The Coupled Hurricane Intensity Prediction System (CHIPS)

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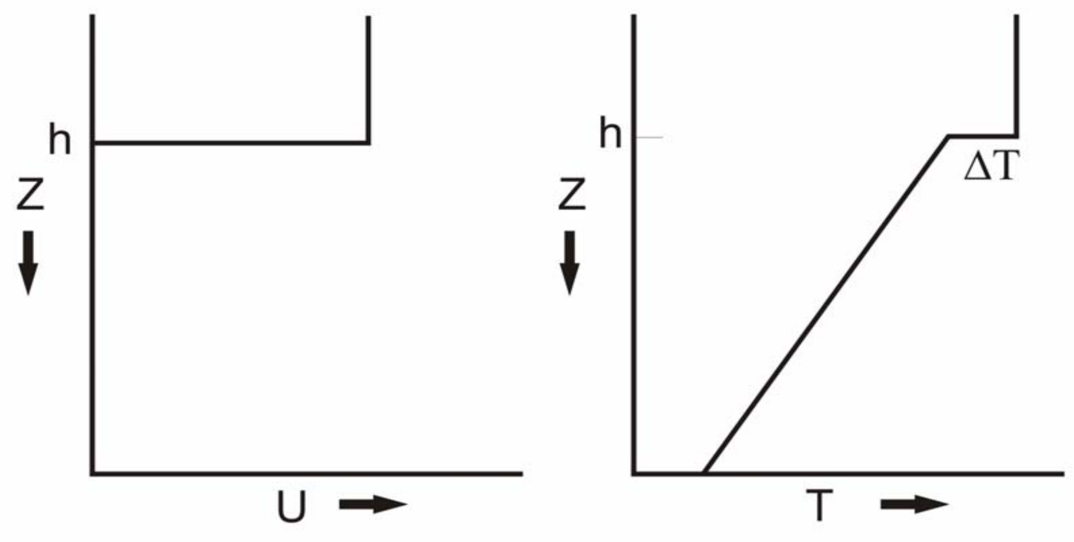
Coupled Model Design

- **Atmospheric Component: (from Emanuel, 1995)**
  - Gradient and hydrostatic balance
  - Potential radius coordinates give very fine (~ 1 km) resolution in eyewall
  - Interior structure constrained by assumption of moist adiabatic lapse rates on angular momentum surfaces
  - Axisymmetric
  - Entropy defined in PBL and at single level in middle troposphere
  - Convection based on boundary layer quasi-equilibrium postulate
  - Surface fluxes by conventional aerodynamic formulae
  - Thermodynamic inputs: Environmental potential intensity and storm-induced SST anomalies

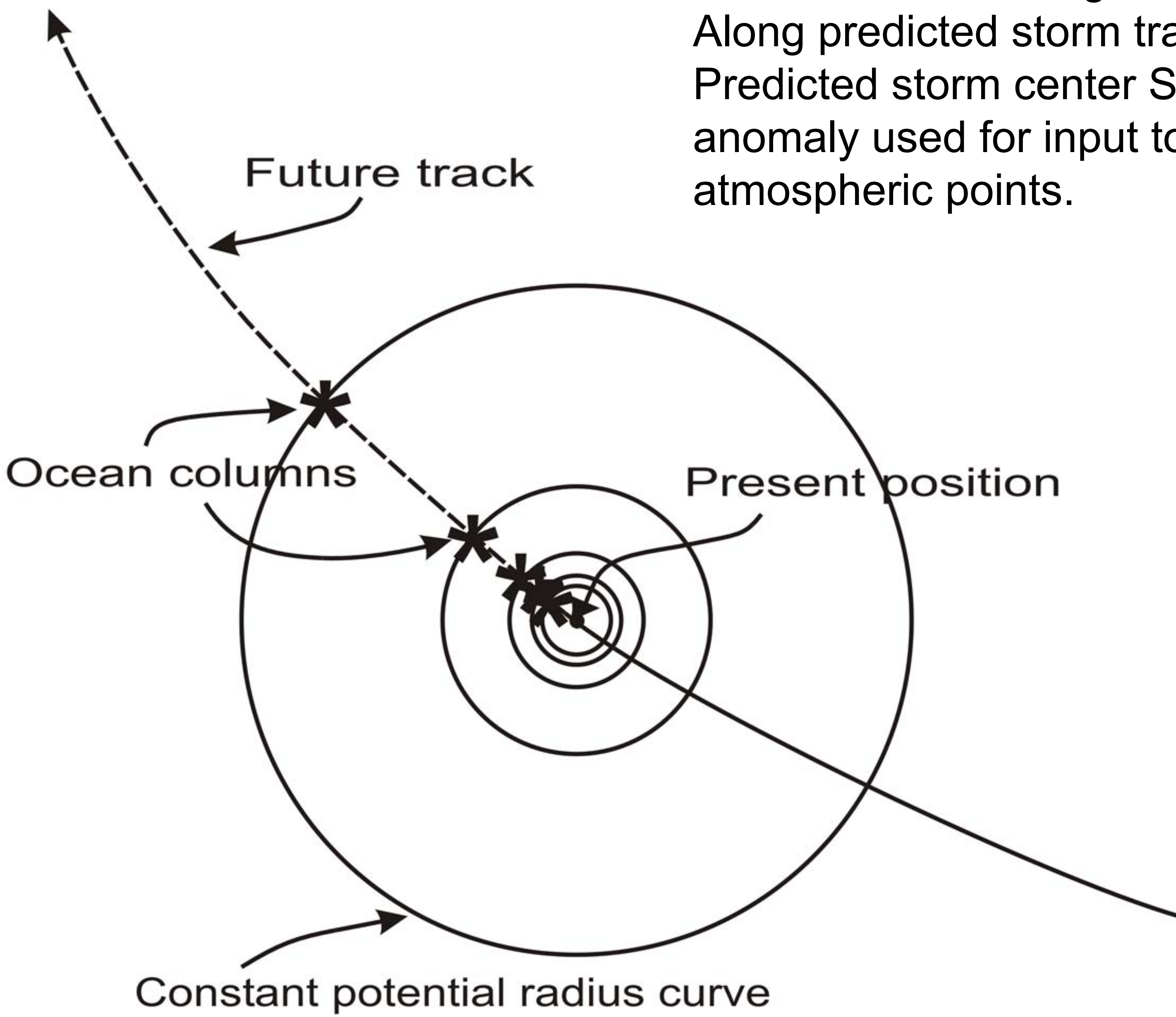
- **Ocean Component**

(Schade, L.R., 1997: A physical interpreatation of SST-feedback. Preprints of the 22nd Conf. on Hurr. Trop. Meteor., Amer. Meteor. Soc., Boston, pgs. 439-440.)

- **Mixing by bulk-Richardson number closure**
- **Mixed-layer current driven by hurricane model surface wind**



Ocean columns integrated only Along predicted storm track. Predicted storm center SST anomaly used for input to ALL atmospheric points.

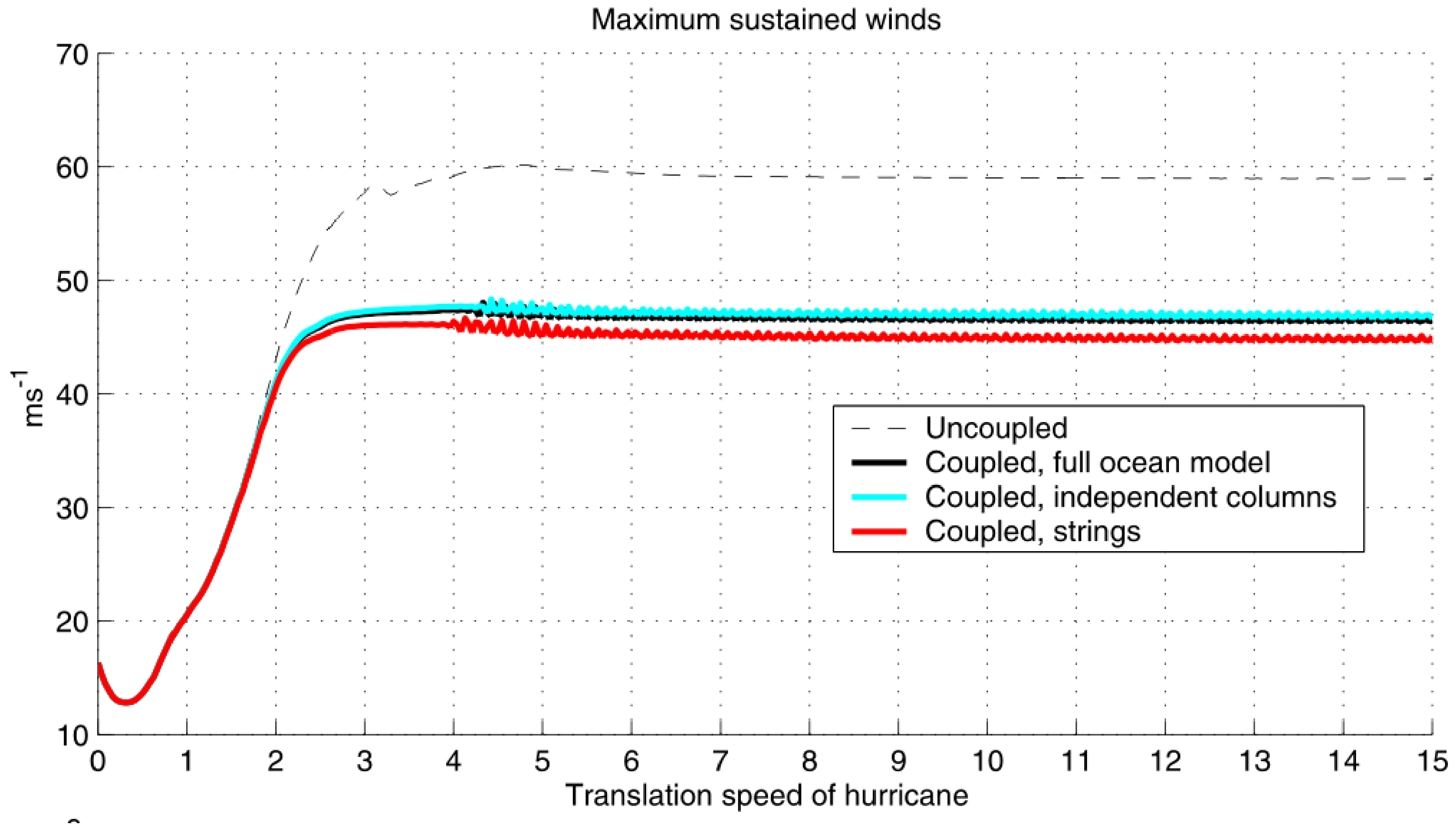


- **Data Inputs:**
  - **Weekly updated potential intensity (1 X 1 degree)**
  - **Official track forecast and storm history (NHC & JTWC)**
  - **Monthly climatological ocean mixed layer depths (1 X 1 degree)**
  - **Monthly climatological sub-mixed layer thermal stratification (1 X 1 degree)**
  - **Bathymetry (1/4 X 1/4 degree)**

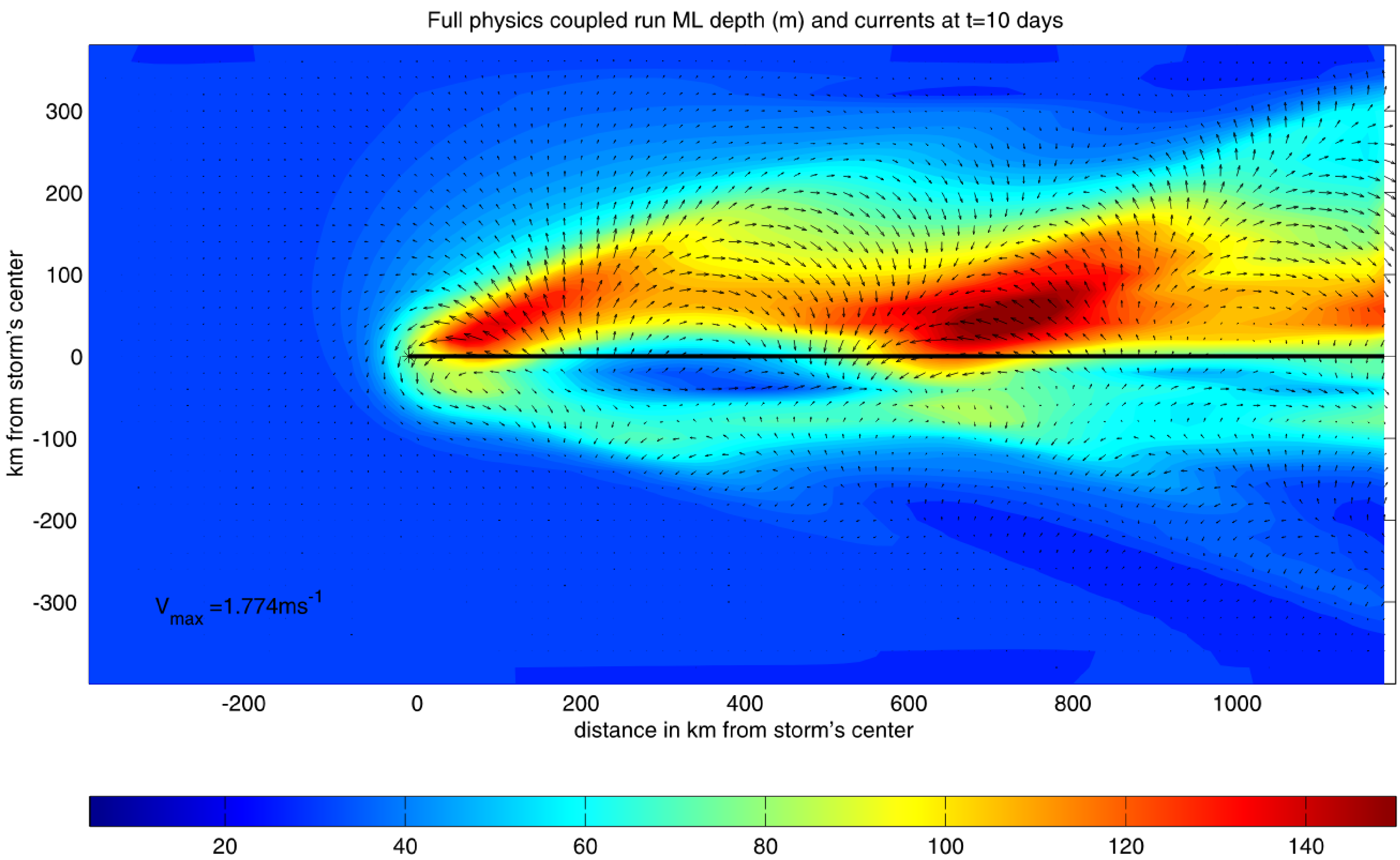
Initialization:

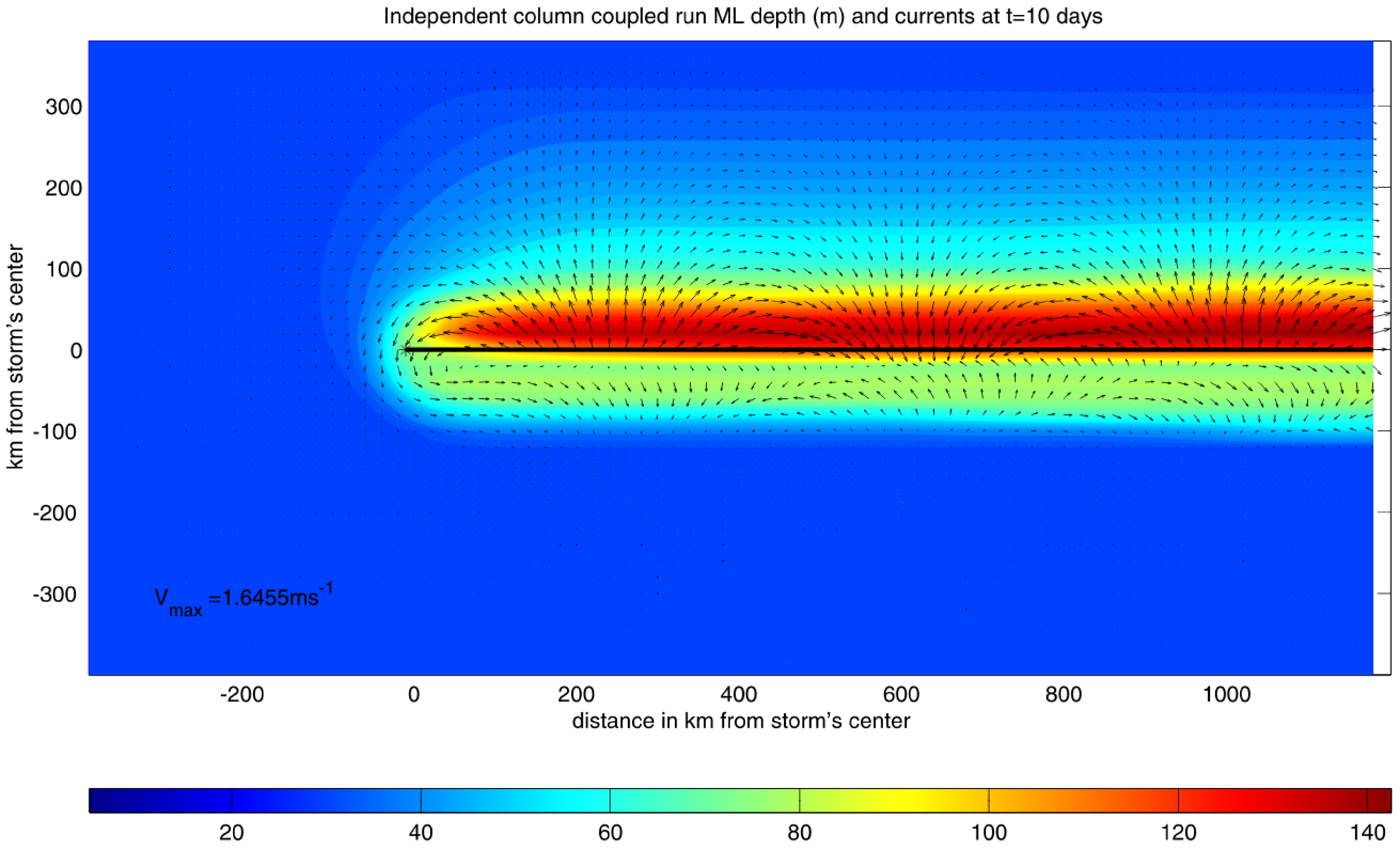
- **Synthetic, warm core vortex specified at beginning of track**
- **Radial eddy flux of entropy at middle levels adjusted so as to match storm intensity to date**
- **This matching procedure effectively initializes middle tropospheric humidity as well as balanced flow**

Comparison with same atmospheric model coupled to 3-D ocean model; idealized runs:
Full model (black), string model (red)



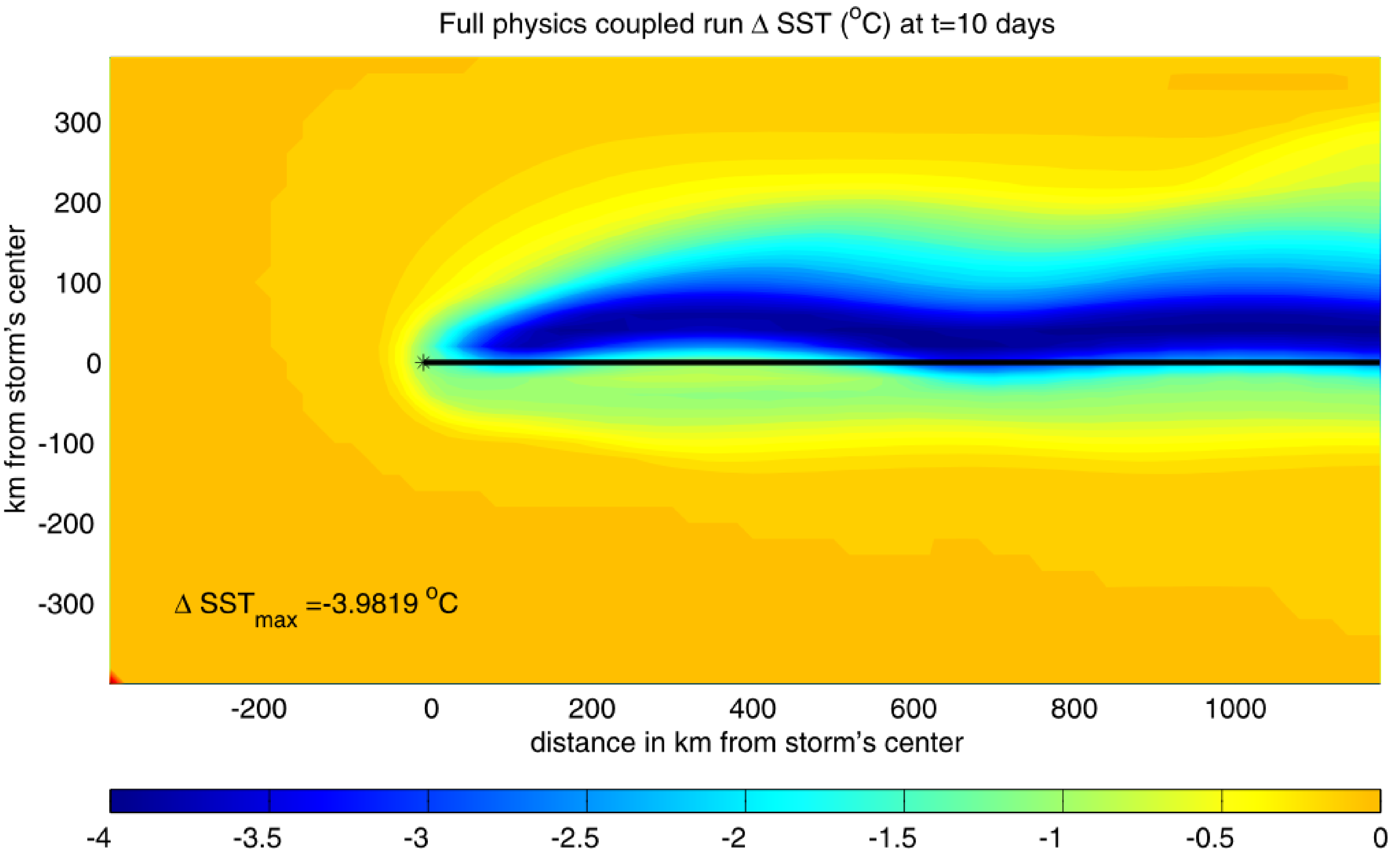
Mixed layer depth and currents



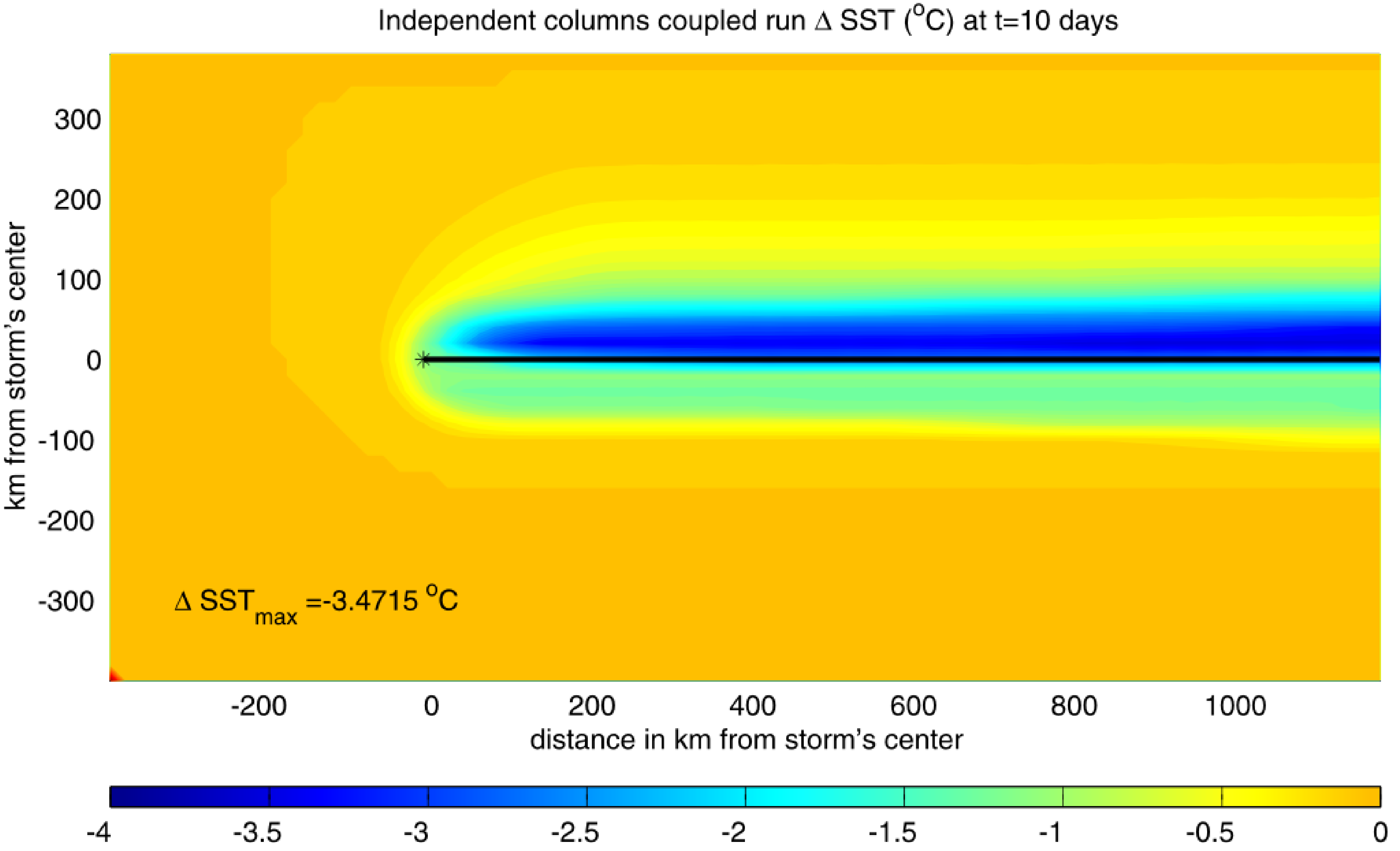


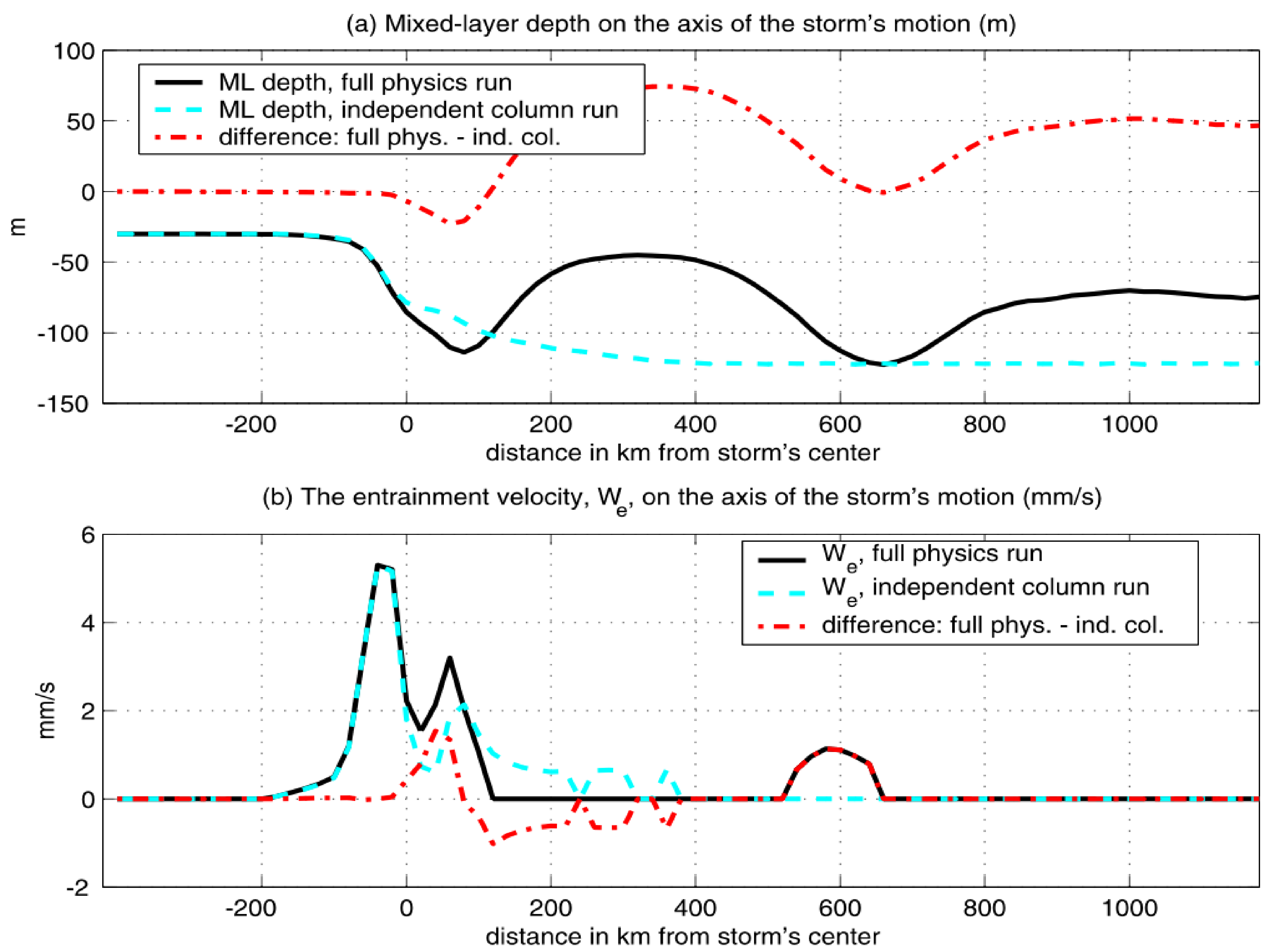
Independent column coupled run ML depth (m) and currents at t=10 days
km from storm's center
300
200
100
0
-100
-200
-300
V_{max} =1.6455ms^{-1}
-200
0
200
400
600
800
1000
distance in km from storm's center
20
40
60
80
100
120
140

SST Change



Full physics coupled run Δ SST (°C) at t=10 days
300
200
100
0
-100
-200
-300
km from storm's center
Δ SST max =-3.9819 °C
-200
0
200
400
600
800
1000
distance in km from storm's center
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0


Independent columns coupled run Δ SST (°C) at t=10 days
300
200
100
0
-100
-200
-300
km from storm's center
Δ SST$_{max}$ =-3.4715 °C
-200
0
200
400
600
800
1000
distance in km from storm's center
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0



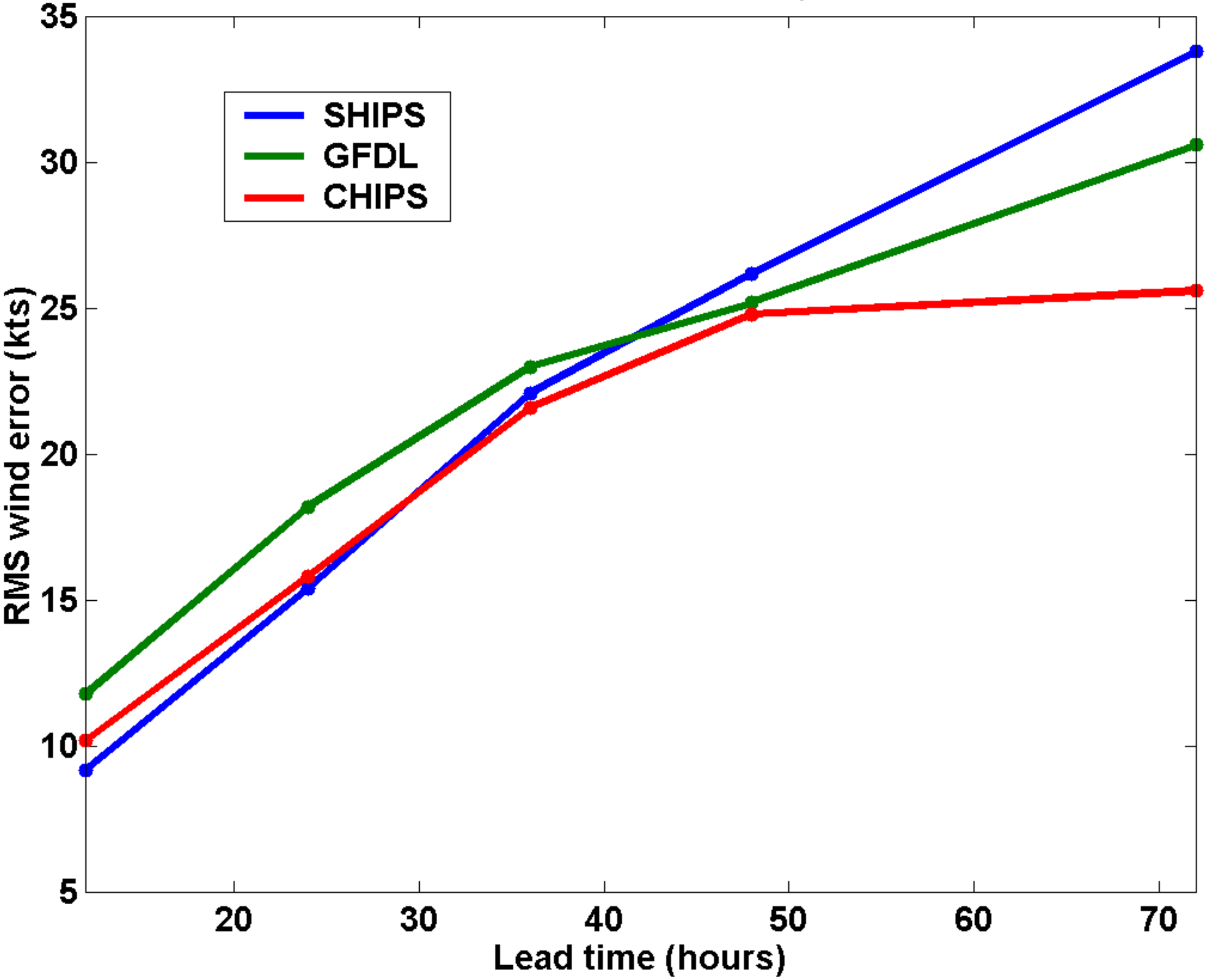
(a) Mixed-layer depth on the axis of the storm's motion (m)
ML depth, full physics run
ML depth, independent column run
difference: full phys. - ind. col.
m
100
50
0
-50
-100
-150
-200
0
200
400
600
800
1000
distance in km from storm's center
(b) The entrainment velocity, W_e, on the axis of the storm's motion (mm/s)
W_e, full physics run
W_e, independent column run
difference: full phys. - ind. col.
mm/s
6
4
2
0
-2
-200
0
200
400
600
800
1000
distance in km from storm's center

Landfall Algorithm:

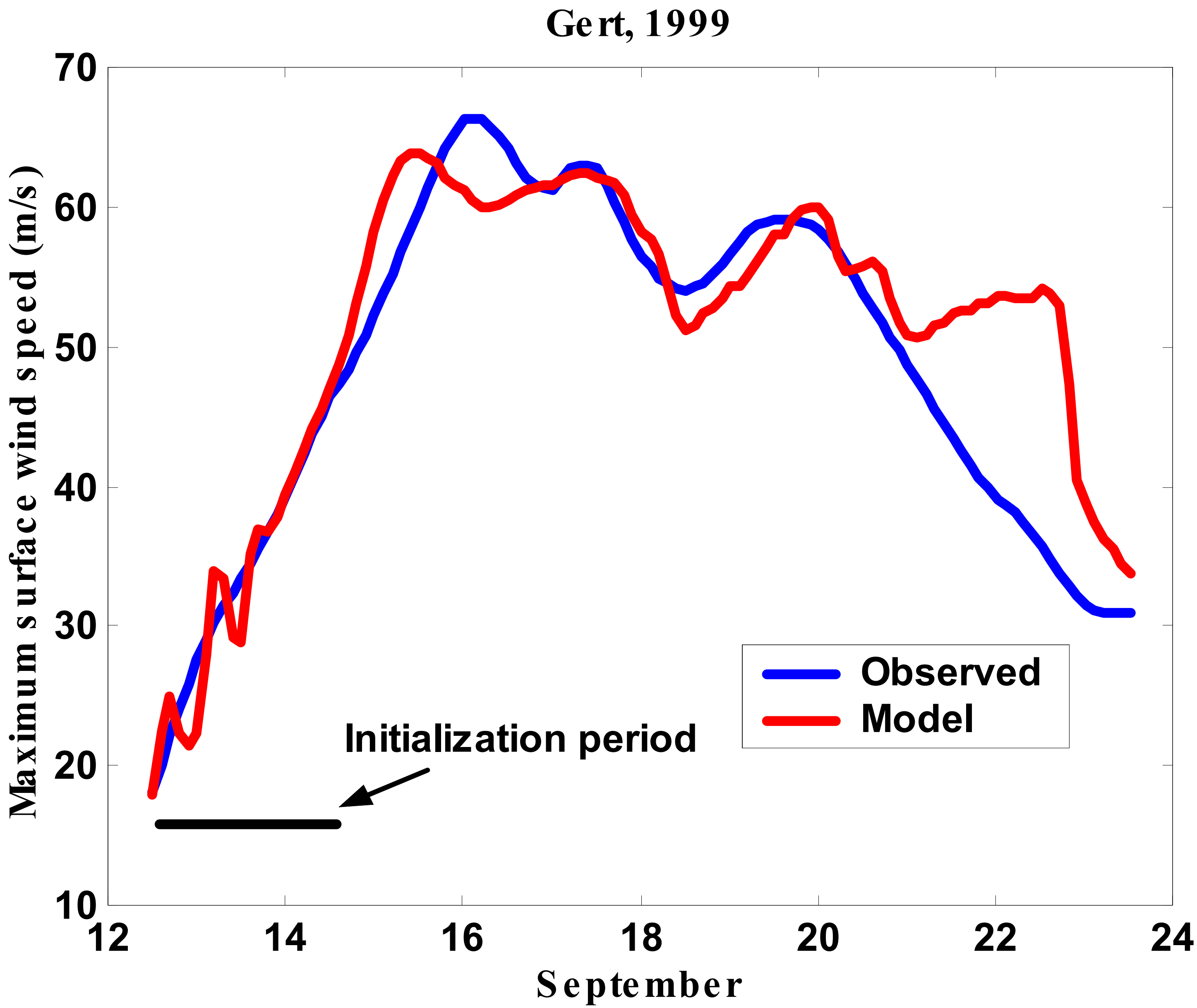
- Enthalpy exchange coefficient decreases linearly with land elevation, reaching zero when h = 40 *m*
- This accounts in a crude way for heat fluxes from low-lying, swampy or marshy terrain

Overall Forecast Performance:

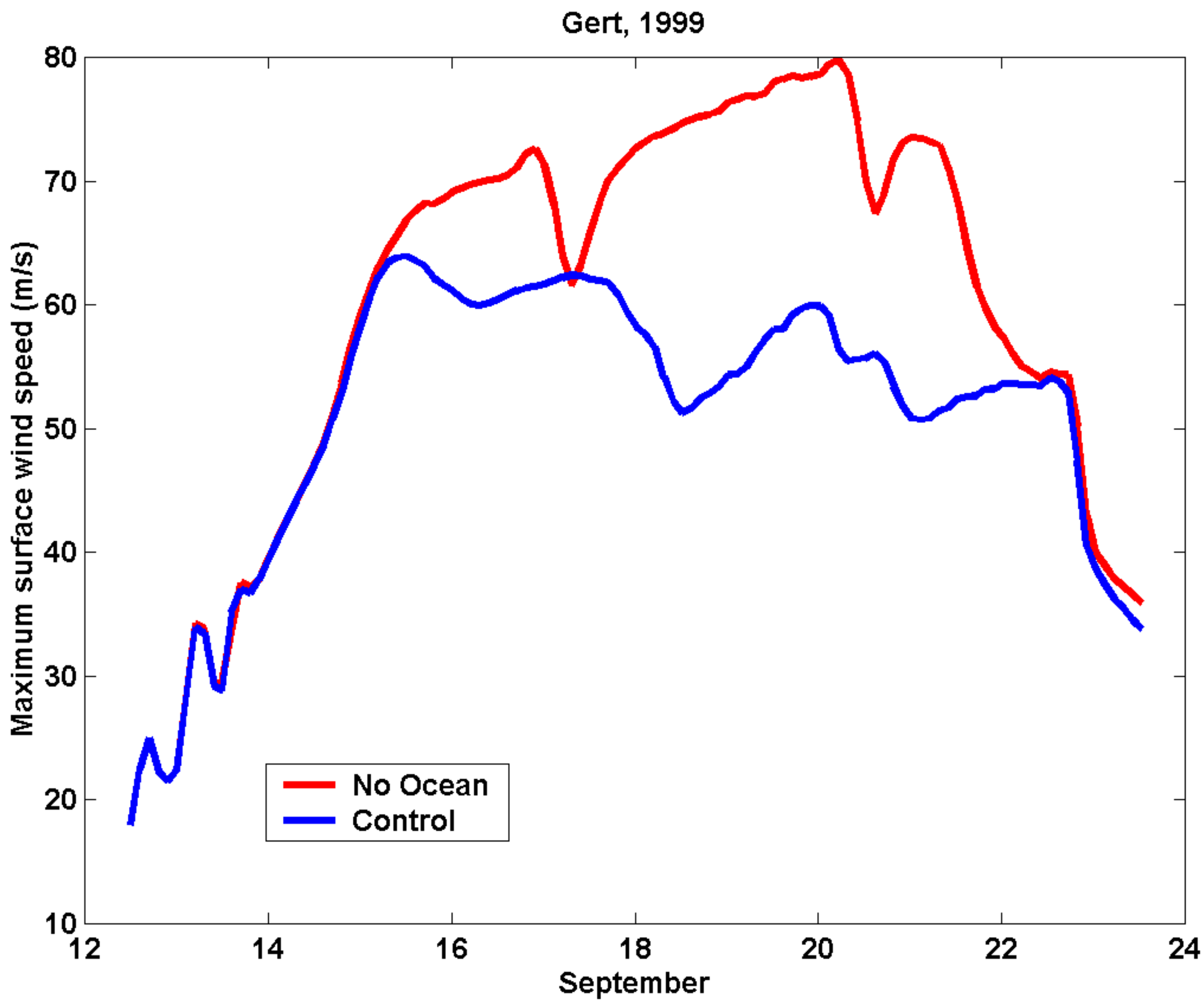
2002 Atlantic Intensity Errors



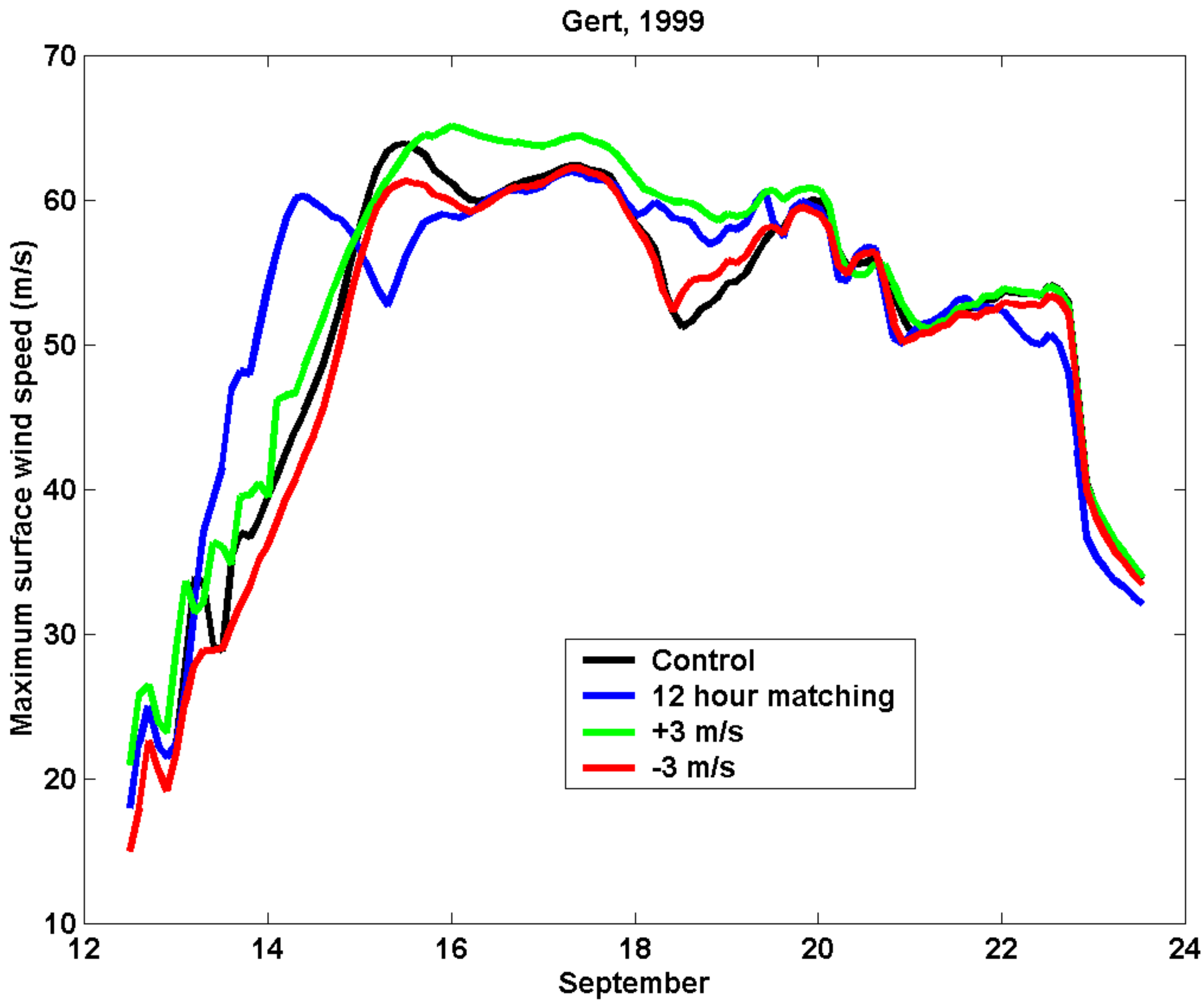
Hurricane Gert occurred in a low-shear environment and moved over an ocean close to its climatological mean state.



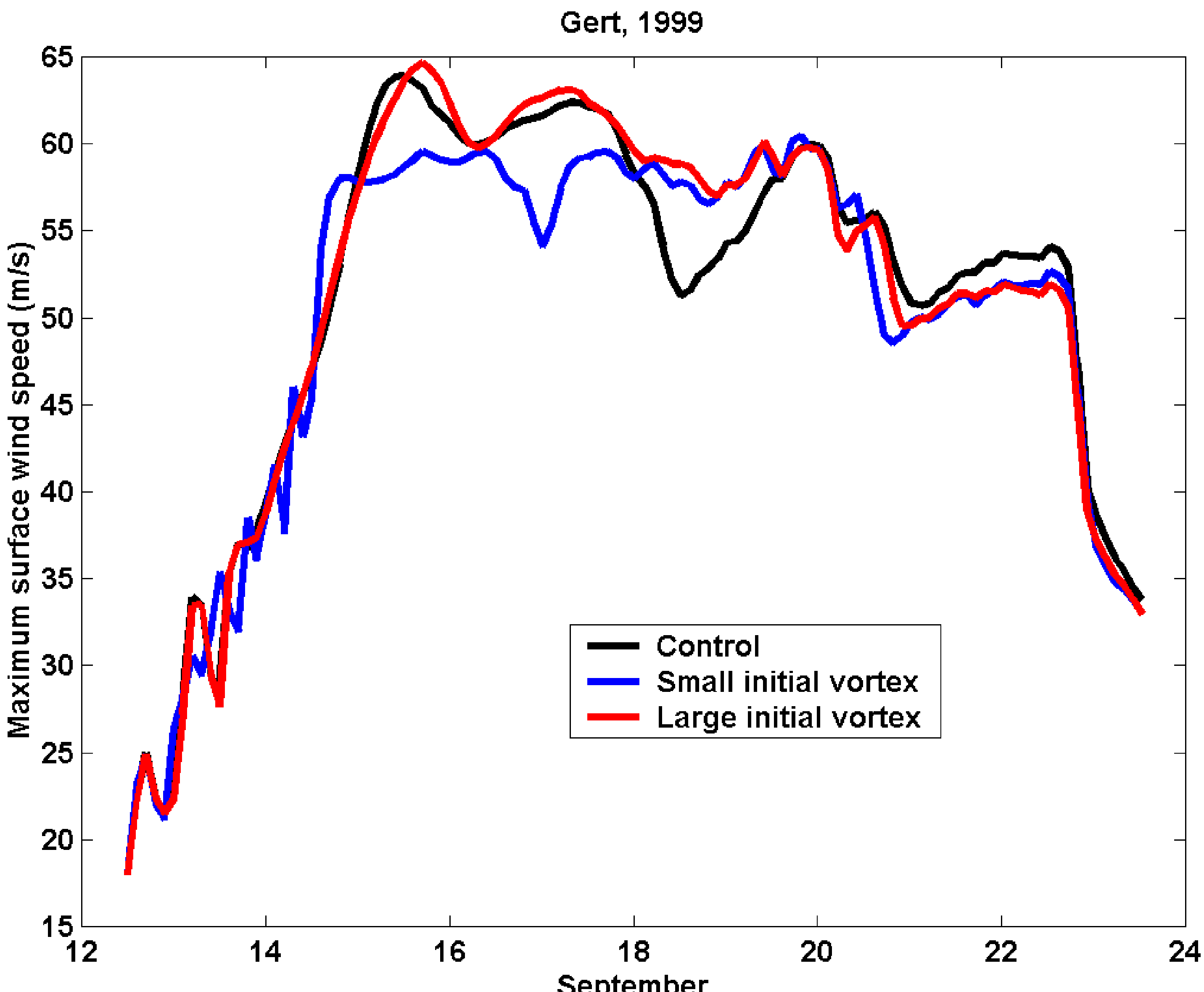
Same simulation, but with fixed SST:



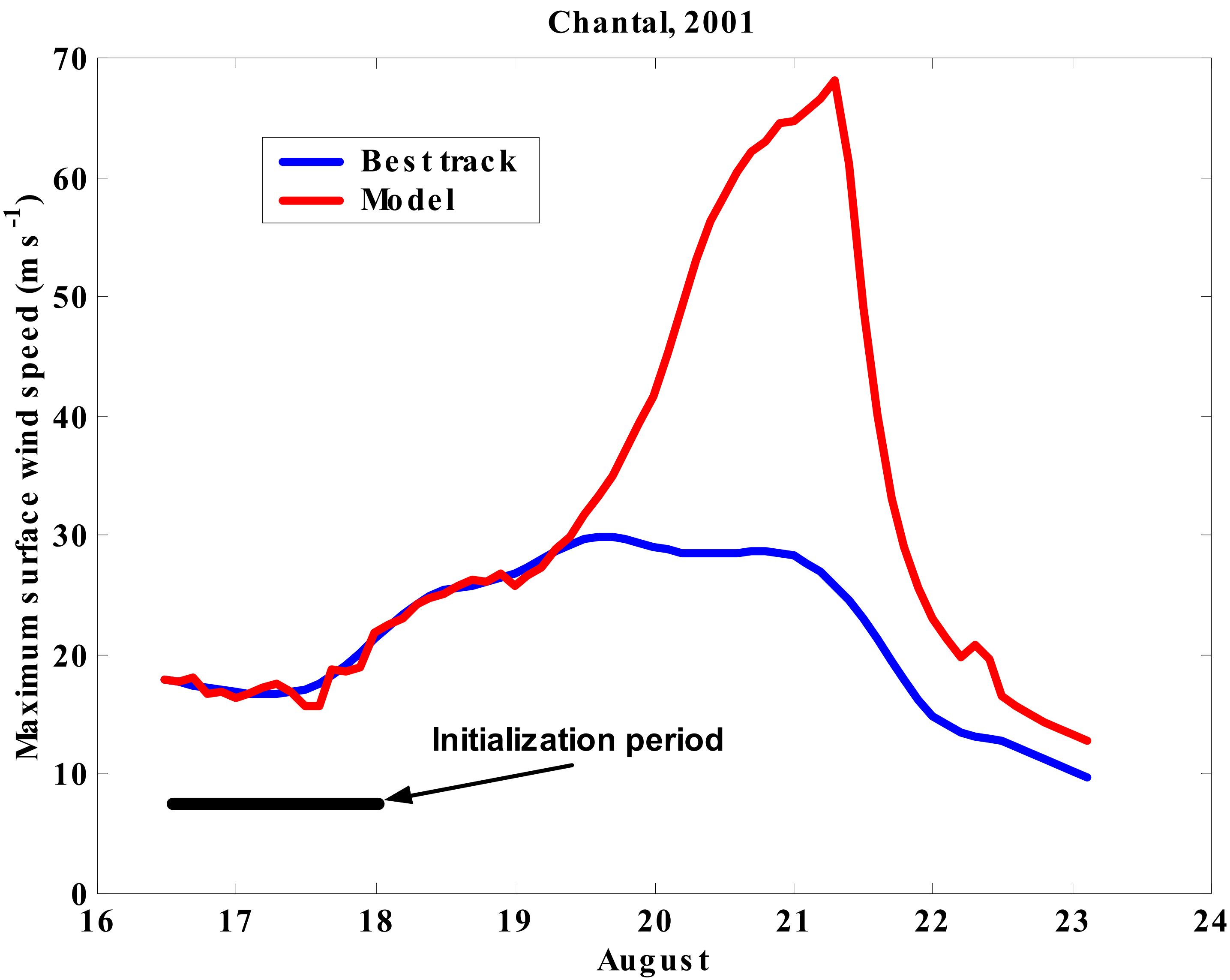
Sensitivity to initial intensity error and length of matching period:



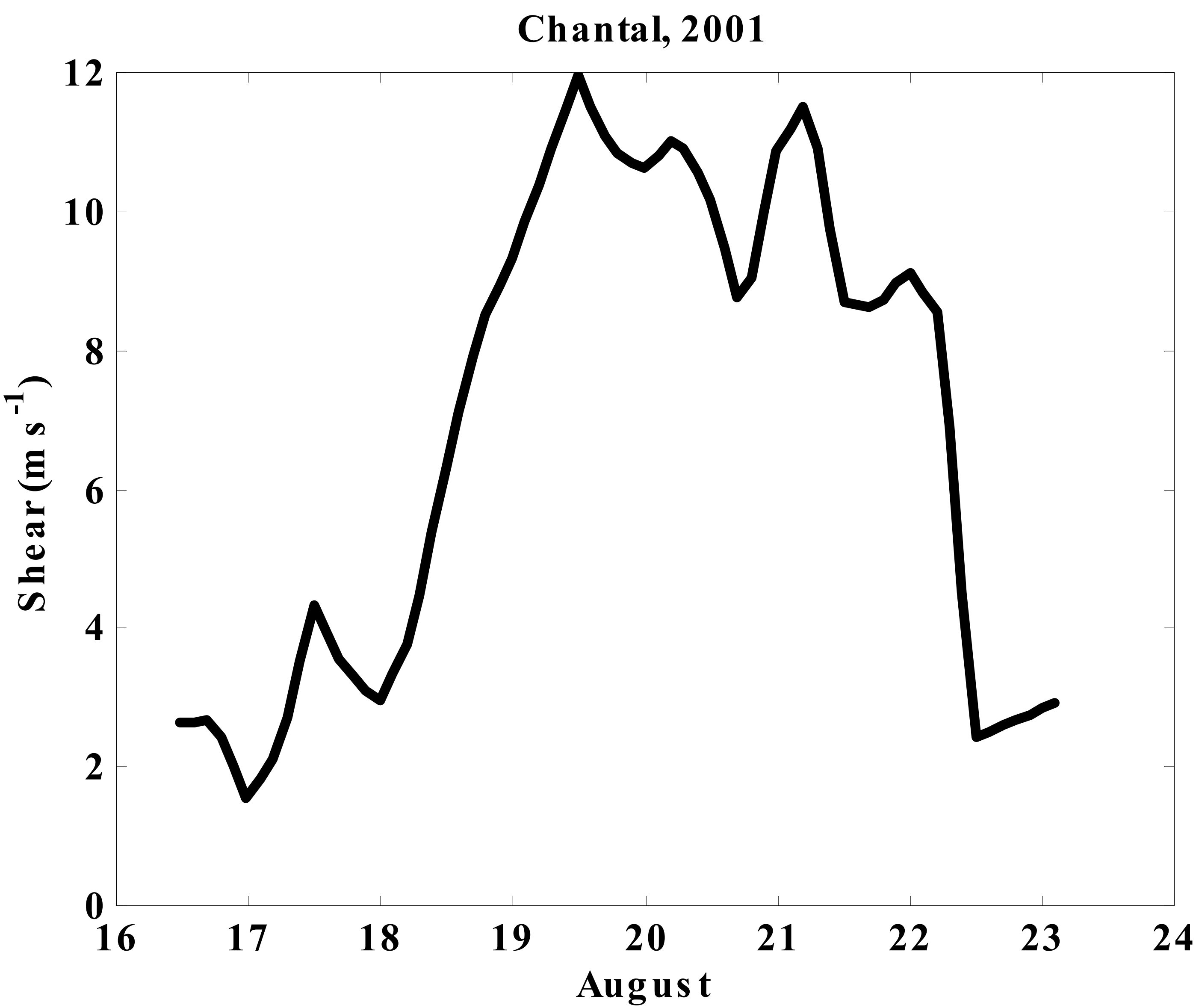
Sensitivity to size of starting vortex



Model performs poorly when substantial shear is present, as in Chantal, 2001:



850 – 200 hPa environmental shear:

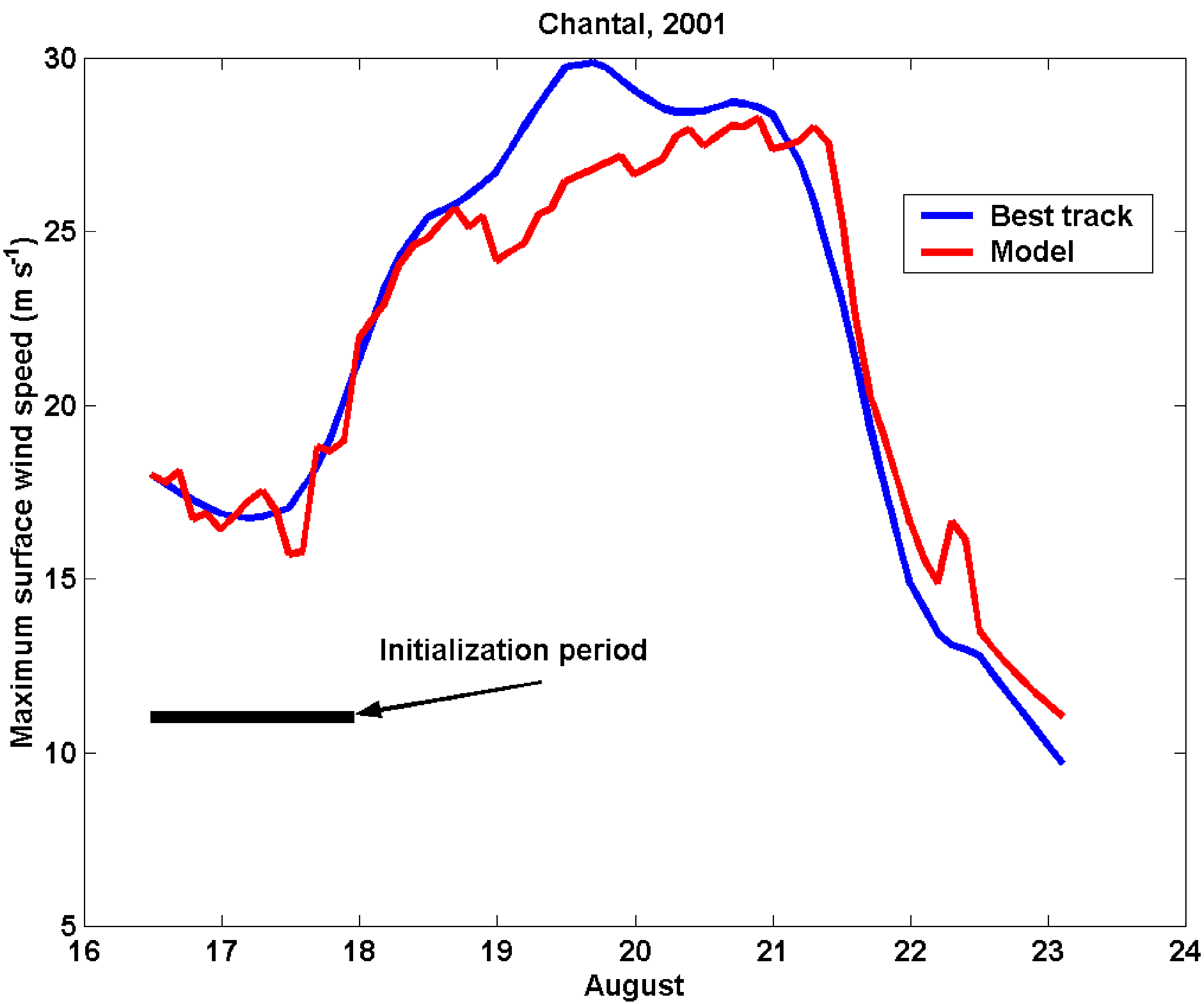


Add “ventilation” term to model equation governing middle level theta_e. Coefficient determined by matching model to long record of observations:

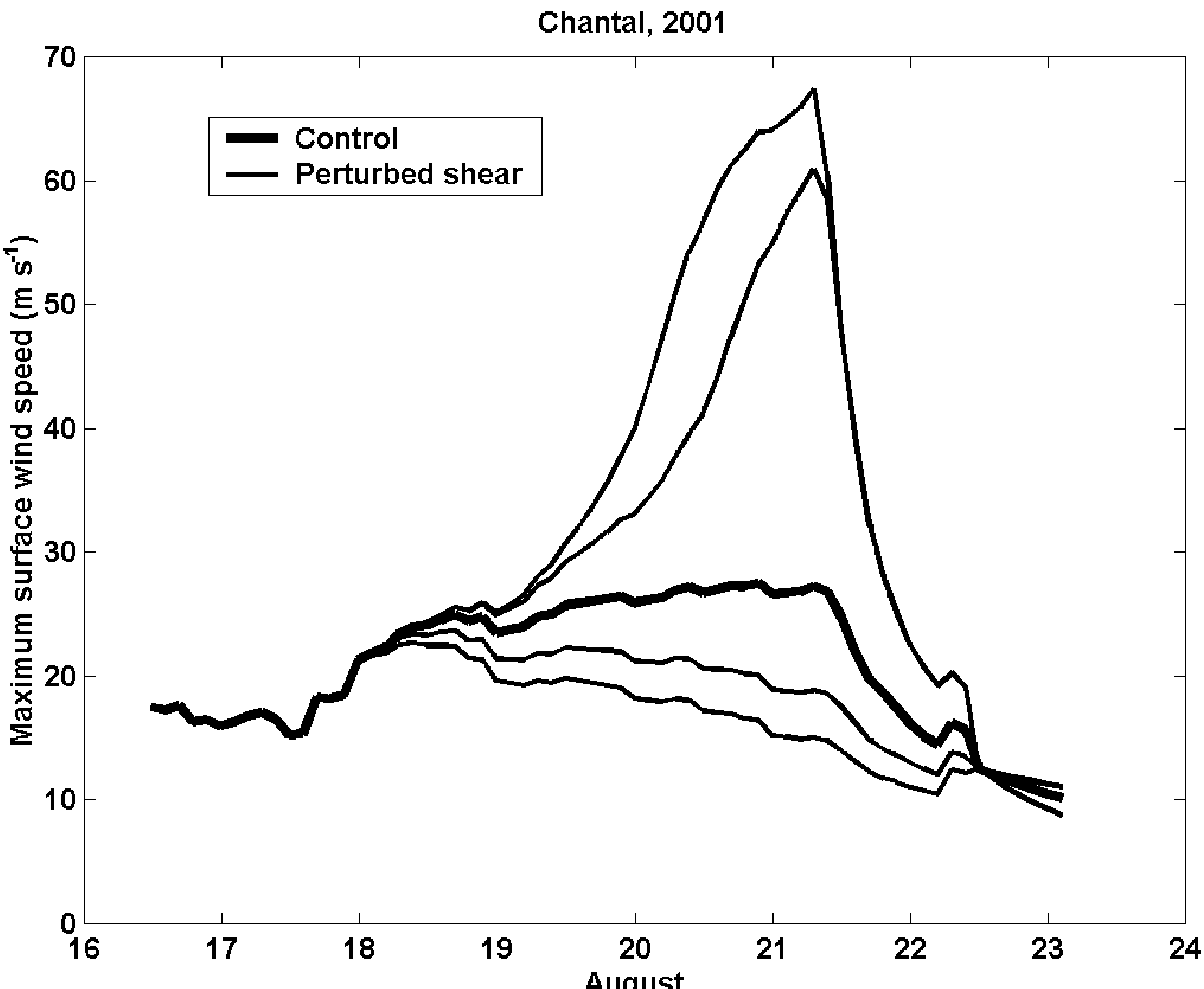
$$\frac{\partial \theta_e}{\partial t} = \ldots - \mathbf{V}\left(\theta_e - \theta_{e0}\right)$$

$$\mathbf{V} = V_{max}^2 \; V_{shear}^2$$

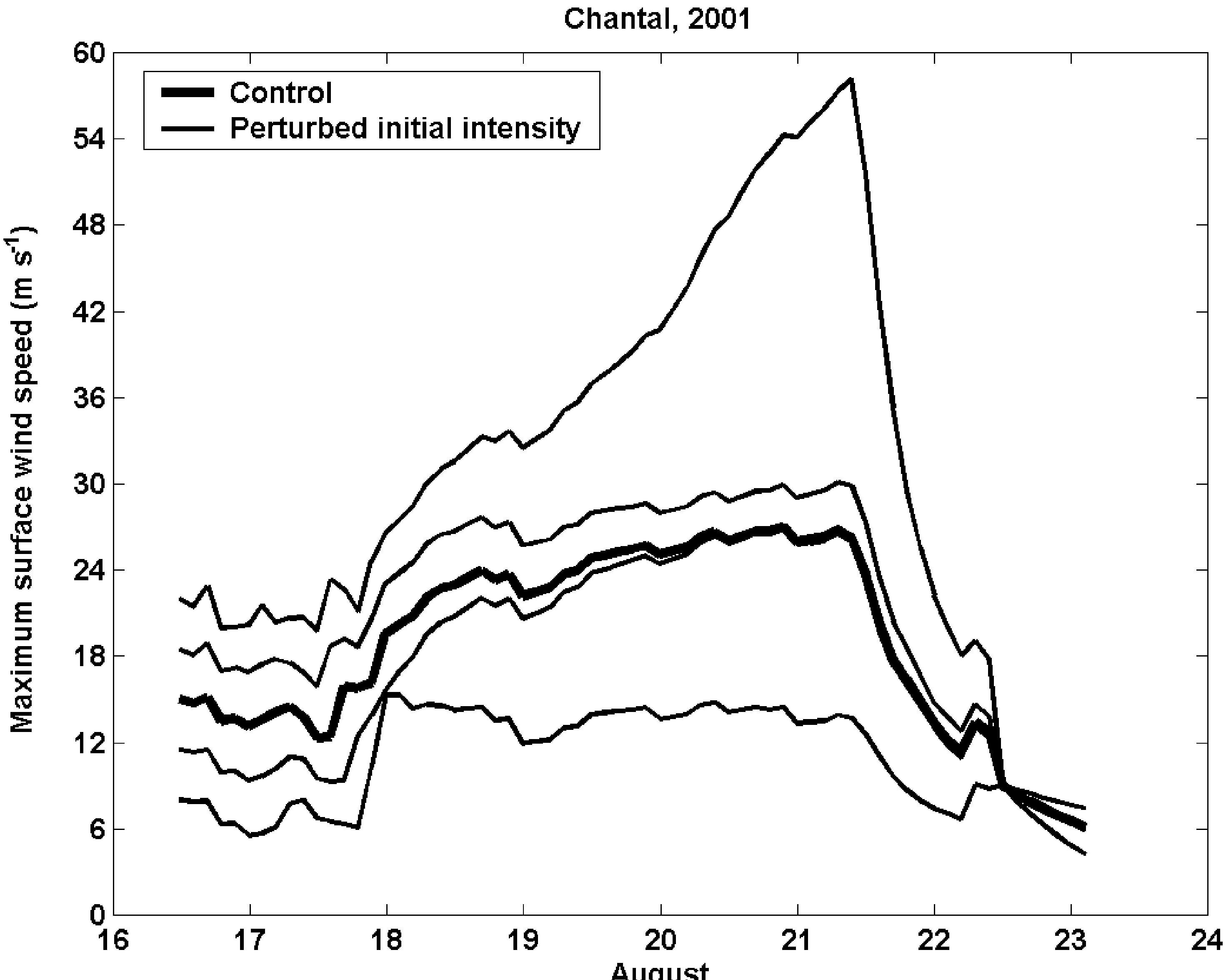
Result:


Chantal, 2001
Maximum surface wind speed (m s-1)
30
25
20
15
10
5
16
17
18
19
20
21
22
23
24
August
Best track
Model
Initialization period

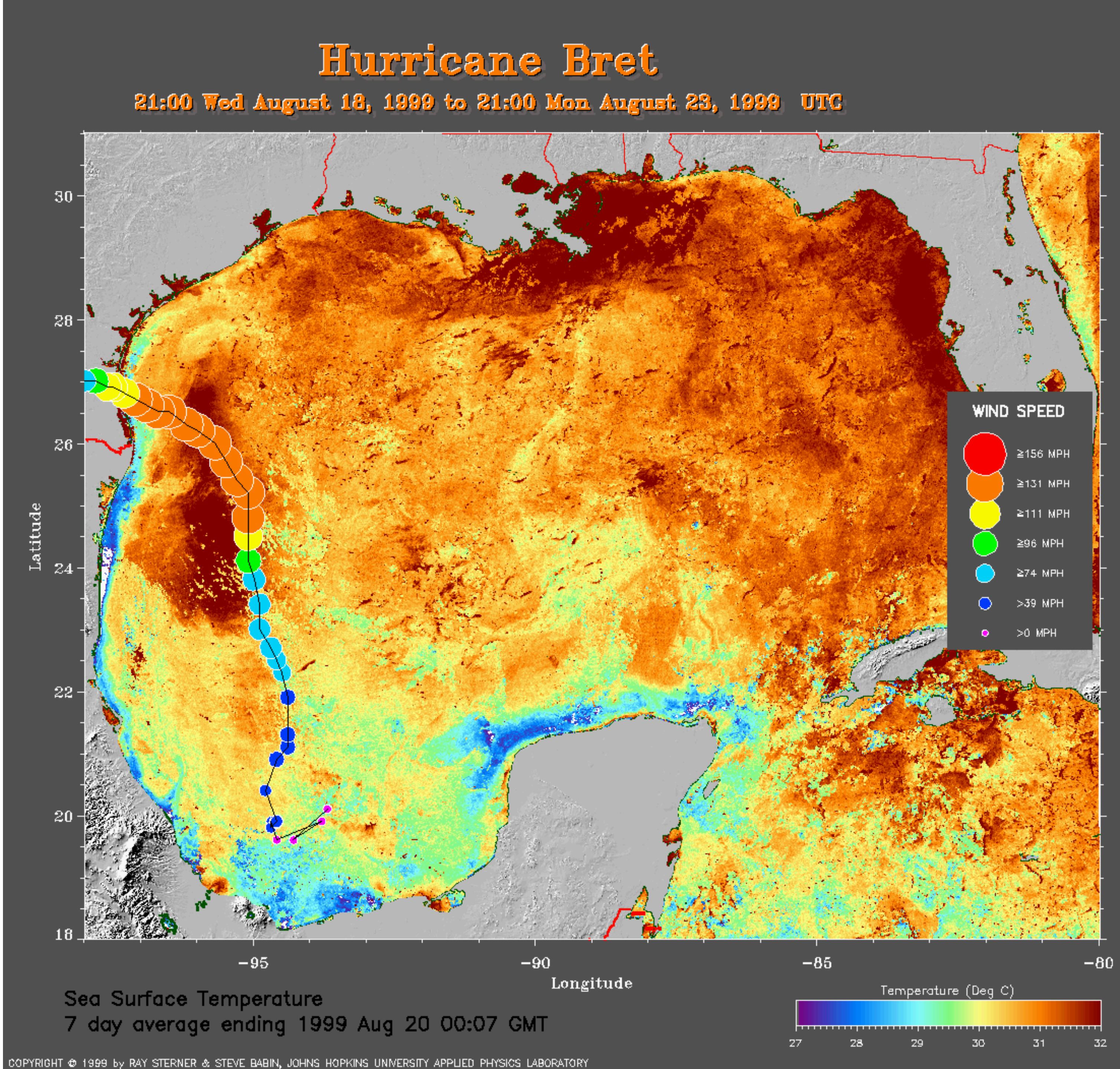
But model sensitive to shear: This shows the results of varying Shear magnitude by +/- 5 kts and +/- 10 kts:



Presence of shear also makes model sensitive to initial conditions. Here the initial intensity is varied by +/- 3 m/s and +/- 6 m/s:



Some storms are influenced by upper ocean anomalies from monthly climatology. An example is that of Hurricane Bret of 1999, which passed over a warm eddy in the far western Gulf, as seen in this satellite image:



Hurricane Bret
21:00 Wed August 18, 1999 to 21:00 Mon August 23, 1999 UTC
WIND SPEED
≥156 MPH
≥131 MPH
≥111 MPH
≥96 MPH
≥74 MPH
>39 MPH
>0 MPH
Latitude
30
28
26
24
22
20
18
-95
-90
-85
-80
Longitude
Sea Surface Temperature
7 day average ending 1999 Aug 20 00:07 GMT
Temperature (Deg C)
27
28
29
30
31
32
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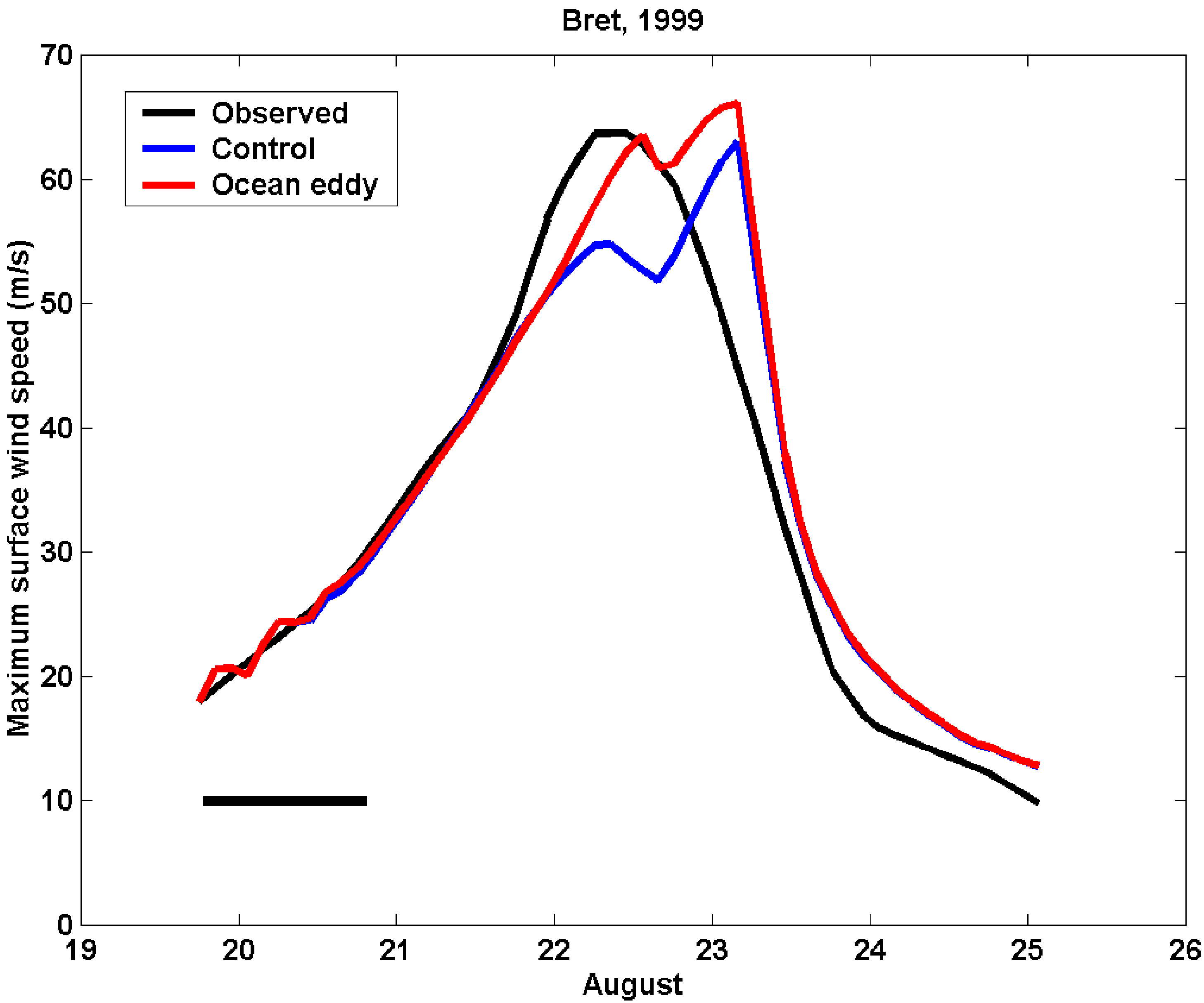
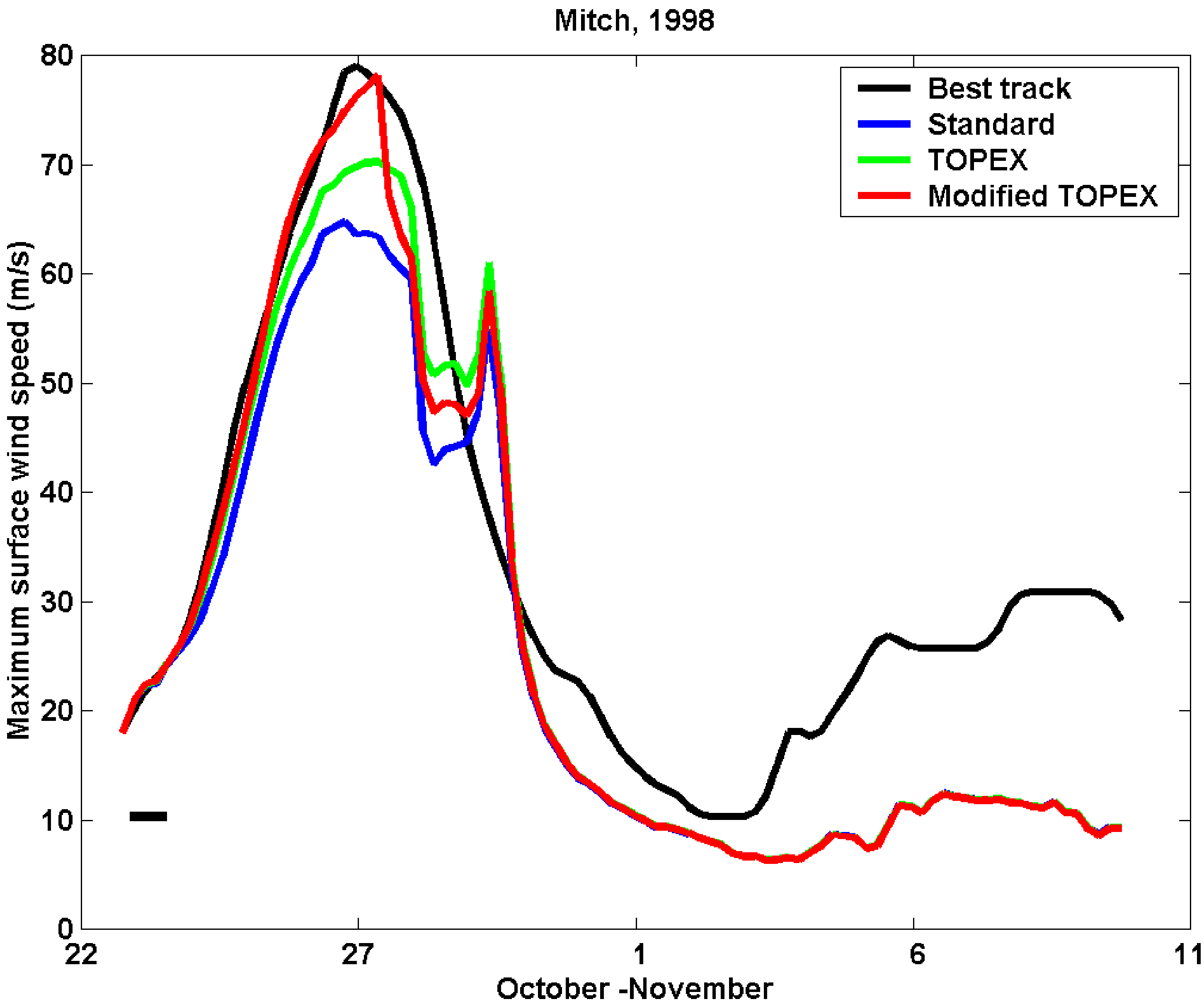
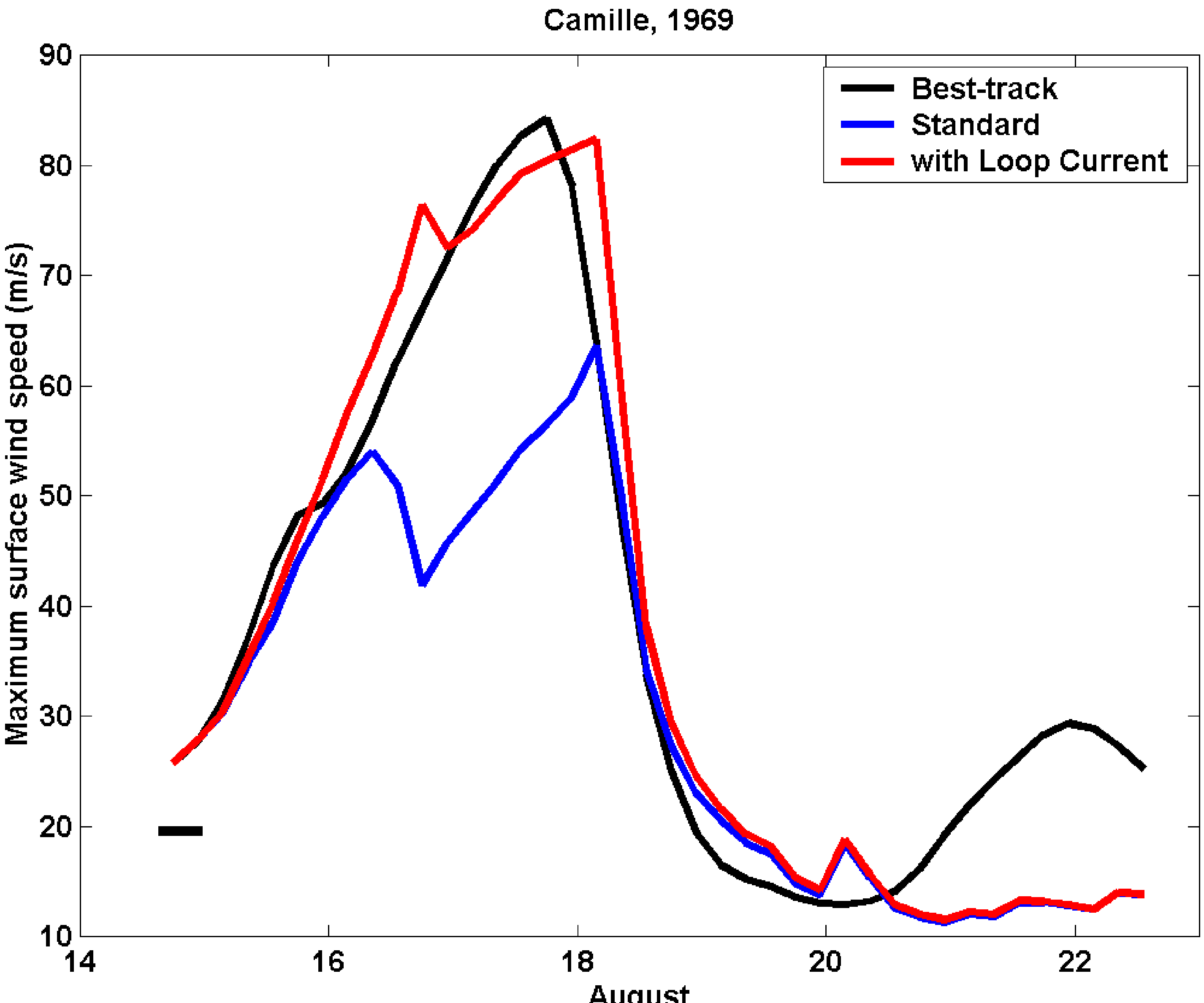
This shows model hindcasts with and without the ocean eddy, as estimated from sea surface altimetry data:



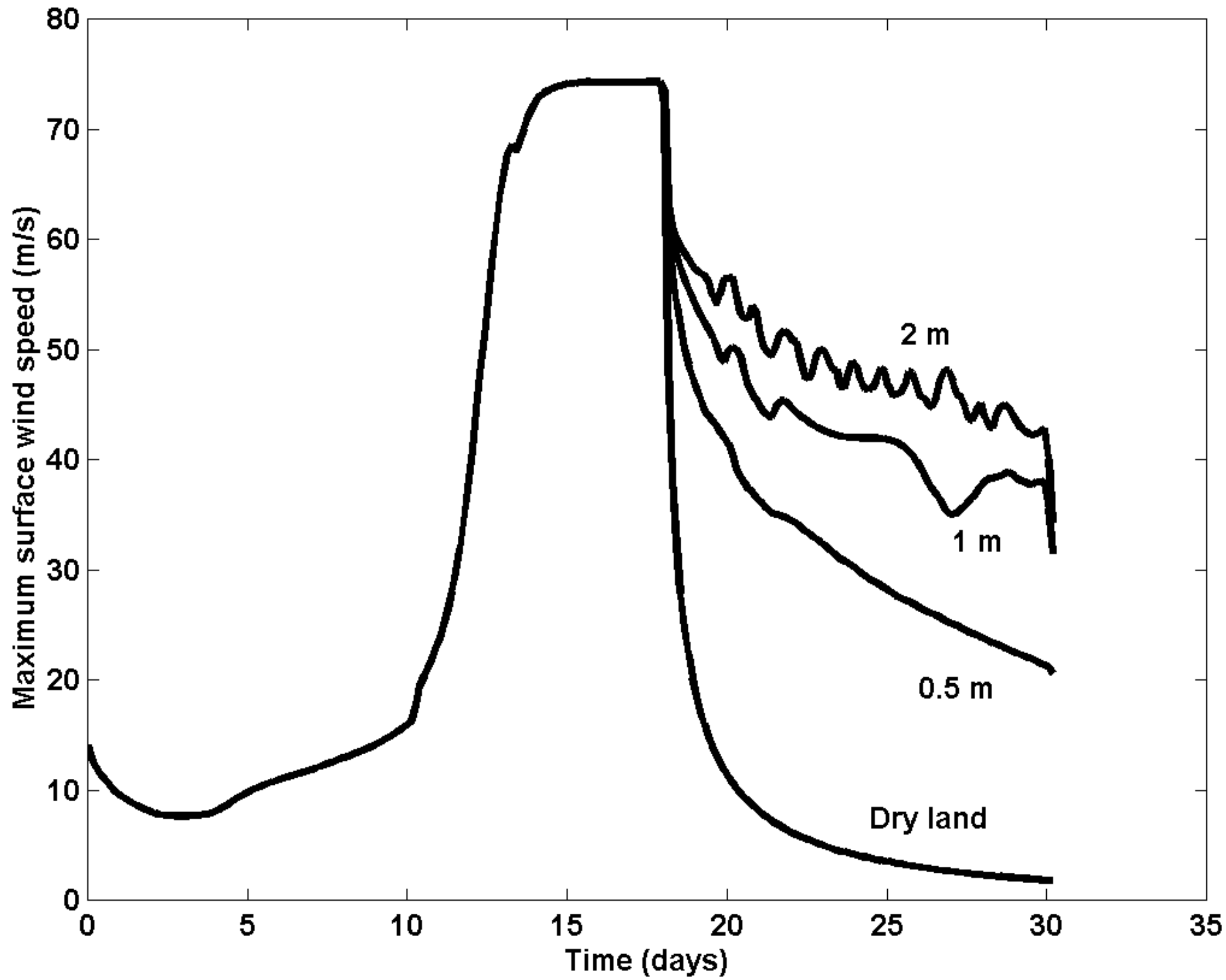
Mitch was also influenced by an ocean eddy. The red curve used TOPEX altimetry modified by de-aliasing the estimated peak amplitude:



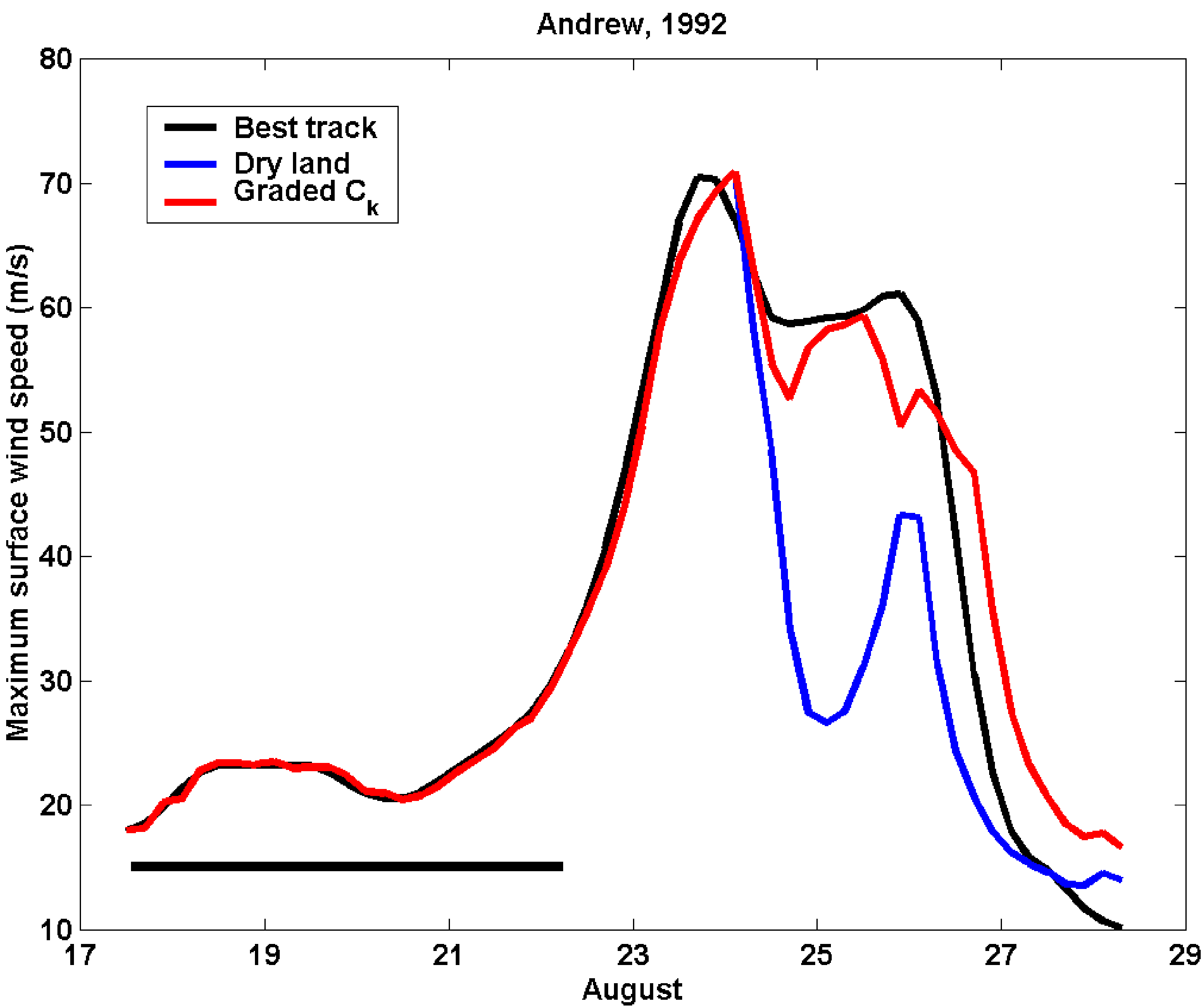
A good simulation of Camille can only be obtained by assuming that it traveled right up the axis of the Loop Current:



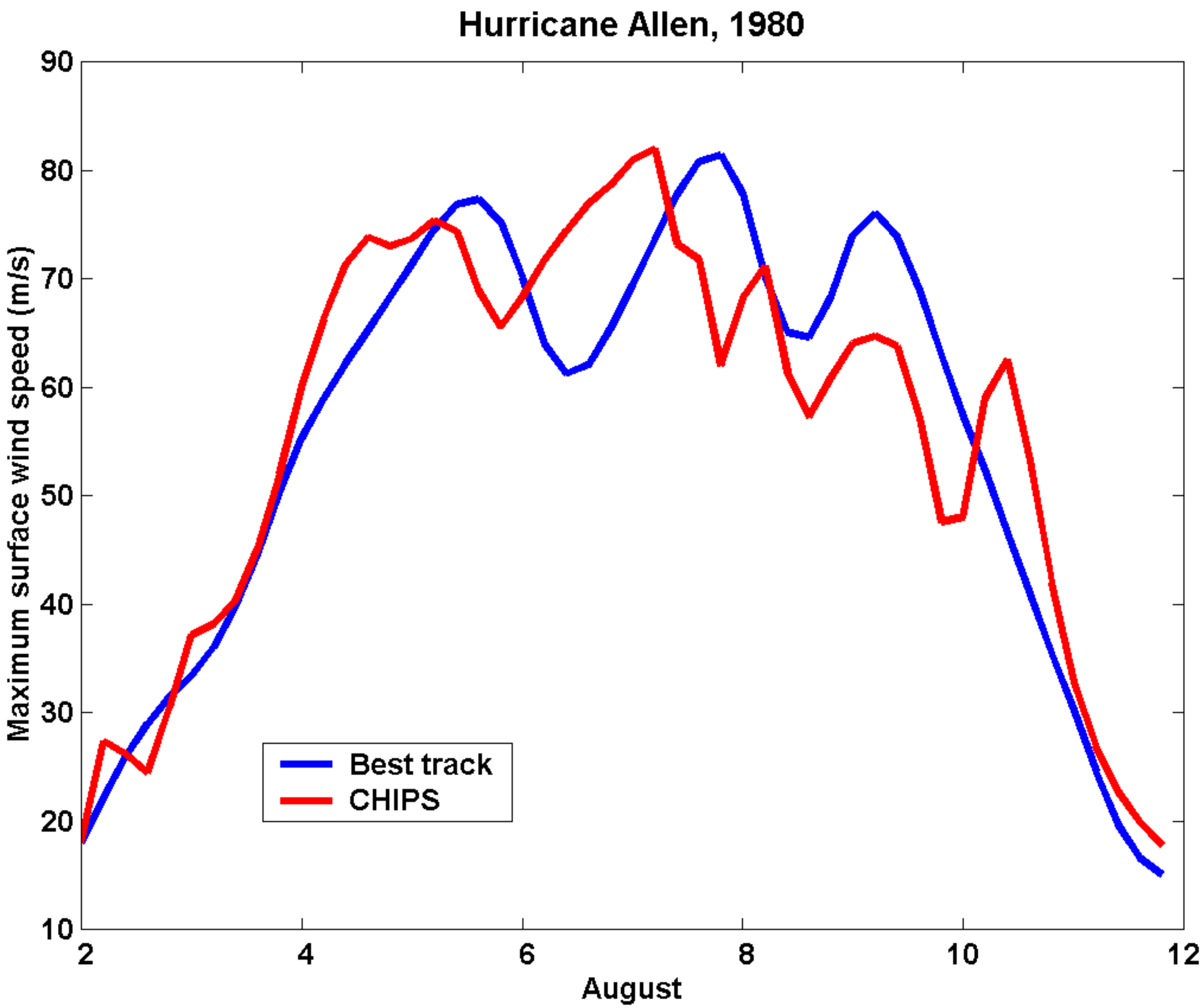
Effect of standing water can be seen in these idealized simulations of storm landfall over dry land and over swamps with indicated depths of standing water:



Hurricane Andrew, with and without the effect of the Everglades, as represented by a elevation-dependent heat exchange coefficient:



Some storms may have large internal fluctuations (e.g. Allen). CHIPS may predict the existence of these, but not their phase:



Summary

- Tropical cyclone intensity appears to be controlled by storm history and environment
- Internal fluctuations usually of secondary importance

Environmental factors critical to intensity prediction:

- Potential intensity along track
- Upper ocean thermal structure
- Environmental wind shear
- Bathymetry
- Land surface characteristics

Major sources of uncertainty:

- Uncertain forecasts of vertical shear
- Shear reduces predictability
- Little real-time knowledge of upper ocean thermal structure