ESCI 344 – Tropical Meteorology
Lesson 1 – Introduction to the Tropics

References: *Forecaster's Guide to Tropical Meteorology* (updated), Ramage
Tropical Climatology (2nd ed), McGregor and Nieuwolt
Tropical Meteorology, Tarakanov
Climate and Weather in the Tropics, Riehl
Tropical Meteorology in Africa, MUNITALP

Reading: *An Introduction to the Meteorology and Climate of the Tropics*, J.F.P. Galvin, Chapters 1 and 2
Hagen et al., "Atmospheric Tides"
Staten et al., "Tropical Widening: From Global Variations to Regional Impact"

GEOGRAPHY

- **For meteorological purposes, the Tropics may be roughly defined as that region lying between the boundaries separating the easterlies and the westerlies in the middle troposphere.**
- **This boundary varies**
  - **seasonally**
  - **longitudinally**
- **A knowledge of geography is important for a meteorologist. Below is a list of places and locations that I expect you to be able to find on a map.**

India	**Marshall Islands**	**Midway Island**
Madagascar	**U.S. Virgin Islands**	**Peru**
Somalia	**The Hawaiian Islands**	**Pacific Ocean**
Japan	**Guam**	**Atlantic Ocean**
Vietnam	**Wake Island**	**Indian Ocean**
Cuba	**Lesser Antilles**	**Caribbean Sea**
Taiwan	**Tahiti**	**Persian Gulf**
Malay Peninsula	**Fiji**	**Bay of Bengal**
Baja California	**Indonesia**	**North Arabian Sea**
Australia	**The Philippines**	**South China Sea**

- **One-half of the Earth's surface area is contained between 30S and 30N.**

MAJOR DIFFERENCES BETWEEN TROPICS AND MIDLATITUDES

- **The main differences between the tropical atmosphere and the midlatitudes are:**
  - **Coriolis parameter is small in Tropics. The implications of this are**
    - **The wind cannot be assumed to be geostrophic, or even quasi-geostrophic.**
    - **The dynamic link between divergence/convergence and vorticity tendency is much weaker than in higher latitudes.**
    - **Circulations must be much larger in order to be affected by rotation of the Earth. One manifestation of this is that land/sea breezes penetrate further inland in Tropics than in midlatitudes.**
  - **Weather systems in the Tropics are dominated by convection and the effects of water vapor and latent heating.**
  - **The planetary boundary layer (PBL) is much deeper in tropics (because of convection).**
  - **The tropopause is much higher and colder in Tropics.**
  - **Sea-level pressure exhibits pronounced diurnal and semi-diurnal cycle due to thermal tides in the atmosphere.**

THE BREAKDOWN OF THE GEOSTROPHIC APPROXIMATION

- **The simplified horizontal momentum equation is**

$$\frac{D\vec{V}}{Dt} = -\nabla\Phi - \hat{k} \times f\vec{V}$$

  - **The first term is the *inertial* term which represents the acceleration of the wind (it includes the local derivative and advection terms).**
  - **The second term is the pressure gradient term.**
  - **The third term is the Coriolis term.**
- **For an axisymmetric circulation of radius R these terms would all act in the radial direction, and for a low pressure would be**

$$\frac{V^2}{R} = |\nabla\Phi| - fV$$

  and for a high pressure would be

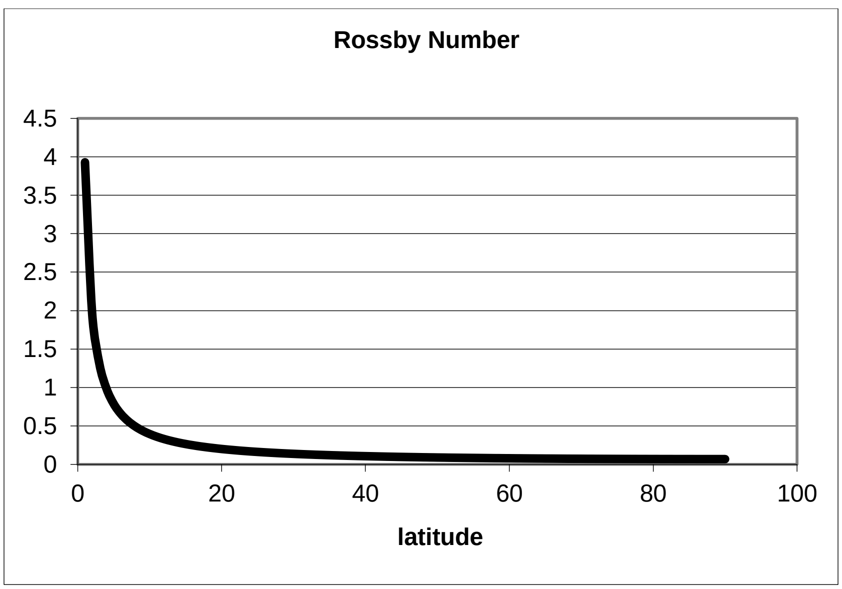
$$\frac{V^2}{R} = -|\nabla\Phi| + fV$$

- **The relative strengths of the terms is indicated by the *Rossby number,***

$$R_o = \frac{U}{fR}$$

where *U* is the characteristic wind speed, *f* is the Coriolis

- **The Rossby number can be thought of as showing the ratio of the *inertial forces* to the Coriolis force.**
  - **A small Rossby number ($R_0 << 1$) implies that the inertial terms are unimportant, and that the pressure gradient force balances the Coriolis force (*geostrophic* balance).**
  - **A large Rossby number ($R_0 >> 1$) implies that the Coriolis term is unimportant, and that the inertial terms and the pressure gradient term balance (*cyclostrophic* balance).**
  - **For Rossby numbers on the order of unity, no term can be ignored, and *gradient* balance holds.**
- **For synoptic scale motions we typically use values of $U \sim 10$ m s^{-1} and $R \sim 10^6$ m. The graph below shows the Rossby number as a function of latitude for these values of *U* and *R*.**



  - **Poleward of 20° the Rossby number is small enough that the geostrophic wind and actual wind are fairly close.**

- **Equatorward of 20° the Rossby number is no longer small, and the geostrophic and actual wind can differ greatly, especially as the Equator is approached.**

- **The comparatively large values of Rossby number in the Tropics vs. the Mid-latitudes means that on the synoptic scale quasi-geostrophic theory isn't very useful in explaining the dynamics of synoptic-scale tropical circulations.**
- **On the *planetary* scale, where *R* ~ 10^7 m, the Rossby number does remain small through most of the Tropics. Therefore, quasi-geostrophic theory may be carefully applied to planetary-scale circulations such as the monsoon, the Walker circulation, etc.**

WIND-PRESSURE RELATION

- **In the mid-latitudes, due to the smallness of the Rossby number, inertial term in the horizontal momentum equation can often be ignored, so that there is a direct relationship between the pressure field and the wind,**

$$\frac{1}{\rho}\nabla p = -\hat{k} \times f\vec{V} \, .$$

  - **This is why in mid-latitudes we analyze isobars on the surface chart, from which we can just look at the map and readily infer wind direction and speed.**
- **In the Tropics, all three terms must be retained, and gradient wind balance is the norm.**
- **There is no longer a simple relation between the pressure field and the wind.**
- **Pressure gradients are quite weak in the Tropics except in tropical cyclones.**
- **Because of the weak pressure gradients and lack of a simple wind-pressure relationship, meteorologists prefer to analyze streamlines and isotachs rather than isobars.**

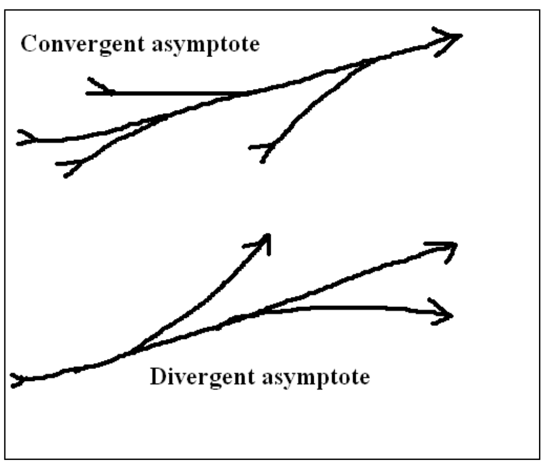
GRADIENT-LEVEL WINDS

- **The two most useful levels for tropical wind analysis are the *gradient level* and the 200 mb level.**

- **The gradient level is defined as the lowest level at which frictional influences from the surface are no longer important (i.e., just above the planetary boundary layer) so that the actual wind will be very close to the gradient wind.**
- **Though the actual gradient level varies with time and location, by convention the gradient level is assumed to be at 850 mb.**
- **So, the 850 and 200 mb charts, analyzed using streamlines, are the two most common (but by no means the only) charts used for tropical analysis and forecasting.**

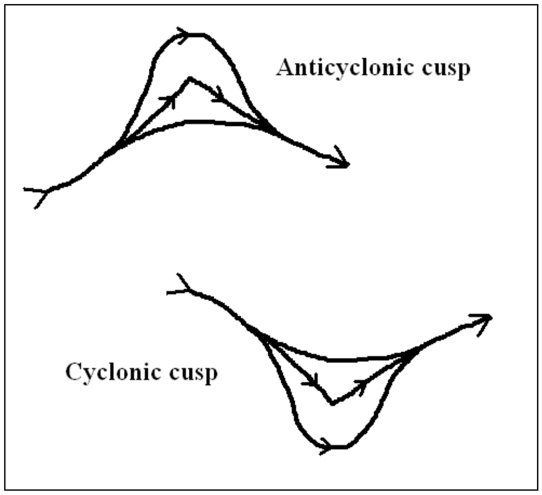
STREAMLINE ANALYSIS

- **Streamline analysis consists of drawing lines that are everywhere parallel to the wind.**
- **Some features that commonly show up on streamline analyses are discussed as follows:**
- **Asymptotes (diverging or converging)**



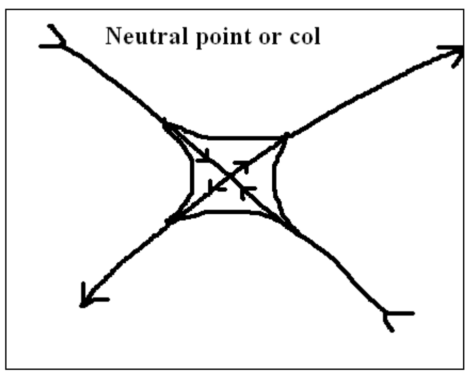
  - **These are streamlines from with other streamlines are either diffluent or confluent.**
  - **Although in general diffluence and confluence don't necessarily imply divergence and convergence, it is common to refer to a diffluent asymptote as a divergent asymptote, and a confluent asymptote as a convergent asymptote.**

- **Cusps**

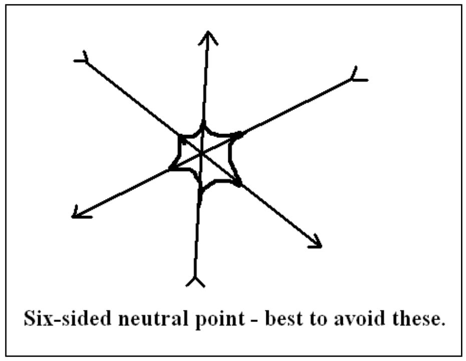


  - **These are intermediate between a wave and a developing closed circulation.**
  - **Cusps may be either cyclonic or anticyclonic.**

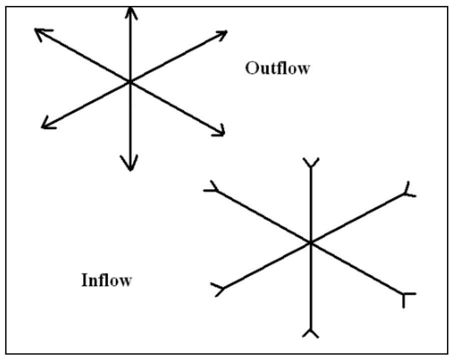
- **Neutral points**



  - **These occur at the intersection of two asymptotes of opposite sign (divergent and convergent).**
  - **They are sometimes referred to as *cols,* because they represent saddle points on a pressure surface.**
  - **Inside a neutral point the wind is very light (theoretically it is zero at the intersection of the asymptotes.)**
  - **It is theoretically possible to have a six-sided neutral point, involving the intersection of three asymptotes; however, most meteorologists consider them unlikely, and they should be avoided unless there is enough data to truly support their existence.**

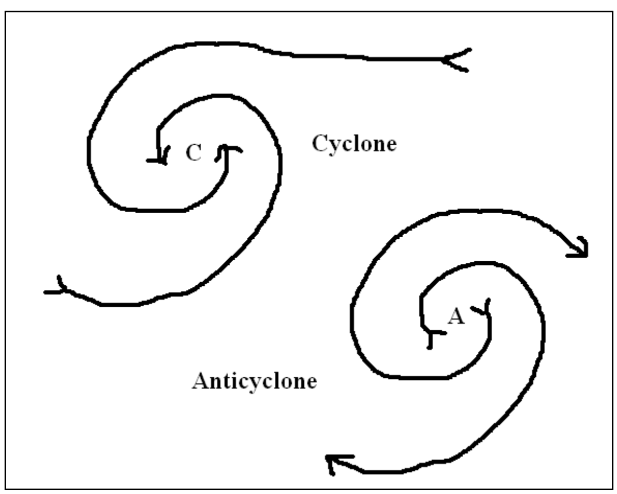


- **Inflow and outflow**



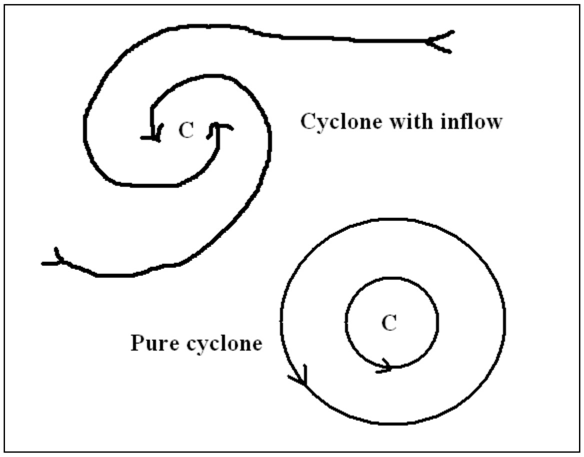
  - **Pure inflow and outflow doesn't usually appear on the synoptic scale. Usually it is accompanied by rotation, and so appears in conjunction with cyclones and anticyclones.**

- **Cyclones and anticyclones**



  - **Cyclones and anticyclones represent closed circulations, which would have closed isobars on a pressure map.**

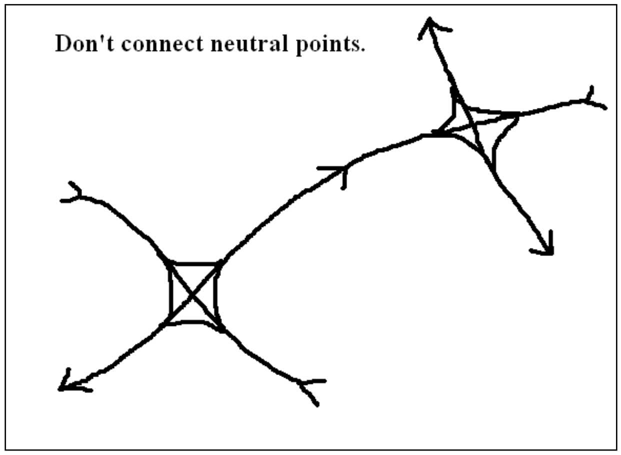
- **They are usually accompanied by either inflow or outflow, and so purely circular or closed streamlines are not usually analyzed.**



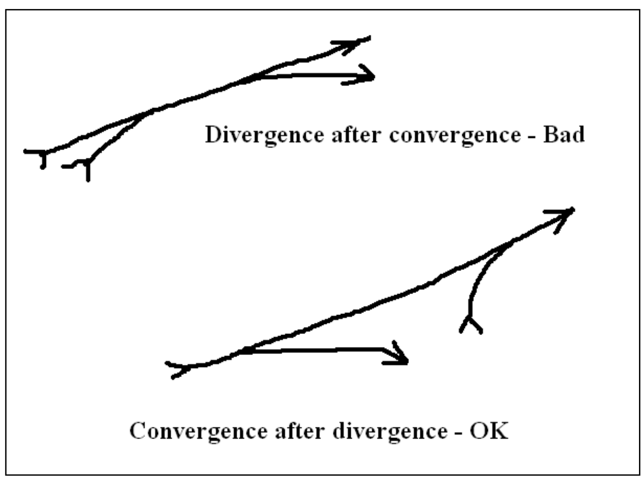
- **Although cyclones usually have inflow and anticyclones usually have outflow, it is possible to have outflow cyclones and inflow anticyclones.**

- **Some general rules and reminders:**
  - **Streamlines are everywhere parallel to the wind**
  - **Neutral points should be kept relatively small, and in areas of light wind.**
  - **Streamlines are not necessarily the same as trajectories (they are equivalent only if the wind field is steady-state.)**
  - **The spacing of the streamlines is rather arbitrary. You should draw enough to be useful. (Some analysts draw more streamlines in areas of strong wind, and fewer in areas of weak wind, but this is not universal.)**
- **Here are two rather arbitrary rules that I was taught to follow by veteran analysts while in the Navy. I've never found these written down in any reliable source, and have never been able to find a dynamical argument for these two rules. I've often seen them violated, so there is nothing sacred about them. I just present them here, because it's the way I was taught. They are:**

- Neutral points should not be connected to each other.



- Don't diverge off of a line downstream of convergence (however, convergence after divergence is OK.)



RELATION BETWEEN ASYMPTOTES AND CLOUDS

- **Since the ageostrophic wind is large in the Tropics, divergence and convergence play an even more accentuated role than they do in the mid-latitudes.**
- **The divergence/convergence pattern can often be inferred by the cloud patterns on a satellite image, and used to aid the streamline analysis.**
- **The following general rules can be very helpful:**
  - **Where the satellite picture shows a distinct, linear cloud feature, there is likely a convergent asymptote on the low-level chart, and a divergent asymptote on the upper-level chart.**

- **In large areas that are cloud free, there is likely a divergent asymptote on the low-level chart, and a convergent asymptote on the upper-level chart.**
- **Sun-glint on the visible image is an indication of light winds, and can be used to help locate ridge axes or neutral points.**

ABSOLUTE VORTICITY

- **The synoptic scale vorticity equation is**

$$\frac{D\eta}{Dt} = -\eta \nabla \bullet \vec{V},$$

where $\eta = \zeta + f$ is the sum of relative and planetary vorticity.

- **On the synoptic scales, relative vorticity is of the order of 10^{-5} per second.**
- **The planetary vorticity varies greatly with latitude.**
  - **In midlatitudes it is of the order of 10^{-4} per second, and so in midlatitudes we often write the vorticity equation as**

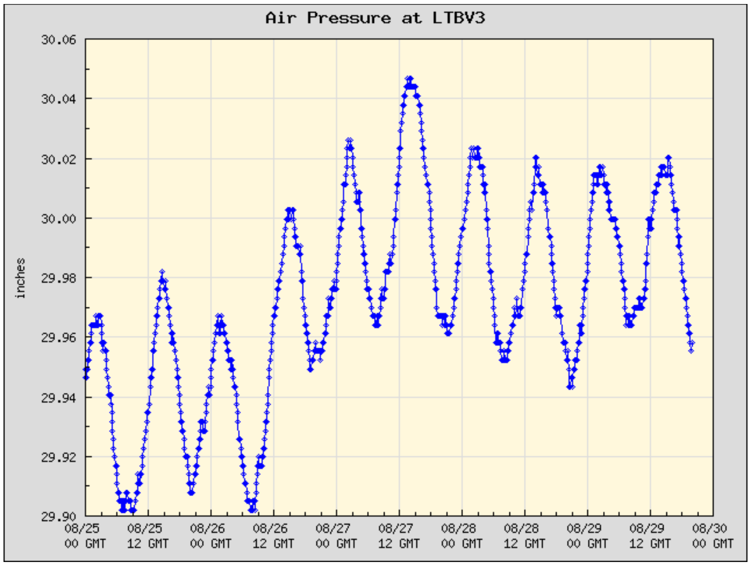
$$\frac{D\eta}{Dt} = -f \nabla \bullet \vec{V}$$

    since $\eta \cong f$.
  - **In the tropics it is of the order of 10^{-5} per second, or even smaller closer to the Equator, and so we have to keep the full absolute vorticity in the divergence term.**
- **Because the absolute vorticity is comparatively weak in the Tropics, a given amount of convergence or divergence will have a much smaller effect on absolute vorticity than it would in the midlatitudes.**
  - **Areas of inflow and outflow with little associated rotation appear on streamline charts in deep Tropics.**
- **Strong anticyclones are not common in deep Tropics, because they would have negative absolute vorticity.**

ATMOSPHERIC TIDES

- **Another interesting difference in the tropics compared to the higher latitudes is the relatively large amplitude, diurnal and semi-diurnal variation of sea-level pressure due to atmospheric tides.**

- **Both the diurnal and semidiurnal tides are due to solar heating and cooling, and are not gravitationally induced.**
- **The solar heating excites three main pressure oscillations in the atmosphere, having periods of 24, 12, and 8 hours.**
    - **The horizontal and vertical structure of each of these modes of oscillation are different.**
- **The 12-hour (semidiurnal) wave has the largest amplitude at the surface, and is the most meteorologically significant of the modes, since it has a range of 1 to 2 mb.**
    - **The amplitude of the semidiurnal variation decreases with height, and is less than 0.5 mb at the tropopause.**
    - **The pressure maxima occur around 1000 and 2200 local time, with the minima at about 0400 and 1600 local.**
- **Due to the superposition of the 24 and 8-hr period waves with the 12-hr wave, the morning pressure maximum is slightly larger than nighttime maximum, while the afternoon minimum is slightly lower than the early morning minimum.**
- **The diagram below shows a 5 day pressure trace Lime Tree Bay, VI (from the National Data Buoy Center website). The semidiurnal variation is readily apparent, with the maxima and minima occurring at the same time every day. Times are GMT, and not local.**



- **Since solar heating and cooling is the primary factor for producing the atmospheric tides, the daily range of the pressure variation can vary with cloudiness, water vapor content, and surface moisture.**
- **In general:**
  - **The tidal range is greater near the Equator, and decreases as you go poleward.**
  - **The tidal range is greater over land than over water.**
  - **The asymmetry of the maximums and minimums is also more pronounced over land.**
- **Though the signal from atmospheric tides can be deduced in the midlatitudes, it is much smaller than in the tropics and isn't really considered important in midlatitude meteorology.**
- **The tides must be accounted for when comparing the pressure tendency at a single station in the Tropics.**
  - **Failure to account for the tides may lead a forecaster to mistakenly conclude that a tropical cyclone is developing or approaching, or may even lead to missing such development.**