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Scientific paper

Atmospheric teleconnection between Japan and the Saint Elias Mountains, Yukon

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Abstract: Cross correlation between time series of (1) total precipitation for a combined four-station network in northern Japan and of (2) the net snow accumulation determined from an ice core obtained from Mount Logan (60.5°N, 5340 m) situated in the Saint Elias Mountains, Yukon, reveals high, statistically significant, cross correlation coefficients of +0.38 for annual data increasing up to +0.71 for seven point smoothing of the two 89 year series. The distance between sites is about 7000 km spanning the complete Pacific Ocean between latitudes of about 40°N and 60°N. A review of the extensive literature of oceanology and climatology for the North Pacific Ocean region indicates that a strong coupling exists between the ocean and the atmosphere especially up to and associated with the Polar Front Zone along which major cyclogenesis occurs during most months of the year. Cyclones track generally from west to east with a strong northerly component especially in the eastern (Gulf of Alaska) sector. Examination of these cyclones on GOES satellite images shows that weather systems can transport moisture from mid latitude ocean sources (<40°N) to high on Mount Logan over the top of the warm front zone and high above intervening coastal topography. Thus, the positive correlation between the two time series can be physically justified and qualifies the link as a genuine teleconnection.

1. Introduction

Teleconnections within the atmosphere are defined as linkages or correlations, over great distances, of weather or climate anomalies. They may be identified using routinely recorded meteorological variables (pressure, temperature, precipitation) as the diagnostic tool. The description, scientific bases and societal impacts of teleconnections are covered in a comprehensive volume edited by Glantz *et al.* (1991). It is now standard practice to identify teleconnections spanning distances of *order* 10^4 km. Teleconnections may be defined by either positive or negative cross correlation coefficients that are statistically significant at a nominal ≥5% level. Negative correlations, associated with anomalies that switch sign on a regular basis, are commonly referred to as 'seesaws'. Here, I describe a positive (stable) precipitation teleconnection spanning a distance of over 7000 km right across the Pacific Ocean. An outline of how this teleconnection was originally discovered is given in Holdsworth (1992). I also describe a 'seesaw' teleconnection between two stations situated on the west coast of North America. Such teleconnections are not successfully produced in current Global General Circulation Models (GGCM's) because model precipitation is not supported by realistic, regional-scale, cyclonic structures. Only very high spatial resolution (20 km × 20 km) regional models (over a surface domain of $< 10^4$ km × $< 10^4$ km) are capable of doing this but then the domain is too restricted for looking at the physical basis for precipitation teleconnections over very large distances.

In this paper I avoid the numerical modeling approach to provide a detailed physical basis for the long distance correlation by using the wealth of published information, as well as satellite imagery, for studying the North Pacific oceanographic and atmospheric domains. These information resources show that there is a strong coupling between the ocean and the atmosphere for the breadth of the Pacific region at mid-latitudes and that cyclogenesis is frequently coherent, on a temporal basis, in the western and eastern Pacific regions. Intense cyclogenesis occurs along the polar front zone (Parker, 1980) extending across the North Pacific Ocean (Fig. 1).

In Section 2 the data will be presented, in Section 3 the cross correlation analyses results will be given and briefly discussed, and in Section 4, the physical basis for the long-distance cross correlation will be qualitatively explained. The overall results will be summarized and conclusions drawn in Section 5.

2. Data

Precipitation data for the stations in Japan were obtained from World Weather Records (1944, 1959, 1967) and from U.S.E.D.S. (1961–1987). Five stations with the longest records (Nemuro, Akita, Miyako, Tokyo and Nagasaki) were intially selected, but on the basis of known differences in regional climate, and on the basis of cross correlations made between station data, Nagasaki was eliminated and the records of the four northern region stations were combined into one mean record. This is referred to as the 'Northern Japan annual precipitation time series' (1889–1986). The corresponding net snow accumulation time series for Mount Logan is taken from data given in Holdsworth *et al.* (1992). The location of sites and stations referred to in this paper are given in Fig. 1 with coordinates given in Table 1. The four stations in northern Japan (J) are marked by black squares. On the eastern Pacific rim, Mt Logan (M) is marked by the black triangle. The stations S (Seward) and V (Victoria) are marked by black squares. The two time series from Japan and Mt Logan are plotted in Fig. 2. The remarkable correspondence in variance may be seen immediately and initially defines the west-east Pacific teleconnection, in empirical terms. Two other data sets that carry important information in the context of Pacific region atmospheric processes are the annual precipitation at Seward, Alaska and at Victoria, British Columbia. These series are shown in Fig. 3 and their significance will be discussed in the next two sections.

3. Data analyses and interpretation

The standard Pearson Product Moment Cross Correlation Coefficient (r) (see *e.g.* Thiébaux, 1994) has been calculated for pairs of (annual value) time series and for different amounts of smoothing applied to the raw series. The two series plotted in Fig. 2 have a cross correlation coefficient of +0.38 (significant at the 1% level). Progressive smoothing using 5-yr and 7-yr width filters increases the cross correlation coefficient successively to

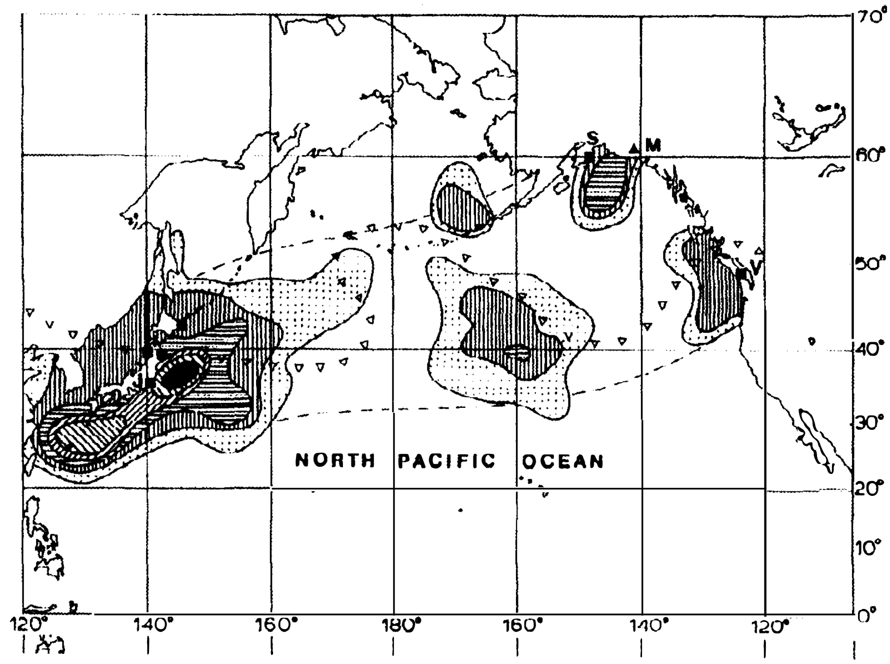

Fig. 1. *Map of the North Pacific Ocean region (after Terada and Hanzawa, 1984). Stations in Japan (J) are shown by black squares (Table 1 lists the coordinates). Northeast Pacific rim stations or sites are Seward (S), Mt Logan (M) and Victoria (V). Contoured regions indicate intensity of cyclogenesis (for contour values see Figure 14 of Terada and Hanzawa, 1984). Black indicates highest intensity of cyclogenesis. These 'centers of action' are associated with the polar front. An instantaneous polar front position is given by the open inverted triangles (after Iribarne and Cho, 1980). The polar front generally occupies positions between the two dashed lines extending across the Pacific. In the text the accepted term 'polar front zone' is generally used to signify its broad and transient nature.*

Table 1. *Coordinates of sites or stations referred to in the text and beginning of record.*

Mount Logan	60°37′N	140°31′W	5340 m	Records AD1693-
Seward, Alaska	60°07′N	149°27′W	76 m	Records AD1908-
Victoria, B.C.	48°25′N	123°19′W	70 m	Records AD1898-
Nemuro, Japan	43°02′N	145°35′E	27 m	Records AD1889-
Akita, Japan	39°43′N	140°06′E	10 m	Records AD1886-
Miyako, Japan	39°38′N	141°59′E	30 m	Records AD1884-
Tokyo, Japan	35°41′N	139°46′E	21 m	Records AD1876-
Nagasaki, Japan	32°44′N	129°52′E	13 m	Records AD1879-

+0.63 and +0.71 (Fig. 4). This latter coefficient is well above the 1% significance level and shows that both time series must contain considerable periodicity at decadal and higher wavelengths. Power spectra given in Holdsworth *et al.* (1992) for the Mount Logan series show peaks at 3.8 yrs (corresponding to ENSO frequency), at approximately 10-11 yrs, and at about two decades.

The application of a 7-yr filter to the data of Fig. 2 has accentuated these lower frequencies and the combined results show that the teleconnection, spanning over 7000 km,

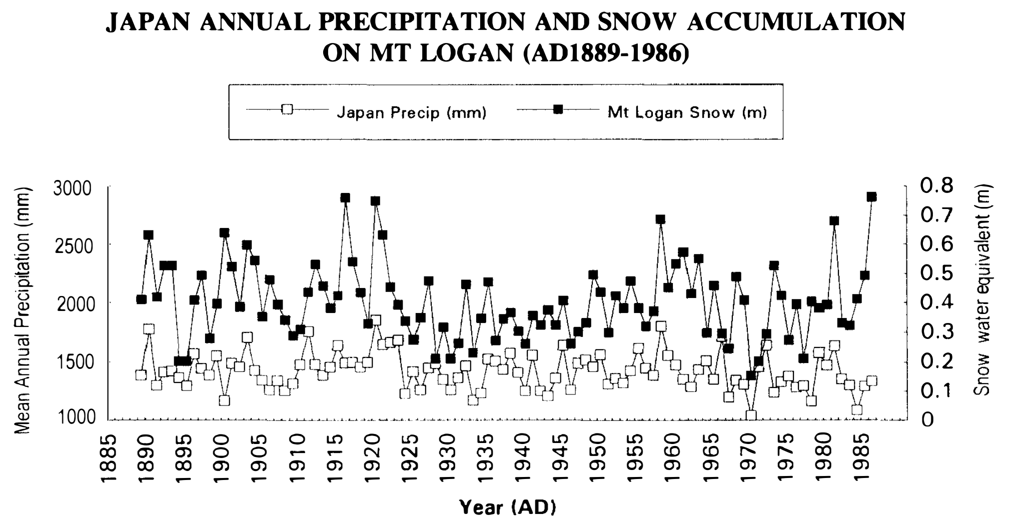

Fig. 2. *Graph of Japan annual precipitation (unweighted mean of four stations in Northern Japan) and net snow accumulation (in water equivalent) for Mount Logan, Yukon.*

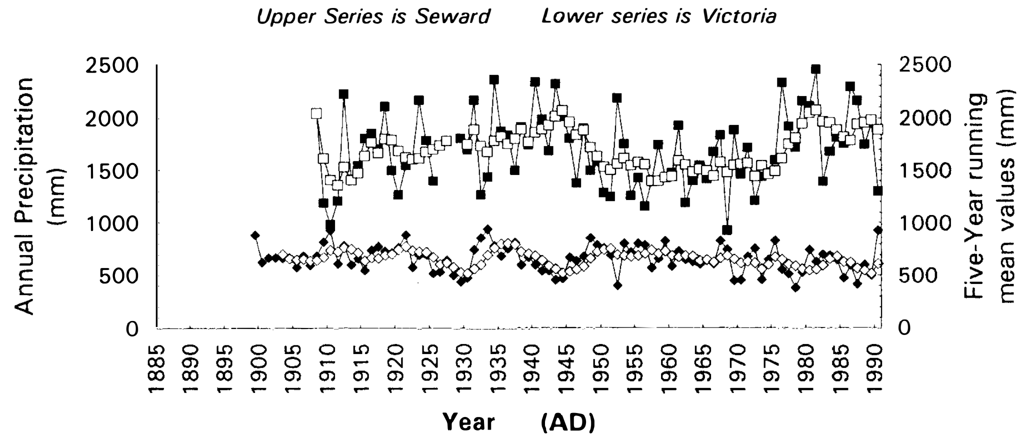

Fig. 3. *Graph of total annual precipitation for Seward, Alaska (1908–1990) and for Victoria (Gonzales Heights), British Columbia (1899–1990). Data are smoothed by a 5-year filter for optimum correlation. The anti-correlation may be clearly seen for most of the series.*

holds for a wide range of frequencies. This defines it as a stable, positive, teleconnection.

In Fig. 3 it is seen that the two North American time series (Victoria and Seward) are in anti-phase. The cross correlation coefficient is −0.41 for the 5-yr filtered series. This value is statistically significant at the 1% level. Such a result suggests the existence of a 'seesaw' teleconnection in a roughly north-south direction (spanning about 2200 km). This interpretation is broadly consistent with a study by Wallace and Gutzler (1981) who found 'seesaw' teleconnections in geopotential height fields in a north-south orientation for the north Pacific region in winter. They identified a *node* at about 50°N which lies between the two stations analysed here.

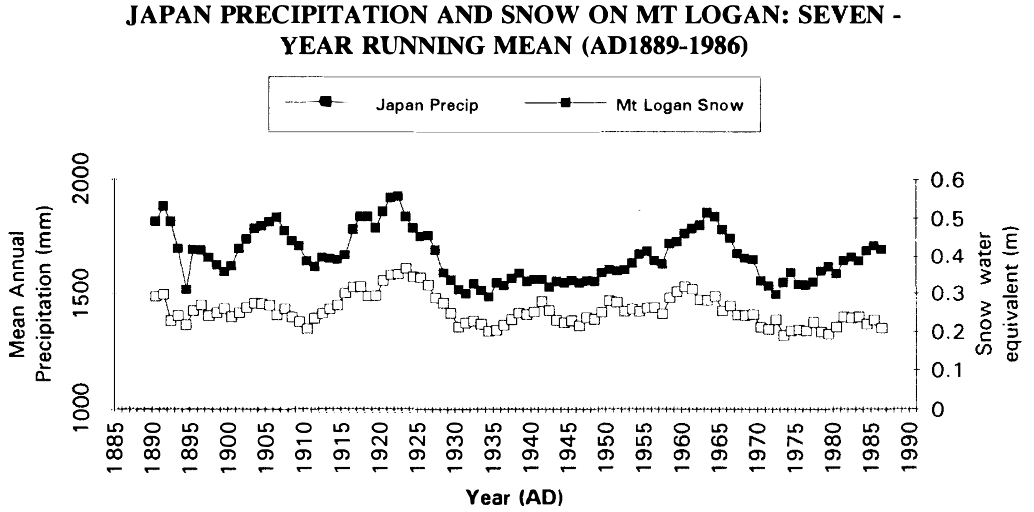

Fig. 4. Graph of Japan precipitation and Mount Logan net accumulation series from Fig. 2 smoothed with a 7-year filter to accentuate the decadal signal and produce the highest cross correlation coefficient (+0.71). See Table 2 for significance levels.

Table 2. Cross Correlation Coefficients (r) between stations/sites given in Table 1. Data have been smoothed by 5 and 7-yr filters. Statistical significance at the 5% and 1% levels apply to the annual data series. Levels for filtered series are slightly higher. A nil entry means r decreases from the value in the last box.

Station/site	Station/site	Annual data	5-yr r/mean	7-yr r/mean	Signif (5%)	Signif (1%)
Mt Logan	Japan (4 stn)	$r=0.38$	$r=0.63$	$r=0.71$	$r=0.200$	$r=0.256$
Nemuro	Akita	$r=0.33$	$r=0.41$	$r=0.40$	$r=0.199$	$r=0.254$
Miyako	Tokyo	$r=0.41$	$r=0.31$	$r=0.28$	$r=0.202$	$r=0.255$
Akita	Miyako	$r=0.317$	$r=0.322$		$r=0.194$	$r=0.253$
Tokyo	Nagasaki	$r=0.199$	$r=0.233$		$r=0.188$	$r=0.245$
Mt Logan	Victoria	$r=0.12$	$r=0.35$	$r=0.40$	$r=0.210$	$r=0.275$
Victoria	Seward	$r=-0.36$	$r=-0.41$		$r=0.224$	$r=0.293$

4. North Pacific oceanology and climatology

4.1. Scope

Only a brief review of the extensive literature on North Pacific region oceanology, meteorology, and climatology is possible here. The relevant information occurs in two general parts: ocean surface processes and atmospheric processes. Although consideration of atmospheric processes alone seems to be able to account for coherence in the North Pacific region atmosphere, a synthesis of the two types of information is attempted here as it appears to lead to a better understanding of how trans-Pacific, zonally linked, teleconnections in atmospheric anomalies can occur.

4.2. Sea surface data

Oceanographic data such as surface currents and Sea Surface Temperature (SST) (Terada and Hanzawa, 1984) clearly show strong coherence in the region of the Kuroshio Current Extension and its bifurcation near the North American coastline especially during the winter months. This east-northeasterly trending strip is the preferred location of the polar front along which intense cyclogenesis takes place especially during the fall and winter months. On satellite SST maps (www.fnoc.navy.mil/otis/archive/) the thermal structure of the Pacific Ocean may be clearly seen for all months of the year. Animations (www.cdc.noaa.gov/) of North Pacific SST's during an El Niño/La Niña cycle show the development of a warm water plume from the east coast of Japan to far out into the eastern Pacific. The position of the circumpolar vortex (a general term for the system bounded by the polar front and arctic front) is known to be modulated by this cycle (Angell and Korshover, 1985).

4.3. Atmospheric data

Figure 1 shows regions of preferred cyclogenesis for the North Pacific Ocean according to Terada and Hanzawa (1984). Preferred Centers of Action (COA) for cyclogenesis are located east of Japan, in the east central Pacific (near 40°N), north of the Aleutian chain, and in the Gulf of Alaska region (Terada and Hanzawa, 1984). Individual cyclones may travel from one COA to another. Also shown are the approximate preferred annual limits of the polar front (dashed lines). A specific winter-time polar front position at the 500 mbar level, is shown by the inverted open triangles (Iribarne and Cho, 1980). This case indicates strong meridional flow. Here, I refer to the polar front generally as the polar front zone (PFZ), because of its broad, as well as transient, nature. On the hemispheric scale, the PFZ is continuous, being the boundary between the polar air mass and subtropical air masses.

Satellite (GOES 10) images show that moisture for Gulf of Alaska cyclones often comes from as far south as below 40°N and from the mid-Pacific. Occasionally, major (winter) Gulf of Alaska cyclone tails are linked to western Pacific cyclones that have formed along the east coast of Japan. Synoptic weather maps for the entire North Pacific (http://weather.unisys.com/upper_air/ua_nhem_500p.html) show that low pressure systems are often occupying the western and eastern parts of the North Pacific simultaneously.

4.4. Synthesis of North Pacific Ocean data and modern analyses of atmospheric processes

By overlaying maps of oceanographic data with maps of atmospheric variables (pressure anomaly fields, the preferred zone of Rossby Waves, wind fields -including the Polar Front Jet Stream, precipitation intensity zones, synoptic charts and satellite images of moisture transport) it becomes apparent that there exists a strong zonal coherency in the atmosphere across the mid-latitude North Pacific. Recent modeling of the stationary wave propagating eastward off the high altitude Asian Plateaus (Plumb, 1985) shows its importance extending as far as the west coast of North America. Analyses of the geopotential height anomalies for the Pacific (Nigam *et al*., 1999) also supports the existence of the stationary planetary wave field. This wave can be considered a type of 'carrier wave' supporting minor modulation by El Niños, internal decadal oscillations in the atmosphere (James and James, 1989) and including solar modulation (Christoforou and Hameed, 1997; Van Loon and Shea, 1999). Both ENSO and decadal scale signals are present in the power spectrum of the Mount Logan time series (Holdsworth *et al.*, 1992). Further details of the ENSO signals and their related PNA-like teleconnection patterns are given in Moore *et al.* (2001).

5. Summary and conclusions

The results of this study show that there is strong coherence between the precipitation records from Japan, (representing the western margin of the mid-latitude North Pacific Ocean) and an ice core snow accumulation record from Mount Logan over a century scale time span. The cross correlation results imply that the high altitude precipitation received on Mount Logan is not derived locally but originates from mid-latitude, possibly mid-Pacific, waters where precipitation modulation processes are in synchroneity within a wide zonal swath across the Pacific. Isotopic data from Mount Logan (Holdsworth *et al.*, 1991) suggests that the ice core site is regularly receiving moisture from above the warm front zone of cyclones centered in the Gulf of Alaska, which implies that much of the water vapor for the snow has a long distance source south of the southern extremity of the Polar Front Zone (PFZ). A review of the extensive oceanographic, meteorologic and climatic data for the North Pacific, as well as a study of weather satellite images, reveals that this is the case. It also appears that a linkage of atmospheric anomalies spans the mid-latitude North Pacific. This linkage could be referred to as the Asia-Pacific-North-American linkage (APNA) evidently related to the PNA pattern of Wallace and Gutzler (1981) but more extensive than it. The APNA linkage seems to provide the physical basis for calling the remarkable cross correlation between precipitation records on either side of the Pacific, a teleconnection. An examination of precipitation records along the North American coastline reveals a persistent 'seesaw' in precipitation between Victoria, British Columbia and Seward, Alaska, which is at about the same latitude as Mount Logan but generally within the polar air mass. This type of teleconnection might be inferred from the results of Wallace and Gutzler (1981). Whereas there is a significant (positive) cross correlation between Mount Logan and Victoria, it is not as large as the one between Mount Logan and Japan. This result could only be due to the fact that complex topography is not *directly* interfering with precipitation processes on Mount Logan at high altitude.

The complete Mount Logan time series is nearly three centuries long. In principle it could be used as 'proxy' for generating an equivalent time series for Japan before the instrumental records. Unpublished, pre-instrumental, climate data for Japan, in the form of abstracted and 'indexed' diary records, are available (Professor M. Yoshimura of Yamanashi University), but these data have not yet been incorporated into the Japan data set. Future ice cores might extend the Mount Logan record back further. The data presented here could be useful for long term hydrologic and agricultural planning purposes.

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