Seasonal and long term evolution of oceanographic conditions based on year-around observation in Kongsfjorden, Arctic Ocean

Article in Polar Science · November 2016
DOI: 10.1016/j.polar.2016.11.001

CITATIONS
0

READS
20

4 authors:

Noufal k k
National Institute of Ocean Technology
2 PUBLICATIONS 1 CITATION

S. Najeem
National Institute of Ocean Technology
8 PUBLICATIONS 7 CITATIONS

G. Latha
Naitonal institute of ocean technology
78 PUBLICATIONS 219 CITATIONS

Ramasamy Venkatesan
National Institute of Ocean Technology
137 PUBLICATIONS 1,305 CITATIONS

Some of the authors of this publication are also working on these related projects:

Seasonal and long term evolution of oceanographic condition in Kongsfjorden, Arctic Ocean View project

All content following this page was uploaded by Noufal k k on 17 November 2016.
The user has requested enhancement of the downloaded file. All in-text references underlined in blue are added to the original document and are linked to publications on ResearchGate, letting you access and read them immediately.
Seasonal and long term evolution of oceanographic conditions based on year-around observation in Kongsfjorden, Arctic Ocean

K.K. Noufal*, S. Najeem, G. Latha, R. Venkatesan

Ocean Acoustics, National Institute of Ocean Technology, Velachery-Tambaram Main Road, Pallikaranai, Chennai 600 100, India

ARTICLE INFO

Article history:
Received 5 April 2016
Received in revised form 2 October 2016
Accepted 2 November 2016
Available online xxx

Keywords:
Temperature
Salinity
Current
Buoyancy frequency

ABSTRACT

Recently measured oceanographic data (Temperature, Salinity and Current) from July 2014–July 2015 in the Kongsfjorden marine environment has been used for studying the seasonal hydrographic variation. Seasonal fluctuation in salinity and temperature for the entire period of observation in different seasons matches with the previous year records. Overall trend of the surface zonal current pattern is towards west compared to eastward flowing bottom current. In order to study stratification and mixing during different seasons (summer and winter), density and buoyancy frequency were derived from temperature and salinity. The observed range difference in the buoyancy frequency clearly supports stratification in summer and mixing during winter seasons. The energy level variation in spectral analysis of temperature also indicates the seasonal variation in stratification. The comparison of temperature with previous year records since 1969 clearly shows a warming trend, which indicates the impact of climate change in Kongsfjorden. Present study confirms the requirement of year around observation in Kongsfjorden, for seasonal as well as long term climate change monitoring studies.

1. Introduction

Arctic Ocean shows a warming nature for the past few decades (Polyakov et al., 2007; Zhang, 2005). North Atlantic Ocean contributes relatively warm and salty water to the Arctic and plays an important role for the thermal balance of Arctic Ocean (Gerdes et al., 2003; Schauer et al., 2002). Initially this warm Atlantic Water (AW) enters the Norwegian Sea through the Faeroe-Shetland channel as the Norwegian Atlantic Current. Part of this continues to flow towards east on the Barents Sea shelf, while another part, West Spitsbergen Current (WSC) flows towards Spitsbergen. WSC is a major mechanism to carry relatively warm and saline water to the Arctic through the eastern side of Fram strait (Gascard et al., 1995; Rudels et al., 1999; Haugan, 1999; Schauer et al., 2004). Based on a recent volume budget study, majority of the volume flux of Atlantic water is transmitted by WSC (Schauer et al., 2008; Smedsrud et al., 2010) and it is also responsible for the major heat transport towards the central Arctic (Aagaard and Greisman, 1975; Walczowski and Piechura, 2007). WSC splits into two parts at a latitude of approximately 79.5 N, where one move towards north-east named as Svalbard branch and supply major fraction of AW to the Arctic Ocean (Aagaard et al., 1987; Bourke et al., 1988; Manley, 1995; Rudels et al., 1999), while the other, Yermak branch move north westward and loss its AW characteristics rapidly (Manley, 1995). The Barents Sea branch also carries warm water to the Arctic, even though its heat capacity is very low compared to WSC (Rudels et al., 1999; Haugan, 1999). In addition to that, Bering Strait contributes heat to the Arctic Ocean from the Pacific and strongly influence ice melting (Steele and Ermold, 2004; Woodgate et al., 2006; Shimada et al., 2006). The Barents Sea branch also carries warm water to the Arctic, even though its heat capacity is very low compared to WSC (Rudels et al., 1999; Haugan, 1999). In addition to that, Bering Strait contributes heat to the Arctic Ocean from the Pacific and strongly influence ice melting (Steele and Ermold, 2004; Woodgate et al., 2006; Shimada et al., 2006).

Atlantic, Arctic and glacial waters interacts in the Western Spitsbergen Shelf (WSS) and its effect reflects in the West Spitsbergen fjord waters (Cottier et al., 2005; Nilsen et al., 2008; Pavlov et al., 2013). Kongsfjorden is a glacial fjord in the Arctic (Svalbard) with strong influence from both Atlantic and Arctic water masses. This is a major fjord in the western Coast of Spitsbergen and treated as the mirror of Arctic climate variability due its varying hydrographic nature caused by both Atlantic and Arctic water masses. The fresh water supply, water temperature and their seasonal patterns to the fjord strongly influences the water mass characteristics and cause impact on stratification with a considerable variation in hydrographic nature (Pickard, 1961; Cade, 1970; Svendsen, 1981; Farmer and Freeland, 1983). A descriptive study about the marine ecosystem and the physical environment of Kongfjorden was...
A study on seasonal change of fjord environment was conducted by Cottier et al., 2005 regarding water mass formation in winter due to convection and sea ice formation and the frontal instability in summer leading to the intrusion of Atlantic water. The initial hydrographic change starts at the mouth opening to the sea and the inner head, where strong fresh water supply is present. The melting of glaciers, change in run-off pattern and the water from Atlantic as well as Arctic cause changes in the fjord through exchange process. One interesting characteristic regarding the Kongsfjorden hydrography is that, it changes from Arctic dominant in winter to Atlantic dominant in summer (Saloranta and Svendsen, 2001). Thus year around monitoring in Kongsfjorden provide a better idea about the seasonal hydrographic changes and long term monitoring in Kongsfjorden is a crucial step for climate change studies in Arctic. Fjords are commonly considered as a link between the ocean and land through cross-shelf exchange and the dynamics of fjord actively respond to the variation in ocean-land-atmospheric conditions. Hence these systems are sensitive indicators of climate change phenomena (Cottier et al., 2005; Nilsen et al., 2008). Oceanographic and Meteorological time series gives better idea about the fjord climatology and provide strong back ground knowledge for regional climate studies. Oceanographic time series can also be used for research related to marine ecology, sea ice coverage and regional climate. Acoustic Doppler Current Profiler (ADCP) time series observation can be used for sea ice coverage estimation (Hyatt et al., 2008) and horizontal current velocity from ADCP helps to find the seasonal variation of ice cover in the surface layers of the fjord (Wallace et al., 2010). Correlation study of current with oceanographic time series such as Temperature, Current, Photosynthetically Active Radiation (PAR) and fluorescence provide insights into the vertical migration of zooplankton in different seasons (Wallace et al., 2010). This study focuses on stratification and mixing in the Arctic shelf water of Kongfjorden in different seasons using hourly sampled one year CTD sensor data and later on the comparison of observed temperature with available previous year records. The current pattern and its seasonal variation using ADCP time series were also analyzed. Density and buoyancy frequency were derived using both the temperature and absolute salinity, to study the seasonal variation. The spectral analysis of temperature clearly indicates the seasonal hydrographic variation. Finally, in order to study the long term evolution of temperature in Kongsfjorden, observed water temperature from previous records for summer, since 1969 was used.

2. Study area

An autonomous sub surface buoy with 6 CTD sensors at different positions was deployed at 200 m depth from July 2014–July 2015 in the marine environment of Kongsfjorden. The location is around 4 km away from the Ny-Ålesund research station and the schematic is shown in Fig. 1. Oceanographic condition in the fjord is strongly influenced by the nature of current flowing through the Svalbard archipelago. Kongsfjorden is frozen during winter (Svendsen et al., 2002), but open and strongly influenced by ocean during the summer. The semi diurnal tidal component, fresh water runoff and local winds are the main driving forces acting in the upper water masses in fjord system. Seasonal and inter annual variability in fresh water supply significantly affect the hydrographic condition of the fjord. The most important fresh water supply to the Arctic fjords are calving and ablation from glaciers, melting of fast ice, direct precipitation on the fjord surface and land/riverine outflow (Weslawski et al., 1991). Fresh water supply from glacier system influence the fjord circulation and mixing (Matthews and Quinlan, 1975; Matthews, 1981). Collective discharge of fresh waters into the surface layers results in stratification during summer, but in winter homogenization of water masses due to vertical convection initiated by salt ejection and surface cooling leads to mixing.

3. Data and methods

3.1. Oceanographic data

The Earth Science System Organization-National Centre for Antarctic and Ocean Research (ESSO-NCAOR) started continuous monitoring of fjord from 2010 onwards for climate variability studies at different time scales. The first under water multisensory mooring IndARC-I was deployed from 2014 July to 2015 July for one year time series observation with different type of sensors such as CT sensor, Photo synthetically active radiation (PAR) and Acoustic Doppler Current Profiler (ADCP). The moored observatory, designed and developed by ESSO-NIOT (National Institute of Ocean Technology) in collaboration with ESSO-NCAOR was deployed from the Norwegian Polar Institute’s Research Vessel Lance in Kongsfjorden area. In this work time series of temperature and salinity for one year as well as current from ADCP was analyzed and later used to study the seasonal hydrographic pattern such as stratification and mixing in both seasons (summer and winter). Hourly sampled time series CTD sensor data for 6 water depths were collected from a single point mooring system from the station and the depth points were 22, 30, 55, 80, 105 and 140 m respectively. Current data from an upward looking ADCP fixed at 175 m depth in the mooring has been used for the present analysis. The data was collected at every 5 m depth interval and 30 min time interval. The sensor details and specifications for CTD sensor and ADCP are provided in Table 1. In order to study the seasonal variation in stratification; density and buoyancy frequency were derived from temperature and salinity time series. Buoyancy frequency is the frequency at which a vertically displaced parcel oscillates within a stable environment and is an indicator to the stratification strength of the fluid medium (Apel, 1987). TEOS-10 standards for density and buoyancy frequency are used for estimating both parameters at different seasons (McDougall and Barker, 2011).

3.2. Meteorological data

The surface temperature and salinity in Kongsfjorden were affected by the local atmospheric conditions. In order study the evolution of air temperature and precipitation, year around data from Ny-Ålesund weather station has been used. Ny-Ålesund is located at the west coast of Svalbard and established in July 1974. The station measures atmospheric parameters such as precipitation, temperature, snow depths and wind speed (http://www.yr.no/place/Norway/Svalbard/Ny-%C3%85lesund/detailed_statistics.html). The weather station is very near to the study location and shows similar climatic condition as Kongsfjorden (Svendsen et al., 2002). The data from the weather station can be taken to compare with surface oceanographic observations and further for studying atmospheric ocean interaction. Daily averaged air temperature and precipitation is collected from this weather station and its time series corresponding to the observation in the present study is shown in Fig. 2.

3.3. Spectral analysis

Spectral analysis is a frequency domain statistical method, useful to unmask periodic components of the time series. In this study spectral analysis is used to identify the frequency distribution in temperature observation. The study of the energy spectrum provides an estimate of tidal components in different seasons.
(summer and winter). Hourly temperature data from all available depths (six points) is subjected to FFT (Fast Fourier Transform) analysis (Cooley and Tukey, 1965) and periodogram function in matlab has been used for constructing the spectral estimate plots. Two month time series from summer and winter were taken for studying the seasonal variation in spectral density. The result from the analysis (Current and Temperature) shows higher energy level for summer and the details are given in Section 4.5.3.

### Table 1

Specification of sensors used in the moored buoy system.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensor type</th>
<th>Make/Model</th>
<th>Resolution</th>
<th>Accuracy</th>
<th>Range</th>
<th>Data recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Thermistor</td>
<td>SBE 37-IMP MicroCAT CT(D)</td>
<td>0.0001 °C</td>
<td>±0.002 °C (−5 to 45 °C); ±0.01 (5 to 45 °C)</td>
<td>−5 to 45 °C</td>
<td>1 h</td>
</tr>
<tr>
<td>Conductivity</td>
<td>Conductivity cell</td>
<td>SBE 37-IMP MicroCAT CT(D)</td>
<td>0.0001 S/m</td>
<td>±0.0003 S/m</td>
<td>0-7 S/m</td>
<td>1 h</td>
</tr>
<tr>
<td>Ocean current</td>
<td>Acoustic Doppler Current Profiler</td>
<td>Teledyne RD Instrument (150 kHz)</td>
<td>Velocity: 0.1 cm/s</td>
<td>Velocity: ± 5 mm/s</td>
<td>0-25 cm/s</td>
<td>30 min</td>
</tr>
</tbody>
</table>

4. Results and discussion

4.1. Temperature

The temperature range of high latitude Arctic water is relatively very low compared to low and mid latitude oceanic waters (Huyer, 1977; Shetye, 1984). The measured temperature shown in Fig. 3a is almost matching with previous year observation from the same
location, especially during summer and winter months. The observed temperature range for the entire year is \(-1.6\text{ to } 6.98\,^\circ\text{C}\). The maximum temperature of 6.98\,^\circ\text{C} is observed in August and the minimum value of \(-1.6\,^\circ\text{C}\) in February. The water column temperature shows negative gradient, positive gradient and almost uniform for the entire period of observation. Relatively strong negative gradient (decrease in temperature with regard to depth) is observed during July–September and changes into positive gradient (increase in temperature with regard to depth) in October–November. December to April shows almost uniform value for the entire water column with minimum temperature range.

4.2. Salinity

Arctic waters exhibit low saline nature especially in surface than tropical waters due to fresh water supply and very low evaporation rate at high latitude. Strong fresh water supply in summer generally enhances the low saline nature in the surface layers (Svendsen et al., 2002). The observed salinity range is 34.1–35.1 with a slight positive vertical gradient found in the entire year of observation as shown in Fig. 3b. Surface layer shows rapid and sharp fluctuation in salinity during July–November 2014 and May–July 2015. Very low fluctuation in salinity is observed in the period of November–May for both the surface and bottom layers. Signal of low saline water is observed in the end of August and middle of September. Ny-Ålesund weather station observed normal rain during August 28 and reaches up to 11.1 mm on August 29. Relatively heavy precipitation of 11 mm and 32.6 mm was reported on September 13 and 14 respectively. The fresh water supply from precipitation might have developed a low salinity condition at surface and slowly extended to deeper layers in the next days. Normal precipitation level observed during summer is less than 5 mm, thus the observed 32.6 mm of precipitation could strongly influence the salinity shift. Down fjord wind induce changes in the vertical salinity distribution in Kongsfjorden and similar change in salinity as shown in Fig. 3b was reported earlier (Ingvaldsen et al., 2001; Cottier et al., 2005).

4.3. Density

Density is calculated from salinity and temperature using TEOS-10 standards (McDougall and Barker, 2011). The derived density using standard oceanographic equation is shown in Fig. 3c for the entire period of one year. The observed density range is 1026.7–1028.7 kg/m\(^3\) and gives different seasonal signature during summer and winter. Compared to winter, relatively high density gradient is observed in summer and this seasonal variation indicates stratification and mixing during both seasons. Apart from density estimation, buoyancy frequency estimation and spectral analysis of temperature are carried out to study the seasonal stratification.

4.4. Currents

Kongsfjorden surface currents are strongly influenced by wind (Svendsen et al., 2002) and towards the mouth and shelf, current pattern are more complex (Cottier et al., 2005). The current pattern (zonal and meridional currents) for the entire year is shown in Fig. 4.
Abnormal peaks were removed from the data by careful quality checking and filtering. Both zonal and meridional currents were filtered by using 25 h moving average, which removed tidal, inertial and other high frequency currents and the rest low frequency currents are shown in Fig. 4 b and d. Previous year ADCP observation in the middle basin of Kongsfjorden shows range for current around −10 to 10 cm/s (Svendsen et al., 2002). Moving average for zonal and meridional current at surface (5 m) and bottom (150 m) for the entire year of observation is shown in Fig. 5. Currents are found to be weak within a range of 0.15 to 0.15 m/s.

The time-averaged velocity for each month is found to be negative for surface zonal current and positive for bottom zonal current, which indicates that the direction of surface currents during most of the months is towards west and bottom current is towards east. The surface meridional current is found to be positive and bottom current is negative, which indicates surface currents are northward and its bottom current is southward during most of the months. Zonal surface currents are strong during January–April and meridional surface currents are strong during February and April as shown in Fig. 5. In both currents (zonal and meridional) surface and bottom flow pattern is opposite in direction in most of the months of observation. Most prominent wind direction throughout the year is from east/south-east around 110° (Maturilli et al., 2013) and it is directed from head of the fjord towards its mouth (Svendsen et al., 2002). Kongsfjorden is aligned from south-east to north-west, and east/south-east wind carry water towards the west and north, so the surface currents shows a common trend in flow towards west for zonal component and towards north for meridional component as shown in Fig. 5.

Surface currents are found to be strong during September–October, January–February and March–April but relatively weak during May–July. May–June experience a relatively weak wind speed of less than 5 m/s (Ito and Kudoh, 1997; Maturilli et al., 2013). Wind pattern strongly influence the surface current in the location and Kongsfjorden is windy in winter and relatively less windy in summer (Ito and Kudoh, 1997). Local orography also affects the main wind direction in Ny-Ålesund. A frequently observed wind direction is around 220° related to katabatic outflow with less than 5 m/s from south westerly direction (Maturilli et al., 2013). Wind pattern strongly affect the surface current, thus wind intensity and direction enhances the westward and northward flow of current (out of fjord) and it is reflected in Fig. 5.

4.5. Seasonal variation in oceanographic parameters

4.5.1. Summer

The observed AW inflow to the Kongsfjorden has seasonal and year to year variation (Svendsen et al., 2002; Cottier et al., 2005;
Willis et al., 2007; Hegseth and Tverberg, 2013). Maximum content of AW is observed in late summer and intrusion of Atlantic water in midsummer leads to shift in hydrography and increase in the heat content of fjord as well as shelf waters (Cottier et al., 2005). Atmospheric temperature range of 6.1 °C to −5.7 °C (Fig. 2) observed from July 23 to the end of September but water temperature range was around 4.0–6.9 °C (Fig. 3) at sub surface layers, which indicates the inflow of AW to the fjord during summer period. Fjord climate is comparable with continental climate during summer (Svendsen et al., 2002), hence measured atmospheric temperature in the weather station can be used to compare with the observed temperature in surface layers. Temperature stratification is clearly observed in summer with a strong negative gradient. Temperature stratification is observed throughout the summer months (July 24–September 24) in the water column within a range of 3–6.5 °C. Salinity also shows stratification nature with slight positive downward gradient with 1 unit difference between surface and bottom layers. Temperature and salinity stratification were strongly influenced by the amount of fresh water discharges to the fjord environment especially during summer. As mentioned above buoyancy frequency (N) is an indicator for stratification and Fig. 6a represents the estimated buoyancy frequency in summer months. The surface layer shows higher level of buoyancy than bottom and the observed range of 0.005–0.025 rad/s indicate strong stratification in the water column.

4.5.2. Winter

Sea ice formation, spring bloom developments and presence of winter zooplankton were strongly affected by AW water inflow to the fjord (Cottier et al., 2005; Willis et al., 2007; Hegseth and Tverberg, 2013). The observed atmospheric temperature in Ny-Ålesund weather station during 2014/2015 winter period (December–February) is −15 °C to −22 °C and this atmospheric condition strongly support the cooling of surface water in the study location. Surface cooling of the homogeneous saline water column leads to vertical convection and results in temperature decrease in the whole water column (Tverberg et al., 2007). During ice formation, the surface layers of the fjord receive dense brines and (Rudels et al., 1990) this highly cooled saline solution enhances the sinking effect. However, the recent year studies (Hegseth and Tverberg, 2013; Nahrgang et al., 2014; Luckman et al., 2015) reveals the lack of ice concentration and freezing point temperature in the water column, which may due to warm Atlantic water inflow to the fjord (Tverberg et al., 2007; Hegseth and Tverberg, 2013). Both salinity and temperature shows a well-mixed pattern during winter. Estimated buoyancy frequency range is 0.0005–0.005 rad/s during winter, which is less than summer and shown in Fig. 6b, hence it strongly support the mixing nature and weak stability during winter.

4.5.3. Spectral analysis of temperature

To estimate the frequency distribution in temperature observation, spectral analysis was carried out. Spectra show peak at semi-diurnal tidal frequencies, mainly at M2 frequency (0.0806 cph) as shown in Fig. 7. Peaks are observed in summer and they are found to be weak during winter season. Peaks are maximum at surface depths as shown in Fig. 7a, b, c. In both seasons, internal tide energy is weak at bottom depths, which can be observed in Fig. 7d, e, f based on missing peak of M2 frequency component. During winter the water column is well mixed, thus the peak for M2 tidal component was found to be weak. The seasonality of internal tide variability can be attributed to the stratification changes in both seasons.

4.6. Comparison of water temperature with previous observations

Hydrographic monitoring of the Kongsfjorden was initiated since 1935 onwards (Tverberg et al., 2007). Most of the observation took place in summer and spring periods such as March–May, June–July, August–September and very few observations were made in winter periods. According to the previous records of temperature in summer (August–September) till 1980, surface water (0–50 m) experience average temperature range of 2–4 °C and around 0 °C (100–300 m) for bottom. After 1985 both surface and bottom temperature increased into the range of 4–5 °C and 2–4 °C respectively for most of the years until 2007. Warming due to WSC clearly reflected in both temperature and salinity of Kongsfjorden for 1995–2007, because of the warm-saline water inflow of Atlantic waters to the fjord (Tverberg et al., 2007). The observations in April–September 2002 from the northern side of Kongsfjorden, shows the range of surface temperature from −1.8–6 °C and bottom temperature within the range

Fig. 5. 25 h moving average for zonal and meridional current at surface (5 m) and bottom (150 m).
of $-1.8$ to $-4 \degree C$ (Cottier et al., 2005). In another study based on six months (October 2005–March 2006) observation of temperature, ocean-atmospheric interaction in Kongsfjorden with wind generated upwelling and winter cooling was reported (Cottier et al., 2005).
Their six months time series with one hour resolution shows temperature ranging from $-1$ to $5^\circ$C. Observation of temperature for the entire water column from September 2005 to August 2008 shows intra and inter annual variability (Hegseth and Tverberg, 2013). The coldest temperature observed during that period was $-1.4^\circ$C in January 2006 and warmest was $7.9^\circ$C in August 2007. In a very recent study based on observations from January 2013 to July 2014, clearly indicates ice-free surface in Kongsfjorden (Nahrgang et al., 2014; Luckman et al., 2015).

Previous year observations clearly indicates strong inter and intra annual variability of water column temperature in Kongsfjorden. In order to compare and analyze the evolution of surface water temperature (averaged over first 50 m) in summer with present observation, previous year records for August–September since 1969 has been taken and the observations are shown in Table 2. In general Kongsfjorden experience a gradual warming tendency since 1969. In order to understand the warming in Kongsfjorden, a linear regression analysis $(T = A \times (\text{year} - \text{year_0}) + B)$ has been carried out for temperature since 1969 (year_0) based on previous observations. Regression analysis has been carried out and the fitted line with temperature data points (August–September) is shown in Fig. 8. The values of constant and variance in regression analysis are given in Table 3. Despite the limited data points, temperature shows an increasing trend for the past 46 years. Observed temperature in the surface layers for Kongsfjorden almost doubled since 1969 which clearly indicates the warming trend. Continuous monitoring of temperature profile in future can be used for estimating the latest trends in temperature evolution. Arctic experience solar heating in the surface during May–June and surface water starts to lose heat to the atmosphere during October, which results in cooling (Hegseth and Tverberg, 2013). Heating and cooling due to solar radiation is reflected in the surface waters for the corresponding period of observation. Thus, time series observations in Kongsfjorden provide useful knowledge for the seasonal as well as climate change monitoring studies.

### Table 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Temperature (°C)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>August</td>
<td>2.8</td>
<td>Tverberg et al., 2007</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>August</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>August</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>August</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>August</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>August</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>August</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>August</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>August</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>June</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>June</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>June</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>June</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>4.5</td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusion

Time series of temperature, salinity and current were collected using a single point mooring system from Kongsfjorden in the Arctic Ocean. The data is analyzed for finding the seasonal variation in measured oceanographic parameters and the present observation in temperature is compared with previous year records. Seasonal fluctuation in temperature clearly matches with the previous year records. Salinity shows normally consistent trend throughout the year except for a few days in summer, due to heavy rainfall and precipitation. Principal observation explained in this work is the shift in hydrographic pattern during different seasons. The seasonal variation in freshwater input creates a very stable stratification in summer and it weakens in winter. Stratification nature in summer is caused by the fresh water discharge such as precipitation, river
run off, glacier ablation and ice melt. During winter strong surface cooling of the homogeneous saline water column enhance the sinking effect with vertical convection leading to a well mixed water column. The energy level variation in spectral analysis of temperature clearly indicates the seasonal variation in stratification. The observed range difference in the buoyancy frequency for summer and winter also underline the seasonal hydrographic shift. Comparison of temperature with previous year records since 1969 clearly shows a warming trend, which indicates the impact of climate change in Kongsfjorden. Time series data with high resolution for oceanographic parameters such as temperature, salinity and current are important for the understanding of inter and intra annual variability in the location. The present study demonstrates seasonal hydrographic changes and its atmospheric influence based on year around observation rather than on episodic observations.

Acknowledgement

Authors express their sincere thanks to Director of National institute of Ocean Technology (NIOT) Chennai, for the facilities provided for this study. We would also like to thank staff from National Centre for Antarctic and Ocean Research (NCAOR) and Norwegian Polar Institute (Norway) for providing ship time for the Research Vessel Lance and technical support by the Crew. Finally, we would like to thank the two anonymous reviewers for their valuable scientific comments and editorial suggestions.

References


Table 3
The values of constant and variance in linear regression analysis.

<table>
<thead>
<tr>
<th>Area</th>
<th>Years</th>
<th>N</th>
<th>A</th>
<th>B</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kongsfjorden</td>
<td>1969–2015</td>
<td>43</td>
<td>0.056</td>
<td>2.936</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Fig. 8. Linear regression analysis of surface temperature since 1969.
Maturilli, M., Herber, A., Langlo, K.G., 2013. Climatology and time series of surface
Nahrgang, J., Varpe, O., Korshunova, E., Muzina, S., Hallanger, I.G., Vieweg, I.,
Berge, J., 2014. Gender specific reproductive strategies of an Arctic key species
(Boreogadussaidaa) and implications of climatic change. PLoS One 9, e98542.
by ice and brine production: the inter annual variation of Atlantic water in
Warming of Atlantic water in two west Spitsbergen fjords over the last century
Pickard, G.L., 1961. Oceanographic features of inlets in the British Columbia main-
Polyakov, I., Timokhov, L., Dmitrenko, I., Ivanov, V., Simmons, H., Beszczyńska, M.A.,
Dickson, R., Fahrbach, E., Fortier, L., Gascard, J.C., Håkansson, H., Hollemann, J., Penny, N.H.,
Hansen, E., Mauritzén, C., Piechura, J., Pickart, R., Schauer, U., Walczowski, W.,
Steele, M., 2007. Observational program tracks Arctic Ocean transition to a
Rudels, B., Larsson, A.M., Sælseth, P.I., 1990. Stratification and water mass forma-
tion in the Arctic Ocean: some implication for the nutrient distribution. Pro-
cedings of the Pro Mare symposium on polar marine ecology Trondheim. Pol.
Res. 10 (1), 19–31.
the Fram strait, oceanic heat transport from three years of measurements.
J. Geophys. Res. 109, C06026.
Variation of measured heat flow through the Fram strait between 1997 and 2006.
In: Dickson, R.R., et al. (Eds.), Arctic-Subarctic Ocean Fluxes: Defining the Role
Shetye, S.R., 1984. Seasonal variability of temperature field off the south-west coast
Shimada, K., Kamoshida, T., Boh, M., Nishino, S., Carmack, E., McLaughlin, E.,
Zimmermann, S., Proshatskaya, A., 2006. Pacific ocean inflow: influence on
33, L08625.
Lett. 31, L24408.
Svendsen, H., 1981. A Study of Circulation and Exchange processes in the Ryfylkef-
Svendsen, et al., 2002. The physical environment of Kongsfjorden—Krossfjorden, an
Tverberg, V., Frank, Nilsen, F., Goszczko, I., Cottier, F.R., Svendsen, H., Gerland, S.,
Water Masses Compared to Historical Data, 8th Ny-Ålesund Science Managers
Committee(NySMAC), At Cambridge, UK 16–17, Volume: Polar Net Technical
Report, pp. 40–43.
Lett. 34, L19608.
Comparison of zooplankton vertical migration in an ice-free and a seasonally
ice-covered Arctic fjord: an insight into the influence of sea ice cover on
Woodgate, R.A., Aagaard, K., Weingartner, T.J., 2006. Inter annual changes in the
Zhang, J., 2005. Warming of the Arctic ice-ocean system is faster than the global