Climate Dynamics Examination

Due date: Friday 14th December at 5pm.

1 Negative atmospheric heat flux feedback on SST

If a sea surface temperature (SST) anomaly occurs in the ocean then the *general* (but not universal) response of the atmosphere is to damp the anomaly by producing a heat flux anomaly which acts to reduce the original SST anomaly. This negative feedback is very important to climate dynamics. A simple $1D$ model of this process is as follows:

The anomalous temperature T of the air directly above the SST anomaly may be written as

$$T_t + uT_x = r(SST - T) + \nu T_{xx}$$

where u is the mean zonal wind; νT_{xx} represents horizontal mixing by atmospheric eddies while the term $r(SST - T)$ is the (sensible) heat transfer from ocean to atmosphere.

The total anomalous turbulent heat flux Q is generally proportional (but greater) to the sensible transfer so we may write

$$Q = -K(SST - T)$$

where a negative sign for Q indicates ocean cooling (and vice versa).

Now assume for concreteness that the SST anomaly has the form

$$SST = T_0 e^{-\mu|x|}$$

where μ is a positive constant. Derive the ***steady state*** solution for the air temperature anomaly under the condition that u, μ, r and ν are constants.

Assume firstly that $u = 0$ and $\nu \neq 0$ (diffusive case). Where is the heat flux feedback negative and where is it positive?

Assume alternatively that $u \neq 0$ and $\nu = 0$ (advective case). Again deduce where the feedback is negative and where it is positive.

Plot both solutions for Q with $u = 0$ $\nu = 3 \times 10^6 m^2 s^{-1}$ $r = 2°C(day)^{-1}$ and $K = 40Wm^{-2}(°C)^{-1}$ for the first case and the same values except $u = 5ms^{-1}$ and $\nu = 0$ for the second case.

Comment physically on why there is a negative feedback operating over most of the SST anomaly.

2 Coupled instability analysis

We consider the basics of coupled ocean-atmosphere interaction in the equatorial Pacific with a simple model.

Assume that the atmospheric zonal wind in response to convective heating is given by

$$U = U_0 e^{i\phi} Q$$

i.e. it is displaced by a phase angle ϕ from Q (this is the case for the Gill model as discussed in class). Assume further that Q is proportional to SST (written here as T) so that

$$U = U_0 e^{i\phi} rT$$

Next assume that the thermocline displacement h in the ocean is in approximate Sverdrup balance with the zonal wind on climate time scales and that zonal currents near the ocean surface are proportional to the zonal wind (again reasonable assumptions). Thus

$$h_x - cU$$

$$u = dU$$

Finally assume that the SST equation for the ocean may be written approximately as

$$T_t + u\overline{T}_x - eh = -sT$$

where $u\overline{T}_x$ represents anomalous advection of mean SST ; eh represents the effect of thermocline displacements on SST and sT is the negative feedback from the atmosphere discussed in the first question.

Assume the standard (x, t) dependence of the from $e^{i(kx+\omega t)}$ for all variables and then derive a complex (real and imaginary) dispersion relation between real k and complex ω under the assumption that r, s, $-\overline{T}_x$, e, c and d are positive constants in the Pacific. Assume also that the atmospheric phase angle ϕ is a constant (but not necessarily positive).

Comment on what is required of the phase angle ϕ for growing (unstable) solutions. Comment on what direction the perturbation propagates as a result of the zonal advection term $(u\overline{T}_x)$ and the thermocline term $(-eh)$ under the assumption that ϕ induces growing solutions.