# Aircraft Ocean Altimetry: Recent Results

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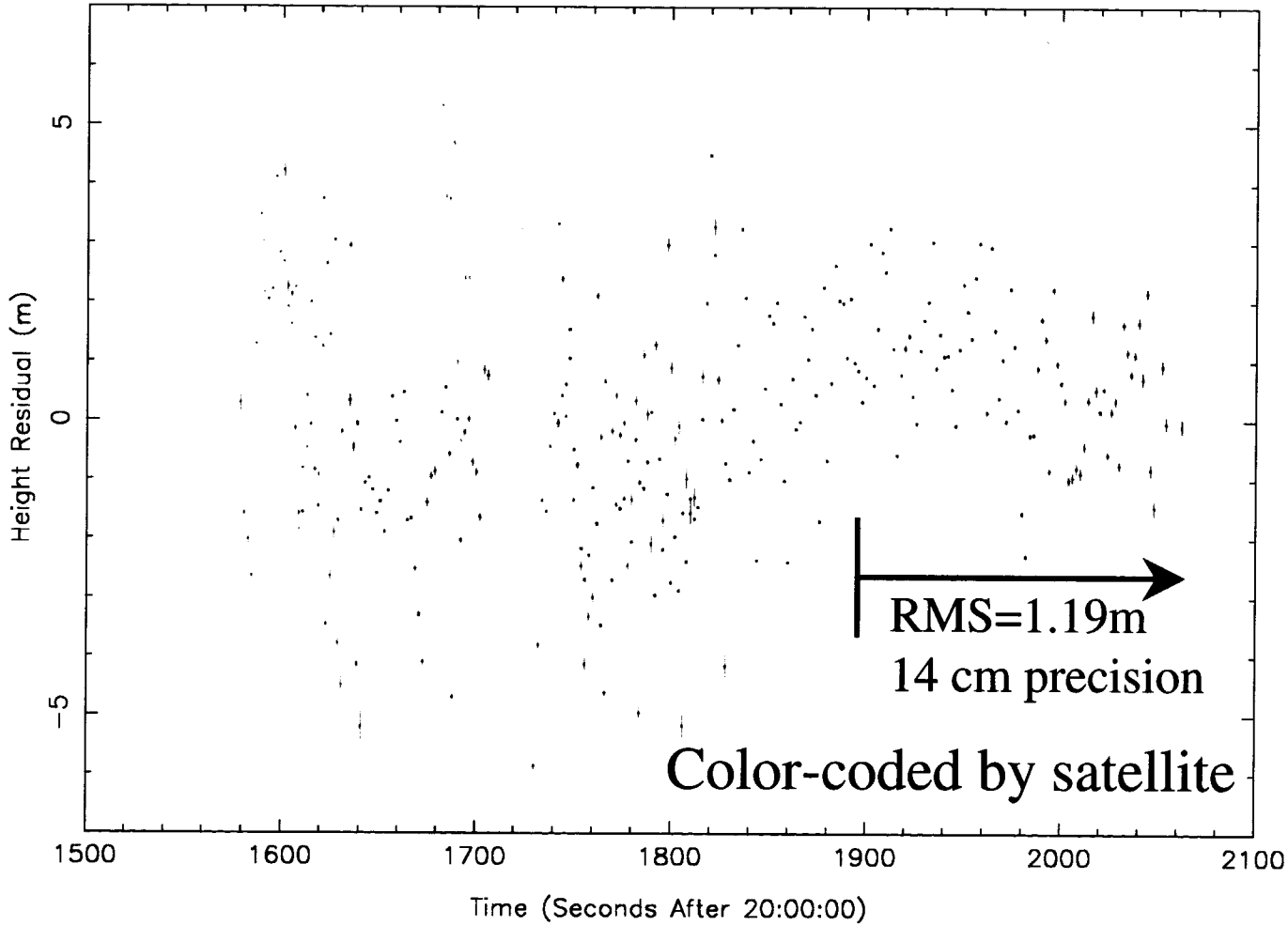
# Outline

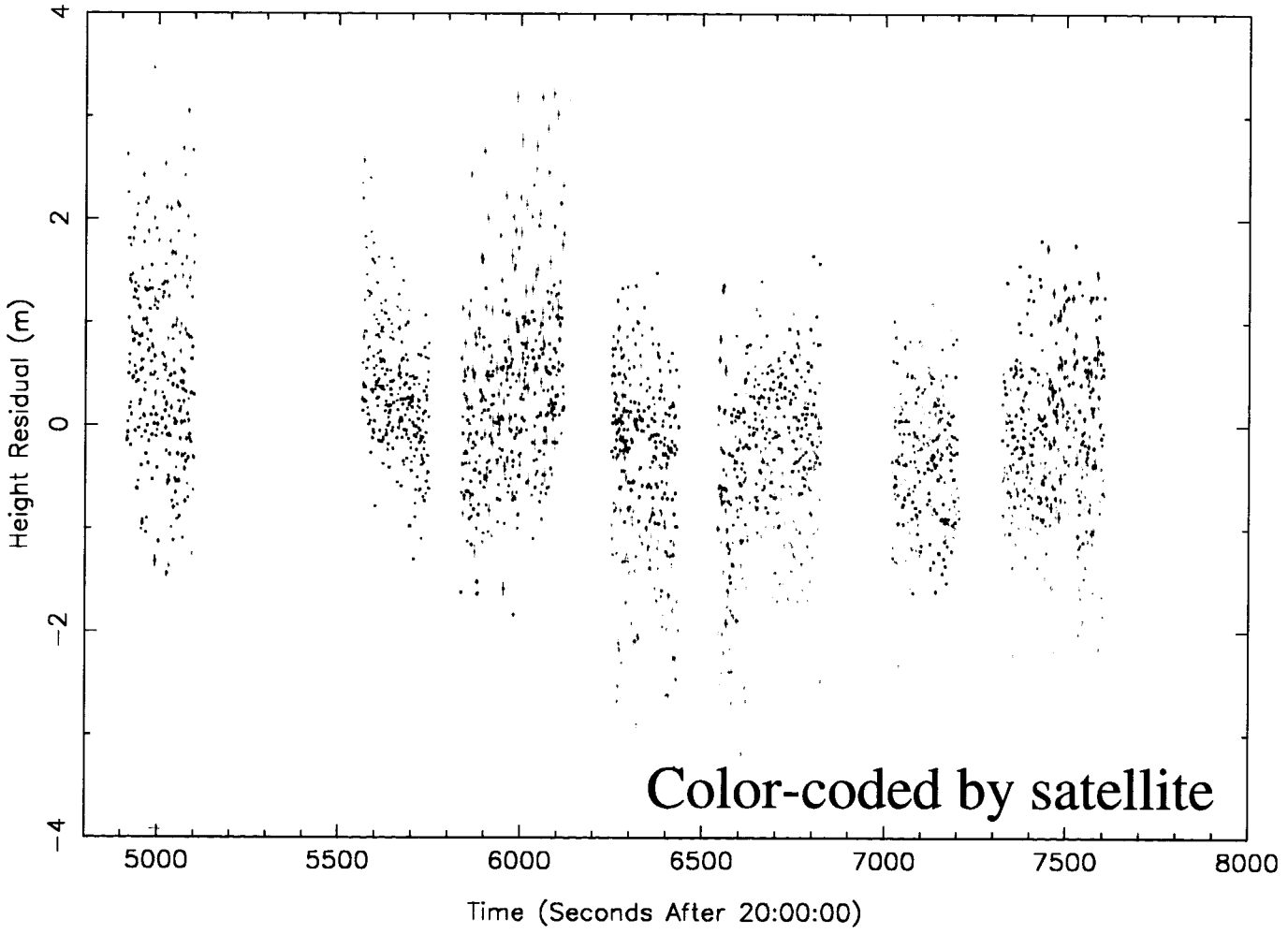
- Past Results: Ocean Altimetry Precision vs Accuracy
  - Geometric (?) mismodelling errors
  - Speckle

- Recent Experimental Results
  - Ocean altimetry (incoherent, group delay)
  - Ocean altimetry (coherent phase delay)
  - Signal coherence properties
  - Speckle characterization

# F2: Oct. 1998 (Y-code)



# F4: Jan. 2001 (Y-code)

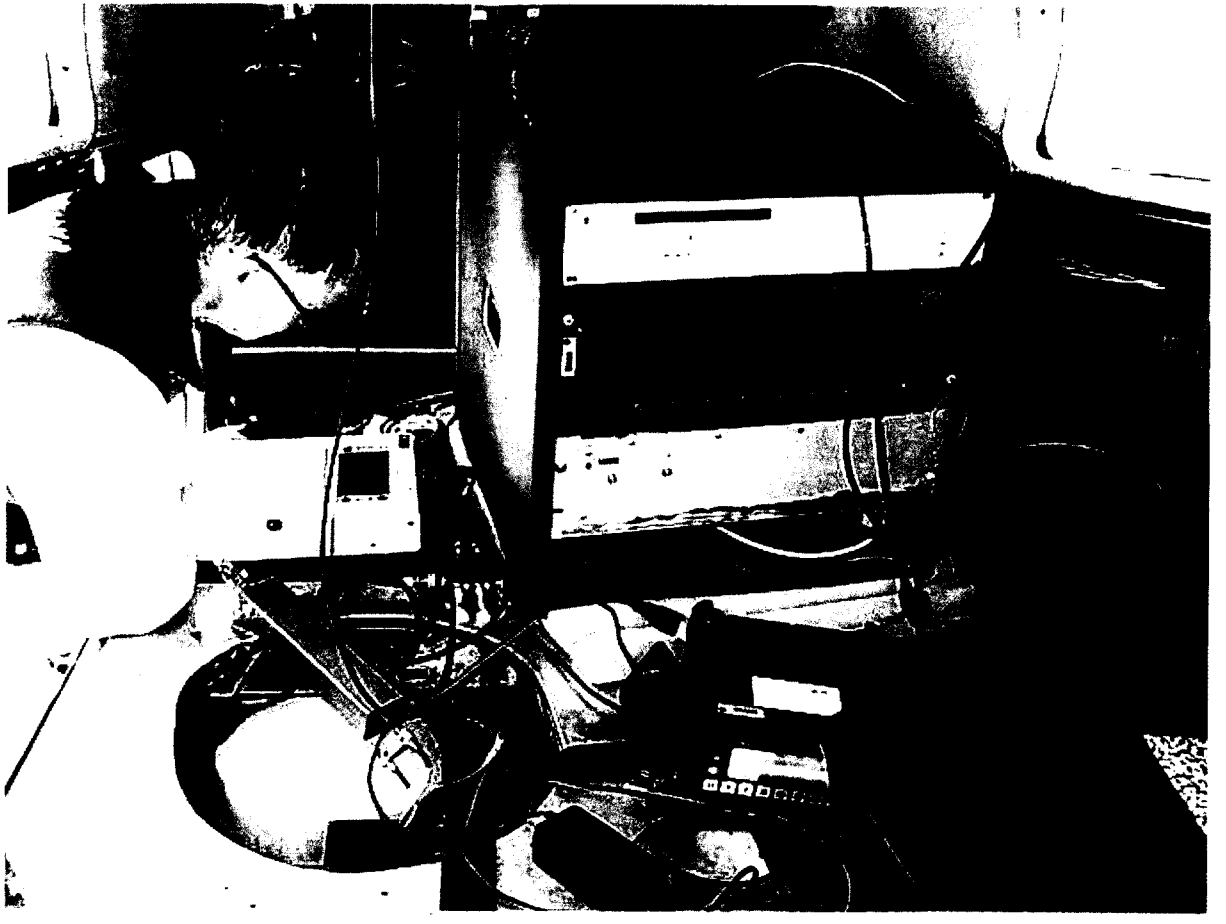


# Systematic Errors

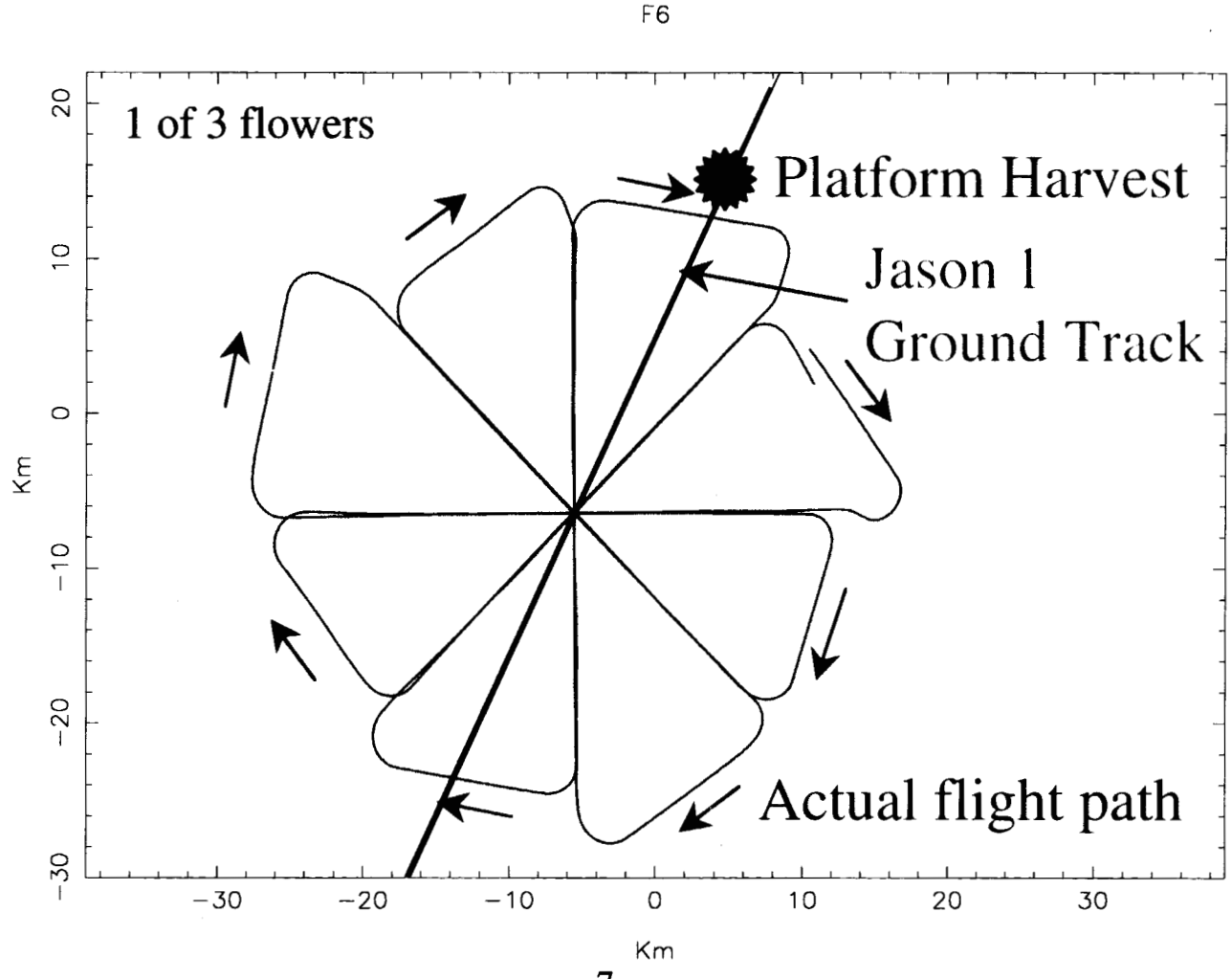
- Large systematic error associated with satellite => Geometric?
- Single-satellite scatter >> system noise, white => speckle

- New experiments to assess above errors
  - F6: Ocean altimetry / Assess satellite systematic
    - Fly flower pattern to fill geometric parameter space
    - Schedule with high elevation GPS satellite
    - Schedule with Jason 1 overpass, flower centered on path
  - F7: GPS SAR-like imaging
    - Assess improved spatial resolution with processing
  - F8: Ocean altimetry / Assess speckle
    - Take data over full range of aircraft height and speed

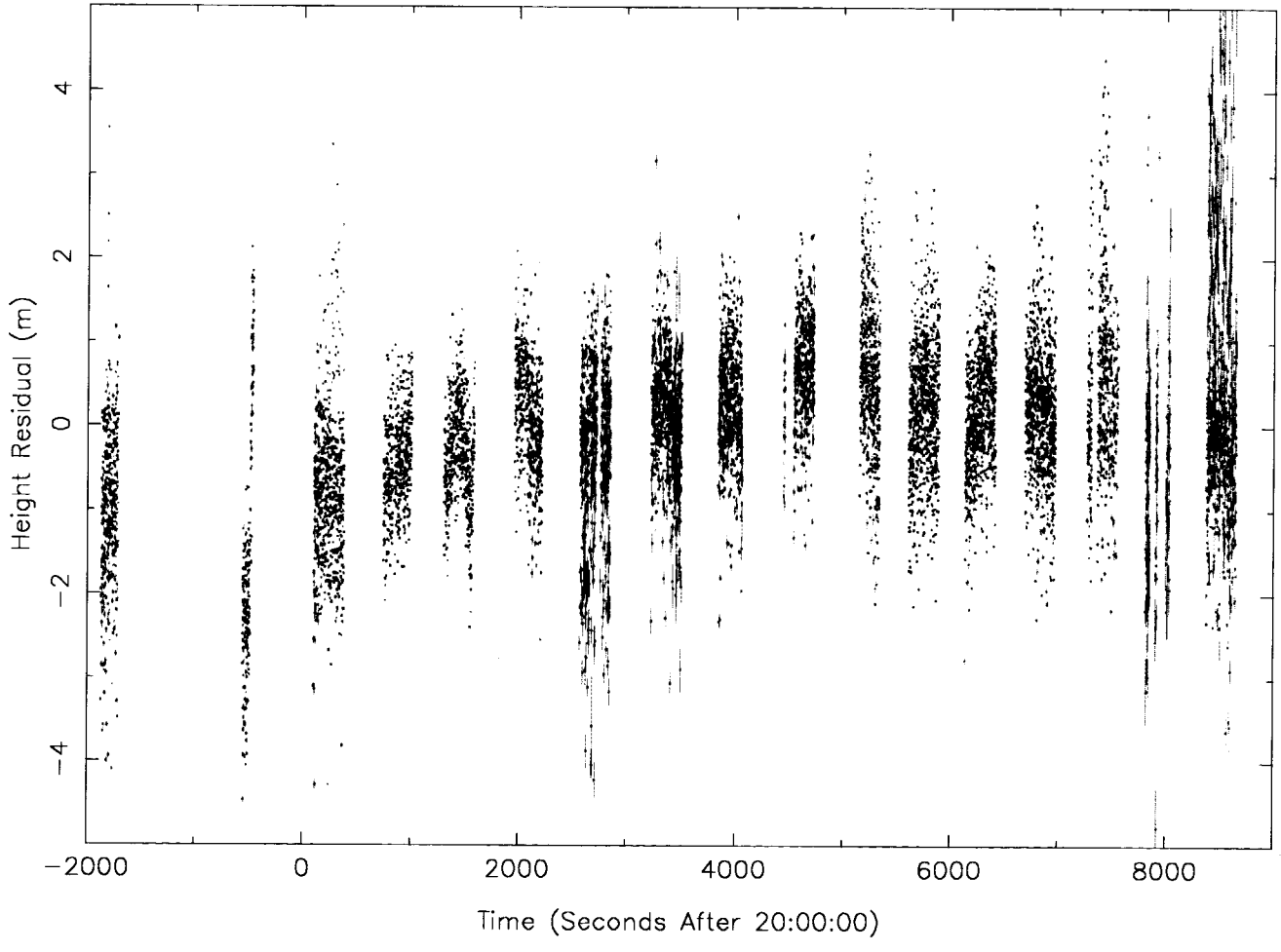
# New Results: Group-Delay Altimetry: F6



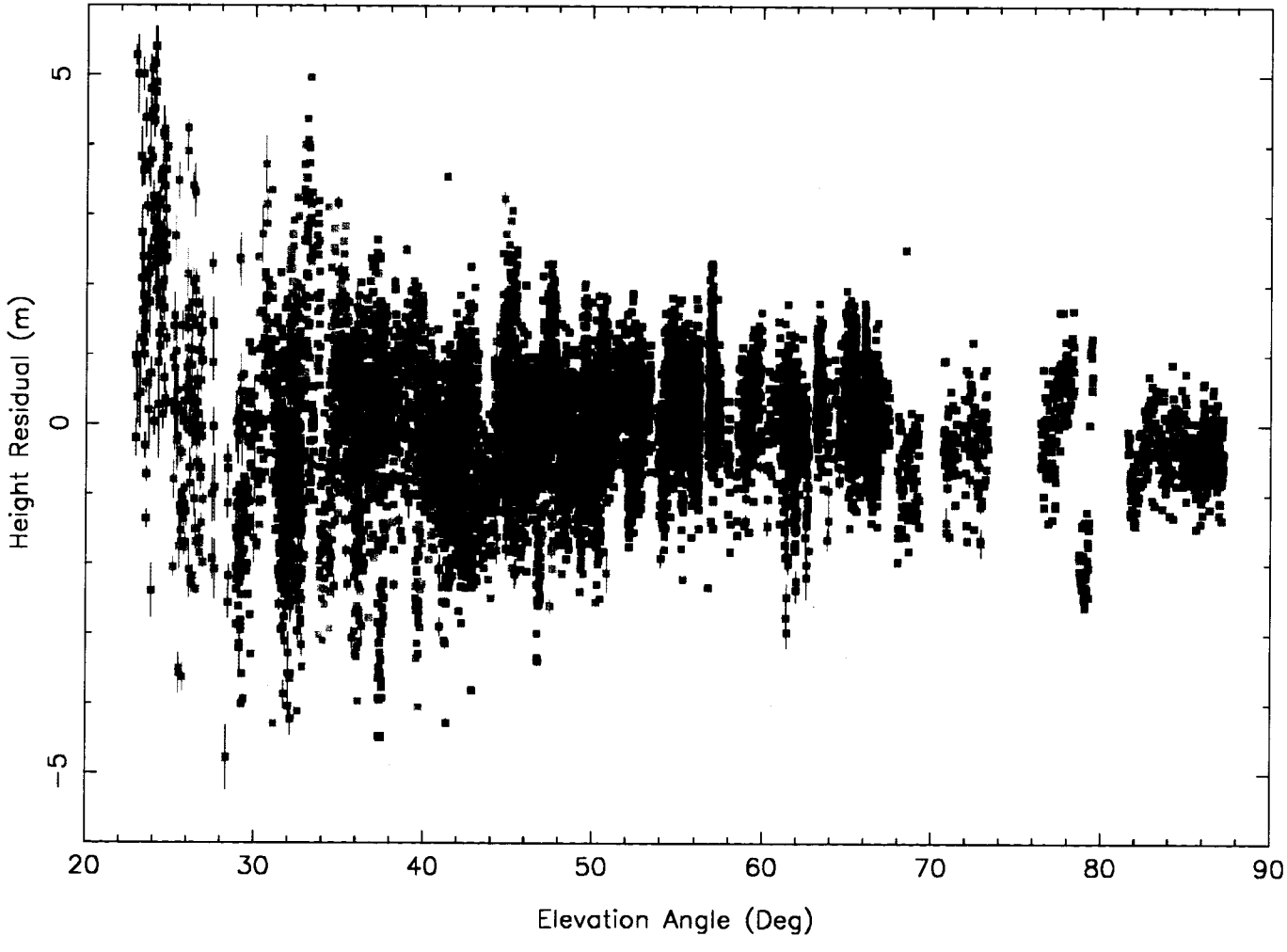
# Group-Delay Altimetry: F6 (cont)



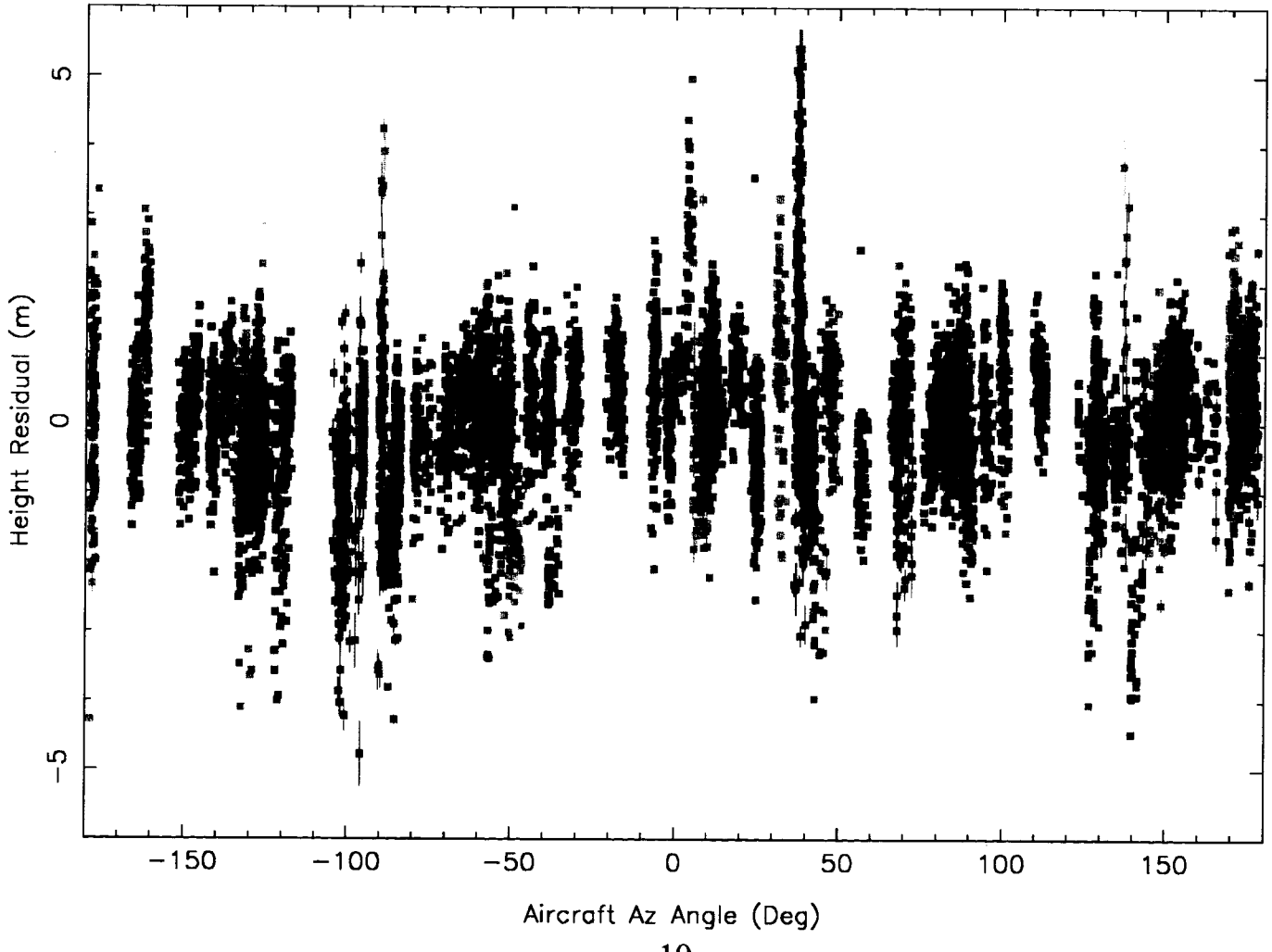
# Group-Delay Altimetry: F6 (cont)



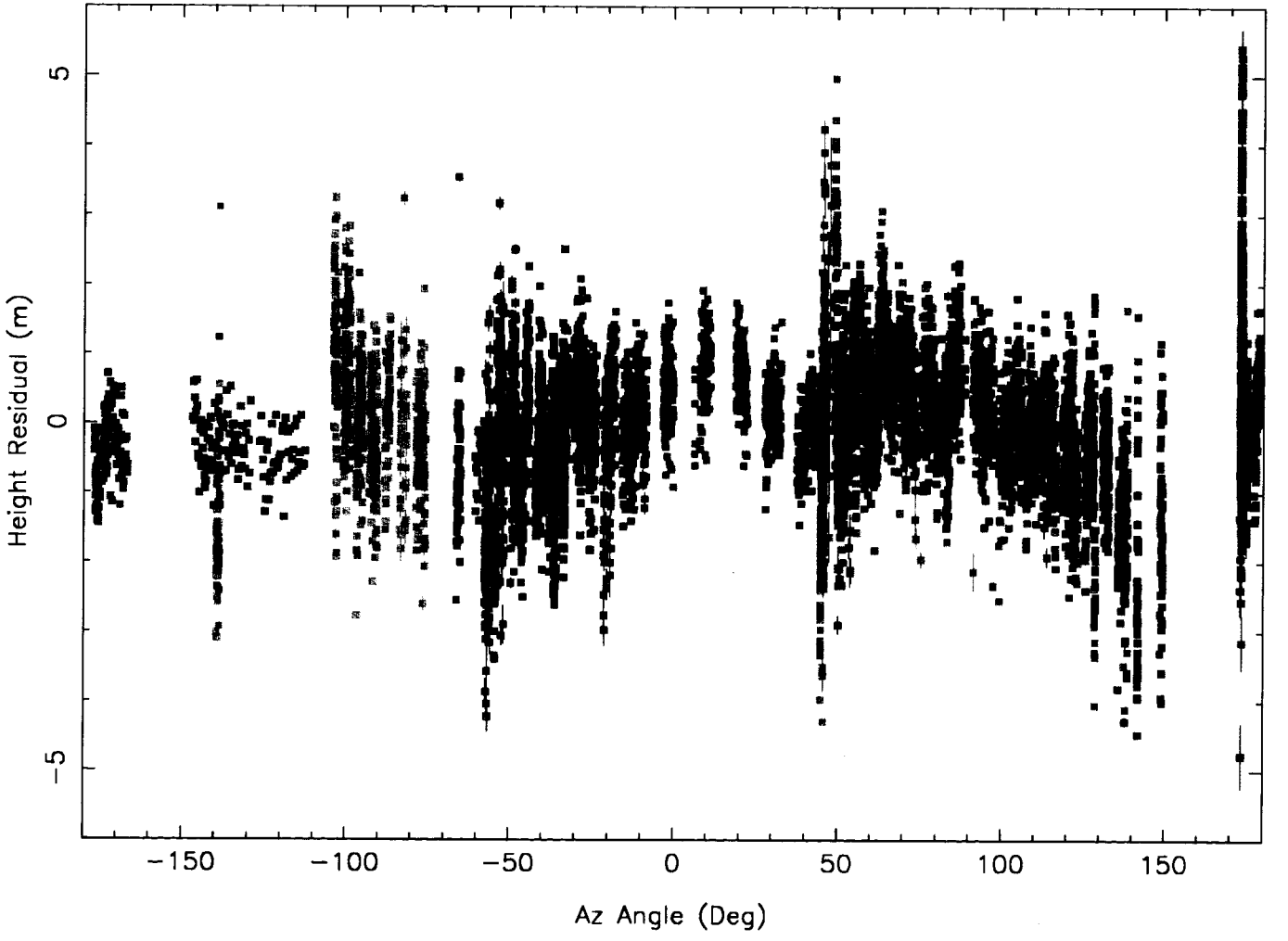
# Group-Delay Altimetry: F6 (cont)



# Group-Delay Altimetry: F6 (cont)



# Group-Delay Altimetry: F6 (cont)



# Group-Delay Altimetry: F6 (cont)

## Summary

- Large (2 m) systematic errors like those in F4 not seen
  - Improved software receiver, with clock tracking (??)
  - Re-process F4 to check this

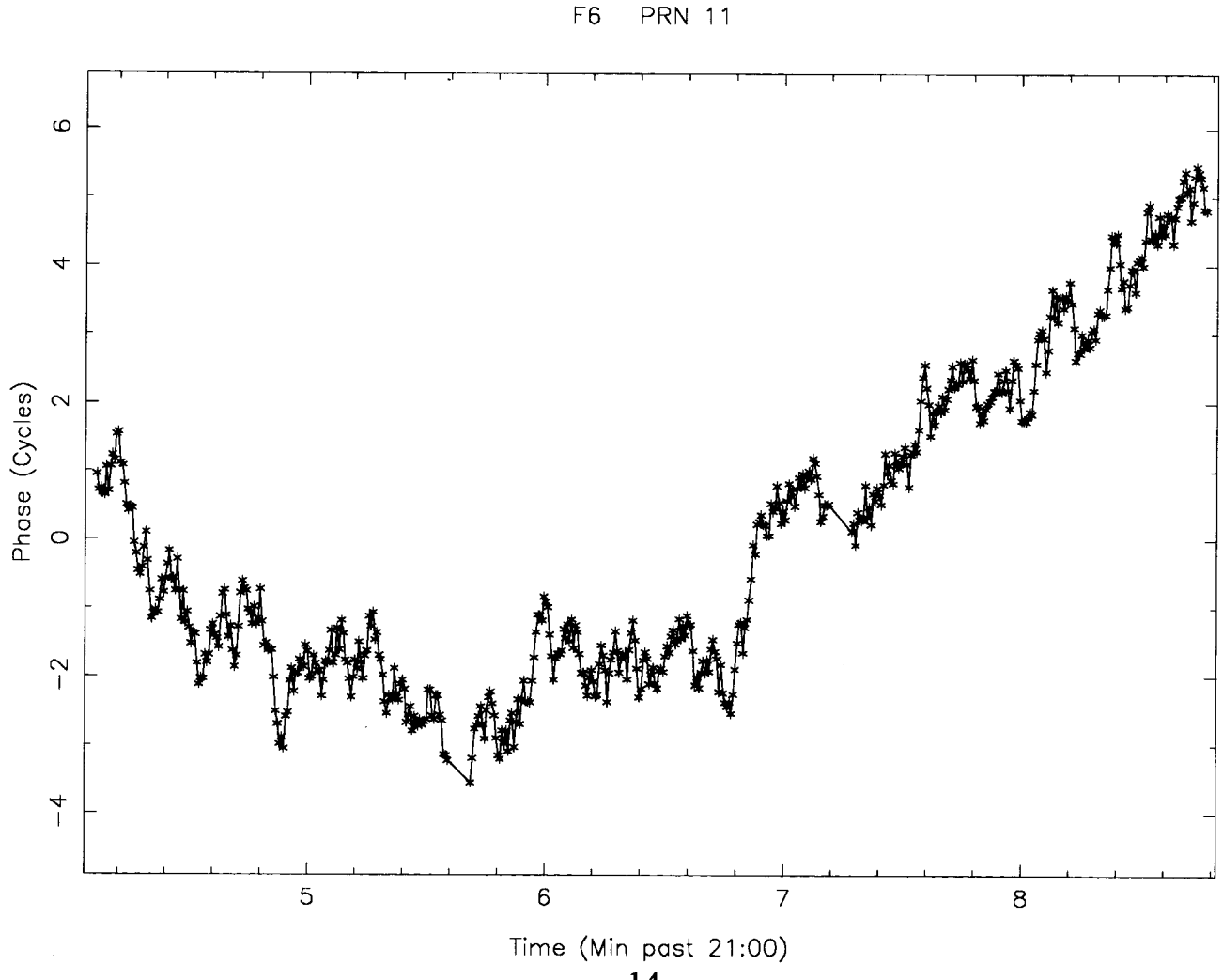
- Better altimetric modeling required to uncover errors
  - Use Jason 1 ground truth (planned)

# New Results: Phase-Delay Altimetry

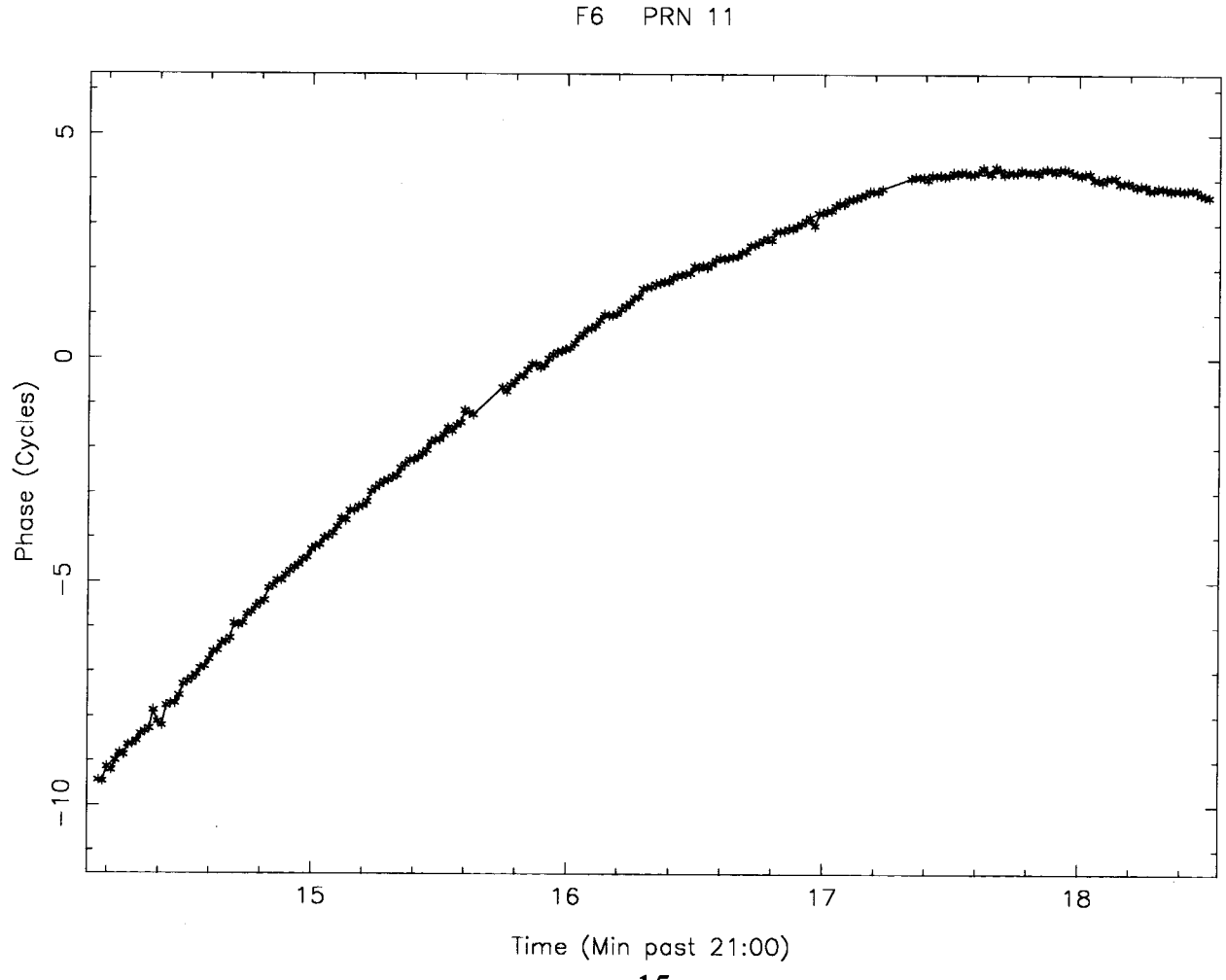
- At low elevation ($0^o$–$5^o$) reflected signal becomes coherent
  - Highly accurate phase delay available
  - Cycle ambiguities required
  - From 3 km altitude (F6) interference between direct and reflected signal ~ 1 Hz

- Interference very apparent in F6 amplitude data
  - Over open ocean: wave height >> $\lambda$
  - Fit lag phasors to get interference phase

# Phase-Delay Altimetry (cont)



# Phase-Delay Altimetry (cont)



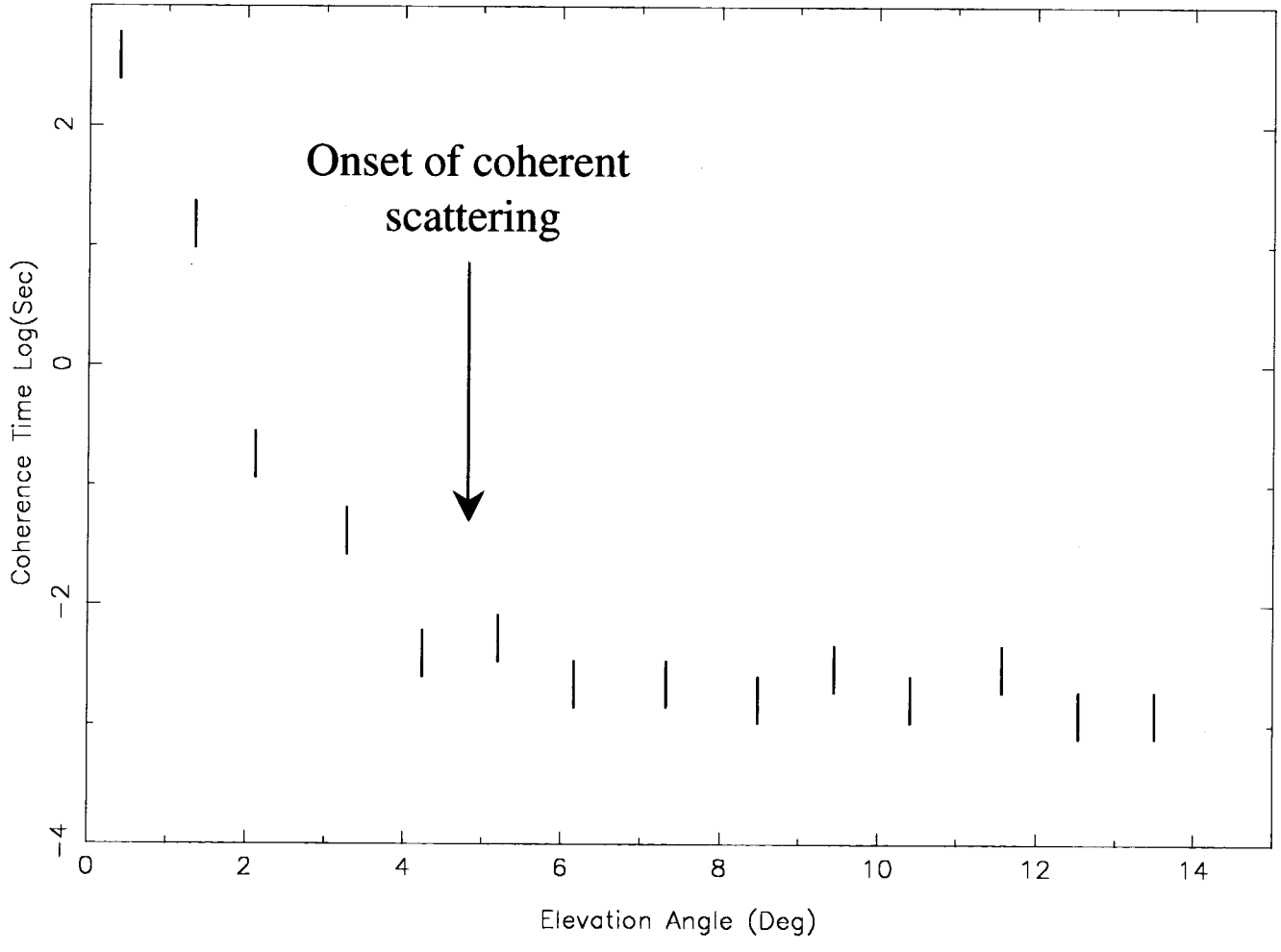
# Phase-Delay Altimetry (cont)

- Verified phase delay observable available over open ocean
- Observed effect below 5°
- Altimetry requires real model (troposphere, scattering,…)

# New Results: Phase Coherence

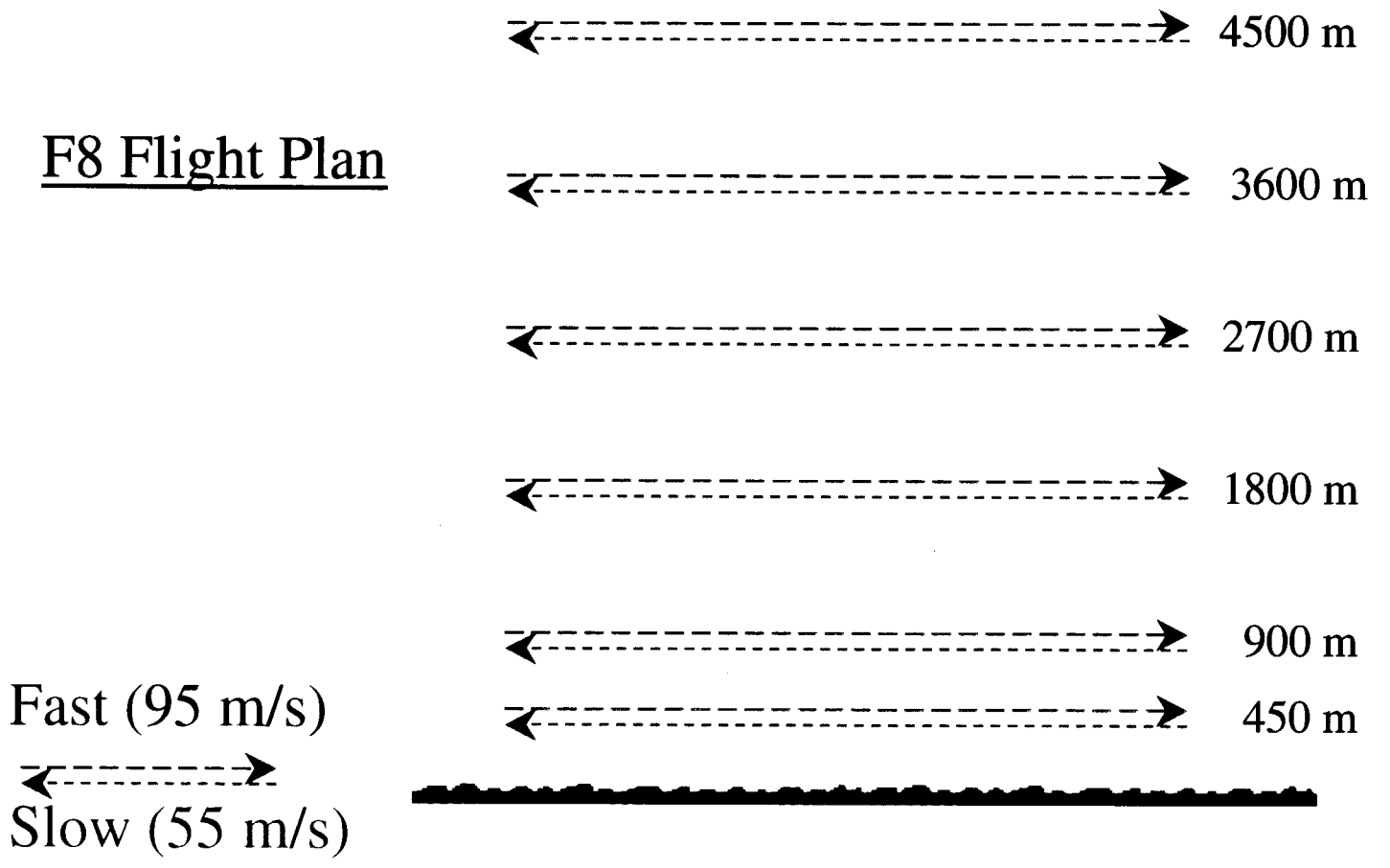
- Verified phase delay observable available over open ocean
- Measure phase coherence as function of elevation angle
- Both C/A and y-code observations

# Phase Coherence (cont)

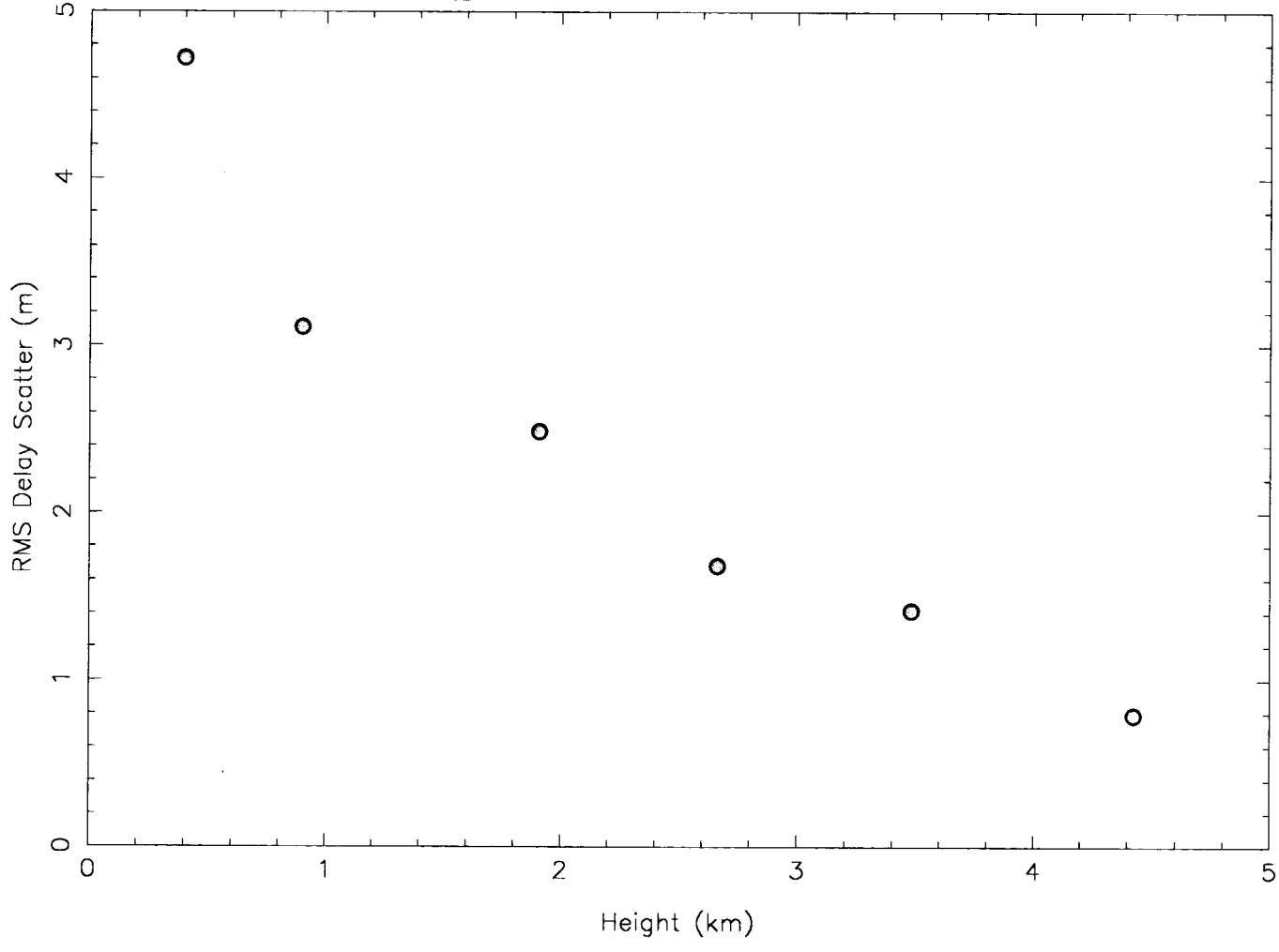


# New Results: Speckle

F8 Flight Plan



# Speckle (cont)



# Speckle (cont)

- Compare data to models
  - Extrapolate to LEO heights
- Indicates upcoming experiments should operate at greater altitudes
- Speckle independent of aircraft velocity
  - Use greatest velocity
  - Trade off with spatial resolution

# Summary

Group Delay Altimetry

Performed experiments to address two dominant errors:

- Mismodeling
  - Systematic errors smaller than previous expt (F4)
  - Need to add Jason 1 ground truth to improve model
- Speckle
  - Determined effect of speckle for C/A and Y-code up to 4 km altitude and 100 m/s
  - Need to compare with models and extrapolate to space

# Summary (cont)

## Phase Delay Altimetry

- Low-elevation phase delay observable observed below ~ 5°
- Over open ocean many km from shore (wave height >> $\lambda$)
- Next: Perform altimetric retrieval

## Signal Coherence

- Signal coherence time was measured as a function of elevation angle
- Both C/A and Y-code
- Onset of phase coherence below 5° clearly seen