ANITA: Current Status and Future Prospects

Ryan Nichol

Photo: H. Schoorlemmer , University of Hawaii

ANITA Collaboration

Ohio State University

University of Kansas

Washington University in St. Louis

University of Delaware

University of California, Los Angeles

Cal Poly, San Luis Obispo

University of Hawaii at Manoa

National Taiwan University

University College London

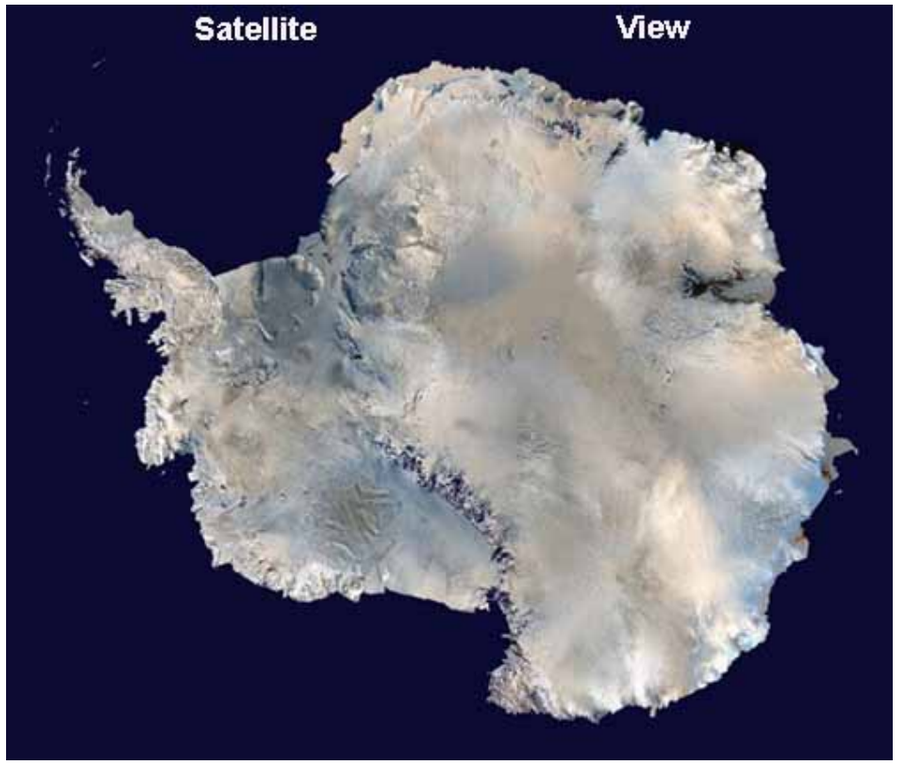
Jet Propulsion Laboratory

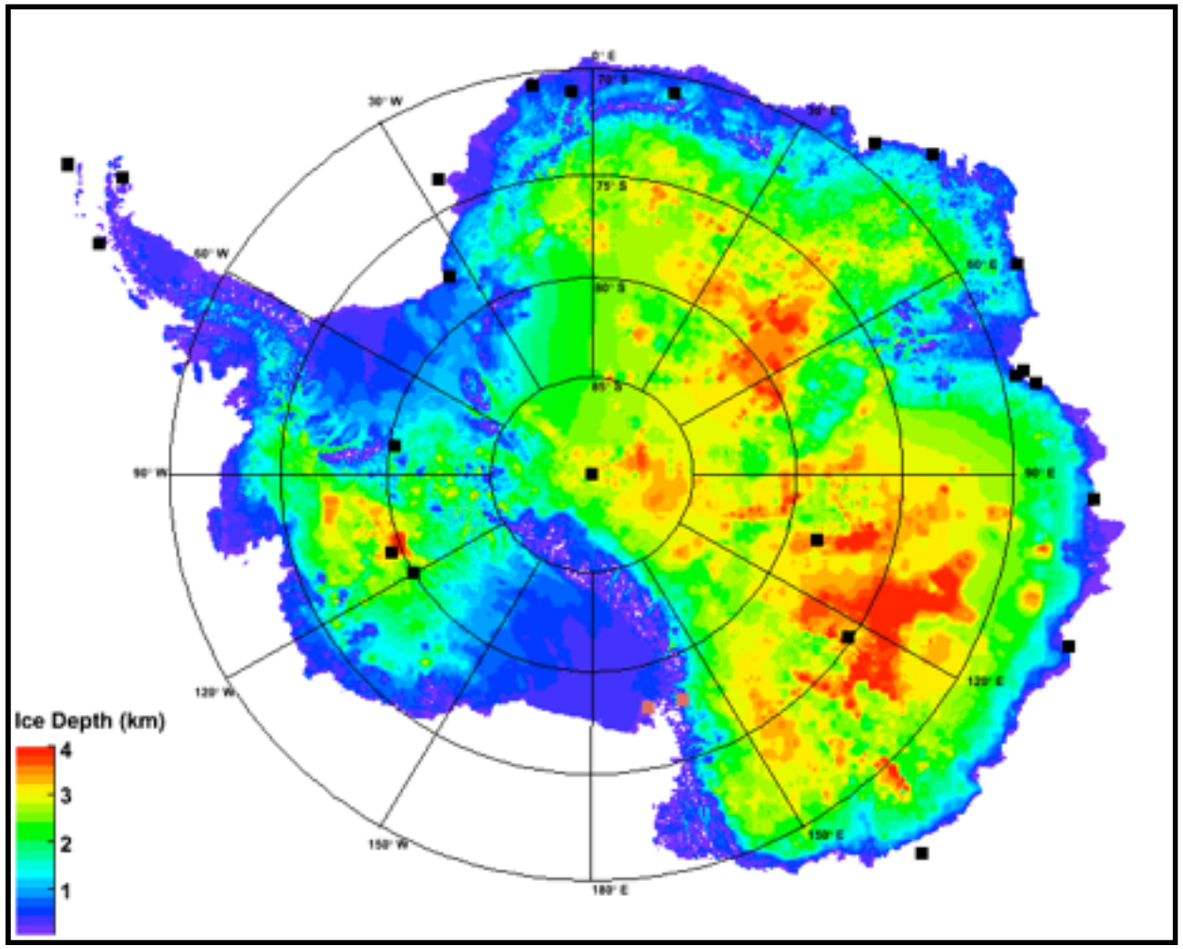
Stanford Linear Accelerator Center

University of Chicago

Why Antarctica?

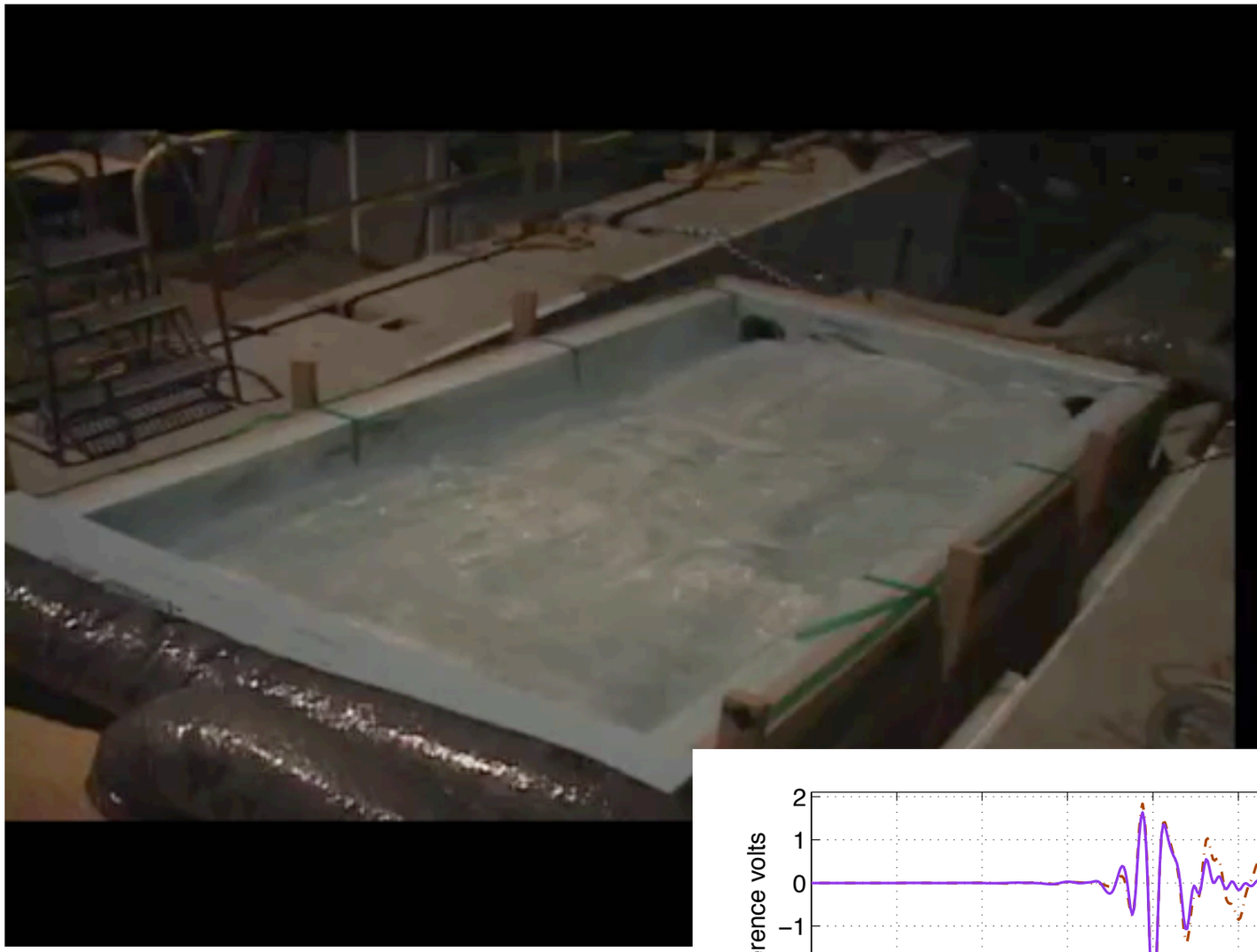
- It is the coldest, driest, windiest place on Earth
- But...
  - Lots of Ice
    - Despite our best efforts
    - Over 4km thick in places
  - Also:
    - The only continent exclusively dedicated to scientific research
    - No indigenous (human) population
    - Home of NASA's long-duration balloon program

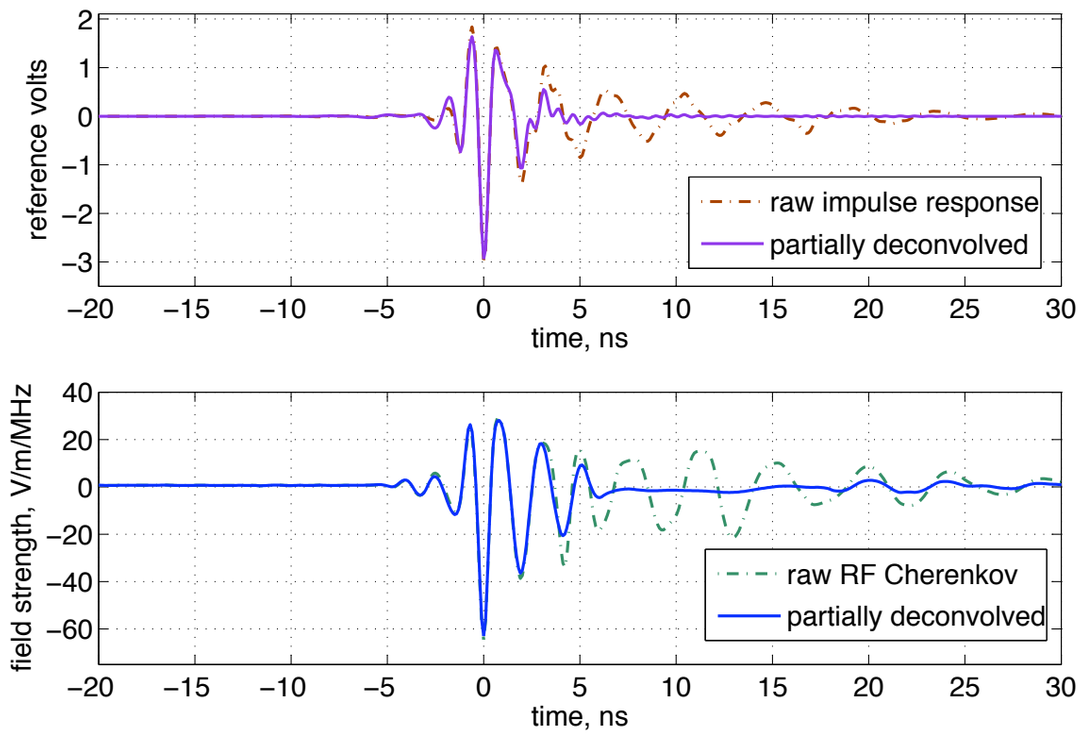


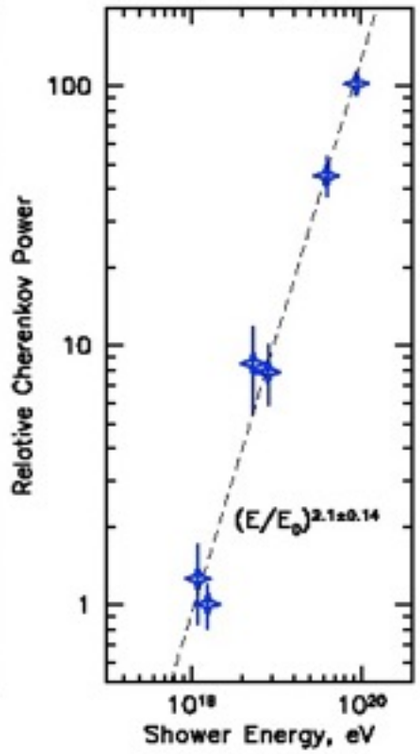


Ice depth data from BEDMAP consortium

Flashy Ice



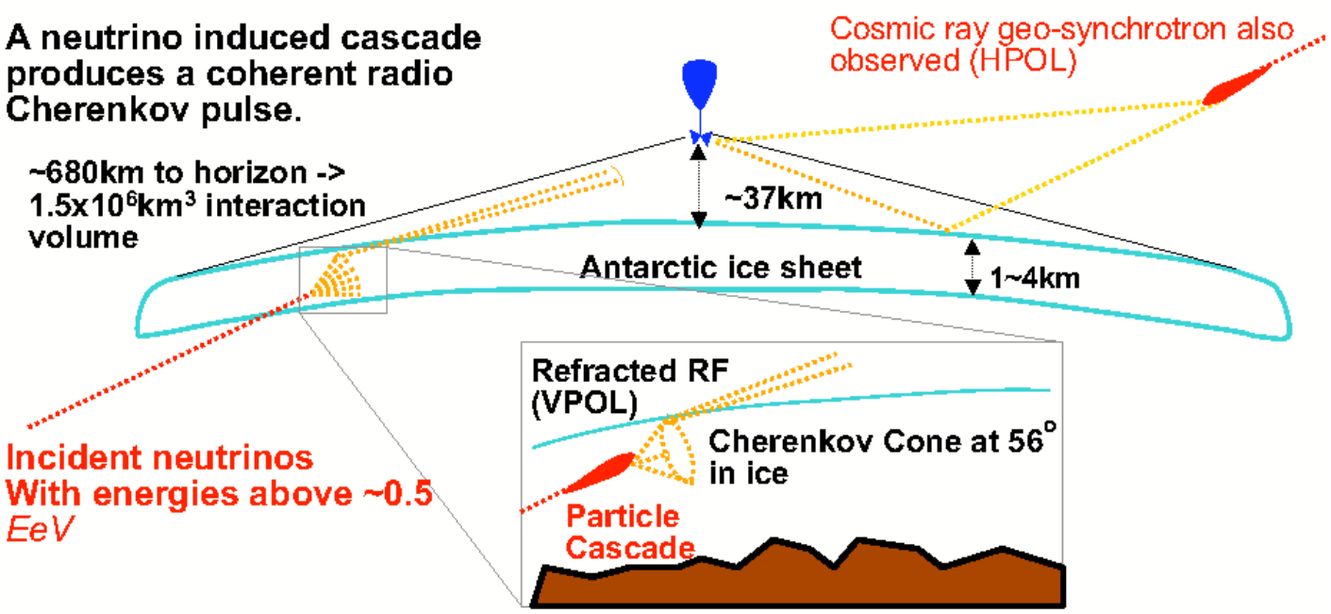




From PRL 99, 171101 (200 ,

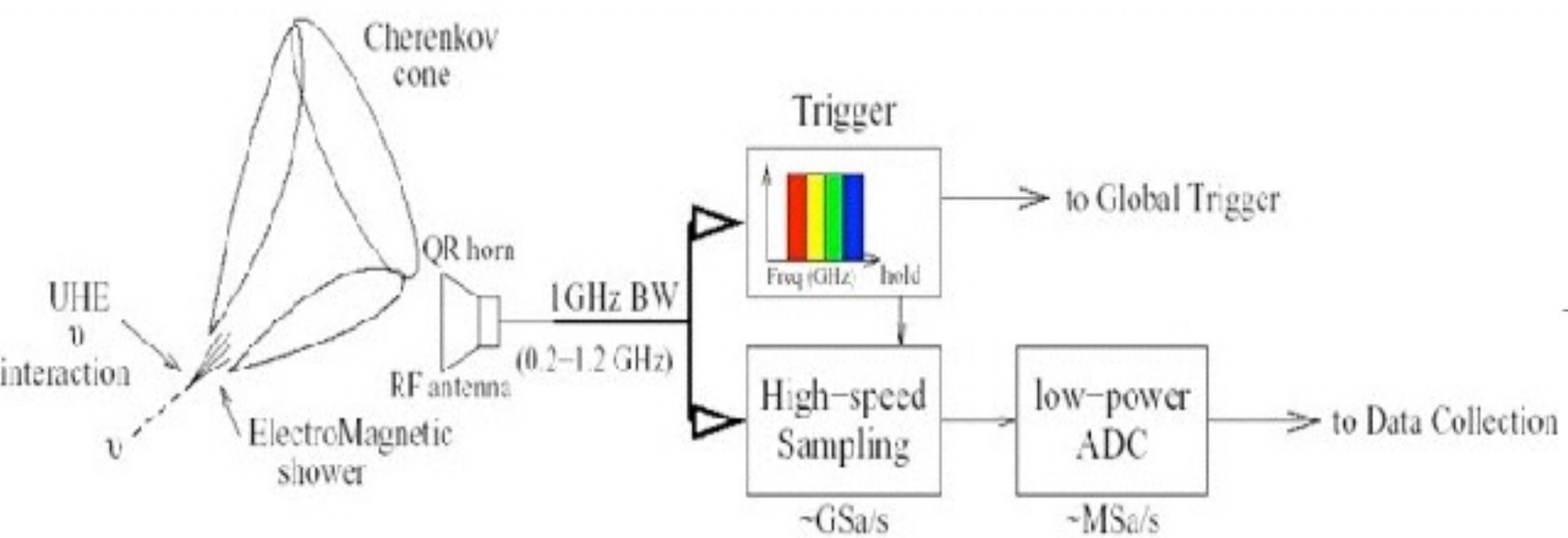
ANITA

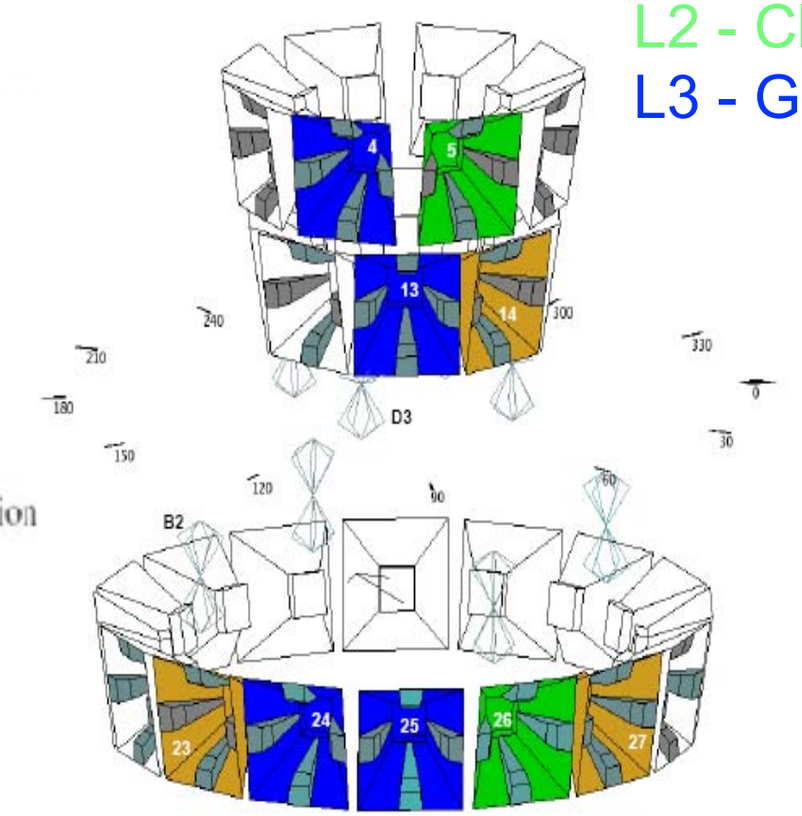
- The ANtarctic Impulsive Transient Antenna
  - A balloon borne experiment
    - 32-48 dual polarisation antennas
    - Altitude of 37km (120,000 ft)
    - Horizon at 700km
    - Over 1 million km^3 of ice visible



ANITA Electronics and Trigger

- Need a low power (only solar energy), 90 channel, multi-GHz bandwidth oscilloscope.

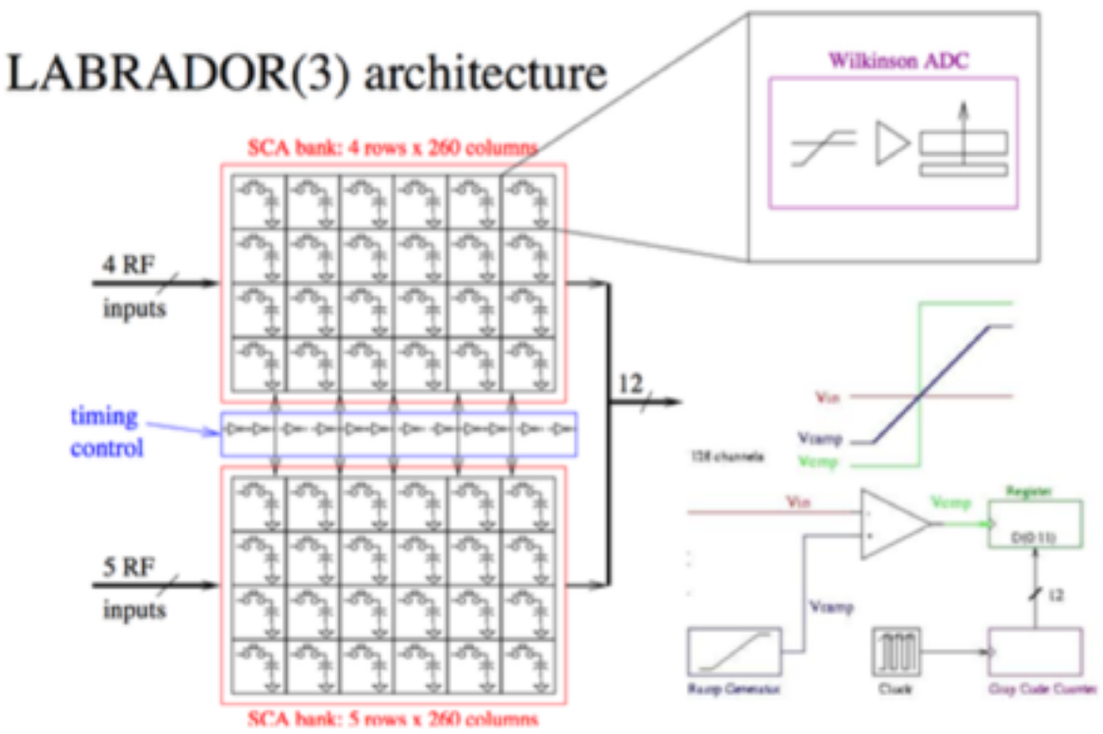


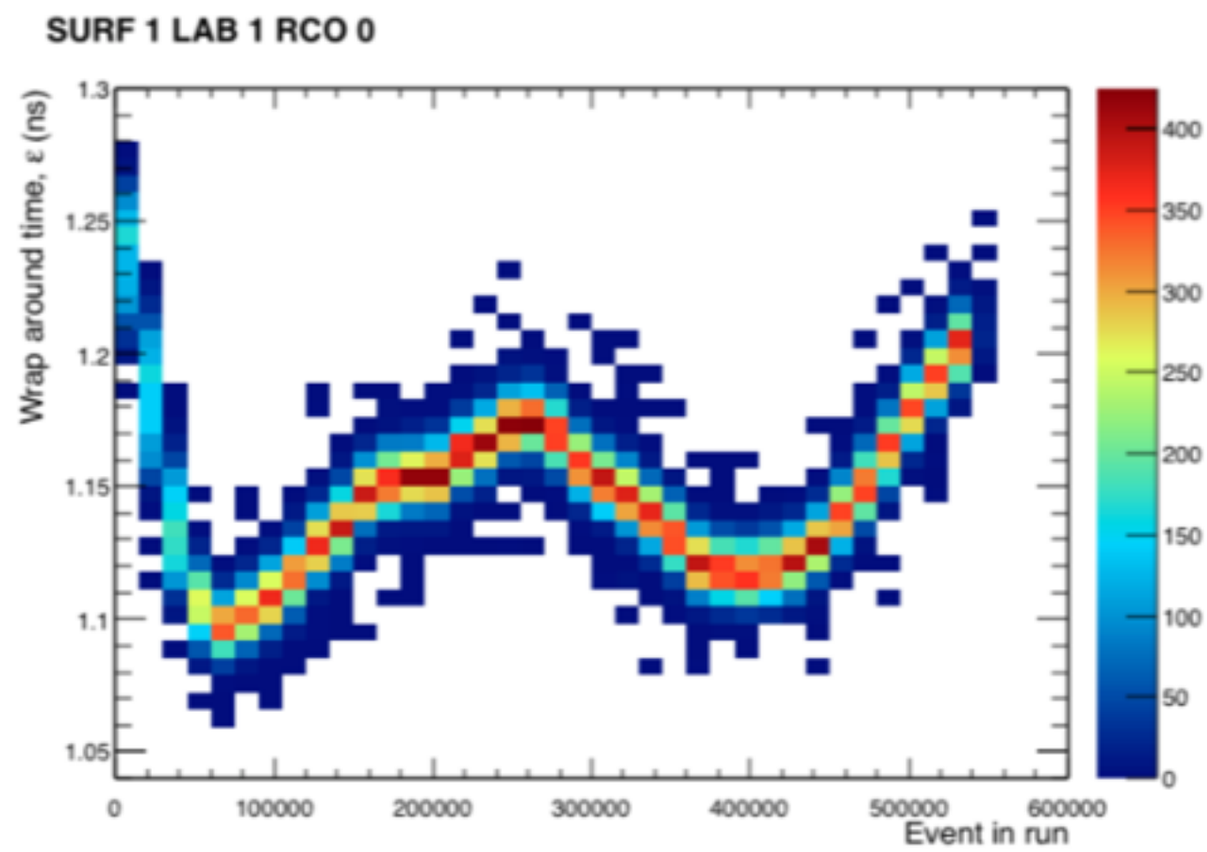


- Split trigger and waveform paths
- Use multiple frequency bands for trigger
- ‘Buffer’ waveform data in switched capacitor array
- Only digitise when we have a trigger

ANITA Calibration

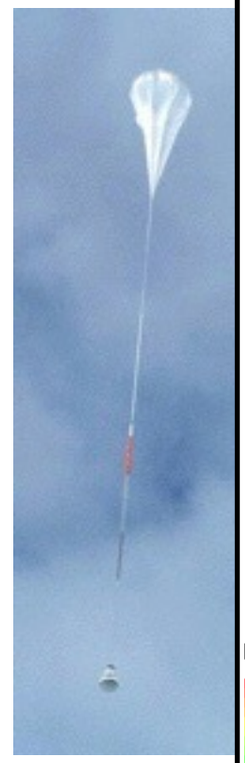
- There are ~12,500 capacitors in the analogue sampling array, each needs to be calibrated
- In addition the timing calibration depends on the temperature, event-by-event trigger jitter, pathologies of the clocks used for the calibration, …

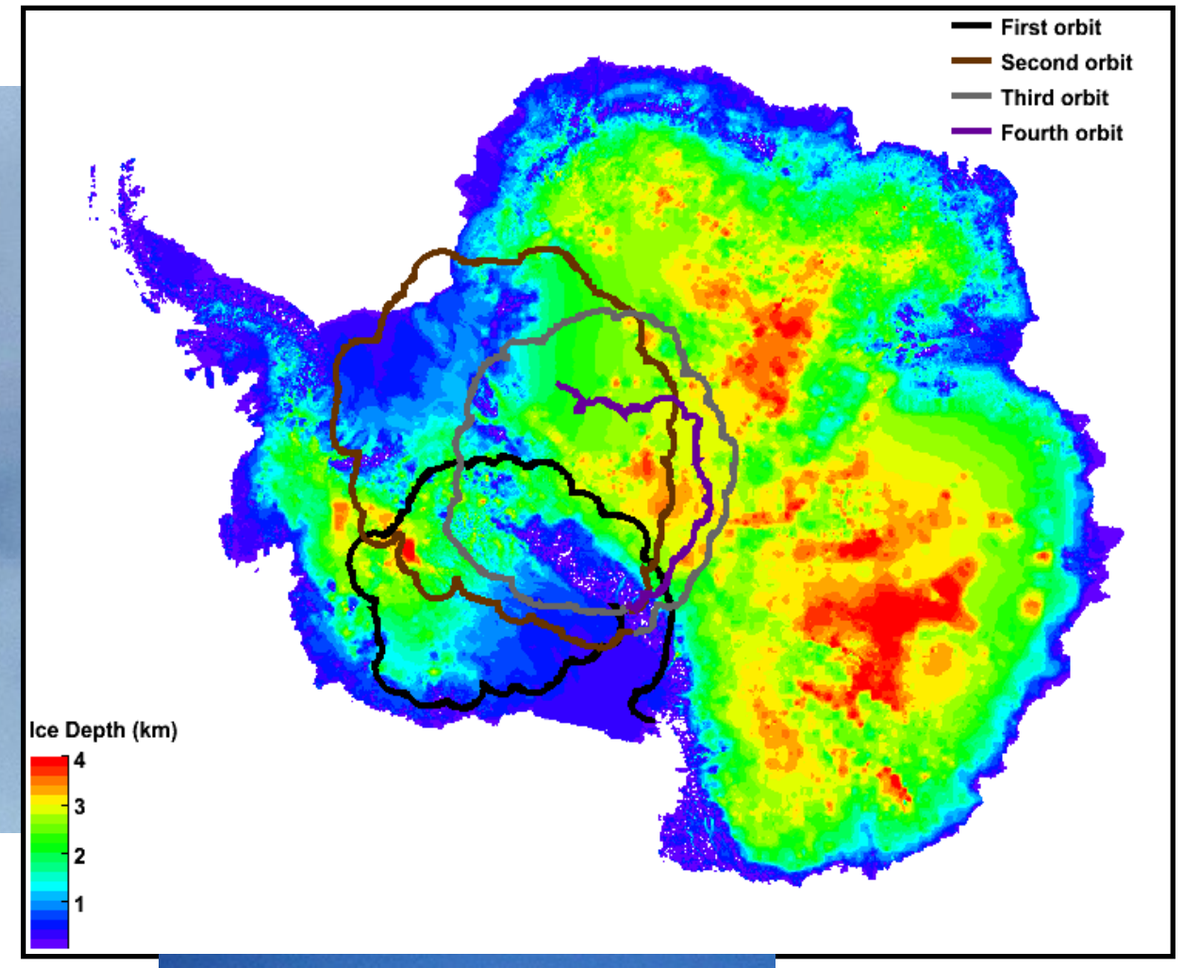




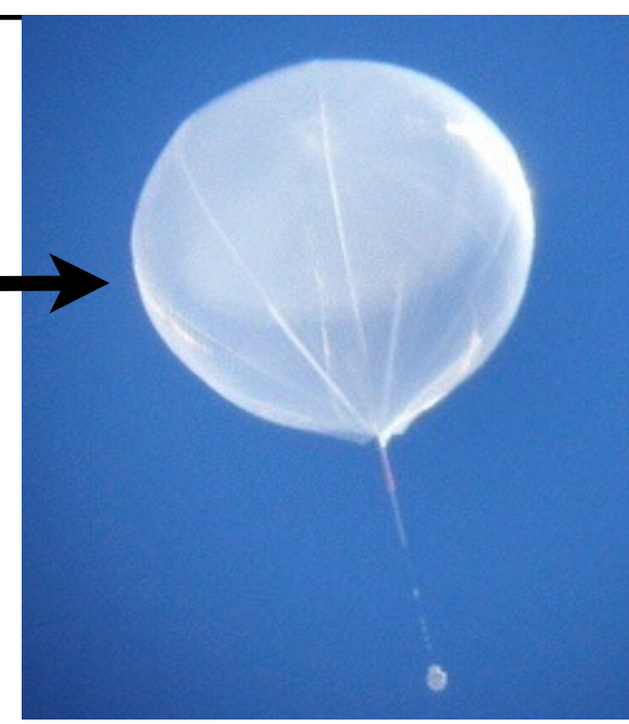
ANITA-1 — 2006/7

- Lasted 35 days (the record is 42)
  - Three and a half sort of polar orbits
  - Recorded over 8 million triggers



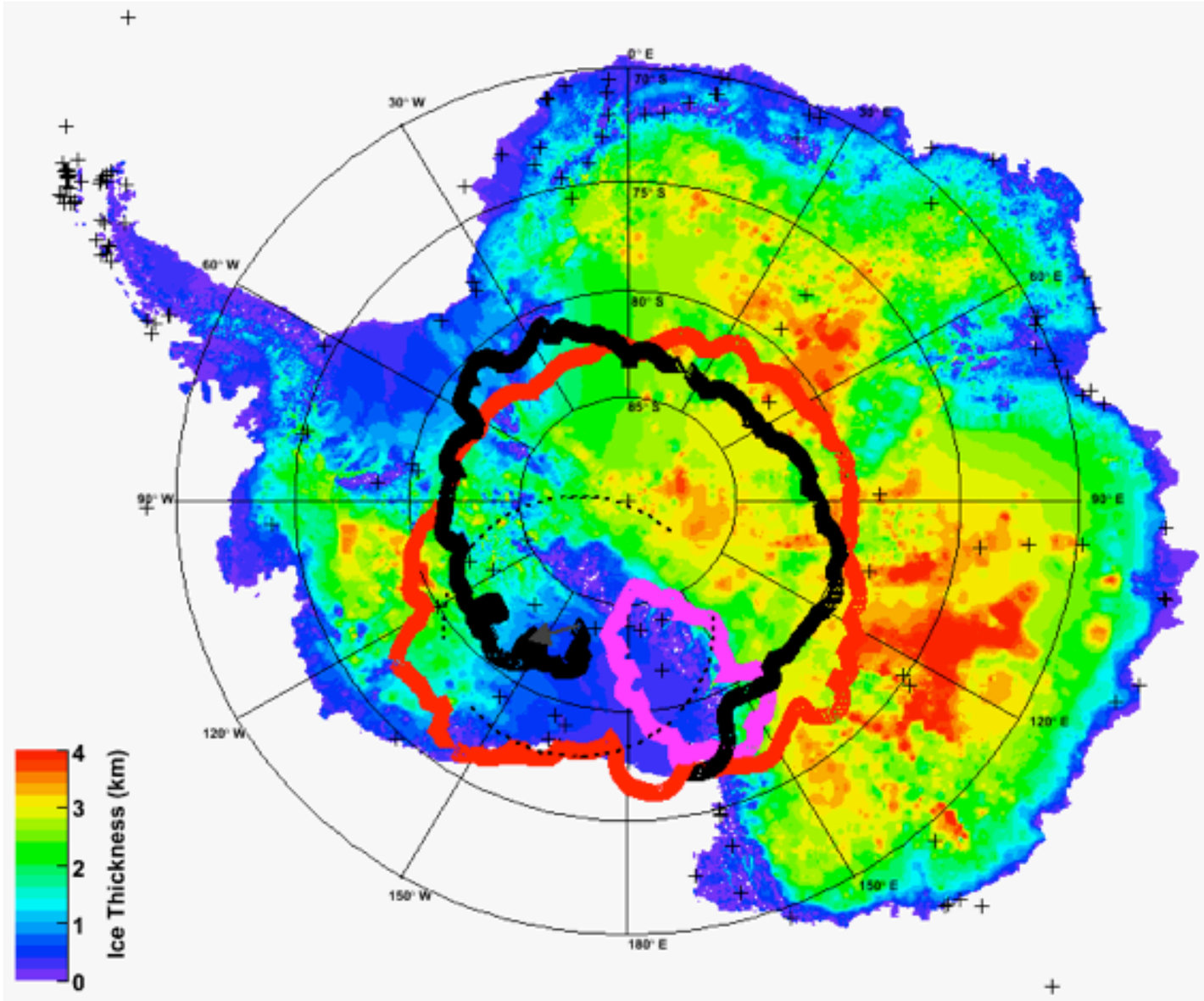


Fits inside the balloon at altitude



ANITA-2 — 2008/9

- Launched Dec 2008
- Terminated after 30 days at float
- Little victories
  - Better flight path
  - Over 27 million events
  - Over 100,000 Calibration pulses
- Data fully recovered
  - Two students spent a week camping out at crash site



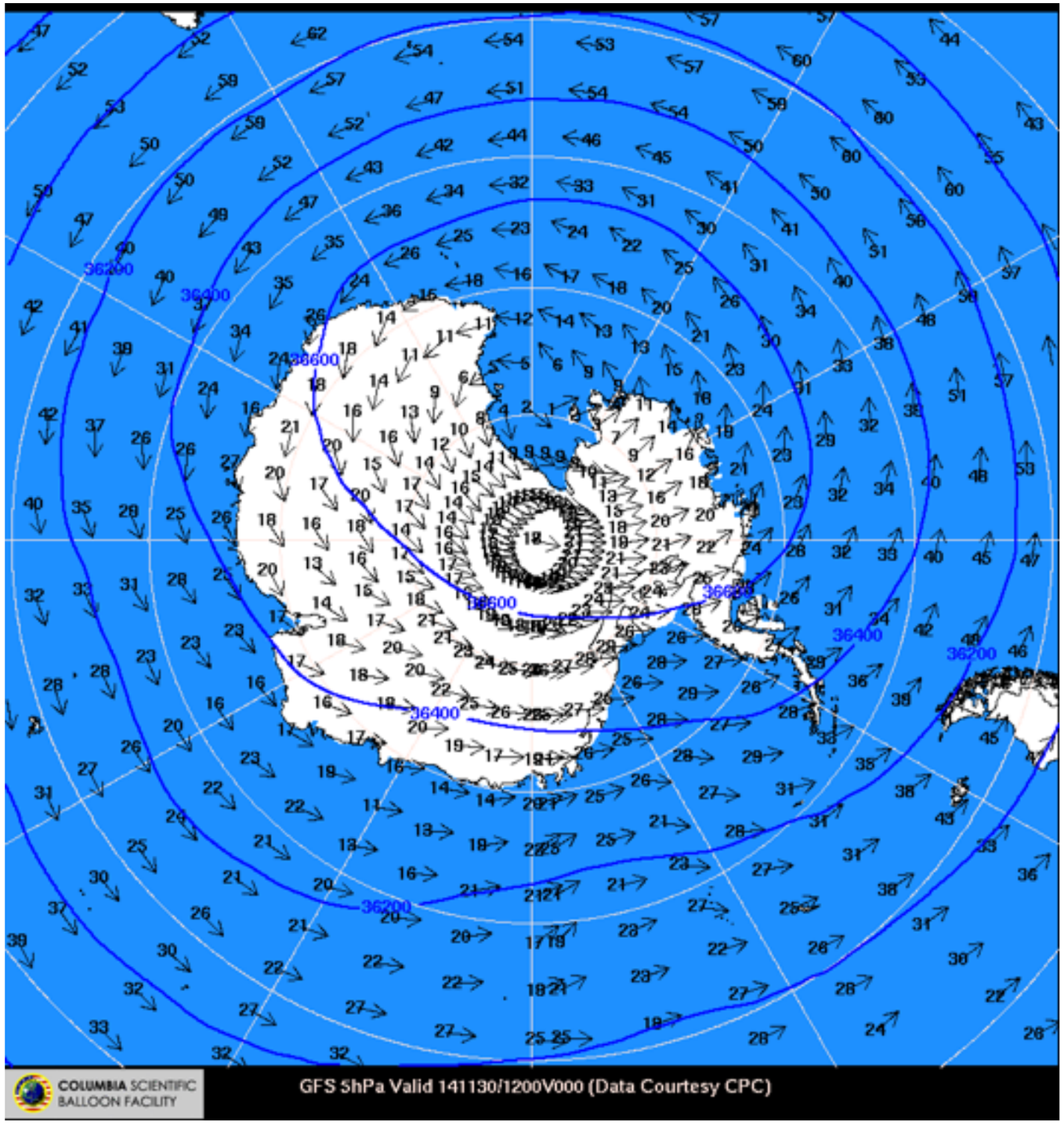
ANITA-3 — 2014/15

- Added an additional 8 antennas
  - Three equal rings of 16 antennas
- Added a new GPU-based software trigger
  - Allowing us to run at a higher rate with lower threshold
- “Improved” antenna design
- Lower noise RF front-end
- Added a low frequency antenna for cosmic ray characterisation

Photo: B. Hill, University of Hawaii

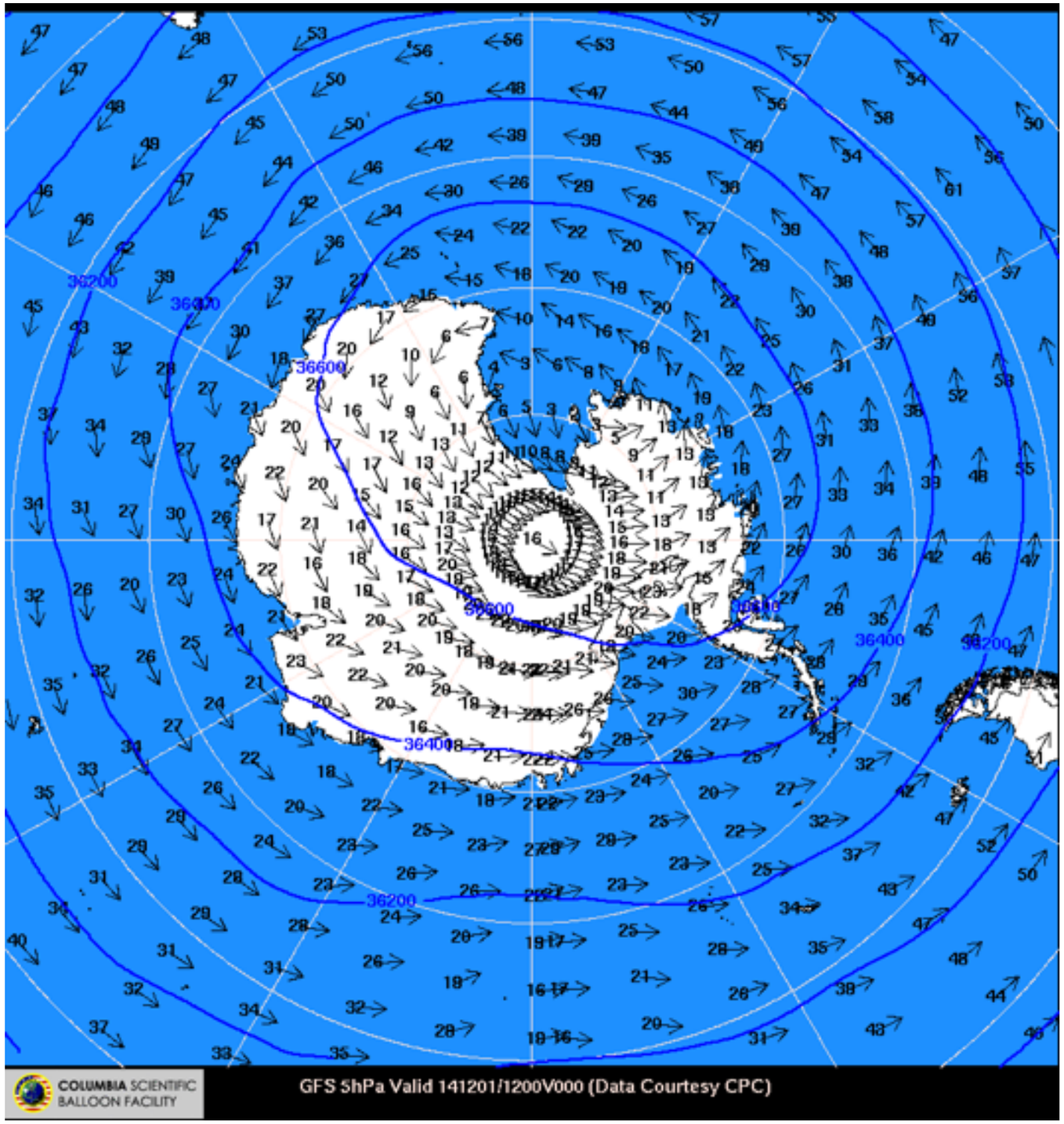
The Weather Game

11/30/2014



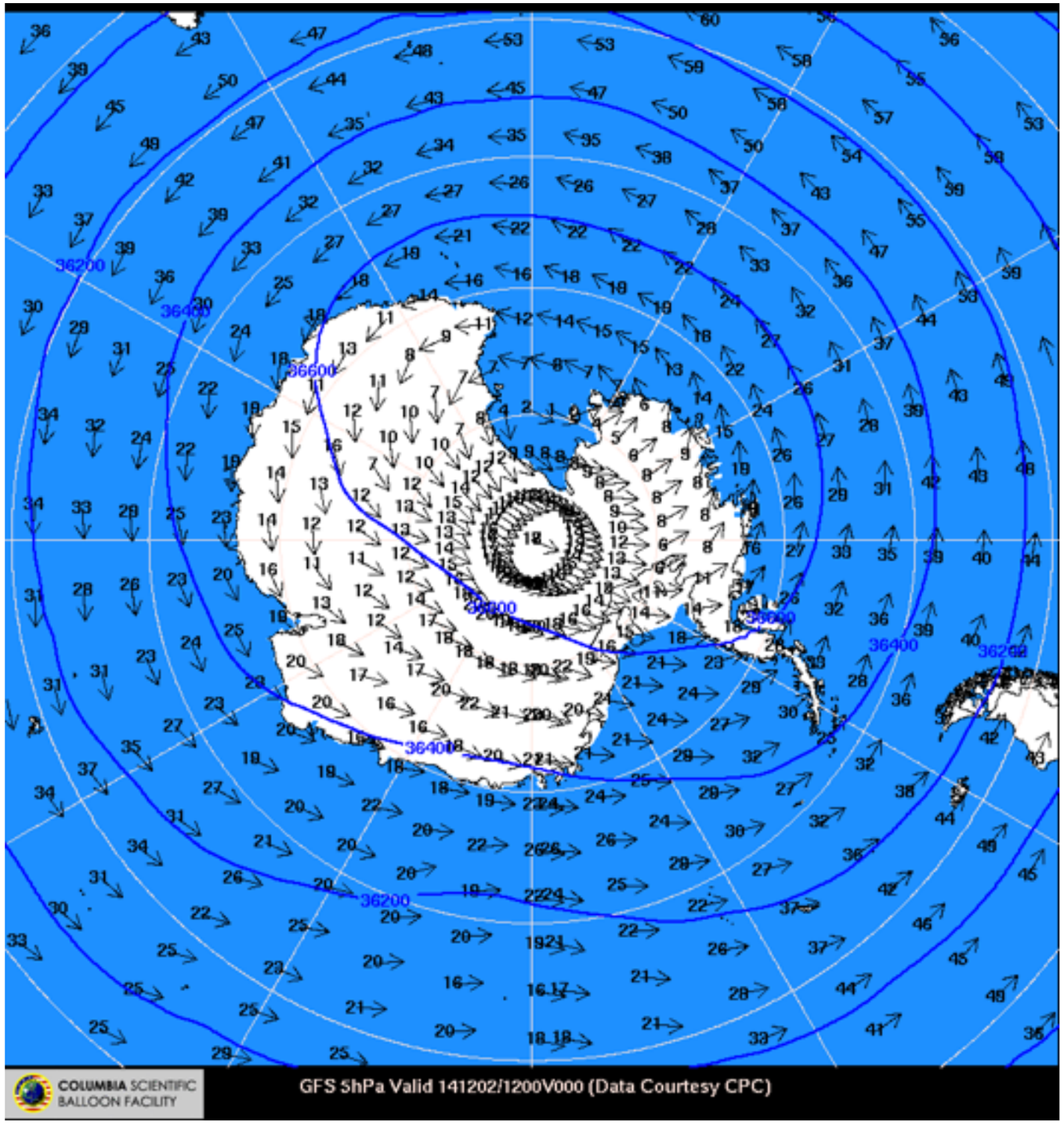
The Weather Game

12/01/2014



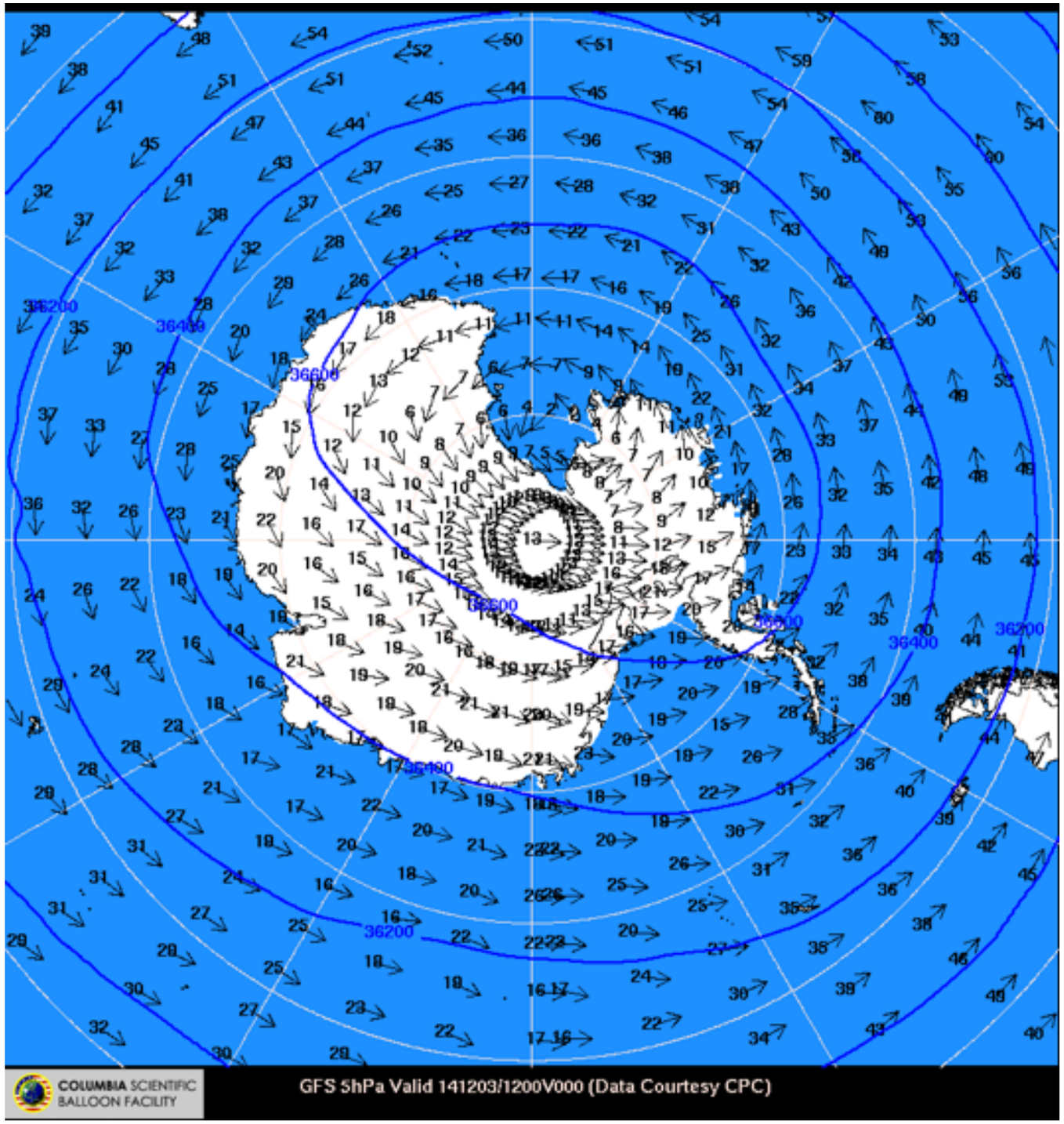
The Weather Game

12/02/2014



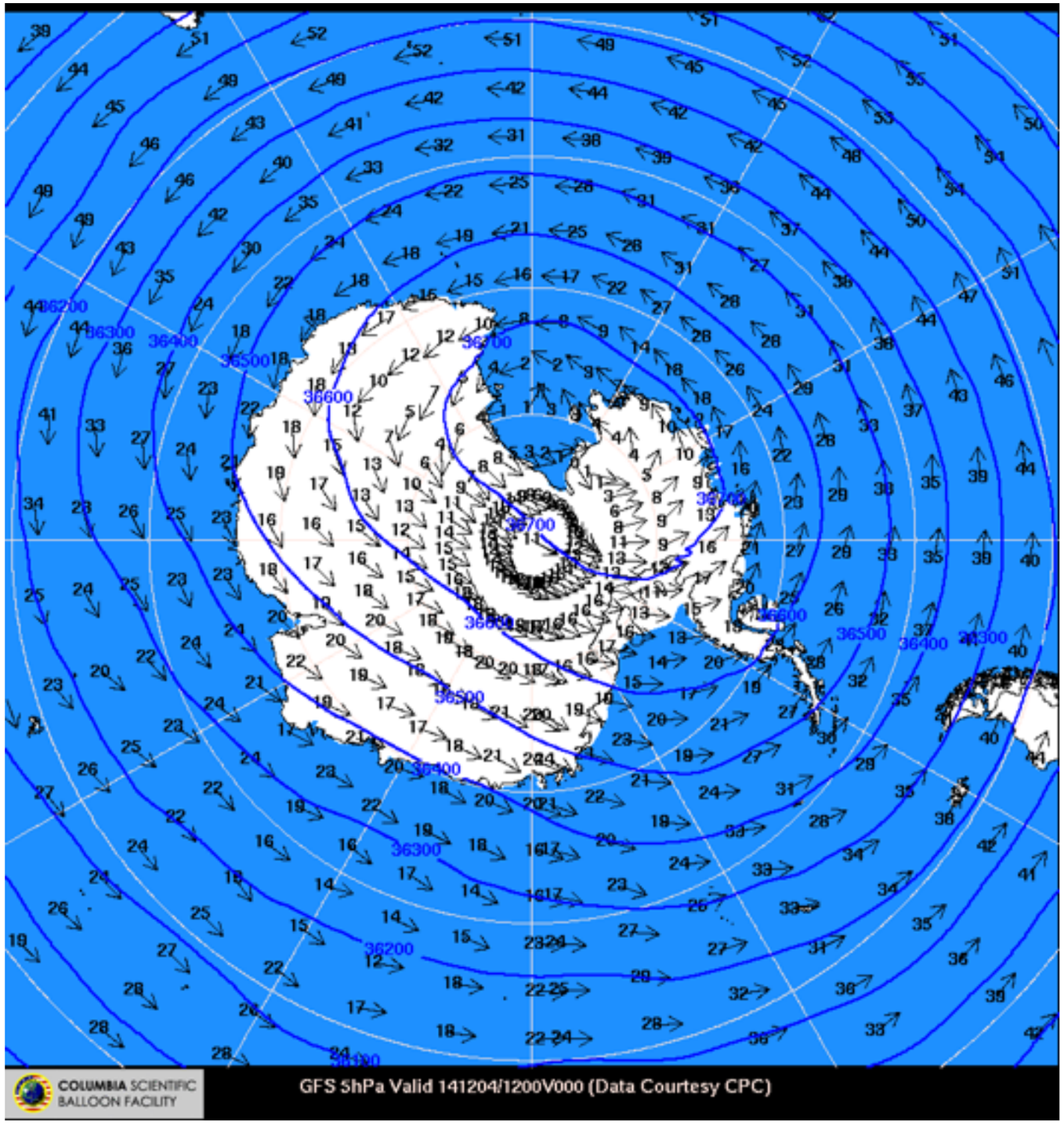
The Weather Game

12/03/2014



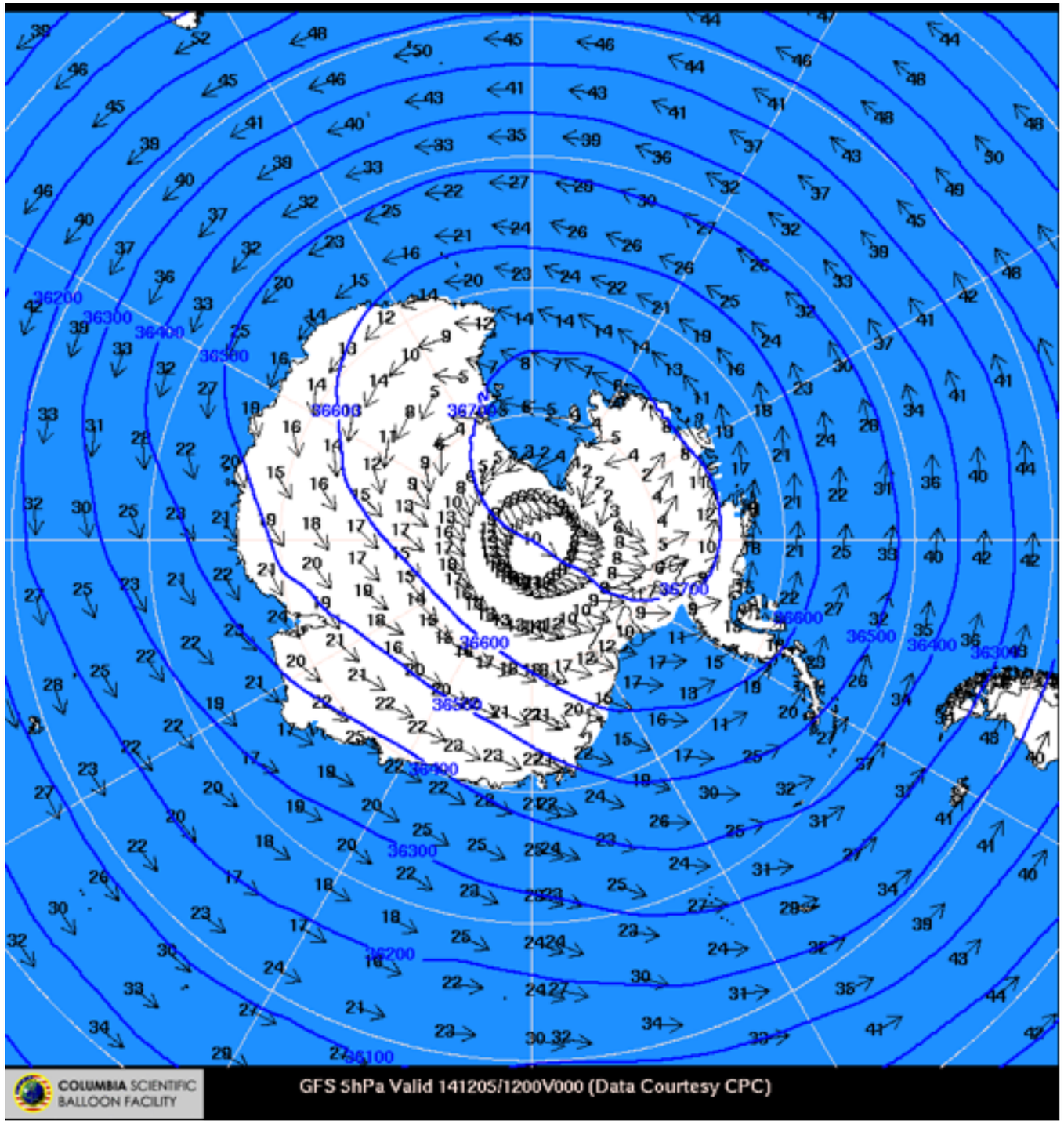
The Weather Game

12/04/2014



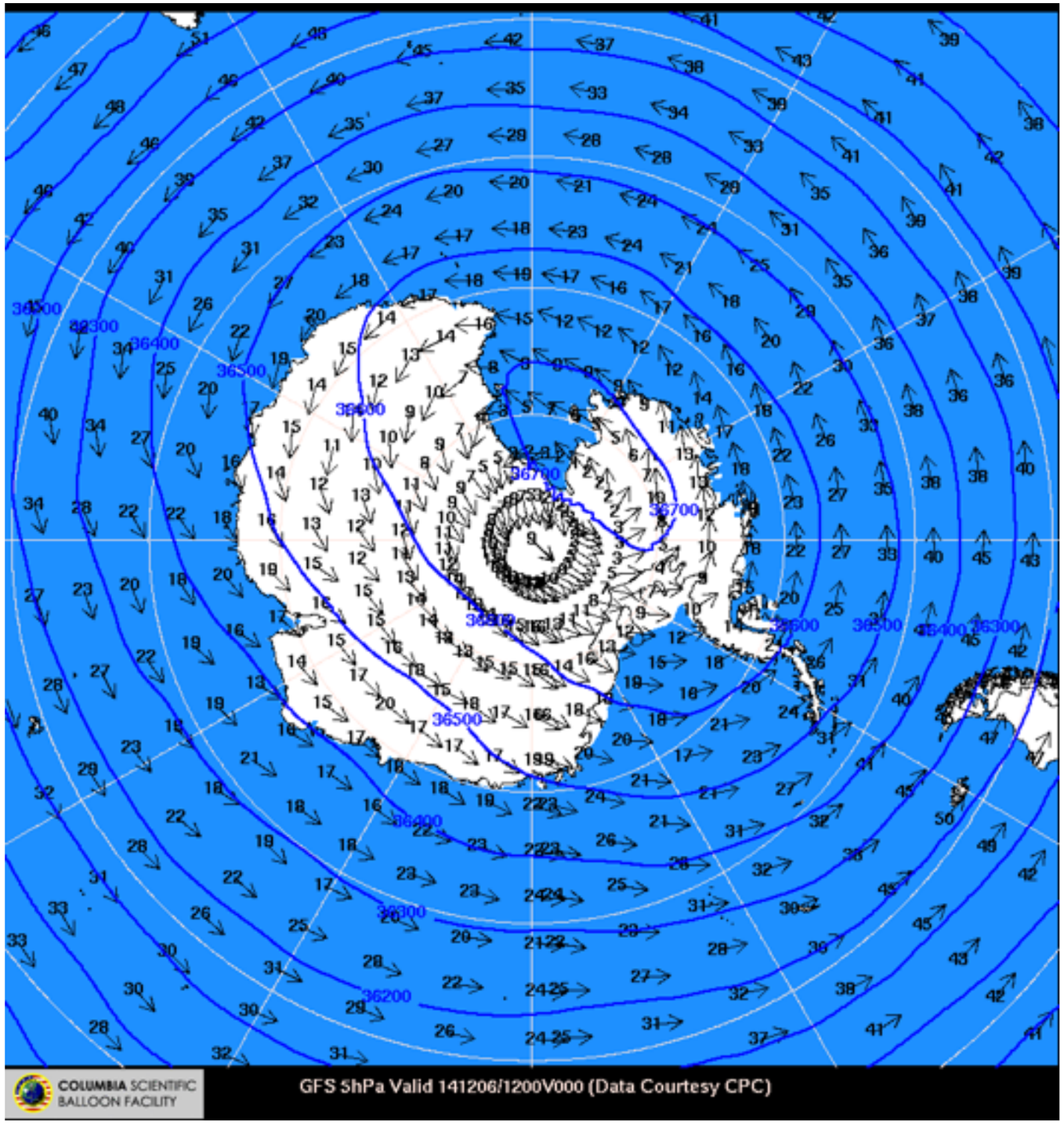
The Weather Game

12/05/2014



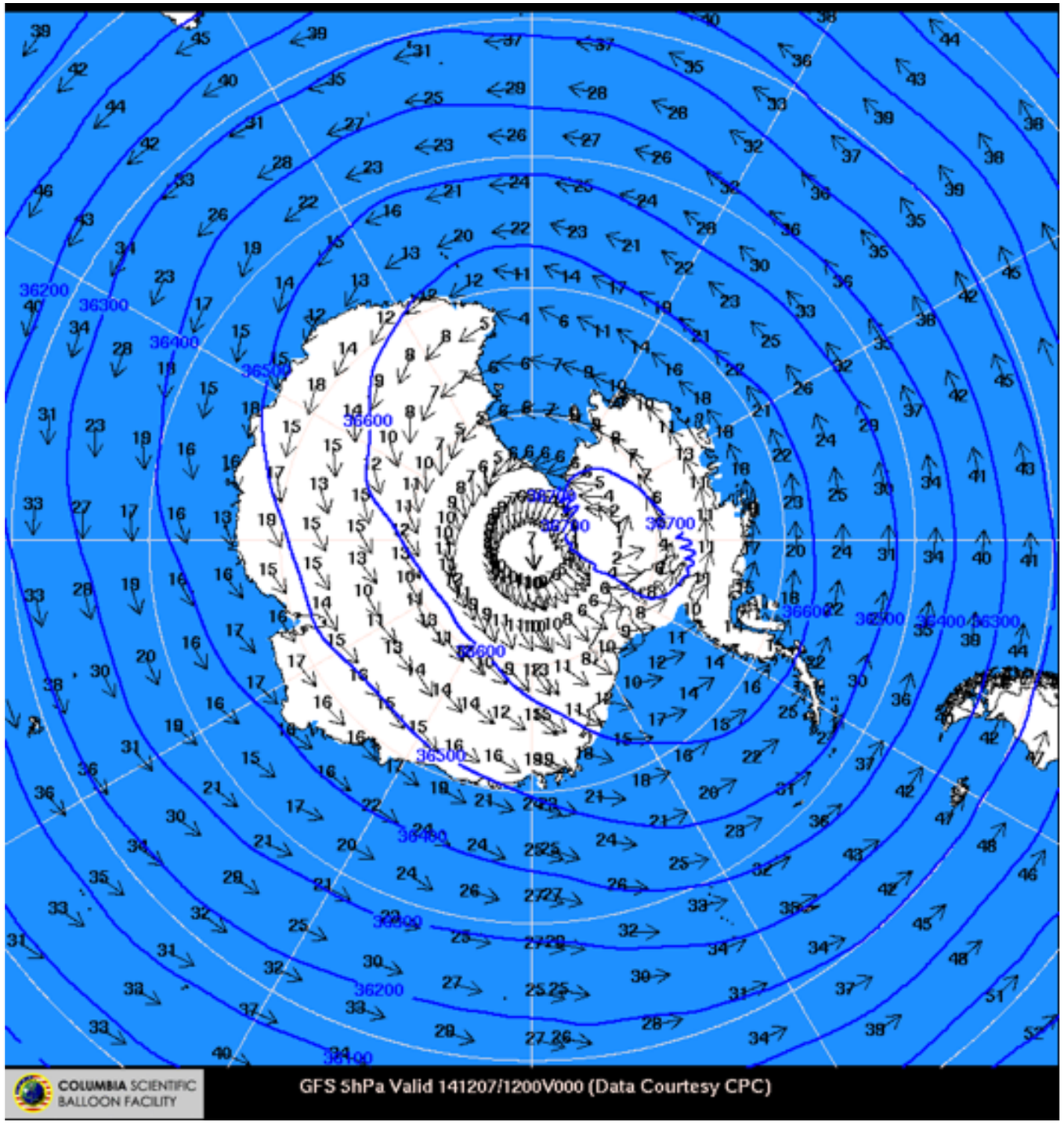
The Weather Game

12/06/2014



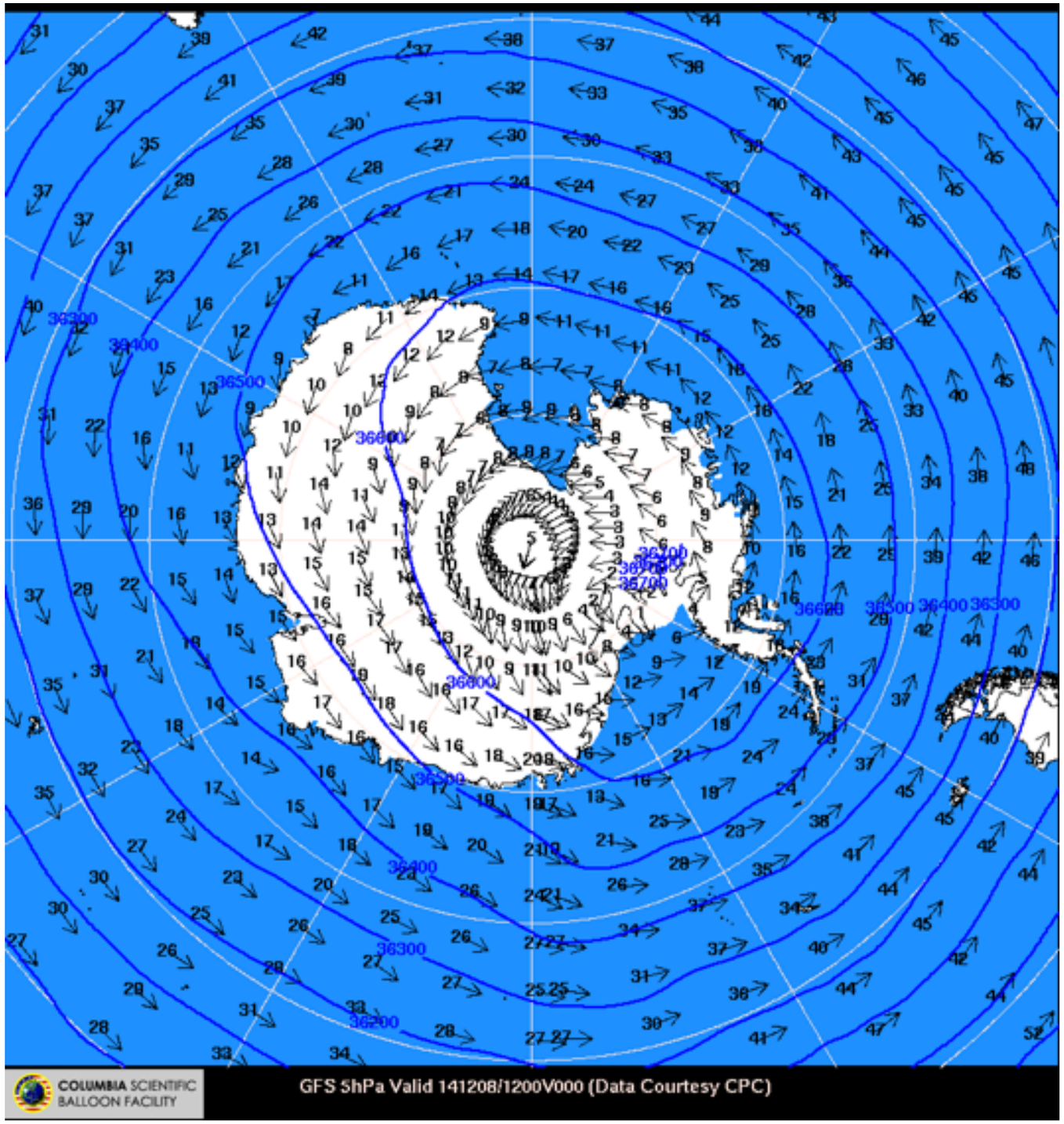
The Weather Game

12/07/2014



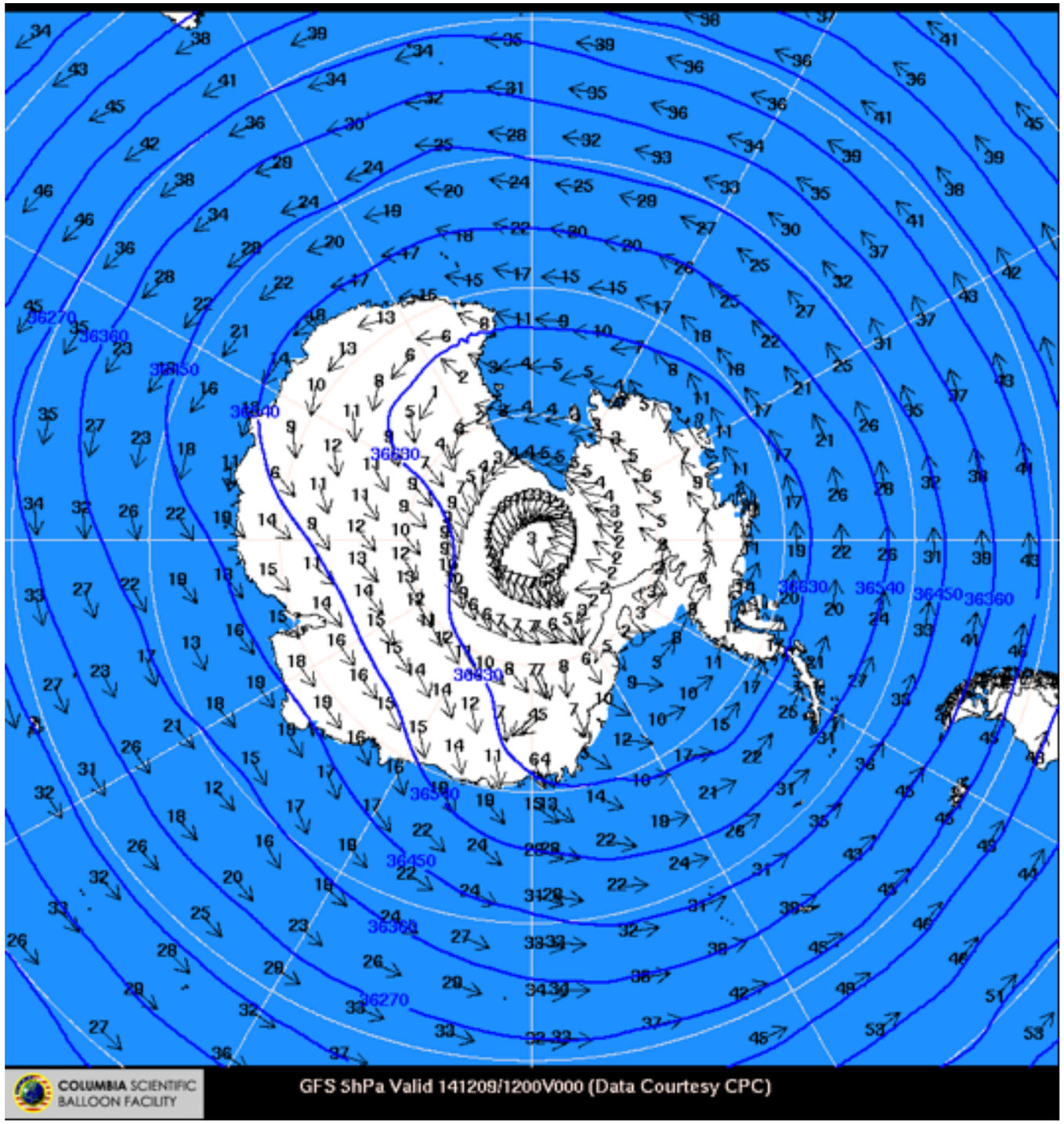
The Weather Game

12/08/2014



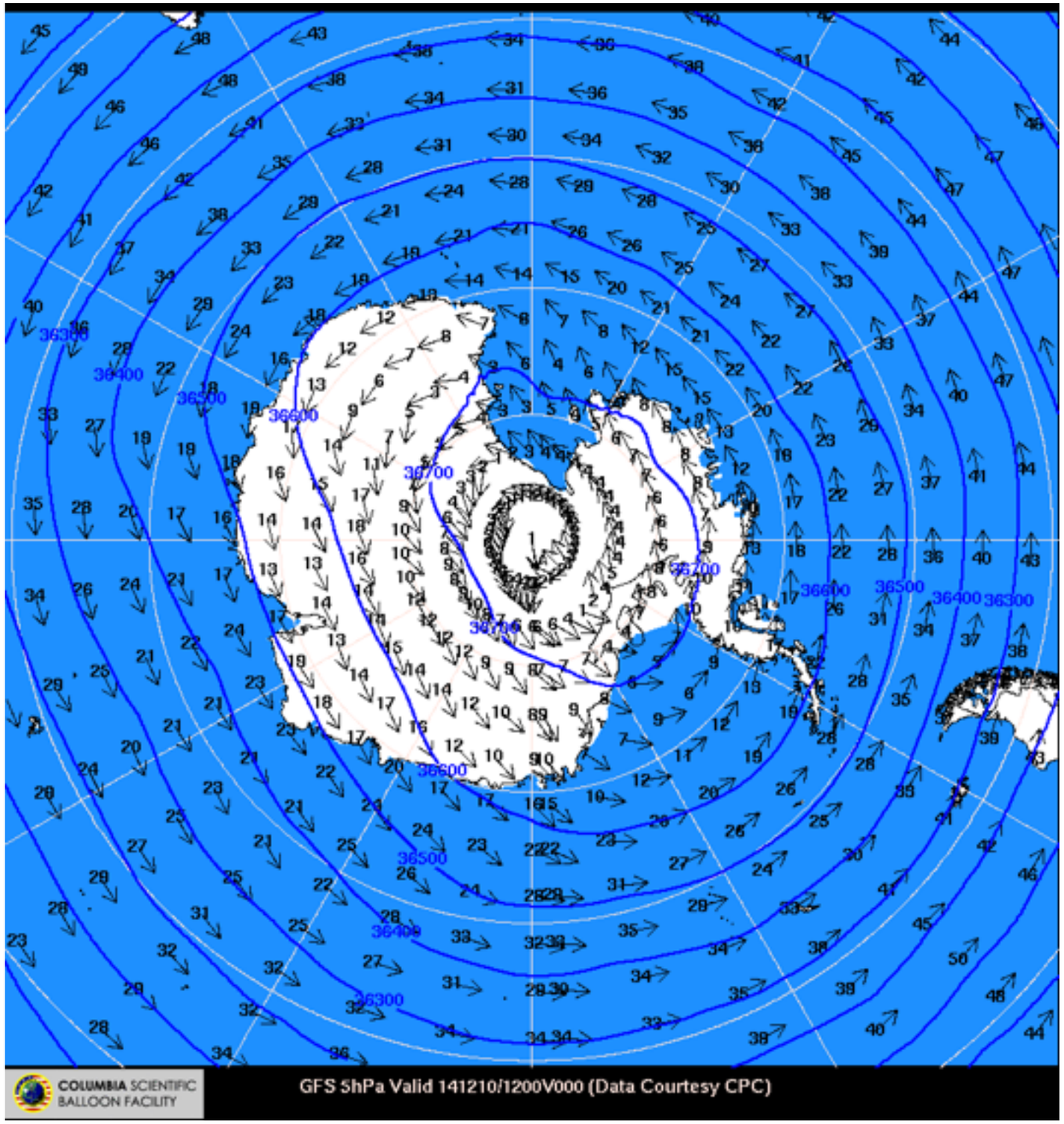
The Weather Game

12/09/2014



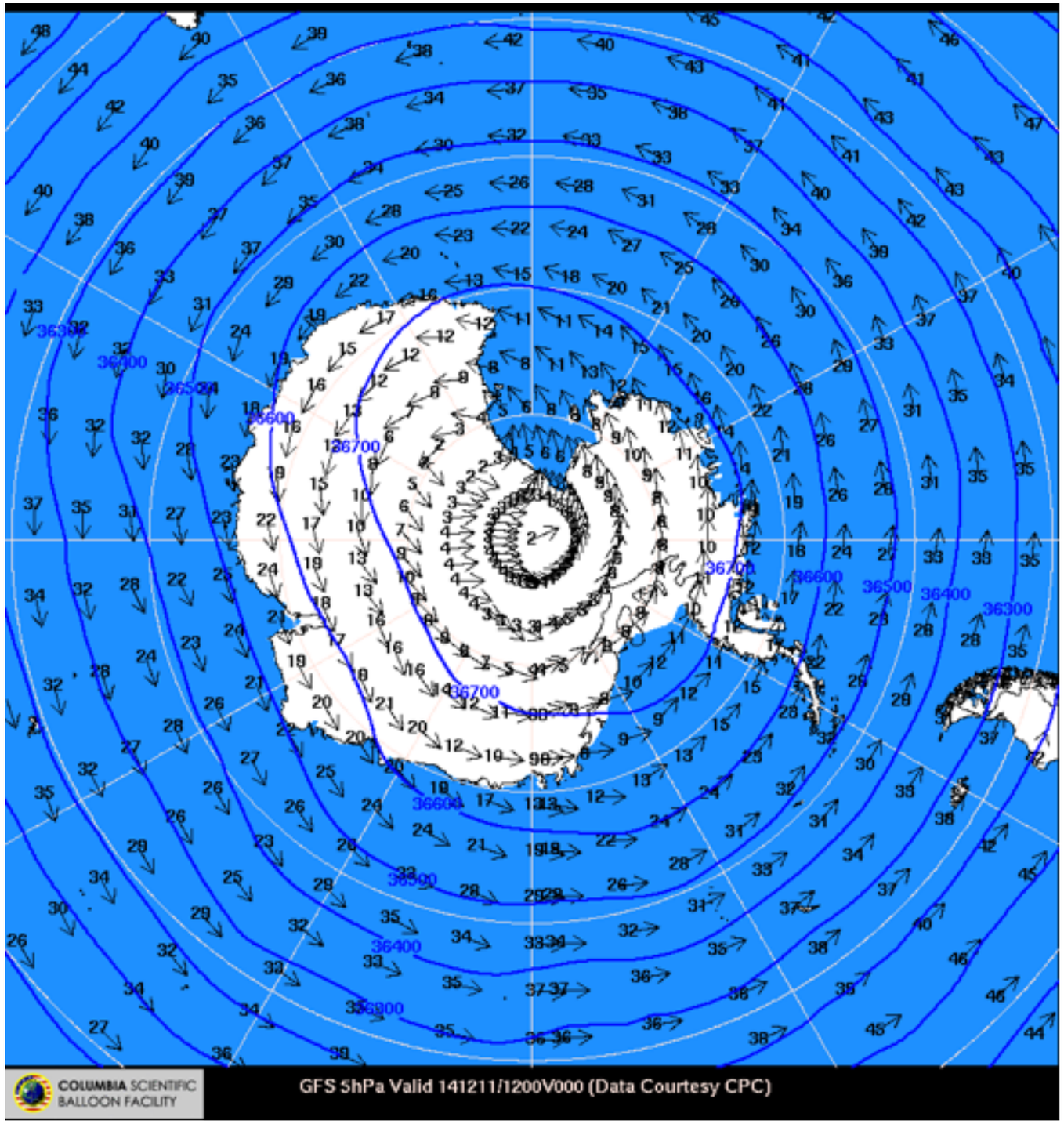
The Weather Game

12/10/2014



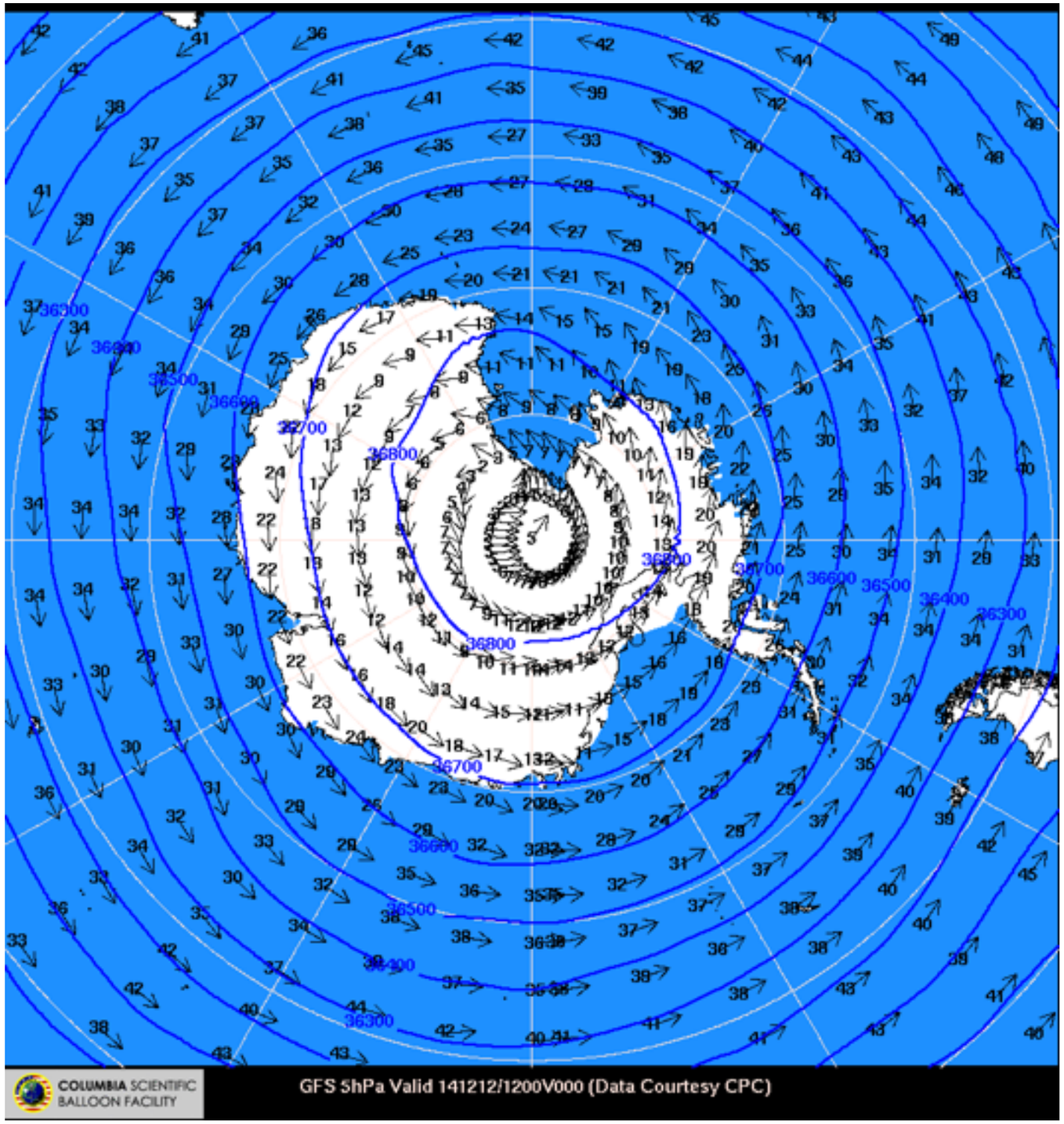
The Weather Game

12/11/2014



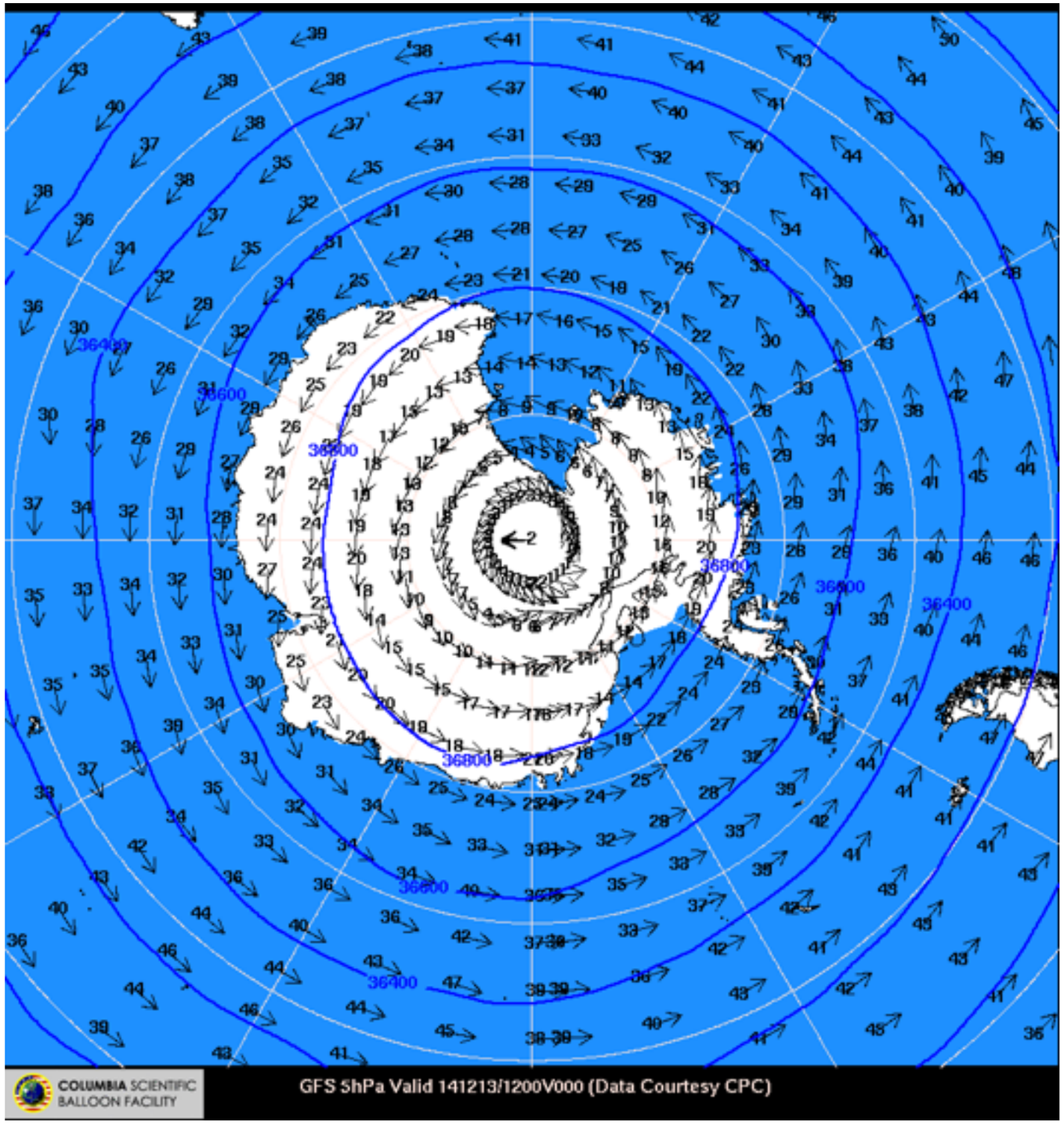
The Weather Game

12/12/2014



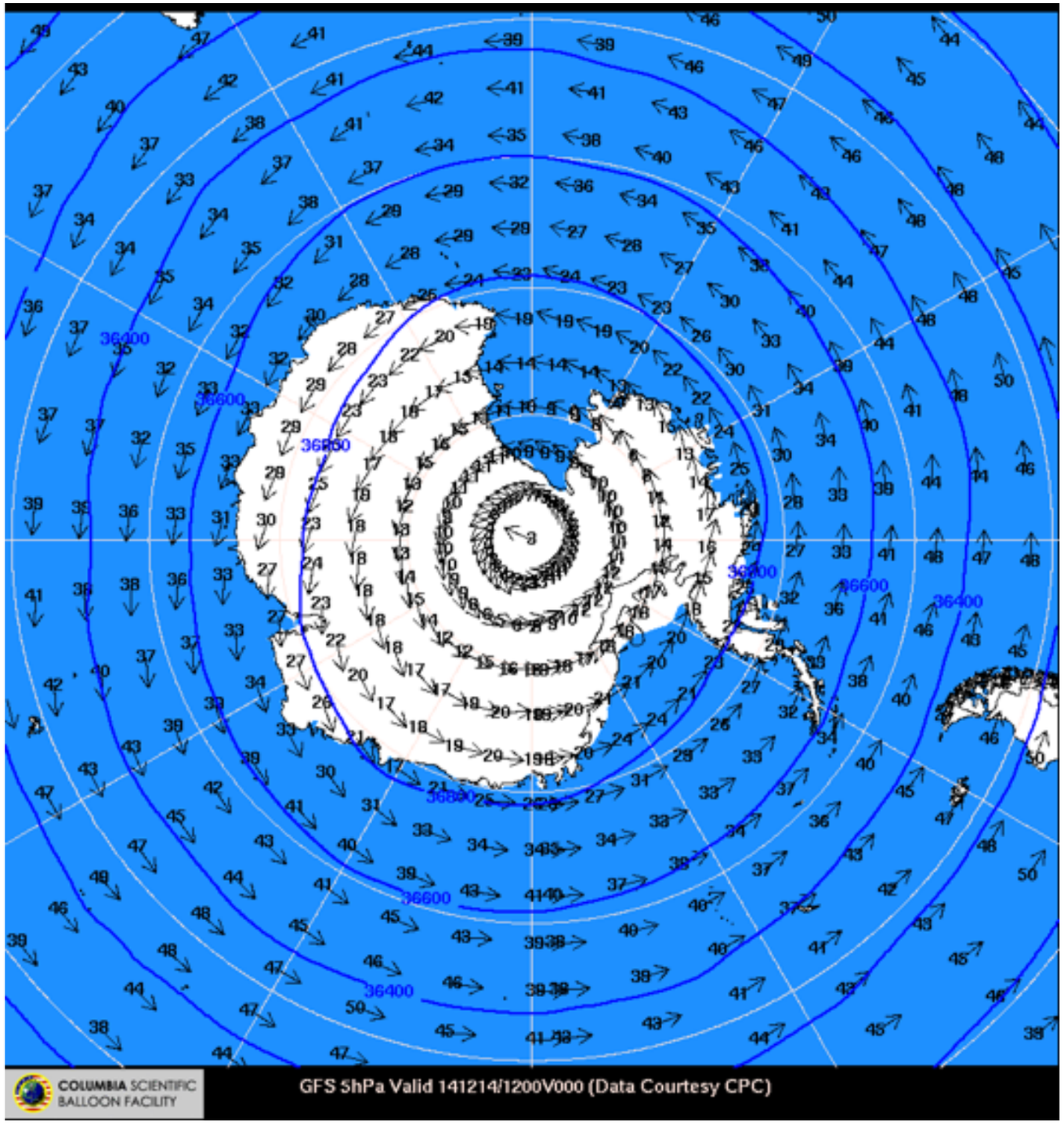
The Weather Game

12/13/2014



The Weather Game

12/14/2014



The Weather Game

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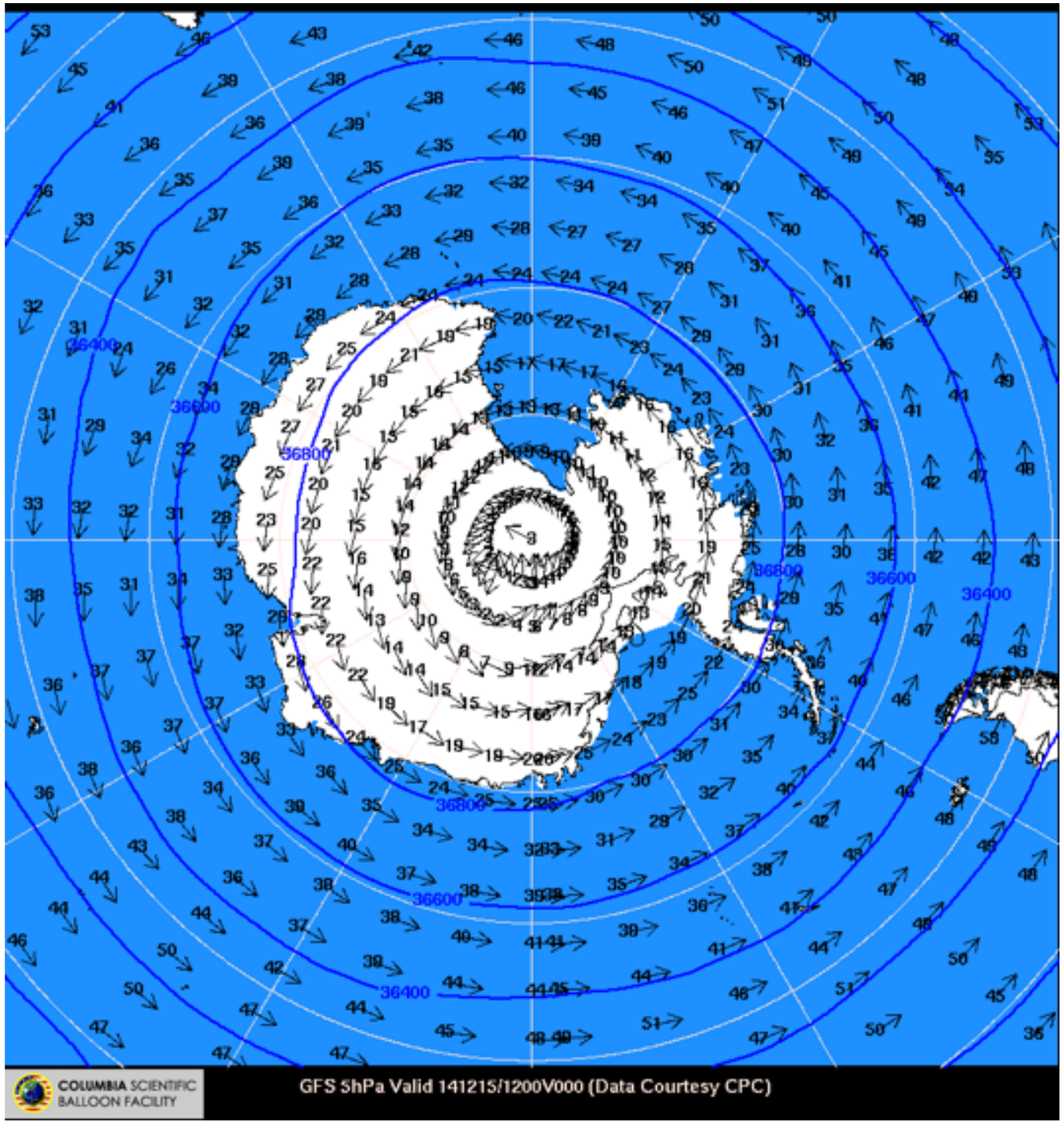
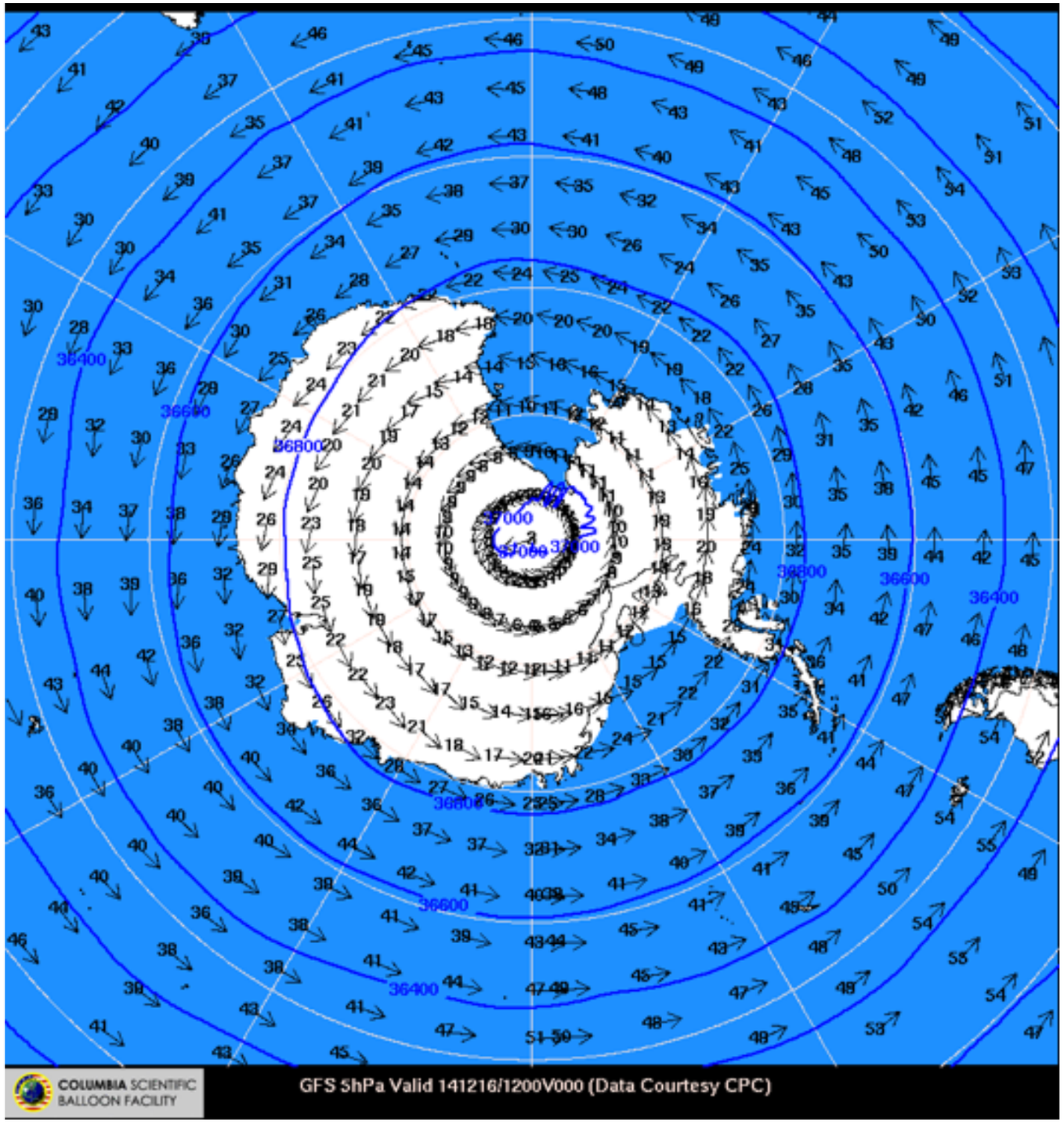


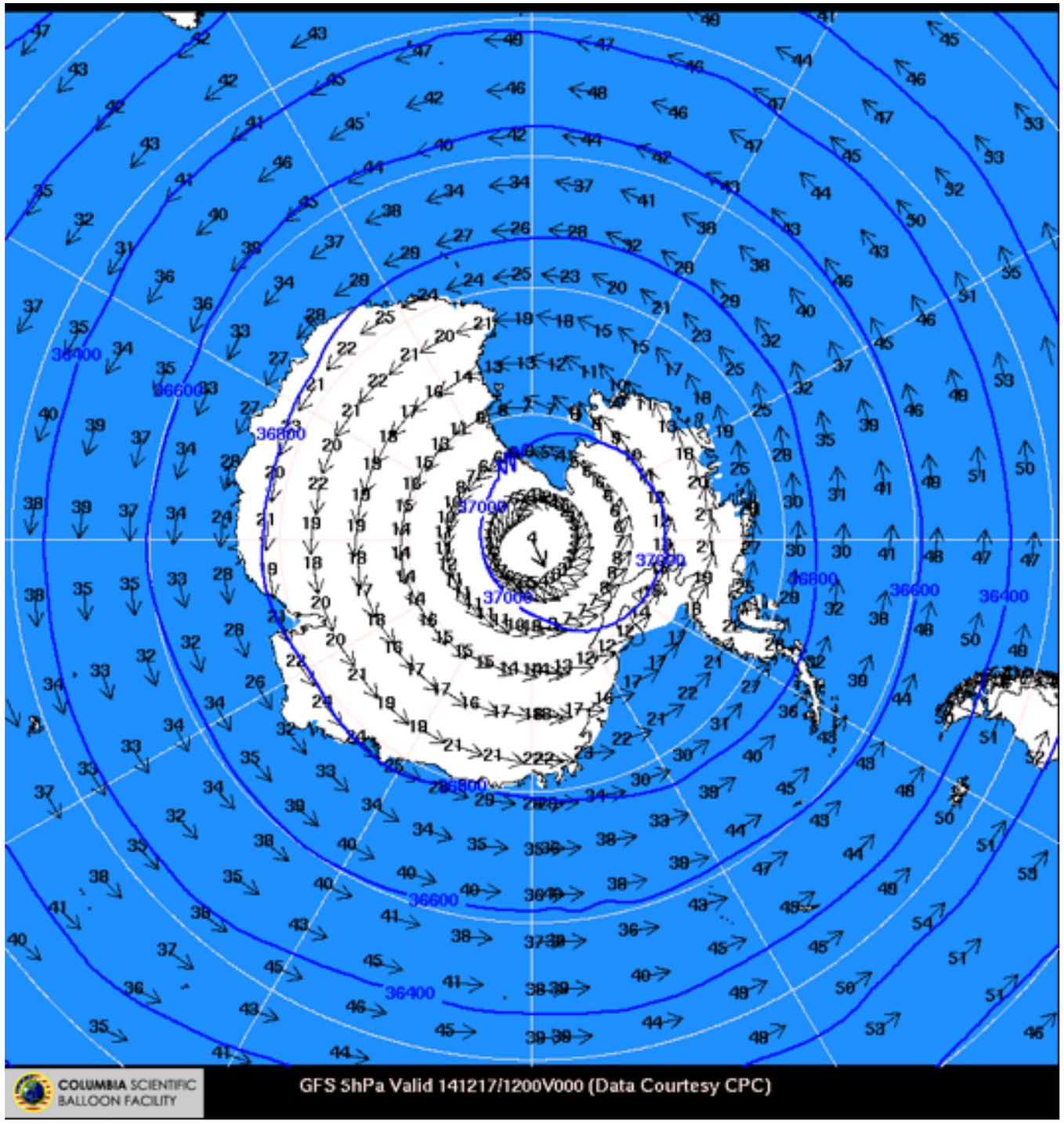
The Weather Game

12/16/2014



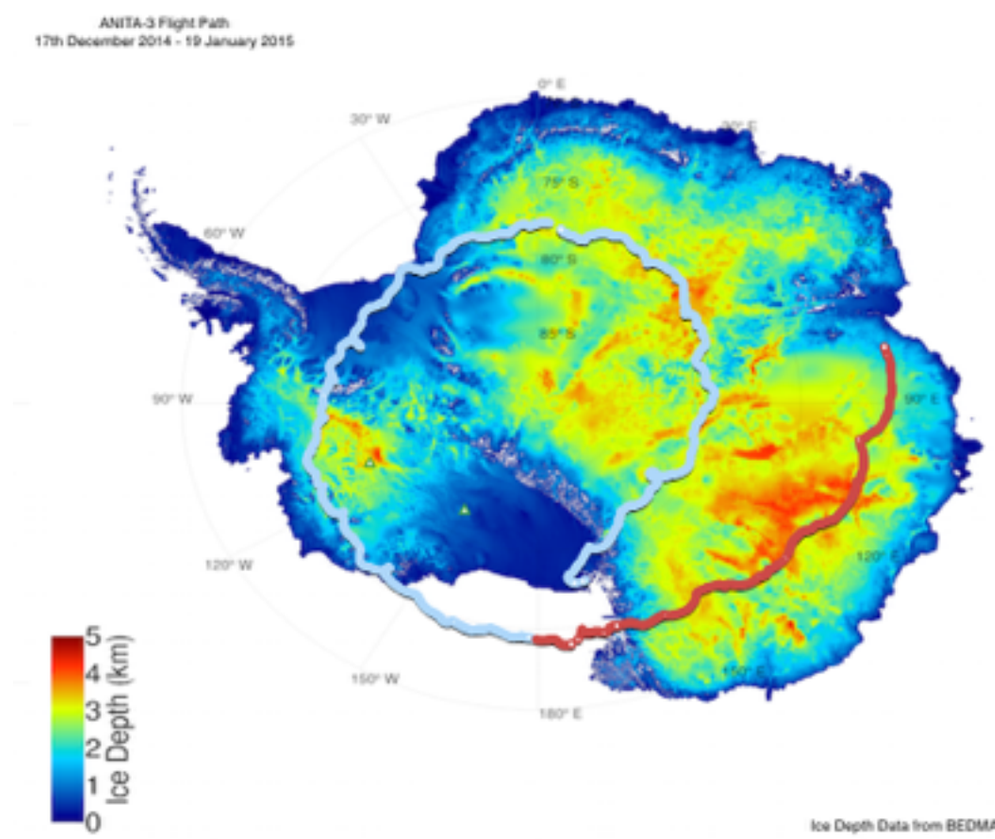
The Weather Game

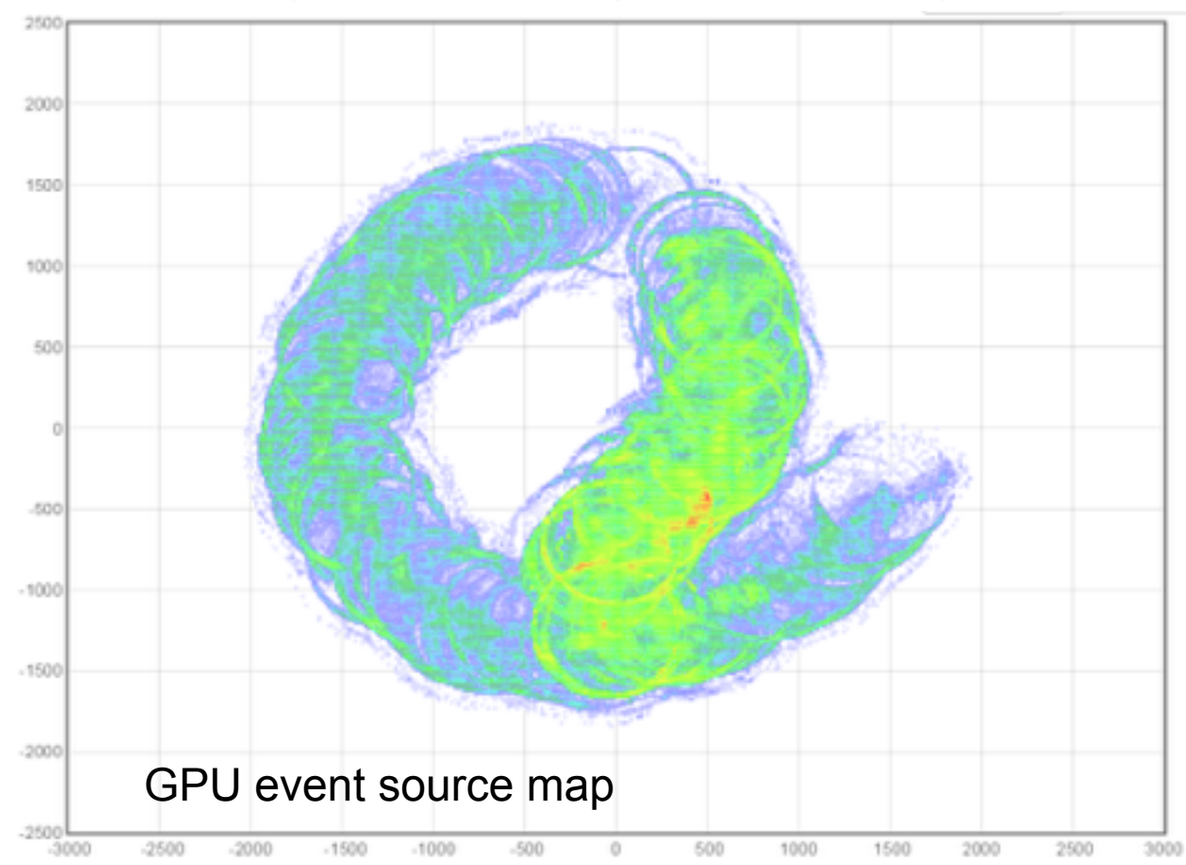
12/17/2014



ANITA-3 Flight

- Launched December 17th 2014
- Landed January 9th 2015
- Had to terminate the flight as payload was about to spiral off the continent
- Recorded over 80 million triggered events.
  - Best guess 0-5 neutrinos
  - Best guess O(200) cosmic ray events
- First step of the analysis was to retrieve the data…

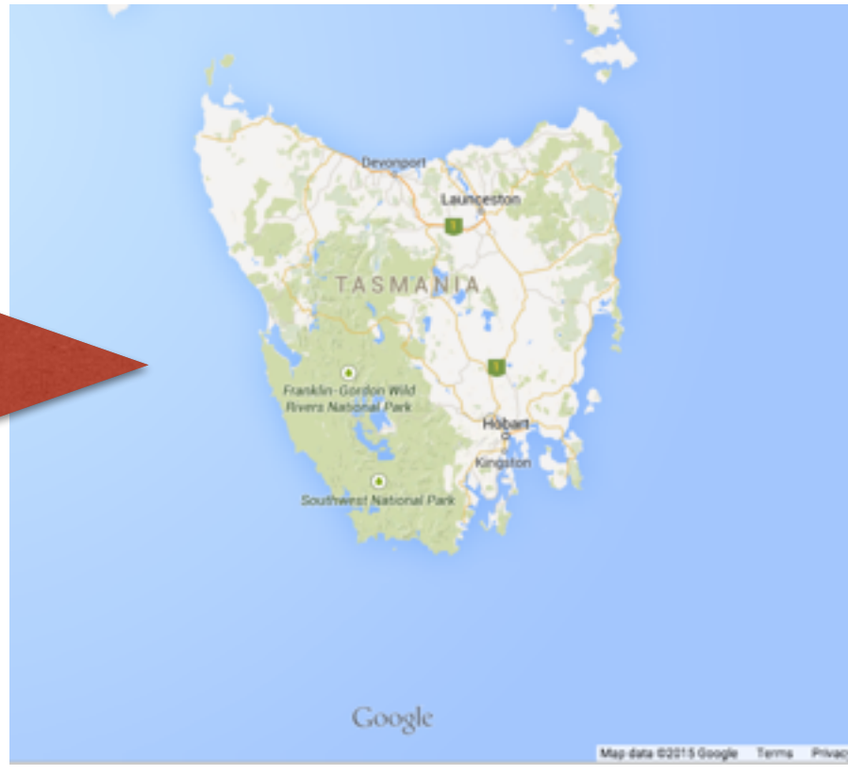




ANITA-3 End of Flight

Image: Josh F., Australian Antarctic Division

What happened to the data?



We got lucky

Antarctica

Aurora Australis icebreaker runs aground during blizzard in Antarctica

Crew and passengers all reported safe after Australian resupply ship broke free of moorings during storm with winds of more than 130km an hour

Paul Karp

@Paul_Karp

Wednesday 24 February 2016 17.02 EST

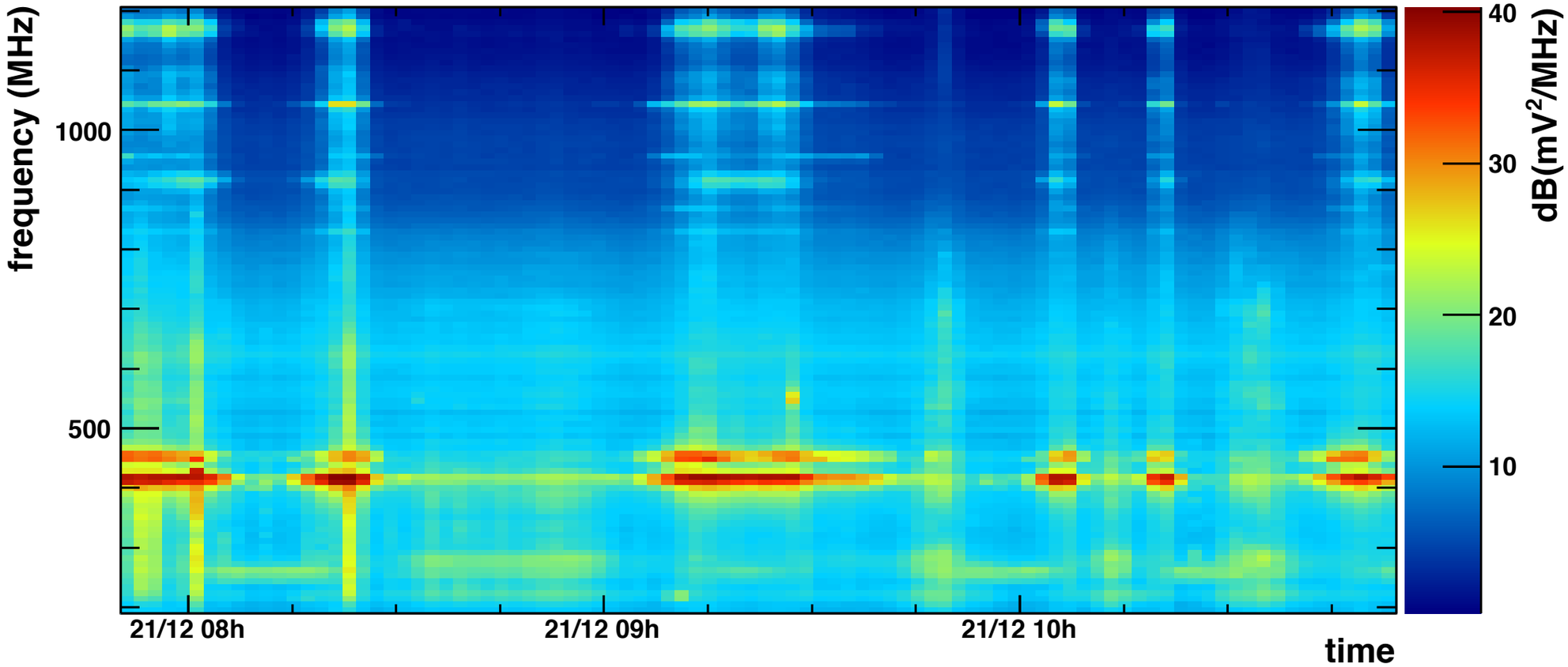
Shares

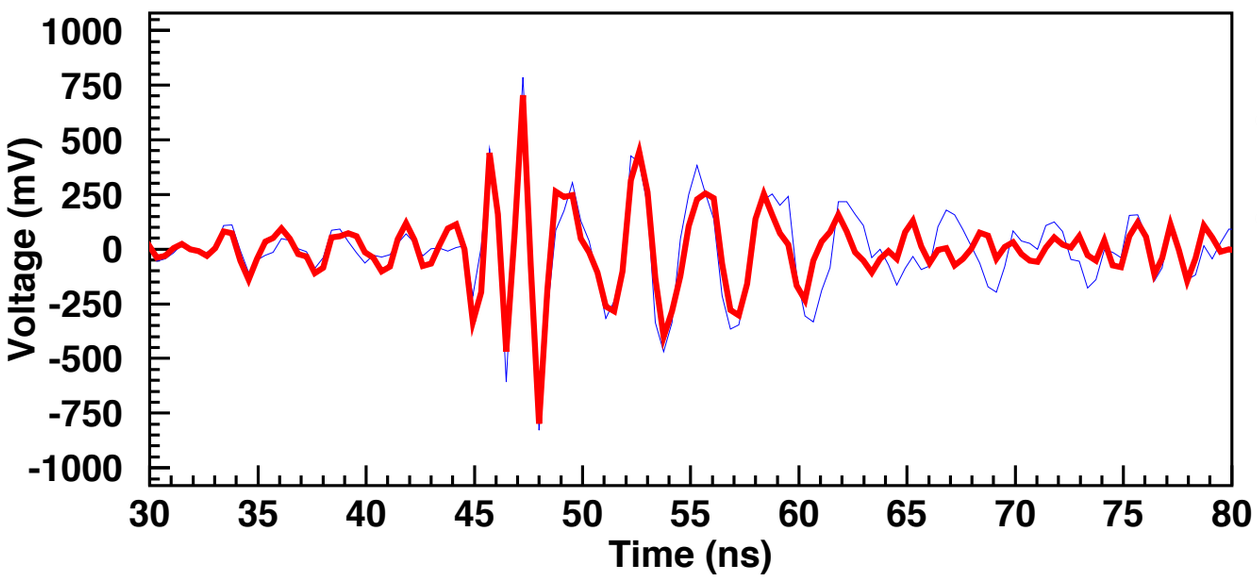
115

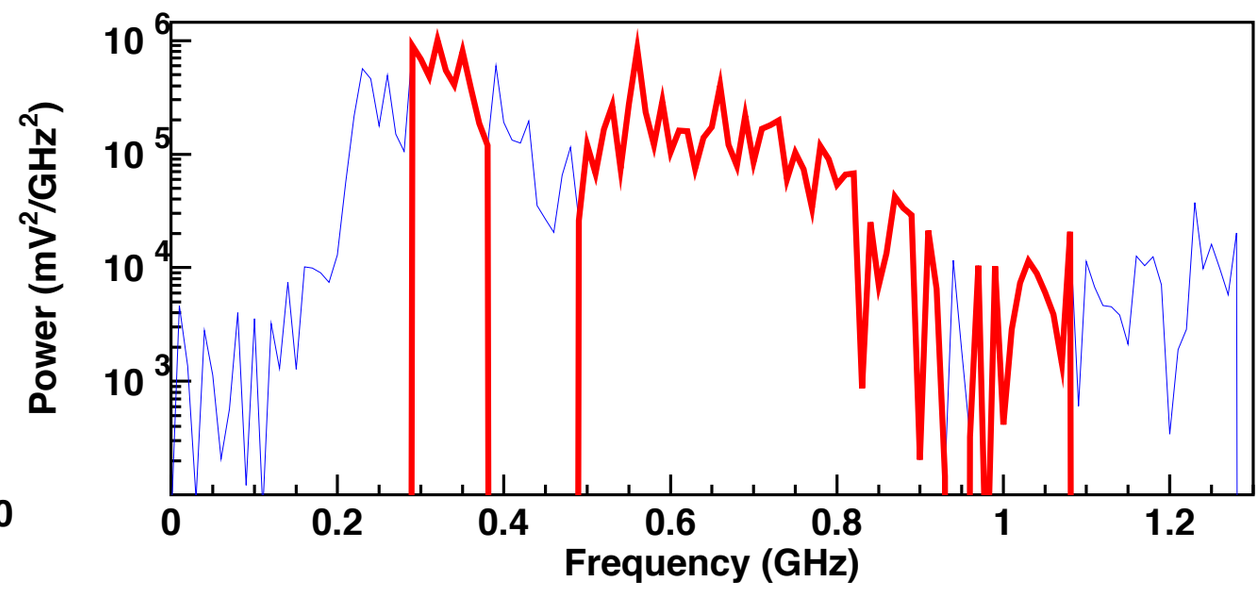
Save for later

The Australian Antarctic Division's chartered icebreaker the Aurora Australis on a previous mission wedged in ice in Commonwealth Bay 10 nautical miles from Mawson's Hut in Antarctica. The ship has now run aground in Horseshoe Harbour after a blizzard. Photograph: Dean Lewins/AAP

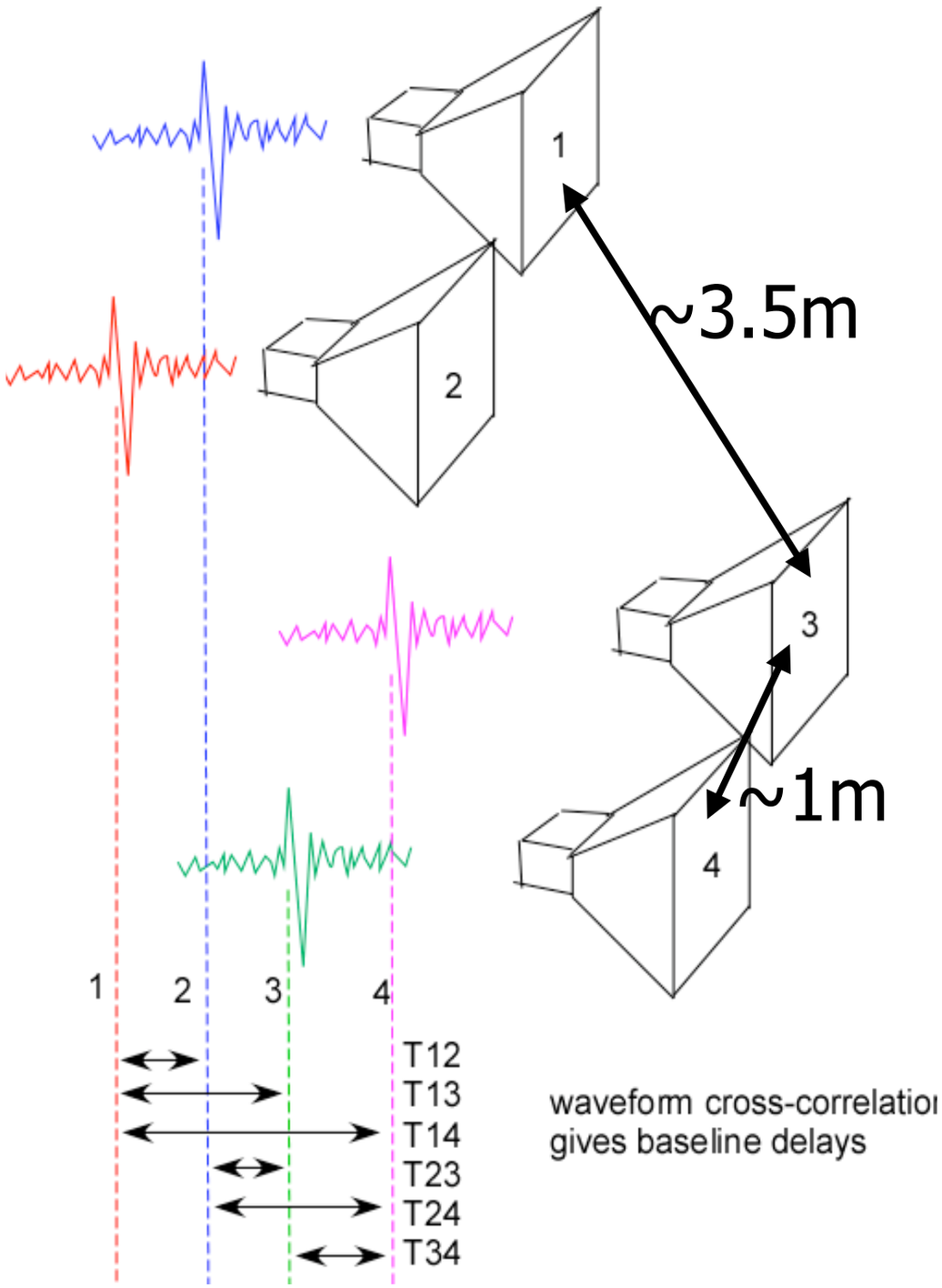
Analysis: Narrowband Noise

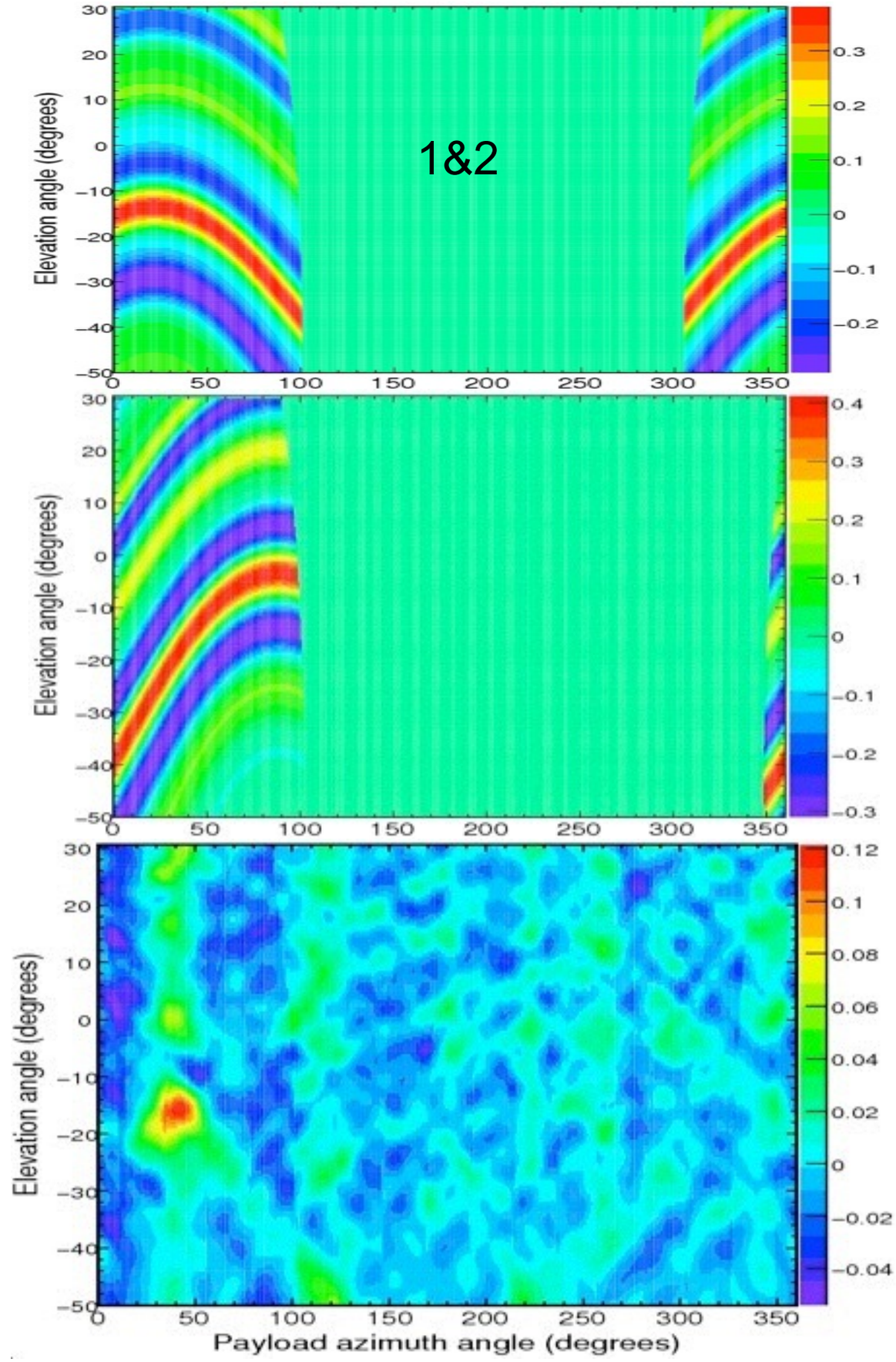






Analysis: Cross Correlation

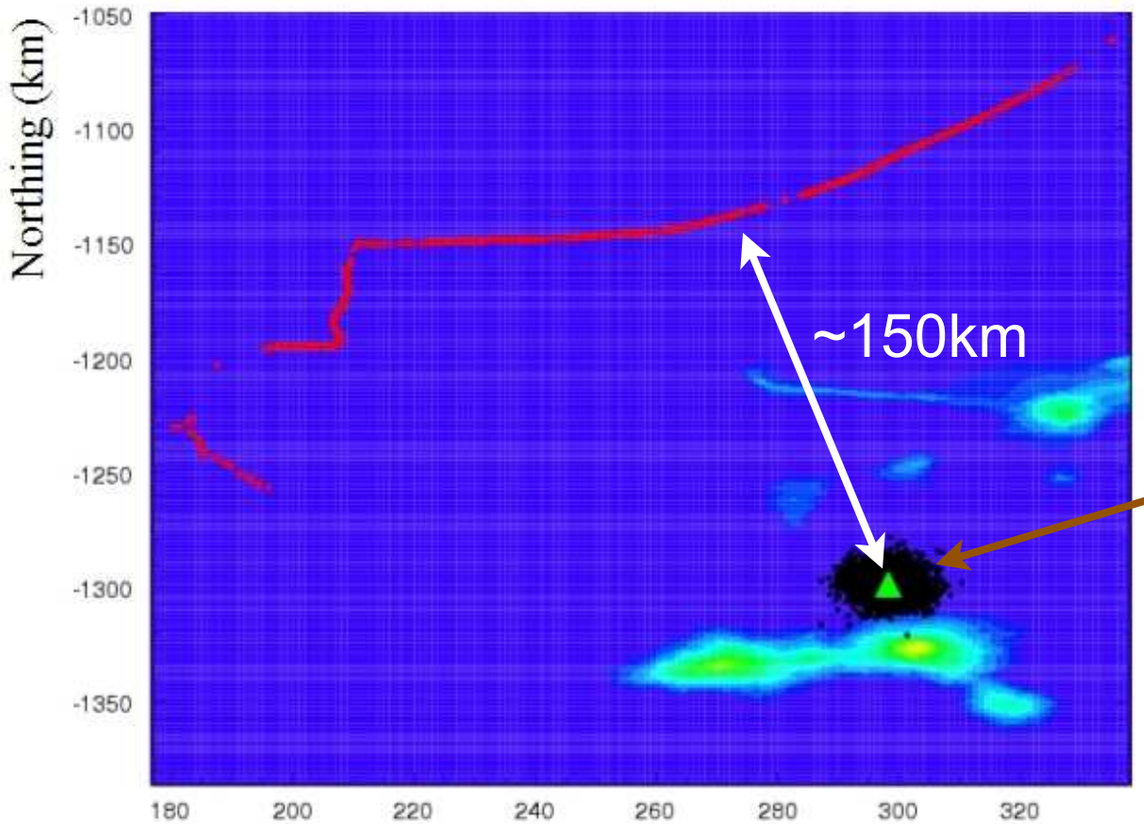




from A. Romero Wolf, Neutrino 2008

http://dx.doi.org/10.1016/j.astropartphys.2014.06.006

Calibration

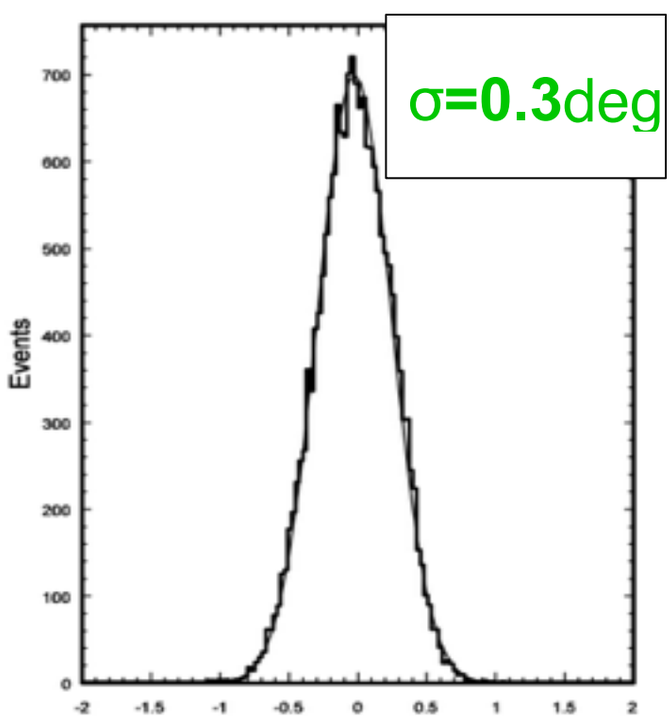


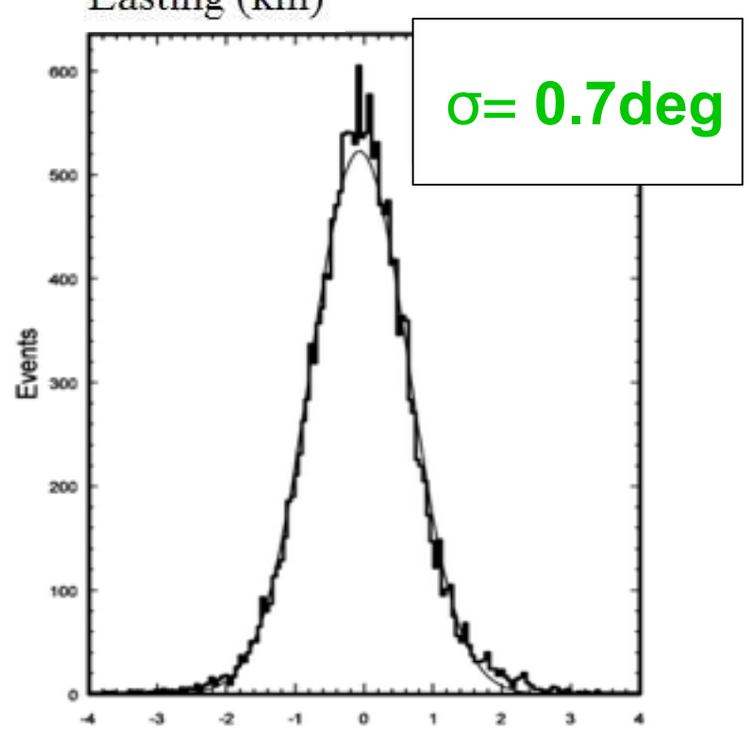
Reconstructed event locations

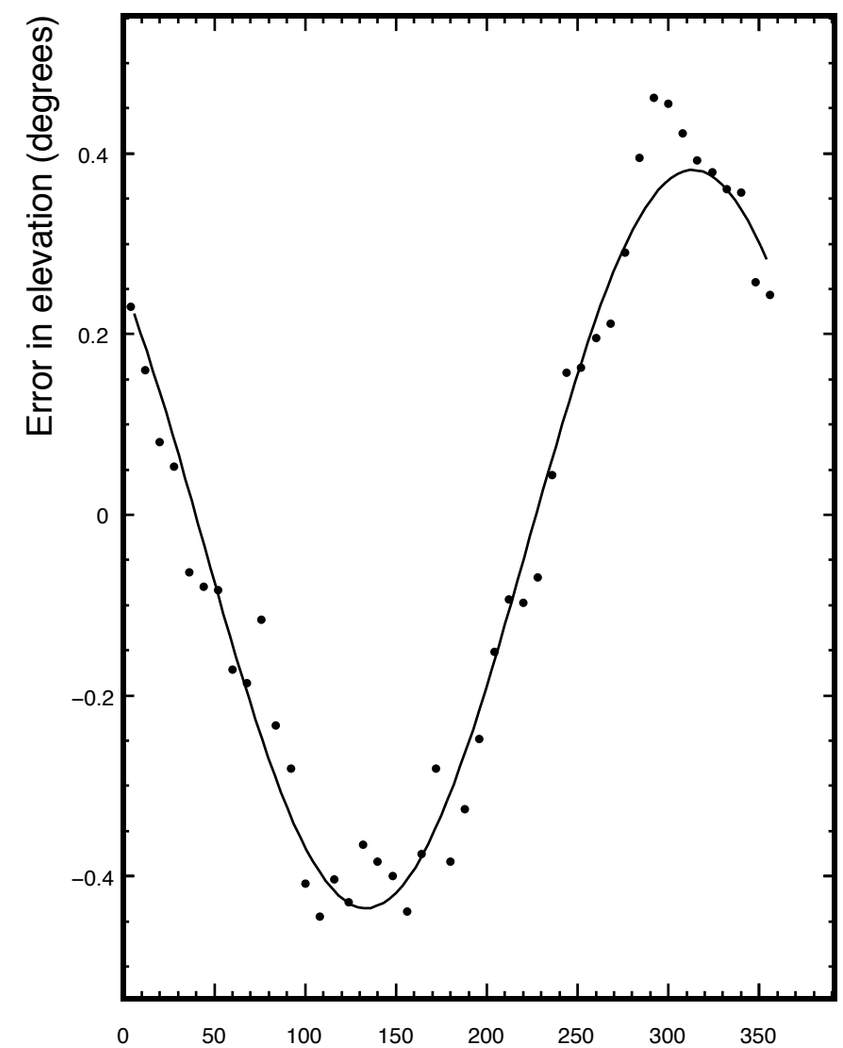
Easting (km)

Use ground and borehole calibration pulsers to calibrate antenna positions and time offsets.

Also calibrate out the tilt of the payload



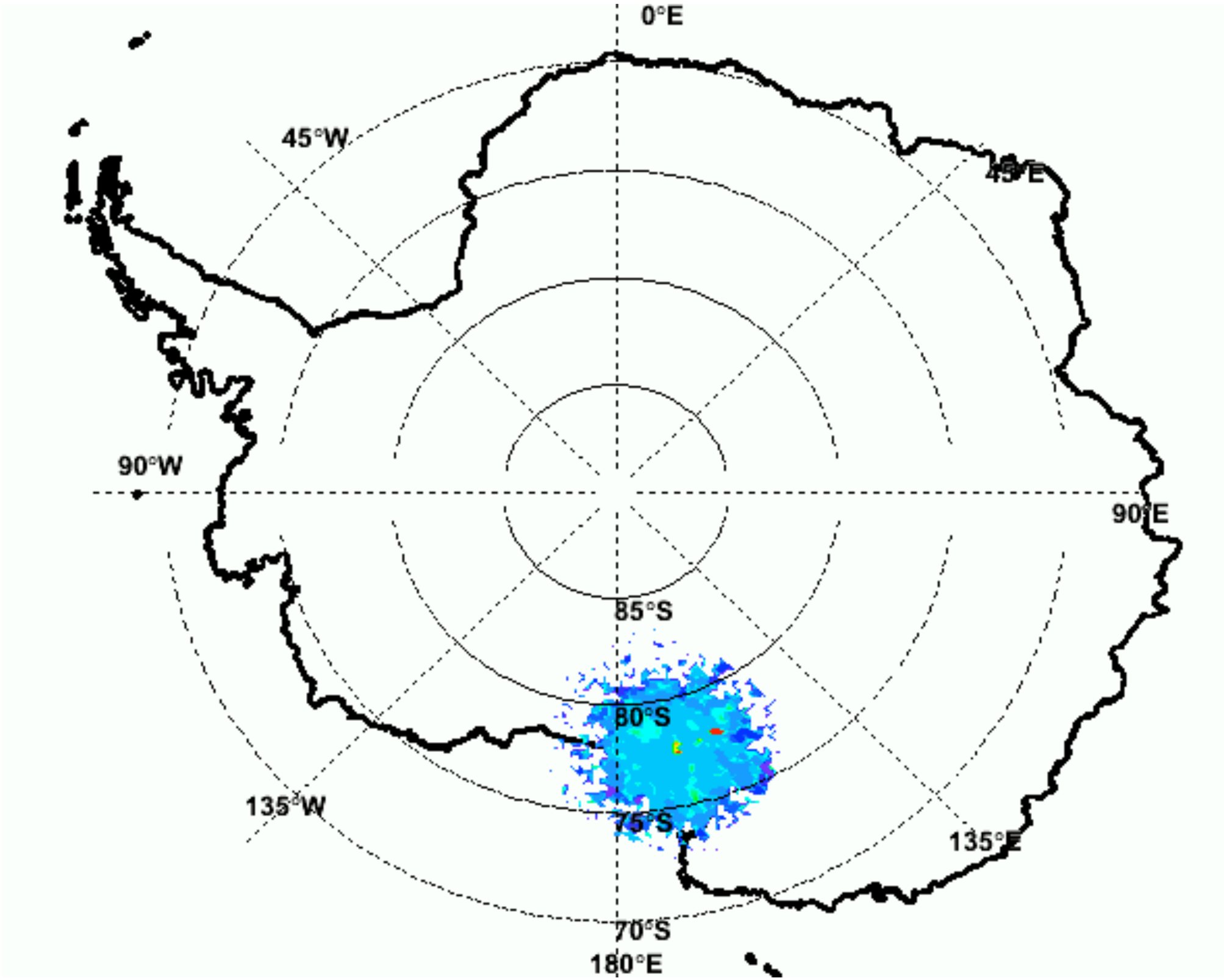




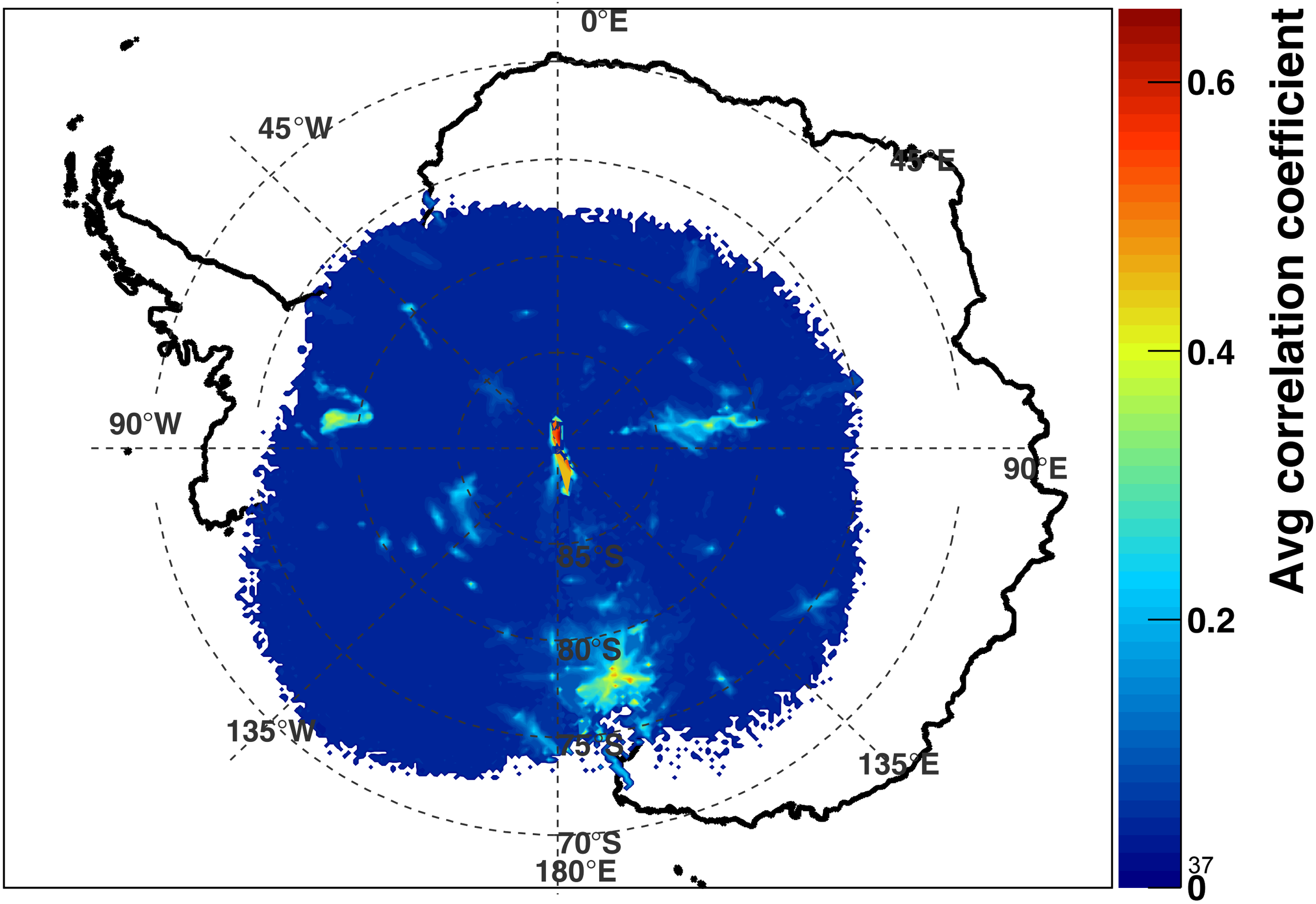
ELEVATION ANGLE **AZIMUTH ANGLE**

from S. Hoover

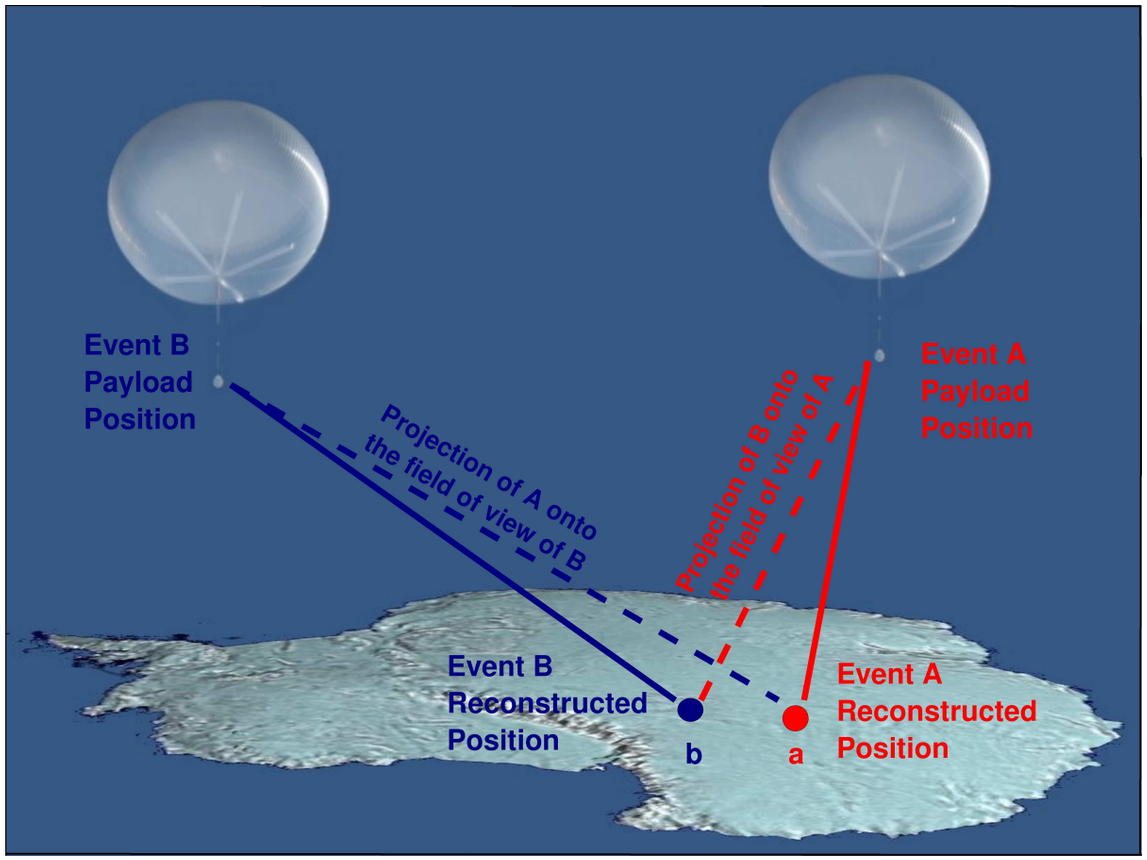
ANITA-2

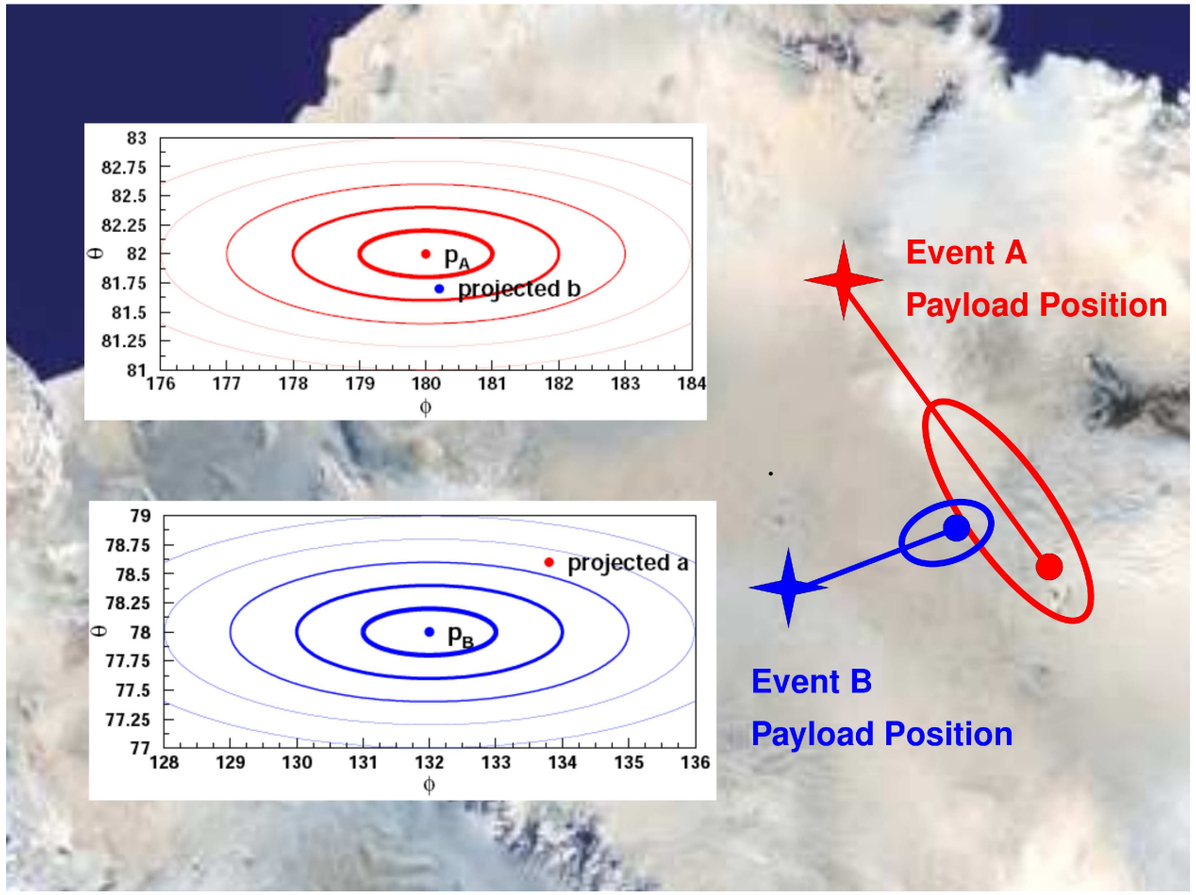


ANITA-2


0°E
45°W
45°E
90°W
90°E
85°S
80°S
75°S
135°W
135°E
70°S
180°E
0.6
0.4
0.2
0
Avg correlation coefficient

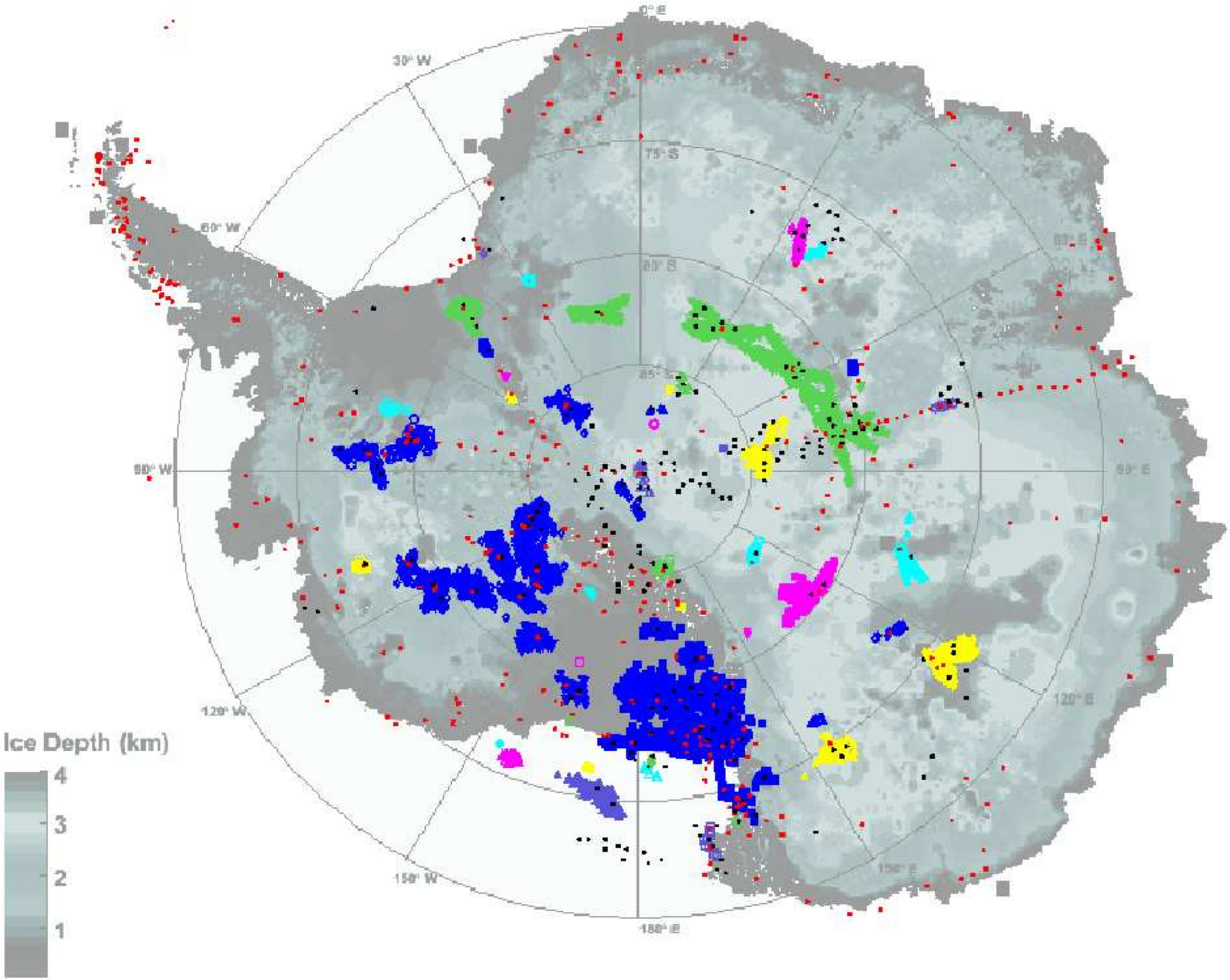
Anthropogenic Backgrounds





- Use clustering algorithms to associate events with known bases and with other events
- Remove all events that cluster leaving only isolated events
- Remaining background is the number of unknown sites of anthropogenic noise which we have not identified... hard to quantify

ANITA-2 Results



Neutrino Limits

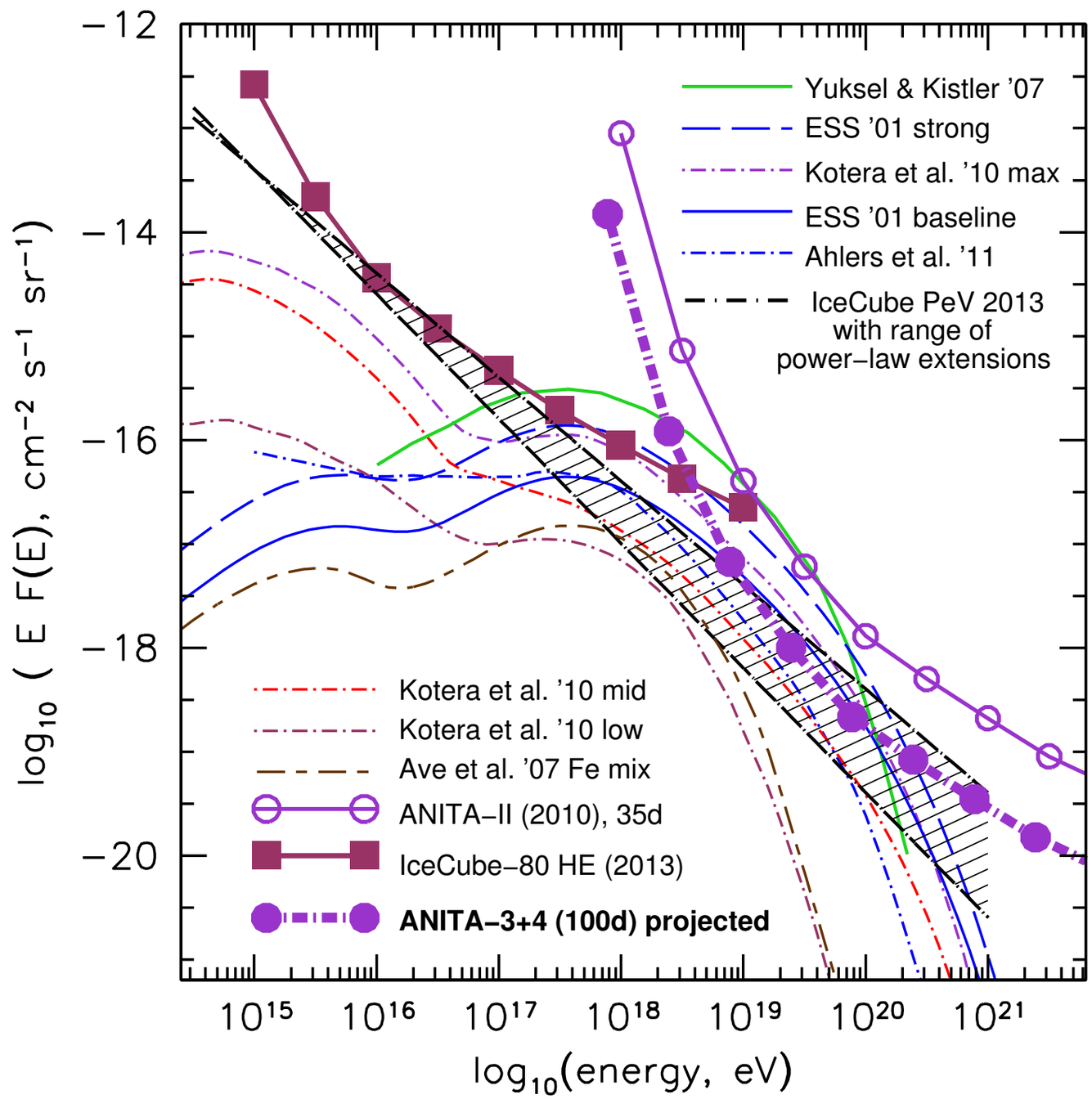
- ANITA-2 Results

Isolated v-pol events	1
Expected background events	0.97 ± 0.42

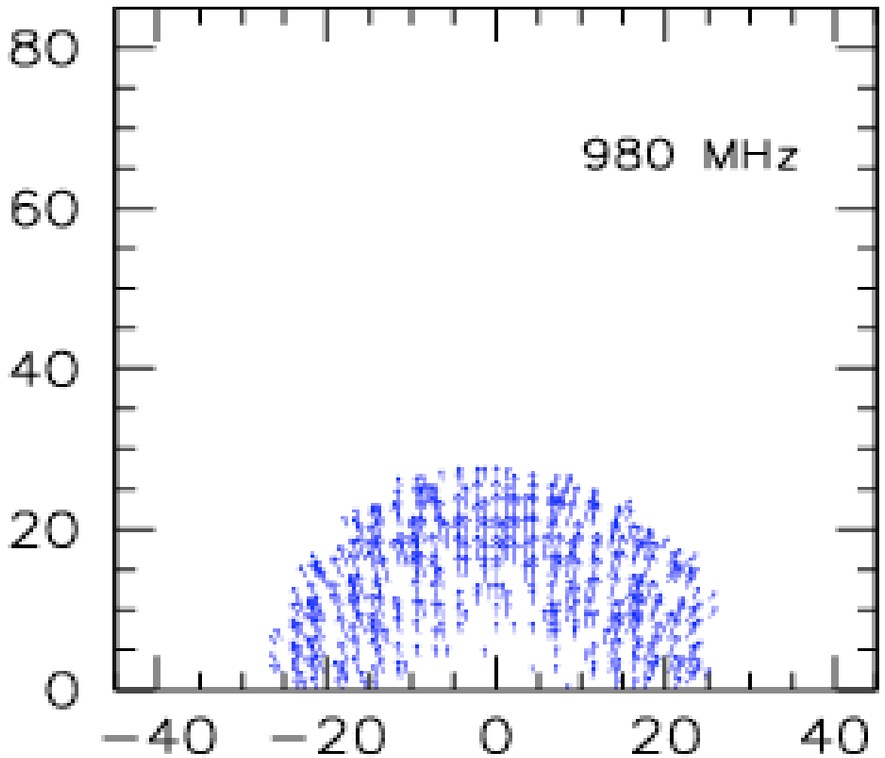
- Use calibration pulser and simulation to determine efficiency and set the best limit on UHE neutrino flux.

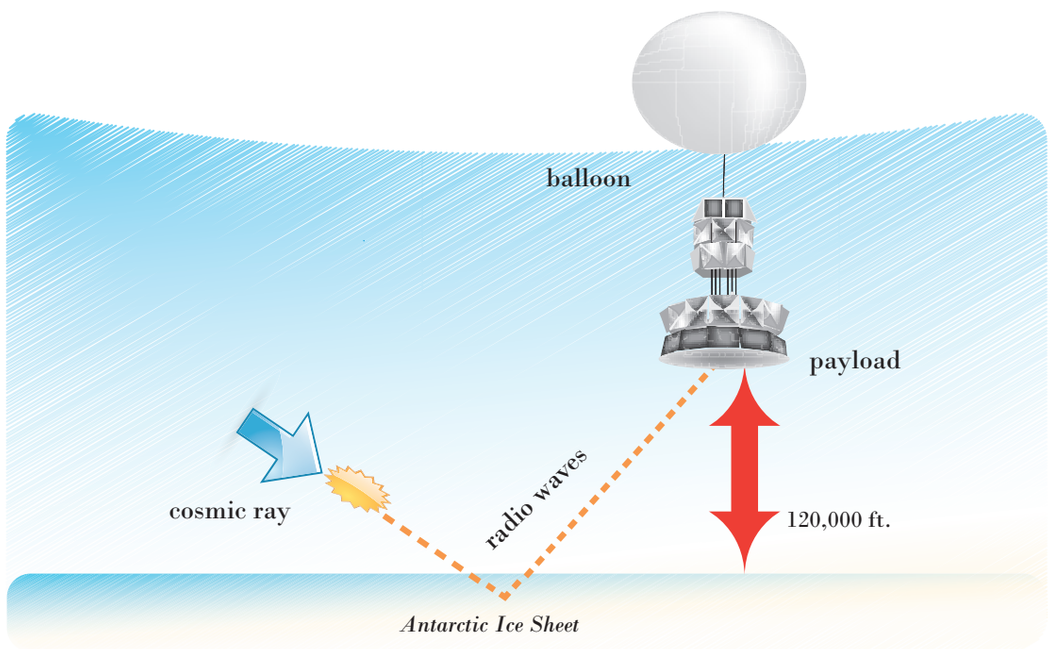
DOI:
10.1103/PhysRevD.85.049901
10.1103/PhysRevD.82.022004

Also limits on magnetic monopoles and neutrinos from gamma-ray bursts

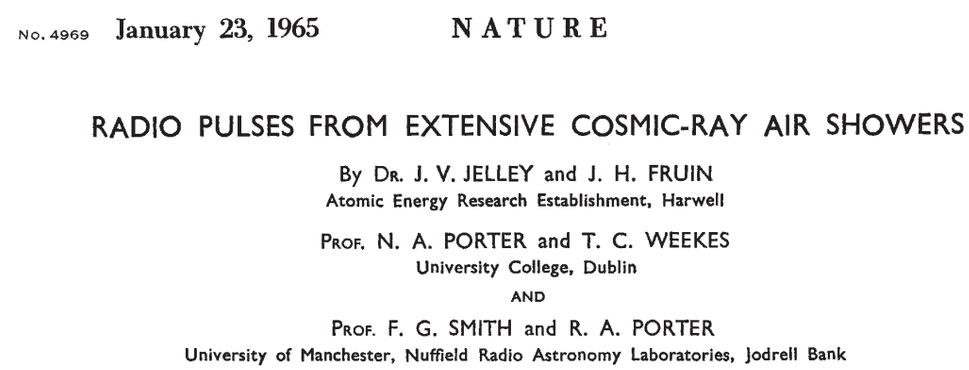


What about Horizontal Polarisation?





- Askaryan signals from neutrinos strongly favour vertical polarisation
  - Only top of Cherenkov cone escapes TIR at surface
  - Fresnel coefficients transmit more V-pol than H-pol
- Reflections from above the horizon sources would favour H-pol over V-pol at the balloon
- What could the signal be?


No. 4969 January 23, 1965 NATURE

RADIO PULSES FROM EXTENSIVE COSMIC-RAY AIR SHOWERS

By Dr. J. V. JELLEY and J. H. FRUIN
Atomic Energy Research Establishment, Harwell

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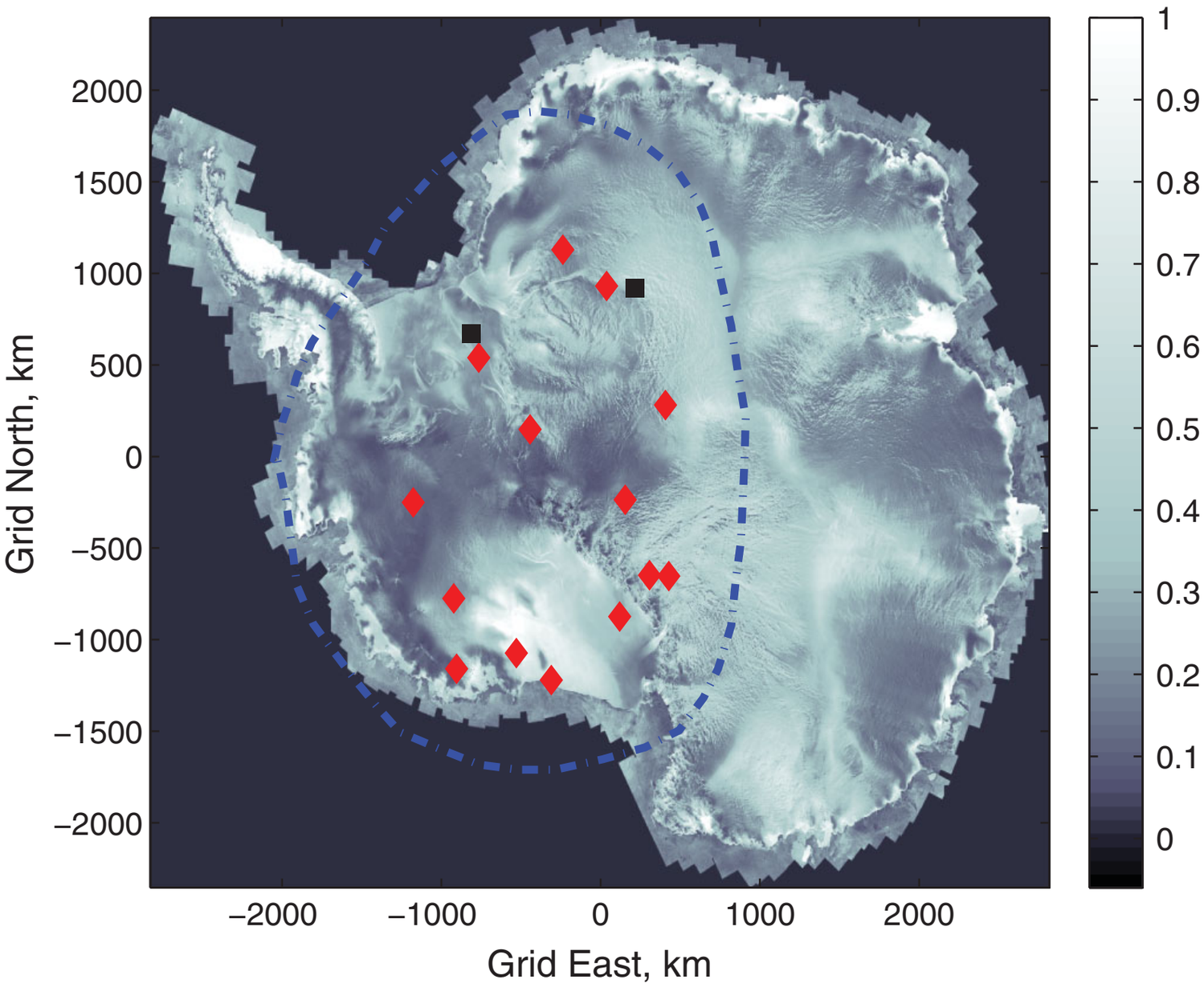
University College, Dublin

AND

Prof. F. G. SMITH and R. A. PORTER
University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank

ANITA-1 H-Pol Results

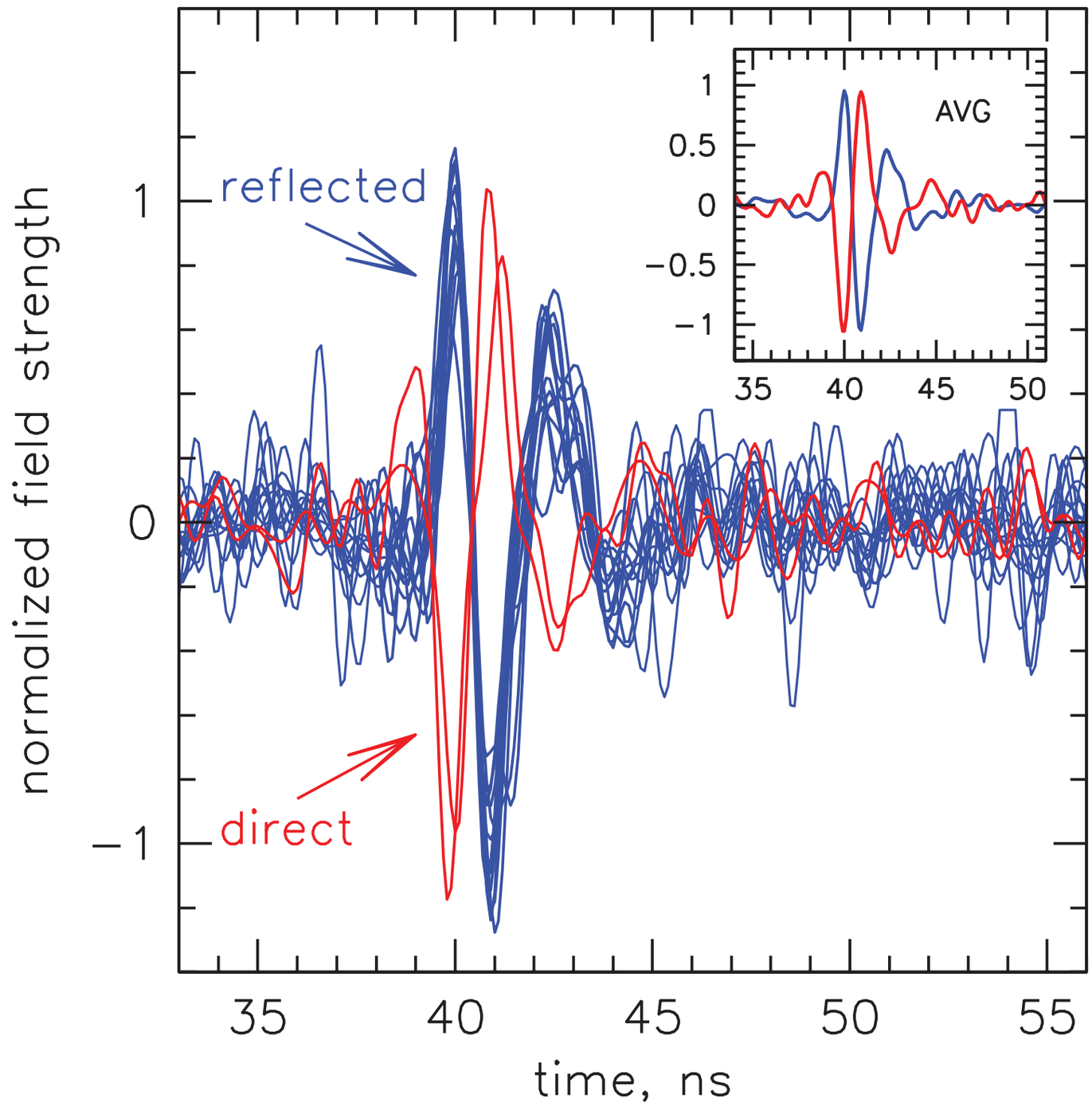


- ANITA-1 detected 16 isolated H-pol candidate UHECR events
- ANITA-2 did not trigger on the H-pol channels
  - Doh!!
- Still detected 5 UHECR candidate events

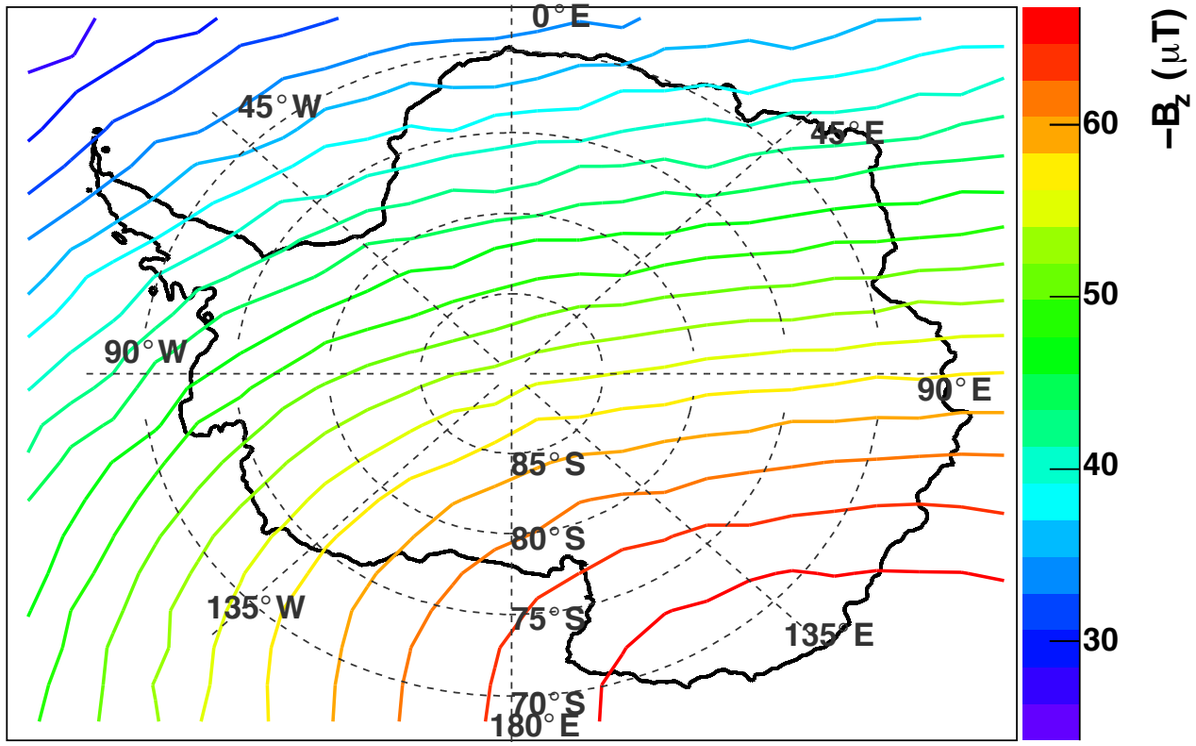
PRL **105**, 151101 (2010)

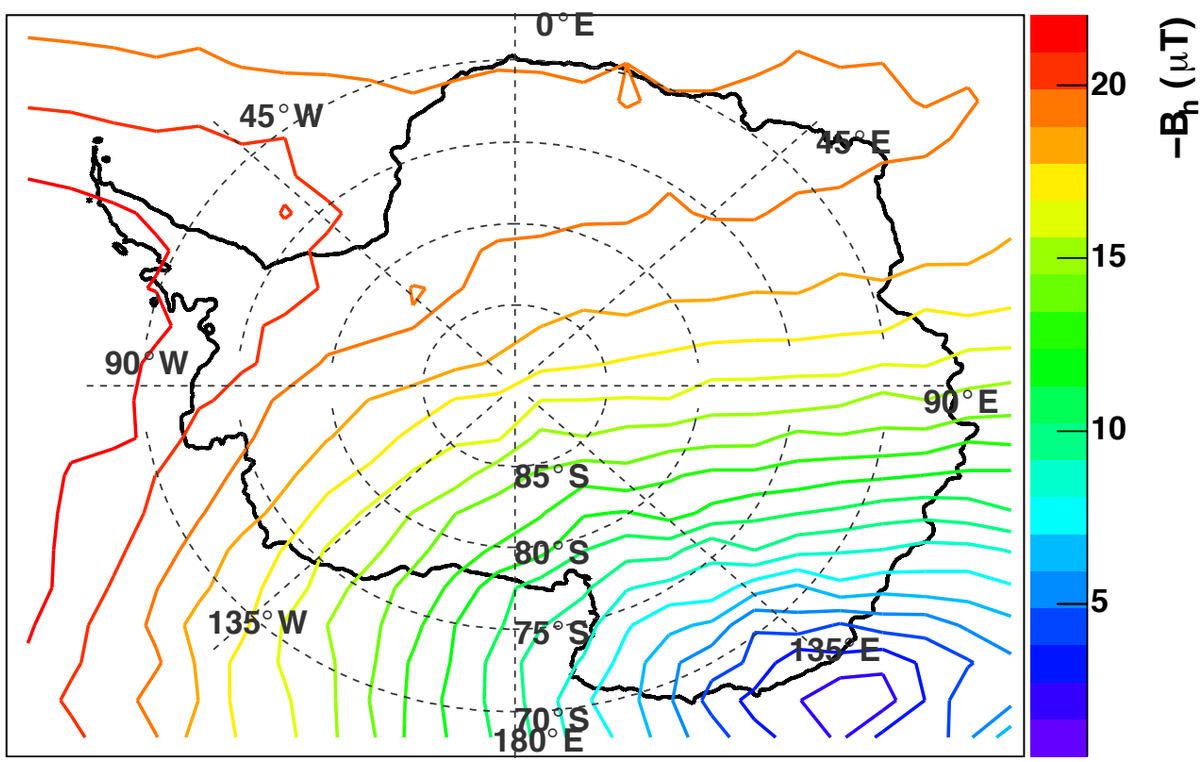
Are they really cosmic ray signals?

- The 14 events that reconstruct to the surface (i.e. are reflections) have very similar waveforms
- The 2 events that reconstruct above the surface have the opposite polarity
- Consistent with some signal that is generated above the surface

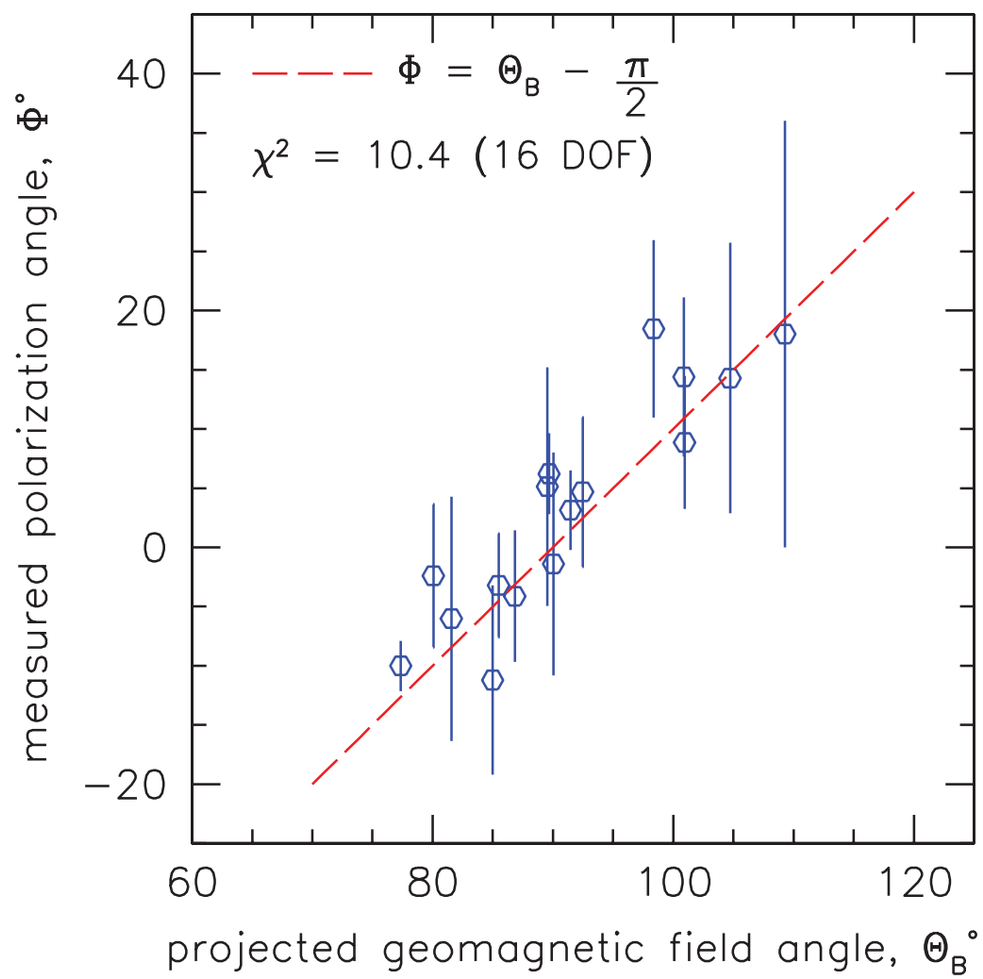


Are they really cosmic ray signals?





- Magnetic field is nearly (but not) vertical in Antarctica
  - **F**=q **v** x **B**



ANITA-4

- Approved by NASA in 2014
- Complete new digitiser and trigger hardware
- Nominal flight date December 2016
- Busy times ahead

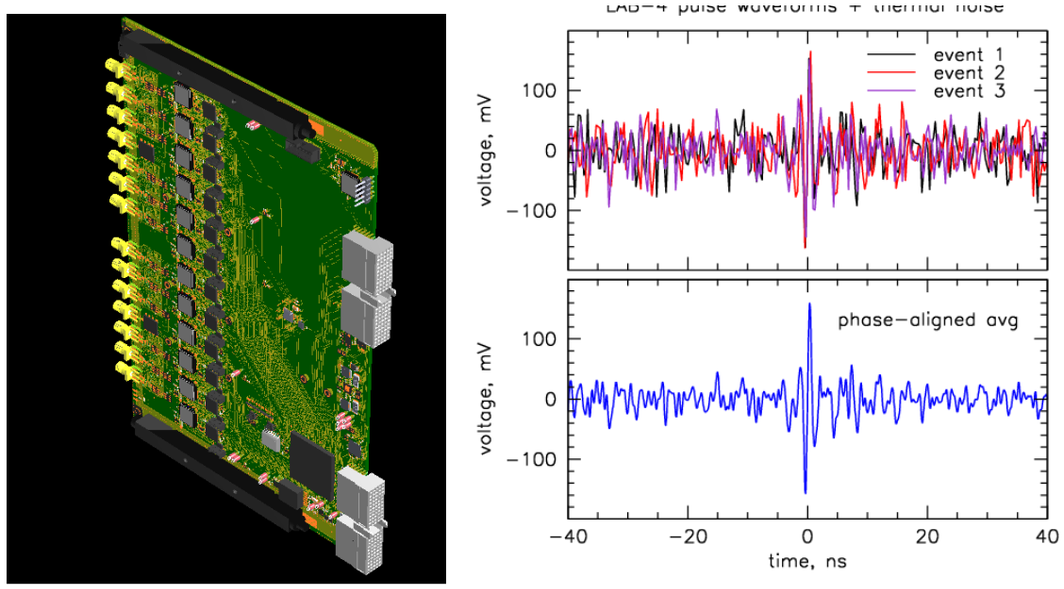
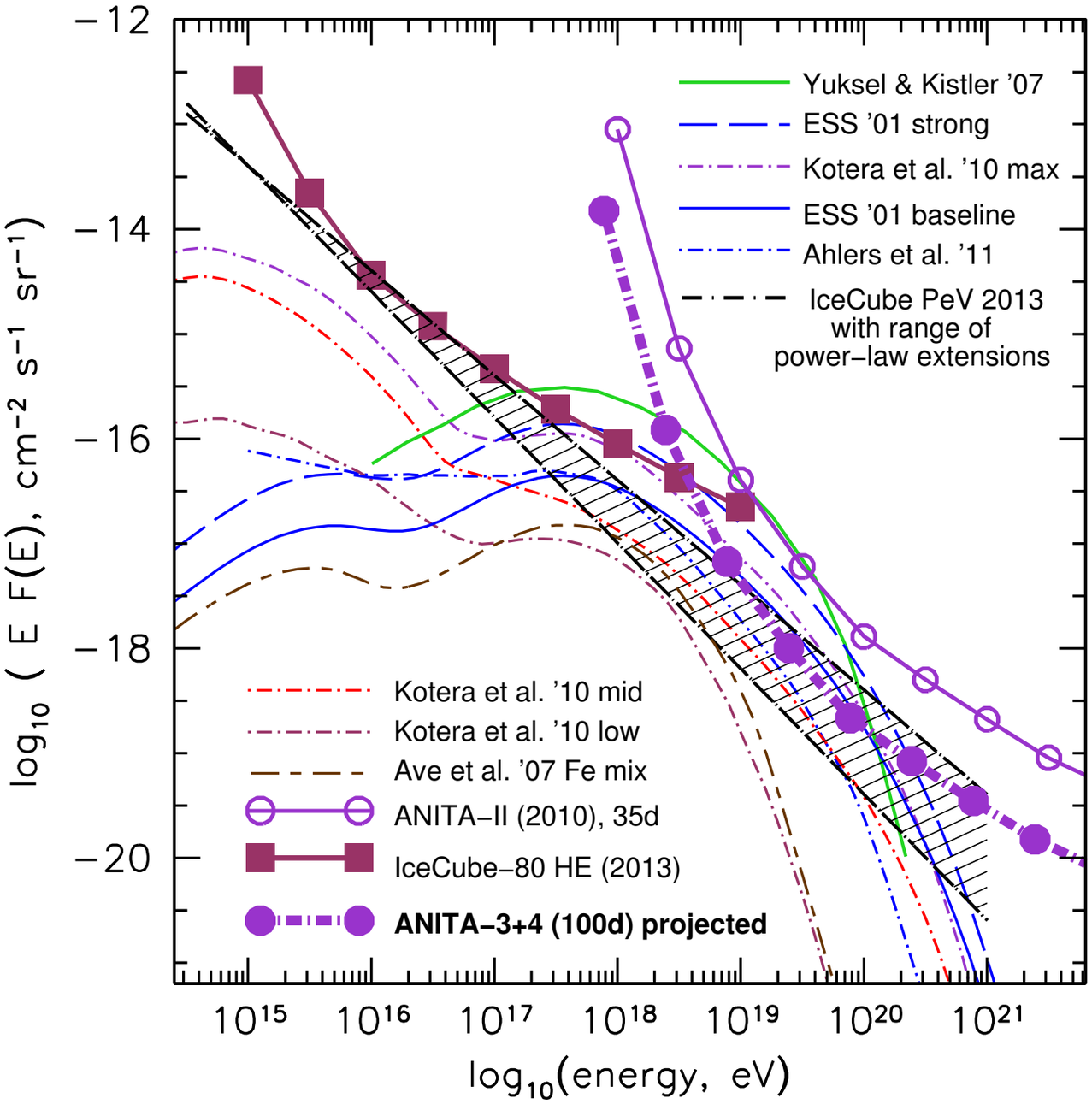


Figure 10: *Left: 3D CAD model of the new digitizer cPCI board for ANITA-3 & 4. Right: ANITA receiver chain test impulse waveforms captured with the LAB4 prototype board, along with phase-aligned average waveform.*



Summary

- The radio detection of high energy particles is undergoing a period of renaissance
- The first two flights of ANITA have been used to set the most stringent limits on the UHE neutrino flux
  - ANITA-1 did detect 16 UHECRs though
  - ANITA-3 should have recorded O(200) UHECR events
- The next generation of neutrino astronomy facilities may finally realise the ambition of probing the universe with “new eyes”.
  - Probing fundamental physics at energies beyond the reach of terrestrial accelerators.
- Hopefully soon we will have the first unambiguous detection of an UHE neutrino.
  - But in the mean time there are the UHECR

Me in front of the Royal Society Range

Photo: H. Schoorlemmer , University of Hawaii

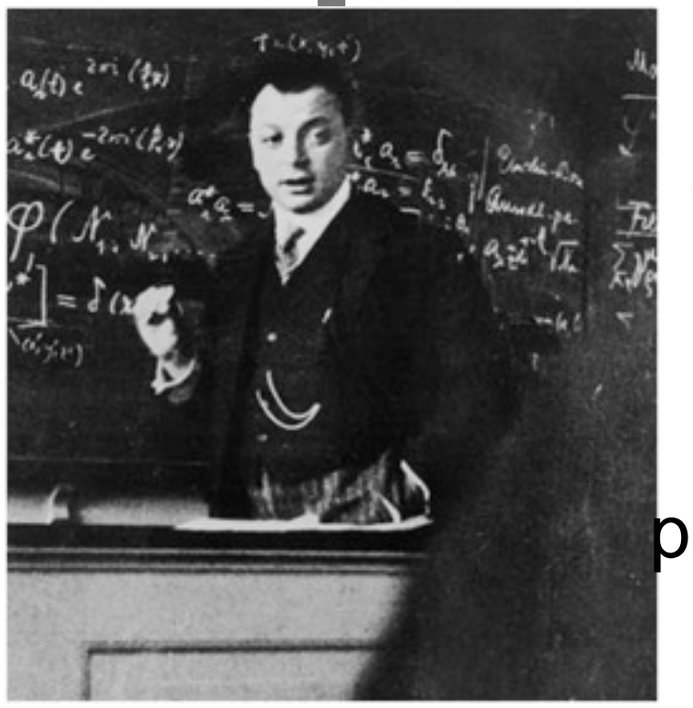
Brief scientific timeline leading to ANITA

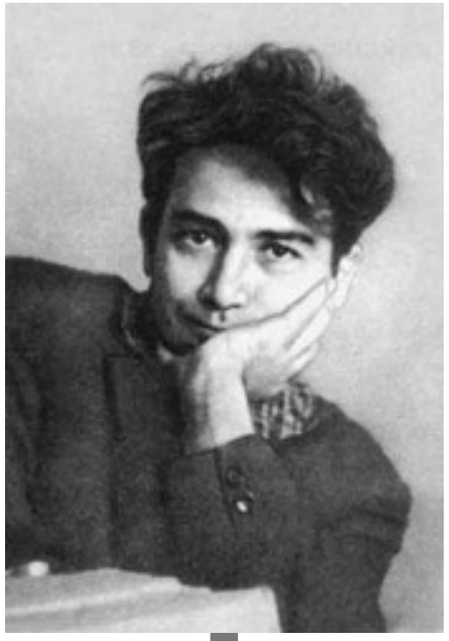
1912

Victor Hess discovers cosmic rays, by flying balloons up to 3 miles above Austria

Wolfgang Pauli does "something very bad"... he postulates the neutrino

1930



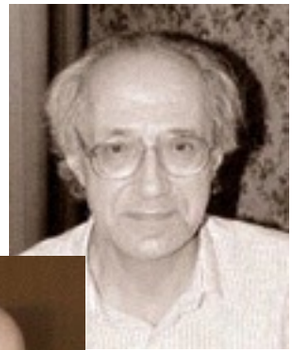


1962

Gurgen Askaryan hypothesises coherent radio emission from particle cascades in dielectric media

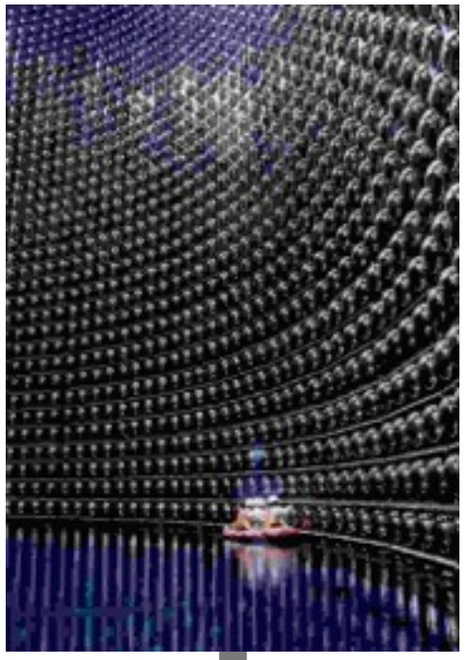
Wilson and Penzias discover the cosmic microwave background

1965



Kamiokande, IMB and Baksan detect neutrinos from a nearby supernova

1987

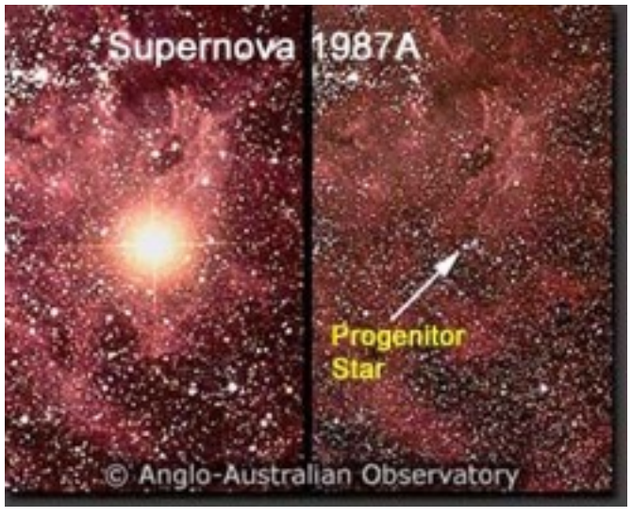


ANITA-I launches from Williams Field in Antarctica

2006

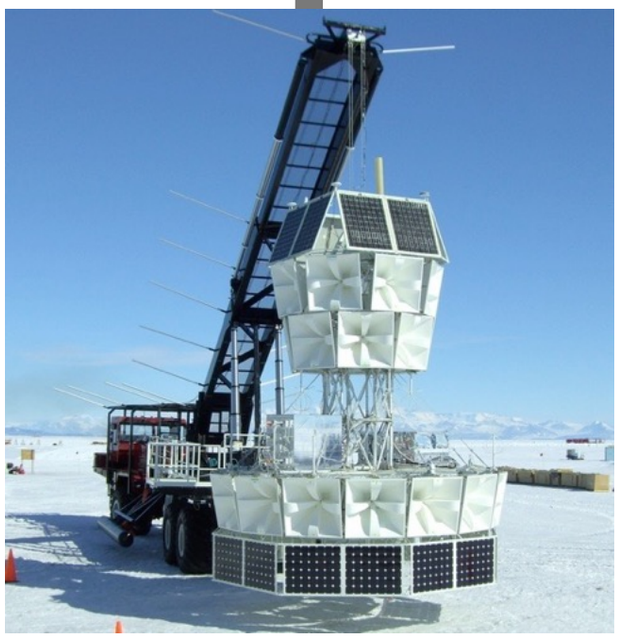
1966

Greisen, Zatsepin & Kuzmin predict the end of the cosmic ray spectrum



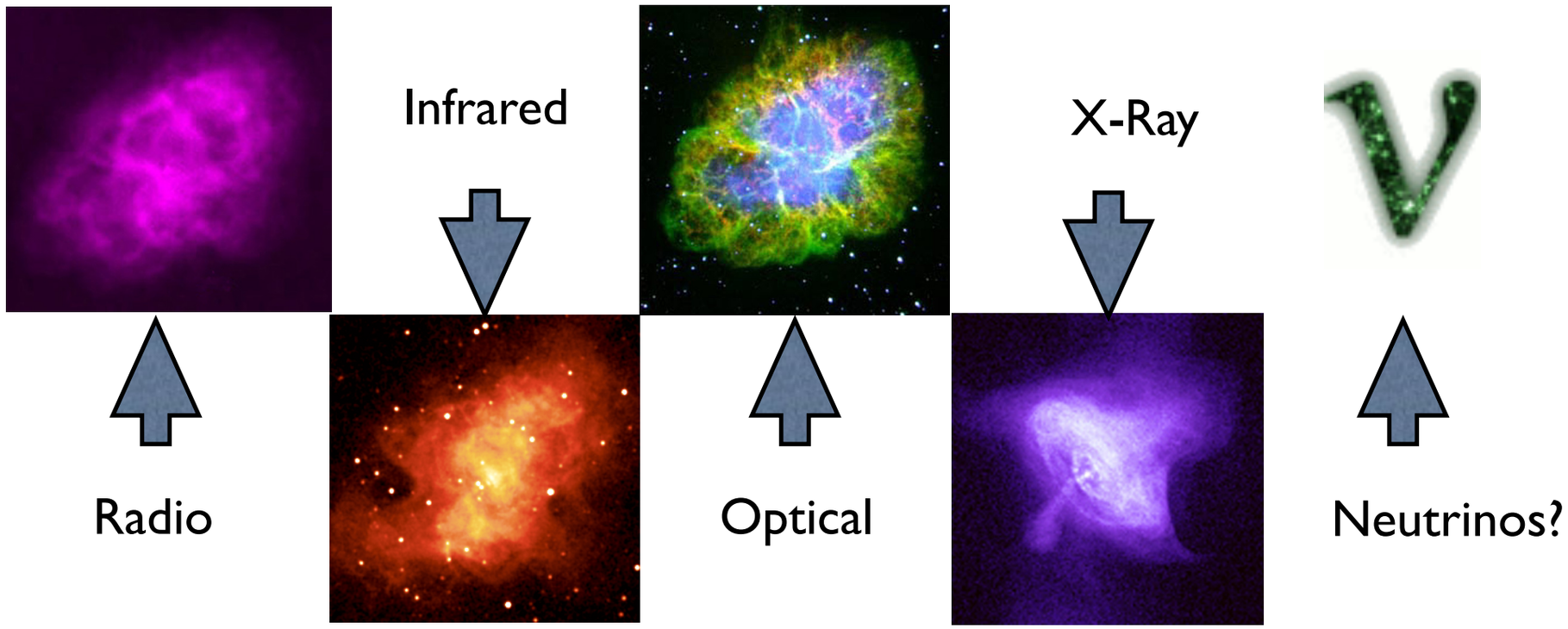
1998

Super-Kamiokande discover neutrinos have mass. Using neutrinos produced by cosmic rays in the atmosphere



Why High Energy Neutrinos?

For Astronomers:
The Pretty Pictures Argument



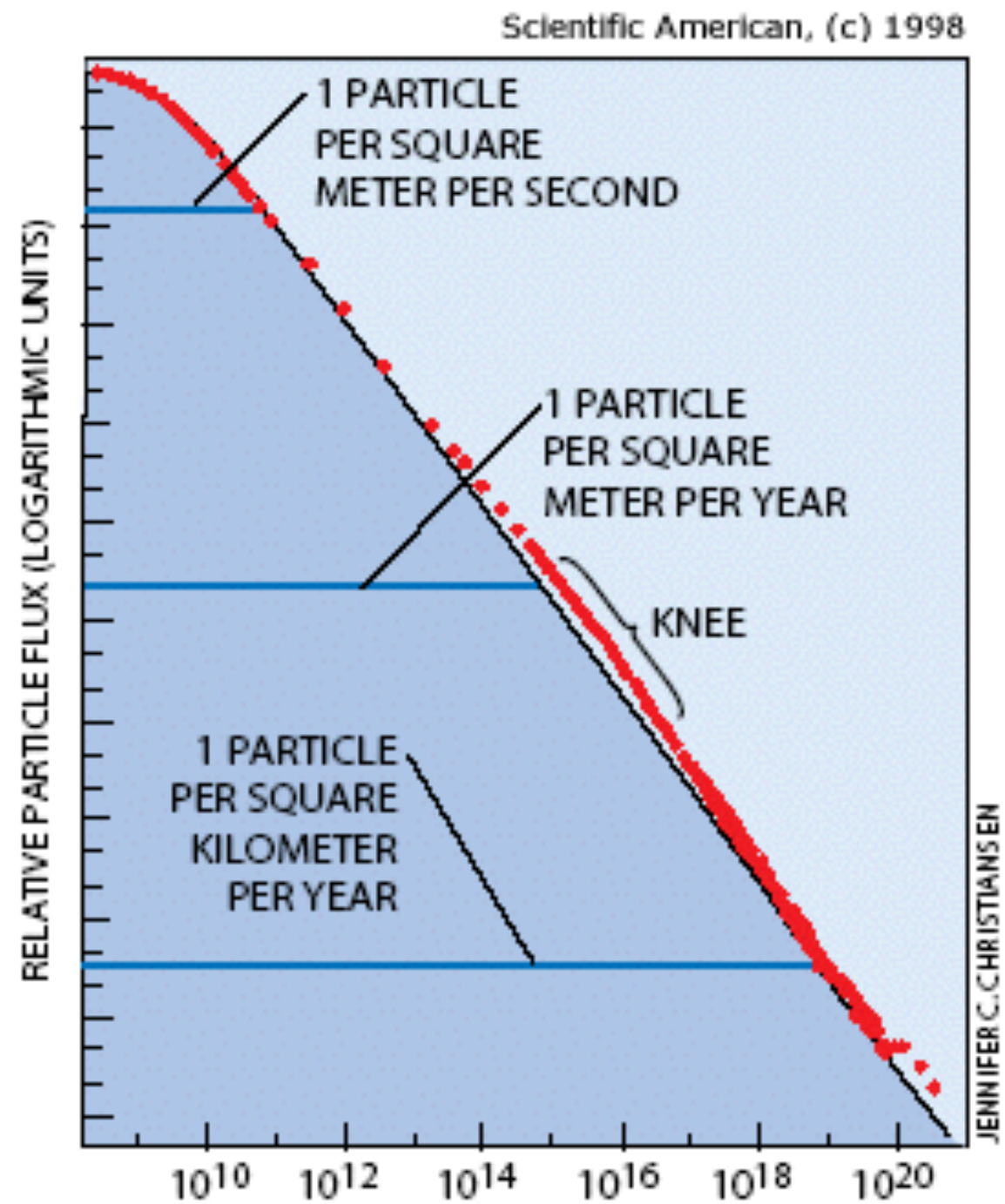
For Particle Physicists:
The 300 TeV (CoM) Neutrino Beam Argument

type	L/E	$t_{proper} \sim (L/c)(m_\nu/E)$
CERN SpS/WANF	500 m/25 GeV	3 attoseconds
Stopped μ (LAMPF)	30 m/ 40 MeV	130 attoseconds
NUMI	735 km/ 4 GeV	30 femtoseconds
Reactor (KamLAND)	150 km/5 MeV	800 femtoseconds
Atmospheric	10,000 km/1 GeV	2 picoseconds
Sun	150,000,000 km/5 MeV	800 nanoseconds
GZK	1 Gpc/100 PeV	50 milliseconds
SN-1987a	50 kpc/15 MeV	1 hour

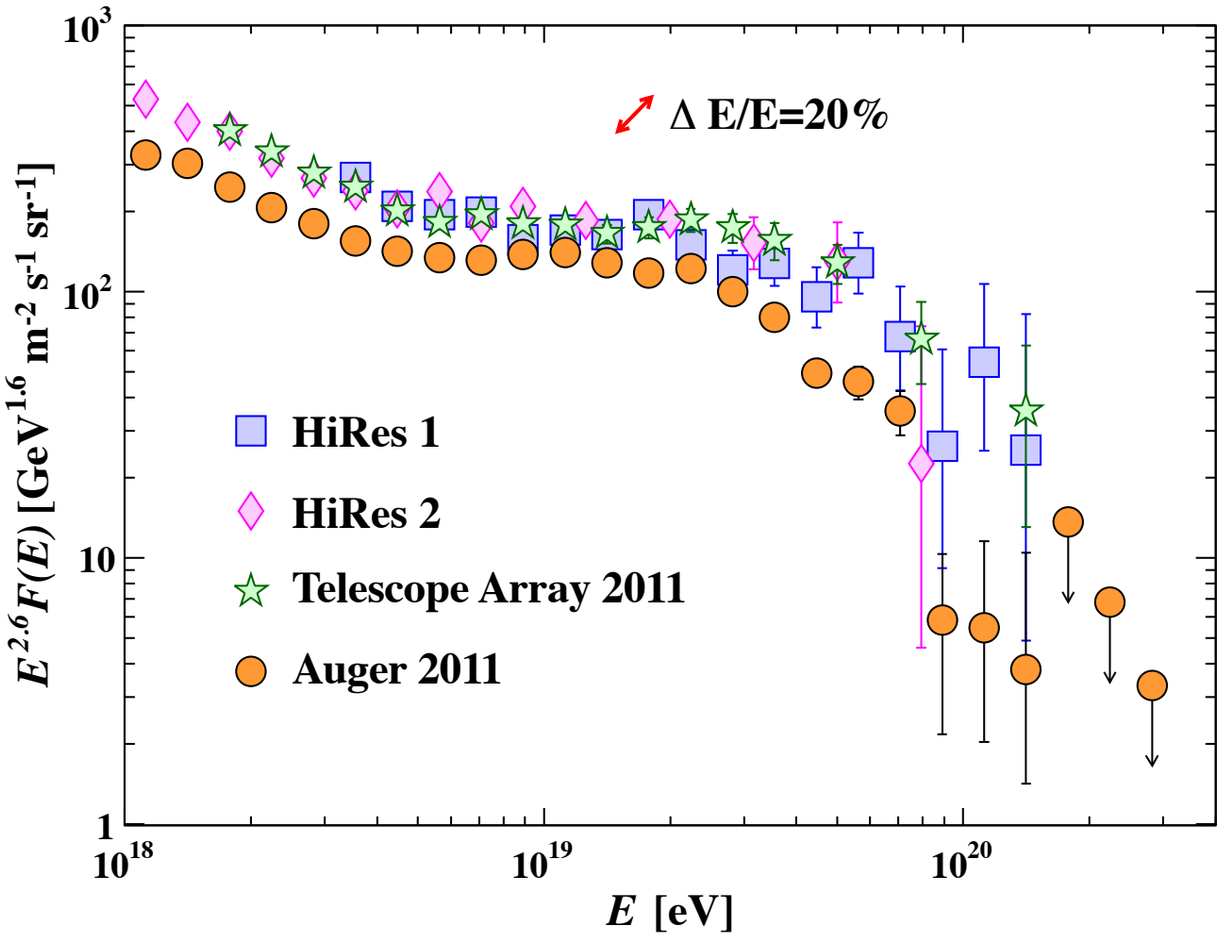
Cosmic Ray Riddle

Symmetry Magazine, Sandbox Studio

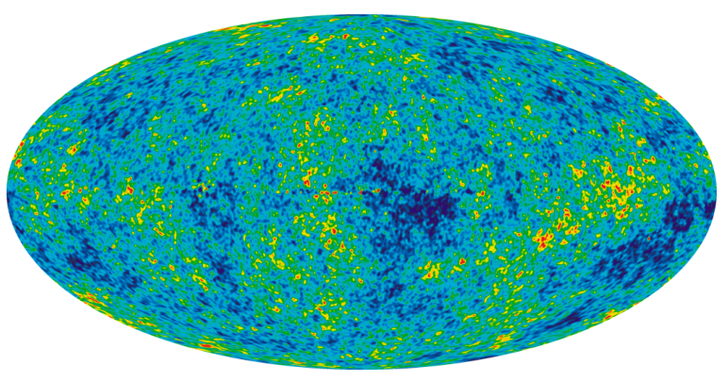
- Where do the highest energy cosmic rays come from?
- Nearby sources should point
- Faraway sources should be attenuated by the cosmic microwave background
- Could neutrinos solve the problem?



Aside: The GZK Effect



+



- Greisen-Zatsepin-Kuzmin (GZK) calculated cosmic rays above $10^{19.5}$eV should be slowed by CMB within 50MPc.
- Berezinksy and Zatsepin realised this would produce a flux of neutrinos

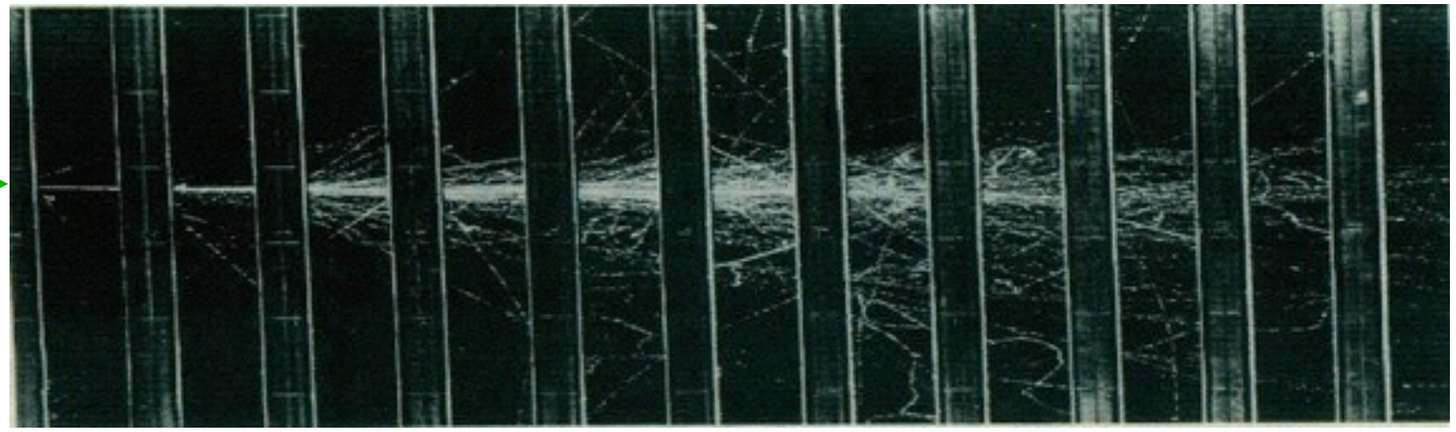
$$p + \Upsilon_{CMB} \rightarrow \Delta^* \rightarrow n + \pi^+$$
$$\searrow \mu^+ + \nu_\mu$$
$$\searrow e^+ + \overline{\nu_\mu} + \nu_e$$

= “Guaranteed” Cosmogenic Neutrino “Beam”!

Radio Cherenkov -- The Askaryan Effect

- In 1962 Gurgen Askaryan hypothesised coherent radio transmission from EM cascades in a dielectric:

$e^{\pm}$ or γ



Typical Dimensions:
$L \approx 10$ m
$R_{Moliere} \approx 10$ cm

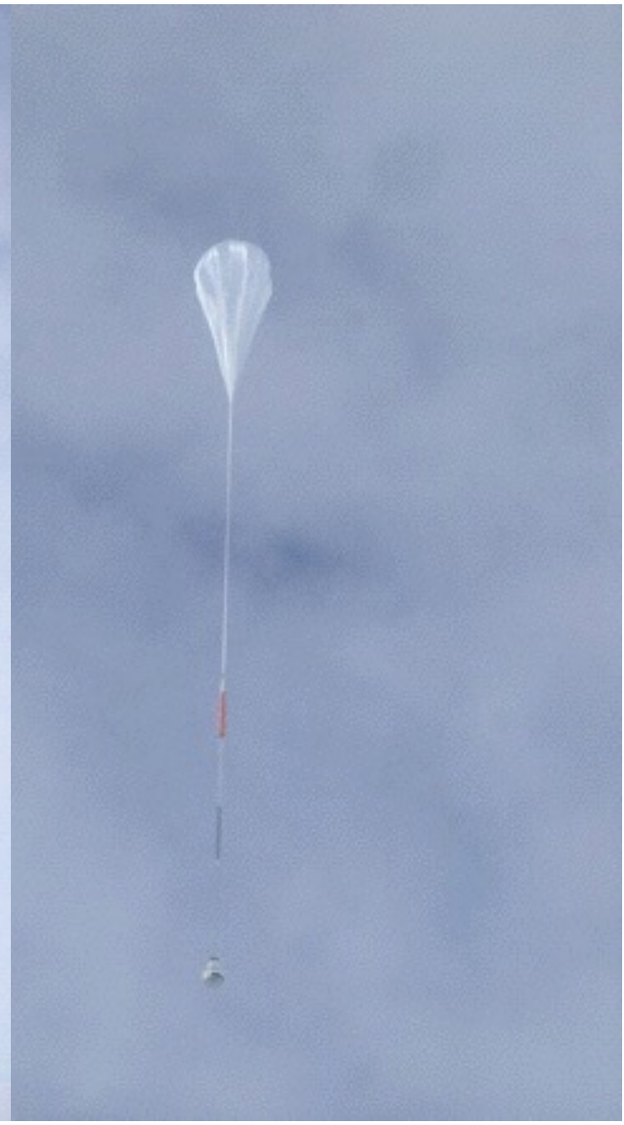
– 20% Negative charge excess:
  - Compton Scattering: $\gamma + e^{-}_{(rest)} \Rightarrow \gamma + e^{-}$
  - Positron Annihilation: $e^{+} + e^{-}_{(rest)} \Rightarrow \gamma\,\gamma$

– Excess travelling with, $v > c/n$
  - Cherenkov Radiation: $dP \propto \nu\, d\nu$

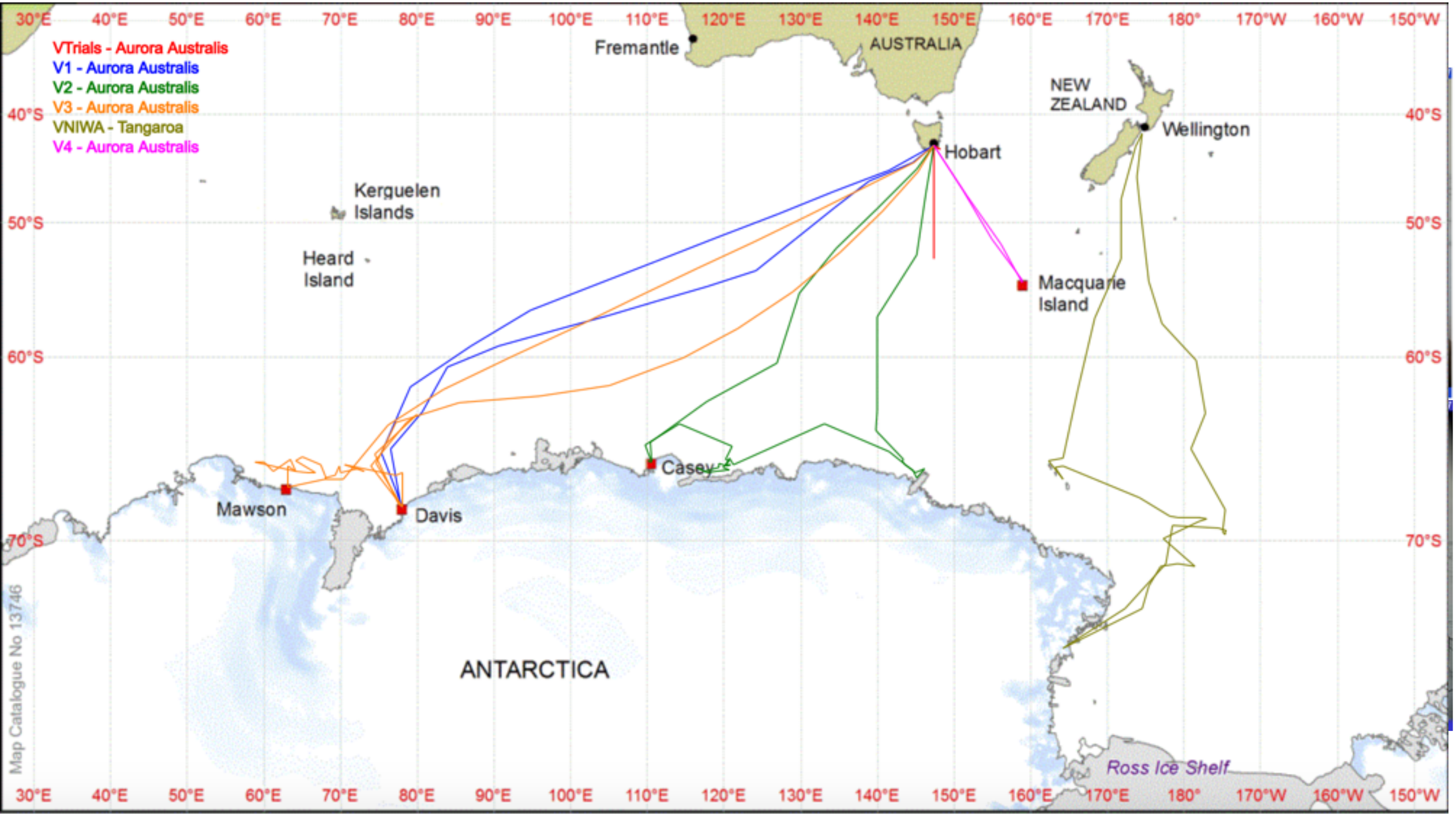
– For $\lambda > R$ emission is coherent, so $P \propto E^{2}_{shower}$

Up, up and away

- The Balloon
  - Just 0.02mm thick
  - Takes 100 million litres of helium (and several hours) to fill



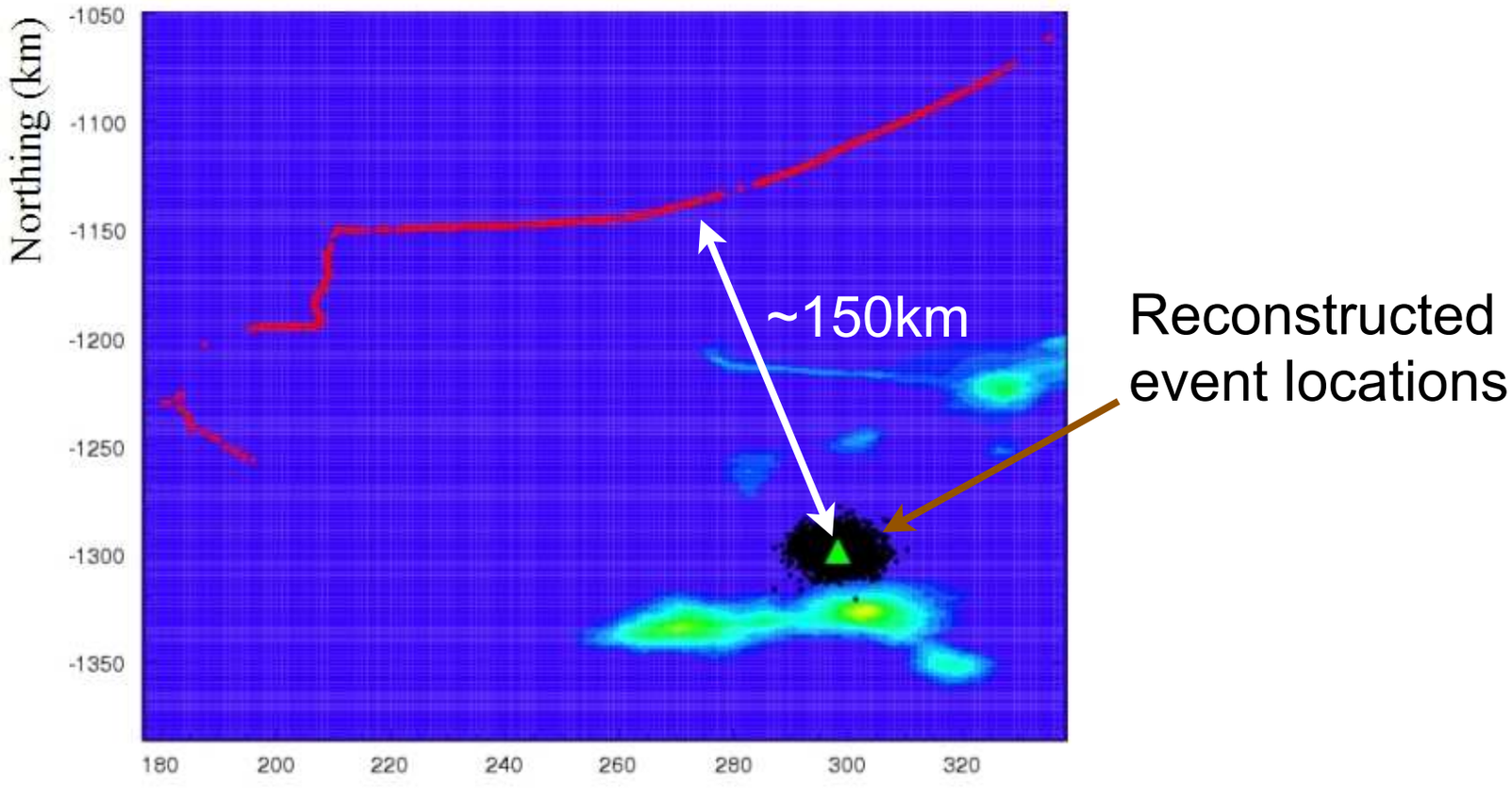
Where is the Aurora Australis?



https://secure3.aad.gov.au/public/schedules/voyageTrack.cfm?season=1415

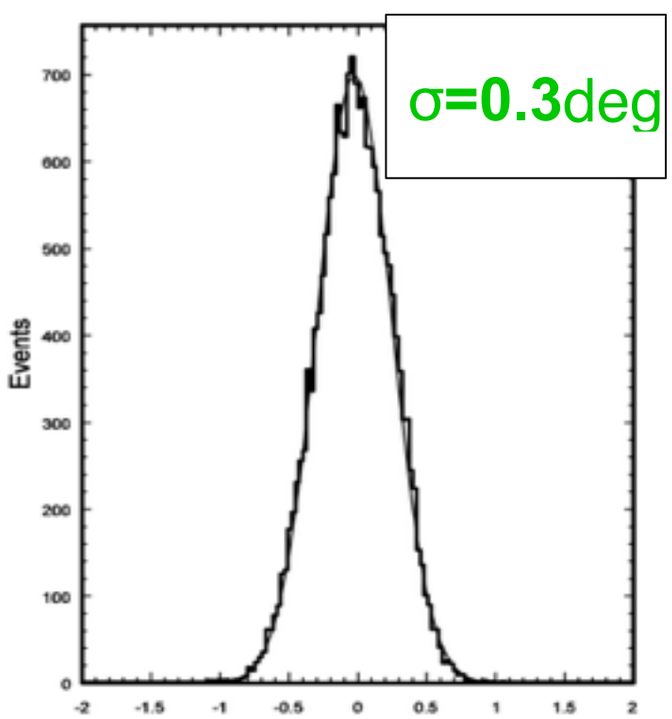
http://www.antarctica.gov.au/webcams/aurora

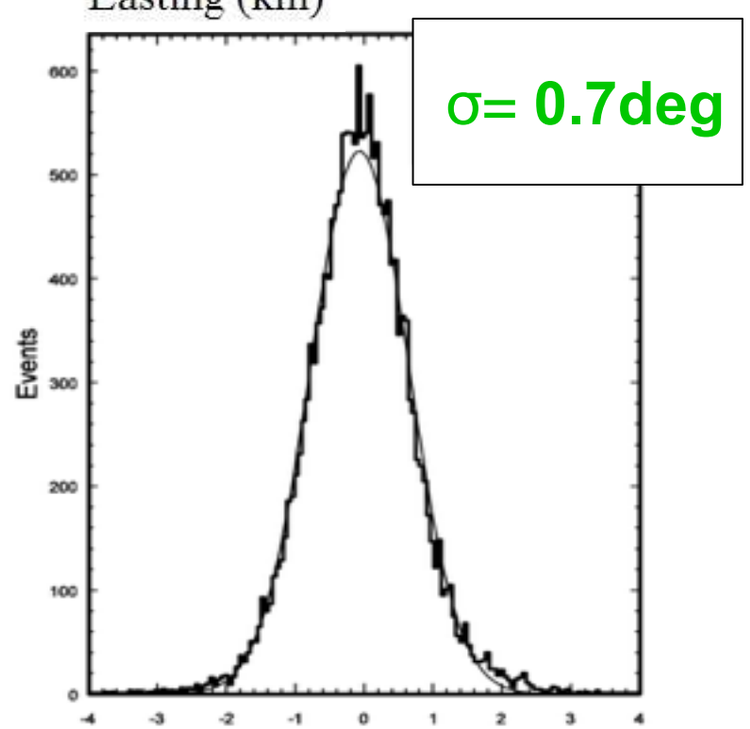
Calibration

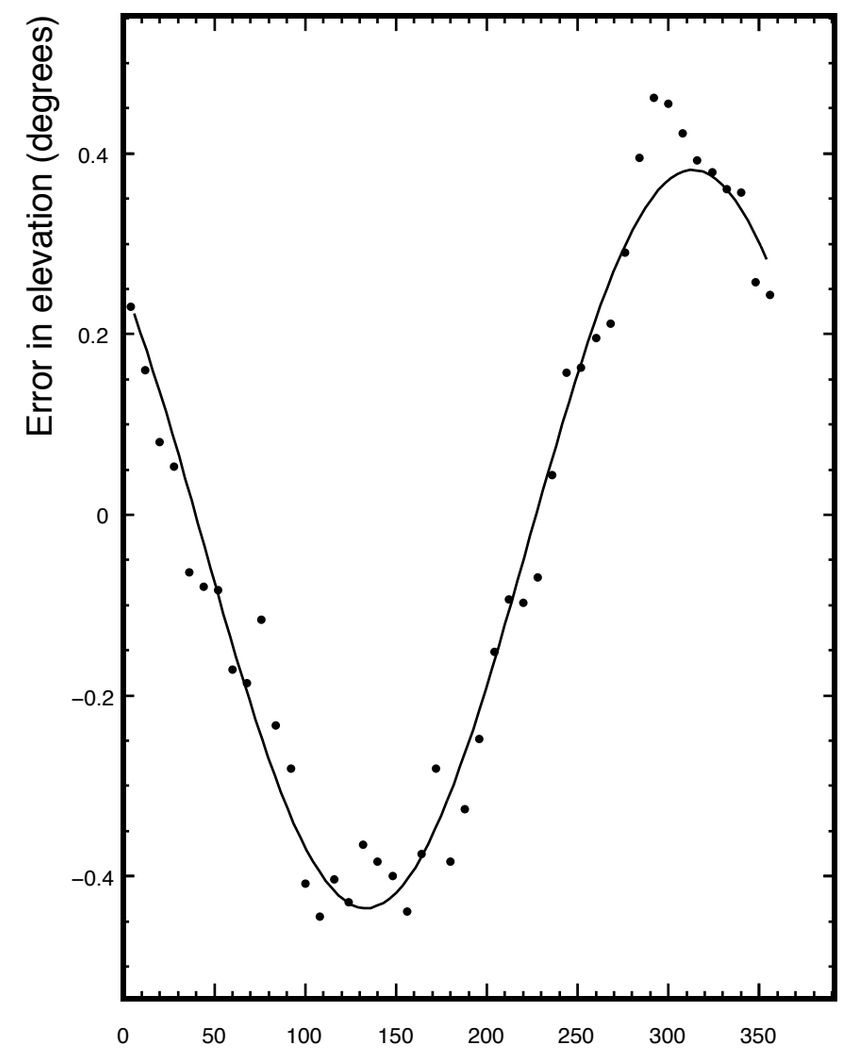


Use ground and borehole calibration pulsers to calibrate antenna positions and time offsets.

Also calibrate out the tilt of the payload

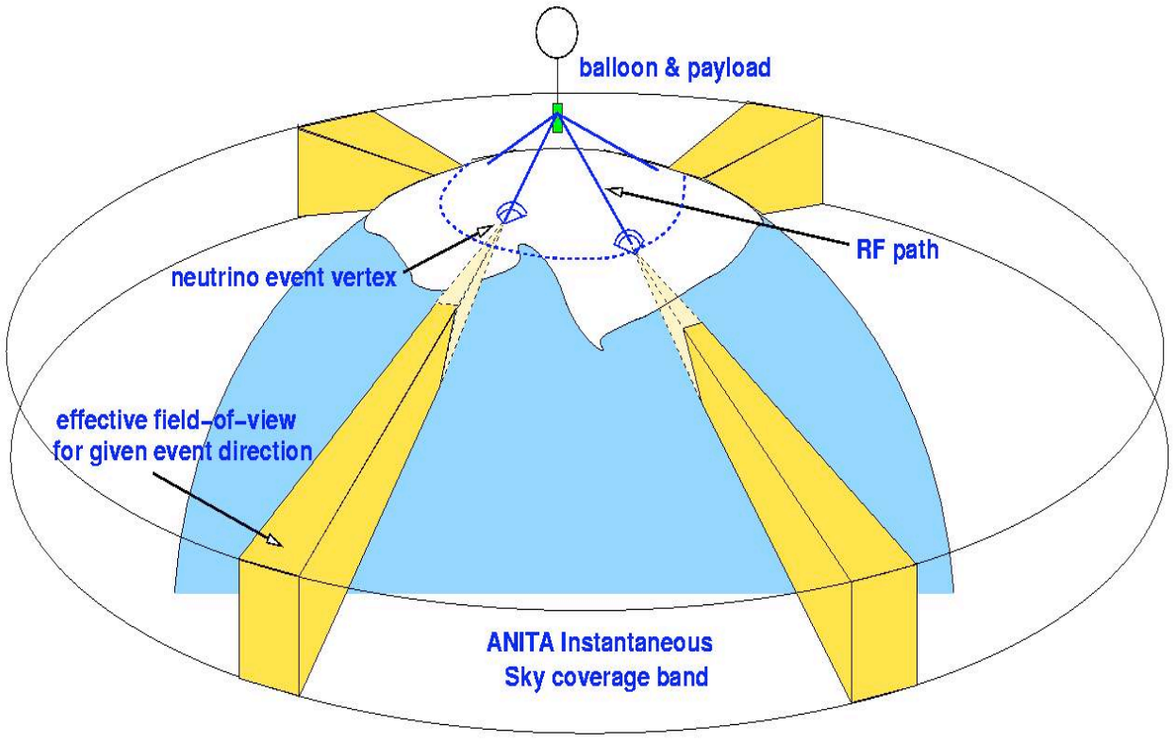


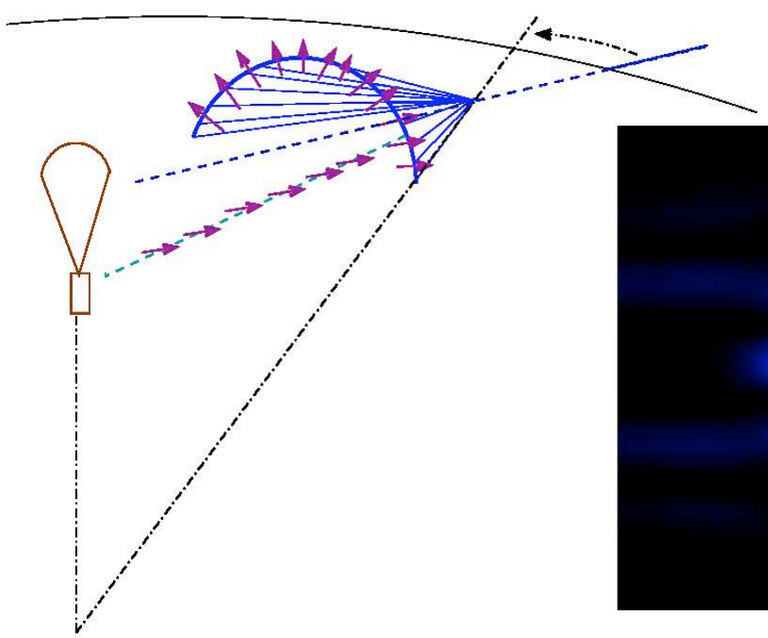


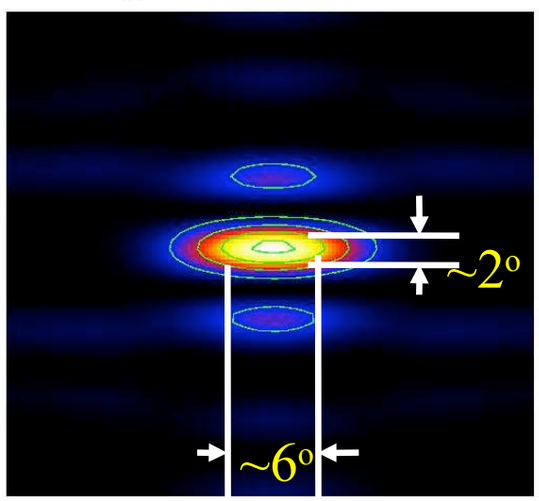


ELEVATION ANGLE **AZIMUTH ANGLE** from S. Hoover

ANITA -- Angular Resolution



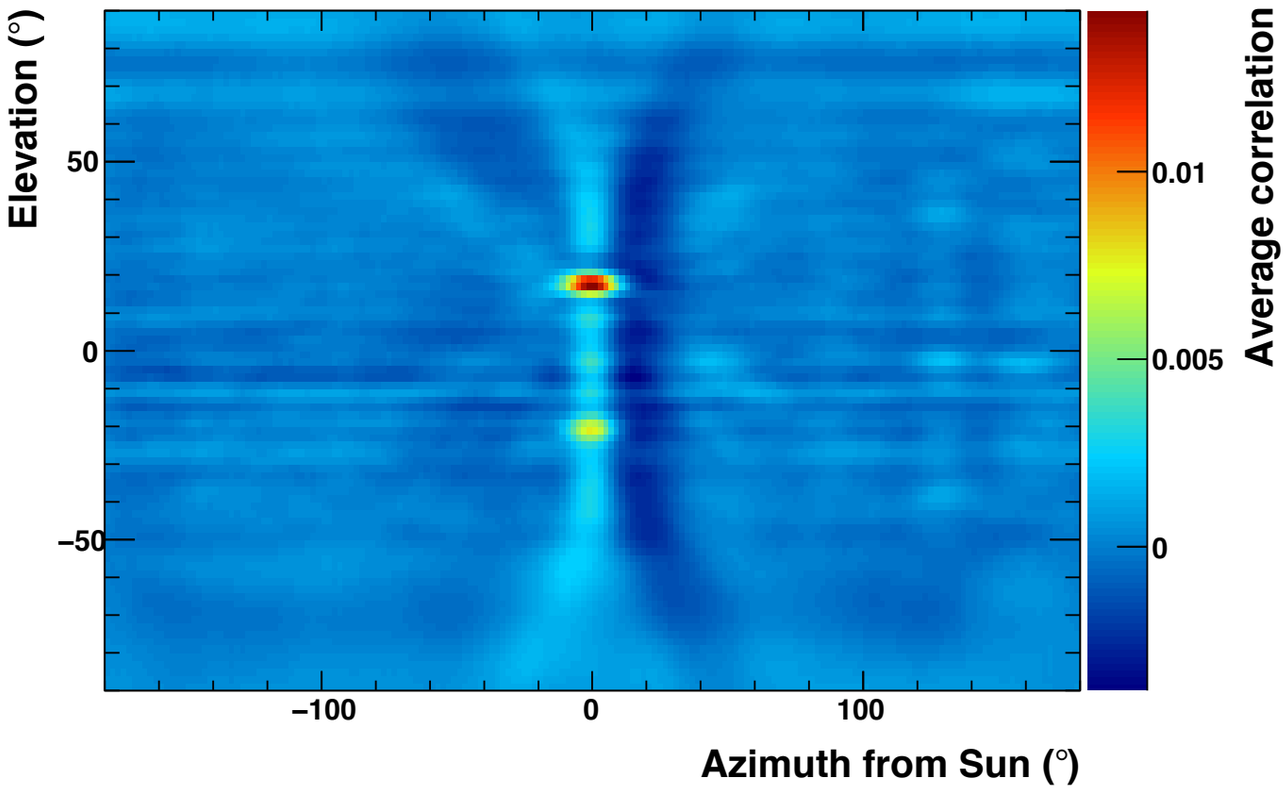


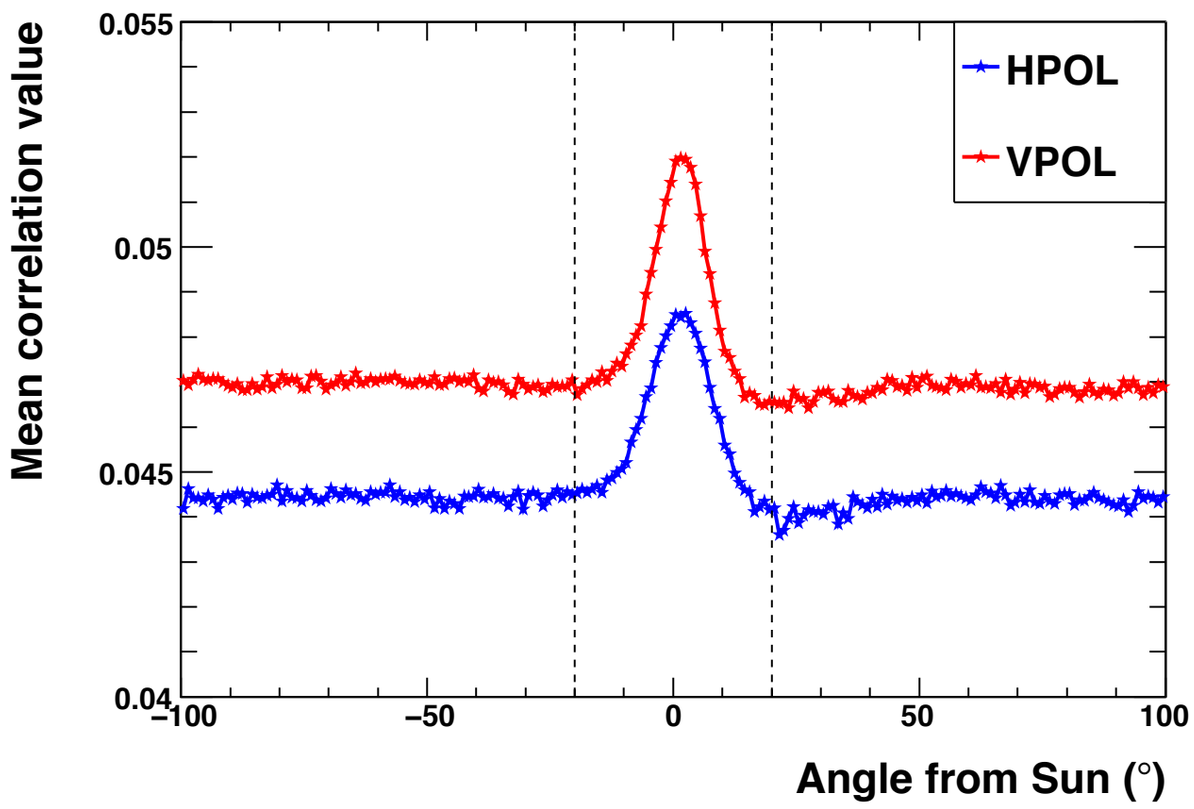


- Using signals from multiple antennas it is possible to measure the direction of arrival of radio pulse to ~0.5° in elevation and ~1.5° in azimuth (based on ANITA-lite calibration data)
- The neutrino direction can vary around radio pulse direction but is constrained to ~2° in elevation and by 3-5° in azimuth by polarization angle.

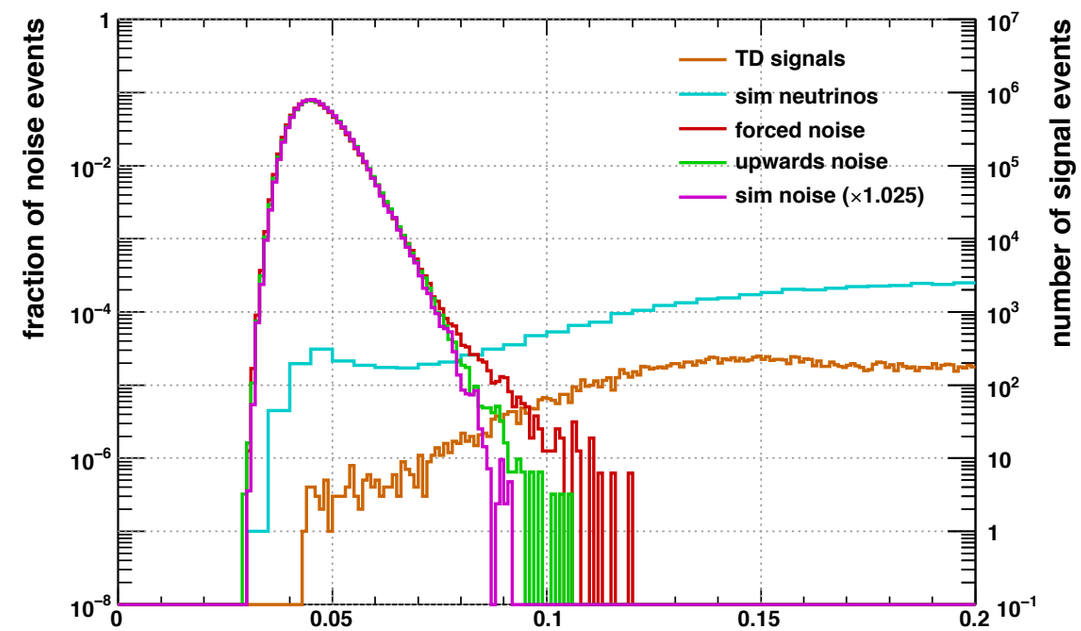
Thermal Noise

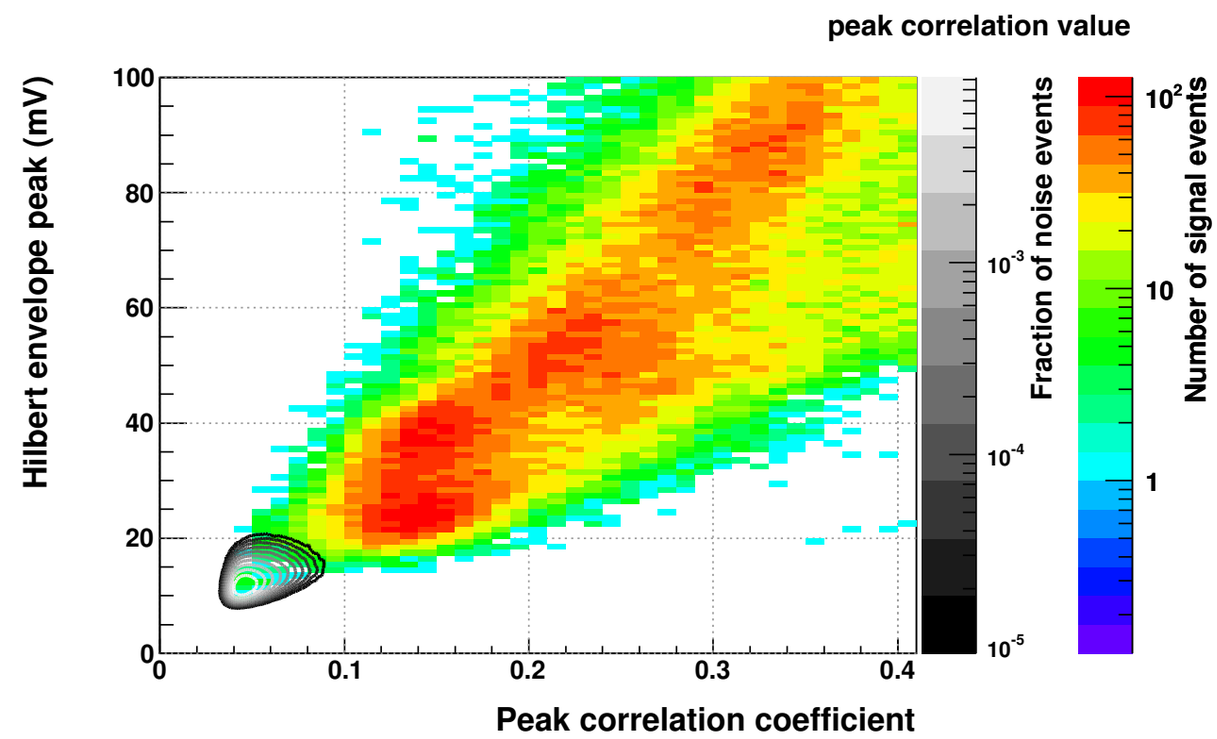
ANITA can "see" the Sun



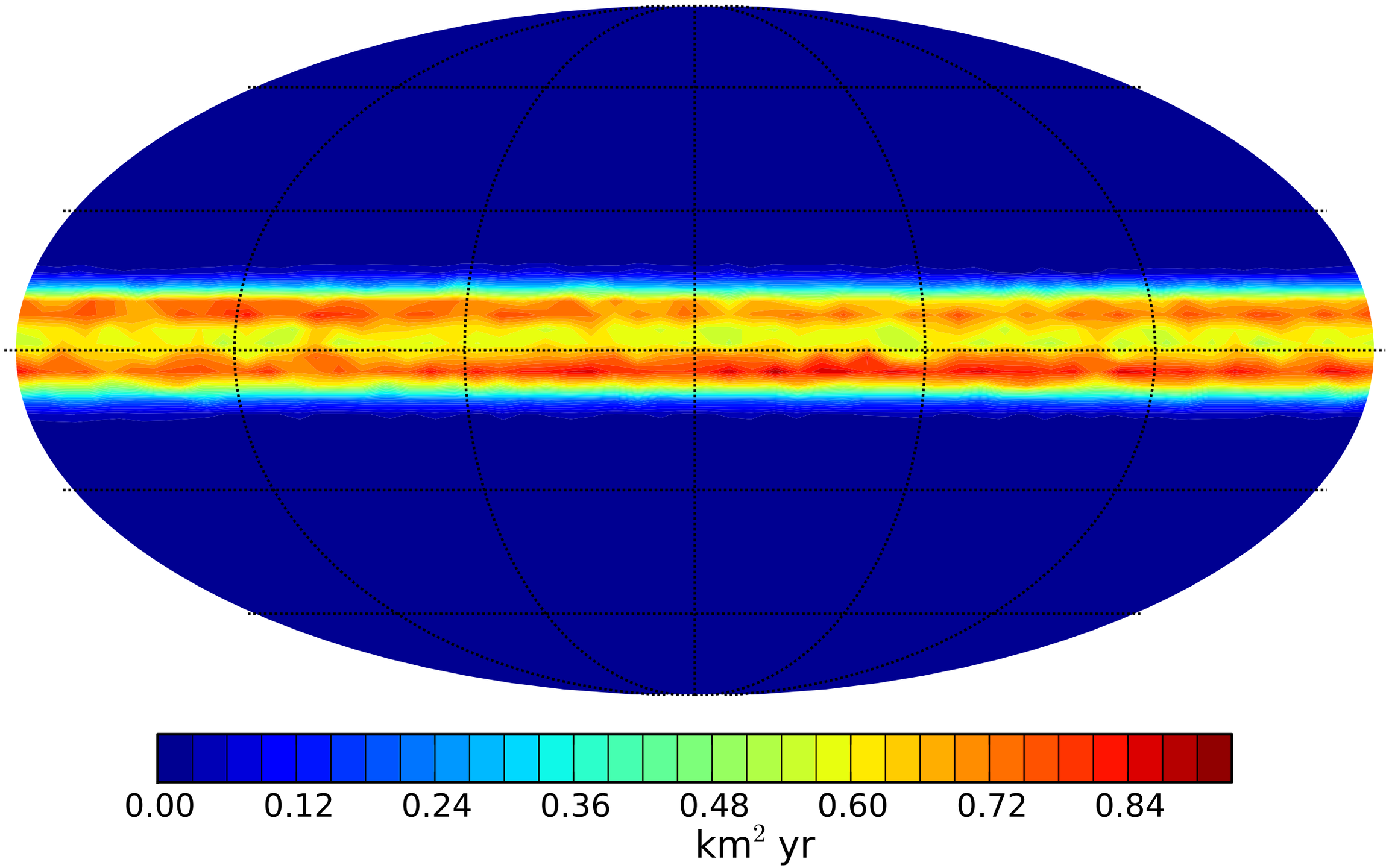


Thermal noise is the dominant source of noise in the data sets.





ANITA-2 Neutrino Sky Map Sensitivity



ANITA -- The Calorimeter

- The observed voltage V_{obs} is proportional to the neutrino energy E_ν:

$$V_{obs} \sim E_\nu \, y \, h_{eff} R^{-1} exp\left(-\frac{\beta^2}{2\sigma_{\beta^2}} - \alpha d \right)$$

y is the fraction of neutrino energy in the cascade

h_{eff} is the effective height of the antenna (gain)

R is the range to the cascade

Gaussian in β from observer position on Cerenkov cone

(estimated from RF spectrum)

Exponential is attenuation in ice at depth d.

(estimated from RF spectrum and polarization effects)

Gives: $\Delta E_\nu / E_\nu \sim 1.9$ (60% of which is intrinsic from y)