

REPORT ITU-R M.2123*

**Long range detection of automatic identification system (AIS) messages
under various tropospheric propagation conditions**

(2007)

1 Introduction

In the 1990s, the International Maritime Organization (IMO), the International Telecommunications Union (ITU) and the International Electrotechnical Commission (IEC) adopted a new navigation aid known as the Automatic Identification System (AIS) to help improve safety-of-navigation, maritime traffic control and efficiency of maritime commerce. The primary purpose of the AIS is to facilitate the efficient exchange of navigation and voyage data between ships, and between ships and shore stations. The technical characteristics of the AIS using time division multiple access (TDMA) techniques in the VHF maritime mobile band are described in Recommendation ITU-R M.1371.

Like most VHF terrestrial systems, the maximum range of AIS communications is normally governed by line-of-sight and diffraction mode propagation mechanisms. Assuming typical technical parameters of AIS equipment, maximum reliable ship-to-ship radiocommunications over sea water is in the range of 20-25 NM. Shore stations, with high antennas, can reliably receive AIS messages from ships at distances of up to 20 to 35 NM, depending on antenna heights above sea level. The safety-of-navigation and traffic control functions provided by the AIS dictate a requirement for high communications reliability in which a high percentage of the AIS messages are detected and corrected decoded.

Because of the continued growing importance of the AIS traffic, a need has arisen to monitor shipping at distances from shore greater than can be achieved via these conventional propagation mechanisms. Recommendation ITU-R M.1371 introduces the concept of long range detection of AIS data but does not define a specific communications mechanism to accomplish long range AIS detection. As contrasted with normal AIS safety-of-navigation functions, this long range AIS capability does not necessarily need the same high degree of communications reliability. This lower reliability requirement follows from the fact that it is necessary to only detect a fraction of the AIS messages sent from a given ship to accomplish the goal of updating ship locations on a regular basis.

This Report addresses long range monitoring of ship locations at sea through detection of AIS messages. Section 2 focuses on concepts that may enhance long range detection of ships at sea by AIS coast stations. Section 3 assesses whether long range detection has similar spectrum sharing characteristics with other co-channel mobile systems as that of normal AIS safety-of-navigation functions. Section 4 provides an overall summary.

* This Report should be brought to the attention of Radiocommunication Study Group 3, the International Maritime Organization (IMO), the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the Comité International Radio Maritime (CIRM).

2 Concepts to enhance the long range detection capabilities of AIS coast stations

2.1 Off-shore platforms

One mechanism to effectively supplement the shore-based reception range of AIS ship messages is through the installation of AIS receivers on off-shore platforms. Two cases are considered herein – off-shore oil platforms and off-shore weather buoys.

2.2 Oil platforms

In some parts of the world, off-shore oil platforms are extensively deployed along coastal areas. These platforms are typically very large, as illustrated in Fig. 1, and have extensive radiocommunications capability with the nearby mainland. Consequently, in such areas, oil platforms can provide a very useful base on which to locate AIS receiving equipment to enhance shore-based coverage.

FIGURE 1
Typical offshore oil platform



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The first step in evaluating the range enhancements possible with the use of offshore oil platforms is the development of a baseline capability for conventional shore-based reception. Table 1 gives representative technical parameters applicable for the AIS ship to shore link. Using these parameters and a radio propagation model as described in Appendix 3, Fig. 2 was developed which shows the median predicted received power for AIS ship to shore radiocommunications as a function of shore station antenna height.

The results from Fig. 2 indicate a median radiocommunication range of about 38 to 60 km (20 to 32 NM) for the antenna heights shown.

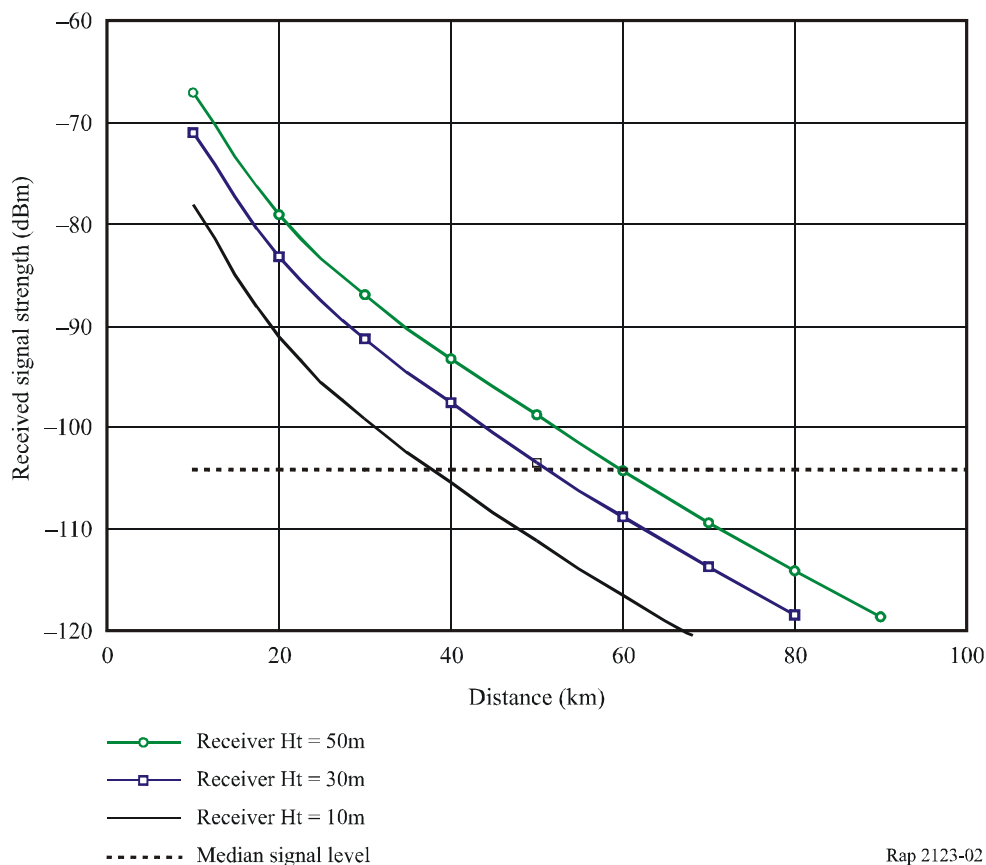
Offshore oil platforms have tower heights considerable higher than the coast station heights used above and consequently have larger communications range with ships at sea.

TABLE 1

Representative technical parameters for AIS ship-to-shore communications

Technical parameter	Typical value
Ship	
Transmit power	41 dBm
Antenna line losses	3 dB
Antenna gain	2 dB
Antenna height	~10 M
Shore station	
Antenna gain	5 dBi (omnidirectional)
Antenna line losses	3 dB
Receiver sensitivity	-107 dBm for 20% per (minimum) -109 dBm for 20% per (typical)
Median received signal level from edge of service range	-104 dBm
Antenna height	10 to 50 m

FIGURE 2

Predicted AIS median received power at shore station

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One such location is the Gulf of Mexico on the Southern Border of the United States of America. Figure 3 gives an overview of the oil platforms deployed in this area. Also shown as dark circles on the figure is one possible arrangement of AIS-equipped platforms. This arrangement of platforms extends reliable AIS reception coverage for ships to at least 120 NM from two major port areas, Houston, Texas and New Orleans, Louisiana in the United States of America.

[illegible]

The communication range enhancement as a result of anomalous propagation modes, primarily atmospheric ducting, discussed later in this section would also be applicable for AIS receivers installed on off-shore platforms. Consequently, on an intermittent basis, AIS reception coverage would extend further out to sea. For the Gulf of Mexico example described here, climatic conditions are often conducive to atmospheric ducting.

2.3 Weather buoys

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FIGURE 4
Typical offshore weather buoy



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These platforms offer an additional opportunity for the installation of AIS receivers to supplement shore-based AIS detection. However, use of off-shore weather buoys presents several additional challenges. The much smaller size of the weather buoys significantly limits the possible height for placement of the antennas; consequently the detection range is smaller than normal shore based reception. Table 2 presents representative technical parameters for a ship-to-weather buoy link.

TABLE 2
Representative link parameters for AIS weather buoy communications

Technical parameter	Typical value
Ship parameters	
Transmit power	41 dBm
Antenna line losses	3 dB
Antenna gain	2 dB
Antenna height	10 m
Weather buoy	
Antenna gain	2 dBi
Antenna line losses	1 dB
Antenna height	~3 m
Median signal level from edge of service area	-104 dBm
Receiver sensitivity	-107 dBm for 20% per (minimum) -109 dBm for 20% per (typical)

Using analysis methods as described earlier, the reliable communication range of weather buoy AIS detection is estimated to be approximately 33 km (18 NM).

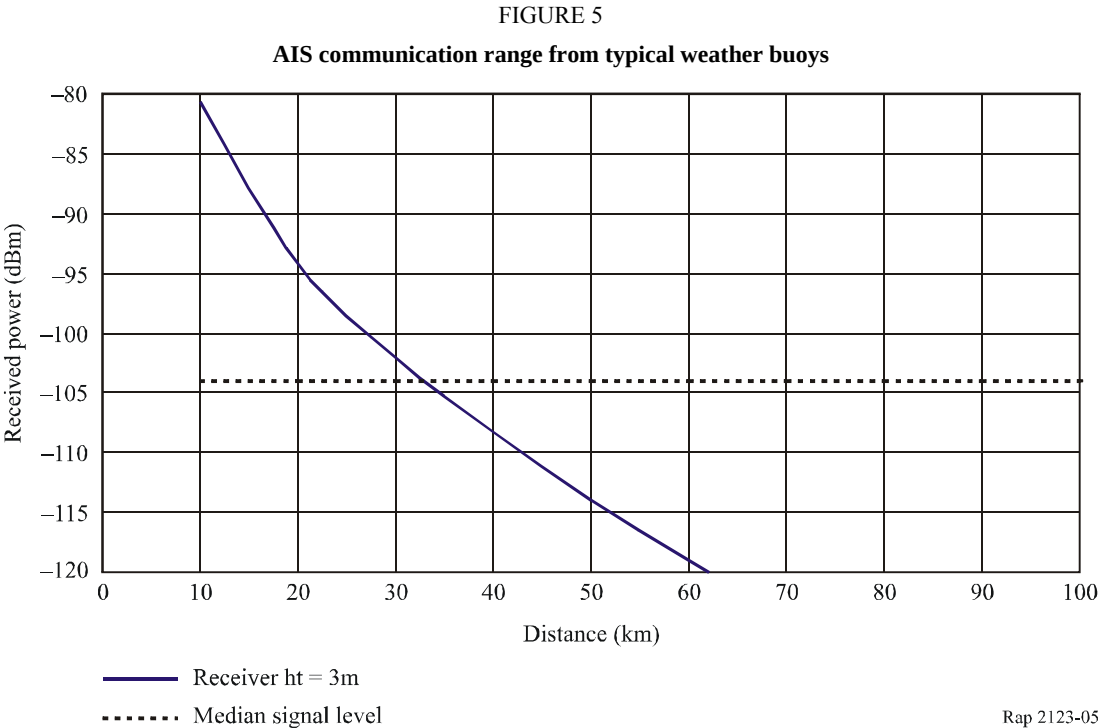
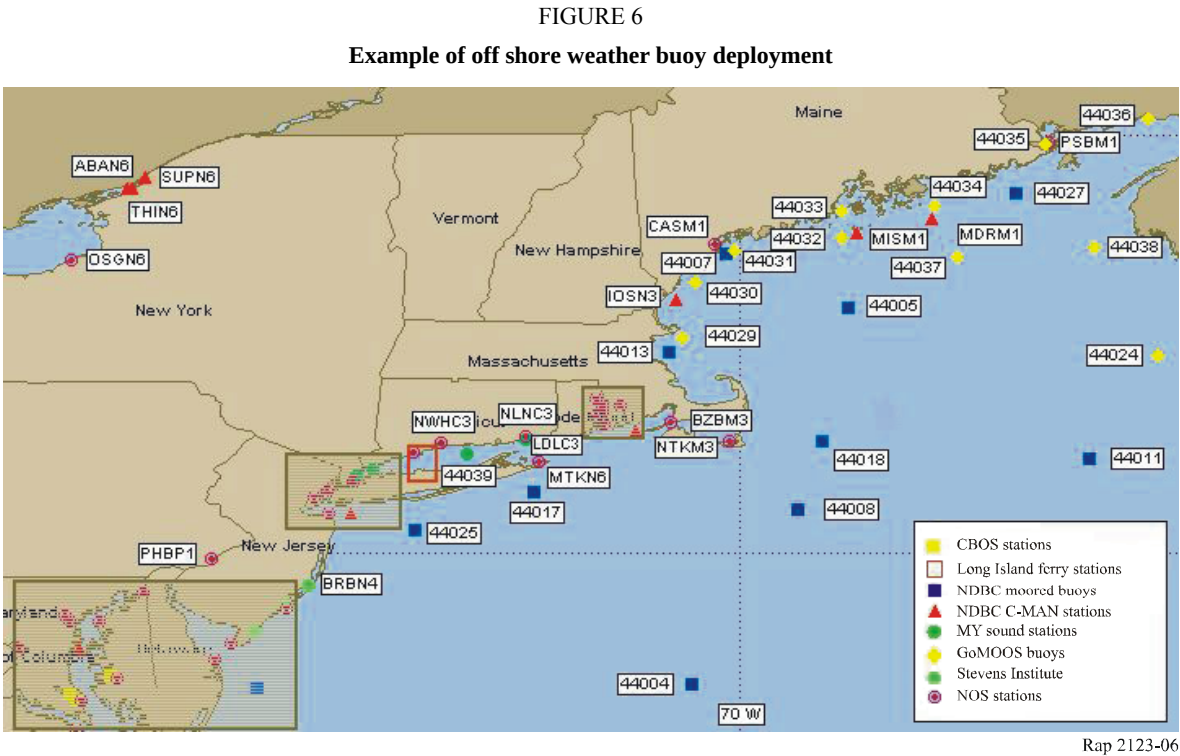


Figure 6 shows one example of the distribution of off-shore weather buoys along the East Coast of the United States of America. As contrasted with the use of oil platforms, the lower density and shorter communication range of AIS-equipped weather buoys typically could not provide enhanced AIS coverage in all directions from a key port area. For this example, installation of AIS receivers on several weather buoys could provide limited enhanced AIS coverage along major shipping lanes approaching the port of New York but not full umbrella coverage.



One significant limitation on the use of weather buoys to enhance AIS range is the mechanism to backhaul the data to shore. While the use of undersea cables is impractical, communication to shore via satellite communications is possible. However, the reliance on solar energy as the source of power limits satellite communications to intermittent, low data rate communications. This limitation, in turn, would require the use of on-board signal processing with the AIS receiver so that only significant new or updated ship information would be sent and all unnecessary repetitive AIS data eliminated.

One option to add the backhaul AIS data to the existing weather data channel via LEO and geostationary earth orbiting (GEO) weather satellite links was investigated. The weather data transmitters installed on the weather buoys typically operate on an intermittent, low-duty-cycle, basis at a data rate of 300 to 1 200 bit/s on a channel shared by many other weather buoys. The sharing of a single uplink channel among many buoys generally limits the transmissions from a given buoy to about once per hour. In order to not significantly impact the primary weather functions, any added AIS data must be limited to some small fraction of the existing weather traffic. With these combined limitations, the use of the existing satellite weather communication channel for AIS derived data on an operational basis appears impractical.

The alternative is to include a separate transmitter on the weather buoy capable of communicating with an existing LEO satellite communications network. The communications requirements of such a link can be estimated as follows:

- a) Assume that the on-board AIS signal processing limits the data forwarded via the satellite link to only a single message when a ship enters its AIS communications zone and one message when a ship leaves the zone.
- b) Assume that the average ship traffic along the associated shipping lane is X inbound ships and Y outbound ships per hour.

Under these assumptions, the net number of AIS messages forwarded via the satellite link would then be $2 \cdot X + 2 \cdot Y$ per hour. Under any reasonable estimate of ship traffic, the transmitted AIS message rate via the satellite link would be quite low.

In summary, the installation of AIS receivers on off-shore weather buoys can provide useful extended range coverage along key shipping routes, although full umbrella coverage will typically not be possible.

2.4 Anomalous propagation

Another concept to take advantage of the lower reliability requirement for long range AIS detection is to supplement normal coverage via line-of-sight and diffraction propagation modes by placing additional reliance on anomalous propagation mechanisms. Several ITU-R Recommendations address the characteristics of a number of these mechanisms including:

Tropospheric scatter	Atmospheric ducting
Meteor burst	Rain scatter
Sporadic-E	

Two of these mechanisms, tropospheric scatter and atmospheric ducting, are investigated in the following paragraphs.

2.4.1 Tropospheric scatter

Tropospheric scatter (hereinafter called troposcatter) is a mode of transhorizon radio wave propagation that results from the random reflections and scattering from irregularities in the dielectric gradient density of the troposphere. This propagation mode is applicable from below 100 MHz to above 8 000 MHz and may extend for distances of several hundred kilometres.

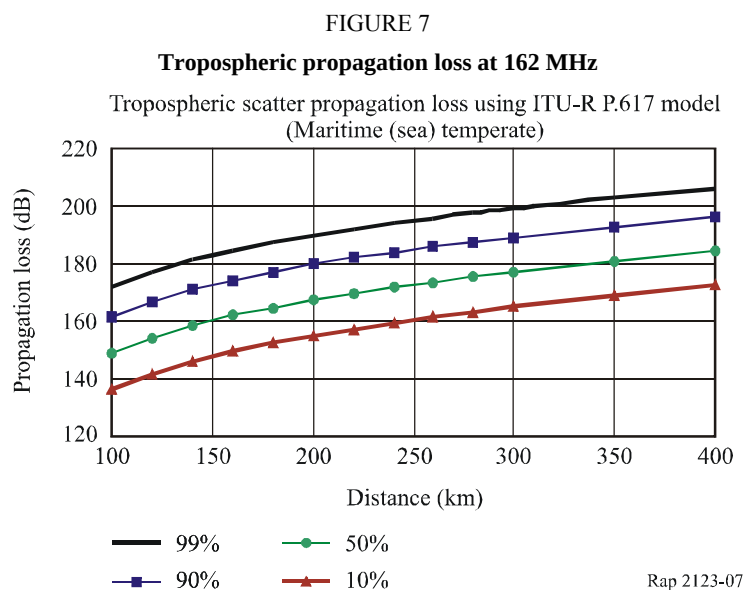
Although it is included herein under the general category of anomalous propagation, the propagation loss resulting from this effect, although quite large, can be sufficiently steady and predictable to support reliable long range communications. Because of the typically large propagation losses involved, it is clear at the outset of this study that reliable reception of AIS messages from ships at sea via troposcatter propagation will not be possible using current AIS coast station designs.

The discussion herein focuses on design factors that may allow reliance on tropospheric scatter for long range AIS detection. Since the characteristics of ship-borne AIS equipment is fixed and cannot be modified in the near term, the key factors are the propagation loss, coast station receiver sensitivity, receiver antenna gain, receiver signal processing, and radio noise.

a) *Propagation loss*

Appendix 1 describes in detail two ITU-R Recommendations that address the characteristics of troposcatter propagation. Recommendation ITU-R P.617 addresses propagation loss from the standpoint of the design of transhorizon communications systems in the frequency range 200 MHz to 5 GHz. Recommendation ITU-R P.452 addresses the evaluation of interference via various propagation mechanisms, including tropospheric scatter, for the frequency range 100 MHz to 50 GHz.¹ Although the latter recommendation is not directly applicable to the present subject, consideration of the recommendation is useful here in that it demonstrates that propagation trends continue smoothly, free from unexpected results, as low as 100 MHz. A third propagation model was examined which similarly showed consistent trends as low as 20 MHz. Consequently, for purposes of this report, the propagation methodologies described in Recommendation ITU-R P.617 are assumed applicable when extrapolated to 162 MHz.

Figure 7, drawn from Appendix 1, describes troposcatter loss as a function of distance and reliability statistics. The curves were developed based on a ship height of 10 m and a receiving antenna height above average terrain of 50 m. However, since troposcatter propagation losses over water are relatively insensitive to antenna heights, the curves will be generally applicable at most practical shore station heights.



¹ The subject recommendation is focused on interference considerations above 700 MHz. However, the recommendation states that the propagation calculation methods described therein are believed to be reliable at frequencies down to 100 MHz, except for the ducting model.

b) *Receiver sensitivity*

The specifications in Recommendation ITU-R M.1371 for receiver sensitivity of ship-borne AIS equipment call for a sensitivity of -107 dBm for a 20% PER or better. Commercial equipment currently on the market typically have a sensitivity of -109 dBm. To successfully communicate via troposcatter, custom designed receivers would be necessary having a significantly higher sensitivity. Textbooks describing optimum receiver performance of differential GMSK modulation indicate that performance at a carrier-to-noise ratio of 13 dB for a bit error ratio (BER) of 10^{-5} is possible, including reasonable implementation losses. This BER approximately corresponds to a PER of 1%. With an assumed receiver noise figure of 3 dB and optimum receiver design, a sensitivity for reception of 9 600 bit/s GMSK modulation of -118 dBm for a 1% PER appears feasible. Relaxing the criteria to 20% PER would further increase sensitivity to approximately -120 dBm.

c) *Receiving antenna*

Similar to the above discussion, current AIS antenna designs with gains of 2 to 5 dBi would be impractical for effective AIS reception via troposcatter. Antennas using a four element collinear vertical array are commercially available for operation at 162 MHz with a peak gain of 8 dBi. The gain can be further increased using offset dipole elements resulting in a cardioid pattern with a peak gain of 11 dBi. Higher gain will likely require custom designs – for example constructing a horizontal array of 2 to 4 elements, where each element is as described above. Using this approach, an antenna main beam gain of up to 17 dBi may be feasible.

d) *Receiver correlation processing*

A much more uncertain improvement factor would take advantage of the repetitive nature of AIS messages. For example, during a 10 min period, a given ship will transmit about 86 AIS messages. During this period, approximately 60% of the bits in each of these AIS ship messages are repeated identically. The MMSI ship identification code is, in particular, repeated with each message. Given the moderately low data rates of AIS transmissions, use of parallel correlation processing techniques may permit an effective increase in receiver sensitivity in a manner somewhat analogous to spread spectrum.

Further study would be required to determine the degree of correlation gain, if any, that may be achievable using this technique. For purposes herein, correlation gains of 0, 5 and 10 dB are considered.

e) *Radio noise environment*

In the VHF band, the environment radio noise can be a significant factor that limits the achievable receiver sensitivity. This would be especially true for the very high receiver sensitivity that would be required for AIS reception via troposcatter propagation. The ambient noise environment results from a combination of natural and manmade sources. At 162 MHz, galactic noise is the predominate natural radio source. Manmade sources of radio noise include vehicular ignitions, power lines and industrial machinery. Recommendation ITU-R P.372 presents typical values of ambient radio noise for galactic radio noise and three generic environments; business, suburban, and rural. The noise density values as a function of frequency are described relative to -204 dB(W/Hz) based on an ambient temperature of 290 K. For 162 MHz, the values are as follows:

Quiet rural	~ 0 dB (limited by galactic noise)
Rural	+ 2 dB
Residential	+5 dB
Business	+12 dB.

To realize the very high receiver sensitivity values described earlier, it is clear that the location of the receiving antenna in a very quiet rural environment is necessary to avoid degrading the achievable sensitivity.

f) Results

Combining the factors described above, a simple link calculation shows the potentially achievable AIS detection range via troposcatter propagation as follows:

$$P_{rec} = EIRP - L_p + G_r + G_{corr} - L_{misc} > Sens$$

where:

- P_{rec} : received power (dBm)
- $EIRP$: ship-borne AIS equivalent isotropic radiated power (dBm)
- L_p : troposcatter propagation loss (dB)
- G_r : receiver antenna gain (dBi)
- G_{corr} : receiver correction gain (dB)
- L_{misc} : miscellaneous cable losses (assumed to be ≤ 1 dB)
- $Sens$: receiver sensitivity (dBm).

Rearranging terms yields:

$$L_p < EIRP + G_r + G_{corr} - L_{misc} - Sens$$

Substitution of values for various assumed parameters yields the results shown in Table 3.

TABLE 3
Calculated AIS detection range via troposcatter
(Based on EIRP = 40 dBm; Sensitivity = -120 dBm; 90% Reliability))

Antenna gain (dBi)	Correlation gain (dB)	Maximum propagation loss (dB)	Detection distance (km)
11	0	170	93
11	5	175	180
11	10	180	157
17	0	176	124
17	5	181	168
17	10	186	230

These results show that with optimized receiver and antenna design, enhanced detection range would be possible using the troposcatter mode of propagation to distances on the order of 100 to 200 km.

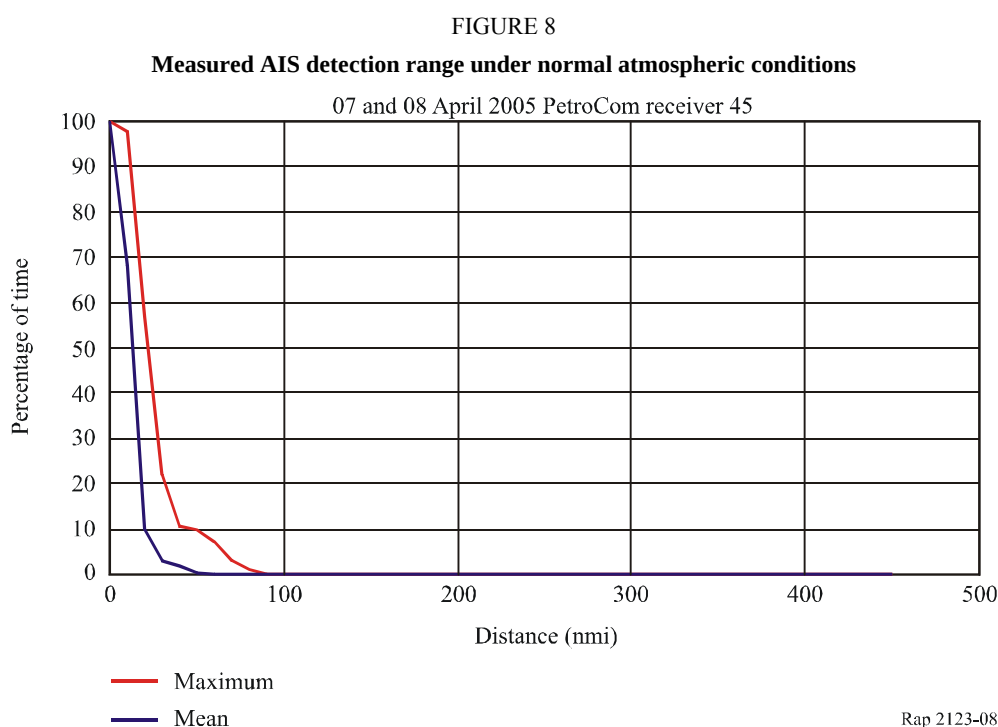
2.4.2 Atmospheric ducting

Atmospheric ducting is a propagation phenomenon that occurs predominately when the atmosphere stratifies into layers of differing temperatures and humidity. This layering results in varying index of refraction at different heights above ground. This situation, in turn, can lead to a condition where radio waves are effectively “trapped” between the layers somewhat similar to a waveguide. The trapping can occur between the Earth’s surface and a ducting layer, called a surface duct, or between two upper atmosphere ducting layers, called an elevated duct.

The key features of this propagation mode are generally low propagation loss values but sporadic and intermittent occurrence. In some instances, the propagation loss values can approach free space values, but more typically is 5 to 30 dB higher than free space for distances in the range of about 50 to 200 km (see “Atmospheric ducting” in Appendix 5). For propagation over sea water, the rate of occurrence is very dependent on the general climatic and current weather conditions. Considerable diurnal and seasonal variations also exist. Conditions to the occurrence of atmospheric ducting may sometimes persist for hours or even days while at other times not occur for many consecutive days. On a long term average, conditions for atmospheric ducting occur less than 20% of the time and in most cases less than 5 to 10% of the time. Geographic areas where atmospheric ducting is most prevalent are humid climates and warm seas. One such area is the Gulf of Mexico and surrounding areas; conditions for atmospheric ducting with higher percentages have been recognized in other areas.

Because of its intermittent nature, reliance on atmospheric ducting propagation conditions for long range AIS detection on a regular basis, such as every four hours, is generally not practical. However, the long range detection capability that does occur can be a useful supplement to normal shore-based AIS detection.

Figure 8 is based on measurements in the Gulf of Mexico and describe the percent of time that AIS equipped ships were detected at an AIS receiver site on two days in April 2005. This represented normal non-ducting conditions. Figure 9 shows the same data collected on two other days when much greater detection distances were achieved from the same site. Only atmospheric ducting can account for these statistical results.



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