The Future of the Ionosphere

IPS – now & the Future

(Why we will still want to know about it 100 years from now)

by Phil Wilkinson
IPS Radio and Space Services
Bureau of Meteorology
Sydney,
AUSTRALIA

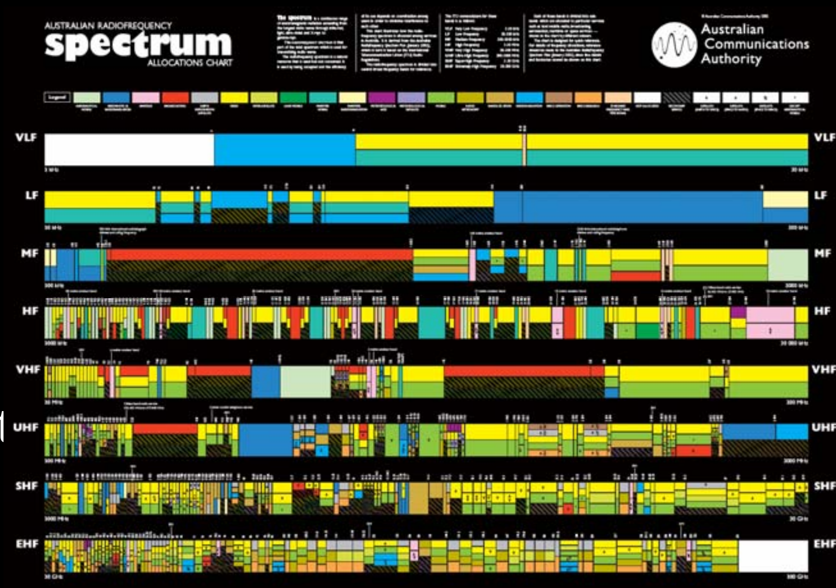
Approach

- The ionosphere forms a natural part of many systems
  - either as the medium
  - or as a part of the degradation process
- Ionospheric knowledge is ~~a useful~~ an <u>essential</u> part of systems management
  - although currently an awkward part for some systems
- This talk briefly reviews
  - the past,
  - looks where we are now
  - and projects this gently forwards
  - highlighting the role the ionosphere will continue to play in the future.

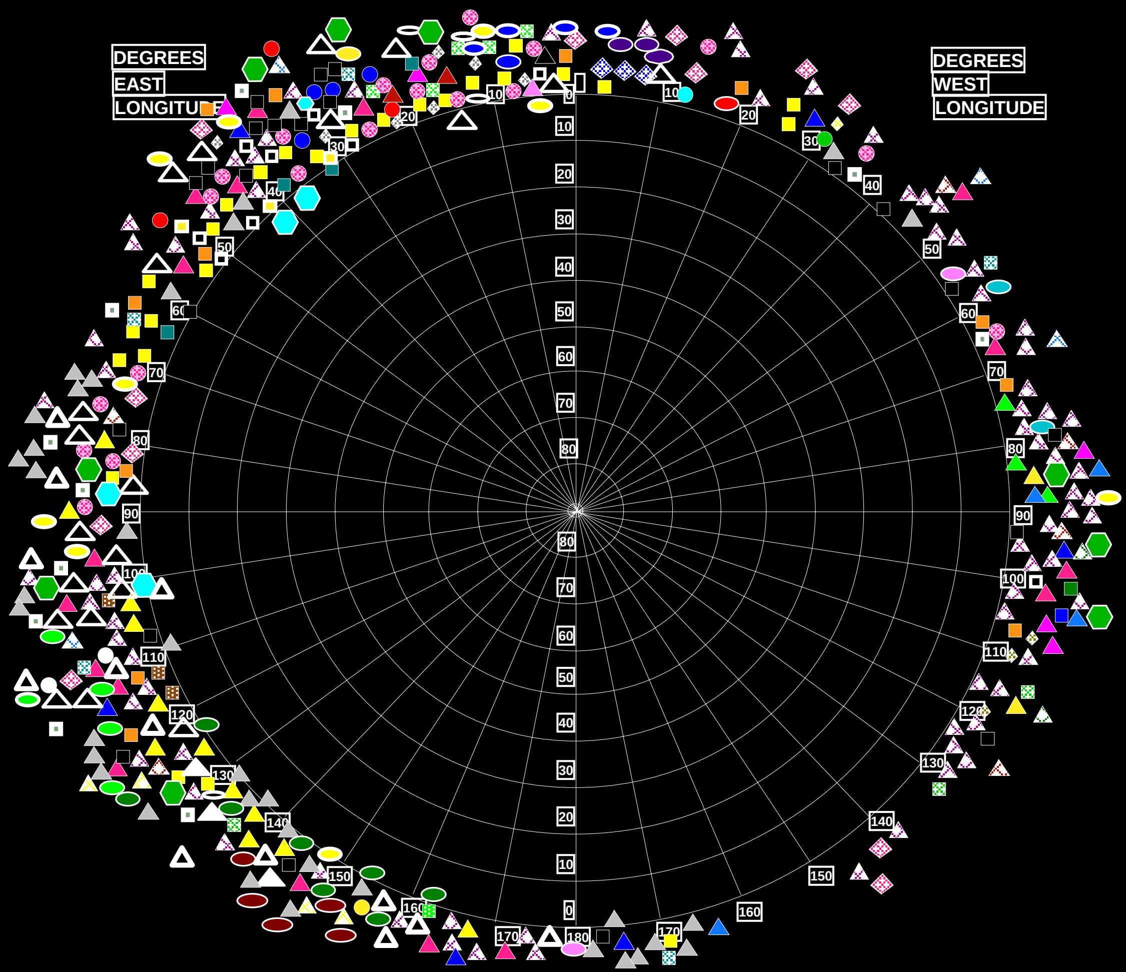
Future Driver: Spectrum management

Spectrum management is changing.

- 20 years ago
  - widely available bandwidth
  - simply fill out the proper paperwork.
- Now
  - *clear channels* paradigm was gradually replaced
  - a more contentious environment,
  - analytic studies allow users to coexist without conflict
  - spectrum demand requires users to *share* spectrum in an actively cooperative manner.
- The next decade
  - assignment of *priority* based on system's value to national and global interests.
- The (far?) future
  - the available spectrum won't increase
  - so everybody will need to be smarter



Geostationary Spectral Congestion - 17 - 20 GHz



The HF Environment

<u>Ionospheric contributions</u>

- Ionospheric climate
- Variability
  - Storms, sporadic E
  - Tilts, gradients
  - Auroral, equatorial regions
- Absorption
  - Flares
- Geomagnetic field
  - Polarization
- Fading
  - TIDs, irregularities

- Green: with us forever
- White: getting better

- Red: alarming developments.

<u>Non-ionospheric contributions</u>

- Atmospheric and galactic noise
- Ground conductivity
- Path length
- Antennas
- Type of service
- Equipment

- Site (man-made) noise
- Interference, radiation hazard
- Available frequencies
- Real estate & facilities
- Regulations
- Resources
  - experience and skill
  - **<u>Funds</u>**

Systems and the Ionosphere

Some use the ionosphere:

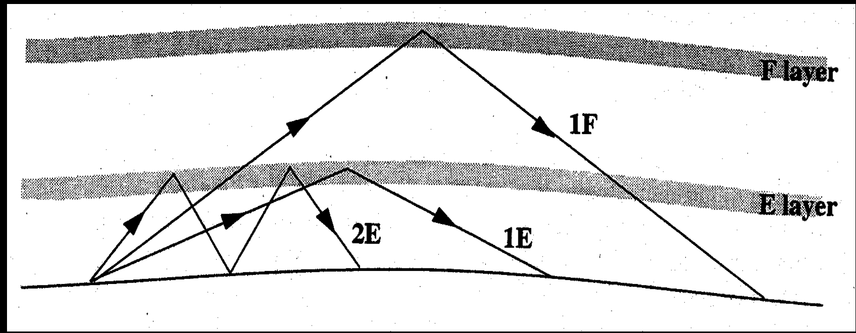
- Amateur radio HF broadcasting ("shortwave" listening),
- HF communication,
- OTH radar, surveillance
- HF direction finding,
  - and many military applications (SIGINT etc)
- MF communication, broadcast
- Time standards,
- VLF-LF communication, navigation, broadcast

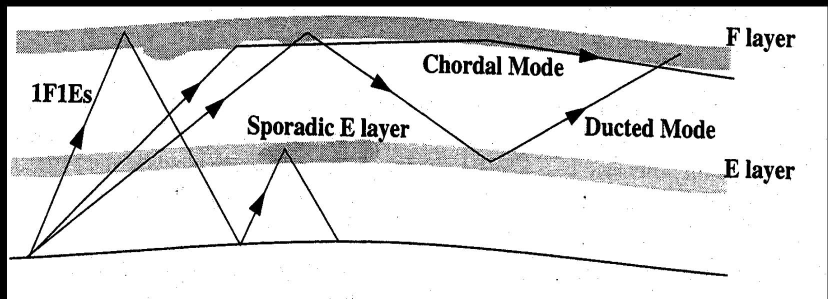
Some just suffer its effects:

- Satellite Communication
- Satellite Navigation (GNSS e.g., GPS & GLONASS)
- Space-based Radar & Imaging
- Terrestrial Radar Surveillance & Tracking
- VHF television, FM radio, aviation, Meteor burst
- *and any other system that uses a signal that passes through the ionosphere.*

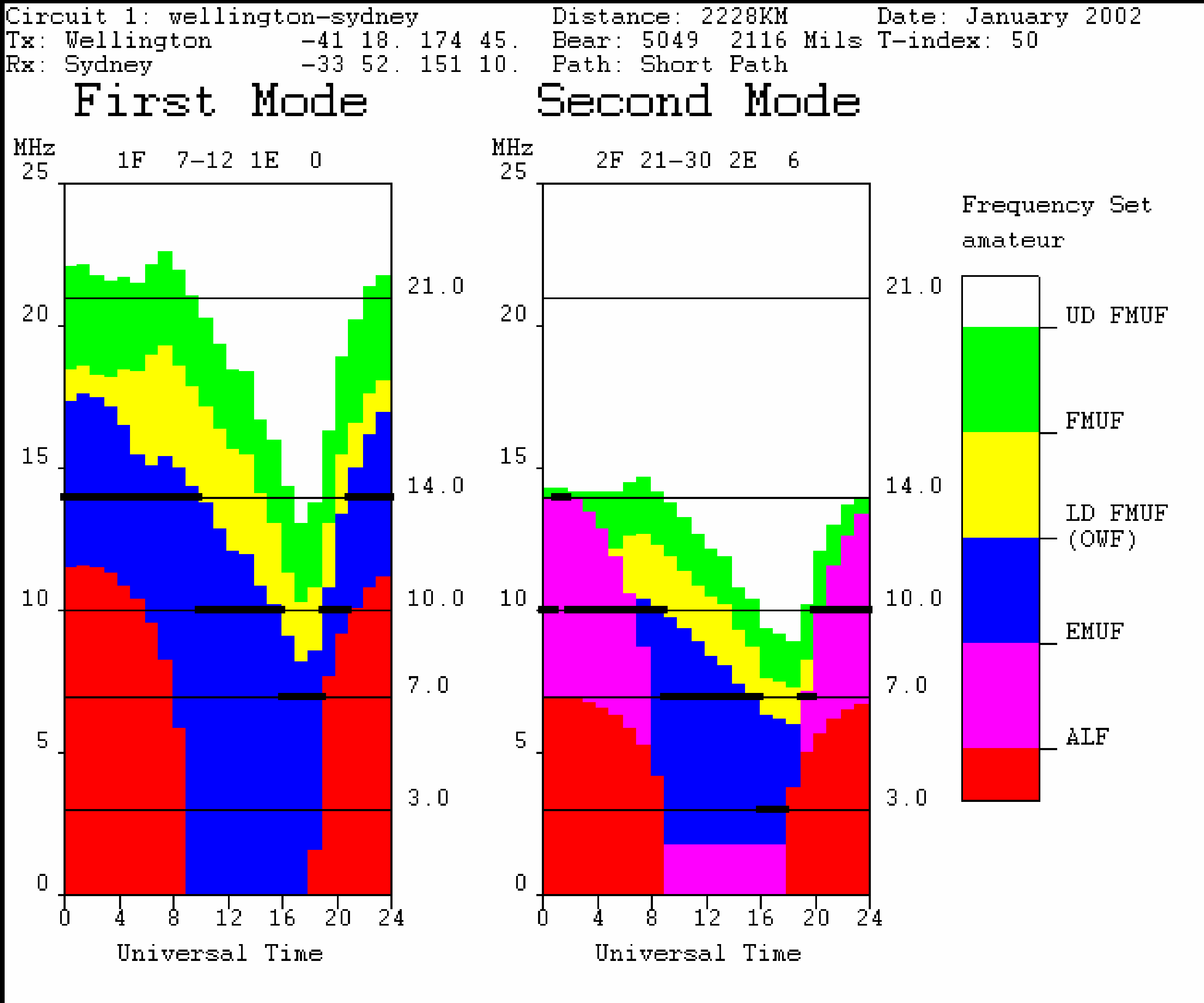
An HF Link: Frequency Availability

- A simple HF system
  - e.g., a single HF link between Wellington and Sydney).
- Given a frequency set, how should it be used?
- Method:
  - take an ionospheric model, including estimates of variability
  - compare the availability of the frequencies in the set.
  - for a selection of likely propagation paths and
  - choose the best frequencies for the time of the day.
- Note: only an ionospheric model is needed.



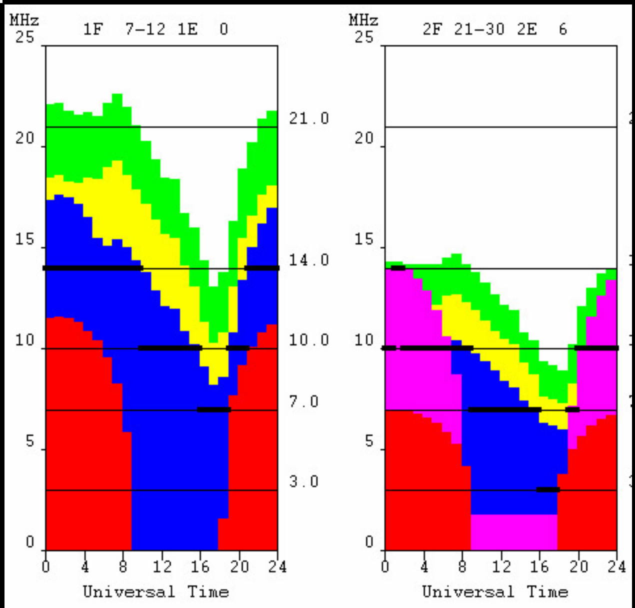


A circuit prediction



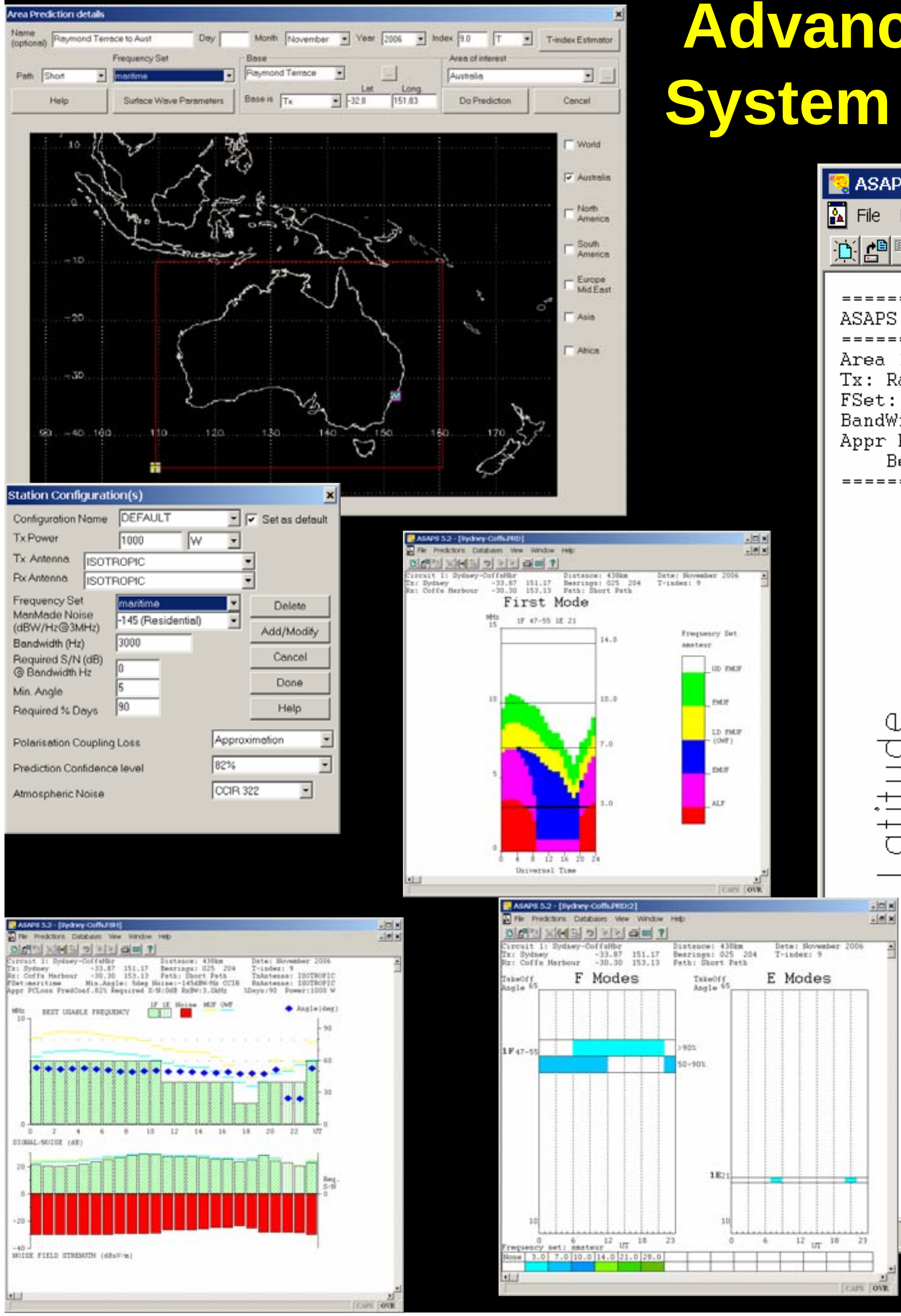
Long-Term HF Predictions

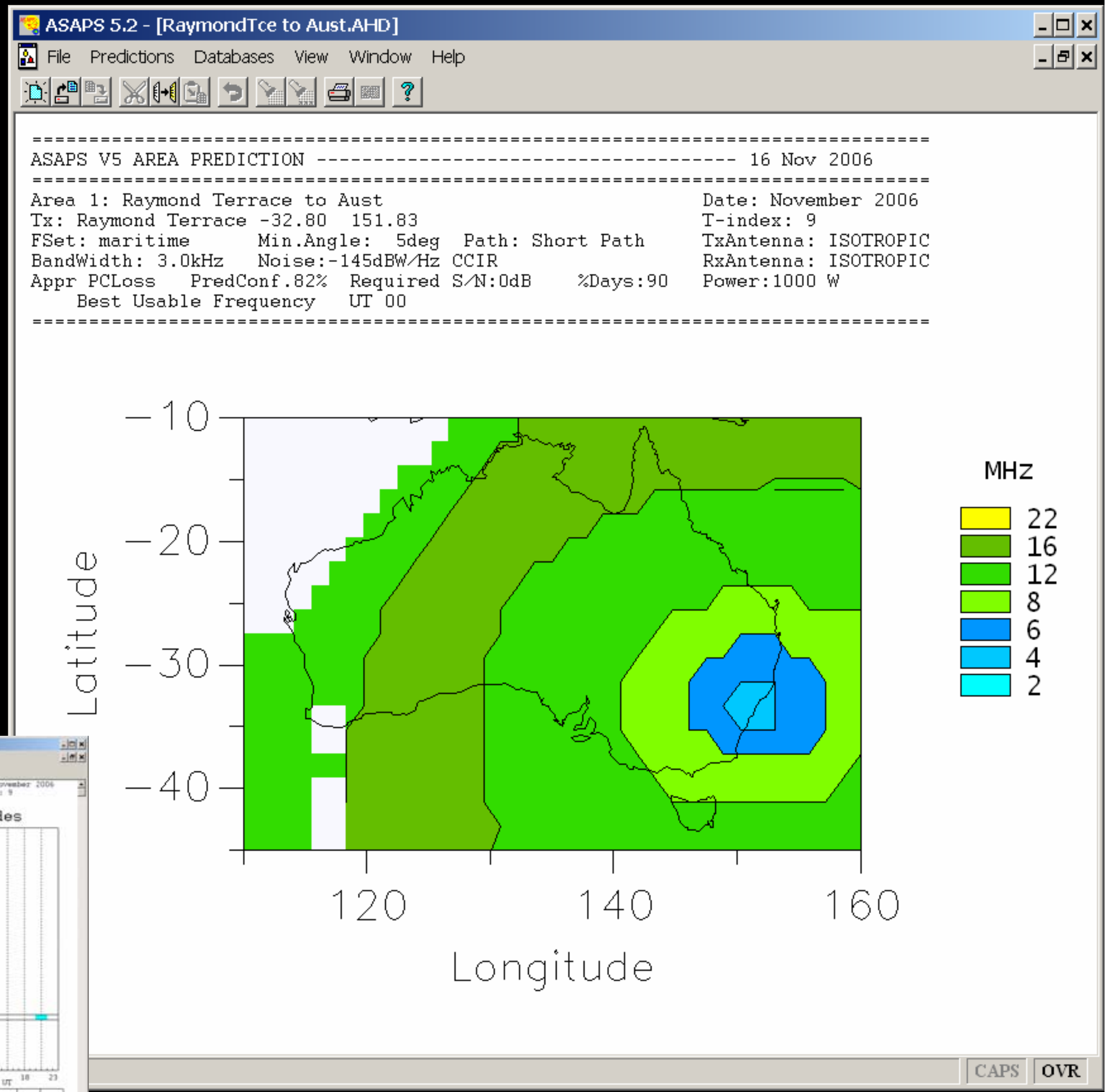
- Long-term predictions are essential for HF planning
- They (hopefully) reflect average, or common conditions,
  - and are a reasonable compromise,
  - given the available ionospheric models accuracy.
- They are necessary in
  - HF broadcasting
  - spectrum management activities where long lead times are required.
- Problems
  - Storms ignored
  - Short-term ionospheric variability handled poorly
  - OWFs ignore 90% of skywave support
  - Virtual ray trace ignores tilts / gradients
  - Special regional problems (high / low latitudes) may not be addressed effectively
  - Models inadequately tested against observations
  - No sporadic E



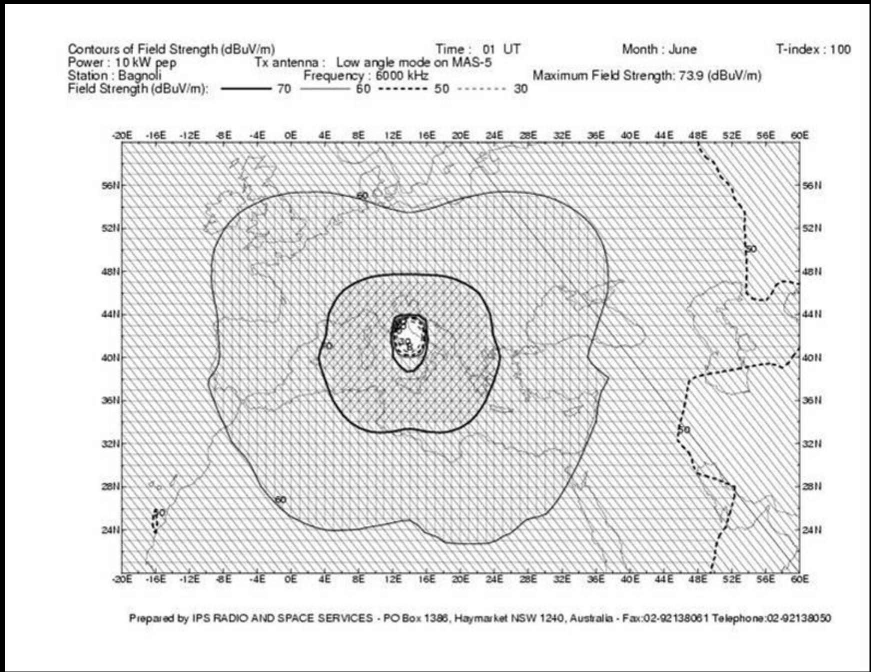
ASAPS

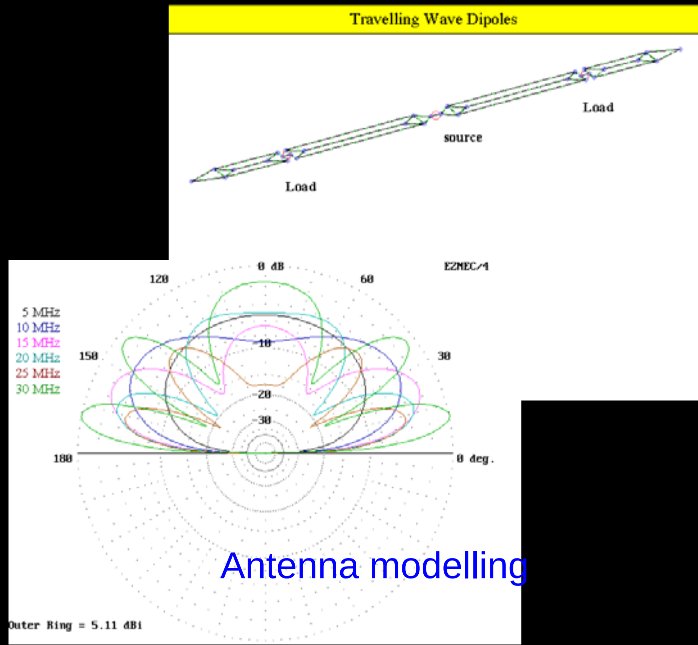
Advanced Stand Alone Prediction System

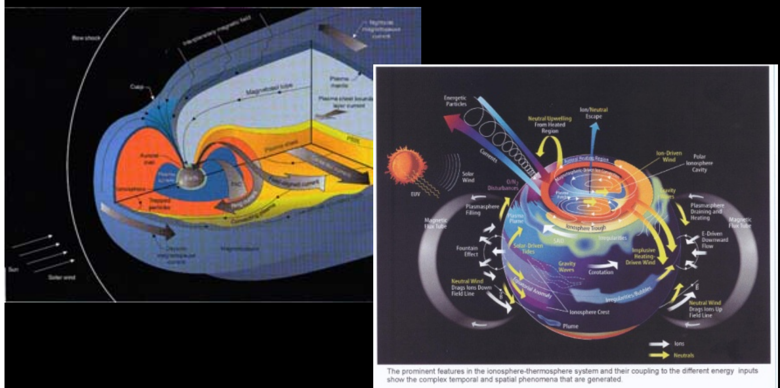


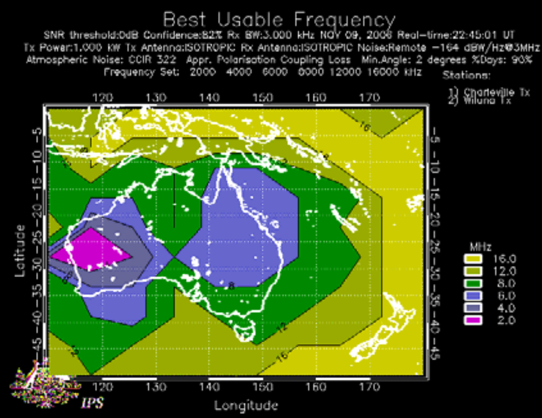


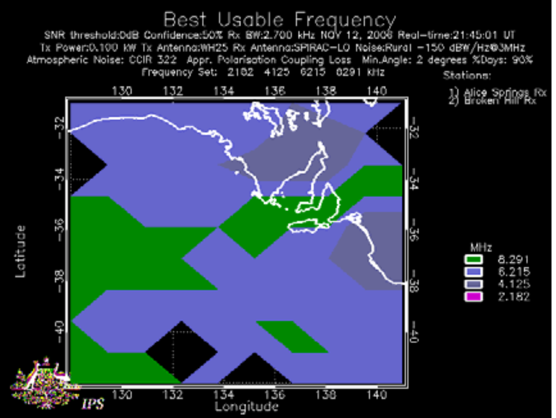
Consultancies: HF system design, planning and operations



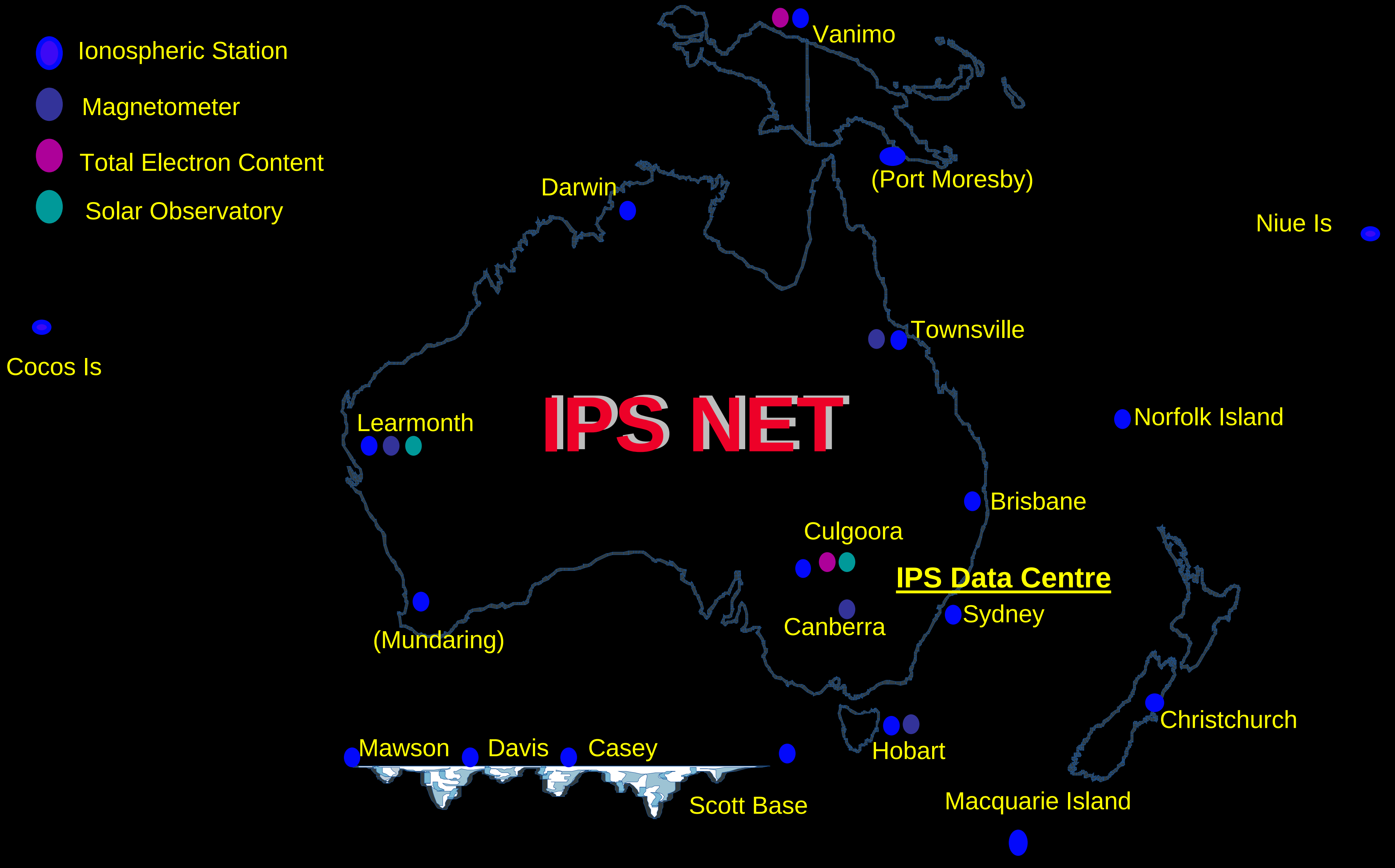








IPSNET: IPS Stations and Observatories



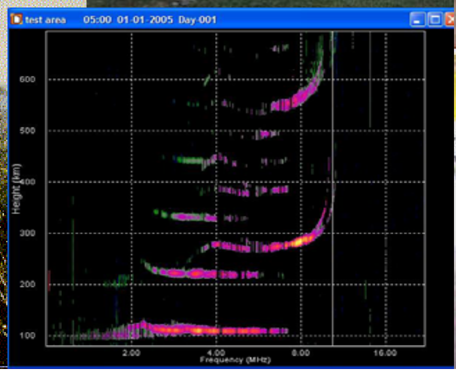
Observatory Support



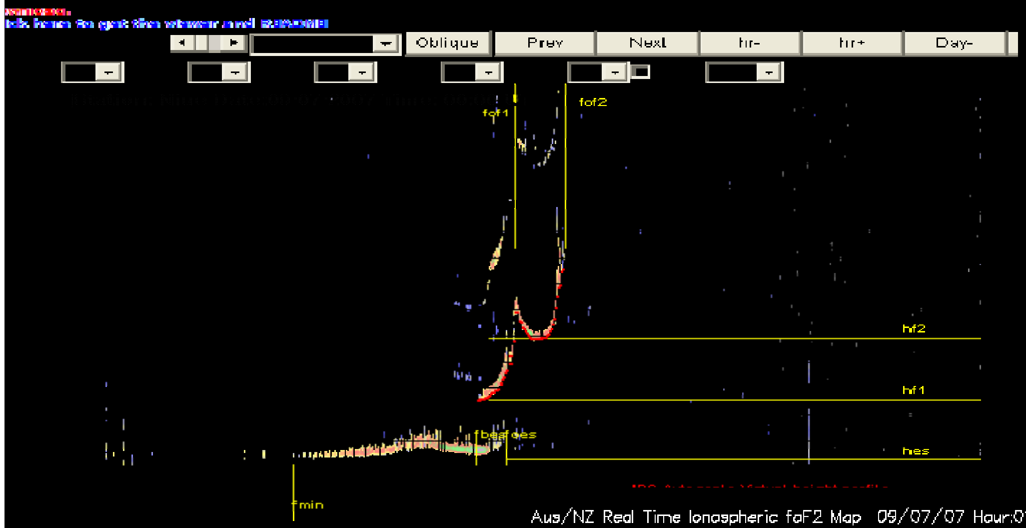






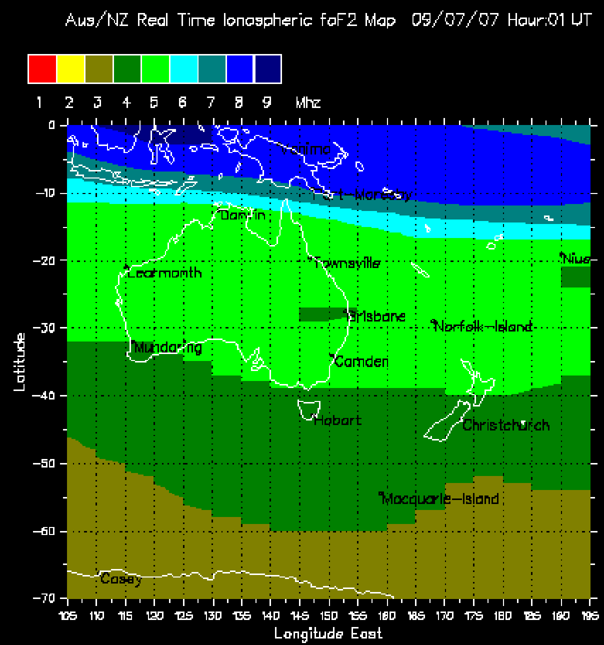


Example from basic data to product: HF Systems

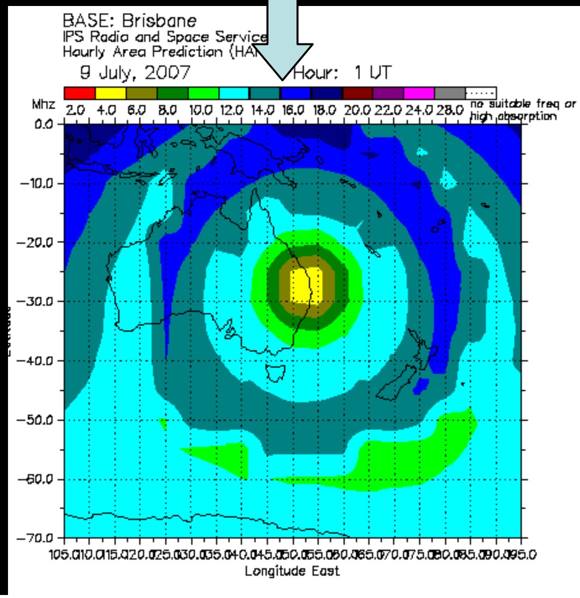


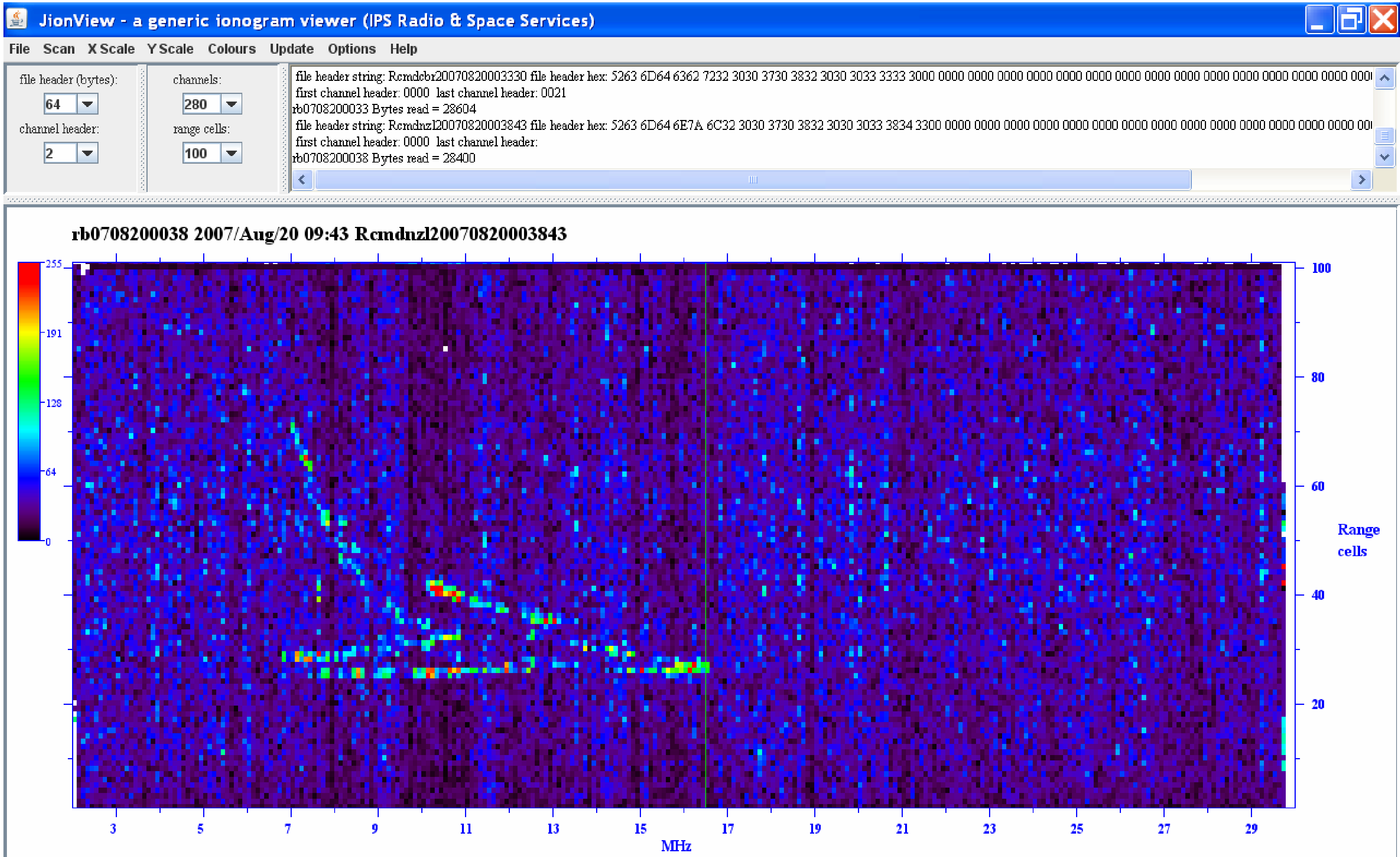
1. Ionogram: the basic ionospheric observation, with automatic measurement

2. Ionospheric map vertical frequencies

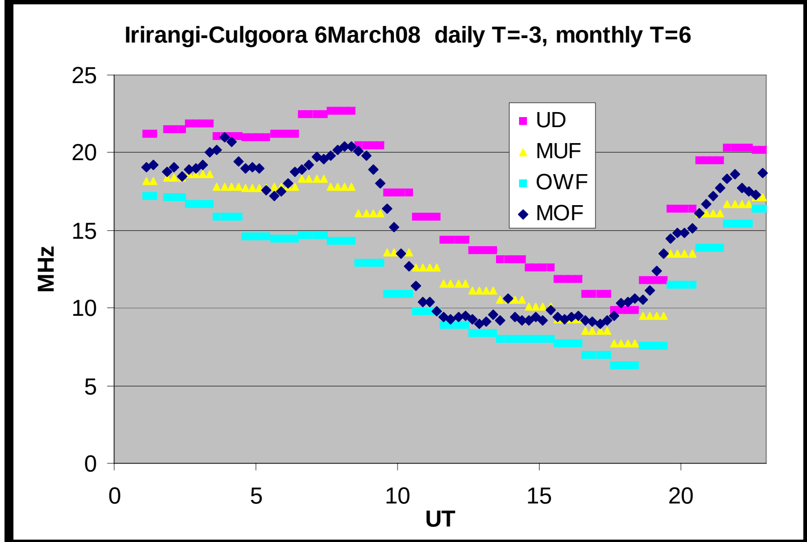


3. Hourly Area Prediction -Base to area with recommended frequencies for the HF communicator

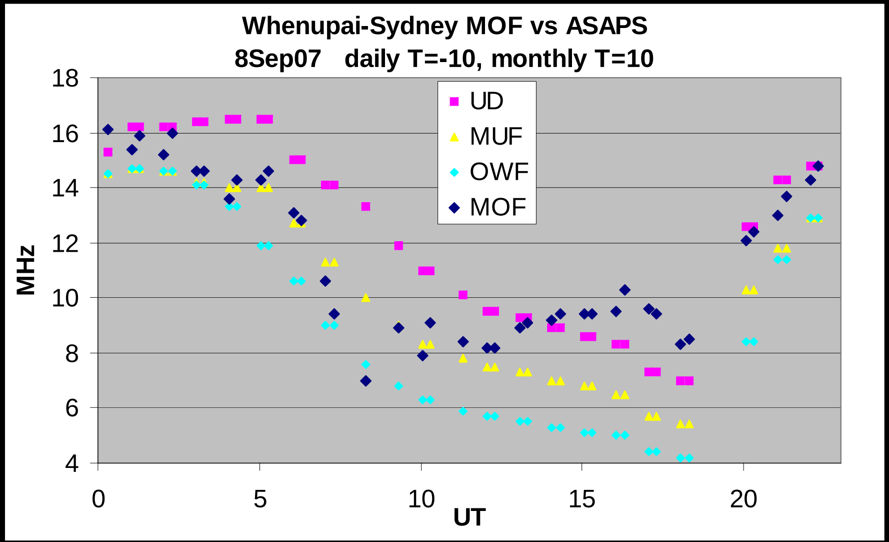




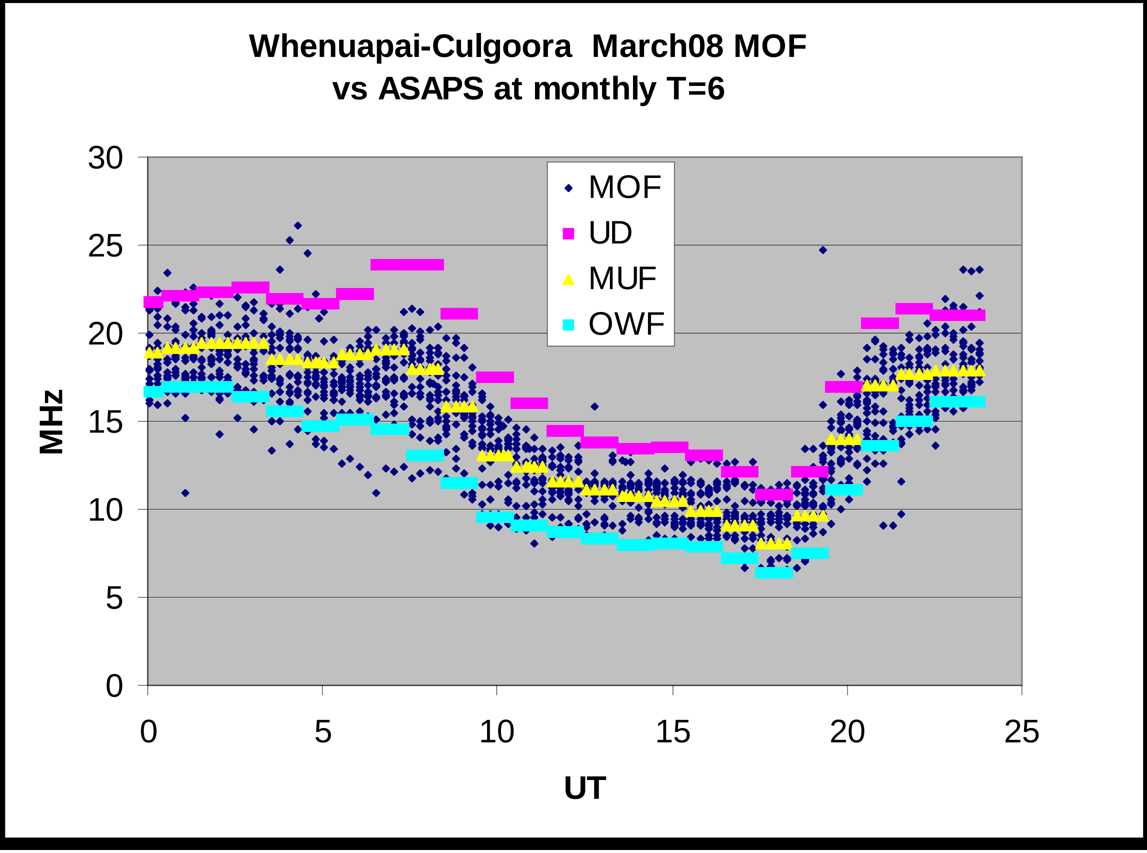
NZ to Sydney (~2200km) Barry RCS-5 Chirpsounder ionogram displayed in the IPS JionView Java software (by S. Hutchinson). Note the autoscaling of the Max Observed Frequency (MOF) by JionView. RCS-5 receivers operated by M. Layoun and TCS-5 transmitters operated by NZDF.



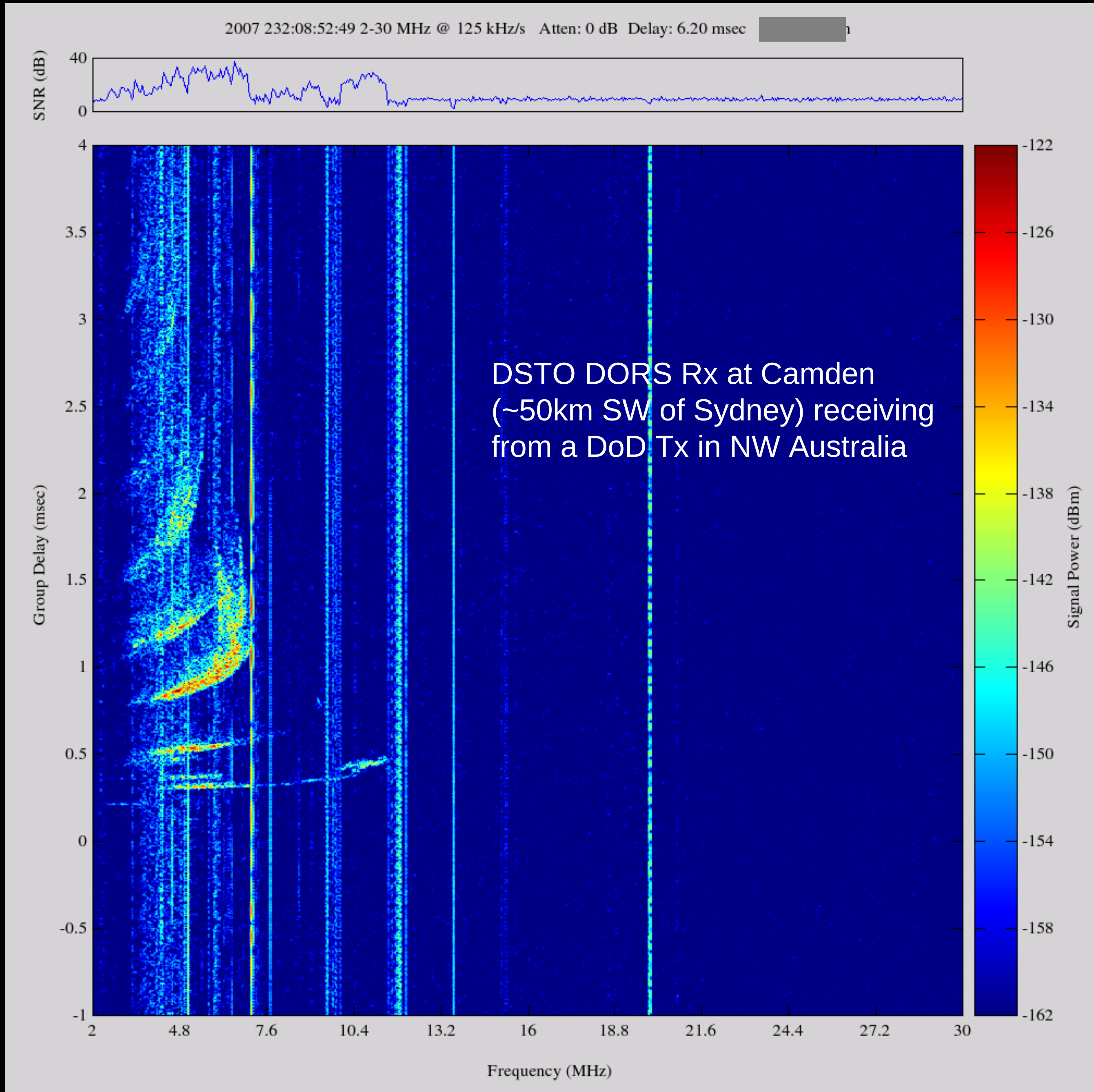
Irirangi-Culgoora 6March08 daily T=-3, monthly T=6
UD
MUF
OWF
MOF
MHz
UT

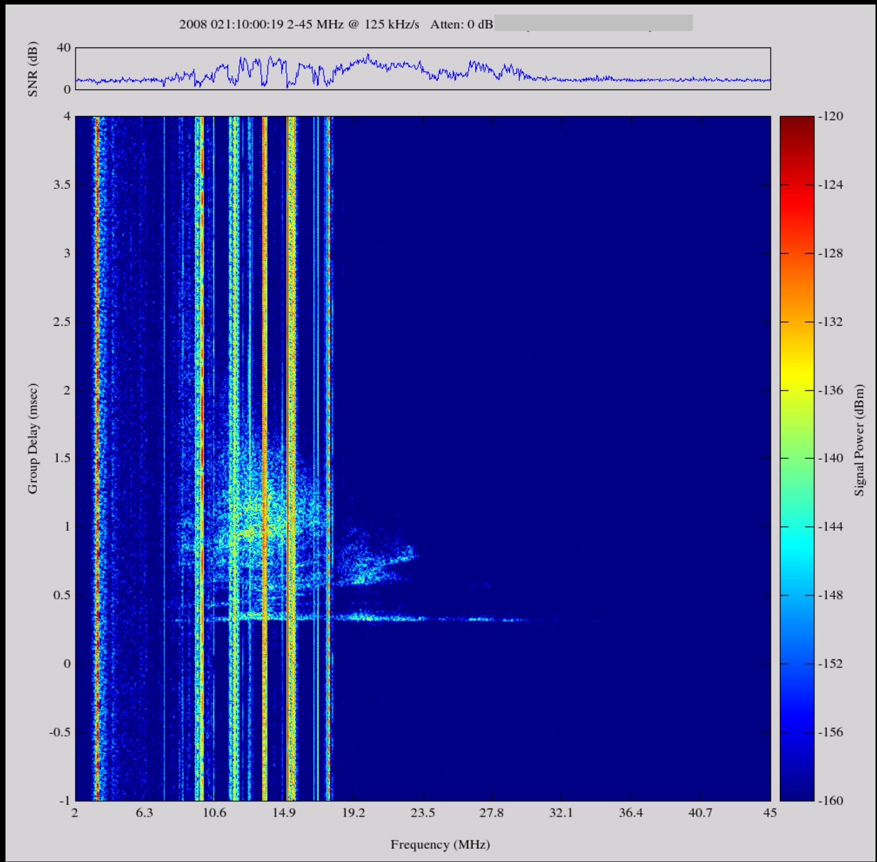


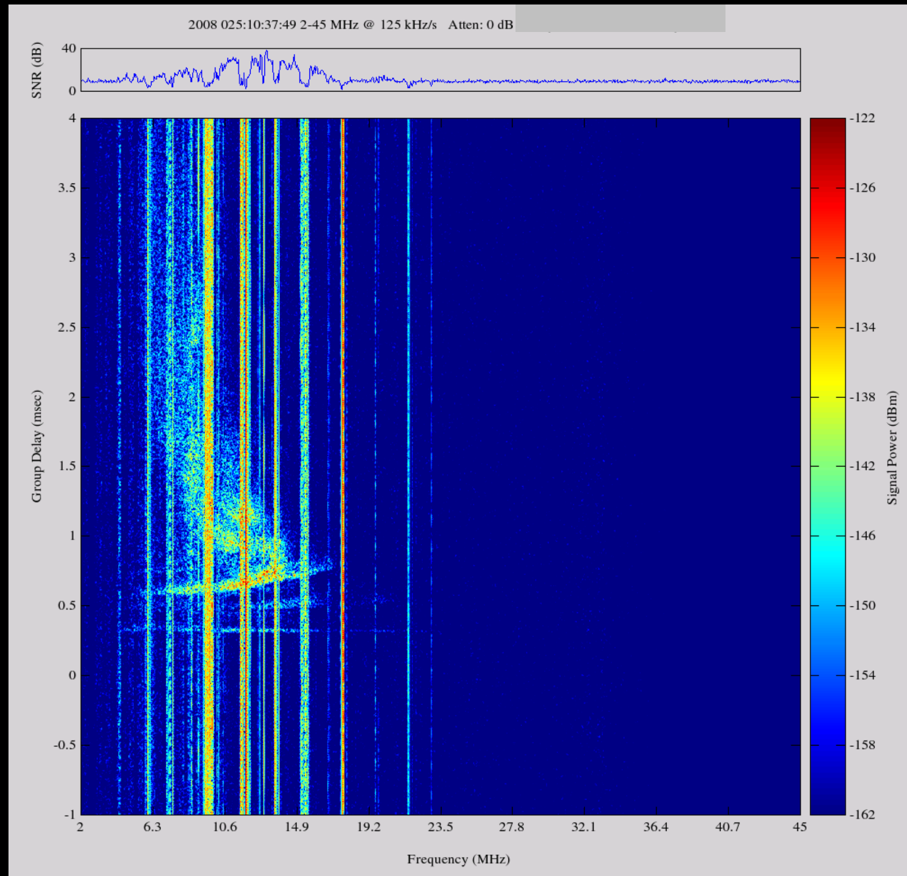
Whenupai-Sydney MOF vs ASAPS
8Sep07 daily T=-10, monthly T=10
UD
MUF
OWF
MOF
MHz
UT



Whenuapai-Culgoora March08 MOF
vs ASAPS at monthly T=6
MOF
UD
MUF
OWF
MHz
UT


2007 232:08:52:49 2-30 MHz @ 125 kHz/s Atten: 0 dB Delay: 6.20 msec
SNR (dB)
40
0
Group Delay (msec)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
Frequency (MHz)
2
4.8
7.6
10.4
13.2
16
18.8
21.6
24.4
27.2
30
Signal Power (dBm)
-122
-126
-130
-134
-138
-142
-146
-150
-154
-158
-162
DSTO DORS Rx at Camden
(~50km SW of Sydney) receiving
from a DoD Tx in NW Australia

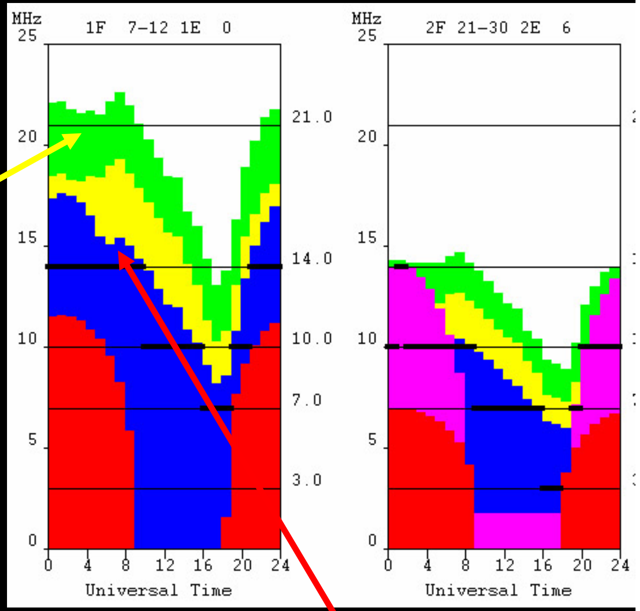




High-latitudes: DSTO DORS (Digital Oblique Receiver System) Rx at Casey from 3 Tx in North-Western Australia at ranges of 5500-6400km at 100W and 1 Tx from southern Australia at 10W, all successfully received.

Long-term HF predictions

- Long-term predictions are essential for HF planning
- They (hopefully) reflect average, or common conditions,
  - and are a reasonable compromise,
  - given the available ionospheric models accuracy.
- They are necessary in
  - Spectrum management activities where long lead times are required,
  - HF communications,
    - point-to-point
    - point-to-area
    - area-to-area (very important)
  - HF broadcasting,
  - OTHR & surveillance
  - etc
- Problems
  - OWFs ignore 90% of skywave support
  - Storms ignored
  - Short-term ionospheric variability handled poorly
  - Virtual ray trace ignores tilts / gradients
  - Special regional problems (high / low latitudes) may not be addressed effectively
  - Models inadequately tested against observations
  - No sporadic E, and so on.



OWF

Forecasting: A start point?

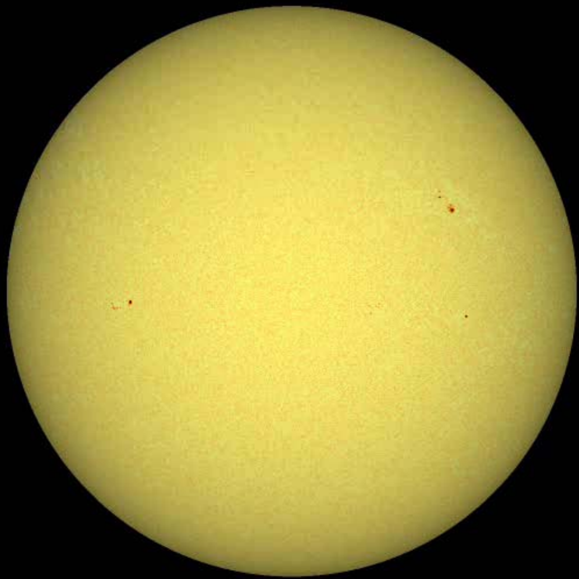
"Sir Edward Appleton" by Ronald Clark

"…. These facts induced Appleton to suggest informally to the Services, soon after the outbreak of war, that ionospheric forecasting of radio conditions might be useful. ….. The situation rose to a head when a number of planes, destined for a leaflet raid on Germany, flew straight up the North Sea until they ran out of petrol."

Ch. 8. P130

But there's much more to it than that.

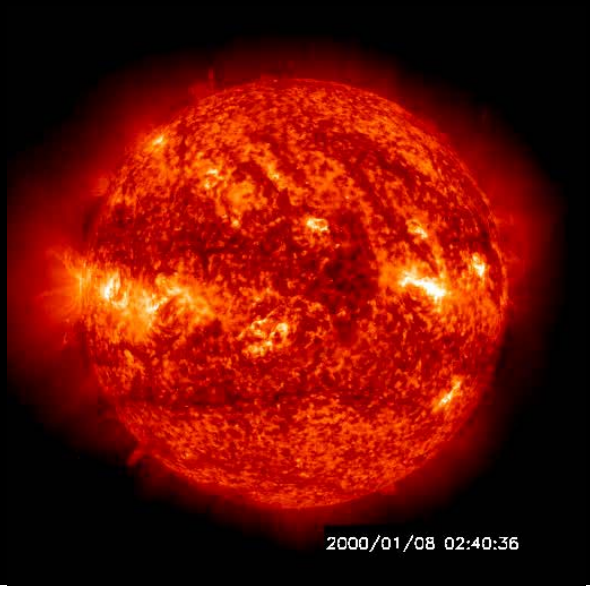
Forecasting space weather will be an integral part of appreciating the ionosphere and managing future systems.



History: Major Limitations in the past

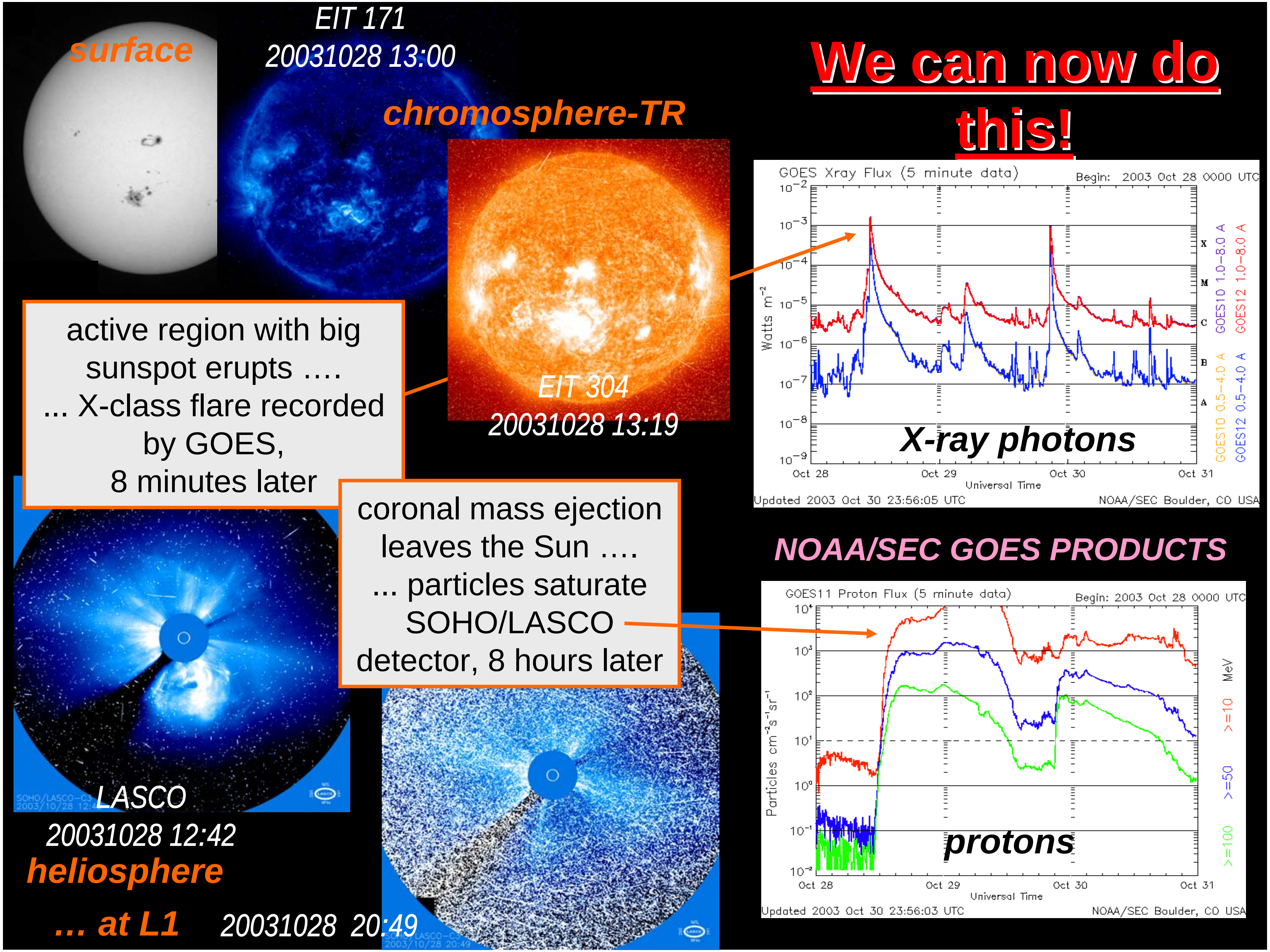
How it was

- Lack of Critical Data
- Slow Exchange Available Data
- Poor Understanding of Science
- Limited Ability to Communicate Forecasts
- Simple Non-Specific Services
- A belief it would get better



Forecasting

- Flares follow a Poisson distribution (a hopeless case)
- Flares $\geqq$ M-class
  - cause fadeouts - alert
- Flares $\geqq$ X-class
  - with Type IV emissions *may* cause geomagnetic storms
- Kp > 3 storms
  - cause ionospheric storms
- M-regions
  - may cause geomagnetic storms
  - they are *recurrent*
    - roll on Skylab



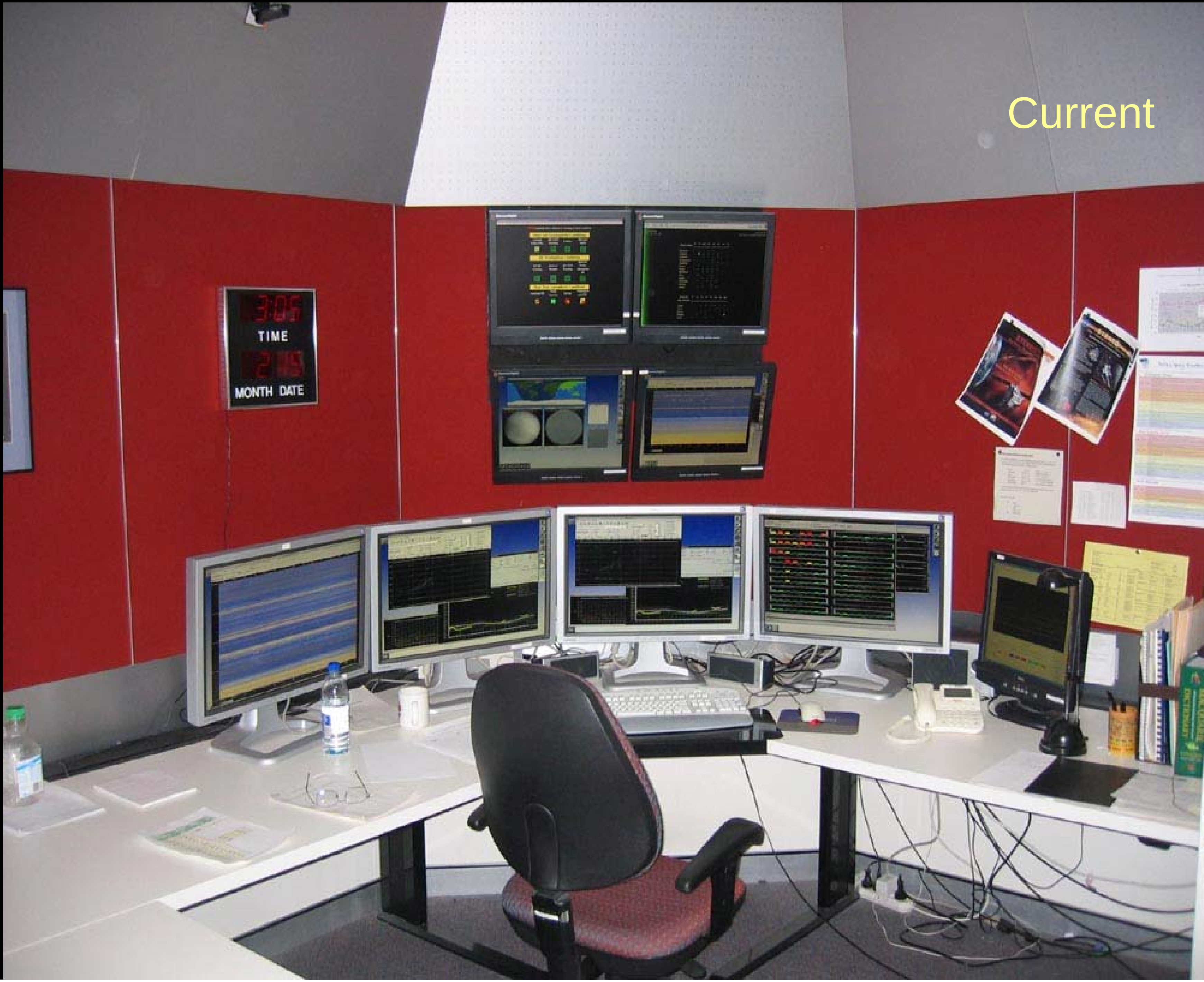
surface
EIT 171
20031028 13:00
chromosphere-TR
EIT 304
20031028 13:19
We can now do this!
active region with big sunspot erupts ….
... X-class flare recorded by GOES,
8 minutes later
coronal mass ejection leaves the Sun ….
... particles saturate SOHO/LASCO detector, 8 hours later
LASCO
20031028 12:42
heliosphere
... at L1
20031028 20:49
GOES Xray Flux (5 minute data)
Begin: 2003 Oct 28 0000 UTC
Watts m⁻²
Oct 28
Oct 29
Oct 30
Oct 31
Universal Time
X-ray photons
GOES10 1.0–8.0 A
GOES12 1.0–8.0 A
GOES10 0.5–4.0 A
GOES12 0.5–4.0 A
Updated 2003 Oct 30 23:56:05 UTC
NOAA/SEC Boulder, CO USA
NOAA/SEC GOES PRODUCTS
GOES11 Proton Flux (5 minute data)
Begin: 2003 Oct 28 0000 UTC
Particles cm⁻²s⁻¹sr⁻¹
protons
Universal Time
>=10 MeV
>=50
>=100
Updated 2003 Oct 30 23:56:03 UTC
NOAA/SEC Boulder, CO USA

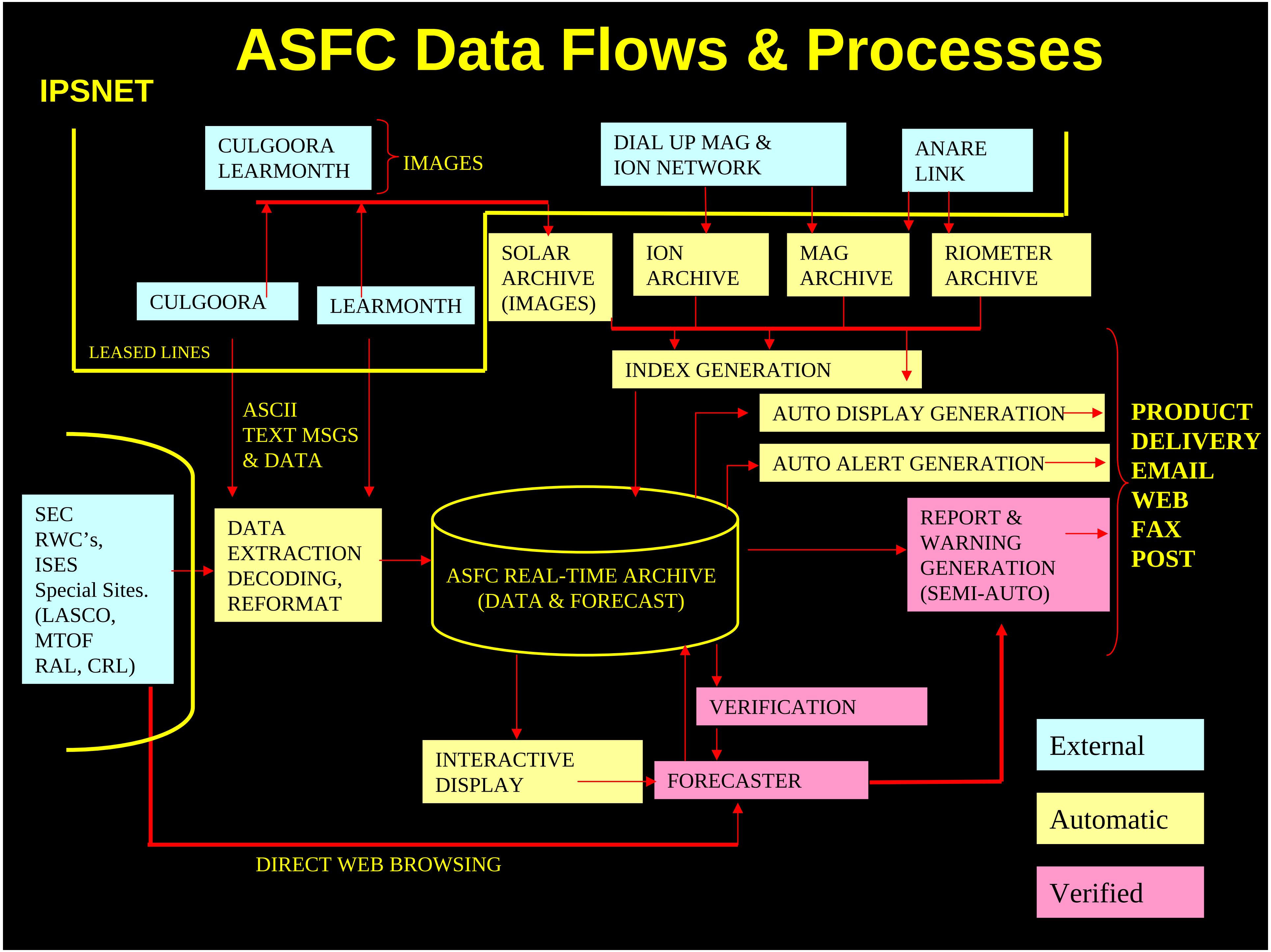
(Less than) thirty years ago

- A hardware oriented environment
- Data:
  - geomagnetic field *in real time*
  - Solar images *daily*
  - Solar emissions *daily*
  - daily selected foF2 *daily*
  - local ionograms *in real time*
- TELEX for rapid, ⇨ worldwide communications
  - *no FAX yet*.


~1990
UNIVERSAL TIM
TIME

Current





ASFC Data Flows & Processes
IPSNET
CULGOORA
LEARMONTH
IMAGES
DIAL UP MAG &
ION NETWORK
ANARE
LINK
SOLAR
ARCHIVE
(IMAGES)
ION
ARCHIVE
MAG
ARCHIVE
RIOMETER
ARCHIVE
CULGOORA
LEARMONTH
LEASED LINES
INDEX GENERATION
AUTO DISPLAY GENERATION
AUTO ALERT GENERATION
PRODUCT
DELIVERY
EMAIL
WEB
FAX
POST
ASCII
TEXT MSGS
& DATA
SEC
RWC's,
ISES
Special Sites.
(LASCO,
MTOF
RAL, CRL)
DATA
EXTRACTION
DECODING,
REFORMAT
ASFC REAL-TIME ARCHIVE
(DATA & FORECAST)
REPORT &
WARNING
GENERATION
(SEMI-AUTO)
VERIFICATION
INTERACTIVE
DISPLAY
FORECASTER
DIRECT WEB BROWSING
External
Automatic
Verified

Other Data Sources: Space-based

Data Set	Local Processing	Use	Issues
SOHO: FTP from NRL solar images (EIT) coronograph (Soft X-ray) UCMEO code solar wind (MTOF Proton Monitor)	JPG image differencing in IDL CME/halo presence Decoded; for guidance on CME extent Velocity and density used when ACE fails;	Flare location CME presence CME extent, set **GEOSTAT=5** Confirm CME arrival	GIF too large None Needs to be more timely ASCII data not available soon enough
ACE: FTP from SEC Interplanetary Magnetic Field Solar wind density Solar wind velocity	Storm strength indicator 47 – 65 keV ion enhancement detected Shock detection (all parameters jump together)	IMF Web display Precursor **ALERT**, forecaster Shock **ALERT**, drives magnetopause applet.	Is there a reliable Bz predictor? Proton contamination kills data
Yohkoh: delivered to IPS FTP Solar images	Coronal holes Returning region seen around limb	Forecaster information	none
GOES: SEC e-mail every 2 mins Solar X-ray fluxes Energetic particles Magnetic fields	Threshold Proton events exceed 10MeV threshold Magnetopause crossings	Flare/SWF **ALERTS** Proton **ALERT** Compare with model	None None None
NOAA/TIROS: Auroral boundary Power index	Auroral oval location Power index	Add oval to HAP chart	none

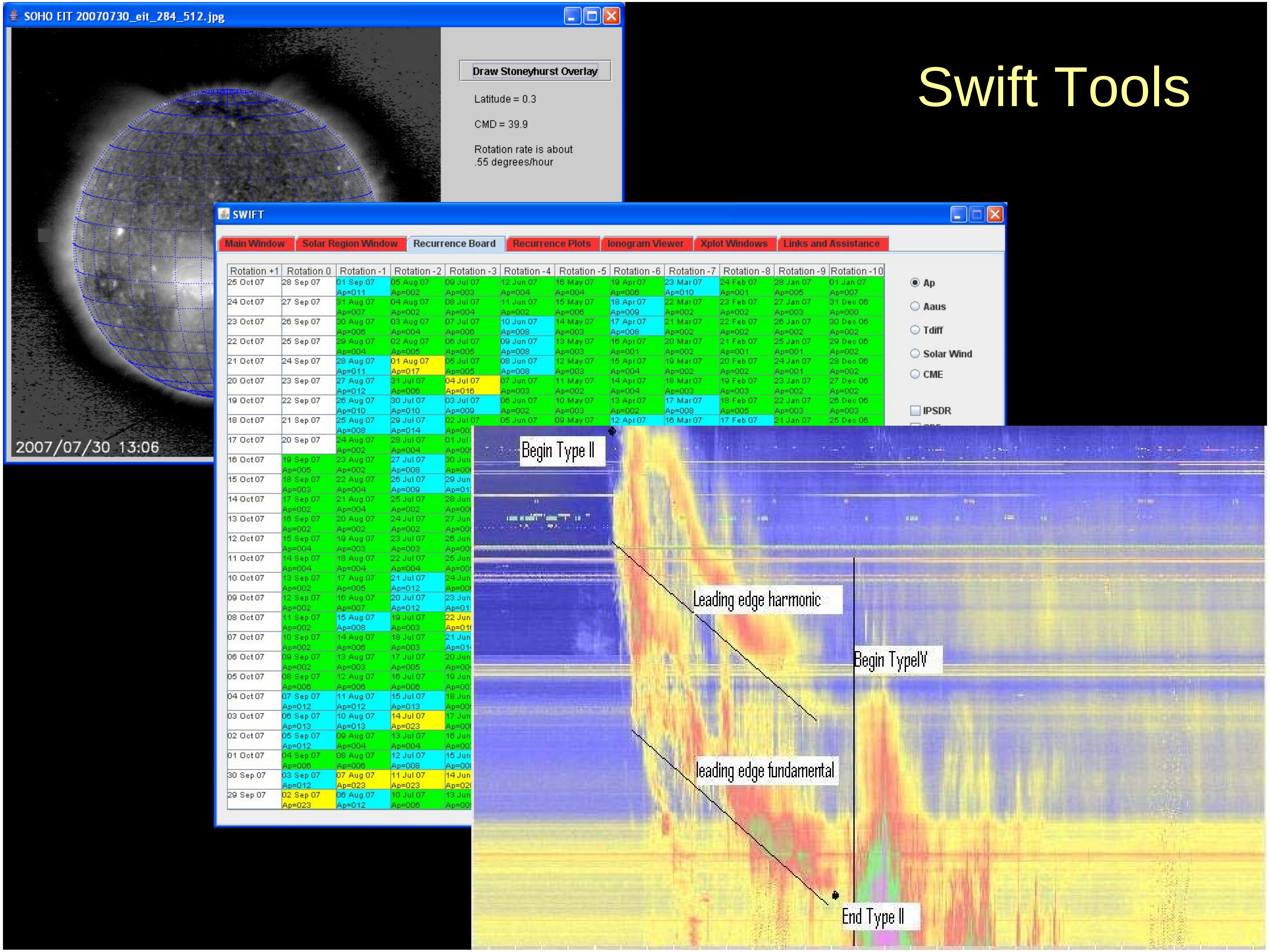
Other Data Sources: Miscellaneous

Data Set	Local Processing	Use	Comments
RSGA / SDF: SEC (22 UT)	split across archives	sets the morning scene supplies 10.7cm flux, ap flares and solar levels	excellent summary
Boulder Events Log: SEC (updated in near real time on Web)	x-ray flare location type II/IV radio bursts, etc.	solar event geo-effectiveness forecasting background	extremely useful
Solar Region Summary: SEC (0030 UT)		Archives	Valuable archive listing
Solar Geophysical Summary (0245 UT)		Supplies Kp, Boulder K	
WWA GEOALERT (0330 UT)	UGEOA, UGEOI, UGEOE, UGEOR	codes extracted and archived	<u>UGEOA contains the consensus forecast</u>
BOUSYD (2 / day)	Codes extracted	FoF2 for global index generation	Extremely useful
Mt Wilson: White light magnetograms		supplement local sources	
RWC URSIGRAMS	All codes extracted		No longer a primary data source
Big Bear solar magnetic gradient alerts	very useful	forecaster alert	
SCDR			SEC cancelled
HF Propagation Reports	Make our own		USAF cancelled

(IPS) Space Weather Ionospheric Forecasting Tool (SWIFT)

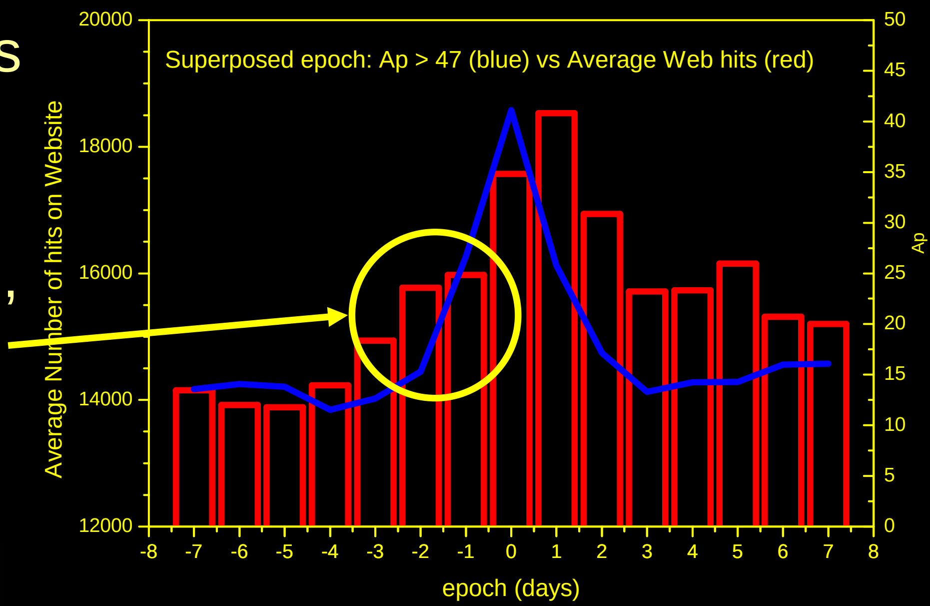
Swift facilitates accessing data and information for forecasting purposes

Swift Tools


SOHO EIT 20070730_eit_284_512.jpg
Draw Stoneyhurst Overlay
Latitude = 0.3
CMD = 39.9
Rotation rate is about
.55 degrees/hour
2007/07/30 13:06
SWIFT
Main Window
Solar Region Window
Recurrence Board
Recurrence Plots
Ionogram Viewer
Xplot Windows
Links and Assistance
Ap
Aaus
Tdiff
Solar Wind
CME
IPSDR
Begin Type II
Leading edge harmonic
Begin TypeIV
leading edge fundamental
End Type II

Is anybody interested? Yes indeed!

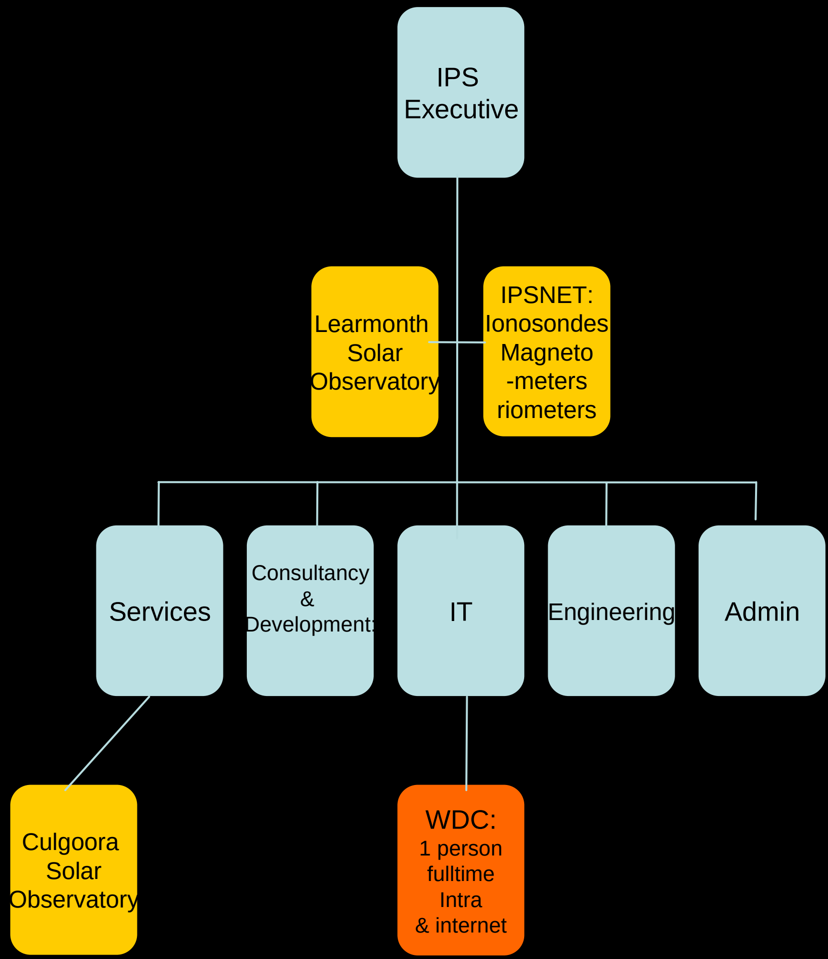
- A wide range of disturbances affect people.
- As activity increases, more customers use the site,
  - and same customers return more frequently
- The services are useful.



Effect	Time scale	Evaluation
Solar cycle	decade	Empirical Model
Seasonal	months	Empirical Model
Storms	Few days	variability
Diurnal cycle	day	Empirical Model
Sporadic E	Few hours	nothing
Flares	Minutes to few hours	warnings
TIDs	Minutes to hours	variability
Terminator	minutes	Empirical model + variability
Fading	Milliseconds to seconds	statistics

World Data Centre for Solar Terrestrial Science

- The WDC for Solar Terrestrial Science
  - is a unit in IPS Radio and Space Services (IPS)
  - and IPS is a Division within the Australian Government.
- <u>Data permeates IPS</u>:
  - Australian Space Weather Centre requirement
  - used by Services (forecasting, service support)
  - archived in the WDC
- Data is managed across IPS
  - generated at observatories
    - using local Engineering equipment
  - collected / verified by Services
  - data quality and flows supervised by C&D staff, working closely with Services
  - Admin maintains Archive records.
  - IT maintains all data sets in IPS.
    - WDC reports to IT
- All IPS staff have a direct interest in the WDC
  - there are organisation-wide responsibilities for data.



IPS WDC PLAN

Description:

The World Data Centre for Solar Terrestrial Science (WDC for STS) is responsible for collecting, preserving, managing and distributing space weather data in support of scientific and industrial research.

Aims of the IPS WDC for STS:

- to enhance Australia's role in space science;
- to be a focal point of regional space weather data;
- to provide a local source of overseas WDC data;
- to effectively manage & coordinate IPS and external data.

The three vital elements required are:

- high quality solar-terrestrial data;
- an efficient (and automated) archival system;
- a retrieval system that is easy to use.

Data Partners & some of the people

- WDC for Solar Terrestrial Science (IPS)
  - Vertical Ionospheric data: K Mitchell, Dr D Neudegg, Dr P Wilkinson
  - Oblique Ionospheric data: Dr D Neudegg, M Lahoun
  - Magnetic data: Dr R Marshall
  - Riometer data: M Hyde
  - FEDSAT, SHIRE, GPS: Dr M Terkildsen
  - Solar: Dr A Brockman, N Prestage, G Patterson
- National data sets
  - Australian Government Antarctic Division (cosmic ray, ionograms, magnetometer, auroral images)
    - Dr M. Duldig, Dr Ray Morris
  - University of Newcastle (magnetometer, micro-pulsation, FEDSAT, SHIRE)
    - Prof B Fraser, Dr F Menk, Dr P Ponomarenko, Dr C Waters
  - La Trobe University (SuperDARN: TIGER / Unwin radars)
    - Prof P Dyson, Dr J Devlin, Dr R Makarevich, Dr M Parkinson
  - Geosciences Australia (magnetometer, GPS – TEC)
  - Defence (scintillation, GPS-TEC)
    - Dr T Harris, Dr R Gardiner-Garden
- International data sets
  - MAGDAS (magnetometer)
    - Prof Yumoto
  - University of Canterbury (Ionosonde)
    - Prof W J Baggaley
- International data exchange
  - SPIDR
  - MOU

Red Auroral Glow — Wisanger Lakes, Kangaroo Island, South Australia (http://www.qist.net.au/assa) © Copyright 1996 David Miller

Note: under-lined data sets are in WDC or being prepared for the WDC

WDC (external) data sets

Australian Government
IPS Radio and Space Services

The Australian Space Weather Agency

Space Weather | Satellite | Geophysical | Solar | HF Systems | Products and Services | Educational | World Data Centre

World Data Centre

Looking for something? Site Search

Home ▸ World Data Centre ▸ FTP Download — Monday, Apr 23 2007 02:29 UT

Data Display and Download
- FTP Download
- Software Tools
- Magnetometer
- Ionospheric
- Ionospheric_Medians
- FEDSAT
- Imaging Riometer
- Cosmic Ray
- Riometer

Data Catalogue
- Solar Data
- Ionosonde Data
- Magnetometer Data
- Riometer Data
- Spectrograph Data
- GPS Data

Related Sites
- WDC Links

Section Information
- Latest News

Data Display and Download

FTP Download:

Datasets currently available for ftp download include the following:

Ionospheric

- Iondata - Australian scaled ionospheric data. (Small files < 200 KB - See README for description of format.)
- Ionospheric Medians - FoF2 and M3000 median data. (Small files < 200 KB - See README for description of format.)
- Ionogram Data - Ionogram raw and clean data. (daily zip files < 1000 KB - See README for description of format.) An IPS Clean Ionogram Viewer (and README) are available for download here. This is a Java application that has been placed in a Java "jar" file. It allows the user to view and print IPS ionograms, as well as providing a simple scaling facility.

Geophysical

- Magnetometer - magnetometer data from Australian and Antarctic stations. (Large - approx 3MB day files)
- Cosmic Ray Data - from Kingston and Mawson. (Small files < 100 KB - See README for details)
- Riometer Data - from Casey, Davis, Macquarie Island and Mawson. (Small files < 50 KB)

Solar

- Spectrograph - data from the Culgoora and Learmonth spectrographs. (Large - approx 30MB day files)
- Solar Images - from the Culgoora Solar Observatory. (Large - approx 2Mb zipped hour files)
- A WINDOWS Culgoora H-Alpha image viewer is available for download here (wdc_ib.zip). After installation you need to download zipped data to Program Files/IPS/wdc_ib on your PC.

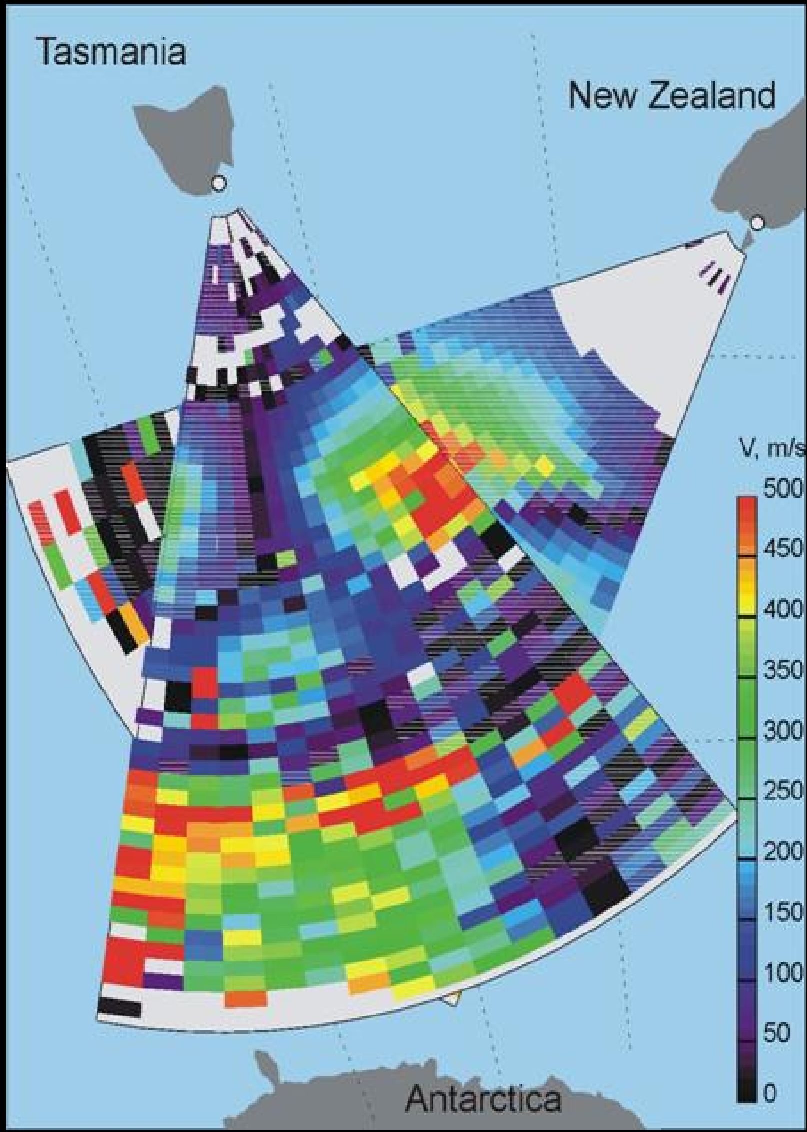
This area is under development. Please revisit regularly for the latest datasets, documentation and software tools.

For further information please address inquiries to: wdc-sts@ips.gov.au

SuperDARN / TIGER-Unwin

Example:

- TIGER / Unwin Coherent Radars
  - Early warning of activity effects
    - gravity waves??
    - auroral oval??
  - Backscatter radar mode
    - HF diagnostic potential
  - Problems:
    - getting in real time
    - resources to implement services

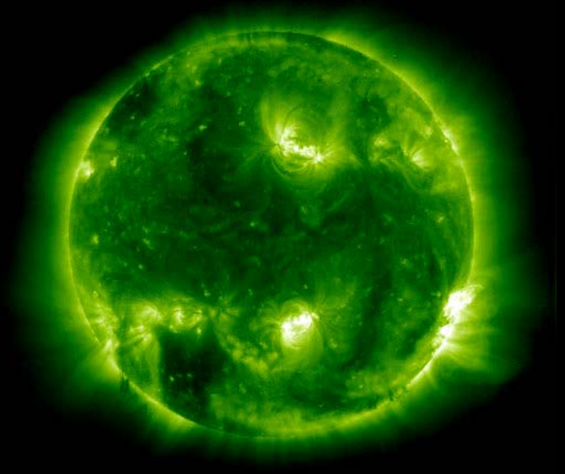


History: Major Limitations in the past

- Lack of Critical Data
- Slow Exchange of Available Data
- Poor Understanding of the Science
- Limited Ability to Communicate Forecasts
- Simple Non-Specific Services
- A belief it would get better

The New Millennium Forecasters

- We observe everything better,
- and get it in real time, decoded,
  as a picture.
- Communications are wonderful
- Services are far more complex



HF: Where now?

We should be moving from this:

"Poor reliability and low circuit quality are the accepted norm;

- HF communications continues to have a bad reputation,
- past technology, available understanding lead to modest reliability, subject to signal distortion, interference and low data rates." (from Barclay, IES-2002).

To this:

New technology offers huge advantages.

- Digital signal processing (DSP)
- Adaptive systems, automated control
- Improved frequency management

“Modern” Digital HF

Digital HF can bring revolutionary changes.

Adaptive HF systems e.g.,

- choice of antenna, frequencies, etc
- Automatic Link Establishment (ALE).

Digital broadcasting to replace analogue systems

- being tested now, and most impressive (e.g., Digital Radio Mondiale, DRM),

Further digital signal processing,

- new modems, new protocols, new world.

Are we making good use of this <u>now</u>?

- Let’s look gently at one example.

The Problem:

HF in the past,

- a skilled radio operator established communications
- and adjusted operating parameters.
- Today, this function can be automated.

All these problems were / will be solved by -

The solution: ALE

HF in the past,

a skilled radio operator established communications
and adjusted operating parameters.
Today, this function can be automated.

ALE systems choose the best HF channel without assistance

ALE

An Example: ALE – a RTCE technique

- HF in the past,
  - a skilled radio operator established communications
  - and adjusted operating parameters.
  - Today, this function can be automated.
- ALE systems choose the best HF channel without assistance.
  - Each HF ALE system has a number of channels.
  - The larger the frequency set, the better (say 10 to 12)
    - Link Quality Assessment is limited by small frequency sets.
    - **propagation** advice can provide a useful frequency set.
  - Periodically, a station attempts to link on each of its frequencies,
    - measures the signal quality, and stores the quality scores.
- When a call is initiated, the radio checks its "memory"
  - determines the best quality frequency to the desired station.
  - Attempts to link on that frequency,
    - then tries on the next best frequency,
    - and so on, until a link is established.

An Example: ALE – a RTCE technique

- HF in the past,
  - a skilled radio operator established communications
  - and adjusted operating parameters.
  - Today, this function can be automated.
- ALE systems choose the best HF channel without assistance.
  - Each HF ALE system has a number of channels.
  - The larger the frequency set, the better (say 10 to 12)
    - Link Quality Assessment is limited by small frequency sets.
    - **propagation** advice can provide a useful frequency set.
  - Periodically, a station attempts to link on each of its frequencies,
    - measures the signal quality, and stores the quality scores.
- When a call is initiated, the radio checks its “memory”
  - determines the best quality frequency to the desired station.
  - Attempts to link on that frequency,
    - then tries on the next best frequency,
    - and so on, until a link is established.

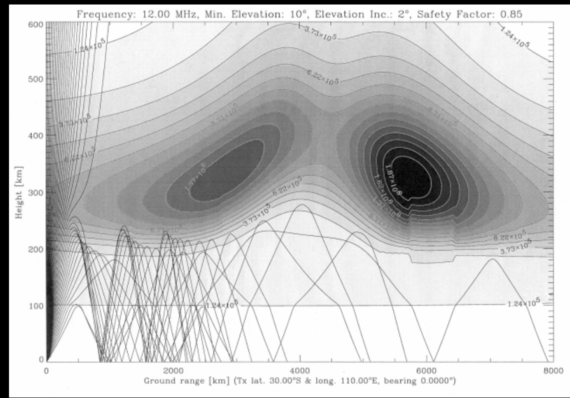
ALE: the Propagation Advantage

- ALE needs several frequencies to be effective
  - But this may be increasing HF interference
  - Reduce the number of frequencies,
    by taking propagation conditions into account
- Operational time and frequency selection compete
  - Reduce the number of frequencies,
    by taking propagation conditions into account
- ALE announces its presence as it sounds on potential operational frequencies (jamming, surveillance threats)
  - Shorten time needed to test path (technology solution)
  - "Shadow the enemy" (propagation options)

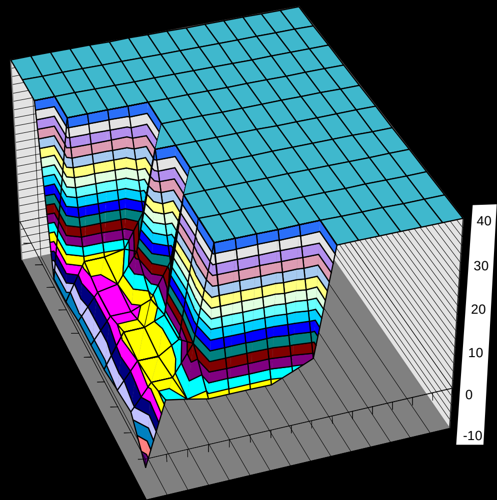
The Issues: multipath and Doppler effects

- "HF performance depends on how well the system design compensates for the propagation channel."
- "In essence the waveform aims to compensate for multipath and Doppler effects, which can compromise the signal integrity."
- "Success depends critically on a good understanding of the radio channel multipath and Doppler characteristics."

(Cannon, Angling & Lundborg, Reviews of Radio Science 2002;
now Radio Science Bulletin www.ursi.org)

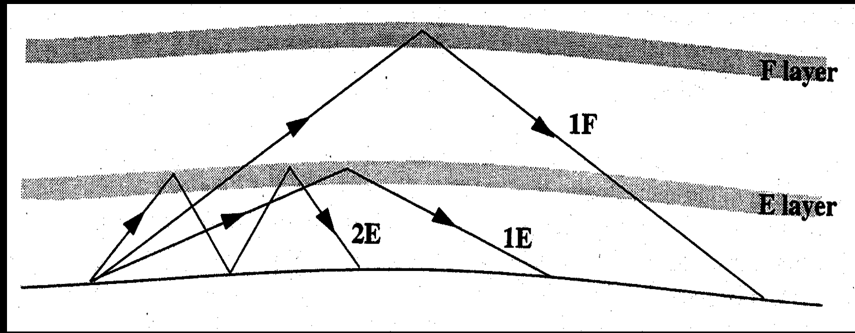


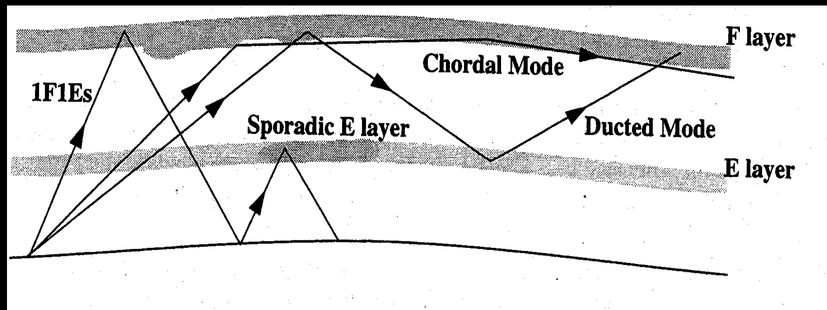
Mil-Std-188-110A serial, short interleaver, 1200bps



Past HF Link: That's where we were

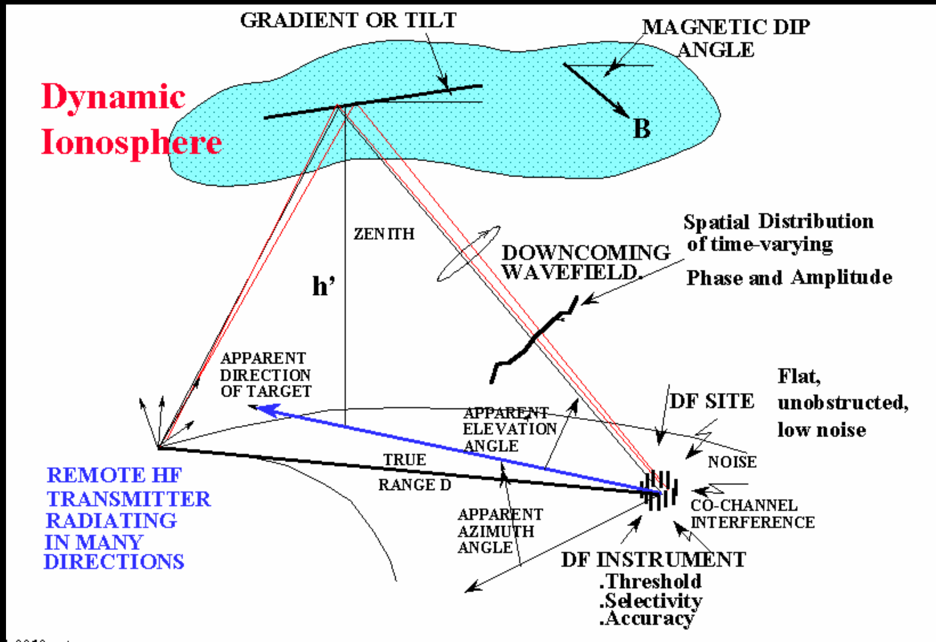
- A simple HF system
  - e.g., a single HF link between Wellington and Sydney).
- Given a frequency set, how should it be used?
- Method:
  - take an ionospheric model, including estimates of variability
  - compare the availability of the frequencies in the set.
  - for a selection of likely propagation paths and
  - choose the best frequencies for the time of the day.
- Note: only an empirical ionospheric model is needed.

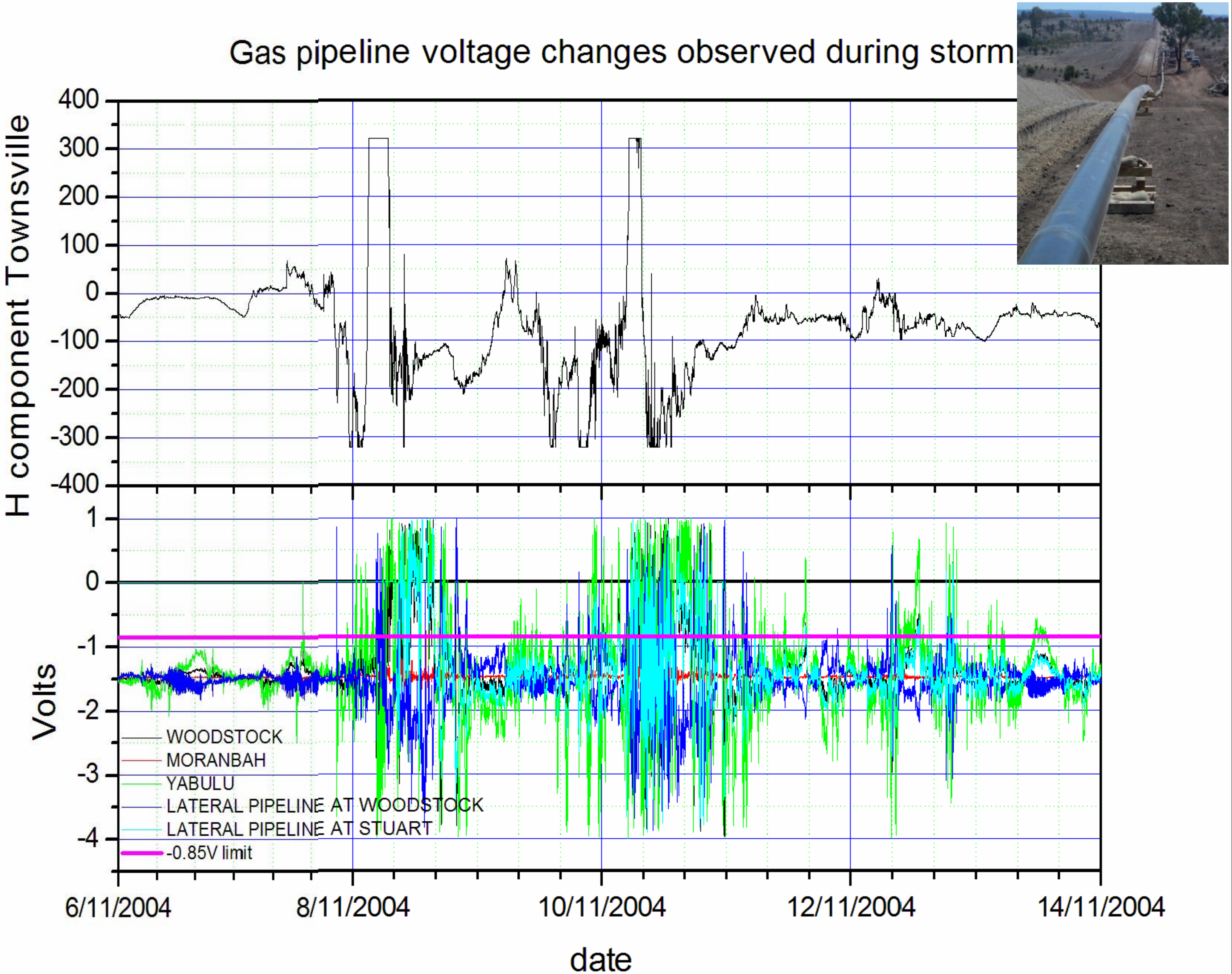




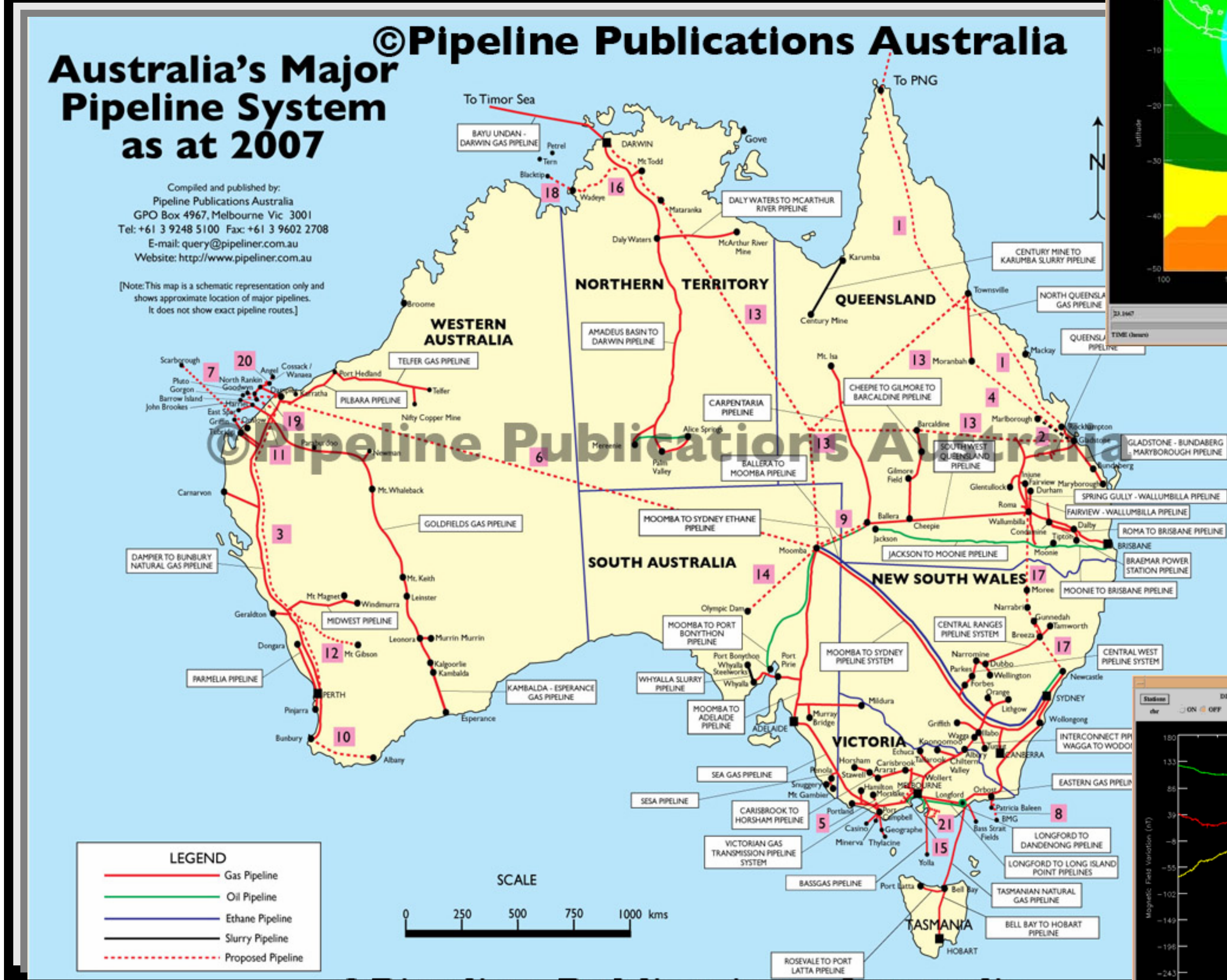
Current HF Link: path propagation

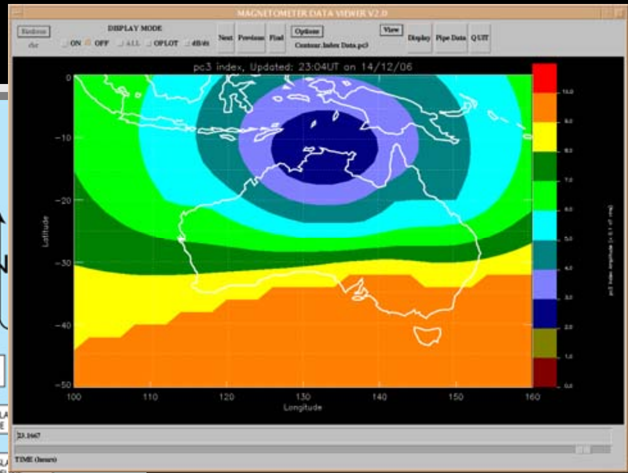
- HF propagation channel is characterized.
  - The signal travels over multiple paths
    - including different layers, ground reflections, polarisation, high/low rays
- Propagation times over the paths are different,
  - spread by several milliseconds.
- Path lengths may change,
  - introducing different frequency (Doppler) shifts
  - on each multipath component.
- The ionosphere is also turbulent
  - causing Doppler spread (fading) of each component,
  - and a resultant fading of the composite received signal.
- Producing signal distortion and degradation in the performance of communication systems.
- Modern HF management <u>will</u> allow for all of this.

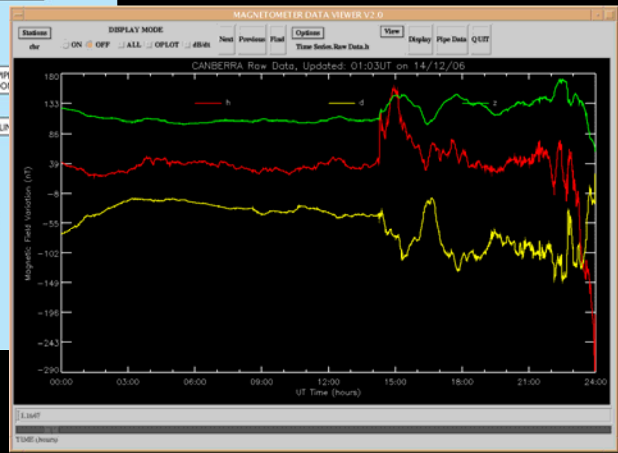



Gas pipeline voltage changes observed during storm
H component Townsville
400
300
200
100
0
-100
-200
-300
-400
Volts
1
0
-1
-2
-3
-4
WOODSTOCK
MORANBAH
YABULU
LATERAL PIPELINE AT WOODSTOCK
LATERAL PIPELINE AT STUART
-0.85V limit
6/11/2004
8/11/2004
10/11/2004
12/11/2004
14/11/2004
date

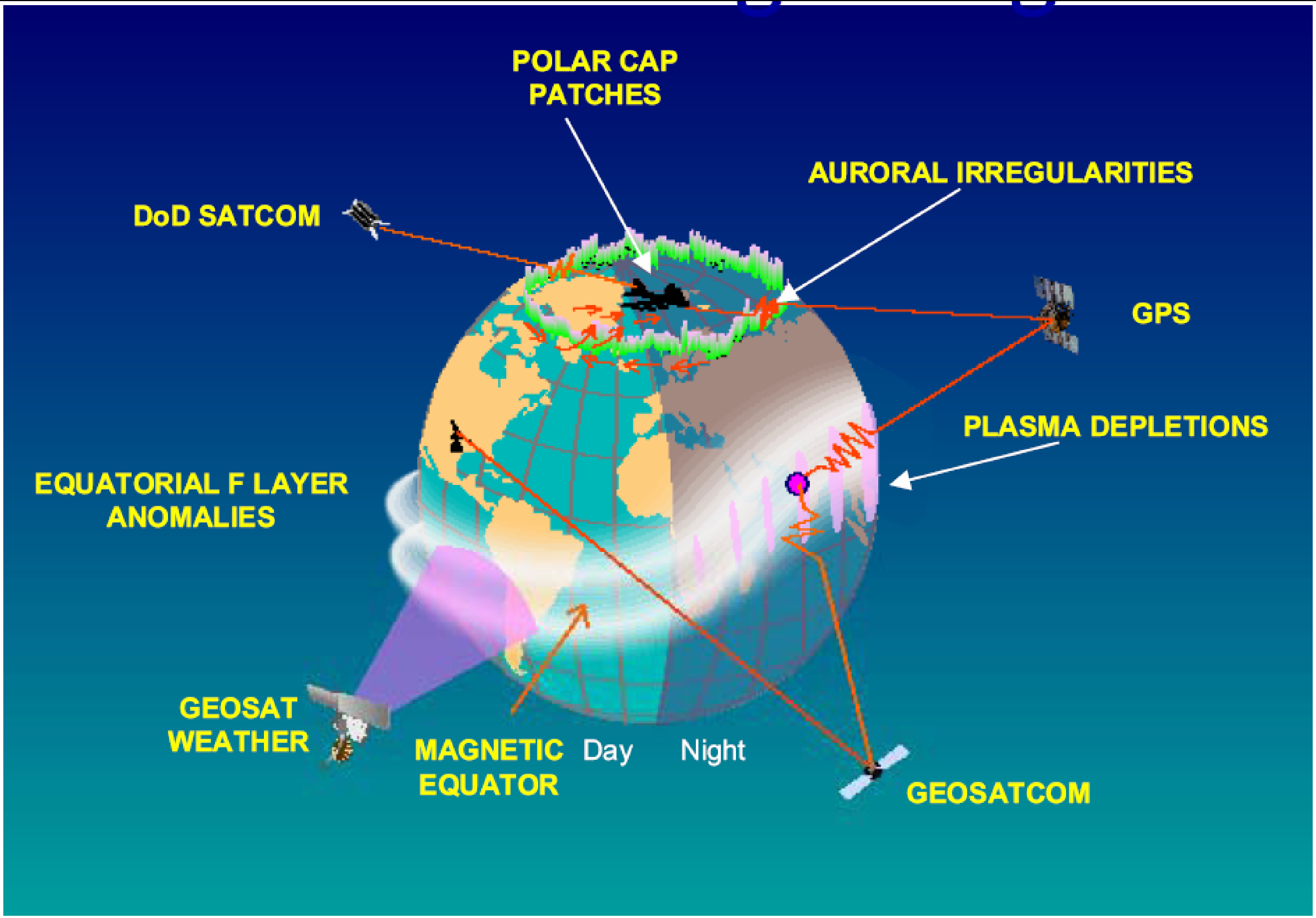
Pipeline Services





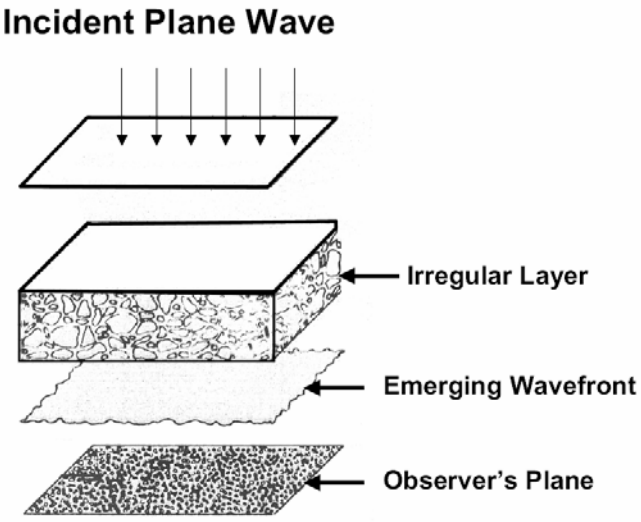


Space-based Assets



Major Focus: Scintillation

- Scintillation of radio wave signals is
  - rapid, random variation in signal amplitude, phase and/or polarization
  - caused by small-scale irregularities in the electron density along a signal's path
- Scintillations cause
  - signal fading / data dropouts on satellite communications links.
- The impact
  - <u>a practical reliability limitation on earth-space systems.</u>
  - causing loss of availability, due to fading, on margin-limited systems
    - For example: reduction in the number of simultaneously useable GPS satellites may result in a potentially less accurate position fix.

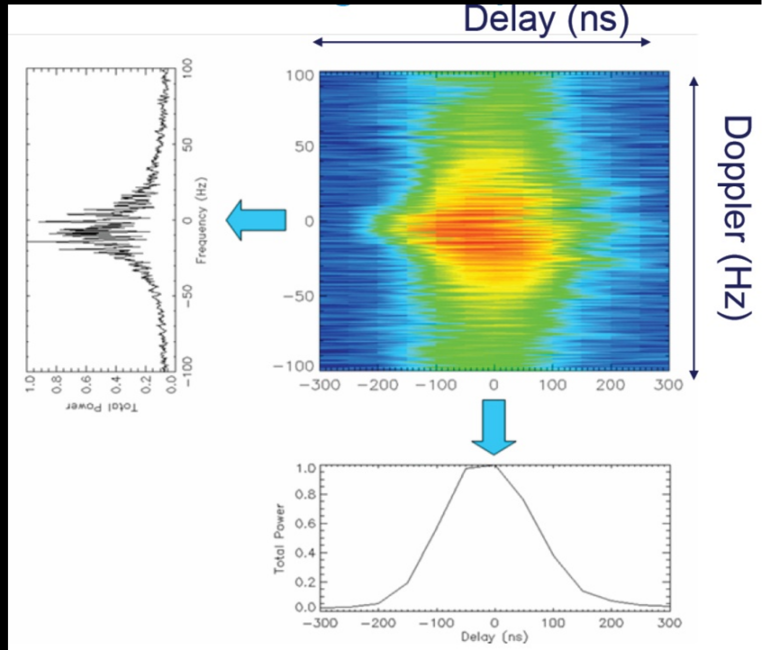


Pictorial illustration of the phase fluctuations Imposed on a wavefront traveling away from an Irregular layer for a vertical radio path.

- The solution
  - Plan for the problem with suitable margins: *climatology & predictions*
  - Anticipate worst cases in real time: *nowcasting and forecasting*
  - And use robust equipment: *technology*

Frequency Dependence of Scintillation

- Often described by:
  $S_4 = \{ \ (\langle I^2 \rangle - \langle I \rangle^2) / \langle I \rangle^2 \}^{1/2}$
  where I is the signal intensity
- Information from satellite studies
  - Fremouw et al. [1978] from Wideband DNA-002
  - employed 10 frequencies from 138 MHz to 2.9 GHz
- For $S_4 < 0.6$, $S_4 \sim \lambda^{1.5}$
- For $S_4 > 0.6$, $S(\lambda)$ is less steep
- The phase scintillation index is as follows:
  - $\sigma_\phi \sim \lambda$ for both weak and strong scattering



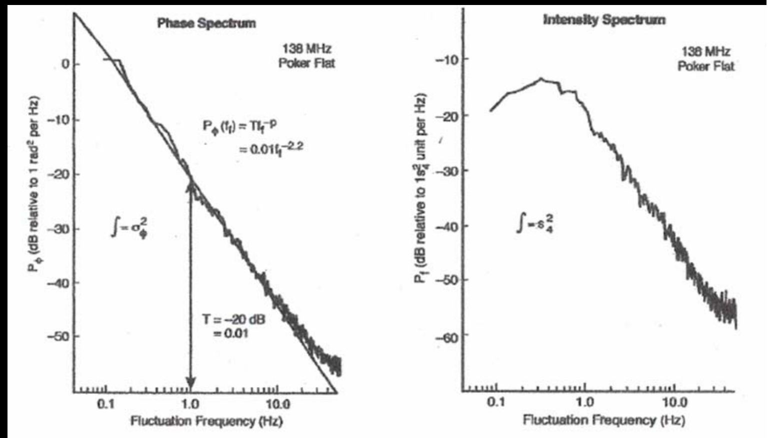
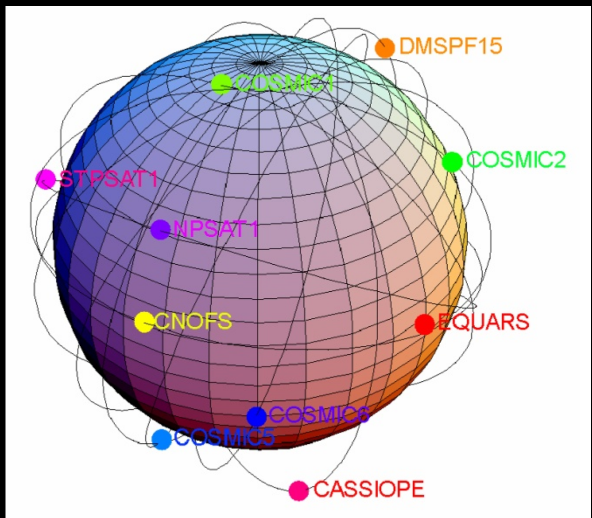
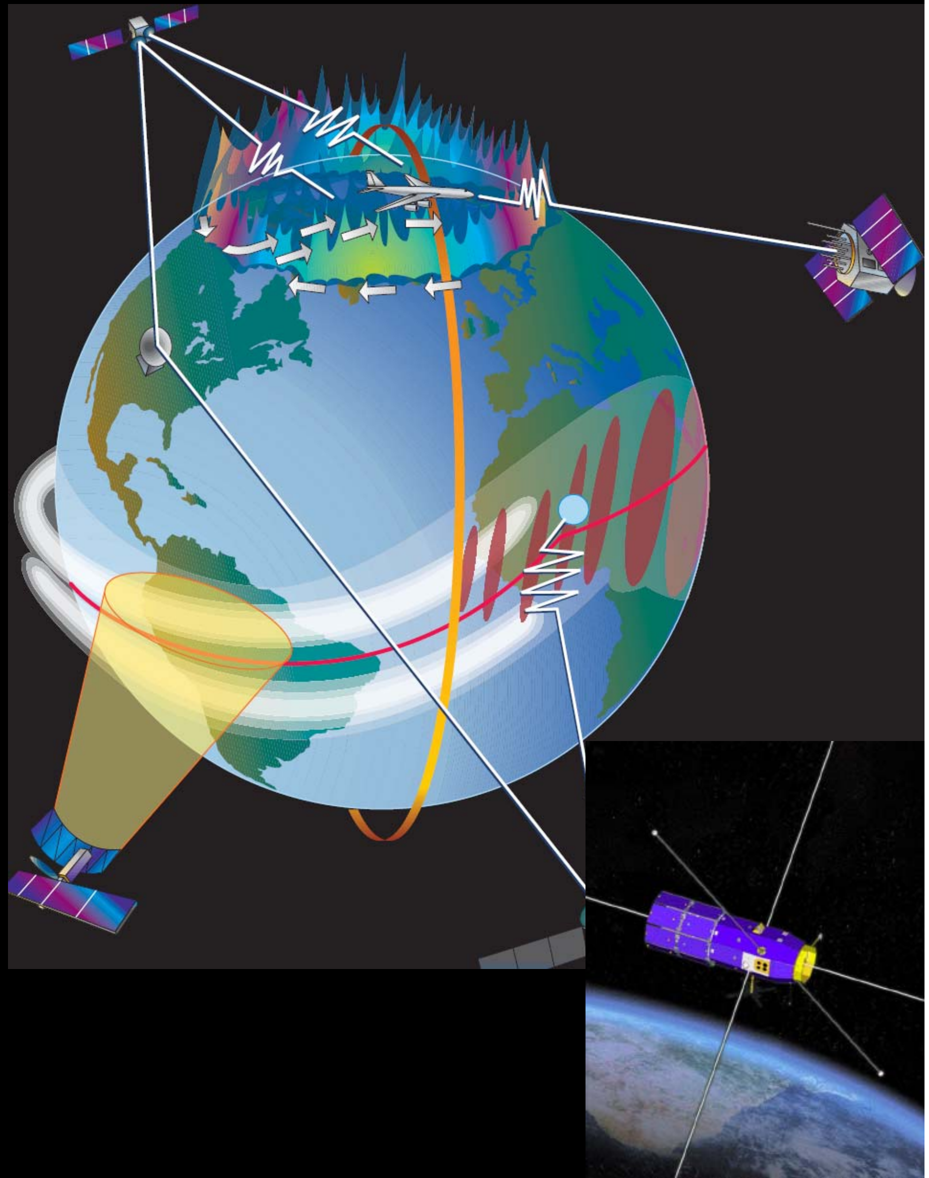


Figure 4-24: Scintillation data at 138 MHz obtained at Poker Flat, Alaska. The abscissa is fluctuation frequency (Hz) for both types of power spectra. (a) Phase spectrum. (b) Intensity spectrum. The so-called S4 index is the integral of the intensity spectrum. Most of the contribution to this integral is at the low frequency Fresnel frequency cutoff. This is a geometrical effect that is not encountered with the phase spectrum, which has no low frequency cutoff. From Secan [1998].

C/NOFS: Communication / Navigation Outage Forecasting System

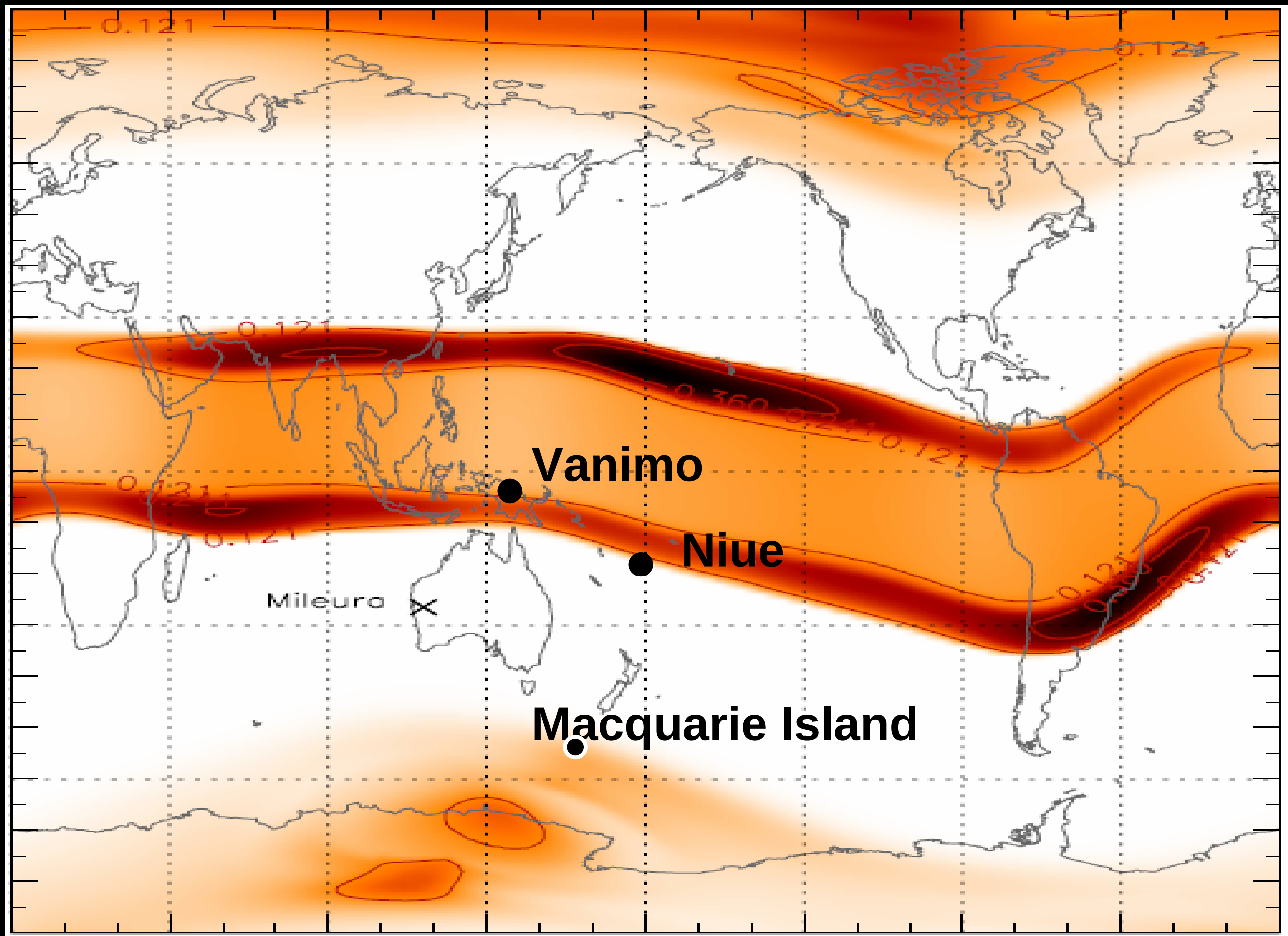
- A space-based warning system
- The main purpose of C/NOFS is to forecast the presence of ionospheric irregularities that would adversely impact communication and navigation systems.





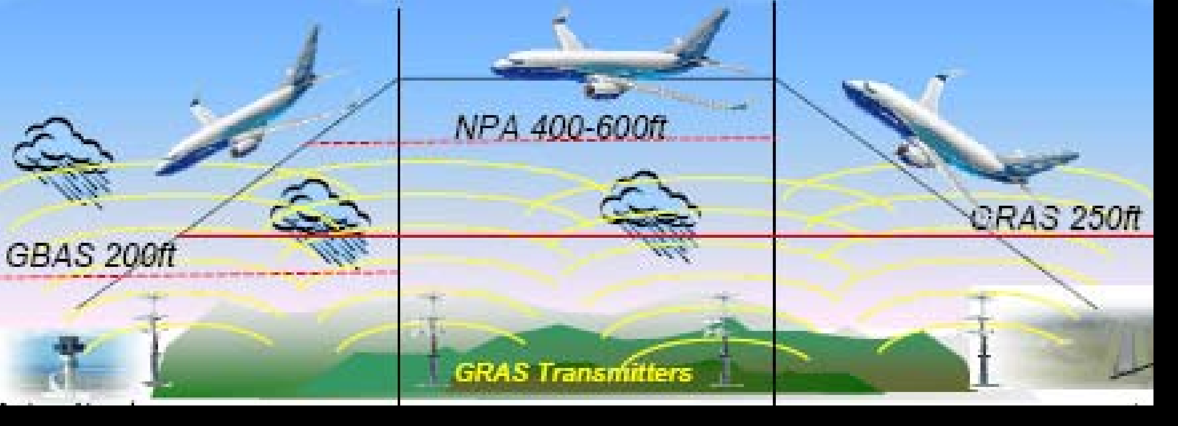
Ionospheric Scintillation Data

- 3 Ionospheric Scintillation Monitors (ISMs) operated by IPS

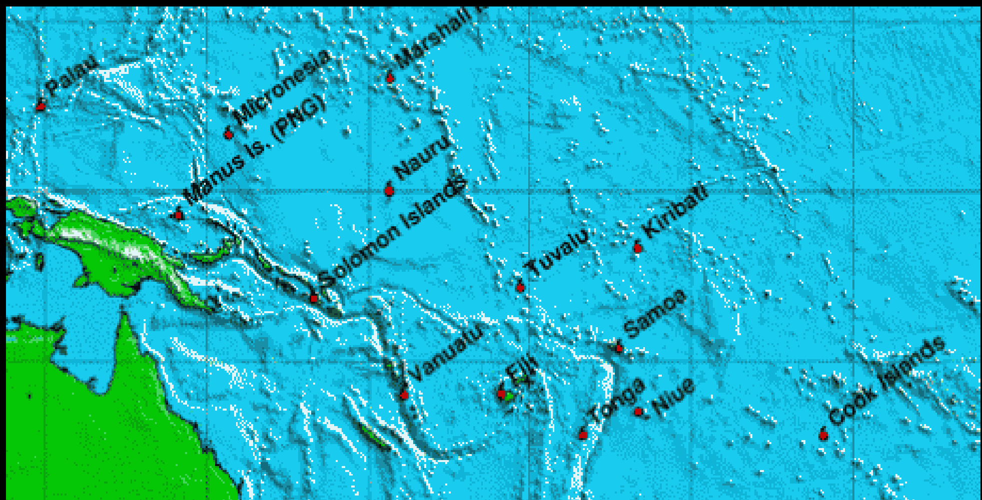


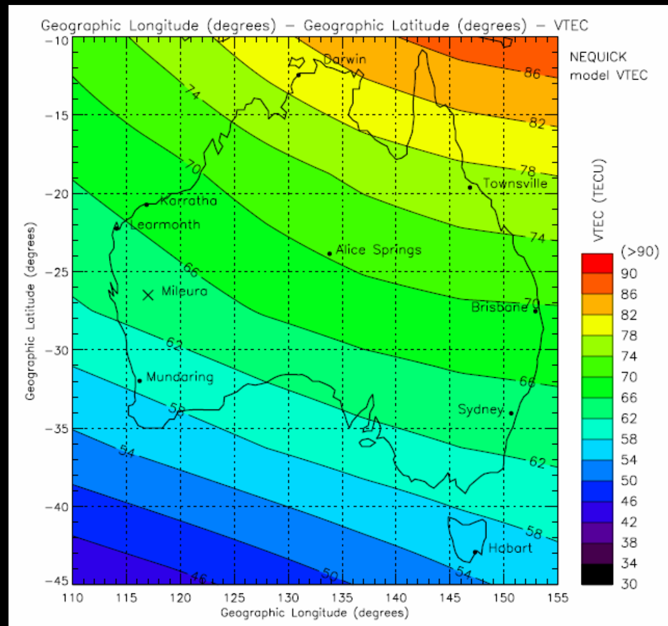
GNSS and scintillation related activities

- GNSS Augmentation Systems for aviation,
  - e.g., Ground-based Regional Augmentation System (GRAS)
  - characterising Australian ionospheric conditions
  - TEC, TEC gradients, ionospheric storms
  - ionospheric irregularities and scintillation



Australian Regional Ionospheric Model





Space Environment Hazards for Typical Orbits.

Space hazard	Spacecraft charging		Single-event effects			Total radiation dose		Surface degradation		Plasma interference with communications	
Specific cause	Surface	Internal	Cosmic rays	Trapped radiation	Solar particle	Trapped radiation	Solar particle	Ion sputtering	O^+ erosion	Scintillation	Wave refraction
LEO <60°	Not applicable	Not applicable	Relevant	Important	Not applicable	Important	Relevant	Relevant	Important	Important	Important
LEO >60°	Relevant	Not applicable	Important	Important	Important	Important	Relevant	Relevant	Important	Important	Important
MEO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
GPS	Important	Important	Important	Not applicable	Important	Important	Important	Relevant	Not applicable	Important	Important
GTO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
GEO	Important	Important	Important	Not applicable	Important	Important	Important	Relevant	Not applicable	Important	Important
HEO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
Inter-planetary	Not applicable	Not applicable	Important	Not applicable	Important	Not applicable	Important	Relevant	Not applicable	Relevant	Relevant

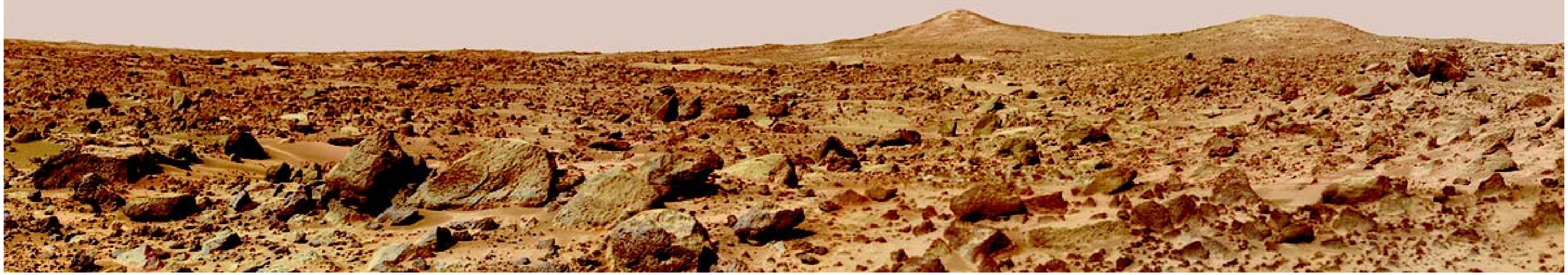
Important — Relevant — Not applicable

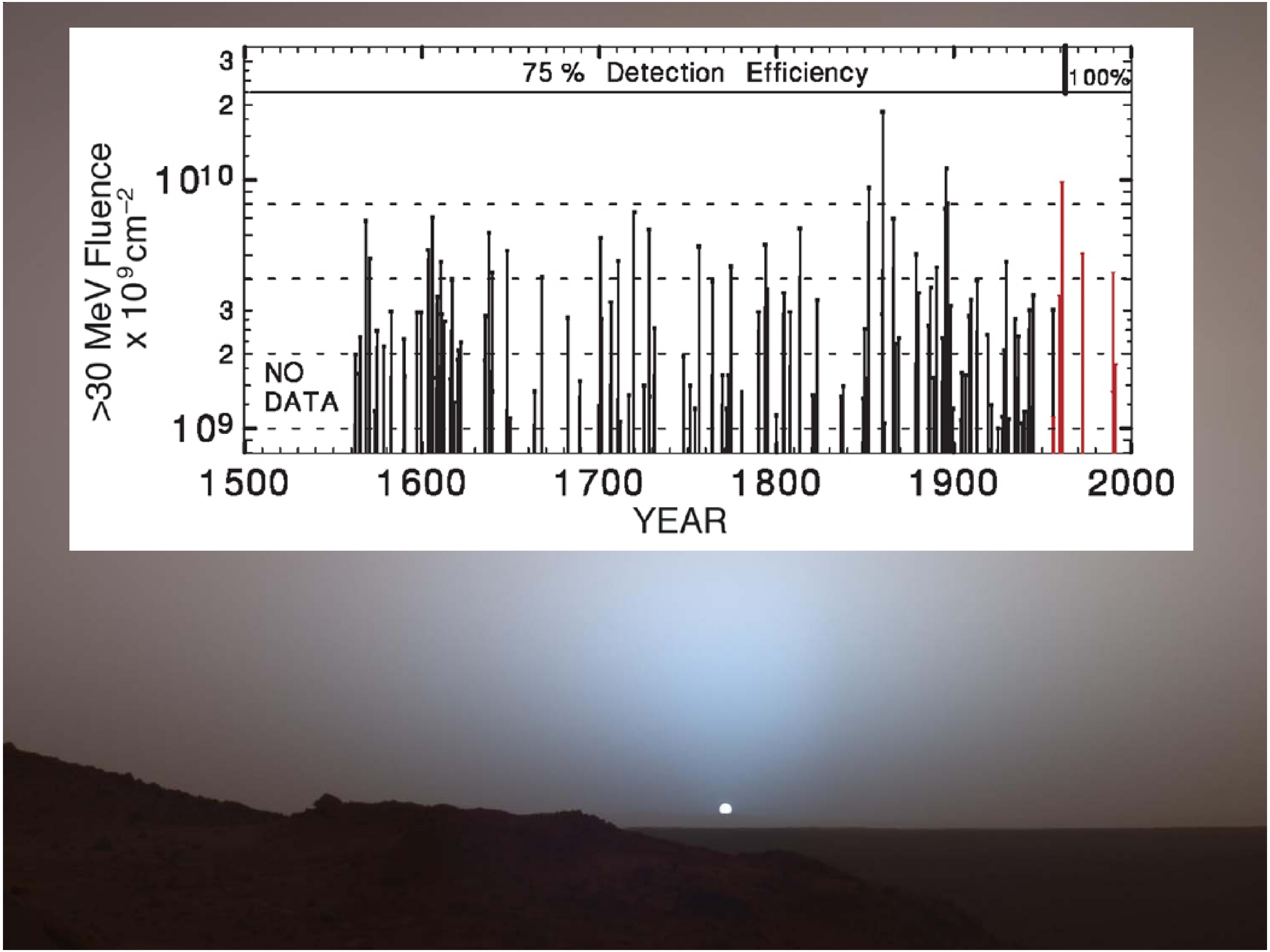
Space environment hazards for typical orbits. Key: LEO <60°—low Earth orbit, less than 60 degrees inclination; LEO >60°—low Earth orbit, more than 60 degrees inclination; MEO—medium Earth orbit; GPS—Global Positioning System satellite orbit; GTO—geosynchronous transfer orbit; GEO—geosynchronous orbit; HEO—highly elliptical orbit; O^+—atomic oxygen.

Crosslink, Summer 2003

Exploring the “real” Mars

Dust,
atmospheric chemistry (CH_4?),
sulfates instead of carbonates?,
toxic molecules and elements,
weather,
subsurface resources?,
electrostatics?,
habitable zones,
planetary protection,
rocks as resources…
RADIATION!

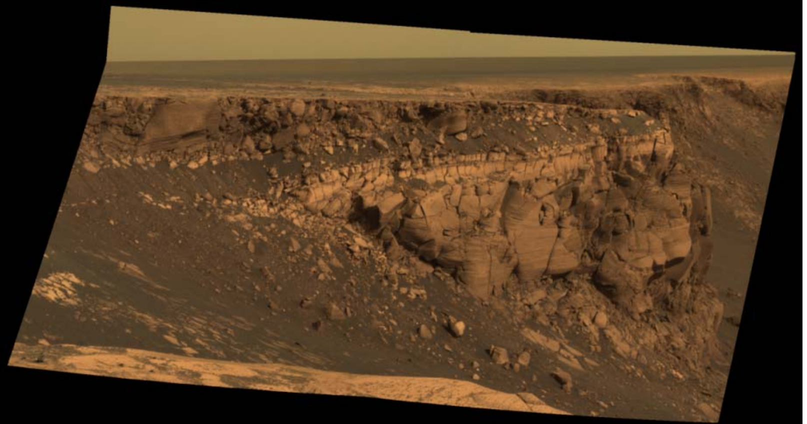




75 % Detection Efficiency
100%
>30 MeV Fluence x 10⁹cm⁻²
NO DATA
YEAR
1500
1600
1700
1800
1900
2000

Particle Summary

- Solar Particle Events
  - require space weather forecasting improvements
  - necessitate a safe area within the spacecraft
  - dictate the minimum spacecraft weight
  - define the minimum shielding
  - solar minimum safest



- Galactic Cosmic Rays
  - provide an accumulative dose
  - critically affect the type of shielding used
  - dictate the maximum duration mission
  - solar maximum safest
- Better forecasting is essential for reducing risks

Next generation forecasting models

- Climatological Models for Planning
  - what to expect, where and when
- Update Methods in Near-Real-Time
  - Is it like we expected and can we use this informaiton constructively
  - Can we detect extreme events and take remedial action?
    - DIAS, IPS, and many more
    - Modern HF Systems Employing Adaptive Diversity Schemes: (e.g., ALE and HFDL)
    - GPS: WAAS
    - Scintillation: SCINDA
- Advanced Modelling
  - Can this be done on an even smarter and more responsive environment
    - GAIM
    - and more

Summary

- IPS was set up in 1948 to supply HF advice to Australia
  - primarily monthly HF predictions
    (*IPS website, and ASAPS now do this on demand*)
- By IGY HF advice included storm warnings
  - delivered by telephone to select customers - 7 days a week
  - and new geomagnetic warnings commenced
- Hardware and knowledge developed through to the 1980s
  - increasing and improving all services
  - and telex (later facsimile) increased the customer base & access
- In the 1990s the Web and PCs have had an amazing impact
  - expanding the breadth of customers
  - expanding the range of data available
  - and expanding diversifying all services
  - the well-known information explosion
- The future has both vast potential and low clarity
  - (as always).