A lifetime exploring atmospheric and space physics

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ELF Electromagnetic Waves and Ionospheric Physics Seminar

Krakow ELF Group, Poland

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Introduction: education and career

- Born, 15 July 1938
- Citizen of the world, European, British
- Education: Merchant Taylors School, 1951-57
- Undergraduate, BSc: Imperial College, London, Physics with Ancillary Maths, 1957-60
- Postgraduate, PhD: Churchill College, Cambridge University, and Cavendish Laboratory, Meteorological Physics Group, 1960-63
- Post-doc: NASA Ames Research Center, California, U.S.A., 1964-65
- Post-doc: Space Physics Group, Imperial College, 1965-66
- Lecturer: Department of Physics, University of Southampton, 1966-79. Established Space Radio Physics Group, and Geophysical Sciences degree between departments of Geology, Oceanography and Physics. One of five British candidates for Payload Specialist aboard Spacelab. Joint Editor, annual COSPAR volumes
- Division Head, British Antarctic Survey, Cambridge, 1979-90
- Professor of Aerospace, Cranfield University, 1990-94. Also Editor in Chief, JASTP
- Head of School, International Space University, Strasbourg, France, 1995-99. Continuing as Editor in Chief, JASTP
- Retirement (!). Editor in Chief, Surveys in Geophysics, 2001-25
- Conclusion: “variety is the spice of life”

The English language

William Wordsworth, 1804

I wandered lonely as a cloud

That floats on high o’er vales and hills,

When all at once I saw a crowd,

A host, of golden daffodils;

Beside the lake, beneath the trees,

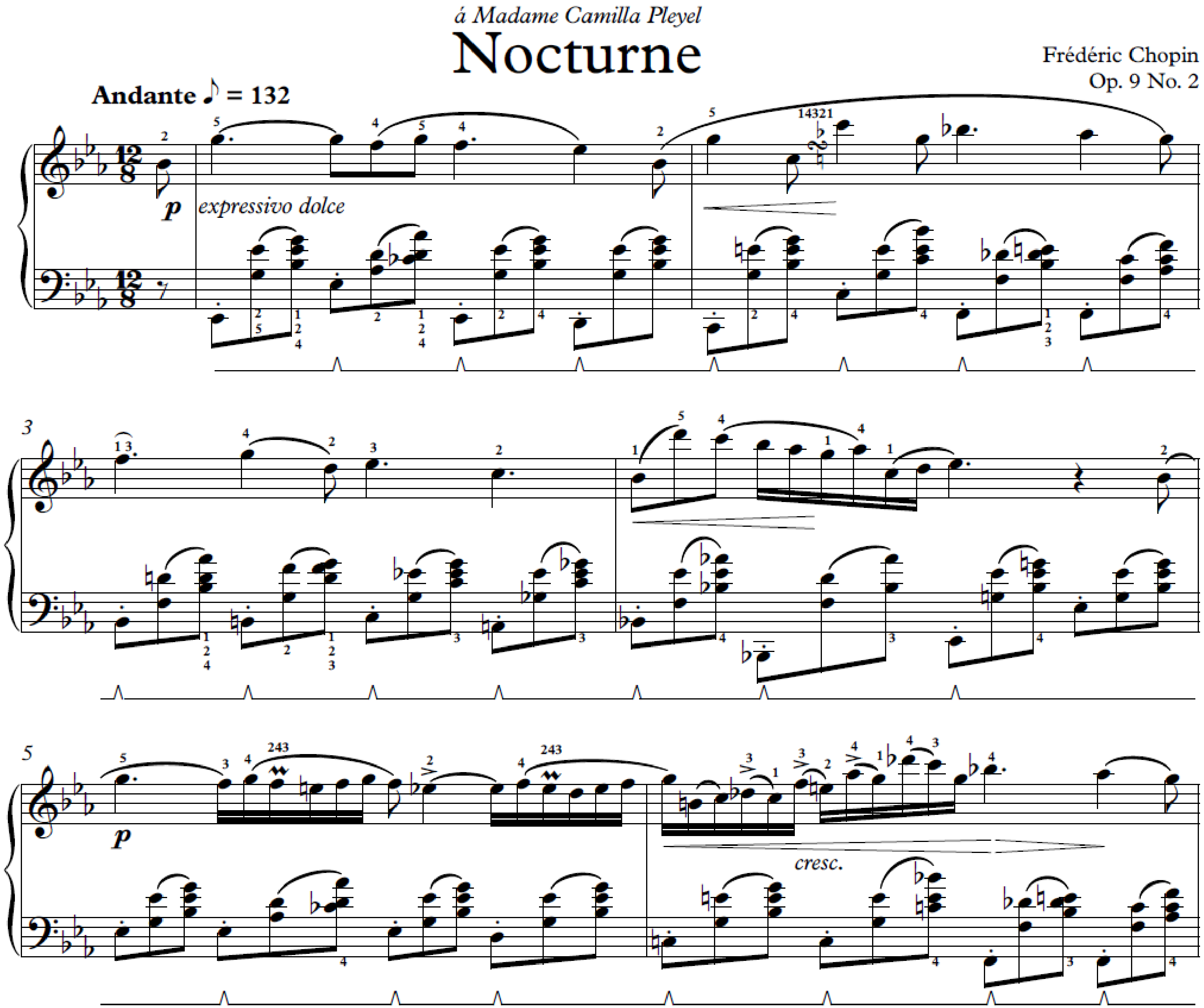
Fluttering and dancing in the breeze.

John Constable paintings

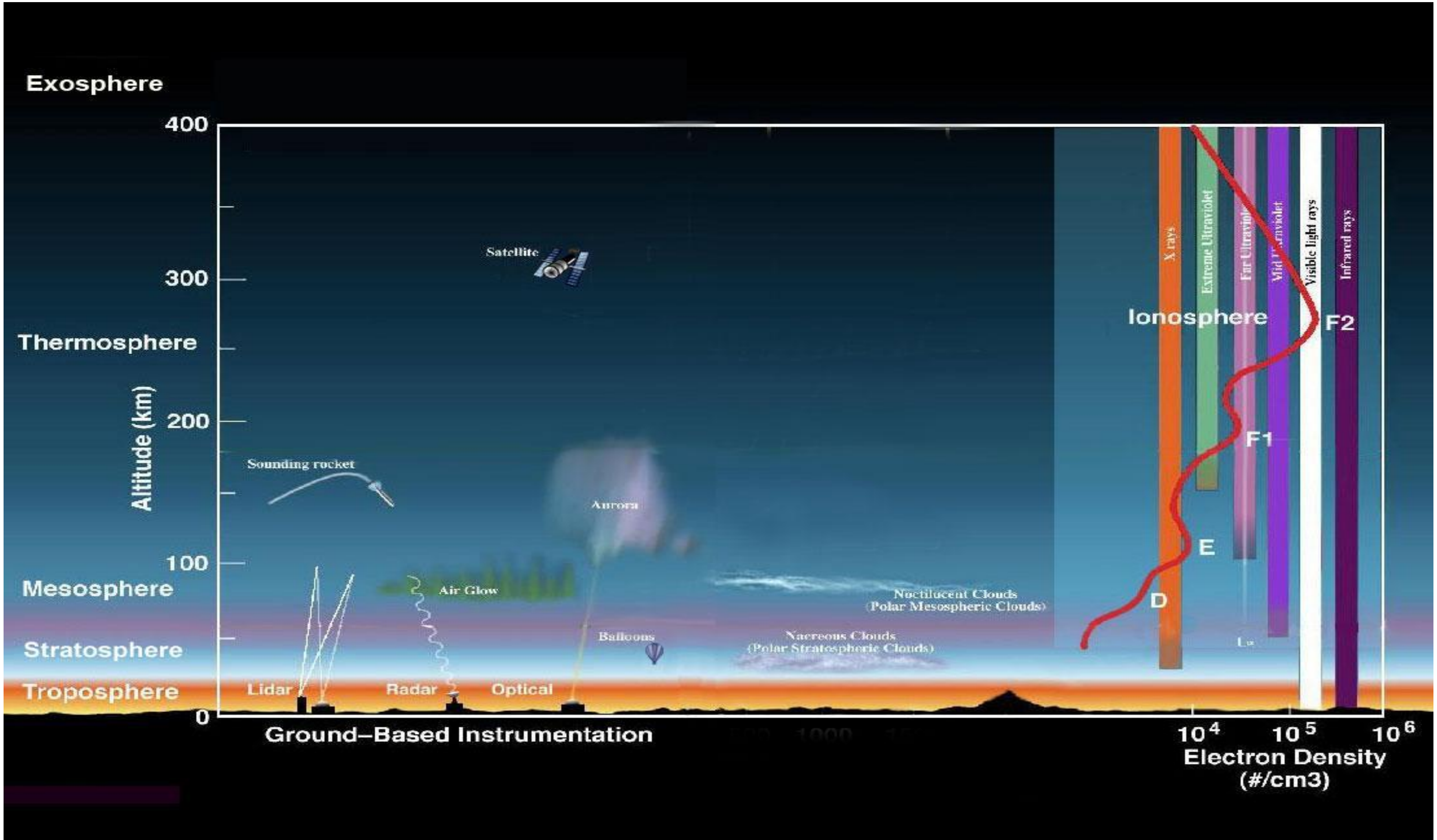
Salisbury Cathedral, 1830

Clouds, 1822

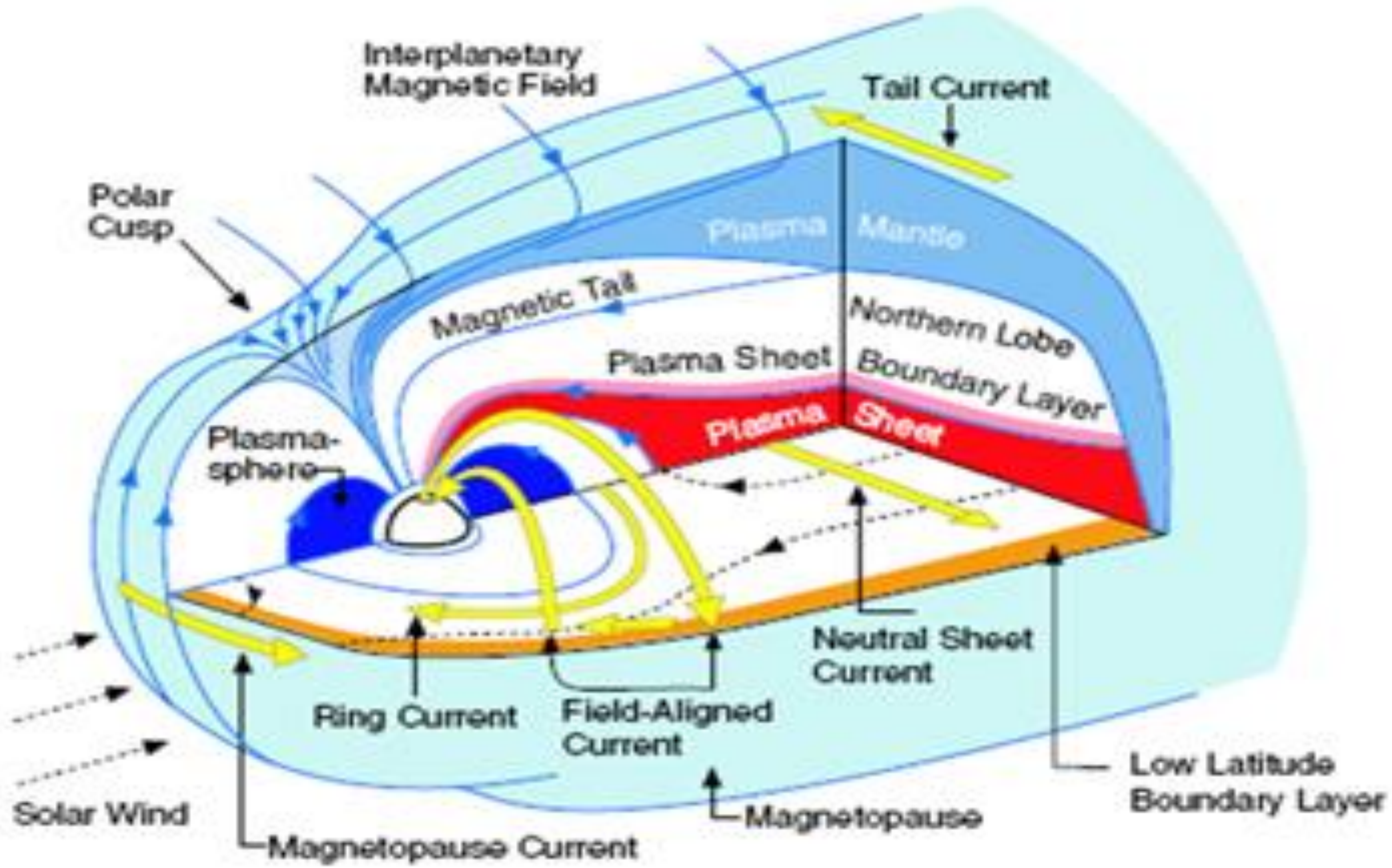
Classical music



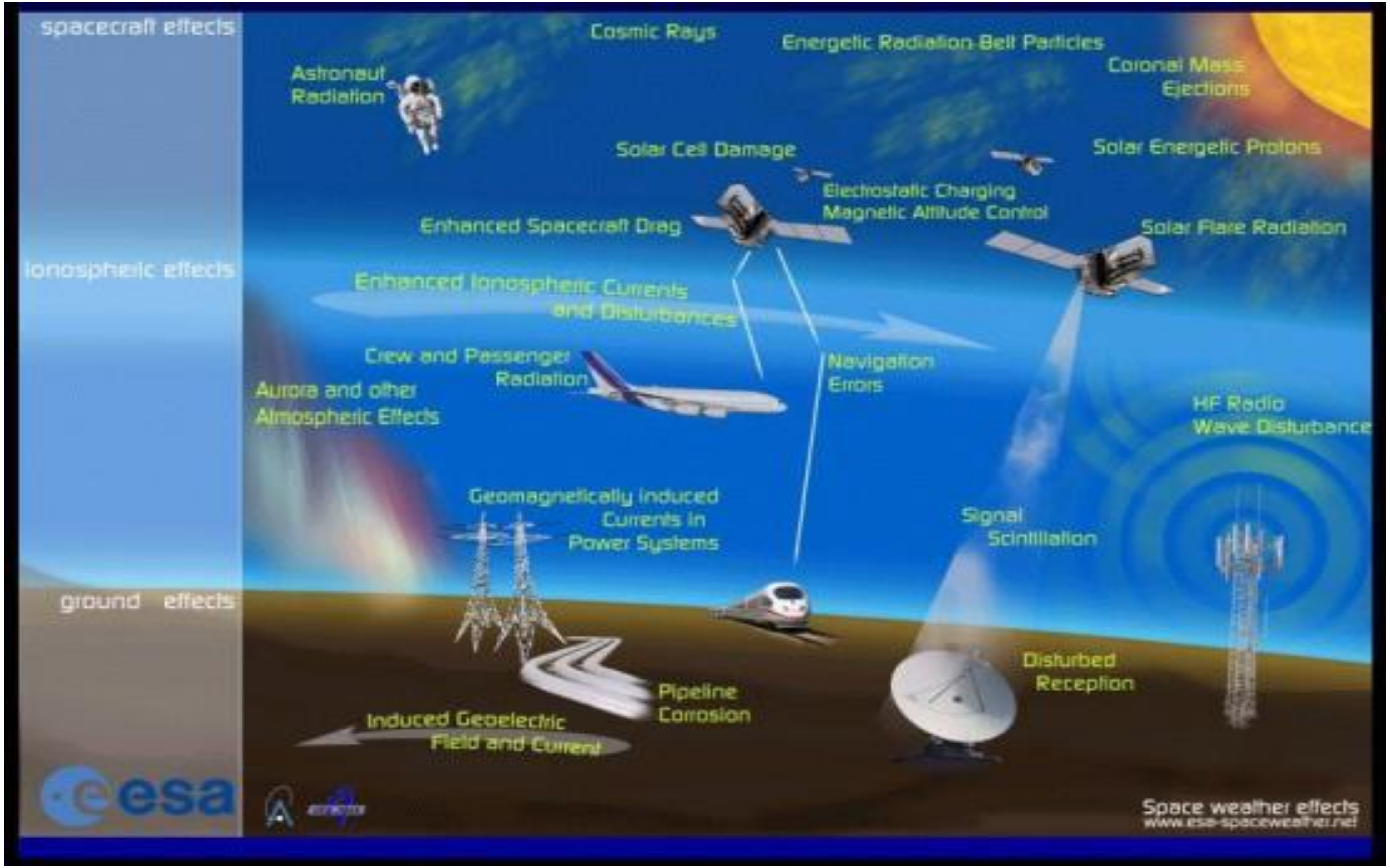
Atmospheric and Space Physics: the laboratory



The Magnetosphere: the Space Physics laboratory



The Importance to Society of Space Weather effects



The Aurora as seen from the International Space Station

Apollo 8 astronaut, Christmas Eve 1968:
Earth as “A grand oasis in the vastness of space”

Whether we are from the old world or from the new, based on our knowledge and understanding we seek the truth (not necessarily a turn to the right!)

Observations of Schumann resonances

Rycroft, JResNBS, 1965 — Pizutti et al., Atmosphere, 2021

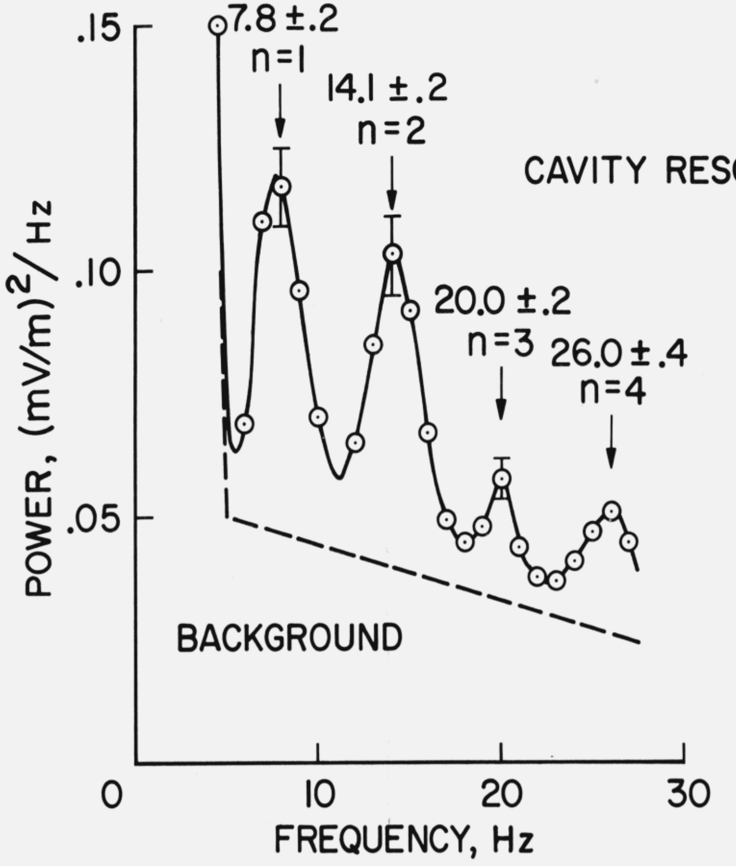
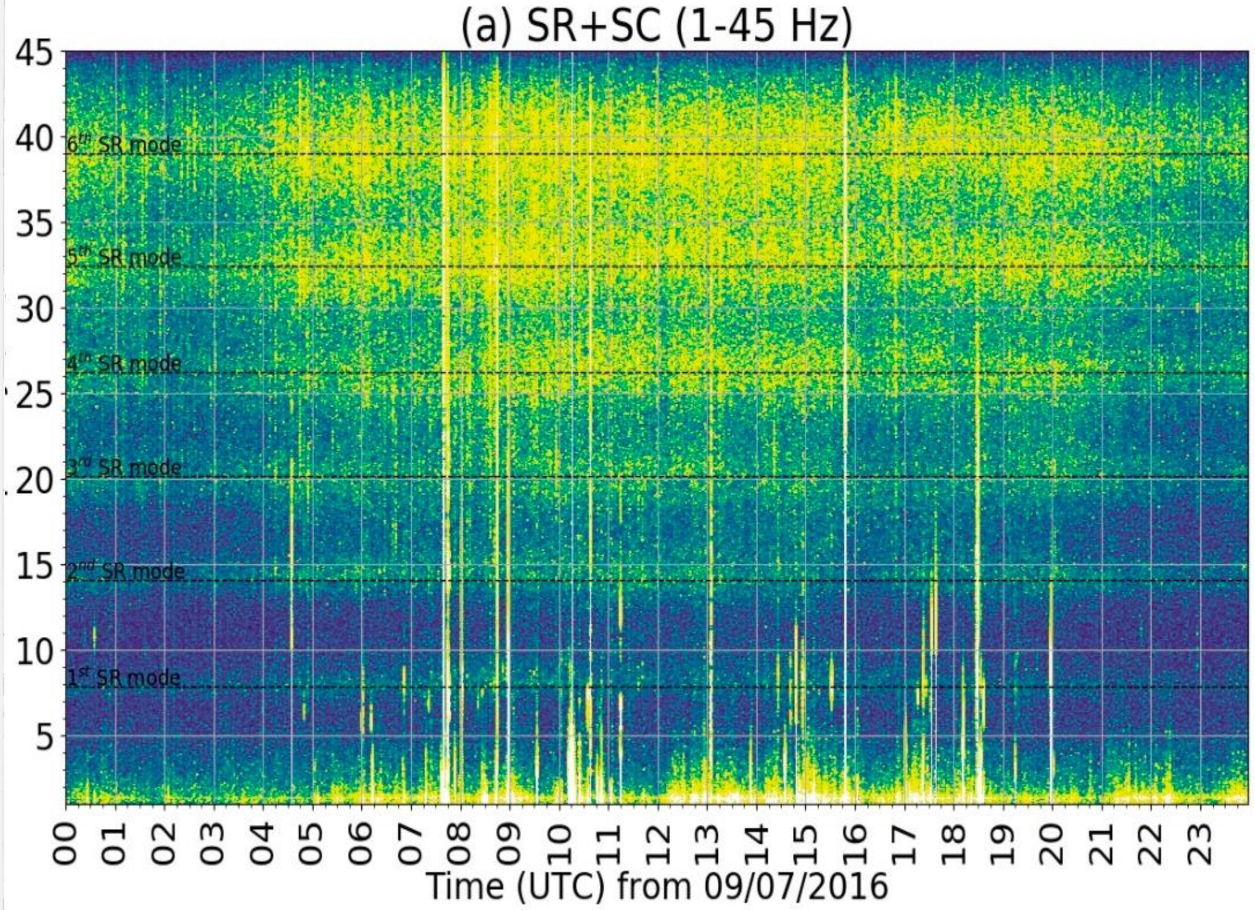
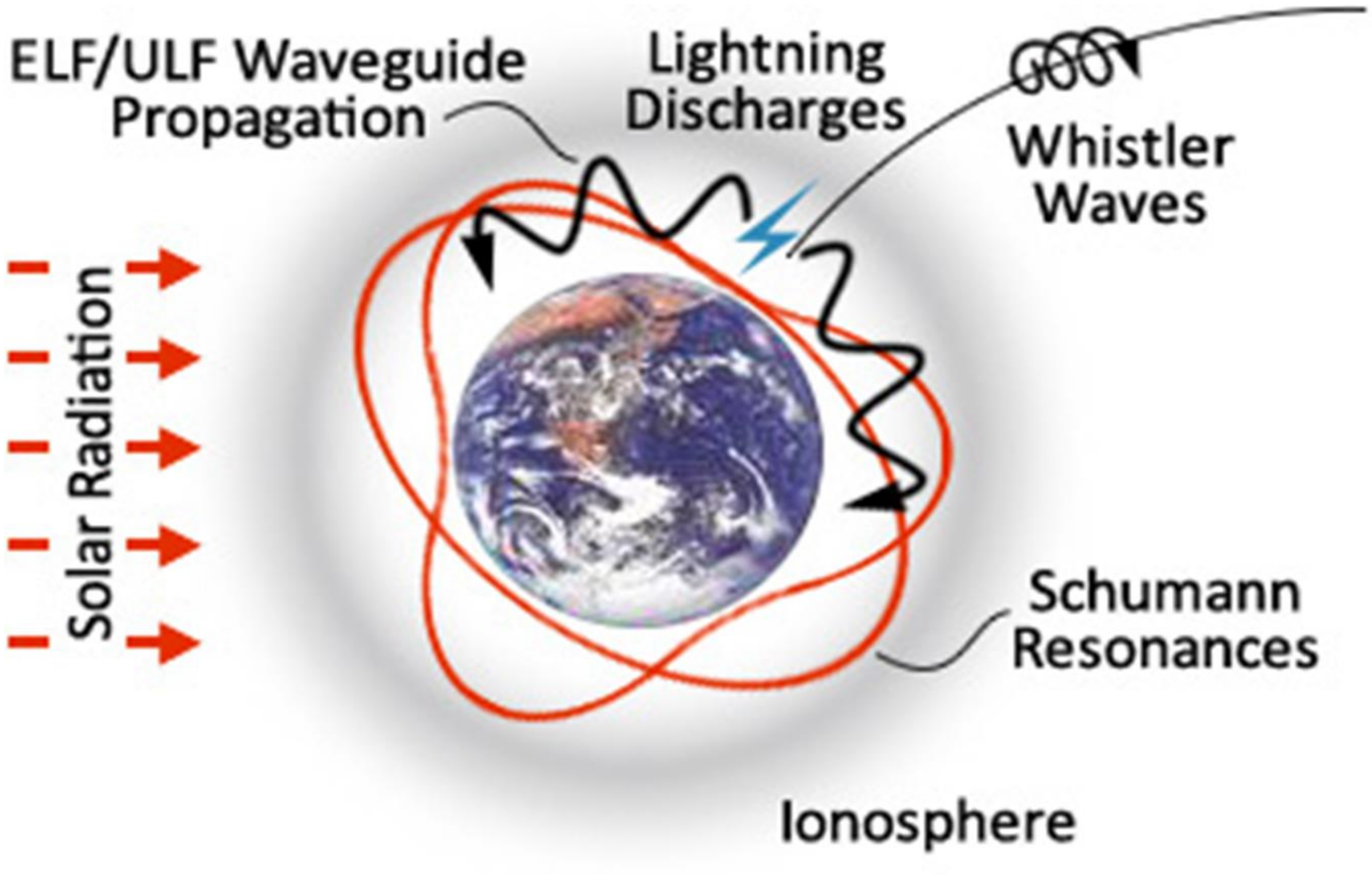


FIGURE 6. *Mean ELF spectrum of the natural vertical electric field observed in 1962 and 1963.*

The similarity of this spectrum to those presented by Gendrin and Stefant [1964] and Stefant [1963] may be noted. Only when the background spectrum shown by the dashed line is subtracted from the mean ELF spectrum do these observations compare with those of Balser and Wagner [1960]. The calculations of Galejs [1963] may be fitted to the observations of Balser and Wagner [1960]. The bars denote the standard error of the mean power at each resonance, derived from 31 records.



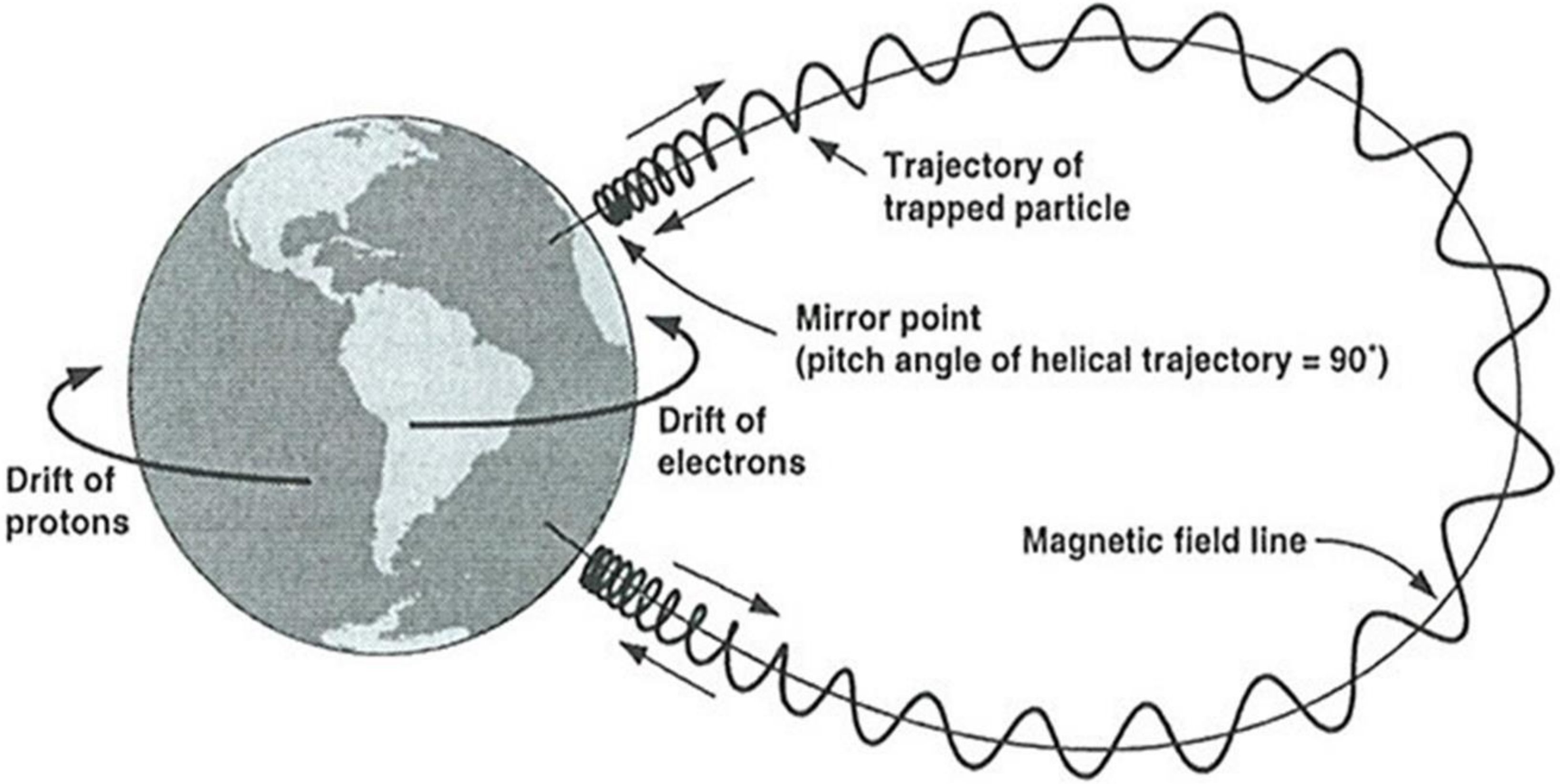
Schumann resonances and whistlers



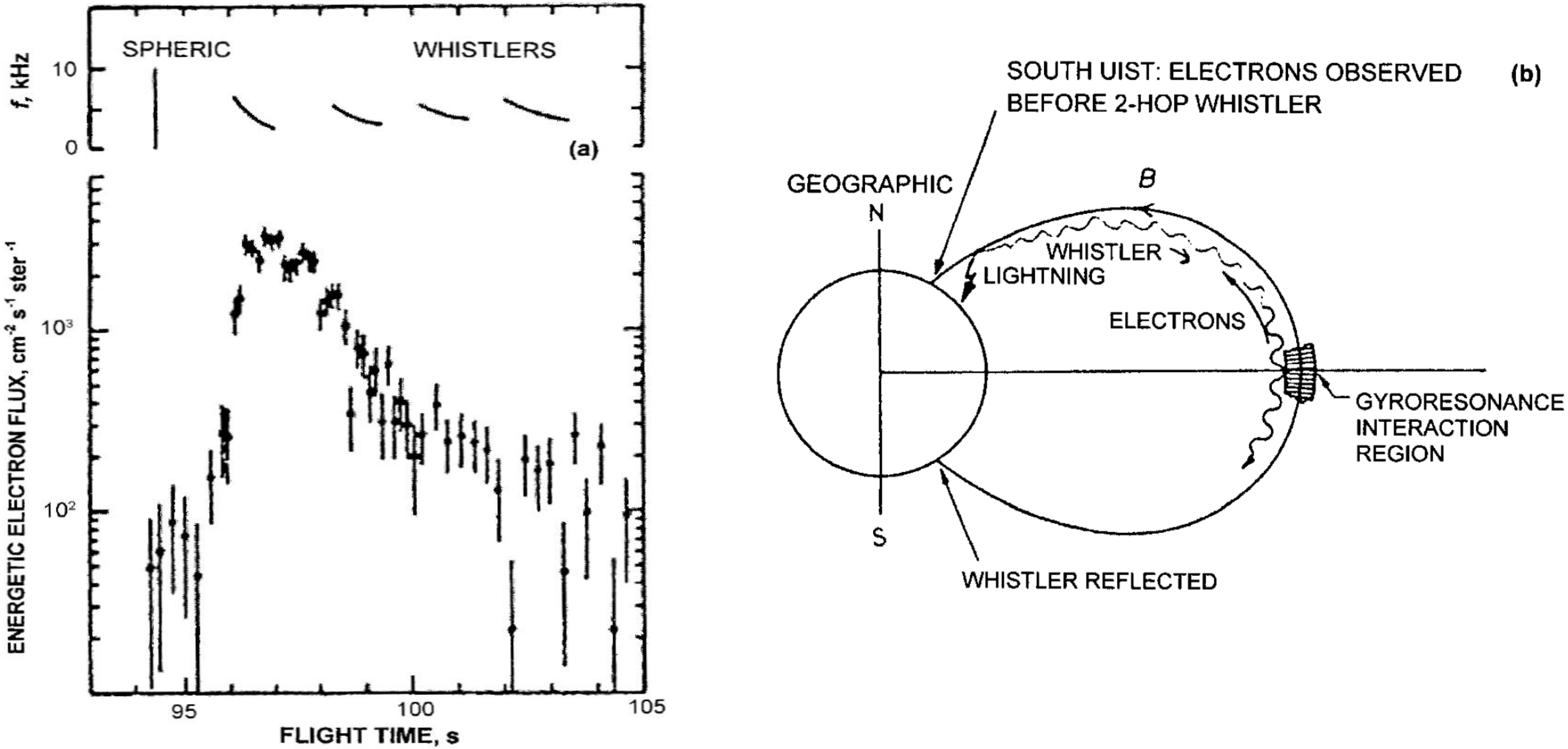
Present situation: Schumann resonances and ELF radio

- Amazingly, still a very active research area, 73 years after Schumann (1952)
- From the analysis of 20 s samples of 1 component in 1962, to analysis of continuous records of 6 components in 2022
- Enormous progress, due to rapid advances in computer technology
- Miracle of the Internet: Google and Google Scholar
- Important in relation to geolocation of lightning discharges around the world, and their seasonal variations
- And in relation to climate change
- New area: are there relationships between Schumann resonances and ELF and the human brain, human health, or other biological or natural phenomena?
- Palmer S J, Rycroft M J, Cermak M (2006). Solar and geomagnetic activity, extremely low frequency magnetic and electric fields and human health at the Earth's surface. Surv Geophys **27**, 557–595

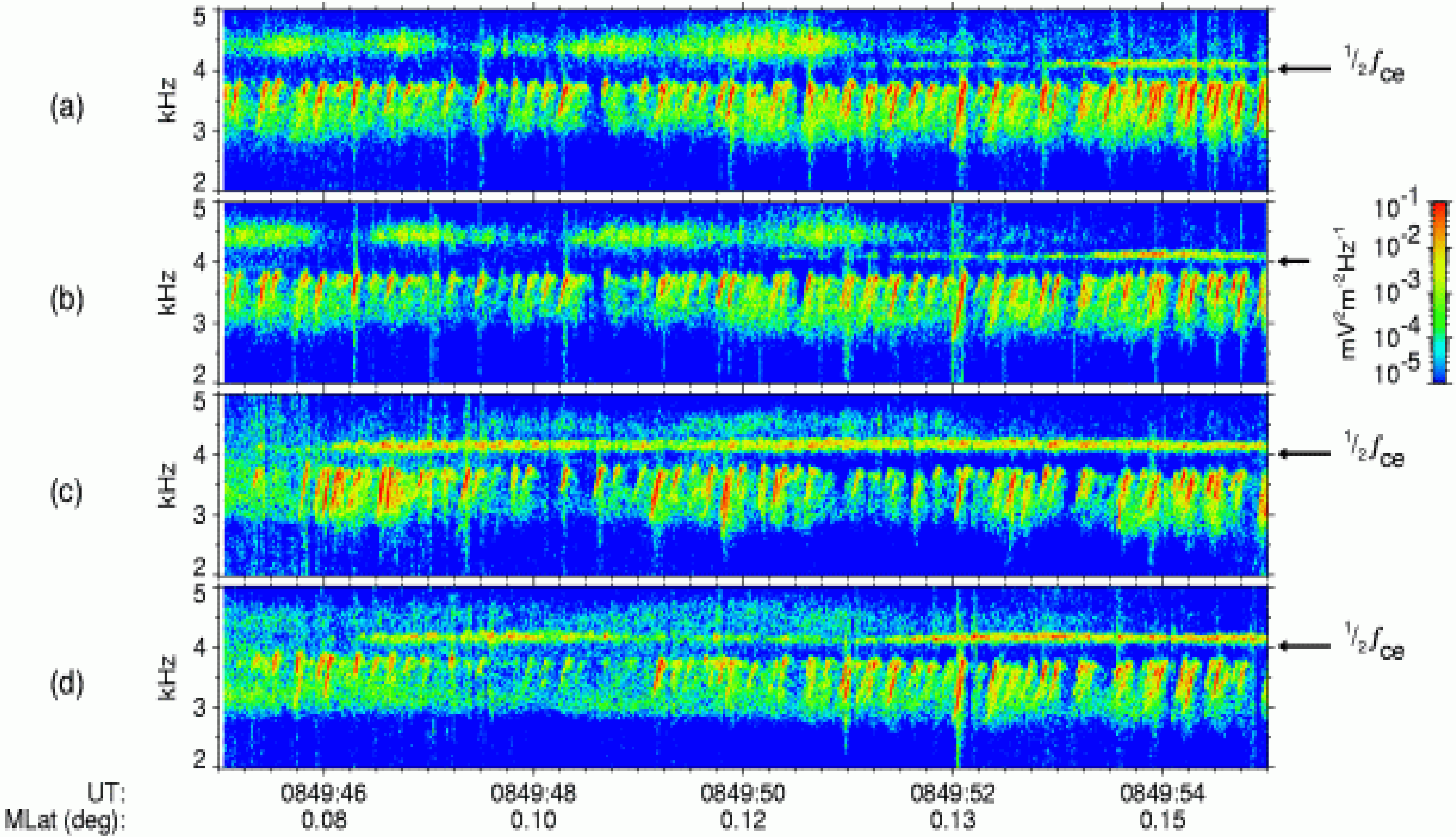
Charged particle motions in the dipolar geomagnetic field



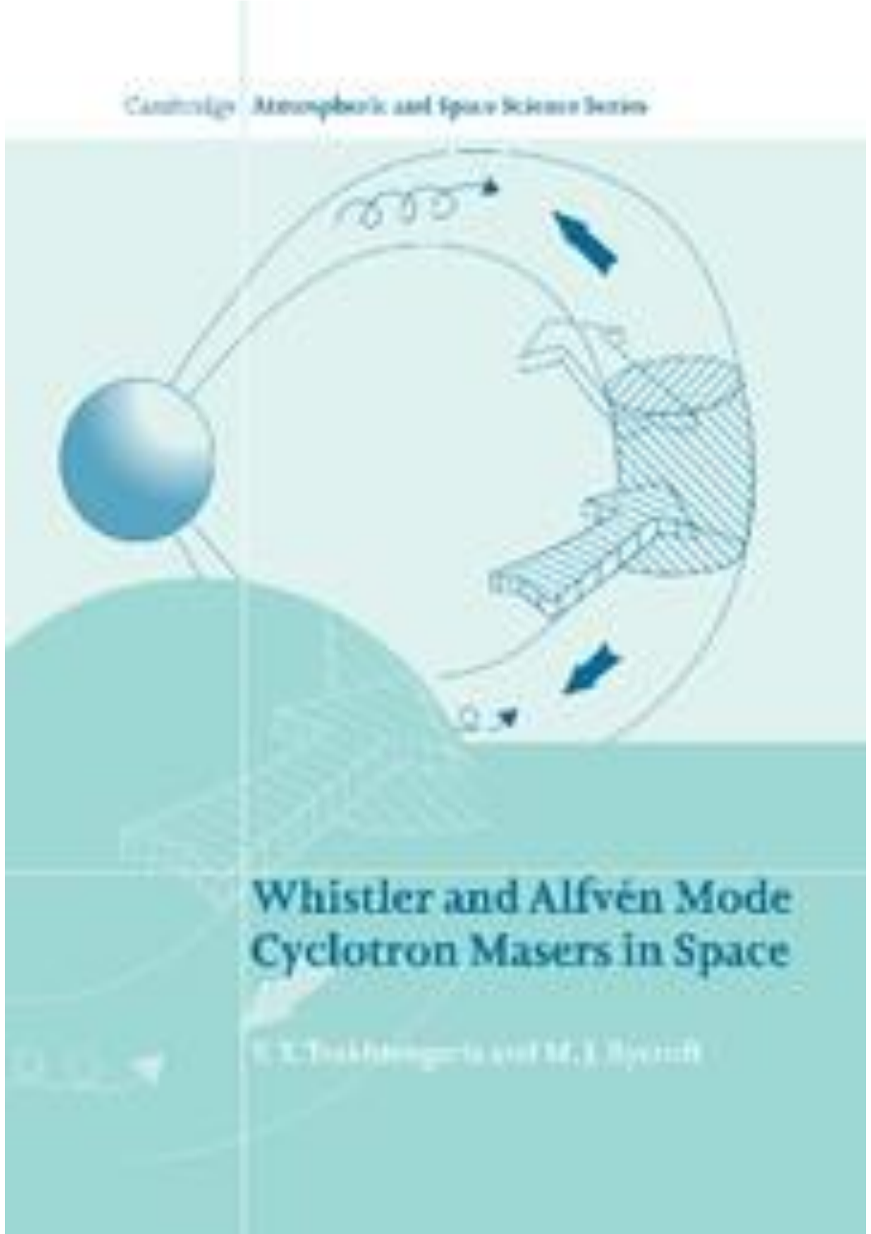
Rycroft M J (1973). Enhanced energetic electron intensities at 100 km altitude and a whistler propagating through the plasmasphere. Planet. Space Sci. **21**, 239–251



Chorus emissions, both lower band and upper band, observed by four Cluster spacecraft near the geomagnetic equator



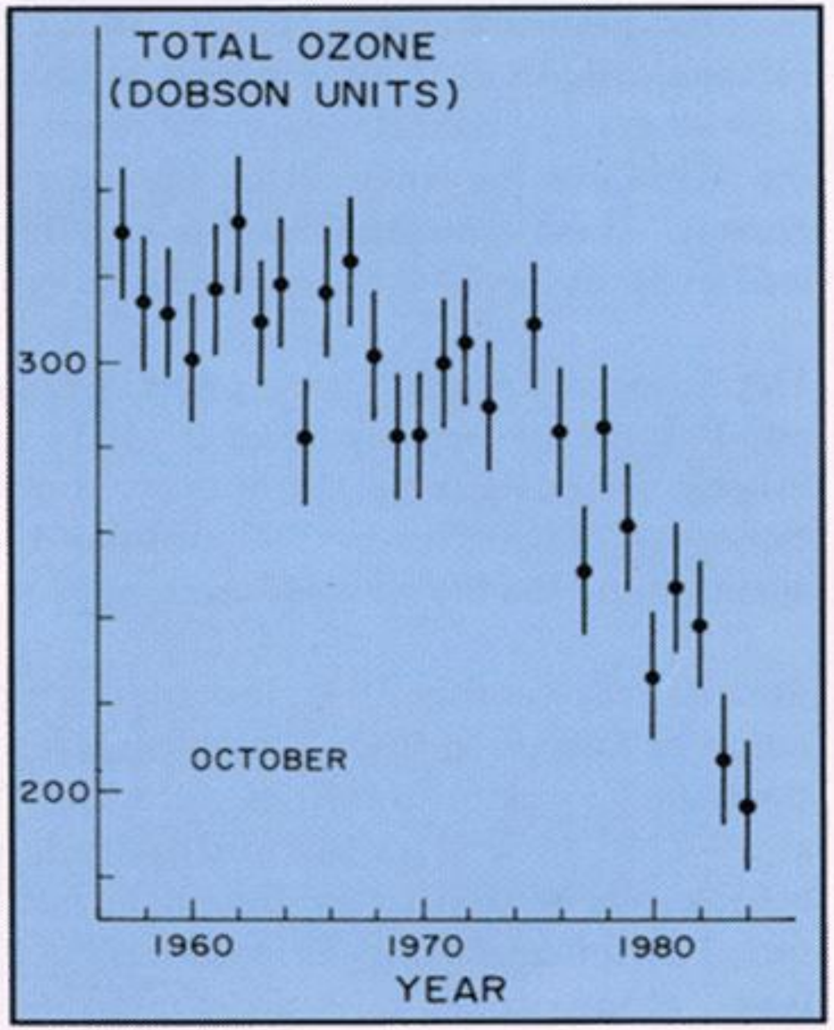
A privilege to work with Victor Trakhtengerts: CUP, 2008



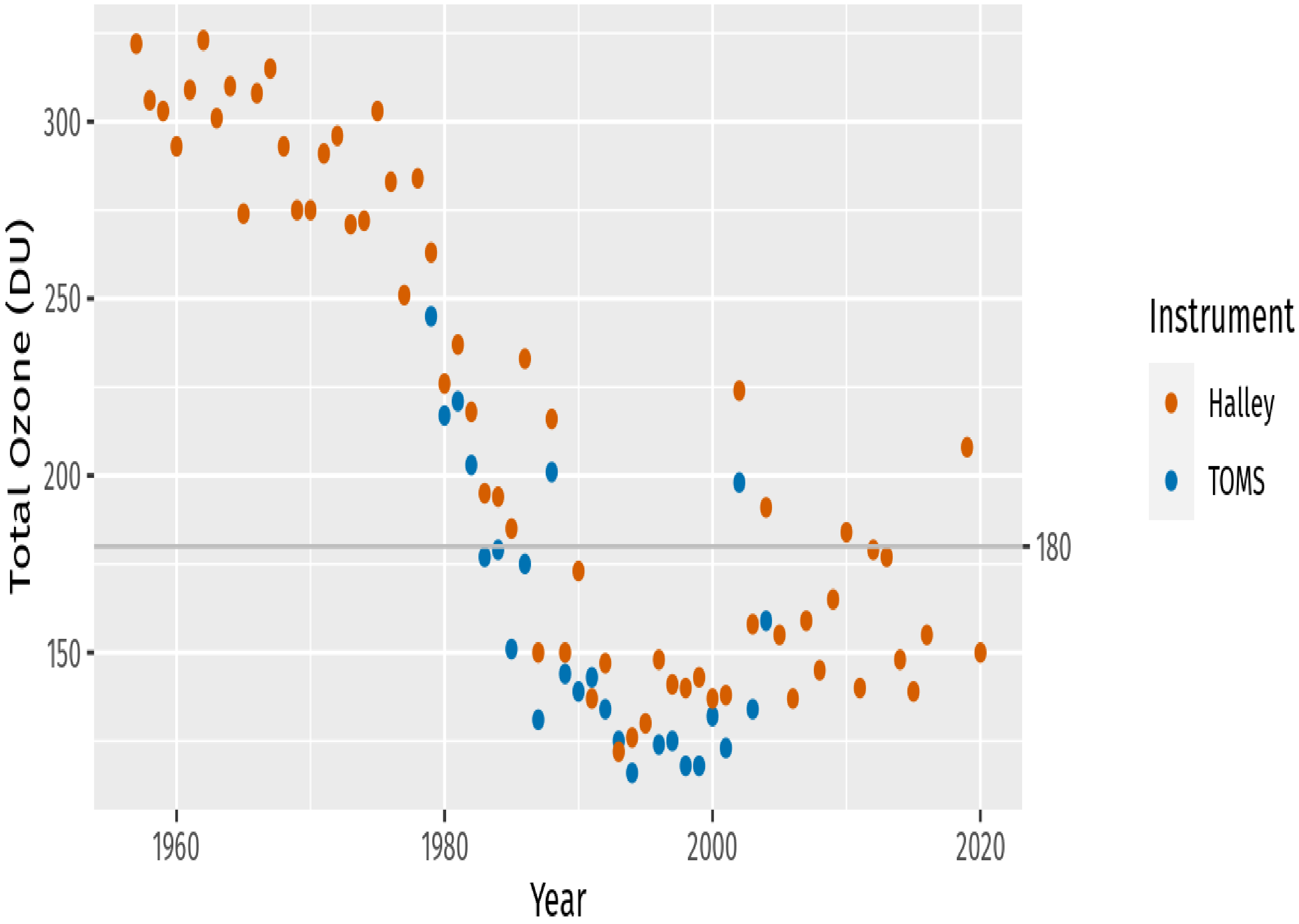
Present situation: whistler mode signals and ELF/VLF emissions

- Natural whistlers and whistler mode emissions interact with trapped energetic electrons in the van Allen belts, accelerating some, and changing the pitch angles of others, and so determine their lifetimes
- Important in terms of space weather effects on different technologies (e.g., GNSS, electrical grids), of relevance to society
- Advanced theoretical work on changes to the distribution functions of energetic electrons caused by whistler mode waves
- Continuing interest in wave-particle interactions in geospace, in interplanetary space and the magnetospheres of other planets, the Sun and other celestial bodies
- Radiation damage to astronauts and electronic equipment aboard satellites

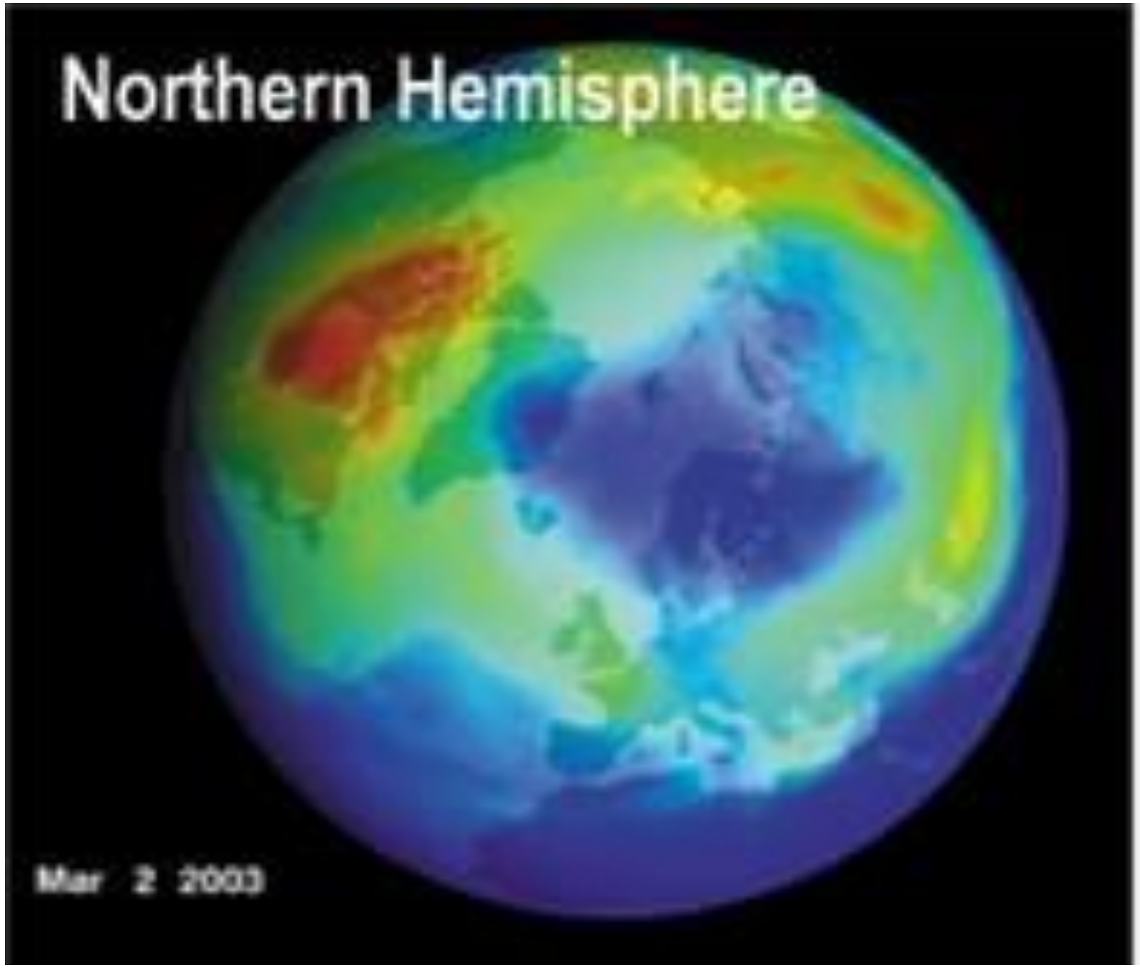
Ozone in atmosphere above Halley, Antarctica

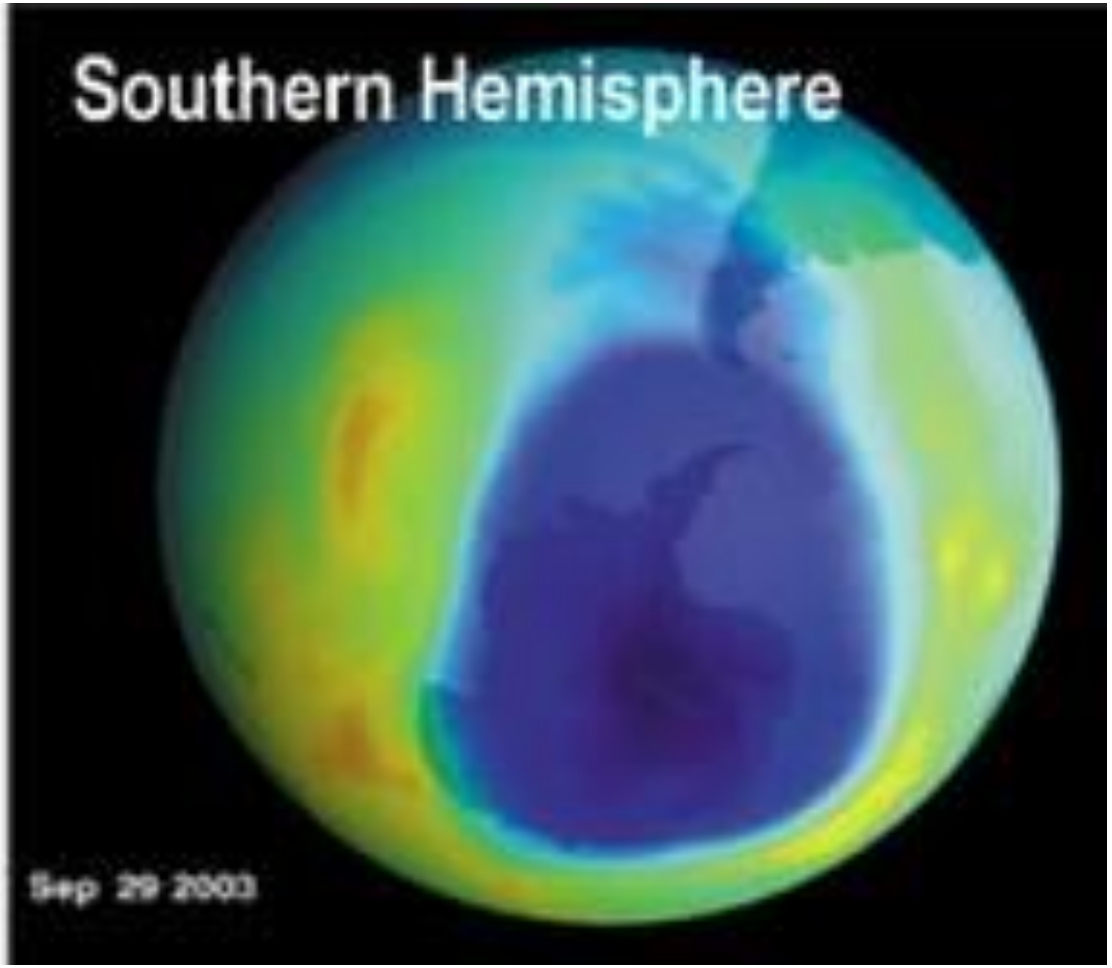


The first sign of the Ozone Hole: October ozone amounts at Halley Bay, Antarctica.

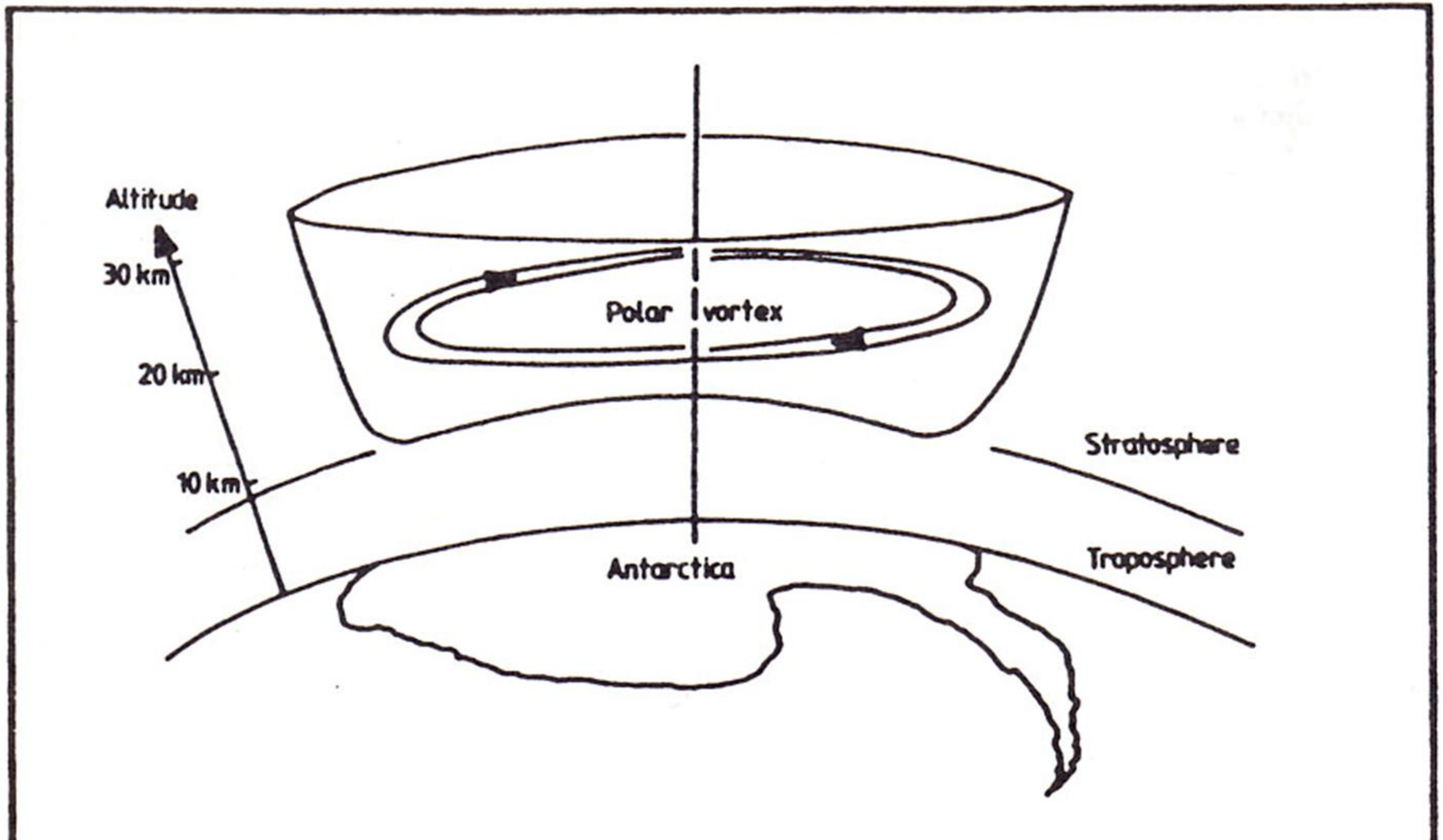


Ozone depletion over the poles in spring





Polar vortex is filled from above with CFCs (freons): chlorine catalytically destroys ozone

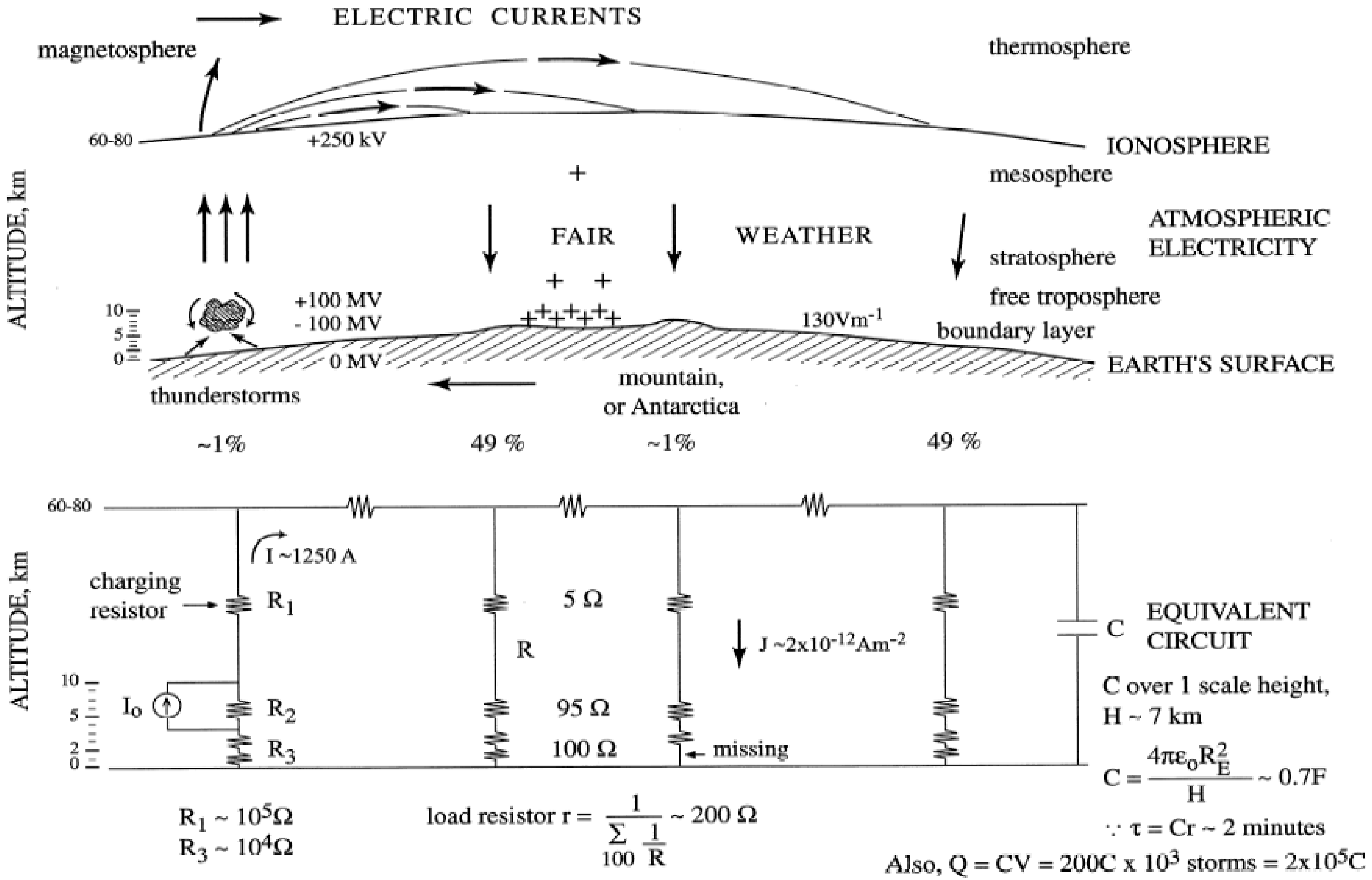


Present situation: anthropogenic changes to the atmosphere

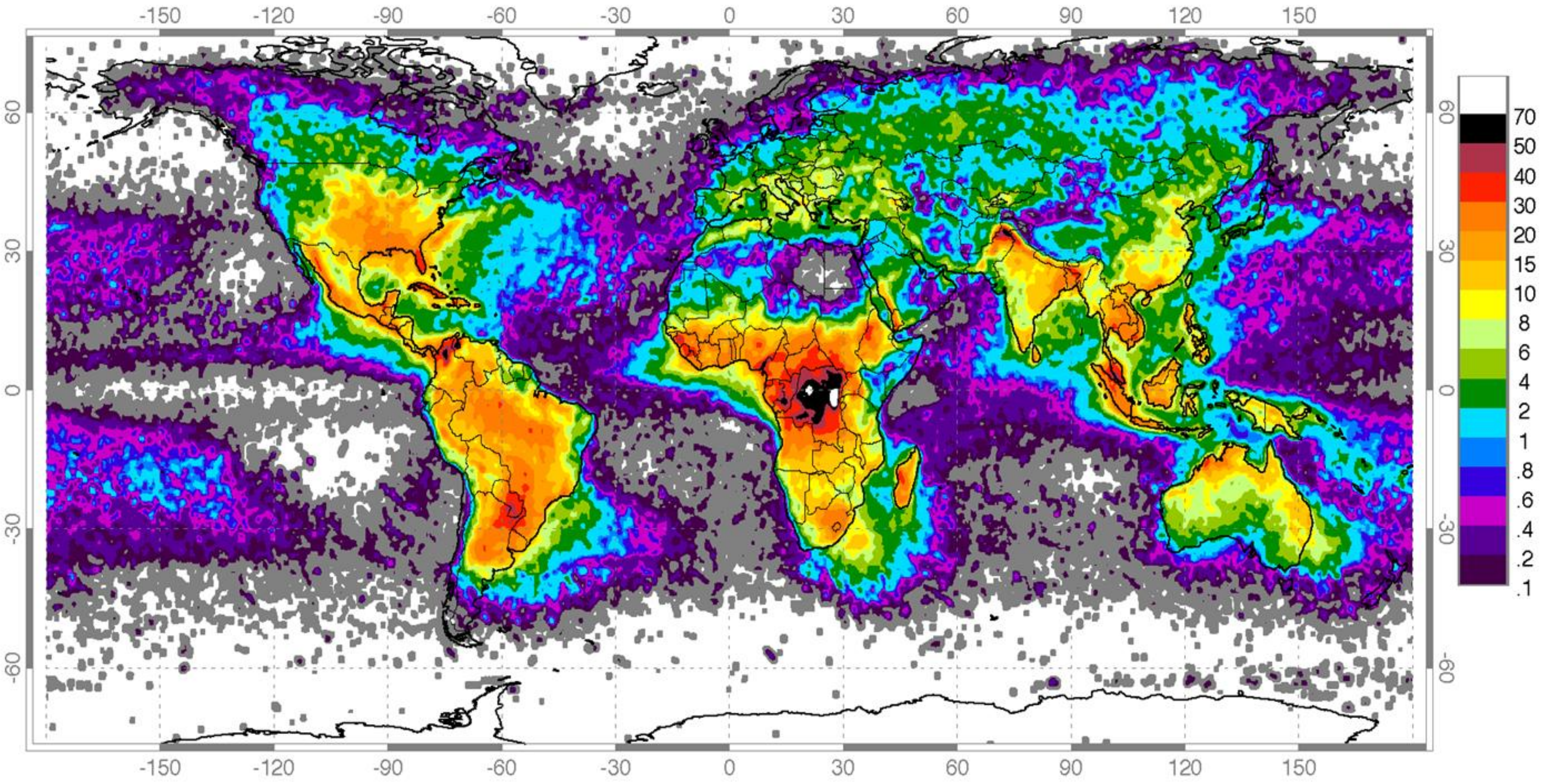
- Recovery of the “ozone hole” due to banning of CFC production, on a 100-year time scale
- Climate change; water vapour, carbon dioxide, methane and freons (CFCs) as the most important infra-red active gases, which cause the increasing “greenhouse effect”, global warming
- Greater variability of the weather, increased risks of flooding and sea level rise: these are of significant importance to human society
- Action to deal with Climate Change as one of the 17 Sustainable Development Goals (SDGs) of the United Nations
- Several other SDGs are related to Geophysics, in the widest sense


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

The global atmospheric electric circuit, JASTP, 2000

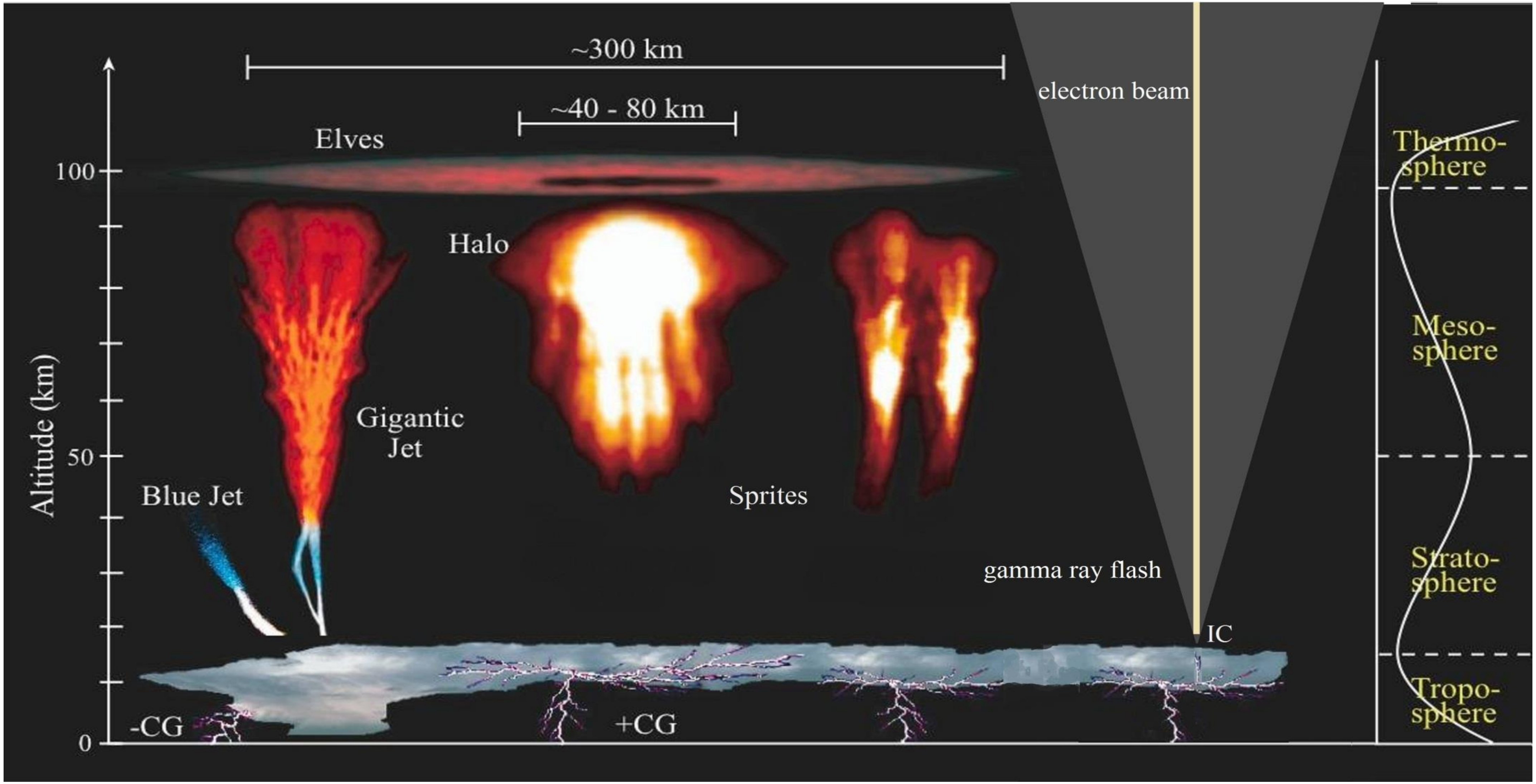


Satellite observations of the number of lightning flashes per km^2 per year

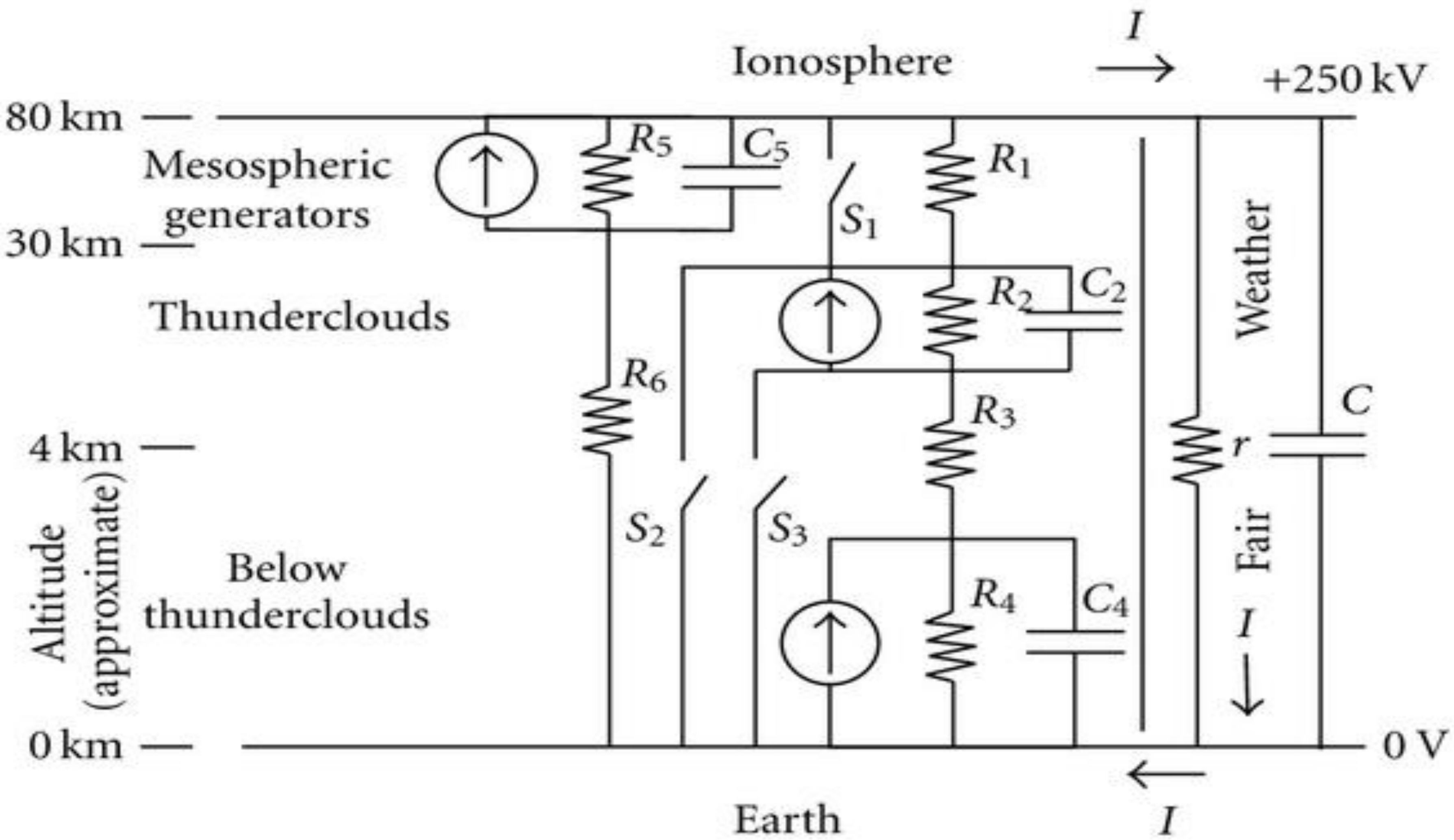


Sprite Observations

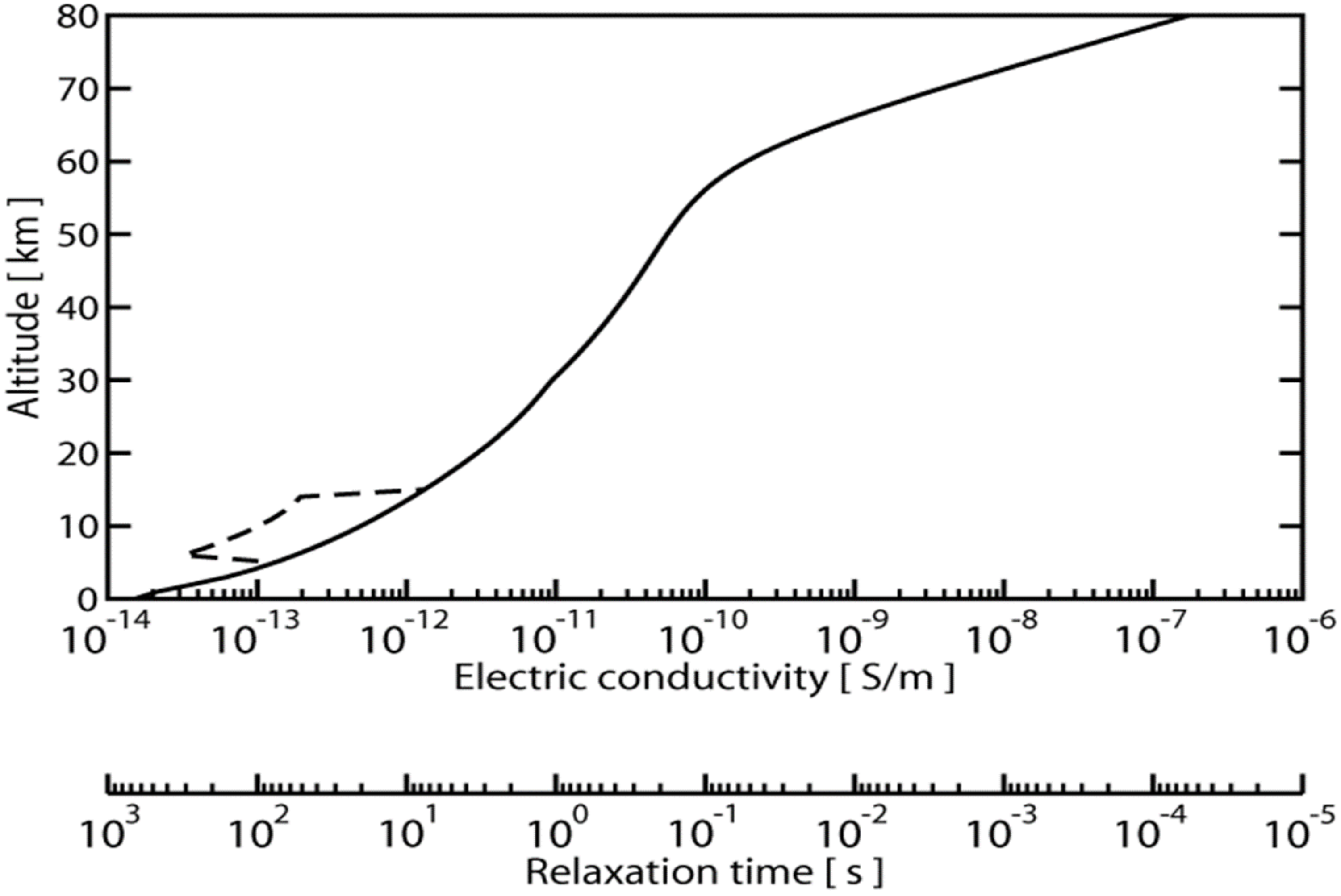
Cloud-to-ground (CG) and Intra-Cloud (IC) lightning discharges: Fullekrug et al., SiG, **34,** 1-41, 2013



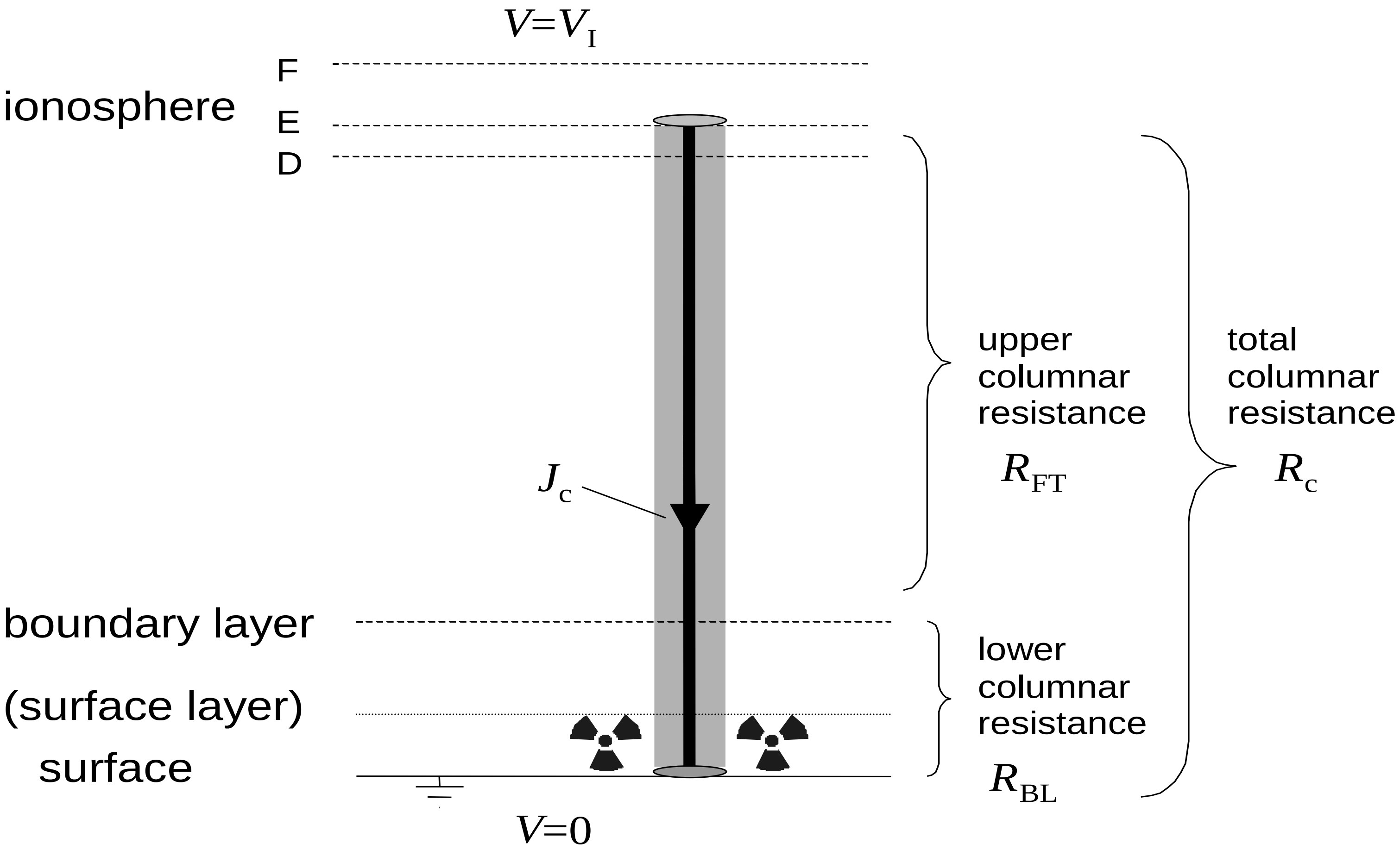
PSpice Modelling of Effects of Sprites on the Ionosphere, with Anna Odzimek



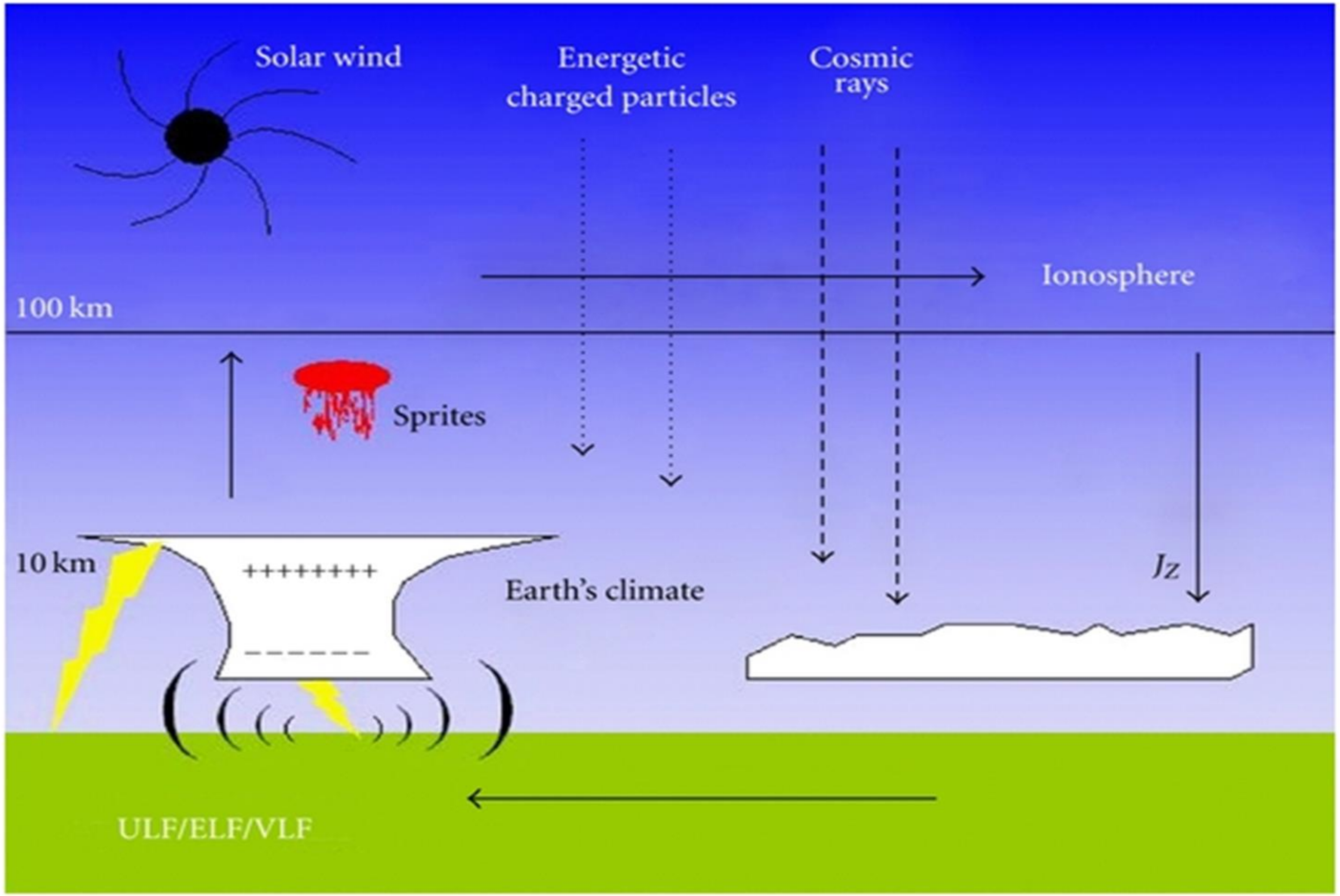
Conductivity profile up through atmosphere
Rycroft et al., JASTP, **69**, 2485, 2007



Global circuit changes before land earthquakes
Concept of Harrison, Aplin, Rycroft, JASTP, **72**, 376, 2010
Atmospheric Lithosphere-Ionosphere Charge Exchange, ALICE



SPECIAL: Space Processes and Electrical Changes Influencing Atmospheric Layers, early 2000s



Present situation: atmosphere

- How does the global circuit respond to space weather influences?
- Do clouds and aerosols respond to such effects?
- Can more be done using PSpice models of the global atmospheric electric circuit?
- Rycroft M J, Füllekrug M (2004). The initiation and evolution of SPECIAL, J. Atmos. Sol.-Terr. Phys. **66**, 1103-1113
- Aplin K L, Harrison R G, Fullekrug M, Lanchester B, Becker F (2020). A scientific career launched at the start of the space age: Michael Rycroft at 80, Hist. Geo. Space. Sci. **11**, 105–121
- Rycroft M J (2025). A personal voyage among Earth and Space physics disciplines, Perspectives of Earth and Space Scientists **6**,

https://doi.org/10.1029/2022CN000182

Summary: atmospheric physics

- Seek the truth, and test hypotheses (e.g., related to ALICE)
- It is a very good idea for geoscientists to have a very broad range of interests in international and interdisciplinary Earth system science

(as well as in music, fine arts, societal issues, human behaviour, ethics, politics and economics)

- “The most beautiful thing we can experience is the mysterious. It is the source of all true art and science”, Albert Einstein

- “We shall not cease from exploration
- And the end of all our exploring
- Will be to arrive where we started
- And to know the place for the first time”,
- T.S.Eliot, from Four Quartets, Little Gidding

Summary of key results: research

- Research should seek the truth, with novel instrumentation or new theoretical methods or computer simulation, leading to:
  new observations, new results, conclusions, new information, new knowledge, new understanding, new explanations, new predictions, new decisions
- It should be both challenging and important scientifically, e.g., involving hypothesis testing or energy exchange processes
- Have a unique station location, or unique time or unique situation (e.g., a solar eclipse) for an advantageous research position
- Processes being studied are also important in related fields, or interdisciplinary
- Importance of the Earth System Science approach: multi-scale phenomena, non-linear phenomena, ranging from μs to centuries, and from mm to Mm
- See Borovsky J E, Valdivia J A (2018). The Earth's Magnetosphere: A Systems Science Overview and Assessment, Surveys in Geophysics **39**, 817–859
- Climate change
- In what ways is the subject area relevant to human society?

Summary of key results: conclusions

- The foundation: a good education, at school, at undergraduate level and postgraduate level (e.g., summer schools)
- Continuing study: hard work, yet Physics is fun
- Experimentalists should study Theory, and vice versa – persevere, work hard
- Statistics: show standard deviations, and discuss statistical significance of results obtained
- Broaden your fields of investigation, be interdisciplinary
- Write original research papers, review papers, Nature News and Views items
- Arrange seminar series and, with colleagues, organise national and international meetings and conferences via scientific Societies (EGU, AGU, COSPAR, IAGA, IUGG, SCOSTEP, URSI)
- Edit Special Issues of journals, edit books, and write books
- Take advantage of serendipity (chance occurrences), variety, and all opportunities that present themselves (e.g., new techniques and new collaborations, both nationally and internationally)

I wish everyone listening to me today, in whatever country they live, success in their researches, and peace in their lives