Lower Atmospheric Radio Refractivity Estimation Using Sea-Borne Radar and Meteorological Statistics

AOS SEMINAR

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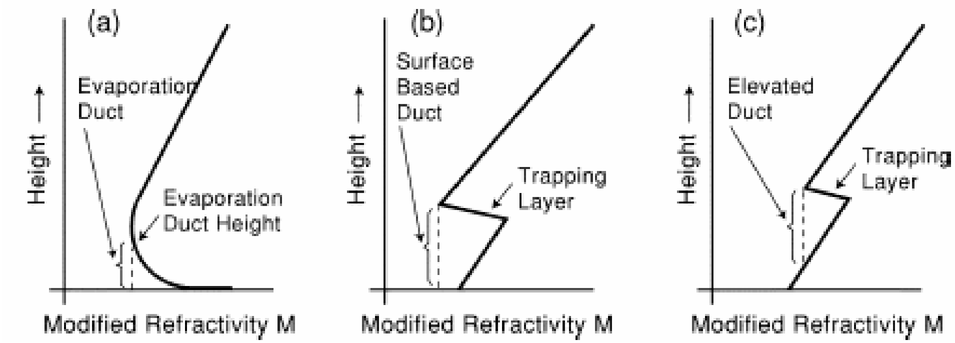
OUTLINE

- Introduction
- Refractivity From Clutter (RFC) Problem
- Factors That Affect the RFC Capability of a System
- Study Case : West Pacific
- Results
- Conclusions

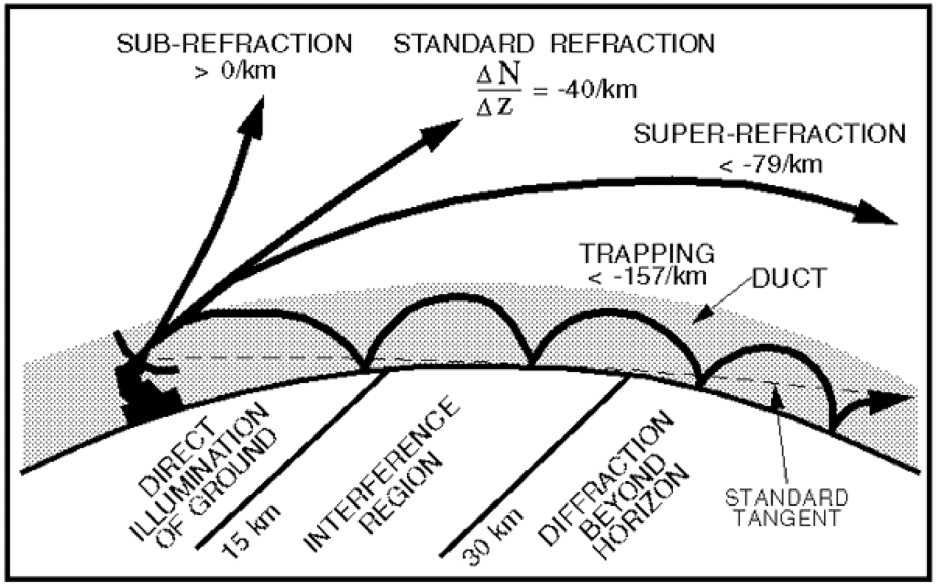
INTRODUCTION

EM Duct in Sea-borne Radar Applications



Three most common ducting profiles

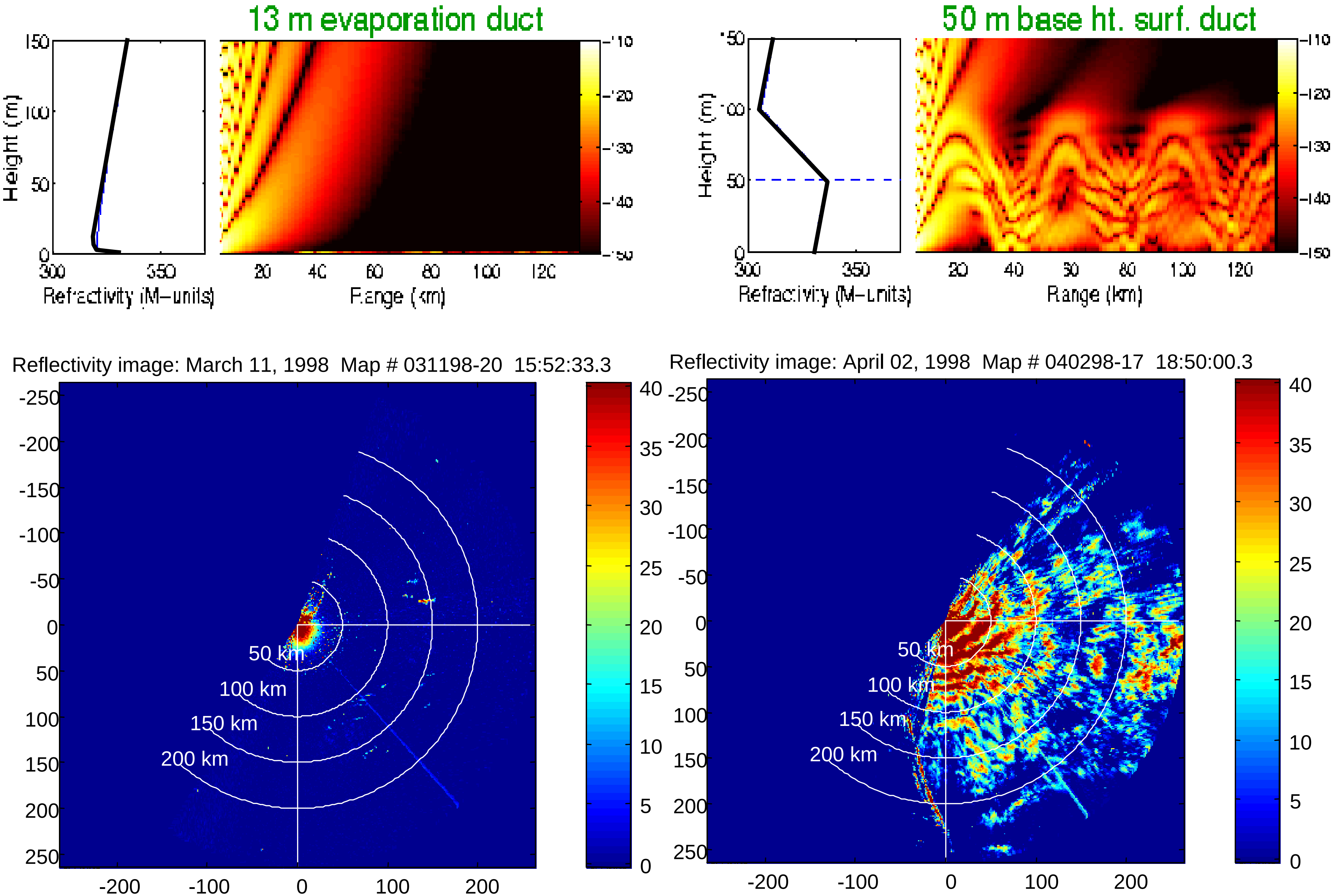
- ***n*** : the index of refraction
- ***c*** : the speed of light in vacuum
- ***v*** : the speed of light in the medium



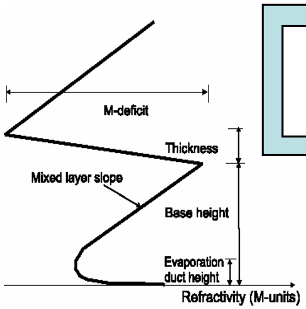
$$n = c/v$$

$$M \sim n$$

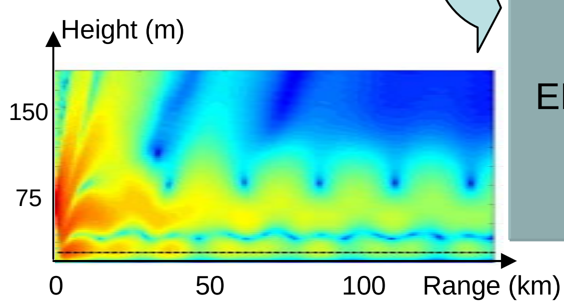
Radar PPI Screen for Evaporative and Surface-Based Ducts



RFC as an Inversion Problem



N Parameter Refractivity Model



EM Parabolic Equation

Other Parameters
- Frequency
- Transmitter Height
- Antenna Pattern
- Antenna Beamwidth
- Elevation Angle

Replica

Clutter

Square-Error Objective Function

Σ

GA/MCMC/ Hybrid Sampler

ML, MAP Estimates

PPD,

Krolik et. al.:

Using the Markovian nature of the parabolic equation steps and Kalman & particle filters.

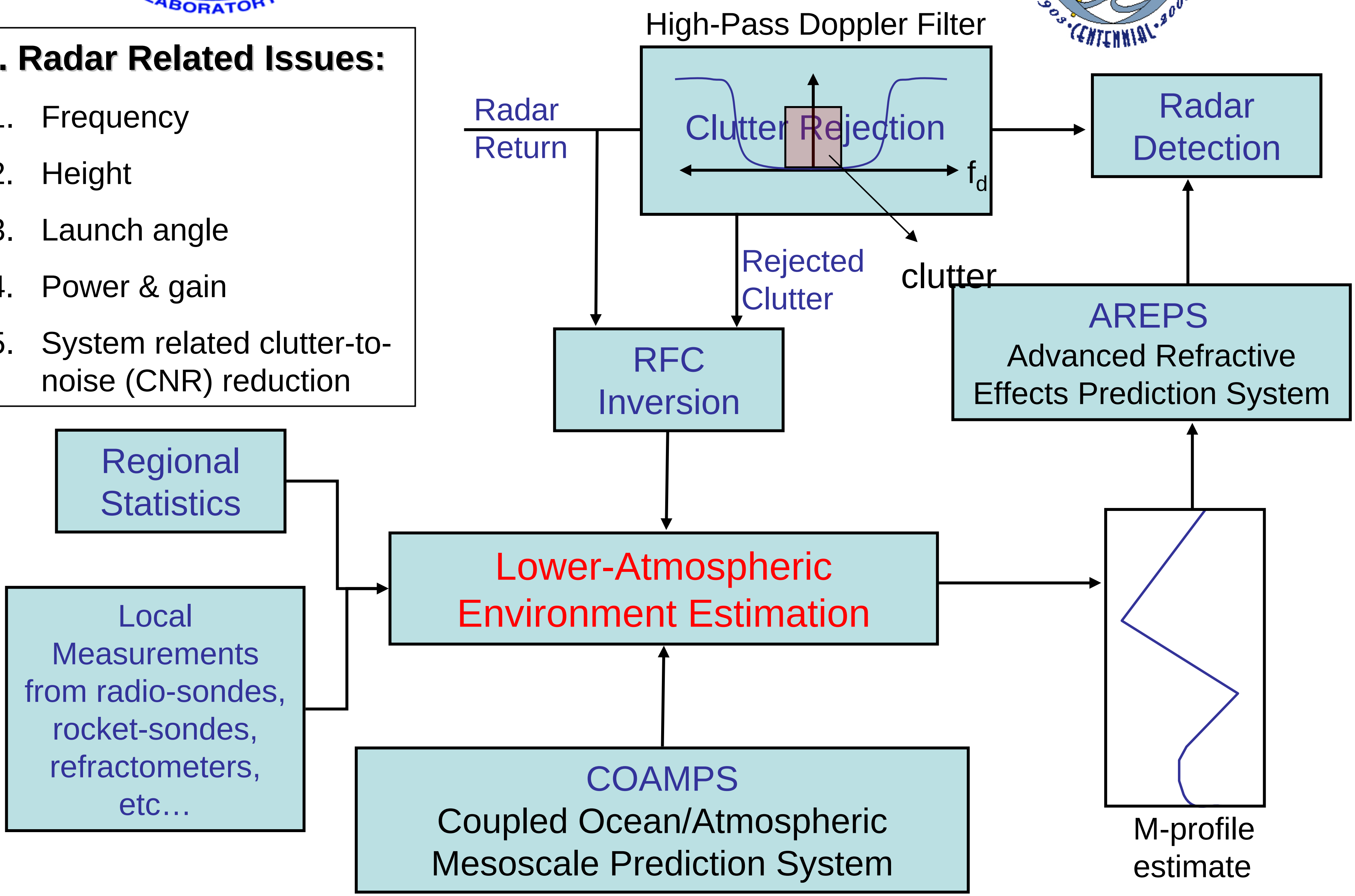
Barrios:

Ray-tracing & rank correlation.

RFC Capability Assessment

I. Radar Related Issues:

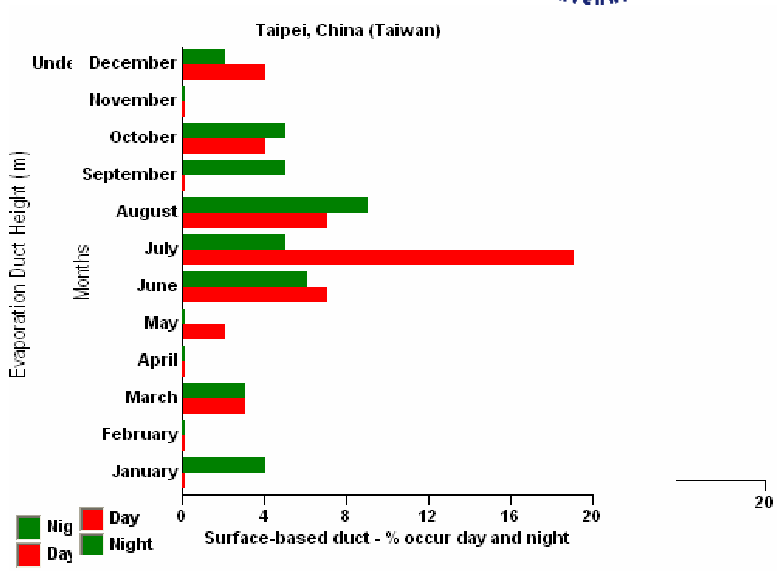
1. Frequency
2. Height
3. Launch angle
4. Power & gain
5. System related clutter-to-noise (CNR) reduction

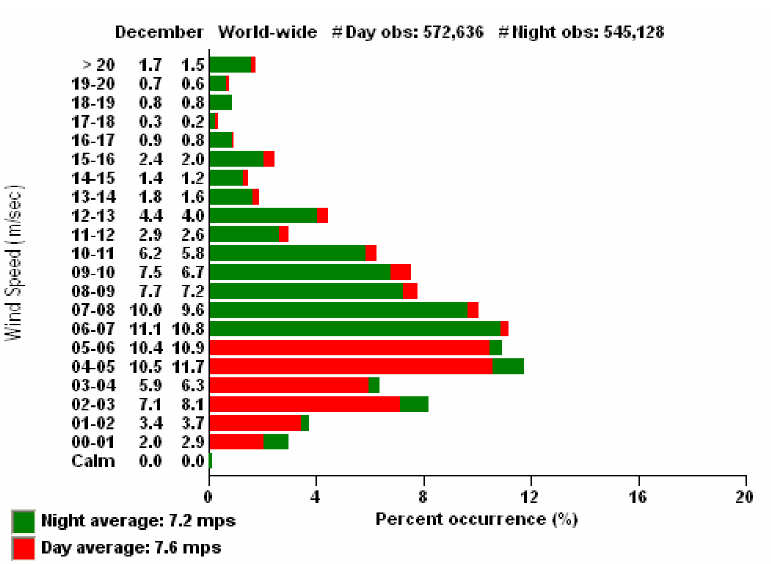


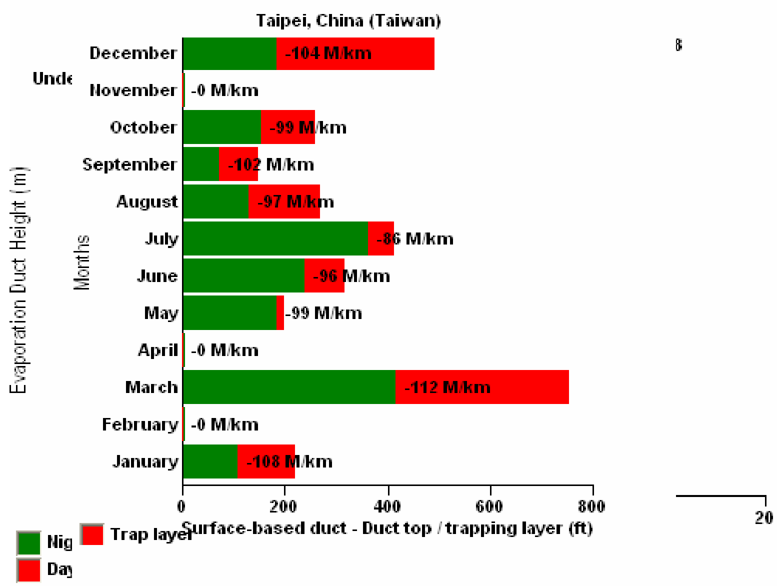
RFC Capability Assessment

II. Issues Related to the Environment:

1. Regional duct statistics
    - 1.a. Evaporation duct
    - 1.b. Surface-based duct
2. Day/night, monthly and seasonal changes
3. Surface wind speed

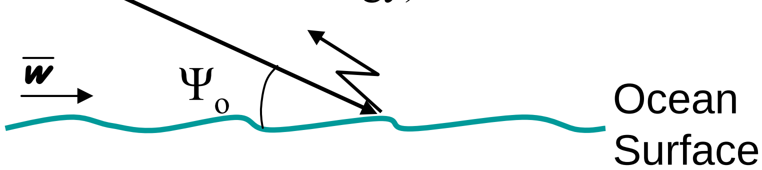




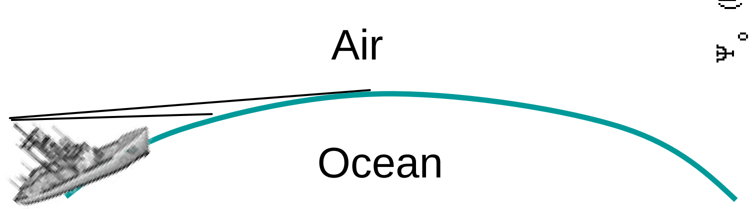


III. Grazing Angle:

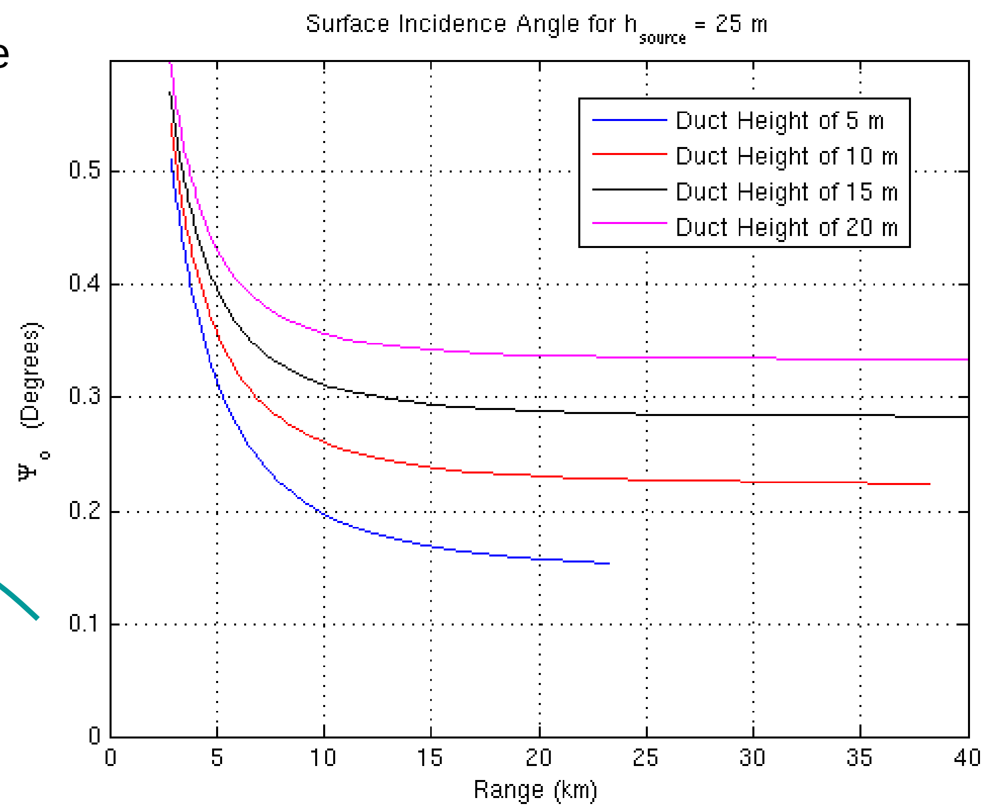
$\sigma^o(\Psi_o,\boldsymbol{w})$: Sea surface back scattering, calculated by a model such as the GIT (Georgia Institute of Technology) model.



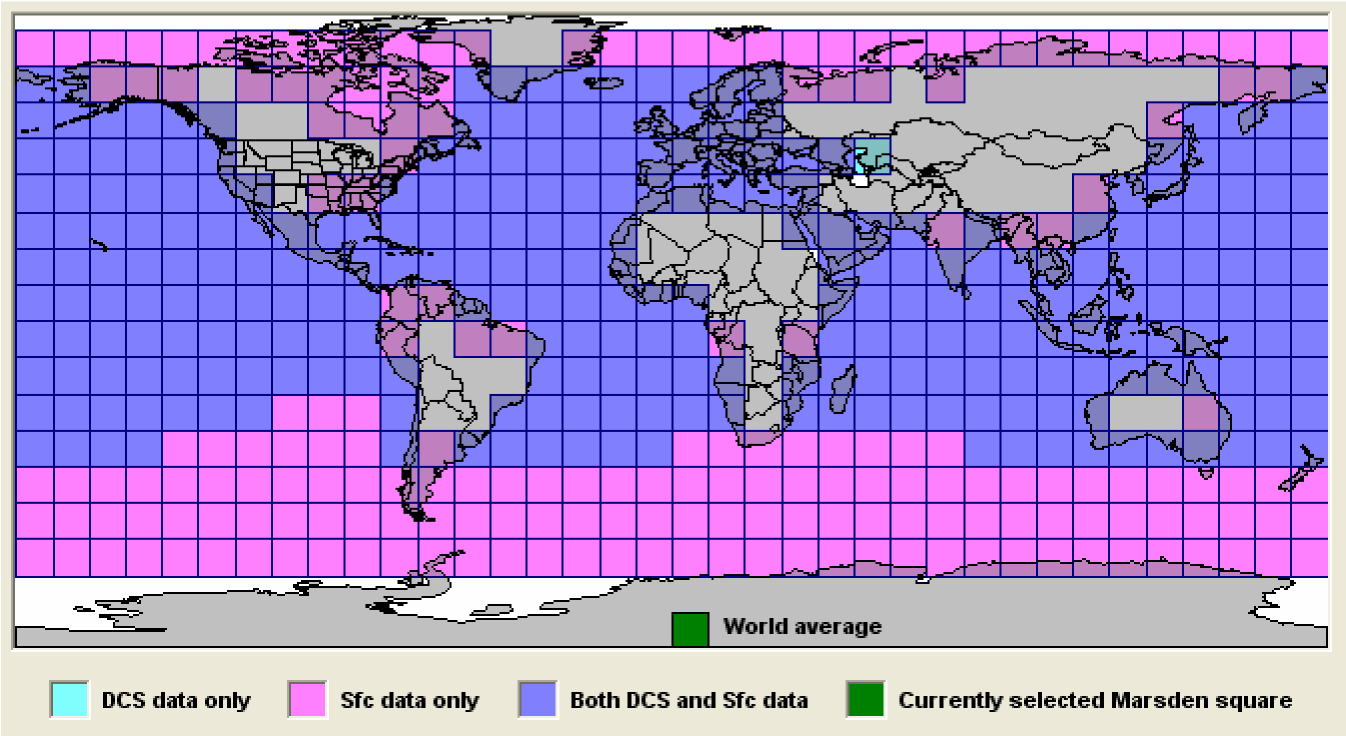
Normally Ψ_o quickly goes to zero as a function of range.



EM Ray-tracing results for various evaporation duct heights



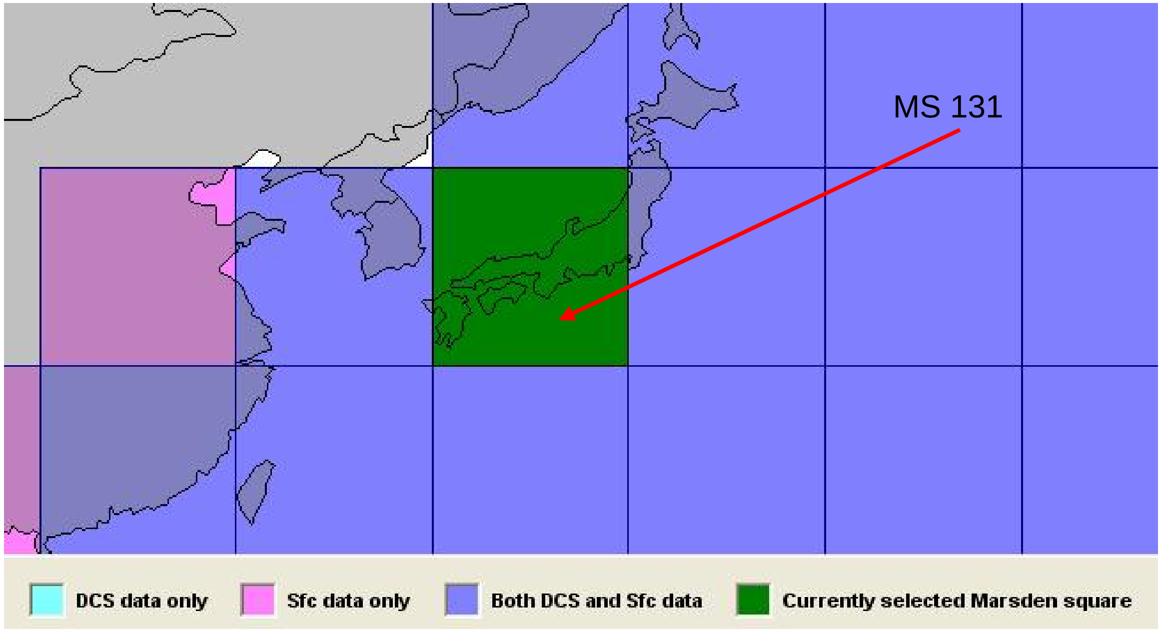
Atmospheric Statistics



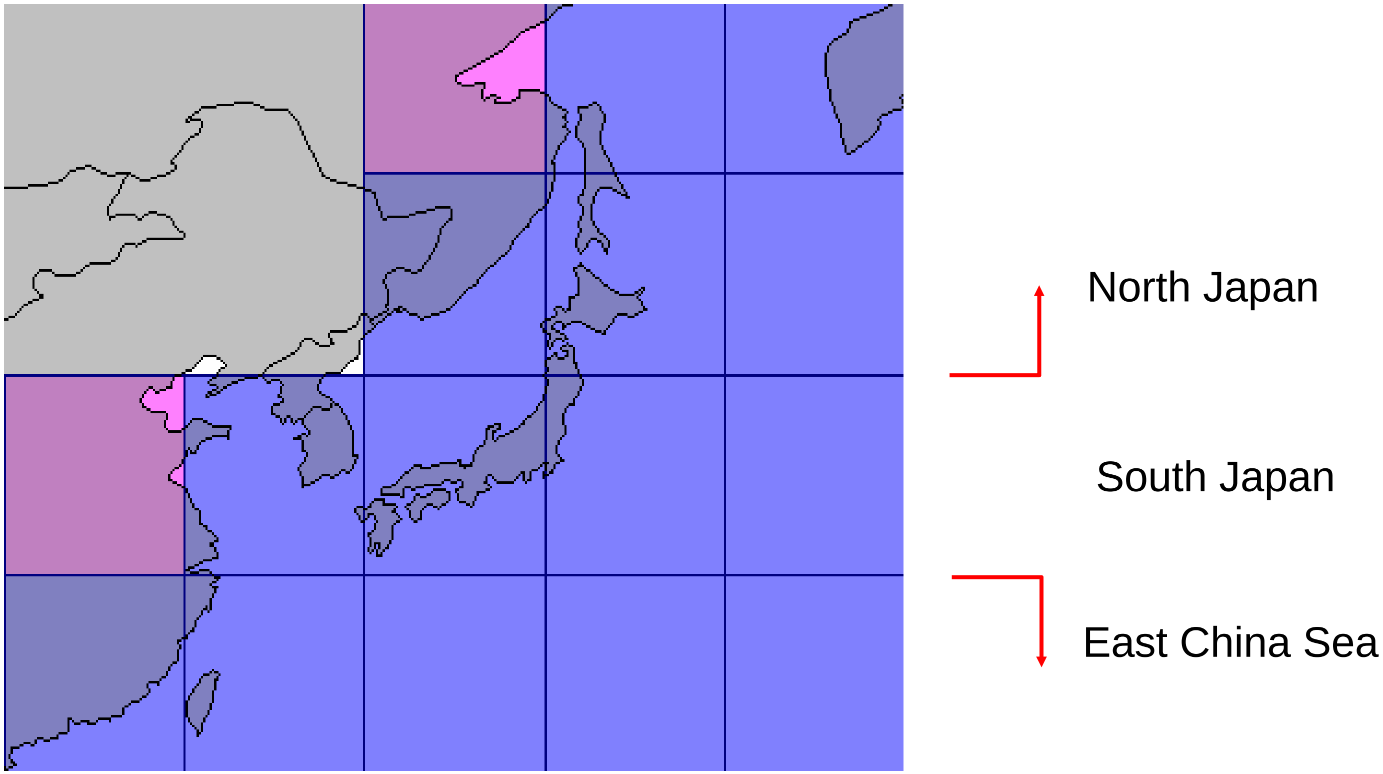
RFC Capability in West Pacific

Purpose: To determine how well RFC will perform with a given radar platform in Sea-of-Japan, Yellow Sea, East China Sea, North West Pacific Ocean, Philippine Sea, and Sea-of-Okhotsk.

Map of Japan

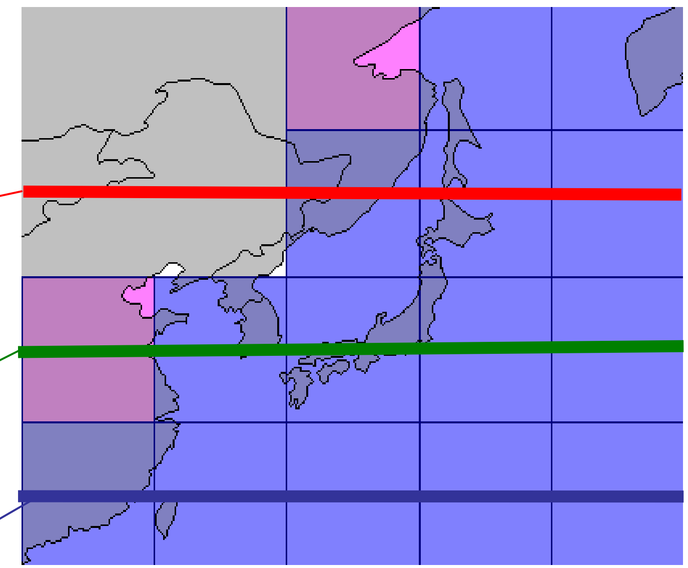


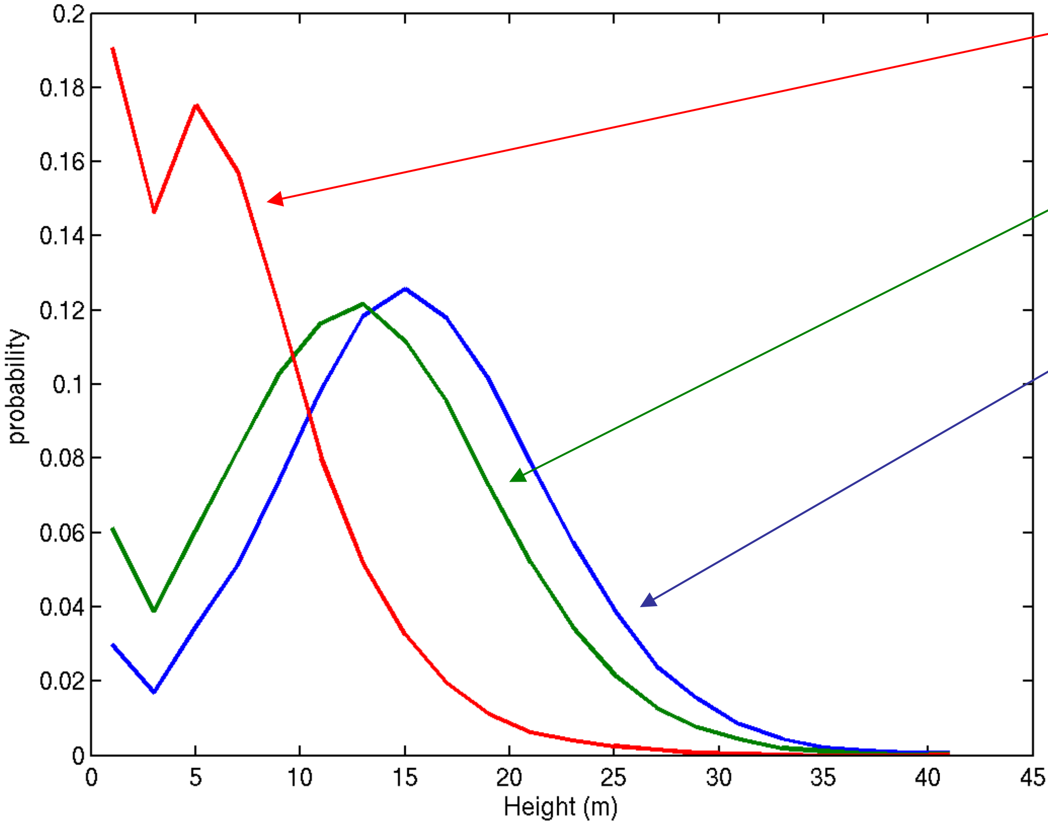
RFC Capability in West Pacific



Three regions: East China Sea, South Japan, and North Japan

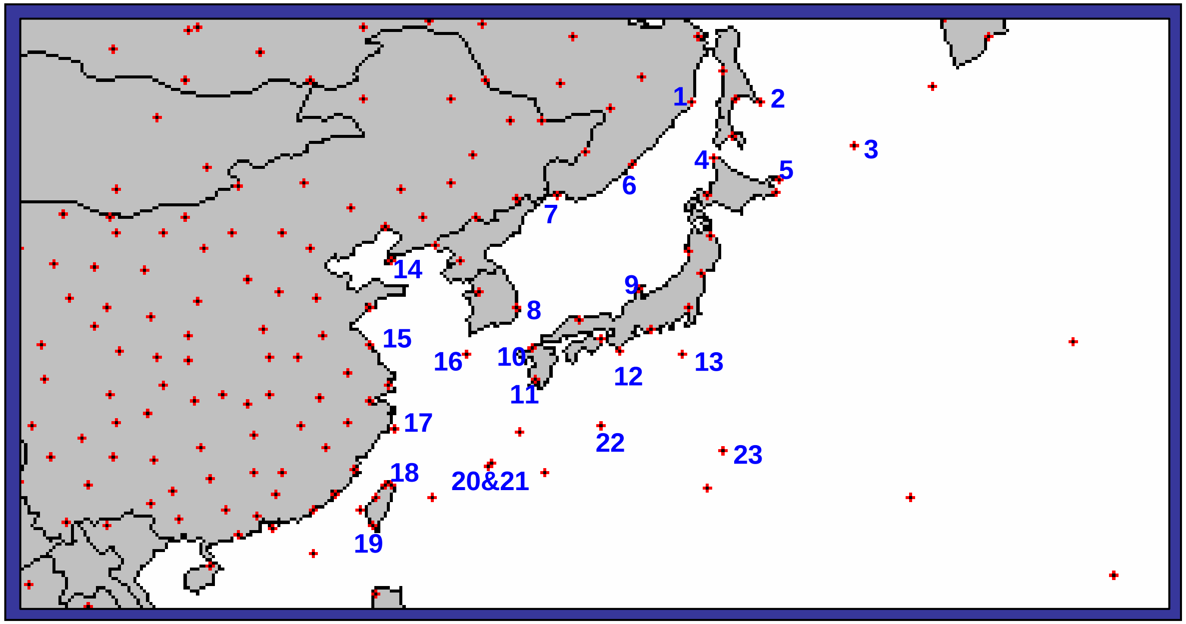
Probability for observing evaporation duct in each of the 3 regions based on annual statistics



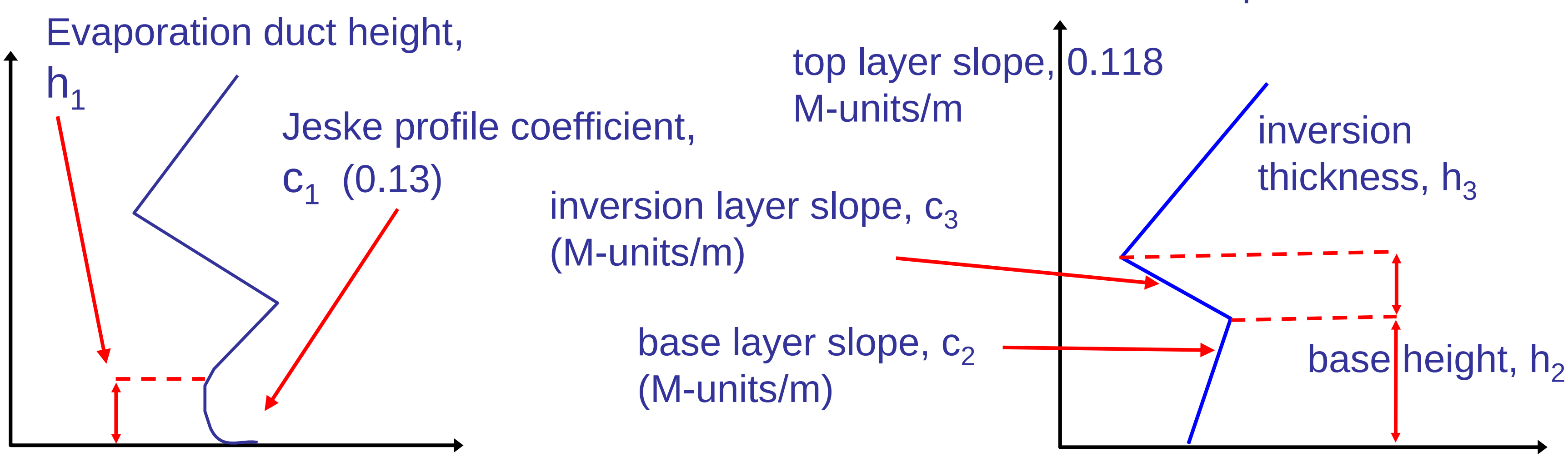


Evaporation duct height increases with latitude

RFC Capability in West Pacific



Range-independent tri-linear M-profile model



RFC Capability in West Pacific

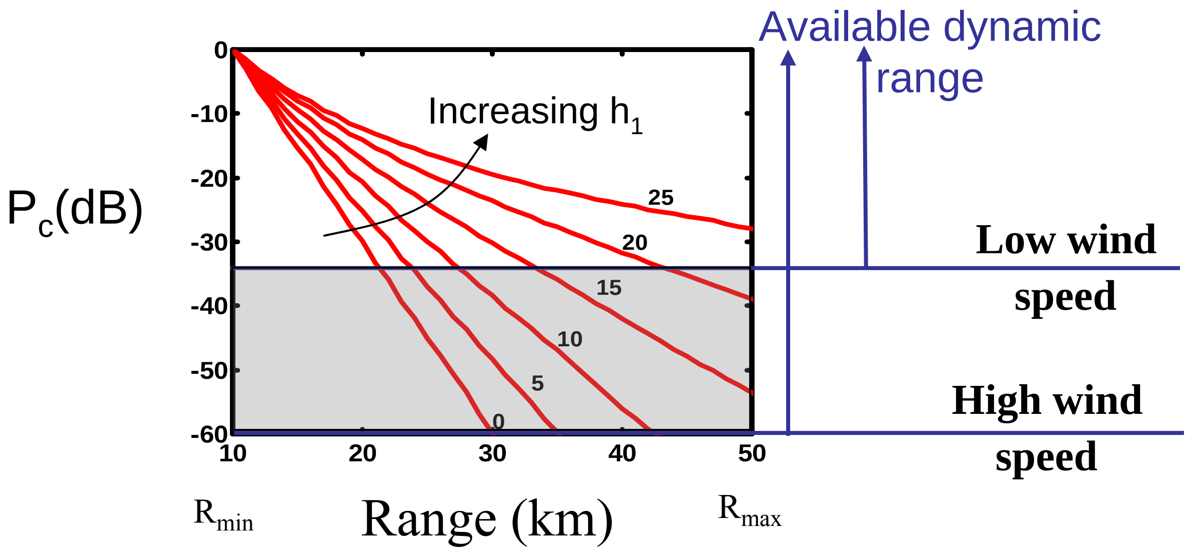
Various duct statistics

	SBD	Elevated	Multiple Elevated	SBD & Elevated
North Japan (15 stations)	5%	4%	0.7%	0.7%
South Japan (20 stations)	9%	11%	3.5%	2.4%
East China Sea (15 stations)	8.5%	18%	4%	2.3%

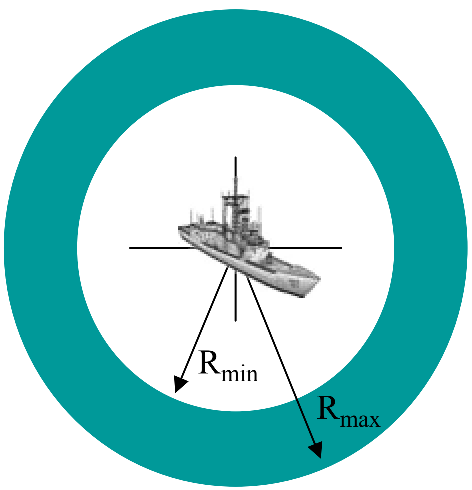
SBD Mean Values (Annual and day/night averaged)

	h_2	h_3	c_2	c_3
North Japan (15 stations)	38 m	68 m	0.112 M-units/m	-0.367 M-units/m
South Japan (20 stations)	51 m	91 m	0.104 M-units/m	-0.350 M-units/m
East China Sea (15 stations)	67 m	122 m	0.101 M-units/m	-0.364 M-units/m

Library of normalized modeled P_c vs. range (3GHz)



Sensing Annulus



- The algorithm takes advantage of averaging over both time and azimuth.
- For evaporation duct with stable conditions ($T_{sea\ surface} = T_{air}$) Jeske profile can be written as:

$$M(z) = c_1\left(z - h_1 \ln(z/z_o)\right),$$

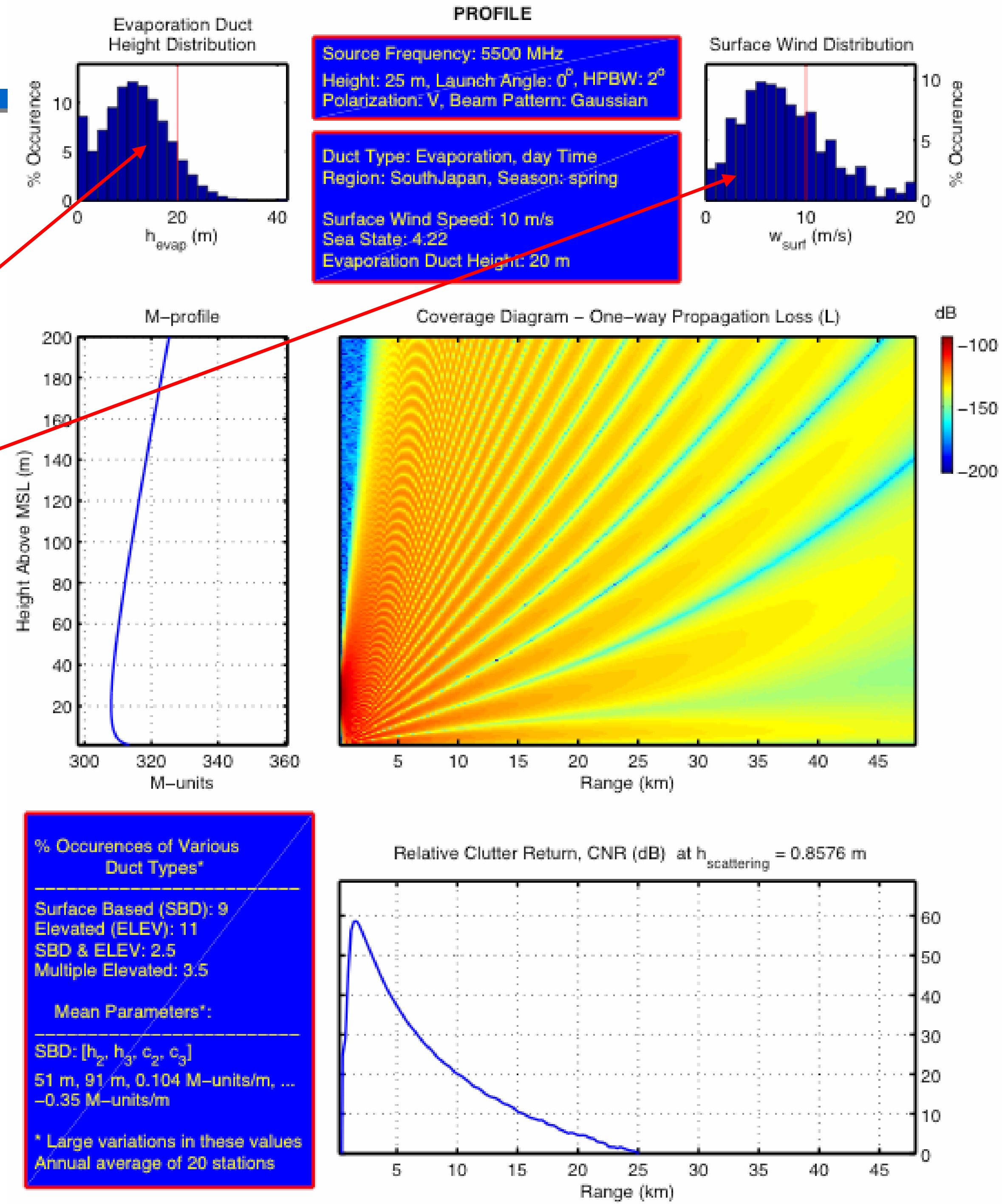
$$c_1 = 0.13, \quad z_o = 1.5\times 10^{-4}$$

Hence, there is only one parameter, duct height. The algorithm just compares the observed clutter return with a library of clutter returns obtained from evaporation ducts with varying heights.

West Pacific

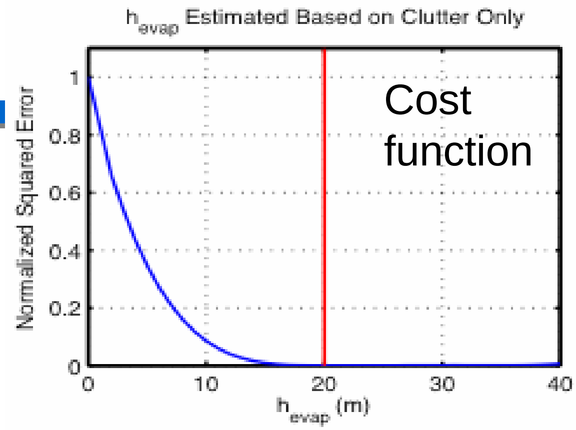
Evaporation Duct

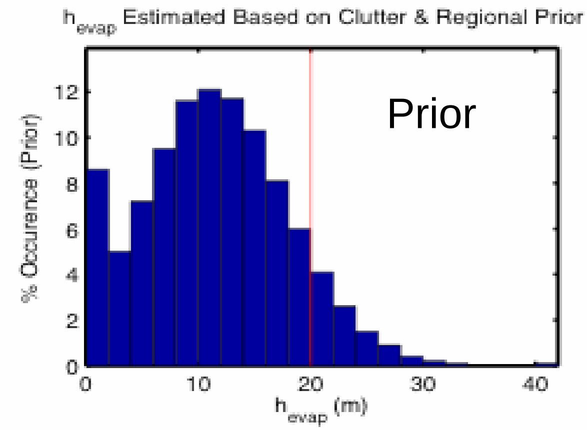
Regional statistics



Evaporation Inversion

Results for 20m duct





Source Frequency: 5500 MHz
Height: 25 m, Launch Angle: 0^o
HPBW: 2^o, Polarization: V
Beam Pattern: Gaussian

Duct Type: Evaporation

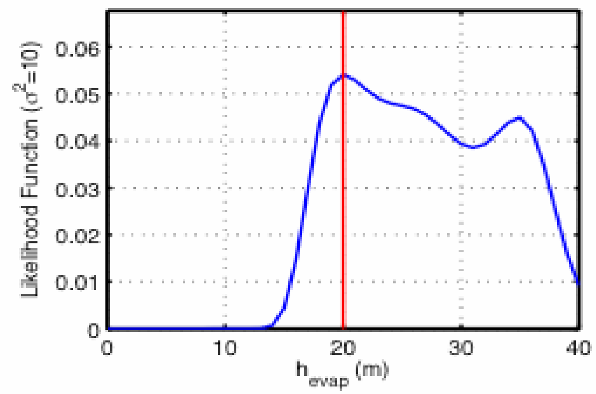
Region: SouthJapan
day Time, Season: spring

Sea State: 4.22
Evaporation Duct Height: 20 m

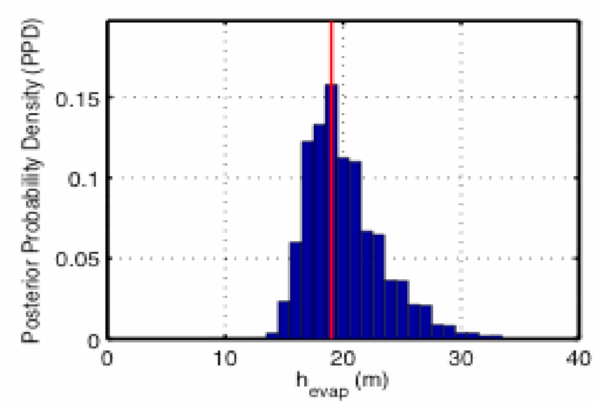
Inversion Results

Clutter Only: 20m
Clutter+Prior: 19m

Likelihood

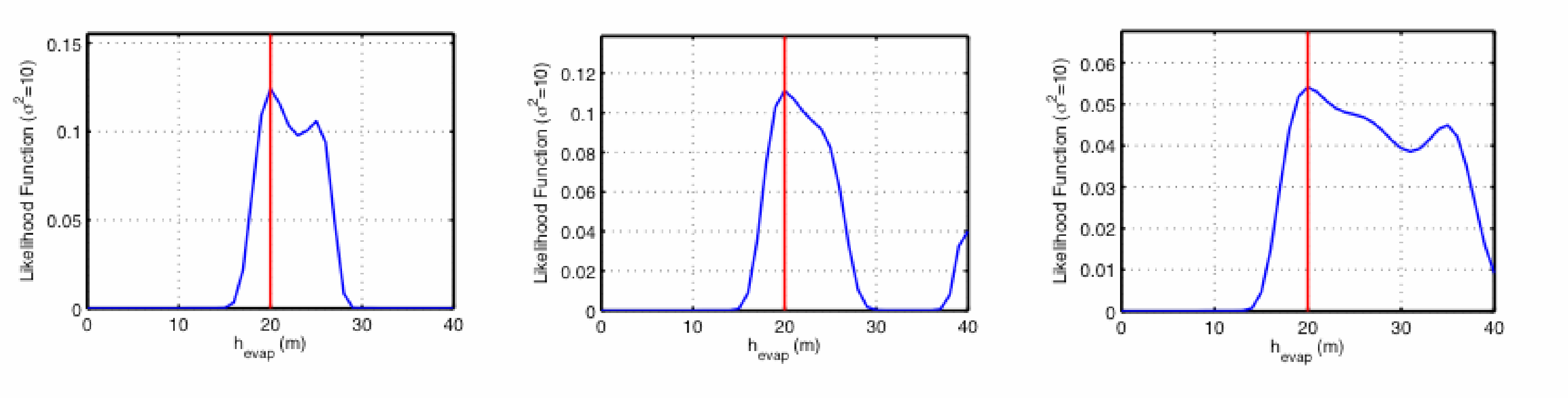


Posterior



Effect of Radar Height

16 m radar   20 m radar   25 m radar



- Almost all radar parameters are critical in RFC. Antenna height is very important in the sense that a very high antenna will not excite the duct and clutter will be low.
- Flexibility in one or more radar parameter can result in substantial improvement in RFC.

Sea clutter can be described as K-distribution. (a closed form solution of a chi-squared distribution modulated by a Rayleigh)

Chi-squre: for slowly varying part

Rayleigh: for fast (speckle) components

$$p(a) = \frac{2b}{\Gamma(\nu)} \left(\frac{ba}{2} \right)^{\nu} K_{\nu-1}(ba)$$

- Clutter fluctuations can be substantial. Time and azimuth averaging may be needed to mitigate this.
- Averaging in azimuth (median filtering) could remove disturbing interferers (other ships, rain showers).

Effects of Averaging in K-Distributed Clutter

Histogram of the best fit from likelihood function using 1000 inversions

True duct height | no averaging | 20 avg | 100 avg

1 m

5 m

10 m

15 m

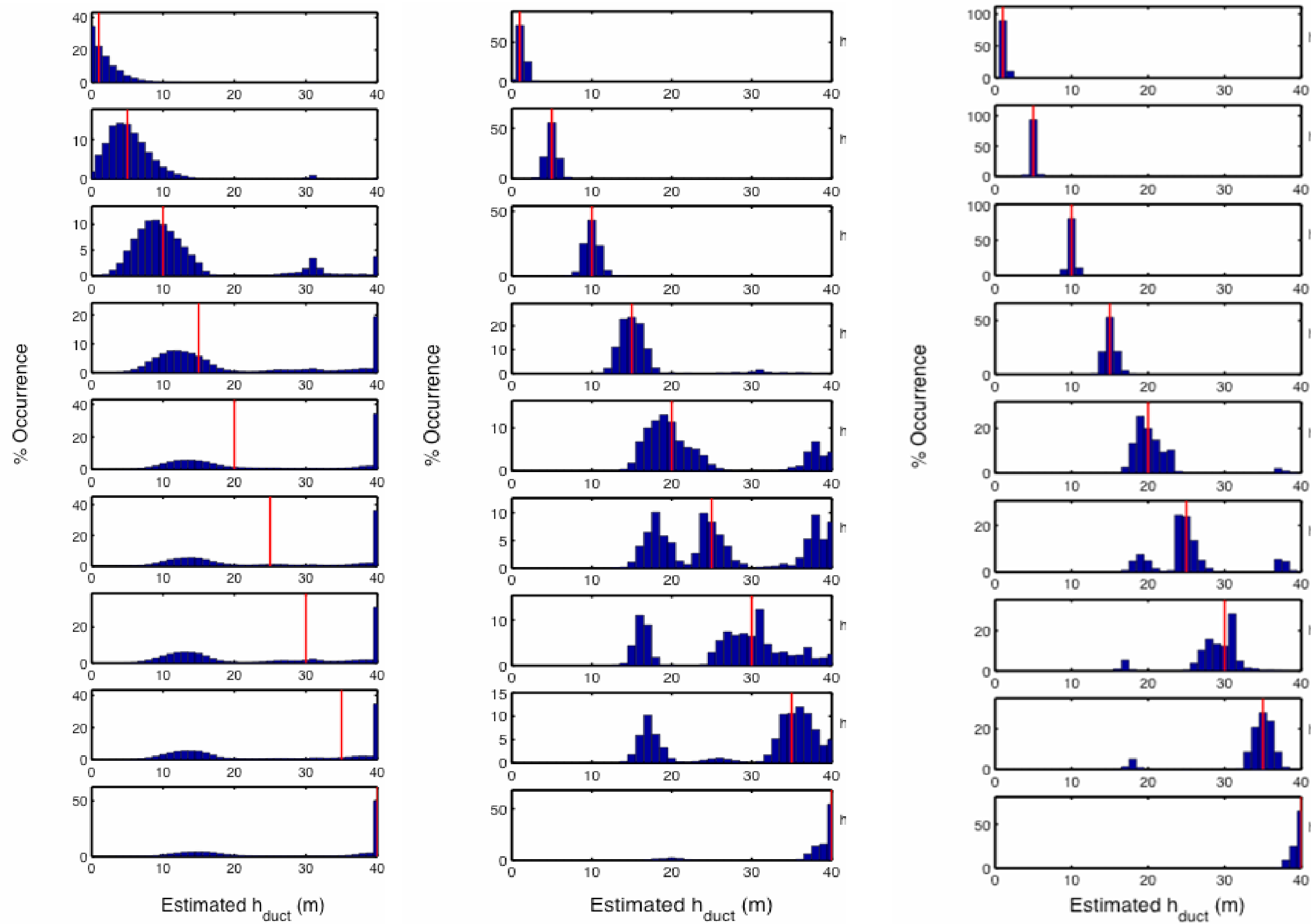
20 m

25 m

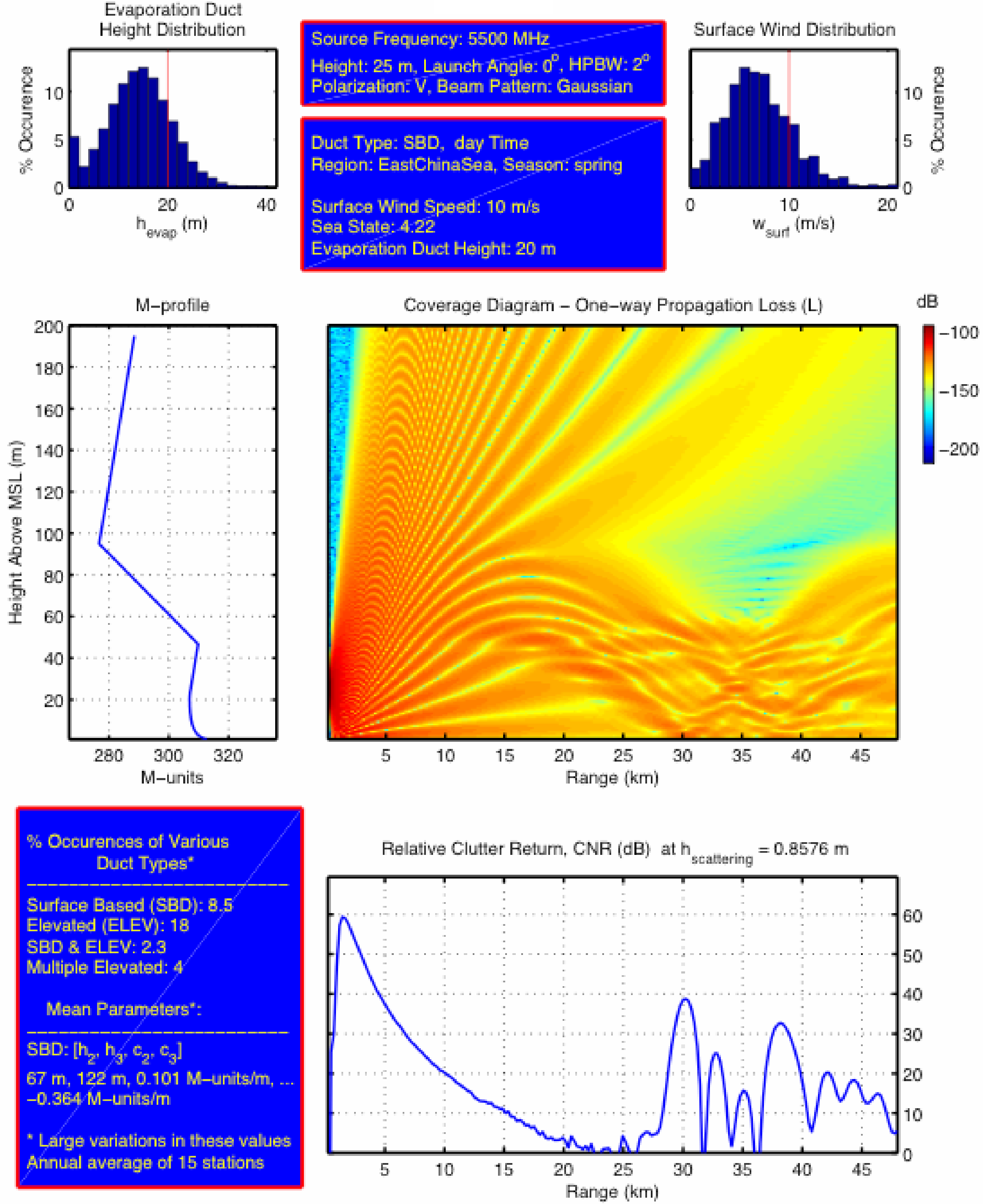
30 m

35 m

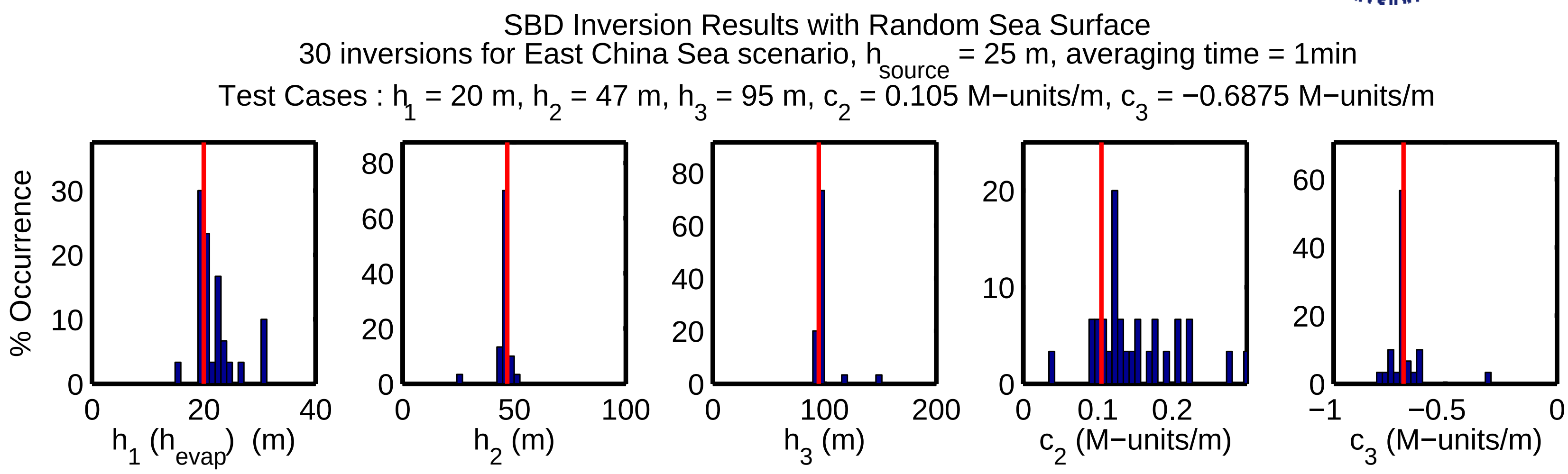
40 m



SBD in East China Sea



SBD Inversion With Sea Clutter



- SBD inversion is done using a genetic algorithm.
- The results shows histogram of the best samples from the GA-simplex codes. Red shows true values.

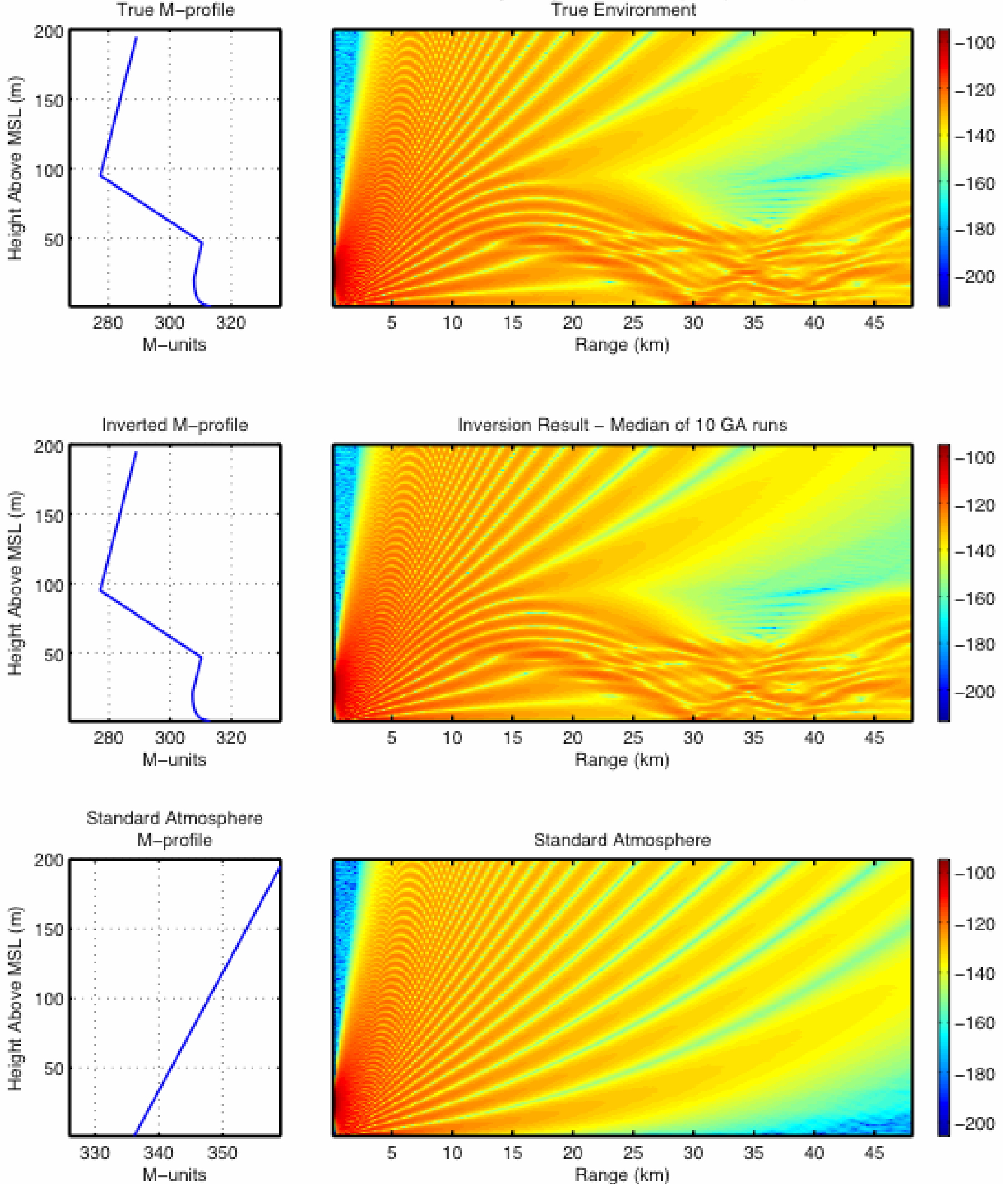
MARINE PHYSICAL LABORATORY

Propagation Loss Comparison

True environment

Inversion result

Standard



CONCLUSIONS

- Applicability of RFC for a given radar system in a given environment is addressed.

- Important issues such as the effects of radar parameter, environmental statistics are discussed.

- Performance is analyzed with noise and sea clutter fluctuations.

Some of the figures are taken from AREPS user manual and created using DCS data