Dawn in the age of robotic oceanography

Oscar Schofield on behalf of many!!!

Take home messages

We have new ways of doing oceanography

Platforms are mature, we need sensors

Sensor webs, no longer about one technology

New directions

CHRISLINDER

This morning session is about thinking big and how can we do things differently

Spanning the scales: Multi-platform approaches for integrated studies of biogeochemistry and physics (Craig Lee, APL/UW)

Stretching the scales of surface ocean observing systems: Biogeochemical observations from the Saildrone USV (Jessica Cross, NOAA/PMEL)

Robotic systems for survey and sampling of the mesopelagic (Dana Yoerger, WHOI)

My biased timeline on how much has changed in my career in ocean robotics (people) that inspired me

Pliestocene

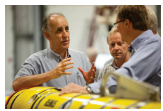
Dad (JPL scientist) built me Star Trek consul and watched bad TV

Late 1980's

Stommel's Bold Vision In TOS

Early 1990's

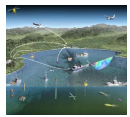
Ray Smith measuring UV under ice with an ROV



Chris von Alt & Jim Bellingham building AUVs

AOSN and LEO-15 alternating coastal experiments

Late 1990's



Early 2000's

Early 2000's

ARGO begins to be deployed

Early 2000's

Late 2000's

Stommel's backyard neighbor Doug Webb realizes Henry's vision

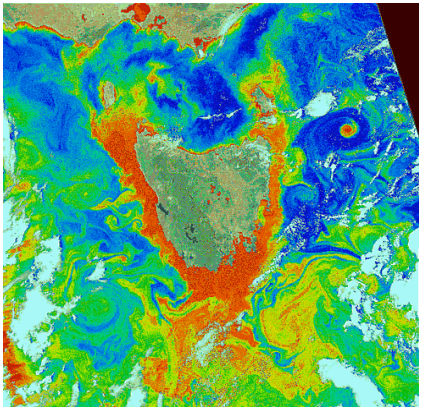
WHY?

-Humans at sea have limits
-Sustain a presence at sea

WHY?

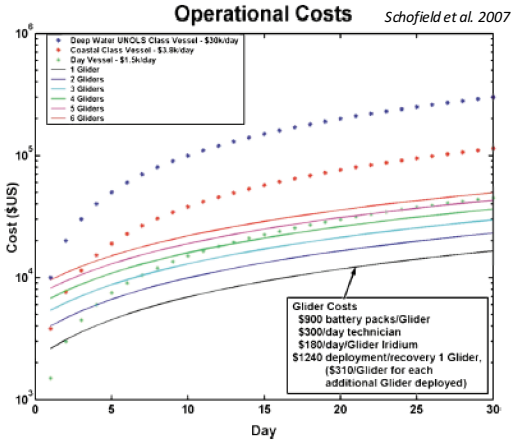
-Sampling Space

GSFC, NASA (thanks Tommy Dickey)



Sample this with a ship……..

-Cost Effective

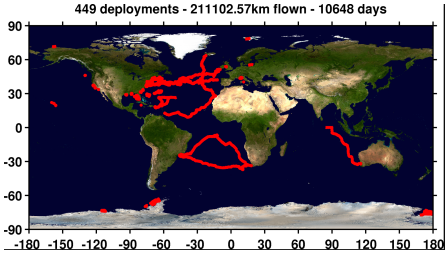


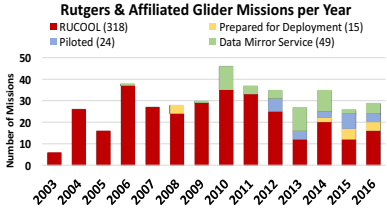
Scalable technology……..

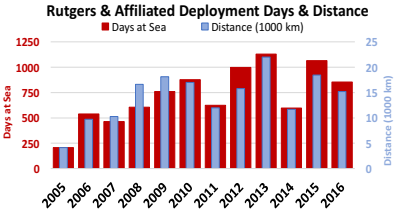
A SMALL GROUP CAN HAVE A BIG FOOTPRINT AS THE PLATFORMS ARE ROBUST

Rutgers COOL deployments

As of June 29th







Standardized* Rutgers Glider Statistics

*as per Rudnick et al, June 2016, Spray Underwater Glider Operations, American Meteorological Society

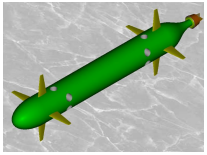
Total Rutgers Only Missions	330
Short Missions Excluded	58
Total Missions Considered	272
Significant Problems	43
Total Successful Missions	229
Number of Losses	9

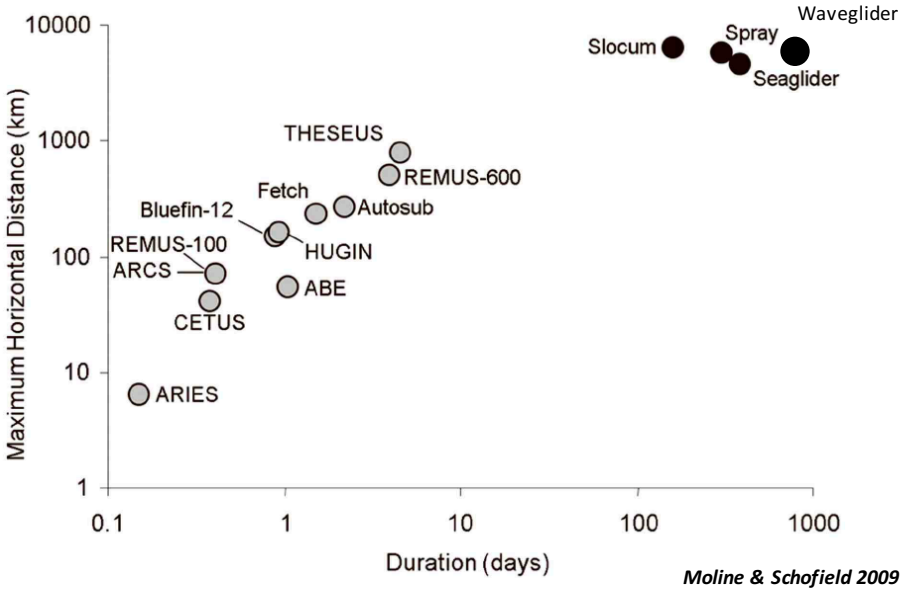
Success Rate **84%**

Loss Rate **2.7%**

Propeller Systems Diverse highly varied and we can sample the ocean interior

Highly capable of studying boundary problems, high resolution sampling, and in general capable of collecting a wider range of data

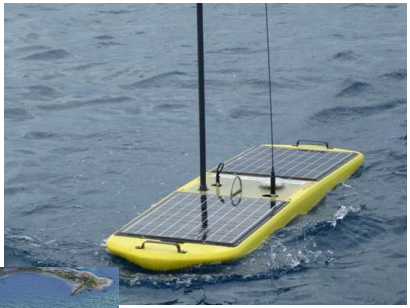


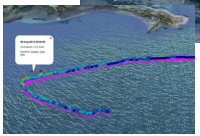


Moline & Schofield 2009

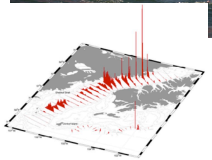
Surface vehicles rapidly maturing! We can sample the interface

Wave Glider





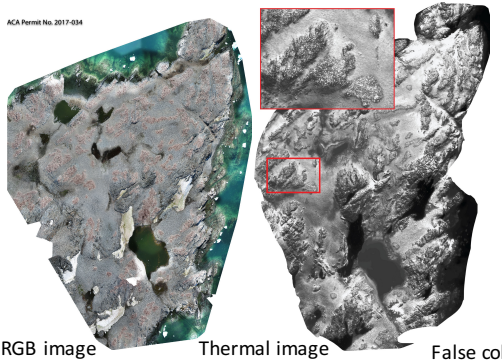
Sail Drone



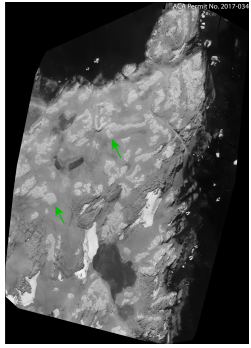
UAV technology rapidly maturing! We can sample lower atmosphere of ocean surface

Multispectral sensors-cheap (relatively speaking)
Ability to repeat surveys frequently
Range of duration and stabilities

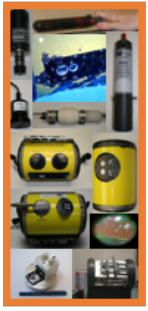
Dave Johnson, Duke University



RGB image Thermal image



False color



WATER COLUMN PHYSICS

Temperature
Salinity
Turbulence

TRANSPORT

ADCP
Estimated geostrophic currents

TRACE GASES

Optical Oxygen
Optical CO2
Mass Spectrometers

Macro/ Micro nutrients & chem

CHEMISTRY

Optical nutrients
Optical CO2
Optical pH
Mass Spectrometers

IN SITU OPTICS

Inherent optics
Absorption (λ)
Scattering (λ)
Volume scattering
Attenuation (λ)
Refractive Index

Apparent Optics
(λ) Light intensity up & down

Chl a → e⁻ → Proteins, Lipids, Carbos

TEP, DOM

PHYTOPLANKTON

Concentration
Spectral Backscatter
Hyperspectral Absorption
Chlorophyll fluorescence
Imagery (visual, holography)

Diversity
Spectral Backscatter (proxy for composition/size)
Imagery (visual, holography)
"Omics"

Rates
Kinetic fluorescence
Photoacoustics
Stimulated oxygen kinetics

ZOOPLANKTON

Concentration
Acoustic backscatter
Imagery (visual, holography)

Diversity
Multi frequency Acoustics
Imagery (visual, holography)
"Omics"

HIGHER TROPHIC LEVELS

Concentration
Acoustic backscatter
Imagery (visual, holography)
Passive acoustics
Acoustic tags + Receiver

Diversity
Multi frequency Acoustics
Imagery (visual, holography)
"Omics"
Passive acoustics
Acoustic tags + Receiver

ORGANIC MATTER FLUX

Concentration
Spectral Backscatter spikes
Particle settling rate
Imagery (visual, holography)

Diversity
Imagery (visual, holography)
"Omics"
Mass Spectrometers

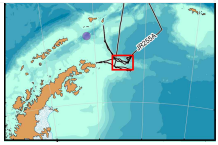
Rates
Spatial calibrated fall rates via imagery

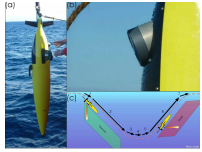
Marine snow & Export Flux

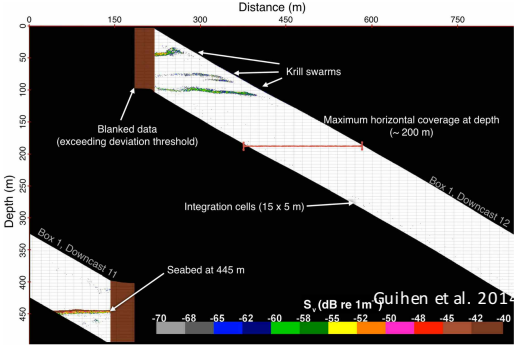
Schofield et al. MTS 2015

Active acoustics to map macro-zooplankton community and concentration

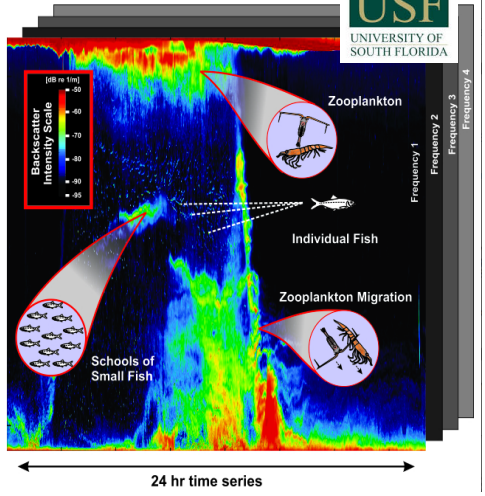
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL





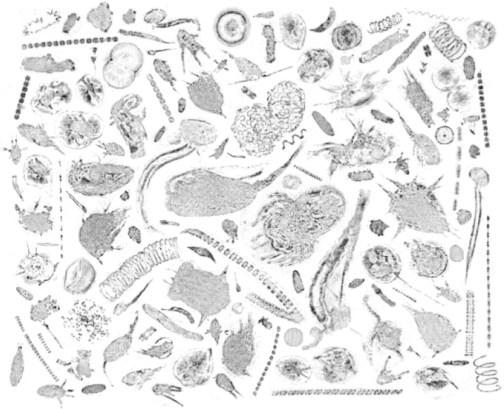


USF
UNIVERSITY OF SOUTH FLORIDA



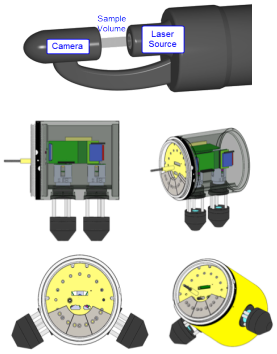
Coming soon (2-4 years) micro- and small zooplankton imaging

Holographic images from Monterey by an AUV

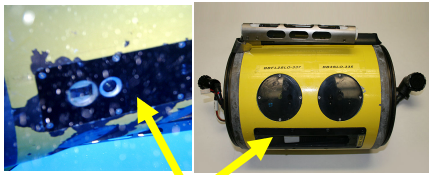


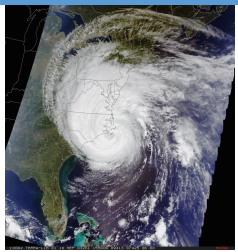
Thanks to James Bellingham (WHOI)

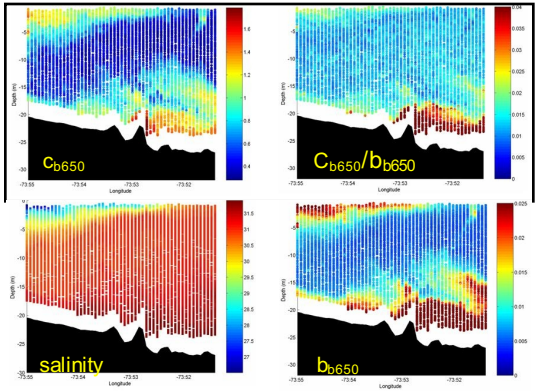
Design strategies are underway



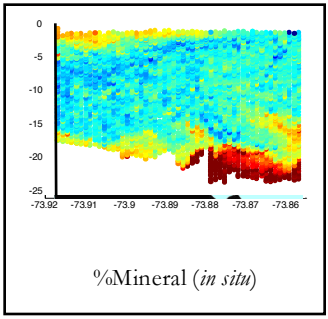
Glider's provide insight into the nature of phytoplankton composition



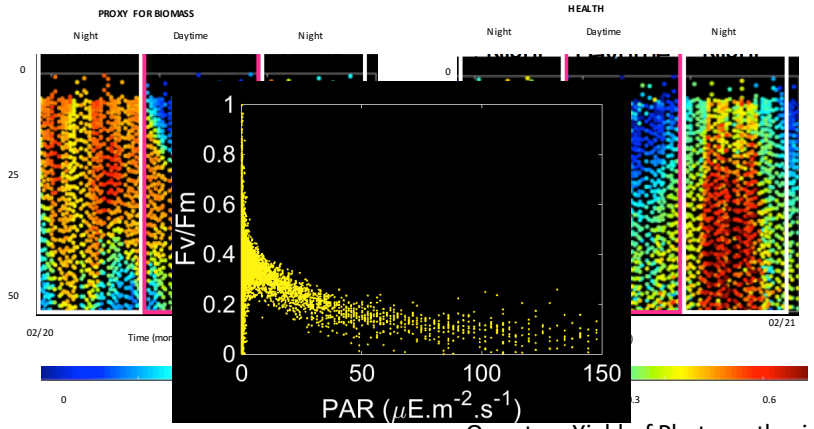




Empirical algorithms



The ability to look at phytoplankton physiology and rate processes



Biomass Proxy (Fm)

Quantum Yield of Photosynthesis (Fv/Fm)

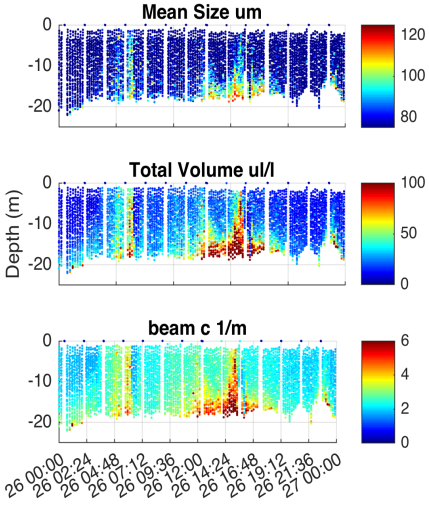
RUTGERS
Center for Ocean Observing Leadership

LISST Glider Integration

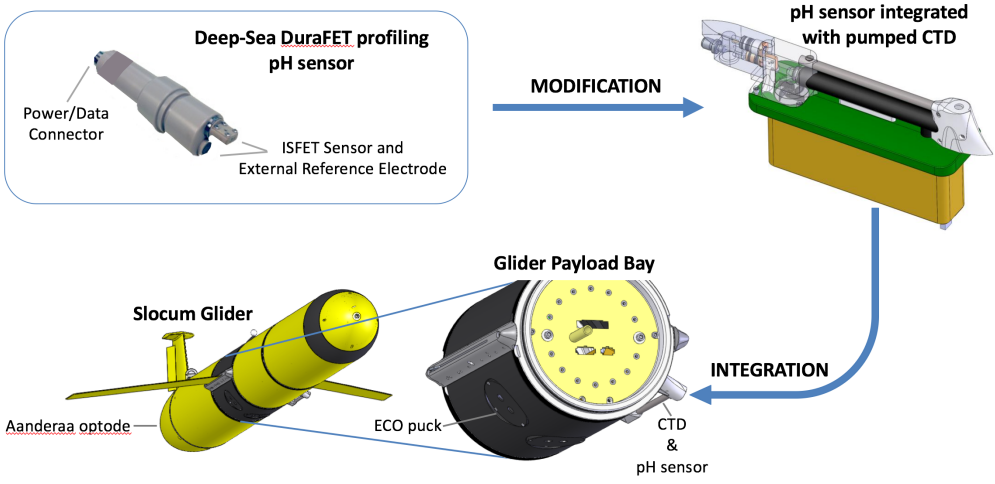
TELEDYNE WEBB RESEARCH
Everywhereyoulook™

SEQUOIA

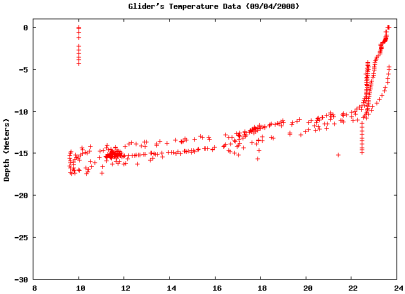
Thanks to Travis Miles

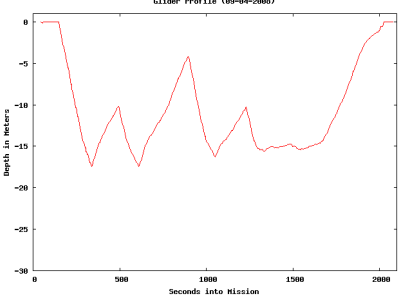


Rutgers and WHOI collaboration: September deployment being tested



MAKE YOUR AUVS SMARTER

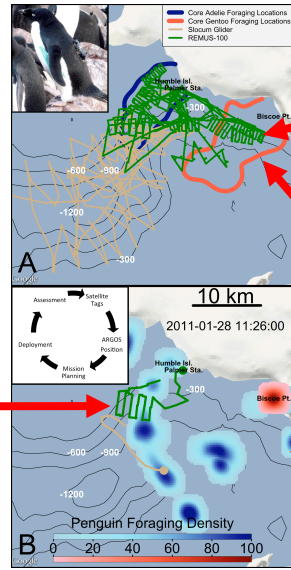




Currently porting over a NVIDIA Jetson TX-1 is an embedded system with 256 CUDA cores, 8 regular cores, with a performance of 1 Tflop

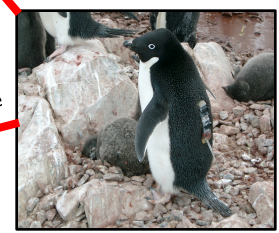
Thanks Uli Kremer (Energy Efficiency Laboratory at Rutgers)

Multi-Platform dynamic analysis of penguin foraging in space

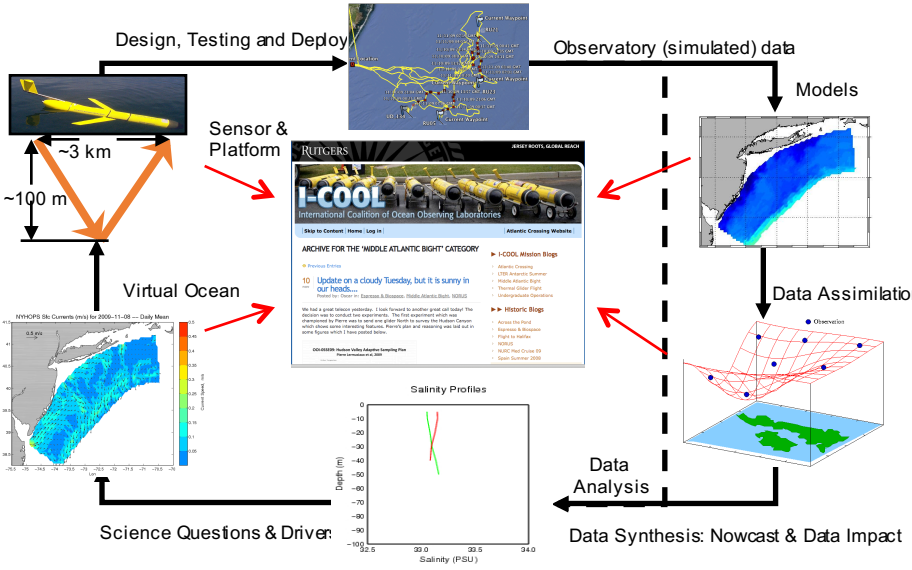


climatologies

Real-time

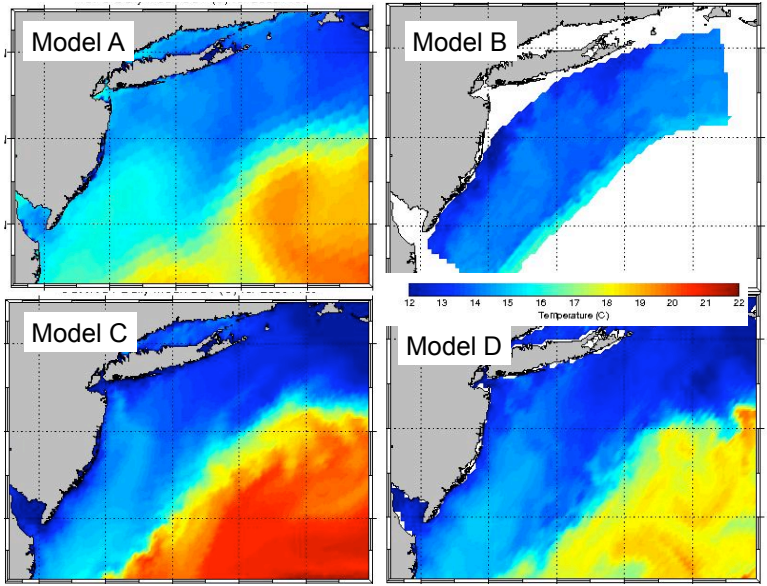


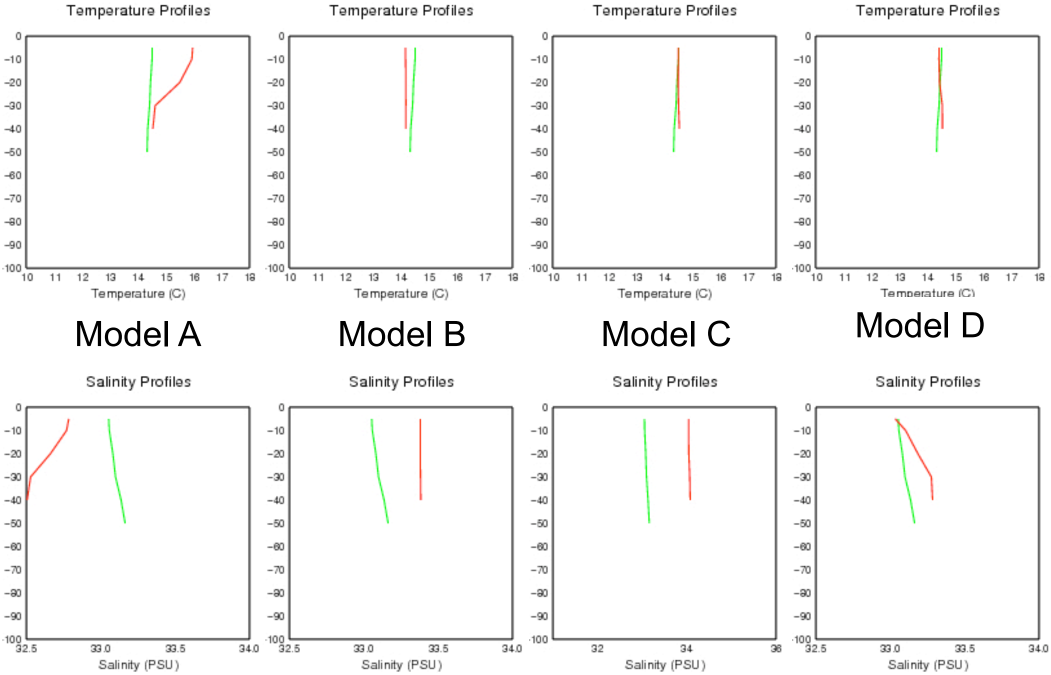
FUTURE: MACHINE TO MACHINE NETWORKS (TEST NOV. 2009)



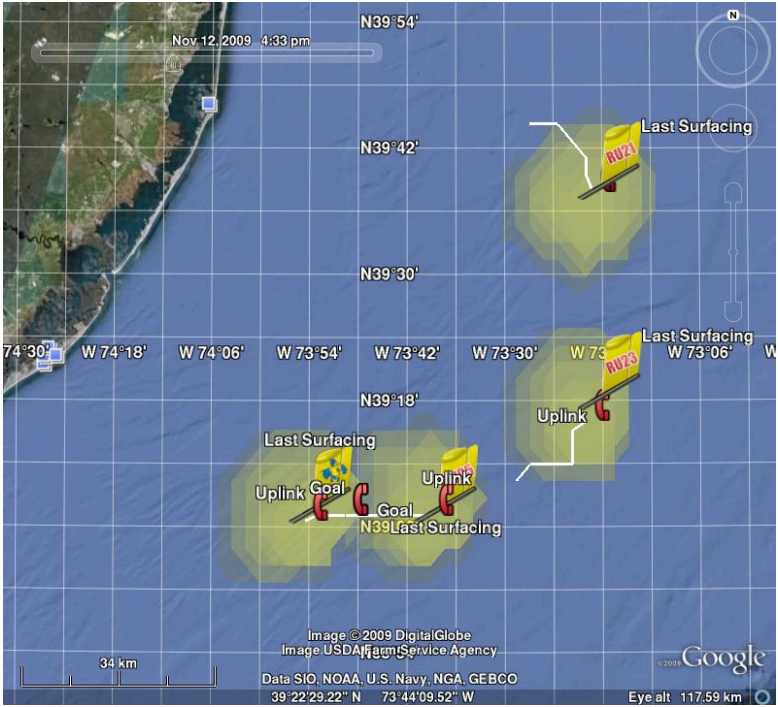
Schofield et al. 2009

5 ocean numerical models run in forecast mode:2
versions of ROMS, 2 versions of HOPs, 1 version of POM

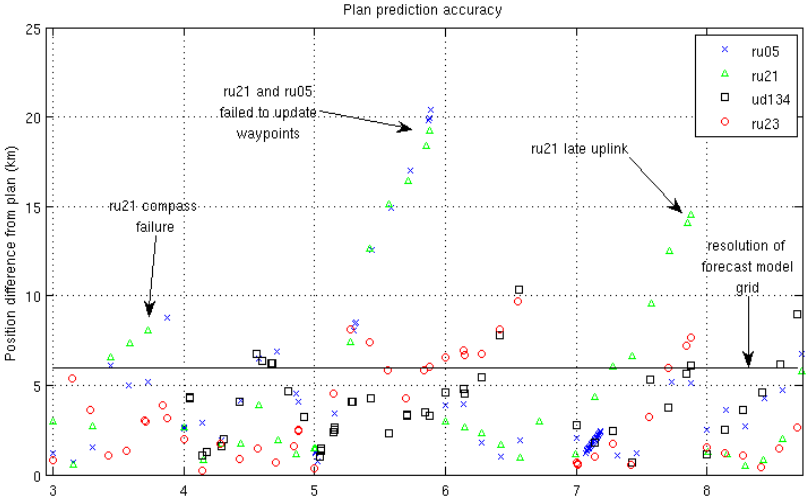




Temperature Profiles
Temperature (C)
Model A
Model B
Model C
Model D
Salinity Profiles
Salinity (PSU)

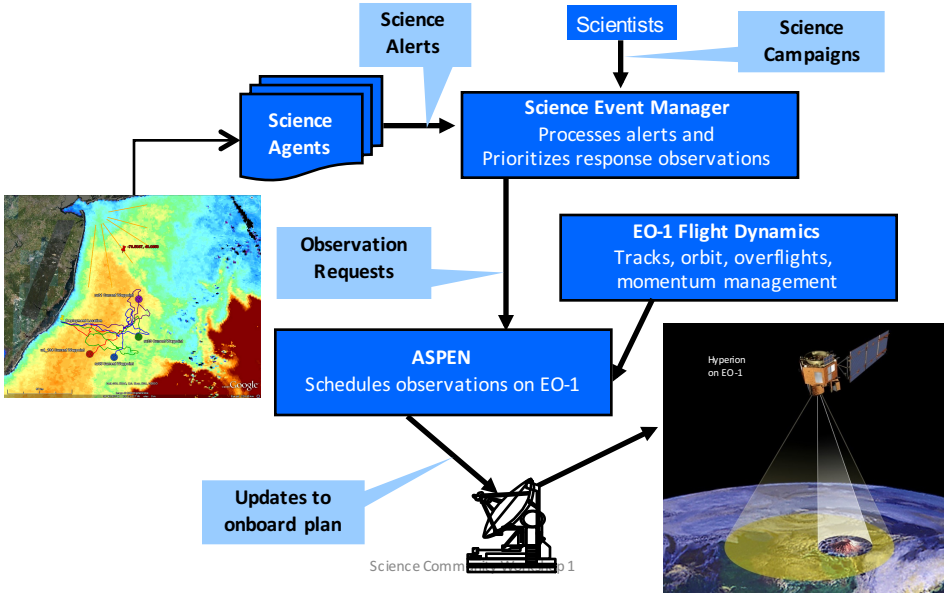

Nov 12, 2009 4:33 pm
N39°54'
N39°42'
N39°30'
N39°18'
74°30'
W 74°18'
W 74°06'
W 73°54'
W 73°42'
W 73°30'
W 73°
W 73°06'
Last Surfacing
RU21
Last Surfacing
RU23
Uplink
Last Surfacing
Uplink
Goal
Uplink
Goal
Last Surfacing
Image © 2009 DigitalGlobe
Image USDA Farm Service Agency
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
34 km
39°22'29.22" N 73°44'09.52" W
Eye alt 117.59 km
Google

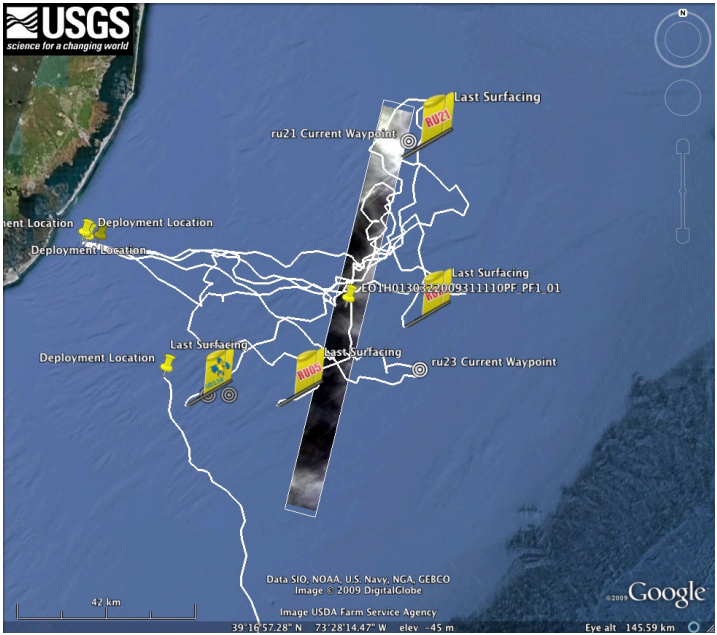
FUTURE: MACHINE TO MACHINE NETWORKS (TEST NOV. 2009)
DID IT WORK?



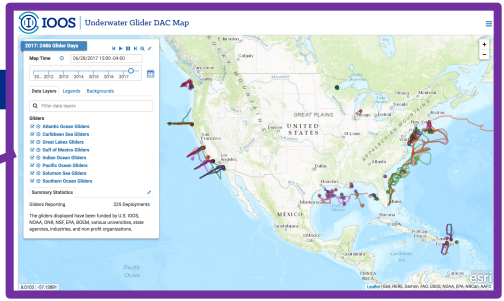
Increase model resolution

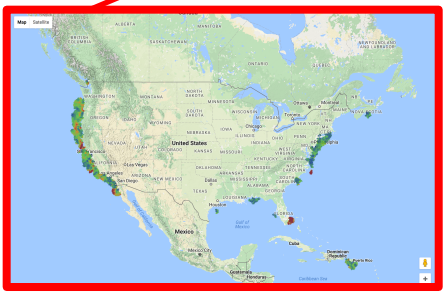
Reduce forecast error

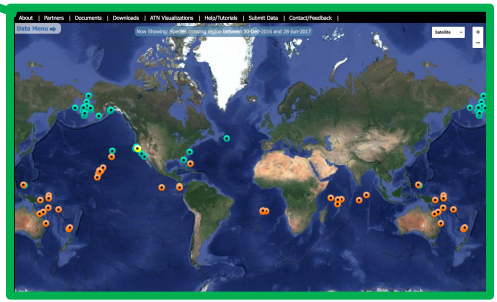

Science Alerts
Scientists
Science Campaigns
Science Agents
Science Event Manager
Processes alerts and
Prioritizes response observations
Observation Requests
EO-1 Flight Dynamics
Tracks, orbit, overflights,
momentum management
ASPEN
Schedules observations on EO-1
Updates to onboard plan
Hyperion on EO-1


USGS
science for a changing world
Last Surfacing
ru21 Current Waypoint
RU21
Deployment Location
Deployment Location
Deployment Location
Last Surfacing
EO1H0130222009311110PF_PF1_01
RU23
Last Surfacing
Deployment Location
Last Surfacing
RU05
ru23 Current Waypoint
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
Image USDA Farm Service Agency
42 km
©2009 Google
39°16'57.28" N 73°28'14.47" W elev -45 m
Eye alt 145.59 km

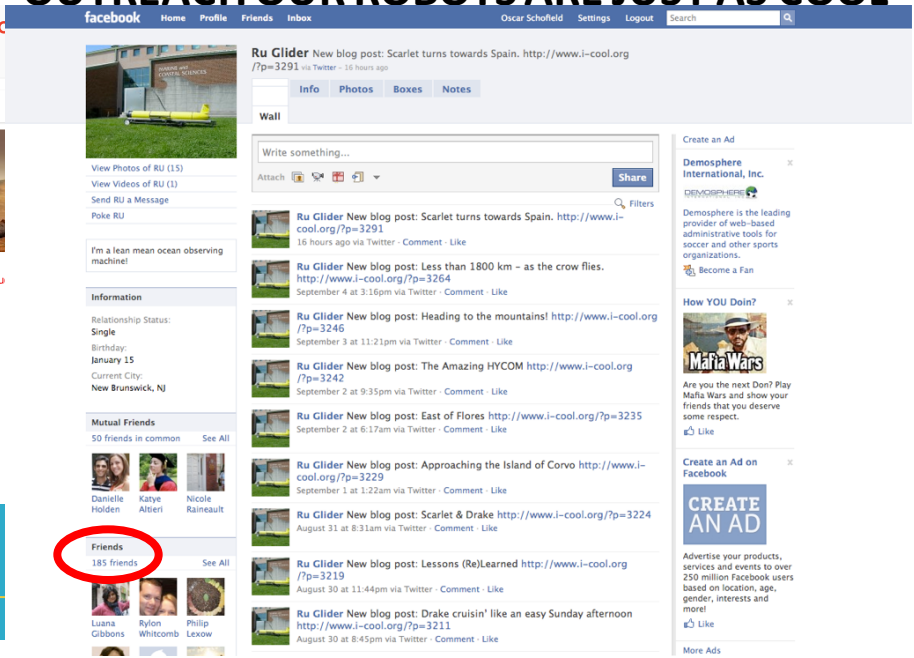
Community data sets coming together through national aggregation efforts



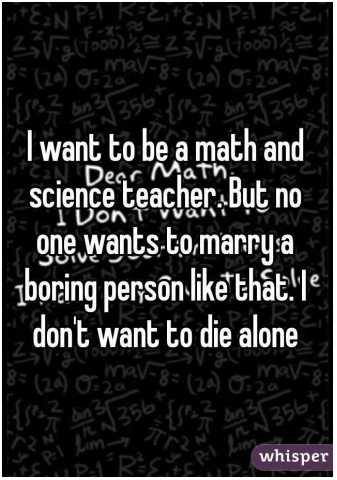




OUTREACH OUR ROBOTS ARE JUST AS COOL



How is science teaching perceived by many?



These will be great tools to convey the excitement of what we do.

Hurdles: Substrates for formation of artificial reefs

Hurdles: Biofouling (see below), pace of sensor integration, slow but accelerating rate of standardization (Calibration, Qa/Qc, etc)

NSF OOI Glider Argentinean Basin