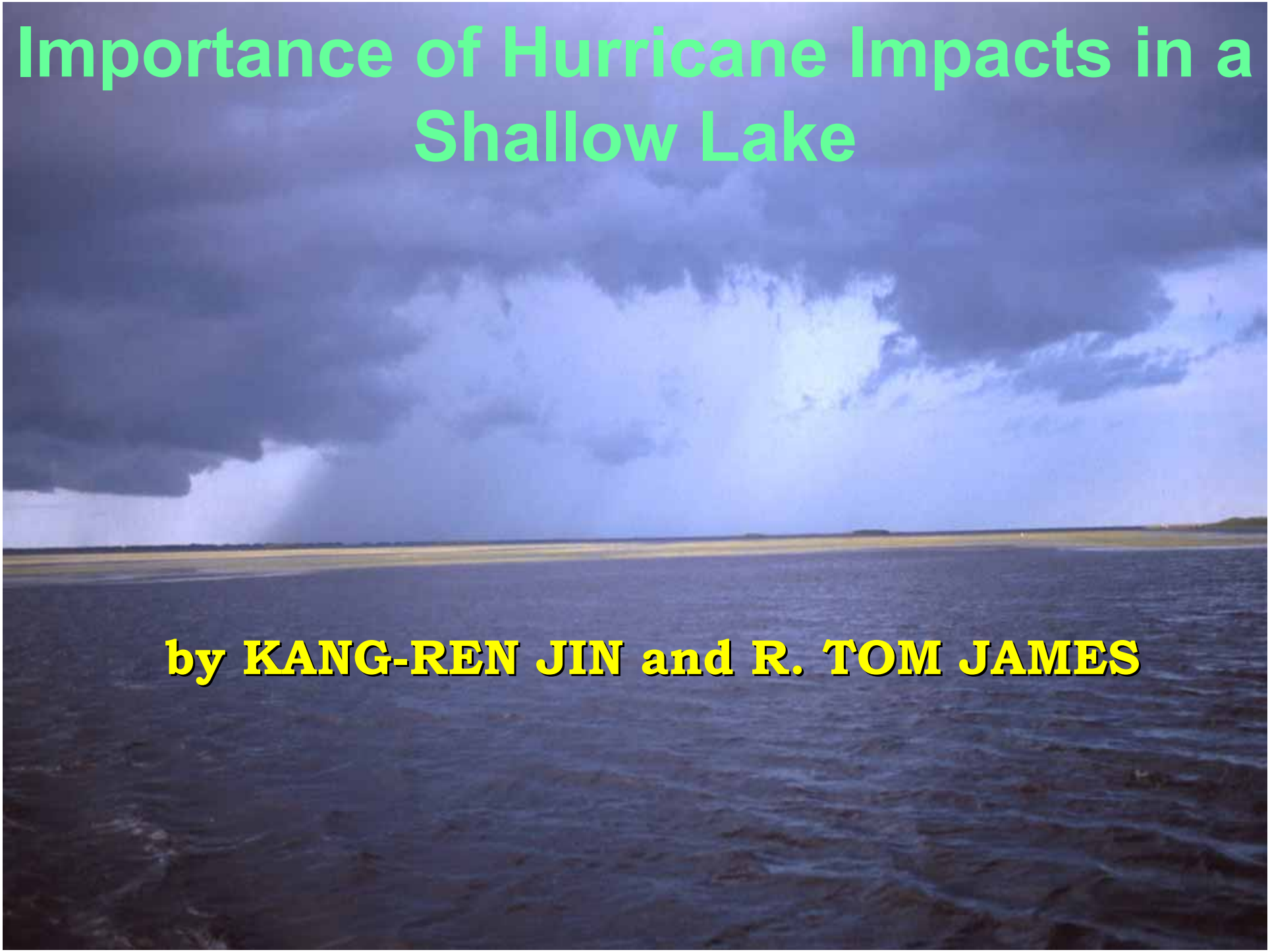
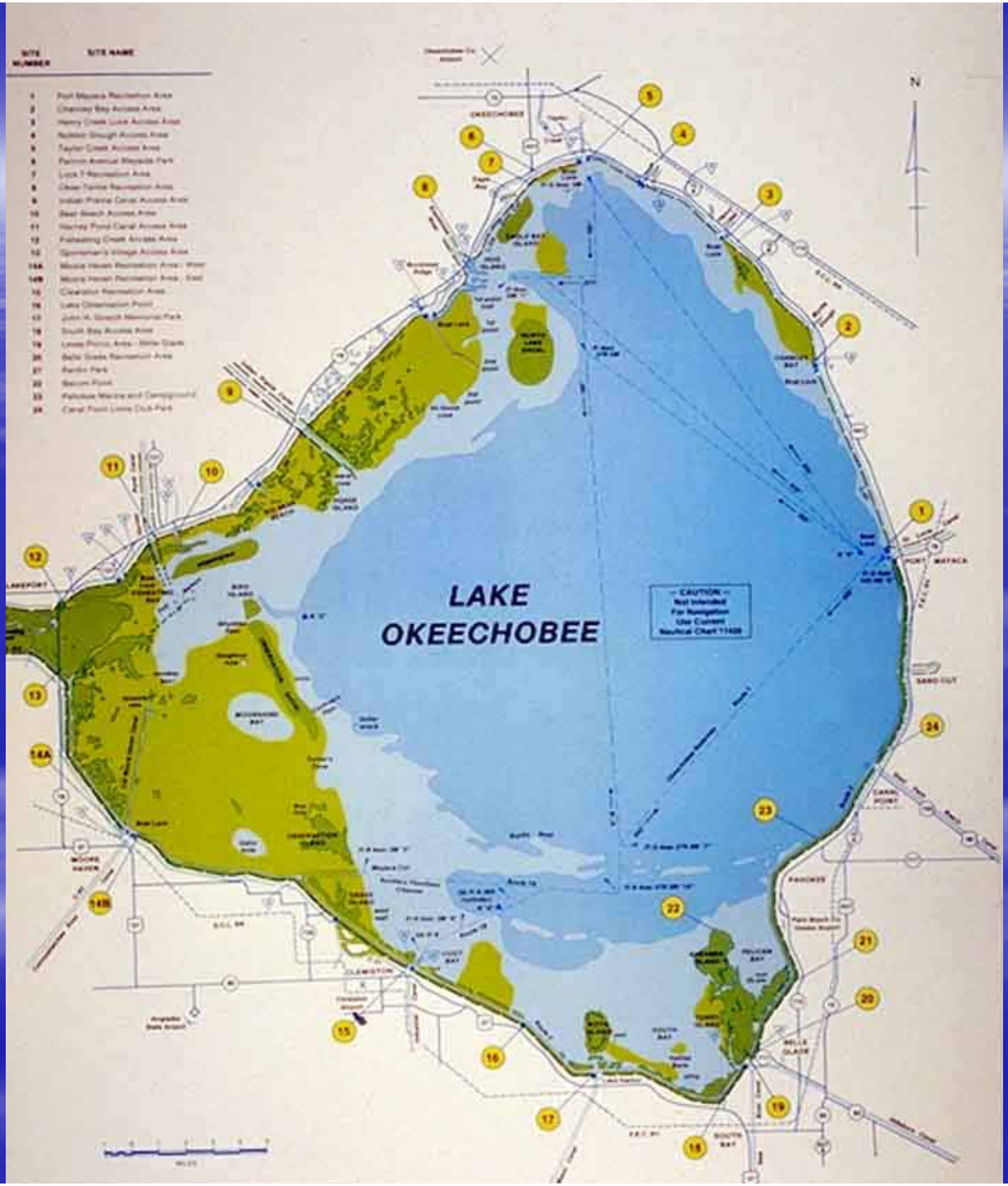
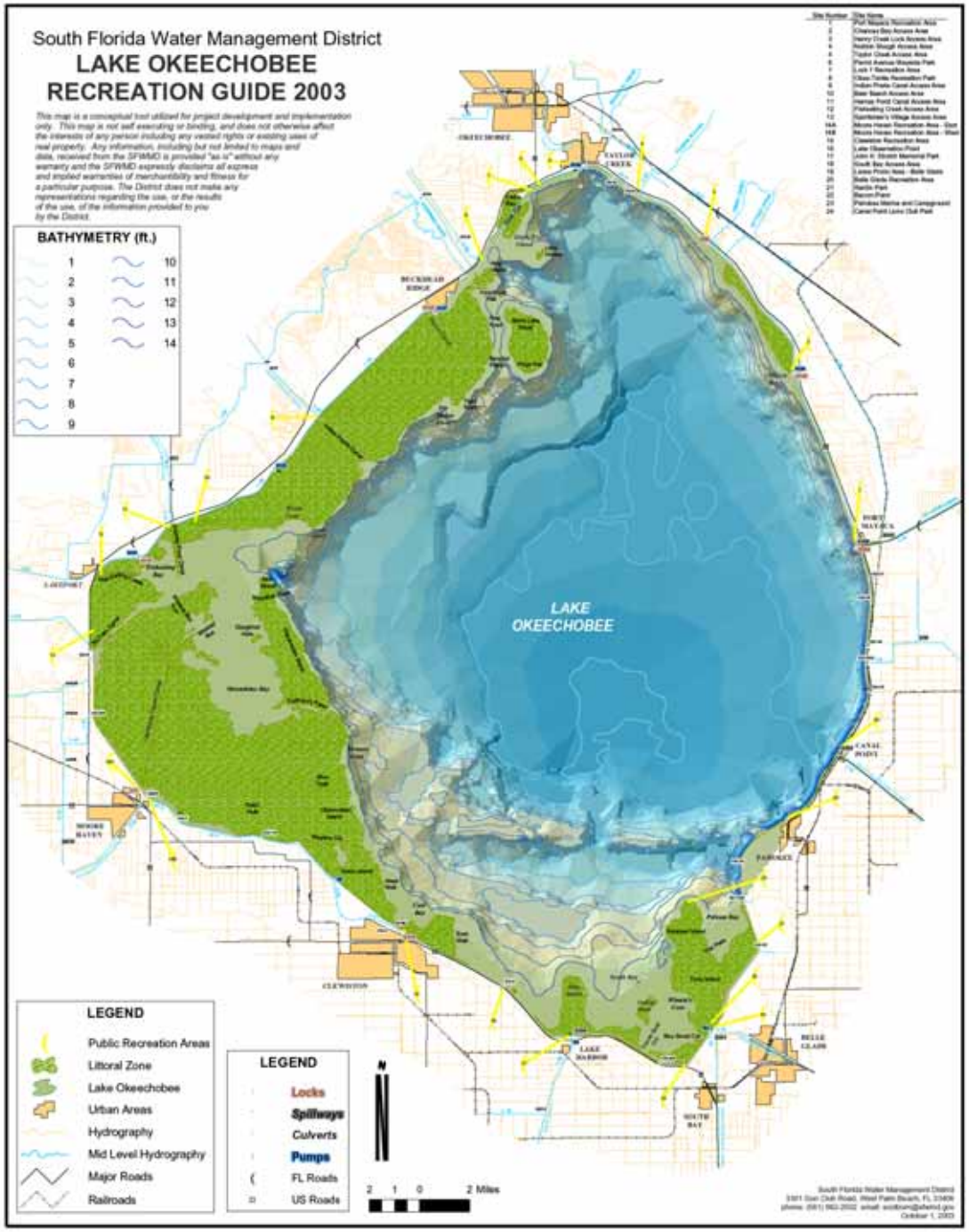
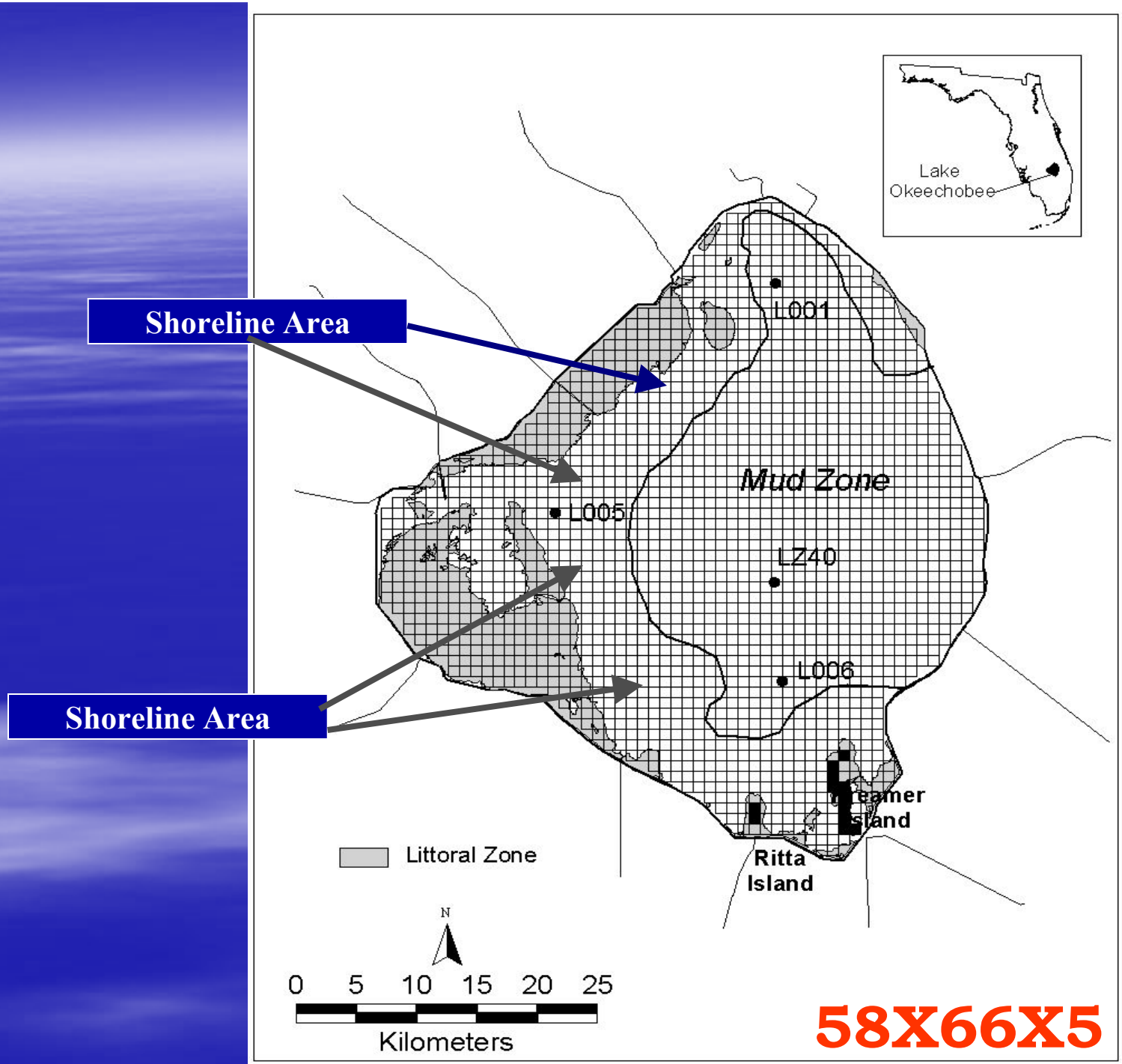
Importance of Hurricane Impacts in a Shallow Lake



by KANG-REN JIN and R. TOM JAMES

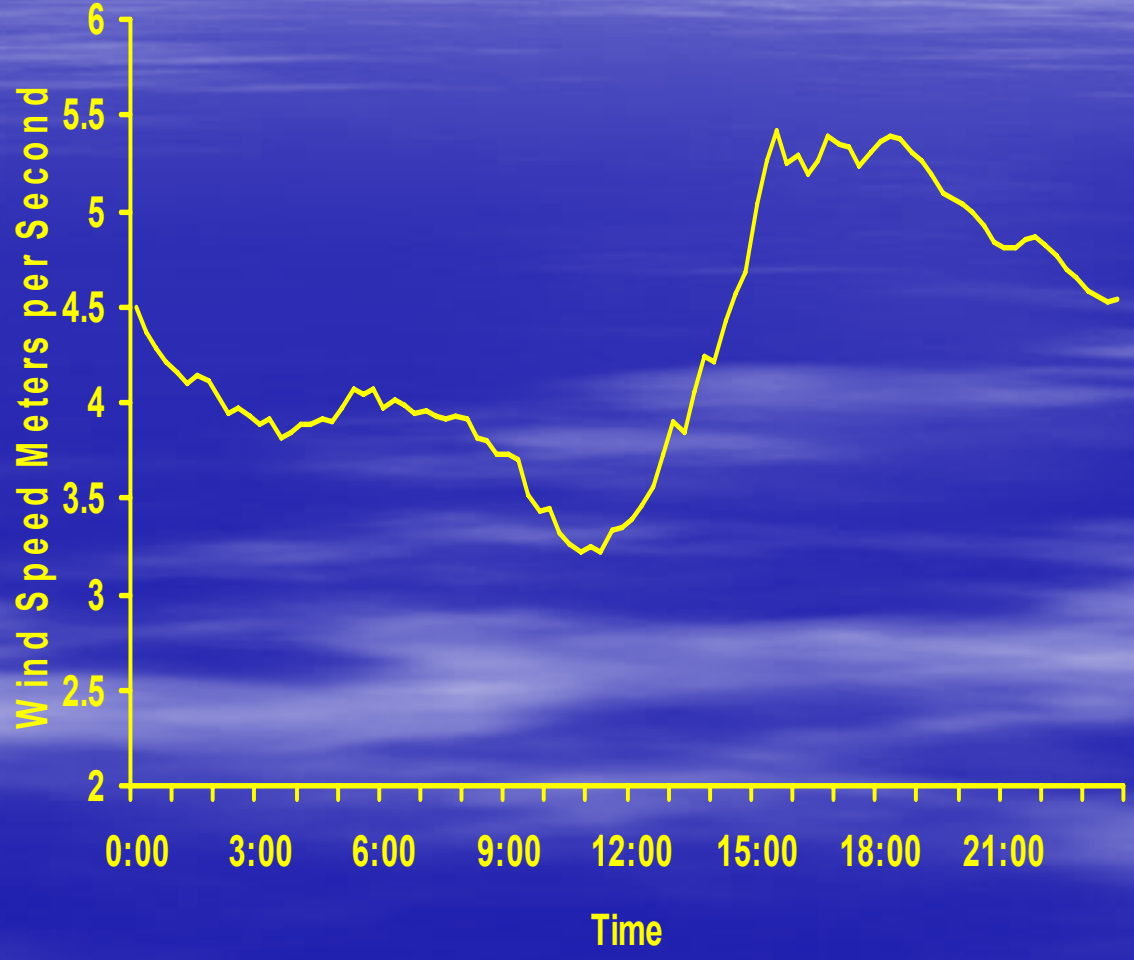

SITE NUMBER
SITE NAME
LAKE OKEECHOBEE
CAUTION
Not Intended For Navigation
Use Current Nautical Chart 11428
N


South Florida Water Management District
LAKE OKEECHOBEE
RECREATION GUIDE 2003
BATHYMETRY (ft.)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
LAKE
OKEECHOBEE
LEGEND
Public Recreation Areas
Littoral Zone
Lake Okeechobee
Urban Areas
Hydrography
Mid Level Hydrography
Major Roads
Railroads
LEGEND
Locks
Spillways
Culverts
Pumps
FL Roads
US Roads
N
2 1 0 2 Miles


Shoreline Area
Shoreline Area
Lake
Okeechobee
L001
Mud Zone
L005
LZ40
L006
Steamer
Island
Ritta
Island
Littoral Zone
N
0 5 10 15 20 25
Kilometers
58X66X5

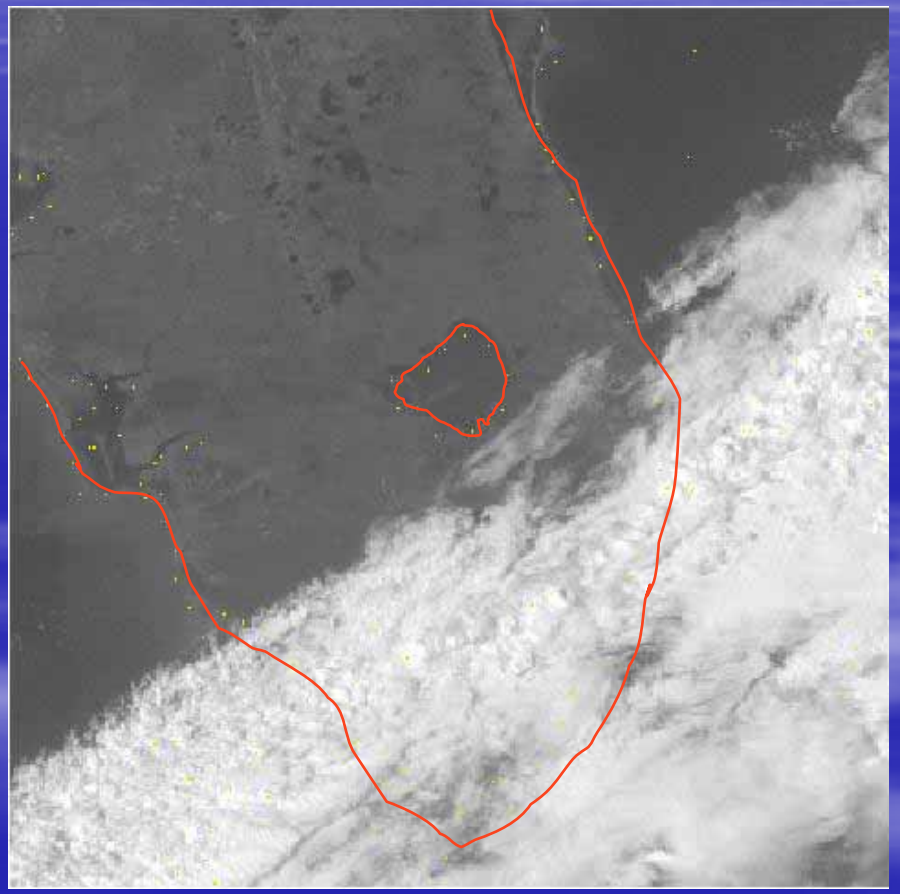
Wind

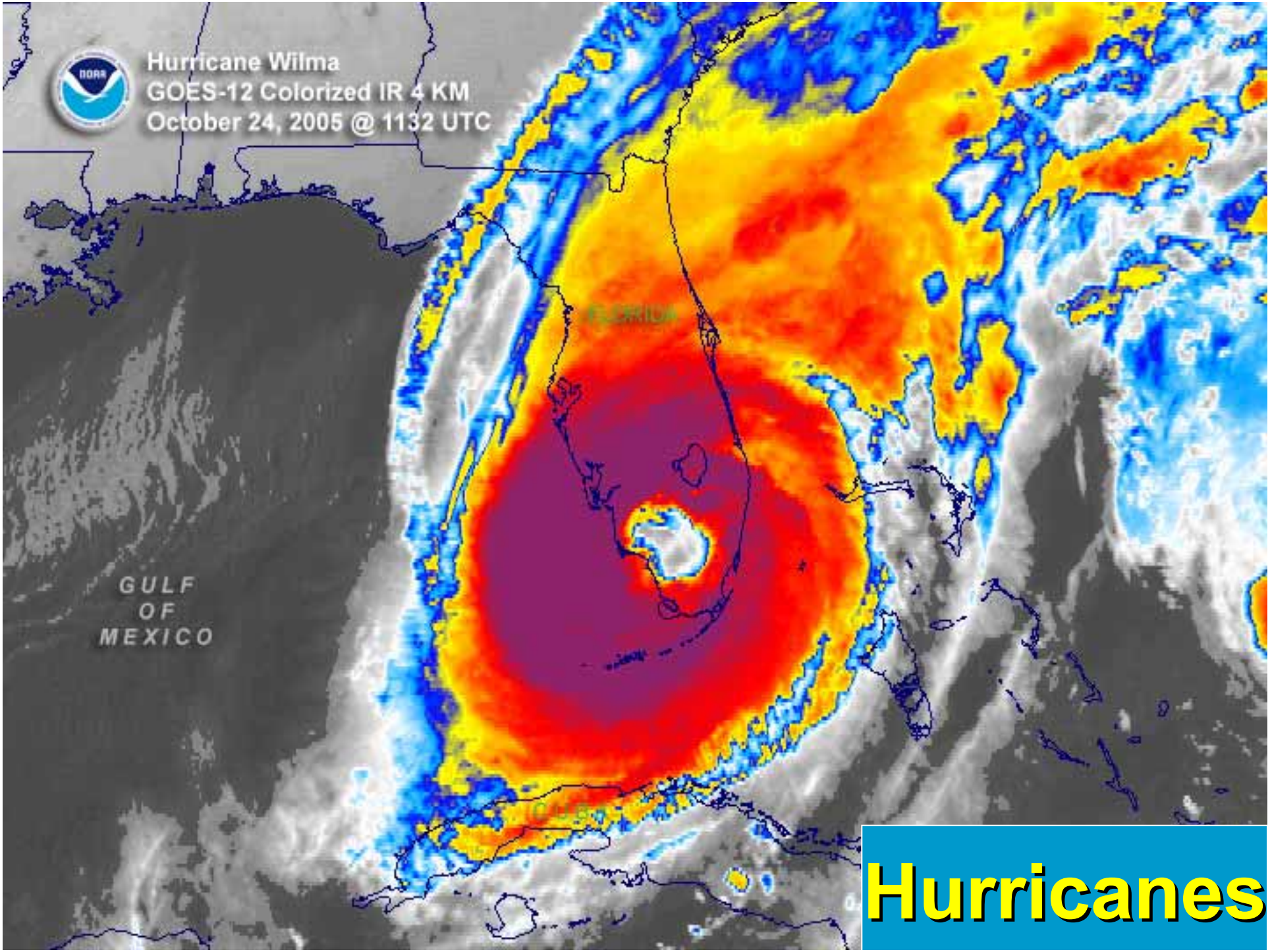
- Diurnal wind pattern in summer
- Local afternoon thunderstorms
- Ocean breeze as land surface heats up

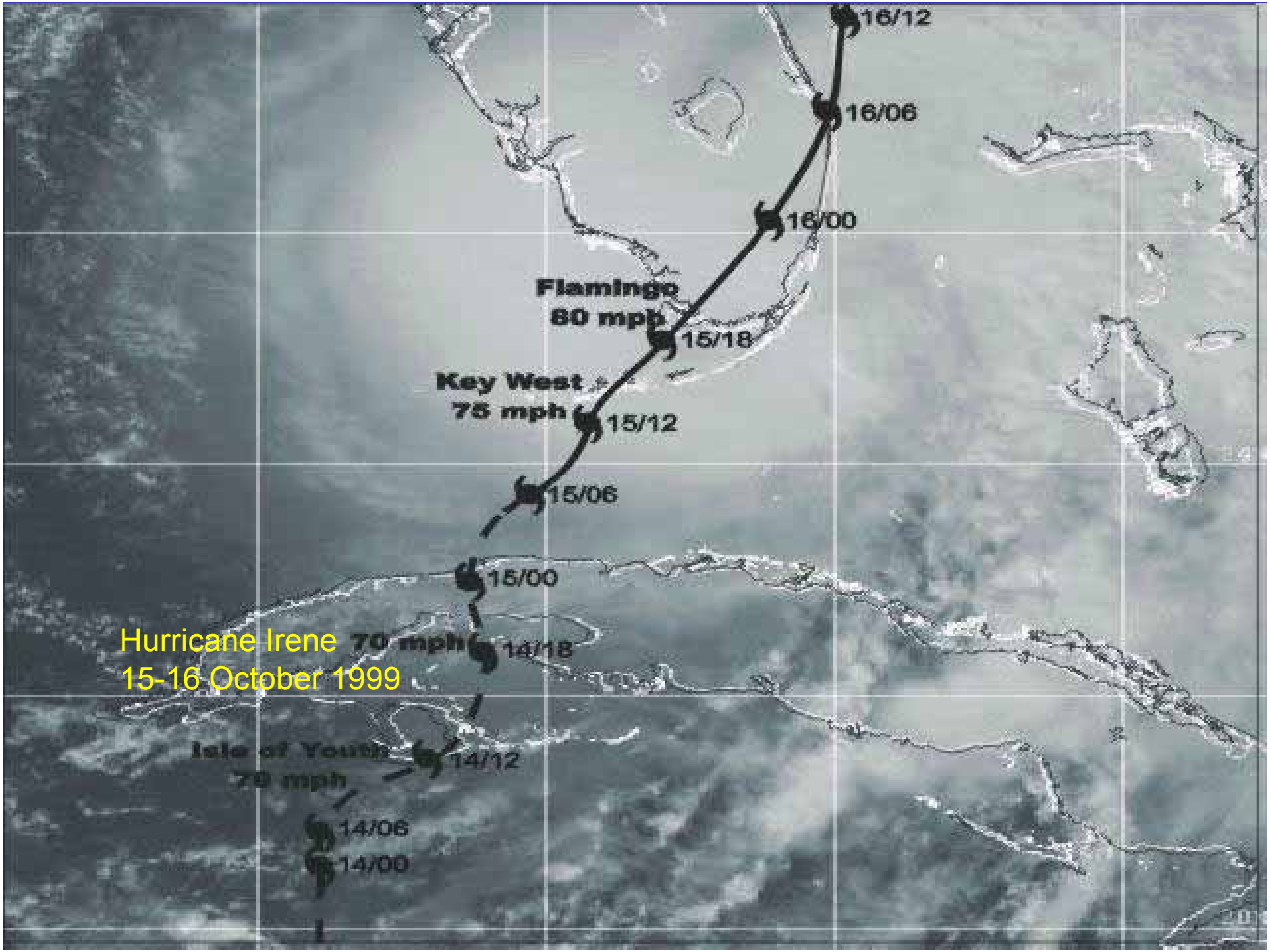


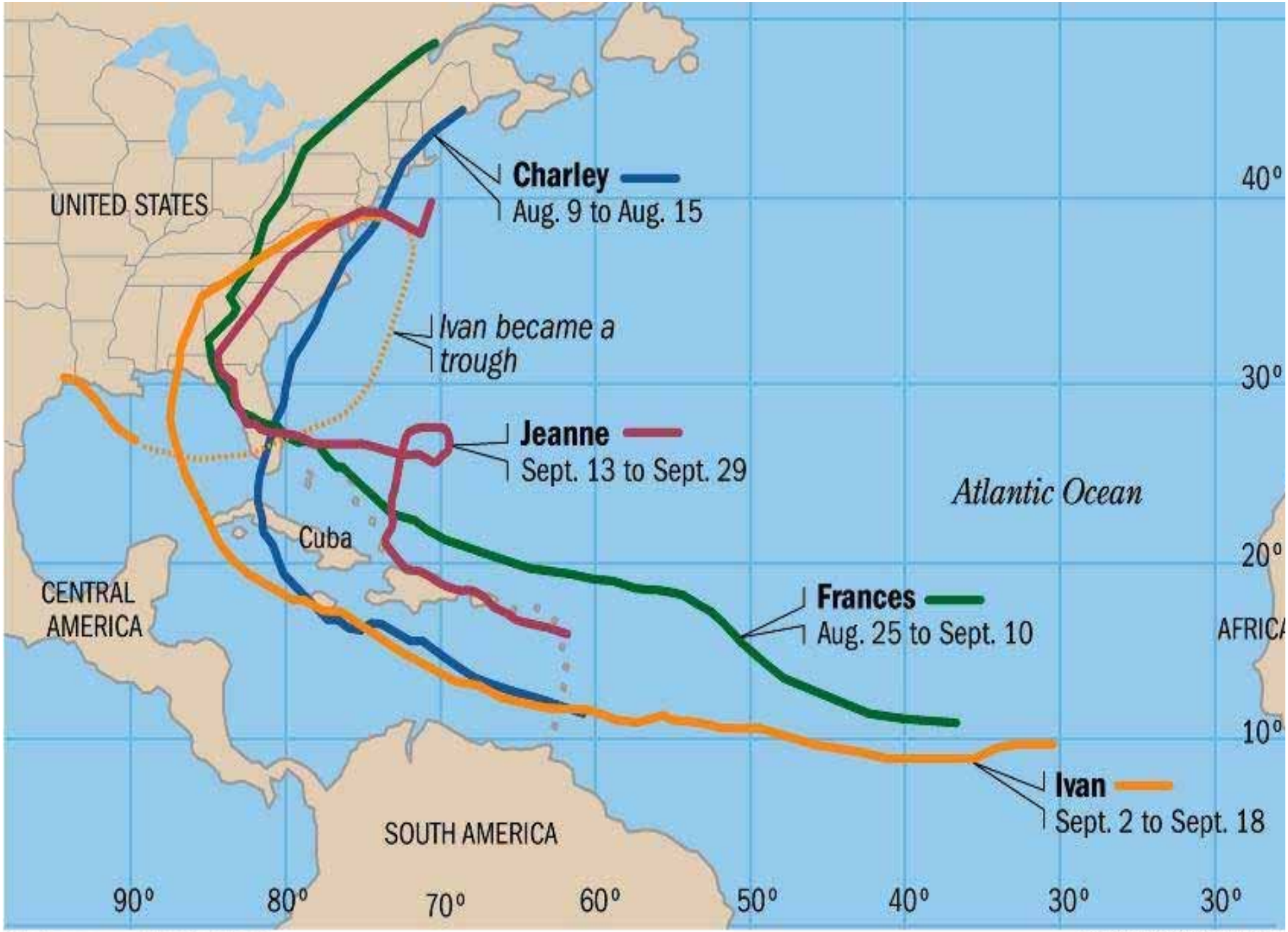
Wind - Winter Cold Fronts

- Move through in 1 to 3 days
- Produce consistent winds in excess of 7-8 m/s
- Create large waves
- Resuspend sediment



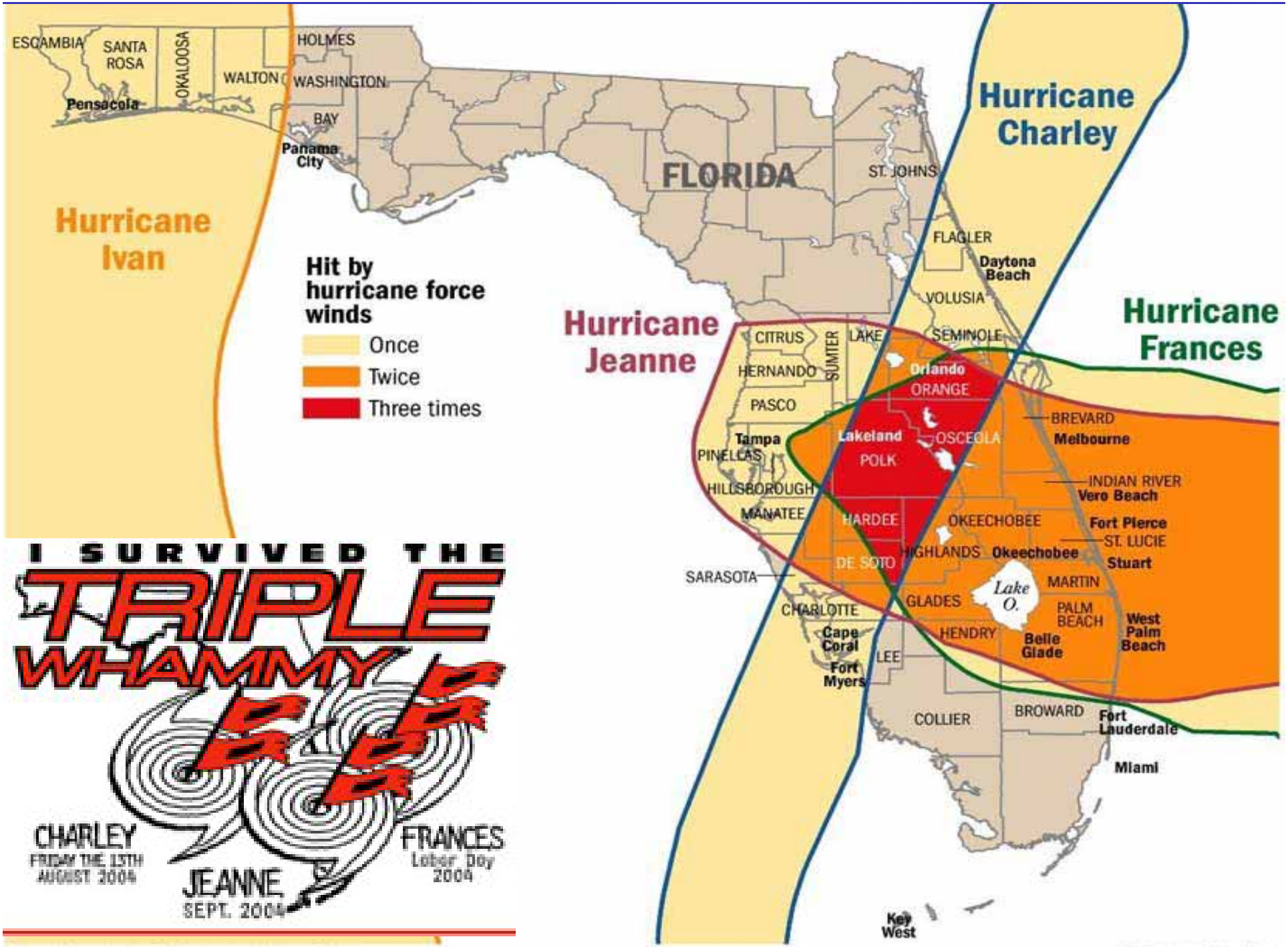

Hurricane Wilma
GOES-12 Colorized IR 4 KM
October 24, 2005 @ 1132 UTC
GULF
OF
MEXICO
Hurricanes


16/12
16/06
16/00
Flamingo
80 mph
15/18
Key West
75 mph
15/12
15/06
15/00
Hurricane Irene
15-16 October 1999
70 mph
14/18
Isle of Youth
70 mph
14/12
14/06
14/00



Source: www.wunderground.com

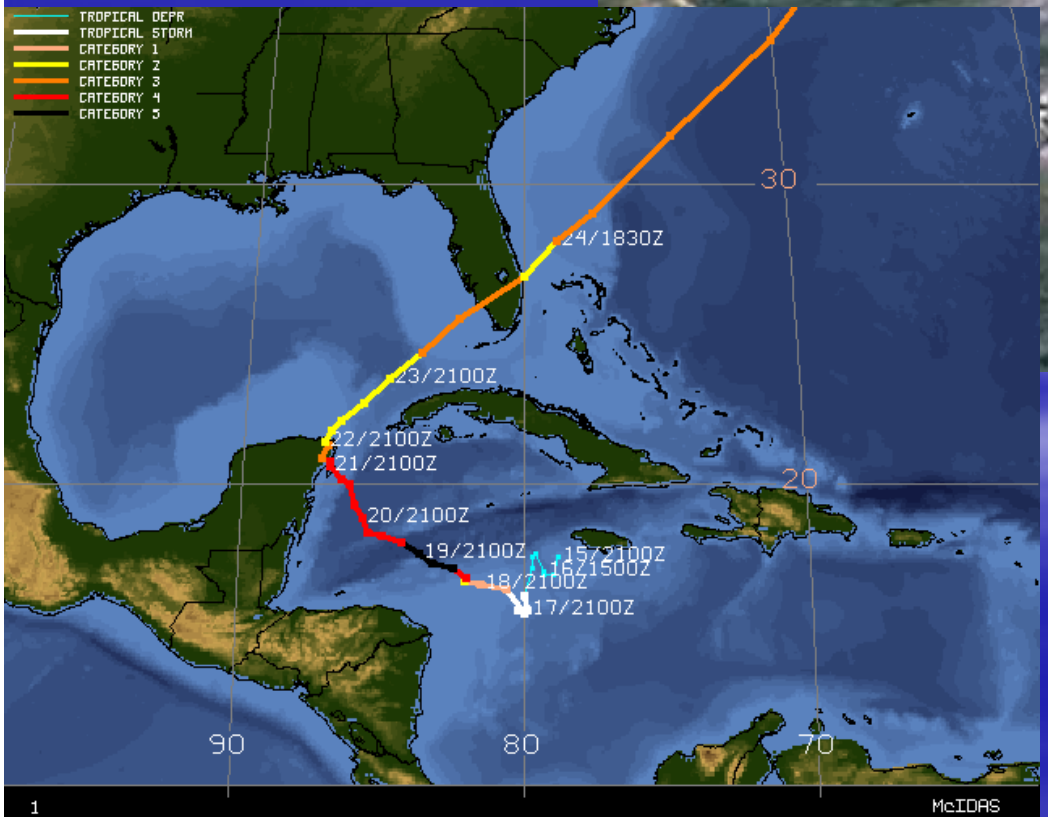
MARK HEMPHILL/Staff Art



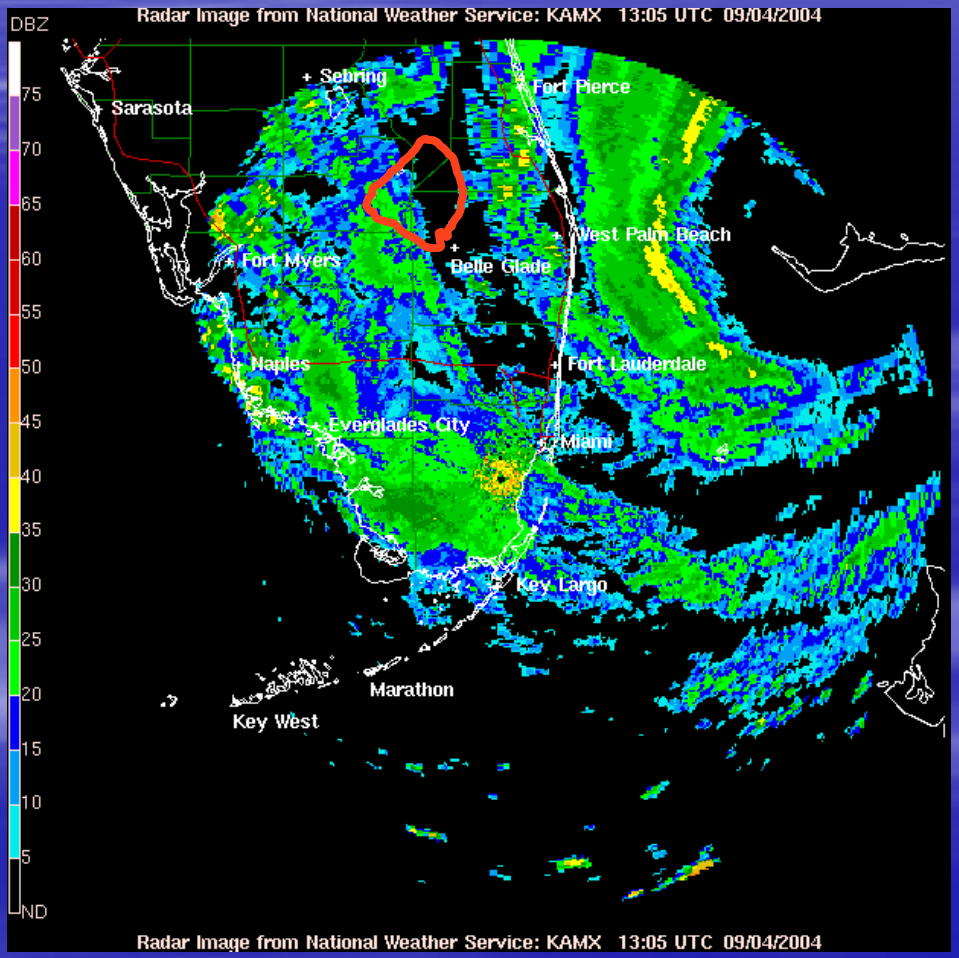
Source: National Weather Service/National Hurricane Center

BRENNAN KING/Staff Artist

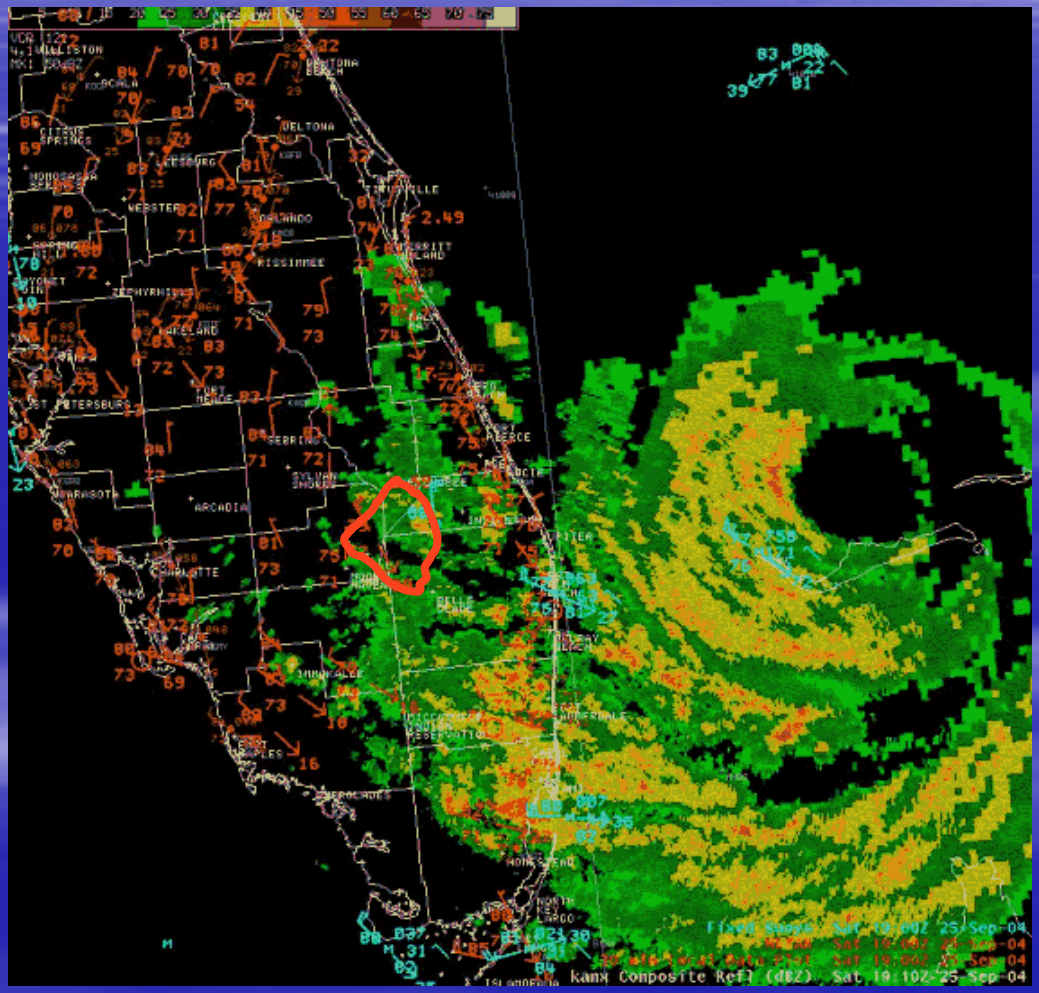
Hurricane Wilma October 15-25 2005



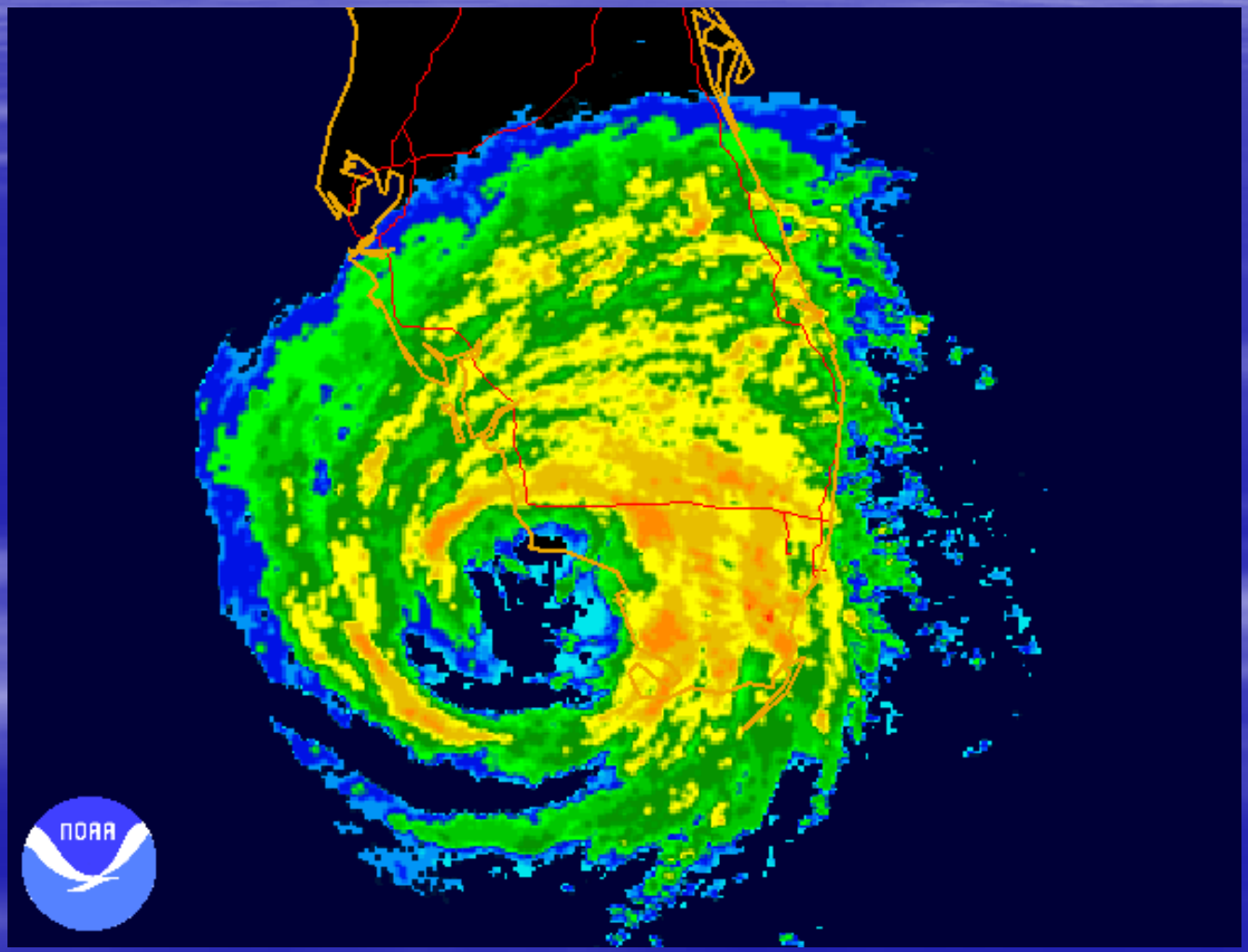
Hurricane
Frances September 4-5 2004

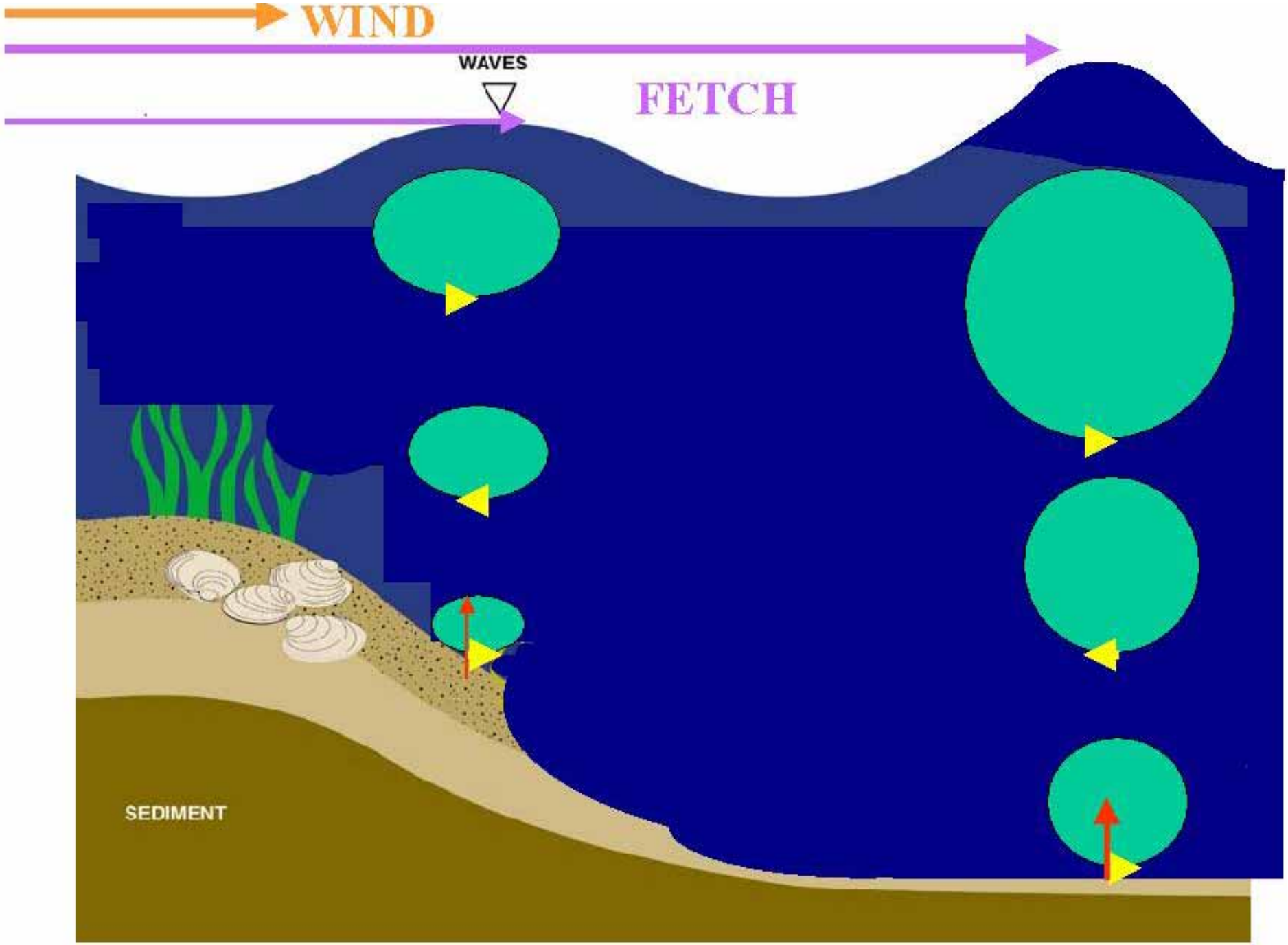


Hurricane Jeanne September 25-26, 2004



Hurricane
Wilma October 24-25 2005

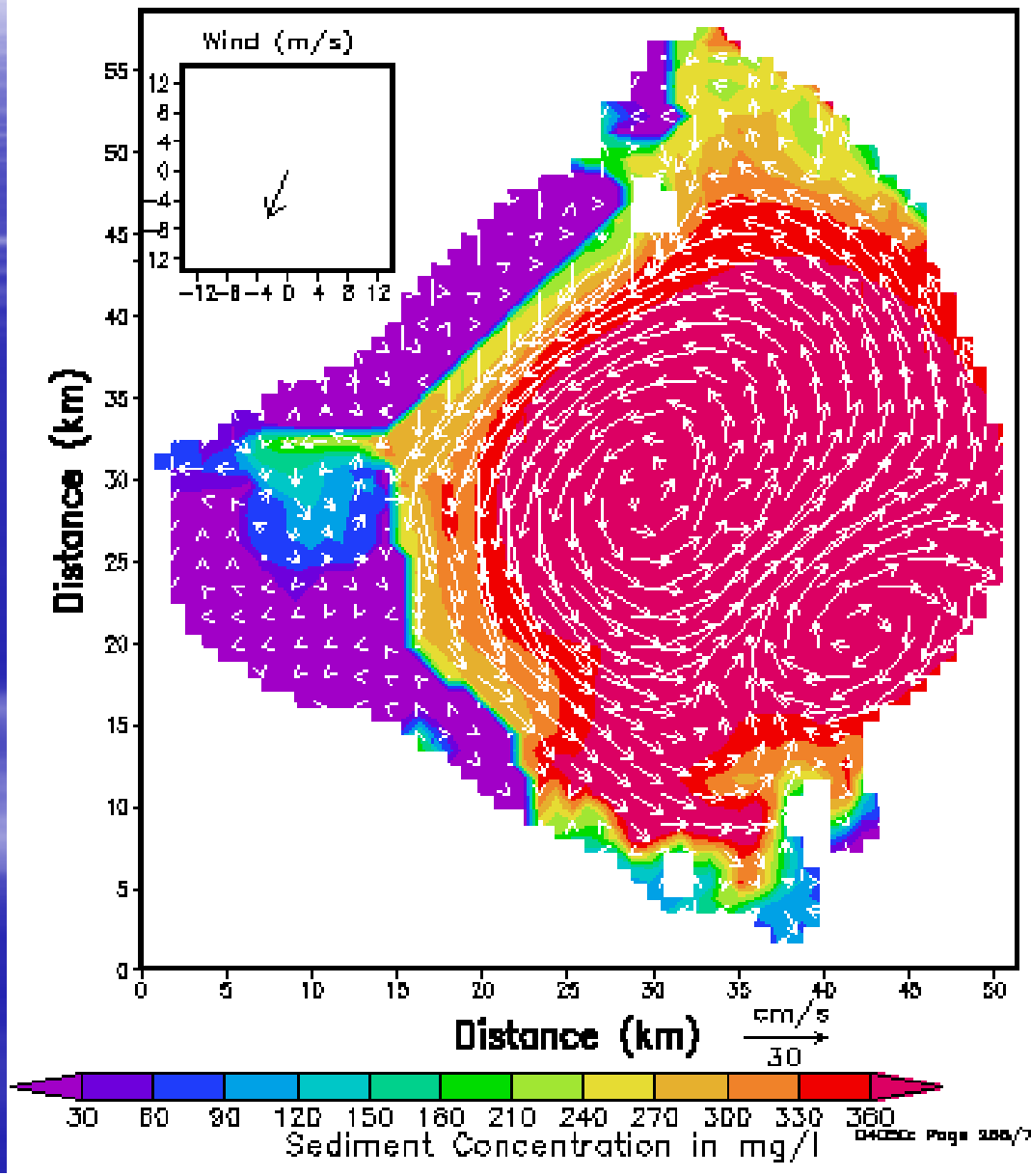


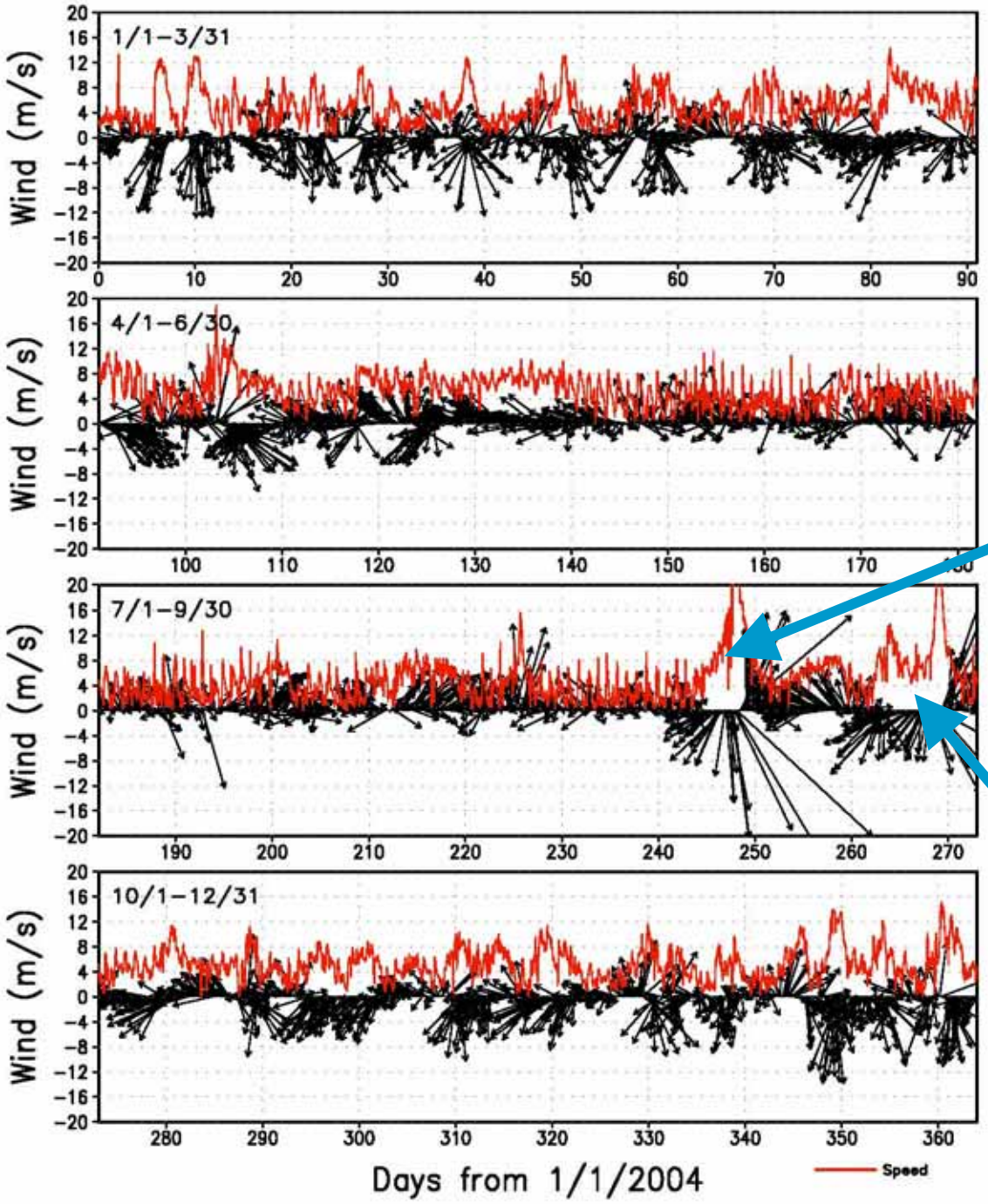

WIND
WAVES
FETCH
SEDIMENT

Hurricane Name	Peak Date	Max Wind Speed (mi/h)	Persistent Time (Days) ≥ (18 mi/h) (8 m/s)	Max. B. Current (m/s)	Max. B Shear Stress (N/m^2)	Max Orbital Velocity (m/s)	Typical Orbital Velocity (m/s)	Typica B Shea Stress (N/m^2
Irene	10/15/99 9PM	50 (52)	2.3	0.10	8.2	0.48	0.01 – 0.1	0.02 – 0.1
Frances	9/5/04 2AM	66 (67)	4.7	0.18	16.0	0.82	0.01 – 0.1	0.02 – 0.1
Jeanne	9/26/04 1AM	70.0 (74)	2.5	0.11	13.2	0.70	0.01 – 0.1	0.02 – 0.1
Wilma	10/24/05 11AM	78 (91)	1.5	0.12	13.4	0.71	0.01 – 0.1	0.02 – 0.1

At Station LZ40

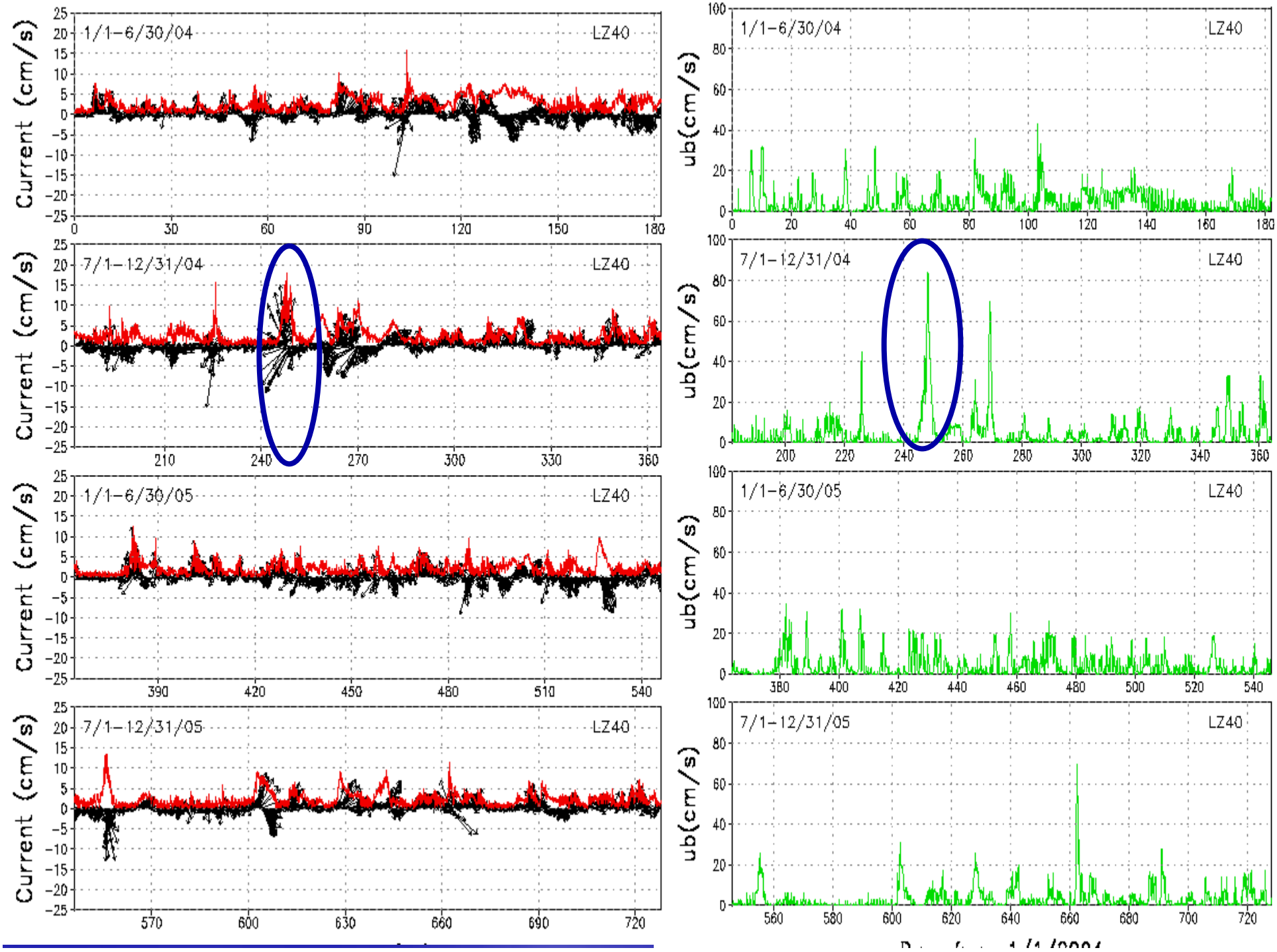
Sediment Concentration in mg/l
1/1/04–12/30/05
Day 267.5

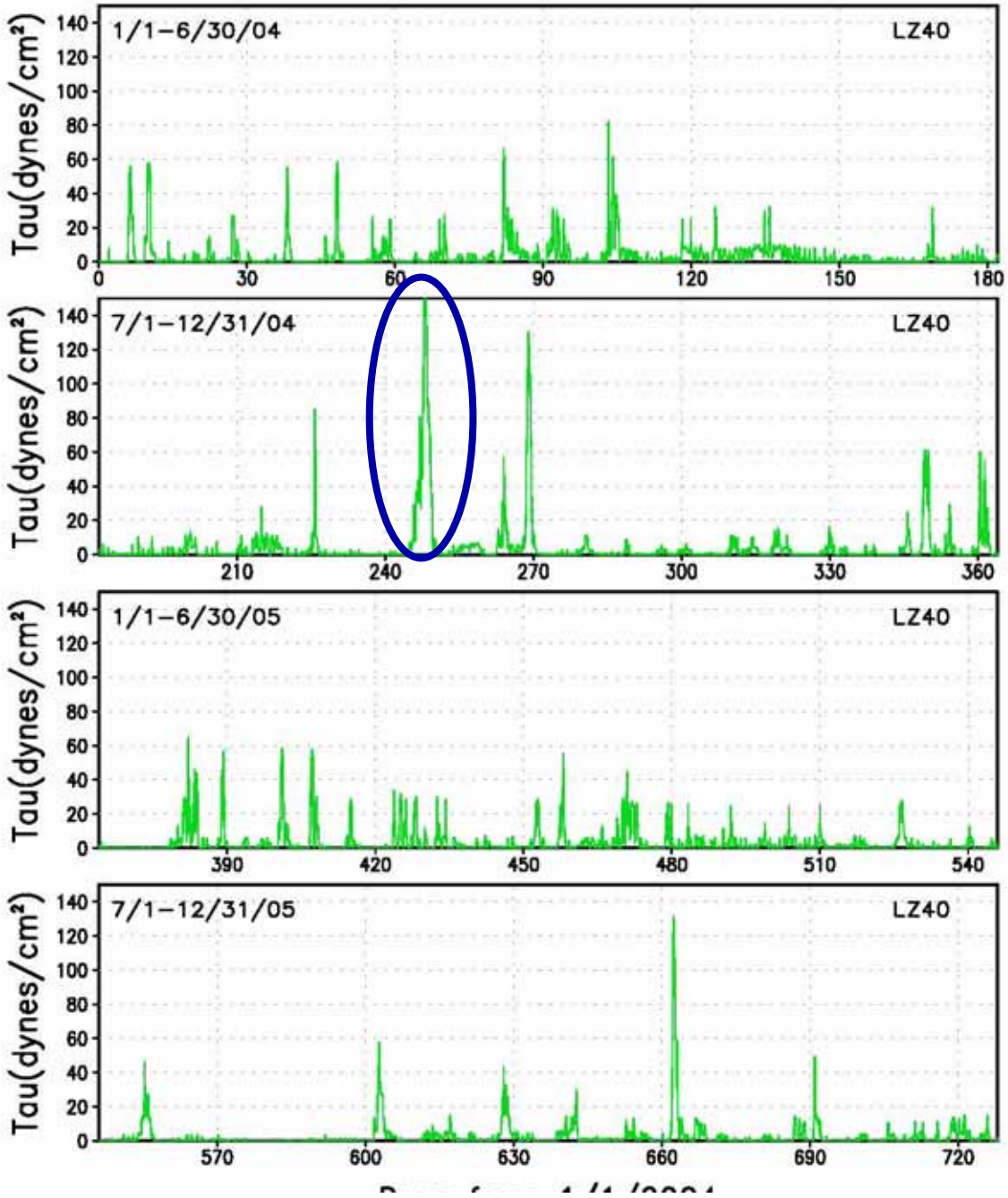


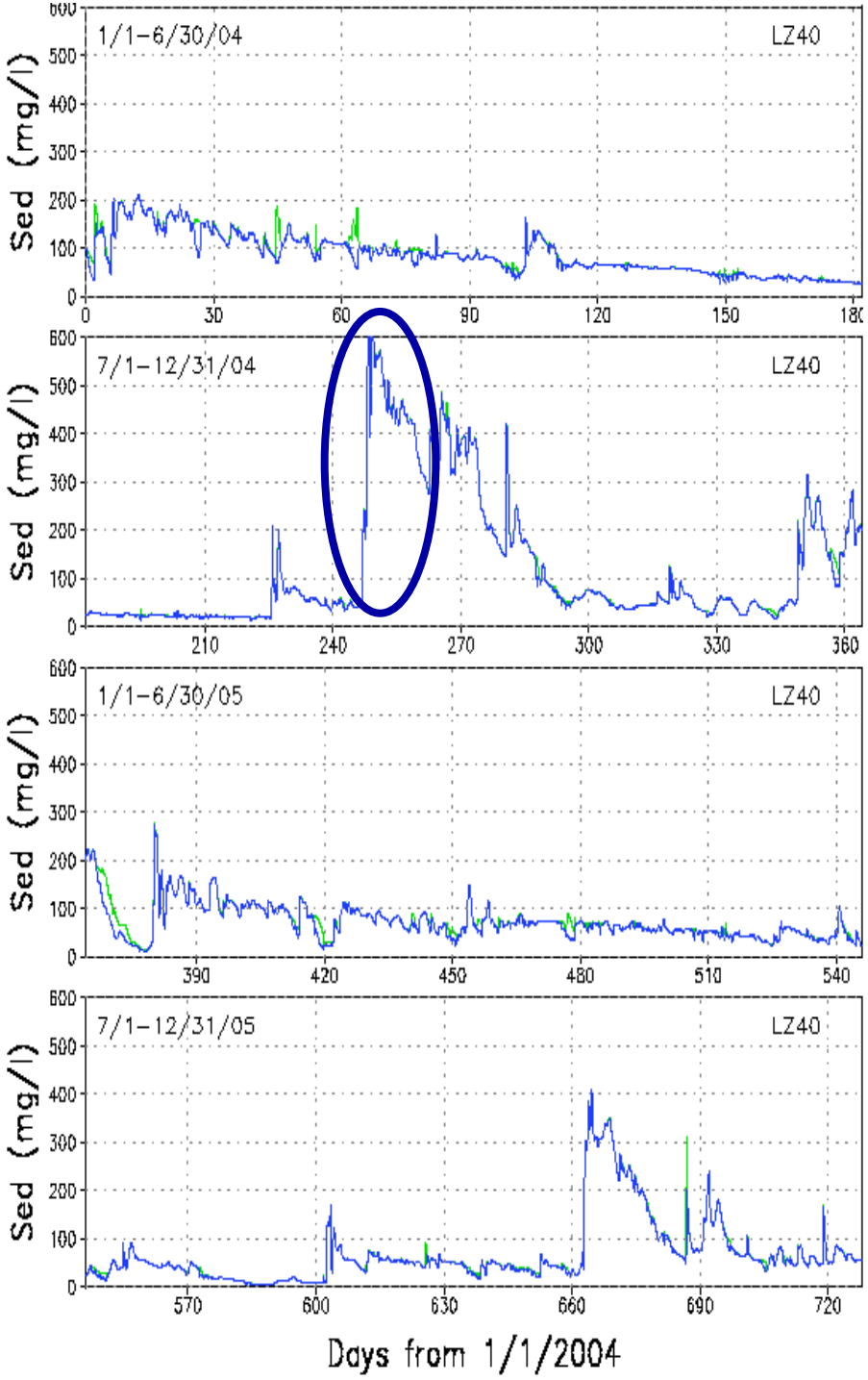


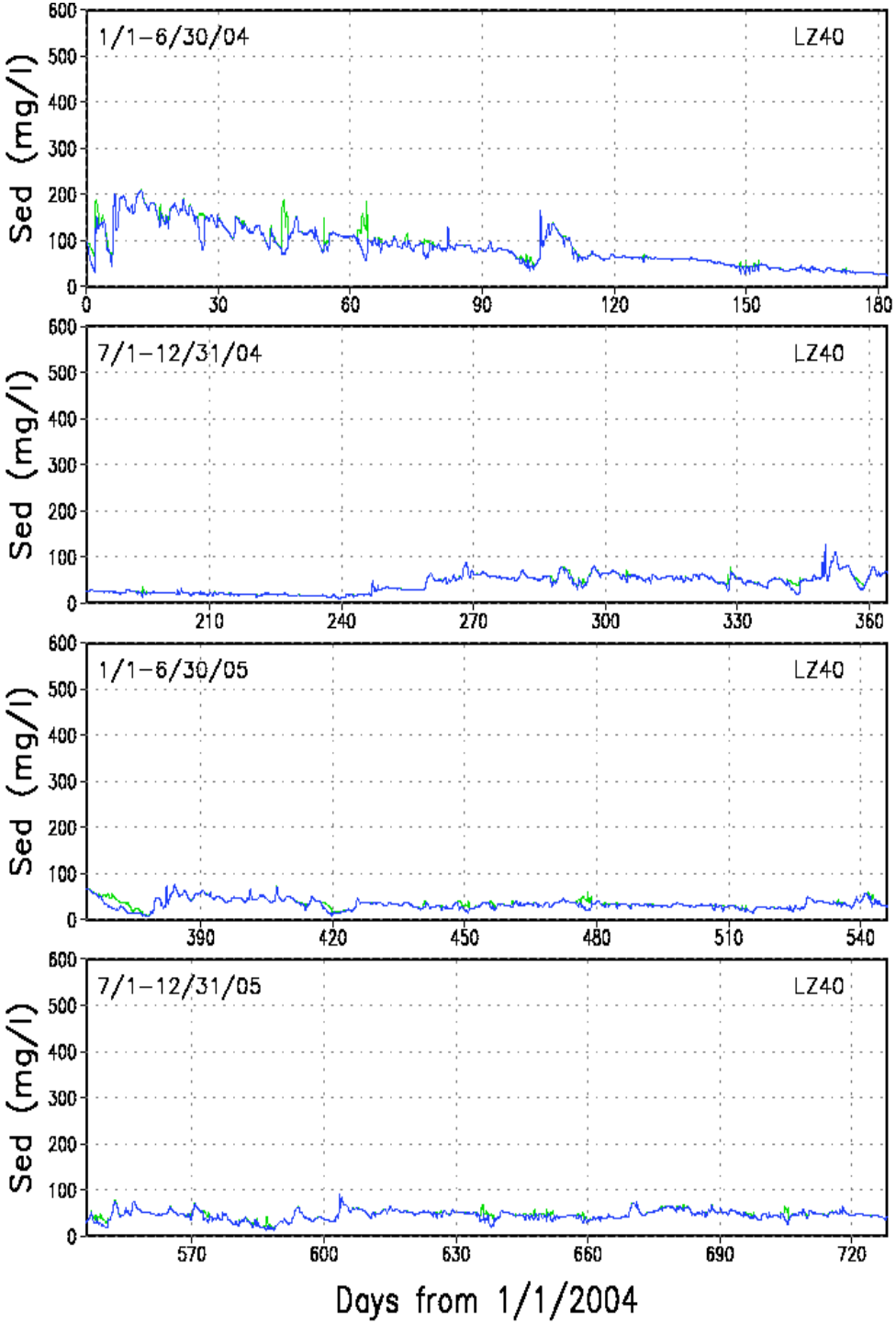
Hurricane Frances
9/2-9/8 (245-252)

Hurricane Jeanne
9/24-9/27 (266-270)


1/1–6/30/04
LZ40
Current (cm/s)
7/1–12/31/04
LZ40
Current (cm/s)
1/1–6/30/05
LZ40
Current (cm/s)
7/1–12/31/05
LZ40
Current (cm/s)
1/1–6/30/04
LZ40
ub(cm/s)
7/1–12/31/04
LZ40
ub(cm/s)
1/1–6/30/05
LZ40
ub(cm/s)
7/1–12/31/05
LZ40
ub(cm/s)


1/1–6/30/04
LZ40
7/1–12/31/04
LZ40
1/1–6/30/05
LZ40
7/1–12/31/05
LZ40
Tau(dynes/cm²)
0
20
40
60
80
100
120
140
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720


1/1-6/30/04
LZ40
7/1-12/31/04
LZ40
1/1-6/30/05
LZ40
7/1-12/31/05
LZ40
Sed (mg/l)
Days from 1/1/2004


1/1-6/30/04
LZ40
7/1-12/31/04
LZ40
1/1-6/30/05
LZ40
7/1-12/31/05
LZ40
Sed (mg/l)
Days from 1/1/2004

Hurricane Name	Peak Date	Max Wind Speed (mi/h)	Persistent Time (Days) ≥ (18 mi/h) (8 m/s)	Max. B. Current (m/s)	Max. B Shear Stress (N/m^2)	Max Orbital Velocity (m/s)	Typical Orbital Velocity (m/s)	Typical B Shear Stress (N/m^2)
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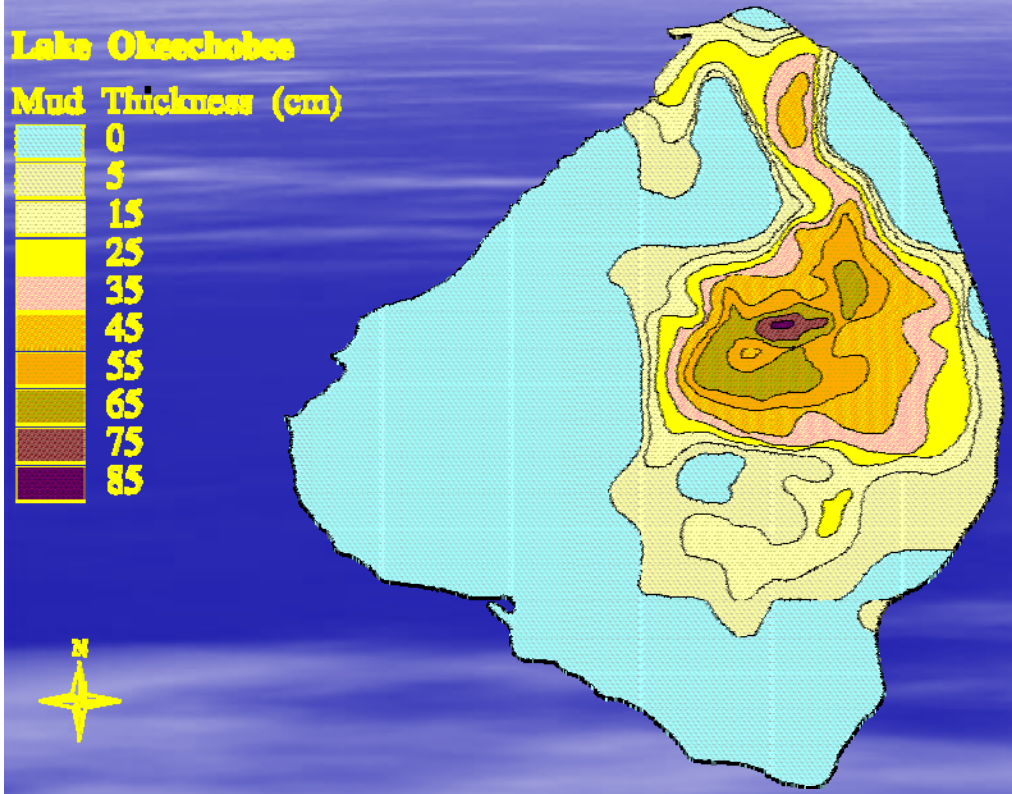
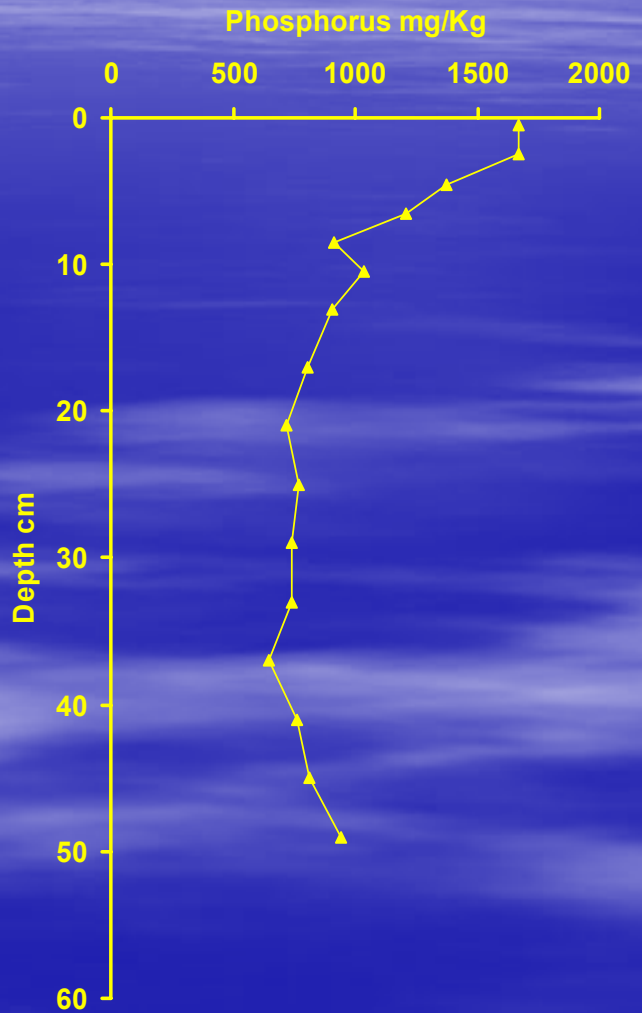
Wilma	10/24/05 11AM	78 (91)	1.5	0.12	13.4	0.71	0.01 – 0.1	0.02 – 0.1

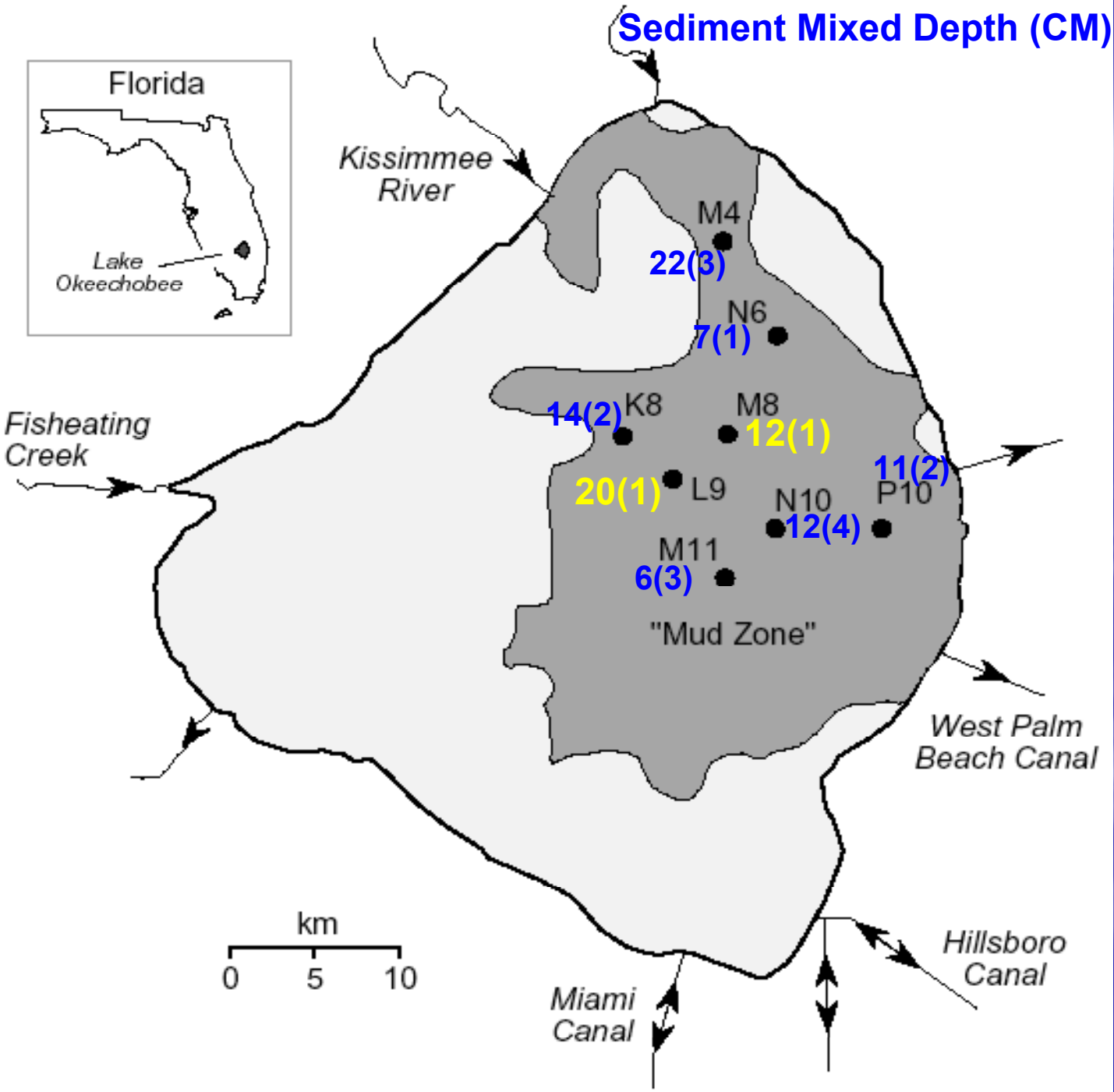
At Station LZ40

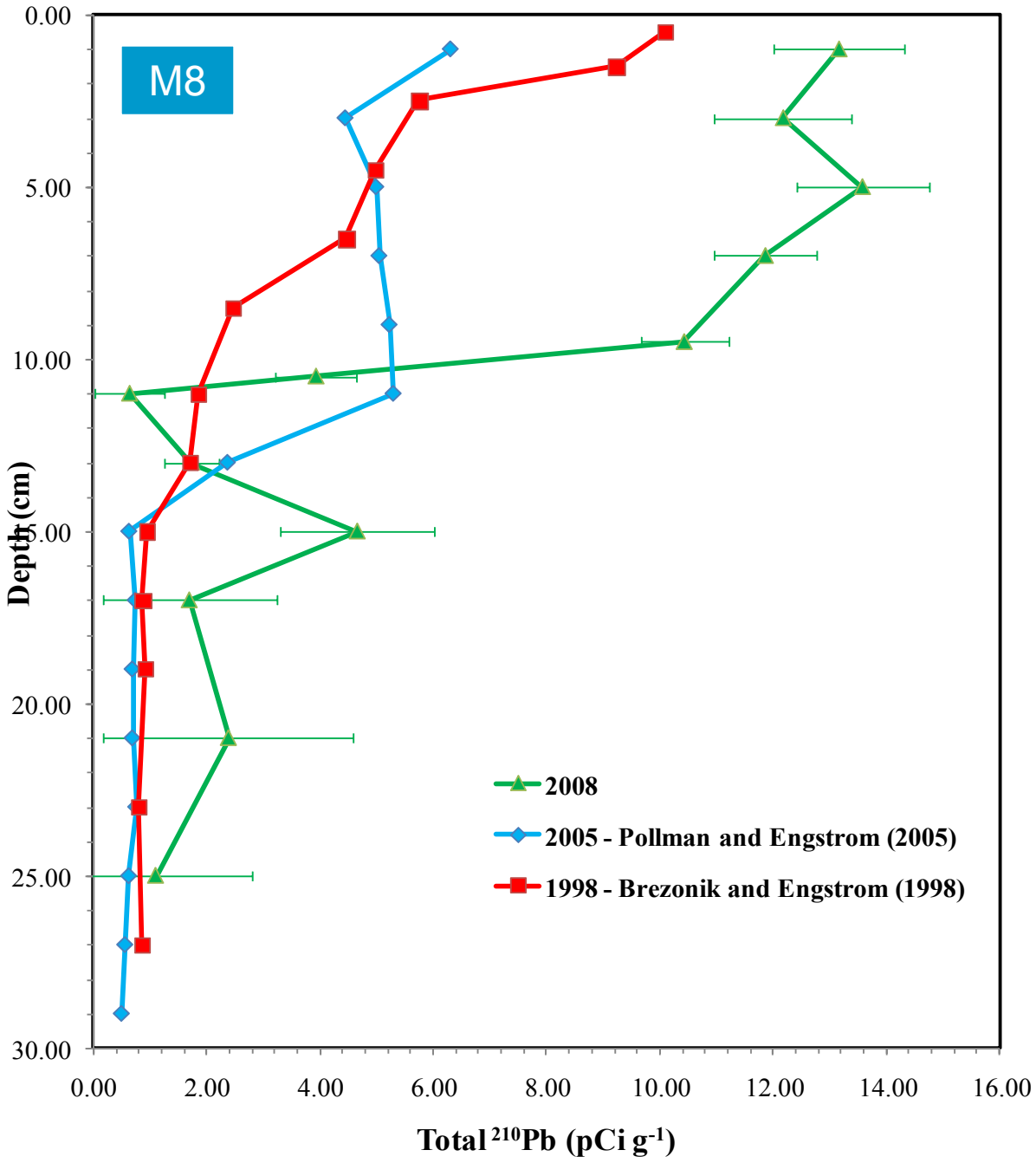
Sediments



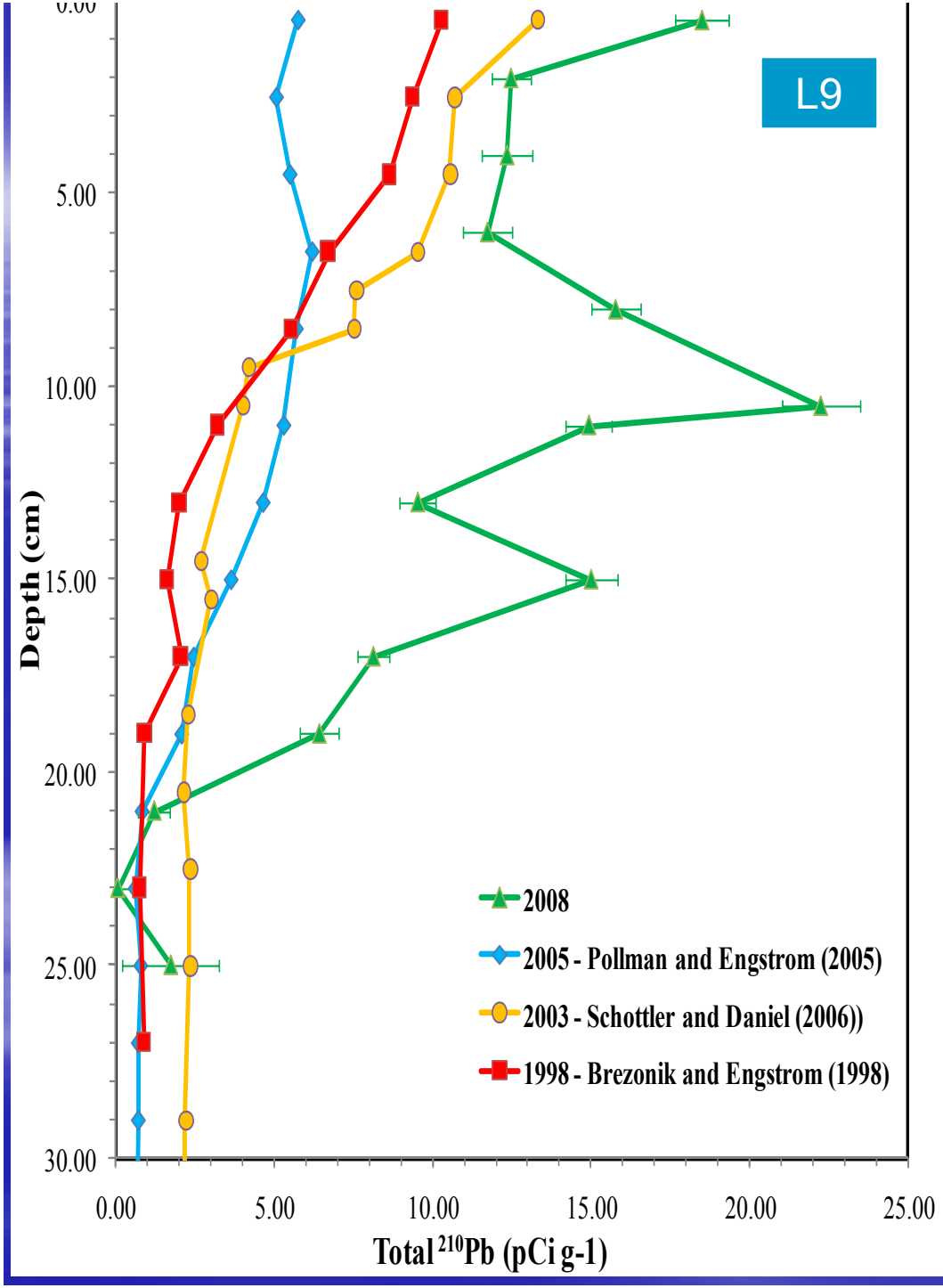


- P laden mud sediments cover over 40% of lake bed


Sediment Mixed Depth (CM)
Florida
Lake Okeechobee
Kissimmee River
M4
22(3)
N6
7(1)
14(2)
K8
M8
12(1)
11(2)
20(1)
L9
N10
P10
12(4)
M11
6(3)
"Mud Zone"
Fisheating Creek
West Palm Beach Canal
Hillsboro Canal
Miami Canal
km
0
5
10



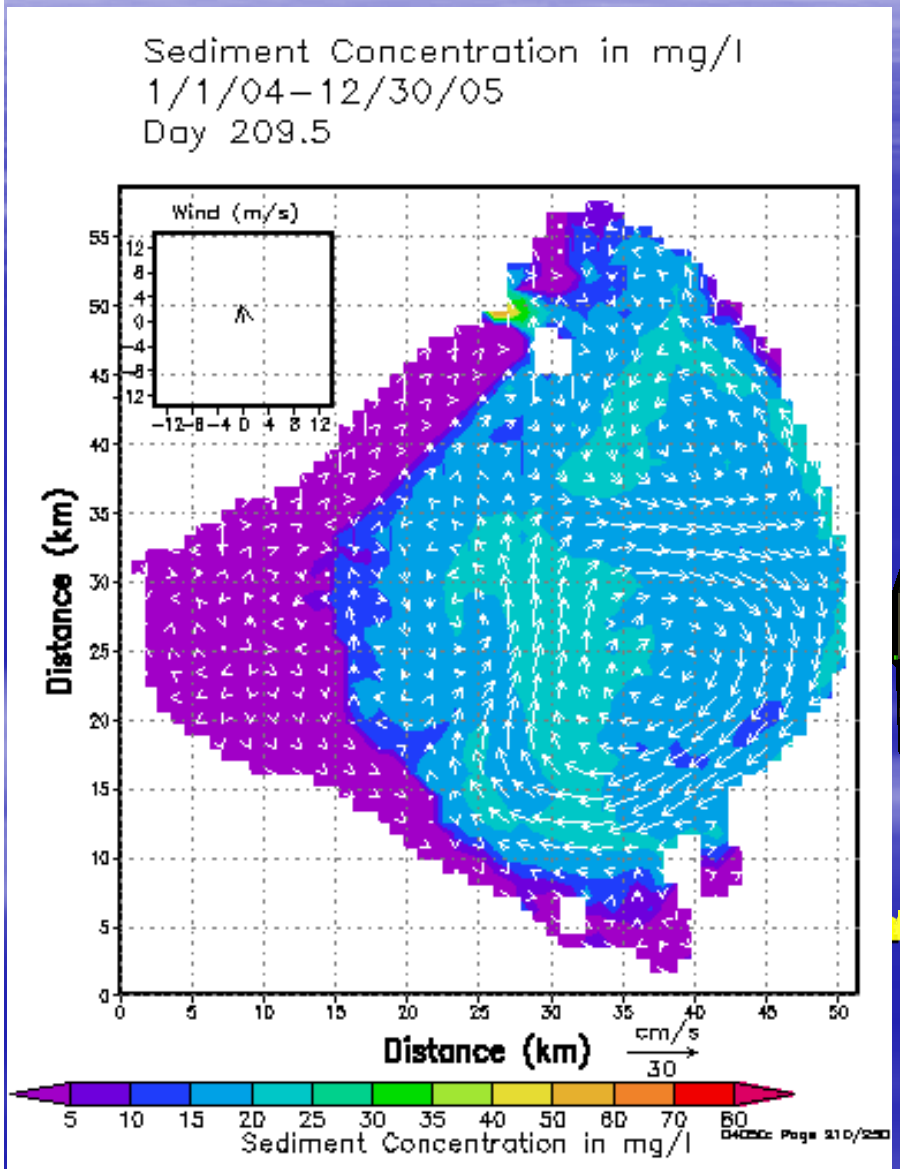
Available Sediment
1cm – before 2004
12cm – after 2004 Hurricanes
15-20cm – after Wilma

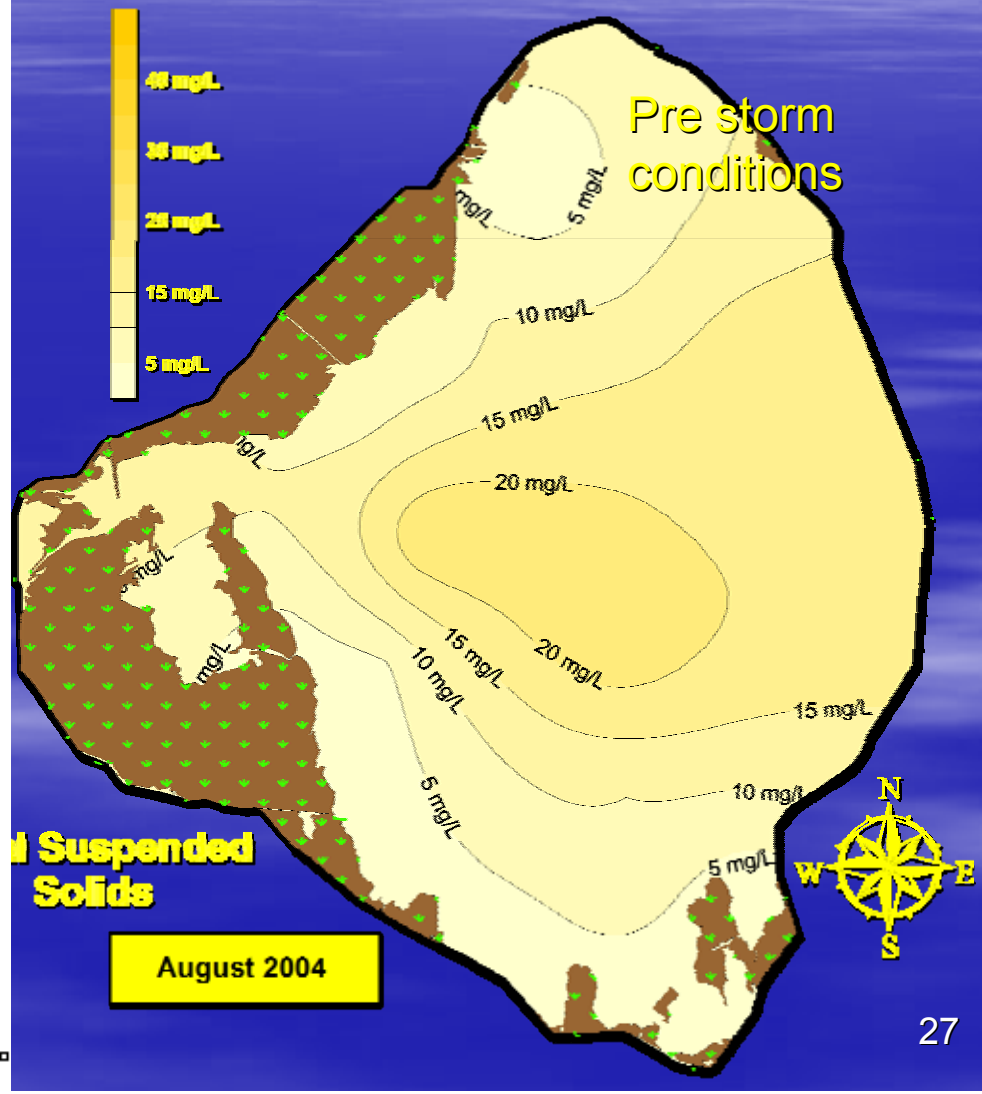


Available Sediment
1cm – before 2004
7cm – after 2004 Hurricanes
15-20cm – after Wilma

Hurricanes

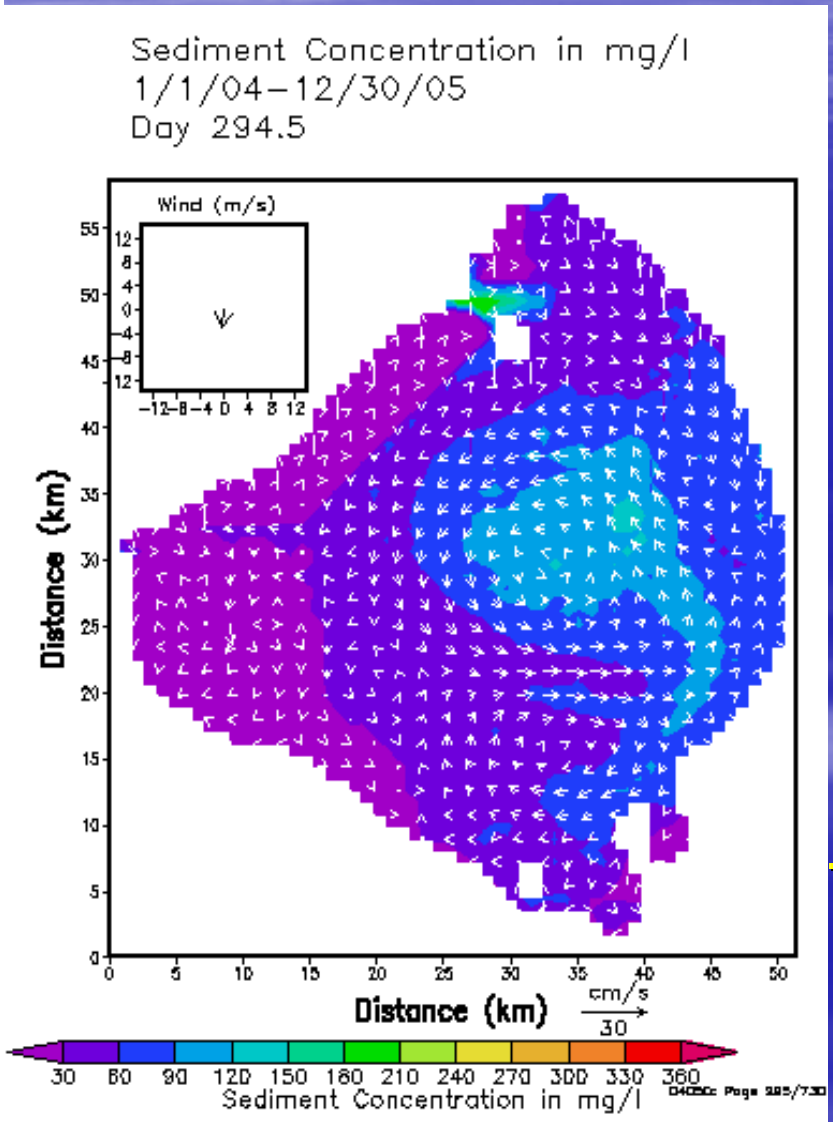
Number of Stations Sampled:	27
Data Range:	1.5 - 25 mg/L
Median Value:	6 mg/L
Mean Value:	8.1 mg/L

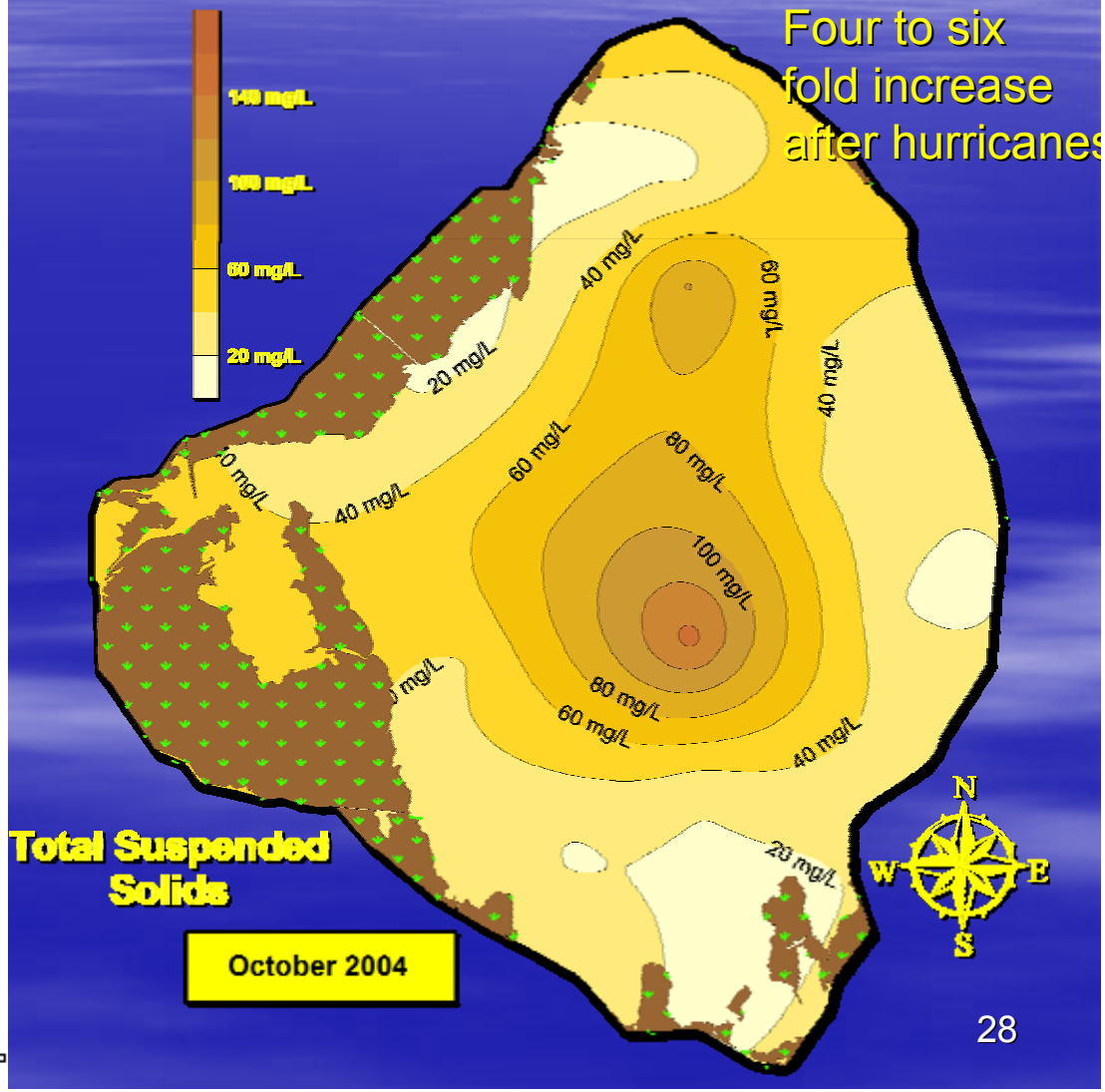


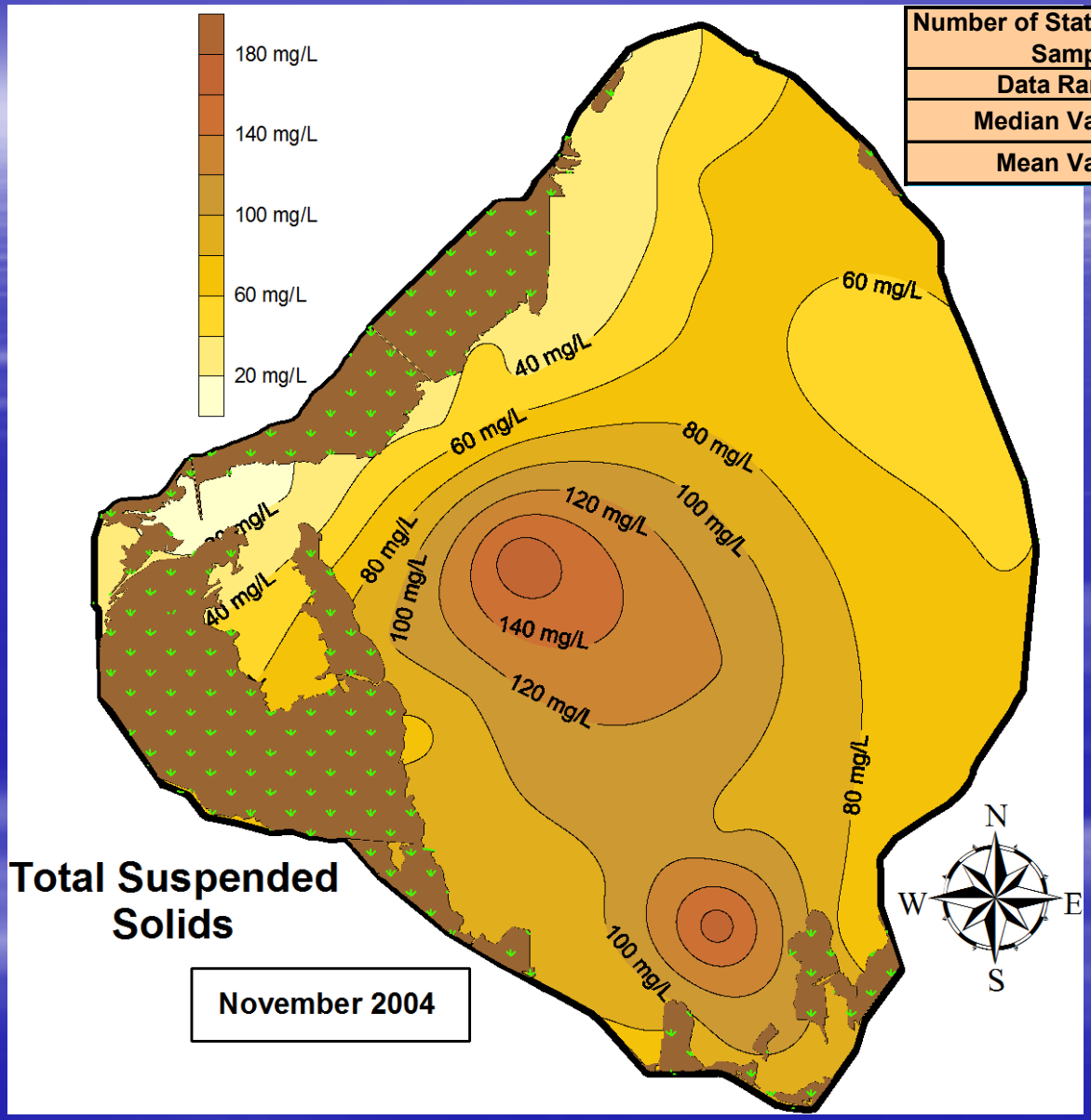


Hurricanes

Number of Stations Sampled:	26
Data Range:	4 - 147 mg/L
Median Value:	27.5 mg/L
Mean Value:	35.8 mg/L



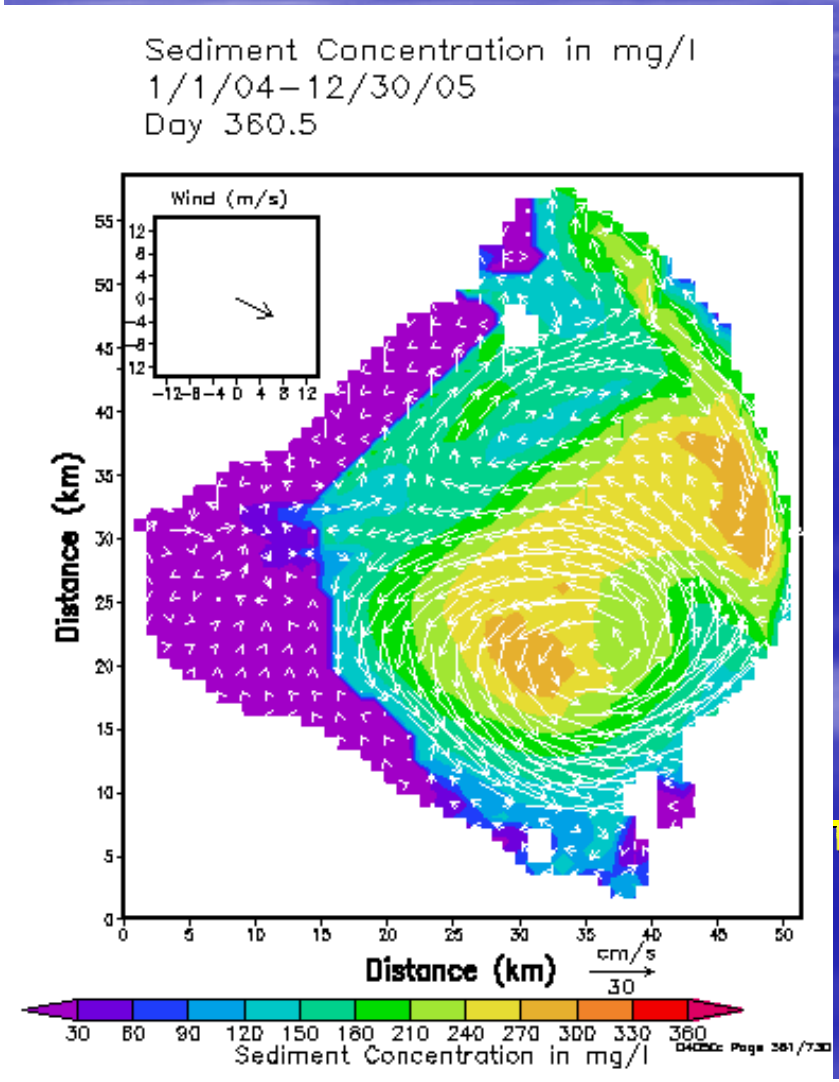


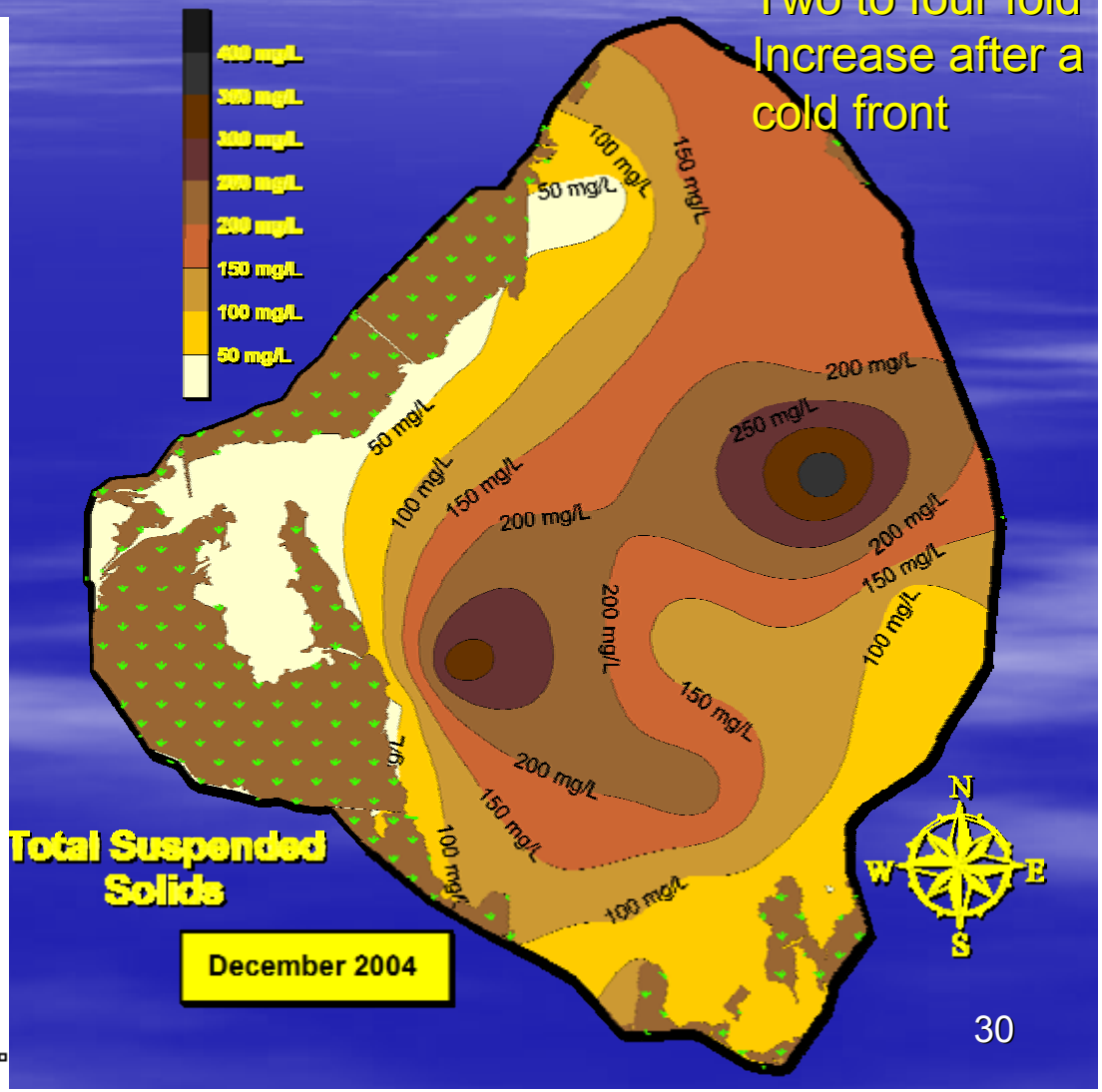


Number of Stations Sampled:	29
Data Range:	12 - 179 mg/L
Median Value:	66 mg/L
Mean Value:	72.3 mg/L

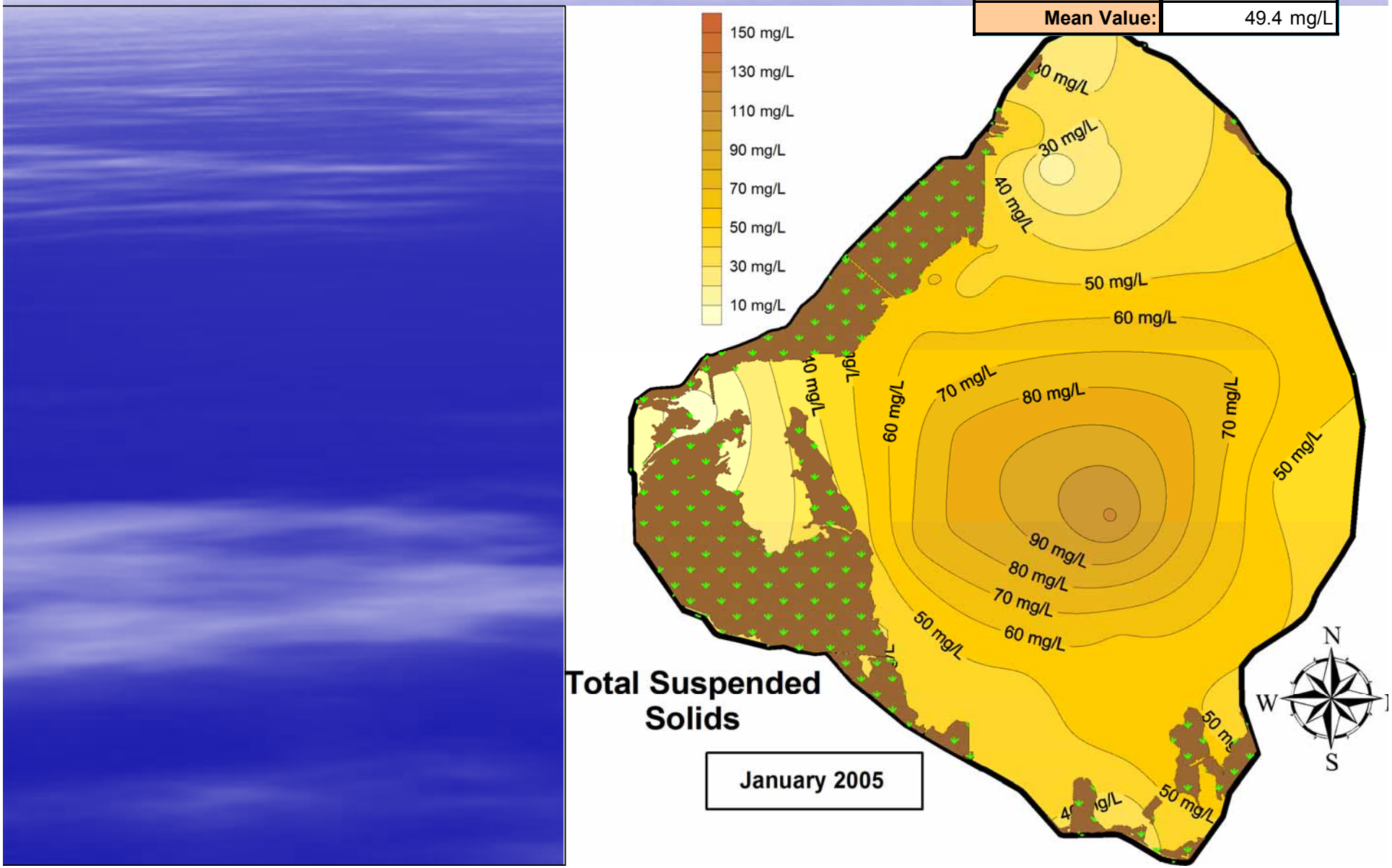
Hurricanes

Number of Stations Sampled:	29
Data Range:	6 - 397 mg/L
Median Value:	77 mg/L
Mean Value:	108.8 mg/L





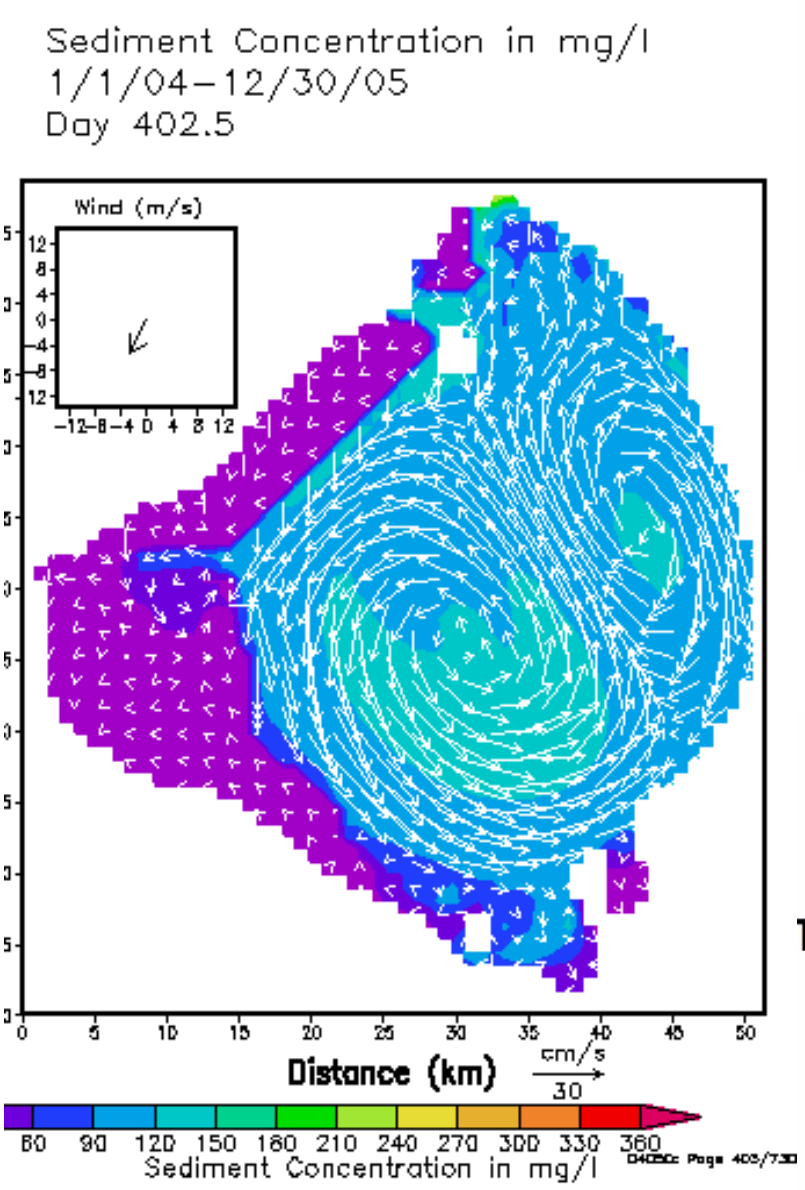
Number of Stations Sampled:	29
Data Range:	6 - 112 mg/L
Median Value:	47 mg/L
Mean Value:	49.4 mg/L

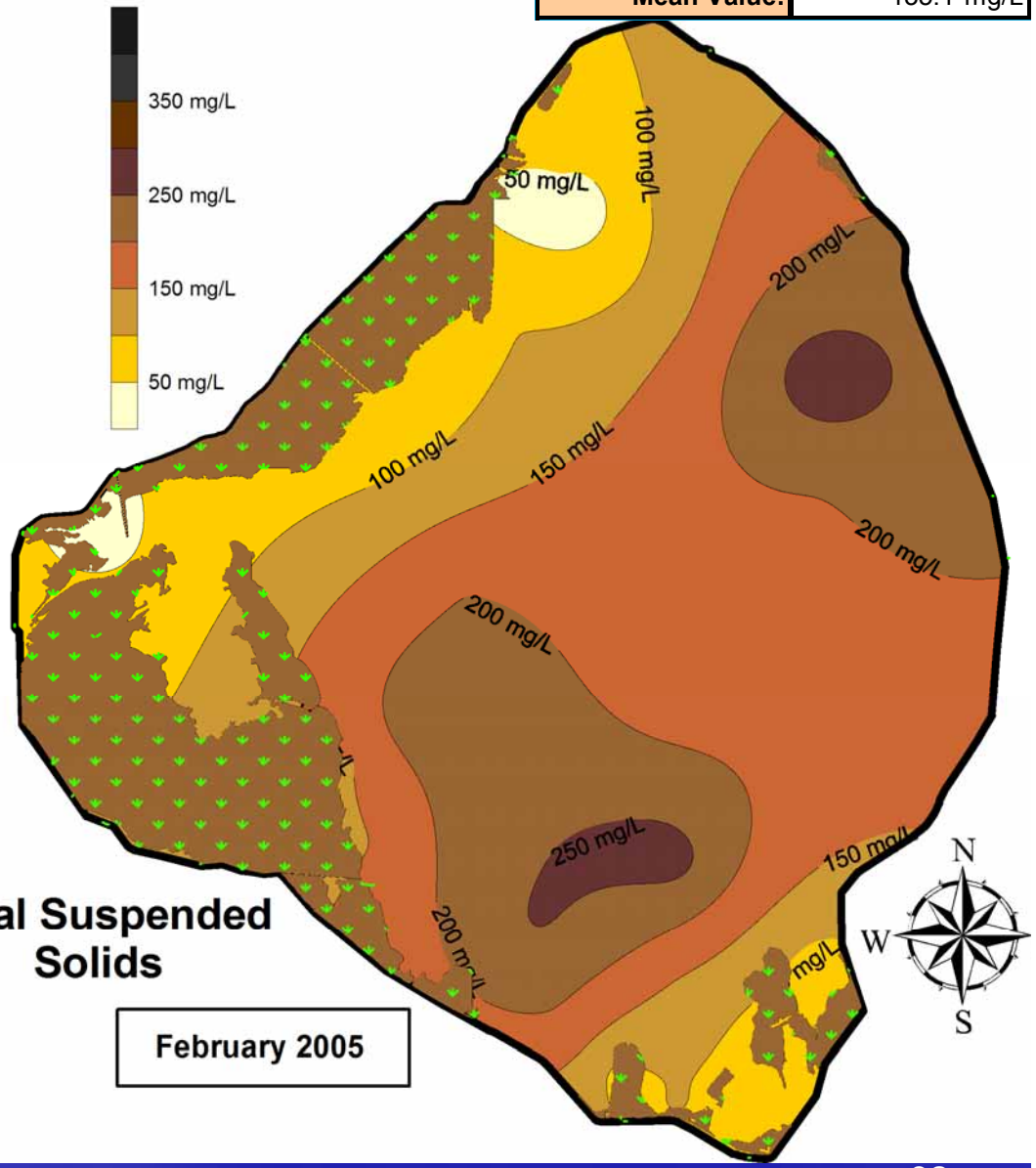


Total Suspended Solids

January 2005

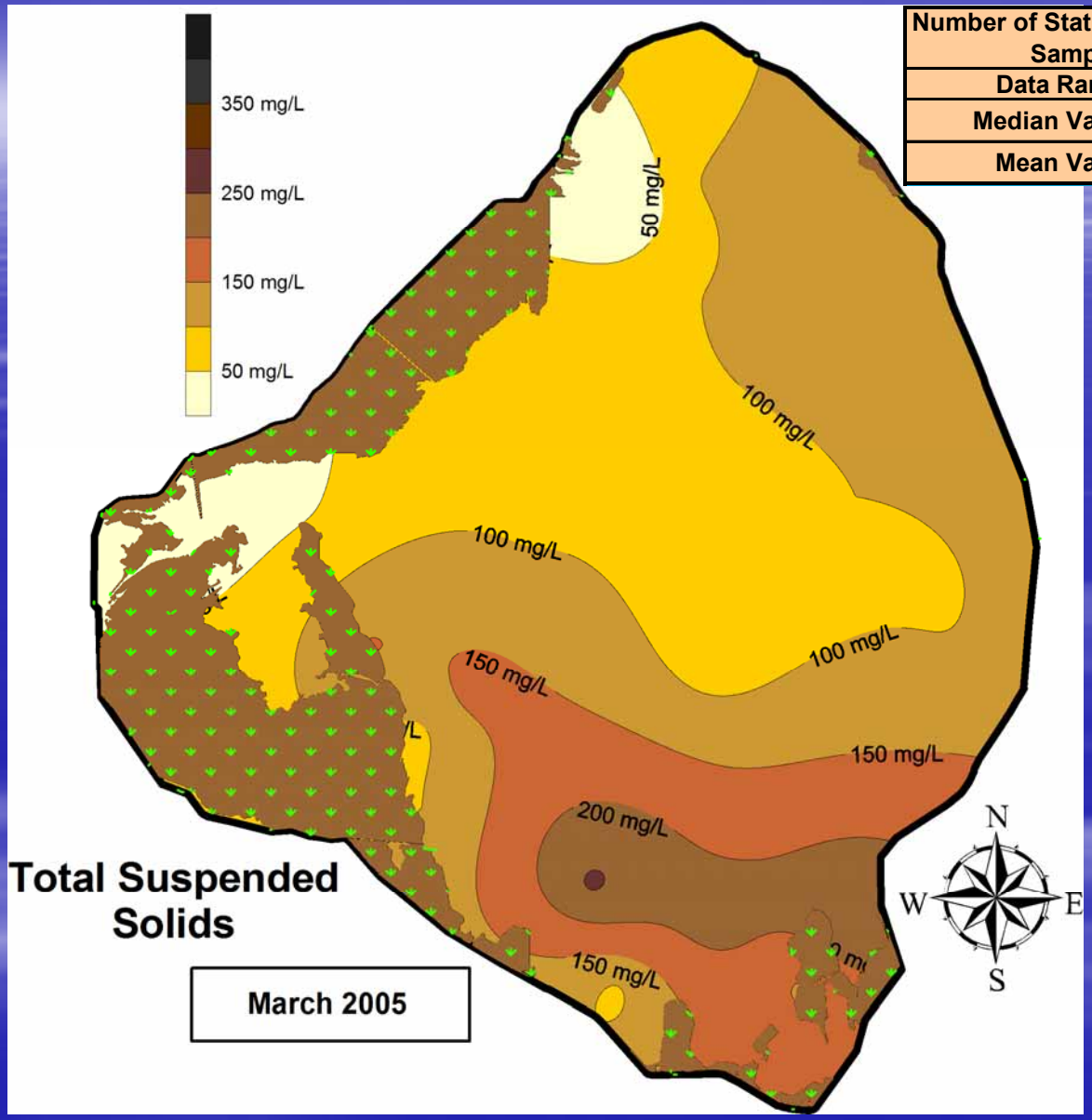
Number of Stations Sampled:	29
Data Range:	17 - 278 mg/L
Median Value:	125 mg/L
Mean Value:	135.1 mg/L



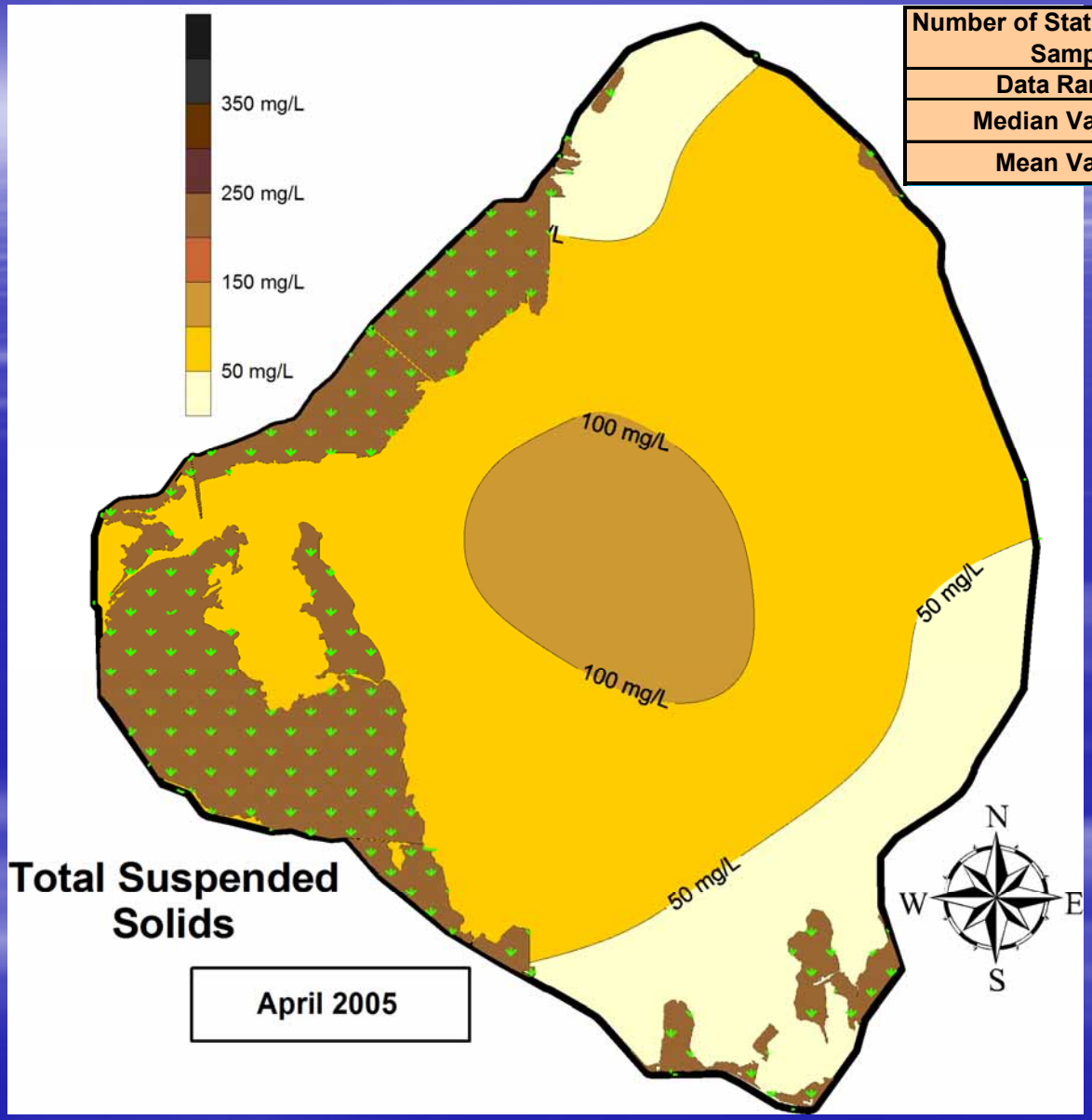


Total Suspended Solids

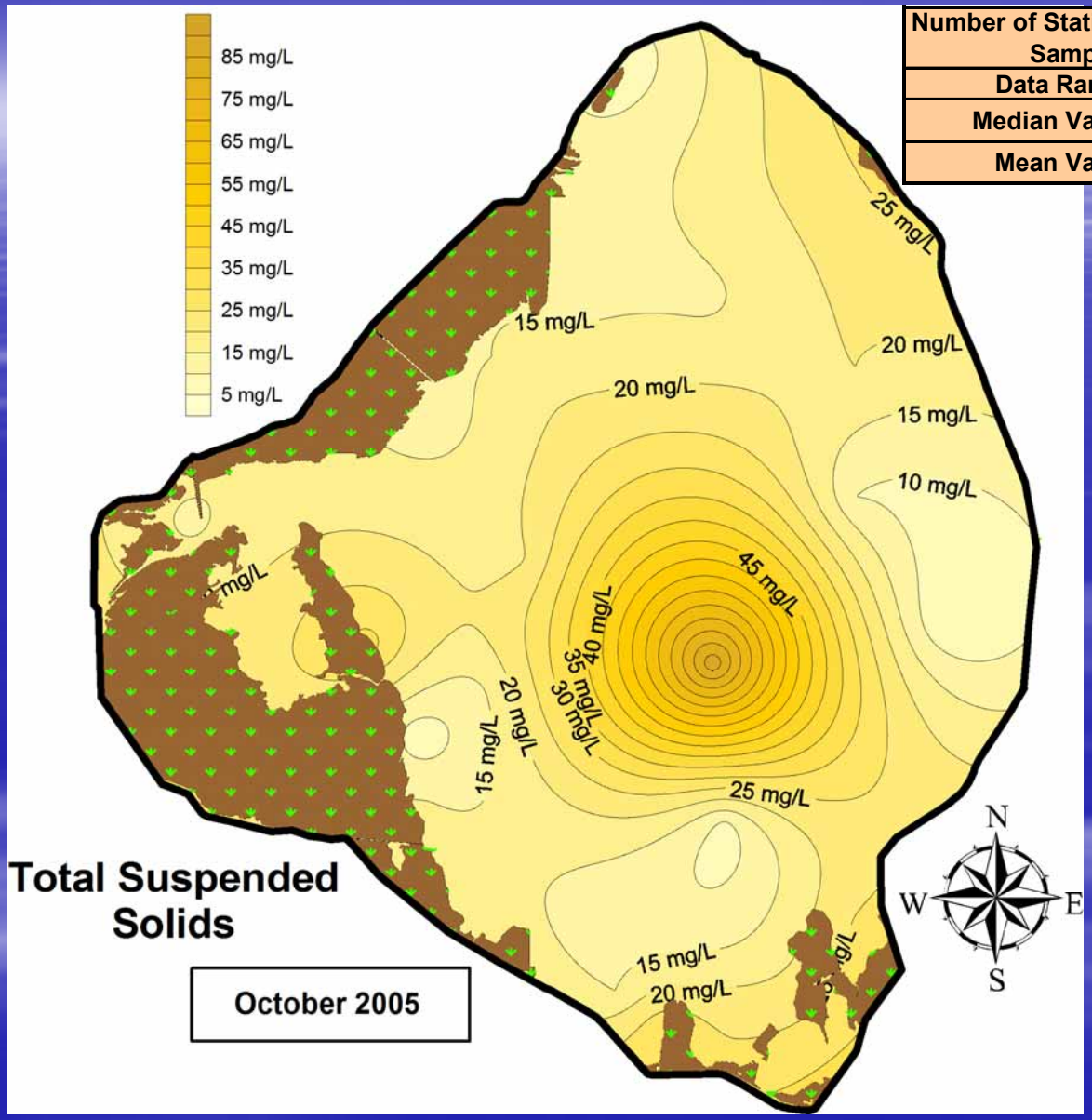
February 2005



Number of Stations Sampled:	29
Data Range:	9.5 - 260 mg/L
Median Value:	101 mg/L
Mean Value:	112.2 mg/L

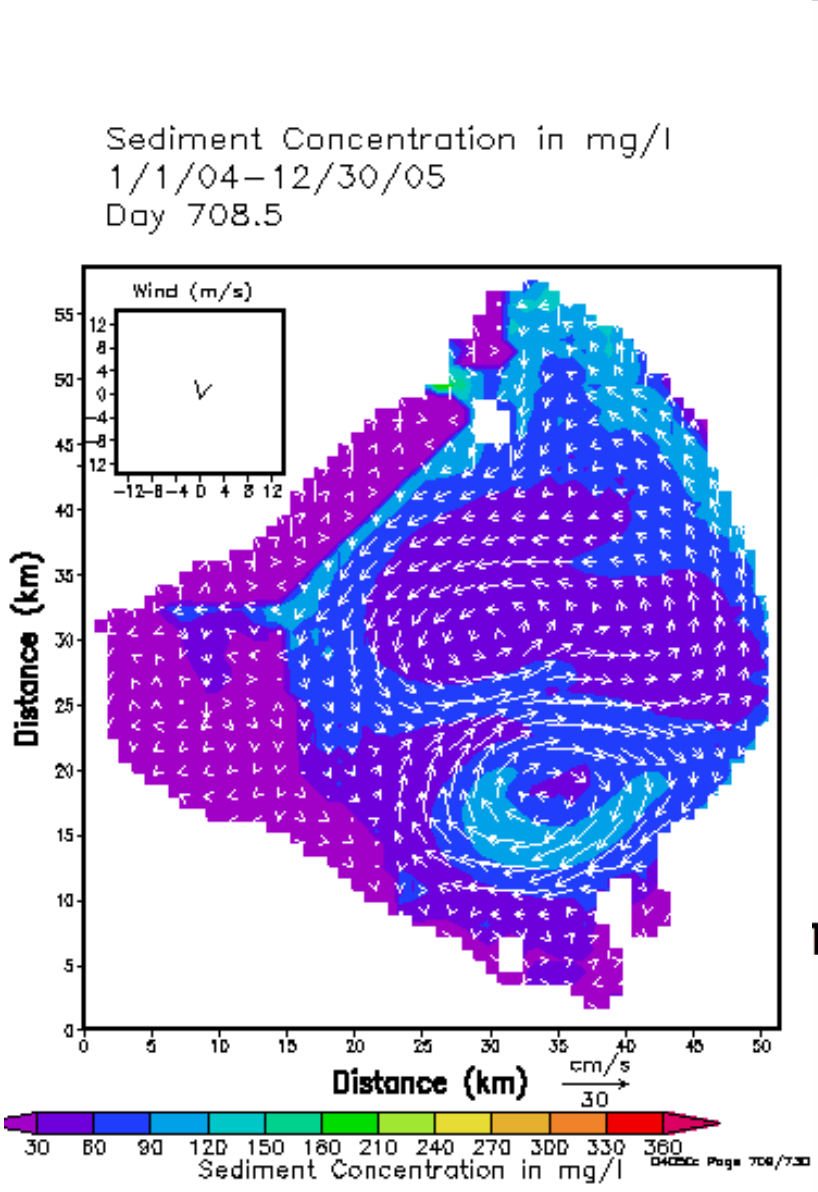


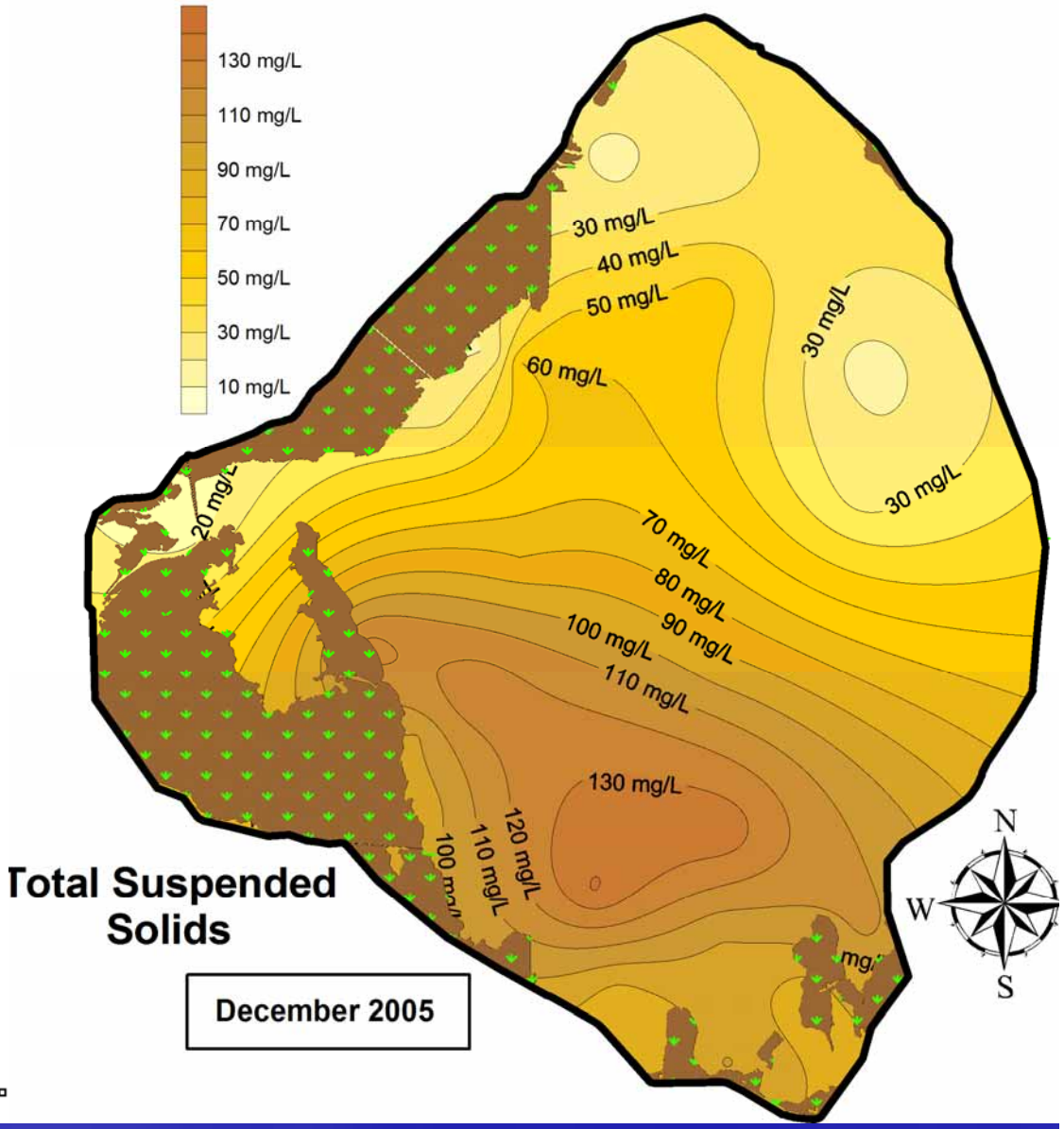
Number of Stations Sampled:	27
Data Range:	6 - 119 mg/L
Median Value:	65 mg/L
Mean Value:	60.6 mg/L



Number of Stations Sampled:	26
Data Range:	5 - 89 mg/L
Median Value:	14.5 mg/L
Mean Value:	18.8 mg/L

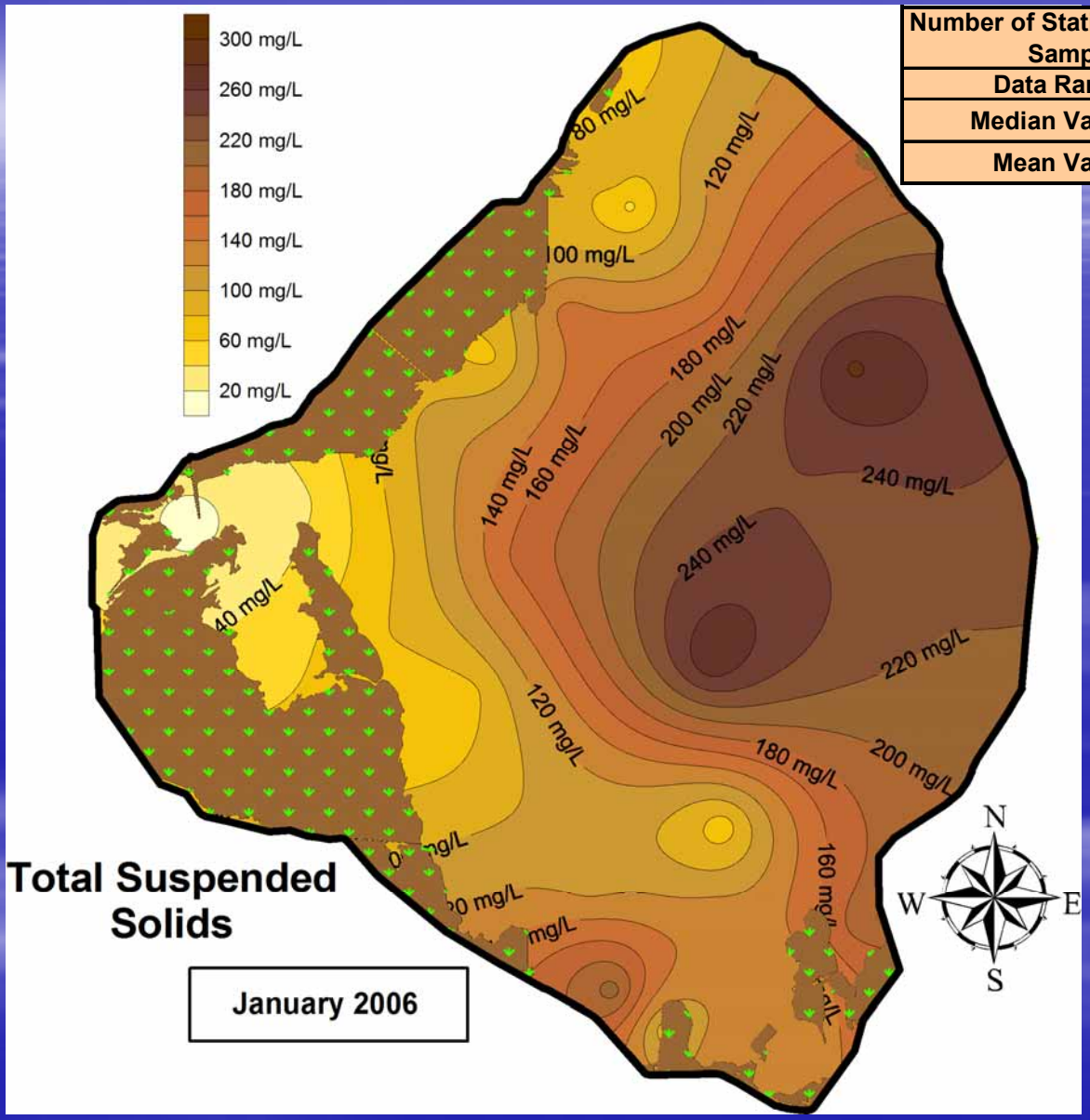
Number of Stations Sampled:	28
Data Range:	10 - 141 mg/L
Median Value:	80.5 mg/L
Mean Value:	70.8 mg/L



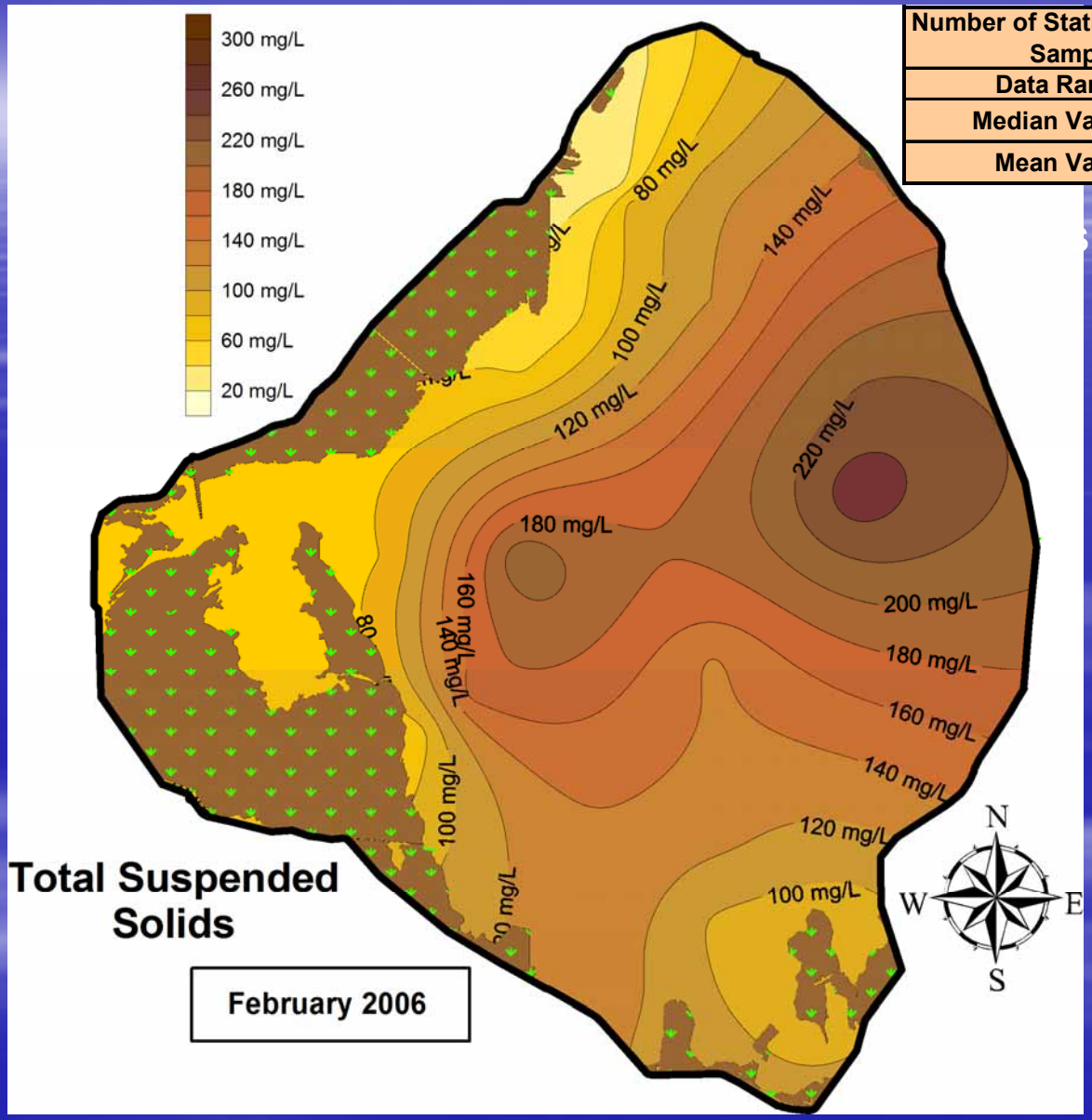


Total Suspended Solids

December 2005

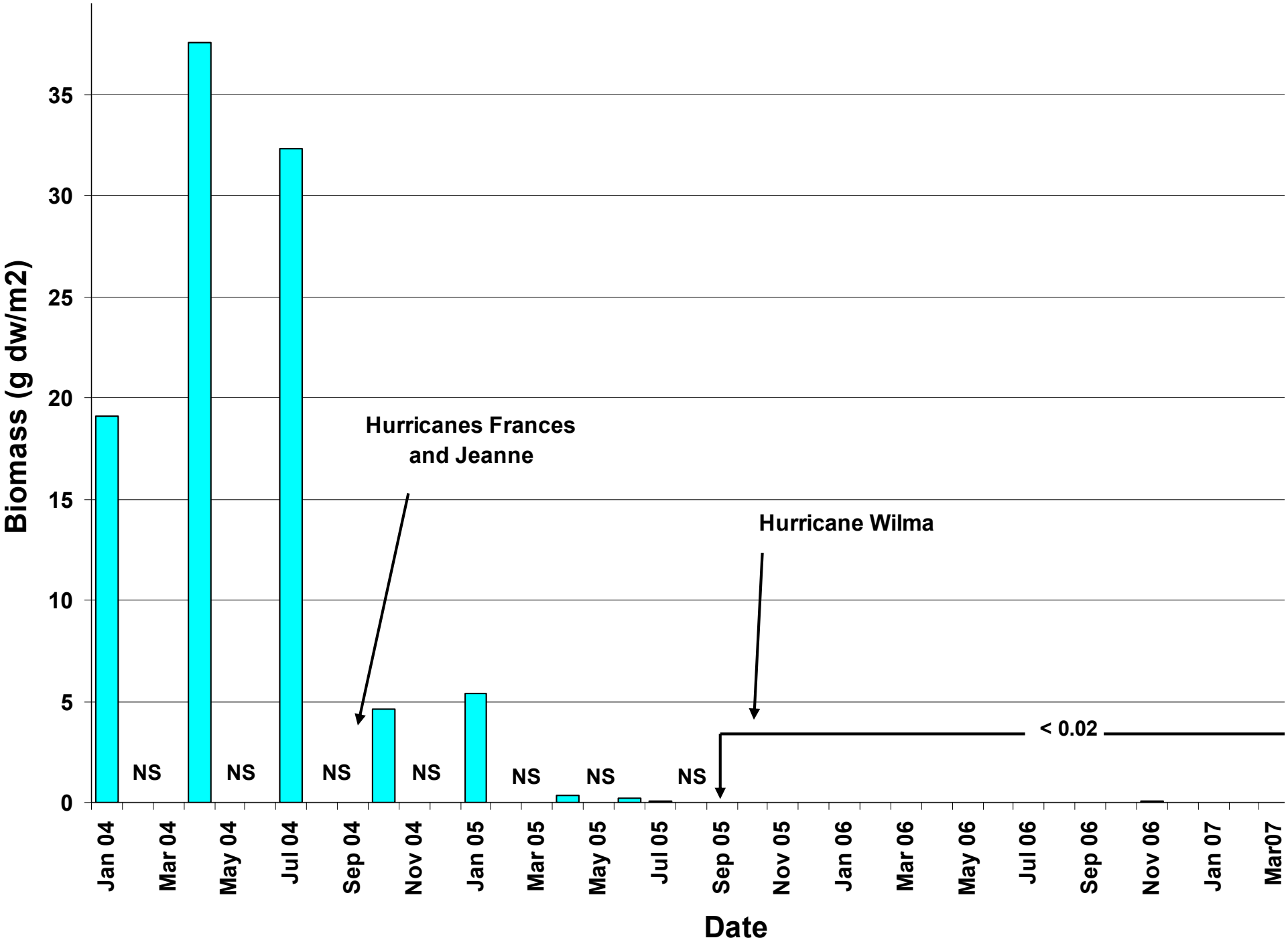


Number of Stations Sampled:	29
Data Range:	14 - 284 mg/L
Median Value:	109 mg/L
Mean Value:	123.5 mg/L



Number of Stations Sampled:	27
Data Range:	24.3 - 252.4 mg/L
Median Value:	96 mg/L
Mean Value:	110.6 mg/L

sional Data


Biomass (g dw/m2)
35
30
25
20
15
10
5
0
Hurricanes Frances
and Jeanne
Hurricane Wilma
< 0.02
NS
NS
NS
NS
NS
NS
NS
Jan 04
Mar 04
May 04
Jul 04
Sep 04
Nov 04
Jan 05
Mar 05
May 05
Jul 05
Sep 05
Nov 05
Jan 06
Mar 06
May 06
Jul 06
Sep 06
Nov 06
Jan 07
Mar07
Date

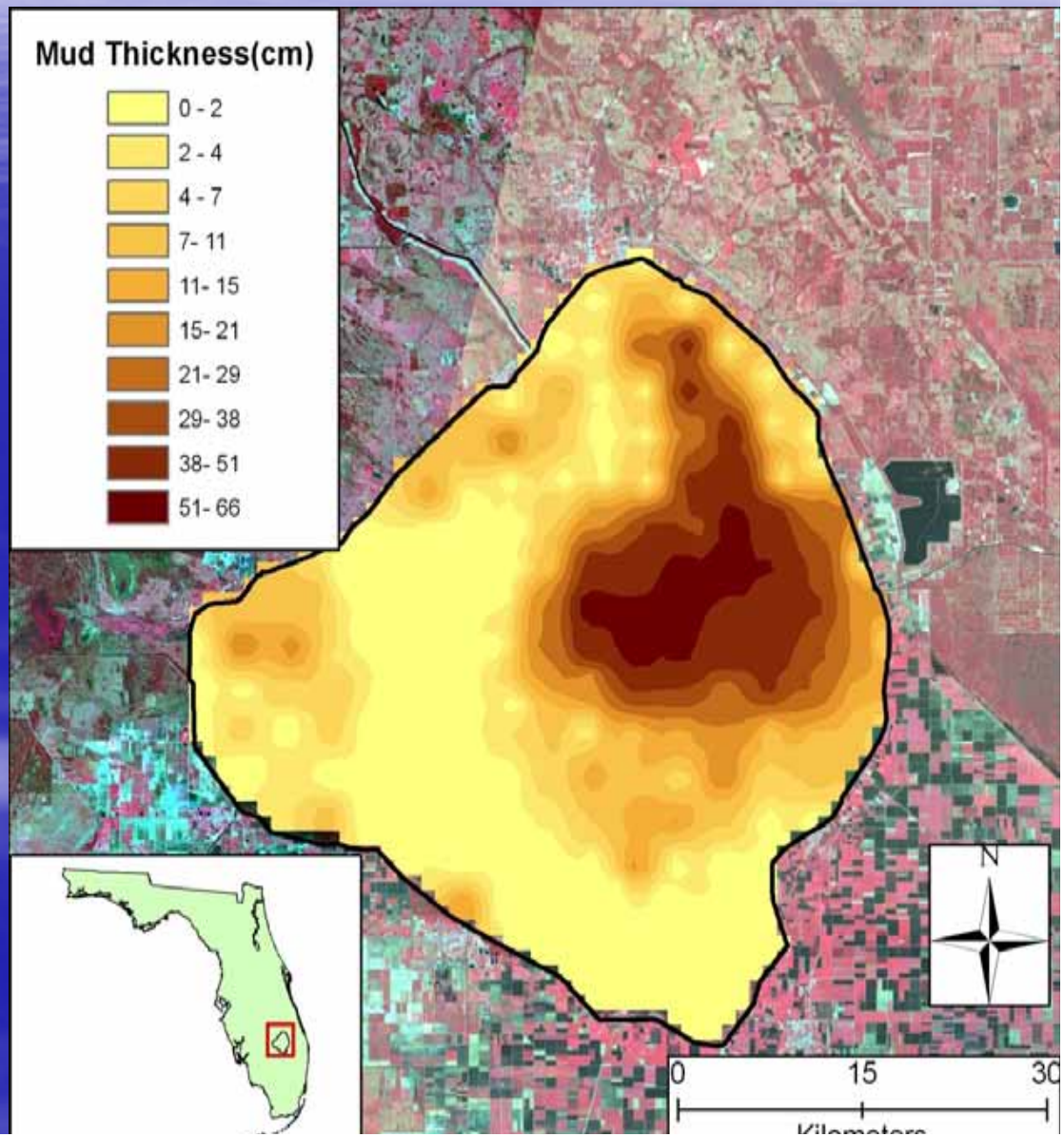
Hurricanes

- Increased available suspended sediments throughout lake
- TSS Increased
- Reduced light availability
- Aquatic vegetation, SAV stressed
- Increased nutrient concentrations
- Impacts extended by cold fronts

Mud thickness-1988

Total mud volume=0.20 km^3

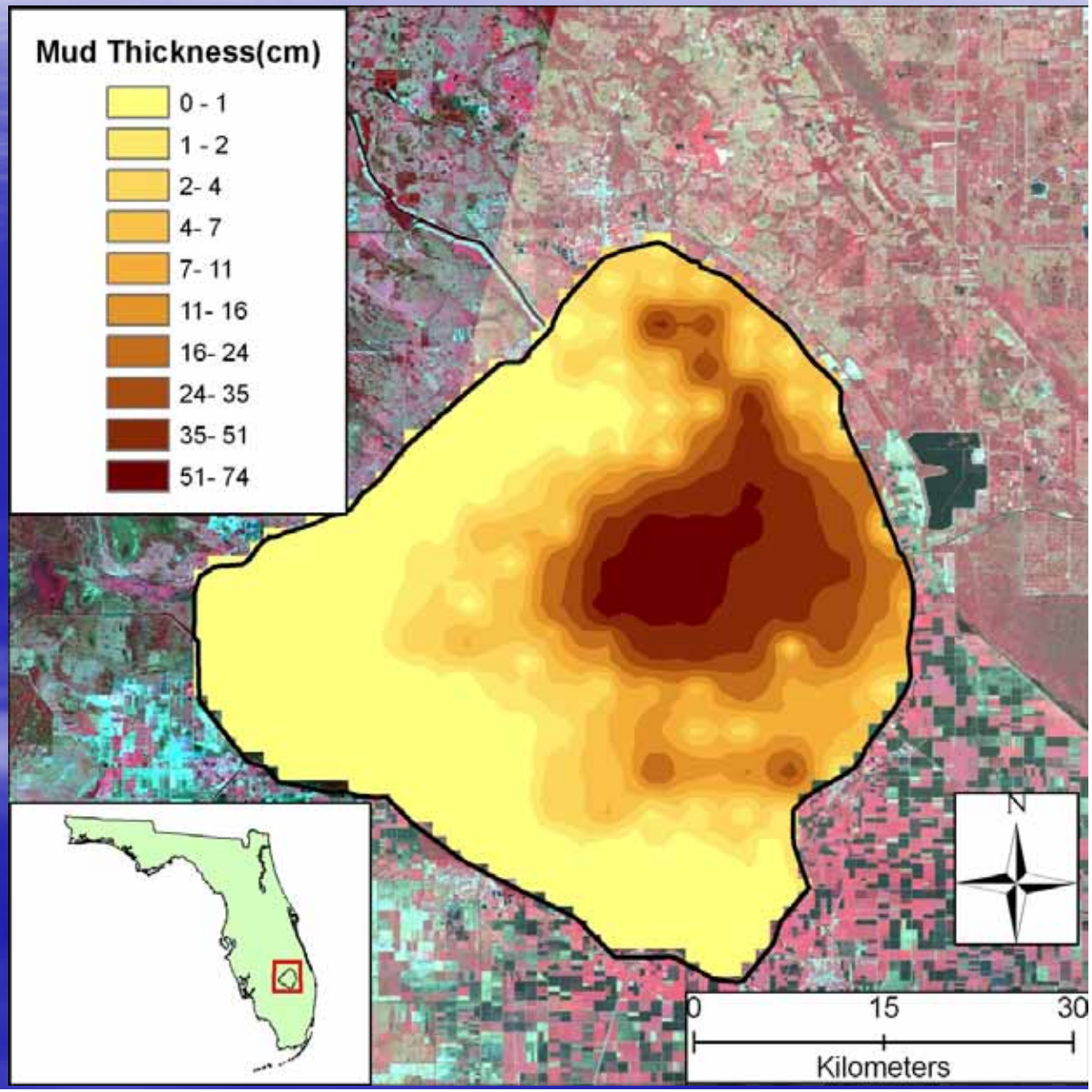
Total mud weight =2.44*10^8 tonnes =244,000,000 tonnes



Mud thickness-1998

Total mud volume=0.17 km^3

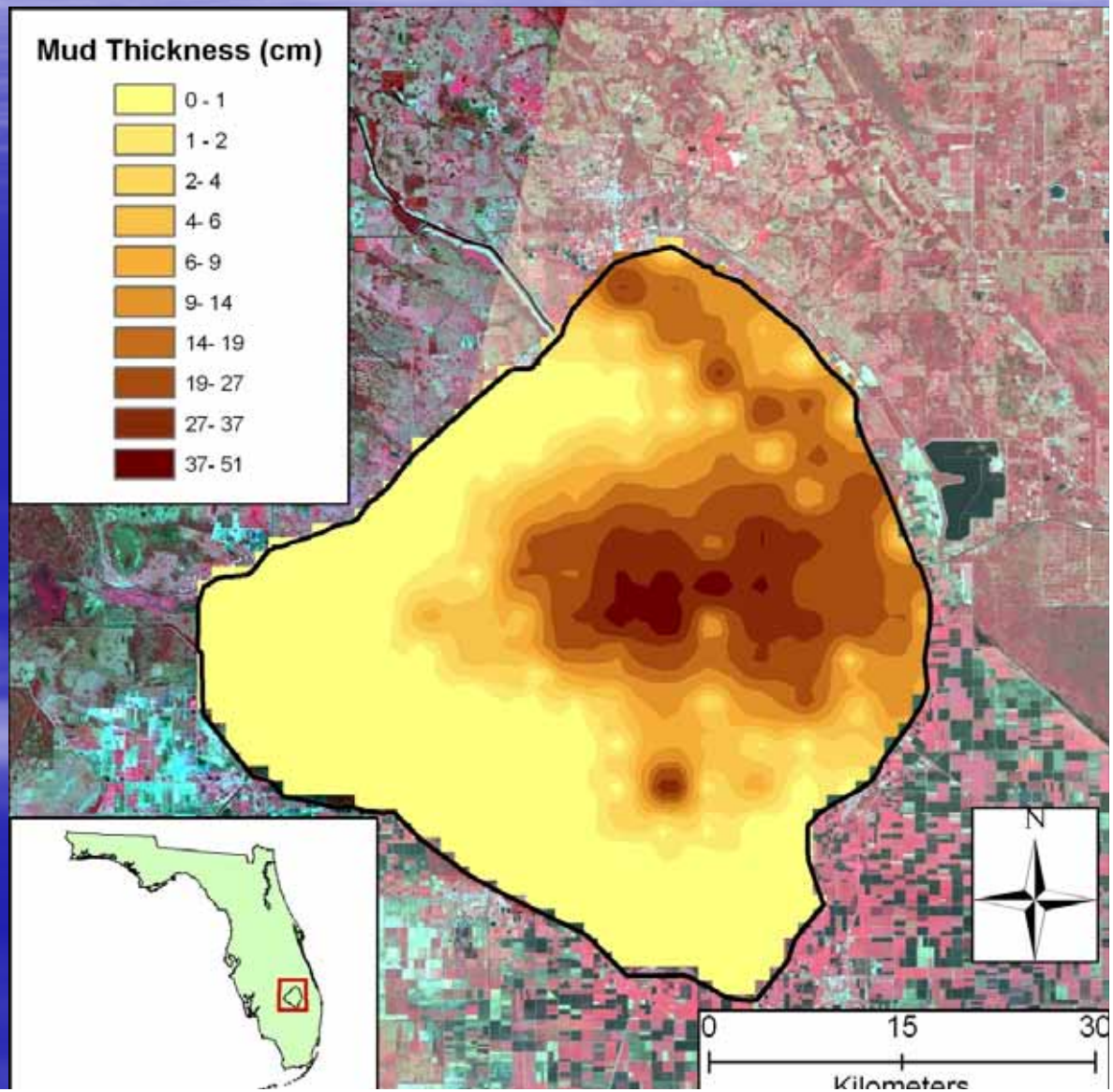
Total mud weight =$2.15*10^8$ tonnes =215,000,000 tonnes



Mud thickness-2006

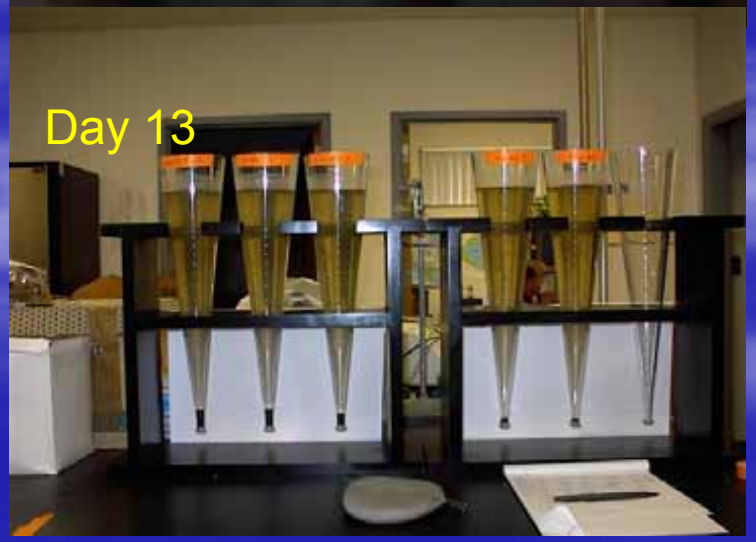
Total mud volume=0.13 km^3

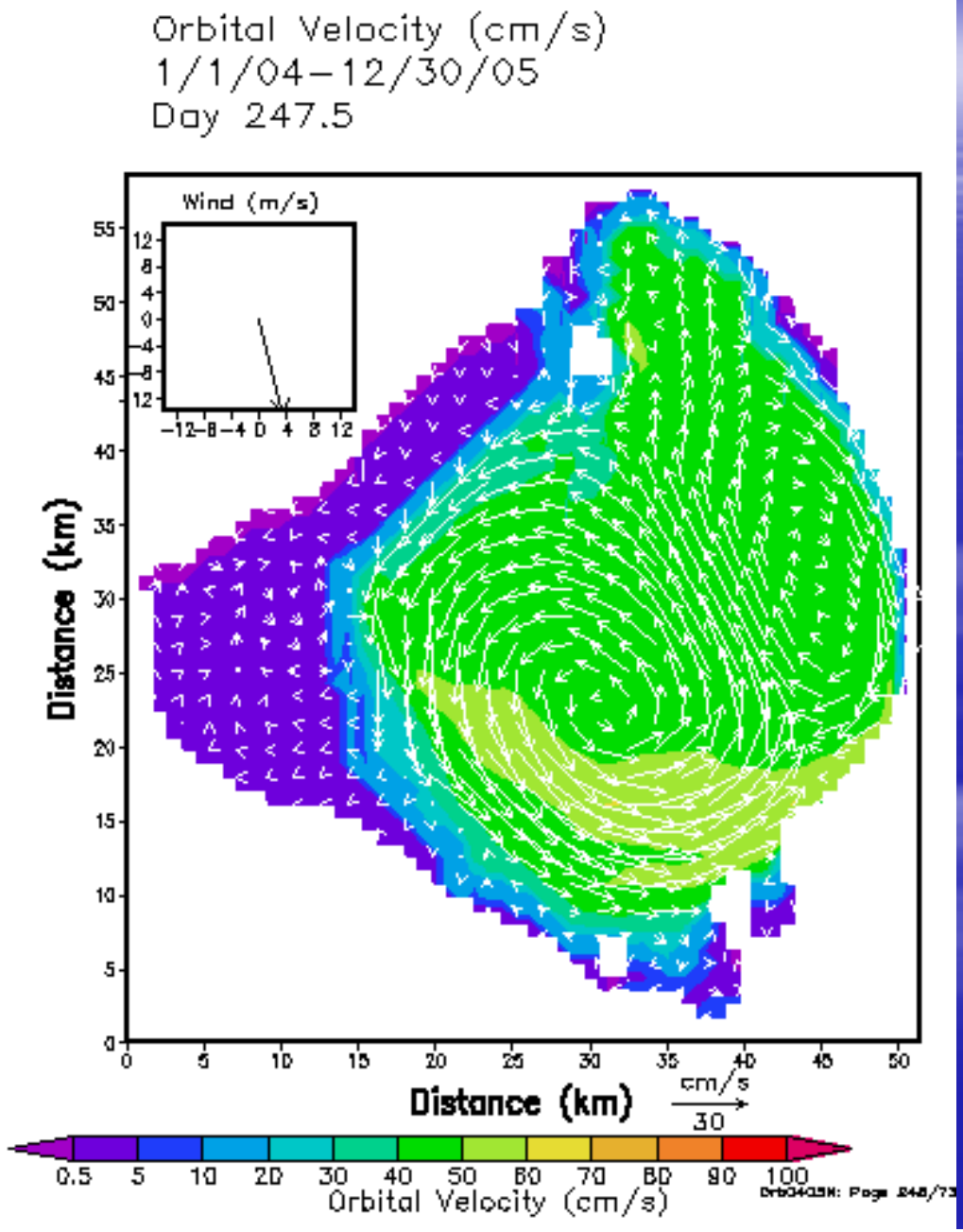
Total mud weight =$1.58*10^8$ tonnes =158,000,000 tonnes



Hurricanes

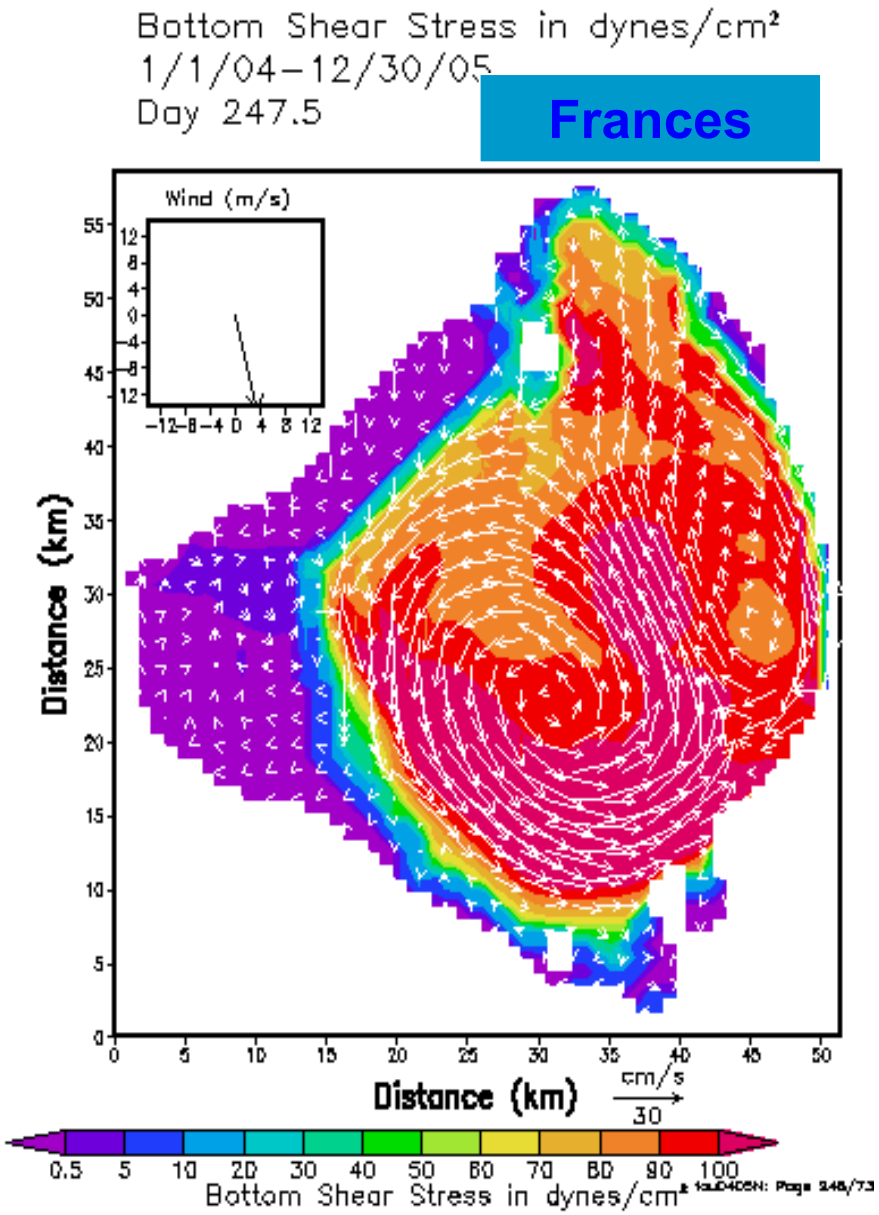
- Fine particles
  - Resuspended
  - Circulated throughout lake
  - Long settling time
  - Consolidation
- Resuspended under calm wind

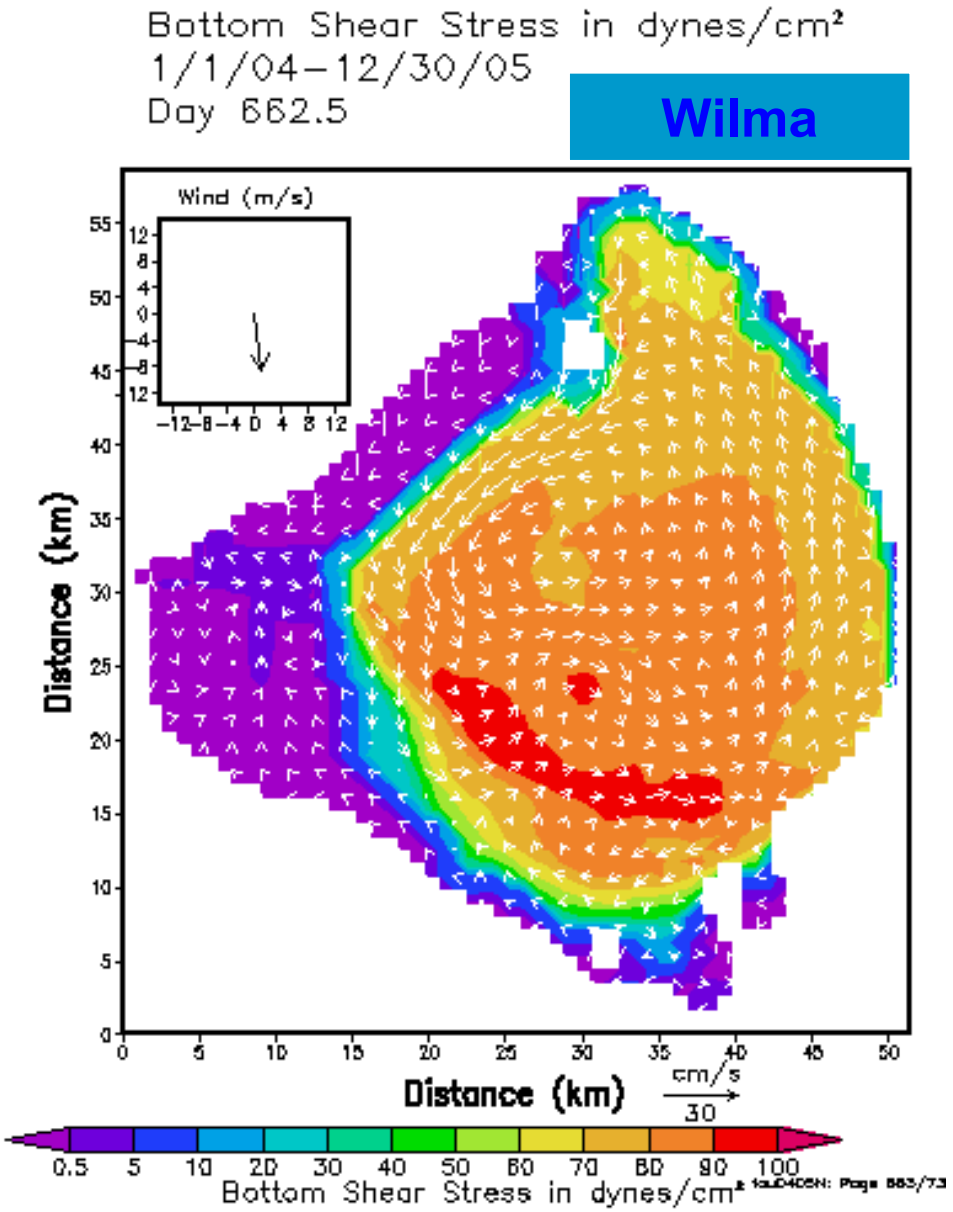


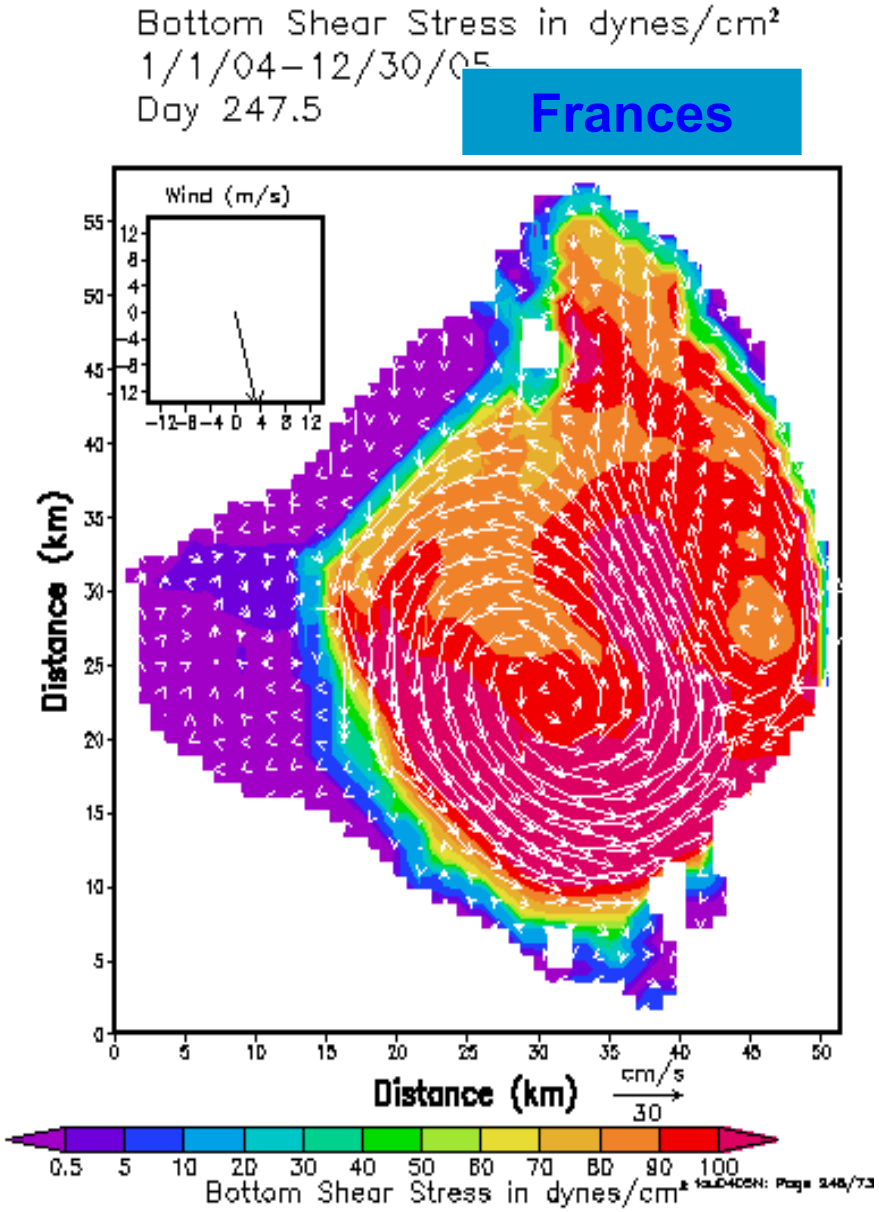

Orbital Velocity (cm/s)
1/1/04–12/30/05
Day 247.5
Wind (m/s)
12
8
4
0
-4
-8
-12
-12 -8 -4 0 4 8 12
Distance (km)
0 5 10 15 20 25 30 35 40 45 50
Distance (km)
cm/s
30
0.5 5 10 20 30 40 50 60 70 80 90 100
Orbital Velocity (cm/s)

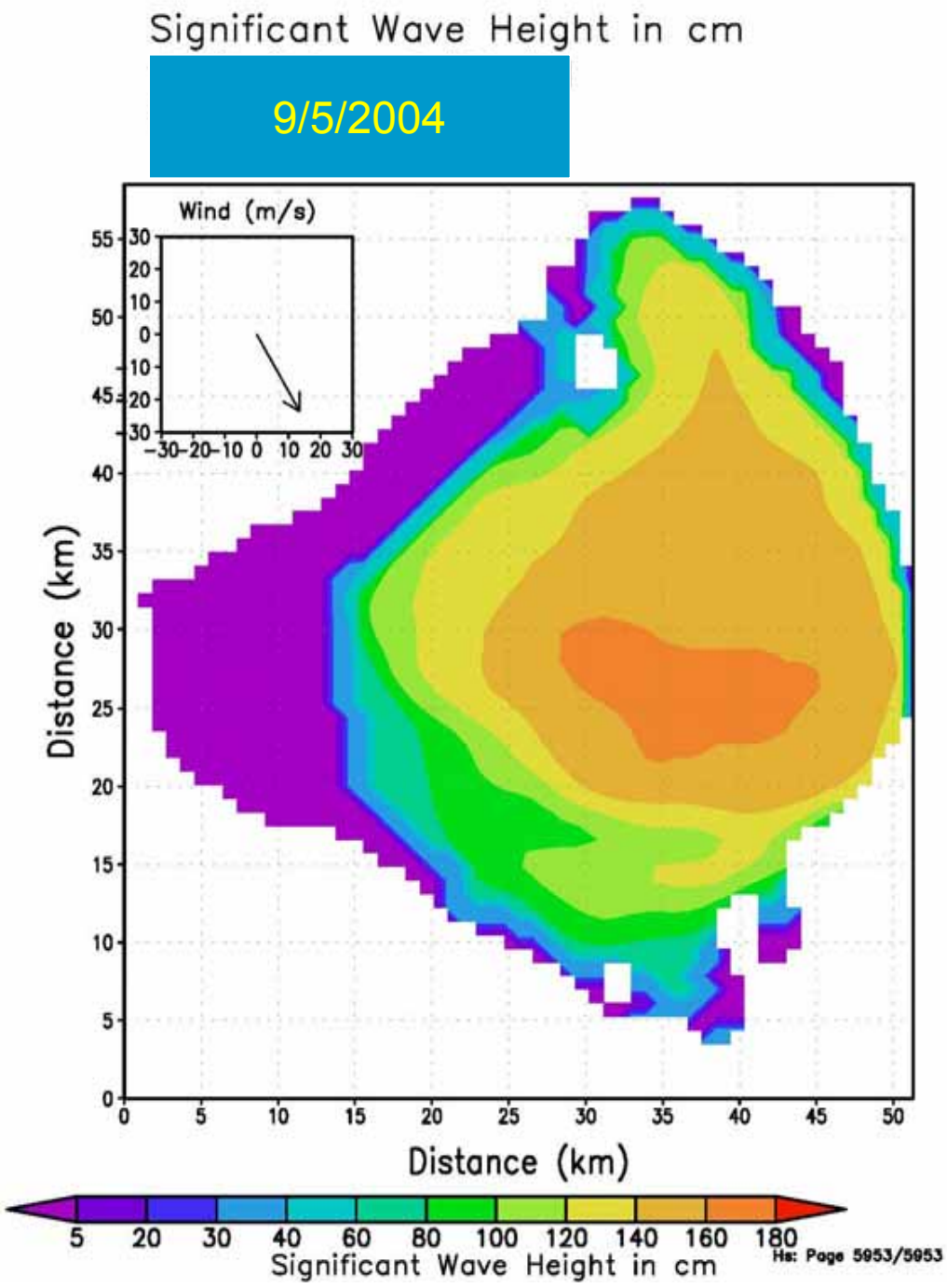
Jeanne

Frances




Bottom Shear Stress in dynes/cm²
1/1/04–12/30/05
Day 662.5
Wilma
Wind (m/s)
Distance (km)
Distance (km)
cm/s
30
0.5 5 10 20 30 40 50 60 70 80 90 100
Bottom Shear Stress in dynes/cm²


Bottom Shear Stress in dynes/cm²
1/1/04–12/30/05
Day 247.5
Frances
Wind (m/s)
Distance (km)
Distance (km)
cm/s
30
0.5 5 10 20 30 40 50 60 70 80 90 100
Bottom Shear Stress in dynes/cm²


Significant Wave Height in cm
9/5/2004
Wind (m/s)
30
20
10
0
10
20
30
−30 −20 −10 0 10 20 30
Distance (km)
0 5 10 15 20 25 30 35 40 45 50 55
Distance (km)
0 5 10 15 20 25 30 35 40 45 50
5 20 30 40 60 80 100 120 140 160 180
Significant Wave Height in cm
Hs: Page 5953/5953

Activity profile for ^{210}Pb for Core M8

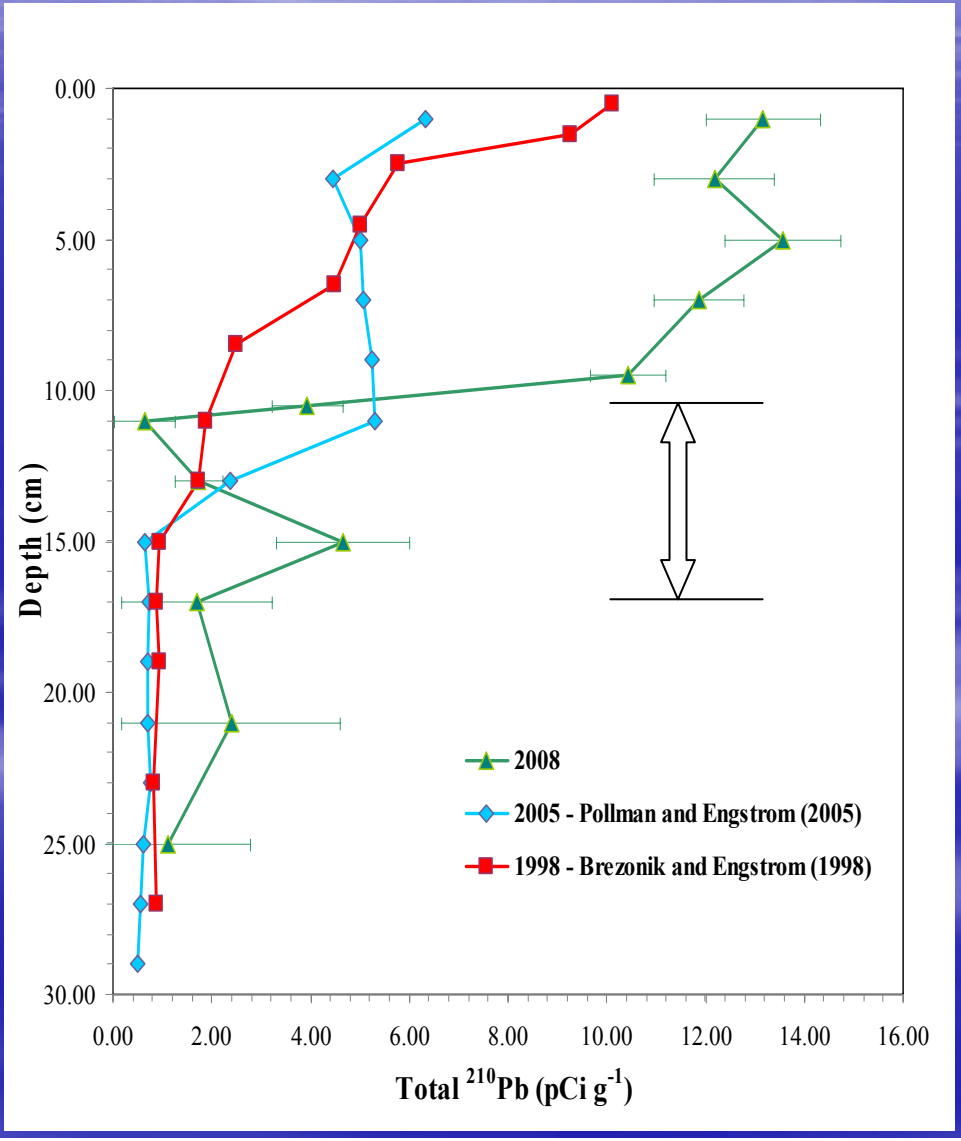
Findings of the 2005 investigation:

Sediment layer from 3 to 12 cm in depth shows that 2004 hurricanes (**Frances** & **Jeanne**) makes them up side down by vertical vortex.

Findings of the 2008 investigation:

Sediment layer from 10 to 11 cm in depth shows that there was a horizontal force in Wilma hurricane that mix the sediment with a strong forcing.

Sediment layers from 3 to 5 cm and 13 to 17 cm show that Wilma hurricane makes them up side down by vertical vortex.



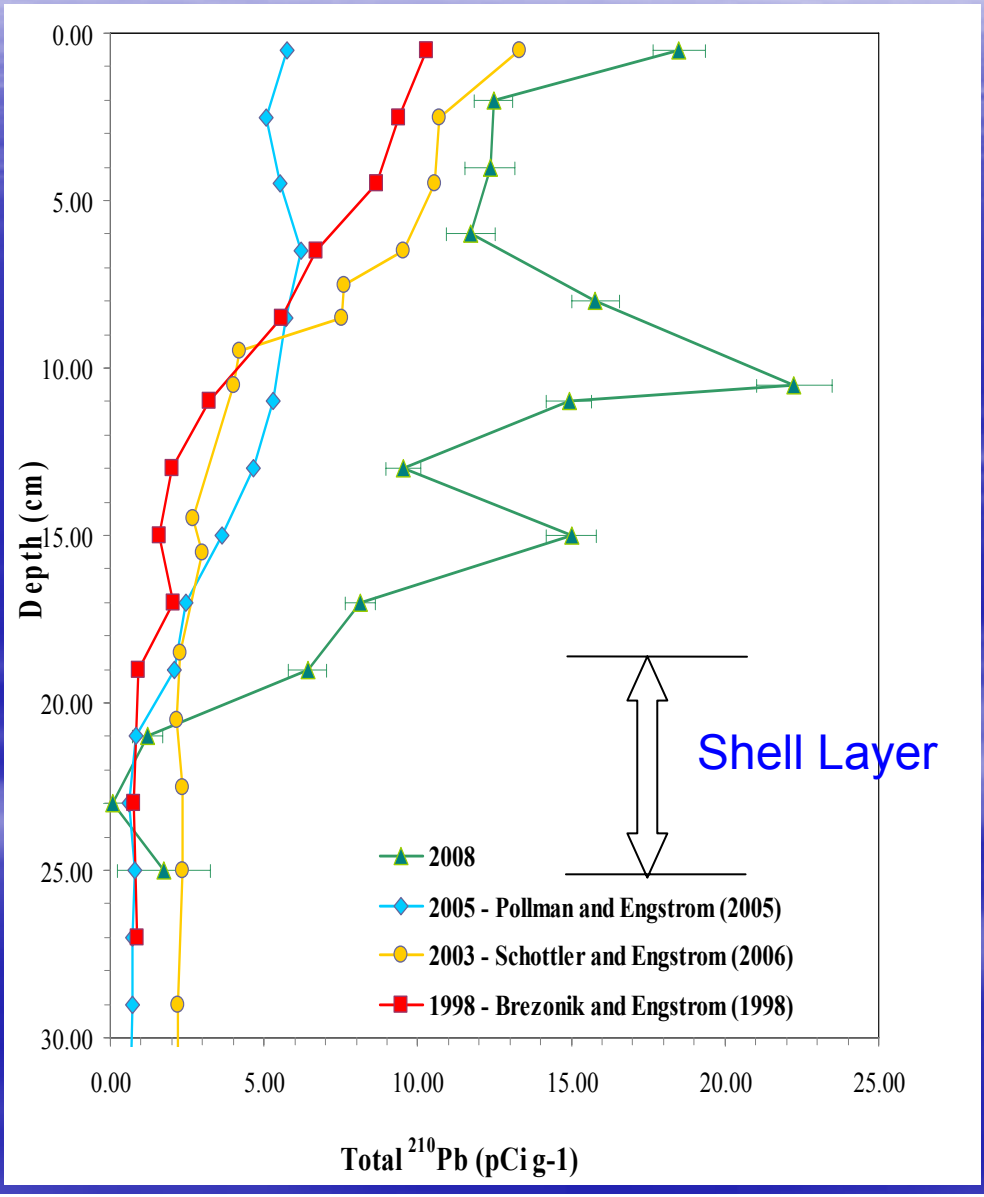
Activity profile for ^{210}Pb for Core L9

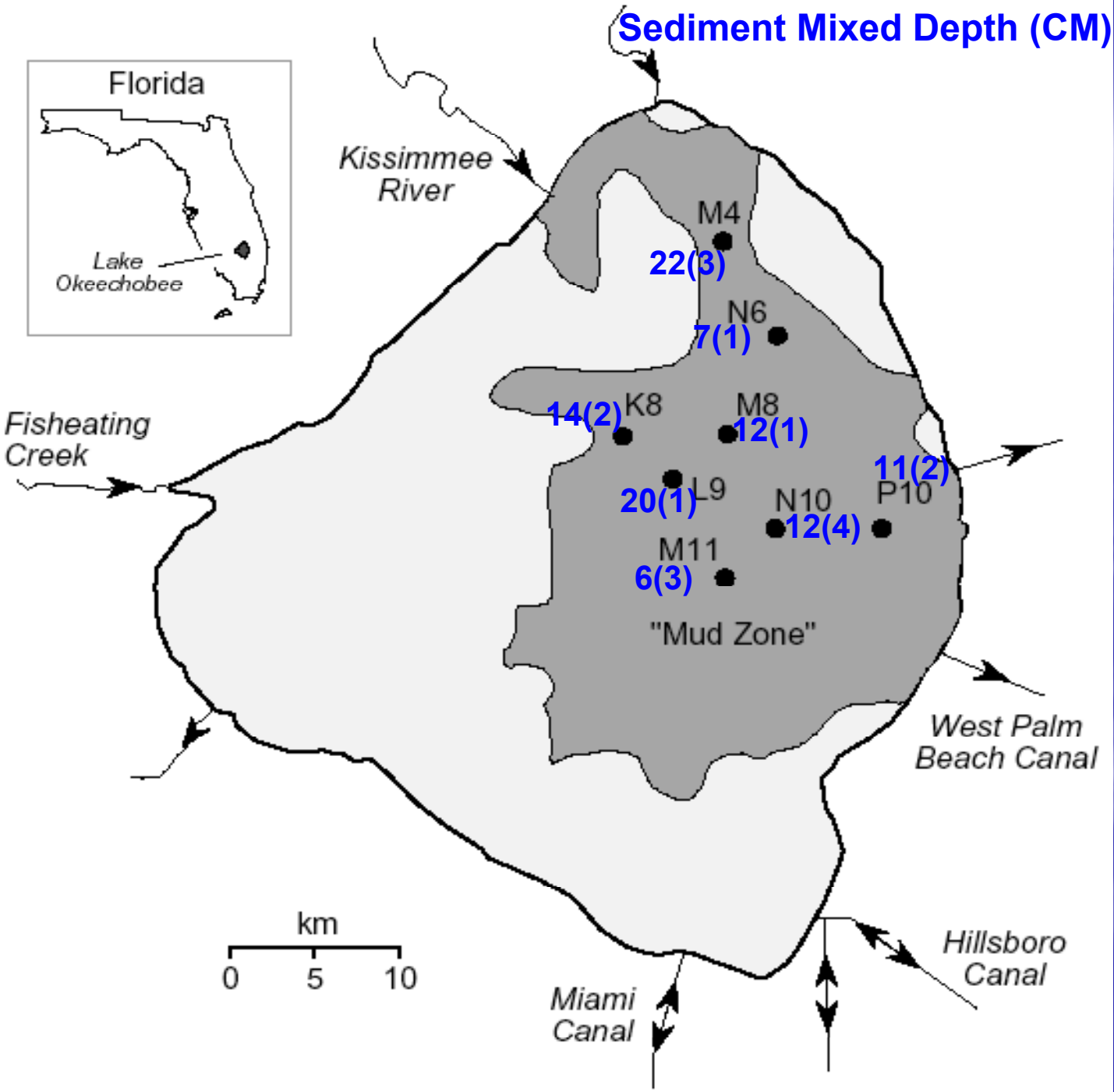
Findings (2005):
Sediment layer from 2.5 to 9 cm in depth shows that 2004 hurricanes (**Frances** & **Jeanne)** makes them up side down by vertical vortex.

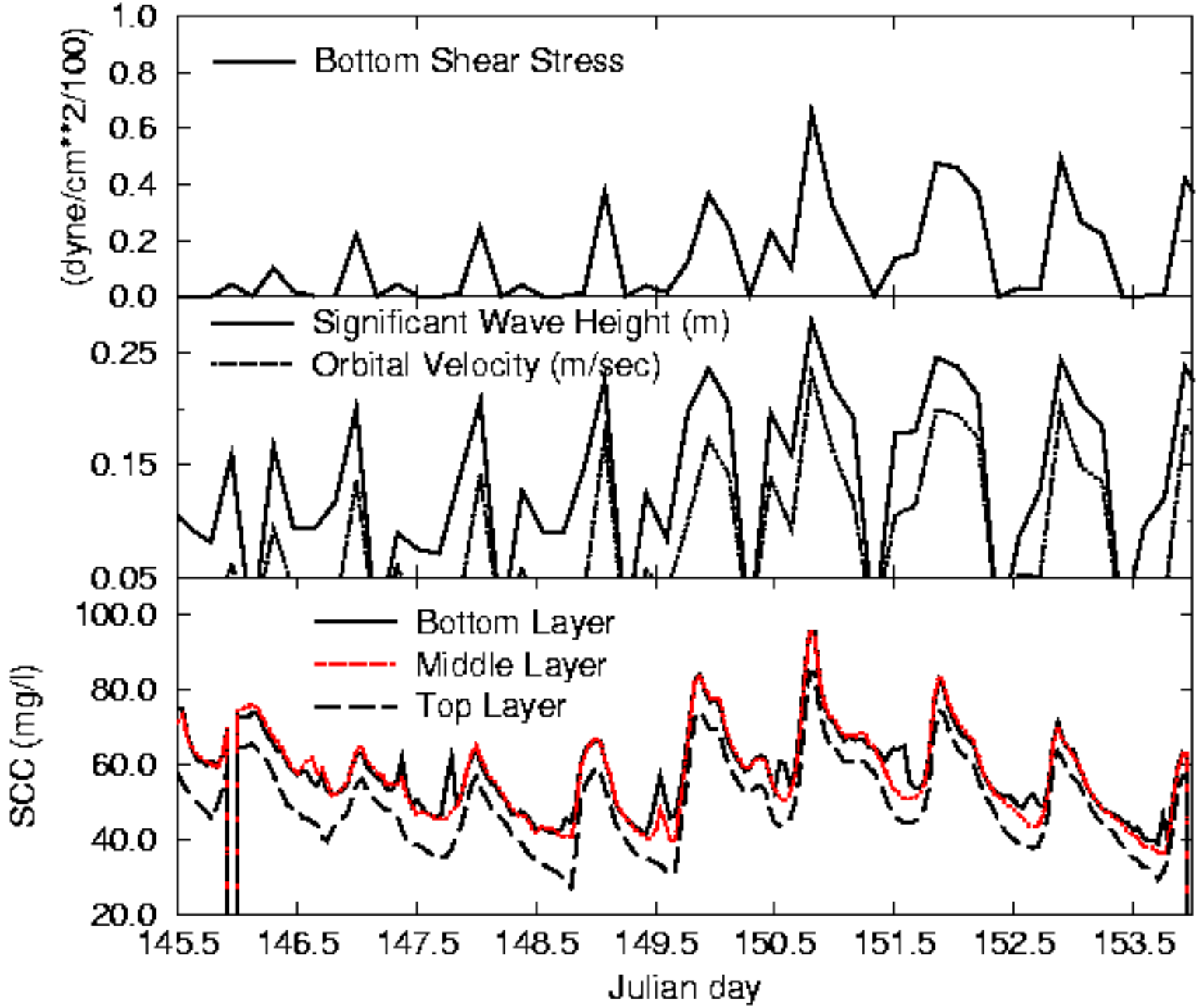
Findings (2008):

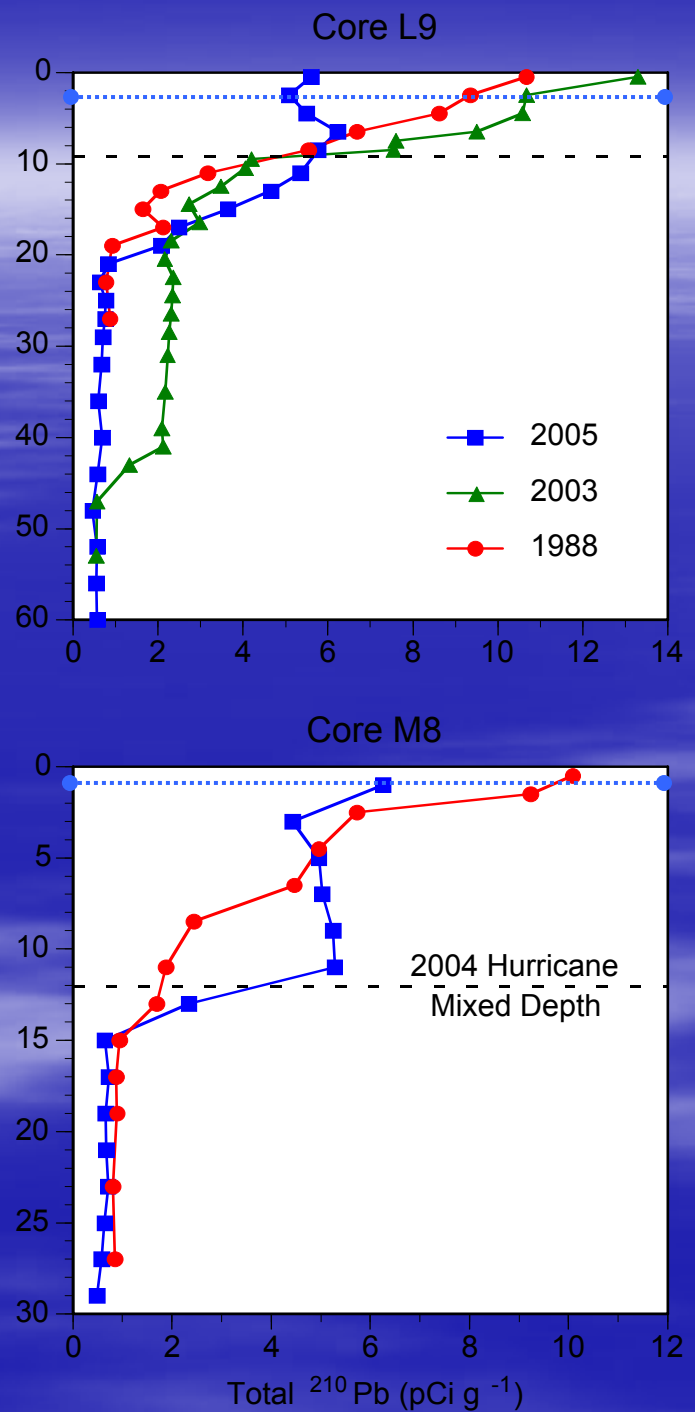
Sediment layers from 6 to 12 cm and from 12 to 17 cm in depth show that Wilma hurricane makes them up side down by vertical vortex.

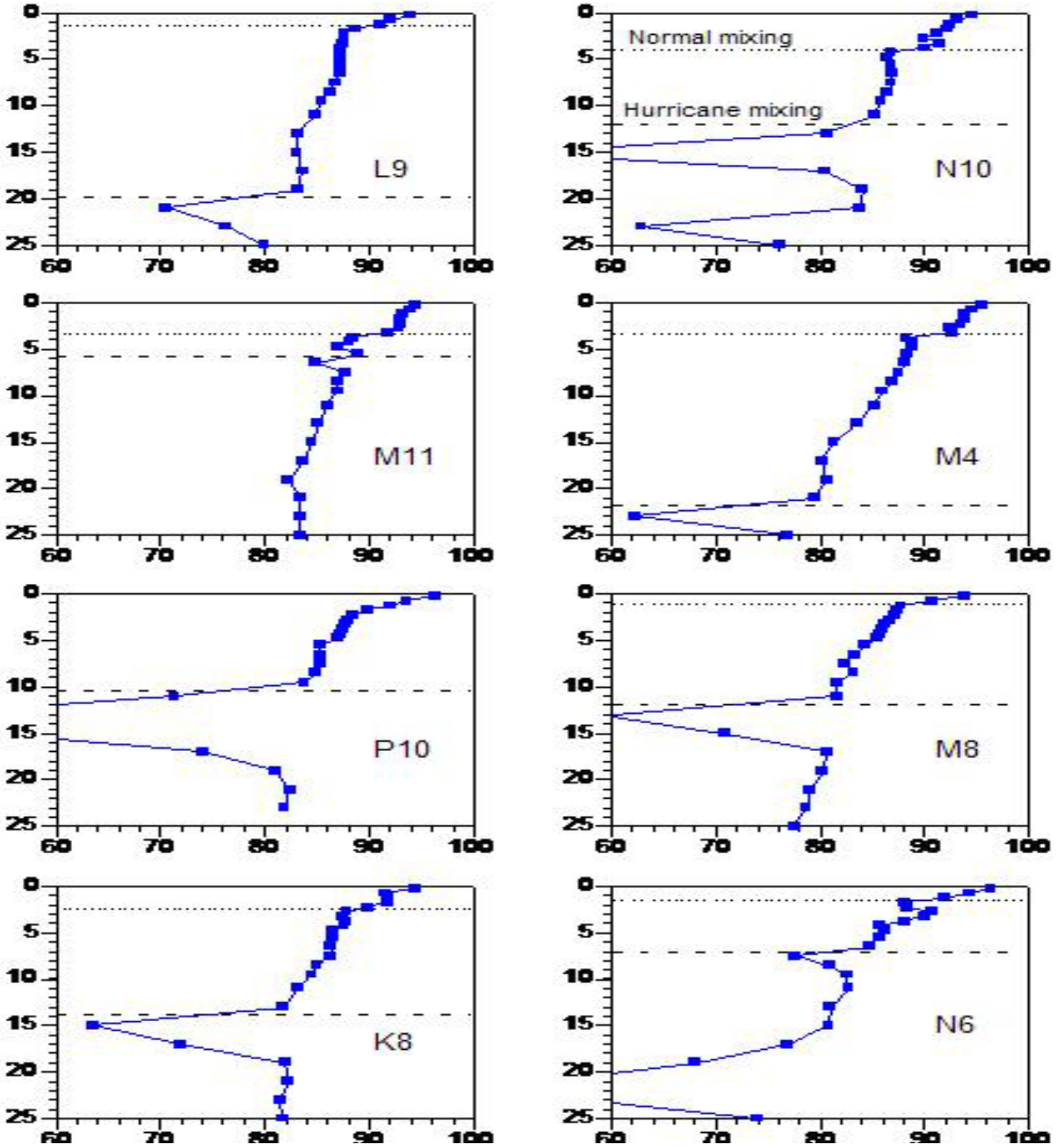
Sediment layer from 2 to 6 cm in depth shows that this layer was moved from other place with aging mud than it would be.




Sediment Mixed Depth (CM)
Florida
Lake Okeechobee
Kissimmee River
M4
22(3)
N6
7(1)
14(2)
K8
M8
12(1)
11(2)
20(1)
L9
N10
P10
12(4)
M11
6(3)
"Mud Zone"
Fisheating Creek
West Palm Beach Canal
km
0
5
10
Miami Canal
Hillsboro Canal

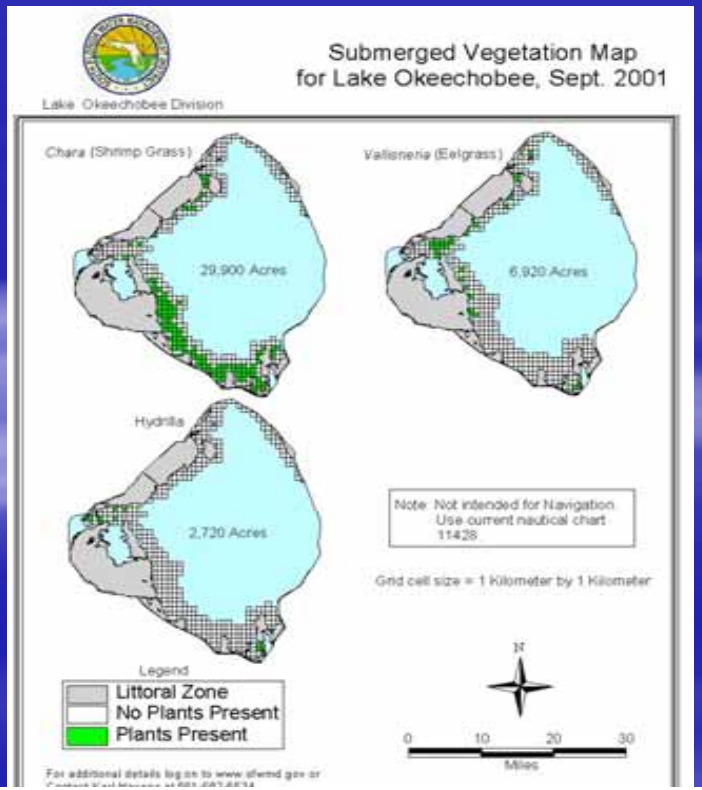

Bottom Shear Stress
(dyne/cm**2/100)
1.0
0.8
0.6
0.4
0.2
0.0
Significant Wave Height (m)
Orbital Velocity (m/sec)
0.25
0.15
0.05
Bottom Layer
Middle Layer
Top Layer
SCC (mg/l)
100.0
80.0
60.0
40.0
20.0
145.5
146.5
147.5
148.5
149.5
150.5
151.5
152.5
153.5
Julian day


Core L9
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
2005
2003
1988
Core M8
0
5
10
15
20
25
30
0
2
4
6
8
10
12
2004 Hurricane
Mixed Depth
Total 210Pb (pCi g -1)

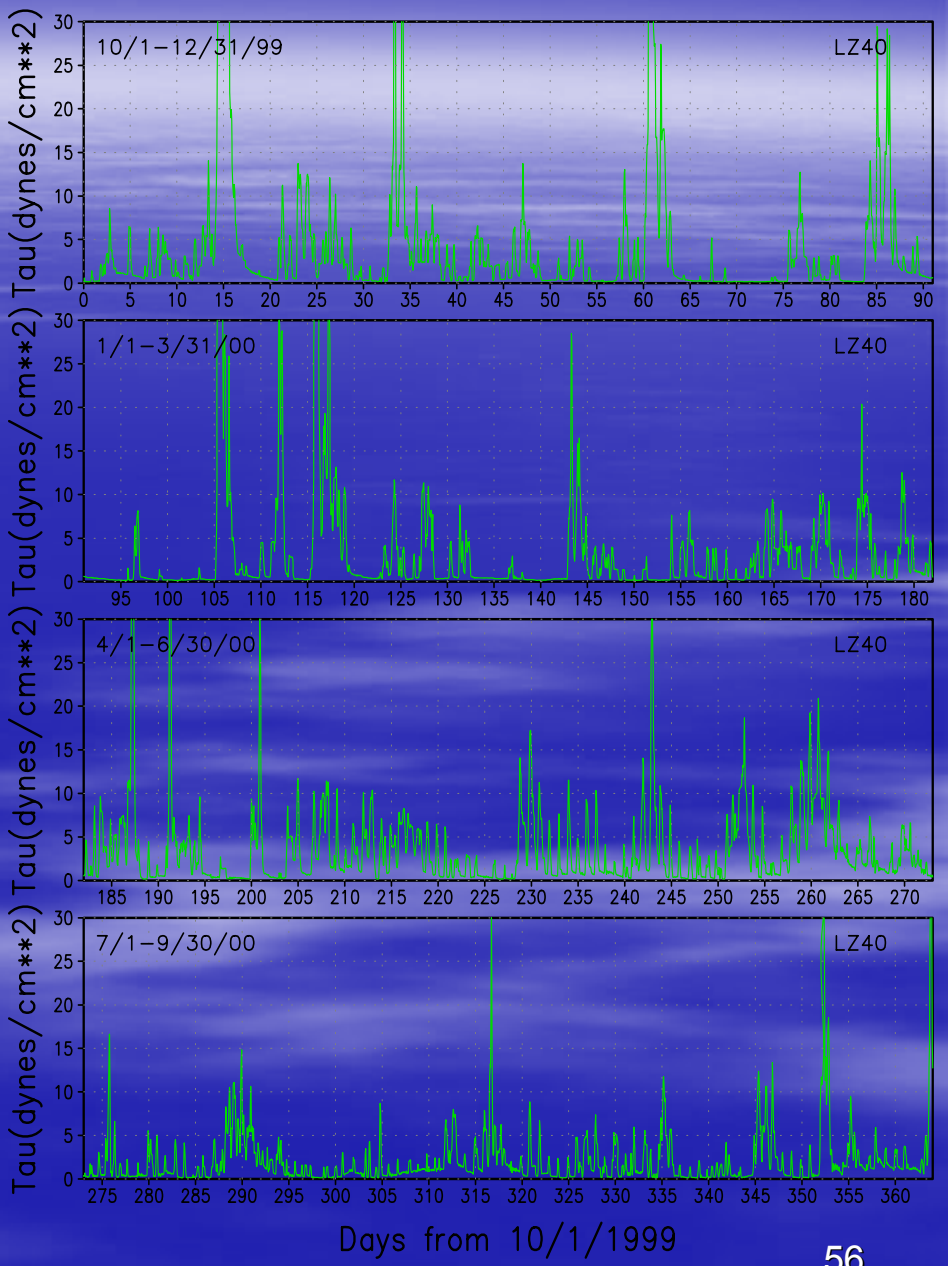

L9
Normal mixing
Hurricane mixing
N10
M11
M4
P10
M8
K8
N6

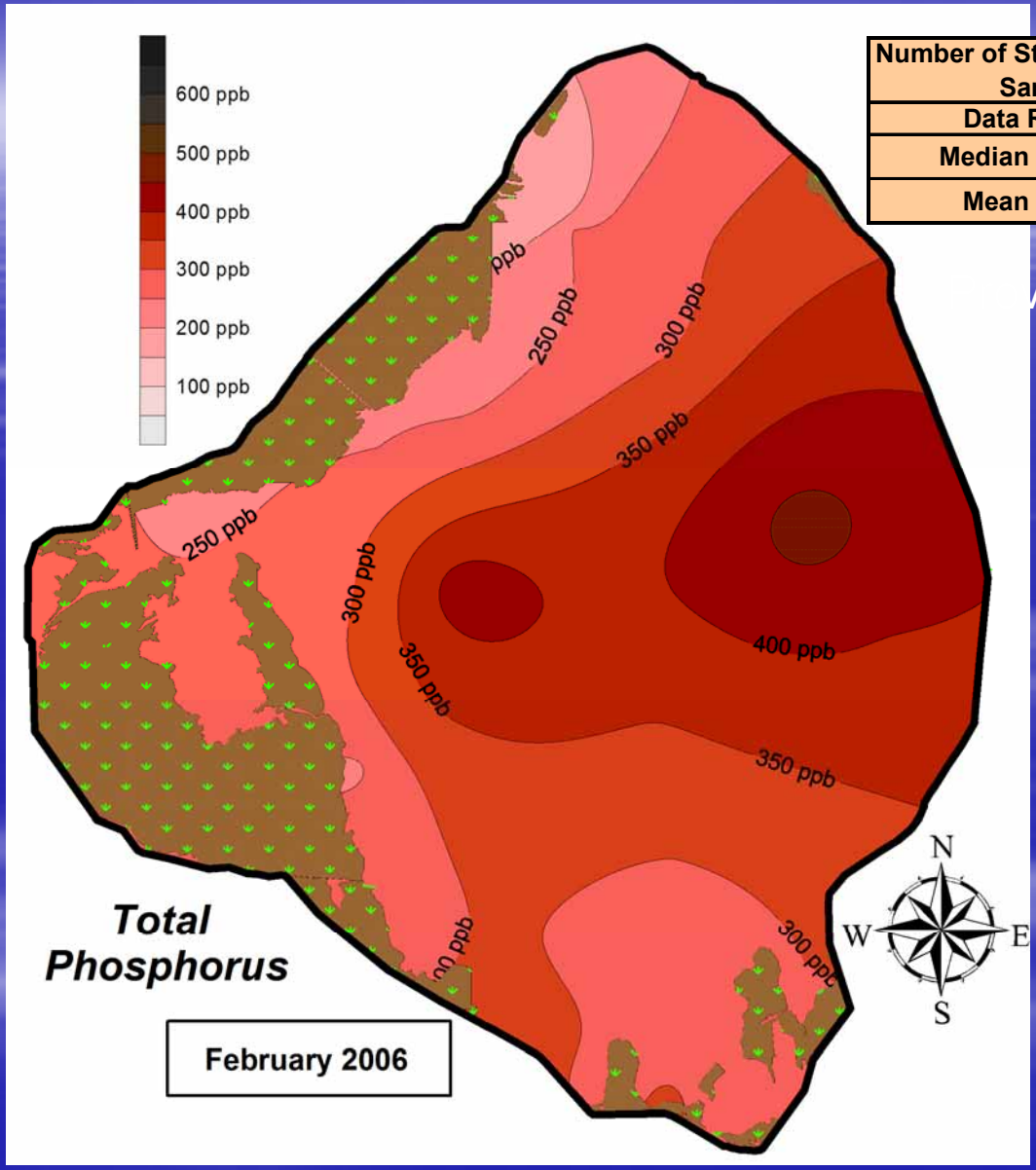
submerged aquatic vegetation

- Dominant species
  - Chara, a branched macro algae
  - Vallisneria (eelgrass)
  - hydrilla
- Distributions



Hurricane Irene BS Stress4-5 N/m**2

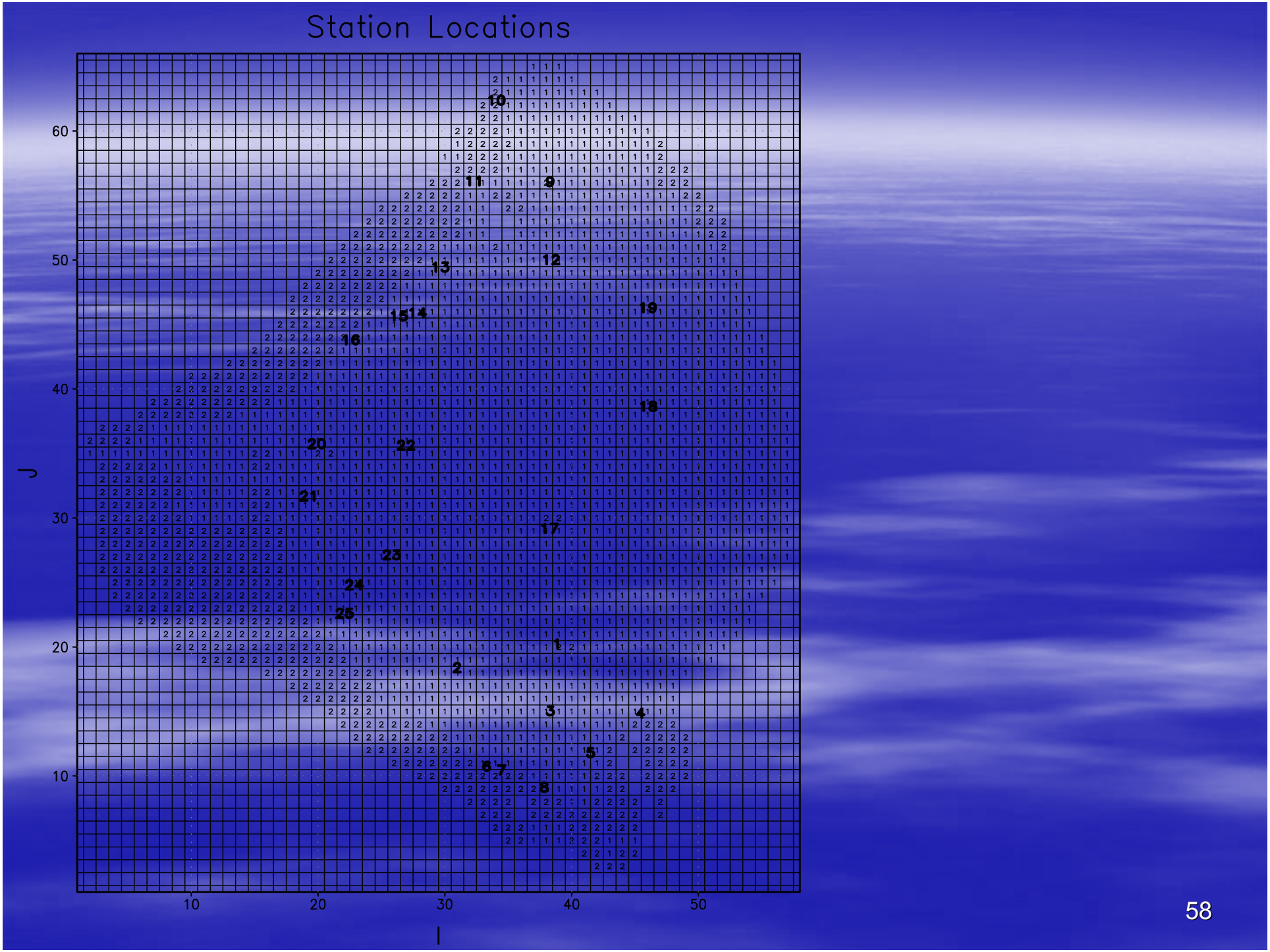


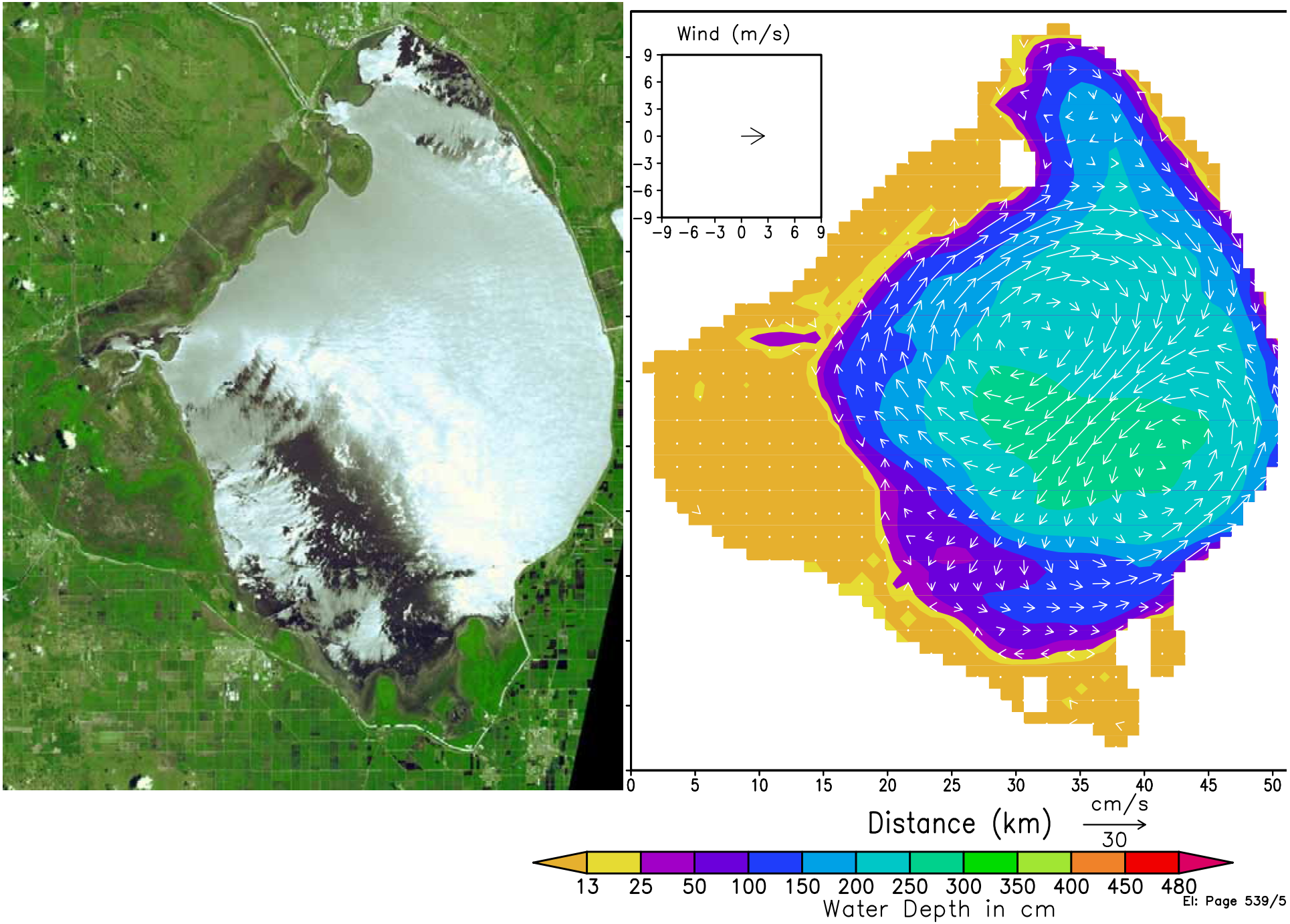


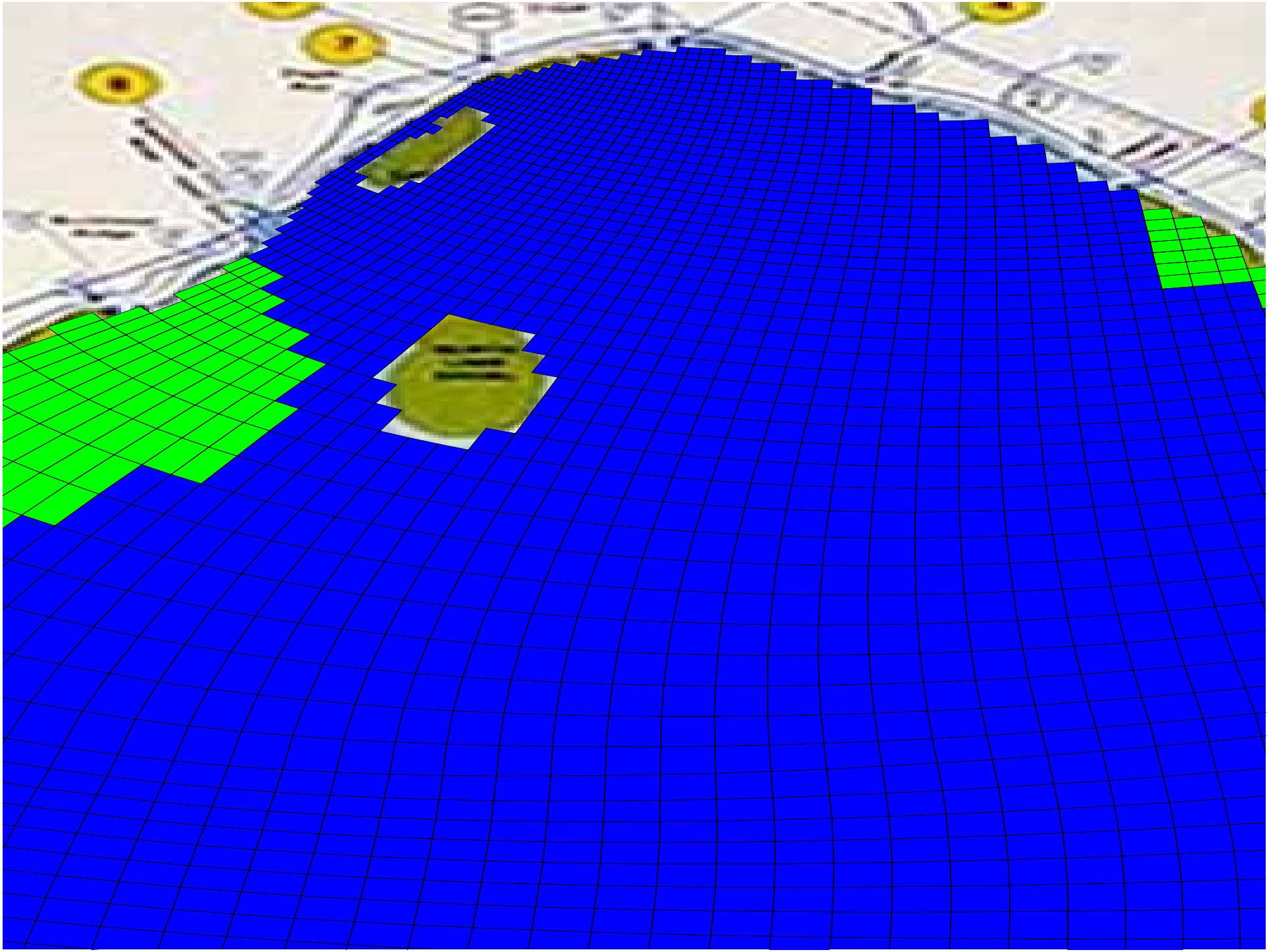
Number of Stations Sampled:	27
Data Range:	151 - 472 ppb
Median Value:	278 ppb
Mean Value:	291 ppb

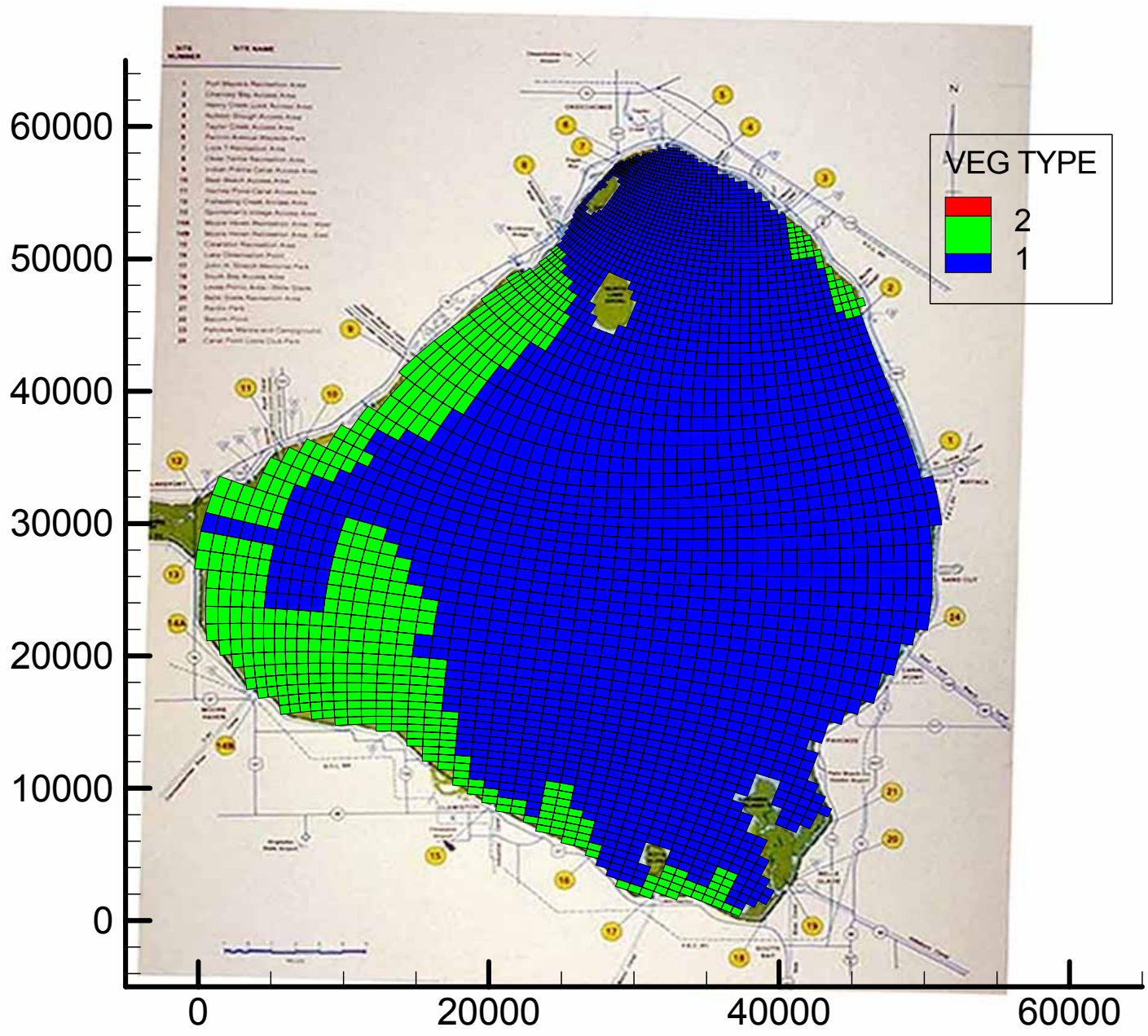
visional Data

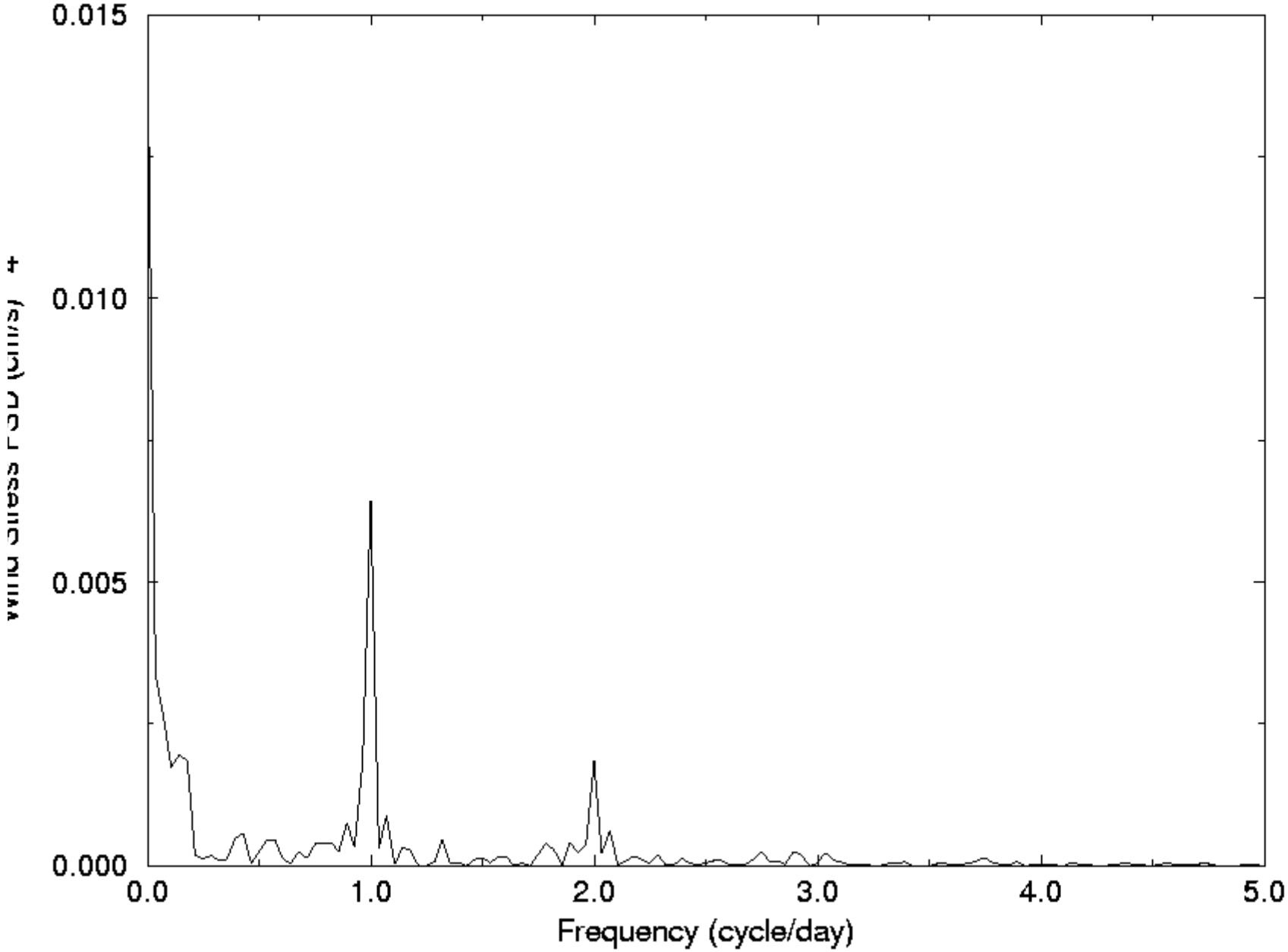
Station Locations

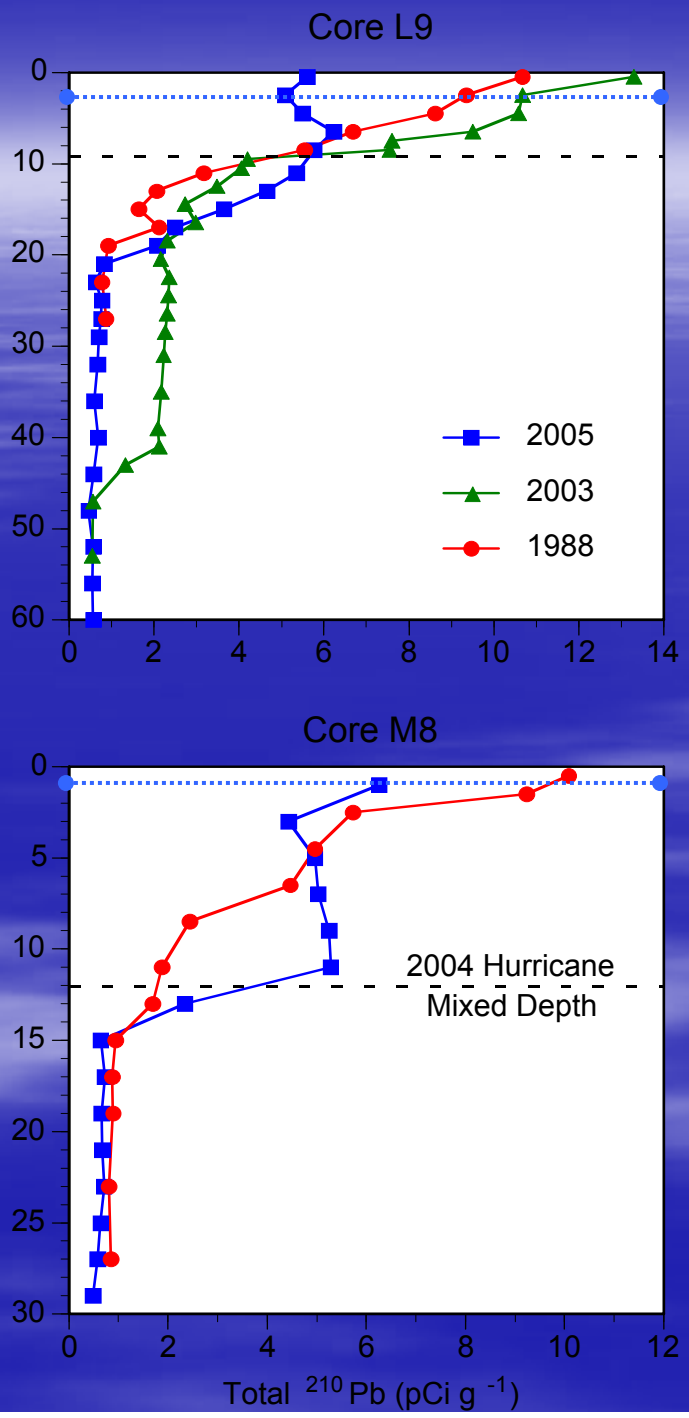



Wind (m/s)
9
6
3
0
−3
−6
−9
−9 −6 −3 0 3 6 9
0 5 10 15 20 25 30 35 40 45 50
Distance (km)
cm/s
30
13 25 50 100 150 200 250 300 350 400 450 480
Water Depth in cm




VEG TYPE
2
1
60000
50000
40000
30000
20000
10000
0
0
20000
40000
60000


0.015
0.010
0.005
0.000
0.0
1.0
2.0
3.0
4.0
5.0
Frequency (cycle/day)


Core L9
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
2005
2003
1988
Core M8
0
5
10
15
20
25
30
0
2
4
6
8
10
12
2004 Hurricane
Mixed Depth
Total 210Pb (pCi g -1)