"MIDDLE ATMOSPHERE RADAR TECHNIQUES"

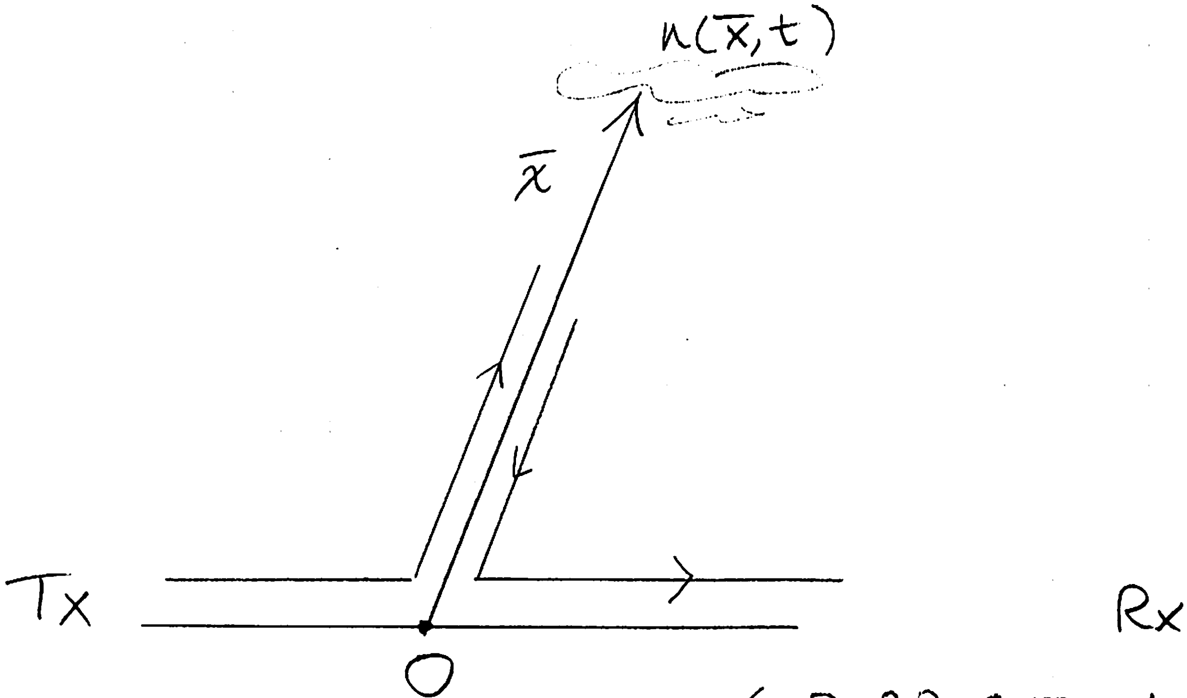
ERHAN KUDEKI

JUNE 1992

OUTLINE

1) RADAR SIGNAL & SPECTRUM MODELS.
2) DOPPLER BEAM SCANNING.
3) CROSS-SPECTRUM MODEL AND INTERFEROMETRY / SPACED ANTENNA.
4) CRITICAL ASSESSMENT OF AVAILABLE TECHNIQUES.

RADAR SIGNAL MODEL



SUPERPOSITION OF:

$$p(t)e^{j\omega_0 t} + c.c. \qquad p\left(t-\frac{2|\bar{x}|}{c}\right)e^{j\omega_0\left(t-\frac{2|\bar{x}|}{c}\right)}a(\bar{x})\,n\left(\bar{x},t-\frac{|\bar{x}|}{c}\right) + c.c.$$

COHERENTLY DETECTED
COMPLEX RADAR SIGNAL:

$$s(t) \equiv i(t) + j\,q(t)$$

$$= \int d\bar{x}\; a(\bar{x})\; p\left(t-\frac{2|\bar{x}|}{c}\right) n\left(\bar{x},t-\frac{|\bar{x}|}{c}\right) e^{-j2k_0|\bar{x}|}$$

SIGNAL POWER

$$S \equiv \langle |s(t)|^2 \rangle$$
$$= \int d\bar{x}' \int d\bar{x}'' \ldots e^{-j2k_o(|\bar{x}'|-|\bar{x}''|)}$$
$$\times \left\langle n\left(\bar{x}', t-\frac{|\bar{x}'|}{c}\right) n^*\left(\bar{x}'', t-\frac{|\bar{x}''|}{c}\right)\right\rangle$$

USING: $\bar{x}' = \bar{x} - \frac{\bar{r}}{2}$, $\bar{x}'' = \bar{x} + \frac{\bar{r}}{2}$

$$\Phi_n(\bar{k}) = \int d\bar{r}\, e^{-j\bar{k}\cdot\bar{r}} \left\langle n\left(\bar{x}-\frac{\bar{r}}{2}, t\right) n^*\left(\bar{x}+\frac{\bar{r}}{2}, t\right)\right\rangle$$

IT FOLLOWS

$$\underline{S = \int d\bar{x}\; B(\bar{x})}$$

$$B(\bar{x}) = |a(\bar{x})|^2 \left|p\left(t - \frac{2|\bar{x}|}{c}\right)\right|^2 \Phi_n\left(2k_o \frac{\bar{x}}{|\bar{x}|}\right)$$

SIGNAL SPECTRUM

1) FROZEN - IN MODEL

ASSUME :

IRREGULARITIES ARE ADVECTED WITH SOME WIND VELOCITY $\bar{u}$

$\Rightarrow$ DOPPLER SHIFT FROM $\omega_0 = -2 \frac{\omega_0}{c} \frac{\bar{x}}{|\bar{x}|} \cdot \bar{u}$

THEN SIGNAL SPECTRUM

$$\Phi_s(\omega) = \int d\bar{x} \; \delta\left(\omega + 2k_0 \frac{\bar{x}}{|\bar{x}|} \cdot \bar{u}\right) B(\bar{x})$$

BY EXCLUDING FROM THE INTEGRAL OF $B(\bar{x})$ ALL $\bar{x}$ FOR WHICH

$$\omega \neq -2k_0 \frac{\bar{x}}{|\bar{x}|} \cdot \bar{u}$$

2) LOCALLY FROZEN-IN MODEL

LET:

$$\bar{u} = \bar{U}_0 + \bar{u}', \qquad \langle \bar{u}' \rangle = 0$$

$$\Rightarrow \quad 2k_0 \frac{\bar{x}}{|\bar{x}|} \cdot \bar{u} = 2k_0 \frac{\bar{x}}{|\bar{x}|} \cdot \bar{U}_0 - \omega'$$

$$\omega' \equiv -2k_0 u_r', \qquad u_r' \equiv \frac{\bar{x}}{|\bar{x}|} \cdot \bar{u}'$$

$$\Phi_s(\omega) = \int d\omega' \, f(\omega') \int d\bar{x} \, \delta\!\left(\omega + 2k_0 \frac{\bar{x}}{|\bar{x}|} \cdot \bar{U}_0 - \omega'\right) B(\bar{x})$$

$$f(\omega') = \frac{g(\omega'/2k_0)}{2k_0}$$ ← PDF FOR ω' WITH WIDTH $2k_0\sigma_u$

$g(u_r')$ ← PDF FOR u_r' WITH WIDTH σ_u

$$\Phi_S(\omega) = \Phi_I(\omega) * \Phi_F(\omega)$$

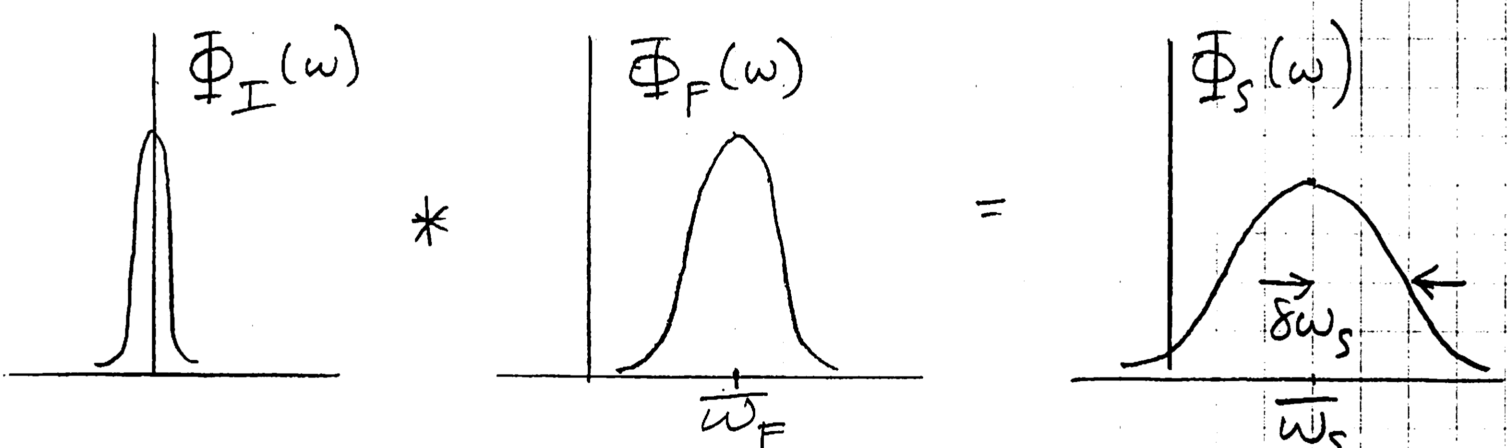
$$\Phi_I(\omega) = f(\omega)$$ "INTRINSIC SPECTRUM"

$$\overline{\omega_I} = 0, \quad \delta\omega_I = 2k\sigma_u$$

$$\Phi_F(\omega) = \int d\bar{x}\, \delta\left(\omega + 2k_0 \frac{\bar{x}}{|\bar{x}|}\cdot\bar{u}_0\right) B(\bar{x})$$

"FROZEN-IN SPECTRUM"

$$\overline{\omega_F}, \quad \delta\omega_F$$



$$\overline{\omega_S} = \overline{\omega_F}, \quad \delta\omega_S = \sqrt{(2k_0\sigma_u)^2 + \delta\omega_F^2}$$

FROZEN-IN SPECTRUM

FOR: $\overline{u}_0 = u\hat{x} + w\hat{z}$

& A VERTICALLY POINTED RADAR BEAM WITH $B(\overline{x})$ CENTERED AT $z_0\hat{z}$

$$\Phi_F(\omega) = \int d\overline{x}\ \delta\left(\omega + 2k_0 \frac{\overline{x}}{|\overline{x}|}\cdot\overline{u}_0\right) B(\overline{x})$$

$$\cong \int dx \int dy \int dz\ \delta\left(\omega + \frac{2k_0(xu + zw)}{z_0}\right) B(x,y,z)$$

$$\propto B_x\left(-\frac{z_0}{2k_0 u}(\omega + 2k_0 w)\right)$$

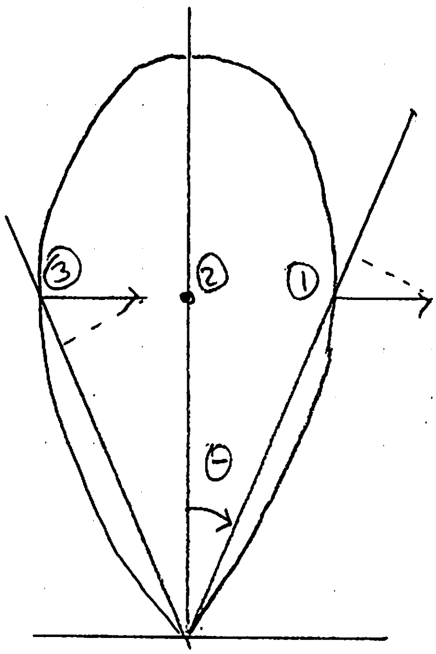
$$B_x(x) = \int dy \int dz\ B(x,y,z)$$

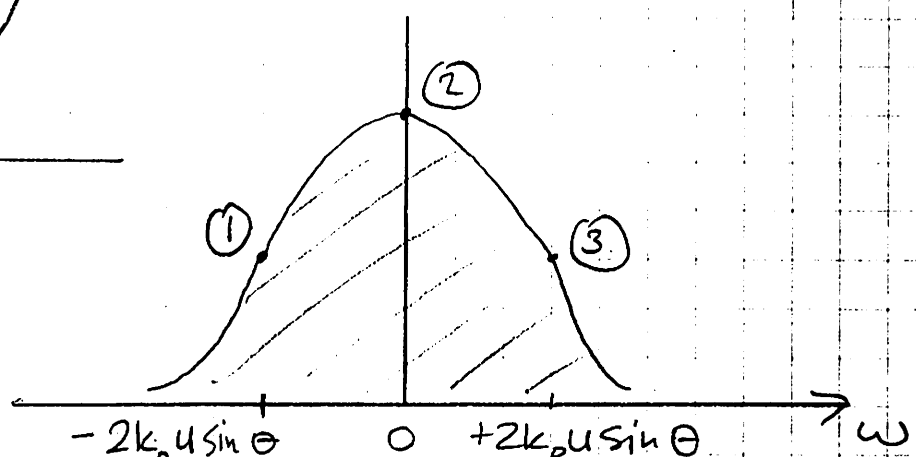
$$\Rightarrow \quad \overline{\omega}_F \cong -2k_0 w \qquad \delta\omega_F \cong 2k_0 |u| \frac{\sigma_x}{z_0}$$

$W=0$, u = FINITE

$V_R = u \sin\theta$

$$\omega = -2k_0 V_R$$
$$= -2k_0 u \sin\theta$$





$2k_0 |u| \sigma_x / z_0$

WITH FINITE W

SPECTRUM SHIFTED BY $-2k_0 W$

WITH FINITE σ_u

FROZEN-IN SPECTRUM IS TURBULENCE BROADENED.

SUMMARY

$$s(t) \longrightarrow \Phi_s(\omega)$$

- $S \equiv \langle \omega^0 \rangle = \int d\omega \; \Phi_s(\omega)$

- $\bar{\omega}_s = \langle \omega^1 \rangle = \int d\omega \; \omega \, \Phi_s(\omega) / S = -2k_0 V_R$

- $\delta\omega_s = \langle (\omega - \bar{\omega}_s)^2 \rangle^{1/2}$

$$= \left\{ \int d\omega \; (\omega - \bar{\omega}_s)^2 \, \Phi_s(\omega) / S \right\}^{1/2}$$

$$= 2k_0 \sqrt{\sigma_u^2 + V_c^2 \tan^2 \theta}$$

V_R – RADIAL WIND VELOCITY

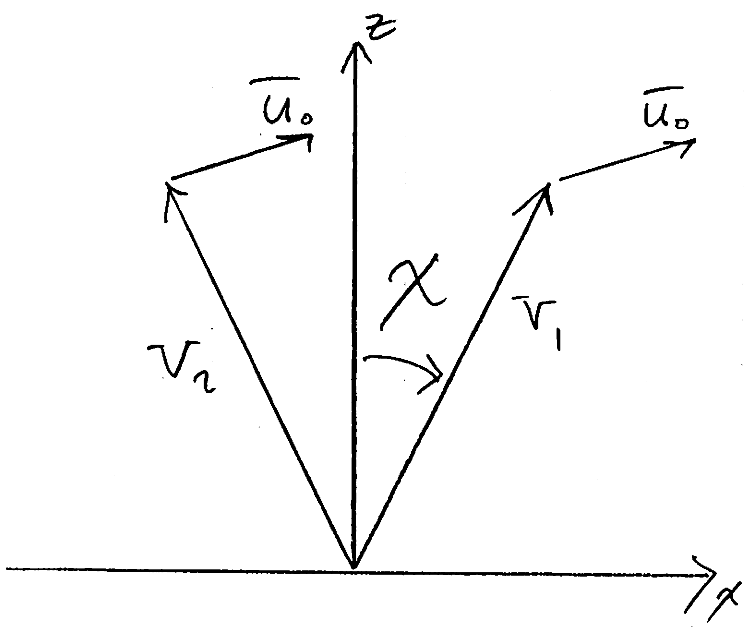
V_c – CROSS BEAM WIND VELOCITY

σ_u – RMS VALUE OF WIND FLUCTUATIONS

θ – EFFECTIVE RADAR BEAMWIDTH

DOPPLER BEAM SCANNING

- MULTIPLE RADAR BEAMS FOR MULTIPLE V_R MEASUREMENTS TO SYNTHESIZE VECTOR WIND COMPONENTS u, v, w:



$$V_1 = u \sin\chi + w \cos\chi$$

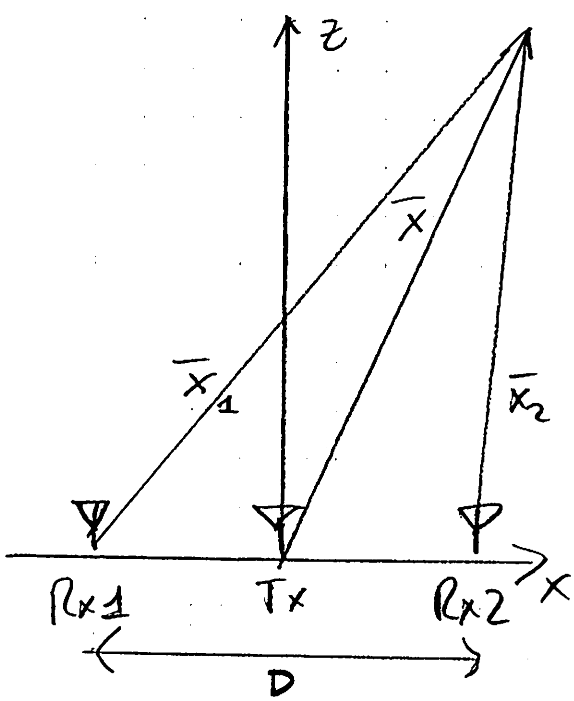
$$V_2 = -u \sin\chi + w \cos\chi$$

$$u = \frac{V_1 - V_2}{2 \sin\chi} \qquad w = \frac{V_1 + V_2}{2 \cos\chi}$$

- POSSIBLE ERRORS DUE TO ASPECT SENSITIVITY INDUCED BEAM OFFSETS AND SPATIAL VARIATION OF THE WIND FIELD.

INTERFEROMETRY / SPACED ANTENNA

- VERTICALLY POINTED BEAM
- MULTIPLE RECEIVING ANTENNA
- CROSS-SPECTRAL / CROSS-CORRELATION ANALYSIS



$$|\bar{x}_2| = |\bar{x}_1| - \frac{\bar{x} \cdot \hat{x} D}{|\bar{x}|}$$

$$\Rightarrow \phi_2 = \phi_1 + k_0 \frac{x D}{|\bar{x}|}$$

$$\Phi_{12}(\omega) = \int d\tau \, e^{j\omega\tau} \langle s_1(t) \, s_2^*(t+\tau) \rangle$$

$$= \int d\bar{x} \; \delta\left(\omega + 2k_0 \frac{\bar{x}}{|\bar{x}|} \cdot \bar{u}_0\right) B(\bar{x}) \, e^{-j k_0 x D / |\bar{x}|}$$

FROZEN-IN CROSS SPECTRUM MODEL

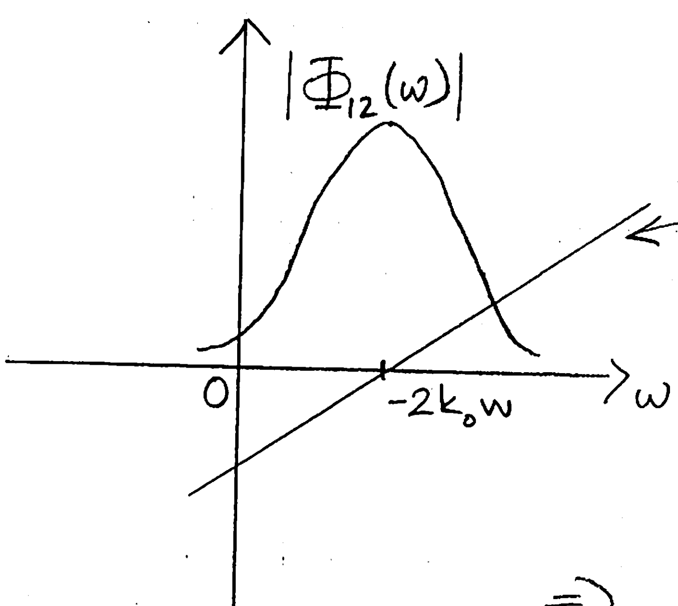
FOR $v = 0$

$$\Phi_{12}(\omega) = \int dx \; \delta\left(\omega + 2k_0 w + 2\frac{k_0 x u}{z_0}\right) B_x(x) e^{-jk_0 x D/z_0}$$

$$x_0(\omega) = -\frac{z_0}{2k_0 u}(\omega + 2k_0 w)$$

$$|\Phi_{12}(\omega)| \propto B_x\left(-\frac{z_0}{2k_0 u}(\omega + 2k_0 w)\right)$$

$$\angle \Phi_{12}(\omega) \equiv \phi_{12}(\omega) = \frac{D(\omega + 2k_0 w)}{2u}$$



$\phi_{12}(\omega)$

WITH SLOPE

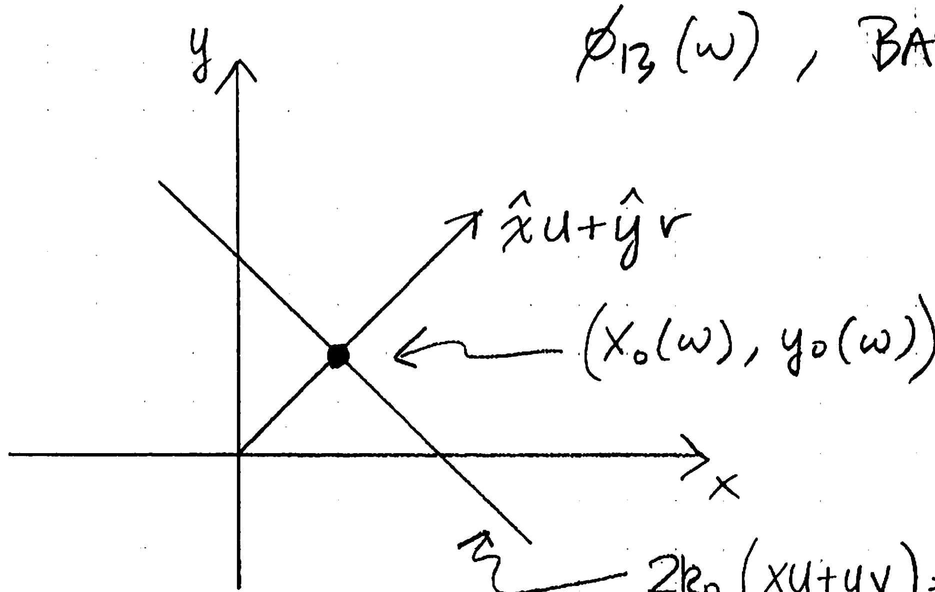
$$\frac{\partial \phi_{12}}{\partial \omega} \equiv \tau_{12}' = \frac{D}{2u}$$

$$\Rightarrow \quad u = \frac{D/2}{\tau_{12}'}$$

GENERAL CASE: $u \neq 0,\ v \neq 0$

3 ANTENNAS $\Rightarrow$ $\phi_{12}(\omega)$, BASELINE $D\hat{x}$
$\phi_{13}(\omega)$, BASELINE $D\hat{y}$

$z = z_0$
PLANE



$$\frac{2k_0}{z_0}(xu + yv) = -(\omega + 2k_0 W)$$

$$x_0(\omega) = \frac{-z_0\,\phi_{12}(\omega)}{k_0 D}, \qquad y_0(\omega) = \frac{-z_0\,\phi_{13}(\omega)}{k_0 D}$$

$$\frac{u}{v} = \frac{x_0(\omega)}{y_0(\omega)} = \frac{\dot{\phi}_{12}(\omega)}{\dot{\phi}_{13}(\omega)} = \frac{\tau_{12}'}{\tau_{13}'} \Rightarrow u = \frac{\tau_{12}'}{K},\ v = \frac{\tau_{13}'}{K}$$

$$\frac{2}{D}\left(\dot{\phi}_{12}\frac{\tau_{12}'}{K} + \dot{\phi}_{13}\frac{\tau_{13}'}{K}\right) = 1 \Rightarrow K = \frac{2}{D}\left({\tau_{12}'}^2 + {\tau_{13}'}^2\right)$$

$$\left\{ u = \frac{D}{2}\,\frac{\tau_{12}'}{{\tau_{12}'}^2 + {\tau_{13}'}^2},\quad v = \frac{D}{2}\,\frac{\tau_{13}'}{{\tau_{12}'}^2 + {\tau_{13}'}^2} \right\}$$

APPARENT VELOCITY ESTIMATORS

- FINITE σ_u
- $\Phi_n\left(2k_0 \frac{\underline{x}}{|\underline{x}|}\right)$ ANISOMETRIC IN (x, y)

$$\left(\phi_{12}(\omega), \phi_{13}(\omega)\right) \not\Rightarrow \left(x_0(\omega), y_0(\omega)\right)$$

APPARENT VELOCITY ESTIMATORS
ARE THEN BIASED.

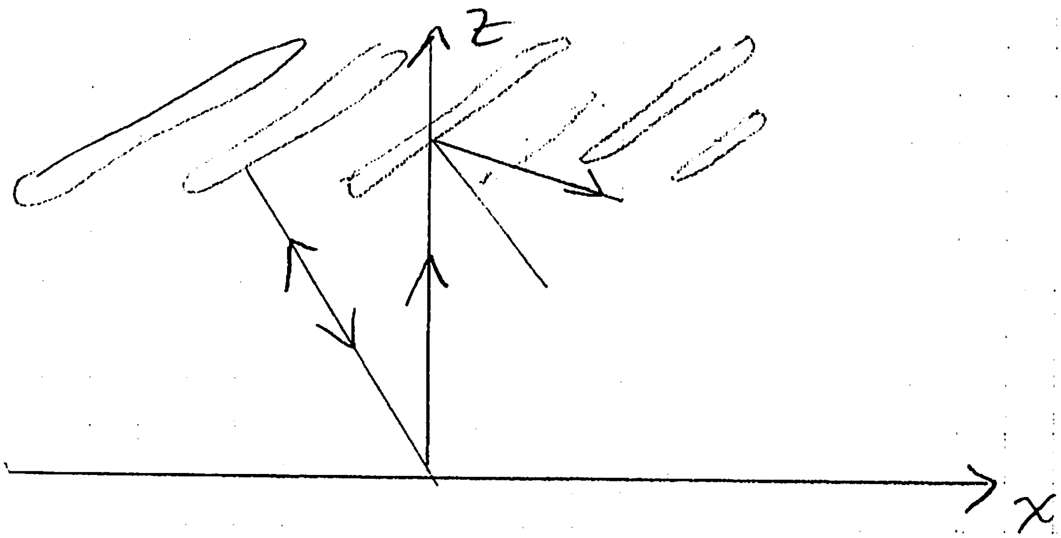
HOWEVER, UNBIASED u & v ESTIMATES
CAN STILL BE OBTAINED USING
"FULL CORRELATION ANALYSIS"
OR "FULL SPECTRUM ANALYSIS"
PROCEDURES:

$\Rightarrow$ u_{true}, v_{true}, σ_u, ASPECT SENSITIVITY.

E.G. BRIGGS, 1984,
MAP HANDBOOK # 13.

ASPECT SENSITIVITY ERRORS IN W-MEAS.

WHEN SCATTERING IRREGULARITIES ARE ELONGATED IN SOME TILTED PLANE



THE "EFFECTIVE RADAR BEAM" IS OFFSET TOWARDS ELONGATED STRUCTURES

$\Rightarrow$ A FINITE EFFECTIVE BEAM POINTING ANGLE θ.

$$\Rightarrow -\frac{\overline{\omega_s}}{2k_0} = V_R = u \sin\theta + w\cos\theta \neq w$$

HORIZONTAL WIND CONTAMINATION IN VERTICAL WIND ESTIMATES.

CORRECTION PROCEDURE
WHEN INTERFEROMETRY AVAILABLE:

- GIVEN $V_R = u\sin\theta + w\cos\theta$ FROM $\overline{\omega_s}$

GET u FROM FCA

" θ FROM $\angle S_{12}$

$$S_{12} = \langle s_1(t)\, s_2^*(t)\rangle = \int d\omega\, \Phi_{12}(\omega)$$

$$S_{12} = \int dx\, B_x(x)\, e^{-jk_0 x D/z_0}$$ FOR ANY σ_u

BY FOURIER SHIFT THM, IF $B_x(x)$ IS SYMMETRIC ABOUT $x = x_0$

$$\angle S_{12} = -k_0 \frac{D x_0}{z_0} \cong k_0 D\theta$$ FOR θ SMALL

OTHER INTERFEROMETRIC METHODS

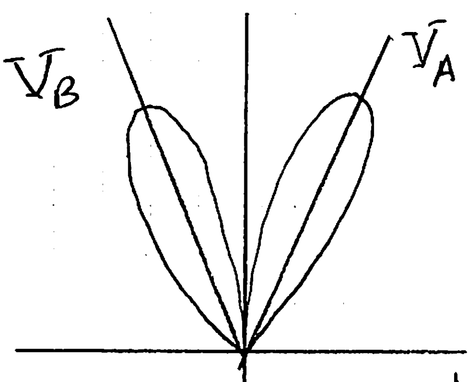
1) SOFTWARE BEAM SYNTHESIS

$$\left\{\begin{matrix} s_1(t) \\ s_2(t) \end{matrix}\right\} \longrightarrow \left\{\begin{matrix} s_A(t) = s_1(t)e^{-j\delta/2} + s_2(t)e^{+j\delta/2} \\ s_B(t) = s_1(t)e^{+j\delta/2} + s_2(t)e^{-j\delta/2} \end{matrix}\right\}$$

$$\downarrow \qquad\qquad\qquad \downarrow$$

$$\left\{\begin{matrix} \Phi_1(\omega) \\ \Phi_2(\omega) \\ \Phi_{12}(\omega) \end{matrix}\right\} \longrightarrow \left\{\begin{matrix} \Phi_A(\omega) = \Phi_1(\omega) + \Phi_2(\omega) + 2\,\mathrm{Re}\left\{\Phi_{12}(\omega)e^{j\delta}\right\} \\ \Phi_B(\omega) = \Phi_1(\omega) + \Phi_2(\omega) + 2\,\mathrm{Re}\left\{\Phi_{12}(\omega)e^{-j\delta}\right\} \end{matrix}\right\}$$

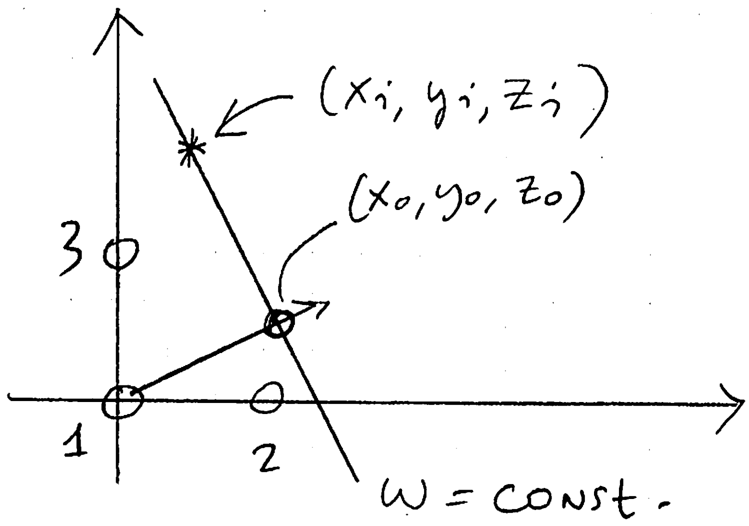
SOFTWARE STEERING OF RECEPTION BEAMS TO $\pm\Theta(\delta)$ TO OBTAIN TWO UNIQUE RADIAL VELOCITIES V_A & V_B



PROCEED AS IN DOPPLER WIND MEASUREMENTS

NO BIASES DUE TO V_u, BUT ASPECT SENSITIVITY RELATED ERRORS POSSIBLE

2) IMAGING DOPPLER INTERFEROMETRY



$$\begin{Bmatrix} s_1(t) \\ s_2(t) \\ s_3(t) \end{Bmatrix} \xrightarrow[FT]{} \begin{Bmatrix} s_1(\omega) \\ s_2(\omega) \\ s_3(\omega) \end{Bmatrix} \quad \underbrace{\begin{matrix} S_{12}(\omega) = S_1(\omega)\, S_2^*(\omega) \\ S_{13}(\omega) = S_1(\omega)\, S_3^*(\omega) \end{matrix}}_{\text{SAMPLE CROSS SPECTRA}}$$

$$\angle S_{12}(\omega_i), \quad \angle S_{13}(\omega_i), \quad r = \sqrt{x_i^2 + y_i^2 + z_i^2}$$

$$\Rightarrow \underbrace{\left(V_i = -\frac{\omega_i}{2k_0}, \quad x_i, y_i, z_i \right)}_{\text{A RADIAL VELOCITY \& EFFECTIVE BEAM DIRECTION}}$$

PROCEEDING AS IN MULTIPLE BEAM DOPPLER WIND TECHNIQUE,

$$V_i = \frac{x_i}{r_i} u + \frac{y_i}{r_i} v + \frac{z_i}{r_i} w \quad , \quad i = 1, \cdots N$$

$$r_i = \sqrt{x_i^2 + y_i^2 + z_i^2}$$

OBTAIN SOLUTIONS FOR (u, v, w) IF $N \geq 3$

FOR $N > 3$ A LEAST SQUARES FIT PROCEDURE IS USED.

- TYPICALLY 4 OR MORE RECEIVERS ARE USED TO CHECK THE CONSISTENCY OF TARGET COORDINATES (x_i, y_i, z_i)
- NO SYSTEMATIC ERRORS DUE TO FINITE σ_u OR ASPECT SENSITIVITY EFFECTS.

SYSTEMATIC ERROR SOURCES

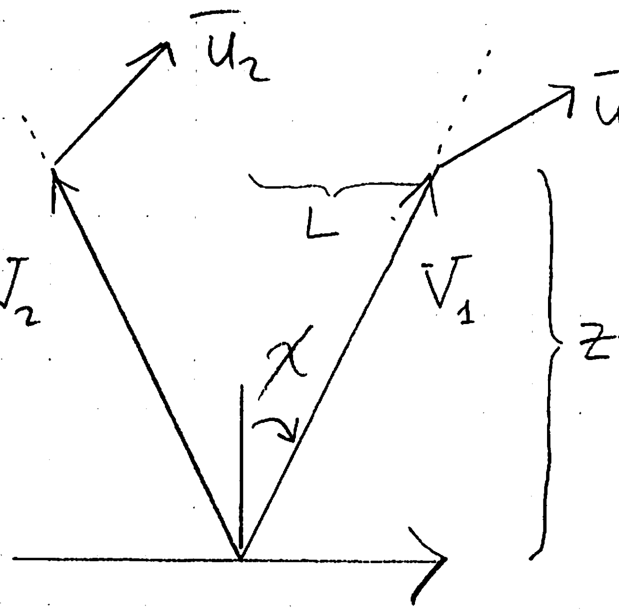
— RANDOM VELOCITIES, ASPECT SENSITIVITY ...

— IRREGULARITIES ARE NOT ADVECTED BY WINDS, BUT PROPAGATE WITH WAVES ... E.G. RECENT AIDA '89 RESULTS

— PREFERENTIAL SAMPLING OF TIME/SPACE VARYING WIND FIELDS BY INHOMOGENEOUS IRREGULARITY DISTRIBUTIONS

* — ERRORS INDUCED BY SPATIAL VARIATIONS IN THE WIND FIELD.

VARIATION INDUCED ERRORS



$$\tan \chi = \frac{L}{z}$$

$$\bar{V}_1 = u_1 \sin \chi + w_1 \cos \chi$$

$$\bar{V}_2 = -u_2 \sin \chi + w_2 \cos \chi$$

$$\hat{u} = \frac{\bar{V}_1 - \bar{V}_2}{2 \sin \chi} = \left(\frac{u_1 + u_2}{2}\right) + z\left(\frac{w_1 - w_2}{2L}\right)$$

$$\hat{w} = \frac{\bar{V}_1 + \bar{V}_2}{2 \cos \chi} = \tan \chi \left(\frac{u_1 - u_2}{2}\right) + \left(\frac{w_1 + w_2}{2}\right)$$

$$\hat{u} = \left(\frac{u_1 + u_2}{2}\right) + z\left(\frac{w_1 - w_2}{2L}\right)$$

FOR LINEAR WIND VARIATION:

$$\hat{u} = u + \underbrace{z \frac{\partial w}{\partial x}}_{\text{BIAS TERM}}$$

E.G. $80 \text{ km} \times \frac{1 \text{ m/s}}{80 \text{ km}} = 1 \text{ m/s}$

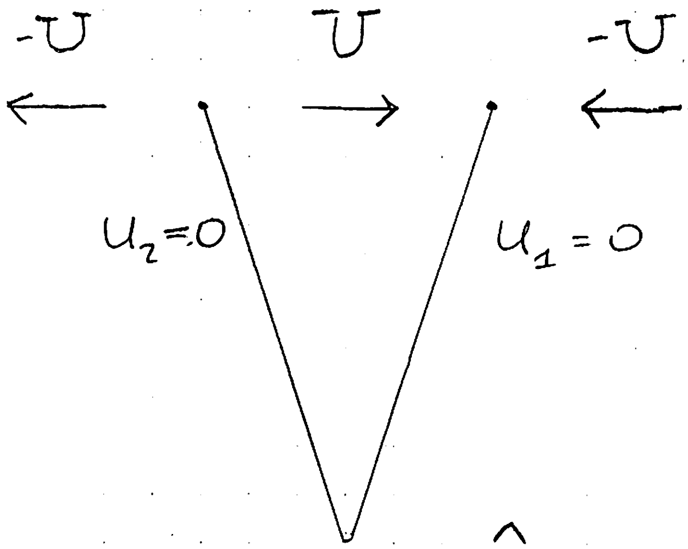
MONOCHROMATIC GRAVITY WAVE:

$W = 1$ m/s

$\lambda_x = 4L$ (~ 80 km @ 80 km, $\chi = 15°$)

$z\left(\frac{w_1 - w_2}{2L}\right) = 80 \text{ km} \times \frac{2 \text{ m/s}}{40 \text{ km}} = 4 \text{ m/s}$

10–20 $\frac{m}{s}$ ERRORS POSSIBLE WITH A FEW m/s W / SMALLER χ / LARGER z



$$\left(\frac{u_1 + u_2}{2}\right) = 0$$

AT ALL PHASES OF THE WAVE

$\hat{u}$ DOES NOT REGISTER u OSCILLATIONS IN A WAVE WITH $\lambda_x = 4L$

ERROR BECOMES NEGLIGIBLE ONLY FOR

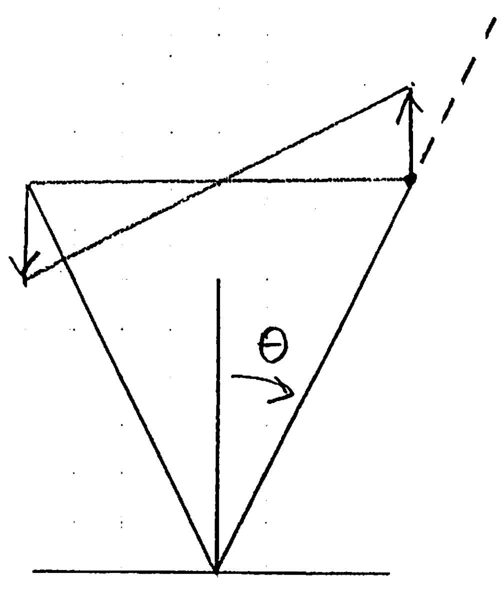
$$\lambda_x \gg 4L = 4z\tan\chi$$

FLUCTUATING COMPONENT OF $\hat{u}(t)$ REPRESENTS A SPATIAL FILTERED COMBINATION OF HORIZONTAL AND VERTICAL WIND FLUCTUATIONS u AND w.

SAME TYPE OF COMBINATION OF u AND w COMPONENTS ALSO OCCURS IN $\hat{u}$ RECORDS OBTAINED WITH INTERFEROMETRY / SPACED ANTENNA TECHNIQUES :

TO ILLUSTRATE :

CONSIDER $u = 0$, $W = x \dfrac{\partial w}{\partial x}$



$$W(\theta) = z \tan\theta \frac{\partial w}{\partial x}$$

$$\left.\frac{\omega}{-2k_0}\right|_{\theta} = W(\theta) \cos\theta$$

$$= \left(z \frac{\partial w}{\partial x} \right) \sin\theta$$

$$\Rightarrow \hat{u} = z \frac{\partial w}{\partial x} \quad \text{IN THIS CASE}$$

ALSO IDI, SOFTWARE BEAM SYNTHESIS, IN ANALOGY WITH DOPPLER BEAM TECHNIQUE.

$$\left\{ \begin{aligned} \hat{u} &= \left(\frac{u_1 + u_2}{2}\right) + \cot\chi \left(\frac{w_1 - w_2}{2}\right) \\ \hat{w} &= \tan\chi \left(\frac{u_1 - u_2}{2}\right) + \left(\frac{w_1 + w_2}{2}\right) \end{aligned} \right\}$$

— ASSUMING,

$$\langle u_1 \rangle = \langle u_2 \rangle = \bar{u} \qquad \Rightarrow \qquad \langle \hat{u} \rangle = \bar{u}$$

$$\langle w_1 \rangle = \langle w_2 \rangle = \bar{w} \qquad \qquad \langle \hat{w} \rangle = \bar{w}.$$

— FURTHERMORE, ASSUMING

$$\langle u_1^2 \rangle = \langle u_2^2 \rangle = \langle u^2 \rangle$$

$$\langle w_1^2 \rangle = \langle w_2^2 \rangle = \langle w^2 \rangle$$

$$\langle u_1 w_1 \rangle = \langle u_2 w_2 \rangle = \langle uw \rangle \quad \ldots \text{ ETC.,}$$

IT IS POSSIBLE TO OBTAIN CORRECT STATISTICS OF FLUCTUATING COMPONENTS OF u, v, AND w IN TERMS OF VARIANCES AND COVARIANCES, OR SELF- AND CROSS-SPECTRA, USING APPROPRIATELY SELECTED MULTIPLE BEAM CONFIGURATIONS.

— INTERFEROMETRIC APPROACH IS ALSO POSSIBLE

EXAMPLE :

$\langle uw \rangle$ — UPWARD FLUX OF ZONAL MOMENTUM PER UNIT MASS.

$$\left\{ \begin{aligned} \hat{u} &= \left(\frac{u_1+u_2}{2}\right) + \cot\chi\left(\frac{w_1-w_2}{2}\right) \\ \hat{w} &= \tan\chi\left(\frac{u_1-u_2}{2}\right) + \left(\frac{w_1+w_2}{2}\right) \end{aligned} \right\}$$

$$\hat{u}\hat{w} = \frac{\tan\chi}{4}\left(u_1^2-u_2^2\right) + \frac{\cot\chi}{4}\left(w_1^2-w_2^2\right)$$

$$\frac{1}{4}(u_1+u_2)(w_1+w_2) + \frac{1}{4}(u_1-u_2)(w_1-w_2)$$

$$\langle \hat{u}\hat{w} \rangle = \frac{1}{4}\left(2\langle u_1 w_1\rangle + 2\langle u_2 w_2 \rangle\right)$$

$$= \langle uw \rangle \checkmark$$

SUMMARY

- BASIC RADAR WIND MEASUREMENT TECHNIQUES USED IN MIDDLE-ATMOSPHERE DYNAMICS STUDIES HAVE BEEN REVIEWED.

- TECHNIQUES FOR BIAS FREE RADIAL WIND MEASUREMENTS ARE AVAILABLE.

- ALTITUDINAL RESOLUTIONS OF ~100 m OR BETTER HAVE BEEN OBTAINED, BUT MORE TYPICAL RESOLUTIONS ARE ~0.5 – 3 km.

- BIAS FREE MEASUREMENTS OF INSTANTANEOUS HORIZONTAL WIND COMPONENTS CANNOT BE ACCOMPLISHED BY A SINGLE RADAR.

- ALL AVAILABLE TECHNIQUES
  - DOPPLER BEAM SCANNING, INTERFEROMETRY/SPACED ANTENNA, IDI, ... – CARRY BIASES OF SIMILAR NATURE.

  HOWEVER BIAS MAGNITUDES DEPEND ON RADAR SYSTEM PARAMETERS SUCH AS BEAM POINTING DIRECTION, BEAM WIDTH, ETC., SO CONCURRENT HORIZONTAL WIND ESTIMATES OBTAINED WITH DIFFERENT INSTRUMENTS CAN EXHIBIT DIFFERENT TYPES OF FLUCTUATIONS.

- ERRORS IN HORIZONTAL WIND ESTIMATES ARE NOISE-LIKE, SO BIAS FREE MEAN WIND ESTIMATES CAN BE OBTAINED WITH SUFFICIENT AVERAGING.

- DESPITE UNAVOIDABLE BIASES IN INSTANTANEOUS u AND v ESTIMATES, CORRECT STATISTICS OF THE FLUCTUATING COMPONENTS OF u, v, AND w CAN BE OBTAINED WITH A SINGLE RADAR.

FURTHER READING:

1) INTERNATIONAL SCHOOL ON ATMOSPHERIC RADAR, LECTURE NOTES, ED. S. FUKAO, KYOTO, JAPAN, 1988

2) COLLECTION OF MAP HANDBOOKS, PUBLISHED BY SCOSTEP, STEP – AVAILABLE FROM SCOSTEP OFFICE AT THE UNIVERSITY OF ILLINOIS, TEL. (217) 333 9005

3) WOODMAN, R.F., A GENERAL STATISTICAL INSTRUMENT THEORY OF ATMOSPHERIC AND IONOSPHERIC RADARS, JGR, 1991,