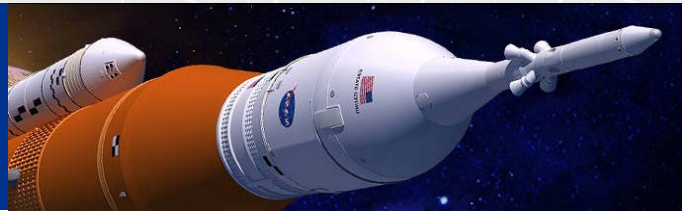
Results from the USAF Boundary Layer Technology Demonstration



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Background

- The United States Air Force (USAF) operates two space launch vehicle launch ranges.
  - Eastern Range (ER) at Cape Canaveral Air Force Station.
  - Western Range (WR) at Vandenberg Air Force Base.
- Both ranges use 915-MHz Doppler Radar Wind Profilers (DRWP) to measure winds within the lowest few kilometers of the atmosphere.
  - Important input in toxic dispersion models and in case of low-level aborts.
- The current 915-MHz DRWPs are experiencing equipment obsolescence.
- The USAF funded evaluations of two boundary layer wind profiling systems, a 915-MHz DRWP and a Lidar, for approximately three months at each range.
- Additionally, the USAF funded NASA Marshall Space Flight Center (MSFC) Natural Environments Branch (NE) to evaluate wind output from the two systems.

Background – Wind Observing Systems

- 449-MHz DRWP.
  - Operates in two modes - Low and High.
    - Low mode observes winds from ~100 m - ~3,000 m in 67 m intervals.
    - High mode observes winds from ~1,600 m - ~7,000 m in 81 m intervals.
  - Observations are made every five minutes.
- WINDCUBE® Lidar.
  - Observes winds from 400 m – 3,000 m in 100 m intervals.
  - Profiles are provided approximately every three seconds.
- 915-MHz DRWP.
  - Observes winds from 130 m – 6,100 m in 100 m intervals.
  - Profiles are provided every 15 minutes.

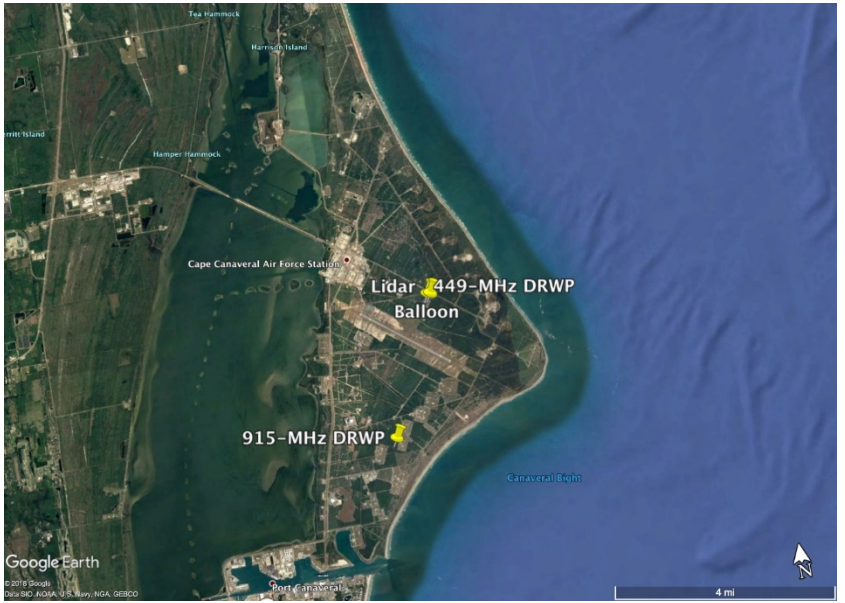
- Automated Meteorological Profiling System (AMPS) Low Resolution (LR) Weather Balloons.
  - Observe winds from the surface to over 30,000 m in one second intervals.

Background – Wind Observing Systems

WR

System	Period of Record
AMPS Balloon	11/20/2017 - 3/14/2018, 5/10/2018 – 5/30/2018
449-MHz DRWP	11/16/2017 - 3/4/2018
Lidar	11/20/2017 - 1/19/2018, 5/10/2018 – 5/30/2018
915-MHz DRWP	11/20/2017 - 3/14/2018

ER



System	Period of Record
AMPS Balloon	2/5/2018 - 4/27/2018
449-MHz DRWP	1/22/2018 – 4/27/2018
Lidar	2/5/2018 – 4/30/2018
915-MHz DRWP	2/1/2018 - 4/29/2018

Analyses

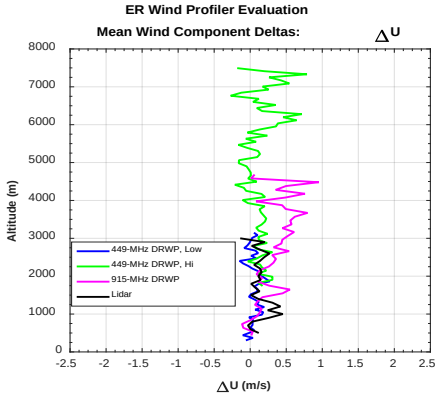
- Compared the U and V wind components to concurrent AMPS measurements to quantify the delta of the three systems relative to balloon measurements.
- Assessed data availability versus altitude to quantify how often it is expected to obtain data to an altitude of interest.
- Examined the Effective Vertical Resolution (EVR) of each system which quantified the granularity of the wind features that each system resolves.
  - This defines the boundary between instrument noise and real wind features.

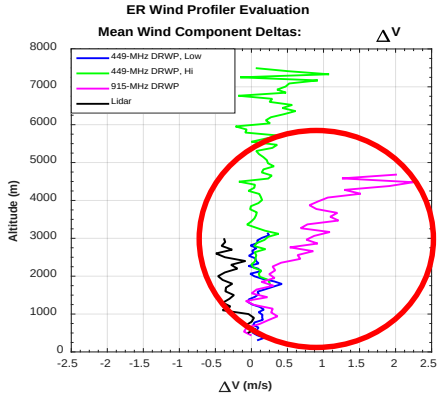
Balloon Comparisons - Methodology

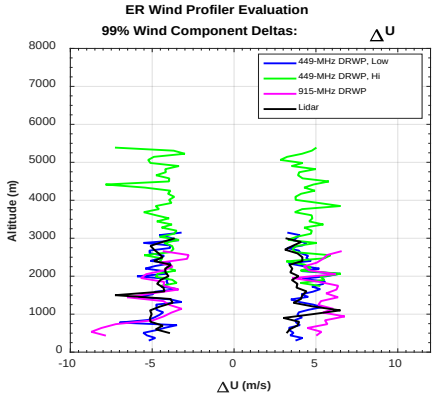
- Wind component profiles from the 449-MHz DRWP, 915-MHz DRWP, and Lidar were compared to concurrent wind component profiles from AMPS.
- Data from each remote sensing system were temporally and vertically matched to AMPS data.
- Mean wind component deltas, root-mean-square (RMS) wind component deltas, and 99% envelopes of the wind component deltas versus altitude were calculated for all systems.
  - The deltas were used to determine system accuracy of each system.
  - RMS deltas were used to provide and estimate of the error of each system.
  - Envelopes characterize extreme wind component deltas from each system.

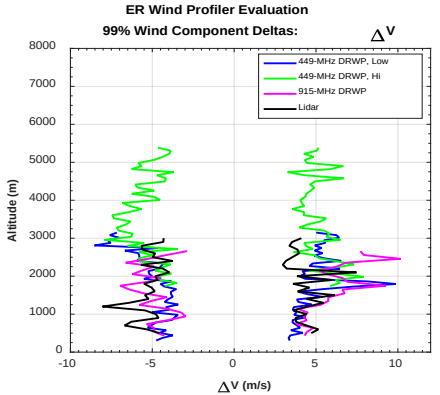
System	Vertical Averaging Interval	Temporal Criteria
449-MHz DRWP, Low	67 m (ER), 64 m (WR)	+/- 2.5 minutes
449-MHz DRWP, High	81 m (ER), 77 m (WR)	+/- 2.5 minutes
915-MHz DRWP	101 m	+/- 7.5 minutes
Lidar	9 m (no averaging)	+/-2.5 seconds

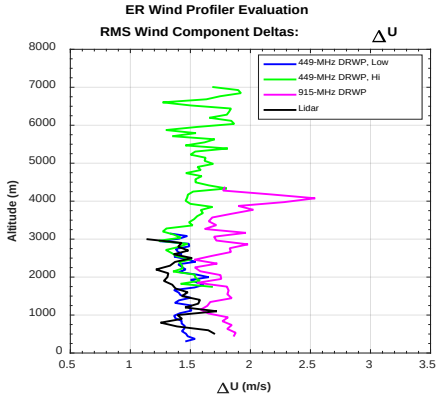
ER Balloon Comparisons - Results

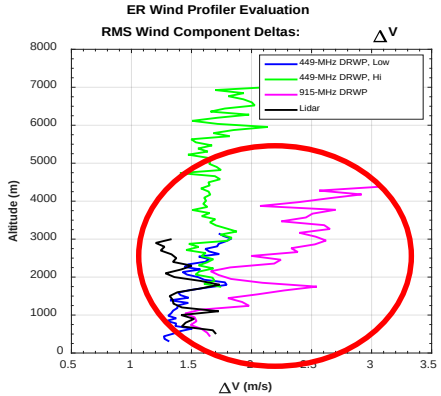


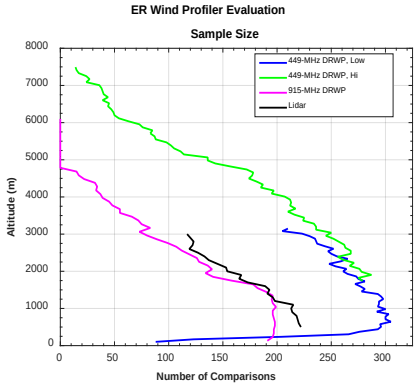












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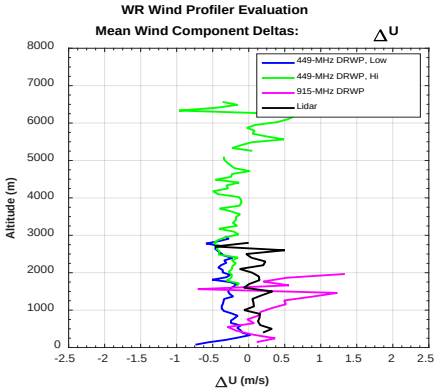
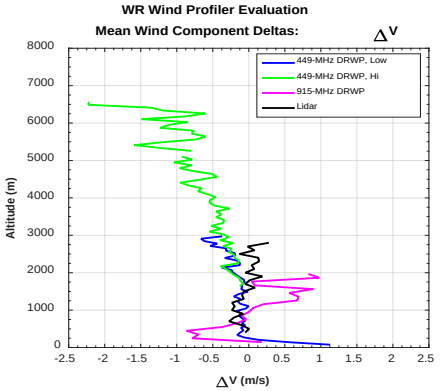
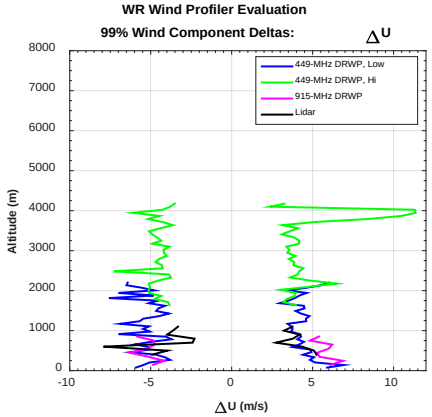
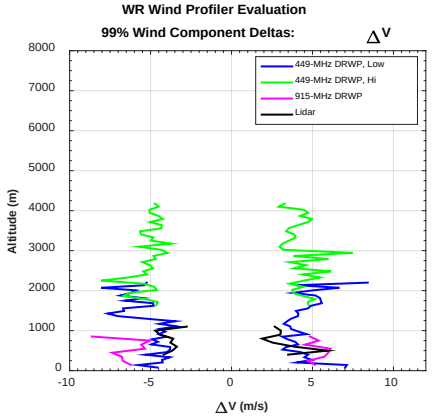
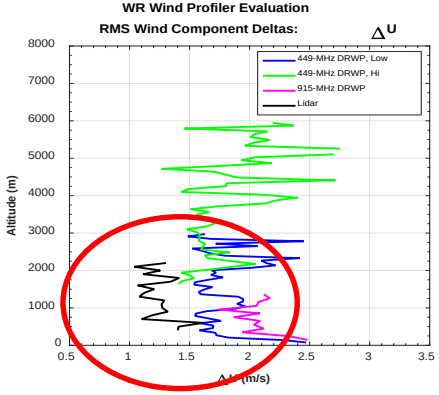
WR Balloon Comparisons - Results

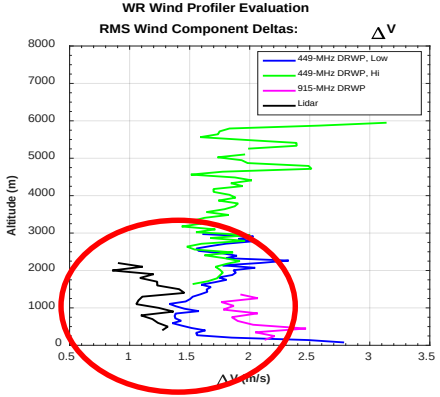


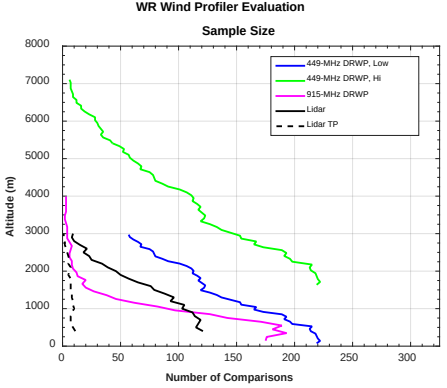






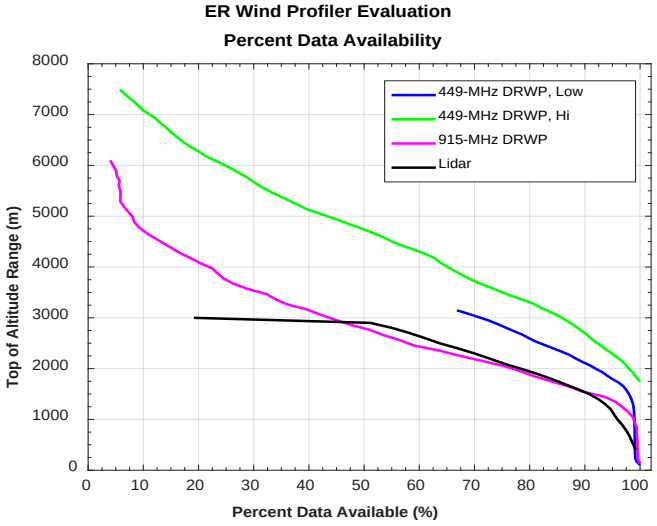


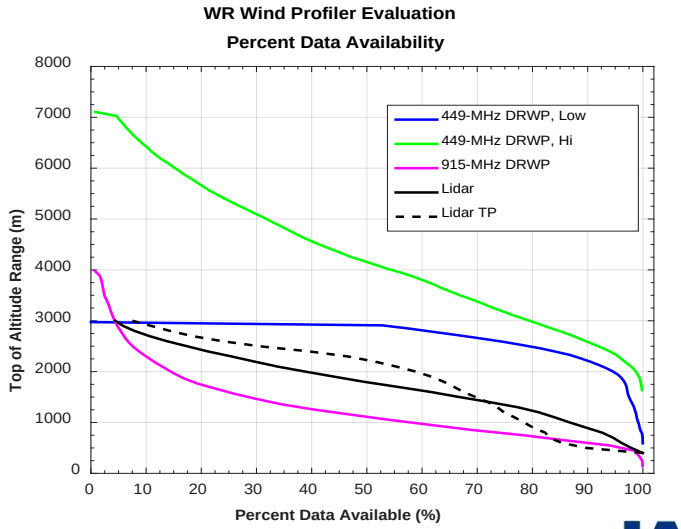




Data Availability

- To show the probability of receiving vertically complete profiles from a given system within a specified altitude range, an analysis of data availability versus altitude was conducted.
- For each system, the number of profiles that contained data at all altitudes between the bottom of the profile and each subsequent altitude was tallied.





Effective Vertical Resolution - Methodology

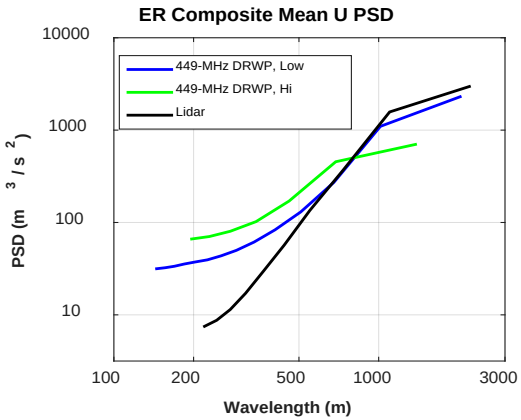
- EVR is determined by examining the magnitude-squared coherence (Coh^2), from Merceret (1999):
  - For an individual day, wind component profile pairs spaced by a specified time were first extracted.
  - Both profiles had to contain continuous data within specified altitude ranges.
  - Once the profiles and pairs were determined, the linear trend was removed from each wind component profile and a Hanning window with zero overlap was applied to the profile.
  - Then the Fast Fourier Transform of each profile was computed as a function of wavelength and used to generate each profile's Power Spectral Density (PSD) and each pair's Cross-Spectral Density (CSD).

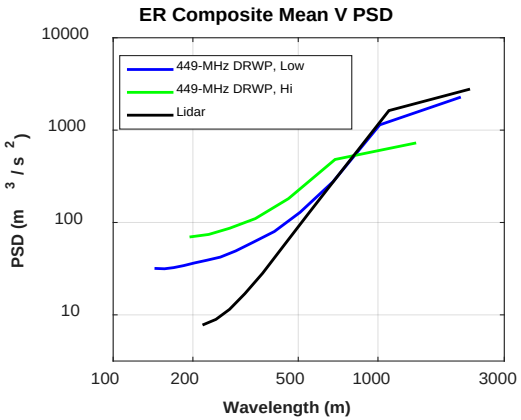
$$Coh^2 = \frac{|\langle CSD \rangle|^2}{\langle PSD_1 \rangle \langle PSD_2 \rangle}$$

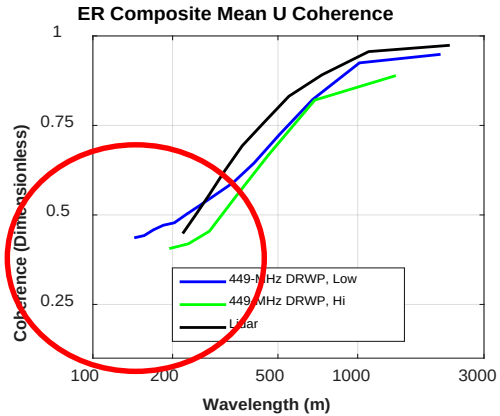
- Coherence describes the relationship between two signals at each wavelength.
  - Incoherent noise dominates this relationship at values below 0.25 as this value corresponds to a signal-to-noise ratio of unity.

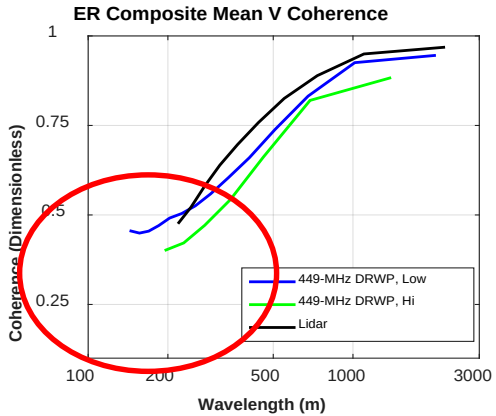
System	Time Between Pairs	Required Altitudes (m AGL)	Sampling Interval (m)
449-MHz DRWP Low Mode	5 minutes	102 – 2,065 m (ER) 76 – 2,007 m (WR)	67.7 m (ER) 64.0 m (WR)
449-MHz DRWP High Mode	5 minutes	1,742 – 3,038 m (ER) 1,636 – 3,022 m (WR)	81.0 m (ER) 77.0 m (WR)
Lidar	1-15 seconds	400 – 2,500 m (ER and WR)	100.0 m (ER and WR)

Effective Vertical Resolution – Results ER

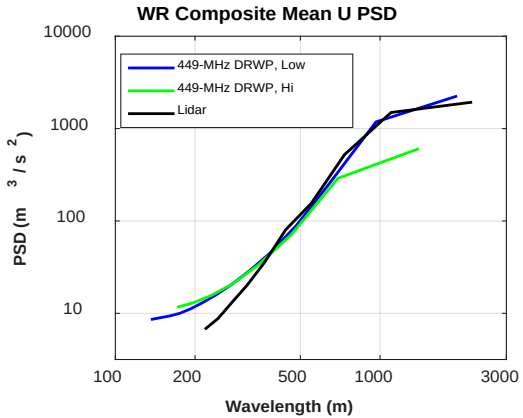


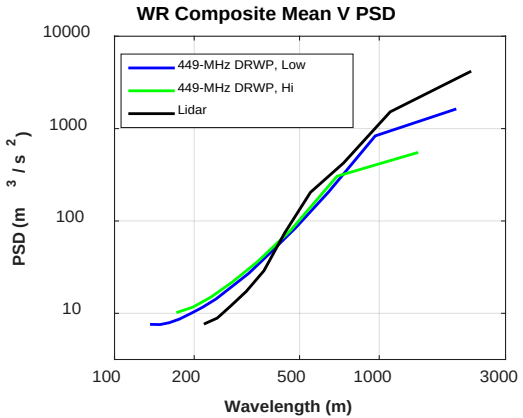


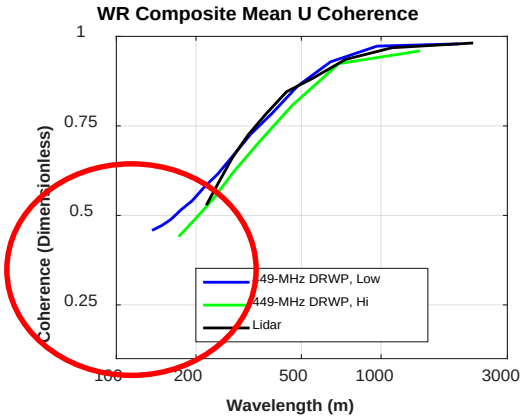


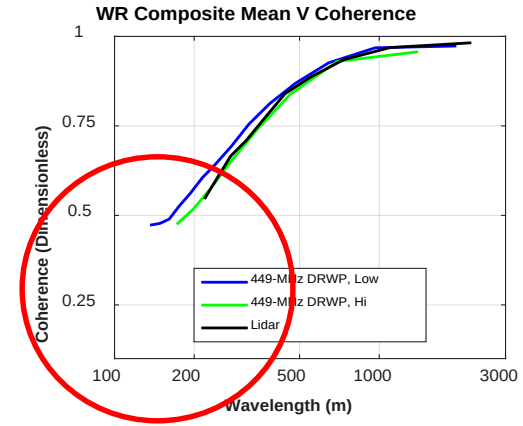


Effective Vertical Resolution – Results WR









Summary

- Wind component profiles from a 449-MHz DRWP, 915-MHz DRWP, and Lidar were compared to concurrent AMPS wind profiles at both the ER and WR.
  - The mean, RMS, and 99% delta of each system was approximately 1.0 m/s, 1.5 – 2.0 m/s, and 5.0 m/s, respectively, at a given altitude. Higher mean and RMS deltas were noted from the 449-MHz DRWP at lower levels at both ranges and at higher altitudes at the WR. The Lidar produced a slightly greater negative bias in ΔV at the ER.
- The percent of complete profiles that reached specified altitudes from the bottom of the profile was examined.
  - The percent of available profiles decreased or remained constant with increasing height for all systems.
  - The 449-MHz DRWP tended to have higher data availability than the Lidar.
- The EVR of each system:
  - All systems found to be Nyquist limited, but the 449-MHz DRWP can resolve smaller features due to its finer altitude spacing.
  - 449-MHz DRWP High Mode: 154m.
  - 449-MHz DRWP Low Mode: 128 m.
  - Lidar: 200 m.

References

F. Merceret, "The Vertical Resolution of the Kennedy Space Center 50 MHz Wind Profiler," *Jounal of Atmospheric and Oceanic Technology,* vol. 16, pp. 1273-1278, 1999.

Questions?