

Atmospheric Oscillations

5.1. Show that the Fourier component $F(x) = \text{Re}[C \exp(i\omega x)]$ can be written as $F(x) = |C| \cos m(x + x_0)$, where $x_0 = \sin^{-1}(\text{Im}(C)/|C|)$ and C stands for the imaginary part of C .

Solutions $\text{Re}[C \exp(i\omega x)] = C_r \cos \omega x + C_i \sin \omega x$, where $C = C_r + iC_i$. Define $C_r = |C| \cos m\omega x$, $C_i = |C| \sin m\omega x$. Thus, $x_0 = \sin^{-1}(\text{Im}(C)/|C|)$, and $F(x) = |C| (\cos \omega x \cos m\omega x - \sin \omega x \sin m\omega x) = |C| \cos[m(x + x_0)]$.

5.2. In the study of atmospheric wave motions, it is often necessary to consider the possibility of amplifying or decaying waves. In such a case we might assume that a solution has the form $\psi = A \cos(\omega x - \nu t - \lambda \phi) \exp(\alpha x)$, where A is the initial amplitude, α the amplification factor, and $\lambda \phi$ the initial phase. Show that this expression can be written more concisely as $\psi = \text{Re}[S e^{i(\alpha x - \nu t)}]$, where both S and c are complex constants. Determine the real and imaginary parts of S and c in terms of A , α , ν , λ , ϕ , and x_0 .

Solutions $\psi = \text{Re}[S \exp[ik(x - \alpha t)]] = \text{Re}[S \exp[ik(x - c, r)] e^{i\alpha t}]$, but from Problem 7.1 we can write this as $\psi = |S| \cos[k(x - c, r) - \lambda \phi] e^{i\alpha t} = A \cos[(\lambda x - \nu t - \lambda \phi)] e^{i\alpha t}$, where $A = |S|$, $\alpha = \lambda c$, $\nu = \lambda \omega$, and $\lambda \phi = -\sin^{-1}(S, A|S|)$. Thus, $S_r = A \cos \lambda \phi$, $S_i = -A \sin \lambda \phi$.

5.3. Several of the wave types discussed in this chapter are governed by equations that are generalizations of the wave equation

$$\frac{\partial^2 \psi}{\partial t^2} = c^2 \frac{\partial^2 \psi}{\partial x^2}$$

This equation can be shown to have solutions corresponding to waves of arbitrary profile moving at the speed c in both the positive and negative x directions. We consider an arbitrary initial profile of the field ψ : $\psi = f(x)$ at $t = 0$. If the profile is translated in the positive x direction at speed c without change of shape, then $\psi = f(x')$, where x' is a coordinate moving at speed c so that $x = x' + ct$. Thus, in terms of the fixed coordinate x , we can write $\psi = f(x - ct)$, corresponding to a profile that moves in the positive x direction at speed c without change of shape. Verify that $\psi = f(x - ct)$ is a solution for any arbitrary continuous profile $f(x - ct)$.

Hint: Let $x - ct = x'$ and differentiate f using the chain rule.

Solutions $\psi = f(x')$, $x' = x - ct$, $\partial x'/\partial x = 1$, $\partial x'/\partial t = -c$. Thus, by the chain rule, $\frac{\partial \psi}{\partial x} = \left(\frac{\partial \psi}{\partial x'}\right) \left(\frac{\partial x'}{\partial x}\right) = \frac{\partial \psi}{\partial x'}$. Differentiating by x gives $\frac{\partial^2 \psi}{\partial x^2} = \frac{\partial^2 \psi}{\partial x'^2}$. Similarly, $\frac{\partial \psi}{\partial t} = \left(\frac{\partial \psi}{\partial x'}\right) \left(\frac{\partial x'}{\partial t}\right) = -c \frac{\partial \psi}{\partial x'}$, which, when differentiated by x , gives $\frac{\partial^2 \psi}{\partial t^2} = c^2 \frac{\partial^2 \psi}{\partial x^2}$. Substituting into the wave equation then shows that $f(x')$ is indeed a solution.

5.4. Assuming that the pressure perturbation for a one-dimensional acoustic wave is given by (7.15), find the corresponding solutions of the zonal wind and density perturbations. Express the amplitude and phase for u' and ρ' in terms of the amplitude and phase of p' .

Solutions From the momentum equation: $(\frac{\partial}{\partial t} + \frac{\partial}{\partial x}) u' = -\left(\frac{1}{\rho} \right) \frac{\partial p'}{\partial x} = -\left(\frac{1}{\rho} \right) A e^{i(\nu t - \alpha x)}$. Substituting in the assumed solution $u' = B e^{i(\nu t - \alpha x)}$ gives $i(\nu t - \alpha x) B = -i(\nu t / B) A$, or $B = A (\nu t / B)^{-1}$. But, $(\nu t / B)^2 = \nu^2 t^2 / B^2$. Thus, $u' = p' (\nu t / B) (\nu t / B)^{-1}$. Now linearizing (5.15) yields $(\frac{\partial}{\partial t} + \frac{\partial}{\partial x}) \rho' = -\frac{\partial p'}{\partial x} = -B \rho' B e^{i(\nu t - \alpha x)}$. Letting $\rho' = C e^{i(\nu t - \alpha x)}$ gives $i(\nu t - \alpha x) C = (B \rho') B$. Thus, $C = B \rho' (\nu t / B)^{-1} = A (\nu t / B)^{-2}$. Hence, $\rho' = p' (\nu t / B)^{-2}$.

Atmospheric Science Solutions Manual

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