ATMOSPHERIC ELECTRICITY ON EARTH AND PLANETS

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9th International Planetary Probe Workshop, Toulouse, June 16-17, 2012.

OUTLINE (1)

TERRESTRIAL ATMOSPHERIC ELECTRICITY

1- THE GLOBAL ATMOSPHERIC CIRCUIT
- The Conductive Atmosphere and Boundaries
- Generators
- Coupling with outer space

2- PHYSICAL PROCESSES
- Charging/Discharging Mechanisms in Clouds and Thunderstorms
- High Altitude Phenomena: Transient Luminous Events
- Acceleration Processes: Transient Gamma Ray Flashes
- EM emissions and Schumann resonances

PLANETARY ATMOSPHERIC ELECTRICITY

1- PLANETARY GLOBAL ELECTRICAL CIRCUITS
- Terrestrial Planets: Venus, Mars
- Giant Planets: Jupiter, Saturn and their moons

2- OBSERVATIONS

OUTLINE (2)

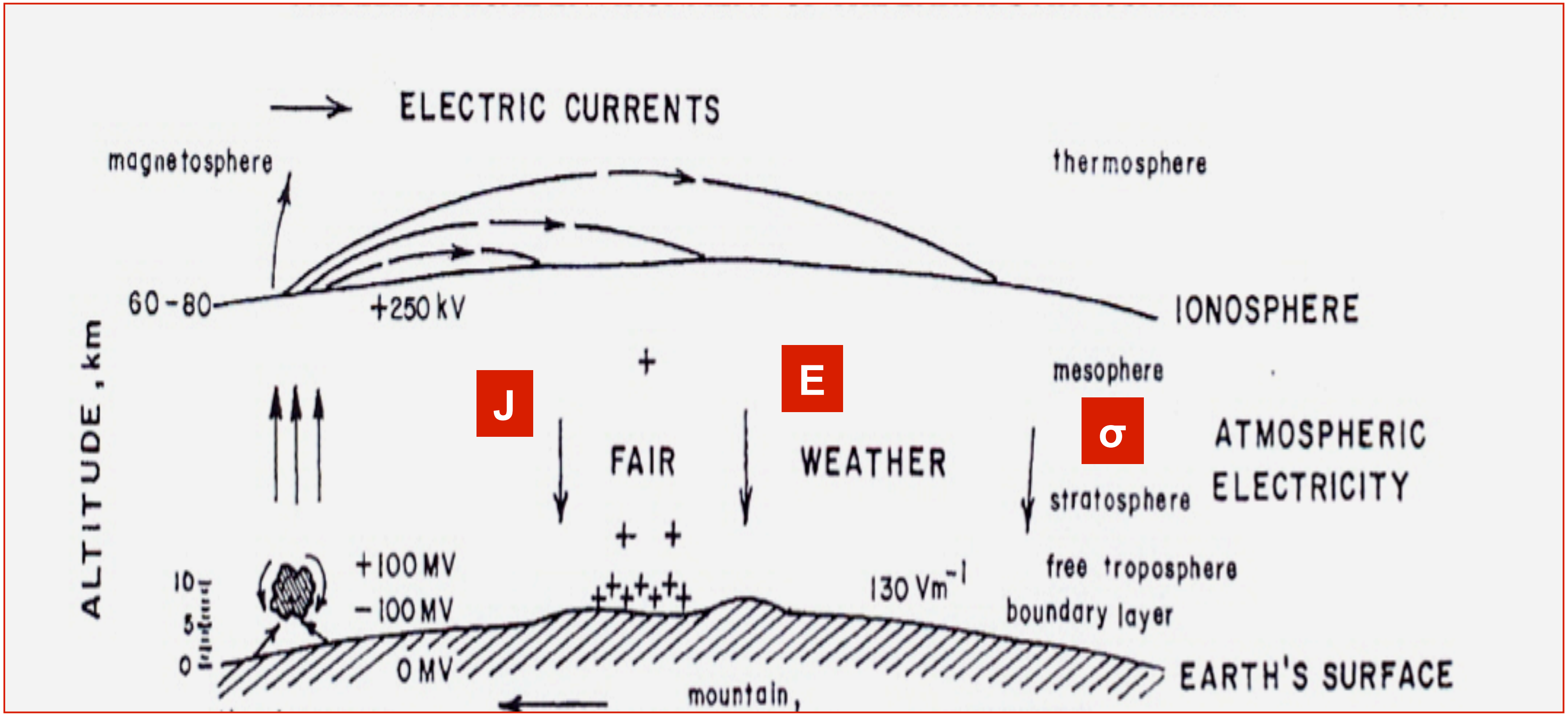
INSTRUMENTATION

1- MEASUREMENT CONDITIONS
- Ground Based Observations
- Observations from Space
- Balloons

2- MEASUREMENTS TECHNIQUES
- Conductivity
- Electric Fields and Waves

3- SOME EXAMPLES

THE EARTH'S GLOBAL ATMOSPHERIC ELECTRIC CIRCUIT



From M.J. Rycroft et al., JASTP, 2000

ATMOSPHERIC CONDUCTIVITY

Production Mechanisms

- Soil radioactivity at low altitude
- Cosmic rays
- Solar sources: UV, X-rays,
- auroral and polar regions: magnetospheric electrons, solar protons

Charged Particles

-Positive and Negative cluster ions

Conductivity profile

- 10^{-14} S/m at ground, scale height H_σ~ atmospheric scale height ~ 6-7 km
- Isotropic till ~ 70 km, anisotropic in the ionosphere $\sigma_{//} >> \sigma$ Hall, σPedersen
- day/night and latitude variations

ATMOSPHERIC CONDUCTIVITY

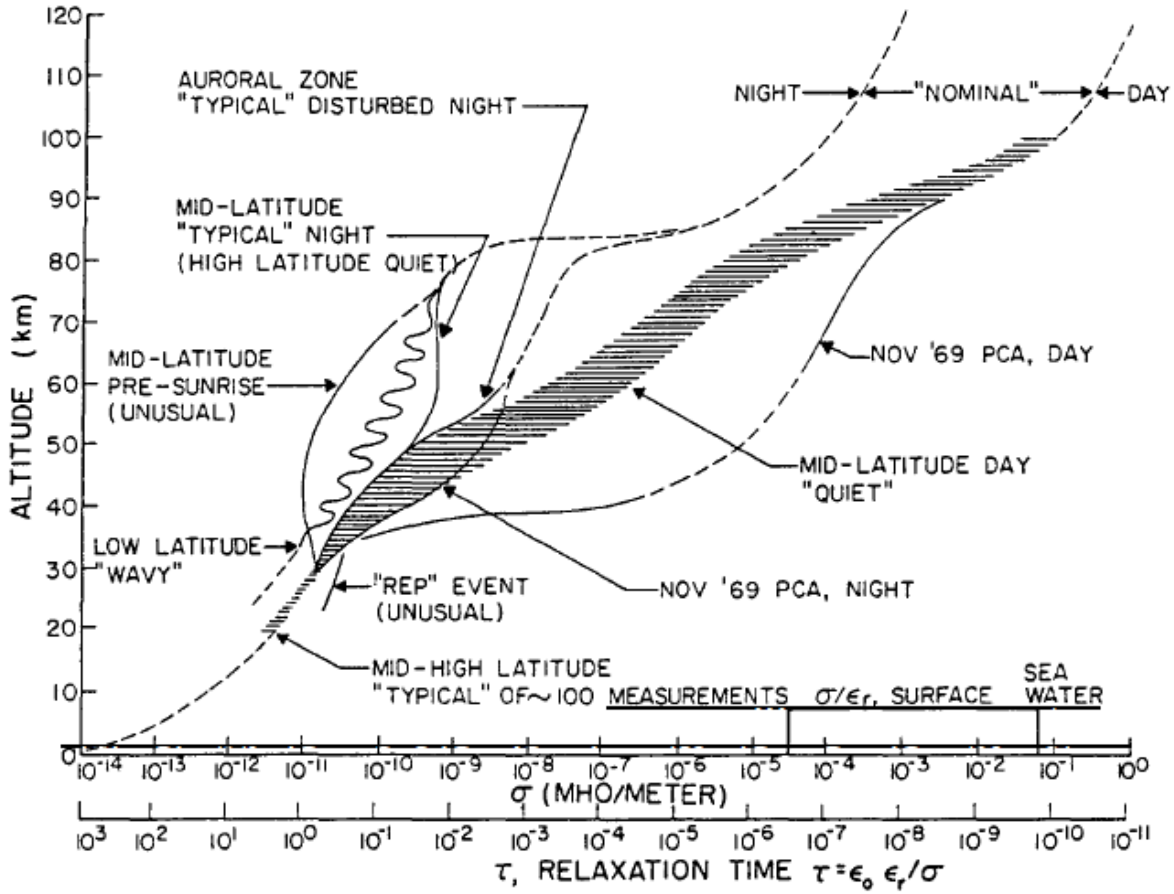


Fig. 3. Total conductivity and corresponding relaxation time under a variety of conditions.

JASR 4:4-H

From Hale, ASR, 1984

GENERATORS, THUNDERSTORMS

CHARGING MECHANISMS

Convective air motion in thunderstorm clouds, temperature profile

Collisional Charging between graupels and rain drops

Electrical structure of Thunderstorm clouds

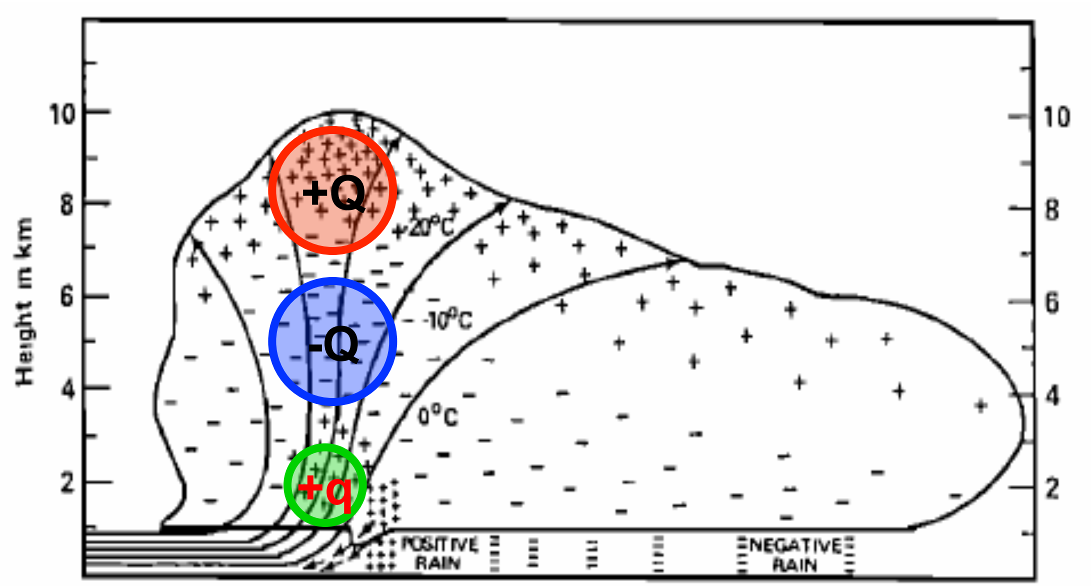
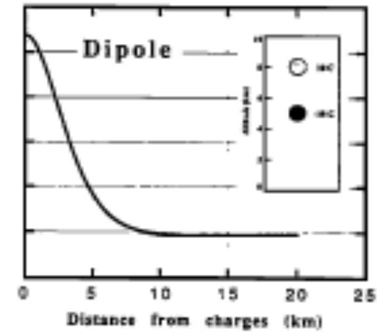
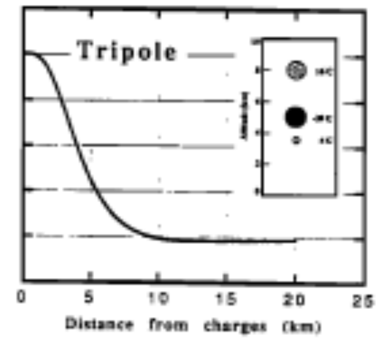
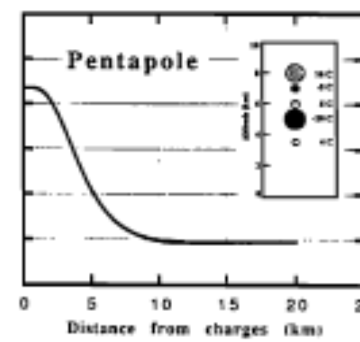


Fig. 1. Illustration of the tripole structure of thunderclouds based on in situ measurements by *Simpson and Scrase* [1937].



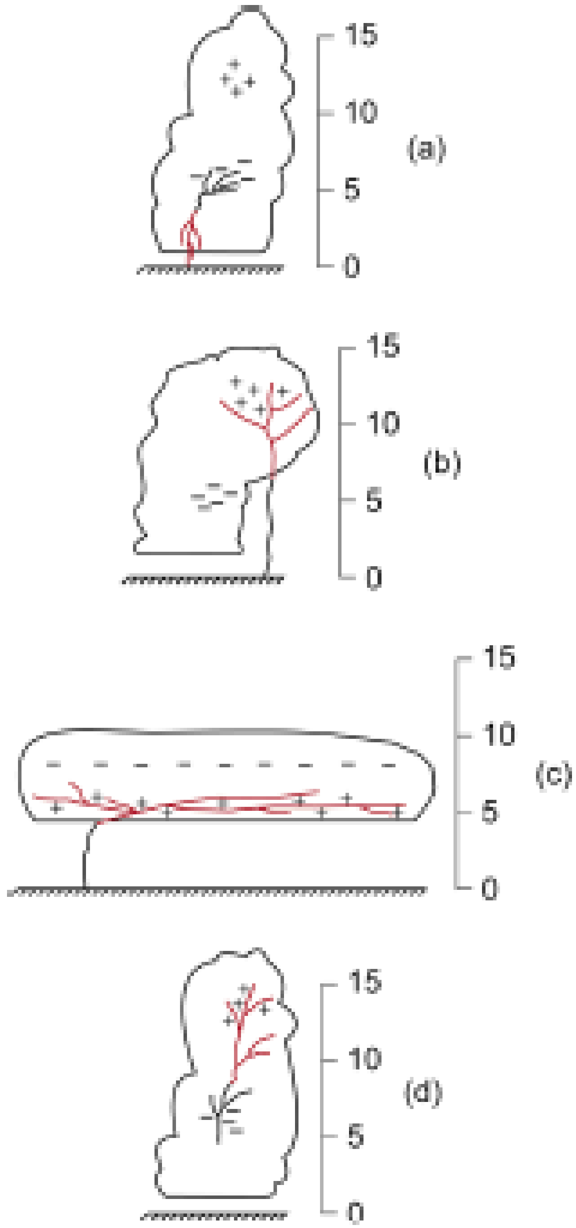




he electric field at the ground beneath three differ utions. The distributions are shown in the inset box tion is net neutral. For each distribution the elect ound changes polarity at a horizontal distance of ab

From Marshall & Rust, JGR, 1991

GENERATORS, LIGHTNING



Negative Cloud to Ground, CG-

Positive Cloud to Ground, CG+

Intracloud IC

Cloud to Cloud CC

GENERATORS, LIGHTNING

Geographic Average Distribution

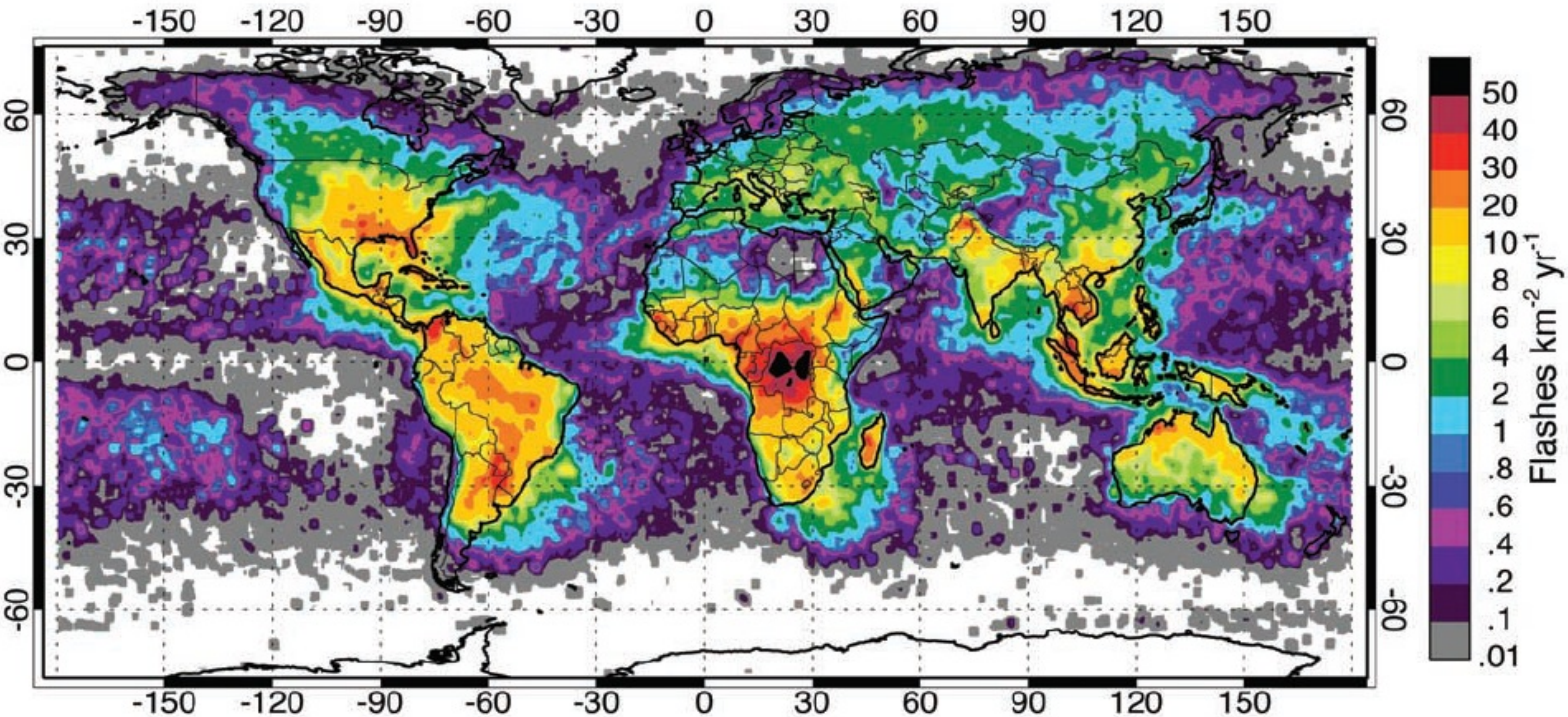
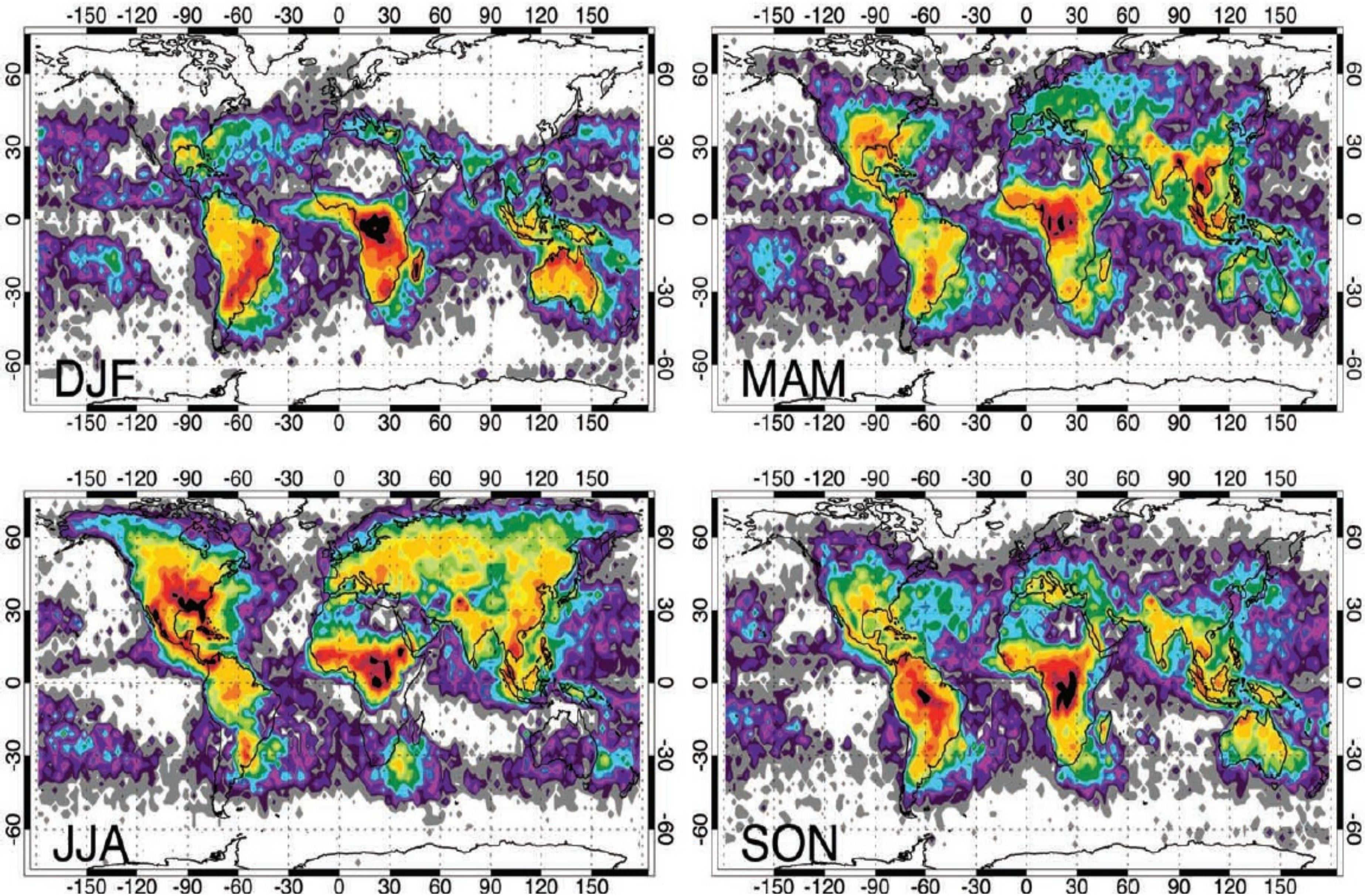


Figure 4. The annualized distribution of total lightning activity (in units of fl km^{-2} yr^{-1}).

From Christian et al, JGR 2003

GENERATORS, LIGHTNING

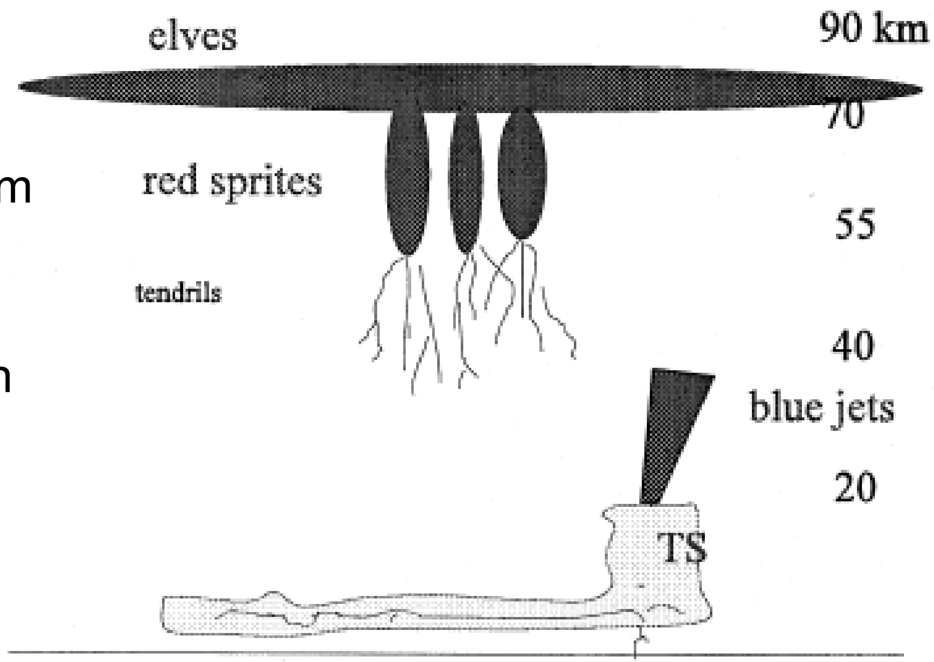
SEASONAL VARIATIONS



GENERATORS, HIGH ALTITUDE DISCHARGES, TLE's

PHYSICAL PROCESSES

TLE's (Sprites, Blue Jets, Elves, Gigantic jets) are electrical discharges in the stratosphere and mesosphere above active thunderstorm clouds



Sprites

Large Electric Field between cloud and ionosphere following a +CG

Break-down threshold reached at ~ 70 km

Elves

Initiated from the EMP following a CG

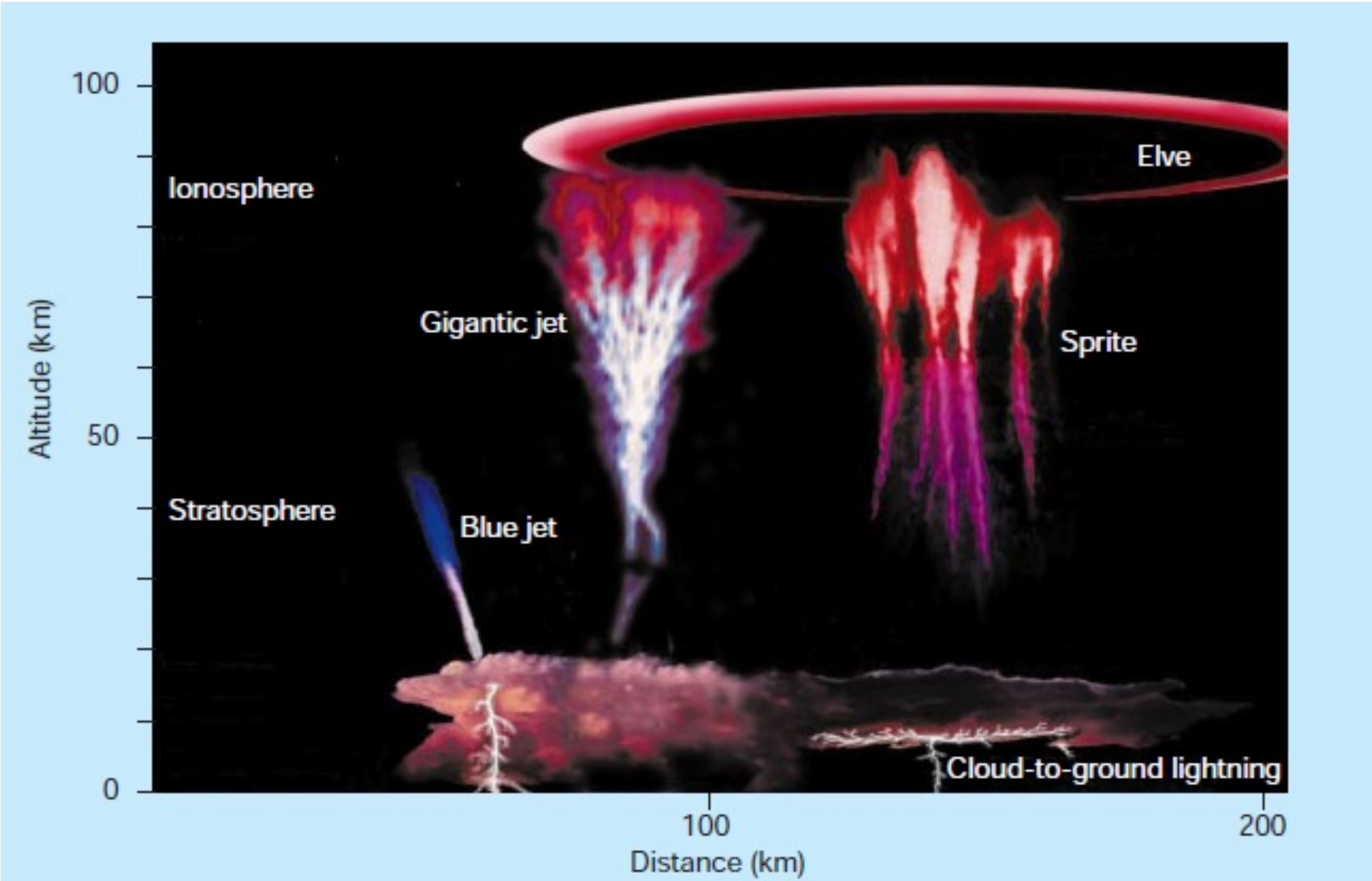
Ionization and luminous halo produced in the mesosphere at ~ 90 km

Blue Jets and Gigantic Jets

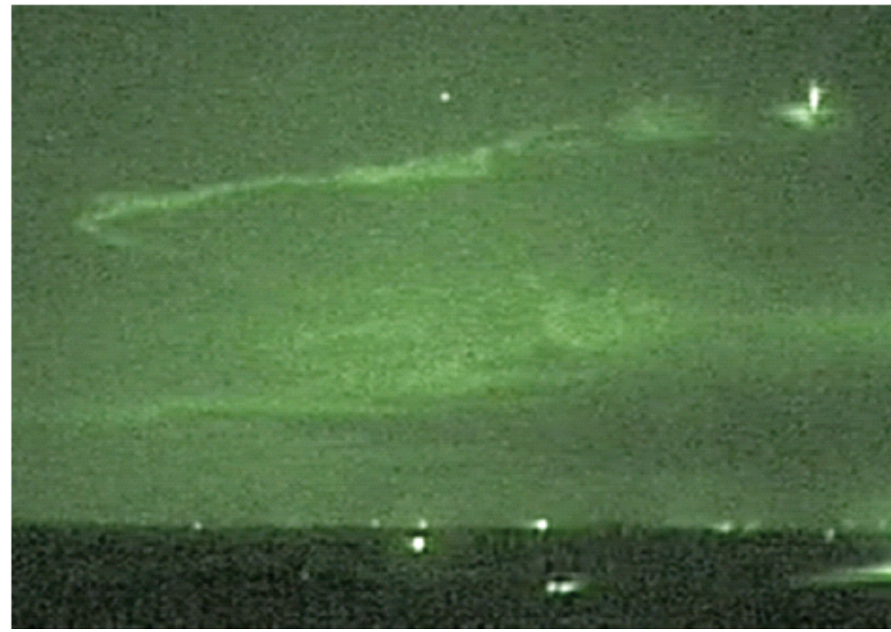
Streamer initiated at cloud top (~ 15-18 km) by localized intensification of the electric field

Propagate up to ~40 km for BJ, ~ 70 km or GJ

GENERATORS, HIGH ALTITUDE DISCHARGES, TLE's



GENERATORS, HIGH ALTITUDE DISCHARGES, TLE's



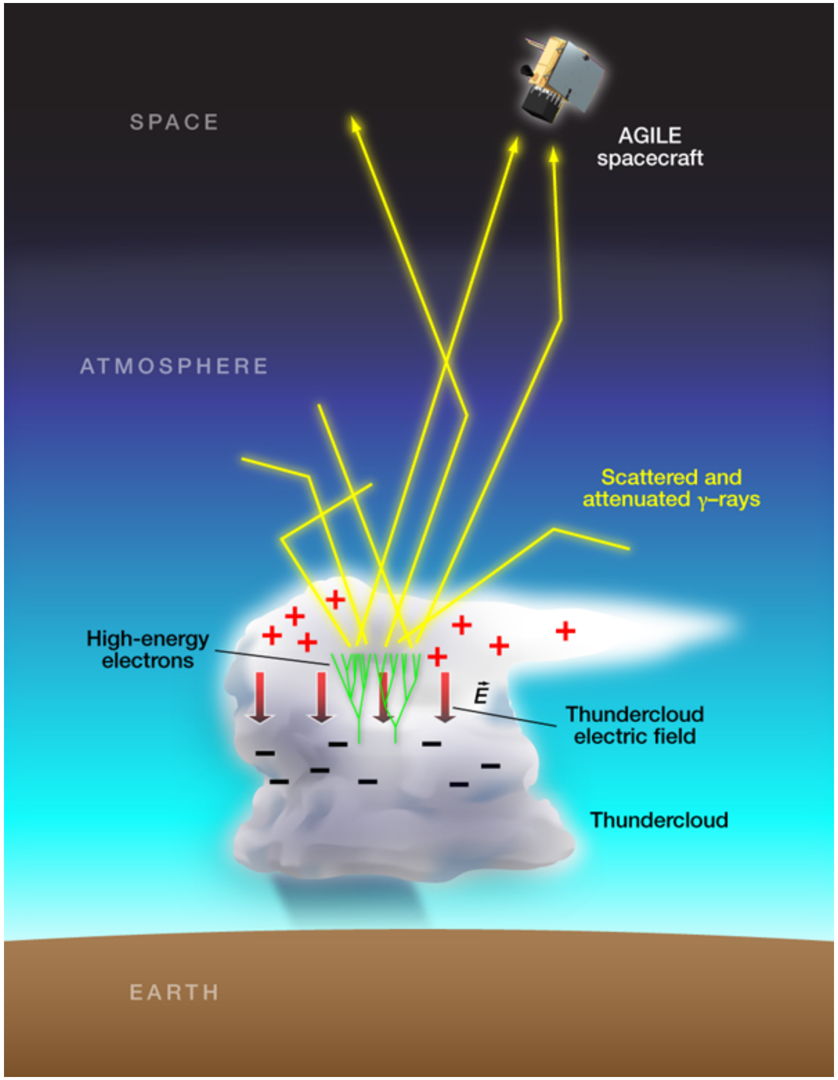
ACCELERATION PROCESSES, TGF

PHYSICAL PROCESSES

Acceleration of Electrons up to ~ 100 MeV

- Relativistic Runaway Electron Avalanche from cosmic ray generated electrons initially proposed. But
(i) cosmic ray showers not a sufficient electron source
(ii) RREA cannot account for the intensity of TGF fluxes.

-Two mechanisms recently proposed (Dwyer2007, 2008):
- Relativistic Feedback mechanism from backward propagating positrons and scattered X,γ rays
- Runaway Electron production in large E-fields reproduces the duration and intensity of TGF



From Dwyer, 2011

ACCELERATION PROCESSES, TGF

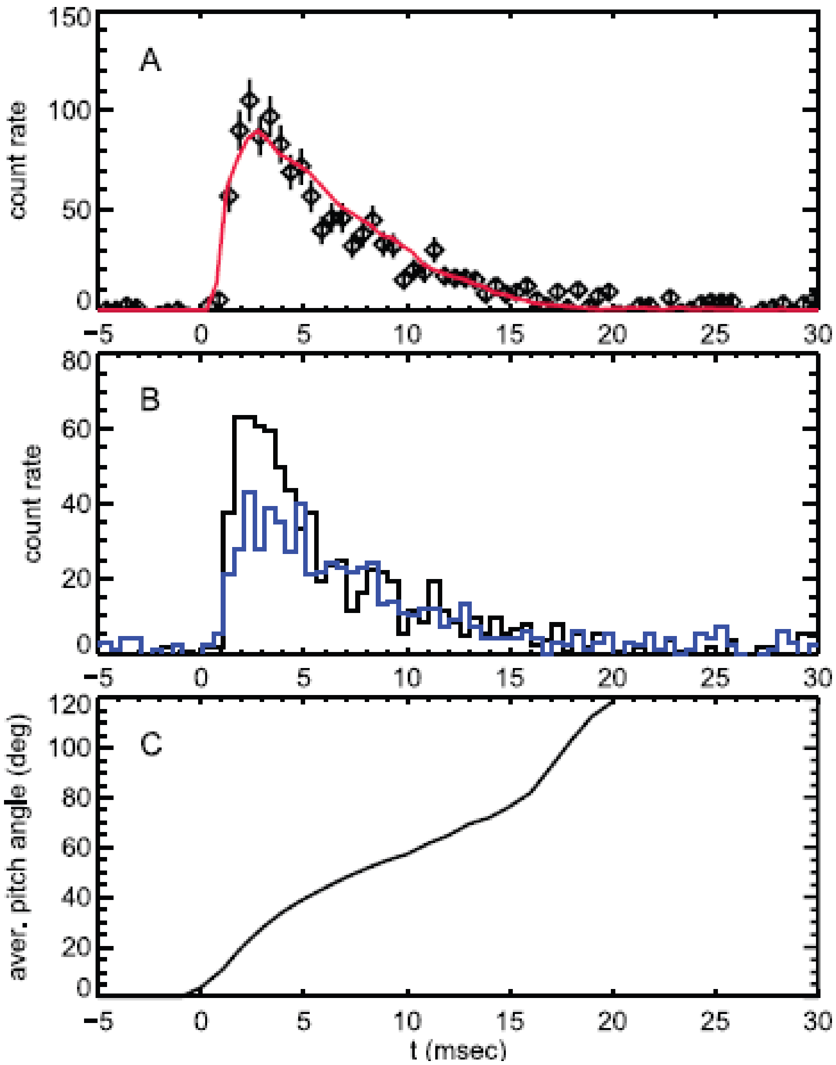
Simulation/Observations comparisons

Electron fluxes:

RHESSI data (black dots)

Simulated fluxes (red curve)

(Dwyer, JGR, 2008)



ELECTRO-MAGNETIC EMISSIONS

Sferics

- frequency spectrum peaked at ~ 10 kHz, extends up to a few MHz

Whistlers

- Ionospheric propagation along Earth's magnetic field and ducts at ELF/VLF

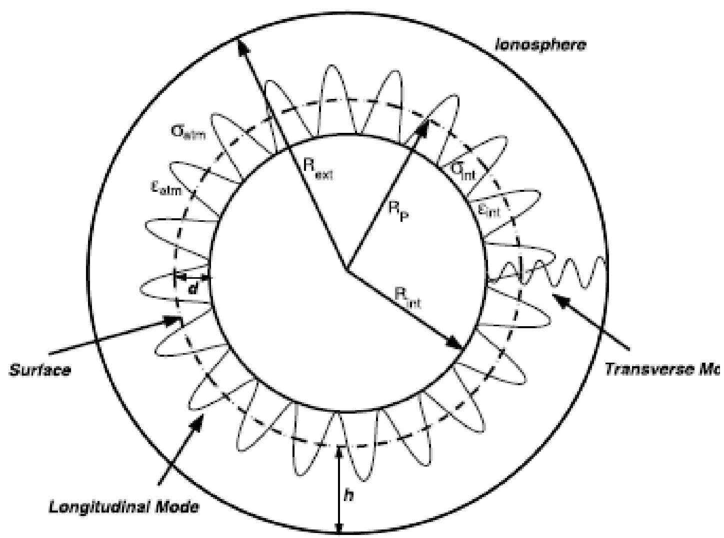
Transverse Resonance

- Between the surface and the lower ionosphere, ~ 1.5 to 3 kHz

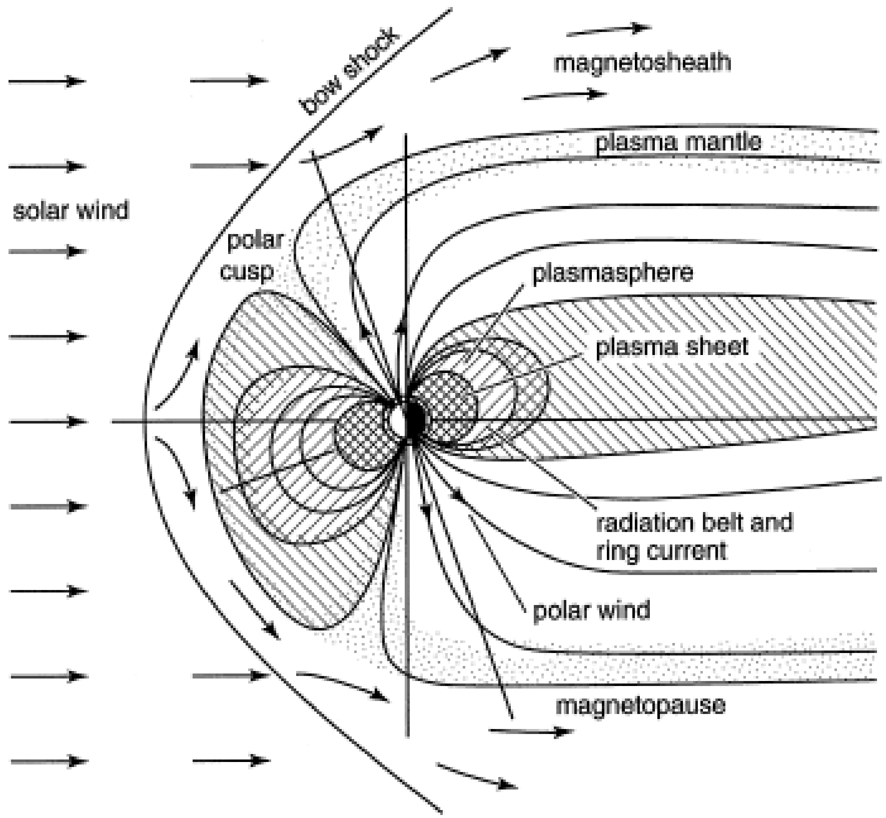
Schumann Resonances

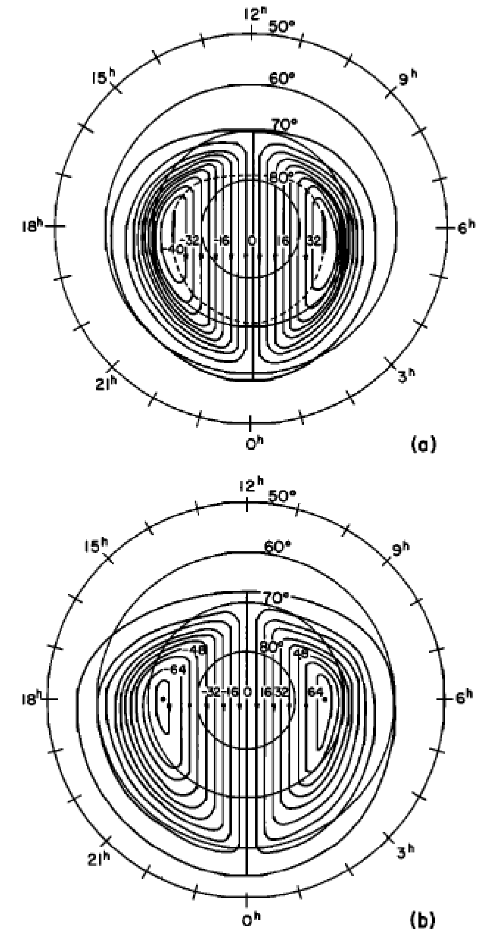
-Resonant modes of the Earth-Ionosphere wave guide $\omega \sim [n(n+1)]^{1/2}\,(c/R)$

- frequencies 7.8, 14.3, 20.8, 27.3, 33.8, …



COUPLING WITH OUTER SPACE





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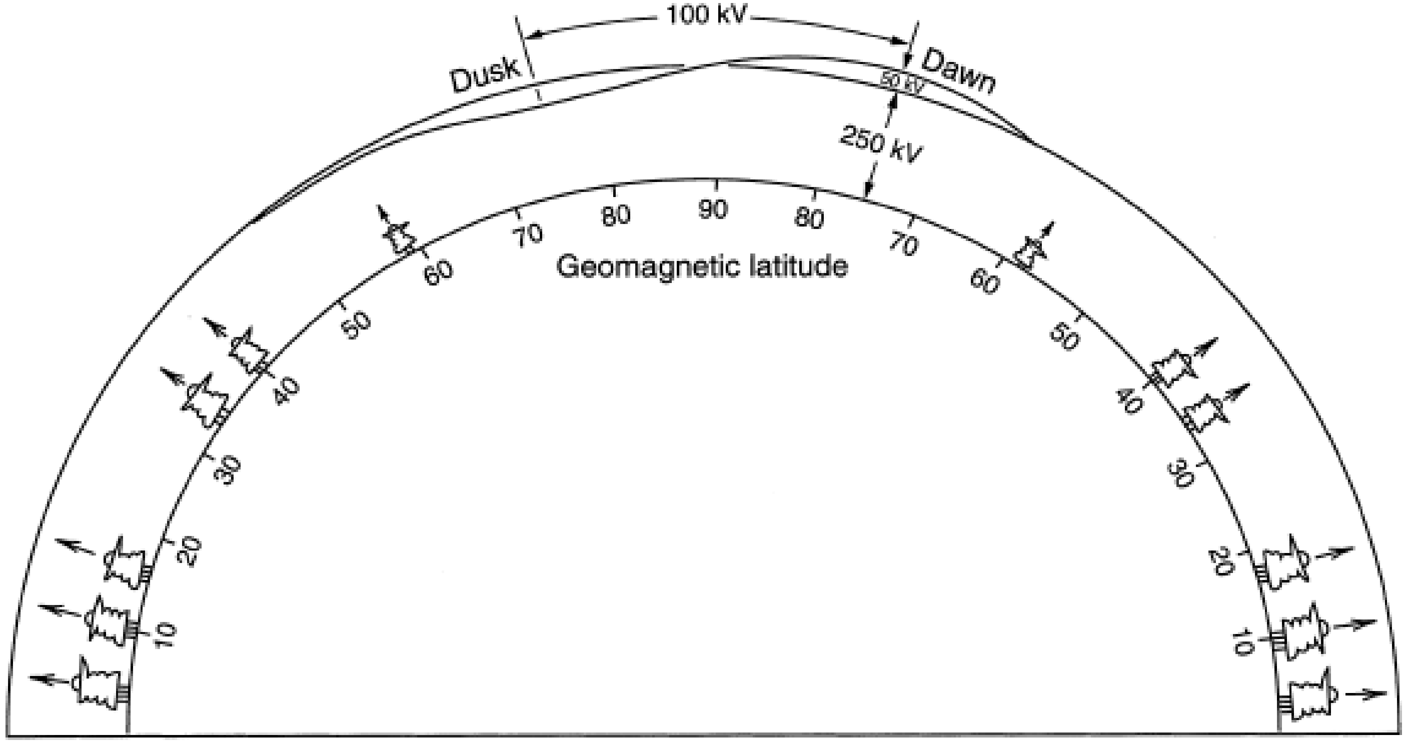


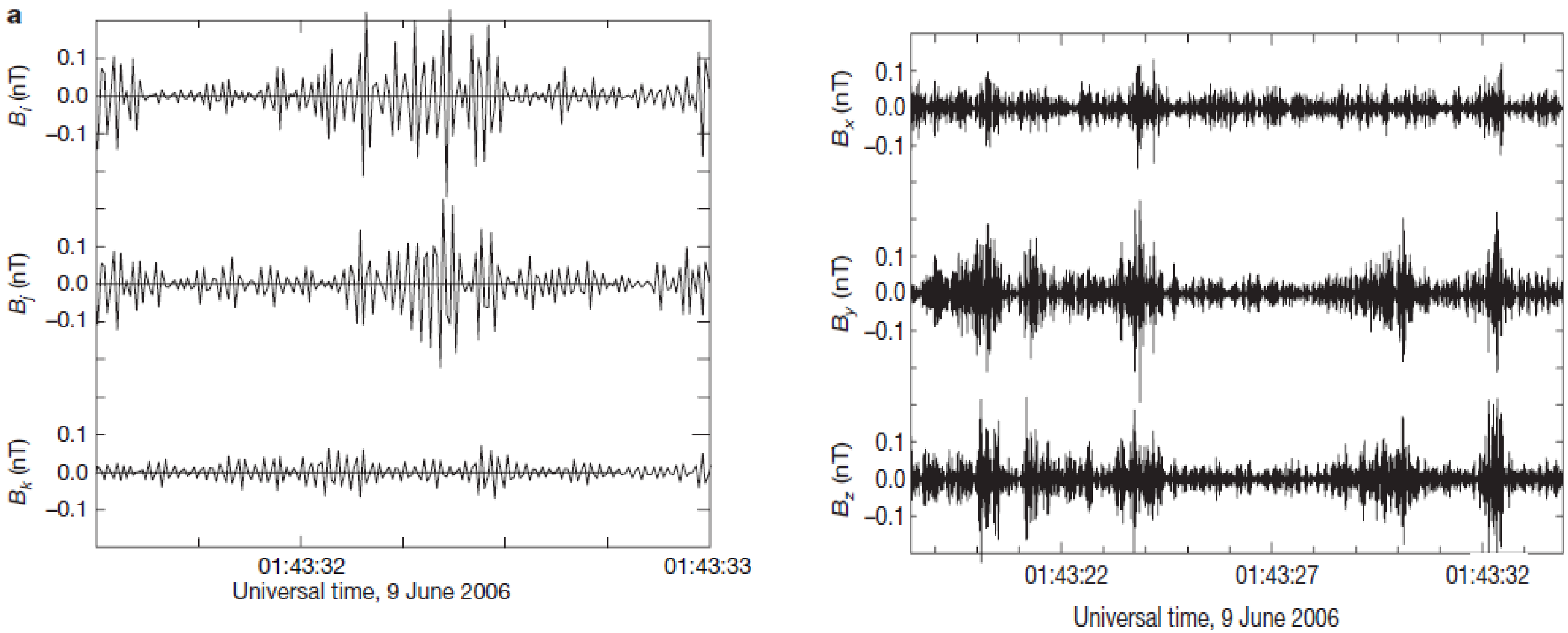
From Rycroft, 2011

PLANETARY ATMOSPHERIC ELECTRICITY

CONDITIONS FOR A GLOBAL ELECTRICAL CIRCUIT ON OTHER PLANETS

	Ion mobility in lower atmosphere	Upper Conductive Boundary	Lower Conductive Boundary	Clouds	Electrification Mechanisms
Venus	yes	Ionosphere	Yes σ_g small	yes	Charge separation Lightning
Mars	yes	Ionosphere	σ_g? Water reservoirs?	Faint, high altitude	Dust impact
Jupiter	Probably not in deep atmosphere	Ionosphere	? Deep layers?	yes	Charge separation lightning
Saturn	Probably not in deep atmosphere	Ionosphere	? Deep layers?	yes	Charge separation Lightning
Titan	Yes, weak at low altitude	Ionosphere	Buried ocean	yes	? Lightning not observed

VENUS



Whistler mode ELF signals from the Venus Express magnetometer
Indicating the existence of lightning

Russel et al., ASR 2008

MARS

Conductivity

- profile similar to Earth
- σ at surface ~ 10^3 σ on Earth

Electrification Mechanism

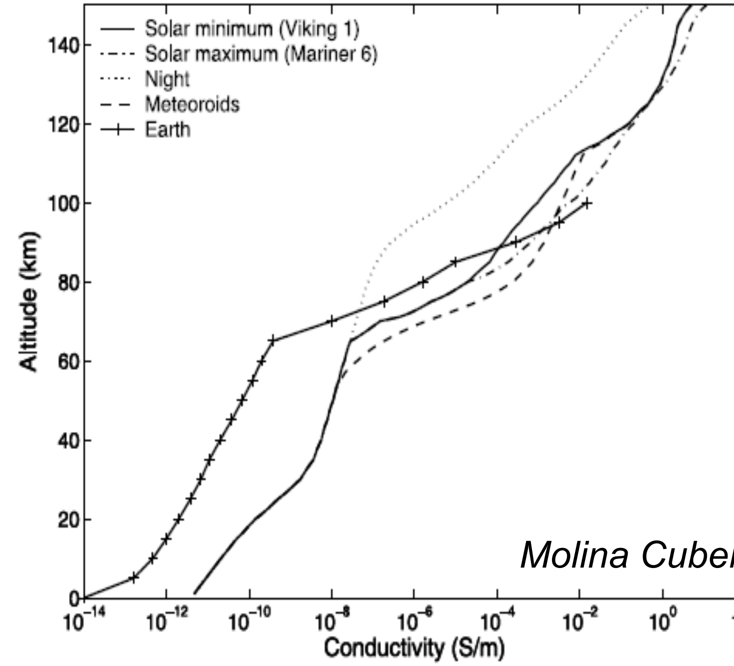
- Dust Impact
- Charge depends on size, material
- Breakdown at ~ 10 kV/m

Generators

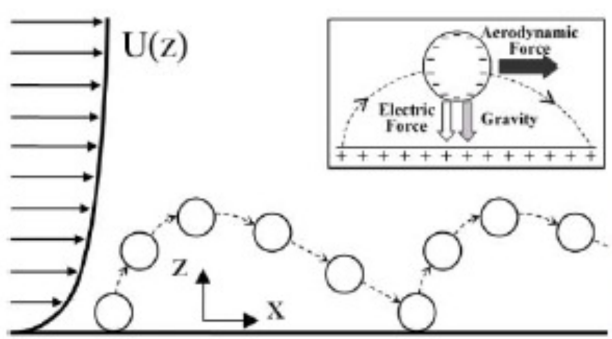
- Dust storms
- Dust Devils

Observations

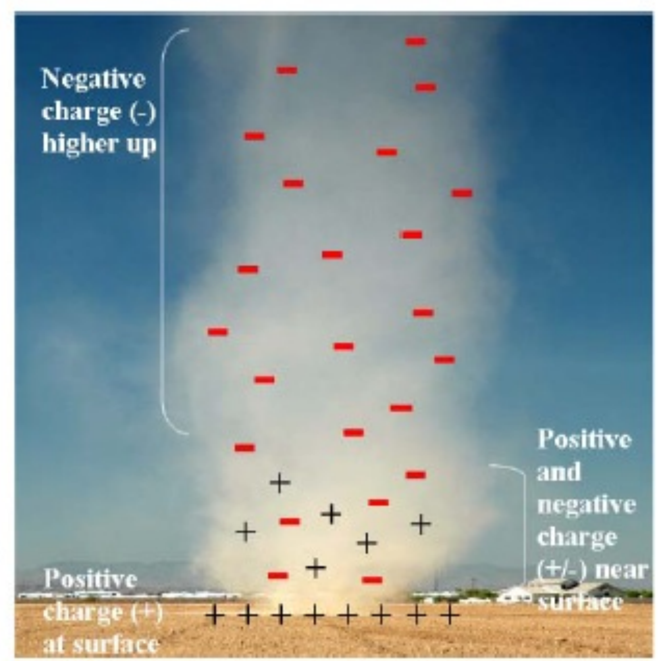
-SR of extremely high amplitude (?)



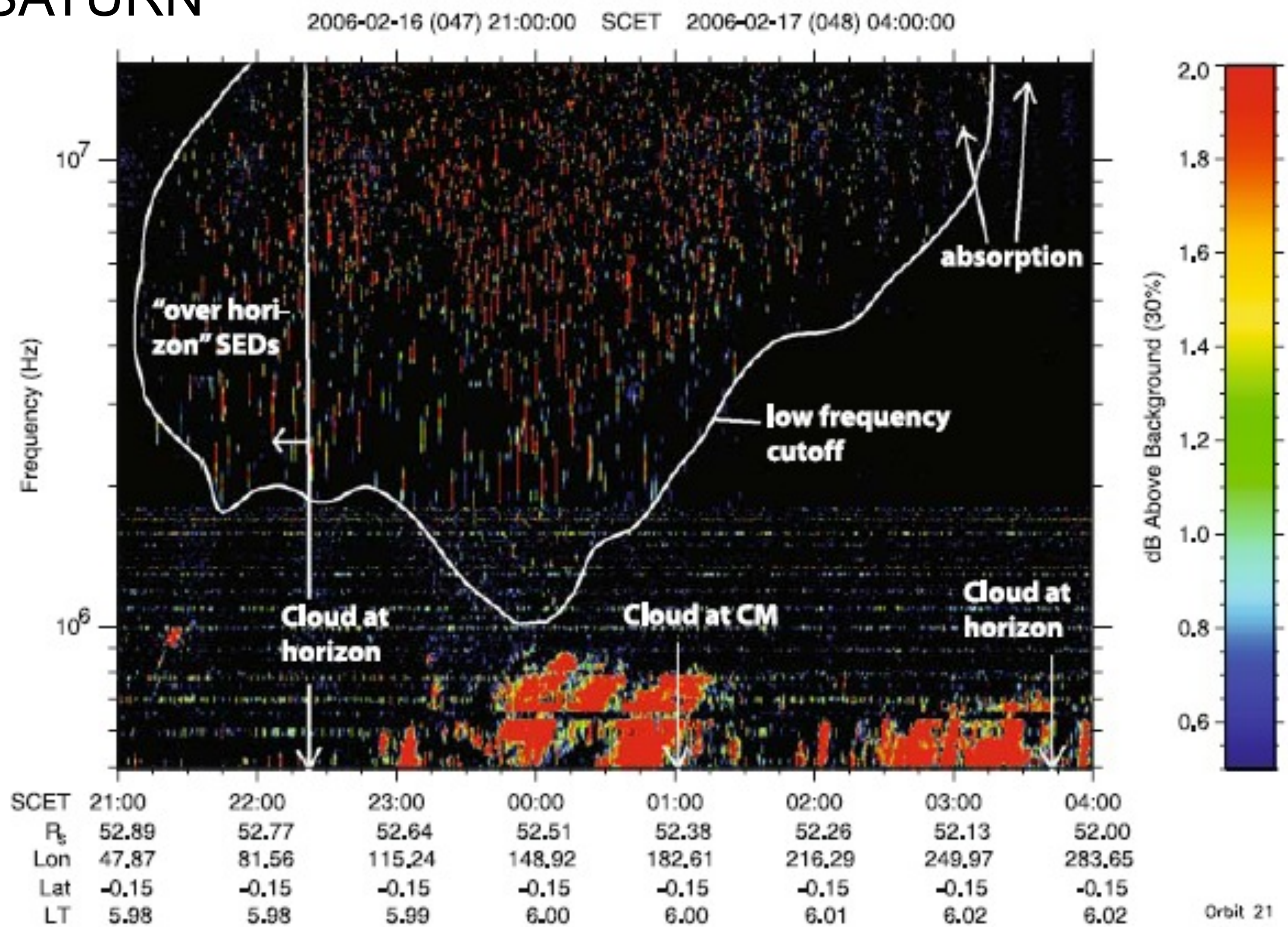
Molina Cuberos, 2006



(Kok, Renno, 2007)



SATURN



« Saturn Electronic Discharges » (SED) observed by RPWS on Cassini
EM emissions from lightning

SATURN and JUPITER

Comparison between Saturn, Jupiter and Earth lightning

Lightning sources :

- Saturn: Giant convective storm systems 3000 km in diameter, equator or 35°S
- Jupiter: numerous storms in ~ 5° latitude bands at ~ 50° N and S
- Updrafting water clouds at levels of ~ 10 bar (Saturn), ~ 5 bar (Jupiter)

Characteristics

- Frequency spectrum: up to 20 MHz / a few kHz / a few MHz
- Spectral power at MHz frequencies 100 W/Hz / ~10 / 0.01

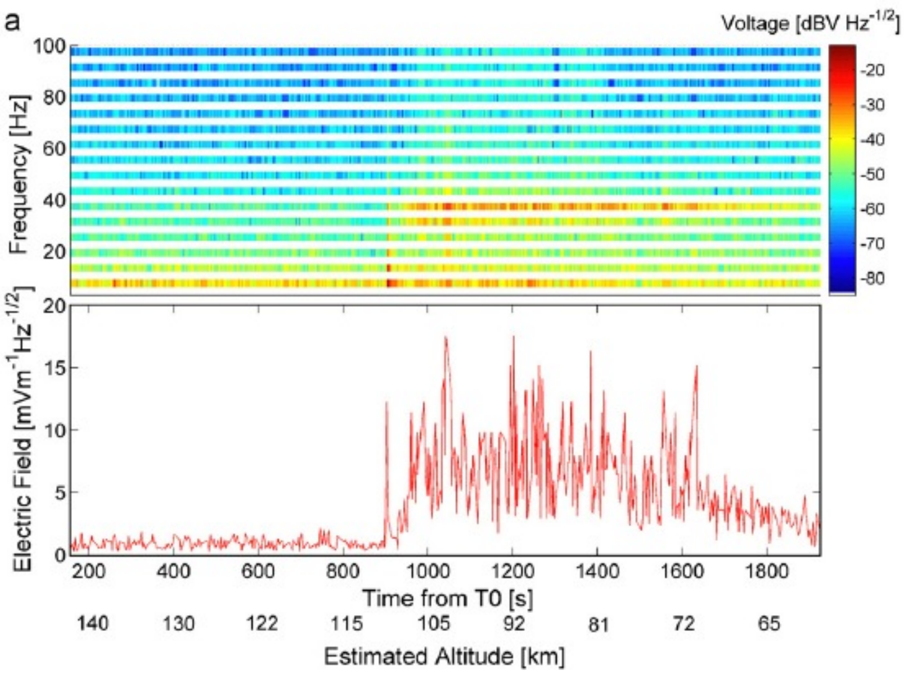
Physical process

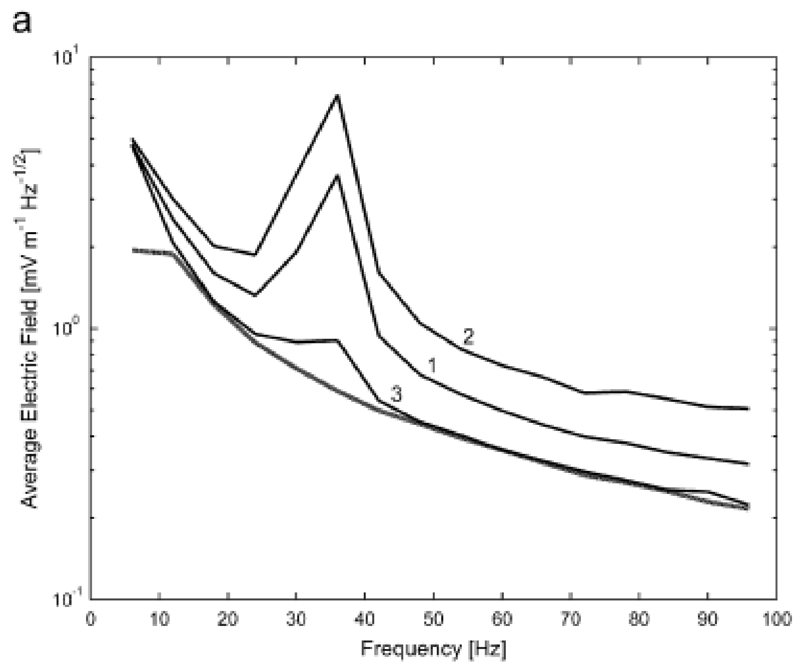
- Saturn: Elves more likely than Sprites
- Jupiter: lightning a few ms long

Desch et al., 2002; Fisher et al., 2008

TITAN

36 Hz peak in ELF AC electric field spectrum
interpreted as the second harmonic of Schumann resonnance
of the planet-ionosphere wave-guide due to a buried ocean at ~ 60-80 km depth





Simoes et al., Icarus, 2007
Beghin et al, 2012

INSTRUMENTATION AND OBSERVATIONS

1- CONDUCTIVITY

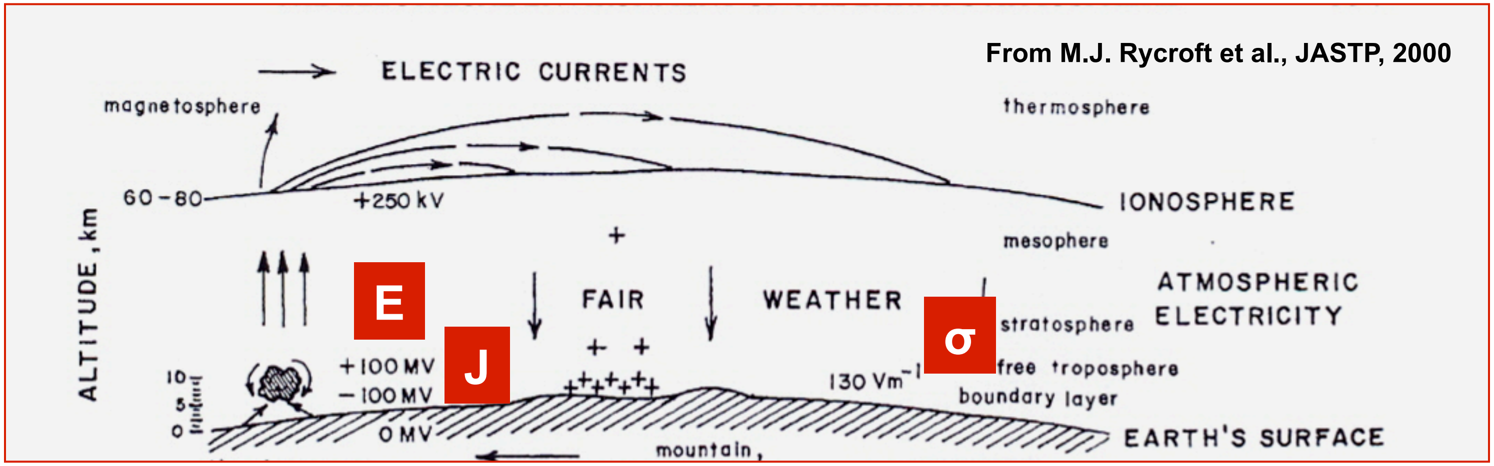
2- ELECTRIC FIELDS AND WAVES

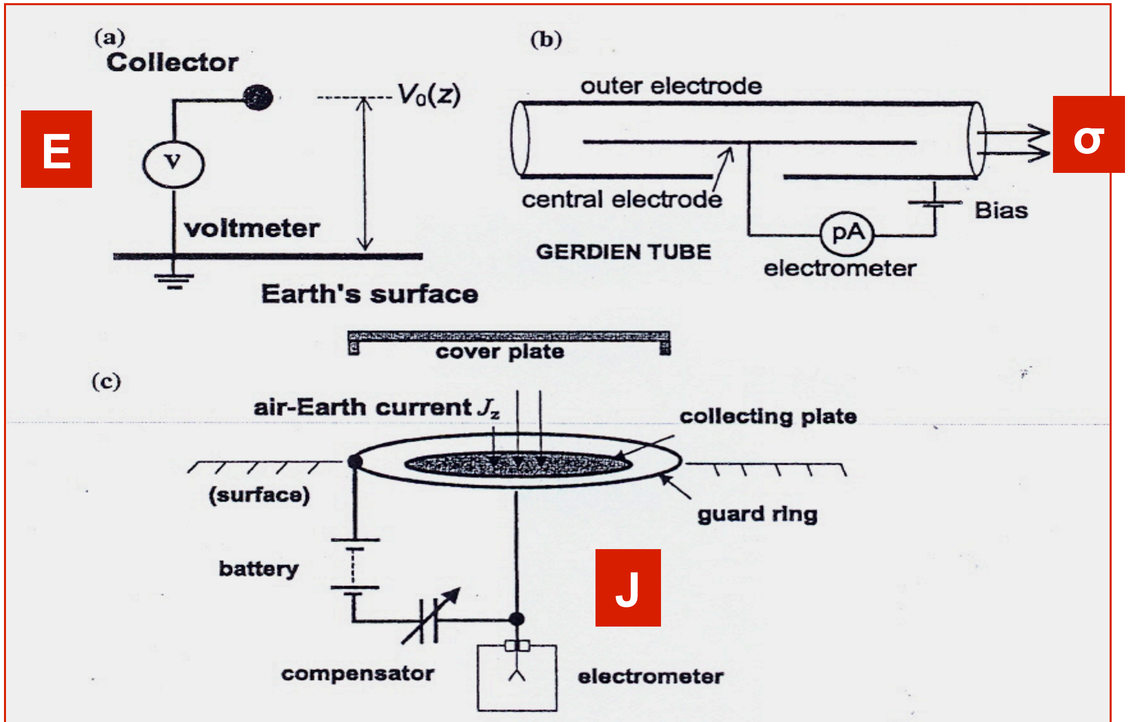
3- CURRENTS

4- EXAMPLES OF OBSERVATIONS

- Stratospheric balloon measurements
- Huygens probe measurements in the atmosphere of Titan

ATMOSPHERIC ELECTRICITY PARAMETERS AND THEIR MEASUREMENTS

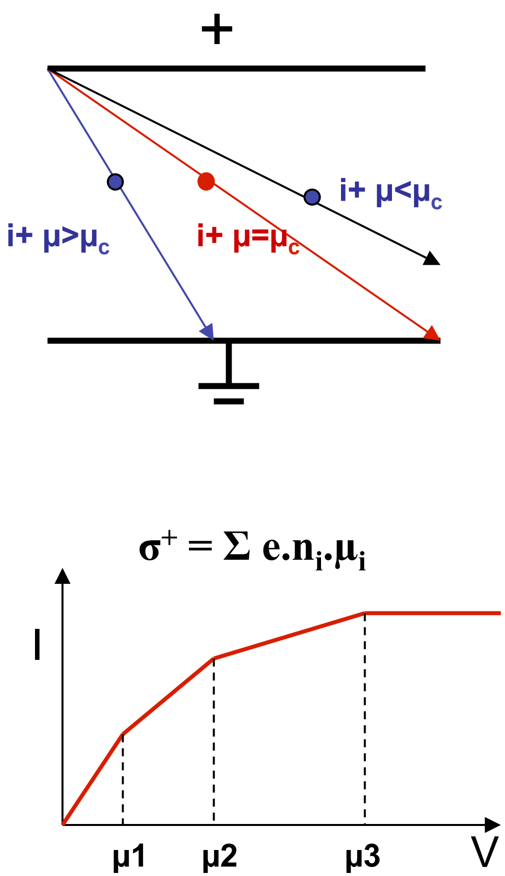




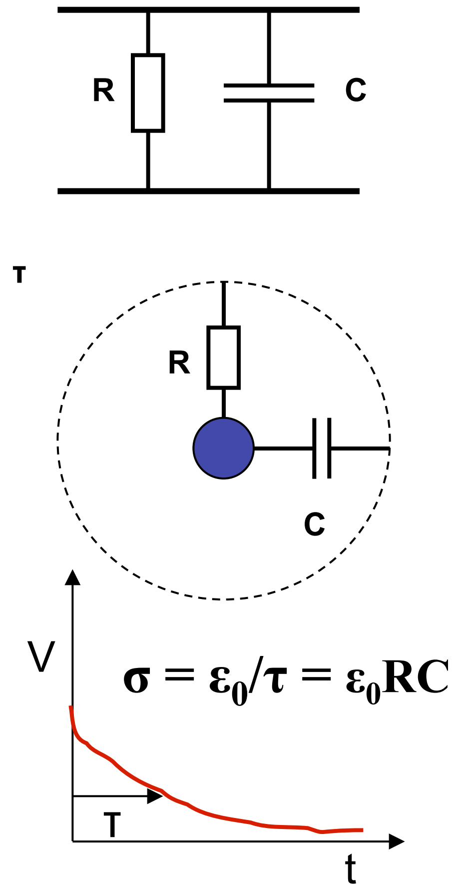
From R.G. Harrison, Surveys in Geophysics, 2004

ATMOSPHERE ELECTRIC CONDUCTIVITY (1)

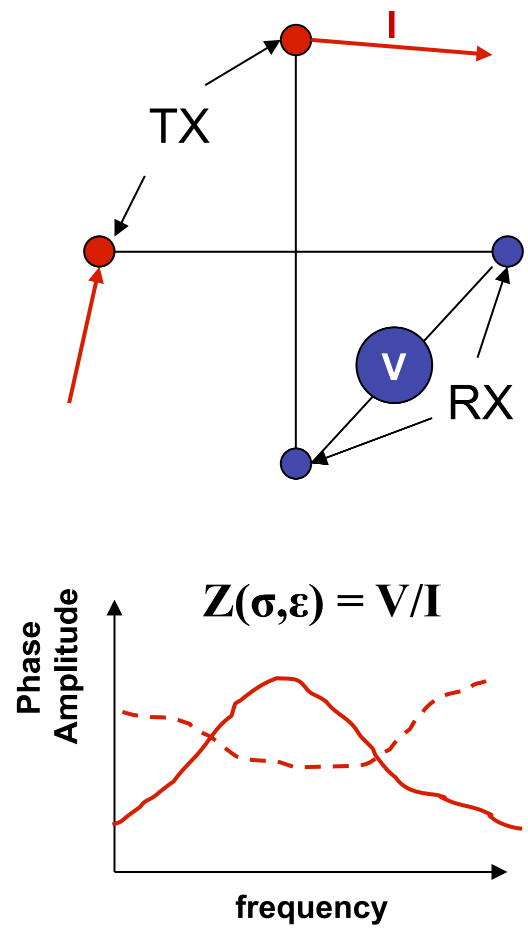
Gerdien Condenser



Relaxation method



Mutual Impedance



ATMOSPHERE ELECTRIC CONDUCTIVITY (2)

Gerdien condenser

- gives access to the ion mobility spectrum
- relaxation method can be included
- requires accurately controlled air flow
- complexity (fan, electronics…)

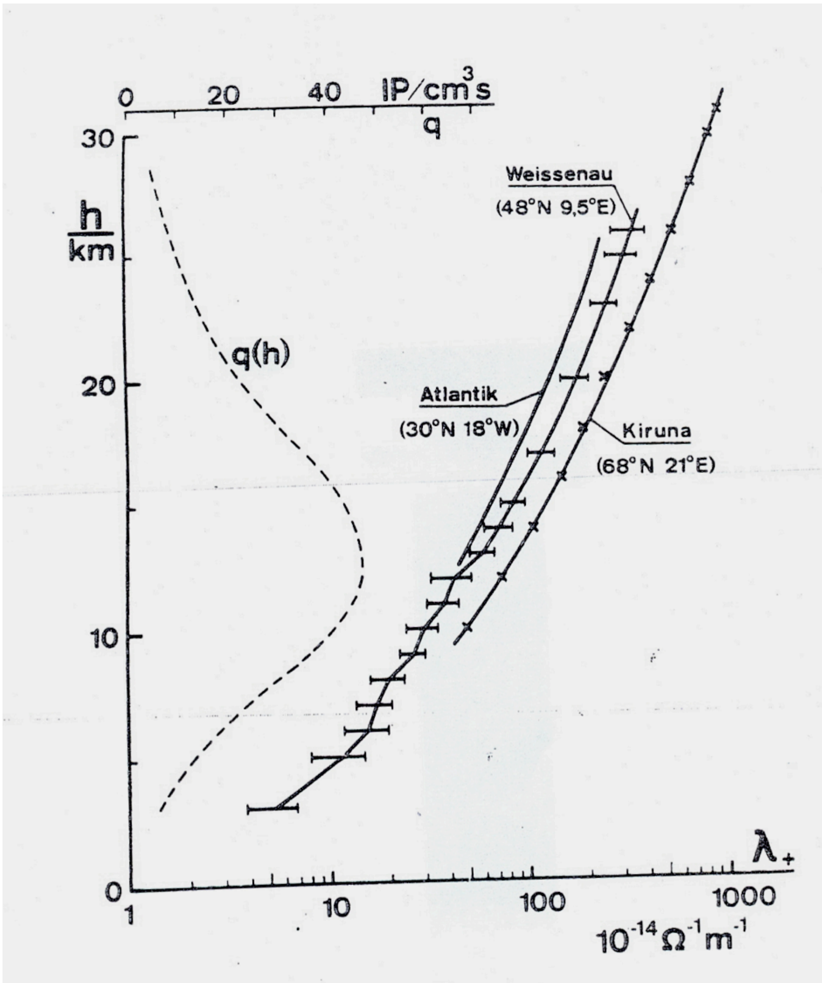
Relaxation method (with electrostatic probes)

- simple, can be easily implemented on double probe
- accurate technique for large enough σ and stable electric field
- analysis difficult with a variable background electric field
- requires specific modeling in case of space charge

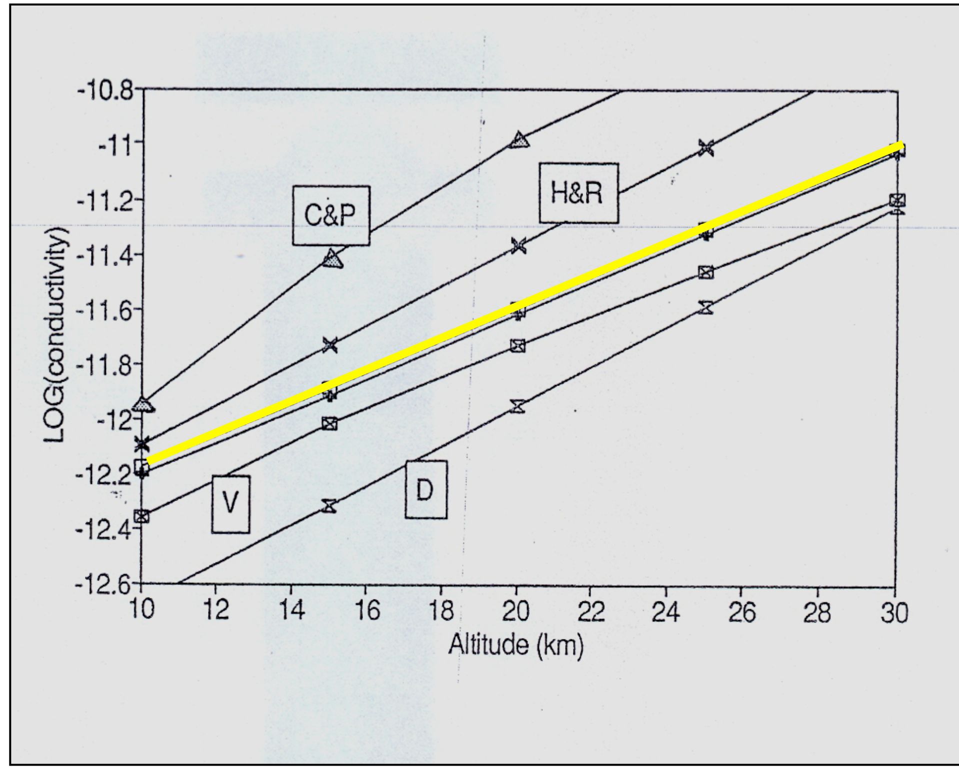
Mutual impedance

- accurate in atmospheres with both ions and electrons
- able to provide soil measurements if landed on planetary surface
- complexity (booms, electronics…)

TERRESTRIAL CONDUCTIVITY PROFILES



From W. Gringel, Prometheus, 1977

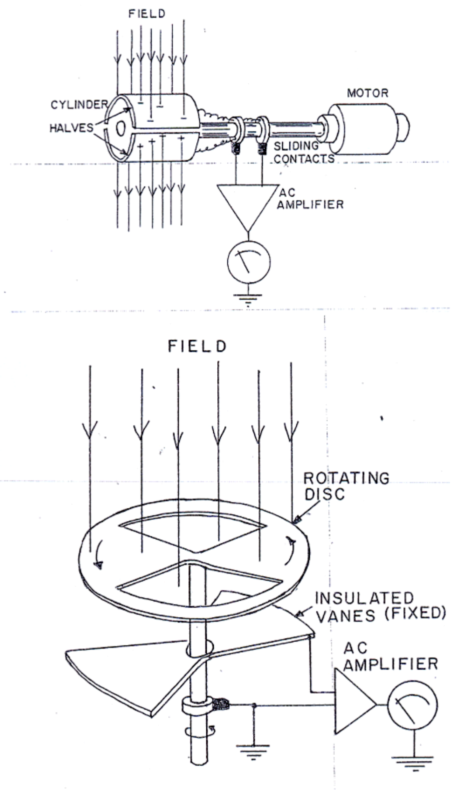


From R.H. Holzworth, JGR, 1991

ELECTRIC FIELD MEASUREMENTS

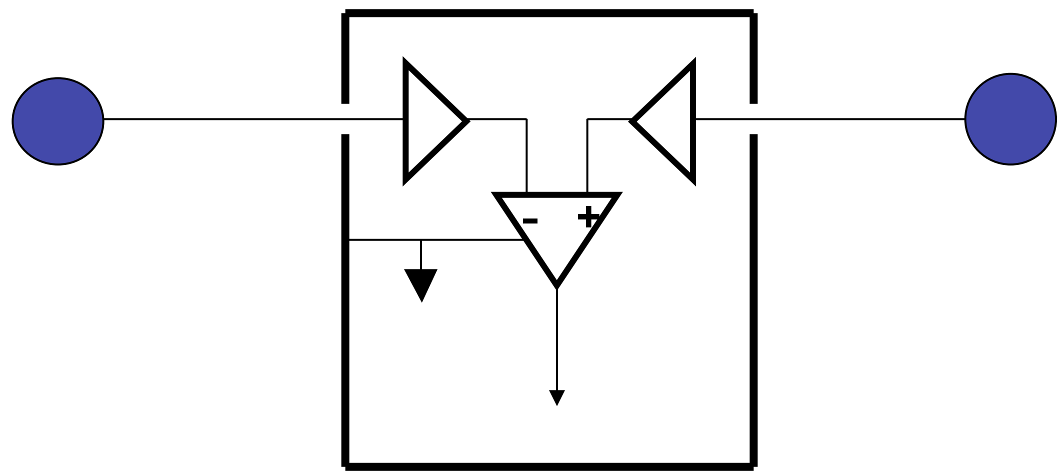
INDUCTIVE COUPLING

THE « FIELD MACHINES »

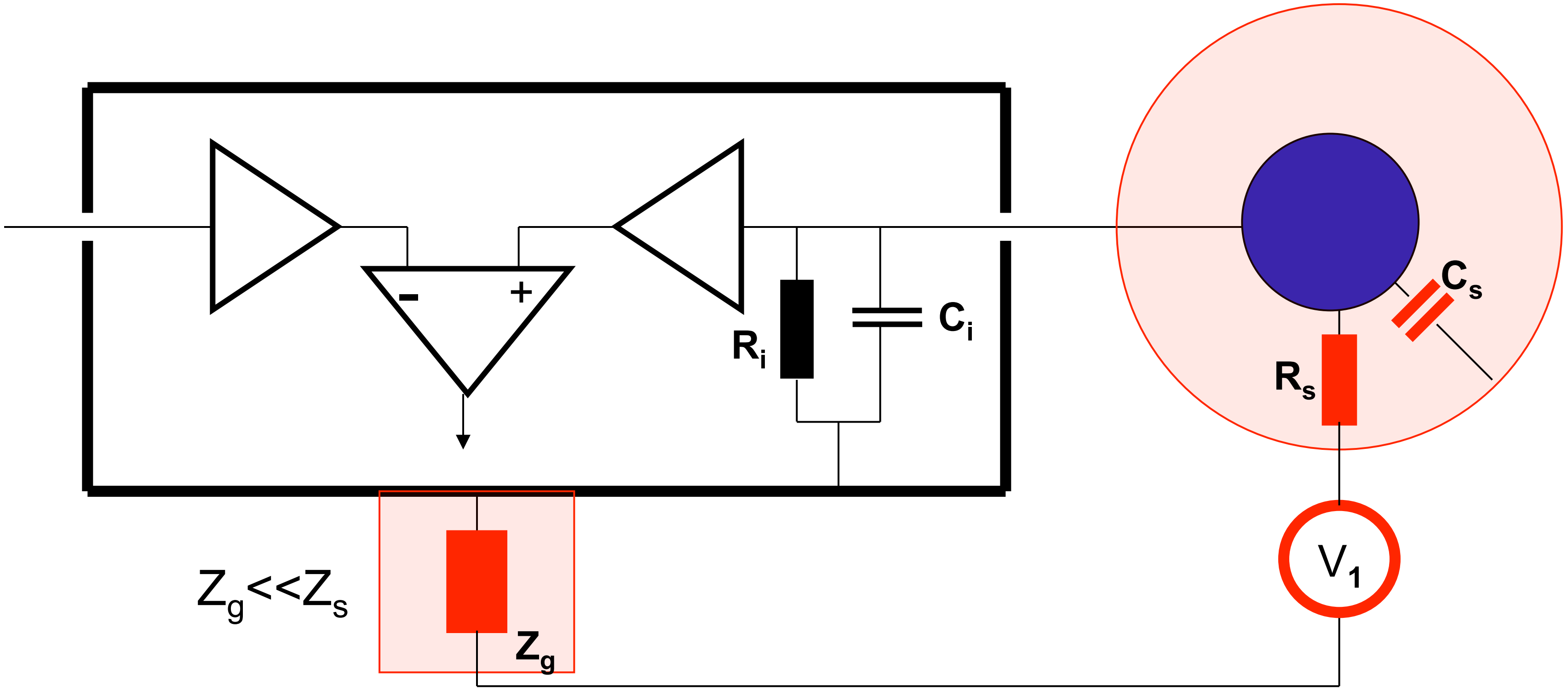


RESISTIVE COUPLING

THE DOUBLE PROBE INSTRUMENT



ELECTRIC FIELD MEASUREMENTS



$$V_{out} = \left[\left(V_1 - V_2 \right) + \left(WF_2 - WF_1 \right) \right] \cdot \left[\frac{Z_i}{Z_i + Z_s} \right]$$

ELECTRIC FIELD MEASUREMENTS

Transition frequency $$\omega_s = \frac{1}{R_s \cdot C_s}$$

Low Frequency limit $$V_{out} = \left(V_1 - V_2\right) \cdot \frac{R_i}{R_i + R_s} \cong \left(V_1 - V_2\right)$$ if $$R_i >> R_s$$

High Frequency Limit $$Z_s \approx 1/\omega C_s \quad Z_i \approx 1/\omega C_i \qquad V_{out} = \left(V_1 - V_2\right) \cdot \frac{C_s}{C_s + C_i}$$

DC-ELF : spherical sensors (with polarization current)

HF : cylindrical long antenna

ELECTRIC FIELD MEASUREMENTS

INDUCTIVE COUPLING, THE « FIELD MACHINES »

- high impedance, can operate in very low σ (Earth's surface)
- can measure large DC electric fields
- Some directional capability, 2D measurement with 1 sensor
- innovative designs in progress, miniaturized devices, vibrating system, ASIC

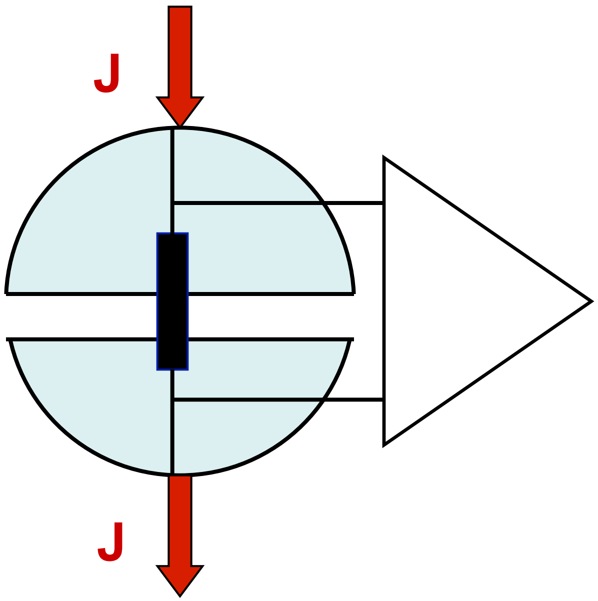
- low sensitivity
- electro-mechanical device (harsh environments, dust, EMI…), signal processing
- low temporal resolution and low frequency capability (no waves)

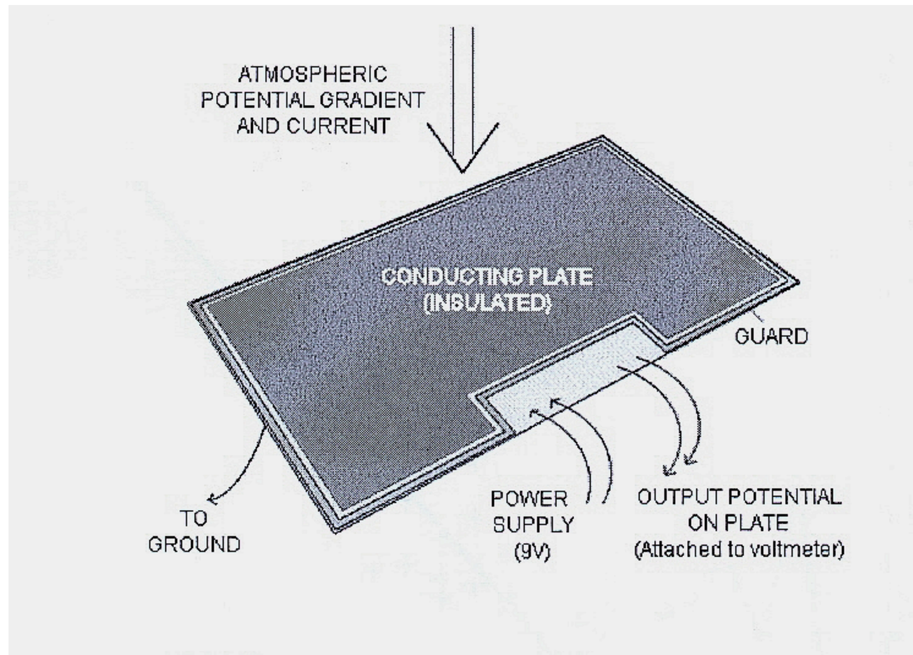
RESISTIVE COUPLING, THE DOUBLE PROBE INSTRUMENT

- simple device and electronics
- high sensitivity (in AC better than $1 \mu V/mHz^{1/2}$)
- high temporal resolution (lightning), high frequency capability (MHz)
- direct measurement, no signal processing
- high amplitude DC and AC electric field measurements in dedicated modes

- booms (deployment, mass,…)
- limited to $\sigma \geq 10^{-13}$ S/m (on Earth above ~ 8 kilometers)

ATMOSPHERIC CURRENT MEASUREMENTS





From A.J. Bennet and R.G. Harrison, Sub. Adv in Geosciences

ELECTRIC FIELDS AND CONDUCTIVITY MEASUREMENTS ON STRATOSPHERIC BALLOON FLIGHTS

HVAIRS Gondola
AMMA Campaign in Niger

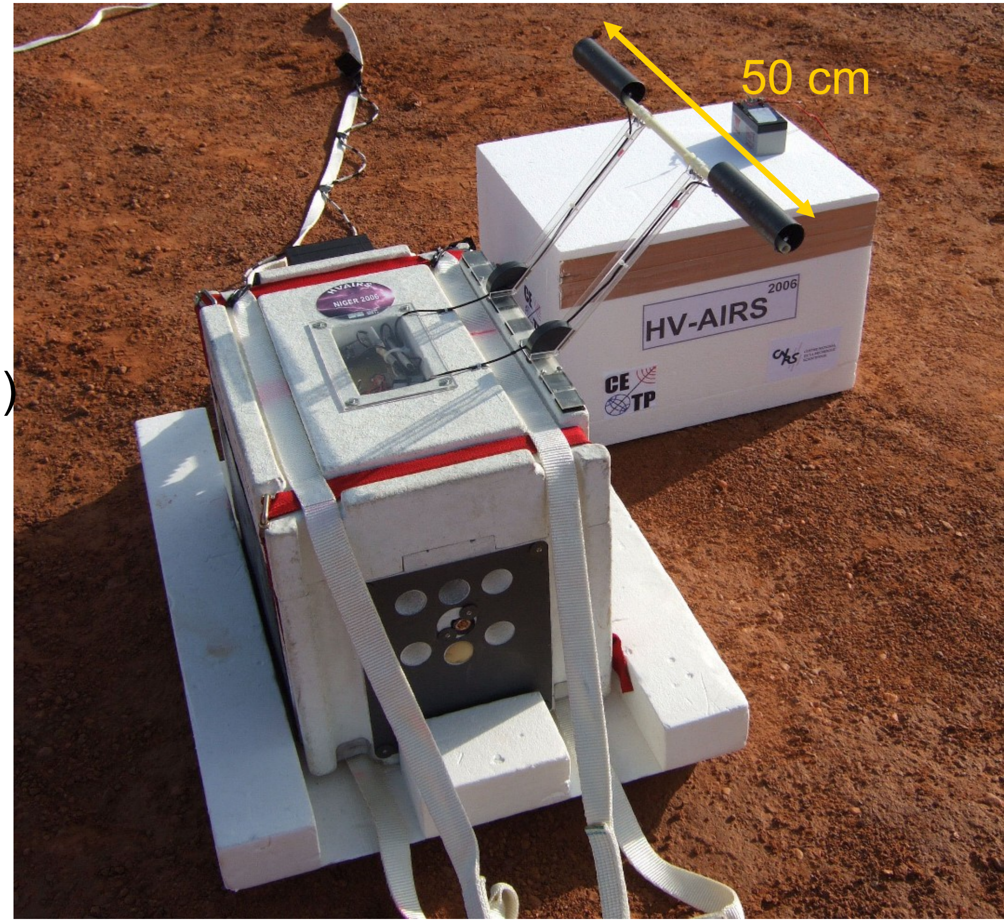
Electric Field Intrument

- Vertical component of Electric Field
  - DC to 3 kHz
  - Large signal « DC channel »
    ~ ± 50 mV/m to ± 200 V/m
    (up to ± 10 kV/m in special mode)
  - Small signal « AC channel »
    sensitivity ~ 30 μV/m. $Hz^{1/2}$
- Conductivity measurements
  - relaxation method

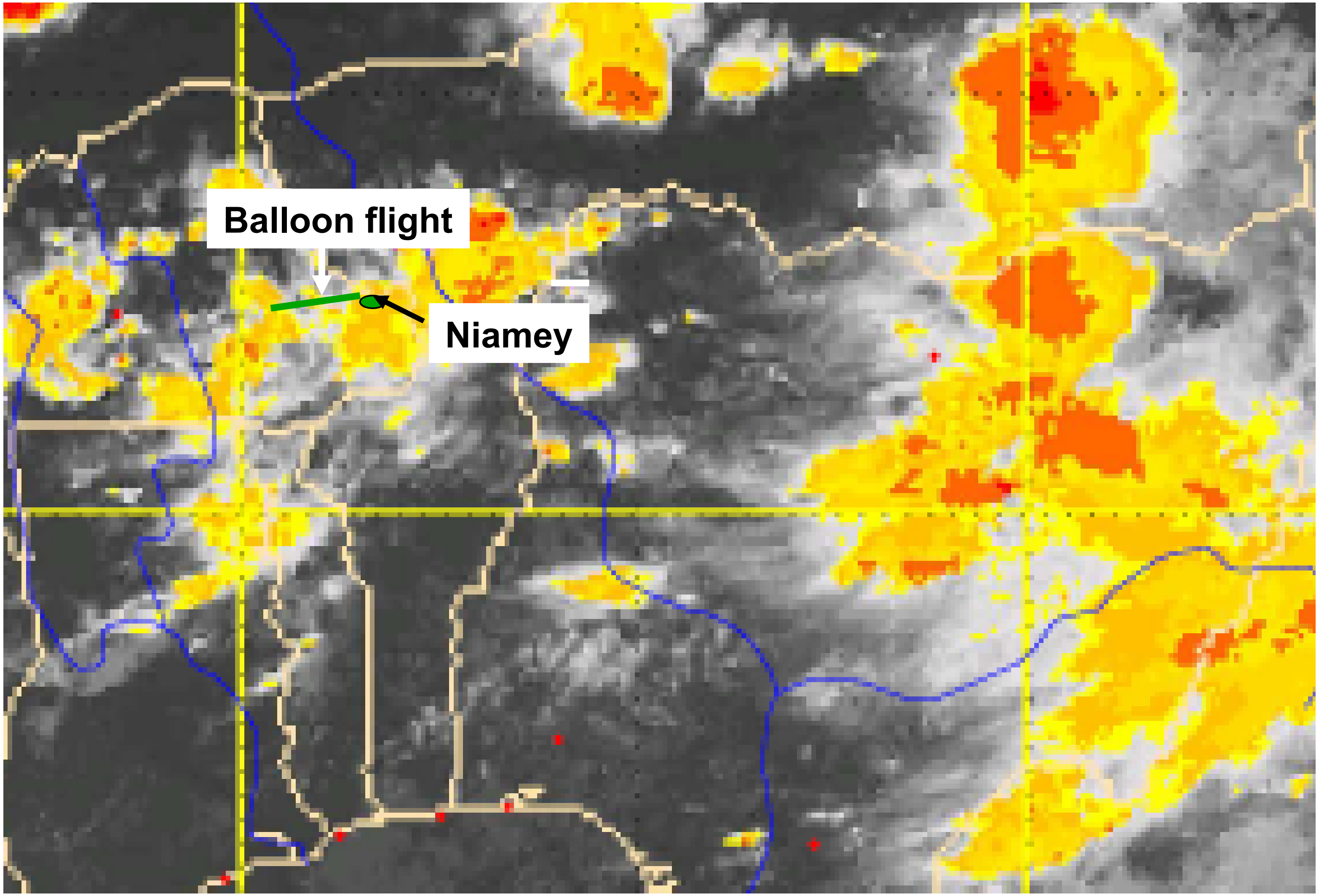
Optical sensors

- photodiode lightning detectors

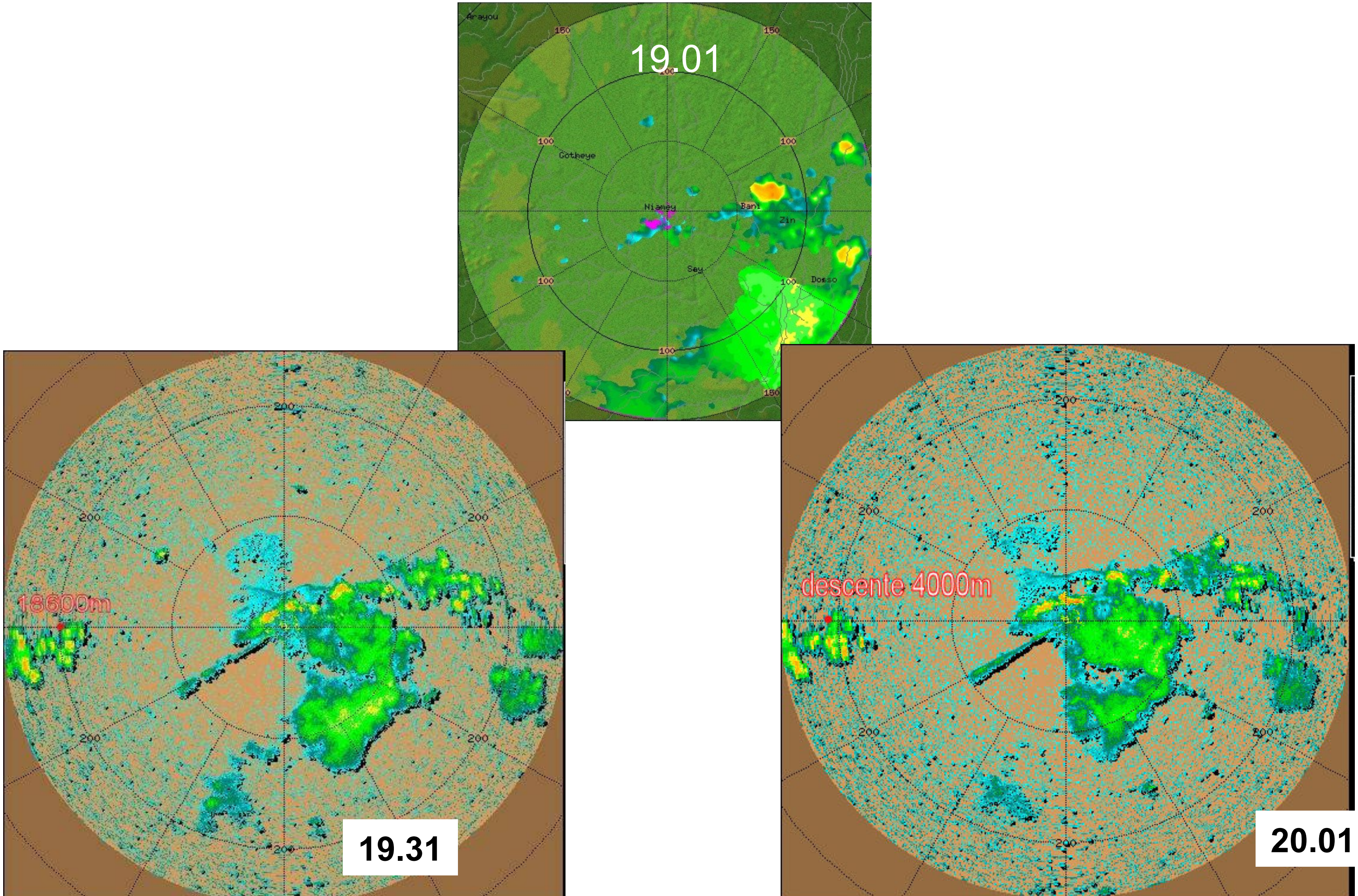
On-Board Data Storage



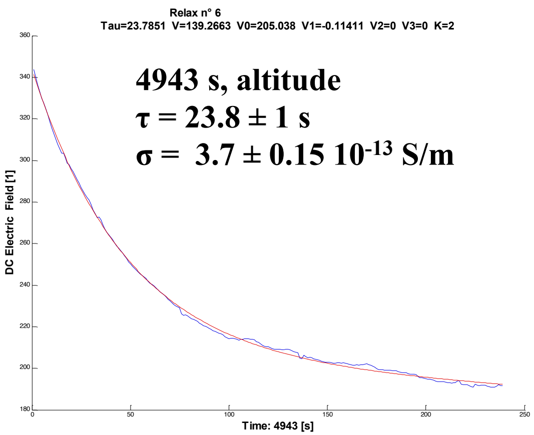
HVAIRS_AMMA, Meteorological Conditions (1)

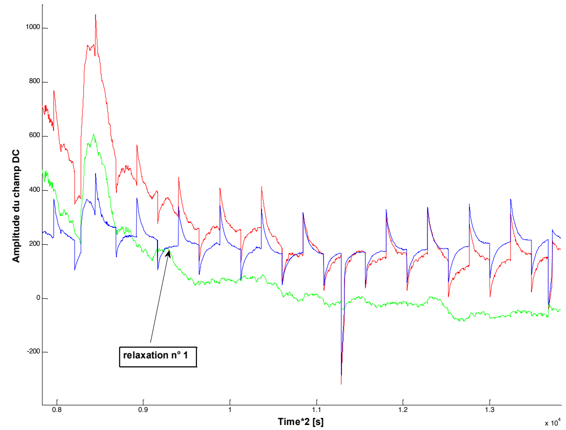


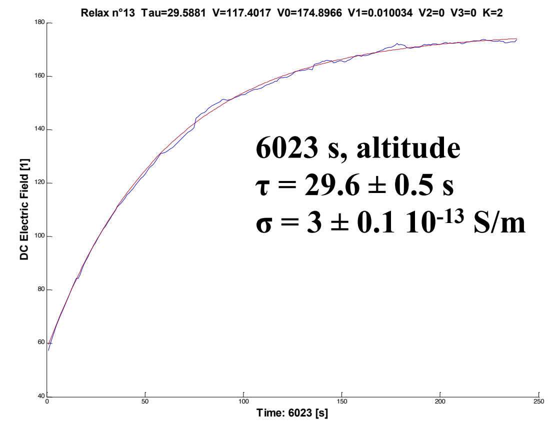
HVAIRS_AMMA, Meteorological conditions (2)

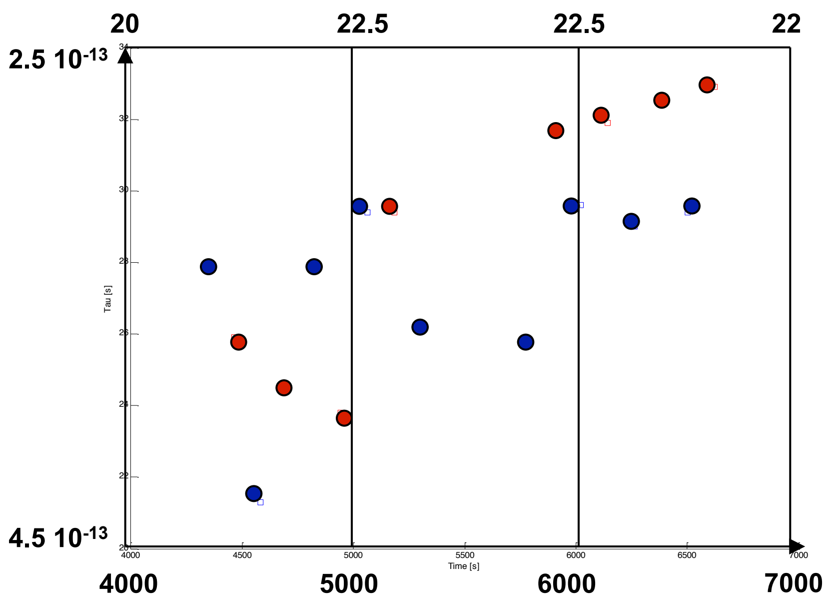


HVAIRS_AMMA, Conductivity Measurements









σ- ~ 3.1 10^{-13} S/m

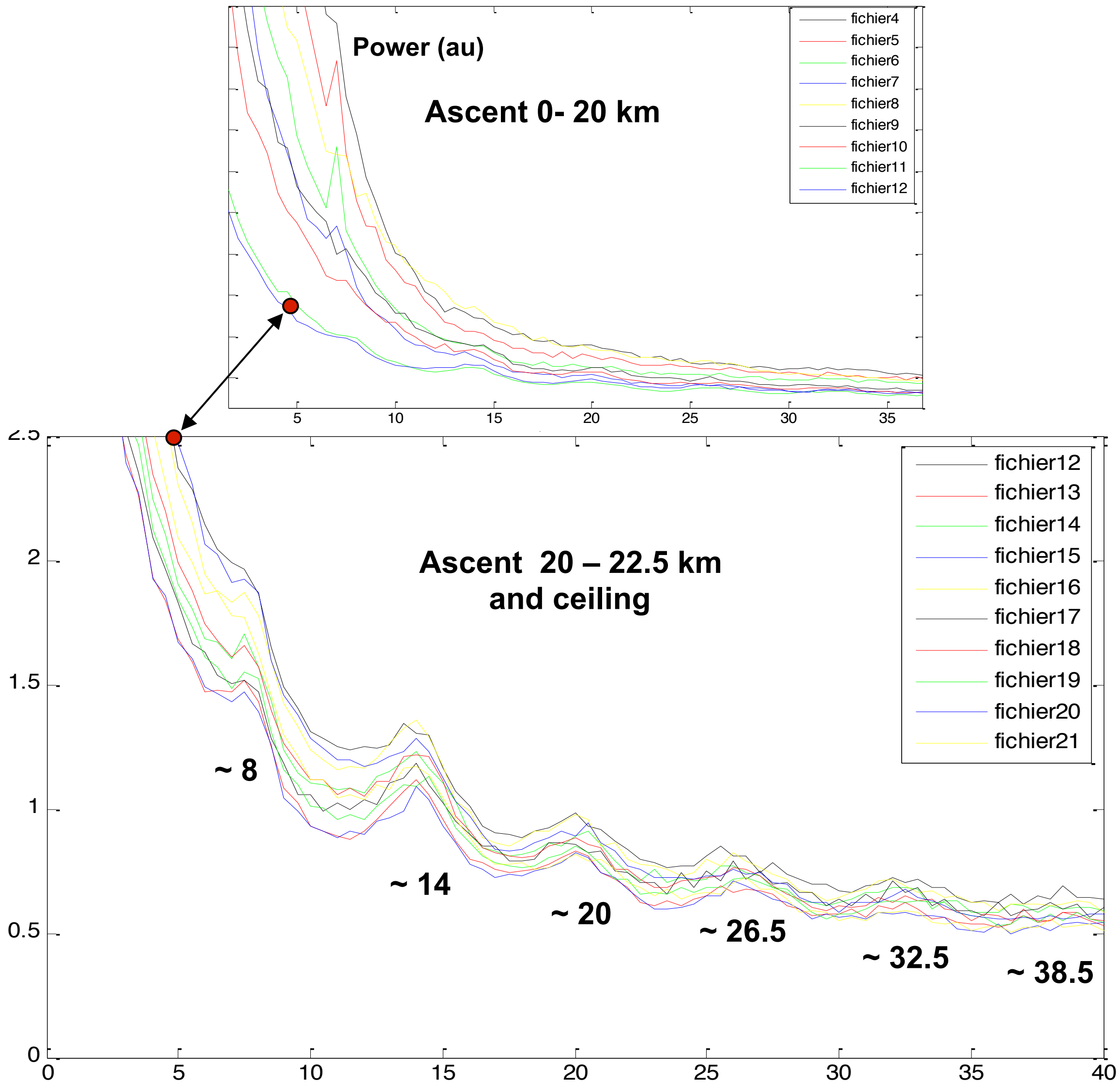
σ+ ~ 3.3 10^{-13} S/m

σ ~ 6.4 10^{-13} S/m

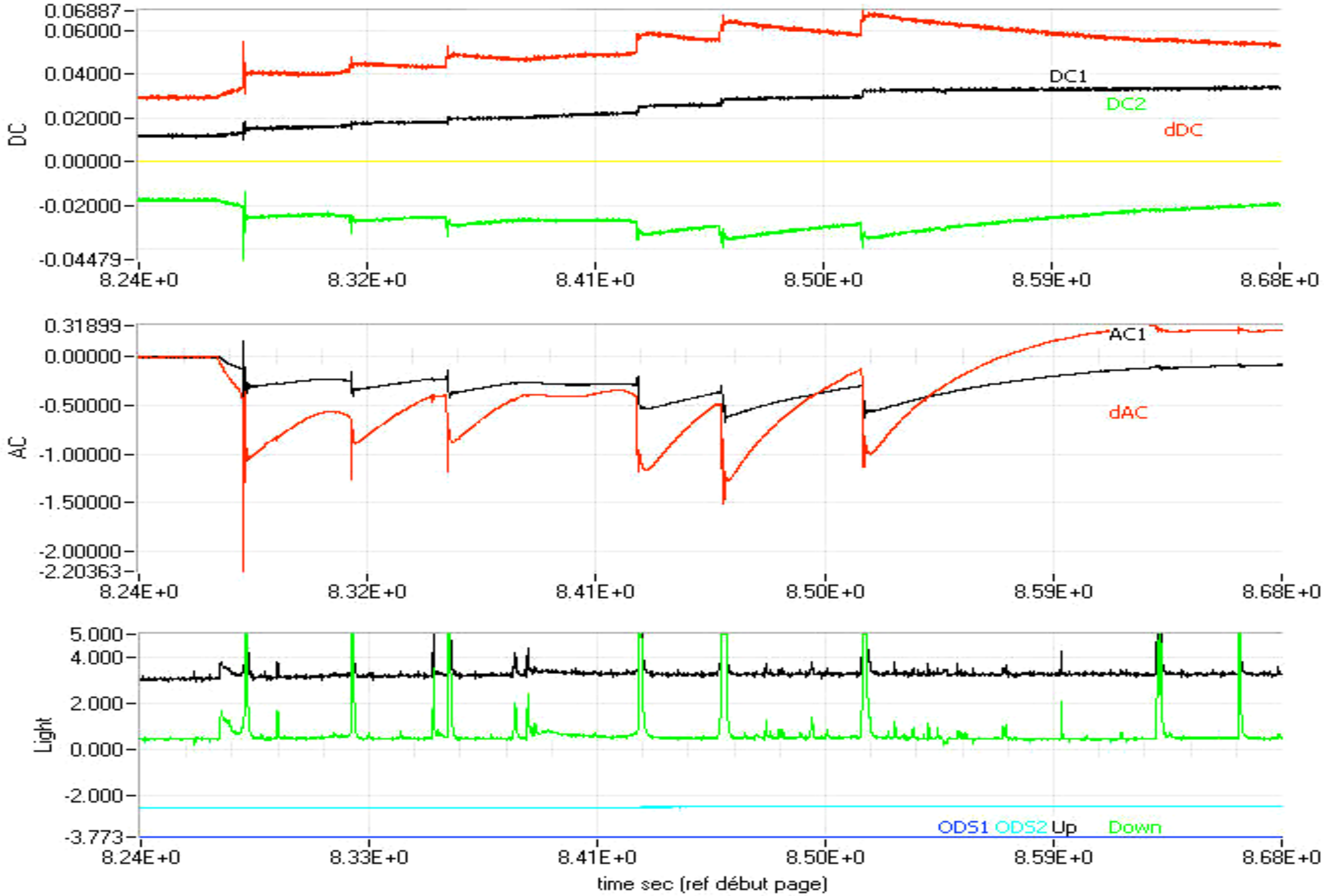
σ ~ 2 10^{-12} S/m
R.H. Holzworth JGR, 1991

σ ~ 1.4 10^{-12} S/m
From W. Gringel, Prometheus, 1977

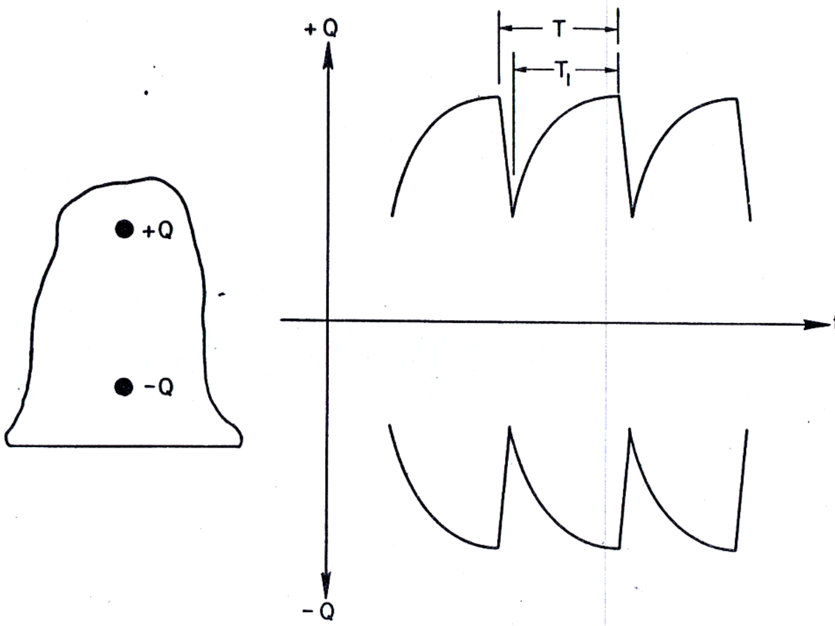
HVAIRS_AMMA, AC ELECTRIC FIELDS
Background noise during ascent and Schumann resonnances



HVAIRS_AMMA, LIGHTNING and DC ELECTRIC FIELDS



DC Electric Fields variations induced by lightning
Intra-Cloud Charge neutralization



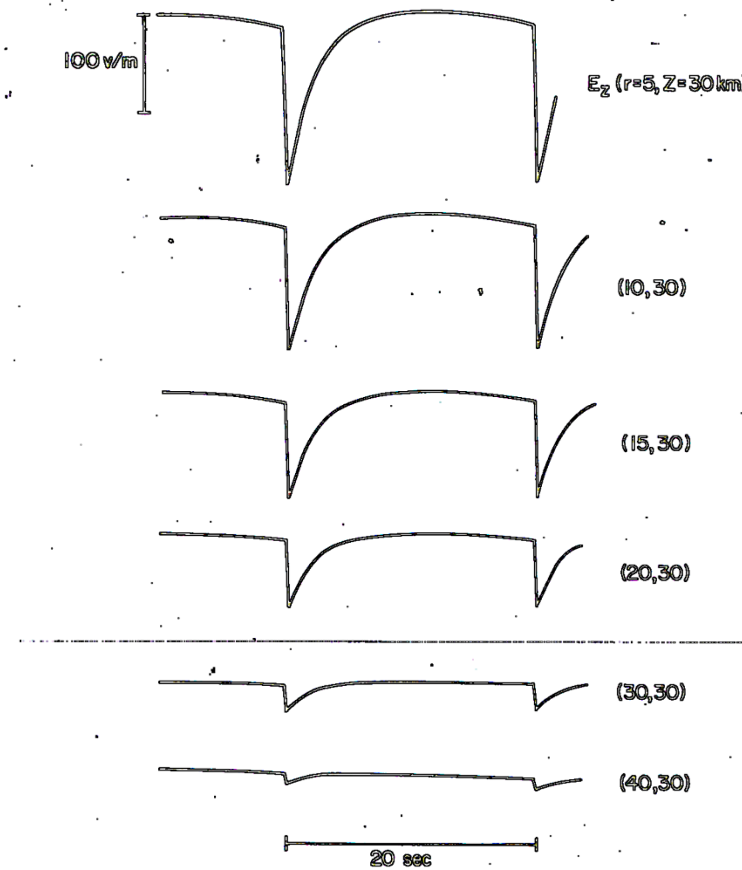
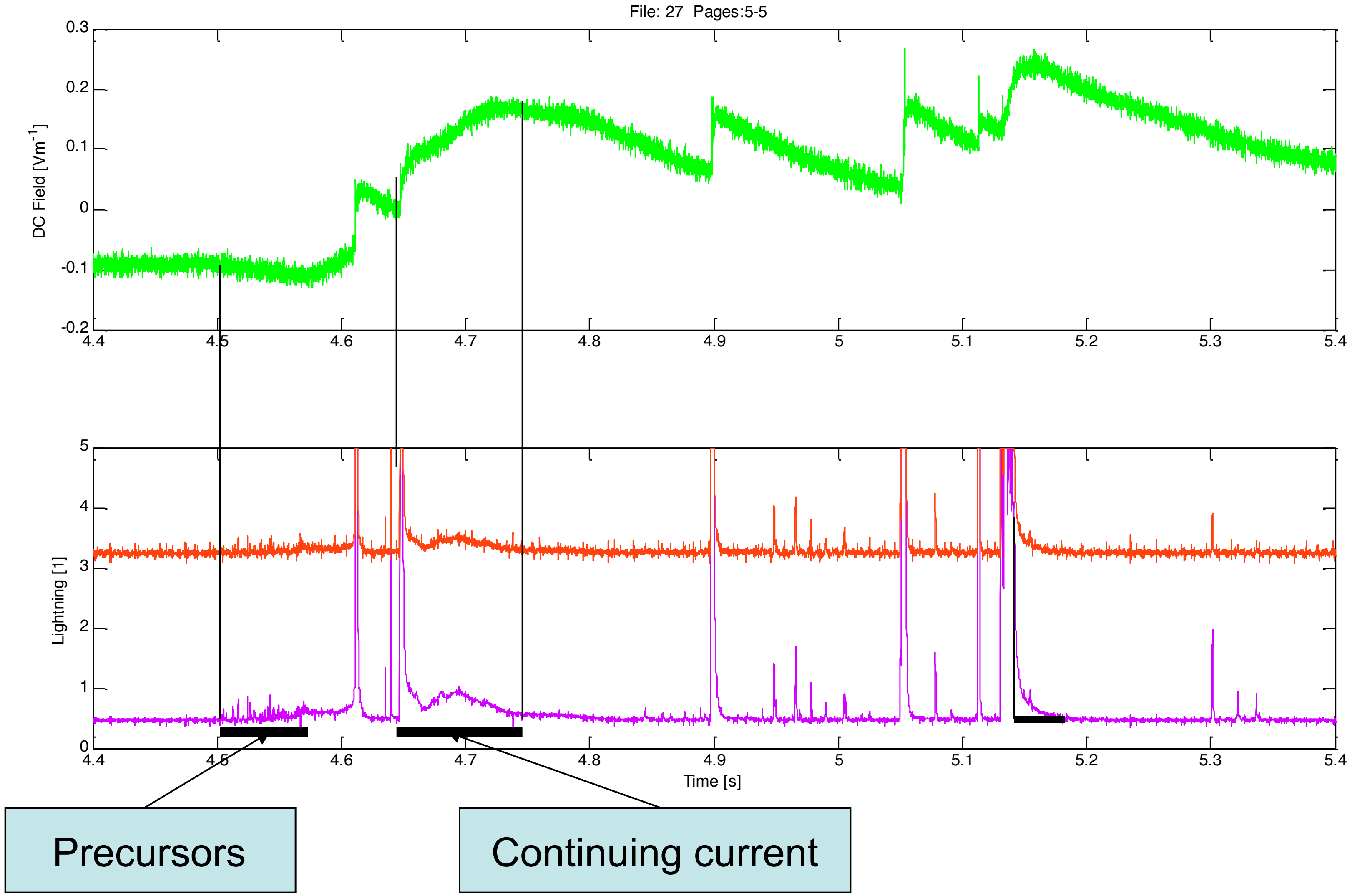


FIGURE 5-26. PLOTS OF E_z AT z = 30 km AND SELECTED VALUES OF r.

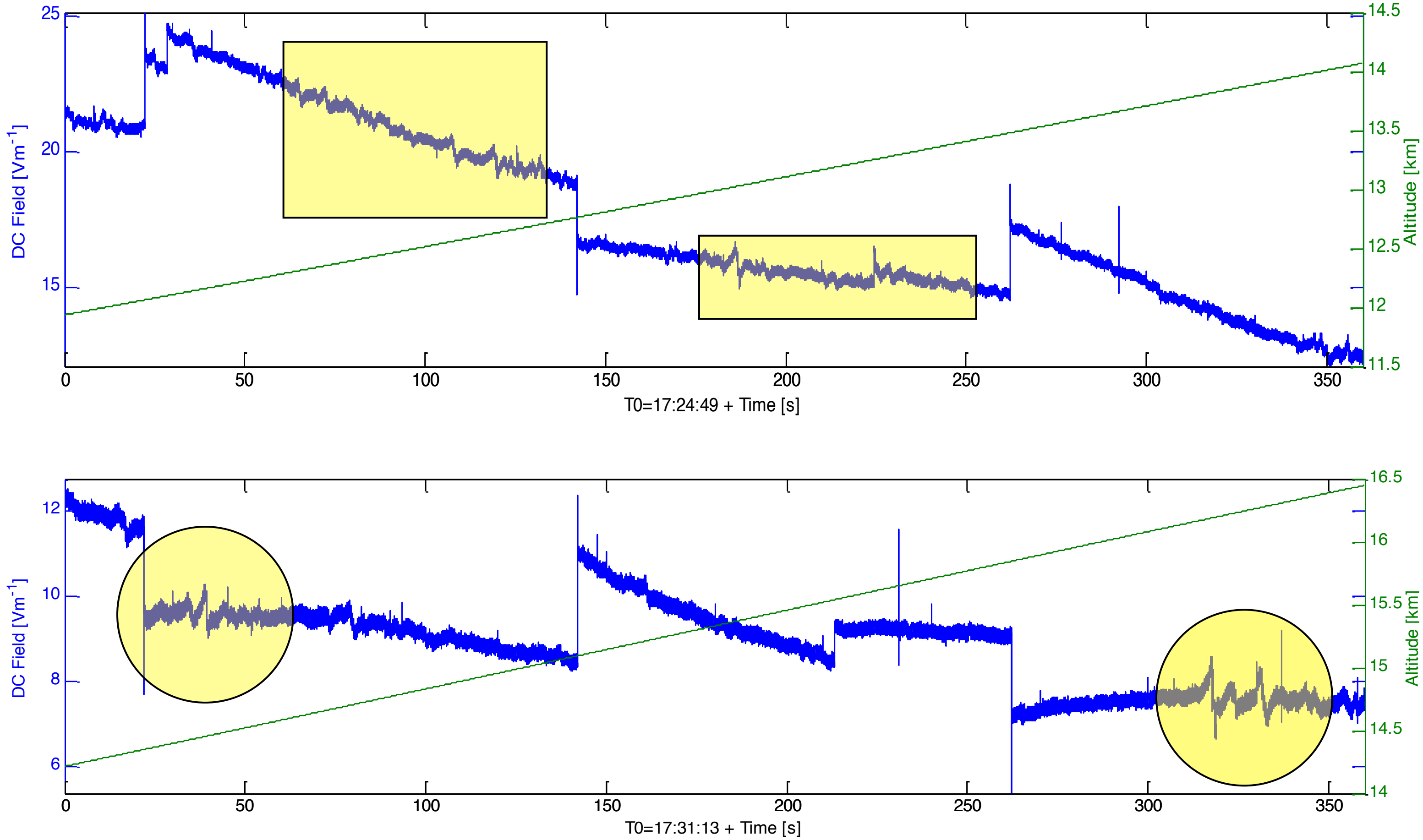
115

Dejnakarintra, 1973

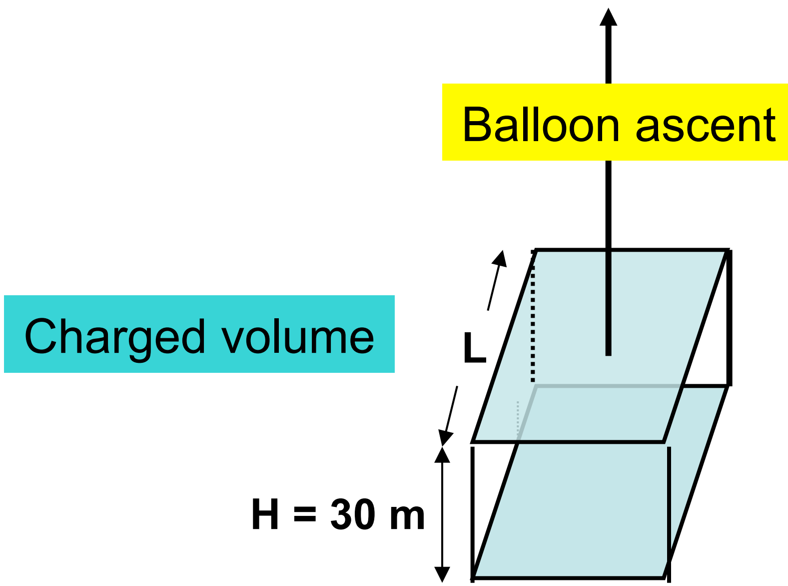
HV-AIRS LIGHTNING and E-FIELD
Precursors and Continuing Currents

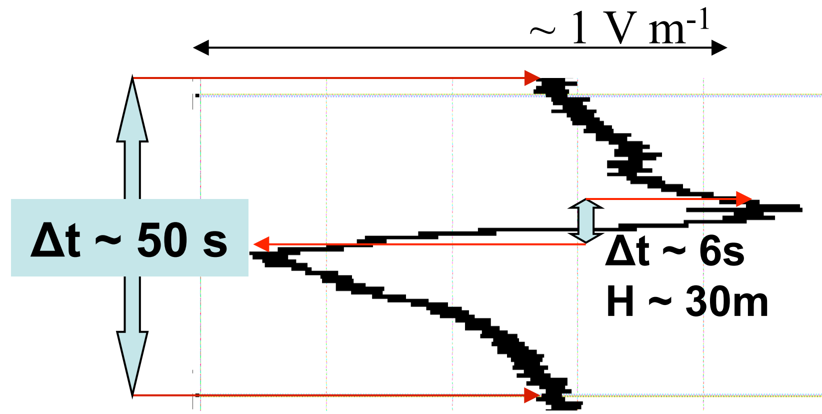


HVAIRS_AMMA, DC Electric Fields
ULF signatures of stratospheric charged clouds

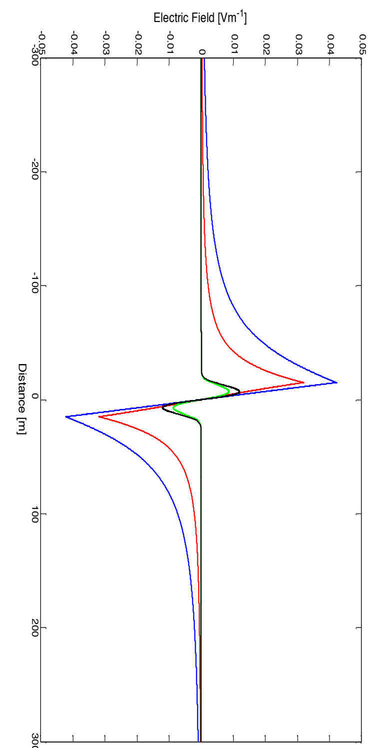


HVAIRS_AMMA, DC Electric Fields
ULF signatures of stratospheric Charged Clouds

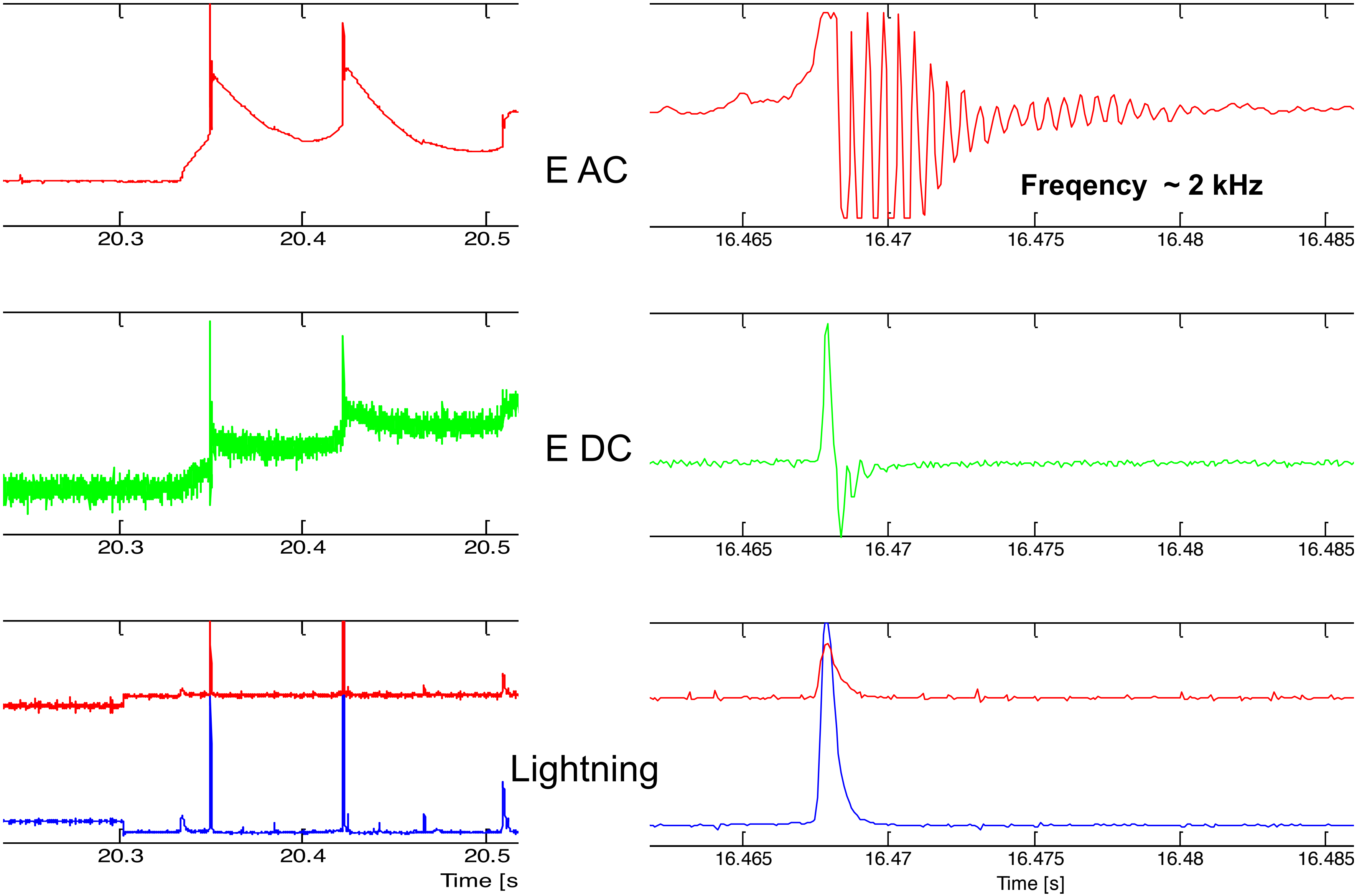




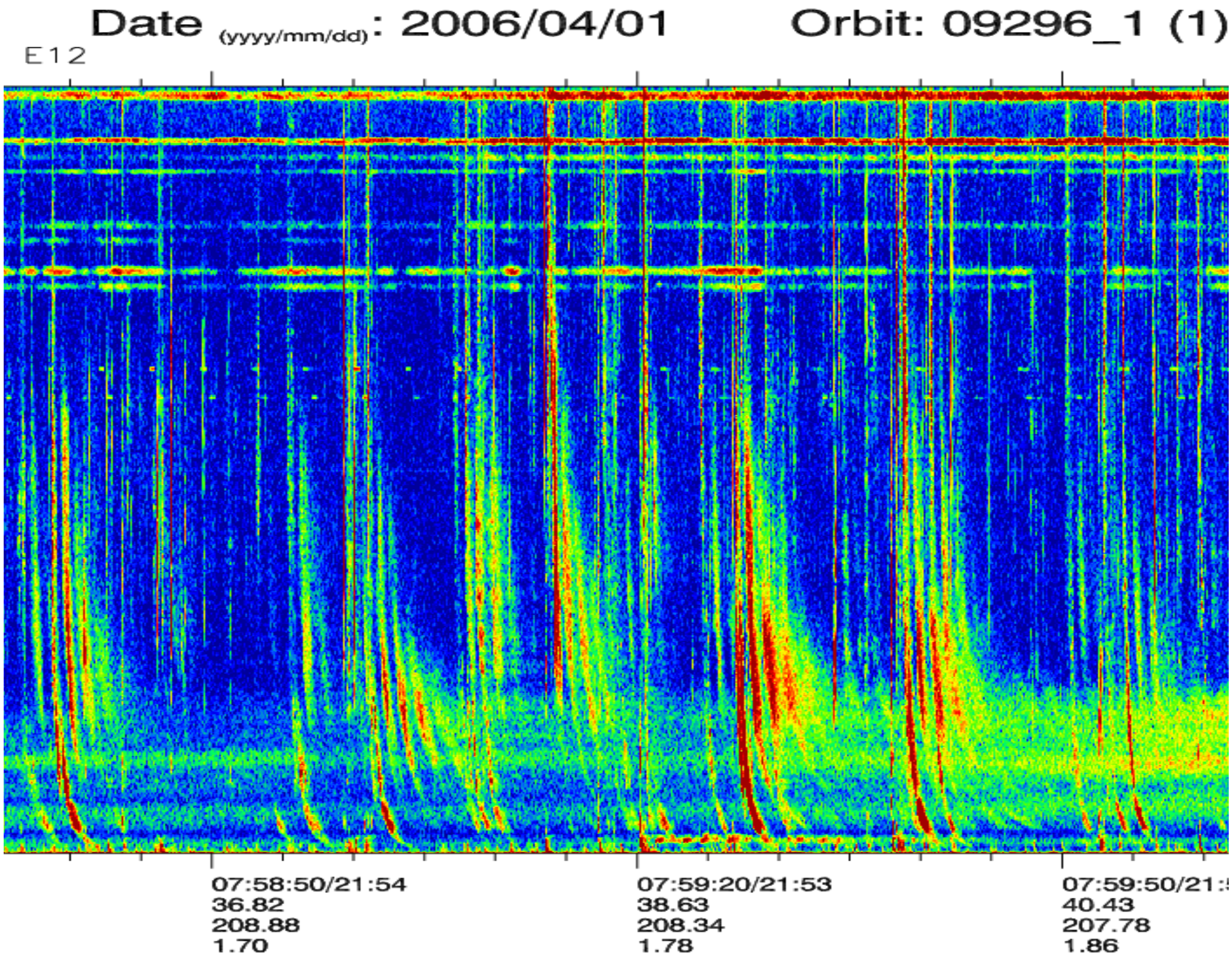
H ~ 30m
L ~ 50-100m
Q~ 10-30 µC



HV-AIRS AMMA, LIGHTNING, EM Pulse and Transverse resonance

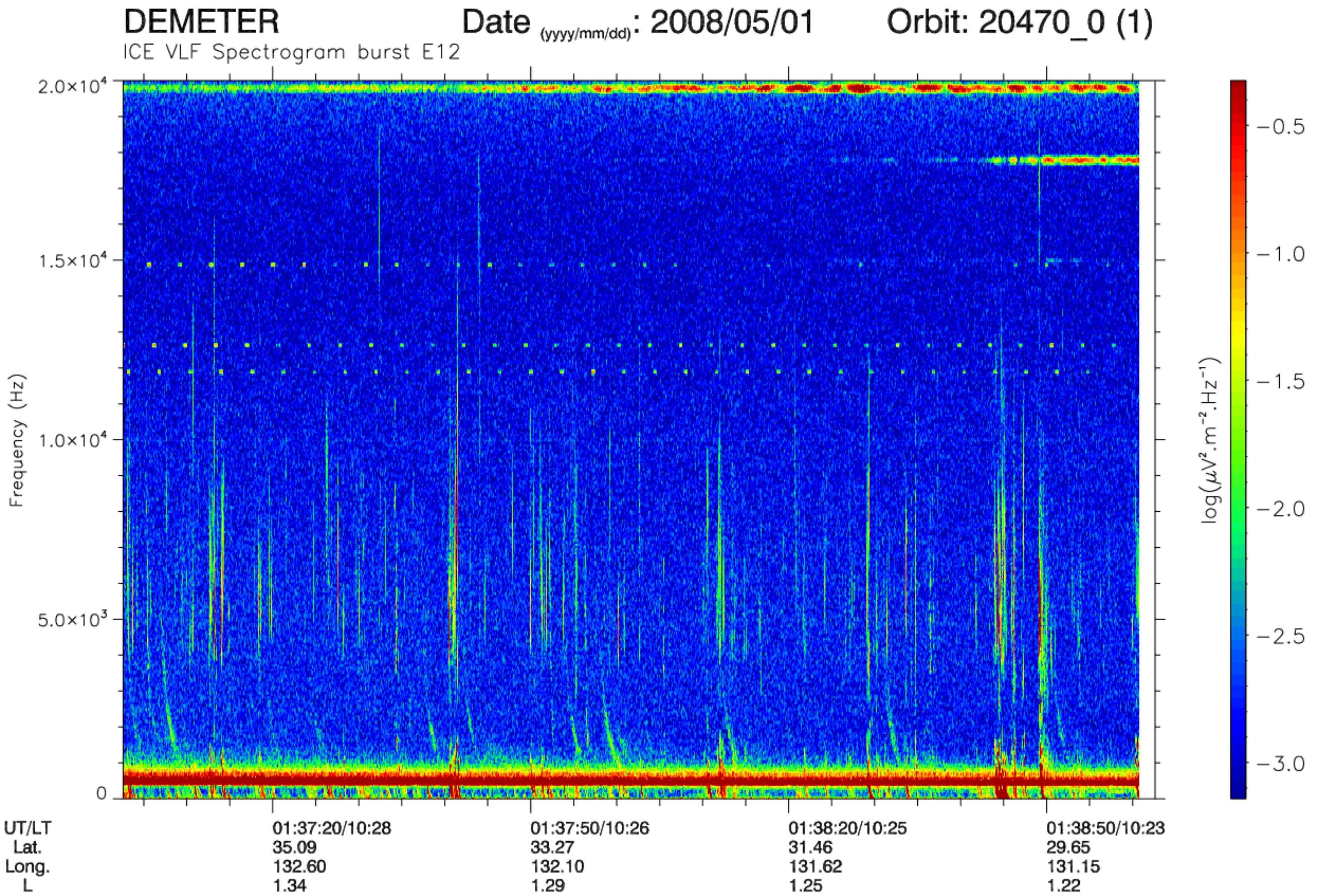


LIGHTNING DETECTION FROM ORBIT
DEMETER Observations at 650 km altitude



LIGHTNING DETECTION FROM ORBIT

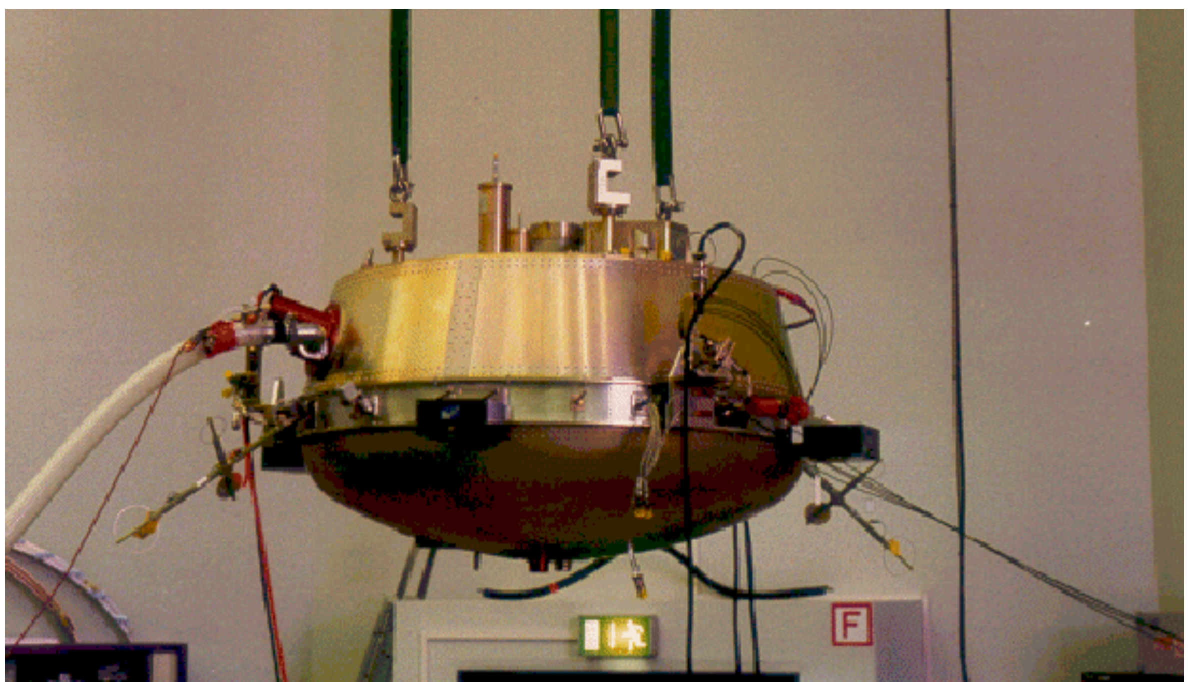
DEMETER Observations at 650 km altitude



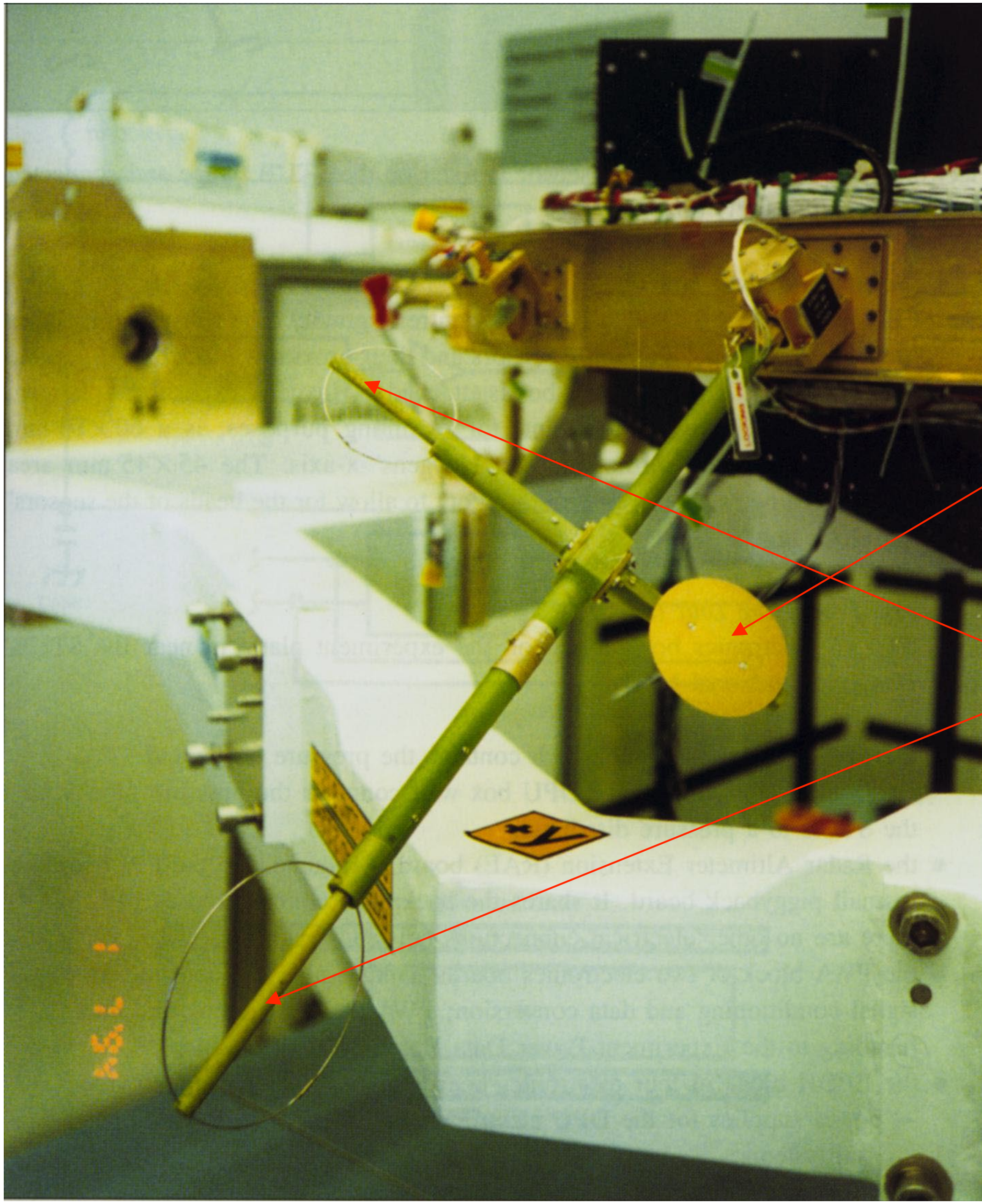
THE HASI/PWA EXPERIMENT ON HUYGENS

PWA aimed at contributing to answering the following questions:

- What are the ion and electron conductivity profiles?
- What is the role of aerosols in atmospheric chemistry?
- Is there lightning on Titan?
- Do standing waves form in the surface-ionosphere cavity?
- What are the dielectric properties of the surface?
- Does a global electric circuit exist on Titan?



PWA ELECTRODES

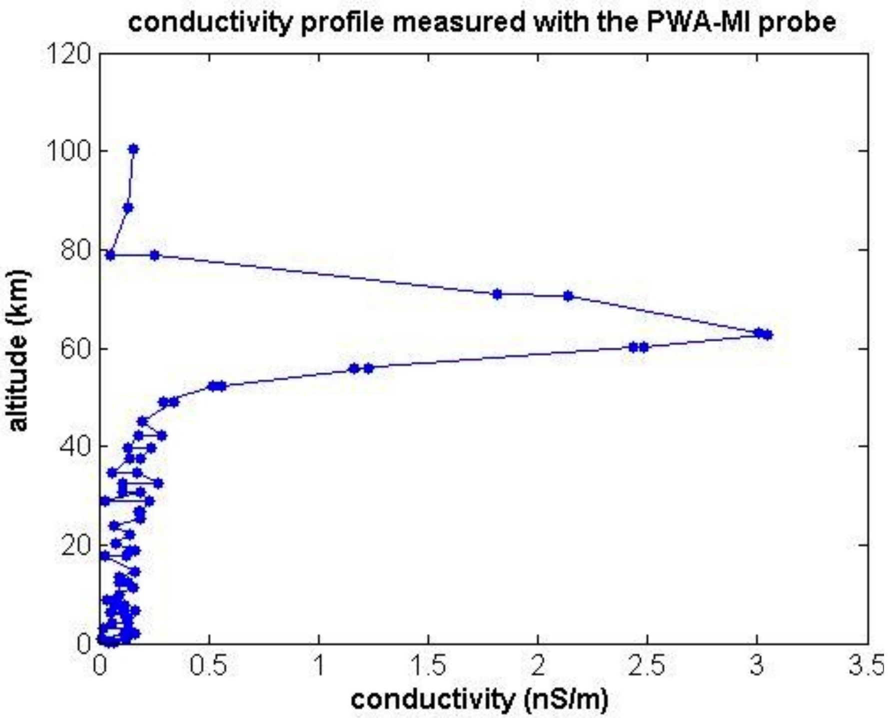


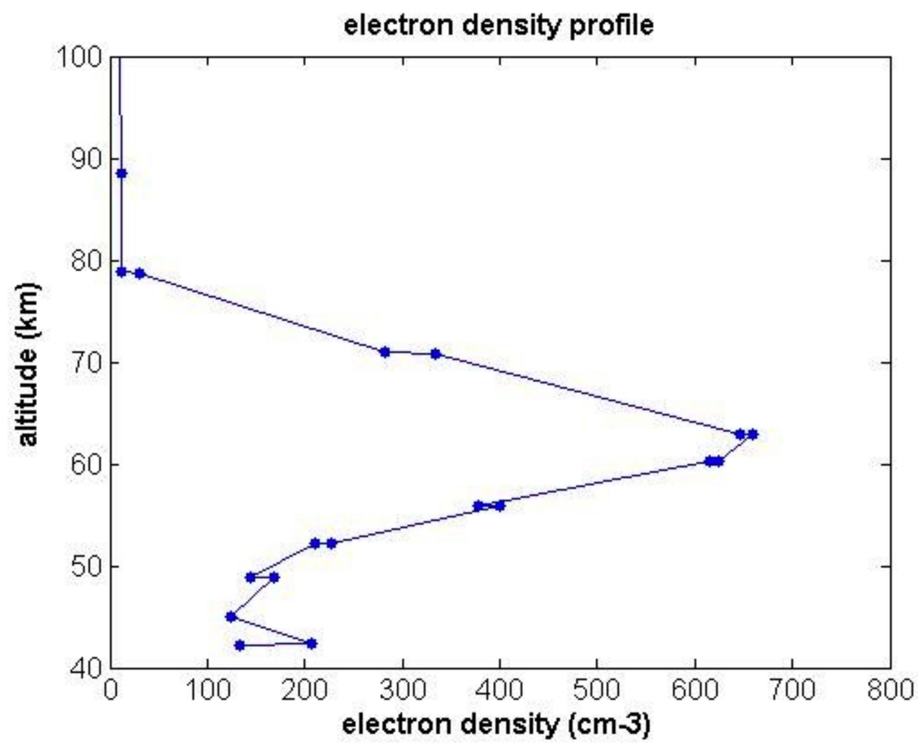
Relaxation Probe RP

Mutual Impedance Probe MIP

PLANETARY CONDUCTIVITY PROFILES: TITAN

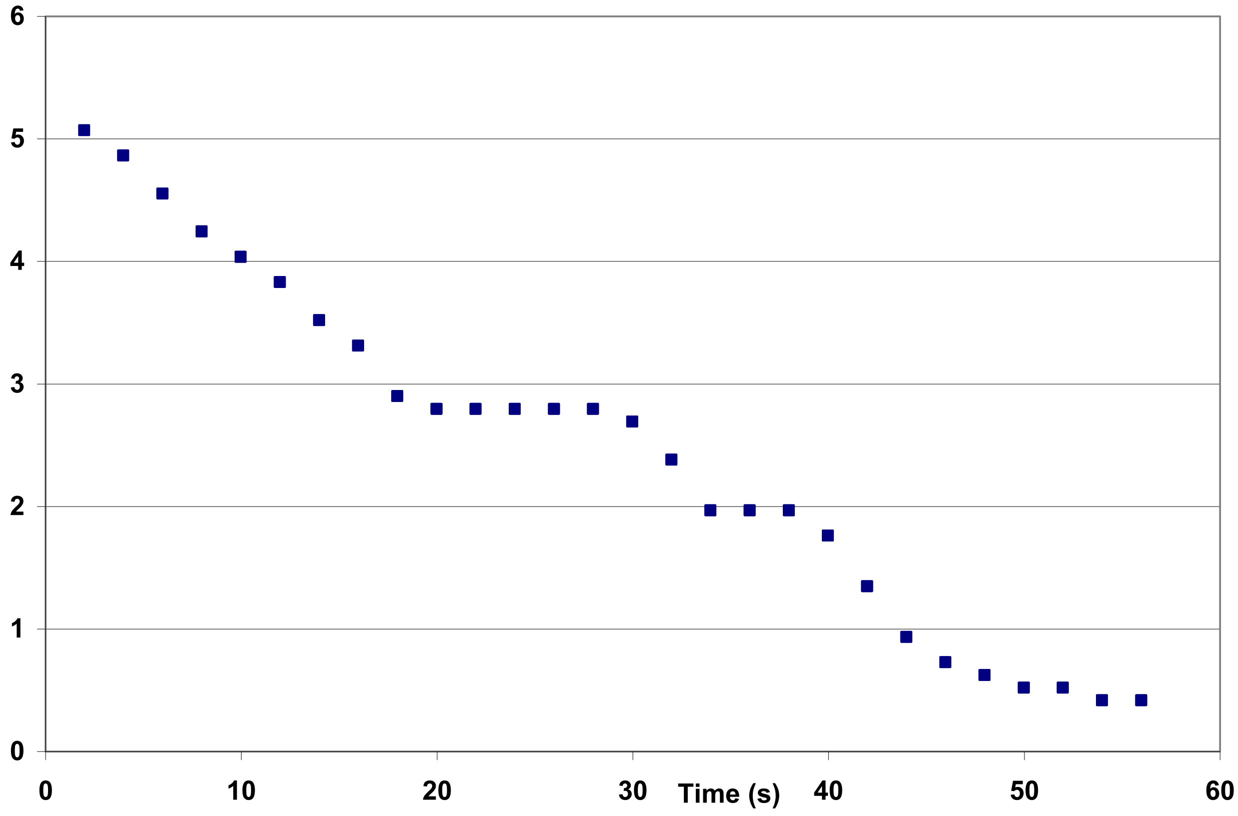
HASI_PWA experiment on HUYGENS



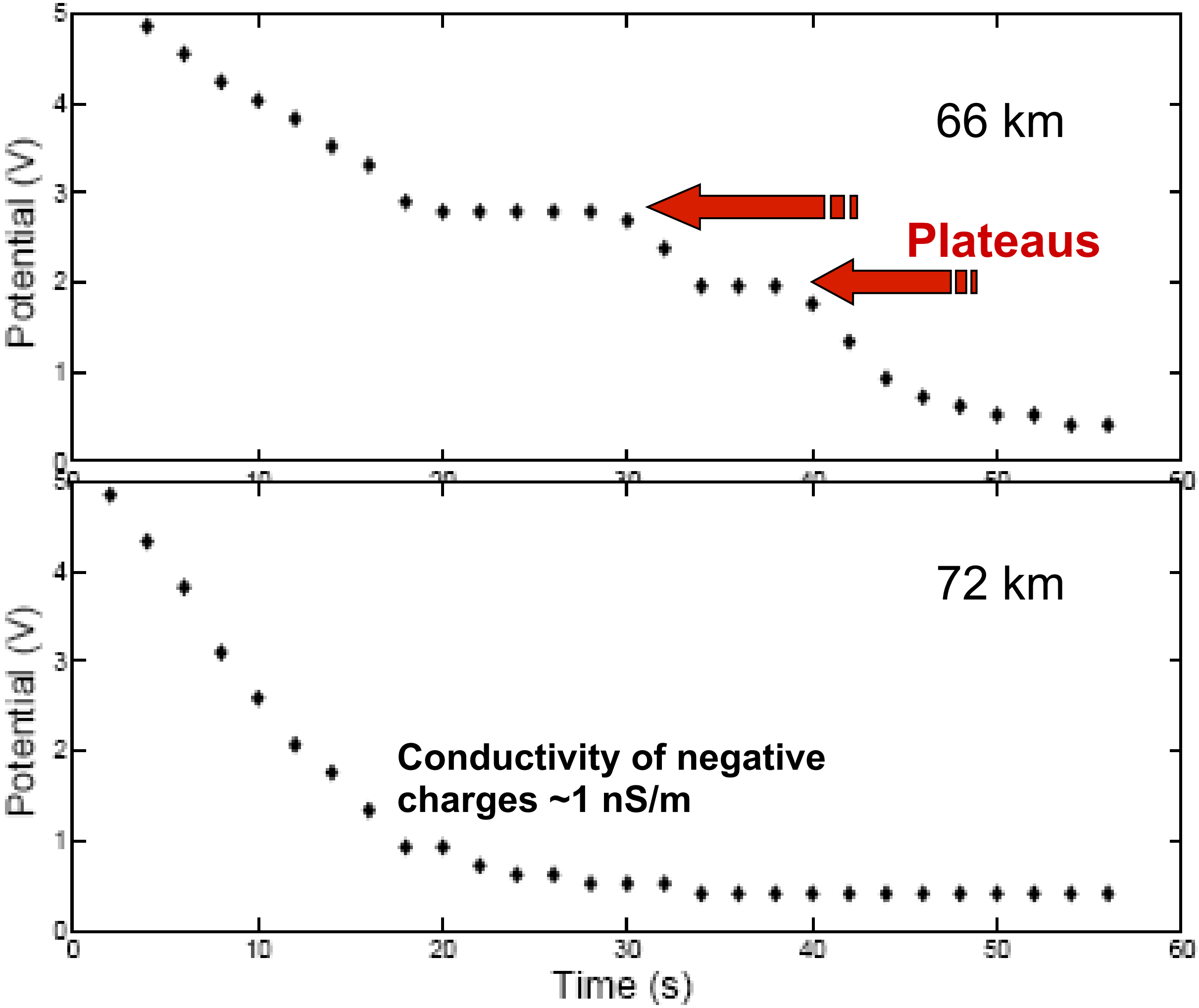


From M. Hamelin et al., PSS, 2007.

HUYGENS: Relaxation Curve with plateaus



RELAXATION PROBE WAVEFORMS
DETECTION OF AEROSOL LAYER IN TITAN ATMOSPHERE



RP measured positive ions and negative ions+electrons

No artefact has been found to explain this behaviour.

Plateaus likely correspond to absence of electrons - aerosol layers or bubbles (*ongoing work*).

Aerosol structure

Altitude [km]	Thickness [km]
94.5	3.3
70 69.7	0.3 0.1
62.2	0.1
57.1 54.3	0.2 0.2
56. 6 50.9	0.1 0.1

López-Moreno et al., 2008