PARAMETER SENSITIVITY FOR IDEALIZED COUPLED HWRF SIMULATIONS IN A SHEARED ENVIRONMENT

Presented for the HFIP Annual Review, 26 June 2013

by

Altug Aksoy[1,2] (PI)

Collaborators:

Jun Zhang[1,2], Brad Klotz[1,2] (Co-Is)

and

Eric Uhlhorn[2], Joe Cione[2], Gopal[2], George Halliwell[3], Vijay Tallapragada[4], J.-W. Bao[5]

1. Cooperative Institute for Marine and Atmospheric Studies, University of Miami
2. Hurricane Research Division, NOAA/AOML
3. Physical Oceanography Division, NOAA/AOML
4. Environmental Modeling Center, NOAA/NCEP
5. Physical Sciences Division, NOAA/ESRL

OUTLINE

- Goals
- Idealized HWRF Configuration
- Observation-Based Initial Vortex
- Control Run
- Sensitivity to Type of Initial Vortex
- Sensitivity to Parameters
- Future Plans
- Summary

GOALS

Investigate HWRF sensitivity to PBL and SL parameterizations in a controlled environment

Gain perspective on how important PBL/SL parameterizations are relative to variations in the environment or initial vortex structure

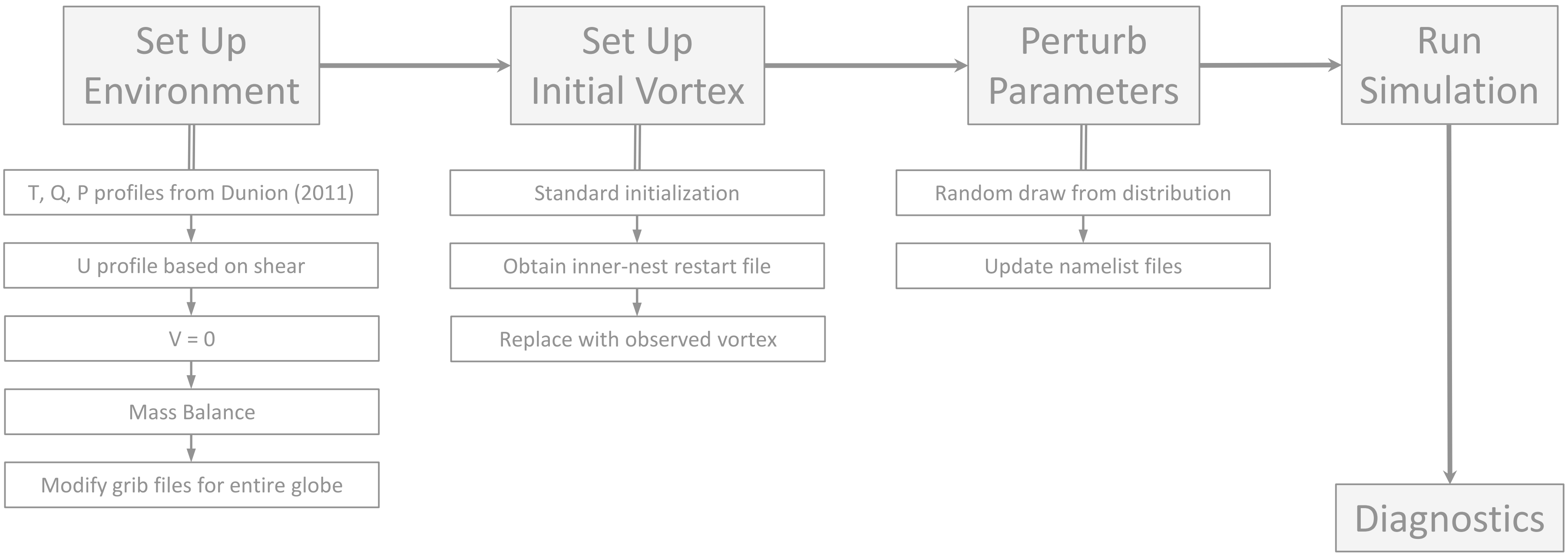
Through calibration, construct HWRF ensembles that include perturbations of similar magnitude from initial and boundary conditions as well as PBL/SL parameterizations

Investigate impact of added PBL/SL perturbations on ensemble-based data assimilation

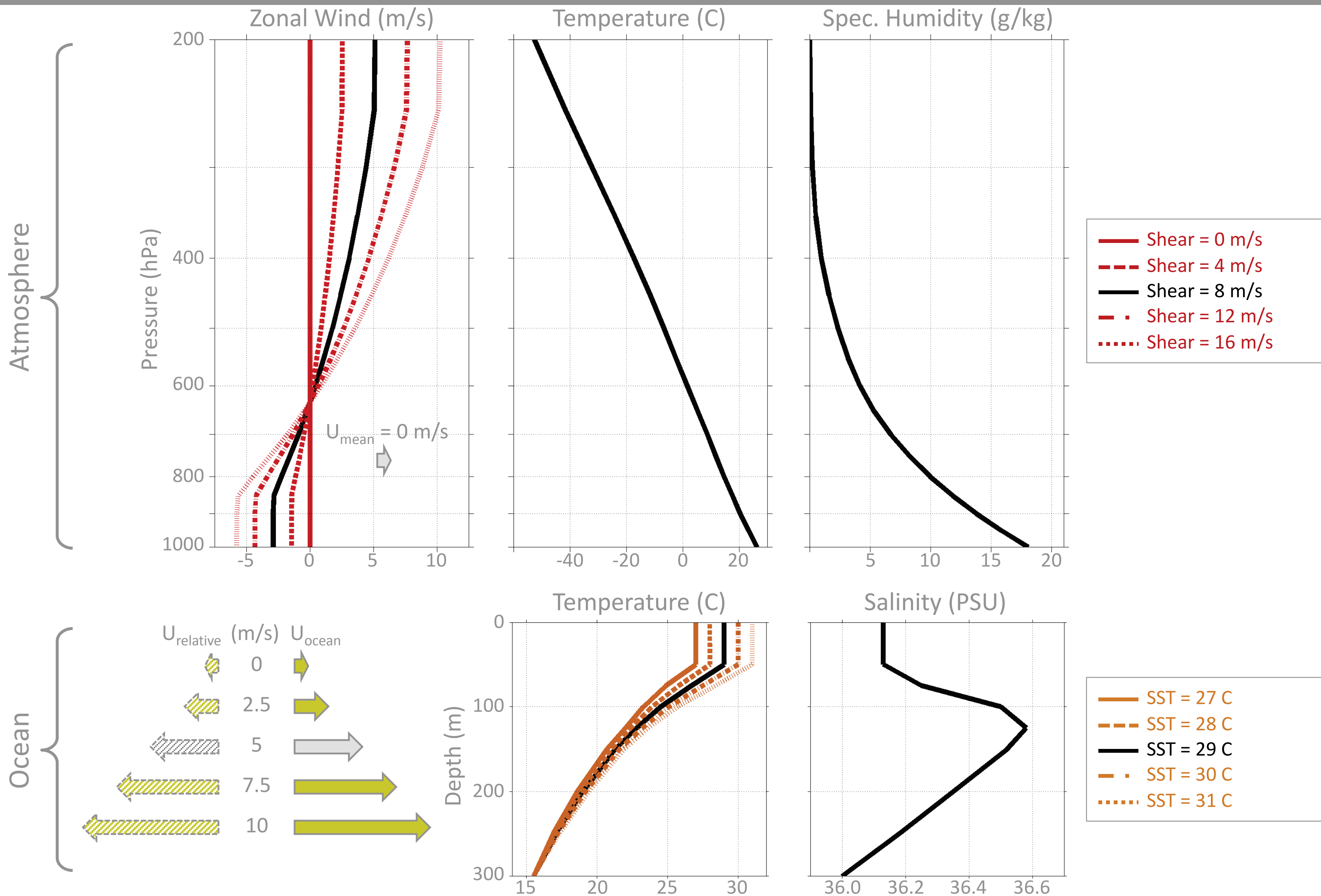
IDEALIZED HWRF CONFIGURATION

- HWRF configuration:
  - 27/9/3 km based on Gopalakrishnan et al. (2011, *MWR*), 10x10 degree inner nest
  - Repository version of the idealized HWRF code
  - 2012 operational HWRF physics settings
- *Entire globe* initialized with a uniform sounding based on Dunion (2011, *J. Climate*) moist tropical sounding:
  - Same thermodynamic profile as in Dunion (2011)
  - Pure easterly flow with specified 850-200 mb shear
  - Mass adjustment in the meridional direction to balance shear (thermal wind) following Nolan (2011, *JAMES*)
  - No layer-averaged mass transport (to keep the simulated storm in the center of domain)
- Coupled with HYCOM one-dimensional ocean model (G. Halliwell, PhOD/AOML):
  - Uniform initial SST
  - Initial 1-d temperature and salinity profiles
  - Constant zonal ocean current (to mimic storm motion relative to ocean)
- Initial vortex options:
  - Observation-based, composited from all available observations
  - Flavors of Bao et al. (2012, *MWR*)

IDEALIZED HWRF WORKFLOW



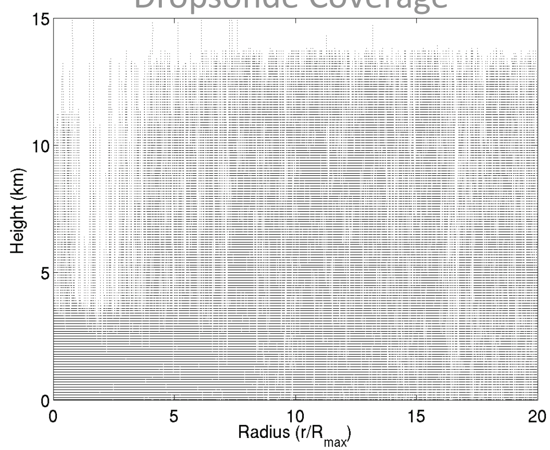
INITIAL ENVIRONMENT



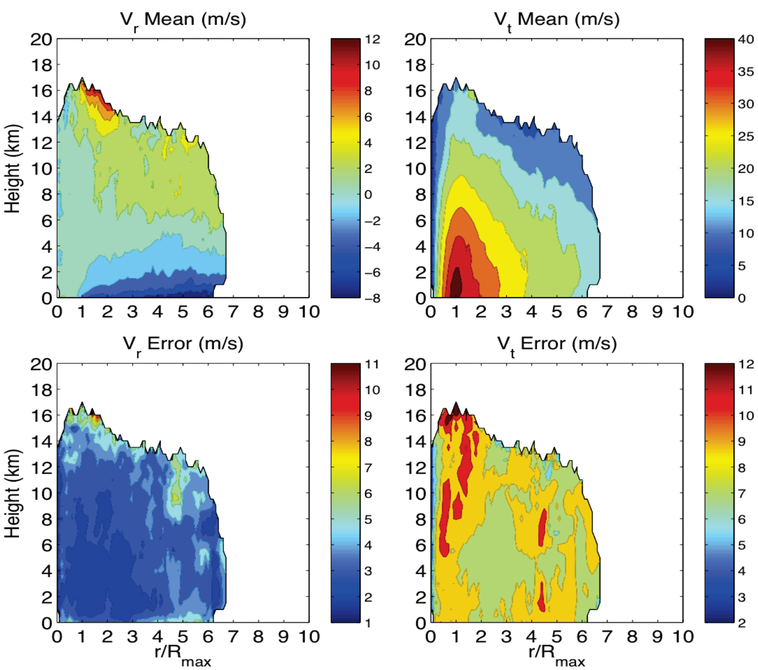
OBSERVATION-BASED INITIAL VORTEX

- Axisymmetric structure of temperature, moisture, and horizontal wind
- Thermodynamic information:
  - Storm-relative GPS dropsonde database (Zhang and Uhlhorn 2012, *MWR*)
  - Historical radius-height cross sections from La Seur and Hawkins (1963, *MWR*), Hawkins and Rubsam (1968, *MWR*), and Hawkins and Imbembo (1976, *MWR*) serve as a low-weight background where significant dropsonde data gaps exist
- Horizontal wind information:
  - Storm-relative GPS dropsonde database (Zhang and Uhlhorn 2012, *MWR*)
  - NOAA P-3 Doppler radar composite analyses
  - HEDAS analyses of Hurricane Earl (2010) by Aksoy et al. (2013, *MWR*) serve as a low-weight background where significant data gaps exist
- Only observations from TCs of:
  - Category-1, steady-state hurricane
  - Moderate shear (5-10 m/s)
  - South of 30N and away from land

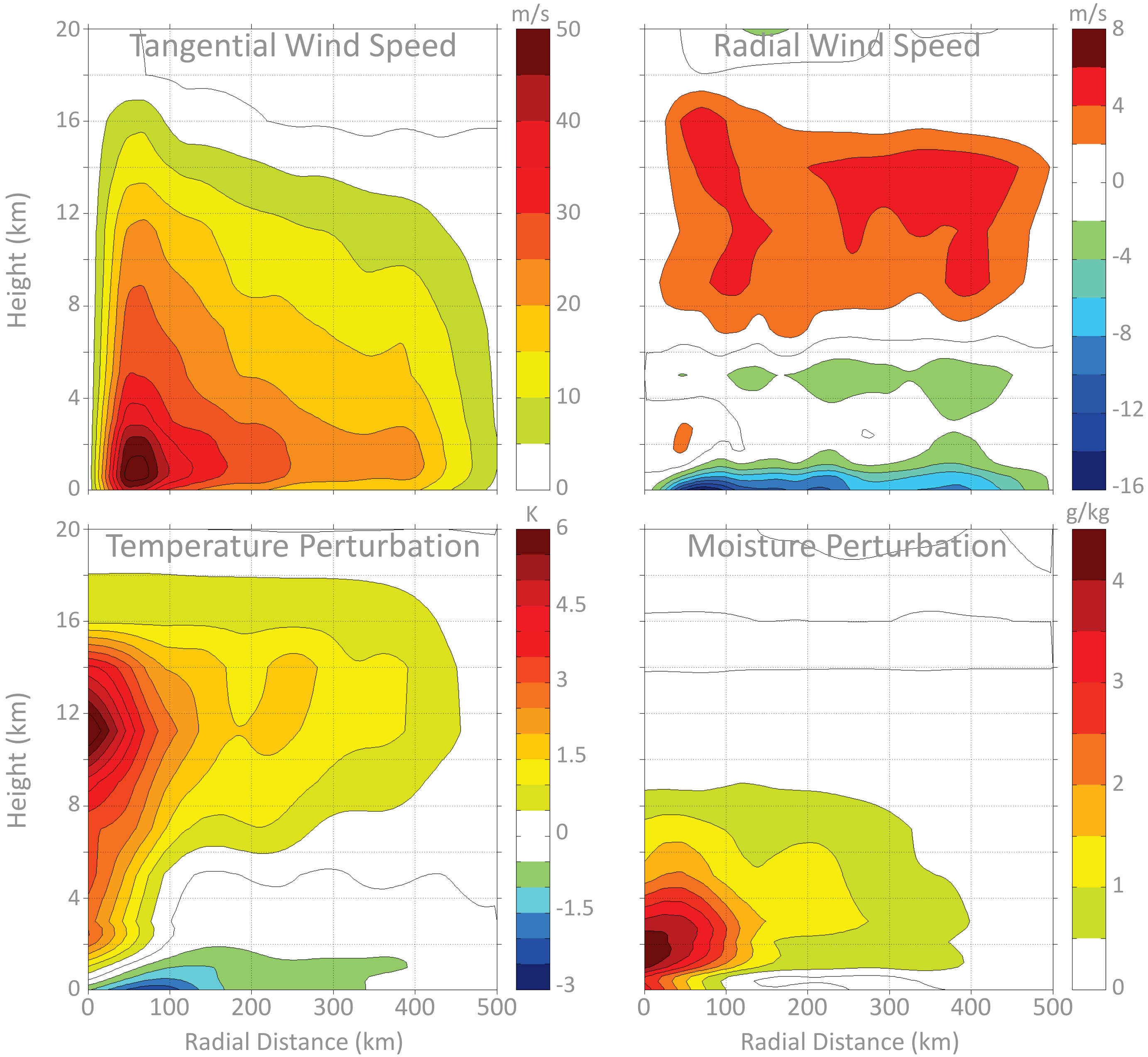
Dropsonde Coverage



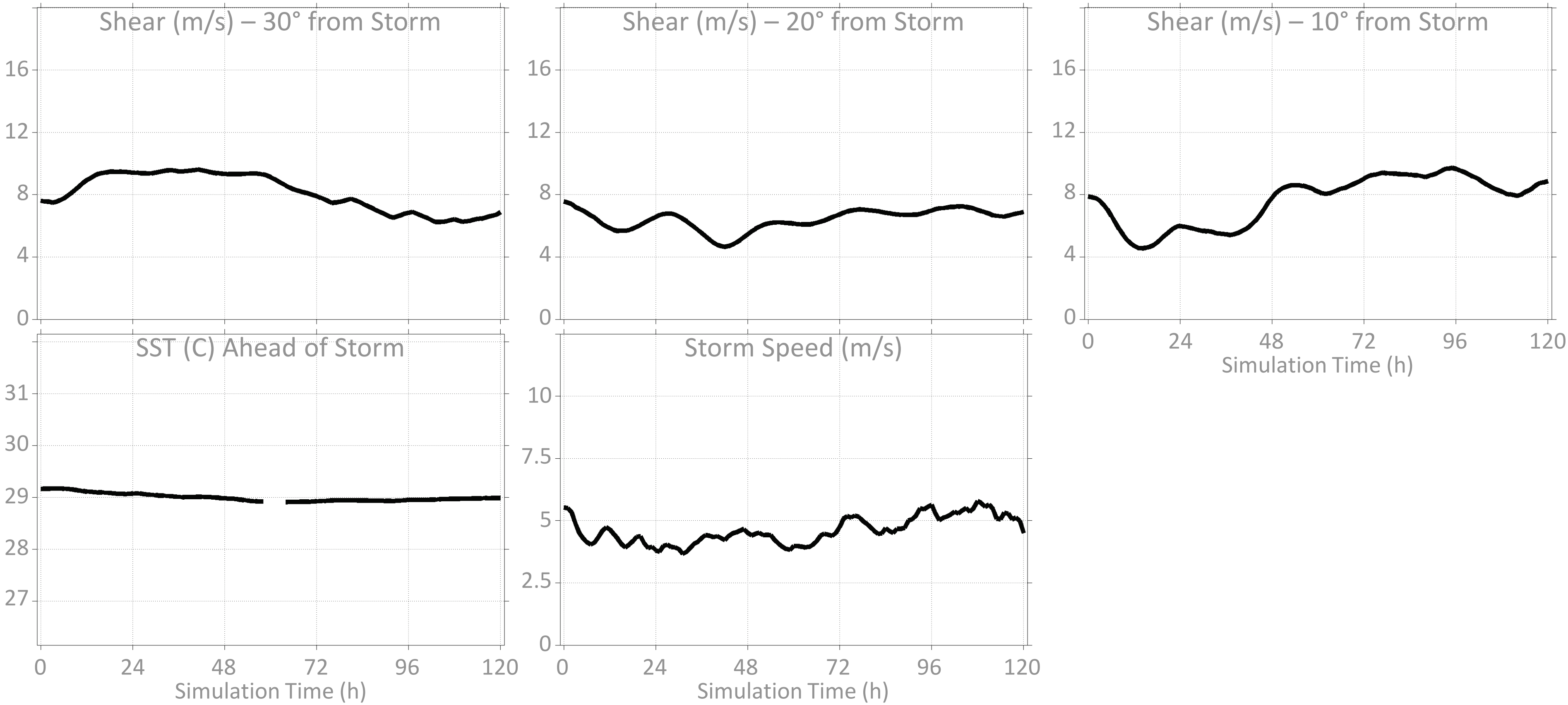
Doppler Radar Coverage



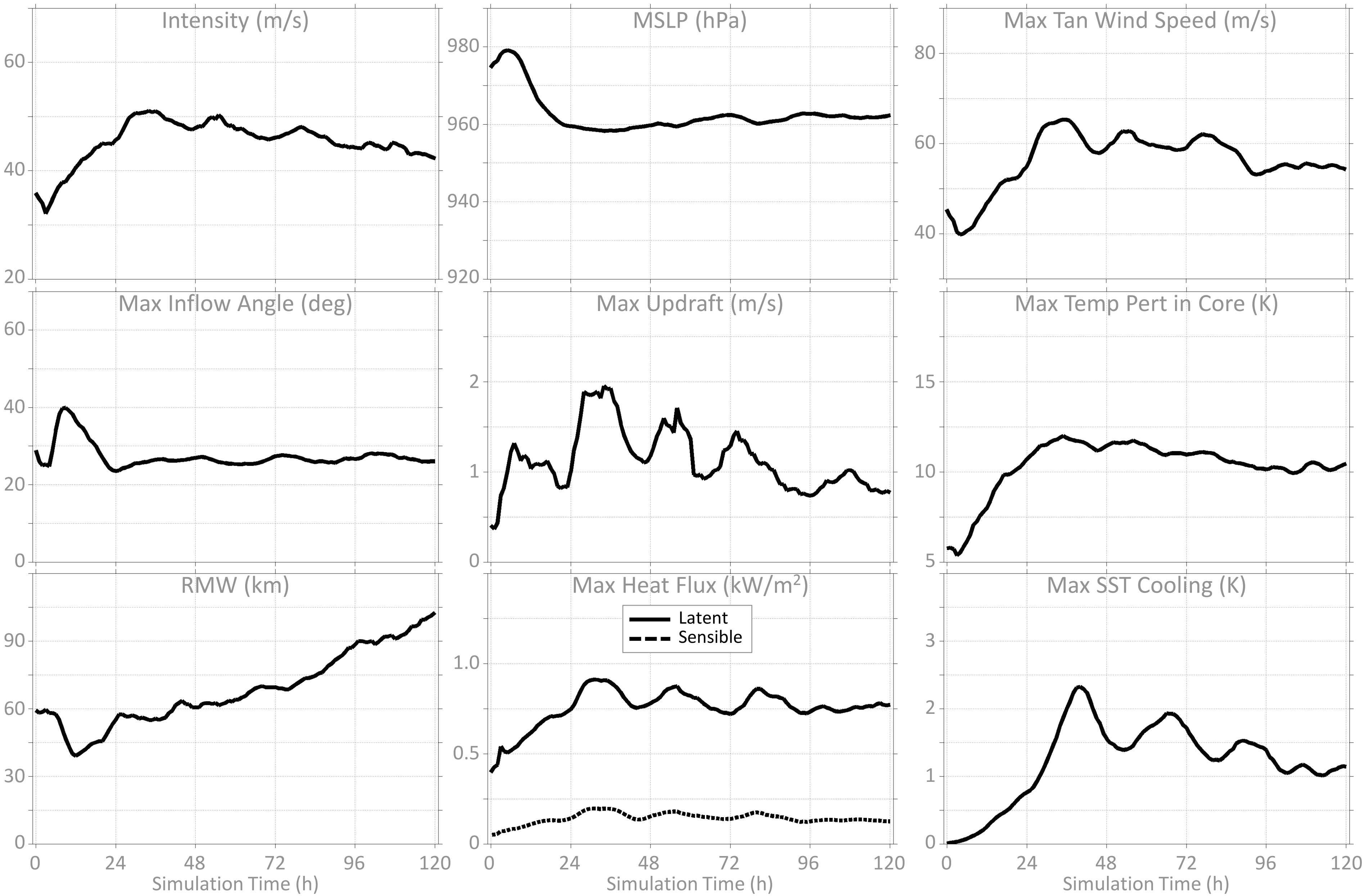
OBSERVATION-BASED INITIAL VORTEX



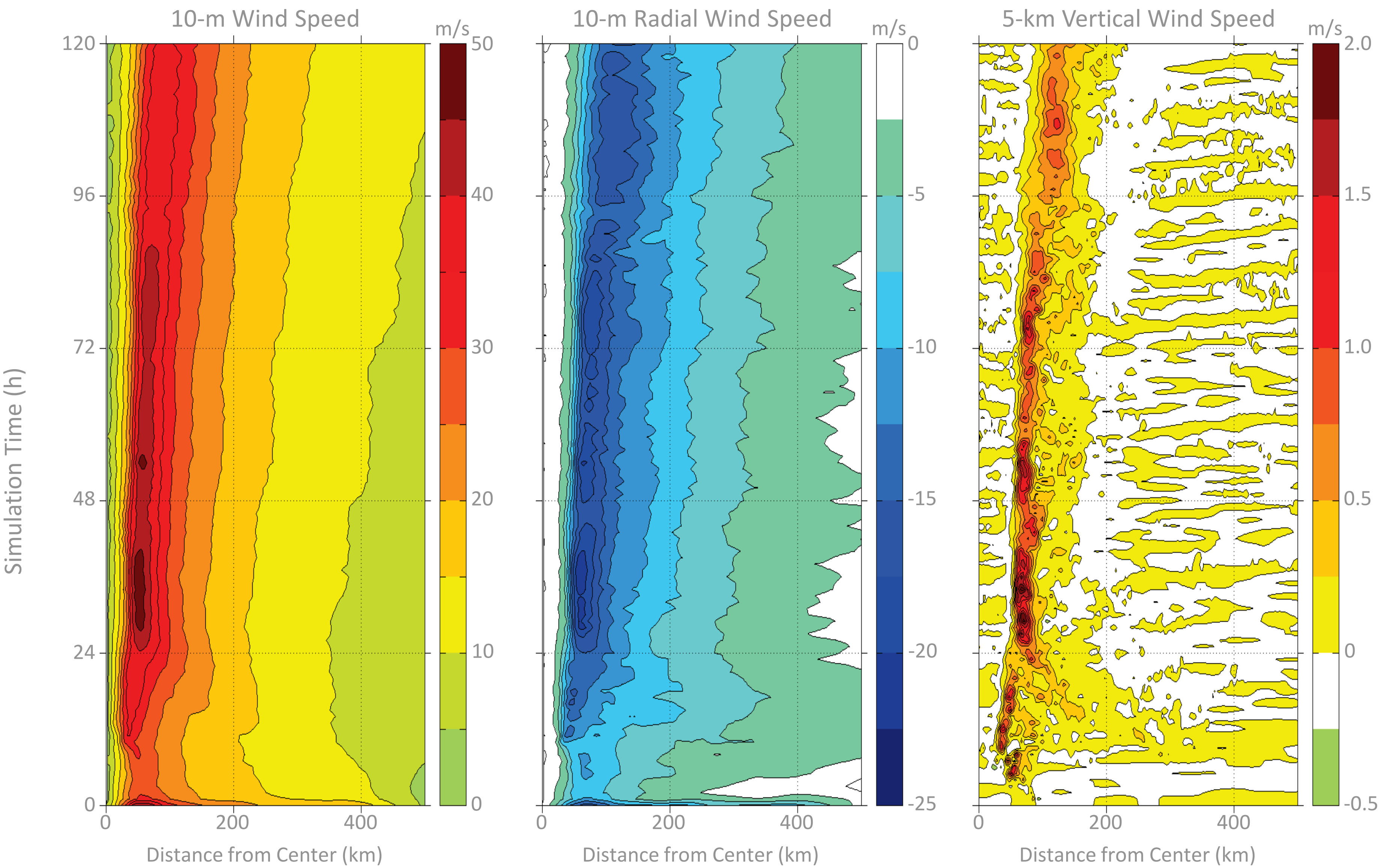
CONTROL RUN


Shear (m/s) – 30° from Storm
Shear (m/s) – 20° from Storm
Shear (m/s) – 10° from Storm
SST (C) Ahead of Storm
Storm Speed (m/s)
Simulation Time (h)
Simulation Time (h)
Simulation Time (h)

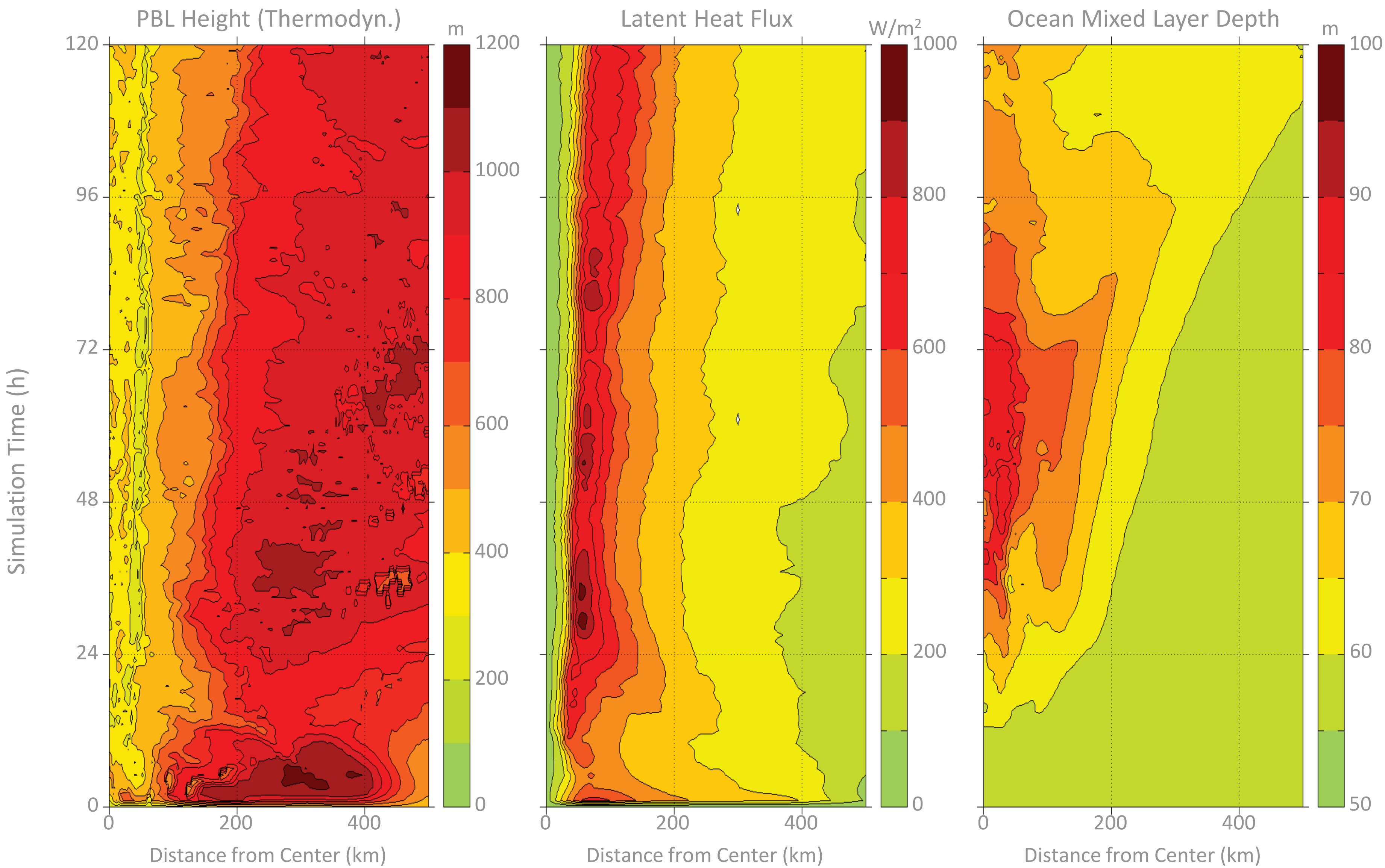
CONTROL RUN


Intensity (m/s)
MSLP (hPa)
Max Tan Wind Speed (m/s)
Max Inflow Angle (deg)
Max Updraft (m/s)
Max Temp Pert in Core (K)
RMW (km)
Max Heat Flux (kW/m²)
Latent
Sensible
Max SST Cooling (K)
Simulation Time (h)

CONTROL RUN

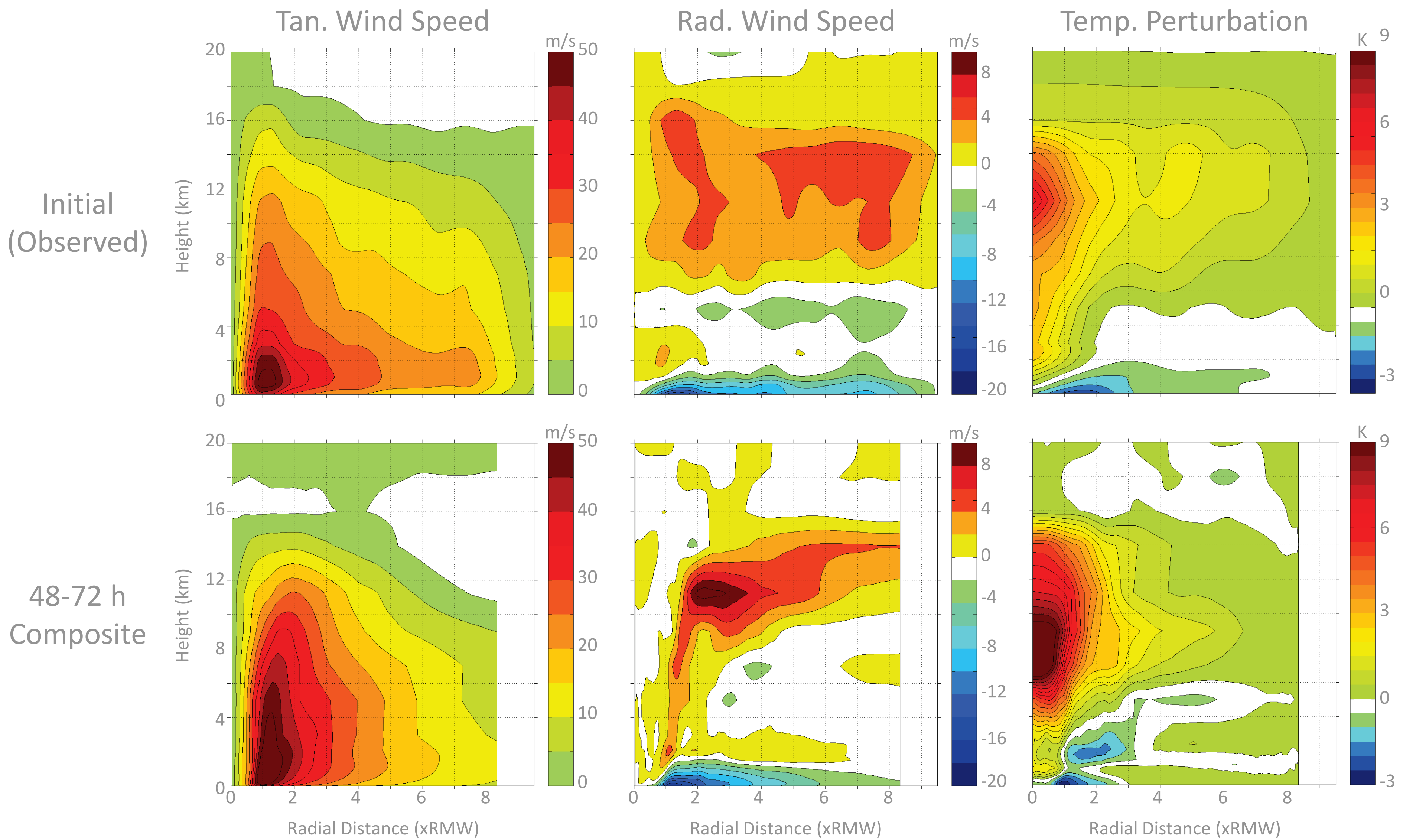

10-m Wind Speed
m/s
50
40
30
20
10
0
10-m Radial Wind Speed
m/s
0
-5
-10
-15
-20
-25
5-km Vertical Wind Speed
m/s
2.0
1.5
1.0
0.5
0
-0.5
Simulation Time (h)
120
96
72
48
24
0
0
200
400
Distance from Center (km)

CONTROL RUN



PBL Height (Thermodyn.)
m
1200
1000
800
600
400
200
0
Latent Heat Flux
W/m²
1000
800
600
400
200
0
Ocean Mixed Layer Depth
m
100
90
80
70
60
50
120
96
72
48
24
0
Simulation Time (h)
0
200
400
Distance from Center (km)
Distance from Center (km)
Distance from Center (km)

CONTROL RUN

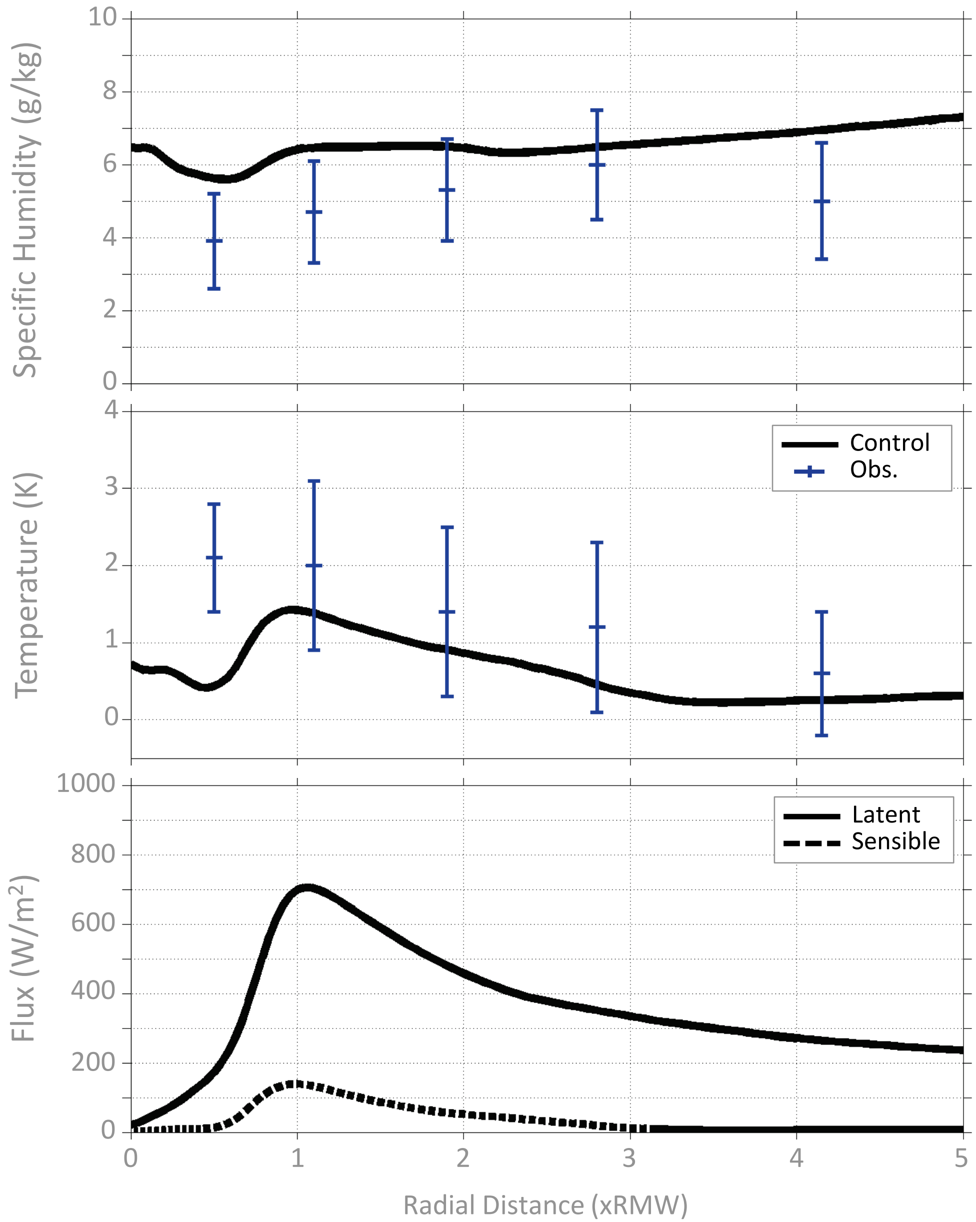

Tan. Wind Speed
Rad. Wind Speed
Temp. Perturbation
Initial (Observed)
48-72 h Composite
Height (km)
Radial Distance (xRMW)
m/s
K
0
4
8
12
16
20
0
10
20
30
40
50
-20
-16
-12
-8
-4
0
4
8
-3
0
3
6
9
0
2
4
6
8

CONTROL RUN

Air-Sea Moisture Contrast

Air-Sea Temperature Contrast

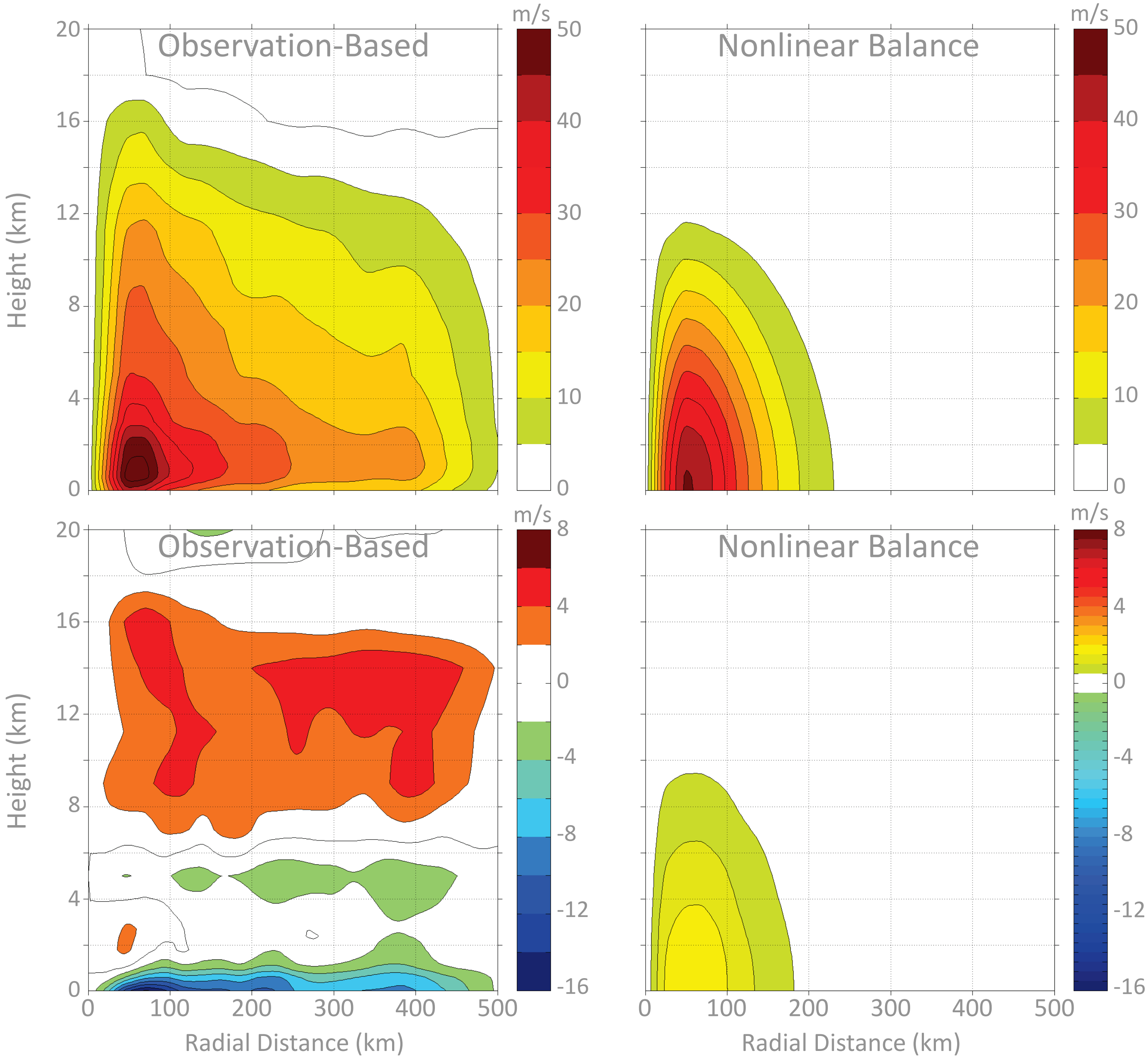
Latent and Sensible Heat Flux



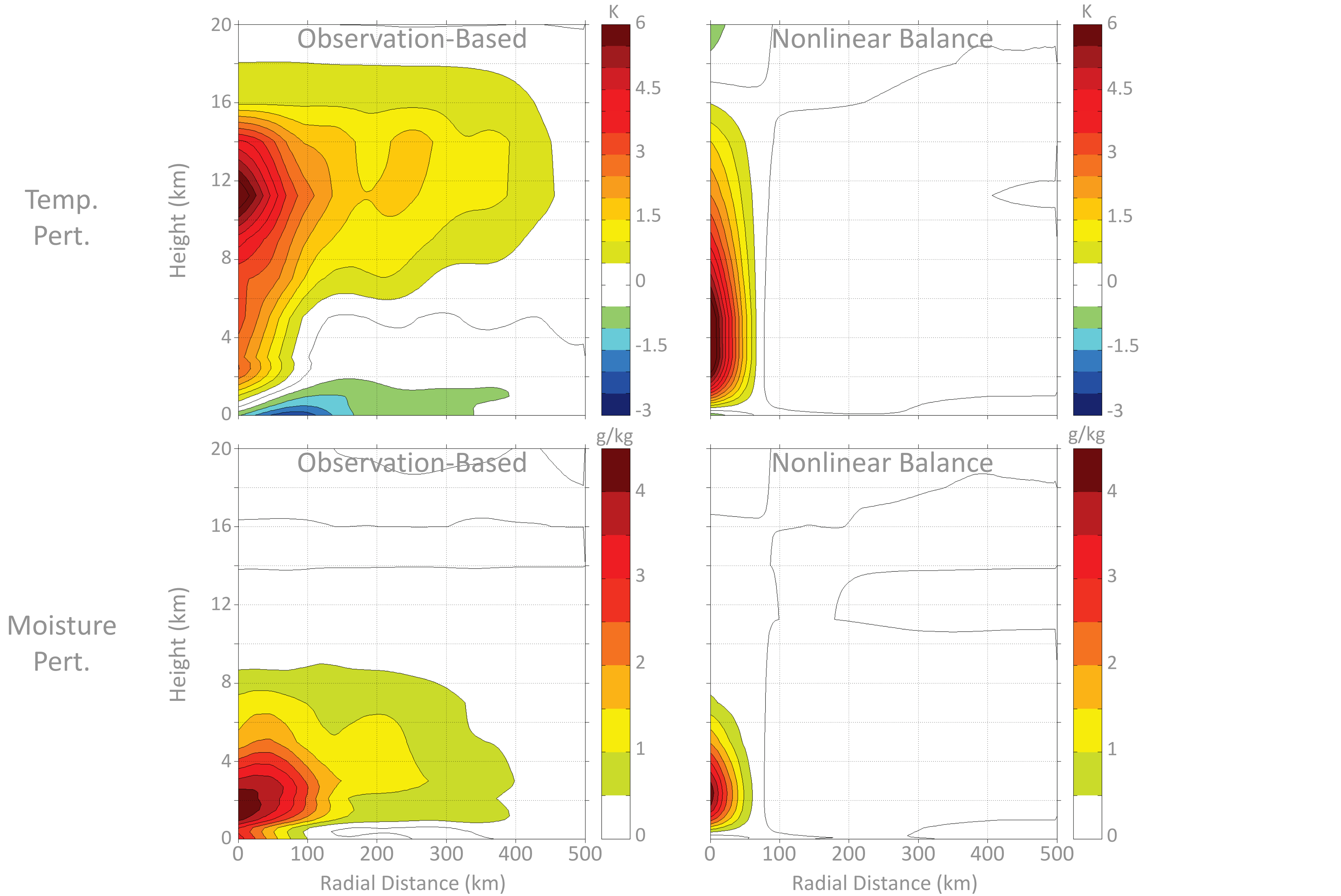
SENSITIVITY TO INITIAL VORTEX STRUCTURE

Tangential Wind Speed

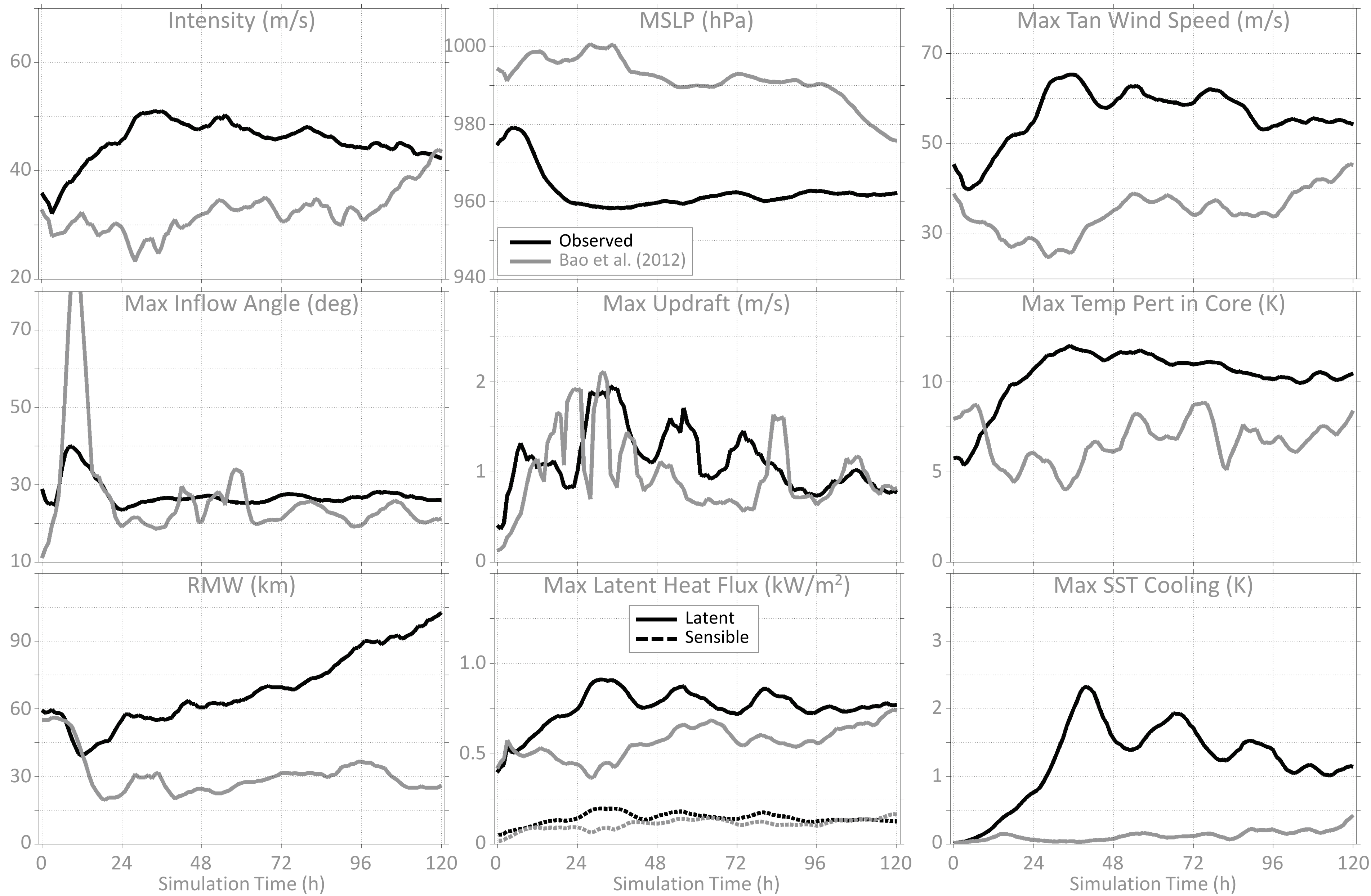
Radial Wind Speed



SENSITIVITY TO INITIAL VORTEX STRUCTURE



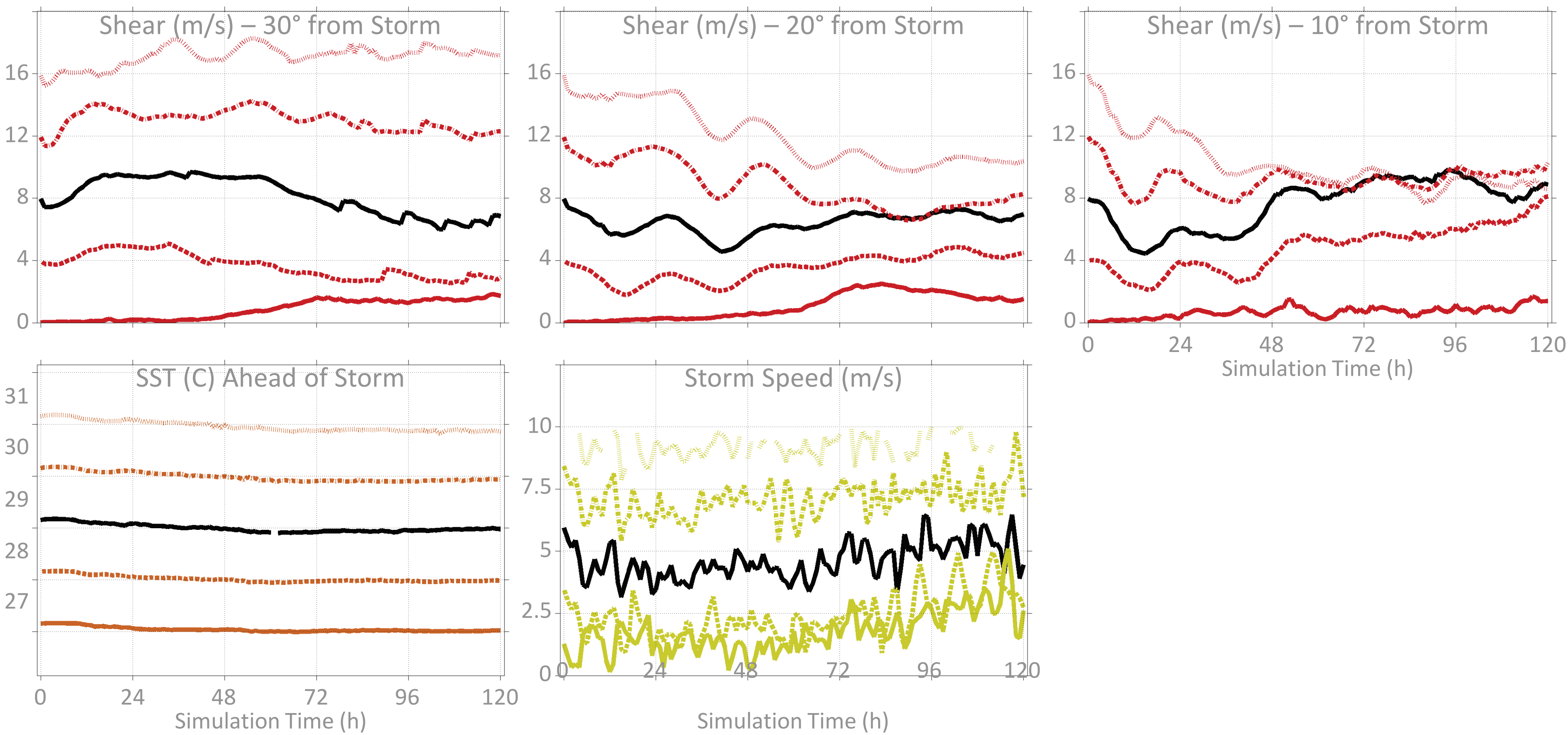
SENSITIVITY TO INITIAL VORTEX STRUCTURE



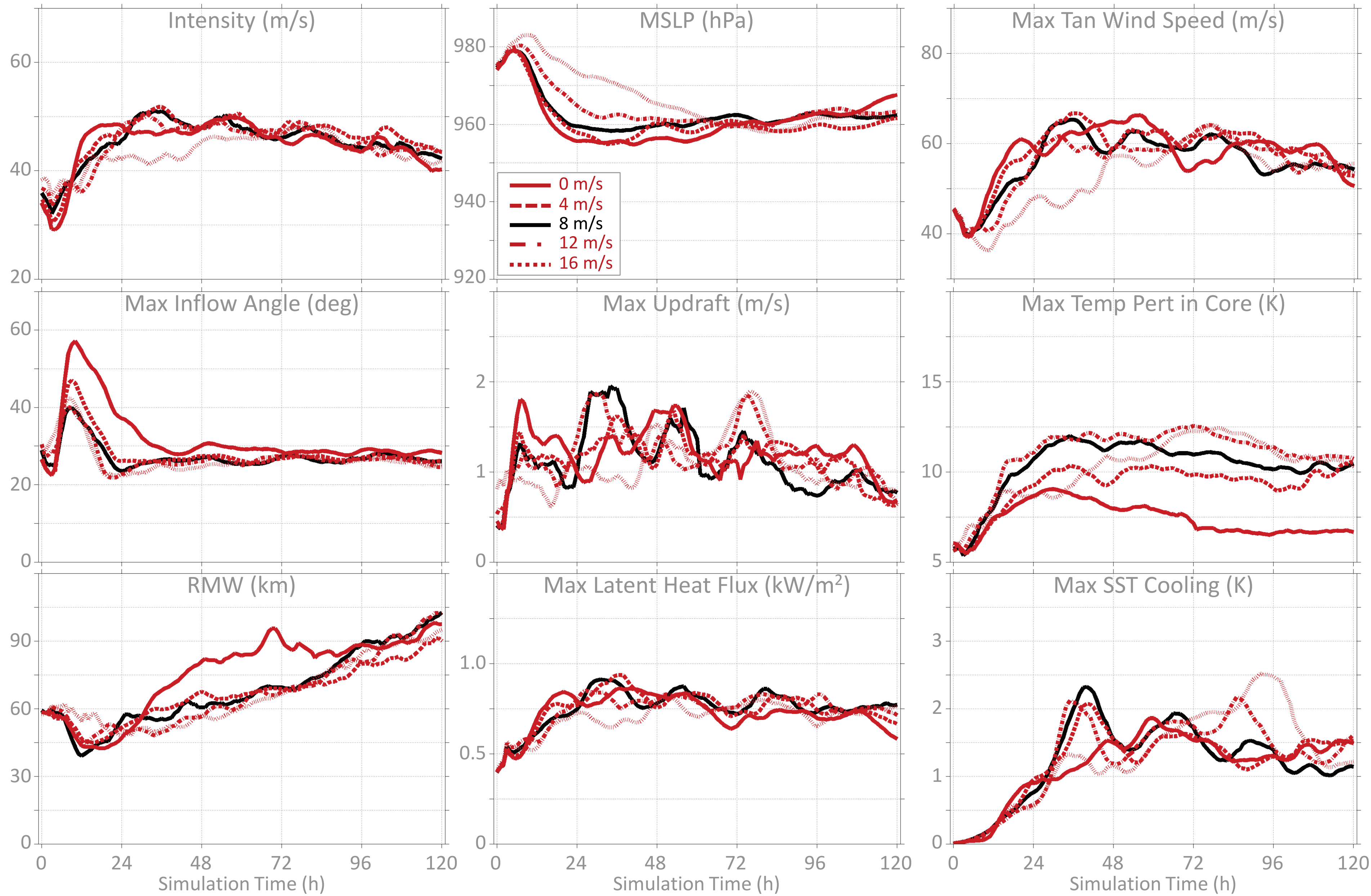
SENSITIVITY TO PARAMETER PERTURBATIONS

		REALIZATION of PARAMETER PERTURBATION				
				Control		
1. Storm Environment						
- Zonal Shear (m/s)		0	4	8	12	16
- Initial uniform SST (C)		27	28	29	30	31
- Westward storm speed (m/s)		0	2.5	5	7.5	10
2. Initial Vortex						
- Vortex Size (RMW, km)		15	30	45	60	75
- Initial intensity (m/s)	N/A			43		
3. PBL/SL Parameters						
- Eddy Diffusivity Multiplier		0.1	0.3	0.5	0.7	0.9
- Momentum Flux Multiplier		0.5	0.75	1.0	1.25	1.5
- Enthalpy Flux Multiplier		0.5	0.75	1.0	1.25	1.5

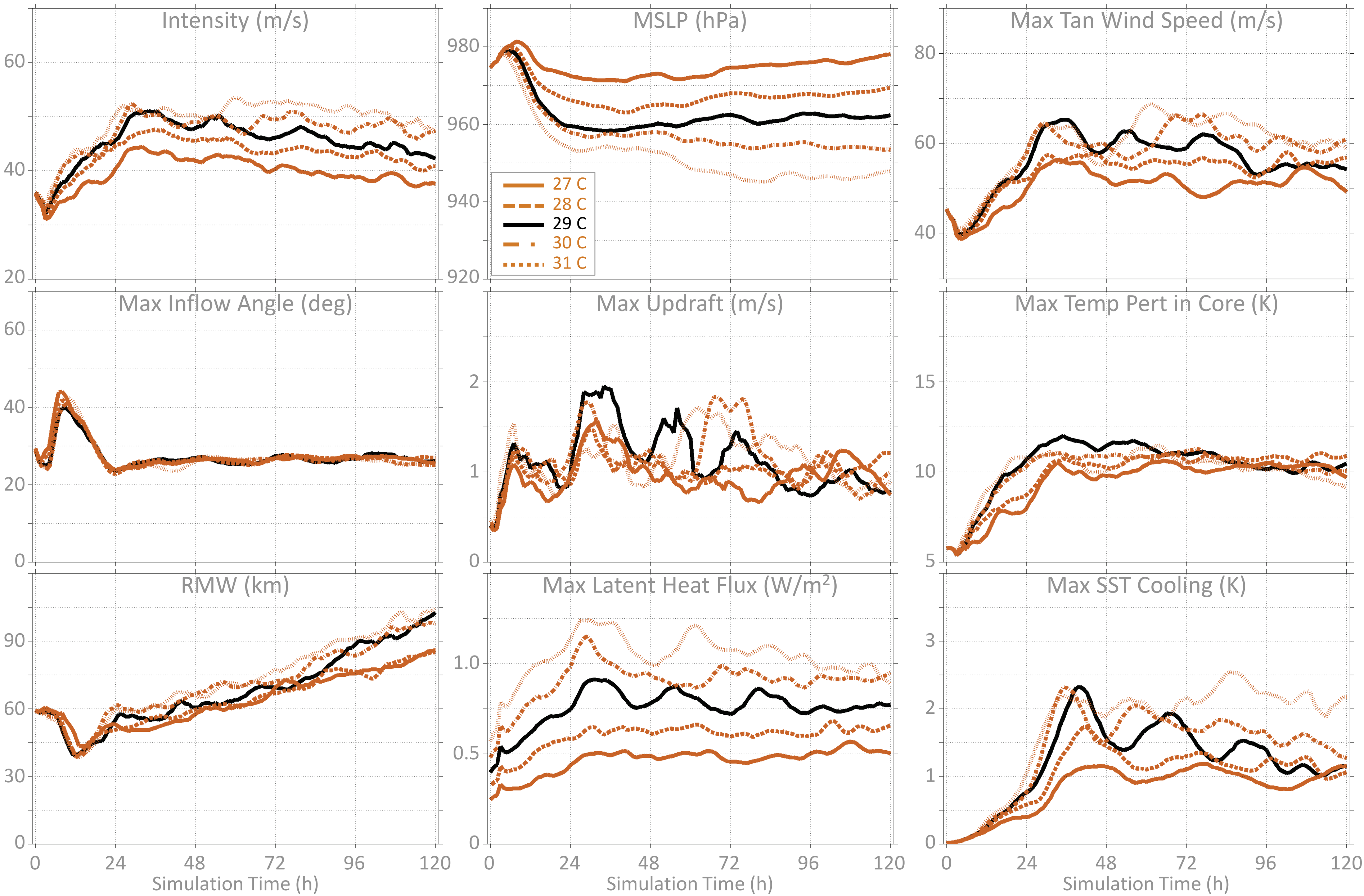
EVOLUTION OF ENVIRONMENT PERTURBATIONS



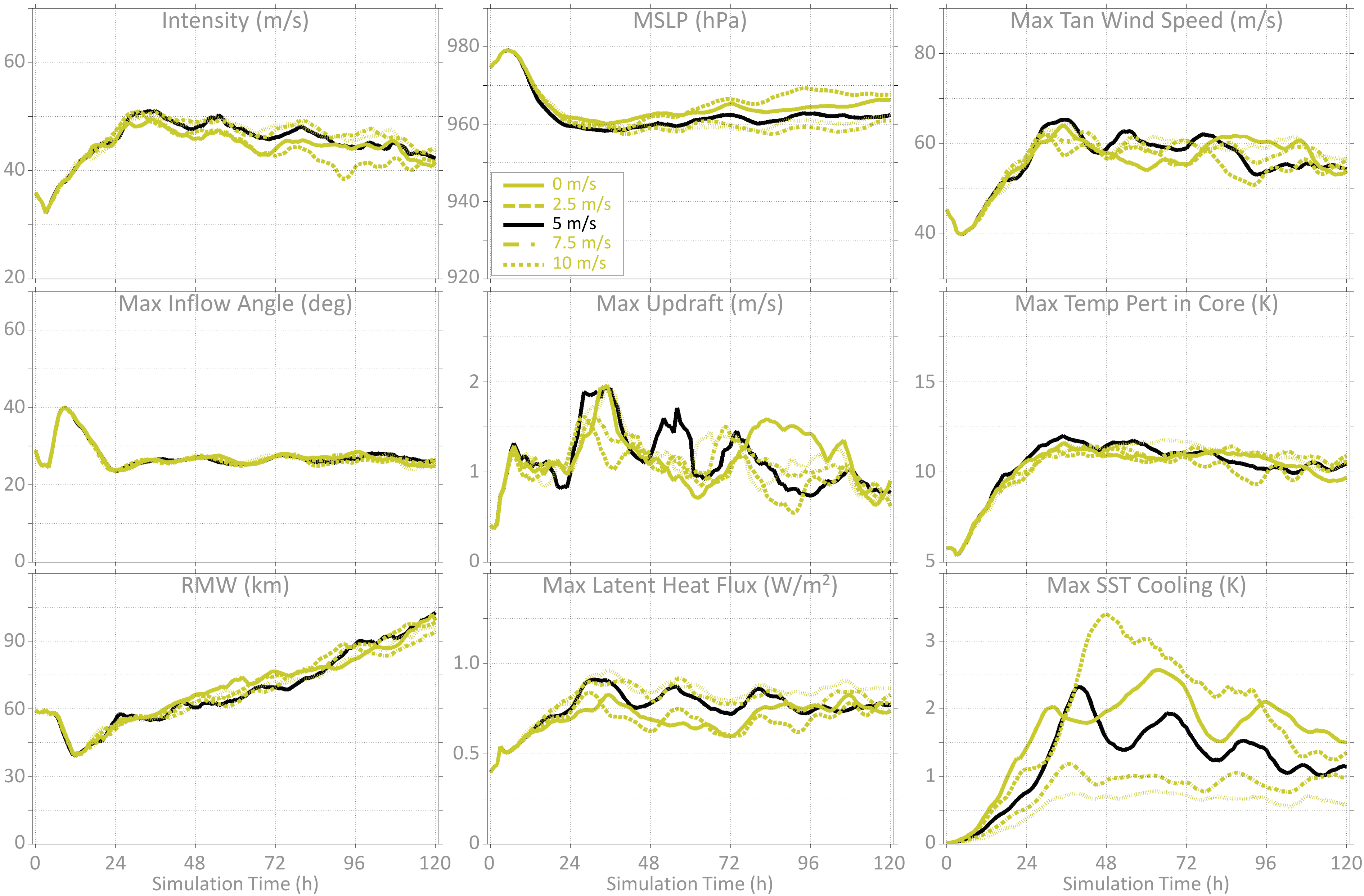
SENSITIVITY TO SHEAR



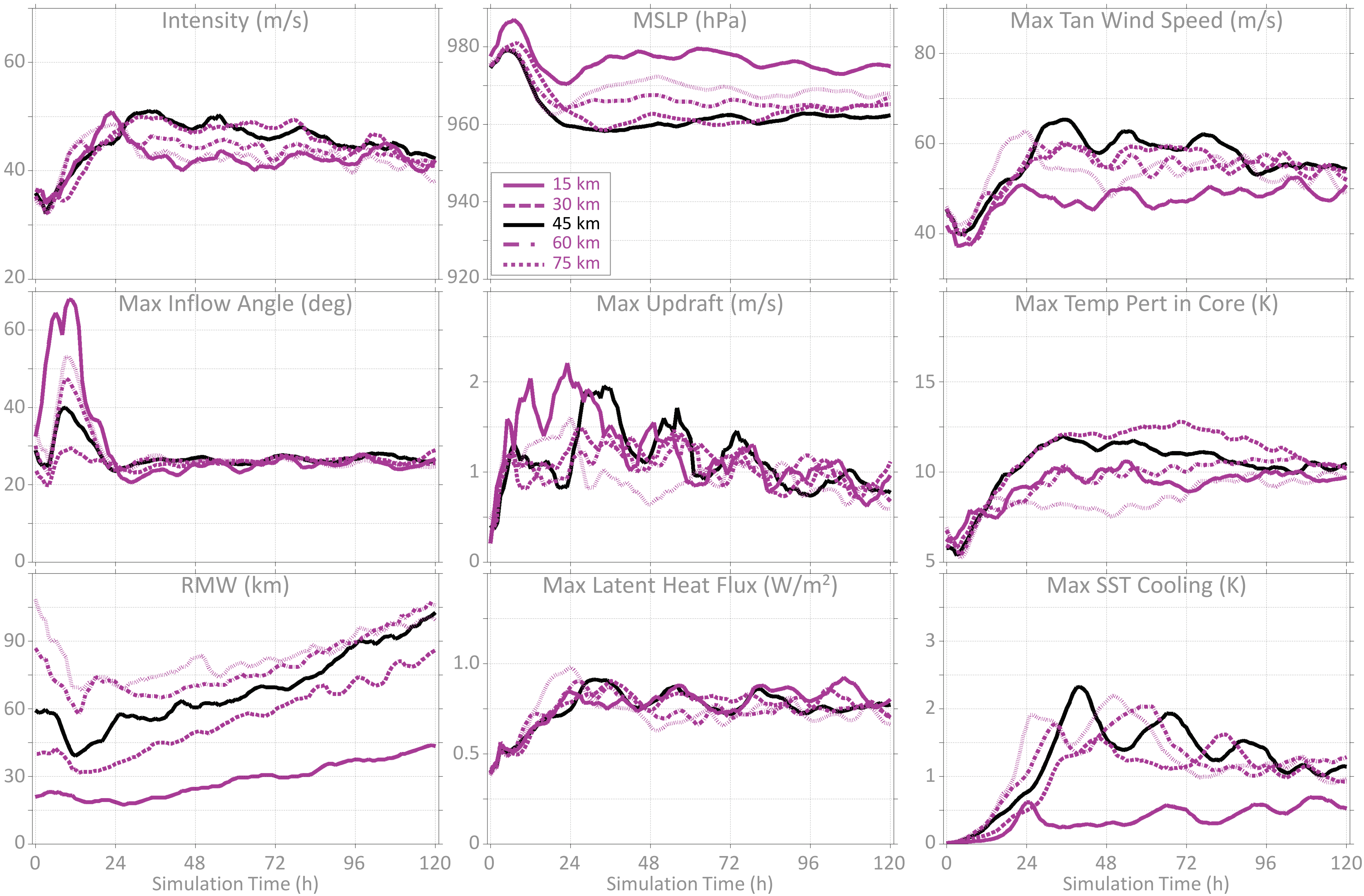
SENSITIVITY TO SST



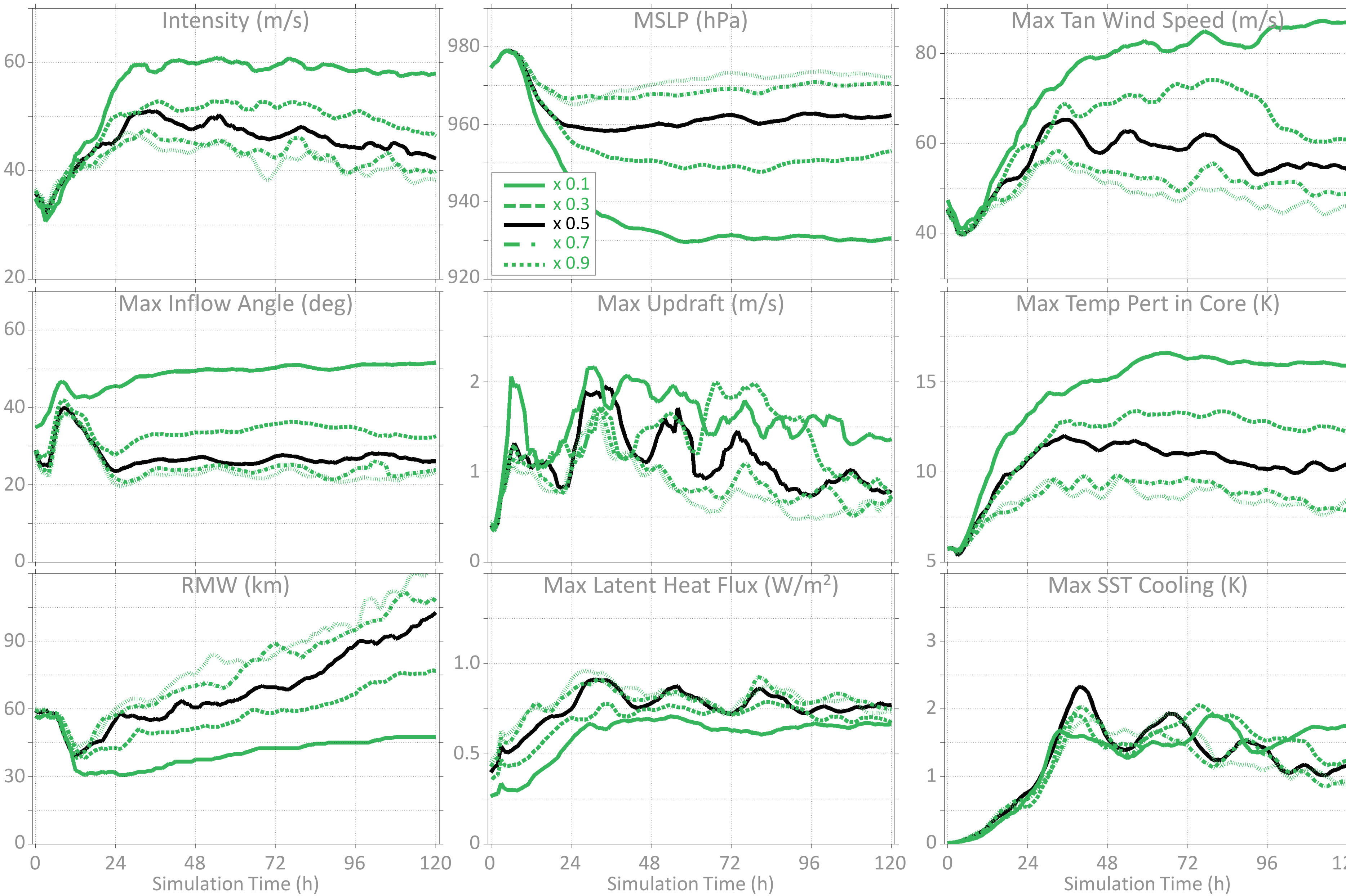
SENSITIVITY TO STORM SPEED



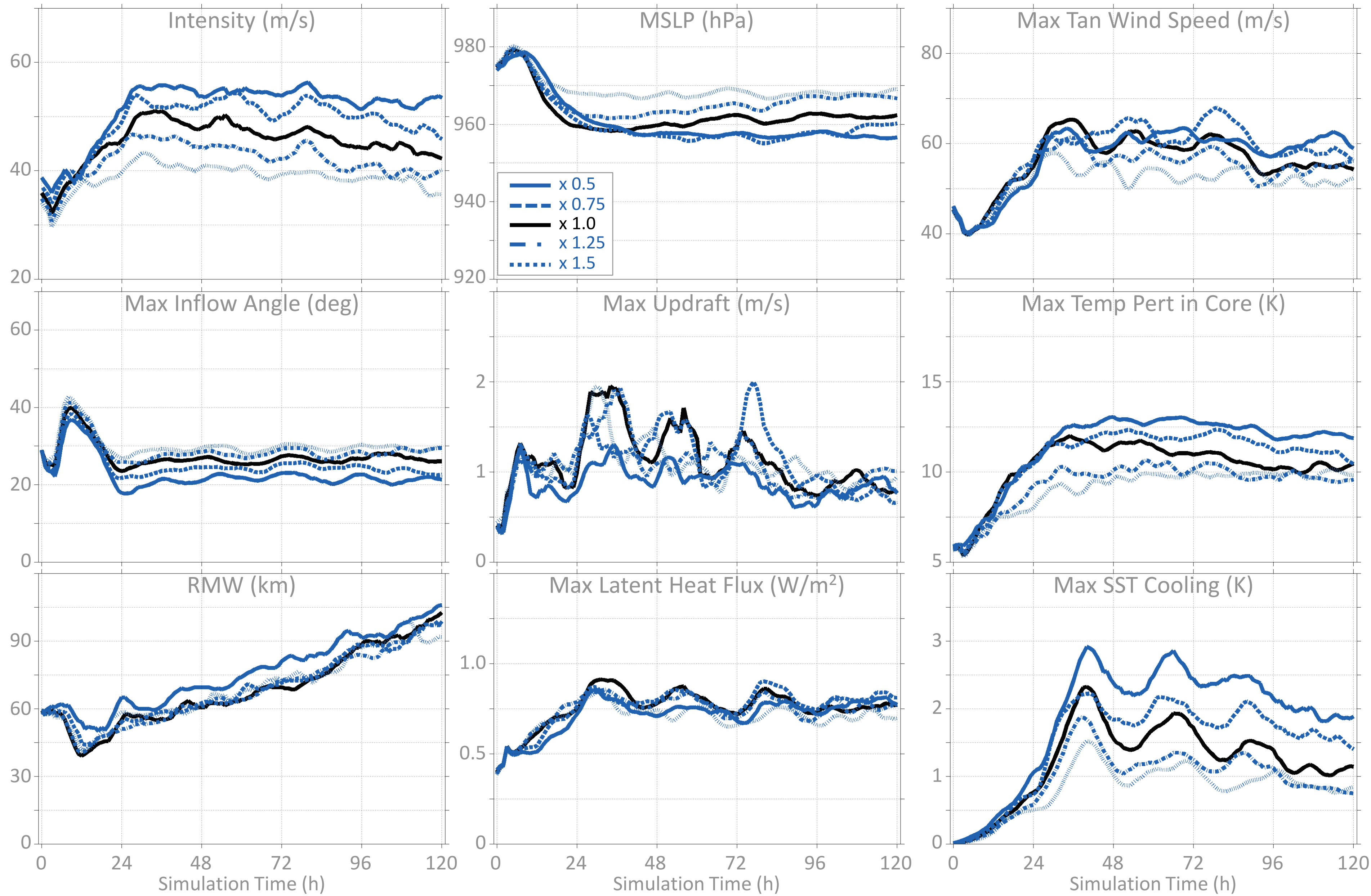
SENSITIVITY TO VORTEX SIZE (RMW)



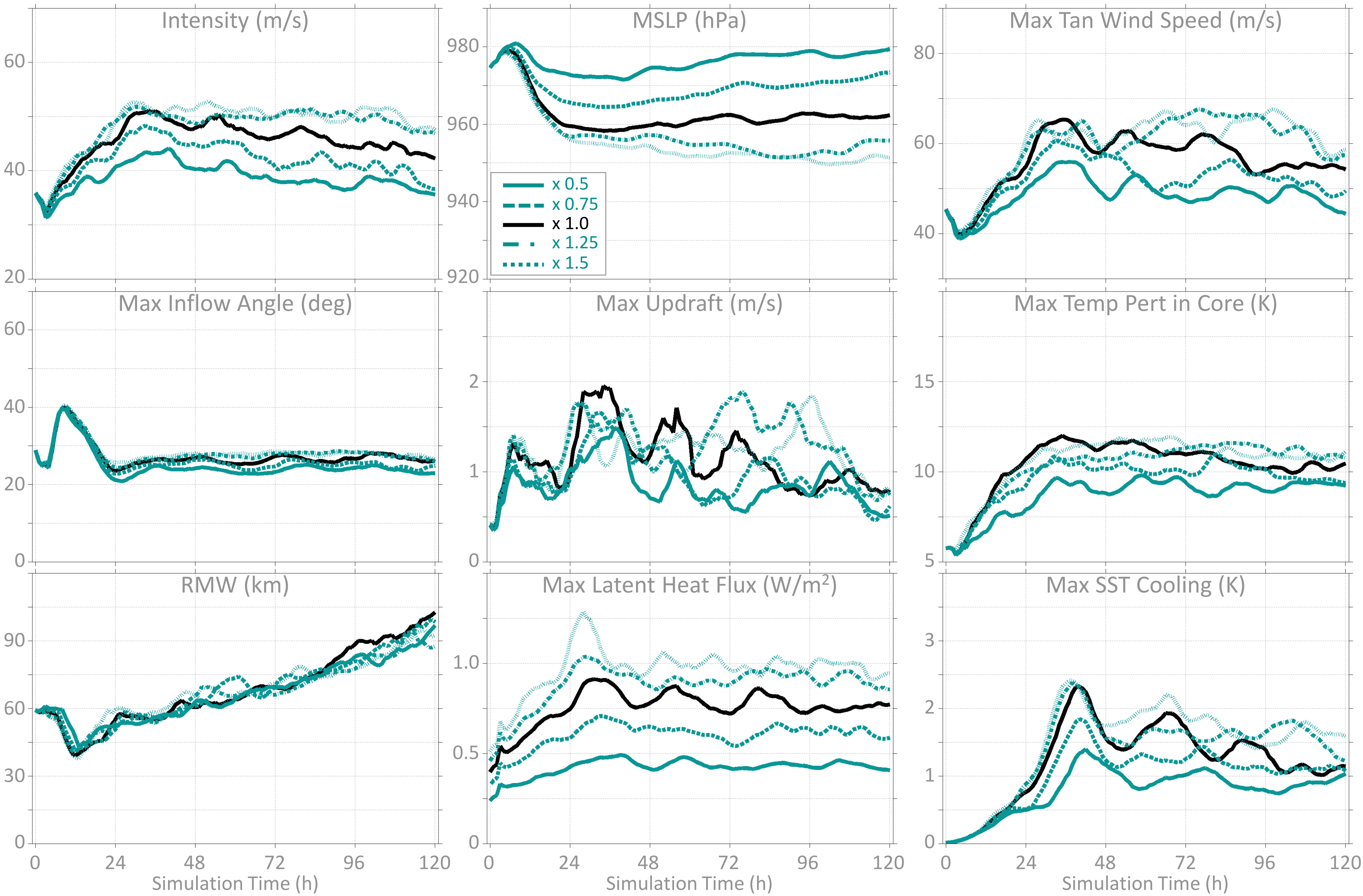
SENSITIVITY TO EDDY DIFFUSIVITY



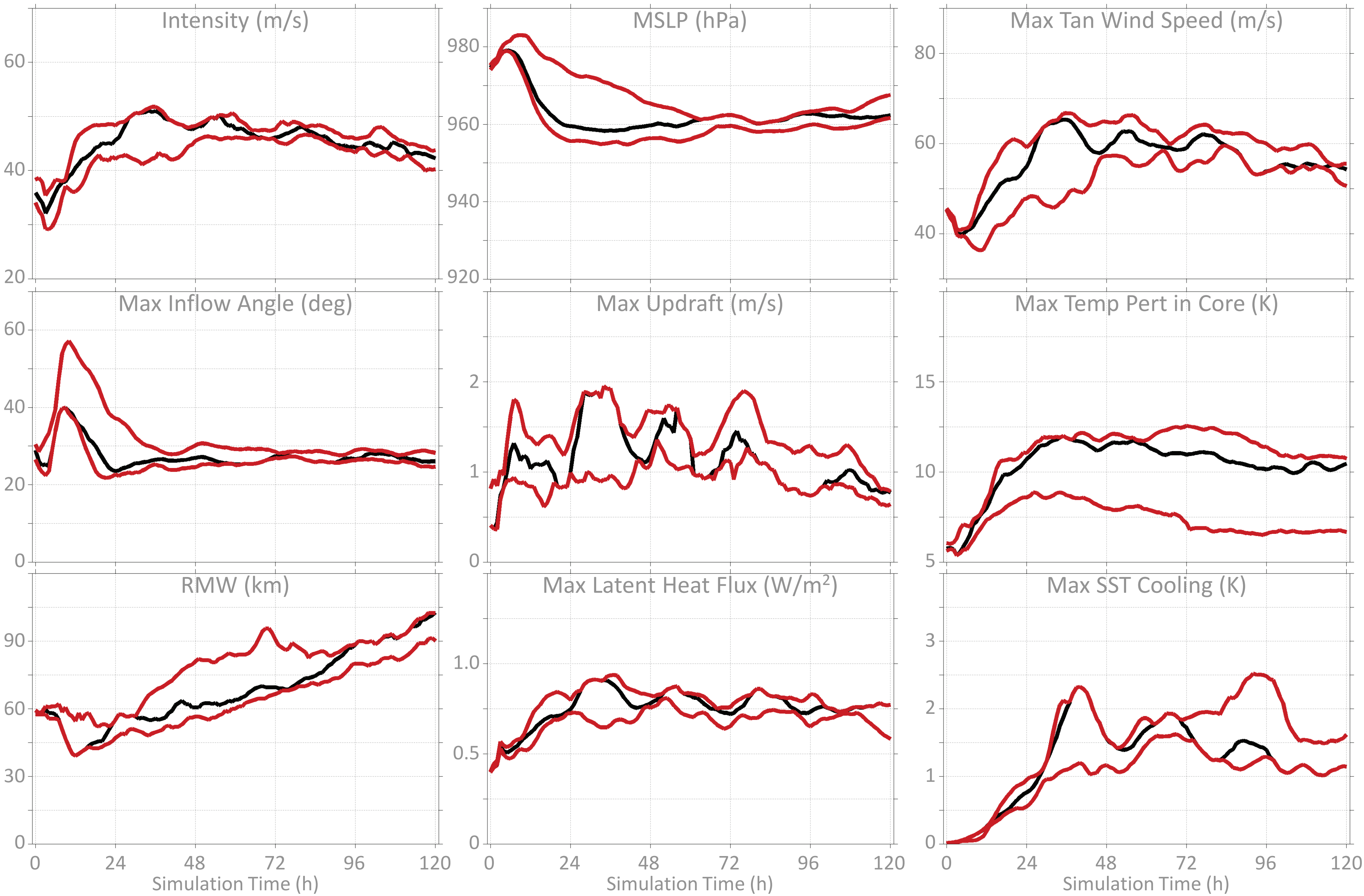
SENSITIVITY TO EXCHANGE COEF. MOMENTUM



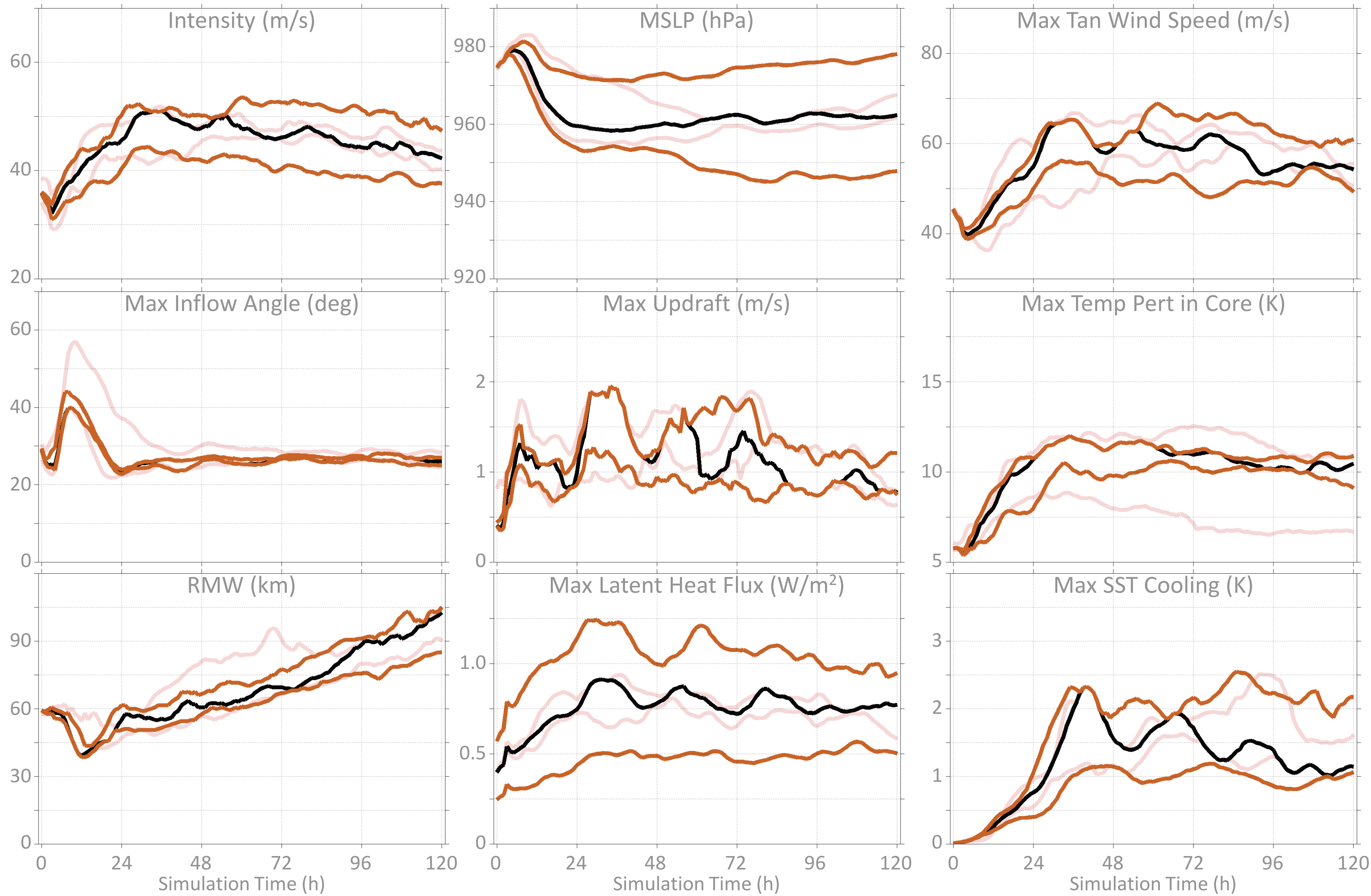
SENSITIVITY TO EXCHANGE COEF. ENTHALPY



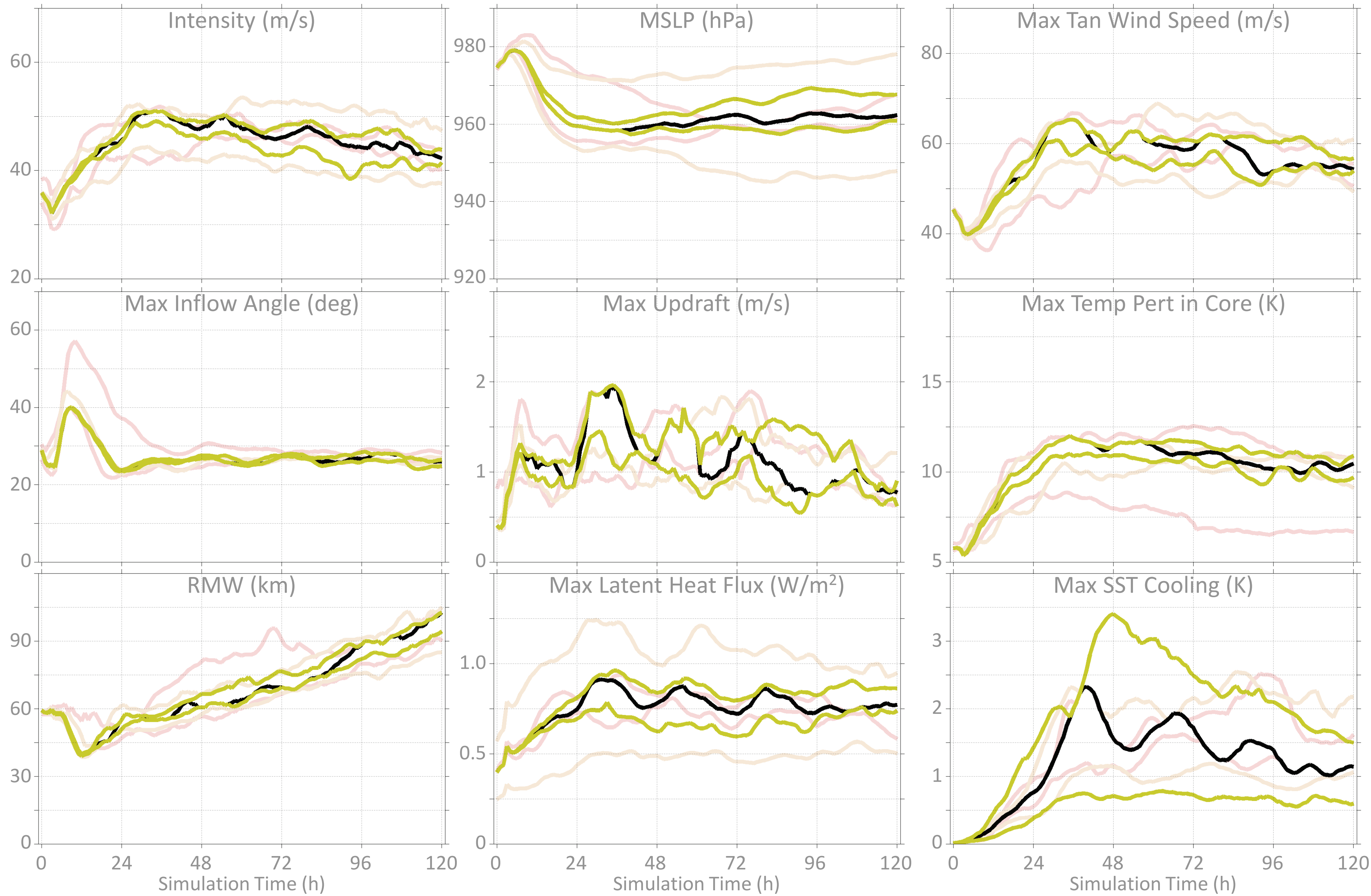
SENSITIVITY TO SHEAR



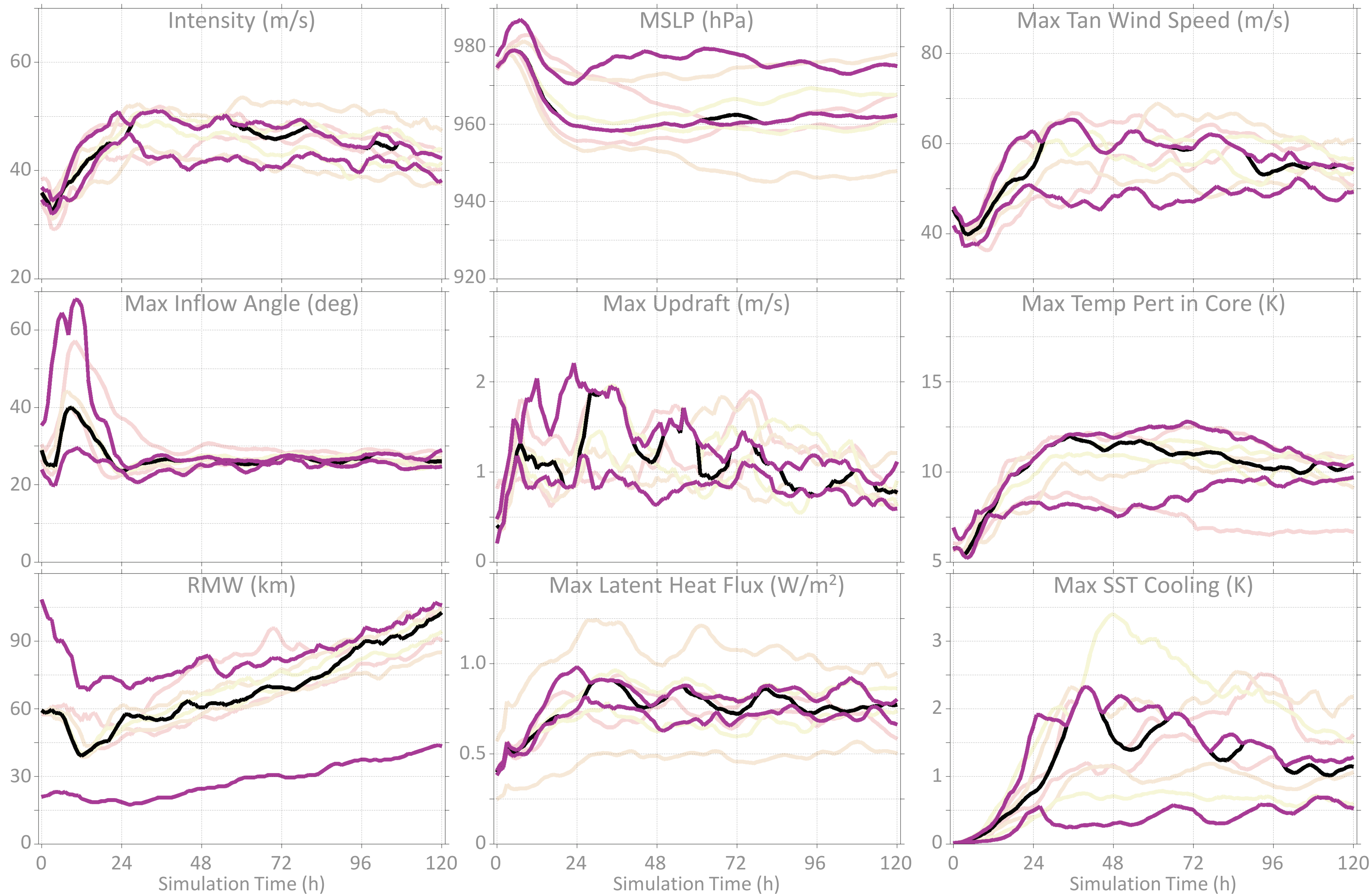
SENSITIVITY TO SST



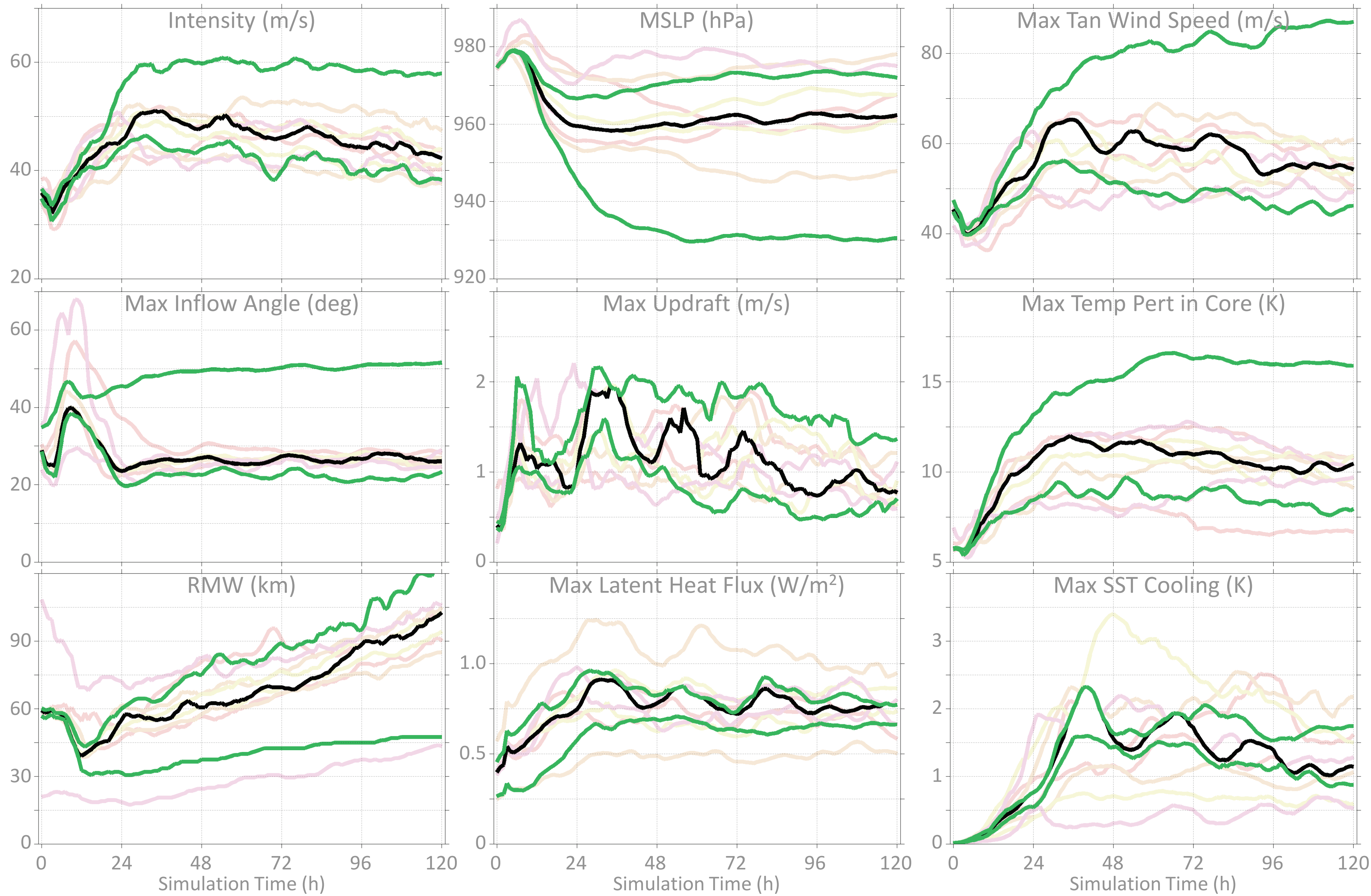
SENSITIVITY TO STORM SPEED



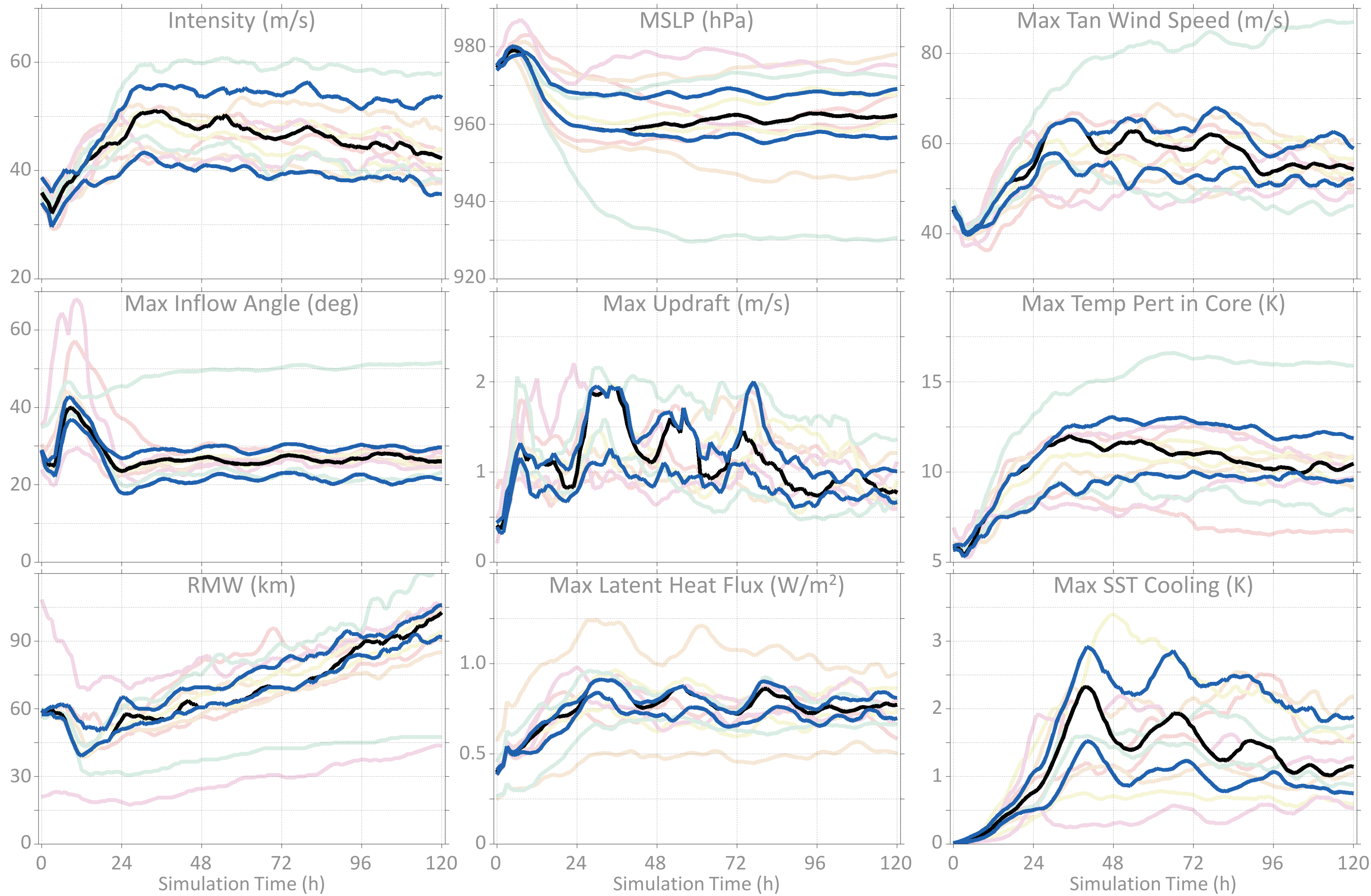
SENSITIVITY TO VORTEX SIZE



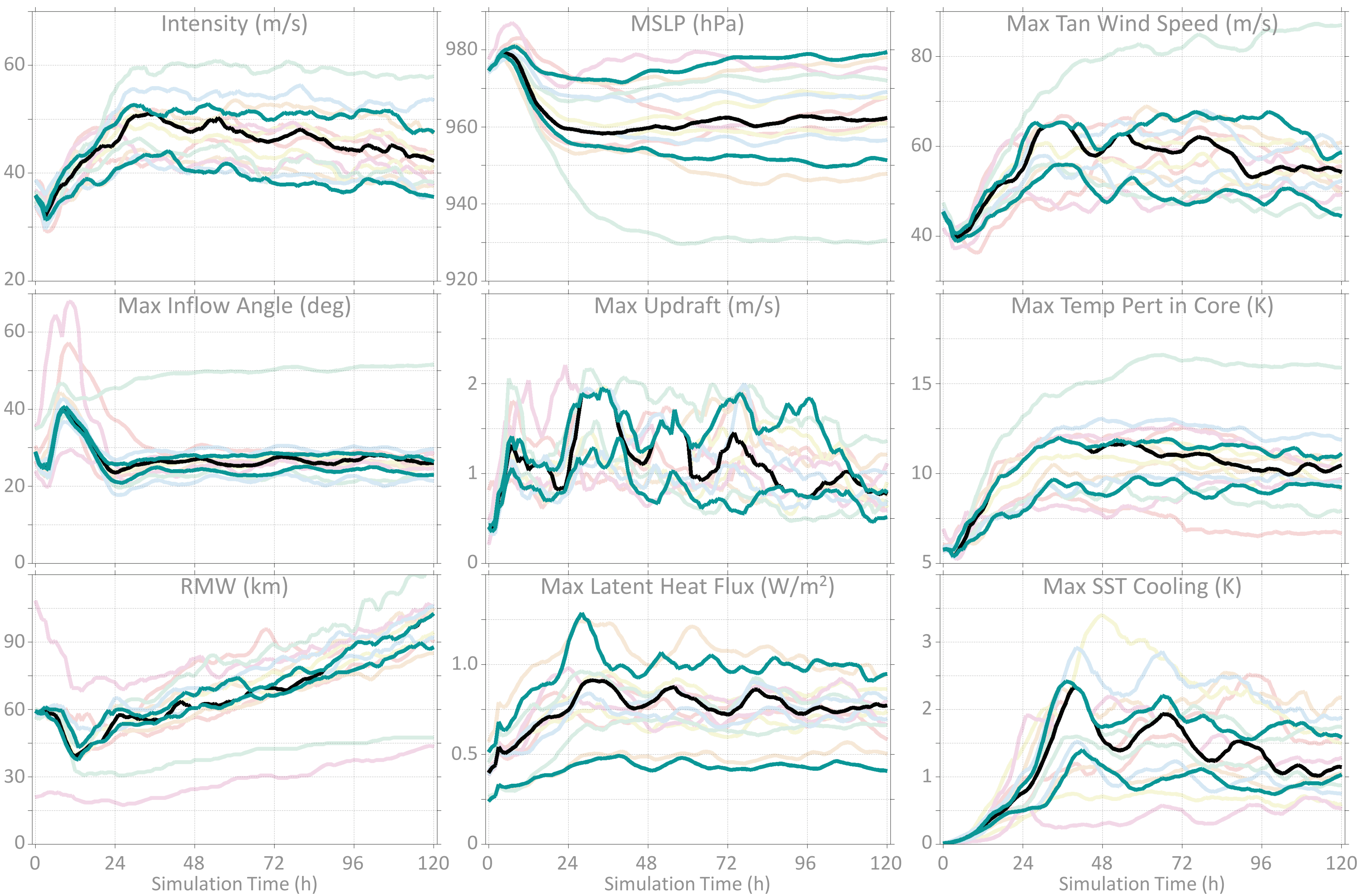
SENSITIVITY TO EDDY DIFFUSIVITY



SENSITIVITY TO EXCHANGE COEF. MOMENTUM



SENSITIVITY TO EXCHANGE COEF. ENTHALPY



COMPARATIVE NORMALIZED SENSITIVITY

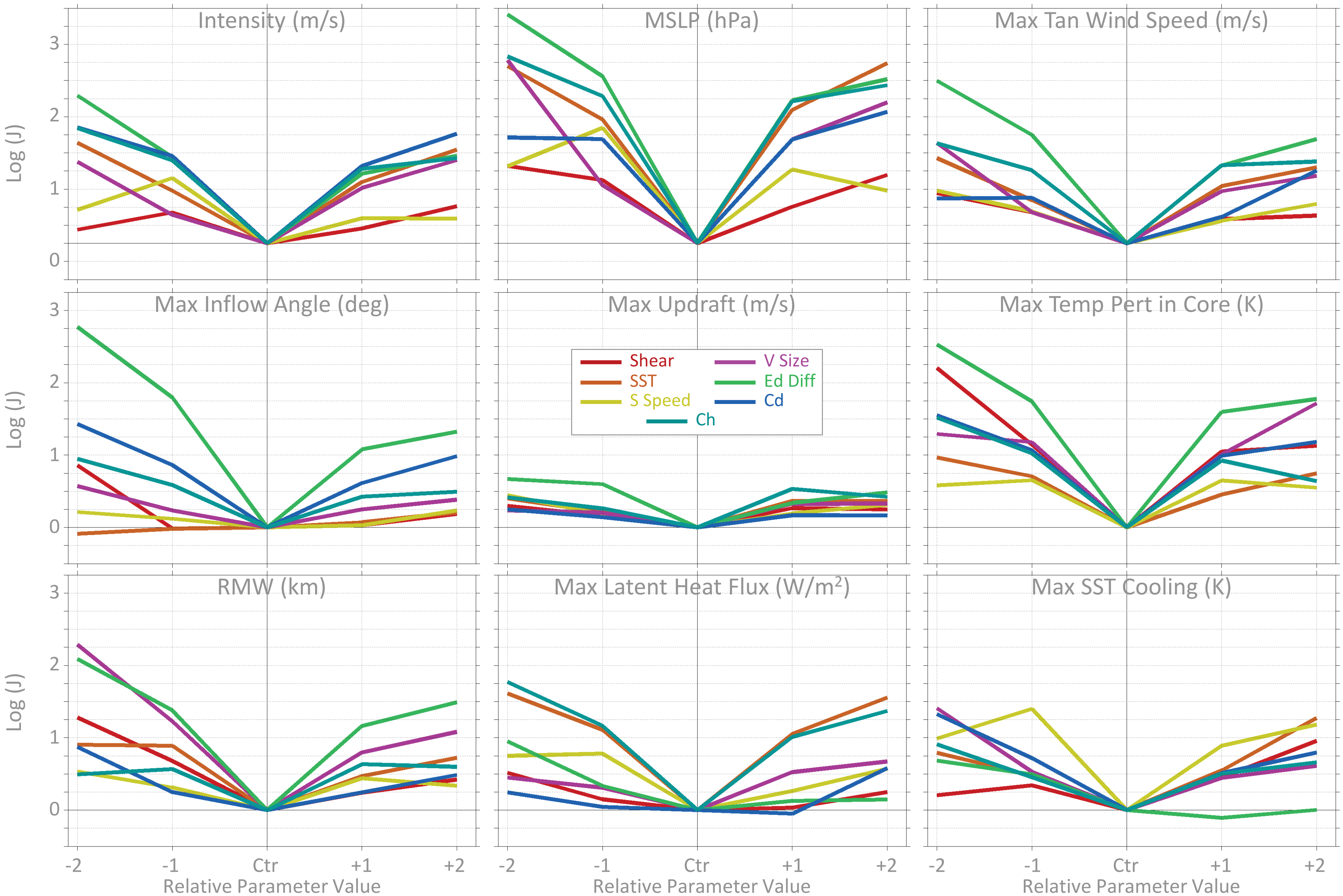
RESPONSE FUNCTION – Similar to Tong and Xue (2008, *MWR*)

- Works for a given metric and parameter combination
  (example: metric = intensity, parameter = shear)
- Compares the time series of the metric from a run with a realization of the parameter perturbation vs. the control run
  (example: realization of shear = 12 m/s)
- Differences are normalized by the variance of the control time series for a fair comparison
- For display convenience, $\log_{10}(J)$ will be plotted

$$J_{p,r}^{M} = \frac{1}{\left(\sigma_{c}^{M}\right)^{2}} \left[\frac{1}{N} \sum_{t=1}^{N} \left(M_{p,r}^{t} - M_{c}^{t} \right)^{2} \right]$$

M: Metric (intensity, MSLP, etc.)
p: Parameter (shear, C_d, etc.)
r: Specific realization of parameter perturbation
c: Control
t: Time -> 48-to-120-h hourly output

COMPARATIVE NORMALIZED SENSITIVITY



FUTURE PLANS

- Sensitivity to initial intensity
- Sensitivity to environmental moisture
- Parameter calibration
- Multi-parameter ensemble runs
- Application to real-data DA

SUMMARY

A coupled, idealized HWRF system is built to work with shear environments and any specified initial vortex

A realistic, steady-state control run is obtained that is in good agreement with observed PBL and SL structures

Significant sensitivity to initial vortex structure is observed

Comparable sensitivity to environment, initial vortex, and PBL/SL parameterizations is demonstrated

REFERENCES

Aksoy, A., S. D. Aberson, T. Vukicevic, K. J. Sellwood, S. Lorsolo, and X. Zhang, 2013: Assimilation of high-resolution tropical cyclone observations with an ensemble Kalman filter using NOAA/AOML/HRD's HEDAS: Evaluation of the 2008-2011 vortex-scale analyses. *Mon. Wea. Rev.*, **141**, 1842-1865.

Bao, J.-W., S. G. Gopalakrishnan, S. A. Michelson, F. D. Marks, and M. T. Montgomery, 2012: Impact of physics representations in the HWRFX on simulated hurricane structure and pressure-wind relationships. *Mon. Wea. Rev.*, **140**, 3278-3299.

Dunion, J. P., 2011: Rewriting the Climatology of the Tropical North Atlantic and Caribbean Sea Atmosphere. *J. Climate*, **24**, 893–908.

Hawkins, H. F. and S. M. Imbembo, 1976: The structure of a small, intense hurricane – Inez 1966. *Mon. Wea. Rev.*, **104**, 418-442.

Hawkins, H. F. and D. T. Rubsam, 1968: Hurricane Hilda, 1964. II. Structure and budgets of the hurricane on October 1, 1964. *Mon. Wea. Rev.*, **96**, 617-636.

La Seur, N. E. and H. F. Hawkins, 1963: An analysis of Hurricane Cleo (1958) based on data from research reconnaissance aircraft. *Mon. Wea. Rev.*, **91**, 694-709.

Zhang, J. and E. W. Uhlhorn, 2012: Hurricane sea-surface inflow angle and an observation-based parametric model. *Mon. Wea. Rev.*, **140**, 3587-3605.

Tong, M., and M. Xue, 2008: Simultaneous estimation of microphysical parameters and atmospheric state with simulated radar data and ensemble square root Kalman filter. Part I: Sensitivity Analysis and Parameter Identifiability. *Mon. Wea. Rev.*, **136**, 1630–1648.