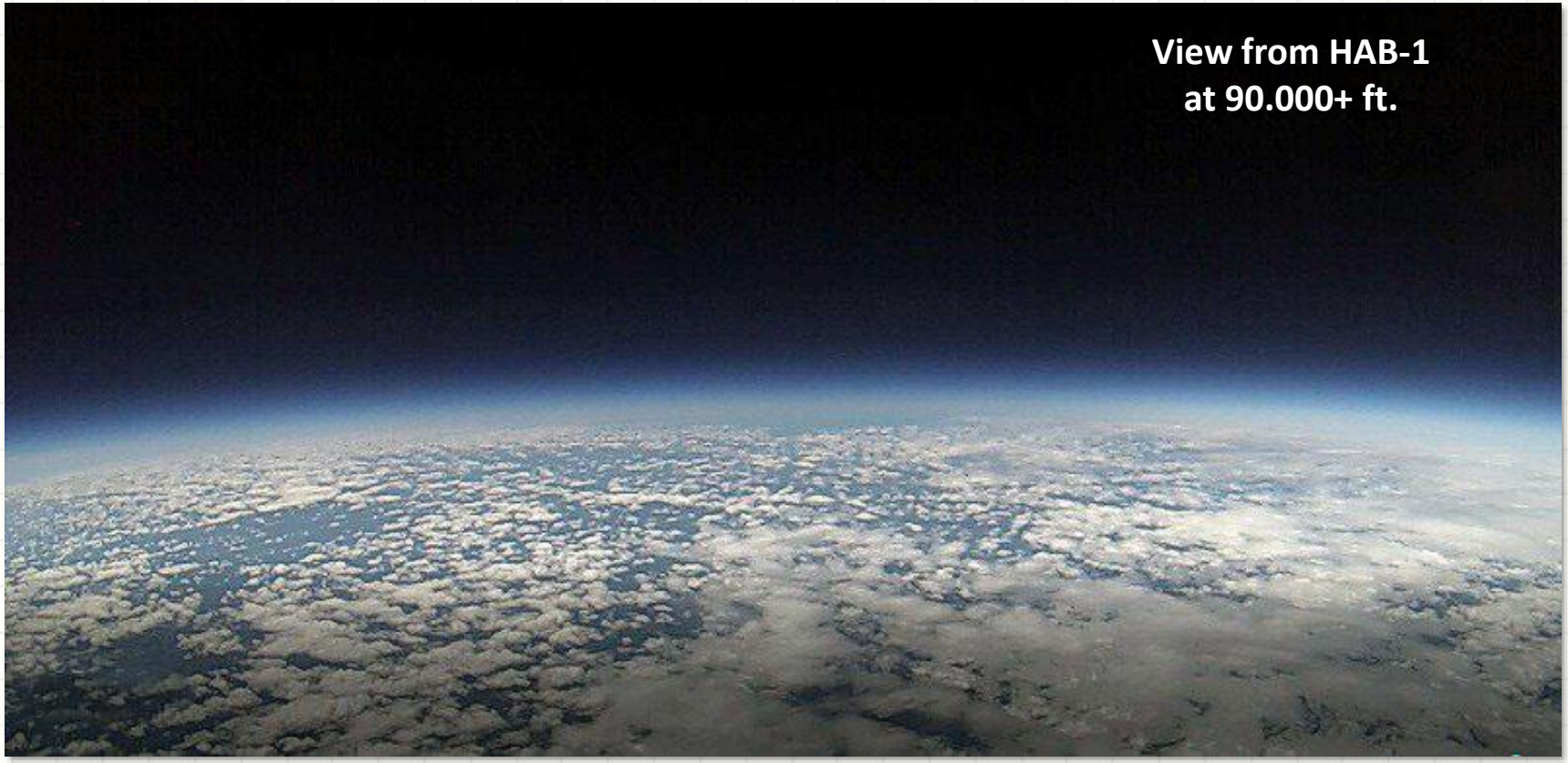
High Altitude Balloons – Amateur Radio at the Edge of Space

Nashua Area Radio Society Tech Night

HAB Project Team

December 12th, 2017

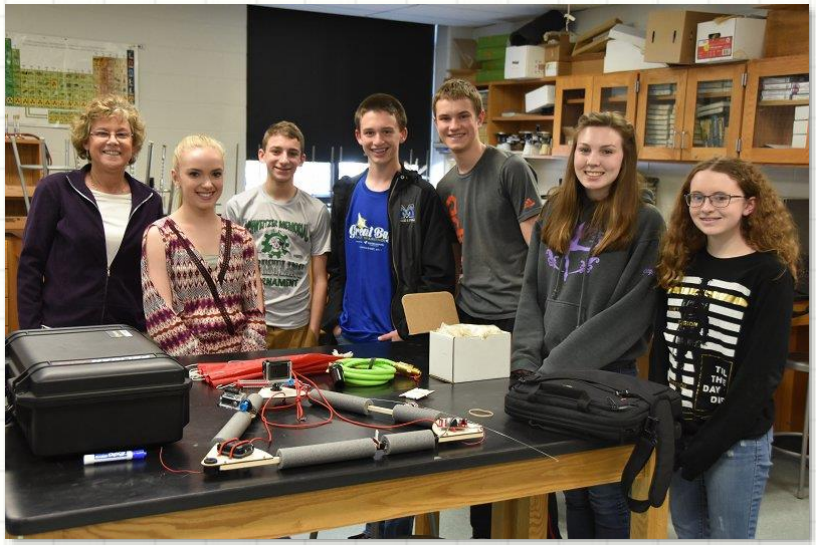
Topics



- Project Goals & Overview - Fred
- HAB Platform Overview – Fred
- HAB Flight Design & Planning – Fred
- HAB Radio Technology (APRS & GPS) – Tony
- HAB Preparation and Launch - Anita
- HAB Flight Data Analysis - Brian
- Tracking and Recovery – Jamey & Curtis
- Learnings & Goals for Future Flights

Our Students and Teachers

Bishop Guertin HS
STEM Club

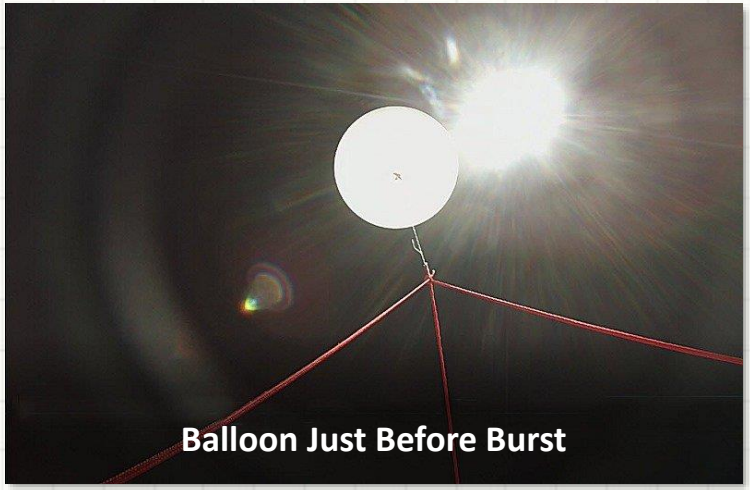


Merrimack HS
Physics Students

Independent Students

HAB Projects

What Our Students Do



- Determine flight parameters for Helium Balloon Platform < 4 lb.
  - Target altitude: 100,000 ft. or more
  - Parachute controls decent after balloon bursts
- Launch and Track HAB via the Internet using on-board 2m APRS Radio Transmitter
  - Flight computer records data throughout the flight
- Capture Video of flight using on-board GoPro Cameras
- Analyze HAB telemetry and sensor data to learn about the atmosphere
- Hands-on activities included –
  - Making HAB flight design decisions
  - Planning the flight path
  - Planning science experiments
  - Testing the payload
  - HAB launch, tracking & recovery
  - Amateur Radio open house
  - Helping to define our goals for additional launches

STEM Learning Outline

Flight Physics

Required Helium (in cubic feet)

124.38834896598486

Estimated Burst Altitude (in meters)

31290

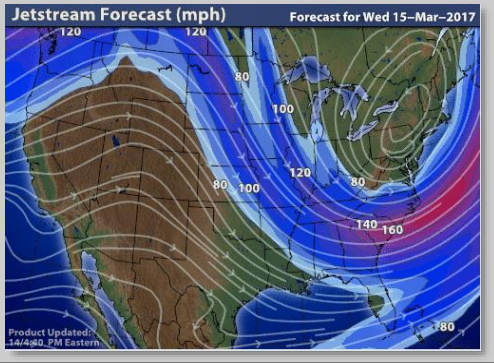
Average Ascent Rate (in meters/second)

5.240119821856709

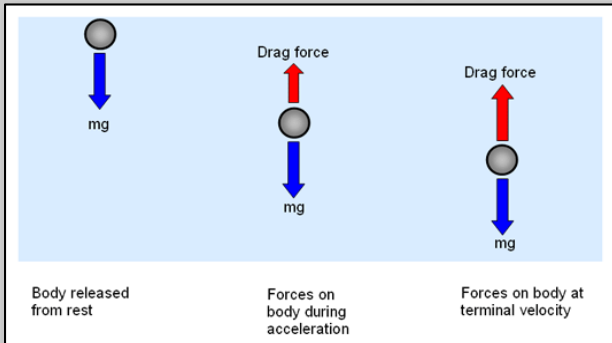
Ascent Time (in minutes)

99.52062504845914

Atmospheric Sci.



Terminal Physics



Atmospheric Science, Balloon Physics and Flight Path Predictions

Radio Telemetry and Sensor Technology

Launch Preparations and Filing a Flight Plan

Space Communications

Launch and Track HAB jointly with additional Schools

Open House at Member's Station to Explore Amateur Radio

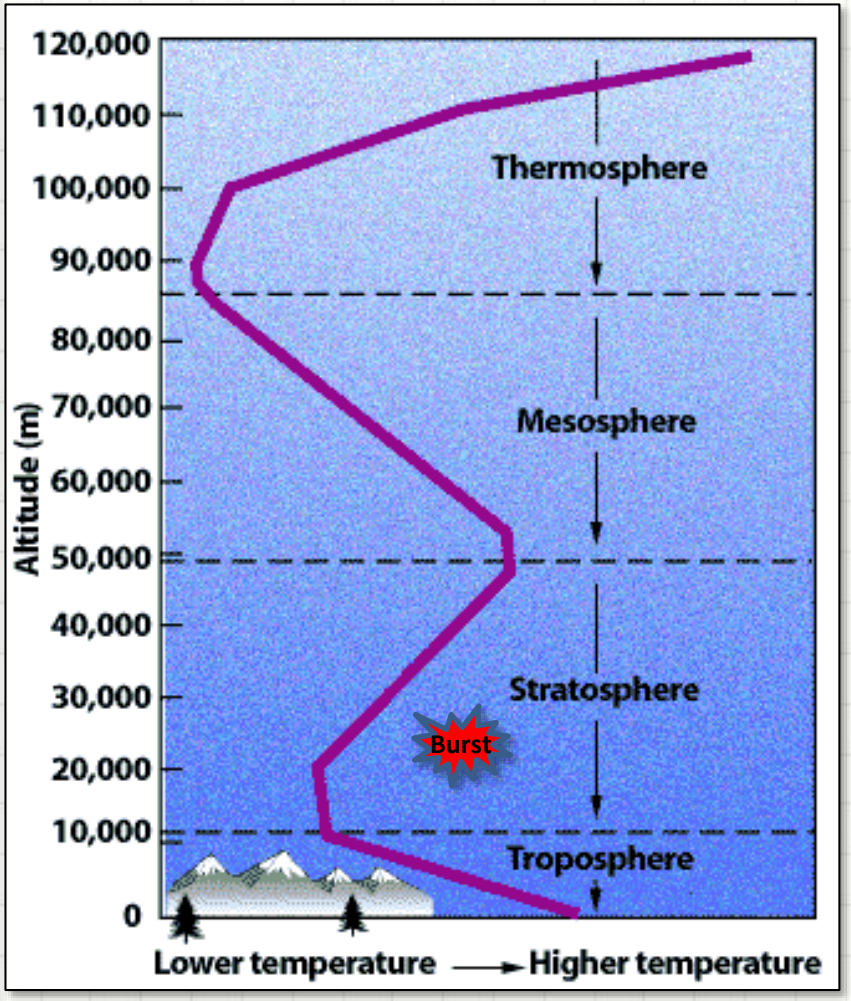
Post-flight Data Analysis and Project Report

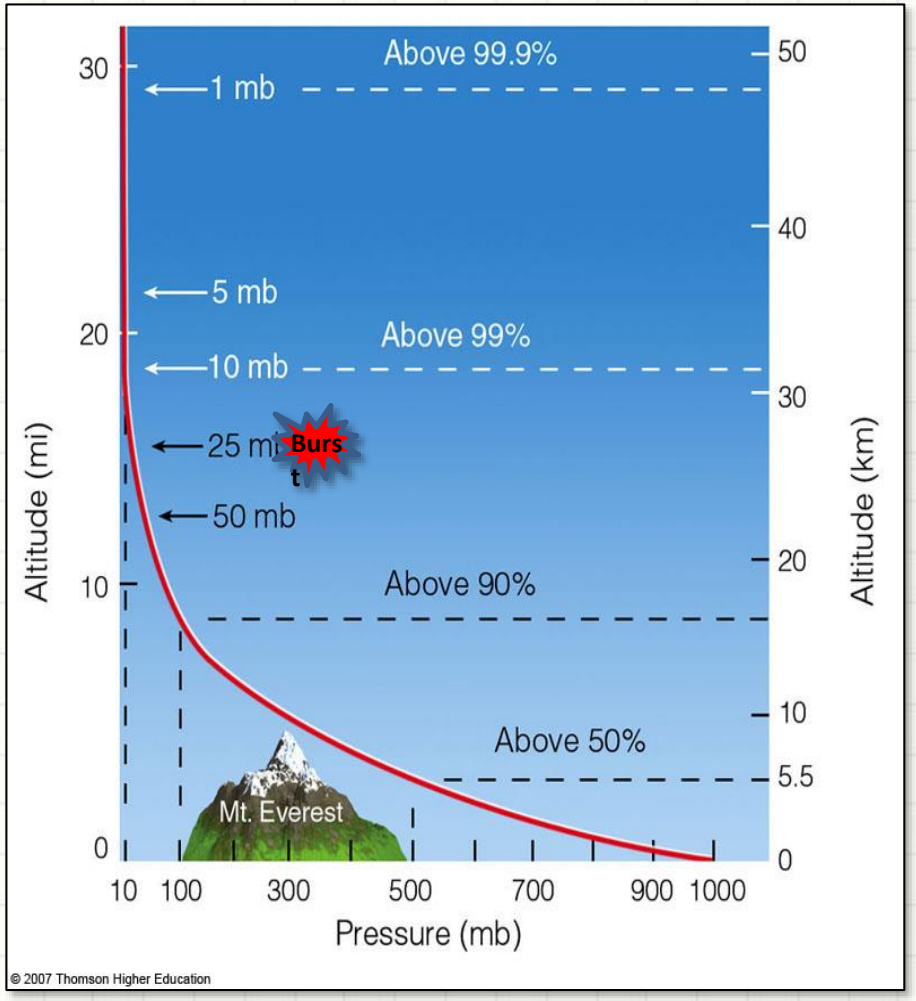
Activity Key

- Pre-Flight Classroom
- Launch Window
- Post-Flight

Atmospheric Science

Example STEM Learning Topics – Temperature and Pressure





HAB Sensors Measure Temperature and Pressure Enabling Students to Compare Actual Flight Conditions to Models

HAM Station Visit

What students see & do

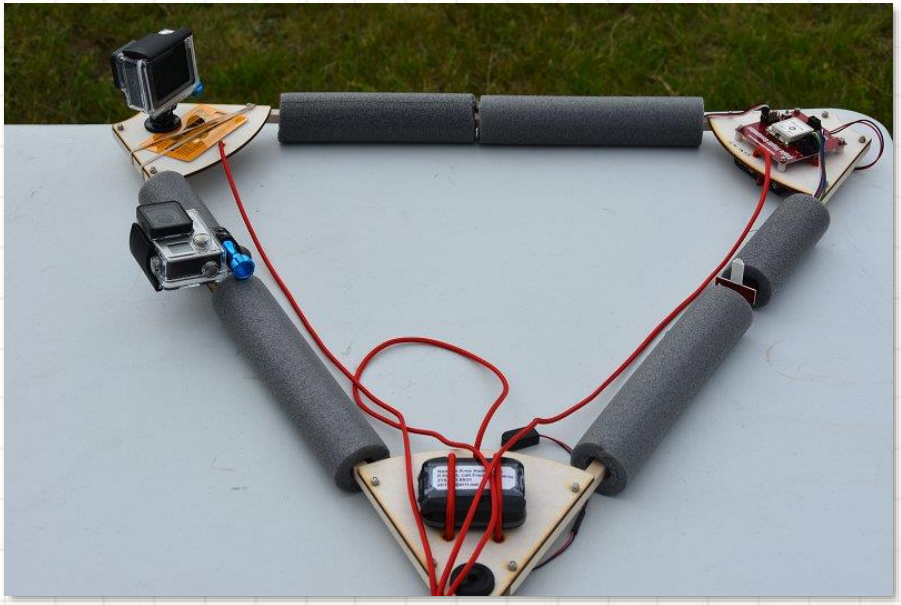
- Tour an Amateur Radio station and learned about Amateur Radio Communications
- Get on the air and talked to Amateurs around the world
- Do Fox Hunts to locate a hidden radio transmitters
- Talk about what's involved in getting a Ham Radio License
- Celebrate their successful HAB Flight!

High-Altitude Balloon Platform Overview

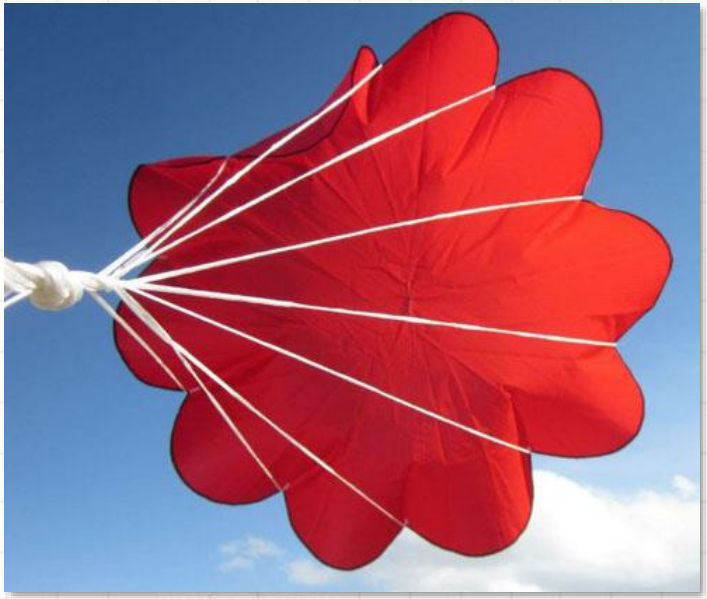
High Altitude Balloon

Our Approach

HAB During Ascent



Flight Platform & Parachute



High Altitude Balloon Project

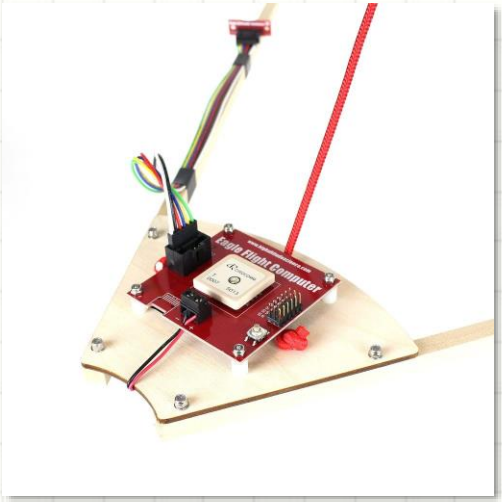
Weather Balloons

Large Balloon
(6-8 ft in diameter on ground)

Burst Diameter
(30+ ft at final altitude)

HAB Flight Platform

Lightweight Components



Flight Computer

GoPro Cameras

APRS Transmitter

Commercial Satellite Tracker

HAB Flight Design and Planning

Predicting the HAB's Flight Path

Balloon Calculator

Required Helium (in cubic feet)

124.38834896598486

Estimated Burst Altitude (in meters)

31290

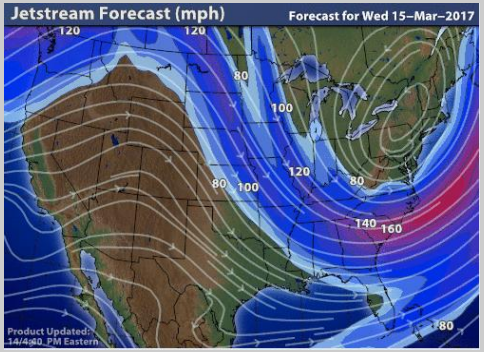
Average Ascent Rate (in meters/second)

5.240119821856709

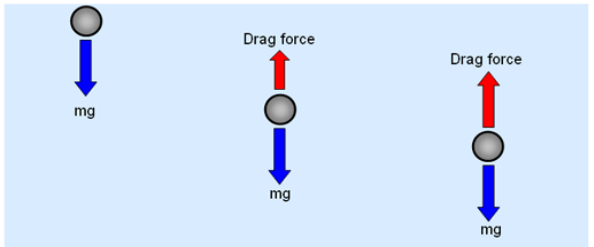
Ascent Time (in minutes)

99.52062504845914

Jetstream



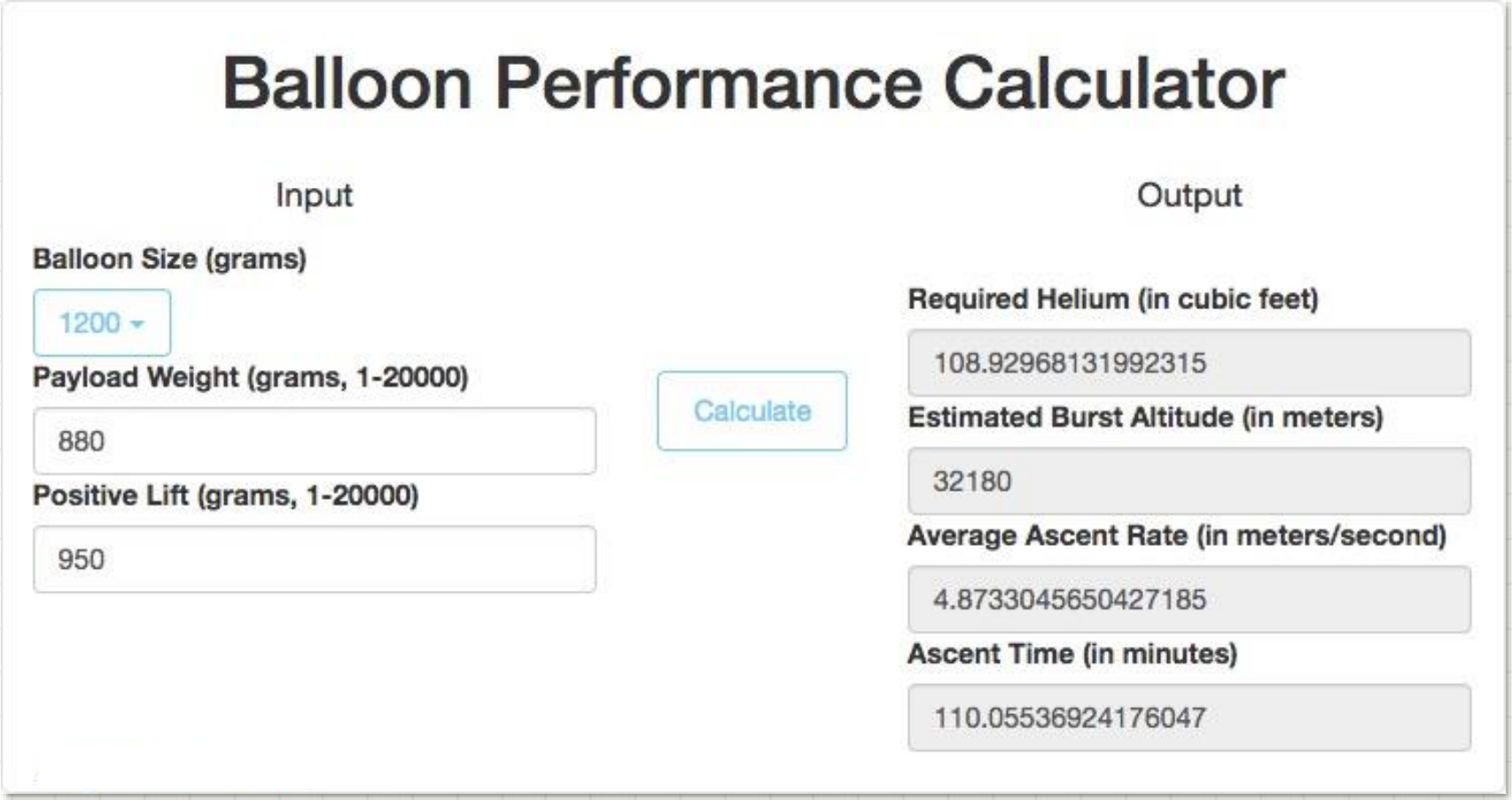
Terminal Velocity



Flight Path Predictions

We Use Calculators to Plan Our Flights

HAB-2 Final Parameters

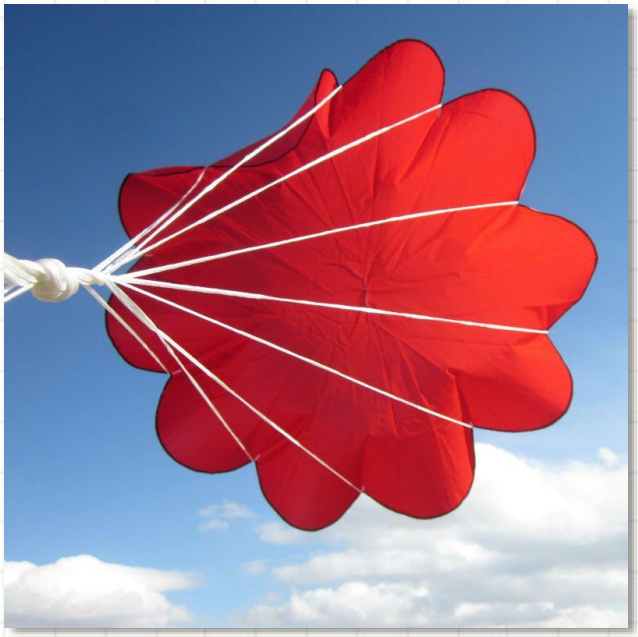


HAB-2 Predicted Burst Altitude was +105,000 ft (~ 20 mi)

Balloon Performance Calculator

Descent Planning

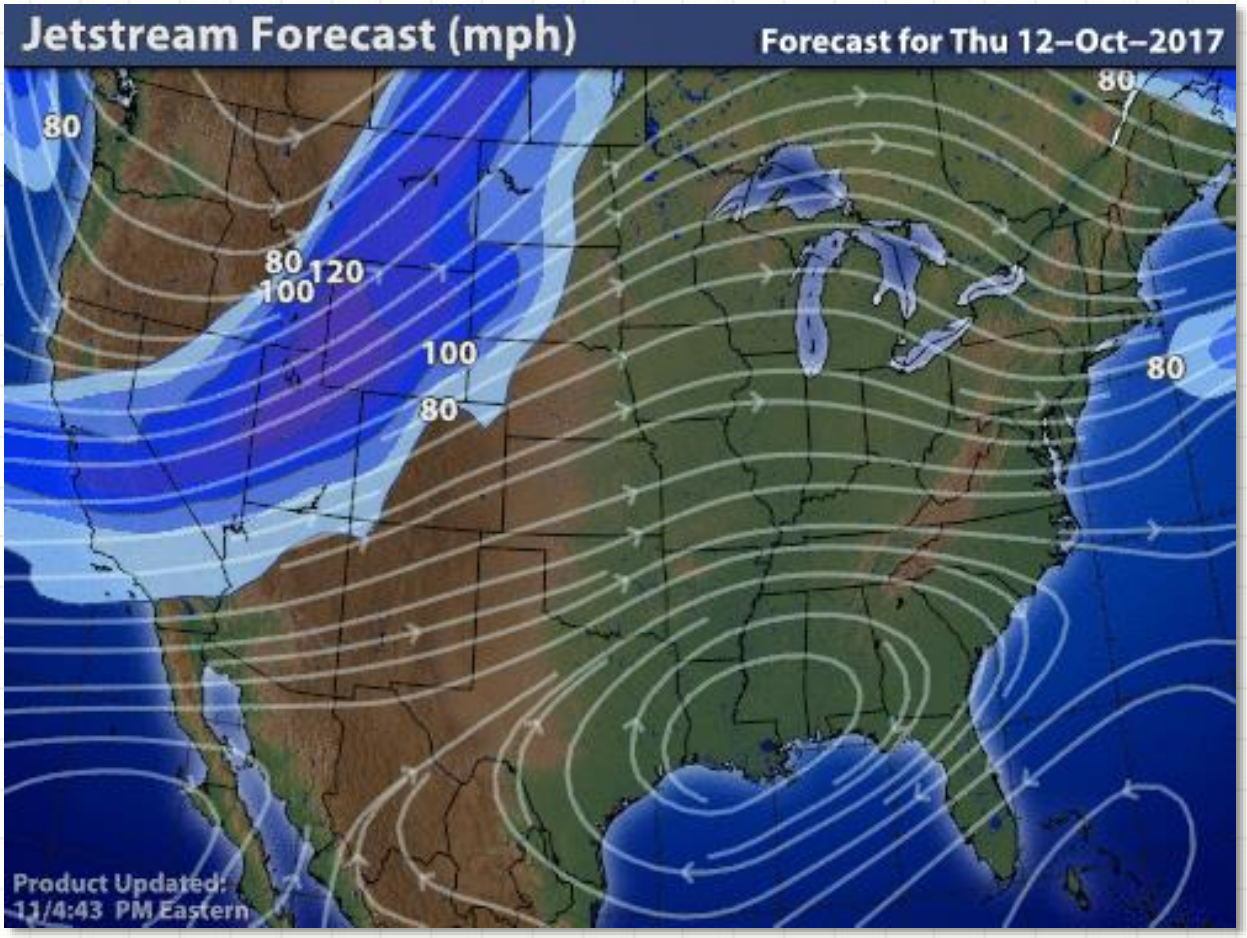
HAB-2 Example



Payload Weight	Landing Speed	Decent Time from 100,00 ft
0.6 kg / 1.3 lb	4.8 m/s ~ 11 mph	50 minutes
0.8 kg / 1.8 lb	5.5 m/s ~ 12 mph	44 minutes
1.0 kg / 2.2 lb	6.2 m/s ~ 14 mph	39 minutes
1.2 kg / 2.6 lb	6.8 m/s ~ 15 mph	36 minutes
1.4 kg / 3.1 lb	7.3 m/s ~ 16.3 mph	33 minutes

Balloon grows to over 30 ft and bursts.
Parachute limits descent speed to 12 – 14 mph

Jetstream Conditions Play a Major Role



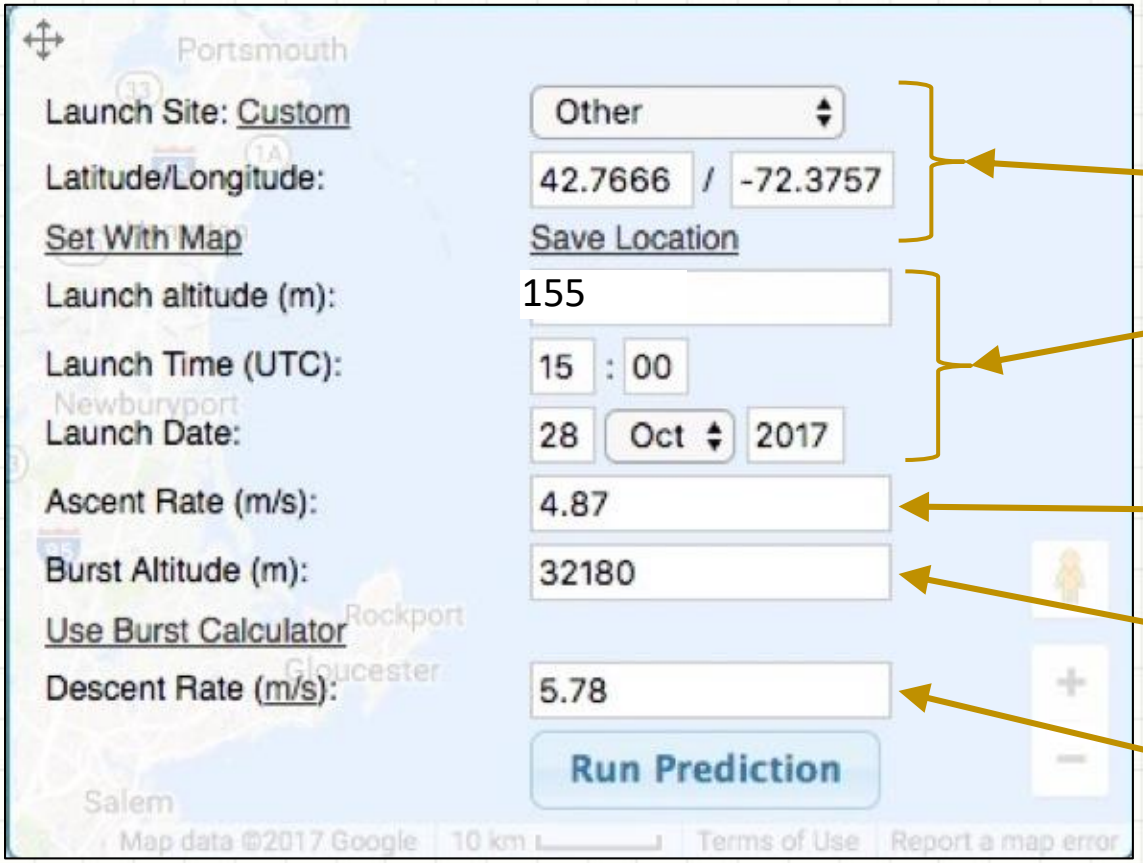
[Current Jetstream Forecast]

We have to wait for favorable Jetstream conditions to avoid landing in the Atlantic Ocean

Flight Planning

Path Calculator

Path Calculator Input Window



Define launch location

Launch date and time

Average ascent speed

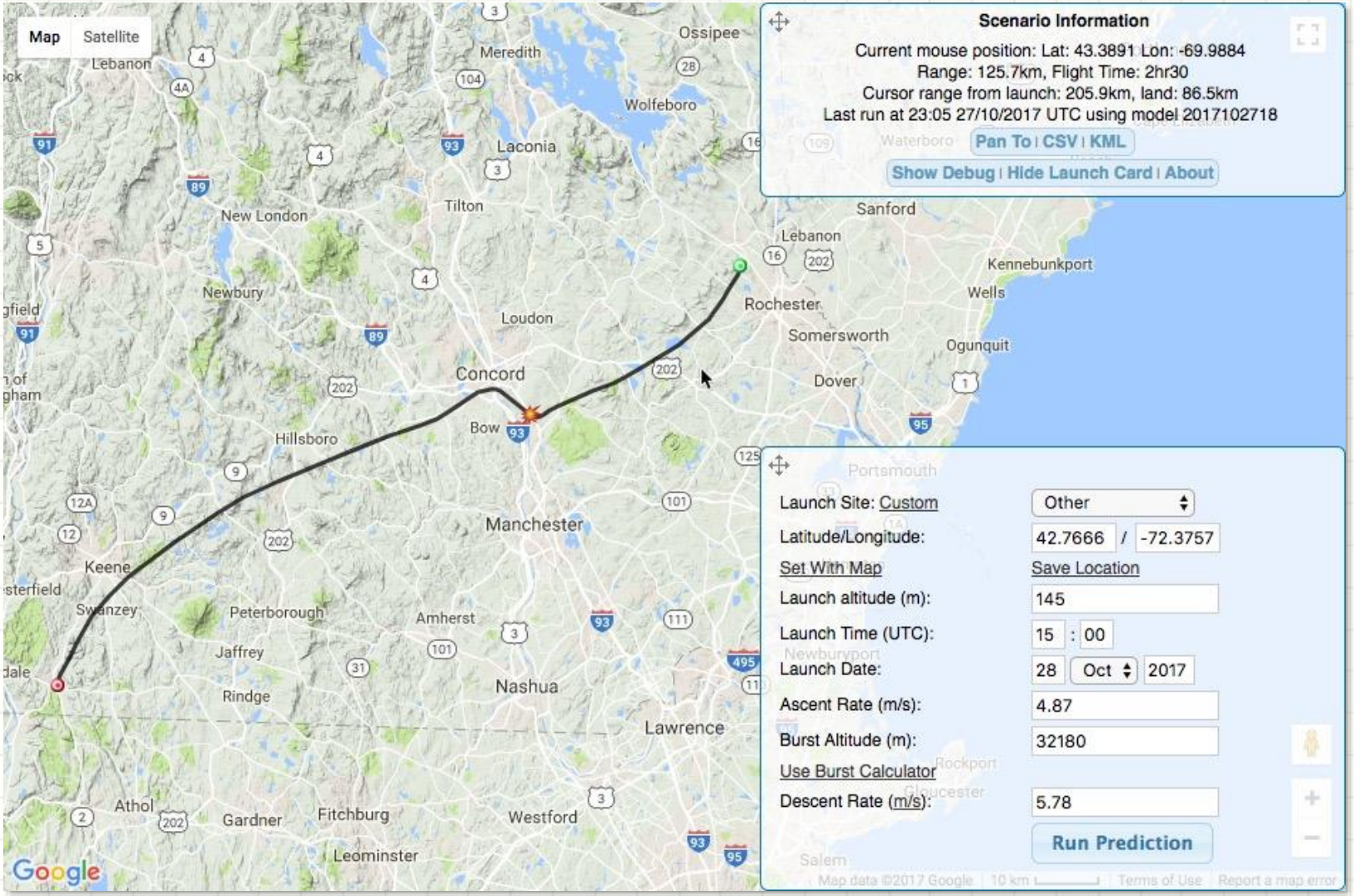
Burst altitude

Descent rate (at impact)

Launch Site: Winchester, NH elem. School: Lat = 42.7666 / Lon = -72.3757

Modeling Used to Predict Flight Path

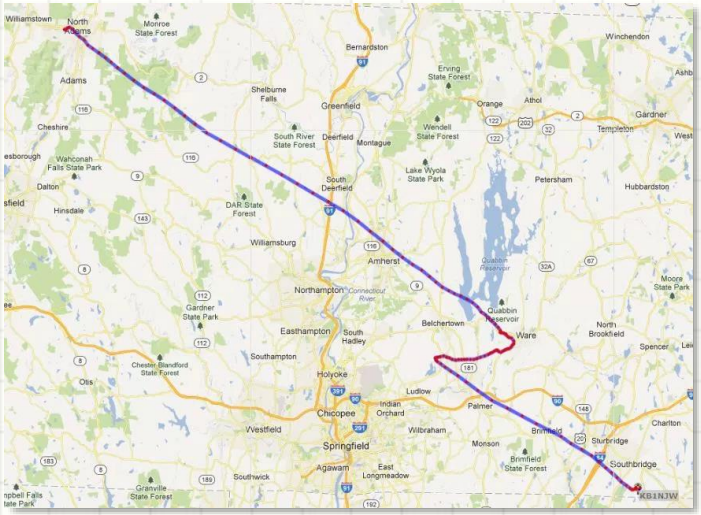
HAB-2 Example



Predicted HAB-2 Landing Near Rochester, NH

HAB Radio Technology – APRS and GPS

Tracking the HAB



Predictions

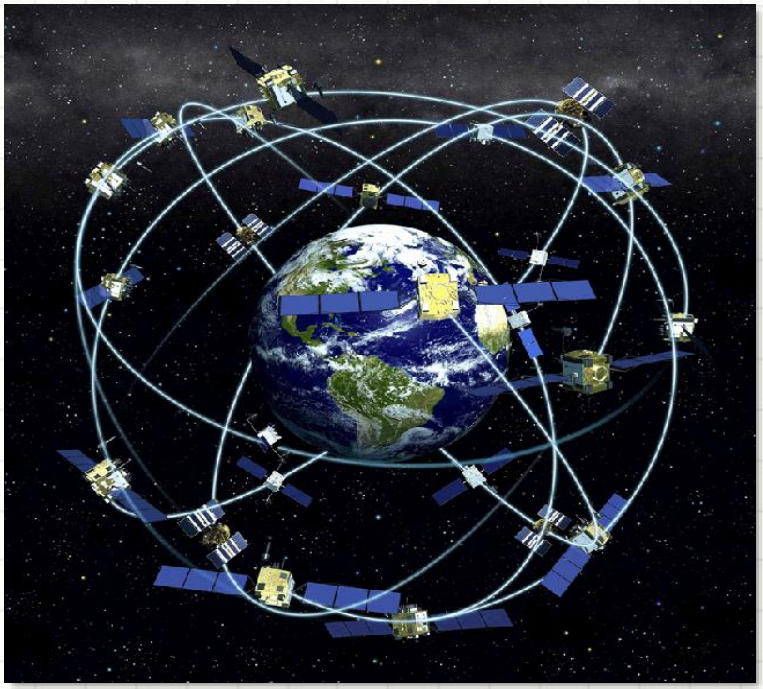
- We can use physics to predict the HAB's flight altitude and path
- On board radios provide actual position to ground stations for tracking
- **GPS = Global Positioning System**: HAB location and altitude
- **APRS = Automatic Position Reporting System**: Relays GPS data to ground stations
- Contact the FAA to alert them of our plans

GPS

APRS

GPS Satellites

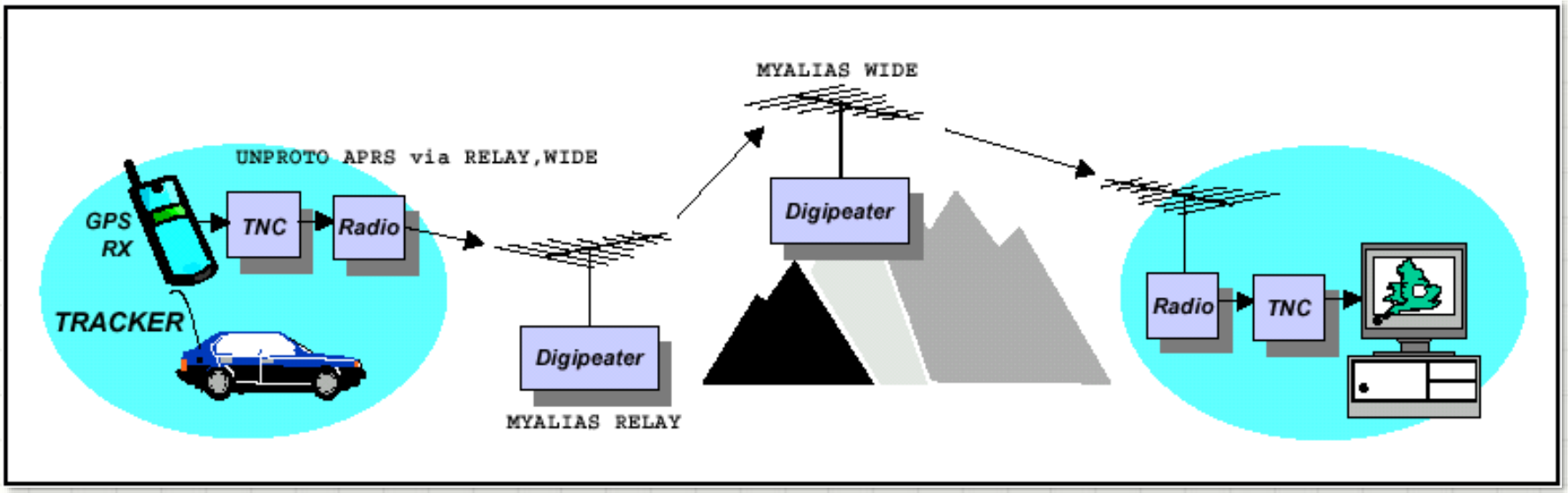
- GPS is a network of 31 Satellites orbiting at ~20,000 km
- Developed for US military navigation, now used by everyone



- Anywhere on the planet there are at least four GPS satellites visible
  - 3 Satellites required to fix your position on the earth
  - 4 Satellites required for clock deviation correction (1 additional)
- GPS device uses a process called **Trilateration** to fix your position

Transmiting APRS Information

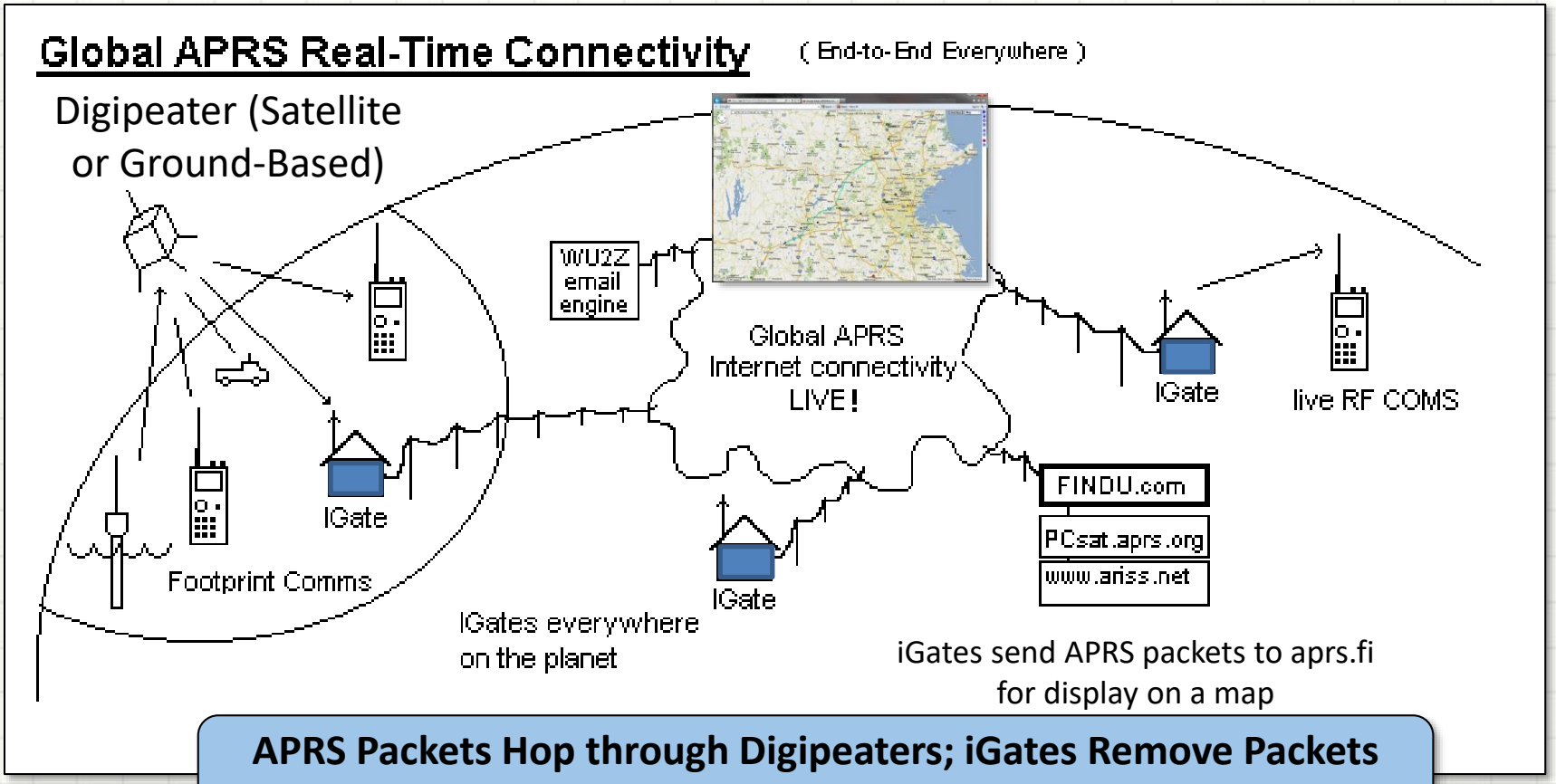
Using Radio Frequency = 144.390 MHz



Amateur Radio Ground-based *Digipeaters* listen for APRS packets on 144.390 and forward them

APRS Network

Forwarding Position Data to Internet/aprs.fi



APRS Packets Hop through Digipeaters; iGates Remove Packets from the APRS Network and Forward Them to http://aprs.fi

Altitude	Path	Path Description
Under 3000 m	WIDE1-1, WIDE2-2	Packet repeated up to three times.
Between 3000 and 5000 m	WIDE2-2	Packet repeated up to two times.
Above 5000 m	WIDE2-1	Packet repeated up to one time.

APRS Packets

Station Service Set Identifiers (SSIDs)

Emergency Go Kit (ex. AB1OC-4)

iPhone APRS Station (ex. AB1OC-5)

Handheld Transceiver or HT (ex. AB1OC-7)

iGates (ex. AB1OC-10)

Our HAB is a Balloon (ex. N1FD-11)

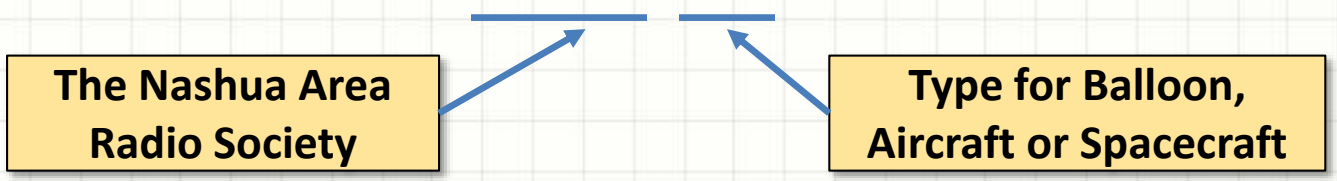
SSID	Description
-0	Your primary station usually fixed and message capable
-1	Generic additional station, digi, mobile, wx, etc
-2	Generic additional station, digi, mobile, wx, etc
-3	Generic additional station, digi, mobile, wx, etc
-4	Generic additional station, digi, mobile, wx, etc
-5	Other networks (Dstar, Iphones, Androids, Blackberry's etc)
-6	Special activity, Satellite ops, camping or 6 meters, etc
-7	Walkie talkies, HT's or other human portable
-8	Boats, sailboats, RV's or second main mobile
-9	Primary Mobile (usually message capable)
-10	Internet, Igates, echolink, winlink, AVRS, APRN, etc
-11	Balloons, aircraft, spacecraft, etc
-12	APRStt, DTMF, RFID, devices, one-way trackers*, etc
-13	Weather stations
-14	Truckers or generally full time drivers
-15	Generic additional station, digi, mobile, wx, etc

APRS SSID tells us what type of device we are tracking.

APRS Packets

HAB Packets (From a HAB Test Session via aprs.fi)

- **Call Sign** – identifies the person or group licensed to transmit
  - May include information about the type of station they are using

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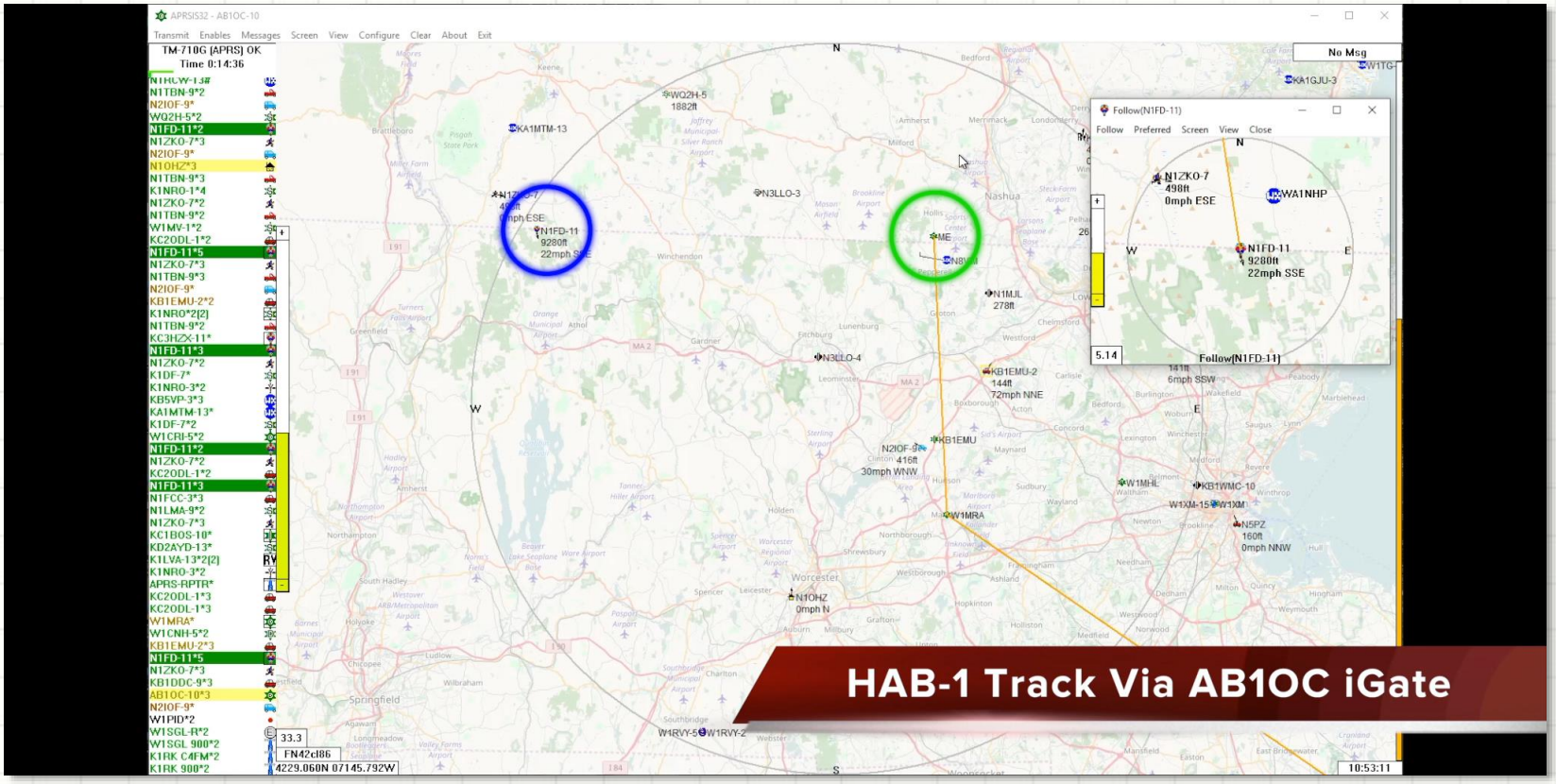
Actual Packets from our HAB during a test

APRS Network Operation

APRS iGate Video

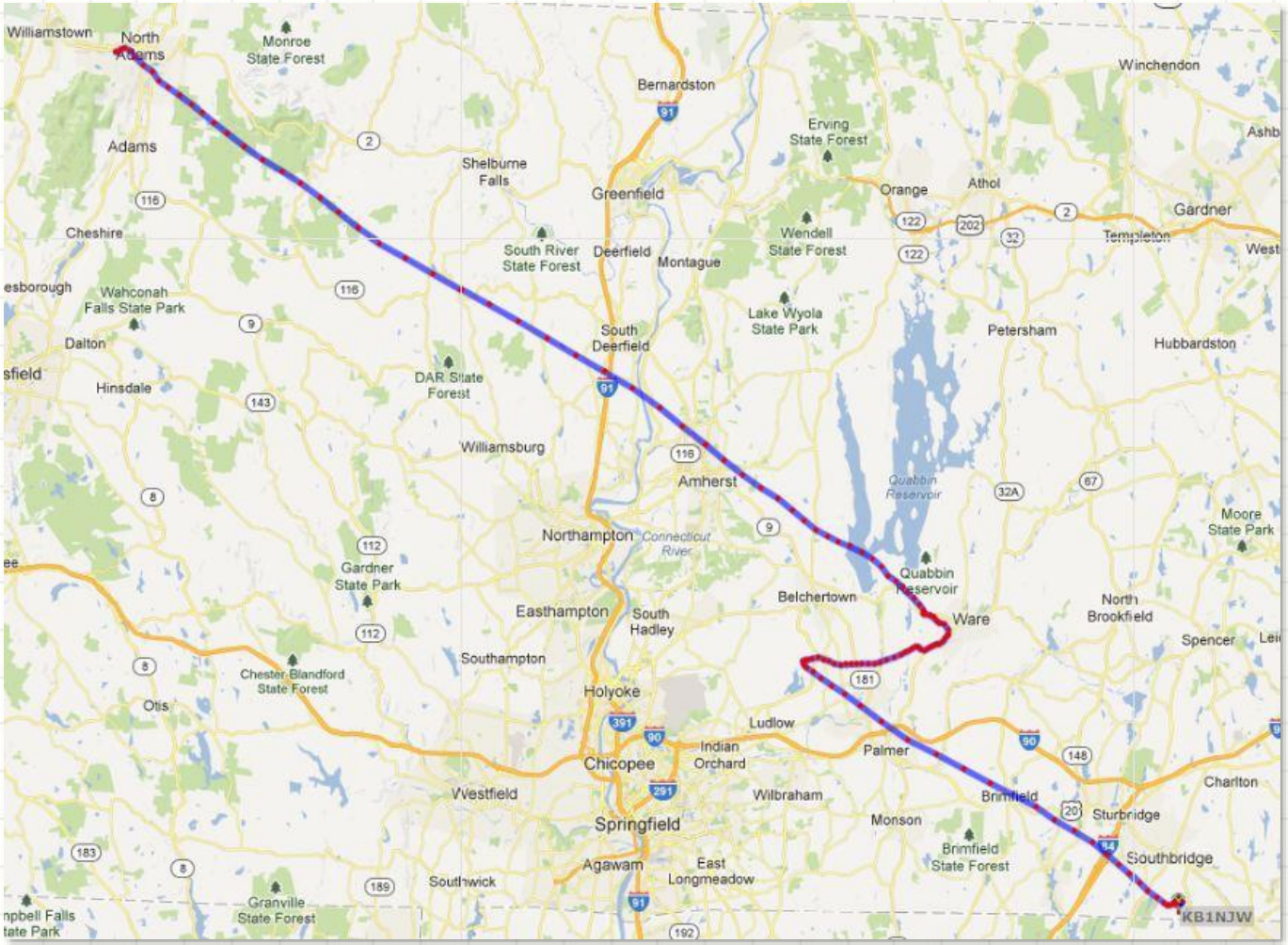
Digipeaters and iGates Relay Information to The Internet



Actual APRS Network Operation (Speed 20X Real-Time)

HAB-1 Actual Flight Path

Tracking via On-Board Radio Transmitter (144 MHz APRS)

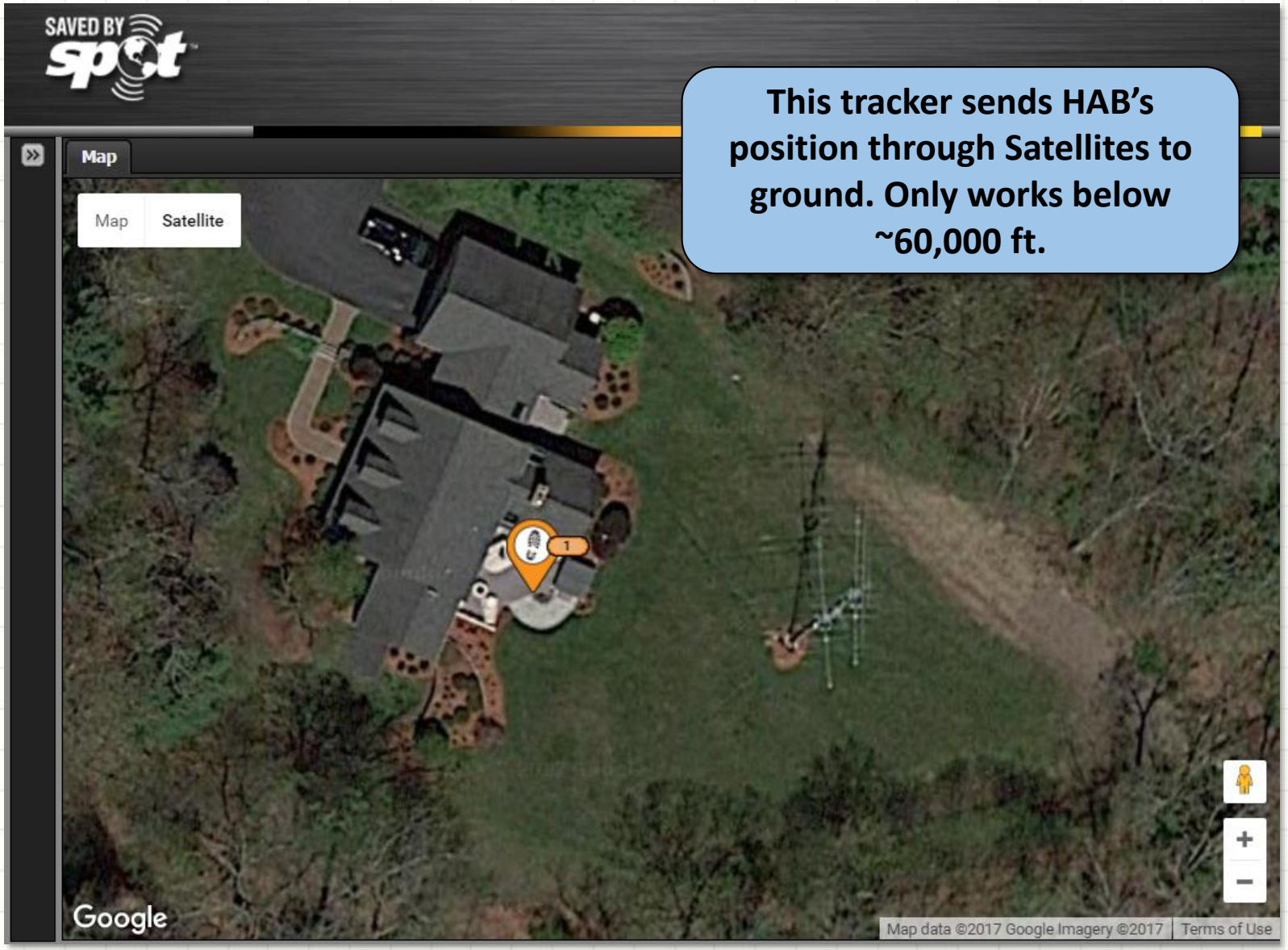


Can Track with Cell Phones, Tablets, anything with a Web Browser

(Actual High-Altitude Balloon Track from aprs.fi)

Satellite Tracker

Backup to APRS - See HAB's Current Location



HAB Final Preparation and Launch

Steps In Launching a HAB

Pre-Launch Checklist

- ✓ Secure permission for multiple launch sites
  - Bennington, VT; Winchester, NH; Hollis, NH
  - Flight predictions 2 days before launch select site
  - Consider ground wind impacts
- ✓ Flight plan filed with FAA afternoon before launch
- ✓ Test all systems a few days before launch; change/charge batteries
- ✓ Safely transport gear to site
- ✓ Build Flight Line
- ✓ Test Radios, Flight Computer and GPS systems
- ✓ Inflate Balloon
- ✓ Start Cameras and Final Electronics Check
- ✓ Launch!

FAA Notification

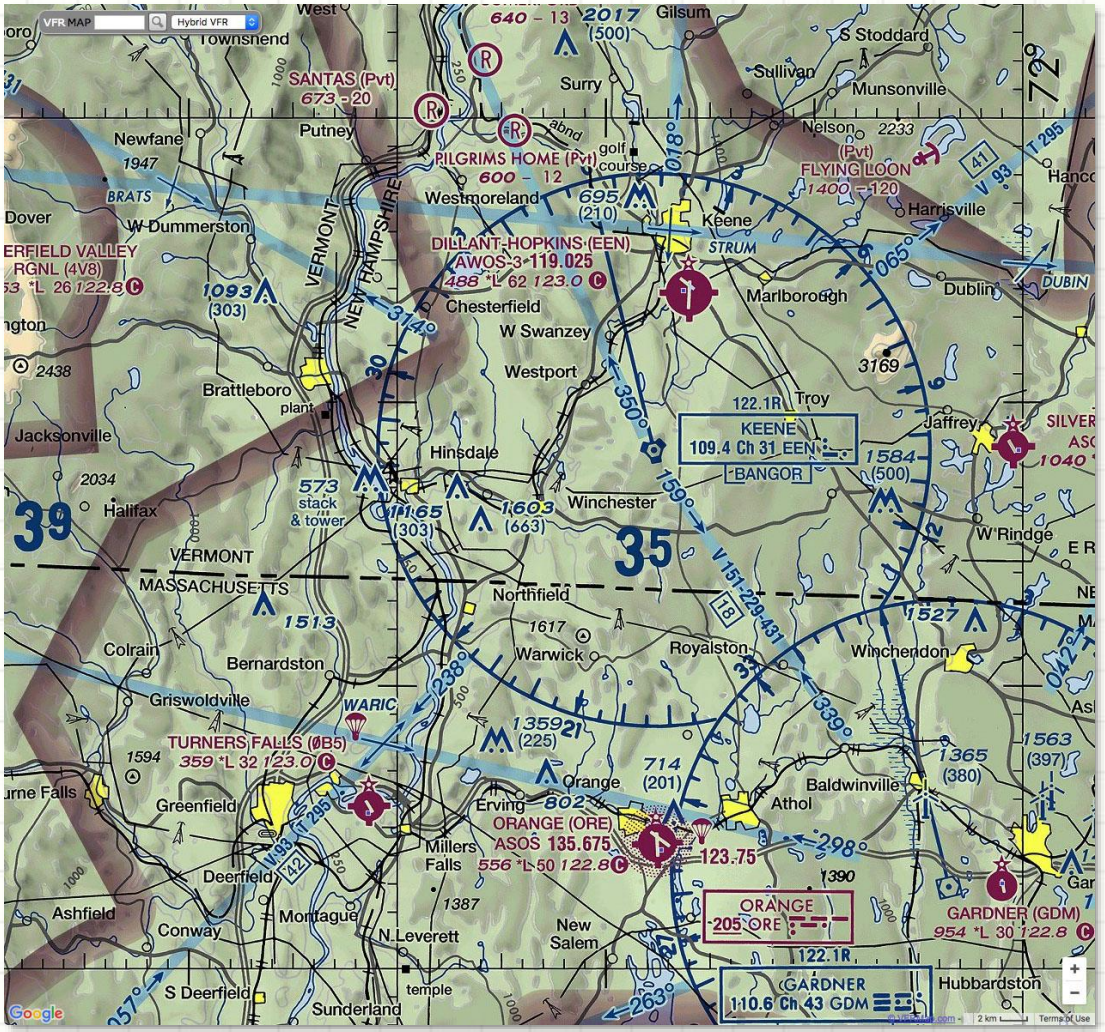
Filing a NOTAM

- Best to notify the FAA about our launch time and intended course
  - Do this by filing a NOTAM (Notice to Airman)
- Communicate our launch location based upon the nearest VOR Beacon (used for Airplane navigation)
- Sectional VOR navigations charts at - http://vfrmap.com/
  - Used by pilots to Navigate via VOR

VOR = Very high-frequency Omnidirectional Ranges. A radio navigation system used by pilots.

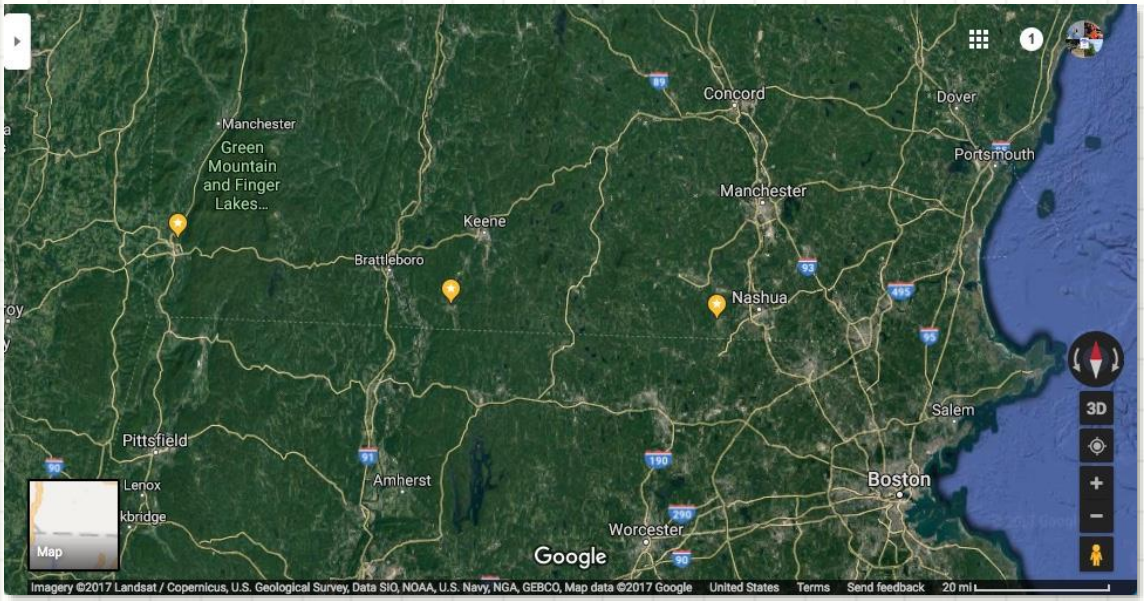
Filing a Flight Plan with the FAA

- Closest VOR beacon is Keene, NH (Call sign E-E-N)
- Launch site heading from this VOR is 260^{O}
- Distance from VOR beacon is approx. 8.6 km or 4.6 nautical miles
  - 1 km = 0.54 nautical mi.
- Launch time and 60 ft. altitude windows
- Direction and estimated landing times



"Launching Echo-Echo-November VOR, Radial Two-Six-Zero, at 4.6 Nautical Miles"

Possible Launch Sites



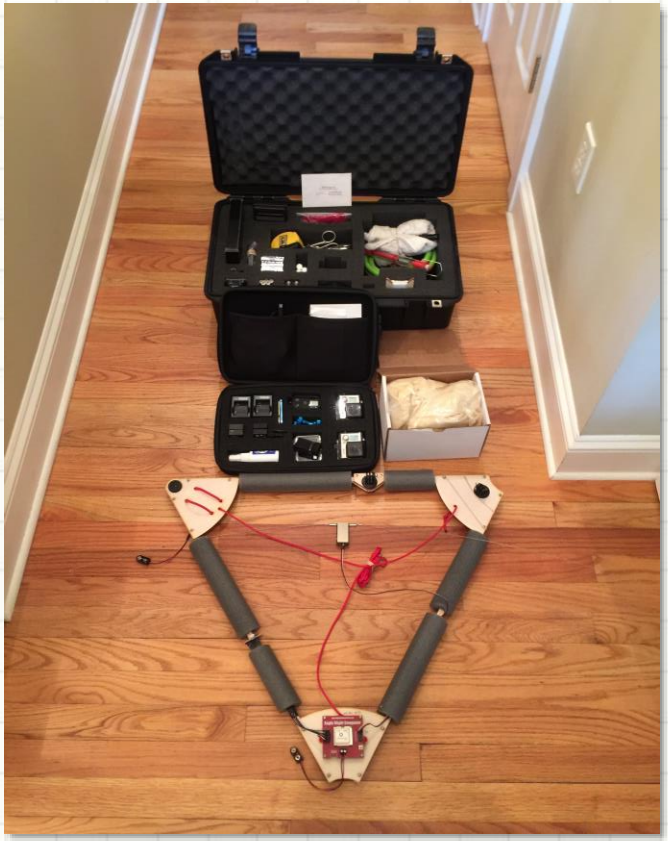
Bennington, VT

Winchester, NH

Launch Sites Selection

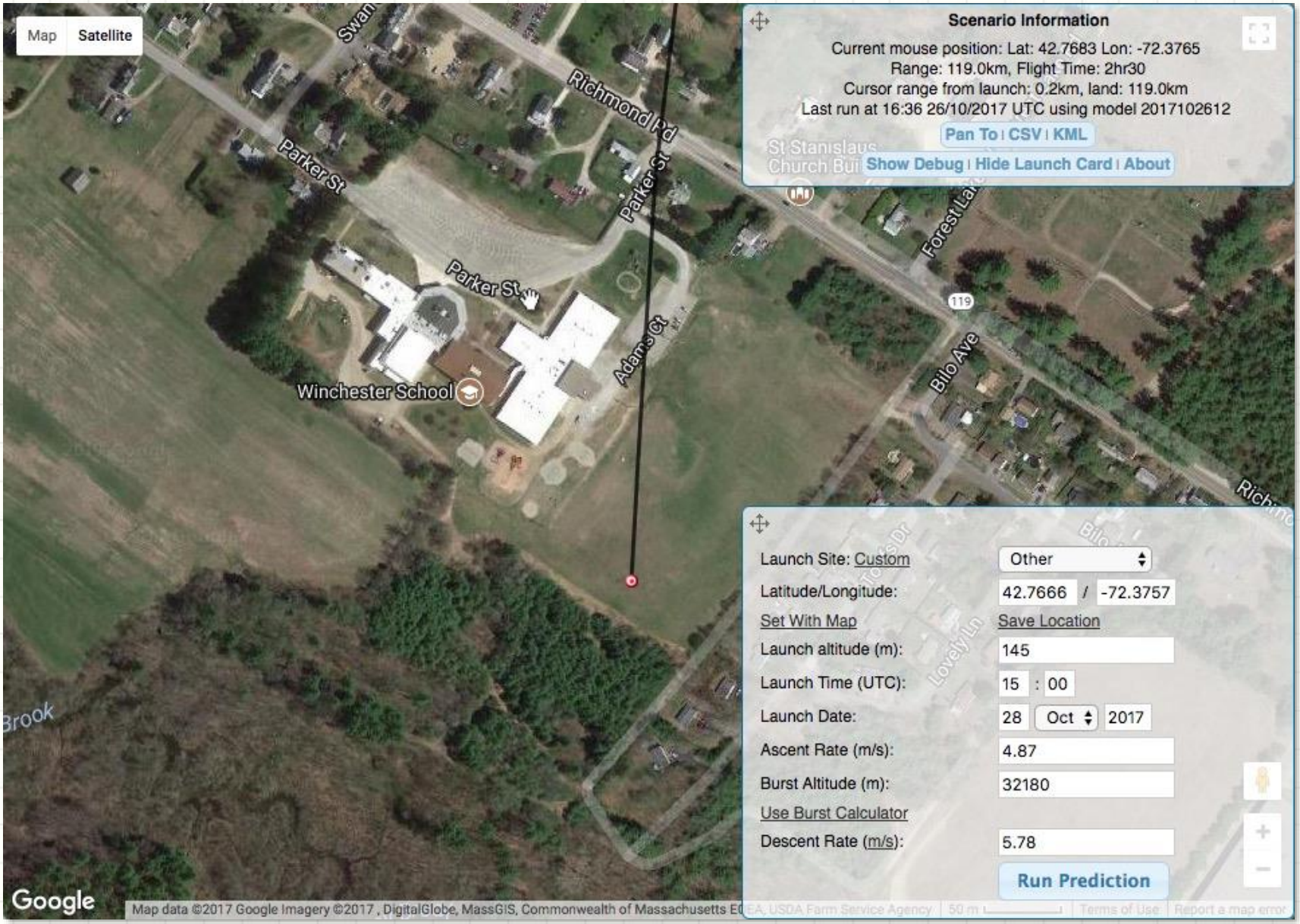
- ✓ Flight path relative to ocean
- ✓ Large, open space
- ✓ Free of low obstructions
- ✓ Favorable relative to winds
- ✓ School site
- ✓ Can secure permission easily
- ✓ Travel Distance
- ✓ Launch day conditions

Pre-Launch Prep and Transport



- ✓ Fully assemble and test HAB
- ✓ Check all support gear
- ✓ Change/charge all batteries
- ✓ Clear Flight Computer and Cameras
- ✓ Load and restrain Helium Cylinders

Winchester NH Launch Site



High Altitude Balloons Launch and Flight

HAB-2

HAB Tracking and Recovery

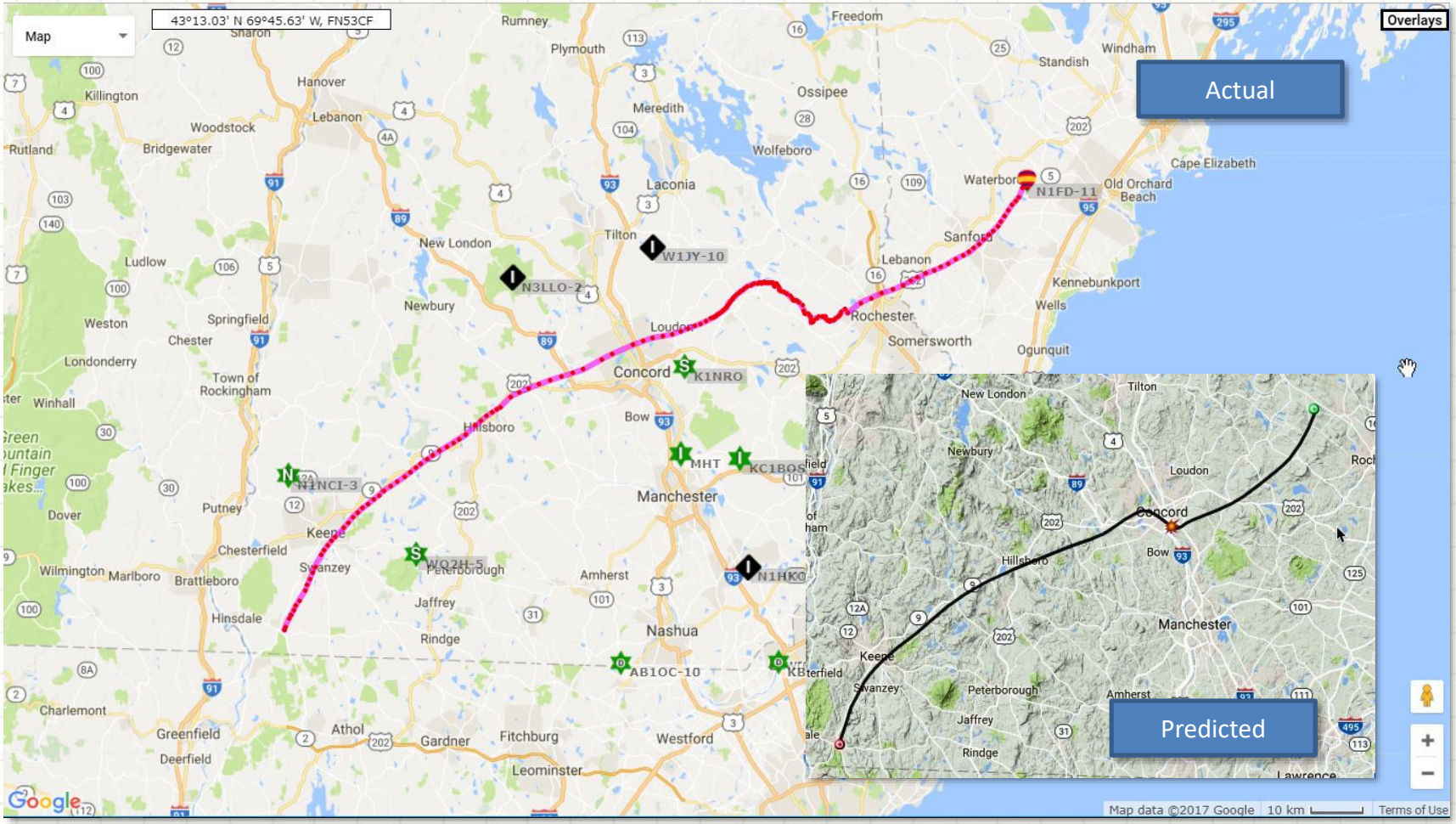
HAB Tracking and Recovery

Flying a HAB in New England…

- ✓ Need to be prepared to climb trees and handle water landings
- ✓ Avoid landing situations in remote areas and the ocean
- ✓ Stage recovery near projected landing loc.
- ✓ Laptop w/Internet Acc., APRS capable radio, and directional antenna are essential tools
- ✓ Recovery is an adventure – you are never sure what to expect!

HAB-2 Flight Path

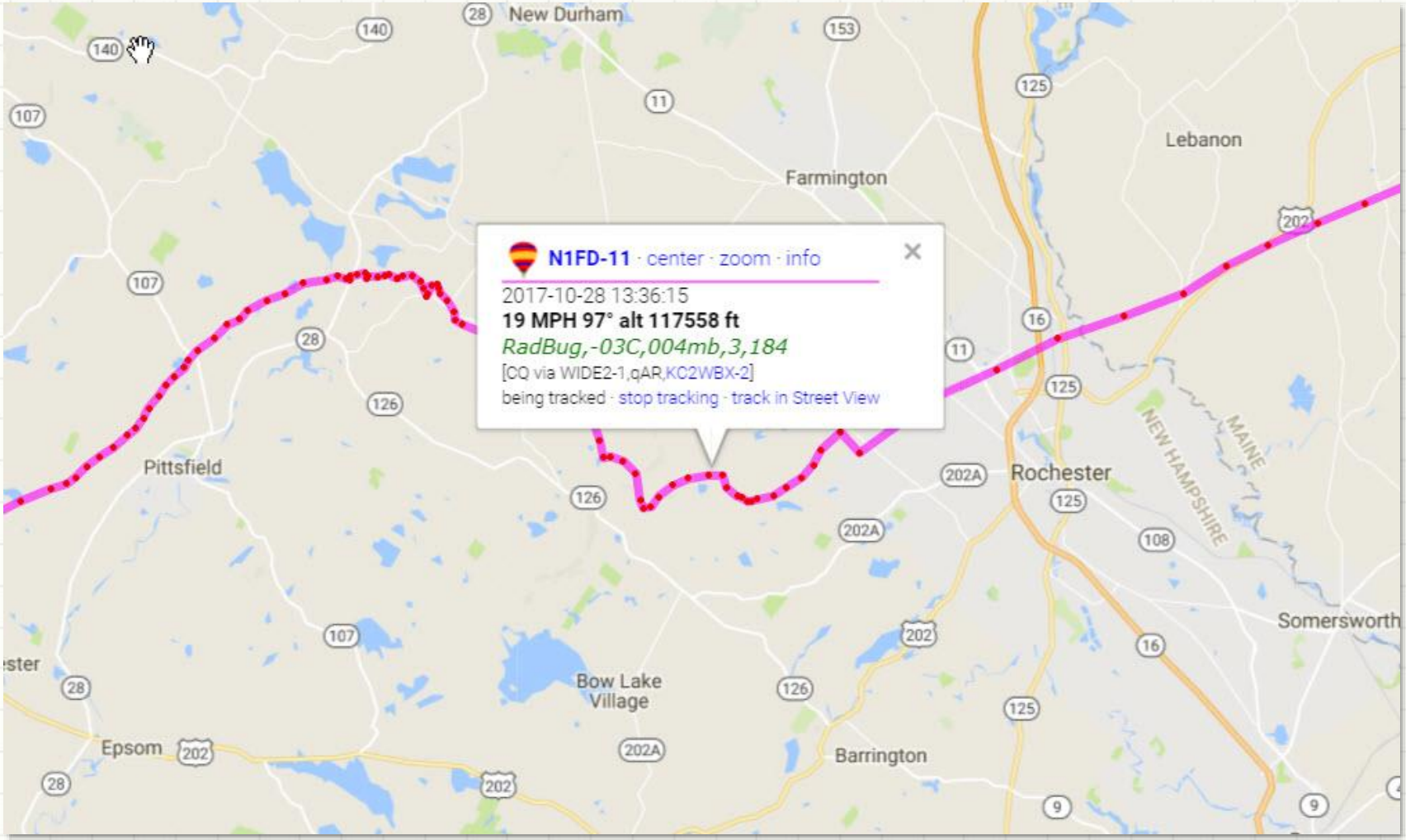
Actual vs. Predicted



HAB-2 flew further, longer and higher than predicted –
Probably not quite enough Helium in the Balloon…
(Actual Burst Altitude was ~118,000 ft or ~ 22 mi)

HAB-2 Burst Telemetry

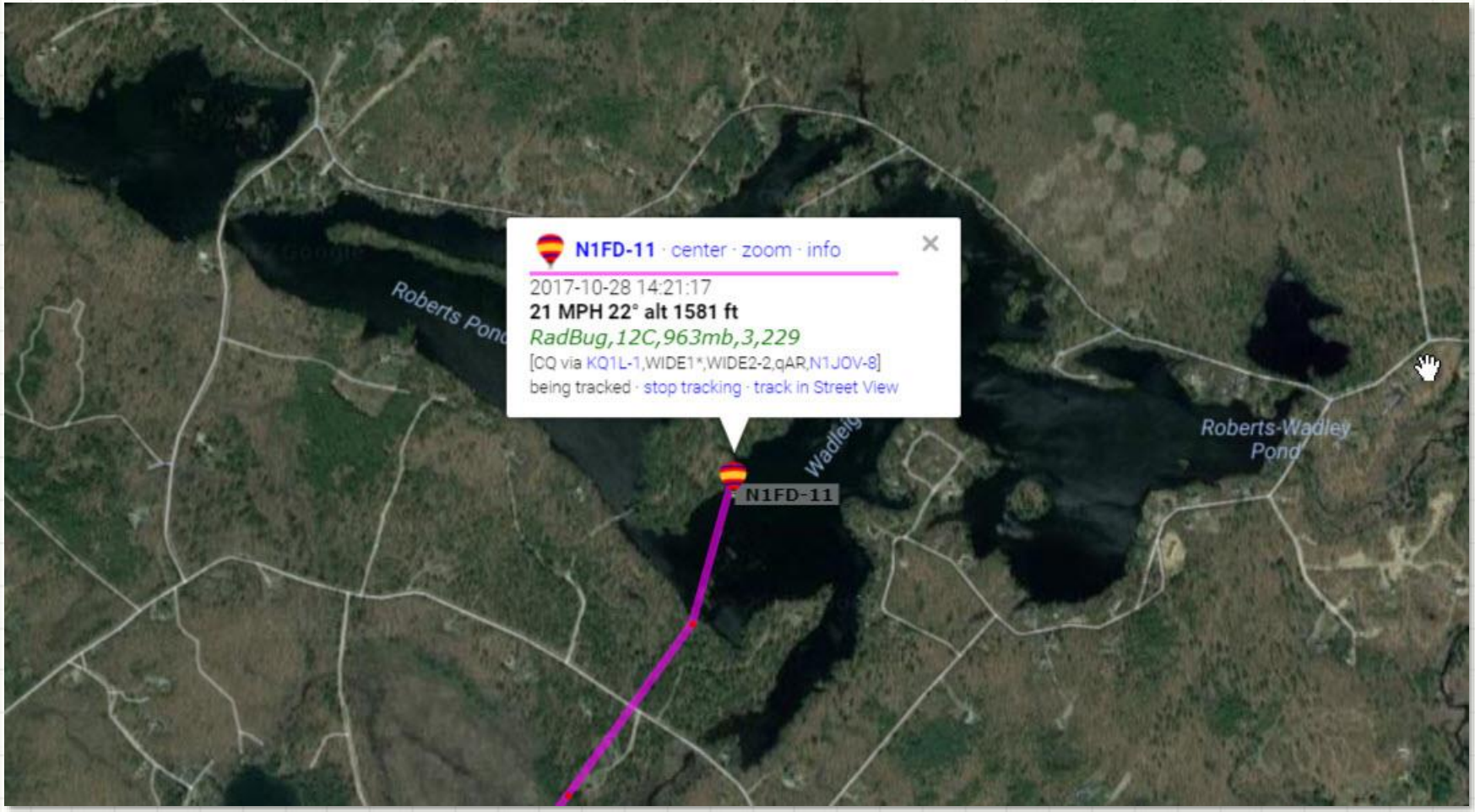
From Nearly +117,500 ft



HAB-2 highest altitude telemetry burst via APR shown. Flight computer recorded a maximum altitude of just under 118,000 ft.

HAB-2 Landing Site

Last APRS Telemetry



HAB-2 flew a few hundred feet after the last telemetry burst was received. Satellite tracker identified exact landing location in pond.

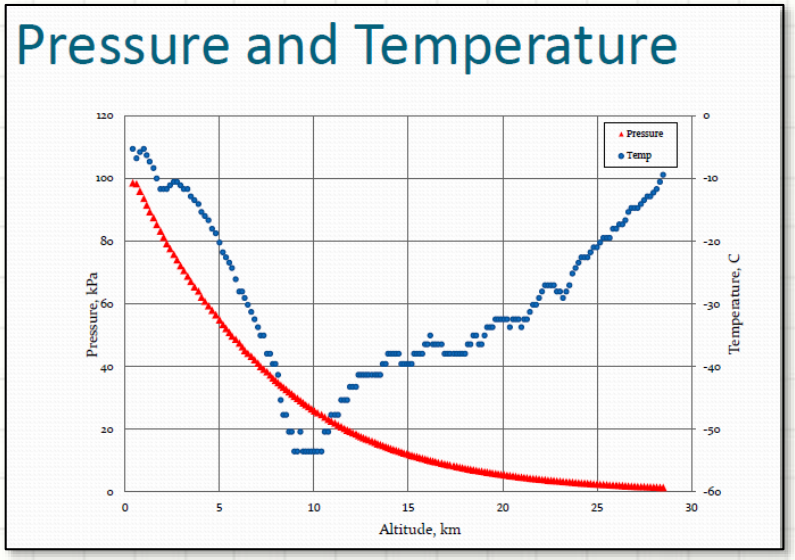
Livestream of HAB-2 Tracking and Recovery

HAB Data Analysis - A STEM Learning Opportunity

Atmosphere Phenomena

What did our Flight Computer record?

- HAB's flight computer measured and recorded data about our flight:
  - ***Position, Heading and Speed***
  - ***Altitude***
  - ***Temperature and Pressure***
- Amateur Radio APRS Transmitter sent this data to ground



Actual HAB Flight Computer Data

```
Date     ,Time     ,Latitude  ,Longitude ,Head,Km/h,Alt-m   ,Lock,Temp C,Pa
10/28/17,17:36:42,+043.30393,-071.11218,0088,0027,+035939,0003,-001.4,000301
10/28/17,17:36:48,+043.30395,-071.11161,0083,0033,+035955,0003,-001.1,000073
10/28/17,17:36:54,+043.30419,-071.11113,0039,0027,+035811,0003,-001.6,000180
10/28/17,17:37:00,+043.30432,-071.11008,0082,0046,+035527,0003,-002.0,000580
```

We compared HAB flight data to our predictions to see how well they matched and we analyzed our data.

APRS Packet Sequence

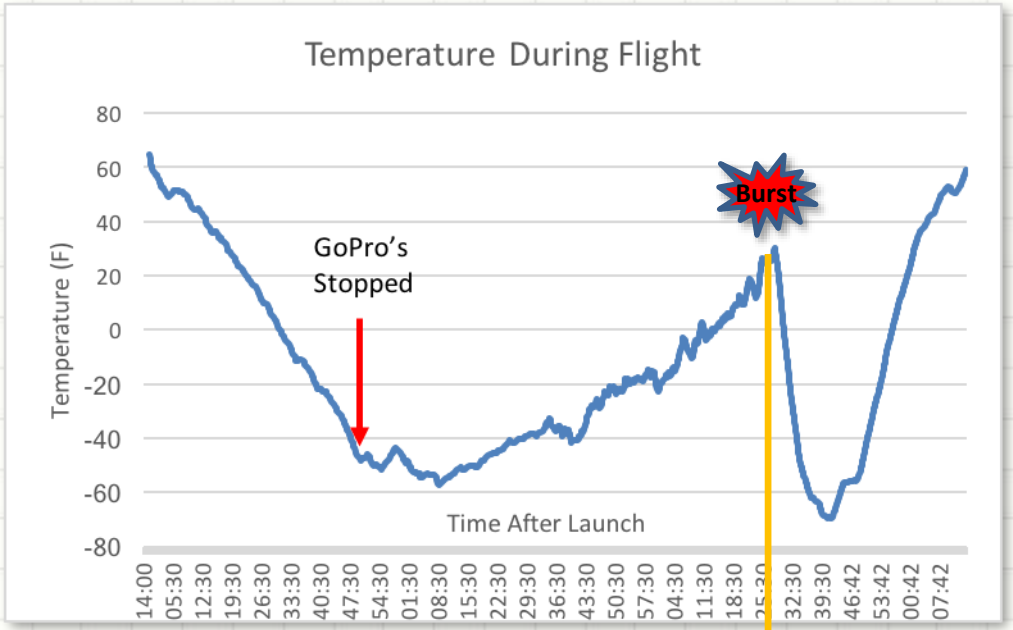
Understanding and Analyzing the Data

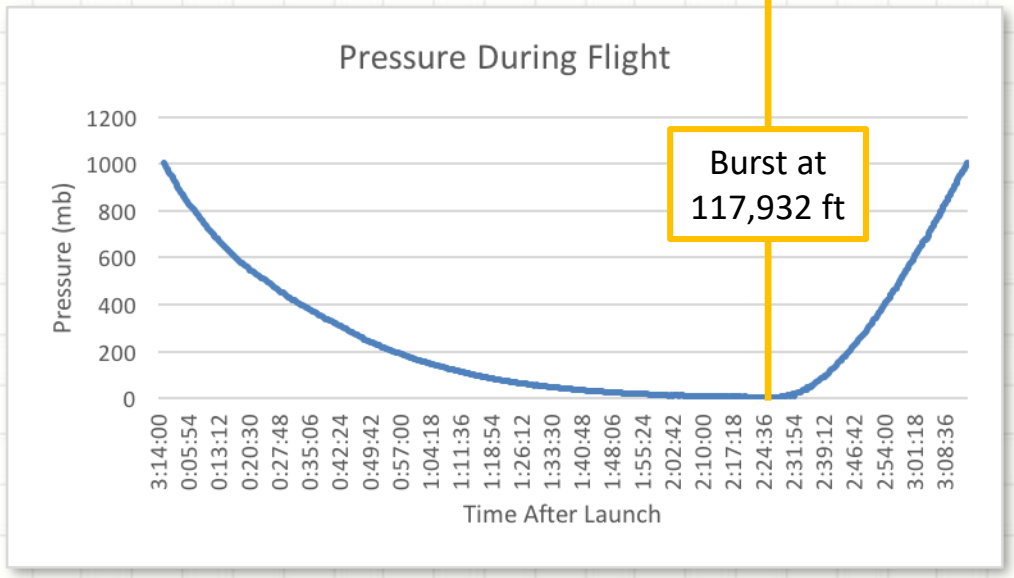
2017-04-07 21:16:50 EDT: **N1FD-11**>CQ,WIDE1-1,WIDE2-2,qAR,NX1W:!4242.70N/07135.41WO148/000/A=000351RadBug,16C,984mb,3,001

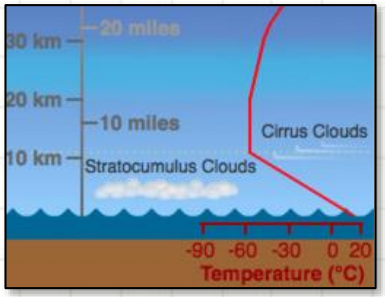
Date/Time	HAB Callsign	APRS Msg. Header	Packet Source (iGate)	iGate Callsign	Latitude (deg - min)	Longitude (deg - min)	Heading (deg. N)	Speed (m/s)	Altitude (feet)	Temperature (deg. C)	Pressure (mBar)	Packet #
2017-04-07 21:16:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	351	16	984	1
2017-04-07 21:17:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.70N	71 35.41W	148	0	354	10	984	2
2017-04-07 21:18:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	360	8	985	3
2017-04-07 21:19:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.70N	71 35.41W	148	0	360	6	985	4
2017-04-07 21:20:50 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	347	5	985	5
2017-04-07 21:21:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	148	0	344	5	985	6
2017-04-07 21:22:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	174	0	347	4	985	7
2017-04-07 21:23:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	174	0	344	4	985	8
2017-04-07 21:24:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	347	4	985	9
2017-04-07 21:24:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	10
2017-04-07 21:26:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	11
2017-04-07 21:27:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	12
2017-04-07 21:28:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	325	0	351	4	985	13
2017-04-07 21:29:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.70N	71 35.41W	109	0	351	4	985	14
2017-04-07 21:30:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	109	0	347	4	985	15
2017-04-07 21:31:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	109	0	351	4	985	16
2017-04-07 21:32:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	266	0	360	4	985	17
2017-04-07 21:33:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	266	0	360	4	985	18
2017-04-07 21:34:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	266	0	360	4	985	19
2017-04-07 21:35:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.70N	71 35.41W	269	0	364	4	985	20
2017-04-07 21:36:51 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	NX1W	42 42.71N	71 35.41W	269	0	367	8	985	21
2017-04-07 21:37:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.71N	71 35.41W	45	1	364	13	984	22
2017-04-07 21:38:52 EDT	N1FD-11	CQ,WIDE1-1,WIDE2-2	qAR	AB1OC-10	42 42.71N	71 35.41W	45	0	367	15	984	23

HAB-2 Atmospheric Measurements

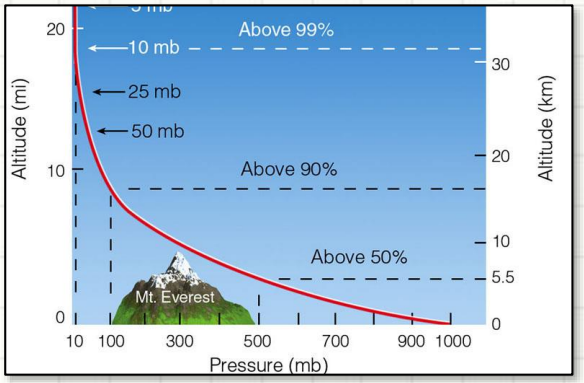
Temperature and Pressure







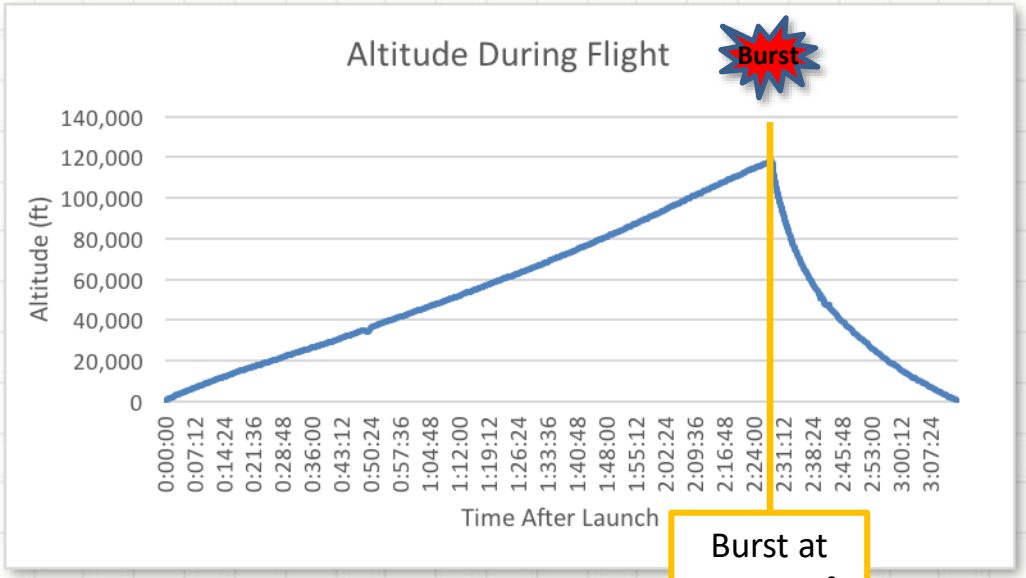
- Very cold temperatures on ascent (-57°F) & descent (-70°F)
- Cameras shutoff at around 40,000 ft due to low temperature
- Shape of temperature changes was as expected

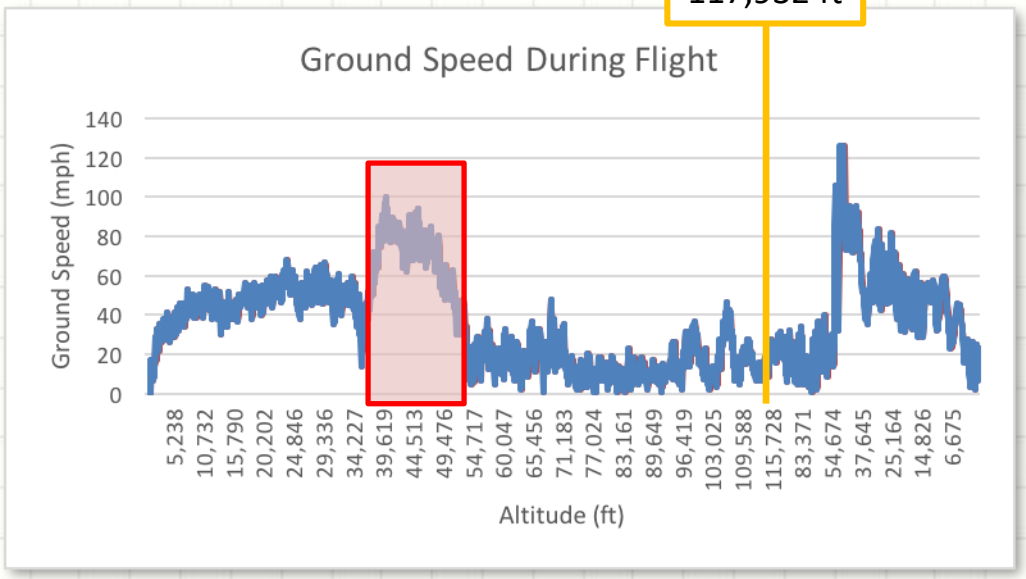


- Measured pressure was as we expected

HAB-2 Speed Measurements

Ground and Descent Speed





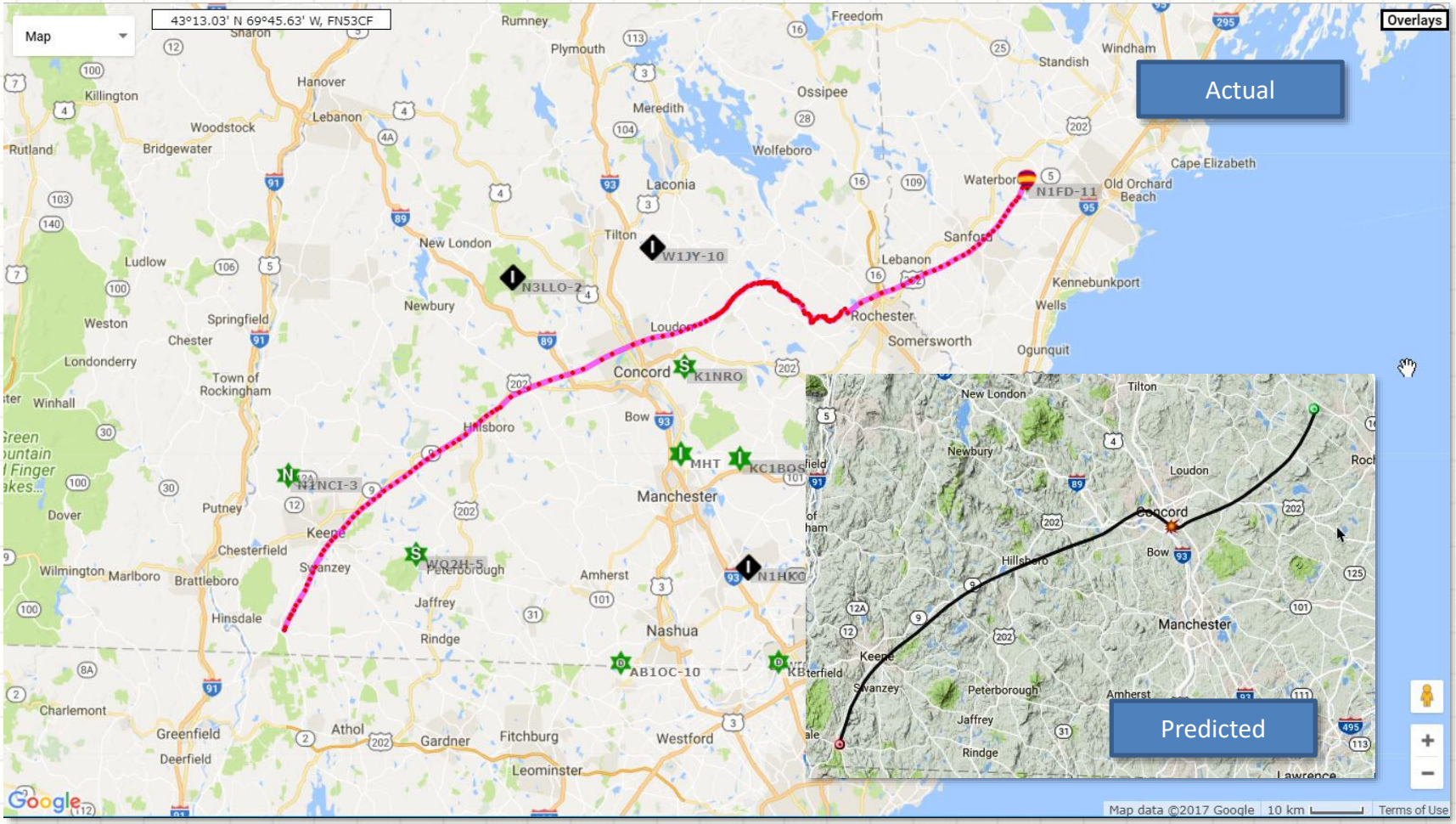
- Ascent rate did not change much between launch and burst
- Jetstream winds increased ground speed significantly
  - ~35,000 – 50,000 ft
  - Max of ~100 mph!
- Not enough air above 50,000 ft to move HAB-2 along ground
- Descent after burst was very rapid until about 50,000 ft

Date	Time (UTC)	Time After Launch	Ground Speed (mph)	Altitude (ft)	Ascent/ Descent Rate (mph)	Notes
10/28/17	18:21:54	3:13:24	25	954	-12	
10/28/17	18:22:00	3:13:30	22	859	-11	500 AGL
10/28/17	18:22:06	3:13:36	7	768	-10	
10/28/17	18:22:12	3:13:42	7	666	-12	
10/28/17	18:22:18	3:13:48	15	567	-11	200 ft AGL
10/28/17	18:22:24	3:13:54	23	469	-11	
10/28/17	18:22:30	3:14:00	19	351	-13	Touchdown!

- Parachute descent rate was about 12 mph at landing
  - About what we expected

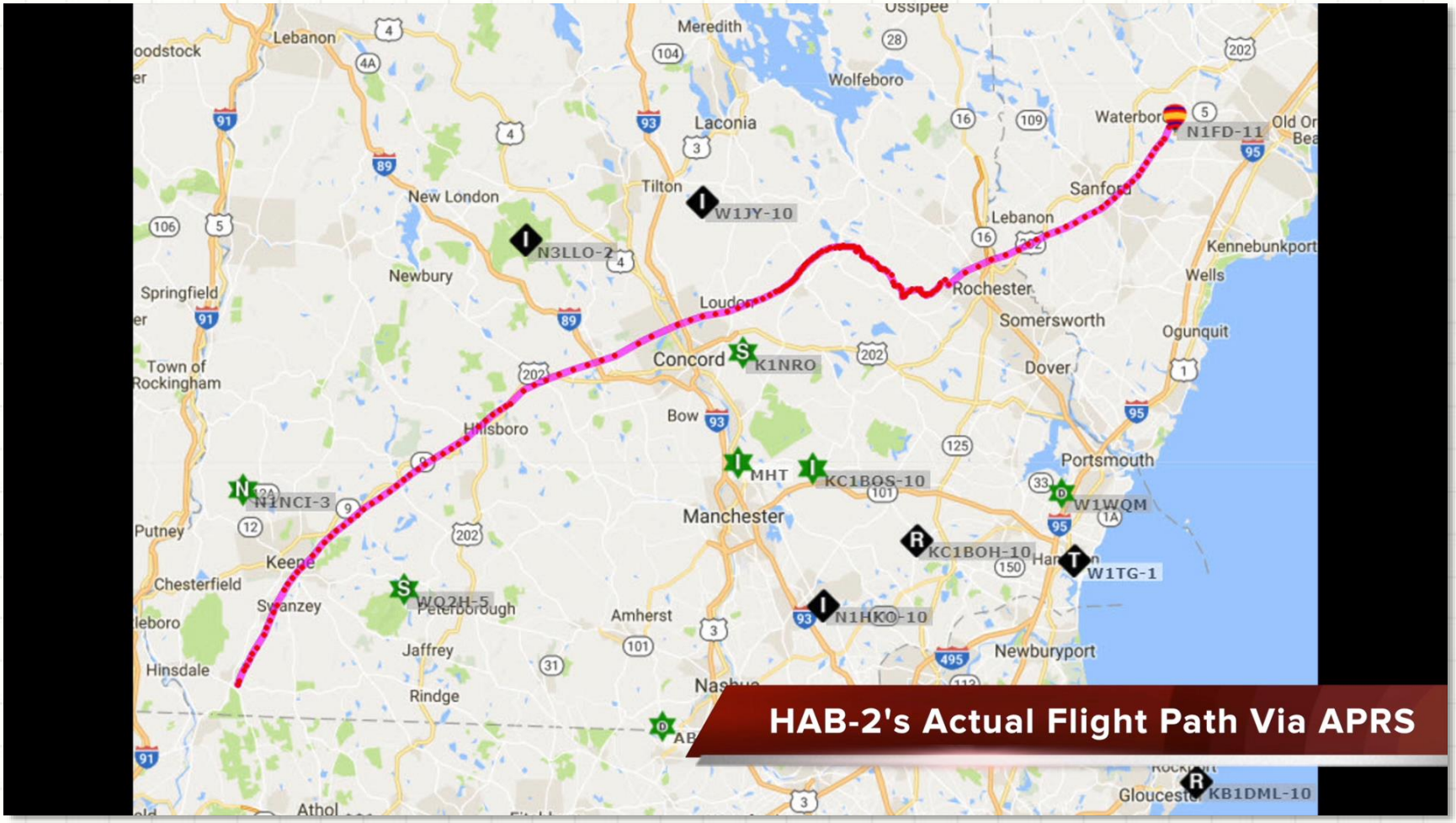
HAB-2 Flight Path

Actual vs. Predicted



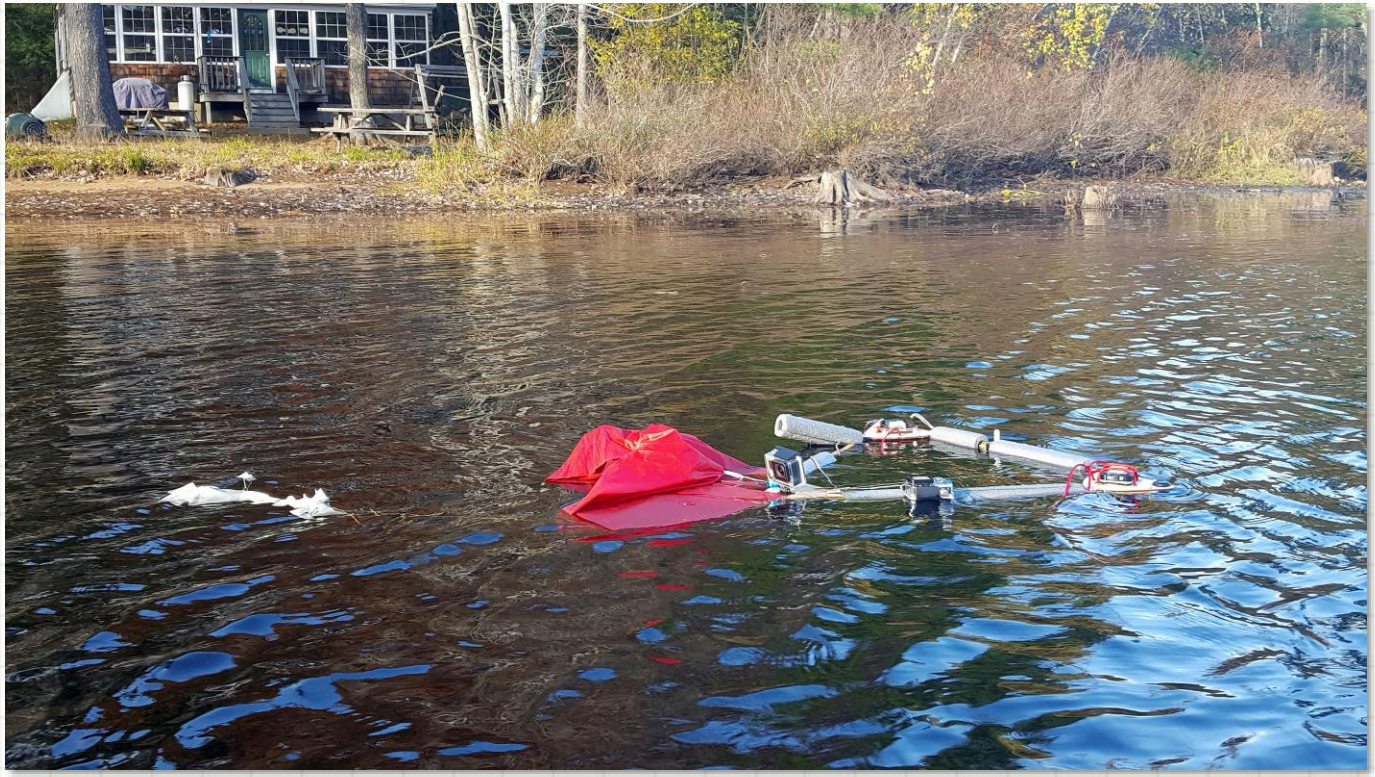
HAB-2 flew further, longer and higher than predicted –
Probably not quite enough Helium in the Balloon…
(Actual Burst Altitude was ~118,000 ft or ~ 22 mi)

HAB-2 Flight Simulation from APRS Data



HAB-2 Conclusions

Some final thoughts…



- Flight path software is accurate if the input data is good
- Need to accurately calibrate our scale to get weights and Helium amount correct
- Need to keep GoPro cameras warm somehow - hand warmer pouches?
- Better waterproofing for cameras, larger floats to keep the HAB's electronics out of the water and some tape on the floats would be good ideas
- We'd like to get entire team together during the HAB-3's flight to track
- We should include the launch in the next Livestream production

Goals for Future HAB Projects

- Focus will stay centered on STEM learning in schools
- We'd really like to capture balloon burst and descent video
- May fly a third camera to capture additional ground angles
- Planning to fly larger 1500g balloon to maximize burst altitude
- Remote school HAB project participation via the Internet
- Also considering payload enhancements including:
  - SSTV transmitter
  - Live, full-motion video during flight
  - Balloon repeater
  - Round-the world HAB flight
  - Additional radiation and UV sensors
  - Temperate range, power and weights are constraining factors

Thank You!

Nashua Area Radio Society HAB Project Team Members:

- Anthony, KC1DXL
- Brian, AB1ZO
- Curtis, N1CMD
- Jamey, KC1ENX
- Anita, AB1QB
- Fred, AB1OC