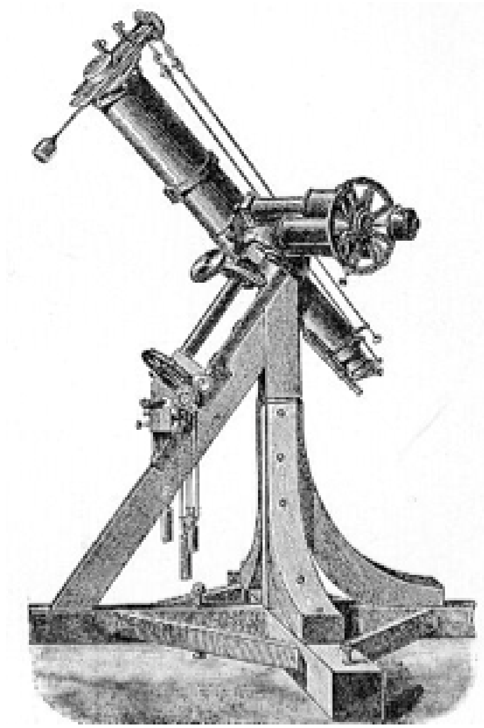
The Ground

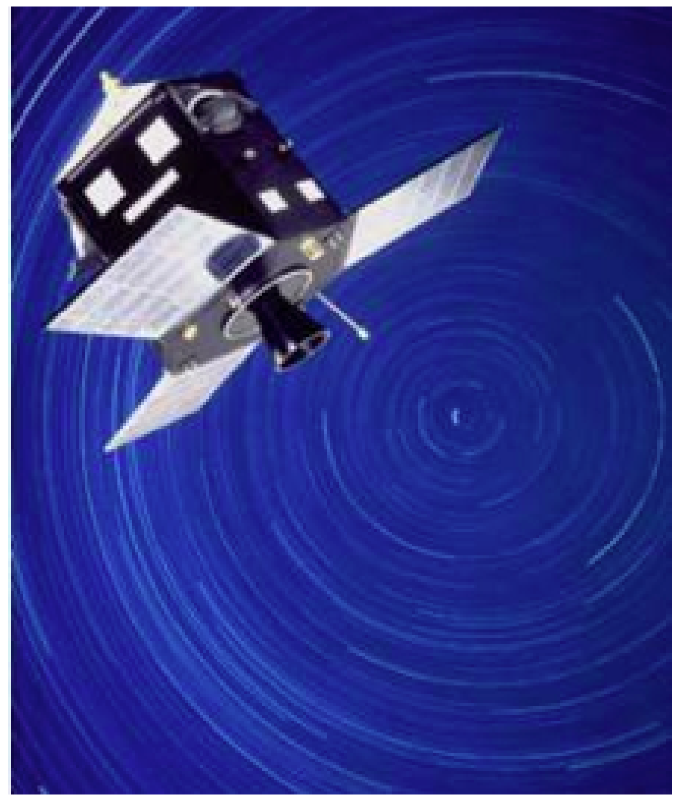
James Lloyd

Cornell University

Ground vs Space

No contest. Space *always* wins.





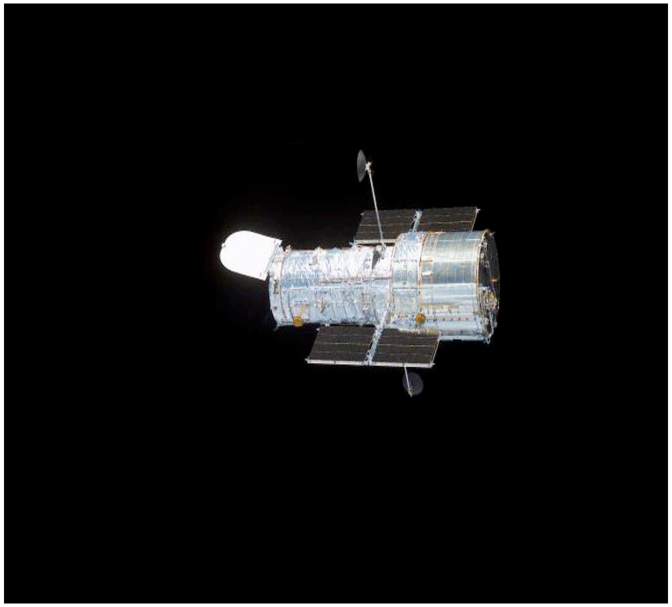
Ground vs Space

Unless…

Ground vs. Space

State of the art astrometry

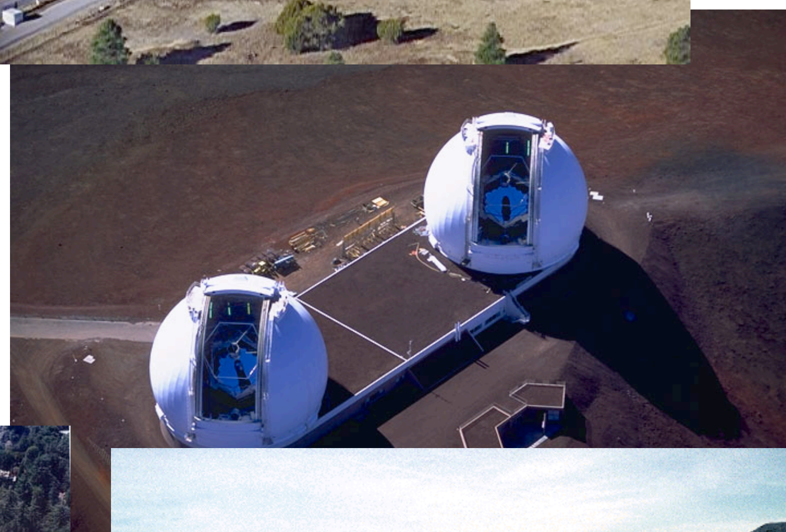
This space is intentionally blank

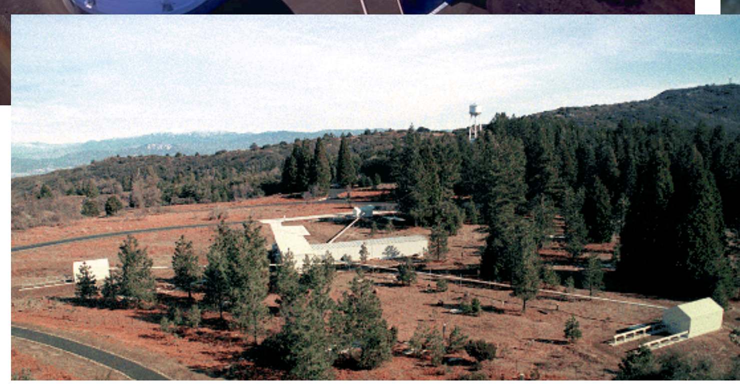


Ground vs. Space

The VLT Array on the Paranal Mountain

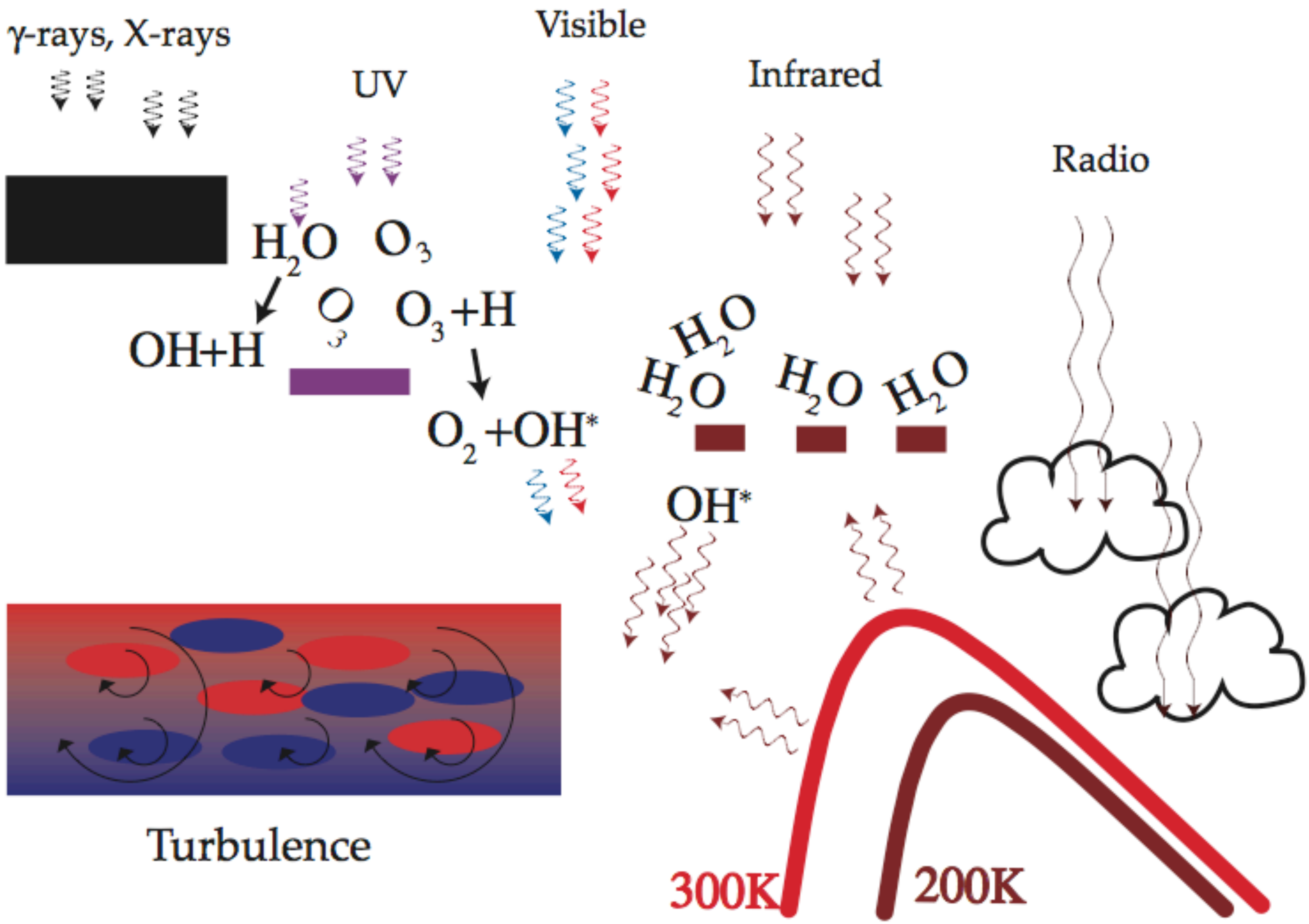
ESO PR Photo 14a/00 (24 May 2000) ©European Southern Observatory





Ground vs Space,
A demonstration

The astronomer's enemy: the atmosphere



Turbulence

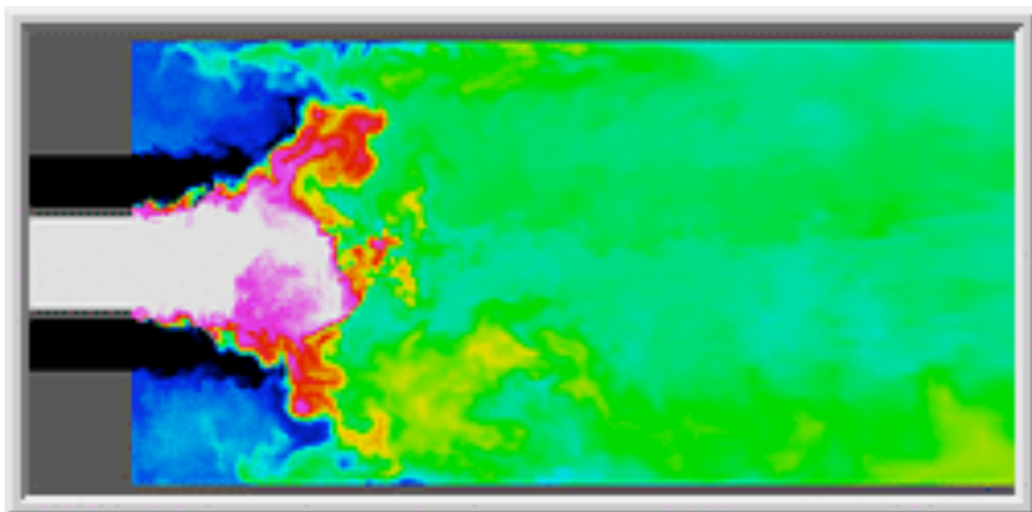
"Before I die, I hope someone would explain quantam mechanics to me. After I die, I hope God will explain turbulence to me."

W. Heisenberg

Turbulence

Greater whorls have lesser whorls,
which feed on their velocity.
And lesser whorls have smaller whorls,
and so on to viscosity.

L.F. Richardson



Animation Credit: Stanford Center for Turbulence Research

Turbulence

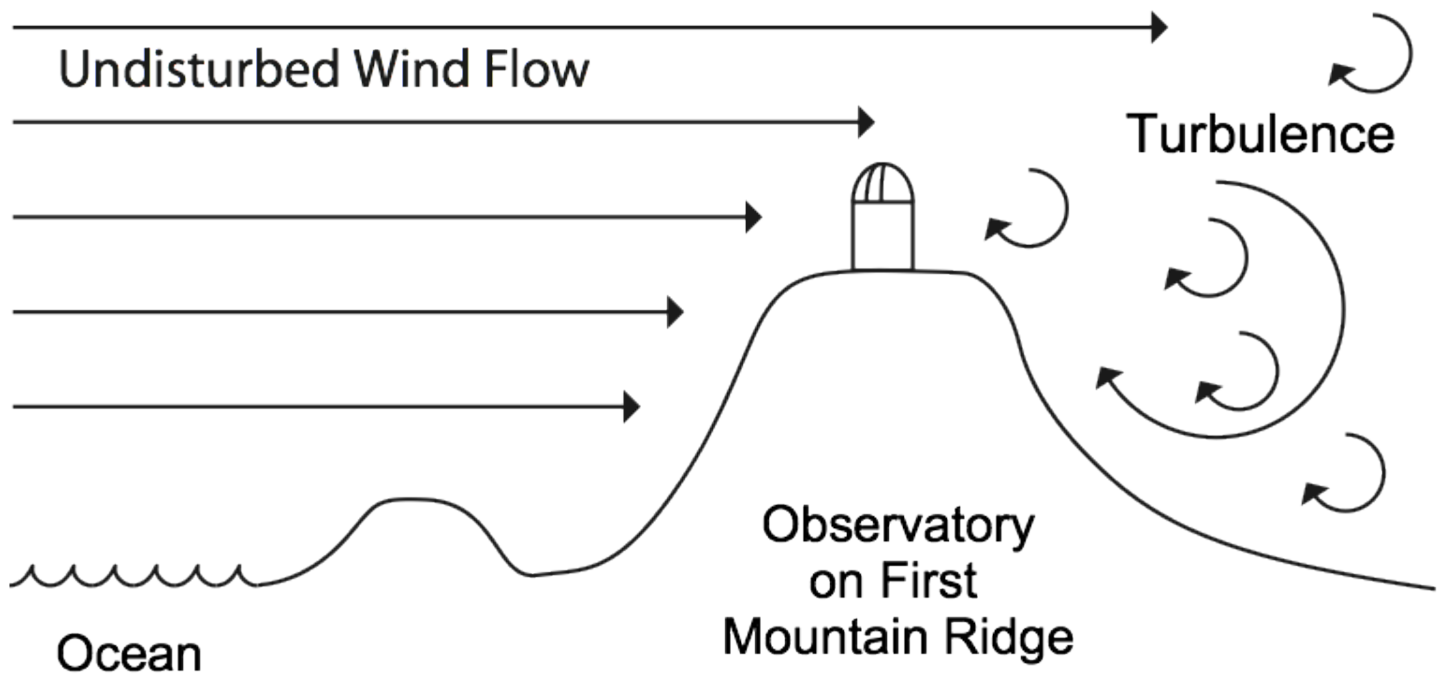
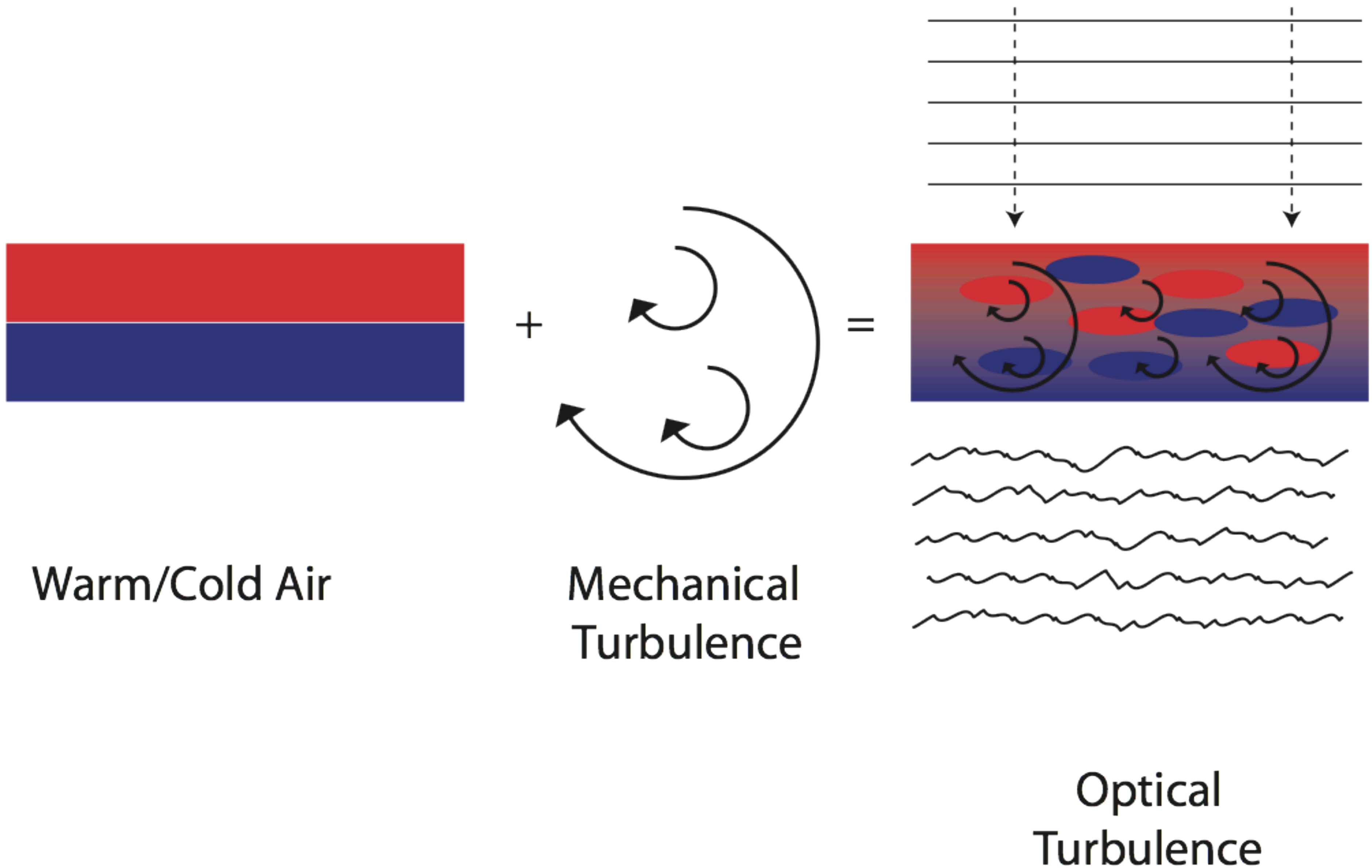


Figure 5.1: Schematic of turbulence generation in the wake of obstacles. Most world-class observatories are located on the first mountain ridge near the coast (or on mountains on islands), with prevailing winds from the ocean.

Physics of Turbulence



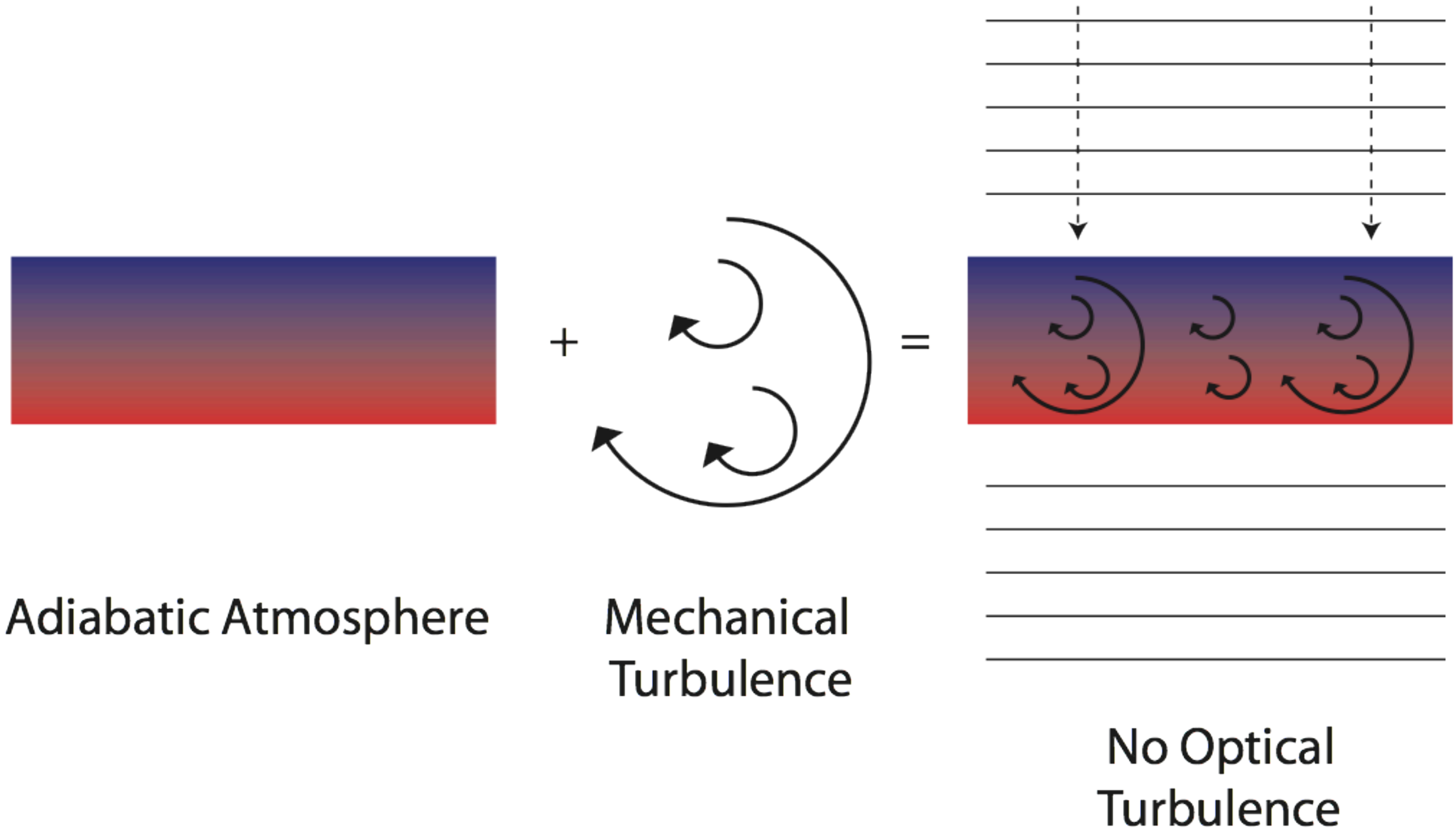
Physics of Turbulence

$$C_n^2 = 2.8 M^2 L^{4/3}$$

$$M^2 = \left[\left(\frac{79 \times 10^{-6} P}{T^2} \right) \left(\frac{dT}{dz} - \gamma \right) \right]^2$$

References:
Quirrenbach, Michelson Summer School "Principles of Long Baseline Interferometry"
http://olbin.jpl.nasa.gov/iss1999/coursenotes.html
AFGL Tech Report: Dewan et. al. "A Model for C_n^2 (Optical Turbulence) Profiles Using Radiosonde Data";
Tatarski "The effects of the turbulent atmosphere on wave propagation";
Sasiela "Electromagnetic Wave Propagation in Turbulence: Evaluation and Application of Mellin Transforms"

Physics of Turbulence

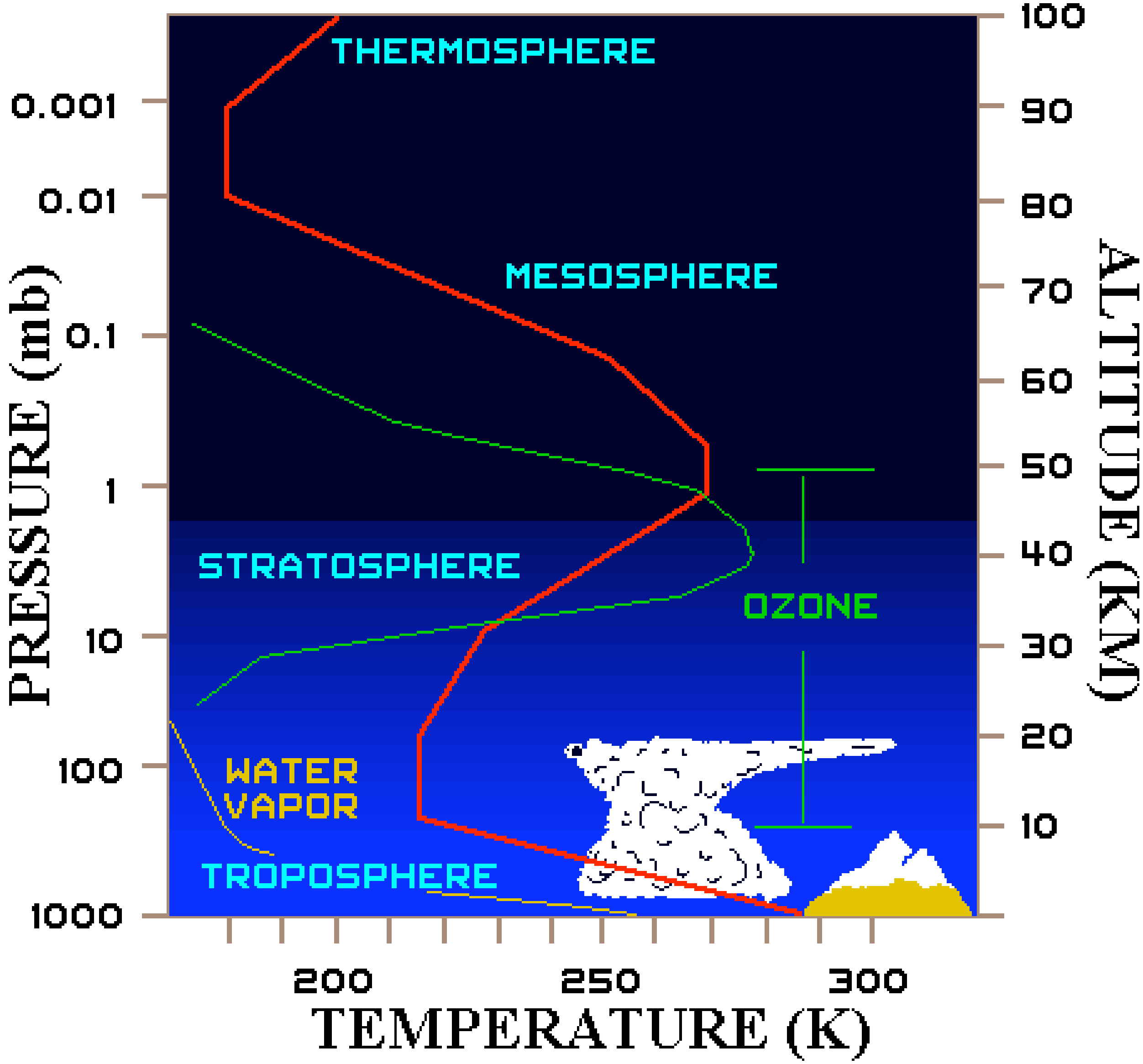


Astrometry

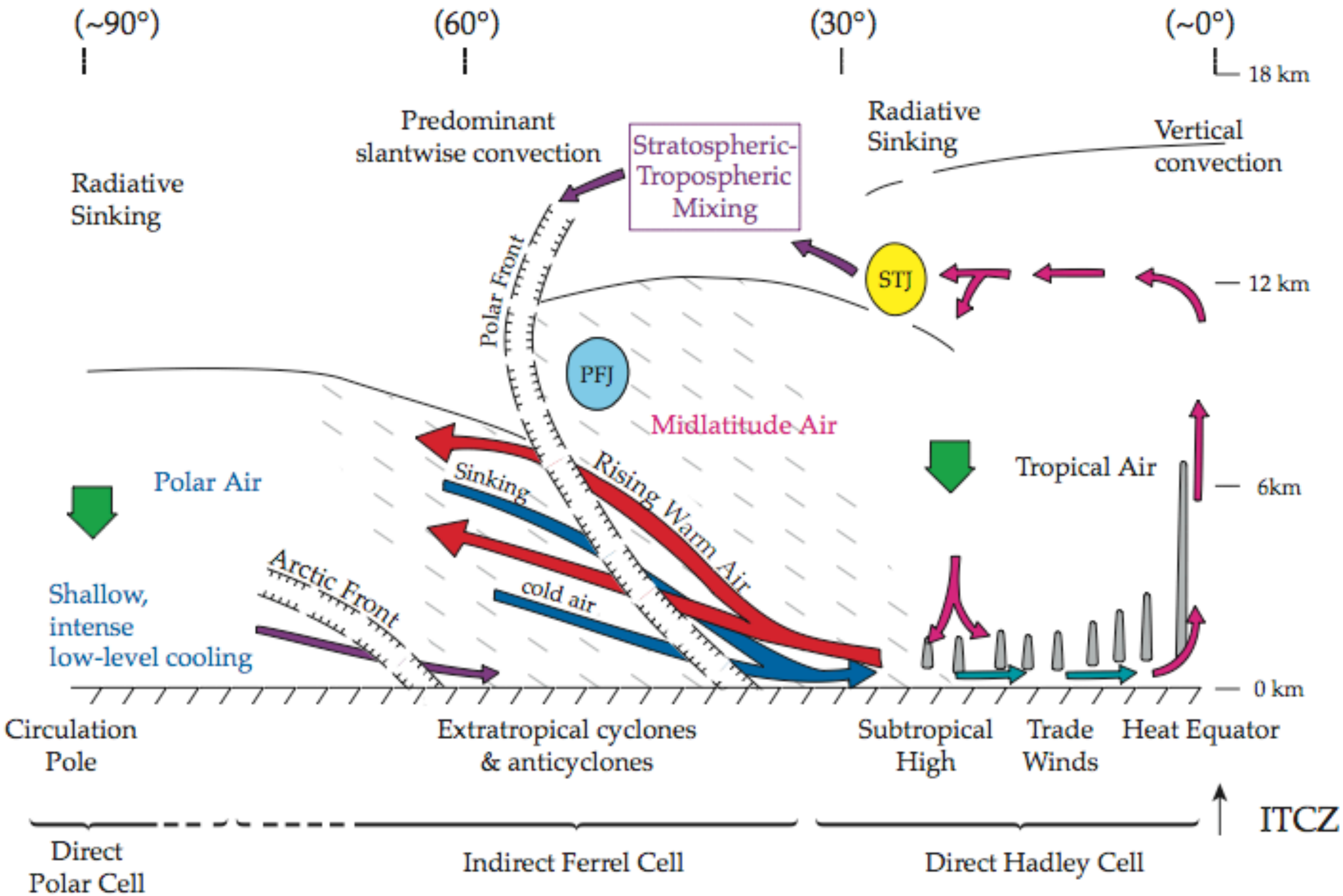
$$\sigma_\delta^2 \propto B^{-4/3}\theta^2 T^{-1} \int C_n^2(h) h^2 dh$$

(Shao & Colavita 1992, Colavita on Monday)

Meterologist's Altitude



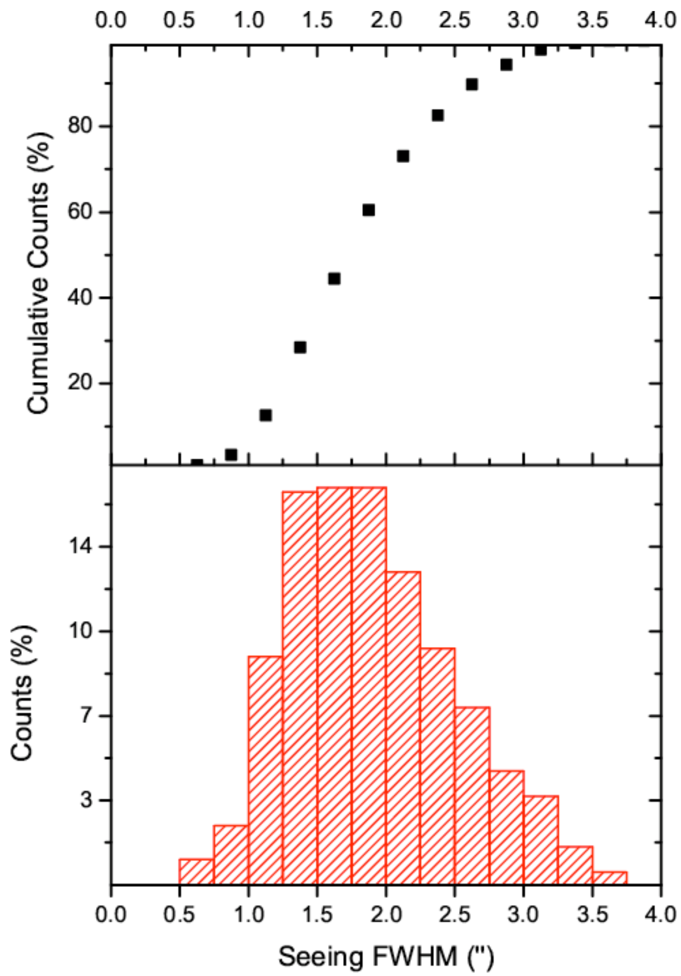
Meterologist's Latitude

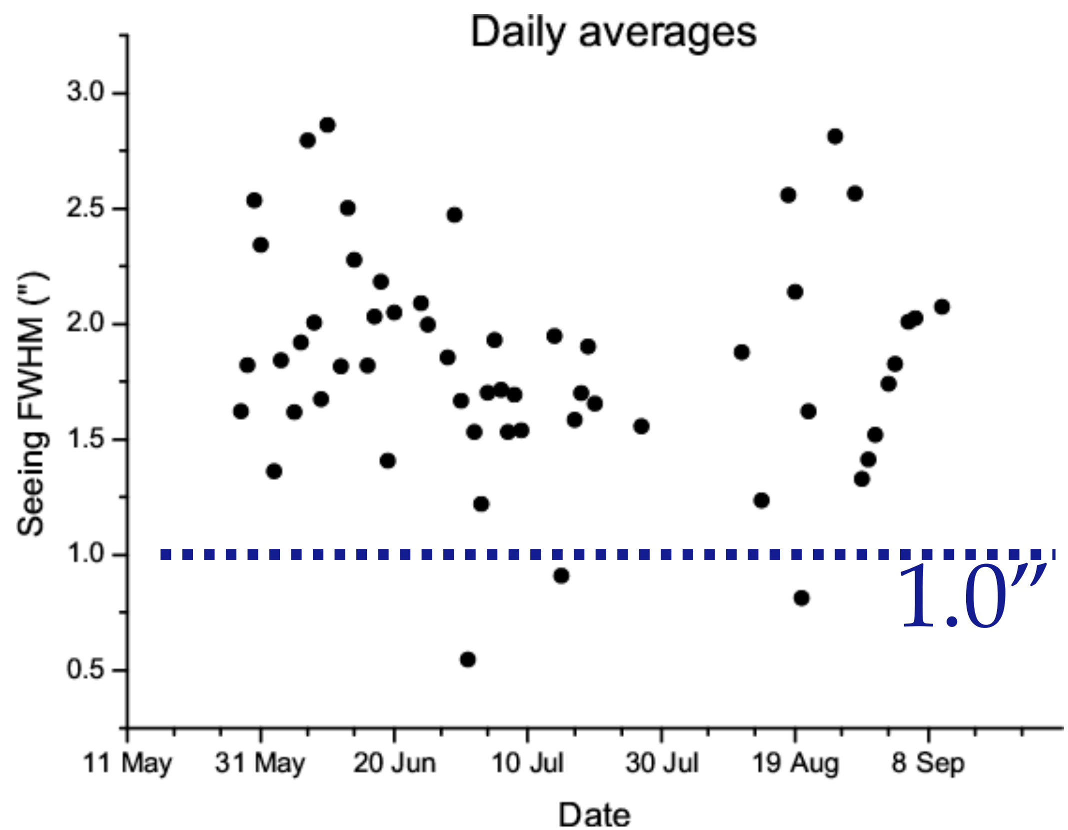


B. Geerts & E. Linacre

Antarctica

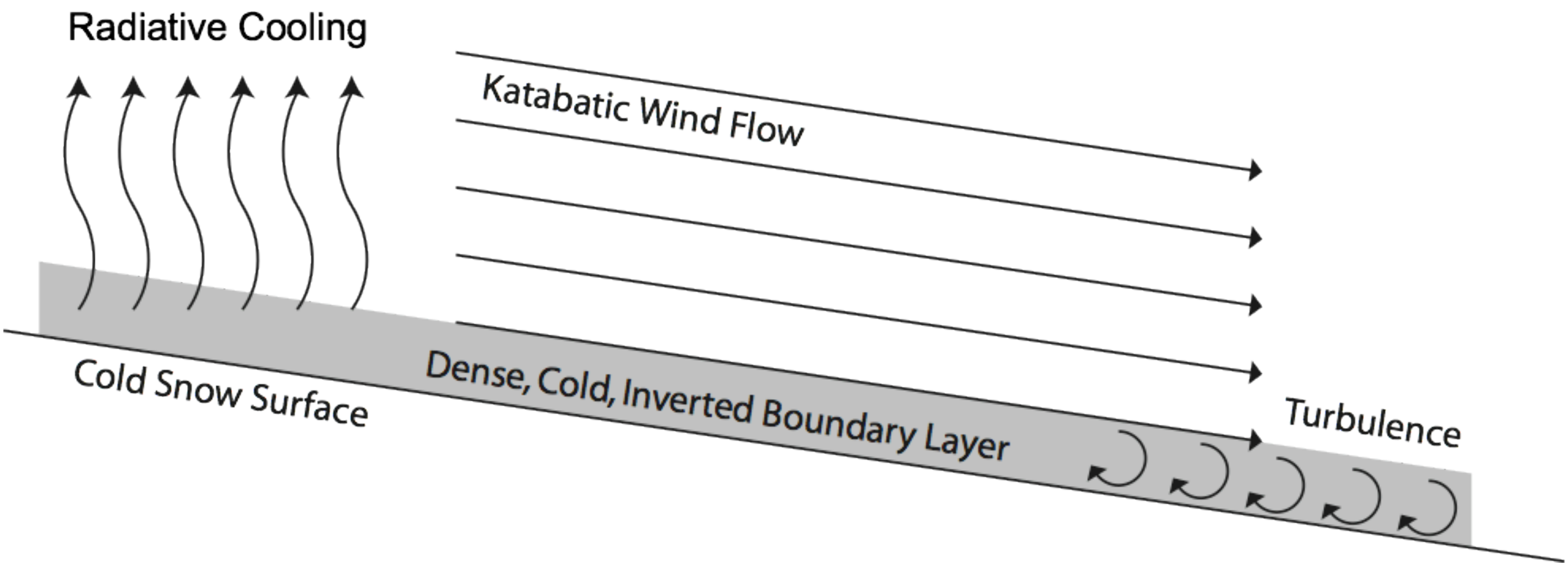
South Pole Seeing



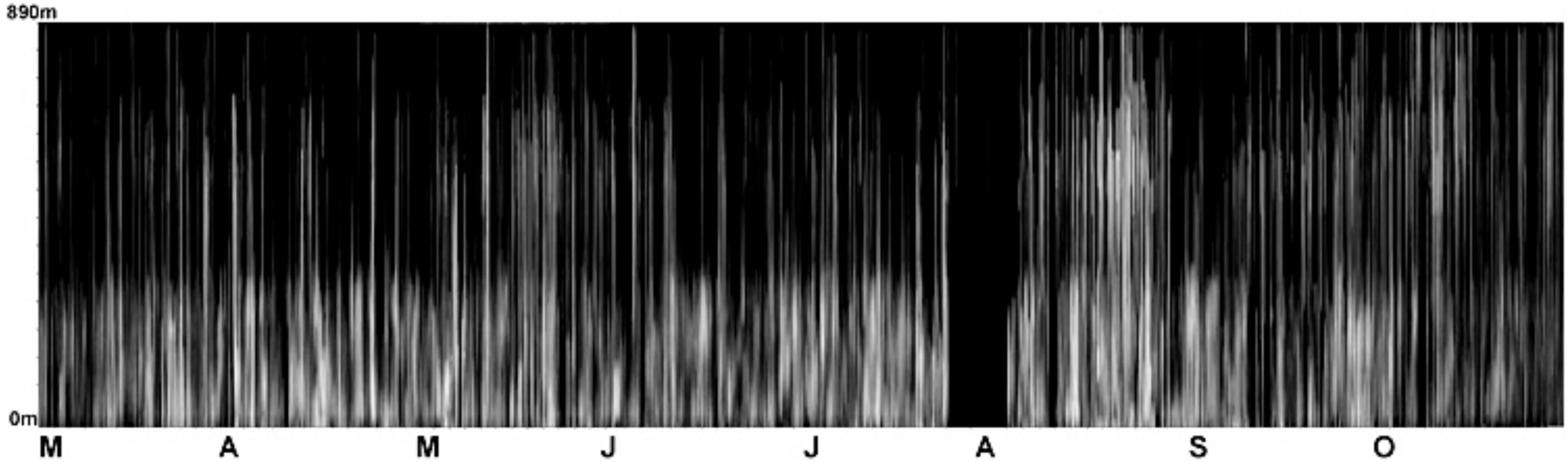


Travouillon et. al 2003

Antarctic Boundary Layer



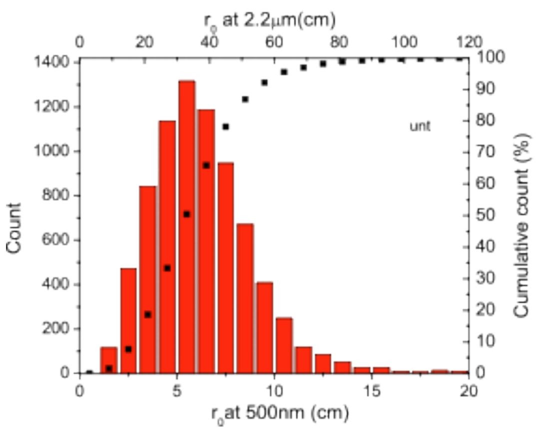
South Pole SODAR

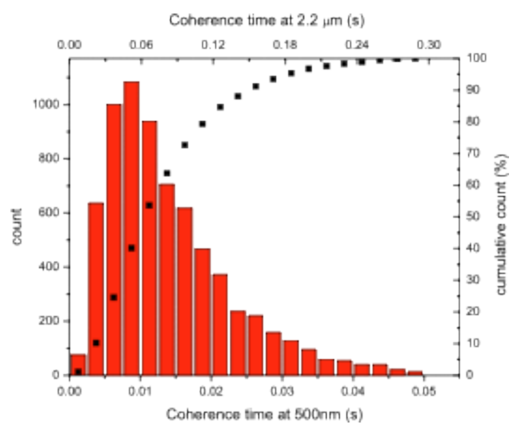


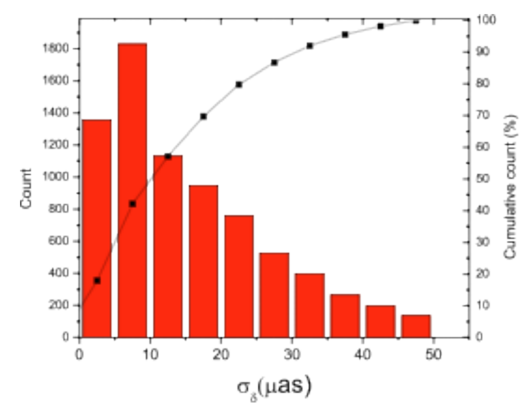
$$f_G = 30 \text{ Hz @ 500nm}$$

$$r_0 = 6 \text{ cm @ 500nm}$$

$$\sigma_\delta = 8\ \mu\text{as}\ (100\text{m}, 1\text{hr}, 1')$$







Travouillon et al 2003, Lloyd et al 2003

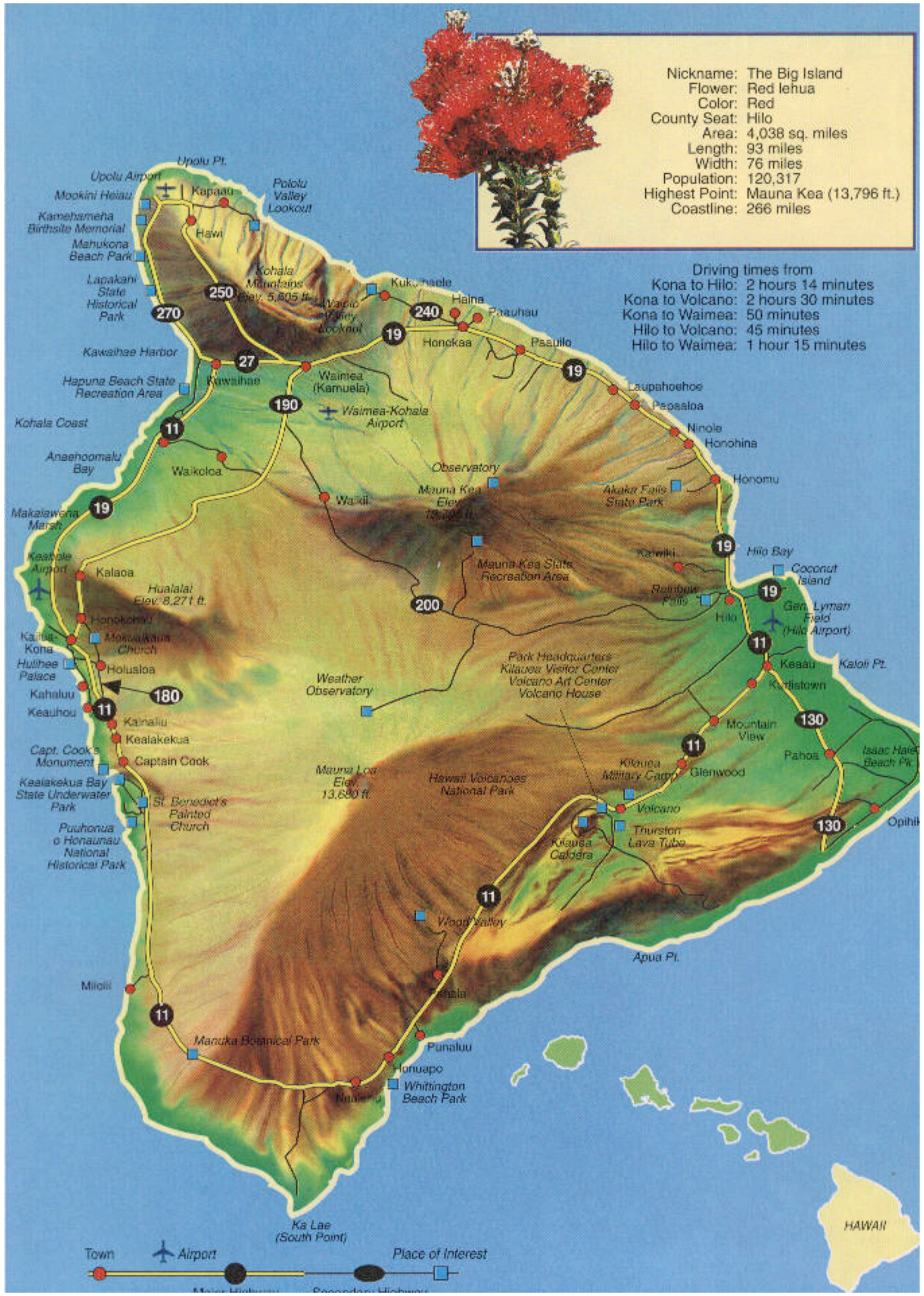
Myth

The seeing is bad at the South Pole

Myth

The seeing is bad at the South Pole

Yes, but it’s always raining in Waimea



Nickname: The Big Island
Flower: Red lehua
Color: Red
County Seat: Hilo
Area: 4,038 sq. miles
Length: 93 miles
Width: 76 miles
Population: 120,317
Highest Point: Mauna Kea (13,796 ft.)
Coastline: 266 miles
Driving times from
Kona to Hilo: 2 hours 14 minutes
Kona to Volcano: 2 hours 30 minutes
Kona to Waimea: 50 minutes
Hilo to Volcano: 45 minutes
Hilo to Waimea: 1 hour 15 minutes
Upolu Pt.
Upolu Airport
Mookini Heiau
Kamehameha Birthsite Memorial
Mahukona Beach Park
Lapakahi State Historical Park
Kawaihae Harbor
Hapuna Beach State Recreation Area
Kohala Coast
Anaehoomalu Bay
Makalawena Marsh
Keahole Airport
Kapaau
Hawi
Pololu Valley Lookout
Kohala Mountains Elev. 5,805 ft.
Waipio Valley Lookout
Kukuihaele
Haina
Paauhau
Honokaa
Paauilo
Laupahoehoe
Papaaloa
Ninole
Honohina
Honomu
Akaka Falls State Park
Kawaihae
Waimea (Kamuela)
Waimea-Kohala Airport
Waikoloa
Observatory
Mauna Kea Elev. 13,796 ft.
Mauna Kea State Recreation Area
Rainbow Falls
Hilo
Hilo Bay
Coconut Island
Gen. Lyman Field (Hilo Airport)
Keaau
Kaloli Pt.
Kurtistown
Mountain View
Pahoa
Isaac Hale Beach Pk.
Opihikao
Glenwood
Kilauea Military Camp
Volcano
Thurston Lava Tube
Kilauea Caldera
Park Headquarters Kilauea Visitor Center Volcano Art Center Volcano House
Weather Observatory
Hualalai Elev. 8,271 ft.
Kalaoa
Honokohau
Mokuaikaua Church
Kailua-Kona
Hulihee Palace
Holualoa
Kahaluu
Keauhou
Kainaliu
Kealakekua
Captain Cook
Capt. Cook's Monument
Kealakekua Bay State Underwater Park
St. Benedict's Painted Church
Puuhonua o Honaunau National Historical Park
Mauna Loa Elev. 13,680 ft.
Hawaii Volcanoes National Park
Wood Valley
Apua Pt.
Pahala
Punaluu
Honuapo
Whittington Beach Park
Naalehu
Milolii
Manuka Botanical Park
Ka Lae (South Point)
HAWAII
Town
Airport
Place of Interest

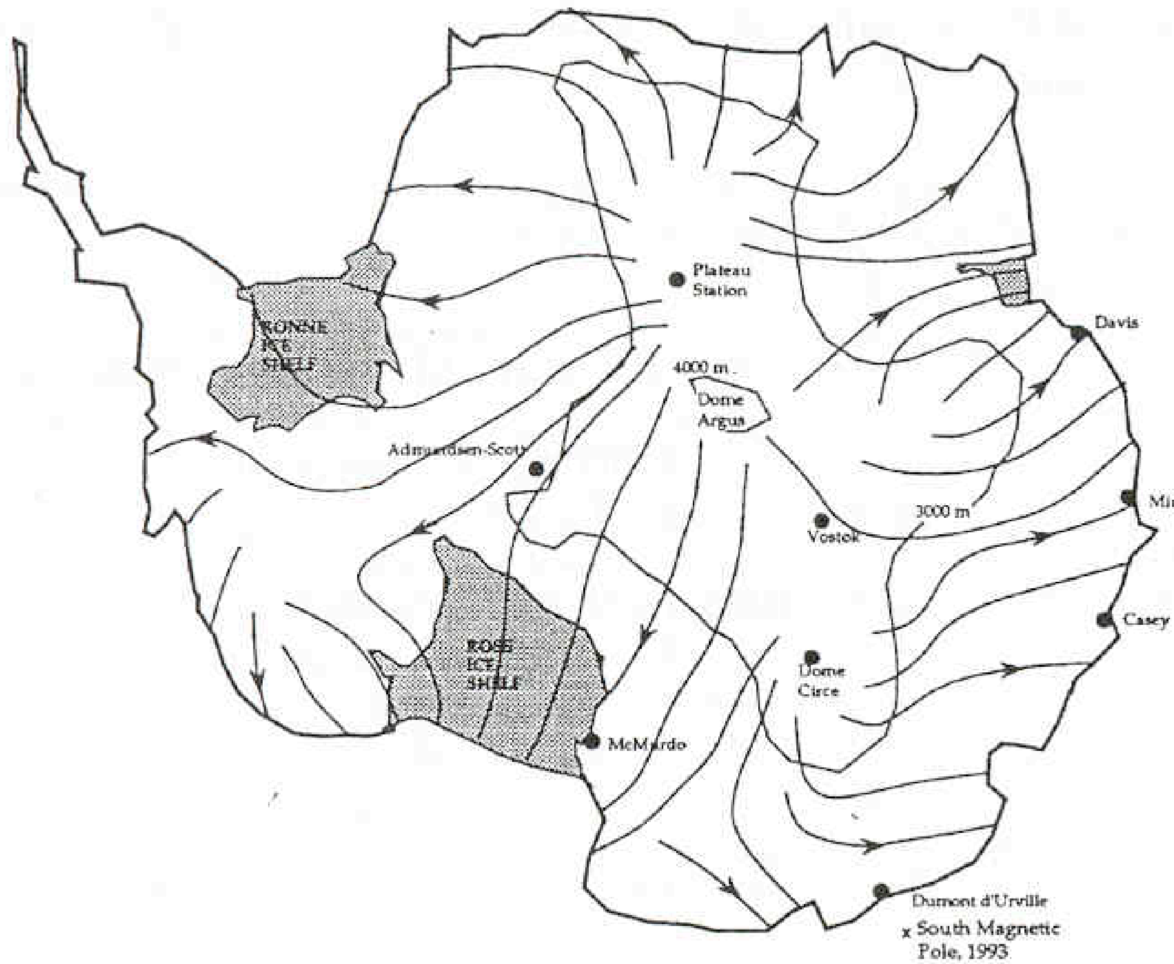
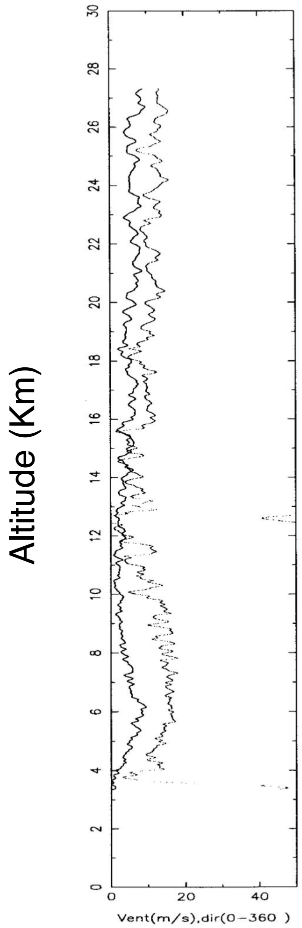


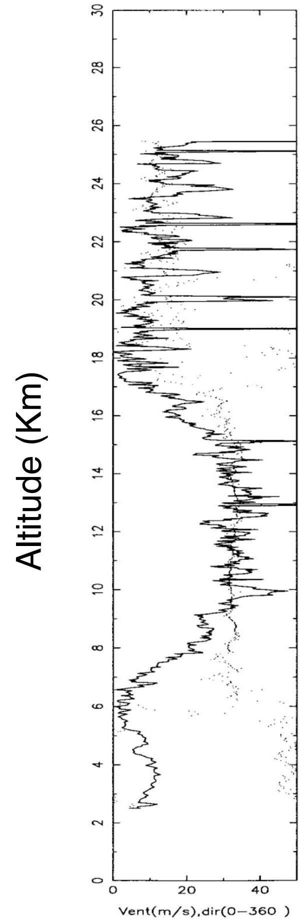
Fig. 8. Contour map of surface wind speeds over Antarctica, from Dopita 1993, based on results of Schwerdtfeger 1984

Marks et al., A&A Sup., 134, 1999

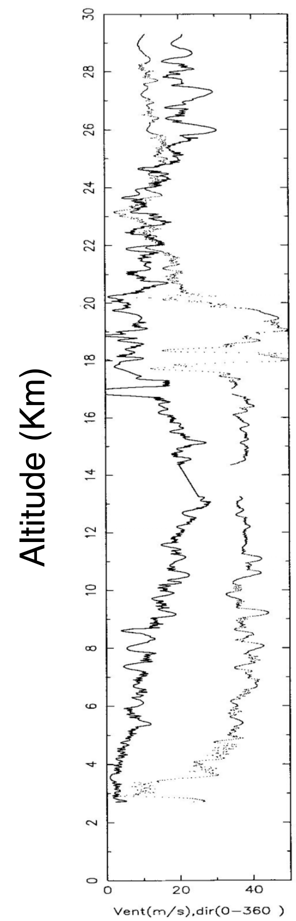
Wind Speed Profiles (University of Nice)



Dome C
(Dec 2000)



Paranal ESO
Chile (1992)



Gemini NOAO
Chile (1998)

Agabi and Fossat (2003)

Dome C

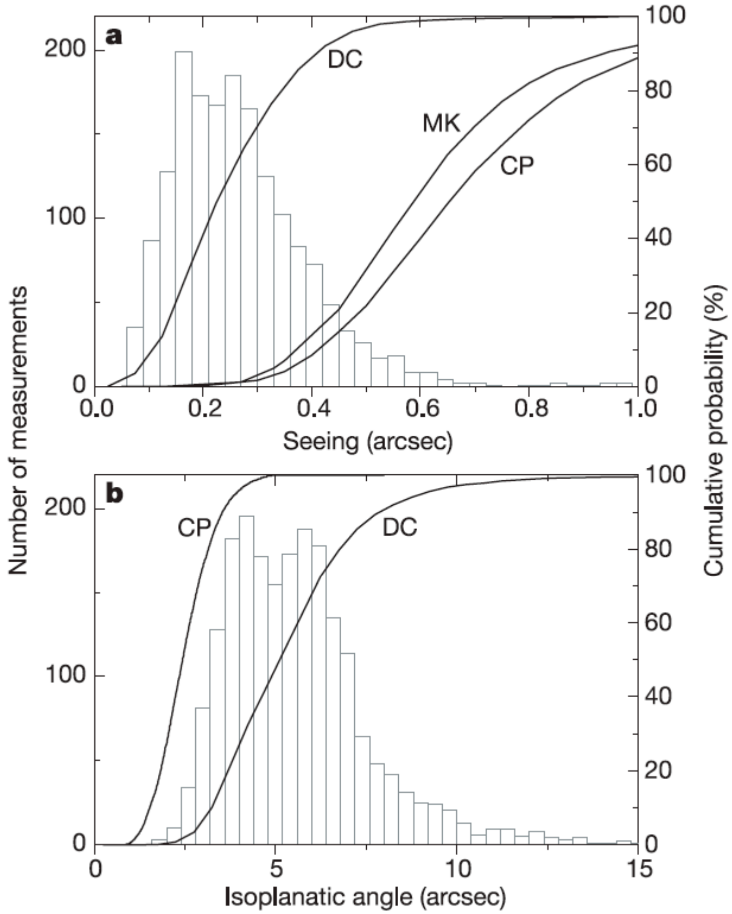


Figure 3 Histograms and cumulative distributions of the atmospheric seeing and the isoplanatic angle. **a**, Histogram of Dome C seeing above 30 m from MASS combined with SODAR, and cumulative distributions of seeing at Dome C (DC), Mauna Kea (MK) (derived from ref. 4), and Cerro Paranal (CP)[2]. **b**, Histogram of Dome C isoplanatic angle derived from the MASS instrument, and the cumulative distribution of isoplanatic angle from Dome C and Cerro Paranal[2].

Lawrence et al, Nature, 2004

The Antarctic Plateau Interferometer

http://www.antarctic-interferometer.org

The Antarctic Plateau Interferometer

The Antarctic Plateau Interferometer (API) is a concept for unique discovery space science enabled by deploying an optical/infrared interferometer at the best accessible site on Earth. Our concept would rely on packaging proven interferometer technology in standard shipping containers for Northern hemisphere sky testing and modular Antarctic deployment. Capable of a broad science program, API would concentrate on key science questions, including the characterization of both exoplanet formation and exoplanets in the habitable zone.

Latest News

25 Mar 05 Harvey Mudd College Clinic Team completes initial analysis of accelerometer data from Dome C traverse

11 Mar 05 Antarctic interferometry presentation tour (12 presentations in 7 countries finishes at Exeter England)

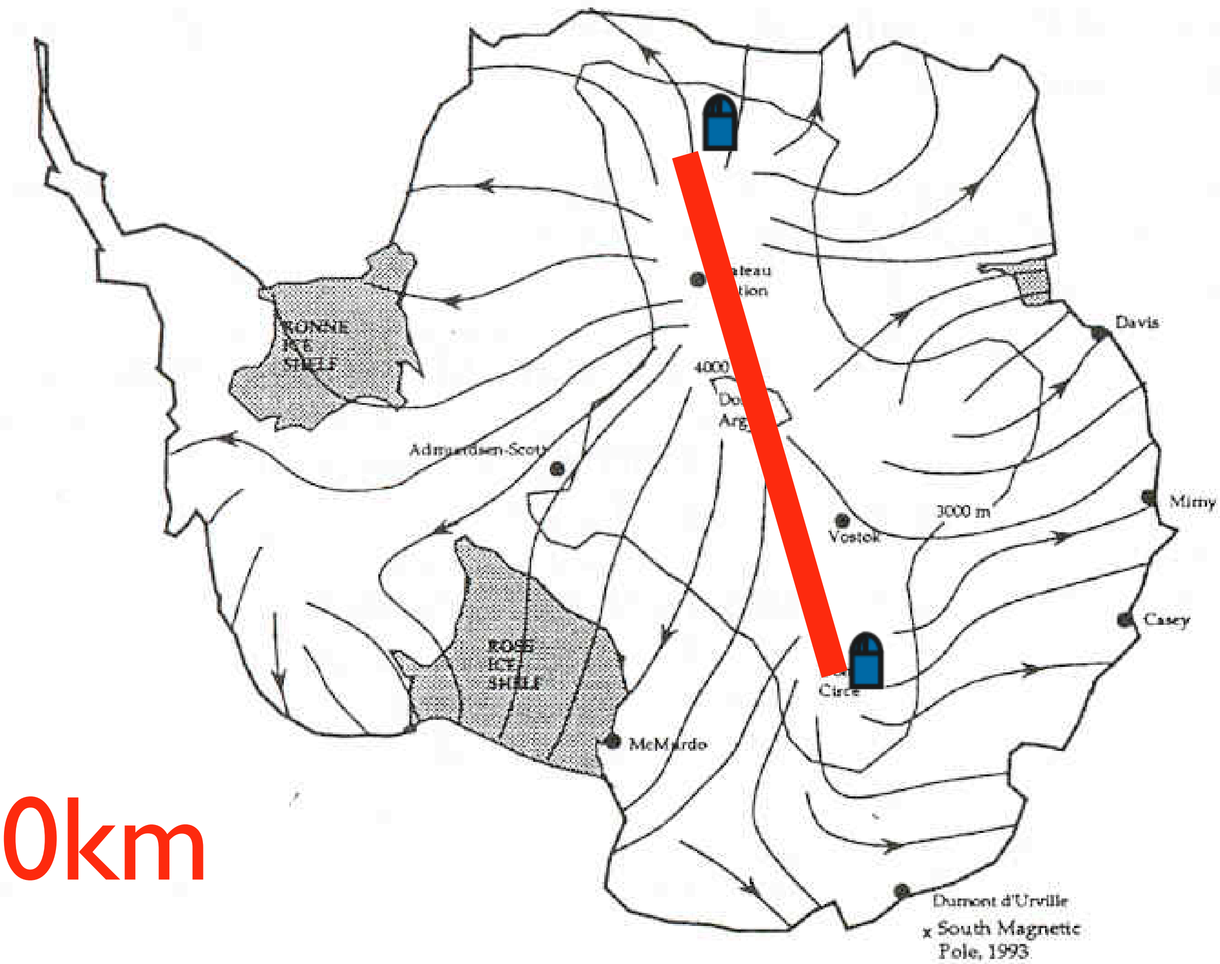
14 Feb 05 Potential for Antarctic interferometry presented to NASA road mapping committee

Mark Swain	Laboratoire d'Astrophysique de Grenoble
Wesley Traub	Harvard-Smithsonian Center for Astrophysics
Chris Walker	University of Arizona
Vincent Coudé du Foresto	l'Observatoire de Paris-Meudon-Nançay
James Lloyd	Cornell University
John Storey	University of New South Wales
Gerard van Belle	Michelson Science Center
Andrew Booth	Jet Propulsion Laboratory
Geoffrey Bower	University of California Berkeley
Adam Burrows	University of Arizona
Michelle Creech-Eakman	New Mexico Institute of Mining and Technology
David Ciardi	Michelson Science Center
Chris Koresko	Michelson Science Center
Benjamin Lane	Massachusetts Institute of Technology
Robert Ligon	Jet Propulsion Laboratory
Patrick Little	Harvey Mudd College
Roger Lynds	National Optical Astronomy Observatory
Fabien Malbet	Laboratoire d'Astrophysique de Grenoble
Rafael Millan-Gabet	Michelson Science Center
Antony Stark	Harvard-Smithsonian Center for Astrophysics
Tony Travouillon	California Institute of Technology
Gautam Vasisht	Jet Propulsion Laboratory

A Final Thought

Interferometrist's rule of thumb: Interferometers grow to fill the available space on their mountaintop

~3000km



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Marks et al., A&A Sup., 134, 1999