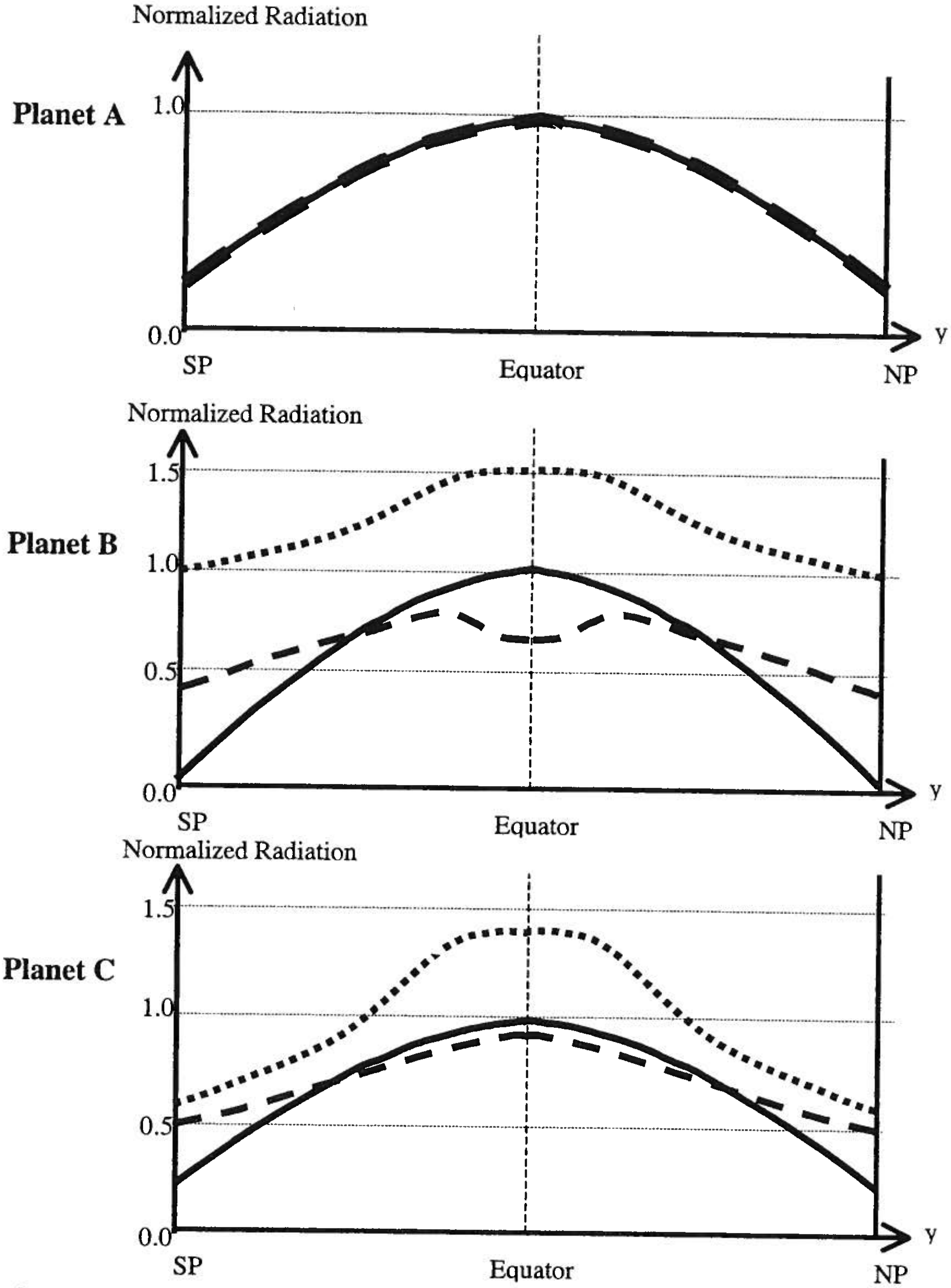
You are asked to provide technical advice to the NASA administrator in 2122. Please refer to the figure below before providing the answer (estimated time: 45 minutes)

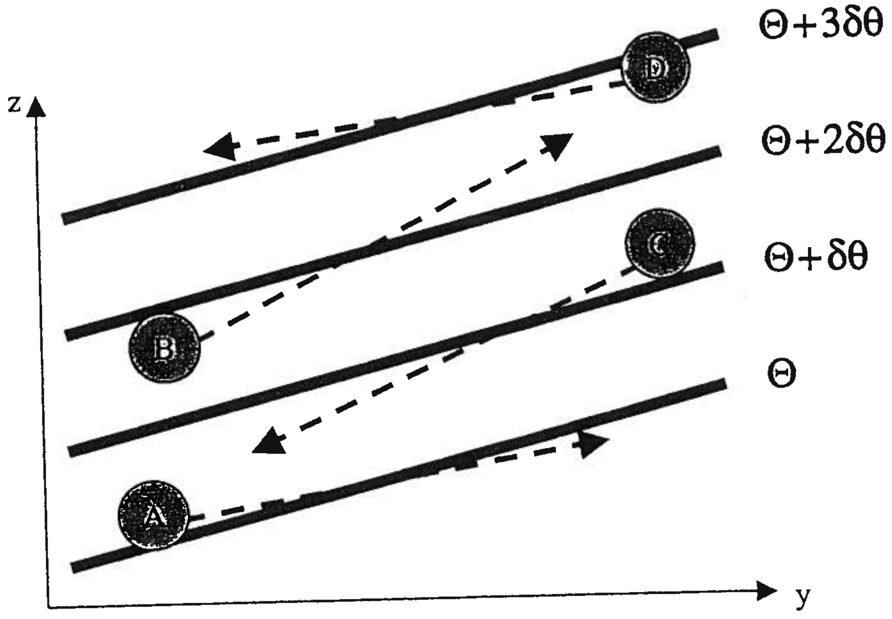
In 2100, three solar systems are discovered and each of the solar systems has an earth-like planet that orbits its own sun at a rate exactly same as the Earth (referred to as the Planet A, Planet B, and Planet C, respectively hereafter). In order to explore the possibility of existing life in these three newly discovered planets, three space vehicles are lunched in 2102 to measure the solar shortwave radiation intercepted by the planets, the terrestrial longwave radiation emitted from the planets to space at a distance of 100km from the planets. Each of the space vehicles also drops off mini sensors as it orbits around the planet to measure the upward longwave radiation at a distance 1km from the planet surface. Plotted in the figures below are the zonally-mean values of measurements from these instruments averaged for the entire 20 years and the measurements are normalized by the maximum solar energy absorbed by the corresponding planet at the equator. Due to the fact that only very limited amount of data are radioed back from the mini sensors to the vehicle that orbits around the Planet A, the measurements of the longwave radiation emitted from the Planet A's surface are not analyzed.

Please provide answers to the following questions based on the measurements plotted in the figures below. Please discuss your reasoning for each question.

1. Which planet least likely has life of any forms?
2. Which planet most likely has an atmosphere and ocean(s)?
3. Which planet most likely does not have annual cycle?
4. Which planet has the largest concentration of greenhouse gases?
5. Please write down the planets in the order of the equator-to-pole surface temperature contrast from the largest to the smallest.
6. Which planet has the strongest jet(s)?
7. Which of the planets, on average, would have the largest number of "weather" events in a year?



Solid Curve: the solar energy absorbed by the planet; **Dashed**: the terrestrial longwave radiation emitted from the planet measured at 100km from the planet; **Dotted**: the upward radiation intercepted by the mini sensors at 1km from the planet surface.



Baroclinic instability essentially is a slant-wise convection in a stably stratified fluid. The schematic above sketches four parcel trajectories (alphabetically labeled dashed arrows) relative to the zonal mean isentropic surfaces (heavy solid lines, $\delta\theta > 0$). Note that all trajectories have a positive slope as the zonal mean isentropic surfaces. Please answer the following questions (estimated time: 60 minutes)

(1) Discuss which parcel trajectories are unstable and which are stable.
(2) Write the inequality between the slopes of the zonal mean isentropic surface and an unstable trajectory. Do the same for a stable trajectory.
(3) Apply the inequality to one unstable and one stable trajectory among the four trajectories and re-write it in terms of the relation between meridional and vertical temperature advection terms.
(4) Discuss stability/instability of the stable and unstable parcel trajectories according to the net temperature tendency due to advection of the mean potential temperature Θ.
(5) Derive the relation between the slope of the most unstable parcel trajectory and the slope of the basic isentropic surface and explain why.
(6) Discuss why an air parcel trajectory with a negative slope would be stable.

Hints: (a) A zonal mean isentropic surface Θ is mathematically defined as $\Theta(y, z) =$ constant. (b) Assume that the most unstable perturbation has to have an equal growth rate in both potential energy and kinetic energy.

The coastal Kevin waves can be illustrated in the so-called "half-plane inertial gravity wave" problem. On a half-plane $x < 0$ (think $x = 0$ corresponds to the US west coast), the small shallow water disturbances on a f-plane ($f > 0$ and $f =$ constant) satisfy

$$\frac{\partial u}{\partial t} = -g\frac{\partial h}{\partial x} + fv \ ,(1); \quad \frac{\partial v}{\partial t} = -g\frac{\partial h}{\partial y} - fu\ , (2); \quad \frac{\partial h}{\partial t} = -H(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}) \ (3)$$

The flow has to satisfy the solid wall boundary condition:

$$u|_{x=0} = 0, \qquad \text{for all y and t} \qquad (4)$$

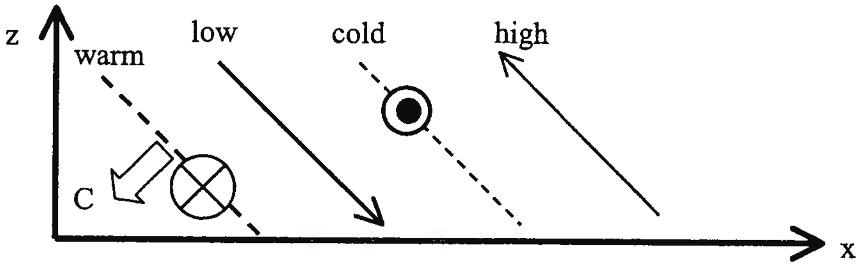
In addition, there is no energy source from the infinity, so the disturbance has to satisfy the energy radiation condition:

$$u, v, h \text{ are finite} \qquad \text{at } x \to -\infty \qquad (5)$$

Please find the linear wave solution and briefly discuss the physical properties of the solution.

Problem #2

There are ONLY TWO errors in the following diagram. Please correct them. Please discuss your reasoning thoroughly. If you find more than two errors, but are able to make the diagram correct, you will earn some partial score (at most 60% of the total score) provided that you will discuss your reasoning thoroughly.



The figure above is a sketch illustrating a westward and downward propagating inertial gravity wave (as indicated by the block arrow) in the Northern Hemisphere. The dashed lines labeled with "warm" and "cold" correspond to the phase of warmest and coldest potential temperature perturbations, respectively. The thin arrows correspond to the lines of constant phases of maximum zonal and vertical velocity fields. The lines coinciding with the thin arrows are the maximum (labeled as "high") and minimum (labeled as "low") pressure perturbation. The lines with symbols ⦿ and ⊗ represent the phase of maximum of the meridional wind that blows out and into the page, respectively.