Wind Measurements: Rockets

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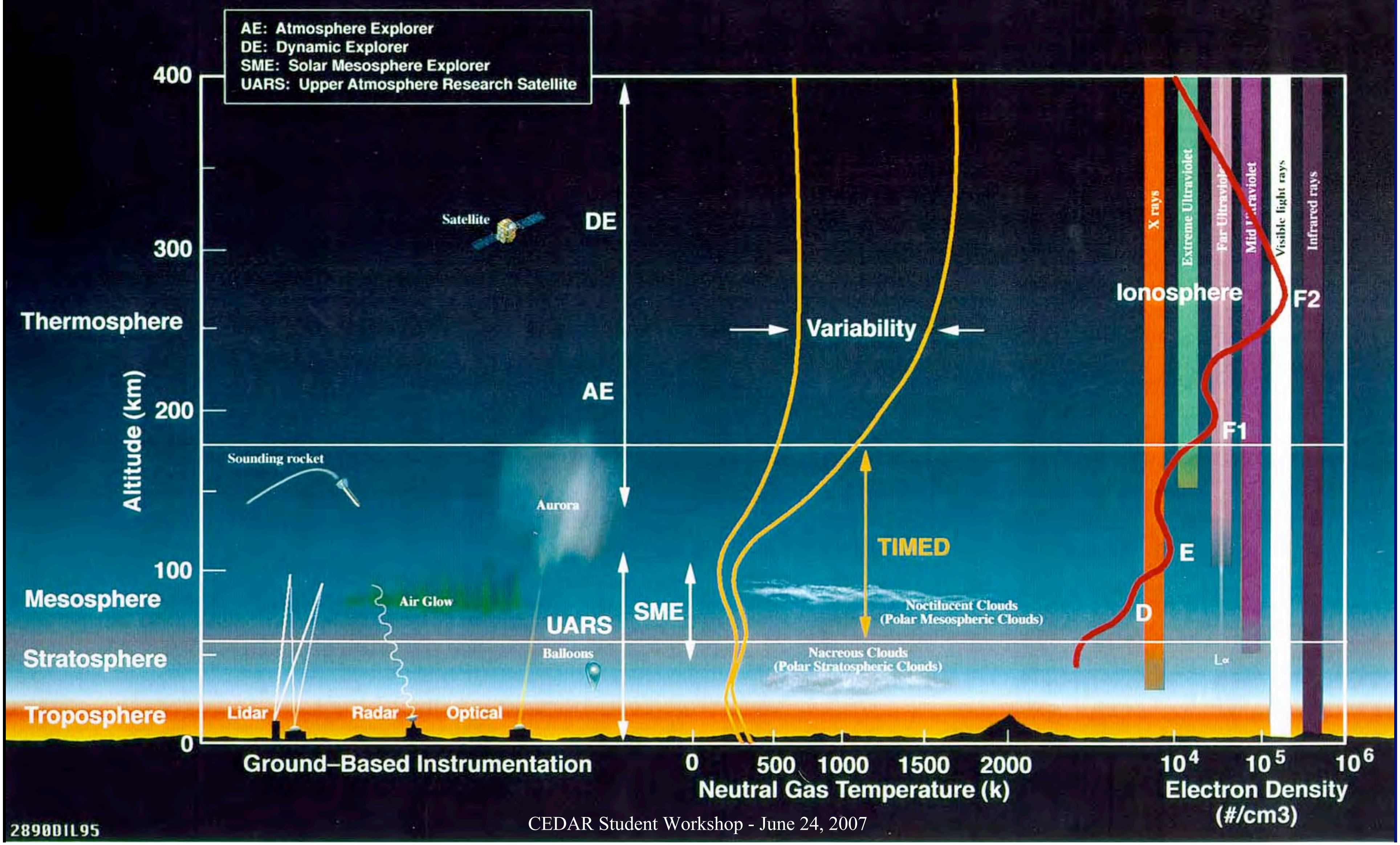
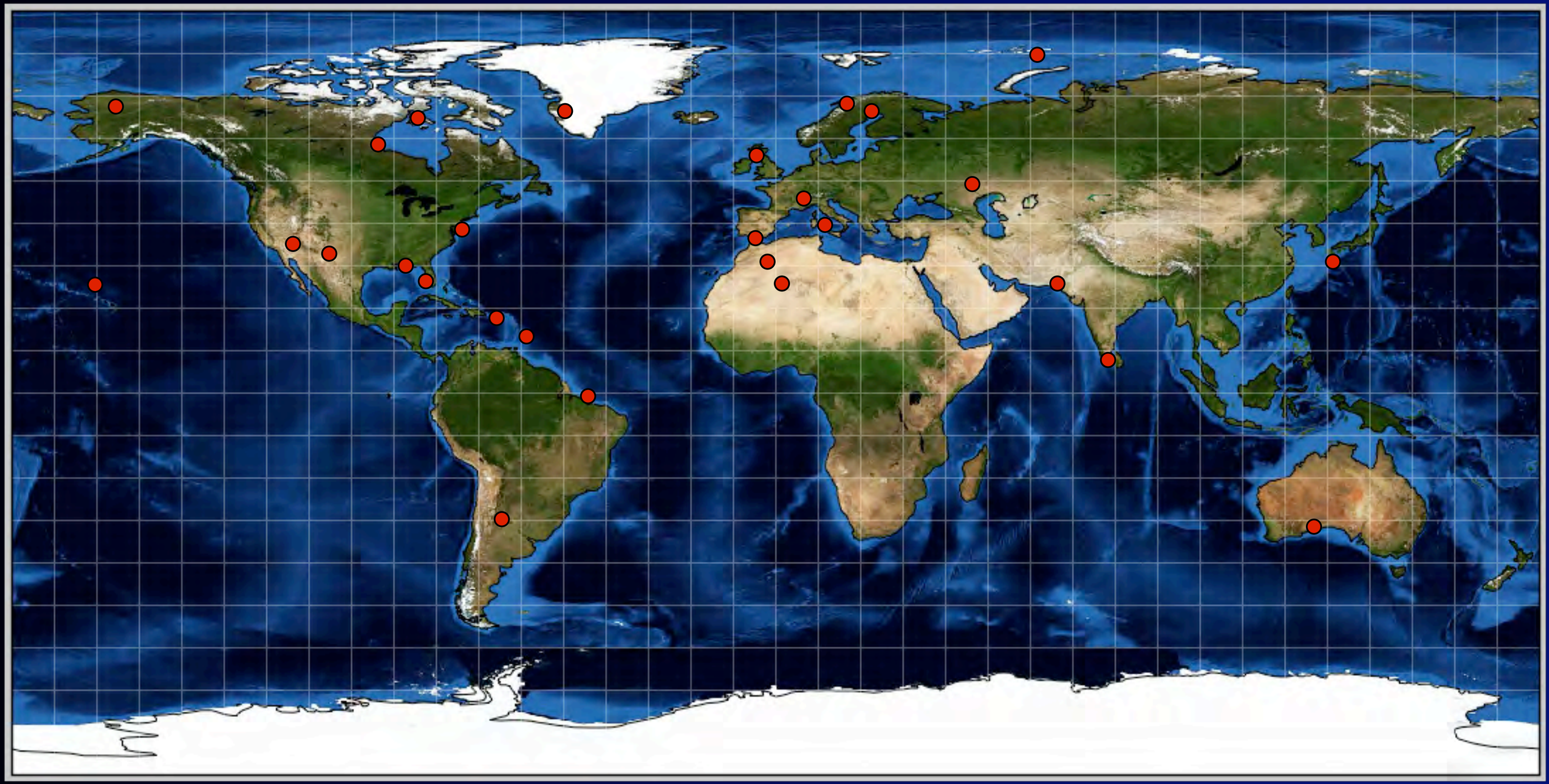
TIMED Science



Launch sites where thermospheric rocket wind measurements have been made



More than 500 wind profile measurements since 1955

(See Larsen, JGR, 2002)

Sodium trail released at twilight as a tracer of the neutral wind motions

January 21, 1955 (and October 12, 1955)

Aerobee rocket

JGR

Emission from a Sodium Cloud Artificially Produced by Means of a Rocket

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Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command, L. G. Hanscom Field, Bedford, Mass.
and
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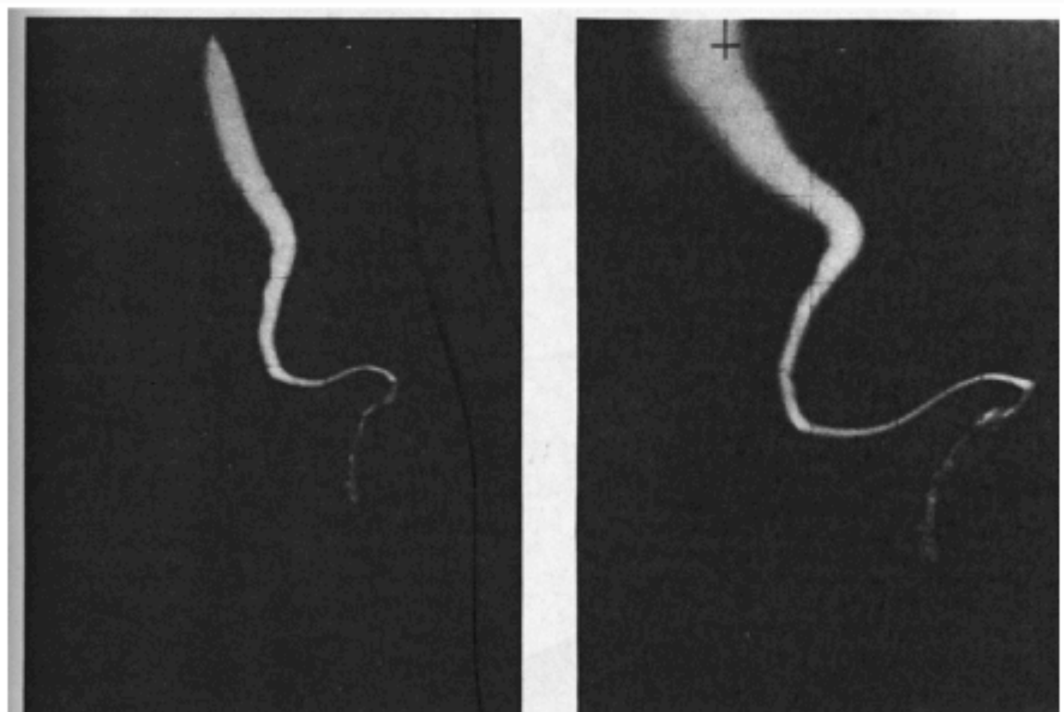
Department of Physics, University of Georgia, Athens, Ga.

Abstract—Following BATES's suggestion, three kilograms of metallic sodium vapour were ejected into the atmosphere from 50 to 113 km by means of two Aerobee rockets. The rockets were launched at the beginning of evening twilight on 21 January and 12 October 1955.

Enhanced sodium emission at 5890 Å was definitely observed visually, photometrically and spectrographically from 85 km to 113 km during twilight. No sharp time discontinuities in intensity were observed when the region was enclosed by the earth's optical shadow. No increase in emission was observed during the night.

Possible explanations are given for the lack of emission below 85 km.

Spreading of the sodium cloud indicated winds at the 85-km level to be 180 m.p.h. from the north-west and 100 m.p.h. from the south-east at the 110-km level.



Chemicals used for neutral wind measurements

Material	Optical Emissions	Altitude Range	Characteristics
Sodium	Green resonant emission	~80-200 km	Requires sunlight to be visible
Lithium	Red resonant emission	~80-300+ km	Requires sunlight to be visible, can be tracked in daylight
Strontium	Blue-green emission	~200-300+ km	Usually released as a 5-10% impurity in Barium releases
Trimethyl Aluminum $Al(CH_3)_3$	White spectrum when unlit, resonant blue emission when sunlit	~80-200 km	Chemiluniscent, visible at night
Nickel Carbonyl $Ni(CO)_4$	White spectrum	~80-200 km	Chemiluminescent, visible at night
Samarium, Neodymium	Red and green emissions, respectively	~100-300+ km	Material ionizes slowly
Titanium Tetrachloride $TiCl_4$	Dense black smoke	~20-50 km	Large chemical tracer mass required

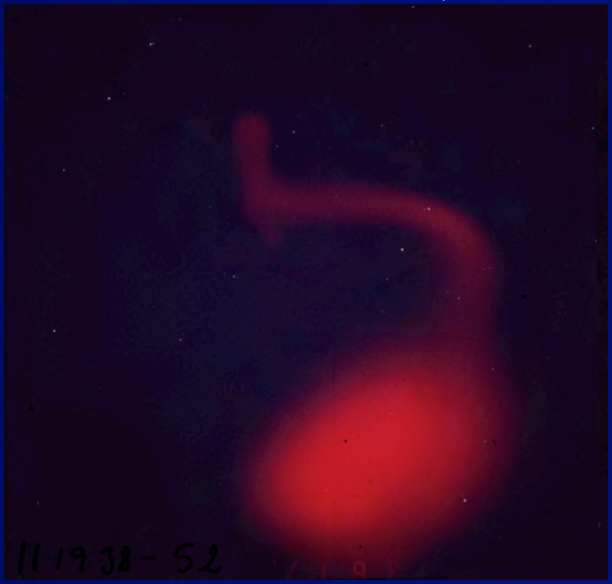
Lithium Trails

Narrow-band emission at 670.7 nm

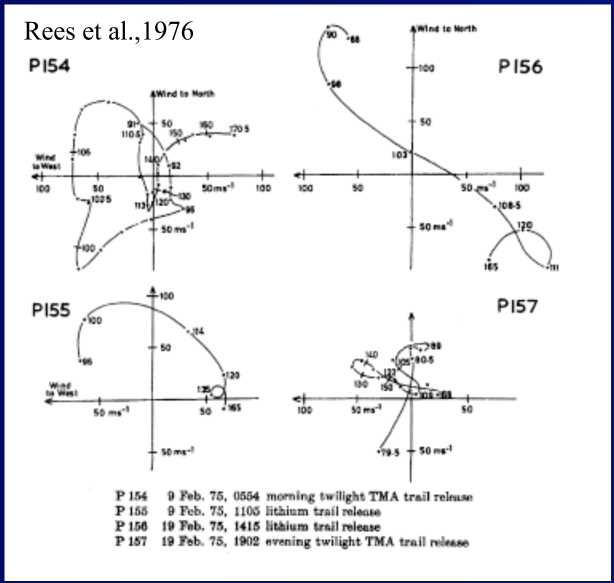
Wallops Island, Virginia - December 1969

(Bedinger et al.)

Greenland - December 12, 1974



Cameras with narrow (1 nm) filters can be used to observe lithium releases in daytime



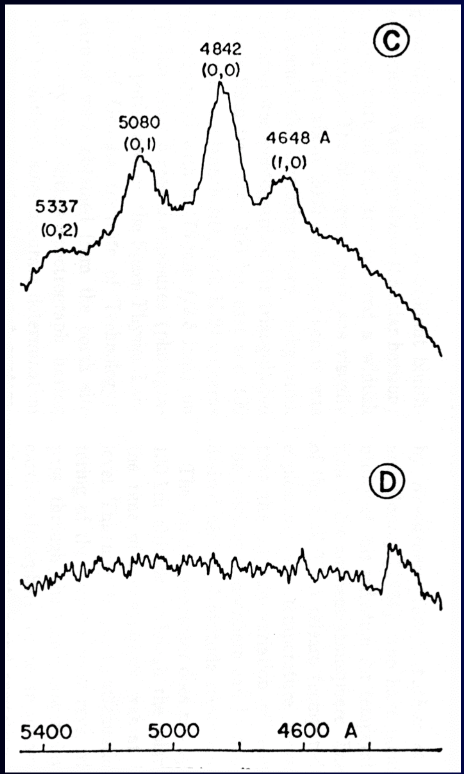
P155 and P156 are daytime measurements from India

Military Missile Rocket Exhaust Trail

Photographed by P. Anderson at evening twilight

Chemilumiscent - reacts slowly with oxygen in the upper atmosphere to produce a broad spectral emission

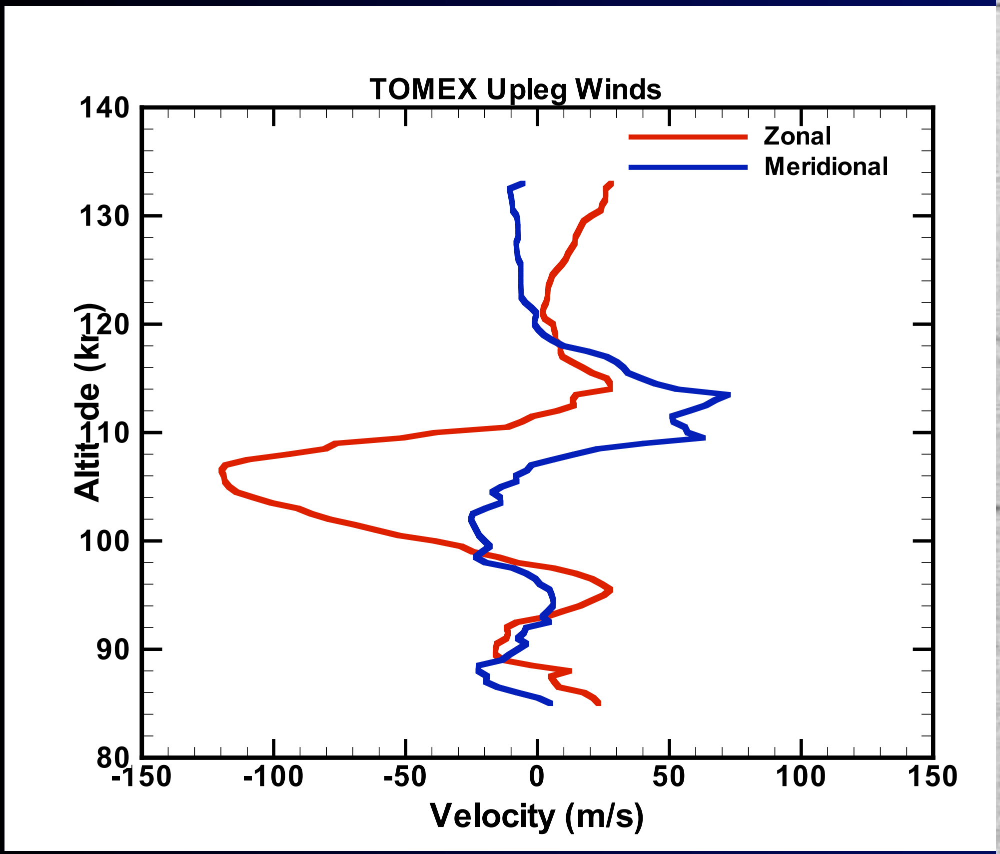
In sunlight - TMA produces resonant blue light emission from aluminum

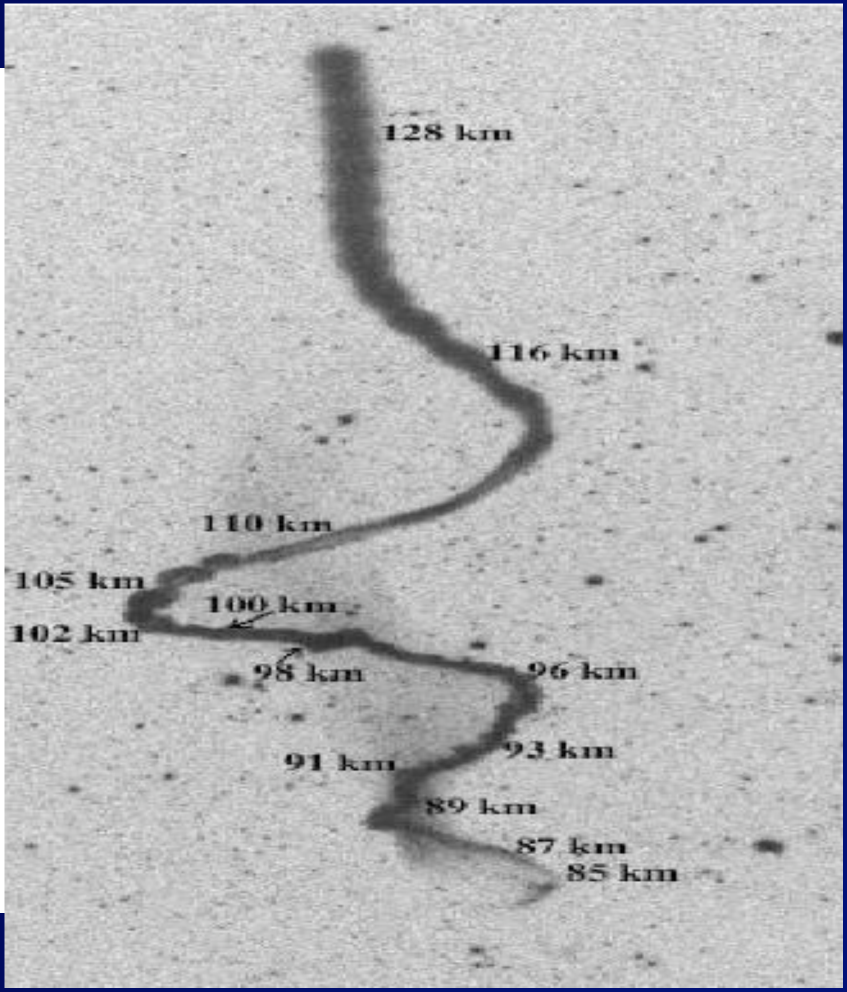


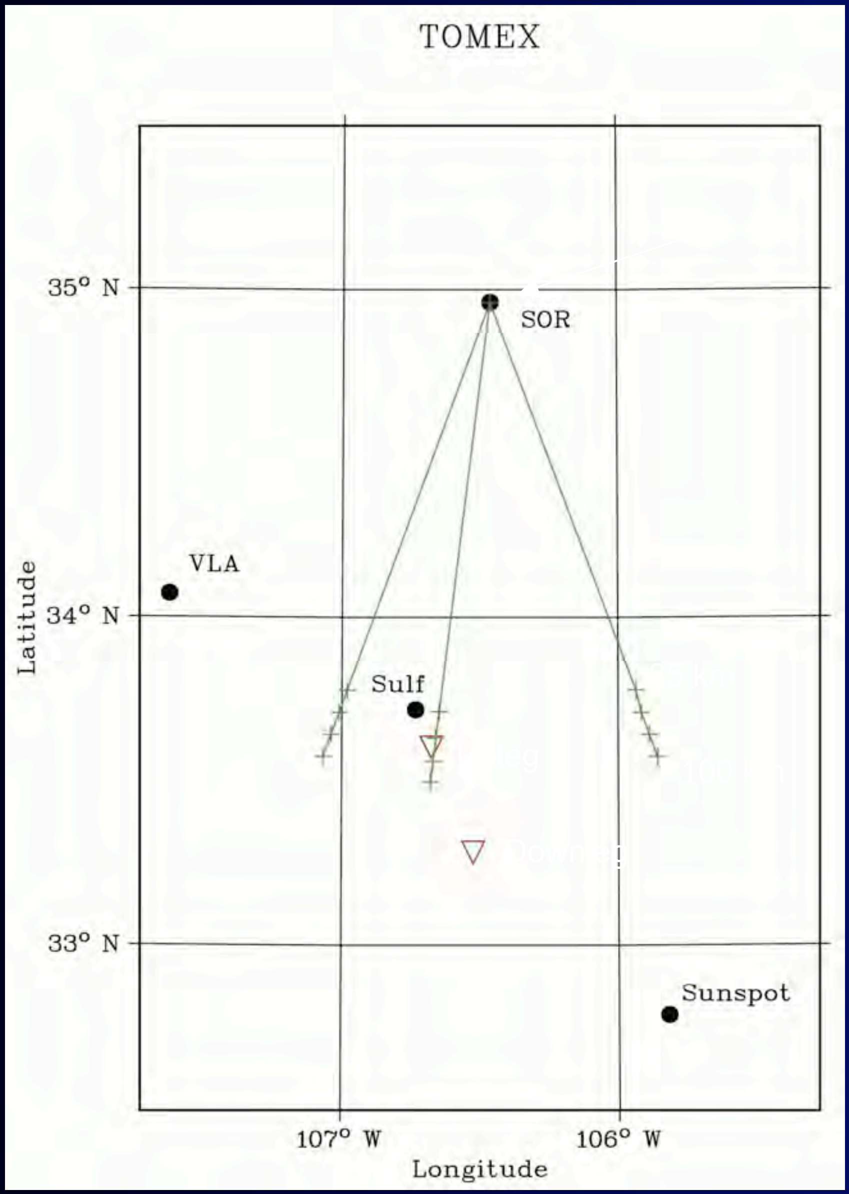
Trimethyl Aluminum (TMA)

Arctic Village, Alaska, March 2, 1978

TOMEX Upleg Wind Profile







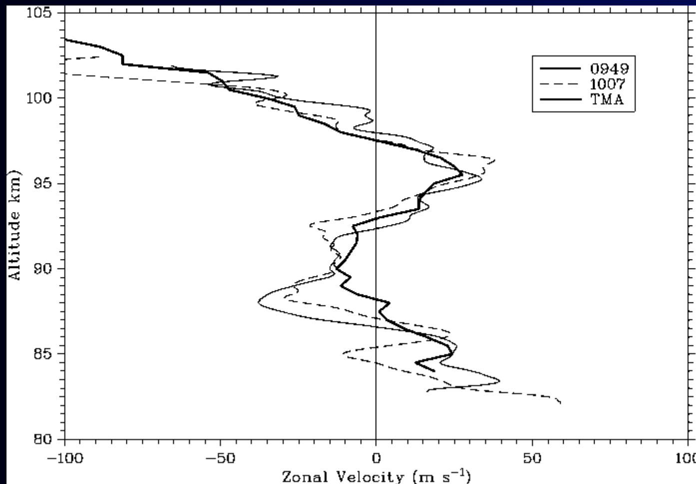
TOMEX Oct 2000

Starfire Optical Range (SOR)

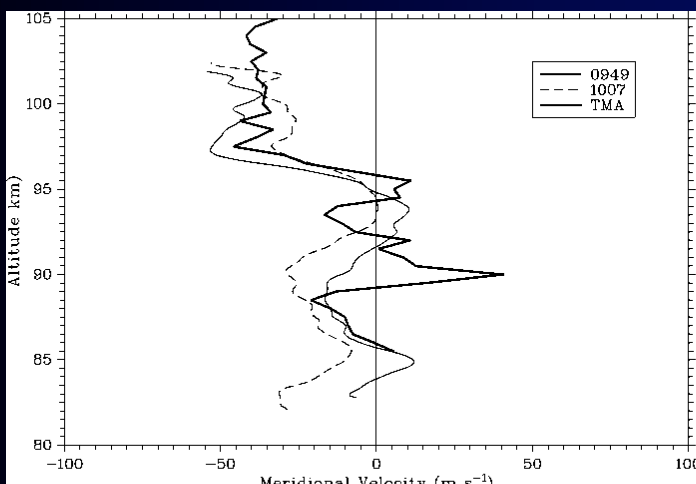
Sensitive Doppler Sodium Lidar

Launch Site: Sulf Site,
White Sands Missile Range

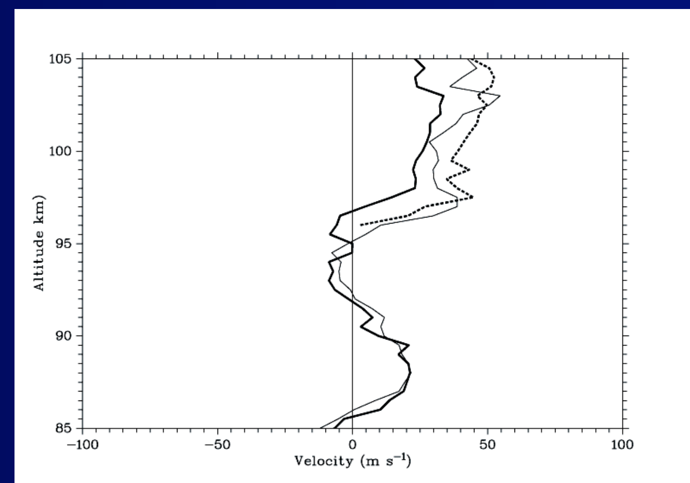
Lidar and TMA Wind Comparisons



Zonal wind



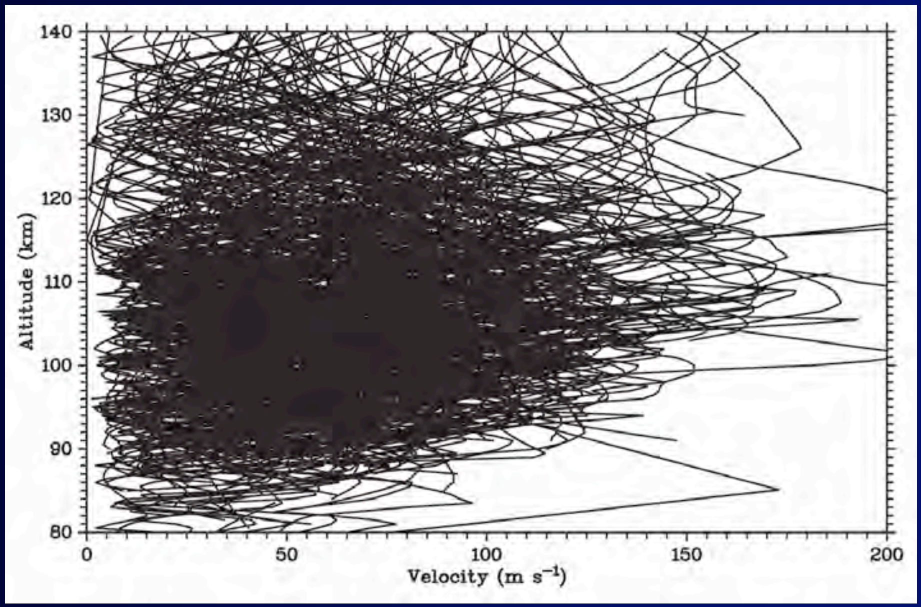
Meridional wind



Line-of-sight wind component

(Larsen et al., GRL, 2003)

Distribution of winds for latitudes equatorward of 60^o from four decades of chemical release wind measurements (>500 profiles)



(Larsen, JGR, 2002)

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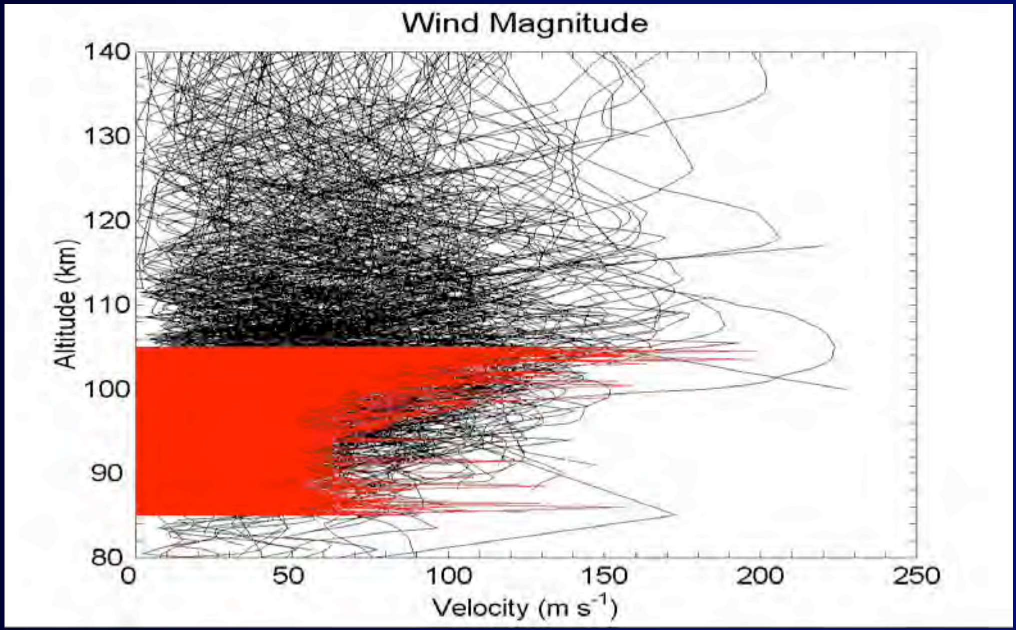

…compared with several years of lidar wind measurements from New Mexico and Hawaii (Zhou et al., 2007)

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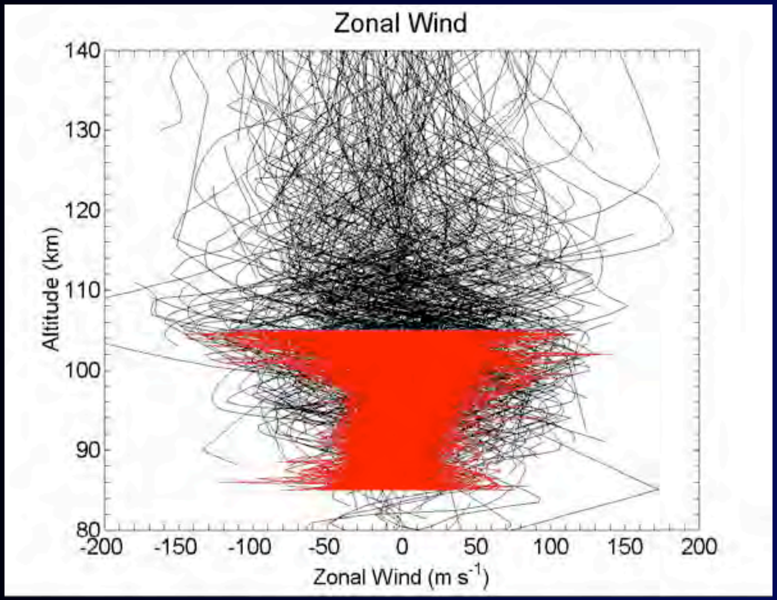

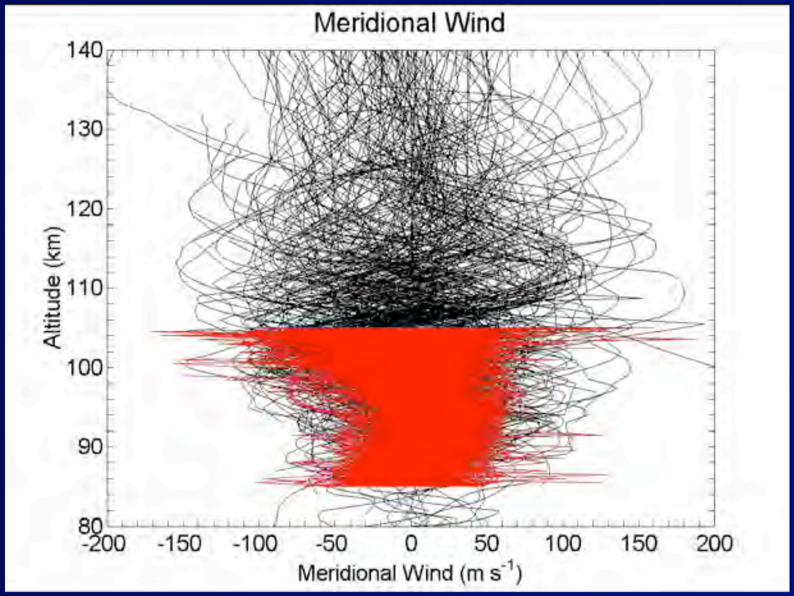

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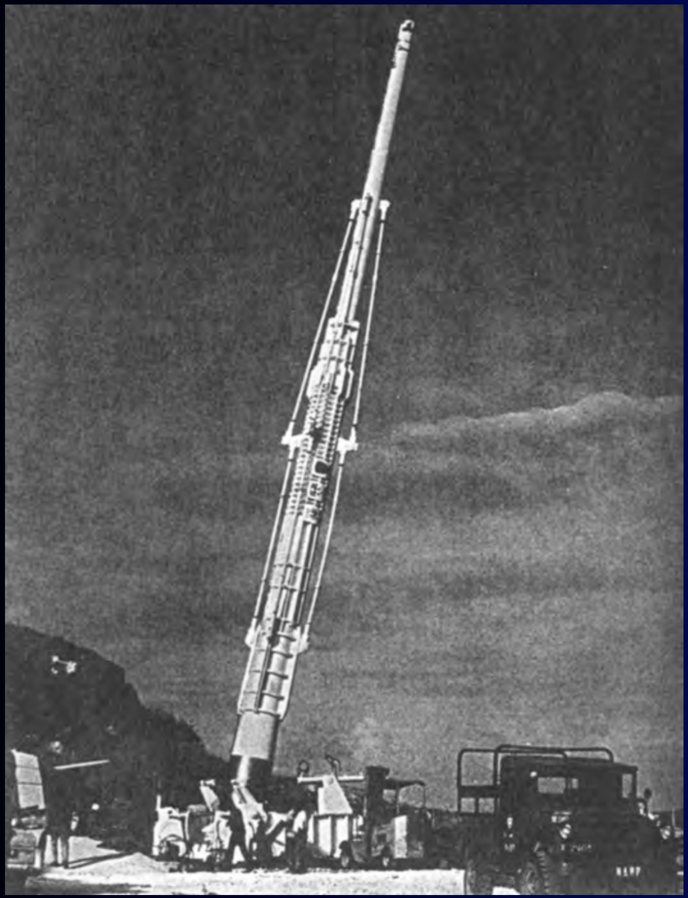
The Big Gun – An alternative launch system

HARP (High Altitude Research Project) 1961 to 1967



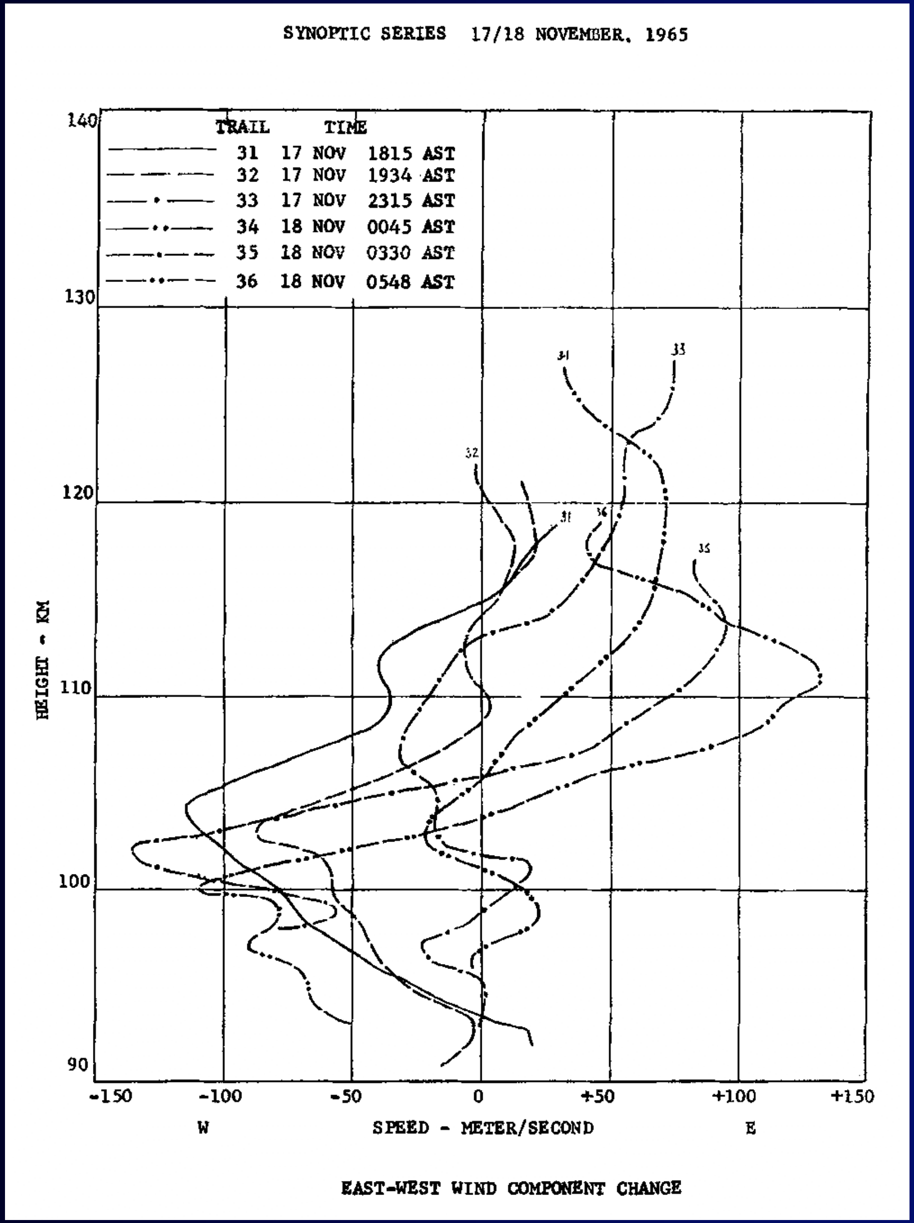
Sixteen-inch gun at Barbados site
(identical to Yuma gun)

Dr. Gerald V. Bull

Barbados 16-inch Gun

- Length: 119 feet including 50-foot muzzle extension
- Gun weight 200 tons
- Rate of fire: every 60-90 minutes
- 185 lb (84 kg) projectile to 590k feet (180 km)
- Number of launches: 150 from Barbados and 30 from Yuma

The Big Gun being fired…



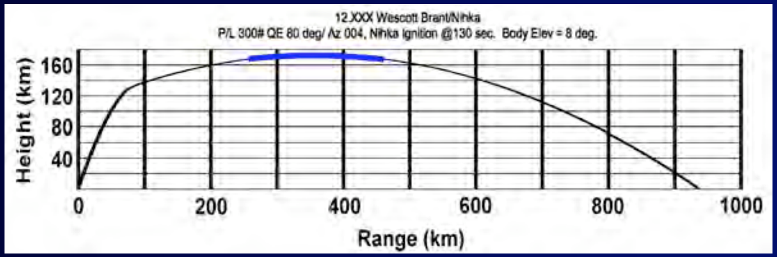
Synoptic wind measurement series

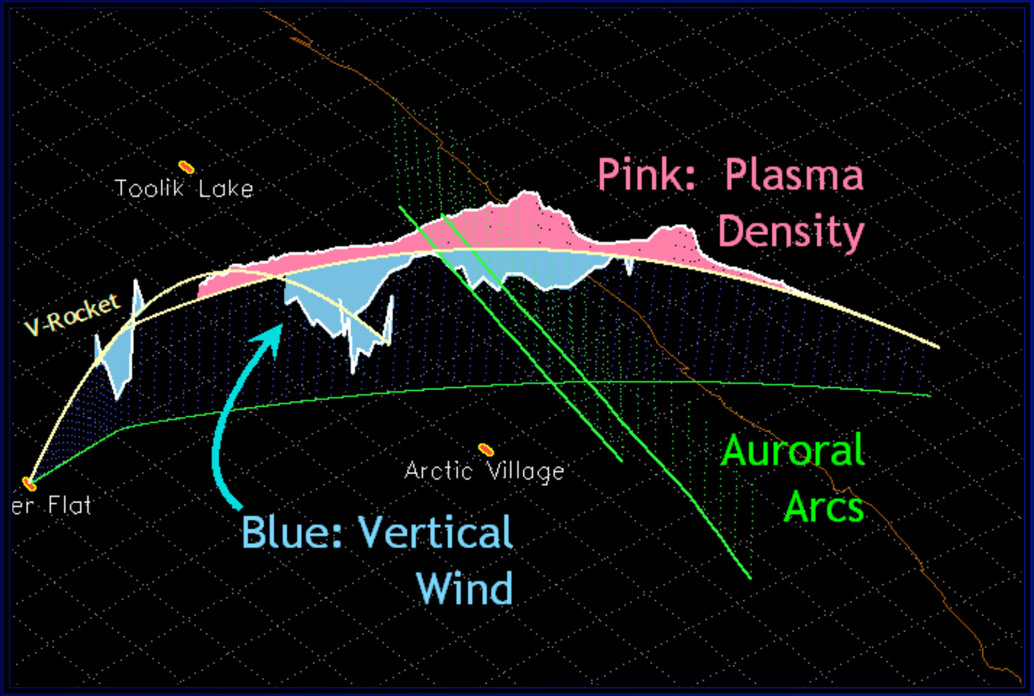
Six TMA wind profiles in a single night

68 wind profile measurements were made at Barbados from 1963 to 1966, many as synoptic series similar to the one shown here.

HEX 1 & 2

(PI's: Conde and Craven -UAF)





Provided by M. Conde

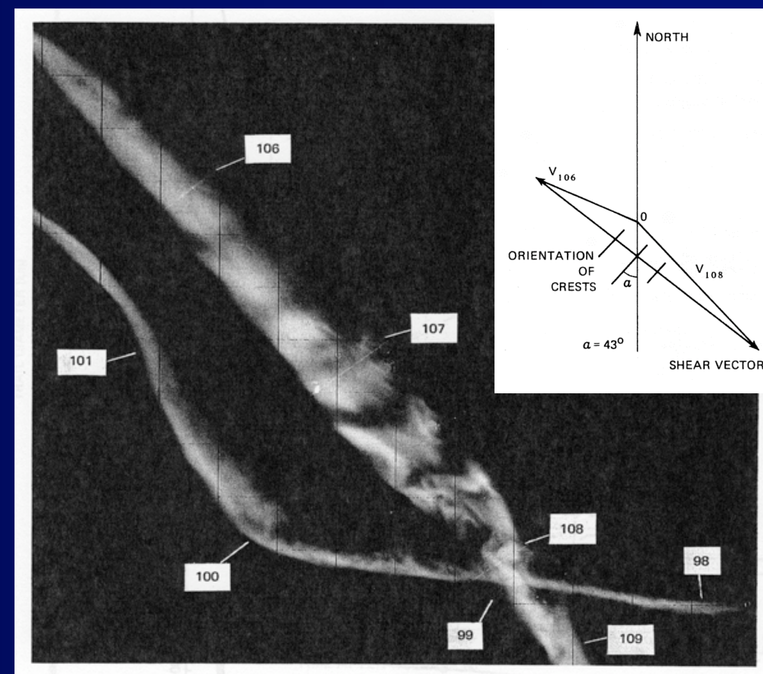
Visualization of instability structures

Kelvin-Helmholtz billows appear in the altitude range between 102 and 108 km in the upleg portion of a trail in the SEEK-2 experiment (Aug 2002, Japan).

Horizontal wavelength approx. 5 km

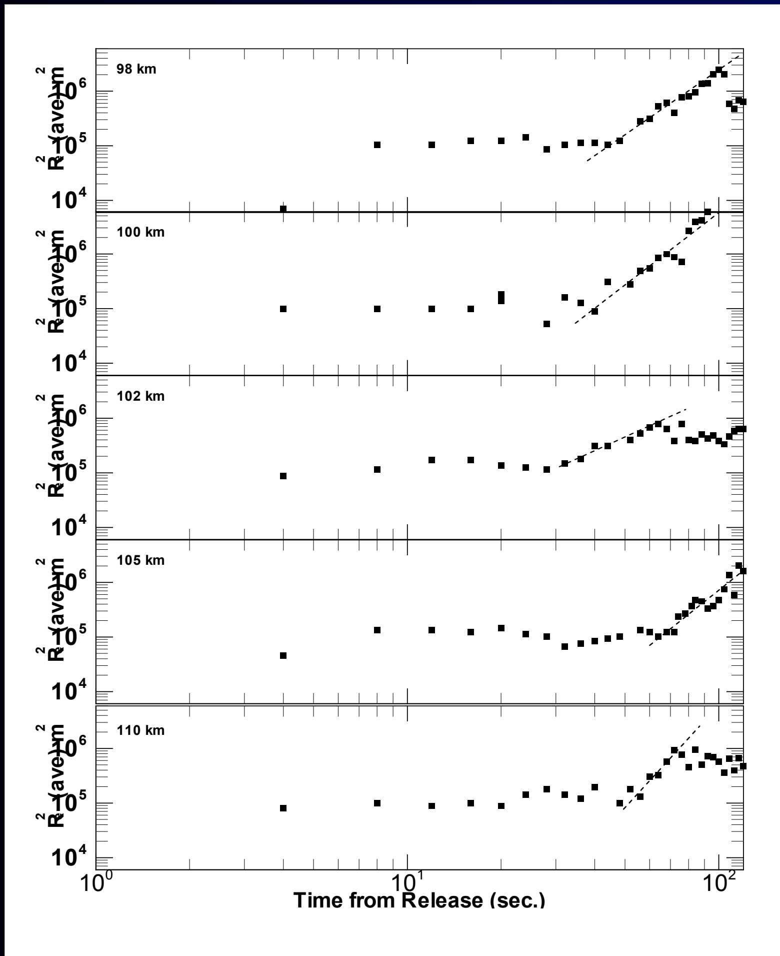
Vertical wavelength approx. 2 km

(Larsen et al., Ann. Geophys., 2005)



Wave fronts are evident in trail between 106 and 108 km altitude in a launch from Australia (Lloyd et al., 1970). The wave fronts are orthogonal to the shear vector.

Turbulent diffusion and turbulent energy dissipation measurements



Bishop et al., JGR, 2006

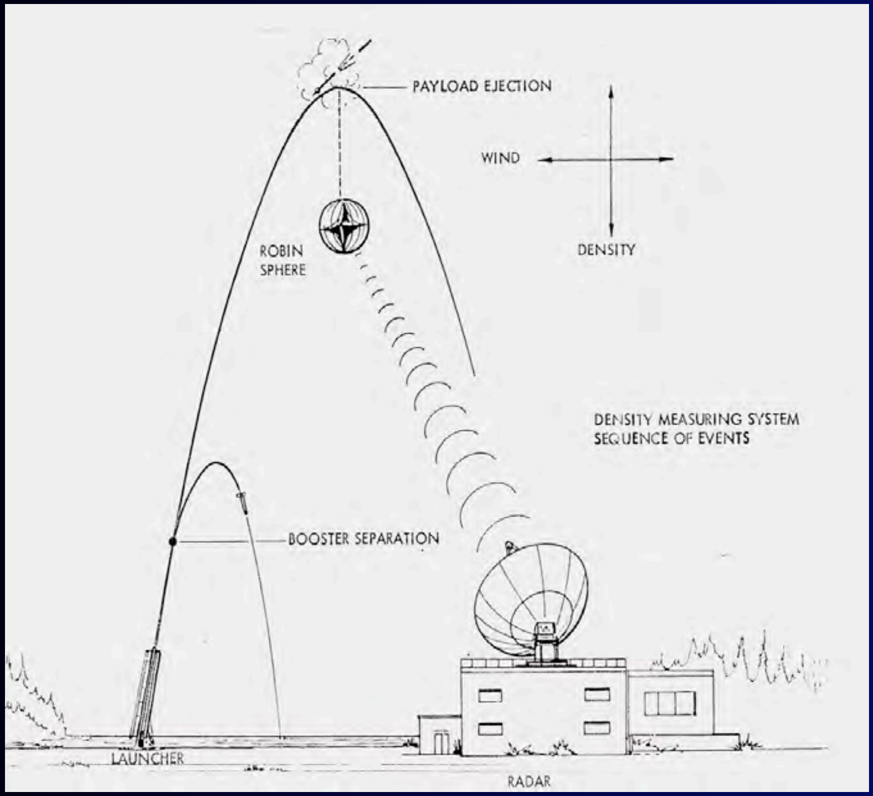
TABLE 3. VARIATION WITH ALTITUDE OF THE CONSTANTS OF THE KOLMOGOROFF MICROSCALE (AFTER ROPER 1966*a*)

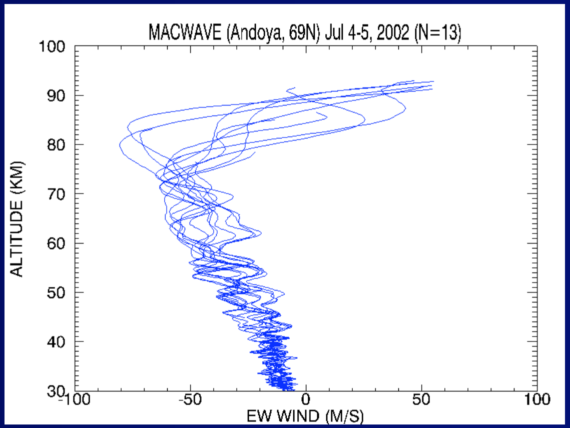
altitude / km	ϵ_R / W kg^{-1}	t_R^* / s	η_R / m
80	0.01	10.0	19.0
81	0.011	10.4	22.0
82	0.0118	10.9	24.6
83	0.0128	11.4	27.4
84	0.0139	11.9	30.5
85	0.015	12.5	33.9
86	0.016	13.2	37.9
87	0.017	13.9	42.4
88	0.0185	14.5	47.2
89	0.0198	15.3	52.8
90	0.021	16.1	59.0
91	0.023	16.8	65.6
92	0.025	17.5	73.0
93	0.027	18.4	81.3
94	0.030	19.0	90.0
95	0.033	19.7	100
96	0.038	20.0	109
97	0.042	20.7	121
98	0.049	20.9	132
99	0.057	21.0	145
100	0.066	21.3	159
101	0.080	21.0	172
102	0.098	20.7	186
103	0.125	19.8	195
104	0.168	18.8	209
105	0.186	19.4	232
106	0.20	20.4	259
107	0.15	25.6	316
108	0.085	37.0	413
109	0.033	64.7	595
110	0.01	128	911

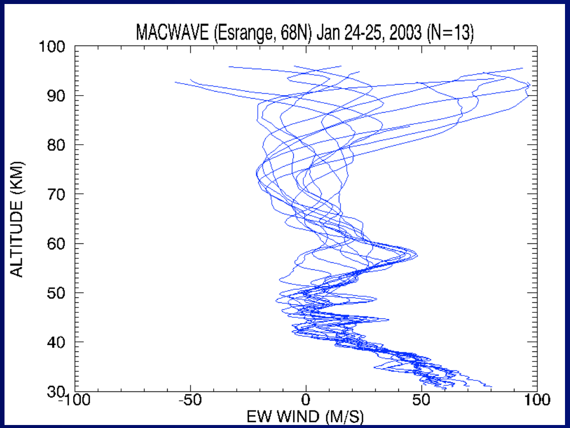
Rees et al., Trans. Roy. Phil. Soc., 1972

FALLING SPHERE LAUNCH

Booster-dart separation occurs at ~2 seconds; Inertia carries dart to ~115 km apogee where a 1-meter diameter sphere is ejected; data processing begins on sphere descent at ~100 km; data typically are valid from ~88-90 km to the end of the radar track.







Courtesy R. Goldberg and F. Schmidlin

FALLING SPHERE INFLATION

Chaff Wind Measurement Technique

Small rockets with apogee near 110-115 km altitude

Chaff dimensions: a few x a few tens millimeters

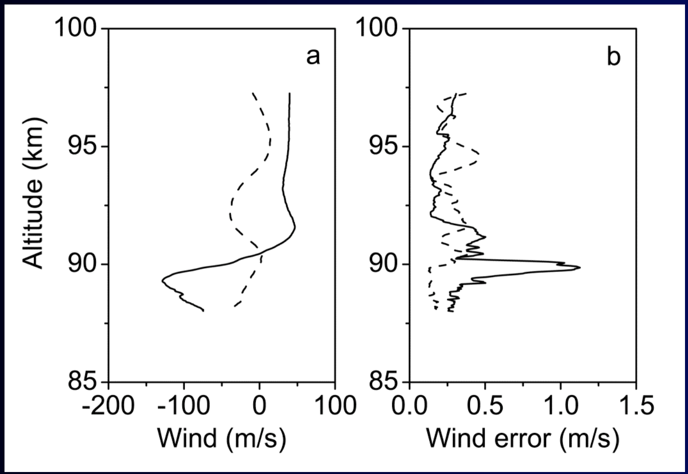
Matched to tracking radar wavelength

Wind profiles from approximately 95 to 75 km

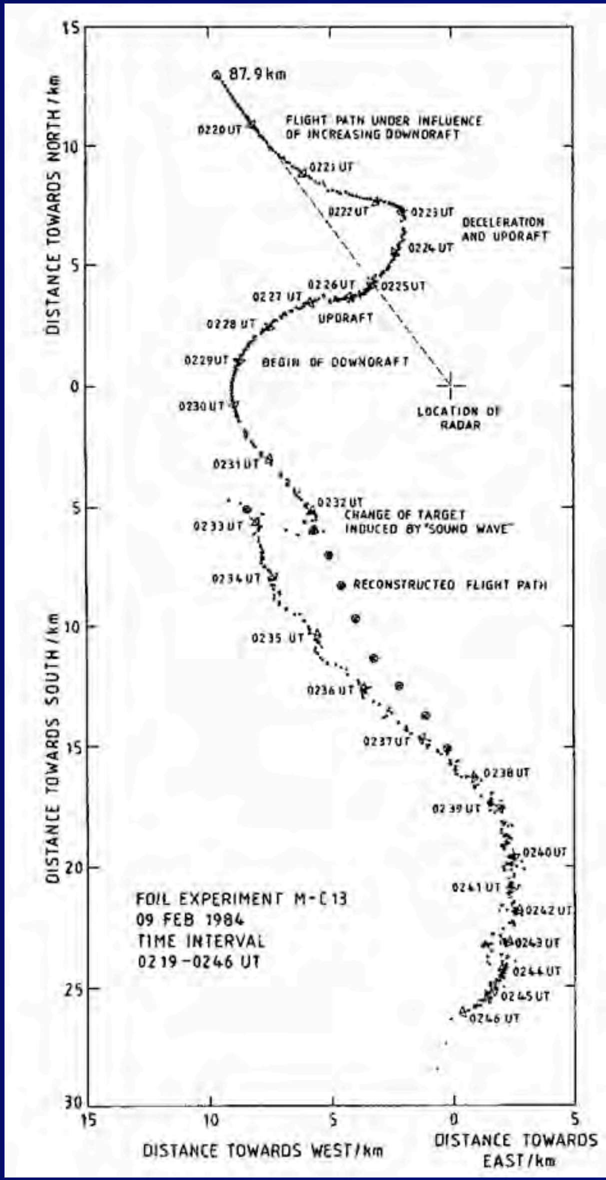
Challenges:

Clumping of chaff

Tracking center of chaff cloud



Wind profile example

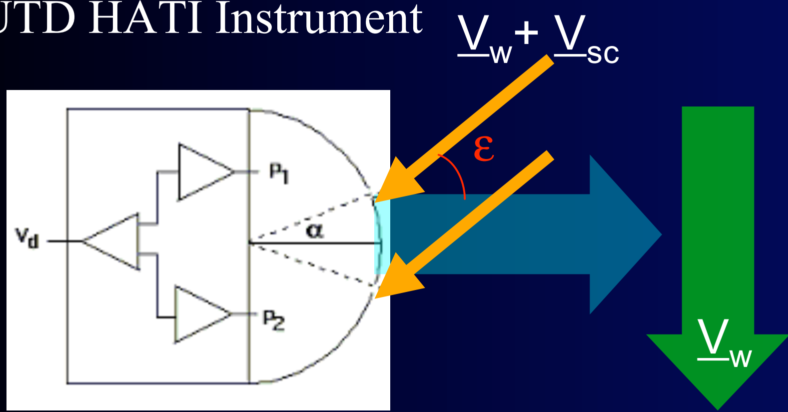


Radar track of chaff cloud

(See, e.g., Widdel, JATP, 1990)

Other Rocket Wind Measurement Instruments

UTD HATI Instrument



Flown from Wallops Island, Virginia, in 2003

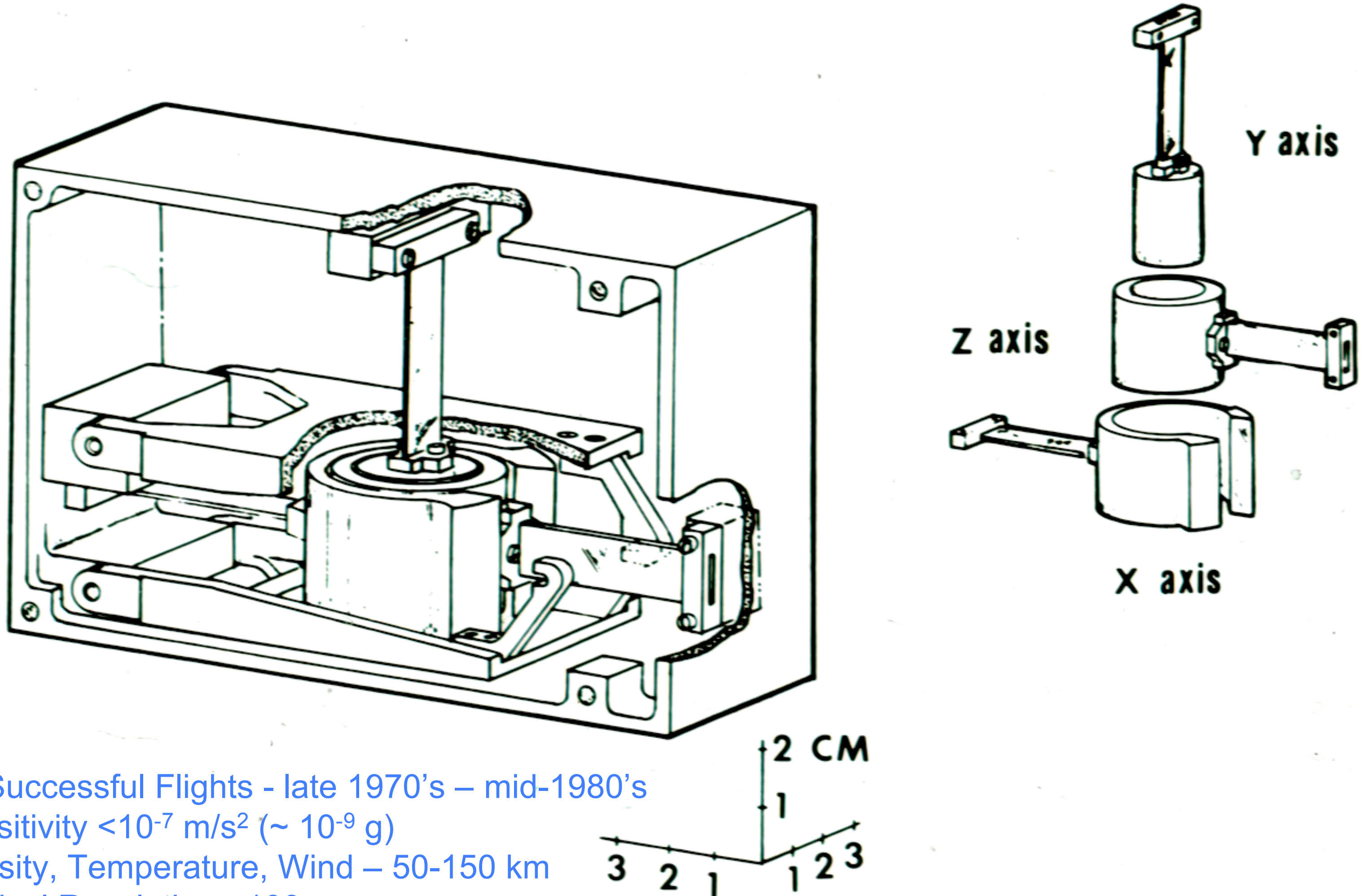
(Diagram courtesy of G. Earle)

An instrument with flight history

Instruments that have been considered or proposed but not flown:

- On-board Fabry-Perot Interferometer using red-line Doppler shifts
- On-board oxygen lamp using Doppler shift of resonant emission
- Instrument based on ionization gauge pressure measurement

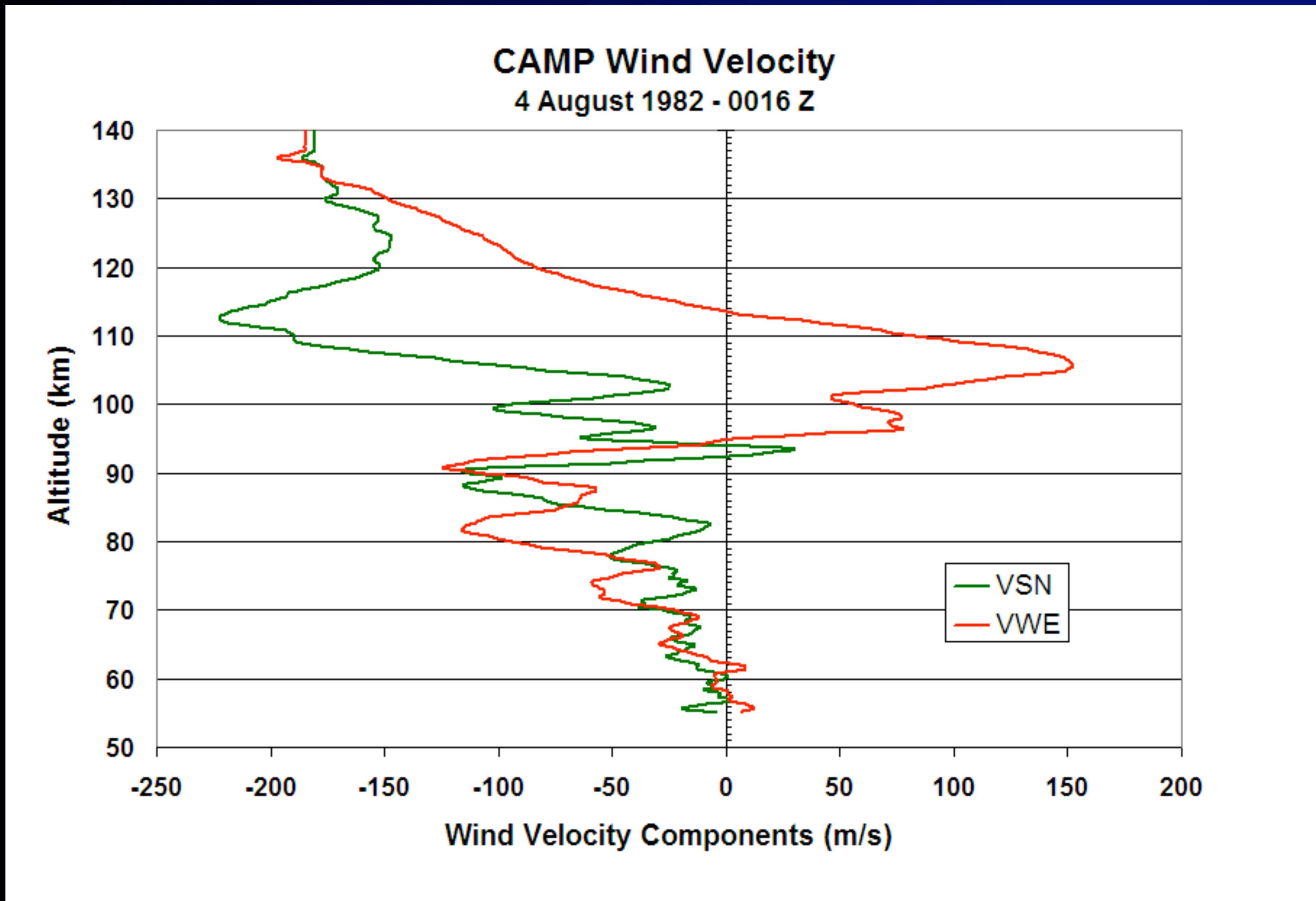
Piezoelectric Accelerometer Measurements



10 Successful Flights - late 1970's – mid-1980's
Sensitivity <10^{-7} m/s^2 (~ 10^{-9} g)
Density, Temperature, Wind – 50-150 km
Vertical Resolution <100 m

Three Axis Piezoelectric Accelerometer

"Measurements of Atmospheric Density at Kwajalein Atoll, 18 May 1977," C.R. Philbrick, A.C. Faire and D.H. Fryklund, AFGL-TR-78-0058 (113 pages), 1978.


CAMP Wind Velocity
4 August 1982 - 0016 Z
Altitude (km)
140
130
120
110
100
90
80
70
60
50
-250
-200
-150
-100
-50
0
50
100
150
200
Wind Velocity Components (m/s)
VSN
VWE

Conclusions

- Rocket wind measurement techniques based on chemical tracers or tracking of objects, such as falling spheres, have been used extensively since the late 1950's and have proven to be reliable and accurate.

- Tracer techniques generally work well at altitudes from the mesosphere to the upper thermosphere and typically provide wind measurements with an accuracy of approximately 5 m/s and an absolute altitude resolution of a few hundred meters.

- Techniques based on in situ instrument measurements have been less successful. Various designs have been considered but few have been flown. A notable exception is the accelerometer technique, which avoids many of the wake and ram effect problems that characterize techniques that sample the atmosphere directly.