Communications relay and autonomous tracking applications for Wave Glider

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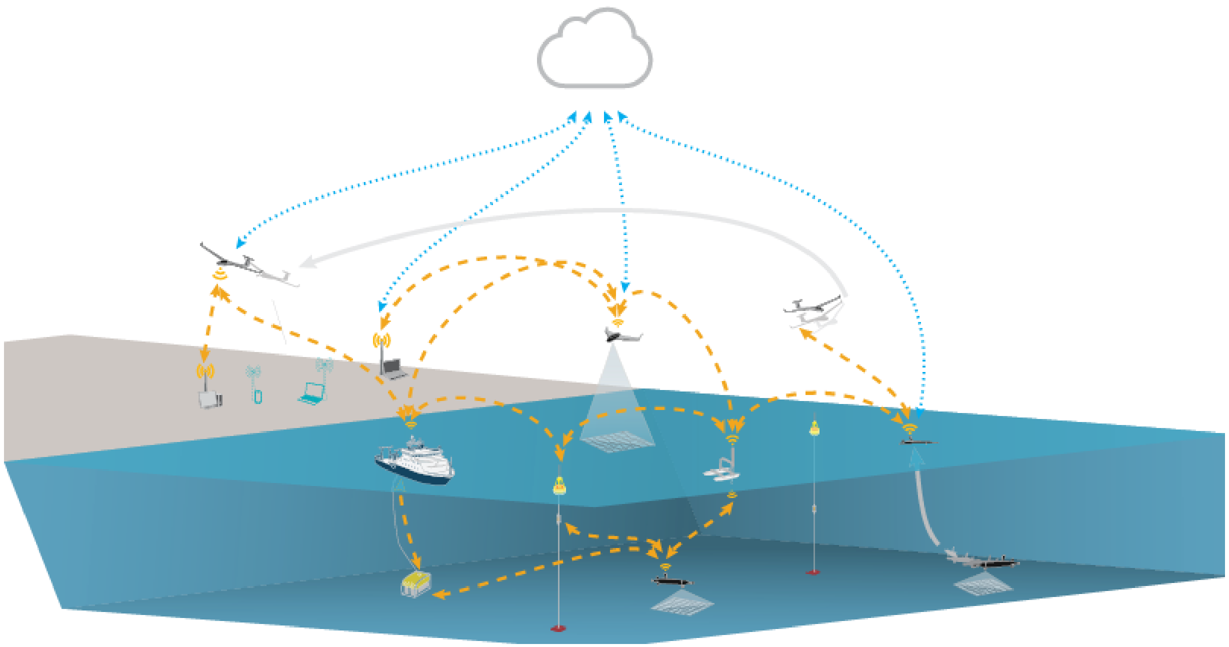
Hot Spot Wave Glider

- Communications relay: Relay data between autonomous sensor platforms, ships, shore
- Acoustics: Localize and track underwater targets

Hot Spot Wave Glider



lsts.fe.up.pt

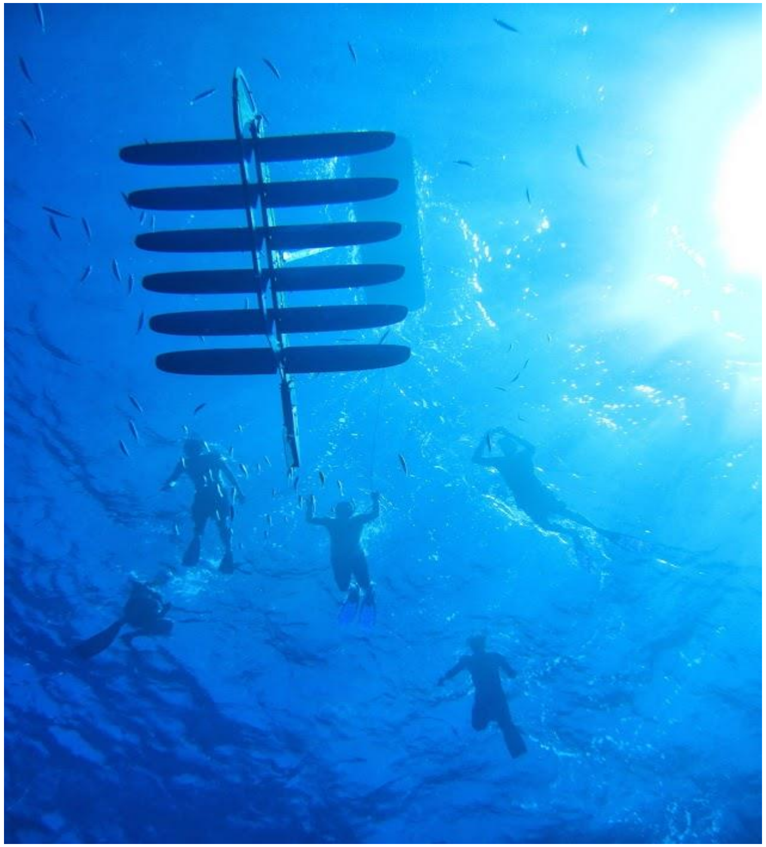
- Inspired by work of Rajan, Borges de Sousa, Pinto, Martins et al (University of Porto LSTS)

Hot Spot Wave Glider
Goals

- Support MBARI's science division (biology, geology...)
  - Operational asset, not experimental platform
- Near real-time high-resolution data retrieval
- Lower ship time, dollar and opportunity costs
- Rapid, low-cost development

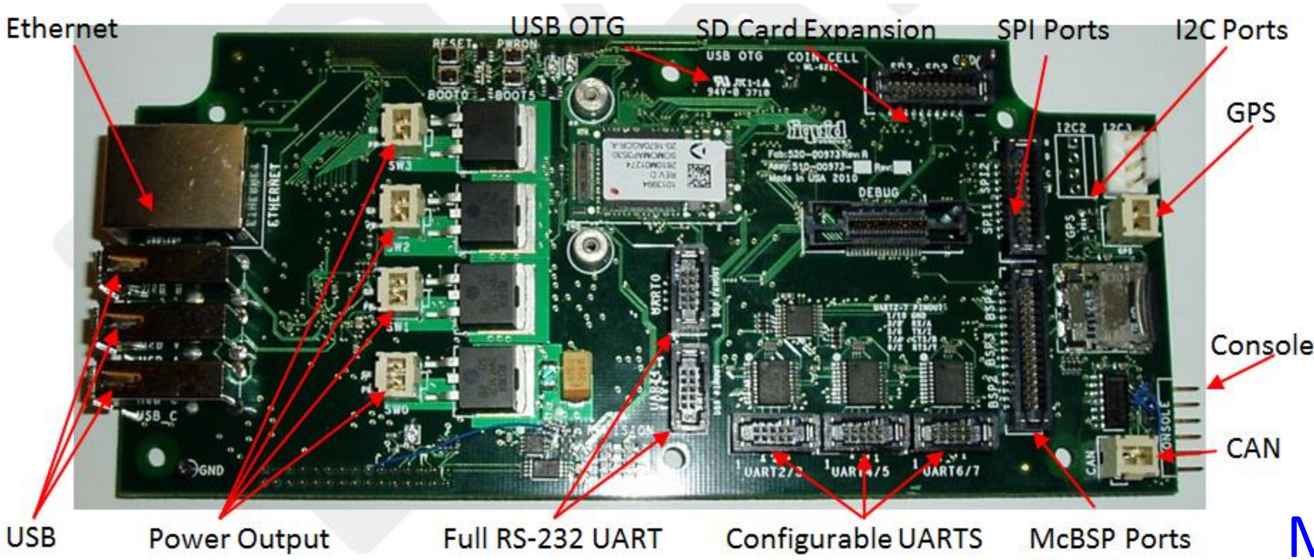
Wave Glider

- Very reliable, long-duration (months), autonomous
- Cheap to operate
- Frees ships for other tasks
- Users develop custom applications and payloads



Hot Spot runs on Wave Glider *Sensor Management Computer*

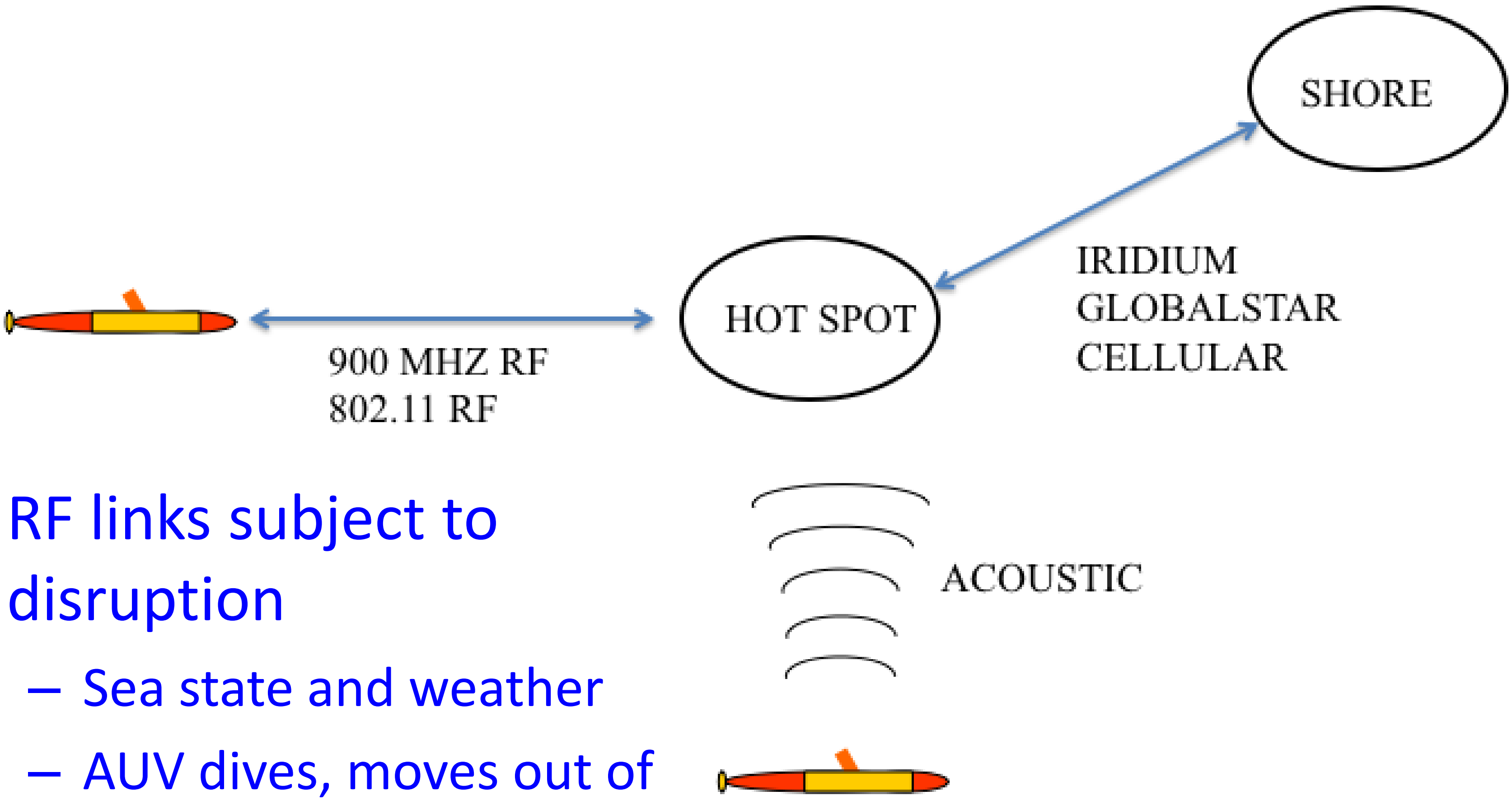
- ARM processor
- Multiple serial ports for radios, modems
- Linux OS: standard tools include Java, Python, bash, etc.
- Interface to main vehicle computer



Main vehicle computer

I. Communications relay

Hot Spot network

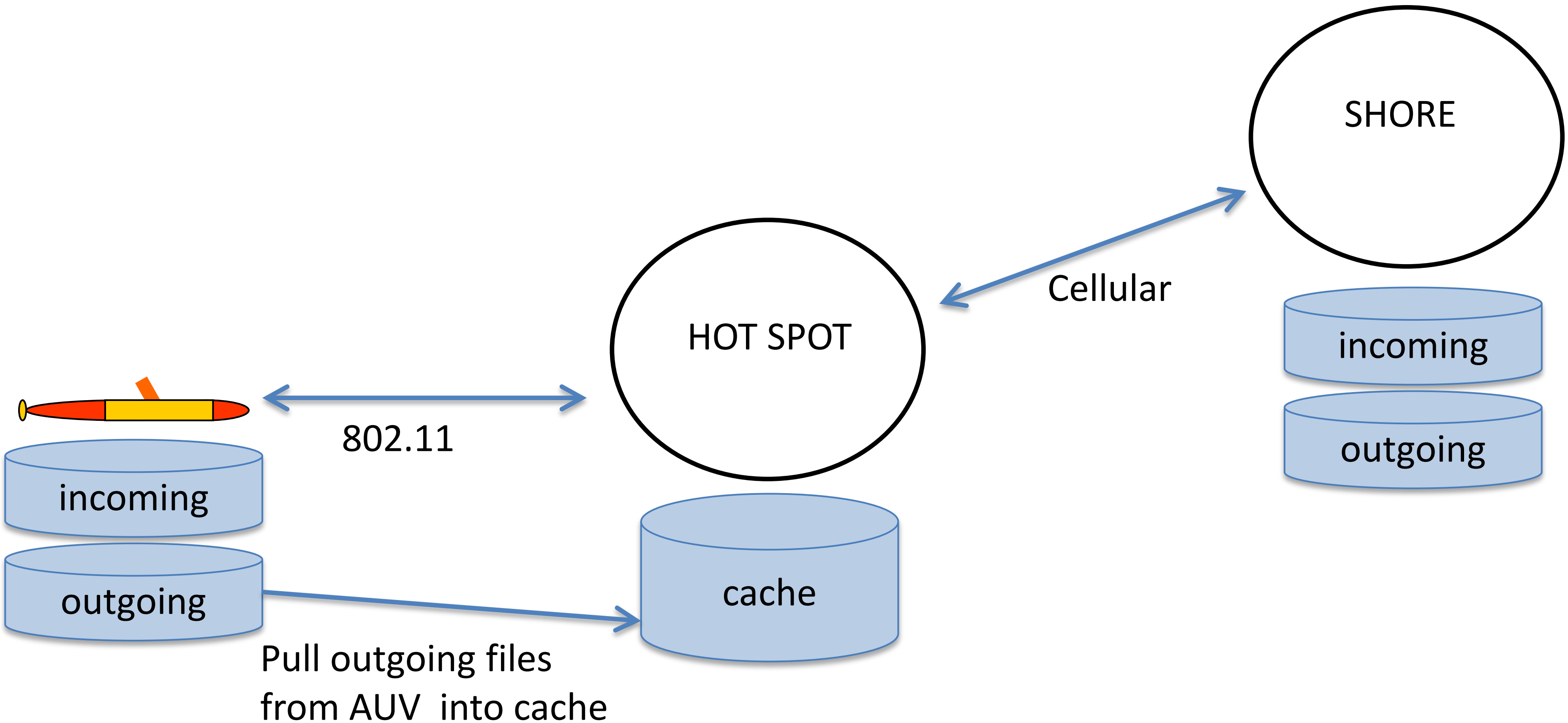


- RF links subject to disruption
  - Sea state and weather
  - AUV dives, moves out of range
  - Satellite/cell availability

Disruption tolerance

- rsync file-transfer protocol
  – It's everywhere; very robust implementations
  – Very efficient "delta-transfer" algorithm
  – Disruption-tolerant; transfer resumes where it left off
  – Requires TCP/IP link

Hot Spot store-and-forward exchange using *rsync*



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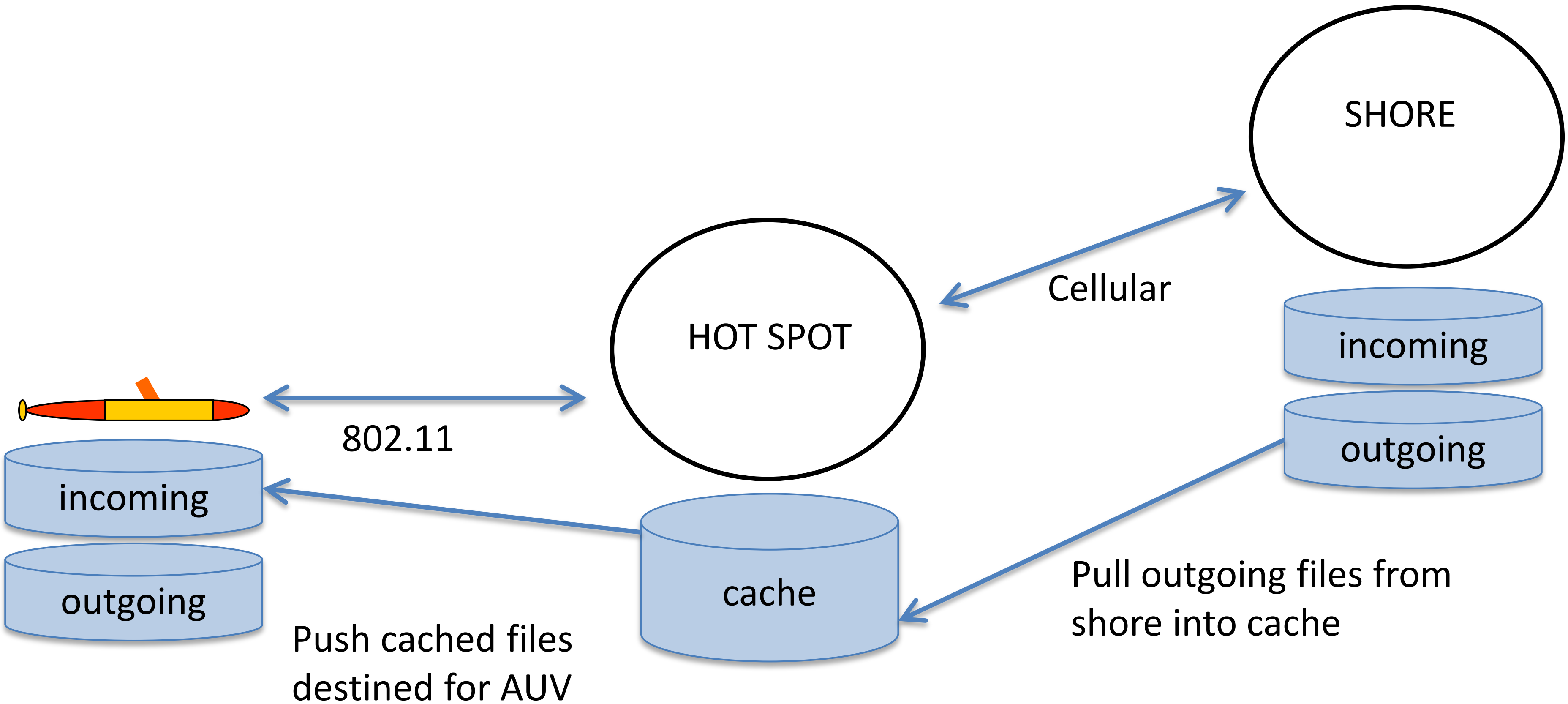
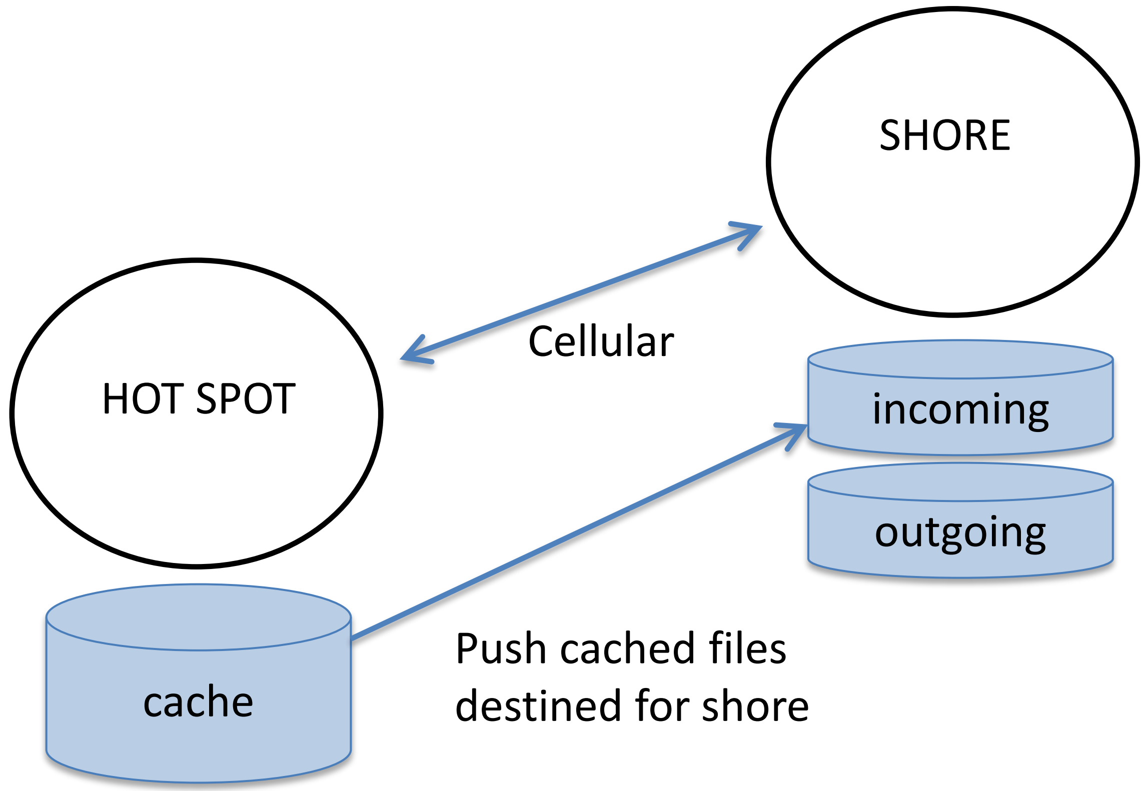


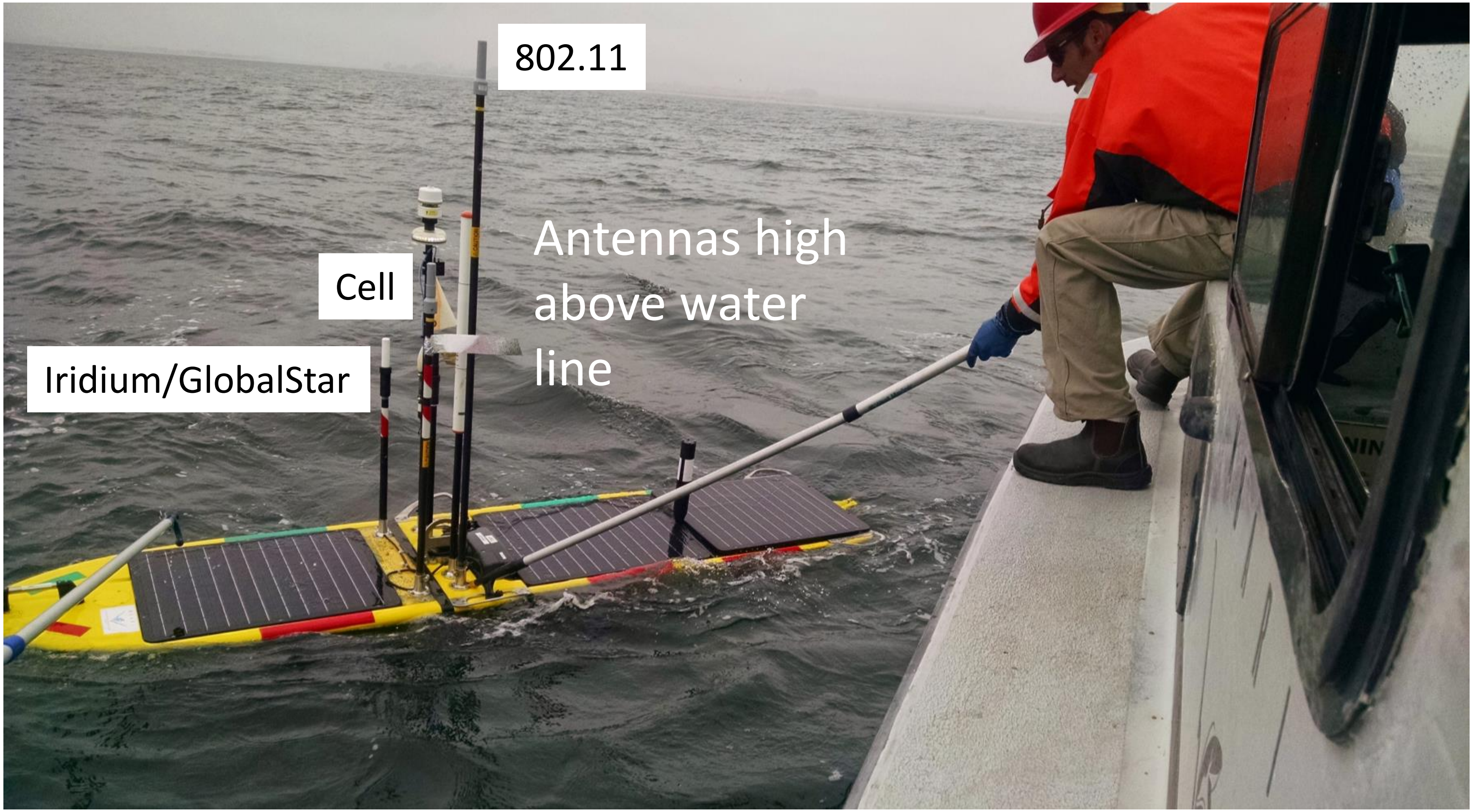
Hot Spot store-and-forward exchange using *rsync*



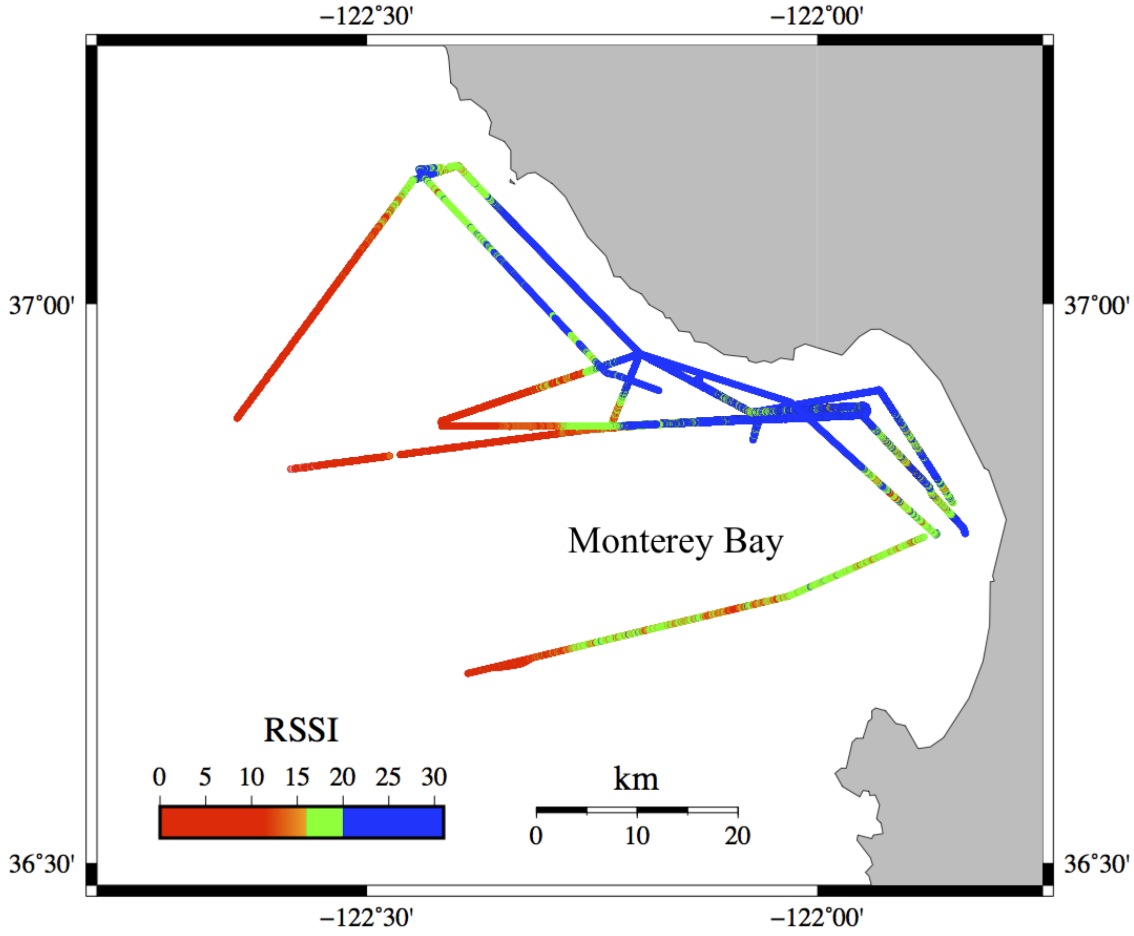
Hot Spot radios

- Line-of-sight to AUV
  - 802.11 Wifi (Ubiquiti)
  - 900 MHz (Freewave)
- Link to shore
  - Cell modem (coastal regions)
  - Globalstar satellite (coastal, some open ocean)
  - Iridium satellite (world-wide)
- Radio links support TCP/IP
- "Console" to Hot Spot from shore

Hot Spot antennas

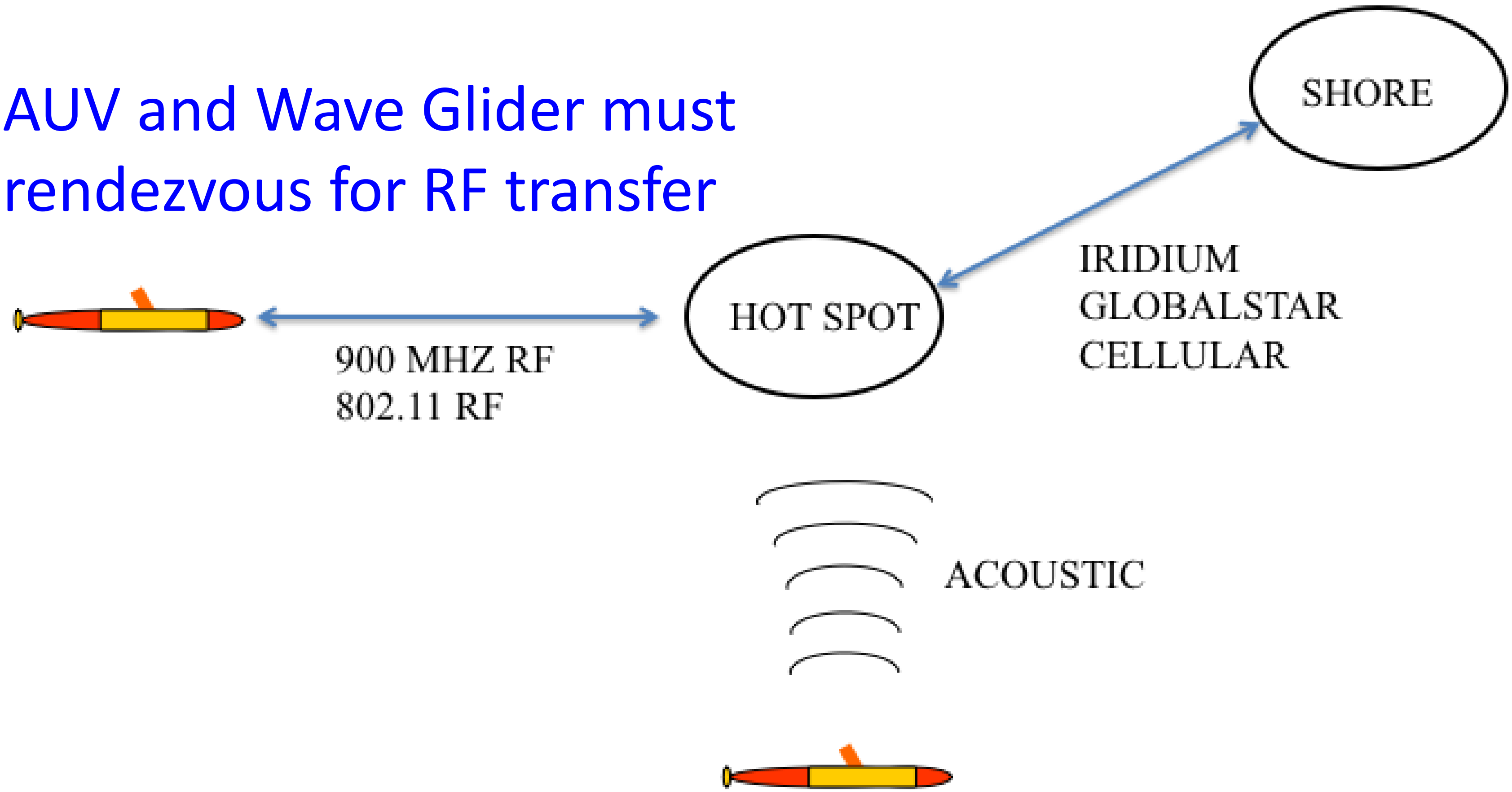


Cell signal strength at Hot Spot

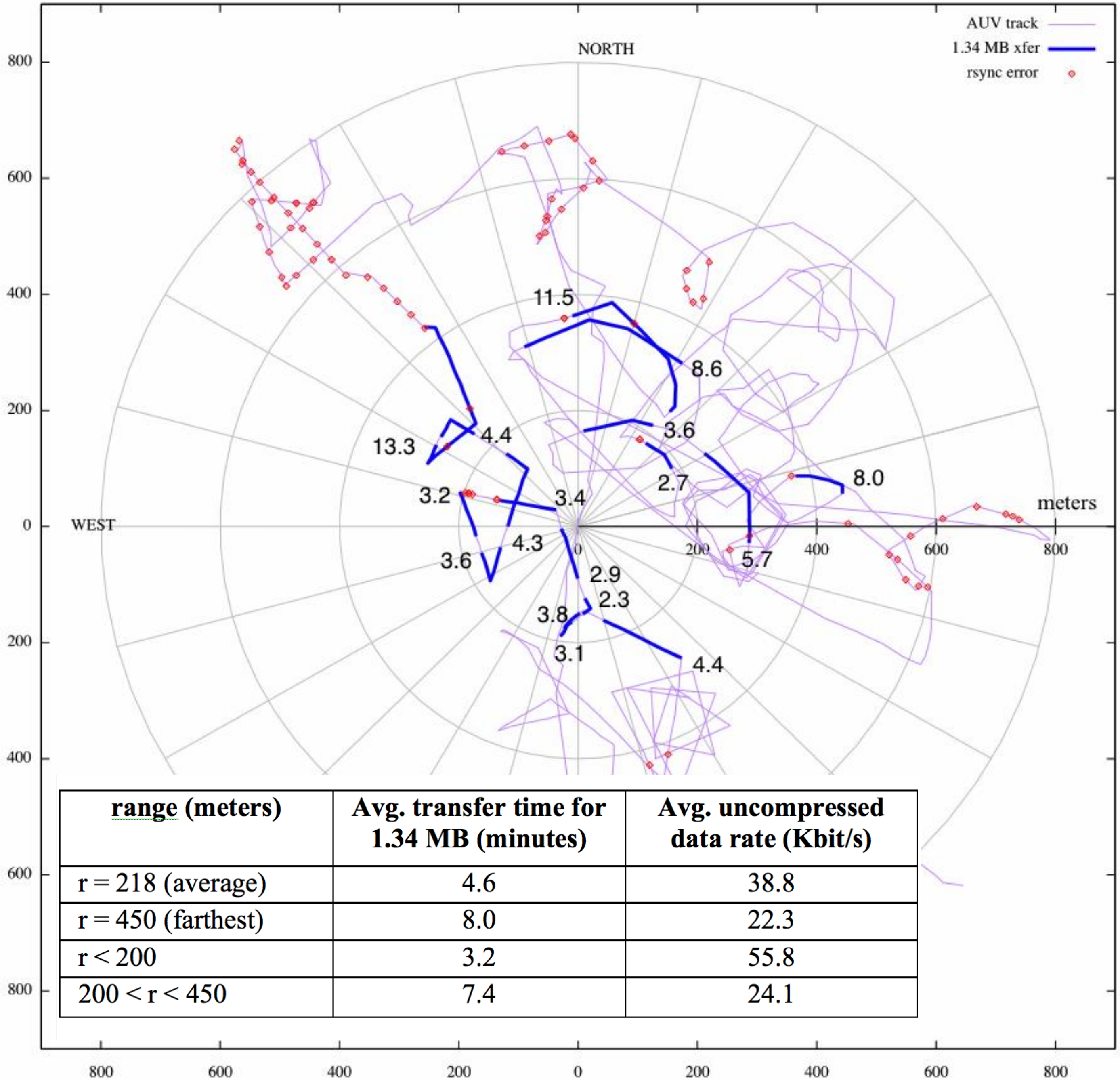


Hot Spot network

- AUV and Wave Glider must rendezvous for RF transfer



File transfers via *rsync* from AUV to Wave Glider over 900 MHz radio



range (meters)	Avg. transfer time for 1.34 MB (minutes)	Avg. uncompressed data rate (Kbit/s)
r = 218 (average)	4.6	38.8
r = 450 (farthest)	8.0	22.3
r < 200	3.2	55.8
200 < r < 450	7.4	24.1

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Cost to transfer 13.4 MB AUV data per day

	AUV-Iridium	AUV-HotSpot-cell	AUV-Hotspot-Globalstar
Total AUV surface time	5.0 hours	46 minutes	46 minutes
Hot Spot operational cost	N.A.	$100	$100
Airtime cost	$380	$1	$13
Total cost	$380	$101	$113

Hot Spot relay applications

- Coordinated ops between MBARI *Dorado* + LSTS *Xtreme-2* AUVs + ecogenomic sensor in Monterey Bay
  - Max 739 meters wifi range
  - Avg 15 Kbit/sec on wifi-cell
  - Avg 102 Kbyte file size
  - Avg 119 sec xfer

LSTS Porto *Xtreme-2* AUV

- *Long Range AUV* in S. California, harmful algal bloom development
  - Relayed 53 MB of AUV data to shore over eight days
  - Troubleshot AUV at sea through Hot Spot console

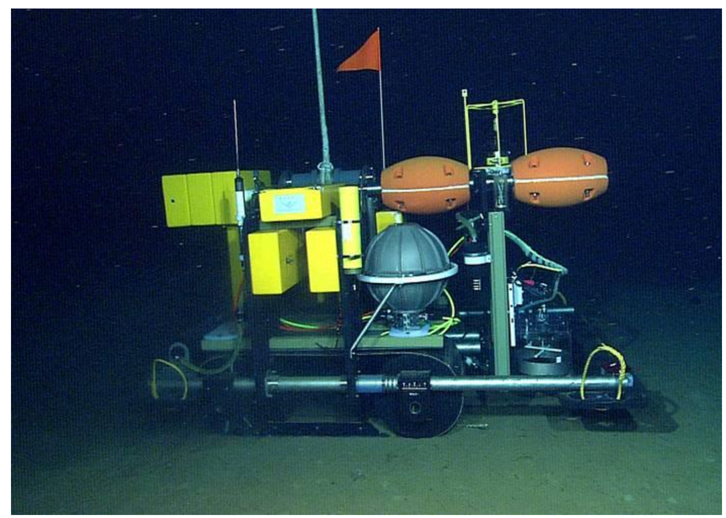
II. Acoustic Hot Spot applications

- Directional Acoustic Transponder (DAT) mounted on WG skeg
  - Gives target range, bearing, elevation
- Target (e.g. AUV) carries acoustic modem or DAT

Acoustic Hot Spot applications

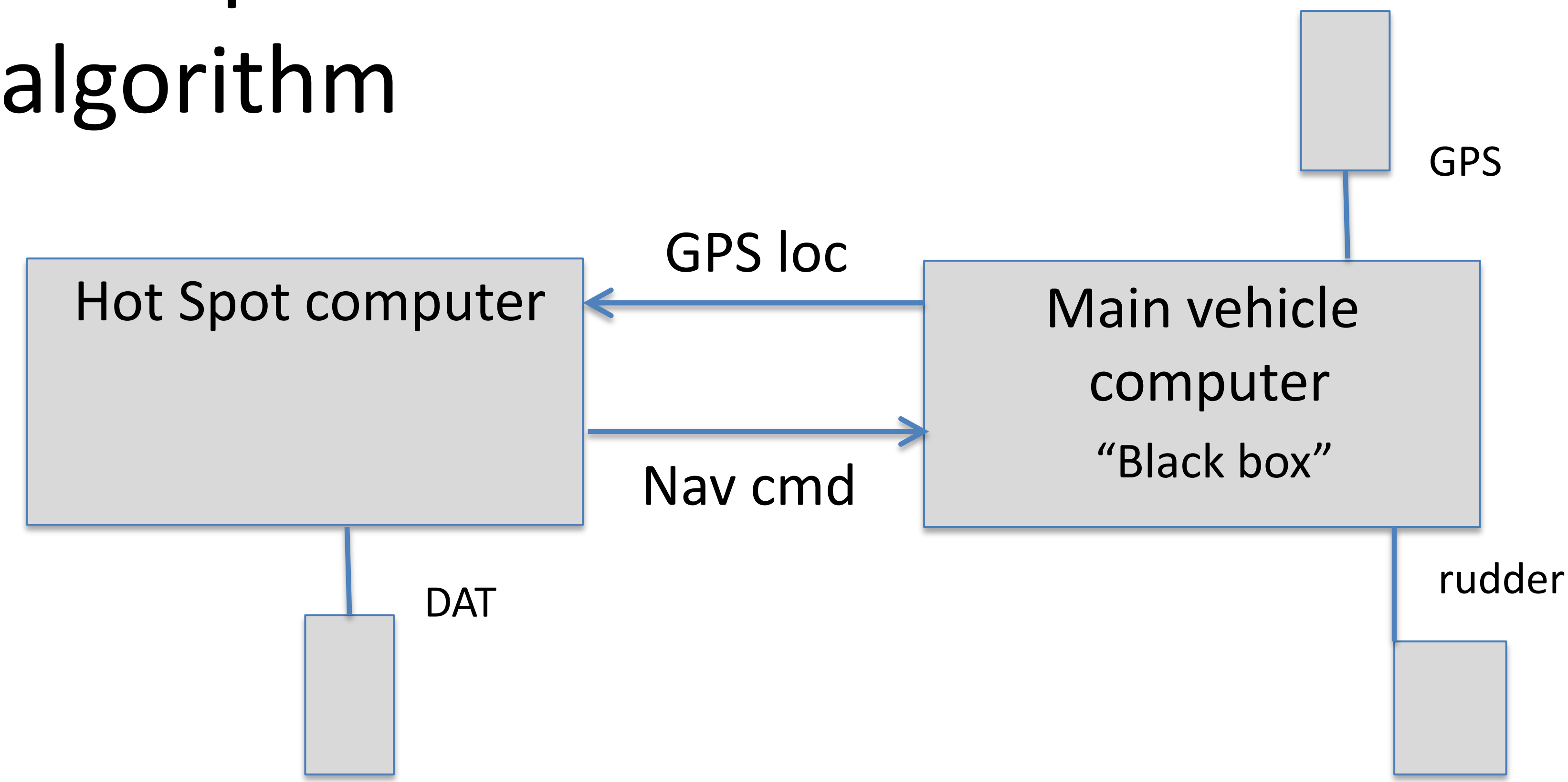
- WG chases submerged AUV
- WG homes on, hovers over stationary target (e.g. benthic rover)
- AUV homes on WG (e.g. for data transfer)

Long Range AUV (LRAUV)



Benthic Rover

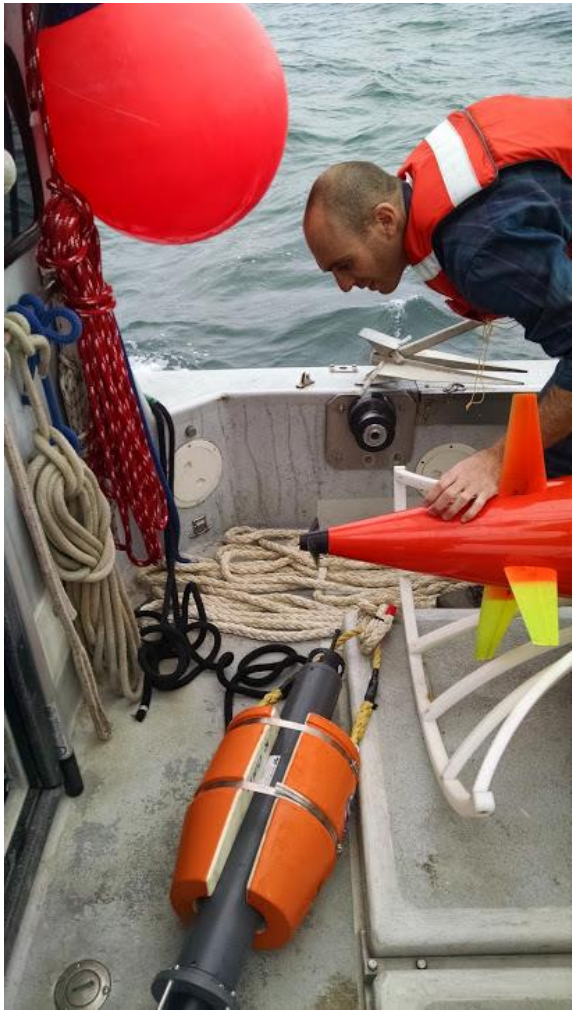
Hot Spot "chase" algorithm



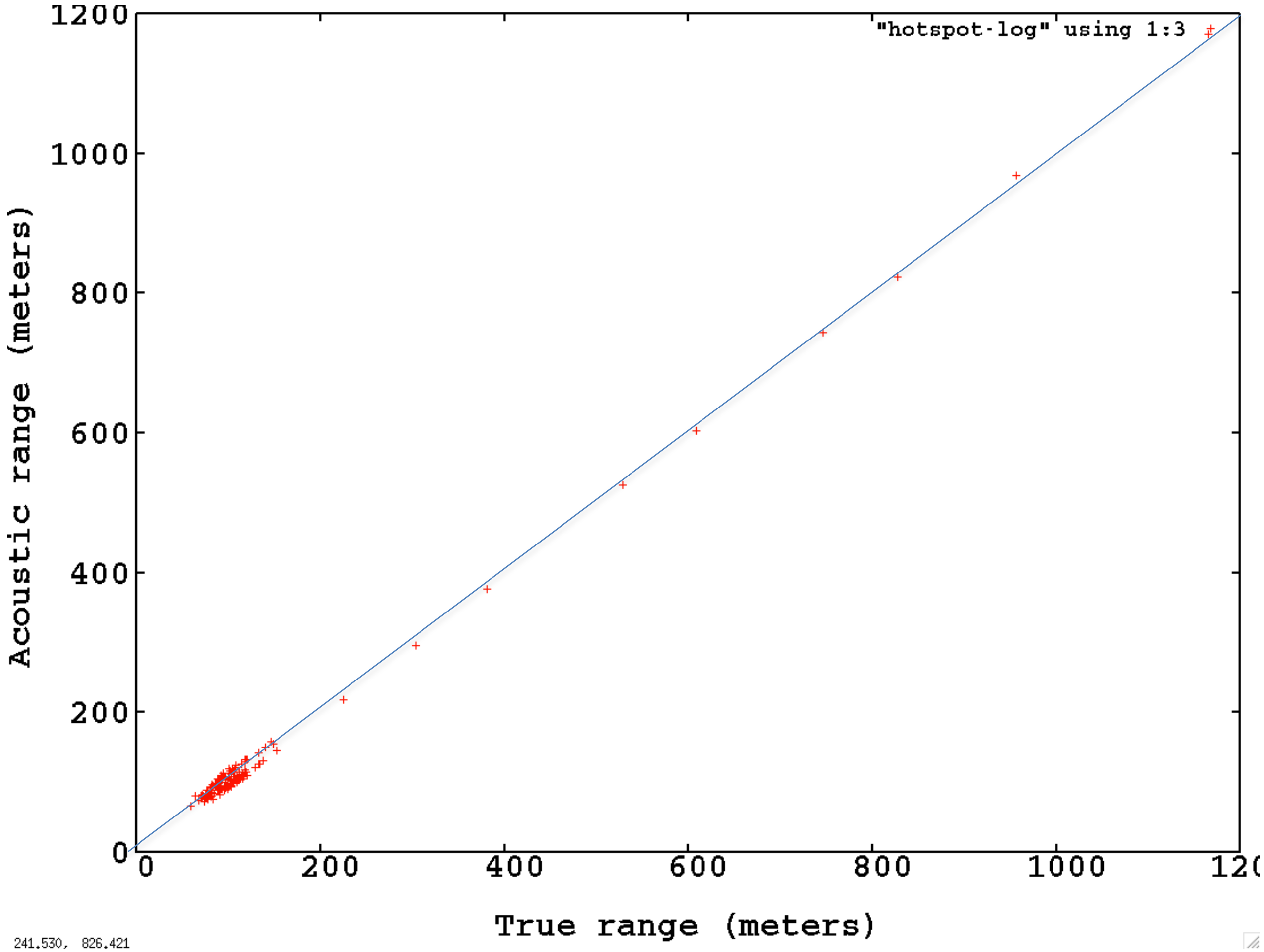
1. Get target bearing/range/elev from DAT
2. Compute target lat/lon
3. If target location is "safe", command vehicle to circle target
4. Repeat every n seconds

Target practice

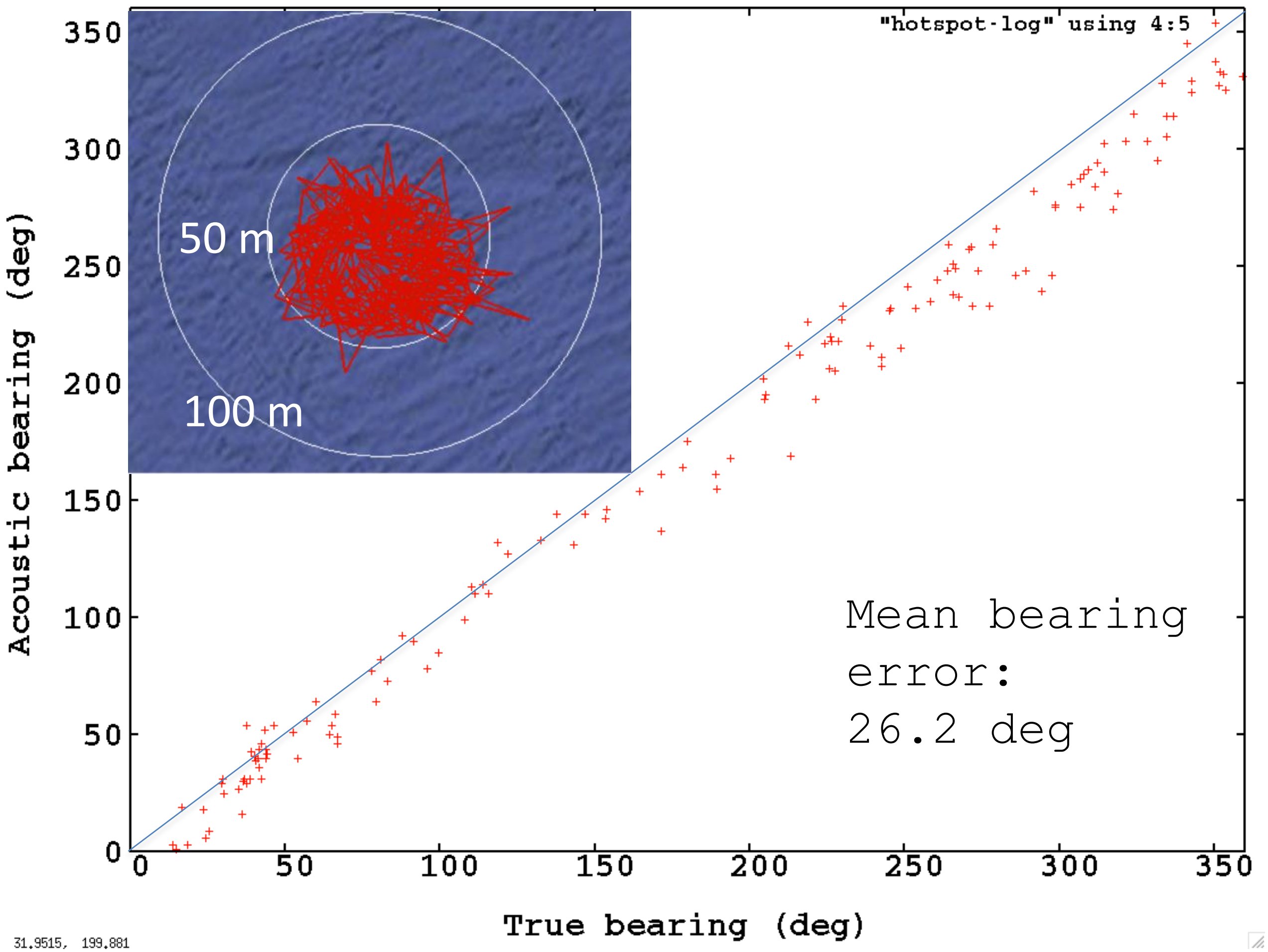
- Moored acoustic modem 10m above sea floor, water depth 50m, known lat/lon
- Wave Glider Hot Spot “chases” modem, circle r=100 m
- Compare computed target location to actual



Acoustic vs true range to stationary target



Acoustic vs true bearing to stationary target



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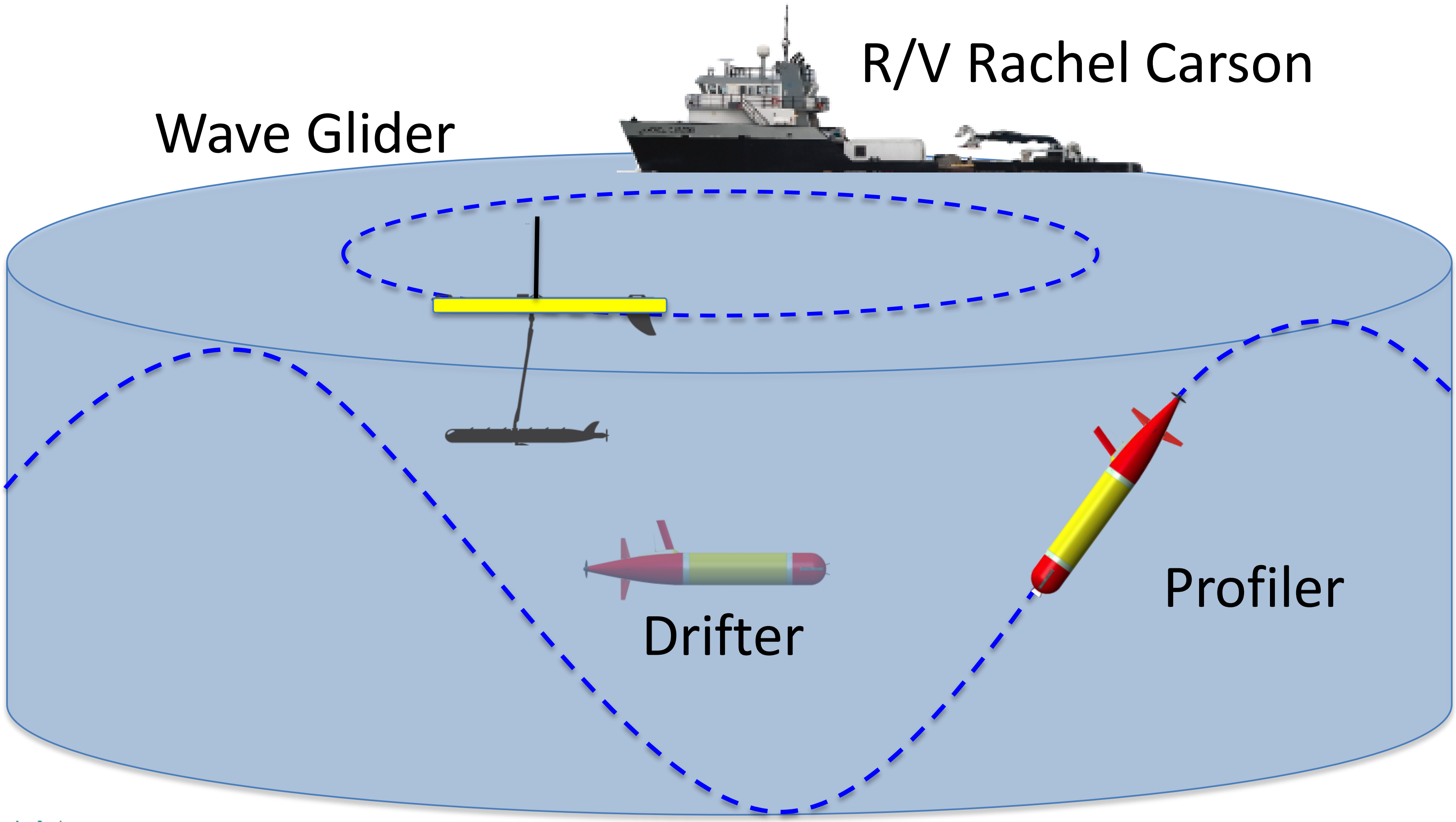
Remineralization during phytoplankton bloom

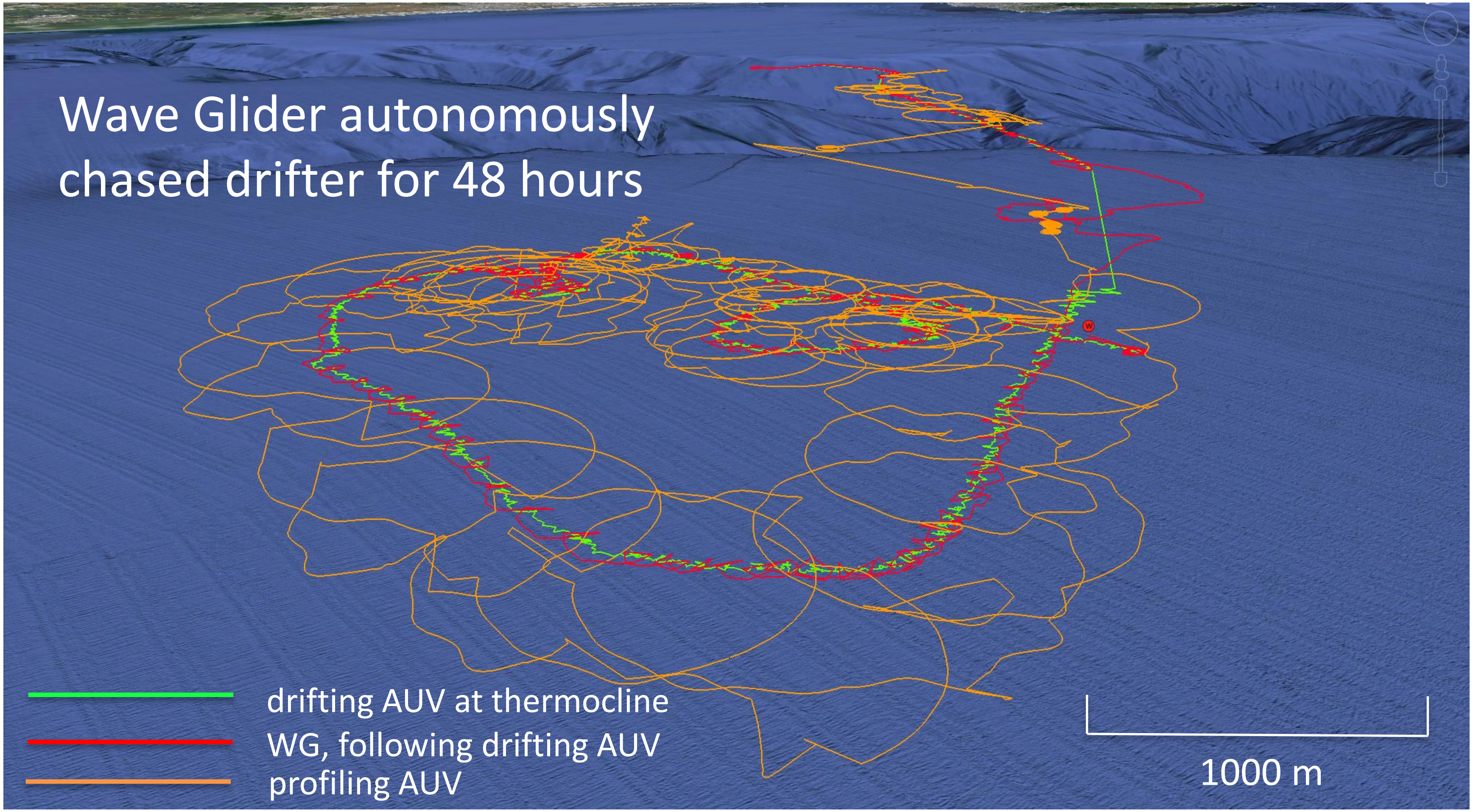
- Characterize chemistry/biology within *drifting* water mass, esp. near thermocline
- Continuously analyze water mass *in situ* with sensors on Wave Glider and AUVs
- Visit water mass with crewed ship each day, collect water samples for lab analysis
- Sample in *Lagrangian* frame

Long Range AUV (LRAUV)

Chase application: Lagrangian drift sampling



Lagrangian drift sampling: October 2014



Conclusions

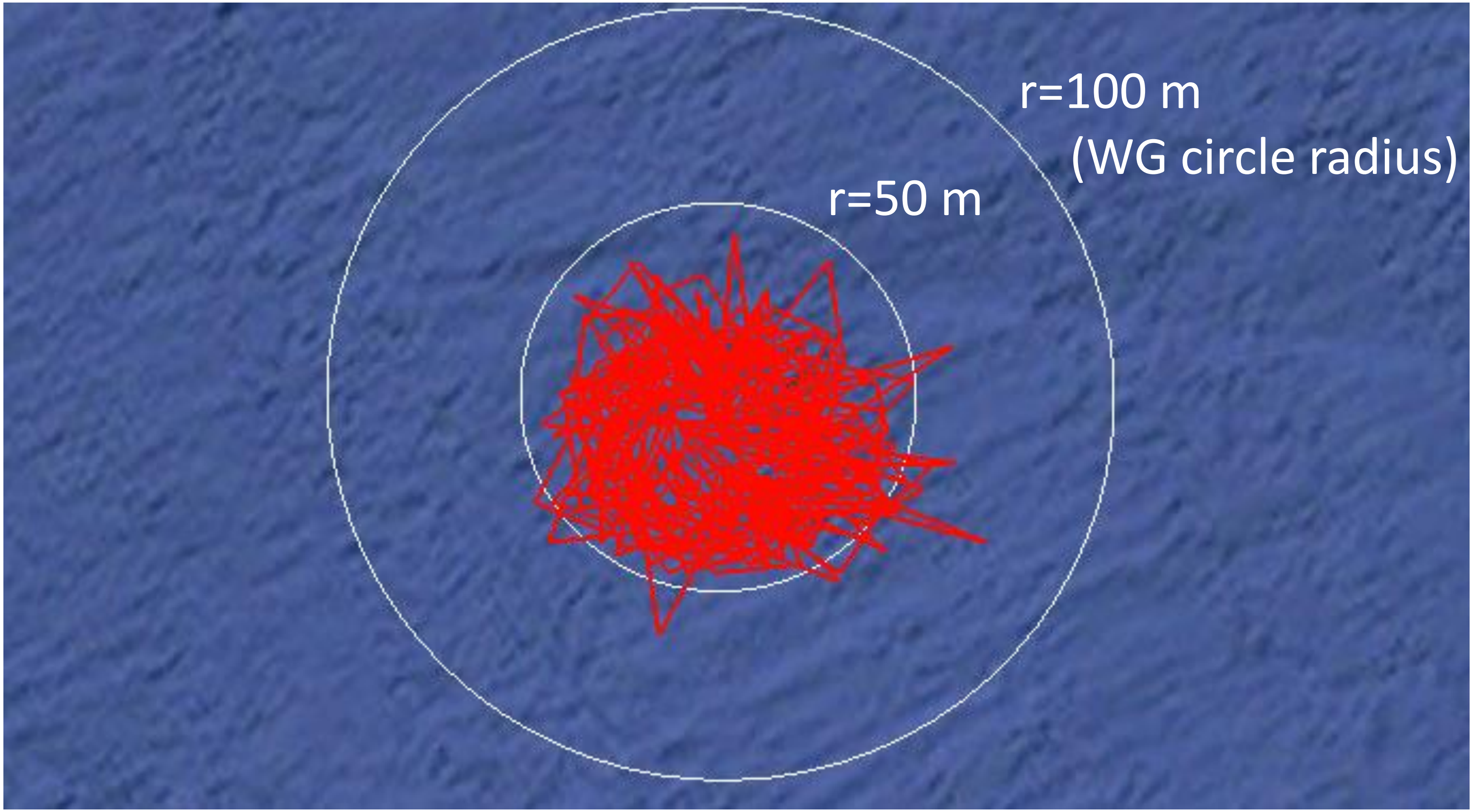
- AUV-Hot Spot file transfer at 10s Kbps at 100s of meters range
- Significant dollar savings (~1/3) and surface time savings (~1/5) over AUV-Iridium
- Autonomously track moving underwater targets within 10s of meters for days
- Wave Glider infrastructure leveraged for these applications

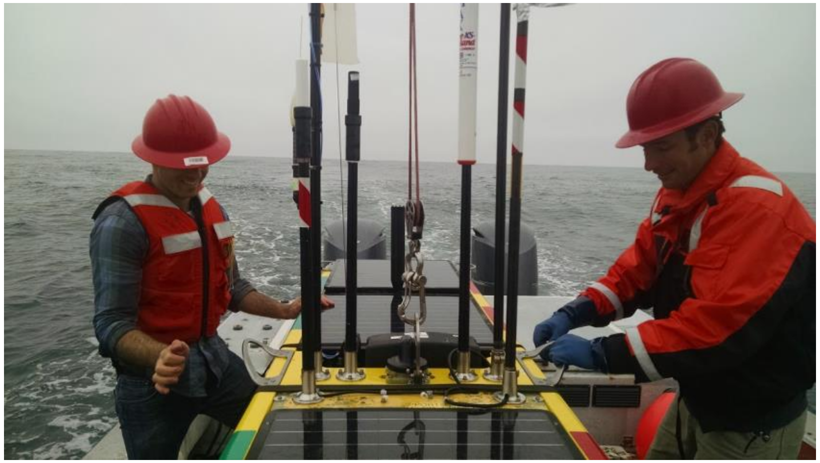
Acknowledgements

- University of Porto: Kanna Rajan, Joao Borges de Sousa, Ricardo Martins, Jose Pinto, Renato Caldas, Pedro Calado, Hugo Dias
- MBARI: Thom Maughan, Fred Py, Brett Hobson, M Jordan Stanway, Francisco Chavez, John Ryan, Kevin Gomes, Hans Thomas
- Liquid Robotics: Mike Cookson, Ryan Carlon
- The David and Lucile Packard Foundation

End

Computed coordinates of "chased" stationary target

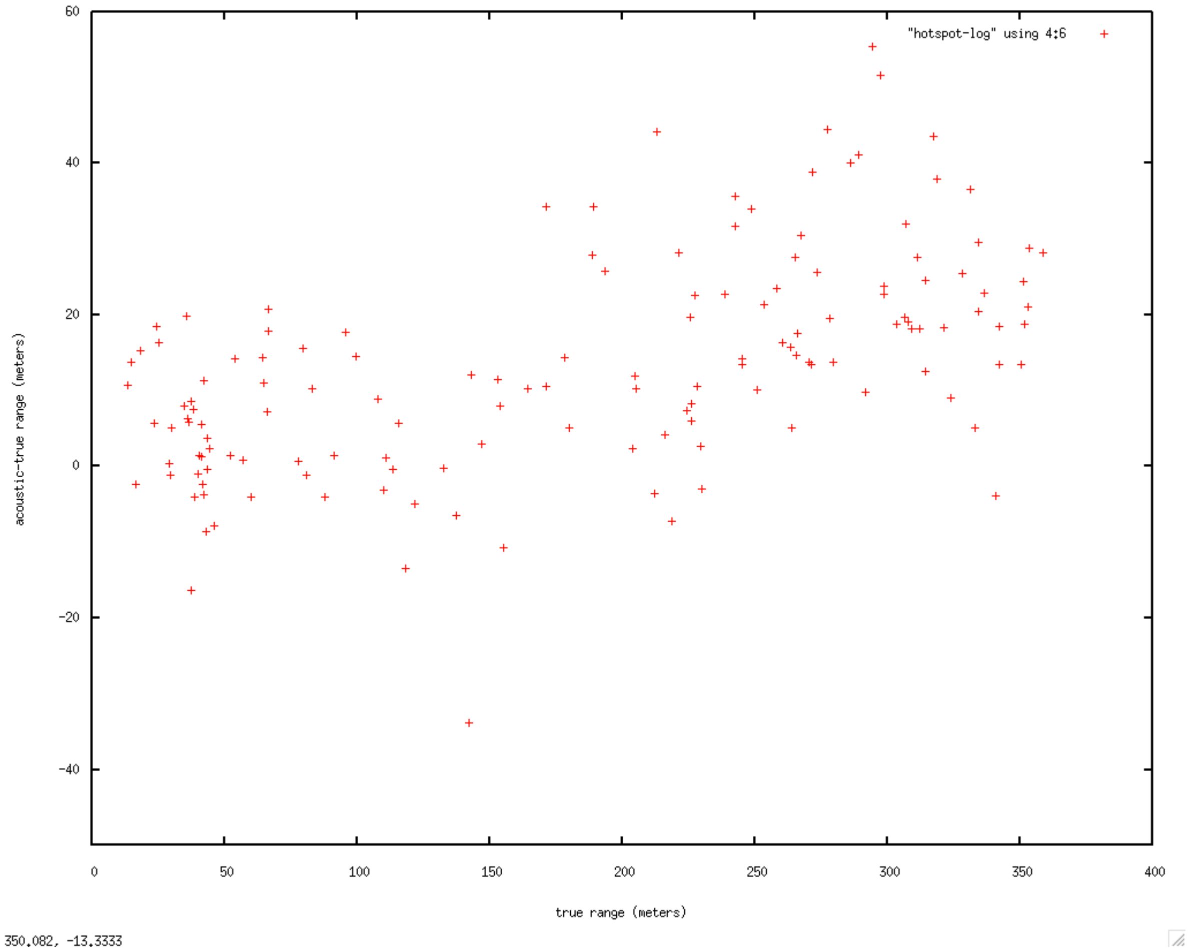




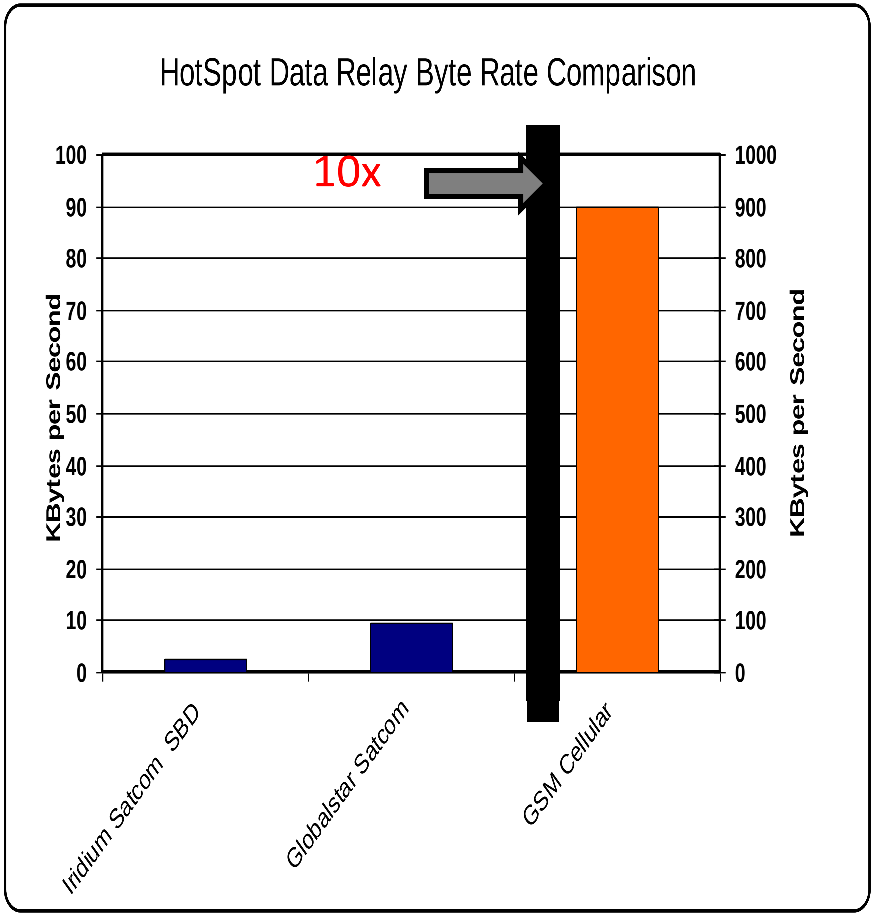
Next steps

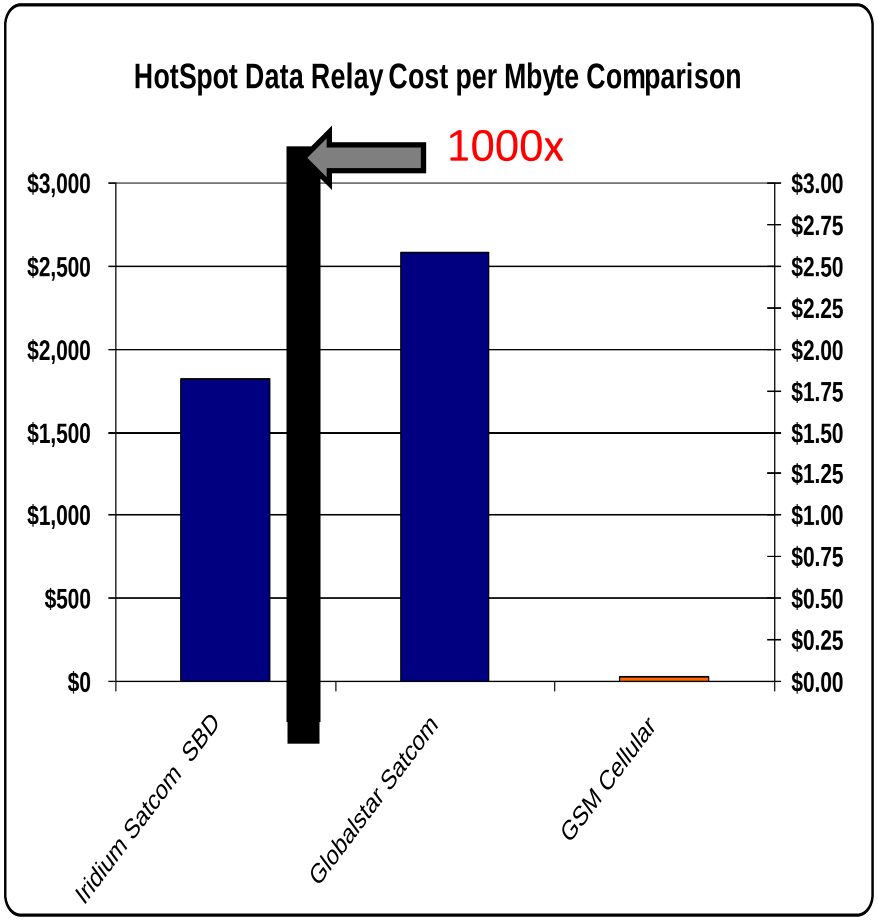
- Account for GPS, DAT, compass offsets
- Automate acoustic data relay through radios (e.g. acoustically-retrieved CTD)
- Refine AUV home to Hot Spot for data relay

Bearing error vs true bearing

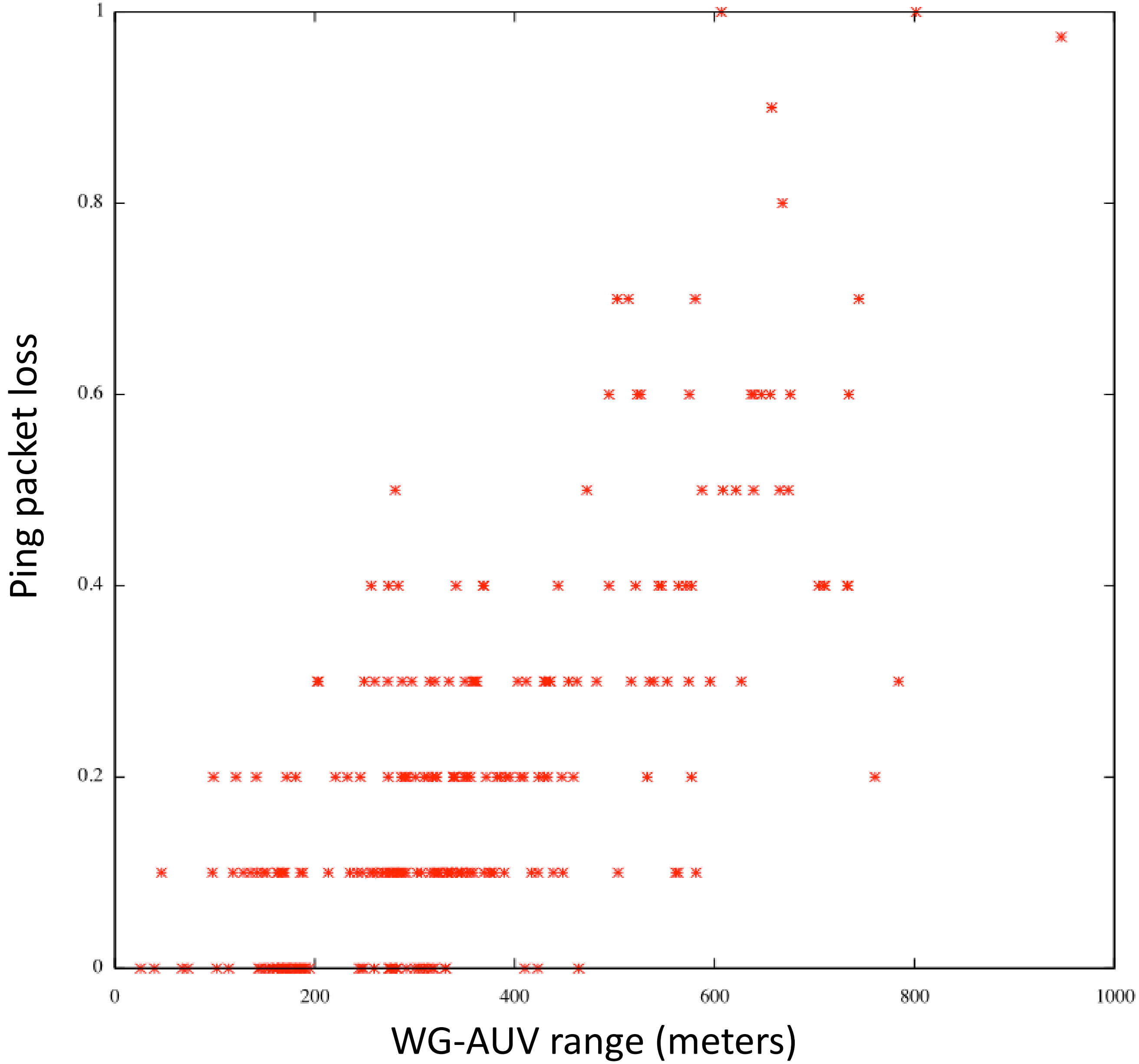


The Communications Revolution - Comparison of Data Rate and Costs for Surface HotSpot Radio Relay

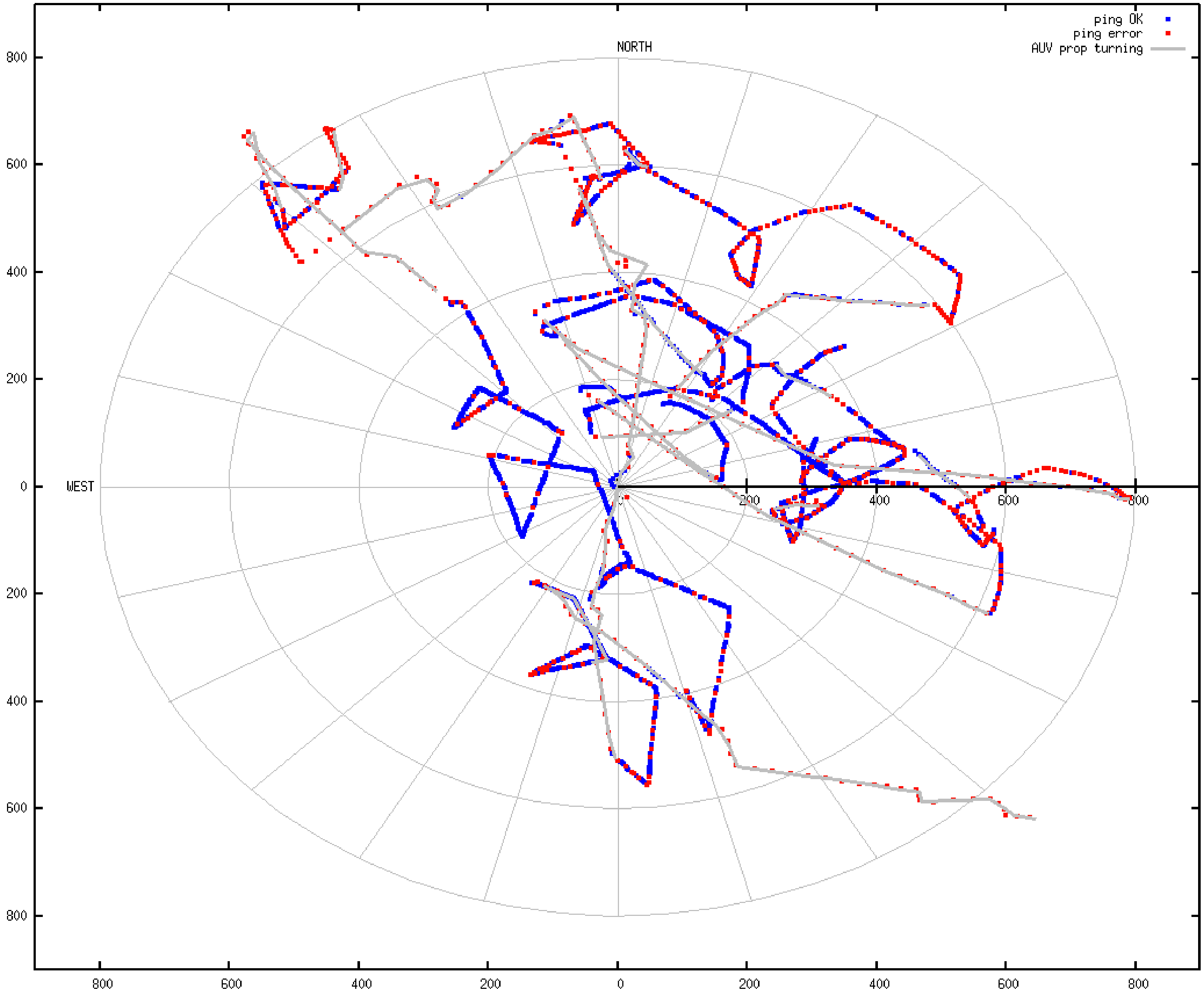




Ping packet loss as a function of WG-AUV range



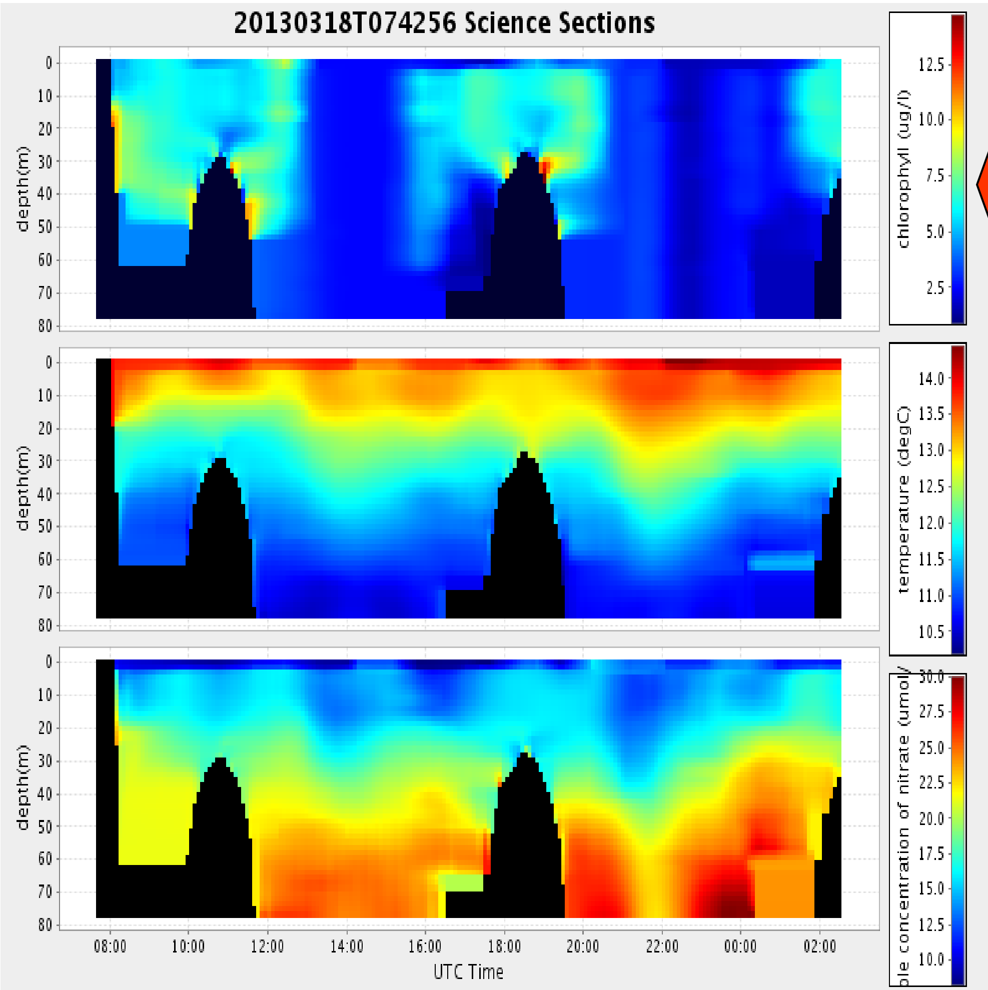
Pings from Wave Glider to AUV



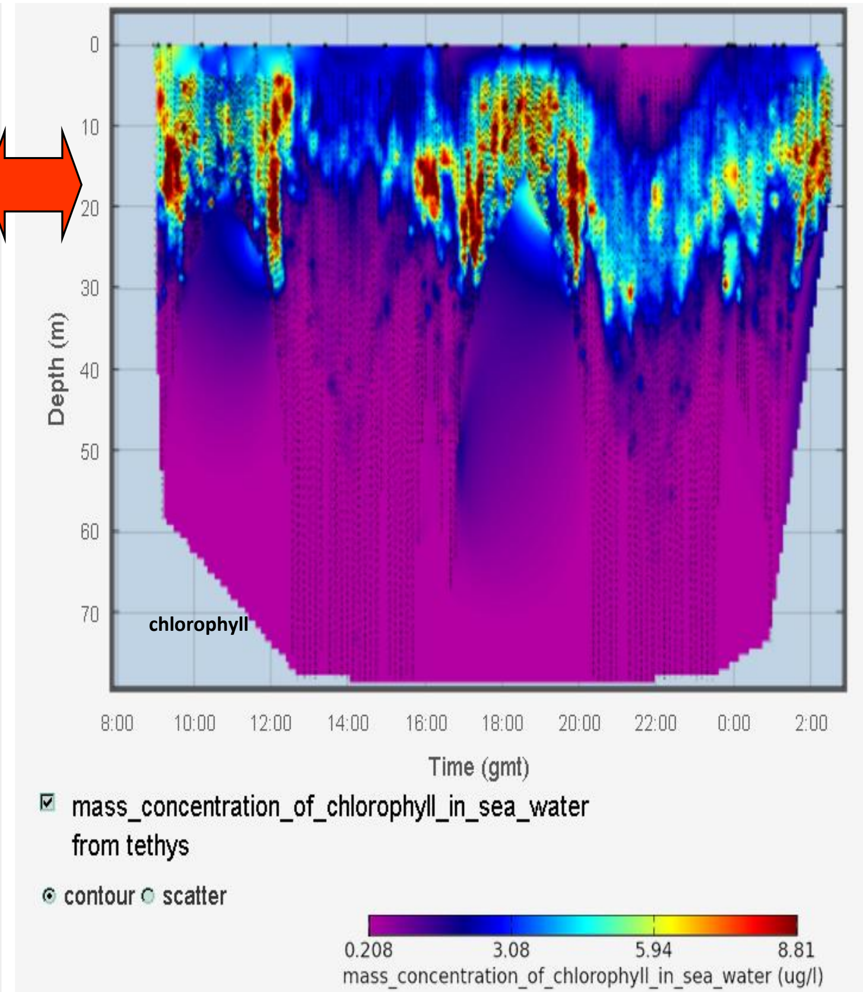
What Can We Expect From More Real-Time Data Return?

an example from Tethys ECOHAB data from March 18, 2013

Real-time returned data – contour plot



10% of all returned data – scatter plot



15,159 data values

AUV surface interval restricted to 5 minutes maximum Each plot represents between 750 and 900 data values

The Importance of Real Time Data Return

- Provides raw data for the MBARI Ocean Decision Support System (ODSS) software application for coordinated mission planning.
- Allows re-directing assets during dynamic field experiments with collaborative adaptive sampling, one of the major themes of our current field initiatives.
  - Coordination of sampling decisions with the ESP where every sample counts.
  - Determining where to take AUV Gulper water samples.
  - Where to take water samples from a ship.

- For returning high quality intermediate data from Tethys during long missions (up to 20 days!).
- All possible due to the communications revolution.

Advantages of a Wave Glider Surface Data Relay – a Radio "Hot Spot"

- Flexibility and access of a surface platform allows the use of faster, less expensive data links.
  - Continuous access to GSM Cellular phone or Satellite communications.
  - Large energy budget for communications.
  - Radio antennas can extend clear of the wave splash zone.
  - Payload space for multiple high powered radios.
- Minimize AUV surface time, air-time costs
- "Console" from shore to AUV
  - Hot Spot radios augment Liquid Robotics radios, which are difficult to access

Dorado and Xtreme-2 AUV coordinated operations

	Dorado (9 MHz)	Xtreme-2 (802.11)
Range to Hot Spot (meters)	min 78, max 2489, avg 687	min 56, max 739, avg 314
File size (uncompressed bytes)	min 36, max 40587, avg 14149	min 2190, max 913932, avg 101831
Total AUV-to-shore transfer time (seconds)	min 14, max 648, avg 182	min 13, max 393, avg 119
Effective AUV-to-shore transfer rate (bits/sec)	min 2, max 7138, avg 1770	min 51, max 224506, avg 15049

Hot Spot relay applications

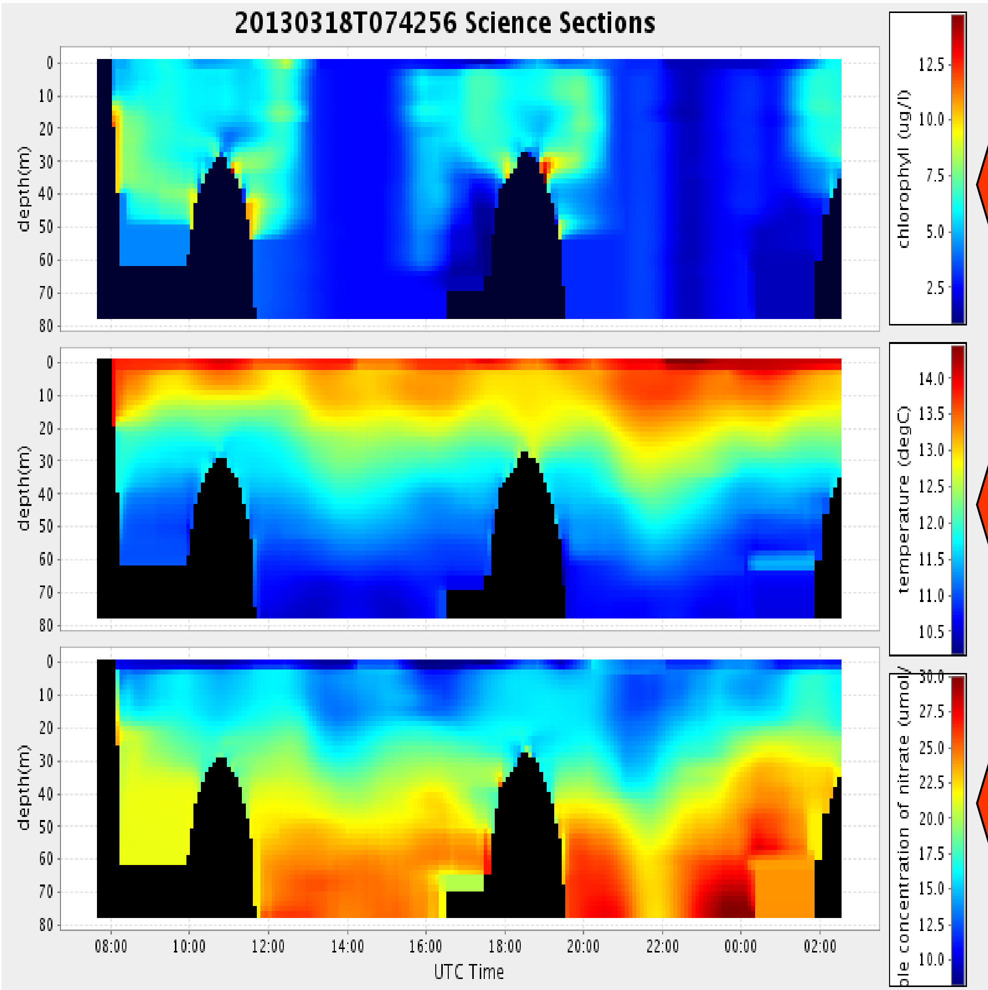
- Fall 2013; coordinated operations between MBARI *Dorado* and LSTS *Xtreme-2* AUVs in N. Monterey Bay
  - Surveyed water masses near M
  - Hot Spot relayed AUV science d
    from shore to AUVs, messages b

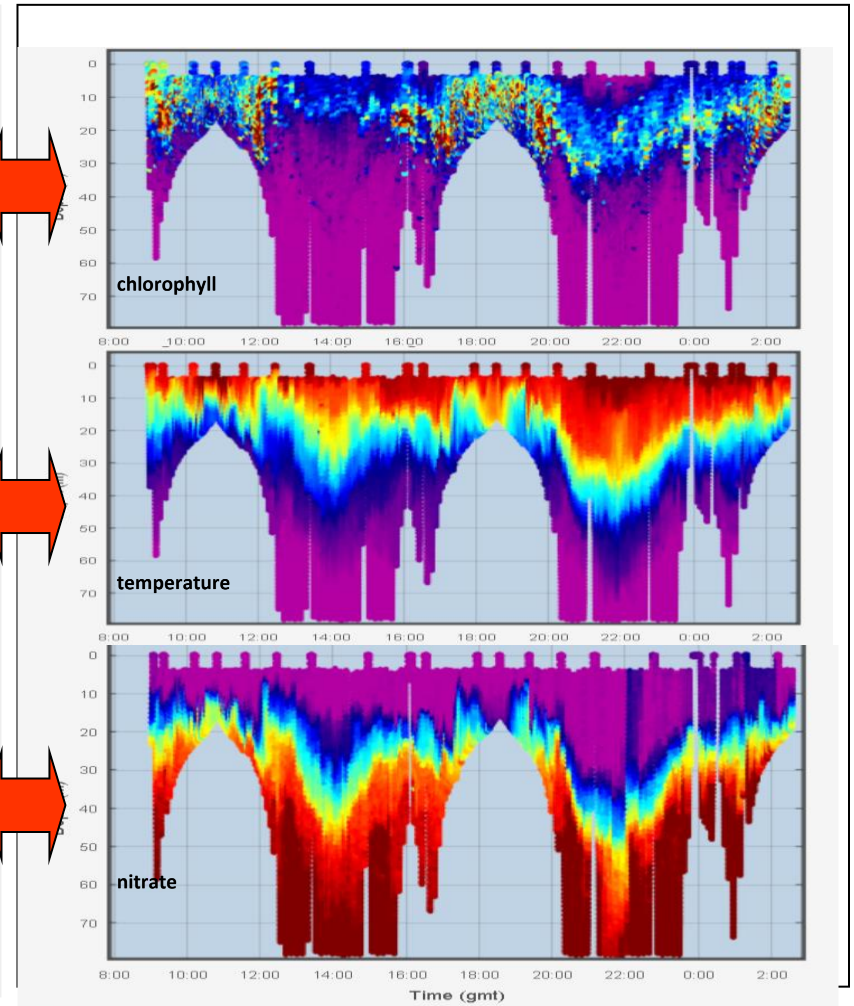
- Spring 2014: *Long Range AUV* in S. California, characterized harmful algal bloom development
  - Relayed 53 MB of AUV data to shore over eight days
  - Troubleshot AUV at sea through Hot Spot Iridium console

Disruption tolerance

- DTN (Delay Tolerant Networking)
  - Powerful, flexible
  - Still in flux, incomplete documentation, serious bugs in at least one implementation
- rsync file-transfer protocol
  - It's everywhere; very robust implementations
  - Very efficient "delta-transfer" algorithm
  - Disruption-tolerant; transfer resumes where it left off

Iridium versus *predicted* Hot Spot real-time data





Iridium: 750 - 900 data values per contour plot

Hot Spot: 15,159 data values per scatter plot

Cost to transfer 13.4 MB AUV data per day

	AUV-Iridium	AUV-HotSpot-cell	AUV-Hotspot-Globalstar
Total AUV surface time	5.0 hours	46 minutes	46 minutes
Hot Spot operational cost	N.A.	$100	$100
Airtime cost	$380	$1	$13
Total cost	$380	$101	$113

AUV - Hot Spot link: 900MHz radio AUV – Hot Spot range: < 400 meters
Iridium bandwidth: 2400 bits/sec
Compression: 2.7 AUV antenna wash-over: 10%
Iridium cost: $1.25/minute GlobalStar cost: $2.58/MB

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Hot Spot acoustic "chase" algorithm (python/java software)

1. Get target bearing/range
2. Compute target lat/lon
3. If target location is "safe", command vehicle to circle target
4. Repeat every *n* seconds

- Target practice: Moored acoustic modem 10m above sea floor, water depth 50m

Hot Spot RF relay advantages

- Fast, cheap continuous link to shore
- Fast radio link to AUV
- Tall antennas
- Large energy budget
- Minimize AUV surface time

- Wave Glider and AUV must rendezvous on surface!