Controlling the global weather weather

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Image from the Historic NWS Collection of NOAA/DOC

Who is interested in controlling controlling the weather?

- Since Noah, mankind has made attempts attempts to mitigate the effects of extreme weather
- Today's efforts to enhance rainfall range range from ceremonies of tribesmen to cloud seeding using aircraft

According to Google

- weather → 27,600,000 results
- weather + modification → 338,000
- “weather modification” → 10,500
- “weather modification” + “cloud
  “cloud seeding” → 1970
- “weather modification” + “rain
  “rain dance” → 17

Today's talk

- A different approach to weather control control
- Based on the sensitivity of the atmosphere
- The same reason why it is so difficult to to predict the weather!

The line of reasoning

- The atmosphere is chaotic
- Implies extreme sensitivity to small changes or “perturbations”
- A series of “just right” perturbations may control the weather

Article in BAMS

- You can download my paper in the Bulletin of of the American Meteorological Society
- Visit: www.ametsoc.org and choose "Browse current journals online". There is no charge
- My paper starts with a quote from Arthur C. Clarke's 1978 book *Fountains of Paradise*

Arthur C. Clarke on weather control

It had not been easy to persuade the surviving superpowers to relinquish their orbital fortresses and to to hand them over to the Global Weather Authority, in in what was---if the metaphor could be stretched that far-- far---the last and most dramatic example of beating swords into plowshares. Now the lasers that had once once threatened mankind directed their beams into carefully selected portions of the atmosphere, or onto heat-absorbing target areas in remote regions of the earth. The energy they contained was trifling compared compared with that of the smallest storm; but so is the the energy of the falling stone that triggers an avalanche, avalanche, or the single neutron that starts a chain reaction

Some things we do control

- We routinely use small forces to control control large complex systems to achieve achieve a precise outcome
- If you drive your car from home to work, work, you are doing just that

Sports and control

- Trained athletes give us good examples of control with incredible precision
  - an archer releasing an arrow at the target
  - a basketball player draining a three pointer
  - a martial arts expert throwing an opponent
  - a baseball pitcher throwing a curve ball

Activities of daily life

- Most of us are blessed enough to control our bodies
- In our daily lives we exhibit incredibly complex complex and precise behaviors:
  - putting on a shirt and tie
  - eating with a knife and fork
  - shaving
  - Even walking!

Characteristics of the atmosphere

- The atmosphere is a fluid unlike a person or an an automobile
  - Motions in the atmosphere transport properties of of the atmosphere
- The atmosphere is huge
- The atmosphere is connected to the ocean and and the land surfaces
- The atmosphere imports solar radiation and exports infrared radiation
- The weather is coupled at many scales from a a raindrop to El Niño

Imagine

- No droughts
- No tornadoes
- No snow storms during rush hour
- No hurricanes allowed to strike the Hawaiian Islands

Images from UCAR

Iniki's Landfall on Kauai

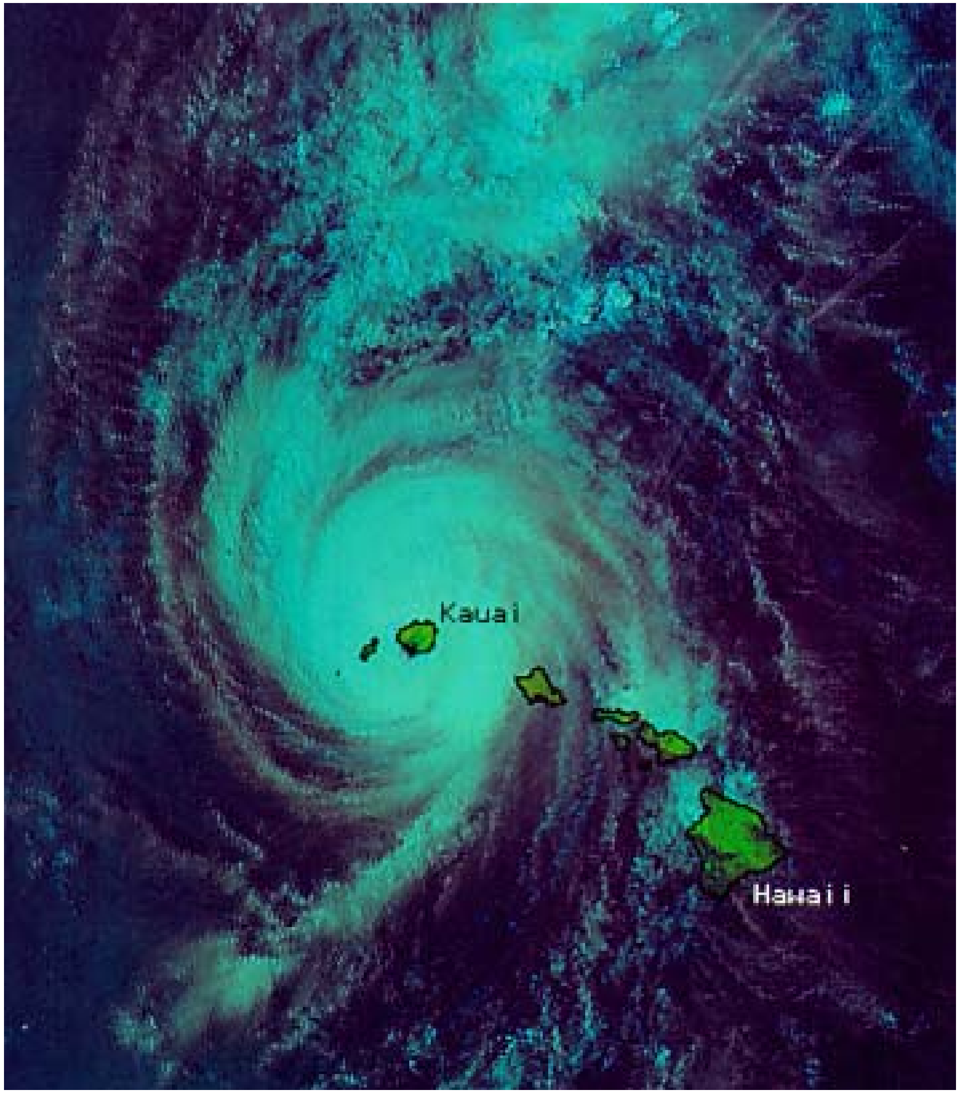
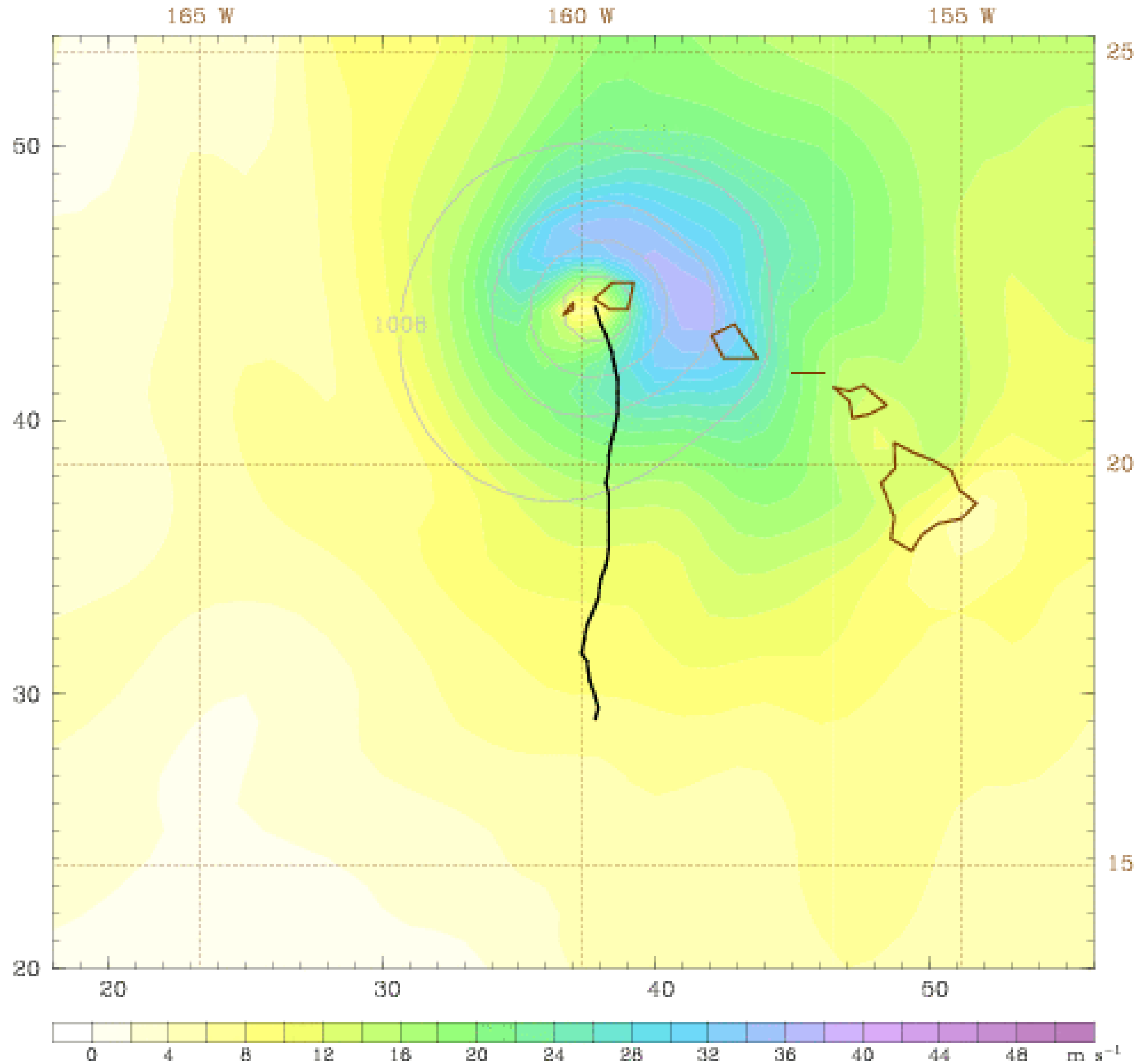


Image from NWS, Honolulu

Our Case Study Hurricane Hurricane Iniki (1992)

- Landfall at Kauai at 0130 UTC 12 September
- Hurricane Iniki at 0000 UTC 12 September 1992 is shown in the following following frame

Iniki Surface Wind Speed



Surface Wind Speed (m/s)

Motivation for controlling hurricanes

- Not to eliminate hurricanes, but to control their paths
- To prevent hurricanes from striking population centers

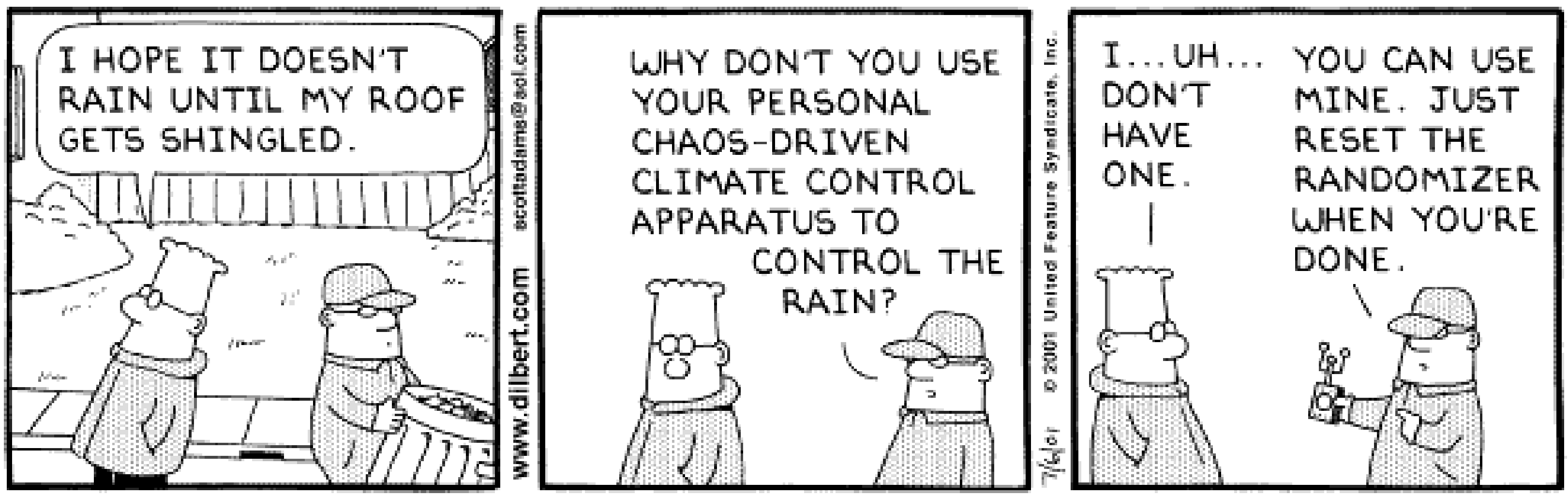
Objectives of our project

- Develop a method to calculate the atmospheric perturbations needed to control the track of a hurricane
- Quantify the size of the perturbations needed to do this
- Estimate the requirements of a weather weather control system

Theoretical basis

- The earth's atmosphere is chaotic
- Chaos implies a finite predictability time limit limit no matter how well the atmosphere is observed and modeled
- Chaos also implies sensitivity to small perturbations
- A series of small but precise perturbations might control the evolution of the atmosphere atmosphere

Dilbert controls the weather



– Scott Adams had it almost right in his 6
6 July 2001 Dilbert comic strip

The atmosphere is unpredictable

- Motions occur over a huge spectrum of scales in the atmosphere
- Smaller spatial scales have shorter time time scales
- Errors in the smallest scales quickly completely contaminate those scales

The atmosphere is unpredictable (2)

- These errors will then induce errors in the next larger scale and so on...
- At the same time, tiny errors on the large large scales will cause large errors on the the smaller scales
- It is no wonder that weather forecasts can be poor!

Current NWP operational practice

- NWP centers have developed forecast techniques which use the known sensitivity of the atmosphere to their advantage

1. 4D variational data assimilation
2. Generation of ensembles
3. Adaptive observations

Current Practice 1: 4D
4D variational data assimilation

- 4D-Var fits all available observations during a time window (6 or 12 hours) with a model forecast
- The fit to the observations is balanced against the fit to the a priori or first guess from a previous forecast
- We use a variant of 4D-Var in our experiments

Current Practice 2: Ensemble Ensemble forecasting

- Estimate of the atmosphere are inexact, so forecasts are inexact
- Ensembles of forecasts from a set of initial estimates quantify our uncertainty
- To bound the uncertainty, it is important to include errors that grow quickly
- Singular vectors are used
  - Singular vectors are the fastest growing finite time time linear perturbations

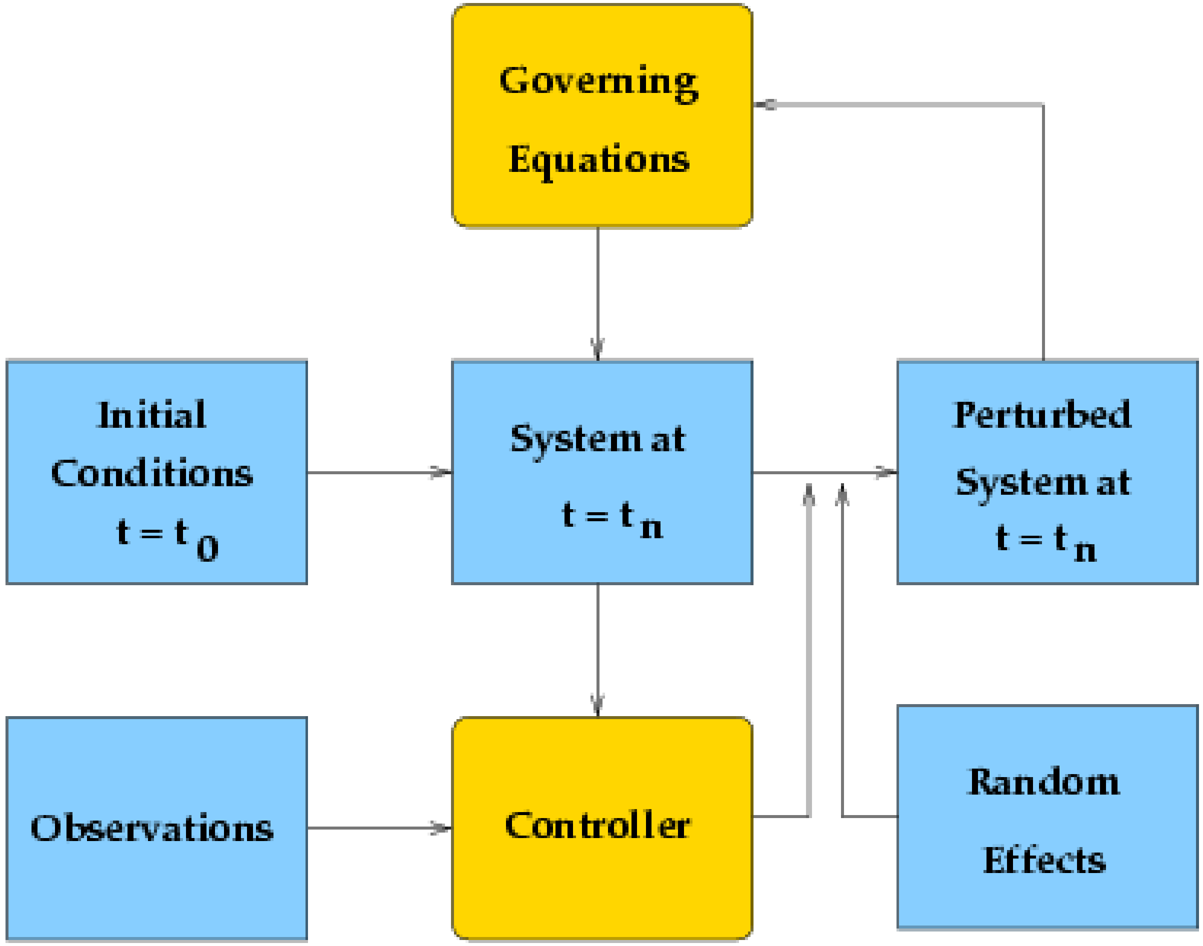
Current Practice 3: Adaptive Adaptive observations

- Adaptive or targeted observations are dropsondes deployed by aircraft in specially selected locations
- The locations are those places where the extra extra observation will do the most good
- To find these locations the sensitivity of the analysis and forecast to additional data is calculated

The components of the global weather weather control system

- Our proposed controller is similar in general to feedback control systems common in many industrial processes

A flowchart of the global weather control system



Complicating factors

- The large number of degrees of freedom freedom required to represent the atmosphere adequately
- The relatively small number observations observations of the atmosphere
- The nonlinear nature of the governing equations

More complicating factors

- The control must be effected at significant time lags
- The difficulty of effecting control
- The problem of defining “optimal”
  – For inhabitants of New Orleans, eliminating eliminating a hurricane threat to that city may take precedence over all else

System components

1. Numerical weather prediction
2. Data assimilation systems
3. Satellite remote sensing
4. Perturbations
5. Computer technology
6. Systems integration

System component 1: Numerical Numerical weather prediction

- Advances in computer power will enable the the refinement of NWP
- Current high resolution mesoscale models point point the way for advances in global models
- Extrapolating over 30 years suggests global model resolution of approximately 250 m
- More and more of the physics of the atmosphere will be resolved explicitly instead instead of being parameterized

System component 2: Data Data assimilation systems

- Data assimilation systems estimate the state of of the atmosphere by blending observations with a previous forecast
- 4D variational data assimilation finds the optimal initial condition at the start of the data data period
- Current research focuses on approximations to to the extended Kalman filter
  - Especially how to efficiently describe and evolve the the huge covariance matrix describing the uncertainty of the system state

System component 3: Satellite Satellite remote sensing

- New sensors have very high spectral resolution resolution
  - And will produce higher vertical resolution for the the retrieved temperature and moisture profiles
- Higher spatial resolution, greater numbers of of satellites, and higher accuracy are expected expected in the future
  - Future lidar sensors will observe winds, temperature, and atmospheric composition

System component 4: Perturbations

- Aircraft contrails: Contrails are essentially cirrus clouds and influence both the solar and and thermal radiation
  - Slight variations in the timing, levels, and routes of routes of aircraft would produce perturbations
- Solar reflectors: In low earth orbit, these would would produce bright spots on the night side side and shadows on the day side of the earth earth

System component 4: Perturbations (2)

- **Space solar power (SSP) generators would downlink microwave energy providing a tunable atmospheric heat source**
- **Wind power: Grids of wind turbines which doubled as fans might transfer atmospheric momentum in the form of electric energy**

System component 5: Computer Computer technology

- **Advances in NWP require that the pace pace of advances in computer technology technology can be maintained:**
  - **nano-technology**
  - **DNA computers**
  - **quantum computing**

System component 6: Systems Systems integration

- The global weather control system is huge by by today's standards
- Tools and methodologies for such huge systems systems are needed by defense and aerospace aerospace projects:
  - space shuttle, space station
  - missile defense systems

4D-Var experimental setup

- The basic experiment is simply a variation on on 4D-Var:
- Consider some initial “unperturbed’’ forecast of a hurricane
- Create a target 6 hours into the forecast with the hurricane positioned ~100 km west of its position in the unperturbed forecast
- Use 4D-Var to find an optimal perturbation at the initial time of the forecast

‘Optimal’ Defined

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

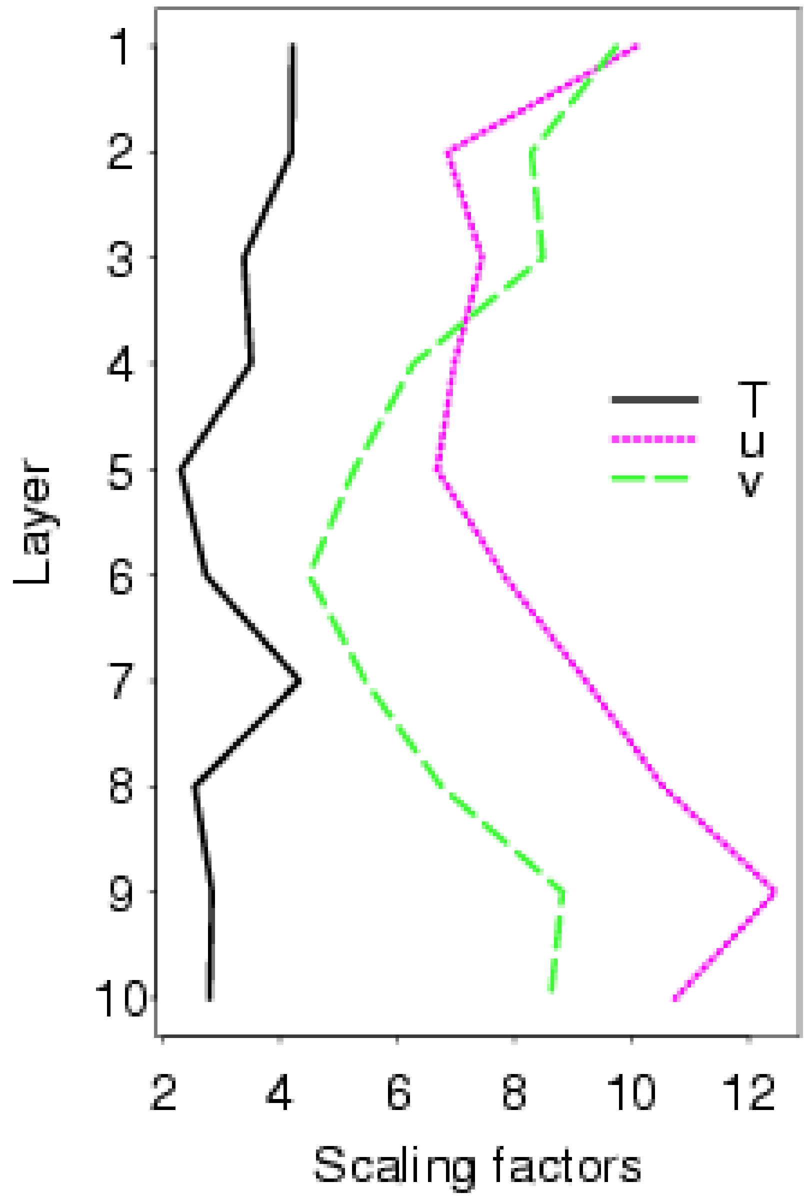
- Optimal is defined as simultaneously minimizing both the goal mismatch and the size size of the initial perturbation as measured by by the sum of squared differences

4D-Var cost function

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

- J is the cost function
- P is the perturbed forecast
- G is the goal
  - G is the target at t=T and the initial unperturbed state at t=0
- S is a set of scales
  - S depends only on variable and level
- x is temperature or a wind component
- i, j, and k range over all the grid points

Cost Function Scalings



(Scalings are for coupled MM5 variables)

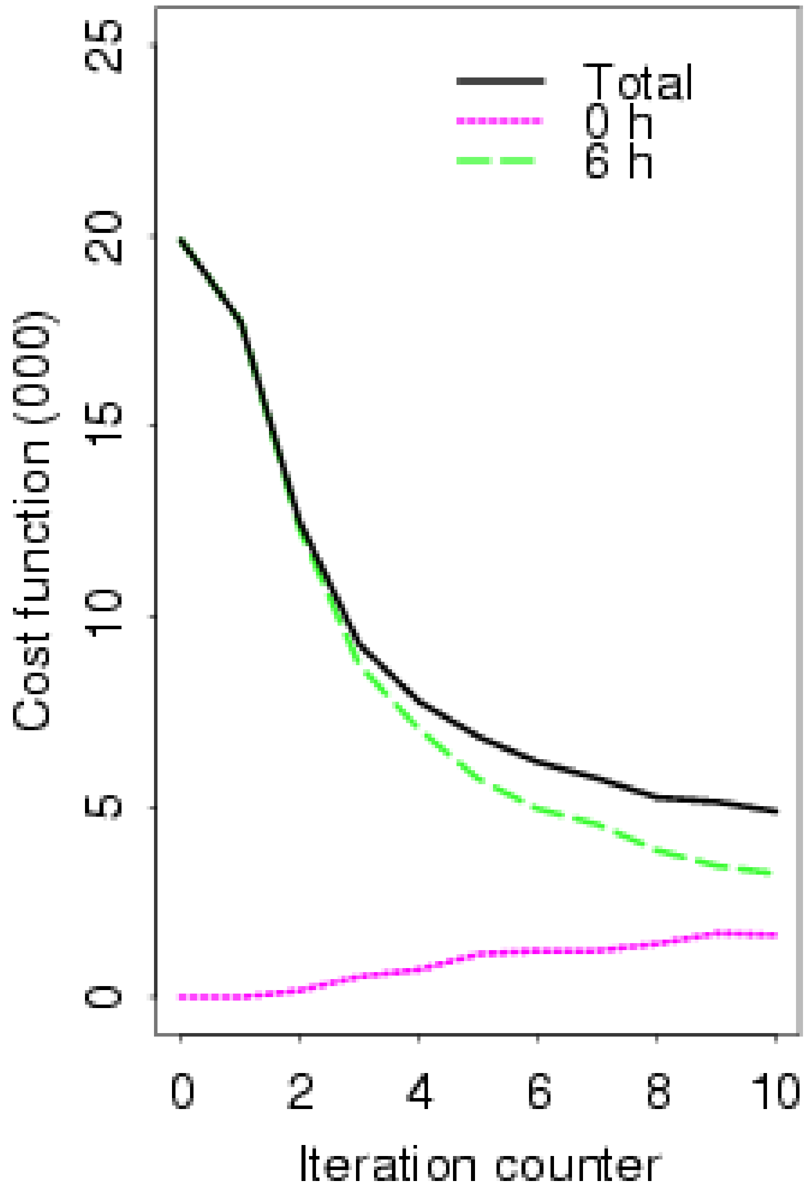
Mesoscale model

- The MM5 computation grid is 97 by 79, with a a 40 km grid spacing, and ten layers in the vertical
- Simplified parameterizations of the boundary boundary layer, cumulus convection, and radiative transfer are used
- The observed sea surface temperature is increased by 5 K everywhere in our simulations simulations
  - We found this was enough to maintain the hurricane hurricane when using the simplified parameterizations

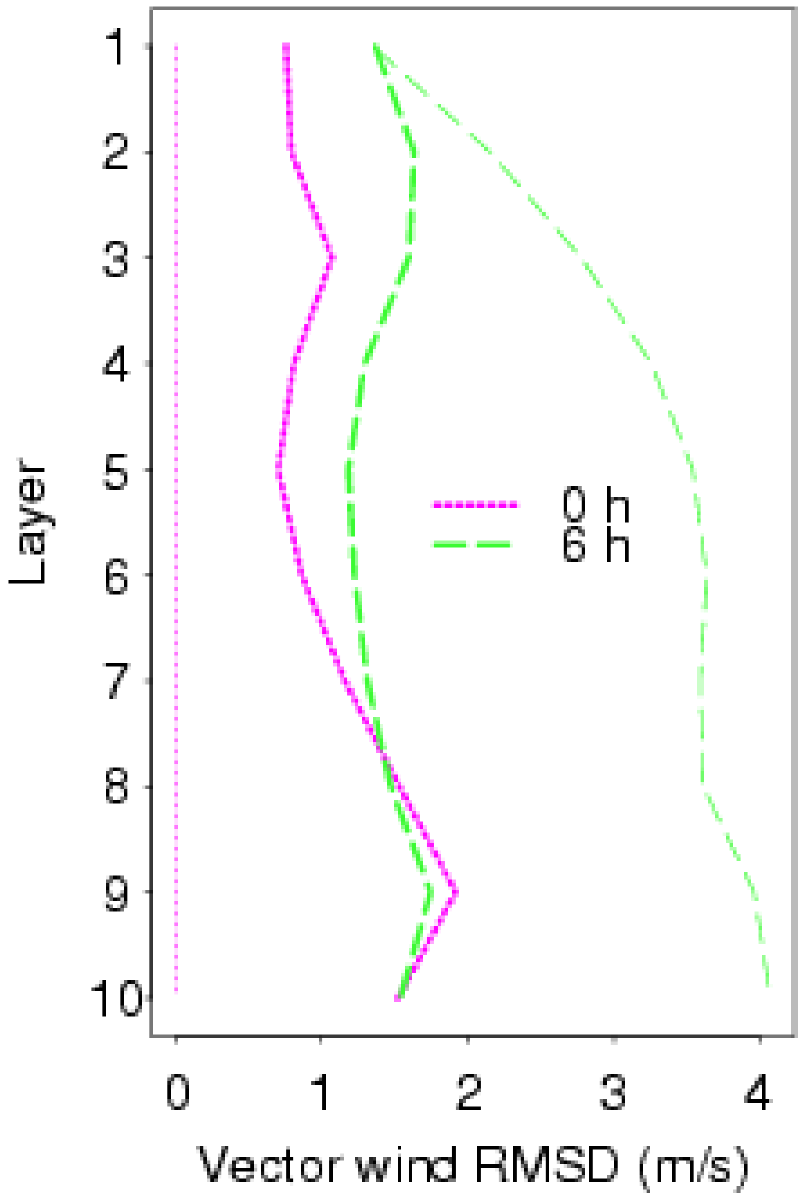
Summary of graphical results

- Cost function vs. iteration
- RMSD for winds and temperature vs. model layer
- Plots of perturbation temperature and wind speed
- Movies of the model surface pressure and and relative humidity

Cost Function vs. Iteration

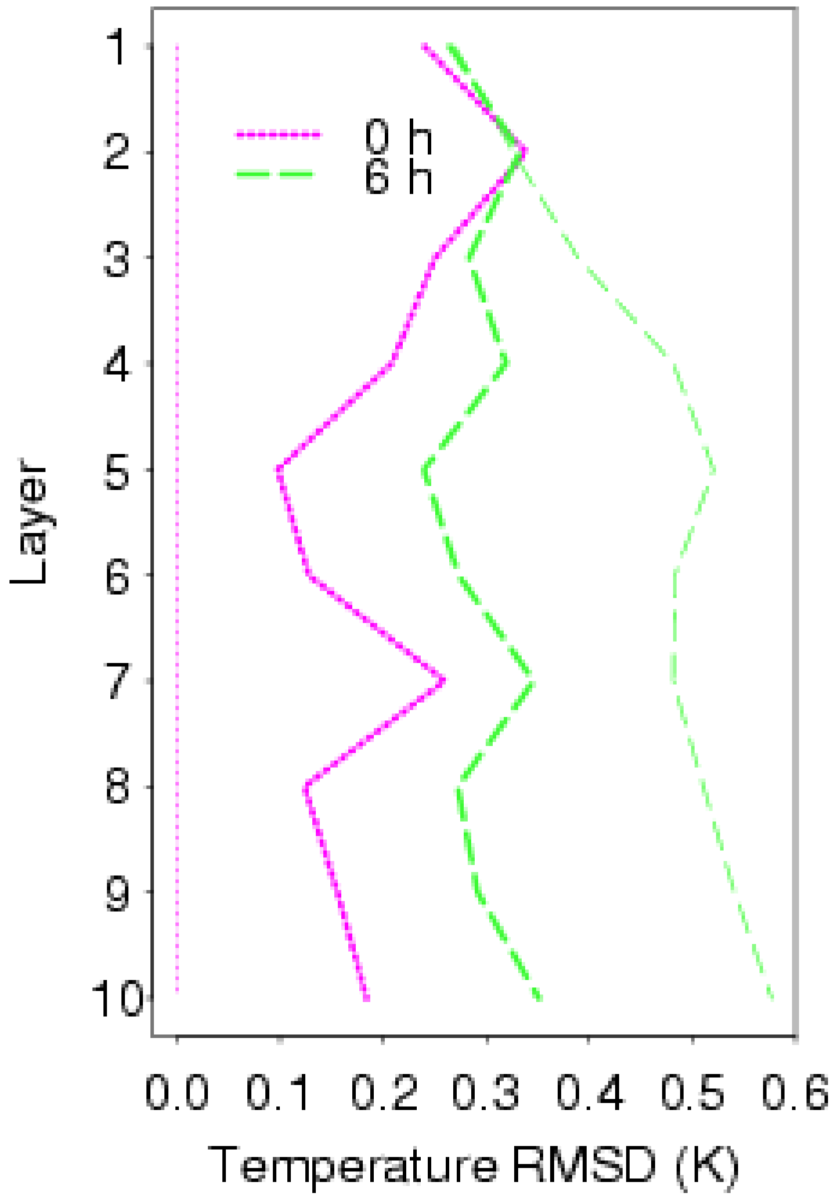


Vector Wind RMSD

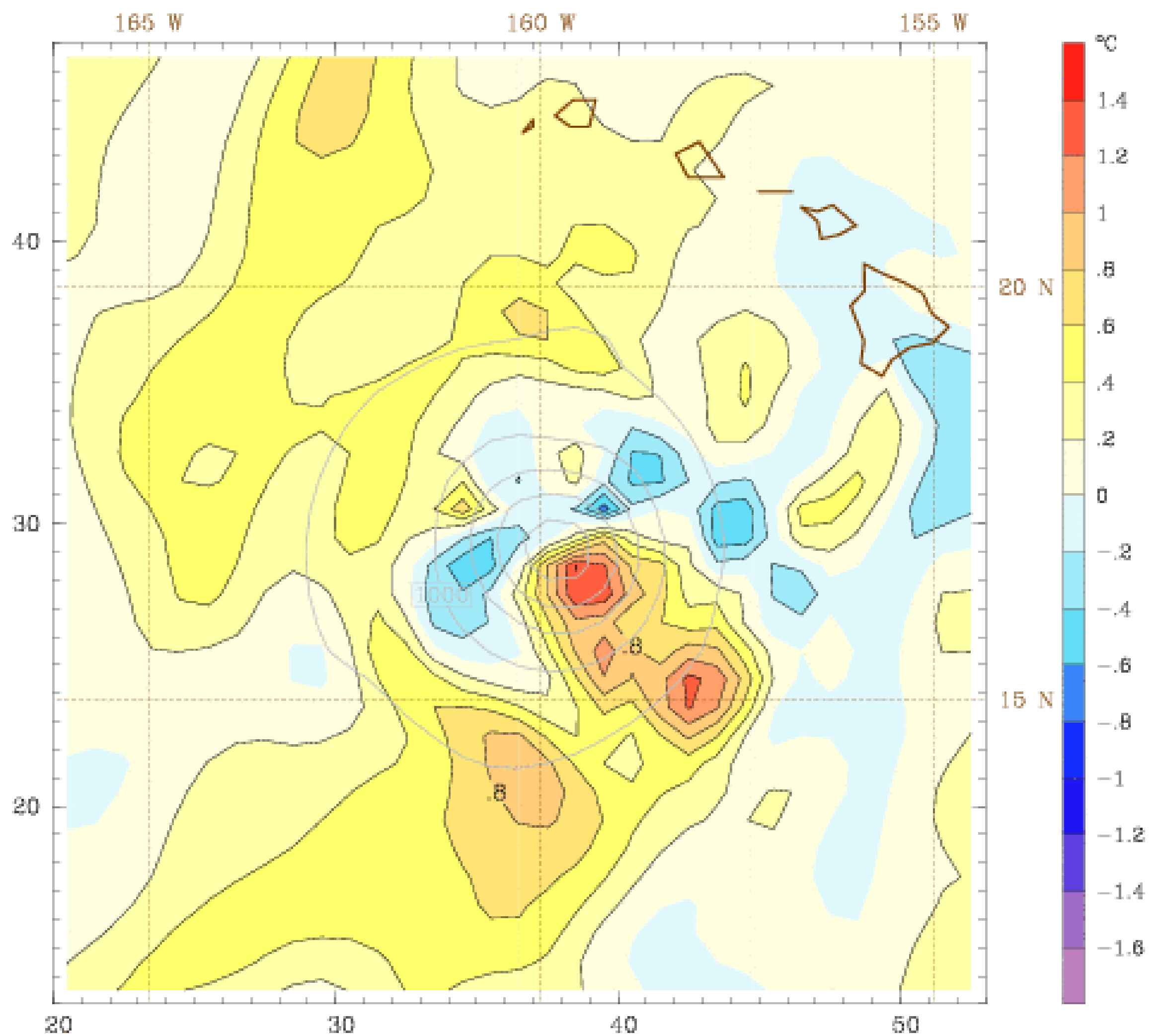


(Anti-diet: thick and thin lines are after and before)

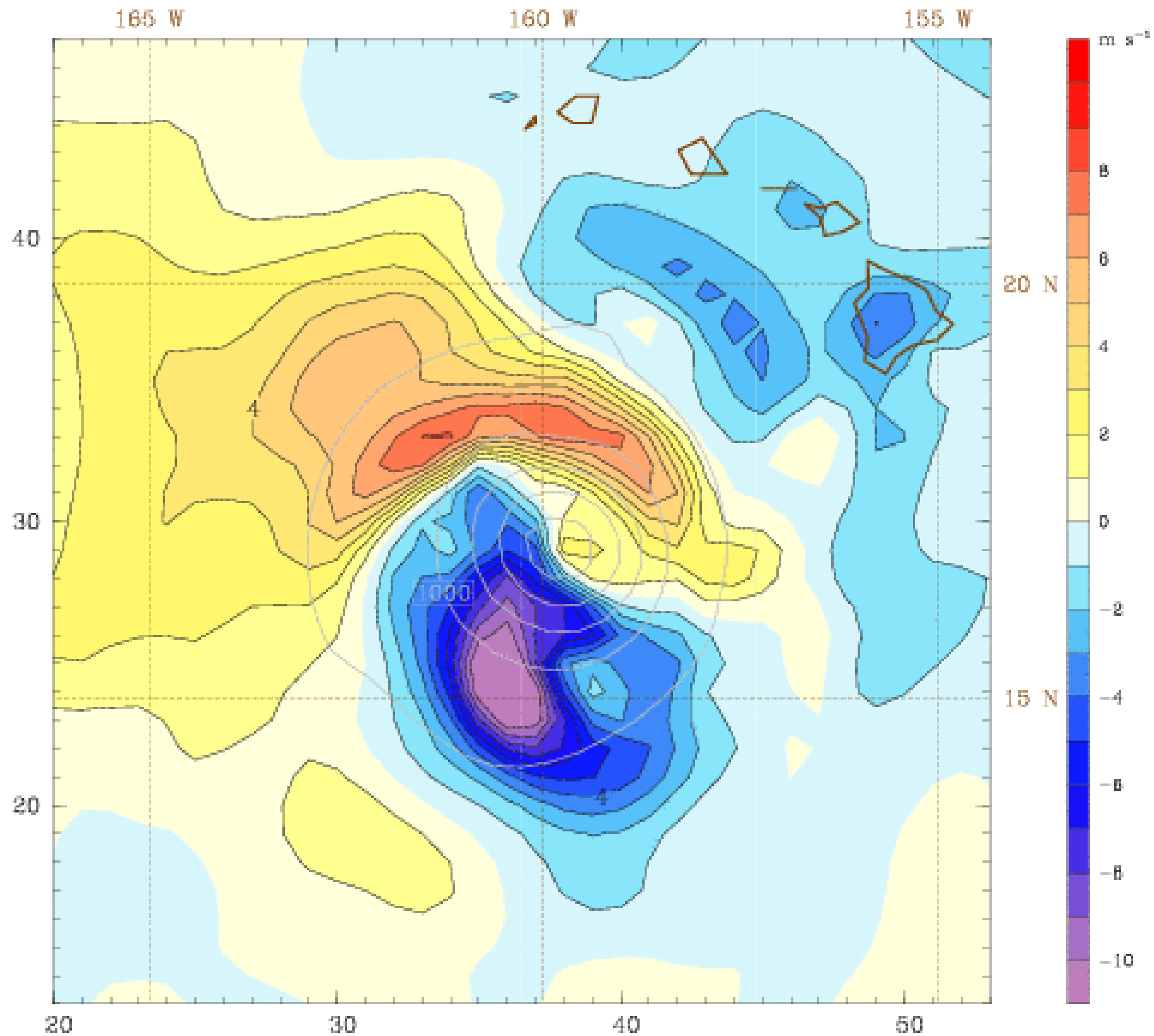
Temperature RMSD



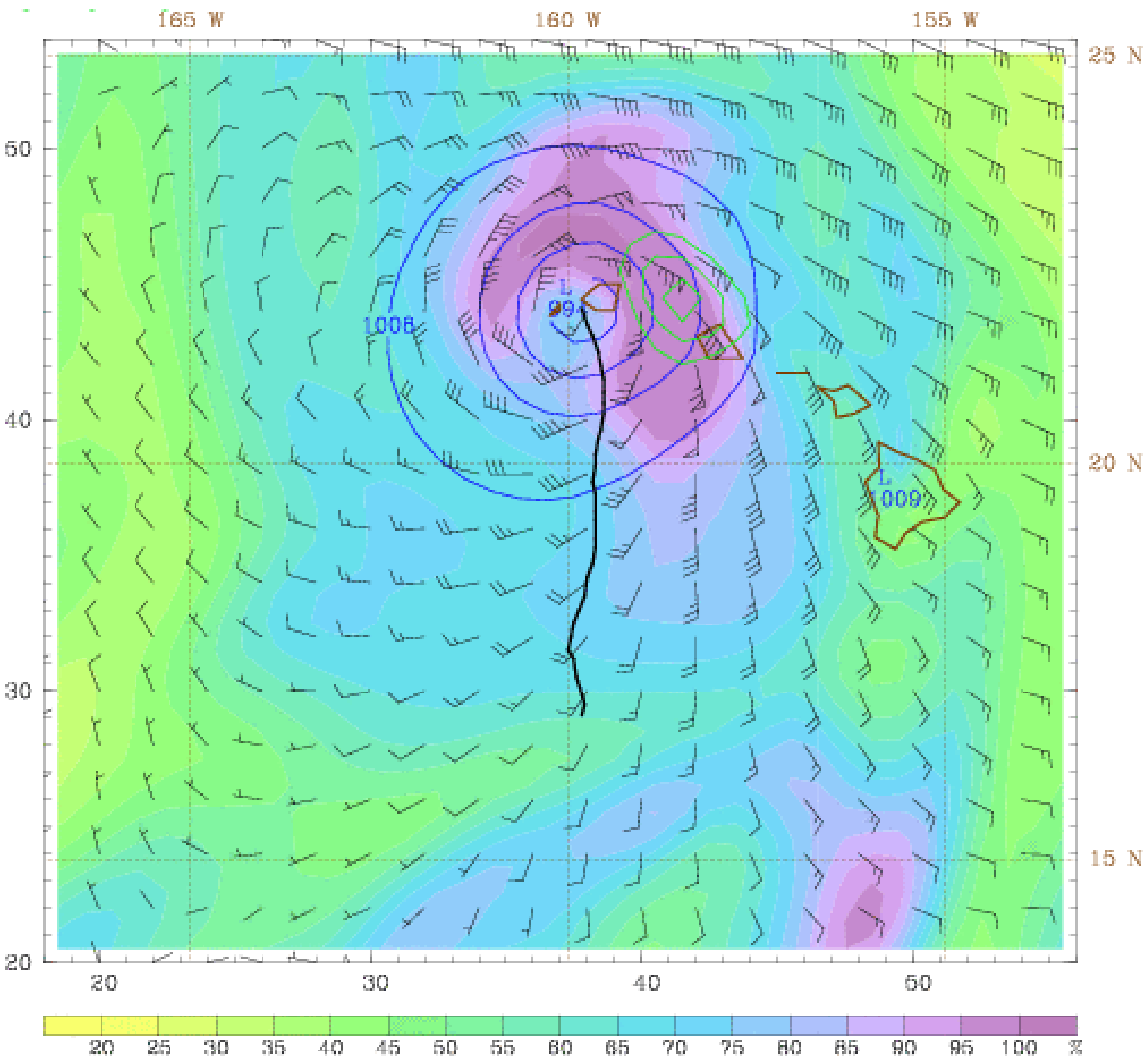
Perturbation Surface Temperature



Perturbation 750-hPa Wind Speed

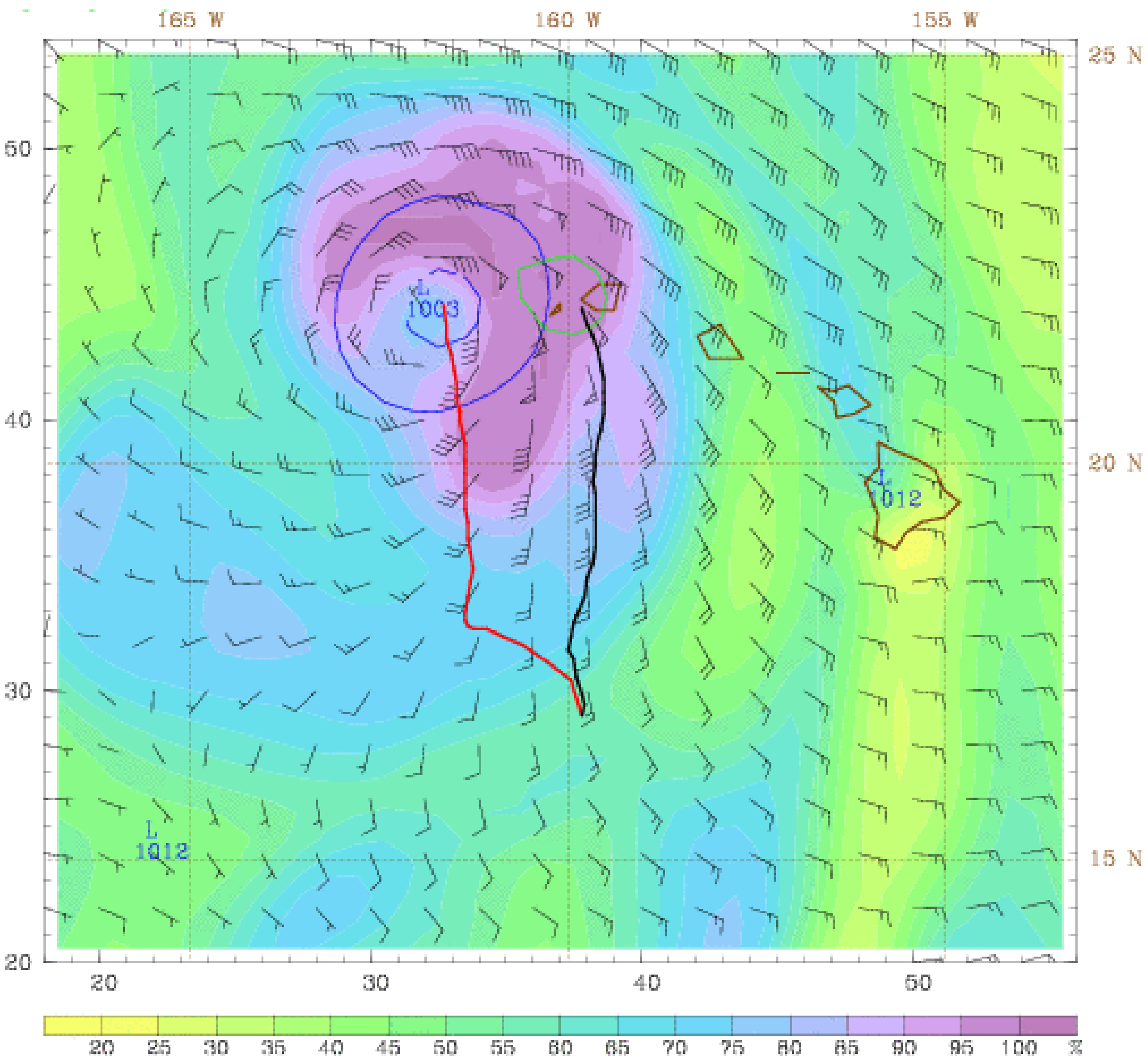


Unperturbed Forecast



750-hPa Relative Humidity

Controlled Forecast



750-hPa Relative Humidity

Future objectives

- Refinements to the 4D-Var study
- Use higher resolution version of MM5 with more accurate physical processes
- Examine the effect of different lead times on the size of the perturbations
- Modify the cost function to:
  - Estimate the property loss (in dollars) as a function function of forecast wind speed
  - Require only that the modeled tropical cyclone avoids certain geographical areas

Future objectives (2)

- Restrict the control vector to specific fields, such as temperature, and so that only certain types of "feasible" perturbations, which are continuous in time, are allowed
- Top level system design: Scale analysis of the the on-orbit system components based on the the solar reflector concept or the SSP-microwave downlink concept

Summary

- Underlying concepts for our approach
- System architecture of a controller for the global atmosphere
- Components of such a controller
- Example calculations for Hurricane Iniki

The future

- Weather modification and weather control raise a number of legal and ethical questions questions
  - If we can, do we want to?
- The global weather controller will build upon upon future advances in several disciplines
  - Numerical weather prediction, observing systems, systems, computer technology, space engineering, engineering, and system engineering
- The existence of the technology to implement implement the weather controller is plausible plausible at the time range of 30--50 years

Business as usual

January 1, 2100

Officials Found to Misuse Weather-Control Satellites

By TONG MEI KUEN

13:02 E.S.T. -- A new system of weather modification satellites, designed and launched at immense cost and still not in full operation, has been repeatedly diverted for personal uses by politicians and senior officials in the Weather Administration, an investigation by The New York Times has learned.

A SPECIAL REPORT: THE RAINMAKERS

The system is intended to help reduce the destructive effects of storms, droughts and temperature extremes by manipulating clouds and wind patterns in the upper

Thank you

- Contact: ross@aer.com
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