Prospecting for atmospheric energy for autonomous flying machines

G. D. Emmitt and C. O'Handley
Simpson Weather Associates

Lidar Working Group Meeting
Snowmass
July 17 – 20 2007

Acknowledgements

- DARPA funding
- Dr. James Hubbard, National Institute of Aerospace (PI for SkyWalker)
- Navy’s Center for Interdisciplinary Remotely Piloted Aircraft Studies (Twin Otter aircraft and Doppler wind lidar)

Objectives

- Fly airborne DWL to explore the feasibility of using Doppler lidar to autonomously prospect for vertical motions and shear within reasonable proximity of an unpiloted aircraft (below 3 km)
- Develop a set of Atmospheric Energy Prospecting Algorithms (AEPAs)
- Develop DWL instrument specifications for future UAVs . “Whisker” class DWLs could sense nearby vertical air motions that would enhance probability of intercepts and thus increase mission duration

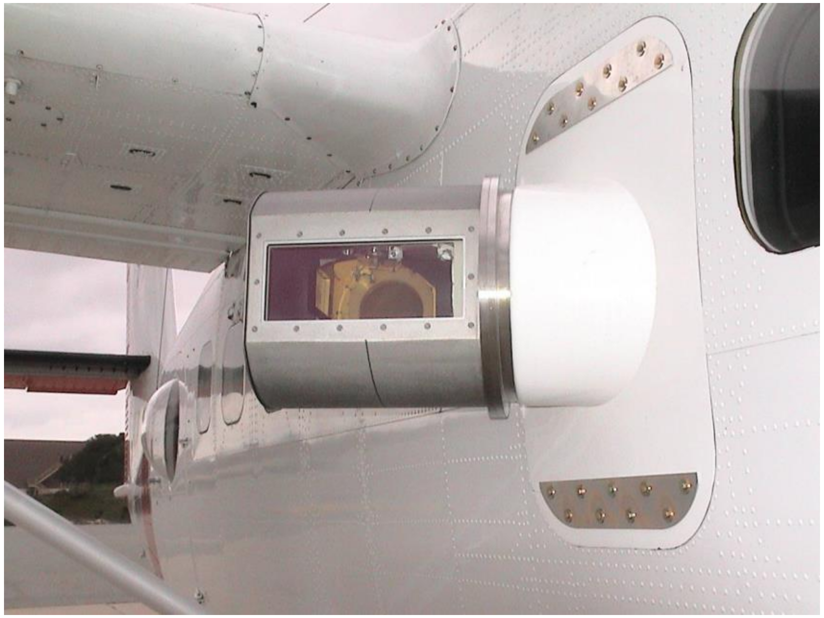
Strategy

- Conduct airborne experiments using the Navy's Twin Otter Doppler Wind Lidar (TODWL) system to collect data to:
  - Identify the DWL detectable signatures of vertical structures (thermals and atmospheric waves) and horizontal wind shear observed ahead of the aircraft at or near flight level;
  - Determine the vertical extent of vertical motion structures that can be reached from the current aircraft position;
  - Rank multiple coincident vertical motion structures based upon risk/benefit metrics.

The TODWL system

A CIRPAS instrument

(Twin Otter Doppler Wind Lidar)

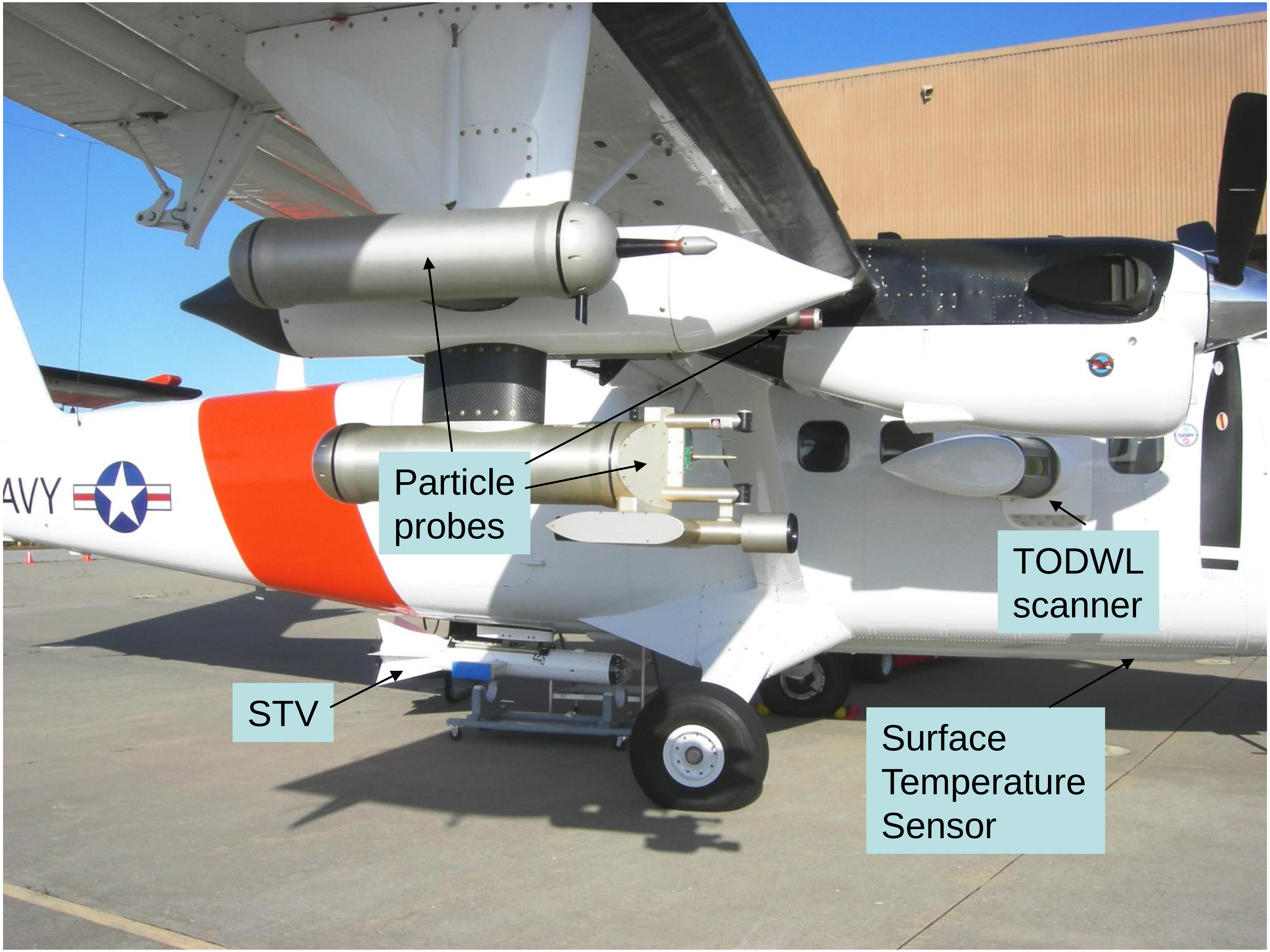


Background

- TODWL has been operated (since 2002) by CIRPAS (Center for Interdisciplinary Remotely Piloted Aircraft Studies), a part of the Naval Postgraduate School, Monterey, CA. Emmitt is the TODWL PI.
- Used by NOAA for investigating lidar performance over the ocean in planning for a future space-based DWL
- Used by USArmy for studies of UAV wind profiling in complex terrain and urban areas.
- Used by Navy to conduct MBL research; recently added the Smart Towed Platform

The instrument

- 2µm coherent detection (CTI MAG1A)
- 2 mJ ; 500 Hz
- 10 cm two axis scanner, side door mounted
- GUI with realtime instrument control and data display
- Range: .3 – 21km depending upon aerosols
- Accuracy: < .10 m/s in three components
- Weight: 700lb   Power: 700 W



AVY
Particle probes
TODWL scanner
STV
Surface Temperature Sensor

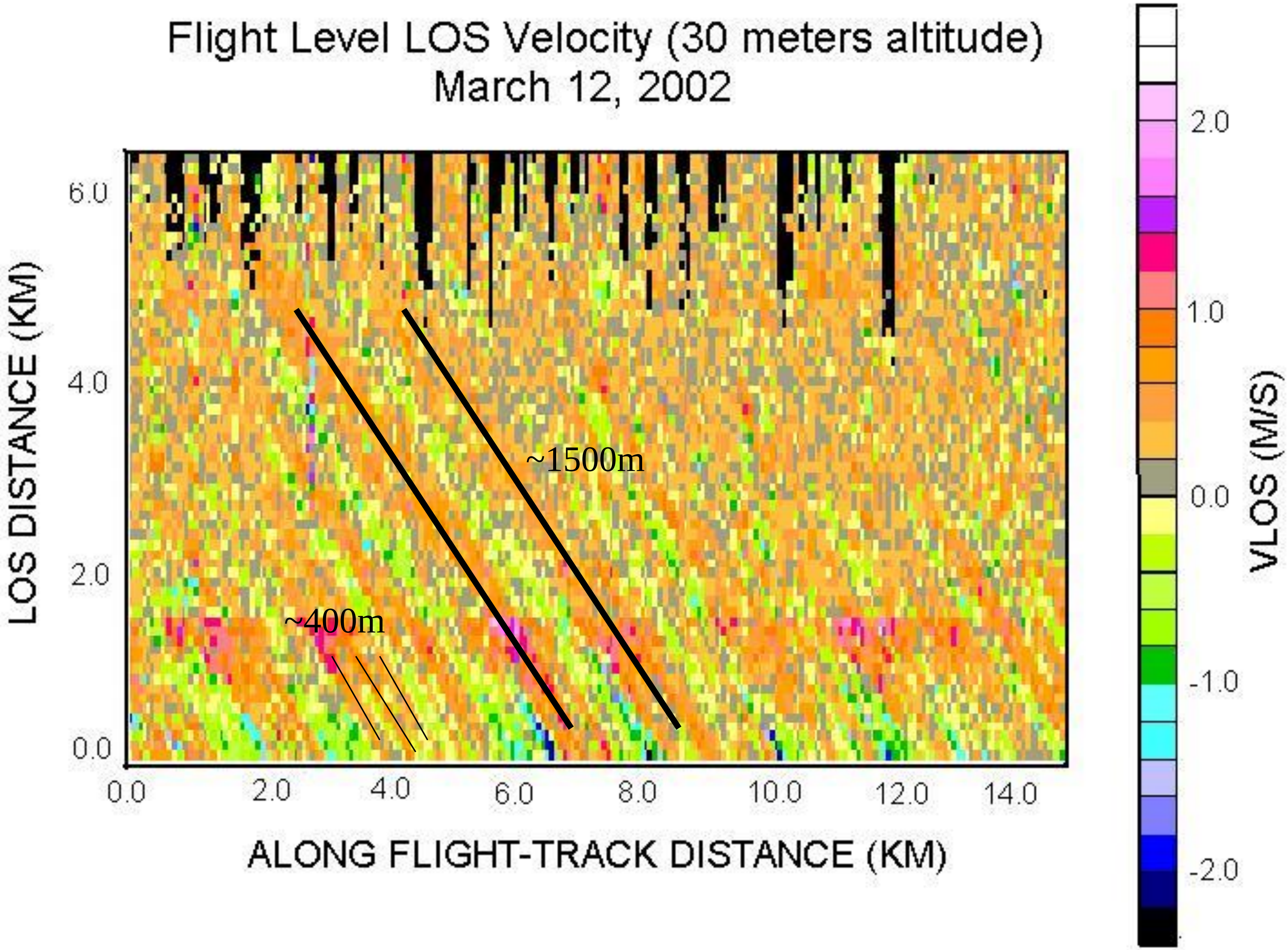
Targets for AEPAs

- Thermal like
  - Thermals (flat land and slope)
  - OLEs
  - Cloud updrafts
- Obstacle flows
  - Orographic upslope currents
- Gravity waves
  - Mountain waves
- Lower tropospheric jets
  - Shear in general

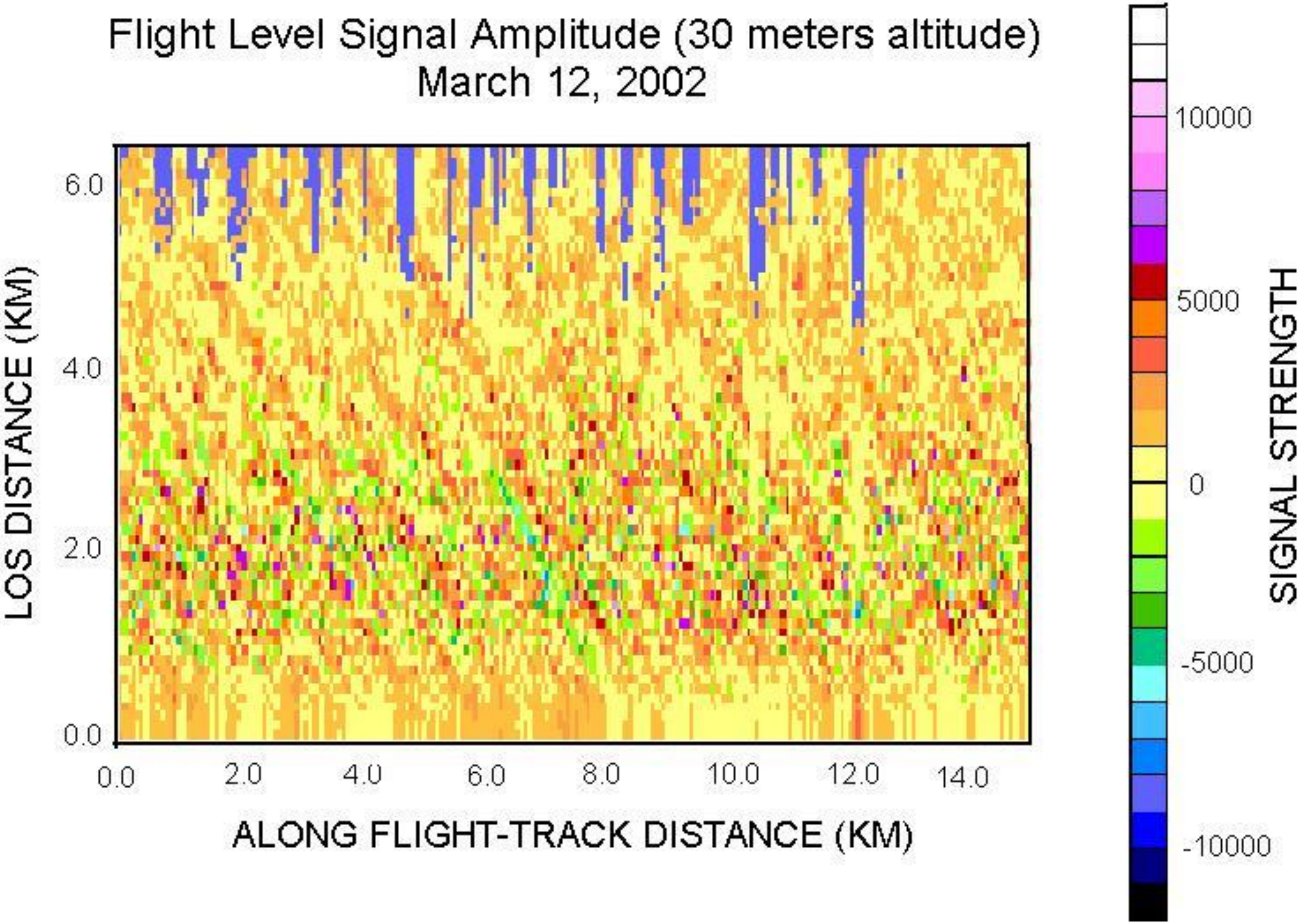
Prospecting Flights
October ‘06 & April ’07
Monterey, CA

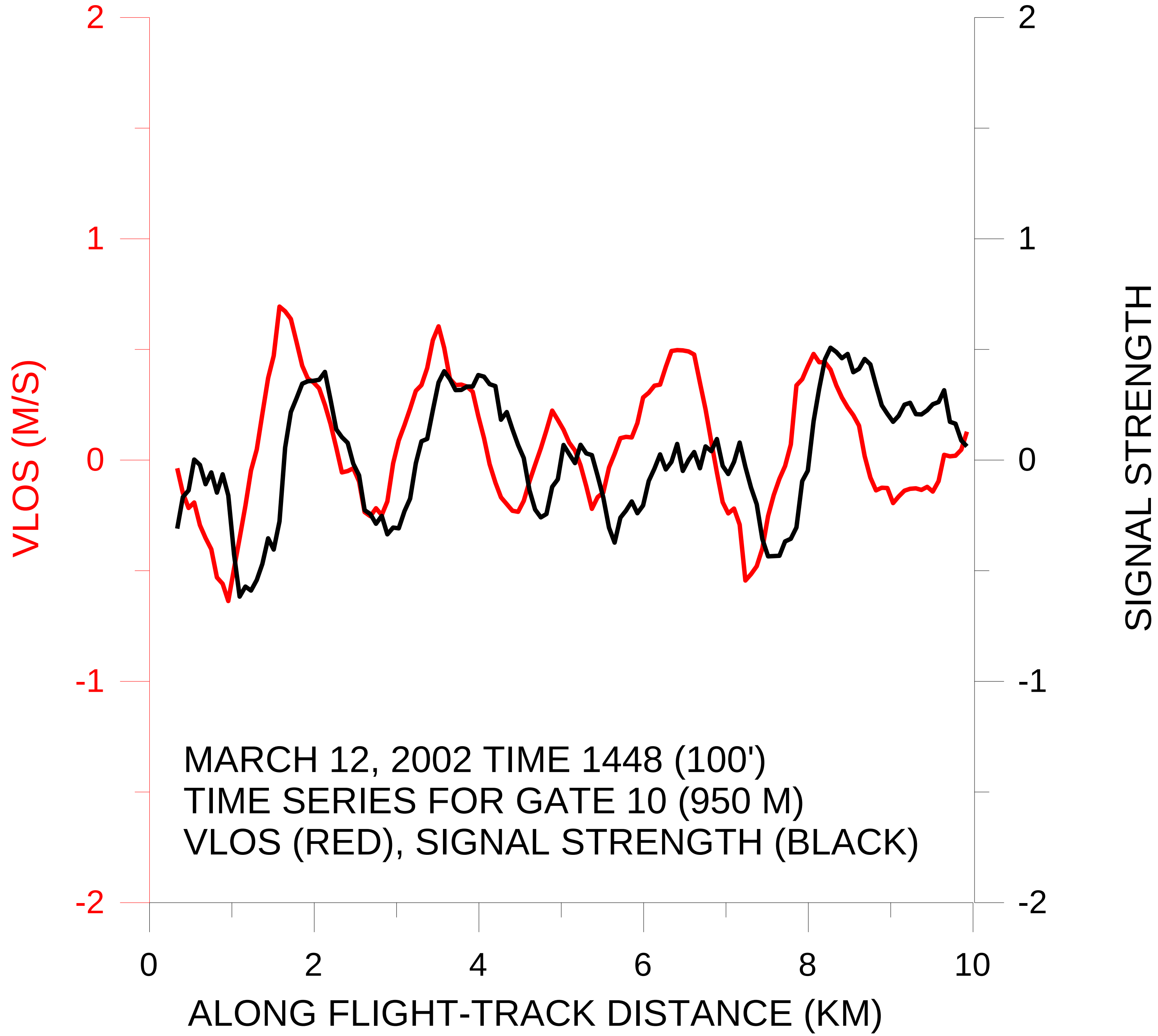
- 20 hours of flight time
- Explored several strategies for scanning lidar (raster, step stare, forward conical)
- Flights targeted ground rooted thermals, Organized Large Eddies (OLEs), orographic waves, low level jets and cloud updrafts

Prospecting for OLEs


Flight Level LOS Velocity (30 meters altitude)
March 12, 2002
LOS DISTANCE (KM)
6.0
4.0
2.0
0.0
~1500m
~400m
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
ALONG FLIGHT-TRACK DISTANCE (KM)
2.0
1.0
0.0
-1.0
-2.0
VLOS (M/S)

Flight Level Signal Amplitude (30 meters altitude)
March 12, 2002




2
1
0
-1
-2
VLOS (M/S)
SIGNAL STRENGTH
0
2
4
6
8
10
ALONG FLIGHT-TRACK DISTANCE (KM)
MARCH 12, 2002 TIME 1448 (100')
TIME SERIES FOR GATE 10 (950 M)
VLOS (RED), SIGNAL STRENGTH (BLACK)

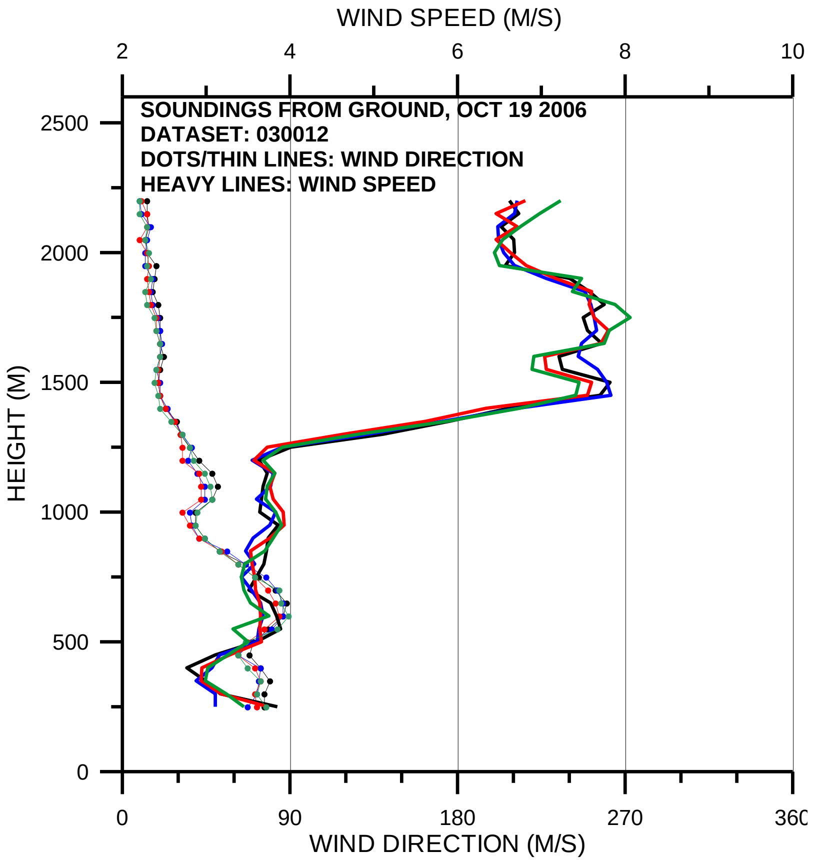
Salinas Valley

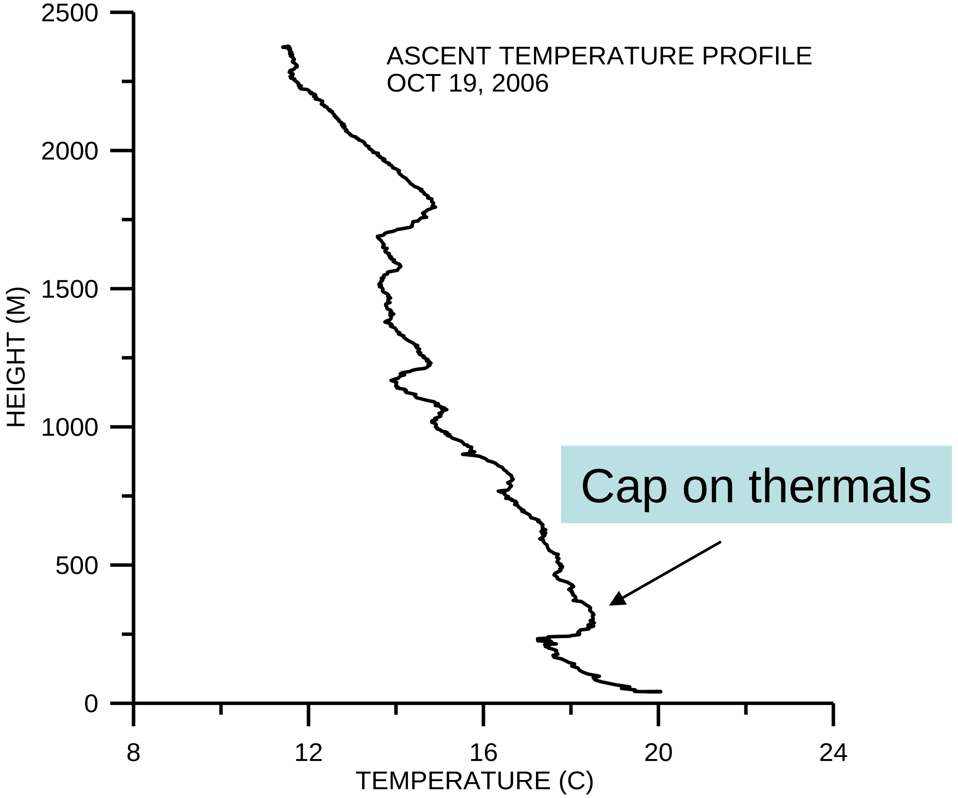
Monterey Mountains

500 feet over Salinas Valley floor

Over Salinas Airport

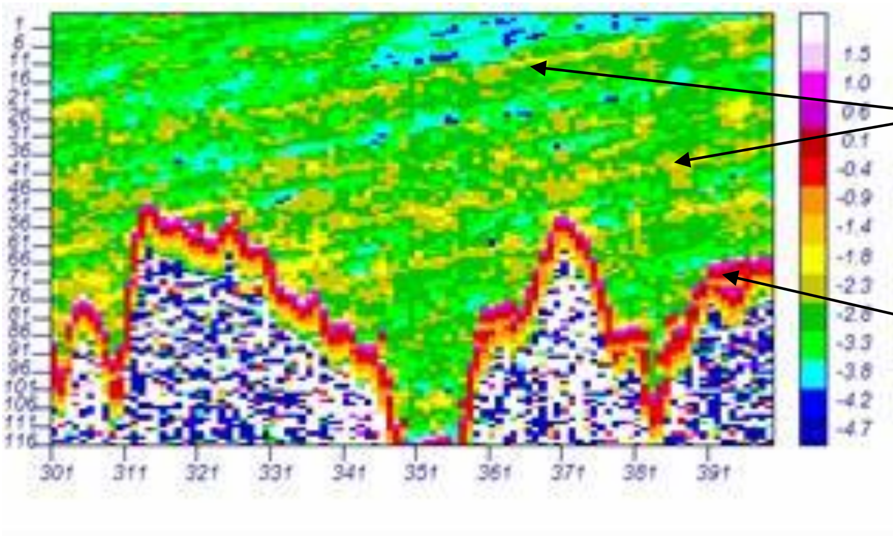
Inputs to Flight Planning





Flight over valley: 150m (~500') FL

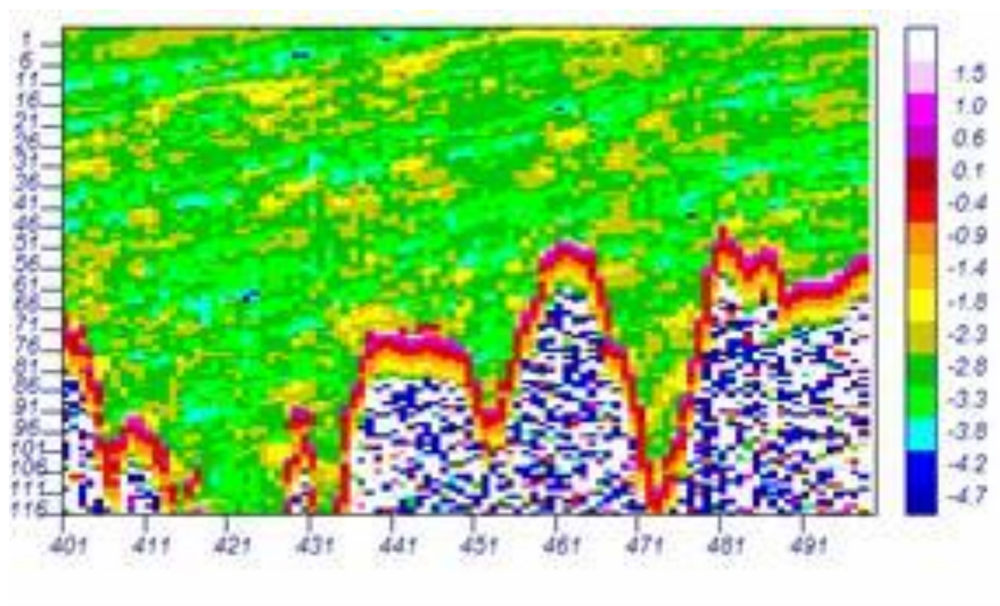
- Purpose was to look ahead of the aircraft for convergence zones that may portend coherent vertical motions and shear layers useful for "dynamic soaring".
- Scanning strategy was to scan beam on a plane oriented ~ 5 degrees below the flight level; scanning was to right side of the aircraft and subtended ~ 10 degrees.



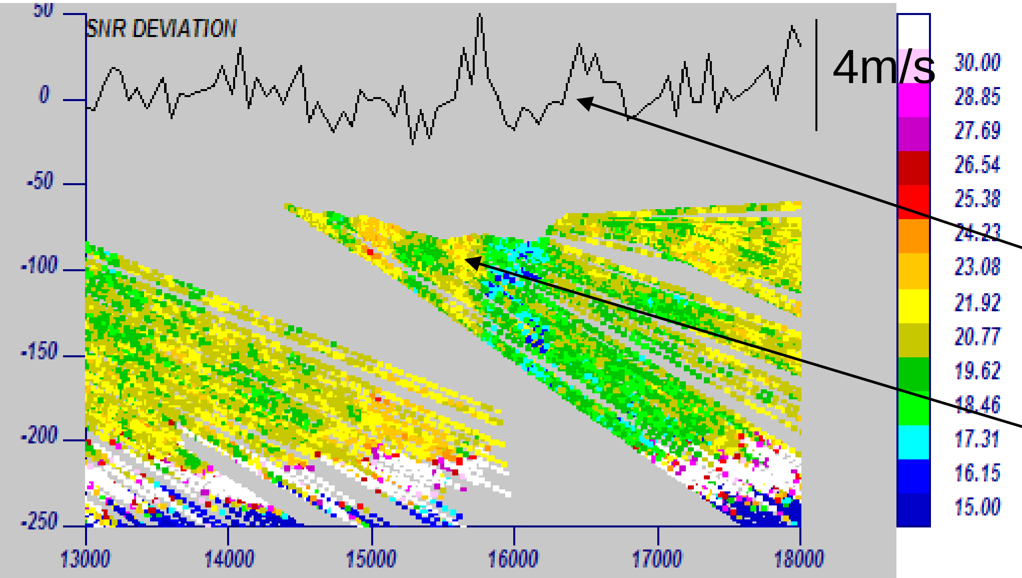
High aspect ratio vertical features

Ground intercept

Not so well organized
or persistent features



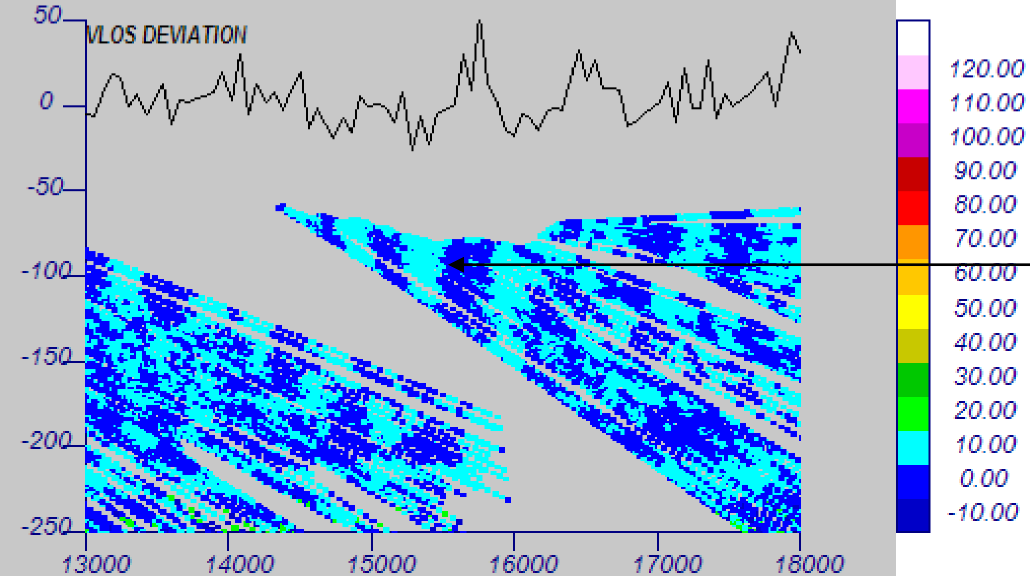
Example of forward sweeping scan of velocity and backscatter



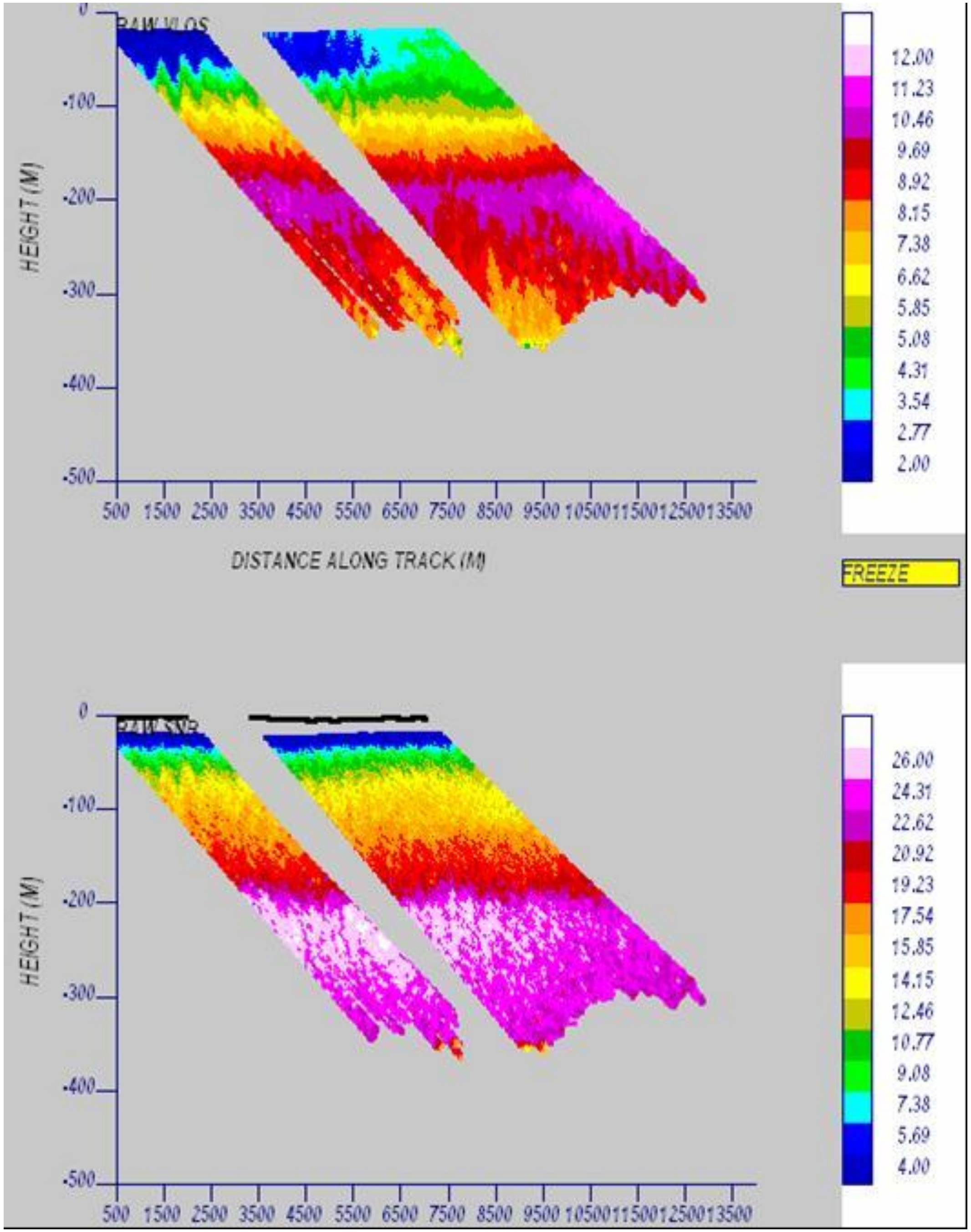
Vertical velocity of aircraft measured by INS on Twin Otter

Aerosol loading appears greatest in upward moving features

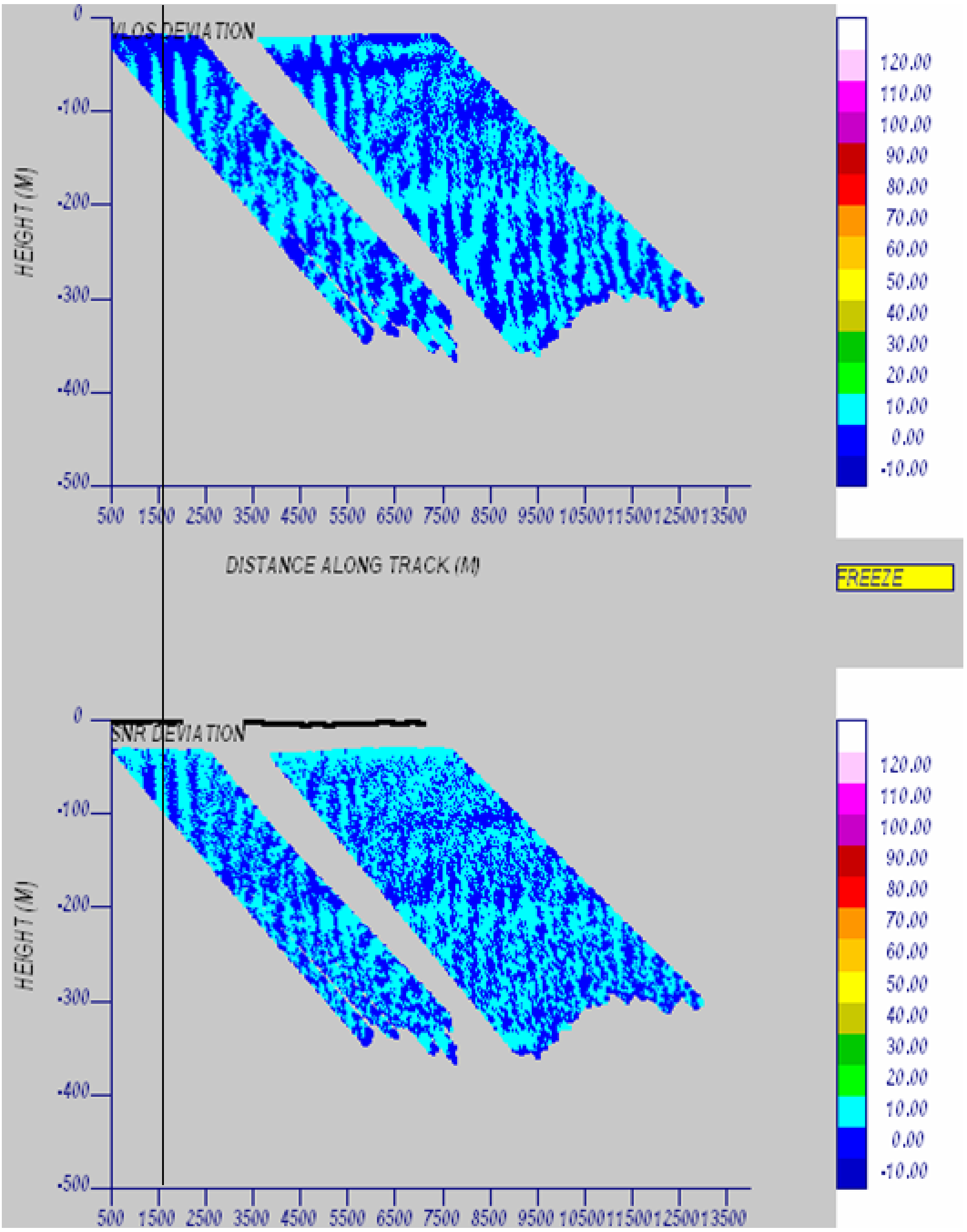
XZ slice w/ x being along track

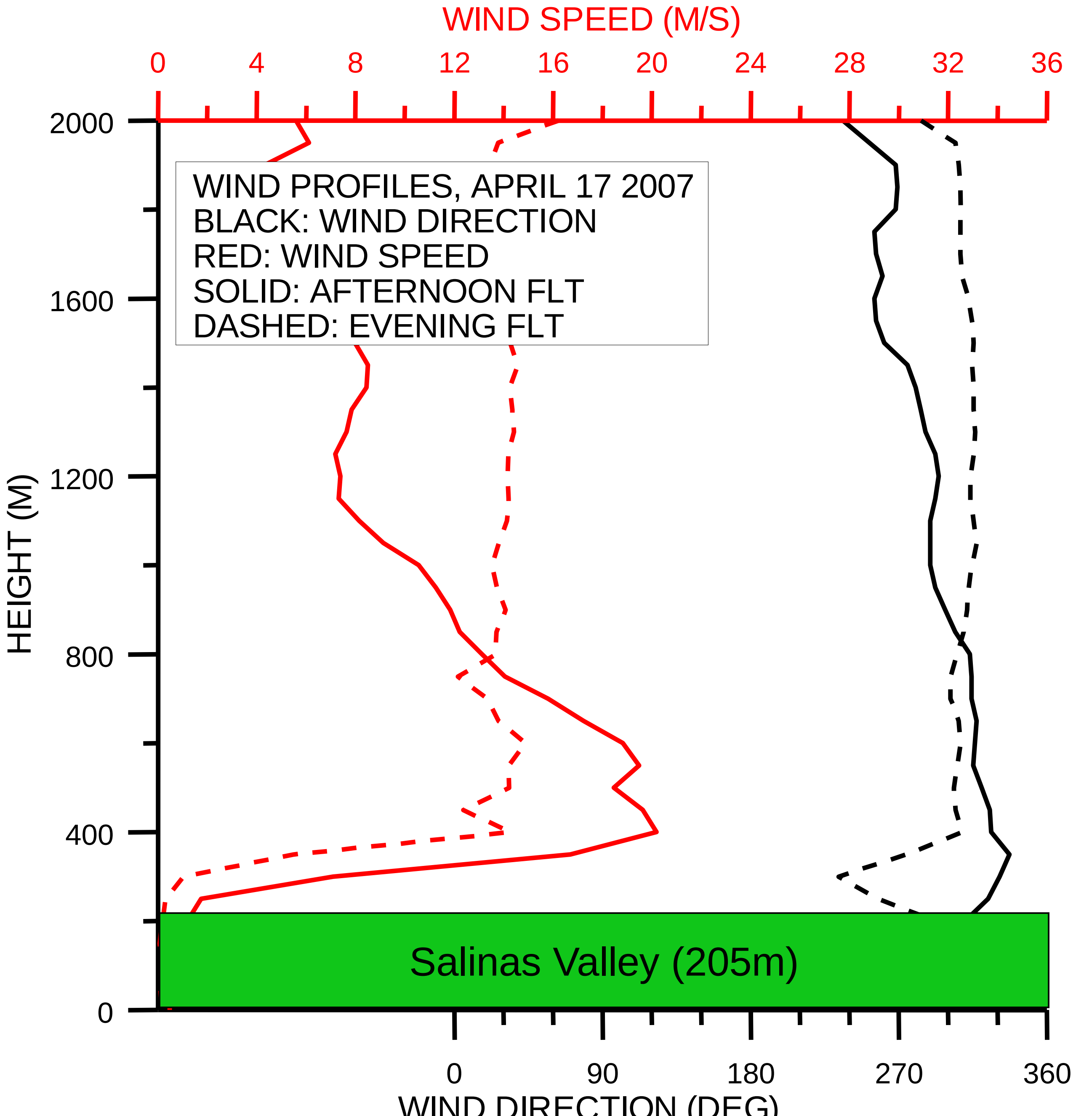


Expect (ideally) that upward motion would occur near switch from positive to negative velocity deviations

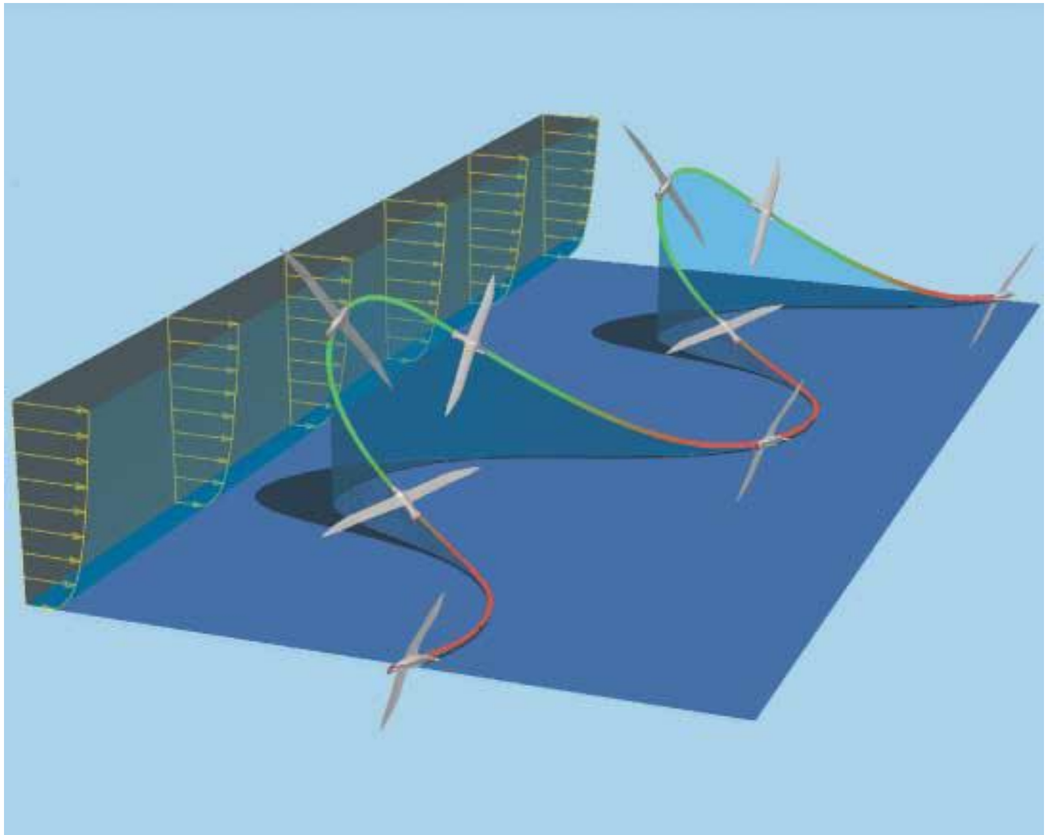


RAW VLOS
HEIGHT (M)
0
-100
-200
-300
-400
-500
500 1500 2500 3500 4500 5500 6500 7500 8500 9500 10500 11500 12500 13500
DISTANCE ALONG TRACK (M)
12.00
11.23
10.46
9.69
8.92
8.15
7.38
6.62
5.85
5.08
4.31
3.54
2.77
2.00
FREEZE
HEIGHT (M)
0
-100
-200
-300
-400
-500
500 1500 2500 3500 4500 5500 6500 7500 8500 9500 10500 11500 12500 13500
26.00
24.31
22.62
20.92
19.23
17.54
15.85
14.15
12.46
10.77
9.08
7.38
5.69
4.00


VLOS DEVIATION
HEIGHT (M)
0
-100
-200
-300
-400
-500
500
1500
2500
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
DISTANCE ALONG TRACK (M)
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
FREEZE
SNR DEVIATION

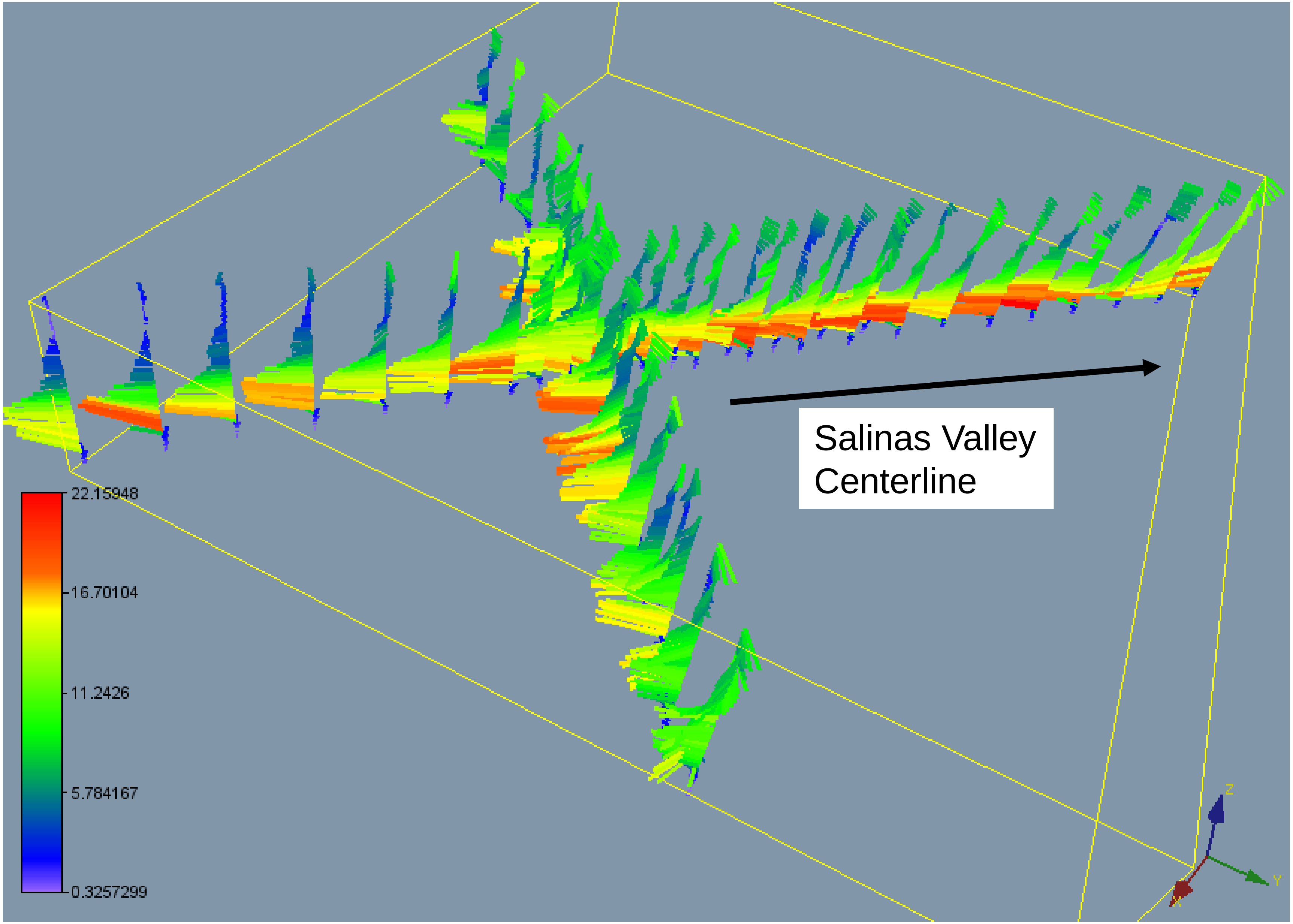

WIND SPEED (M/S)
0
4
8
12
16
20
24
28
32
36
2000
1600
1200
800
400
0
HEIGHT (M)
WIND PROFILES, APRIL 17 2007
BLACK: WIND DIRECTION
RED: WIND SPEED
SOLID: AFTERNOON FLT
DASHED: EVENING FLT
Salinas Valley (205m)
0
90
180
270
360
WIND DIRECTION (DEG)

Dynamic Soaring

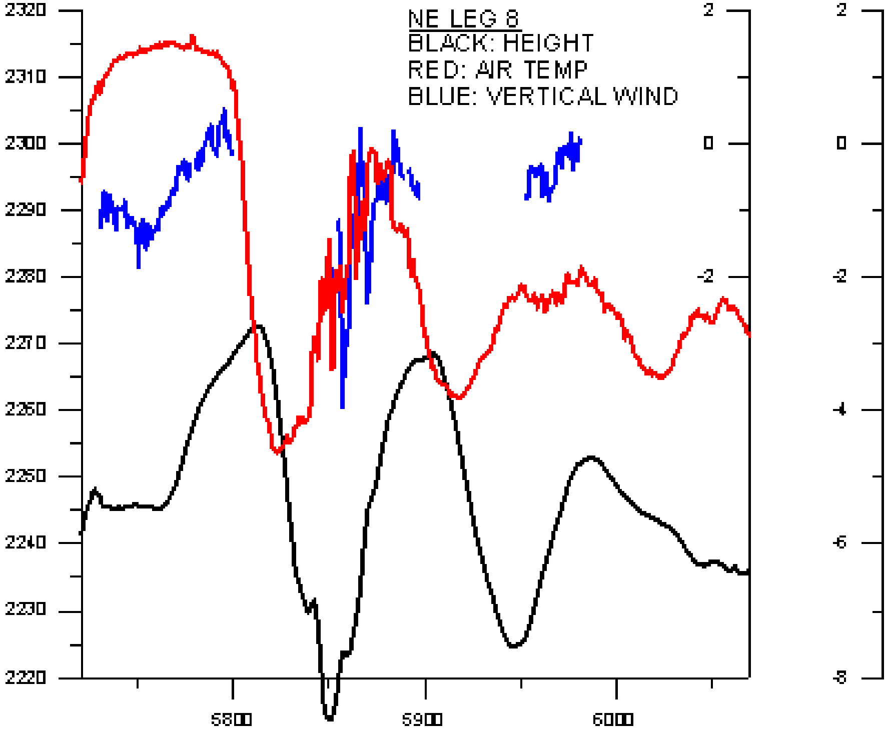


For the albatross, the minimum V(10m) = 8.9 m/s

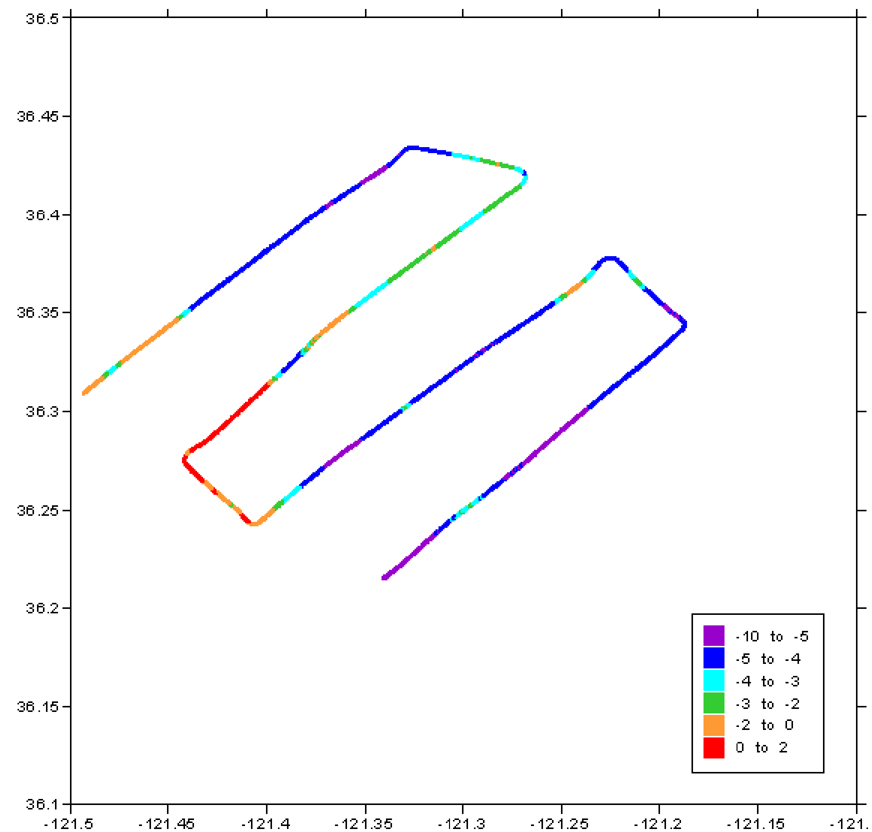
From Gottfried Sachs (2005)



Salinas Valley
Centerline
22.15948
16.70104
11.2426
5.784167
0.3257299
Z
Y
X

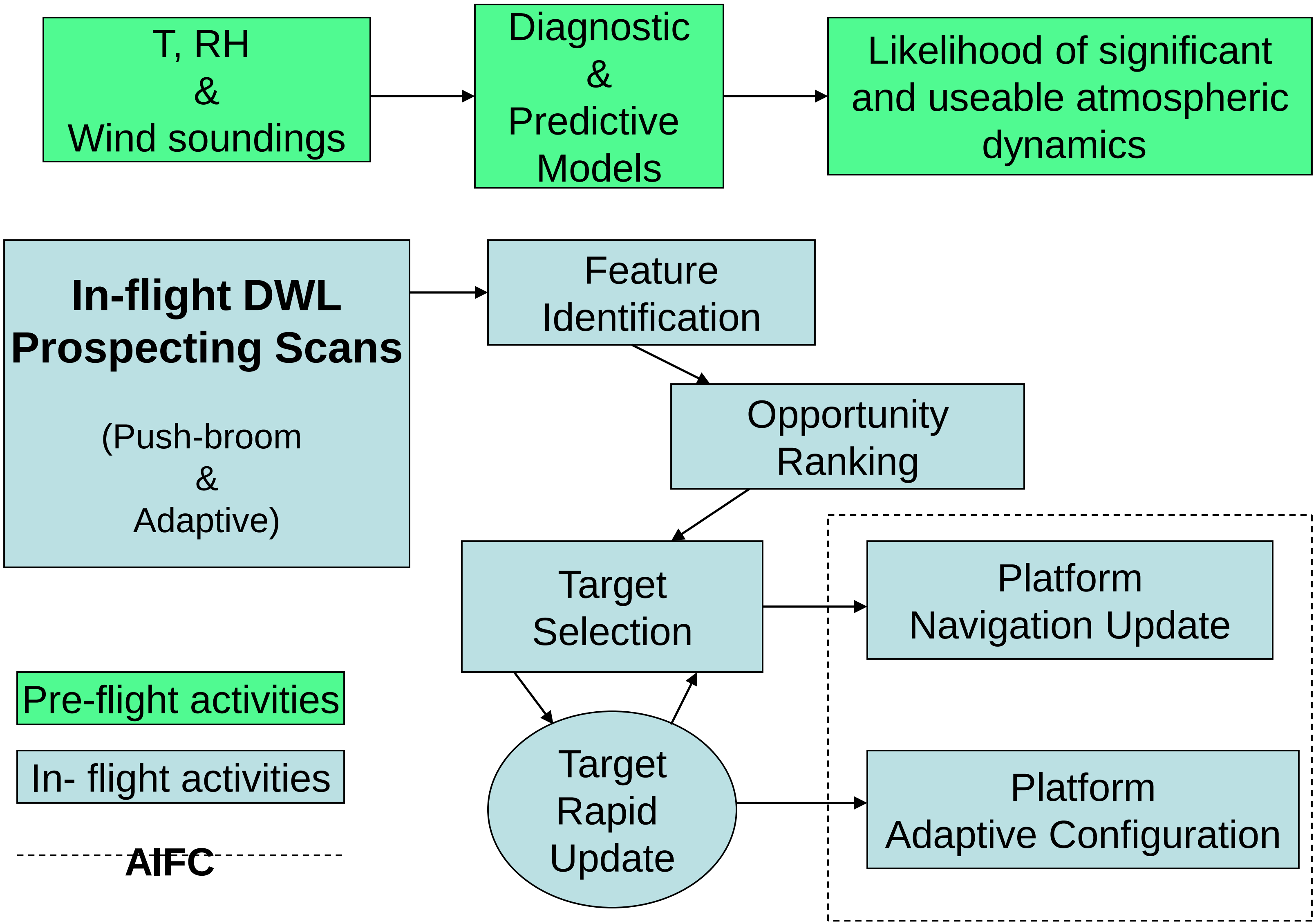


Mountain Waves?



1944 PDT 17 April 2007
near King City, CA

Atmospheric Energy Prospecting



Summary

- The continuous or random raster scans are the best options for the detection and characterization of vertical velocity features
- The vertical velocities inferred from the LOS convergence/divergence observations appear to be reasonable and useful
- The correlation of aerosol loading and vertical motion may be useful. However, the interpretation of this relationship requires further study.
- Airborne prospecting for clear air vertical motion features appears very feasible and may easily be extended to clouds, waves and shear situations.
- In November, TODWL flights will focus on nocturnal atmospheric advantages: gravity waves, low level jets (dynamic soaring) and cloud updrafts.