High-Resolution Data Assimilation of Ocean Vector Winds for Tropical Cyclone Prediction Using a Coupled Atmosphere-Ocean Model

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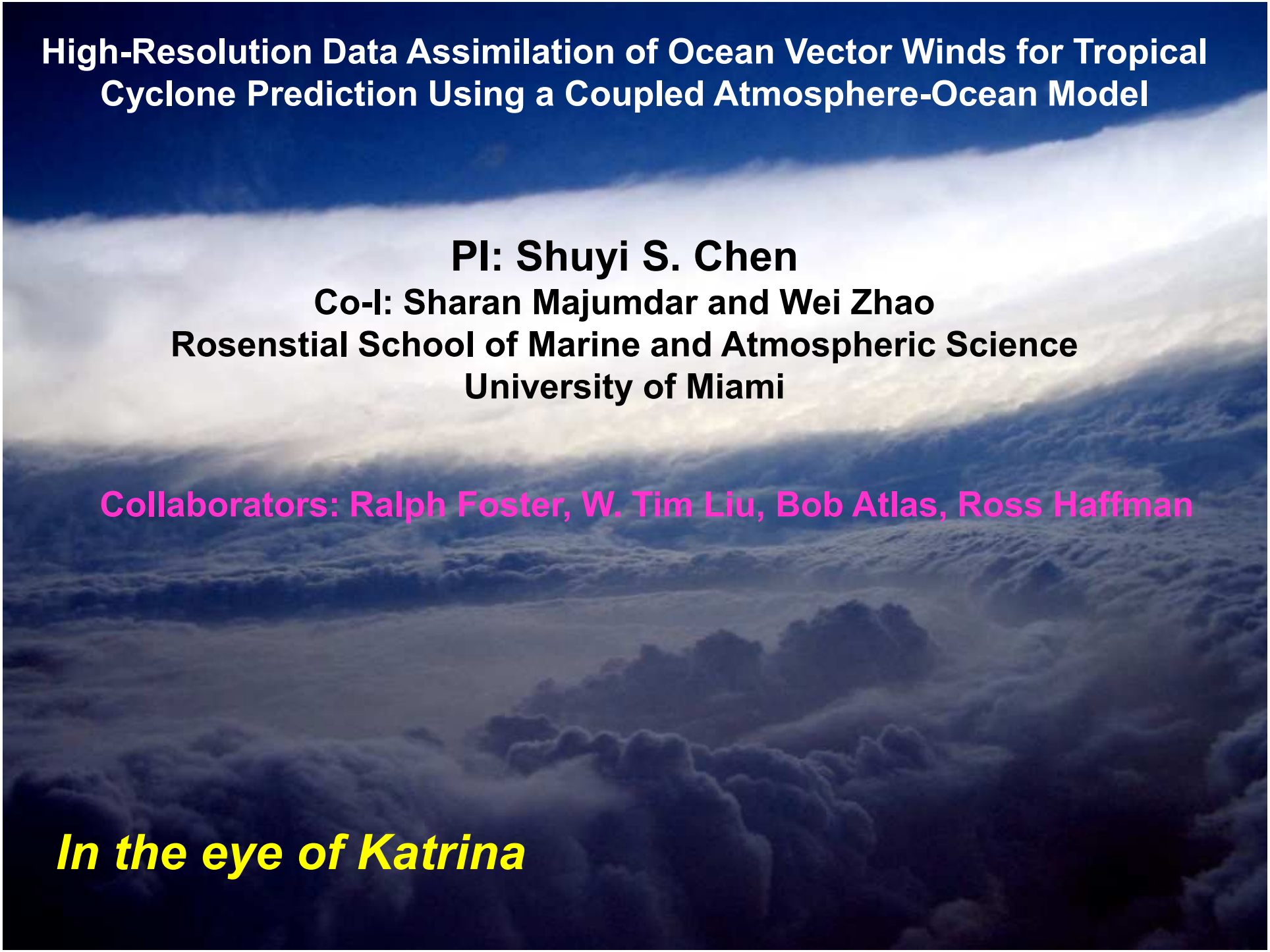
University of Miami

Collaborators: Ralph Foster, W. Tim Liu, Bob Atlas, Ross Haffman



In the eye of Katrina

OBJECTIVES

To develop initialization method and data assimilation for high-resolution (~1 km) hurricane research and future prediction model (e.g., WRF and fully coupled atmosphere-wave-ocean model) using scatterometer winds.

- National Science Board: Toward a National Agenda for Hurricane Science and Engineering (2006)
  NOAA Science Advisory Board: Hurricane Intensity Research Working Group Report (2006)

Hurricane Fabian (2003)

Aug 30 0000 UTC	1200 UTC	Aug 31 0000 UTC	1200 UTC	Sep 01 0000 UTC	1200 UTC	Sep 02 0000 UTC	1200 UTC	Sep 03 0000 UTC	1200 UTC	Sep 04 0000 UTC	1200 UTC	Sep 05 0000 UTC	1200 UTC	Sep 06 0000 UTC
	SW 0135	SW 1359	(SW) 0110	(SW) 1334	(SW) 0225	SW 1450		SW 1424	(SW) 0135		SW 0251	SW 1515	SW 0225	SW 1450
	QS 0901	QS 2125	(QS) 0835	(QS) 2059		QS 2213	QS 0924	QS 2148		(QS) 2303		QS 2236	QS 0946	

Full

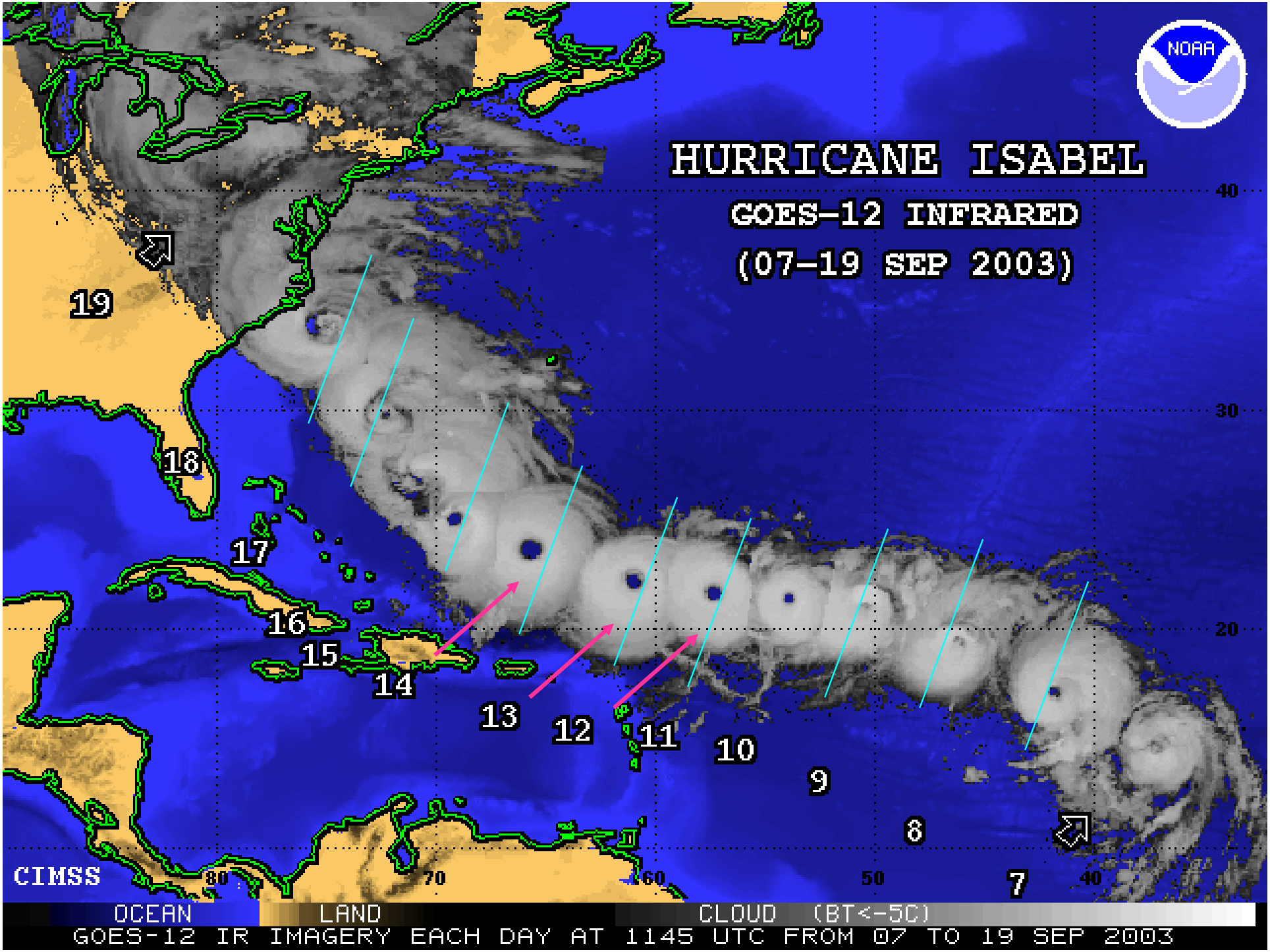
Partial

Hurricane Isabel (2003)

Sep 09 0000 UTC	1200 UTC	Sep 10 0000 UTC	1200 UTC	Sep 11 0000 UTC	1200 UTC	Sep 12 0000 UTC	1200 UTC	Sep 13 0000 UTC	1200 UTC	Sep 14 0000 UTC	1200 UTC	Sep 15 0000 UTC	1200 UTC	Sep 16 0000 UTC	1200 UTC	Sep 17 0000 UTC	1200 UTC	Sep 18 0000 UTC	1200 UTC
SW 1335	(SW) 0045	(SW) 1309	(SW) 0200	SW 1425	SW 0135	SW 1400		(SW) 1515	SW 0226	SW 1450	SW 0201	(SW) 1425	(SW) 0316	SW 1541	SW 0251	SW 1515	SW 0226	(SW) 1450 (SW) 1631	
QS 2053	(QS) 0803		QS 0917	QS 2141	QS 0851	(QS) 2115	(QS) 1006	(QS) 2230	QS 0940	QS 2204	(QS) 0914	(QS) 2319	QS 1029	QS 2253		(QS) 2226	(QS) 0937	QS 2341	QS 1051

Full

Partial

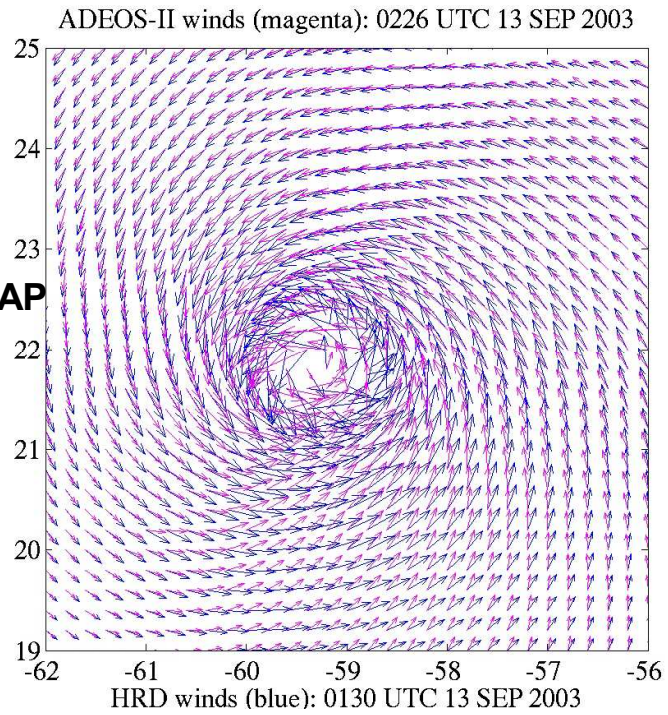

HURRICANE ISABEL
GOES-12 INFRARED
(07-19 SEP 2003)
NOAA
19
18
17
16
15
14
13
12
11
10
9
8
7
40
30
20
80
70
60
50
40
CIMSS
OCEAN
LAND
CLOUD (BT<-5C)
GOES-12 IR IMAGERY EACH DAY AT 1145 UTC FROM 07 TO 19 SEP 2003

Comparisons of Three Model Functions +BYU high-res and HWind

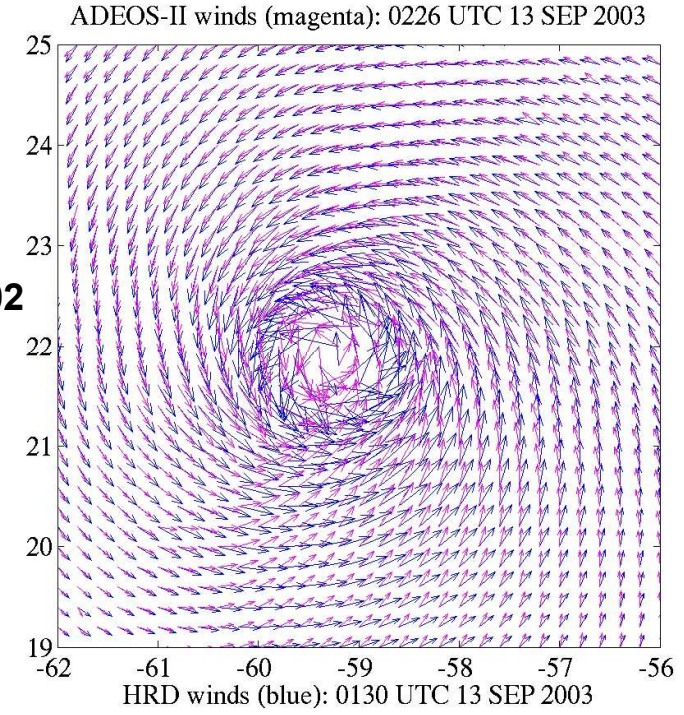
- QS-IWRAP (25km)
- QSCAT1 (25km)
- SCTC02 (25km)
- BYU High-Res (2km)
- HWIND (2km)

Isabel SeaWinds

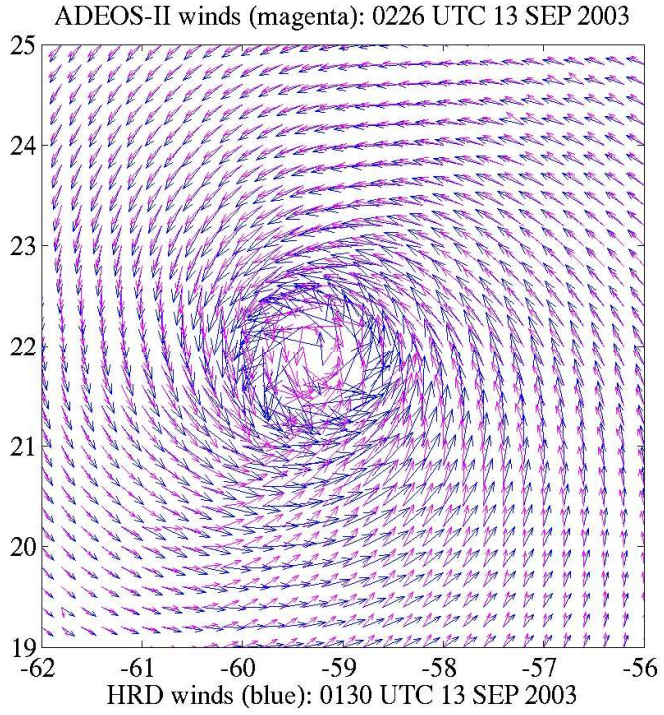
QS_IWRAP



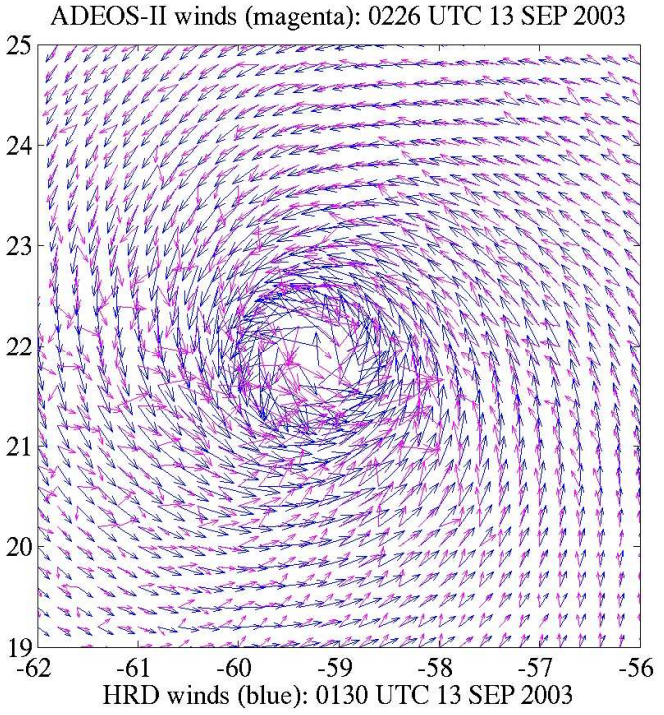
QSTC02



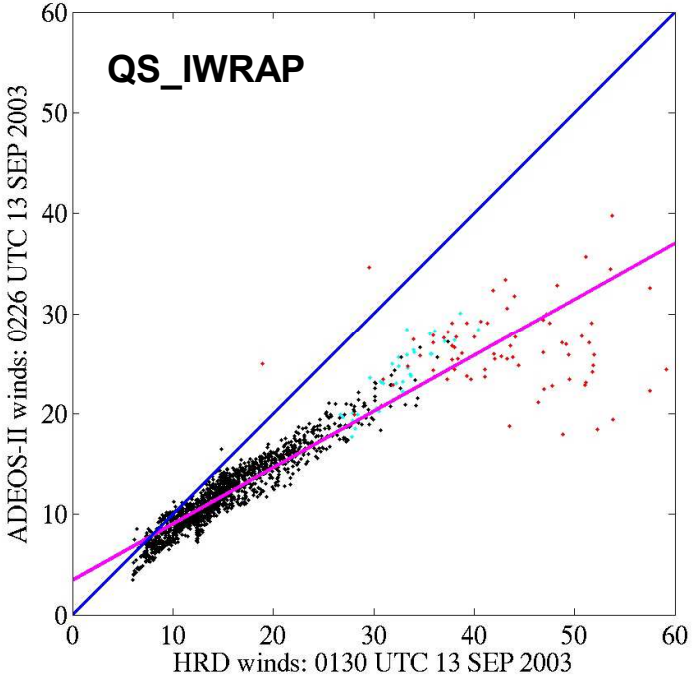
QSCAT1

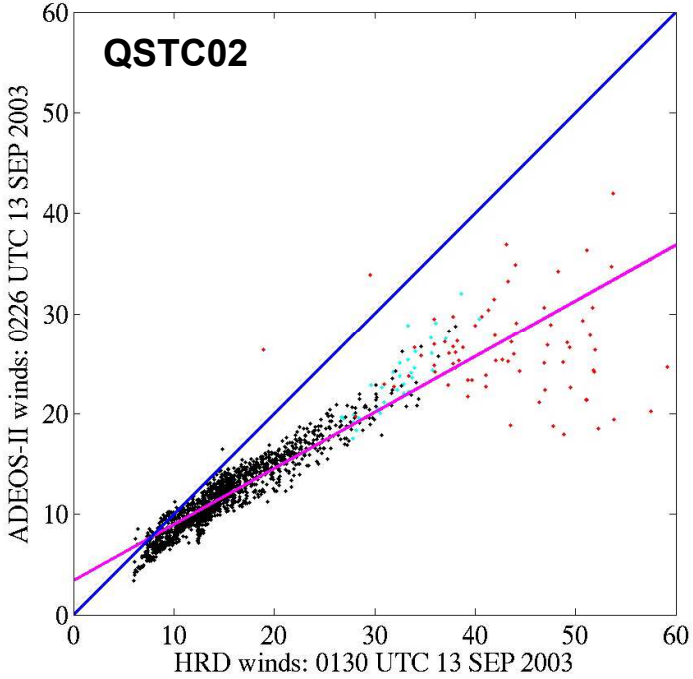


BYU



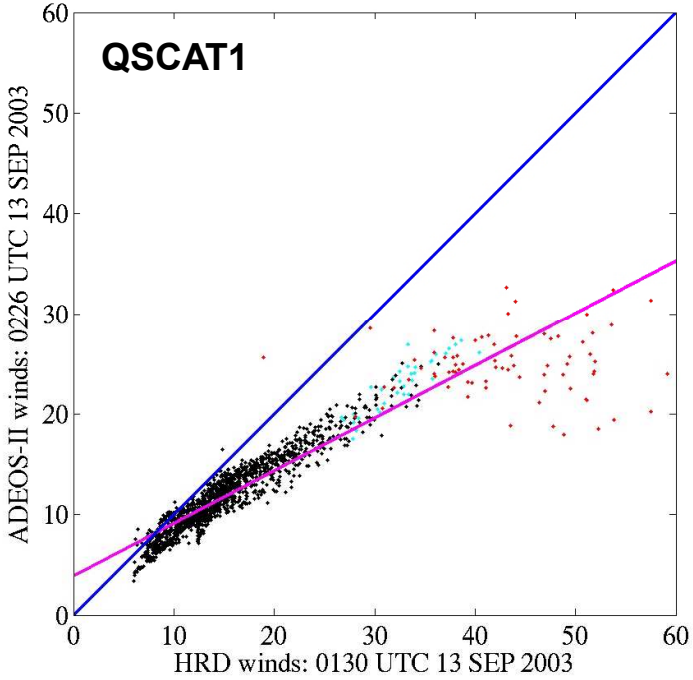
Isabel

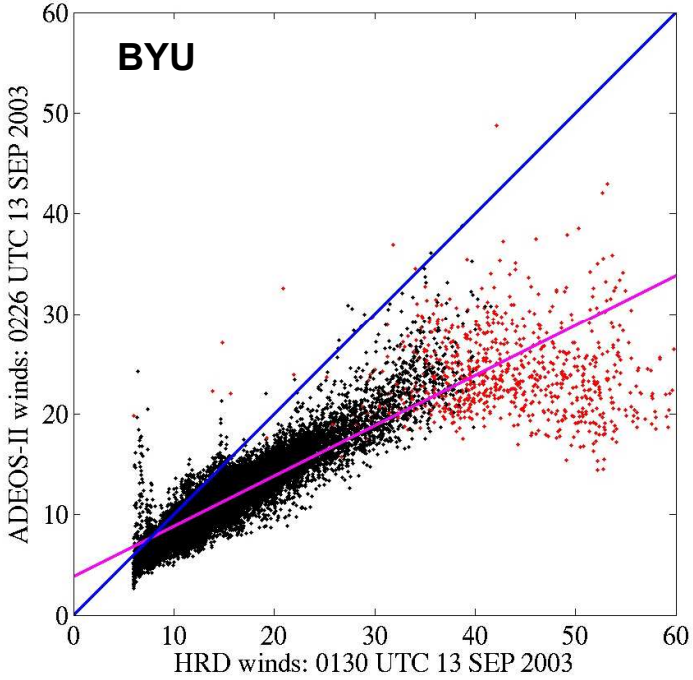


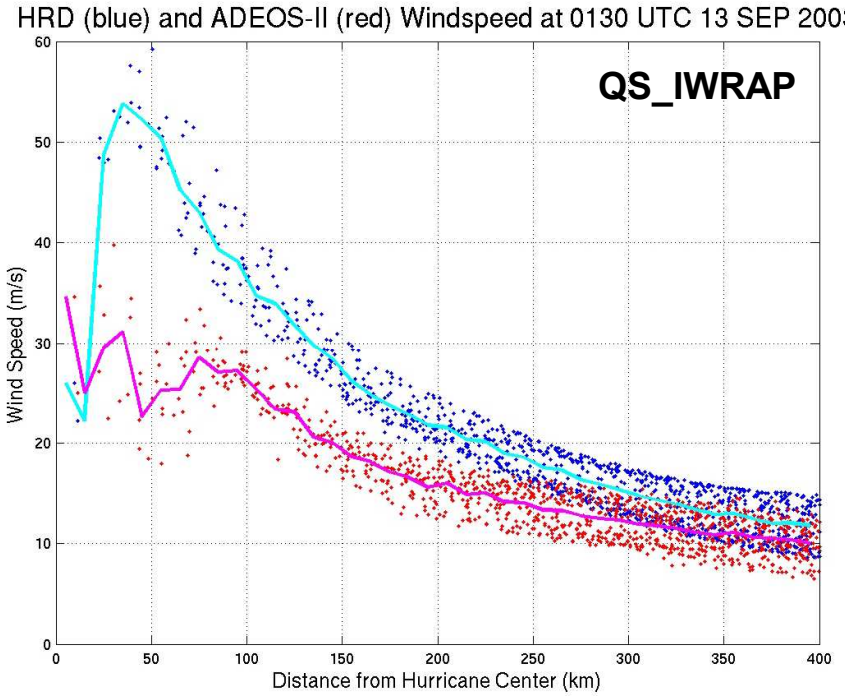


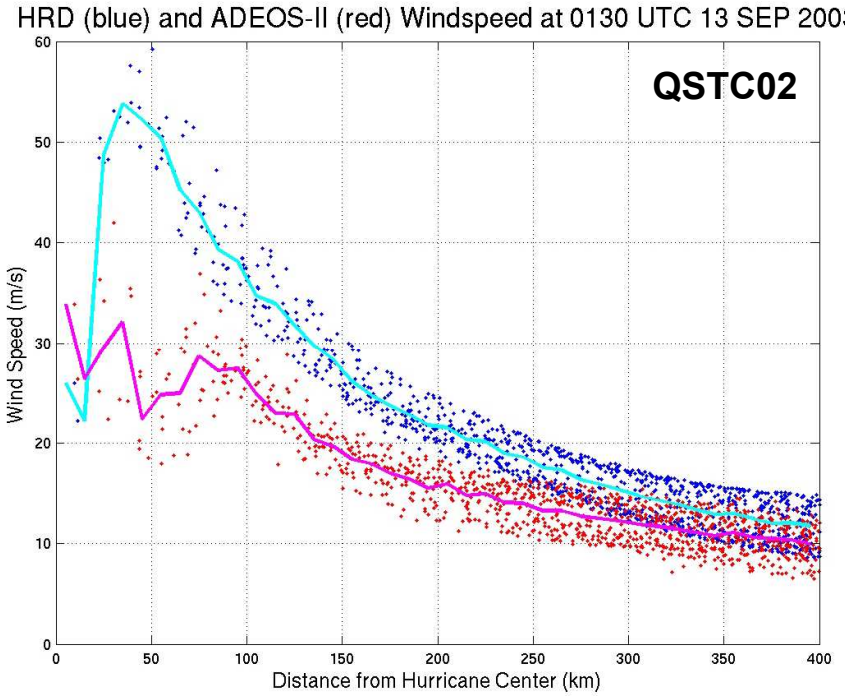
Rain flagged

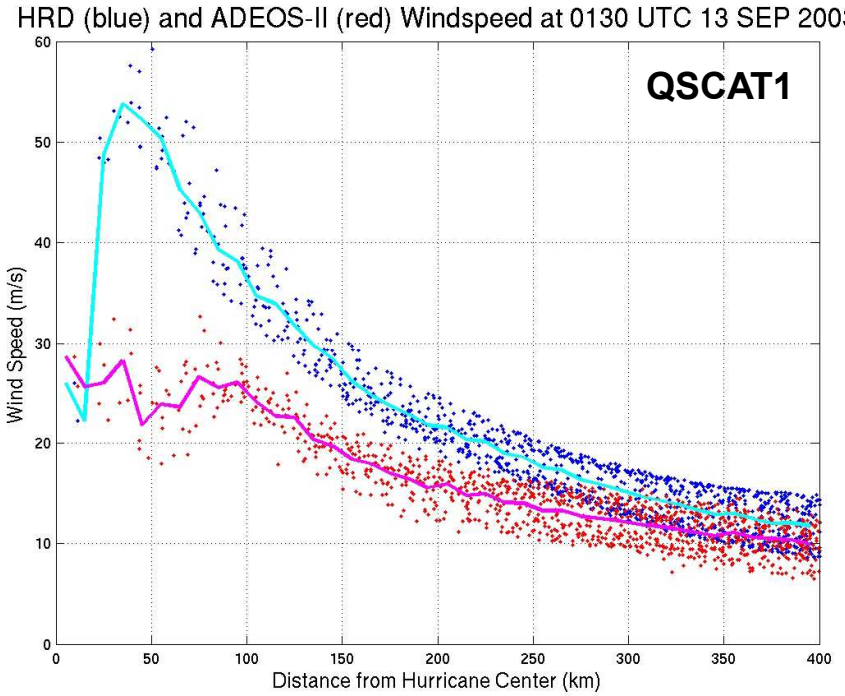
Within 100 km radius

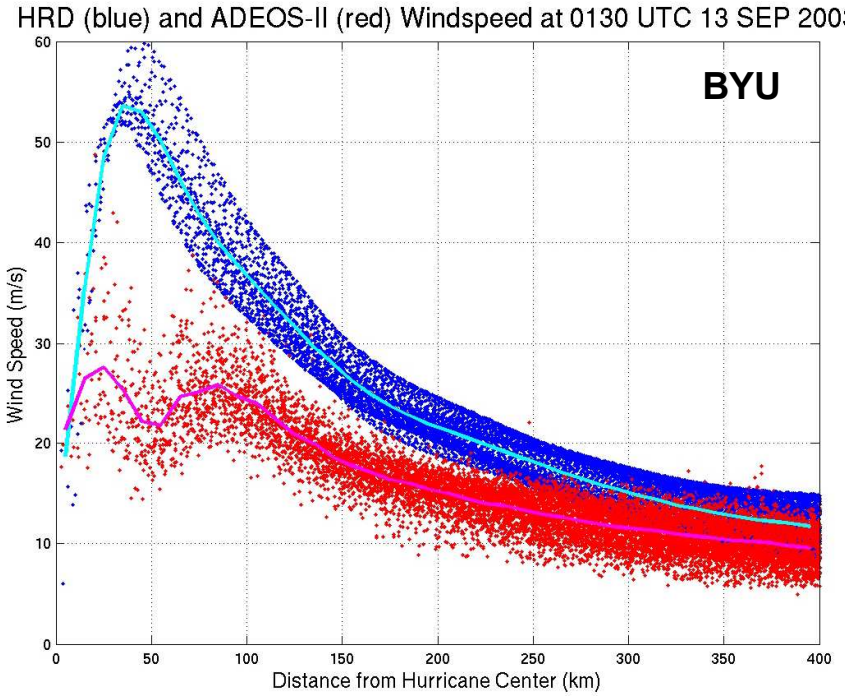


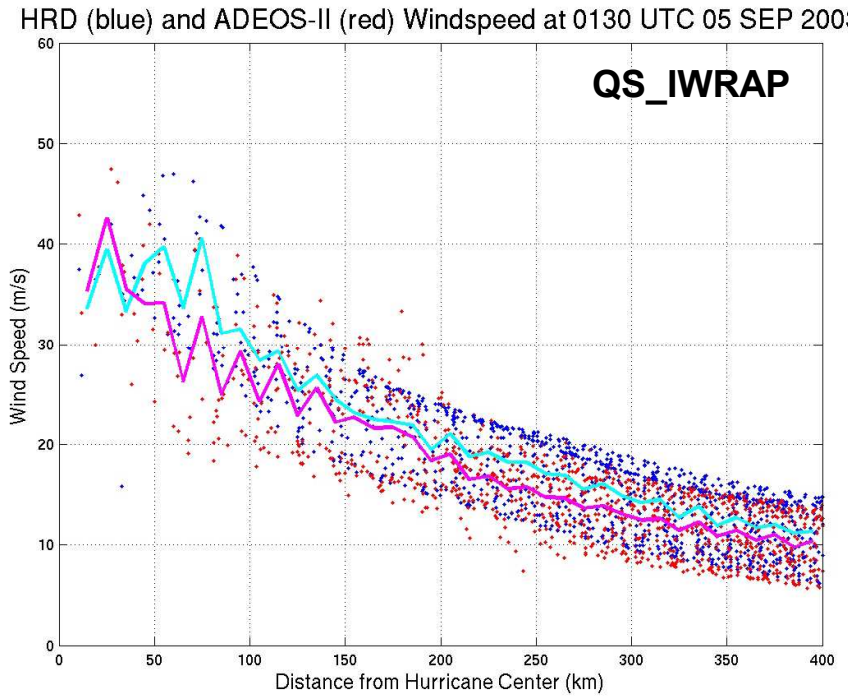


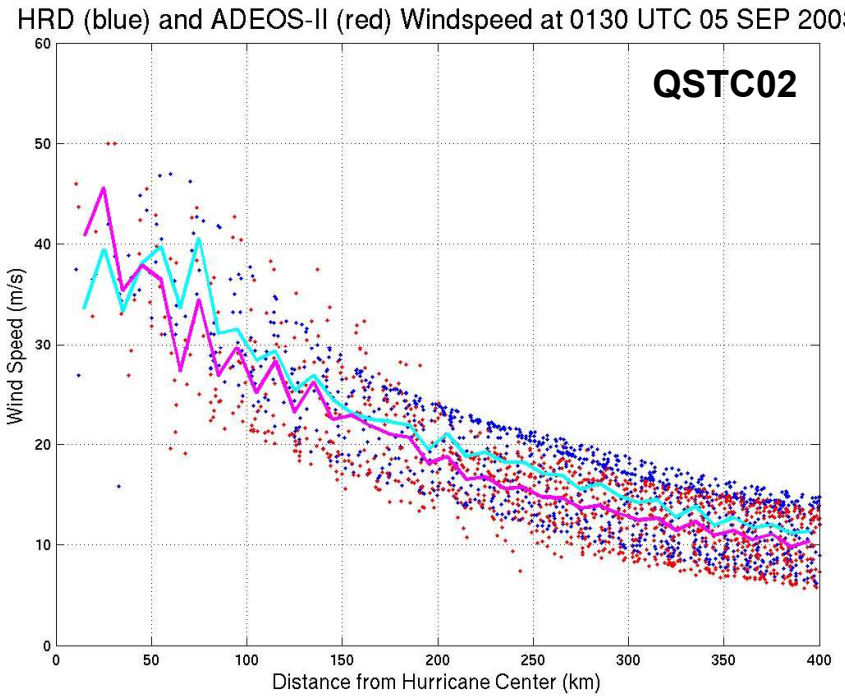

HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 13 SEP 2003
QS_IWRAP
Wind Speed (m/s)
Distance from Hurricane Center (km)

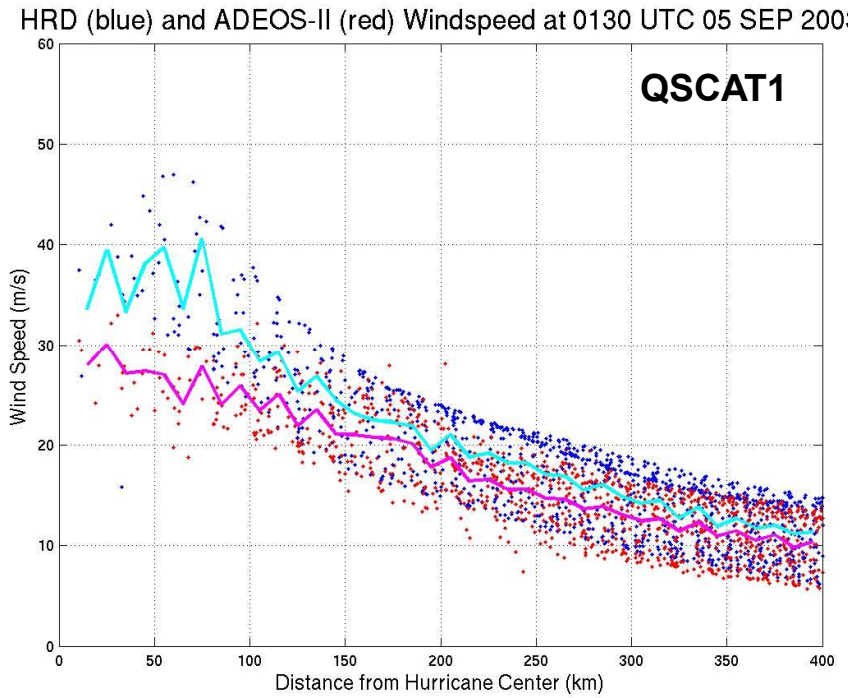

HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 13 SEP 2003
QSTC02
Wind Speed (m/s)
Distance from Hurricane Center (km)

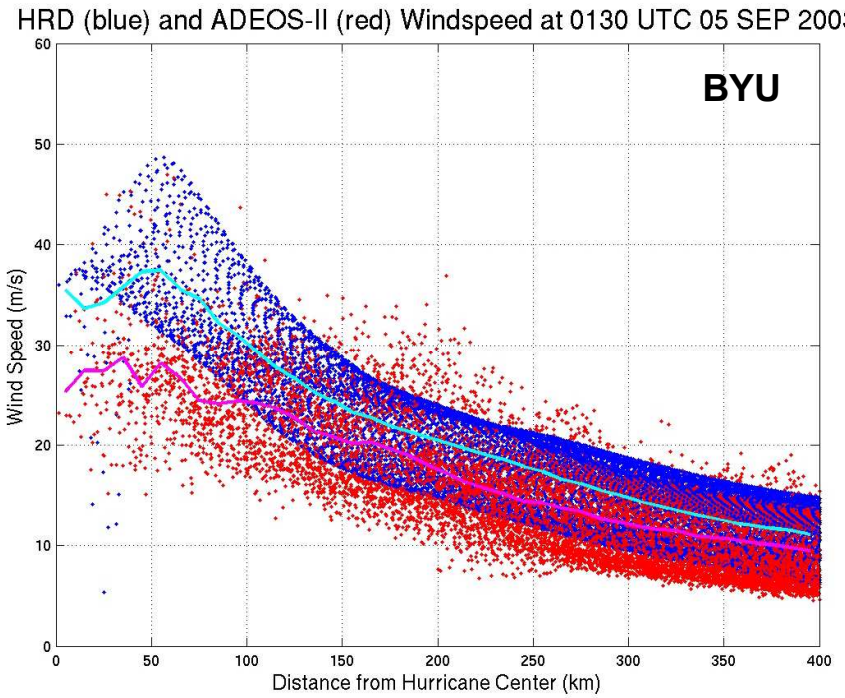

HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 13 SEP 2003
QSCAT1
Wind Speed (m/s)
Distance from Hurricane Center (km)

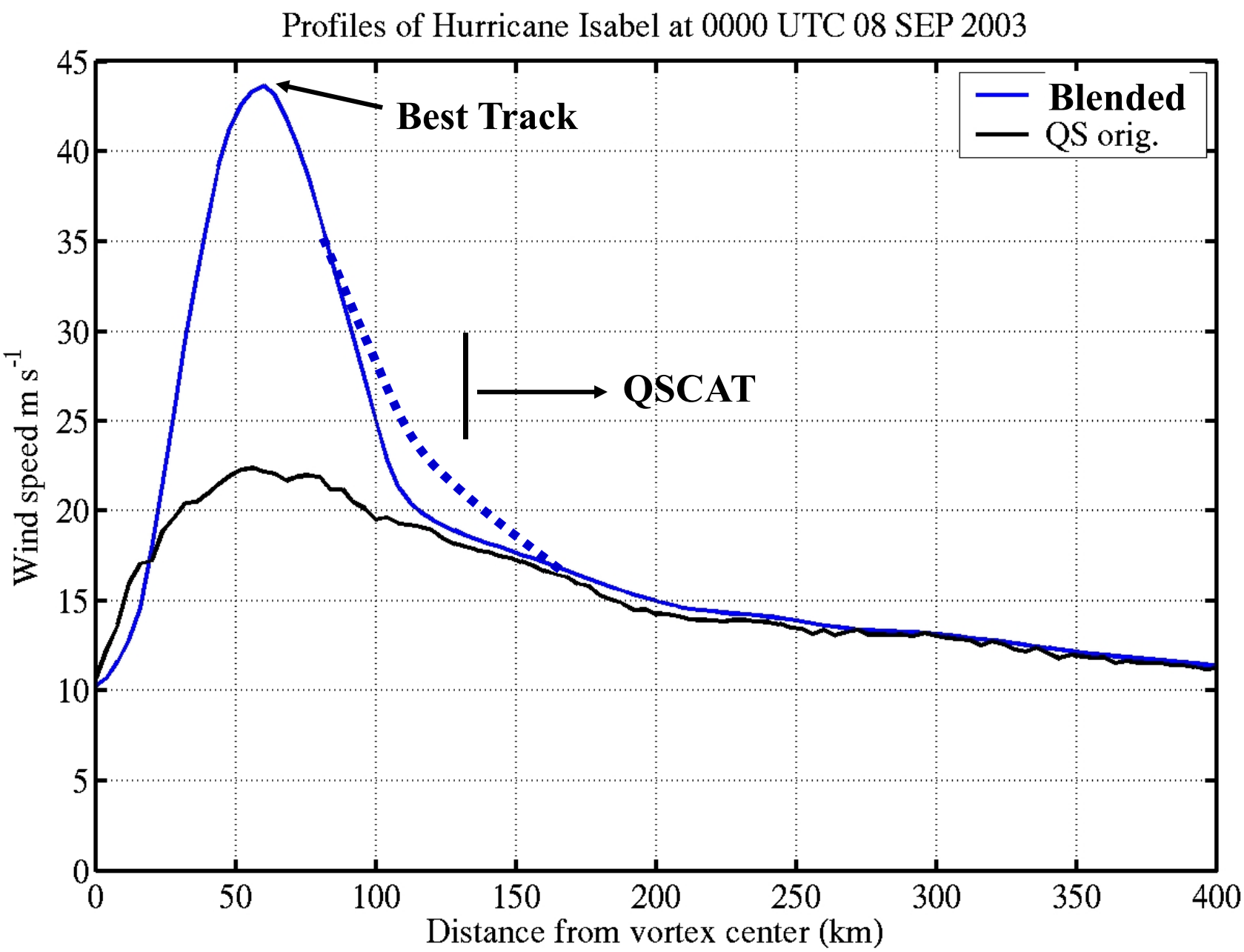

HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 13 SEP 2003
BYU
Wind Speed (m/s)
Distance from Hurricane Center (km)


HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 05 SEP 2003
QS_IWRAP
Wind Speed (m/s)
Distance from Hurricane Center (km)


HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 05 SEP 2003
QSTC02
Wind Speed (m/s)
Distance from Hurricane Center (km)

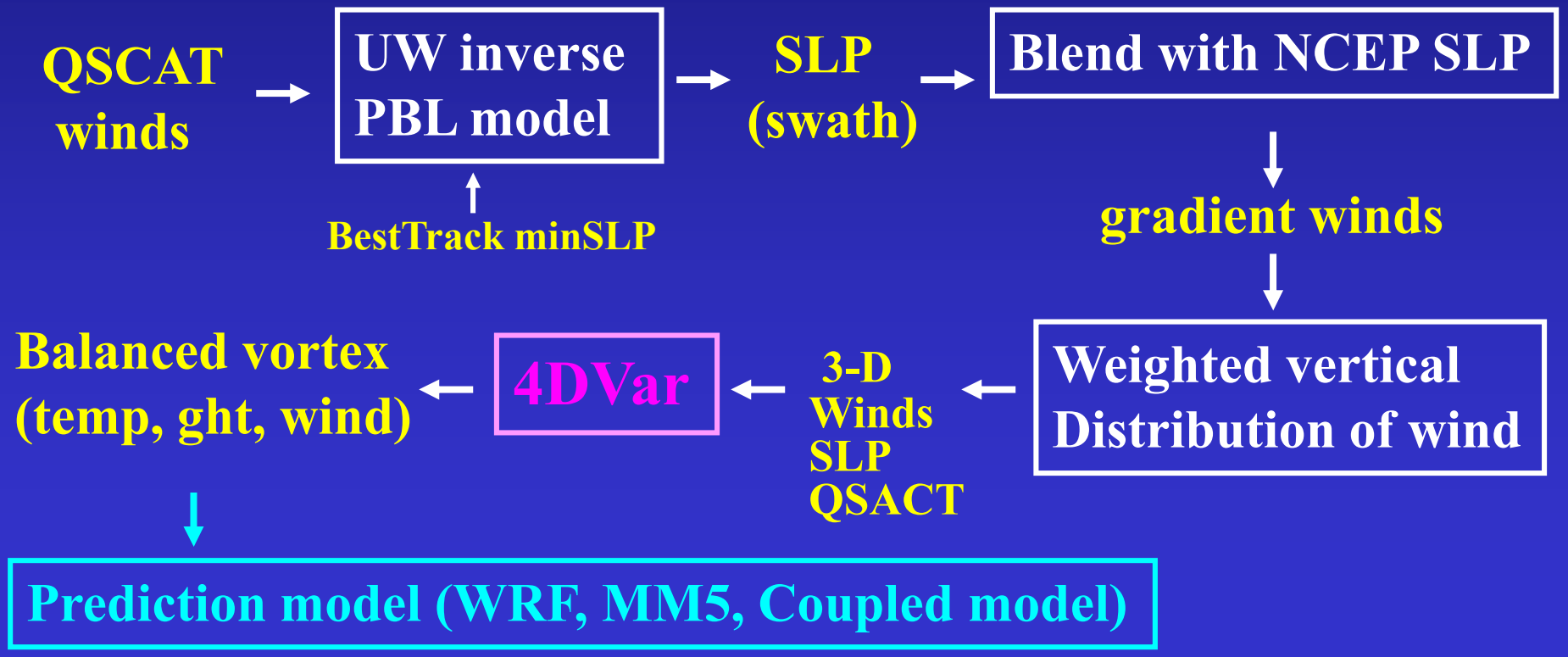

HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 05 SEP 2003
QSCAT1
Wind Speed (m/s)
Distance from Hurricane Center (km)


HRD (blue) and ADEOS-II (red) Windspeed at 0130 UTC 05 SEP 2003
BYU
Wind Speed (m/s)
Distance from Hurricane Center (km)


Profiles of Hurricane Isabel at 0000 UTC 08 SEP 2003
Best Track
QSCAT
Blended
QS orig.
Wind speed m s-1
Distance from vortex center (km)
0
5
10
15
20
25
30
35
40
45
0
50
100
150
200
250
300
350
400

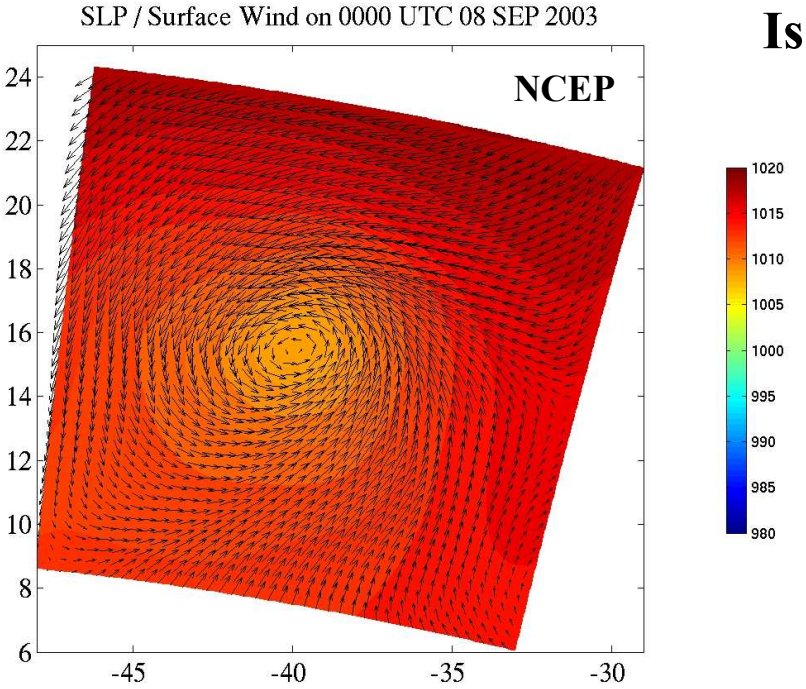
Initialization Method

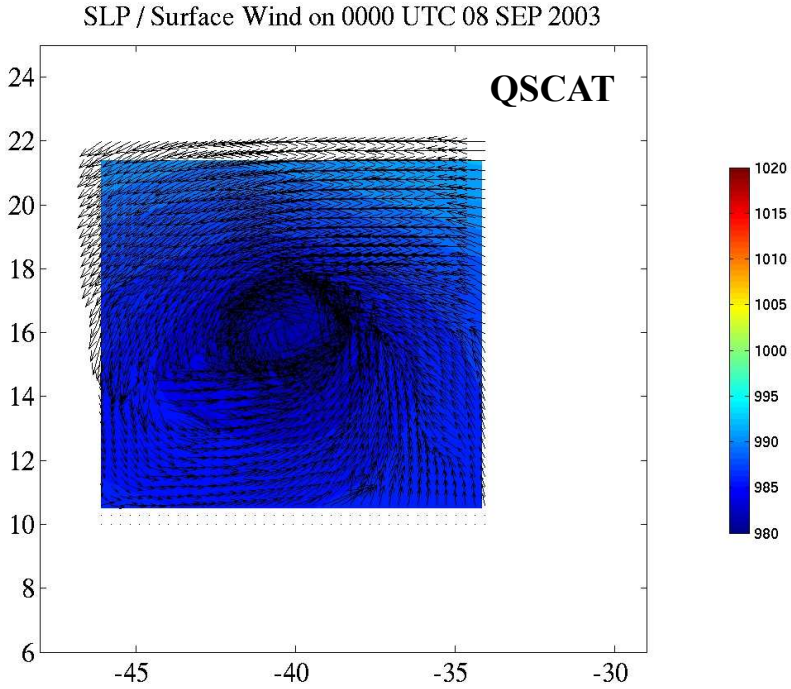
- Construct 3-D vortex using QuikSCAT winds
- Generate dynamically/thermodynamically balanced initial vortex using 4DVar

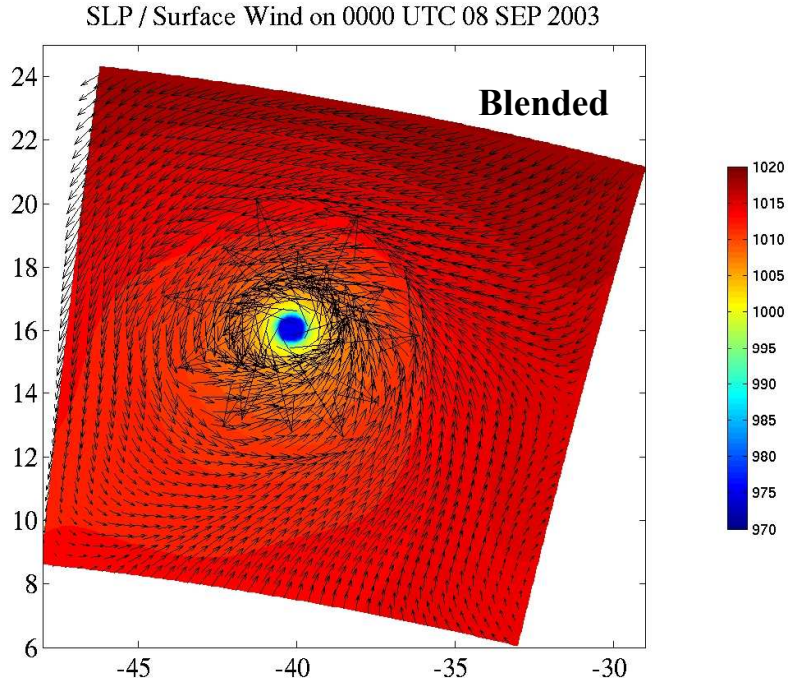


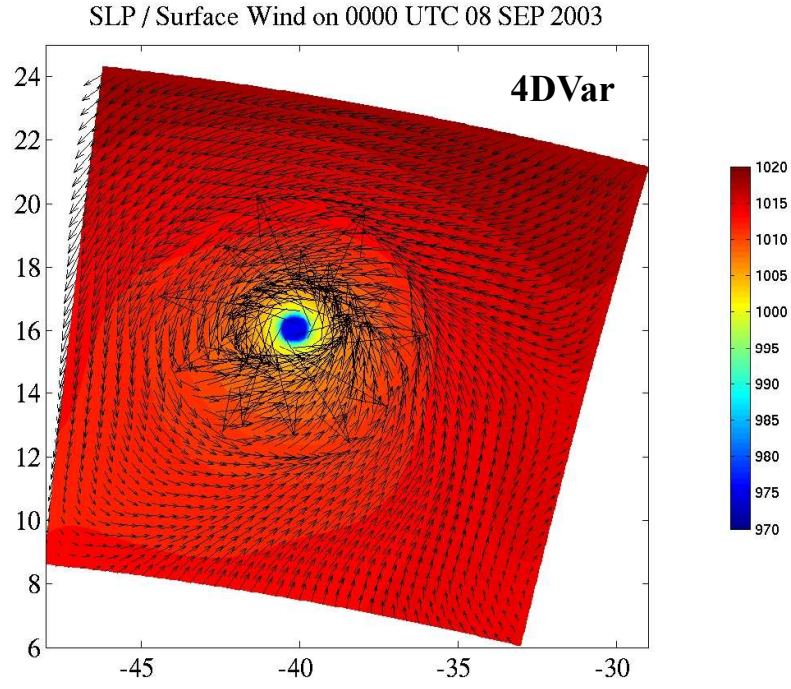
Experiments of Hurricanes Fabian and Isabel (2003)

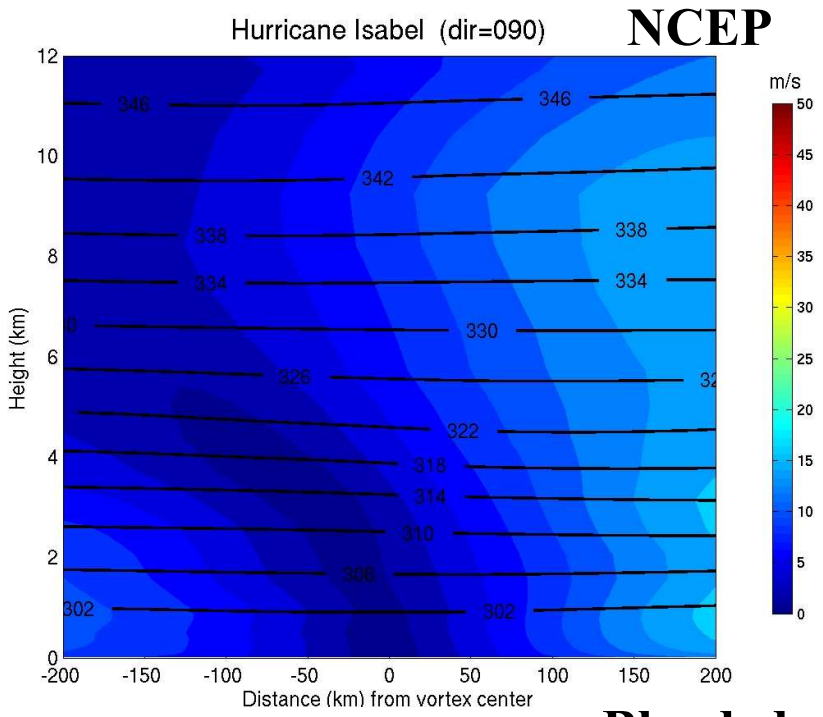
Isabel


SLP / Surface Wind on 0000 UTC 08 SEP 2003
NCEP
24
22
20
18
16
14
12
10
8
6
-45
-40
-35
-30
1020
1015
1010
1005
1000
995
990
985
980

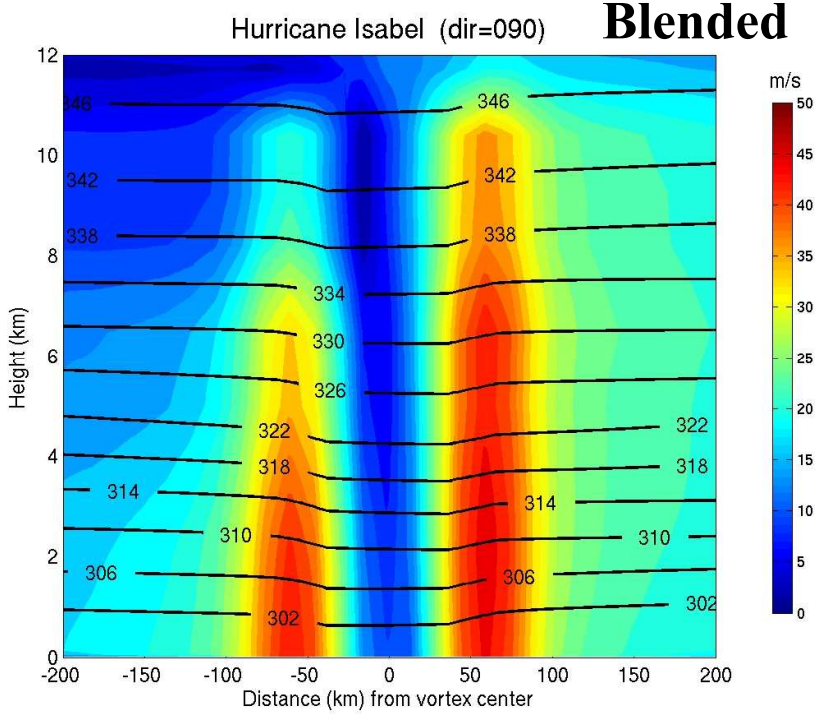

SLP / Surface Wind on 0000 UTC 08 SEP 2003
QSCAT
24
22
20
18
16
14
12
10
8
6
-45
-40
-35
-30
1020
1015
1010
1005
1000
995
990
985
980

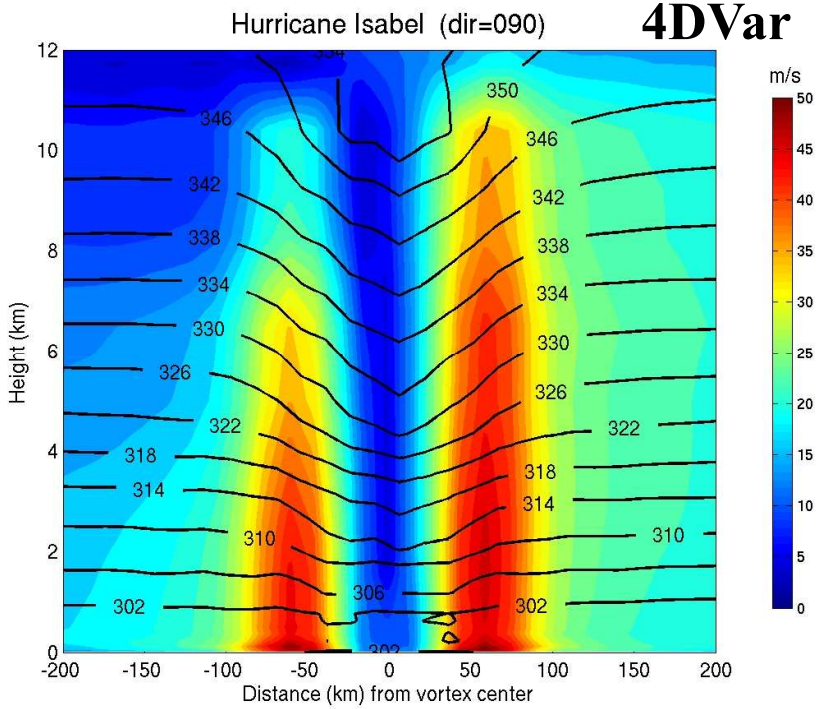

SLP / Surface Wind on 0000 UTC 08 SEP 2003
Blended
24
22
20
18
16
14
12
10
8
6
-45
-40
-35
-30
1020
1015
1010
1005
1000
995
990
985
980
975
970

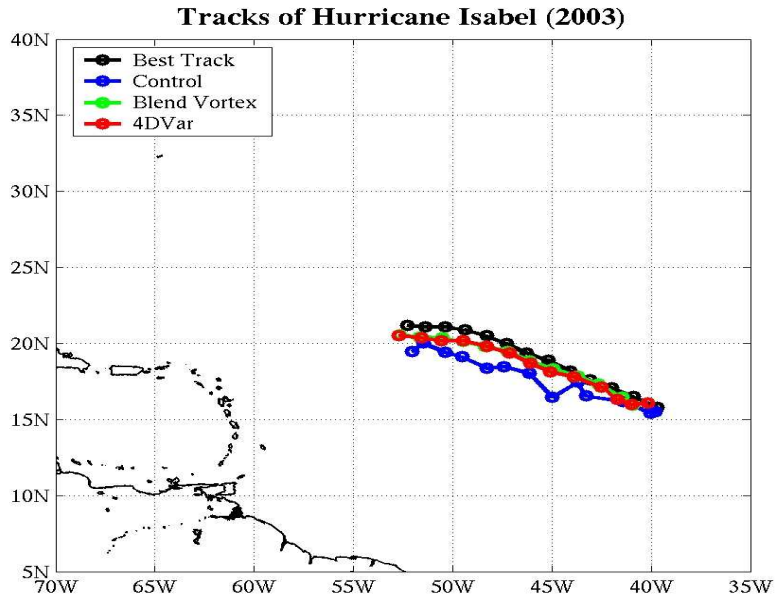

SLP / Surface Wind on 0000 UTC 08 SEP 2003
4DVar
24
22
20
18
16
14
12
10
8
6
-45
-40
-35
-30
1020
1015
1010
1005
1000
995
990
985
980
975
970

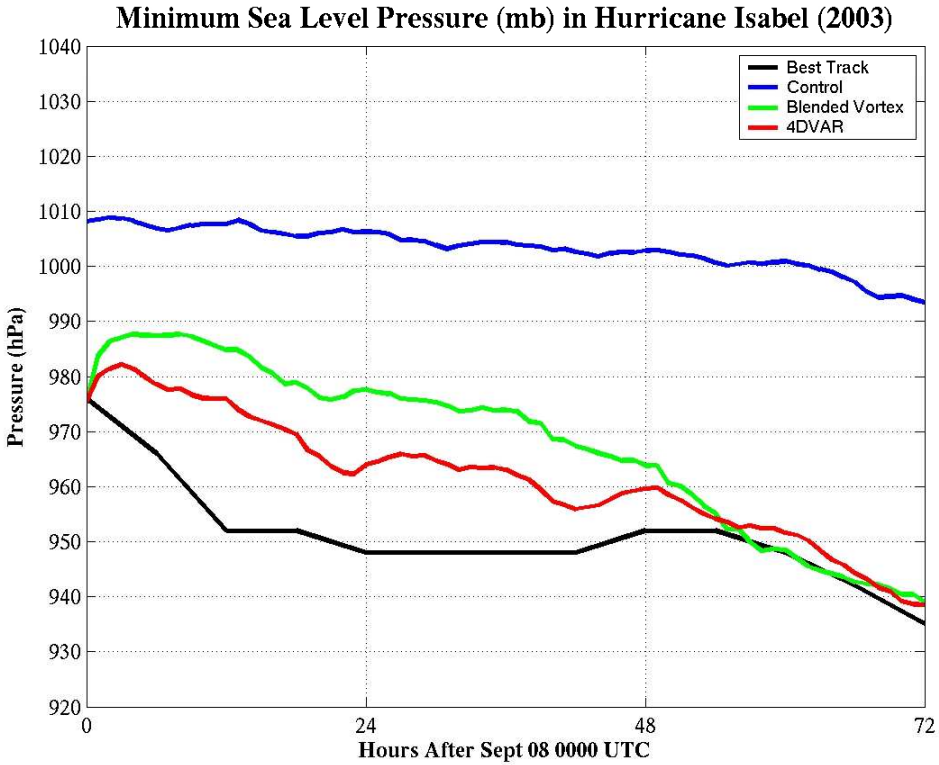


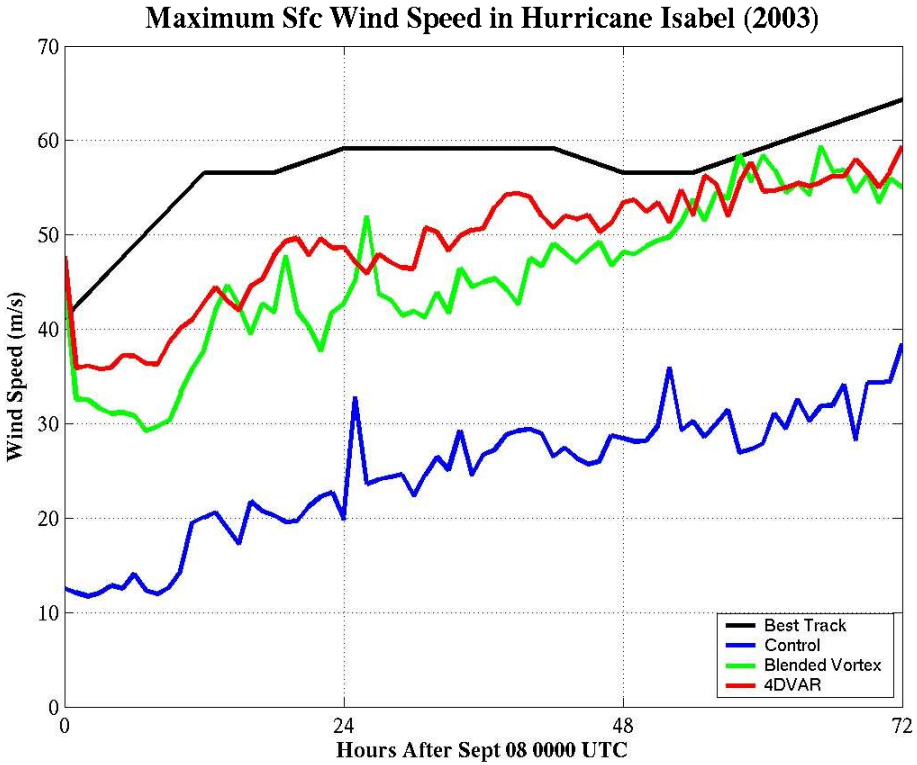
Vertical cross sections of potential temperature (black lines) and wind speed (color).



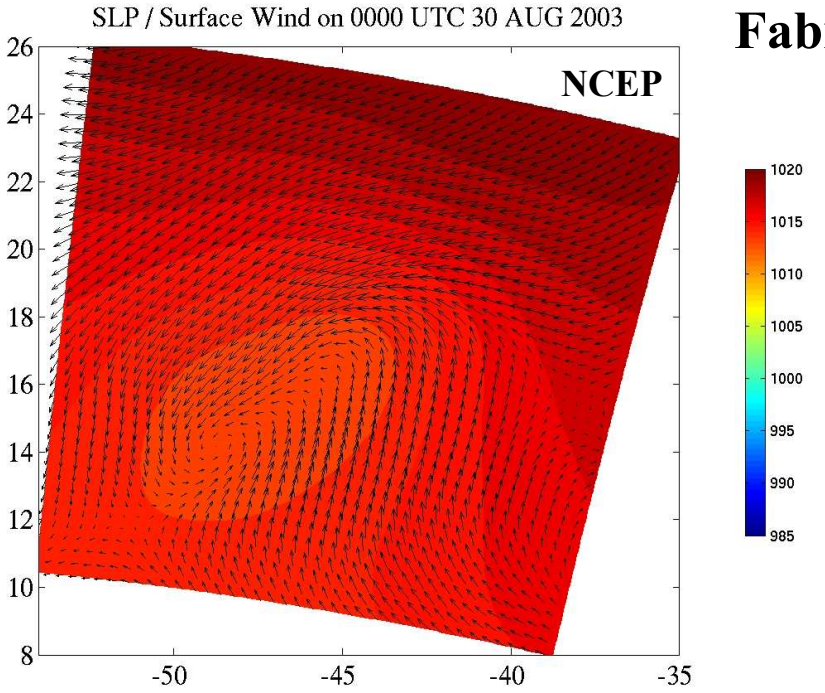


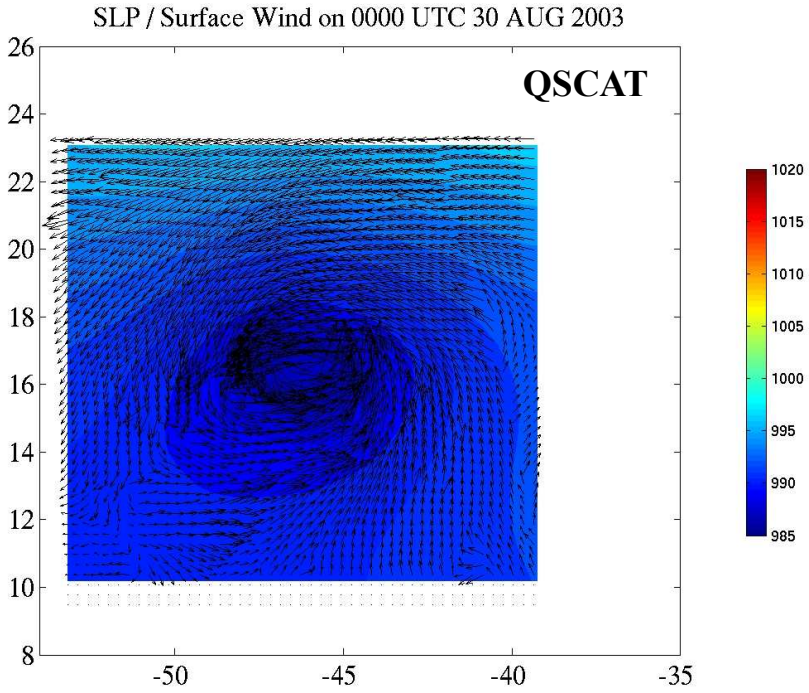

Tracks of Hurricane Isabel (2003)
Best Track
Control
Blend Vortex
4DVar
40N
35N
30N
25N
20N
15N
10N
5N
70W
65W
60W
55W
50W
45W
40W
35W

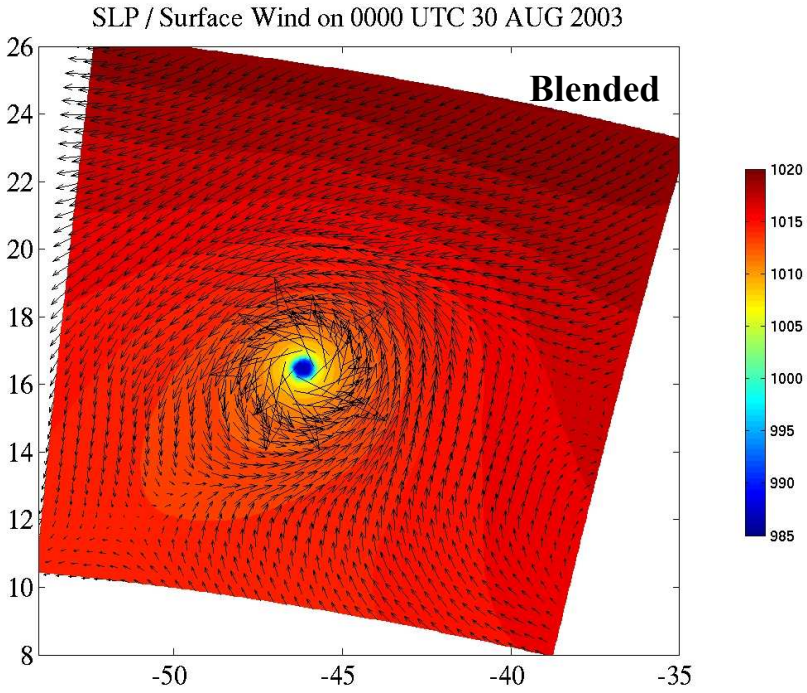

Minimum Sea Level Pressure (mb) in Hurricane Isabel (2003)
Best Track
Control
Blended Vortex
4DVAR
Pressure (hPa)
1040
1030
1020
1010
1000
990
980
970
960
950
940
930
920
0
24
48
72
Hours After Sept 08 0000 UTC

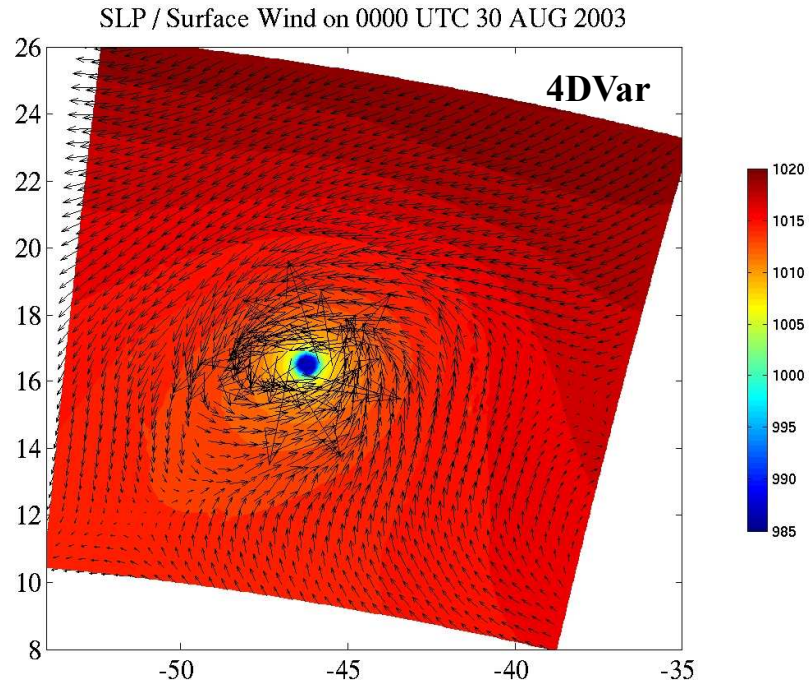

Maximum Sfc Wind Speed in Hurricane Isabel (2003)
Best Track
Control
Blended Vortex
4DVAR
Wind Speed (m/s)
70
60
50
40
30
20
10
0
0
24
48
72
Hours After Sept 08 0000 UTC

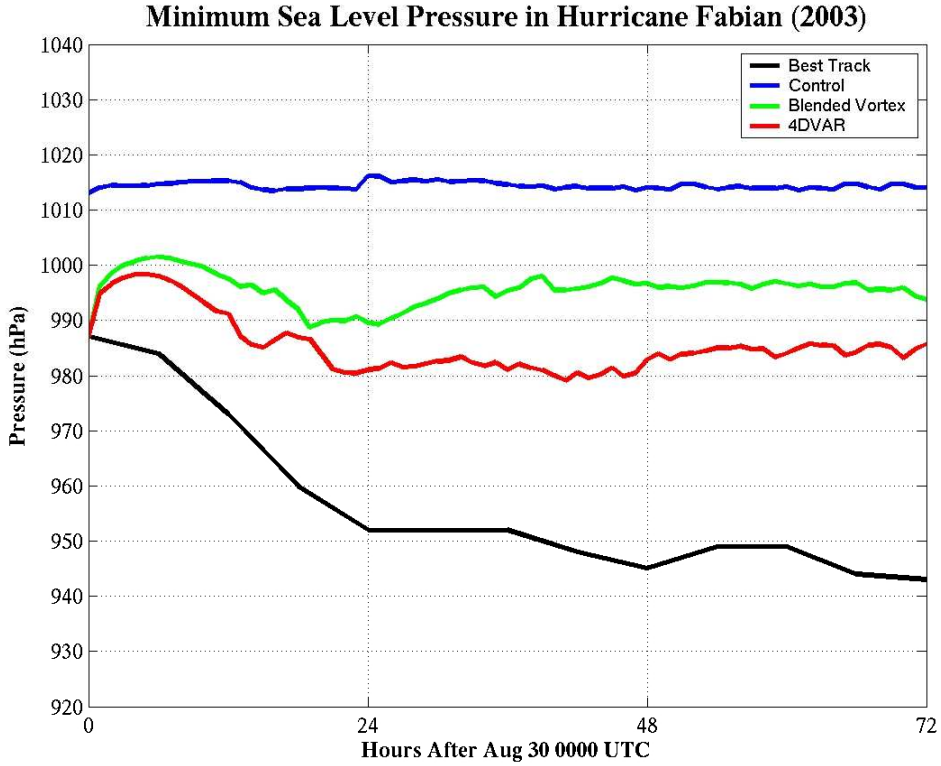
Fabian

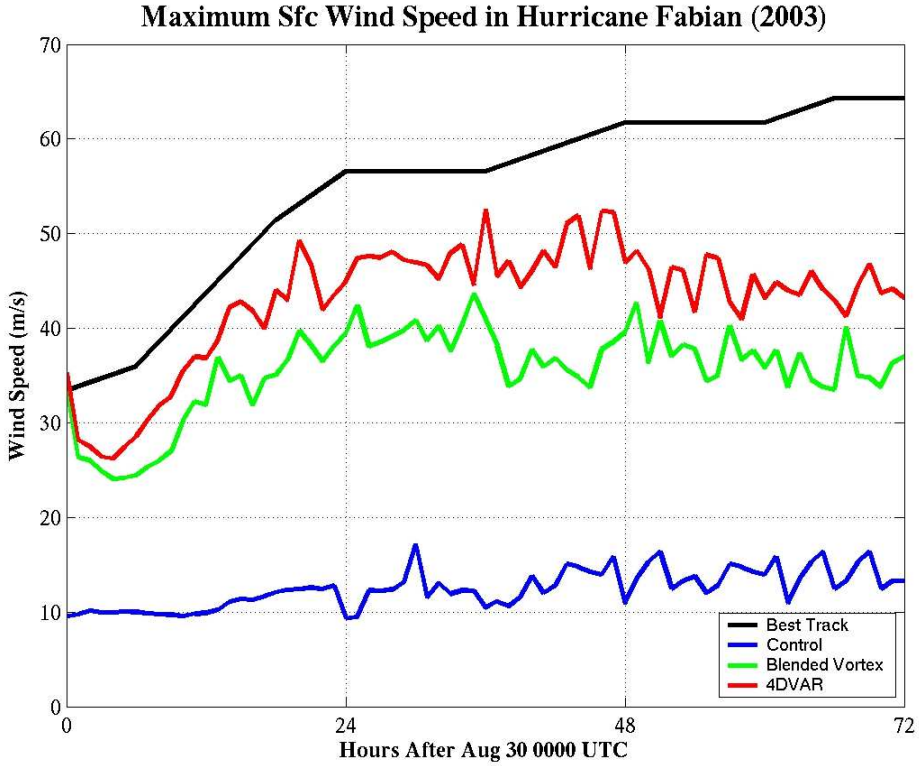

SLP / Surface Wind on 0000 UTC 30 AUG 2003
NCEP
26
24
22
20
18
16
14
12
10
8
-50
-45
-40
-35
1020
1015
1010
1005
1000
995
990
985


SLP / Surface Wind on 0000 UTC 30 AUG 2003
QSCAT
26
24
22
20
18
16
14
12
10
8
-50
-45
-40
-35
1020
1015
1010
1005
1000
995
990
985

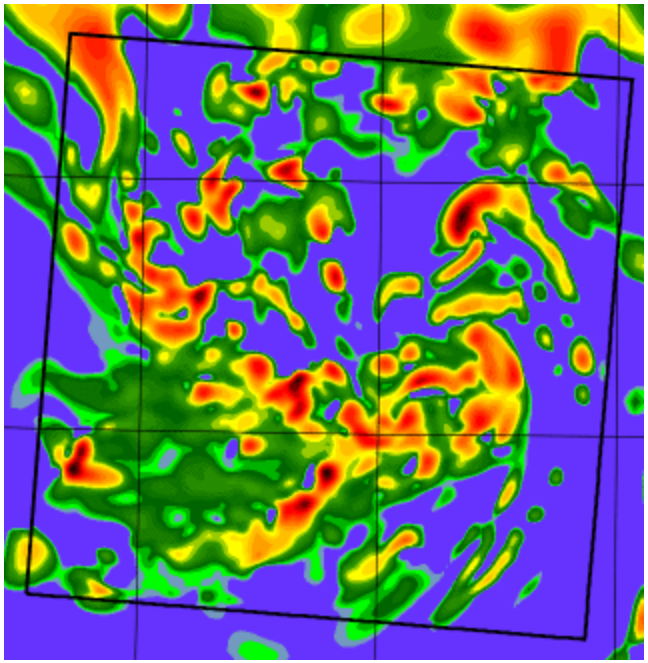

SLP / Surface Wind on 0000 UTC 30 AUG 2003
Blended
26
24
22
20
18
16
14
12
10
8
-50
-45
-40
-35
1020
1015
1010
1005
1000
995
990
985


SLP / Surface Wind on 0000 UTC 30 AUG 2003
4DVar
26
24
22
20
18
16
14
12
10
8
-50
-45
-40
-35
1020
1015
1010
1005
1000
995
990
985

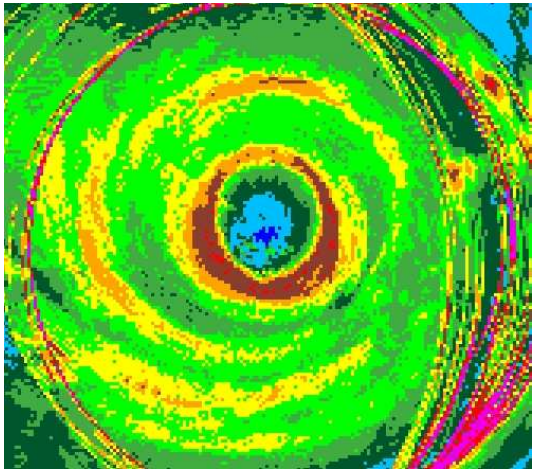

Minimum Sea Level Pressure in Hurricane Fabian (2003)
Pressure (hPa)
Hours After Aug 30 0000 UTC
Best Track
Control
Blended Vortex
4DVAR
1040
1030
1020
1010
1000
990
980
970
960
950
940
930
920
0
24
48
72


Maximum Sfc Wind Speed in Hurricane Fabian (2003)
Wind Speed (m/s)
Hours After Aug 30 0000 UTC
Best Track
Control
Blended Vortex
4DVAR
70
60
50
40
30
20
10
0
0
24
48
72

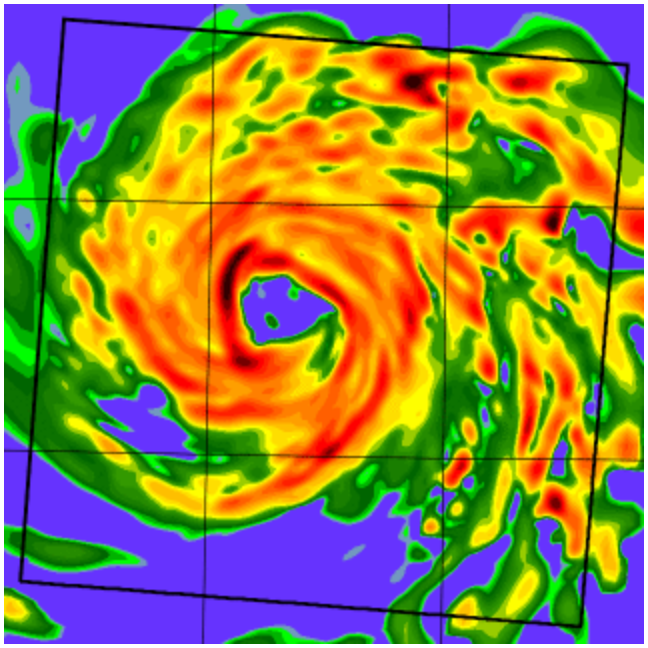
CTL NCEP



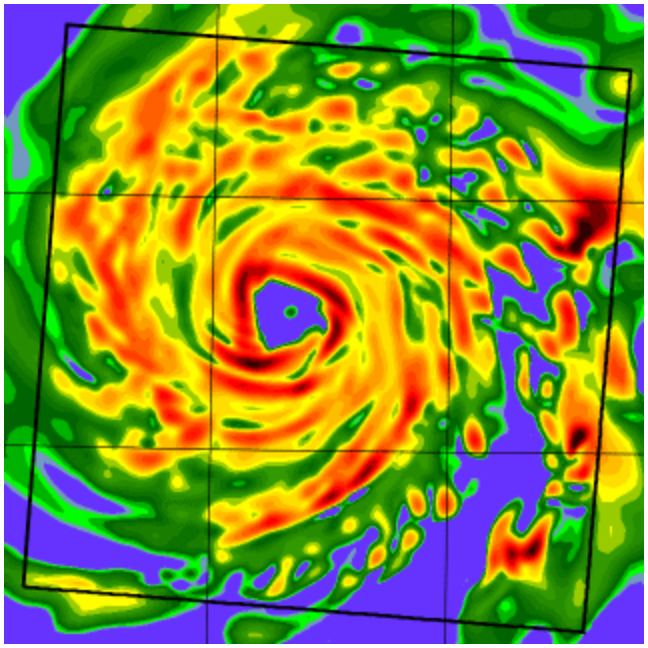
HRD P3 LF Radar Reflectivity



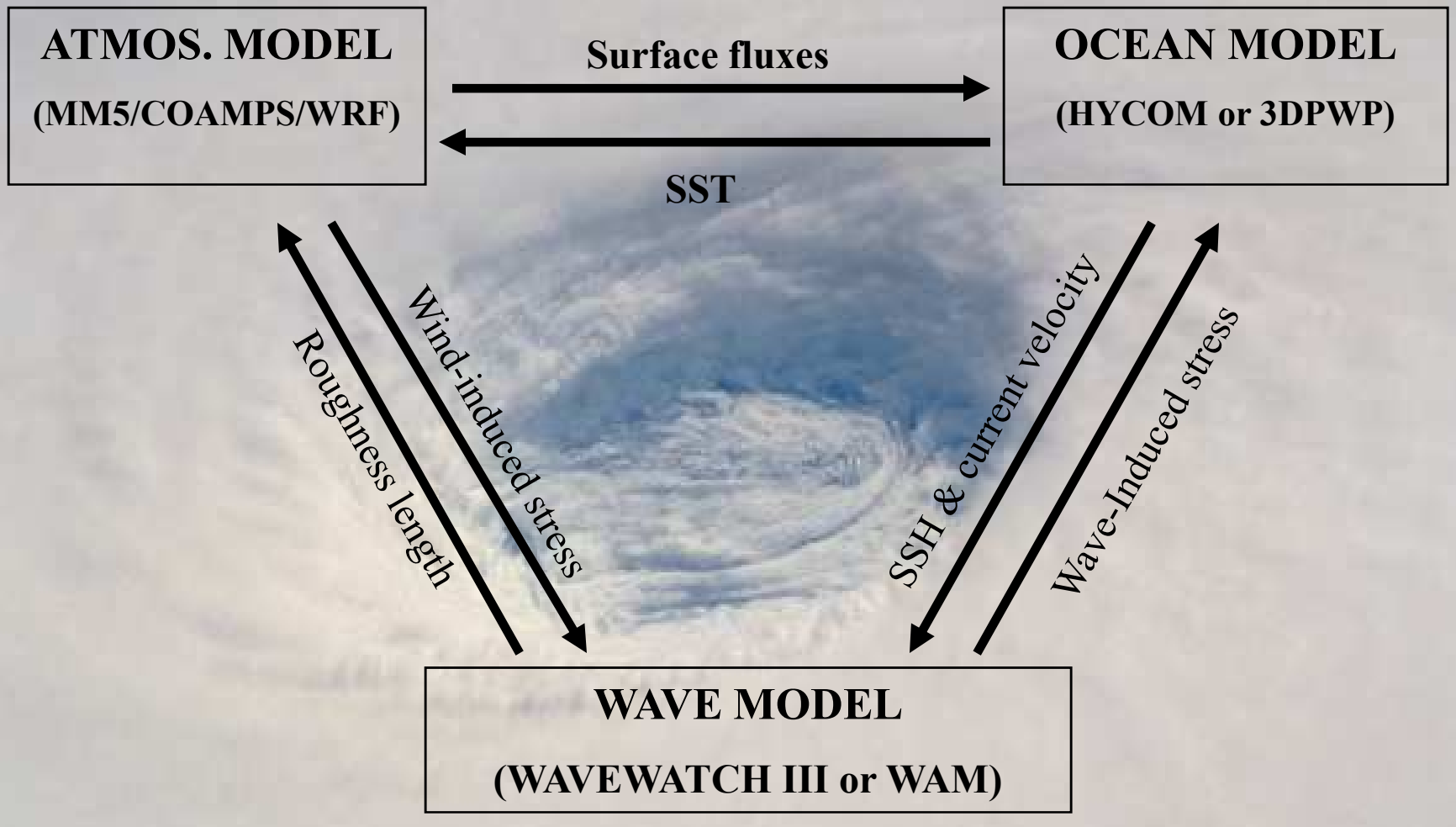
Qscat Blended



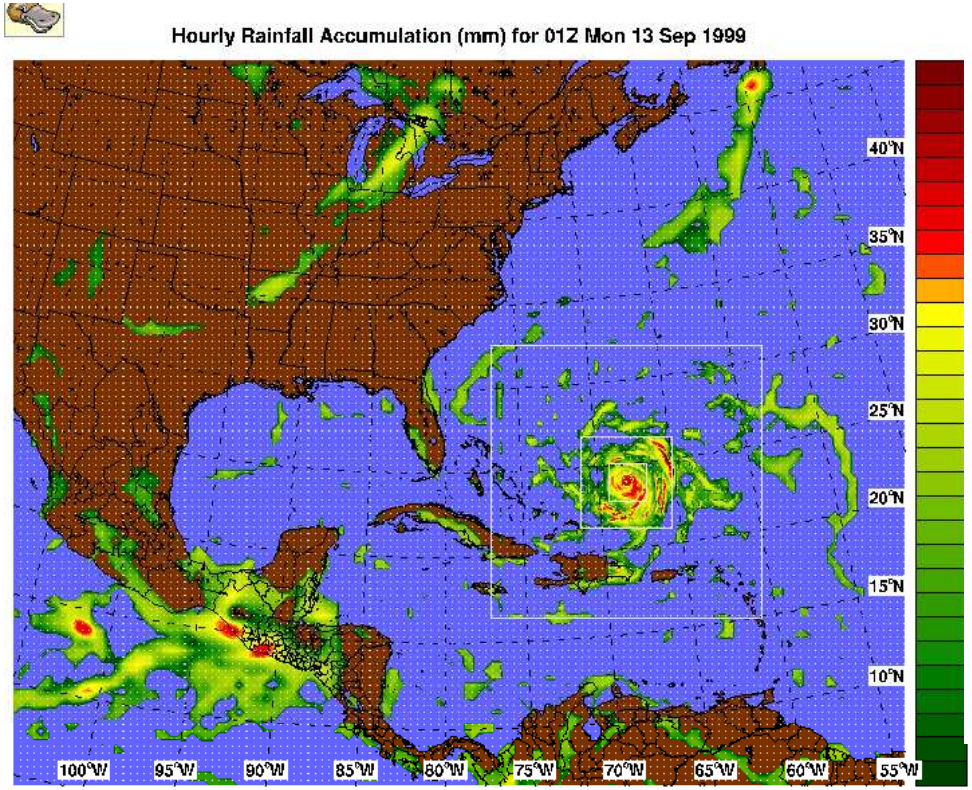
Qscat 4DVar

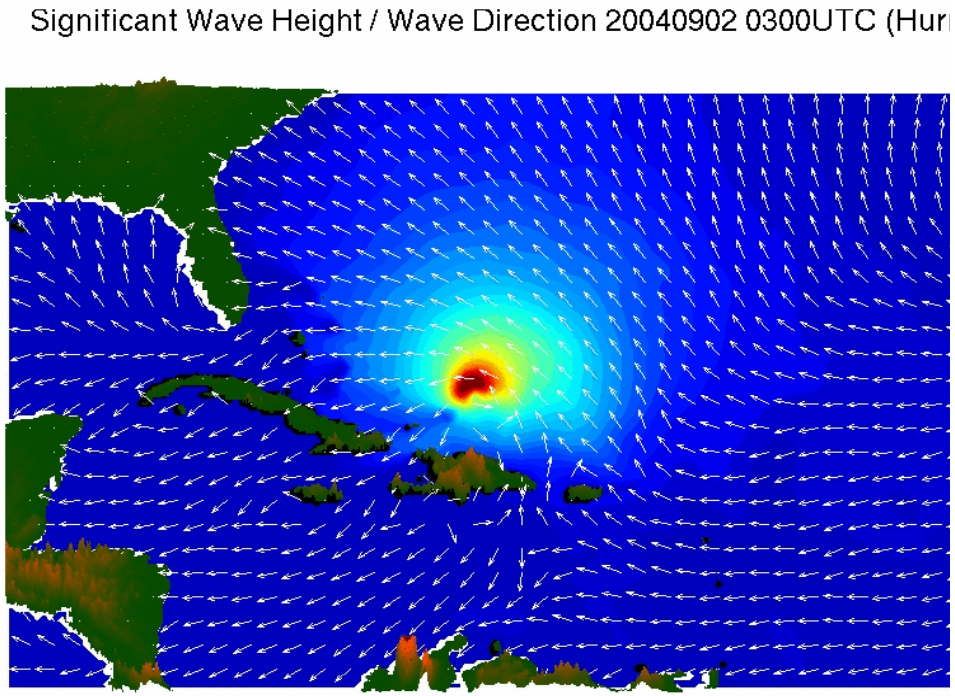


Coupled Atmosphere-Wave-Ocean Modeling System for Hurricane Predictions

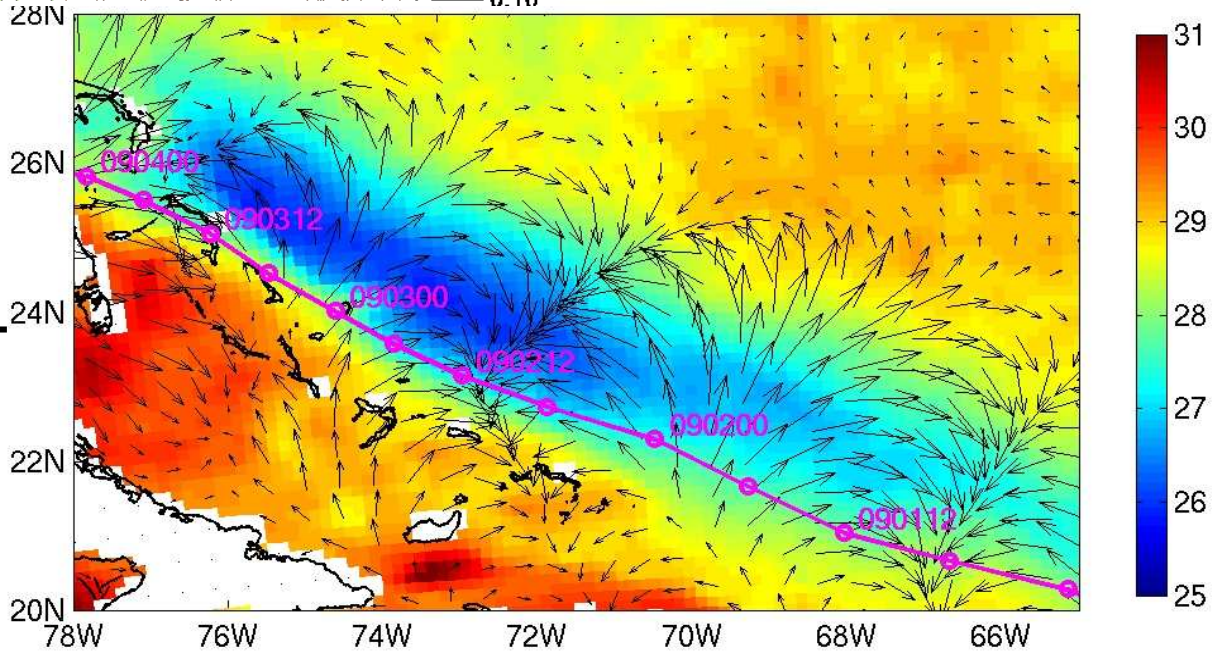


Chen et al. (2006)



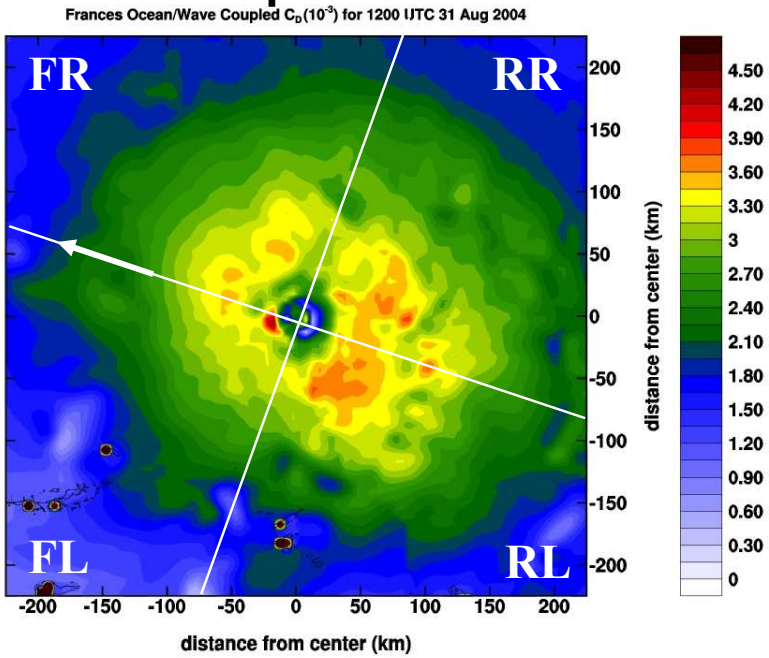


Coupled model SST and sfc current

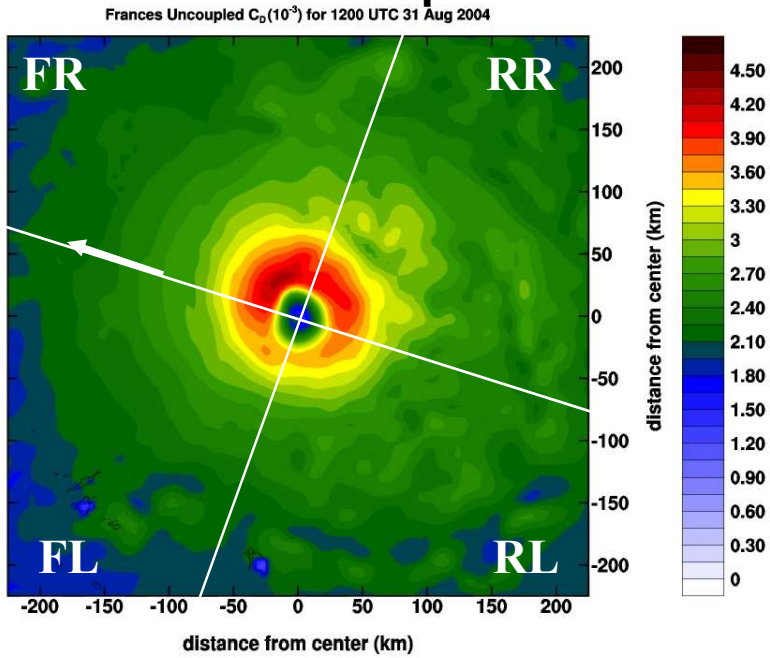


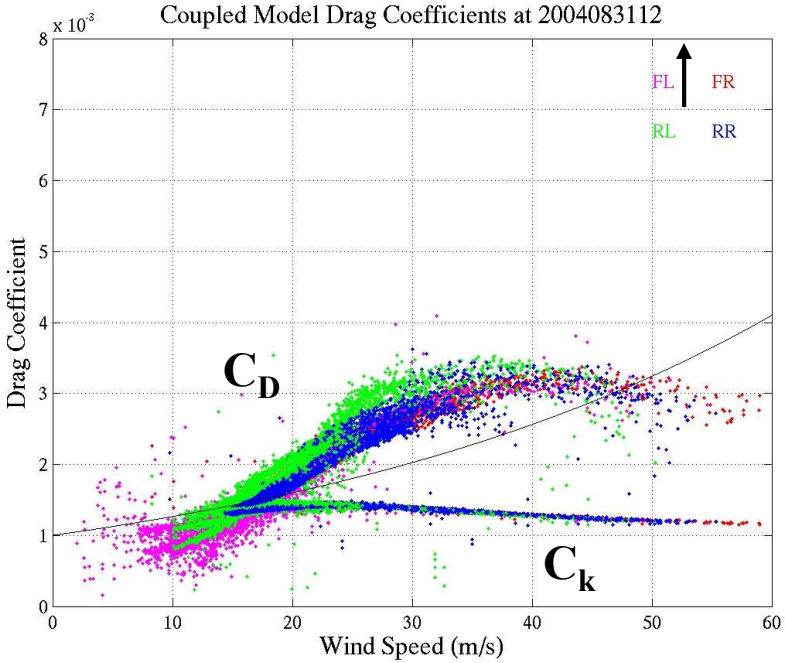
Hurricane Frances (2004)

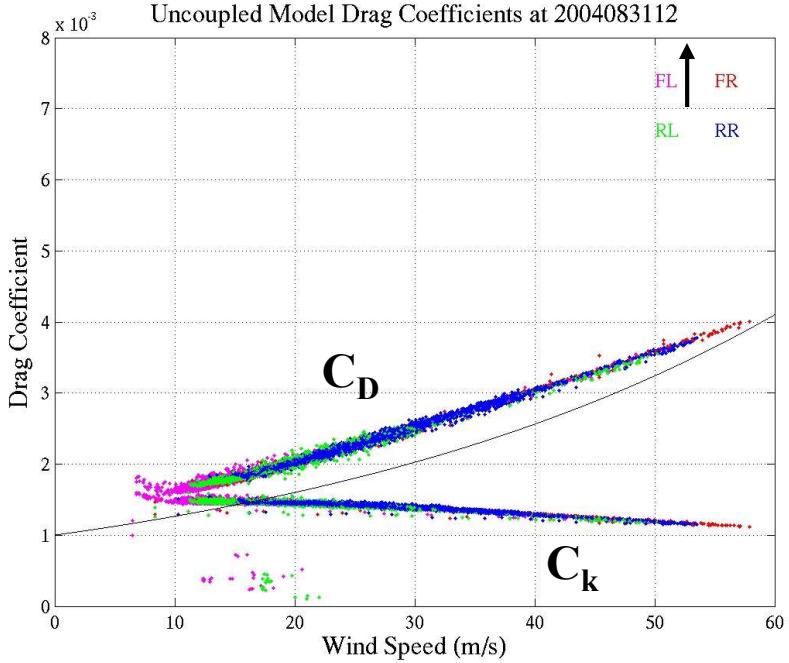
Coupled



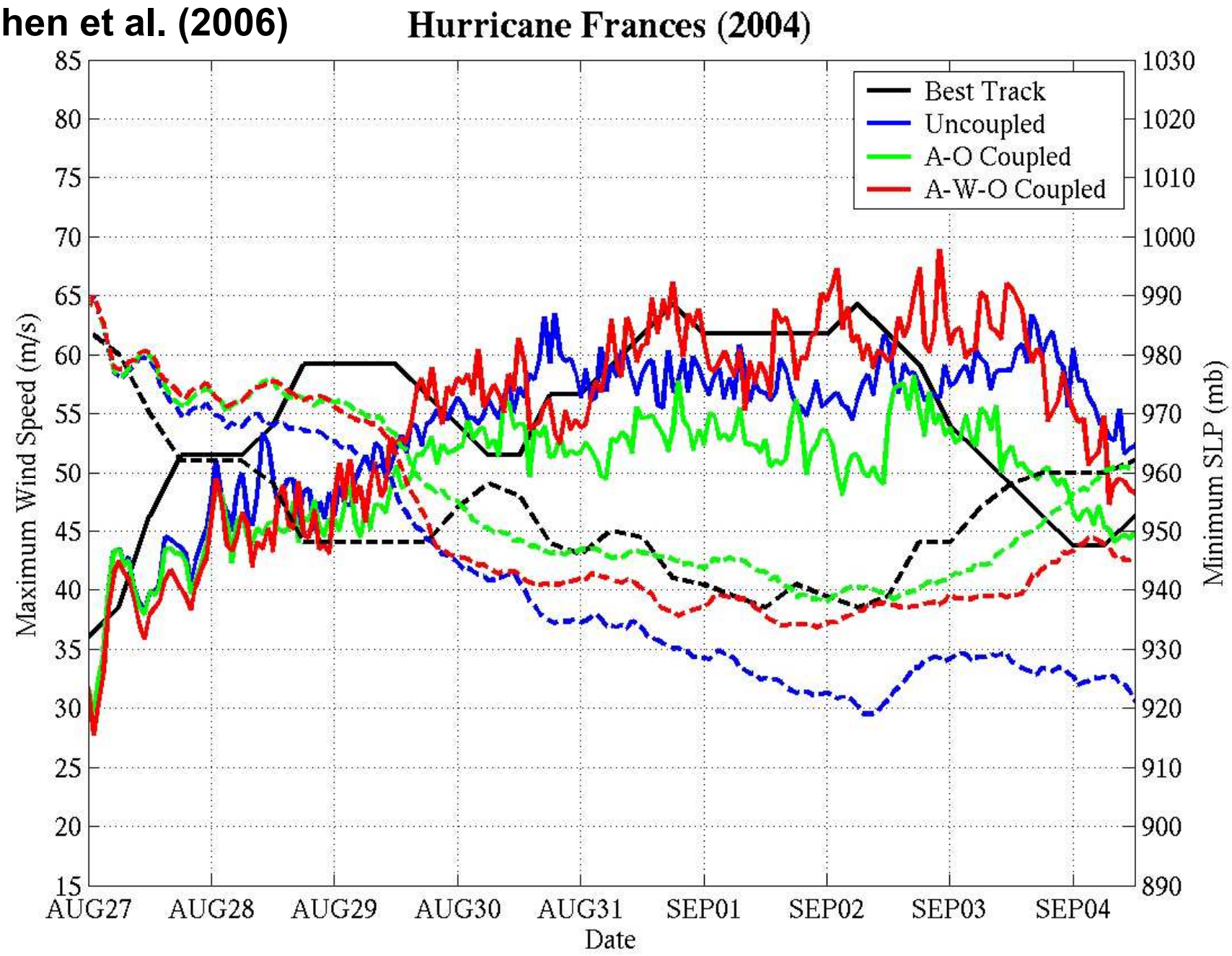
Uncoupled



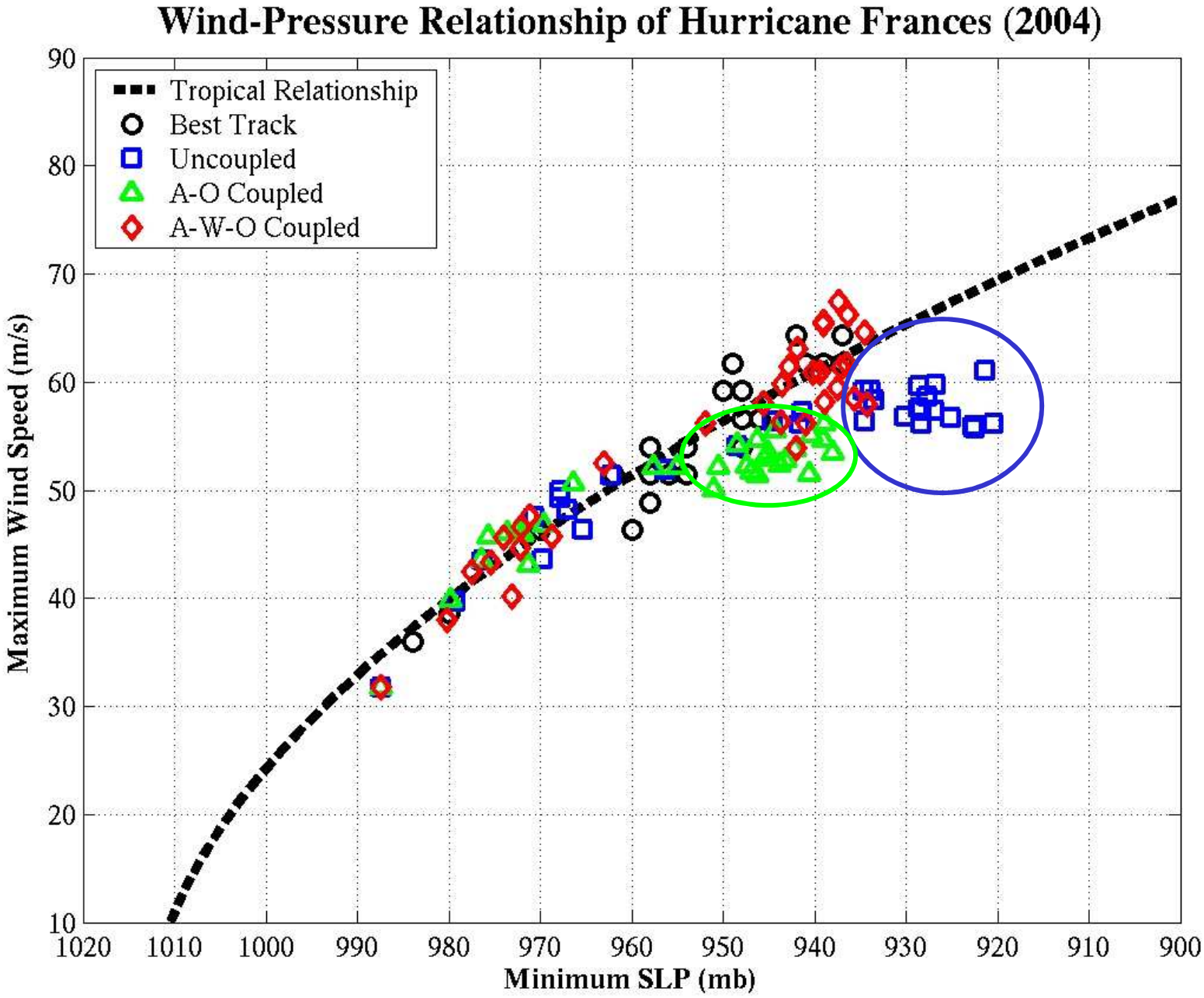




Chen et al. (2006)

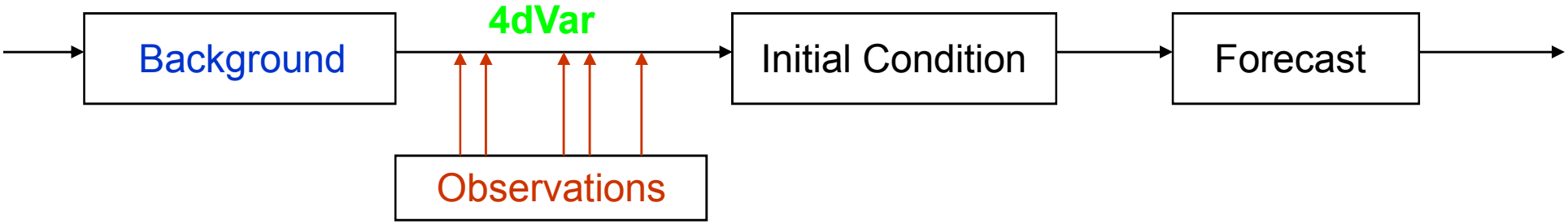


Chen et al. (2006)



Future Work

- How to improve data assimilation (DA)?
  - Traditional DA combines one 'background' estimate (from the model) with observations.



  - Background and observations contain errors.
  - Moreover, errors in the background field are correlated; e.g. surface wind field is correlated with surface pressure field, and the wind field aloft in a hurricane.

Future Work

- Errors in the background field need to be specified accurately in data assimilation
  - Current specification in 4dVar is poor
    - No time-dependence
    - No flow-dependent covariance structure
  - Prescribe background-error covariance via short-range MM5/WRF ensemble forecasts.
  - Exploit strengths of ensemble and 4dVar; potentially powerful in operational forecasts.

Hybrid Ensemble Kalman Filter / 4dVar

- Improved ensemble-based background-error covariance is fed into 4dVar, to provide a new initial state.
- A new ensemble of initial states is then produced via adding the above initial state to a linear combination of perturbations computed from the background ensemble.
- Generate probabilistic forecasts of hurricane track, intensity and rainfall.