Mid-Latitude Cyclones Climatology over Caspian Sea Southern Coasts – North of Iran

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Abstract

The southern coasts of Caspian Sea is subject to synoptic/mesoscale weather systems ranging from locally enhanced sea breeze formation and small local front systems to synoptic scale cyclones. The intensity and structure of these weather systems cover a wide spectrum, which include cold-cored weather systems from the Siberian highs as well as warm-cored mid-latitude cyclones, hereinafter referred to as Westerly systems. Heavy coastal rain and combined effects of wind and sea state accompanying these cyclones threaten life and property in the southern coasts of Caspian Sea. This study presents climatology of cyclones over the southern coasts of Caspian Sea covering a ten year period 1996-2005. Altogether 57 cyclones were formed during the ten year period. A noticeable seasonality is observed in evolution of cyclones over the entire Caspian region, a majority of the 57 cyclones (73.7%) were developed during winter and fall seasons while the remaining (26.3%) occurred during spring and summer seasons. Most of the cyclones were of low intensity, out of 57 cyclones observed during the ten year period 16 (28%) were deep depressions and 24 (42.1%) were cyclonic storms. Altogether 5 super cyclonic storms were observed during the period, out of which 4 were observed during winter and fall seasons. Mid-tropospheric, large-scale processes and local features were responsible for the initial development of all weather systems. The Mediterranean Sea plays a significant role in cyclogenesis and propagation of the systems the Caspian region. Further, a Mediterranean cyclonic system formed during October 2001 was studied in detail using backward trajectory Lagrangian model: Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT). The HYSPLIT model outputs confirmed the observed synoptic features for the weather system of the case study.

Key Words: High-Pressure Systems, Mid-Latitude Cyclones, Moisture Convergence, ECMWF, APHRODITE, HYSPLIT Model, North of Iran

Introduction

Southern coasts of Caspian Sea *i.e.* a distance between the Alborz mountain range and Caspian Sea itself, is considered as the smallest climatic area of Iran (Alijani, 1997). The Caspian Sea as the world's largest lake plays a significant role in the climate of the northern areas of Iran. It is often subject to synoptic and mesoscale weather systems that threaten life and property at sea or on the coast. These systems range from locally enhanced sea breeze formation (Khoshhal, 1997) and small local front systems near the southern coasts (Khalili, 1971), to synoptic scale trough and westerly cyclone (Moradi, 2006). They, however, vary in intensity and structure across a spectrum that includes both weak and intense cold-cored systems from Siberian high to warm-cored mid-latitude cyclones called as westerly systems. Westerly systems are so named particularly in autumn season, because subtropical cyclones can have warm-cored centers with spiral convective rain bands over the southern coasts of Caspian Sea. In this study we concentrate on cyclones in Caspian Sea that threaten life and property as a result of heavy coastal rain (above 50 mm) or the combined effects of wind and sea state. A ten-year climatology of Caspian Sea cyclones from 1996 to 2005 in five

weather stations reveals a range of the heavy rainfall events. The study has three objectives. The main objective is to present a preliminary climatology of southern Caspian Sea cyclonic systems and mapping their tracks over the area north of 35.5° N, south of 38.5° N, west of 55° E and east of 48° E for the period 1996 to 2005. The next objective is to study the Westerly high-pressure system of October 2001, on the basis of a synoptic analysis of life cycle of this particular storm from its beginning as a weak high in the Caspian Sea, to its landfall and a heavy rainfall event over land. The third objective is to bring out the backward trajectories on the mid-latitude cyclone, employing the *Hybrid-Single Particle Lagrangian Integrated Trajectory* (HYSPLIT) model, which was developed by NOAA ARL.

Data and methodology used for case study

In order to examine the selected storm (cyclone) over the southern coasts of Caspian Sea synoptically, different data sources *i.e. National Centers for Environmental Prediction/National Center for Atmospheric Research* (NCEP/NCAR) reanalysis data (Kalnay *et al*., 1996), the *European Centre for Medium-Range Weather Forecasts* (ECMWF), *Highly-Resolved Observational Data Integration Towards Evaluation of the Water Resources* (APHRODITE), and *National Oceanic and Atmospheric Administration – Air Resources Laboratory* (NOAA–ARL) ranging from hourly to daily variables at multiple levels of the atmosphere was utilized. In synoptic analysis, however, we considered the following variables: surface and upper pressure levels, relative humidity, zonal and meridional wind components, convective available potential energy, precipitable water, and hourly and daily total precipitation. The meteorological charts then produced using *Grid Analysis and Display System* (GrADS) software (Doty, 1996). Additionally, the HYSPLIT model, developed by NOAA ARL, was used to compute the backward trajectories discussed in this study (Draxler and Rolph 2011; Rolph 2011). Each backward trajectory was computed for 48 hour duration with three ending levels (500, 1500 and 5000 m above ground level). The meteorological input for the trajectory model was the reanalysis dataset. HYSPLIT uses archived 3-dimensional meteorological fields generated from observations and short-term forecasts (Stunder, 1997). Furthermore, the hourly and daily precipitation data used for the selected cyclone, gathered from ECMWF and APHRODITE's water resources project (Yatagai *et al*., 2009), respectively. Details of the data sets used for the analysis is shown in Table 1.

Table 1 Details of different data sets used for the cyclone under study in October 2001

Data Sources	Variables/Model	Units	Temporal Coverage	Spatial Coverage	Levels
NCEP/NCAR	geopotential height	m	4-times daily and daily	2.5 x 2.5 degree grid	multiple level
	precipitable water	kg m^{-2}	4-times daily	″	surface
	relative humidity	%	″	″	″
	sea surface pressure (SLP)	hPa	″	″	″
	u and v wind components	m s^{-1}	″	″	″
	air temperature	˚C	″	″	″
	relative vorticity	10^{-5} s^{-1}	″	″	″
	moisture convergence*	g kg^{-1} s^{-1}	hourly	″	″
ECMWF	Convective Available Potential Energy (CAPE)	J kg^{-1}	″	0.5x0.5 degree grid	″
	total of precipitation	mm	″	″	″
APHRODITE	total of precipitation	mm	daily	0.25x0.25-degree grid	″
NOAA ARL	HYSPLIT backward trajectory	AGL	hourly	360 x 180 at 1 degree	multiple level

*Moisture convergence was computed with GrADS software using 7 variables: relative humidity, air temperature, vapour pressure, mixing ratio, u and v wind components and dew point temperature.

Summary

A climatology of cyclonic systems affecting the southern coasts of Caspian Sea bounded by the area, north of 36˚N, south of 38˚N, west of 55˚E and east of 48˚E, based on the systems formed during 1996-2005 has been

developed. The climatology includes severe cyclonic systems with at least one analyzed closed SLP contour in addition to rainfall falling within threshold criteria (above 50 mm) at selected coastal observing stations. Stations located in the west of the Caspian region received the extreme rainfall during late summer and early autumn seasons. On the contrary, the eastern stations in the Caspian region received the severest rainfall during winter season. Approximately 73.7% of the systems (42 out of 57), occurred from August through December months, and 26.3% of the systems (15 out of 57) took place from January through May over the entire Caspian region. As well as most cyclones occur within the categories of 1 and 2 with 16 (28%), and 24 (42.1%) as deep depressions and cyclonic storms, respectively. Meanwhile, during the cold seasons, 4 super cyclonic storms (classified as fifth category) also took place within a ten-year period over the Caspian region. Mid-tropospheric, large-scale processes and local features were responsible for the initial development of all systems. Generally, the quantity of precipitation in the eastern stations was less than one third of the amount in the western stations, which means that the total precipitation is decreased gradually from west to east in the Caspian region. During the warm-months, the daily tracks of cyclones were largely shifted to north Caspian Sea due to the predominance of sub tropic high pressure.

Therefore, not only the frequency of the cyclones over Iran, compared to cold seasons, was considerably decreased, but also rainfall events in summer were mostly limited to the Caspian region. On the whole, the Mediterranean Sea plays a significant role in cyclogenesis and transferring them to the Caspian region. The detailed synoptic analysis of the October 2001 high-pressure system over the Caspian Sea has been described. On the basis of the analysis of the system up to its landfall, we found that the average wind speed was more than 10 ms^{-1} and 24-h total rainfall exceeded 220 mm mainly in Bandar-e-Anzali station. The positive vorticity, which exceeded $7X10^{-5}s^{-1}$ over the region, was quite in a good agreement with those of geopotential height fields, as positive vorticity at 500 hPa is associated with cyclones or storms at upper levels, and tend to coincide with troughs in the geopotential height field. Areas of persistent moisture convergence over the southern coasts of Caspian Sea were favored regions for the storm development, since other factors *e.g.*, instability were quite favorable. Generally, there are good agreements both between the amounts of the precipitable water and CAPE values as well as moisture convergence and wind fields during the study period over the southern coasts of Caspian Sea, and the HYSPLIT model outputs confirmed the observed synoptic features for the system of October 2001discussed as case study.

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