出國報告(出國類別：其他)

參加「航空氣象現代化作業系統汰換及更新計畫協調會議」視訊報告

服務機關：交通部民用航空局飛航服務總臺
姓名職稱：余祖華 主任、許依萍 技正
派赴國家：臺灣，中華民國
出國期間：民國 111 年 10 月 28 日至 10 月 28 日
報告時間：民國 111 年 12 月 20 日

列印 匯出

提 要 表

系統識別號：	C11101024
視訊辦理：	是
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：	參加航空氣象現代化作業系統汰換及更新計畫協調會議視訊報告
計畫主辦機關：	交通部民用航空局

出國人員：

姓名	服務機關	服務單位	職稱	官職等	E-MAIL 信箱
余祖華	交通部民用航空局飛航服務總臺		主任		
許依萍	交通部民用航空局飛航服務總臺		技正		聯絡人 epin@anws.gov.tw

前往地區：	臺灣，中華民國
參訪機關：	無
出國類別：	其他

實際使用經費：

年度	經費種類	來源機關	金額

出國計畫預算：

年度	經費種類	來源機關	金額
111年度	其他經費	民航事業作業基金	0元

出國期間：	民國111年10月28日 至 民國111年10月28日
報告日期：	民國111年12月20日
關鍵詞：	AOAWS，AOAWS-RU，亂流，ADS-B，IA#18
報告書頁數：	9頁

報告內容摘要：

飛航服務總臺基於提升飛航安全與服務品質，達成亞太地區飛航服務提供領先者之組織目標，自110年起至113年間推動「航空氣象現代化作業系統汰換及更新計畫(Advanced Operational Aviation Weather System Renewal and Update；AOAWS-RU)」，並與美國簽訂「駐美國臺北經濟文化代表處與美國在臺協會間航空氣象現代化作業系統發展技術合作協議」「第十八號執行辦法」(IA#18)，為順利推動IA#18相關工作，爰透過視訊與美國國家大氣科學研究中心(NCAR)協調雙方合作工作事宜，確認雙方合作發展之年度工作成果及未來工作規劃，確保計畫執行進度及成效。本次會議NCAR分享NCAR亂流及無人機觀測霧簡報、確認年度工作成果及未來工作規劃討論。

報告建議事項：

建議事項	狀態	說明
一、 持續關注美國發展使用ADS-B資料進行亂流預報進度，評估引進臺灣之可行性，提升亂流預報準確率。	研議中	
二、 持續與國內氣象及學術單位多方進行合作，擴	研議中	

	展國內航空氣象科研能量。
電子全文檔：	C11101024_01.pdf
出國報告審核表：	C11101024_A.pdf
限閱與否：	否
專責人員姓名：	莊順淑
專責人員電話：	02-23496197

列印 匯出

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壹、 目的

本總臺基於提升飛航安全與服務品質，達成亞太地區飛航服務提供領先者之組織目標，自 110 年起至 113 年間推動「航空氣象現代化作業系統汰換及更新計畫 (Advanced Operational Aviation Weather System Renewal and Update；AOAWS-RU)」，並與美國簽訂「駐美國臺北經濟文化代表處與美國在臺協會間航空氣象現代化作業系統發展技術合作協議」「第十八號執行辦法」(IA#18)，主要目的係為引進美國最新航空氣象技術委託美國大氣研究大學聯盟之國家大氣科學研究中心(NCAR)發展航空氣象預報演算法，提升我國之航空氣象預報品質，得以跟上先進國家腳步，持續與國際接軌。

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）要求之航空氣象系統架構，透過本計畫取得國際最新飛航服務規劃，以期有效提升相關作業準備效率。

為順利推動 IA#18 相關工作，爰規劃前往美國國家大氣科學研究中心(NCAR)協調計劃期間雙方合作工作事宜，確認雙方合作發展之年度工作成果及對未來工作規劃，確保計畫執行進度及成效。

貳、 過程

本案原定前往美國執行，為受新冠肺炎(COVID-19)疫情影響，經雙方協調改為以視訊會議方式辦理。會議時間為 111 年 10 月 28 日上午 9 時~12 時，共計 3 小時，會議議程包含：(一) 氣象專題研究報告分享。(二)111 年工作進度報告。及(三)航空氣象預報演算法安裝相關議題討論。

本次會議美方由本案專案主持人許榮祥博士主持，各工作項目負責人(科學家)參與，我方則由民用航空局飛航管制組官岱煒技正、飛航服務總臺總臺長室余曉鵬簡任技正、飛航業務室于守良課長及臺北航空氣象中心余祖華主任率相關作業同仁參與。

參、 會議內容及重要結論摘要

一、 氣象專題研究報告分享

(一) 講題：「Deriving Turbulence From ADS-B Reports」。

1. 報告人：Larry Cornman/Kent Goodrich/Greg Meymaris， NCAR。
2. 研究目標：

   由於亂流在空間和時間上之變化快速，需要同時考慮增加觀測量和改進亂流預測方法。廣播式自動監視(Automatic Dependent Surveillance – Broadcast，ADS-B)資料是一種飛機位置/速度自動報告系統，ADS-B 信號提供大量資料，包含飛機的位置、速度、氣壓、高度以及相對於地球的水平和垂直速度。其中垂直速度信息是判斷亂流的關鍵資訊(如圖 1)。

   目前飛航作業上僅能透過機師空中報告及機載實測渦流消散率(Eddy Dissipation Rate，EDR)偵測器取得亂流觀測資料，惟有關資料常因機師人為判斷及貨航機未配置 EDR 偵測設備而受限，因此如能使用資料量大的 ADS-B 資料進行亂流觀測判斷，對飛航作業將有很大的幫助。

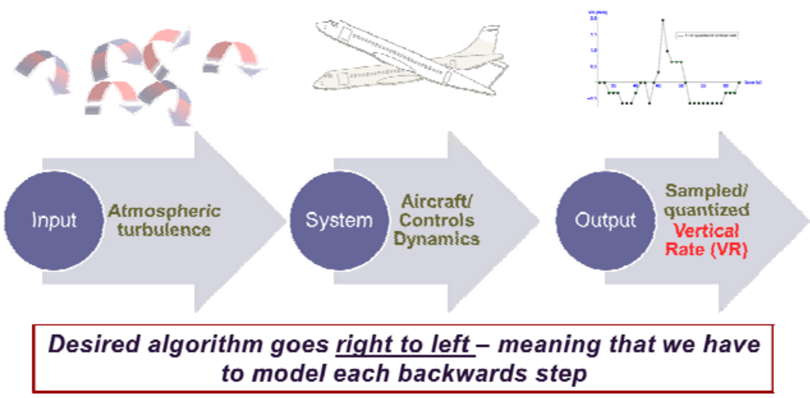


圖 1、使用航機 ADS-B 訊號進行亂流演算概念圖。

3. ADS-B 特性及研究方法：
   (1) 多數航機配備 ADS-B 設備，且具有良好的空間和時間精確度。
   (2) ADS-B 資訊無須在航機上安裝額外的設備，且不需要資料下傳費用。
   (3) 本研究是使用航機垂直速率(VR)計算 EDR 之演算法，並使用模擬的和實際的航機報告進行驗證。航機垂直率是由於大氣（波浪和湍流）和人為操控（主要是高度變化）造成的，在使用 ADSB 進行亂流演算時需要經由複雜的程序將兩者分開，才不會造成誤

報。

(4) 進行個案分析，並與實際之航機 EDR 觀測資料進行比對。

4. 研究成果與未來發展：

(1) 本項研究已經完成階段性發展，且已完成 ADS-B EDR 演算法原型開發及實作，目前正在進行測試階段。

(2) 初步測試結果相當良好，但有發現部分案例有高估或低估 EDR 的情況(如圖 2)，NCAR 將持續進行演算法調整、進行更多的個案研究及統計效能分析，以減少高估或低估 EDR 的情況。

(3) 在更遠的未來將可能發展為獨立空中報告、甚至納入亂流圖形化指引即時預報（GTGN）作業中。

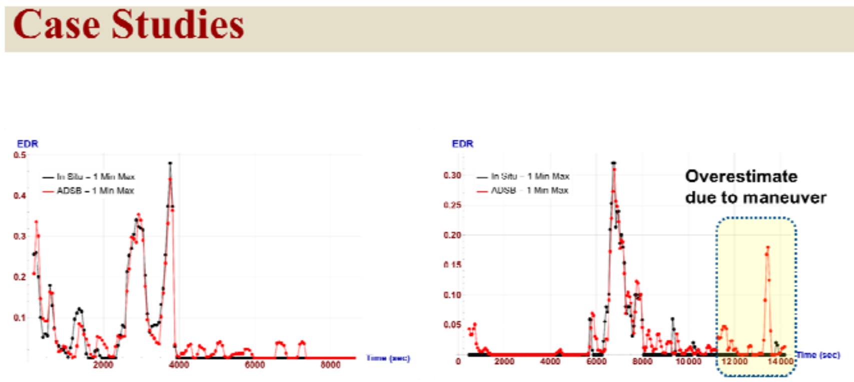


圖 2、左圖個案顯示，ADS-B EDR 與實測 EDR 相當接近，右圖顯示 ADS-B EDR 因受操作行為影響有明顯高估情況。

(二) 講題：「C&V Drone Fog Study - FOGMAP」。

1. 報告人： James Pinto，NCAR；Sean Baily，University of Kentucky。

2. 研究目標：評估無人駕駛飛機系統（UAS/無人機）觀測對改進霧預測的潛在好處。

3. 重點摘要：

此研究主要討論利用無人機系統增進霧的觀測，可以觀測垂直向的資訊，進而提升模式預報霧的發生時間、嚴重程度以及消散時間之能力。研究團隊在河谷中針對數個霧發生的事件進行詳細的觀測及模擬，研究區域約 90 公里左右，附近有兩個機場以及兩個探空站可以進行資料比較。研究團隊發現使用無人機觀測穩定/潤濕邊界層對大氣垂直發展之掌握度比在 90 公里外之探空觀測更好。除實地觀測外，研究團隊也利用以天氣研究與預報模式(WRF)為基礎之高解析度快速更新模式(High-Resolution Rapid Refresh，HRRR)進行模擬，可以發現模式預報的雲水混合比與能見度在數個觀測點一致，相對濕度則有普遍低估的現象。在相對濕度及能見度發生頻率部分，相對濕度較高時，模式的低能見度發生頻率則普遍有低估情形(高能見度期間除外)。由於這些低估

現象，在未來必須要持續提升模式之能見度及相對濕度預報。研究團隊將使用 Perform Observing System Experiments (OSEs) with DART (EnKF) 方法進行更多之研究實驗。此外，地形特徵分辨率、水面類型及河水溫度都將影響預報結果。

二、 111 年工作進度報告

本次會議係依據 111 年第 3 次季工作報告(111 年 8 月~10 月)為基礎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。相關重要工作成果及決議事項說明如下：

(一) 專案管理與資料提供

1. NCAR 測試環境平台已於 111 年 10 月中旬建置完成，並提供演算法系統安裝套件給總臺參考，以確保後續系統安裝工作順遂。
2. 每月及每季提供工作報告。

(二) 工作項目 1 - 更新飛行中積冰診斷及預報產品

1. 在 NCAR 主機安裝執行臺灣版本之演算法程式(TCIP2/TFIP2)並進行測試，進行個案分析和校驗，並依據校驗結果進行演算法調教。
2. 由於臺灣地區積冰之飛行員報告（PIREP）數量不足，NCAR 運用領域相關方法(Domain Relation Approach)作為校驗方法，在美國建立與臺灣數值預報模式完全相同設定之數值模式資料、並結合美國地區之飛行員報告、探空及衛星觀測資料對 TCIP2/TFIP2 表現進行定量評估，確保 TCIP2/TFIP2 在臺灣地區表現符合總臺需求，並完成測試及校驗計畫最終版。
3. 本項計畫預計於 112 年安裝到總臺測試環境，並匯集使用者意見進行調整，並於 112 年完成所有工作。

(三) 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)

1. NCAR 完成 GTG4 雛型發展，並安裝在 NCAR 主機上，演算法可提供晴空亂流、山岳波亂流及對流引發亂流預報。GTG4 產品是將晴空亂流、山岳波及雲中亂流預報取最大值並進行相加後進行整合的。
2. 完成 GTG4 個案分析及雛型預報能力評估，評估結果顯示預報能力符合作業需求。
3. 完成 GTG4 程式執行時間評估，若以 32 個核心運算，執行時間低於 2 分鐘。
4. 完成臺灣 GTGN 建置可行性評估，臺灣 GTGN 將使用 NCAR 亂流偵測演算法產品（NTDA）、實測渦流消散率（EDR）及機場天氣報告（METAR）等觀測資料進行演算，而 PIREP 及閃電資料則因數量及品質不符需求而不納入 GTGN 演算法中。

5. NCAR 已經開發了 IWXXM 轉 NCAR 非網格資料格式(SPDB)應用程序，且目前除 GTGN 之外的所有算法都從 SPDB 讀取觀測結果。後續 NCAR 將確認 GTGN 讀取觀測資料(METAR/SPECI)之方法。

(四) 工作項目 3 - 更新 NCAR 亂流偵測演算法

1. 完成雷達資料格式之適用性評估，初步確認中央氣象局五分山、七股、花蓮、墾丁、林園、南屯及樹林及空軍清泉崗、馬公及綠島等，共 10 個雷達資料，初步評估均可納入 NTDA 演算法中，惟最終決定將依 112~113 年演算法後續測試結果而定。
2. 適用性評估結果顯示部分雷達受無線電干擾（如綠島及林園）、雜波（林園及花蓮）及波束遮蔽（如樹林）影響資料品質，後續 NCAR 將持續調整演算法以提升 NTDA 表現。
3. 在 NCAR 主機執行 NTDA 進行個案分析並完成資料處理程式調整，以順利讀取所有雷達資料。
4. 本項演算法已完成發展，並將於 112 年安裝至總臺測試環境進行測試作業。

(五) 工作項目 4 -更新雲頂高預測產品(CTH/CDO)

1. 在 NCAR 主機執行 CTH/CDO 並調整外延法預報程式參數設定，使外延法預報區域延伸至臺北飛航情報區（TFIR）外。
2. 以颱風及強對流系統進行外延法 1 小時預報能力評估，分析結果顯示符合作業需求。
3. NCAR 將持續評估 CTH/CDO 所需調整，以配合衛星資料改為向日葵衛星 9 號，並確保程式執行順利。
4. CDO 產品與 CDO 外延產品(1 小時)的最佳呈現方式為分別使用色塊(Shading)和等值線疊加顯示。
5. NCAR 將於 111 年 12 月 1 日提交 CTH/CDO 初版程式碼，並於總臺 AOAWS-RU 測試環境完成系統安裝。

(六) 工作項目 5 -更新機場雲幕與能見度預測產品(C&V)

1. NCAR 持續進行資料收集、調校預報應用程序。
2. NCAR 每季提交以即時資料校驗 C&V 及其預報能力評估，分析結果顯示於冬及春季，北部地區機場測站之 C&V 預報表現比傳統模式輸出統計法（MOS）更準確。
3. 有關對 C&V 不同季節的校準結果不一致問題，NCAR 建議使用更長時間資料（3 個月或過去 1 年，而不是目前的 1 個月）進行校準，但相關工作相當俱挑戰性。

(七) 工作項目 6 - 發展 0-8 小時的風暴預報能力（ASPIRE）

1. 完成 ASPIRE 擴充混合系統初版程式，並安裝於美國測試環境中。
2. NCAR 將於 111 年 12 月提交混合（雷達+ NWP 模型）反射率預測資料和效能指標範例及系統特性及短時預報技術之綜合性能評估文件。

3. 本項演算法將於 112 年安裝至總臺測試環境進行測試。

(八) 工作項目 7 - 發展與實作氣象報告之 XML 格式資料轉換程式

1. 本項資料格式轉換工作已於 110 年完成，後續將於 112 年安裝至總臺測試環境進行資料接收測試。

(九) 工作項目 8 - 技術諮詢和基礎發展協助

1. NCAR 提交與氣象相關之廣泛資訊管理(SWIM)之諮詢文件。
2. NCAR 提交與氣象相關之全球空中航行計畫(GANP)和航空系統組塊升級(ASBUs)更新之諮詢文件。

(十) 工作項目 9 - 技術轉移及教育訓練

1. NCAR 於 111 年 8 月 16 日至同年 11 月 23 日辦理「研習航路及機場天氣預報產品演算法原理及發展技術」技術轉移訓練。

三、 議題討論

(一) 演算法主機作業環境建置、演算法程式測試及監控作業協調

1. 總臺測試發展環境已經完成建置，可提供 NCAR 演算法進行安裝及相關測試作業。
2. 資訊廠商已完成 NCAR 演算法主機通行帳號與系統服務帳號建立，且完成所需系統套件安裝，後續仍須進行 NetCDF 函式庫安裝。
3. NCAR 將於 2022 年底前開始在總臺測試環境安裝演算法程式，以確認可正確使用輸入資料及輸出演算法產品。
4. NCAR將提供現行 AOAWS 系統之系統監控資訊(包含流程和程序)予資訊廠商進行系統監控判別，但需要定時執行 NCAR 之 procmap 和 datamapper 兩個執行程序。後續雙方將進行技術細節討論，相關作業預計於 112 年 5 月底前完成。
5. 資訊廠商正在進行系統整合工作，NCAR 將會提供有關協助。資訊廠商將於 11 月初與 NCAR 討論資料輸入、資料到位通知及觸發機制等技術細節進行討論，相關流程將在 112 年 3 月底前完成。
6. 有關氣象報告部分，現階段將使用傳統電報格式(TAC)資料，未來可改為使用 ICAO 氣象交換模式(IWXXM)。

(二) 在 GTGN 和 CDO 中使用閃電資料時機討論

1. 因總臺提供之閃電資料僅限於臺灣周邊，考慮系統效能 NCAR 將研究是否將閃電資料運用於 GTGN 演算法中。
2. CDO 團隊決定僅將閃電資料運用於台北飛航情報區範圍，較大範圍區域則不使用。

(三) NCAR 演算法資料輸出垂直層場討論

1. TFIP2/TCIP2 可提供每一千英呎高度間隔輸出資料，並額外提供 925 百帕及 850 百帕高度資料。

2. GTG4/GTGN 目前已提供每一千英呎高度間隔輸出資料，需要針對提供 925 百帕及 850 百帕高度資料進行額外評估。
3. NTDA 因有線的高度層限制，只能提供每三千英呎高度間隔輸出資料，NCAR 將與資訊廠商討論增加提供 925 百帕及 850 百帕高度資料做法。
4. 目前 NCAR 演算法可能沒有任何產品提供高達 55,000 英呎高度，經協商 GTG4/GTGN 可配合提供，TFIP2/TCIP2 與 NTDA 則因產品特性，只提供到 45,000 英呎高度資料。

肆、 心得與建議

本年度航空氣象現代化作業系統汰換及更新計畫(AOAWS-RU)協調會議持續因受國際新冠肺炎(COVID-19)疫情影響調整為視訊會議(3 小時)。美方在有限的時間內，除安排 111 年度工作成果報告外，亦依總臺建議安排專題報告分享，包含使用 ADS-B 資料進行亂流預報演算法之最新進度報告以及使用無人機進行濃霧觀測研究，相關研究都相當具參考性，值得持續關注後續發展。

AOAWS-RU 計畫推動包含民航局、氣象局、NCAR 及國內資訊廠商之多方合作，計畫推動需要嚴謹的協調溝通，複雜度高，須由各方投入大量人力及物力資源才能成功。謹就參與本次會議心得提報建議事項如下：

一、持續關注美國發展使用 ADS-B 資料進行亂流預報進度，評估引進臺灣之可行性，提升亂流預報準確率。

NCAR 發展即時亂流預報產品(GTGN)需仰賴即時觀測資料(飛機報告及渦流消散率(EDR))進行演算，惟亞太地區飛機報告數量偏少，另本總臺雖已洽空中運輸協會引進 EDR 資料，EDR 資料需要航機搭載 EDR 偵測設備，經初步觀察，相關報告數量仍不如美國地區密集。

美國發展使用 ADS-B 資訊反演亂流資訊，本次會議也提到如若未來相關技術發展成熟，可考慮引入臺灣 GTGN 演算法，使用本總臺 ADS-B 資料，將有助於本區空域亂流偵測，提升飛航安全，亦將有助於航空氣象預報產品發展及驗證。

二、持續與國內氣象及學術單位多方進行合作，擴展國內航空氣象科研能量。

1. AOAWS-RU計畫目前聘請臺灣大學氣象顧問團隊協助針對NCAR發展之航空氣象演算法產品提供建議，並協助發展風力預報演算法。然 NCAR 演算法包含中高層之積冰、亂流及低層之能見度與雲幕高預報及風暴預報，涵蓋範圍廣泛，非單一氣象專家可深入探究。建議增加氣象顧問量能，邀請不同研究領域之氣象學者參與，應可更全面性的了解 NCAR 演算法產品。
2. 科研發展應為長遠計畫，需要更多的人來參與，本總臺於 111 年參加科技部自然司辦理之「大氣科學學門研究成果發表會」，介紹 AOAWS-RU 計畫，讓國內學界了解民航局之航空氣象預報發展方向及願景，有多位學者表達對航空氣象觀測及預報議題之關注，爰建議民航局持續鼓勵同仁參與國內氣象科研會議，甚或編列航空氣象相關研究計畫預算，吸引

更多有興趣的學者參與航空氣象議題研究，以達民航局航空氣象在地生根之期望。

伍、 附錄

一、 Deriving Turbulence From ADS-B Reports, Larry Cornman /Kent Goodrich/Greg Meymaris, NCAR.

二、 C&V Drone Fog Study - FOGMAP, James Pinto, NCAR；Sean Baily,University of Kentucky.

三、 AOAWS-RU IA#18Project Management Review Meeting 簡報

四、 AOAWS-RU IA#18 Project Management Review Meeting 紀錄

Deriving Turbulence From ADS-B Reports

Larry Cornman
Kent Goodrich
Greg Meymaris
National Center for Atmospheric Research

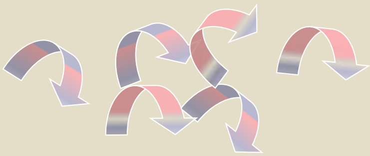
NCAR

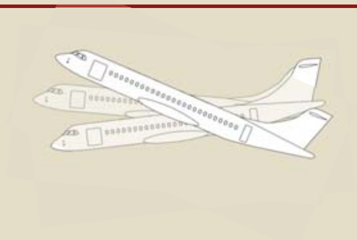
Potential Benefit of ADS-B Turbulence Reports is Significant

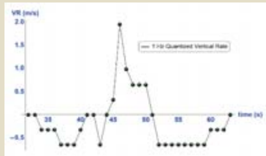
- **Large numbers of a/c**
  - Most a/c in US controlled airspace are now required to have ADS-B Out.
  - ***As of June 1, 2022 there are 152,760 US a/c reporting, including 103,556 fixed-wing GA a/c.***
  - Compare to ~1600 a/c reporting *in situ* EDR and ~1200 turbulence PIREPS/day (on average).
- **Good spatial and temporal accuracy**.
- **No need to deal with aircraft side of implementation**.
- **No downlink communication costs.**

NCAR

Turbulence from ADS-B Reports: High-Level Concept







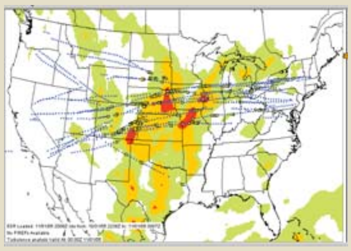
Input → Atmospheric turbulence → System → Aircraft/ Controls Dynamics → Output → Sampled/ quantized Vertical Rate (VR) → **EDR**

Desired algorithm goes <u>right to left</u> – meaning that we have to model each backwards step

NCAR

Background

- Turbulence encounters continue to be a significant operational problem.
- Given the spatial and temporal variability of turbulence, large numbers of observations are needed.
- **Automatic Dependent Surveillance-Broadcast (ADS-B) is an aircraft position/velocity reporting system that has the potential to augment existing turbulence observations.**



***In situ* EDR reports overlaid on GTG**

ADS-B Infrastructure

ADS-B was not designed for turbulence reporting – but can it be used for that?

NCAR

Potential Benefit of ADS-B Turbulence Reports is Significant

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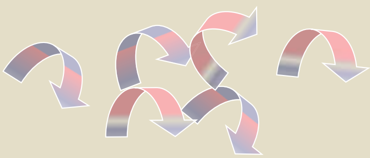
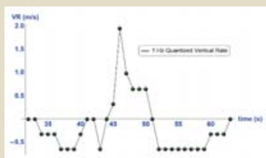
NCAR

Turbulence from ADS-B Reports: High-Level Concept





Input → Atmospheric turbulence → System → Aircraft/ Controls Dynamics → Output → Sampled/ quantized Vertical Rate (VR) → **EDR**

Desired algorithm goes <u>right to left</u> – meaning that we have to model each backwards step

NCAR

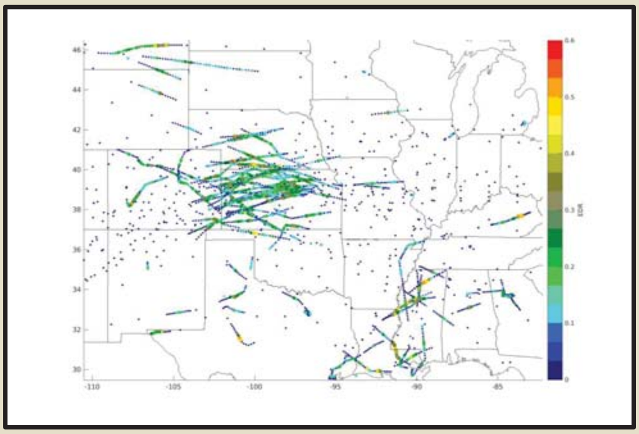
Algorithmic Challenges

- **Extracting accurate turbulence information from the ADS-B vertical rate (VR) requires that we deal with:**
  - Low sampling rate (~1/sec).
  - Large quantization (*64 fpm* $\approx 0.325\ m/s$).
  - Maneuver/wave contamination.
  - Scaling between different a/c types and operating conditions.

NCAR

Real-World ADS-B/*in situ* EDR Case Studies

- Looked at 67 flights where peak *in situ* EDRs > 0.3
- Totaling over 11,000 one-minute EDR reports.
- 737-700 and 737-800's.
- Mostly full flights, i.e., take-off to landing.



Peak *in situ* EDR reports

NCAR

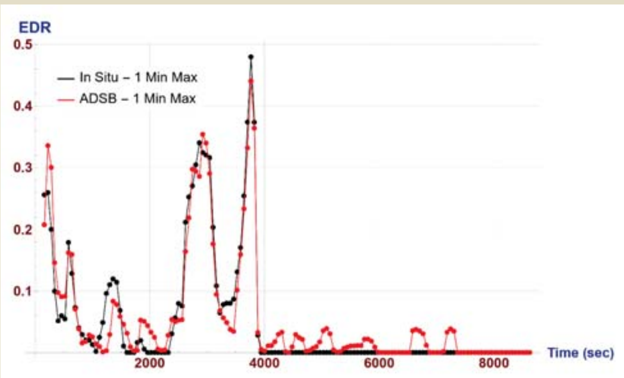
Qualitative assessment of real-world ADS-B case studies

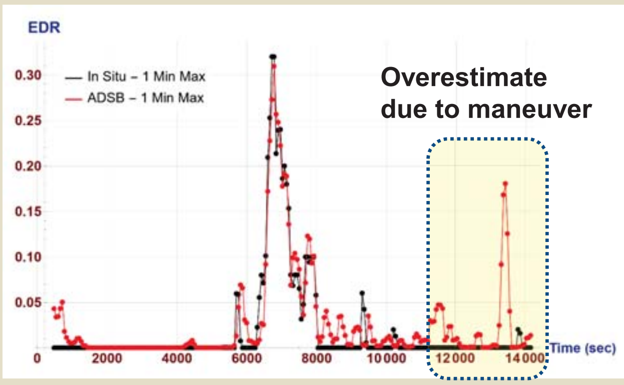
- **Event detection in general is good, in terms of timing and "seeing the same thing as *in situ* EDR."**
- **Overestimates coming from**:
  - "Maneuver transitions." (often during take-off/climb-out periods)
  - "Short-wave" events
- **Underestimates coming from**:
  - Over-filtering
  - Sampling/quantization
  - Scale factors (?)

We are working on mitigating these discrepancies

NCAR

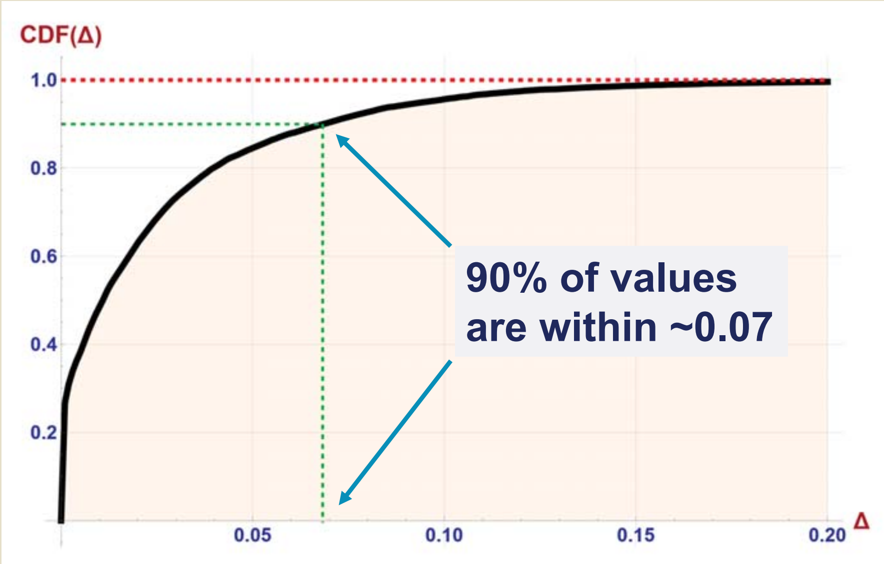
Case Studies





NCAR

Cumulative Distribution Function of ADS-B to *in situ* EDR Differences



NCAR

Ongoing Algorithm Efforts

- Aircraft vertical rate is due to atmospheric (waves & turbulence) and control (mainly altitude changes), inputs.
- Separating the two is fairly complicated, but important:
  - We don't want to false alert due to maneuvers.
  - We don't want to miss detections by mistaking turbulence for maneuvering.
  - *In situ* EDR is designed to not alert on wave-like structures, so we want to be consistent.

NCAR

Summary/Status

- We have reached a milestone stage in the algorithm development efforts:
  - A (mostly) complete end-to-end ADS-B EDR prototype algorithm has been developed, implemented, and is undergoing testing.
  - Results are positive – events detected (wrt *in situ* EDR), with some under/overestimates.
  - Efforts are on-going to reduce the under/overestimates.
  - More case studies are being analyzed.
  - Statistical performance analysis will be executed.
- **Ready to move towards parallel development/demonstration phase…**

NCAR

ADS-B in Taiwan

- Is there interest in pursuing an ADS-B turbulence capability in Taiwan?
- Integration with GTGN?
- ADS-B is mandatory for all aircraft operating within the Taipei FIR, at or above FL290.
- Are vertical rate reports available? At what update rate?

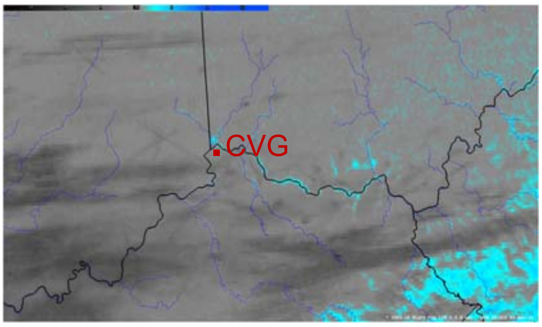
NCAR

Project Overview

Goal: Evaluate the potential benefit of targeted Uncrewed Aircraft System (UAS/drone) observations for improving fog prediction (onset, severity, duration).

Talk Outline

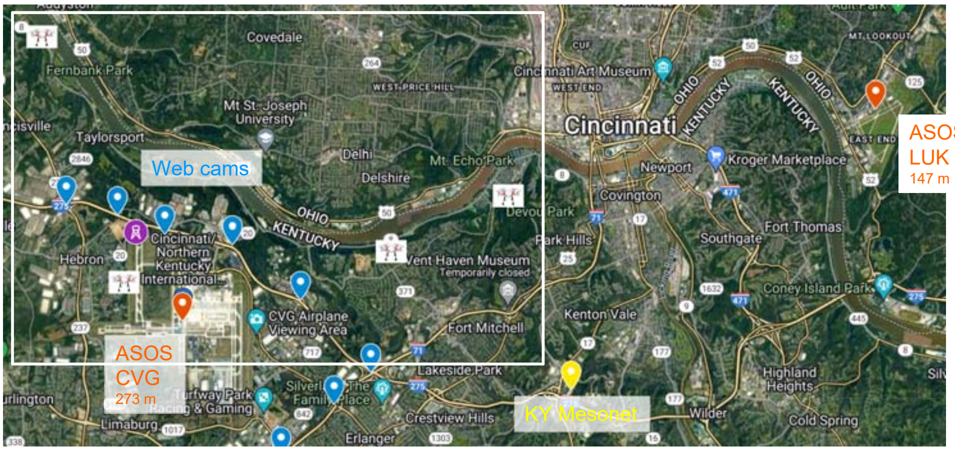
- Overview of UAS field campaign
- Case Study
- Model Evaluation



Airport Impacts: Frost and Localized fog
NAS Impacts : Ground Stops for arrivals

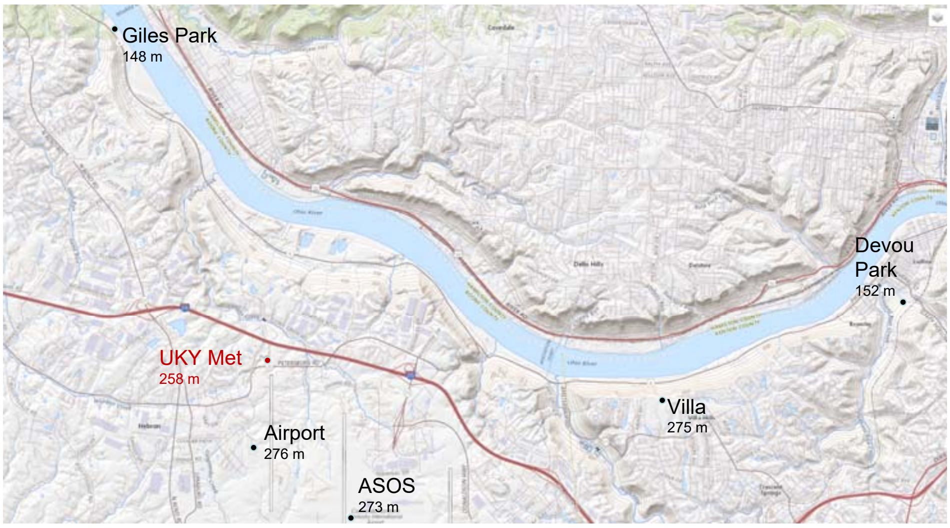
2

Deployment Strategy



Determine operations periods (~36 hours in advance) based on guidance from the Wilmington, Ohio WFO
Each IOP: Select 2 UAS Profiling Sites along Ohio River – West of Cincinnati
Ancillary datasets including UK fixed site (purple tower icon) as marked.
Distance between CVG and LUK is 22 km
Difference in elevation CVG vs LUK is 126 m

UAS Profiling Sites



- Fixed Site and four UAS profiling sites distributed along the Ohio River
- Note height difference between Fixed Site and Airport Profiling Site (add timeseries from two sites).

UAS Specifications

Hover1
Quadcopter
Trisonica anemometer – vertical boom
2 basic met sensors (I-MET, SAMA)

S1000
DJI Octocopter
4 sonic Calypso anemometers – horizontal booms
2 basic met sensors (I-MET, SAMA)

5

Overview of IOPs

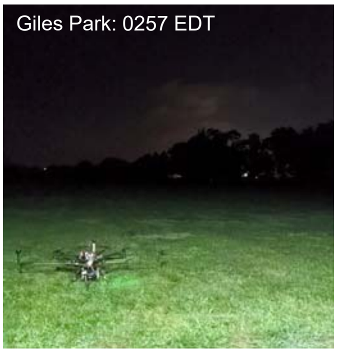
IOP	Start Date (UTC)	Start-End Time (UTC)	Profiling Sites (Hover1/S1000)	Flights	Max CVG RH (%)	Min CVG Vis (miles)	Min LUK Vis (miles)	Notes/Sensors (Hover1/S1000)
1	03-02-2022	0300-1100	Airport/Villa	24	82	7.0	10	Issue with S1000 required avging, RH failed, I-MET/I-MET
2	06-24-2022	0300-1045	Airport/Devou	26	70	10	0.75	S1000 winds unavailable and had a hard landing half way through ops. Hover1 RH not available, I-MET/SAMA
3	07-13-2022	0300-1045	Airport/Giles	30	97	8.0	5.0	Fog observed at Giles, I-MET/SAMA
4	07-19-2022	0245-0915	Airport/Giles	26	100	1.75	0.25	Light fog obs at CVG and Giles. Issue with u,v measurements – low winds. SAMA/SAMA
5	08-11-2022	0300-1015	Devou/Giles	30	100	7.0	0.25	Fog observed at both profiling sites. SAMA/SAMA
6	09-15-2022	0300-0915	Airport/Devou	26	100	6.0	0.25	Grnd Fog @ Devou. Fog evident in satellite along much of Ohio River. SAMA/SAMA

*1.75 mile visibility at CVG lasted only 5 min

Case Study

6

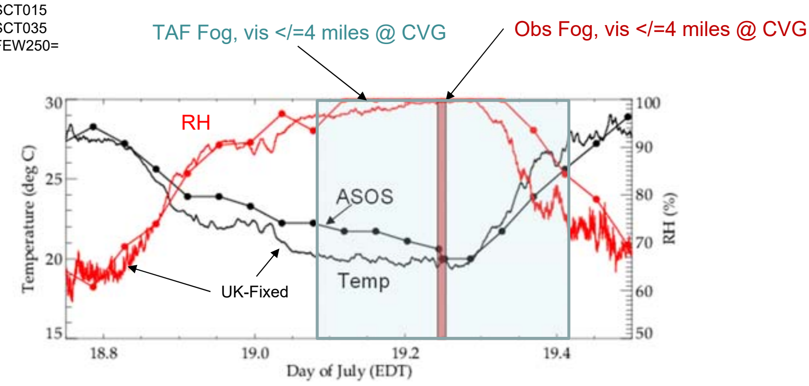
Images from IOP#4



IOP#4: CVG ASOS Observations

TAF issued 00 UTC 7/19/22

FTUS41 KILN 182326
TAFCVGTAF
KCVG 182326Z 1900/2006 VRB03KT P6SM FEW040
FM190600 00000KT 4SM BR FEW250
FM190800 00000KT 2SM BR FEW002
TEMPO 1909/1912 1SM BR SCT002
FM191400 00000KT P6SM SCT015
FM191600 23005KT P6SM SCT035
FM200100 20004KT P6SM FEW250=



TAF Performance

0000 UTC Issuances valid at 0600-1200 UTC

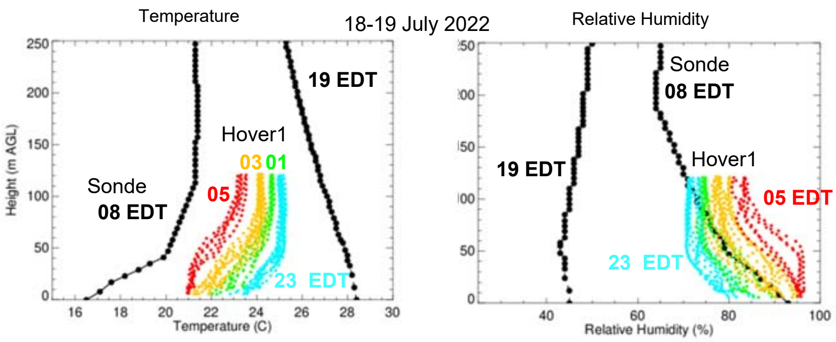
IOP	Start Date (UTC)	Start-End Time (UTC)	Profiling Sites (Hover1/S1000)	Flights	Max CVG RH (%)	Min CVG Vis (miles)	Min CVG Vis (miles)	TAF-performance Case Type
1	03-02-2022	0300-1100	Airport/Villa	24	82	7.0	10	CVG Correct Null LUK Correct Null
2	06-24-2022	0300-1045	Airport/Devou	26	70	10	0.75	CVG Correct Null LUK Hit
3	07-13-2022	0300-1045	Airport/Giles	30	97	8.0	5.0	CVG Correct Null LUK False Alarm
4	07-19-2022	0245-0915	Airport/Giles	26	100	1.75*	0.25	CVG Overpredicted intensity/duration LUK Hit
5	08-11-2022	0300-1015	Devou/Giles	30	100	7.0	0.25	CVG False Alarm LUK Underforecast (timing/duration/intensity)
6	09-15-2022	0300-0915	Airport/Devou	26	100	6.0	0.25	CVG False Alarm LUK Underforecast (timing/duration)

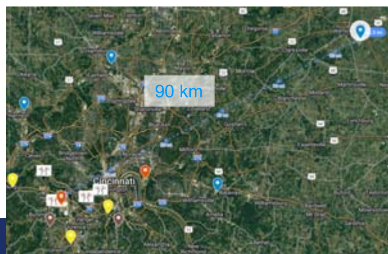
*1.75 mile visibility at CVG lasted only 5 min

Case Study

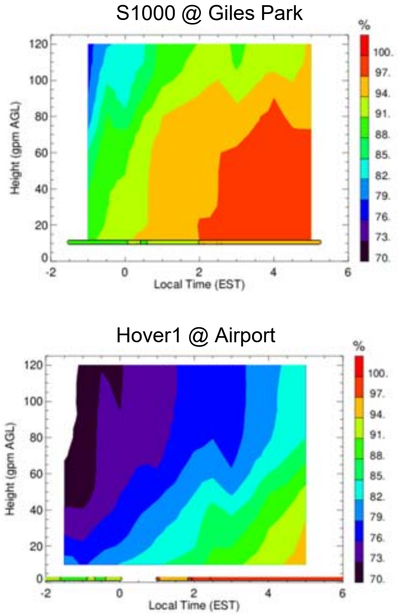
Event based TAF %correct for IOP#2-6 (CVG,LUK) = 30%

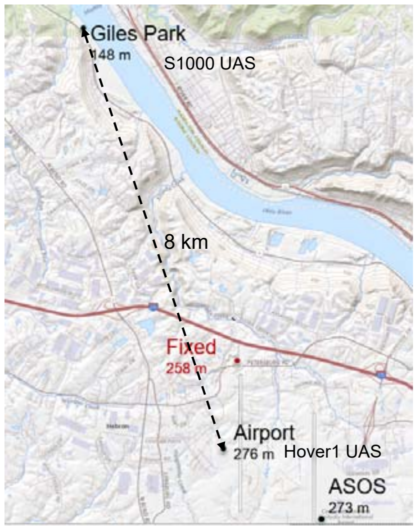
IOP#4 UAS vs ILN Radiosonde





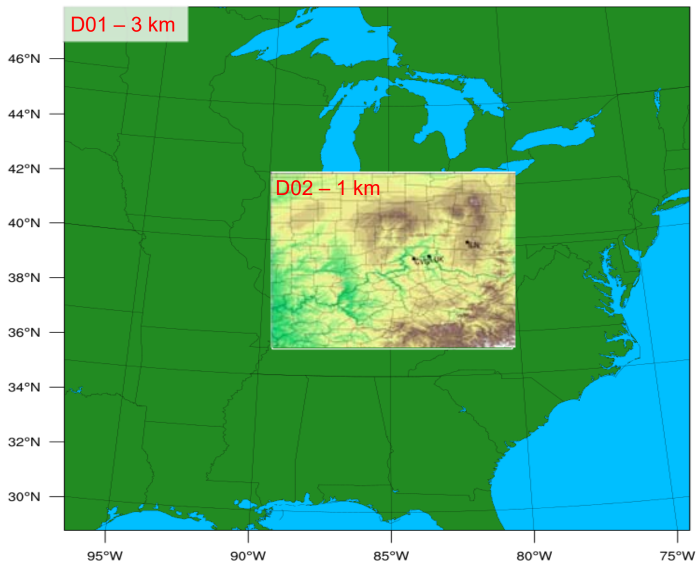
IOP#4: UAS Observations of RH



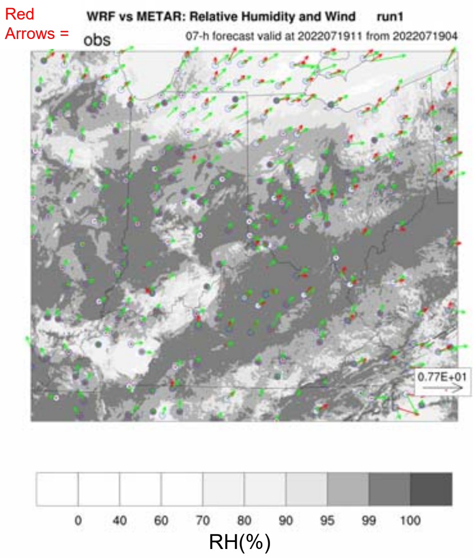


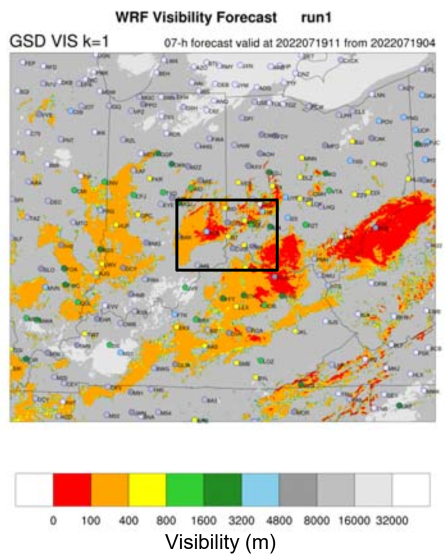
WRF Model Simulations (NoDA)

- Simulations Conducted for IOP#3-6
- Initialized at 0000 and 0400 UTC from HRRR IC/BCs
- HRRR physics suite
- 8 simulation total



IOP#4: Issued:0400_F07h_Valid:_1100UTC

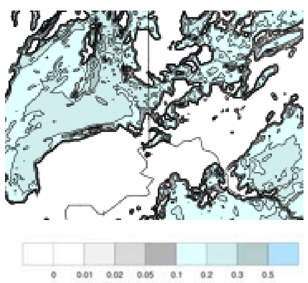




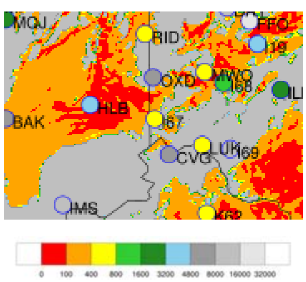
*HRRR Visibility from UPP

IOP#4: Issued:0400_F07h_Valid:_1100UTC

Cloud Water Mixing Ratio (g kg-1)

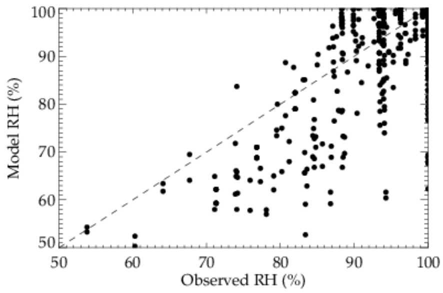


Visibility (m)



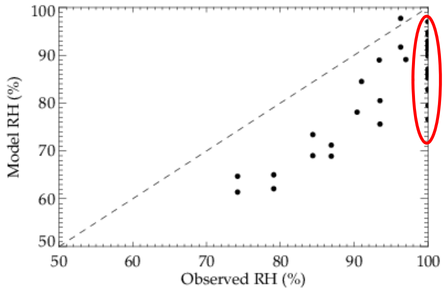
Model Evaluation: IOP#4

Comparisons within 100 km of CVG
All Runs/All Times



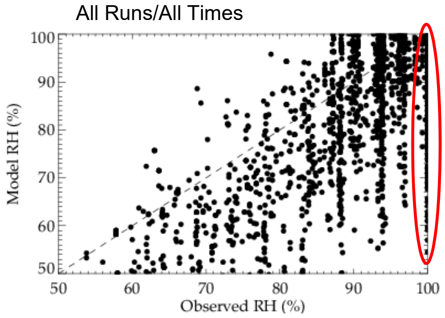
CVG and LUK Only
All Runs/All Times

RH 100% vastly underpredicted



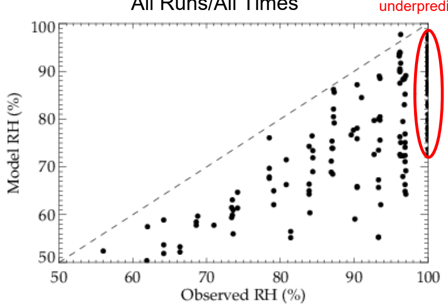
Model Evaluation: RH IOP#3-6

Comparisons within 100 km of CVG
All Runs/All Times

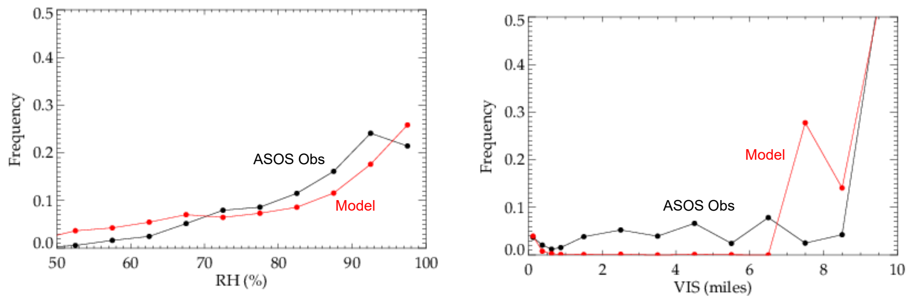


CVG and LUK Only
All Runs/All Times

RH 100% vastly underpredicted



Model Evaluation: RH and Visibility Distributions



Comparisons within 100 km of CVG
All Runs/All Times

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Summary/Next Steps

– Six IOPs have been conducted – (4 good cases collected)
– UAS observations capture evolution of lower portion of the stablizing / moistening boundary layer better than sounding 90 km away.
– Initial evaluations of 1 km NoDA WRF runs indicate dry bias and underprediction of the frequency of visibility restrictions of 1-4 miles.
– Further exploration of model skill & visibility diagnostic needed.
– Perform Observing System Experiments (OSEs) with DART (EnKF)
    - Conventional Obs Only
    - UAS + Conventional
    - 30 min cycling / 40 members, with free 10 member ensemble forecast every 2 hours (04, 06, 08 UTC)
– Importance of resolving river valleys
    - Resolution of terrain features
    - Land/water surface type distinction / river water temperatures

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NCAR

Status Update from Product Development Teams

AOAWS-RU Project Management Review Meeting
October 28, 2022

Aviation Applications Program
Research Applications Laboratory

NCAR

Task 1. Update the In-flight Icing(IFI) Products

Taiwan FIP2 and CIP2
Status Update

Gary Cunning & Dan Adriaansen

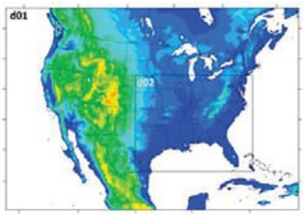
Aviation Applications Program
Research Applications Laboratory

Taiwan FIP2 and CIP2 Status Update

- Created special WRF runs over CONUS
  - WRF configuration selected to closely as possible match CWB's WRF
  - Four time periods (list them)
    - 01/13/2022 – 01/23/2022
    - 02/05/2022 – 02/14/2022
    - 03/072022 – 03/17/2022
    - 03/21/2022 – 03/30/2022

domain	dx/dy	nx	ny	nz
d01	15km	388	776	61
d02	3km	268	636	61

Physics	Options Used
planetary boundary layer	YSU (Yongsei University)
surface layer	Original MM5 Monin-Obukhov
Land surface model	Noah
microphysics	Goddard 4-ice
convective parameterization	Kain-Fritsch (d01 only)
radiation: shortwave	RRTMG
radiation: longwave	RRTMG

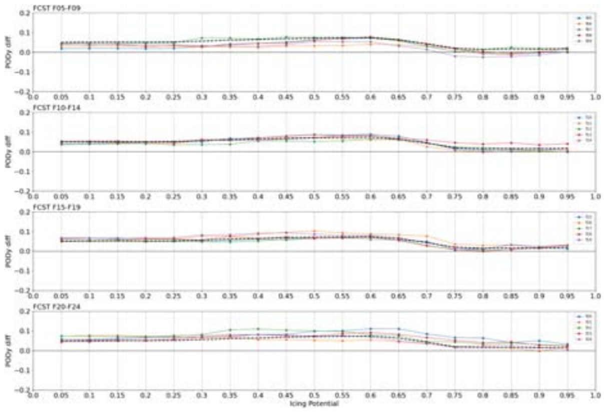


Taiwan FIP2 and CIP2 Status Update

- Collected HRRR model results and observations for the time periods
  - GOES-R satellite, GLM lightning, METARs, MRMS radar mosaics, and PIREPs
- Created GitHub repository for TFIP2 and TCIP2 source code and parameter files
- Built and installed FAA FIP2 and CIP2 applications on server
- Performed initial adaptations of FAA FIP2 and CIP2 applications
  - Created process to calculated one-hour accumulated precipitation fields for TFIP2
  - Created new version of CipAlgo, by removing the use of 3-D dual-pol moments. Application only uses 3-D radar reflectivity
- Built and installed TFIP2 and TCIP2 applications on server
- Processed data four time periods
  - Ran FAA FIP2 applications
  - Ran TFIP2 applications
- Performed comparative analysis between FAA FIP2 and TFIP2
  - Results documented in recent deliverable
  - TFIP2 performance close to FAA FIP2
  - Consider TFIP2 configuration the baseline going forward

Taiwan FIP2 and CIP2 Status Update

- 5hr – 24hr forecast leads were compared.
- 17,989 PIREPs were used in the study
- Variation across all forecast hour leads is very similar.
- At most, the performance of TFIP2 is no more than 10% lower than FAA FIP2.
- Because of model differences, improvement of TFIP2 may require considerable effort that would fall outside adjustment to configuration parameters
- The similarity of performance highlights the robustness of the FIP2 algorithms



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Taiwan FIP2 and CIP2 Status Update

Next Steps

- Complete TCIP2 baseline with the special WRF runs over the CONUS
- Prepare for user feedback exercise
- Preform TCIP2 & TFIP2 verification, following the plan, with data over the Taiwan domain collected over winter.
- Prepare and deliver source code, along with build and install scripts
- Prepare and deliver final training sessions

Review of Deliverables

Deliverable	Due Date	Status
Draft plan for testing & verification of CIP & FIP v2.0 provided as part of quarterly report	October 15, 2021	Delivered & Accepted
Design document	April 15, 2022	Delivered & Accepted
Report on test results provided as part of quarterly report	October 14, 2022	Delivered
Final version of testing & verification plan	December 2, 2022	In progress

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Taiwan FIP2 and CIP2 Status Update

Review of previous accomplishments

- Initial datasets were reviewed for completeness for the TCIP2 and TFIP2 systems. It was confirmed that the Goddard microphysics package is part of the CWB's WRF configuration. TCIP2 and TFIP2 will be adapted to use CWB model results
- Files from 10/9/21 in the archive datasets are being used to configure initial versions of TCIP2 and TFIP2. All inputs have been converted to MDV or SPDB formats for the downstream applications to process.
- Documents from the previous phase were reviewed to establish a rough outline for the test and evaluation processes for the icing products. With information gleaned from the previous phase a test and evaluation plan was developed for TCIP2 and TFIP2.
- Initial investigations into the utility of voice PIREPS and anti-icing indicator data from airlines. The limited number will relegate them to be used in conjunction with any icing case studies that become a part of the testing and verification processes.
- Underlying libraries that support the MDV file format have been updated to write CF-1.6 compliant NetCDF-formatted files. These libraries are part of TCIP2 and TFIP2 builds.

Task 2. GTG

Graphical Turbulence Guidance

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	Verification report detailing the implementation as part of quarterly report	December 2, 2022	Ran initial GTG4 set ups in archive mode for WRF domain 1 and 2 output data. Evaluating initial performance based on statistics and case studies.
2	Status report on activities performed as part of quarterly report	December 2, 2022	Worked on case selection and studies for product development. Investigating in situ and NTDA EDR data for GTG tuning and verification.
2	GTGN implementing plan	December 2, 2022	Investigating feasibility of GTGN and as part of that investigating possible input data sources.

GTG4 System Readiness Status

	Subsystem		
Instance[1]	Algorithm functionality	Initial Diagnostic Mapping to EDR and Diagnostic Selection (Calibration)	Final Calibration
D1 - GTG4 CAT component	A	A	Tasking IA#19
D1 - GTG4 MWT component	A	A	Tasking IA#19
D2 - GTG4 CAT component	A	A	Tasking IA#19
D2 - GTG4 MWT component	A	A	Tasking IA#19
D2 - GTG4 CIT component	T2	T2	Tasking IA#19

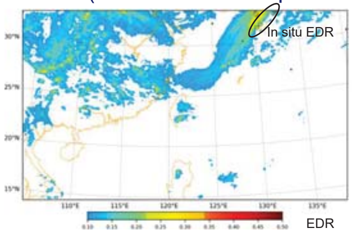
Notes:
- D1-GTG4 will not include CIT because of its coarse grid spacing. CIT has been developed for higher grid resolution <= 3km
- Final calibration requires sufficient in situ data that is still being collected through mid of next year

StatusKey	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

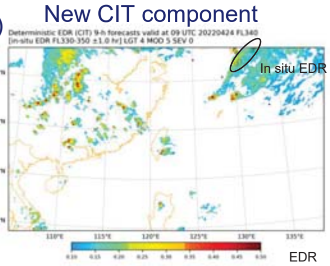
Prototype GTG4 – D2 (CWB's 3-km WRF)

Valid time: 09 UTC April 24, 2022
9-h forecasts at FL340

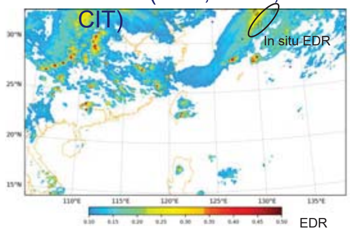
GTG4 (CAT & MWT components)



New CIT component



GTG4 (CAT, MWT, CIT)



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
3	Status report on activities performed and the results of the radar data evaluation provided as part of quarterly report	December 2, 2022	Continuing to evaluate the C-band radars, making adjustments to the Gematronik ingester as needed. Case study analysis is on-going. Evaluation of the radar data quality, and operating modes continues.

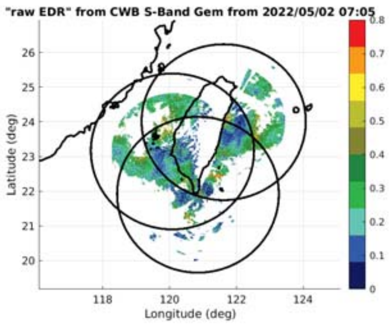
NTDA Upgrade Readiness Status

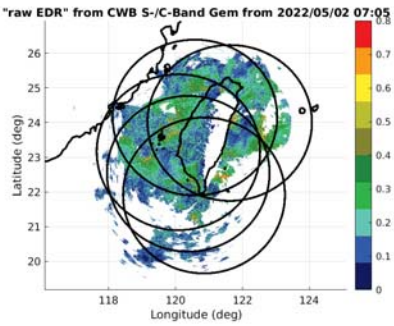
Instance	Algorithm functionality
NEXRAD Ingester Component	A
Gematronik Ingester Component	T2[1]
NTDA Polar (Radar by Radar) Component	T2
Mosaic component	T1[2]

Notes
1. Adaptations are being made to accommodate new Gematronik radars. Much effort was put into understanding the format and operational modes of the new radars.
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

StatusKey	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

Example from 2022/05/22 from Gematronik Radars
Composite of "raw" EDR before/after addition of CWB C-bands





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

NCAR

CTH/CDO Deliverable Tracking

AOAWS-RU Task #	Deliverable	Due Date	Status
4	Validation report for the convection extrapolation performance provided as part of quarterly report	December 2, 2022	Under Development. A large portion of the statistical verification/analysis has been conducted.

NCAR

System Readiness Status

	Subsystem			
Instance [1]	CTH	CDO-Lite [2]	CTH-Extrap	CDO-Lite-Extrap
WRF D1	A	A	A	A
WRF D2	A	A	A	A

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

StatusKey	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

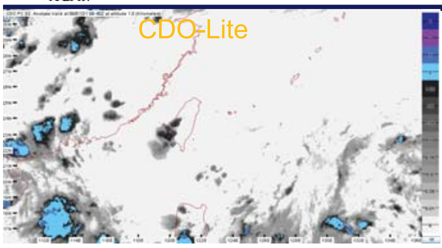
System Readiness Status

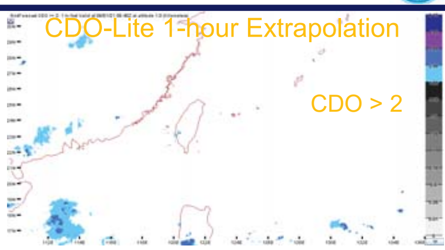
	Subsystem			
Instance [1]	CTH	CDO [2]	CTH-Extrap	CDO-Extrap
DFIR	A	T2	A	T2

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

StatusKey	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

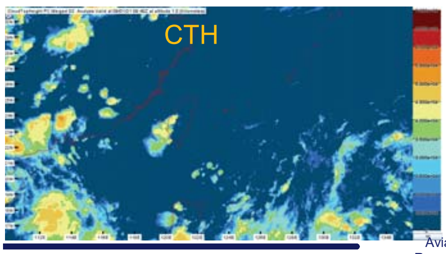
CTH & CDO-lite with 1-hr Extrap. Example Images

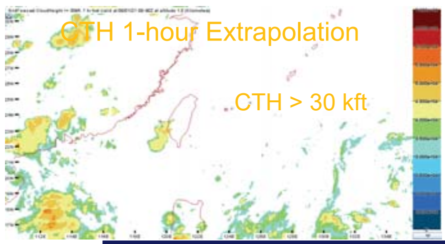




1 Sept. 2021
Valid: 0940Z

Inputs:
Himawari
WRF D2





Task 5. C&V (FOCAL-QM)

Ceiling and Visibility Enhancements
FOrecast CALibration – Quantile Matching

Jim Cowie, Bill Petzke, James Pinto, Dan Megenhardt

Deliverable Tracking

AOAWS-RU Task #	Deliverable	Due Date	Status
5	Results of calibration system tests on historical data Part III (Dec 2021 - Feb 2022)	April 15, 2022	Delivered with quarterly report #4
5	Results of calibration system tests on historical data Part IV (Mar – May 2022)	July 15, 2022	Delivered with quarterly report #5
5	Results of calibration system tests on historical data Part V (Jun – Aug 2022)	October 14, 2022	Delivered with quarterly report #6
5	Results of calibration system tests on historical data Part VI (Sep – Nov 2022*)	December 2, 2022	To be delivered with quarterly report #7

* Due to time constraints, only part of November 2022 will be used in the evaluation.

System Readiness Status

	Subsystem		
Instance[1]	**Ingest** (METAR, 3KM WRF, UPP)	**Calibration** (PtGridFrequencyMatch)	**Forecast** (CVmodelCal)
Ceiling	R	A	A
Visibility	R	A	A

Notes
1. Calibration of ceiling and visibility are performed in parallel, forecasts of C&V are produced in series from latest WRF/UPP run.

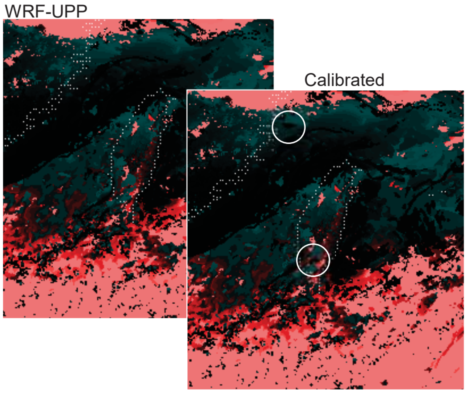
StatusKey	Subsystem Development Phase
C	Code Development
T1	Testing and Configuration
T2	Testing with CWB Sample Data
A	Assessing Performance and Fine Tuning
R	Ready to Deliver

Example of Forecast Calibration

Ceiling

WRF-UPP

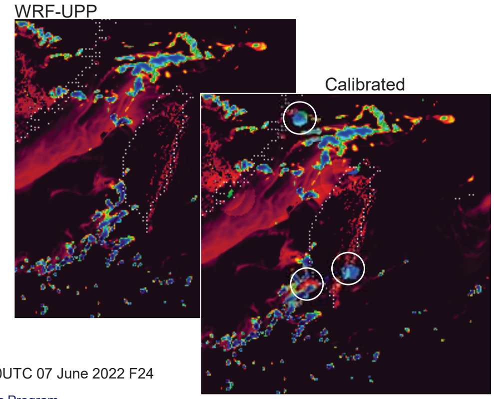
Calibrated



Visibility

WRF-UPP

Calibrated



00UTC 07 June 2022 F24

Task 6. ASPIRE

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

James Pinto, Dan Megenhardt, Dave Albo, Tina Kalb, Joe Grim, Sue Dettling

ASPIRE Deliverable Tracking

AOAWS-RU Task #	Deliverable	Due Date	Status
6	Initial version of AOAWS-RU Blending installed at UCAR	August 12, 2022	Run in archive mode for case study, Sample files from ASPIRE V1.0 delivered.
6	As negotiated, provide examples, either via case studies or a real-time feed, of blended (radar + NWP model) reflectivity forecast data and performance metrics to CAA provided as part of quarterly report	December 2, 2022	Calibration Tuning complete, Statistics and Weights modules tested. Case Study periods selected.
6	Blending performance assessment document describing the characteristics of the blending system and the skill of the short term forecasts provided as part of quarterly report	December 2, 2022	Validation scripts developed.

ASPIRE System Readiness Status

	Subsystem					
Instance[1]	Ingest	Extrapolation[2]	Model Calibration	Model Phase Correction	Dynamic Weights	Heuristic Blending
Composite Reflectivity	R	A	A	T2	T2	T2
Storm Top Heights	R	NA	T2	NA	NA	T2
Rain Rate	R	NA	T2	NA	NA	T2

Notes
1. Storm Top Heights and Rain Rate use same motion vectors, phase correction and weights as derived from composite reflectivity.
2. Script being developed to optimize performance for hourly model output.

StatusKey	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

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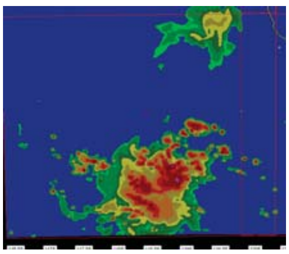
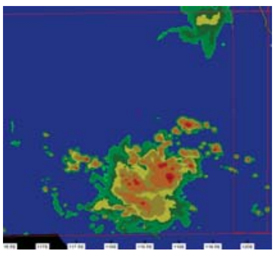
Example of Model Reflectivity Calibration

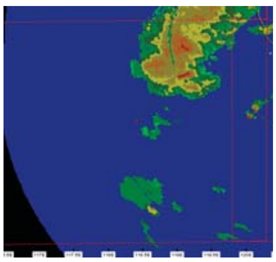
RWRF



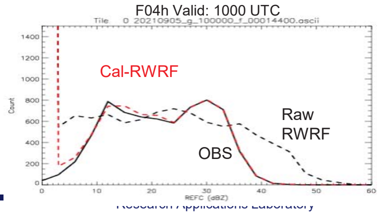
Calibrated-RWRF



Radar Mosaic



F04h Valid: 1000 UTC



IA#18 Project Management Review Meeting

Friday, October 28, 2022

01:00 UTC

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Attendees

CAA: 于守良，Ching-Yao Chuang, David Kuan, Yiping Hsu, Chia-Wei Lan，余祖華，余曉鵬, Chia-Ling Wu，Li-Wei Kuo
IISI: Jenq-Dar Tsay, Yi-Heng Lin
NCAR: Rong-Shyang Sheu, Gary Cunning, Greg Meymaris, James Pinto, Jim Cowie, Ken Stone, Larry Cornman, Wiebke Deierling,

Agenda

1. Opening remarks – Chief Yu
2. NCAR recent science and technology highlight presentation – Recent advancement in Automatic Dependent Surveillance-Broadcast (ADS-B) Derived Turbulence – Larry Cornman
3. Coordination between IISI and NCAR – CAA, IISI, NCAR
    a. CAA high-performance computing environment is ready for NCAR testing
        i. User accounts and service accounts have been set up
        ii. NCAR access IPs (from aoawsru{1,2}) have been provided to IISI
        iii. All packages have been installed, including Intel oneAPI packages.
            1. Still needs NetCDF libs (and the dependency, e.g., HDF5, szip) compiled with Intel compilers. Currently of lower priority

               IISI: Please let us know if there are any updates on the Ansible YAML file for third-party package installation.

    b. Plans for algorithm testing in CAA test environment by the end of 2022

    i. Goal is to verify algorithms capable of using input properly and generating output for validation
    ii. Candidates TBD
c. Integration of NCAR products/processes monitoring into system monitoring. Possible options:
    i. System monitoring reads and parses SysView information for subsequent use. This requires that NCAR turns on SysViews, which was not in NCAR planning.
    ii. System monitoring reads information from processes/utilities that generate information that is used in SysView. No need to turn on SysView, but need to run procmap and datamapper regularly

    IISI: We agree with NCAR. Item (ii) is a better way. More discussions of technical details between NCAR and IISI will be held after the middle of December to ensure a mutual understanding of the design details. This system will be ready by the end of May next year.

d. Other than products/processes monitoring, what other items in system integration planning require coordination between IISI and NCAR? Are there any areas in which NCAR can assist? Is there a system integration plan? If not at the moment, when is it expected?

    IISI: (Yi-Heng) Indeed, we are working on system integration now. We will let TAMC and NCAR know if we need more assistance from NCAR.

    We plan to discuss with NCAR about technical details of data injection, data arrival notification, trigger mechanism, etc., in early November. The flow of injecting data, computing algorithms, and delivering output data to the data center could be materialized by the end of March next year.

e. On aviation meteorological information reports, currently TAC is in use. Can use IWXXM reports moving forward.

4. Progress updates
    a. In-flight icing – Gary Cunning/Dan Adriaansen
    b. GTG4/GTGN – Wiebke Deierling
    c. NTDA – Greg Meymaris/Wiebke Deierling
    d. CTH/CDO – Ken Stone
    e. FOCAL-QM (C&V) – Jim Cowie
    f. ASPIRE – James Pinto

5. NCAR recent science and technology highlight presentation – Assimilating Uncrewed Aircraft System (UAS) observations to improve fog prediction: Field Study Description and Initial Findings – James Pinto
6. CAA/NCAR coordination discussions
    a. Use of lightning data in GTGN and CDO
        i. In fact, GTGN team will do more investigation before finalizing the decision whether to use lightning data in D2
        ii. Lightning will be used in DFIR
            1. Recommendation is in display call it CDO-Lite for D1/D2 results; retain CDO for DFIR results
    b. Product output levels
        i. Products on 3D:
            1. TCIP2/TFIP2 – can use the 1000 ft (lower levels) and 2000 ft (higher levels) with additional levels corresponding to 925 and 850 hPa levels
            2. GTG4/GTGN – currently 1000 ft; need more work to accommodate the extra levels corresponding to 925 and 850 hPa levels
            3. NTDA – normally uses 3000 ft interval; there are only limited altitudes; CAA suggests preserving the 3000 ft interval but adding two additional levels roughly corresponding to 925 and 850 hPa levels. And we also will discuss this issue with IISI.
            4. There may not be any products going all the way to 55,000 ft; GTG/GTGN can go that high; but does not quite make sense for IFI; can just go up to 45,000 ft; NTDA also can go up to 45,000 ft
            5. Forget about 2000 ft intervals; use consistent 1000 ft intervals throughout for IFI and GTG/GTGN

Notes

1. On using IWXXM reports, all algorithms, except GTGN, read observations from SPDB. NCAR has already developed the IWXXM -> SPDB utility. However, we need to look into how GTGN reads observations (METARs)
2. Question raised over C&V inconsistent calibration results from season to season. Jim suggests using a longer period of data (3 months, instead of 1 month currently) to use for calibration; suggests even going back as far as 1 year. The latter is challenging.

3. Question on the turbulence results – how the CAT/MWT and the CIT component combine into the overall result. It is done by taking the maximum values from each component and adding them up.
4. Yiping asks the best way to present the CDO results of analysis and 1-hour extrapolation. Ken suggests the results at these two times can be overlaid, with the 1-hour extrapolation results bounded by contours