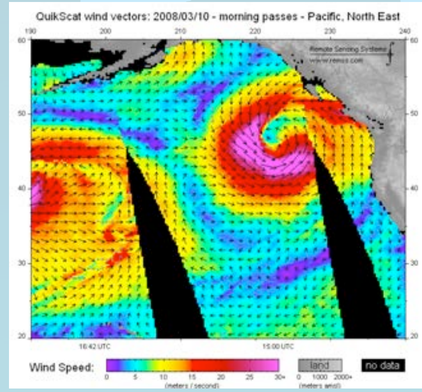
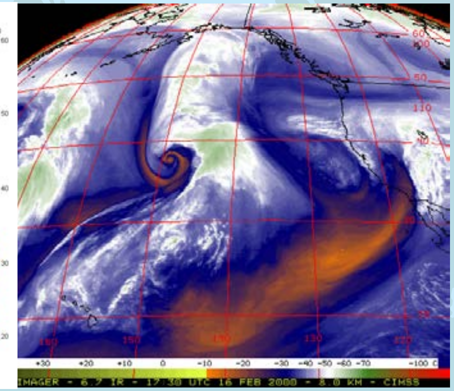
MET 200 Lecture 21
Synoptic-Planetary Scale Interaction and High Impact Weather

The Global and Synoptic context of High Impact Weather Systems

Previous Lecture – Lost at Sea: Hurricane Force Wind Fields and the North Pacific Ocean Environment





Typhoon Haiyan

Typhoon Haiyan

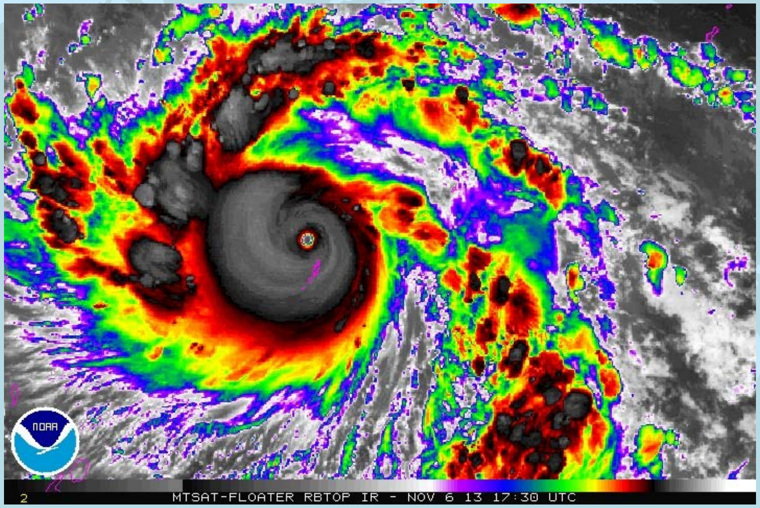
Last Friday's super typhoon Haiyan struck the Philippines.

Officials estimate that 10,000 or more people were killed by Haiyan, washed away by the churning waters that poured in from the Pacific or buried under mountains of trash and rubble. But it may be days or even weeks before the full extent of the destruction is known.

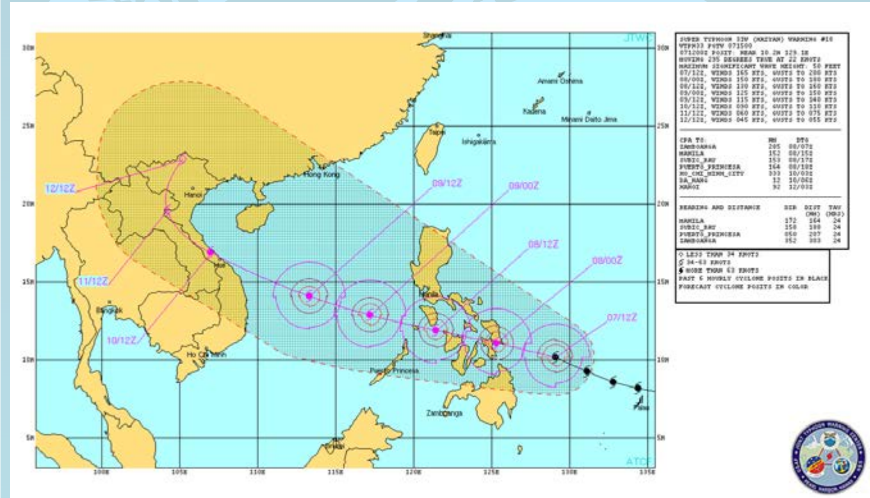
A 6-meter (20-feet) storm surge swept through Tacloban, capital of the island province of Leyte, which saw the worst of Haiyan's damage.

While the storm surge proved deadly, much of the initial destruction was caused by winds blasting at 235 kilometers per hour (147 mph) that occasionally blew with speeds of up to 275 kph (170 mph), howling like jet engines.

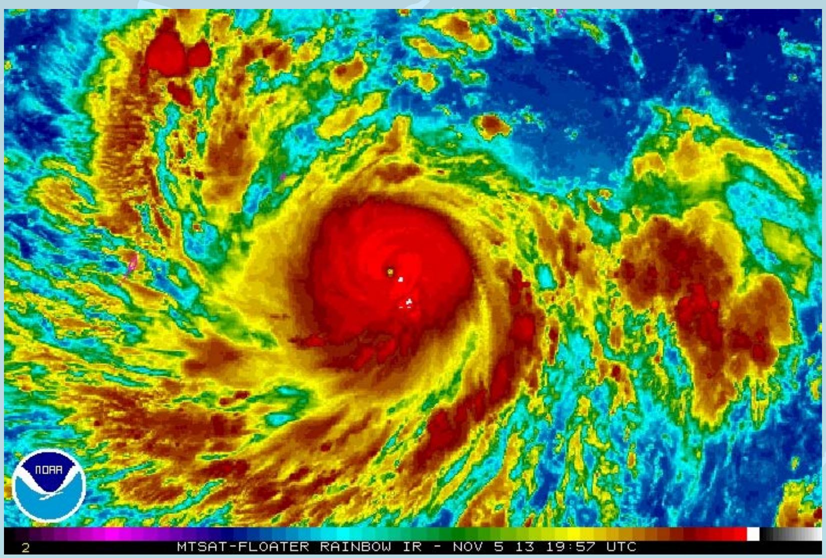
Typhoon Haiyan



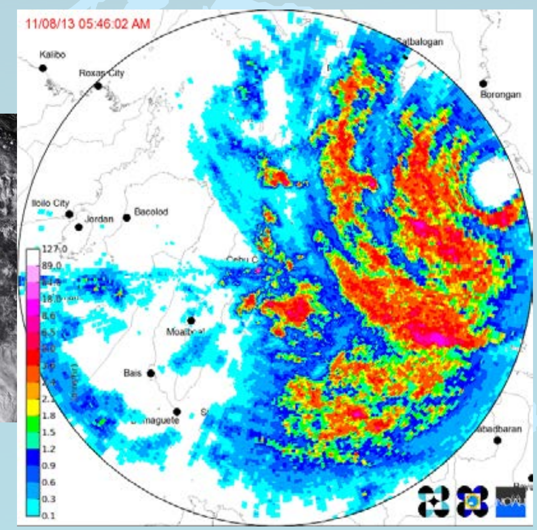
Typhoon Haiyan



Typhoon Haiyan



Typhoon Haiyan



Typhoon Haiyan

Why Wasn't the Population better Protected?

The Philippines, which sees about 20 typhoons per year, is cursed by its geography. On a string of some 7,000 islands, there are only so many places to evacuate people to, unless they can be flown or ferried to the mainland.

The Philippines' disaster preparation and relief capacities are also hampered by political factors. It lacks a strong central government and provincial governors have virtual autonomy in dealing with local problems.

Philippine officials had not anticipated the 6-meter (20-feet) storm surges that swept through Tacloban, capital of the island province of Leyte, which saw the worst of Haiyan's damage.

The population needs additional education regarding the potential impact of the strongest storms and their destructive storm surge.

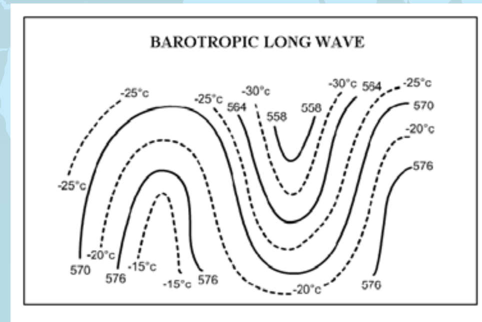
Significance of Rossby Waves

Rossby Waves

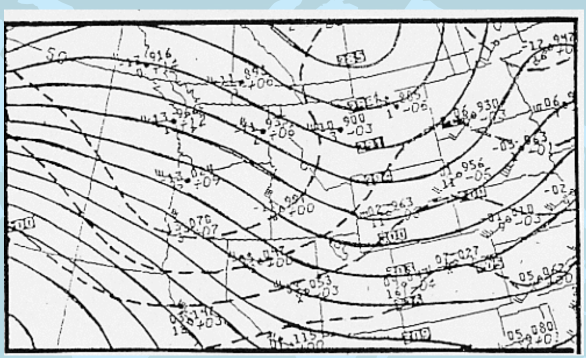
- define the average jet stream location and storm track along the polar front
- determine the weather regime a location will experience over several days or possibly weeks.
- advect cold air equatorward and warm air poleward helping to offset the Earth's radiation imbalance.

Equivalent Barotropic

- Thermal/contour trough axes in phase.
- Thermal/contour ridge axes in phase.
- Longwave troughs - cold core
- Longwave ridges - warm core.



Baroclinic Condition



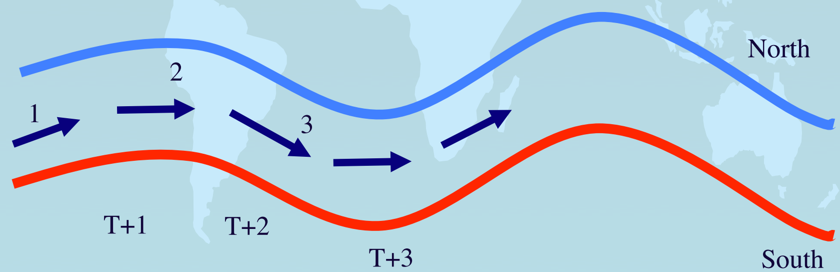
- The state of the atmosphere where isotherms exist on isobaric charts and these isotherms intersect the height contours (i.e., isotherms and height contours are "out-of-phase" with one another).
- Vertical shear is allowed. Wind direction changes with height, and is usually accompanied by speed changes.

Absolute Vorticity is Conserved

at the level of non-divergence

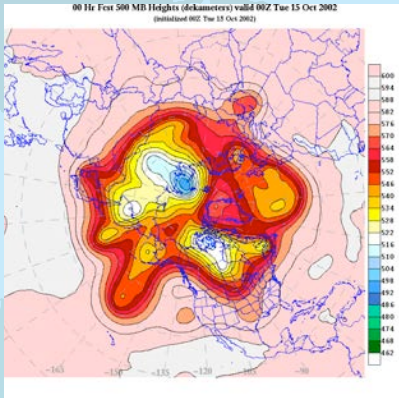
$$\frac{d}{dt}(\zeta + f) \cong 0 \Rightarrow \zeta + f \cong \textit{Constant}$$

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

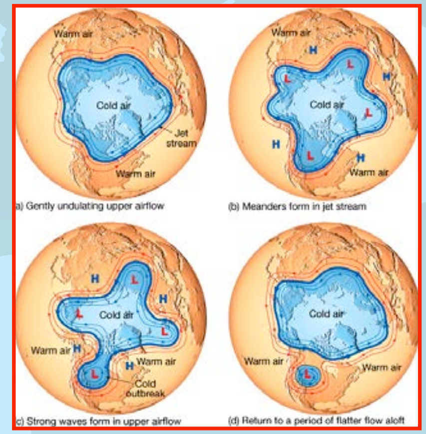


Rossby Waves

- 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.



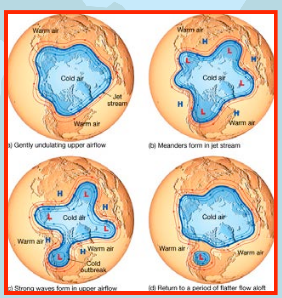
Rossby Waves



Center or axis of polar front jetstream outlines the Rossby wave pattern.

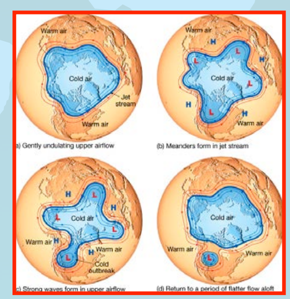
Zonal Flow

- 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



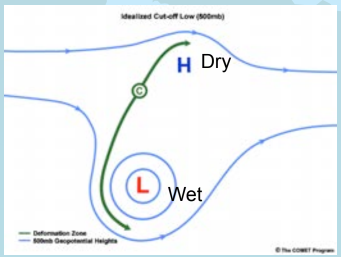
Meridional Flow

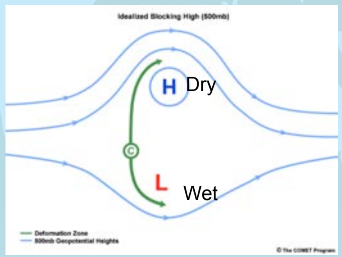
- Large north to south component to the flow
- Large-scale north−south energy transfer occurs.
- North to south temperature variations quickly weaken.
- Large west to east temperature variations.
- Weather systems are often strong and slower moving, with cyclones, producing large cloud and precipitation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



Blocking Patterns in Highly Meridional Flow

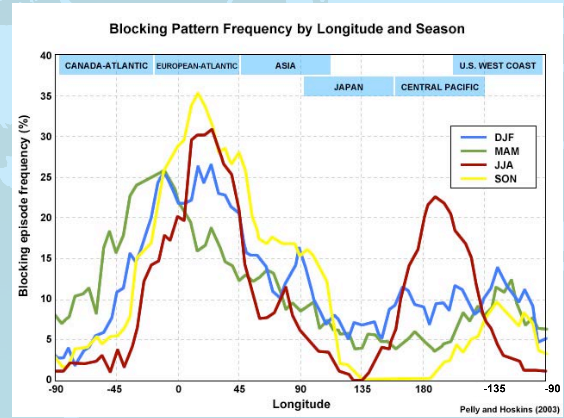
Identifying blocking patterns helps forecasters decide where to focus their attention over the forecast period. When blocking patterns develop, surrounding weather becomes more predictable, and understanding when the block will break down gives forecasters a better picture of the future progressive atmosphere.





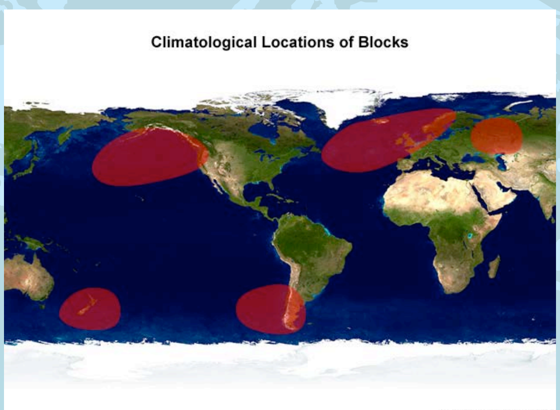
Green lines denote deformation zones.

Blocking Patterns



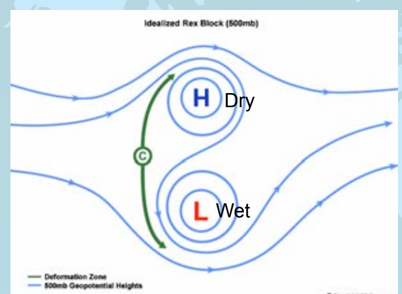
Blocking pattern frequency by longitude and season

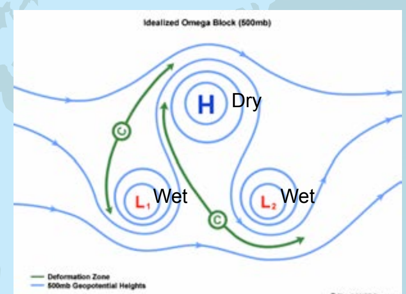
Blocking Patterns



Climatological locations of blocks.

Blocking Patterns



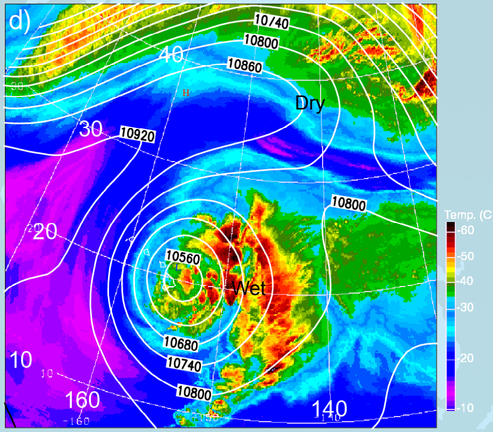


Rex block - high over low pattern - blocking generally lasts ~one week.

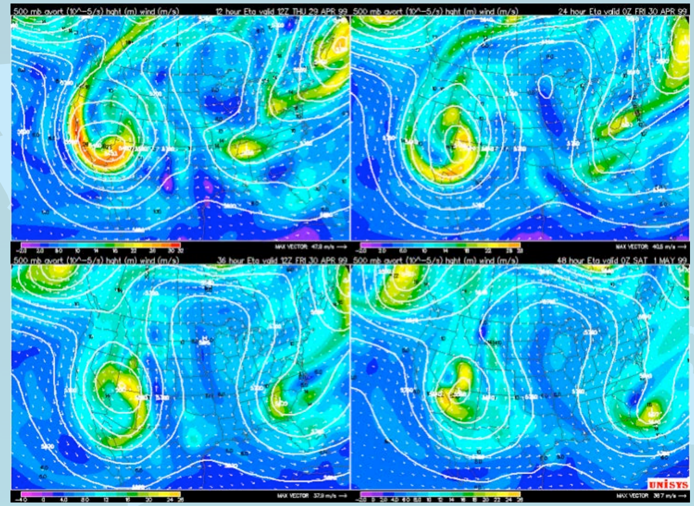
Omega block - blocking ridge with a characteristic “Ω” signature - blocking generally lasts ~ten days.

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.

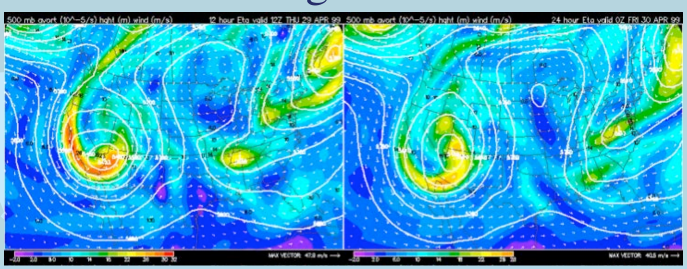


Omega Block



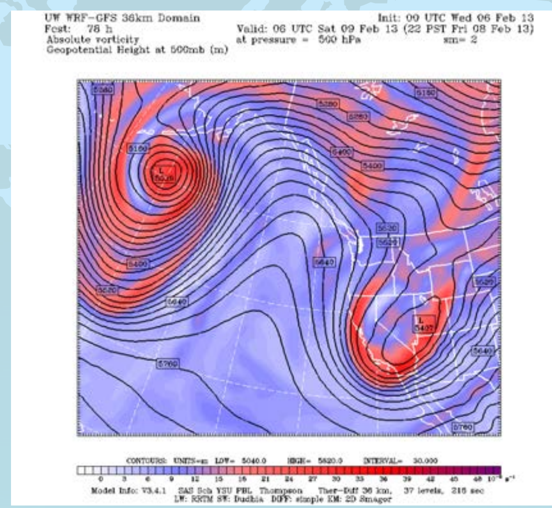
An omega blocking pattern has a life expectancy of 10-14 days. Chart shows 500-mb heights and absolute vorticity.

Omega Block

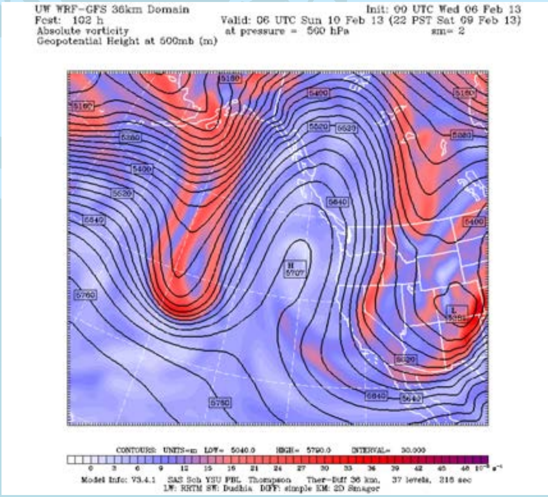


- The region under the omega block experiences dry weather and light wind for an extended period of time while rain and clouds are common in association with the two troughs on either side of the omega block.
- Omega blocks make forecasting easier since you can pinpoint areas that will be dominated by 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.

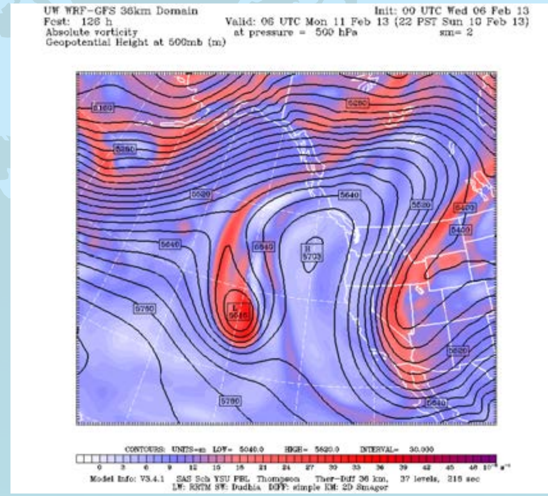
Omega Block



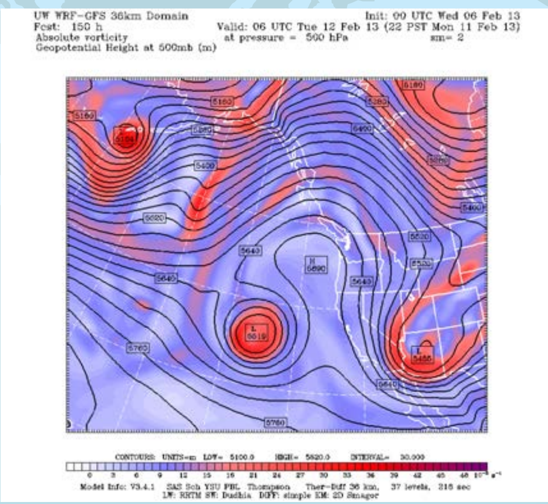
Omega Block



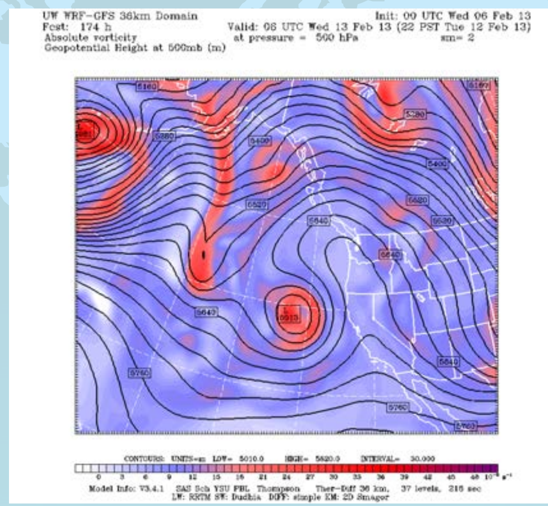
Omega Block



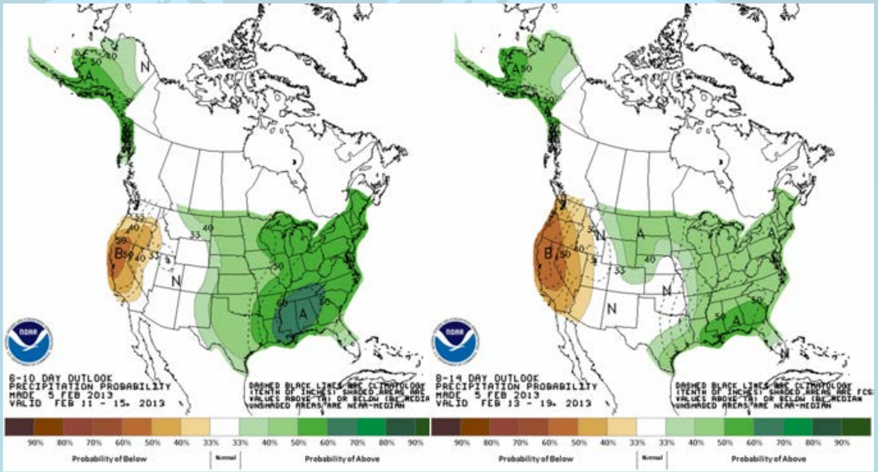
Omega Block



Omega Block

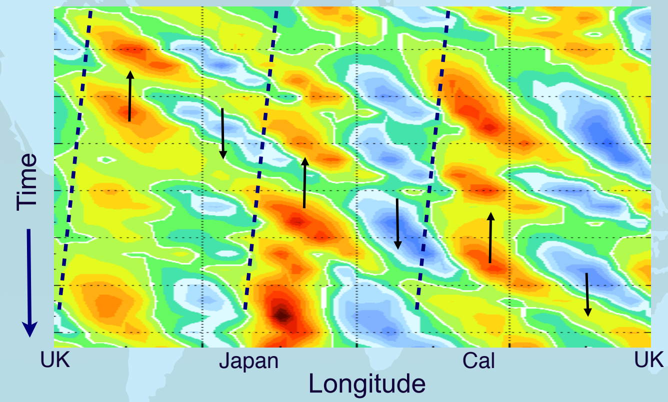


6-10 Day Precipitation Outlook



Diagnosing Rossby Waves

Hovmuller Diagram



250-mb Meridional Wind (m s^{-1}); 35-60 N

Red: S, Blue: N 6-28 November 2002

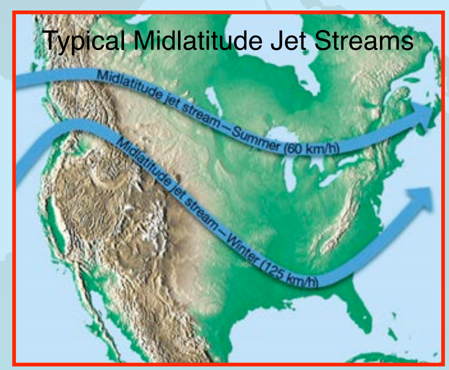
What Influences Rossby Wave Patterns?

Climatological positions and amplitudes are influenced by:

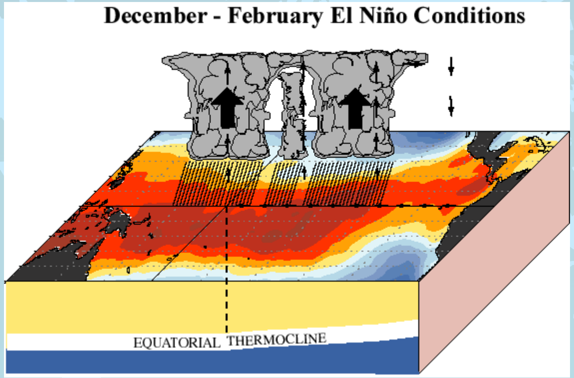
- Oceans
- Land masses
- Terrain features (such as mountain ranges)

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

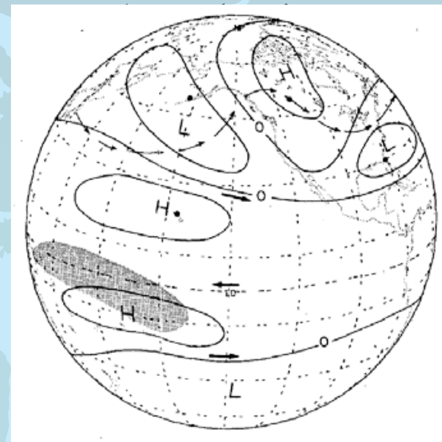


Rossby Wave Forcing by El Niño



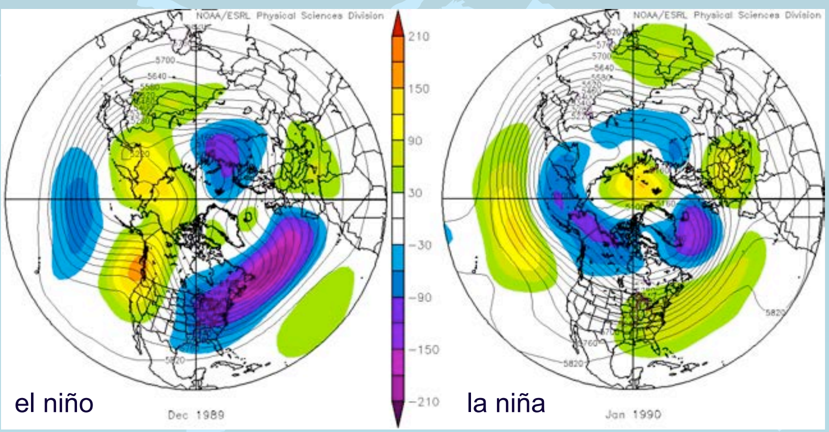
Enhanced convection over the central equatorial Pacific results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern.

Rossby Wave Forcing



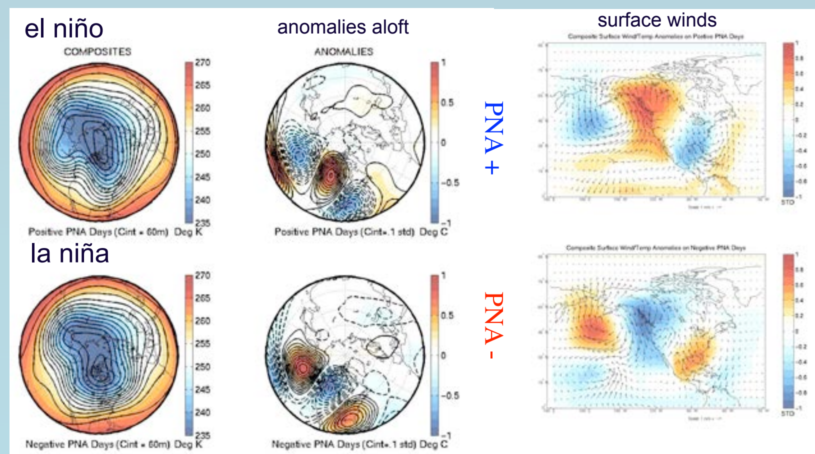
Enhanced convection over the central equatorial Pacific during el niño results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern (Horel and Wallace 1981).

Rossby Wave Forcing by ENSO



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

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.

Planetary Wave Forcing

PNA+ leads to

drought over Hawaii with large surf.

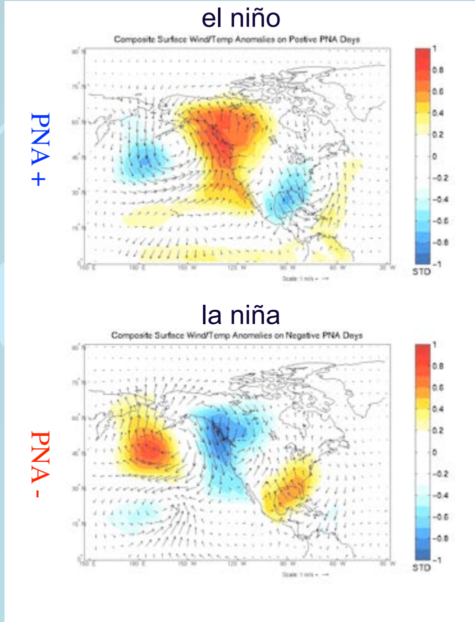
Warm and dry in the Pacific NW.

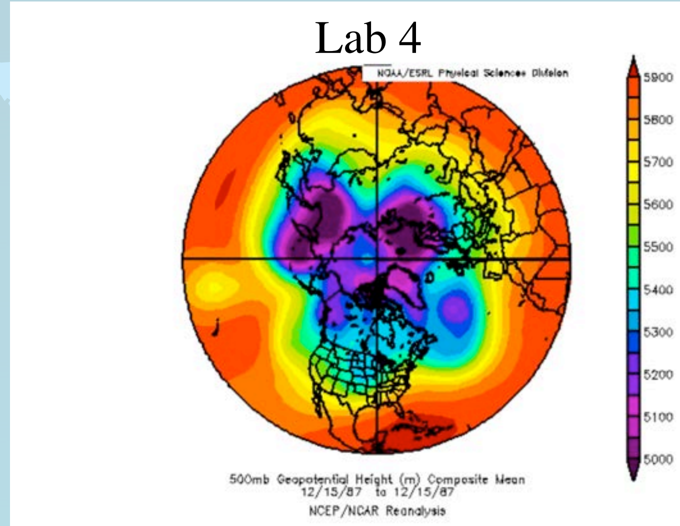
Wet over CA and wet and cold over the SE US.

PNA- leads to

Wet for Hawaii

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





Where are the Rossby Wave Trough Axes?

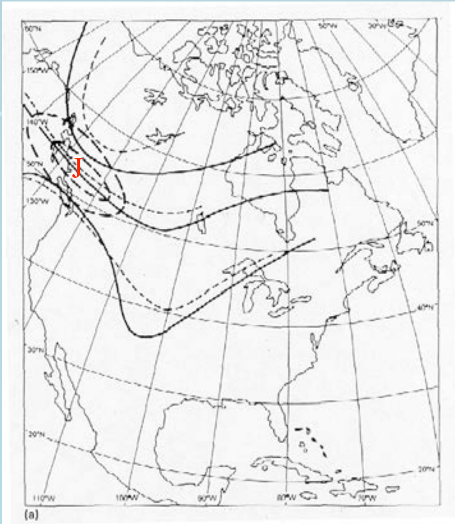
Rossby Waves Summary

- 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.

Shortwaves and Jet Streaks

- Superimposed upon the Rossby waves are shorter waves (often of quite small amplitudes) traveling rapidly (e.g. ≥ 20-30 m/s) through the slowly moving train of long waves.
- Jet streak: an isotach maximum embedded within a jet stream and is associated with short waves.
- Jet streaks are instrumental in high-impact weather.

Conceptual Model of Shortwave/Jet Streak



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

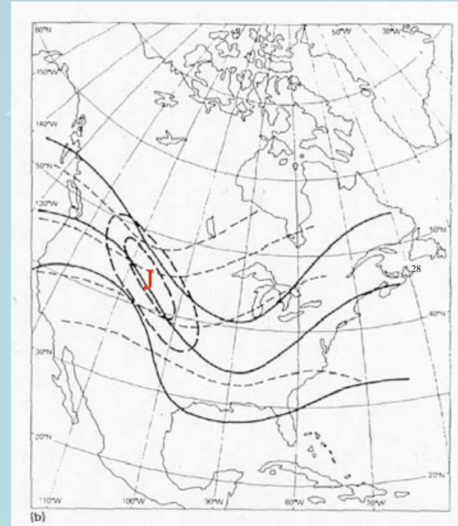
Solid lines: height lines

Thick dashed lines: isotachs

Thin dashed lines: isentropes

Time = t_0

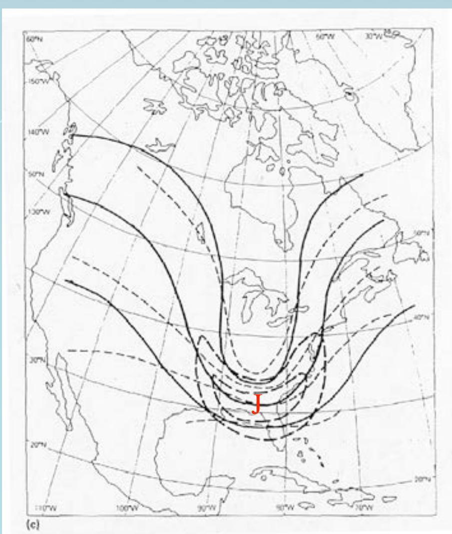
Conceptual Model of Shortwave/Jet Streak



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

Time = t_0 + 24 h

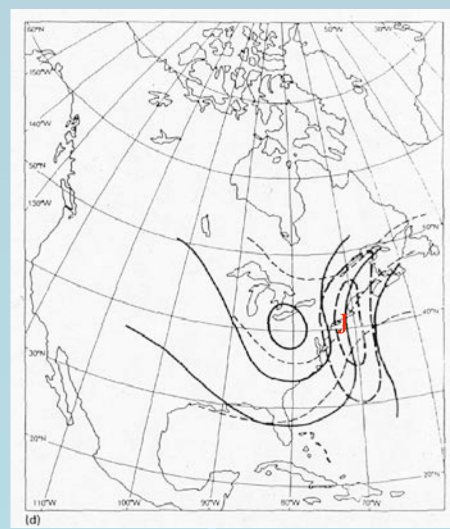
Conceptual Model of Shortwave/Jet Streak



Jet streak at the trough axis of a nearly fully developed wave. Often a new jet streak develops on eastern side of trough.

Time = t_0 + 48 h

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 = t_0 + 72 h

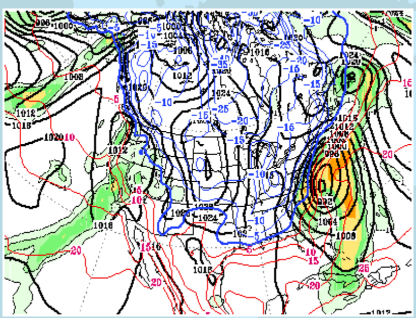
High-impact forecasts with limited skill

The Great Snowstorm: 25-27 January 2000

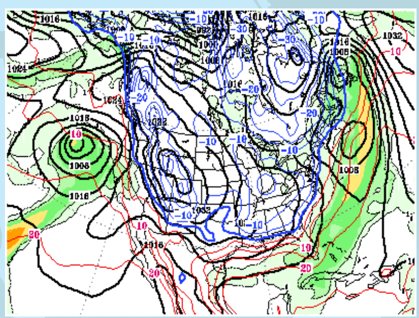
SeaWiFS Project NASA/ Goddard: 31 January 2000

Washington D.C., 27 January 2000

=NCEP 96-h Forecast versus Verification



MRF Analysis



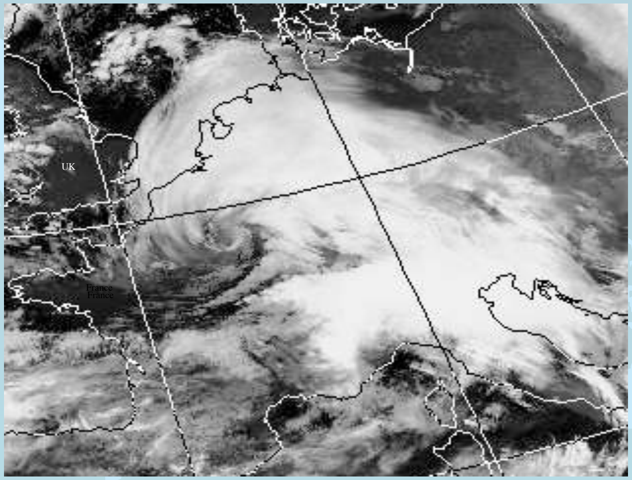
MRF 96-h Forecast

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

European Wind Storm: December 1999

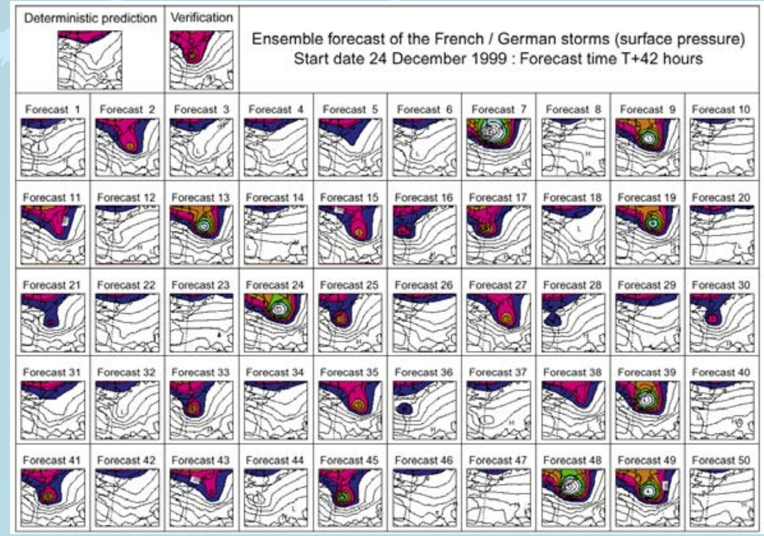
Destruction of the church in Balliveirs (left) and the devastation of the ancient forest at Versailes (below).

Lothar

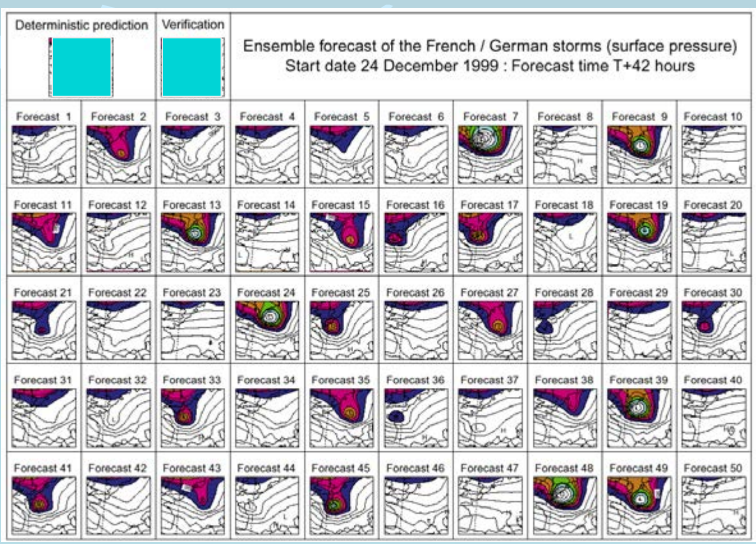


Dundee Satellite Station: 0754 UTC 26 December 1999

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



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



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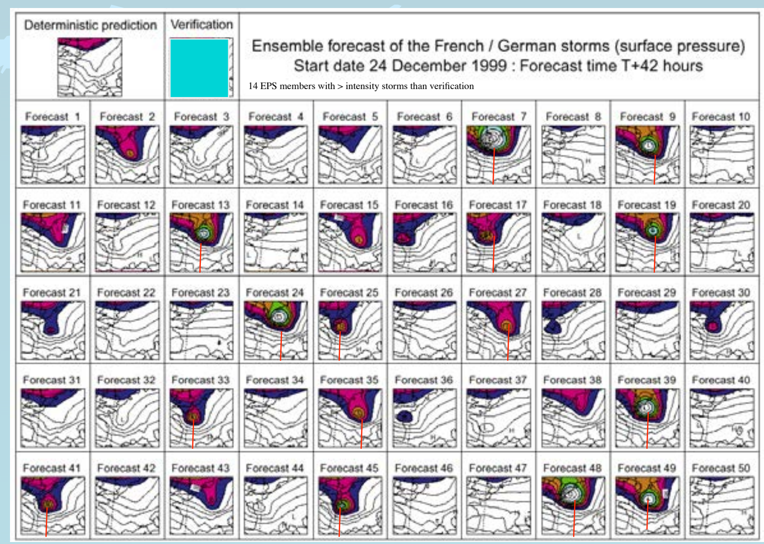
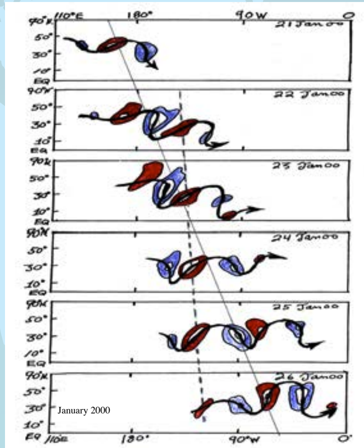
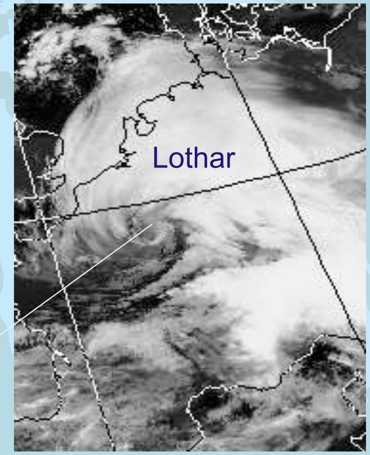


Rossby Wave Trains



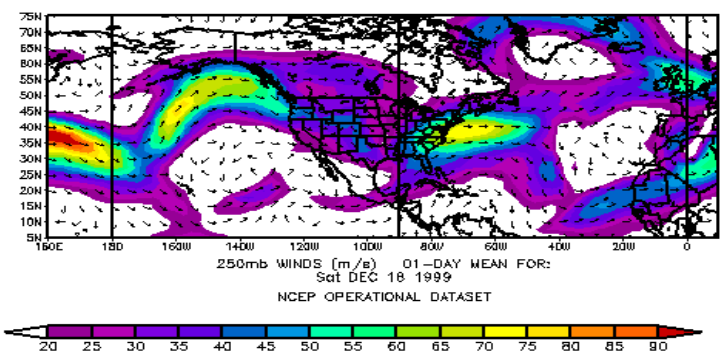
Rossby Wave Trains

European Wind Storm



0754 UTC 26 December 1999

Rossby Wave Trains



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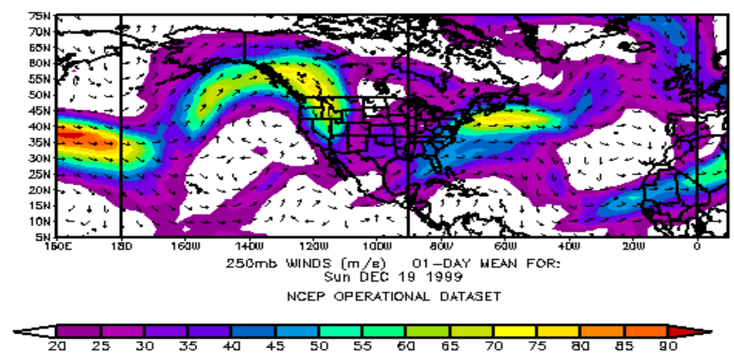

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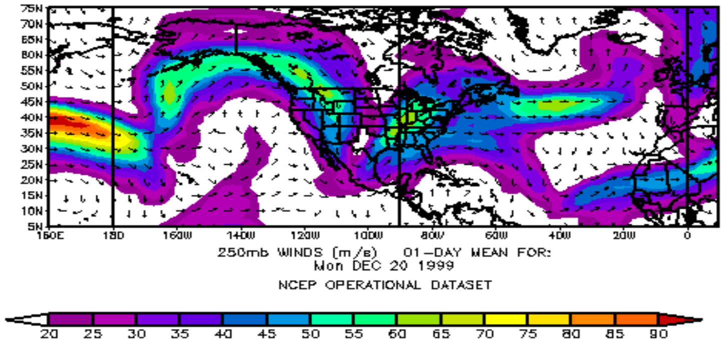

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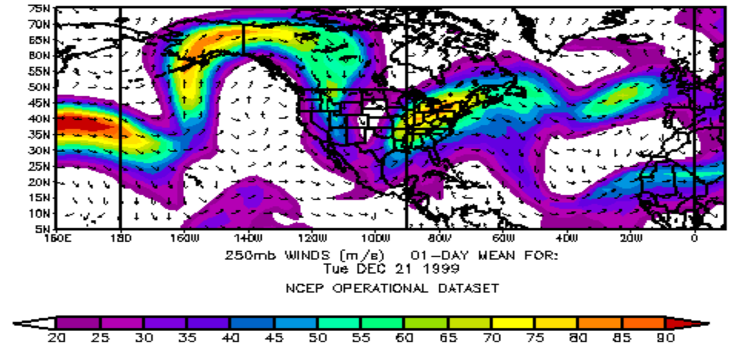

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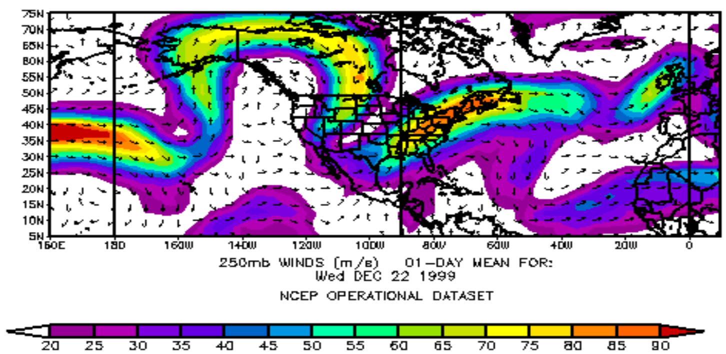

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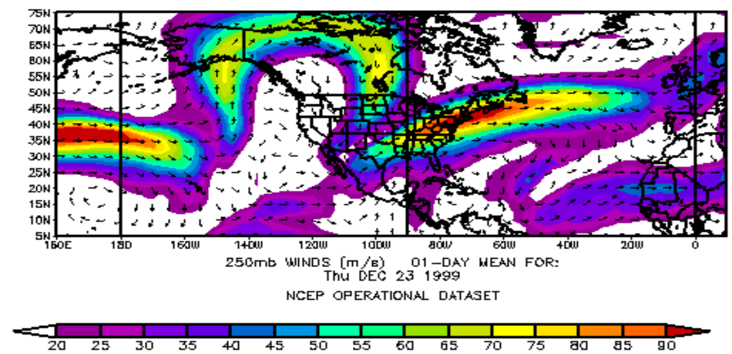
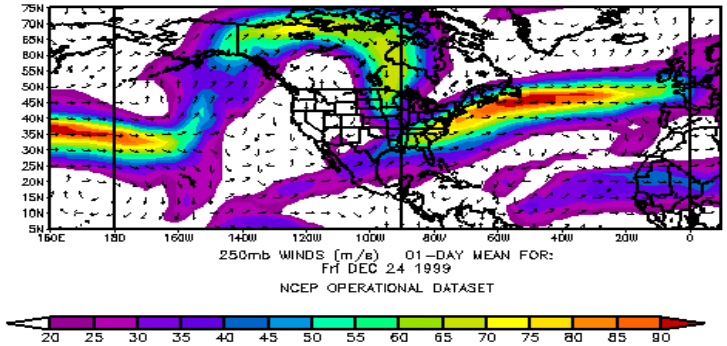
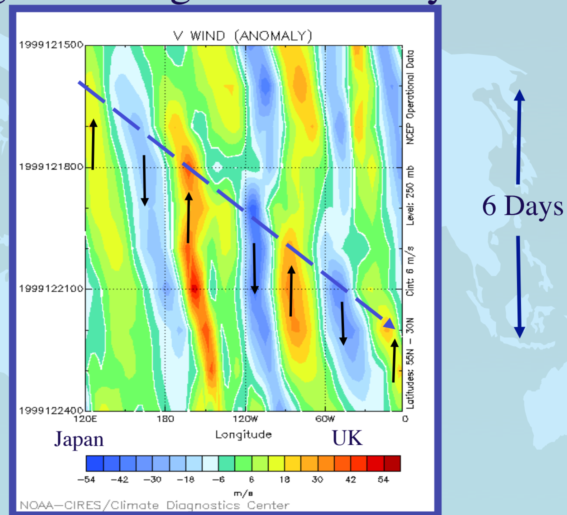


Rossby Wave Trains



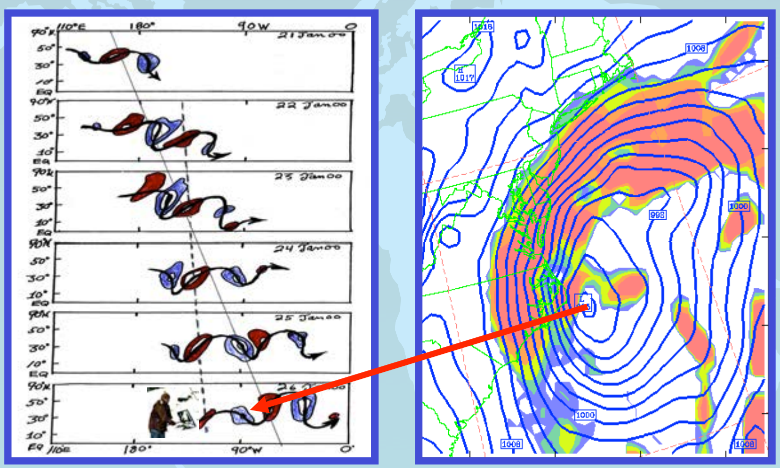
Time-Longitude Diagram of Rossby Wave Train



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

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

Rossby Wave Trains

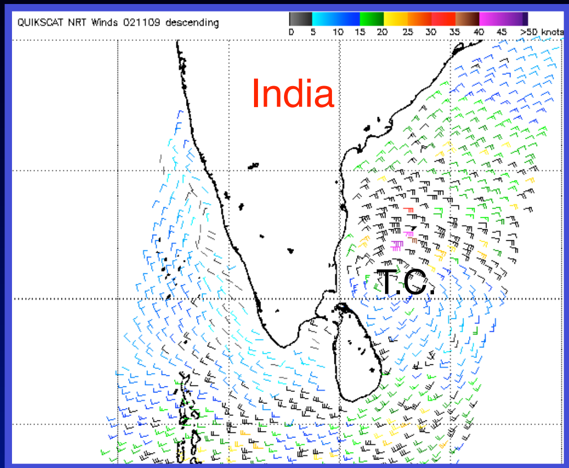


January 2000 Blizzard

Societal Economic Impacts of Extreme Weather

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

Tropical Cyclone: 9 November 2002



QUIKSCAT Surface Winds (knots)

Bay of Bengal Tropical Cyclone: 10 November 2002

~200 fisherman lost at sea

US Tornado Outbreak: 11 November 2002

US Tornado Outbreak: 11 November 2002

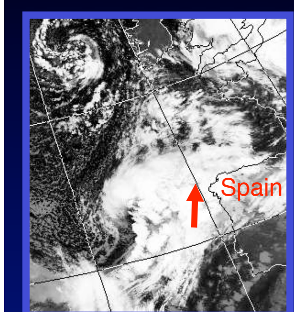
12 November 2002

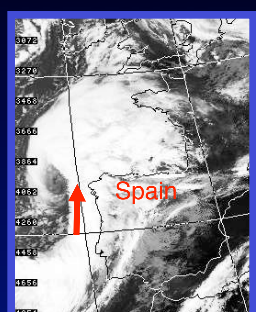
Poorly forecast rainfall event over Eastern Vancouver Island
40-50 mm in 24 h. Impacts: Mudslides, power outages

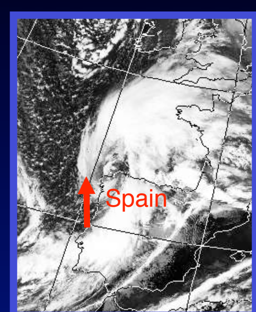
Oil Tanker "Prestige" Disaster

13-19 November 2002

13 November 2002
Oil Tanker

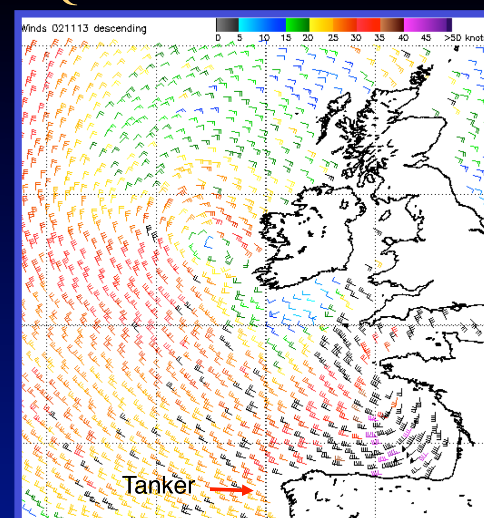






Dundee Satellite Station

QUIKSCAT Surface Winds



13 November 2002

Oil Tanker “Prestige”Disaster

Alpine Floods: 16-17 November 2002

Swiss -Italian Flooding: 0000 UTC 16 November

Eastern Switzerland: 17 November 2002

Austrian-German Alpine Wind Storm

17 November 2002

Austrian-German Alpine Wind Storm

Eastern US-Canadian Snow and Ice Storm

16 November 2002

November 18/19 2002

School Gymnasium in Vancouver collapses under heavy rains.

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)

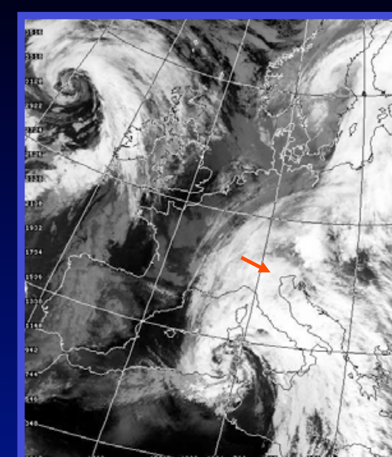
"Rain in Spain creates liftoff pain"

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

Moroccan Flood: 0600 UTC 25 November 2002

Italian Alps: 26 Nov 2002

Dundee Satellite Image

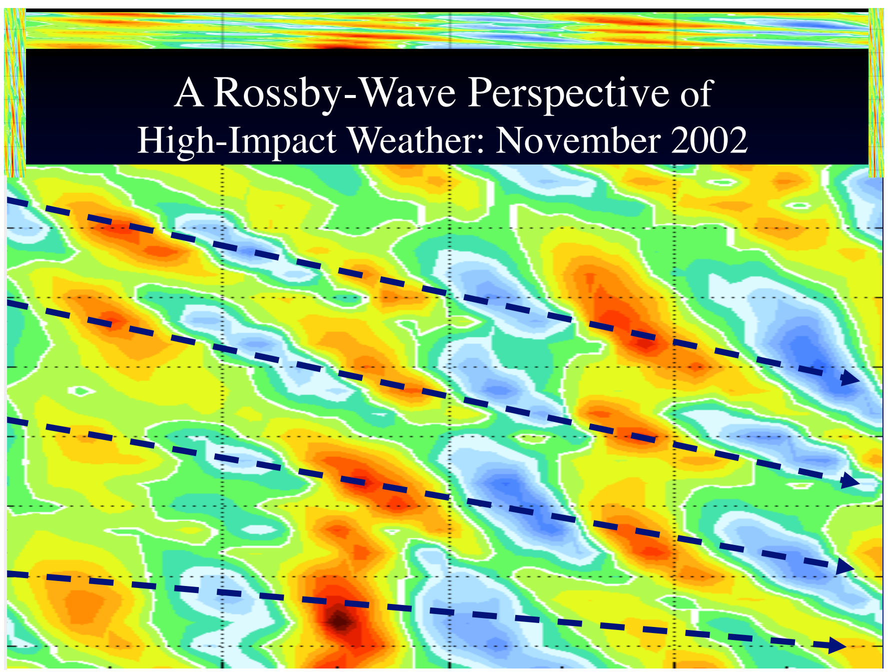


Flooding in Italian Alps

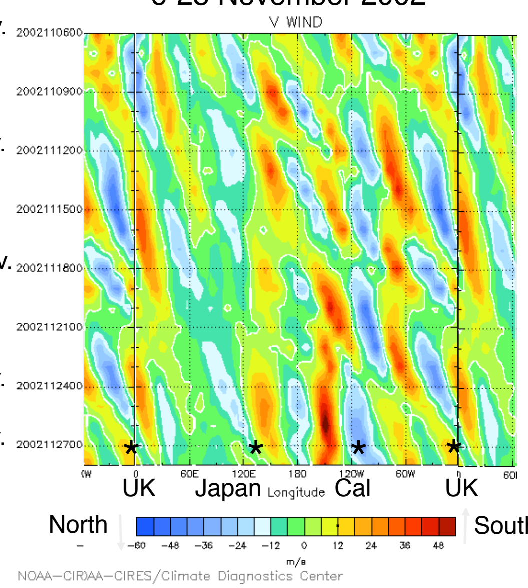
Lago Maggiore:
26 November 2002

Northern Italy
28 November 2002

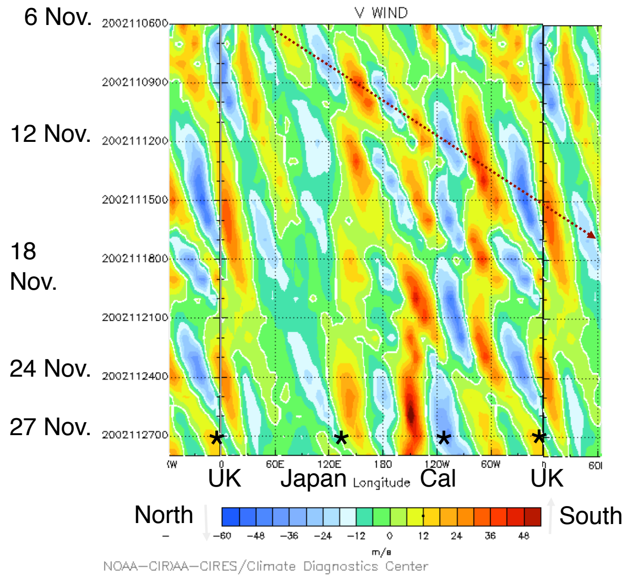
A Rossby-Wave Perspective of High-Impact Weather: November 2002



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



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



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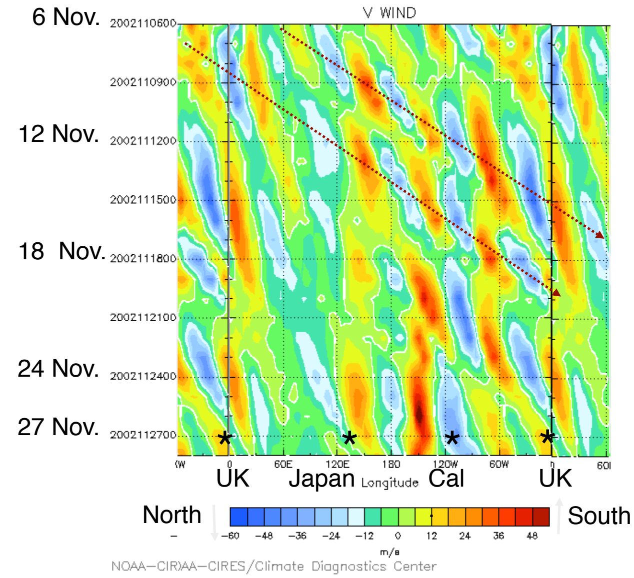

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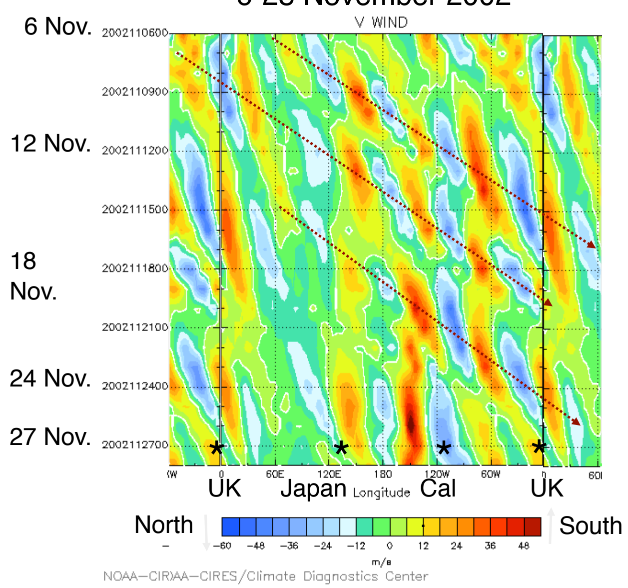
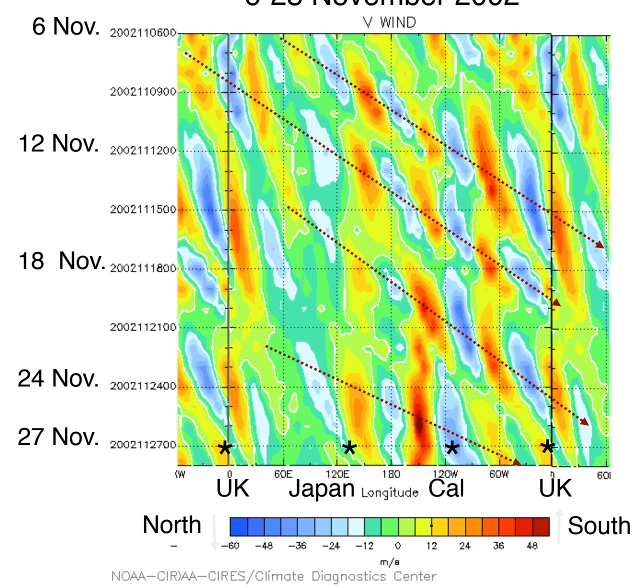
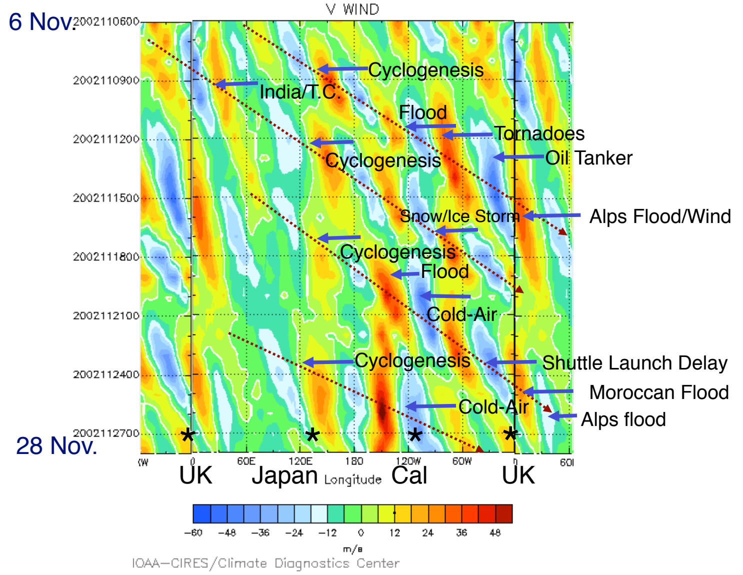


Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N
6-28 November 2002



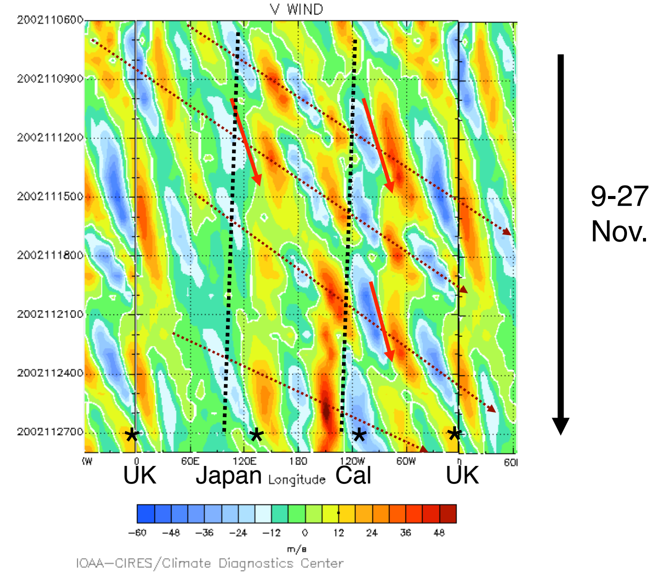
Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1})

Latitude Belt (35-60 N) 6-28 November 2002

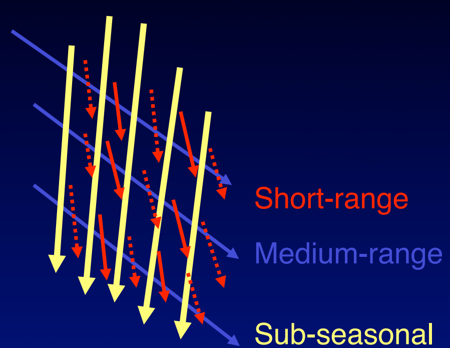


Time/Long. Diagram: 250-mb Meridional Wind (m s^{-1}); 35-60 N

6-28 November 2002



Three Interacting Time Scales



Scale Interaction

- Short Range - jet streaks and winter storms – days to a week
- Medium Range - Rossby wave trains – order of two weeks
- Sub-seasonal - Rossby waves – sub-seasonal, a month or more

Questions?