

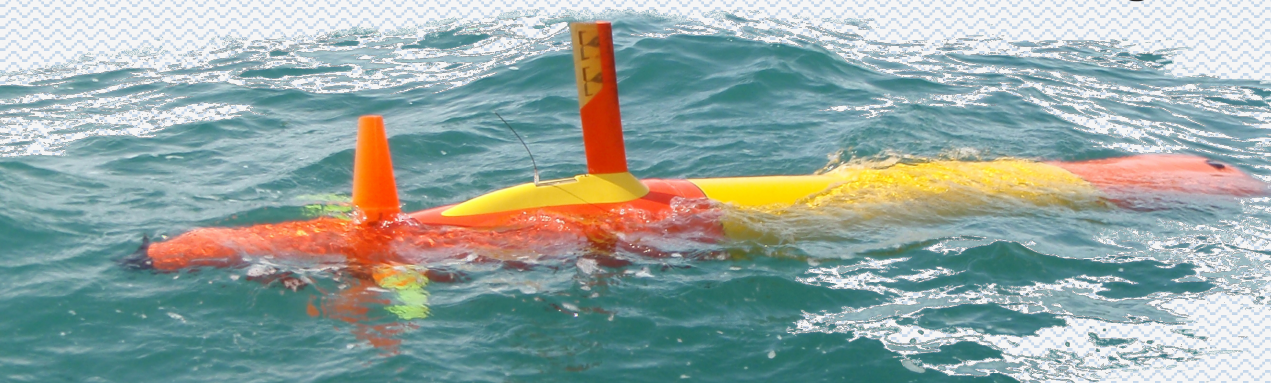
AUVs that fix themselves

Fault detection for LRAUV missions with minimal human intervention

Drew Gashler Memorial Summer Internship

Ben Yair Raanan

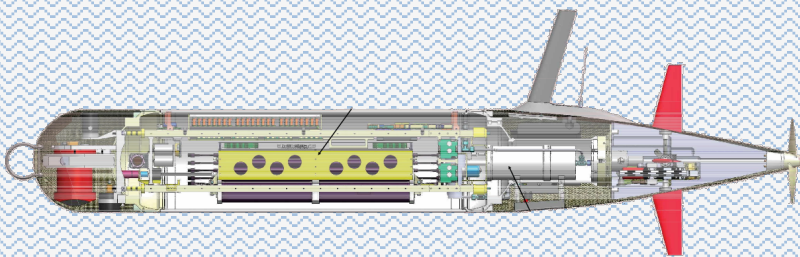
Dr. James G. Bellingham



LRAUV

Tethys class long-range AUV

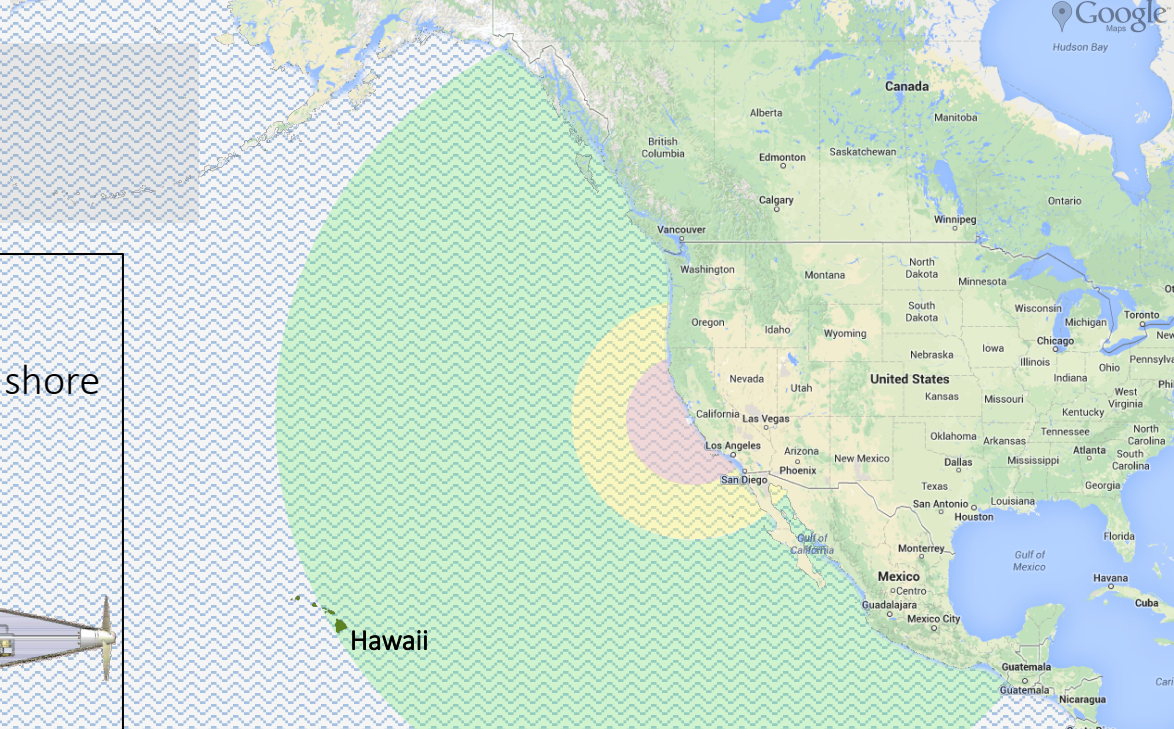
LRAUV is designed to be operated from shore via Iridium Satellite link



Faults necessitate human intervention

Maximum MTBOI* of 150 hours at best

mbari.org/auv/LRAUV.htm



Increase reliability by automation

Detection



Diagnosis



Response

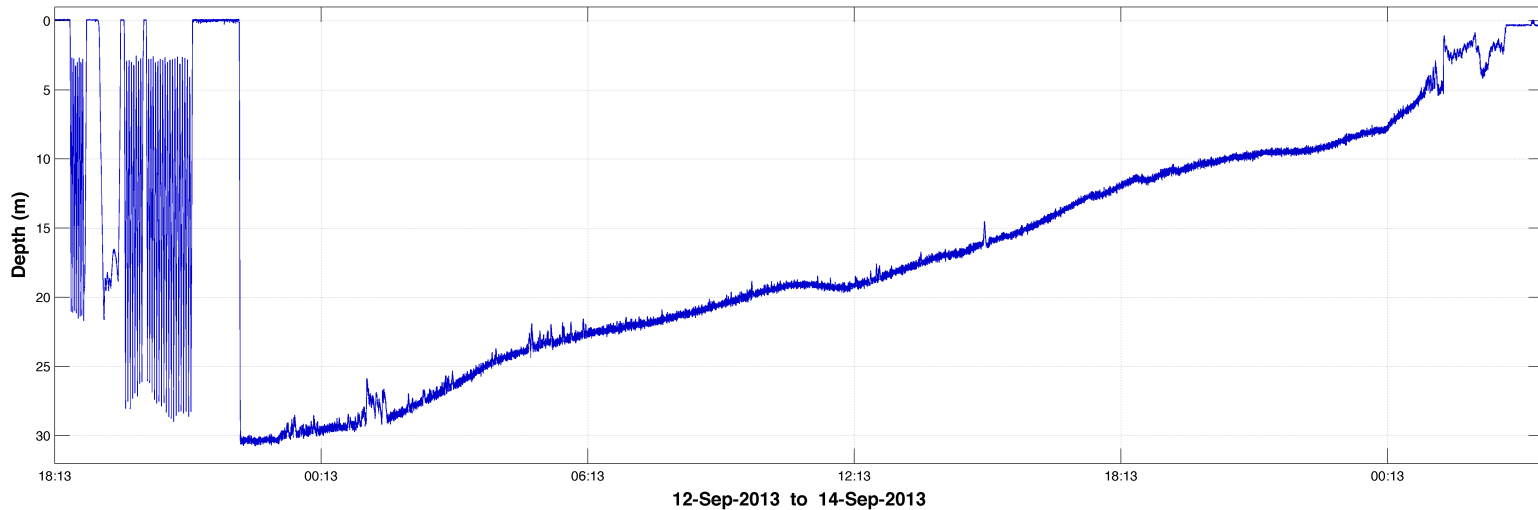
LRAUV faults

Fault: u

Total r
fa

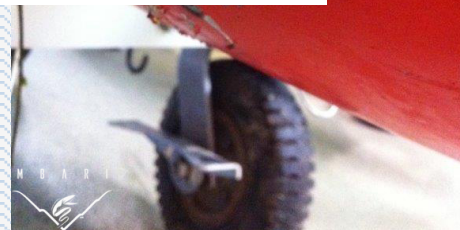
5

Mission depth profile



Tethys attacked by a Great
White

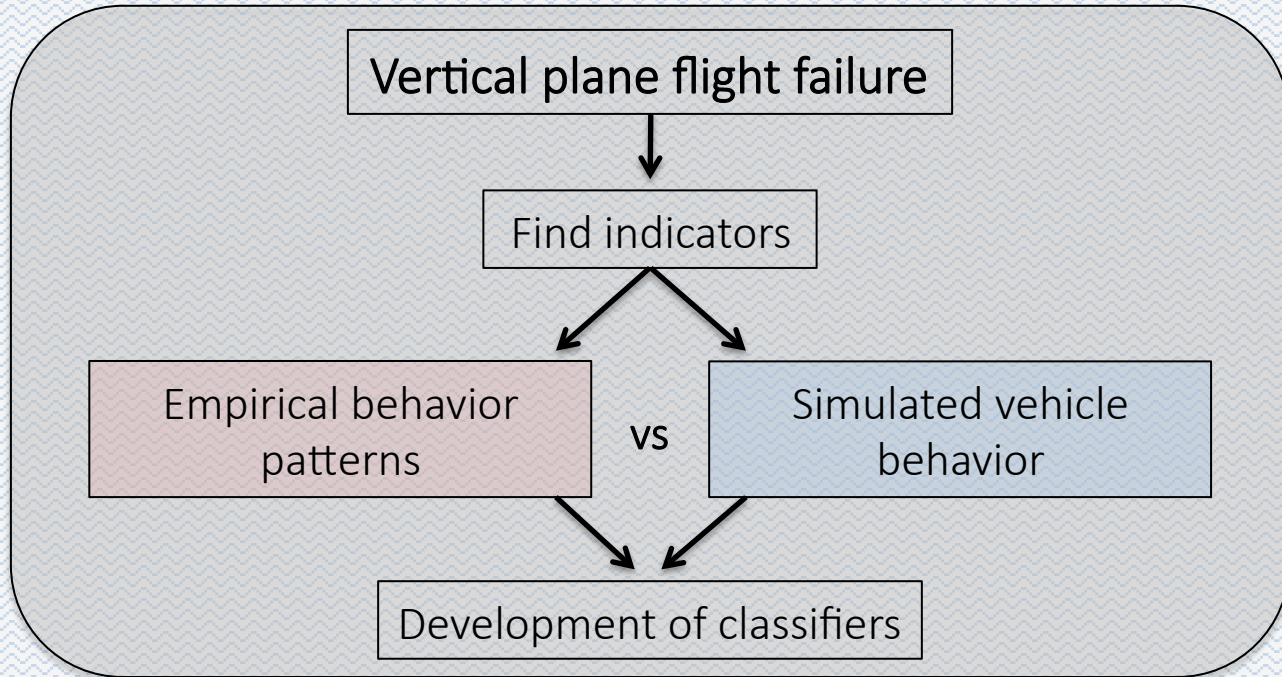
September 30th, 2013



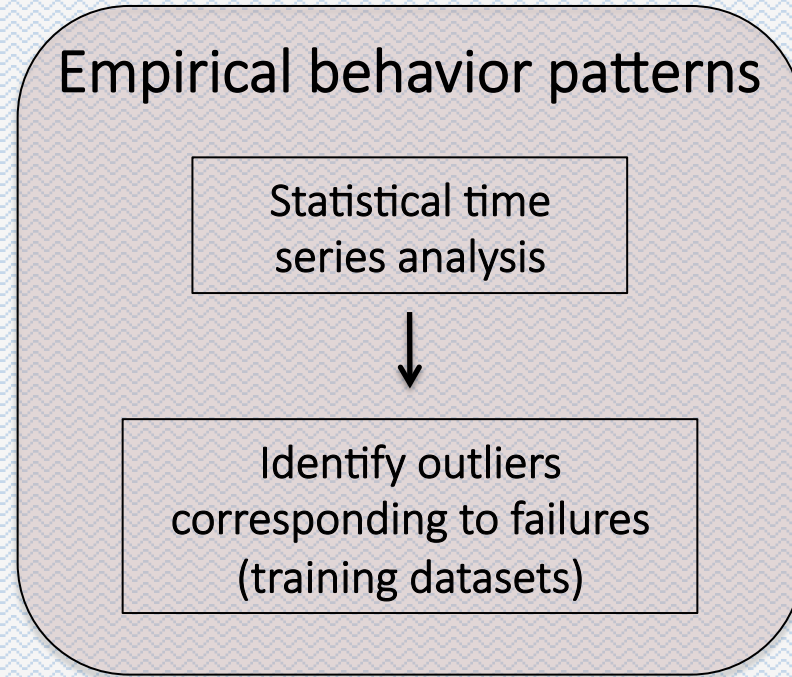
Photos: LRAUV group, MBARI

Project plan

Objective: Develop methods to detect anomalies in vertical plane flight performance of LRAUV



Empirical indicators

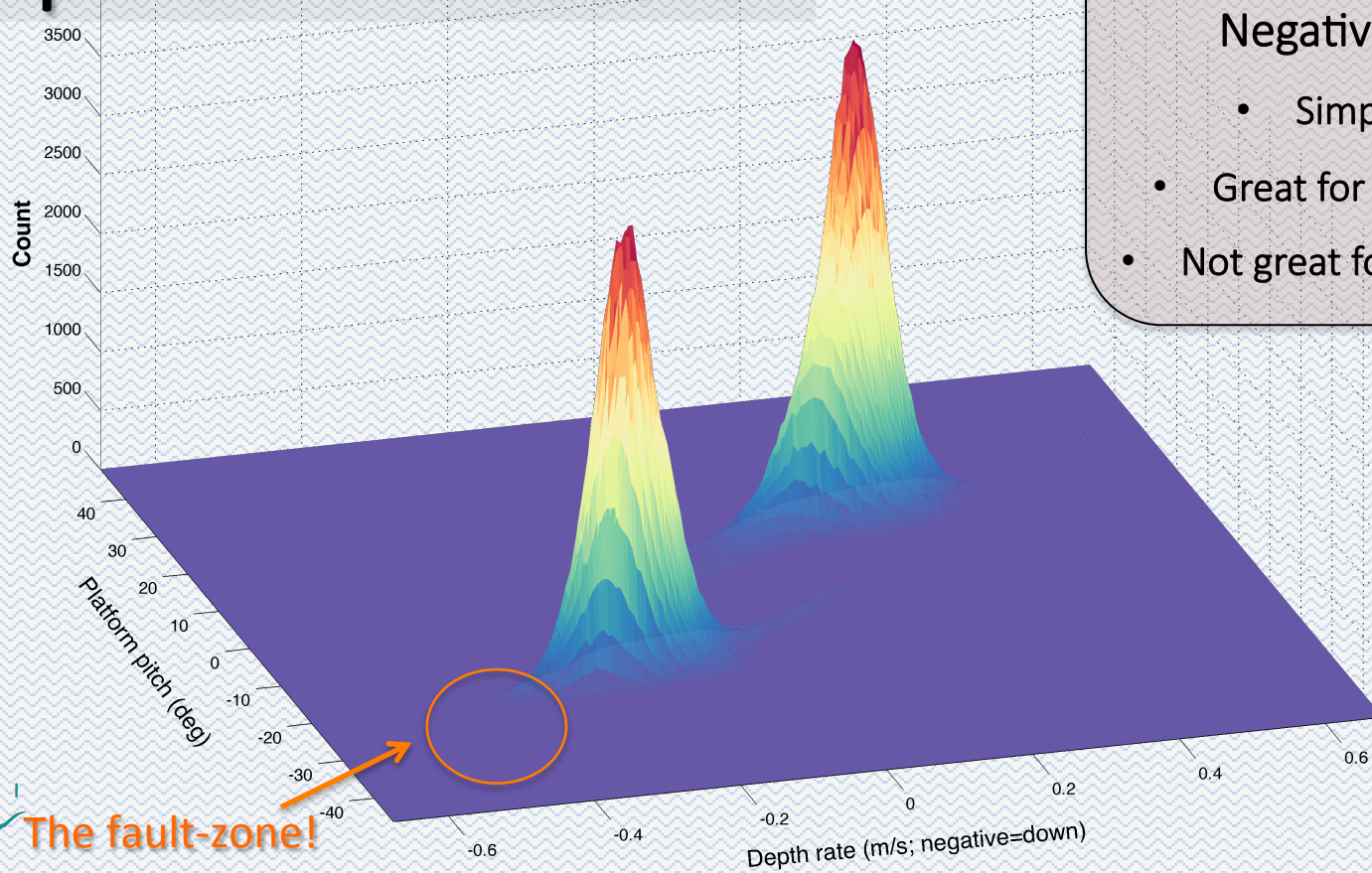


Empirical indicators

Empirical failure indicator:

Negative pitch angle

- Simple(r) to derive
- Great for “off the mountain”
- Not great for “on the mountain”



The fault-zone!

Simulated indicators

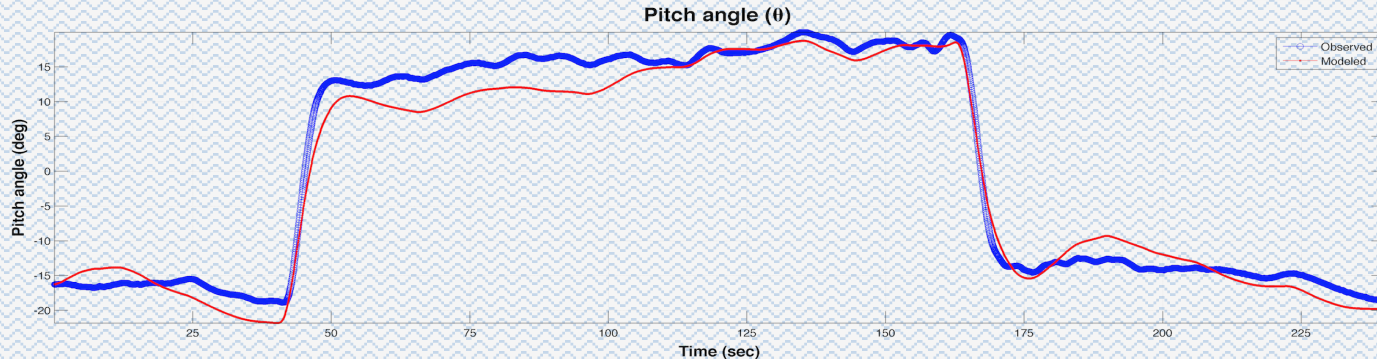
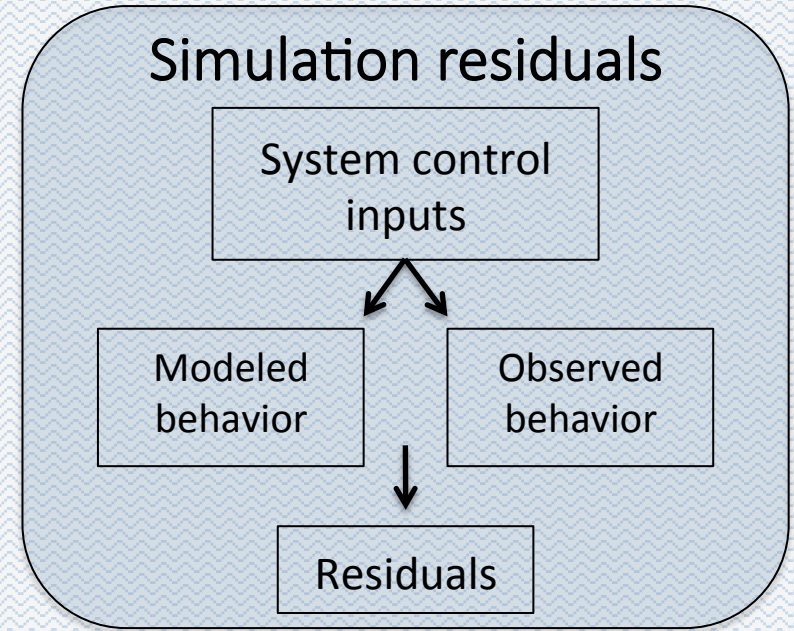
LRAUV simulator

Abkowitz [1969]

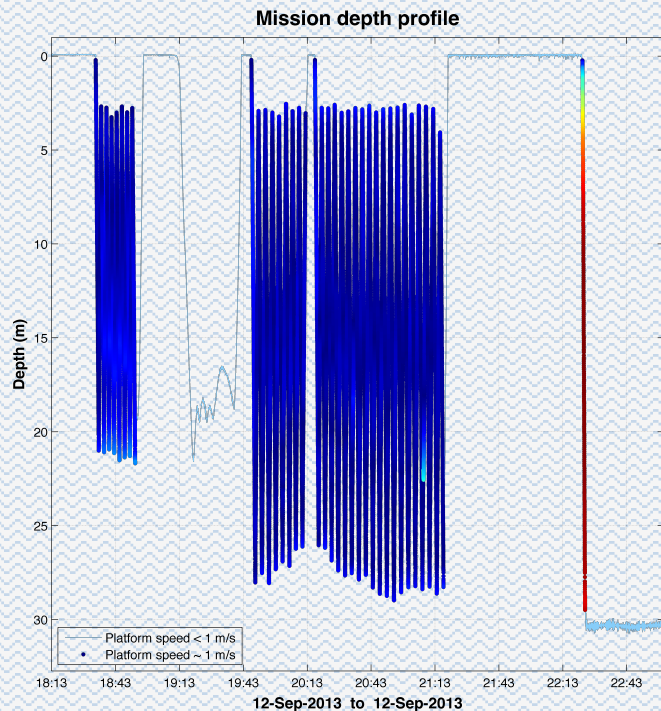
Numerical integration of the vehicle's 6 DOF equations of motion

Requires 134 coefficients to run!

Hybrid of existing LRAUV simulator [Kieft et al., 2011] & REMUS model [Prestero, 2001]



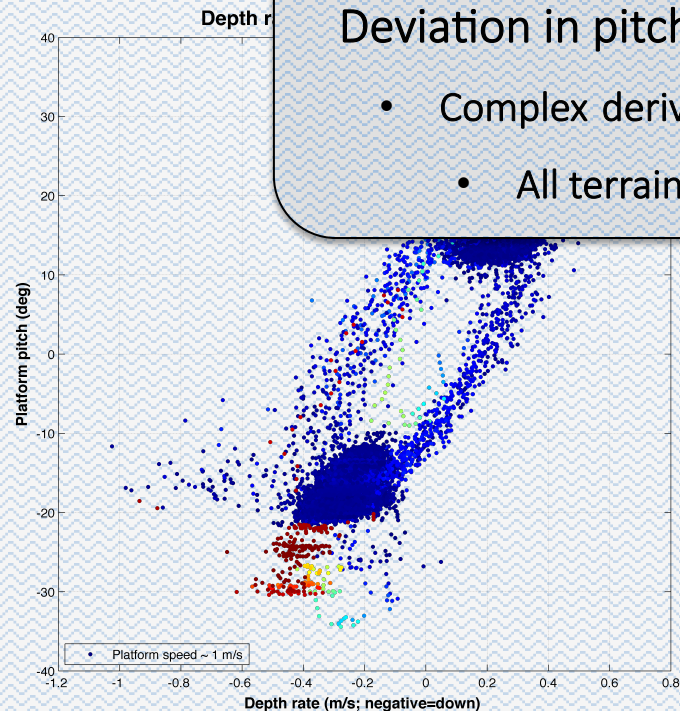
Simulated indicators



Simulator failure indicator:

Deviation in pitch angle

- Complex derivation
- All terrain!



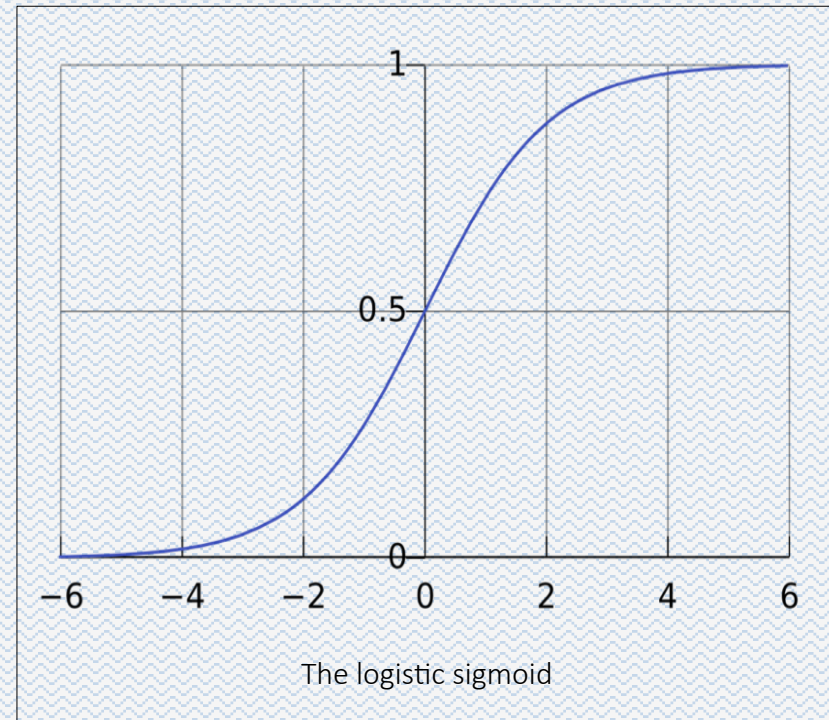
Binary classification

Logistic regression predictive framework

Gelman and Hill [2007]

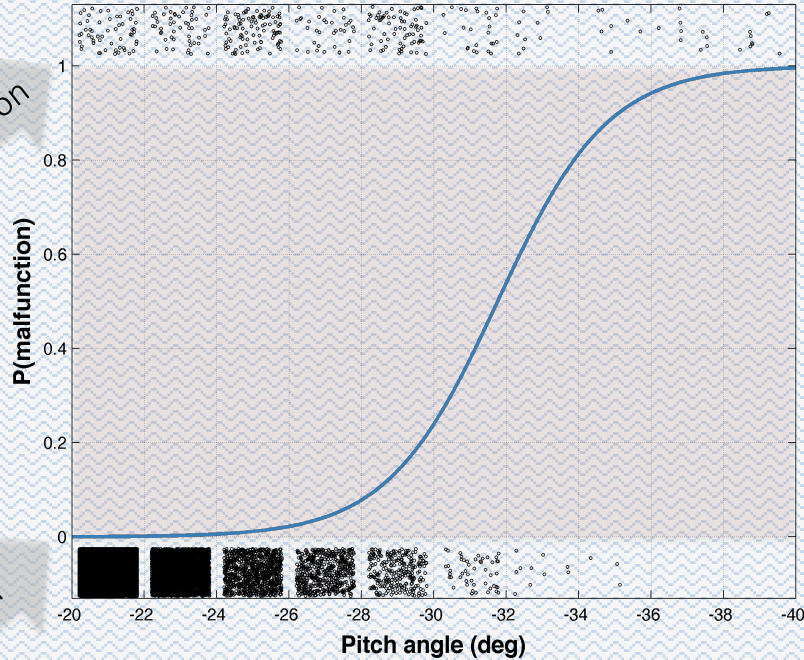
Logistic regression model (written in terms of the <i>logit</i> function)	$\ln\left(\frac{p(y=1)}{1-p(y=1)}\right) = \beta_0 + \beta_1 x$
Logistic regression model (written in terms of the <i>logistic</i> function)	$p(y=1) = \frac{e^{\beta_0 + \beta_1 x}}{1 + e^{\beta_0 + \beta_1 x}}$

Where p = probability, x = measurement variable and $\beta_{0,1}$ = regression coefficients

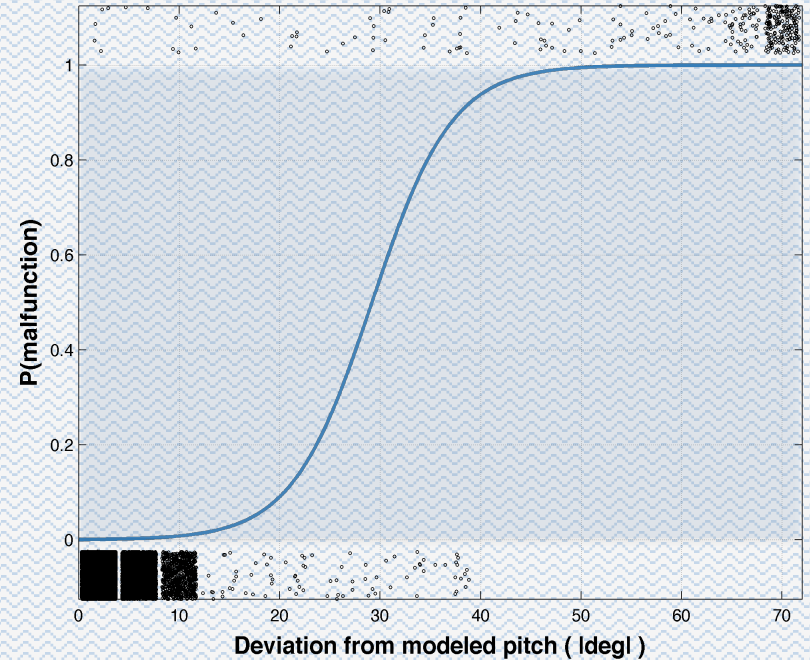


Binary classification

Fitted logistic regression curve - Empirical classifier



Fitted logistic regression curve - Simulator classifier



Classifier performance

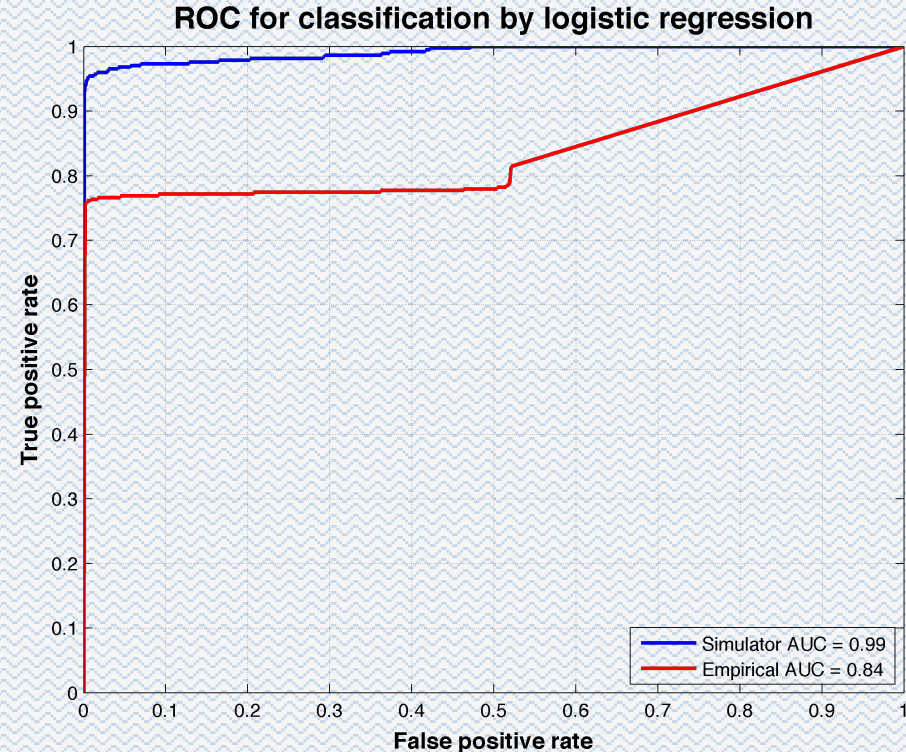
Receiver operating characteristic (ROC)

$$\text{TPR} = \frac{\text{true positives}}{\text{total actual positives}}$$

$$\text{FPR} = \frac{\text{false positives}}{\text{total actual negatives}}$$

Optimal operating point:

TPR	FPR	Threshold
0.9	0	0.17
0.747	0.001	0.0013



Conclusion

Framework for detecting anomalous vertical plane flight performance of LRAUV has been established

Simulator approach outperformed the empirical approach and offers a single classification solution for a wide verity of scenarios

While simulator requires complex fitting routines, the empirical classifier is simple to derive and will probably be easier to implement onboard LRAUV

Framework can be applied as powerful mission debriefing system



Acknowledgments

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Tomo Eguchi, NOAA

Brynn Kaufman, MLML

OSU

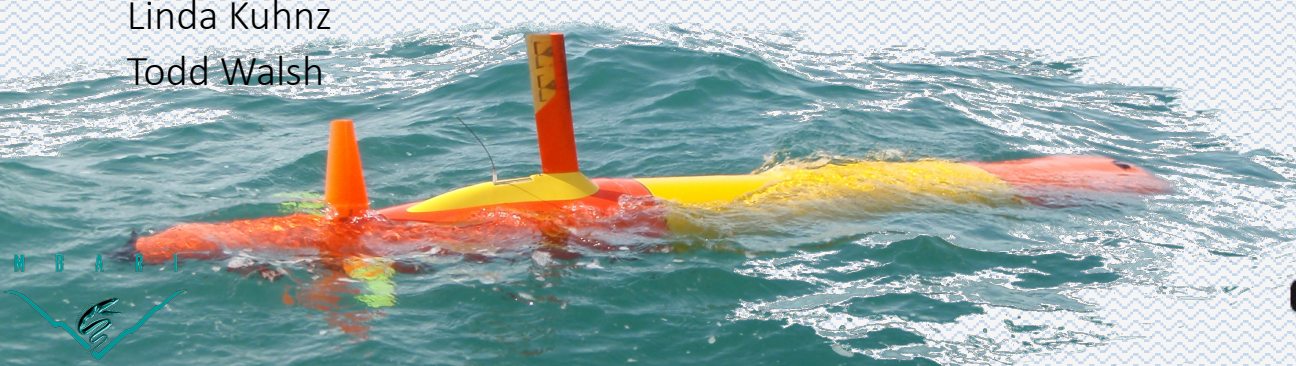
Mark Abbott

Will Dillon

Drew Gashler Memorial Internship



M B A R I



Oregon State
UNIVERSITY

OSU



Sources

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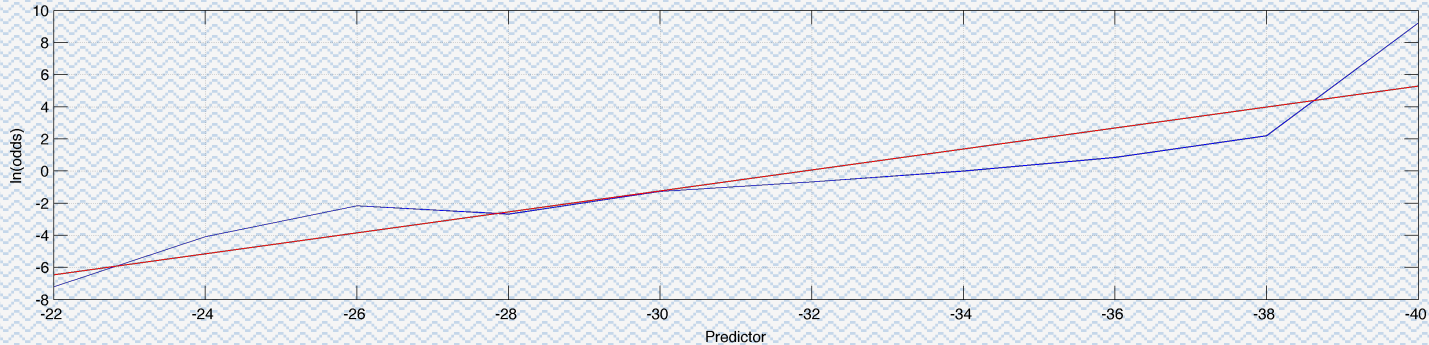
Prestero, Timothy Timothy Jason. *Verification of a six-degree of freedom simulation model for the REMUS autonomous underwater vehicle*. Diss. Massachusetts institute of technology, 2001.



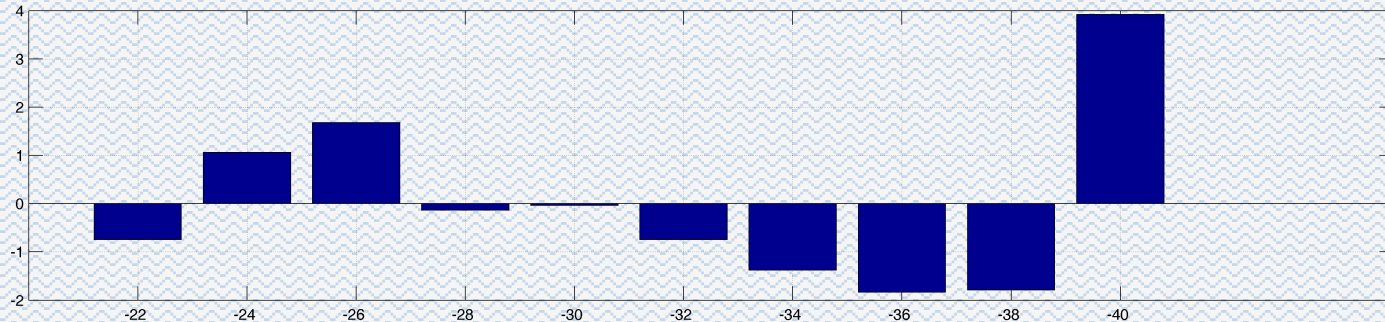
Binary classification

Empirical Logit:

$$\ln(p(y=1)/1-p(y=1)) = b_0 + b_1 x$$



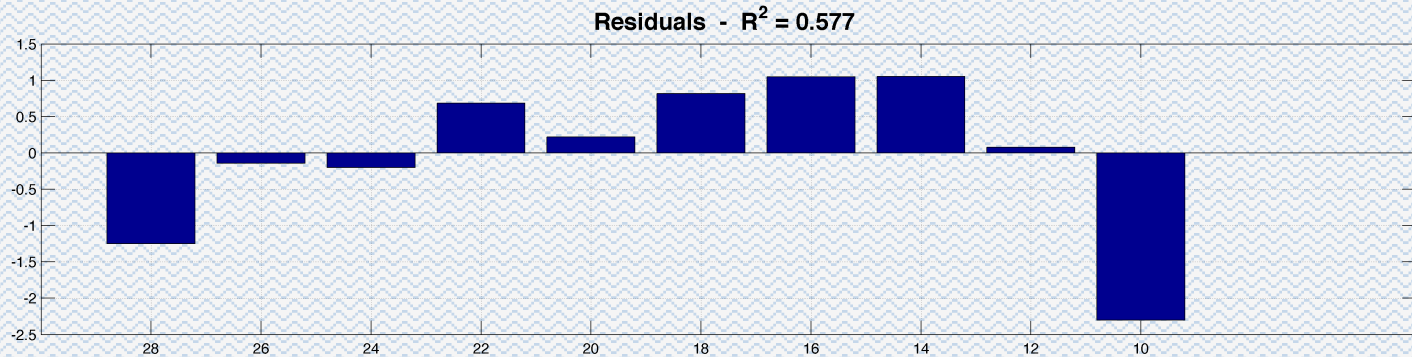
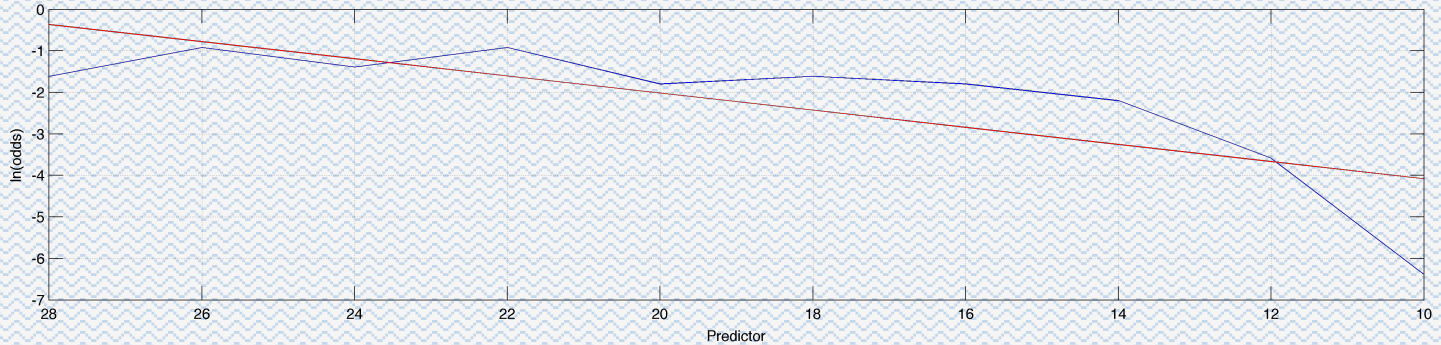
Residuals - $R^2 = 0.83$



Binary classification

Simulation Logit:

$$\ln(p(y=1)/1-p(y=1)) = b_0 + b_1x$$

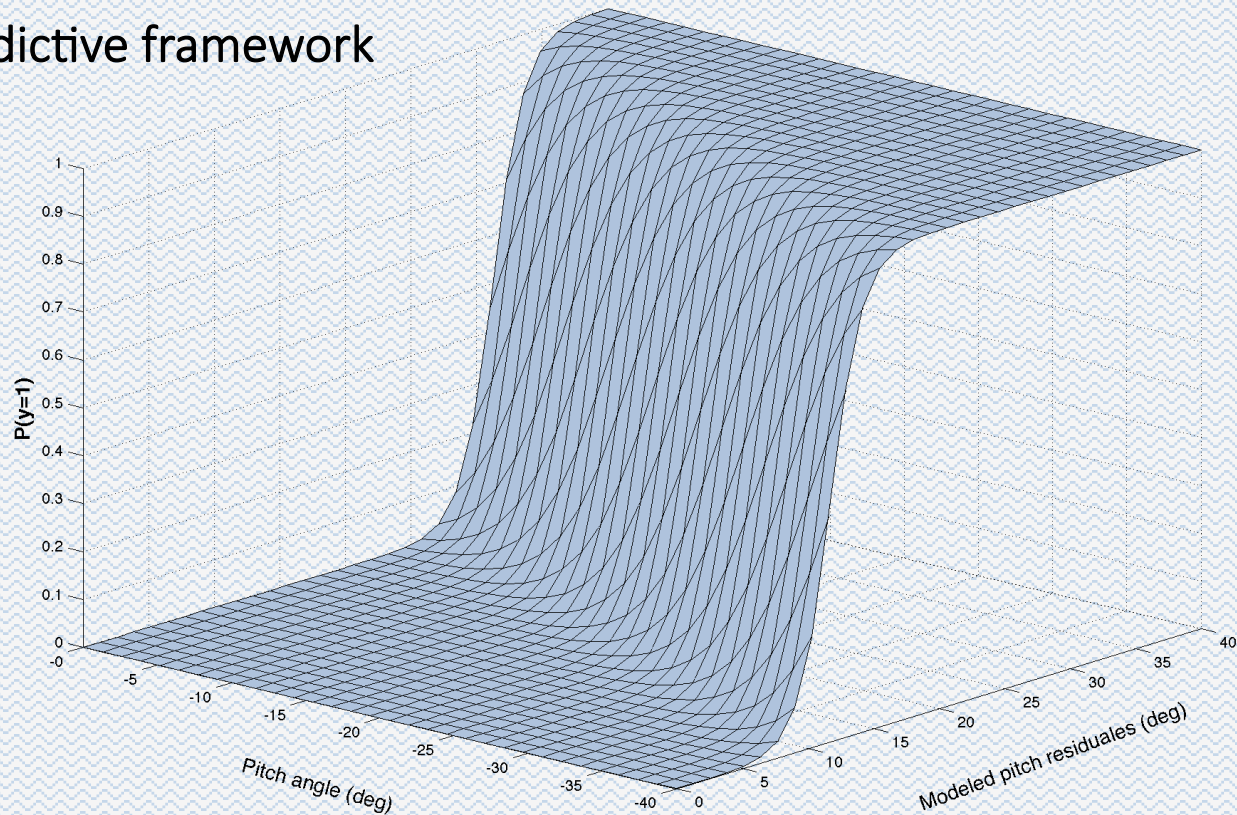


Binary classification

Logistic regression and predictive framework

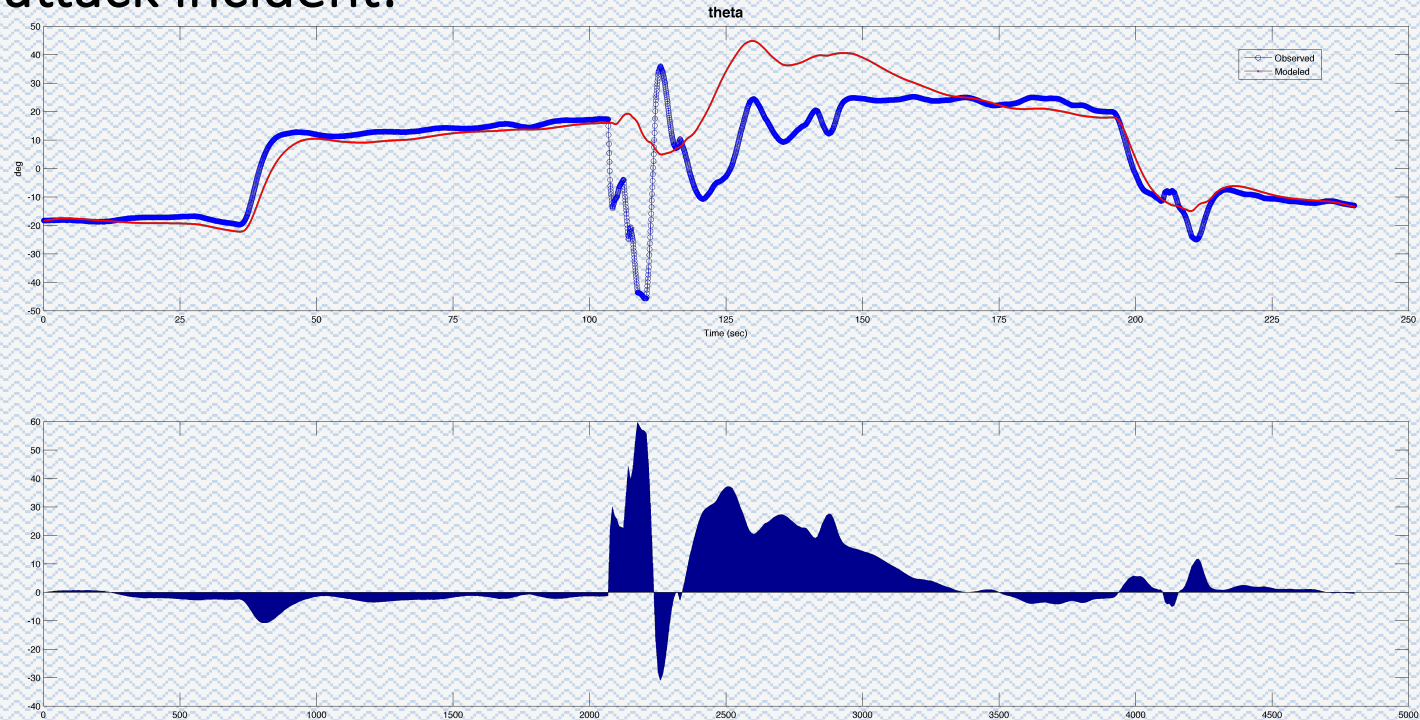
*Kruschke [2010] and Gelman and Hill [2007]

$$P(y=1) = \text{sig}(b_0 + b_1 * x_1 + b_2 * x_2)$$



Simulated predictors

Shark attack incident:



Fault database

Identifying past critical failures

CRITICAL fault message - rough syntax:

“[CBIT] (CRITICAL): <text> in component: <component name>”

“[<component name>] (CRITICAL): <text>”

Components that relate to vertical control:

'MassServo', 'ElevatorServo', 'BouyancyServo', 'VerticalControl', 'ThrusterServo', 'DropWeight'.

Others (indirect): 'Depth_Keller', 'DVL_micro'.

Extract using Linux command set – find | grep | egrp

Eliminate redundancy and sort chronologically | by component (MATLAB)

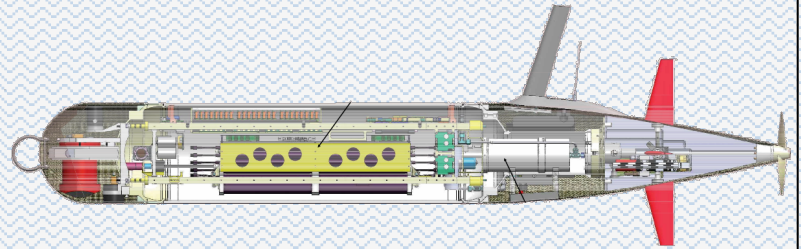
LRAUV

Tethys class long-range AUV

Tethys provides capabilities falling between existing propeller driven vehicles and buoyancy-driven vehicles (gliders)

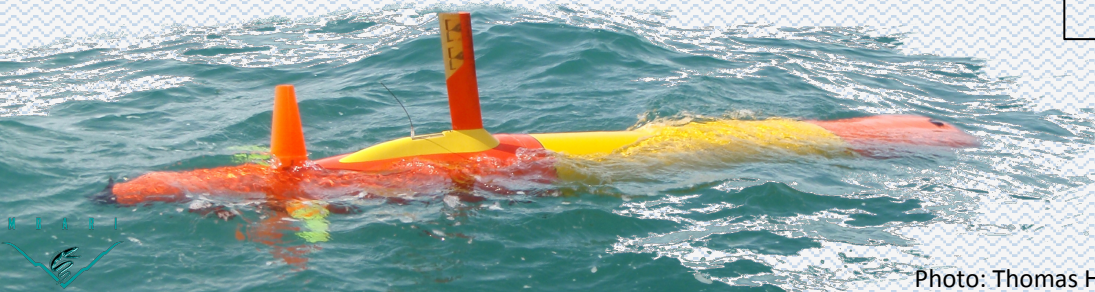
Supports an 8 watt biological and chemical sensor payload for distances in excess of 1000 km at 1 m/s

LRAUV is designed to be operated from shore like a glider, via an Iridium Satellite link



Tethys is capable of trimming to neutral buoyancy and drifting in a low power mode

Bellingham et al. 2010, Hobson et al. 2012



LRAUV

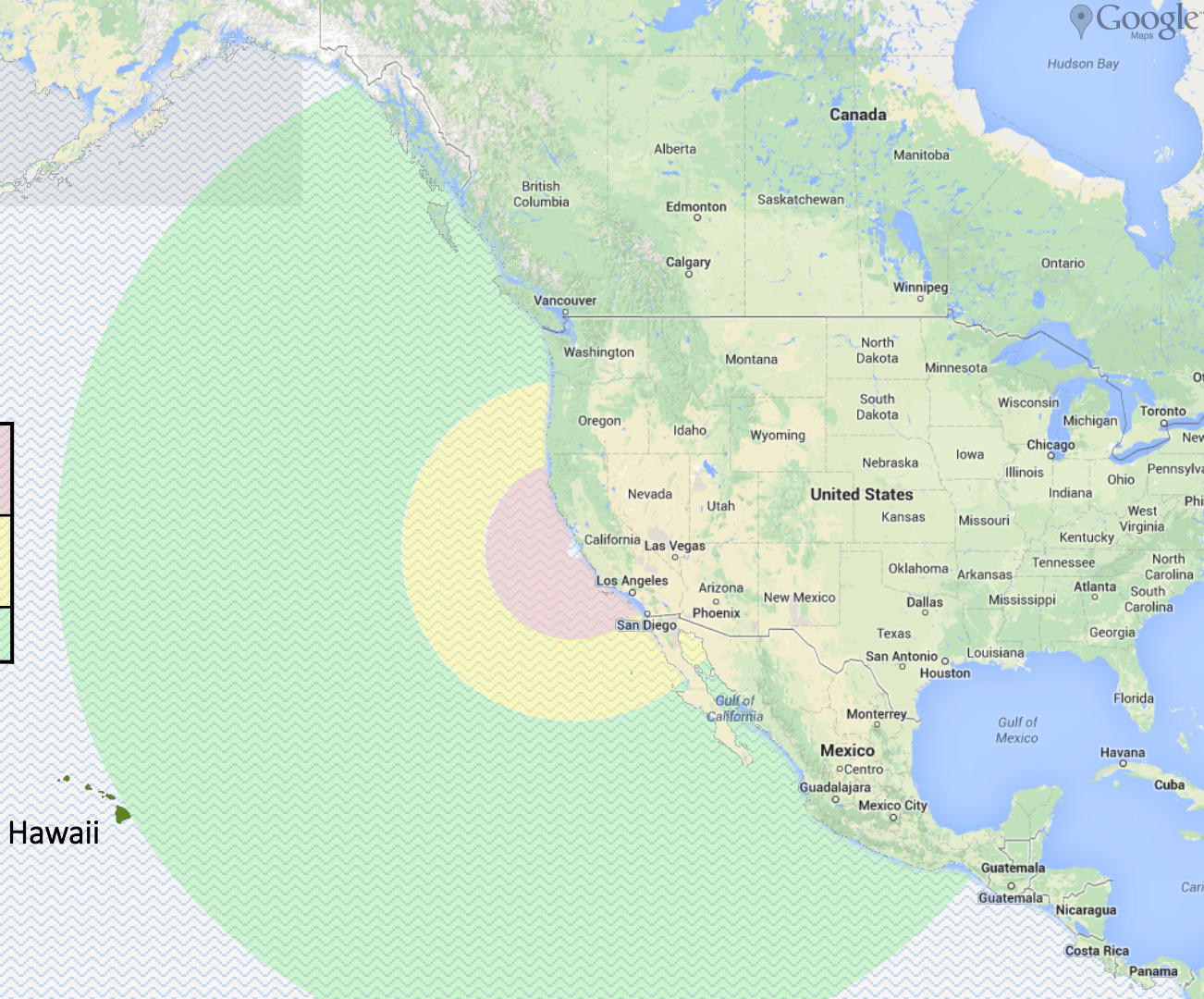
Studying phytoplankton
blooms from boom to bust

Rechargeable batteries	1 week	315 miles
Expendable batteries	3 weeks	945 miles
Goal	-	2300 miles

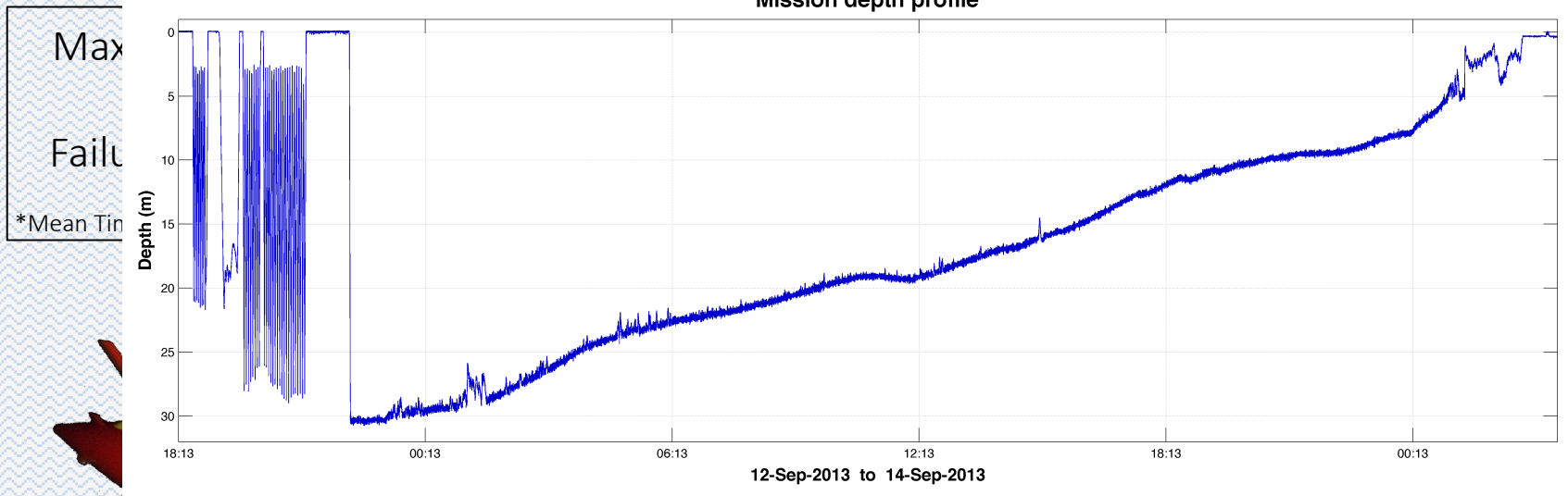
Hawaii



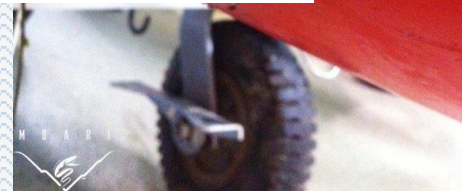
Slide credit: Thomas Hoover, MBARI



LRAUV failures



Tethys attacked by a Great
White
September 30th, 2013



LRAUV failures



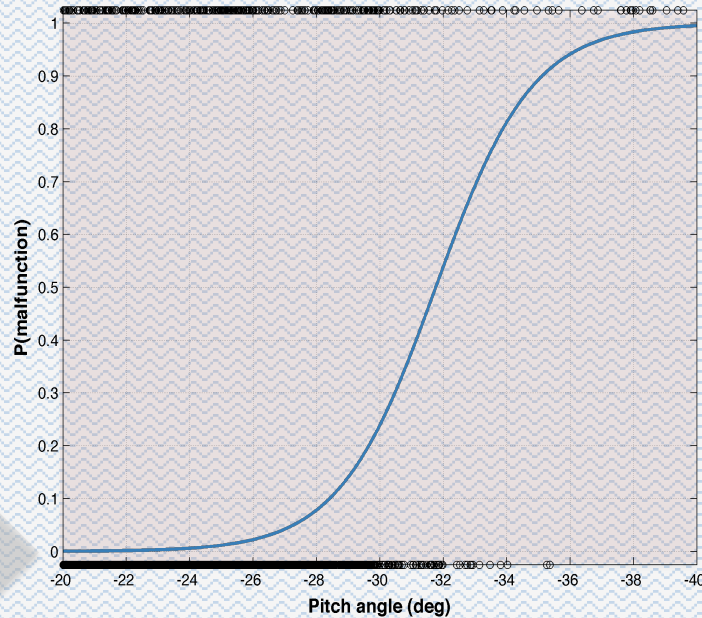
Photos: LRAUV group, MBARI



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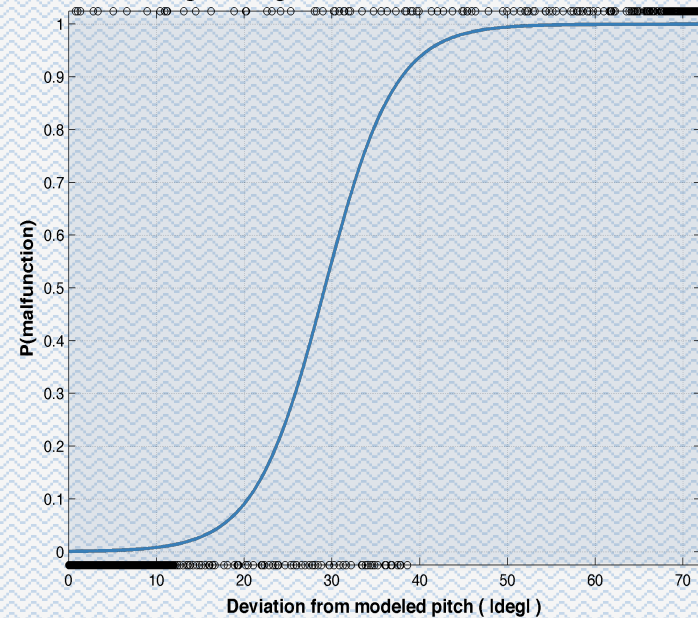
Binary classification

Fitted logistic regression curve - Empirical classifier



Normal

Fitted logistic regression curve - Simulator classifier



Malfunction

$$p(y=1) = \frac{e^{-7.325 + 0.251 \cdot (\text{Pitch})}}{1 + e^{-7.325 + 0.251 \cdot (\text{Pitch})}}$$

$$p(y=1) = \frac{e^{-20.816 - 0.655 \cdot (\text{Residual})}}{1 + e^{-20.816 - 0.655 \cdot (\text{Residual})}}$$

