所造成的飛機機組零件故障情況。雖尚未有相關事故發生，但相關現象已陸續在全球各地發現，亦包含熱帶地區。因此 NCAR 已開始著手進行相關調查，並進行 HIWC 天氣演算法發展，目前採用澳洲、法屬圭亞那及英國等地資料進行訓練及驗證。
2. GTG4 升級至 GTG4.5：本升級想法即是將 AI 技術納入原本 GTG4 演算法中，’嘗試透過 AI 進行資料分析及判斷，並輸出對應之 EDR 數值。
3. GTGN 升級：同樣透過 AI 技術分析飛機所得 EDR 數值，並進行產出亂流發生機率資料。
4. NTDA：持續發展更佳的資料管控技術，如濾除鳥類及昆蟲移動之偽訊號。
5. Ensemble Prediction of Oceanic Convective Hazards (EPOCH)：由於海洋地區的對流系統對航班亦構成相當程度的安全威脅，係因正在形成和現有的對流風暴系統上方和/或附近可能引發亂流。而跨洋航班飛行時間長，航空公司需要長達

未來36小時的相關預報資訊。因此NCAR正在開發網格概率預報指南的方法，超越氣象數值模式預報時間長度的海洋對流系統演算法。

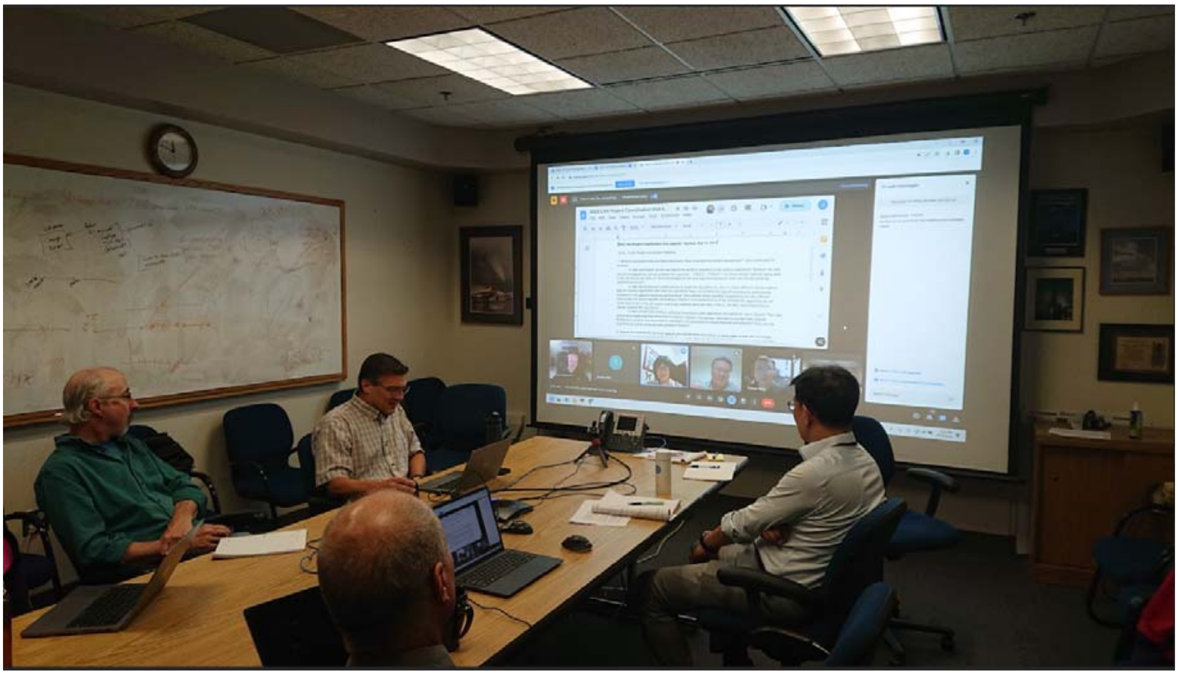


圖12、9月19日會議

三、 跨尺度天氣預報模式(**MPAS**)發展

MPAS 英文全名為 Model for Prediction Across Scales，中文暫譯為跨尺度天氣預報模式。

跨尺度預測模式(MPAS)是一個合作項目，旨在開發用於氣候、區域氣候和天氣研究的大氣、海洋和其他地球系統模擬組成。主要開發合作夥伴包括洛斯阿拉莫斯國家實驗室(Los Alamos National Laboratory)和 NCAR。這兩個主要合作夥伴負責 MPAS 框架、應用程序共用的運算符和工具；洛斯阿拉莫斯國家實驗室主要負責海洋和陸地冰模型，而 NCAR 主要負責大氣模型。

MPAS 的特點是非結構化 Voronoi 網格和 C-網格離散化，它們被用作許多模型組件的基礎。非結構化的 Voronoi 網格，正式稱為球形中心 Voronoi 剖分（SCVTs），允許對球進行準均勻離散化和局部細化。C-格離散化，其中單元邊緣上的速度的法向分量被預測，特別適用於更高分辨率的中尺度大氣和海洋模擬。陸地冰模型利用 SCVT 雙網格，這是一種三角形 Delaunay 曲面細分，適合與基於有限元素的離散化一起使用。

MPAS 模式網格點(採非結構化網格)

本討論會議主要由 NCAR 之 Mesoscale & Microscale Meteorology Laboratory 及中央氣象署進行討論，但考量到民航局 AOAWS-RU 計畫各式演算法與氣象數值模式之關聯性，爰邀請民航局及 NCAR 之 Research Applications Laboratory(AOAWS-RU 計畫之預報演算法發展單位)與會。

目前 MPAS 第 8 版本已於 112 年 6 月 16 日釋出，該版本主要為增加新的 I/O 層、為圖形處理設計交換模組、模式初始化更新(以解決模式資料邊界問題及靜態場平行執行)、動態更新及物理化更新等部分。

MPAS 模式後續預計於今(112)年年底起於美國國家海洋暨大氣總署(NOAA)進行試用，而中央氣象署部分，目前持續由中央氣象署進行相關資訊研究及準備工作，雖已完成 MPAS 測試平臺，持續透過校驗及驗證工具比較 MPAS 及目前運作中之天氣研究及預報模式(WRF)效能，但正式上線取代現行作業的時間尚未明確。但可以預期時間應該是 10 年左右。對於中央氣象署而言，WRF 及 MPAS 是可以共存的，因此無由 WRF 過度至 MPAS 之議題，而目前作業中之天氣研究及預報模式(WRF)亦將持續於資料同化部分進行強化，另規劃於 MPAS 進行後續新的測試及研究部分相關工作。而就民航局而言，現階段因 MPAS 尚在臺灣地區發展中，因此暫對於本計畫所引入之天氣預報演算法無立即性之影響，後續仍需持續與中央氣象署確認發展情況，並適時擬定因應策略。

圖 13、9 月 20 日 MPAS 討論會議

肆、心得與建議

民航局自 86 年至 103 年間透過「臺美航空氣象現代化作業系統發展技術合作協定」與美國國家大氣研究中心(NCAR)合作，整合現代化氣象測報資料、中尺度航空氣象數值模式及其餘各類預報產品，完成「航空氣象現代化作業系統（Advanced Operational Aviation Weather System, AOAWS）」之建置，提供臺北飛航情報區內飛航作業相關單位即時且精緻之航空氣象資訊服務，並與美國 NCAR 維持過往得來不易合作關係，以持續關注國際間先進氣象科技，於適當時機引進最先進的航空天氣作業概念及關鍵技術。

現因國際間航空氣象預報及資訊技術高速發展，現有系統漸有老化及出現維運困難情況，爰自 110 年起啟動「航空氣象現代化作業系統汰換及更新計畫(The Advanced Operational Aviation Weather System Renewal and Update，AOAWS-RU)」，本計畫採三方合作模式進行，資訊系統整合採委託國內資訊系統發展公司方式進行發展，另與美方合作發展最新預報天氣演算法，以期新一代系統提供更為靈活且精緻之航空氣象資訊服務。

然計畫推動以來，受新冠肺炎疫情影響，使原訂赴美國進行之協調會議改為視訊會議方式辦理，對於會議討論效率略有影響。今年度舉辦之協調會議為疫情影響減緩後首次赴美舉行，經本次會議除了解各項天氣演算法發展情況外，亦討論到多項航空氣象國際規定近況及技術發展情況，並首次與中央氣象署與美國 NCAR 等單位共同討論 MPAS 模式發展情況，可謂成果豐碩。謹就參與本次會議建議事項如下：

一、 關注新一代世界區域預報系統(WAFS)發展情況，並擬定因應策略

新一代世界區域預報系統規劃於 112 年 11 月起分階段調整服務資料內容及方式，考量其為本區重要航空氣象資料，為確保後續作業及服務穩定，建議持續關注並擬定因應策略。

二、 研議國際民航組織(ICAO)全系統信息管理(SWIM)計畫資料交換及服務事宜

ICAO 刻正推動 SWIM 計畫，歐美等先進國家已經著手進行相關因應，民航局飛航服務總臺雖業透過 AOAWS-RU 購置 SOLACE 設備，並規劃利用其進行飛航資料交換，惟經本次會議討論初步確認，前述設備為符合 SWIM 架構之資料交換管道，尚有註冊及資料訂閱部分需要確認，為使我國航空氣象資訊服務與國際發展期程接軌，建議持續關注並透過鄰近區域及其他國際間友好合作單位協助取得相關資訊。

三、 留意跨尺度天氣預報模式(MPAS)發展情況

民航局與中央氣象署基於政府資源共享理念，依行政程序法第十九條簽訂氣象資料與預報模式系統作業技術合作協議，雙方協議於權限範圍內互相協助，促進氣象測報資訊之飛航應用。民航局透過該協議取得中央氣象署發展之天氣研究與預報模式(WRF)資料，並納入日常作業及預報演算法運算。依本次會議所得 MPAS 發展趨勢，該模式可能成為新一代氣象數值預報模式之主流，爰建議後續留意該模式之發展情況，並擬定資料接收及系統調整策略。

四、 持續派員參與國際性航空氣象會議及訓練

AOAWS-RU 計畫將於 113 年年底完成，但我們因非 ICAO 會員國，且受限於國際情勢，國際間航空氣象資訊發展及作業最新規定取得不易，若能在計畫完成後，持續編列出國計畫並選派優秀興趣同仁前往 NCAR 或其他國際氣象單位進行交流和訓練，除可提升自身專業知能及拓展國際視野外，並能了解國際間發展情況與持續規劃相關合作，將有助於精進本區航空氣象作業及服務品質。

伍、附錄

一、會議簡報

Task 1. Update the InFlight Icing (IFI) Products

Taiwan CIP2 & TFIP2 Status Update

Gary Cunning & Dan Adriaansen

Aviation Applications Program
Research Applications Laboratory

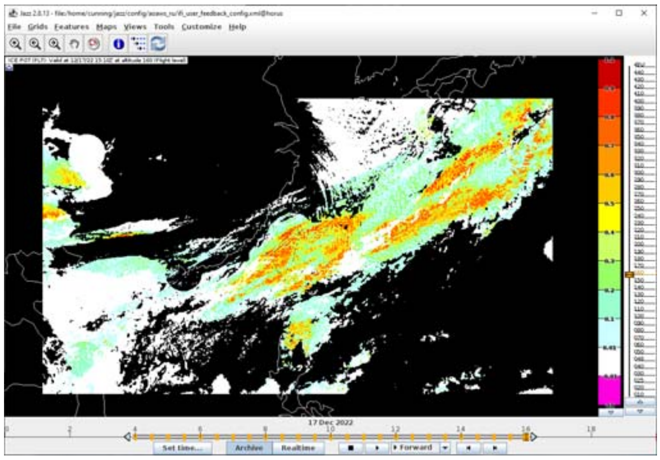
Taiwan FIP2 and CIP2 Status Update

Review of Deliverables

Deliverable	Due Date	Status
User feedback assessment documentation	7/2/23	Delivered
Report on test and evaluation	9/1/23	Delivered
Technical documentation	10/2/23	On track
Software delivery via a USB thumb drive	10/2/23	On track

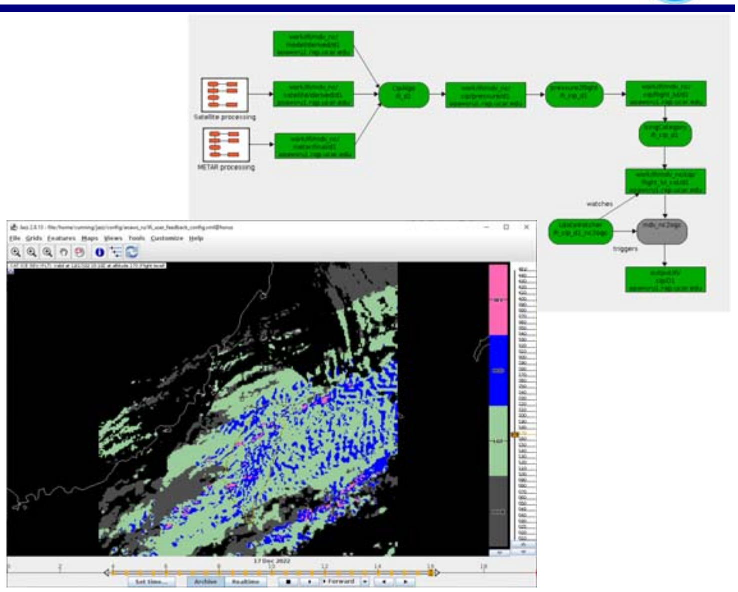
Taiwan FIP2 and CIP2 Status Update

- Collected Taiwan datasets from 12/15/23 through 3/15/23
- Ran TCIP2 and TFIP2 on the three months of data to create the baseline configuration
- Completed special CONUS CWB-WRF run evaluation
- Performed evaluation of baseline TCIP2 & TFIP2 configuration results from three months of data
- Wrote and delivered evaluation report (deliverable).

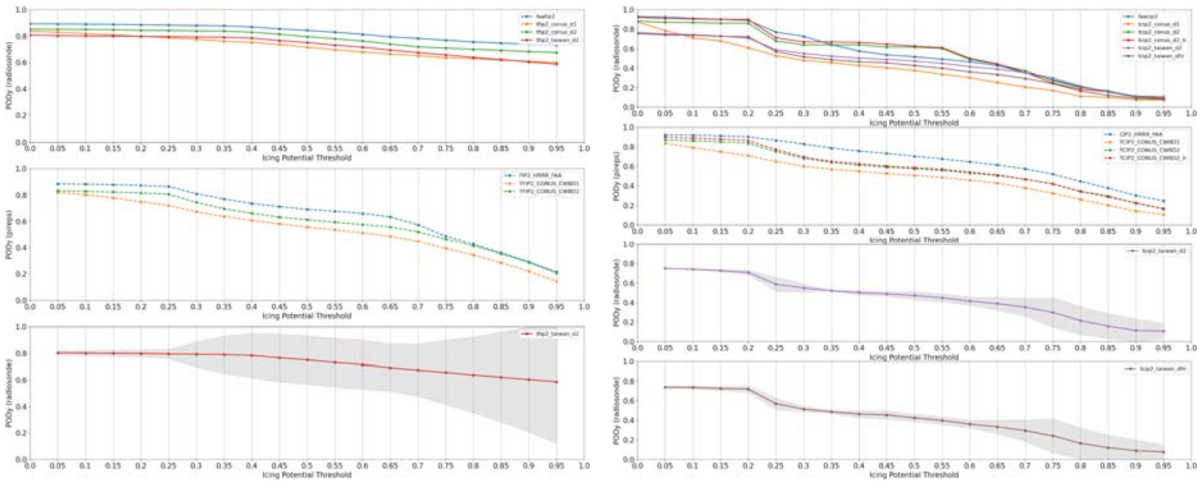


Taiwan FIP2 and CIP2 Status Update

- Prepared for user feedback survey by creation of four cases for user feedback study, created questions, staged data for study, and created Jazz configuration file for study participants
- Reviewed survey results and documented analysis of results in a report (deliverable).
- Created and test build and install scripts
- Created test harness
- Created SysView diagrams.
- Built and installed TCIP2 & TFIP2 on NCAR test server
- Built and installed TCIP2 & TFIP2 on CAA test server
- Monitoring performance and making changes to TCIP2 & TFIP2



Taiwan FIP2 and CIP2 Evaluation Results



Taiwan FIP2 and CIP2 Status Update

Next Steps

- Update test and evaluation report, if NASA H9 Global satellite icing products are available.
- Complete technical documentation.
- Monitor performance and make changes as needed to TCIP2 & TFIP2 installed on CAA test server.
- Re-install TCIP2 & TFIP2 on CAA test server as needed.
- Complete test harness script; script needs to include TCIP2 on CWB WRF D1 domain.
- Prepare and deliver source code.

Issues/Challenges

- Low reliability of data feeds is affecting evaluation of TCIP2 and TFIP2 on CAA server.
- Limited computing disk space and memory on CAA server.
- Gaps, ordering, and latencies of CWB WRF files. This directly affects the performance of TCIP2 and TFIP2.
- Limited access to the CAA server is slowing down progress.

Task 2. GTG

Graphical Turbulence Guidance
and
Graphical Turbulence Guidance Nowcast

Wiebke Deierling, Hailey Shin, Jason Craig, Julia Pearson, Teddie Keller, Jeff Hancock, Greg Meymaris, Bob Sharman

GTG Deliverable Tracking

AOAWS-RU Task #	Deliverable	Due Date	Status
2	Install GTG4 software in CAA test environment	June 30, 2023	Complete
2	GTG4 testing report	October 31, 2023	Have set up GTG4 in CAA test environment
2	GTG4 user feedback assessment documentation	October 31, 2023	Underway
2	Report on one or more GTGN case studies as part of quarterly report	December 1, 2023	Report development underway
2	GTG4/GTGN status report on activities performed as part of quarterly report	December 1, 2023	Report development underway

GTG4/GTGN System Readiness Status

Instance[1]	Algorithm Development	Initial Diagnostic Mapping to EDR and Diagnostic Selection (Calibration)	Final Diagnostic Mapping to EDR and Diagnostic Selection (Calibration)	Verification
D1 - GTG4	Done	Done	Underway	To Do
D2 - GTG4	Done	Done	Underway	To Do

Notes:
- D1-GTG4 will not include CIT component because of its coarse grid spacing. CIT has been developed for higher grid resolution <= 3km
- Final calibration requires sufficient in situ data that was collected through mid of this year, final calibration underway followed by evaluation

Instance[1]	Algorithm Development	Tuning based on Case Studies	Evaluation based on Case Studies
GTGN	Underway	Winter 2023/Spring 2024	Spring/Summer 2024

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GTG4 Software Implementation and Updates

- Completed an initial installation of GTG4 software on the CAA test server
  - Documentation of the installation was provided at the end of June 2023.
  - We are now evaluating the performance of the system utilizing the real-time data on the CAA test server.
- Development of a script to compere GTG4 output with observations
  - An option to output IATA in-situ EDR and matching GTG output has been implemented into the GTG4 code and is under testing
- Statistical evaluation of initial GTG4 system completed. Calibration of GTG4 based on ~2 years worth of in situ data underway.

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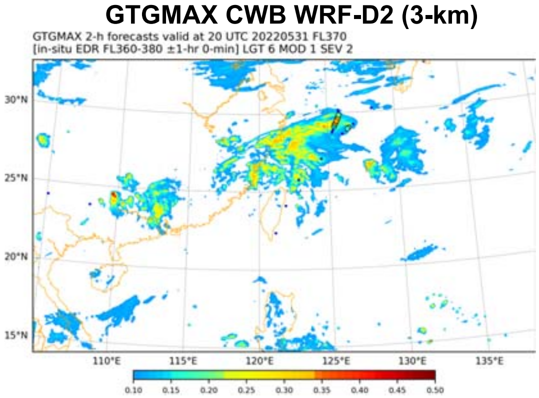
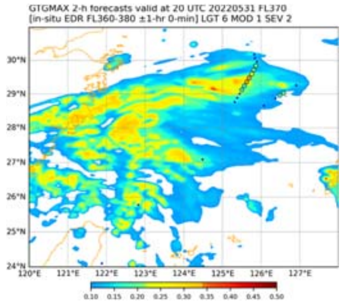
Prototype GTG4 – Case Studies

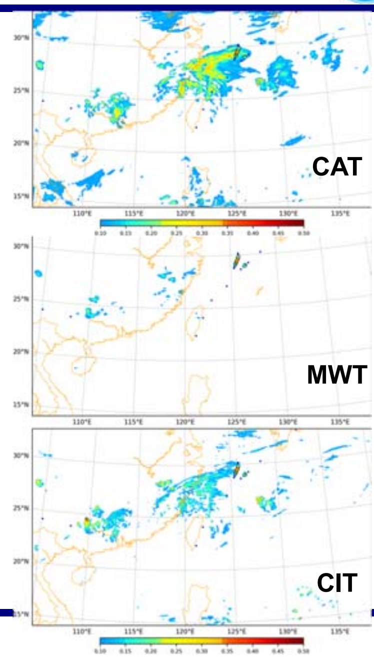
- Identified a number of additional cases in various weather regimes and altitudes
- Some of these cases will be provided for the User Feedback Survey
- **05-31-2022 20 UTC Case: An Example**
  - **Mei-Yu front positioned to the North of Taiwan**

GTGMAX CWB WRF-D2 (3-km)



zoom-in





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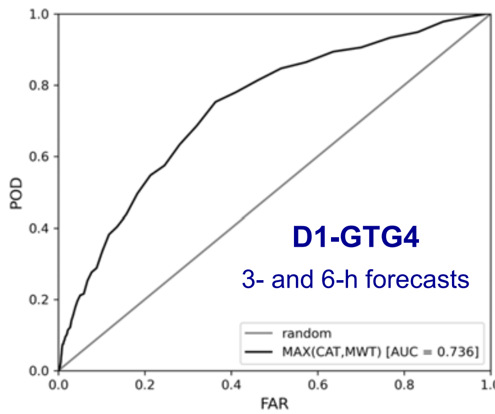
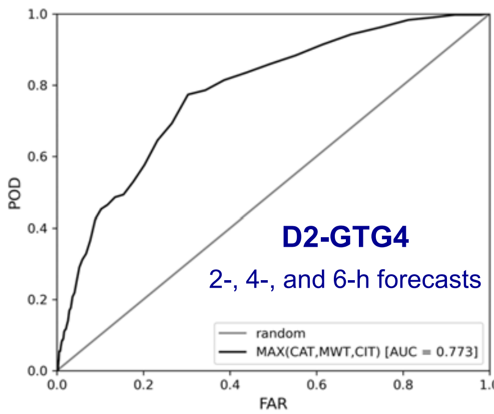
Prototype GTG4 – Initial Statistical Evaluation

- Verification Period: 1 July 2021 – 30 September 2022
- Vertical Level: FL200–FL600

ROC curves for Moderate-or-greater (MOG) turbulence





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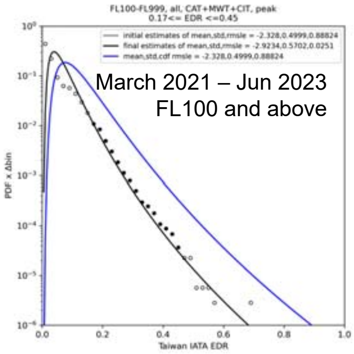
GTG4 Calibration – Updated Diagnostic Mapping to EDR

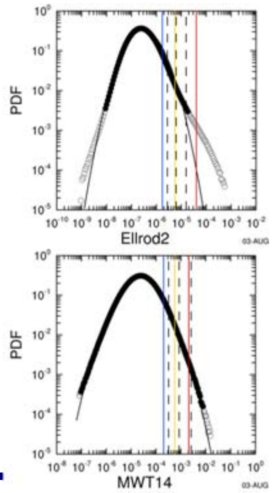
- **CAT and MWT Diagnostics**

IATA in-situ EDR over WRF-D2 for log-normal PDF fitting



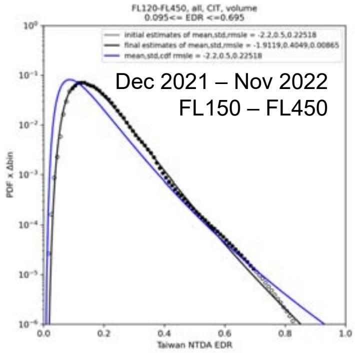
=> obtained mean and STD of ln<EDR> to be use for mapping of diagnostics to EDR

Diagnostic mapping to EDR

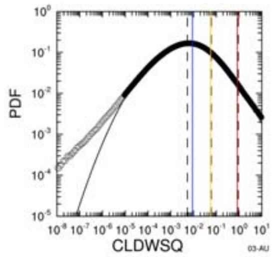


- **CIT Diagnostics**

Taiwan NTDA EDR for log-normal PDF fitting



Diagnostic mapping to EDR



GTGN Updates

- Completed GTGN feasibility and implementation study and document recommending GTGN for Taiwan and specifying what input data should be included
- Developed Input data processing:
  - Developed an application for preparing IATA EDR turbulence data from Taiwan as input into GTGN
  - Developed a script for converting the combined METARS into the correct input format into the GTGN system.
- Developed code to identify and output an observation influence field (obsMask) that identifies areas of GTGN that differ from the underlying forecast based on incorporated observations (NTDA, IATA in situ EDR, METARs)
- Identified case studies for GTGN near Taiwan by reviewing NTDA and IATA in situ EDR data. Have begun work on running and analyzing a prototype GTGN for these case studies.

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Issues / Challenges

- Model data has gaps and variable latencies.
  - Sometimes the first few lead times arrive well after other lead times.
- Some GTG runs on the CAA test server are experiencing unusually long delays (to be detailed in testing report)
- Running GTG out to 48hrs will be challenging with current compute power
- Low reliability of data feeds (e.g. model) will be a challenge for GTGN installation

Planning

- Final calibration of GTG4 underway followed by evaluation. Final fine tuning as needed.
- Finalizing prototype GTGN based on case studies and transferring system to CAA

Task 3. NTDA

AOAWS NCAR Turbulence Detection Algorithm

Gregory Meymaris, Jason Craig, Scott Ellis, Wiebke Deierling

NTDA Deliverable Tracking

AOAWS-RU Task #	Deliverable	Due Date	Status
3a	Install NTDA software in CAA test environment	June 30, 2023	Completed.
3b	Report on NTDA case studies and evaluation as part of the quarterly report	Dec. 1 2023	Continuing to compile and evaluate case studies.
3c	NTDA status report on activities performed as part of quarterly report	Dec. 1 2023	Modifications to the Gematronik ingester were implemented to work with the recently upgraded CWB radars (RKCT and RCHL). Testing continues, especially on any downstream impacts.

NTDA Upgrade Readiness Status

Instance	Algorithm functionality
NEXRAD Ingester Component	A
Gematronik Ingester Component	T2[1]
NTDA Polar (Radar by Radar) Component	T2[1]
Mosaic component	T2[2]

Notes
1. Further adaptations were recently made to accommodate upgraded Gematronik radars. Effort was needed to analyze the upgraded format.
2. Much of the work here will depend upon the radar selection, which is on-going. A preliminary radar selection will be made this phase, with a final selection made in IA19

Status Key	Subsystem Development Phase
C	Code Development
T1	Testing and Configuration
T2	Testing with CWB Sample Data
A	Assessing Performance and Fine Tuning
R	Ready to Deliver

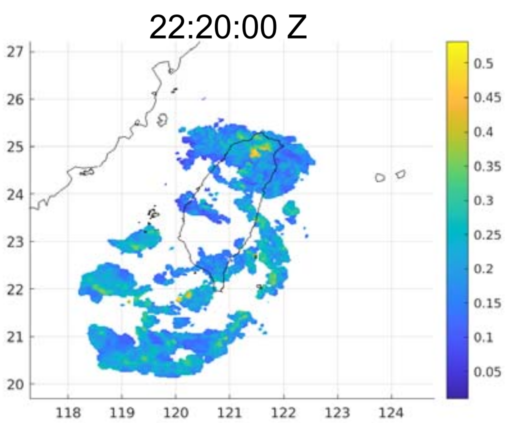
Plans

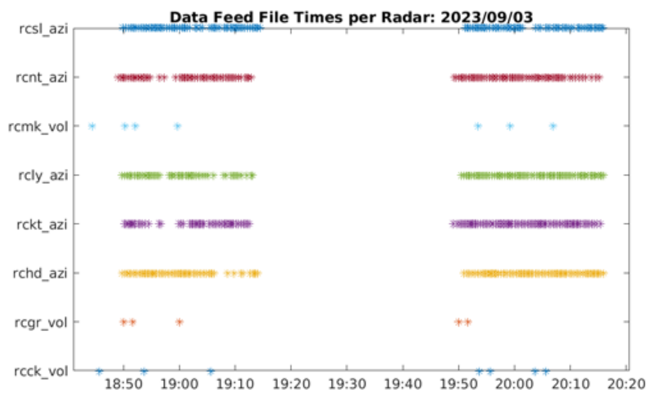
- Continue testing modifications needed due to the recently upgraded radars (RCKT, RCHL)
  - Upgraded RCCG is a completely new type of radar (Toshiba) - requires more extensive review
- Continue to evaluate (e.g. case studies) and tune NTDA as needed.
- Finalize list of radars to be used by NTDA
- Develop regression test procedure
- Collect user feedback and make adjustments as necessary

Issues / Challenges

- Recent radar upgrades have increased workload/costs and delayed progress.
- Reliability of the data feed has complicated case study analysis (time gaps, missing files, incomplete files)
  - NCAR is not receiving RCCG data in the feed since the upgrade and thus cannot evaluate it. Unlikely to be able to evaluate before the end of this year.

Example from 2023/09/03 from Gematronik Radars Composite of EDR / Data Feed Reliability





Task 4. Update the Cloud Top Height (CTH) Prediction Products

Status Update
Including Convection Diagnosis Oceanic (CDO) and CDO-Lite

Ken Stone, Dan Megenhardt, Josh Lave, Tom Blitz

Task 4 Deliverable Status

AOAWS-RU Task #	Deliverable	Due Date	Status
4	a) Install updated version of CTH/CDO in CAA test environment	December 1, 2023	Complete
4	b) CTH/CDO Confirmation report on algorithm changes	December 1, 2023	Report development underway 1 and 2 hour extrapolation performance and improvements to parallax correction

System Readiness Status

	Subsystem			
Instance [1]	CTH	CDO-Lite [2]	CTH 1 and 2 hr Extrapolation	CDO-Lite 1 and 2 hr Extrapolation
WRF D1	R	R	A	A
WRF D2	R	R	A	A

Notes
1. Intersection of WRF domain(s) with Himawari footprint using regular equal-angle grid.
2. CDO-Lite does not use Lightning data.

Status Key	Subsystem Development Phase
C	Code Development
T1	Testing and Configuration
T2	Testing with CWB Sample Data
A	Assessing Performance and Fine Tuning
R	Ready to Deliver

System Readiness Status

	Subsystem			
Instance [1]	CTH	CDO [2]	CTH 1 and 2 hr Extrapolation	CDO 1 and 2 hr Extrapolation
DFIR	R	R	A	A

Notes
1. Intersection of FIR domain with Himawari footprint using regular equal-angle grid
2. CDO uses Lightning data.

Status Key	Subsystem Development Phase
C	Code Development
T1	Testing and Configuration
T2	Testing with CWB Sample Data
A	Assessing Performance and Fine Tuning
R	Ready to Deliver

Plans

Deliverable Focus

- Confirmation report on algorithm changes including extrapolation performance (2023)
- More Validation Work and Test Report Development (2024)
- Obtain user feedback & generate report (2024)
- Algorithm Updates report, as needed (2024)

Possible R&D

- Improving CDO in D1 and D2 with additional IR channels using ML techniques.
- Improve depiction of early storm development.

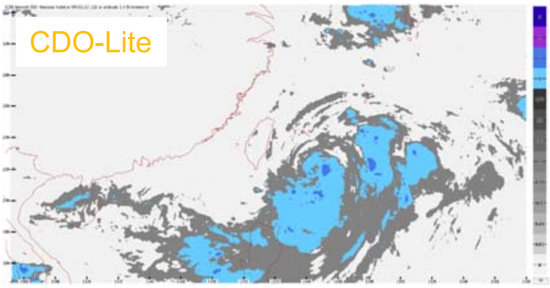
Issues and Challenges

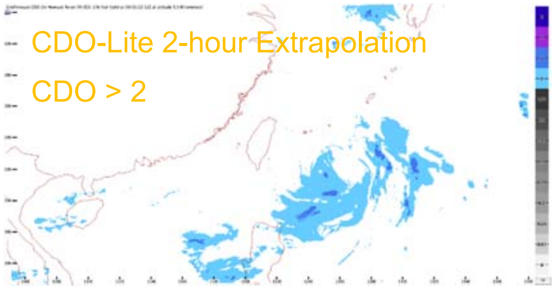
- No Current Issues.

Challenges:

- Extrapolation - performance in dynamic conditions (storm acceleration, growth, and decay).
- Nowcast - Depicting initial storm growth.

CTH & CDO-lite with 2-hr Extrap. Example Images

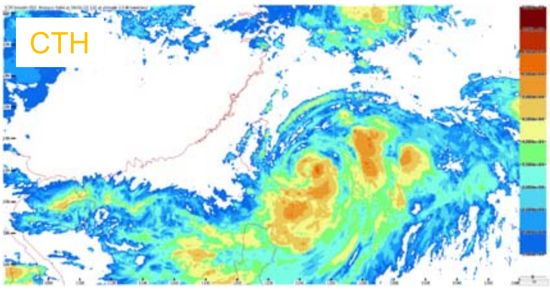


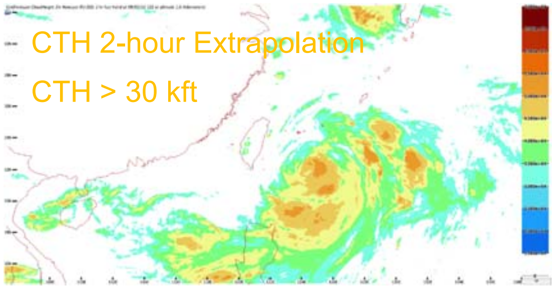


Typhoon Hinnamnor

2 Sept. 2022
Valid: 1200Z

Inputs:
Himawari
WRF D2





NCAR

Task 5. Ceiling and Visibility

Forecast Calibration Quantile Matching (FOCAL-QM)

Status and Planning Update

Jim Cowie, Bill Petzke

NCAR

Task 5 Deliverable Status

AOAWS-RU Task #	Deliverable	Due Date	Status
5	Status report and results of calibration performance on recent data	July 17, 2023	Complete
5	Install FOCAL-QM in CAA test environment	August 31, 2023	Complete
5	Status report and results of calibration performance on recent data	December 1, 2023	Will write report in late November

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System Readiness Status

	Subsystem		
Instance [1]	**Ingest** (3KM WRF/UPP, METAR)	**Calibration** (PtGridFrequencyMatch)	**Forecast** (CVmodelCal)
Ceiling	R	A	A
Visibility	R	A	A
Pass-Through Variable[2]	R	N/A	R

Notes
1. Calibration of ceiling and visibility are performed in parallel, forecasts of C&V are produced in series from latest WRF/UPP run.
2. Pass-through variables bypass the calibration step.

Status Key	Subsystem Development Phase
C	Code Development
T1	Testing and Configuration
T2	Testing with CWB Sample Data
A	Assessing Performance and Fine Tuning
R	Ready to Deliver
N/A	Not Applicable

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Plans

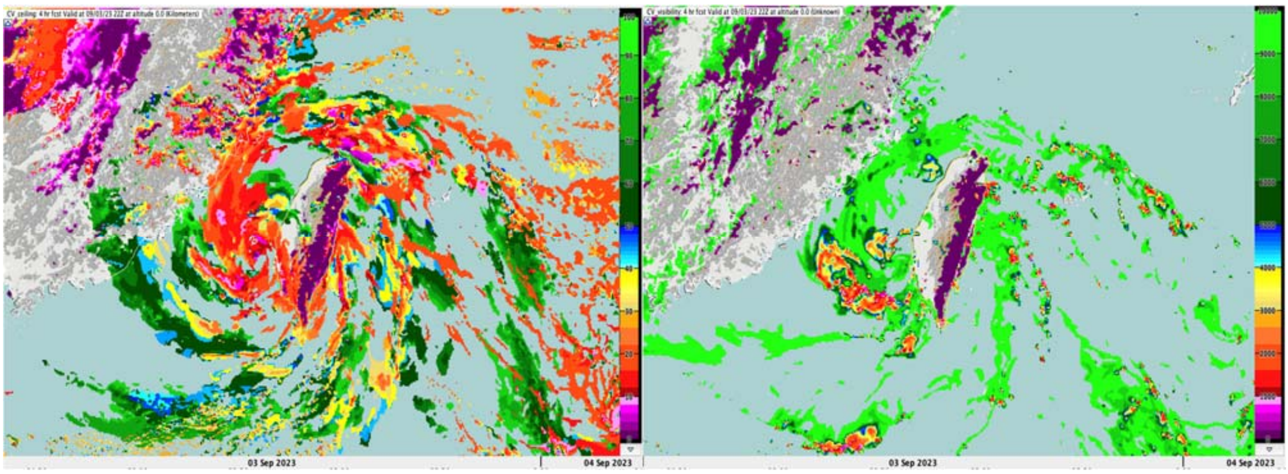
- Deliver technical presentation to CAA (October 2023)
- Complete performance report (December 2023)
  - Check for performance changes due to CWB WRF upgrade
- Testing report with evaluation (February 2024)
- Obtain user feedback & generate report (March 2024)
- Monitor issues and challenges and develop solutions where appropriate

Issues and Challenges

- CWB WRF upgrade caused a problem in the UPP (July 17, 2023)
  – Visibility no longer produced
  – UPP was fixed
- Occasional missing input data and outages
- Calibration can cause circular artifacts
- How to “boot-strap” system which requires 30 days of WRF/METAR data?

Ceiling and Visibility Sample Images

Ceiling 22UTC Sept 3, 2023 Visibility



Task 6. ASPIRE

AOAWS **S**hort-term **P**rediction of **I**ntense **R**ainfall and **E**chotops

James Pinto, Dan Megenhardt, Sue Dettling, Dave Albo, Tina Kalb, Jeff Hancock, Tom Blitz

Aviation Applications Program
Research Applications Laboratory

ASPIRE Deliverable Tracking

AOAWS-RU Task #	Deliverable	Due Date	Status
6	Provide case examples to CAA for initial feedback	January 30, 2023	**Complete.** Run in archive mode for case study, Sample files from ASPIRE V1.2 delivered.
6	Install ASPIRE, V1.0 within CAA real-time test environment	March 31, 2023	**Complete.** ASPIRE V1.2 installed on CAA host on 10 March and run in archive mode due to lack of realtime data feeds. Initial comparison results differed due to use of a random seed in CTREC which was subsequently modified all us to produce identical results on CAA host.
6	ASPIRE testing report with evaluation	July 31, 2023	**Complete**/Ongoing. Realtime testing on CAA host started on June 8th. Issues with input data made troubleshooting realtime issues challenging. Report delivered on assessment of archive mode output. Note: A number of code fixes and a new forecast data sequencer application have been implemented. Latest version is called V1.5
6	User feedback assessment documentation	August 15, 2023	**Complete**/Ongoing. Developed JAZZ config and google web survey and obtained initial feedback before data feeds went down. Delivered report. Improved JAZZ run selector and performed JAZZ training to aid in ASPIRE user evaluation.

Aviation Applications Program
Research Applications Laboratory

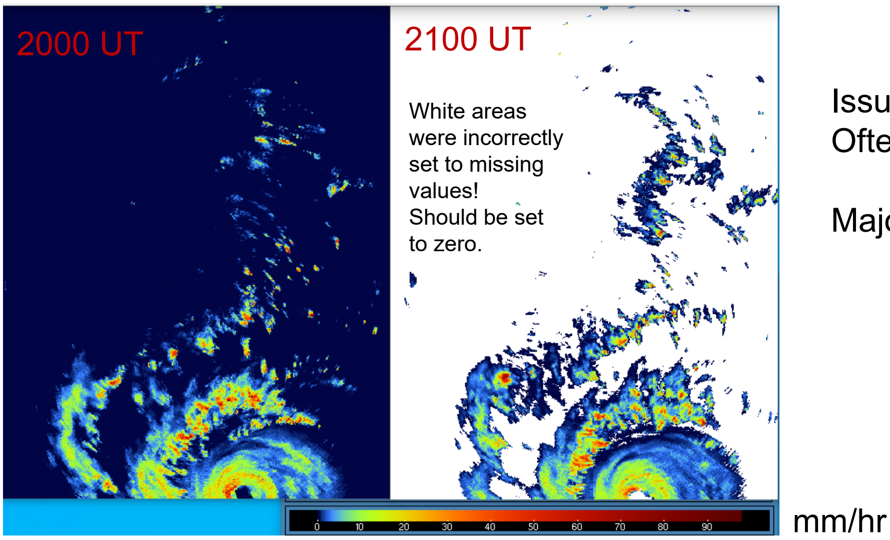
ASPIRE V1.5 System Readiness Status

	Subsystem					
Instance	Ingest[1,2]	Extrapolation	Model Calibration[3]	Model Phase[3] Correction	Dynamic Weights[3]	Heuristic[3] Blending
Composite Reflectivity	D	D	R	R	R	R
Storm Top Heights	D	D	R	NA	NA	R
Rain Rate	D	D	R	NA	NA	R

Notes
1. Recently fixed a bug causing issue with QPESUMS data. Fixed issue with UPP conversion causing occasional missing lead times.
2. New app developed to handle receipt of forecast leadtimes out of chronological order.
3. Reliability of inputs has hampered efforts to finalize realtime installation and degraded system performance (as well as offline runs) due to reliance of calibration and weighting on 18-day history.

Status Key	Subsystem Development Phase
C	Code Development
T1	Testing and Configuration
T2	Testing with CWB Sample Data
R	Realtime Testing
D	Ready to Deliver

Fixed QPESUMS ingest



Issue happened randomly, Often for only part of domain.

Major impact on calibration!

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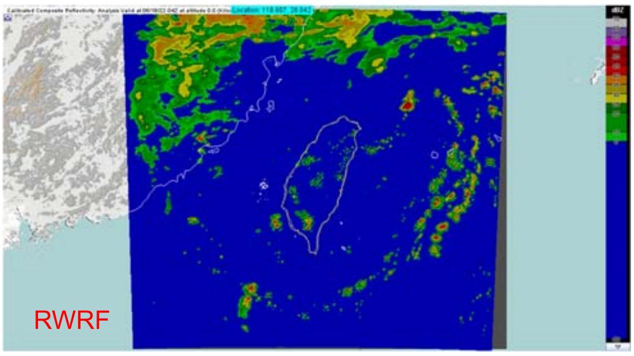
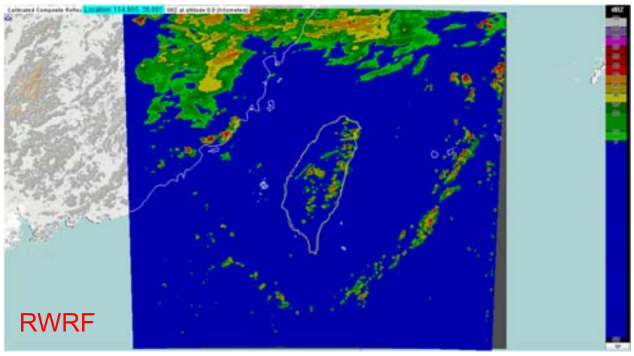
Model Forecasting Biases : Storm Initiation

2022-06-18: RWRF 0 hr fcst valid at 0400 UTC



2023-06-18: RWRF 2 hr fcst valid at 0600 UTC



Calibrated RWRF model data shown (raw has much more storm area).
Model too early and to large with storm initiation areas
Bias begins to manifest at analysis time.

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Performance Assessment

Skill of Offline Case Period 17-21 Jun 2022

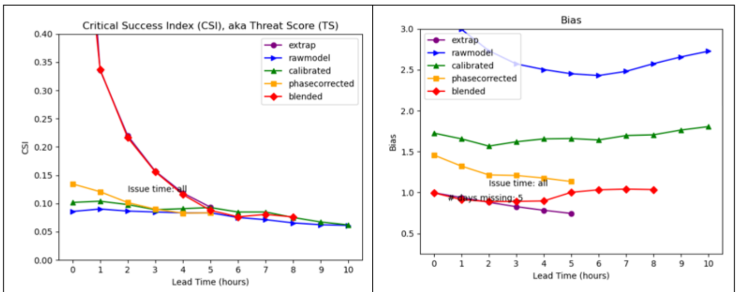
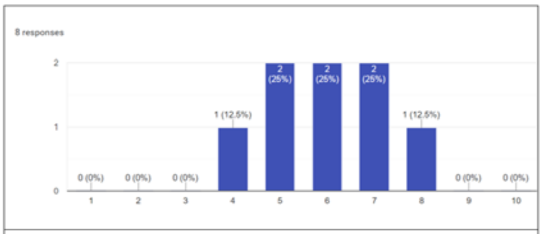


Figure 4. (left) CSI and (right) Bias as a function of lead time using data from the period 17-21 June 2022. Note that the CSI score from extrapolation lies directly beneath that for blending for lead hours less than or equal to 4 indicating that the extrapolation skill exceeds that of the model for lead hours less than 4.

Initial CAA Feedback 4-12 August 2023



Distribution of scores from (1 worst – no skill) to (10 – highly skillful) indicating subjective determination of the skill of ASPIREV1.2 over the period 4-12 August 2023.

Issues / Challenges

- Low reliability of data feeds (obs and model) have increased costs and delayed installation and evaluation of ASPIRE V1.2
- Model data has many gaps and highly variable latencies.
  – Sometimes the first few lead times arrive well after other lead times.
- Limited disk space on CAA host limits ability to evaluate performance and diagnose issues.
- Limited access to the CAA host (i.e., weekday only from 8a-5p) also hampers progress.
- Model performance – skill tends to be lower than extrapolation through 4-5 hours, also struggles with initiation.
- Challenging weather – need help from CAA to identify most challenging short-term forecast problems.

Planning

- Work with CAA/CWB to stabilize input feeds on CAA host
- Finalize realtime installation and perform evaluations
- Restart ASPIREV1.5 evaluation survey
- Implement utilization of 20 min RWRF output.
- Improve blending heuristics
- Install ASPIRE2.0 on NCAR system.
  – Improved phase correction enabled by 20 min model output
  – Improved blending heuristics
- Detailed performance evaluations of ASPIRE1.5 vs ASPIRE2.0.

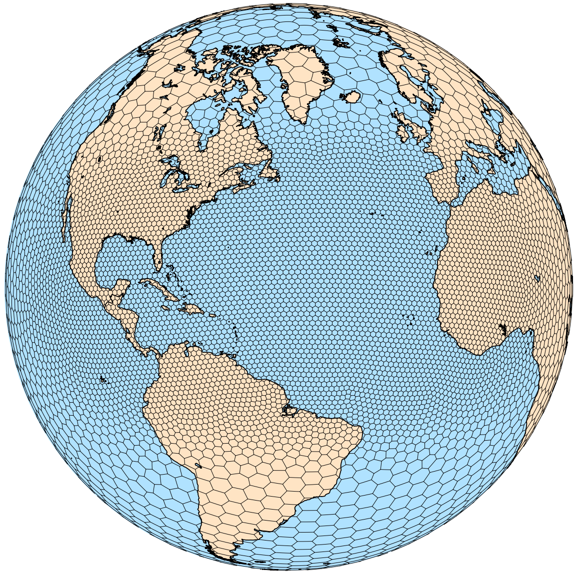
MPAS Update

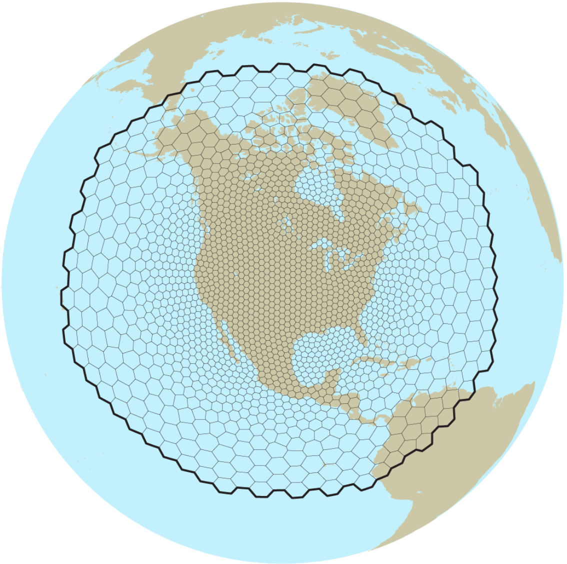
Bill Skamarock and the MPAS Team
Mesoscale and Microscale Meteorology Laboratory

NCAR

CWA – MPAS Update, 20 September 2023

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.





Model for Prediction Across Scales (MPAS)

MPAS-Version 8 released on 16 June 2023

Previous releases:

Version 7.0: 8 June 2019
Version 7.1: 3 September 2021
Version 7.2: 14 February 2022
Version 7.3: 24 March 2022

- Atmosphere and land only
- Open Source: https://mpas-dev.github.io/
- Global and regional, variable-resolution capabilities
- GPU-enabled for some configurations (V6.x, October 2020)
- DA – both DART and JEDI

Today:

- Updates
- Current and future development

MPAS Release Paradigm

New version numbering: MAJOR.MINOR.PATCH

- Beginning with MPAS v8, version numbers will be MAJOR.MINOR.PATCH
- More or less following Semantic Versioning

MPAS v8.1.3

MAJOR - signifies major changes or lack of compatibility with previous versions of MPAS

MINOR - new model features with backward compatibility

PATCH - bug fixes to MAJOR.MINOR

MPAS Version 8 – What's New?

Infrastructure

- SMIOL (Simple MPAS IO Layer)
- Refactored halo communications.

Initialization updates

- Extrapolations below analyses lower boundary
- Static field parallel execution
- CAM-MPAS grid creation

Dynamics updates

- Regional MPAS LBCs
- Upper absorbing layer generalization
- Diagnostics
- Vertical interpolation
- Length-scale specification
- CAM-MPAS extensions

Physics updates

New I/O Layer: The Simple MPAS I/O Layer (SMIOL)

- Provides an alternative to the Parallel I/O (PIO) library
- SMIOL source code is included in MPAS-Model source tree
- Minimal library dependencies: only MPI and PNetCDF

The use of SMIOL in place of PIO is activated at compile time by *not* setting the `$PIO` environment variable.

New I/O Layer: The Simple MPAS I/O Layer (SMIOL)

- Build summary indicates whether SMIOL or PIO was used

```
*****************************************************************************
MPAS was built with default single-precision reals.
Debugging is off.
Parallel version is on.
Papi libraries are off.
TAU Hooks are off.
MPAS was built without OpenMP support.
MPAS was built without OpenMP-offload GPU support.
MPAS was built without OpenACC accelerator support.
Position-dependent code was generated.
MPAS was built with .F files.
The native timer interface is being used
Using the SMIOL library.
*****************************************************************************
```

New OpenACC-friendly group halo exchange module

- Allows MPI messages to be aggregated across fields whose halos are communicated at the same point in solver
- Specifically designed to be adaptable for direct GPU-to-GPU communication of halos with OpenACC

Example of a group of halo exchanges in MPAS v7:

```
call mpas_dmpar_exch_halo_field(theta_m_field)
call mpas_dmpar_exch_halo_field(scalars_field)
call mpas_dmpar_exch_halo_field(pressure_p_field)
call mpas_dmpar_exch_halo_field(rtheta_p_field)
```

New OpenACC-friendly group halo exchange module

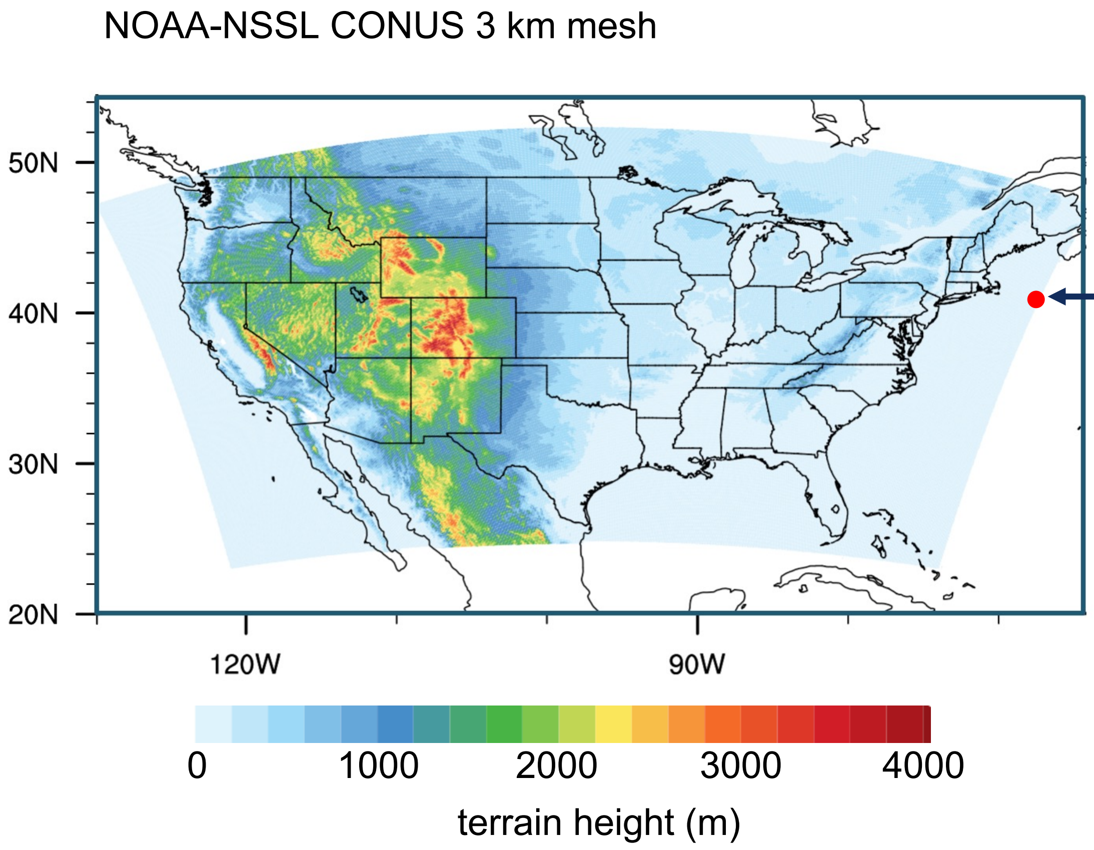
- Allows MPI messages to be aggregated across fields whose halos are communicated at the same point in solver
- Specifically designed to be adaptable for direct GPU-to-GPU communication of halos with OpenACC

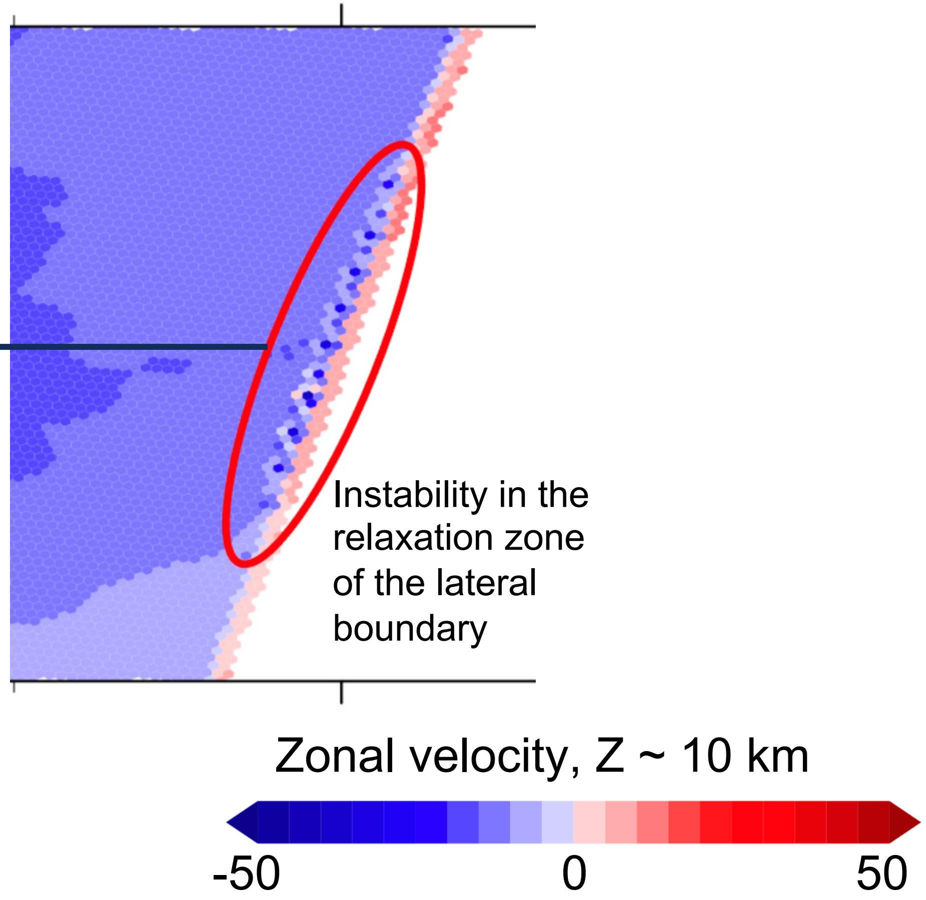
Equivalent group halo exchange in MPAS v8.0:

```
call exchange_halo_group(domain, &
             'dynamics:theta_m,scalars,pressure_p,rtheta_p')
```

Regional MPAS Lateral Boundary Conditions

Horizontal momentum filter change in the relaxation zone





Regional MPAS Lateral Boundary Conditions

Horizontal momentum filter change in the relaxation zone

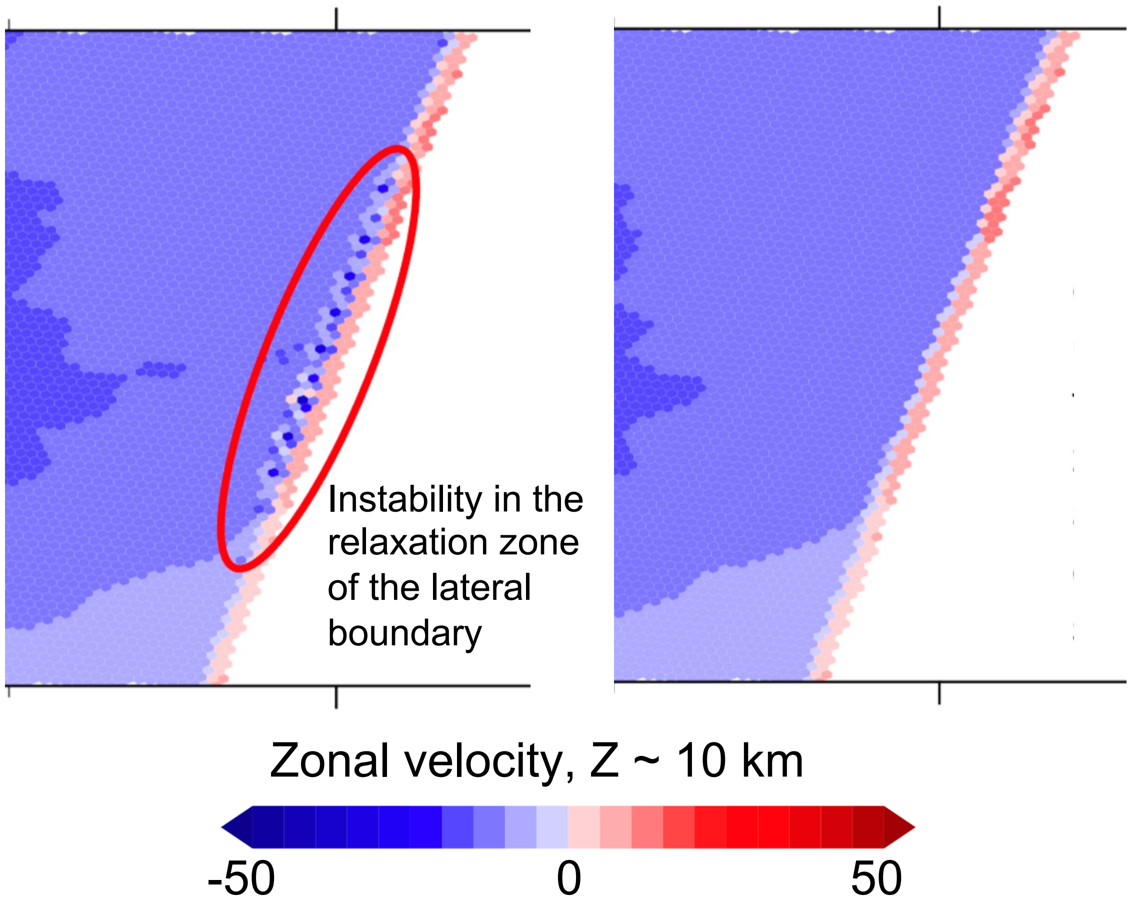
2^{nd}-order Laplacian for the horizontal momentum in MPAS

$$K\,\nabla^2 u_i = K\left(\frac{\partial}{\partial x_i}\nabla_\zeta\cdot\mathbf{v}_h - \frac{\partial\eta}{\partial x_j}\right)$$

We've added a coefficient to scale the divergent component of the Laplacian

$$K\,\nabla^2 u_i = K\left(\gamma_D\frac{\partial}{\partial x_i}\nabla_\zeta\cdot\mathbf{v}_h - \frac{\partial\eta}{\partial x_j}\right)$$

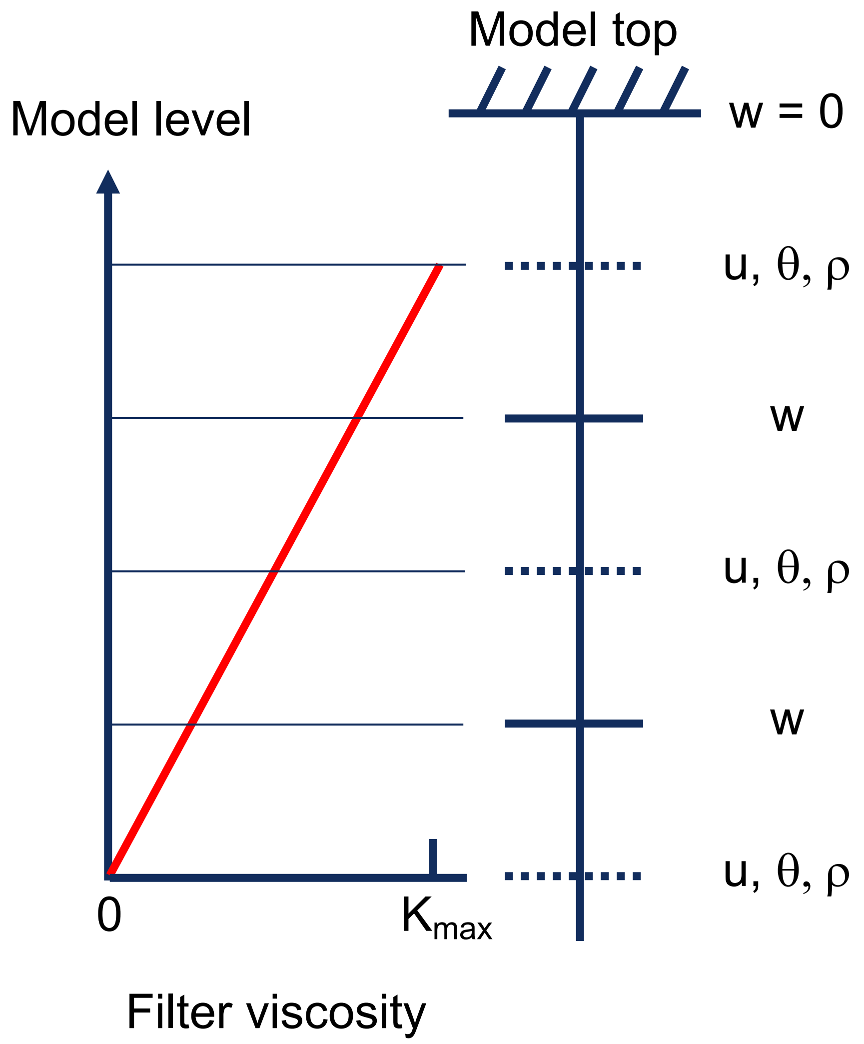
We are using $\gamma_D = 6.0$



Upper Absorbing Layer Generalization

There is an option to apply a 2nd-order horizontal filter to u, w and θ near the model top. We have generalized this formulation so that the damping coefficient linearly varies linearly, with increasing model level, from zero to a user-specified maximum value as a function of model level, beginning at a user-specified model level.

New: User specification of (1) number of levels to apply damping, and the linear dependence of K.



Diagnostics: ln(p) Interpolation for Isobaric Heights

In previous MPAS-A releases, we diagnosed heights on isobaric levels with interpolations using pressure that resulted in a positive bias in heights. We now interpolate using *ln(p)* to remove this bias.

This has no effect on MPAS-A solutions, just the isobaric heights in the diagnostic output.

Layer to Interface Projection

Interface: w   Layer: u, θ, ρ

In previous MPAS-A releases, to project layer variables (u, θ, ρ) to interfaces we would interpolate linearly in height.

In the new release we integrate over the layers sharing the interface, assuming (u, θ, ρ) are constant in a layer, and take the average value.

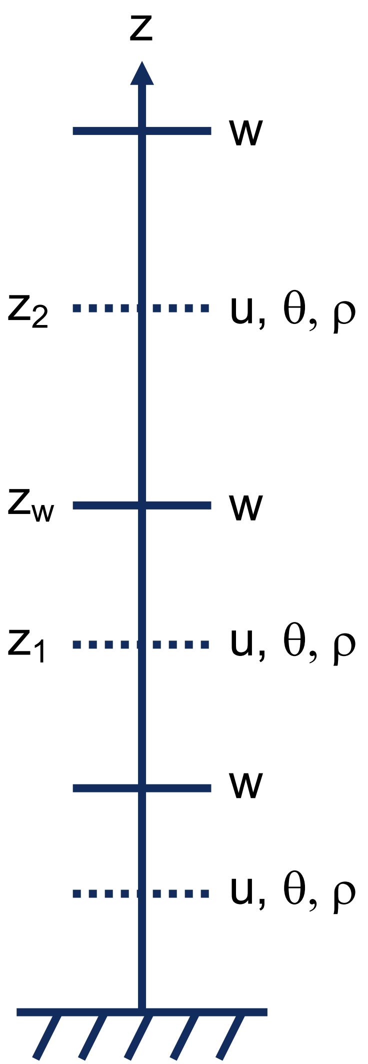
Differences in the solutions are small. The new approach is energetically more consistent, and also gives us a consistent hydrostatic relation integrating between layers or interfaces.

Old

$$\rho(z_w) = \frac{(z_2 - z_w)}{(z_2 - z_1)}\rho_1 + \frac{(z_w - z_1)}{(z_2 - z_1)}\rho_2$$

New

$$\rho(z_w) = \frac{(z_w - z_1)}{(z_2 - z_1)}\rho_1 + \frac{(z_2 - z_w)}{(z_2 - z_1)}\rho_2$$



MPAS-A Initialization: Extrapolations

- Reset the default for the lower air-temperature extrapolation (config_extrap_airtemp) from "linear" to "lapse-rate" in the namelist. This applies to initializations and to lateral boundary condition generation for MPAS-A.
- Set the condition for the lower extrapolation of the horizontal velocity such that it returns the lowest analysis level value instead of a linear extrapolation when the requested level is below the lowest analysis level. Applies to initializations and LBC generation.

MPAS-A Initialization: Static Fields Generation

- We have enabled parallel remapping of static fields with arbitrary graph partition files; special CVT partition files are no longer required.

MPAS Physics Updates in V8

Update the Noah land surface scheme to the WRF 4.5 release.

Update the MM5 surface layer scheme to the WRF 4.5 release.

Implemented the CCPP-compliant version of:

- the revised MM5 surface layer scheme;
- the parameterization of the gravity-wave drag over orography;
- the YSU Planetary Boundary Layer scheme;
- the scale-aware nTiedtke parameterization of convection; and
- the WSM6 cloud microphysics parameterization.

MPAS Developments: Physics

CCPP-compliant version of moist physics for the convection-permitting suite (using WRF-release 4.5.1).

- EDMF version of the MYNN Planetary Boundary Layer scheme.
- Option to use the two-moment graupel and hail prognostic variables version of the Thompson cloud microphysics scheme.

CCPP-compliant version of the RRTMG longwave and shortwave radiation codes

Merge the physics and 3D grid analysis nudging Four-Dimensional Data Assimilation (FDDA) codes provided by the EPA developers (summer 2023).

Merge the *refactored* version of the Noahmp land surface scheme

Implementation of physics to run aquaplanet experiments

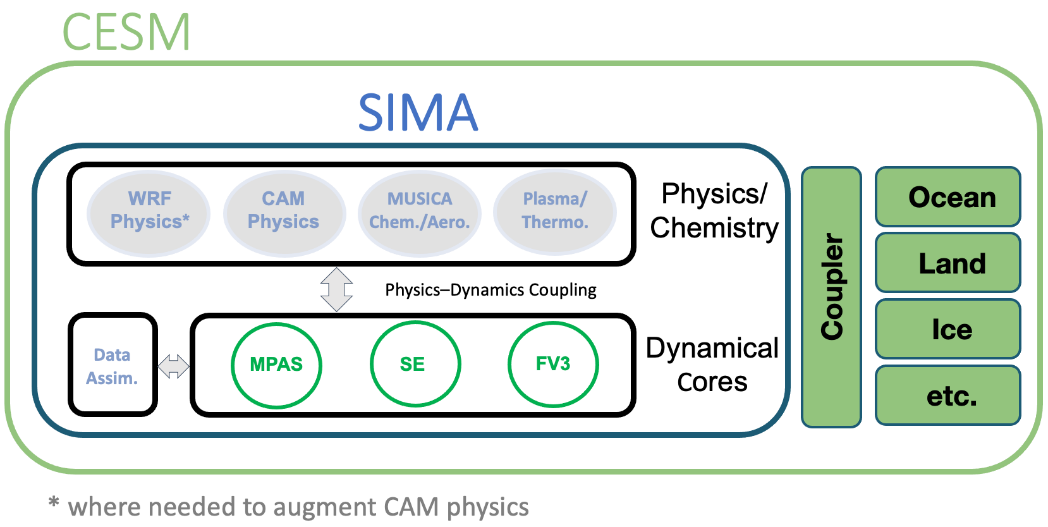
Aerosol-aware option of the Thompson cloud microphysics scheme

- To do: Provide physically-based surface emissions of anthropogenic and natural aerosols (linked to chemistry).

MPAS Developments: SIMA

System For Integrated Modeling of the Atmosphere (SIMA)

SIMA is the effort to unify NCAR-based community atmospheric modeling across Weather, Climate, Chemistry, and Geospace applications



CESM/SIMA pulls MPAS directly from the MPAS repository in its build.

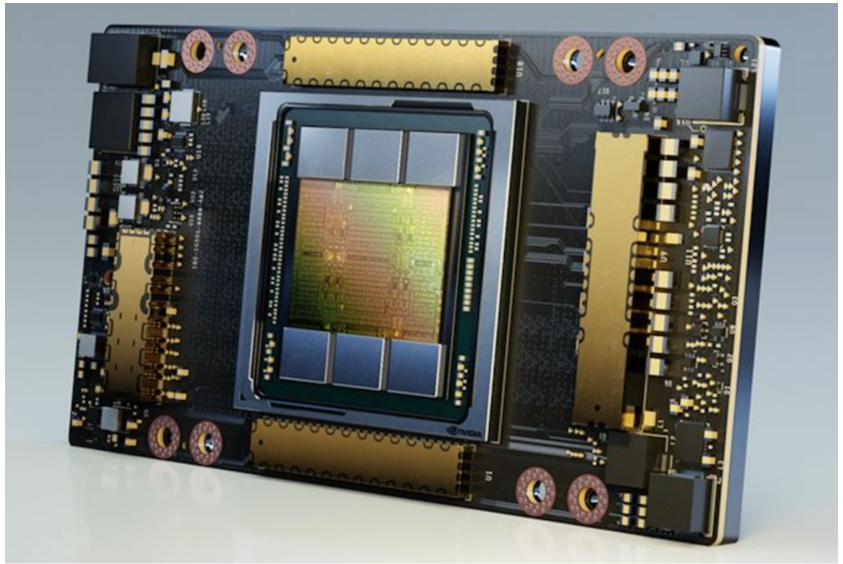
These changes have not changed any user requirements for running MPAS-A.

Observations:

- MPAS with CAM6 physics in SIMA is much slower than MPAS with MPAS/WRF physics
- MPAS/SIMA takes much more memory than MPAS with MPAS/WRF physics
- MPAS/SIMA has not yet been released
- MPAS/SIMA is not yet capable of efficient high-resolution applications (global, km scale)

MPAS Developments: GPU capabilities

We released the GPU-enabled MPAS-Atmosphere in October 2020 as a branch from MPAS Version 6.1.



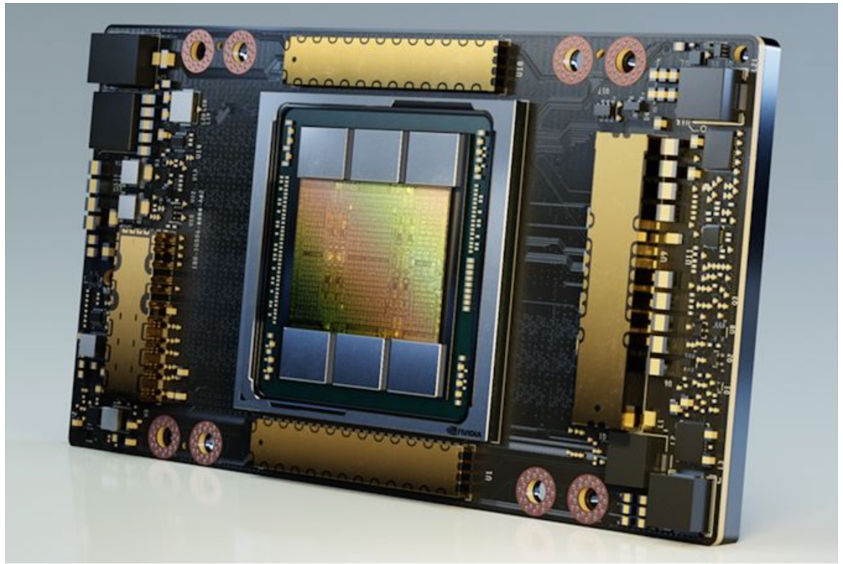
NVIDIA Ampere A100 GPU

What is in current (2020) release:

- GPU-enabled MPAS dynamical core using OpenACC directives.
- Some GPU-enabled physics (e.g. YSU, WSM6, M-O, scale-aware nTiedtke)
- Asynchronous execution capability on heterogenous architectures - currently radiation (lagged) and NOAH land model on CPUs, all else on GPUs

MPAS Developments: GPU capabilities

We released the GPU-enabled MPAS-Atmosphere in October 2020 as a branch from MPAS Version 6.1.



NVIDIA Ampere A100 GPU

What is *NOT* in this release:

- Regional capability
- Most of the physics options

We are currently evaluating the MPAS GPU implementation. We are considering re-implementing this capability given what we have learned in this first implementation.

Recent Development & Future Plans of CWA NWP Systems

Ting-Chi Wu, Po-Hsun Lin, Guo-Yuan Lien, Jing-Shan Hong
and CWA Regional & Global NWP team members

Central Weather Administration*, Taipei, Taiwan
*CWB was officially re-organized into CWA on September 15, 2023

September 18, 2023 @ NCAR, Boulder, CO

Outline

#	Topic	Speaker(s)
1	*Recent Development of the CWA Regional NWP Systems (WRF-based)*	Ting-Chi Wu Po-Hsun Lin Guo-Yuan Lien
2	*Recent Development of CWA Global NWP Systems, and Toward a More Integrated NWP Suite Across Scales*	Guo-Yuan Lien
3	*CWA's Future Plans and Discussions*	Guo-Yuan Lien Po-Hsun Lin
4	*Some Perspectives on the Rise of AI/ML-based NWP Models and its Impact to our NWP Community*	Guo-Yuan Lien

交通部中央氣象署 Central Weather Administration

CWB re-organized into CWA on Sep 15, 2023

- An elevation to a sub-ministerial level agency under the Ministry of Transportation and Communications, ROC.
- Responsible of planning, formulation, and execution of policies and regulations for meteorological and seismic operations
- Changes related to NWP research and development:

Central Weather Bureau

Research and Development Center
- **Global NWP Team**
  - Modeling
  - Data Assimilation
- **Climate Prediction Team**

Meteorological Information Center
- **Regional NWP Team**
  - Modeling
  - Data Assimilation
  - Ensemble
  - AI
- **Climate Prediction Team**

Central Weather Administration

Technology Development Division
- **Numerical Models Section**
- **Data Assimilation Technology Section**

  Global + Regional:
  Modeling, Data Assimilation, Ensemble, AI
- **Climate Simulation Section**

Marine Meteorology and Climate Division
- **Climate Forecast Section**

1. Recent Development of the CWA Regional NWP Systems (WRF-based)

- ***Overview of the CWA Regional NWP Systems***
- *Regional Deterministic Systems:*
  - *a) WRFD and TWRF Upgrades*
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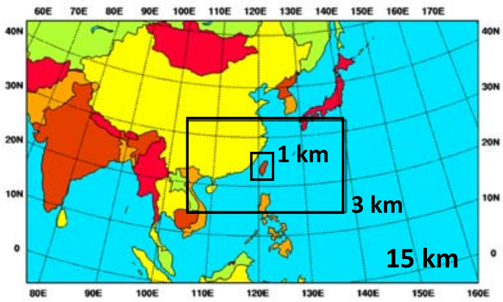
  - *a) Surface DA Development (VarBC & SFC_ASSI_OPTION = 2)*
  - *b) Additive Noise, LBC Perturbations, Deterministic Analysis, and KDP DA*

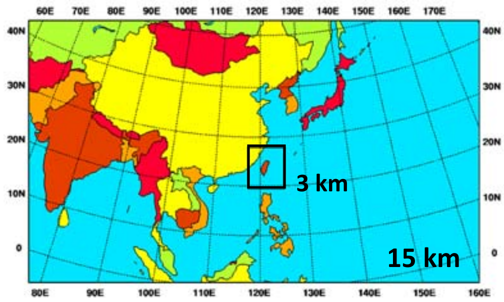
An Overview of the CWA Regional NWP systems (1/2)

Deterministic



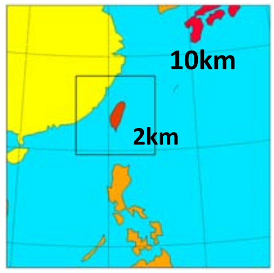
WRFD & **TWRF**
- ✓ Grid spacings: 15/3/1 km
- ✓ Update every 6 hr (00, 06, 12, 18 UTC)
- ✓ Forecast Length: 126 hr

Ensemble



WEPS: 20 members
- ✓ Grid spacings: 15/3 km
- ✓ Update every 6 hr (00, 06, 12, 18 UTC)
- ✓ Forecast Length: 108 hr

Convective scale



RWRF & **LETKF**
- ✓ Grid spacings: 10/2 km
- ✓ Update every 30 min
- ✓ Forecast Length: 13 hr

- **CWA-UCAR Collaborative Project** was initiated in 2005.
- WRFD: **2007** (45/15/5 km) → **2016** (15/3km)
- WEPS: **2011**
- RWRF: **2016**
- RWRF-LETKF: **2018**

An Overview of the CWA Regional NWP systems (2/2)

Their role and dependency

East Asia Domain 5 day Forecast 6 Hourly Update

Deterministic Forecast: TWRF 15/3 km; WRFD 15/3 km — EnVar: Conv + RO + GPS ZTD

Provide background perturbations for hybrid EnVar

Ensemble DA: EAKF 15 Km

Provide initial perturbations for ensemble forecast

Ensemble Forecast: WEPS 15/3 km

Taiwan Domain for 12 hour Forecast Hourly Update

Deterministic Forecast: RWRF 2 km — EnVar: SFC + Radar

Provide background perturbations for hybrid EnVar

Ensemble DA: LETKF 2 Km

Provide initial perturbations for ensemble forecast

Ensemble Forecast: CEPS 2 km, Schedule for OPE late 2023

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Recent Upgrades of WRFD

OP441 -> OP50 *(CWA Regional Deterministic Forecast Version)*

- **Upgrade WRF and WPS to Version 4.4.2**
- **Physical scheme**
  - *GWD3、CWBGCE、NOAH LSM Adjustment*
- **Static data**
  - *Land cover、Green vegetation fraction、Terrain height*
- **Additional observations for DA**
  - *Wind profiler、FORMOSAT-7/COSMIC-2 (3 km)*
- **Dual-resolution hybrid 3DEnvar for 3 km domain in WRFD**
- **Update background error covariance**
- **Bug fix for blending scheme**

Summary

- **OP50 can improve the performance of prediction.**
- **But OP50 still have some problem over Taiwan…**
  - *Cold bias*
  - *Strongly wind speed*
  - *Dry bias*

Domain-Averaged Verification (3 km)

	H	T	RH	U	V
Upper Level	-2.382	-2.520	-3.860	0.584	0.736
Mid Level	-2.129	-2.227	-2.499	-0.803	0.598
Lower Level	-3.829	0.056	-0.755	-3.877	-1.113

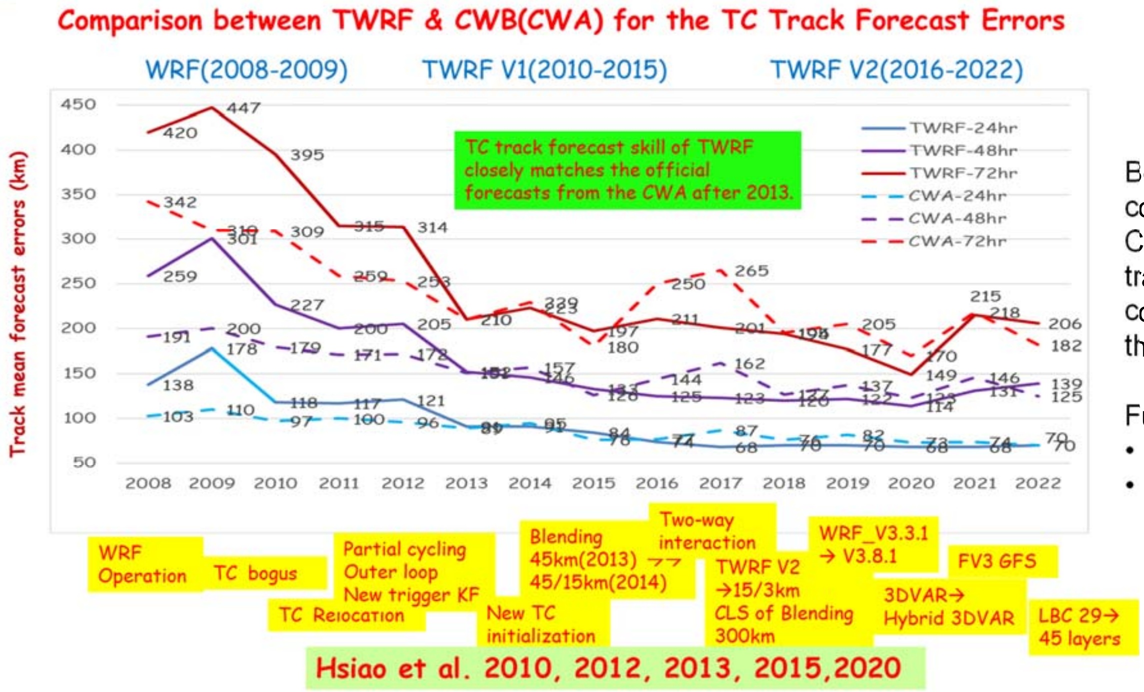
Surface Verification

	T2	Q2	WIND10
15 km	-1.895	-2.578	-1.383
3 km	-2.628	-5.536	0.743
3 km(Taiwan)	-1.941	-6.104	-0.889

Neutral (<= 1 %)
% Worse (+ %)
% Better (- %)

Percentage Difference in RMSE Between the Two Model Versions
(OP50-OP441)/(OP441)*100

Recent Upgrades of TWRF & TC Track Forecast



Benefited from the collaboration between CWA and NCAR, the TC track forecasting has continued to improve over the past decade.

Future plans are as follows:

- **Hybrid IC and BC**
- **Update SST in model prediction**

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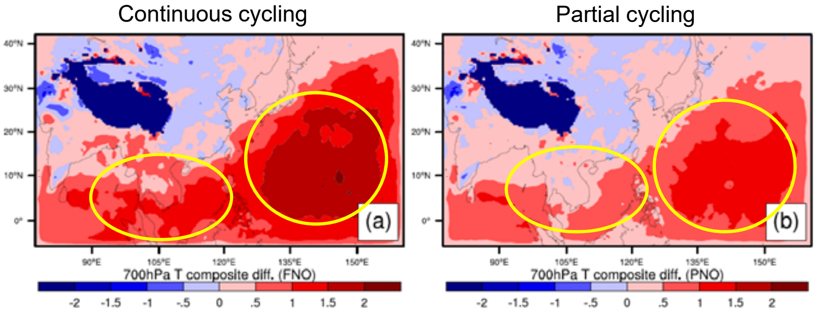
CWA's regional NWP has benefited a lot from the *partial cycling* + *blending* approaches

Mean error of the composite analysis from 78 cases: 700 hPa Temperature (K)

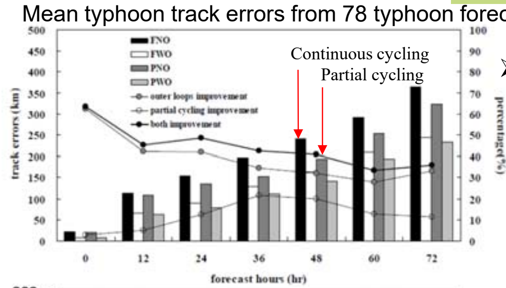
Continuous cycling | Partial cycling

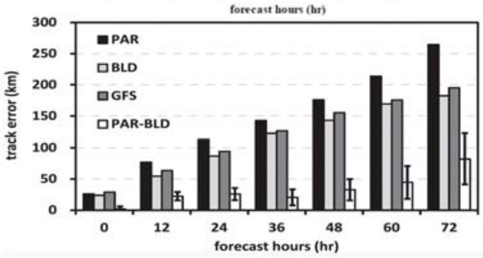


- **To remove the accumulated systematic bias over data sparse area found in the continuous cycling experiment.**

Hsiao et al. (2010)

Mean typhoon track errors from 78 typhoon forecasts





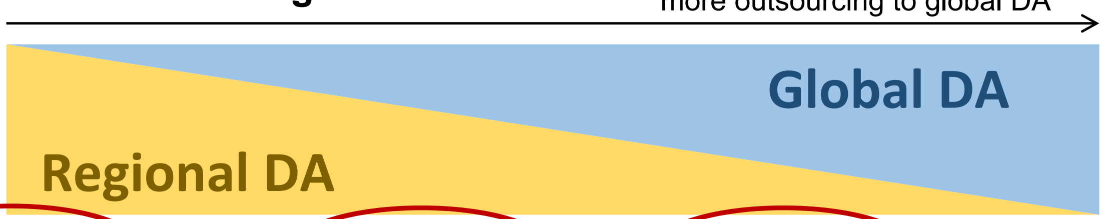
- **Blending further improves typhoon track forecasts upon the partial-cycling approach.**

Hsiao et al. (2010, 2015)

"… it seems sensible to rigorously **revisit partial versus continuous cycling for limited-area modeling applications**, especially with modern DA systems incorporating flow-dependent background error covariances like the ensemble Kalman filter …" **(Schwartz et al. 2022, WAF)**

Partial cycling & blending as "outsourcing"

Degrees of "outsourcing":



Continuous cycling | Continuous cycling + blending | Partial cycling + blending | Downscaling

X Partial cycling (no blending)

Suggested by Schwartz et al. (2022)

Current system

"On one's own":

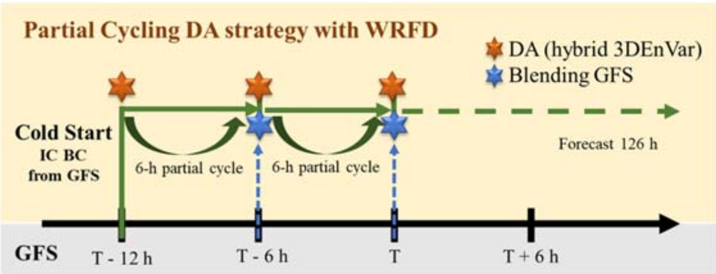
- Difficult to outperform global DA
- Potential to improve the short-range high-resolution forecast
- Possibly have more balanced analysis (not necessarily)
- Preserve full freedom to develop/study regional DA; simplify the goal of development

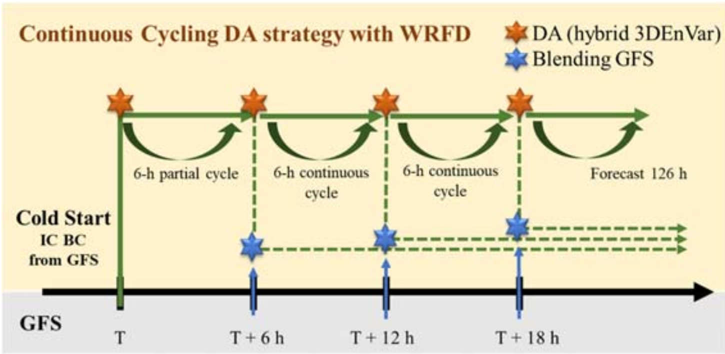
"Outsourcing":

- Easy to achieve reasonably good performance, especially in longer-range, large-scale forecast
- Reduce the requirement to have skillful regional (self) DA
- Easy to maintain (operationally and for research)
- Difficult to see the impact of regional DA
- Have no control to the (external) global DA development

Partial vs. continuous cycling experiments with the current CWA WRFD

Exp.	DA Cycling Strategy	Blending	WRF/WRFDA Version	Data Assimilation Method
PC	Partial Cycling	After the 2nd and 3rd DA	4.4.2/4.4.2	hybrid 3DEnVar
CC	Continuously Cycling	Before longer forecast (independent from DA cycling)	4.4.2/4.4.2	hybrid 3DEnVar





CC spin up:

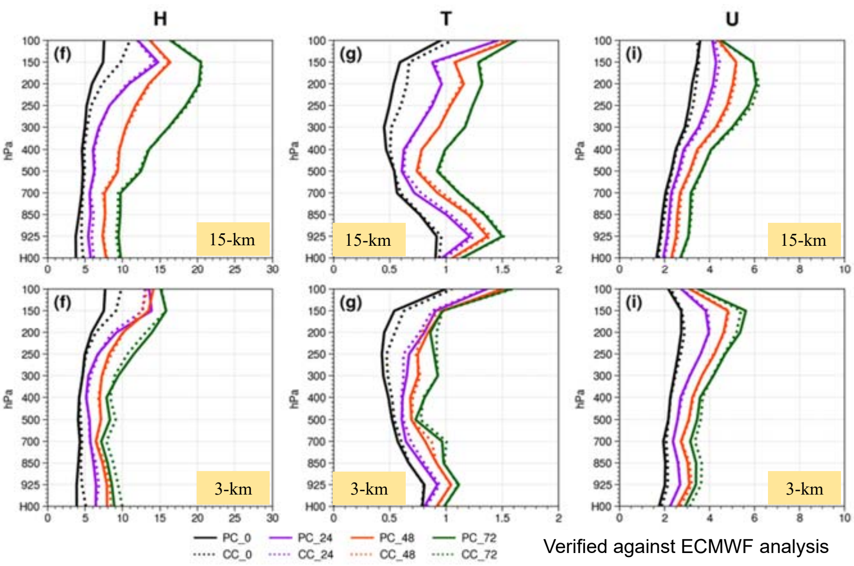
- 2022/06/15 12Z to 2022/06/18 18Z, with 6-hr cycling

Testing periods:

- 2022/06/19 00Z to 2022/06/30 12Z, total 24 cases (only at 00Z and 12Z)
- CC keeps 6-hr cycling but produces longer forecasts only at 00Z and 12Z
- Assimilated observations: same as operation (synop, metar, ship, gpspw, gpsref, sound, airep, buoy, wind profiler)

Results from the PC vs. CC experiments (1/2)

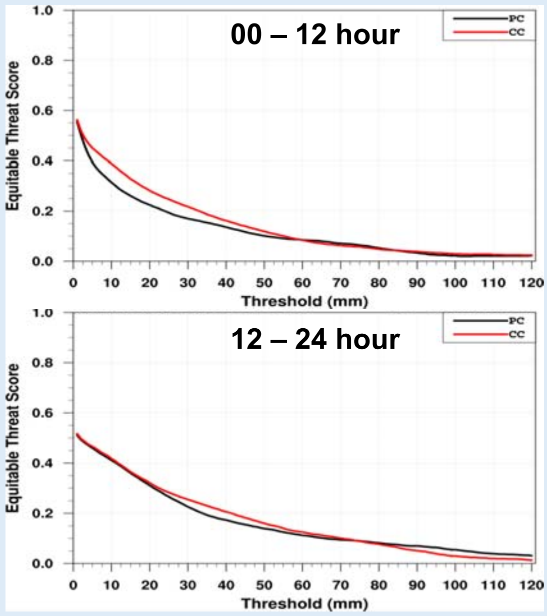
Mean Domain-Averaged RMSE (2021/06/19 to 2021/06/30)



Verified against ECMWF analysis

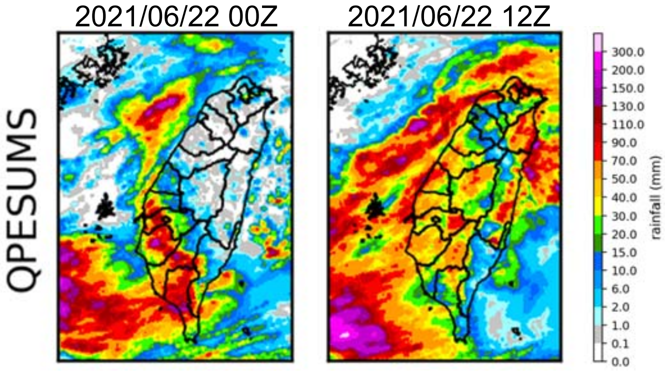
➢ When verified against ECMWF analysis, PC performance is slightly better than CC up to 72 hour forecasts.

ETS of 00-24 h Precipitation Forecast

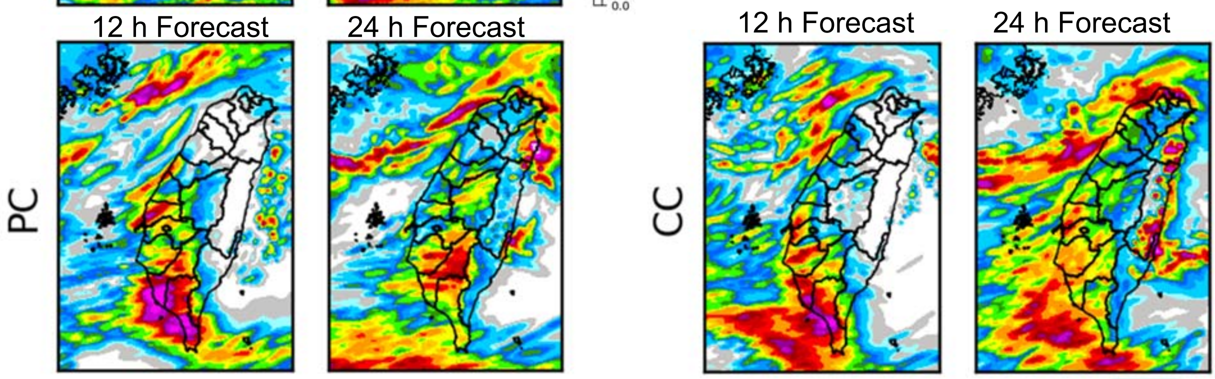


➢ CC shows better precipitation forecast, especially 0 to 12 hour forecasts

Results from the PC vs. CC experiments (2/2)



- In this case, some improvements on precipitation forecast are evident in the CC approach.
- Comparison between PC and CC approaches from more cases with different types of weather systems is being carried out.



Summary and Future Plan for the partial vs. continuous cycling experiments with CWA WRFD

- With the current CWA WRFD system, the newly tested **"continuous cycling + blending" approach (CC)** seems to be a competitive alternative to the operational **"partial cycling + blending" approach (PC)**.
  - CC shows slightly worse domain-averaged synoptic forecast performance.
  - However, CC shows better short-term (up to ~24 hours) precipitation forecast!
- We plan to set up a parallel run using the **CC** approach to carefully and systematically evaluate its long-term performance compared to **PC**, and thus we will make decision whether to switch from PC to the CC approach in operation.
- Continue to improve the hybrid 3DEnVar DA of the WRFD system (e.g., assimilate more satellite observations, investigate the proper blending cut-off length for 15 km/3 km domain, etc)

交通部中央氣象署 Central Weather Administration

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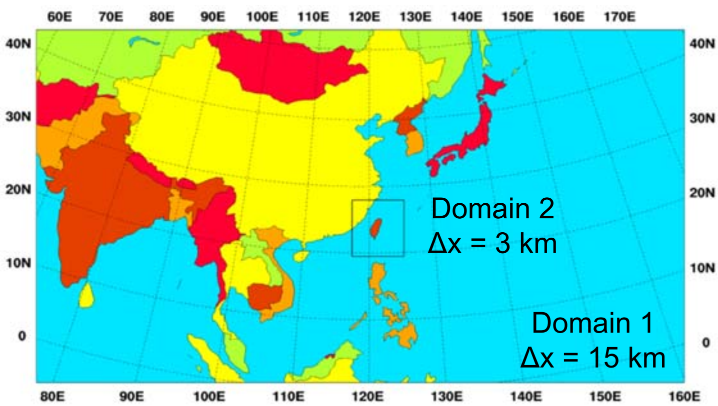
WRF Ensemble Prediction System (WEPS)

Configuration of WEPS:

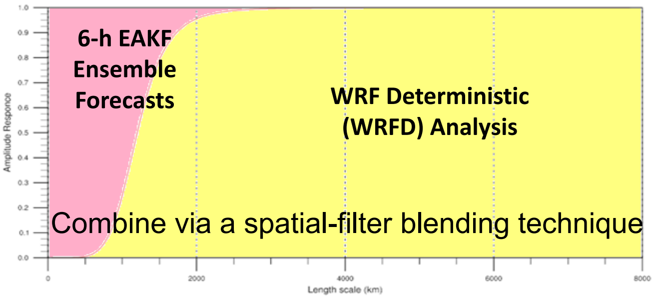
- WRF v3.8.1
- Domain 1/2 grid spacing: 15 km / 3km
- 52 vertical layers with model top at 20 hPa
- Runs 4 times a day (00, 06, 12, 18 UTC)
- Provides 108-h regional ensemble forecasts (3 km forecasts at nested domain via ndown)

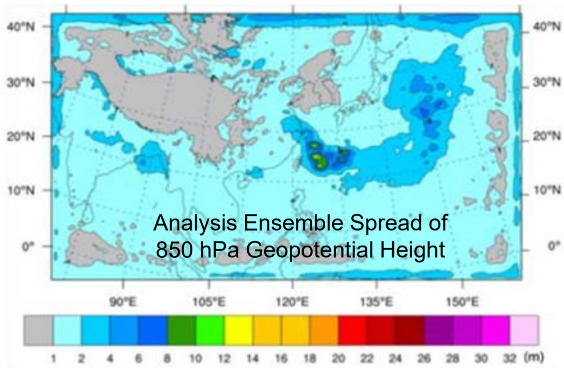


Ensemble Size	20
Initial Perturbations	Blend EAKF short-range forecast with WRFD analysis
Boundary Perturbations	NCEP GEFS
Number of GEFS Members Used	10 (2 WEPS members share 1 GEFS member)
Model Perturbations	Multi-Physics + Stochastic Kinetic Energy Backscatter (SKEB) + Stochastically Perturbed Physics Tendency (SPPT) + Stochastically Perturbed Parameterizations for Planetary Boundary Layer (SPP_PBL)

See *Li et al. (2020)* for more details

WEPS: Issue with Initial Perturbations





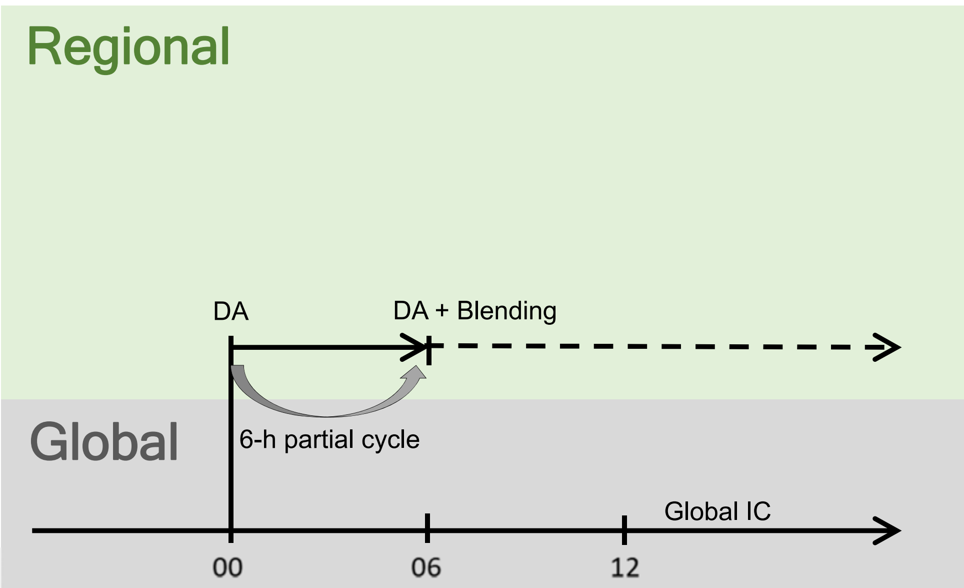
Motivations:

1. The lack of large-scale perturbations due to blending the EAKF members with WRFD.
2. Initializing a regional EPS with a global EPS is a widely used approach: recently, 0.25 degree NCEP GEFS data becomes publicly available.
3. In the meantime, the CWA FV3-based Global (TGFS) EPS can also serve as initial conditions for WEPS
4. Maintenance overheads due to having multiple operating systems (e.g., currently WEPS needs input from EAKF, WRFD and NCEP GEFS)

A New Framework: Ensemble Partial Cycle (1/2)

Inspired by the CWA **partial cycle strategy** & Ensemble of Data Assimilation (EDA) framework in ECMWF

➢ Each WEPS member is initialized by running a partial cycle where ICs come from a global EPS.



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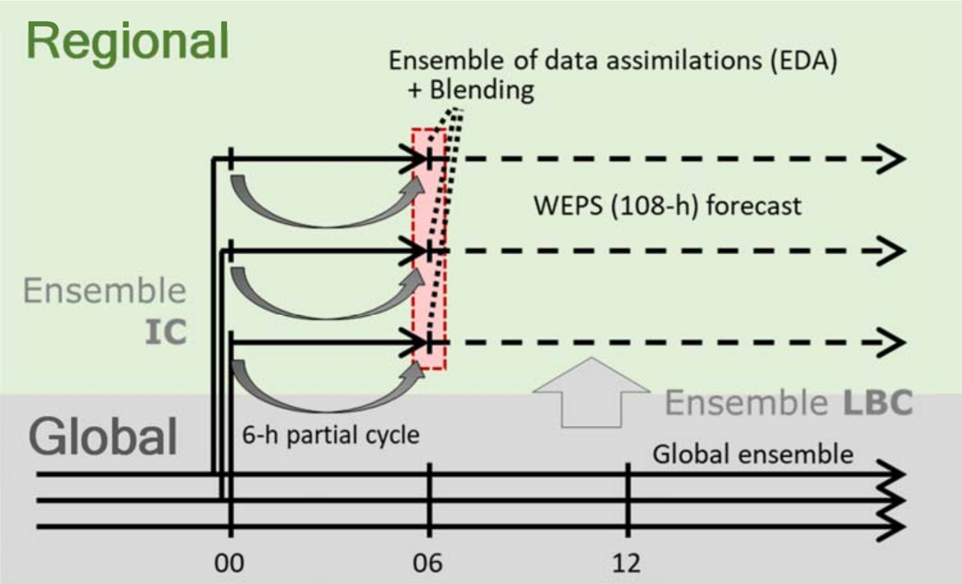


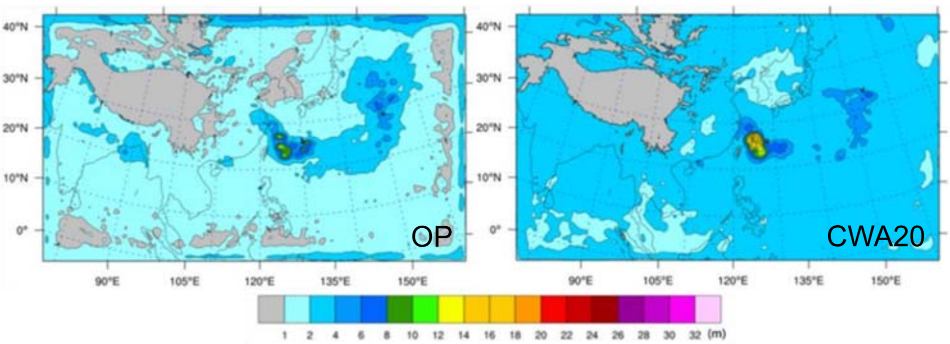
Objectives:

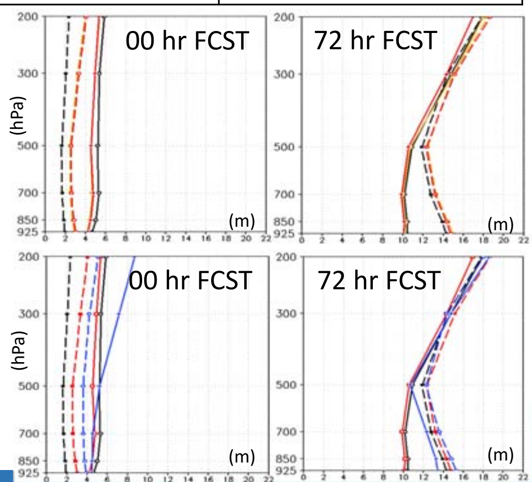
- Reduced code maintenance and development overheads by sharing much of the WRFD DA code
- The ultimate goal is to initialize WEPS with EnPC using CWA TGFS EPS.
- To establish a better connected CWA global and regional NWP system via integrating the R&D efforts of the global and regional NWP teams.
- WEPS can provide flow-dependent background error estimates for the WRFD hybrid EnVar

WEPS_EnPC: the Initial Implementation

Exps	Ens. Size	Initial Perturbations	Boundary Perturbations	# of Global EFS members used
OP	20	EAKF blend with WRFD	NCEP GEFS	10 (1-2 approach)
NCEP10	20	***EnPC*** with IC from NCEP GEFS	NCEP GEFS	**10 (1-2 approach)**
NCEP20	20	***EnPC*** with IC from NCEP GEFS	NCEP GEFS	**20 (1-1 approach)**
CWA20	20	***EnPC*** with IC from CWA TGFS EPS	CWA TGFS EPS	20 (1-1 approach)

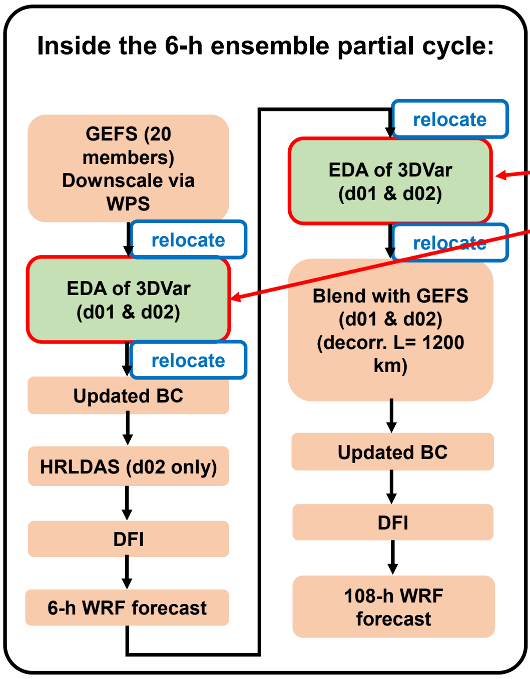
Analysis Ensemble Spread of 850 hPa Geopotential Height (m)





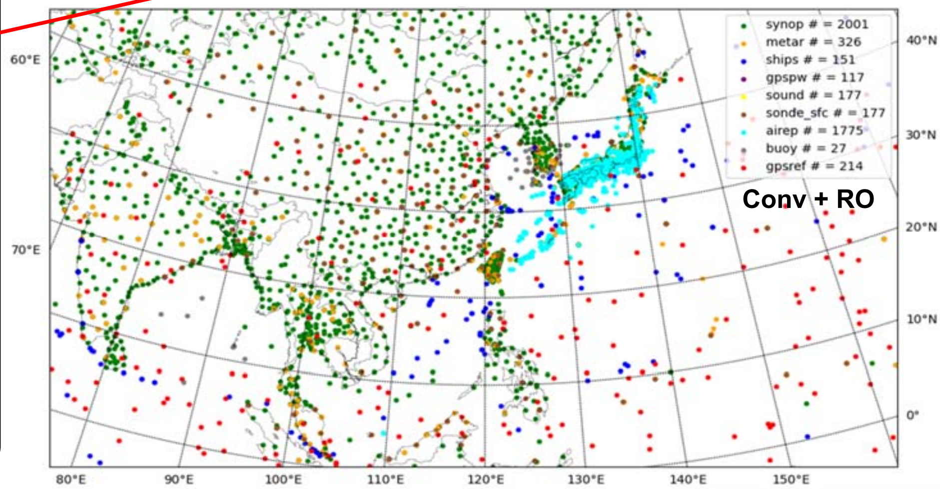
Solid line : RMSE
Dash line: spread

Further Development of WEPS_EnPC (1/2)



Currently, the EnPC has yet to include "***perturbed observations***" in its EDA of 3DVar step. There is still room for further improvement.

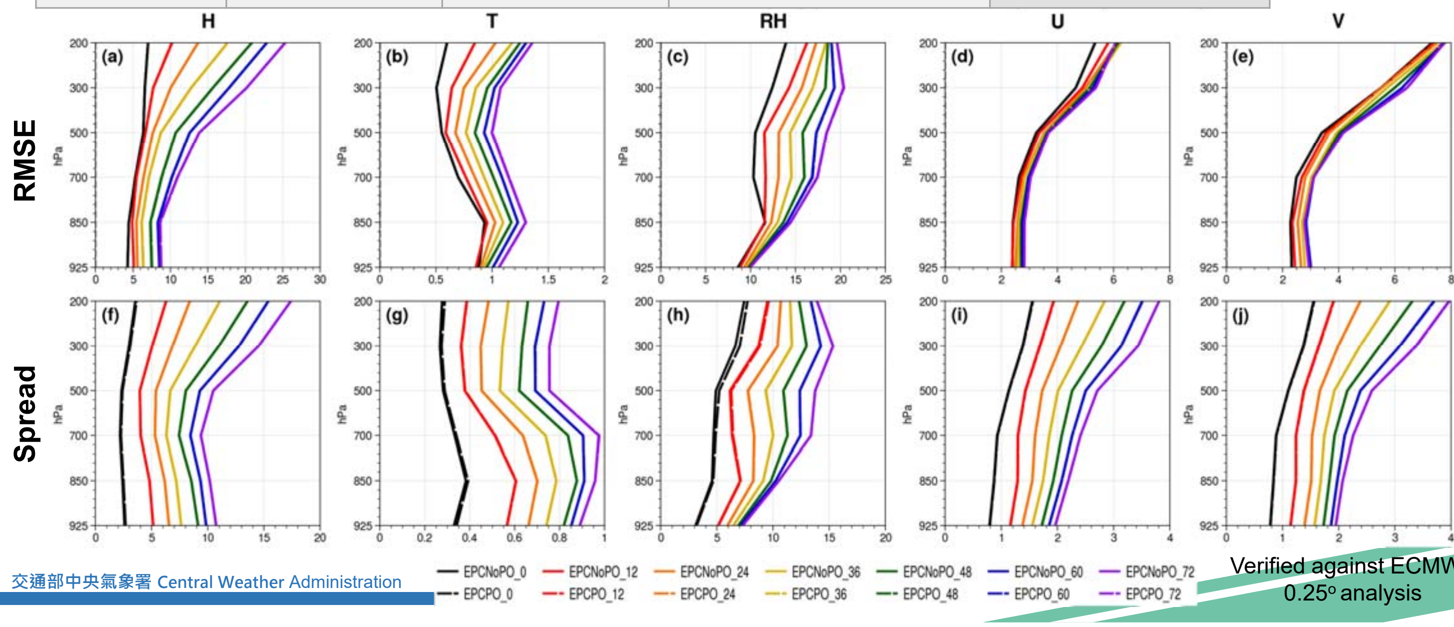
Observations assimilated in d01 of WEPS: 2021/12/02 00 UTC



Further Development of WEPS_EnPC (2/2)

Exp	Obs assimilated	Obs perturbed	# of perturbed observation members	Experiment Period
EnPC_NoPO	CONV + RO	None	0	December 1-4, 2021: 00 & 12 UTC (8 runs)
EnPC_PO	CONV + RO	CONV + RO	**20**	

Forecast



Verified against ECMWF 0.25° analysis

Summary & Future Work of WEPS_EnPC

- The new EnPC framework that combines the partial cycle strategy and EDA approach has been successfully implemented for WEPS.

- WEPS initialized via EnPC mitigates several issues in the current OP:
  - Insufficient ensemble spread due to the lack of initial large-scale perturbations: ***improved spread***
  - Dependency on EAKF (a separate system to maintain): ***removed***
  - Dependency on external data (NCEPGEFS): ***could be potentially replaced by CWA TGFS EPS***
  - Spin-up issue in WEPS domain 2: ***domain 2 is also initialized via EnPC as opposed to ndown***

- In addition, compared to OP, WEPS initialized via EnPC has shown increased ensemble spread without degrading RMSE, encouraging results.

- **Plan to** make adjustments to the workflow to explore the best strategy to use or not use blending under the WEPS_EnPC framework

- **Plan to** revisit the current settings of model perturbations to find the best combination for WEPS_EnPC.

- **Plan to** explore the impact of using WEPS_EnPC to estimate BEC for the hybrid EnVar of WRFD

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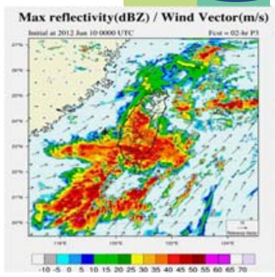
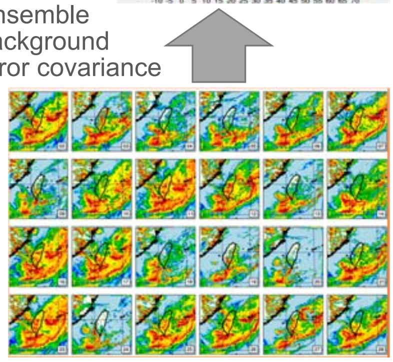
CWA's convective-scale prediction systems

- **RWRF: WRF Data Assimilation (WRFDA) hybrid 3DEnVar**
  - Thanks to NCAR for fulfilling many development tasks requested by CWA e.g., cloud CV option, direct reflectivity assimilation, improved gen_be utilities, …



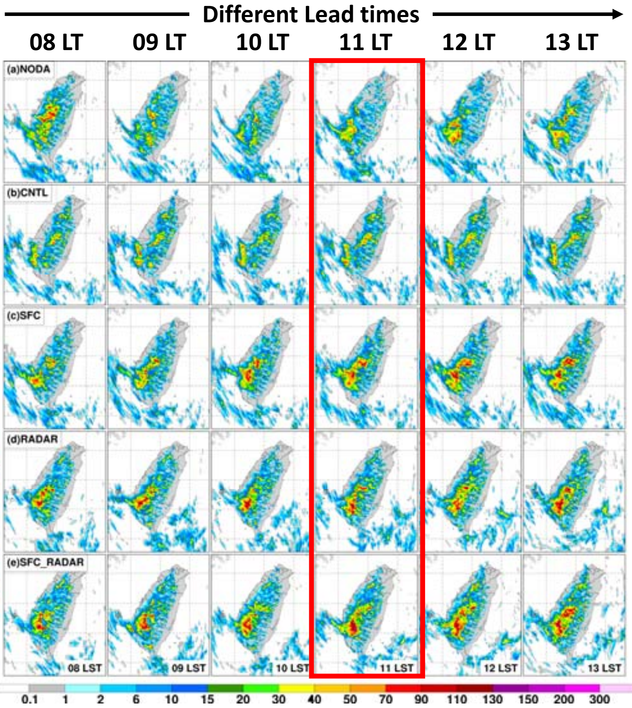
Ensemble background error covariance



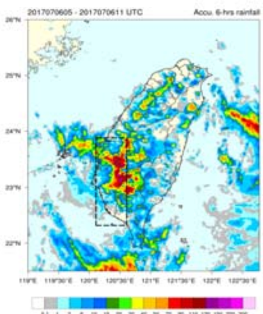
- **RWRF-LETKF: NCU-LETKF + CWA's development**
  - Originally from Prof. Shu-Chih Yang at National Central University
  - Code refactored by CWA (Yi-Chuan Lo)

Assimilation of dense AWS surface data in CWA's RWRF system (beneficial!) (Chen et al. 2020, WAF)

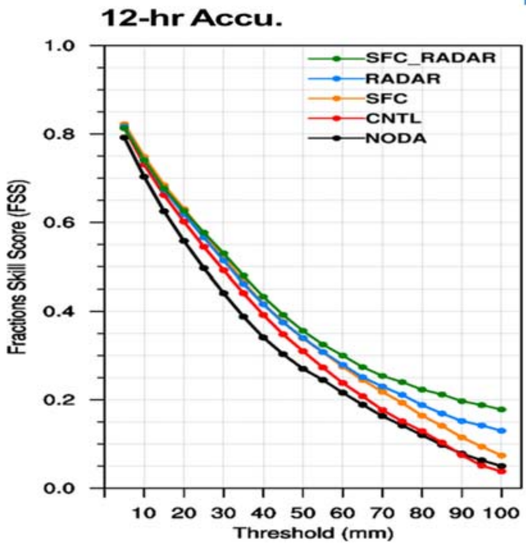
6-h accumulated precipitation forecast during 13-19 LT 06 July 2017



Observation

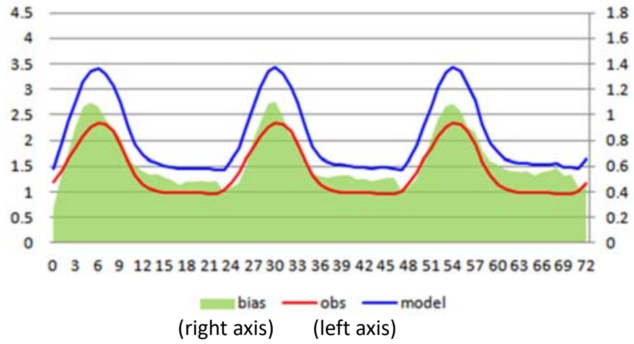


Fractions skill score (FSS) verified against radar QPE



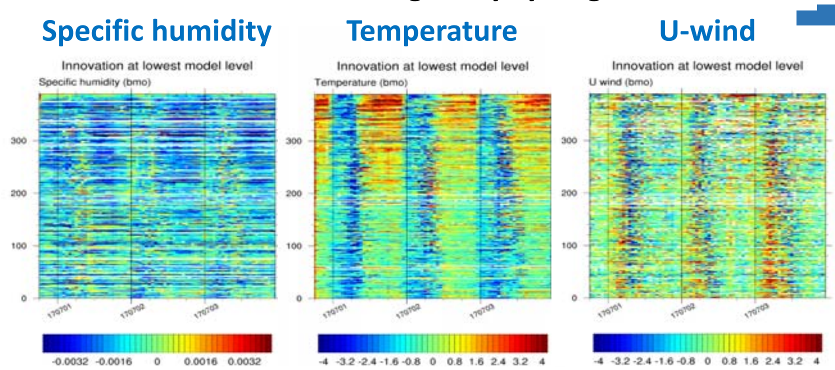
Significant biases for surface data: Examples

Average wind speed biases in 3-day model forecasts



- The model tends to over-forecast surface wind speeds compared to observation.
- The biases are larger in daytime.

Observation-minus-background (O–B) values of each surface station during 3-day cycling assimilation



X-axis: Time (over 3.25 days)
Y-axis: Station number, sorted by elevation

- In several previous studies, the biases in surface DA have been corrected in some **physical ways**, i.e.,
  - Correcting the surface temperature biases assuming a constant lapse rate.
  - Correcting the wind biases using the similarity theory.
- However, **there are many other sources of biases** that are difficult to be handled using the physical ways; therefore, **we seek a statistical way** to represent the total biases from different sources. → **Variational bias correction (VarBC)**

Variational bias correction (VarBC)

(e.g., Derber and Wu 1998; Dee 2005)

- The **variational bias correction (VarBC)** technique has been proposed and commonly used in the assimilation of satellite radiances and aircraft observations.

$$J(\mathbf{x},\beta)=(\mathbf{x}^b-\mathbf{x})^{\mathrm{T}}\mathbf{B}_{\mathbf{x}}^{-1}(\mathbf{x}^b-\mathbf{x})+(\beta^b-\beta)^{\mathrm{T}}\mathbf{B}_{\beta}^{-1}(\beta^b-\beta)+[\mathbf{y}-\tilde{\mathbf{h}}(\mathbf{x},\beta)]^{\mathrm{T}}\mathbf{R}^{-1}[\mathbf{y}-\tilde{\mathbf{h}}(\mathbf{x},\beta)]$$

$$\tilde{\mathbf{h}}(\mathbf{x},\beta)=\mathbf{h}(\mathbf{x})+\mathbf{b}(\mathbf{x},\beta), \qquad \mathbf{b}(\mathbf{x},\beta)=\sum_{i=1}^{N_p}\beta_i\mathbf{p}_i(\mathbf{x})$$

  - Bias correction coefficients (β) are updated as well as the model's state variables (x) in the variational minimization.
- Current VarBC in WRF-DA: Satellite radiances & aircraft (Gao et al. 2019).
- We implement the VarBC for surface observations (temperature, humidity, winds) in the WRF-DA, based on the same bias models described in the next slide.
  - Currently, all surface observations are applied with the same bias models.

Temperature:

$$b^{\mathrm{T}} = \beta_0^{\mathrm{T}} + \beta_1^{\mathrm{T}}\underbrace{(Z_{\mathrm{obs}} - Z_{\mathrm{model}})}_{\text{elevation difference}} + \beta_2^{\mathrm{T}}\underbrace{(T_{\mathrm{s,\,model}} - T_{\mathrm{2,\,model}})}_{\text{proportional to heat flux}}$$

Humidity:

$$b^{\mathrm{Q}} = \beta_0^{\mathrm{Q}} + \beta_1^{\mathrm{Q}}\underbrace{(Z_{\mathrm{obs}} - Z_{\mathrm{model}})}_{\text{elevation difference}} + \beta_2^{\mathrm{Q}}\underbrace{(q_{\mathrm{s,\,obs}}) \times 0.3 \times 1000}_{\text{saturation humidity obs.}}$$

Winds:

$$b^{\mathrm{U}} = \beta_0^{\mathrm{U}}(U_{\mathrm{obs}}/Wspd_{\mathrm{obs}}) + \beta_1^{\mathrm{U}}\left(-Wspd_{\mathrm{10m,\,model}}\cos\left(Wdir_{\mathrm{10m,\,model}}\right)\right)/std_{\mathrm{U1}} + \beta_2^{\mathrm{U}}\left(-\sin\left(Wdir_{\mathrm{10m,\,model}}\right)\right)/std_{\mathrm{U2}}$$

$$b^{\mathrm{V}} = \beta_0^{\mathrm{V}}\underbrace{(V_{\mathrm{obs}}/Wspd_{\mathrm{obs}})}_{\text{projection to u, v components using the observed wind}} + \beta_1^{\mathrm{V}}\underbrace{\left(Wspd_{\mathrm{10m,\,model}}\sin\left(Wdir_{\mathrm{10m,\,model}}\right)\right)/std_{\mathrm{V1}}}_{\text{wind direction bias}} + \beta_2^{\mathrm{V}}\underbrace{\left(-\cos\left(Wdir_{\mathrm{10m,\,model}}\right)\right)/std_{\mathrm{V2}}}_{\text{wind speed bias}}$$

Bias models for surface observation variables

$$\tilde{h}\left(\mathbf{x}^b\right) = h\left(\mathbf{x}^b\right) + b, \quad b = \sum_{i=1}^{N_p} \beta_i\, p_i\left(\mathbf{x}^b, y^o\right)$$

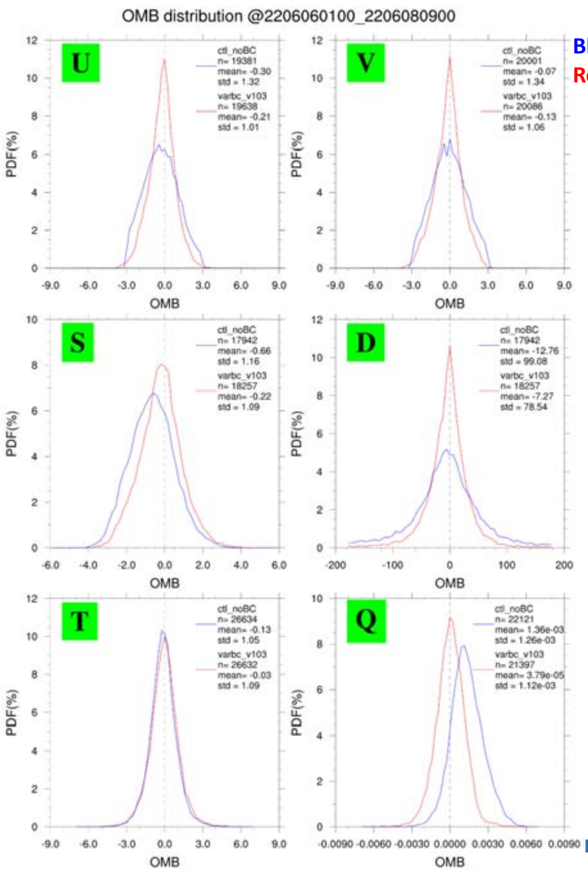
β_i, p_i : Bias correction predictors and the coefficients

Pourret et al., 2021

- $b^{\mathrm{T}}, b^{\mathrm{Q}}, b^{\mathrm{U}}, b^{\mathrm{V}}, b^{\mathrm{Wspd}}$: The observation-minus-background biases of surface temperature, specific humidity, u, v winds, and wind speed, respectively
- $Z_{\mathrm{obs}}, Z_{\mathrm{model}}$: The elevations of the station and the model terrain, respectively
- $T_{\mathrm{s,\,model}}$: Skin temperature in the model
- $T_{\mathrm{2,\,model}}$: 2-m temperature in the model
- $Wspd_{\mathrm{10m,\,model}} = \sqrt{U_{\mathrm{10m,model}}^2 + V_{\mathrm{10m,model}}^2}$: 10-m wind speed in the model
- $Wspd_{\mathrm{obs}} = \sqrt{U_{\mathrm{obs}}^2 + V_{\mathrm{obs}}^2}$: Surface wind speed observation
- $q_{\mathrm{s,\,obs}}$: saturation humidity observation, ×1000 to fit the order of other bias models
- $std_{\mathrm{U}i,\mathrm{V}i}$: standard deviation between 2206060100 – 2206080900 associated with each predictor

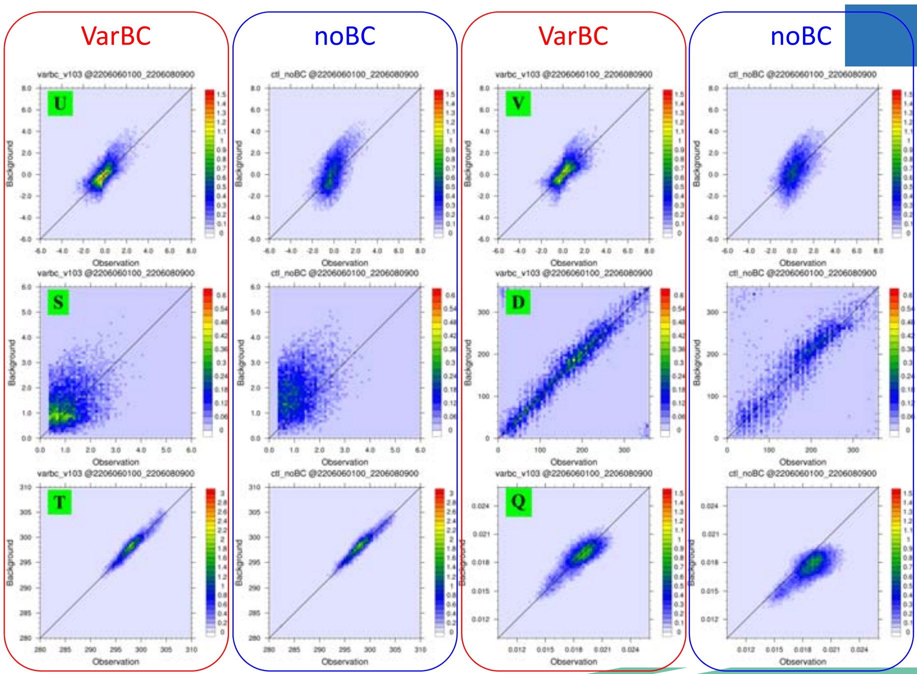
交

O–B distributions and scatter plots



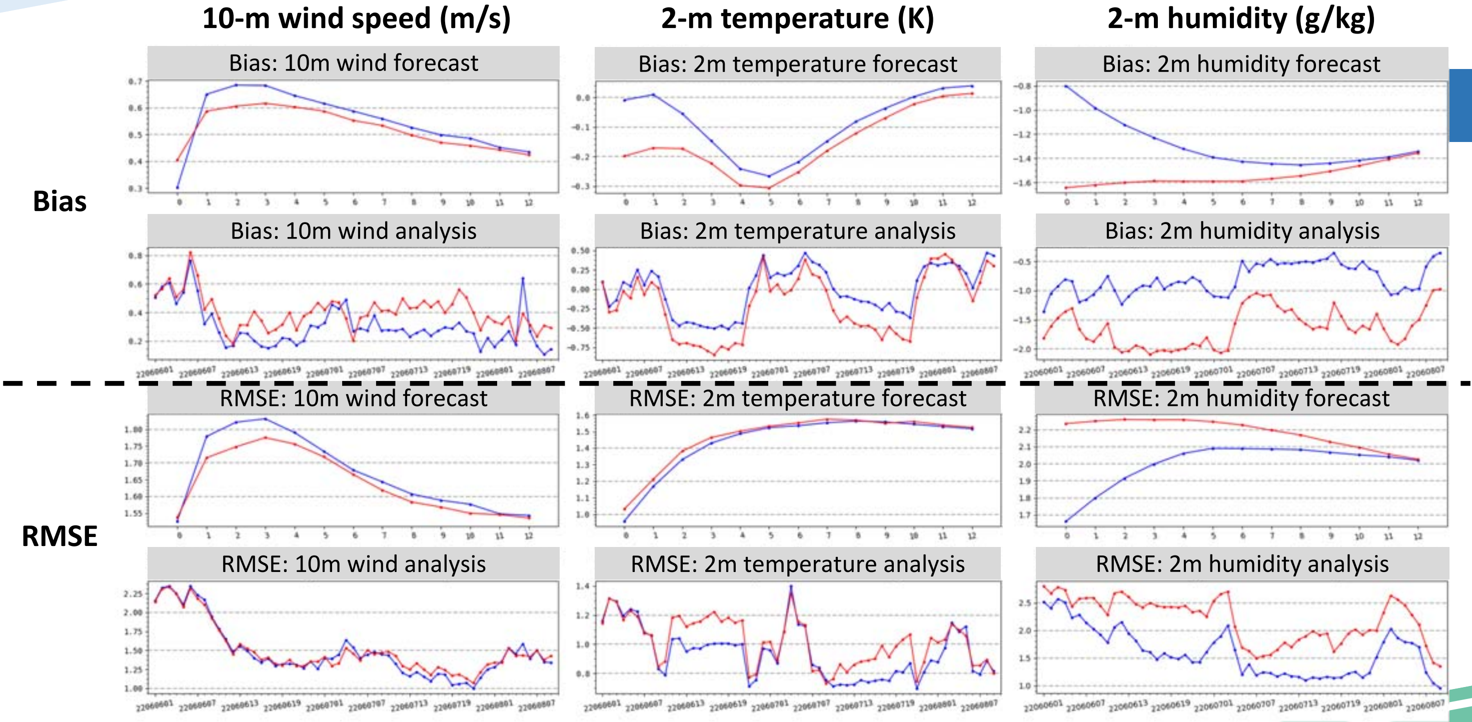
Blue: noBC
Red: VarBC

The results demonstrate the correctness and effectiveness of the surface VarBC.



Surface analysis and forecast verification

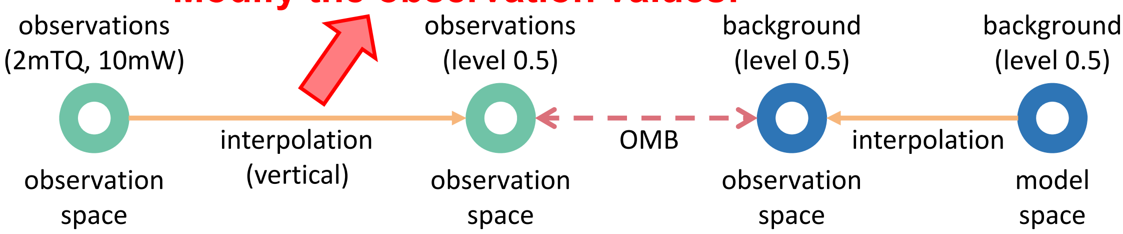
Blue: No BC (analyses are **after DFI**)
Red: VarBC (analyses are **after DFI**)



Surface assimilation options in WRFDA

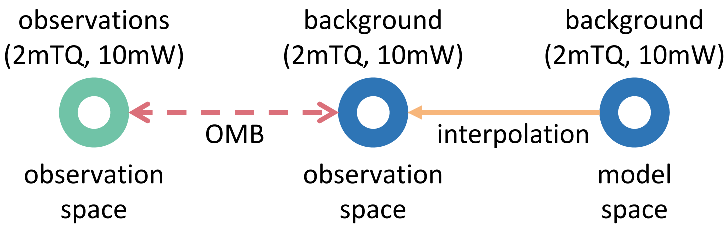
SFC_ASSI_OPTIONS=1 (default)

Modify the observation values!



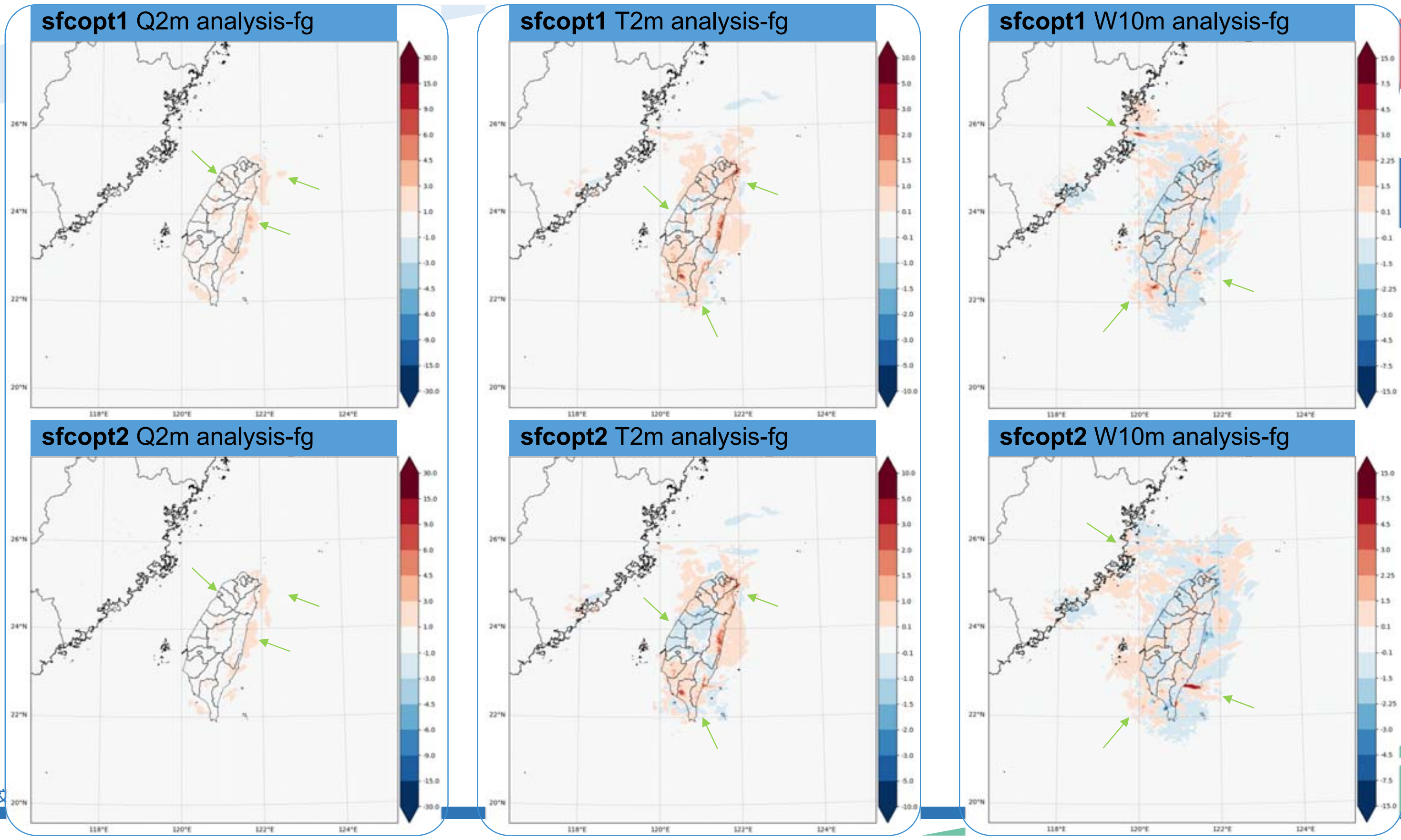
SFC_ASSI_OPTIONS=2

A more "natural" way for DA



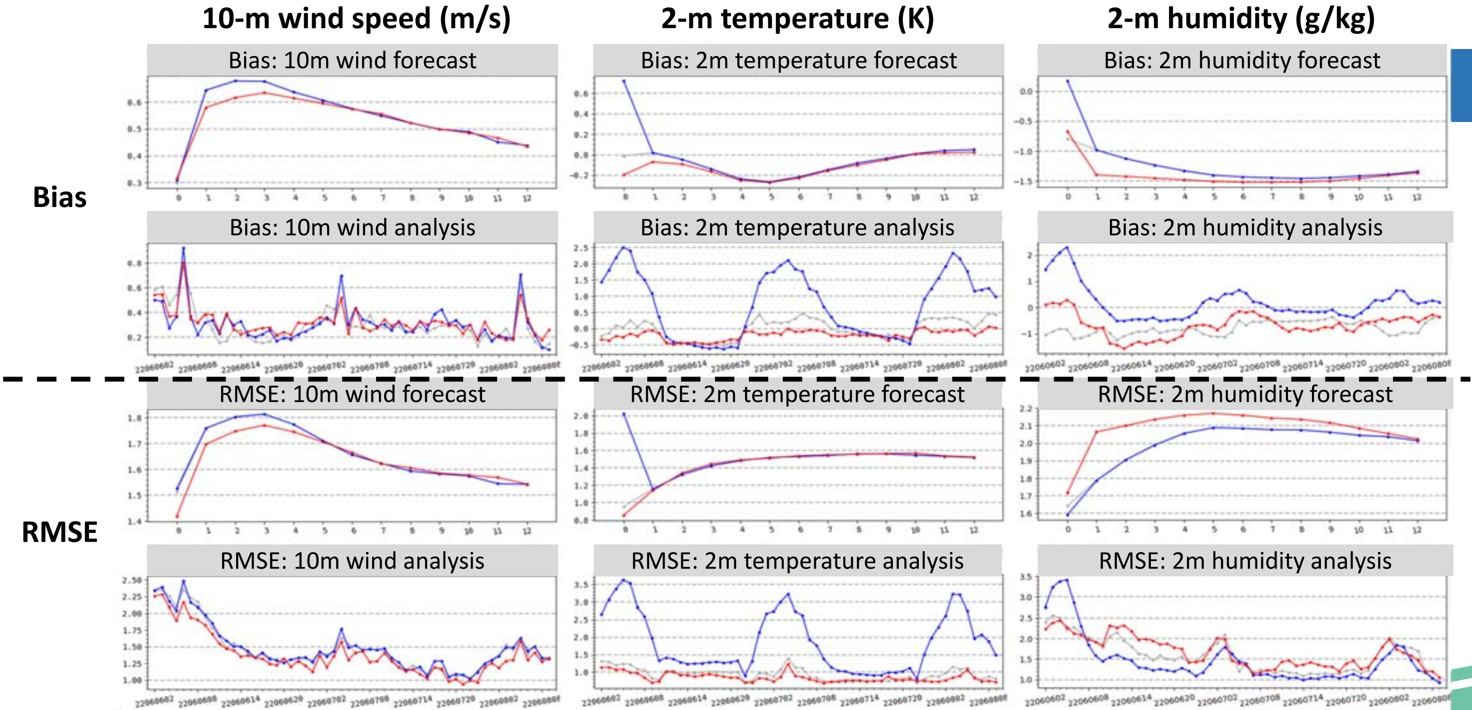
Bugfixes and improvements of SFC_ASSI_OPTIONS=2 to make it basically work

- Substantially revise the tangent linear and adjoint code of the observation operator for SFC_ASSI_OPTIONS=2, and fix a number of associated bugs. (da_transform_xtowtq_adj, da_sfc_wtq_adj, da_sfc_wtq_lin)
- Implement the update of heat and moisture flux in the outer loop. This is required to properly update T2m and Q2m. (da_transform_xtowtq, da_sfc_wtq, da_transfer_wrftoxb)
- Use error propagation formula to calculate qv error (f_qv_from_rh.f90)
- Correct a bug of converting to mixing ratio when qsfc_wrf (surface specific humidity) is present. (da_sfc_wtq)
- Fix a minor bug when t2m, q2m, u10m, v10m are coming directly from first guess but still call da_sfc_wtq in order to get regimes. (da_transfer_wrftoxb)



Surface analysis and forecast verification

Blue: opt1 (analyses are **before DFI**)
Gray: opt1 (analyses are **after DFI**)
Red: opt2 (analysis are **before DFI**)



Summary of surface data assimilation development
(surface VarBC and SFC_ASSI_OPTIONS=2)

- **Surface VarBC:**

Bias	10m wspd.	2m temp.	2m humi.
Analysis	(–)	(–) night time	(–)
Initial	(–)	(–) night time	(–)
forecast	(+)	(–)	(–)

RMSE	10m wspd.	2m temp.	2m humi.
Analysis		(–) night time	(–)
Initial		(–) night time	(–)
forecast	(+)		(–)

  - Limitations:
    - The lack of “anchor observations” in the CWA RWRF system may result in over-correction (i.e., converge to the model biases) in the current surface VarBC??
    - The current method employs a set of “global” bias models for surface observations. However, additional station-dependent bias corrections may be needed.

- **Surface assimilation option 2:**

Bias	10m wspd.	2m temp.	2m humi.
Analysis		(++)	(mixed)
Initial	(+)	(+)	(–)
forecast	(+) early time		(–)

RMSE	10m wspd.	2m temp.	2m humi.
Analysis	(+)	(++)	(–) night time
Initial	(+)	(+)	(–)
forecast	(+) early time		(–)

  - It improves the wind and temperature results
  - More investigations are needed for the humidity.

→ Combined use of these two methods is anticipated!

1. Recent Development of the CWA Regional NWP Systems (WRF-based)

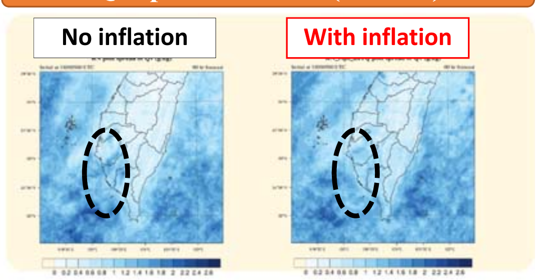
- *Overview of the CWA Regional NWP Systems*
- *Regional Deterministic Systems:*
  - *a) WRFD and TWRF Upgrades*
  - *b) Partial Cycling vs. Continuous Cycling*
- *Ensemble System: WEPS with Ensemble Partial Cycle*
- ***Convective-Scale Systems: RWRF & RWRF-LETKF***
  - *a) Surface DA Development (VarBC & SFC_ASSI_OPTION = 2)*
  - ***b) Additive Noise, LBC Perturbations, Deterministic Analysis, and KDP DA***

LETKF – Covariance inflation: RTPS & additive noises

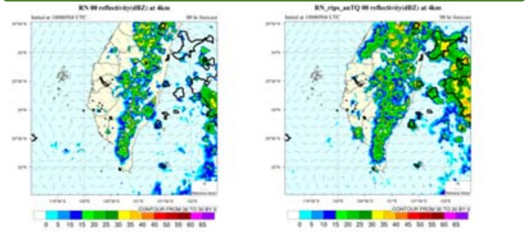
(Tsai et al., to be submitted)

- Employ RTPS and additive noise (Dowell and Wicker 2009) schemes to improve the ensemble spread in RWRF-LETKF.
- Evaluated with afternoon thunderstorm and Mei-Yu frontal rainfall cases.

Qv spread at 1 km (00~05Z)

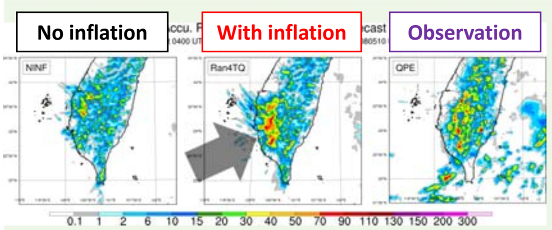


Reflectivity forecast at 4 km (init: 8/5 04Z)



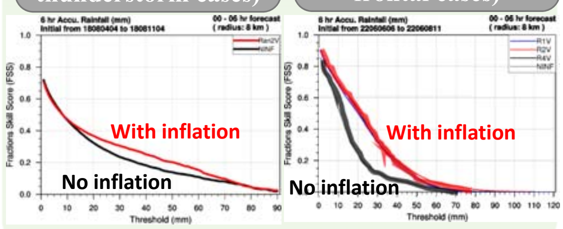
Black contour: 30 dBZ observed reflectivity

0 to 6-h accu. rainfall (init: 8/5 04Z)

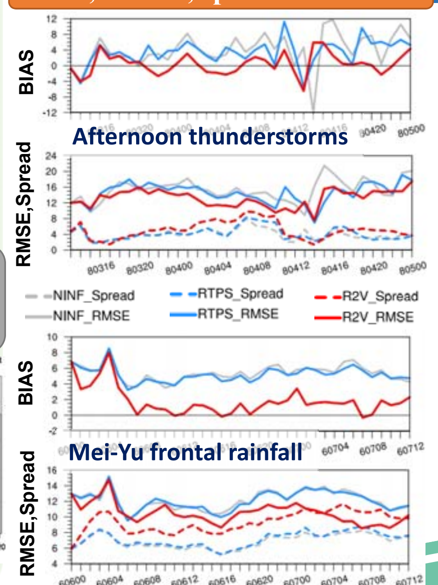


FSS: 0 to 6-h accumulated rainfall (8 afternoon thunderstorm cases)

FSS: 0 to 6-h accumulated rainfall (54 Mei-Yu frontal cases)



Bias, RMSE, spread evolution



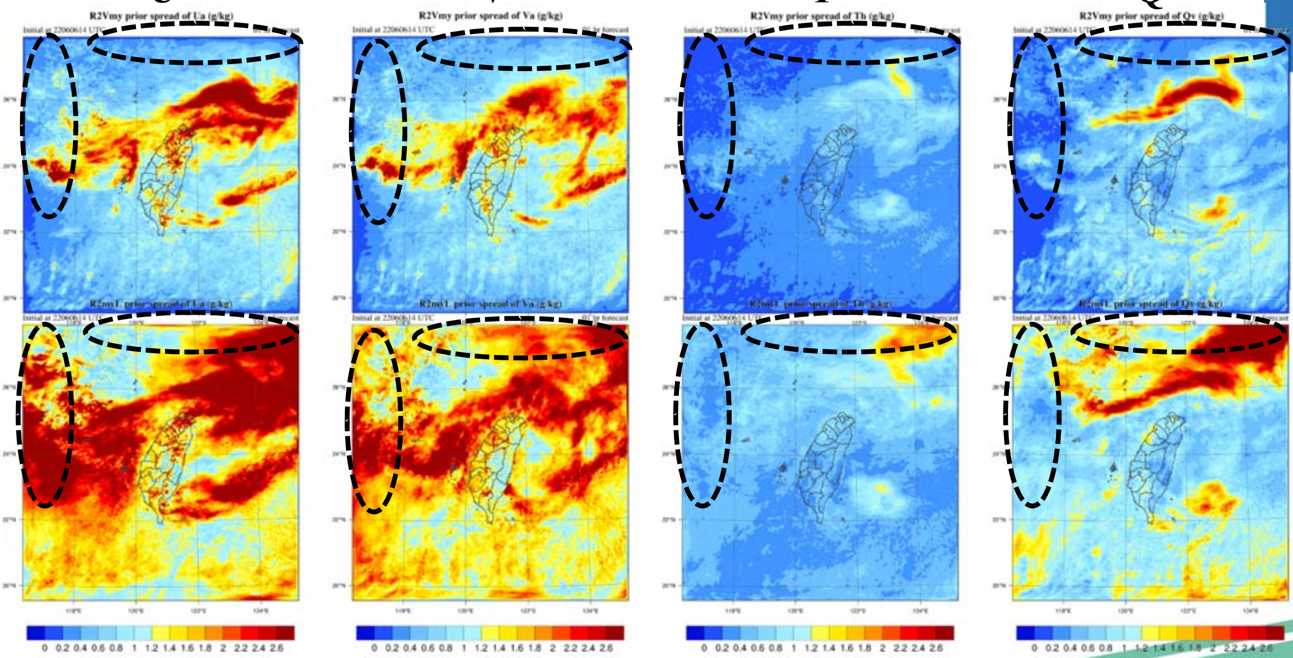
LETKF – Perturbation of lateral boundary conditions (LBC)

Background ensemble spread at 06/06 14Z

U V T Q

No LBC perturbations

With LBC perturbations taken from CWA WEPS



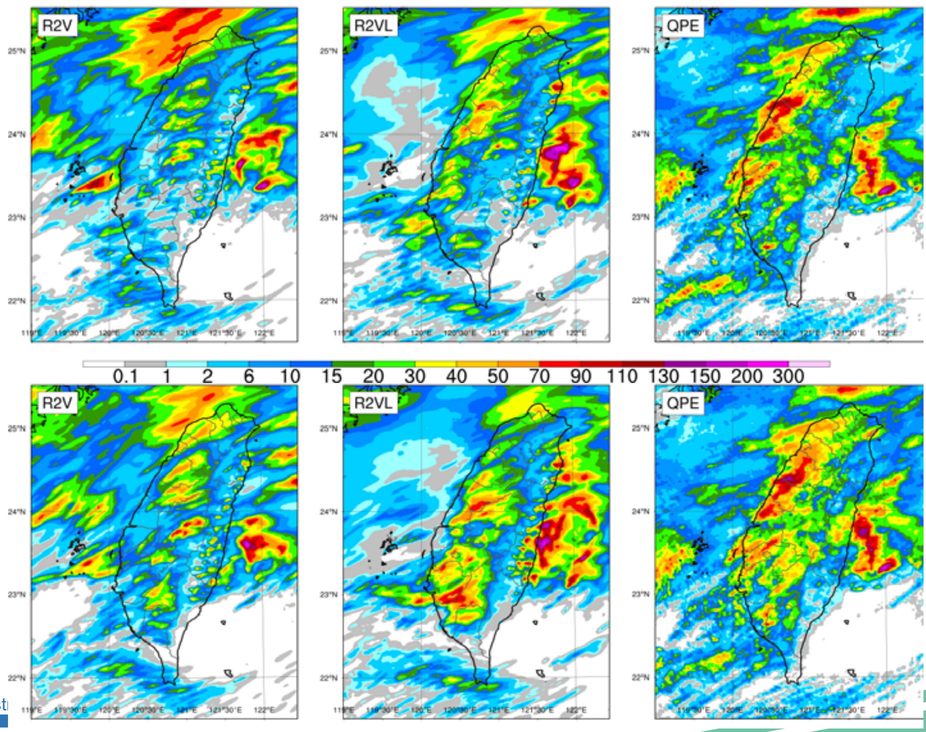
LETKF – Perturbation of lateral boundary conditions (LBC)

No LBC perturbations **With LBC perturbations** **Observations**

0 to 6-h accumulated rainfall forecast

Initialized at 06/07 00Z

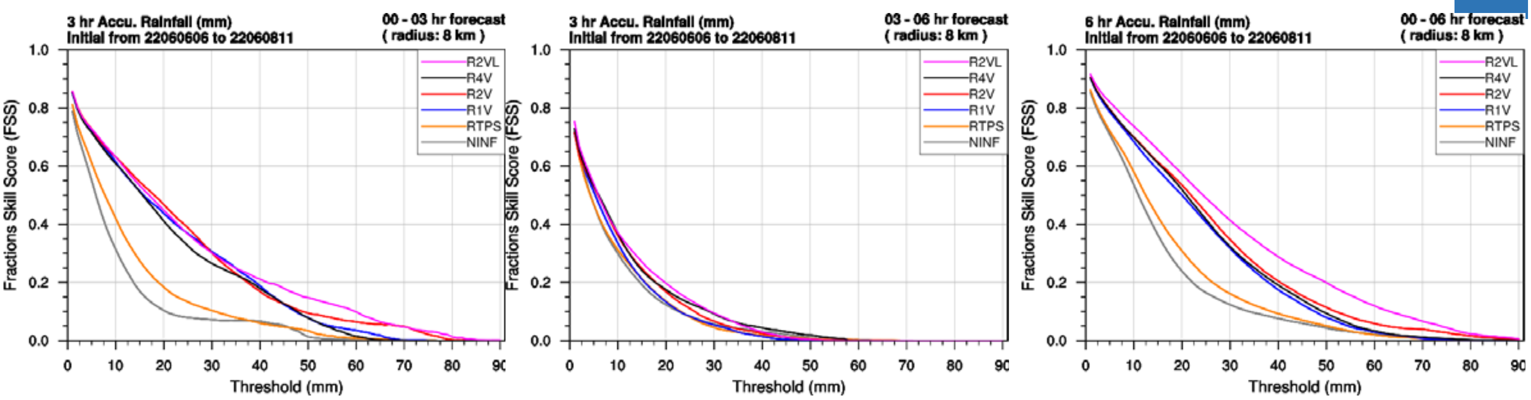
Initialized at 06/07 01Z



LETKF – Perturbation of lateral boundary conditions (LBC)

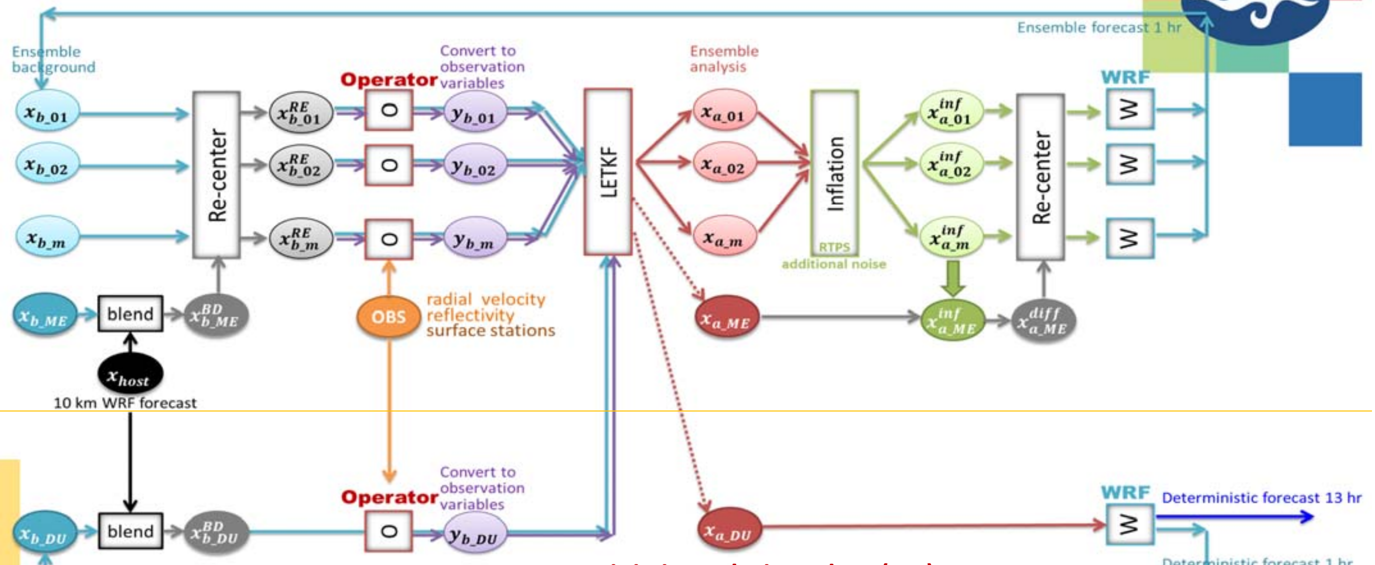
Fraction skill score (FSS)

0-3 h forecast | **3-6 h forecast** | **0-6 h forecast**



- The BDY perturbations significantly improve the QPF performance.
- The effect of BDY perturbations can be clearly identified after about 10 hourly forecast-analysis cycles.
- Results **suggest the application of BDY perturbations for the RWRF-LETKF system.**

LETKF – Implementation of a "deterministic run"



Addtional deteministic run

Deterministic analysis update (DU):

$$\mathbf{x}^a_{\text{det}} = \mathbf{x}^b_{\text{det}} + \mathbf{K}\left[\mathbf{y}^o - H\left(\mathbf{x}^b_{\text{det}}\right)\right]$$

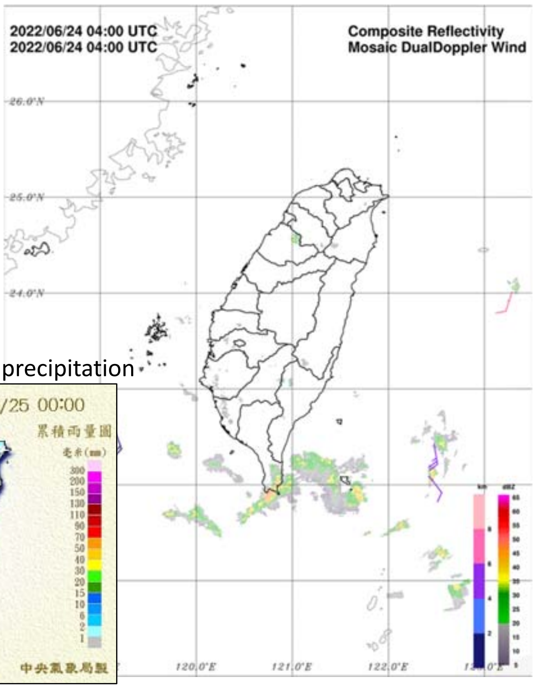
Same Kalman gain as used for the ensemble analyses

Schraff et al. (2016)

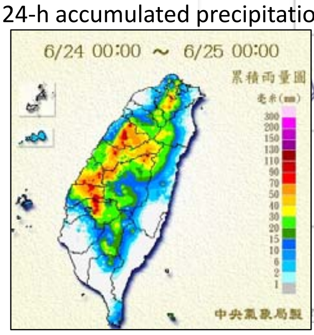
- To provide an unperturbed "best" estimate of the true state, avoiding smoothed results with the ensemble mean.

LETKF – Deterministic analysis & KDP assimilation

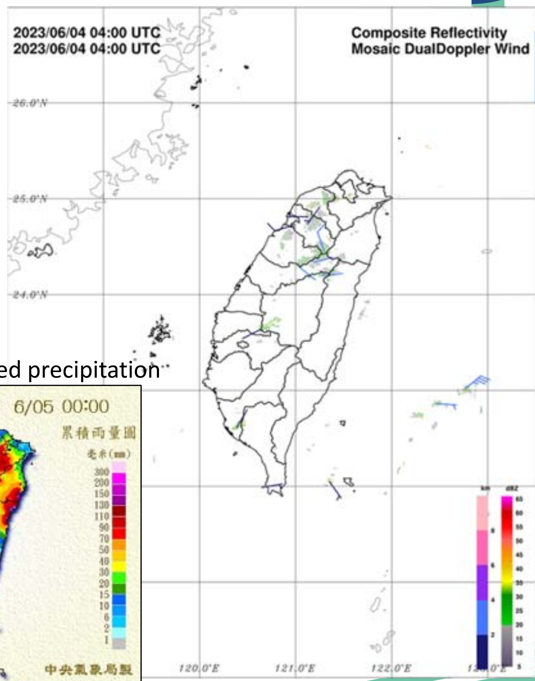
Afternoon thunderstorm



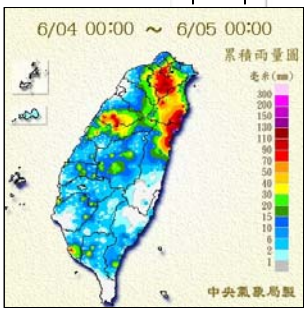
24-h accumulated precipitation



Night-time precipitation



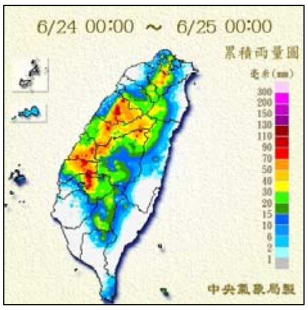
24-h accumulated precipitation

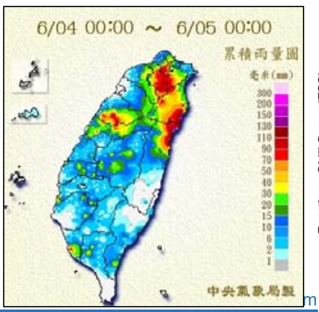


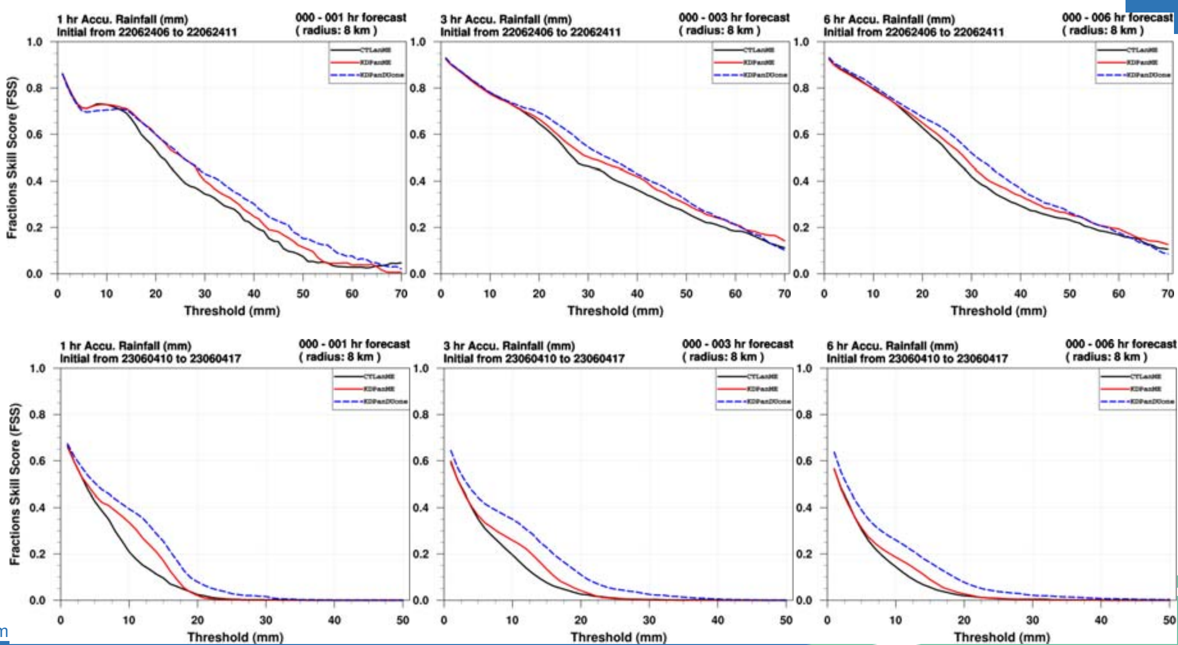
LETKF – Deterministic analysis & KDP assimilation

CTL — KDP — KDP + deterministic analysis

0-1 hr | 0-3 hr | 0-6 hr

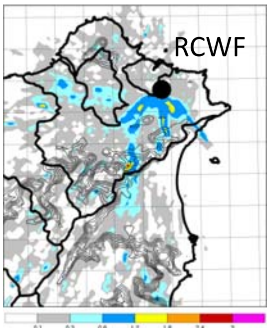


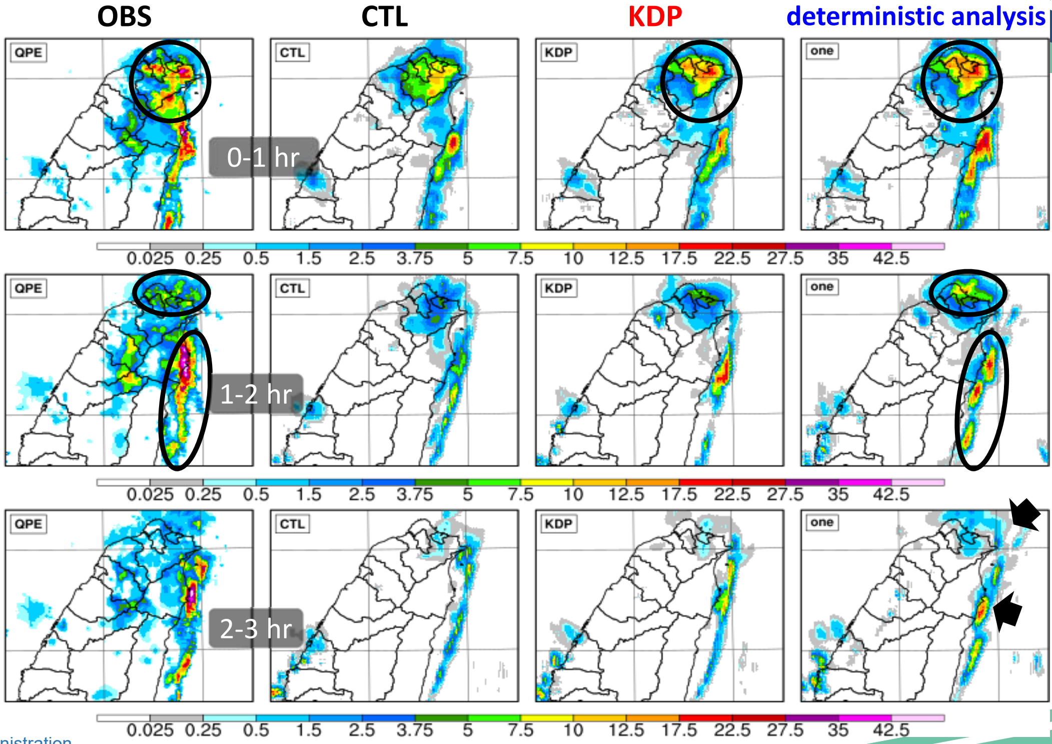




LETKF – Deterministic analysis & KDP assimilation

KDP OBS 1-4 km Max.

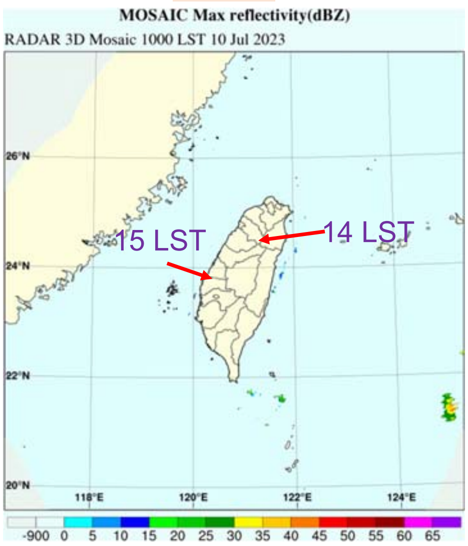




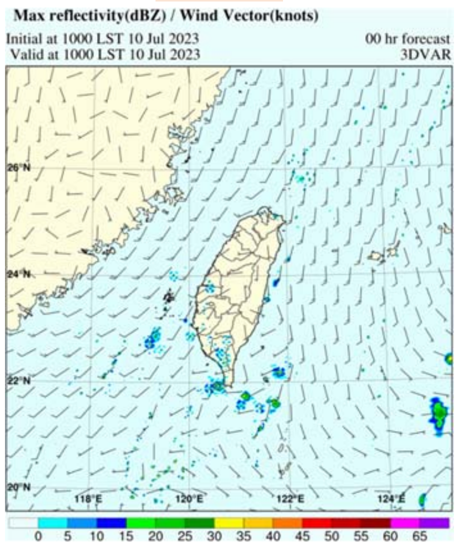
RWRF and RWRF-LETKF operational forecasts

Init: 2023/07/10 02:00 UTC – Afternoon thunderstorms

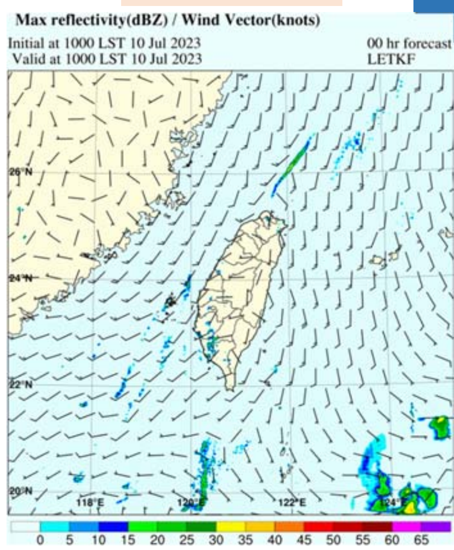
OBS



RWRF



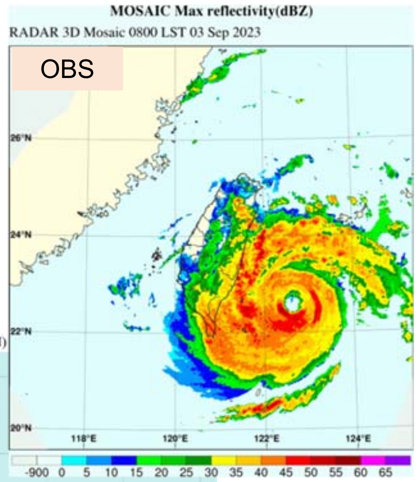
RWRF-LETKF

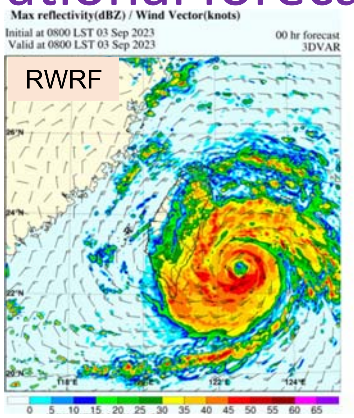


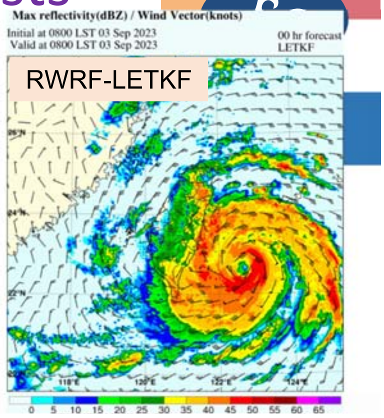
The issue of early initiation of afternoon thunderstorms is still obvious.

RWRF and RWRF-LETKF operational forecasts

Init: 2023/09/03 00:00 UTC – Typhoon Haikui (2023)







First landfalling typhoon during the past 4+ years! (longest on record)

2. Recent Development of CWA Global NWP Systems, and Toward a More Integrated NWP Suite Across Scales

- ***CWA global NWP system: Taiwan Global Forecast System (TGFS)***
- *CWA's NWP suite: Global Ensemble Prediction System (GEPS), and more…*

CWA global NWP system

CWBGFS | TGFS v1

2002	2003	2004	2007	2010	2011	2014	2016	2020	2023
T119L30	SSI 3DVar	T179L30	T239L30	GSI 3DVar	T319L40 (~40 km)	GSI hybrid 3DEnVar	T511L60 (~25 km)	TCo639L72 (~18 km)	FV3 C384L64 (~25 km) GSI hybrid 4DEnVar

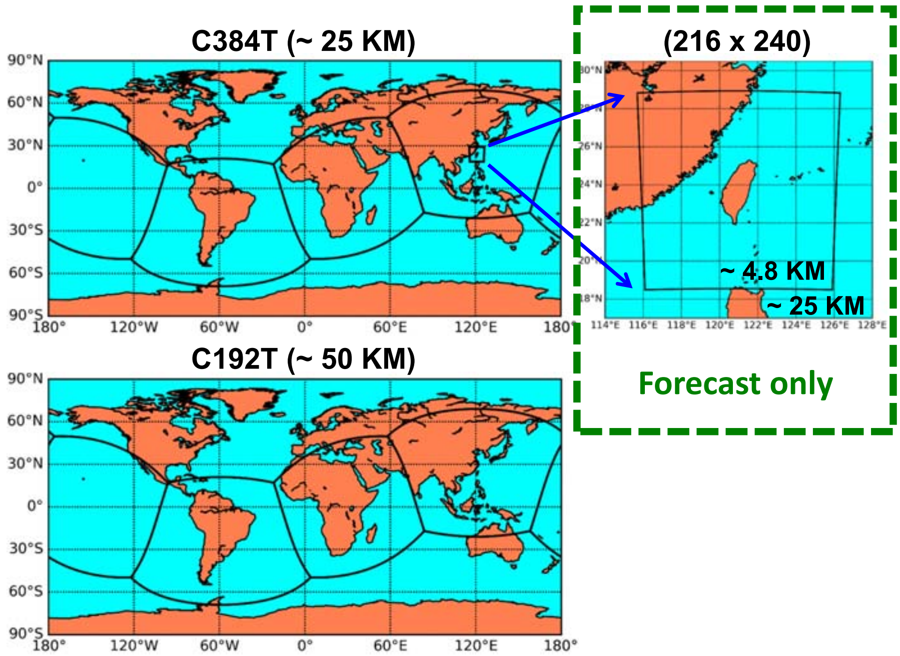
In collaboration with NCEP/EMC since 2016,
CWB has adapted the NCEP GFS v15 as its new operational global NWP system

- **2019**: Port GFS v15 (FV3GFS) model code
- **2020**: Port GSI code (for GFS v15) and the complete data assimilation workflow
- **2021**: Start semi-operational (near-real-time) run / research & performance tuning
- **2022**: Research & performance tuning / Port to CWB's 6th-generation HPC (Fujitsu FX1000; ARMv8.2-A)
- **2023**: Research & performance tuning / Operation → **Taiwan Global Forecast System (TGFS) v1**
- **Continuous research & performance tuning**

Taiwan Global Forecast System (TGFS) v1

Deterministic system
hybrid 4DEnVar
using time-lagged ensemble
(global domains)

Ensemble system
EnKF
(32 members)



cf. NCEP:

C768 (~13 km)
for deterministic

C384 (~25 km)
for ensemble

NCEP GFS v15 vs. CWB TGFS v1

CWB TGFS v1 is largely based on NCEP GFS v15.1, with the following main differences:

	NCEP GFS v15	CWB TGFS v1
Global grid setting	Deterministic: C768L64 (13 km) / Ensemble: C384L64 (25 km) (zonal tile arrangement)	Deterministic: C384L64 (25 km) / Ensemble: C192L64 (50 km) (Taiwan-centric tile arrangement)
Nested tile	N/A	Taiwan-nested tile (4.8 km; forecast-only; initialized from global DA analysis)
Ensemble size	80	32 + 32 (12-h time-lagged forecast)
Cumulus scheme	New SAS	Global: CWB modified New SAS (Lin et al. 2022; based on Kwon and Hong 2017) Nested: CWB modified New Tiedtke
Land model and static data	NCEP fix data	Updated land-use, soil type (from WRF/MODIS), vegetation fraction (from EUMETSAT) Land model updates (based on NCEP GFS v16)
Gravity wave drag scheme		Fix a bug associated with air density
Assimilated observations	NCEP observation	NCEP observation – those not publicly available on NOAA NOMADS + CWB-processed **conventional data** (early run only) + CWB-processed **COSMIC-2 RO** + CWB-processed **Himawari-8 AHI**
RO assimilation	Error specified using absolute values	Error specified using fractional values

NCEP GFS v15 vs. CWB TGFS v1

CWB TGFS v1 is largely based on NCEP GFS v15.1, with the following main differences:

Main inferiorities to NCEP GFS:

1) Lower resolution (25 vs. 13 km)
2) Fewer ensemble members (32(+32) vs. 80)
3) Fewer observations assimilated

	NCEP GFS v15	CWB TGFS v1
Global grid setting	Deterministic: C768L64 (13 km) / Ensemble: C384L64 (25 km) (zonal tile arrangement)	Deterministic: C384L64 (25 km) / Ensemble: C192L64 (50 km) (Taiwan-centric tile arrangement)
Nested tile	N/A	Taiwan-nested tile (4.8 km; forecast-only; initialized from global DA analysis)
En	80	32 + 32 (12-h time-lagged forecast)
C		Global: CWB modified New SAS (Lin et al. 2022; based on Kwon and Hong 2017) Nested: CWB modified New Tiedtke
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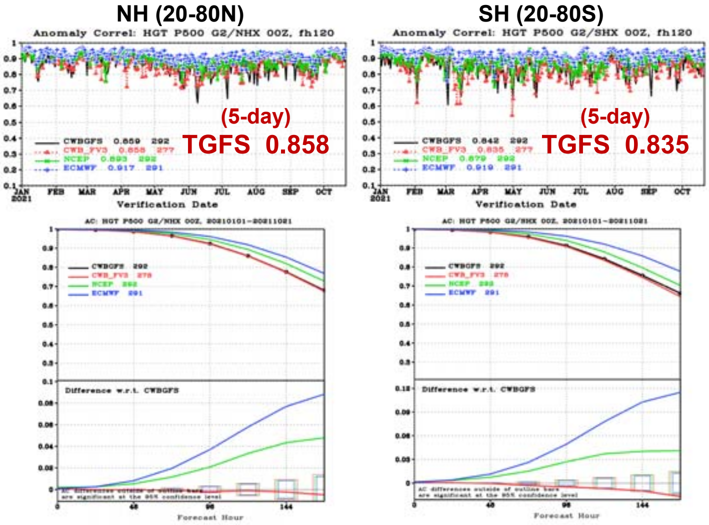
Gravity wave drag scheme		Fix a bug associated with air density
Assimilated observations	NCEP observation	NCEP observation – those not publicly available on NOAA NOMADS + CWB-processed **conventional data** (early run only) + CWB-processed **COSMIC-2 RO** + CWB-processed **Himawari-8 AHI**
RO assimilation	Error specified using absolute values	Error specified using fractional values

TGFS v1 semi-operational test: 2021

2021/01/01 ~ 2021/10/21

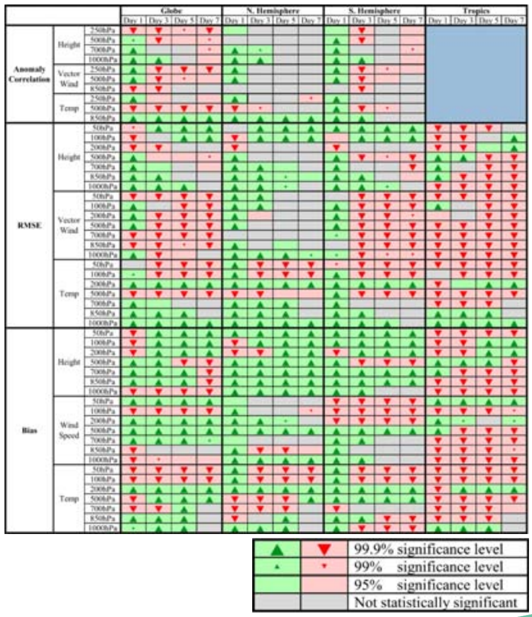
500-hPa Height ACC

NH (20-80N) SH (20-80S)



CWBGFS (18 km; DA at 25 km with "EC bogus data")
TGFS (C384; 25 km)
NCEP GFS (C768; 13 km)
ECMWF IFS (9 km)

Scorecard – Green/Red :
TGFS is Better/Worse than CWBGFS



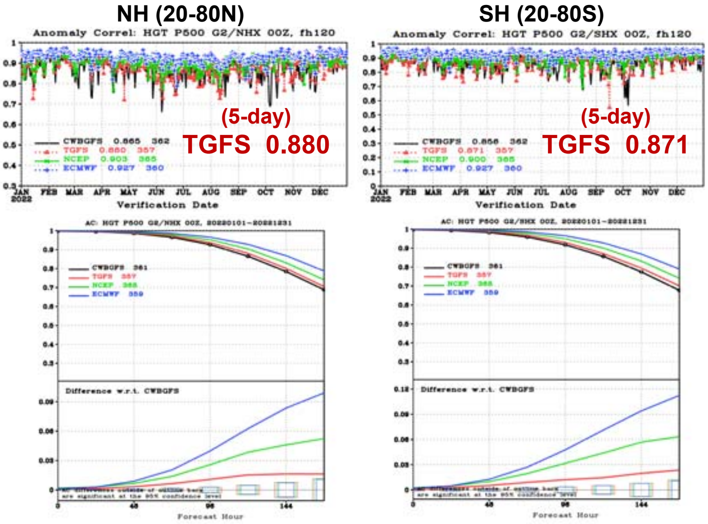
Verified against NCEP analysis

TGFS v1 semi-operational test: 2022

2022/01/01 ~ 2022/12/31

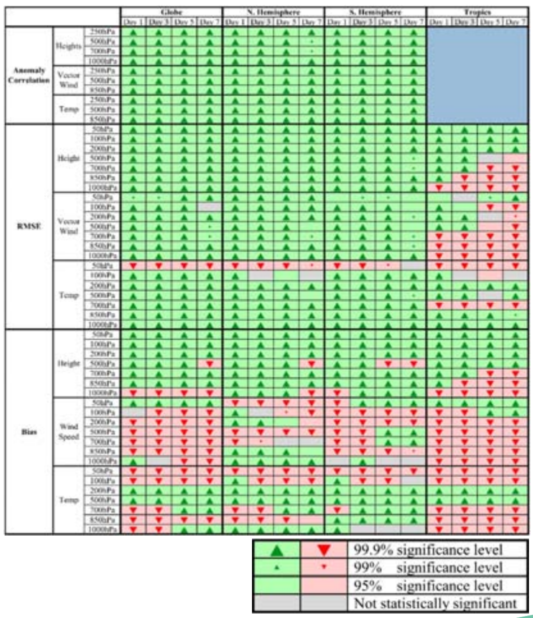
500-hPa Height ACC

NH (20-80N) SH (20-80S)



CWBGFS (18 km; DA at 25 km with "EC bogus data")
TGFS (C384; 25 km)
NCEP GFS (C768; 13 km)
ECMWF IFS (9 km)

Scorecard – Green/Red :
TGFS is Better/Worse than CWBGFS

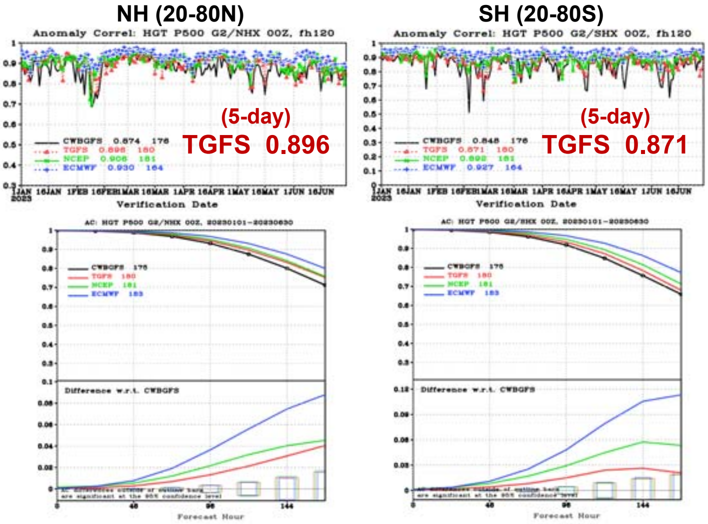


Verified against NCEP analysis

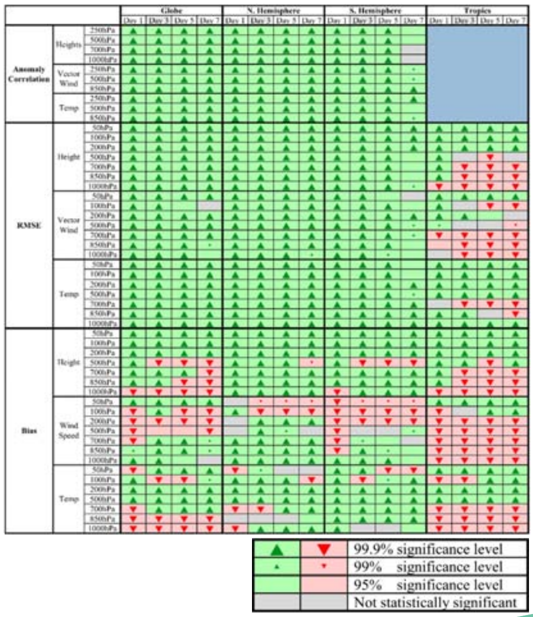
TGFS v1 semi-operational test: 2023H1

2023/01/01 ~ 2023/06/30

500-hPa Height ACC



Scorecard – Green/Red :
TGFS is Better/Worse than CWBGFS



Verified against NCEP analysis

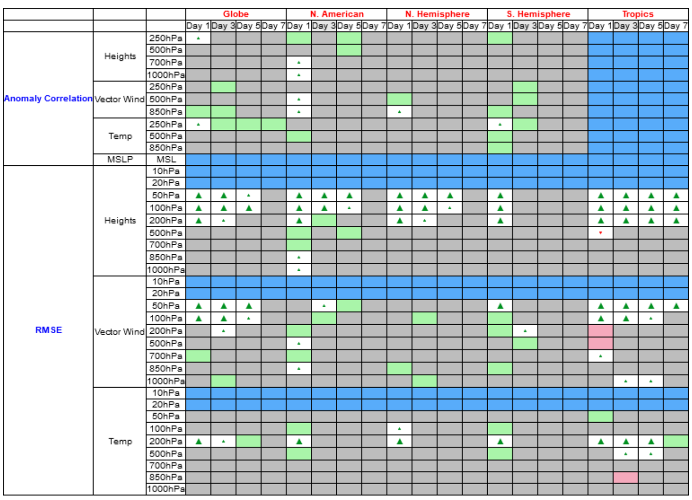
- CWBGFS (18 km; DA at 25 km with "EC bogus data")
- TGFS (C384; 25 km)
- NCEP GFS (C768; 13 km)
- ECMWF IFS (9 km)

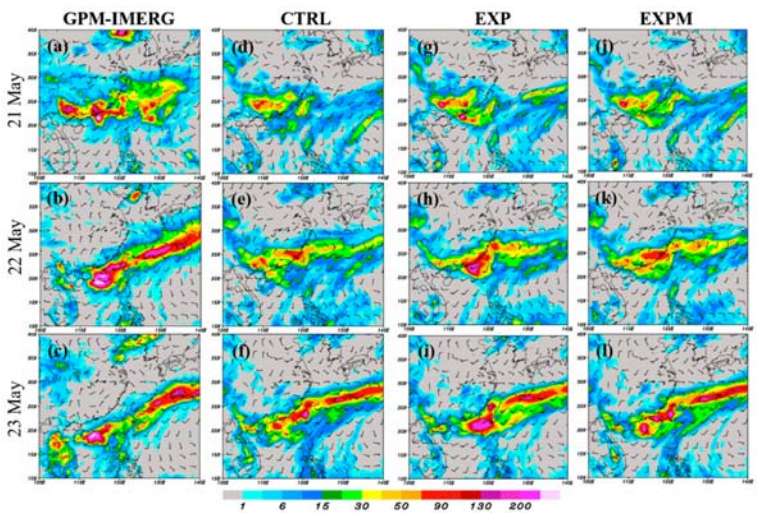
TGFS: Improvement of NSAS cumulus scheme

[**Lin et al. (2022)**, based on **Kwon and Hong (2017)**]

Scorecard – Green/Red :
EXP is better/worse than CTRL

Verification data: ERA5
Time period: 20210904~20211009

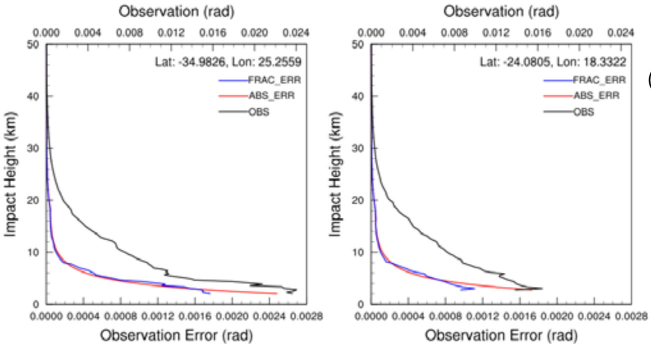




TGFS: Improvement of GNSS RO observation error – Fractional errors

CTRL : Absolute RO bending angle observation error (GSI default)
FracErr : Relative (fractional) RO bending angle observation error

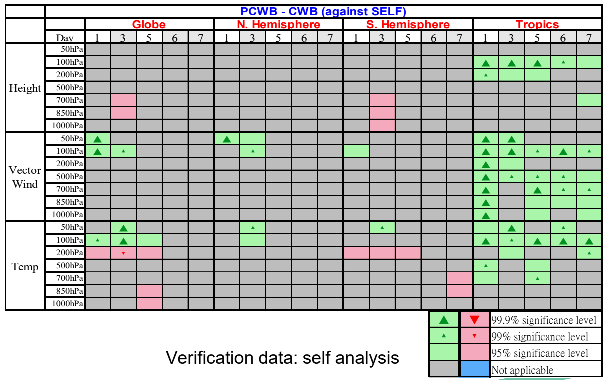
RO absolute vs. fractional errors



(RO observation samples)

- Observation
- Absolute error
- Fractional error = OBS × α (%)

Scorecard (RMSE) – Green/Red : FracErr is Better/Worse than CTRL



Verification data: self analysis

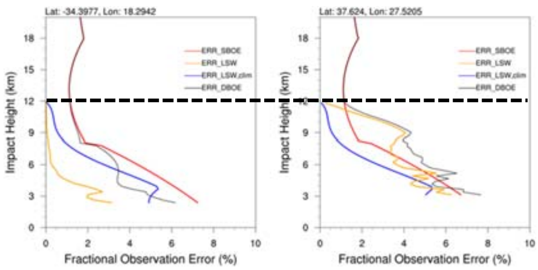
TGFS: Improvement of GNSS RO observation error – using Local Spectral Width (LSW)

- Zhang et al. (2023) demonstrated a positive impact of LSW-based dynamic RO observation errors in a global NWP system.
- Inspired by Zhang et al. (2023), we propose a new statistically-consistent approach to formulate a bending angle observation error model, which by design meets the following assumptions:
  - The long-term average of the profile-dependent observation error variance always converges to traditional (statistically determined) static observation error variance.
  - Upper-level RO data use exactly the static observation errors (i.e., not profile-dependent).
  - The observation errors of lower-level RO data are largely determined by their LSW values.

$$\sigma = \sqrt{\sigma^2_{static} + \sigma^2_{dyn} - \sigma^2_{dyn,\,clim}}$$

σ_{static} : Traditional static errors $\quad \sigma_{dyn} = \mathrm{LSW}/3 \quad \sigma_{dyn,\,clim} = \sqrt{\overline{\sigma^2_{dyn}}}$

Two random samples of RO error profiles

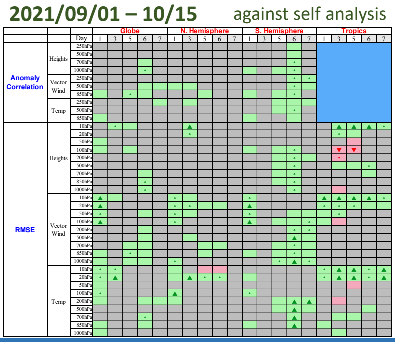


Red: Original static observation error
Gray: The new dynamic observation error

Impact of RO dynamic observation errors

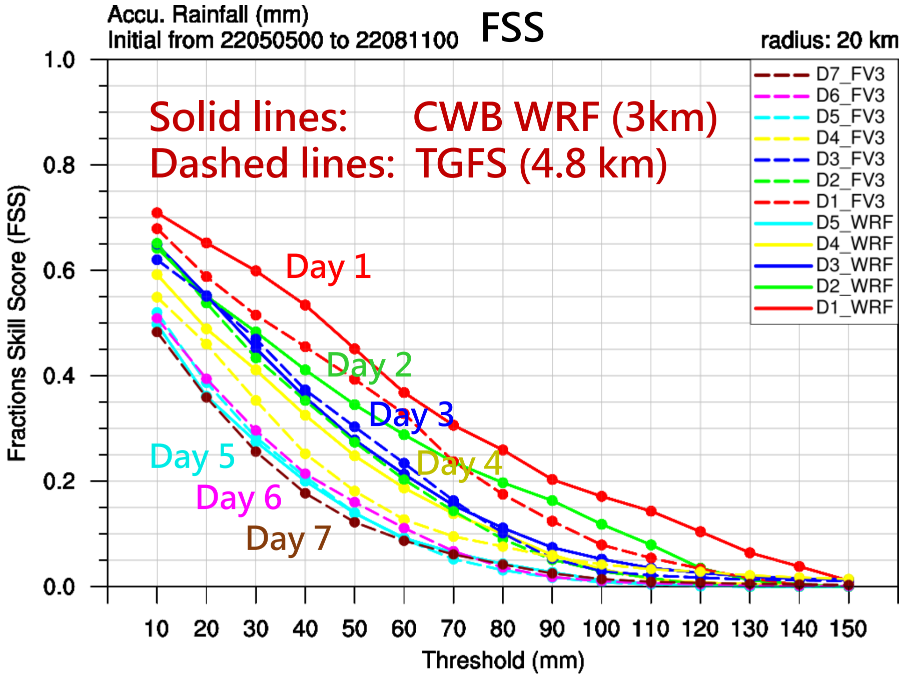
[Dynamic obs errors] is **better/worse** than [static obs errors]

2021/09/01 – 10/15 against self analysis



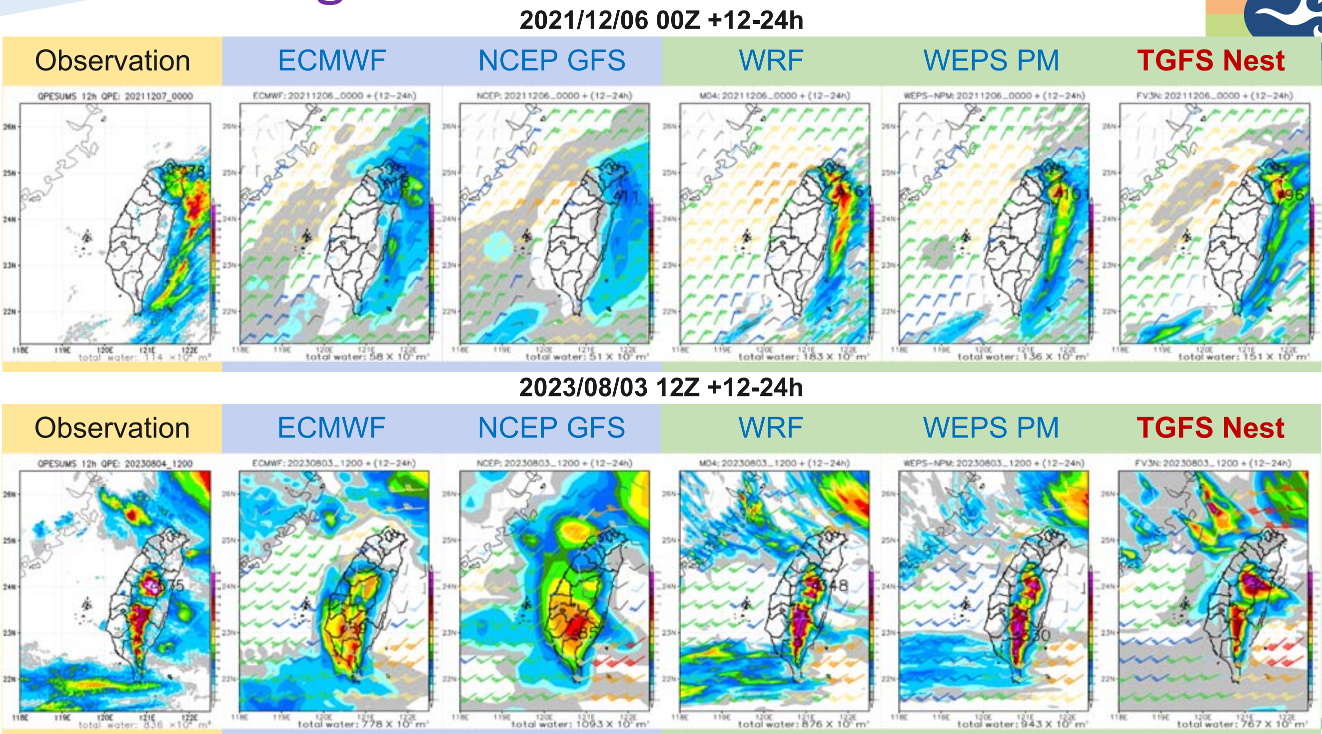
- This positive impact can only be obtained by simultaneously relaxing some GSI built-in QC criteria.
- If the QC is not relaxed, the effect of RO dynamic observation errors is not significant.

TGFS v1 semi-operational test: **Taiwan nested tile**



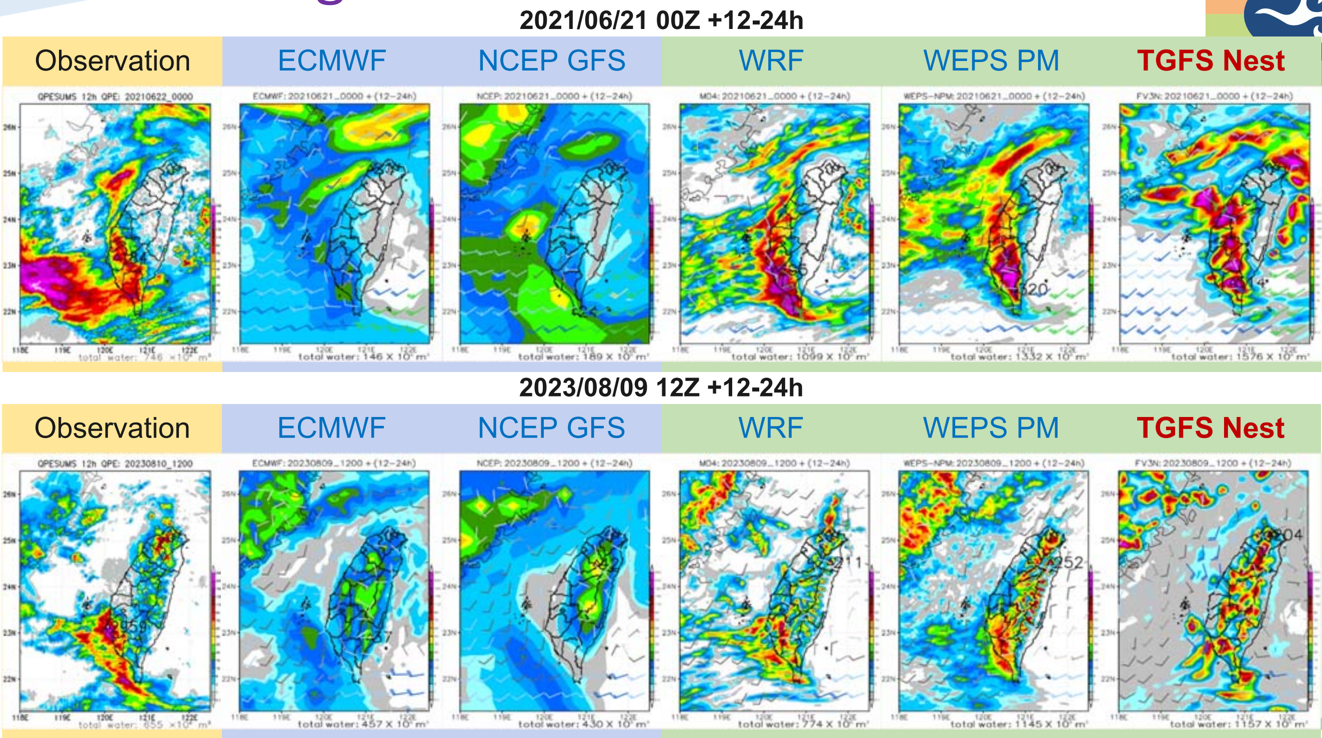
Taiwan QPF guidance

(All QPF figures are 12-24h forecasts)



Taiwan QPF guidance

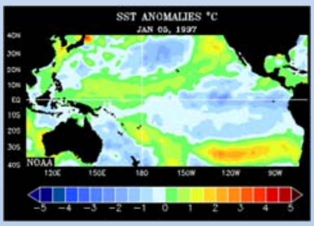
(All QPF figures are 12-24h forecasts)



2. Recent Development of CWA Global NWP Systems, and Toward a More Integrated NWP Suite Across Scales

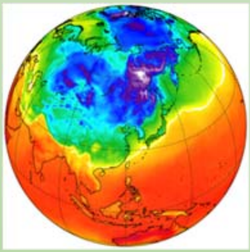
- *CWA global NWP system: Taiwan Global Forecast System (TGFS)*
- ***CWA's NWP suite: Global Ensemble Prediction System (GEPS), and more…***

CWA's NWP suite from global to regional, from weather to climate, from deterministic to ensemble



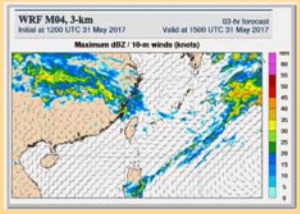
Extended weather & Short-term climate

- CWB GEPS (45 days)
- TCWB 1T1.1 (8 months)
  → CWBCFS (global + RSM)



Global weather

- CWBGFS (16 days)
  → CWB TGFS



Regional weather

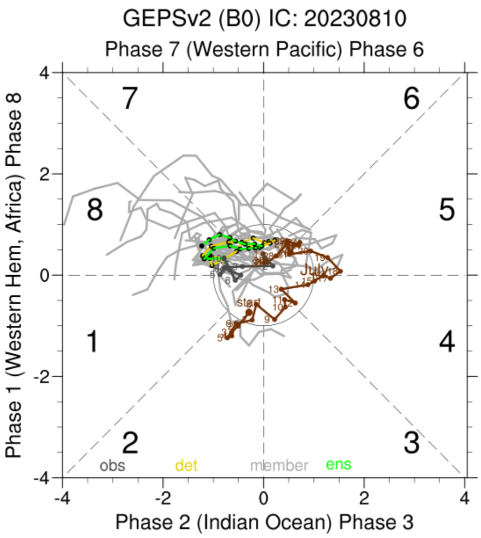
- CWB WRFD (5 days)
- CWB TWRF (typhoon)
- CWB WEPS
- CWB RWRF (13 hours)
- CWB CEPS

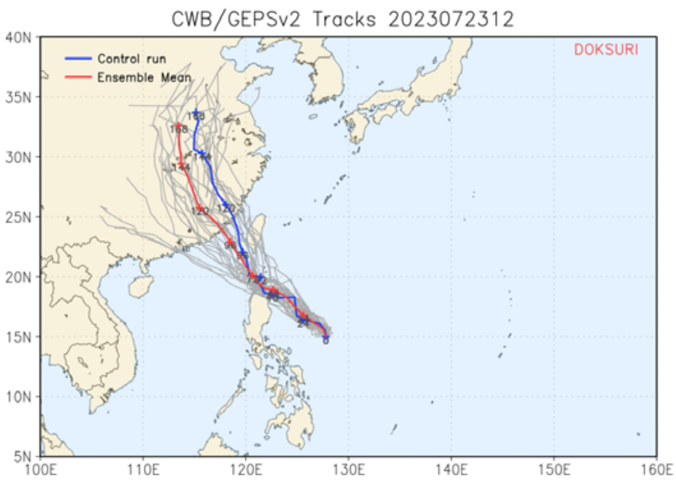
Numerical modeling
Data assimilation
Observing systems
Ensemble forecasting
Coupled modeling

CWB Global Ensemble Prediction System (GEPS)

CWB GEPS v1 (2017) → **CWB GEPS v2** (2023)

IC from Singular Vector (SV) → ICs from TGFS EnKF

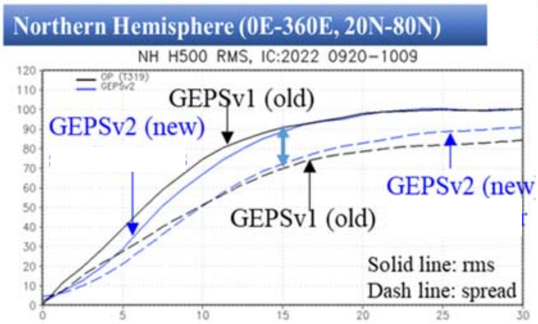


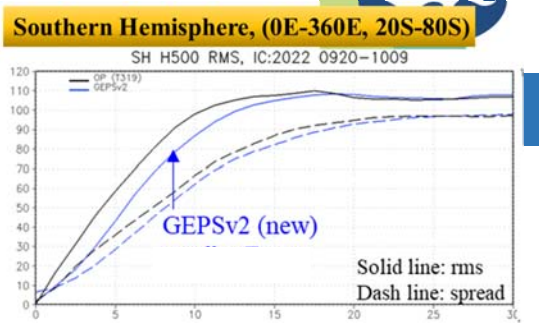


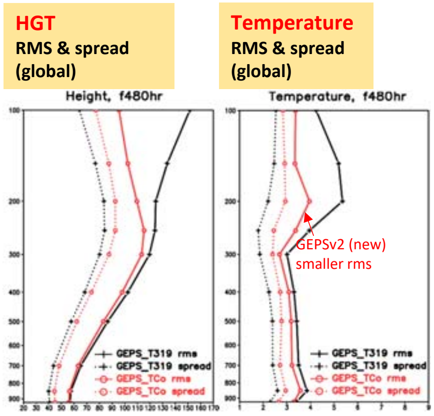
GEPS v2.0 vs. GEPS v1.1

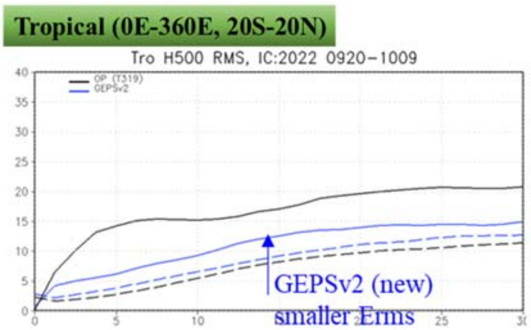
(Solid line: ensemble anomaly correlation or ensemble root mean square error)
(Dash line: ensemble spread)

GEPSv1.1 (black line) (old version)
GEPSv2.0 (blue line, red line) (new version)



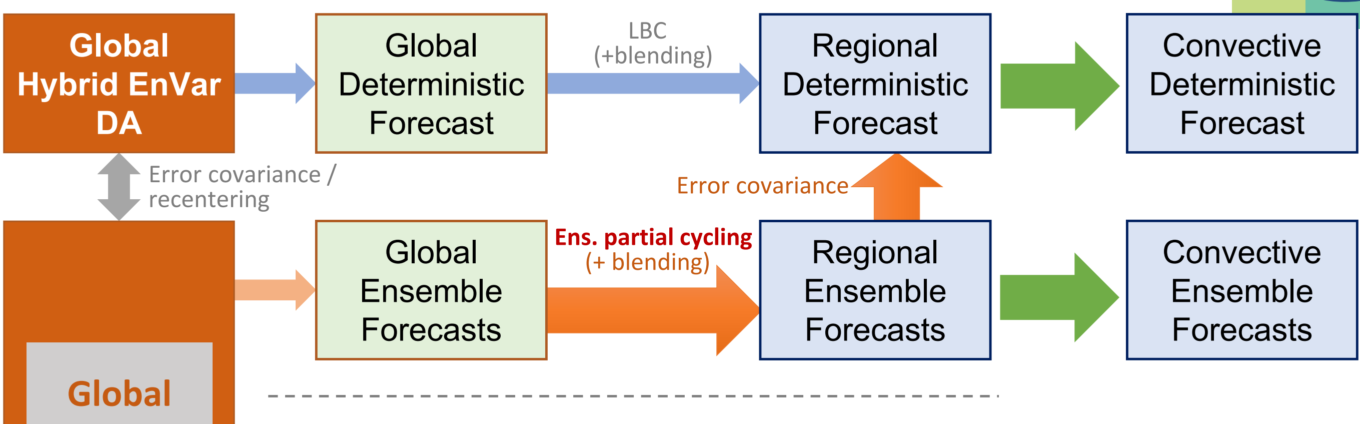






Overall, GEPS v2.0 is better than GEPS v1.1

Prospect of CWA NWP suite (NOT current status)



- ***Global ensemble DA is as a HUB to bridge the NWP system from convective scale to climate scale.***

3. CWA's Future Plans and Discussions

CWA regional NWP: Ongoing and future development work

- Continuous cycling (+ blending) for WRFD
- Ensemble partial cycling and EDA for WEPS (which also provides ensemble error covariance for WRFD)
- Improvement of model physics (e.g., CWBGCE microphysics, Noah-MP, and more)
- Improvement of convective-scale data assimilation in RWRF and RWRF-LETKF systems
  - [RWRF] Surface VarBC and SFC_ASSI_OPTIONS=2
  - [RWRF] Improvement of hybrid 3DEnVar data assimilation
  - [RWRF] Direct radar reflectivity assimilation [Task 1.2 of 2019, 2020, 2021]
  - [RWRF] Incremental Analysis Update (IAU) **[Task 1.3]**
  - [RWRF & RWRF-LETKF] Improvement of radar DA with CWBGCE (and other advanced) microphysics schemes
  - [RWRF-LETKF] Lower boundary perturbations
  - [RWRF-LETKF] Dual-pol radar assimilation **[Task 1.2]**
  - [RWRF-LETKF] All-sky radiance assimilation **[Task 3.1]**
  - RWRF-LETKF-based ensemble prediction: CEPS
  - Taiwan's regional "Real-Time Mesoscale Analysis (RTMA)" and regional reanalysis
- Enhancing the code management: CWA's code branch of WRF and WRFDA (and MPAS, …)
- Utilizing MPAS and MPAS-JEDI

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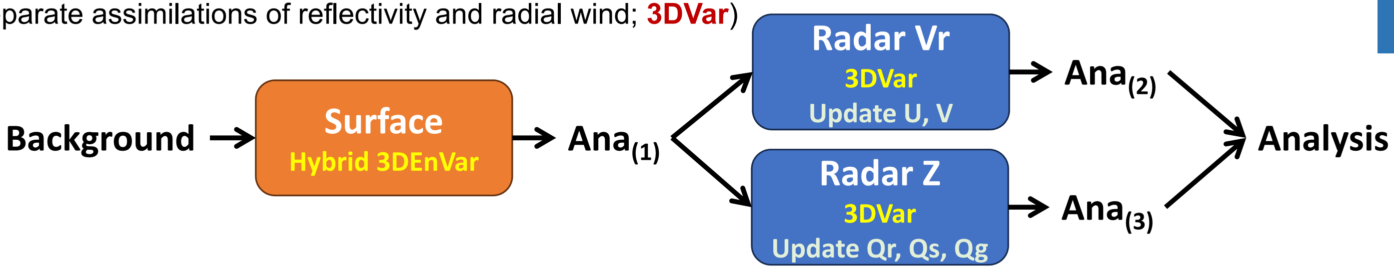
- **Utilizing MPAS and MPAS-JEDI**

CWA RWRF (variational) data assimilation

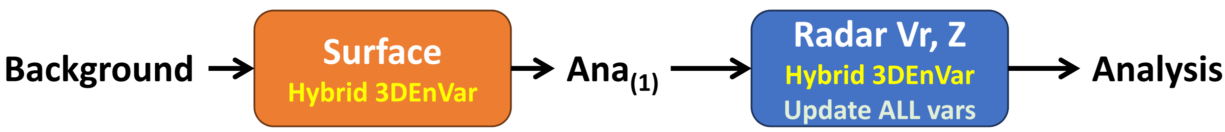
Current operational version

(separate assimilations of reflectivity and radial wind; **3DVar**)

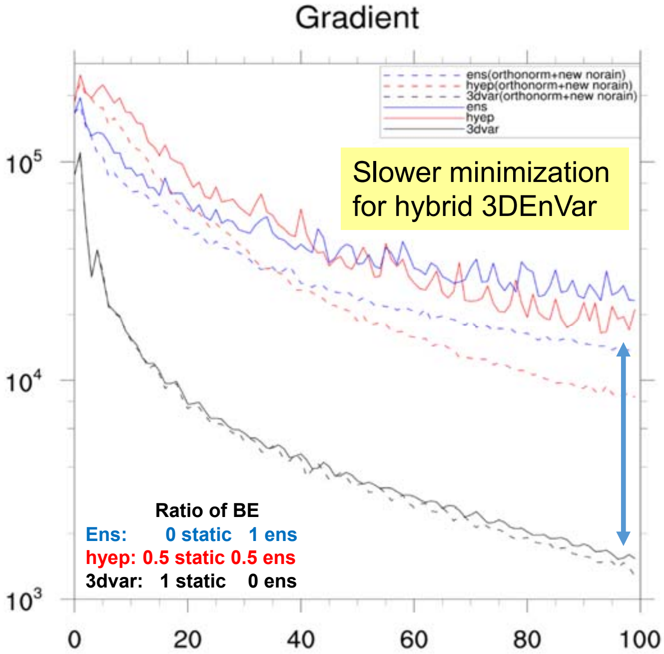


Next version (will be in operation soon)

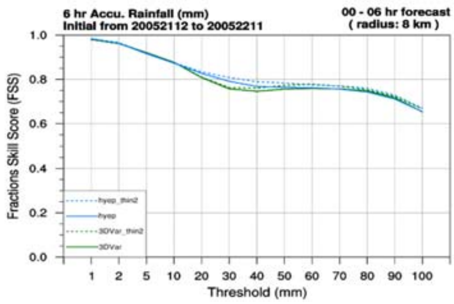
(simultaneous assimilation of reflectivity and radial wind; **hybrid 3DEnVar**)



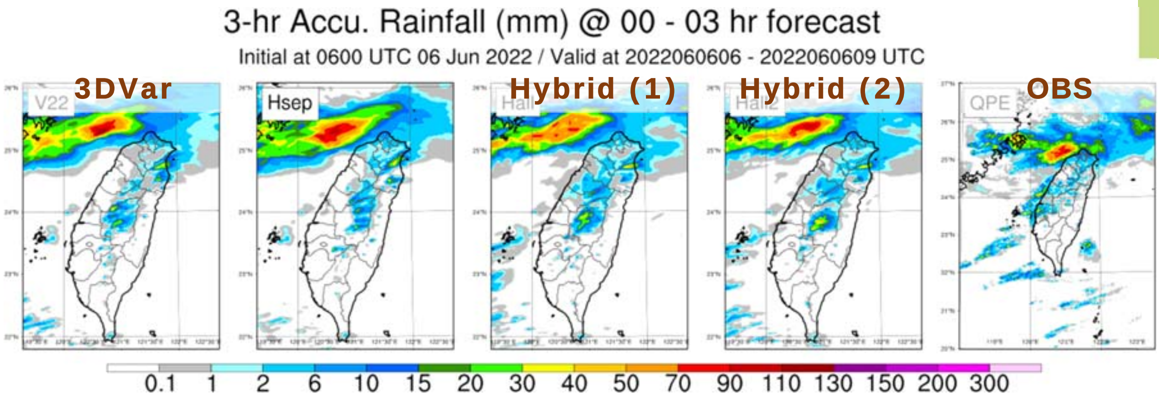
RWRF – 3DVar vs. Hybrid 3DEnVar data assimilation

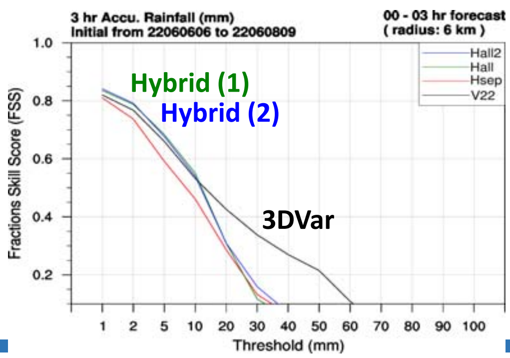


- precondition_cg: worse convergence
- orthonorm_gradient: better convergence
- Thinning of reflectivity data is required.



RWRF – 3DVar vs. Hybrid 3DEnVar data assimilation





RWRF – Direct vs. Indirect radar reflectivity assimilation

(assimilation of hydrometer retrievals)

Model

DA

OBS

$$Z_e = \begin{cases} Z_{qr} & \dots T_b > 5^\circ C \\ Z_{qs} + Z_{qh} & \dots T_b < -5^\circ C \\ \alpha Z_{qr} + (1-\alpha)[Z_{qs} + Z_{qh}] & \dots -5^\circ C < T_b < 5^\circ C \end{cases}$$

Qr Qr

Convenient but with high uncertainty

Sun and Crook (1997); Xiao et al. (2005,2007); Xiao and Sun (2007); Gao and Stensrud (2012); Chen at el. (2020); Zheng et al (2023);

indirect

Z

direct

Qr

Tangent Linear

Adjoint

Z Z

Complicated in variational DA

Jung et al. 2008;Li and Mecikalski 2016; Wang and Wang 2016;Kawabata et al. 2018; Wang and Liu 2019; Liu et al. (2020); Yang and Wang 2023;

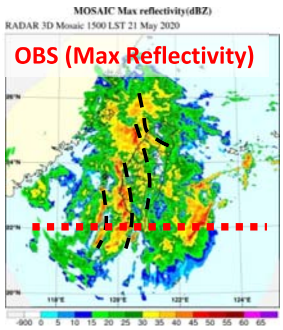
Task 1.2 of 2019, 2020, 2021

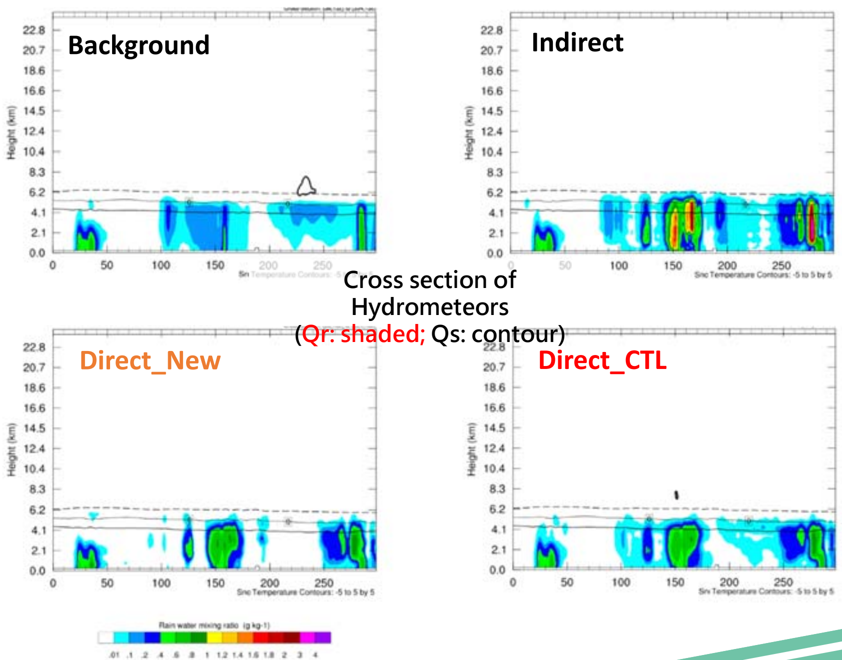
Thank Dr. Zhiquan Liu

Possibility to use in operation

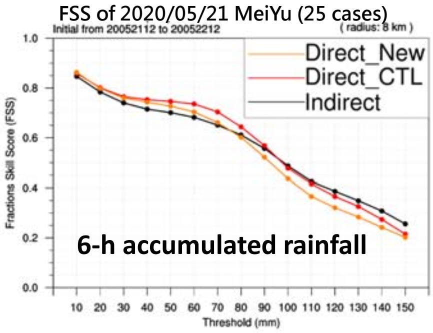
RWRF – Direct vs. Indirect radar reflectivity assimilation

Mei-Yu front case



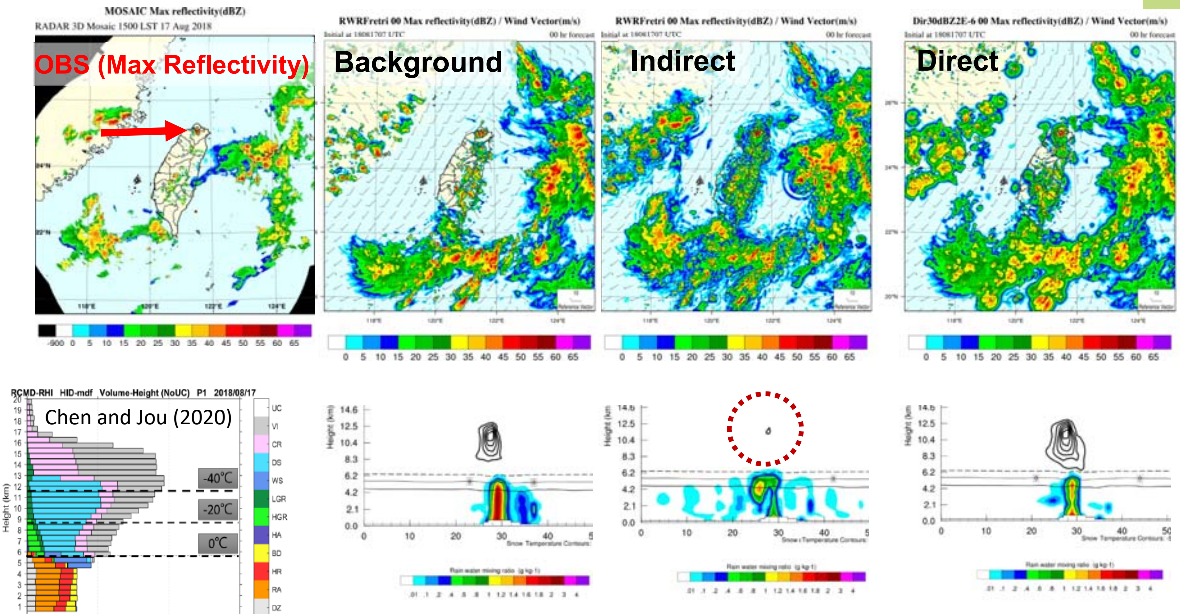


Cross section of Hydrometeors (Qr: shaded; Qs: contour)



RWRF – Direct vs. Indirect radar reflectivity assimilation

Afternoon thunderstorm case



X-Cross section of hydrometeors (Qr: shaded; Qs: contour)

CWA RWRF (variational) data assimilation

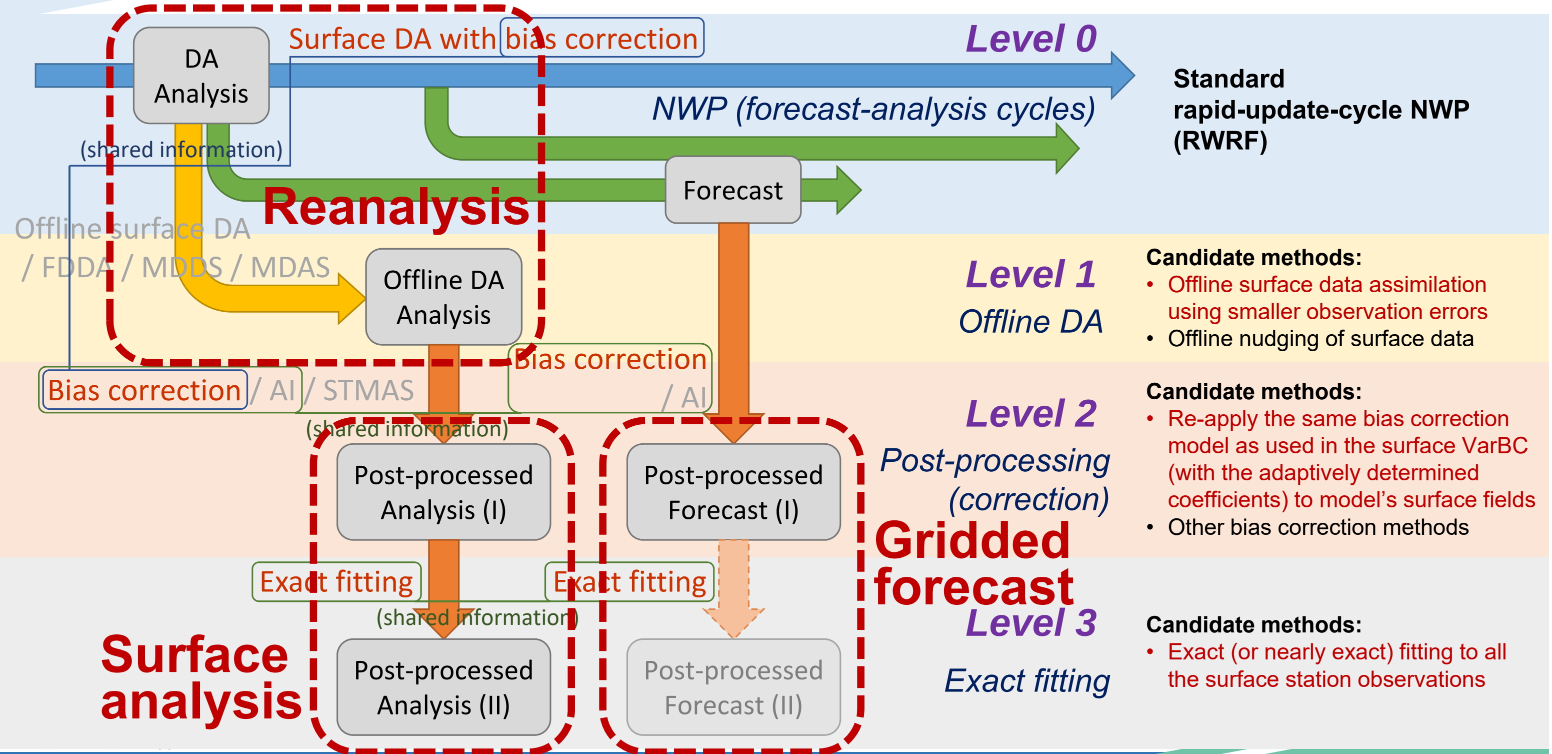
- The radar data will be assimilated with hybrid 3DEnVar in our next operational version. Though, its improvement compared to 3DVar assimilation remains not clearly shown.
  - However, we believe that flow-dependent error covariance is one of the most critical things for convective-scale data assimilation! So we need to make this move and continue to improve our RWRF's hybrid 3DEnVar.
- The directly reflectivity assimilation capability has been implemented in WRFDA (Task 1.2 of 2019, 2020, 2021 conducted by Dr. Zhiquan Liu); however, a more careful evaluation of this capability with our current RWRF system is urgently required to determine the possibility to use it in CWA's operation.
  - We speculate that the full power of this direct reflectivity assimilation should be seen in the hybrid EnVar data assimilation, since then it would have more chances to properly update model's dynamical and thermodynamical variables through the cross-variable error covariances. (?)
- We will further explore combining the steps of surface data assimilation and radar assimilation into one step. This may be important for surface VarBC being developed.

Background → [**Surface** / Hybrid 3DEnVar] → **Ana$_{(1)}$** → [**Radar Vr, Z** / Hybrid 3DEnVar / Update ALL vars] → **Analysis**

Taiwan's regional "Real-Time Mesoscale Analysis (RTMA)" and regional reanalysis (based on RWRF)

- So far, CWA's RWRF has been designed and developed primarily for the purpose of being "a prediction system."
- However, we believe that it can serve for other purposes, more than a prediction system:
  - **Regional realtime surface (2D) analysis (similar to NOAA's RTMA)**
    - **Targeted applications:** Gridded observation fields, "ground truth" for validation of official forecast
    - **Requirement:** More close fit to observations than typical NWP analyseis
    - Previously this kind of products has often been done using simpler interpolation (such as Kriging) of observation data, without using an NWP model.
  - **Regional (3D) reanalysis**
    - **Targeted applications:** Regional weather and climate studies, **training dataset for AI/ML-based NWP models**
    - A product that has NEVER been available for Taiwan!

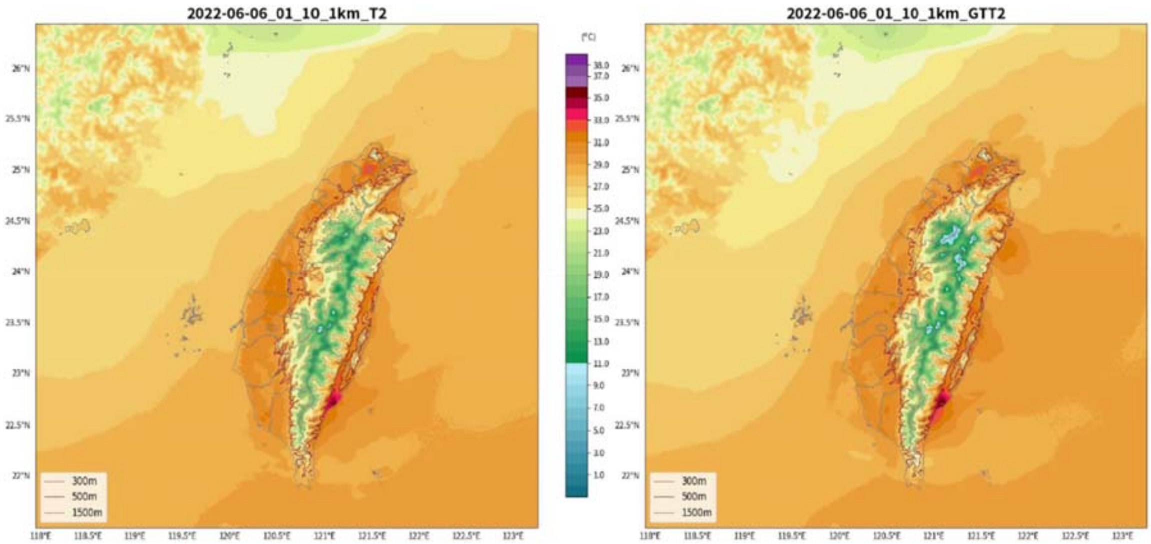
Taiwan's regional "Real-Time Mesoscale Analysis (RTMA)" and regional reanalysis



Experimental product of the regional “RTMA”

RWRF’s 2-m temperature

RWRF’s 2-m temperature + correction
(interpolation of the “delta” field)



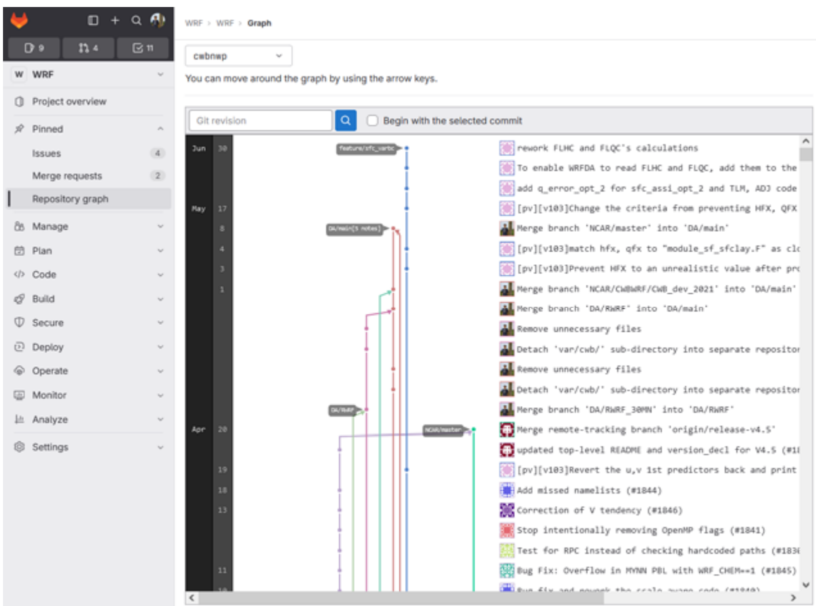
(Courtesy of CWA forecast center and collaborators)

- Our “ultimate” goal is the realtime high-resolution analysis of the **surface wind** and **gust** fields, which we believe is difficult to be done without using an NWP model.

Enhancing the code management:
CWA NWP team started using Git version control

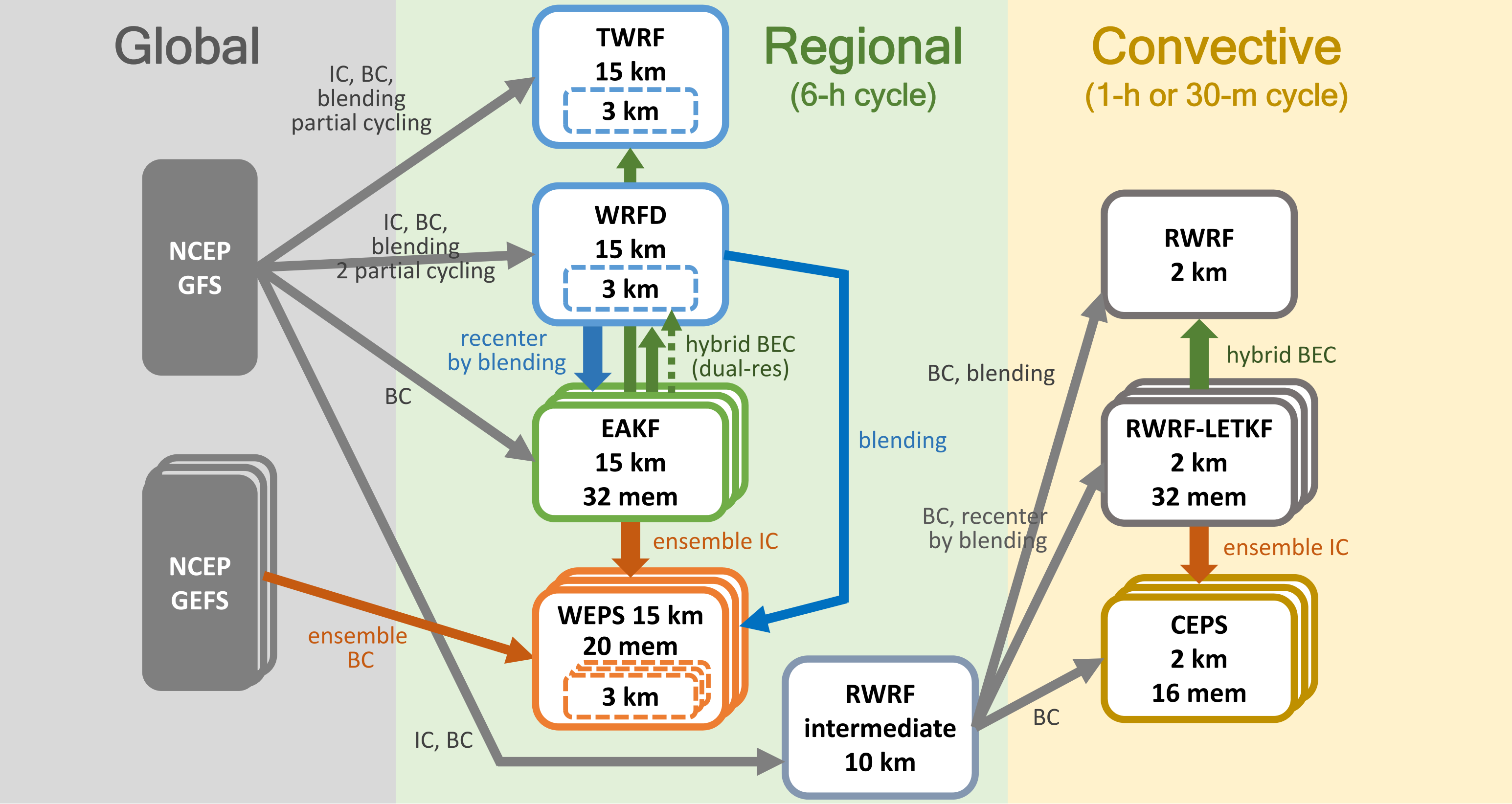
- In recent 1~2 years, most of our colleagues started using Git version control.
- We now have CWA’s code branch of WRF, WRFDA, and MPAS on our forks of the NCAR repositories, and do the entire code management by ourselves.
- We will be happy to collaborate with NCAR through GitHub (or any Git platforms).

CWA’s internal GitLab for NWP research teams

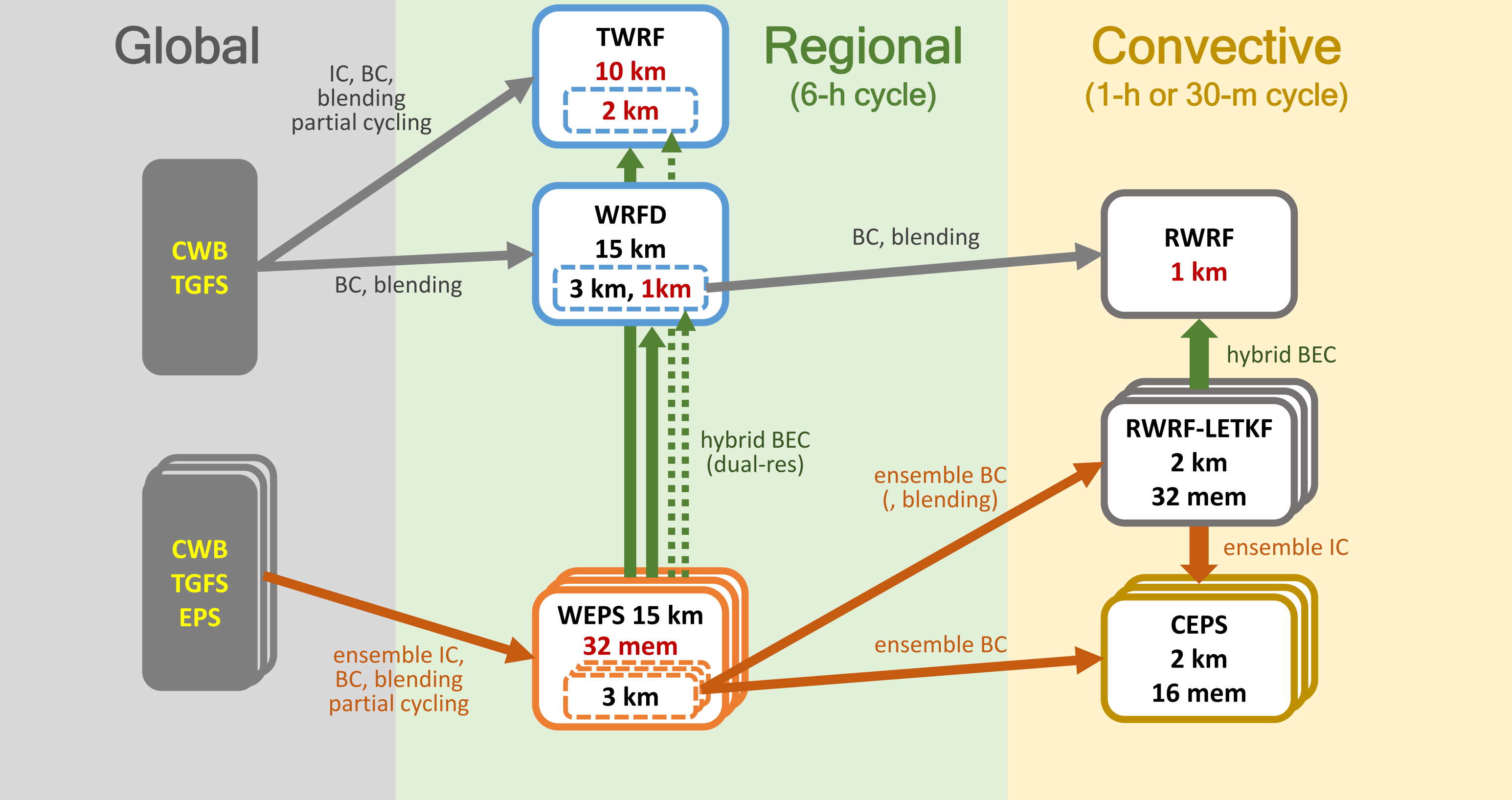


A pathway for CWA to utilize MPAS and MPAS-JEDI

Dependency of CWA's regional NWP systems



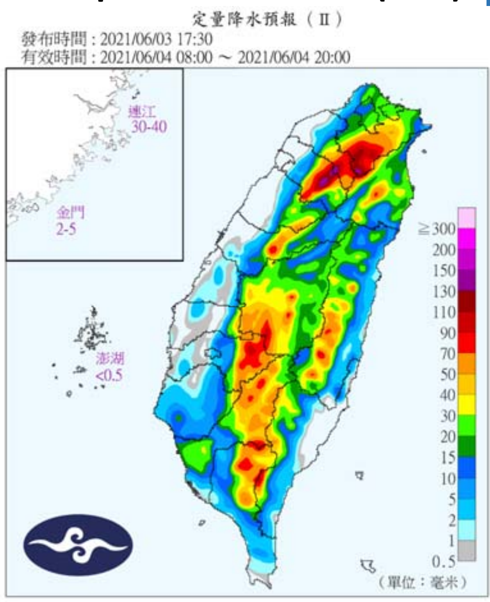
Dependency of CWA's regional NWP systems **(future plan)**



CWA weather forecast relied on high-resolution NWP

CWB Township forecast

CWB Quantitative Precipitation Forecast (QPF)



交通部中央氣象署 Central Weather Administration

Status of the current CWA WRF-based systems

- CWA's WRF-based NWP systems have been so successful, and they are heavily used in daily weather forecast.
- We have several systems representing different scales with different purposes developed over the years and they have been running operationally in CWA.
  - They require convective-scale data assimilation (radar, surface data, ZTD, …), stochastic physics or multi-physics schemes, utilities for blending and offline nesting, dual-resolution hybrid EnVar and LETKF, TC relocation, etc.
- Many development plans to further enhance our current systems have been proposed and implemented.
- However, like many NWP centers, we also have limited human resources.

CWA's Perspective on utilizing MPAS & MPAS-JEDI

Our Principles:

- CWA is going to make efforts to utilize MPAS/MPAS-JEDI.
- For CWA, **WRF/WRFDA and MPAS/MPAS-JEDI can CO-EXIST.**
  - It is NOT an issue of transitioning from WRF/WRFDA to MPAS/MPAS-JEDI.
- We do NOT attempt to "duplicate" the current WRF/WRFDA systems.
- We plan to explore new applications, new demands, and new sciences with the MPAS/MPAS-JEDI system.

A pathway for CWA to utilize MPAS & MPAS-JEDI

Target

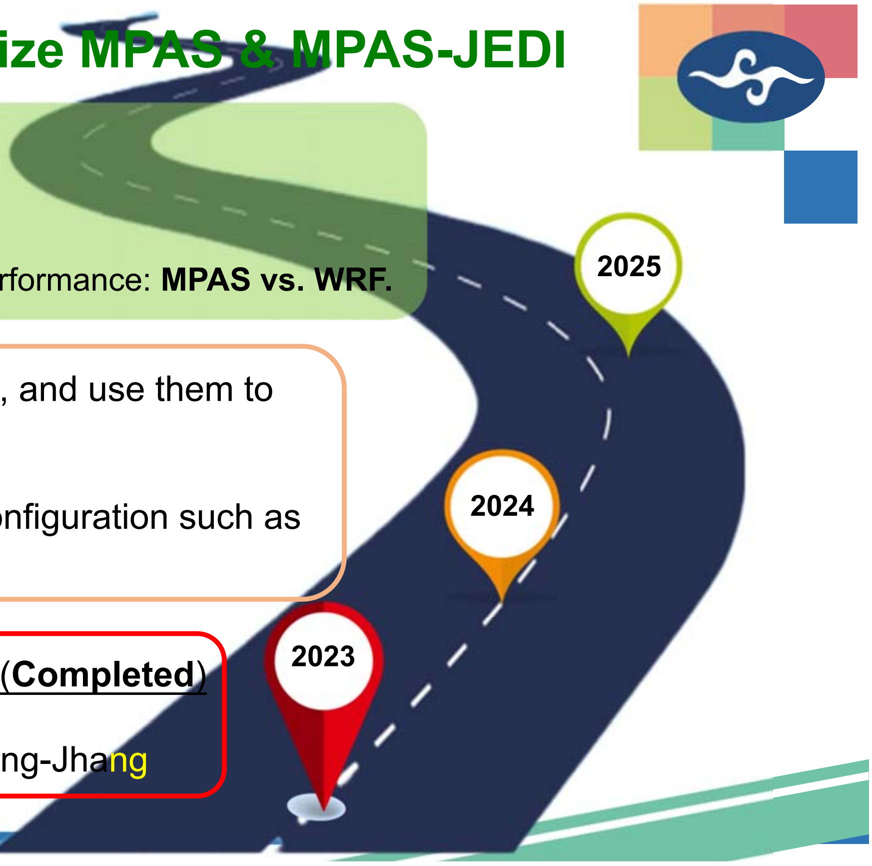
- An MPAS testbed in CWA
- Systematic assessment of forecasting performance: **MPAS vs. WRF.**

> Build verification and diagnostic tools, and use them to compare MPAS with WRF (**Ongoing**)

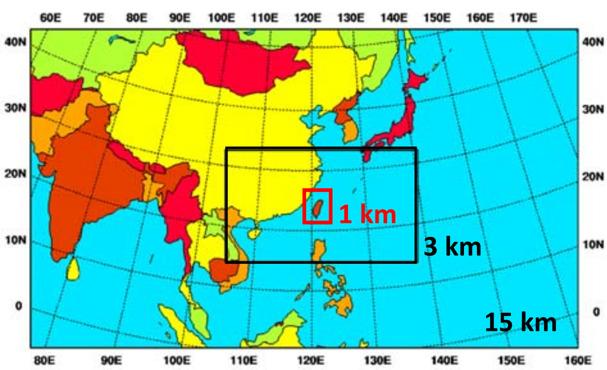
> Customize the system to use local configuration such as static data (**Ongoing**)

> Compile, install, and run in cold start (**Completed**)

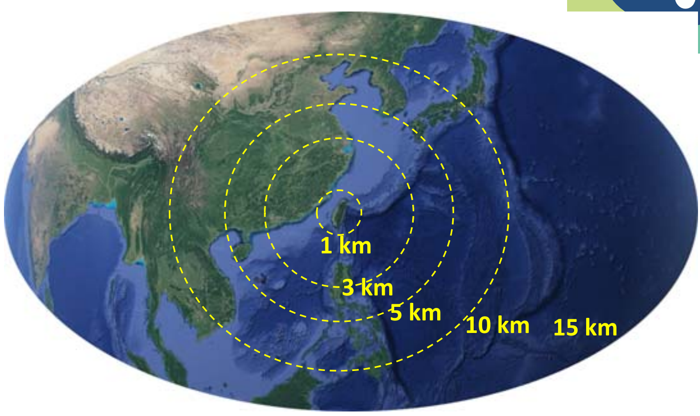
Thanks to our NCAR collaborators & Ying-Jhang



WRFD 15/3 + 1 km grids vs. MPAS 15 → 1 km grid



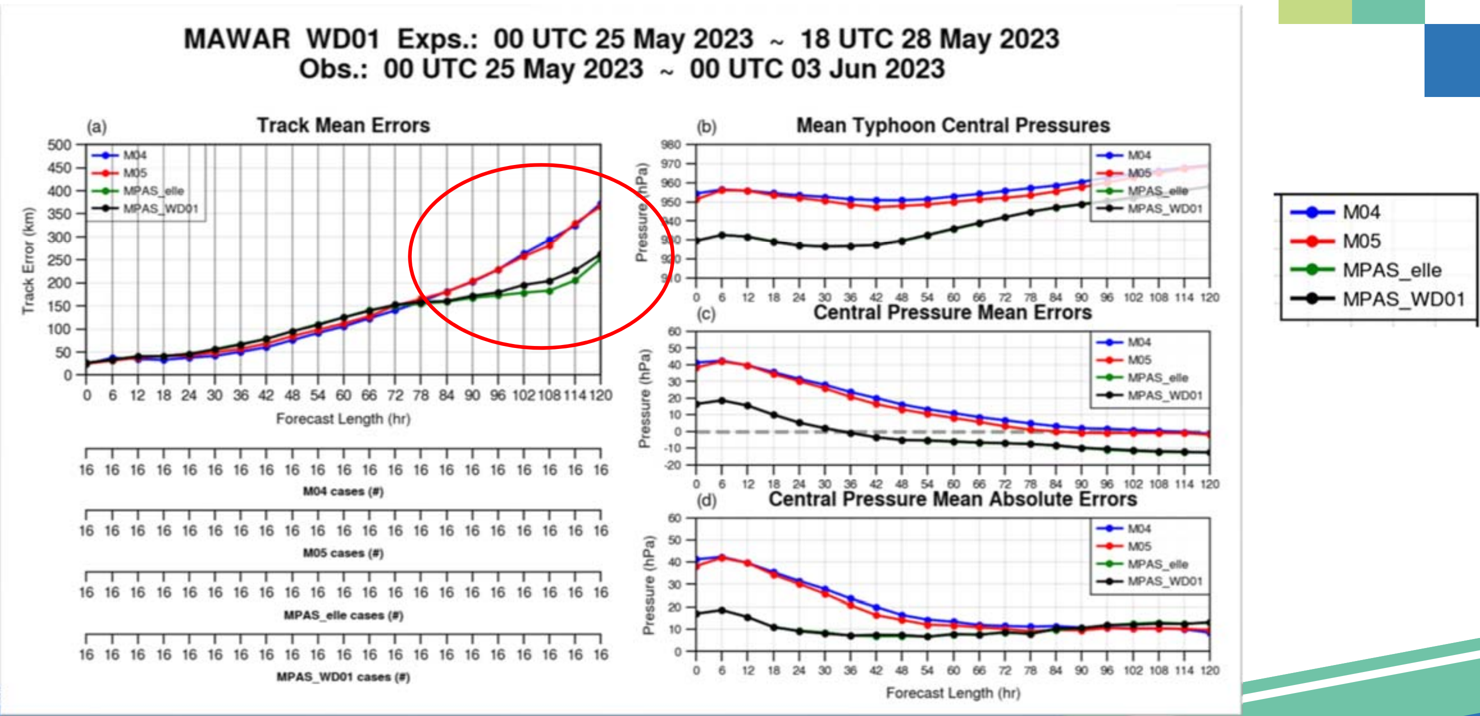
15 / 3 km: One-way online-nested domains (operation: 2016)
+
1 km: Offline-nested (ndown) domain (operation: 2023)



Single
15 → 1 km variable-resolution mesh
(2024 ??)

- **No duplication of the current system:** Skip mimicking the 15/3 km WRFD with a 15 → 3 km mesh.
- **Explore new things with MPAS/MPAS-JEDI:** One single mesh downscaling to 1 km!

Preliminary Comparison on TC Forecast: MPAS vs. WRF



Summary of CWA Workplan for Utilizing MPAS

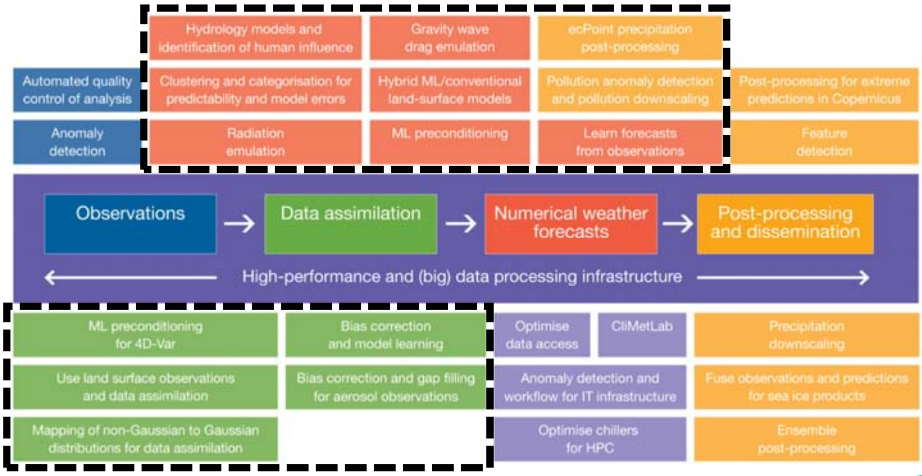
- **CWA will built an MPAS testbed and ingest the Taiwan static data in MAPS model. Develop verification and diagnostic tools to assess the forecasting performance of the MPAS model.**
- **Collaborations between CWA and NCAR in 2024-2025:**
  - Consult and troubleshoot on CWA's MPAS evaluation
  - Continue to provide the latest update and information about MPAS
  - Implement the stochastic physics methods in MPAS
  - Provide the latest status and information of MPAS-GPU

4. Some Perspectives on the Rise of AI/ML-based NWP Models and its Impact to our NWP Community

Applications of AI/ML in weather forecast

- In recent years, Artificial Intelligence (AI)/Machine Learning (ML) technologies have drawn more and more attention in the meteorology community, and almost all NWP centers have started exploring the applications of AI/ML technologies in weather forecast.
- However, I believe that almost no one in our NWP community had expected that the "revolution" would come so quickly.

No plan for developing a fully AI/ML-based NWP model



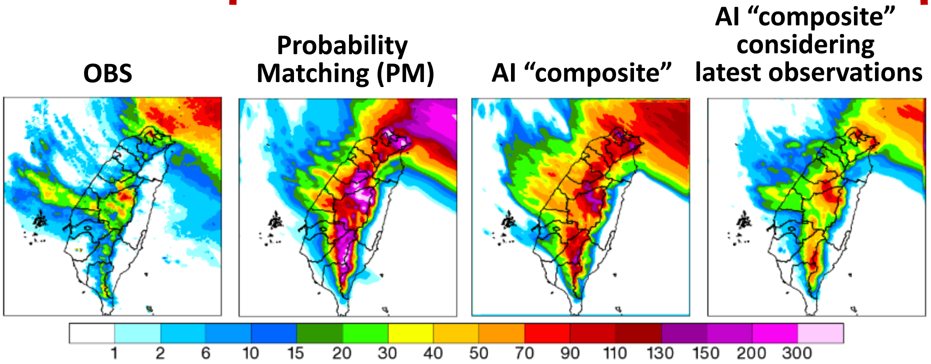
The heart of the data assimilation (4DVar) is untouched

ECMWF's AI/ML application roadmap (Dueben et al. **2021**)

CWA's efforts on AI/ML development

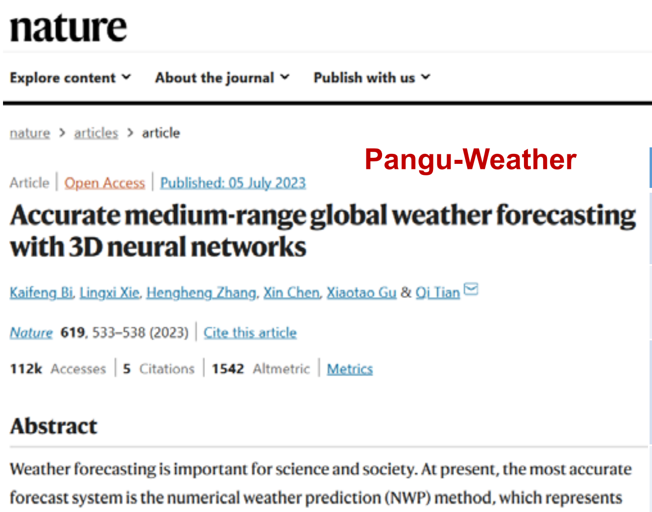
- We have developed a number of systems and products using AI/ML techniques, including:
  - Heat index, cloud amount, and air-quality forecasts
  - Bias correction of NWP forecast
  - **AI-based ensemble QPF post-processing**

Different ways to "average" 20 WEPS members' QPFs to make a single QPF map



Initial time at 23080212
006 to 030 hr fcst 024 Accum. rainfall from 23080218 to 23080318

A revolution suddenly comes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Article | Open Access | Published: 05 July 2023

Accurate medium-range global weather forecasting with 3D neural networks

Kaifeng Bi, Lingxi Xie, Hengheng Zhang, Xin Chen, Xiaotao Gu & Qi Tian

Nature 619, 533–538 (2023) | Cite this article

112k Accesses | 5 Citations | 1542 Altmetric | Metrics

Abstract

Weather forecasting is important for science and society. At present, the most accurate forecast system is the numerical weather prediction (NWP) method, which represents

Pangu-Weather

	FourCastNet	Pangu-Weather	GraphCast
AI methods	AFNO (transformer)	3DEST (transformer)	GNN
Computational cost for training	64X A100 / 16 hours	192X V100 / 16 days	32X TPU v4 / 3 weeks
Computational cost for 10-day forecast	Single A100 / 2.8 seconds	Single V100 / 14 seconds	Single TPU v4 / 60 seconds
Forecast skill (ACC)	Worse than ECMWF IFS	Close or slightly better than ECMWF IFS	
Number of variables X layers	20	69	227
Open-source?	V	V	V

Pangu-Weather

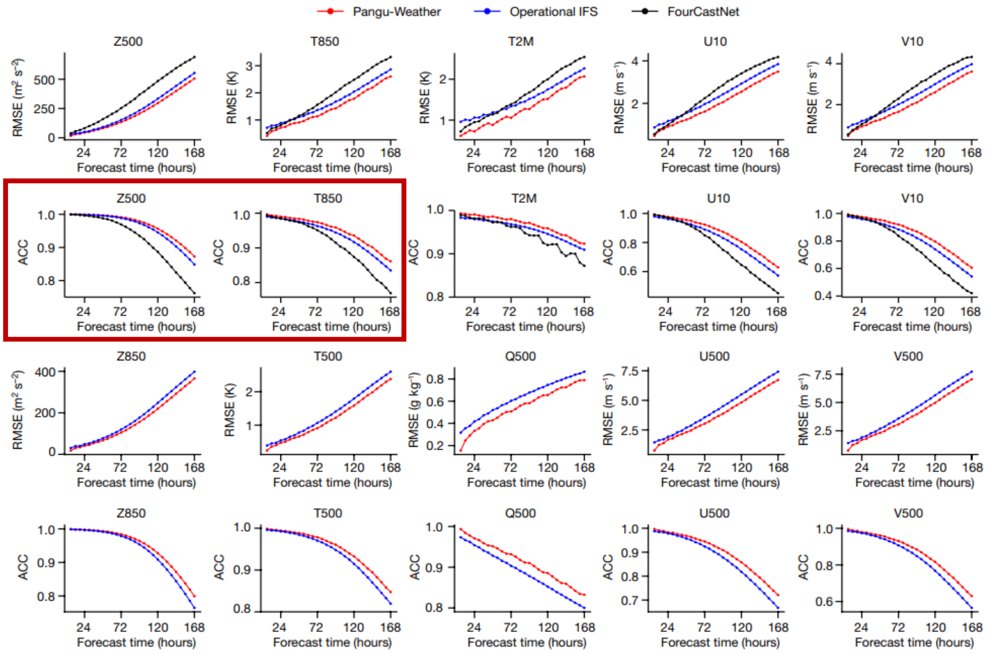


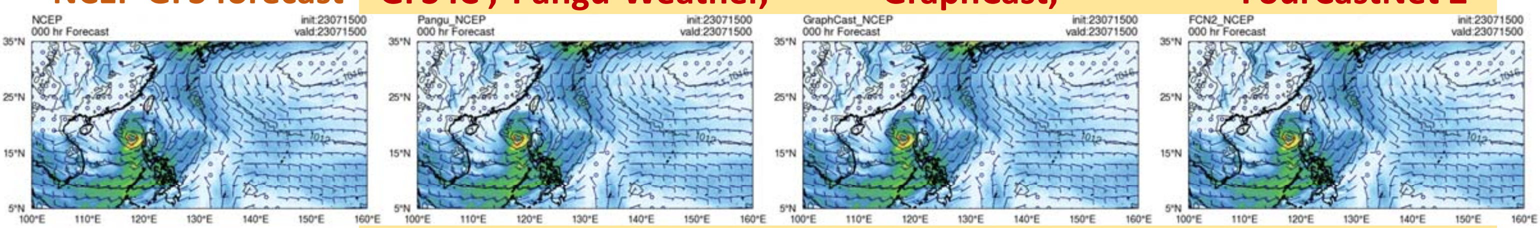
Fig. 2 of Bi et al. (2023, Nature)

AI/ML model prediction

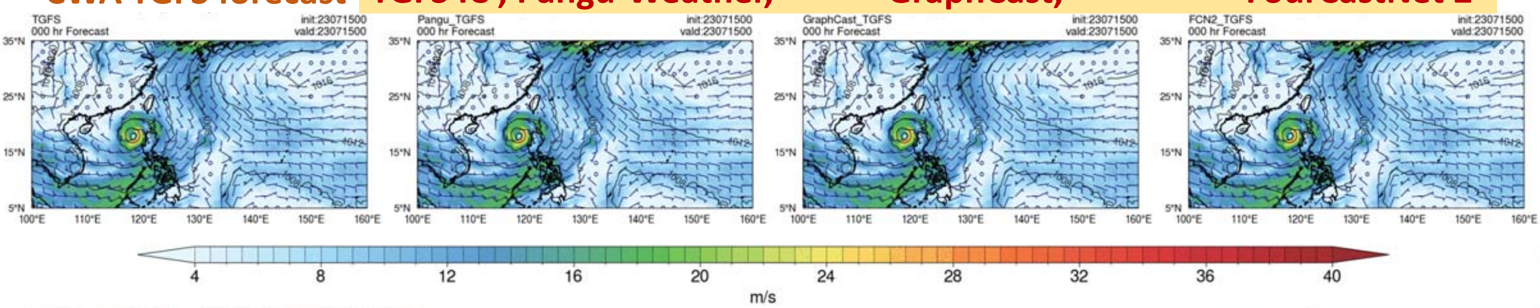
- All the AI/ML models can predict the **genesis** of Typhoon Doksuri with **~5 days lead time** *!!*

Typhoon Doksuri (2023)

NCEP GFS forecast **GFS IC ; Pangu-Weather, GraphCast, FourCastNet 2**



CWA TGFS forecast **TGFS IC ; Pangu-Weather, GraphCast, FourCastNet 2**



AI/ML-NWP model: Achievements and limitations

- **Achievements:**
  - It performs equally well to (or even slightly better than) the state-of-the-art physical based NWP models in global medium-range forecasts.
  - It is trained **solely based on reanalysis data** (finding the relations between two or more consecutive times), without using any prediction data from existing physical-based models.
    → This opens the door that the AI/ML-based models can possibly outperform the current physical-based models.
  - The computational cost of **training** is quite **expensive**;
    however, the cost of making a **prediction** is **very low**: Everyone can run it on a normal PC.
- **Current limitations:**
  - It may not be able to forecast extreme events. **(?)**
  - It lacks several important diagnostic variables, such as precipitation.
  - The model resolution, vertical levels, domain coverage are not configurable (without re-training). **(?)**
  - It is unclear how to specify changing boundary conditions (such as SST, CO2, … etc.).
  - It is unclear whether the same success can be repeated for making an AI/ML-based regional high-resolution, convective-scale model.
  - There is **no physical interpretation**; therefore,
    it may not be possible to design scientific controlled experiments with these AI/ML models. **(?)**

The unbelievable AI/ML-NWP model development

- **It breaks some of our NWP knowledges or assumptions:**
  - [❌] Because the atmospheric dynamics are nonlinear and with multi-scale interactions, so the AI/ML-based model may not be capable of solving this kind of problem.
  - [❌] In order to make skillful forecasts, the spatial and temporal resolutions of the model are very important.
  - [❌] Each physical process (e.g., radiation, microphysics, PBL) needs to be separately and carefully described.
- **It breaks some of our roadmap to use AI/ML in weather forecast:**
  - [❌] The AI/ML techniques are used to assist the existing physical-based model development, and they will be implemented from individual components, step by step (e.g., post-processing, single physical parameterizations).
  - [❌] The amount of observation data may not be enough or qualified for training an AI/ML model, so using model simulation data (from existing physical based models) for training is preferred.
    → Then the AI/ML model becomes just an "emulator" of the current models.

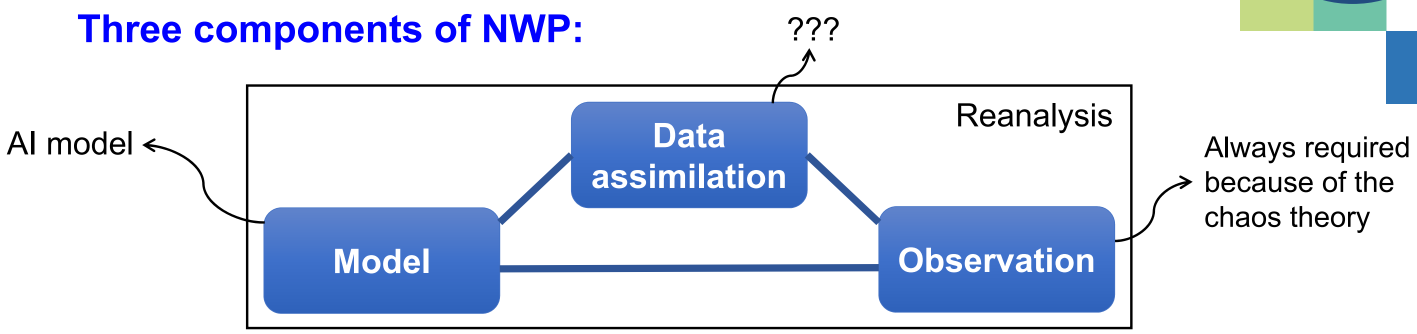
The amazing things of the AI/ML models

- The excellent performance is achieved with rather low horizontal and vertical model resolutions, few prognostic variables, and fairly large time steps.
  - The Pangu-Weather model can run with 4 different time steps: 1 h, 3 h, 6 h, and 24 h.
    → The forecast run with a 24-h time step is the most accurate!
    Dividing the prediction into **smaller time steps makes the results worse… *???***
  - Variables associated with physical processes, such as microphysics and radiation, are absent!

- **A plausible explanation on the success of the AI/ML-NWP models:**
  - The AI/ML models learn all the atmospheric dynamics and physics at the same time, and the deep neural network of the large AI/ML models effectively **realizes all the sub-grid and sub-timestep parameterizations, in a way that we cannot understand**.

Wait, the NWP is NOT only about the model

Three components of NWP:



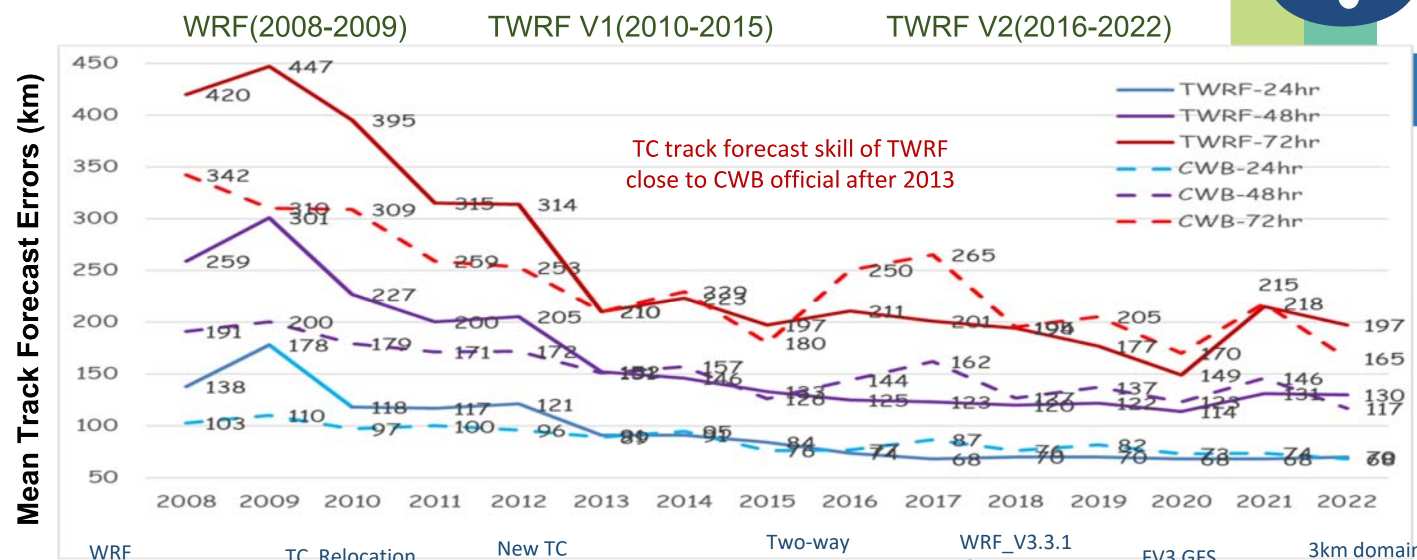
- The traditional physical based numerical modeling is facing a huge competition from the AI/ML-based modeling.
- The traditional data assimilation techniques are still unhurt at this time. However, we do not know if some days it will also face the competition.
- The observation will always be important and unreplaceable.

Some final thoughts

- The success of the AI/ML-based NWP models is certainly a wonderful and exciting news for all humankind: The accuracy of weather forecast is likely going to be boosted again!
- However, this is really a huge threat to our "traditional" NWP researchers.
- The success comes from big technology companies (such as Google, NVIDIA, Huawei). The immense research efforts from our domain scientists during the past several years did not lead to this achievement.
  → Has the domain knowledge ever become an obstacle?
- In the near future, the "hybrid AI-physics based models" may become the mainstream of the NWP development; however, the way of the "hybridization" may be quite different from what we thought before.

交通部中央氣象署 Central Weather Administration

Typhoon Track Forecast: TWRF



WRF Operation

TC bogus

TC Relocation

Partial cycling
Outer loop
New trigger KF

New TC initialization

Blending
45km(2013) → 45/15km(2014)

Two-way interaction

TWRF V2(15/3km)
Blending CLS=
300km

WRF_V3.3.1
→ V3.8.1

3DVAR→
Hybrid 3DVAR

FV3 GFS

LBC 29→
45 layers

3km domain moveable

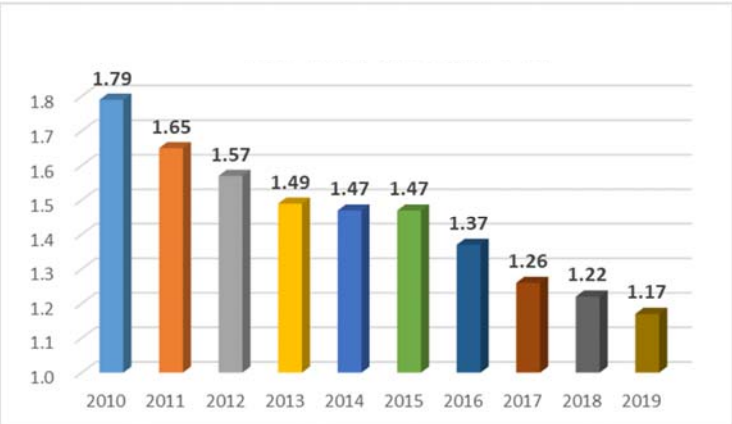
Hsiao et al. 2010, 2012, 2013, 2015, 2020

Note: TWRF with 6hr lag to CWB

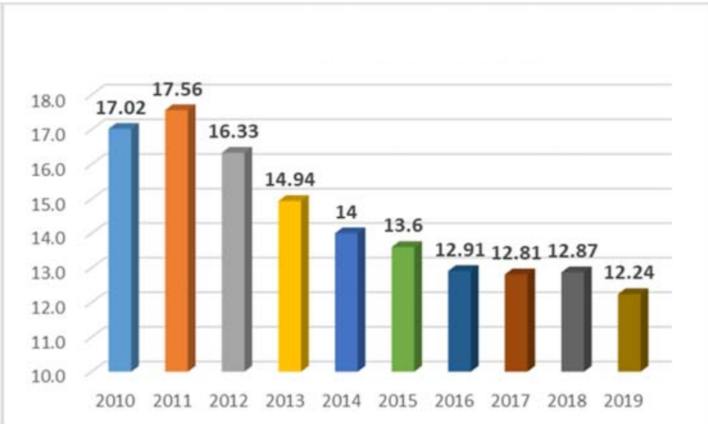
Continuous Improvement of the CWB WRF Systems

?

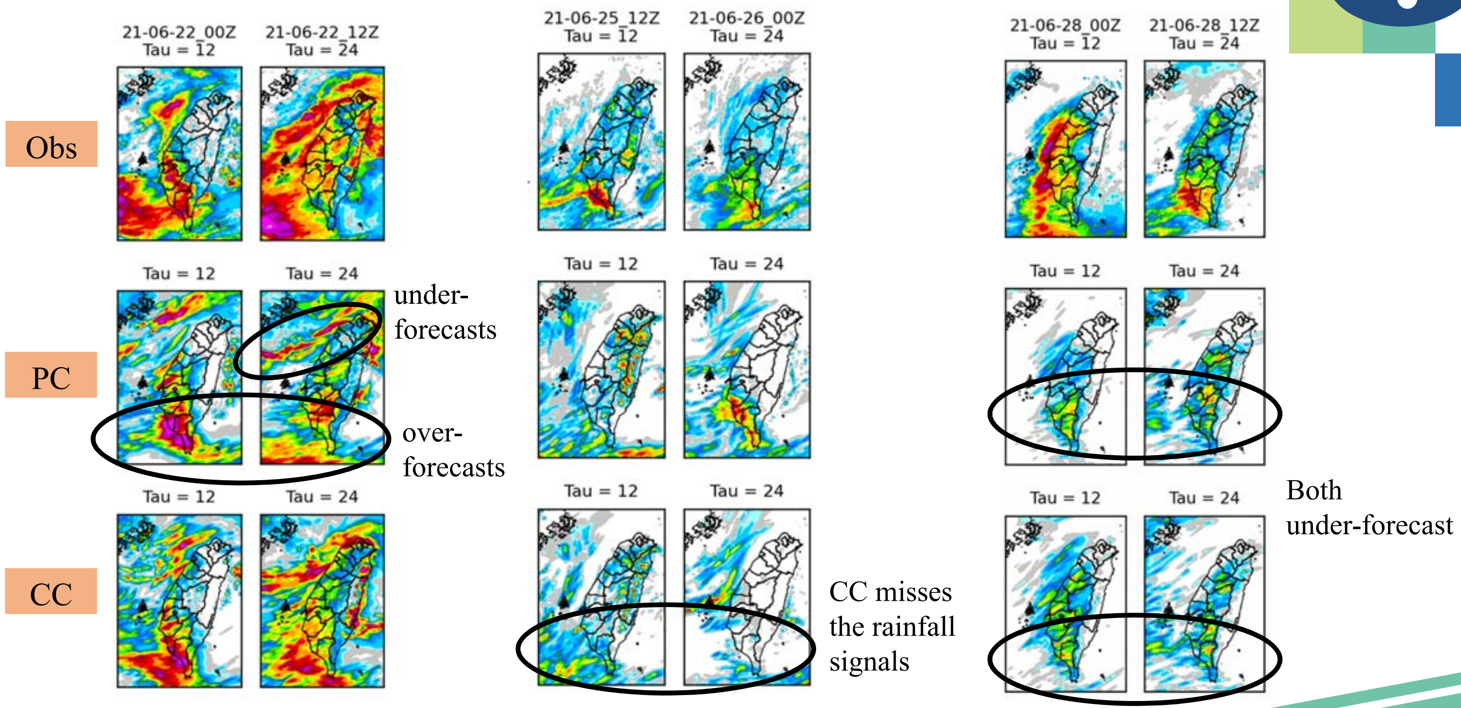
72-h forecast 850-hPa Temperature (K)



72-h forecast 500-hPa Height (m)



Partial vs. continuous cycling experiments (2/2)



Plans and Status of the MPAS Assessment at CWA

Work items	Status	Remarks
Compile, Install, and Run in cold start	Completed	Thanks to the contributions from our NCAR collaborators and Ying-Jhang.
Built verification and diagnostic tools, and use them to compare MPAS with WRF	Ongoing	A preliminary comparison has been made between WRF and MPAS in their performance of forecasting Typhoon Mawar.
Customize the system to use local configuration (e.g. static files)	Ongoing	Investigating on how to use Taiwan local static data in MPAS.

Target

- **Built an MPAS testbed in CWA in 2024**
- **Conduct systematic assessment of the forecasting performance between MPAS and WRF.**