APPENDIX C: SCHEMATIC REPRESENTATIONS OF SOME METEOROLOGICAL CONDITIONS FAVORABLE FOR ANOMALOUS RADIO PROPAGATION

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This appendix categorizes for the telecommunications system design engineer, some of the meteorological conditions associated with the atmospheric refractivity (N) layers that are favorable for anomalous radio wave propogation. These layers may be categorized in terms of their position (surface or elevated), their refractivity gradients (subrefractive, superrefractive), and their causative physical processes (advection, evaporation, etc.). These layers are exemplified by simplified plots (straight-line segments) of their refractivity profiles (N versus elevation h), or their associated temperature (T in °C), or relative humidity (RH in %), profiles (i.e., T and RH versus elevation h above the surface). The geographic, synoptic, and generalized surface conditions associated with the occurrence of each type of layer are described qualitatively. In some cases, specific locations are identified as examples.

The layer categorizations are summarized in four charts: Chart I describes surface superrefractive layers ($\Delta N/\Delta h < -100$ N units/km); Chart II depicts surface subrefractive layers ($\Delta N/\Delta h > 0$); Chart III treats elevated superrefractive layers; and Chart IV describes elevated subrefractive layers. When the Chart I layers have sufficiently superrefractive gradients (i.e., ducting gradients where $\Delta N/\Delta h < -157$ N units/km), the surface layer also constitutes a surface radio duct. Elevated refractivity layers with ducting gradients may constitute either elevated or ground-based ducts (See Figure 7 of the text).

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Chart I Surface Superrefractive Layers ($\Delta N/\Delta h < -100$ N-units/km)

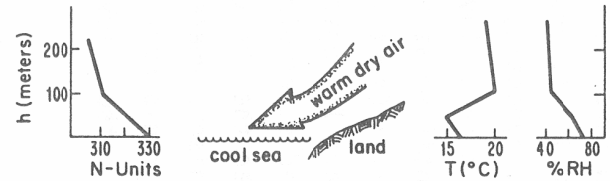
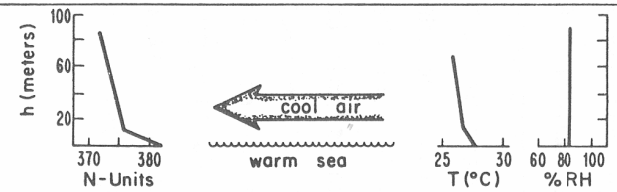
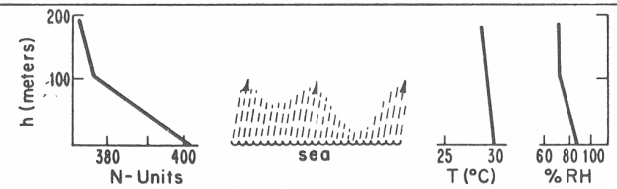
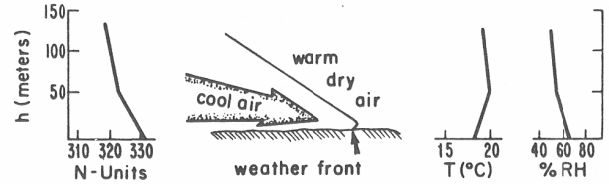
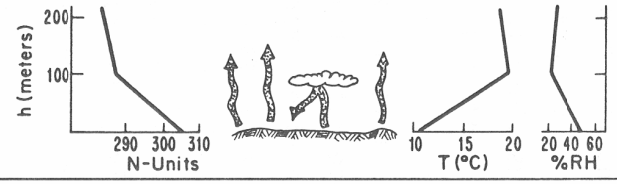
	CAUSATIVE PROCESS	DESCRIPTION (N-Profile, T-Profile, RH-Profile)	OCCURRENCE
A	**ADVECTION** Horizontal motion of warm dry air across a cool moist surface (sea or moist ground). The warmer and drier the air, the stronger the gradient.		(1) Over large bodies of water such as lakes, bays, gulfs and seas; particularly along desert coastal regions (e.g., in the Mediterranean and Red seas, the Gulf of Arabia or in the English Channel during summers). The layers have been observed to extend up to 70 meters above the sea surface and out to 20 km from the shore. (2) Over cool irrigated valleys, below hot dry mountain slopes, just after sunset.
B	**QUASI-ADVECTION** Horizontal motion of cool air across a warm moist surface (sea or moist ground). The stronger the wind, the stronger the gradient.		(1) Over the poleward portions of temperate-zone seas in the winter (e.g., the North Atlantic). (2) Over moist land areas near the tropics. (e.g., Florida) during early winter. (3) In temperate-zones following a cold front passage.
C	**EVAPORATION** Evaporation from wet surfaces (sea or moist ground) to air at the same or higher temperatures. The less the wind speed, the stronger the gradient. The warmer the air, the weaker the gradient.		(1) Over land in moist tropical regions, particularly with vegetation and foliage cover and more commonly in the daytime. (2) Over the sea when the air is as warm as or warmer than the sea and in the absence of strong winds. (3) Over the sea in the tradewind regions as a "semi-permanent" layer extending up to 6 to 20 meters.
D	**FRONTAL WEATHER PROCESSES** The advance of cool air along the surface, lifting a stable warm air mass.		Over land in the near vicinity of the front (the junction of the two air masses at the surface)
E	**RADIATION** The radiation of heat from the warmer ground to the colder sky.		Clear skies and light surface winds, at night, result in considerable cooling of the earth causing the formation of a temperature inversion (an increase of temperature with height) Of major importance in the polar regions and during the winter at temperate latitudes where solar heating is confined to a limited surface depth. Probably unusual in tropical regions or in humid regions during the summer.

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Chart II Surface Subrefractive Layers ($\Delta N/\Delta h > 0$ N-units/km)

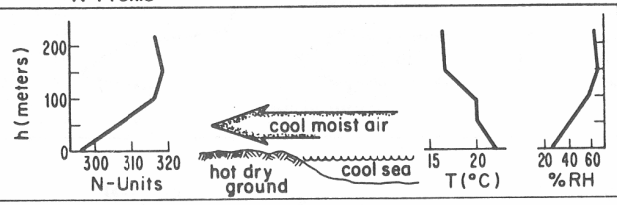
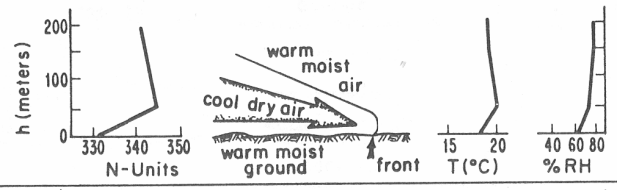
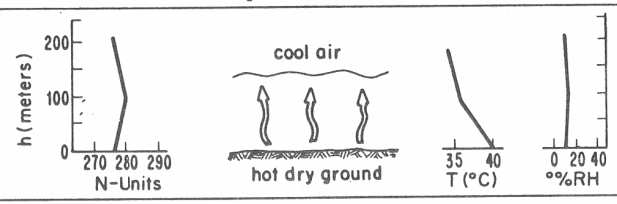
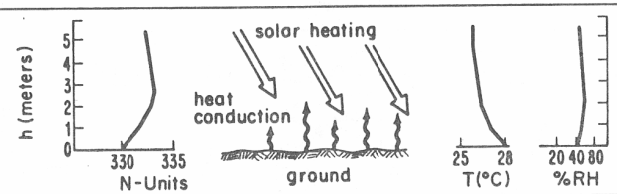
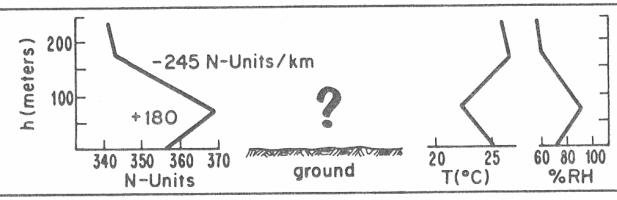
	CAUSATIVE PROCESS	DESCRIPTION (N-Profile, T-Profile, RH-Profile)	OCCURRENCE
A	**ADVECTION** Horizontal motion of cool moist air across a dry hot surface.		Over land in coastal regions, during the summer at temperate latitudes. On the eastern coasts in the tradewind regions.
B	**FRONTAL WEATHER PROCESSES** The advance of cool dry air along a warm moist surface, lifting a warm moist air mass.		Over land, with passage of a front so that warm moist air overlies cool air.
C	**AUTO CONVECTION** The convection of heat from an extremely hot surface. Due to cooler air lying above a hot surface (surface temperatures in excess of 30°C due to solar heating) a temperature lapse exists far in excess of the adiabitic temperature lapse rate.		Over land. Encountered in the summer for any desert or semi-arid region (e.g. , the interior of Australia, North Africa, the Middle East, the Caspian Sea region and parts of southwestern U.S.). This is rare in winter in the temperate zones.
D	**CONDUCTION** The effect of solar heating of a surface and the heating (conduction) of air near the surface is to cause a sharp increase in air temperature in the immediate vicinity of the surface.		Over land on sunny days during the warm part of the day. This surface boundary layer can occur in any climate and is especially common in tropical deserts and semi-arid climates.
E	Process undefined but the effect is a strong elevated superrefractive layer (gradient less than −157 N-Units/km) lying above a subrefractive layer.		Over land. Has been observed in the temperate zones. May occur due to the intrusion of moist air into a dry air mass close to the surface of the ground.

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Chart III Elevated Superfractive Layers ($\Delta N/\Delta h < -100$ N-Units/km)

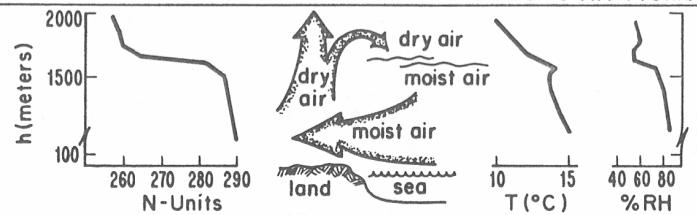
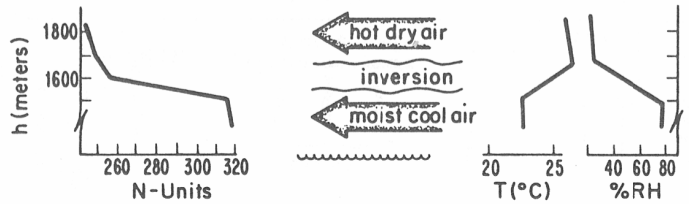
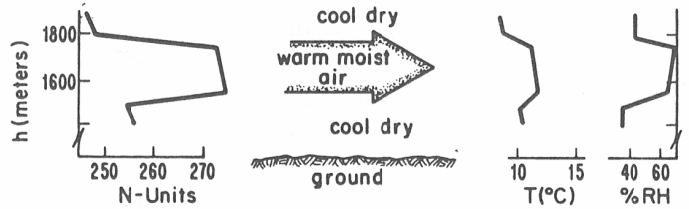
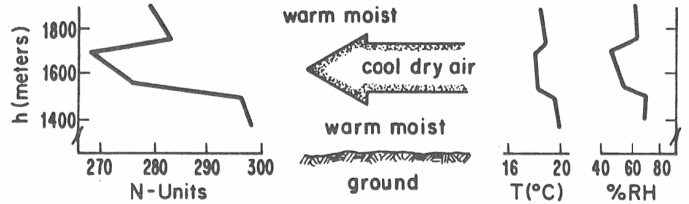
	CAUSATIVE PROCESS	DESCRIPTION (N-Profile, T-Profile, RH-Profile)	OCCURRENCE
A	**ADVECTION** Horizontal motion of dry air over moist air.		Over land and water near the coast, the subsidence of the dry land air over moist sea air may occur. Daytime solar heating of land surfaces causes a rising of warm dry air near the land and a horizontal motion of moist air from sea to land (sea breeze).
B	**SUBSIDENCE** The flow of air from a high pressure cell such that hot, dry air flows out (subsiding) over cool moist air.		Over water roughly between 5° and 25° North and South latitude, elevated layers occur which are known as the Tradewind Inversion. These are due to subsidence of dry air from high altitudes which subsides over moist cool air over the sea. Over land, the subsidence can occur due to a large slow moving high pressure system associated with the afore-mentioned over-water highs.
C	**ADVECTIVE INTRUSION** The horizontal motion of air, such that one air mass intrudes into another, can produce multiple elevated layers.		**WARM MOIST INTRUSION** A tongue of warm moist air intruding into a cool dry air mass results in the combination of a superrefractive layer positioned above a subrefractive layer. Observed mainly over land in the temperate zone. Fairly common occurance. **COOL MOIST INTRUSION** A tongue of cool moist air intruding into warm dry air produces a similar super/sub type of N profile. Uncommon except possibly in some warm desert areas near cold water coasts.
			**COOL DRY INTRUSION** A tongue of cool dry air intruding into a warm moist air mass results in the combination of a subrefractive layer positioned above a superrefractive layer. Observed mainly over land in the temperate zone. Fairly common. **WARM DRY INTRUSION** A tongue of warm dry air intruding into a cooler moist air mass produces the same sub/super N profile. Common in tropical and subtropic areas.

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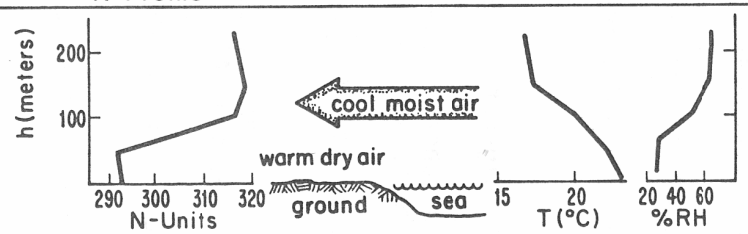
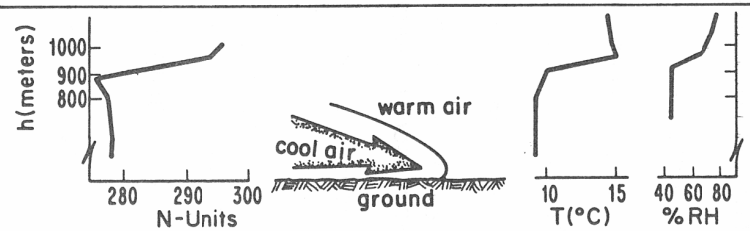
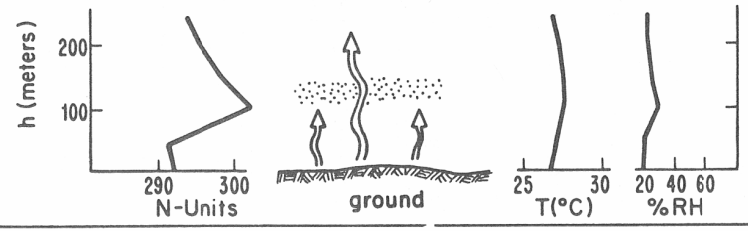
Chart IV Elevated Subrefractive Layers ($\Delta N/\Delta h > 0$ N-Units/km)

	CAUSATIVE PROCESS	DESCRIPTION (N-Profile, T-Profile, RH-Profile)	OCCURRENCE
A	**ADVECTION** Horizontal motion of cool moist air across a warm dry surface.		Over land, the horizontal motion of cool moist air over warm dry land (e.g. a sea breeze)
B	**FRONTAL WEATHER PROCESS** The advance of cool air along a surface, lifting warm moist air (cold front).		Over land, after passage of a cold front, so that warm moist air overlays cool air. The layers occur up to 50 km behind the front, at altitudes of 1000 km.
C	**RESIDUAL PROCESS** The effects of changes in surface temperatures upon previously developed surface layer.		Over land in the early evening following the daytime formation of auto-convective layers, there is a radiation of heat from ground to clear cool sky and to the moisture trapped above the surface. Over land in the early morning, following a nighttime formation of a radiation layer. Solar heating raises the surface temperature to produce the same elevated subrefractive N profile.

APPENDIX D: LIST OF SYMBOLS

A	general term for excess propagation losses within a duct, in decibels; see (8).
A_c	the aperture-media coupling loss in decibels, see (10).
c	constant of proportionality, see page 30.
d	path length from transmitting site to receiving site in kilometers.
d_o	that portion of a path length, less than d, that lies immersed within a duct.
dn/dh	the vertical refractive index gradient in n units/km, see (1b).
dN/dh	the vertical refractivity gradient in N units/km, see (1b).
dM/dh	the vertical modified-refractivity gradient in M units/km, see (2b).
D	duct thickness in meters, see (4), or (6), and (A7).
$E(p)$	the field exceeded for p percent of the time, see (18).
E_o	the free-space field, see (18).
f	the radio transmission frequency in gigahertz, see (8), and (9).
f_t	the minimum trapping frequency in gigahertz, see (7); the frequency is expressed in megahertz in Figures 11, B-1, and B-2.
g	the vertical refractivity gradient across an atmospheric layer in N units/km, see (A3).
G	the vertical modified refractivity gradient across an atmospheric layer in M units per meter, M units/m; see (A3).
G_o	the modified refractivity gradient of the ducting layer in M units/m, see (A7).
G_b	the modified refractivity gradient of the non-ducting layer in M units/m, see (A7).
h	the elevation in meters above some reference elevation level.
h_a	the elevation in meters of the top of a ducting layer, see Figure 7.
h_b	the elevation in meters of the base of an atmospheric duct, see Figure 7.
h_o	the elevation in meters of the base of a ducting layer, see Figure 7.
L_b	the basic transmission loss in decibels, see (8).
L_{bo}	the free-space basic transmission loss in decibels, see (9).

$M(h)$	the modified-refractivity profile, see (20).
N	the refractivity profile, see (1a).
$N(h)$	the refractivity profile, see (1a).
$n(h)$	the refractive-index profile, see (1a).
p	the percent of the time.
$Q(x)$	a factor in determining distance and elevation along a wave trajectory, see (A11) through (A14).
R	the subscript to identify receiving terminal parameters, see (14).
R_e	the effective earth radius.
R_o	the true earth radius, R_o = 6370 km.
RH	the relative humidity in percent.
T	the subscript to identify transmitting terminal parameters, see (14).
T	the temperature in degrees centigrade.
x	the distance along a reference elevation level in kilometers, see (A1).
$\hat{x}$	the distance at which a trajectory has a zero elevation angle, see (A8).
x_{max}	the maximum distance segment over which an arching (trapped) trajectory will remain within a layer of the duct, the chord length; see (A16).
y	the elevation in meters of a trajectory above a ducting layer base, see Figure 7.
$\hat{y}$	the peak elevation of a trajectory within a ducting layer, see (A9).
$\hat{y}_b$	the minimum elevation of a trapped trajectory eithin a duct, see (A15).
δ	the layer thickness measured in radio wave lengths.
δh	the ducting layer thickness in meters, see (A6), or (A7).
δM	the modified refractivity change through an atmospheric layer in M units/m, see (A5), or (A6).
δM_o	a modified refractivity change used as a reference.
ΔH	a measure of terrain irregularity; the central 10% to 90% range of elevations in meters for the central 90% of the terrain profile between a transmitting and receiving site.
α	a propagation loss coefficient in dB/km for a duct, see

ρ the reflection coefficient for an elevated layer.

θ the local elevation angle of a wave trajectory, usually in milliradians; see (A2).

θ_o the initial elevation angle of a trajectory in milliradians, see (A1).

$\hat{\theta}_o$ the initial elevation angle of a trajectory which has a zero elevation angle at the elevation $\hat{y}$ and the distance $\hat{x}$; $\hat{\theta}_o = \theta_c$.

θ_c the critical initial elevation angle for a duct, see (A5).

Ω the antenna half-power beam width in milliradians, see (10), directed along a duct; it may represent a sidelobe.

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This report categorizes the manner in which atmospheric stratification can complicate the problems of frequency allocation and radio regulation by inhibiting service fields and enhancing interference fields. For the United States and its border regions, preliminary contour maps are presented for those parameters associated with the atmospheric layering (ducts) conducive to the propagation of unusually strong UHF and SHF fields over extremely long distances. The parameters of interest are: the percent occurrence of elevated ducts, a minimum trapping frequency, the modified refractivity lapse, the ducting-layer base height, the duct-base height, and the duct-top height. The role of these duct parameters in the prediction of potential interference fields is detailed by engineering formulas and illustrated by numerical examples. These predictions of duct characteristics from historical (radiosonde) data are necessarily preliminary because of present inadequacies of the data sample. Approaches for improving estimates of duct parameters are described. Appendices detail expressions for duct trajectories and map the variation of duct characteristics.

16. Key Words *(Alphabetical order, separated by semicolons)*

anomalous propagation; atmospheric ducts, layers, or stratification; ducting; interference fields; ray trajectories; SHF; UHF

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