

Volume Transport and Variability at Windward Passage



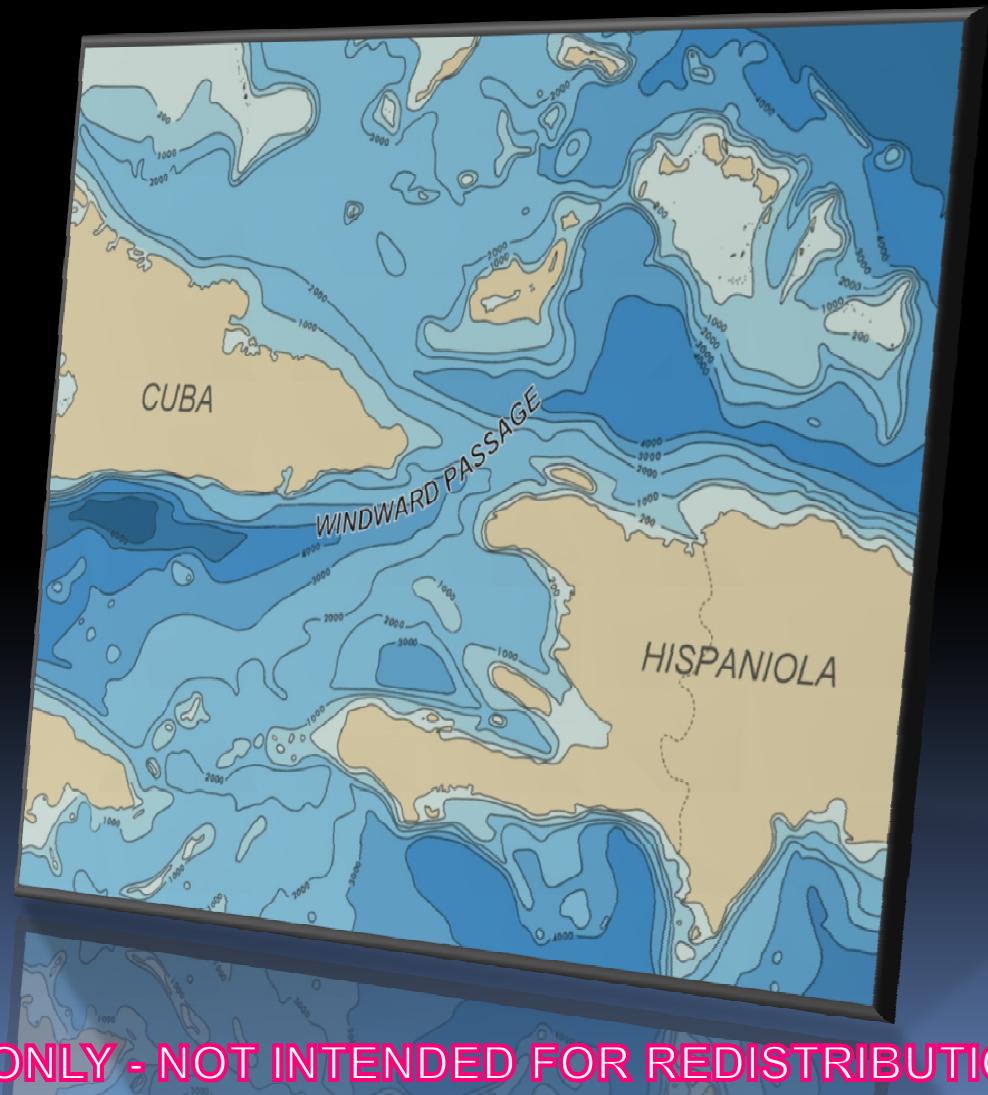
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Physical Oceanography
RSMAS, University of Miami

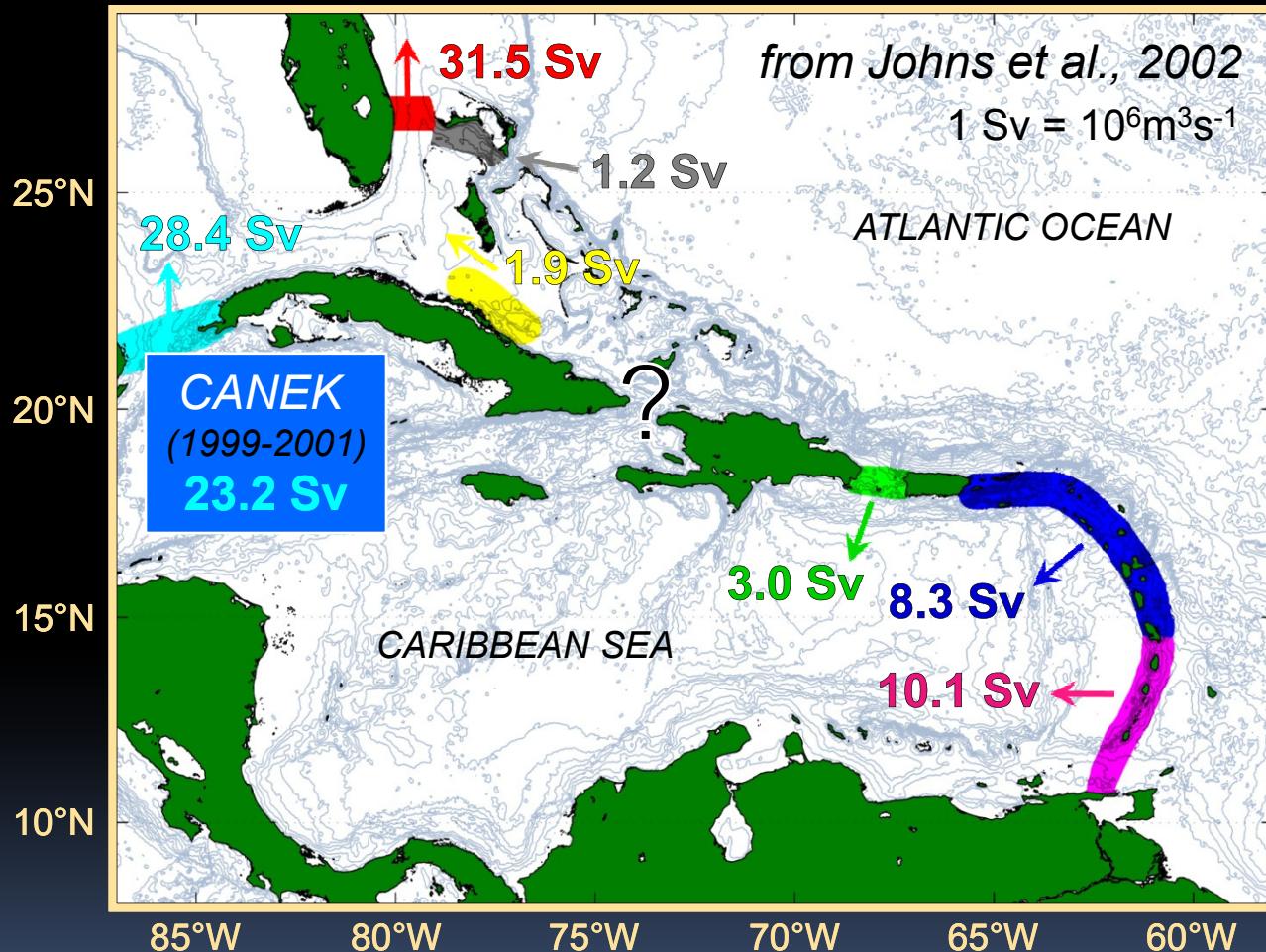
AGU Joint Assembly
Acapulco, Mexico
May 25, 2007



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Windward Passage: Historically under-sampled...

*Windward Passage
Experiment
(2003-2005)*



Typically estimated (indirectly) by differencing other measured transports ($28.4 - 21.4 = 7.0 \text{ Sv} ???$) ...

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Objectives:

- ❖ Determine the mean inflow, including its horizontal and vertical structure
- ❖ Define a better relationship between inflow at Windward Passage and other Caribbean passages
- ❖ Improve understanding of inflow pathways through the southern Bahamas (towards Windward)

Windward Passage Experiment

Cruise #	Ship	Mission	Date
1	<i>R/V Seward Johnson</i>	Deploy Moored Array CTDO ₂ /LADCP Survey	Oct. 6-21, 2003
2	<i>NOAA Ship Ronald H. Brown</i>	CTDO ₂ /LADCP Survey	Mar. 29 - Apr. 13, 2004
3	<i>NOAA Ship Ronald H. Brown</i>	CTDO ₂ /LADCP Survey	Oct. 10-18, 2004
4	<i>R/V Seward Johnson</i>	Recover Moored Array CTDO ₂ /LADCP Survey	Feb. 9-28, 2005



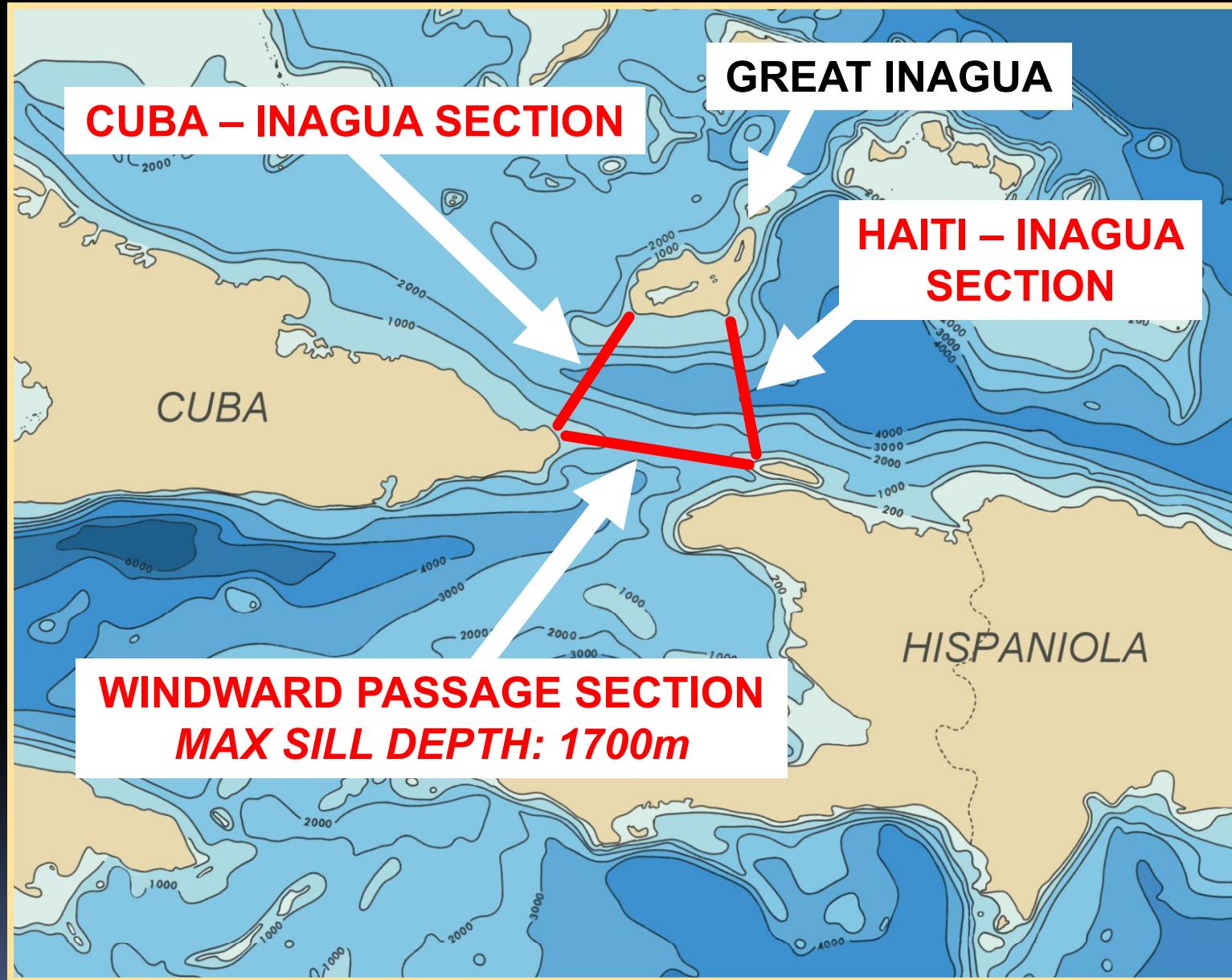
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Typical CTDO2/LADCP Survey:



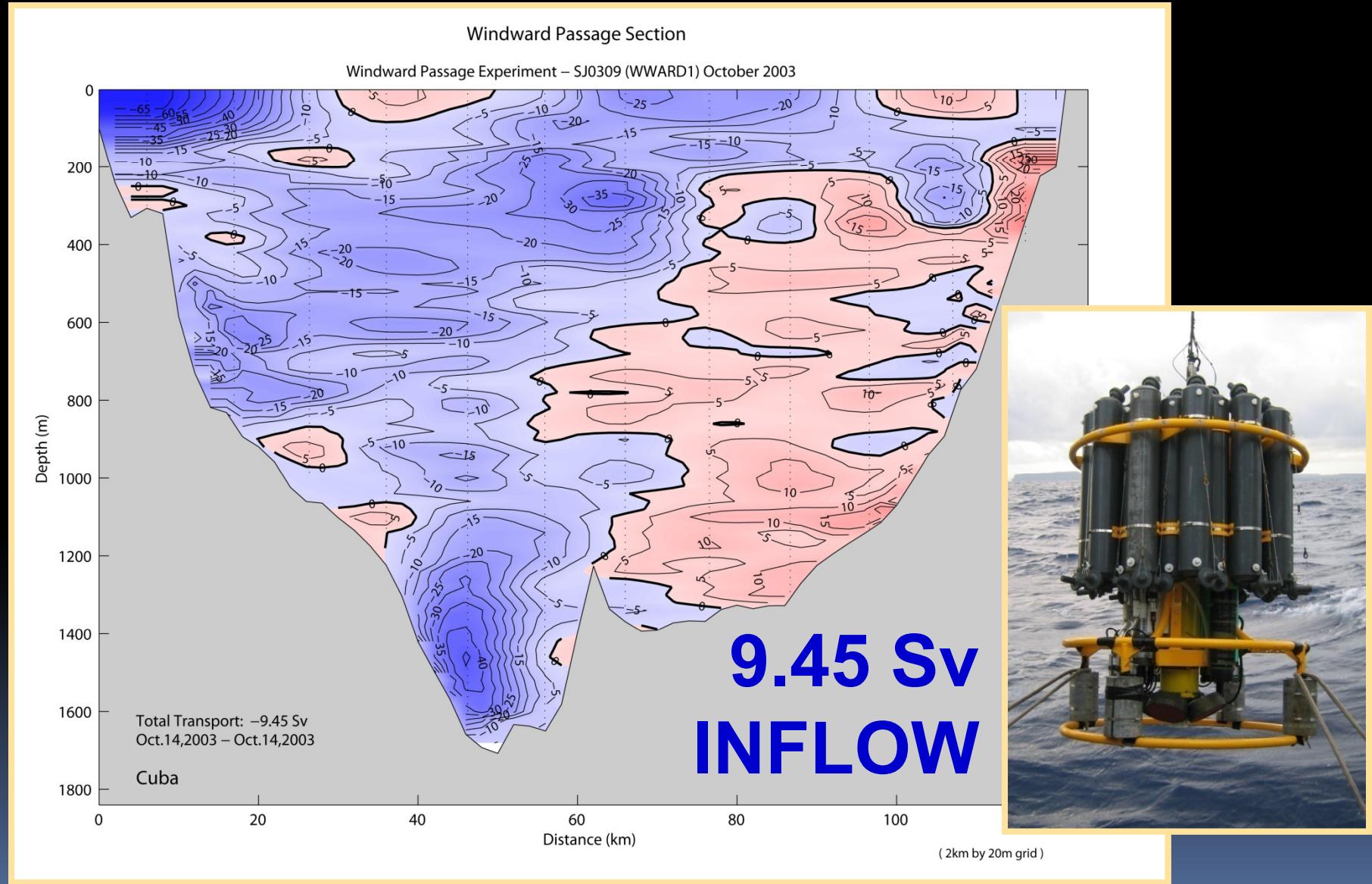
Cruise #2 (Mar. 29 – Apr. 13, 2004)
78 Stations / 12 Sections

*Continuous Hull-Mounted ADCP
Continuous Flow-Through Data*

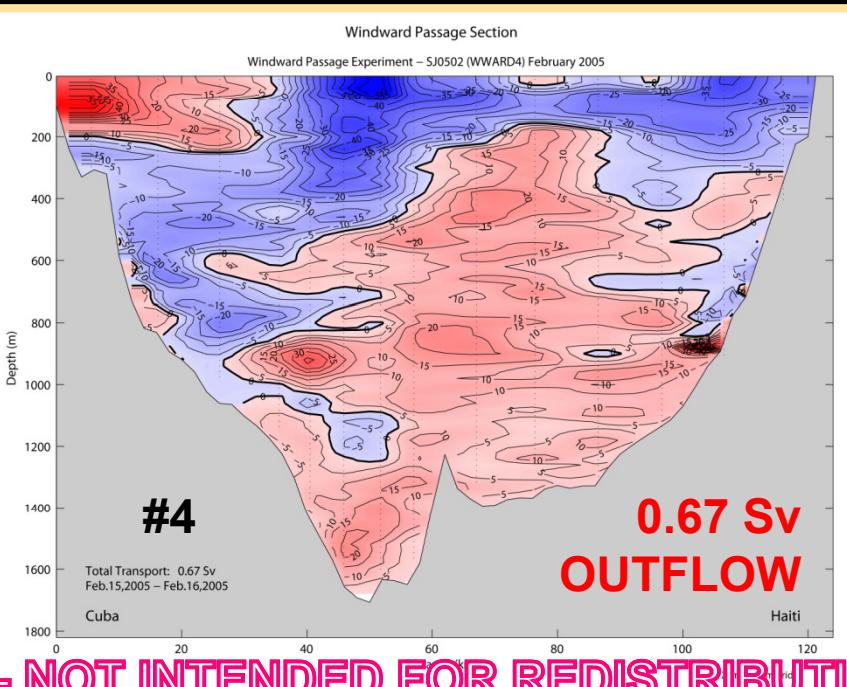
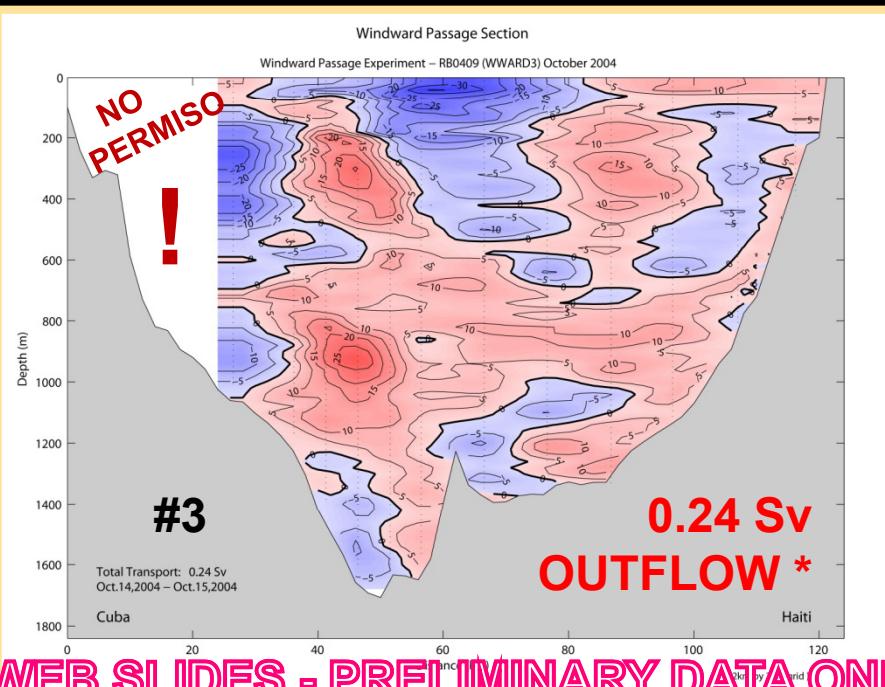
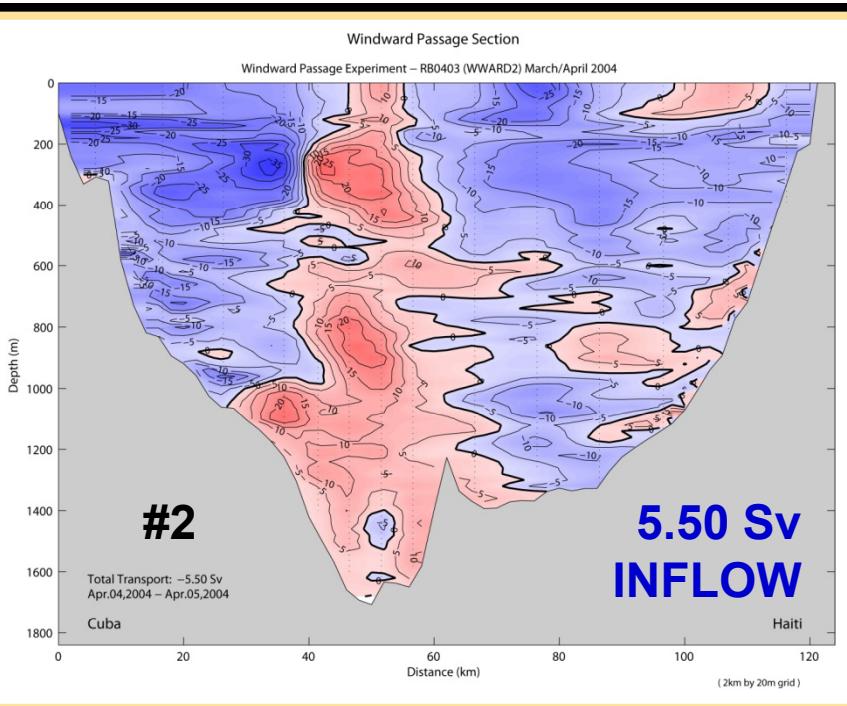
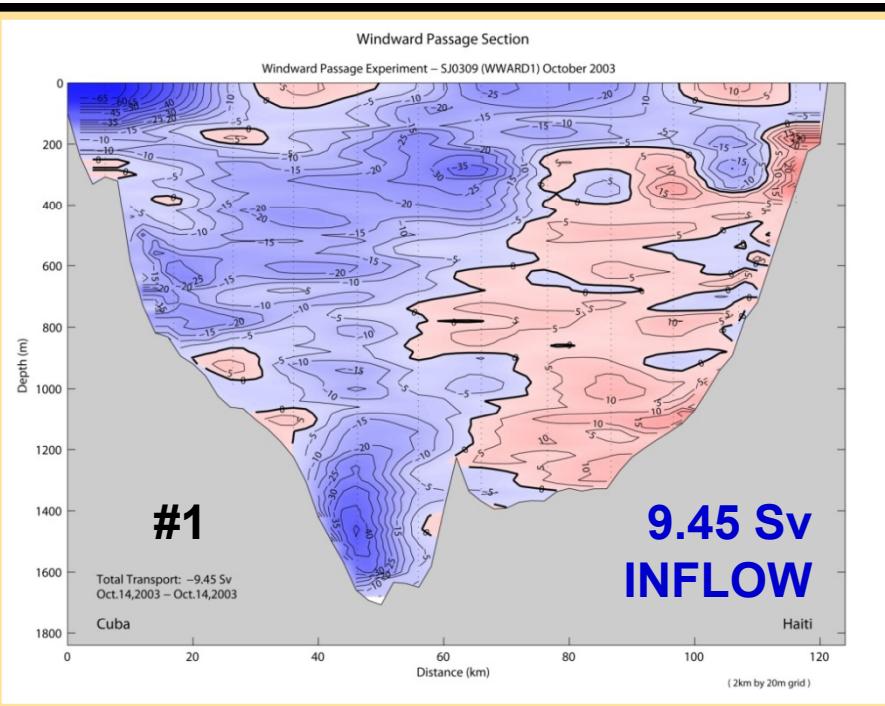


Cruise #1 - Windward Passage Section

Cross-Track Velocity

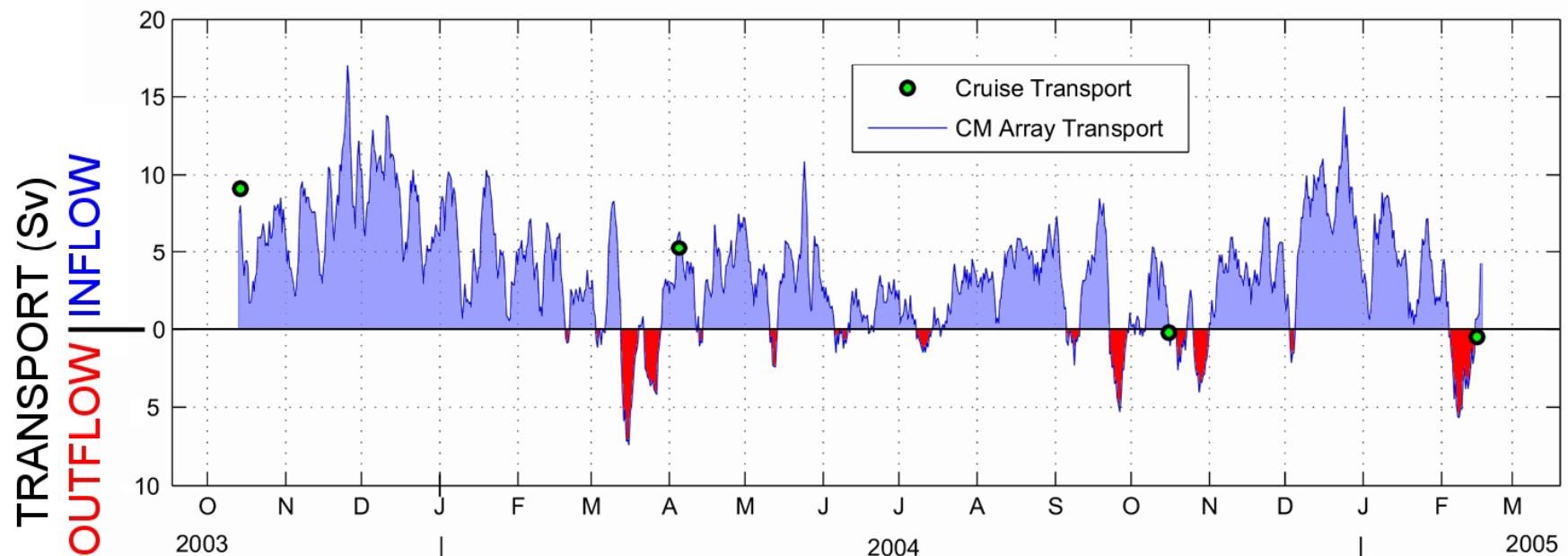


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Cruise transports agree with moored array time-series...

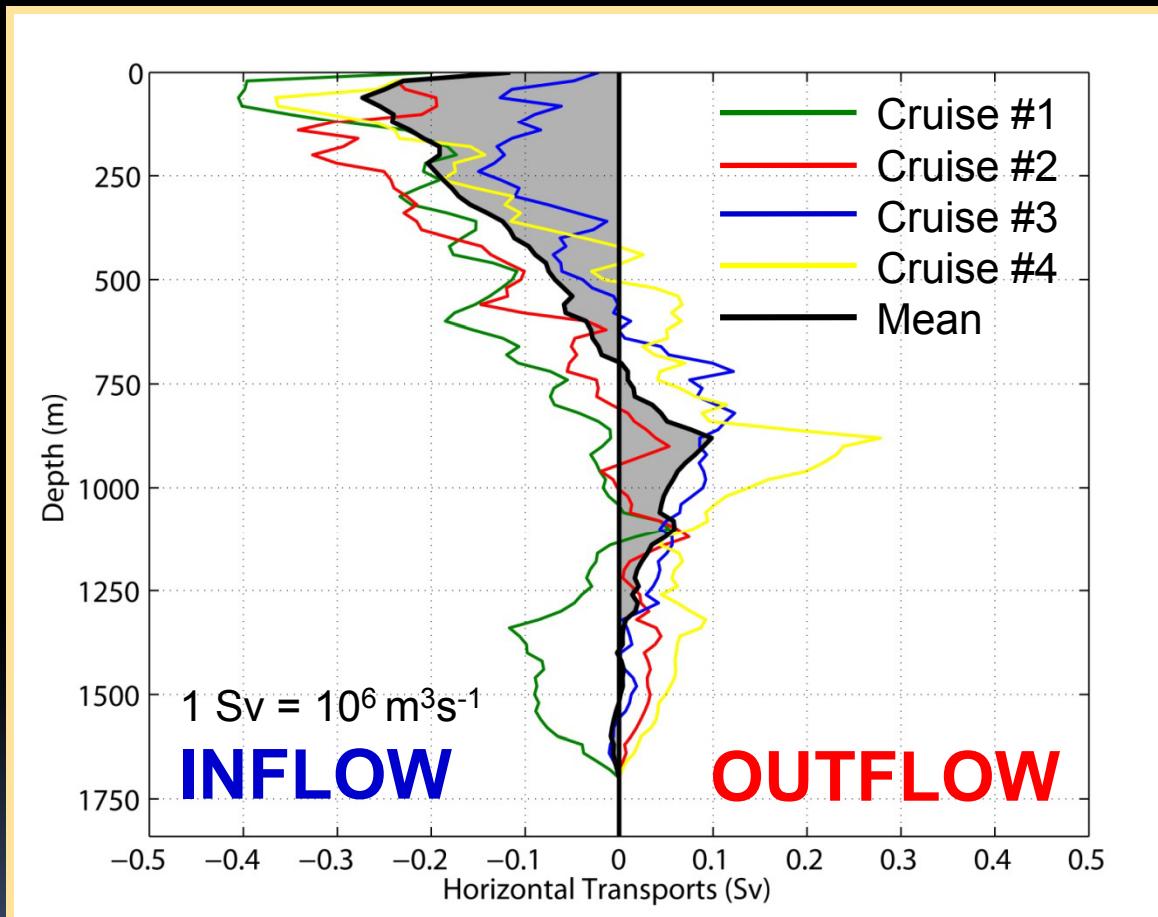


Mean Transports:

LADCP station data (4 cruises): 3.5 Sv Inflow ($SE = 2.1$ Sv)

Moored CM array (16 month time-series): 3.6 Sv Inflow ($SE = 1.7$ Sv)

Windward Passage Horizontal Transport Profiles:

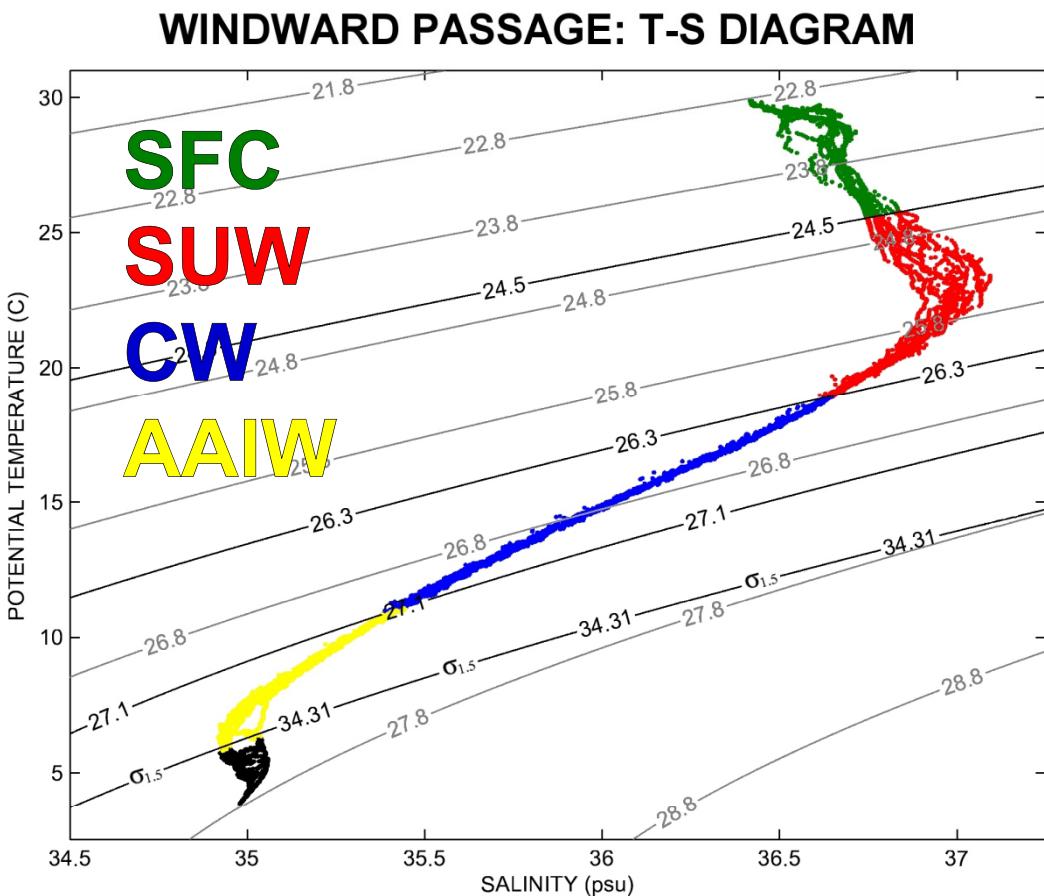


- ❖ Mean inflow to the Caribbean in surface and thermocline layers
- ❖ Mean outflow from the Caribbean in intermediate layers

By what pathways do specific layers / water masses flow into and out of the Caribbean through Windward Passage?

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Water Mass Classification Temperature-Salinity Diagram



Water Mass
Density (m^3kg^{-1})

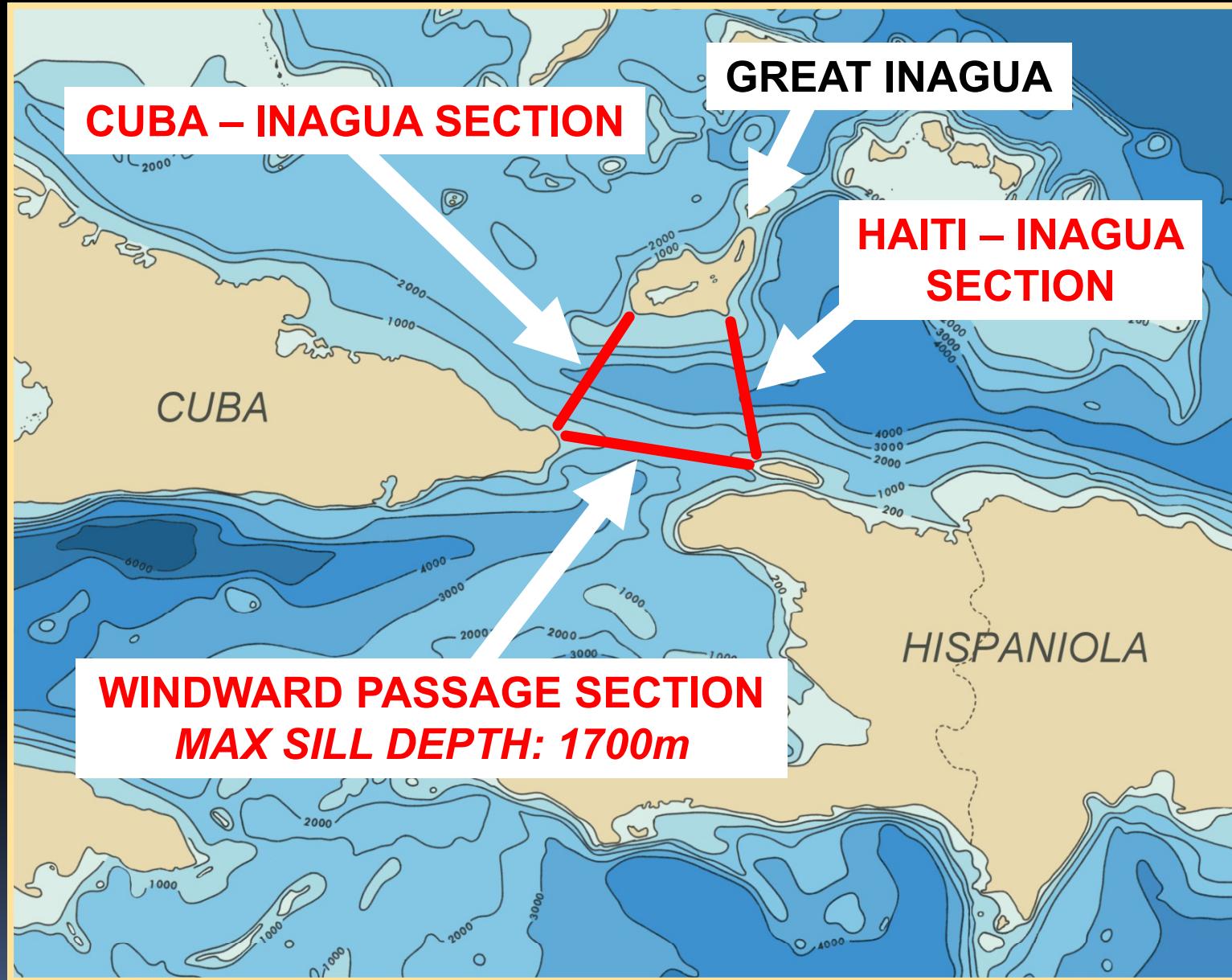
Surface Water (SFC)
 $\sigma_\theta \leq 24.5$

Subtropical
Underwater (SUW)
 $24.5 < \sigma_\theta \leq 26.3$

Lower Thermocline /
Central Water (CW)
 $26.3 < \sigma_\theta \leq 27.1$

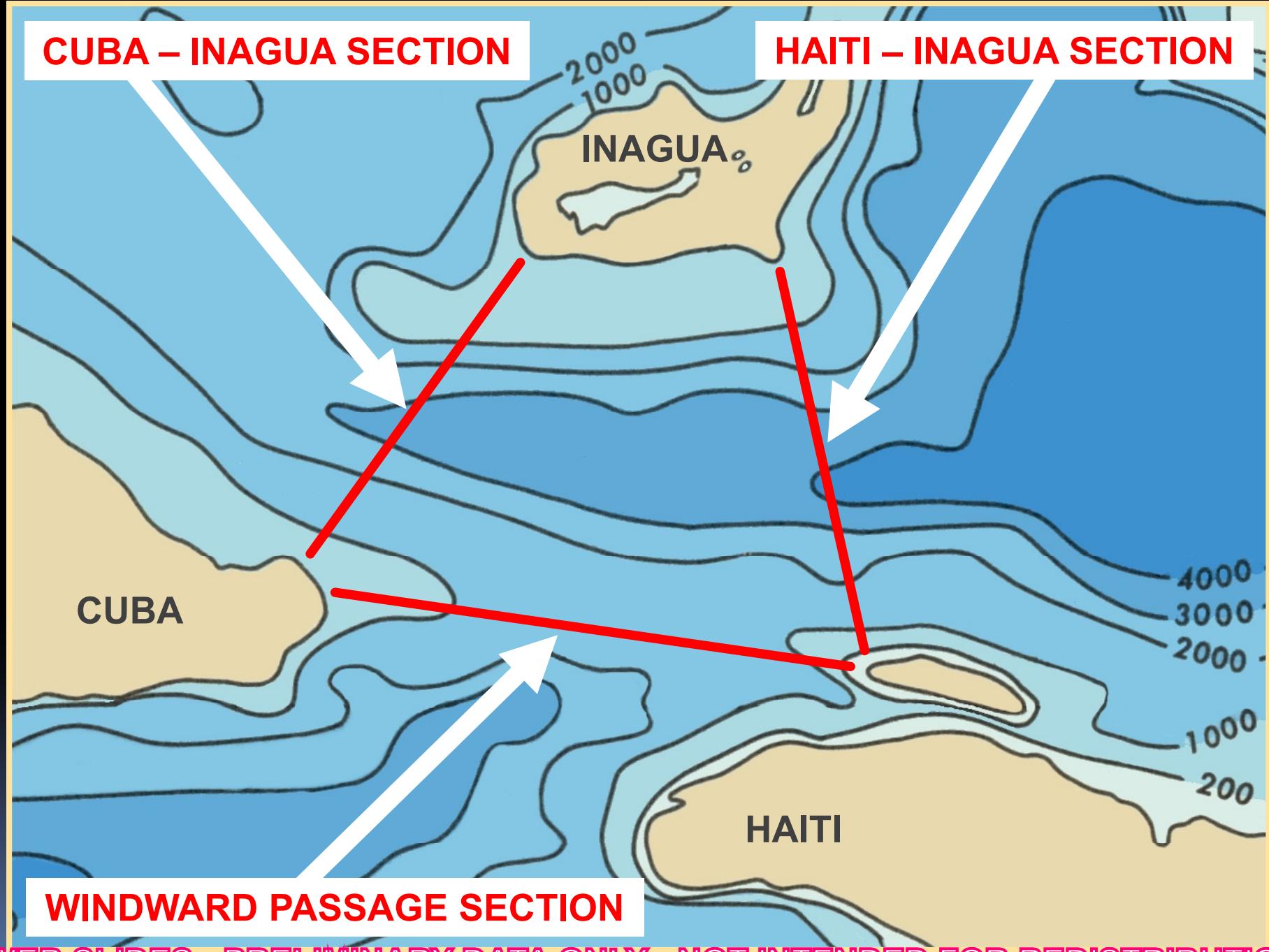
Antarctic
Intermediate
Water (AAIW)
 $27.1 < \sigma_\theta \& \sigma_{1.5} \leq 34.31$

Deep Water
 $34.31 < \sigma_{1.5}$



CUBA – INAGUA SECTION

HAITI – INAGUA SECTION



WINDWARD PASSAGE SECTION

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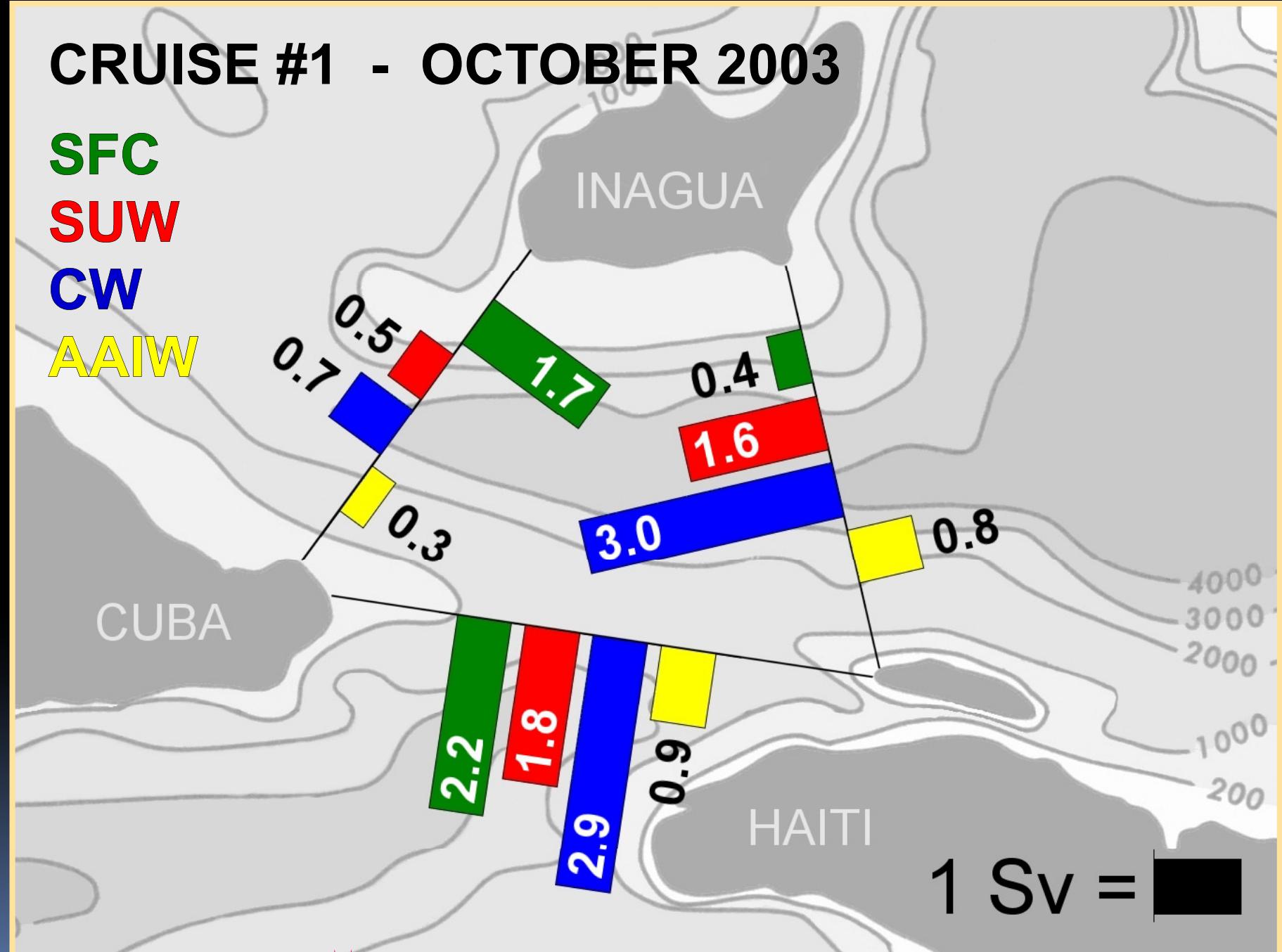
CRUISE #1 - OCTOBER 2003

SFC

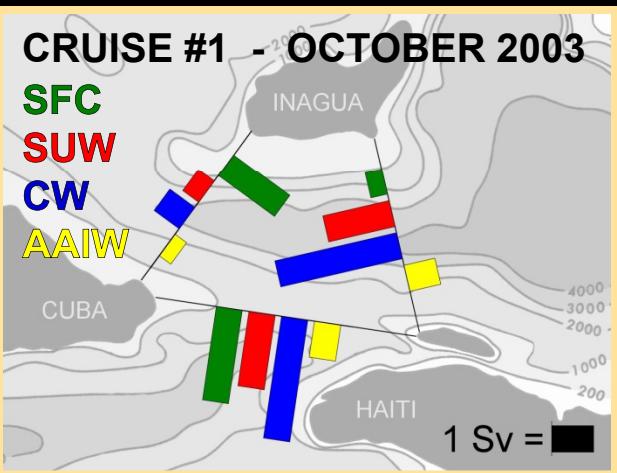
SUW

CW

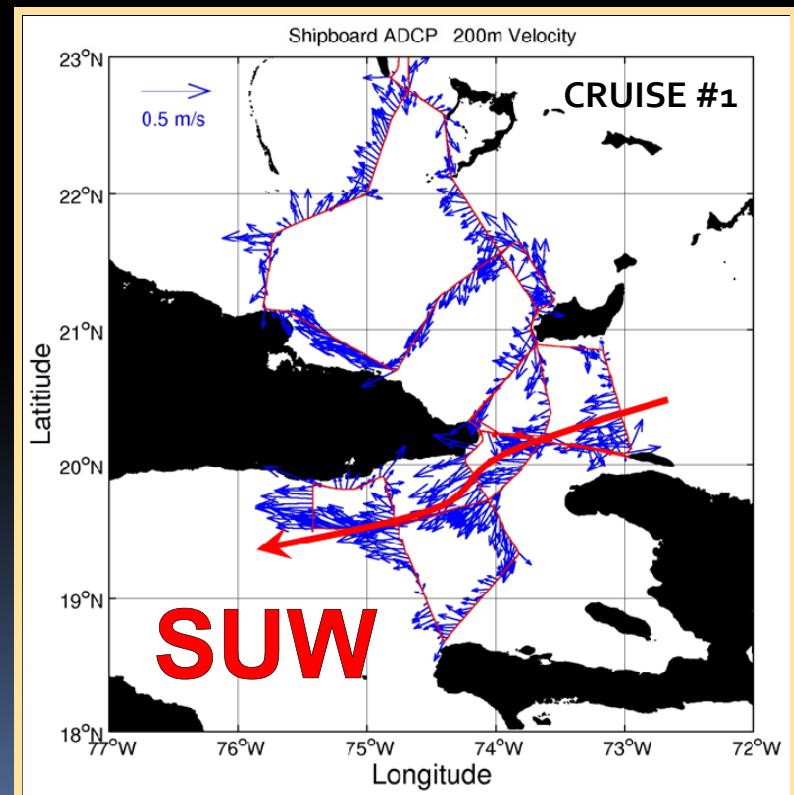
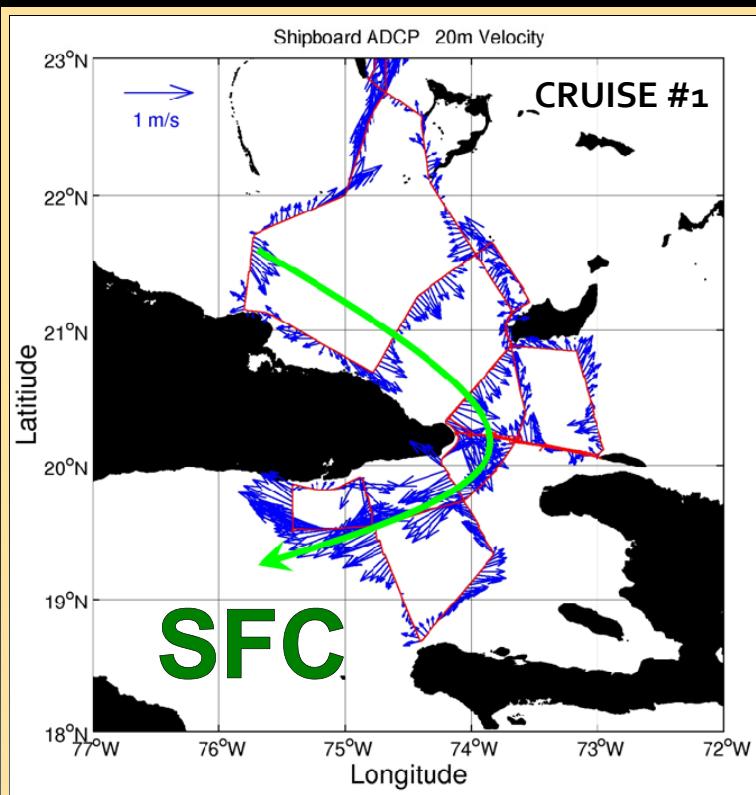
AAIW



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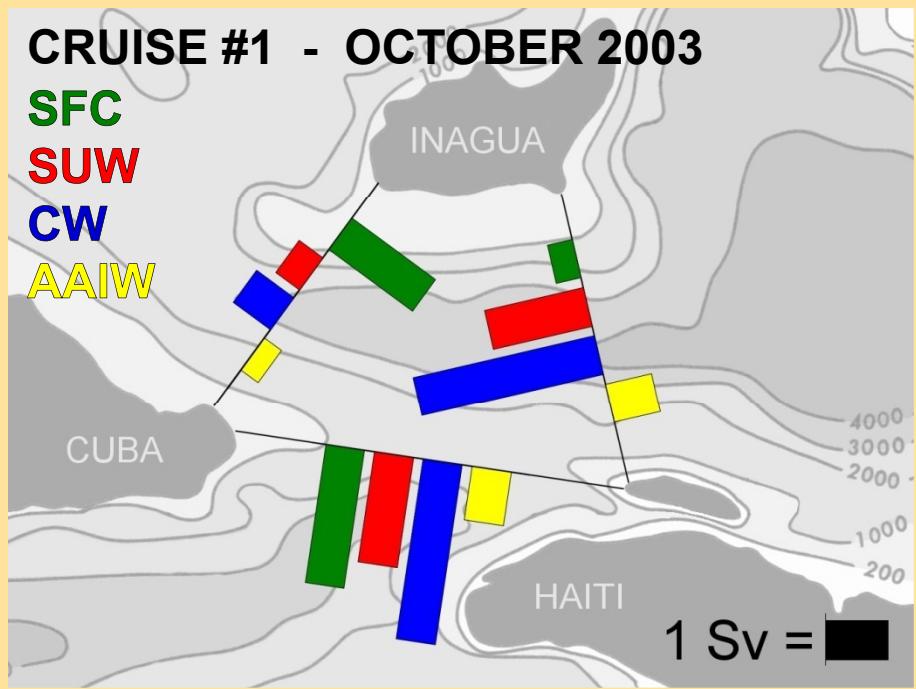


Hull-mounted ADCP velocity measurements confirm the water mass pathways revealed in the lowered ADCP station data...



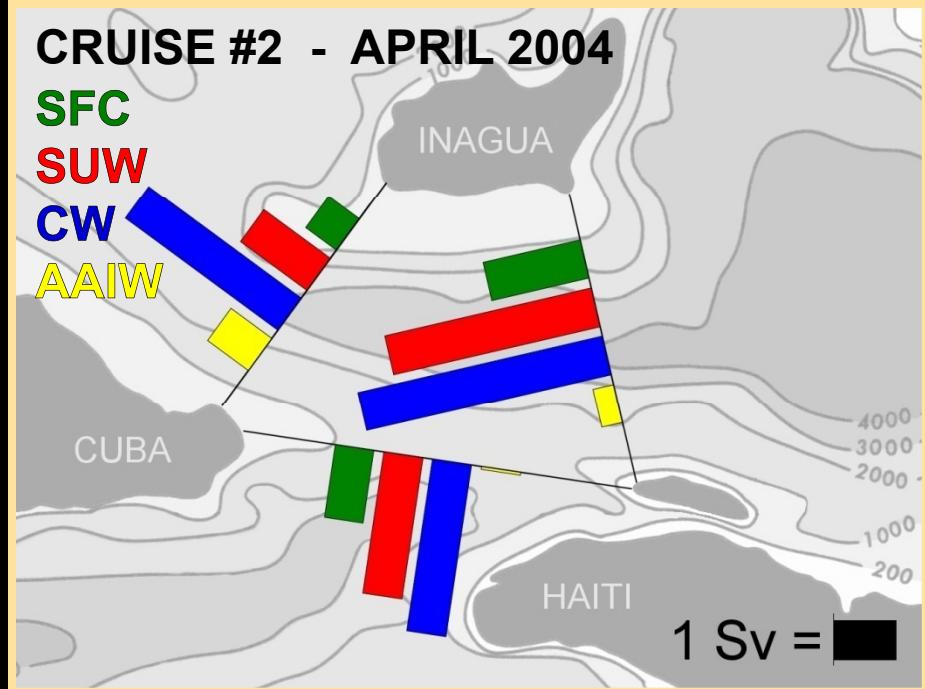
CRUISE #1 - OCTOBER 2003

SFC
SUW
CW
AAIW



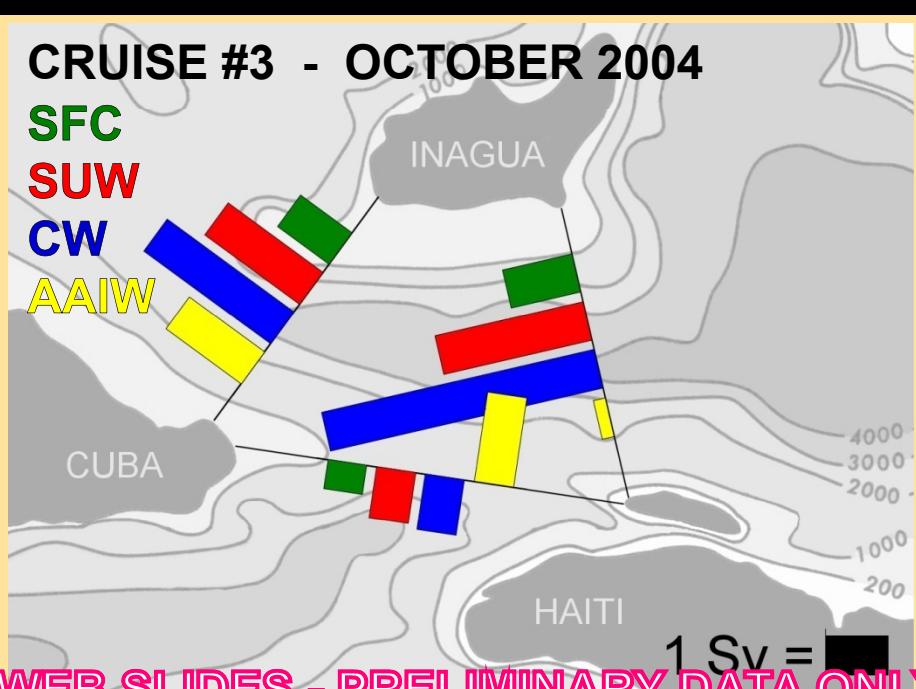
CRUISE #2 - APRIL 2004

SFC
SUW
CW
AAIW



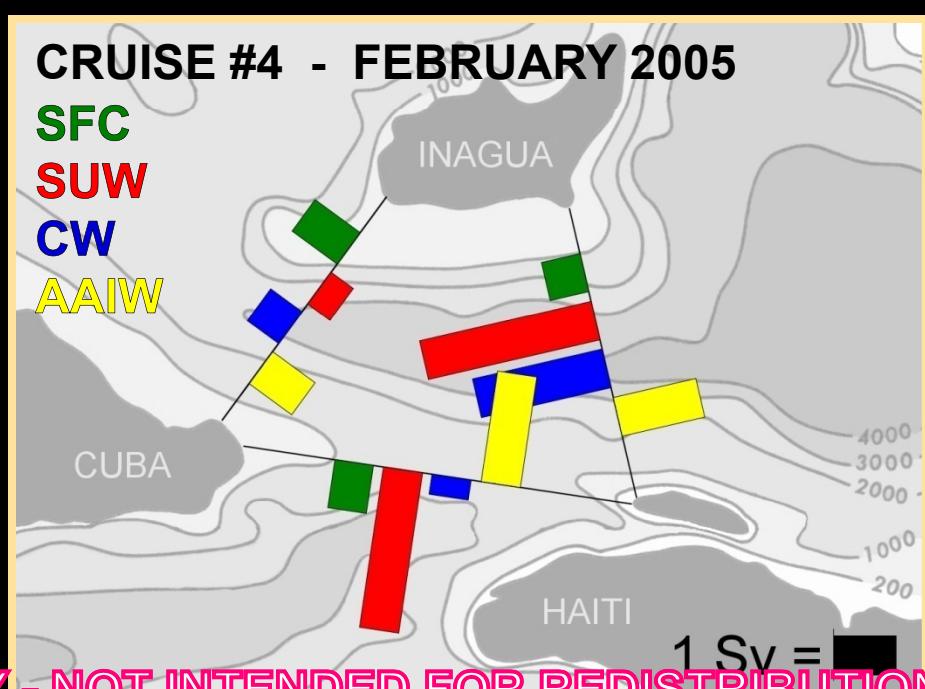
CRUISE #3 - OCTOBER 2004

SFC
SUW
CW
AAIW



CRUISE #4 - FEBRUARY 2005

SFC
SUW
CW
AAIW



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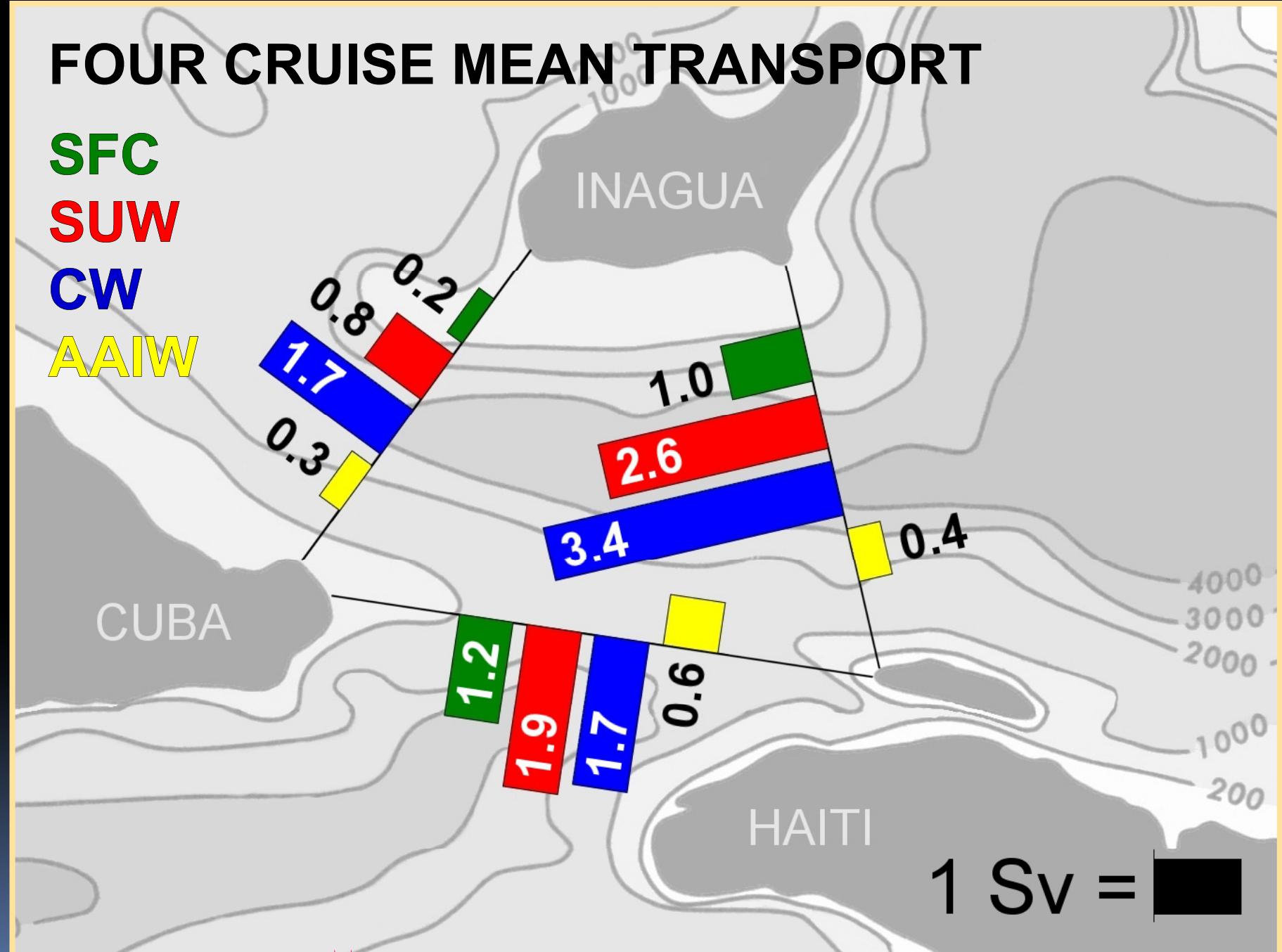
FOUR CRUISE MEAN TRANSPORT

SFC

SUW

CW

AAIW



1 Sv = [black square]

Conclusions:

- ❖ *Total transport through Windward Passage and internal flow patterns are highly variable.*
- ❖ *The velocity structure in Windward passage can be characterized by inflow of surface and thermocline waters and outflow of intermediate waters.*
- ❖ *Detided lowered ADCP data collected during four occupations of the passage yield a mean inflow of 3.5 Sv. Though the standard error of this measurement is quite large (2.1 Sv), moored current meter data collected over the 16 month field study, support a similar transport value of 3.6 Sv (SE=1.7 Sv).*

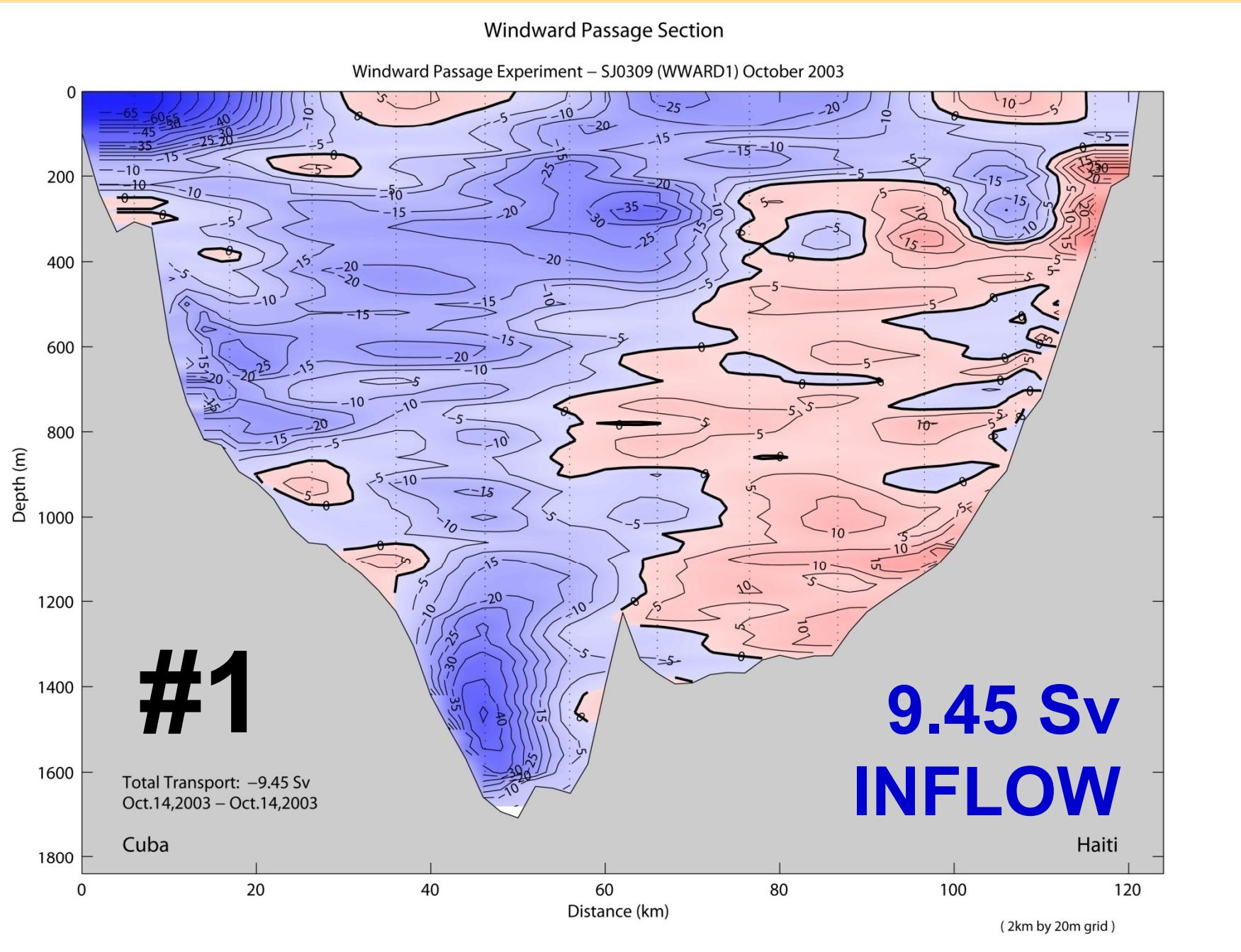
Conclusions (continued):

- ❖ *Mean water mass transports at Windward Passage were found to be:*
Surface Water (SFC): 1.2 Sv inflow (SE: 0.3 Sv)
Subtropical Underwater (SUW): 1.9 Sv inflow (SE: 0.3 Sv)
Central Water (CW): 1.7 Sv inflow (SE: 0.6 Sv)
Antarctic Intermediate Water (AAIW): 0.6 Sv outflow (SE: 0.5 Sv)
- ❖ *Water mass recirculation within the passage, contributes to the large differences seen in the net transport of each water class parameterized (and to the resulting high standard error).*
- ❖ *Though not directly apparent by total transport calculations (i.e. AAIW outflow), all four cruises reveal a persistent inflow jet (~15 cm/s) of Antarctic Intermediate Water against the western side of the passage at approximately 750-850 meters.*

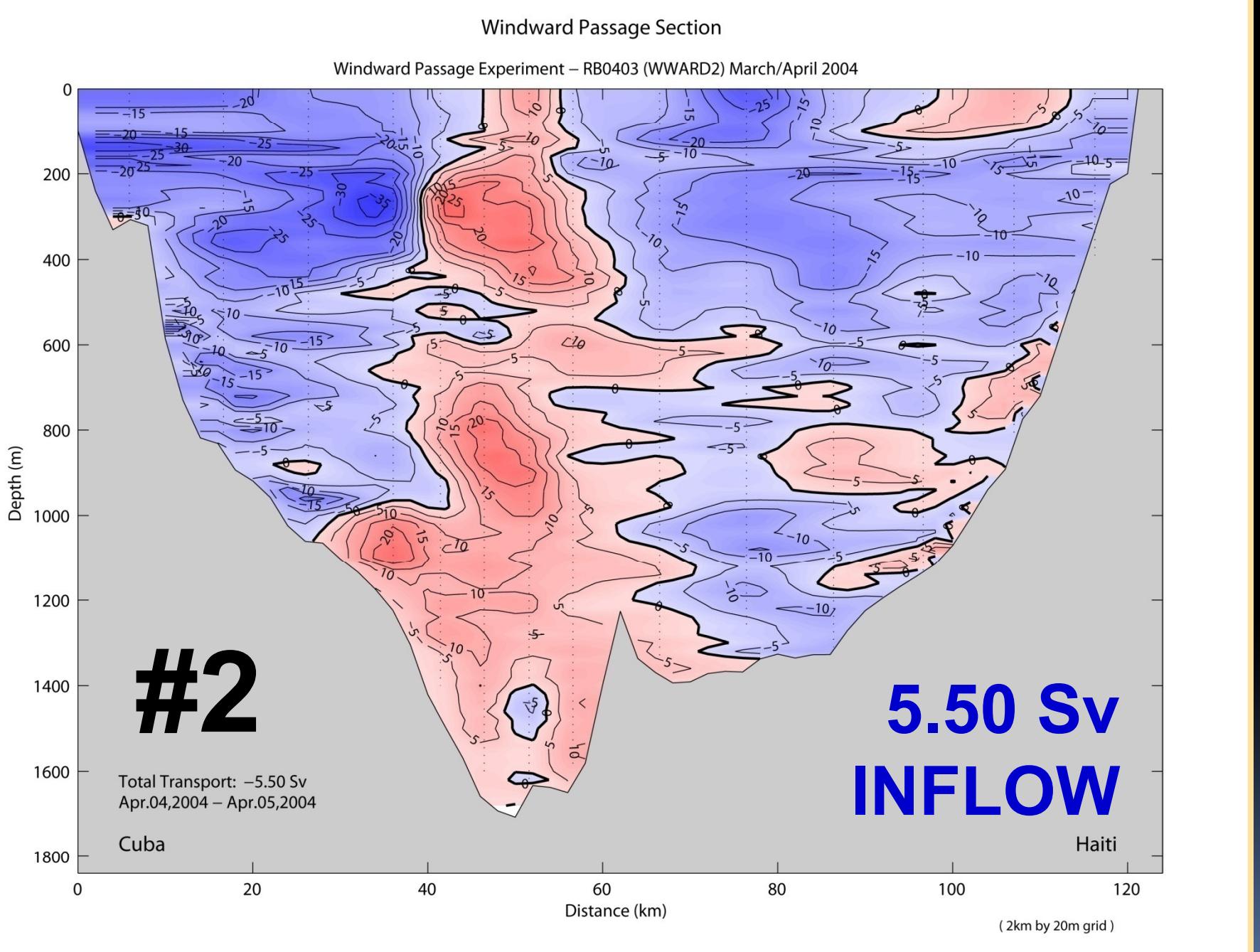
Conclusions (continued):

- ❖ *Mean water mass transport calculations for the “triangle” between Cuba, Haiti, and Inagua show Surface Water and Subtropical Undewater enter the domain from the east and predominantly flow into the Caribbean through Windward Passage. Central Water enters from the same direction and bifurcates, with roughly equal proportions flowing south (into the Caribbean), and west (north of Cuba). The net transport of Antarctic Intermediate water is out of the Caribbean with similar amounts flowing west and east to either side of Inagua.*
- ❖ *Volume transport calculations for Windward Passage from lowered ADCP and moored current meter datasets do not account for the total flow required to balance the established Caribbean water mass budget. With new, lower transport values recently recorded at the Yucatan Channel (Badan et al., 2005), questions arise as to what pathways account for the remaining flow seen at 27N in the Florida Straits.*

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**NO
PERMISO**

!

Depth (m)

0

200

400

600

800

1000

1200

1400

1600

1800

#3

Total Transport: 0.24 Sv
Oct.14,2004 – Oct.15,2004

Cuba

Windward Passage Section

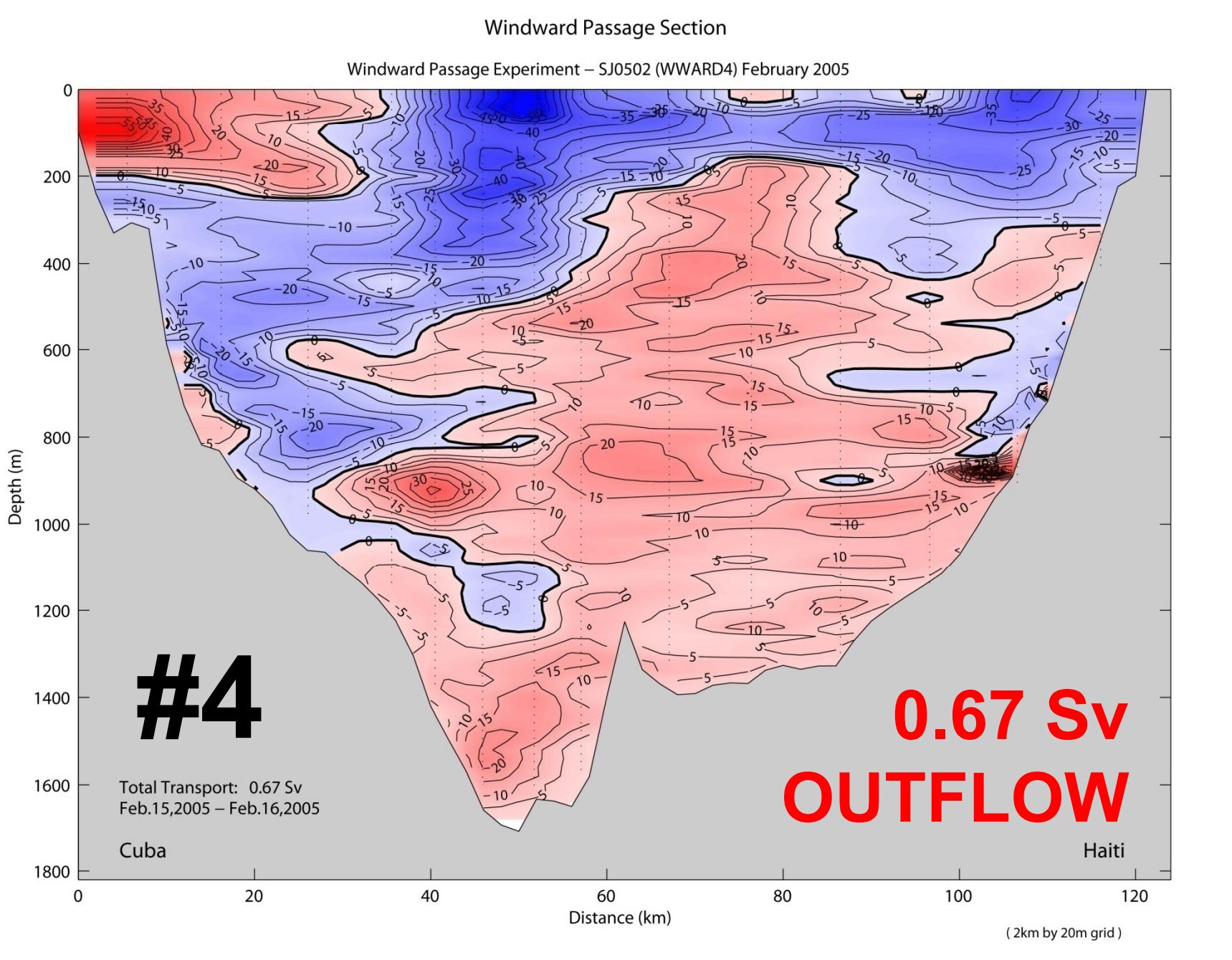
Windward Passage Experiment – RB0409 (WWARD3) October 2004

Distance (km)

(2km by 20m grid)

**0.24 Sv
OUTFLOW**

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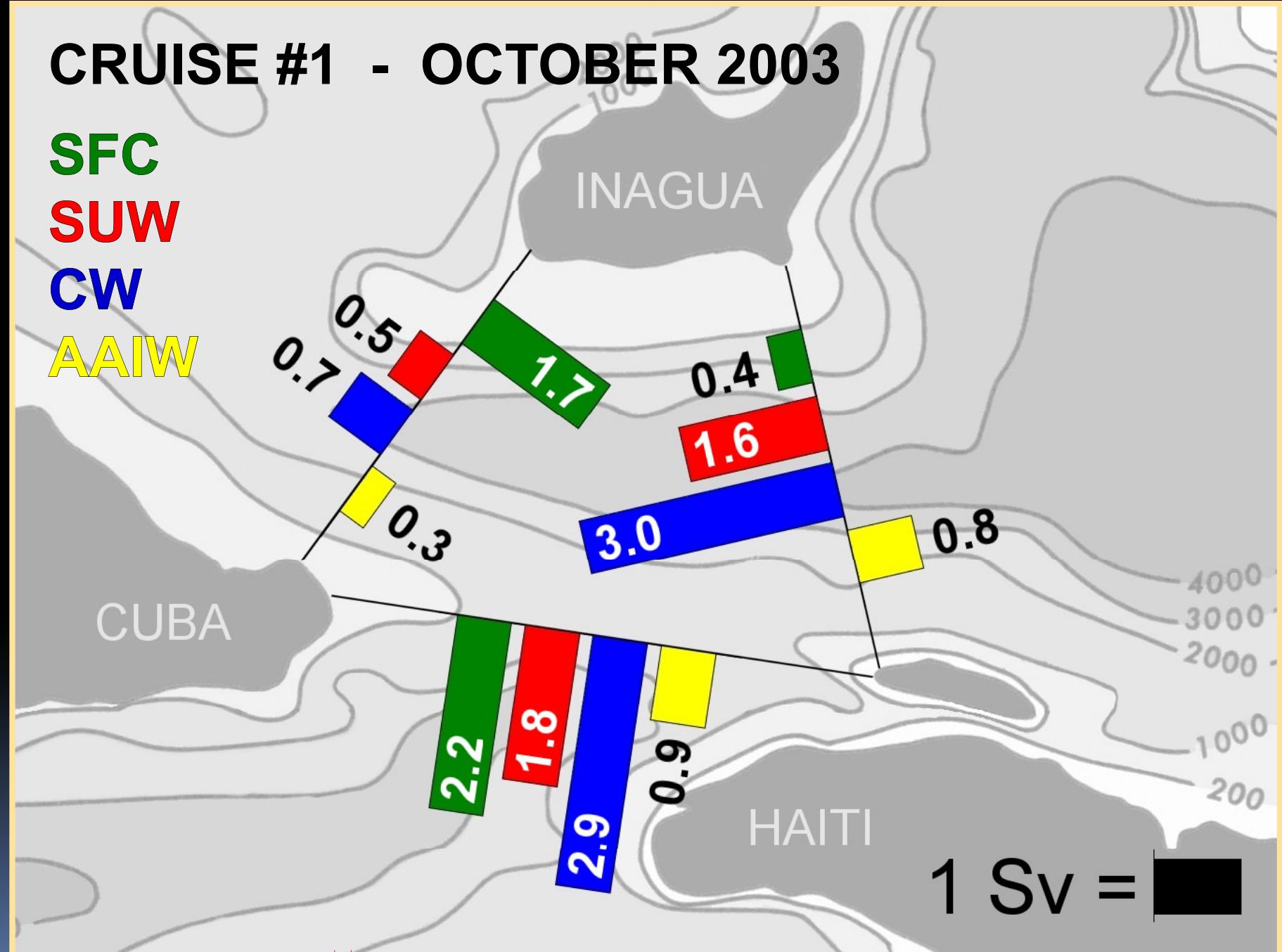
CRUISE #1 - OCTOBER 2003

SFC

SUW

CW

AAIW



1 Sv = ■

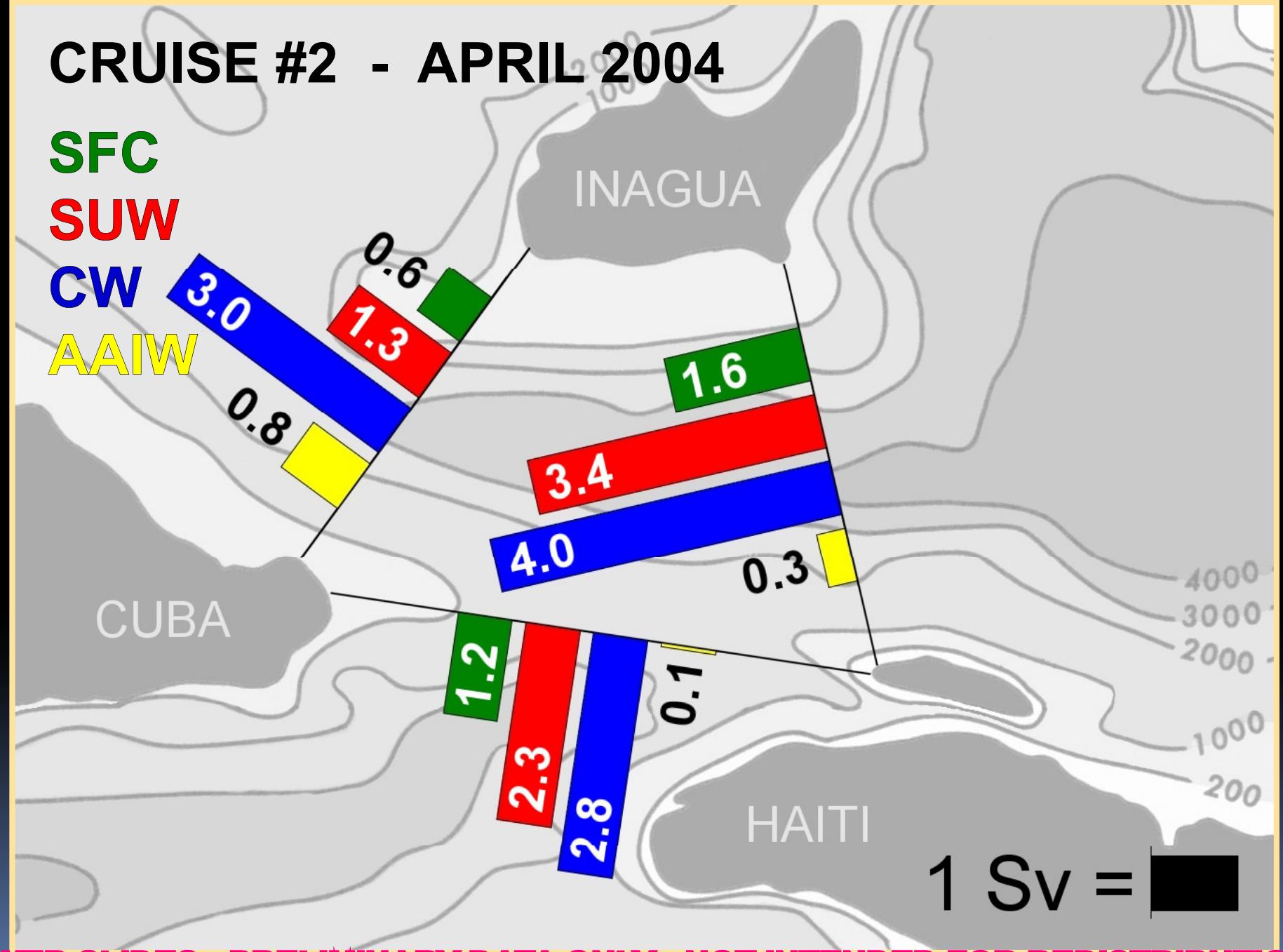
CRUISE #2 - APRIL 2004

SFC

SUW

CW

AAIW



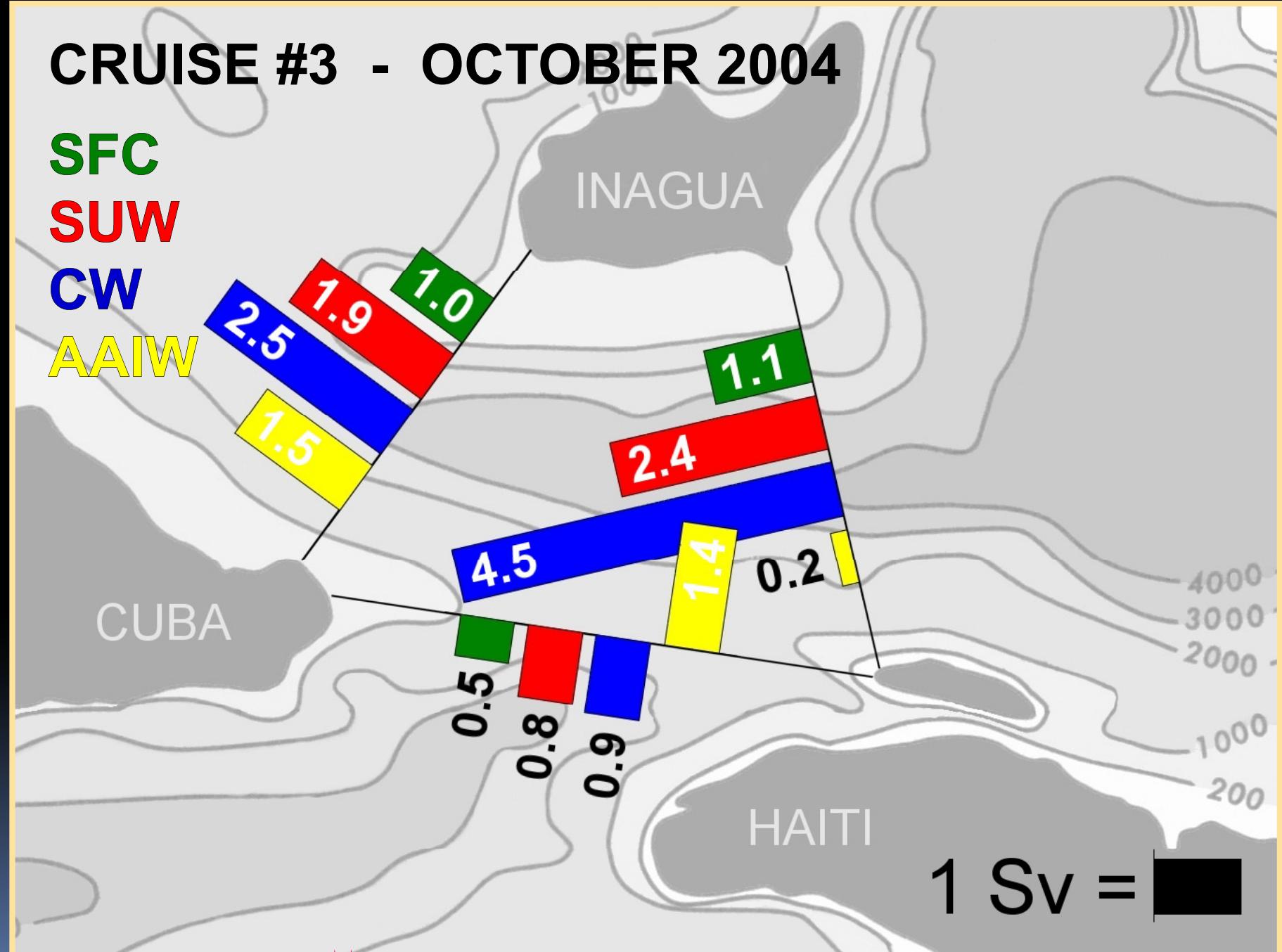
CRUISE #3 - OCTOBER 2004

SFC

SUW

CW

AAIW



1 Sv = []

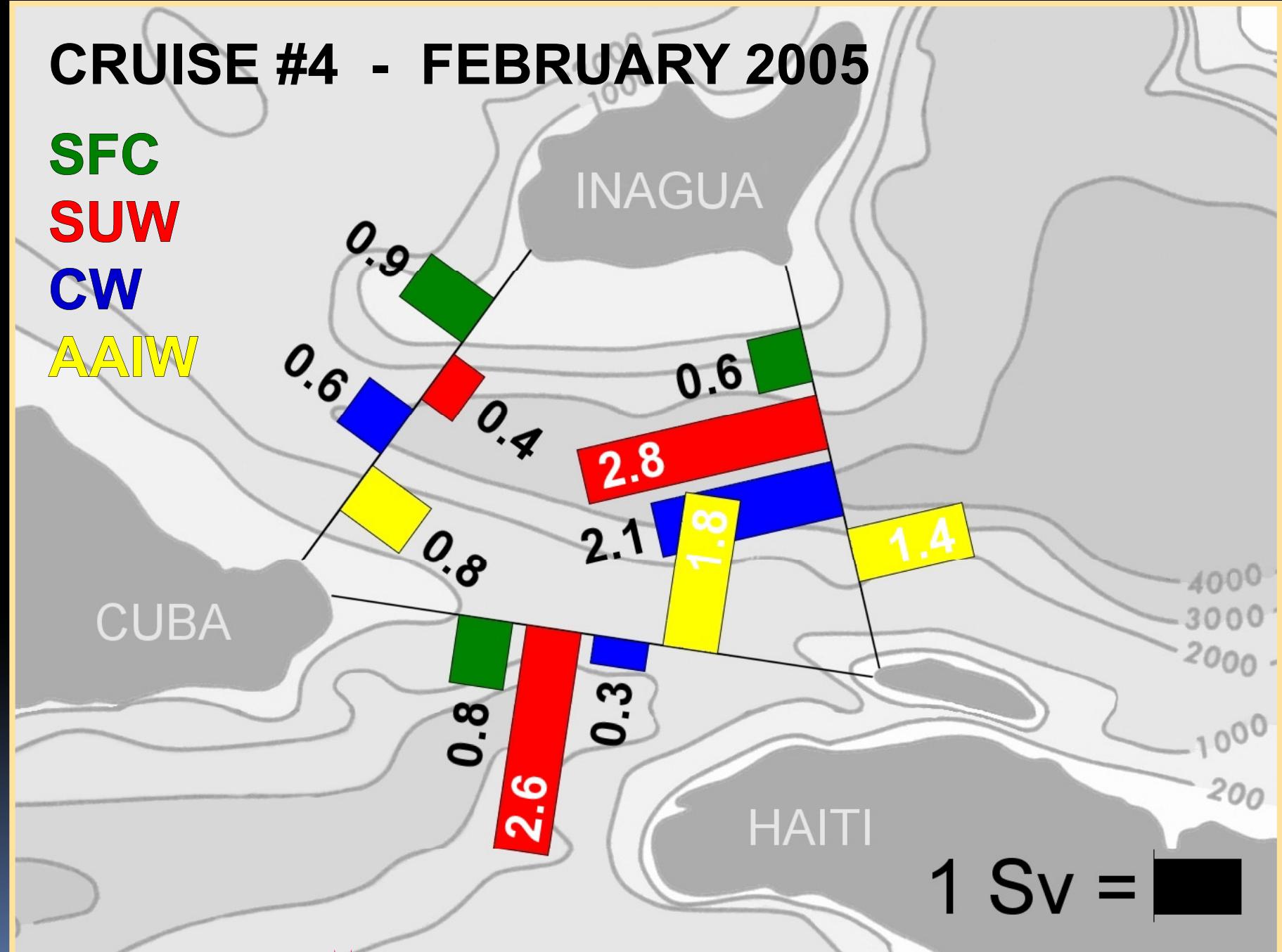
CRUISE #4 - FEBRUARY 2005

SFC

SUW

CW

AAIW



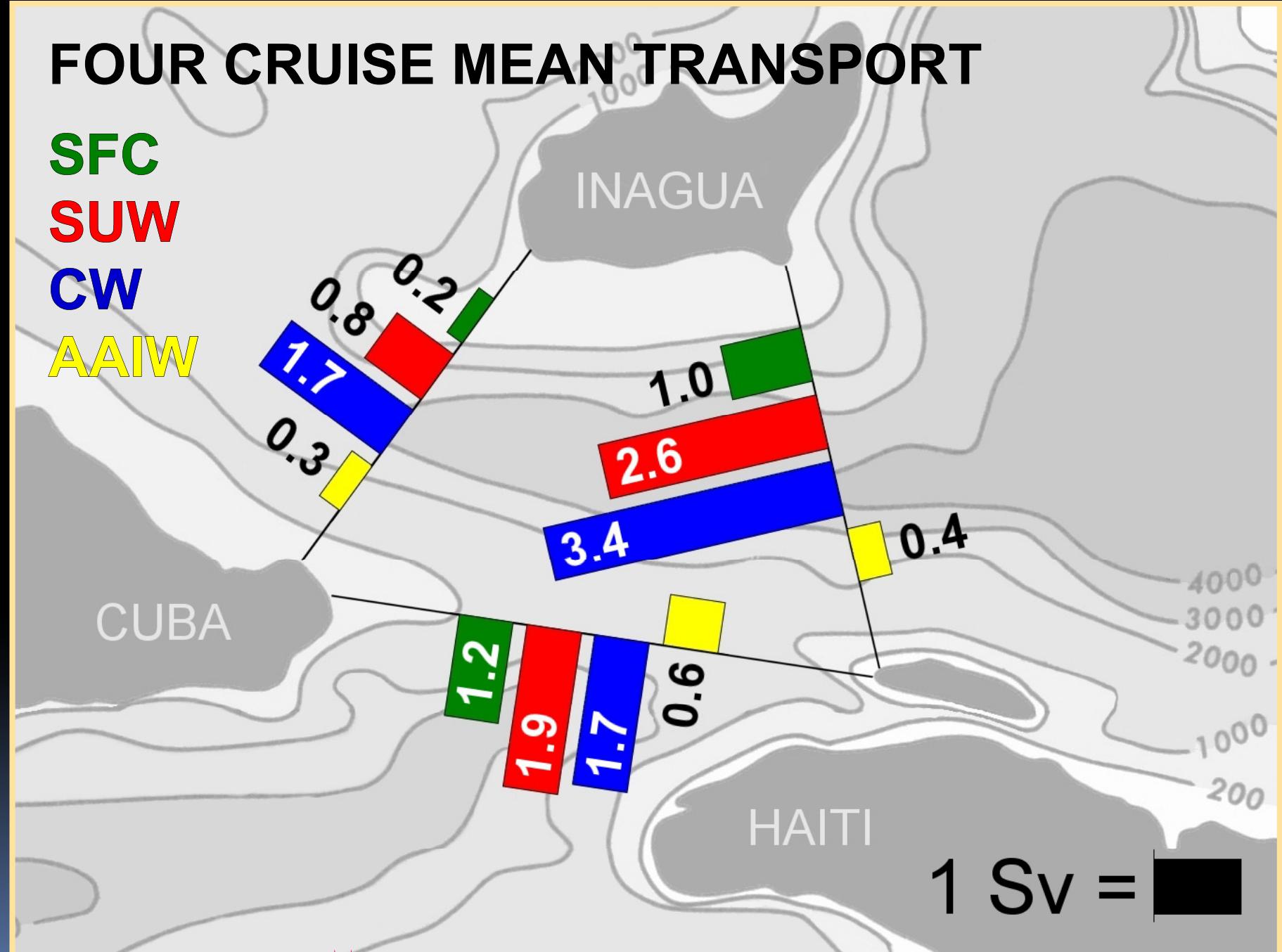
FOUR CRUISE MEAN TRANSPORT

SFC

SUW

CW

AAIW



1 Sv = [black square]