DART Initial Conditions for a Refined Grid CAM-SE Forecast of Hurricane Katrina

Kevin Raeder (IMAGe)
Colin Zarzycki (ASP)

Motivation

Thousands of processors on current supercomputers.

-> new CAM dynamical core (Spectral Element)

-> new DART interface for non-rectangular grid (cubed sphere).

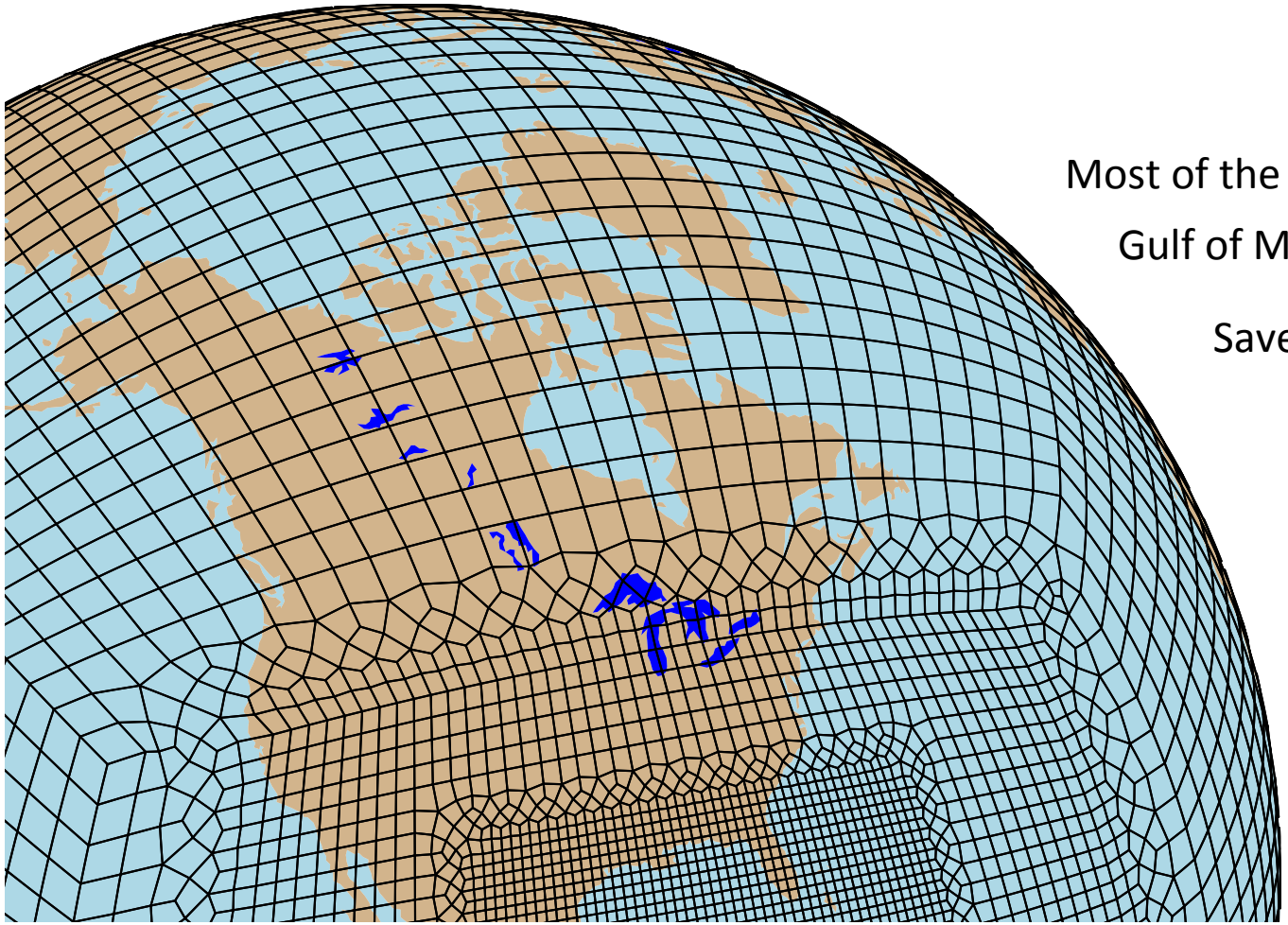
Colin Zarzycki -> “Let’s forecast hurricanes with CAM-SE!”

The Model Grid "Elements"

Each element is a quadrilateral defined by a 4x4 array of grid points.

Identifying the grid box which contains a location can't be done directly by formulas.

We must search the grid boxes for the right one . . . fast.



Most of the globe has ~1° resolution

Gulf of Mexico has ~¼°

Saves a lot of computation!

Is it any good?

image from Zarzycki

The problem

- Want initial conditions for the forecast, on the refined CAM-SE grid:
  - high resolution; hurricanes are complicated.
  - balanced; minimize shocks to the model.
  - sensitivity; want an ensemble of ICs
- Traditional solution; interpolate from a "foreign" model (re)analysis.
- Maybe use a digital filter or some kind of initialization to reduce noise.

The problem

- Want initial conditions for the forecast, on the refined CAM-SE grid:
  - high resolution; hurricanes are complicated.
  - balanced; minimize shocks to the model.
  - sensitivity; want an ensemble of ICs
- Traditional solution; interpolate from a "foreign" model (re)analysis.
- Maybe use a digital filter or some kind of initialization to reduce noise:

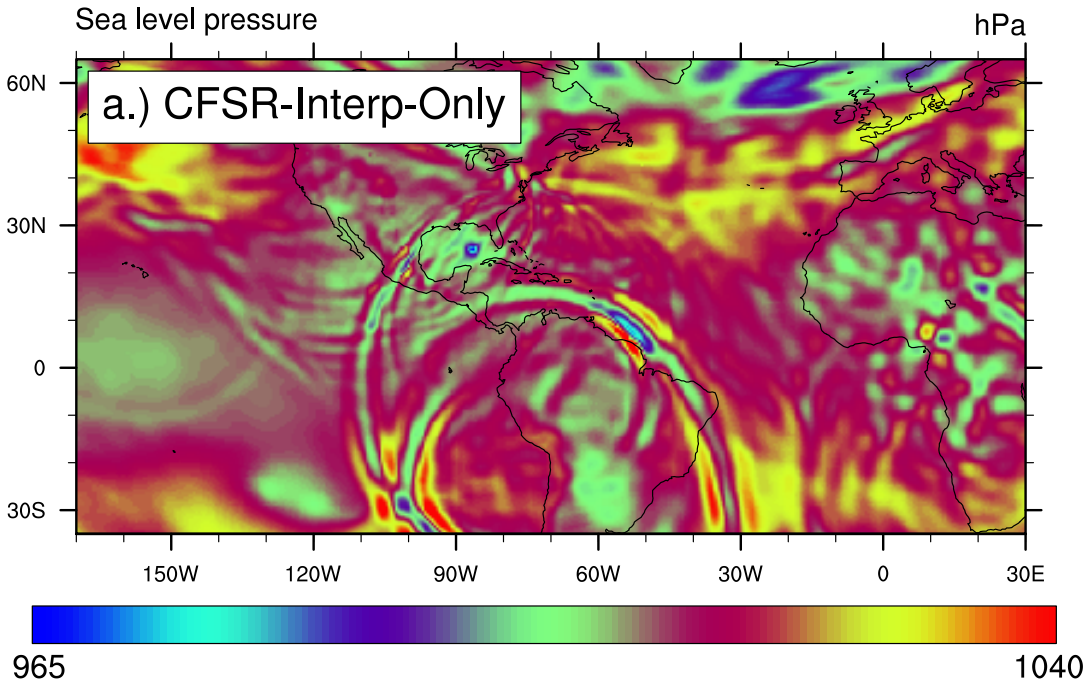


image from Zarzycki

3 hour SLP forecast from Climate Forecast System Reanalysis at 0Z Aug 27 2005 interpolated to the refined grid with no filtering.

Imbalances at rough topography generate strong gravity waves.

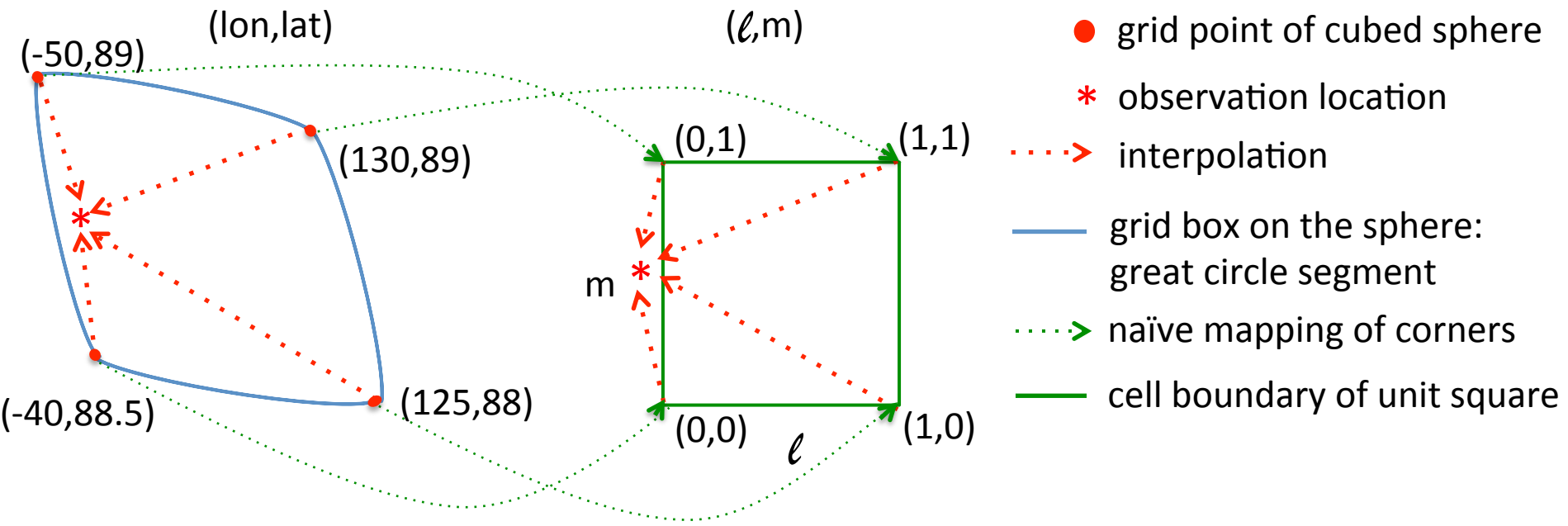
CAM-SE is less diffusive than CAM-FV, so gravity waves can persist longer.

Our Solution

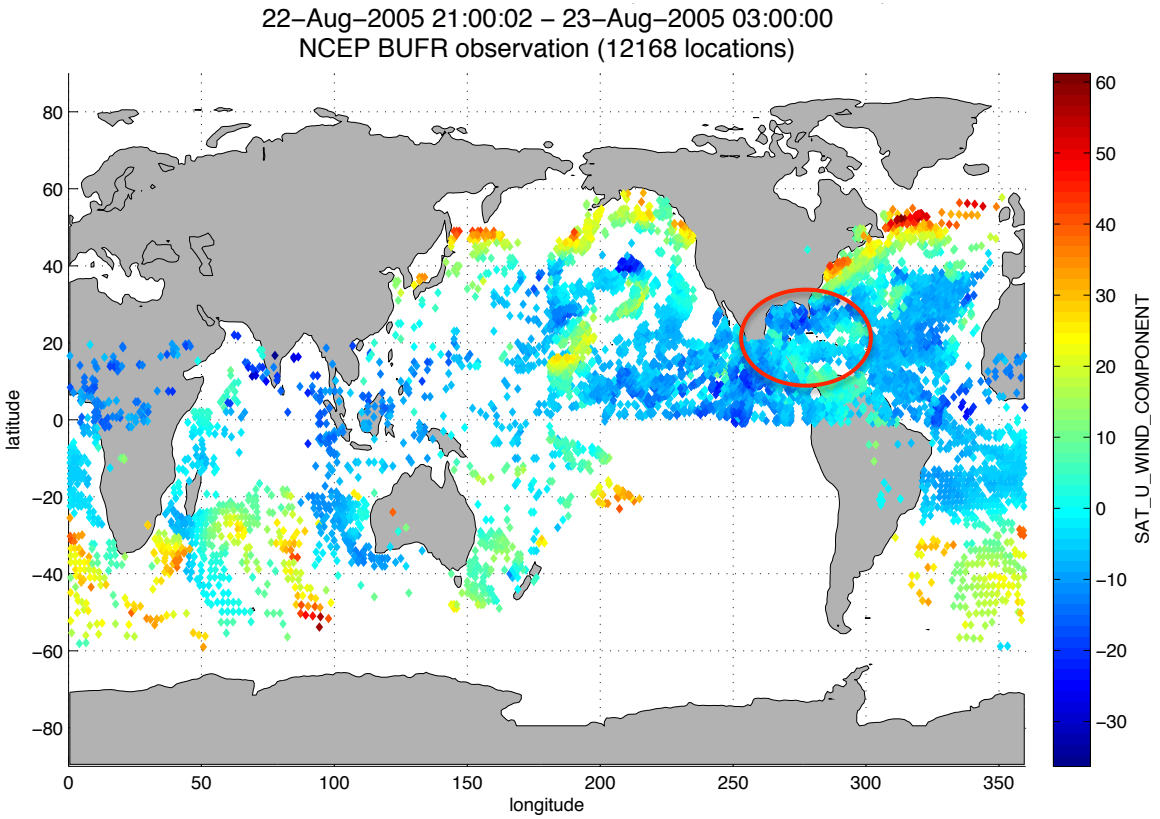
- Want initial conditions for the forecast, on the refined CAM-SE grid:
  - high resolution; hurricanes are complicated.
  - balanced; minimize shocks to the model.
  - sensitivity; want an ensemble of ICs
- Traditional solution; interpolate from a "foreign" model state.
- Maybe use a digital filter or some kind of initialization to reduce noise:
- Our solution; create ICs using
  - the actual forecast model,
  - a suitable set of observations,
  - the Data Assimilation Research Testbed to merge them together.

Our Solution

- Another challenging part: interpolation on the new grid, robustly, accurately, and . . . fast.

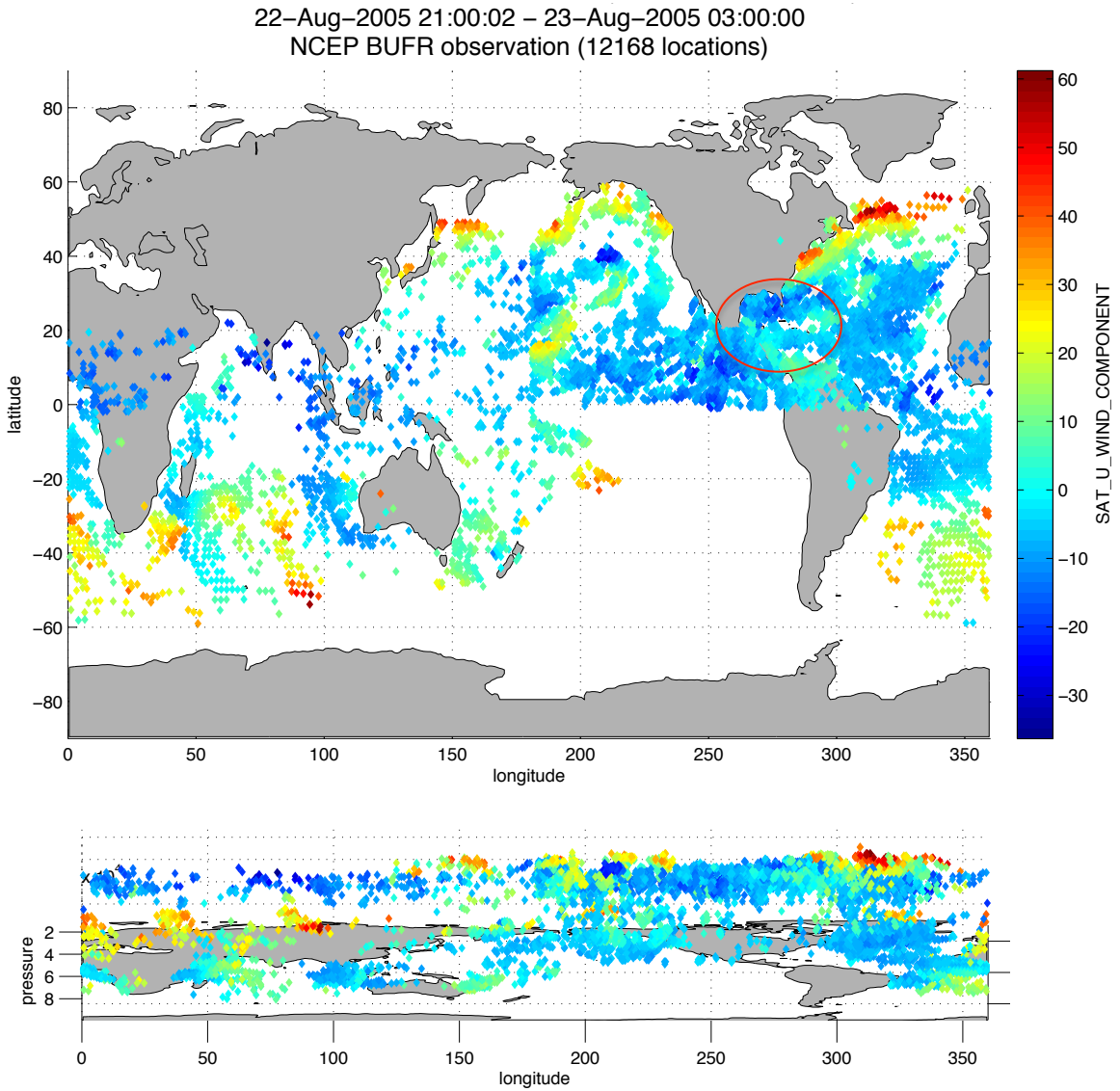


Obs used: Satellite cloud drift winds



Looks like dense coverage where Katrina should be…

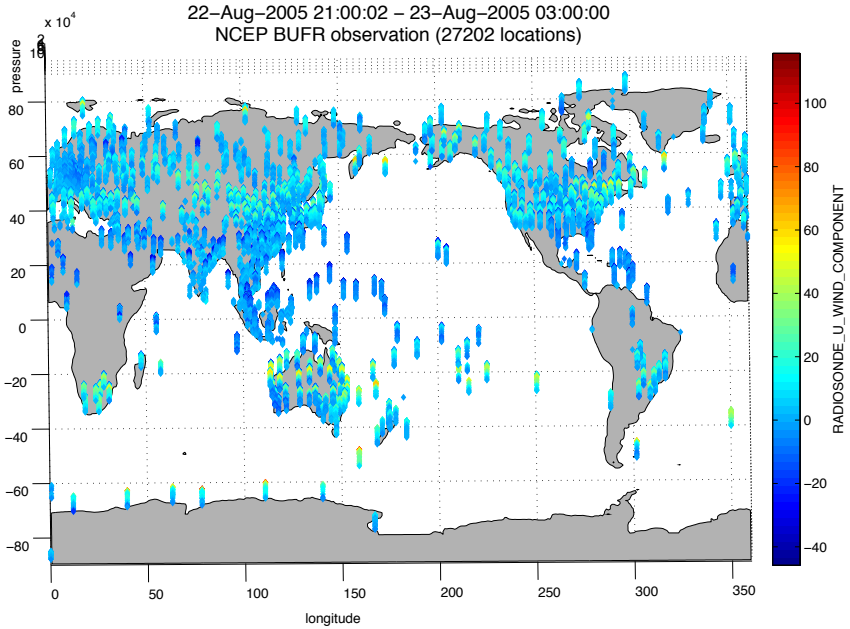
Obs used: Satellite cloud drift winds

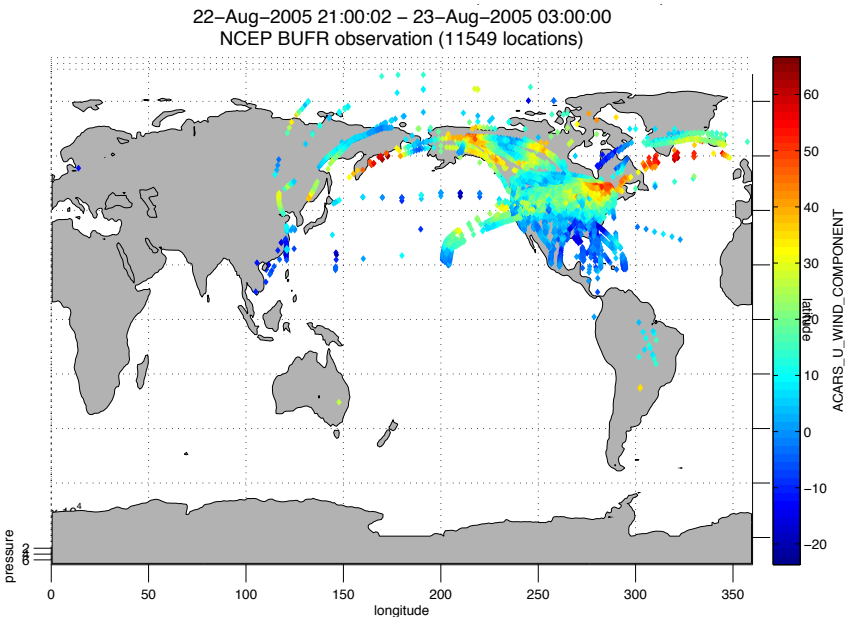


Looks like dense coverage where Katrina should be…

but they're mostly at cloud top

Obs Used; Radiosondes, Airplanes

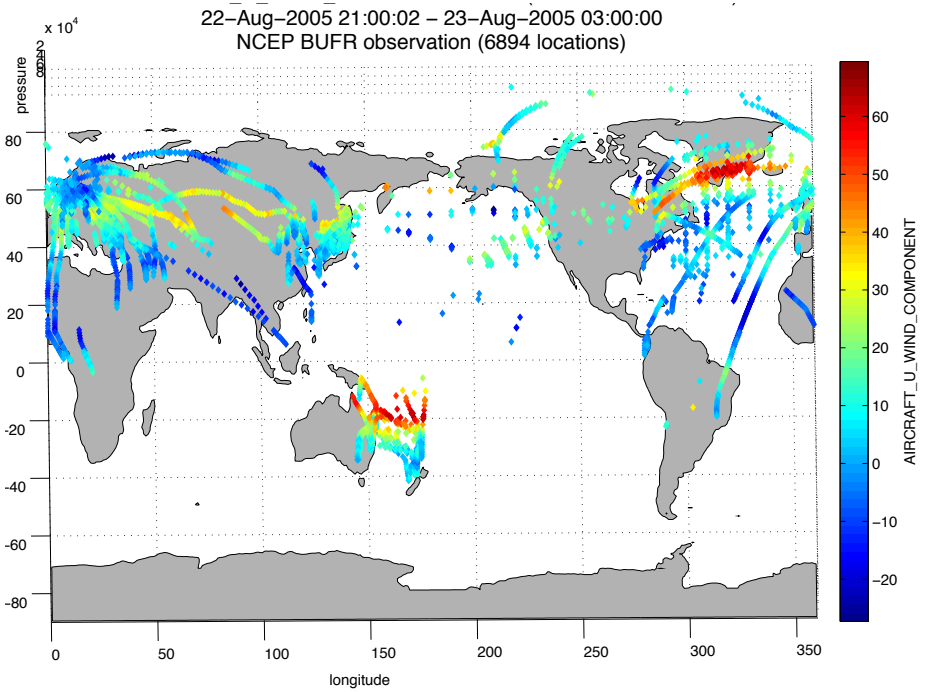




Sparse

Concentrated over land

No storm-focused observations

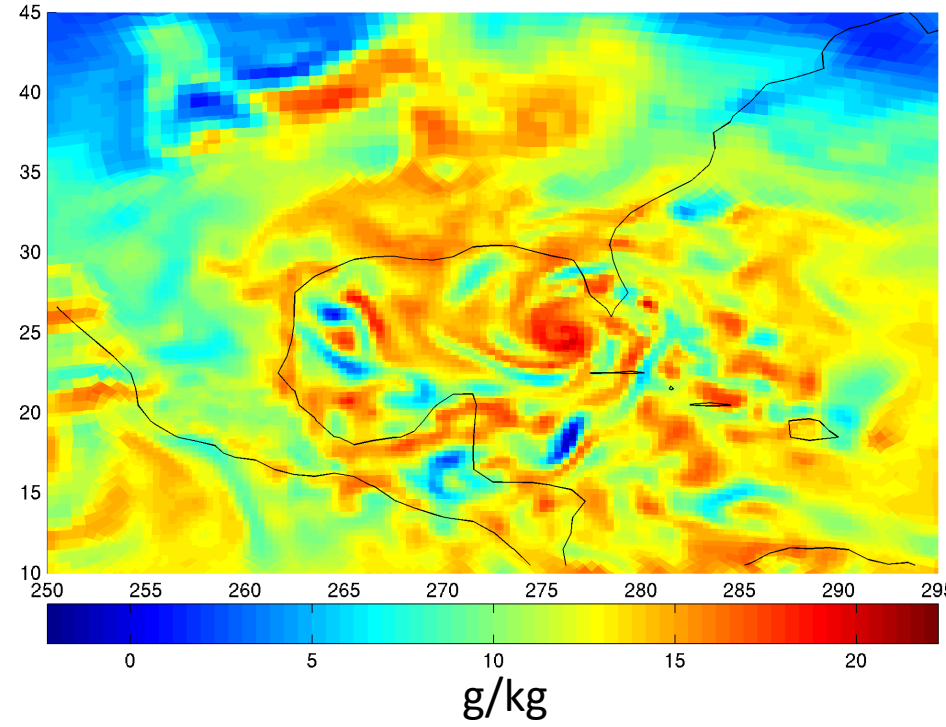


We start from an Aug. 1 from a climate run, assimilate these sets of observations into CAM-SE over a couple weeks and get . . .

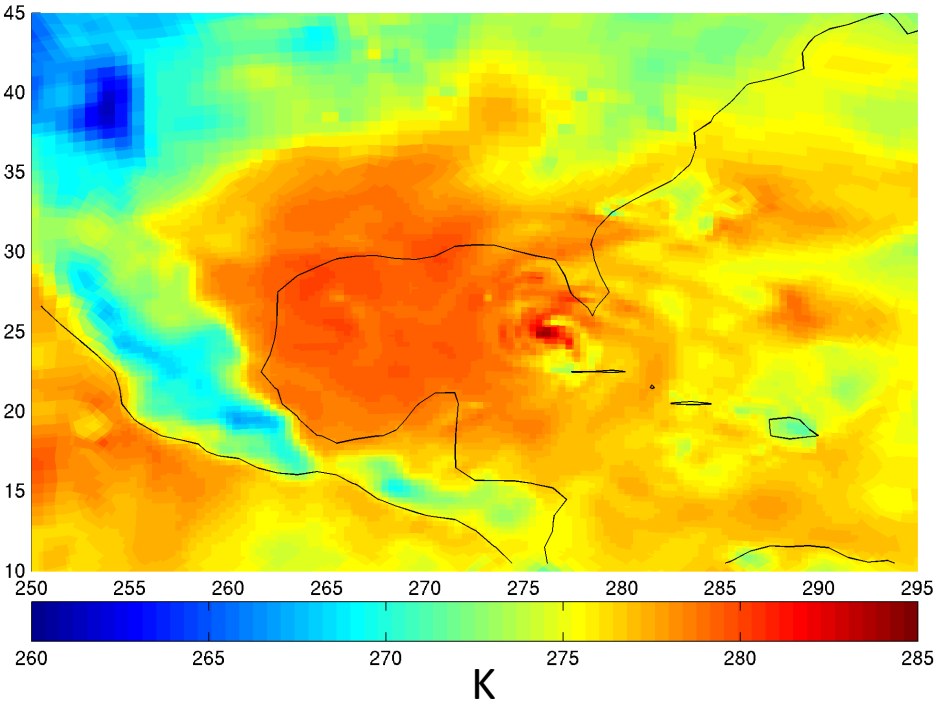
Hurricane Katrina

Member 27, 0Z 2005-08-27

Q level 24 (~860 hPa)



T level 20 (~610 hPa)



Banded structure evident in moisture field.

The "warm core" is clearly evident.

Variable resolution enables this level of fidelity where we want it, without paying for it where we don't.

Comparison to “Foreign” ICs

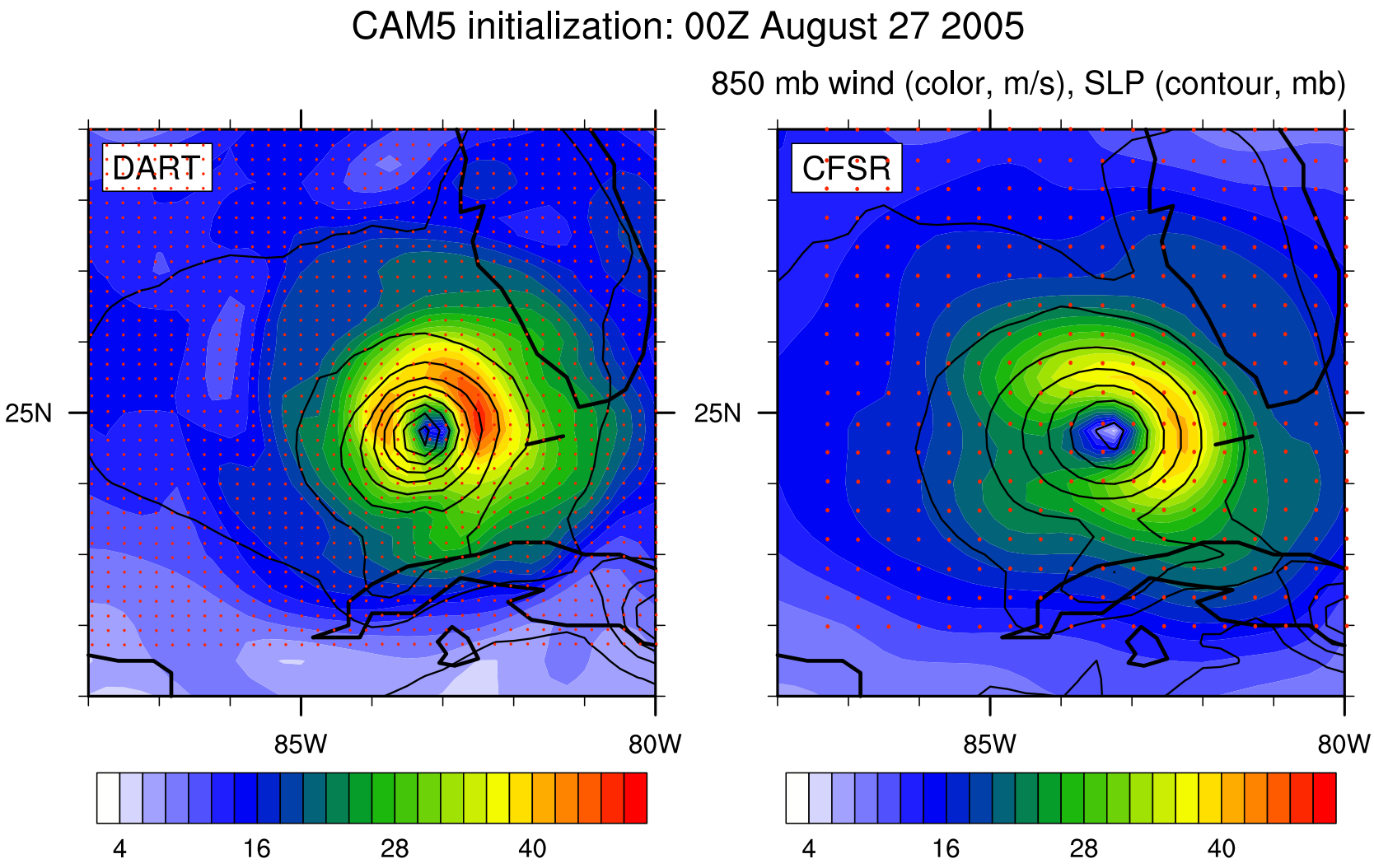


image from Zarzycki

Hour 3 Forecast Comparison

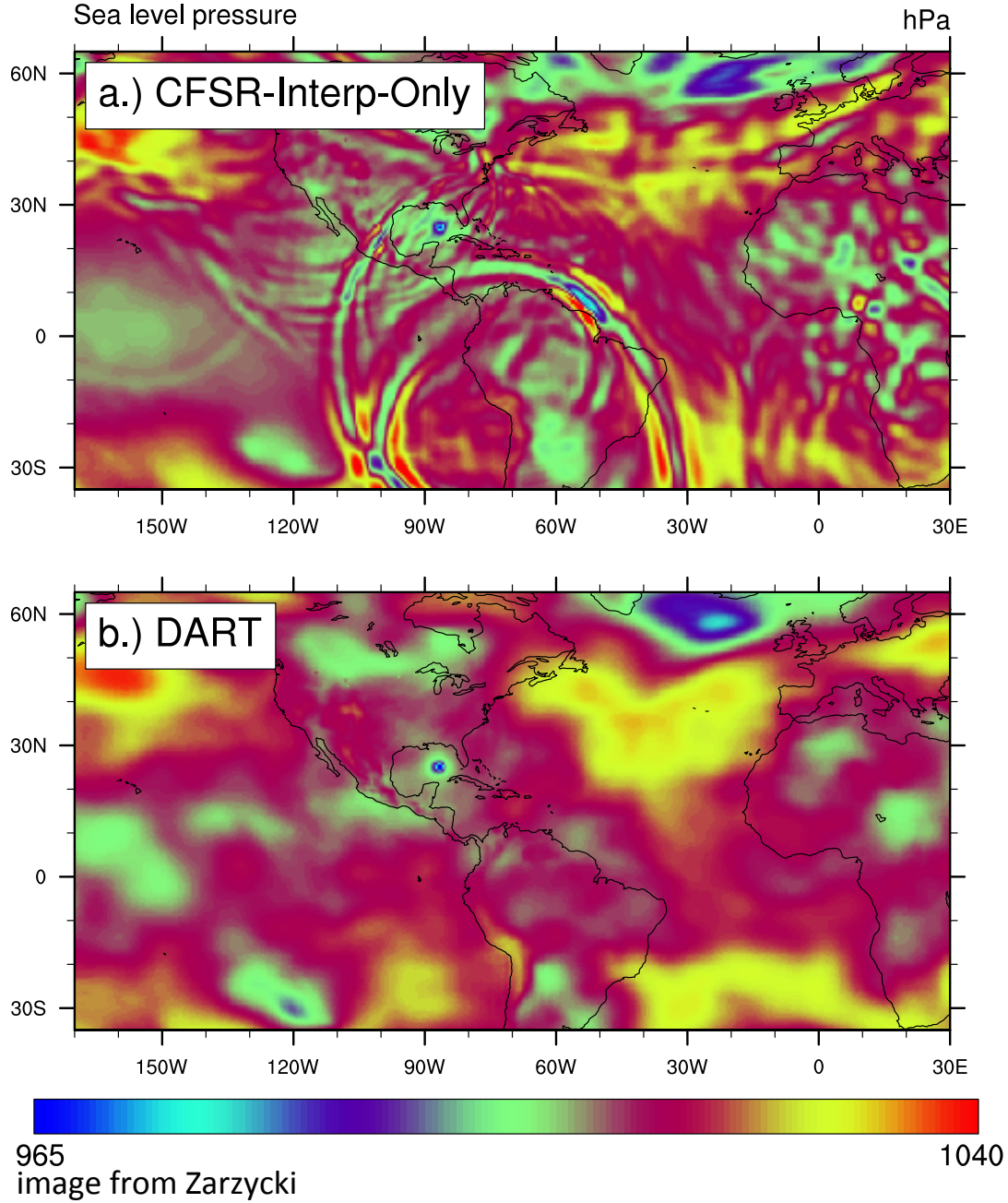
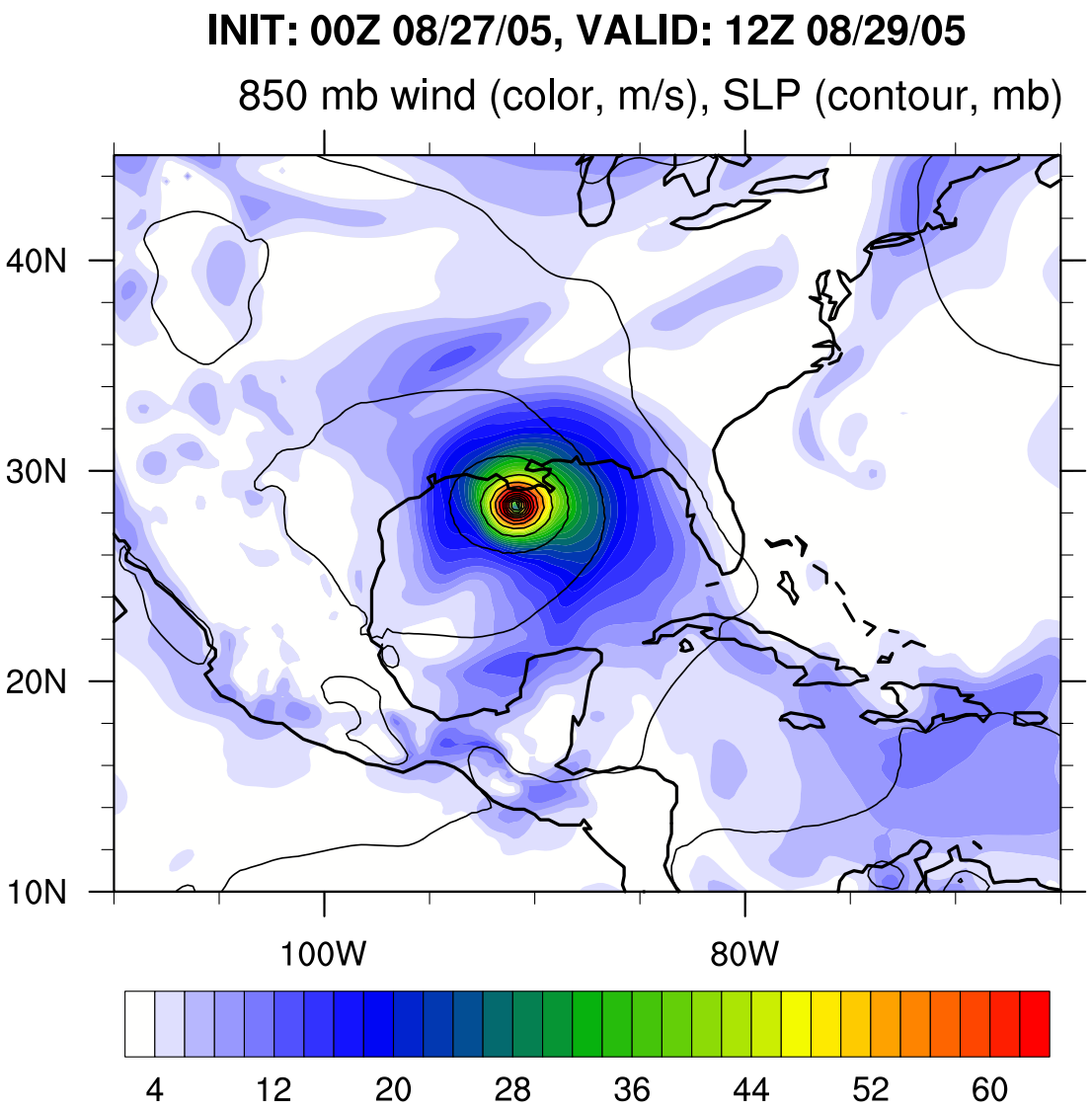


image from Zarzycki

The magnitude of the hurricane is *almost* as large as the biggest gravity waves.

60-hour Forecast from DART ICs



Maximum wind, central pressure, and landfall are all realistic. The eye is resolved.

Test for robustness and/or sensitivity; ensemble forecast from up to 80 equally likely initial conditions.

image from Zarzycki

What can we do with this?

- Evaluate how CAM handles actual hurricanes and similarly sized weather features;
  - winter storm systems,
  - tropical convective complexes,
  - weather over more realistic mountains,…
- This can clarify shortcomings in CAM and lead to better climate forecasts.
- Forecasts are most improved in the first day; less noise from CAM adjusting to the initial conditions. So we get useful forecasts sooner.
- Ensemble of CAM analyses gives a measure of model uncertainty and the ability to start from different, but equally likely, ICs.
- Framework enables comparison of CAM output directly to observations.

Next

- More detailed hurricane forecast research with CAM-SE
- Public release of DART interface to CAM-SE, WACCM, and CAM-Chem
- DART workshop and tutorial (grad students) Aug. 3-7, 2015, an IMAGe “Theme of the Year” event
- Work toward “cross-component” assimilation in coupled CESM

- Our solution
  - Generate ICs using the same model as the forecast
  - Start with high confidence in the wrong answer
  - Assimilate *these* observations for a few weeks
  - Katrina pops up on schedule, in the right place
  - Any 6 hour time slot can be used to start a free-running forecast.
  - Reduced noise in short forecasts.
  - ? Better longer forecasts?

DART+CAM interface

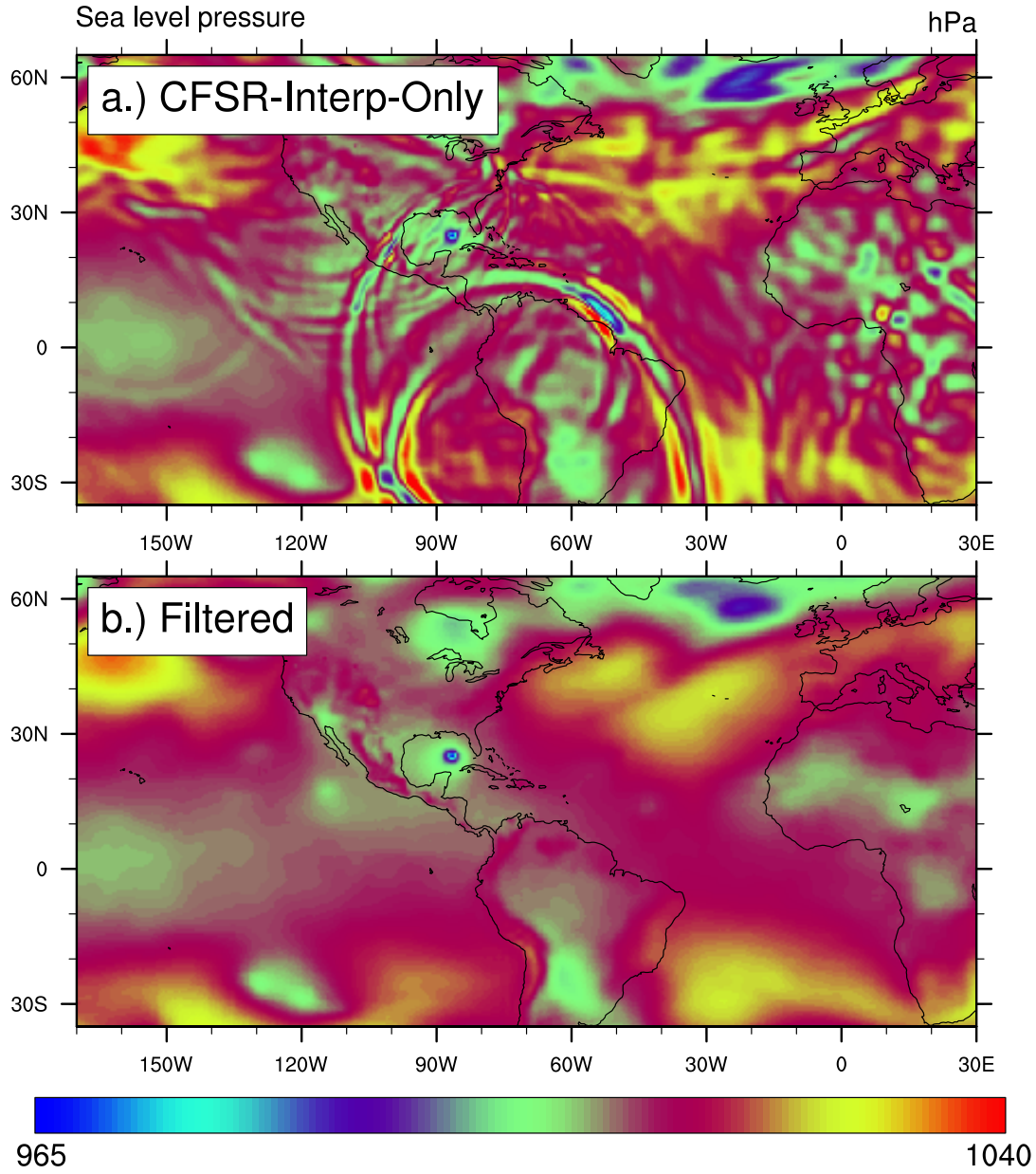
Data assimilation = merging of forecasts and observations of a physical system to produce a picture (model state) which is better than either of them.

Forecast was: "Front Range high temperatures in the 30s tomorrow"
Observations: Fort Collins = 36°F, Colorado Springs = 41°F
Assimilation: Fort Collins = 35-37°F, Denver = 35-38°F, Colorado Springs = 39-41°F

But I use a complex forecast model and thousands of observations

- Data Assimilation Research Testbed = software which enables data assimilation by non-experts.
- Community Atmosphere Model = a component of the Community Earth System Model (NESL/CGD).
- Software that communicates all necessary information between the two.

Hour 3 Forecast Comparison: Surface Pressure

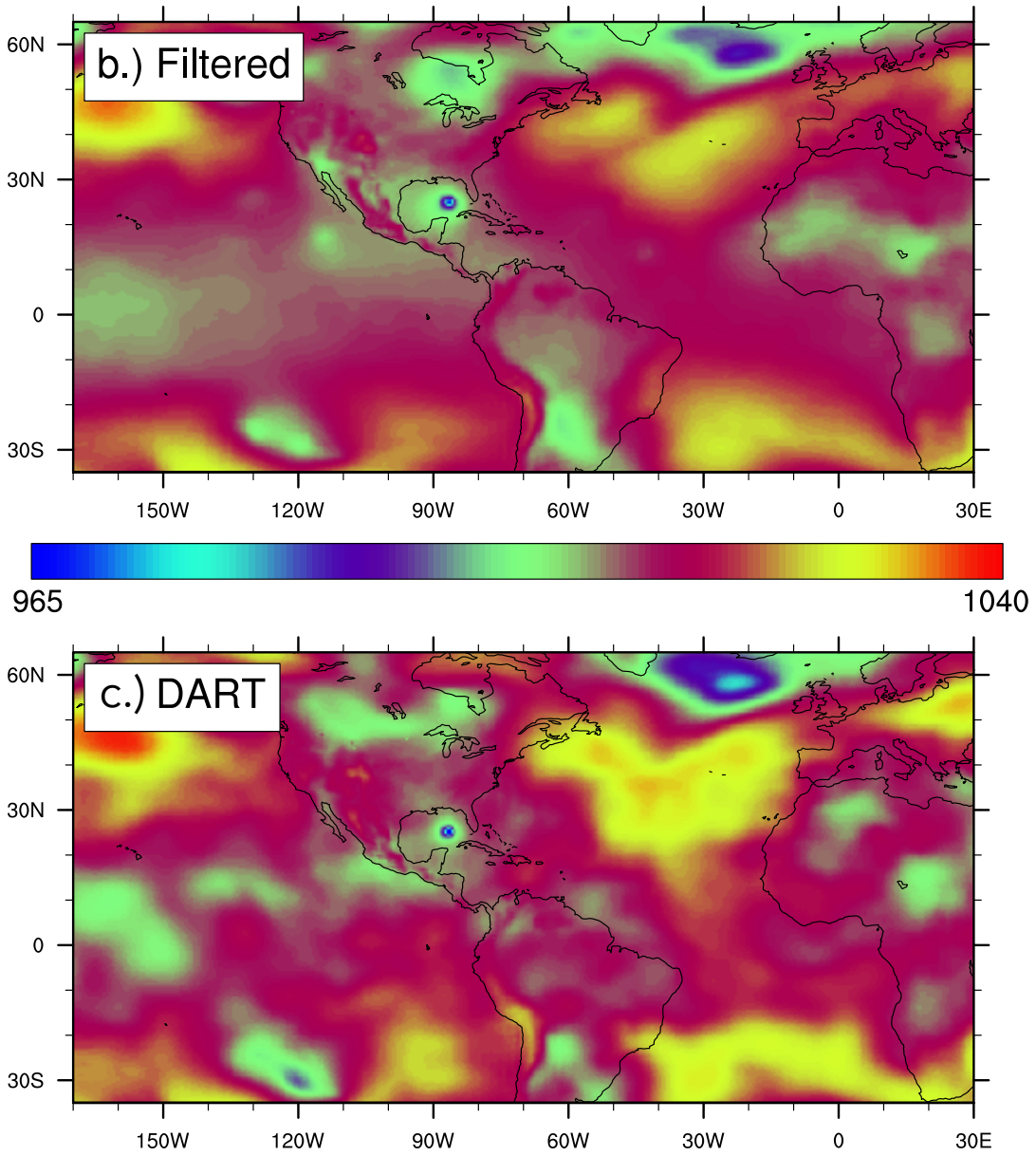


CFSR PS at 03Z Aug 28 2005 interpolated to the refined grid with no filtering.

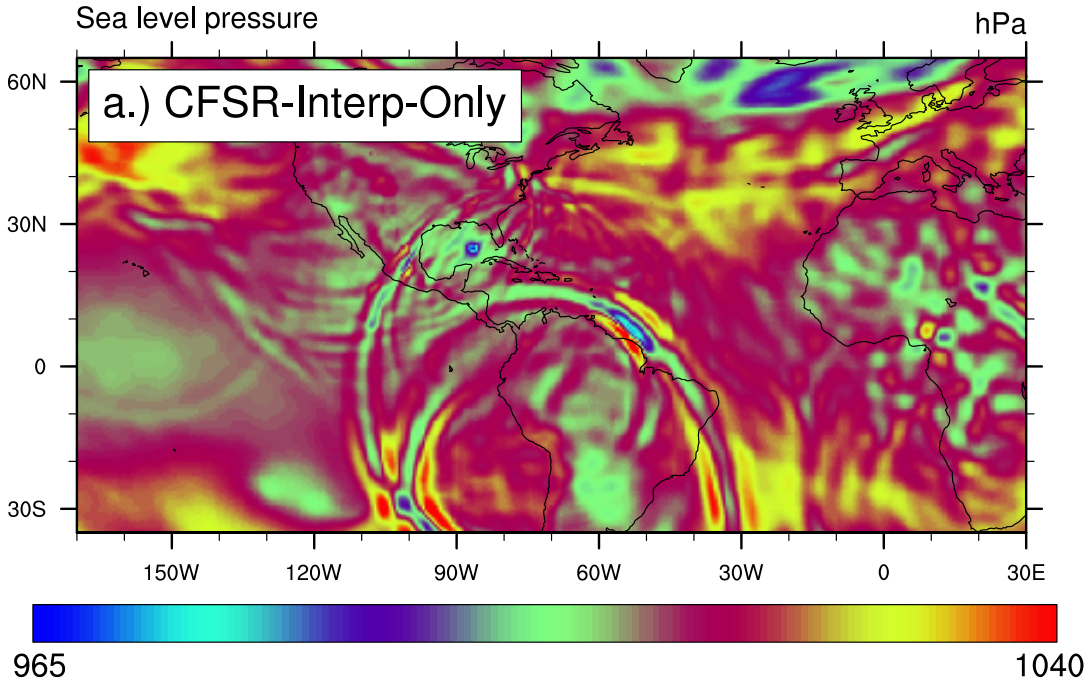
Applying a digital filter (Fillion 1995) to the ICs eliminates the obvious noise.

Hour 3 Forecast Comparison: Surface Pressure

DART ICs; A single, randomly chosen, ensemble member.



Hour 3 Forecast Comparison: Surface Pressure



CFSR PS at 03Z Aug 27 2005 interpolated to the refined grid with no filtering.

Imbalances at rough topography generate strong gravity waves.

CAM-SE is less diffusive than CAM-FV, so gravity waves can persist longer.

Sources of Differences from CFSR

Some come from the:

- DART member choice,
- observations used to generate the analyses,
- digital filter (if used),
- biases in the forecast model used by CFSR.

But some differences come from the higher resolution in the DART ICs (1/4°)