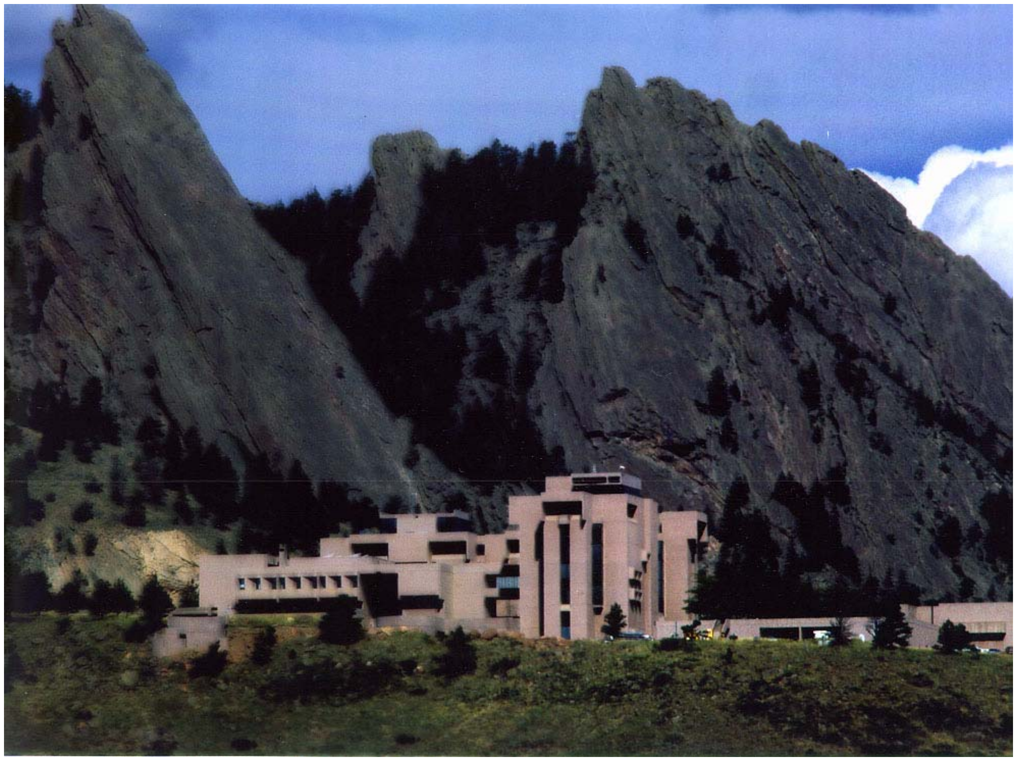
The Relationship Between Airborne Radar Observables and Predicted Aircraft g-Loads



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The Turbulence Problem (Grossly Oversimplified):

"The vertical component of turbulent eddies which are larger than 100 meters and smaller than 3000 meters (approximately) produce aircraft motions which can be difficult -- or impossible -- to control.

With small-amplitude eddies, these induced motions may be simply uncomfortable to passengers. Large amplitude eddies, on the otherhand, can result in passenger injuries or even structural damage to the aircraft."

Radar Observables

- **The typical products from airborne radars are the first three moments of the Doppler spectra:**
  - The zeroth moment gives the total returned power.
  - The first moment gives the reflectivity-weighted average radial velocity in the pulse volume.
  - The second moment gives the reflectivity-weighted variance of the radial velocities in the pulse volume.
- **These moments are available as a function of range and azimuth over the scanning domain.**

The Challenge

- The radar is essentially measuring quantities associated with the longitudinal component of the wind field, whereas the aircraft is most sensitive to the vertical component.

- For a purely isotropic turbulent wind field, the longitudinal and vertical components are uncorrelated with each other.

The Challenge, cont'd.

- **Nevertheless, the *variances* of the longitudinal and vertical components will be identical (for infinite averaging).**
- **For a "physically reasonable" averaging domain, the variances will be unequal, but hopefully close.**
- **Therefore, an algorithm based upon estimates of the wind field variances is desired.**

The Theory (Highly Simplified)

- **With certain assumptions, the second moment of the Doppler spectrum can be related to the variance of the longitudinal wind field:**

$$M_2(\boldsymbol{x}) = F_R(p_1 \cdots p_n; \boldsymbol{x})\, \sigma_u^2(\boldsymbol{x})$$

The Theory, cont'd.

- **Similarly, the variance of the aircraft vertical acceleration can be related to the variance of the vertical wind component:**

$$\sigma_{\Delta n}^2(\boldsymbol{x}) = F_A(q_1 \cdots q_m; \boldsymbol{x})\, \sigma_w^2(\boldsymbol{x})$$

The Theory, cont'd.

- **If it is assumed that the variances of the longitudinal and vertical wind components are equal, the predicted variance of the aircraft's vertical acceleration can be related to the radar-measured second moment:**

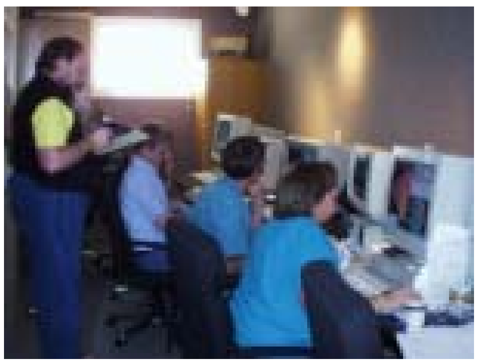
$$\hat{\sigma}^2_{\Delta n}(\boldsymbol{x}) = \frac{F_A(q_1 \cdots q_m; \boldsymbol{x})}{F_R(p_1 \cdots p_n; \boldsymbol{x})} \hat{M}_2(\boldsymbol{x})$$

Theory vs. Practice

- **In the above development, a number of critical assumptions were made:**
  - The variances in the longitudinal and vertical wind components were assumed to be equal.
  - A specific model for the turbulent wind field is assumed in the calculations of the “F” functions.
  - The Doppler spectra have been sufficiently averaged to produce accurate second moments.
  - A specific (though representative) model for the aircraft response is assumed in the calculation of it’s “F” function.

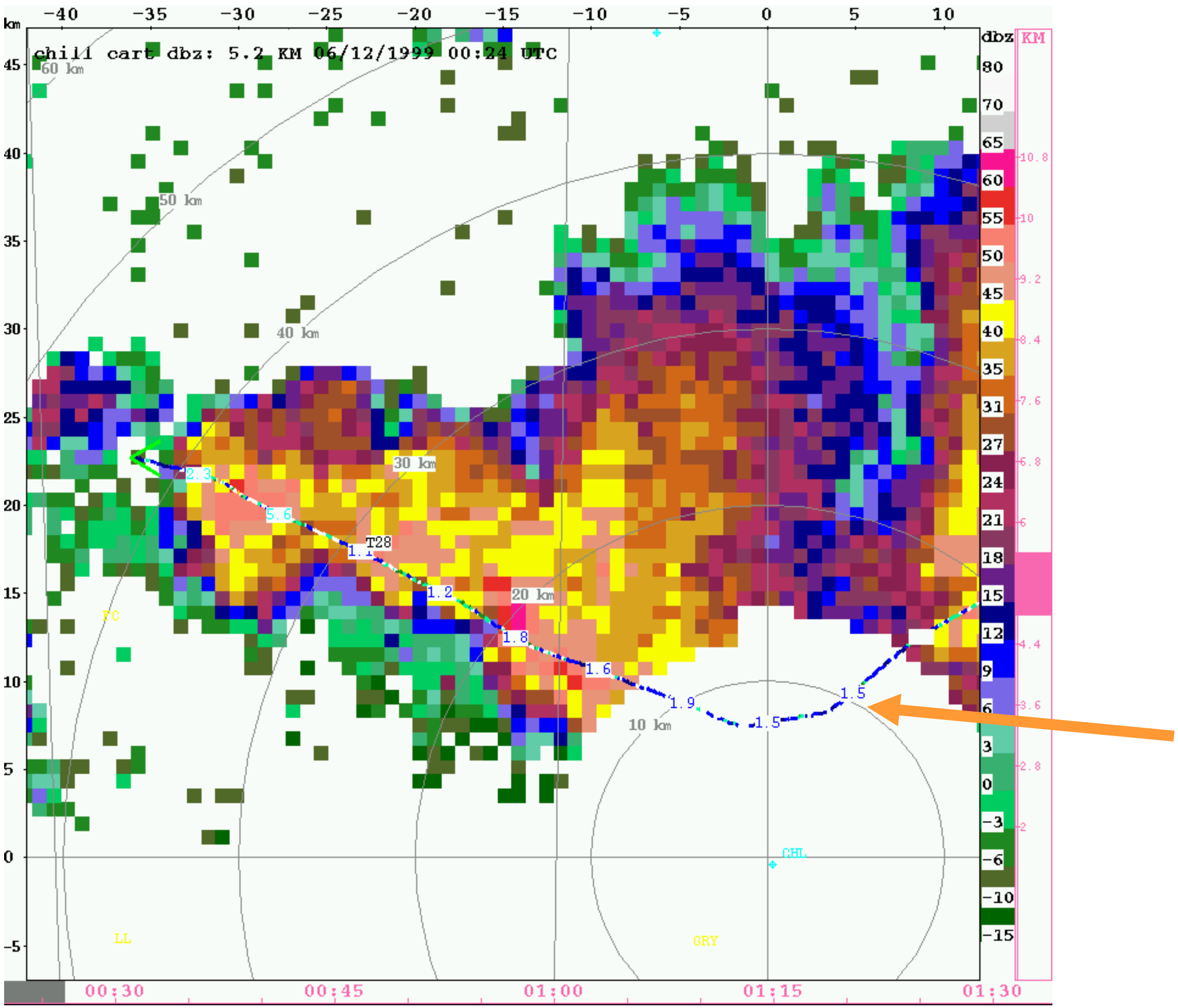
Summary and Future Work

- A preliminary algorithm design has been developed based upon the above concepts.
- Testing on simulated and flight data is underway.
- This preliminary algorithm will be implemented for the FY00 NASA 757 flight test.
- Modifications based upon real-world and further simulation testing will occur in FY01.



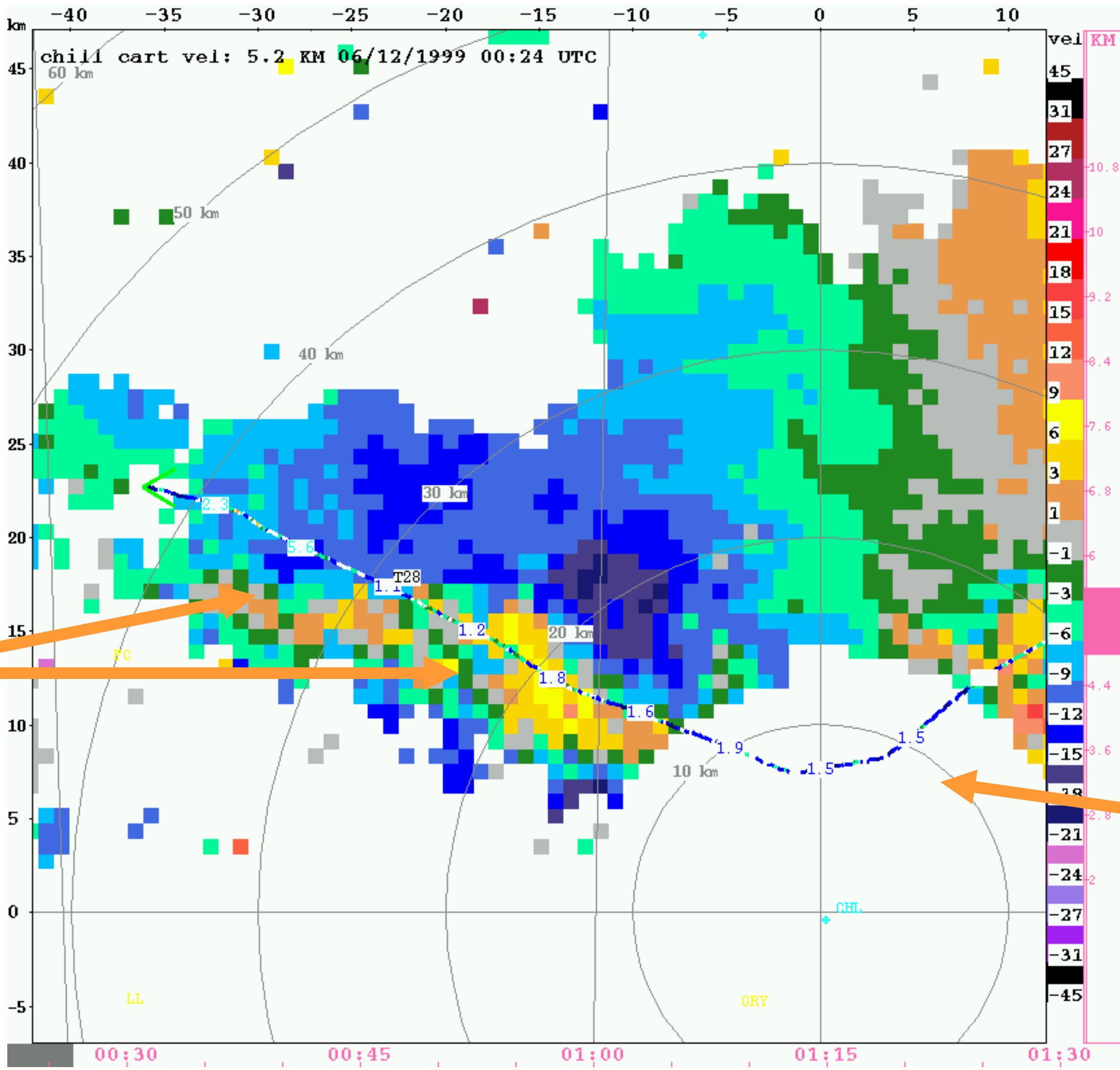
AlliedSignal Research Aircraft

Radar Reflectivity: Constant Elevation Slice at 5.2 km (Ground-Based Radar)



Aircraft Flight Track

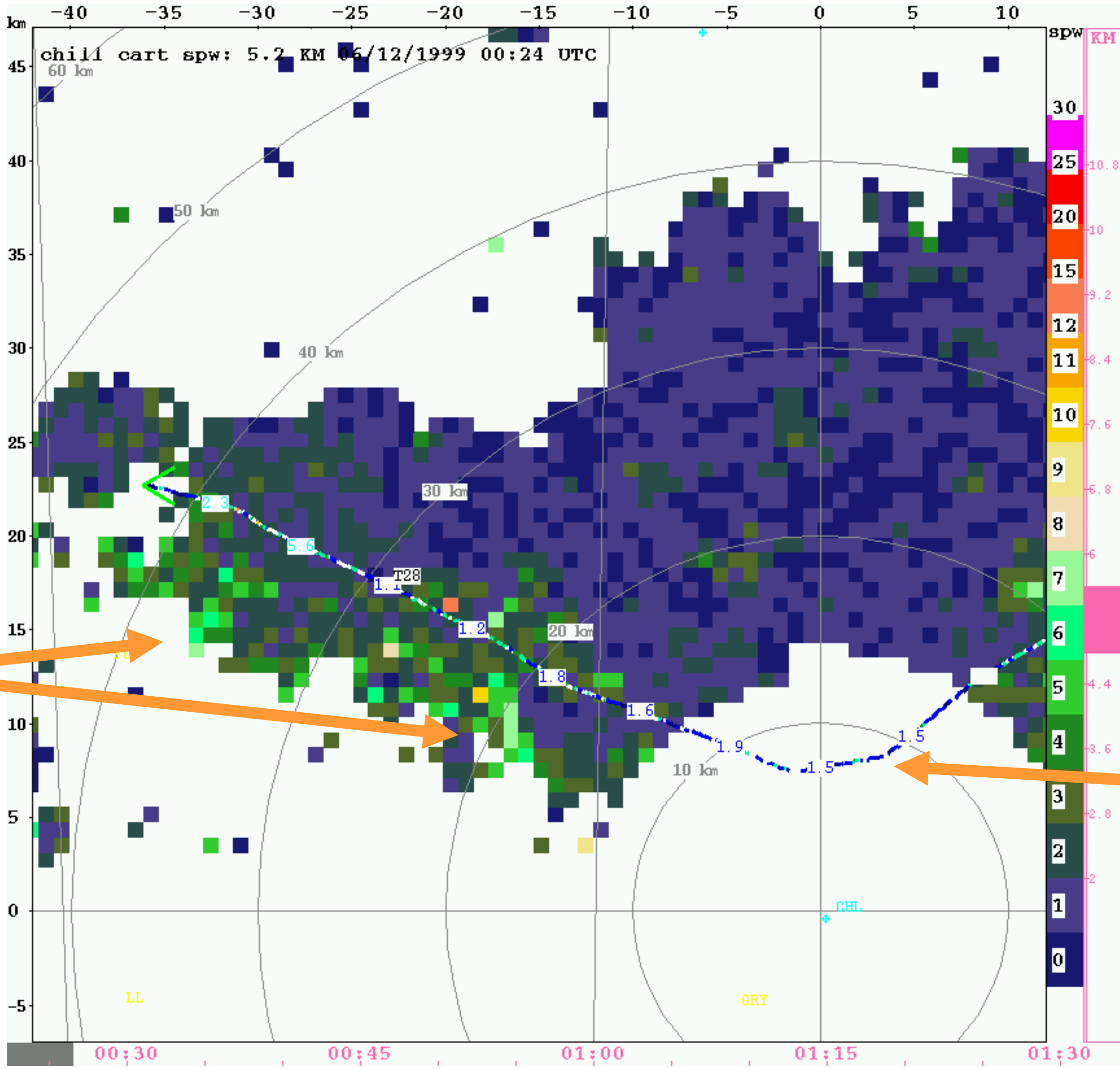
Radar Velocity: Constant Elevation Slice at 5.2 km (Ground-Based Radar)



Disturbed Flow

Aircraft Flight Track

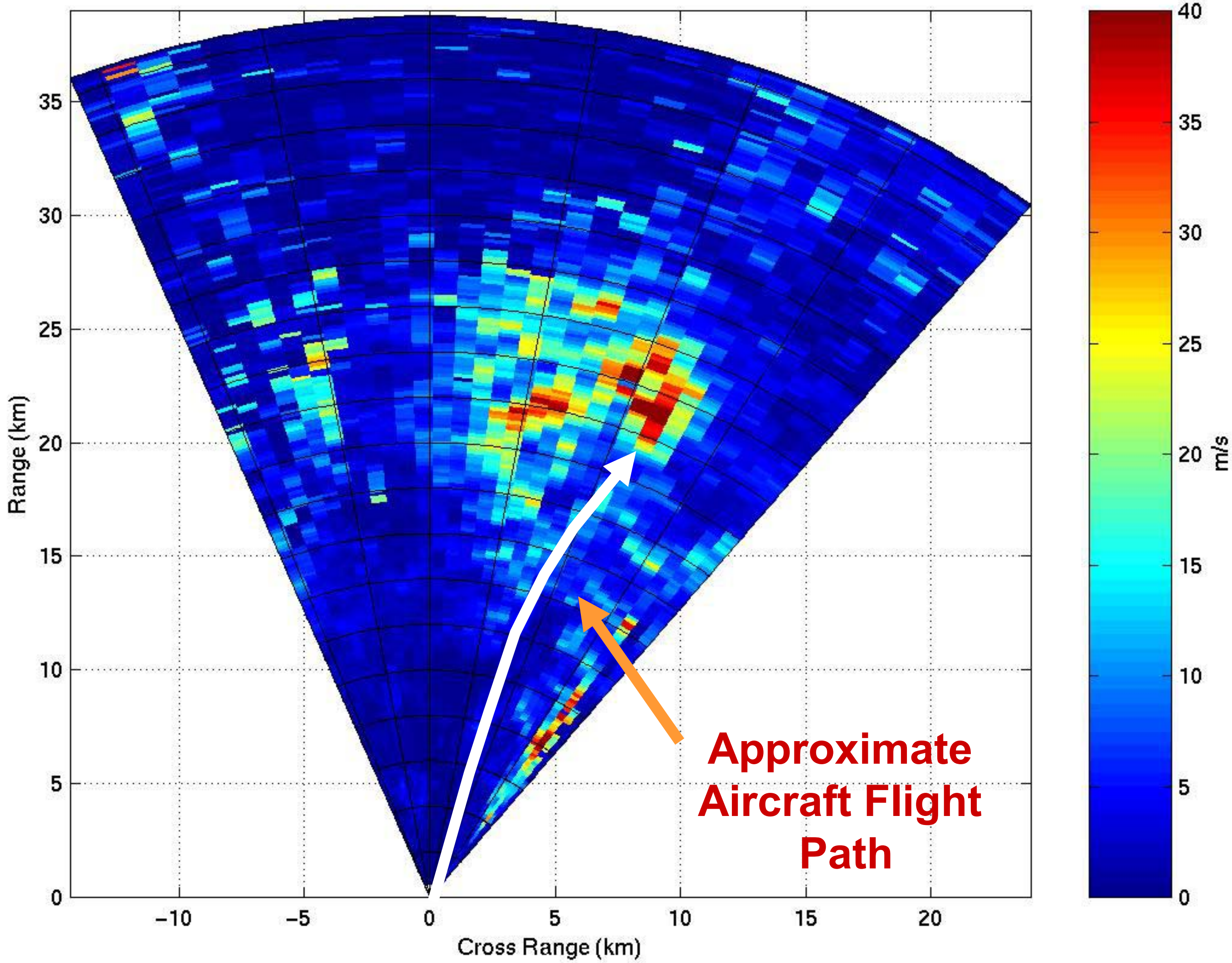
Radar Spectrum Width: Constant Elevation Slice at 5.2 km. (Ground-Based Radar)



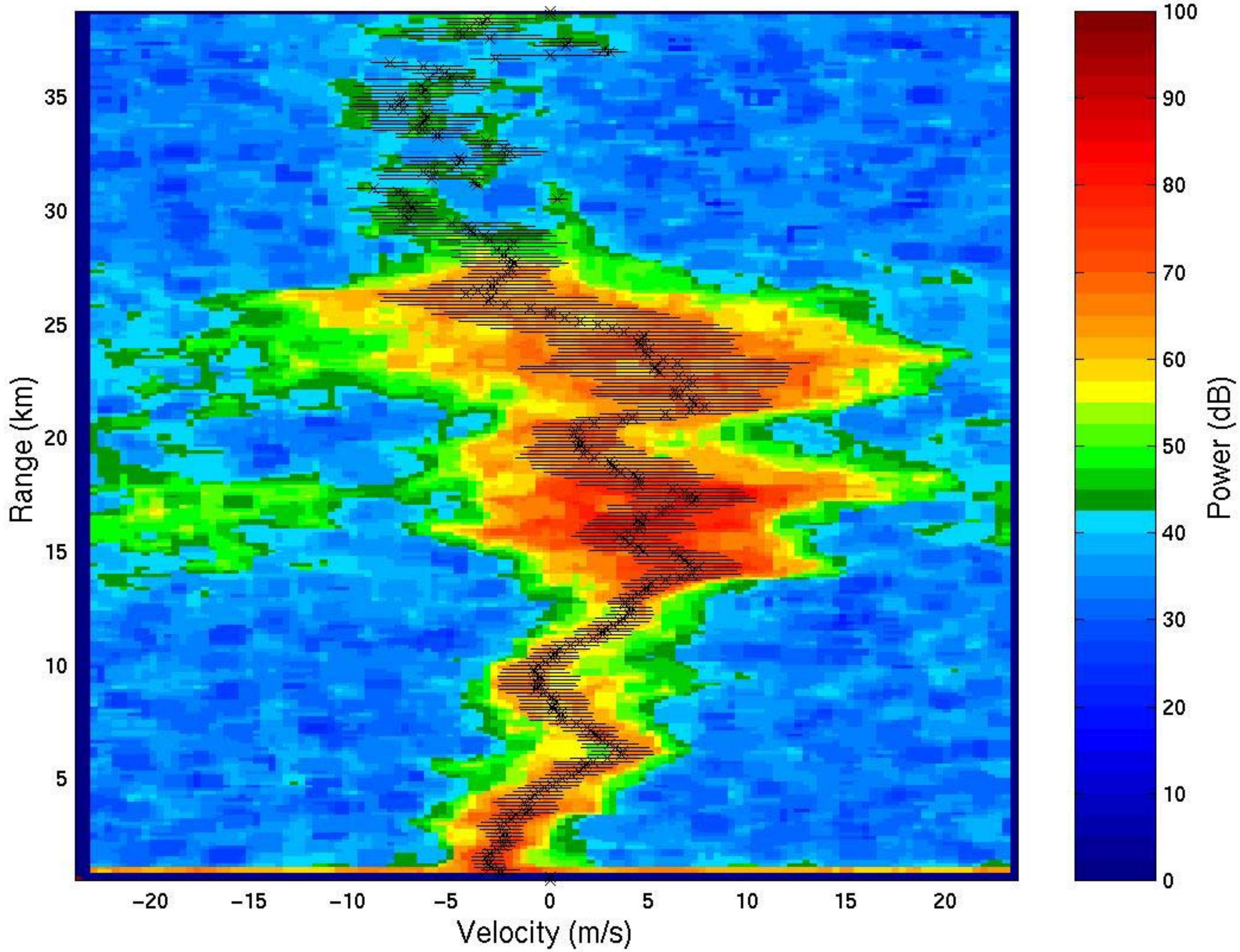
Enhanced Spectrum Width

Aircraft Flight Track

Radar-Measured Doppler 2nd Moment (Airborne Radar)

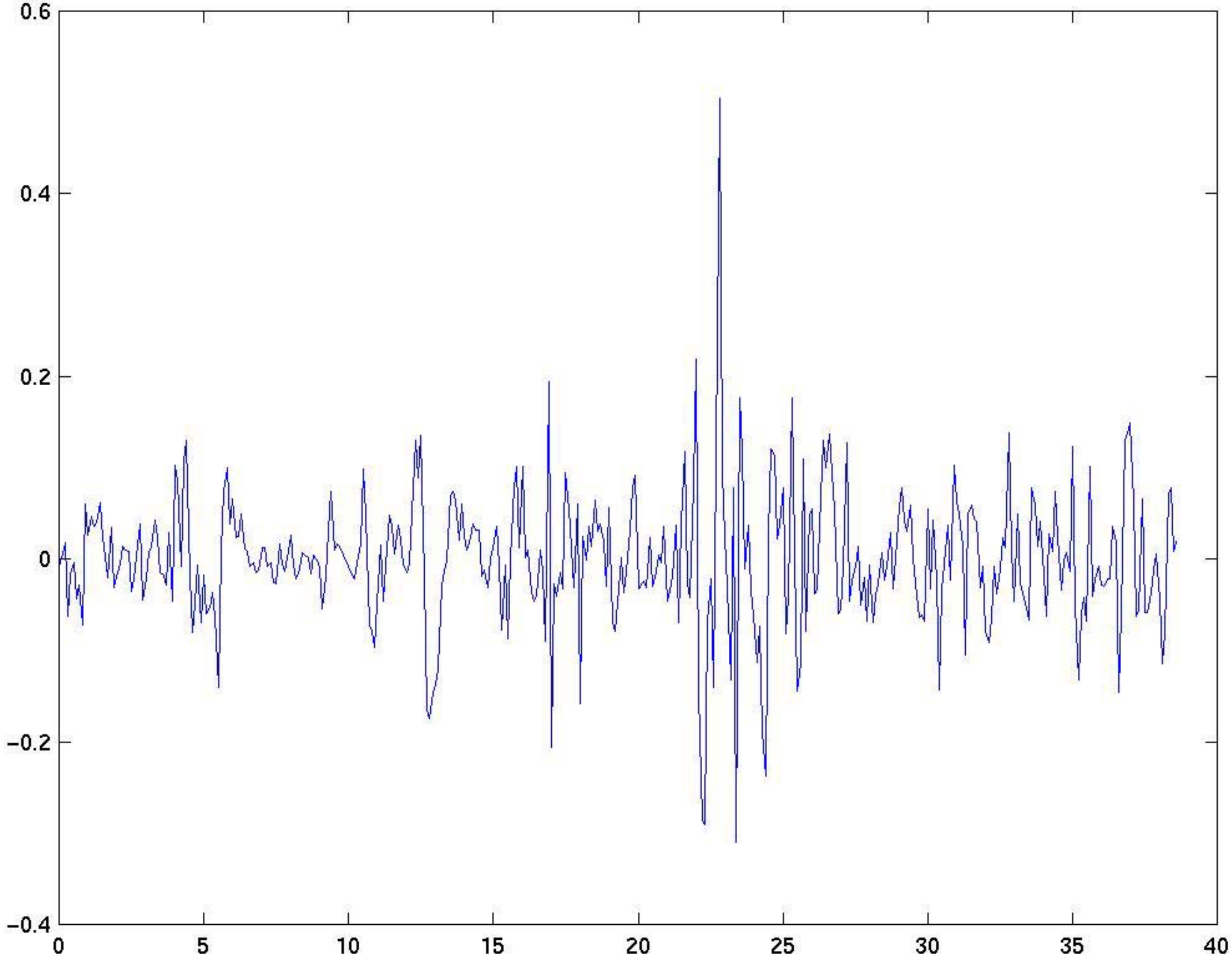


Doppler Spectrum From Radar Beam Along Flight Path (Airborne Radar)



Vertical Acceleration As Measured By Research Aircraft

Vertical Accel. (in g's)



Distance in km.