MORE ON NOISE:

NOISE CAN BE PICKED UP BY THE ANTENNA FROM THE SURROUNDING EARTH (~ 290 K)

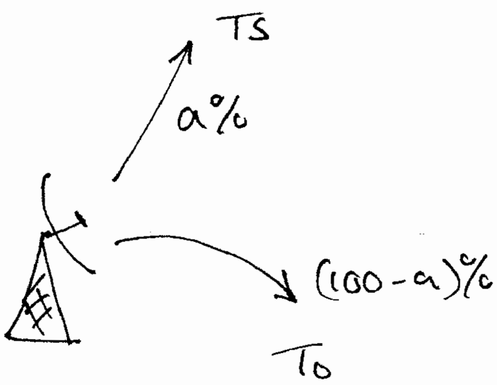
AT HIGH ELEVATION ANGLES THIS IS MINIMIZED PROVIDING THAT THE ANTENNA SIDELOBES ARE MINIMIZED TOO.

IN GENERAL WE CAN WRITE THE ANTENNA NOISE AS:

$$T_A = \frac{a}{100} T_S + \frac{(100-a)}{100} T_O$$

a - PERCENTAGE, DEPENDENT ON ELEVATION
T_O - GROUND NOISE (~290K)
T_S - LARGELY DEPENDENT ON FREQUENCY OF OPERATION.

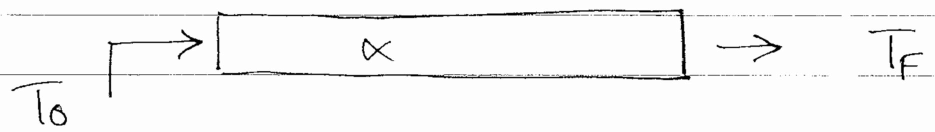
FOR EXAMPLE



IF $a = 80\%$, $T_S = 60K$ $\Rightarrow$ $T_A = 106K$

NOISE TEMPERATURE OF FEEDERS

FOR A FEEDER WITH A LOSS FACTOR $L > 1$ (OR A GAIN $\alpha = 1/L$) WHICH IS MATCHED TO A SOURCE OF TEMPERATURE T_0;



$$\text{OUTPUT NOISE} = \alpha(kT_0B) + kT_FB$$

INPUT NOISE AMPLIFIED BY α

NOISE DUE TO THE LOSS

SINCE THE FEEDER IS MATCHED TO THE SOURCE, THE AVAILABLE POWER AT THE OUTPUT OF THE FEEDER IS ALSO kT_0B;

$$kT_0B = \alpha(kT_0B) + kT_FB$$

$$\Rightarrow T_F = T_0(1-\alpha)$$

OR

$$T_F = T_0\left(1 - \frac{1}{L}\right)$$

THIS IS THE NOISE TEMPERATURE AT THE OUTPUT OF THE FEEDER

THE TROPOSPHERE

THE TROPOSPHERE IS THE LOWEST REGION OF THE ATMOSPHERE (SEE DIAGRAM FROM THE FIRST LECTURE.

THE HEIGHT OF THE TROPOSPHERE (THE TOP OF THE TROPOSPHERE IS CALLED THE TROPOPAUSE) VARIES ACCORDING TO OUR GEOGRAPHIC LOCATION;

~ 6km AT THE POLES

~ 18km AT THE EQUATOR

THE TROPOSPHERE CAN BE CHARACTERIZED BY VARIOUS PARAMETERS;

* TEMPERATURE
* PRESSURE
* HUMIDITY (OR WATER VAPOUR PRESSURE)

WE CAN USE SOME SIMPLE MODELS FOR THESE PARAMETERS. IN THE LOWEST 1-2 km WE CAN USE A SIMPLE LINEAR RELATIONSHIP

AS A FUNCTION OF HEIGHT h (IN km)

$$T(h) = 290 - 6.5h \qquad (K.)$$
$$P(h) = 950 - 117h \qquad (mB.)$$
$$p(h) = 8 - 3h \qquad (mB.)$$

FOR HIGHER REGIONS OF THE TROPOSPHERE THE APPROXIMATION FOR TEMPERATURE IS STILL QUITE GOOD, BUT FOR PRESSURE WE MUST RESORT TO AN EXPONENTIAL APPROXIMATION

$$P(h) = P_0 \exp(-gh'/R\bar{T})$$

WHERE: P_0 IS THE PRESSURE AT $h' = 0$
h' IS THE HEIGHT (m)
R IS THE SPECIFIC GAS CONSTANT
$R \simeq 287 \ m^2 s^{-2} K^{-1}$
$g = 9.81 \ ms^{-2}$
$\bar{T} = \frac{1}{2}(T(h) + T(0))$

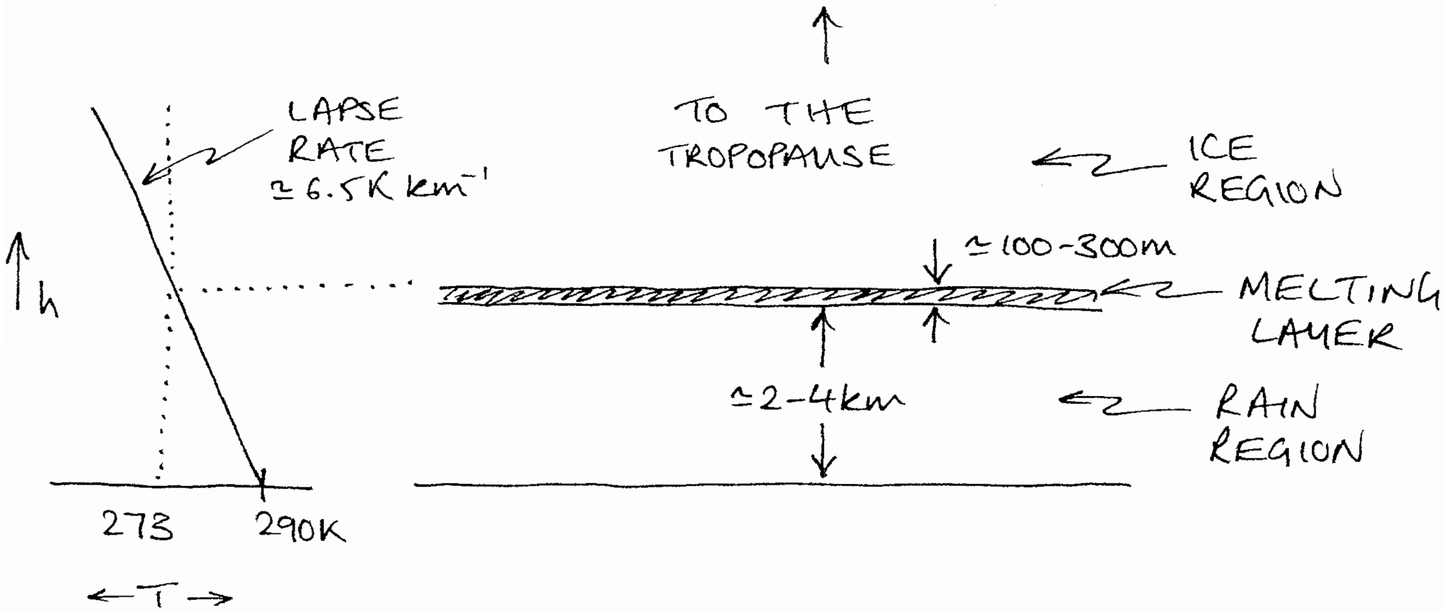
TYPICALLY THE PRESSURE DECREASES BETWEEN 113 - 119 mB km^{-1}.

THE MELTING LAYER

SINCE THE TEMPERATURE DECREASES WITH HEIGHT AT A RATE OF 6.5K km^{-1} (CALLED THE "LAPSE RATE") WE HAVE REGION OF FREEZING (OF WATER).

THIS "FREEZING LEVEL" OR "ZERO-DEGREE ISOTHERM" OCCURS AT THE TOP OF

THE MELTING LAYER:



THE ATMOSPHERE CONTAINS A NUMBER OF GASES AND HYDROMETEORS (PRECIPITATION)

GASES : NITROGEN ~78% (BY VOLUME)
OXYGEN ~21%
WATER VAPOUR 0–4%

PLUS OTHERS e.g Argon CO_2 CO etc.

PRECIPITATION: RAINDROP
SNOW FLAKES
SNOW PELLETS
GRAUPEL
HAIL
ICE - PRISMS

PERMITTIVITY / REFRACTIVITY OF THE TROPOSPHERE

THE PERMITTIVITY OF THE TROPOSPHERE ALONG WITH THE PERMEABILITY DETERMINES THE VELOCITY OF PROPAGATION V;

$$V = \frac{1}{\sqrt{\mu \epsilon}} \qquad \epsilon_r = \frac{\epsilon}{\epsilon_0} \qquad \mu_r = \frac{\mu}{\mu_0}$$

IN A HOMOGENEOUS MEDIUM THE WAVES PROPAGATE IN STRAIGHT LINES.

BUT THE PERMITTIVITY OF THE EARTH'S ATMOSPHERE IS NOT HOMOGENEOUS, IT IS HORIZONTALLY STRATIFIED. HENCE E-M WAVES DO NOT PROPAGATE IN STRAIGHT LINES.

THE PERMITTIVITY OF THE TROPOSPHERE CAN BE DEFINED (IN TERMS OF P, T AND ρ) AS;

$$\epsilon_r = 1 + \frac{155.1}{T}\left[P + \frac{4810\rho}{T}\right] \times 10^{-6}$$

SO, SUPPOSE WE HAVE;

$$T(0) = 17^\circ C = 290K \;;\quad P(0) = 950\,mB \;;\quad \rho(0) = 8\,mB$$

$$\Rightarrow \quad \epsilon_r = 1.000579$$

AT A HEIGHT OF 1km; (USING OUR LINEAR APPROXIMATION

$$\Rightarrow \quad \epsilon_r = 1.000502$$

THUS THE VARIATION WITH HEIGHT IS QUITE SMALL!

ELECTROMAGNETIC WAVES "BEND" WHEN THEY PROPAGATE THROUGH DIFFERENT MEDIA WITH DIFFERENT ϵ_r.

THE "BENDING" IS A FUNCTION OF THE VELOCITY v, WHICH WE CAN WRITE AS;

$$v = \frac{c}{\sqrt{\epsilon_r}} \qquad c = 3\times10^8\,\mathrm{ms^{-1}}$$

WE CAN WRITE $\sqrt{\epsilon_r} = n$, WHERE n IS THE <u>REFRACTIVE INDEX</u>.

HENCE;

$$n = \sqrt{\epsilon_r} = \left[1 + \frac{155.1}{T}\left[P + \frac{4810e}{T}\right]\times10^{-6}\right]^{1/2}$$

(THIS IS THE "SMITH-WEINTRAUB" RELATIONSHIP)

$$n \simeq 1 + \frac{77.6}{T}\left[P + \frac{4810e}{T}\right]\times10^{-6}$$

(USING THE BINOMIAL APPROXIMATION)

CHANGES IN REFRACTIVE INDEX "n" OF ONLY A FEW ppm CAN HAVE A SUBSTANTIAL EFFECT ON THE ELECTROMAGNETIC WAVE PROPAGATION.

THE REFRACTIVE INDEX IS ALSO VERY CLOSE TO UNITY SO TO MAKE LIFE EASY(!) WE USUALLY WORK WITH A NORMALIZED VERSION OF n;

$$N = (n-1) \times 10^6.$$

<u>STRICTLY</u> WE CALL "N" <u>REFRACTIVITY</u>, BUT

WE OFTEN JUST CALL "N" REFRACTIVE INDEX. NOW WE HAVE $N(0) = 289$, $N(1) = 251$

WE CAN WRITE "N" AS;

$$N = \frac{77.6P}{T} + \frac{\rho}{T^2} \times 3.73 \times 10^5$$

THIS IS ACCURATE TO WITHIN 0.5% FOR PRESSURES 200 − 1100 mB AND TEMPERATURE 240 − 310K AND $\rho < 30$ mB, AND FOR FREQUENCIES < 30 GHz.

WE CAN SPLIT "N" INTO TWO PARTS;

$$N = N_{DRY} + N_{WET}$$

WHERE OBVIOUSLY; $N_{DRY} = \frac{77.6P}{T}$; $N_{WET} = \frac{3.73\times10^5 e}{T^2}$

AT LOW TEMPERATURES N_{WET} BECOMES VERY SMALL EVEN FOR SATURATED AIR
$\Rightarrow$ N ALMOST INDEPENDENT OF RELATIVE HUMIDITY.

AT HIGH TEMPERATURES AND HIGH HUMIDITY "N" IS VERY SENSITIVE TO SMALL CHANGES IN TEMPERATURE AND RELATIVE HUMIDITY

$\Rightarrow$ VARIABILITY OF "N" IS HIGHER IN TROPICAL REGIONS THAN IN COLDER CLIMATES

VARIATION OF "N" WITH HEIGHT

THE ITU-R DEFINES A STANDARD ATMOSPHERE;

$$N(h) = N_0 \exp(-h/h_0)$$

$N_0 = 315$ $h_0 = 7.35$ km h - IN km.

- WE OFTEN SPECIFY N_0 AS BEING IN N-UNITS

GENERALLY FOR THE TEMPERATE REGIONS THE MEDIAN OF THE MEAN GRADIENT;

$$\Delta N = \frac{dN}{dh} = -40\,N\ km^{-1}$$

FOR OTHER REGIONS OF THE WORLD WE USUALLY HAVE TO BE A LITTLE MORE CAREFUL – LUCKILY WE CAN LOOK AT THE ITU-R DATA.

WE OFTEN MEASURE THE DEWPOINT TEMPERATURE (SAY FROM A RADIOSONDE OR METEOROLOGICAL MODEL) IN THIS CASE WE CAN RELATE T_D TO p BY;

$$p = 6.11 \exp\left([T_D - 273]/[(T_D - 273) - 273]\right)$$

FIGURE 1

Monthly mean values of N_0: February

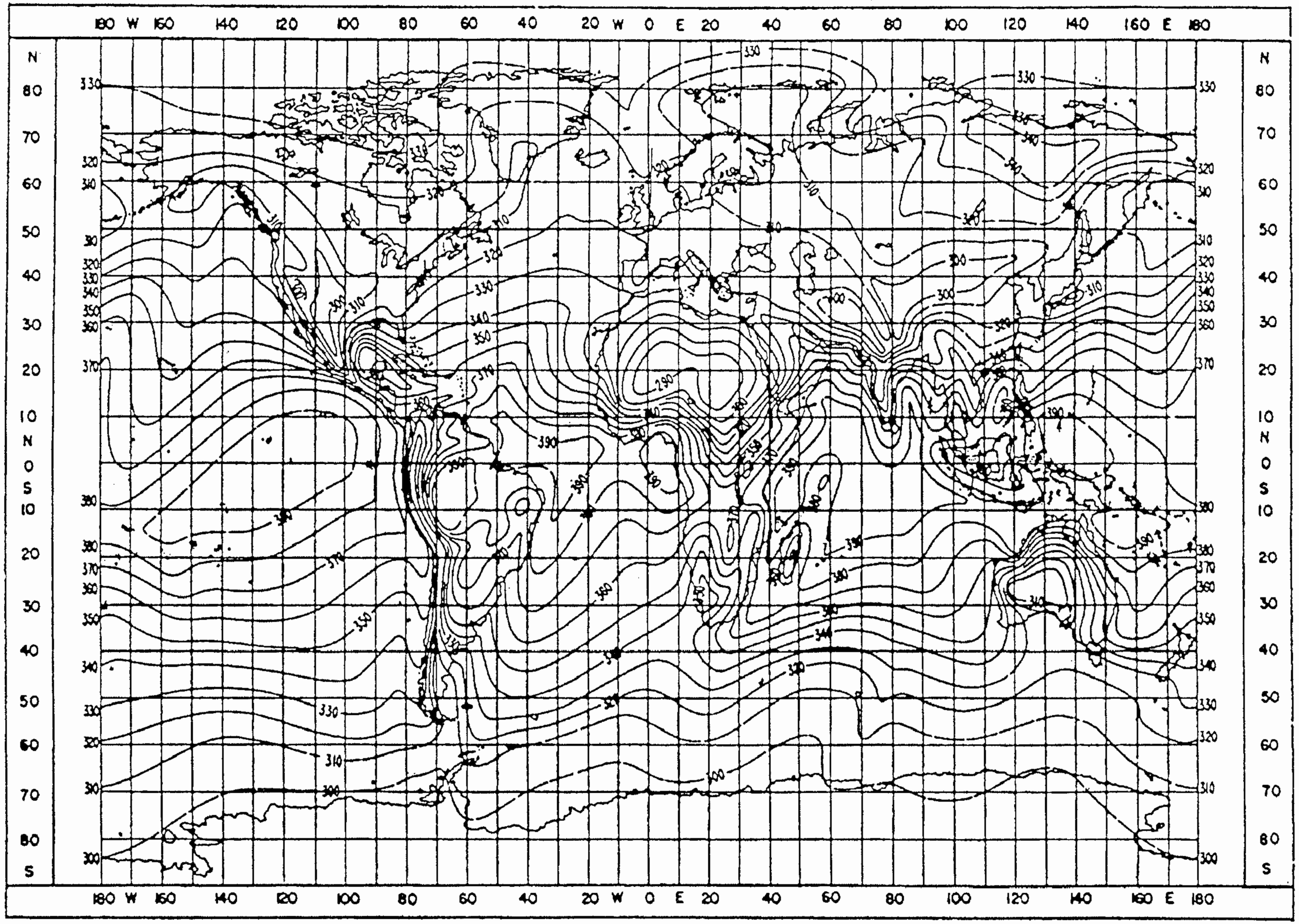


FIGURE 2

Monthly mean values of N_0: August

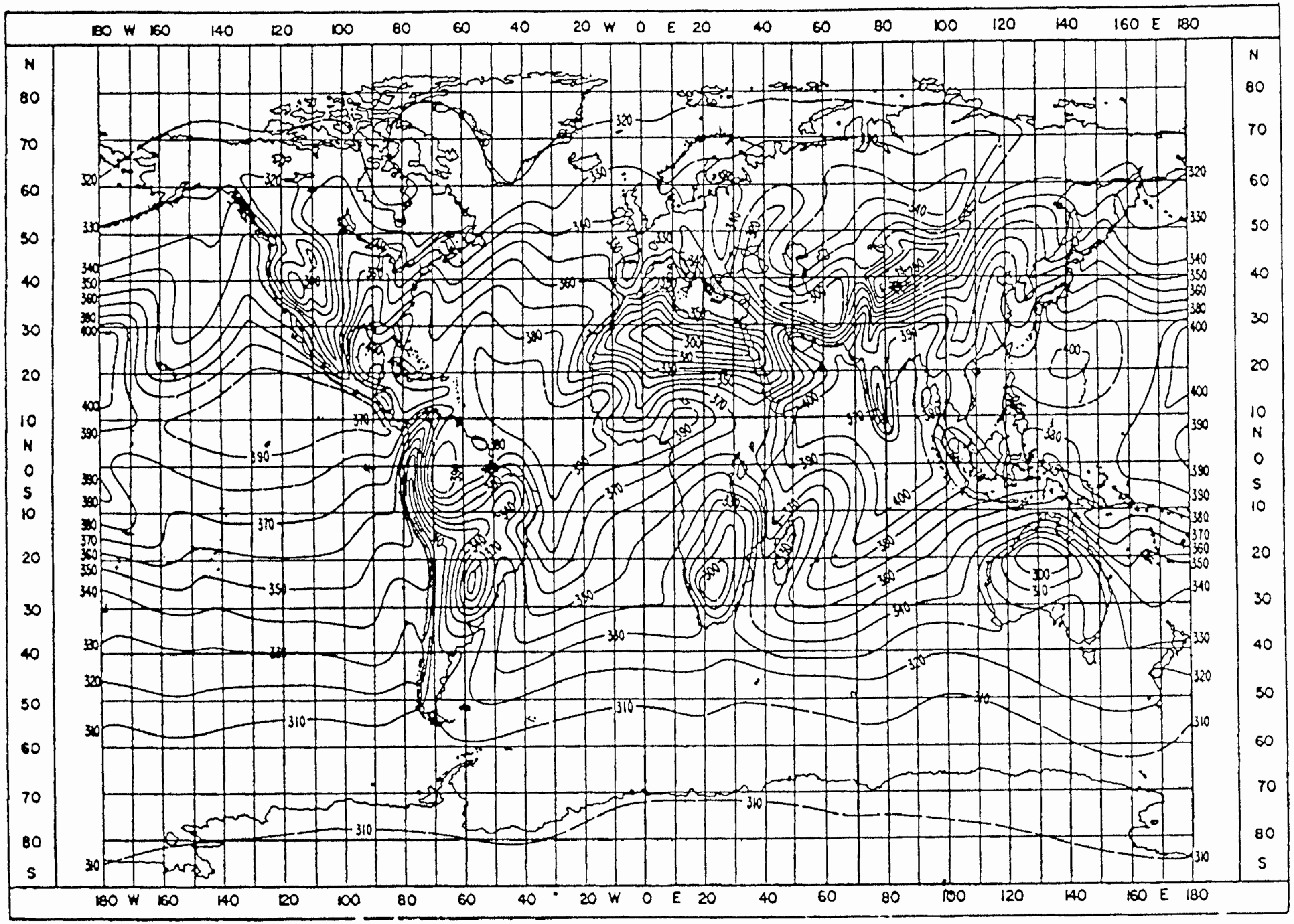


FIGURE 3

Monthly mean values of ΔN: February

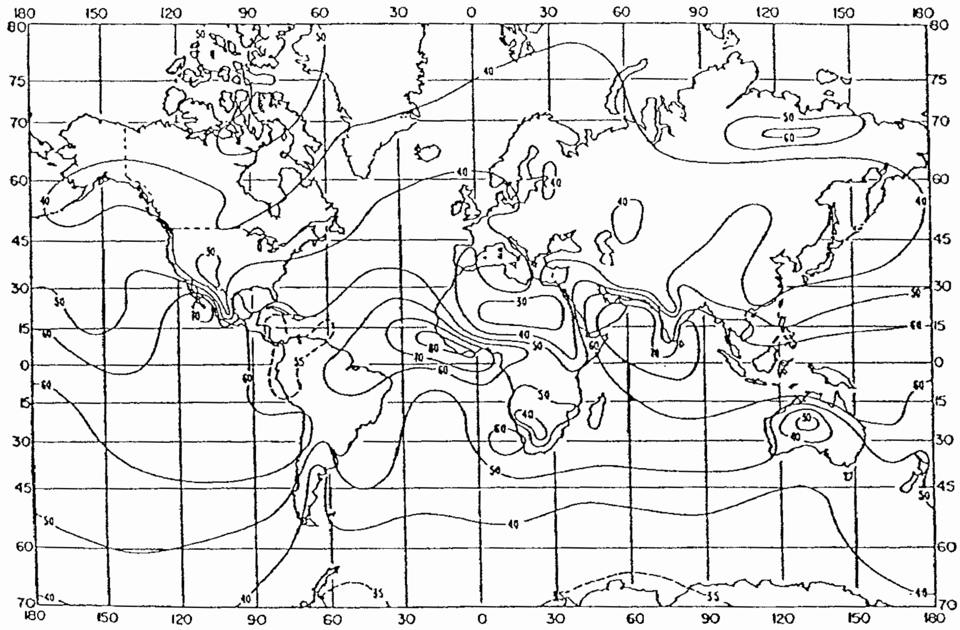
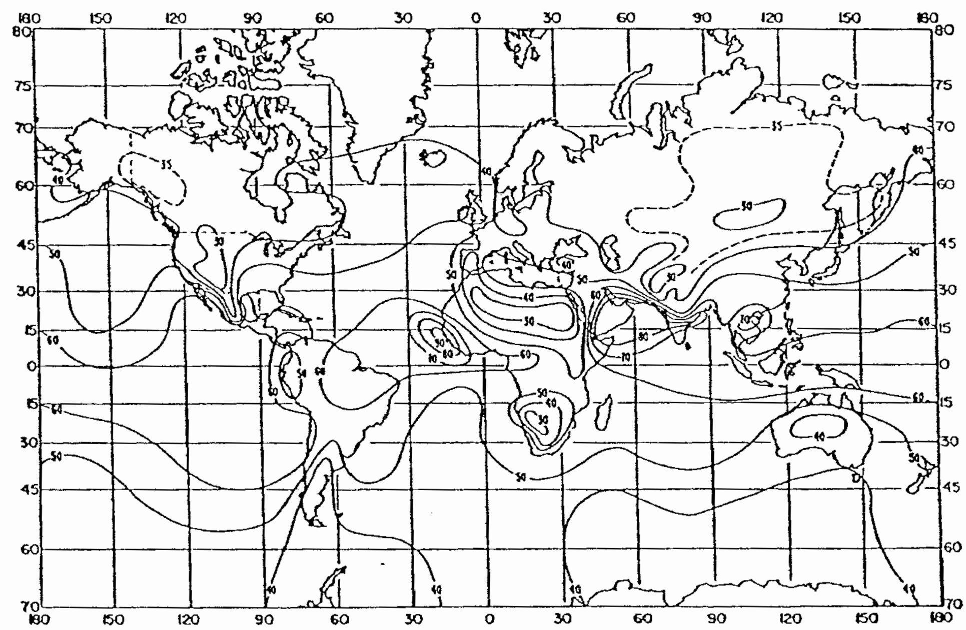


FIGURE 4

Monthly mean values of ΔN: May



0453-3-4

FIGURE 5

Monthly mean values of ΔN: August

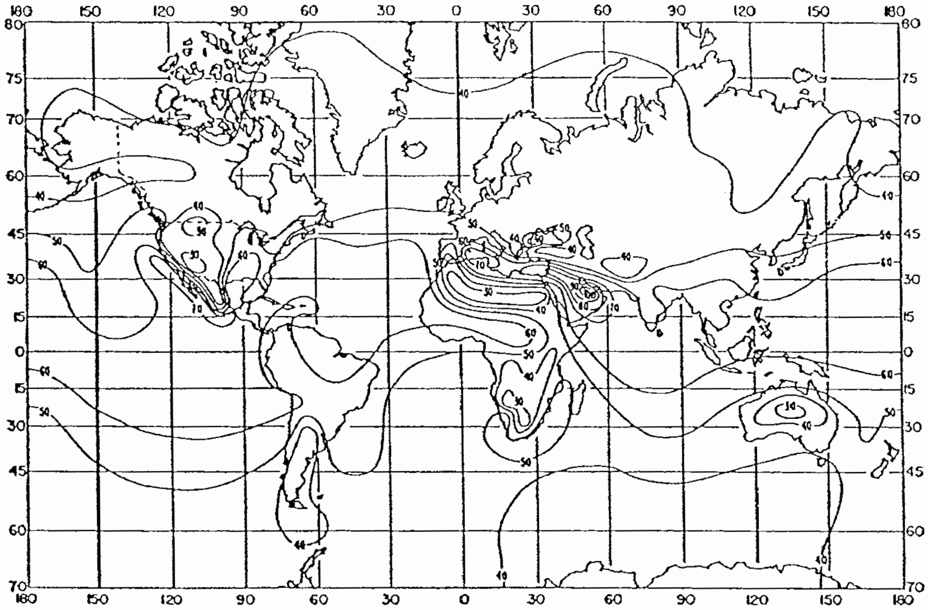
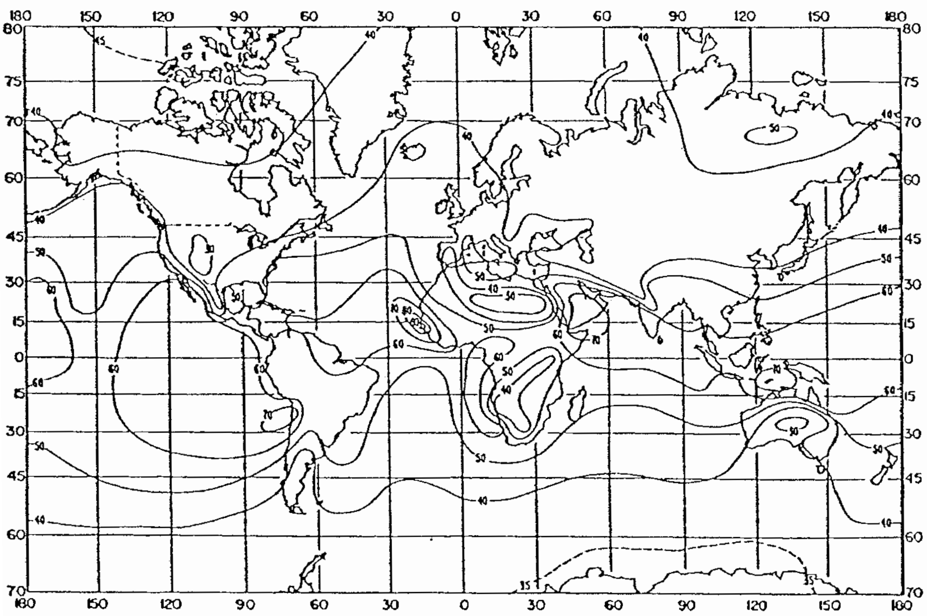


FIGURE 6

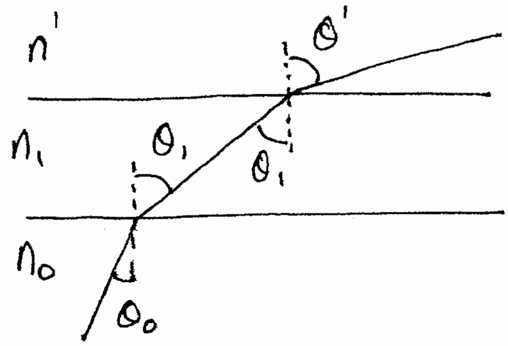
Monthly mean values of ΔN: November



0453-5-6

REFRACTION OVER A FLAT EARTH

SUPPOSE WE HAVE THE FOLLOWING SITUATION:



FROM SNELL'S LAW WE HAVE;

$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

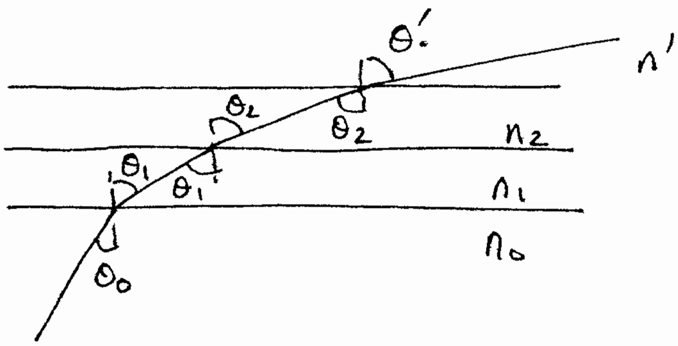
AND

$$n_1 \sin\theta_1 = n' \sin\theta'$$

HENCE $$n_0 \sin\theta_0 = n' \sin\theta'$$

THE DIRECTION OF TRAVEL OF THE WAVE IN REGION n' IS INDEPENDENT OF THE REFRACTIVE INDEX IN n_1, BEING FULLY DETERMINED BY ITS DIRECTION OF TRAVEL IN REGION n_0 AND BY THE RATIO OF n'/n_0

SUPPOSE WE ADD AN EXTRA LAYER SUCH THAT WE HAVE ...



WE NOW HAVE;

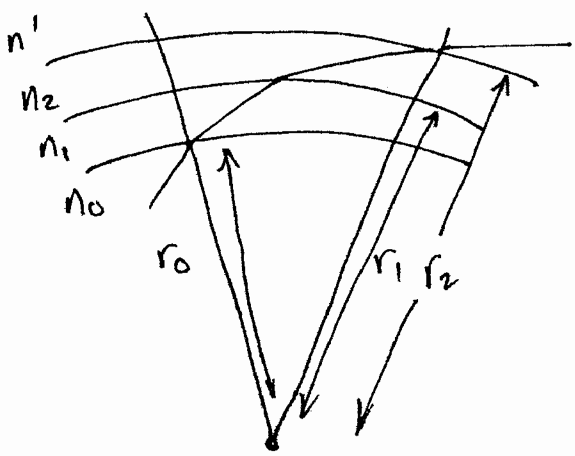
$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$n_2 \sin\theta_2 = n' \sin\theta'$$

AGAIN WE CAN END UP WITH $n_0 \sin\theta_0 = n' \sin\theta'$

IF WE USE AN INFINITE NUMBER OF INFINITESIMALLY THIN LAYERS WE STILL BY INDUCTION END UP WITH THE SAME $n_0 \sin\theta = n' \sin\theta'$

IN THIS CASE, THE WAVE FOLLOWS A CURVED PATH THROUGH OUR NOW NON HOMOGENEOUS MEDIUM $n(h)$ (OR $N(h)$)

REFRACTION OVER A SPHERICAL EARTH



FOR A SPHERICAL EARTH WE HAVE A SITUATION LIKE THIS

WILL A LITTLE TRIGONOMETRY WE CAN SHOW THAT WE CAN WRITE;

$$n_0 r_0 \sin\theta_0 = n' r_2 \sin\theta'$$

HENCE WE CAN WRITE THIS AS;

$$n(h)\,(h + R'_E)\cos\alpha(h) = k$$

WHERE;

$n(h)$ - REFRACTIVE INDEX AS A FUNCTION OF HEIGHT h.

α - ELEVATION ANGLE OF RAY W.R.T HORIZONTAL

k - IS A CONSTANT ALONG A RAY

R'_E - RADIUS OF THE EARTH.

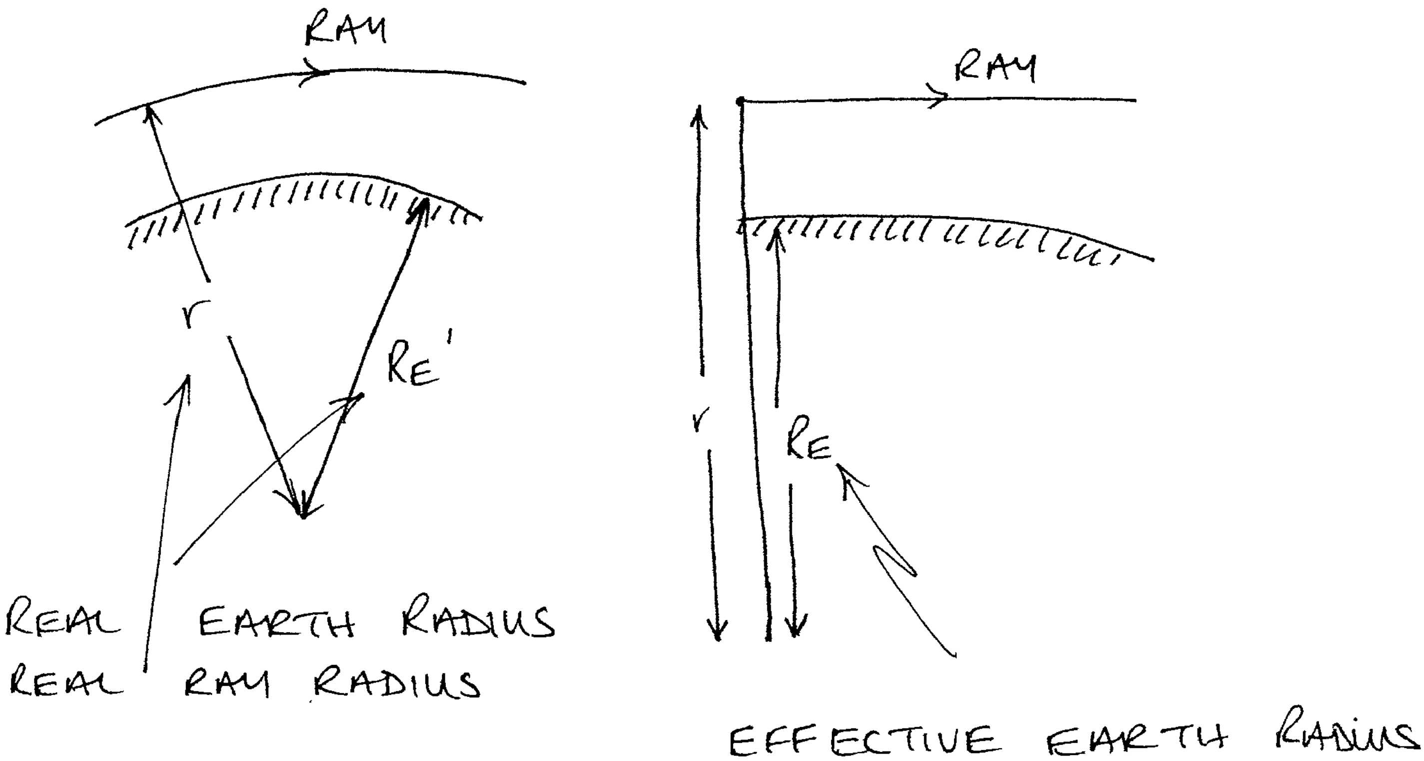
IT MAY BE SHOWN THAT FOR A VERTICAL GRADIENT OF REFRACTIVE INDEX dn/dh THE RAYS ARE REFRACTED TOWARDS THE REGION OF HIGHER REFRACTIVE INDEX WITH CURVATURE r SO;

$$\frac{1}{r} = \frac{1}{n}\frac{dn}{dh}\cos(\alpha)$$

UNDER THE ASSUMPTION OF CONSTANT REFRACTIVE INDEX GRADIENT OVER SOME HEIGHT INTERVAL WE CAN EXPRESS THE CURVATURE RELATIVE TO THE CURVATURE OF THE EARTH. WITH $\alpha = 0$ AND $n \simeq 1$ WE CAN WRITE;

$$\frac{1}{R_E} = \frac{1}{R_E'} - \frac{1}{r} = \frac{1}{R_E'} + \frac{dn}{dh}$$

GRAPHICALLY IT LOOKS LIKE THIS.



WE CAN DEFINE k_e - THE EFFECTIVE EARTH RADIUS FACTOR;

$$k_e = \frac{R_E}{R_E'}$$

EFFECTIVE EARTH RADIUS

REAL EARTH RADIUS

FROM OUR STANDARD ATMOSPHERE WE CAN DEDUCE (FOR $\Delta N = -40 N\ km^{-1}$) THAT $k = 4/3$ CORRESPONDS TO "STANDARD CONDITIONS"

FROM THE DEFINITION OF "N" WE CAN WRITE

$$\frac{1}{R_E} = \left(157 + \frac{dN}{dh}\right) \times 10^{-6}$$

$$R_E' \cong 6400\,\text{km}; \; R_E = \frac{4}{3}\,6400 \simeq 8500\,\text{km}$$

$$\left[157 \simeq \frac{1}{6400} \times 10^{6}\right]$$

WE CAN DEFINE THREE REGIONS DEPENDING ON $\frac{dN}{dh}$

DUCTING REGION: $\frac{dN}{dh} < -157$

SUPER REFRACTION REGION: $\frac{dN}{dh}$ BETWEEN -157 AND -4

SUBREFRACTION REGION: $\frac{dN}{dh} > -40$

WE ALSO DEFINE A MODIFIED REFRACTIVE INDEX M;

$$M = N + \frac{h}{R_E'} \times 10^{6}$$

OR

$$\frac{dM}{dh} = \frac{dN}{dh} + 157 \quad N\,\text{km}^{-1}$$