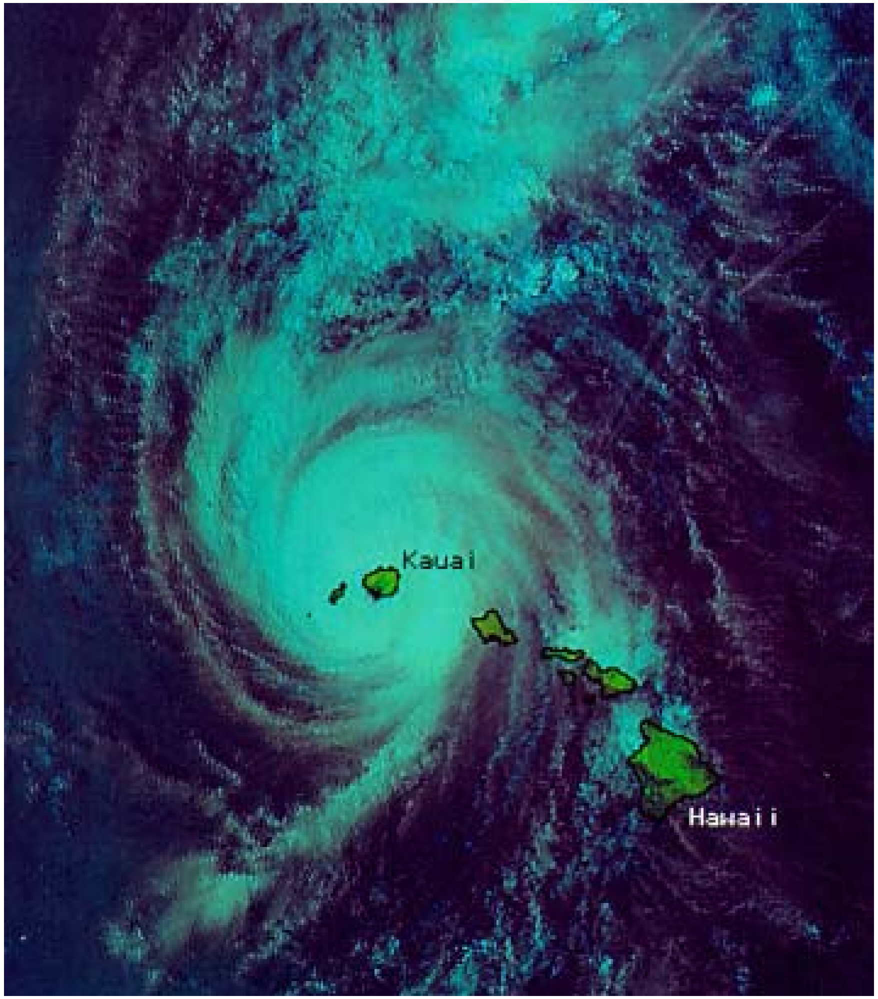
Chaos & Weather Control



H. Iniki 1992 (NWS image)

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Atmospheric and Environmental Research

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Atlanta

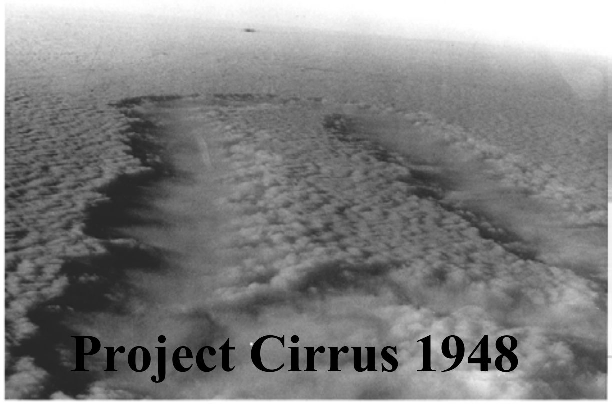
Acknowledgments

- Co-investigators: John Henderson, Mark Leidner, George Modica
- Supported by a NIAC phase 2 contract
- DOD CHSSI project supported the development of the parallel version of the MM5 4d-VAR system at AER

Today's talk

- Experiments to control hurricanes
- A different approach to weather control–not just hurricanes
- Based on the sensitivity of the atmosphere
- The same reason why it is so difficult to predict the weather!

Conventional WxMod



- Rain enhancement
- Fog dissipation
  - Cold fog – ice nuclei
  - Warm fog – jet engines provide heat
- Frost prevention (Florida citrus)
- Hail suppression – ice nuclei
- Lightning suppression – chaff

Rain enhancement

- **Cold clouds – ice nuclei**
- **Warm clouds – CCN; hygroscopic flares; brine spray**
- **Anthropogenic aerosols and dust result in inadvertent WxMod**
- **Adding CCNs or ice nuclei can increase or decrease rainfall**
  - **Too many and the drops are too small. Too few and there are not enough drops**

Critical Issues in Weather Modification Research

- New National Academies Report
  - Committee on the Status and Future Directions in U.S Weather Modification Research and Operations, National Research Council
  - The prepublication online version:
  - www.nap.edu/books/0309090539/html/

Future WxMod

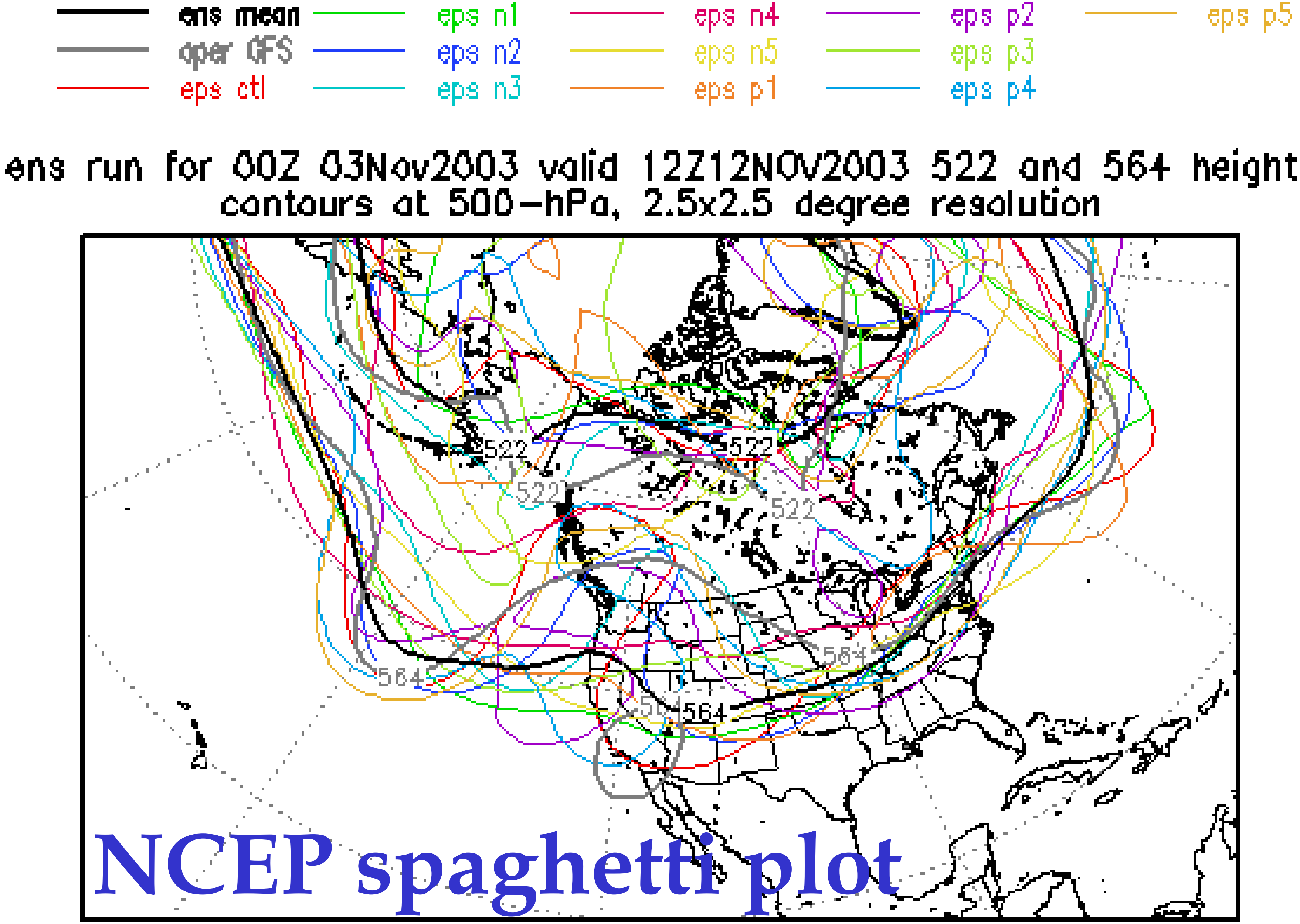
- Improved models, observations, and assimilation systems will advance to the point where forecasts are:
  - much improved, and
  - include an estimate of uncertainty
- Thus allowing advance knowledge that a change should be detectable in particular cases

Theoretical basis

- The earth's atmosphere is chaotic
- Chaos implies a finite predictability time 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

Current NWP operational practice

- NWP centers have developed forecast techniques that capitalize on the sensitivity of the atmosphere
  1. 4D variational data assimilation
  2. Generation of ensembles
  3. Adaptive observations



NCEP spaghetti plot

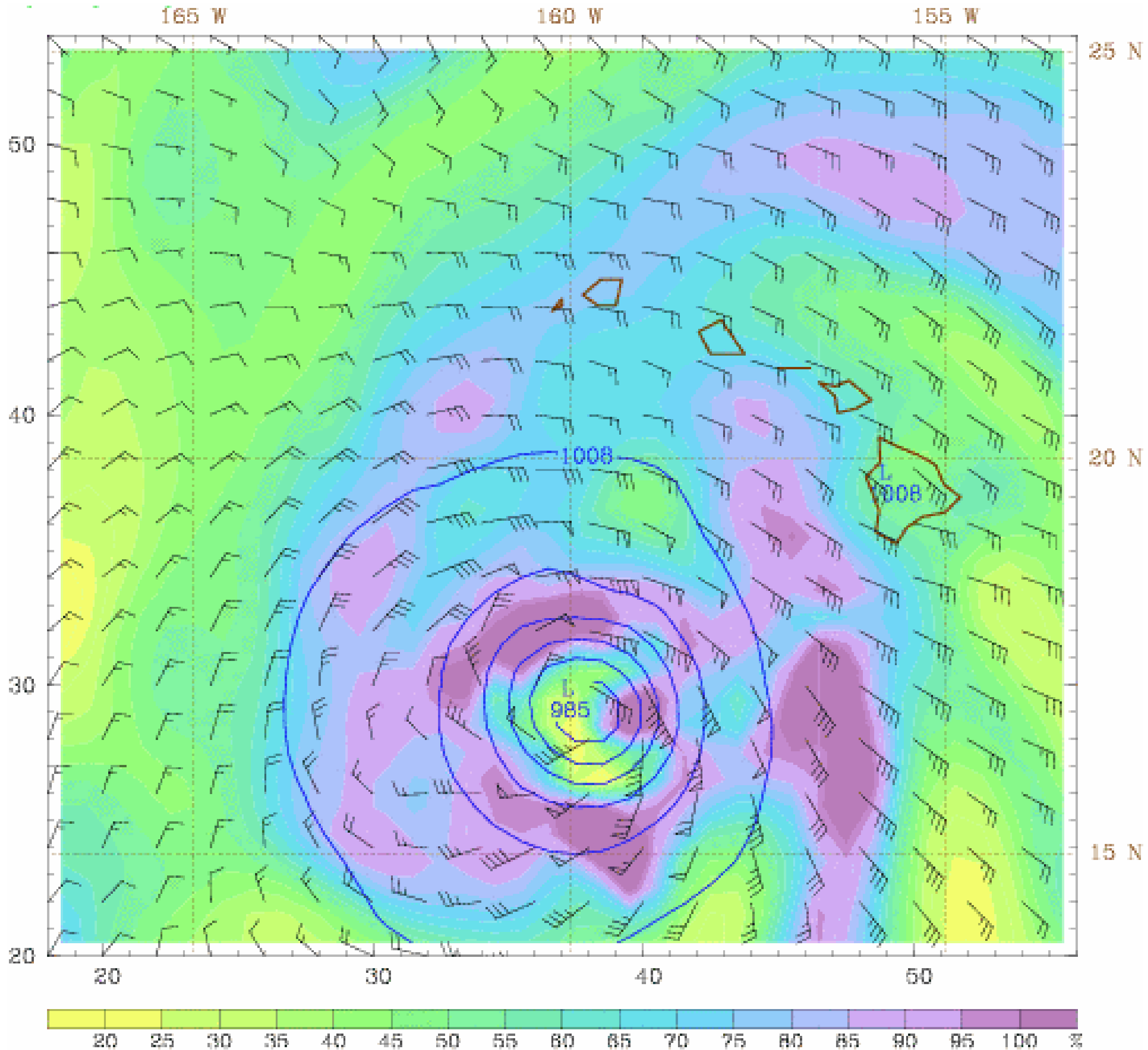
System components

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

Why hurricanes?

- Public interest: Threat to life and property
- History: Project Stormfury (1963)
- Sensitive to initial conditions
- MM5/4d-VAR: Available tools

Iniki Simulation



750-hPa Relative Humidity

Hurricane WxMod

- Energetics
  - Biodegradable oil
  - Pump cold water up to the surface
- Dynamic perturbations
  - Stormfury: cloud seeding
  - Space based heating

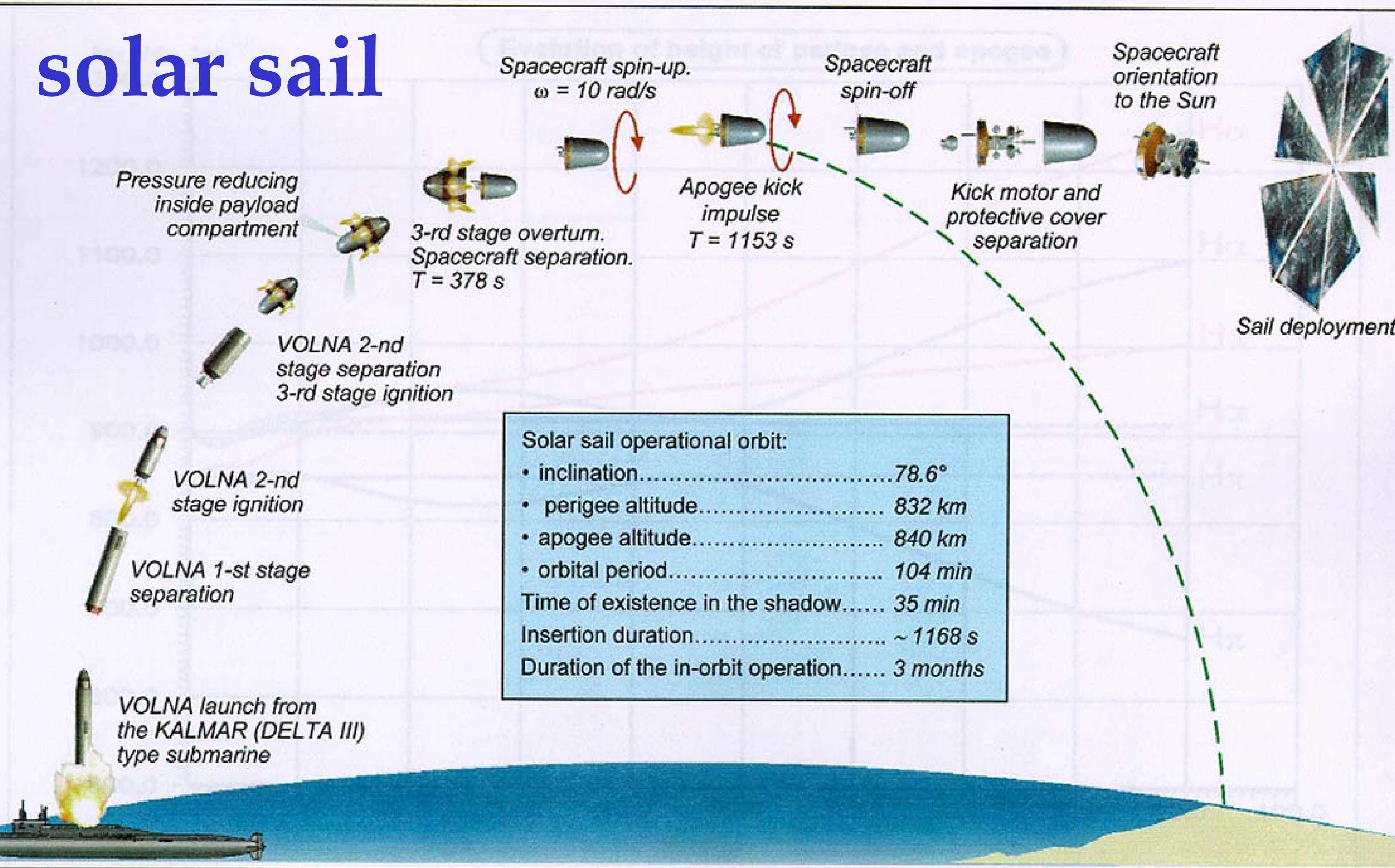
Space based heating

- **Solar reflectors: bright spots on the night side and shadows on the day side**
- **Space solar power (SSP): microwave downlink could provide a tunable atmospheric heat source**

Cosmos 1 solar sail

2-ND PHASE – DEMONSTRATION EXPERIMENT

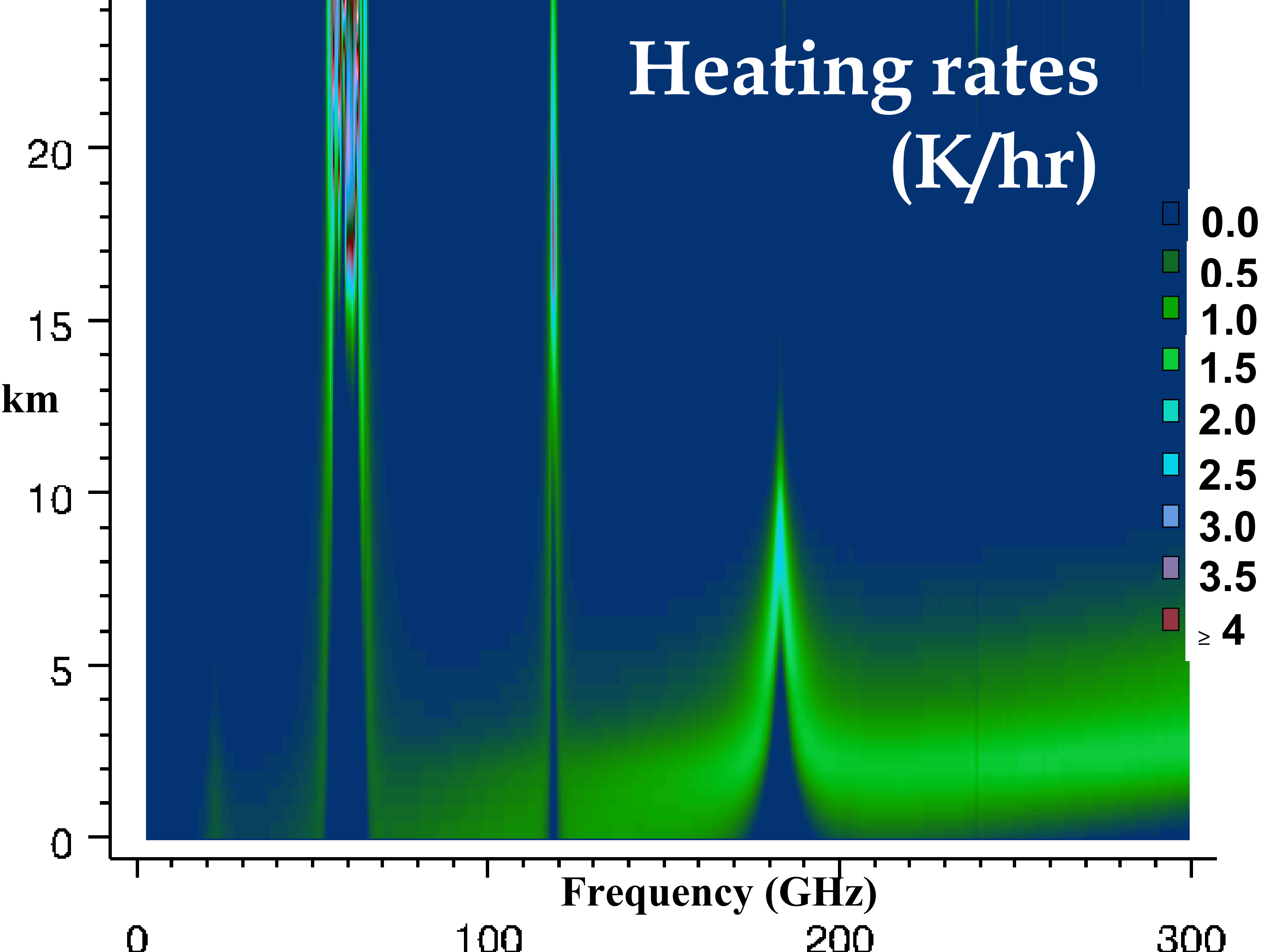
MISSION PROFILE




NASA artwork by Pat Rawlings/SAIC
Space solar power

Microwave spectrum

- Water and oxygen are the main gaseous absorbers
  - H2O lines at 22, 183 GHz
  - H2O continuum
  - O2 lines at 60, 118 GHz
- Frequency and bandwidth control the heating profile


Heating rates
(K/hr)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
≥ 4
km
0
5
10
15
20
Frequency (GHz)
0
100
200
300

Power requirements

- Heating rates calculated for 1500 W/m^2
- Equal to 6 $GW/(2\ km)^2$
- Current experiments require similar heating rates over an area 100s times larger
- Longer lead times, higher resolution will reduce these requirements significantly

Determination of perturbations

- Optimal control theory
- 4d-Var methodology baseline
- Modified control vector: temperature only
- Refined cost function: property damage

Mesoscale model

- The MM5 computation grid is 200 by 200, with a 20 km grid spacing, and ten layers in the vertical
- Physics are either
  - Simplified parameterizations of the boundary layer, cumulus convection, stratiform cloud, and radiative transfer; or
  - Enhanced parameterizations of these physical processes and a multi-layer soil model

4D variational data assimilation

- 4D-Var adjusts initial conditions to fit all available observations during a 6 or 12 hour time window
- 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

Standard 4D-Var cost function

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

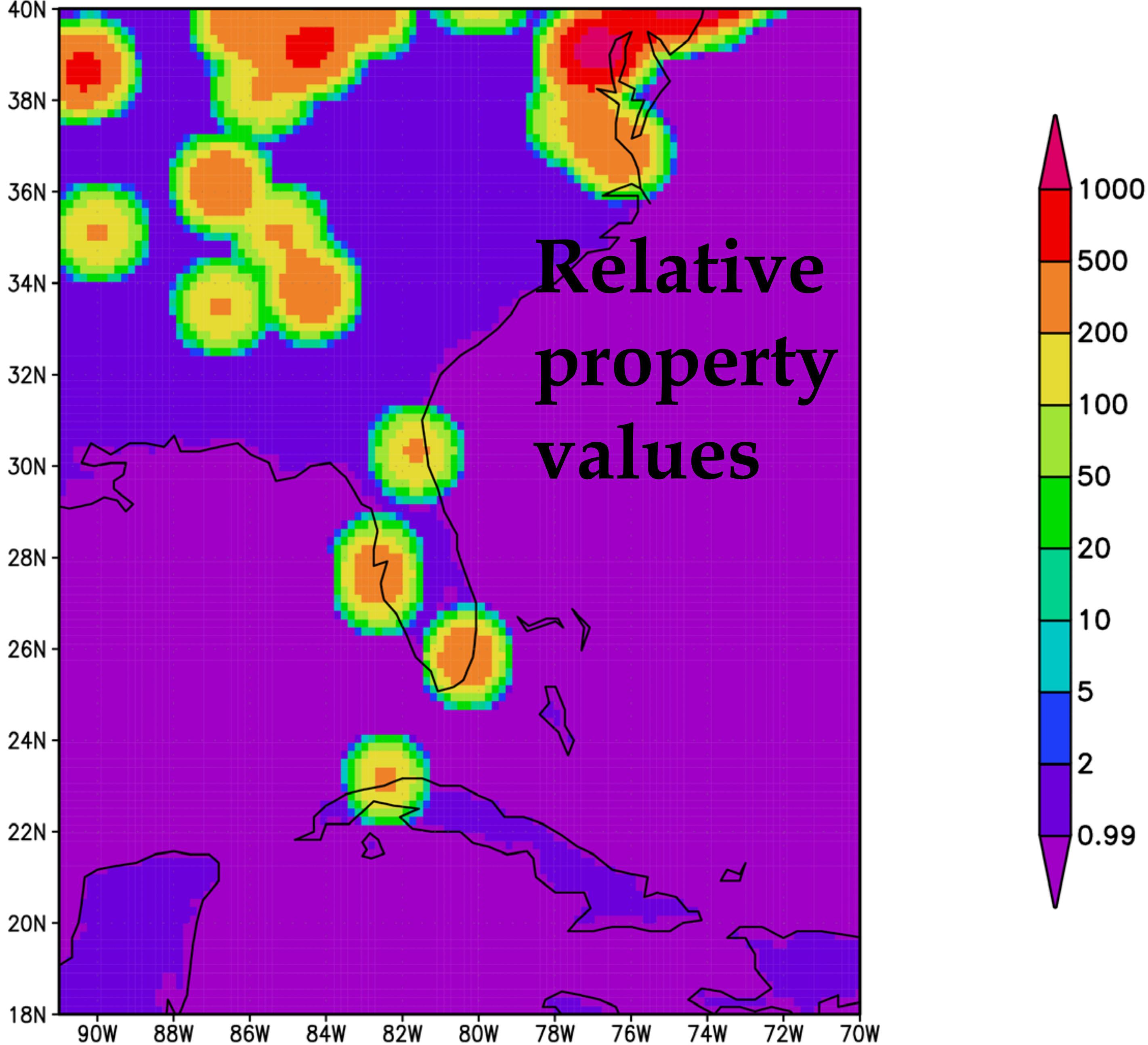
- J is the cost function
- P is the perturbed forecast
- G is the goal
  - G is the target at t=T and the initial unperturbed state at t=0
- S is a set of scales
  - S depends only on variable and level
- x is temperature or a wind component
- i, j, and k range over all the grid points

Modified control vector

- Control vector can be restricted by variable and by geographic region
  - Temperature only
  - Locations far from the eye wall

Refined cost function

- $J_D = \sum_{ijt} D_{ij}(t)\ C_{ij}$
- C is the replacement cost
- D is the fractional wind damage
  - $D = 0.5\ [1 + \cos(\pi(V_1 - V)/(V_1 - V_0))]$
    - $D=0$ for $V<V_0 = 25$ m/s
    - $D=1$ for $V>V_1 = 90$ m/s
  - Evaluated every 15 min. for hours 4–6

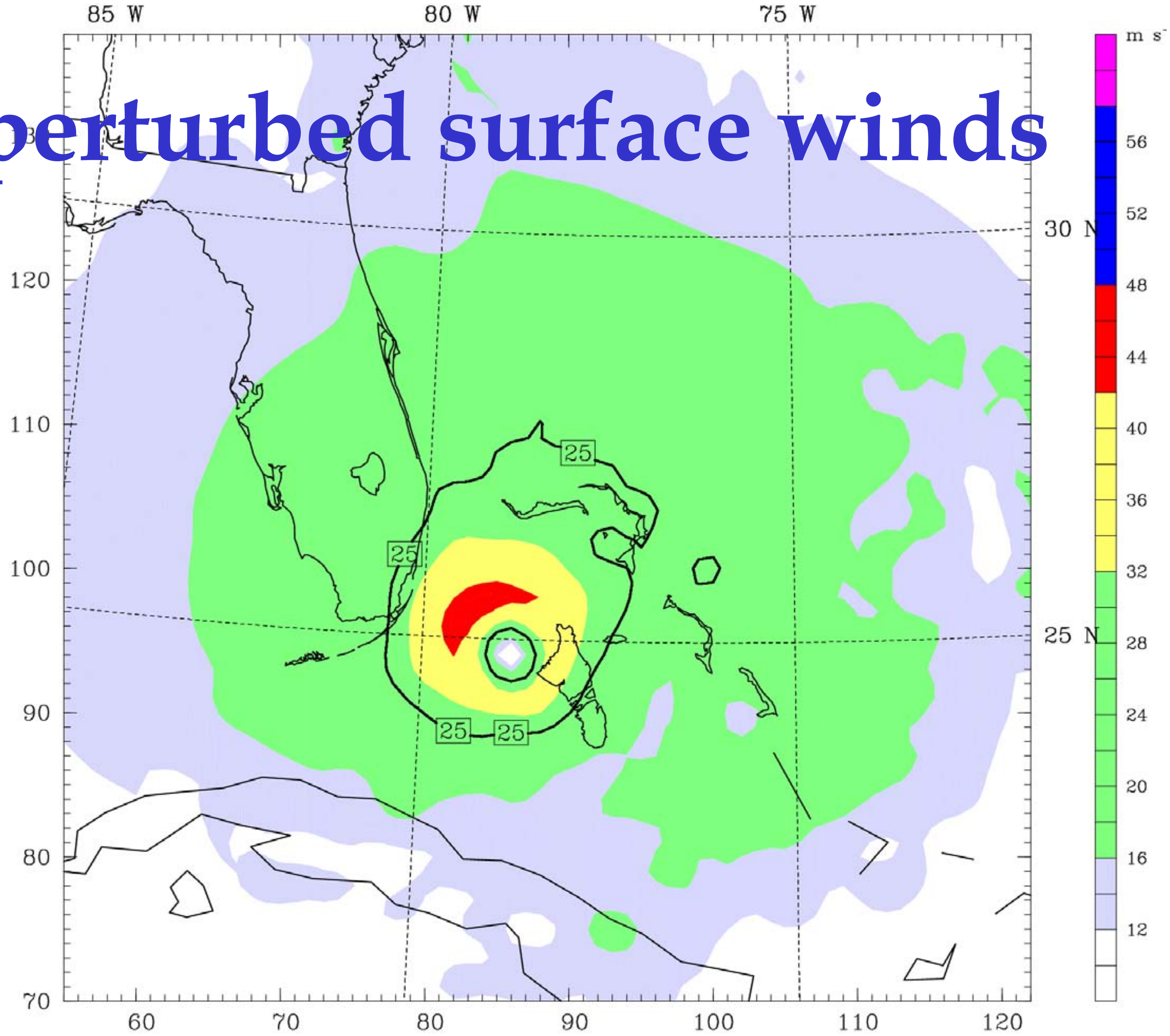


Relative property values
40N
38N
36N
34N
32N
30N
28N
26N
24N
22N
20N
18N
90W
88W
86W
84W
82W
80W
78W
76W
74W
72W
70W
1000
500
200
100
50
20
10
5
2
0.99

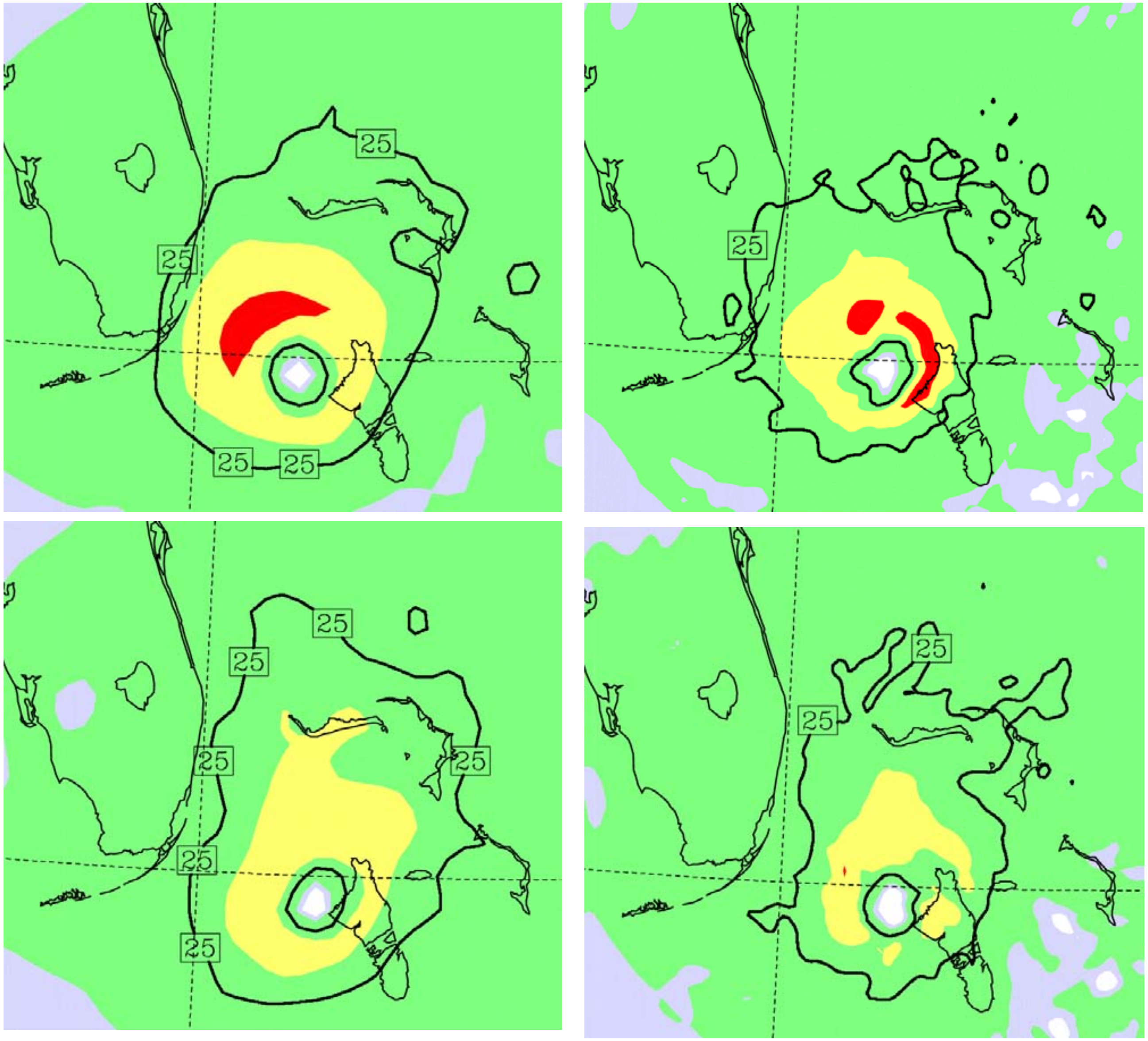
Experiments

- **Hurricane Andrew simulations starting at 00 UTC 24 Aug 1992**
- **Initial conditions from an earlier 6 h forecast; NCEP reanalysis; bogus vortex**
- **4d-Var over 6 h (ending 06 UTC 24 Aug); 20 km grid; temperature increments only; simple physics**
- **Simulations for unperturbed vs. controlled; 20 km simple physics vs. 7 km enhanced physics**

Unperturbed surface winds



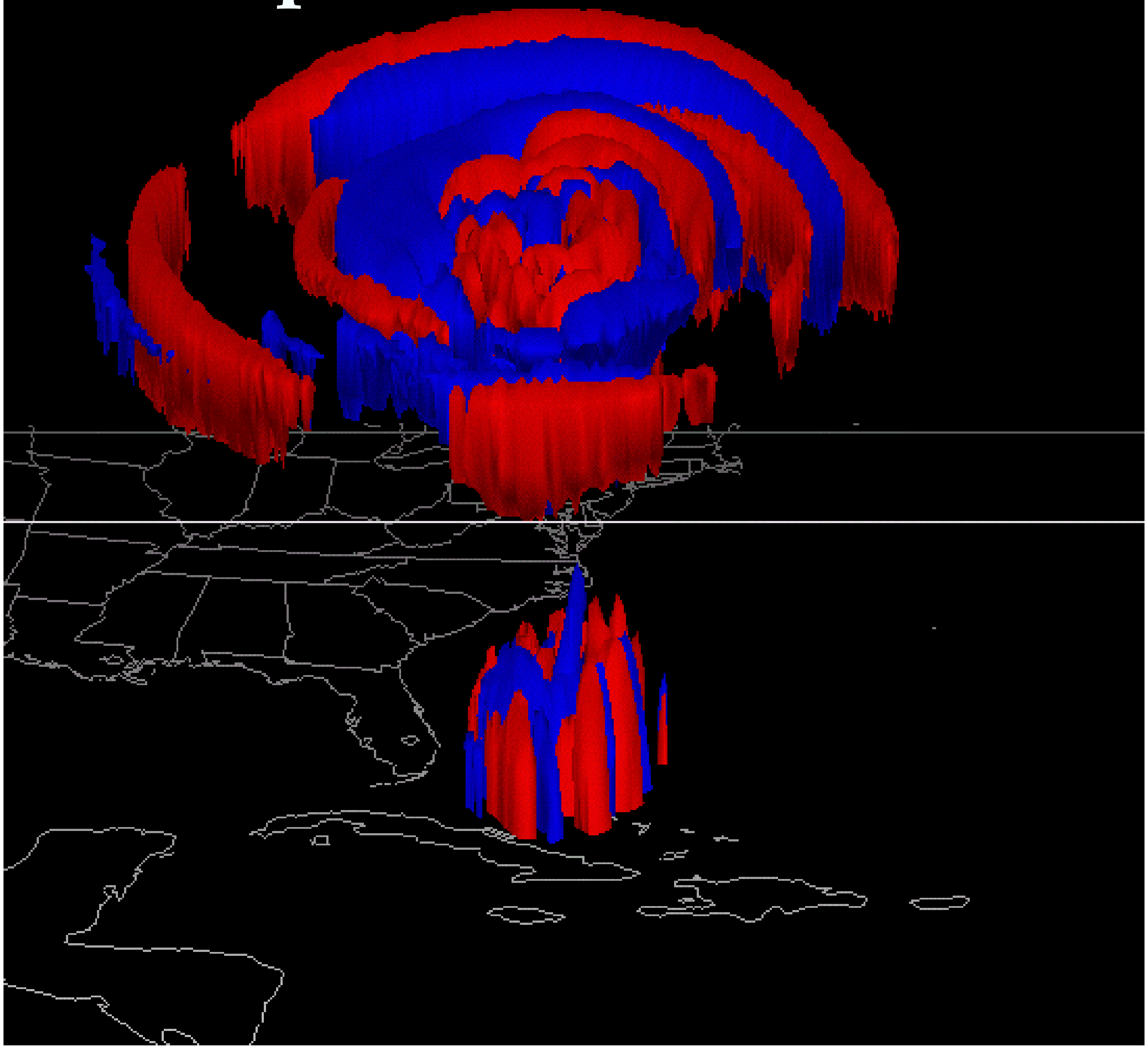
Unperturbed



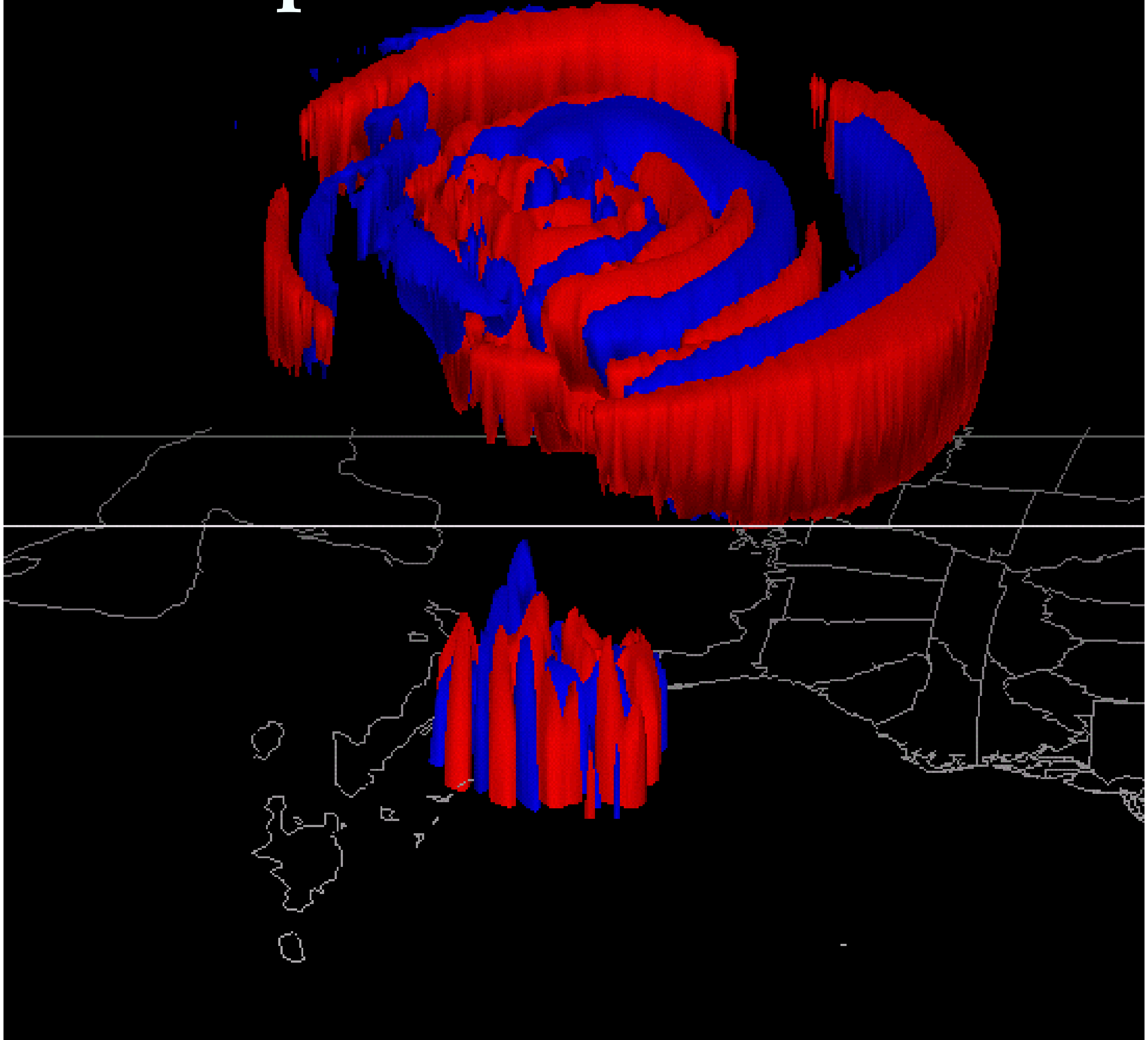
20 km | **7 km**

Controlled

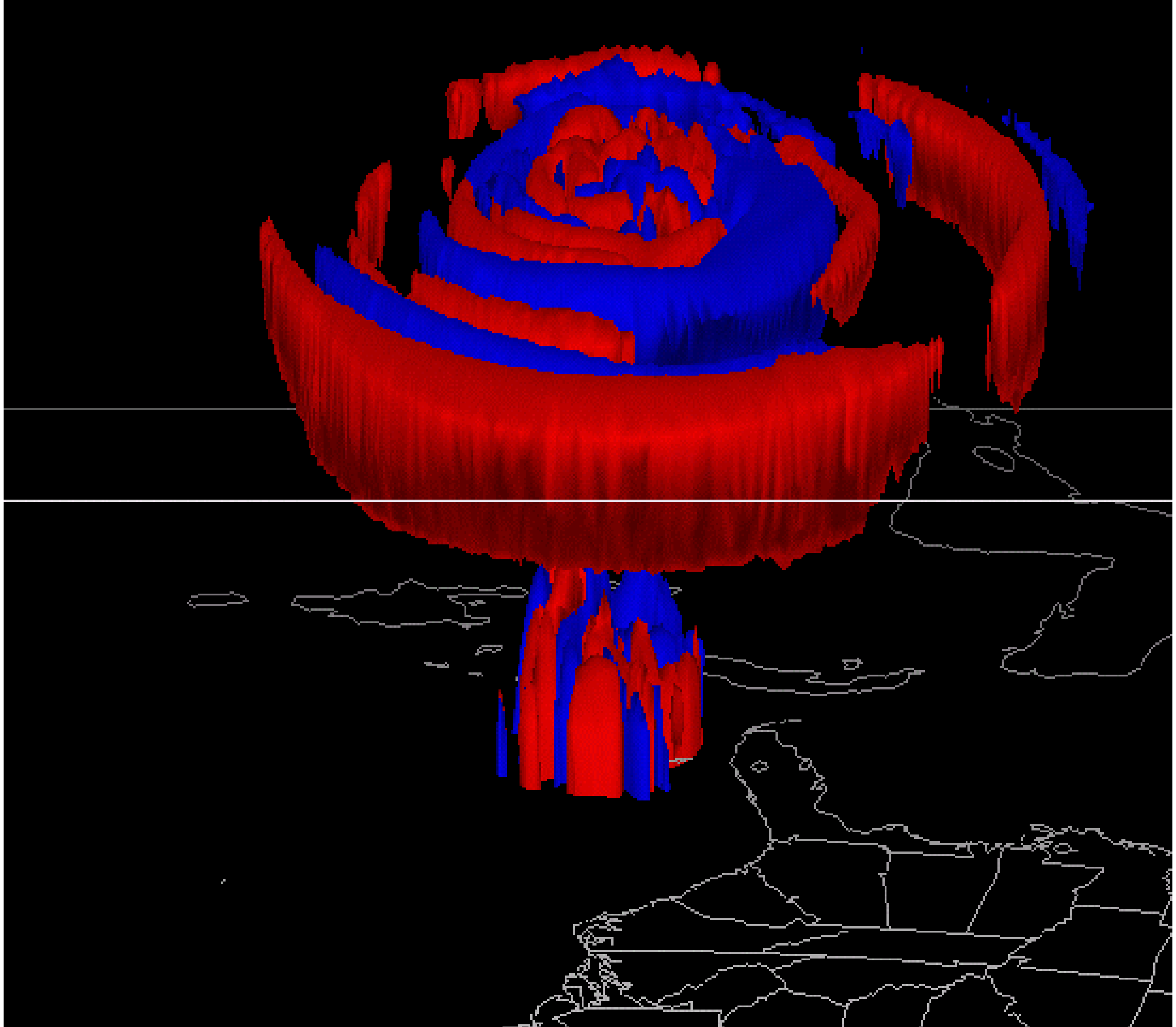
Temperature increments



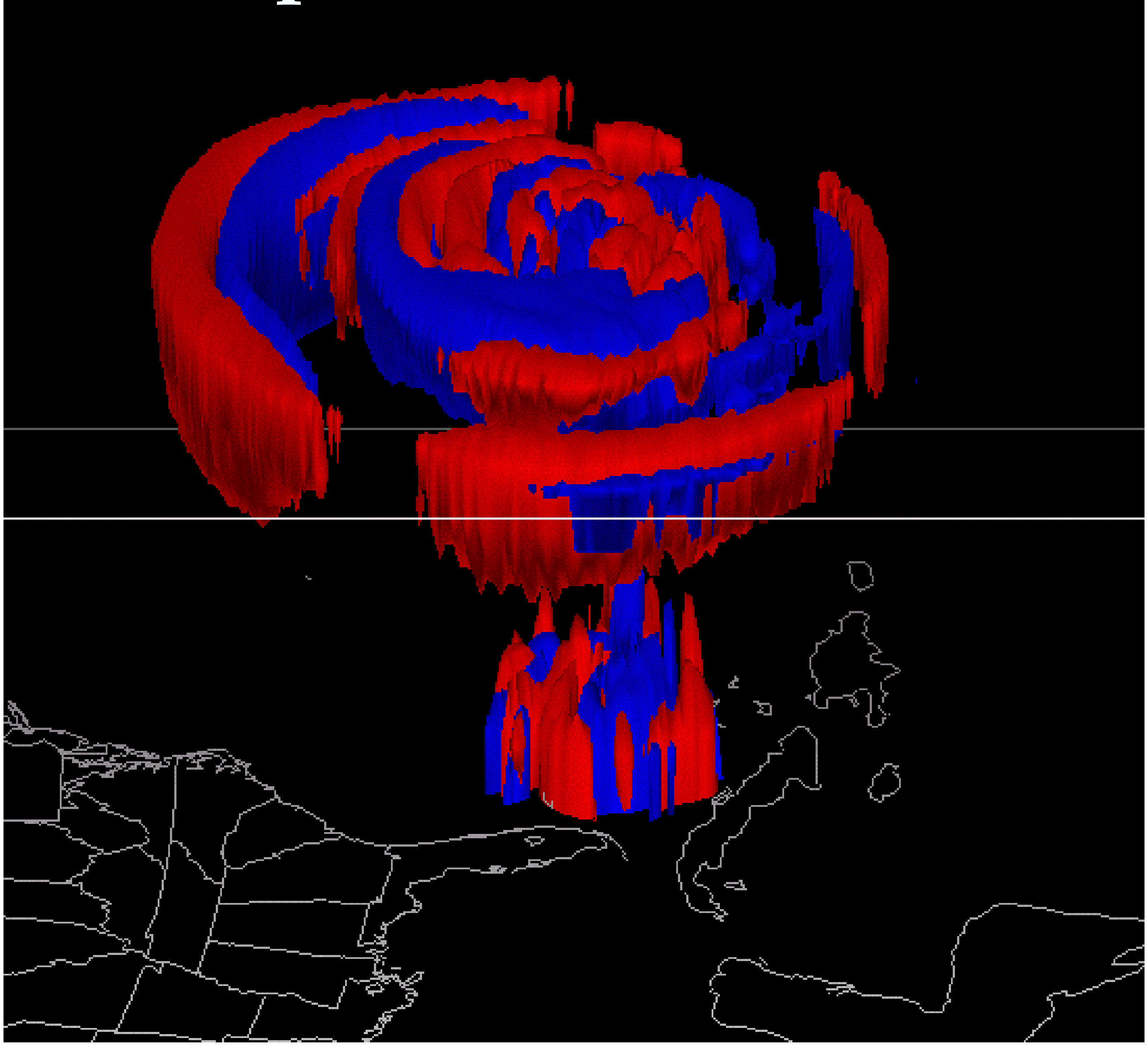
Temperature increments



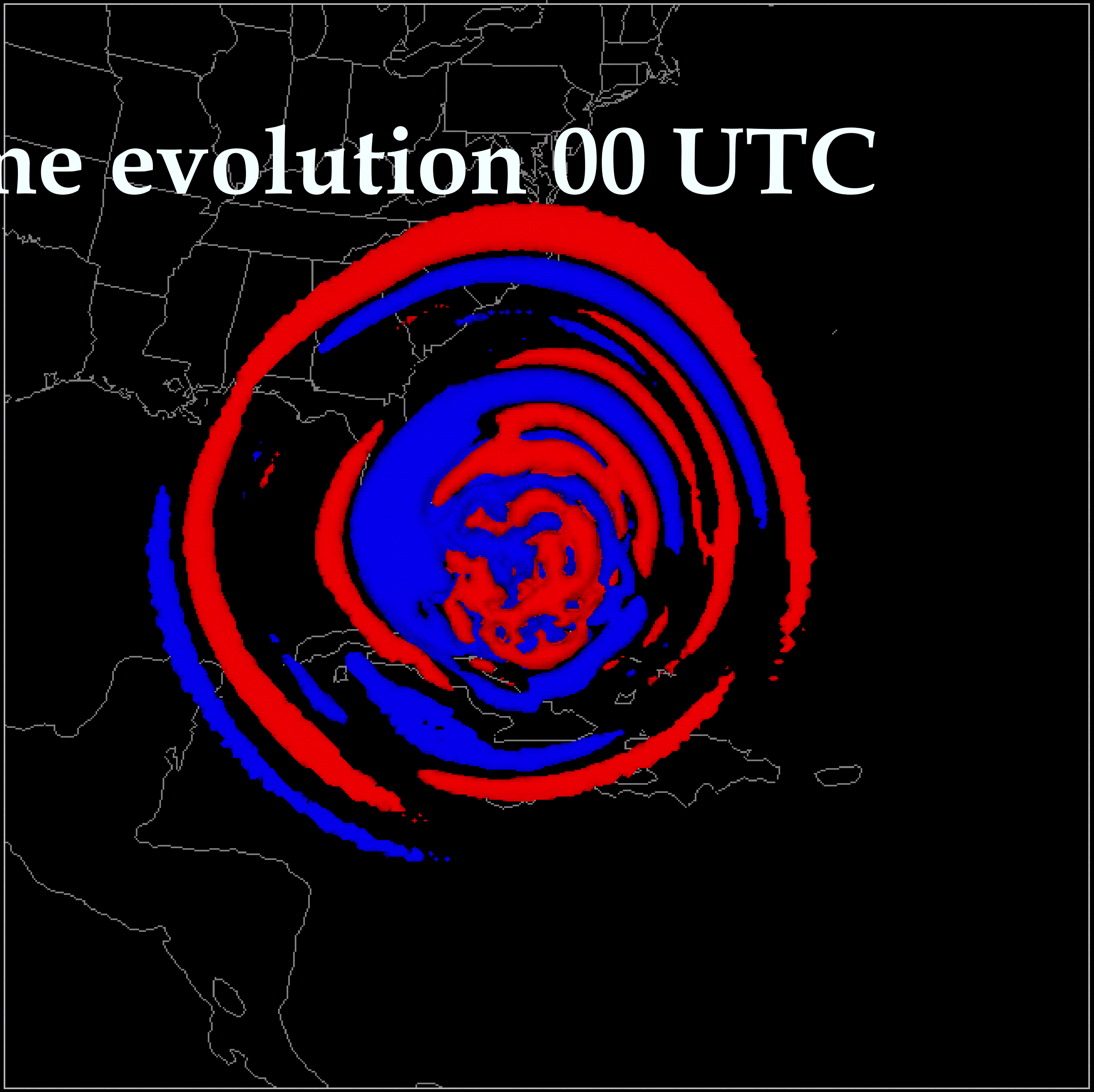
Temperature increments



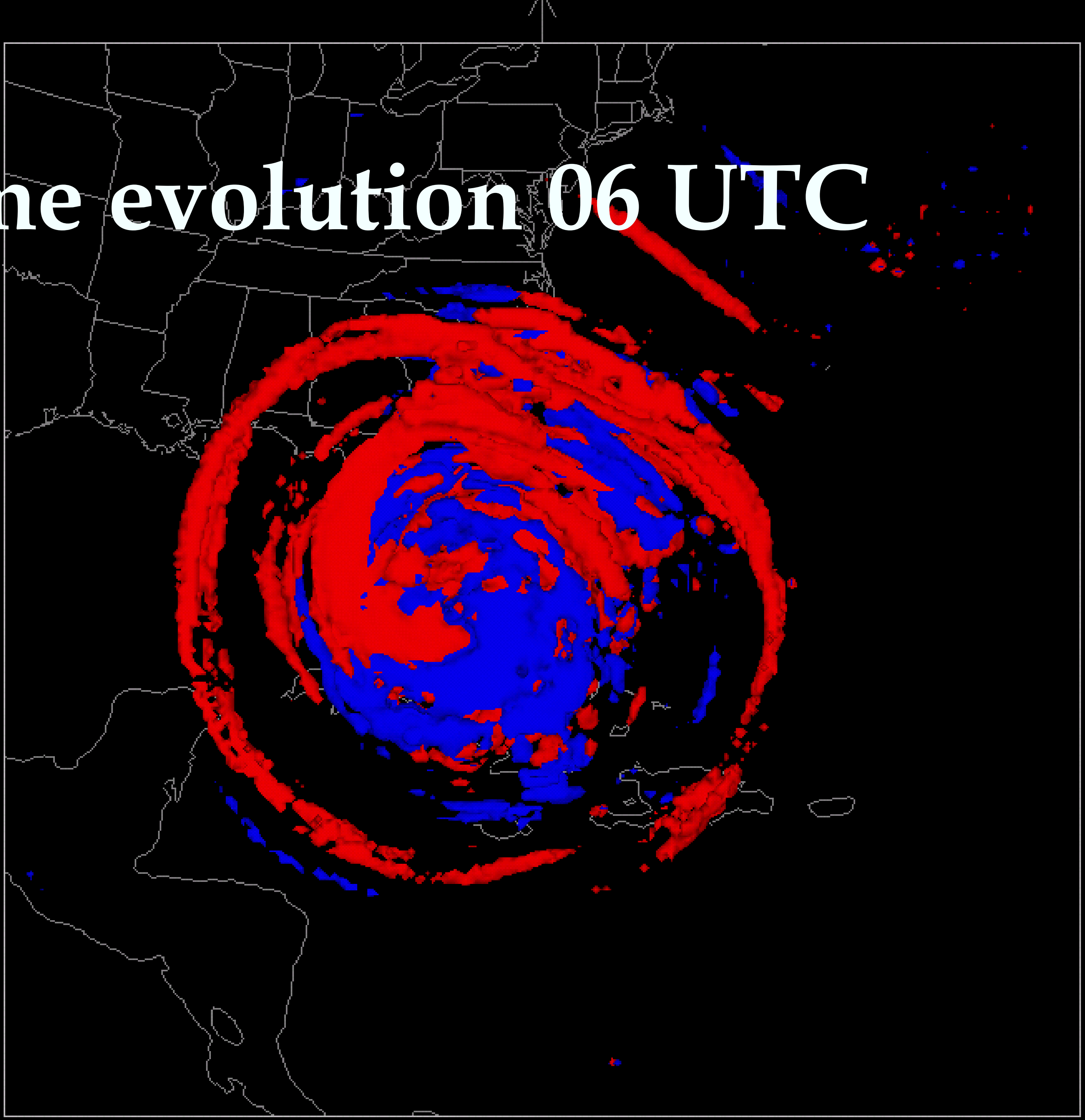
Temperature increments



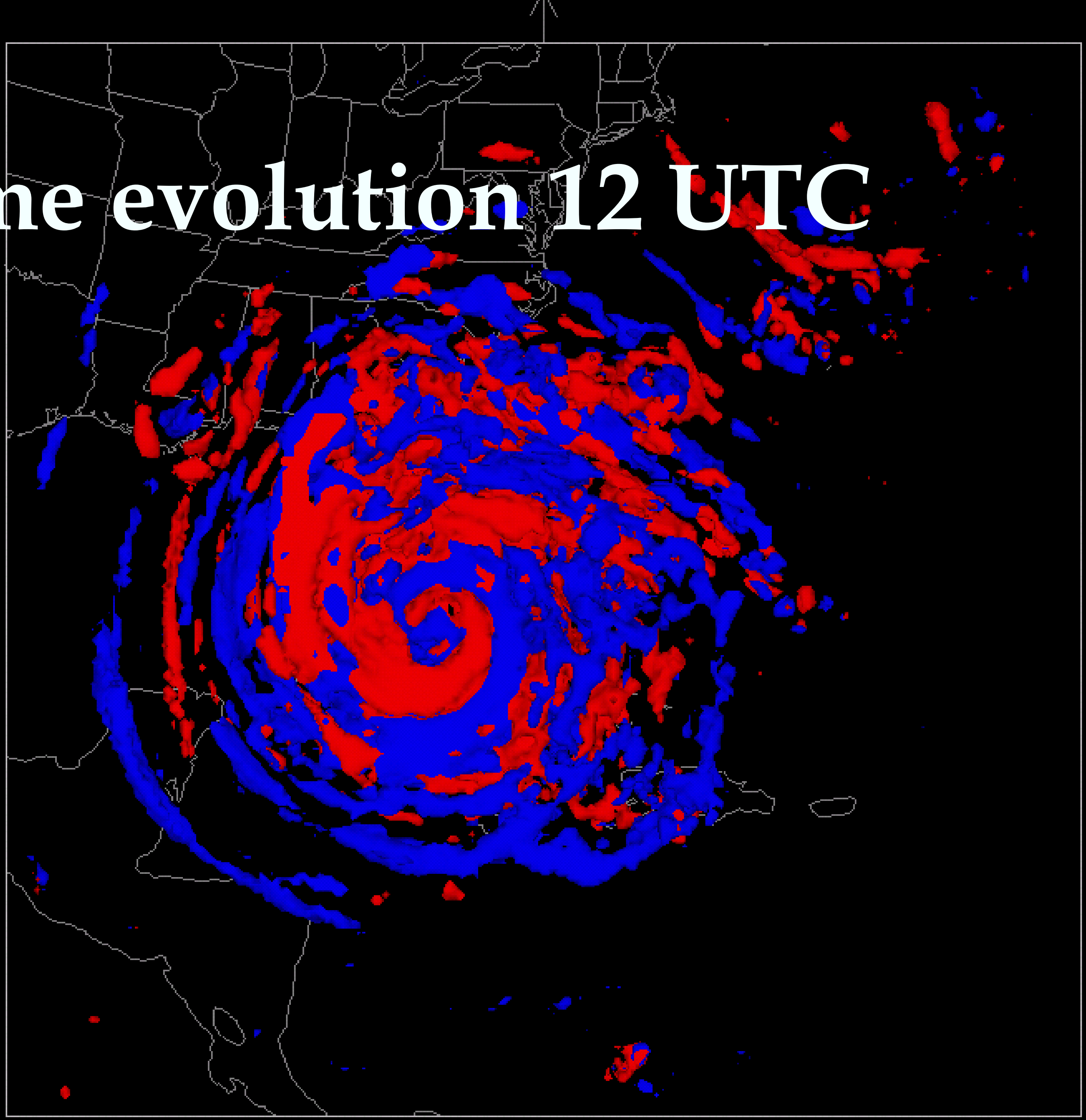
Time evolution 00 UTC



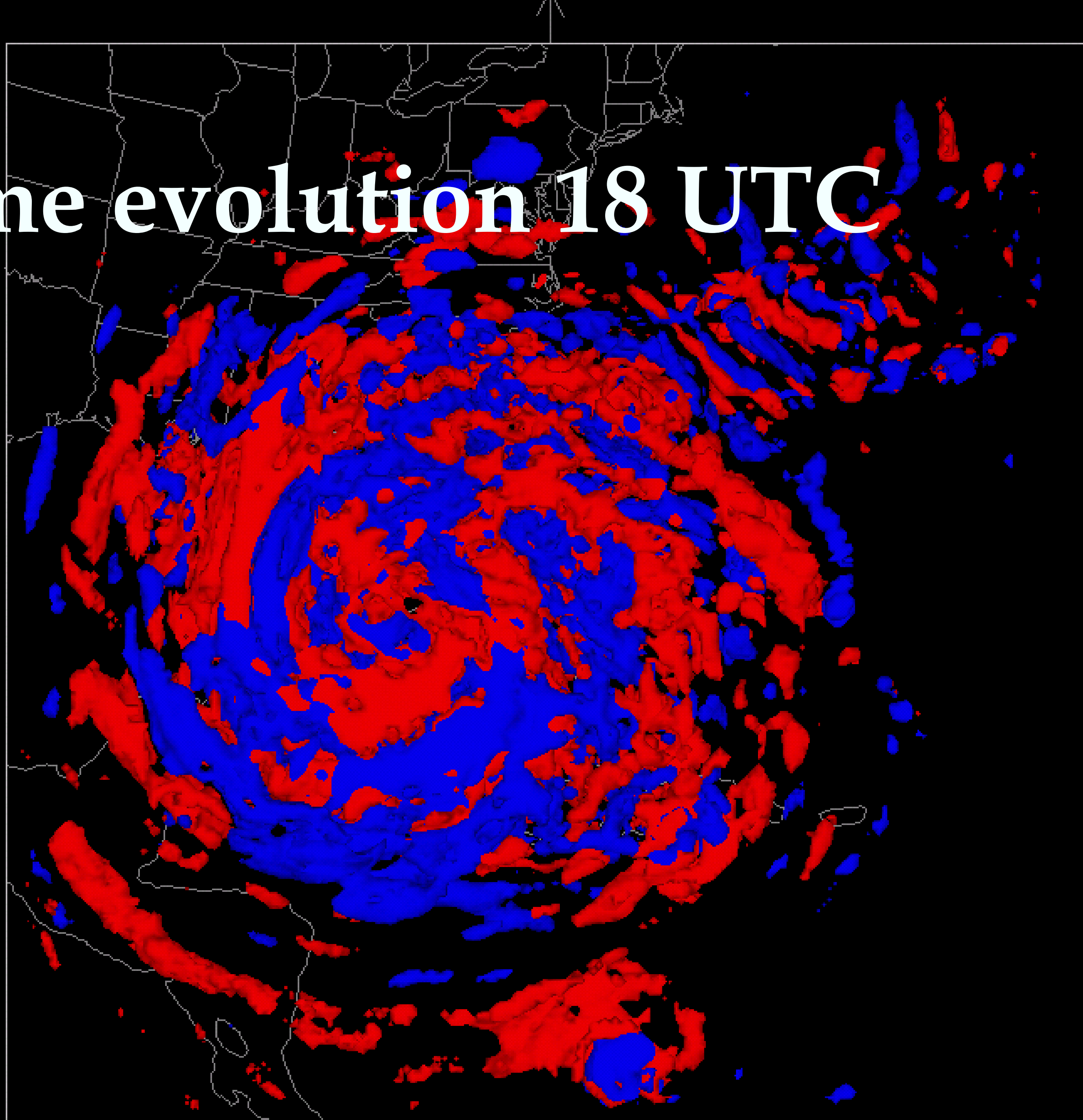
Time evolution 06 UTC



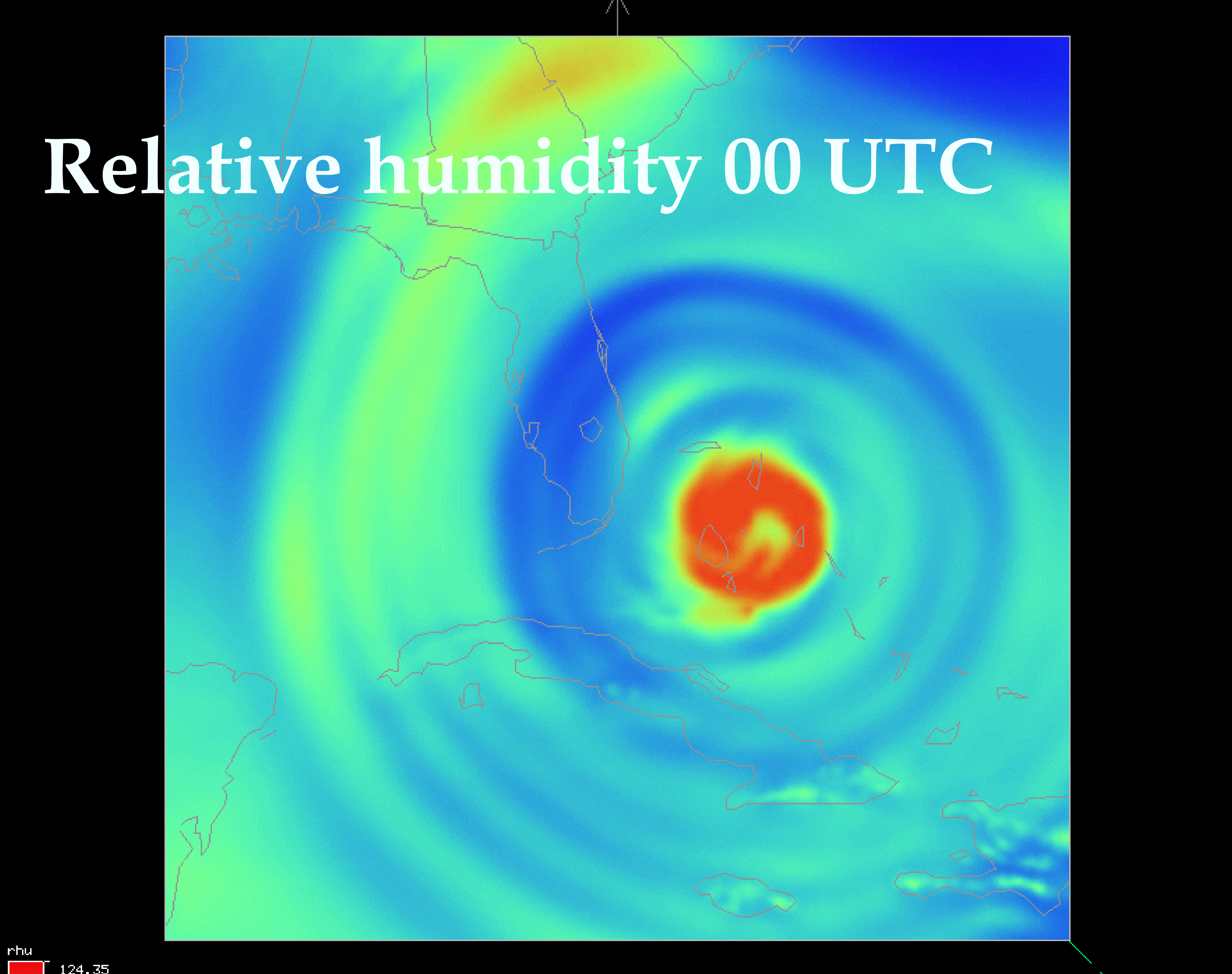
Time evolution 12 UTC



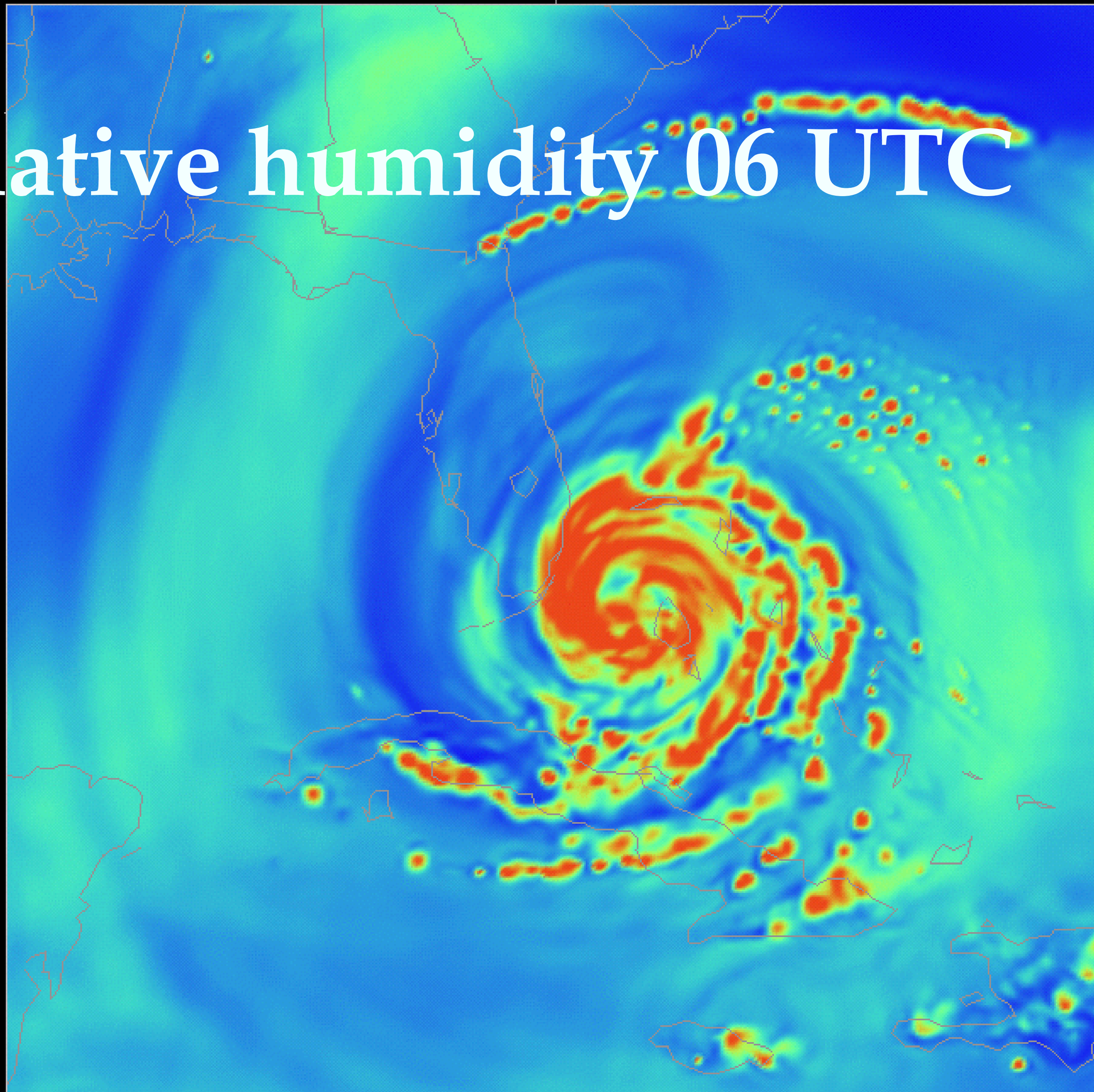
Time evolution 18 UTC



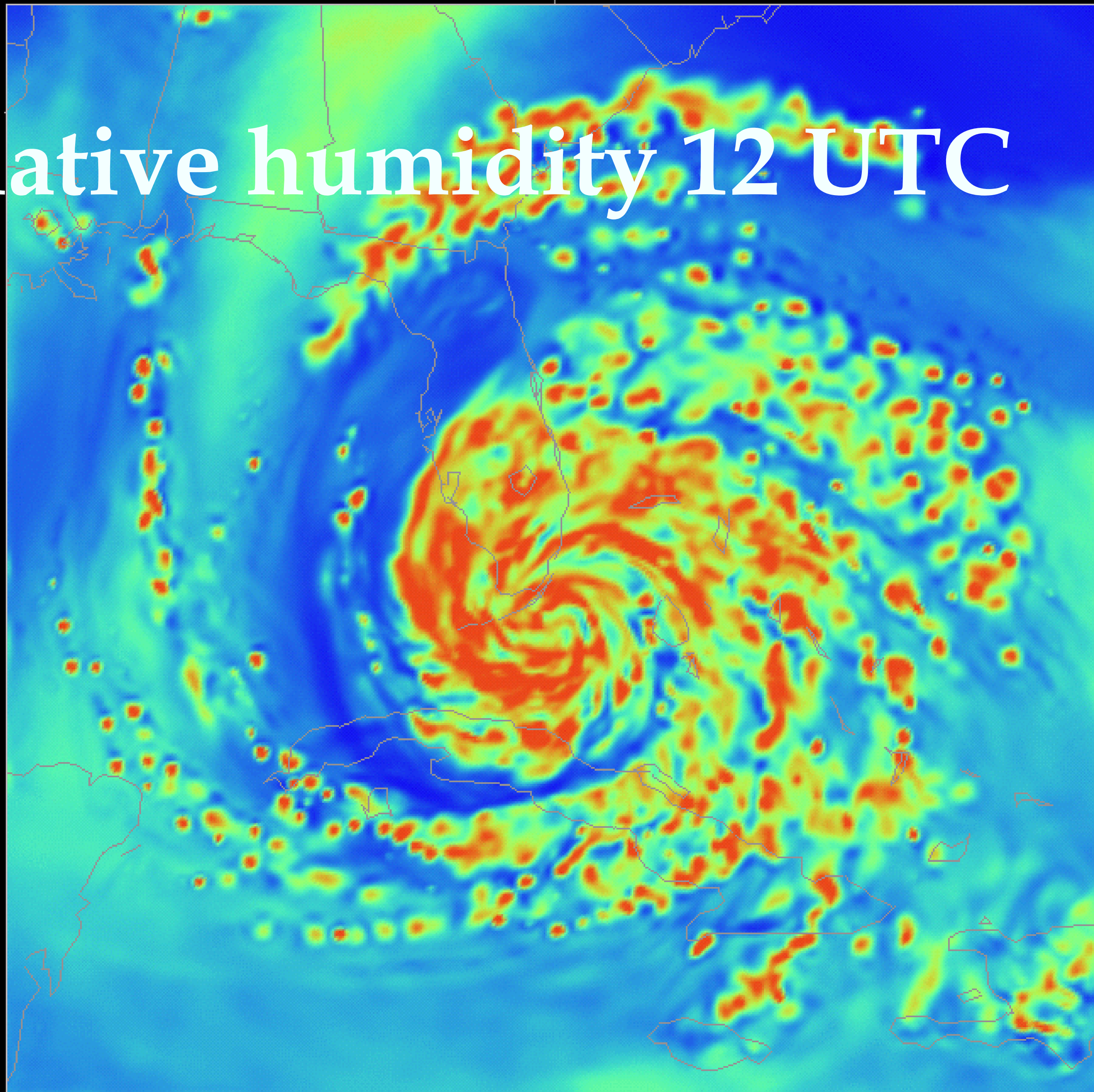
Relative humidity 00 UTC



Relative humidity 06 UTC

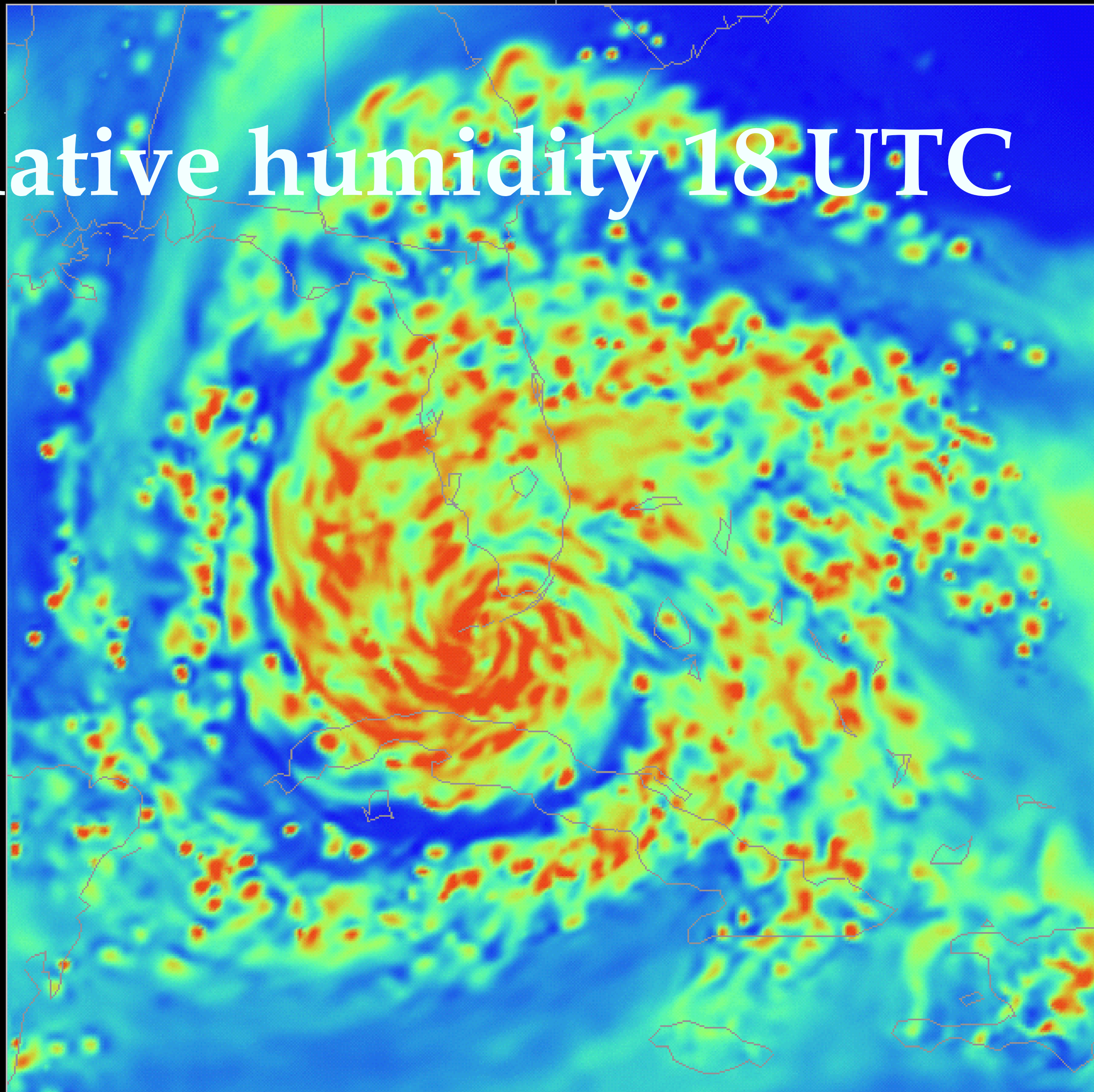


Relative humidity 12 UTC



rhu
124.35

Relative humidity 18 UTC



rhu
124.35

Summary

- Perturbations calculated by 4d-Var
- Control path, intensity of simulated hurricane
- Power requirements are huge
  - Higher resolution, longer lead times may help
  - Very large scale SSP could meet the requirements

The future

- More realistic experiments: resolution, physics, perturbations
- Future advances in several disciplines will lead to weather control capabilities
  - The first experiments will not be space based control of landfalling hurricanes!
- Can legal and ethical questions be answered

end

- **Contact:**
  - **ross@aer.com**
- **Background:**
  - **R. N. Hoffman. Controlling the global weather. *Bull. Am. Meteorol. Soc.*, 83(2):241--248, Feb. 2002.**