出國報告（出國類別：實習）

# 研習航空氣象現代化作業系統調校技術

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出國期間：103 年 9 月 1 日至 9 月 21 日
報告日期：103 年 11 月 5 日

# 研習航空氣象現代化作業系統調校技術

## 目錄

# 壹、目的

航空氣象現代化作業系統（Advanced Operational Aviation Weather System；AOAWS)自 91 年 6 月驗收完成並正式啟用，提供航空氣象服務產品。航空氣象現代化作業系統是一套完整的航空氣象系統，包含四大部分，分別為資料收集與傳輸、資料格式轉換與演算、終端顯示系統及系統監控。透過收集各種航空氣象資料，將資料轉換成特定格式給相關演算法進行計算，分析出各項航空氣象產品，再利用網頁與顯示介面讓使用者參考。在所有子系統中都有備援機制，資料處理主機都有兩部並且互為備援，當其中一部主機有問題時，另一部可直接切換繼續提供系統運作與服務。除了資料處理與備援機制外，還有完整即時監控系統介面，讓系統維護者可以迅速排除問題。

為提升臺北飛航情報區航空氣象服務品質，並保持航空氣象現代化作業系統符合最新的作業需求，自民國 100 年起執行為期 4 年的「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）。至今 AOAWS 已歷經 17 年之持續建置、發展及強化作業，本(103)年度是計畫執行的最後一年，本年度計畫主要工作包含強化即時積冰診斷產品（Current Icing Product；CIP)，將中央氣象局閃電資料引入 CIP，提升在深對流中積冰診斷能力；完成以 WRF（Weather Research and Forecasting）數值預報模式為基準的模式輸出統計數據（Model Output Statistics；MOS）預報模式，提供臺北飛航情報區 10 個民航機場逐時的風向風速、能見度、雲幕高度、溫度、露點與地面氣壓等預報產品，同時也新增 MOS 校驗系統，透過校驗系統能讓預報員了解模式的預報誤差，作為預報修正的參考依據；美國國

家大氣研究中心（NCAR）即時亂流偵測演算法（NCAR Turbulence Detection Algorithm；NTDA）則整合中央氣象局都卜勒氣象雷達資料，利用雷達回波資料即時分析診斷雲中亂流及其強度，提供最即時的亂流偵測產品，並可加強低層雲中亂流之偵測。為了改善航空氣象資料外部傳輸服務的效率，新增外部資料服務（External Data Services System；EDSS）功能，透過 EDSS 更有效率提供航空氣象資料給下游使用者。

因應 AOAWS 發展計畫之結束，及為提升民用航空局飛航服務總臺員工對於 AOAWS 之瞭解及維護能力， AOAWS-TE 計畫自民國 100 年起即逐年規劃 AOAWS 研習課程，選派人員前往 NCAR 學習 AOAWS 航空氣象產品之調校與系統維護技術。本年度之訓練課程針對 AOAWS 之資料處理、各預報子系統與資料更新等流程，以及未來若新增氣象觀測資料的格式與現有資料不同時，如何順利進行資料格式轉換的方法進行說明。

# 貳、過程

職等二人於 103 年 9 月 1 日(星期一)下午，自臺灣桃園國際機場搭乘長榮航空 BR-12 班機前往美國洛杉磯(Los Angeles)，再轉搭美國國內線班機飛往美國中部丹佛市(Denver)，並於美國當地時間 9 月 1 日晚間 10 點抵達目的地波德市(Boulder)。

9 月 2 日(星期二)，今日並未安排課程，職等利用空檔熟悉 NCAR 周邊道路環境，並且適應當地時差。

9 月 3 日(星期三)，與 NCAR 子合約商資拓宏宇國際股份有限公司兩位陪同受訓之工程師張永佳及顏煥廷會合，由 NCAR 顧問 Celia Chen 的陪同下，至 NCAR 的 FL2 大樓 1 樓櫃台，辦理參訪人員之登記手續並取得臨時通行證，隨後由 NCAR 工程師 Jim Cowie 帶領職等一行人前往訓練期間的專用辦公室，分配美國國家大氣科學研究中心提供給訓練學員使用的電腦主機，設定電腦主機網路環境及帳號密碼，登入 AOAWS 實驗室環境測試連線功能是否正常。

9 月 4 日(星期四)，上午由 NCAR 工程師 Dan Adriaansen 為我們講解即時積冰產品(CIP)更新項目，下午由 NCAR 工程師 Paul Prestopnik 為我們講解即時積冰產品(CIP)處理程序與各項參數設定說明。

9 月 5 日(星期五)，上午由 NCAR 工程師 Jim Cowie 為我們介紹 Model Output Statistics (MOS)理論與 MOS 校驗系統，下午則由 NCAR 工程師 Paul Prestopnik 為我們講解 MOS 校驗系統繪圖程序與 MOS 校驗測試網頁。課

程結束後，教官為我們介紹下週上課的 Unidata 部門工程師，並且在每個人的隨身筆記型電腦上安裝 Linux 模擬器。

9 月 8 日(星期一)，今年 NCAR 在 AOAWS 架設外部資料服務系統（External Data Services System；EDSS)，這套系統所使用的工具系由 UCAR 的 Unidata 部門研發，今日安排 Unidata 工程師 Tom Yoksas 為我們講解 Unidata 部門的相關研究，包含內部資料管理（Local Data Manager；LDM)、主題即時環境分布數據服務資料系統（Thematic Real-time Environment Distributed Data Services Data Server；TDS)與整合資料顯示（Integrated Data Viewer；IDV) 系統。下午由 Unidata 工程師 Ward Fisher 為我們講解 NetCDF 資料格式與最新發展。

9 月 9 日(星期二)，由 Unidata 工程師 Sean Arms 為我們講解 THREDDS Data Server (TDS)，THREDDS 是 Thematic Real-time Environmental Distributed Data Services 的縮寫，TDS 可以讓用戶端透過網路連線來伺服器端抓取資料，與 LDM 運行方式相反，LDM 由伺服器端主動傳輸特定資料給用戶端，概略說明其運行方式後，教官指導每位學員在筆記型電腦上安裝 TDS 模擬環境，並且教導學員如何架設 TDS 資料傳輸網頁。

9 月 10 日(星期三)，上午由 Unidata 工程師 Steven Emmerson 為我們講解 LDM 資料傳輸架構與控制流程，下午教官指導我們在個人筆記型電腦的 LINUX 模擬環境上安裝 LDM 系統，並進行資料傳輸示範與參數設定。

9 月 11 日(星期四)，上午由 Unidata 工程師 Sean 講解如何使用 python

程式語言將 TDS 系統傳輸資料用網頁顯示，利用 python 控制程序可以即時將觀測或模式資料顯示於網頁上。下午由 Unidata 工程師 Yuan Ho 示範 IDV 系統，這套系統可以將接收到的氣象資訊顯示於全球地圖上，使用者可以自行設定所需區域範圍與氣象資料，方便即時觀看最新觀測與模式預報資料。在場每位學員都安裝此套系統，並且使用 Unidata 部門處理的資料進行測試。因為在 UCAR 網域中可以下載所有 Unidata 部門處理的資料，所以先在教室中進行 IDV 系統運行。若不在 UCAR 網域環境，也可能下載其他研究單位的氣象資料進行測試。

9 月 12 日(星期五)，由 Gary Cunning 為我們介紹 AOAWS 新增的 EDSS 架構與程序，藉由 EDSS 系統可以在伺服器端與使用者接收端建立迅速且安全的資料傳輸方式，未來可作為 AOAWS 與下由使用者資料傳輸的方式。

9 月 15 日(星期一)，上午由 NCAR 工程師 Greg Meyaris 與 John Williams 講解 AOAWS 的 NCAR Turbulence Detection Algorithm (NTDA)版本更新與個案測試，並且將新版 NTDA 在臺北飛航情報區區域中選取實際個案進行測試。下午由 NCAR 工程師 Jason Craig 講解如何於 NTDA 系統中加入新的雷達資料，本次測試以七股雷達資料模擬作為新加入的雷達資料。

9 月 16 日(星期二)，由 NCAR 工程師 Andy Gaydos 與 Nancy Rehak 介紹航空氣象現代化作業系統之產品顯示系統，包含 JMDS 與 AWOS 系統新增功能，以及新版本控制流程。JMDS 新增即時 METAR 與 TAFOR 校驗工具、不同高度層控制工具、MET REPORT 和 SPECIAL 報文顯示與增加

ICAO 縮放工具。

9 月 17 日(星期三)，由 NCAR 工程師 Paul 為我們介紹 NCAR 使用在 AOAWS 上的版本控制系統 Concurrent Versions System (CVS)，解講如何利用 CVS 進行版本控管以及 AOAWS 整體架構。下午則講解如何架設 AOAWS 模擬環境，因為 NCAR 都是利用模擬環境進行新產品測試與研發，所以說明架設 AOAWS 模擬環境所需機器與相關設定。未來若由總臺與外維廠商自行維護 AOAWS，也需先架設 AOAWS 模擬環境進行程序除錯與測試，才能在不影響正常作業下進行系統維護與調校。

9 月 18 日(星期四)，參加臺北航空氣象中心與 NCAR 的第二天管理會議，共同討論今年 NCAR 研發項目，會議結束後舉行受訓學員結業式，由 NCAR 工程師 Jim Cowie 頒發合格證書給受訓學員。

9 月 19 日(星期五)，自丹佛搭美國國內線飛機至洛杉磯，翌日凌晨轉機返回臺灣，並於臺灣時間 9 月 21 日(星期日)清晨抵達臺灣桃園國際機場。

# 參、心得

## 一、即時積冰診斷產品（Current Icing Product；CIP）

### (一)概述

航空氣象現代化作業系統已於去年年底正式將即時積冰診斷產品（Current Icing Product；CIP）上線作業，CIP 與過去所使用的預報積冰潛勢（Forecast Icing Potential；FIP）不同，過去 FIP 只使用數值模式預報進行診斷，模式本身的預報誤差將會影響診斷結果。CIP 則是結合了數值模式預報與即時觀測資料（如：衛星、雷達、METAR 和飛機報告。），使用決策樹與模糊邏輯法，診斷出積冰可能發生區域與積冰強度，並以三維網格點方式顯示在 JMDS 系統上，提供最新積冰診斷結果，有助於預報員與簽派員使用在積冰預報上。

### (二)使用資料類別與方式

1.雷達資料

都卜勒氣象雷達利用發射電磁波，接收雨滴粒子反射的電磁波強度，得到空間上的降水資訊，因氣象雷達會做不同仰角的掃描，可以得到一組三維空間的降水資料。CIP 採用中央氣象局 4 座（RCWF，五分山；RCCG，七股；RCHL，花蓮；RCKT，墾丁）都卜勒氣象雷達資料，其中五分山（RCWF）為美國 NEXRAD 系統，其餘 3 個為德國 GEMTRONIK 系統，因此 CIP 使用中央氣象局輸出的三維合成資料進行分析診斷。

CIP 選用模式網格點附近 8 個網格點所圍成的範圍分成四等分，取四等分的雷達資料進行比對，依雷達回波強度大小排列，選取 25%、（75%-25%）和 75%三種雷達回波值，由模擬中發現若採用 75%會造成低回波值被過濾掉，若採用（75%-25%）則較為線性，較能完整表現出實際

狀況，因此 NCAR 研究人員更新 CIP 設定，改採用（75%-25%）雷達回波值。受限於雷達觀測資料網的大致僅涵蓋 Domain 3 的範圍，因此 CIP 只在 Domain 3（Domain 3，網格空間解析度為 5 公里）中加入雷達三維合成資料。

2.數值預報模式資料

CIP 採用 WRF 數值預報模式資料，WRF 模式每天進行四次預報。數值模式提供網格點上的溫度、水氣含量、相對濕度、垂直速度和積雲等為物理參數，利用以上資訊可以計算出網格中的三維雲滴分布狀態。CIP 的模式資料演算與 FIP 相同，除了計算過冷水滴外，還增加雲層的冰相。

同時考慮兩者可以預報出大部分的積冰區域，但也會增加過度預報的區域，因此 CIP 藉由觀測資料來診斷出最可能發生積冰區域，並且濾除過度預報區域，這是 CIP 對於積冰診斷重要的改進。因此觀測資料是否完善且正確，將會影響 CIP 對於積冰診斷的準確性。

3.地面觀測資料

地面觀測資料（METAR）提供機場當地的雲量、雲幕高度以及降雨和地表溫度等天氣資料。CIP 利用同心圓理論將地面觀測資料加入分析診斷，每一個網格點僅採用一定半徑範圍內之觀測資料作為 CIP 演算之用，而半徑最低門檻值設定在 40 公里，若在 40 公里內沒有地面觀測資料，最多將影響半徑擴大到 125 公里，若某一網格點在 125 公里半徑內沒有觀測資料時則會在此網格點上留白。

4.衛星資料

CIP 使用紅外線、可見光與反照率等衛星資料，紅外線頻道提供雲頂溫度，搭配水汽頻道的分布計算出雲頂高度，因為雲頂以上幾乎沒有雲滴粒子，可利用雲頂高度濾除部分數值模式預報過度預報的區域。可見光頻道提供水汽粒子分布狀況，雲圖中較亮的區域可能存在粒子較小的液態水，而較暗的區域則為粒子較大的過冷水滴，大粒子的過冷水滴容易形成積冰，其移動速度快且不容易被濾除，因此有過冷水滴的區域為積冰較為嚴重的區域。反照率可用來推估雲中的液態水含量，也可以提供給 CIP 進行積冰診斷。

5.飛機報告資料

飛機報告提供即時積冰狀況，過去研究顯示飛機報告能有效改善短期（1～2 小時）積冰預報，且可利用飛機報告來進行積冰預報校驗。CIP 在啟動時會檢視 2 小時內，分析格點上水平 200 公里及垂直 4000 英呎範圍內的飛機積冰報告，將其加入積冰診斷演算。並依報告中的積冰等級與權重因子計算分項總和，推估出飛機積冰報告的網格積冰資訊。在美國有許多航機提供寶貴的飛機報告，但本區因飛機報告次數與品質較不穩定，因此目前 CIP 並未加入飛機報告，未來若飛機報告品質改善，可直接將其資料加入 CIP 進行演算。

6.閃電資料

鋒面、西南氣流與夏季午後熱對流容易引發旺盛的深對流，深對流中氣流上下劇烈運動常伴隨著閃電，且高層有大粒子水滴與過冷水存在，也是積冰發生區域。CIP 以網格點半徑 25 公里內，在 15 分鐘內有閃電觀測

後，將會啟動積冰演算流程，當觀測的閃電次數愈頻繁，積冰發生的機率越高。今年已提供中央氣象局閃電資料給 NCAR 研究人員進行測試，預計在年底 AOAWS 更新版中使用加入閃電資料的新版 CIP。

### (三)演算法架構

CIP 的積冰診斷演算法是在數值模式預報網格資料中加入即時的觀測資料，利用決策樹與模糊邏輯進行診斷，得到積冰發生區域與積冰強度。目前 AOAWS 的 CIP 使用 WRF 數值預報模式資料、紅外線與可見光頻道同步衛星資料、雷達三維合成（mosaic）資料、地面觀測（METAR）資料。CIP 所診斷的積冰潛勢數值介於 0.0 與 1.0 間，當空間某點的積冰潛勢數值超過 0.05，即判定為輕度積冰。當診斷出過冷大水滴（SLD）時，CIP 會根據過冷水（SLW）的含量將積冰的嚴重性警示提升至中度積冰以上等級。以下為 CIP 的積冰診斷演算法計算步驟：

#### 1.計算積冰發生機率

利用數值預報模式結合雷達資料、衛星資料、地面觀測資料（METAR）、飛機報告（因本區飛機報告次數與品質不穩定，目前未加入 CIP 進行演算）與閃電資料（年底 AOAWS 更新版中加入）等觀測資料，進行積冰演算推估，計算出區域中積冰發生機率，再利用統計資料與模糊邏輯計算積冰強度，如圖 1 所示。

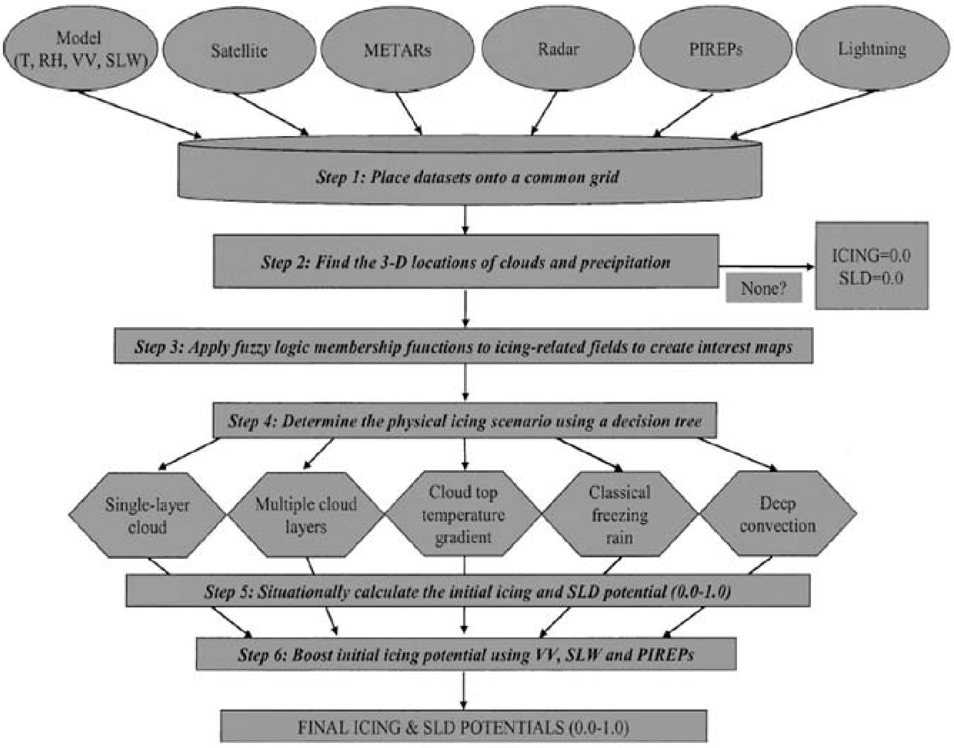


FIG. 2. Flowchart of the CIP process.

圖 1　CIP 計算積冰發生機率流程

2.計算積冰等級

當區域中診斷出有積冰發生機率，CIP 會根據數值預報模式與觀測資料在不同高度上的氣象資訊進行分析，如圖 2 所示。過去 NCAR 研究人員收集美國地區 3 個月的飛機的積冰報告，將其與 CIP 診斷結果進行比對，得到一組積冰強度的統計數值，此數值介於 0 到 1 之間。等級＜0.01 為無積冰；0.01≦等級≦0.175 為冰跡；0.175＜等級≦0.375 為輕度積冰；0.375＜等級≦0.7 為中度積冰；等級＞0.7 為強烈積冰。經過上述積冰診斷流程後，CIP 演算出區域中三維的積冰機率與強度，提供預報員在天氣預報作業時參考。

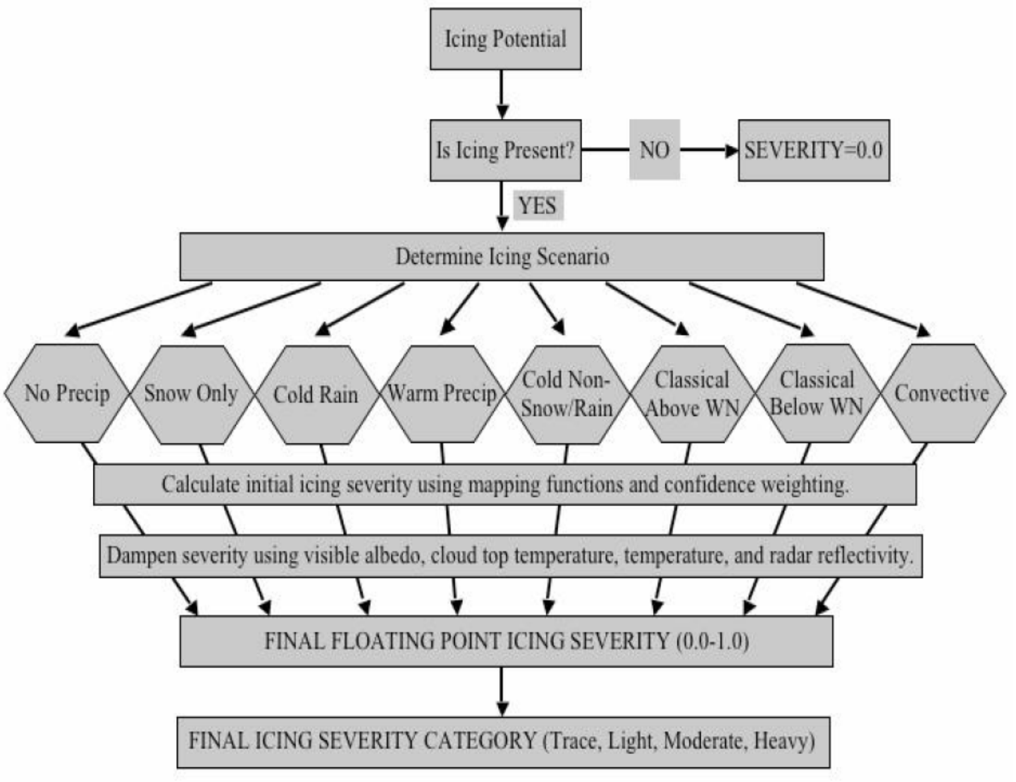


圖 2　CIP 演算積冰等級流程

## 二、模式輸出統計數據（Model Output Statistics；MOS）

### (一)概述

風場、雲幕、能見度與天氣現象是機場預報中重要的預報產品，在AOAWS 的 WRF 數值預報模式的預報產品中有風場、相對溼度、雷達回波與累積雨量等資訊，讓預報員在做機場預報時可以判別該地的風場變化與天氣現象。對於雲幕與能見度預報則無法提供相關資訊，雖然也可以由相對濕度與雲中水氣含量進行分析，其預報結果的好壞將取決於預報員的主觀判定與分析。若能提供數值預報模式相關產品，提供客觀預報資訊將有助於預報員做預報時參考。但是 WRF 數值預報模式中並未有雲幕與能見度預報輸出，NCAR 研究人員選用模式輸出統計數據（Model Output Statistics，MOS）。MOS 預報模式是使用數值模式預報對於不同預報時間的樣本資料進行建模，透過統計迴歸式納入模式本身的系統性誤差，但這樣的取樣方式是需要一個凍結模式，即數值預報模式不能被更動的。但這樣的限制是無法被滿足的，因為 AOAWS 的 WRF 數值預報模式是不斷地更新改進，並且不容易維護長時間的模式訓練資料，所以 MOS 預報模式使用 WRF 數值預報模式資料輸出是有其限制。因此 NCAR 研究人員在設計 AOAWS 的 MOS 預報模式中進行部分修改，使其能滿足現階段數值預報模式更新與作業環境的限制。

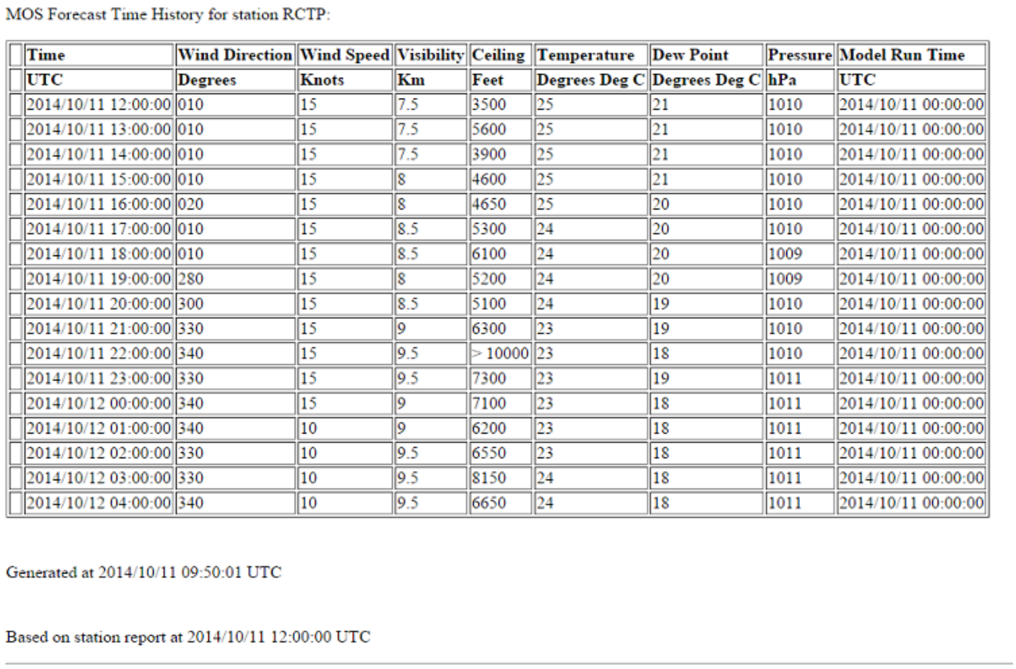
### (二)AOAWS 的 MOS 預報模式

受到現行 AOAWS 環境與 WRF 數值預報模式的限制，AOAWS 的 MOS 預報模式有以下幾點特性：

1. MOS 線性迴歸統計模組每天進行更新，使其有效使用 WRF 數值預報模式資料與即時觀測資料。

2. 使用最近 60 天 WRF 數值預報模式輸出資料，作為 MOS 預報模式統計迴歸所需的訓練資料，因此 AOAWS 需要保存只少 60 天的 WRF 數值預報模式資料。
3. 減少統計迴歸式中的預報因子，使 MOS 預報模式可即時提供預報產品。
4. 自動化處理動力條件、處理模組與季節變化，減少人員針對 MOS 預報模式的修改。
5. 關閉部分傳統 MOS 預報模式的功能，使其能迅速作出統計數據預報。
6. 溫度、露點、風向風速與地面氣壓使用單一統計迴歸式，即使用單一變數且預報因子與預報量相同，因為這些在 WRF 數值預報模式中都有輸出。雲冪與能見度則使用多元統計迴歸式，使用多項預報因子，包括雲中水含量、冰濃度、風速、垂直速度、降雨率、相對溼度、氣壓、對流舉升指數與不同高度層間溫度差異等預報因子，透過多元統計迴歸式計算出雲冪與能見度的預報量。

經過 NCAR 研究人員針對 AOAWS 的 MOS 預報模式進行的修改後，AOAWS 的 MOS 預報模式提供風向風速、能見度、雲冪高度、溫度、露點與地面氣壓等資訊。目前每天提供四次 10 個民航機場預報的 24 小時預報（每小時輸出），預報機場分別為桃園（RCTP）、松山（RCSS）、高雄（RCKH）、金門（RCBS）、北竿（RCMT）、南竿（RCFG）、台東（RCFN）、綠島（RCGI）、蘭嶼（RCLY）與恆春（RCKW），以桃園機場為例，如圖 3 所示。



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 |
| | 2014/10/11 12:00:00 | 010 | 15 | 7.5 | 3500 | 25 | 21 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 13:00:00 | 010 | 15 | 7.5 | 5600 | 25 | 21 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 14:00:00 | 010 | 15 | 7.5 | 3900 | 25 | 21 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 15:00:00 | 010 | 15 | 8 | 4600 | 25 | 21 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 16:00:00 | 020 | 15 | 8 | 4650 | 25 | 20 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 17:00:00 | 010 | 15 | 8.5 | 5300 | 24 | 20 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 18:00:00 | 010 | 15 | 8.5 | 6100 | 24 | 20 | 1009 | 2014/10/11 00:00:00 |
| | 2014/10/11 19:00:00 | 280 | 15 | 8 | 5200 | 24 | 20 | 1009 | 2014/10/11 00:00:00 |
| | 2014/10/11 20:00:00 | 300 | 15 | 8.5 | 5100 | 24 | 19 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 21:00:00 | 330 | 15 | 9 | 6300 | 23 | 19 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 22:00:00 | 340 | 15 | 9.5 | > 10000 | 23 | 18 | 1010 | 2014/10/11 00:00:00 |
| | 2014/10/11 23:00:00 | 330 | 15 | 9.5 | 7300 | 23 | 19 | 1011 | 2014/10/11 00:00:00 |
| | 2014/10/12 00:00:00 | 340 | 15 | 9 | 7100 | 23 | 18 | 1011 | 2014/10/11 00:00:00 |
| | 2014/10/12 01:00:00 | 340 | 10 | 9 | 6200 | 23 | 18 | 1011 | 2014/10/11 00:00:00 |
| | 2014/10/12 02:00:00 | 330 | 10 | 9.5 | 6550 | 23 | 18 | 1011 | 2014/10/11 00:00:00 |
| | 2014/10/12 03:00:00 | 330 | 10 | 9.5 | 8150 | 24 | 18 | 1011 | 2014/10/11 00:00:00 |
| | 2014/10/12 04:00:00 | 340 | 10 | 9.5 | 6650 | 24 | 18 | 1011 | 2014/10/11 00:00:00 |

Generated at 2014/10/11 09:50:01 UTC

Based on station report at 2014/10/11 12:00:00 UTC

圖 3　桃園機場（RCTP）MOS 預報模式的逐時預報產品

(三)MOS 預報校驗

NCAR 研究人員今年在 AOAWS 增加 MOS 預報校驗系統，利用地面觀測 METAR 資料進行校驗，並可即時於網頁上產生校驗結果圖形。MOS 預報校驗系統提供校驗變數有溫度、露點、風向風速、氣壓、雲幕與能見度，可選擇 3 種不同校驗時間長度，分別為週、月與季。除了十個民航機場外，還可選擇全部民航機場與群組機場（1：SS、TP＆KH；2：MT、FG＆BS；3：FN、GI、LY＆KW）顯示方式。以下簡略說明 MOS 預報校驗系統所使用的校驗方法：

1.平均絕對誤差（Mean Absolute Error，MAE）：

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|f_i - y_i|$$

$$f_i = froecast \text{ ； } y_i = observed$$

取預報減掉觀測的絕對總和，再除以樣本數，得到平均絕對誤差，因為計算相差時取絕對值，所以 MAE 數值永遠為正值，與平均或平均誤差相似，MAE 值越小表示預報越準確。MAE 適合用來校驗連續的預報變量，但一點點小誤差就可能失去統計意義。在 MOS 預報校驗系統中 MAE 用來校驗溫度、露點、風向風速與氣壓，不適合用來校驗雲冪與能見度。

2.均方根誤差（Root Mean Squared Error，RMSE）：

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

$y_i = forecast$ ；$\hat{y}_i = observed$

取預報減掉觀測的平方總和並除以樣本數後再開根號，RMSE 與 MAE 相同都為正值，因為 RMSE 為誤差值的平方，所以數值較 MAE 值大，RMSE 值越小表示預報越準確。與 MAE 相同，在 MOS 預報校驗系統中用來校驗溫度、露點、風向風速與氣壓，也不適合用來校驗雲冪與能見度。

3.偏差（Bias）：

$$\mathrm{MSD}(\hat{\theta}) = \sum_{i=1}^{n}\frac{\hat{\theta}_i - \theta_i}{n}.$$

$\hat{\theta}_i = forecast$ ；$\theta_i = observed$

預報減掉觀測除以樣本數再取總和，因為未取絕對值或平方開根號，所以偏差有正負值，搭配 MAE 與 RMSE 一起檢視，可以知道是什麼樣的偏差造成預報誤差。與 MAE 和 RMSE 相同，在 MOS 預報校驗系統中用來校驗溫度、露點、風向風速與氣壓，也不適合用來校驗雲冪與能見度。

4.檢測概率（Probability of Detection，POD）：

$$POD = \frac{H}{H+M}$$

上述 3 種校驗方法（MAE、RMSE 與 Bias）讓預報員了解模式預報結果的誤差值，但無法顯示這個模式預報是否為準確，尤其在特定類型中，例如：雲幕與能見度。檢測概率（POD）利用設定門檻值校驗預報是否有達到，例如：雲幕＜1000 英呎（是與否），再透過排序組合來計算。

| | 地面觀測 | |
|---|---|---|
| 模式預報 | 是 | 否 |
| 是 | 命中（H） | 過度預報（FA） |
| 否 | 失誤（M） | 沒發生（Non-Event） |

例如：檢視雲幕是否＜1000 英呎。

H：模式預報有，地面觀測也有，命中。

M：模式預報沒有，但地面觀測有，失誤。

FA：模式預報有，但地面觀測沒有，模式過度預報。

Non-Event：模式預報沒有，地面觀測也沒有，事件沒有發生。

POD 值介於 0 到 1 間，越接近 1 表示模式表現越好。但 POD 有其限制，H＋M 不能為 0，即至少有一種事件發生，且需要夠多的樣本數，最少需要一個月的樣本資料，使用季來檢視更有代表性，此種校驗方法適合用在雲幕與能見度的校驗。若能增加命中次數，減少失誤次數，都可以增加 POD 值，改善 MOS 預報模式的準確度。

5.準確關鍵指標（Critical Success Index，CSI）：

$$CSI = \frac{H}{H + M + FA}$$

準確關鍵指標（CSI）與檢測概率（POD）相似，將過度預報（FA）加入進行計算，更能顯示 MOS 預報模式的準確度。與 POD 相同，適合用來校驗雲幕與能見度的準確度，且需要長時間的樣本資料，最少需要一個月。CSI 值介於 0 到 1 間，越接近 1 表示模式表現越好。同樣地，H＋M＋FA 不能等於 0，若能增加命中次數，減少失誤與過度預報次數，都可以增加 CSI 值，進而改善 MOS 預報模式的準確度。

以上為 MOS 預報校驗系統，藉由此系統可以讓預報員了解 MOS 預報模式在不同季節與天氣型態的預報準確度，NCAR 預計在年底 AOAWS 更新版中新增此系統。任何模式預報結果都需要實際觀測資料進行校驗，才能了解模式預報誤差，作為預報員修正模式預報結果的參考依據，進而改進預報準確度。臺北航空氣象中心對於這類模式的調校與研發較為缺乏，未來可透過研討會或教育訓練等交流來提升相關模式研發技術。

## 三、NCAR 亂流偵測演算法（NCAR Turbulence Detection Algorithm；NTDA）

### (一)概述

亂流常造成飛行器損害，甚至人員傷亡，因此如何有效改善亂流的偵測與預報是很重要的議題，NCAR 近年來開發 NTDA 亂流偵測演算方法，與過去整合亂流預報演算法（Integrated Turbulence Forecast Algorithm；ITFA）不同，ITFA 是依據 WRF 數值預報模式的預報產品，搭配過去美國飛機報告與所測得的渦流耗散率（Eddy Dissipation Rate；EDR）推導權重值，計算出 ITFA 指數，在 4 公里與 20 公里解析度範圍的 ITFA 使用不同的指數，不同的解析度範圍 (domain)使用稍微不同的權重。ITFA 將這些指數加權後求得總和，這個單一數值可解釋為預期可能發生亂流的強度。由 ITFA 所計算出來的亂流指數可透過圖形化亂流導引（Graphical Turbulence Guidance；GTG）來顯示，GTG 係利用圖形化方式來顯示亂流偵測結果，讓預報員能輕易辨別出亂流發生位置與其強度。NTDA 則是利用雷達資料計算出 EDR 來偵測亂流強度，EDR 可用來量度大氣中運動能量的耗散率，當大氣運動中混亂程度越大，EDR 數值越大。ITFA 主要針對晴空亂流進行偵測，對於雲中或雲周邊水氣旺盛區域較難掌握，而以雷達資料為基礎的 NTDA 可以補足在對流區域的亂流偵測。另外，當缺乏 NTDA EDR 資料表示該區域無適當資料進行計算，但不表示無亂流，因此需要搭配 ITFA 的晴空亂流偵測，以提供最即時且完整的亂流偵測資訊。臺北航空氣象中心於去年開始提供中央氣象局都卜勒雷達網的資料給 NCAR 進行測試，今年已完成雷達資料處理程序，並於年底 AOAWS 更新版時讓 NTDA 正式上線作業。

### (二)資料處理

中央氣象局都卜勒雷達網共有 4 座都卜勒氣象雷達，分別為五分山（RCWF）、七股（RCCG）、墾丁（RCKT）和花蓮（RCHL）。其中五分山為美國 NEXRAD 雷達系統，其餘三座為德國 GEMTRONIK 雷達系統，有兩種不同的雷達資料格式，NCAR 研究人員針對這兩種雷達資料格式撰寫不同資料轉換程序。如圖 4 所示，先由 cwb-caasv1/2 主機傳送四座雷達的平面位置指示器( Plan Position Indicator；PPI )的水平掃描資料到 tamc-data1/2 主機，再由 tamc-data1/2 將 PPI 資料傳送到 tamc-algorithm1/2 主機進行資料格式轉換，五分山雷達使用 Nexrad2Netcdf 轉換程序，其餘德國雷達使用 Gemtronik2Netcdf 轉換程序。雷達資料轉換格式後，NCARTurbDetecAlg 程序是利用 NCAR 亂流演算法來偵測是否有亂流？當偵測出有亂流，此程序同時也會計算出亂流強度。

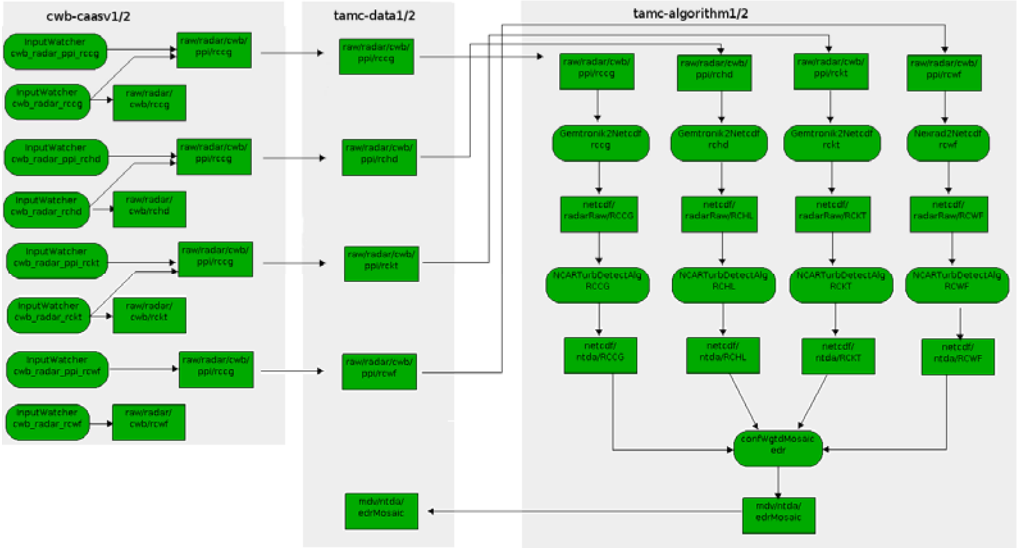


圖 4　NTDA 處理流程

因為五分山雷達為美國 NEXRAD 雷達系統，與 NCAR 在美國地區研發的 NTDA 格式相同，所以處理五分山雷達資料相當容易。另外三座德國 GEMTRONIK 雷達系統資料格式與 NEXRAD 雷達系統不同，需重新撰寫資料格式轉換程式。使用德國 GEMTRONIK 雷達資料有兩項小缺點，第一，德國 GEMTRONIK 雷達資料中缺少信躁比（Signal to Noise Rate；SNR）資料，NCAR 採用雷達反射率來計算 SNR，但 SNR 可能會被低估，影響部分亂流演算。第二，因為臺灣地區地形陡峭，雷達的 PPI 掃描資料常受到地形干擾，產生地形雜波。德國 GEMTRONIK 雷達資料中缺少雜波位置地圖，因此需要雜波位置地形圖。利用一年的雷達資料進行取樣分析，計算出三座雷達雜波位置圖（如圖 5、圖 6 與圖 7 所示）。經過這些資料處理程序後，才能將雷達資料進行亂流偵測演算程序。

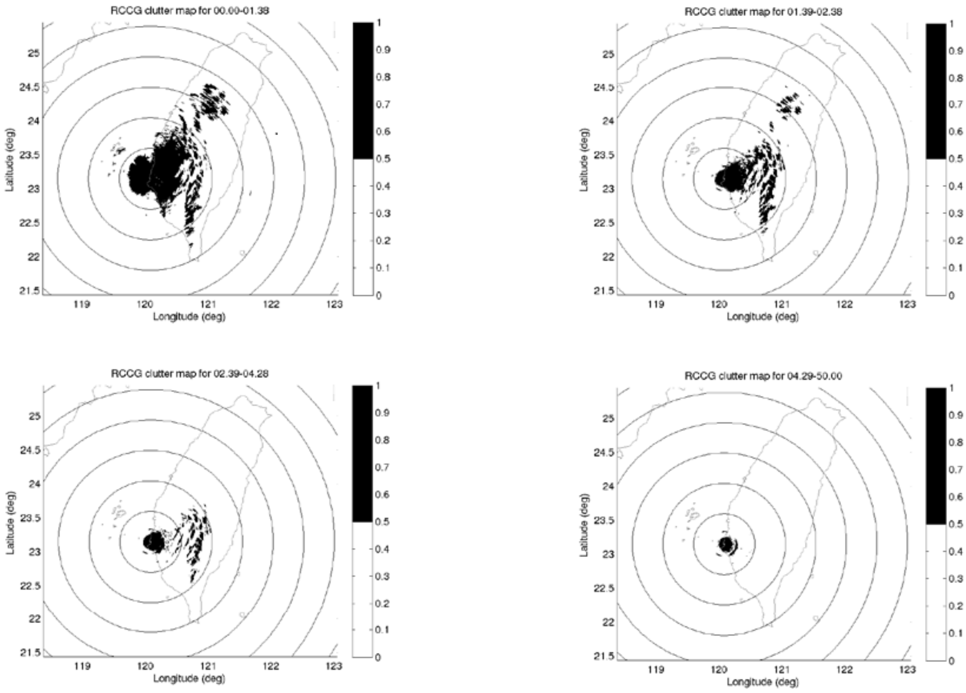


圖 5　七股雷達雜波位置圖

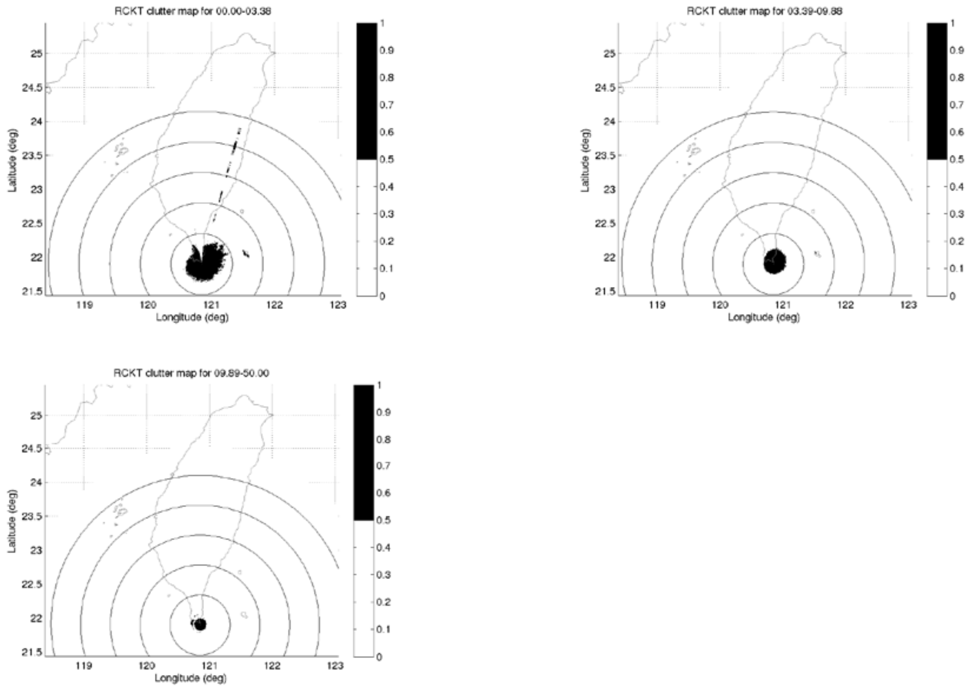


圖 6　墾丁雷達雜波位置圖

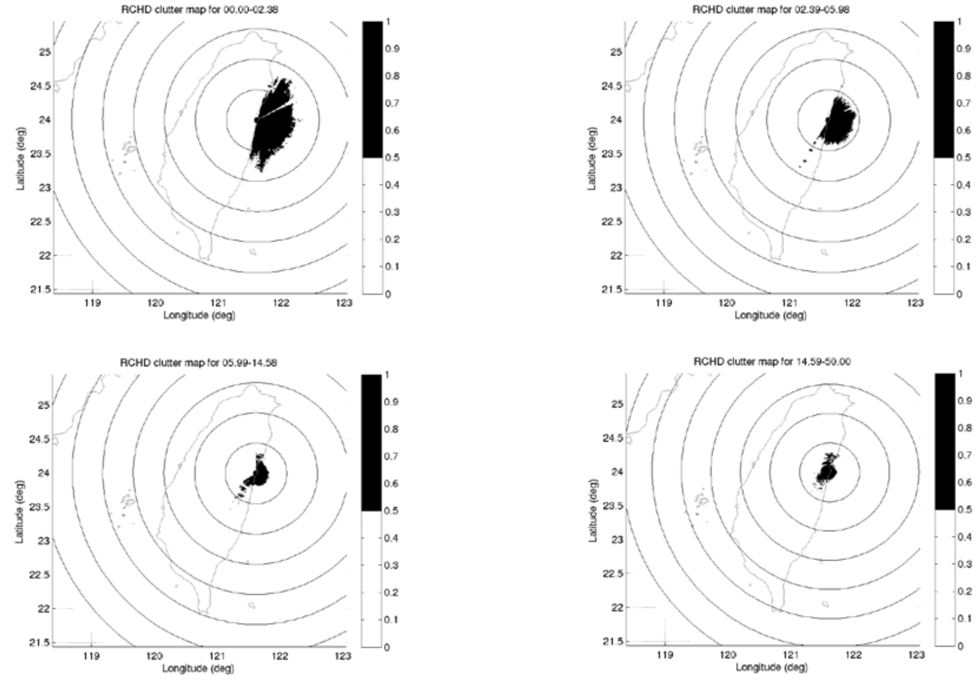


圖 7　花蓮雷達雜波位置圖

### (三)增加新雷達資料

在臺灣地區除了中央氣象局有都卜勒氣象雷達外，空軍也建置都卜勒氣象雷達，同樣也是德國 GEMTRONIK 雷達系統，有鑑於未來可能新增其它的都卜勒氣象雷達資料，所以在這次教育訓練中也增加如何新增都卜勒氣象雷達資料於 NTDA 系統流程中，以七股雷達資料作為虛擬用之新增雷達資料進行操作，操作流程如下：

1. 先到 cwb-caasv1 主機上，

```
cd /d1/aoaws/projDir/cwb_relay/params
vim IputWatcher.cwb_radar-->新增 rccg 項目
vim proc_list-->新增 rccg 項目
cd /d1/aoaws/projDir/cwb_relay/scripts
vim start_InputWatcher.cwb_radar-->新增 rccg 項目
vim copy_cwb_radar_file_long_pilse.py-->新增 rccg 項目
cd /d1/aoaws/projDir/data/raw/radar/cwb/ppi
mkdir rccg
cd /d1/aoaws/projDir/data/raw/radar/cwb/ppi/rckt
cp _DsFileDist ../rccg
stop_all
start_all
ssh cwb-caasv2
```

進行上述相同操作，即完成 cwb-caasv1/2 主機雷達資料傳送程序設定。

2. 到 tamc-data1 主機上，

```
cd /d1/aoaws/projDir/data/raw/radar/cwb/ppi
mkdir rccg
cd /d1/aoaws/projDir/data/raw/radar/cwb/ppi/rckt
cp _DsFileDist ../rccg
cd /d1/aoaws/projDir/data/raw/radar/cwb/ppi/rccg
snuff DsFileList  & &  start_DsFileDist
stop_all
start_all
ssh cwb-data2
```

進行上述相同操作，即完成 cwb-data1/2 主機雷達資料接收程序設定。

3. 到 tamc-algorithm1 主機上，

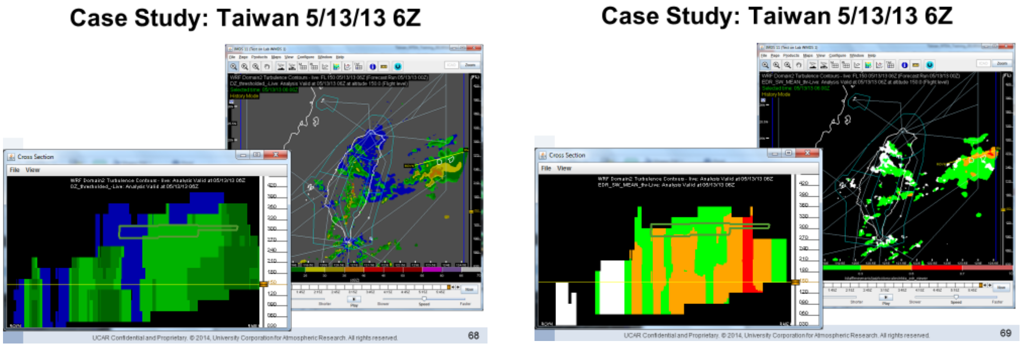
```
cd /d1/aoaws/projDir/data/raw/radar/cwb/ppi
mkdir rccg
cd /d1/aoaws/projDir/data/raw/radar/cwb/ppi/rckt
cp _DsFileDist ../rccg
cd /d1/aoaws/projDir/cwb_relay/params
vim proc_list-->新增 rccg 項目
snuff_inst confWgtMosaic edr  & &  start_confWgtMosaic.edr
stop_all
start_all
ssh cwb-algorithm2
```

進行上述相同操作，即完成 cwb-algorithm1/2 主機 NTDA 程序設定。

以上程序為新增雷達資料於 NDTA 亂流偵測演算系統，目前 NCAR 已完成美國 NEXRAD 與德國 GEMTRONIK 雷達系統資料處理流程，未來若是加入這兩類雷達資料都可以直接使用 NDTA 進行亂流偵測。在 AOAWS 的 NTDA 系統中所使用的雷達資料為 S 波段（波長 10 公分）的雷達資料，前面提到軍方的都卜勒氣象雷達也是德國 GEMTRONIK 雷達系統，但是軍方為 C 波段（波長 5 公分）的雷達資料，與 NCAR 研究人員討論後，可能需要修改 Gemtronik2Netcdf 轉換程序，目前沒有軍方雷達資料，暫時無法進行測試與修改。

4.臺北飛航情報區個案研究

NCAR 在今年完成 NTDA 系統後，針對臺北飛航情報區選取 4 個個案進行測試與分析，分別為 102 年 5 月 13 日（圖 8）、今年 7 月 19 日（圖 9 左）、7 月 22 日（圖 9 左）與 8 月 13 日（圖 10）。由圖中可知，在有深對流的雷達回波區域都能偵測出亂流資訊，提供重要的亂流資訊給預報員分析與預報。



Case Study: Taiwan 5/13/13 6Z

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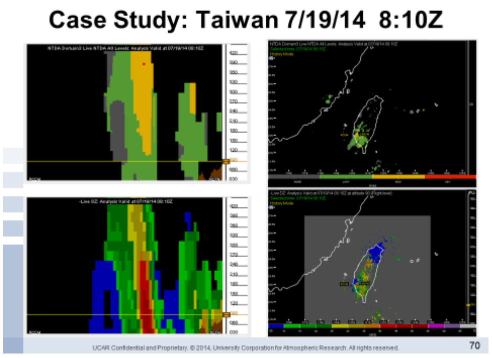
圖 8　102 年 5 月 13 日個案



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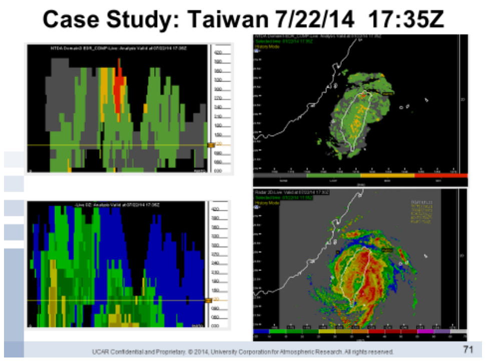

Case Study: Taiwan 7/22/14 17:35Z

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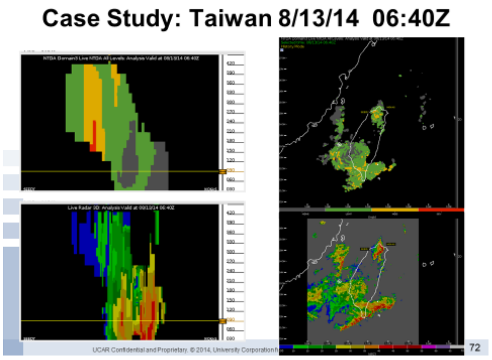
圖 9　103 年 7 月 19 日與 7 月 22 日個案



Case Study: Taiwan 8/13/14 06:40Z

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圖 10　103 年 8 月 14 日個案

## 四、外部資料服務系統（External Data Service System；EDSS）

### (一)概述

現在 AOAWS 整合了即時觀測與最新模式預報資料，提供最新的航空氣象資訊。有許多航空相關產業申請加入航空氣象服務網，利用網頁查詢航空氣象相關資訊。雖然網頁可以即時查詢航空氣象資料，但需要主動提出需求，再經由系統篩選後顯示於網頁上。鑒於提升航空氣象服務及資訊安全因素，NCAR 協助發展外部資料服務系統（EDSS），透過外部網路通訊方式，以點對點方式提供航空氣象資料給下游使用者。目前美國聯邦航空署（Federal Aviation Administration；FAA）使用 NextGen OpenGIS 工具與資料格式進行資料傳輸，但這套系統有幾項缺點。例如：系統發展不夠成熟、沒有廣泛地測試和不支援外部使用者等。NCAR 採用 UCAR 的 Unidata 工具與資料格式，Unidata 傳輸的資料格式為 netCDF，這種資料格式在全世界都廣泛地被使用。例如：WRF 數值預報模式的初始場、邊界場與預報產品都使用 netCDF 格式，所以使用 Unidata 工具進行外部資料服務較為便利。

### (二)處理流程

Unidata 工具使用兩種方式傳輸資料，分別為 1.傳送資料（push data），用於伺服器對伺服器間，使用內部資料管理（Local Data Manger；LDM）系統來傳輸資料。2.接收資料（pull data），用於伺服器與使用者，使用主題即時環境分布數據服務資料系統（Thematic Real-time Environmental Distributed Data Services；TREDDS Data Server；TDS）系統來傳輸資料。LDM 與 TDS 分別扮演兩種角色，如圖 11 所示。LDM 為主動傳輸資料給指定伺服器，由資料提供者控制給什麼樣資料，及在什麼時間傳輸資料；TDS 則

為被動傳輸資料，當下游使用者提出資料需求，系統將會偵測是否有相關資料，若有資料就可讓下游使用者下載。

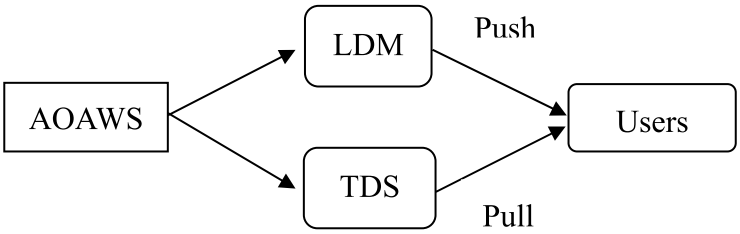


圖 11　EDSS 資料傳輸流程圖

以下簡略說明如何使用 LDM 與 TDS 系統傳輸資料，及檢視資料內容。

使用 LDM 系統進行資料傳輸作業時，AOAWS 與使用者伺服器都需要安裝 LDM 系統，且伺服器作業系統需為 Linux。因為 LDM 使用 netCDF 資料格式進行資料傳輸，所以 AOAWS 需將資料格式轉換成 netCDF 格式，使用者則需在 Linux 系統中安裝 netCDF 程序，才能順利接收與解讀 netCDF 格式檔案。另外，LDM 也能傳輸 XML 格式資料給 textserver 使用。NCAR 今年度在 AOAWS 架設的 EDSS 子系統，未來也可代替用 FTP 傳輸資料給航空情報服務系統（Aeronautical information Services System；AISS）的方式，提供更快速且安全的傳輸方式。

LDM 下載網頁：

http://www.unidata.ucar.edu/software/ldm/

netCDF 下載網頁：

http://www.unidata.ucar.edu/software/netcdf/

使用 TDS 系統進行資料傳輸作業時，僅需要在 AOAWS 安裝 TDS 系統，使用者無需安裝，可透過 AOAWS 中 TDS 系統建置的資料庫網頁，

登入後提出下載資料請求，再由 TDS 系統審核其權限後，且資料庫中有該請求資料，使用者就可以透過 TDS 系統下載資料。因為 TDS 系統也是使用 netCDF 格式資料進行傳輸，所以使用者的作業環境也需要安裝 netCDF 程序，才能接收資料與解碼。

TDS 下載網頁：http://www.unidata.ucar.edu/software/thredds/current/tds/

當使用者下載資料後，可使用 netCDF 內建 ncdump 指令檢示 netCDF 格式資料內容，若接收資料為網格點資料，可使用 ncview 只令用圖形方式顯示網格點資料。另外，Unidata 部門提供一個整合資料顯示系統（Integrated Data Viewer；IDV），讓使用者可以直接將接收的資料以圖形方式顯示，IDV 需先設定資料來源的位置或網址，才能接收資料顯示。

IDV 下載網頁：

http://www.unidata.ucar.edu/software/idv/

今年 NCAR 在 AOAWS 的 tamc-wmds1/2 主機架設 EDSS 子系統，其架構如圖 12、圖 13，圖 14 所示，新增處理程序如下：

●應用程序

A.Mdv2NetCDF：轉換 mdv 資料為 netCDF 格式。

B.Spdb2NetCDF：轉換 spdb 資料為 netCDF 格式。

C.LdataMultWatcher：將傳輸資料加入 LDM 程序中。

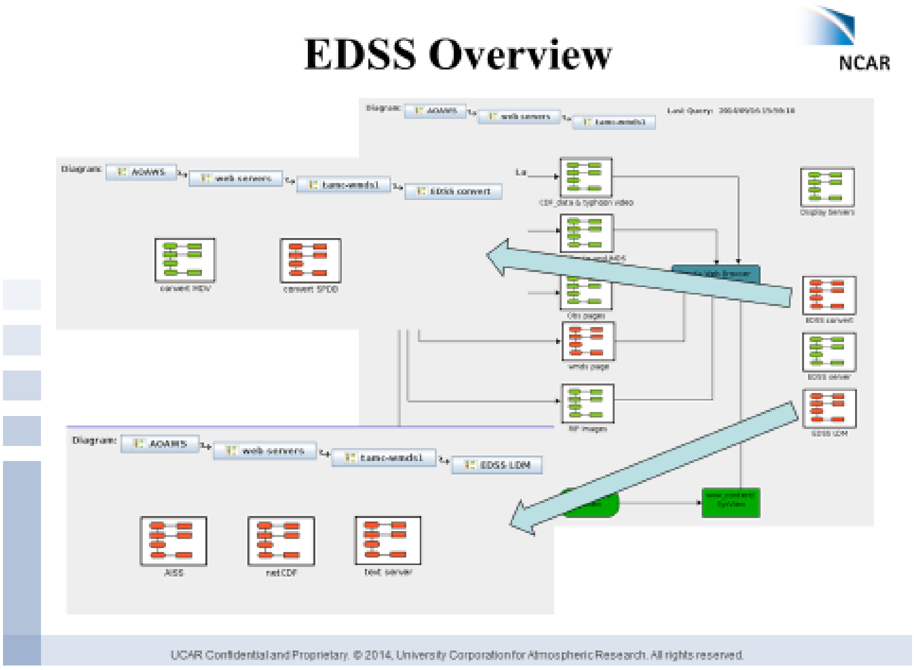
D.MdvCombine：合併 MTSAT 衛星 mdv 資料。

●控制流程

A.netcdf_ldm_insert.py：加入 netCDF 於 LDM 中。

B.textserver_ldm_insert.py：加入 textserver 於 LDM 中。

C.Janitor parameter file：資料管理控制參數表



## EDSS Overview

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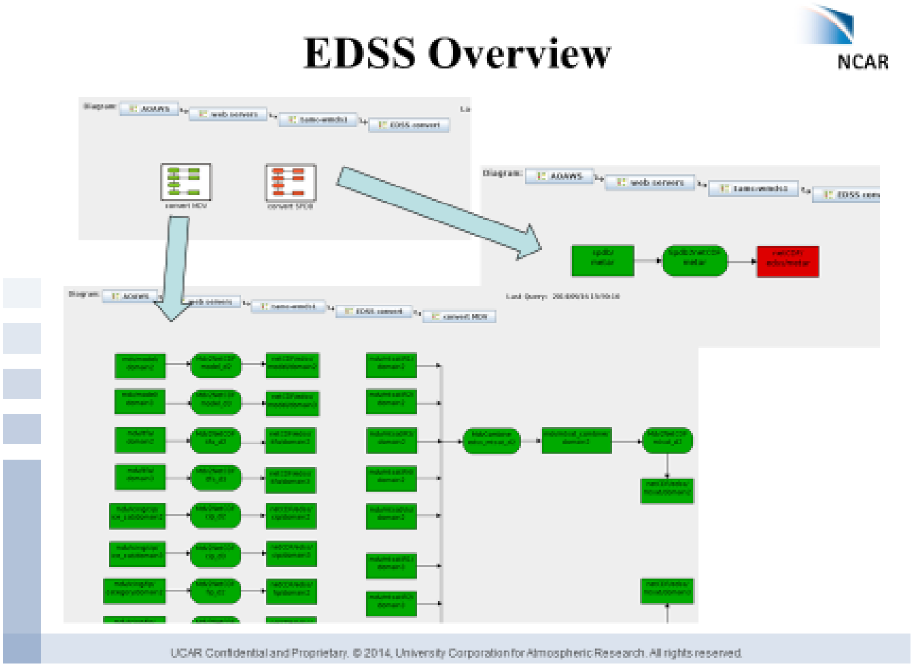
圖 12 tamc-wmds1 主機 EDSS 流程



## EDSS Overview

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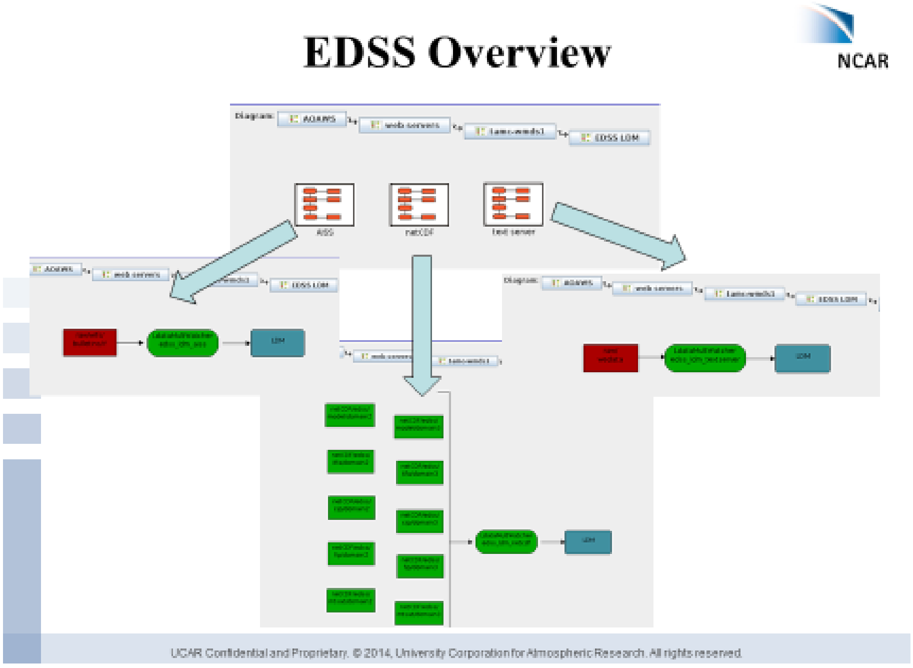
圖 13 tamc-wmds1 主機 EDSS 轉換 mdv 與 spdb 資料



EDSS Overview

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圖 14　tamc-wmds1 主機 EDSS 傳輸資料（AISS、netCDF 與 text-server）

# 肆、建議

職等參與 NCAR 舉辦的訓練課程收穫良多，除了可以廣泛了解 AOAWS 整體架構外，還能學習 NCAR 研究人員在開發相關產品時所面臨的問題與解決問題的方式。第一週與第三週在 NCAR 的 RAP 實驗室學習 AOAWS 更新項目，包含積冰與亂流產品演算法更新、MOS 預報模式及預報校驗系統、資料顯示系統更新、AOAWS 模擬環境和外部資料服務系統（EDSS）等，因為 EDSS 系統使用 Unidata 開發工具，第二週則到 UCAR 的 Unidata 部門學習資料傳輸工具（LDM、TDS、netCDF 與 IDV），課程內容相當豐富，雖然訓練時間短暫，教官仍竭盡所能將最新資訊與系統介紹給職等，讓職等更加了解 AOAWS 發展。

雖然今年是 AOAWS 第三期計畫最後一年，但是 NCAR 仍努力在今年更新多項預報產品與資料傳輸系統，使 AOAWS 更加完備，提供更多元化的航空氣象資料產品服務。為了協助未來與下游使用者資料傳輸便利，特別開發 EDSS 資料傳輸系統，並與 Unidata 部門合作針對 AOAWS 設計適用的資料傳輸系統。職等在 Unidata 學習相關工具，並且瞭解有多個國家都使用 LDM 系統來傳輸資料。未來需要更深入研究 AOAWS 的 EDSS 系統，有機會應該推廣給下游使用者。

MOS 預報模式提供 WRF 數值預報模式缺少的雲冪與能見度預報產品，讓預報員多了可參考的依據，但其顯示方式與產品特性仍需有相關文件讓預報員了解，並且透過更多的校驗結果，才能讓預報員對此模式預報結果增加參考的信心度。即將上線的 NTDA 亂流偵測演算法產品，利用雷達資料來改進亂流偵測演算法，從今年 4 個臺北飛航情報區的研究個案顯示，能有效提供亂流偵測資訊，對於未來亂流偵測與預報提供重要的參考。

以下為職等此次研習之建議：

## 一、建置 AOAWS 模擬環境

今年是與 NCAR 合作 AOAWS 第三期計畫最後一年，明年開始將由氣象中心與委外維護廠商共同維護 AOAWS 運作，而 AOAWS 是個複雜且龐大的系統，若有任何變動可能牽一髮而動全身，貿然對線上運行中的系統進行變動，無法完全評估於其可能造成的影響，例如：（1）WRF 數值預報模式解析度提升後，是否能順利產製下游航空氣象服務產品？（2）新的觀測資料，如：衛星資料與雷達資料等，對於新的資料格式，現行 AOAWS 能否正確解碼資料？（3）在現行航空氣象預報產品中仍有部分需要改進，是否有能力可以進入預報模式中修改程式？以上都是未來系統維護後所可能遇到的狀況。NCAR 在此次訓練中提供架設 AOAWS 模擬實驗室概念與方法，建置現行 AOAWS 模擬環境。若日後有程式修改、新資料引入時，先由 AOAWS 模擬環境測試，評估其輸出的產品是否合乎預期、產品輸出的效果以及對於系統穩定性的影響…等等，確認一切符合需求後，再更新線上的 AOAWS 作業系統，這也是目前 NCAR 研發人員在開發新系統或是系統除錯時所用的方法，故建議建置 AOAWS 模擬環境，以俾未來維護工作之順利。

## 二、建置及推廣外部資料服務策略

外部資料服務為本次研習重點之一，職等在 NCAR Unidata 學習如何在筆記型電腦上，利用 Linux 模擬器安裝內部資料管理（Local Data Manger；LDM）與主題即時環境分布數據服務資料系統（Thematic Real-time Environmental Distributed Data Services；TREDDS Data Server；TDS）。安裝過程都很順利，且可以正常運作，但筆記型電腦並不適合用來當作工作站

進行資料傳輸。建議俟建立 AOAWS 測試環境後，先行在內部建立模擬測試環境，利用模擬測試環境完整地評估外部資料服務提供之資料種類、傳輸資料量、網路頻寬限制以及符合資訊安全等，經由內部模擬環境測試評估後，需與總臺相關單位開會討論提供資料給外部單位的管理規定，待總臺核准後，再以網頁或書面公告通知使用者。依需求可邀請相關下游使用者參加外部資料服務系統說明會或教育訓練，彙整使用者相關意見後，再開放外部資料服務系統，以提供更穩定且符合使用者需求的 AOAWS 外部資料服務。

## 三、持續接觸最新的預報技術與產品

航空氣象現代化作業系統歷經 17 年之發展，目前已建立一套具世界一流水準的航空氣象預測報產品系統，並且能隨時引入新的觀測資料來源進入系統顯示或演算診斷，然而科技發展日新月異，未來新的技術或資料與現行系統整合的難度必定逐漸提升，掌握最新預測報科技與應用產品的技術與發展成果，有助於及早規劃因應新科技的發展，以提供符合世界先進水準的預測報產品。因此建議適時派員至 NCAR 或國際相關研究中心研習，持續不間斷地學習世界先進預測報及系統發展科技，以增進臺北飛航情報區預報能力與服務品質。

# 伍、攜回之參考資料

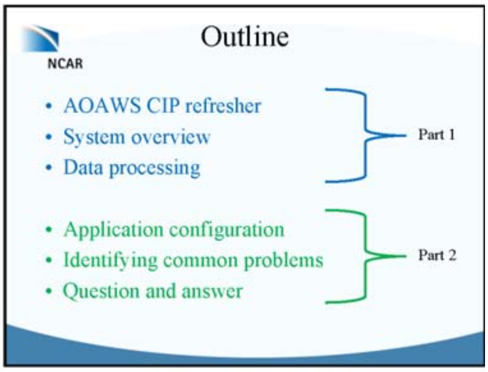
## 一、*Current Icing Product（CIP）*


NCAR

Current Icing Product (CIP): System Overview, Configuration and Troubleshooting

**Dan Adriaansen**
**Paul Prestopnik**
**04 September 2014**

National Center for Atmospheric Research


NCAR

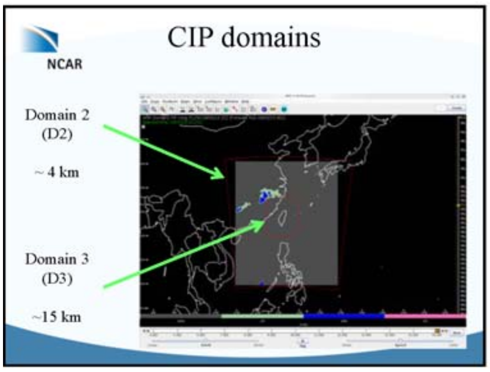
Outline

- AOAWS CIP refresher
- System overview
- Data processing

Part 1

- Application configuration
- Identifying common problems
- Question and answer

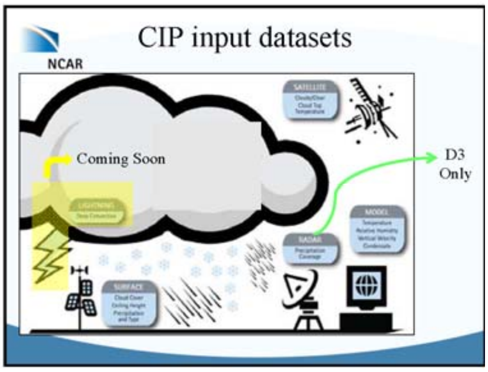
Part 2


NCAR

CIP domains

Domain 2 (D2)
~ 4 km

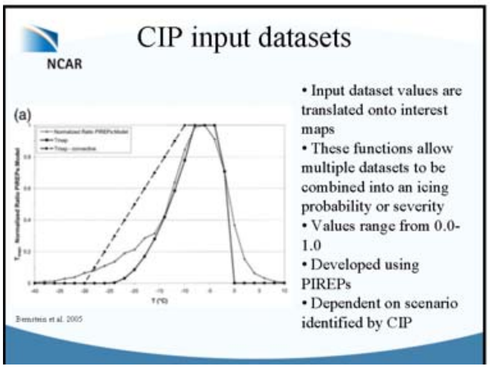
Domain 3 (D3)
~15 km


NCAR

CIP input datasets

Coming Soon

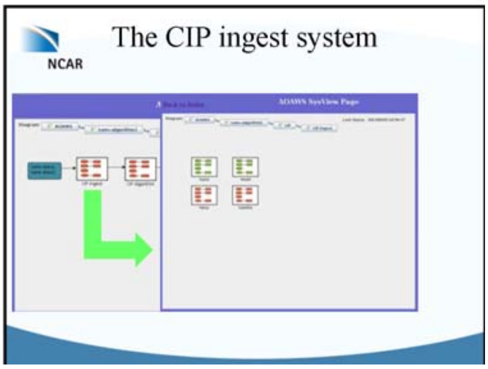
D3 Only


NCAR

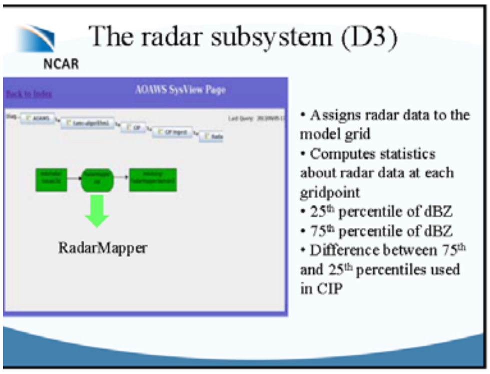
CIP input datasets

Bernstein et al. 2005

- Input dataset values are translated onto interest maps
- These functions allow multiple datasets to be combined into an icing probability or severity
- Values range from 0.0-1.0
- Developed using PIREPs
- Dependent on scenario identified by CIP


NCAR

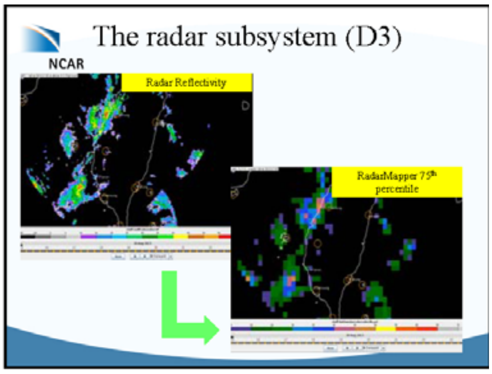
The CIP ingest system



### The radar subsystem (D3)

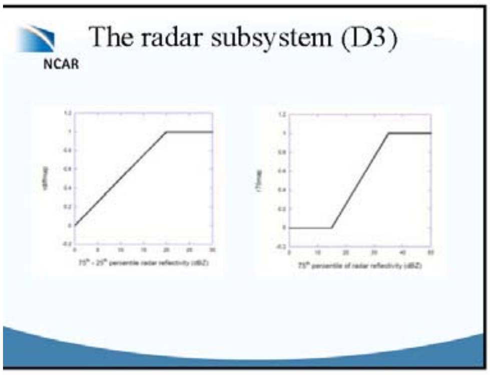
NCAR

- Assigns radar data to the model grid
- Computes statistics about radar data at each gridpoint
- 25th percentile of dBZ
- 75th percentile of dBZ
- Difference between 75th and 25th percentiles used in CIP



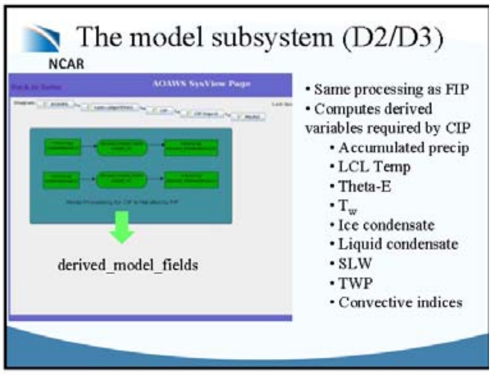
### The radar subsystem (D3)

NCAR



### The radar subsystem (D3)

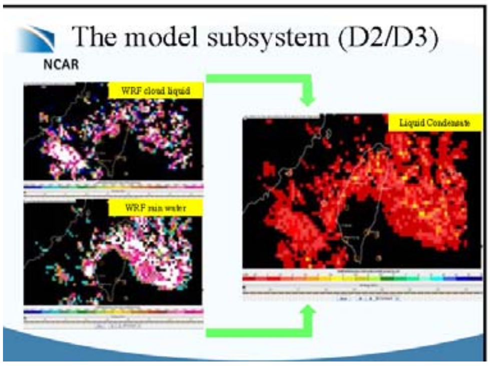
NCAR



### The model subsystem (D2/D3)

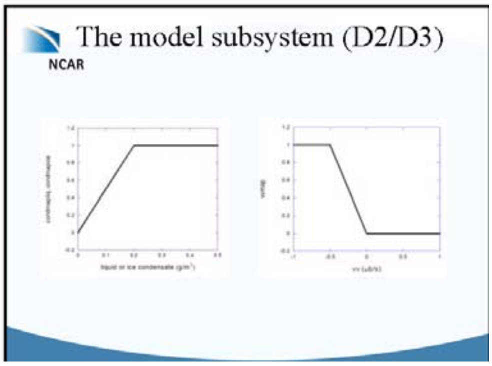
NCAR

- Same processing as FIP
- Computes derived variables required by CIP
  - Accumulated precip
  - LCL Temp
  - Theta-E
  - $T_w$
  - Ice condensate
  - Liquid condensate
  - SLW
  - TWP
  - Convective indices



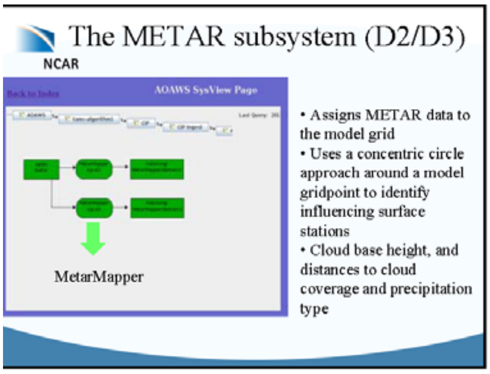
### The model subsystem (D2/D3)

NCAR



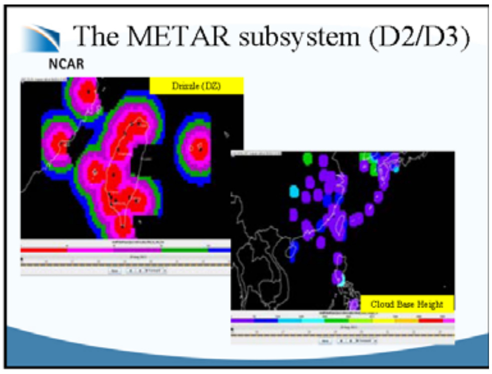
### The model subsystem (D2/D3)

NCAR

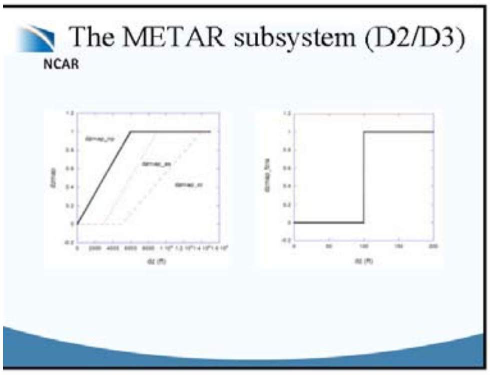


## The METAR subsystem (D2/D3)

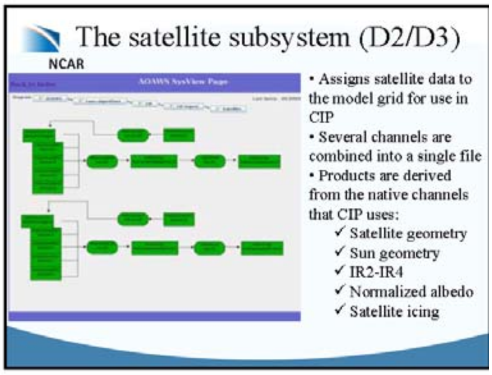
- Assigns METAR data to the model grid
- Uses a concentric circle approach around a model gridpoint to identify influencing surface stations
- Cloud base height, and distances to cloud coverage and precipitation type



## The METAR subsystem (D2/D3)

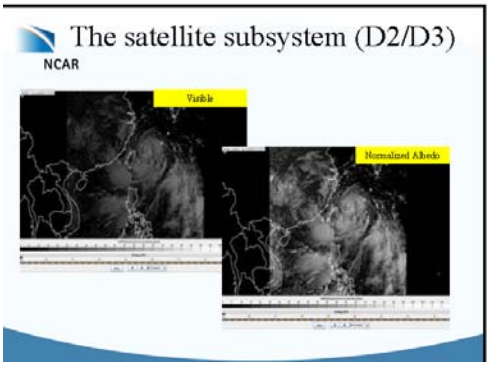


## The METAR subsystem (D2/D3)

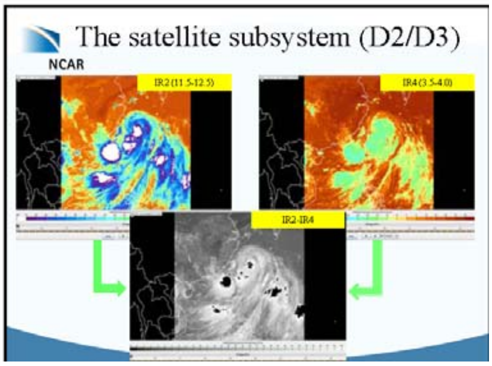


## The satellite subsystem (D2/D3)

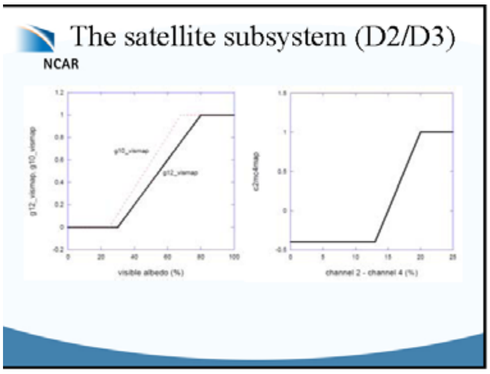
- Assigns satellite data to the model grid for use in CIP
- Several channels are combined into a single file
- Products are derived from the native channels that CIP uses:
  - ✓ Satellite geometry
  - ✓ Sun geometry
  - ✓ IR2-IR4
  - ✓ Normalized albedo
  - ✓ Satellite icing



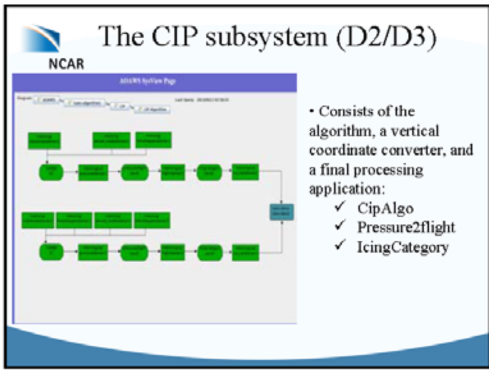
## The satellite subsystem (D2/D3)



## The satellite subsystem (D2/D3)

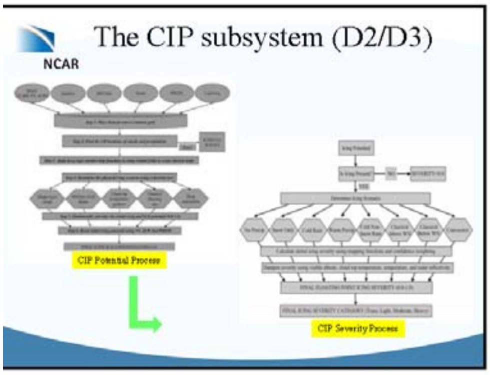


### The satellite subsystem (D2/D3)

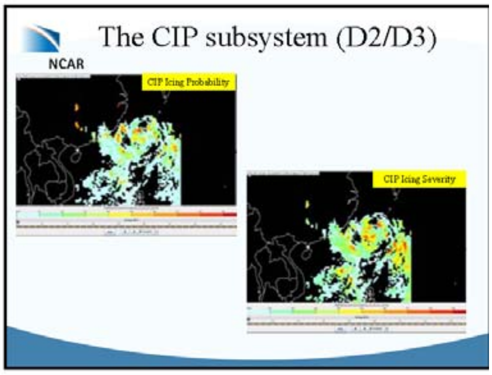


### The CIP subsystem (D2/D3)

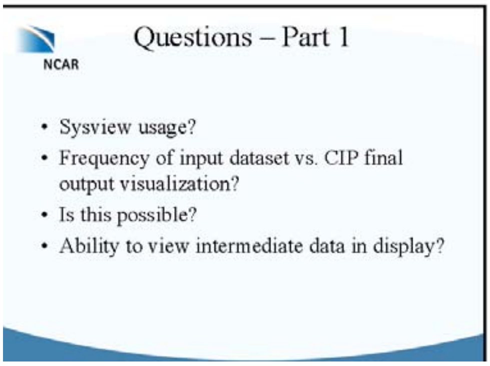
- Consists of the algorithm, a vertical coordinate converter, and a final processing application:
  - ✓ CipAlgo
  - ✓ Pressure2flight
  - ✓ IcingCategory



### The CIP subsystem (D2/D3)

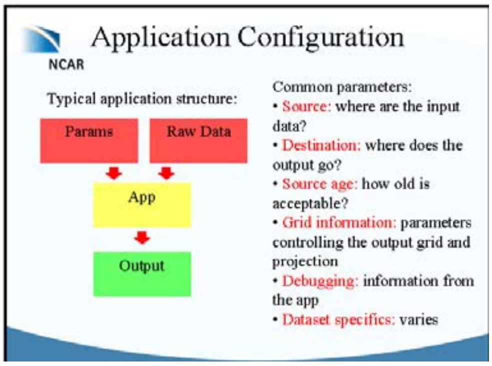


### The CIP subsystem (D2/D3)



### Questions – Part 1

- Sysview usage?
- Frequency of input dataset vs. CIP final output visualization?
- Is this possible?
- Ability to view intermediate data in display?



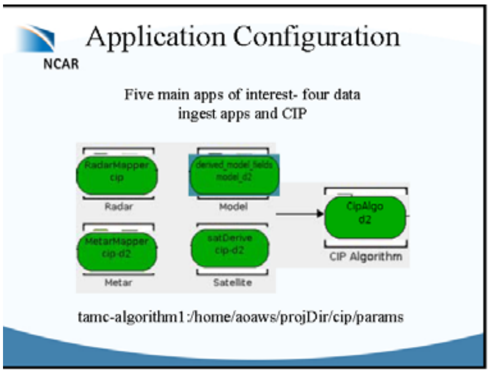
### Application Configuration

Typical application structure:

Params
Raw Data
App
Output

Common parameters:

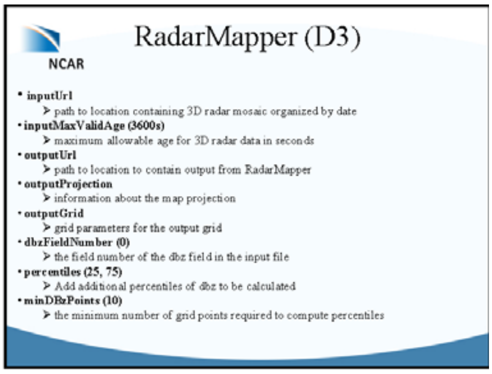
- Source: where are the input data?
- Destination: where does the output go?
- Source age: how old is acceptable?
- Grid information: parameters controlling the output grid and projection
- Debugging: information from the app
- Dataset specifics: varies



## Application Configuration

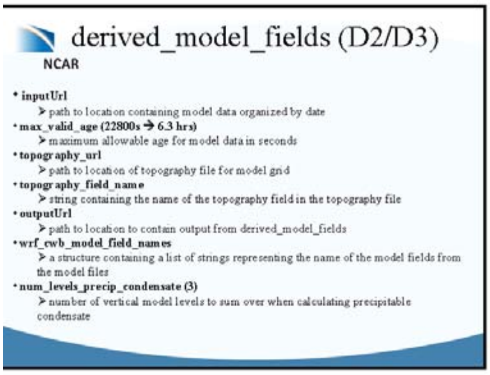
Five main apps of interest- four data ingest apps and CIP

tamc-algorithm1:/home/aoaws/projDir/cip/params



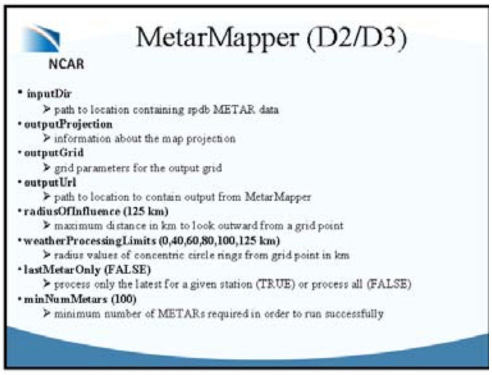
## RadarMapper (D3)

- **inputUrl**
  - path to location containing 3D radar mosaic organized by date
- **inputMaxValidAge (3600s)**
  - maximum allowable age for 3D radar data in seconds
- **outputUrl**
  - path to location to contain output from RadarMapper
- **outputProjection**
  - information about the map projection
- **outputGrid**
  - grid parameters for the output grid
- **dbzFieldNumber (0)**
  - the field number of the dbz field in the input file
- **percentiles (25, 75)**
  - Add additional percentiles of dbz to be calculated
- **minDBzPoints (10)**
  - the minimum number of grid points required to compute percentiles



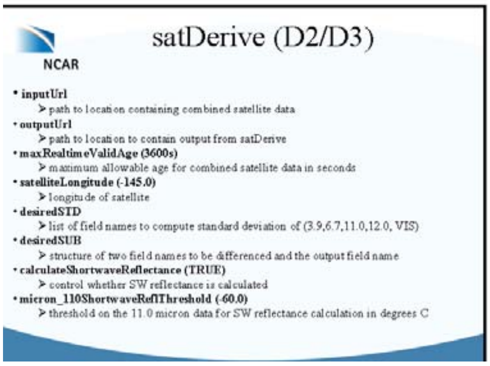
## derived_model_fields (D2/D3)

- **inputUrl**
  - path to location containing model data organized by date
- **max_valid_age (22800s → 6.3 hrs)**
  - maximum allowable age for model data in seconds
- **topography_url**
  - path to location of topography file for model grid
- **topography_field_name**
  - string containing the name of the topography field in the topography file
- **outputUrl**
  - path to location to contain output from derived_model_fields
- **wrf_cwb_model_field_names**
  - a structure containing a list of strings representing the name of the model fields from the model files
- **num_levels_precip_condensate (3)**
  - number of vertical model levels to sum over when calculating precipitable condensate



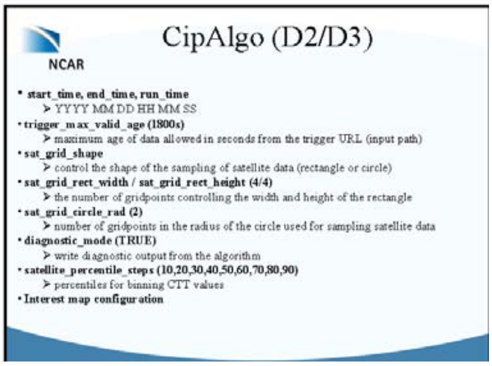
## MetarMapper (D2/D3)

- **inputDir**
  - path to location containing spdb METAR data
- **outputProjection**
  - information about the map projection
- **outputGrid**
  - grid parameters for the output grid
- **outputUrl**
  - path to location to contain output from MetarMapper
- **radiusOfInfluence (125 km)**
  - maximum distance in km to look outward from a grid point
- **weatherProcessingLimits (0,40,60,80,100,125 km)**
  - radius values of concentric circle rings from grid point in km
- **lastMetarOnly (FALSE)**
  - process only the latest for a given station (TRUE) or process all (FALSE)
- **minNumMetars (100)**
  - minimum number of METARs required in order to run successfully



## satDerive (D2/D3)

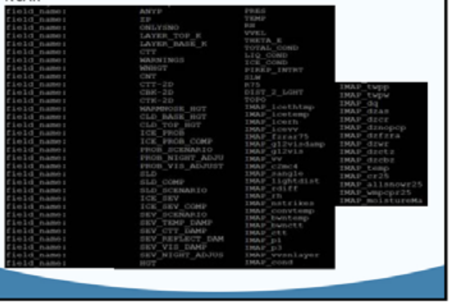
- **inputUrl**
  - path to location containing combined satellite data
- **outputUrl**
  - path to location to contain output from satDerive
- **maxRealtimeValidAge (3600s)**
  - maximum allowable age for combined satellite data in seconds
- **satelliteLongitude (-145.0)**
  - longitude of satellite
- **desiredSTD**
  - list of field names to compute standard deviation of (3.9,6.7,11.0,12.0, VIS)
- **desiredSUB**
  - structure of two field names to be differenced and the output field name
- **calculateShortwaveReflectance (TRUE)**
  - control whether SW reflectance is calculated
- **micron_110ShortwaveReflThreshold (-60.0)**
  - threshold on the 11.0 micron data for SW reflectance calculation in degrees C



## CipAlgo (D2/D3)

- **start_time, end_time, run_time**
  - YYYY MM DD HH MM SS
- **trigger_max_valid_age (1800s)**
  - maximum age of data allowed in seconds from the trigger URL (input path)
- **sat_grid_shape**
  - control the shape of the sampling of satellite data (rectangle or circle)
- **sat_grid_rect_width / sat_grid_rect_height (4/4)**
  - the number of gridpoints controlling the width and height of the rectangle
- **sat_grid_circle_rad (2)**
  - number of gridpoints in the radius of the circle used for sampling satellite data
- **diagnostic_mode (TRUE)**
  - write diagnostic output from the algorithm
- **satellite_percentile_steps (10,20,30,40,50,60,70,80,90)**
  - percentiles for binning CTT values
- **Interest map configuration**

## CipAlgo diagnostic output



```
field_name:          ANYP                PRES
field_name:          IP                  TEMP
field_name:          ONLYSNO             RH
field_name:          LAYER_TOP_K         VVEL
field_name:          LAYER_BASE_K        THETA_E
field_name:          CTT                 TOTAL_COND
field_name:          WARNINGS            LIQ_COND
field_name:          WNHGT               ICE_COND
field_name:          CNT                 PIREP_INTRT
field_name:          CTT-2D              SLW
field_name:          CBK-2D              R75              IMAP_twpp
field_name:          CTK-2D              DIST_2_LGHT      IMAP_twpw
field_name:          WARMNOSE_HGT        TOPO             IMAP_dq
field_name:          CLD_BASE_HGT        IMAP_icethtmp    IMAP_dzas
field_name:          CLD_TOP_HGT         IMAP_icetemp     IMAP_dzcr
field_name:          ICE_PROB            IMAP_iceth       IMAP_dznopcp
field_name:          ICE_PROB_COMP       IMAP_icevv       IMAP_dzfzra
field_name:          PROB_SCENARIO       IMAP_fzrar75     IMAP_dzwr
field_name:          PROB_NIGHT_ADJU     IMAP_g12visdamp  IMAP_dzctz
field_name:          PROB_VIS_ADJUST     IMAP_g12vis      IMAP_dzcbz
field_name:          SLD                 IMAP_vv          IMAP_temp
field_name:          SLD_COMP            IMAP_c2mc4       IMAP_cr25
field_name:          SLD_SCENARIO        IMAP_sangle      IMAP_allsnowr25
field_name:          ICE_SEV             IMAP_lightdist   IMAP_wmpcpr25
field_name:          ICE_SEV_COMP        IMAP_rdiff       IMAP_moistureMa
field_name:          SEV_SCENARIO        IMAP_rh
field_name:          SEV_TEMP_DAMP       IMAP_nstrikes
field_name:          SEV_CTT_DAMP        IMAP_convtemp
field_name:          SEV_REFLECT_DAM     IMAP_bwntemp
field_name:          SEV_VIS_DAMP        IMAP_bwnctt
field_name:          SEV_NIGHT_ADJUS     IMAP_ctt
field_name:          HGT                 IMAP_p1
                                         IMAP_p3
                                         IMAP_vvenlayer
                                         IMAP_cond
```

## CipAlgo troubleshooting

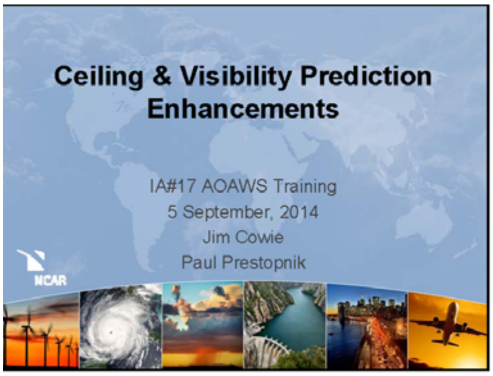
- **Missing input datasets**
- **Data too old**
- **Incorrect data format**
- **Partial dataset**
- **Intermediate apps**

tamc-algorithm1:/d1/aoaws/data/logs/errors/today/

## Questions – Part 2

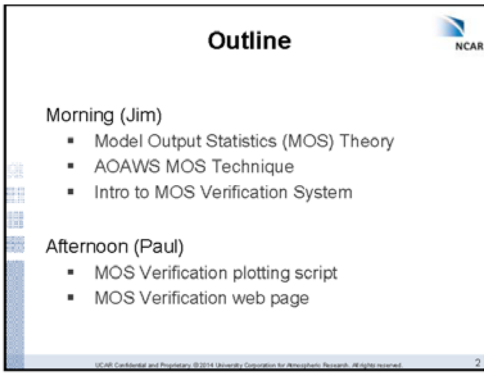
- Need for archived runs?
- Diagnostic output?
- CIP literature

# 二、*Ceiling & Visibility Prediction Enhancements*（*C&V CIP*）



## Ceiling & Visibility Prediction Enhancements

IA#17 AOAWS Training
5 September, 2014
Jim Cowie
Paul Prestopnik



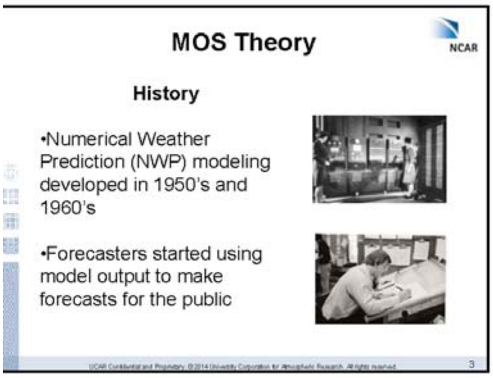
## Outline

Morning (Jim)

- Model Output Statistics (MOS) Theory
- AOAWS MOS Technique
- Intro to MOS Verification System

Afternoon (Paul)

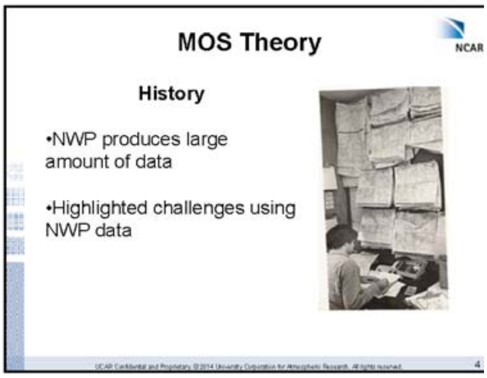
- MOS Verification plotting script
- MOS Verification web page



## MOS Theory

### History

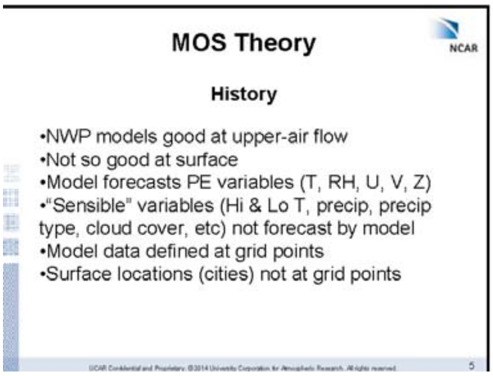
- Numerical Weather Prediction (NWP) modeling developed in 1950's and 1960's
- Forecasters started using model output to make forecasts for the public



## MOS Theory

### History

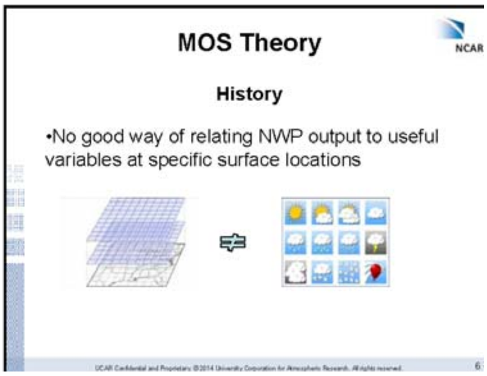
- NWP produces large amount of data
- Highlighted challenges using NWP data



## MOS Theory

### History

- NWP models good at upper-air flow
- Not so good at surface
- Model forecasts PE variables (T, RH, U, V, Z)
- "Sensible" variables (Hi & Lo T, precip, precip type, cloud cover, etc) not forecast by model
- Model data defined at grid points
- Surface locations (cities) not at grid points



## MOS Theory

### History

- No good way of relating NWP output to useful variables at specific surface locations

## MOS Theory

### History

- •Model Output Statistics (MOS) attempts to solve this problem
- •Pioneered by US National Weather Service in 1960's and 1970's (Glahn, Lowry, Klein)
- •Objective way to relate NWP output with surface variables at specific locations
- •Statistics used to derive relationships between model data and observation points
- •Technique has been used for decades

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## MOS Theory

### Some Operational MOS Products

- NWS MAV (72 hr MOS based on GFS)
- NWS MET (72 hr MOS based on NAM)
- NWS MEX (7 day MOS based on GFS)
- NWS LAMP (24 hr MOS based on GFS +)
- Canadian MOS
- Australian MOS

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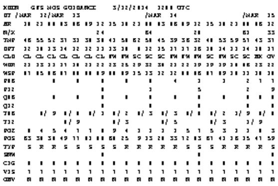
## MOS Theory

### Example: MAV MOS



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## MOS Theory

### Benefits of MOS

- •Condenses large volumes of model data to small number of forecasts at specific points
- •Allows the forecast of variables not predicted natively by the model
- •Can be applied to any model provided adequate training history exists
- •Removes (average) model bias at forecast locations

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## MOS Theory

### Challenges of MOS

- •Requires training history (years) of model and observation data to develop MOS equations*
- •Models should be static*
- •Site locations should not move*
- •Addition of new sites may not be possible until observation history is available
- •Sample size for some events may be small
- •Does not remove model error

* For optimal MOS performance

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## MOS Theory

### Creating MOS Equations

- •We want to forecast a predictand variable using one or more predictors
- •The predictors are variables from a model (example: WRF)
- •The predictands are the observation (METAR) elements
- •Linear regression is used to relate predictors and predictands

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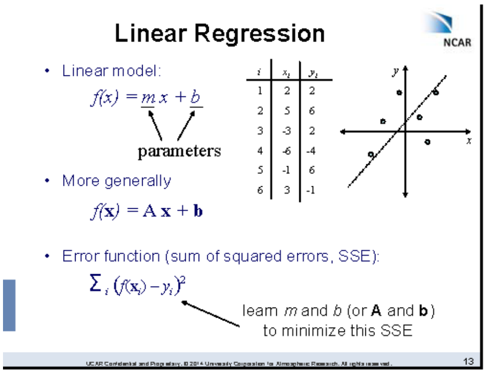

### Linear Regression

- Linear model:

$$f(x) = \underline{m}\, x + \underline{b}$$

parameters

| $i$ | $x_i$ | $y_i$ |
|---|---|---|
| 1 | 2 | 2 |
| 2 | 5 | 6 |
| 3 | -3 | 2 |
| 4 | -6 | -4 |
| 5 | -1 | 6 |
| 6 | 3 | -1 |

- More generally

$$f(\mathbf{x}) = \mathbf{A}\,\mathbf{x} + \mathbf{b}$$

- Error function (sum of squared errors, SSE):

$$\sum_i (f(\mathbf{x}_i) - y_i)^2$$

learn *m* and *b* (or **A** and **b**) to minimize this SSE

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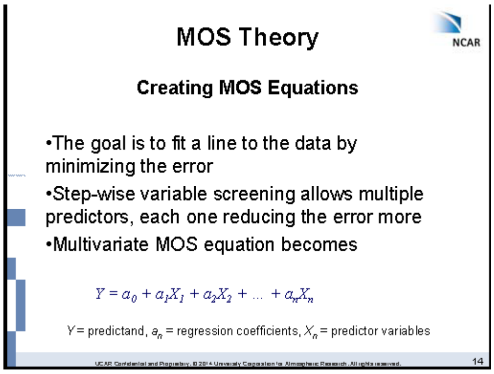

### MOS Theory

**Creating MOS Equations**

- •The goal is to fit a line to the data by minimizing the error
- •Step-wise variable screening allows multiple predictors, each one reducing the error more
- •Multivariate MOS equation becomes

$$Y = a_0 + a_1X_1 + a_2X_2 + \ldots + a_nX_n$$

$Y$ = predictand, $a_n$ = regression coefficients, $X_n$ = predictor variables

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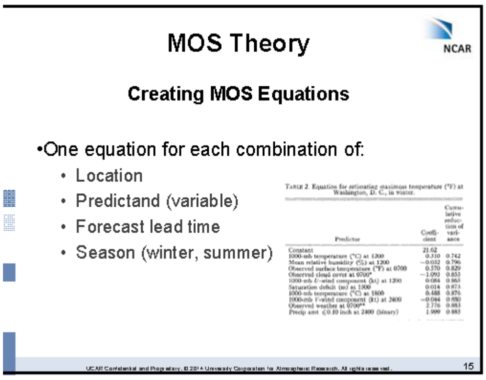

### MOS Theory

**Creating MOS Equations**

•One equation for each combination of:

- Location
- Predictand (variable)
- Forecast lead time
- Season (winter, summer)

TABLE 2. Equation for estimating maximum temperature (°F) at Washington, D. C., in winter.

| Predictor | Coefficient | Cumulative reduction of variance |
|---|---|---|
| Constant | 21.62 | |
| 1000-mb temperature (°C) at 1200 | 0.310 | 0.742 |
| Mean relative humidity (%) at 1200 | −0.032 | 0.796 |
| Observed surface temperature (°F) at 0700 | 0.570 | 0.829 |
| Observed cloud cover at 0700* | −1.093 | 0.853 |
| 1000-mb *U*-wind component (kt) at 1200 | 0.084 | 0.865 |
| Saturation deficit (m) at 1500 | 0.014 | 0.873 |
| 1000-mb temperature (°C) at 1800 | 0.488 | 0.876 |
| 1000-mb *V*-wind component (kt) at 2400 | −0.044 | 0.880 |
| Observed weather at 0700** | 2.776 | 0.883 |
| Precip amt ≤0.10 inch at 2400 (binary) | 1.999 | 0.885 |

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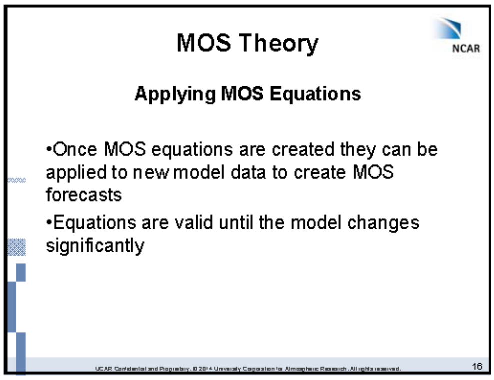

### MOS Theory

**Applying MOS Equations**

- •Once MOS equations are created they can be applied to new model data to create MOS forecasts
- •Equations are valid until the model changes significantly

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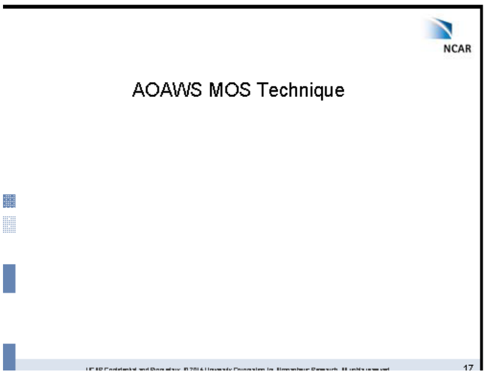

AOAWS MOS Technique

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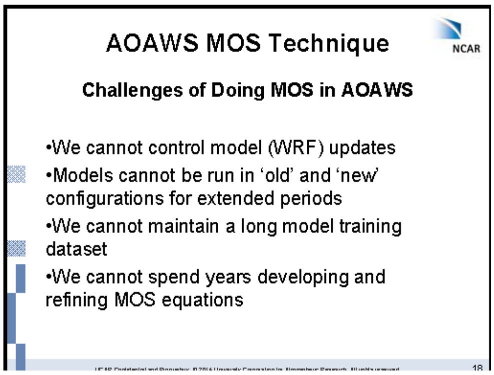

### AOAWS MOS Technique

**Challenges of Doing MOS in AOAWS**

- •We cannot control model (WRF) updates
- •Models cannot be run in ‘old’ and ‘new’ configurations for extended periods
- •We cannot maintain a long model training dataset
- •We cannot spend years developing and refining MOS equations

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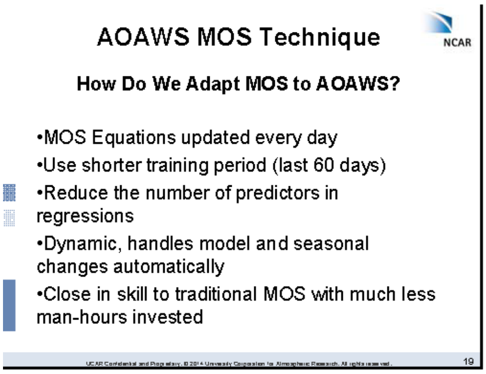

## AOAWS MOS Technique

### How Do We Adapt MOS to AOAWS?

- •MOS Equations updated every day
- •Use shorter training period (last 60 days)
- •Reduce the number of predictors in regressions
- •Dynamic, handles model and seasonal changes automatically
- •Close in skill to traditional MOS with much less man-hours invested

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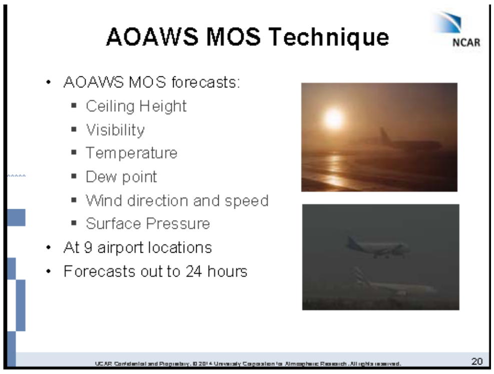

## AOAWS MOS Technique

- AOAWS MOS forecasts:
  - Ceiling Height
  - Visibility
  - Temperature
  - Dew point
  - Wind direction and speed
  - Surface Pressure
- At 9 airport locations
- Forecasts out to 24 hours

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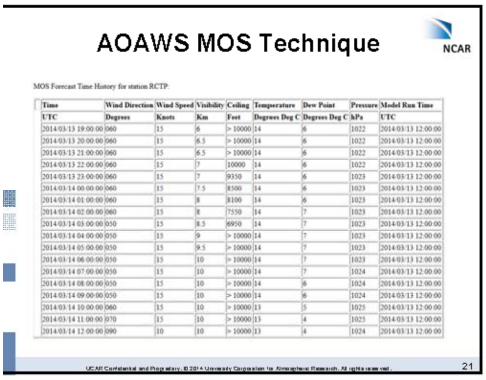

## AOAWS MOS Technique

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 |
| 2014/03/13 19:00:00 | 060 | 15 | 6 | > 10000 | 14 | 6 | 1022 | 2014/03/13 12:00:00 |
| 2014/03/13 20:00:00 | 060 | 15 | 6.5 | > 10000 | 14 | 6 | 1022 | 2014/03/13 12:00:00 |
| 2014/03/13 21:00:00 | 060 | 15 | 6.5 | > 10000 | 14 | 6 | 1022 | 2014/03/13 12:00:00 |
| 2014/03/13 22:00:00 | 060 | 15 | 7 | 10000 | 14 | 6 | 1022 | 2014/03/13 12:00:00 |
| 2014/03/13 23:00:00 | 060 | 15 | 7 | 9350 | 14 | 6 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 00:00:00 | 060 | 15 | 7.5 | 8500 | 14 | 6 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 01:00:00 | 060 | 15 | 8 | 8100 | 14 | 6 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 02:00:00 | 060 | 15 | 8 | 7550 | 14 | 7 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 03:00:00 | 050 | 15 | 8.5 | 6950 | 14 | 7 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 04:00:00 | 050 | 15 | 9 | > 10000 | 14 | 7 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 05:00:00 | 050 | 15 | 9.5 | > 10000 | 14 | 7 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 06:00:00 | 050 | 15 | 10 | > 10000 | 14 | 7 | 1023 | 2014/03/13 12:00:00 |
| 2014/03/14 07:00:00 | 050 | 15 | 10 | > 10000 | 14 | 7 | 1024 | 2014/03/13 12:00:00 |
| 2014/03/14 08:00:00 | 050 | 15 | 10 | > 10000 | 14 | 6 | 1024 | 2014/03/13 12:00:00 |
| 2014/03/14 09:00:00 | 050 | 15 | 10 | > 10000 | 14 | 6 | 1024 | 2014/03/13 12:00:00 |
| 2014/03/14 10:00:00 | 060 | 15 | 10 | > 10000 | 13 | 5 | 1025 | 2014/03/13 12:00:00 |
| 2014/03/14 11:00:00 | 070 | 15 | 10 | > 10000 | 13 | 4 | 1025 | 2014/03/13 12:00:00 |
| 2014/03/14 12:00:00 | 090 | 10 | 10 | > 10000 | 13 | 4 | 1024 | 2014/03/13 12:00:00 |

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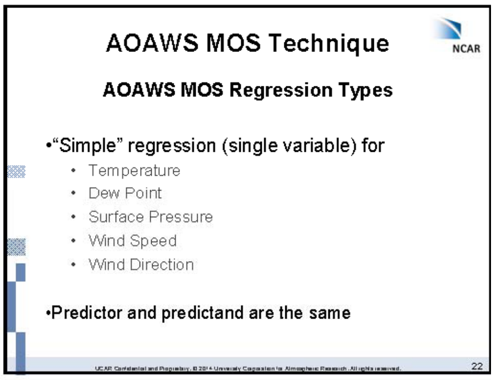

## AOAWS MOS Technique

### AOAWS MOS Regression Types

- •“Simple” regression (single variable) for
  - Temperature
  - Dew Point
  - Surface Pressure
  - Wind Speed
  - Wind Direction

•Predictor and predictand are the same

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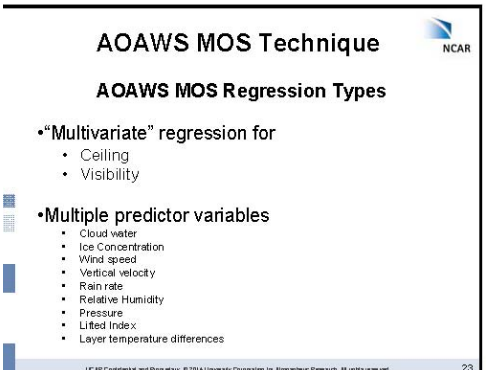

## AOAWS MOS Technique

### AOAWS MOS Regression Types

- •“Multivariate” regression for
  - Ceiling
  - Visibility

- •Multiple predictor variables
  - Cloud water
  - Ice Concentration
  - Wind speed
  - Vertical velocity
  - Rain rate
  - Relative Humidity
  - Pressure
  - Lifted Index
  - Layer temperature differences

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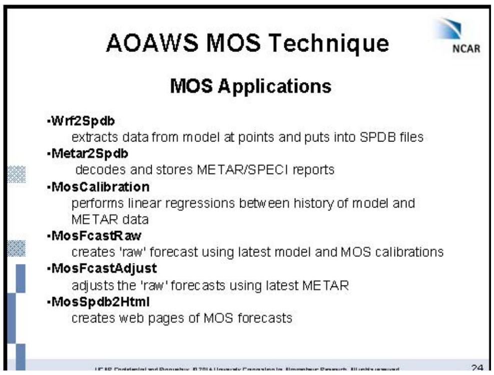

## AOAWS MOS Technique

### MOS Applications

**•Wrf2Spdb**
extracts data from model at points and puts into SPDB files

**•Metar2Spdb**
decodes and stores METAR/SPECI reports

**•MosCalibration**
performs linear regressions between history of model and METAR data

**•MosFcastRaw**
creates 'raw' forecast using latest model and MOS calibrations

**•MosFcastAdjust**
adjusts the 'raw' forecasts using latest METAR

**•MosSpdb2Html**
creates web pages of MOS forecasts

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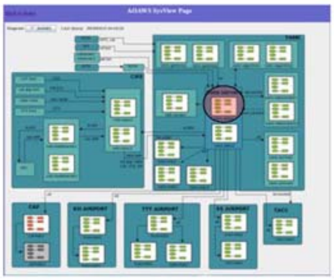
## AOAWS MOS Technique



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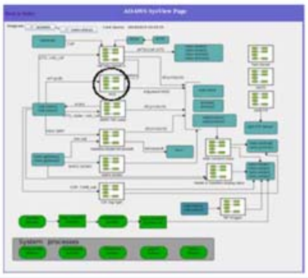
## AOAWS MOS Technique



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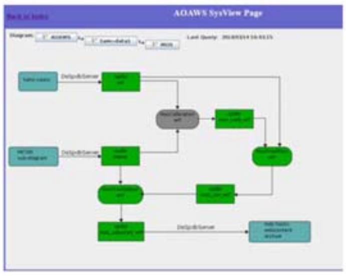
## AOAWS MOS Technique



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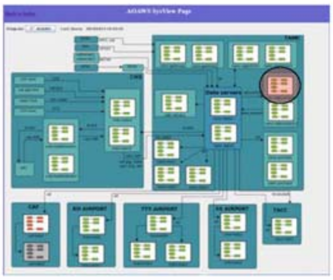
## AOAWS MOS Technique



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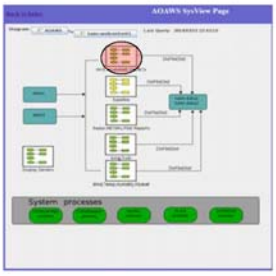
## AOAWS MOS Technique



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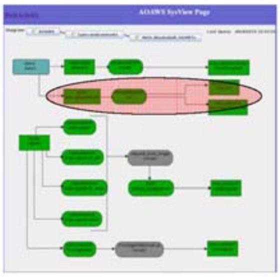
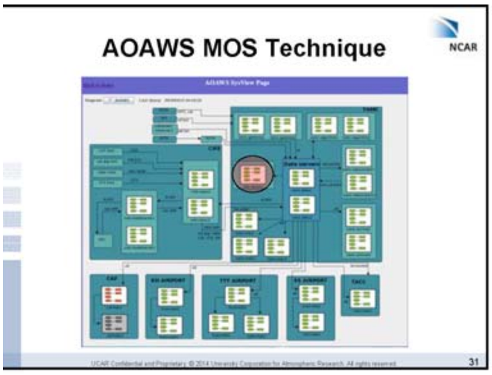
## AOAWS MOS Technique





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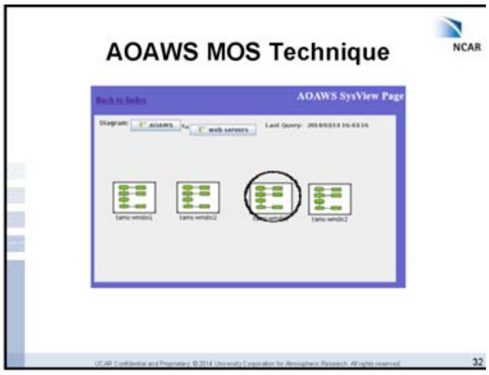

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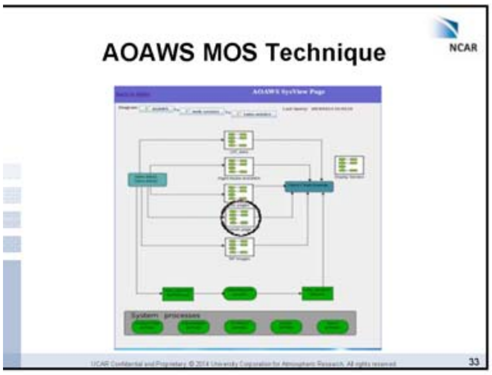

## AOAWS MOS Technique

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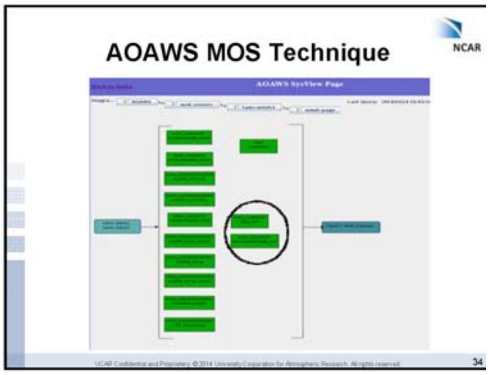

## AOAWS MOS Technique

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## AOAWS MOS Technique

### Wrf2Spdb

- Extracts data from inner WRF domain
- Airport METAR locations
- Bi-linearly interpolated
- All predictor variables
- 4 Updates per day
- Forecast times T+3 to T+24
- Stored in $DATA_DIR/spdb/wrf

## AOAWS MOS Technique

### Metar2Spdb

- Used by MOS system and other parts of AOAWS
- All METAR/SPECI decoded
- Several instances for different data feeds (gts, aftn, etc)
- Stored in $DATA_DIR/spdb/metar

## AOAWS MOS Technique

### MosCalibration

- Runs daily from cron to generate regression coefficients
- Regressions based on recent 60-day period
- Uses $DATA_DIR/spdb/wrf and metar
- Performs Simple and Multivariate regressions
- Different predictor coefficients for each predictand, location, forecast time
- MOS coefficients saved in $DATA_DIR/spdb/mos_calib_wrf

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## AOAWS MOS Technique

### MosFcastRaw

- Applies MOS coefficients to latest WRF data
- 'Raw' because they do not take into account the recent METAR
- For each location & forecast lead time
- Simple regression MOS equation
  - T(f) = T_const + T(wrf) * T_coeff
- Multivariate regression MOS equation
  - Vis(f) = vis_const + wspd(wrf) * wspd_coeff + rh(wrf) * rh_coeff + pres(wrf) * pres_coeff + ….. Etc
- 'Raw' forecasts saved in $DATA_DIR/spdb/mos_raw_wrf

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## AOAWS MOS Technique

### MosFcastAdjust

- Adjusts 'raw' forecast using latest METAR
- Adjustment is the difference between raw fcst and METAR
- Adjustment applied to all forecasts, decreasing linearly in time out to 12 hours
- Applied to all variables at each METAR location
- Adjusted forecasts saved in $DATA_DIR/spdb/mos_adjusted_wrf

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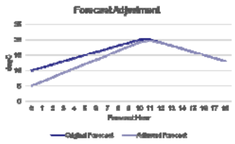
## AOAWS MOS Technique

### How is Adjustment Made?

**At forecast time 0:**

Original Forecast: 10 degC
METAR: 5 degC
Adjustment = 5-10 = -5 degC



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## AOAWS MOS Technique

### MosSpdb2Html

- Creates HTML from adjusted MOS forecasts
- Individual times: $DATA_DIR/www_content/Mos_wrf
- Time series including past METAR: $DATA_DIR/www_content/MosTrendTable_wrf

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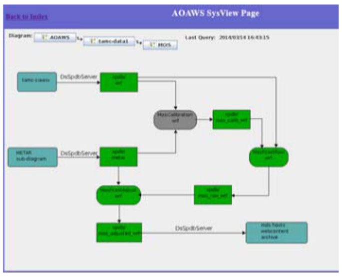
## AOAWS MOS Technique



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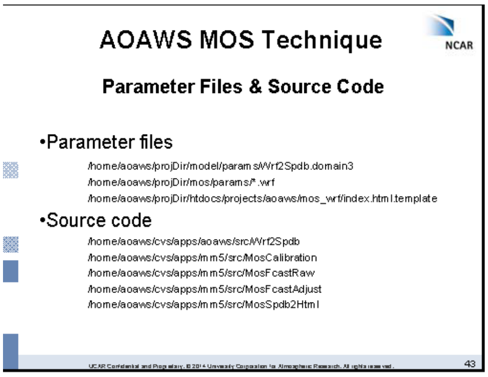

## AOAWS MOS Technique

### Parameter Files & Source Code

- Parameter files
  - /home/aoaws/projDir/model/params/Wrf2Spdb.domain3
  - /home/aoaws/projDir/mos/params/*.wrf
  - /home/aoaws/projDir/htdocs/projects/aoaws/mos_wrf/index.html.template
- Source code
  - /home/aoaws/cvs/apps/aoaws/src/Wrf2Spdb
  - /home/aoaws/cvs/apps/mm5/src/MosCalibration
  - /home/aoaws/cvs/apps/mm5/src/MosFcastRaw
  - /home/aoaws/cvs/apps/mm5/src/MosFcastAdjust
  - /home/aoaws/cvs/apps/mm5/src/MosSpdb2Html

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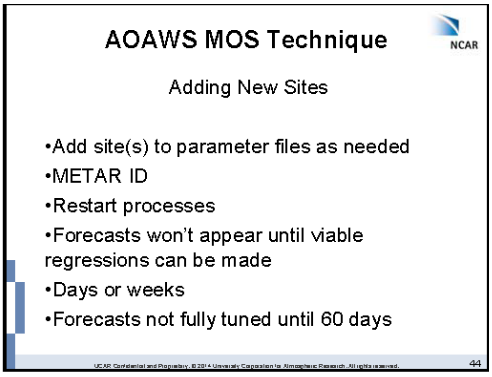

## AOAWS MOS Technique

### Adding New Sites

- Add site(s) to parameter files as needed
- METAR ID
- Restart processes
- Forecasts won't appear until viable regressions can be made
- Days or weeks
- Forecasts not fully tuned until 60 days

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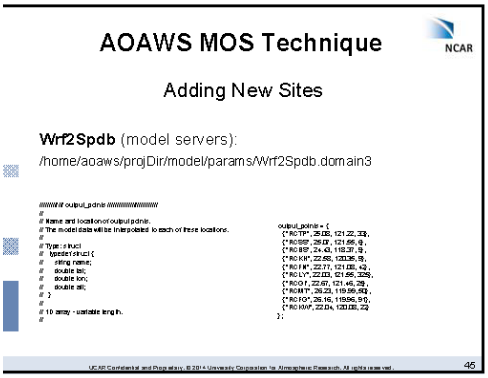

## AOAWS MOS Technique

### Adding New Sites

**Wrf2Spdb** (model servers):
/home/aoaws/projDir/model/params/Wrf2Spdb.domain3

```
///////////// output_points //////////////////////
//
// Name and location of output points.
// The model data will be interpolated to each of these locations.
//
// Type: struct
//   typedef struct {
//      string name;
//      double lat;
//      double lon;
//      double alt;
//   }
//
// 1D array - variable length.
//
```

```
output_points = {
  {"RCTP", 25.08, 121.22, 33},
  {"RCSS", 25.07, 121.55, 6},
  {"RCBS", 24.43, 118.37, 5},
  {"RCKH", 22.58, 120.35, 9},
  {"RCFN", 22.77, 121.08, 42},
  {"RCLY", 22.03, 121.55, 325},
  {"RCGI", 22.67, 121.46, 28},
  {"RCMT", 26.23, 119.99, 50},
  {"RCFG", 26.16, 119.96, 91},
  {"RCKW", 22.04, 120.08, 22}
};
```

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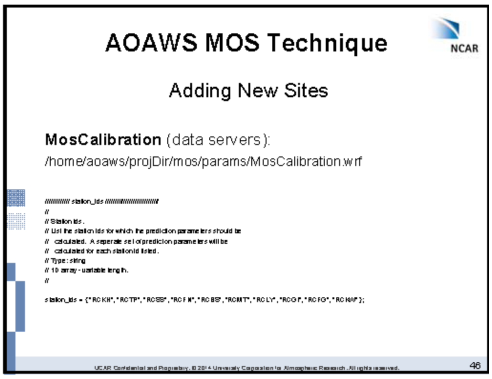

## AOAWS MOS Technique

### Adding New Sites

**MosCalibration** (data servers):
/home/aoaws/projDir/mos/params/MosCalibration.wrf

```
///////////// station_ids //////////////////////
//
// Station ids.
// List the station ids for which the prediction parameters should be
//   calculated.  A seperate set of prediction parameters will be
//   calculated for each stationid listed.
// Type: string
// 1D array - variable length.
//

station_ids = {"RCKH","RCTP","RCSS","RCFN","RCBS","RCMT","RCLY","RCGI","RCFG","RCKW"};
```

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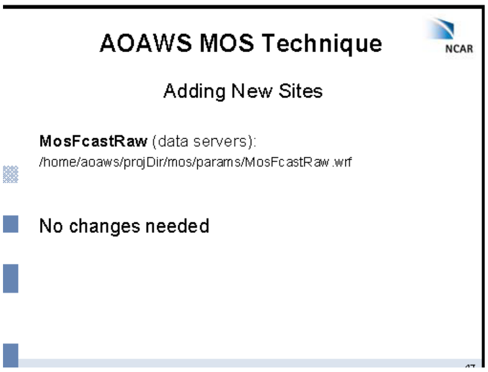
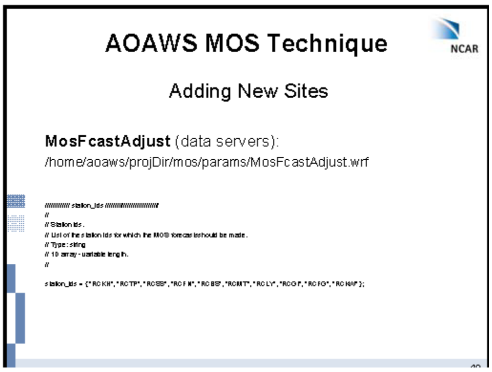


## AOAWS MOS Technique

### Adding New Sites

**MosFcastRaw** (data servers):
/home/aoaws/projDir/mos/params/MosFcastRaw.wrf

No changes needed



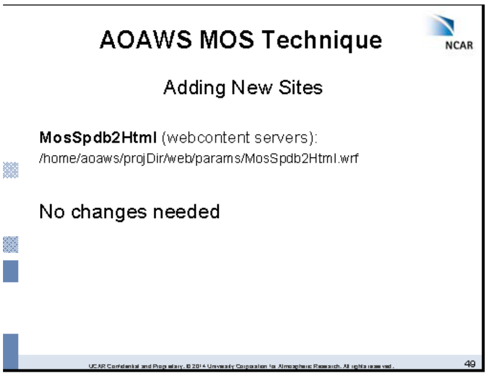
## AOAWS MOS Technique

### Adding New Sites

**MosFcastAdjust** (data servers):
/home/aoaws/projDir/mos/params/MosFcastAdjust.wrf

```
///////////// station_ids //////////////////////
//
// Station ids.
// List of the station ids for which the MOS forecast should be made.
// Type: string
// 1D array - variable length.
//

station_ids = {"RCKH","RCTP","RCSS","RCFN","RCBS","RCMT","RCLY","RCGI","RCFG","RCKW"};
```



## AOAWS MOS Technique

### Adding New Sites

**MosSpdb2Html** (webcontent servers):
/home/aoaws/projDir/web/params/MosSpdb2Html.wrf

No changes needed

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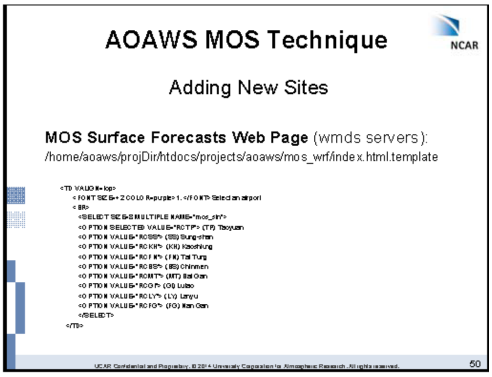

## AOAWS MOS Technique

### Adding New Sites

**MOS Surface Forecasts Web Page** (wmds servers):
/home/aoaws/projDir/htdocs/projects/aoaws/mos_wrf/index.html.template

```
<TD VALIGN=top>
   <FONT SIZE=+2 COLOR=purple>1. </FONT> Select an airport
   <BR>
     <SELECT SIZE=8 MULTIPLE NAME="mos_stn">
     <OPTION SELECTED VALUE="RCTP"> (TP) Taoyuan
     <OPTION VALUE="RCSS"> (SS) Sung-shan
     <OPTION VALUE="RCKH"> (KH) Kaoshiung
     <OPTION VALUE="RCFN"> (FN) Tai Tung
     <OPTION VALUE="RCBS"> (BS) Chinmen
     <OPTION VALUE="RCMT"> (MT) Bai Gan
     <OPTION VALUE="RCGI"> (GI) Lutao
     <OPTION VALUE="RCLY"> (LY) Lanyu
     <OPTION VALUE="RCFG"> (FG) Nan Gan
     </SELECT>
  </TD>
```

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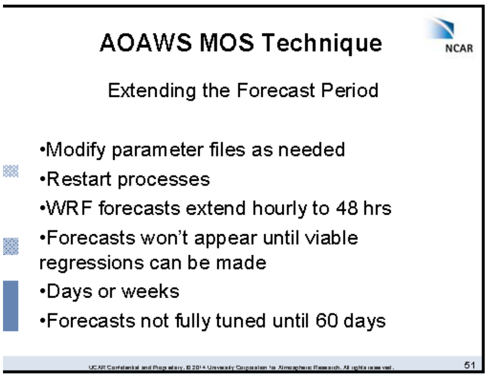

## AOAWS MOS Technique

### Extending the Forecast Period

- •Modify parameter files as needed
- •Restart processes
- •WRF forecasts extend hourly to 48 hrs
- •Forecasts won't appear until viable regressions can be made
- •Days or weeks
- •Forecasts not fully tuned until 60 days

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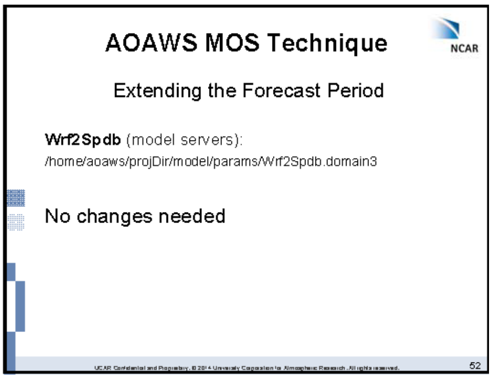

## AOAWS MOS Technique

### Extending the Forecast Period

**Wrf2Spdb** (model servers):
/home/aoaws/projDir/model/params/Wrf2Spdb.domain3

No changes needed

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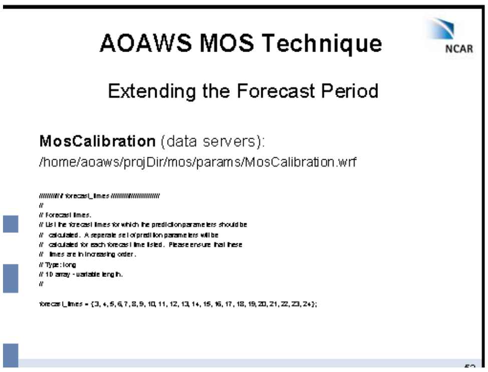


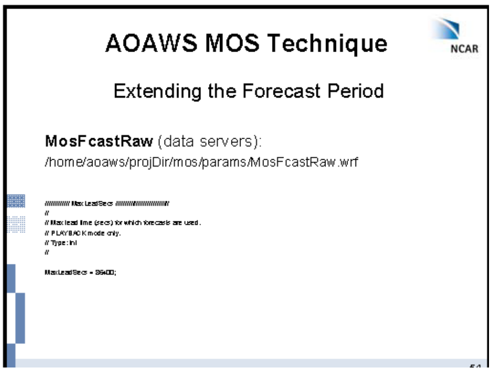
## AOAWS MOS Technique

### Extending the Forecast Period

**MosCalibration** (data servers):
/home/aoaws/projDir/mos/params/MosCalibration.wrf

```
///////////// forecast_times //////////////////////
//
// Forecast times.
// List the forecast times for which the prediction parameters should be
//   calculated.  A seperate set of predition parameters will be
//   calculated for each forecast time listed.  Please ensure that these
//   times are in increasing order.
// Type: long
// 1D array - variable length.
//

forecast_times = {3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24};
```



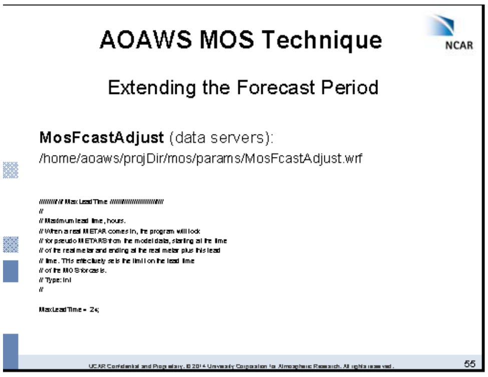
## AOAWS MOS Technique

### Extending the Forecast Period

**MosFcastRaw** (data servers):
/home/aoaws/projDir/mos/params/MosFcastRaw.wrf

```
/////////// MaxLeadSecs //////////////////////
//
// Max lead time (secs) for which forecasts are used.
// PLAYBACK mode only.
// Type: int
//

MaxLeadSecs = 86400;
```



## AOAWS MOS Technique

### Extending the Forecast Period

**MosFcastAdjust** (data servers):
/home/aoaws/projDir/mos/params/MosFcastAdjust.wrf

```
///////// MaxLeadTime //////////////////////
//
// Maximum lead time, hours.
// When a real METAR comes in, the program will look
// for pseudo METARS from the model data, starting at the time
// of the real metar and ending at the real metar plus this lead
// time. This effectively sets the limit on the lead time
// of the MOS forcasts.
// Type: int
//

MaxLeadTime = 24;
```

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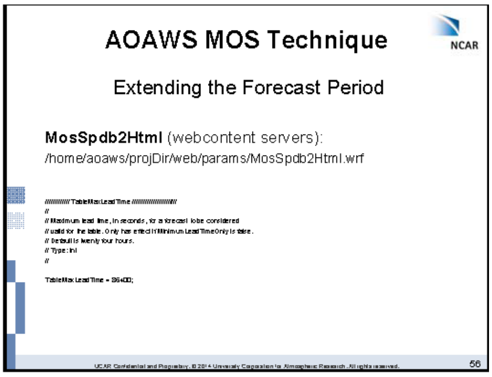

## AOAWS MOS Technique

### Extending the Forecast Period

**MosSpdb2Html** (webcontent servers):
/home/aoaws/projDir/web/params/MosSpdb2Html.wrf

```
/////////// TableMaxLeadTime //////////////////////
//
// Maximum lead time, in seconds, for a forecast to be considered
// valid for the table. Only has effect if MinimumLeadTimeOnly is false.
// Default is twenty four hours.
// Type: int
//

TableMaxLeadTime = 86400;
```

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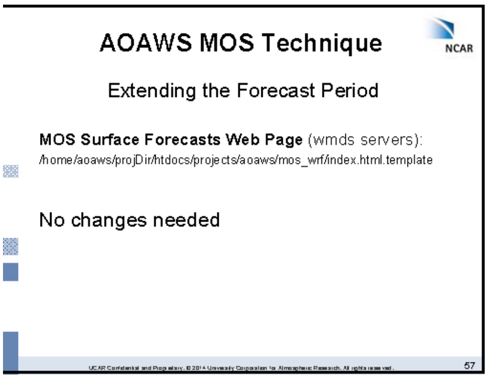

## AOAWS MOS Technique

### Extending the Forecast Period

**MOS Surface Forecasts Web Page** (wmds servers):
/home/aoaws/projDir/htdocs/projects/aoaws/mos_wrf/index.html.template

No changes needed

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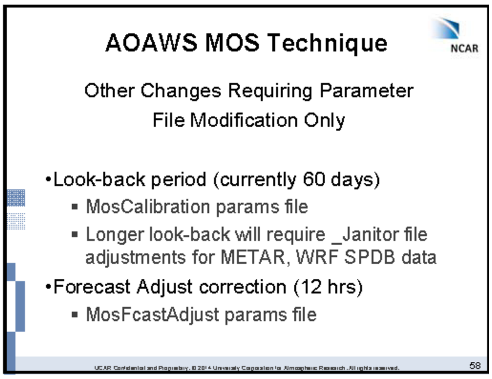

## AOAWS MOS Technique

### Other Changes Requiring Parameter File Modification Only

- Look-back period (currently 60 days)
  - MosCalibration params file
  - Longer look-back will require _Janitor file adjustments for METAR, WRF SPDB data
- Forecast Adjust correction (12 hrs)
  - MosFcastAdjust params file

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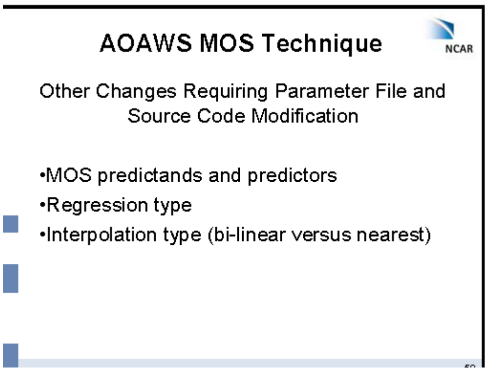
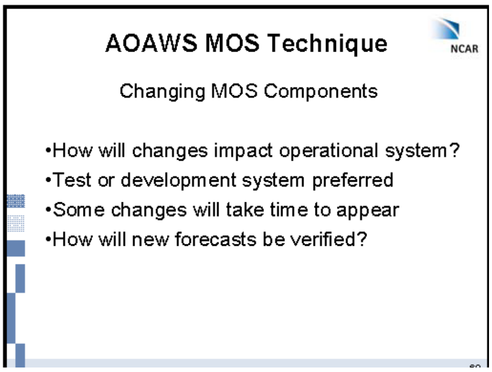


## AOAWS MOS Technique

### Other Changes Requiring Parameter File and Source Code Modification

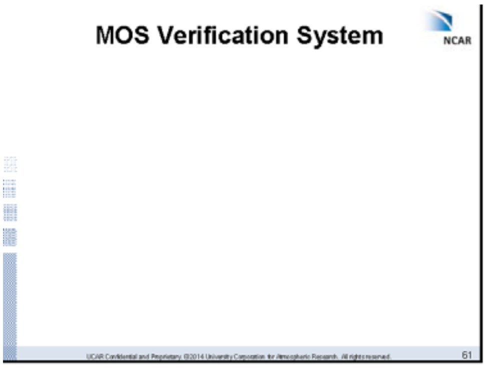
- MOS predictands and predictors
- Regression type
- Interpolation type (bi-linear versus nearest)



## AOAWS MOS Technique

### Changing MOS Components

- How will changes impact operational system?
- Test or development system preferred
- Some changes will take time to appear
- How will new forecasts be verified?



## MOS Verification System

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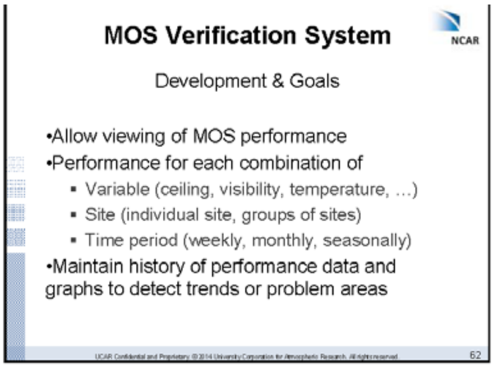

## MOS Verification System

Development & Goals

- Allow viewing of MOS performance
- Performance for each combination of
  - Variable (ceiling, visibility, temperature, …)
  - Site (individual site, groups of sites)
  - Time period (weekly, monthly, seasonally)
- Maintain history of performance data and graphs to detect trends or problem areas

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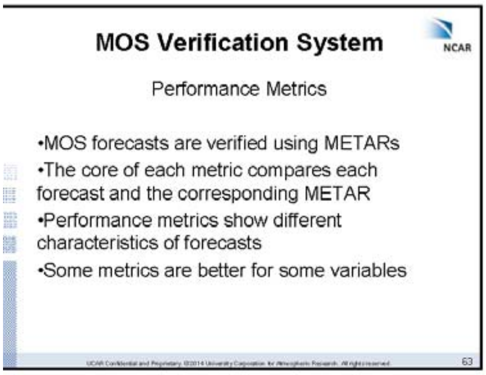

## MOS Verification System

Performance Metrics

- MOS forecasts are verified using METARs
- The core of each metric compares each forecast and the corresponding METAR
- Performance metrics show different characteristics of forecasts
- Some metrics are better for some variables

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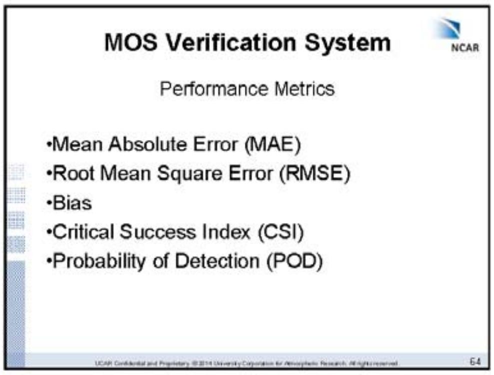

## MOS Verification System

Performance Metrics

- Mean Absolute Error (MAE)
- Root Mean Square Error (RMSE)
- Bias
- Critical Success Index (CSI)
- Probability of Detection (POD)

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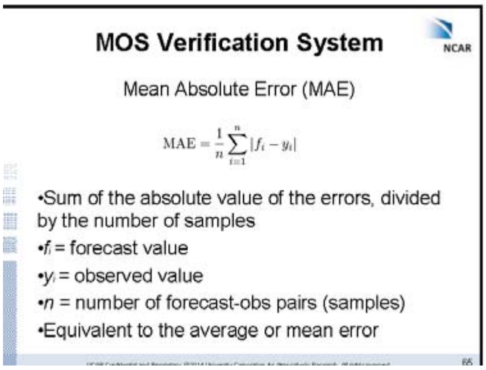

## MOS Verification System

Mean Absolute Error (MAE)

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} |f_i - y_i|$$

- Sum of the absolute value of the errors, divided by the number of samples
- $f_i$ = forecast value
- $y_i$ = observed value
- $n$ = number of forecast-obs pairs (samples)
- Equivalent to the average or mean error

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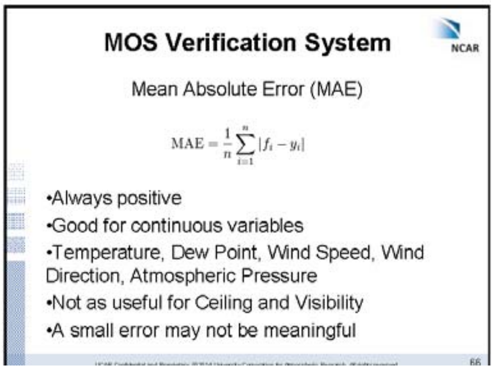

## MOS Verification System

Mean Absolute Error (MAE)

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} |f_i - y_i|$$

- Always positive
- Good for continuous variables
- Temperature, Dew Point, Wind Speed, Wind Direction, Atmospheric Pressure
- Not as useful for Ceiling and Visibility
- A small error may not be meaningful

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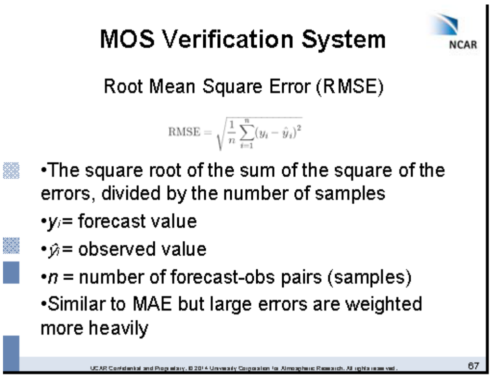

## MOS Verification System

NCAR

Root Mean Square Error (RMSE)

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

- The square root of the sum of the square of the errors, divided by the number of samples
- $y_i$ = forecast value
- $\hat{y}_i$ = observed value
- $n$ = number of forecast-obs pairs (samples)
- Similar to MAE but large errors are weighted more heavily

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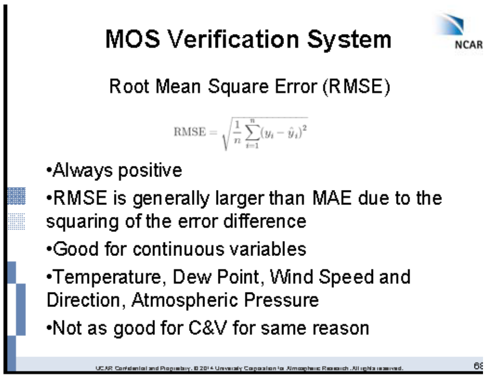

## MOS Verification System

NCAR

Root Mean Square Error (RMSE)

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

- Always positive
- RMSE is generally larger than MAE due to the squaring of the error difference
- Good for continuous variables
- Temperature, Dew Point, Wind Speed and Direction, Atmospheric Pressure
- Not as good for C&V for same reason

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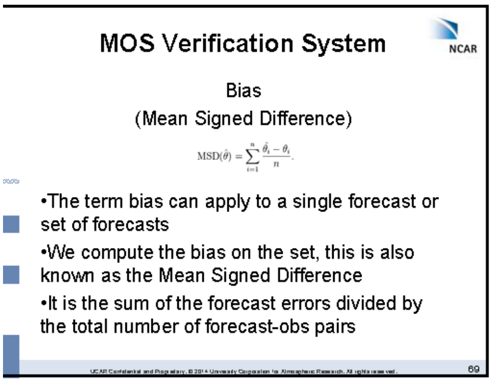

## MOS Verification System

NCAR

Bias

(Mean Signed Difference)

$$\mathrm{MSD}(\hat{\theta}) = \sum_{i=1}^{n}\frac{\hat{\theta}_i - \theta_i}{n}.$$

- The term bias can apply to a single forecast or set of forecasts
- We compute the bias on the set, this is also known as the Mean Signed Difference
- It is the sum of the forecast errors divided by the total number of forecast-obs pairs

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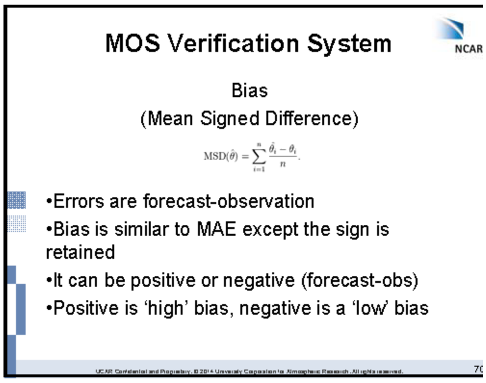

## MOS Verification System

NCAR

Bias

(Mean Signed Difference)

$$\mathrm{MSD}(\hat{\theta}) = \sum_{i=1}^{n}\frac{\hat{\theta}_i - \theta_i}{n}.$$

- Errors are forecast-observation
- Bias is similar to MAE except the sign is retained
- It can be positive or negative (forecast-obs)
- Positive is 'high' bias, negative is a 'low' bias

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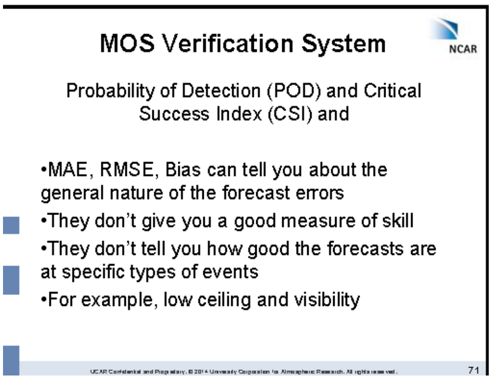

## MOS Verification System

NCAR

Probability of Detection (POD) and Critical Success Index (CSI) and

- MAE, RMSE, Bias can tell you about the general nature of the forecast errors
- They don't give you a good measure of skill
- They don't tell you how good the forecasts are at specific types of events
- For example, low ceiling and visibility

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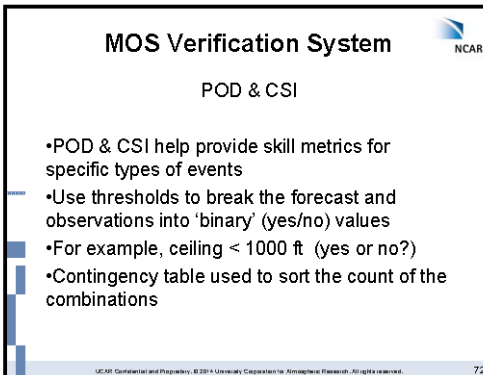

## MOS Verification System

NCAR

POD & CSI

- POD & CSI help provide skill metrics for specific types of events
- Use thresholds to break the forecast and observations into 'binary' (yes/no) values
- For example, ceiling < 1000 ft (yes or no?)
- Contingency table used to sort the count of the combinations

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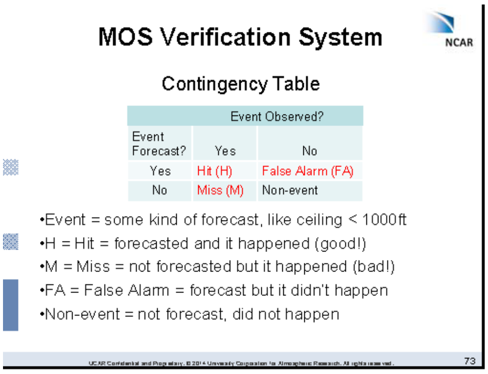

## MOS Verification System

### Contingency Table

| | Event Observed? | |
|---|---|---|
| Event Forecast? | Yes | No |
| Yes | Hit (H) | False Alarm (FA) |
| No | Miss (M) | Non-event |

•Event = some kind of forecast, like ceiling < 1000ft
•H = Hit = forecasted and it happened (good!)
•M = Miss = not forecasted but it happened (bad!)
•FA = False Alarm = forecast but it didn't happen
•Non-event = not forecast, did not happen

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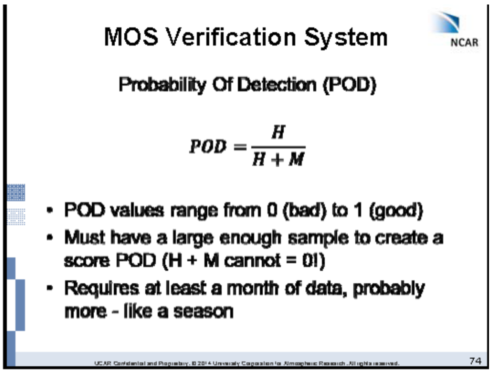

## MOS Verification System

### Probability Of Detection (POD)

$$POD = \frac{H}{H + M}$$

- **POD values range from 0 (bad) to 1 (good)**
- **Must have a large enough sample to create a score POD (H + M cannot = 0!)**
- **Requires at least a month of data, probably more - like a season**

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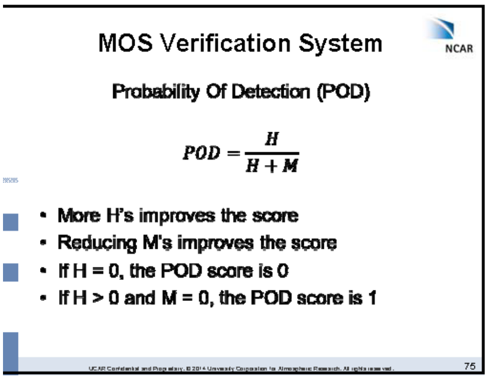

## MOS Verification System

### Probability Of Detection (POD)

$$POD = \frac{H}{H + M}$$

- **More H's improves the score**
- **Reducing M's improves the score**
- **If H = 0, the POD score is 0**
- **If H > 0 and M = 0, the POD score is 1**

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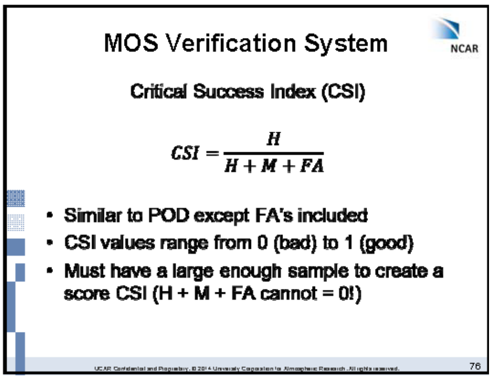

## MOS Verification System

### Critical Success Index (CSI)

$$CSI = \frac{H}{H + M + FA}$$

- **Similar to POD except FA's included**
- **CSI values range from 0 (bad) to 1 (good)**
- **Must have a large enough sample to create a score CSI (H + M + FA cannot = 0!)**

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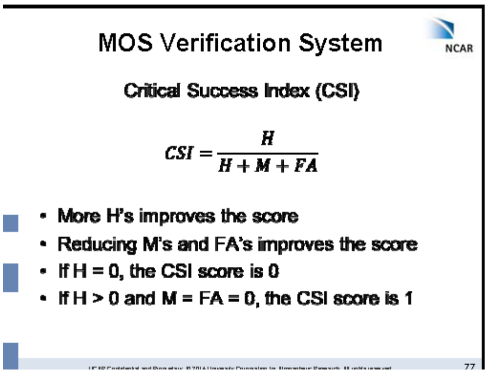

## MOS Verification System

### Critical Success Index (CSI)

$$CSI = \frac{H}{H + M + FA}$$

- **More H's improves the score**
- **Reducing M's and FA's improves the score**
- **If H = 0, the CSI score is 0**
- **If H > 0 and M = FA = 0, the CSI score is 1**

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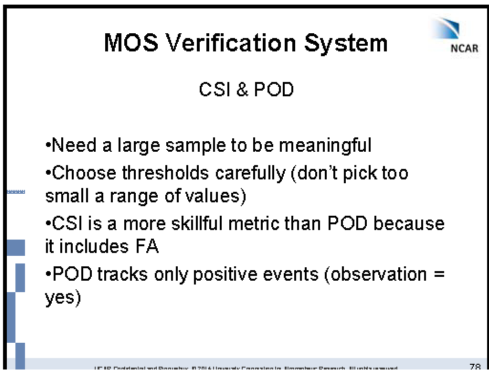

## MOS Verification System

### CSI & POD

•Need a large sample to be meaningful
•Choose thresholds carefully (don't pick too small a range of values)
•CSI is a more skillful metric than POD because it includes FA
•POD tracks only positive events (observation = yes)

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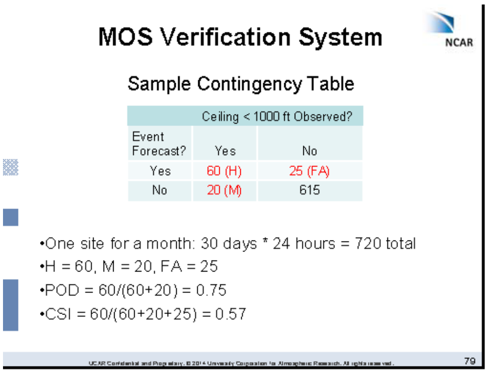

## MOS Verification System

### Sample Contingency Table

| | Ceiling < 1000 ft Observed? | |
|---|---|---|
| Event Forecast? | Yes | No |
| Yes | 60 (H) | 25 (FA) |
| No | 20 (M) | 615 |

- One site for a month: 30 days * 24 hours = 720 total
- H = 60, M = 20, FA = 25
- POD = 60/(60+20) = 0.75
- CSI = 60/(60+20+25) = 0.57

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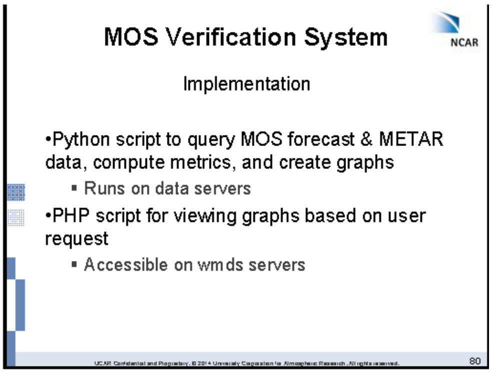

## MOS Verification System

### Implementation

- Python script to query MOS forecast & METAR data, compute metrics, and create graphs
  - Runs on data servers
- PHP script for viewing graphs based on user request
  - Accessible on wmds servers

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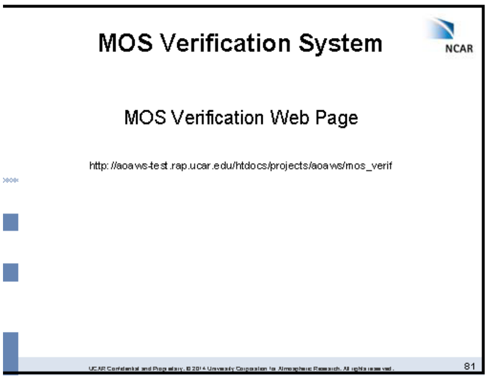

## MOS Verification System

### MOS Verification Web Page

http://aoaws-test.rap.ucar.edu/htdocs/projects/aoaws/mos_verif

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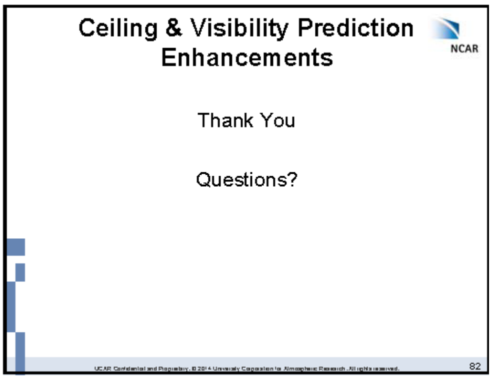

## Ceiling & Visibility Prediction Enhancements

Thank You

Questions?

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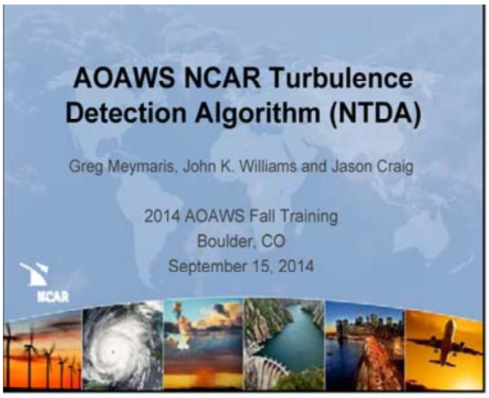
# 三、AOAWS NCAR Turbulence Detection Algorithm（NTDA）



## AOAWS NCAR Turbulence Detection Algorithm (NTDA)

Greg Meymaris, John K. Williams and Jason Craig

2014 AOAWS Fall Training
Boulder, CO
September 15, 2014

## Introductions

1. NCAR NTDA core development team
    - Greg Meymaris
    - John Williams
    - Jason Craig
2. CAA attendees
    - Lin, Yun Tien (林昀瑱) Joseph
    - Kuan, Dai Wei (官岱煒) David
3. IISI attendees
    - Chang, Yung-Chia (張永佳) Charlie
    - Yen, Huan-Ting (顏煥庭) Henry
    - Chen, Yuru (may attend)

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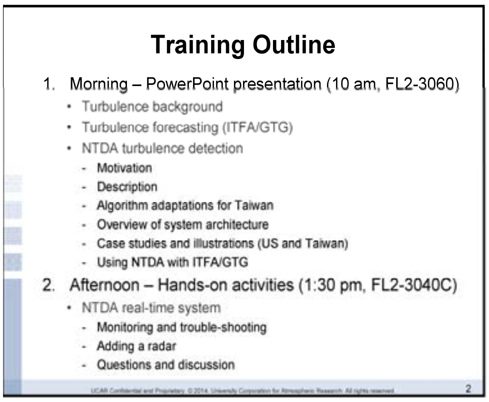

## Training Outline

1. Morning – PowerPoint presentation (10 am, FL2-3060)
    - Turbulence background
    - Turbulence forecasting (ITFA/GTG)
    - NTDA turbulence detection
        - Motivation
        - Description
        - Algorithm adaptations for Taiwan
        - Overview of system architecture
        - Case studies and illustrations (US and Taiwan)
        - Using NTDA with ITFA/GTG
2. Afternoon – Hands-on activities (1:30 pm, FL2-3040C)
    - NTDA real-time system
        - Monitoring and trouble-shooting
        - Adding a radar
        - Questions and discussion

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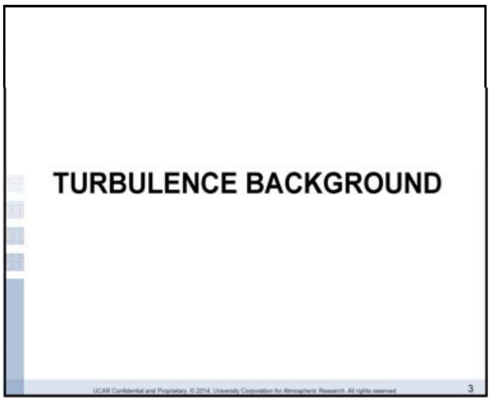

## TURBULENCE BACKGROUND

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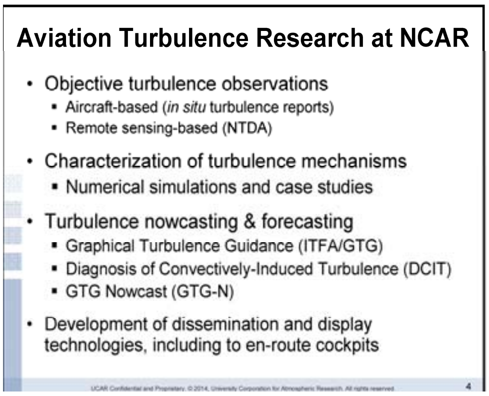

## Aviation Turbulence Research at NCAR

- Objective turbulence observations
    - Aircraft-based (*in situ* turbulence reports)
    - Remote sensing-based (NTDA)
- Characterization of turbulence mechanisms
    - Numerical simulations and case studies
- Turbulence nowcasting & forecasting
    - Graphical Turbulence Guidance (ITFA/GTG)
    - Diagnosis of Convectively-Induced Turbulence (DCIT)
    - GTG Nowcast (GTG-N)
- Development of dissemination and display technologies, including to en-route cockpits

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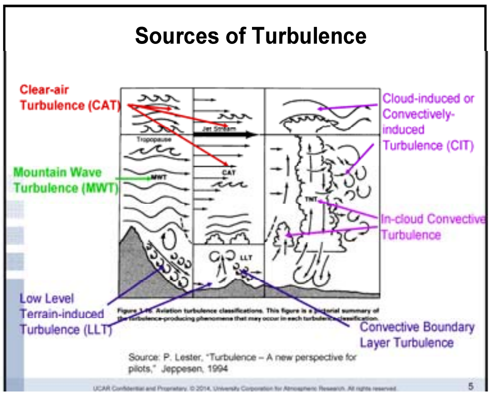

## Sources of Turbulence

Figure 1-16: Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

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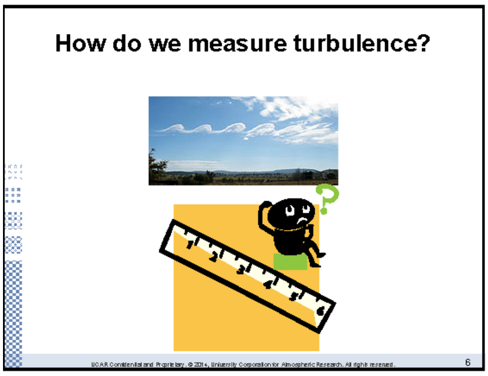
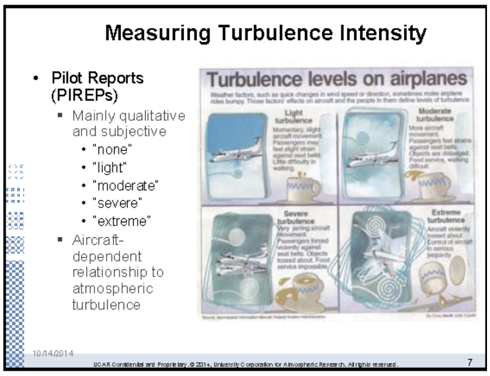


## How do we measure turbulence?



## Measuring Turbulence Intensity

- Pilot Reports (PIREPs)
  - Mainly qualitative and subjective
    - "none"
    - "light"
    - "moderate"
    - "severe"
    - "extreme"
  - Aircraft-dependent relationship to atmospheric turbulence

**Turbulence levels on airplanes**

Weather factors, such as quick changes in wind speed or direction, sometimes make airplane rides bumpy. Those factors' effects on aircraft and the people in them define levels of turbulence.

**Light turbulence** Momentary, slight aircraft movement. Passengers may feel slight strain against seat belts. Little difficulty in walking.

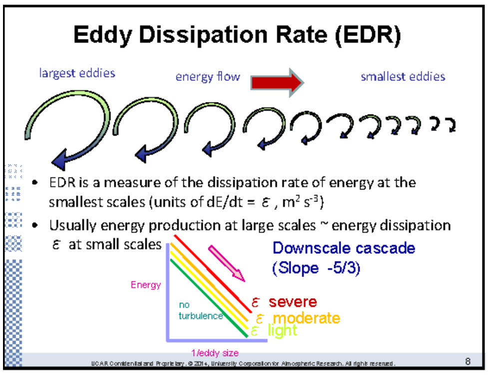
**Moderate turbulence** More aircraft movement. Passengers feel strains against seat belts. Objects are dislodged. Food service, walking difficult.

**Severe turbulence** Very jarring aircraft movement. Passengers forced violently against seat belts. Objects tossed about. Food service impossible.

**Extreme turbulence** Aircraft violently tossed about. Control of aircraft in serious jeopardy.

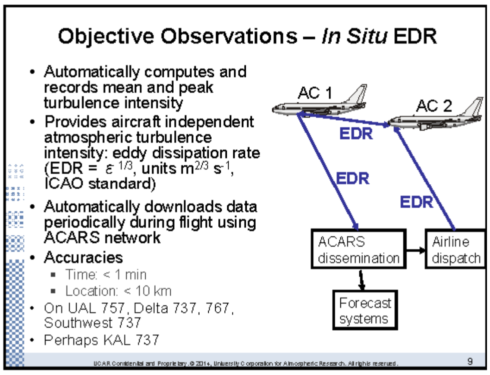
Source: Aeronautical Information Manual, Federal Aviation Administration

10/14/2014



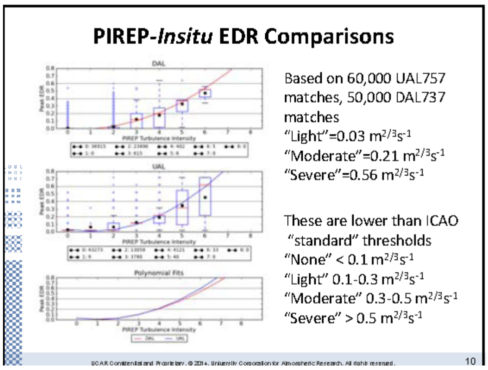
## Eddy Dissipation Rate (EDR)

- EDR is a measure of the dissipation rate of energy at the smallest scales (units of $dE/dt = \varepsilon$, $m^2 s^{-3}$)
- Usually energy production at large scales ~ energy dissipation $\varepsilon$ at small scales



## Objective Observations – *In Situ* EDR

- Automatically computes and records mean and peak turbulence intensity
- Provides aircraft independent atmospheric turbulence intensity: eddy dissipation rate (EDR = $\varepsilon^{1/3}$, units $m^{2/3} s^{-1}$, ICAO standard)
- Automatically downloads data periodically during flight using ACARS network
- Accuracies
  - Time: < 1 min
  - Location: < 10 km
- On UAL 757, Delta 737, 767, Southwest 737
- Perhaps KAL 737



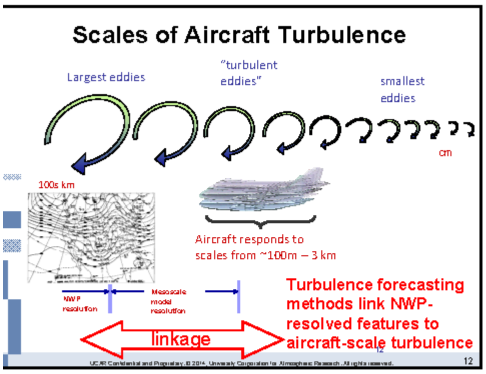
## PIREP-*Insitu* EDR Comparisons

Based on 60,000 UAL757 matches, 50,000 DAL737 matches
"Light"=0.03 $m^{2/3}s^{-1}$
"Moderate"=0.21 $m^{2/3}s^{-1}$
"Severe"=0.56 $m^{2/3}s^{-1}$

These are lower than ICAO "standard" thresholds
"None" < 0.1 $m^{2/3}s^{-1}$
"Light" 0.1-0.3 $m^{2/3}s^{-1}$
"Moderate" 0.3-0.5 $m^{2/3}s^{-1}$
"Severe" > 0.5 $m^{2/3}s^{-1}$

## TURBULENCE FORECASTING:

## INTEGRATED TURBULENCE FORECAST ALGORITHM (ITFA) A.K.A. GRAPHICAL TURBULENCE GUIDANCE (GTG)



## Scales of Aircraft Turbulence

Aircraft responds to scales from ~100m – 3 km

**Turbulence forecasting methods link NWP-resolved features to aircraft-scale turbulence**

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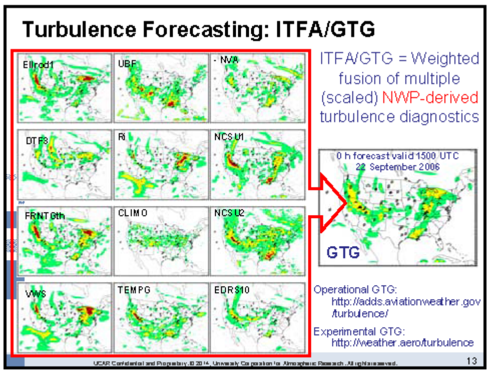

## Turbulence Forecasting: ITFA/GTG

ITFA/GTG = Weighted fusion of multiple (scaled) NWP-derived turbulence diagnostics

Operational GTG:
http://adds.aviationweather.gov/turbulence/

Experimental GTG:
http://weather.aero/turbulence

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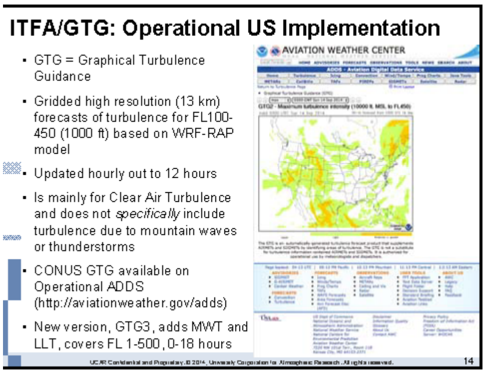

## ITFA/GTG: Operational US Implementation

- GTG = Graphical Turbulence Guidance
- Gridded high resolution (13 km) forecasts of turbulence for FL100-450 (1000 ft) based on WRF-RAP model
- Updated hourly out to 12 hours
- Is mainly for Clear Air Turbulence and does not *specifically* include turbulence due to mountain waves or thunderstorms
- CONUS GTG available on Operational ADDS (http://aviationweather.gov/adds)
- New version, GTG3, adds MWT and LLT, covers FL 1-500, 0-18 hours

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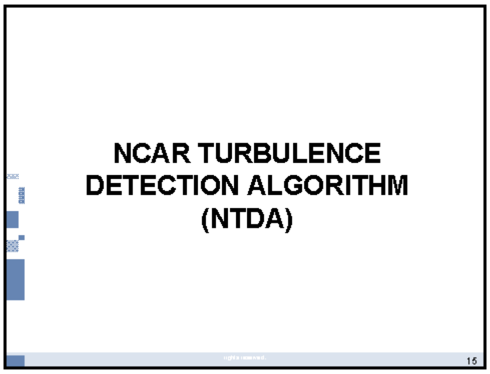
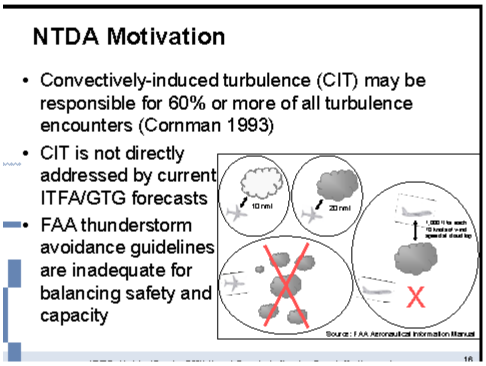


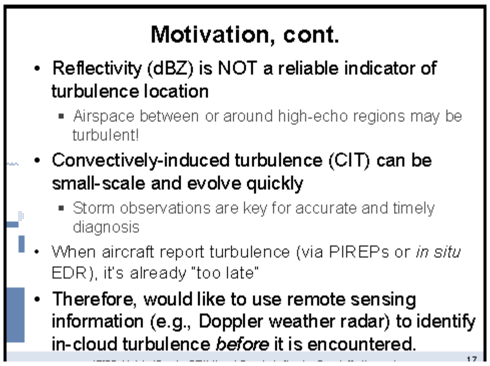
# NCAR TURBULENCE DETECTION ALGORITHM (NTDA)



## NTDA Motivation

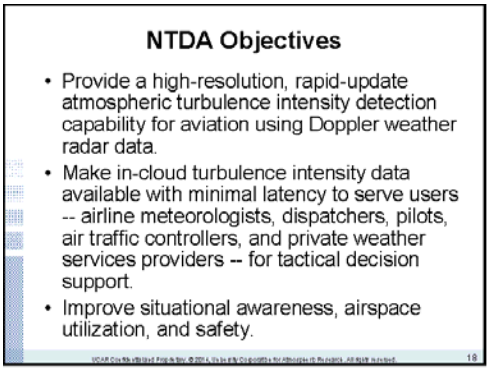
- Convectively-induced turbulence (CIT) may be responsible for 60% or more of all turbulence encounters (Cornman 1993)
- CIT is not directly addressed by current ITFA/GTG forecasts
- FAA thunderstorm avoidance guidelines are inadequate for balancing safety and capacity

Source: FAA Aeronautical Information Manual



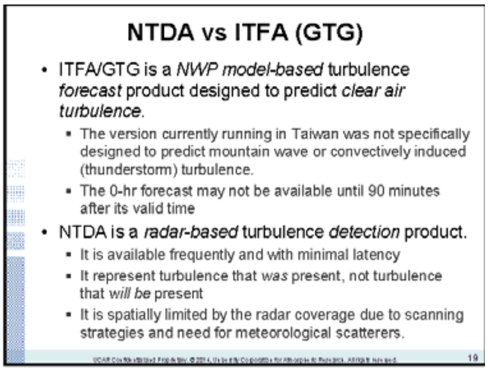
## Motivation, cont.

- Reflectivity (dBZ) is NOT a reliable indicator of turbulence location
  - Airspace between or around high-echo regions may be turbulent!
- Convectively-induced turbulence (CIT) can be small-scale and evolve quickly
  - Storm observations are key for accurate and timely diagnosis
- When aircraft report turbulence (via PIREPs or *in situ* EDR), it's already "too late"
- Therefore, would like to use remote sensing information (e.g., Doppler weather radar) to identify in-cloud turbulence *before* it is encountered.



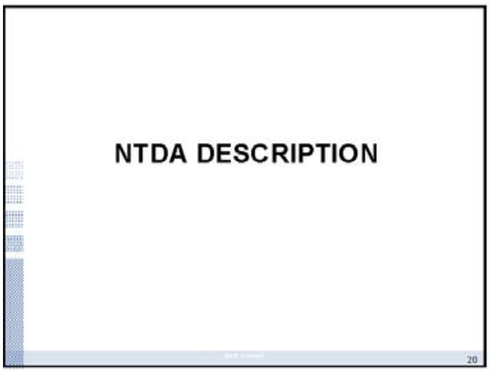
## NTDA Objectives

- Provide a high-resolution, rapid-update atmospheric turbulence intensity detection capability for aviation using Doppler weather radar data.
- Make in-cloud turbulence intensity data available with minimal latency to serve users -- airline meteorologists, dispatchers, pilots, air traffic controllers, and private weather services providers -- for tactical decision support.
- Improve situational awareness, airspace utilization, and safety.

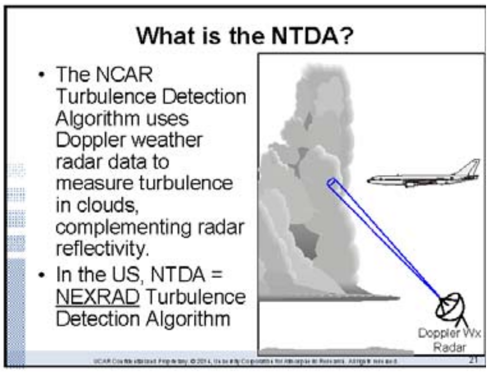


## NTDA vs ITFA (GTG)

- ITFA/GTG is a *NWP model-based* turbulence *forecast* product designed to predict *clear air turbulence*.
  - The version currently running in Taiwan was not specifically designed to predict mountain wave or convectively induced (thunderstorm) turbulence.
  - The 0-hr forecast may not be available until 90 minutes after its valid time
- NTDA is a *radar-based* turbulence *detection* product.
  - It is available frequently and with minimal latency
  - It represent turbulence that *was* present, not turbulence that *will be* present
  - It is spatially limited by the radar coverage due to scanning strategies and need for meteorological scatterers.

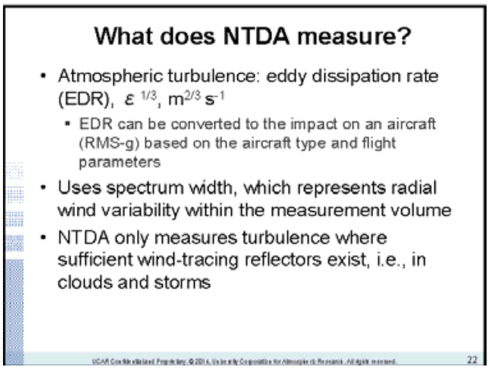


## NTDA DESCRIPTION



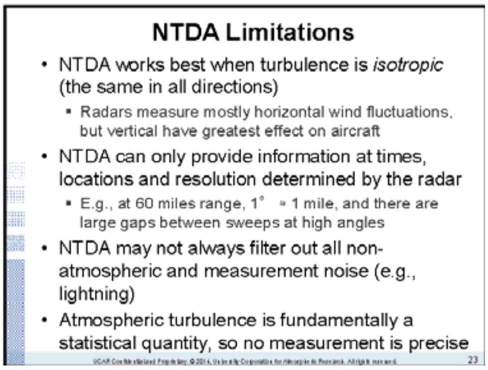
## What is the NTDA?

- The NCAR Turbulence Detection Algorithm uses Doppler weather radar data to measure turbulence in clouds, complementing radar reflectivity.
- In the US, NTDA = NEXRAD Turbulence Detection Algorithm



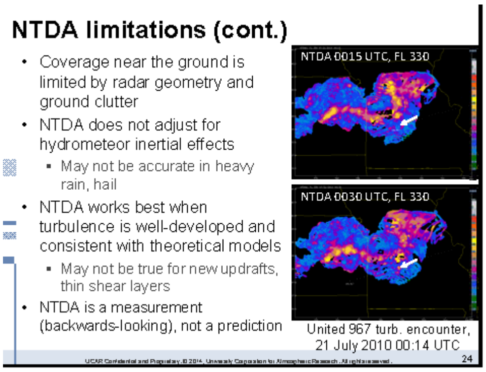
## What does NTDA measure?

- Atmospheric turbulence: eddy dissipation rate (EDR), $\varepsilon^{1/3}$, $m^{2/3}\ s^{-1}$
  - EDR can be converted to the impact on an aircraft (RMS-g) based on the aircraft type and flight parameters
- Uses spectrum width, which represents radial wind variability within the measurement volume
- NTDA only measures turbulence where sufficient wind-tracing reflectors exist, i.e., in clouds and storms



## NTDA Limitations

- NTDA works best when turbulence is *isotropic* (the same in all directions)
  - Radars measure mostly horizontal wind fluctuations, but vertical have greatest effect on aircraft
- NTDA can only provide information at times, locations and resolution determined by the radar
  - E.g., at 60 miles range, 1° ≈ 1 mile, and there are large gaps between sweeps at high angles
- NTDA may not always filter out all non-atmospheric and measurement noise (e.g., lightning)
- Atmospheric turbulence is fundamentally a statistical quantity, so no measurement is precise



## NTDA limitations (cont.)

- Coverage near the ground is limited by radar geometry and ground clutter
- NTDA does not adjust for hydrometeor inertial effects
  - May not be accurate in heavy rain, hail
- NTDA works best when turbulence is well-developed and consistent with theoretical models
  - May not be true for new updrafts, thin shear layers
- NTDA is a measurement (backwards-looking), not a prediction

United 967 turb. encounter, 21 July 2010 00:14 UTC

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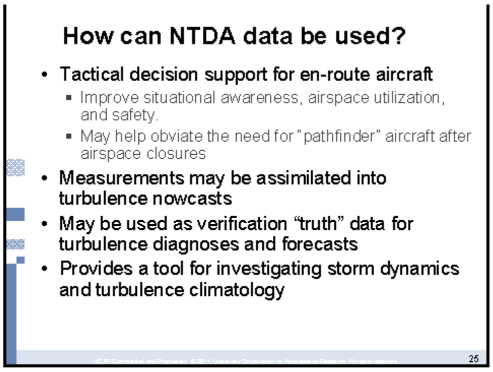

## How can NTDA data be used?

- Tactical decision support for en-route aircraft
  - Improve situational awareness, airspace utilization, and safety.
  - May help obviate the need for "pathfinder" aircraft after airspace closures
- Measurements may be assimilated into turbulence nowcasts
- May be used as verification "truth" data for turbulence diagnoses and forecasts
- Provides a tool for investigating storm dynamics and turbulence climatology

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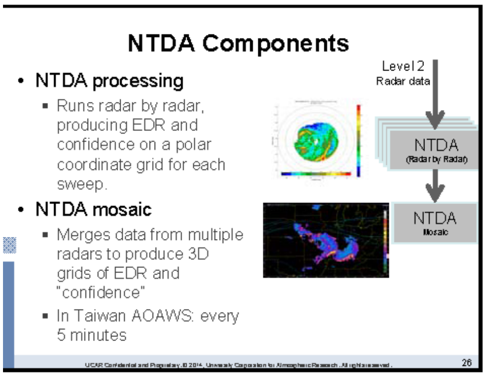

## NTDA Components

- NTDA processing
  - Runs radar by radar, producing EDR and confidence on a polar coordinate grid for each sweep.
- NTDA mosaic
  - Merges data from multiple radars to produce 3D grids of EDR and "confidence"
  - In Taiwan AOAWS: every 5 minutes

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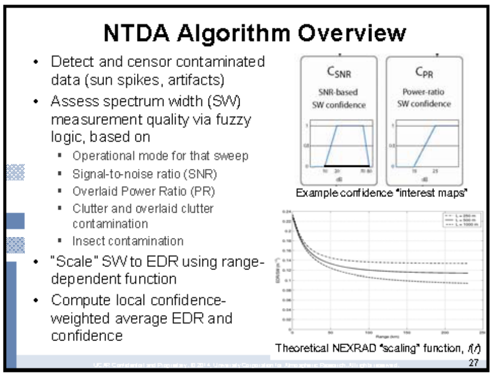

## NTDA Algorithm Overview

- Detect and censor contaminated data (sun spikes, artifacts)
- Assess spectrum width (SW) measurement quality via fuzzy logic, based on
  - Operational mode for that sweep
  - Signal-to-noise ratio (SNR)
  - Overlaid Power Ratio (PR)
  - Clutter and overlaid clutter contamination
  - Insect contamination
- "Scale" SW to EDR using range-dependent function
- Compute local confidence-weighted average EDR and confidence

Example confidence "interest maps"

Theoretical NEXRAD "scaling" function, *f*(*r*)

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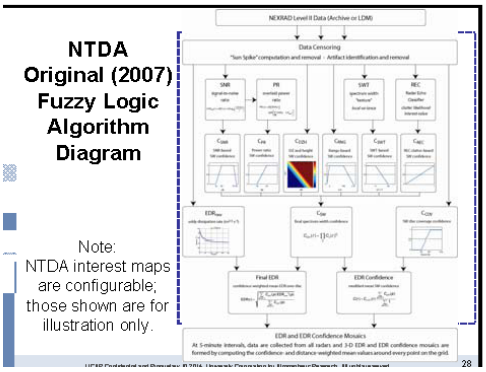

## NTDA Original (2007) Fuzzy Logic Algorithm Diagram

Note:
NTDA interest maps are configurable; those shown are for illustration only.

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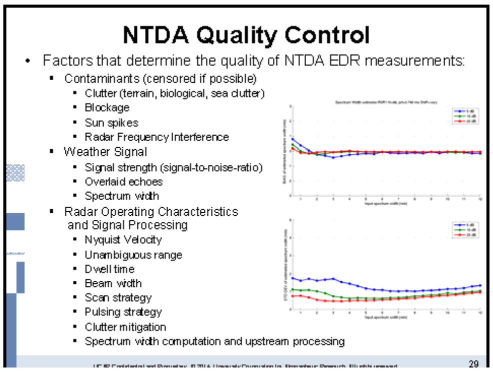

## NTDA Quality Control

- Factors that determine the quality of NTDA EDR measurements:
  - Contaminants (censored if possible)
    - Clutter (terrain, biological, sea clutter)
    - Blockage
    - Sun spikes
    - Radar Frequency Interference
  - Weather Signal
    - Signal strength (signal-to-noise-ratio)
    - Overlaid echoes
    - Spectrum width
  - Radar Operating Characteristics and Signal Processing
    - Nyquist Velocity
    - Unambiguous range
    - Dwell time
    - Beam width
    - Scan strategy
    - Pulsing strategy
    - Clutter mitigation
    - Spectrum width computation and upstream processing

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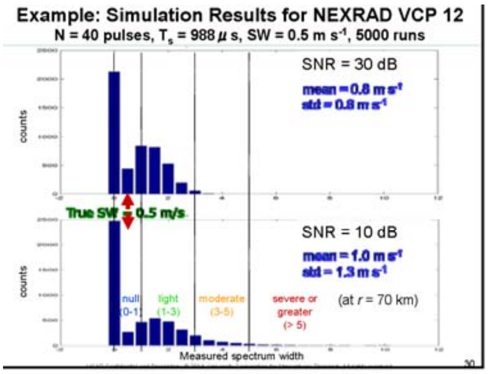
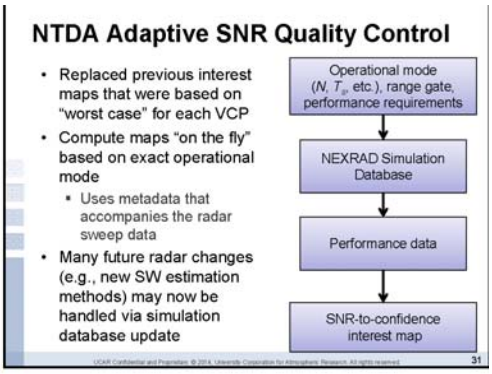


## Example: Simulation Results for NEXRAD VCP 12

N = 40 pulses, $T_s$ = 988 $\mu$ s, SW = 0.5 m $s^{-1}$, 5000 runs



## NTDA Adaptive SNR Quality Control

- Replaced previous interest maps that were based on "worst case" for each VCP
- Compute maps "on the fly" based on exact operational mode
  - Uses metadata that accompanies the radar sweep data
- Many future radar changes (e.g., new SW estimation methods) may now be handled via simulation database update

Operational mode ($N$, $T_s$, etc.), range gate, performance requirements

NEXRAD Simulation Database

Performance data

SNR-to-confidence interest map

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## ALGORITHM ADAPTATIONS FOR TAIWAN

## NTDA Validation and Tuning

- In the absence of aircraft turbulence observations, validation was performed via case studies and comparisons of NTDA output from adjacent radars
- It was determined that the same spectrum width to EDR translation tables could be used for Gematronik and NEXRAD radars, and thus didn't need to be updated
- Radar simulations have been performed to characterize spectrum width accuracy for various radars, operational modes, and signal-to-noise ratio values to tune the quality control process.

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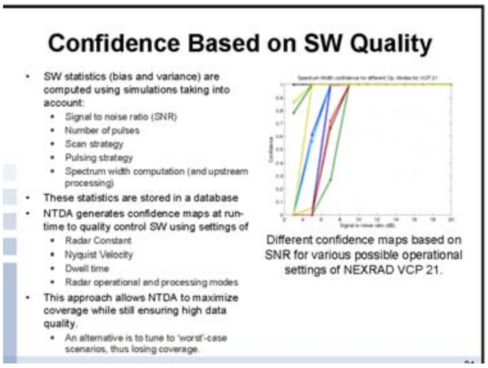
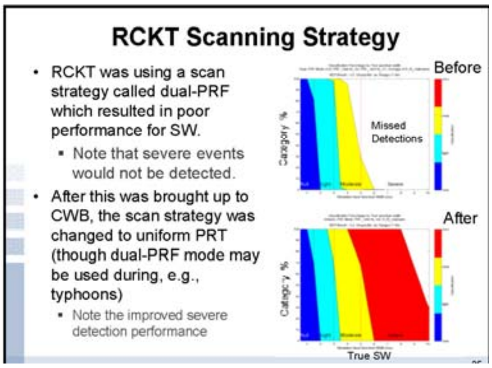


## Confidence Based on SW Quality

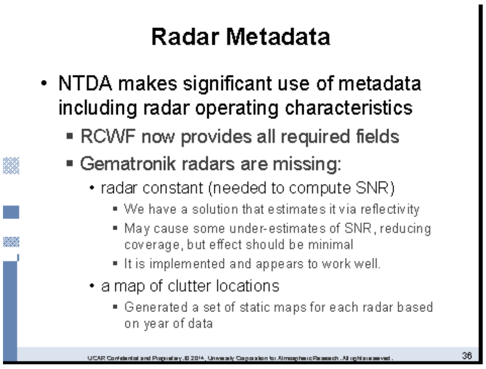
- SW statistics (bias and variance) are computed using simulations taking into account:
  - Signal to noise ratio (SNR)
  - Number of pulses
  - Scan strategy
  - Pulsing strategy
  - Spectrum width computation (and upstream processing)
- These statistics are stored in a database
- NTDA generates confidence maps at run-time to quality control SW using settings of
  - Radar Constant
  - Nyquist Velocity
  - Dwell time
  - Radar operational and processing modes
- This approach allows NTDA to maximize coverage while still ensuring high data quality.
  - An alternative is to tune to 'worst'-case scenarios, thus losing coverage.

Different confidence maps based on SNR for various possible operational settings of NEXRAD VCP 21.



## RCKT Scanning Strategy

- RCKT was using a scan strategy called dual-PRF which resulted in poor performance for SW.
  - Note that severe events would not be detected.
- After this was brought up to CWB, the scan strategy was changed to uniform PRT (though dual-PRF mode may be used during, e.g., typhoons)
  - Note the improved severe detection performance



## Radar Metadata

- NTDA makes significant use of metadata including radar operating characteristics
  - RCWF now provides all required fields
  - Gematronik radars are missing:
    - radar constant (needed to compute SNR)
      - We have a solution that estimates it via reflectivity
      - May cause some under-estimates of SNR, reducing coverage, but effect should be minimal
      - It is implemented and appears to work well.
    - a map of clutter locations
      - Generated a set of static maps for each radar based on year of data

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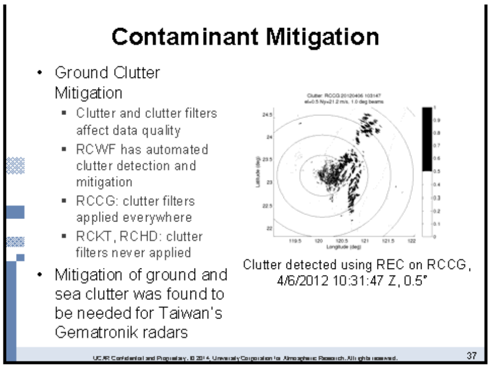

## Contaminant Mitigation

- Ground Clutter Mitigation
  - Clutter and clutter filters affect data quality
  - RCWF has automated clutter detection and mitigation
  - RCCG: clutter filters applied everywhere
  - RCKT, RCHD: clutter filters never applied
- Mitigation of ground and sea clutter was found to be needed for Taiwan's Gematronik radars

Clutter detected using REC on RCCG, 4/6/2012 10:31:47 Z, 0.5°

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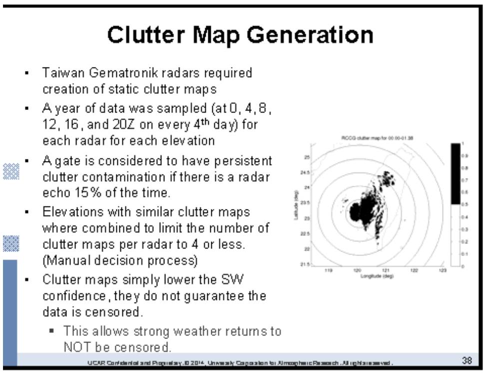

## Clutter Map Generation

- Taiwan Gematronik radars required creation of static clutter maps
- A year of data was sampled (at 0, 4, 8, 12, 16, and 20Z on every 4th day) for each radar for each elevation
- A gate is considered to have persistent clutter contamination if there is a radar echo 15% of the time.
- Elevations with similar clutter maps where combined to limit the number of clutter maps per radar to 4 or less. (Manual decision process)
- Clutter maps simply lower the SW confidence, they do not guarantee the data is censored.
  - This allows strong weather returns to NOT be censored.

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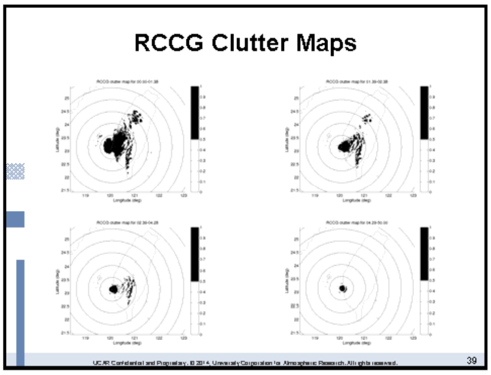

## RCCG Clutter Maps

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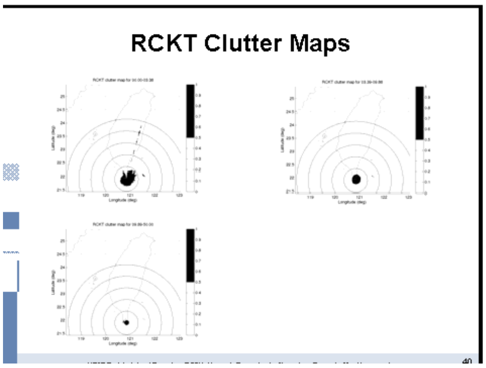
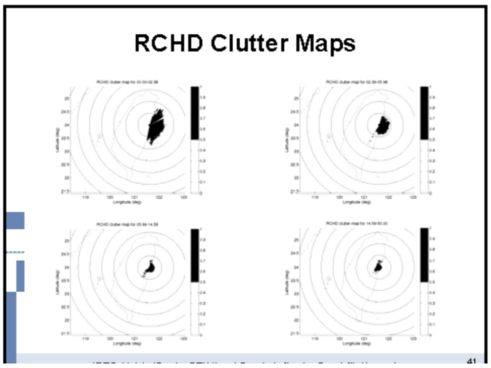
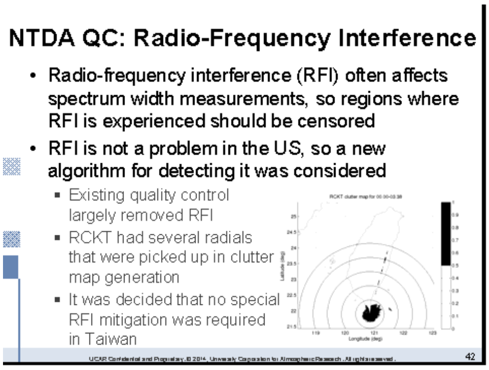


## RCKT Clutter Maps



## RCHD Clutter Maps



## NTDA QC: Radio-Frequency Interference

- Radio-frequency interference (RFI) often affects spectrum width measurements, so regions where RFI is experienced should be censored
- RFI is not a problem in the US, so a new algorithm for detecting it was considered
  - Existing quality control largely removed RFI
  - RCKT had several radials that were picked up in clutter map generation
  - It was decided that no special RFI mitigation was required in Taiwan

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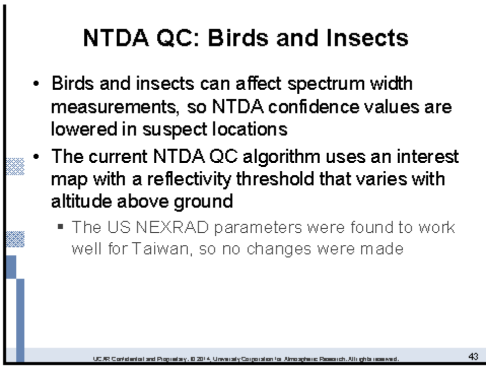

## NTDA QC: Birds and Insects

- Birds and insects can affect spectrum width measurements, so NTDA confidence values are lowered in suspect locations
- The current NTDA QC algorithm uses an interest map with a reflectivity threshold that varies with altitude above ground
  - The US NEXRAD parameters were found to work well for Taiwan, so no changes were made

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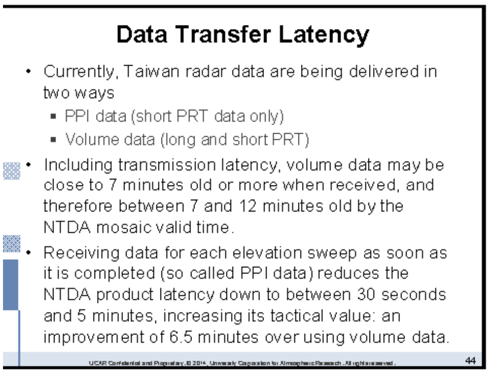

## Data Transfer Latency

- Currently, Taiwan radar data are being delivered in two ways
  - PPI data (short PRT data only)
  - Volume data (long and short PRT)
- Including transmission latency, volume data may be close to 7 minutes old or more when received, and therefore between 7 and 12 minutes old by the NTDA mosaic valid time.
- Receiving data for each elevation sweep as soon as it is completed (so called PPI data) reduces the NTDA product latency down to between 30 seconds and 5 minutes, increasing its tactical value: an improvement of 6.5 minutes over using volume data.

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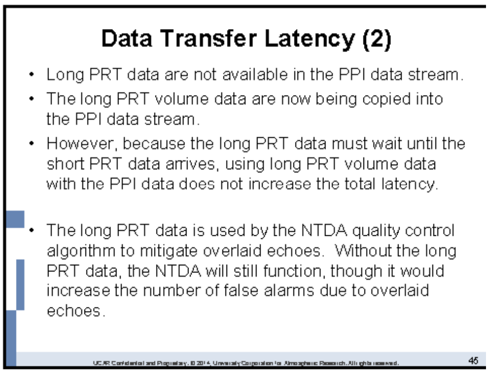

## Data Transfer Latency (2)

- Long PRT data are not available in the PPI data stream.
- The long PRT volume data are now being copied into the PPI data stream.
- However, because the long PRT data must wait until the short PRT data arrives, using long PRT volume data with the PPI data does not increase the total latency.
- The long PRT data is used by the NTDA quality control algorithm to mitigate overlaid echoes. Without the long PRT data, the NTDA will still function, though it would increase the number of false alarms due to overlaid echoes.

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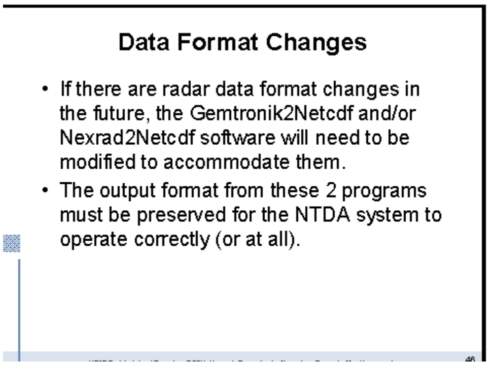
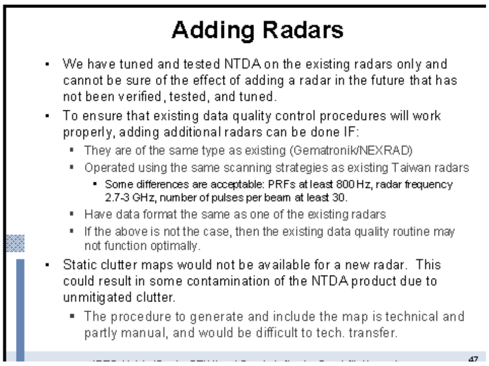


## Data Format Changes

- If there are radar data format changes in the future, the Gemtronik2Netcdf and/or Nexrad2Netcdf software will need to be modified to accommodate them.
- The output format from these 2 programs must be preserved for the NTDA system to operate correctly (or at all).

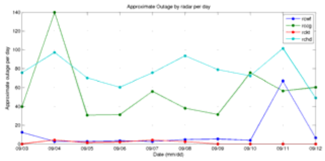


## Adding Radars

- We have tuned and tested NTDA on the existing radars only and cannot be sure of the effect of adding a radar in the future that has not been verified, tested, and tuned.
- To ensure that existing data quality control procedures will work properly, adding additional radars can be done IF:
  - They are of the same type as existing (Gematronik/NEXRAD)
  - Operated using the same scanning strategies as existing Taiwan radars
    - Some differences are acceptable: PRFs at least 800 Hz, radar frequency 2.7-3 GHz, number of pulses per beam at least 30.
  - Have data format the same as one of the existing radars
  - If the above is not the case, then the existing data quality routine may not function optimally.
- Static clutter maps would not be available for a new radar. This could result in some contamination of the NTDA product due to unmitigated clutter.
  - The procedure to generate and include the map is technical and partly manual, and would be difficult to tech. transfer.

## Data Outages

- We are seeing substantial radar data outages.
- It appears to be upstream or at data arrival from cwb-caasv1/2.
- Different radars experience very different outages: RCKT and RCWF experience minimal data loss, RCHD(L) and RCCG have been experiencing around 1 hour per day.
- Outages cause NTDA output to have reduced coverage



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## SYSTEM ARCHITECTURE

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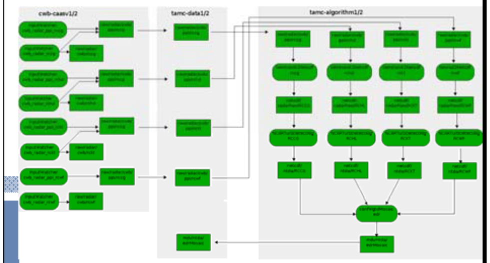
## Taiwan NTDA Implementation



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## NTDA CASE STUDIES AND ILLUSTRATIONS

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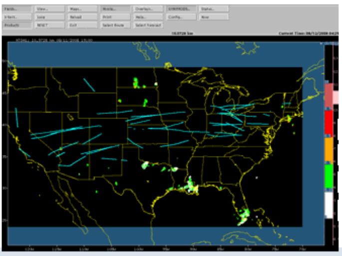
## NTDA Mosaic Animation

- Moderate or severe turbulence in storms may appear quickly and last as little as a few minutes



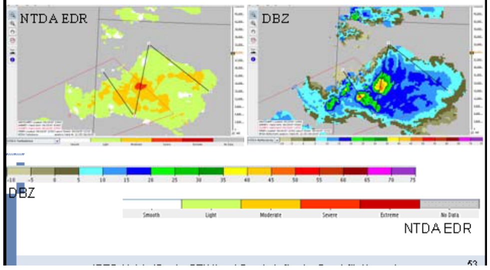
CIDD research display: NTDA mosaic 6-hr loop on 11 August 2008, 36,000 ft.

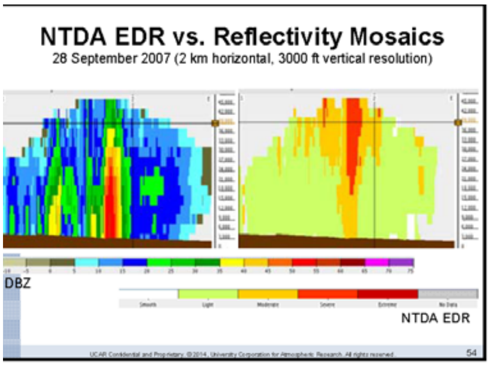
Overlaid are *in situ* EDR measurements from United Airlines B-757s

---

## NTDA EDR vs. Reflectivity Mosaics

28 September 2007 (2 km horizontal resolution)





## NTDA EDR vs. Reflectivity Mosaics

28 September 2007 (2 km horizontal, 3000 ft vertical resolution)

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## Field Program: NASA B-757 Flight Tests 3 April – 18 May 2002

- 11 flights in and around thunderstorms over the south-eastern US
- High-rate aircraft data used to compute EDR along flight track
- Results compared to NTDA EDR mosaic computed from nearby NEXRADs

The NASA Langley B-757 aircraft

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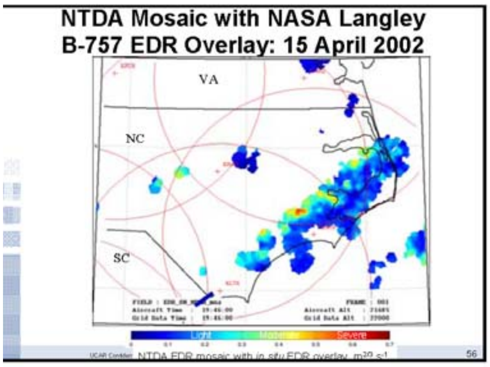

## NTDA Mosaic with NASA Langley B-757 EDR Overlay: 15 April 2002

NTDA EDR mosaic with *in situ* EDR overlay, $m^{2/3}\ s^{-1}$

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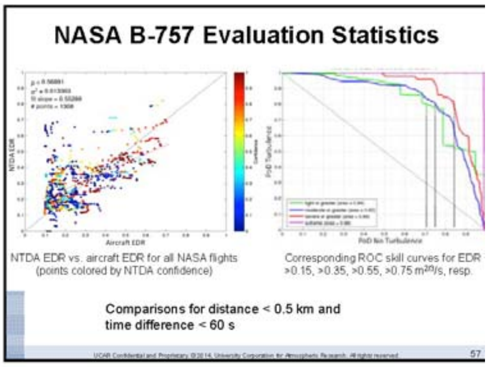

## NASA B-757 Evaluation Statistics

NTDA EDR vs. aircraft EDR for all NASA flights (points colored by NTDA confidence)

Corresponding ROC skill curves for EDR >0.15, >0.35, >0.55, >0.75 $m^{2/3}/s$, resp.

Comparisons for distance < 0.5 km and time difference < 60 s

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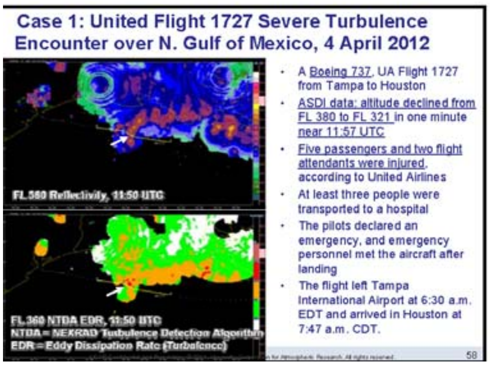

## Case 1: United Flight 1727 Severe Turbulence Encounter over N. Gulf of Mexico, 4 April 2012

- A Boeing 737, UA Flight 1727 from Tampa to Houston
- ASDI data: altitude declined from FL 380 to FL 321 in one minute near 11:57 UTC
- Five passengers and two flight attendants were injured, according to United Airlines
- At least three people were transported to a hospital
- The pilots declared an emergency, and emergency personnel met the aircraft after landing
- The flight left Tampa International Airport at 6:30 a.m. EDT and arrived in Houston at 7:47 a.m. CDT.

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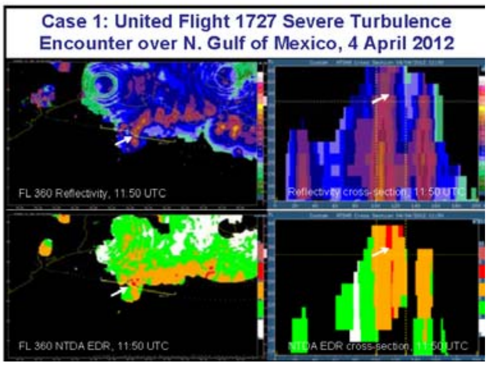
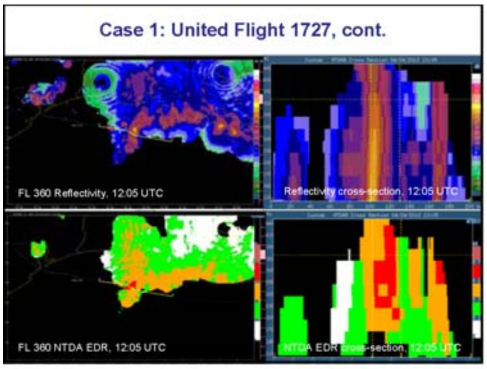
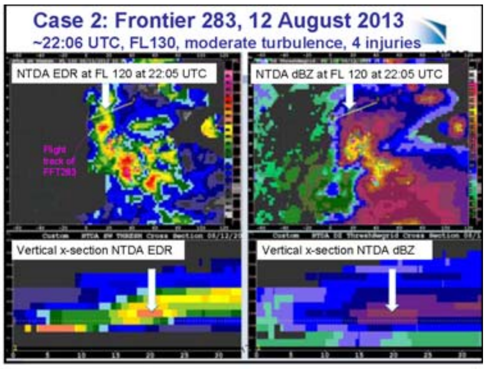


## Case 1: United Flight 1727 Severe Turbulence Encounter over N. Gulf of Mexico, 4 April 2012

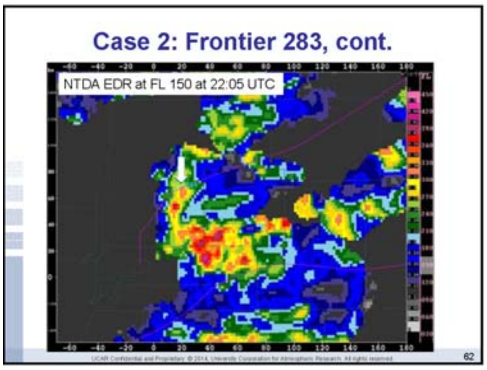


Case 1: United Flight 1727, cont.



Case 2: Frontier 283, 12 August 2013

~22:06 UTC, FL130, moderate turbulence, 4 injuries



Case 2: Frontier 283, cont.

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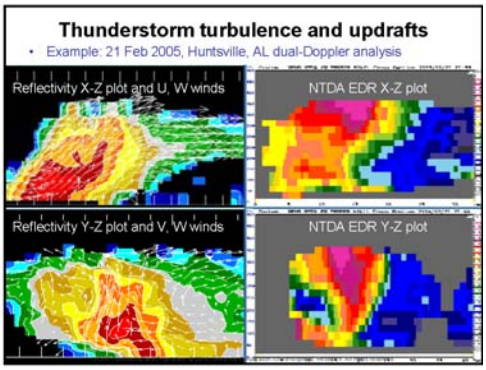
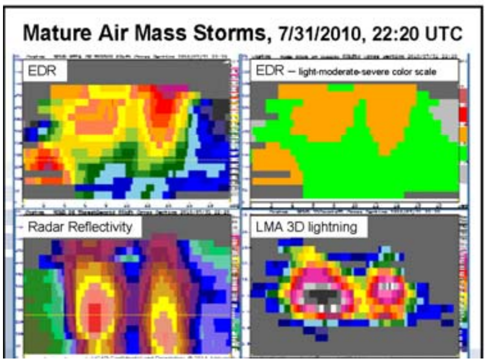
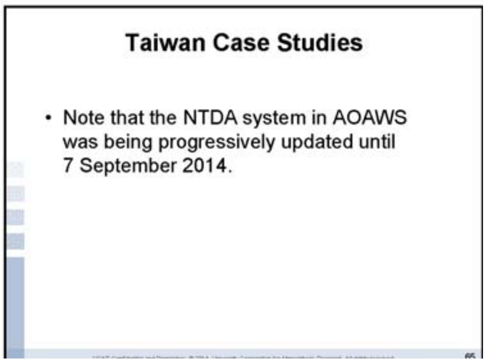


Thunderstorm turbulence and updrafts

- Example: 21 Feb 2005, Huntsville, AL dual-Doppler analysis

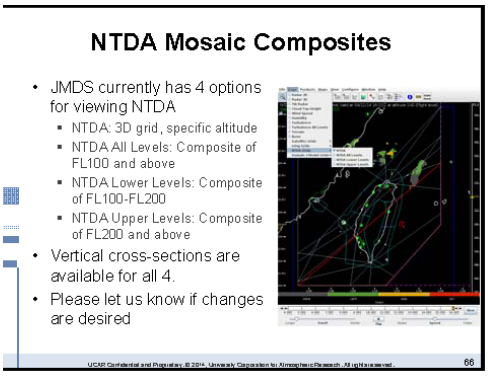


Mature Air Mass Storms, 7/31/2010, 22:20 UTC



Taiwan Case Studies

- Note that the NTDA system in AOAWS was being progressively updated until 7 September 2014.



## NTDA Mosaic Composites

- JMDS currently has 4 options for viewing NTDA
  - NTDA: 3D grid, specific altitude
  - NTDA All Levels: Composite of FL100 and above
  - NTDA Lower Levels: Composite of FL100-FL200
  - NTDA Upper Levels: Composite of FL200 and above
- Vertical cross-sections are available for all 4.
- Please let us know if changes are desired

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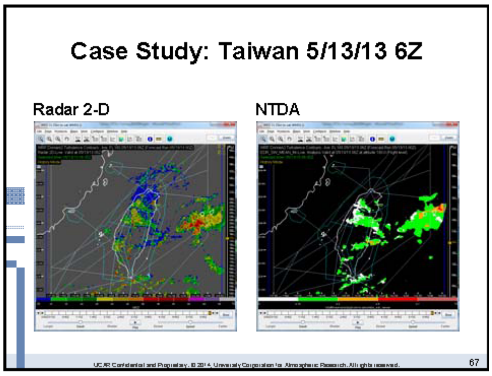

## Case Study: Taiwan 5/13/13 6Z

**Radar 2-D**

**NTDA**

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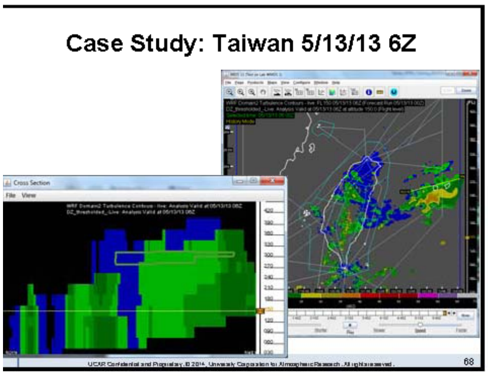

## Case Study: Taiwan 5/13/13 6Z

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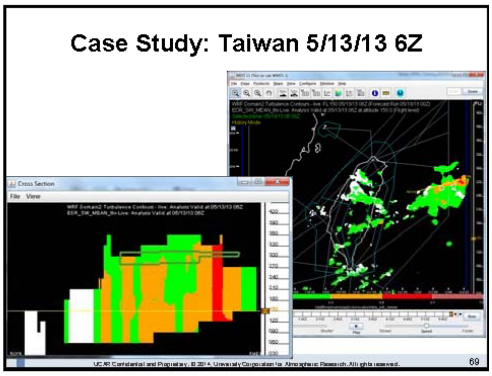

## Case Study: Taiwan 5/13/13 6Z

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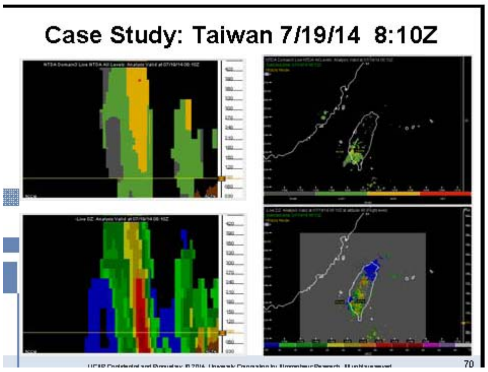
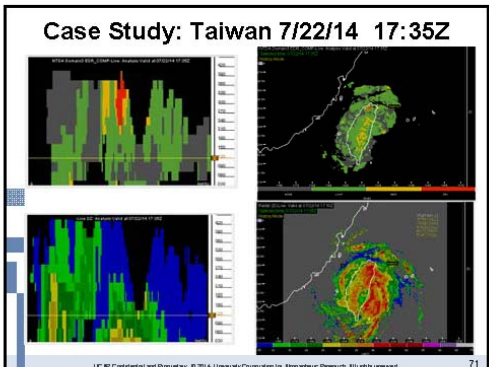
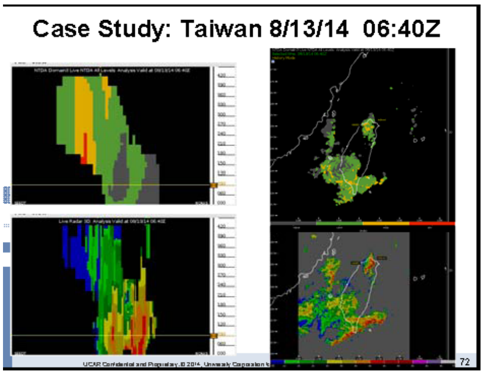


## Case Study: Taiwan 7/19/14 8:10Z



## Case Study: Taiwan 7/22/14 17:35Z



## Case Study: Taiwan 8/13/14 06:40Z

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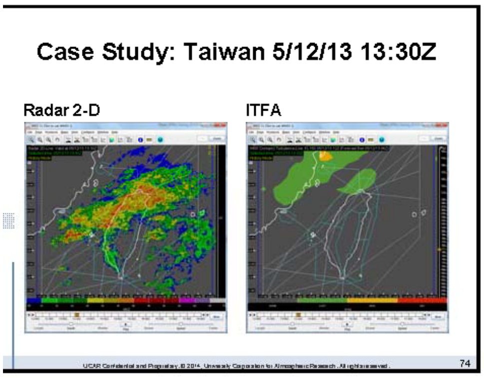
## USING NTDA WITH ITFA/GTG



## Case Study: Taiwan 5/12/13 13:30Z

Radar 2-D

ITFA

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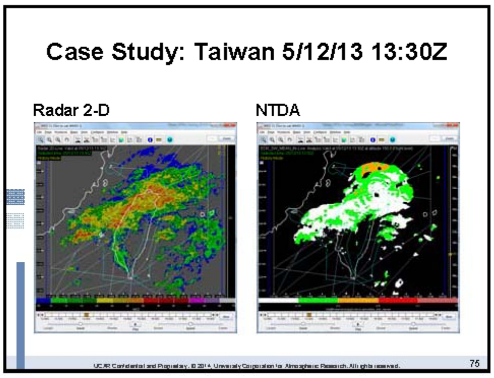

## Case Study: Taiwan 5/12/13 13:30Z

Radar 2-D

NTDA

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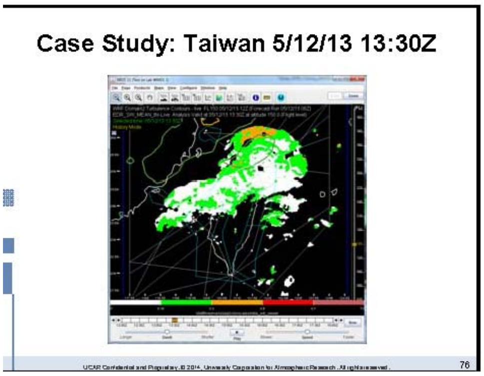

## Case Study: Taiwan 5/12/13 13:30Z

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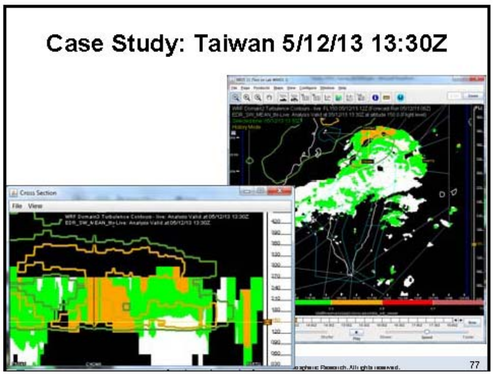

## Case Study: Taiwan 5/12/13 13:30Z

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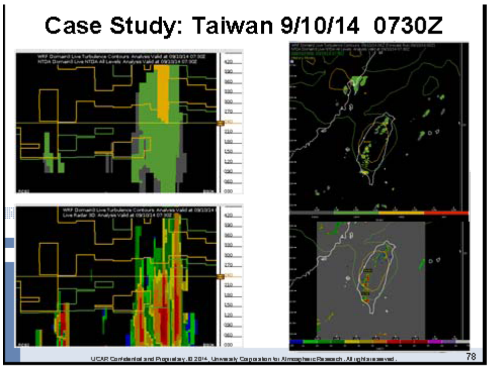

## Case Study: Taiwan 9/10/14  0730Z

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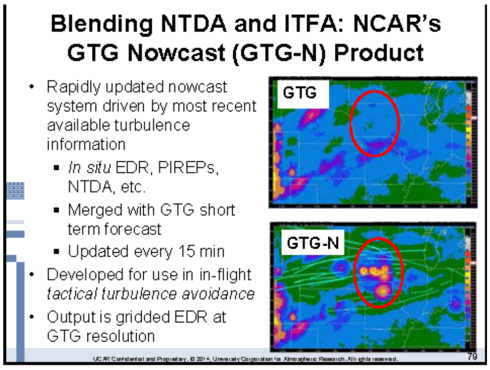

## Blending NTDA and ITFA: NCAR's GTG Nowcast (GTG-N) Product

- Rapidly updated nowcast system driven by most recent available turbulence information
  - *In situ* EDR, PIREPs, NTDA, etc.
  - Merged with GTG short term forecast
  - Updated every 15 min
- Developed for use in in-flight *tactical turbulence avoidance*
- Output is gridded EDR at GTG resolution

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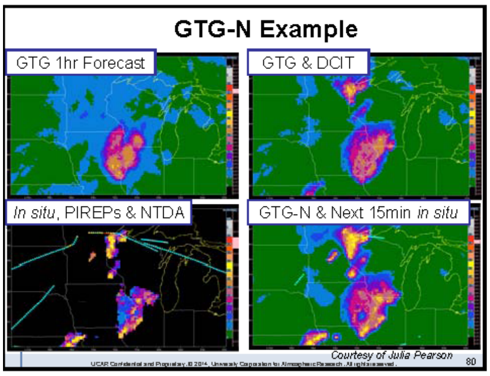

## GTG-N Example

*Courtesy of Julia Pearson*

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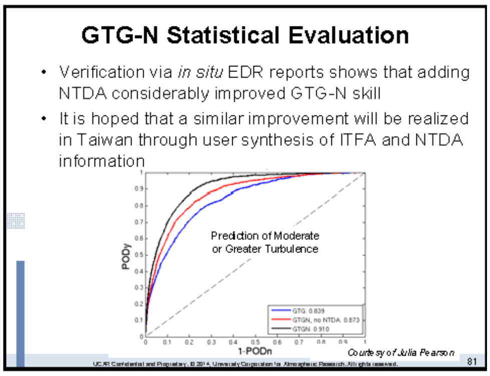

## GTG-N Statistical Evaluation

- Verification via *in situ* EDR reports shows that adding NTDA considerably improved GTG-N skill
- It is hoped that a similar improvement will be realized in Taiwan through user synthesis of ITFA and NTDA information

*Courtesy of Julia Pearson*

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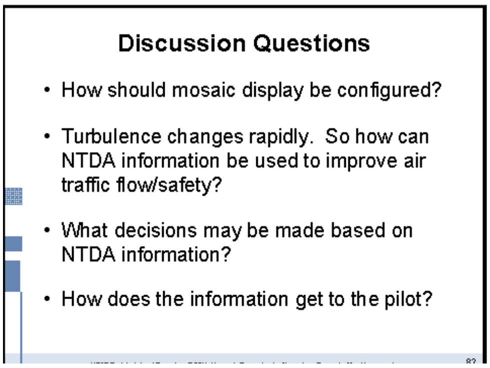
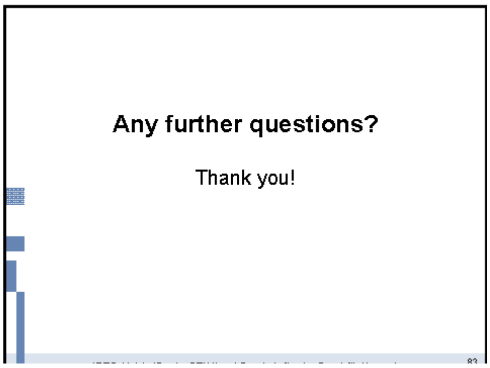


## Discussion Questions

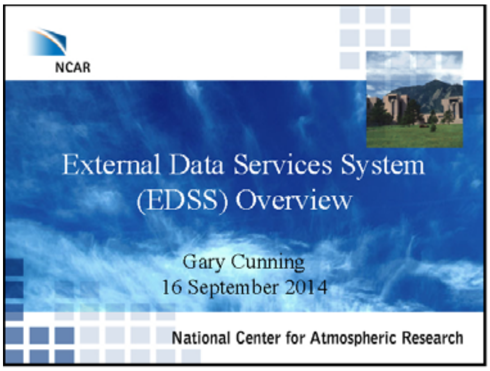
- How should mosaic display be configured?
- Turbulence changes rapidly. So how can NTDA information be used to improve air traffic flow/safety?
- What decisions may be made based on NTDA information?
- How does the information get to the pilot?



## Any further questions?

Thank you!

## *四、External Data Services System（EDSS）*

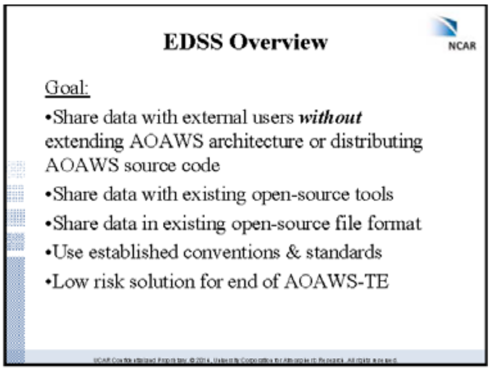


NCAR

External Data Services System (EDSS) Overview

Gary Cunning
16 September 2014

National Center for Atmospheric Research

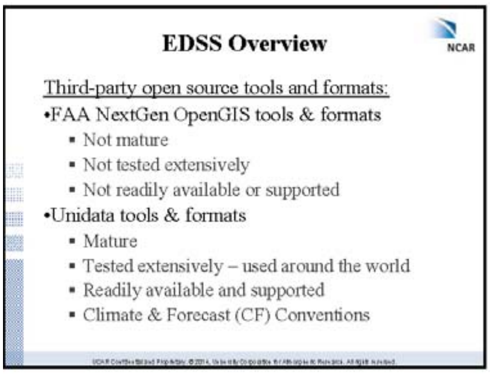


### EDSS Overview

NCAR

Goal:

- Share data with external users ***without*** extending AOAWS architecture or distributing AOAWS source code
- Share data with existing open-source tools
- Share data in existing open-source file format
- Use established conventions & standards
- Low risk solution for end of AOAWS-TE

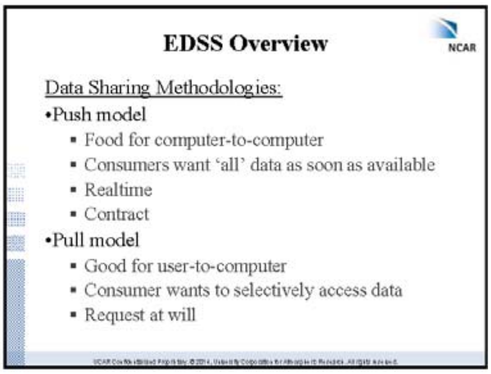


### EDSS Overview

NCAR

Third-party open source tools and formats:

- FAA NextGen OpenGIS tools & formats
  - Not mature
  - Not tested extensively
  - Not readily available or supported
- Unidata tools & formats
  - Mature
  - Tested extensively – used around the world
  - Readily available and supported
  - Climate & Forecast (CF) Conventions

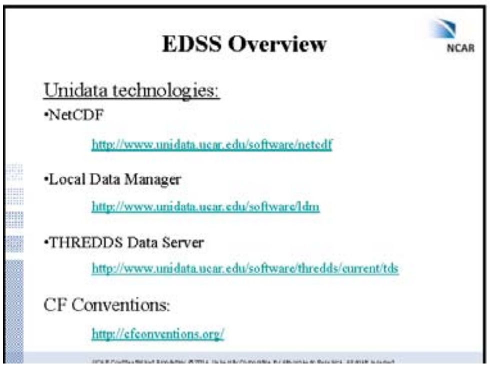


### EDSS Overview

NCAR

Data Sharing Methodologies:

- Push model
  - Food for computer-to-computer
  - Consumers want ‘all’ data as soon as available
  - Realtime
  - Contract
- Pull model
  - Good for user-to-computer
  - Consumer wants to selectively access data
  - Request at will



### EDSS Overview

NCAR

Unidata technologies:

- NetCDF

  http://www.unidata.ucar.edu/software/netcdf

- Local Data Manager

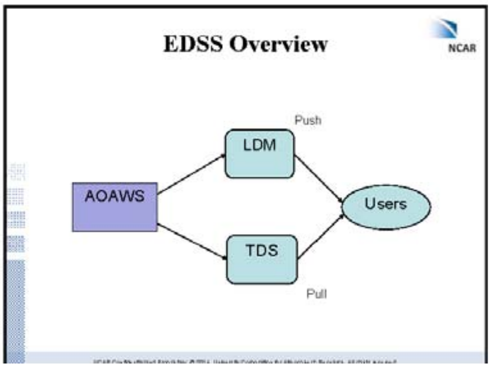
  http://www.unidata.ucar.edu/software/ldm

- THREDDS Data Server

  http://www.unidata.ucar.edu/software/thredds/current/tds

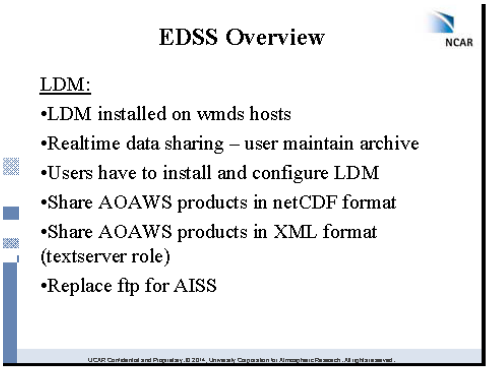
CF Conventions:

  http://cfconventions.org/



### EDSS Overview

NCAR



## EDSS Overview

LDM:

- LDM installed on wmds hosts
- Realtime data sharing – user maintain archive
- Users have to install and configure LDM
- Share AOAWS products in netCDF format
- Share AOAWS products in XML format (textserver role)
- Replace ftp for AISS

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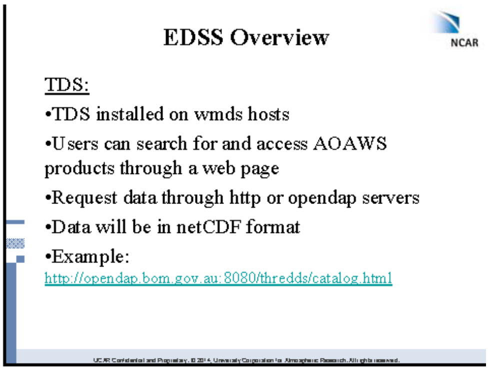

## EDSS Overview

TDS:

- TDS installed on wmds hosts
- Users can search for and access AOAWS products through a web page
- Request data through http or opendap servers
- Data will be in netCDF format
- Example: http://opendap.bom.gov.au:8080/thredds/catalog.html

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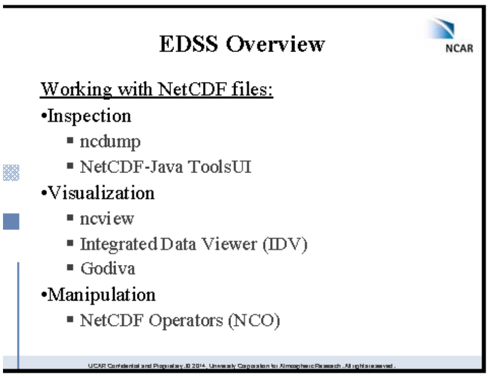

## EDSS Overview

Working with NetCDF files:

- Inspection
  - ncdump
  - NetCDF-Java ToolsUI
- Visualization
  - ncview
  - Integrated Data Viewer (IDV)
  - Godiva
- Manipulation
  - NetCDF Operators (NCO)

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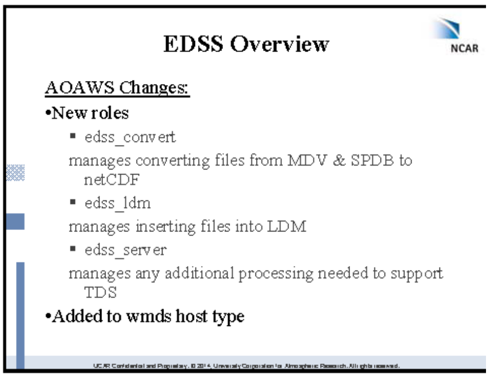

## EDSS Overview

AOAWS Changes:

- New roles
  - edss_convert

    manages converting files from MDV & SPDB to netCDF
  - edss_ldm

    manages inserting files into LDM
  - edss_server

    manages any additional processing needed to support TDS
- Added to wmds host type

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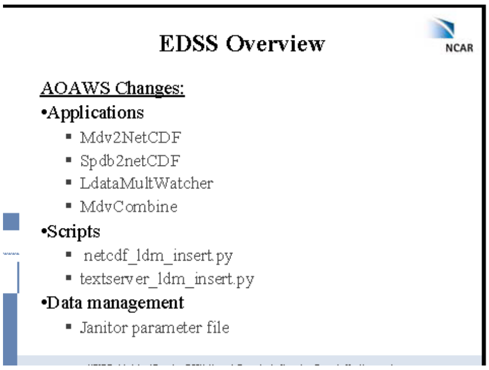
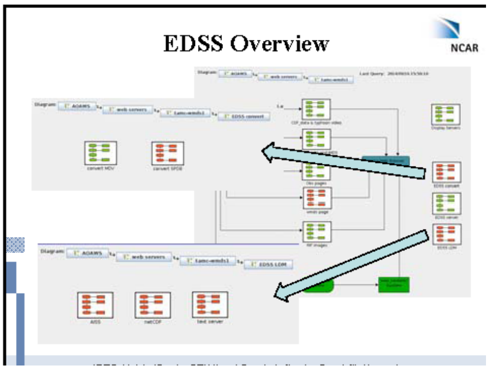


## EDSS Overview

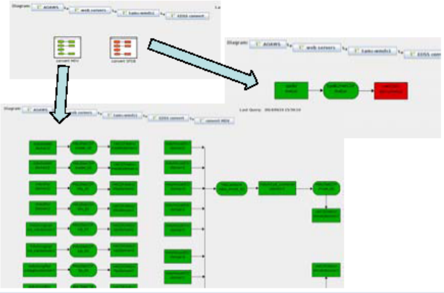
AOAWS Changes:

- Applications
  - Mdv2NetCDF
  - Spdb2netCDF
  - LdataMultWatcher
  - MdvCombine
- Scripts
  - netcdf_ldm_insert.py
  - textserver_ldm_insert.py
- Data management
  - Janitor parameter file



## EDSS Overview

## EDSS Overview



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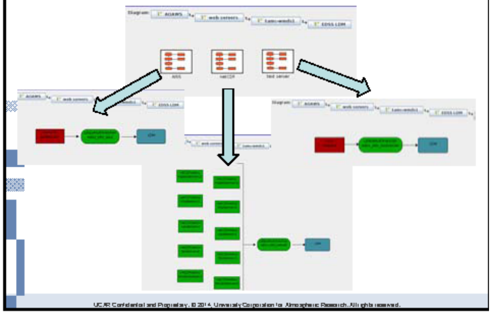
## EDSS Overview



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## EDSS Overview

Mdv2NetCDF

- Converts MDV files to netCDF
- Follows CF conventions
- Demonstrating conversion of CIP, FIP, ITFA MTSAT, NTDA and radar in lab
- Highly configurable parameter file

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## EDSS Overview

MdvCombine

- Used to combine individual MTSAT in separate MDV files into one MDV file
- Parameter file allows for many ways to combine and trigger

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## EDSS Overview

Spdb2netCDF

- Used to convert SPDB data into netCDF files
- Follows CF conventions – point data is not well explored or defined.
- Converts METARs
- Can be expanded to convert other SPDB types

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## EDSS Overview

LdataMultWatcher:

- Used to trigger scripts that insert files into LDM product queue

netcdf_ldm_insert.py & textserver_ldm_insert.py:

- Manipulate filename
- Create the product ID
- Execute pqinsert command

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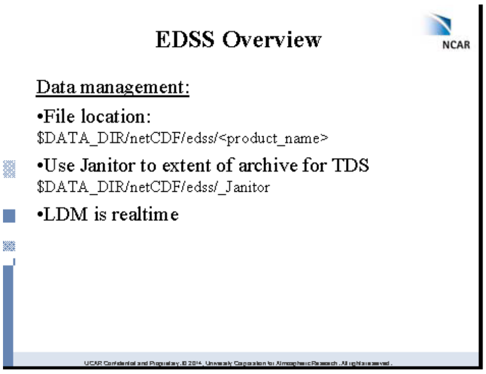

## EDSS Overview

Data management:

•File location:
$DATA_DIR/netCDF/edss/<product_name>

•Use Janitor to extent of archive for TDS
$DATA_DIR/netCDF/edss/_Janitor

•LDM is realtime

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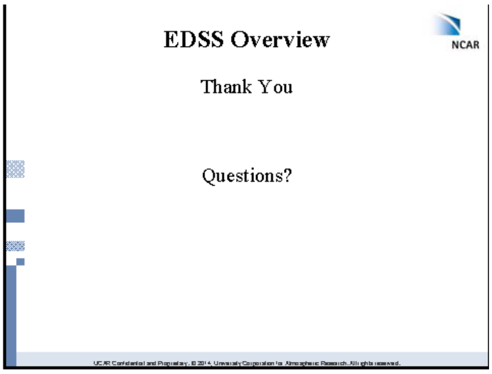

## EDSS Overview

Thank You

Questions?

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