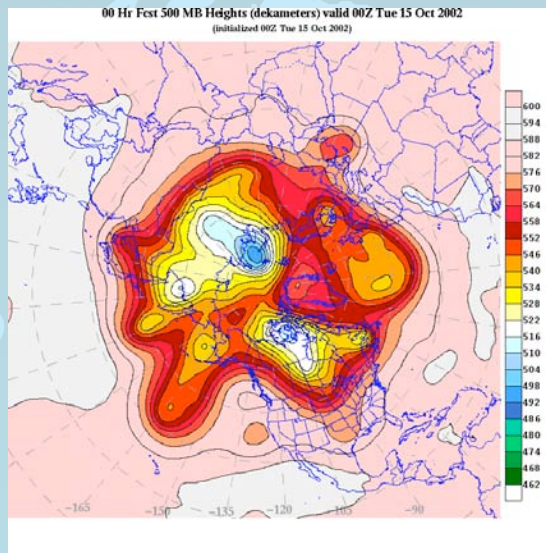


Lecture 1b Planetary (Rossby) Waves

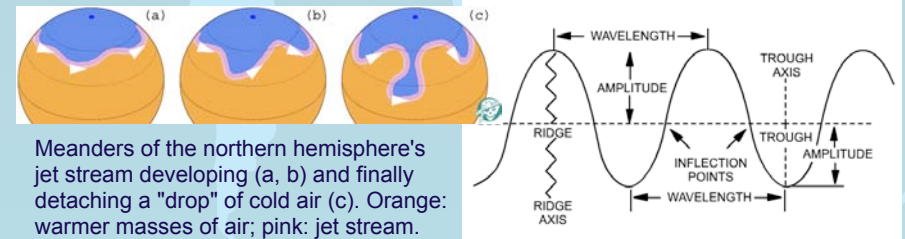
Outline

- Definition
- Significance to Forecasting
- Characteristics
- Formation
- Propagation
- Forcing



Rossby Wave Definition

Rossby (or Planetary) waves are giant meanders in high-altitude winds that are a major influence on weather. Their emergence is due to shear in rotating fluids, so that the Coriolis force changes along the sheared coordinate. In planetary atmospheres, they are due to the variation in the Coriolis effect with latitude. The waves were first identified in the Earth's atmosphere in 1939 by Carl-Gustaf Rossby who went on to explain their motion. Rossby waves are a subset of inertial waves.



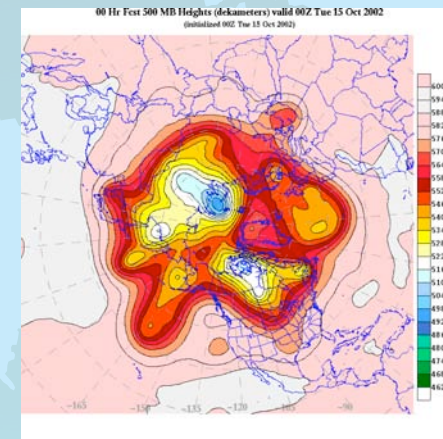
Significance of Planetary Waves

Planetary Waves

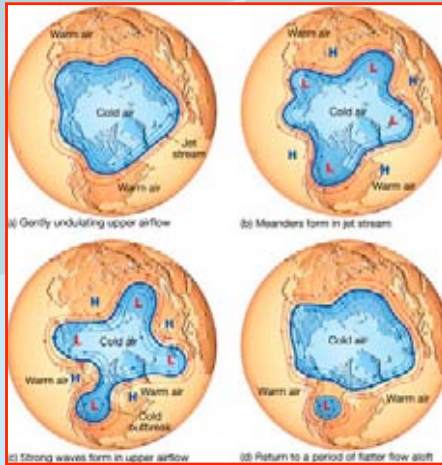
- Define the average jet stream location and storm track along the polar front
- Determine the weather regime a location will experience over several days or possibly weeks.
- Help move cold air equatorward and warm air poleward helping to offset the Earth's radiation imbalance.

Rossby Waves

- Wavelength: 50° to 180° of longitude.
- Wave number: Varies with the season (typically 4 to 5)
- The number of waves per hemisphere ranges from 6 to 2.



Rossby Waves

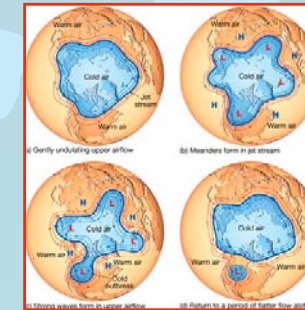


Axis of polar front jetstream outlines the Rossby wave pattern.

5

a) Zonal Flow

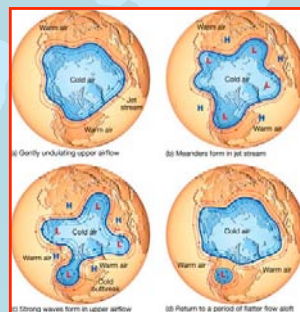
- Basic flow - west to east
- Little north to south energy (heat and moisture) transfer occurs.
- Large north to south temperature variations quickly develop.
- Small west to east temperature variations.
- Minimal phasing of waves.
- Weather systems tend to be weak and move rapidly from west to east



6

c) Meridional Flow

- Large north to south component to the flow
- Large-scale north-south energy transfer occurs.
- North to south temperature variations quickly weaken.
- Large west to east temperature variations.
- Weather systems are often strong and slower moving, with cyclones, producing large cloud and precipitation shields.



7

Blocking Patterns in Highly Meridional Flow

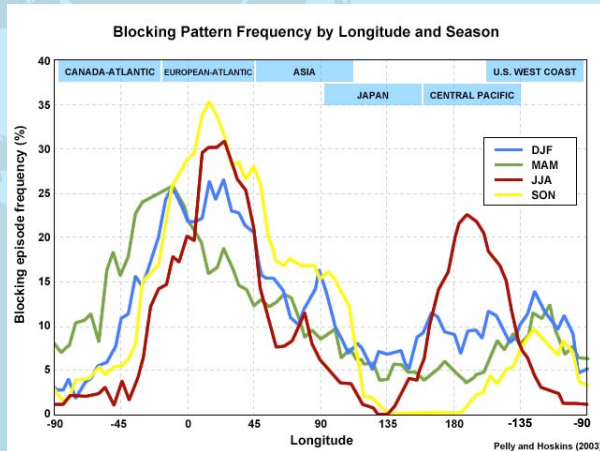
Identifying blocking patterns helps forecasters decide where to focus their attention over the forecast period. When blocking patterns develop, surrounding weather becomes more predictable, and understanding when the block will break down gives forecasters a better picture of the future progressive atmosphere.



Green lines denote deformation zones.

8

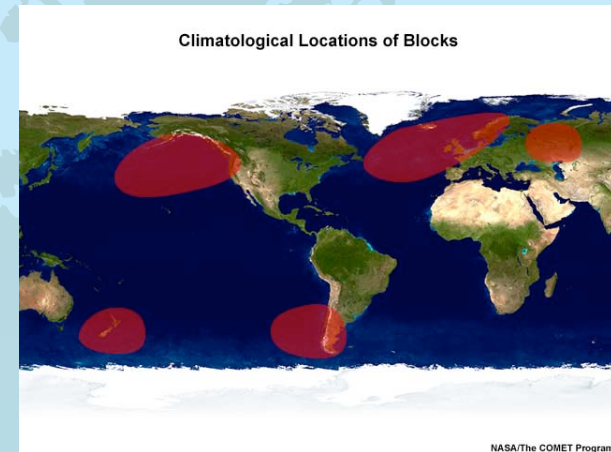
Blocking Patterns



Blocking pattern frequency by longitude and season

9

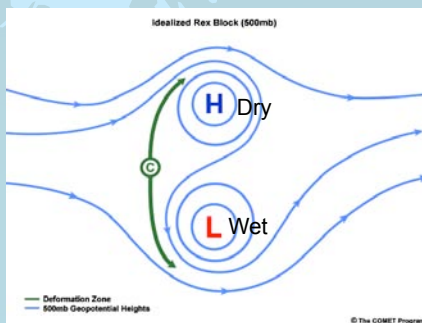
Blocking Patterns



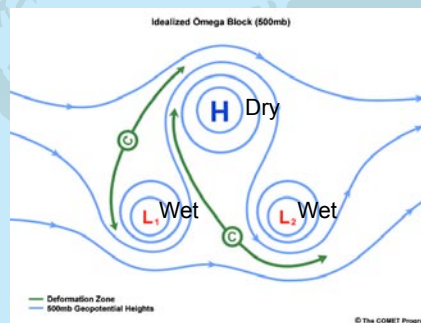
Climatological locations of blocks.

10

Blocking Patterns



Rex block - high over low pattern - blocking generally lasts ~one week.

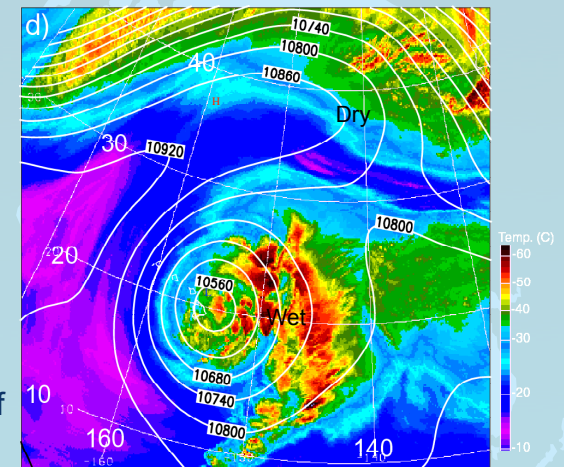


Omega block - blocking ridge with a characteristic "Ω" signature - blocking generally lasts ~ten days.

11

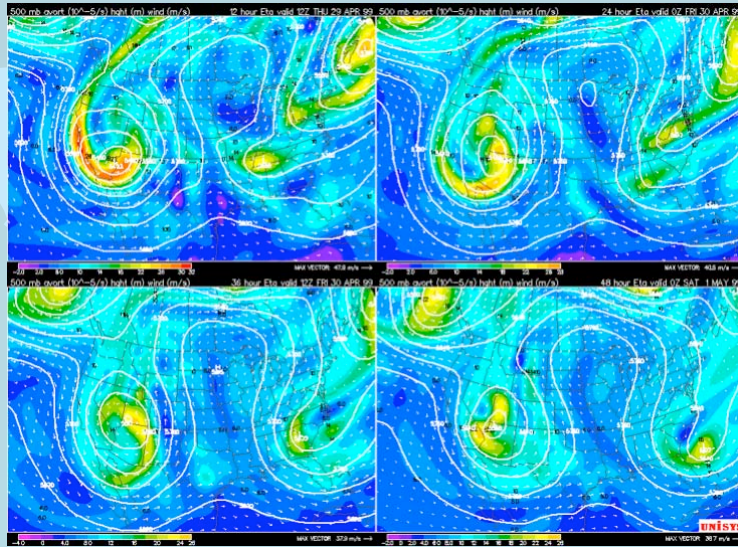
Rex Block

A Rex block is a high over low pattern, with the low to the south cut off from the westerlies. Kona lows occur with a Rex block low near or over Hawaii. The westerlies are split upstream of the block. A Rex blocking pattern has a life expectancy of 6-8 days.



12

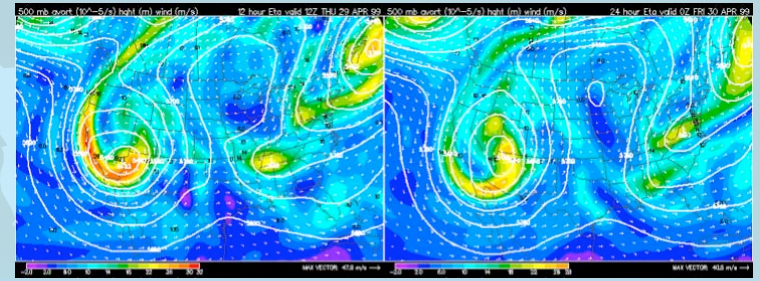
Omega Block



An omega blocking pattern has a life expectancy of 10-14 days. Chart shows 500-mb heights and absolute vorticity.

13

Omega Block

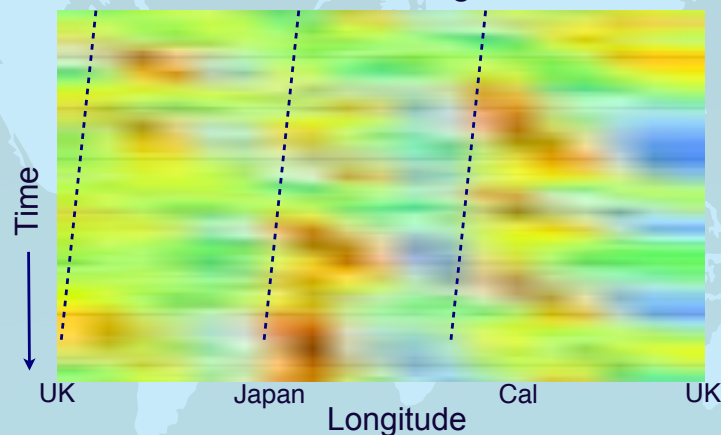


- The region under the omega block experiences dry weather and light wind for an extended period of time while rain and clouds are common in association with the two troughs on either side of the omega block.
- Omega blocks make forecasting easier since you can pinpoint areas that will be dominated by dry or rainy weather for several days.
- The right side of the omega block will have below normal temperatures (due to CAA) while the region to the left will have above normal temperatures (due to WAA) in this case.

14

Diagnosing Rossby Waves

Hovmuller Diagram



250-mb Meridional Wind (m s^{-1}); 35-60 N
Red: S, Blue: N 6-28 November 2002

15

Why do Rossby Waves form?

First let's review vorticity

1. A measure of the intensity of a vortex
2. Related to the spin in 3 dimensions. only vertical is considered in evaluating the dynamics of Rossby Waves.
3. Twice the rate of angular rotation for solid body rotation. $\zeta_r = 2V/r$
4. + for cyclonic, - for anticyclonic (Northern Hemisphere)

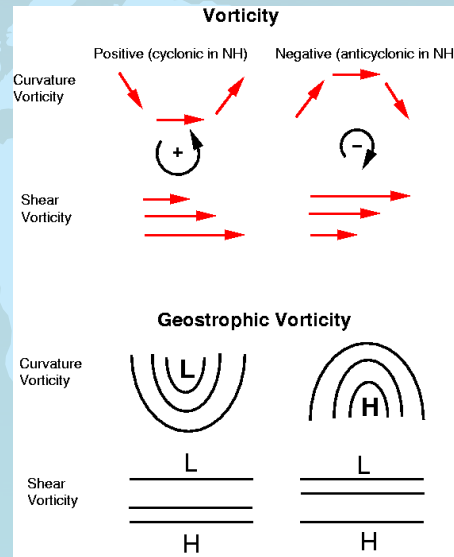
16

Planetary and Relative Vorticity

Relative Vorticity: $\zeta = \nabla \times \mathbf{V}$
Planetary Vorticity: $f = 2\Omega \sin\theta$

There are two parts or components of relative vorticity.

1. Shear vorticity
2. Curvature vorticity



17

Earth's Vorticity



- Spin is maximum at poles
- Spin is zero at equator
- Vorticity is twice spin

The contribution of the Earth's vorticity locally in the atmosphere, depends on the component of the Earth's vorticity that maps onto the local vertical.

- Vorticity = 2Ω at poles and 0 at the equator
- Vorticity = $2\Omega \sin\theta$ at latitude θ
- Earth's vorticity = Coriolis parameter
 $f = 2\Omega \sin\theta$

18

Vorticity Equation

Vertical component of vorticity equation in isobaric coordinates is obtained by taking the x-derivative of the v-momentum equation and subtracting the y-derivative of the u-momentum equation and can be written

$$\zeta \equiv \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

$$\frac{d\zeta}{dt} + v \frac{\partial f}{\partial y} + (\zeta + f) \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) + \frac{\partial v}{\partial p} \frac{\partial \omega}{\partial x} - \frac{\partial u}{\partial p} \frac{\partial \omega}{\partial y} \equiv 0$$

$$v \frac{\partial f}{\partial y} = \frac{df}{dt}$$

$$\frac{d}{dt}(\zeta + f) + (\zeta + f) \nabla_p \cdot \mathbf{V} = \frac{\partial u}{\partial p} \frac{\partial \omega}{\partial y} - \frac{\partial v}{\partial p} \frac{\partial \omega}{\partial x} \equiv 0$$

19

Simplified Vorticity Equation

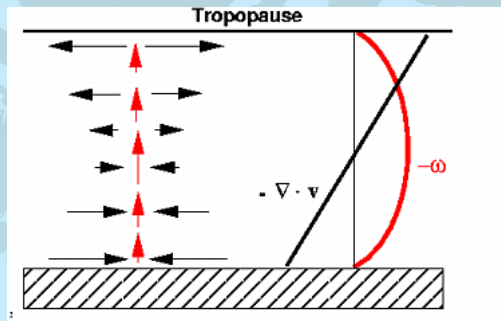
Thus the vorticity equation can be simplified to

$$\frac{d}{dt}(\zeta + f) \equiv -(\zeta + f) \nabla_p \cdot \mathbf{V}$$

The rate of change of absolute vorticity of particular portions of fluid is equal to minus the absolute vorticity multiplied by the divergence.

20

Absolute Vorticity is Conserved



If we look back to our simplified model of upper-level and lower-level divergence, at mid levels the divergence must approach zero. **At that level, absolute vorticity is conserved.**

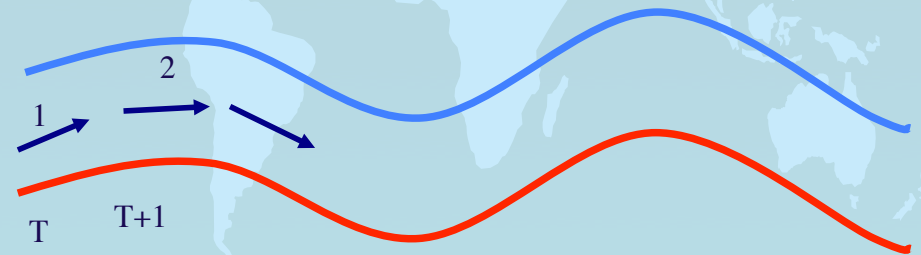
$$\frac{d}{dt}(\zeta + f) \approx 0 \Rightarrow \zeta + f \approx \text{Constant}$$

21

Absolute Vorticity Conservation

$$\frac{d}{dt}(\zeta + f) \approx 0 \Rightarrow \zeta + f \approx \text{Constant}$$

Point 1 to 2, f increases so ζ decreases, curvature becomes anticyclonic and the flow turns southward.

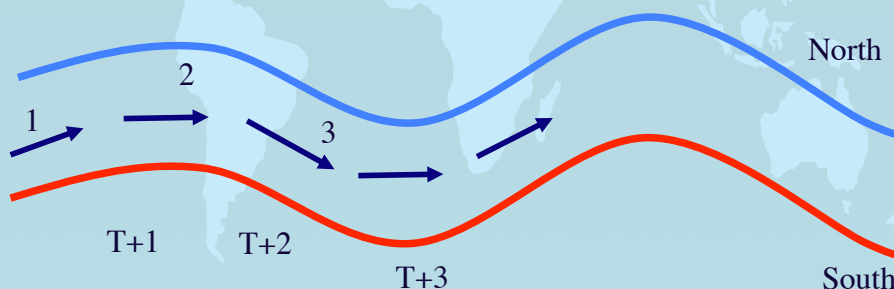


22

Absolute Vorticity is Conserved

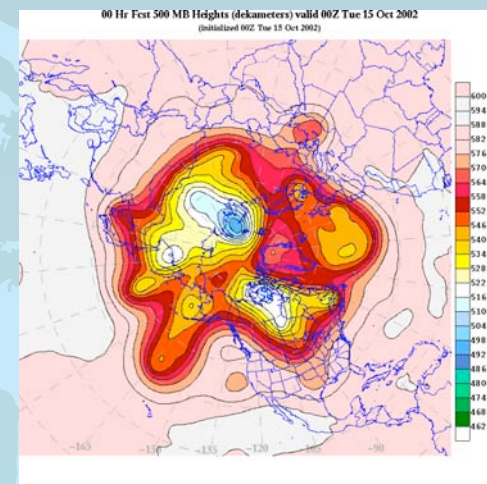
$$\frac{d}{dt}(\zeta + f) \approx 0 \Rightarrow \zeta + f \approx \text{Constant}$$

Point 2 to 3, f decreases so ζ increases, curvature becomes cyclonic and the flow is forced northward.



23

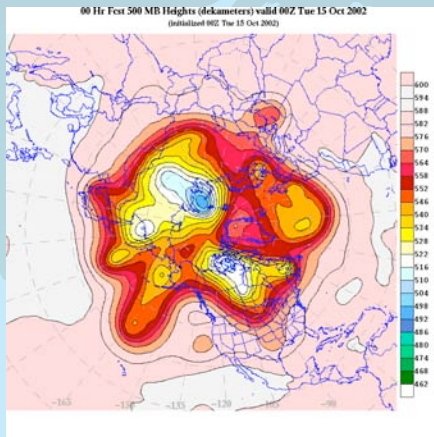
Planetary Waves Conserve Absolute Vorticity



This cyclonic (anticyclonic) oscillation of air parcels as they move equatorward (poleward) describes the alternating trough/ridge pattern seen in the mid-latitude westerlies.

24

Planetary Wave Propagation



For Planetary waves, which generally span more than 10,000 km, f -advection is much greater than ζ advection. Therefore, the sign of the f advection determines whether η ($\equiv \zeta + f$) advection will be + (PVA $\rightarrow$ falling heights) or - (NVA $\rightarrow$ rising heights)

25

Rossby Wave Propagation

- In northwesterly flow upstream of the trough axis, f advection is positive (wind is blowing from higher toward lower values of f). Thus PVA produces height falls upstream (west) of the trough.
- In southwesterly flow downstream of the trough axis, f advection is negative (the wind is blowing from lower toward higher values of f). Thus NVA produces height rises downstream (east) of the trough
- Height falls west of the trough axis and height rises east of the trough axis force the trough to move westward (retrograde) against the flow.

26

What Influences Rossby Wave Patterns?

Climatological positions and amplitudes are influenced by:

- Oceans
- Land masses
- Terrain features (such as mountain ranges)



27

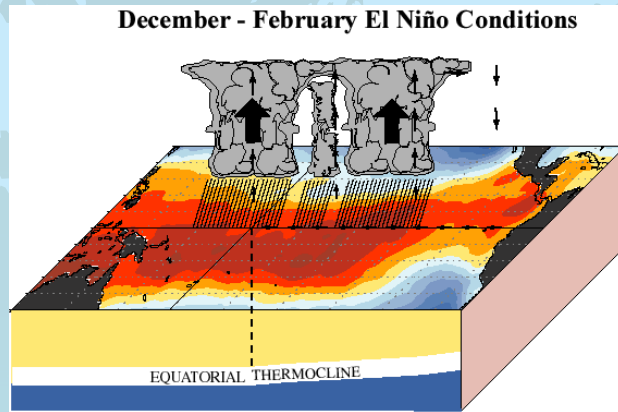
Rossby Wave Forcing

- Mountains set up waves in westerlies (Rockies, Andes)
- Regions of strong thermal heating also set up waves. (e.g., ENSO and MJO)
- Regions of strong thermal contrast: cold land to warm sea



28

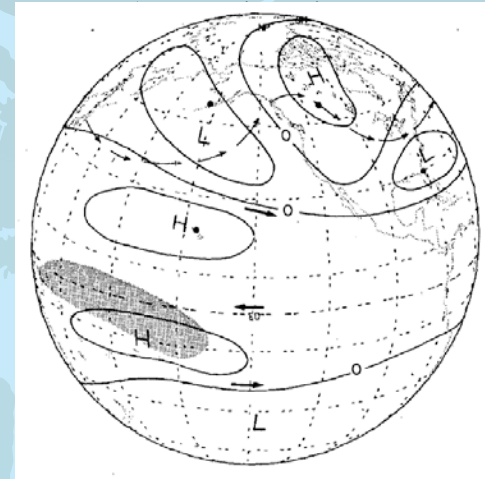
Rossby Wave Forcing by El Niño



Enhanced convection over the central equatorial Pacific results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern.

29

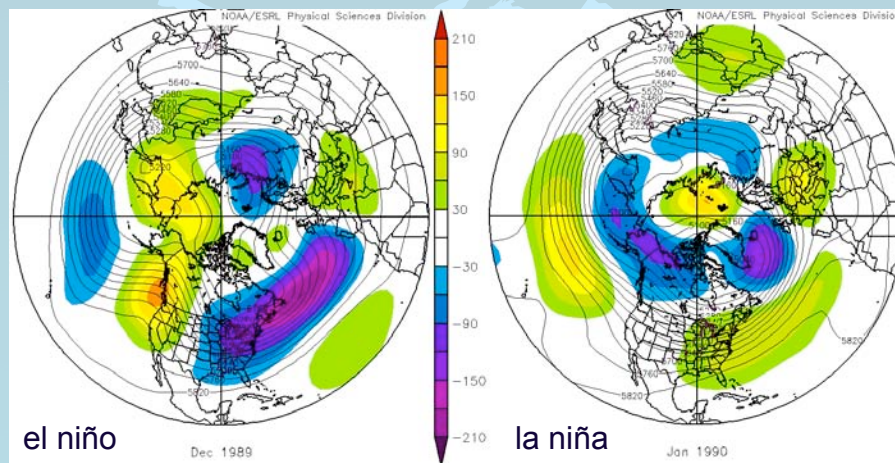
Rossby Wave Forcing



Enhanced convection over the central equatorial Pacific during el niño results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern (Horel and Wallace 1981).

30

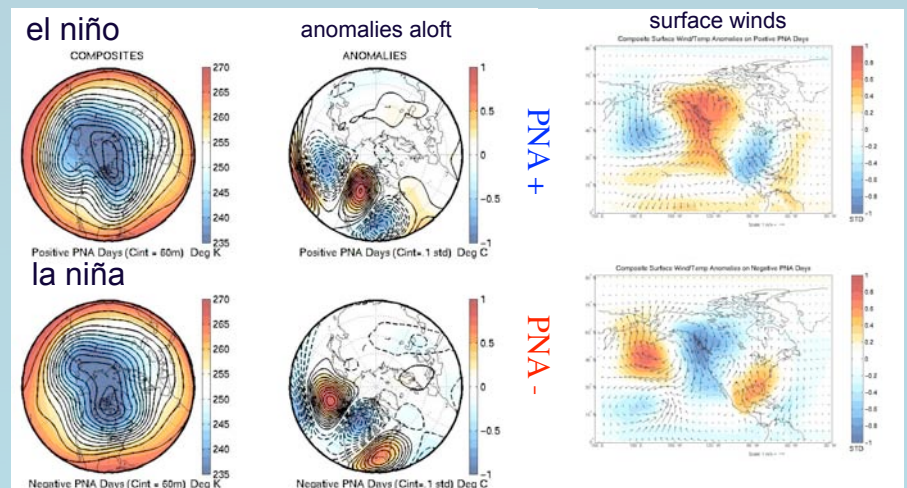
Rossby Wave Forcing by ENSO



Enhanced convection over the central equatorial Pacific results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern.

31

Rossby Wave Forcing



Enhanced convection over the central equatorial Pacific results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern. La Niña results in a -PNA pattern.

32

Planetary Wave Forcing

PNA+ leads to

drought over Hawaii with large surf.

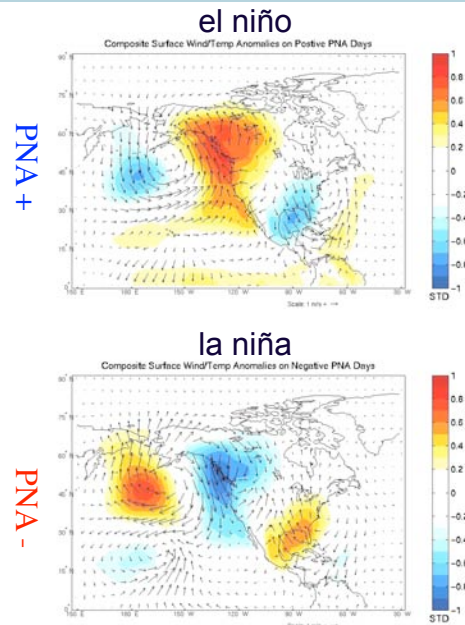
Warm and dry in the Pacific NW.

Wet over CA and wet and cold over the SE US.

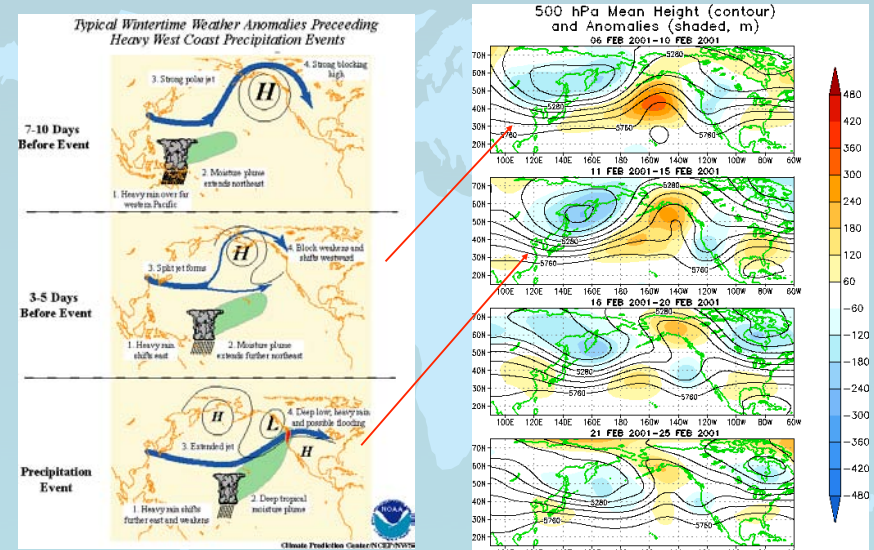
PNA- leads to

Wet for Hawaii

Cold and snowy over the Pacific NW and dry over the SE US

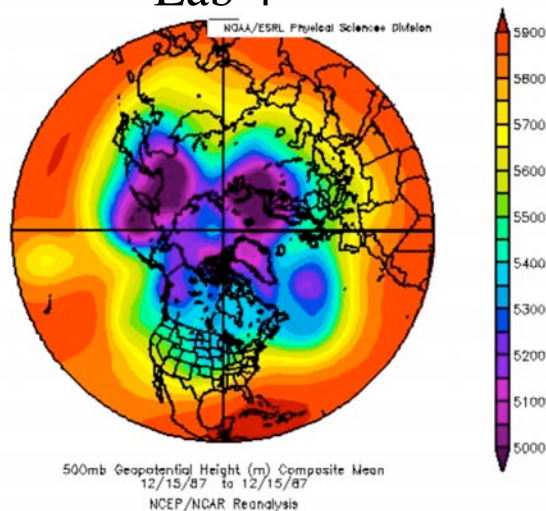


Madden-Julian Oscillation



MJO Influence on US Temperature and Precipitation

Lab 4



Where are the Rossby Wave Trough Axes?

Rossby Waves Summary

- Jet-stream dynamics are governed by Rossby Waves.
- Rossby waves are the result of instability of the jet stream flow with waves forming as a result of the variation of the Coriolis force with latitude.
- Rossby waves are a subset of inertial waves. In an equivalent barotropic atmosphere Rossby waves are a vorticity conserving motion.
- Their thermal structure is characterized by warm ridges and cold troughs.
- The lengths of individual long waves vary from about 50° to 180° longitude; their wave numbers correspondingly vary from 6 to 2, with strong preference for wave numbers 4 or 5.
- Effective forecast period associated with Rossby waves is a week to 10 days.



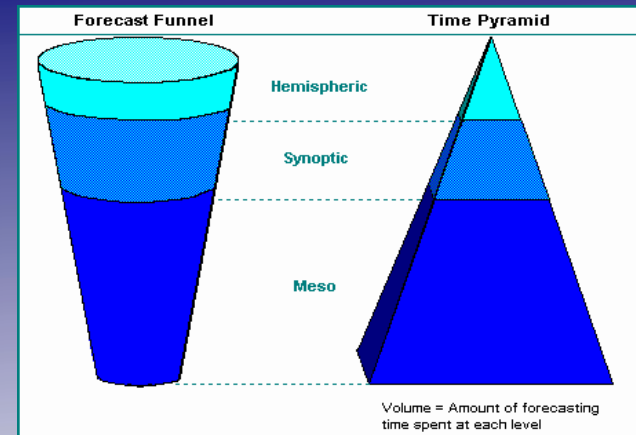
Synoptic-Planetary Scale Interaction

The Global and Synoptic context of High Impact Weather Systems



37

The Forecast Context



- Forecast Funnel – focus attention from the global scale on down to the local scale.
- Time Pyramid – gauge the amount of time that may be needed to assimilate the different scales of interest.

38

High-impact forecasts with limited skill



39

The Great Snowstorm: 25-27 January 2000



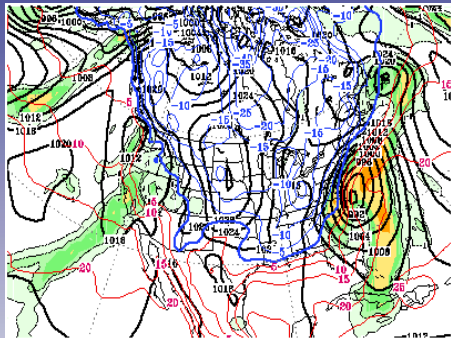
SeaWiFS Project NASA/
Goddard: 31 January 2000



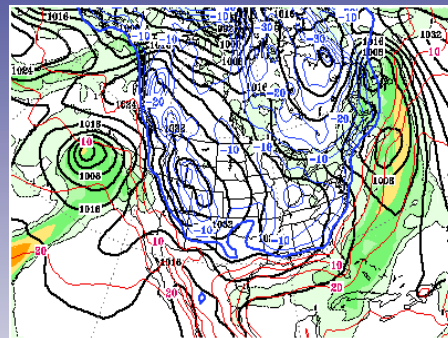
Washington D.C., 27 January 2000

40

=NCEP 96-h Forecast versus Verification



MRF Analysis



MRF 96-h Forecast

Medium-range 96-h sea-level pressure forecast valid at 1200 UTC 25 Jan. 2000

41

European Wind Storm: December 1999

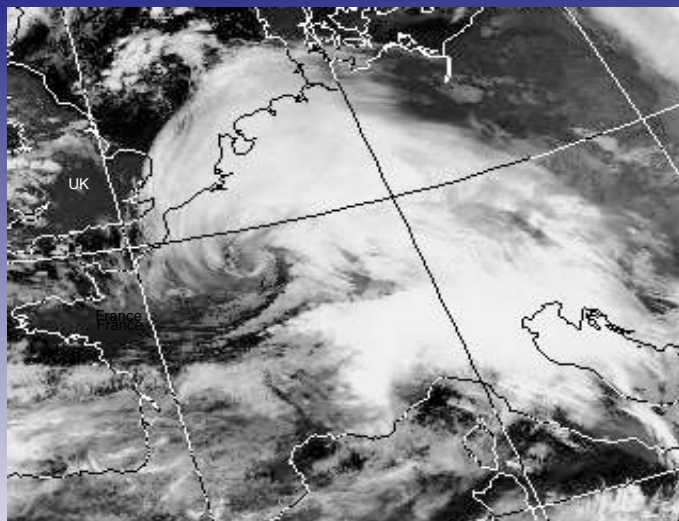


Destruction of the church in Balliveirs (left) and the devastation of the ancient forest at Versailles (below).



42

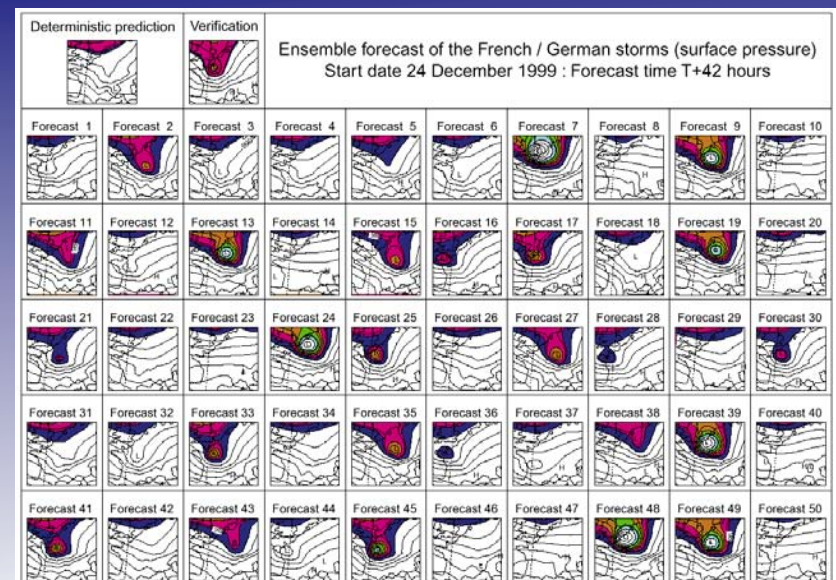
Lothar



Dundee Satellite Station: 0754 UTC 26 December 1999

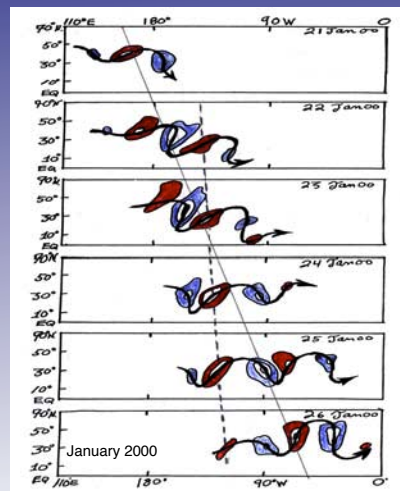
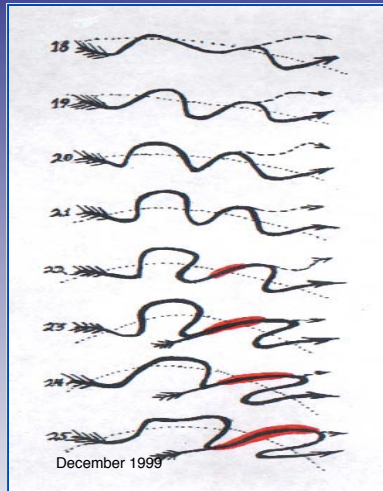
43

Lothar (T+42 hour TL255 rerun of operational EPS)



44

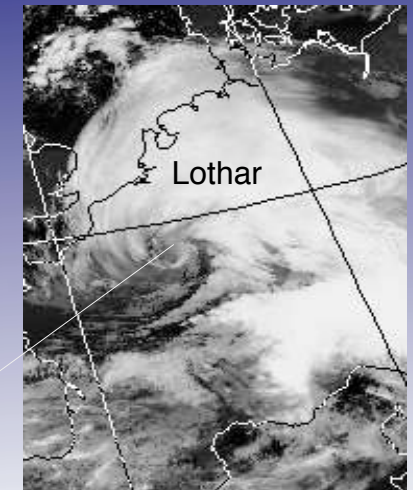
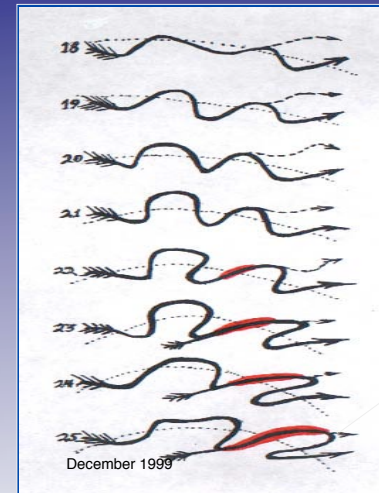
Rossby Wave Trains



45

Rossby Wave Trains

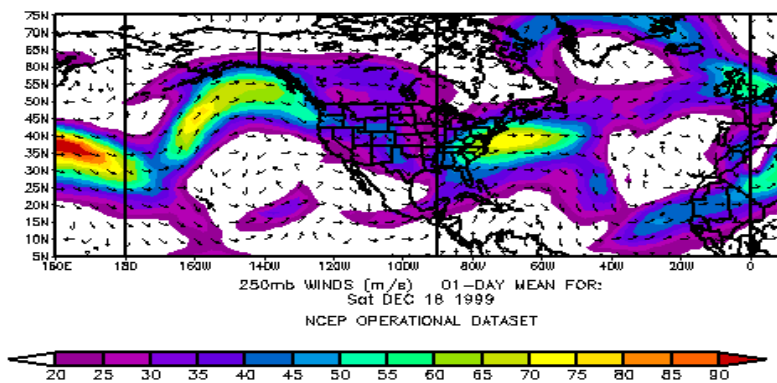
European Wind Storm



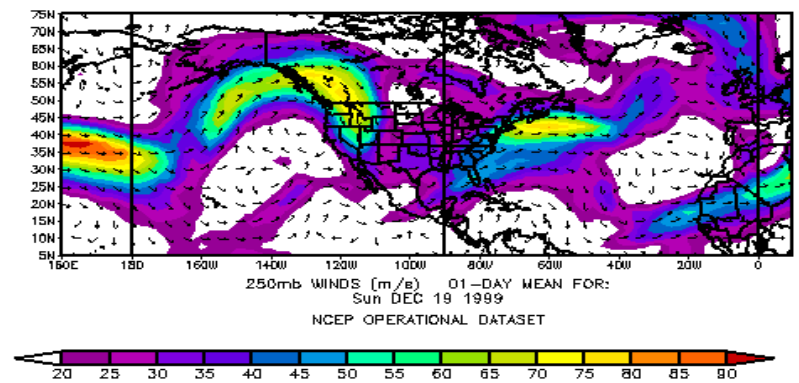
0754 UTC 26 December 1999

46

Rossby Wave Trains



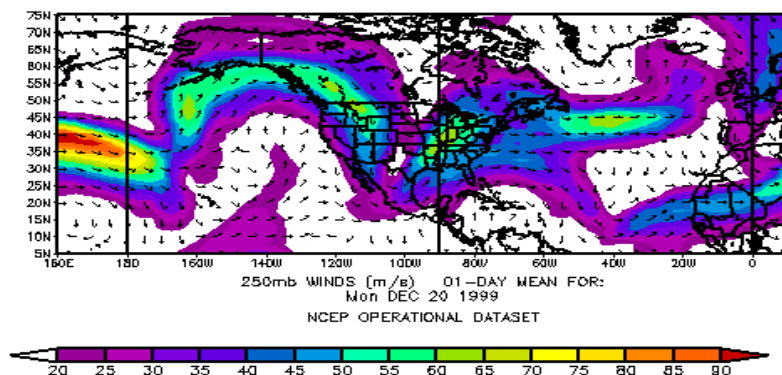
Rossby Wave Trains



47

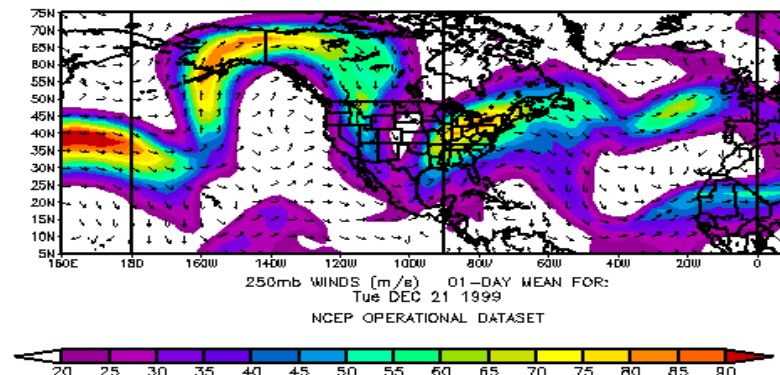
48

Rossby Wave Trains



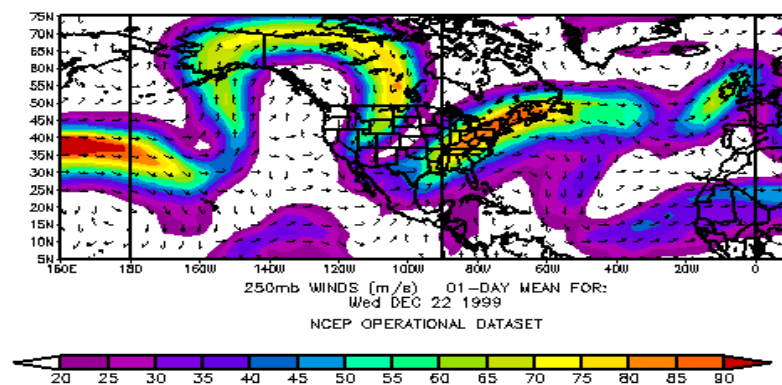
49

Rossby Wave Trains



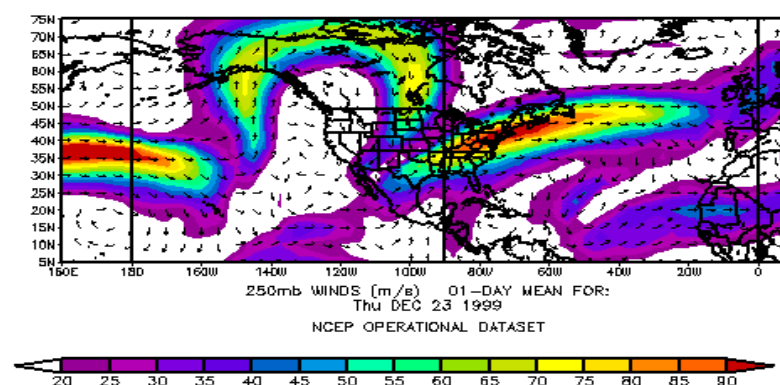
50

Rossby Wave Trains



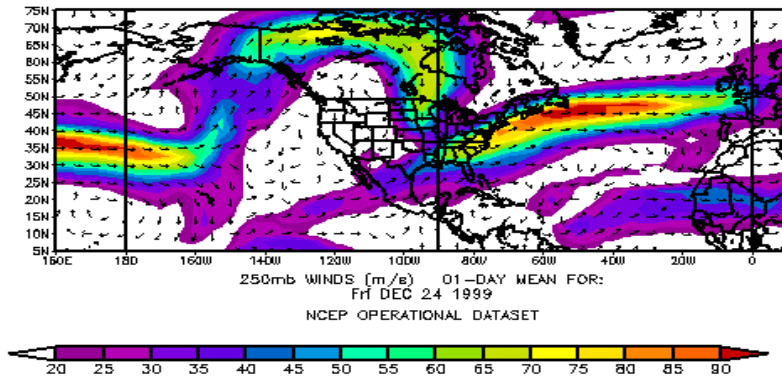
51

Rossby Wave Trains



52

Rossby Wave Trains



53

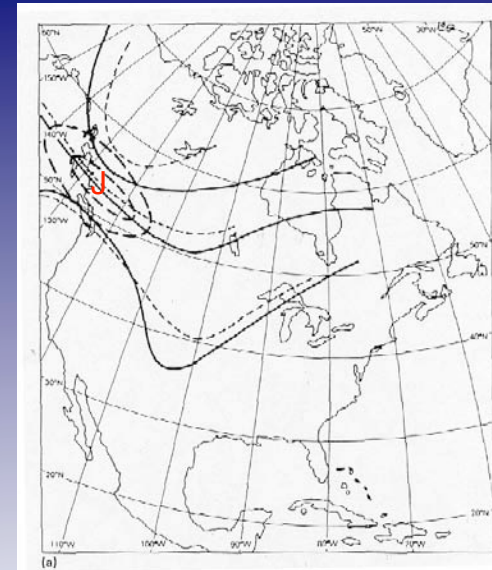
Conceptual Model of Shortwave/Jet Streak

Schematic depiction of the propagation of a mid-tropospheric jet streak through a Rossby wave over 72 h.

Solid lines: height lines

Thick dashed lines: isotachs

Thin dashed lines: isentropes

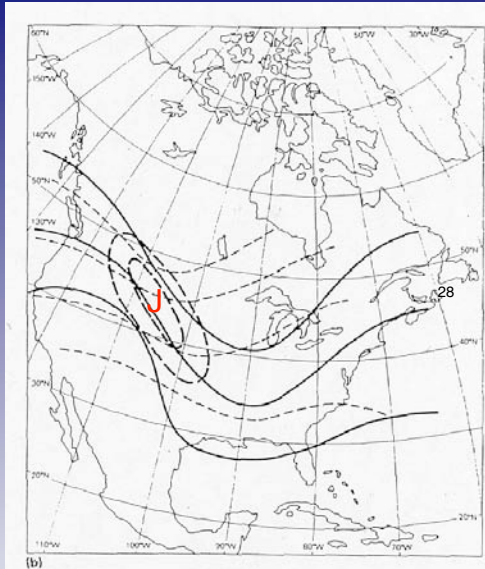


Time = t_0

54

Conceptual Model of Shortwave/Jet Streak

Jet streak on northwestern side of diffluent trough at mid-tropospheric levels; note cold advection into amplifying trough.

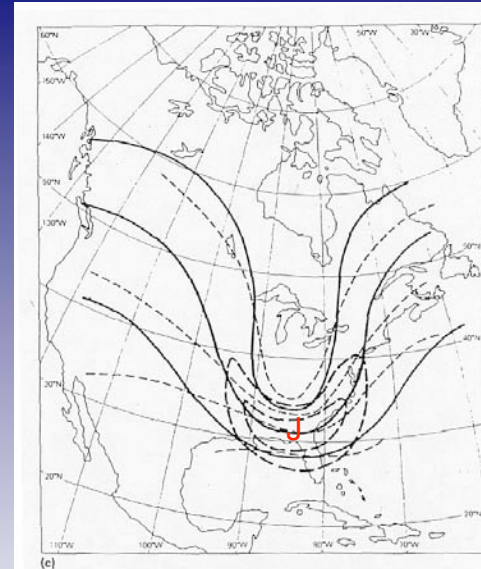


Time = $t_0 + 24$ h

55

Conceptual Model of Shortwave/Jet Streak

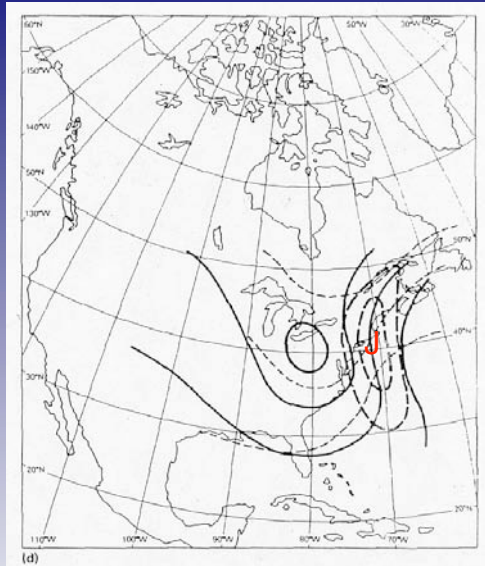
Jet streak at the trough axis of a nearly fully developed wave. Note: banana-shaped jet streak is not often seen due to strong upstream ageostrophic flow in base of trough. Often a new jet streak develops on eastern side of trough.



Time = $t_0 + 48$ h

56

Conceptual Model of Shortwave/Jet Streak

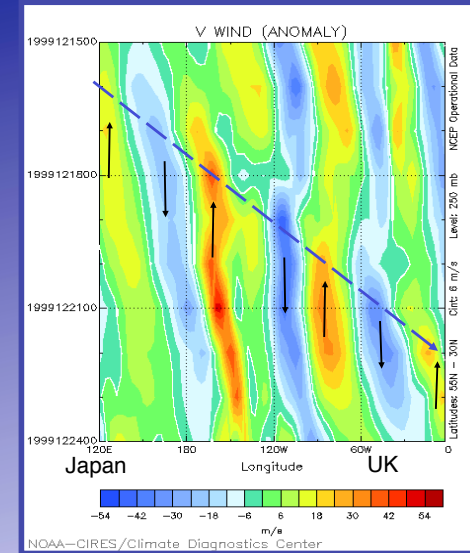


Jet streak situated in the southwesterly flow of the short wave trough (i.e., lifting wave) that is deamplifying. Note: surface system is typically still deepening during this stage.

Time = 11:47Z

57

Time-Longitude Diagram



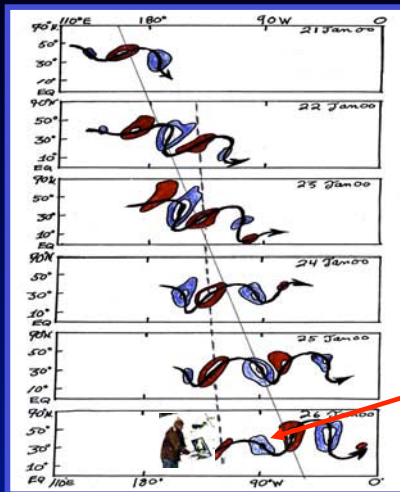
250-mb meridional wind (m s^{-1})

15-24 Dec. 1999, Lat. 30-55 N, Long. 120 E-360

6 Days

58

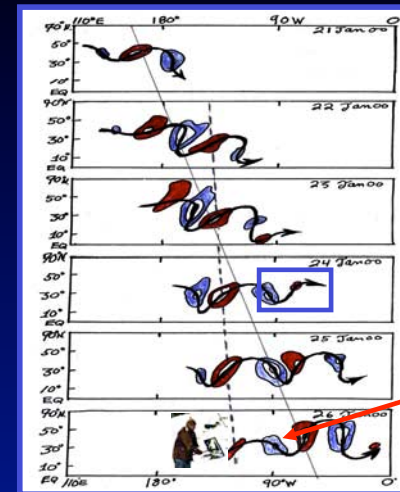
Rossby Wave Trains



January 2000 Blizzard

59

Rossby Wave Trains



January 2000 Blizzard

60



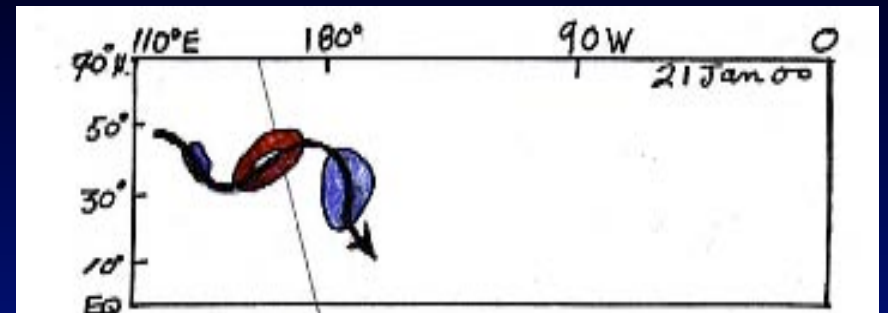
61



62



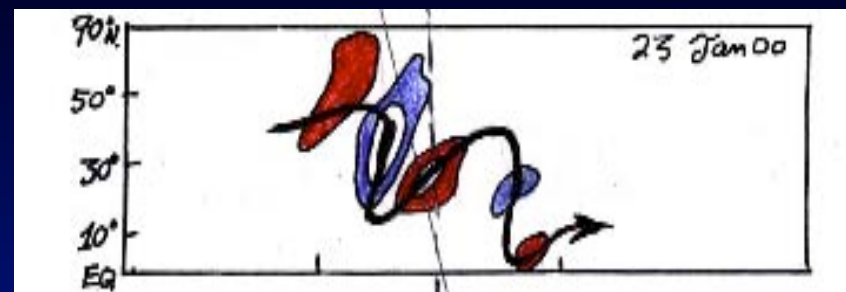
63



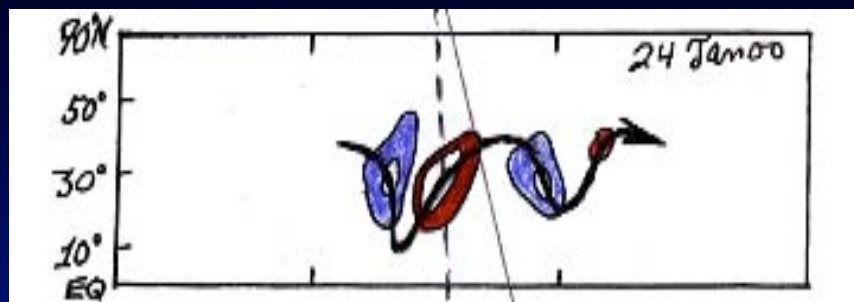
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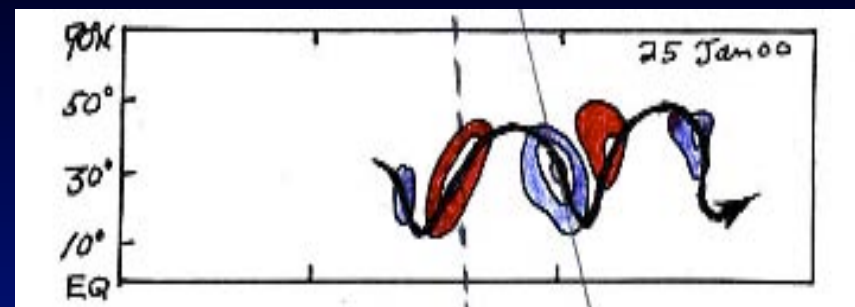
65



66



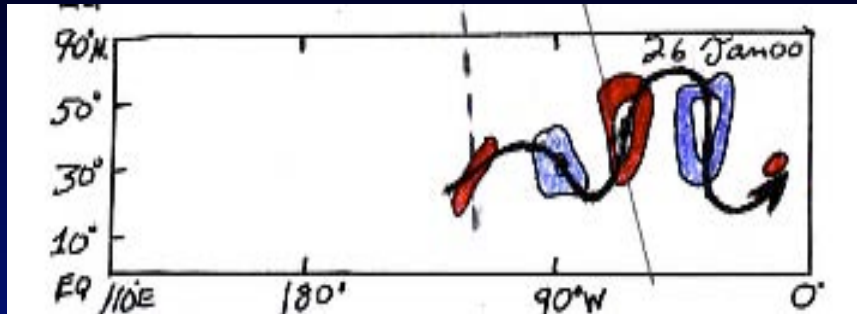
67



68

Societal Economic Impacts of Extreme Weather

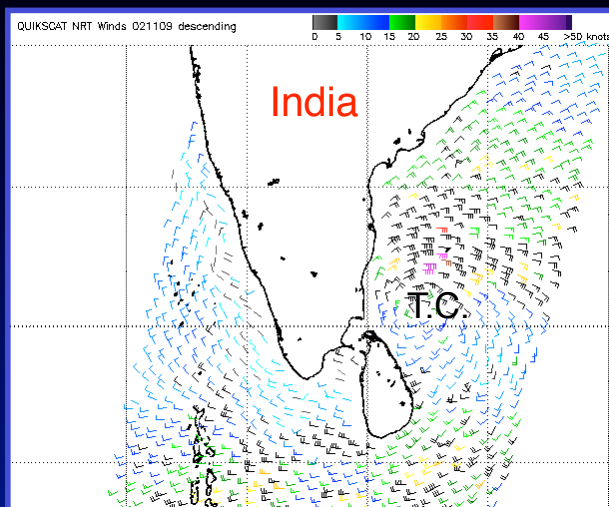
A Global-to-Regional Perspective of The events of November 2002



69

70

Tropical Cyclone: 9 November 2002



QUIKSCAT Surface Winds (knots)

71

Bay of Bengal Tropical Cyclone: 10 November 2002



~200 fisherman lost at sea

72

US Tornado Outbreak: 11 November 2002



73

US Tornado Outbreak: 11 November 2002



74

12 November 2002



Poorly forecast rainfall event over Eastern Vancouver Island
40-50 mm in 24 h. Impacts: Mudslides, power outages

75

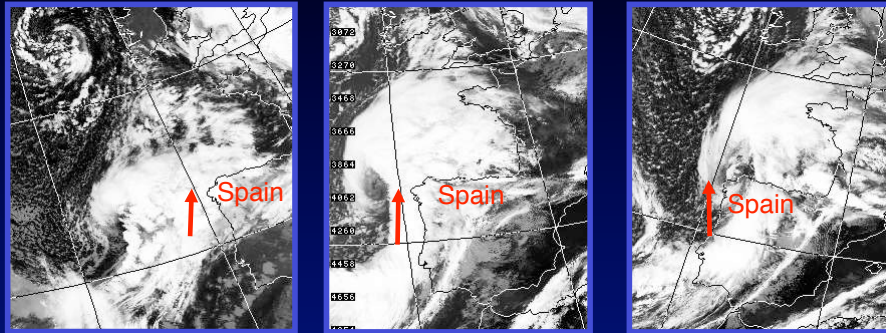
Oil Tanker “Prestige” Disaster



13-19 November 2002

76

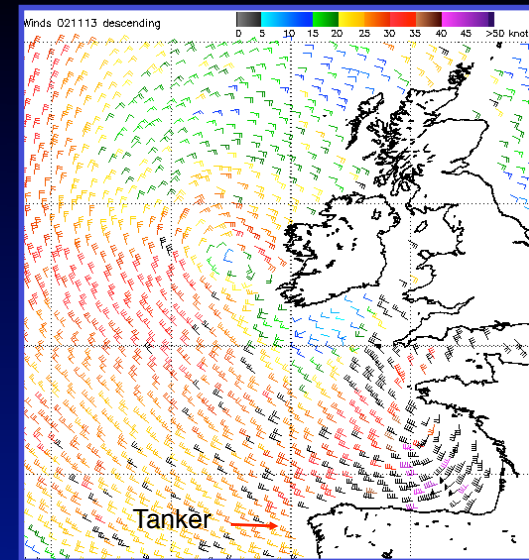
13 November 2002 Oil Tanker



Dundee Satellite Station

77

QUIKSCAT Surface Winds



13 November 2002

78

Oil Tanker “Prestige” Disaster



79

Alpine Floods: 16-17 November 2002



80

Swiss -Italian Flooding: 0000 UTC 16 November



81

Eastern Switzerland: 17 November 2002



82

Austrian-German Alpine Wind Storm



17 November 2002

83

Austrian-German Alpine Wind Storm



84

Eastern US-Canadian Snow and Ice Storm



16 November 2002



85

November 18/19 2002



School Gymnasium in Vancouver collapses under heavy rains.

86



NASA space shuttle Endeavor
and crew prepare for liftoff
23 November 2002



Spanish-born, U.S. astronaut Michael Lopez-Alegria, right, waves as he leaves the Operations and Checkout Building at Kennedy Space Center in Cape Canaveral, Fla., Saturday afternoon with fellow crew members, John Herrington, left, the first tribal registered American-Indian astronaut, and Don Pettit, center, for a trip to launch pad 39-A for a planned liftoff onboard the space shuttle Endeavour. (AP Photo)

87

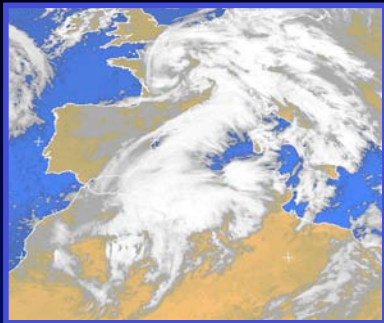
“Rain in Spain creates liftoff pain”



“ NASA fueled space shuttle Endeavor for liftoff Saturday,
but storms in Spain loomed as a possible show stopper – again”.

88

Moroccan Flood: 0600 UTC 25 November 2002

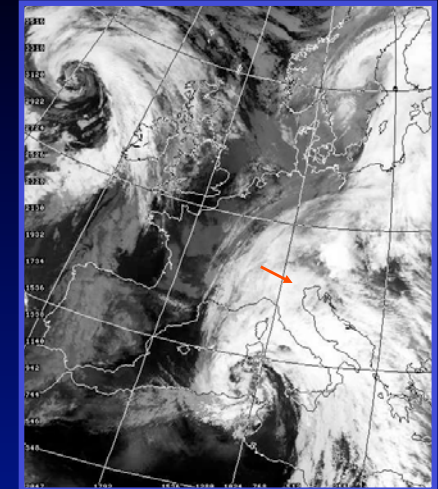


89

Italian Alps: 26 Nov 2002



Dundee Satellite Image



90

Flooding in Italian Alps



Northern Italy
28 November 2002

Lago Maggiore:
26 November 2002

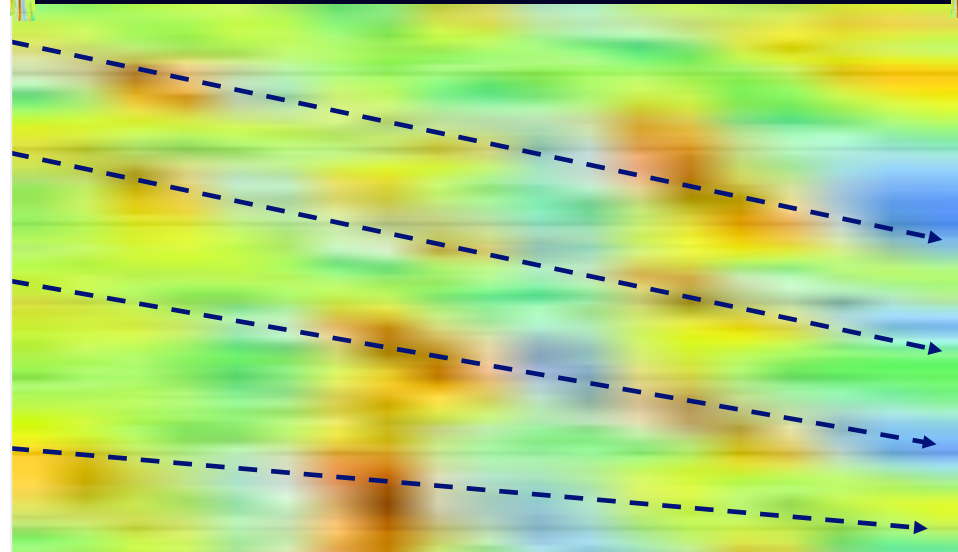


91



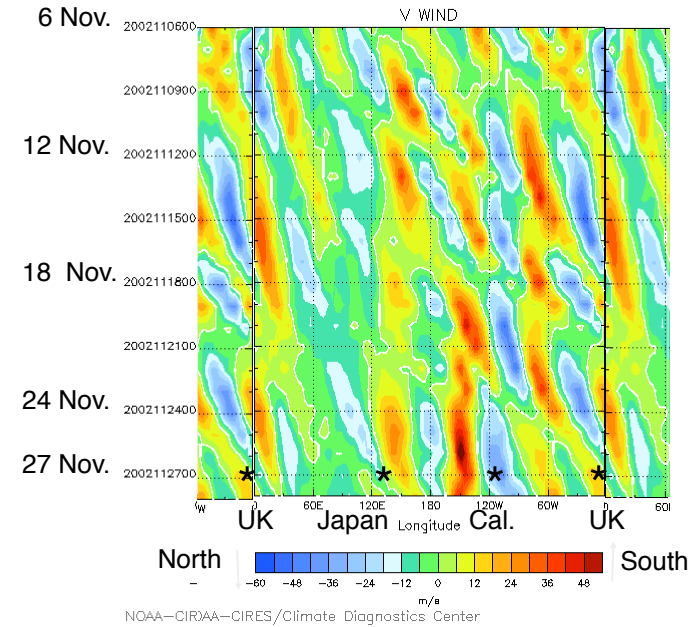
92

A Rossby-Wave Perspective of High-Impact Weather: November 2002



93

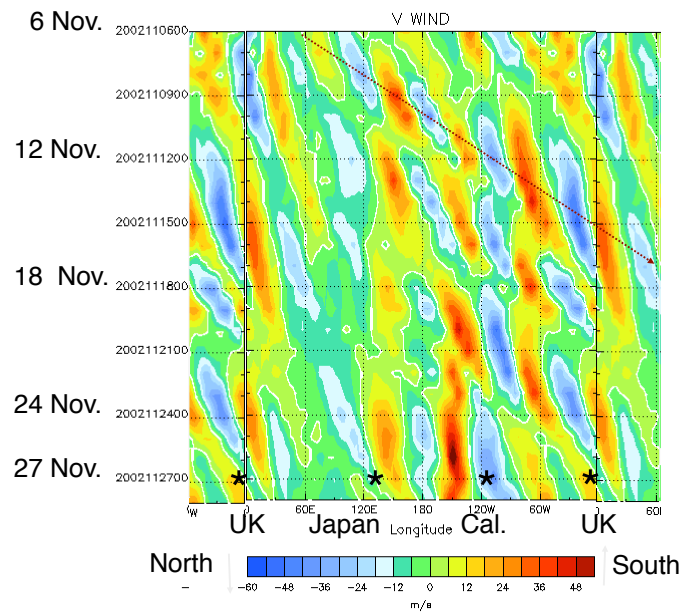
Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N
6-28 November 2002



NOAA-CIRJAA-CIRES/Climate Diagnostics Center

94

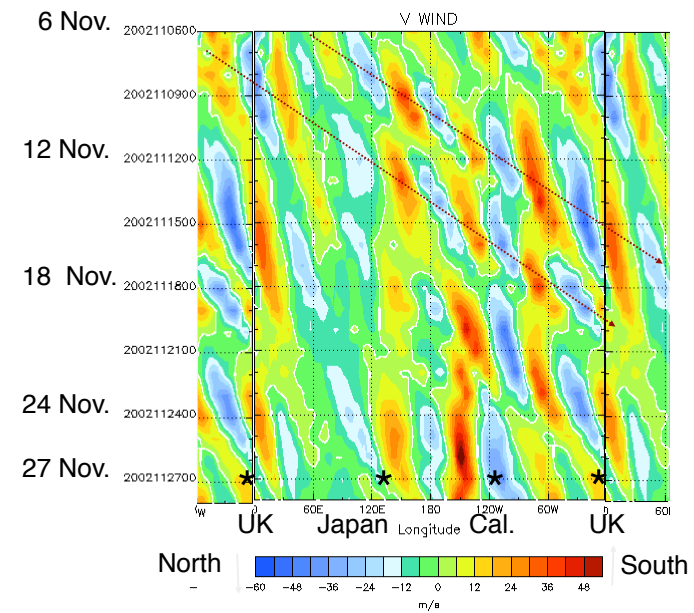
Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N
6-28 November 2002



NOAA-CIRJAA-CIRES/Climate Diagnostics Center

95

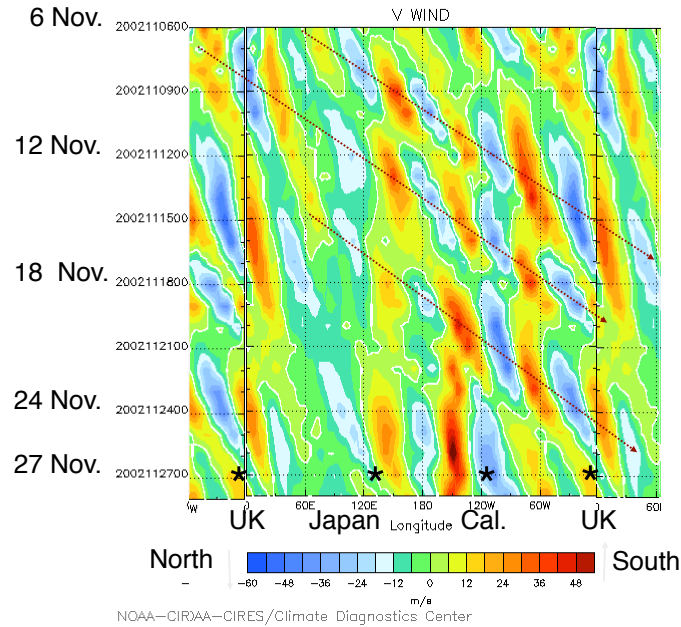
Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N
6-28 November 2002



NOAA-CIRJAA-CIRES/Climate Diagnostics Center

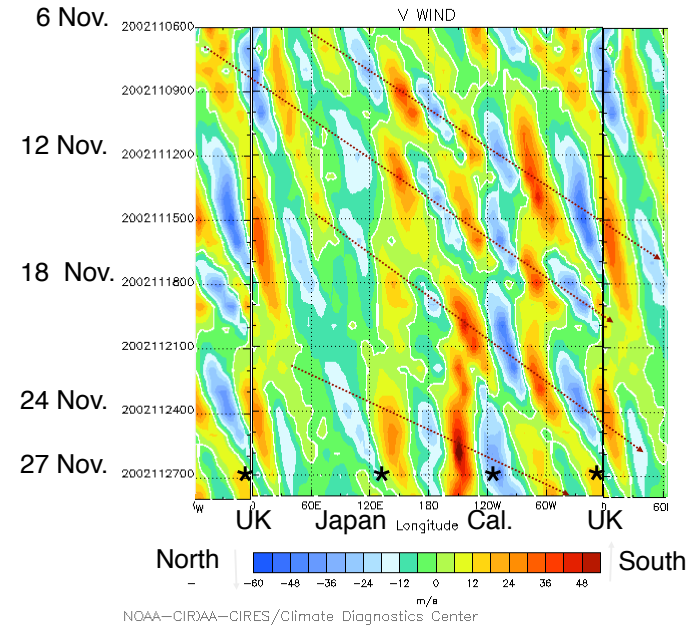
96

Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N
6-28 November 2002



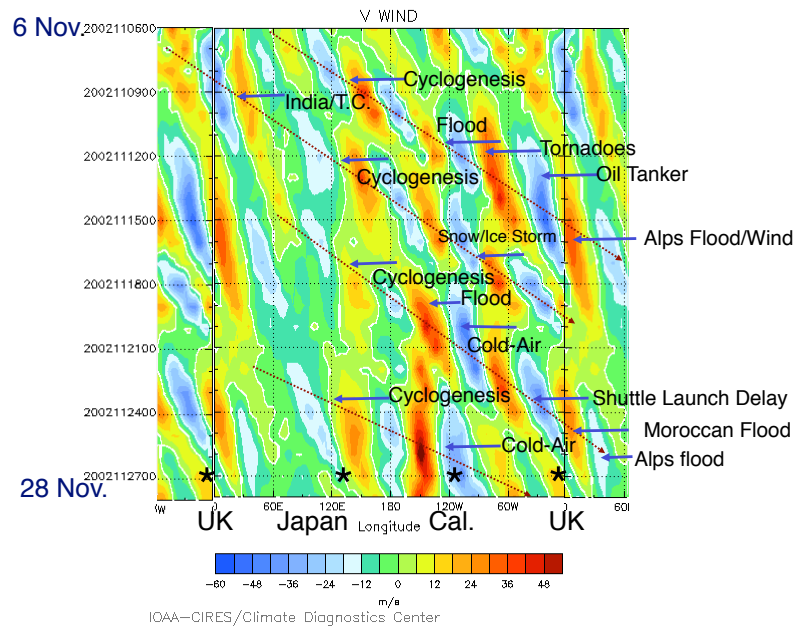
97

Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N
6-28 November 2002



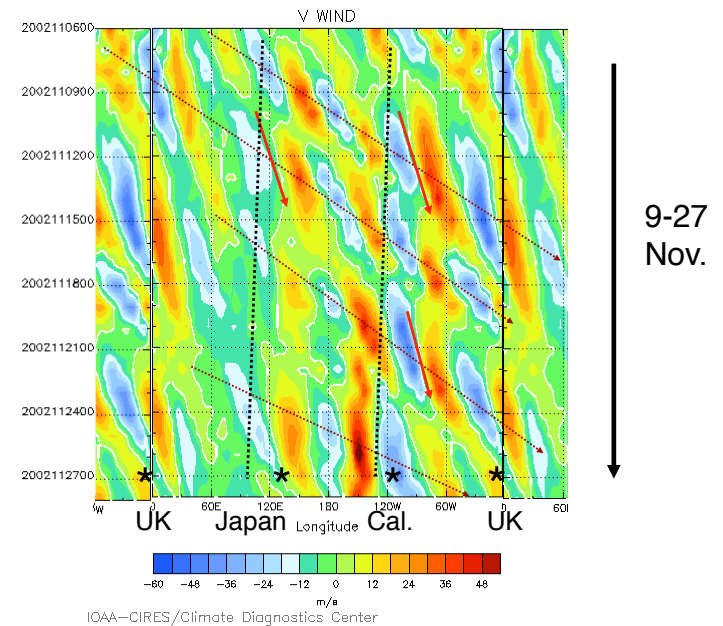
98

Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1})
Latitude Belt (35-60 N) 6-28 November 2002



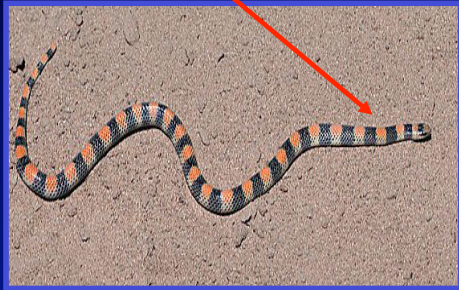
99

Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N
6-28 November 2002



100

High-impact weather develops at the **leading edge** of expanding Rossby wave trains



101

Northwestern Floods

October 2003



Two sub-tropical weather systems dropped 470 millimetres -- 18.5 inches -- of rain on some parts of coastal B.C. in a six-day period"

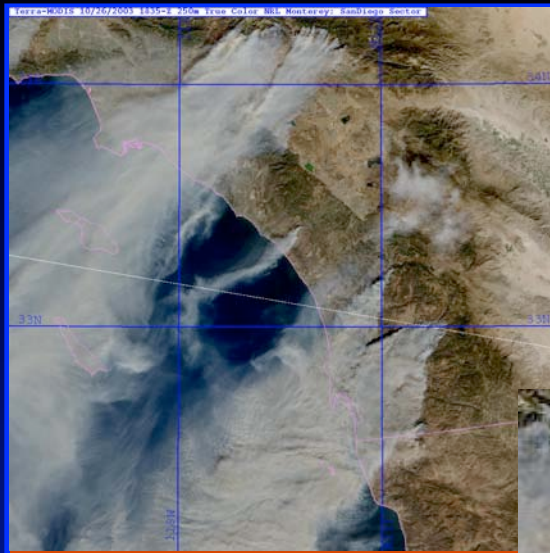
British Columbia - Record breaking heavy rain in Vancouver, Abbotsford and Victoria on October 16. Bridge washout cuts access to Pemberton, BC. "It is being called the worst flood of the past century" in British Columbia.



Washington - Snohomish, Nooksack and Skagit rivers overflowed October 17-18. Seattle broke a one-day rainfall record on October 20. Record levels on Skagit River at Concrete. Record levels on Snohomish River on October 21. Entire town of Hamilton under water. Flood damages have exceeded \$160 million.

102

California Wild Fires



October 2003



103

California Wild Fires



October 2003

104

California Mud Slides



November 2003

105

October 2003

Synoptic-scale-waves



Wave-trains

Time-mean planetary-waves

3-5 billion dollar catastrophe

106

October 2003

Synoptic-scale waves

Wave trains

Time-mean planetary-waves

3-5 billion dollar catastrophe

107

October 2003

Synoptic-scale waves

Wave trains

Time-mean planetary-waves

3-5 billion dollar catastrophe

108

October 2003

Synoptic-scale waves

Wave trains

Time-mean planetary-waves

3-5 billion dollar catastrophe

109

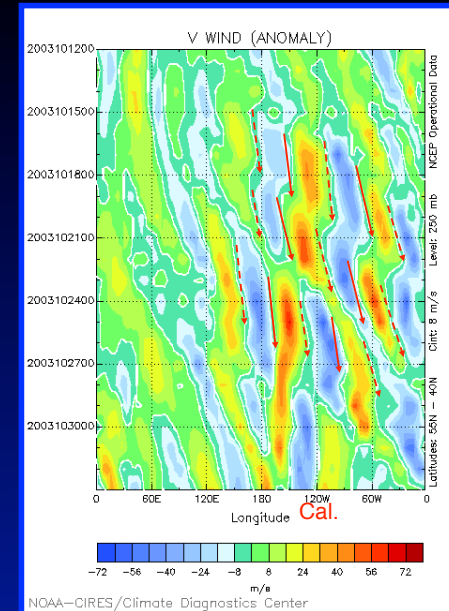
Time/Longitude: 250-mb Meridional Wind (m s^{-1}); 55-40N.

Oct. 12

Oct. 18

Oct. 24

Nov. 3



Synoptic Waves

Ridge Axes

Trough Axes

3-4 day life cycle

110

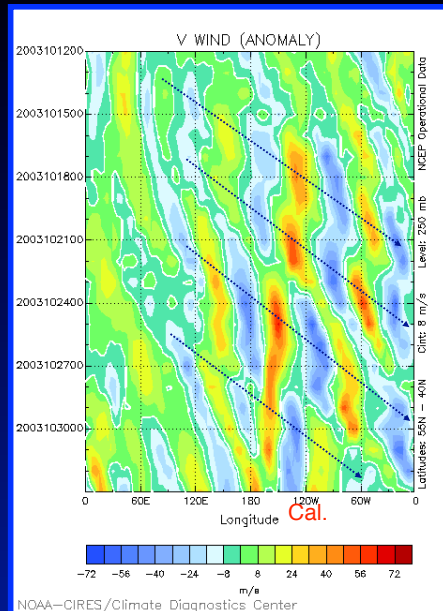
Time/Longitude: 250-mb Meridional Wind (m s^{-1}); 55-40N.

Oct. 12

Oct. 18

Oct. 24

Nov. 3



Rossby Wave Trains

6-14+day life cycle

111

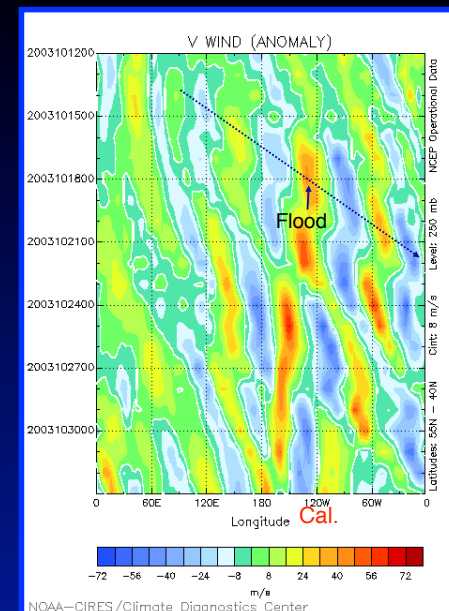
Time/Longitude: 250-mb Meridional Wind (m s^{-1}); 55-40N.

Oct. 12

Oct. 18

Oct. 24

Nov. 3



Flood

112

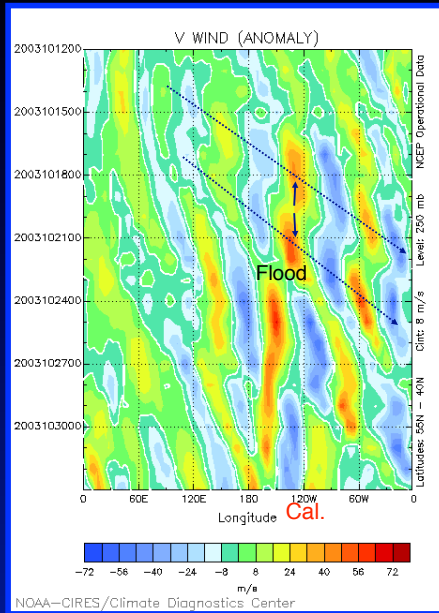
Time/Longitude: Meridional Wind (m s^{-1}); 55-40N.

Oct. 12

Oct. 18

Oct. 24

Nov. 3



113

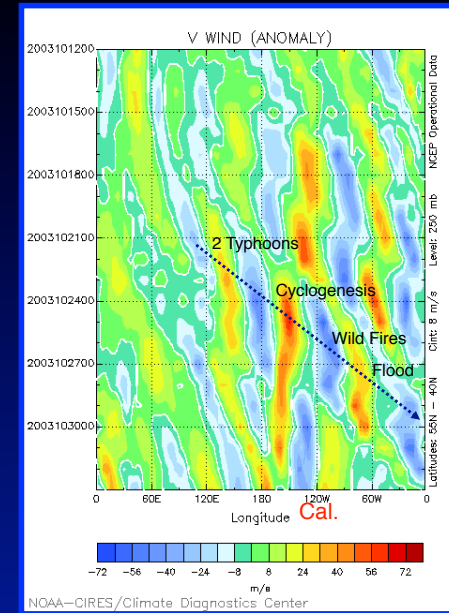
Time/Longitude: Meridional Wind (m s^{-1}); 55-40N.

Oct. 12

Oct. 18

Oct. 24

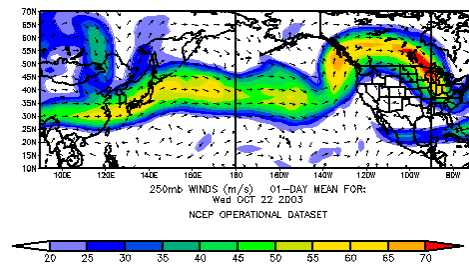
Nov. 3



114

Rossby Wave Trains

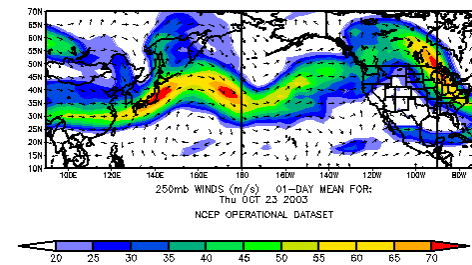
22 OCT



115

Rossby Wave Trains

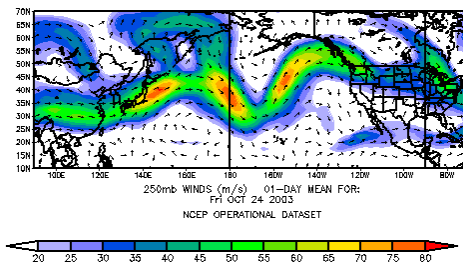
23 Oct



116

Rossby Wave Trains

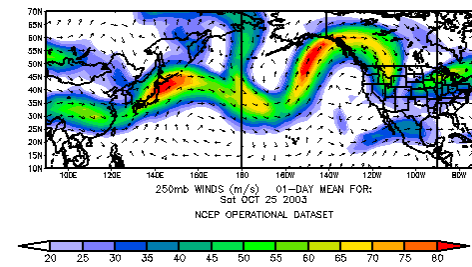
24 Oct



117

Rossby Wave Trains

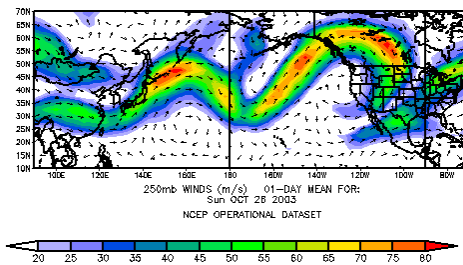
25 Oct



118

Rossby Wave Trains

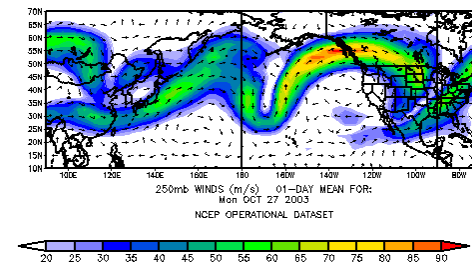
26 Oct



119

Rossby Wave Trains

27 Oct



120

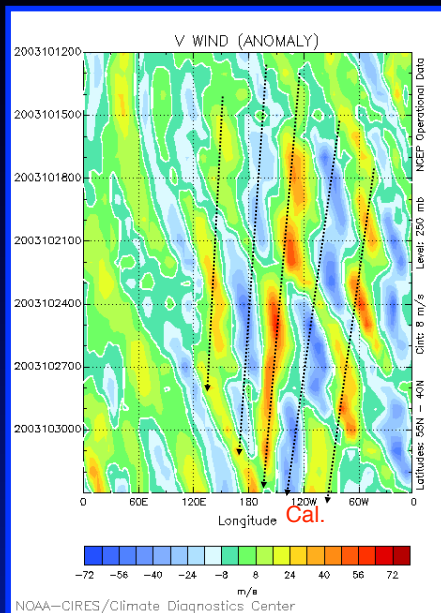
Time/Longitude: Meridional Wind (m s^{-1}); 55-40N.

Oct. 12

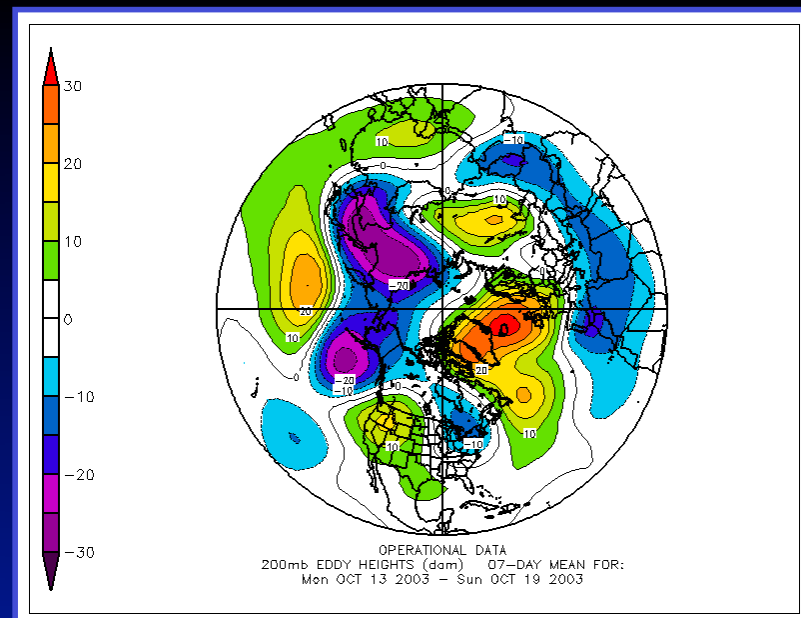
Oct. 18

Oct. 24

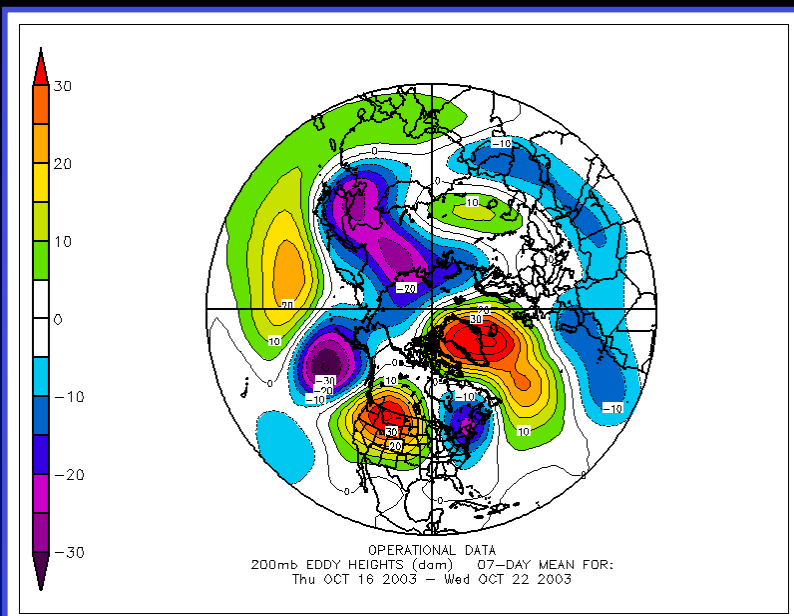
Nov. 3



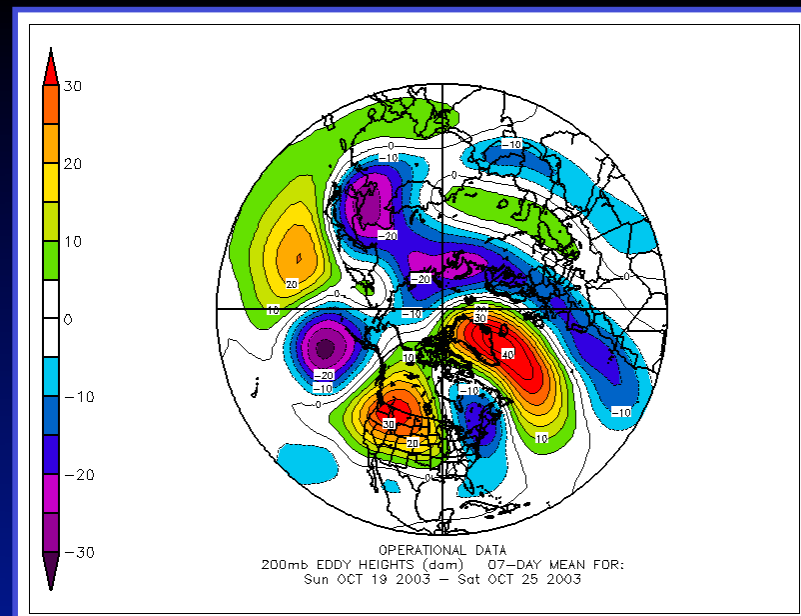
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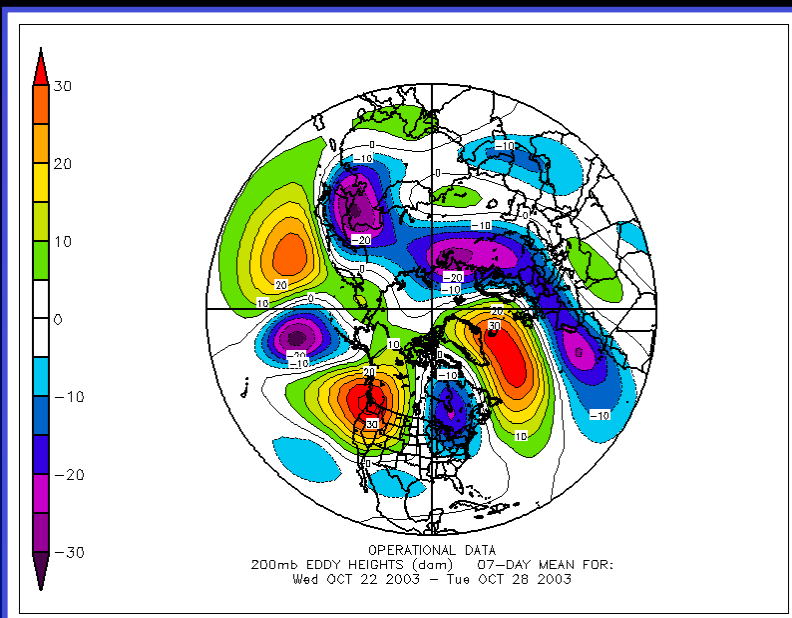
122



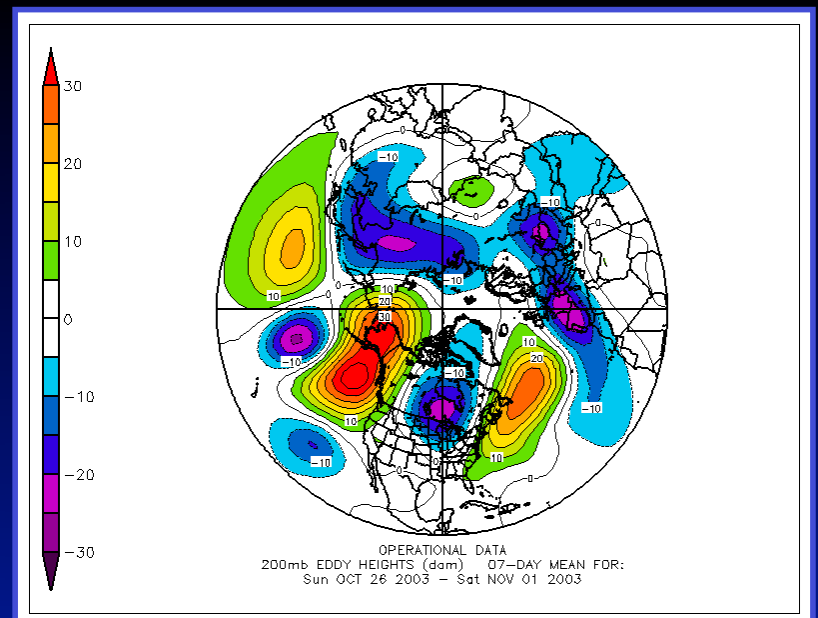
123



124



125



126

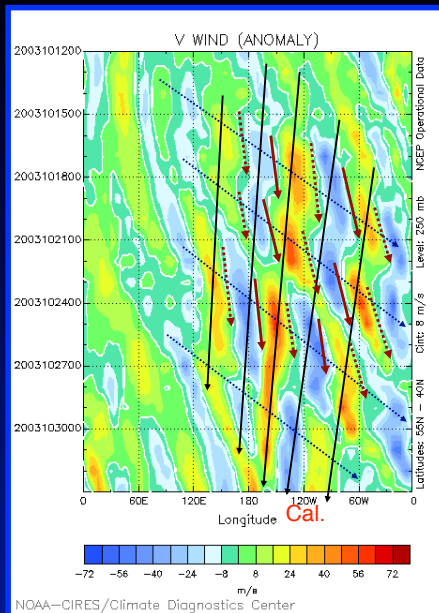
Time/Longitude: Meridional Wind (m s^{-1}); 55-40N.

Oct. 12

Oct. 18

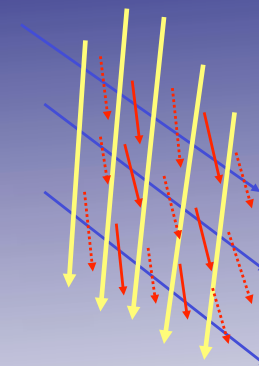
Oct. 24

Nov. 3



127

Three Time Scales



128

Synoptical-Scale



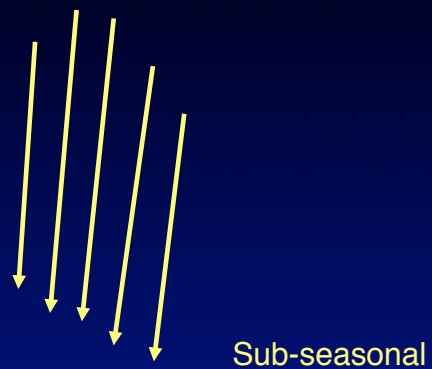
129

Rossby Wave Trains



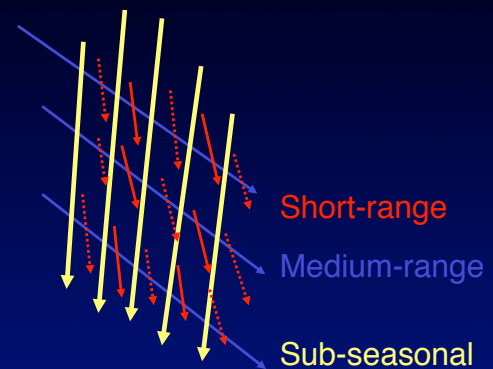
130

Planetary Rossby Waves



131

Three Interacting Time Scales

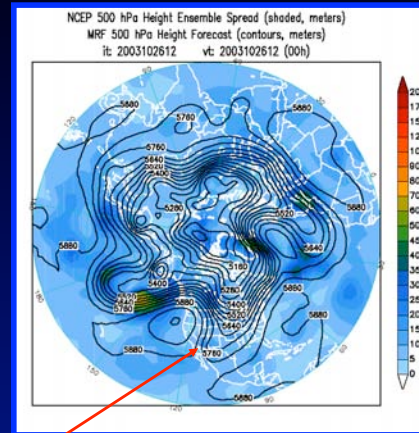
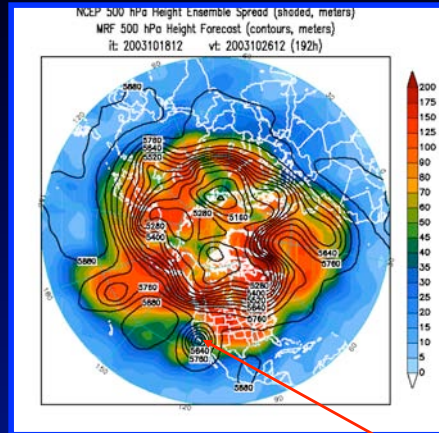


132

NOAA/NCEP Global Forecast System

196-h Forecast: 12:00 UTC 18 Nov. 2003

Verifying Analysis



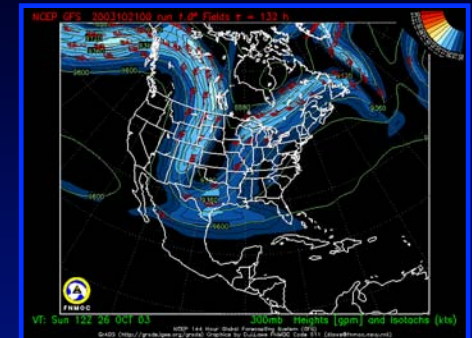
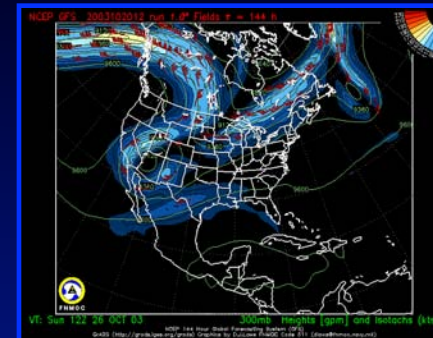
California wild fires: Forecast Bust?

133

Major changes in the deterministic forecast within 12 hours

NCEP 144-h Forecast

NCEP 132-h Forecast



Verification: 1200 UTC 26 Oct 2003

134

Tropical to Extratropical Interactions

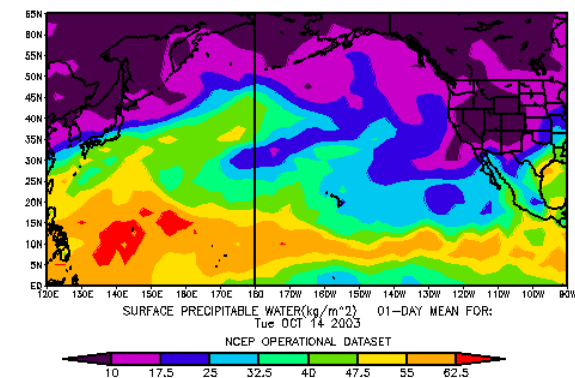
Energy from tropical convection can propagate into the extratropics to influence predictive skill.

- El Niño and La Niña regimes have significantly different extratropical sensitive regions.
- Lothar storm may have been influenced by a Madden-Julian Oscillation event over the eastern Pacific ocean 10 days earlier.

135

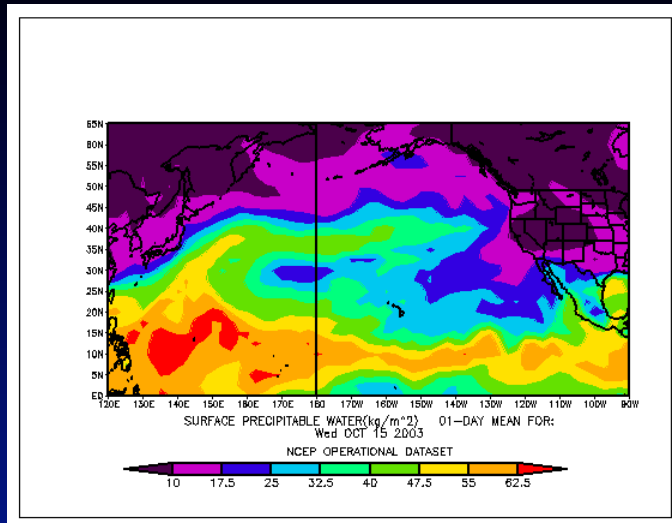
Tropical to Extratropical Interactions

October 14



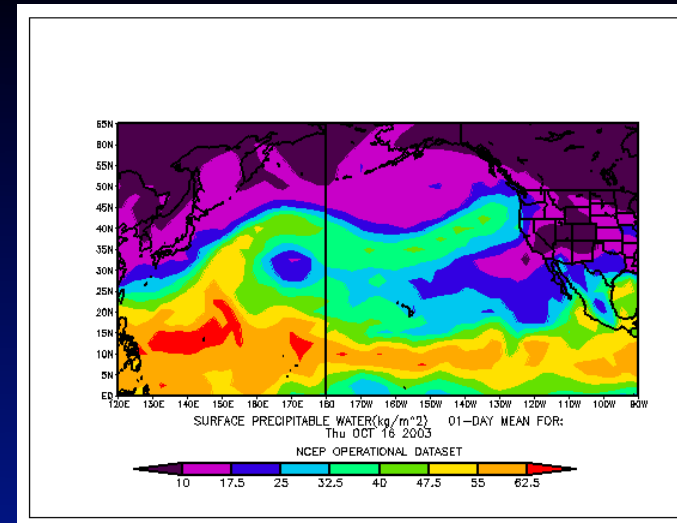
136

Tropical to Extratropical Interactions



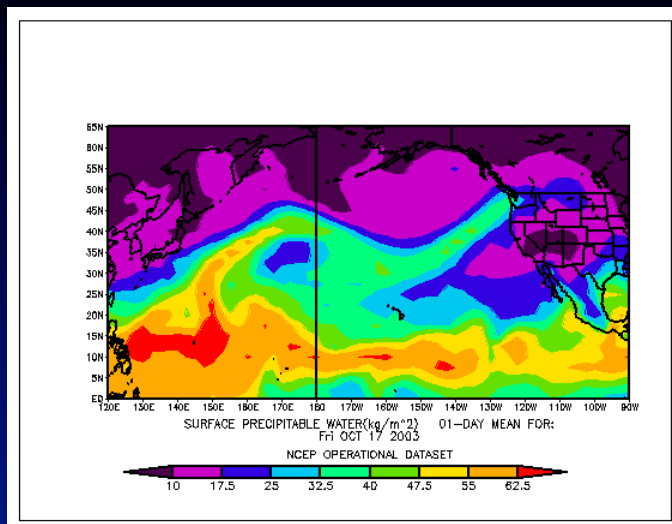
137

Tropical to Extratropical Interactions



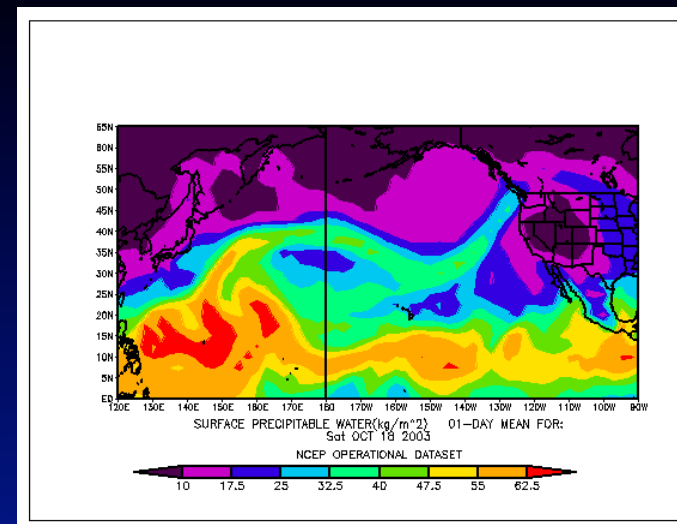
138

Tropical to Extratropical Interactions



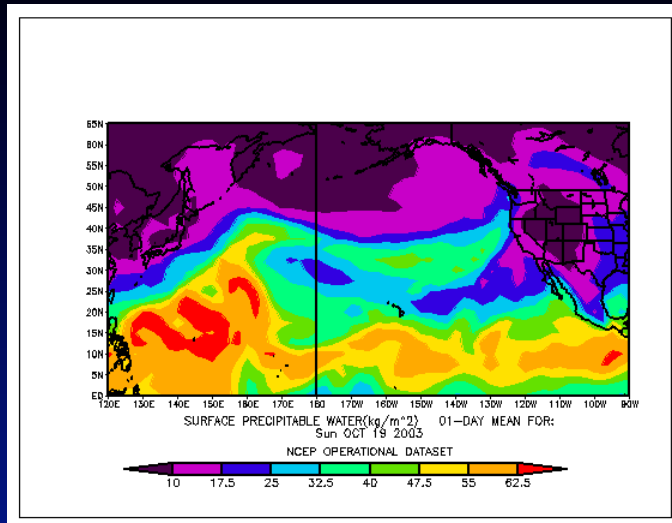
139

Tropical to Extratropical Interactions



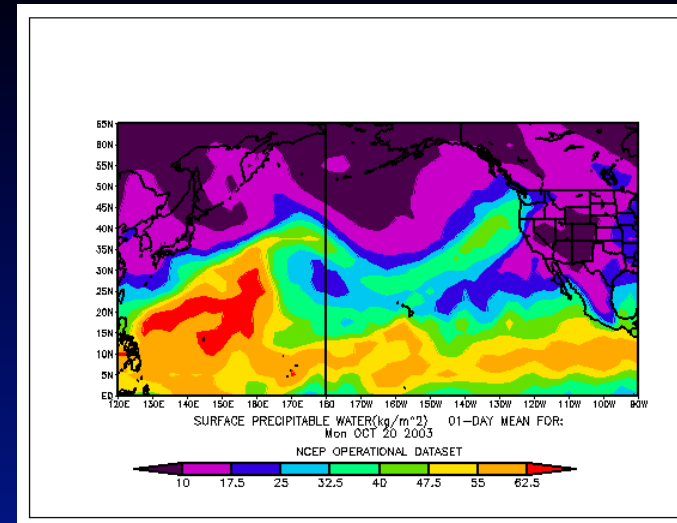
140

Tropical to Extratropical Interactions



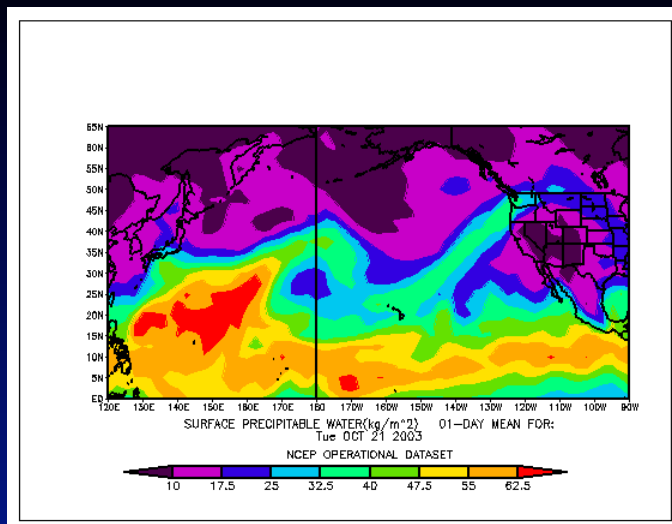
141

Tropical to Extratropical Interactions



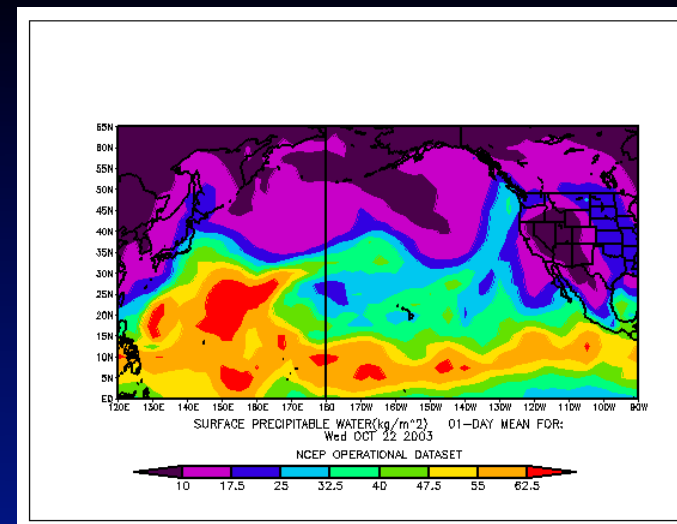
142

Tropical to Extratropical Interactions



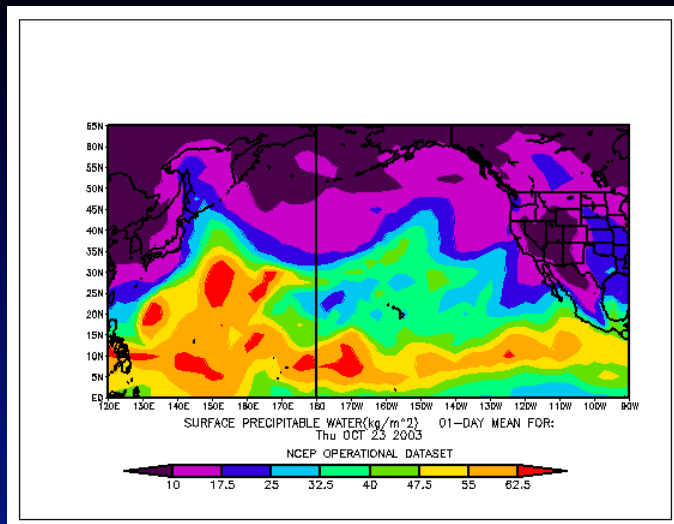
143

Tropical to Extratropical Interactions



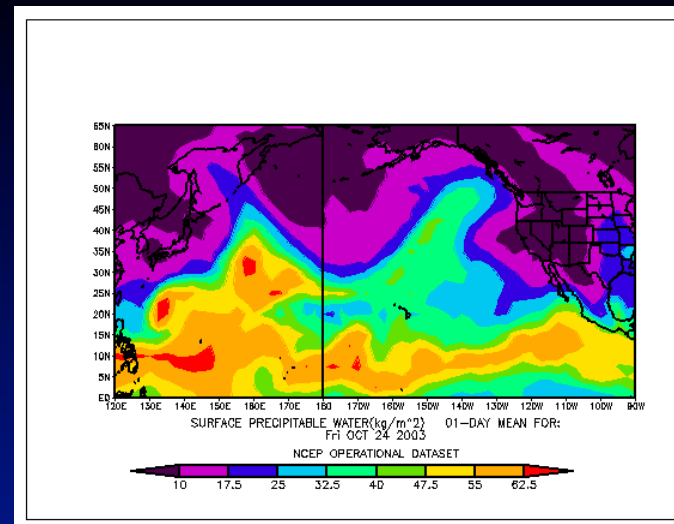
144

Tropical to Extratropical Interactions



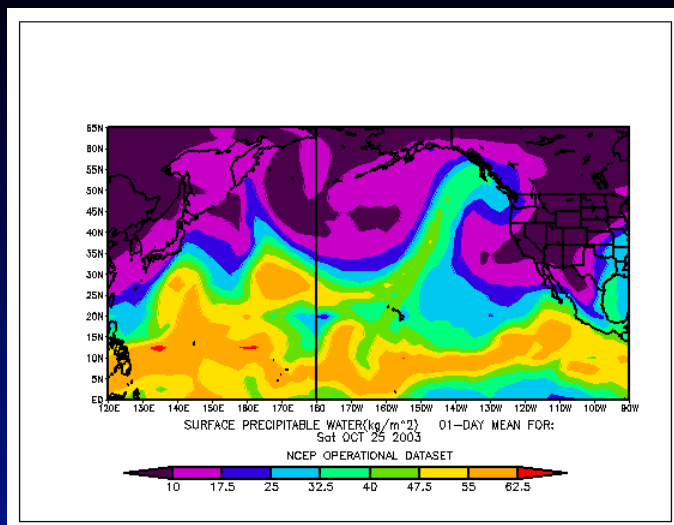
145

Tropical to Extratropical Interactions



146

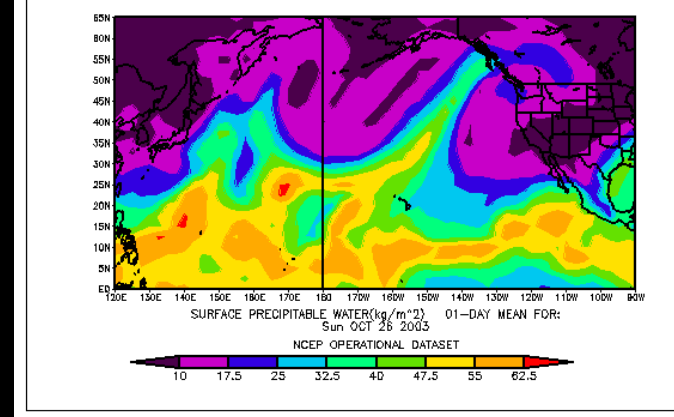
Tropical to Extratropical Interactions



147

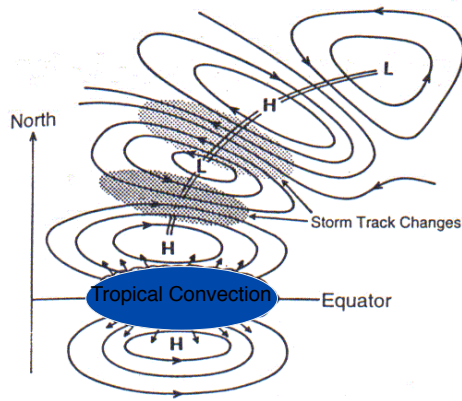
Tropical to Extratropical Interactions

October 26



148

Northward Propagating Rossby-Wave Train

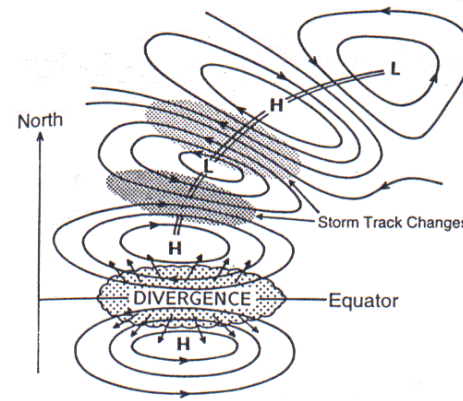


(Trenberth, et al. 1998)

Figure 4. Schematic view of the dominant changes in the upper troposphere, mainly in the northern hemisphere, in response to increases in SSTs, enhanced convection, and anomalous upper tropospheric divergence in the vicinity of the equator (scalped region). Anomalous outflow into each hemisphere results in subtropical convergence and an anomalous anticyclone pair straddling the equator, as indicated by the streamlines. A wave train of alternating high and low geopotential and streamfunction anomalies results from the quasi-stationary Rossby wave response (linked by the double line). In turn, this typically produces a southward shift in the storm track associated with the subtropical jet stream, leading to enhanced storm track activity to the south (dark stipple) and diminished activity to the north (light stipple) of the first cyclonic center. Corresponding changes may occur in the southern hemisphere.

149

Northward Propagating Rossby-Wave Train

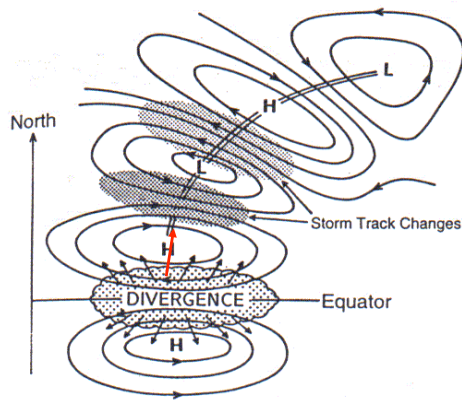


(Trenberth, et al. 1998)

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150

Northward Propagating Rossby-Wave Train

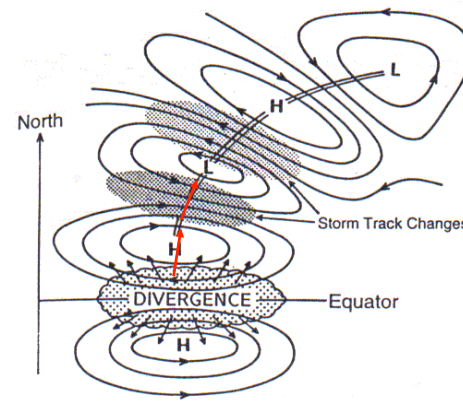


(Trenberth, et al. 1998)

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151

Northward Propagating Rossby-Wave Train

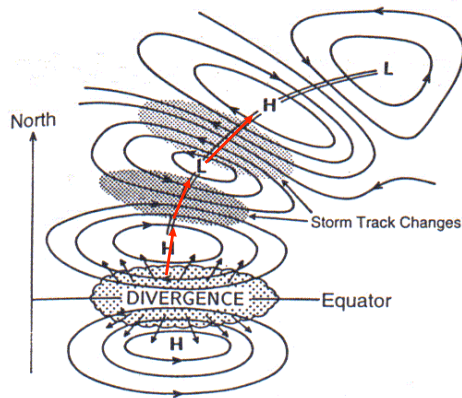


(Trenberth, et al. 1998)

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152

Northward Propagating Rossby-Wave Train

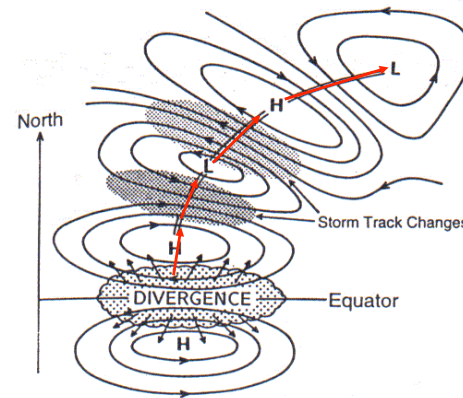


(Trenberth, et al. 1998)

Figure 4. Schematic view of the dominant changes in the upper troposphere, mainly in the northern hemisphere, in response to increases in SSTs, enhanced convection, and anomalous upper tropospheric divergence in the vicinity of the equator (scalped region). Anomalous outflow into each hemisphere results in subtropical convergence and an anomalous anticyclone pair straddling the equator, as indicated by the streamlines. A wave train of alternating high and low geopotential and streamfunction anomalies results from the quasi-stationary Rossby wave response (linked by the double line). In turn, this typically produces a southward shift in the storm track associated with the subtropical jet stream, leading to enhanced storm track activity to the south (dark stipple) and diminished activity to the north (light stipple) of the first cyclonic center. Corresponding changes may occur in the southern hemisphere.

153

Northward Propagating Rossby-Wave Train



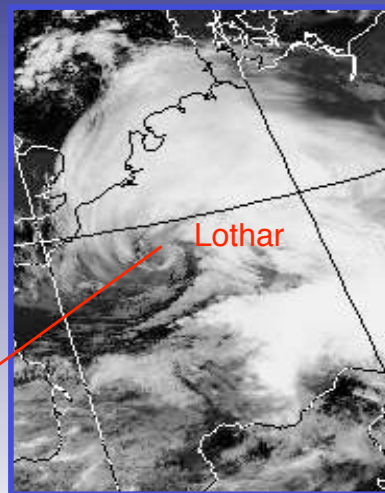
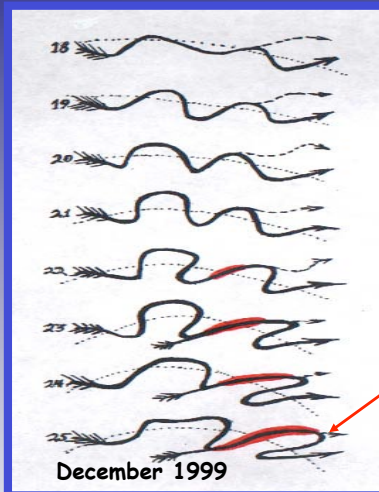
(Trenberth, et al. 1998)

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154

Questions?

European Wind Storm



0754 UTC 26 December 1999

155