1. The Madden Julian Oscillation

Instructor Notes: In this lesson we will discuss the Madden Julian Oscillation or MJO and it's affect on the climate system and in particular winter time precipitation

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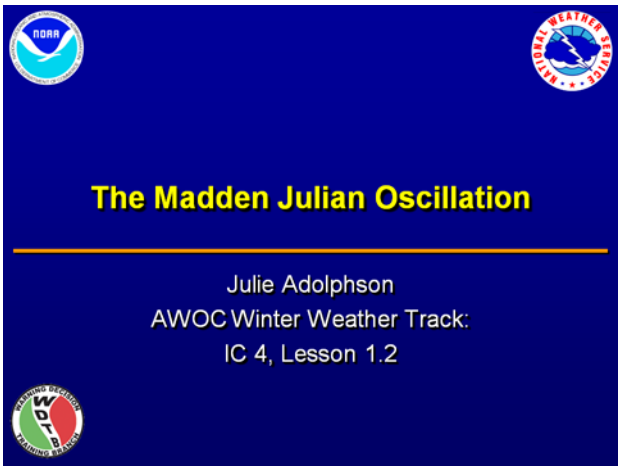

2. IC 4.1 Part 2 Learning Objectives

Instructor Notes: We will focus on helping you look at the "big picture" in space and time to help you assess the potential for upcoming winter storms in your area of responsibility. You will understand the size and time scale of the Madden-Julian Oscillation, as well as identify the physical nature of this phenomena and how if affects winter weather in the US. You will be able to describe the effects of the MJO on weather during the winter in your area.

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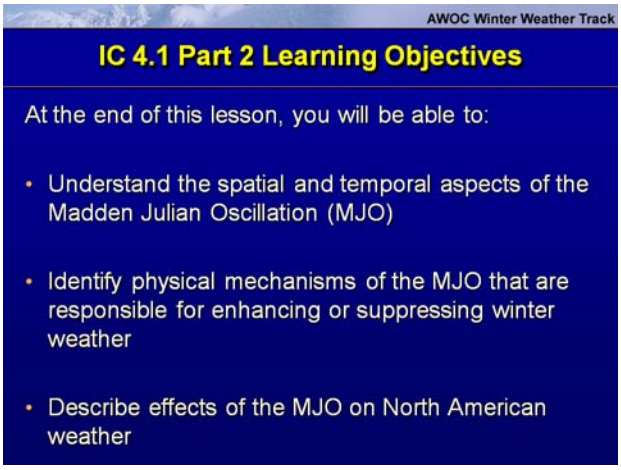

3. Performance Objectives

Instructor Notes: After this lesson you should be able to investigate the current state of the atmosphere in large temporal and spatial scales and correlate them to the potential (or lack thereof) of increased/decreased winter storms and the relationship between the strength of the MJO activity and what to expect for the season in terms of temperature and precipitation anomalies (or lack thereof). You will understand how the MJO can contribute to an increased/decreased probability of winter time storms in your area. Finally, you will be able to use different data sets, mainly found on the internet, to determine how active the Madden-Julian Oscillation is at any given time, and understand its significance to winter weather in the US.

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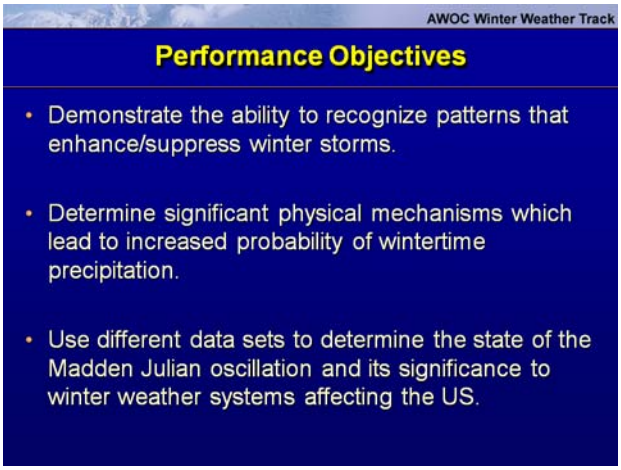

4. IC 4.1 Part 2: Madden Julian Oscillation

Instructor Notes: Here is an outline for this section. We'll define the Madden-Julian Oscillation or the "MJO", find out how we monitor it, and then further investigate the effects that the MJO has on the winter weather in the US.

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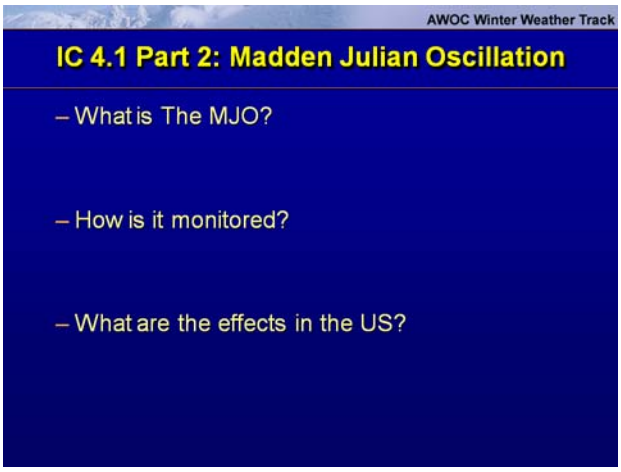

5. The Madden Julian Oscillation

Instructor Notes: Large and complex cloud systems have been shown to move from the Indian Ocean into the central Pacific Ocean at 5-10 m/s with time scales from ~30 to 60 days. These cloud systems have been shown to directly affect Indian rainfall and tropical storm formation, along with effects even in globally averaged quantities and mid-latitude weather. These cloud systems have been identified as being associated with the Madden-Julian Oscillation (MJO).

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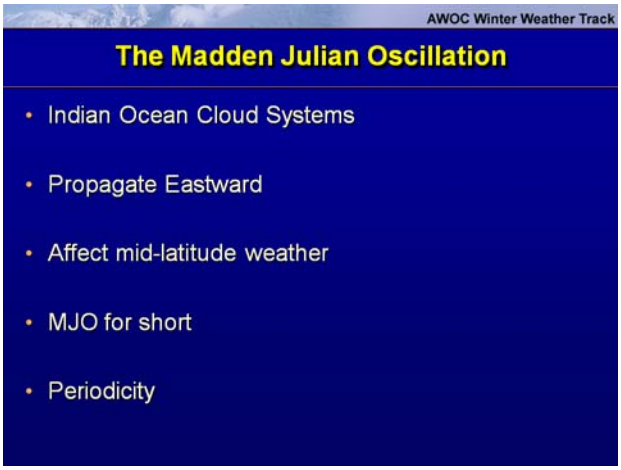

6. So Just What Is MJO?

Instructor Notes: In 1971, Roland Madden and Paul Julian discovered a 30-60 day oscillation when analyzing zonal wind anomalies in the tropical Pacific. They used ten years of pressure records at Canton (at 2.8 degrees S in the Pacific) and upper level winds at Singapore. The MJO gained significant attention after the 1992-1993 El Niño event. The MJO turns out to be the main intra-annual fluctuation that explains weather variations in the tropics. The MJO affects the entire tropical troposphere but is most evident in the Indian and western Pacific Oceans. The MJO involves variations in wind, sea surface temperature (SST), cloudiness, and rainfall. Because of the strong forcing of convection in the tropics, the MJO can have strong effects in the mid-latitudes, similar to effects from ENSO, but on shorter time-scales.

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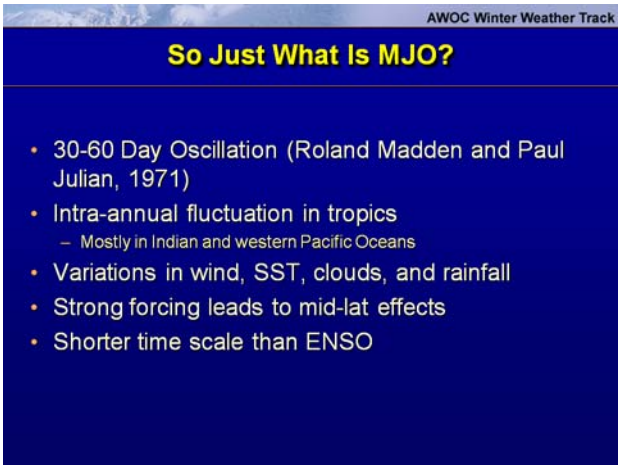

7. OLR Animation of the MJO Life Cycle

Instructor Notes: OLR: Outgoing Longwave Radiation. The blue and green area is where OLR is suppressed, this is because increased convection is preventing OLR. Alternatively, the orange area is where OLR is enhanced because there is relatively little convection. Note the propagation of the areas in the animation are from west to east, and that the areas of convection diminish as they move over the cooler waters of the eastern tropical Pacific. (Note: the reference for this graphic is Matthews, A. J., 2000: Quart. J. Roy. Meteorol. Soc., 126, 2637-2651).

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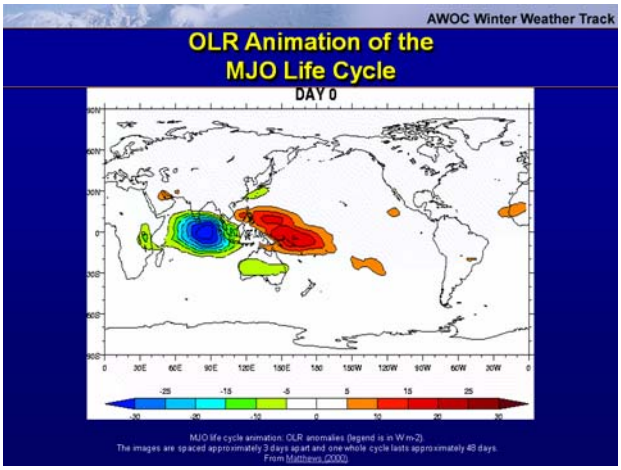

8. Idealized MJO Dynamics

Instructor Notes: Convection forms, leading to anticyclones developing aloft, then cyclonic circulations form, enhancing subsidence ahead. Surface air flows toward enhanced convection regions. In the upper troposphere, anomalous easterlies exit the west side of the enhanced convection When suppressed convection is strong from the Indian Ocean to the middle Pacific Ocean, anomalous cyclonic circulations at 200 mb (the red area at 200 mb) trail the region of suppressed convection. Similarly, anticyclonic

circulations at 200 mb (the blue area at 200 mb) trail the enhanced convection region once it becomes strong in the Indian and western Pacific Oceans. Circulation couplets in the opposite sense are produced at surface, but they are much weaker than the ones aloft. The zonal circulation and horizontal circulation patterns are important processes by which the MJO shuffles mass around the tropics. (Note: the reference for this image is Rui, H. and B. Wang, 1990: Development characteristics and dynamic structure of tropical intraseasonal convection anomalies, J. Atmos. Sci., 47, 357-379.)

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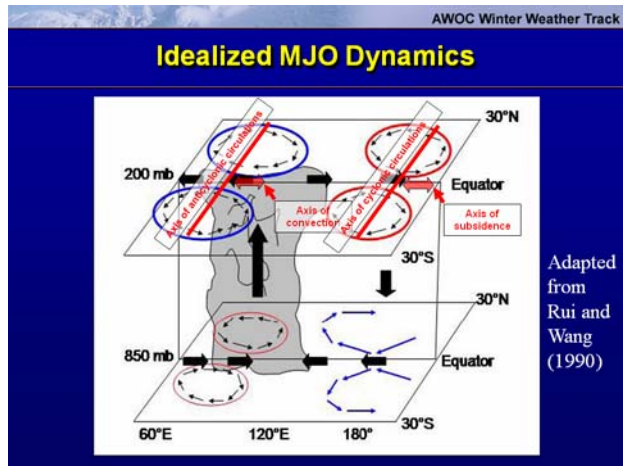

9. Structure of a Madden-Julian Wave

Instructor Notes: Where the trade winds flow into convection we see a lowering pressure (the red areas) and upward vertical motion; and also slightly warmer SSTs. Convection and the associated Kelvin wave move eastward across this area. The structure of the MJO wave is comprised of two regimes. One regime has upper-level divergence, and low-level convergence, which leads to rising motion and the visible convection which can be seen in satellite imagery. You can see this well in F, G, H, A, and B…where you see the upward motion and well-developed convective cloud mass. The other regime has upper-level convergence and low-level divergence, leading to sinking air and suppressed convection. This is most notable in C, D, and E where you see the downward arrows and surface divergence dominating. This results in higher surface pressures, depicted in blue, which are propagating along with the trade winds. Specifically, within the center of suppressed convection, clear skies associated with a stronger-than-normal trade wind inversion allow more shortwave radiation to reach the ocean surface, causing a slight SST increase as the wave travels eastward. The Trade winds too are stronger than normal, explaining enhanced evaporation from the sea surface. A fast Kelvin signal moves across the Pacific in G-A representing the easterly inflow into the onset of convection over the west Pacific. Kelvin waves propagate eastward, while equatorially trapped Rossby waves propagate westward creating downward motion via upper-level convergence. Propagating westward is a Kelvin wave response to the convection; Kelvin wave energy travels faster, catches up to convection to the west, and after it passes, a weakening of the convection is noted. Easterly winds (and the evaporation rate) weaken near the western edge of the suppressed convection region, leading to low-level

moisture convergence. See this in the top diagram, labeled ‘F.’ This triggers deep convection, leading to the visible portion of the MJO, i.e. the region of enhanced convection. There can be multiple areas of convection, especially when the active center is over the western hemisphere, e.g., dateline, South America, Africa. Also, the Kelvin-Rossby wave response to convection can give multiple suppressed centers. One last thing to note in this diagram is the absence of visible convection in the far right of the image. Recall that I mentioned that convection from the MJO is often significantly diminished as it propagates over cooler ocean waters in the eastern pacific. It is important however, to remember that the “waves” associated with an MJO are still present, even if clouds and convection are not visible, and that the “waves” associated with the MJO do indeed continue to propagate around the globe. (Note: the reference is Madden, R. A., and P. R. Julian, 1971: Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific.J. Atmos. Sci., 28, 702-708. Madden, R. A. and P. R. Julian, 1972: JAS, 29, 1109-1123.)

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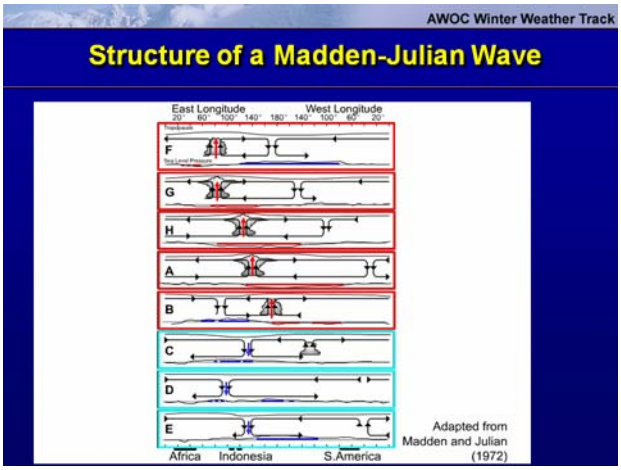
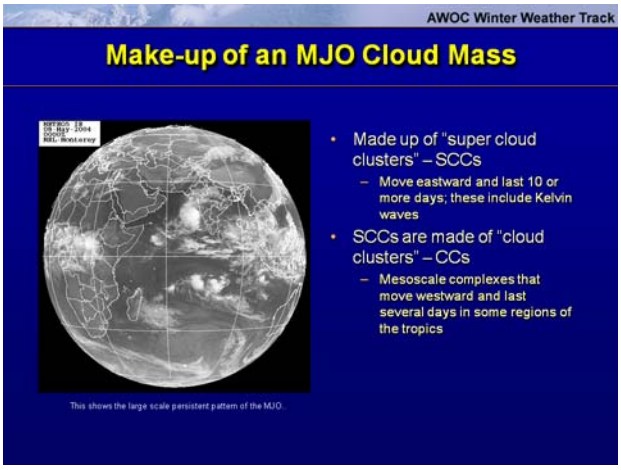


10. Make-up of an MJO Cloud Mass

Instructor Notes: Satellite imagery is helpful in determining the state of MJO…especially time loops of satellite imagery. MJO is characterized by “super cloud clusters” that move eastward (recall this is the latitude of trade winds and kelvin waves propagating).

Student Notes:



11. Who Cares What Happens in the Tropics?

Instructor Notes: Deep persistent convection in the tropics (the large red area at around 100 E) can excite a Rossby wave train (the purple Hs and Ls) that moves rapidly away from the tropics. These Rossby waves, depending on the current "weather" pattern, can enhance or break blocking patterns and lead to enhancements or weakening of the current jet stream. Note, for example the strong High and Low couplet near the dateline. You can see the enhanced jet stream in this area. The Rossby waves can get involved with and organize synoptic wavetrains in mid-latitudes. This has obvious effects on the wintertime precipitation over the U.S. It is important to note, however, that MJO variability and the overall weather pattern during a given MJO varies; therefore, the synoptic pattern during a given MJO will also be variable. As the MJO event moves eastward, so does the Rossby wave train forcing, enhancing winter time synoptic scale systems as it moves. (note: Reference is Kiladis, G. N., and K. M. Weickmann, 1997: Horizontal structure and seasonality of large-scale circulations associated with submonthly tropical convection. Mon. Wea. Rev., 125, 1997-2013.)

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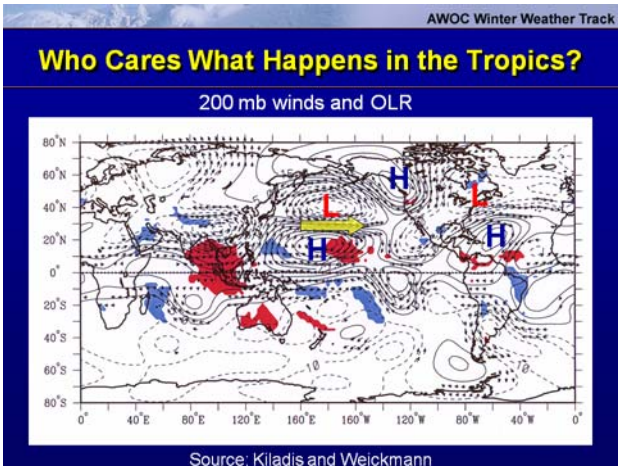

12. Natural Variability with the MJO

Instructor Notes: There is strong year-to-year variability in MJO activity, with long periods of strong activity followed by periods in which the oscillation is weak or absent. This interannual variability of the MJO is partly linked to the ENSO cycle. Strong MJO activity is often observed during weak La Niña years or during ENSO-neutral years, while weak or absent MJO activity is typically associated with moderate to strong El Niño episodes. Since each MJO occurs in a different synoptic pattern, the effects of the MJO on the extratropics tend to also be different from MJO to MJO, making forecasting of effects difficult. The MJO has been shown to have been an important player in initiating or ending of several ENSO events. Why doesn't EVERY MJO trigger an El Niño event? Could be the Charge/Discharge Theory, which states that: MJO is the TRIGGER—it happens much more often than the El Niño event itself, and not every trigger is exactly right. Even when the trigger is right, maybe ocean conditions are not yet right. Once things have charged up properly, and the ocean-atmospheric coupled system is ready, an El Niño occurs. MJOs may play a role in the transition to an El Nino or La Nina. This means they help determine details of the timing and/or amplitude of a warming or cooling event. However, the transitional stage of an ENSO event is complicated and the MJO's role is still being investigated. MJOs were prominent during the 1996-97 northern winter at the early stage of the 1997-98 El Nino and this led to heightened awareness of a possible MJO-ENSO link. The 1996-97 MJO activity was by some measures the greatest in the ~30 year record of outgoing longwave radiation.

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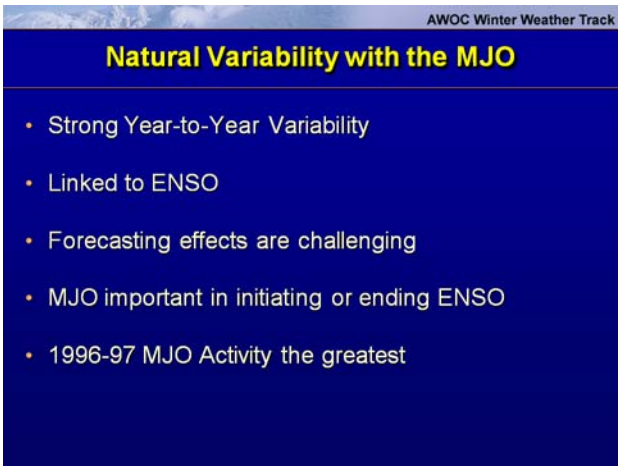

13. Potential Impacts on the U.S.

Instructor Notes: The MJO can have significant impacts on the wintertime atmospheric circulation over the North Pacific and western North America. The strongest impacts of intraseasonal variability on the U.S. occur during the winter months over the western U.S. During the winter this region receives the bulk of its annual precipitation. Storms in this region can last for several days or more and are often accompanied by persistent atmospheric circulation features. From these studies it is known that extreme precipita-

tion events can occur at all phases of the ENSO cycle, but the largest fraction of these events occur during La Niña episodes and during ENSO-neutral winters. In these winters there is a stronger linkage between the MJO events and extreme west coast precipitation events. It is also a contributor to blocking activity (i.e. atmospheric circulation features that persist near the same location for several days or more) and block evolution over the high latitudes of the North Pacific, which is another important component of winter weather patterns over North America. In any given year there are periods of enhanced / suppressed tropical storm/hurricane activity within the season. There is evidence that the MJO modulates this activity by providing a large-scale environment that can be favorable or unfavorable for development. The strongest tropical cyclones tend to develop when the MJO favors enhanced precipitation. As the MJO progresses eastward, the favored region for tropical cyclone activity also shifts eastward from the western Pacific to the eastern Pacific and finally to the Atlantic basin, assuming other environmental factors are favorable for tropical disturbances to form and persist. Velocity Potential graphics are very useful for viewing this. Since tropical cyclones will be covered in future AWOC training, we will not cover more about them here.

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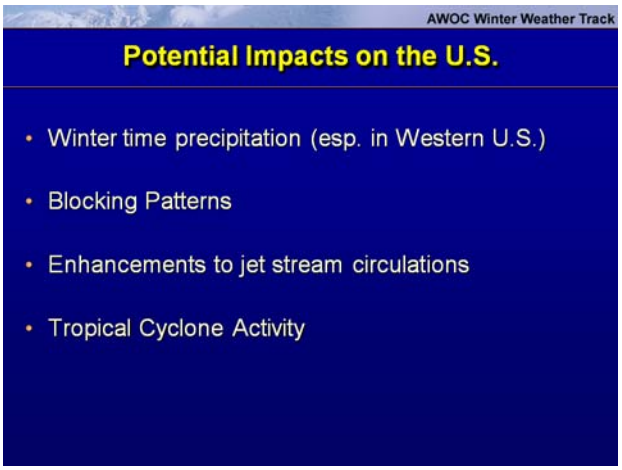

14. Heavy West Coast Precipitation Events

Instructor Notes: The typical scenario linking the pattern of tropical rainfall associated with the MJO to extreme precipitation events along the West Coast features a progressive (i.e. eastward moving) circulation pattern in the tropics and a retrograding (i.e. westward moving) circulation pattern in the mid-latitudes of the North Pacific. The MJO is more likely to generate this type of event when a positive Pacific-North American Teleconnection, or PNA, pattern is already in place. We'll discuss more about the PNA and other teleconnections in the next sub-lesson, 1.3. (note: The figure comes from http://www.cpc.ncep.noaa.gov/products/intraseasonal/ intraseasonal_faq.html)

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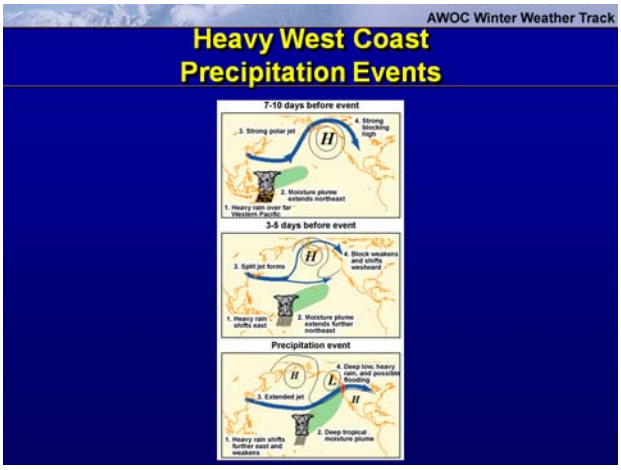

15. General Relationship Between Persistent Tropical Convection and West Coast Precipitation

Instructor Notes: If you think about the further west the disturbance is, then you will envision that the Low that develops is also further west. Therefore, the downstream ridging from this will also be further west and then the resulting precipitation will be further north. It is important to note that the overall linkage between the MJO and extreme west coast precipitation events weakens as the region of interest shifts southward along the west coast of the United States. (note: The figure comes from http://www.cpc.ncep.noaa.gov/products/intraseasonal/intraseasonal_faq.html)

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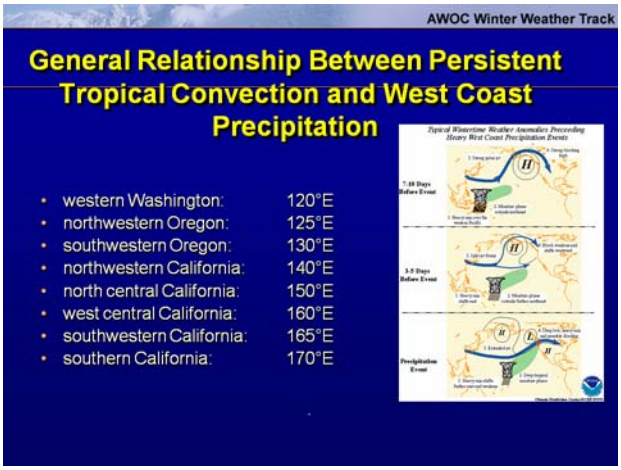

16. Monitoring and Predicting the MJO

Instructor Notes: Due to its slowly evolving nature, accurate prediction of the MJO and its effects is fundamentally related to our ability to monitor the feature and to assess its relative position and strength. Dynamical models generally do not predict the MJO well, partly because of the inherent difficulties that still remain regarding the correct mathe-

matical treatment of tropical convective (rainfall) processes. Satellite-derived data are used to indicate regions of strong tropical convective activity, and regions in which the convective activity departs substantially from the long-term mean.

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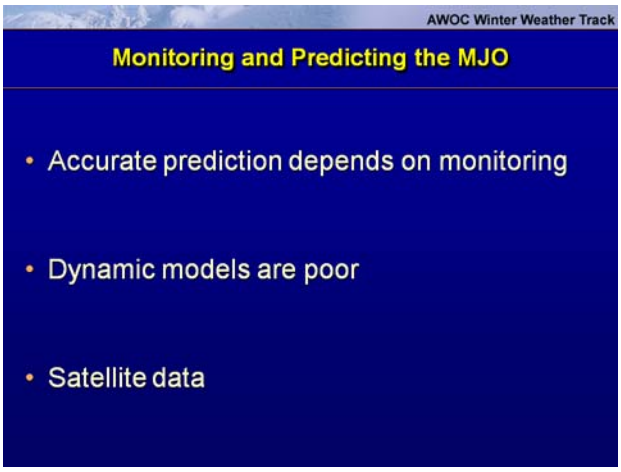

17. Monitoring and Predicting the MJO

Instructor Notes: A second fundamental data source used to monitor the MJO is the global radiosonde network which provides crucial information regarding the atmospheric winds, temperature, moisture, and pressure at many levels of the atmosphere. There are several diagnostic variables that allow us to directly monitor the MJO. The variables are often displayed in time-longitude format so as to reveal the propagation, amplitude and location of the MJO-related features. Typical variables include: 1) Outgoing Long-wave Radiation, which is a satellite-derived measure of tropical convection and rainfall, 2) Velocity Potential, which is a derived quantity that isolates the divergent component of the wind at upper levels of the atmosphere, 3) Upper-level and lower-level wind anomalies, which show the large-scale cyclones and anticyclones (i.e., wavenumbers 1-3) that straddle the convection 4) 500 mb height anomalies, which can represent the atmospheric response in midlatitudes.

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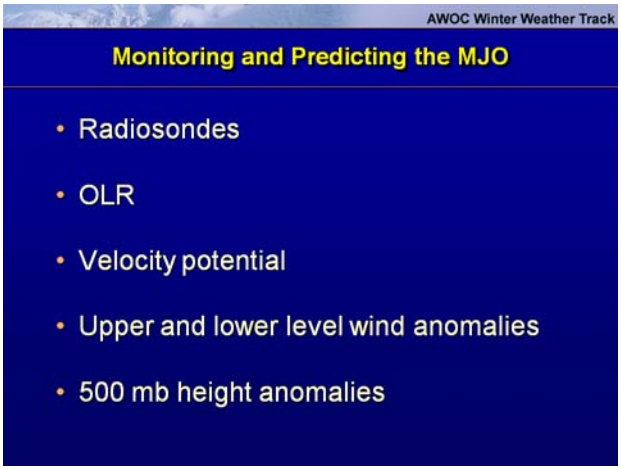

18. Outgoing Longwave Radiation (OLR)

Instructor Notes: Most tropical rainfall is convective. Deep convective cloud tops are very cold so they emit only small amounts of longwave radiation. The MJO is most obvious in the variation of outgoing longwave radiation (OLR), as measured by an infrared sensor on a satellite. OLR anomalies in the eastern hemisphere propagate to the east at around 5 m/s with a recurrence interval of about 30 to 60 days. The OLR signal is weaker in the western hemisphere. The blue areas on the right image show propagating areas of OLR suppressed areas (ie, MJOs) The MJO activity is quite variable as shown above on the left.

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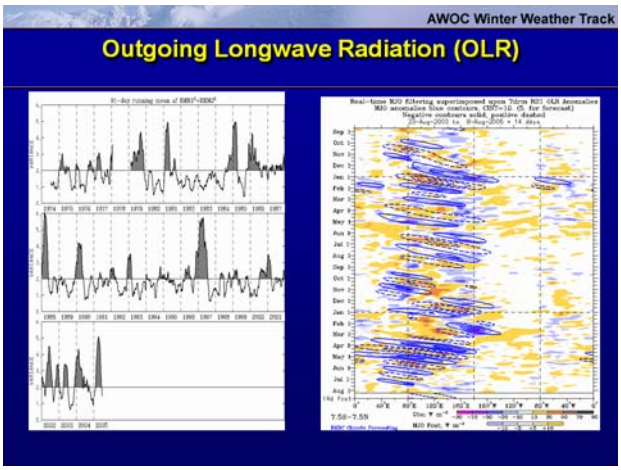

19. Velocity Potential

Instructor Notes: Velocity potential anomalies at 150 or 200 mb are proportional to upper level divergence and convergence; the green contours correspond to regions of large-scale upper-level divergence where convection tends to be enhanced; whereas the brown contours correspond to areas of upper-level convergence, where convection is suppressed. Using plan view maps such as this helps scientists locate and track MJO activity. Ref: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ir_anim_monthly.shtml

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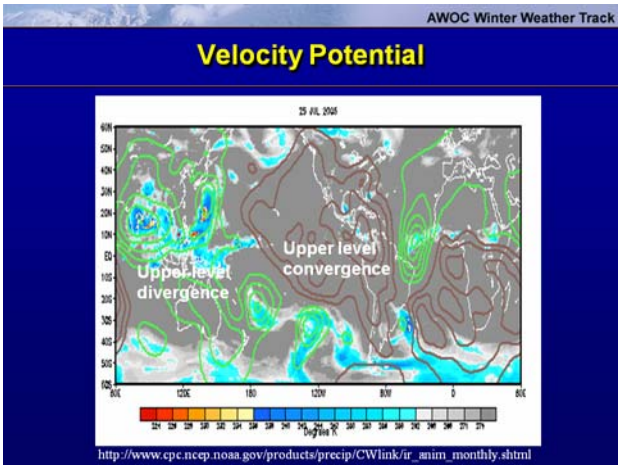

20. Wind Anomalies

Instructor Notes: Examining wind anomalies both in the low levels (weakening easterlies or westerly wind bursts) and especially at high levels (cyclonic and anticyclonic gyres) can be useful in identifying the strength and the possible large-scale mid-latitude effects of an MJO event. http://www.cdc.noaa.gov/map/clim/glbcir.quick.shtml

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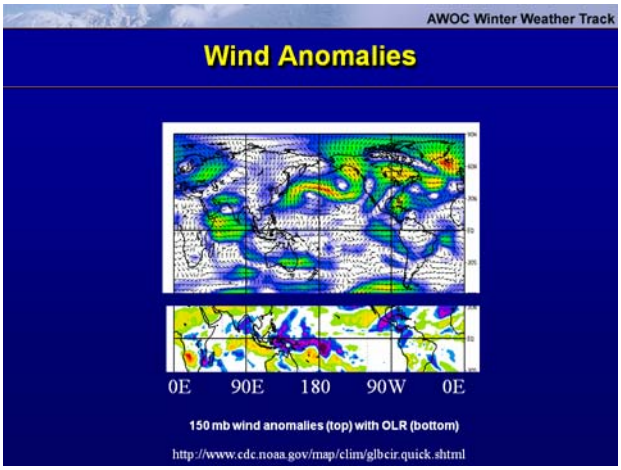
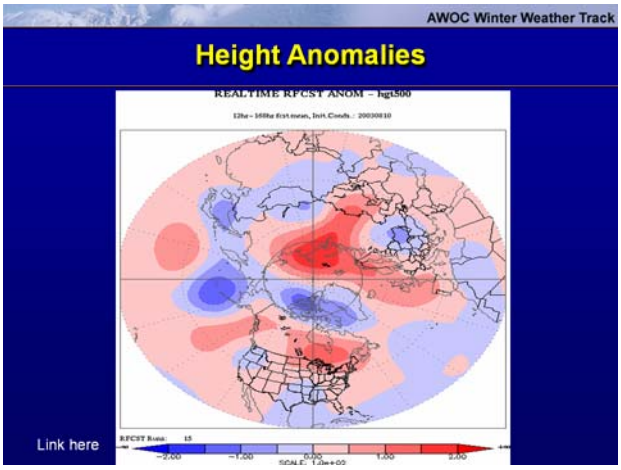


21. Height Anomalies

Instructor Notes: Look for the tilt of the waves – resultant pattern which can then affect the background weather pattern. Use of height anomalies can highlight the Rossby wave train effects that can occur with vigorous long-lived convection in tropical regions. Time-longitude diagrams of 250 mb height anomalies averaged between 30-60 N can be used to monitor synoptic wave activity and to diagnose MJO-related impacts. Ref: http://www.cdc.noaa.gov/MJO/Forecasts

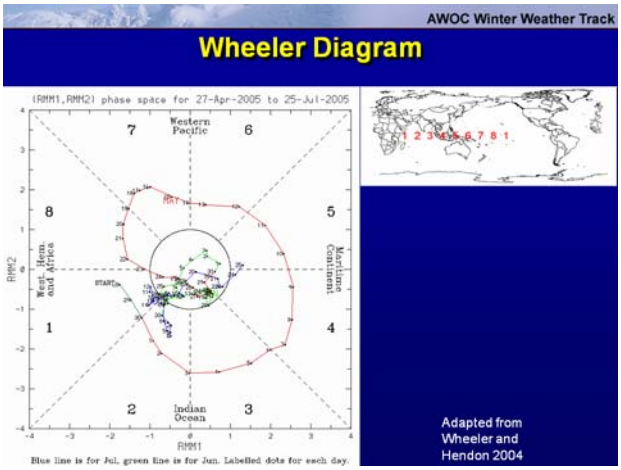
Student Notes:



22. Wheeler Diagram

Instructor Notes: Based on analyses of 200 mb zonal wind, 850 mb zonal wind and OLR, eight different phases of the MJO were defined by Wheeler and Hendon (2004). The Wheeler Diagram plots the location of the center of active convection of the MJO in a representative phase space. A point's distance from the origin is a measure of the MJO signal strength. This graphic shows a strong MJO propagating into the western hemisphere during late May 2005 (red line) and then weakening as it approaches Africa. MJO activity remained weak during most of June and July 2005. The index can be used for forecasting the MJO and for diagnosing local weather conditions for the different MJO phases. You should be aware that sometimes there are problems with this diagram, particularly when the atmosphere is transitioning from one ENSO state to another. Therefore, what may look like an MJO signal, may not actually be one. This was the case in Jan/Feb 2006, as we transitioned from neutral to La Nina conditions. Later, you will be given references to find real time wheeler plots and all of the other data you've been shown in this lesson. Ref: "An All-Season Real Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction: Matthew C. Wheeler and Harry H. Hendon, 2004: Monthly Weather Review, 132, 1917-1932.

Student Notes:



23. Monitoring MJO

Instructor Notes: The next two slides have many links to data which scientists use to monitor the MJO. Take a few minutes to look over the list and consider more in-depth viewing of this data when you want to analyze the current state of the atmosphere and in particular how the tropics and extratropics oceans/atmosphere are behaving; this could be part of your forecast funnel in the winter to assess/predict the potential for large scale slowly evolving long wave patterns to set up and affect the development and track of synoptic systems.

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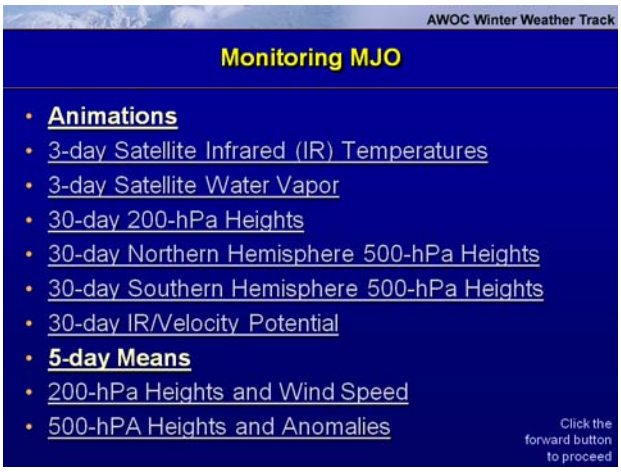

24. Monitoring MJO (continued)

Instructor Notes:

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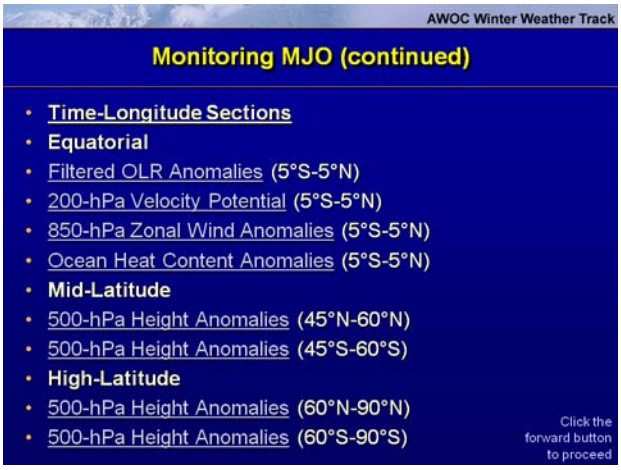

25. CDC and Other MJO Resources

Instructor Notes: Here is a list of some of the resources you can use to find out more about the MJO and forecasting it's effects. The first one is a "blog" or comment(s) by the Science and Operations Officer in Dodge City, KS, Ed Berry. Ed updates this "discussion" whenever something of interest is occurring in the climate system, in particular with regard to the MJO*. The rest are either CPC or CDC links to useful information. The next slide offers information on an "Interactive Tool" that you may find useful in your climate studies and outreach services. *Note: Ed Berry's log is an unofficial climate related product. Refer to the CPC for all official climate related forecast and diagnostic products disseminated by NOAA.

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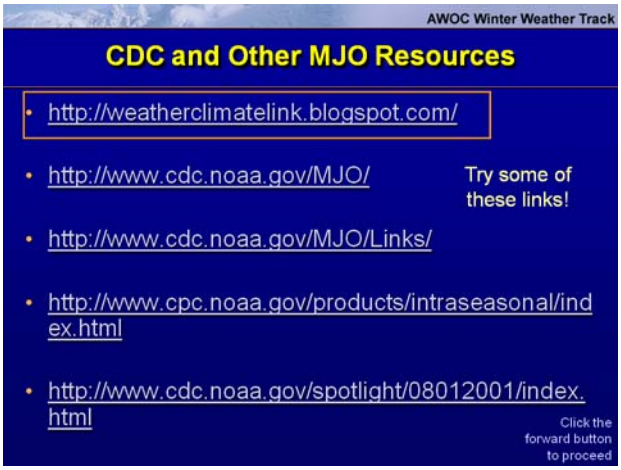
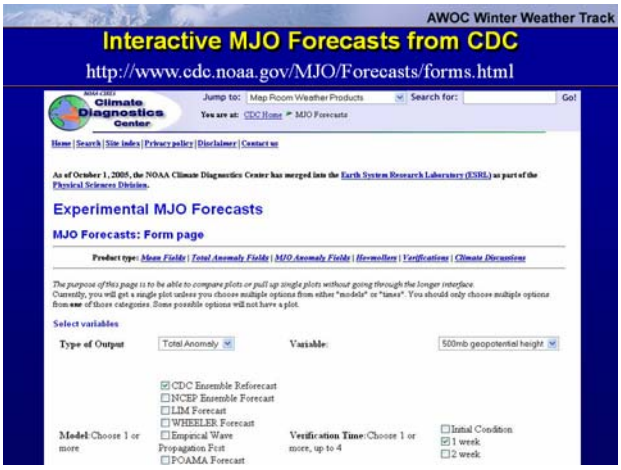


26. Interactive MJO Forecasts from CDC

Instructor Notes: Hosted on Climate Diagnostics Center page, this link is of particular interest, as it allows the user to change parameters to customize output of the forecasts of the MJO. There are many such interactive interfaces, I recommend that you look them over and consider if you would like to conduct a local study using the information that is provided by these pages.

Student Notes:



27. Other Interactive Forecasts

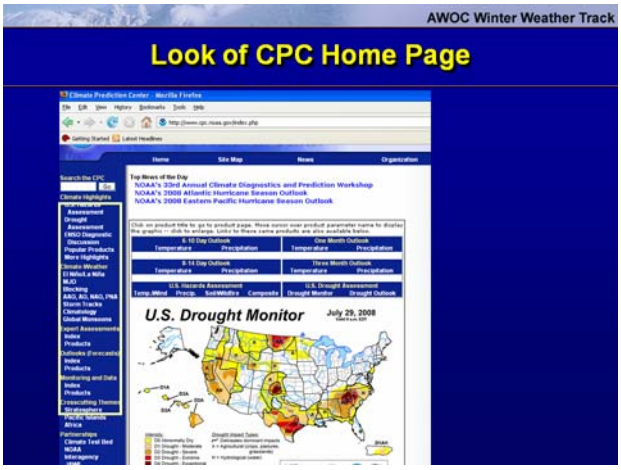
Instructor Notes: Here is another one of CDC's interactive pages. On this particular page, you can plot a time series for a given station, parameter, and level. These types of analyses can be used to depict expected conditions for different stages of the MJO, for example. Again, you might find these pages useful in conducting local studies or answering questions posed by your customers, particularly for questions regarding effects of the state of the climate system on seasonal forecasts.

Student Notes:

28. Look of CPC Home Page

Instructor Notes: We've just discussed some of the MJO information available from the Climate Diagnostics Center in Boulder, Colorado. Here is the "front page" of the Climate Prediction Center's web site. Note, it has the traditional layout with the left-hand margin containing a list of topics. The includes "MJO" under the "Climate-Weather" heading. If you click on that the list on the next slide appears.

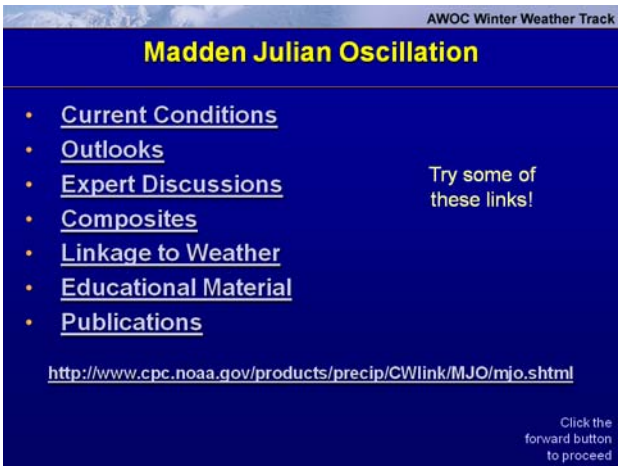
Student Notes:



29. Madden Julian Oscillation

Instructor Notes: Underneath the “ENSO” listing on the left hand side of the “Climate-Weather Link” you will find “MJO.” If you click on that, you’ll get this list plus other information on the current and predicted state of the MJO.

Student Notes:



30. MJO Quiz

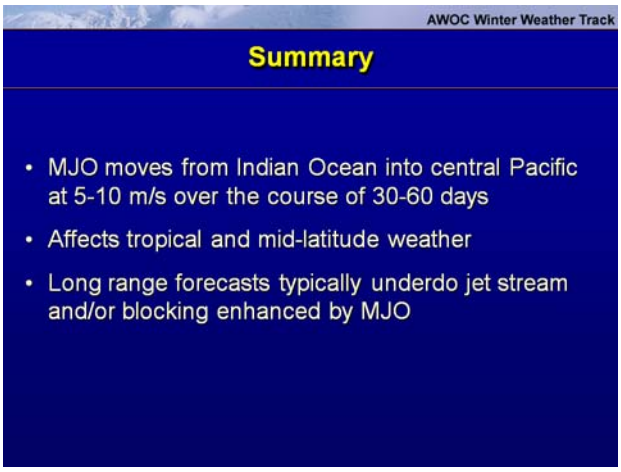
Instructor Notes:

Student Notes:

31. Summary

Instructor Notes: The MJO is a naturally occurring phenomenon which moves from the Indian Ocean into the central Pacific Ocean at 5-10 m/s with time scales from ~30 to 60 days. The MJO has been shown to directly affect Indian rainfall and tropical storm formation, along with effects even in globally averaged quantities and mid-latitude weather. Numerical models handle tropical convection poorly, so long-range forecasts will typically be underdone with jet stream energy, or not anticipate mid-latitude blocking forced by the tropical heating.

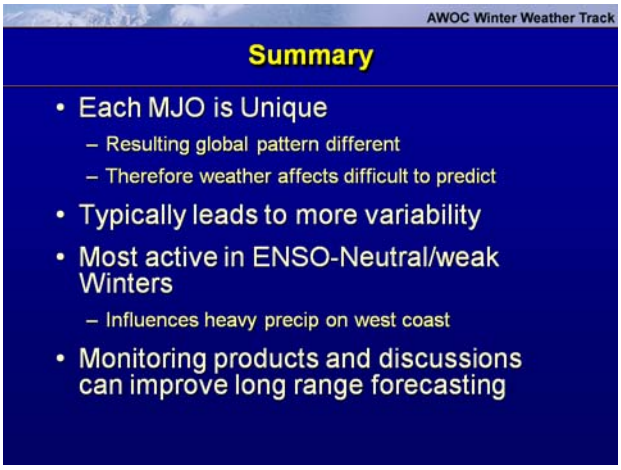
Student Notes:



32. Summary

Instructor Notes: Because each MJO is different, and the global pattern which the MJO is occurring in is also different, the resultant modifications to the weather pattern can be difficult to predict. However, the location of the tropical heating does lead to some “more likely” scenarios, as shown through research. The MJO typically leads to increased variability, especially in the winter. It can produce ENSO-like features on time scales of approximately 30-60 days. The MJO is most active during ENSO-neutral and weak-ENSO winters, and influences the occurrence of extreme weather events, such as floods, along the Pacific Northwest Coast. Monitoring CPC products and discussions regarding the MJO can lead to possible improvements in the long-range forecasts issued by the NWS, in a probabilistic sense.

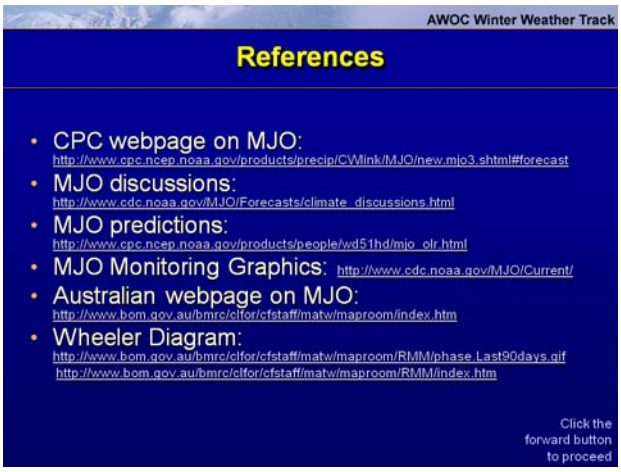
Student Notes:



33. References

Instructor Notes: Here are some references on MJO that you may want investigate further.

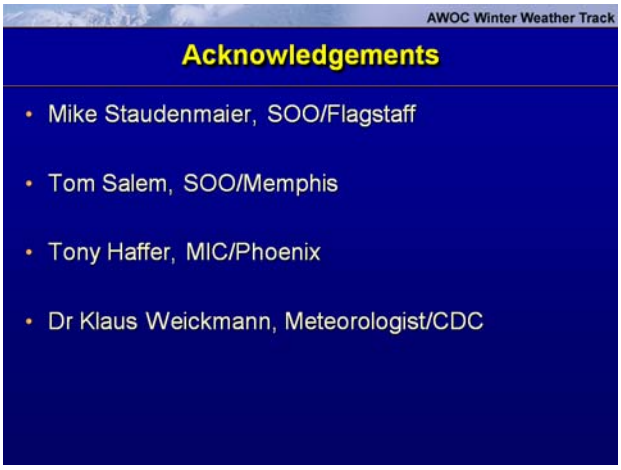
Student Notes:



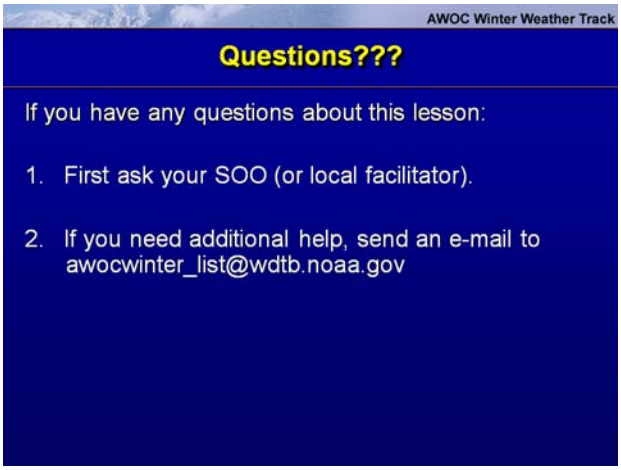
34. Acknowledgements

Instructor Notes: I would like to thank the following individuals for their support in the creation of this module: Mike Staudenmaier, SOO/Flagstaff, Tom Salem, SOO/Memphis. Tony Haffer, MIC/Phoenix, AZ, and Dr. Klaus Weickmann, Meteorologist/CDC

Student Notes:



35. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page.

Student Notes: