SPAWAR
Systems Center
San Diego

EM Propagation Modeling and System Performance Assessment

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http://sunspot.spawar.navy.mil

AREPS History

Over water only, single mode propagation for ducting conditions, 100 MHz – 20 GHz.

Integrated Refractive Effects Prediction System **(IREPS)** (1972-1989)

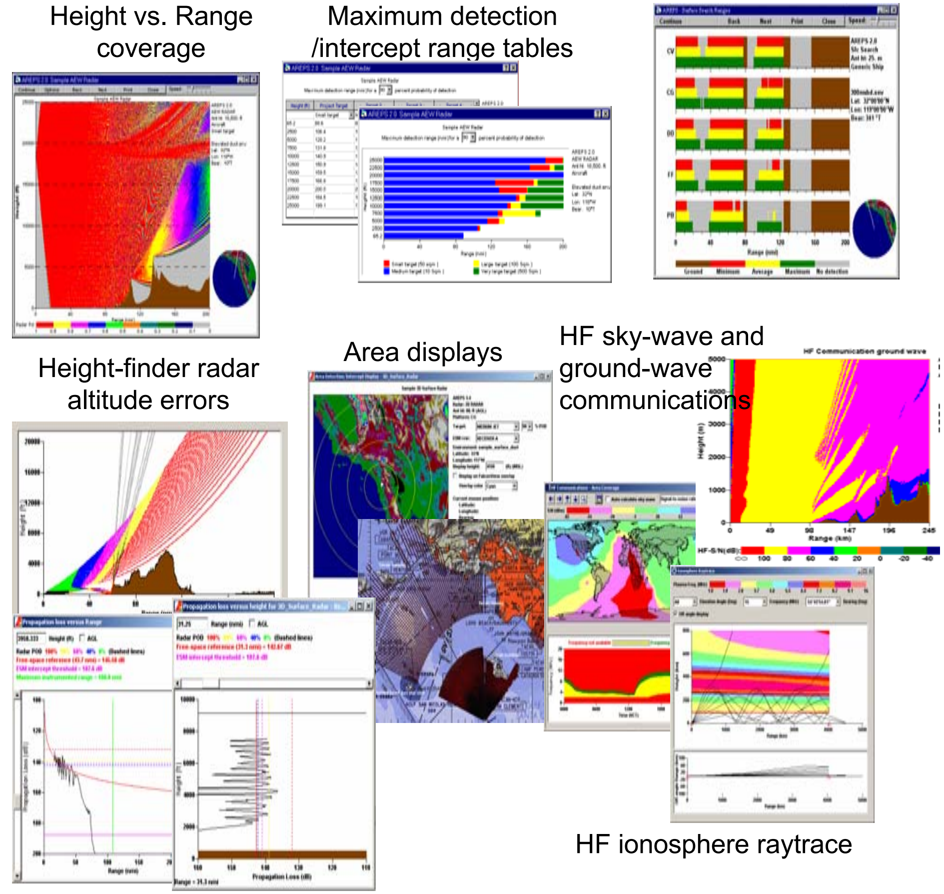
Engineer's Refractive Effects Prediction System **(EREPS)** (1988-present)

Advanced Refractive Effects Prediction System **(AREPS)** (1998-present)

Height vs. Range coverage

Maximum detection /intercept range tables

Surface-search radars



Height-finder radar altitude errors

Area displays

HF sky-wave and ground-wave communications

HF ionosphere raytrace

Constant height and range displays

EM Propagation Models

SSC SD

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Physical Environment

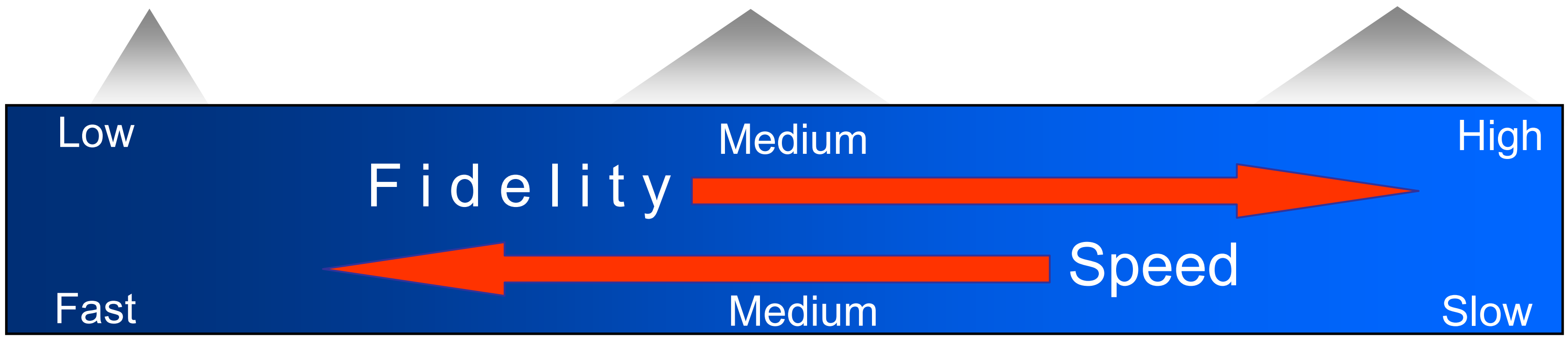
Climatological
Linear gradient
Range-independent refractivity

Range-independent refractivity
Ray trace
Gaseous absorption
Electron density

Linear gradient
Varying terrain

Linearly segmented profiles
Rough ocean surface
Parameterized ducts

Range-dependent refractivity
PE / ray optics
Gaseous absorption
Linearly segmented profiles
Varying terrain
Varying surface conductivity
Rough ocean surface



Models

4/3 earth

MINIMUF-85 / QLOF*

HF Skywave* (LtlFld, Mod. Damboldt)

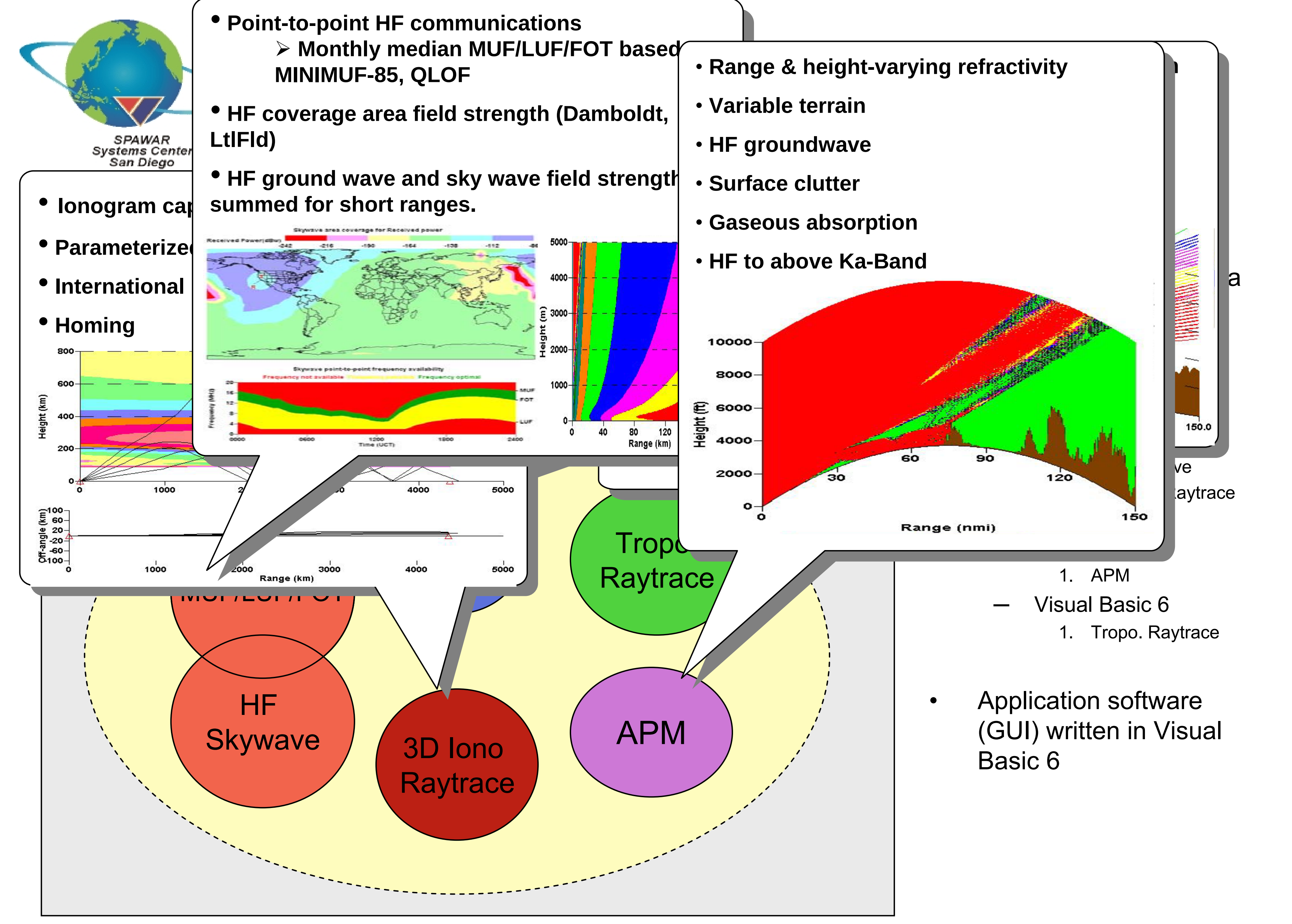
FFACTR

Tropospheric Raytrace

3D Ionospheric Raytrace*

APM

* POC: Richard Sprague (richard.sprague@navy.mil)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• Point-to-point HF communications
➢ Monthly median MUF/LUF/FOT based
MINIMUF-85, QLOF
• HF coverage area field strength (Damboldt, LtlFld)
• HF ground wave and sky wave field strength summed for short ranges.
Skywave area coverage for Received power
Skywave point-to-point frequency availability
Time (UCT)
Height (m)
Range (km)
• Range & height-varying refractivity
• Variable terrain
• HF groundwave
• Surface clutter
• Gaseous absorption
• HF to above Ka-Band
Height (ft)
Range (nmi)
• Ionogram cap
• Parameterize
• International
• Homing
Height (km)
Off-angle (km)
Range (km)
Tropo Raytrace
HF Skywave
3D Iono Raytrace
APM
1. APM
– Visual Basic 6
1. Tropo. Raytrace
• Application software (GUI) written in Visual Basic 6

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APM Capabilities Within AREPS

Propagation Effect / Mechanism	Due to Environment			APM (Ver. 2.3)
	Sea	Terrain	Atmos.	
Range-dependent refractive conditions			●	✓
Variable terrain		●		✓
Multi-path	●	●	●	✓
Diffraction	●	●		✓
Terrain Masking		●		✓
Troposcatter			●	✓
Rough (sea) surface	●			✓
Surface wave (HF)	●	●		✓
Finite conductivity (range-varying dielectric constants)	●	●		✓
Obstacle Gain		●		✓
Surface Clutter	●	●		✓
Gaseous absorption*			●	Ver. 2.4
Vegetation effects		●		X
Rain attenuation*			●	Ver. 2.4

SURFACE WAVE

We have extended APM to frequencies below 50 MHz (HF) by including a surface wave prediction capability for propagation over water and/or terrain:

- For predictions over a rough ocean surface, we have implemented a modified version of the standard rough-ocean surface impedance model (Barrick) .

- For propagation prediction over terrain, we have included the mixed-transform model used in parabolic equation methods.

- These frequencies generally require large antennas and we have included a 'typical' HF antenna (1/4-wave ' monopole).

APM Surface Clutter Model

Surface clutter-to-noise (CNR) ratio in dB defined as:

$$CNR = 10 \log_{10} \left(\frac{P_C}{P_N} \right)$$

where

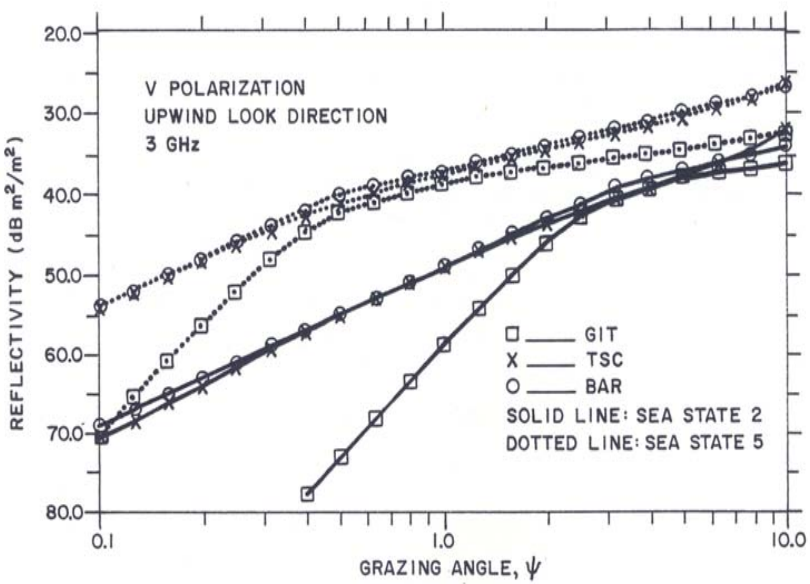
$$P_C = \frac{P_t G^2 \lambda^2 A_c \sigma^o F^4}{(4\pi)^3 R^4 L}$$

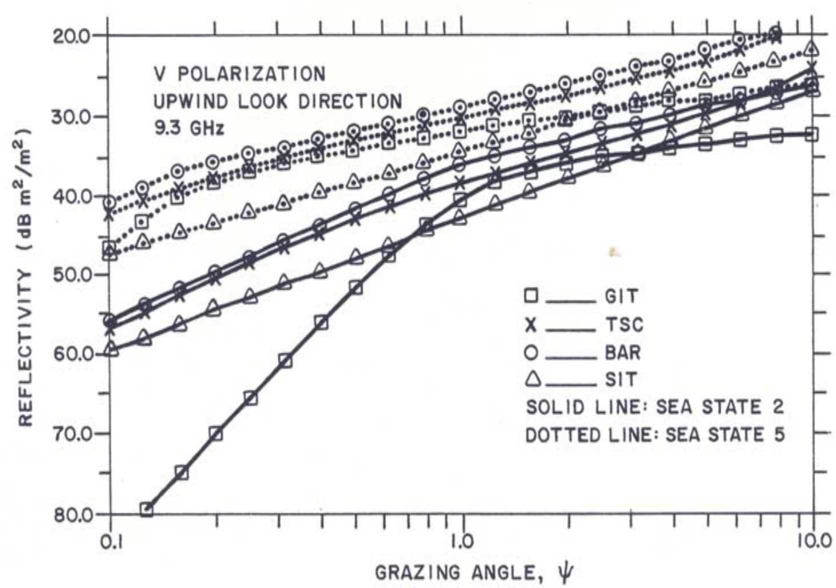
$$P_N = \frac{4 \times 10^{-15} N_f}{\tau}$$

Variable	Definition	Limits
P_t	Transmitter power	> 0 Watts
G	Antenna gain	≥ 0 dBi
λ	Wavelength	$0.015 \le \lambda \le 3$ m
R	Range	> 0 km
L	Miscellaneous system losses	≥ 0 dB
N_f	Noise figure	≥ 0 dB
τ	Pulse length	≥ 0.1 μsec
A_c	Area of clutter cell	APM
σ^o	Reflectivity	APM
F	Propagation factor	APM

Sea Surface Reflectivity

- Reflectivity based on (semi-) empirical models where the measured quantity is "σF^4" or "$\sigma° F^4$".
- No separation of atmospheric effects in collected data, so what is measured, and therefore what is modeled is an *effective* $\sigma°$*.*
- GIT model shows a steeper rate of increase in reflectivity at low grazing angles indicative of standard atmosphere conditions.





Reflectivity Models

Over water:

Sea surface reflectivity in APM is a modification to the Georgia Institute of Technology (GIT) model.

a) GIT σ° model first modified for use in FFACTR and EREPS (Engineer's Refractive Effects Prediction System) to account for evaporation ducts.

b) JHU/APL improved this technique producing a more general reflectivity model to account for any refractivity profile, whether homogeneous or inhomogeneous.

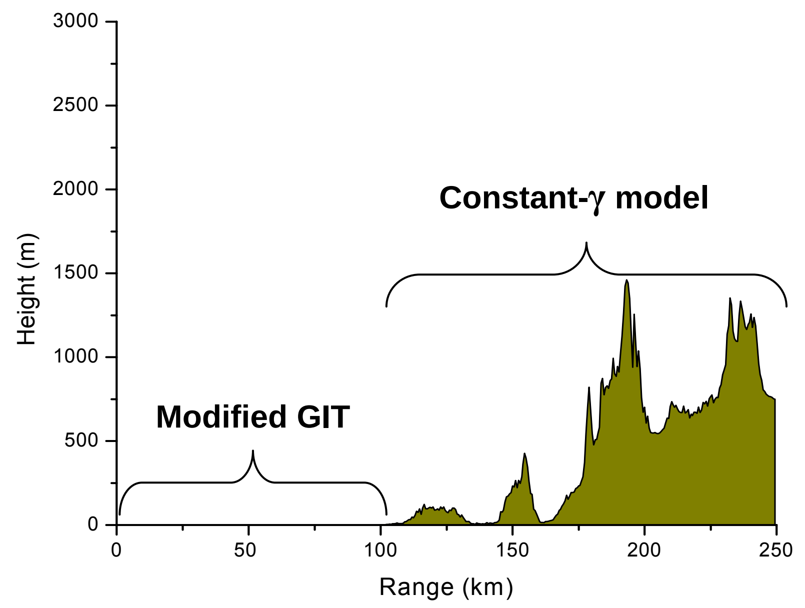
Over land:

Surface reflectivity is computed from the "constant-γ" model:

$$\sigma^{o} = \gamma \sin\psi$$

γ = backscattering effectiveness of the surface

ψ = grazing angle



Modified GIT Reflectivity

- Underlying assumption:

$$\sigma^o_{GIT} = \sigma^o \, F^4 (standard \;\; atmosphere)$$

- To account for a variable refractivity profile:

$$\sigma = \frac{\sigma^o_{GIT}}{F^4_{Std}} F^4 (refrac.\, profile) \; A_c$$

- Propagation factor, *F*, is determined from the forward-scatter solution at 1.0 m above the surface by normal execution of APM. The area of the clutter cell is computed as:

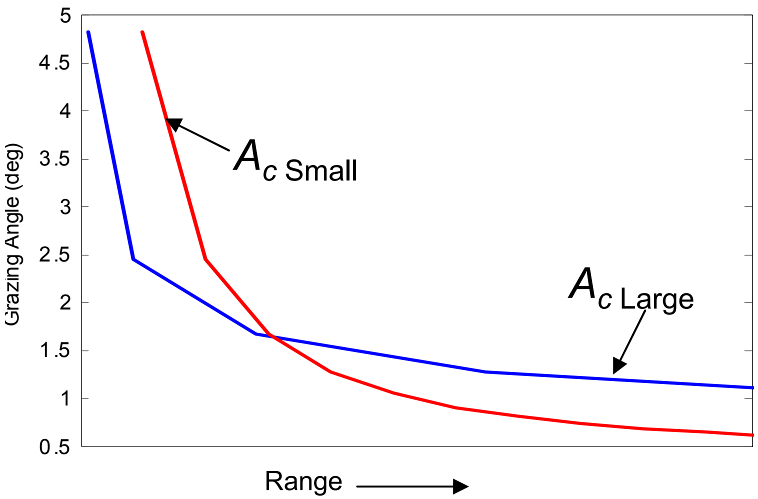
$$A_c = \frac{\theta_{hbw} c_o \tau \, R}{2\sqrt{2}}$$

Surface (Land) Clutter Cross Section
Constant-γ Reflectivity Model

Clutter cell area at a given range determined from the smaller of the two quantities:

$$A_C = \frac{\pi R^2}{\sin\psi}\tan\left(\frac{\theta_{vbw}}{2}\right)\tan\left(\frac{\theta_{hbw}}{2}\right); \quad \text{for large } \psi$$

$$A_C = \frac{R c_o \tau}{\cos\psi}\tan\left(\frac{\theta_{hbw}}{2}\right); \quad \text{for small } \psi$$



$$\sigma = (\gamma \sin\psi) A_c$$

γ is provided by the user.

Suggested values:

-10 to -15 dB for crops, bushes, trees

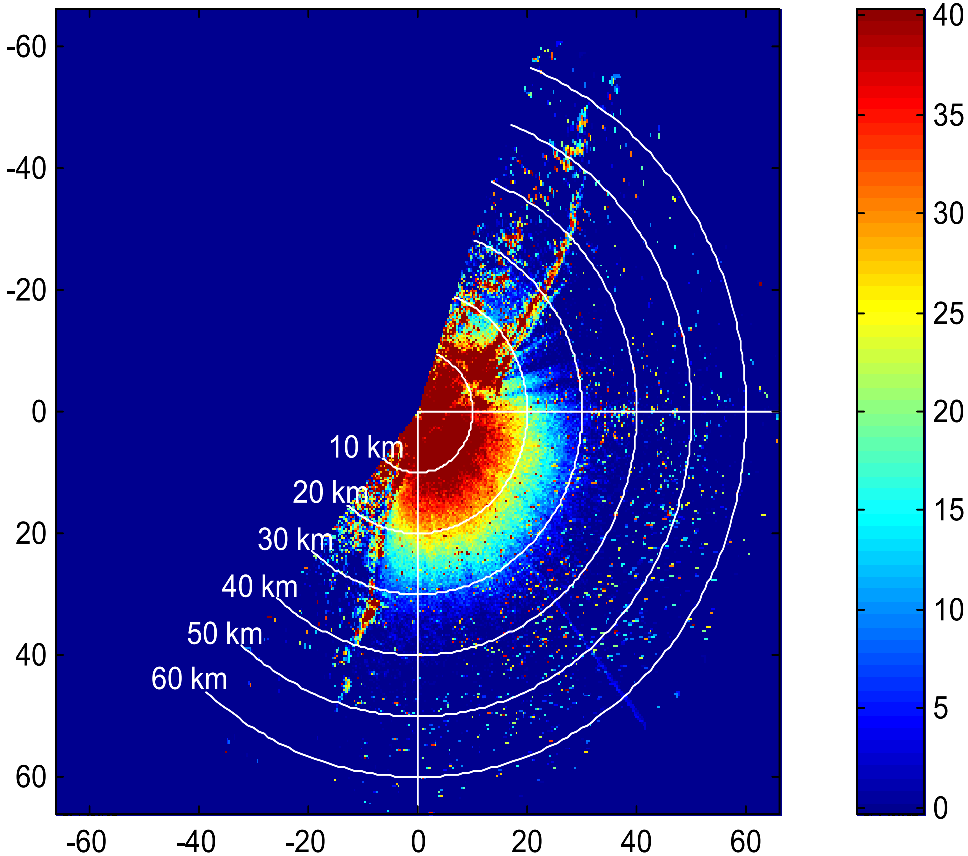
-20 dB for desert, grassland, marshy terrain

-5 dB for urban, mountain area

Sea Clutter Comparison

Ref.: Rogers, Hattan, Stapleton

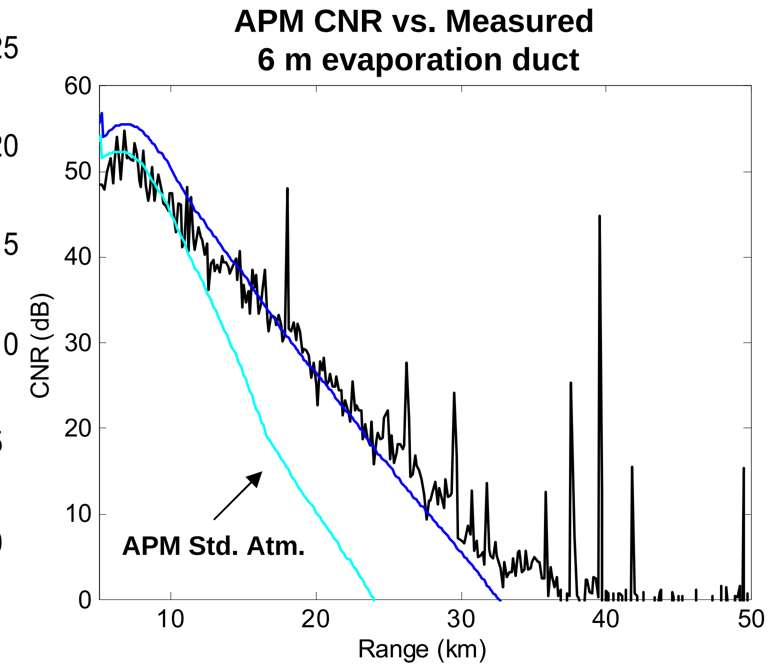
Reflectivity image: March 11, 1998 Map # 031198-02 14:52:19.3



Reflectivity data collected from the SPANDAR at Wallops Island

Bulk measurements obtained via boat and buoys at 150° radial

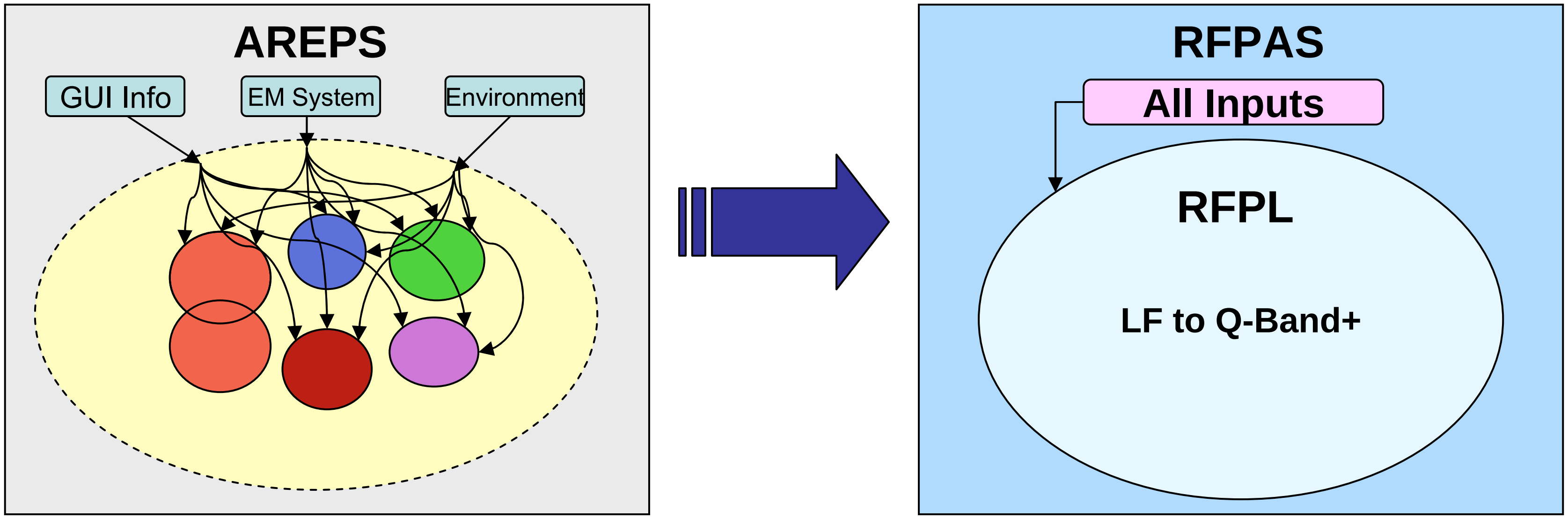
7.5 m/s wind speed



Additional Models/Capabilities
(FY07-FY08)

- **NTIA/ITS LF/MF Propagation Model**
  - 150 kHz to 1705 kHz
  - Groundwave and skywave field strength at LF/MF
  - Antenna models specific to LF/MF
- **MUF/LUF & HF Skywave models to be replaced by VOACAP**
- **Earth-to-Satellite Propagation Metoc Model (ESPM^2)**
  - SATCOM, GPS applications
  - Height and range varying refractivity
  - Valid over water only
  - Frequencies from VHF to above Q- band
- **ITU gaseous absorption and rain attenuation models**
  - ITU-R P.676-5, P.838-2, P.839-3
- Model/GUI separation using Radio Frequency Propagation Library (RFPL)
  - Propagation models will be packaged and available for release as one .dll /.lib called the RF Propagation Library (RFPL)
  - AREPS will be renamed to the RF Performance Assessment System (RFPAS)

RFPL Features



Black box to GUI designer

- Common input interface
- Intel Visual Fortran language (95%), Visual Basic .NET (5%)
- Portable across Linux platforms*
- Configuration managed by SSC SD
- No license required
- No export restrictions

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AREPS / RFPAS vs. RFPL

Input Handling (Atmosphere)

AREPS / RFPAS

Can ingest:

- COAMPS, PTH profiles, WMO, climatology database (included), and bulk measurements for determination of height/refractivity profiles

- PTH profiles, Lat/Lon, and time-of-year for determination of ITU gaseous absorption and rain attenuation rates

RFPL

Requires:

- Height / M-unit refractivity profiles with user-specified range variation

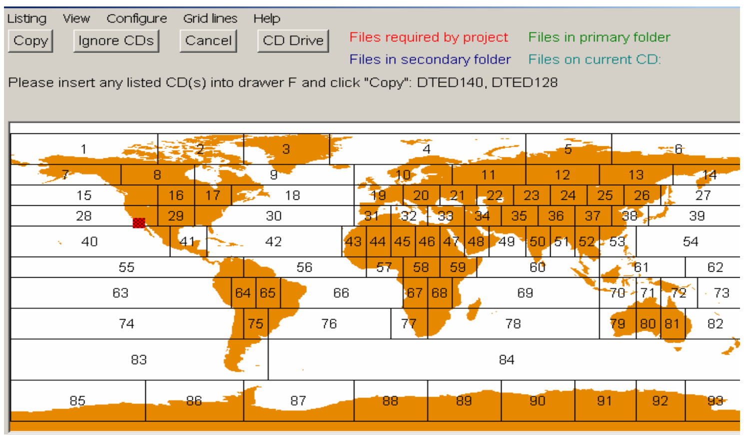
- Attenuation rates for gaseous absorption and rain losses

AREPS / RFPAS vs. RFPL

Input Handling (Terrain)

AREPS / RFPAS

- Automatically reads DTED-format files with Lat/Lon specification



- Automatic extraction of surface characteristics from ITU database with Lat/Lon specification

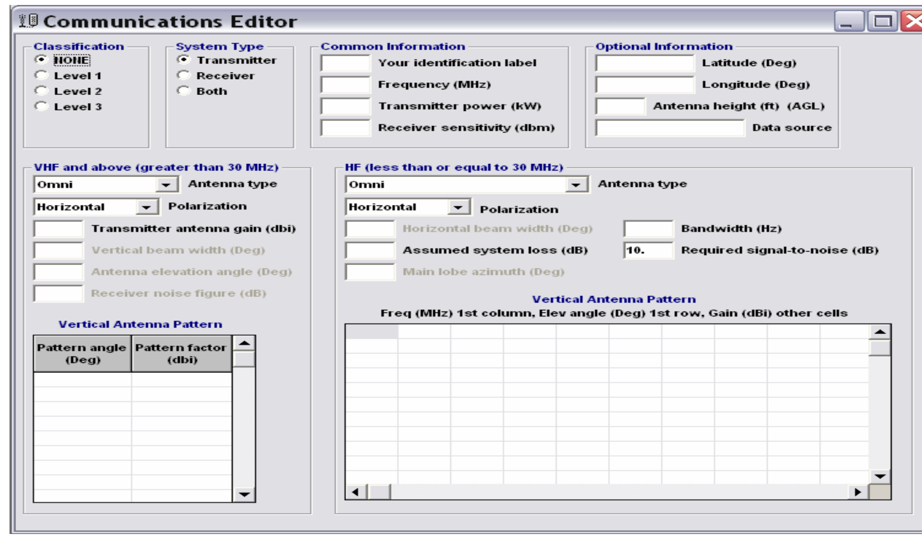
RFPL

- Terrain elevation / range profile required for each bearing
- Requires general surface type descriptor from a fixed list or specified conductivity and permittivity pairs

AREPS / RFPAS vs. RFPL
Input Handling (EM System Parameters)

AREPS / RFPAS

- EM system parameters fed from user-populated or SECRET classified (U.S. military accessible only) database
- System (radar/comm) models for computing thresholds
- Prob. of detection, PFA, LPI, S/N, etc., is post-processed manipulation of RFPL output



RFPL

- Requires minimal system inputs* due to
  - No radar models included
  - Primary product of RFPL is field strength, or propagation loss, due to the environment

*with the exception of VOACAP functionality

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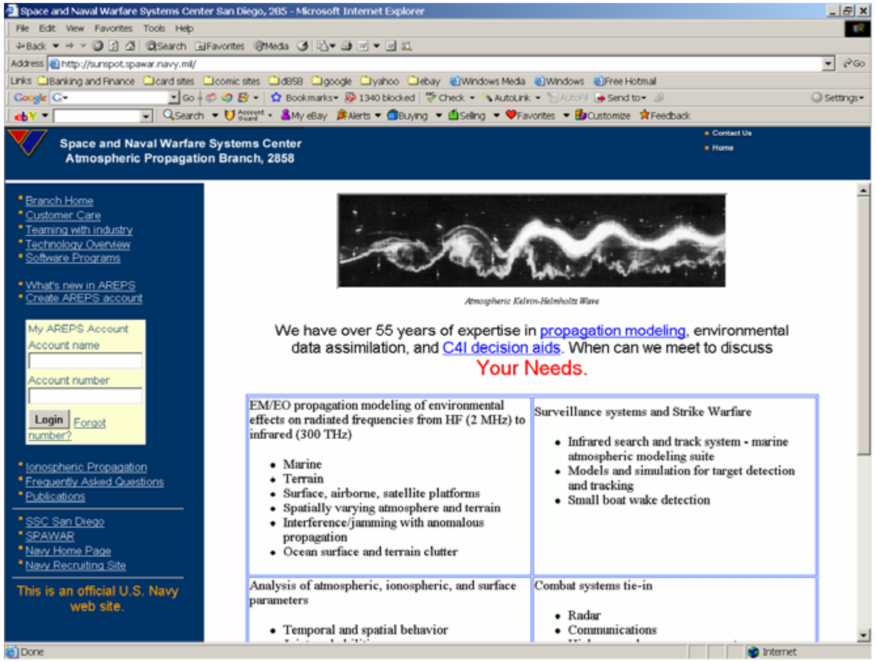
Availability



- AREPS (RFPAS) executable is (will be) available via free download from our home page:

  http://sunspot.spawar.navy.mil
- RFPL module will be available to
  - **U.S. DoD:** free with no tech support
  - **Non-U.S. DoD:** we provide various levels of funded tech support services (see "Teaming With Industry" link)

- Source code *can* be made available on a case-by-case basis, however, we will not distribute
  - NTIA/ITS LF/MF model source
  - VOACAP implementation within RFPL (visit http://www.its.bldrdoc.gov/elbert/hf.html for source code)

AREPS / RFPAS POC: Wayne Patterson (wayne.patterson@navy.mil)
APM / RFPL POC: Amalia Barrios (amalia.barrios@navy.mil)