ASSIMILATION OF SATELLITE–DERIVED WINDS INTO THE COMMUNITY HURRICANE MODELING SYSTEM (CHUMS) AT PENN STATE

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ABSTRACT

Challenges relating to forecasting in the tropics often differ from the midlatitudes due to: (i) weak dynamical constraints, (ii) rapidly evolving, mesoscale weather systems, (iii) the important role of convection and (iv) sparseness of the conventional data network in the tropics. Faithful representations of divergent flow and mesoscale features are necessary to resolve and simulate tropical weather phenomena accurately. The argument is that improving the initial conditions (IC) of a proven numerical model will optimize the reliability of the forecast.

Hurricane Floyd (1999) was the deadliest hurricane to affect the United States since Agnes in 1972 (NHC 1999). Hurricane Floyd (1999) tracked along the entire eastern seaboard of North America on its way out into the Atlantic towards Britain. The standard observing network lay to the left of the storm center as it tracked up the coast. This asymmetric coverage of the standard observations on a rapidly changing storm provides an ideal test of the potential impacts of using satellite–derived wind data to define the mesoscale detail of a rapidly evolving, intense weather system. Static analyses (with and without these wind data) of hurricane Floyd are compared for two key times in the storm's evolution. The radius of influence (horizontal and vertical) and observations/ analysis weightings mix are varied. The second component of this study is to perform a four dimensional data assimilation (FDDA) of these winds into the Penn State Community Hurricane Modeling System (CHUMS). In the present study, only satellite–derived winds are used. Asymmetries in the distribution of the satellite winds aloft seem to contribute to a degradation of the FDDA product. The results obtained here indicate that thermal fields, which can be derived from the AMSU–A sounder may hold promise for FDDA improvements. The impacts of moisture soundings from AMSU–B should also be investigated.

1. Experiment Design

Two approaches to assimilation of the winds data are presented here: a static, Cressman–type analysis and the MM5 four dimensional data assimilation (FDDA) cycle. Each approach has merits in assessing the value of the satellite winds to the analysis of the storm system structure. VIS, IR and WV winds (satwinds) from both GOES–8 and METEOSAT–7 are incorporated into both analysis systems. Data incorporated into the analyses presented here are not the operational GTS winds, but are an advanced version of high-density multispectral vectors derived in real time at CIMSS. These satwinds are derived using the advanced UW-CIMSS/NOAA-NESDIS algorithm (Velden *et al.* 1997; 1998). The data is processed to 60ºN however, the satwinds density at the highest latitudes is greatly diminished due to scan angle considerations. Two time periods in the lifecycle of hurricane Floyd were compared using this technique (see below).

Once read into MM5, the satwinds are sorted and their heights are estimated against a (case–specific) thermodynamic reference state. They are then incorporated into the model initial conditions through either the Cressman or FDDA procedure. US Navy Operational Global Atmospheric Prediction System (NOGAPS) and NCEP AVN model analysis fields (interpolated to the mesoscale model grid) are used as the first guess fields and also control analyses against which the impacts of the winds on the analyses are evaluated. While some satellite–derived winds are assimilated into these global models in real time, the data density is dramatically improved here. All available satwinds (CIMSS quality control only) within the vertical layers specified are incorporated into the Cressman analyses presented. Typically, over 2500 winds (additional quality control) are successfully assimilated in the CHUMS analyses at all times through the FDDA cycle. A 60 h continuous nudging FDDA cycle is compared with an equivalent 60 h forecast for the time leading up to the landfall of hurricane Floyd (1999) in North Carolina. Before reviewing these results, a brief review of the key elements in the lifecycle of hurricane Floyd (1999) is presented.

2. Case Study of Hurricane Floyd (1999)

Hurricane Floyd (1999) was responsible for 56 deaths in the United States, making it the deadliest US hurricane since Agnes (1972). In spite of quite reasonable track forecasts, this storm was the third in a series of hurricanes to make landfall in the Carolinas in the 1999 season and caused devastating flooding in large areas of the mid–Atlantic states. The storm was almost a category 5 system (921 hPa) as it approached the Bahamas on September 13, 1999. After exiting the islands, Floyd turned northward ahead of an approaching midlatitude trough and made landfall in North Carolina around 0630 UTC on 16 September 1999 as a weak Category 3 storm (965 hPa). It then tracked along the US east coast and Canadian Maritimes for over 2 days from until late on 18 September 1999. In all of this time, the structure of Floyd was continually evolving from a tropical, warm–cored system toward a midlatitude, cold–cored system as the storm underwent an extratropical transition. Floyd began to transition when it was offshore of New York state late on September 16th and completed transition about 72 h later, as it sped across the Northern Atlantic Ocean near 48ºN, caught up in the westerlies. While the U.S. National Hurricane Center (NHC) ceased tracking the system on 1800UTC at 19 September 1999, post–processing of global model analyses (both AVN and NOGAPS) reveals that the system was reintensifying to at least 985hPa at 10ºW as it approached Britain. This and a number of other recent studies compel us to recall the work of earlier researchers, who highlighted tropical systems as a potential source of damaging midlatitude storms.

3. Wind Assimilation Effects

While Floyd tracked along the North American coast, the standard network data was concentrated to its west. This asymmetric data distribution is problematic, especially as this storm is undergoing extratropical transition: a process of evolution from a relatively symmetric, tropical system to a highly asymmetric, extratropical system. The supplementary satellite–derived winds incorporated in the analyses presented here was almost entirely ocean–based. Rather than eliminating a data distribution bias, this asymmetry in data type produced its own complications.

3.1 Cressman Analyses

The Cressman–type analyses are static interpolations of the wind fields and have no temporal integration of the observations. This straightforward approach has the advantage of being very fast, allowing rapid assessment of a large variety of weighting structures for the asynoptic observations. These analyses are used to experiment with horizontal and vertical weighting functions for the satwinds. The control simulation uses a horizontal radius of influence (ROI) of 250 km and a vertical range of ±25 hPa from the model level. Two variations on this weighting structure have been tested: ROI=250km at all levels, ±50 hPa and varying ROI with height such that ROI=500km at 200 hPa, ROI=250km at 500hPa, and ROI=100km at 850hPa (vertical range of ±25 hPa at all levels). This last experiment is designed to reflect the decreasing inertial stability of the tropical cyclone with height. For weak inertial stability (at 200 hPa) external forcing will have more impact over a wider area than the highly inertially stable lower levels. In all cases the winds are weighted either at the same level as the analysis (50/50) or as the dominant observation (85/15) wherever they exist. The 85/15 weighting is an attempt to approximate the effects of the winds if little or no other data were available for an analysis cycle (if satellites were the only data source, for example!).

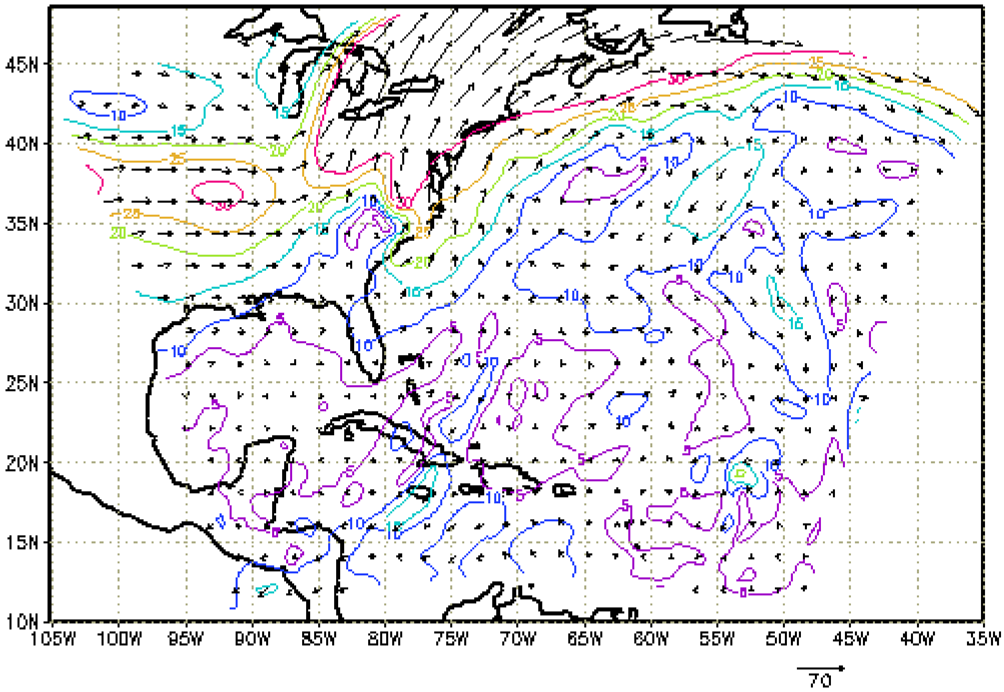

Figure 1. 200 hPa winds at 1200 UTC on 16 September 1999. Hurricane Floyd is located just off the North Carolina coast at (35.7ºN, 76.8ºW) and has minimum central pressure of 965 hPa.

Snapshots of two distinct stages in the lifecycle of Hurricane Floyd were studied in detail: (i) a weakening Category 3 hurricane (965 hPa) just exiting the North Carolina coast [16 September 1999 1200UTC] and (ii) a rapidly accelerating extratropical system in the midlatitude westerlies [18 September 1999 0000UTC]. Only analyses from the 16 September 1999 1200UTC are presented.

The 200 hPa winds for 1200UTC, 16 September 1999 are plotted in Figure 1. The tropical cyclone is at (35.7ºN, 76.8ºW) recurving just ahead of a midlatitude upper trough; the trough is associated with a surface front. These are the only significant flow features evident in the region. The poleward outflow jet of Floyd appears to merge with the strong upper jet ahead of the approaching trough.

Figure 2 is designed as a summary plot, highlighting the key features of the ROI and weighting variation. In all cases, the winds in the vicinity of the tropical cyclone modify the outflow near the storm center and in the vicinity of the trough/jet feature. In all cases, the poleward steering flow over the storm is weakened and a more cyclonic shear is evident over the storm. Not surprisingly, these effects are amplified for stronger weighting of the satwinds. Increasing the ROI also amplifies these changes (compare panels (a) and (c)), as well as weakening Floyd's poleward outflow jet and increasing the divergent flow in the right jet entrance region. This last wind change could affect low level cyclogenesis in the region (Lackmann et al. 1997). Modifications evident in the tropics are unlikely to have any effect on the evolution of Floyd which is accelerating into the midlatitudes at this time.

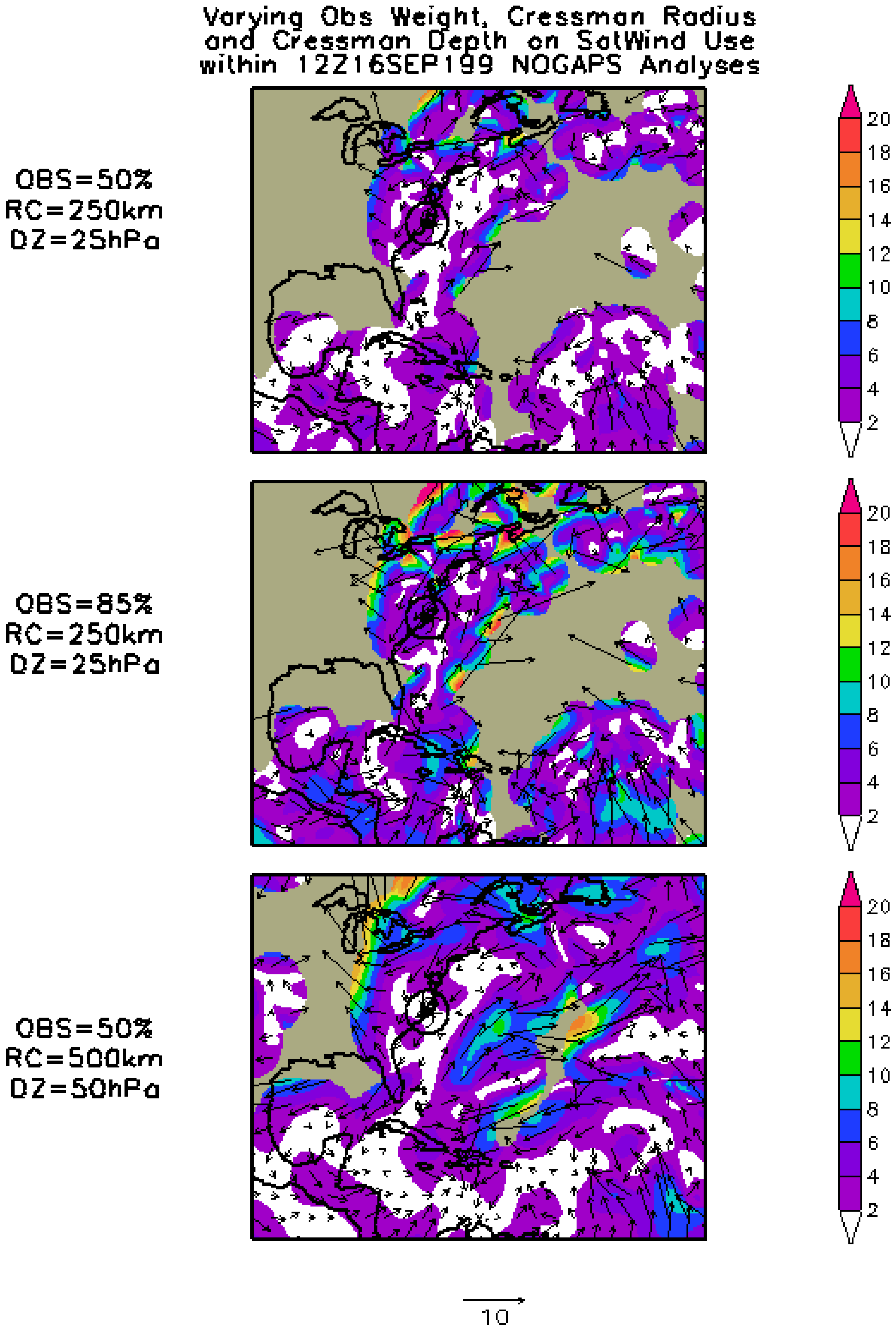

Figure 2. Impacts of different satwinds treatments on the 200 hPa wind analysis. 200 hPa difference fields (*satwinds*–control) for NOGAPS first guess fields are plotted: (a) ROI=250km, δp=±25, ω=0.5; (b) ROI=250km, δp=±25, ω=0.85; and (c) ROI=500km, δp=±50, ω=0.5. Both the tropical cyclone location and a circle with radius equal to the ROI are plotted on each panel. Grey shading indicates regions which are unaffected by the satellite–derived winds (outside the ROI of the closest wind).

3.2 Four Dimensional Data Assimilation

The MM5 FDDA procedure is based on a *Newtonian relaxation* (*nudging*) procedure (Stauffer and Seaman 1994) and readily allows assimilation of asynoptic data such as satwinds. Error characteristics for different data types are assigned either objectively or subjectively and are incorporated into weightings for each observation type that have both horizontal and vertical structure. Hence, for example, near–surface winds may only be assimilated in one layer, but may have broad horizontal influence on the final analysis field.

Two 60 h model simulations are compared here: an *"FDDA run"* in which the CHUMS forecast includes FDDA (3 hourly nudging to the satwinds) for the entire forecast cycle and a *"non–FDDA"* run in which no satwinds are used. In both cases, NOGAPS *analyses* are used to provide initial and boundary conditions. Since the purpose of this experiment is to investigate the impact of FDDA on the CHUMS forecast, continuous FDDA on the entire forecast was used for maximum impact; in a real–time forecast setting, a 12 h FDDA step, followed by a 48 h forecast would be a more typical cycle. The period studied extends from 14 September 0000 UTC to 16 September 1200 UTC 1999.

The impact of the FDDA on the forecast was unexpected and raises a number of issues. The track of hurricane Floyd was well simulated by the control (no satwinds) forecast of the model is shown in Figure 3. Inclusion of the satwinds in this case has resulted in a degradation of the track forecast. The intensity forecast (not shown) is improved by 5-10% in the FDDA simulation, although the model resolution is too coarse to expect it to agree closely with observations.

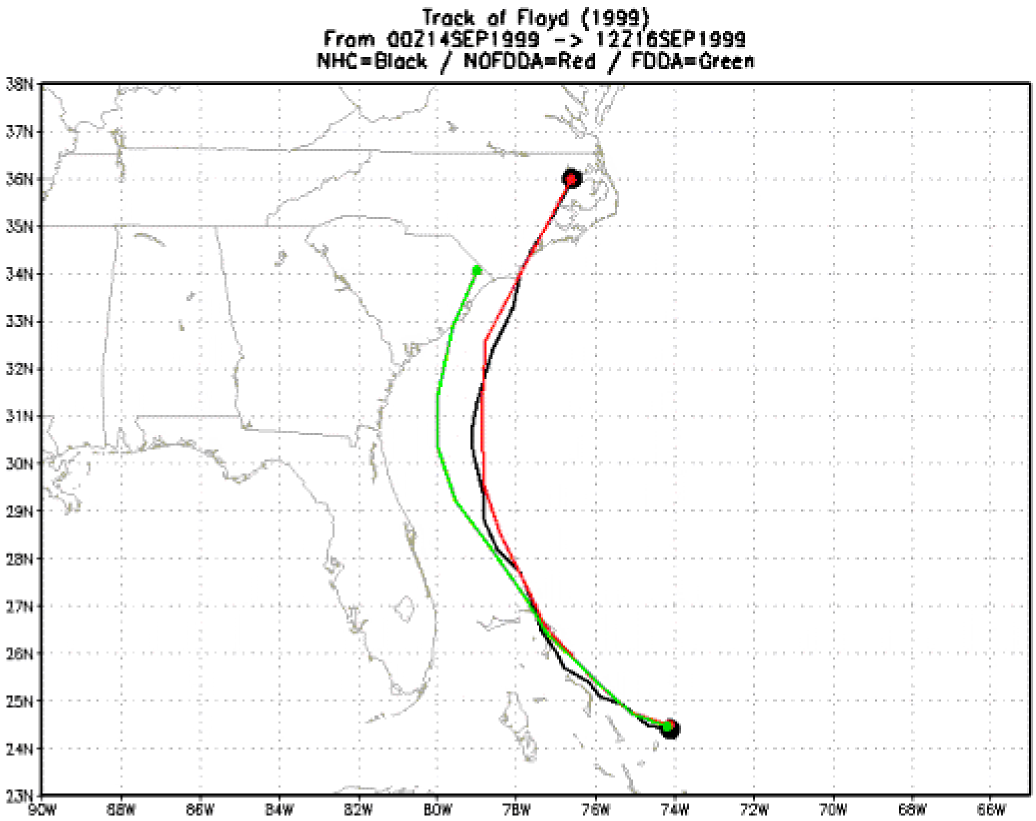

Figure 3: Comparison of the tracks of Floyd: NHC best-track (black), 60 h control forecast (red) and 60 h FDDA satwinds forecast (green). Forecasts initialized on 0000 UTC 14 September 1999.

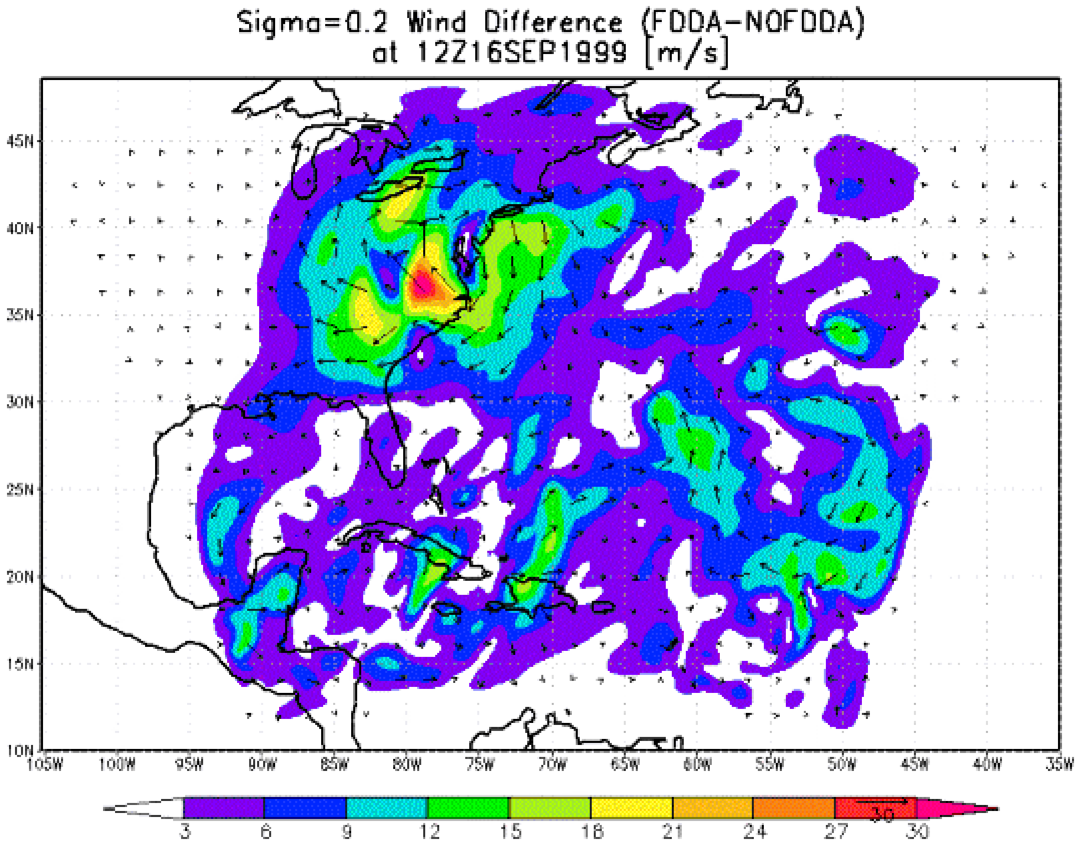

Figure 4: 200 hPa wind difference (FDDA-control) for 16 September 1999 at 1200UTC.

A number of avenues are being explored to progress from this result. The immediate work involves incorporating a more uniform coverage of satwinds and repeating the experiment. For 20/22 datasets used here, we had satwinds over the ocean only. Thus, inclusion of these winds vastly increased the description of the upper troposphere over the ocean, without directly impacting the flow over land. Even at 60h, the differences in upper tropospheric flow are predominantly over the ocean or in the immediate vicinity of the storm (Figure 4). Optimal satwinds weights and ROI are also being sought.

4. Summary

Cressman analyses of combined satwinds and global model analyses demonstrated the potential for variation of the radius of influence (ROI) of observations with height (Figure 2) and allowed for efficient exploration of optimal ROI values for this case. The time presented here (16 September 1999 at 1200 UTC) was one of two windows in which the satwinds data available were distributed across the entire (land and ocean) domain show here.

While initial results for the FDDA are somewhat disappointing, the bias in the satwinds spatial distribution is an obvious cause for concern. Simulations with full resolution satwinds will be repeated immediately and these results will be presented at the AMS Tropical Meteorology and Tropical Cyclones Conference in May 2000.

ACKNOWLEDGEMENTS

Support for this research by the Large-Scale Dynamics Program of the National Science Foundation (grant ATM-9911212) is gratefully acknowledged. Many thanks to Mr Robert Hart of Penn State for his excellent programming and graphics work. The satwinds data used here were provided by Mr Christopher Velden and colleagues at CIMSS, University of Wisconsin.

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