# Gravity in an Optionally Piloted Airplane

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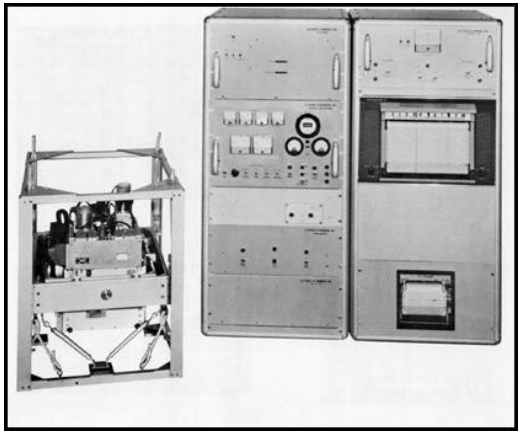
# Project participants

- **NOAA/NGS: Unmanned Aerial System-Borne Gravimeter Small Business Innovative Research (SBIR) Grant**
- **Aurora Flight Sciences: Centaur Optionally-Piloted Aircraft (OPA)**
- **MicrogLaCoste: TAGS-7 airborne gravimeter system**

# Historical perspective: 1959

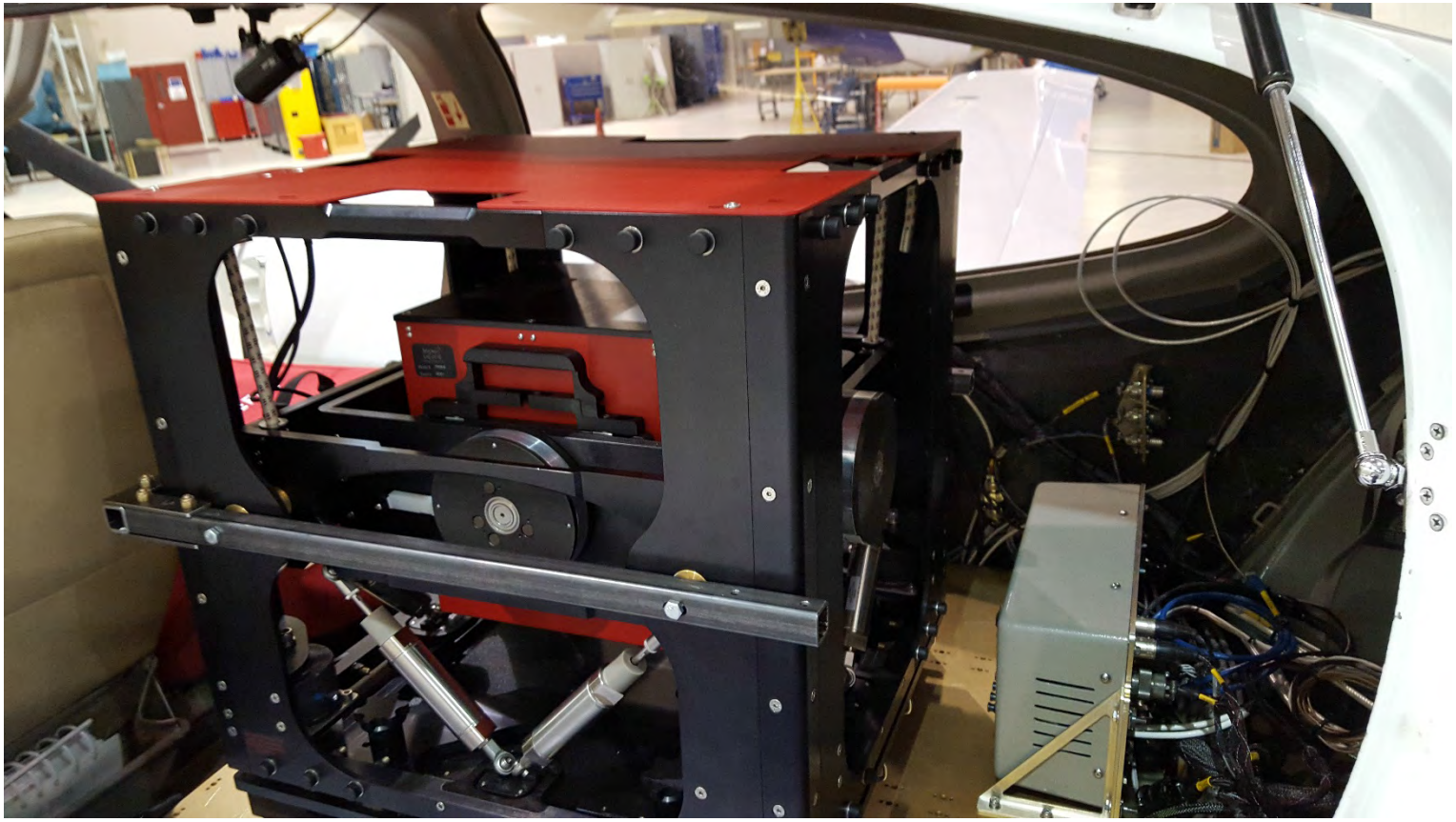



# Historical perspective: 2016

# TAGS-7

- Evolution of TAGS-6
  - Full-force feedback: no memory
    - ★No spring tension
    - ★No viscous damping
- Improvements over TAGS-6
  - Electronics improved
  - Mechanical design improved
  - Feedback gain 4x increase over TAGS-6

# TAGS-7 installed



# Centaur OPA

- Based on Diamond Aircraft DA-42 MPP
  - Basic design: 4-seater twin-engine
  - Diesel engines: highly fuel-efficient, low noise/vibration
  - Modern avionics
- Can be flown:
  - Conventional pilot / co-pilot
  - Robot pilot / safety pilot *
  - Fully autonomous

# DA-42 TwinStar

# Not the autopilot…

# George, the robot pilot

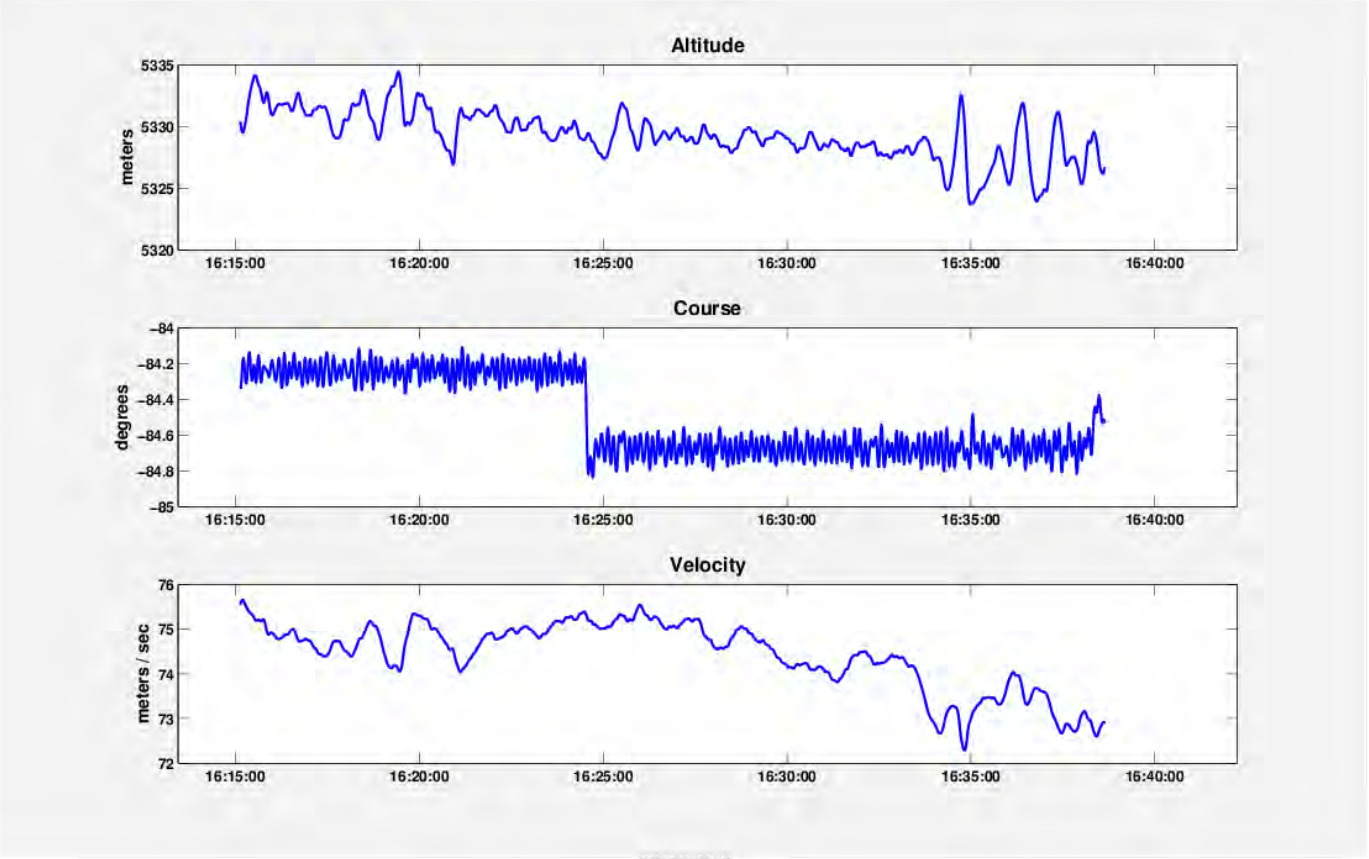
# Centaur operations

- George can be installed in 1 day
- In fully autonomous mode, left-hand seat can be replaced by fuel tank
- Data link LOS or satellite
- GPS: WAAS, Omnistar, RTK from ground

# Centaur OPA flight characteristics

- Cruise from 95 to 180 knots IAS: no difference seen
- Incredible ability to hold course
- Speed and altitude similar to high-quality autopilot (+/- 1 m/s, +/- 2 meters up to 10 meters)

# Centaur OPA flight data




# Test schedule

- Operated from Aurora facility at Manassas Regional Airport, Virginia
- System integration April 4-5, 2016
- 5 test flights April 12-18

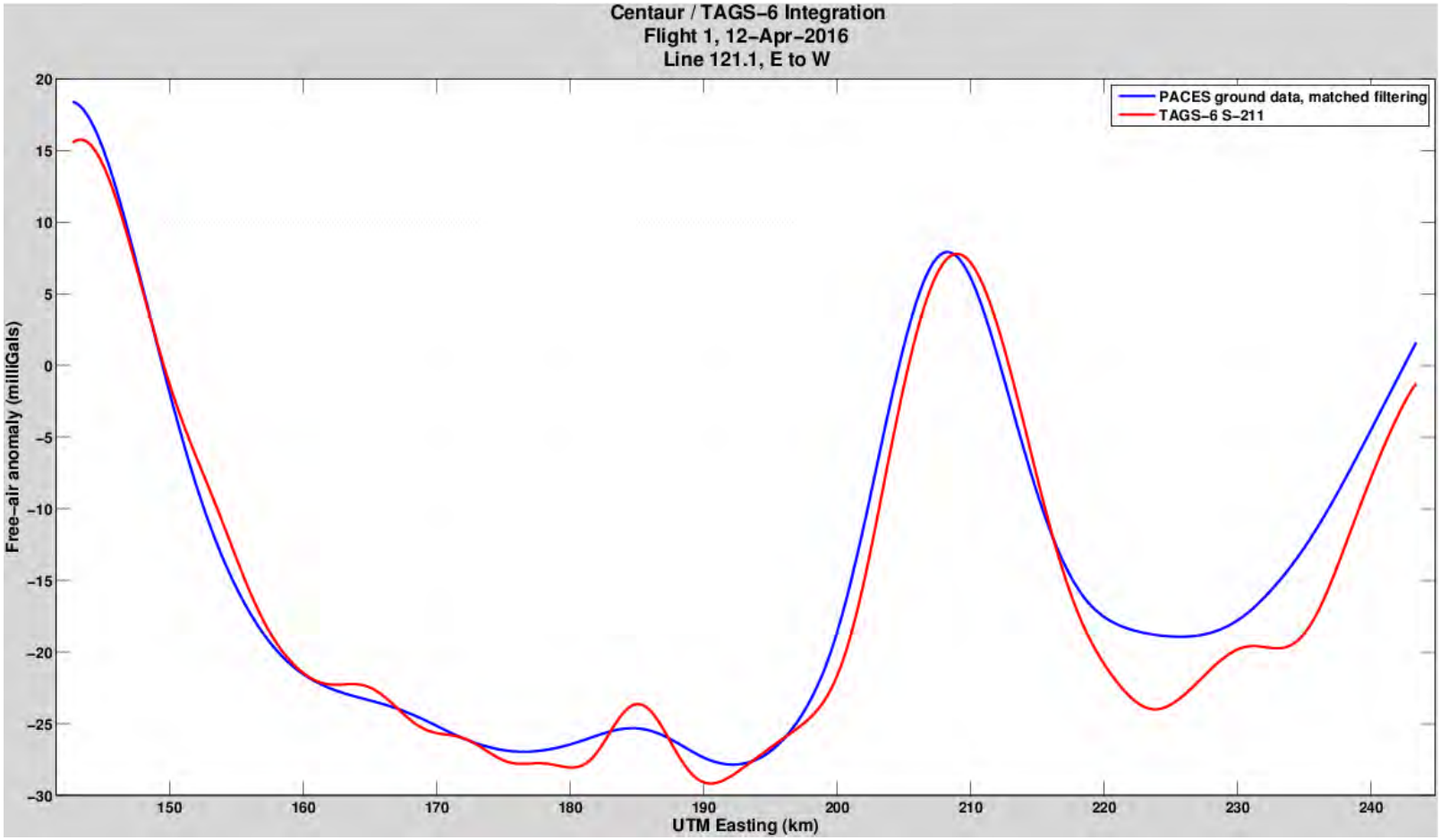
# Ground truth

- Onshore: station gravity from Pan-American Center for Environmental Studies (PACES)
- Offshore: Earth Geopotential Model 2008 (EGM2008)
- Upward continued to flight height
  - Plane-to-plane continuation done: probable small errors due to topography
- Filtered along profile to match airborne filtering

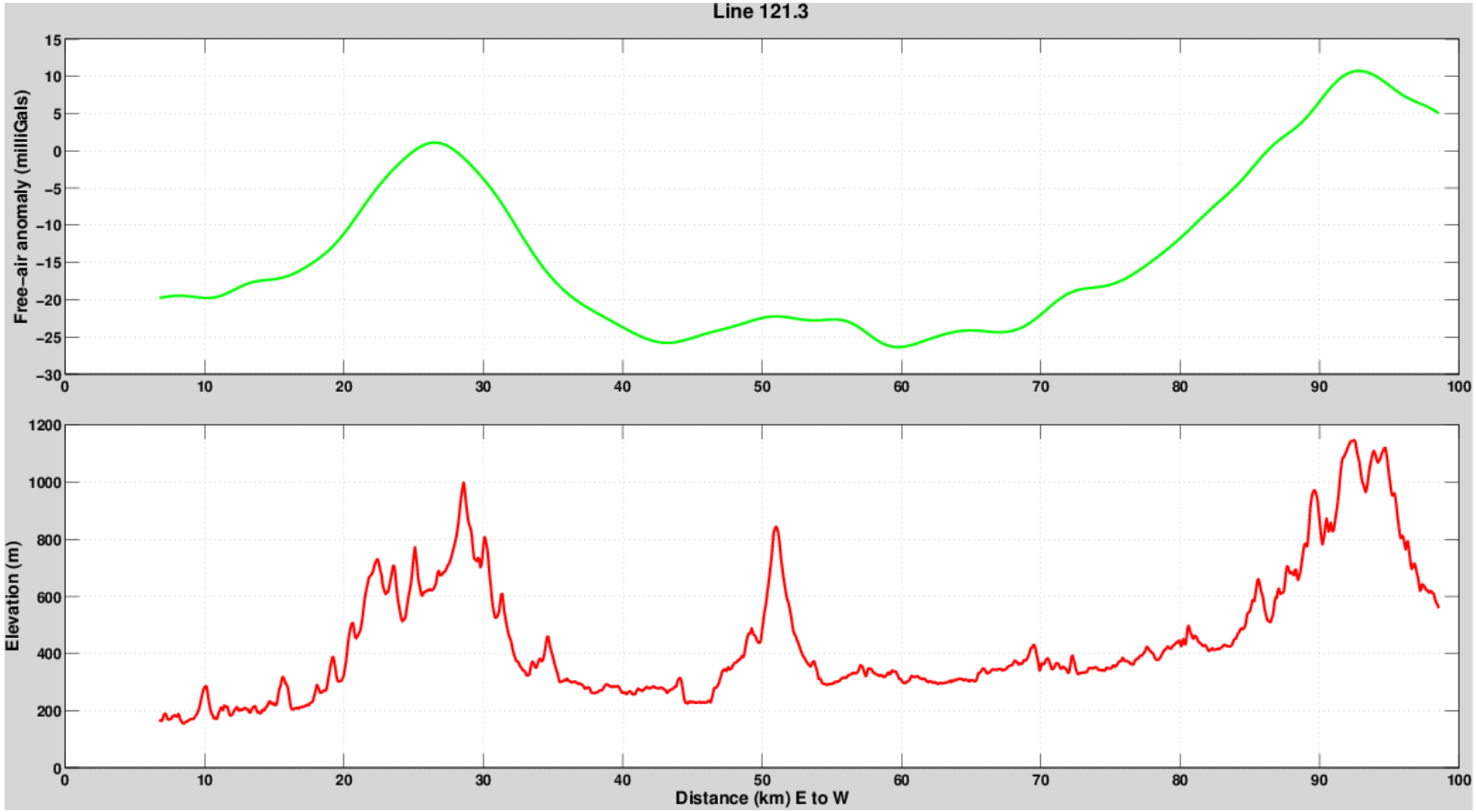
# Flight 1: April 12

- Flew E-W line (NGS line 121), Westbound then Eastbound
- Westbound at 10,500’, speed over ground 110 knots (30 knot headwind)
- Eastbound at 11,500’, speed over ground 180 knots (30 knot tailwind)
- As expected, gravity Eastbound was smoother (higher altitude, faster)

# Flight 1 with ground truth



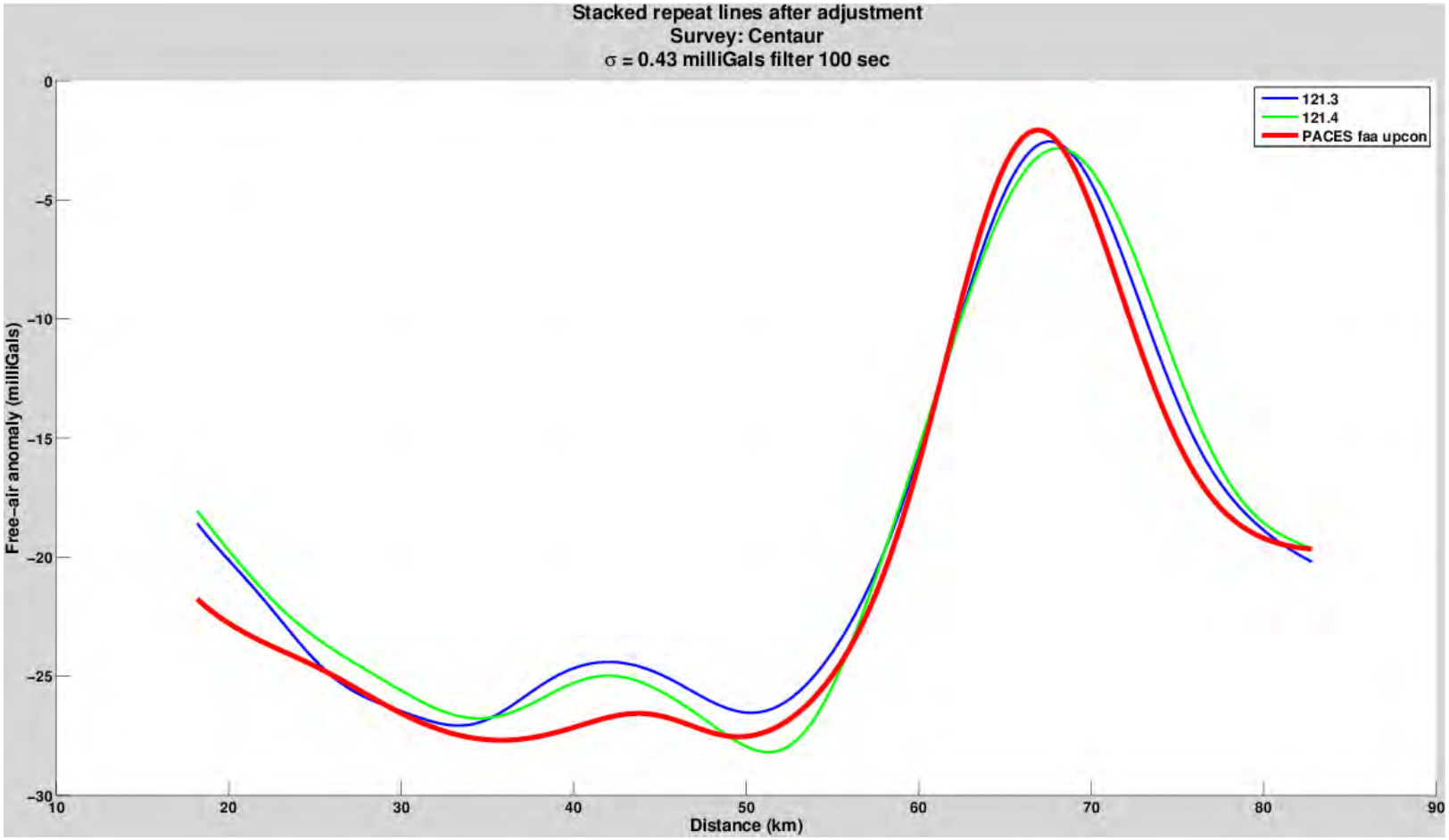
# Flight 1 gravity and topography



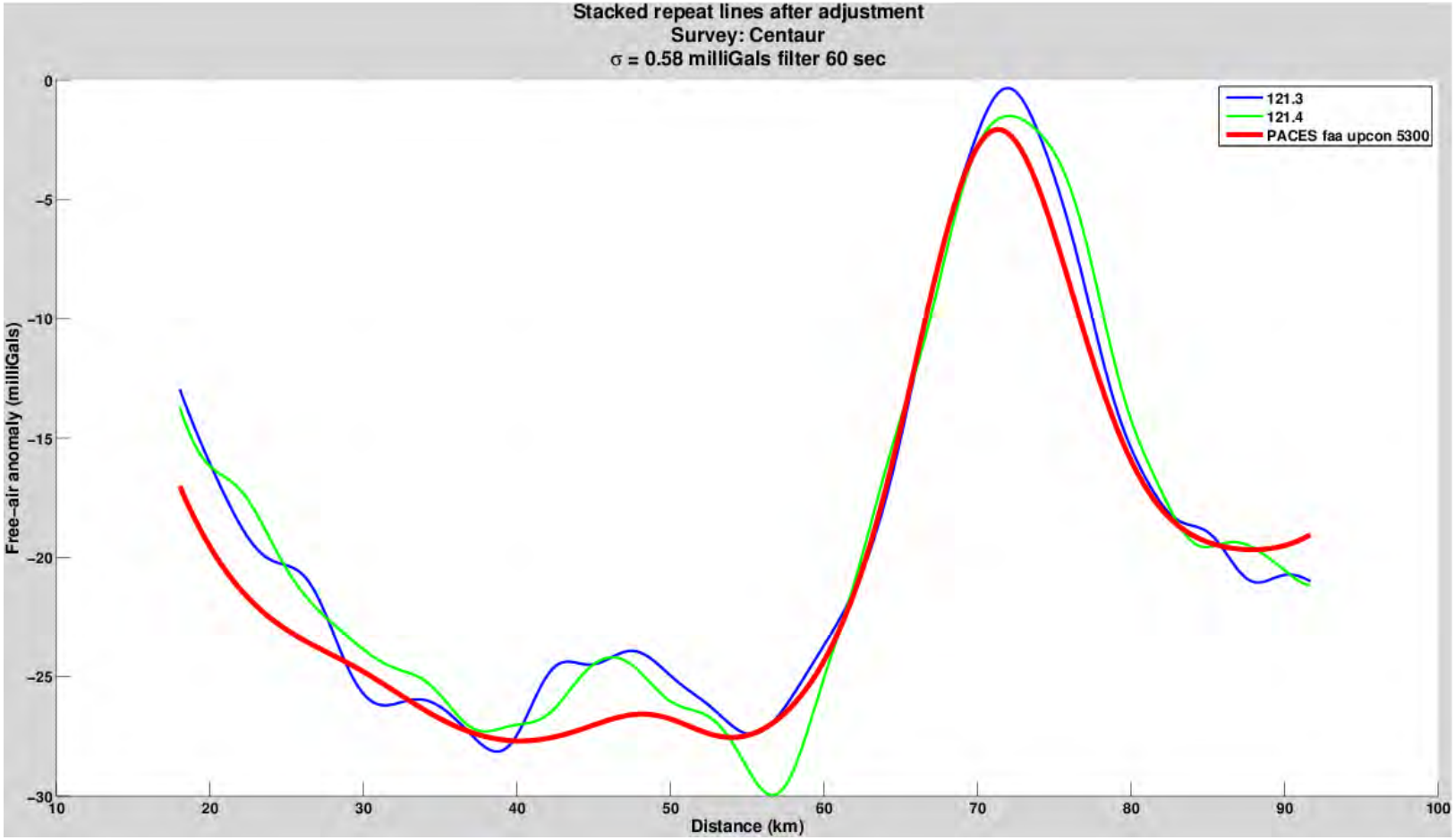
# Flight 2: April 13

- Repeated line 121
- Both directions at 17,500’
- Speed over ground matched with headwind/tailwind: both directions 145 knots
- Repeatability remains very good at 60 second filtering

# Flight 2 with ground truth



# Flight 2 repeats, 60 second filter



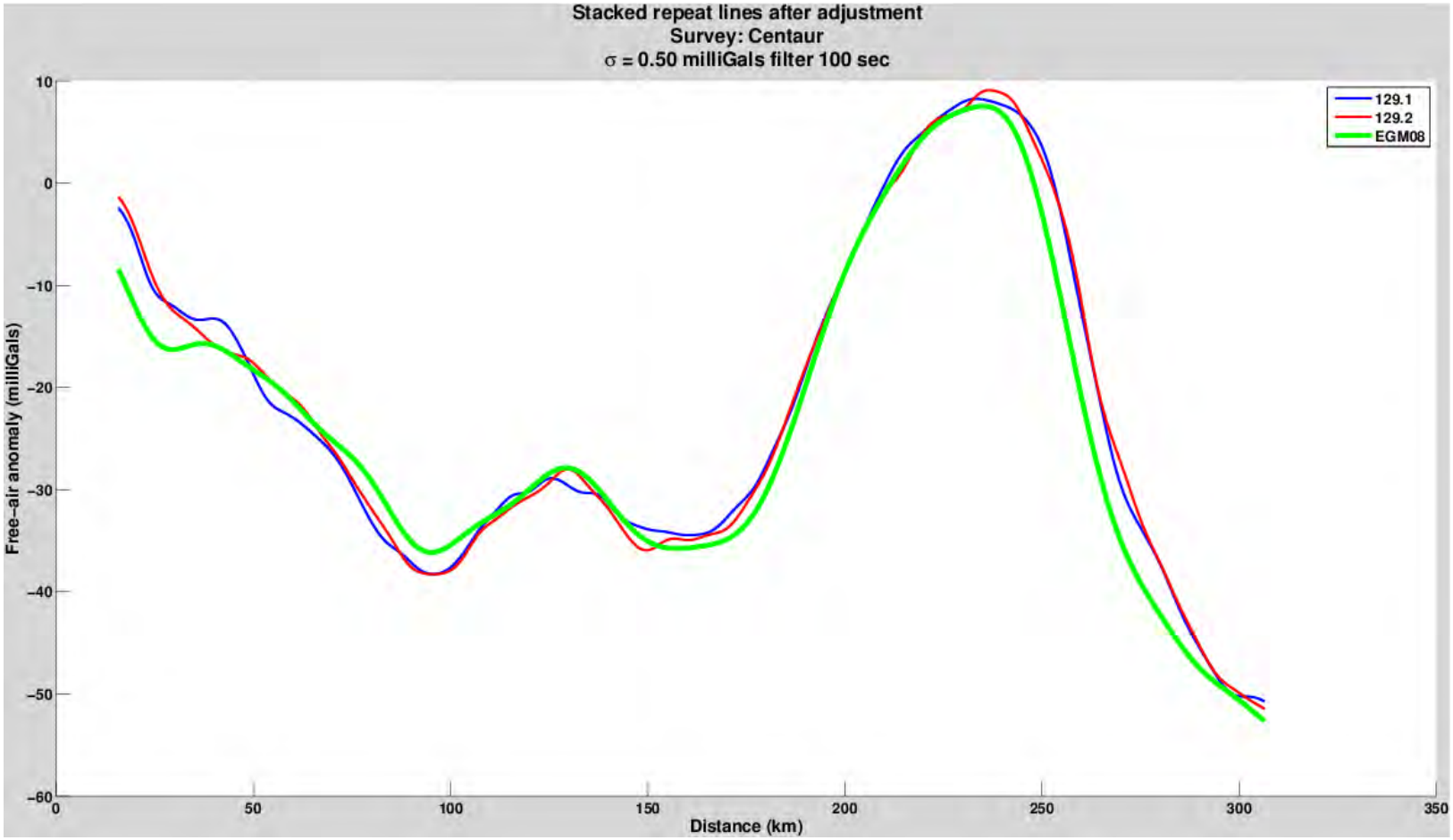
# Flight 3: April 14

- Shortened version of Flight 2 (demo for NGS)
- 30 knot crosswind: no lateral hunting
- Fully ground-controlled flight

# Flight 4: April 17

- NGS line 129: long flight, mainly overwater
  - GPS baseline 400 km
- GCS computer carried onboard: no ground link

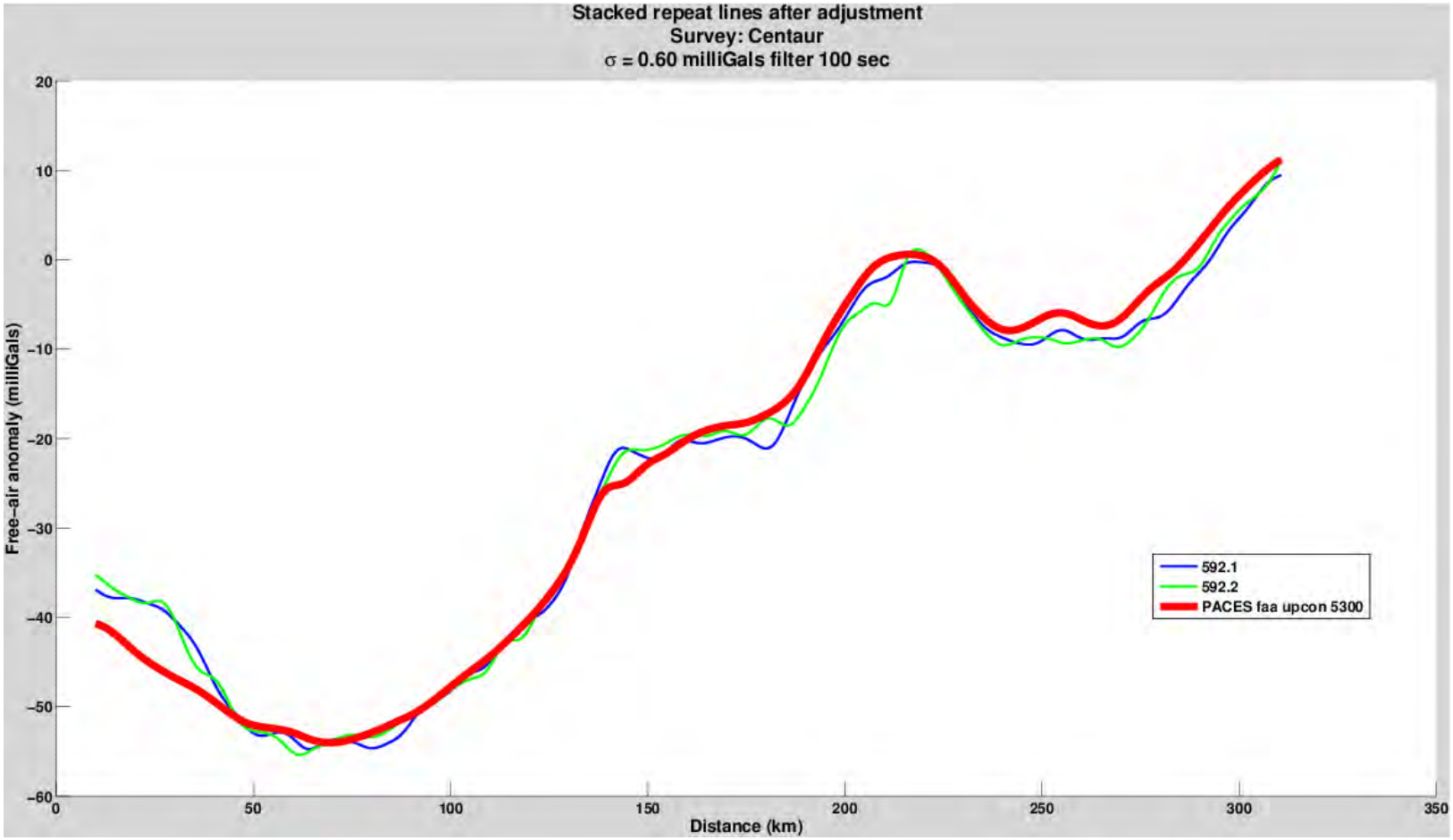
# Flight 4 with ground truth



# Flight 5: April 18

- NGS line 592: long flight, North across Appalachians to central Pennsylvania
- Flight conditions more turbulent than previous flights

# Flight 5 with ground truth



# Summary

- Five flights, geodetic profiles
- Headwinds, tailwinds, crosswinds, mountain waves
- Consistent high quality
  - Repeats well under 1 milliGal
  - Excellent comparison with ground truth
- Data remains coherent with minimal filtering