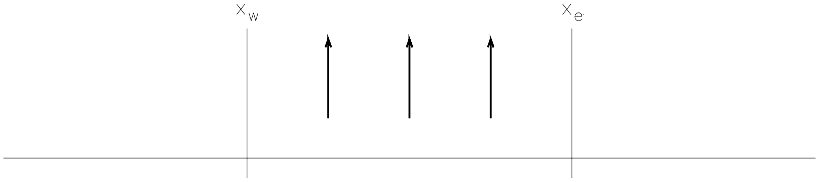
Why does El Niño advance eastward?

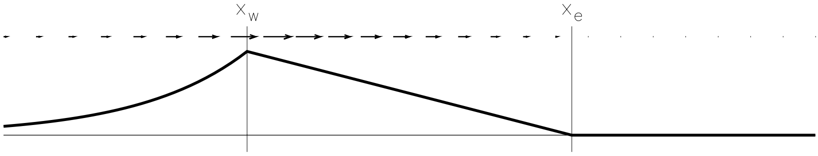
A schematic, eastward-propagating El Niño can be formulated in a steady, damped, linear system based on the Gill atmosphere and a single-active-layer ocean whose SST is related to thermocline depth. The essential physics was explained by Clarke (1994, J.Climate, p1623-1627), who showed why equatorial winds are dominated by westerlies under convection, rather than an equal easterly-westerly convergence. The following is an adaptation of Clarke's idea.

The Clarke (1994) mechanism works as follows. Consider an imposed patch of rising air over an equatorial ocean (say it is convection over a patch of warm SST).



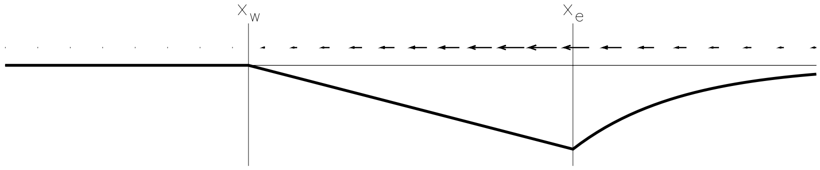
The patch is located between longitudes x_w and x_e. Within the patch: $w_z > 0$, so $u_x < 0$.

Since the system is linear, consider the Rossby and Kelvin reponses separately, integrating along wave characteristics. For the Rossby reponse, there is no signal east of x_e. From x_e to x_w, the Rossby zonal wind increases westerly, since $u_x < 0$. West of x_w, the Rossby westerlies decay exponentially to the west:

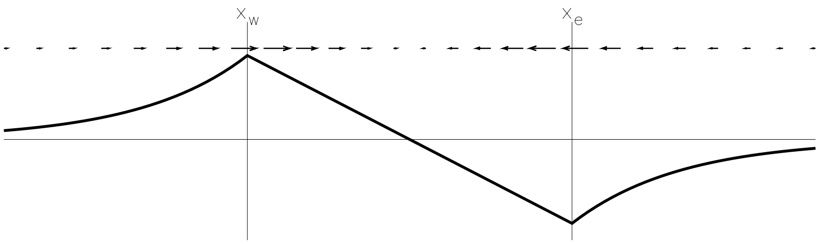


The line graphs the zonal winds, and the vectors display the same winds.

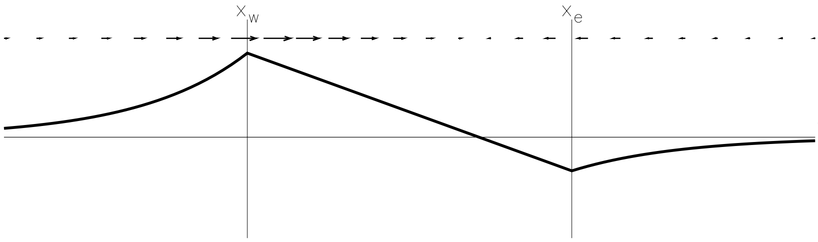
For the Kelvin response, do the same kind of integration, but from the west. There is no Kelvin response west of x_w. From x_w to x_e, the Kelvin zonal wind increases easterly, since $u_x < 0$. East of x_e, the Kelvin easterlies decay exponentially:



If the Kelvin and Rossby responses are equal, the sum is symmetric. Winds converge equally from both sides into the center of the box:



Clarke (1994) argued that equatorial convection has a meridional scale (~10° latitude) that is much smaller than the atmospheric Rossby radius, and therefore the Kelvin response would be only weakly forced compared to (some of) the Rossby modes. The following plot shows the Rossby + Kelvin sum with the Kelvin response reduced to 40% of the Rossby signal:



The convergence necessary to balance the convection comes predominantly from the west, and extends most of the way under the convection.

Now, if:

1. The convection was due to a patch of warm SST, and if
2. In the ocean the thermocline slope balances the zonal wind, and if
3. Deeper thermocline implies warmer SST,

then the initial SST perturbation will grow. The local ocean response to the winds deduced for the asymmetric case will be a tendency for deepening of the thermocline and thus warming of SST under the westerlies in and to the west of the initial patch, with a smaller area of thermocline shoaling and SST cooling under the easterlies.

However, the thermocline will slope (anomalously) down to the east under the westerlies, and to a lesser degree up to the east under the (weaker) easterlies. This imbalance means rest of the equatorial thermocline (east and west of the directly influenced region) will also have to adjust. Ignoring boundaries, the region to the east of the forced region will adjust more downward (or less upward) than the region to the west. The distribution of the adjustment will be determined by the how the thermocline perturbation projects onto the ocean wave modes. The Rossby radius in the ocean is close to the scale of equatorial convergence, so one would expect a strong forcing of Kelvin waves, and consequently that much of the necessary adjustment will occur by deepening the thermocline to the east of the forced region. Thus the result of the imposed patch of convection will be a relatively large warming of SST under the patch itself, and a weaker warming to the east of the patch.

If, in addition, convection depends on an absolute value of SST (27.5°?), then the area of SST this warm will be extended somewhat to the east of the initial area of convection. As this feeds back to the atmosphere, the convection will spread to the east, and the whole pattern will “propagate” itself eastward, but the speed of advance will be less than that of a Kelvin wave, even though Kelvin dynamics are crucial to the eastward advance.