# An Application of 4d-VAR to Weather Control

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## Motivation

•**Weather Control** - determination of the perturbations needed to locally "control" the weather (Henderson et al. 2005; Hoffman 2002)

•The motivation to modify the weather is especially strong in the case of tropical cyclones (TC):

•Central Pacific Hurricane Iniki (1992) had a tremendous impact on parts of the Hawaiian Islands, causing extensive damage to property and vegetation and killing six people (CPHC 1992); 60 $ms^{-1}$ winds, min SLP 945 hPa.

•Iniki would have had less impact, in terms of wind damage, on the Hawaiian Islands had the track had been displaced farther west by as little as 100 km.

•Hurricane Andrew (1992) made landfall with 70 $ms^{-1}$ gusts and a SLP of 922 hPa; extensive wind damage occurred over southern Florida (Wakimoto and Black 1994; Willoughby and Black 1996)

•**Goals of two experiments: minimize wind damage over land using initial conditions (IC) modified by Four-Dimensional Data Assimilation (4d-VAR) by 1) repositioning a simulated TC away from land and 2) directly penalizing high winds via a cost function term**

## Hurricane Iniki: Target Experiments

•**MM5 4d-VAR uses the adjoint of the linearized version of the MM5 to solve the nonlinear minimization problem of finding the smallest perturbation at the start of the data assimilation period (i.e., small changes to the IC) so that the solution best fits all the available data.**

•Our procedure : Seek initial state C(t=0h) close to observed initial state G(0h), such that at a later time (t=6h), the controlled simulation C is close to a target state G in which the storm has been repositioned to the west by ~100 km.

•Controlled IC found by simultaneously minimizing difference (scaled by S) from target (i.e., C(6h)-G(6h)) and initial state (i.e., C(0h)-G(0h)).

The 4d-VAR cost function J for model variables X=T, U, V:

$$J = \sum_{xijkt} \left[ \frac{C_{xijk}(t) - G_{xijk}(t)}{S_{xk}} \right]^2$$

•G(6h) generated using the FCA technique (Hoffman and Grassotti 1996)

•Control vector allows changes to T, U, V, W, specific humidity and perturbation pressure

## Hurricane Iniki: Track Modifications

•Path of simulated TC in the controlled MM5 run (red) in Fig. 1 is repositioned to the west of the Hawaiian Islands compared to unperturbed run (black)

•Wind speeds over Kauai have been reduced; strongest winds largely are west of the islands

•Controlled simulation shifts the simulated tropical cyclone to the northwest close to the target storm in the first 6 h

•Note that distance between the unperturbed and controlled storms appears to grow exponentially during first 6 h of the forecasts

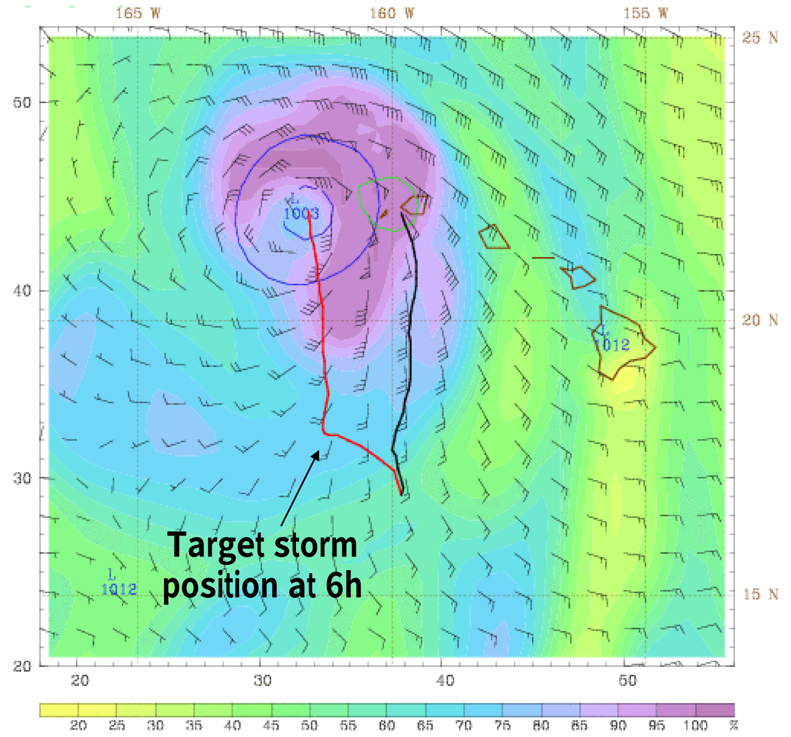


Fig. 1 – Surface wind field (full (half) barb = 10 (5) m/s; 750-hPa RH shaded (%)) at 30-h in controlled MM5 simulation valid 0000 UTC 12 September 1992. Unperturbed and controlled tracks from hourly output plotted in black and red, respectively.

•After satisfying requirements of 4d-VAR at hour 6, controlled storm translates almost due north with steering flow

## Hurricane Andrew: Wind Damage Experiments

•Simultaneously minimize magnitude of initial-time perturbations (as for Iniki) and a wind damage-based cost function $J_d$:

$$J_D = \sum_{ijt} D_{ij}(t) C_{ij}$$

•C is the replacement cost of property (Fig. 2)

•D is the fractional wind damage:

$$D = \sum 0.5\left[1 + \cos\left(\pi \frac{V_1 - V}{V_1 - V_o}\right)\right]$$

•D=0 for $V<V_o$= 25 $ms^{-1}$; D=1 for $V>V_1$=90 $ms^{-1}$

•Cost function evaluated every 15 min for hours 4-6

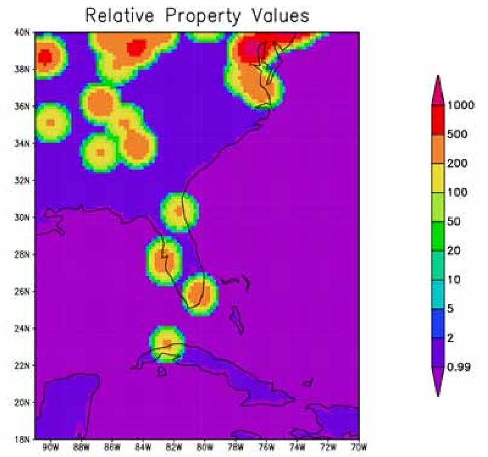


Fig. 2 – Property values: all land points have a value of at least one. The choice of contours highlights the location of cities.

## Hurricane Andrew: Evaluation of Perturbations and Wind Reductions

•Time series of differences between controlled and unperturbed simulations (Fig. 3) shows complex high-magnitude adjustments near the storm and smaller concentric rings at greater distances

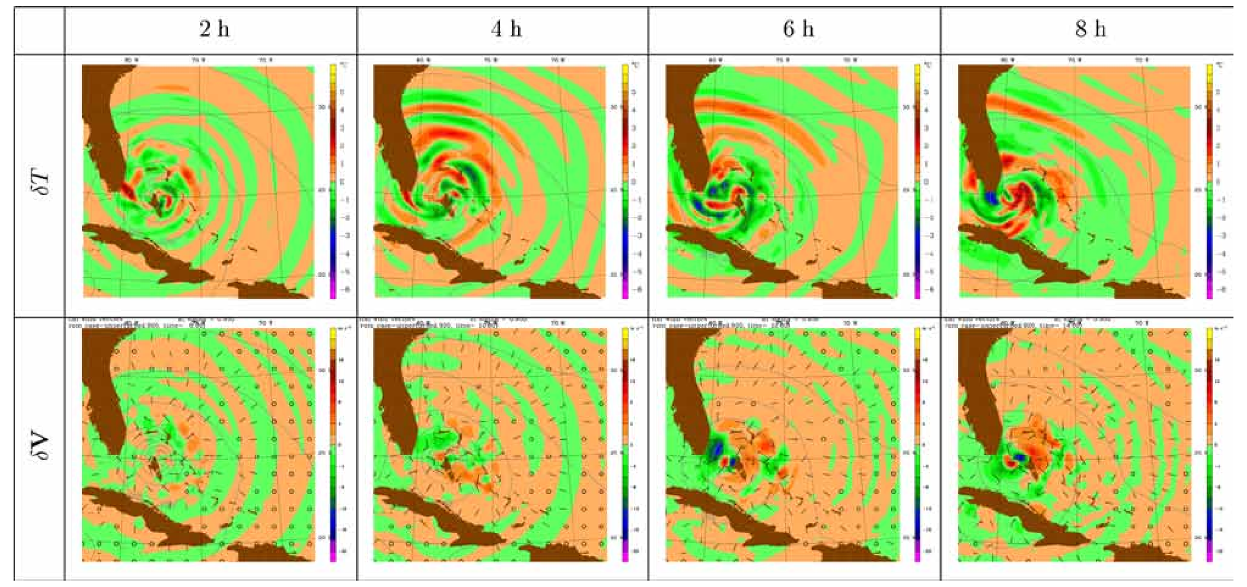


Fig. 3 – Temperature (top; Celsius degrees at ~450 hPa) and vector wind (bottom; plotted as in Fig. 1 at ~955 hPa) perturbations for hours 2, 4, 6 and 8. Starting time (i.e., hour 0) of 6-h 4d-VAR window is 0000 UTC 24 August 1992

•Temporary reduction of winds can be seen on southeast Florida coast during times when $J_d$ is evaluated (i.e., hours 4 and 6) in controlled simulation (Fig. 4)

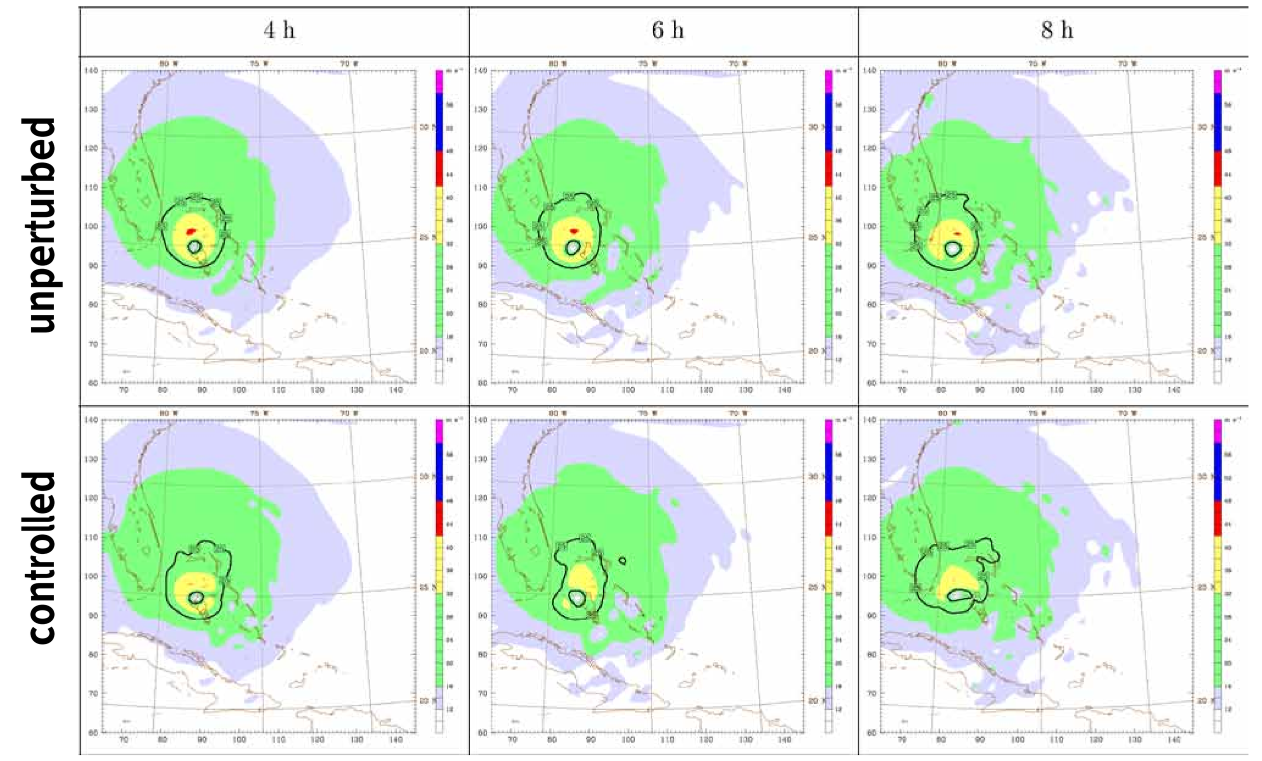


Fig. 4 – Lowest model layer wind for the unperturbed (top) and controlled simulations (bottom) valid at hours 4, 6 and 8. Winds are shaded according to Saffir-Simpson category.

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## Considerations

•**Related to this numerical methods study**:

•Large amount of energy contained in the increments (~$10^{16}$J)

•Coarse resolution of model grid (20 km)

•Simplistic physical parameterizations available in this version of 4d-VAR

•Effect on wind speed is transient

•**Other considerations**:

•Moral issues - we must fully understand the consequences of our actions

•Legal issues – TCs may be redirected and cause damage elsewhere
•hurricane rainfall can be beneficial

•Engineering – extremely difficult and costly to implement the precise adjustments required for "weather control"
•Enable technologies: space solar power, biodegradable oil?

•Conflicts between nations that have the technology and those that don't

## Conclusions

•A non-standard application of 4d-VAR significantly effects changes in the mass and momentum structure, and eventual path, of a simulated TC

•The track of Hurricane Iniki is repositioned to the west of the Hawaiian islands so that the maximum winds remain over the ocean; surface wind speeds for Hurricane Andrew are significantly, though temporarily, reduced over Florida

•The consequences of weather control must be carefully thought through

**References**

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# An Application of 4d-VAR to Exigent Forecasting

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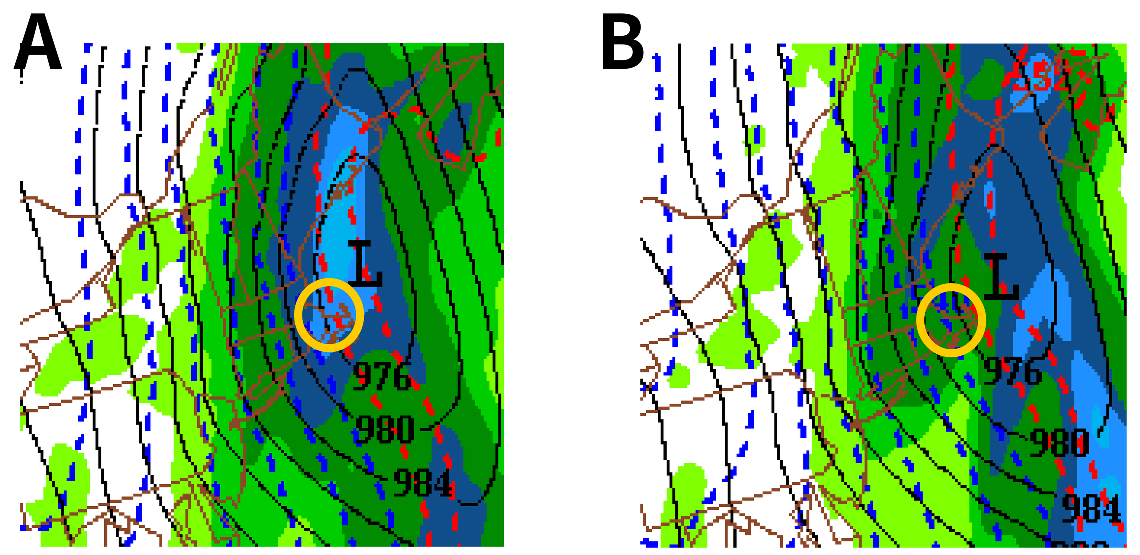
•**Exigent Forecasting** - operational determination of the likelihood of a potential weather event (Henderson et al. 2005)

- •Is an upcoming weather event of interest possible?
- •As a forecaster, should I be concerned with a near-miss event or an outlier model solution?
- •This potential technique could determine the IC changes required to prevent a damaging high-wind event – such as demonstrated in the "Weather Control" presentation.

## Basic Concept

**What is the likelihood of forecast A verifying over Cape Cod given forecast B?**




•Are changes to the model's initial conditions that result in forecast A reasonably likely?

•Does the envelope of uncertainty in the observations and model fields encompass the changes to the initial conditions of B that lead to A?

•Definition of exigent:, adj:
- •1: requiring immediate aid or action (URGENT)
- •2: requiring or calling for much (DEMANDING)

•Exigent conditions may include events with nonlinear response in societal or economic costs compared to meteorological parameters:
- •subtle track changes that greatly affect snowfall totals
- •occurrence of sub-freezing temperatures in the orange growing region of Florida
- •a mid-level thermal cap breaking ahead of the dryline in Oklahoma

## Potential Technique

Forecast B is a short-range operational model forecast available to forecasters

Of concern is the possibility of heavier QPF over Cape Cod. How likely is this?

Forecaster identifies snowfall threshold of concern over Cape Cod using GUI

⬇

"**Exigent 4d-VAR**" minimizes:
model forecast B
available observations
cost function term that penalizes low QPF over Cape Cod
using typical NWP definitions of model spatial, and obs instrument, errors

⬇

Final value of $J_b$+ $J_o$ terms quantify how likely these changes are to the initial temperature, wind and moisture that will produce heavier QPF over Cape Cod

Subjective evaluation, including pattern matching, by forecasters may aid in the usefulness of the technique

## Conclusions and Future Work

•A potential aid to operational forecasters is introduced whereby the likelihood of occurrence of a weather event is quantified

•Other applications: identification of model or analysis system deficiencies when applied to poorly predicted historical cases

•The future: computer power is currently a limitation; eventually local forecasters may request this tool in their local offices

**Reference:**

•**Henderson, J. M., Ross N. Hoffman, S. Mark Leidner, Thomas Nehrkorn, and Christopher Grassotti, 2005: A 4D-Var study on the potential of weather control and exigent weather forecasting. *Q. J. R. Meteorol. Soc.*, 612, 3037-3051, doi:10.1256/qj.05.72**