Ocean Gliders and the Argo float program

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WHOI

for INMARTECH Conference, Oct 06

- A brief history
- The Argo float program
- Gliders - how they work
- Some results from gliders
- The Future

Glider Lineage

- Ocean gliders evolved from sub-surface floats
- Swallow Floats (John Swallow, 1960)
  - Sent out acoustic (sound) signals, tracked from ships
  - Crease and Swallow, while visiting Stommel at WHOI tried to measure predicted abyssal circulation, bottom limb of “Conveyor Belt,” instead discovered ocean weather (eddies)
  - Swallow, Worthington and Volkmann measured deep velocities in Gulf Stream
- SOFAR floats (Rossby and Webb, 1970)
  - Acoustically tracked with listening stations (U.S. Navy or moored), tracking range 1000-2000 km

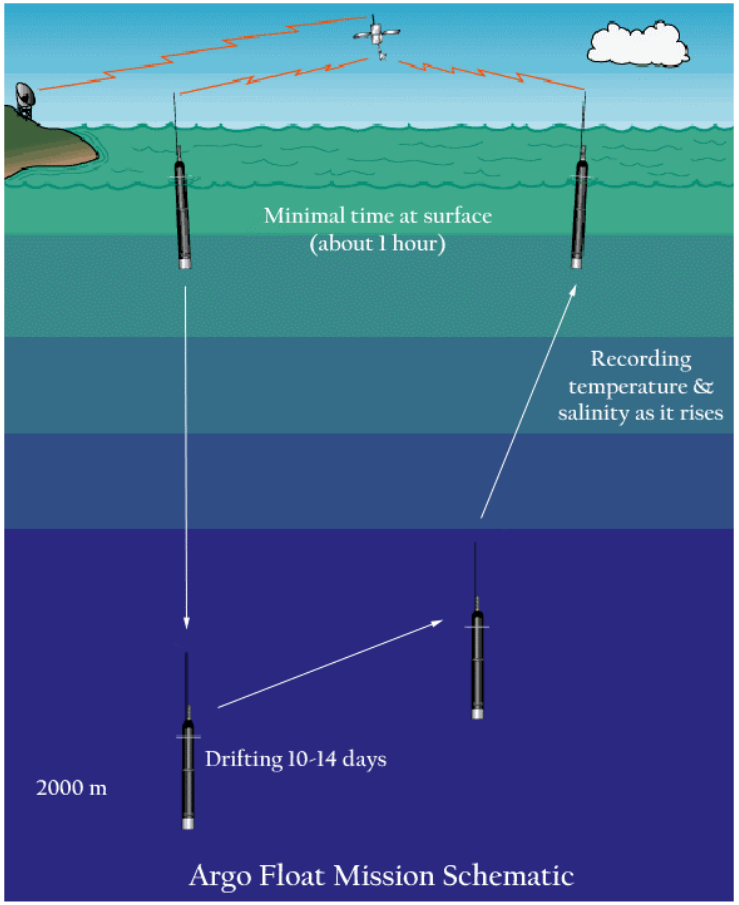
  weight ~400 kg
- RAFOS floats
  reverse system to SOFAR: moored sources, small, 10 kg floats, single trip to surface
- ALACE floats (Davis and Webb, 1990), for the World Ocean Circulation Experiment (WOCE)
  - Global, drift at depth, rising to surface for satellite positioning
  - These floats measured profiles of Temperature and Salinity
  - SOLO, APEX and PROVOR floats are the basis of the Argo float program (the ocean analog of the weather balloon network used in meteorology)

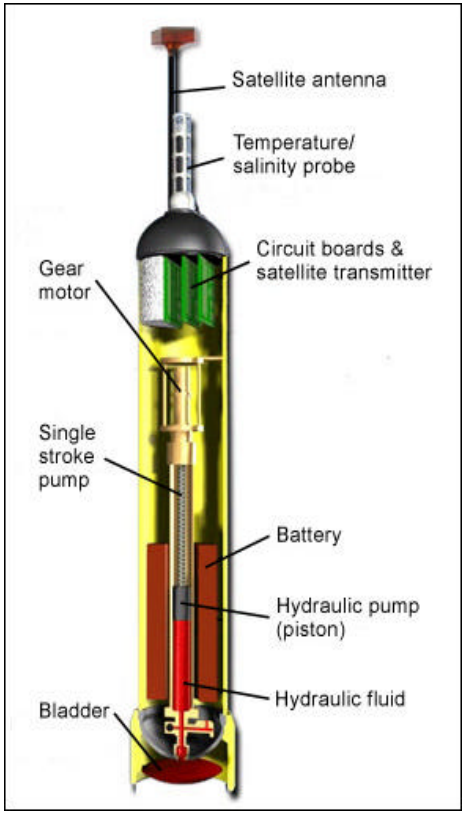
  weight 25 kg

John Swallow and Gordon Volkmann launching a float in the Gulf Stream, circa 1960

Profiling Alace Float

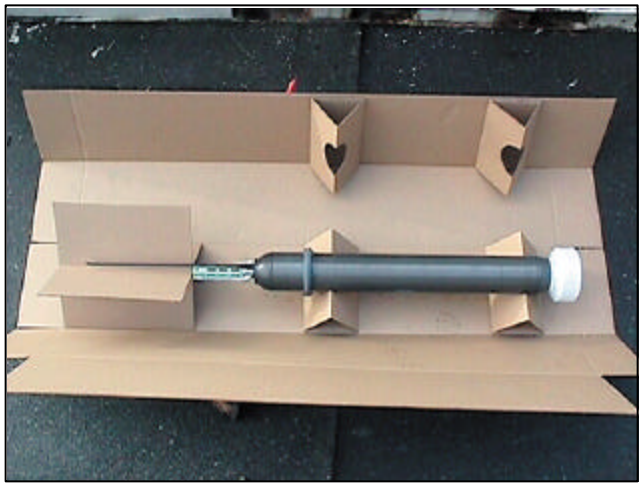
These are oceanic analogues to radiosondes used in operational meteorology, basis of Argo float Program (3000 floats globally).

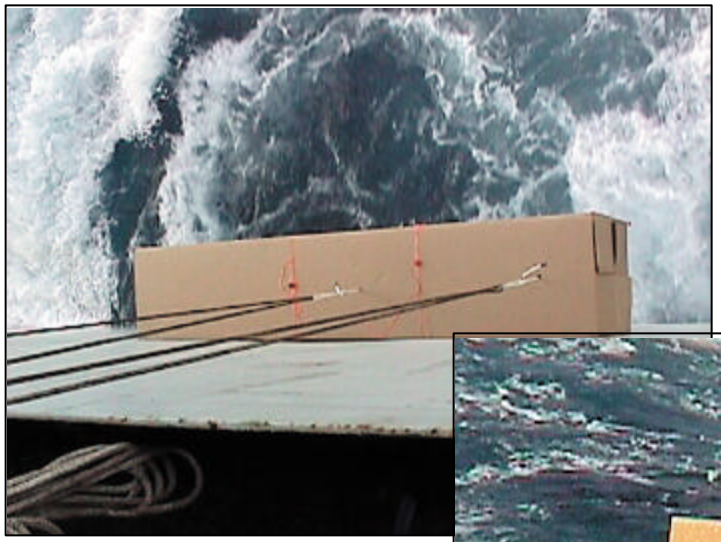




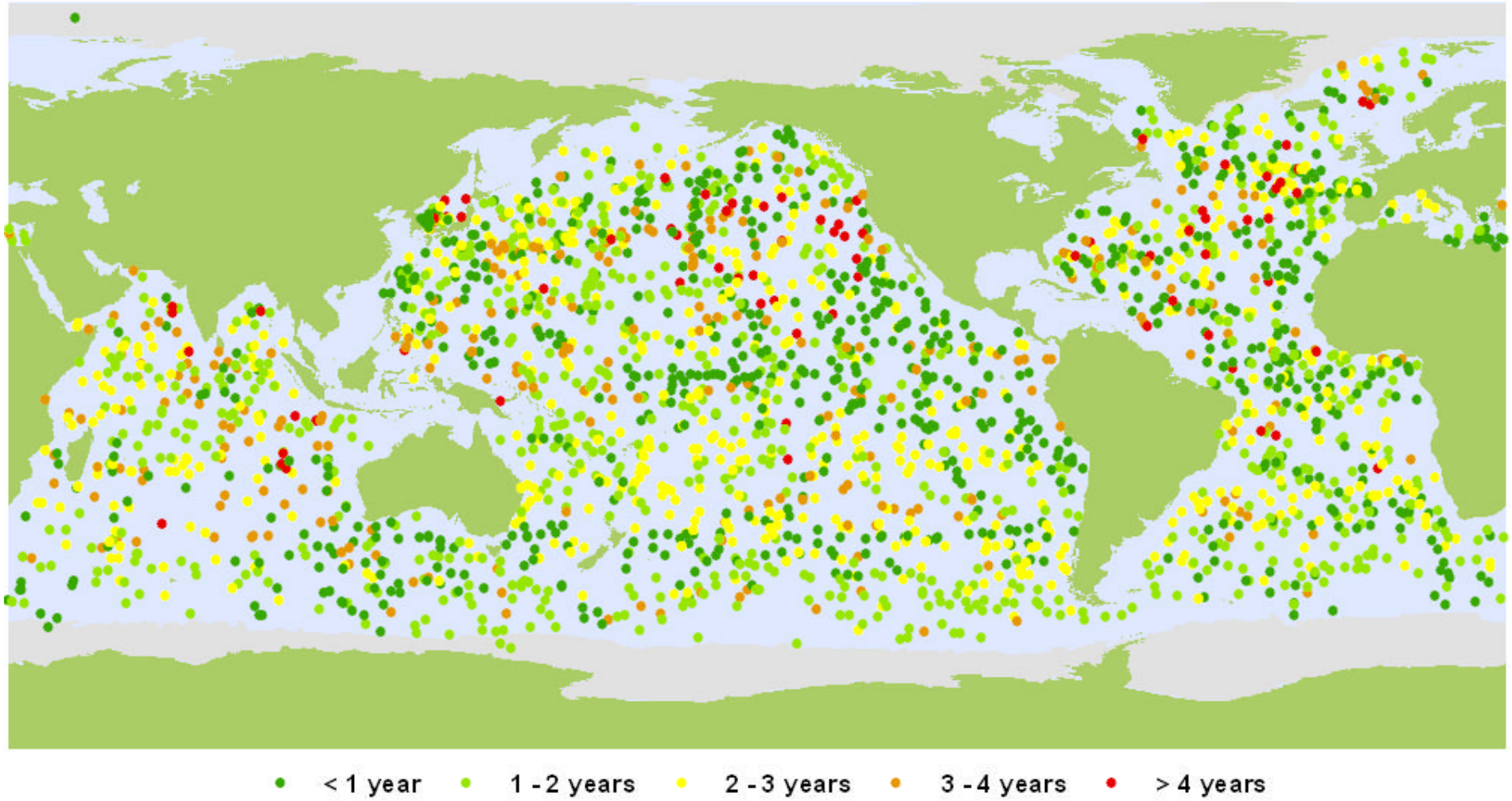
Argo Floats

- ~ 2600 floats deployed, report every 10 days
- Data distributed in real time
- Deployments from VOS and research ships
  - difficulties reaching remote areas
  - deployed in boxes to avoid damage during launch
  - initiated in port, launched underway



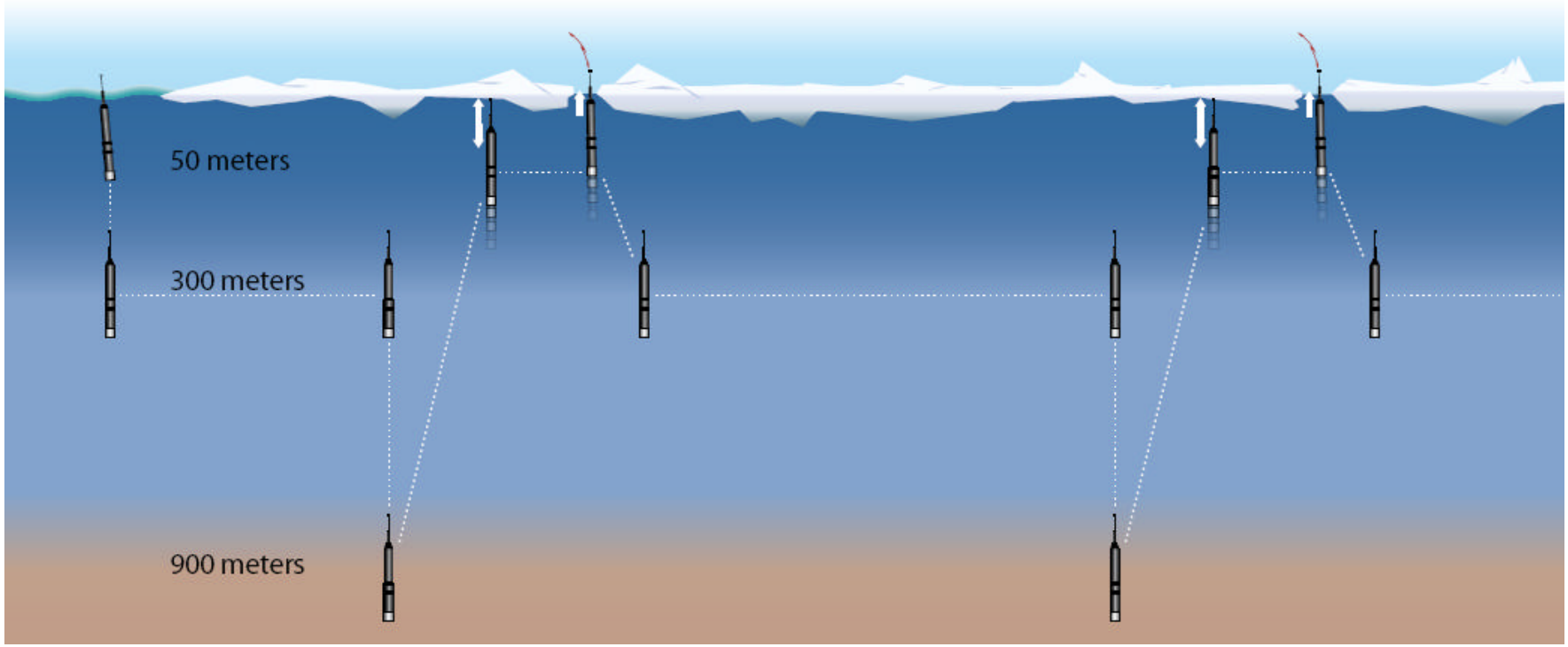


Global Coverage of profiling floats (Argo)



Note conspicuous lack of coverage in polar oceans.

Polar Profiling Floats



Repeated search for open water (leads) at surface, repeated search from 50 m. Time between surfacing is programmable. Could be as little as 5 days or once a year.

Can track floats during sub-surface drift phase or rely on surface positions for navigation.

Example of new results from Argo

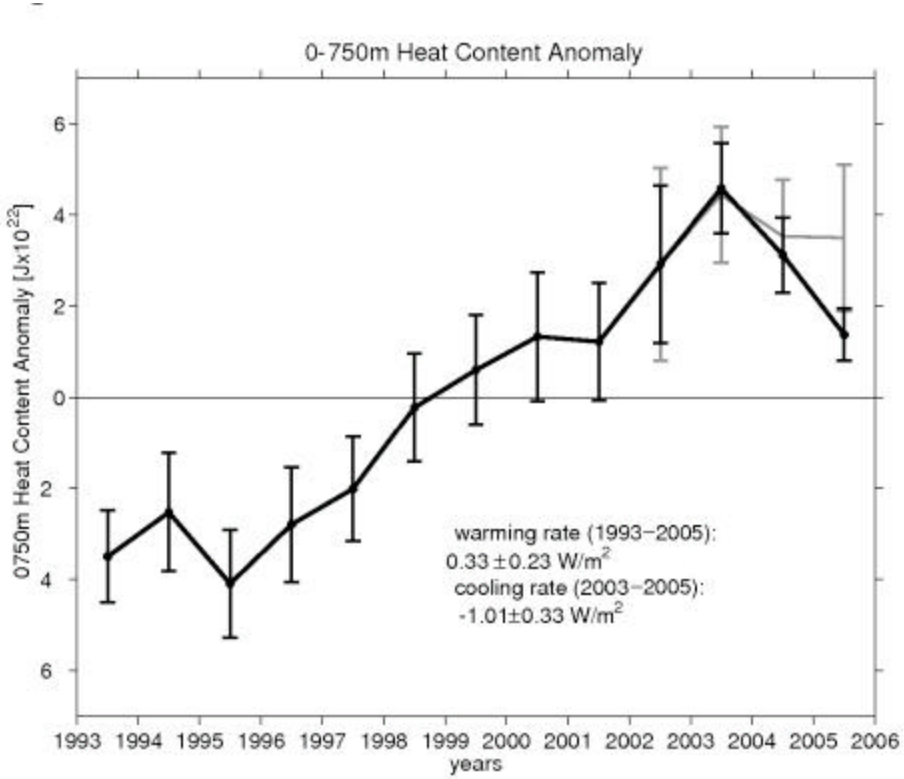


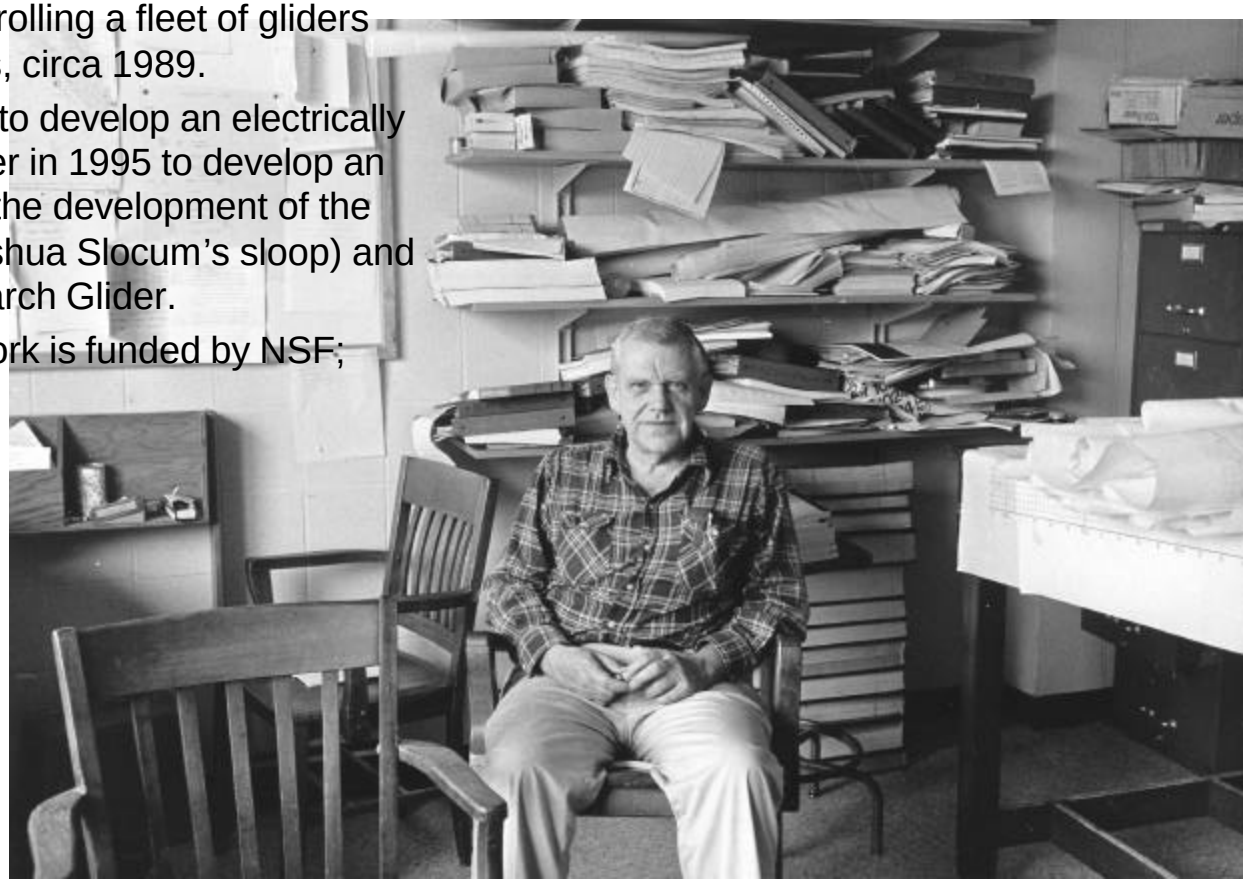
Figure 1. Globally averaged annual OHCA [10^{22} J] in the upper 750 m estimated using in situ data alone from 1993 through 2005 (black line) and using in situ data excluding profiling floats (gray line). Error bars (from Figure 3) reflect the standard error estimates discussed in Section 3. Linear trends are computed from a weighted least square fit [*Wunsch*, 1996] and reflect the OHCA estimate made using all available profile data. Errors for inset linear trend estimates are quoted at the 95% confidence interval.

Lyman, Willis, and Johnson, 2006. Geophysical Research Letters

Controversial analysis combining Argo data with earlier global data sets. May be due to difference in sampling, ie Argo more global.

The early days of ocean gliders

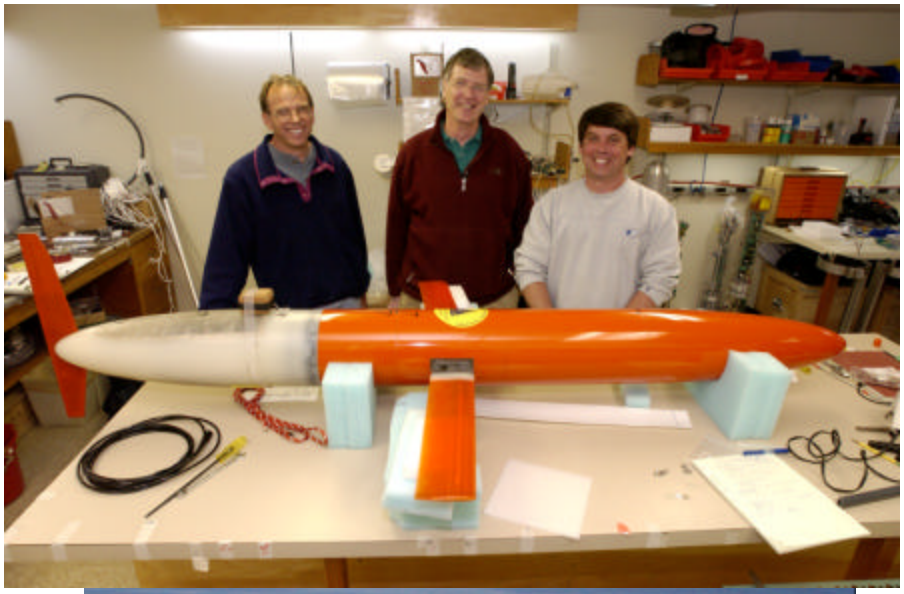
- Stommel and Webb started the development of the Slocum Glider which would extract energy from the vertical temperature difference for propulsion, circa 1988. The name Slocum was chosen to honor Joshua Slocum, the first person to sail alone around the world.
- Stommel wrote a futuristic article in Oceanography Magazine about The Slocum Mission with a control center for the “World Ocean Observing System (WOOS) on Nonamesset Island controlling a fleet of gliders traveling the world’s oceans, circa 1989.
- We received an ONR grant to develop an electrically powered version of the glider in 1995 to develop an ocean glider. This funded the development of the Spray glider (Spray was Joshua Slocum’s sloop) and the start of the Webb Research Glider.
- The present Gulf Stream work is funded by NSF; funding started in 2002.

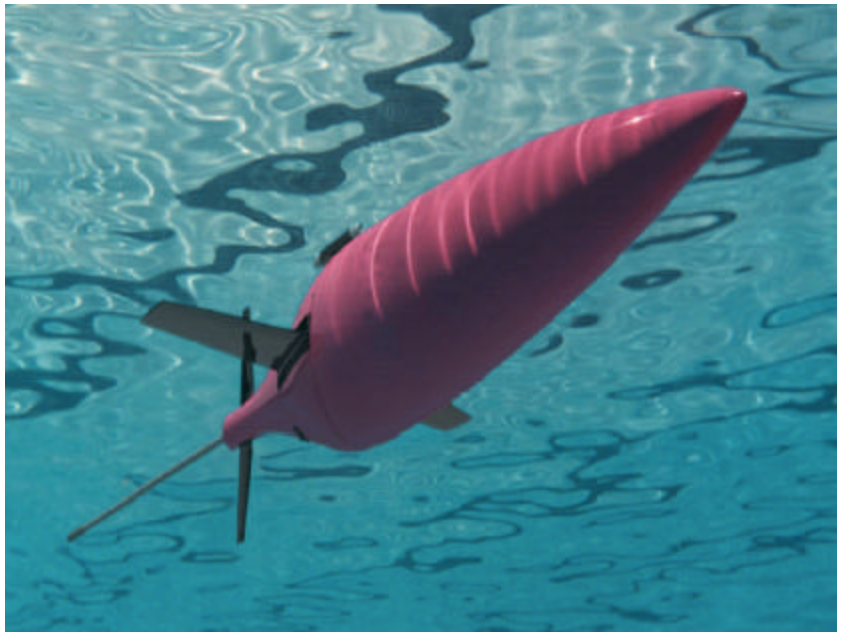


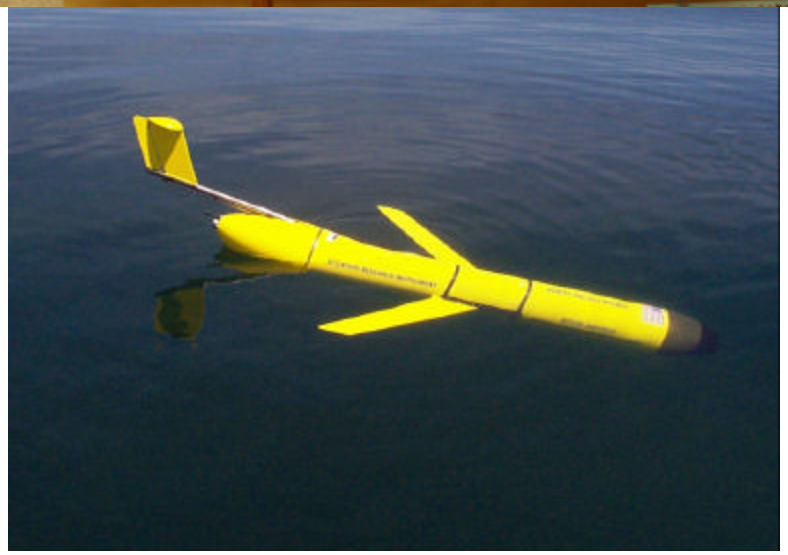
Ocean Gliders

- 3 gliders all developed under 1995 ONR grant
- Spray Glider
  SIO/WHOI
- Webb Glider
- UW/APL Seaglider

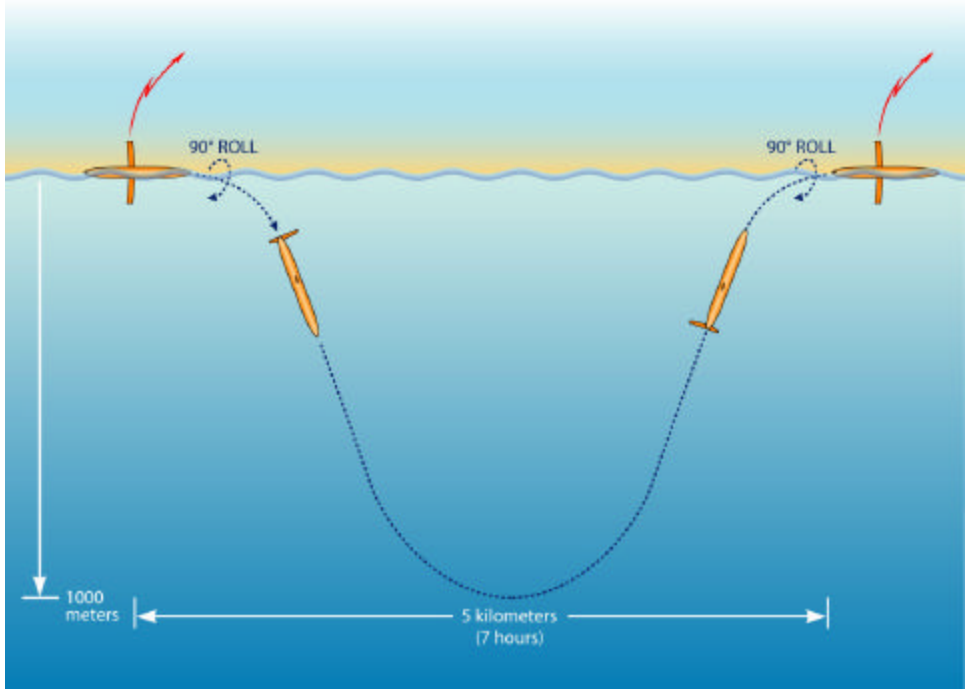
- All gliders work on similar principles
- Different depth ranges
  Different design philosophies



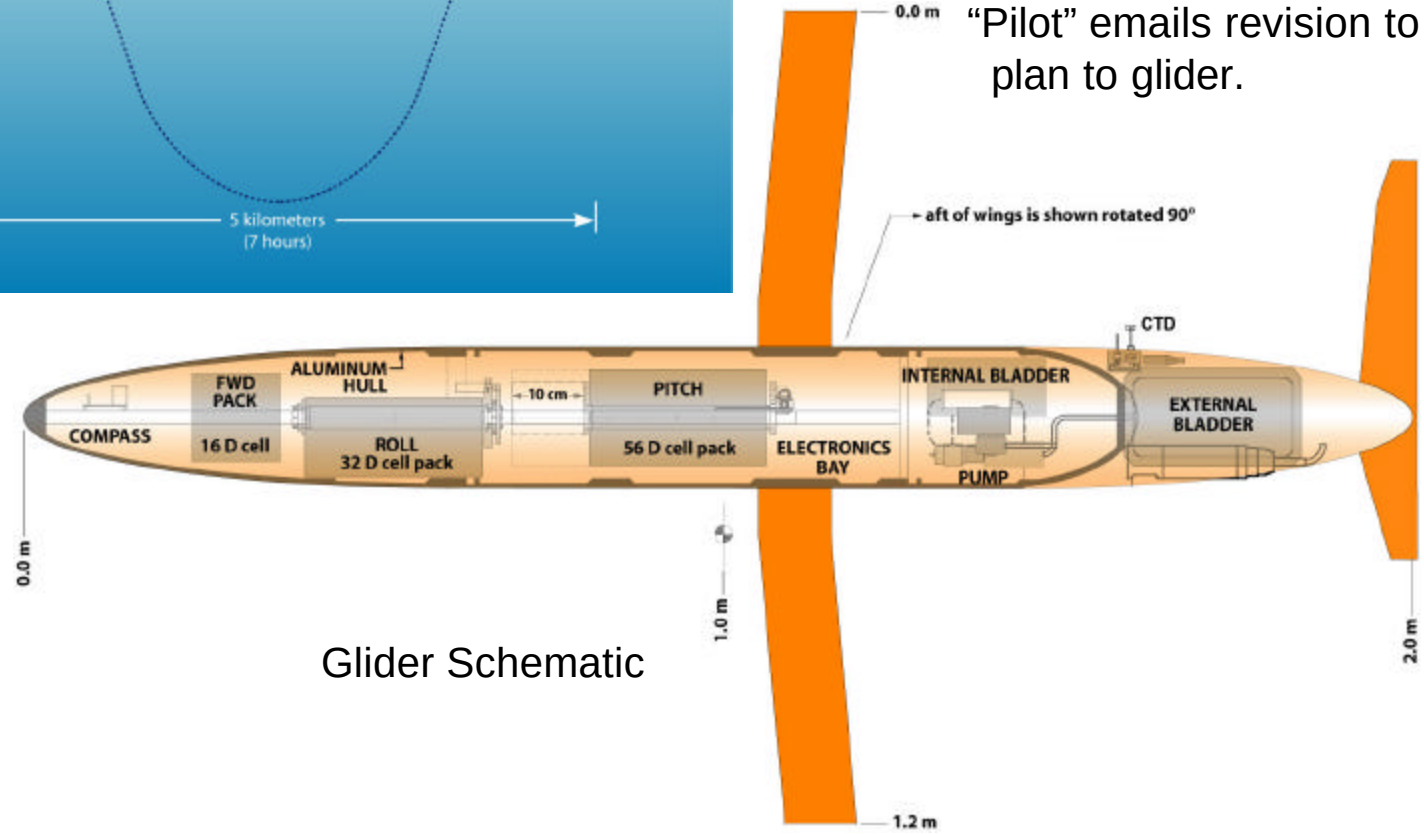




Nominal Glider Dive

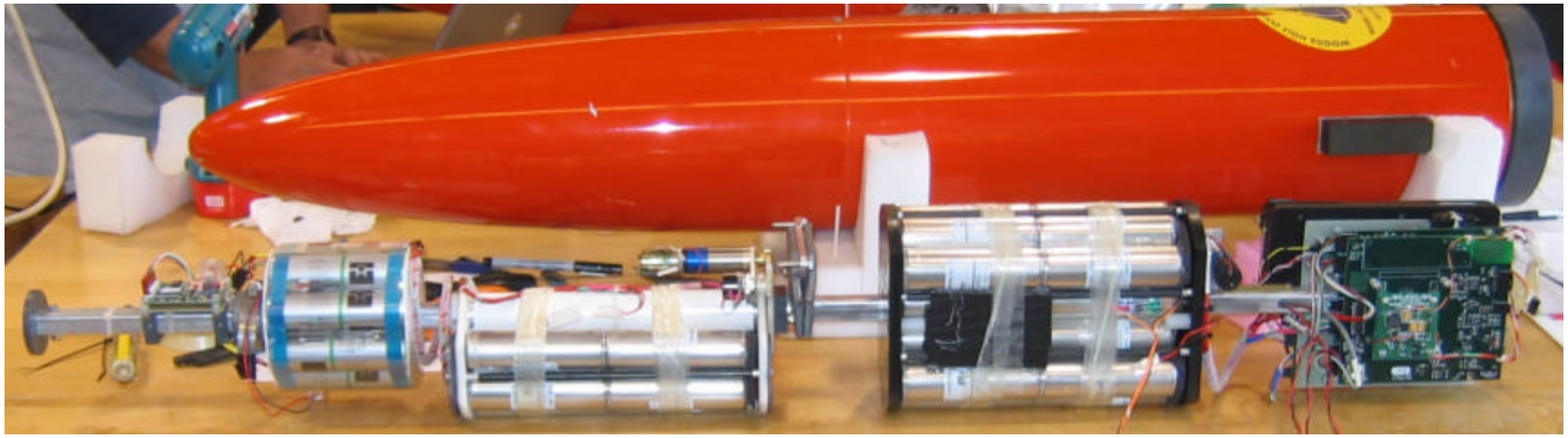


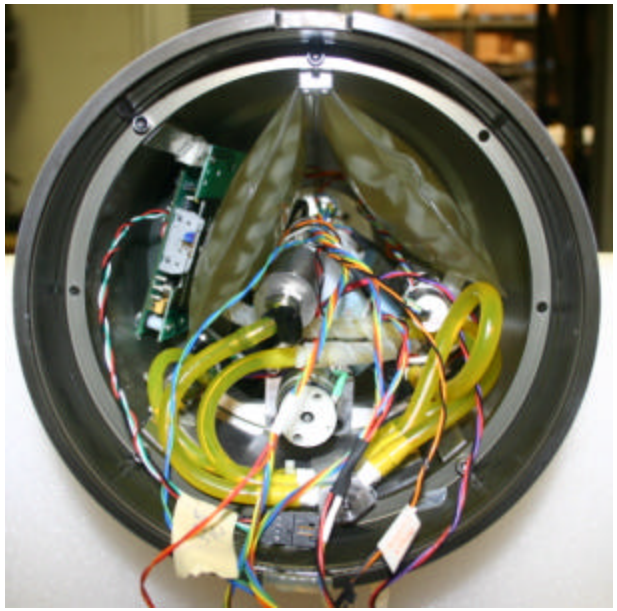
No external moving parts:
External bladder filled ?
glider rises
External bladder empty ?
glider sinks
Moving batteries inside pressure case same as pilot of hang glider moving yoke to steer
Glider emails data to workstation which puts data onto website
“Pilot” emails revision to mission plan to glider.



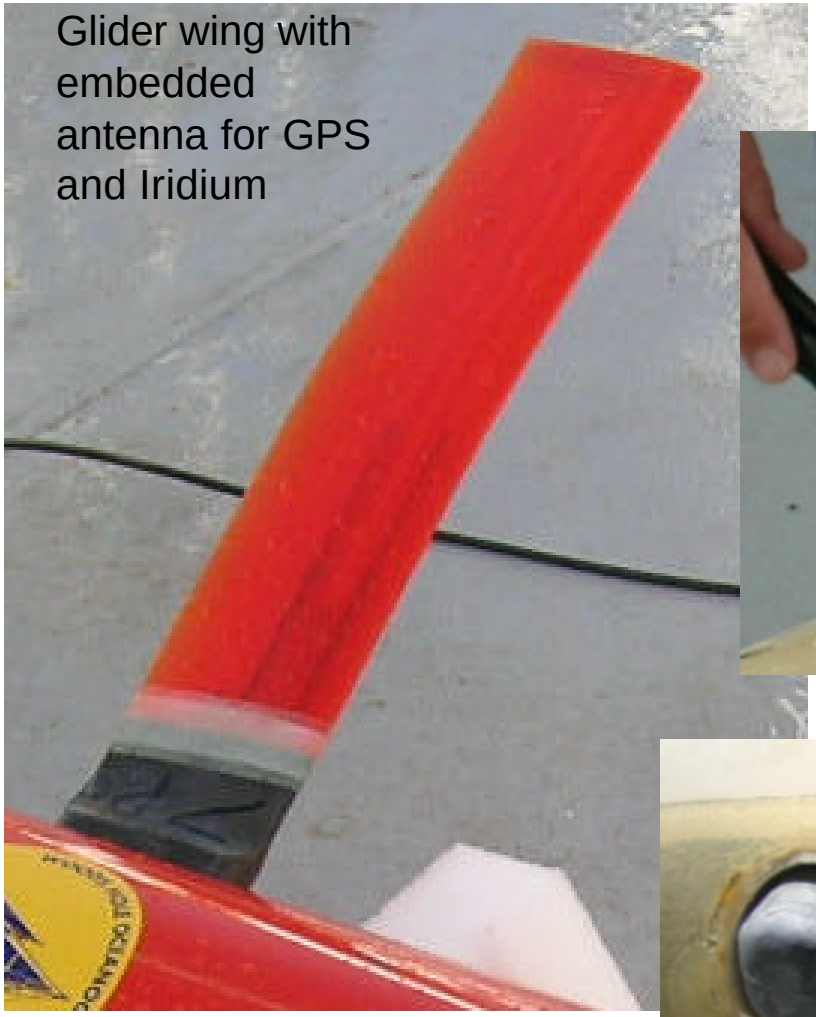
Glider Schematic

Glider batteries and electronics

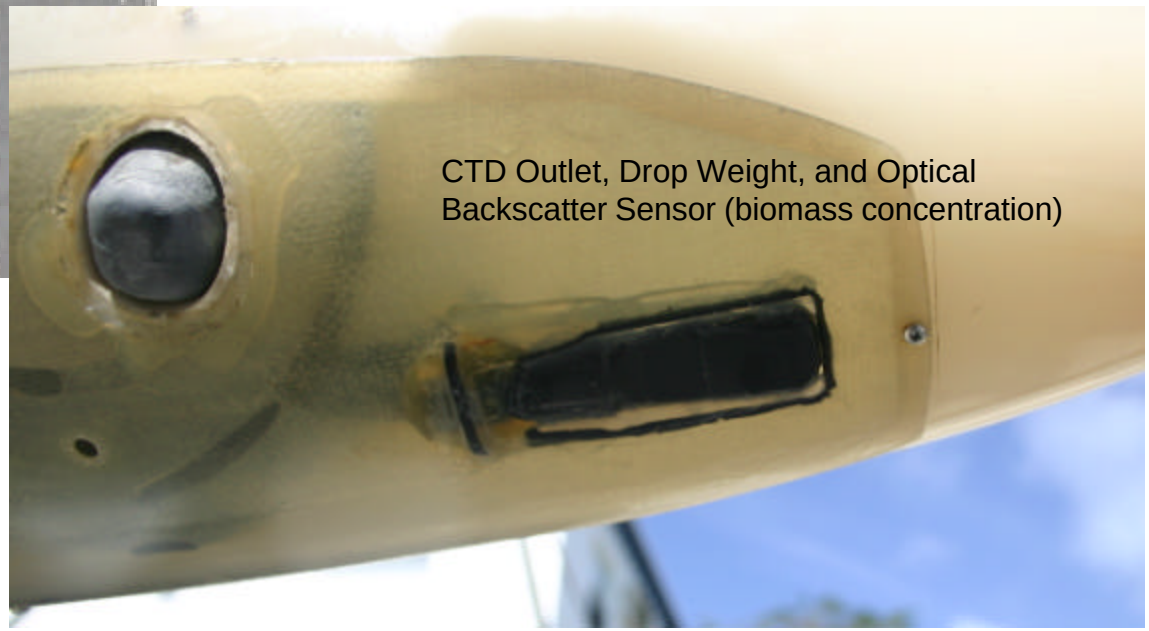




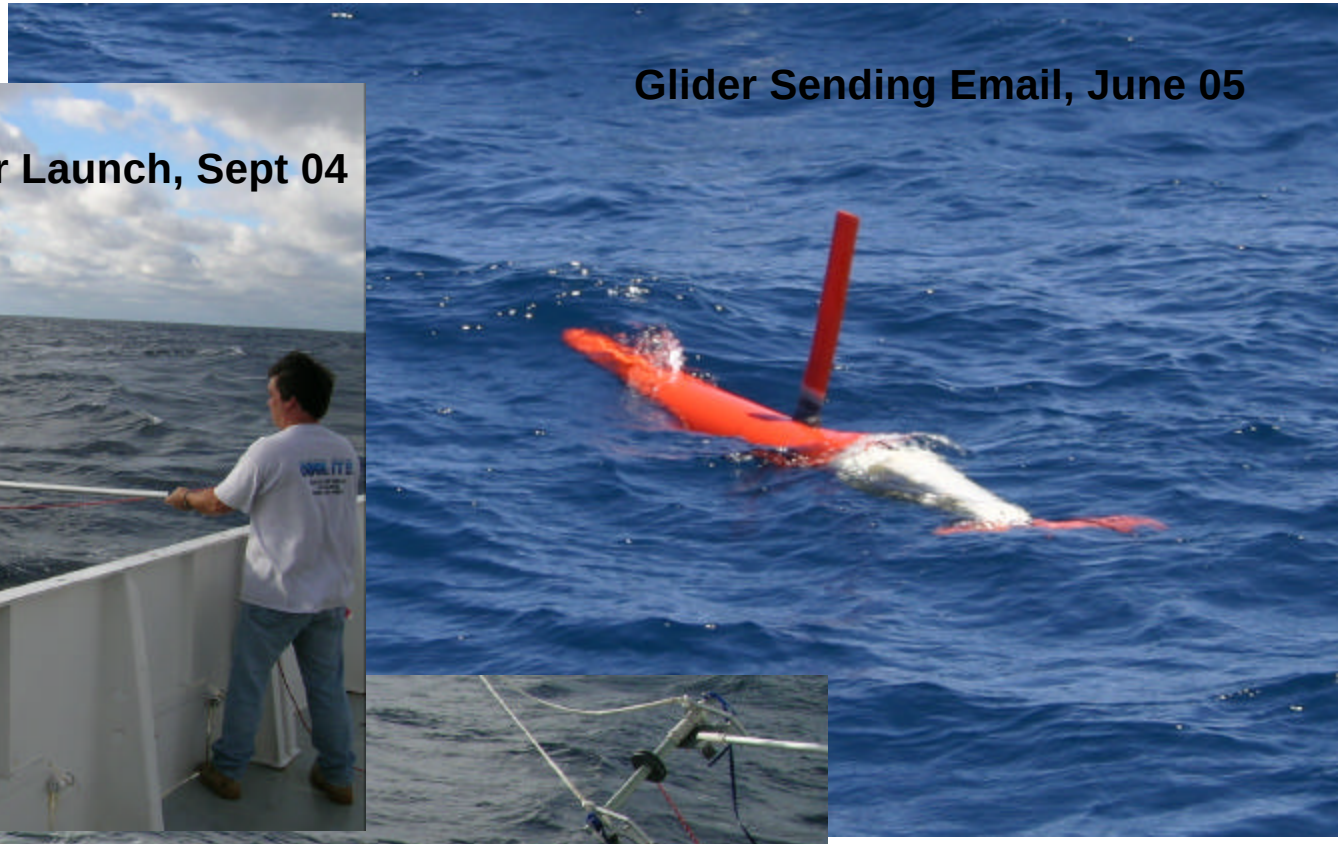
Glider hydraulic system

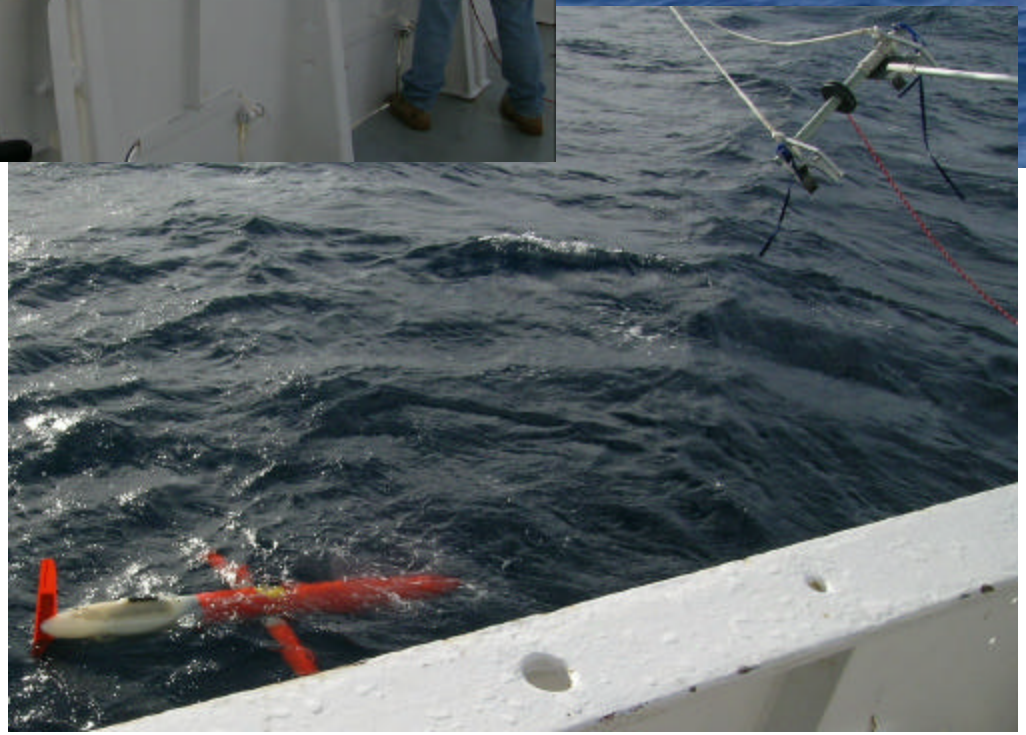

Glider wing with
embedded
antenna for GPS
and Iridium

CTD Sensor:
Temperature
Salinity (conductivity)
Pressure


CTD Outlet, Drop Weight, and Optical
Backscatter Sensor (biomass concentration)

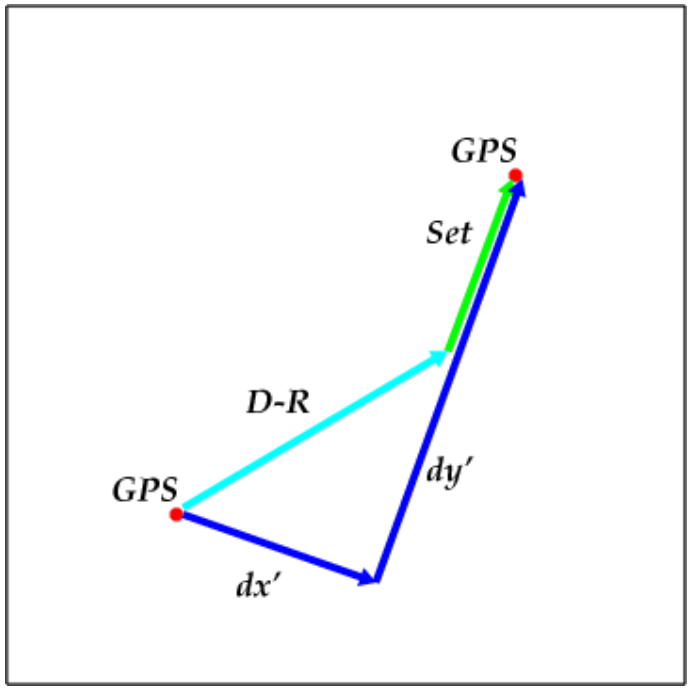
Glider Launch, Sept 04


Glider Sending Email, June 05



Glider Instrumentation for Gulf Stream

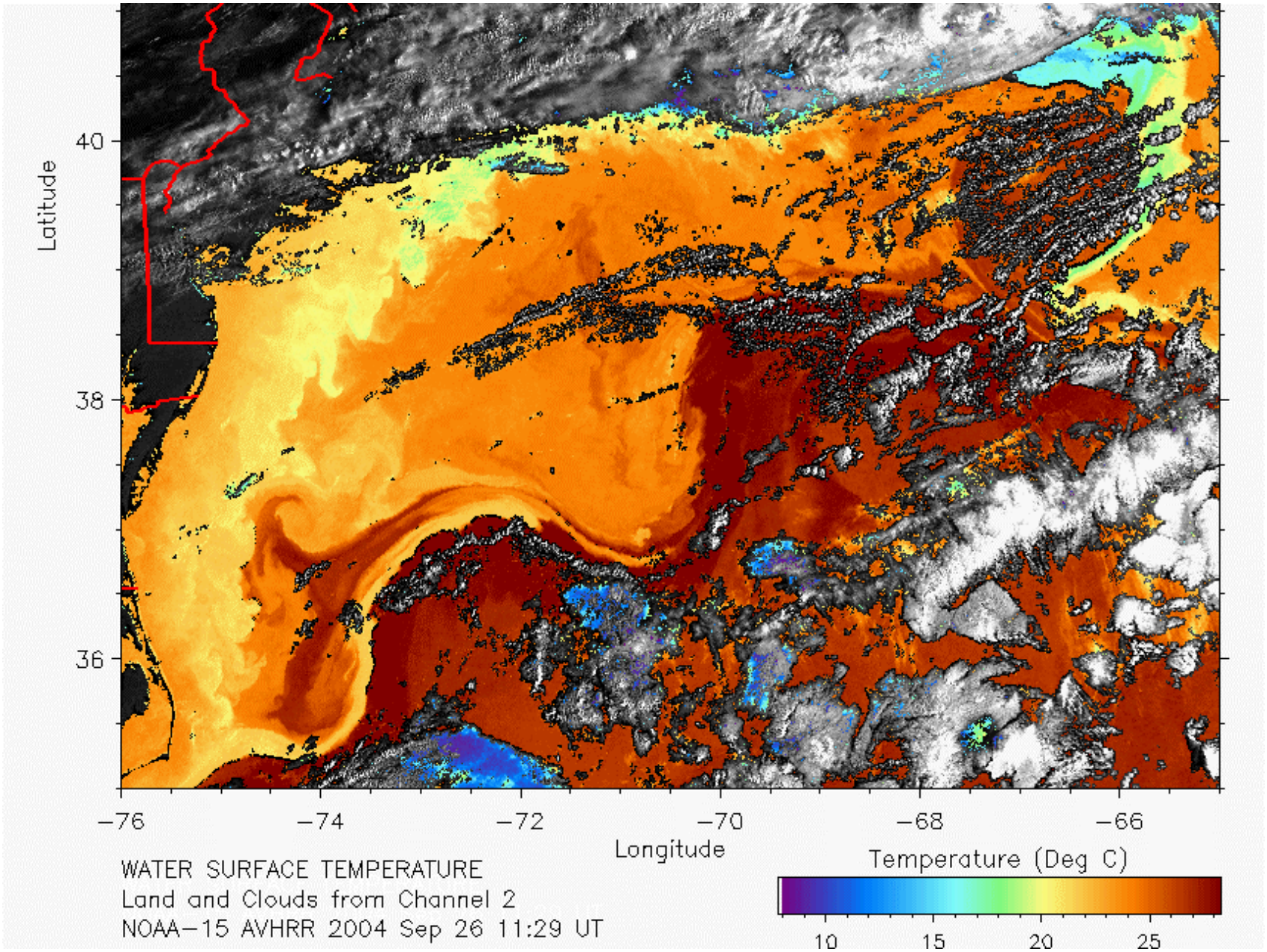
- CTD (including pump)
  20% of battery energy allocated to pumped CTD
- Optical Backscatter (measure of biomass)
- GPS at start and end of dive
- Dead-reckoning from direction and attitude
  with GPS gives depth integrated ocean current
- Iridium Satellite Phone modem to send and receive emails.
- Service Argos Transmitter for
  recovery and tracking if glider fails.



Problems for navigating to Bermuda

- Need additional data. Examples of analyses of satellite measures include:
  - JHU/APL Satellite AVHRR Sea Surface Temperature (SST)
  - NLOM (US Navy) based on Altimetry (sea surface height) + SST
  - Data Assimilation analysis (HYCOM)
- Glider moves at 0.25 m/s (0.5 kts) encountering 1 m/s (2 kts) depth averaged currents
  - Crossing the Gulf Stream = "Swimming out of Rip Current"
- Glider can encounter eddies and Gulf Stream Rings (very strong eddies) that have currents nearly as strong as the Gulf Stream. These are often not visible in SST images. They do seem to show up in altimetry analyses. These features can stall the glider (analogous to a foul current for a ship), so a similar strategy as for the Gulf Stream is required.
- Some significant guidance from a "pilot" ashore is required.

Image for 26 Sept 04



Glider Track 04

Initial boost SW from Warm Core Ring

Meander deepened faster than glider moved Southward

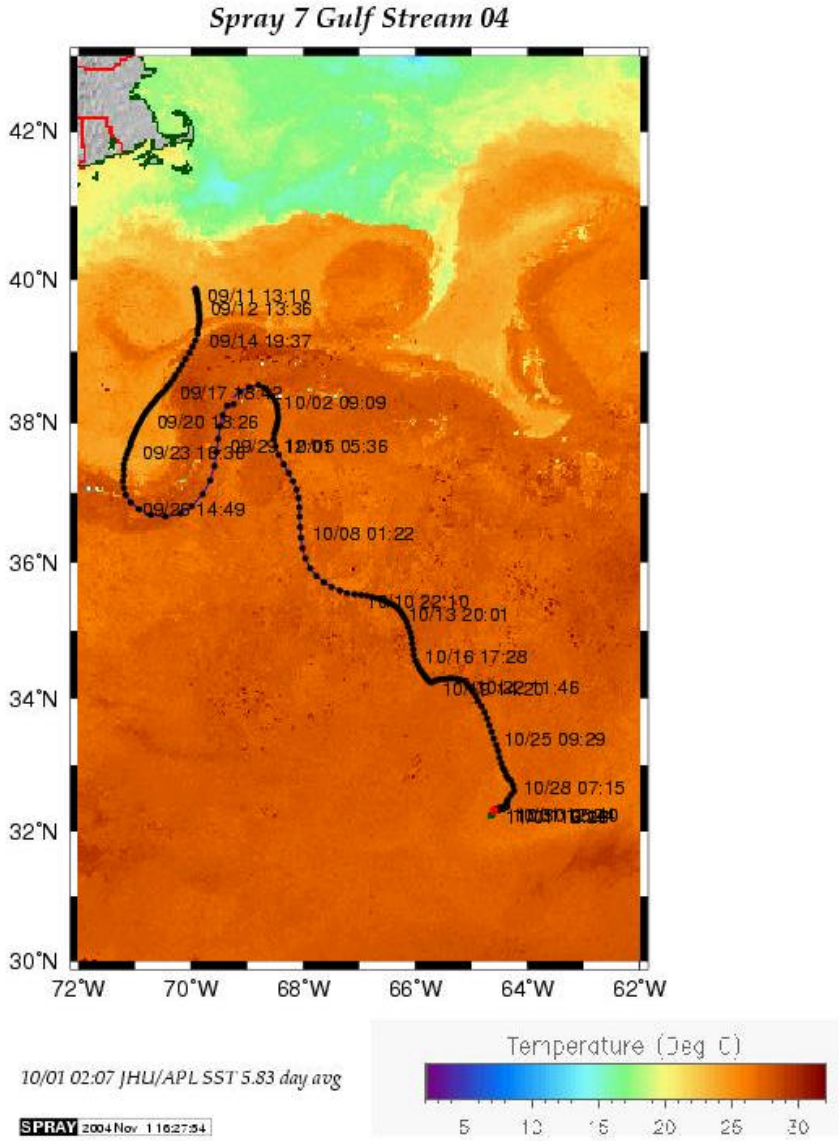
Crossed Gulf Stream, steering perpendicular to ocean set

Encountered strong ring and/or eddies south of Gulf Stream

Low pressure ridge extending N/S near Bermuda

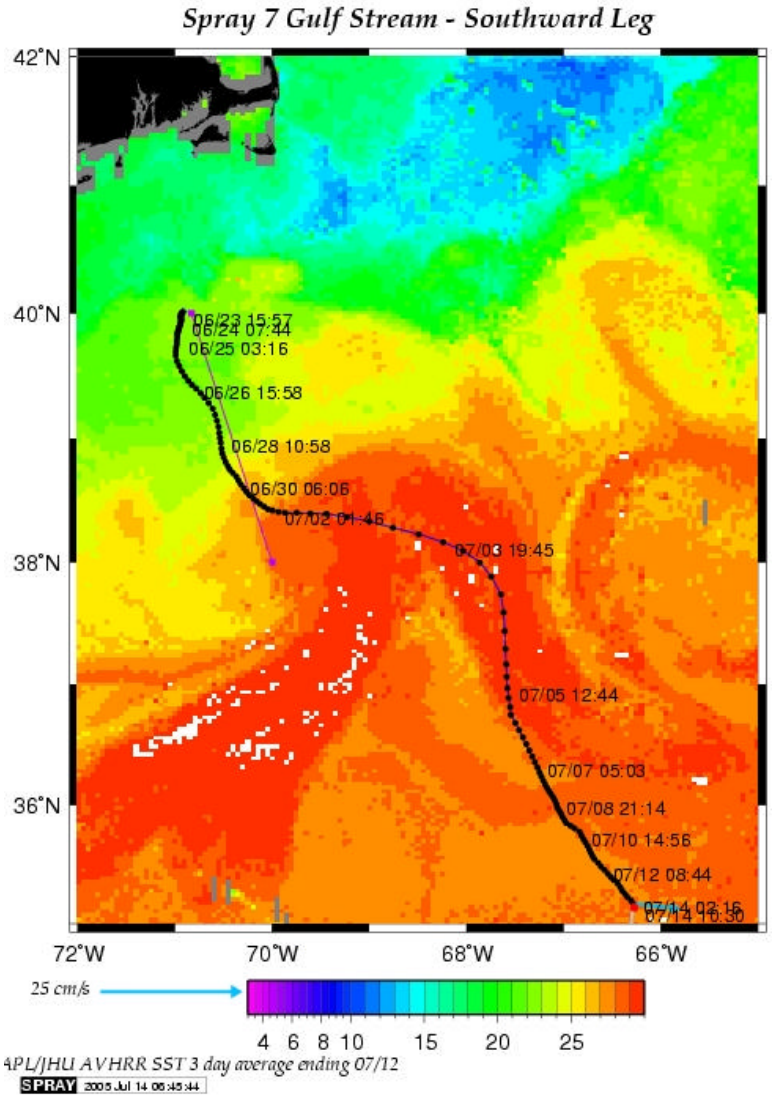
Lessons learned:

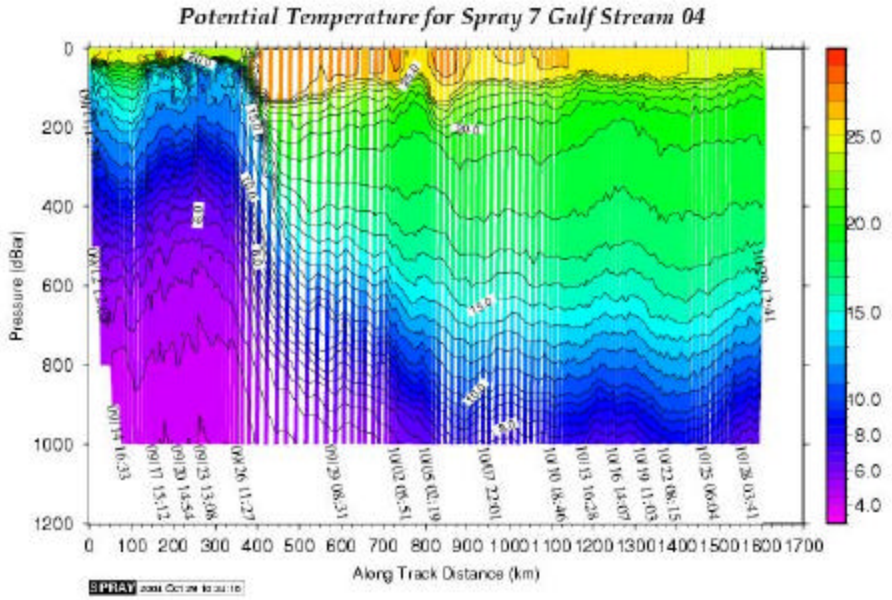
1. Get out of rings early, steer towards Gulf Stream
2. Automate steering across Gulf Stream
3. Navigation requires lots of attention

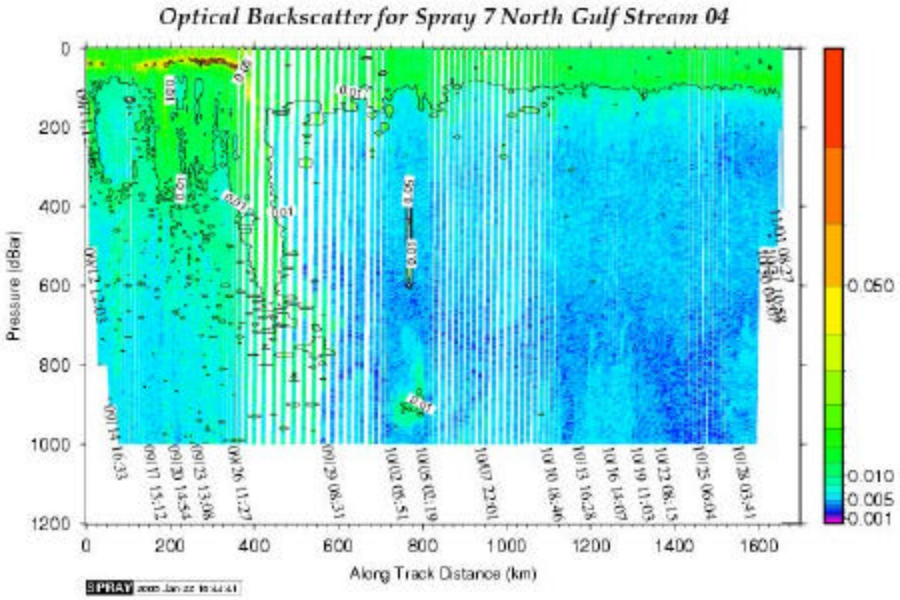


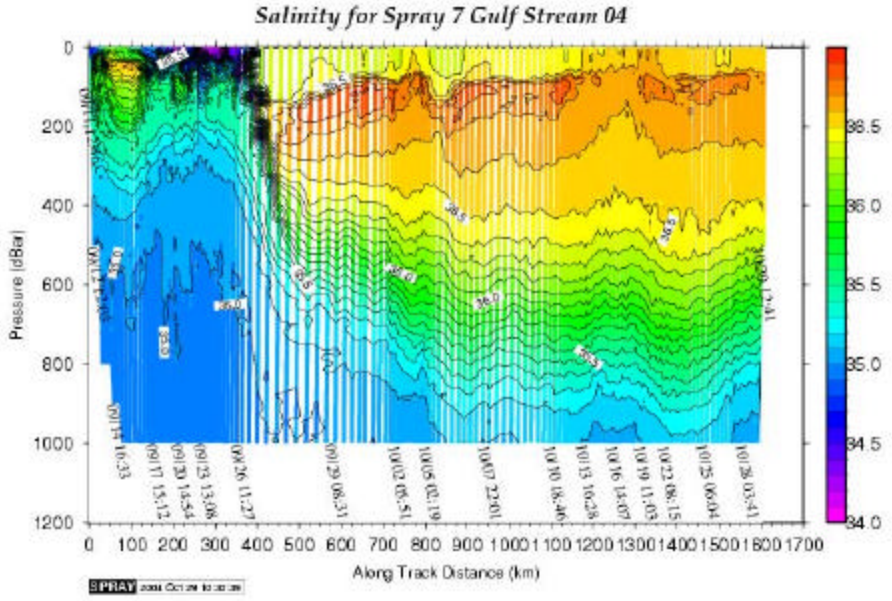
Glider Track 05

- Steered directly for Gulf Stream after launch
- Used automated command to find waypoint to steer across Gulf Stream
- Required significantly less communications with glider









- Colors are data points, apparent gaps are when the glider is moving rapidly in the Gulf Stream
- Strong Temperature and Salinity fronts associated with Gulf Stream
- Bio-mass suggested downwelling on north side of Gulf Stream. Alternate explanation for deep turbidity is sediment re-suspension between Florida Straits and Cape Hatteras. Signal seen in '04, '05, and '06.
- Salinity shows interleaving (mixing) along northern edge of Gulf Stream
- Isotherm displacements associated with strong eddies
- Resolution (5 km) higher than from ship-based sections.

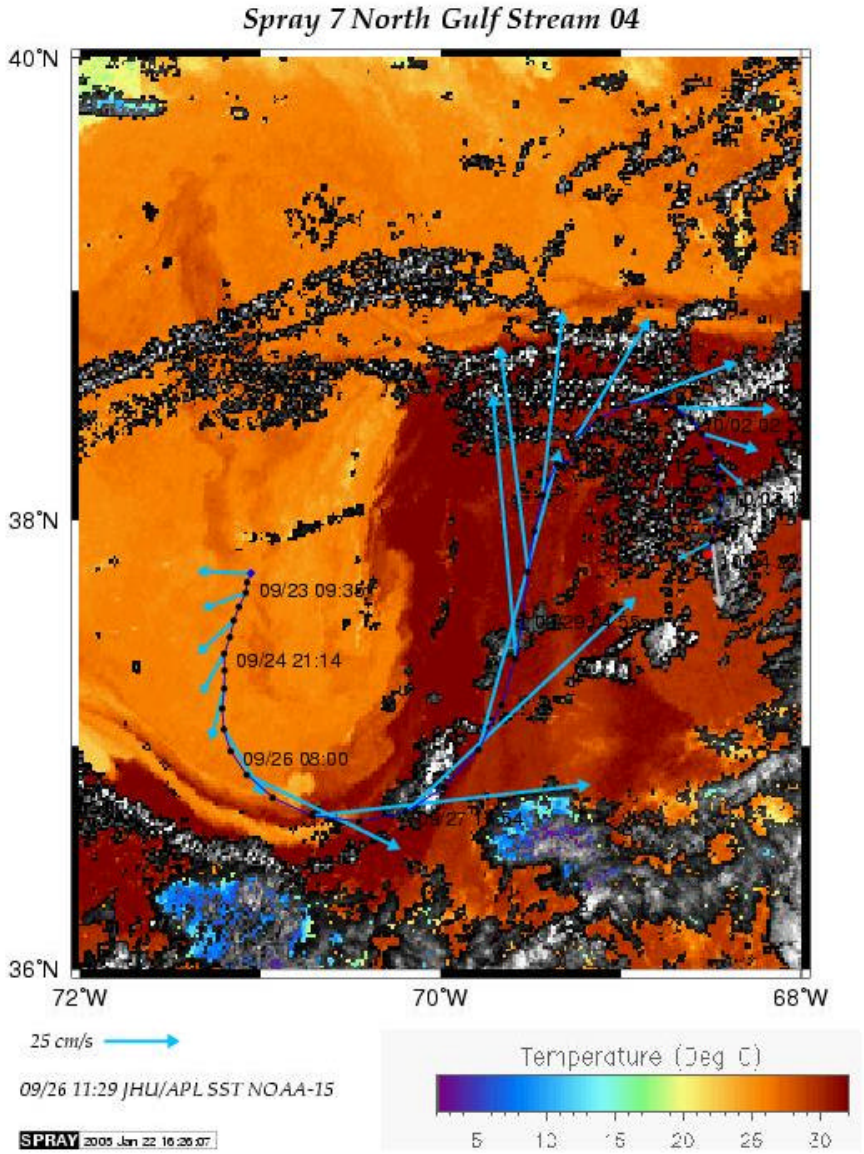
Data for Dives 50-90, approach to and crossing of Gulf Stream

Current initially to west, probably helps explain deepening of trough

Gulf Stream 0-1000 m average velocities aligned with SST

Peak Gulf Stream velocity > 1 m/s

Had to update waypoint every 7 hours to cross Gulf Stream. Updated waypoint sent before receiving most recent data. Have to predict next dive positions to give waypoint. New code includes instruction to steer at prescribed direction relative to apparent ocean set.



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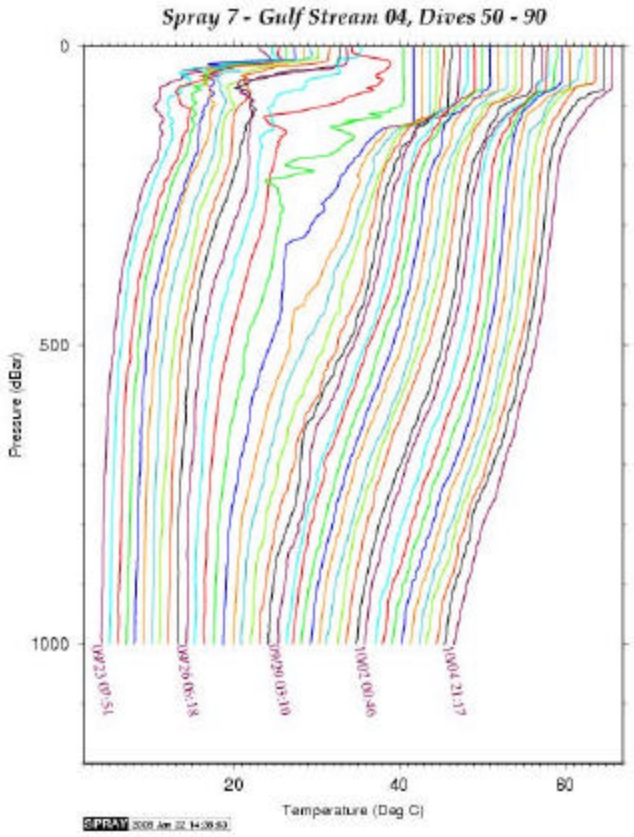

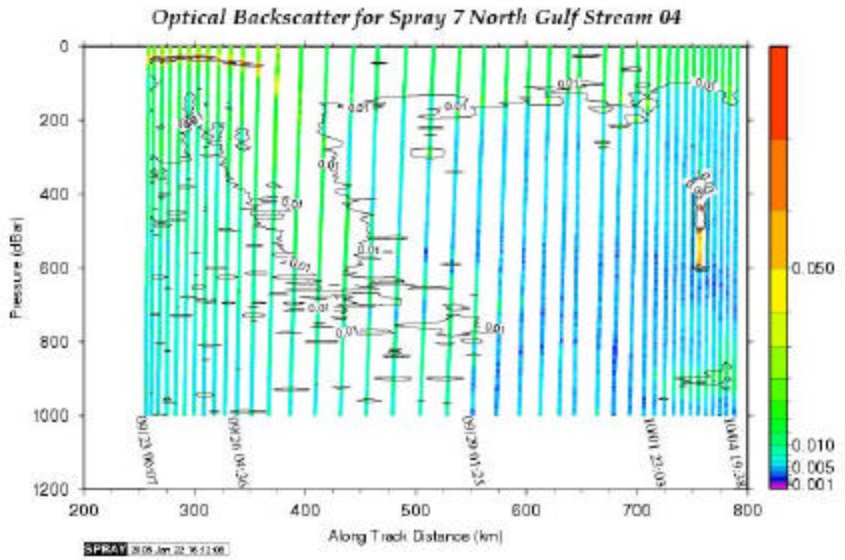

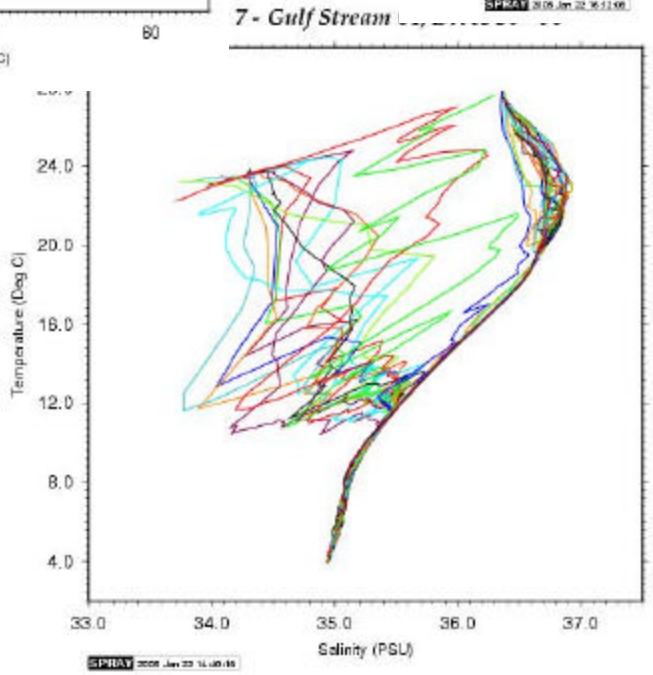

Strong interleaving suggesting significant mixing just north of the North Wall of the Gulf Stream.

Biomass suggests deep mixing at northern section of Gulf Stream. How does this happen?
-convergence due to wind stress (Ekman layers)?
- downwelling associated with meandering?
Alternatively, deep sediment re-suspension.

Conclusions

- Glider and float successes due to strong collaboration with world class scientists and engineers.
- Both instruments are now providing interesting new scientific results.
- Floats provide global coverage of upper 2000 m of ocean. Argo array is approaching designed 3000 array and global coverage.
- Gliders are now operational. Can operate for ~6 months and can remain in regions of strong currents. Gliders are now being operated by a number of research groups rather just by the original developers. They can be launched and recovered from any sized ship.

- Future developments:
  - Plans to integrate new sensors into both platforms:
    O2 sensors
    velocity
      - Electro-magnetic for floats
      - Doppler velocity for gliders
    More optical sensors
      - Chlorophyll A & CDOM
  - Need for more low-powered sensors.
  - Improved high latitude operations for both floats and gliders.

For more details on Spray in the Gulf Stream see Oceanus article:

http://www.whoi.edu/oceanus/index.do and search for: A glide across Gulf stream

For more details on how the glider works see:

http://www.whoi.edu/instruments/sprayglider

R/V Henry M. Stommel