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AUTUMN COLLEGE

ON

THE TROPOSPHERE, STRATOSPHERE AND MESOSPHERE

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MEASURING TECHNIQUES AND MEASUREMENTS

(continuation)

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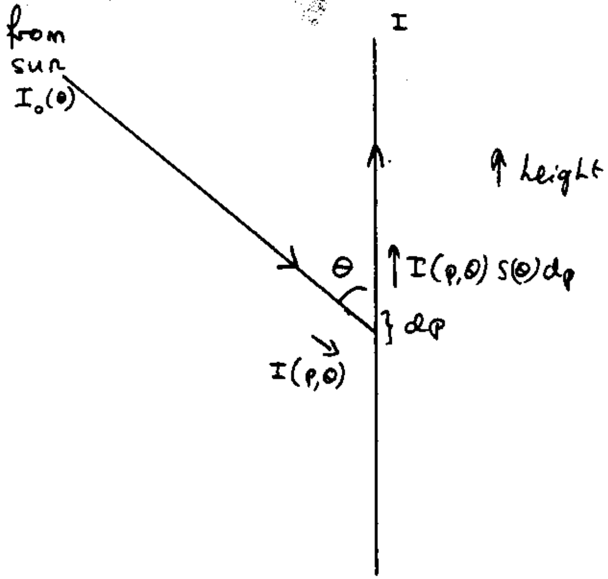
Backscatter Ultra Violet (BUV) instruments.



Radiation from sun travels to level p.

Absorption by absorber
Beam loses energy by Rayleigh Scattering

$$I(p,\theta) = I_o(\theta)\, e^{\underbrace{-\sigma\chi(p)\sec\theta}_{\text{gaseous absorption}}\ \underbrace{-\alpha p\sec\theta}_{\text{scattering loss}}}$$

scattering loss (proportional to mass of gas above p i.e. to p)

where $\chi(p)$ is mass of absorber above p
σ and α are absorption and scattering coefficients.

S, I_o, σ, α are functions of wavelength

let $S(\theta)$ be scattering coefficient

Radiation scattered upwards $= I(p,\theta)\, S(\theta)\, dp$

Now consider absorption on upward (vertical) path

$$dI = I(p,\theta)\, S(\theta)\, e^{-\chi(p) - \alpha p}\, dp$$

dI is element of I arising from scattering at level p

$$dI = I_o\, S(\theta)\, e^{-(\sigma\chi(p) + \alpha p)(1+\sec\theta)}\, dp$$

The αp term is generally much smaller than $\sigma\chi(p)$ and we will ignore it for a simple treatment.

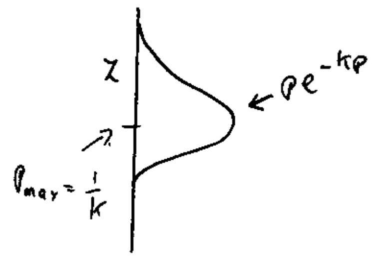
Thus the total upward radiation is given by

$$I(\nu) = I_o(\nu)\, S(\theta,\nu) \int_0^{p_o} e^{-\sigma\chi(p)(1+\sec\theta)}\, dp$$

Consider ~~usi~~ constant mixing ratio $\chi(p) \propto p$
change vertical coordinate to $z = -\log p$

$$dz = -\frac{dp}{p}$$

$$\Rightarrow\ I(\nu) = I_o(\nu)\, S(\theta,\nu) \int_0^{\infty} p\, e^{-kp}\, dz \qquad (k = \sigma(1+\sec\theta))$$



This weighting function shows which scattering levels are most important in contributing to total radiation.

Suppose we measure $I(\nu, \theta)$ at several ν and constant θ. Choose ν, so that scattering occurs at different levels.

Solutions :

I <u>change vertical coordinate to χ</u>

$$I(\nu) = I_0(\theta,\nu)\, S(\theta) \int e^{-K_\nu \chi} \frac{dp}{d\chi}\, d\chi$$

(we have replaced $\sigma_\nu(1+\sec\theta)$ by K_ν; note that θ is fixed).

Regard I as function of K (rather than ν)

$I(k)$ is Laplace transform of $\frac{dp}{d\chi}$

– find inverse to get $\frac{dp}{d\chi}$ and χ, in principle.

II <u>Linearise about standard mixing ratio profile.</u>

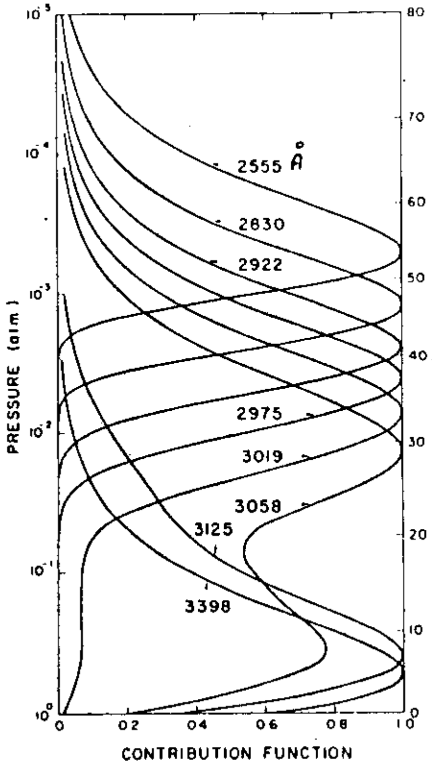
put $\chi(p) = \bar{\chi}(p) + \chi'(p)$

$$I(\nu) = I_0(\nu)\, S(\theta,\nu) \int e^{-K(\nu)\bar{\chi}(p)}\, e^{-K(\nu)\chi'(p)}\, dp$$

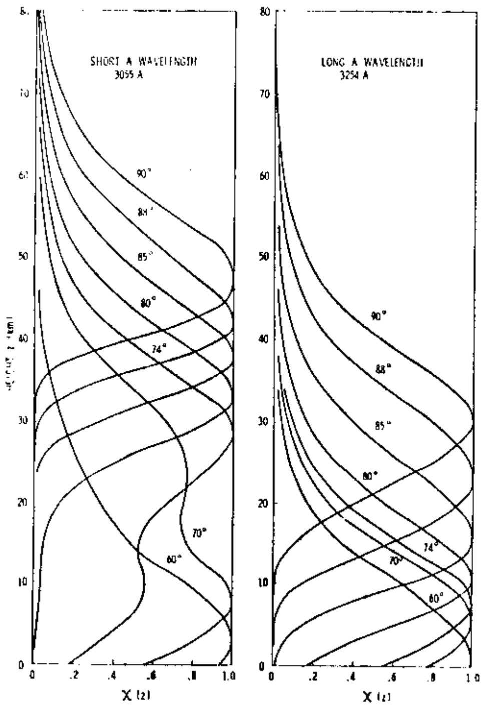
$$= \underbrace{I_0(\nu)\, S(\theta,\nu) \int e^{-K(\nu)\bar{\chi}(p)}\, dp}_{\bar{I}(\nu)} - \int \underbrace{e^{-K(\nu)\bar{\chi}(p)}\, K(\nu)}_{\text{weighting function}} \chi'(p)\, dp$$

This time weighting function gives sensitivity of I to χ changes

as before like $p e^{-ap}\, d\ln p$



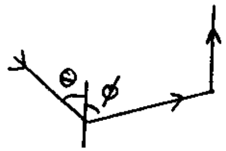
BUV weighting functions
$\theta = 60°$ 336 m atm-cm total ozone.
<u>All orders of scattering</u>



Ground-based Umkehr weighting functions various θ

<u>Multiple Scattering</u>

Below about 30 km get significant return from multiple scattering.
Effects difficult to calculate.
Limit retrieval to about this level



<u>Total Ozone</u> measured by reflection off clouds – use 2 wavelengths absorbed to different extent by O_3.

BUV used 2 pairs (A) 3125 Å, 3312 Å
(B) 3175 Å, 3398 Å

to cover range of solar zenith angle 0–90°

<u>Total Ozone retrieval</u>

Take family of profiles, various Θ.
Calculate radiances for each. – obtain table.
To retrieve pair of measurements – look up in table.

<u>BUV Expt.</u> Nimbus 4 1972 – approx 1980
monochromator 2500 – 3400 Å

Designed to use sun or moon light, but Van Allen radiation belts gave spurious signals stronger than moonlight.

<u>SBUV/TOMS.</u> improved BUV. 2500 – 3300 Å
Nimbus 7. 12 wavelengths 10 Å bandpass.
1978 – now profile 28 – 55 km plus total troposphere too

TOMS is imaging total O_3
6 wavelengths 3100 – 3800 Å.

SBUVs also will fly on Tiros – N series

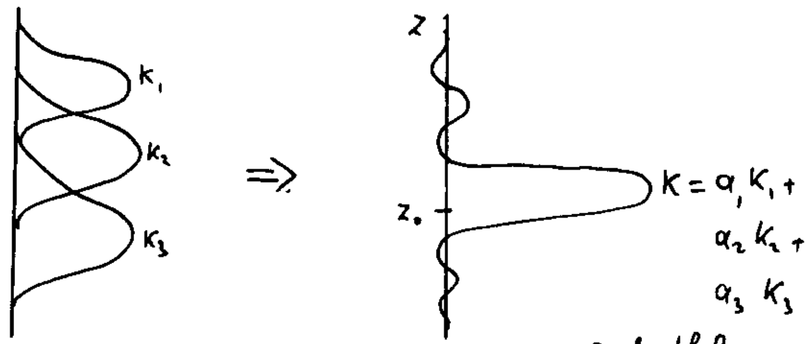
<u>Temperature Retrieval Theory.</u>

Complex subject. See review by Rodgers (1976) Rev. Geophys. Space Phys. 14, 609 – 624.

1) <u>Backus – Gilbert weighting function combinations</u>

see Conrath J. Atmos. Sci. 29, 1262 – 1271 (1972)

Synthesize narrow weighting function from linear combination:



such that $a_1 + a_2 + a_3 = 1$

Suppose require weighting function centred at z_0.

To find minimum width can minimize $\int K^2(z)(z - z_0)^2\,dz$

If all channels have noise variance σ^2,

Combined noise $= \sigma^2 (a_1^2 + a_2^2 + a_3^2)$.

Minimize $\lambda \int (z - z_0)^2 K^2(z)\,dz + (1 - \lambda) \sum a_i^2$

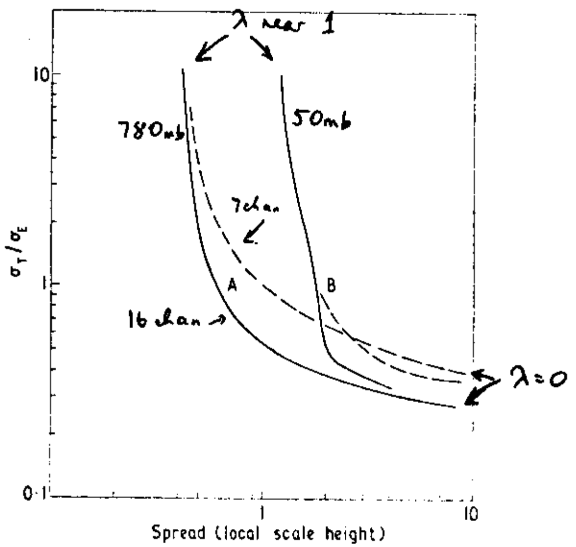
where $0 \le \lambda \le 1$ and $\sum a_i = 1$.

$\lambda = 1$ gives minimum width (whatever noise)

$\lambda = 0$ gives minimum noise (whatever width).

$\lambda = 0$ gives $a_1 = a_2 = a_3 = 1/3$ i.e. very broad weighting function.

different λ give points on trade off curve.



Trade-off diagram. Error σ_T in temperature measurement compared with noise equivalent temperature of radiometer σ_E as a function of vertical resolution (for definition of spread see text) for IRIS instrument. Curves A for 780 mbar, and curves B for 50 mbar. Full lines, 16 channels; broken lines, 7 channels. From Conrath (1972).

must compromise and use coefficients which give desired width and noise.

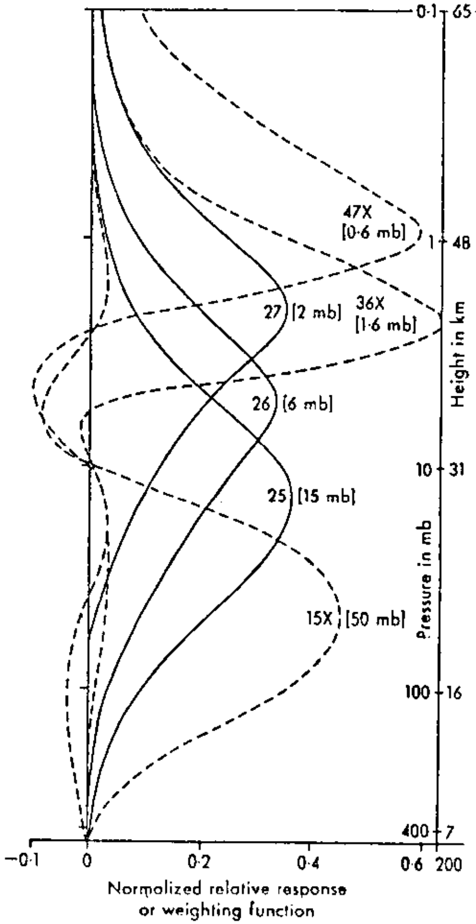
As $\lambda \to 1$ width gets narrow very slowly
noise rises very fast.

use of Backus-Gilbert combinations:

a) good way to analyse and understand instrument response

b) sometimes need to synthesize narrow channel; when do not want to do full retrieval.

e.g. Nash used channels 15X, 36X, 47X obtained by combining SSU ch 25, 26, 27 $\Rightarrow$



2) Statistical methods.

Previously discussed theory of least square fits. m observations
n quantities fitted.

$m = n$ ⇒ exact solution
can be noise problems

$m > n$ least squares fit

minimize $\Sigma (\underset{\text{obs}}{I_i} - \underset{\text{retrieved}}{I_i^r})^2$

$m < n$ possible if supply extra information
e.g. atmospheric statistics.

important approach is to assume Gaussian statistics and maximize probability of profile.

Probability $\propto e^{-A}$ where

$$A = \underbrace{(\underset{\text{observed}}{\underline{I}} - \underset{\text{retrieved}}{\underline{I}^r})^T \underline{E}^{-1} (\underline{I} - \underline{I})}_{\text{probability of } \underline{I} \text{ being consistent with } \underline{I}^r} + \underbrace{(\underset{\text{retrieved}}{\underline{B}} - \underset{\text{climatology}}{\underline{\bar{B}}})^T \underline{S}^{-1} (\underline{B} - \underline{\bar{B}})}_{\text{probability of } \underline{B} \text{ given mean is } \underline{\bar{B}}}$$

$\underline{E}$ is instrument noise covariance

$\underline{S}$ is atmospheric variation covariance matrix

$$\underset{m \times m}{E_{ij}} = \overline{(I_i - I_i')(I_j - I_j')}$$

I_i' is true radiance
I_i is measured "
(differ by radiometric noise)

$$\underset{n \times n}{S_{ij}} = \overline{(B_i - \bar{B}_i)(B_j - \bar{B}_j)}$$

$\overline{}$ means long term mean

$\bar{B}$, $\bar{E}$ and $\bar{S}$ would be precomputed

Typically E diagonal
S diagonally dominant if B_i, B_j are Planck function at various levels.

Result of maximising probability, i.e. minimiz A is

$$\underline{B} = \underline{\bar{B}} + S K^T (K S K^T + E)^{-1} (\underline{I} - \underbrace{\underline{K}\underline{\bar{B}}}_{= \bar{I}})$$

Can iterate if K is temperature dependent but must think carefully about noise and meaning of statistics.