Ionospheric Research Perspectives 1975-2015

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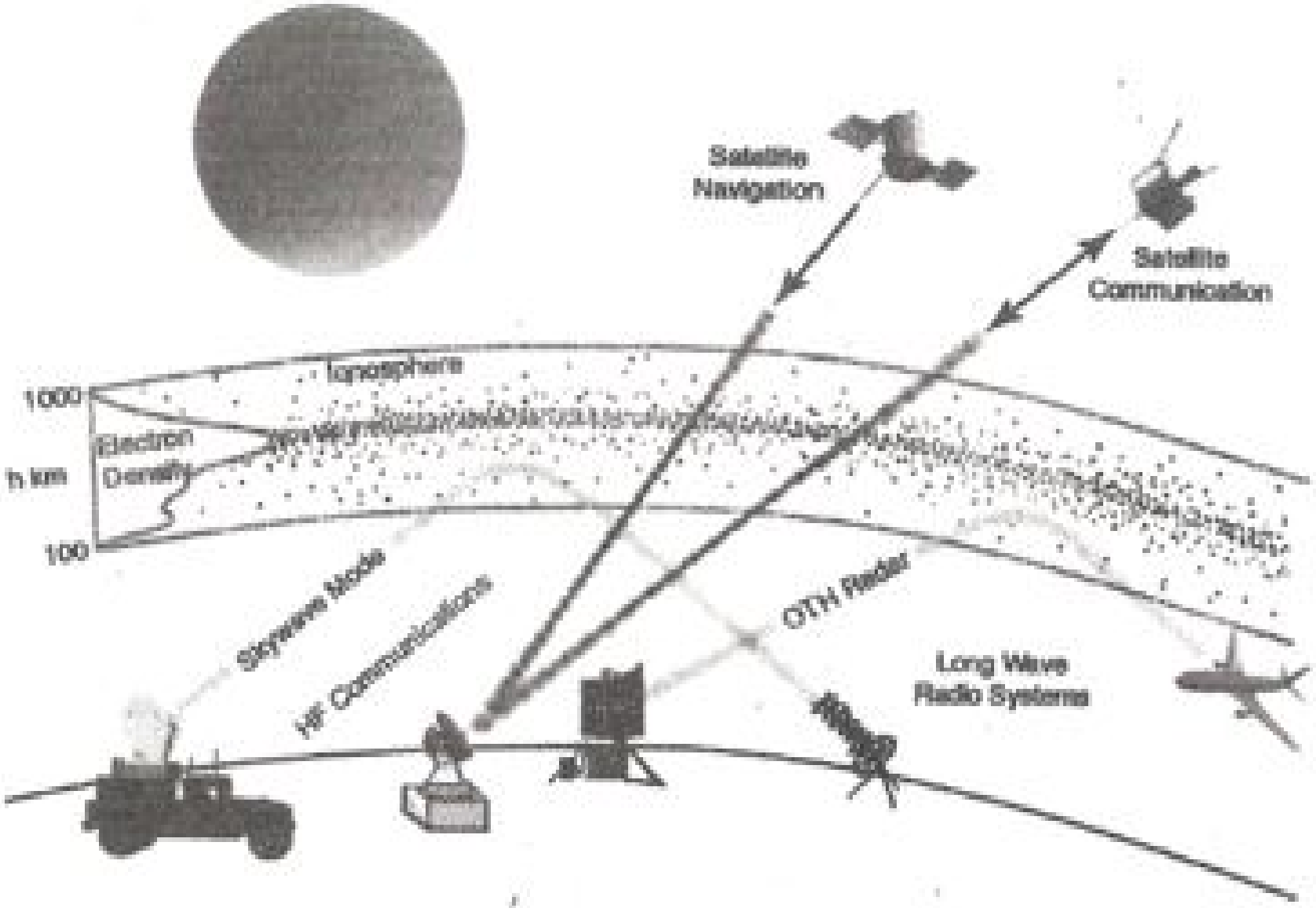
JMG Associates

May 12, 2015

Contents

- Some Introductory Remarks
- Where were we then? (circa 1970-1980)
- Where are we now? (2015)
- Challenges

NRL Randle Cliff Radar at CBD, Maryland (150-ft Diameter Dish Antenna)


Satellite
Navigation
Satellite
Communication
Ionosphere
1000
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Electron
Density
100
Skywave Mode
HF Communications
OTH Radar
Long Wave
Radio Systems

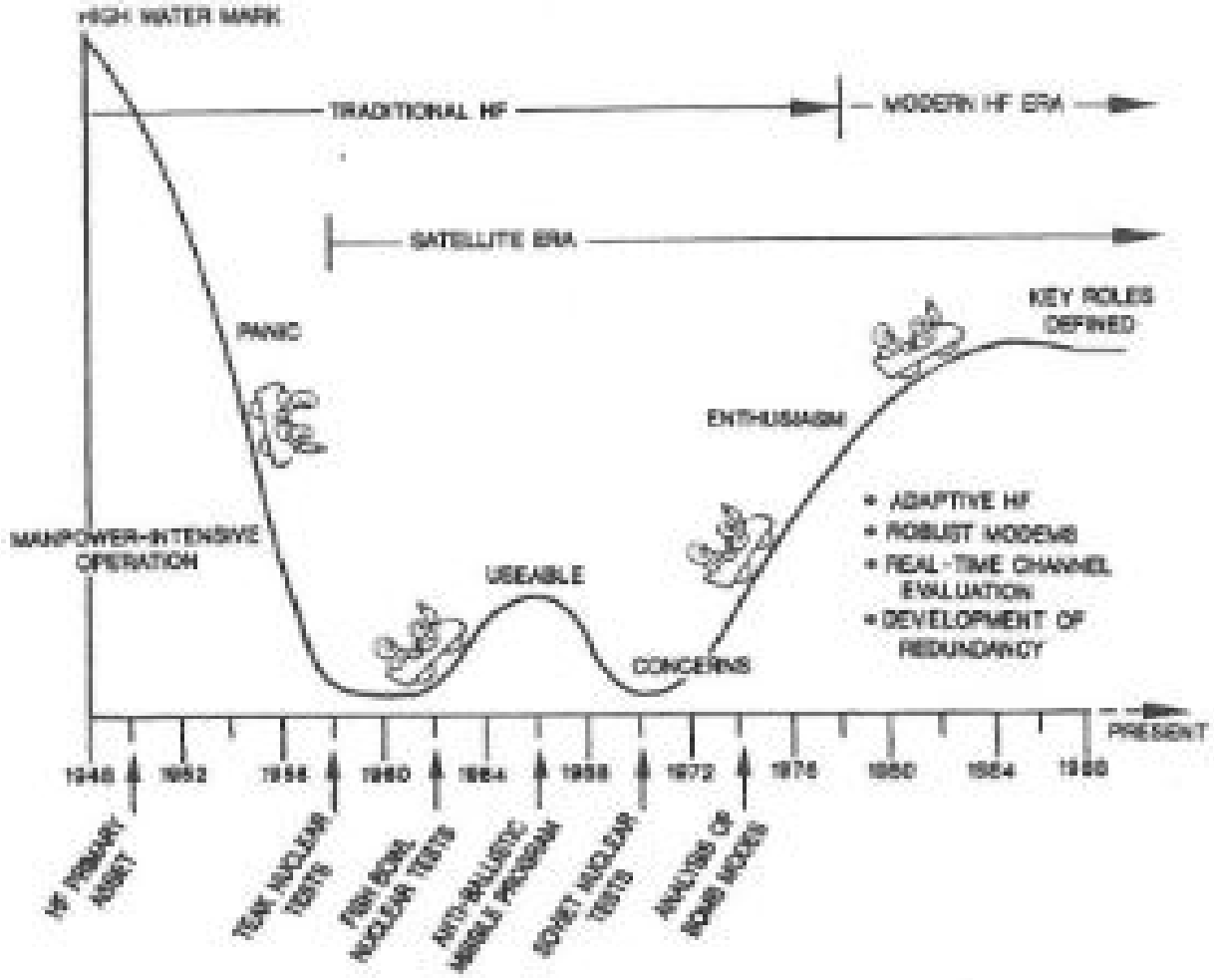


Fig.1-2. The HF *Roller Coaster* ride since the end of World War II.

IES History

- Motivations
- Early and Enduring Sponsors
- Notable Session Chairmen over the years
- Topics solicited
- Featured Speakers of IES

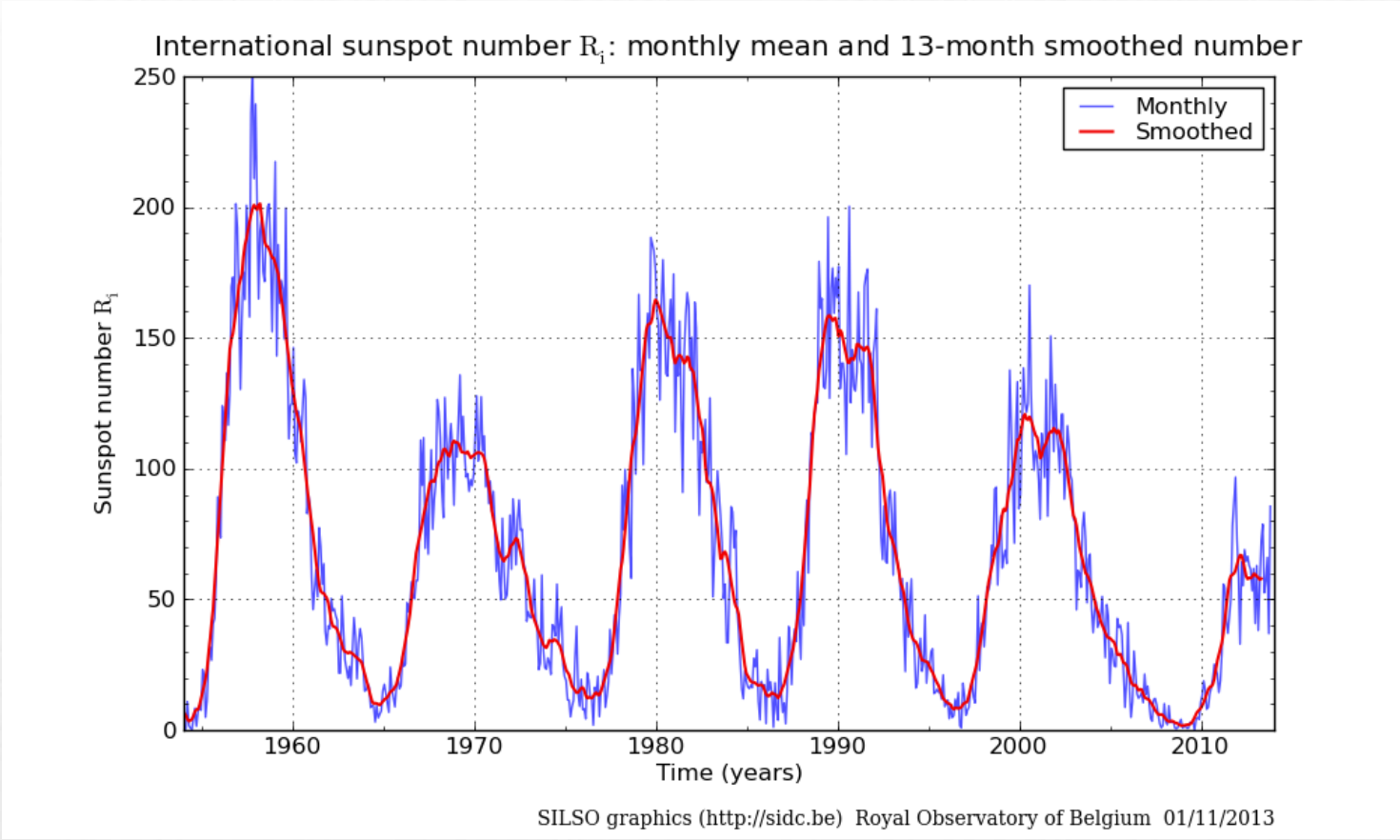
MOTIVATIONS for IES

- Jules Aarons and his "Radio Astronomical and Satellite Studies of the Atmosphere"
- NATO-AGARD topical conferences
- Sought to emphasize DoD and civilian applications of ionospheric science
- Sought to distinguish IES from IEEE, URSI, COSPAR, ITU
- Attempted to couple ionospheric specialists with users

IES Number of Papers by Year

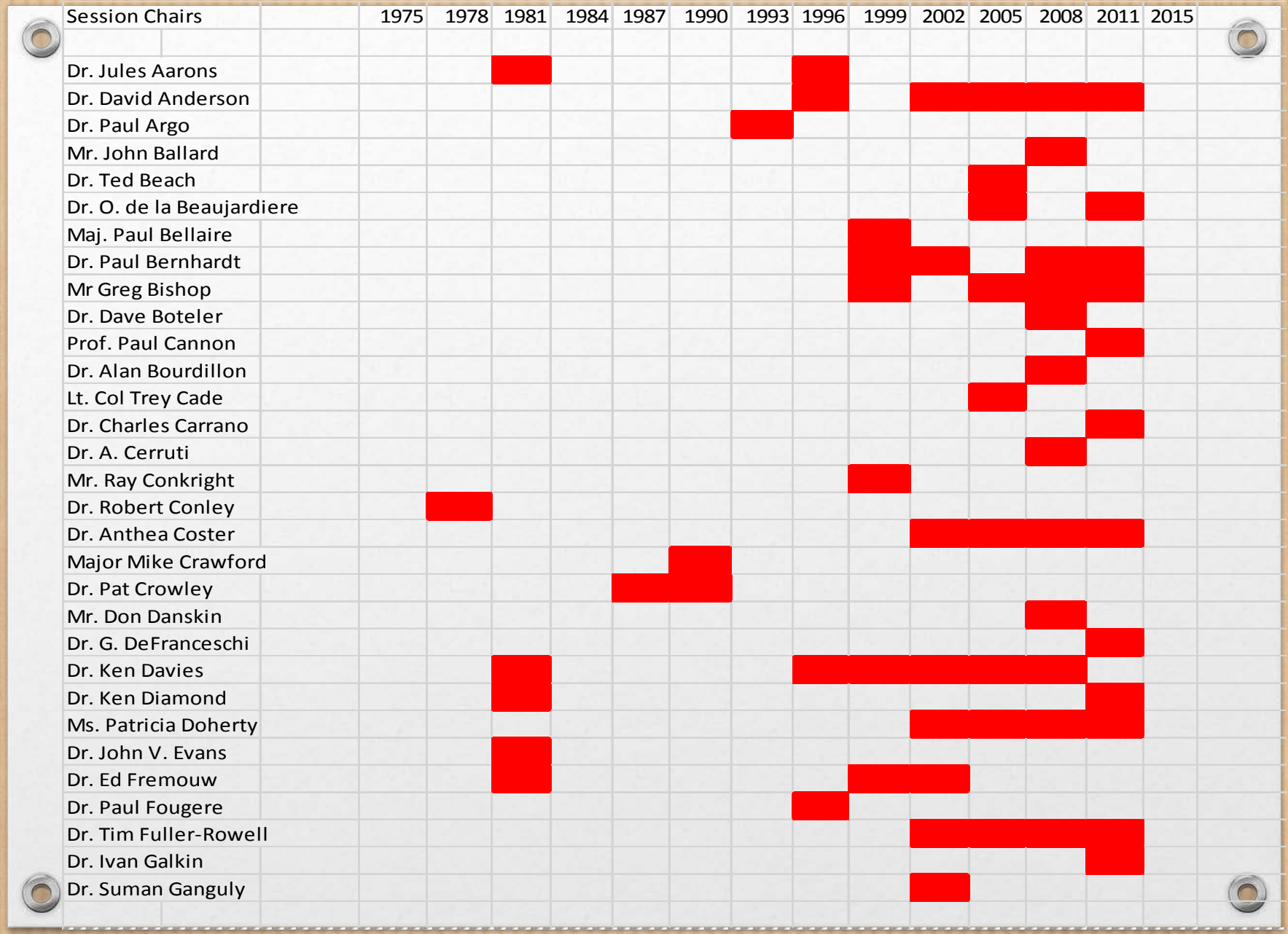
Year	No. of Papers	Year	No. of Papers
1975	67	1996	60
1978	88	1999	90
1981	72	2002	103
1984	61	2005	117
1987	75	2008	110
1990	61	2011	137
1993	99	2015	130+

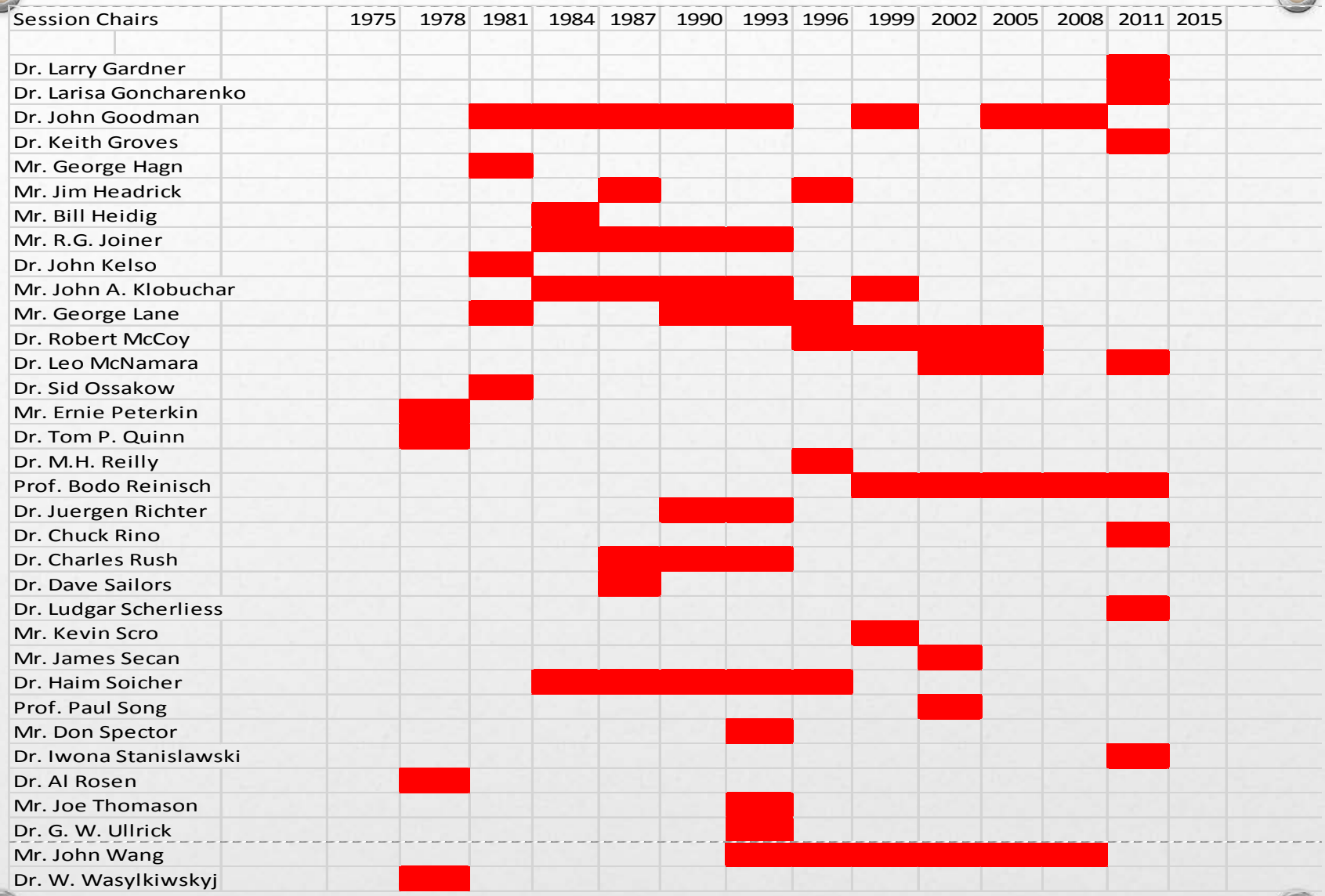
IES & Sunspot Number



Keynote and Featured Speakers

- Dr. Herbert Friedman (NRL. 1975)
- Dr. Herbert Rabin (NRL, 1978)
- Dr. Robert Naka (Chief Scientist, USAF, 1978)
- Dr. Hans Mark (1981)
- Dr. J. N. Birch (1981)
- Prof. J.A. Van Allen (1981)
- Dr. Donald Latham (DoD, 1984)
- Dr. Owen K. Garriott (Scientist-Astronaut, 1984)
- Capt. David Hart (US Navy, 1987)
- Dr. Bruce Wald (NRL, 1987)
- Dr. Tom Quinn (DoD, 1990)
- Dr. Gerald Hawkins (1990)
- Prof. William Gordon (1993)
- Mr. John A. (Jack) Klobuchar (1996)
- Lt. General Emmit Paige Jr. (DoD, 1996)
- Dr. John V. Evans (COMSAT, 1999)
- Dr. Kenneth Davies (NOAA, 1999)
- Prof. Les Barclay (2002)
- Mr. Roger Easton (2002)
- Dr. Ernest Hildner (NOAA, 2005)
- Lt. Col Trey Cade (USAF/AFWA, 2005)
- Dr. Paul Cannon (2008)
- Prof. Lou Lanzerotti (NJIT, 2008)
- Dr. Paul Bernhardt (NRL, 2011)


Session Chairs
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011
2015
Dr. Jules Aarons
Dr. David Anderson
Dr. Paul Argo
Mr. John Ballard
Dr. Ted Beach
Dr. O. de la Beaujardiere
Maj. Paul Bellaire
Dr. Paul Bernhardt
Mr Greg Bishop
Dr. Dave Boteler
Prof. Paul Cannon
Dr. Alan Bourdillon
Lt. Col Trey Cade
Dr. Charles Carrano
Dr. A. Cerruti
Mr. Ray Conkright
Dr. Robert Conley
Dr. Anthea Coster
Major Mike Crawford
Dr. Pat Crowley
Mr. Don Danskin
Dr. G. DeFranceschi
Dr. Ken Davies
Dr. Ken Diamond
Ms. Patricia Doherty
Dr. John V. Evans
Dr. Ed Fremouw
Dr. Paul Fougere
Dr. Tim Fuller-Rowell
Dr. Ivan Galkin
Dr. Suman Ganguly


Session Chairs
1975
1978
1981
1984
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1996
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2002
2005
2008
2011
2015
Dr. Larry Gardner
Dr. Larisa Goncharenko
Dr. John Goodman
Dr. Keith Groves
Mr. George Hagn
Mr. Jim Headrick
Mr. Bill Heidig
Mr. R.G. Joiner
Dr. John Kelso
Mr. John A. Klobuchar
Mr. George Lane
Dr. Robert McCoy
Dr. Leo McNamara
Dr. Sid Ossakow
Mr. Ernie Peterkin
Dr. Tom P. Quinn
Dr. M.H. Reilly
Prof. Bodo Reinisch
Dr. Juergen Richter
Dr. Chuck Rino
Dr. Charles Rush
Dr. Dave Sailors
Dr. Ludgar Scherliess
Mr. Kevin Scro
Mr. James Secan
Dr. Haim Soicher
Prof. Paul Song
Mr. Don Spector
Dr. Iwona Stanislawski
Dr. Al Rosen
Mr. Joe Thomason
Dr. G. W. Ullrick
Mr. John Wang
Dr. W. Wasylkiwskyj

Jules Aarons

- An inspirational Factor for IES
- Radio Astronomical & Satellite Studies of the Atmosphere
- NATO-AGARD Conferences

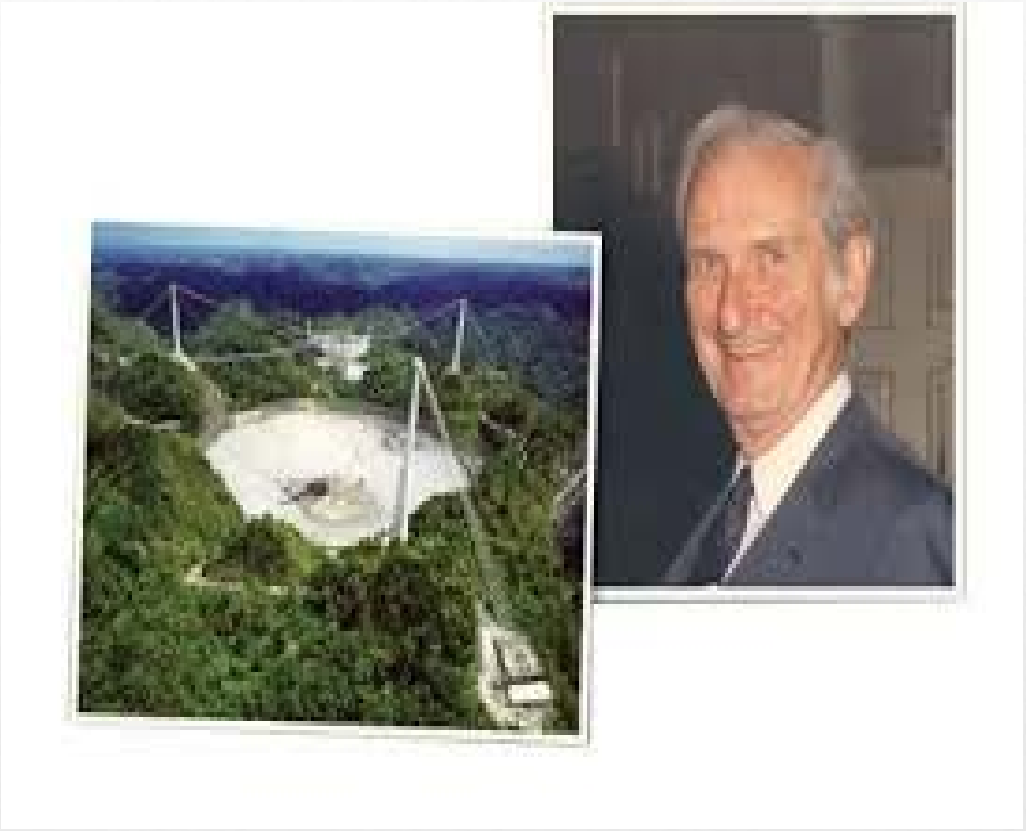
John A. "Jack" Klobuchar

- AF Co-Chairman for IES
- Noted TEC Investigator
- 1975 "1st Order Worldwide Time Delay Algorithm"
- ION Fellow

Professor James Van Allen

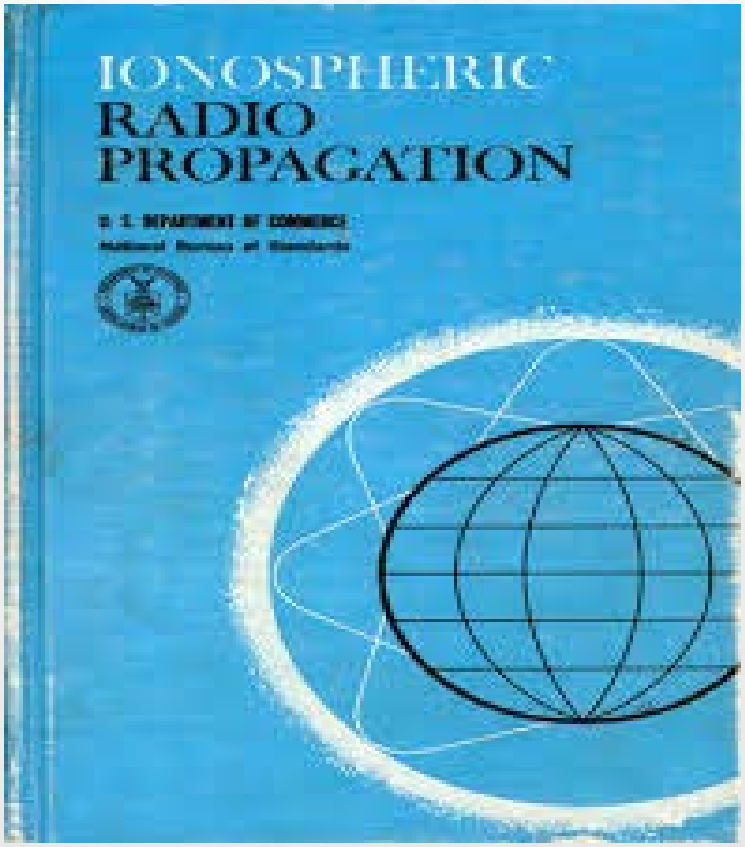
- Radiation Belts

Professor William Gordon



- Incoherent Scatter Radar
- Arecibo

Dr. Kenneth Davies

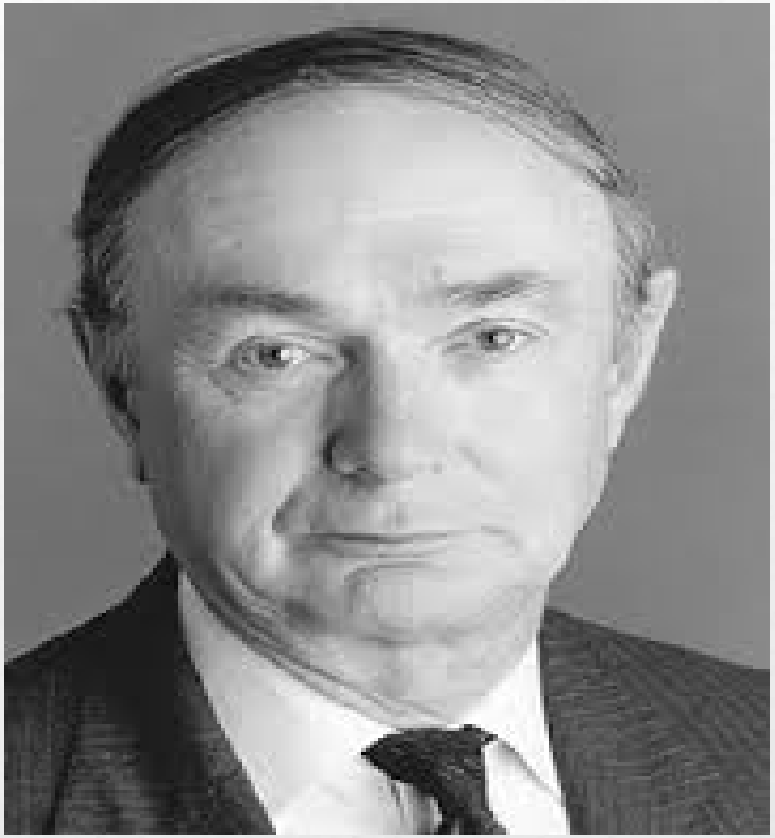


- Several Noteworthy Books
- Monograph 80

Dr. Owen K. Garriott

- Book
- Scientist Astronaut

Dr. John V. Evans



- Book
- Thomson Scatter Radar at Millstone Hill
- Jodrell Bank radar studies
- Cis-lunar ionosphere studies
- COMSAT

Prof. Paul Cannon

- Ionospheric studies
- Radio Systems
- Communications
- URSI

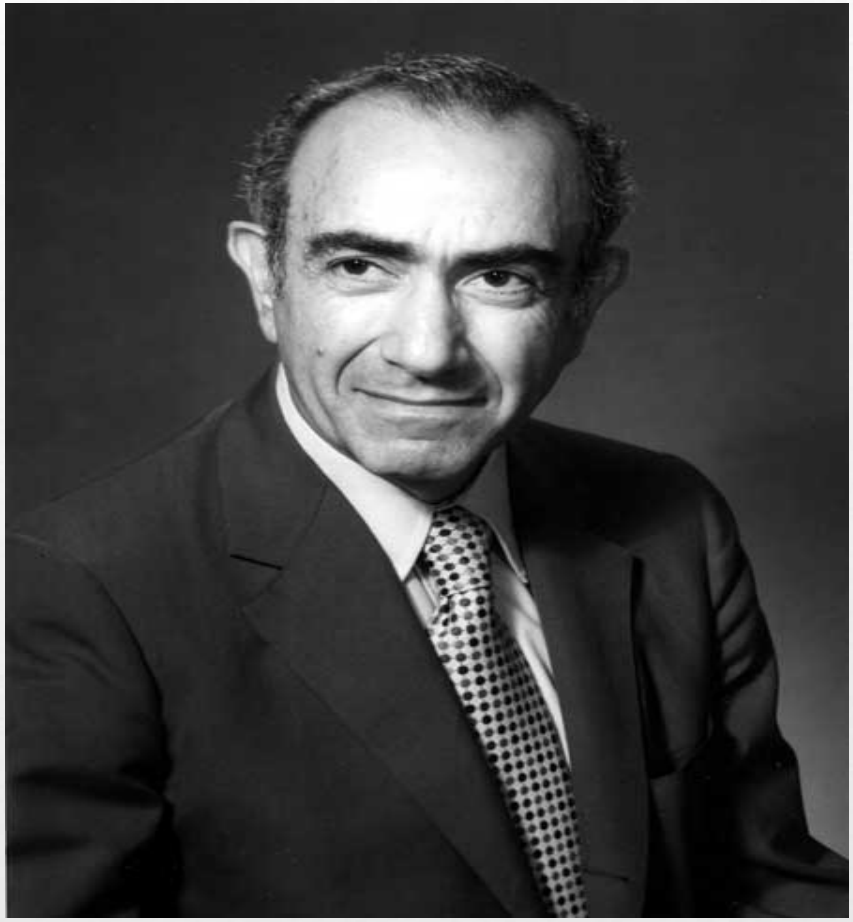
Professor Les Barclay

- HF Propagation Specialist
- CCIR/ITU contributions
- Numerous Publications
- Books

Roger Easton

- Father of GPS
- Space Surveillance System
- Timing & Navigation

Dr. Herbert Friedman



- Noted Astrophysicist
- Early rocket studies
- X-ray studies of lower ionosphere

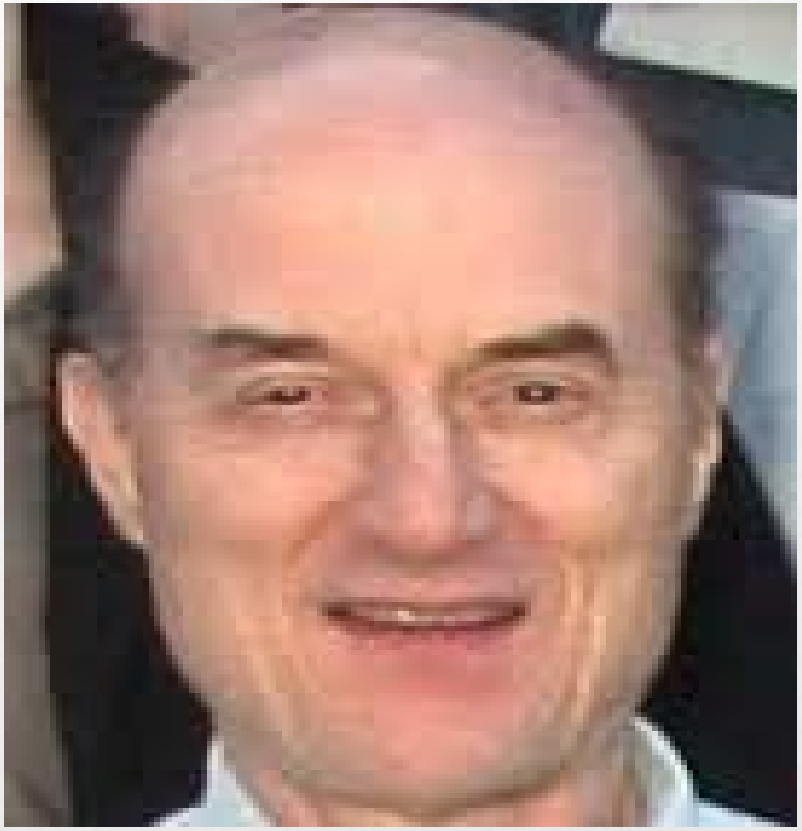
Professor Louis Lanzerotti

- Plasma physics
- Telecommunications
- Space Weather Quarterly -Editor

Dr. Ernie Hildner

- Director, NOAA-SEC
- Forecasting
- Space Weather

Dr. Paul Bernhardt



- Ionospheric Modification
- Satellite & Terrestrial studies

Authorship Continuity 1975 and 2015

- Herbert Carlson
- Dennis Knepp
- Charles Rino

Technical Sessions: IES1975

- Scintillation & Irregularities (3 sessions)
- Heating Effects
- TEC Modeling
- NAVSTAR/GPS
- In-Situ Probes

Technical Sessions: IES1978

- Scintillation (2 Sessions)
- Radio Propagation (ELF-HF)
- Spacecraft Charging
- Ionospheric Forecasting
- Ionospheric Modification
- Ionospheric Effects: Ranging and Navigation

Technical Sessions: IES1981

- Ionospheric Modification (2 Sessions)
- Ionospheric and Scintillation Modeling
- Auroral & Equatorial Scintillation
- HF Propagation
- Remote Sensing
- Ionospheric Modification
- Ionospheric Effects: Ranging and Navigation

Technical Sessions: IES1984

- Adaptive HF Systems & Channel Assessment
- HF Probing & Performance Analysis
- Transionospheric Propagation
- Ionospheric Predictions & Modeling
- LF Propagation
- Artificial Modification
- Ionospheric Diagnostic Technology

Technical Sessions: IES1987

- Wideband HF Channels
- High Frequency Measurements
- HF Modeling
- Longwave Propagation Modeling
- Transionospheric Propagation & TEC
- Transionospheric Propagation & Scintillation
- Ionospheric Modification
- High Latitude Ionospheric Interactions
- Spacecraft Glow, Related Phenomena and Measurements

Technical Sessions: IES1990

- High Latitude Phenomena
- Scintillation Effects
- HF Radio Effects
- Radar System Effects
- Meteor Burst & Miscellaneous Systems
- TEC Modeling
- TEC and GPS
- Diagnostics: Sounders, Probes, and Radars
- Longwave Systems
- Modification

Technical Sessions: IES1993

- OTH Radar
- Ionospheric Tomography and Radar Applications
- Direction Finding Systems and Applications
- Meteor Burst Communications
- Transionospheric Propagation, Scintillation, TEC, etc.
- HF Propagation & Modeling
- Ionospheric Sounding & Probes
- High Latitude Phenomena
- Longwave Systems & Effects
- Radio Noise Modeling
- Ionospheric Heating and Modification

Technical Sessions: IES1996

- Ionospheric Tomography (3 sessions)
- OTH Radar
- HF Communication & Noise
- Ionospheric Utilities, Resources, & Forecasting
- Ionospheric Mapping & Sounding
- Ionospheric Modeling
- Ionospheric Scintillation & Spread-F
- Ionospheric Measurements (2 sessions)
- Propagation Experiments & Studies
- Total Electron Content & GPS Studies (3 sessions)

Technical Sessions: IES1999

- Space Weather
- Computerized Ionospheric Tomography
- Ionospheric Scintillation
- Sounder Methods & Measurements
- TEC Studies
- Mitigation of Ionospheric Effects on GPS: WAAS
- Ionospheric Modeling
- Ionospheric Measurements & Campaigns
- HF Propagation & Communication
- Longwave Measurements & Effects
- Radar and Radio Propagation Effects
- New Methods & Algorithms

Technical Sessions: IES2002

- Space Weather
- Ionospheric Models & Data Assimilation (2 Sessions)
- Satellite Navigation Systems & WAAS
- HF Propagation & Systems
- Advanced Ionospheric Sounding
- Total Electron Content (2 Sessions)
- Radiowave Scintillation (2 Sessions)
- Lower Ionosphere
- Tomography & Optical Measurements
- Panel on Ionospheric Modeling

Technical Sessions: IES2005

- Solar Flares & Storms (3 sessions)
- Ionospheric Radio Propagation
- HF Propagation & Systems (2 Sessions)
- HF Sounder Technology
- Ionospheric Effects on Space-Based Augmentation (2 Sessions)
- Limb Scanning Technology
- Miscellaneous GPS studies
- TEC
- Ionospheric Tomography
- Ionospheric Specification, Data Assimilation & Forecasting
- Scintillation (2 Sessions + C/NOFS session)
- General System Effects

Technical Sessions: IES2008

- Radio Burst & Solar Flare Effects
- Lower Ionospheric Effects
- Arctic Ionosphere
- Space Weather Effects on Communication & Navigation
- Ionospheric Effects on Aviation Systems
- Ionospheric Phenomena
- GPS Techniques and Applications
- Radio Propagation and HF Systems (2 Sessions)
- Modeling & Forecasting (2 Sessions)
- Sounder Methods & Measurements (2 Sessions)
- Irregularities & Scintillation
- Sensors & Measurement Techniques (3 Sessions)

IES2011 Topics

- Lower Atmosphere & Ionosphere
- Ionospheric Effects on Navigation
- GPS and TEC
- C/NOFS
- Sounder Methods & Measurements (3 Sessions)
- HF Radio & Communication Systems
- Radio Diagnostics
- Radar Applications
- Tomography
- Rocket Exhaust Effects & High Power Radio Modification
- Space Weather
- Equatorial Ionosphere (2 Sessions)
- Geomagnetic Storm Effects
- Modeling & Simulation (2 Sessions)
- Scintillation (2 Sessions)
- Radio Propagation
- SAR and Related Techniques

Technical sessions: IES2015

- HF-TIDs
- Scintillation & Irregularities
- Ionospheric Modification
- Storms & Anomalous Conditions
- Ionosphere & Space Weather Models
- GPS/GNSS
- Ionospheric Studies
- Mission & Data Services
- Natural Hazards

Consistent Themes

- Understanding the earth-space path
- Understanding of the HF skywave path
- Ionospheric modification
- Solar-Terrestrial and Space Weather relationships
- Ionospheric Modeling
- Ionospheric remote sensing
- Other less consistent themes

Some Ionospheric phenomena we don't know very well

- Inhomogeneities
- TIDs
- Ionospheric Storm

Scenario-Dependent Situations

CONSEQUENCES

- Search for credible methods to specify "truth"
  - Update climatology?
  - Insertion of more physics?
  - Both?
- Situation has led variety of update schema and data assimilation techniques.

Where do we go from here?

Too much emphasis on development of models without experimental validation ?

- Calculation, in general, is NOT an experiment.

Conclusions

- Consistent progress in understanding of the ionosphere has been made in the last half century
  - Better Diagnostics
  - Improved Computational Tools
  - Improved awareness of importance to Society
- IES conferences have mirrored changes

BACKUP

Where are we now?

- Ionospheric Propagation Studies & Modeling
  - Scintillation (C/NOFS)
  - TEC

Where were we then?

- Remote Sensing Technologies
  - VIS and OIS Sounding, Topside Sounding, OTHR
  - Rocket Probes
  - In-Situ plasma measurements
  - Incoherent Scatter Radar (Thomson Scatter)
  - DoD and NASA studies Space Program assets

Where are we now?

- Remote Sensing Technologies
  - VIS and OIS Sounding
    - Global quasi-real-time
  - ISR, EISCAT,
  - SuperDARN,
  - OTHR
  - TIDBIT
  - Occultation
  - Tomography
  - airglow

Where were we then?

- Ionospheric Modification
  - Heating (HF heaters and Luxembourg effect)
  - Chemical Releases (i.e., actual modification and diagnostic)
  - Man-Made
    - chemical reagents from exhaust such as Skylab
    - nuclear effects (principally HANE)]

Where are we now?

- Ionospheric Modeling
  - Continuing editions of IRI
  - Assimilative models (GAIM, etc.)

Where were we then?

- Ionospheric Propagation Studies & Modeling
  - Scintillation (Radio Star, SATCOM)
  - TEC, Dispersive & Differential Doppler

Where were we then?

- Ionospheric Modeling
  - Penn State Mark 1, Appleton Lab, CCIR Models → ITU-R Models
  - AF4D, AMBCOM
  - HFMUFES→ RADARC → ICEPAC→IONCAP→VOACA

Where do we go from here?

Methodology

- Participate in Interdisciplinary Experiments. Generally a good thing but there are budgets to consider
- Incorporate known physics without sacrificing empirical results and insight
- Develop models of behavior (leading to forecasting, prediction, and simulation)
- Communicate with ultimate Users of Basic & Exploratory Research (collaboration should be considered)
- Conduct Challenge Workshops
- Publish results & submit to IES and other topical and/or general conferences (AGU, URSI, IEEE, etc)

Where are we now?

- Ionospheric Modification
  - Heating (HF heaters)
  - Chemical Releases and Man-Made (i.e., chemical reagents from exhaust, and nuclear effects)

Where were we then?

- Systems for Navigation and Timing
  - Loran
  - Transit
  - Navy Timation,
  - GPS Constellation
- Communication System Studies
  - Satellites (VHF, UHF, SHF)
  - HF radio (emergent adaptive HF systems)

Where are we now?

- System Studies
  - Communication
  - Surveillance
    - Radar (e.g., OTHR)
    - HFDF (i.e., HFGeo)
  - Navigation (GNSS)
    - GPS and augmentation system
    - GLONASS
    - European system