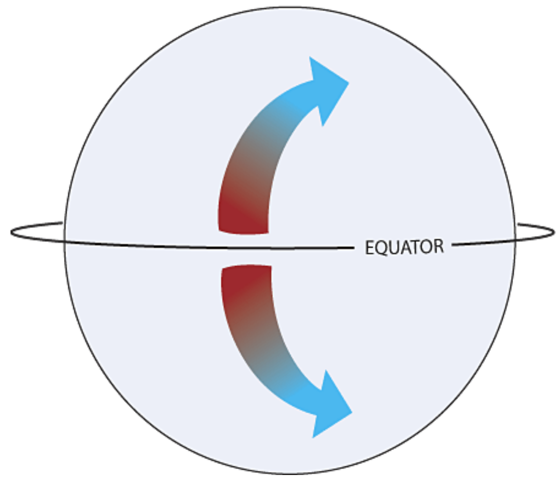
Winter Storm Track Variability in the Northern Hemisphere

Earth Gauge
A National Environmental Education Foundation Program

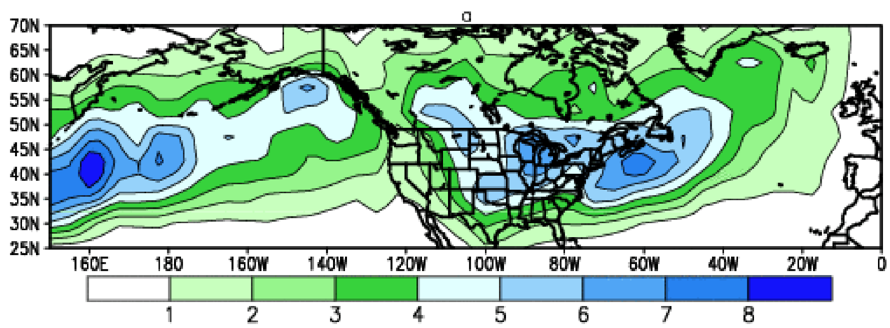
WHAT IS A STORM TRACK?

In the midlatitudes, mobile high and low pressure systems (swirling eddies that average 600 miles across) account for much of the day-to-day variability in weather. This is especially true during winter in the northern hemisphere. The simplest definition of a storm track is an area in which cyclones are more frequent than other areas. A more complex definition deals with the atmosphere's baroclinic energy, or the energy generated by inequalities in temperature and pressure. Because the equatorial regions receive larger amounts of solar energy than the rest of the globe, a pressure gradient develops between the low latitudes and the poles, causing "wave packets" (in this context defined as discrete "bundles" of air masses) to move to higher latitudes. As they travel, the Coriolis force, or the deflective force resulting from the Earth's rotation, causes these "wave packets" to appear to "steer" to the right in the northern hemisphere (they steer to the left in the southern hemisphere). Eventually, this steering causes the wave packets to turn into eddies, or swirling air masses. Storm tracks emerge where these two forces (the pressure gradient force and the Coriolis force) balance, and composites of individual wave packets coalesce into weather systems.



Above: The Coriolis effect causes traveling objects not attached to the earth's surface to appear to move to the right in the northern hemisphere, and to the left in the southern. Image courtesy of NOAA.

Storm tracks have "source regions," or areas where eddies strengthen and become systems the size you see on weather maps. In the northern hemisphere, the two strongest source regions are in the western Pacific near the poleward moving Kuroshio ocean current off the east coast of Japan, and from the northeastern U.S. into the Atlantic Ocean, near the poleward moving Gulf Stream. The heat and moisture these currents bring to regions that would otherwise be much colder is crucial to the development of the localized baroclinic energy necessary for storm track formation.



Above: average frequency of winter storm development from the period 1950-2002. Image Courtesy of NOAA

STORM TRACKS, THE JET STREAM, AND OCEANIC FRONTAL ZONES

Are the position and strength of storm tracks determined by the position and strength of the polar jet stream (also known as the geostrophic wind, or the wind that forms at the top of the troposphere – about seven miles up – and blows around the world at up to 200 miles per hour)? Or is the strength and position of the polar jet stream determined by the eddy activity in the lower parts of the atmosphere? Similarly, is the strength and position of a storm track determined by the properties of the sea-surface temperature (SST) frontal zones (the border of an area of the ocean with uniform temperature)? Or are the positions of the SST frontal zones determined by the behavior of a storm track? The dynamics of any one of these three variables (jet streams, storm tracks, and SST frontal zones) can be understood only through understanding the other two.

For example, ocean currents such as the Gulf Stream, which moves warm water from the equatorial Atlantic to Greenland, maintains the SST frontal zones along which the western hemisphere storm track travels. This westerly storm track is largely responsible, through the momentum created by the wind moving over the water, for driving the Gulf Stream that creates the SST frontal zone in the first place. In other words, it is just as accurate to say that the currents drive the storm tracks as it is to say that the storm tracks drive the currents. A strengthening of the Gulf Stream due to factors occurring outside of the North Atlantic may lead to a stronger storm track, which may lead to a strengthening of the jet stream. This strengthening of the jet stream, however, is thought to ultimately lead to a weakening of the Gulf Stream, thus providing a negative feedback loop that keeps the western Hemisphere storm track within certain parameters.

While a stronger jet stream generally suggests there is more baroclinic energy available for eddy development, as well as a greater potential for stronger storms, stronger jet streams do not always translate into stronger storm tracks. In the midwinter (around February 1st) when the jet stream is at its strongest, the Pacific storm track is at its weakest, which is referred to as the midwinter minimum. Debate exists about the reasons for this. One explanation involves the wintertime intensification of the subtropical jet, which works to essentially "trap" developing eddies before they have a chance to move poleward. This effect is more pronounced over the Pacific by virtue of its size.

MUTLIANNUAL CLIMATE CYCLES AND STORM TRACKS

Two multiannual climate cycles, the Northern Annular Mode (NAM) and the El Niño-Southern Oscillation (ENSO) are associated with shifts in storm track behavior.

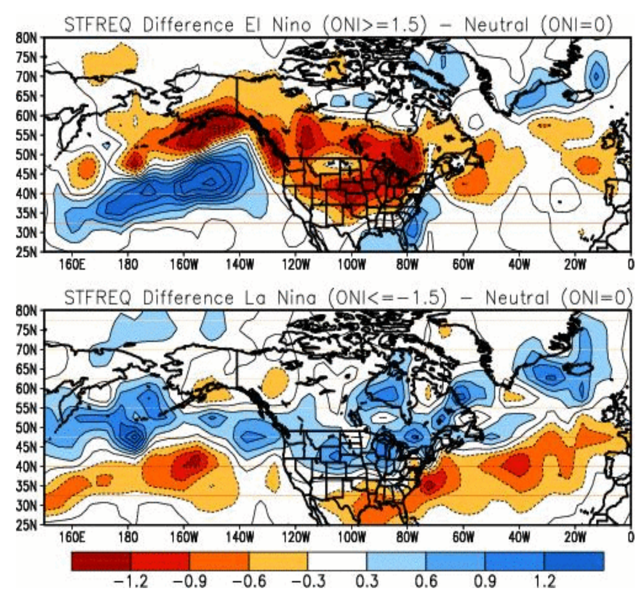
The Northern Annular Mode (NAM)

The Northern Annular Mode (NAM) is defined as a semi-regular north-south shift in the atmospheric mass between the mid-latitudes (30-35 degrees North) and the poles (55-60 degrees North). This means that air concentrations are higher or lower in different locations in the northern hemisphere depending on the NAM's phase, which is reflected in changes in atmospheric pressure. Positive phases mean lower than normal pressure over the polar regions and higher than normal pressure over the midlatitudes, with the opposite being the case for the negative phases. Analysis of high-altitude eddy activity shows that during strong positive phases versus strong negative phases, the western Pacific storm track extends westward (i.e. storms develop closer to Asia than North America), while the western hemisphere storm track intensifies, shifts northward, and shifts downstream (i.e. storms develop farther away from North America). Since the 1960's, the NAM has favored positive phases, with this trend being the most pronounced during the winter. It has become less positive over the past decade, however, and at least another decade of data will be needed to know whether this trend towards greater positivity is continuing.

The last few decades of consistently positive NAM index have been linked to reduced spring precipitation over the western United States, contributing to the overall drying trend in the region. More specifically, the western Pacific storm track fragments after positive winters, meaning fewer organized storm systems are developing. Positive winters also lead to the development of an east-west break in the storm track over North America, meaning storms that do develop miss the west, leaving the region drier. Thus, positive NAM winters are linked to an earlier transition from the wet (winter) season to the dry (summer) season.

The El Niño-Southern Oscillation (ENSO)

As illustrated in the diagram to the right, significantly warm ENSO phases (El Niño) work to shift the western Pacific storm track to the south and increase its overall strength, while reducing the number of storms over the Atlantic. Significantly cool (La Niña) phases mean essentially the opposite, with the western Pacific storm track shifting to the north and weakening, and the western hemisphere storm track strengthening. During warm (El Niño) phases, the amplified and more southerly storm track brings moisture and cooler air to the southern United States, leaving the northern United States warmer and drier. This corresponds to more storms hitting the California coast and a noticeably higher rate of coastal erosion during those years. The opposite effect is observed during the cool (La Niña) phase, as the storm track is shifted further to the north, bringing especially cold weather into Canada, and especially wet weather into the Pacific Northwest. The southern United States is generally drier than average during cool (La Niña) phases.



Above: The difference in storm development over different locations for El Niño (top) and La Niña phases (bottom) compared to neutral phases. Image courtesy of NOAA

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