

## Post-tsunami changes in littoral environment along southeast coast of India.

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### Abstract

The 26<sup>th</sup> December 2004 Indian Ocean tsunami devastated coastal regions of the Indian subcontinent. Andaman and Nicobar Islands, coastal stretches of Tamil Nadu, Andhra Pradesh and Kerala were the most affected regions of India. Changes in the beach profiles, long shore currents, breaking wave characteristics in the surf zone at selected locations along the Tamil Nadu coast were studied during January, April, October 2005 and January 2006. Long shore sediment transport rates were estimated from the observed parameters. Studies were carried out earlier (1995-96 and 1998) to understand the coastal environment over one year cycle in the study region. The post-tsunami observations were compared with the earlier studies to establish the variations in the littoral environment and to ascertain the normalcy of the littoral environment in the post-tsunami scenario. From the changes in the beach profiles, shoreline is observed to recede by about 20 m and built up of backshore by about 0.5 m at most locations. Observations from the field investigations and comparisons with earlier studies along this stretch of the coastline indicate that the coastline is yet to return completely to normalcy.

Keywords: Indian Ocean tsunami, Tamil Nadu coast, beach profile, long-shore sediment transport, littoral observations.

## 1.0 Introduction

An earthquake of magnitude 9.3 on Richter scale occurred on 26<sup>th</sup> December 2004 off Sumatra island of Indonesia, with its epicenter located at shallow depths of seabed at 3.316°N, 95.854°E off the coast of Sumatra in the Indonesian Archipelago at 00:59 hrs GMT (06:29 hrs IST). This earthquake occurred in the vicinity of seismically active zone, close to Sunda Trench in water depth about 1300 m with its hypocenter located relatively at about 30 km below the ocean floor (Chaddha et al, 2005). This earthquake triggered a set of tsunamis that traveled in the open ocean and devastated coastal regions in the Indian Ocean, Bay of Bengal and Arabian Sea. On the Indian subcontinent, Andaman and Nicobars Islands, coastal stretches of Tamil Nadu, Andhra Pradesh and Kerala states were the most the affected regions. From the epicenter of the earthquake, around at 500km, the Nicobar Islands were first to be hit by tsunami waves.

Post-tsunami surveys were carried out along the southeast coast of India adjoining the Bay of Bengal by the authors and others primarily to investigate the inundation limits and run-up heights (Chaddha et al, 2005; Jayakumar et al, 2005; Ramanamurthy et al, 2005). Initial survey by the National Institute of Oceanography (NIO) covered the region between Vedaranyam to Chennai in Tamil Nadu (24 locations) (Fig. 1) and at Krishnapatnam in Andhra Pradesh. Details of the surveys carried out by NIO are available in the form of technical reports (Anonymous, 2005; Ilangovan et al, 2005). Further to the initial post-tsunami survey during January-February 2005 (Phase-1), investigations on beach profiles and littoral environmental observations at eleven locations were carried out during April 2005 (Phase-2),

October 2005 (Phase-3) and January 2006 (Phase-4). These locations are Uroor Alcott Kuppam in Chennai, Mahabalipuram, Periyakalpet, Thevanampattinam near Cuddalore, Nanjalingampettai, Poompuhar, Tarangambadi, Karaikal, Nagore, Samanthanpettai near Nagapattinam and Velangani. The beach at Uroor Alcott Kuppam in Chennai is relatively flat in the backshore region with a steep shoreface. Average height of the backshore with respect to the water line is about 3 m. Heavy breakers are observed in this region. Mahabalipuram beach is characterised by a long narrow beach to the south and a rubble mound seawall on the northern side of the study site protecting the shore temple. The shoreface is steep with heavy breakers breaking on the seawall and rip currents were observed in this region. Periyakalpet has a long narrow beach with the backshore elevated about 2 m from water line. Foreshore dunes about 2 to 3 m high are seen to the north and south of the study site. Thevanampattinam, near Cuddalore, has a narrow beach with high dunes along the coast. However the approach road to the beach is devoid of any dune protection to the hinterland. South of this location, a wide beach without any dune is present and this region constitutes the confluence of River Uppanar with the Bay of Bengal. Nanjalingampettai has a narrow shoreface with high backshore dunes about 5 m high. The beach at Poompuhar is elevated about 1 m from the high water line and the backshore is devoid of dunes. A small stretch of the coast is protected with rubble near the structures of archaeological importance. River Cauvery joins the Bay of Bengal about a kilometer south of the study location. The beach at Tarangambadi is narrow with the hinterland elevated by about a meter high from the high tide line. Karaikal beach is a wide unobstructed beach without

any high dunes in the vicinity. River Arasalaru joins Bay of Bengal close to the study site. The beach at Nagore is a wide beach with low foreshore and a flat backshore, but with dunes present both north and south of the study location. The beach at Samanthanpettai near Nagapattinam is low. On both north and south of the study site were long beaches with Nagapattinam port situated about 2 km south. The beach at Velangani is low and very narrow. A river joins the Bay of Bengal about 100 m south of the study location. Except at Nanjalingsampettai and Karaikal, all other locations had structures within 100 m from the water line while beach shacks at Velangani being the most closest (~5 m) to the water line.

Periodical observations on the littoral environment including the beach profiles provide information on the stability of the coastal environment. Such information is essential for effective management of the shoreline. An attempt is made in this manuscript to study the recovery of the coastal profile and the effect of tsunami on the littoral environment through surveys carried out on the beach profiles and littoral environmental parameters over one year period.

## **2.0 Methodology**

Survey on the inundation limits, littoral environmental observations, eyewitness accounts, sedimentological studies and visual observations on tsunami-induced structural damages were carried out during the Phase-1 survey. This survey was carried out following the UNESCO guidelines (UNESCO, 2002) for post-tsunami survey. A brief account on the methodology adopted in determining the inundation limits and run-up heights is presented in Jayakumar, et al (2005). During the Phase-2, Phase-3 and

Phase-4 surveys, beach profiles and littoral environmental observations were measured. During Phase-1 observations, measurements at four locations (Uroor Alcott Kuppam, Periyakalapet, Thevanampattinam and Nanjalingampettai) were carried out during first week of February 2005. However, for ease of representation these were considered as work carried out during January 2005. A temporary benchmark was fixed on the initial cross section profile, taken during Phase-1 survey and the beach profiles till the water line were considered. Profiles were measured using an Automatic Level, a measuring tape and a standard measuring staff, at intervals of 5 m wherever the profile was gentle sloping and at much shorter intervals where the profile was highly varying. These profiles were then compared with each other to ascertain the beach recovery. Seasonal variations in the profile widths and foreshore slopes are studied and compared with earlier studies carried out.

Littoral environmental observations were carried according to Schneider (1981). These observations consisted of breaker wave height, wave period, longshore current velocity and surfzone width. Though the observations are taken arbitrarily on a day for each of the month, they are considered as representative for that month. These parameters are used to estimate the longshore sediment transport, which is required to ascertain the sediment budget of the region. The longshore sediment transport rate was estimated using Walton's equation (Walton and Bruno, 1989),

$$Q = \frac{1290 \rho g H_b w v C_f}{0.78 \left( \frac{5\pi}{2} \right) \left( \frac{v}{v_o} \right)}$$

where,  $Q$  = annual longshore sediment transport rate in  $\text{m}^3/\text{year}$ ,  $\rho = 1025$   $\text{kg}/\text{m}^3$ ,  $g = 9.81$   $\text{m}/\text{s}^2$ ,  $C_f = 0.01$ ,  $H_b$  = Breaking wave height in m,  $w$  = surf zone width in m,  $v$  = longshore current velocity in m/s,  $(v/v_o)$  = theoretical dimensionless longshore current velocity (Longuet-Higgins, 1970).

### **3.0 Results and Discussion**

#### **3.1 Beach profiles**

The tsunami occurred during the northeast monsoon period, when the beach widths are shorter due to removal of sediments from the beach and would be deposited in the surfzone by the monsoon waves. From the sediment deposits observed on the backshore and hinterland, the tsunami appears to have transported large amount of sandy and heavy sediments, onshore during its forward motion, thereby increasing the sediment availability in the surfzone and nearshore regions. And while the tsunami retreated these sediments from the beach region would have been moved offshore. Thus the net quantities of sediments available for rebuilding the beaches depend on net effect of the forward and return motions of tsunami and related sediment movement.

At some places (e.g., Periyakalpet and Thevanampattinam) obvious tsunami water marks on the walls of houses were seen and were confirmed with the eyewitnesses which also revealed that the water was stagnant for some period and then receded slowly. In such cases, the sediments brought in by the tsunami would get deposited onshore and the movement of these sediments offshore would be comparatively low.

The active northeast monsoon during November and December increases the short crested and short period wave climate and the effect is observed on reduction of the beach width and increase in steepness of the foreshore slopes. On retreat of the northeast monsoon there is a gain in beach width due to the action of swells bringing back the offshore deposited sediments. This trend has been observed from monthly beach profiles carried out earlier along the Tamil Nadu coast (Jena, 1997). Onshore winds assist the movement of beach sediments on to the backshore assisting in formation of dunes.

The tsunami had occurred at the end of northeast monsoon period and therefore it is possible that the sediments deposited offshore in the form of bars during the monsoon might have been washed ashore as well as onto the surfzone. The slow retreating tsunami would possibly do not carry these sediments further offshore thereby increasing the availability of more sediments in the surfzone immediately after the tsunami. This 'excess' sediment in the surfzone would help to build a wider beach which has been observed immediately after the tsunami during January 2005. It has been reported that the beaches in Thailand and Indonesia have recovered within weeks immediately after the tsunami (<http://walrus.wr.usgs.gov/tsunami/>). Dalrymple and Kriebel (2005) noted that the beaches in Thailand had recovered dramatically within one month, on the order of a meter/ day. Also there has been a report of post-tsunami beach recovery between groynes in Chennai (Sundar, 2005). On the west coast of India, Kurian et al (2006) report that erosion has prevailed after the tsunami. However, these reports of beach

recovery do not present the changes over an annual cycle and therefore the complete recovery of the coastline is not known.

The beach width variations at different periods of the survey are attributed to the seasonal variations of the coastal climate (Figs. 2 to 13). The foreshore widths, i.e., distance between the low water line and high water line, varied between 10 m and 35 m over the study period. The foreshore slopes were observed to be consistent for all of the beaches with respect to January 2005 profile indicating that the beaches did not undergo major changes during this period. An increased elevation in the berm height for the January 2006 profile is observed at all the locations except at Mahabalipuram. Formation of dunes and wide beaches were obvious during April - October 2005 indicating that the material deposited offshore by the retreating tsunami and the short period monsoon waves have been brought back by the long period waves and deposited on the beach. Karaikal beach was the widest among the surveyed locations and also varied the most in terms of width and height.

Recession of the berm position during January 2006 compared to January 2005 was observed at all the locations except for Karaikal where there was no shift. Mahabalipuram had a maximum berm retreat of 55 m whereas at Karaikal it was absent. However at Tarangambadi an advancement of the berm by about 5 m is seen. Considering the distance of the measuring interval and the beach widths involved, and the swash zone that is more than 5 m, this advancement of 5 m can be considered negligible. There is also an increase in the backshore height indicating that there is recovery of beach material through aeolian transport helping in formation of dune systems. It is observed during April 2005 to January 2006 that the wind



induced transport on the beach is significant thereby increasing the existing dune heights or forming new dunes on the beach. About 20 m recession of the shoreline is seen during January 2006 indicating that the January 2005 profile has not been reached in terms of the beach width, though an increase of backshore height by about 0.5 m is seen at most locations. The receded berm and increased height for the January 2006 profiles could be attributed to the normal seasonal variations of the beach profiles in this region. The recession that is observed compared to January 2005 profile might not be a real recession since it is possible that the January 2005 profiles might be wider due to presence of excess sediments in the surfzone.

### 3.2 Littoral environment:

Breaker wave heights during January 2005 were comparatively higher than January 2006 as well as October 2005 (Table 1). Wave heights during April were mostly similar to that during January 2005. On the northern region of the coast at Mahabalipuram, Chennai and Periyakalpet the waves were relatively higher compared to the waves in the southern region at Nagore, Samanthanpettai and Velangani. Wave periods were higher during October compared to other periods indicating the presence of swells except at Poompuhar where the periods were about 6 s caused due to local wind effects. Wave periods were observed to be higher in the southern region compared to the northern region during January 2006 whereas during January 2005 the wave periods in the southern region were smaller than those on the northern region. During April the wave periods were of similar magnitude along the coast. Breaker waves were mostly parallel to the coast at all the locations otherwise a small inclination about  $2^{\circ}$  to  $5^{\circ}$  with respect to

coast is observed. Plunging and spilling type breakers with occasional spilling breakers were mostly observed.

Longshore currents were predominantly southerly during January 2005 and January 2006 owing to the northeast monsoon winds and waves whereas it was northerly during April and October 2005. Stronger longshore currents were seen during October. Earlier studies during 1995-96 showed similar trend in the longshore currents along this region (Jena et al 1997 & 2001). The daily longshore currents measured at Nagapattinam region during 1998-99 showed that the average longshore current speed was 0.25 m/s and was predominantly towards the north during March-October and towards the south during the rest of the year (Sanil Kumar et al, 2002).

Longshore sediment transport (LST) estimated during 2005-06 using the littoral environmental parameters observed during the field investigations showed an average annual gross sediment transport of  $0.793 \times 10^6 \text{ m}^3$  and a net sediment transport of  $0.18 \times 10^6 \text{ m}^3$  in the northern direction. The net LST was predominantly towards south during April compared to October and January. During January 2006 the net LST was higher than that of January 2005 indicating that the transport is active in the post-tsunami period. LST in the region north of Poompuhar was seen to be higher than that in the southern region (Table 2).

Studies on the estimation of LST using ship reported wave data and CERC formula in Shore Protection Manual (1984) has been reported by Chandramohan et al (1990) and Chandramohan and Nayak (1991). These studies provided an estimate of LST along the Indian and Sri Lankan coasts. Annual gross and net LST rates about  $1.79 \times 10^6 \text{ m}^3$  and  $0.44 \times 10^6 \text{ m}^3$  were

estimated for the coast between Pondicherry and Pt. Calimere (Chandramohan et al, 1990) with a net northward transport. Studies along the coastline between Periyakalpet and Nagapattinam based on littoral environmental observations and Walton's equation indicate annual gross LST of  $0.175 \times 10^6 \text{ m}^3$  in the northerly direction (March to October) and  $0.273 \times 10^6 \text{ m}^3$  in the southerly direction (November to February) and annual net LST of  $0.098 \times 10^6 \text{ m}^3$  in the southerly direction and the annual gross LST was  $0.448 \times 10^6 \text{ m}^3$  (Jena, 1997). Comparison of LST at four locations (Table 3) for the pre and post tsunami indicates that the gross LST during 2006 is higher than that during 1995. Higher gross LST rate means more quantities of sediments in motion thereby indicating that the recovery of the tsunami effect is very much in the process. The annual net LST estimated using CERC formula (Shore Protection Manual, 1984) and the computed wave data in the surfzone, using measured offshore wave data off Nagapattinam, was  $0.006 \times 10^6 \text{ m}^3$  in the northerly direction and annual gross LST was  $0.6 \times 10^6 \text{ m}^3$  (Jena, et al, 2001). Thus it can be seen that the gross LST rates are of same order of magnitude as that of pre-tsunami but the quantities are almost double ascertaining the ongoing processes of recovery of the coastal profile.

#### **4.0 Conclusions**

Due to deposition of sediments in the hinterland by the tsunami and removal of sediments from the beach due to retreating tsunami, the January 2005 profile was lowered in the backshore. Considerable recovery of the beach is seen during April and October in terms of increased foreshore widths and depositions of the sediments in the backshore region which is attributed to the seasonal variation. The recession observed in January 2006 profile

compared to January 2005 profile might not be a real recession in true sense due to the possibility of January 2005 profiles being widened due to presence of excess sediments in the surfzone, brought onshore by the forward motion of tsunami as well as deposited in the nearshore by the slow retreating tsunami. The beach profiles measured over one-year period might not be sufficient enough to comment on the regain of normalcy of the coastline. Continuous and periodic measurements over longer periods are needed to ascertain the coastline regain after tsunami. Drastic changes in the pre and post tsunami longshore-currents and breaking wave characteristics were not observed. LST rates indicated that the quantities in the post-tsunami regime are higher than the pre-tsunami regime at two locations and vice versa at other two locations, indicating that the process of returning to normalcy of the environment is still in progress.

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### Figure Legends

1. Map showing locations of post-tsunami survey
2. Beach profile at Uroor Alcott Kuppam
3. Beach profile at Mahabalipuram
4. Beach profile at Periyakalapet
5. Beach profile at Thevanampattinam
6. Beach profile at Nanjalingampettai
7. Beach profile at Poompuhar
8. Beach profile at Tarangambadi
9. Beach profile at Karaikal
10. Beach profile at Nagore
11. Beach profile at Samanthanpettai
12. Beach profile at Velangani

### Table Legends

1. Monthly variations of littoral environmental parameters at various locations
2. Post-tsunami longshore sediment transport rate ( $\times 10^6 \text{ m}^3 / \text{year}$ )
3. Longshore sediment transport rate comparison between pre and post tsunami periods ( $10^6 \text{ m}^3 / \text{year}$ )



Location	Month	H <sub>b</sub> (m)	T (s)	α <sub>b</sub> (deg)	W (m)	*LSC (m/s)
Uroor Alcott Kuppam	Feb-05	1.26	11	5	40	0.12
	Apl-05	1.5	6	5	80	-0.58
	Oct-05	0.5	10	0	50	0.00
Mahabalipuram	Jan-06	0.5	6	5	100	0.11
	Feb-05	1.75	8	0	30	0.05
	Apl-05	1	8	0	20	-0.42
Periyakalpet	Oct-06	1.2	10	0	80	0.67
	Jan-06	1	8	5	80	0.07
	Feb-05	1.03	9	3	20	0.07
Thevanampattinam	Apl-05	1.2	6	15	10	-0.25
	Oct-06	1.5	10	0	25	-0.46
	Jan-06	1	6	10	100	0.33
Nanjalingampettai	Feb-05	1.19	8	0	20	-0.22
	Apl-05	0.5	4	0	30	-0.20
	Oct-06	1.2	12	2	50	-0.37
Poompuhar	Jan-06	1	8	5	100	0.42
	Jan-05	1.3	10	0	20	-0.13
	Apl-05	0.5	4.5	2	30	-0.42
Tarangambadi	Oct-05	1.2	12	0	150	-0.20
	Jan-06	1	9	2	40	0.54
	Jan-05	0.8	6	0	40	0.25
Karaikal	Apl-05	1	6	5	30	-0.42
	Oct-05	0.8	6	2	60	-0.75
	Jan-06	0.9	5	2	150	0.25
Nagore	Jan-05	0.8	4	0	20	0.17
	Apl-05	0.7	6	1	50	-0.33
	Oct-05	0.4	12	2	80	-0.17
Samanthan pettai	Jan-06	0.5	7	0	150	0.17
	Jan-05	0.75	4	0	1.2	0.25
	Apl-05	0.8	8	0	50	-0.10
Velangani	Oct-05	0.5	12	2	100	0.13
	Jan-06	0.4	11	0	180	0.33
	Jan-05	0.4	3	2	70	0.33
Samanthan pettai	Apl-05	0.4	4	0	50	-0.23
	Oct-05	1	10	0	50	-0.33
	Jan-06	0.5	10	0	100	0.08
Velangani	Jan-05	0.4	3	5	20	0.33
	Apl-05	0.8	6	0	20	-0.33
	Oct-05	1	15	0	40	-0.50
Velangani	Jan-06	0.3	6	0	30	0.25
	Jan-05	0.7	4	5	75	0.05
	Apl-05	0.4	5	0	30	-0.20
Velangani	Oct-05	0.8	8.5	2	30	-0.33
	Jan-06	0.4	11	12	50	0.18

H<sub>b</sub> = Breaking wave height ; T= Wave period; α<sub>b</sub> = Wave breaking angle respect to coast;  
W = Surface zone width; \* LSC = Longshore current speed;  
(-) transport towards North (+) transport towards South

Table 1

Location	Jan. 05	Apr. 05	Oct. 05	Jan. 06	Annual Net	Annual Gross
Chennai	0.135	2.565	0.000	-0.262	0.610	0.740
Mahabalipuram	0.048	0.120	-2.370	-6.545	-2.187	2.271
Periyakalpet	0.021	0.029	0.276	-1.439	-0.278	0.441
Thevanampattinam	-0.075	0.055	0.581	-1.831	-0.317	0.635
Nanjalingampettai	0.155	0.055	-5.897	-0.107	-1.449	1.554
Poompuhar	-0.086	0.232	1.074	6.032	1.813	1.856
Tarangambadi	0.018	0.302	0.200	-0.760	-0.060	0.320
Karaikal	0.002	0.105	-0.283	-0.990	-0.292	0.345
Nagore	-0.308	0.120	0.432	-0.174	0.017	0.259
Samanthanpettai	-0.038	0.075	0.671	-0.041	0.167	0.206
Velangani	-0.092	0.044	0.146	-0.094	0.001	0.094
Average	-0.020	0.337	-0.470	-0.565	-0.180	0.793
(-) transport towards North			(+) transport towards South			

Table 2

Location	Net	Gross	Net	Gross
	Pre-tsunami*		Post-tsunami#	
Periyakalpet	-0.487	0.658	-0.278	0.441
Poompuhar	-0.146	0.479	1.813	1.856
Tarangambadi	-0.201	0.369	-0.060	0.320
Samanthan pettai	-0.006	0.590	0.167	0.206

\* averaged over 12 months (Jena, 1997); # averaged over 4 months  
 (-) transport towards North      (+) transport towards South

Table 3

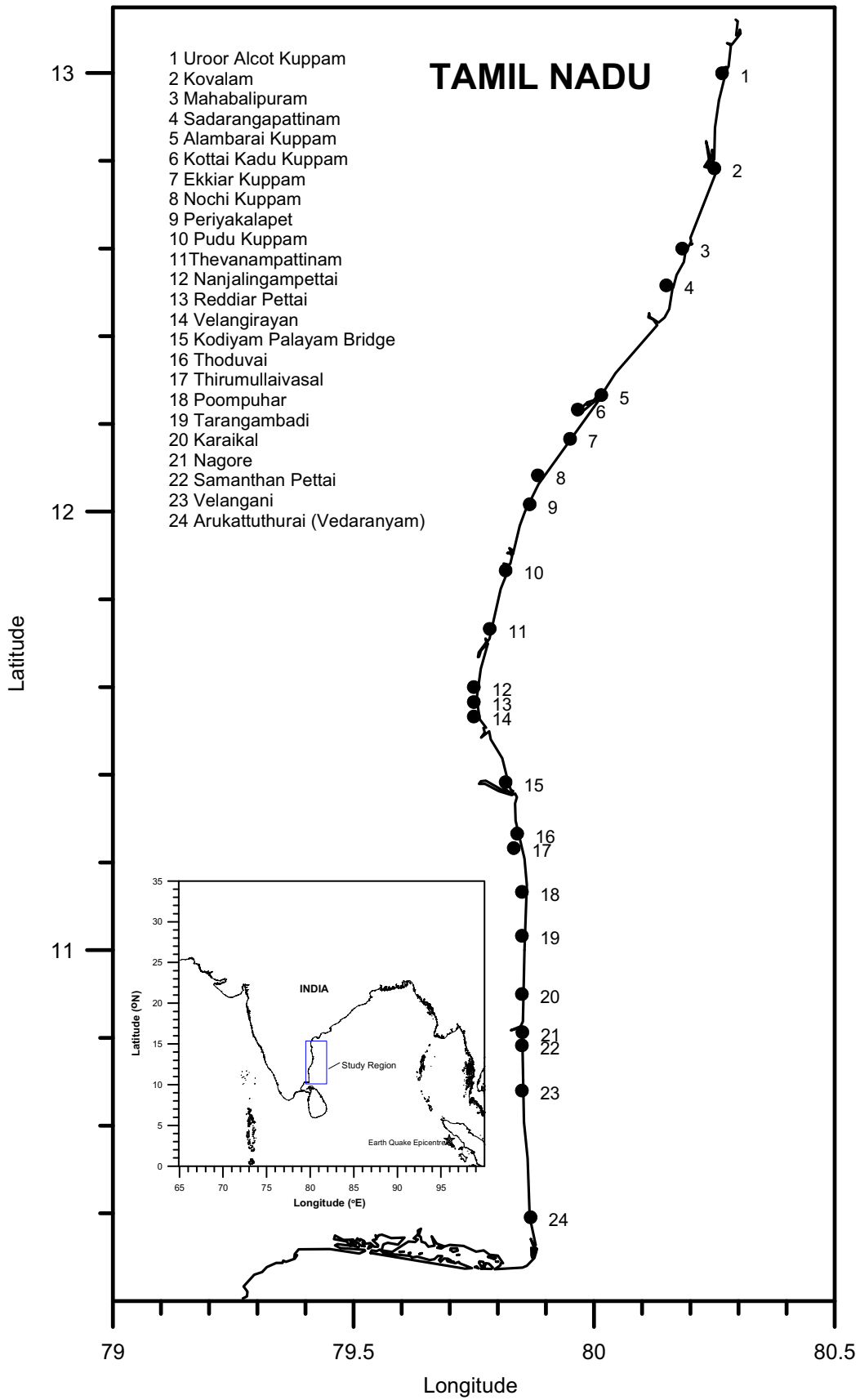


Figure 1

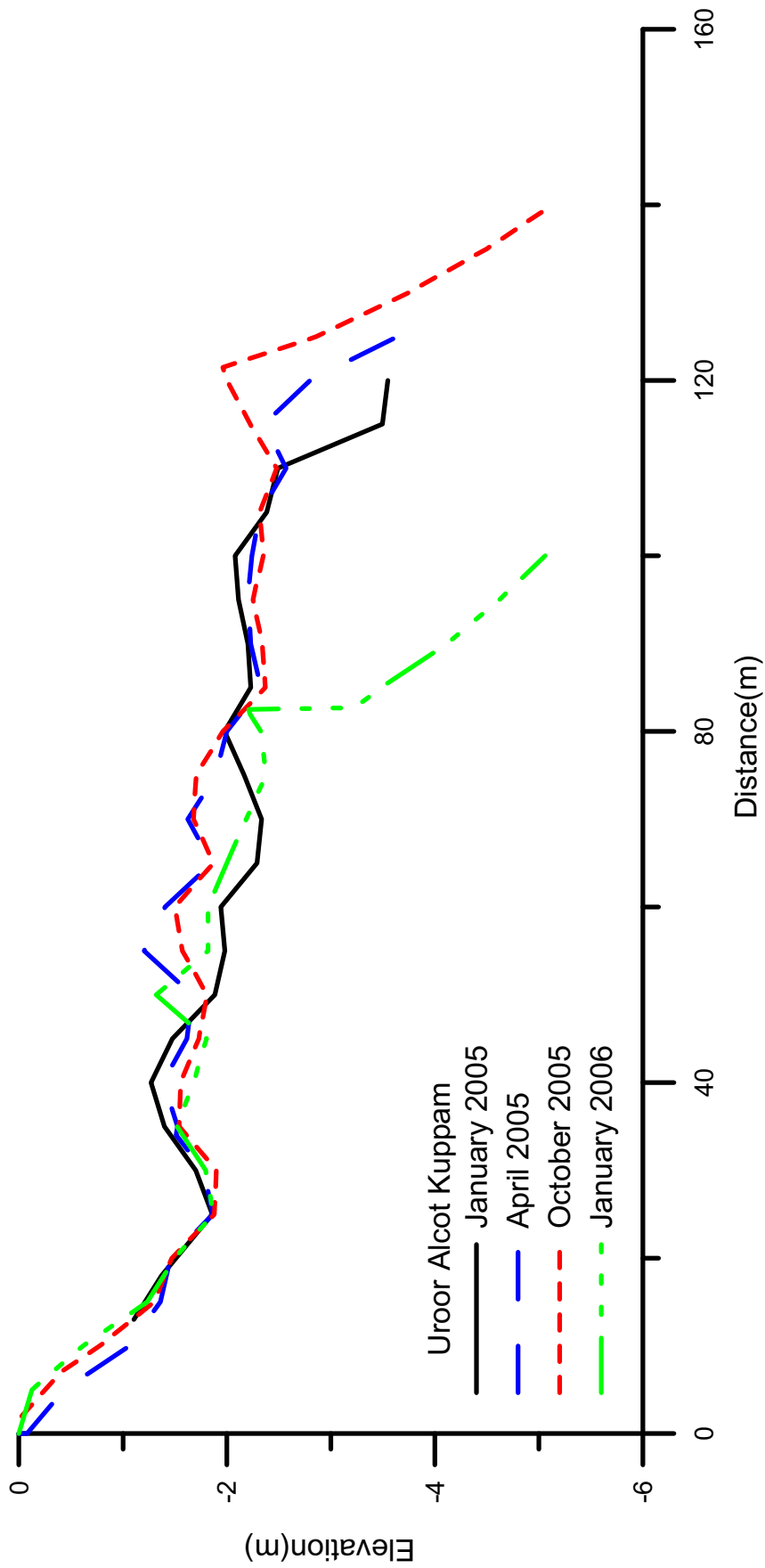


Figure 2

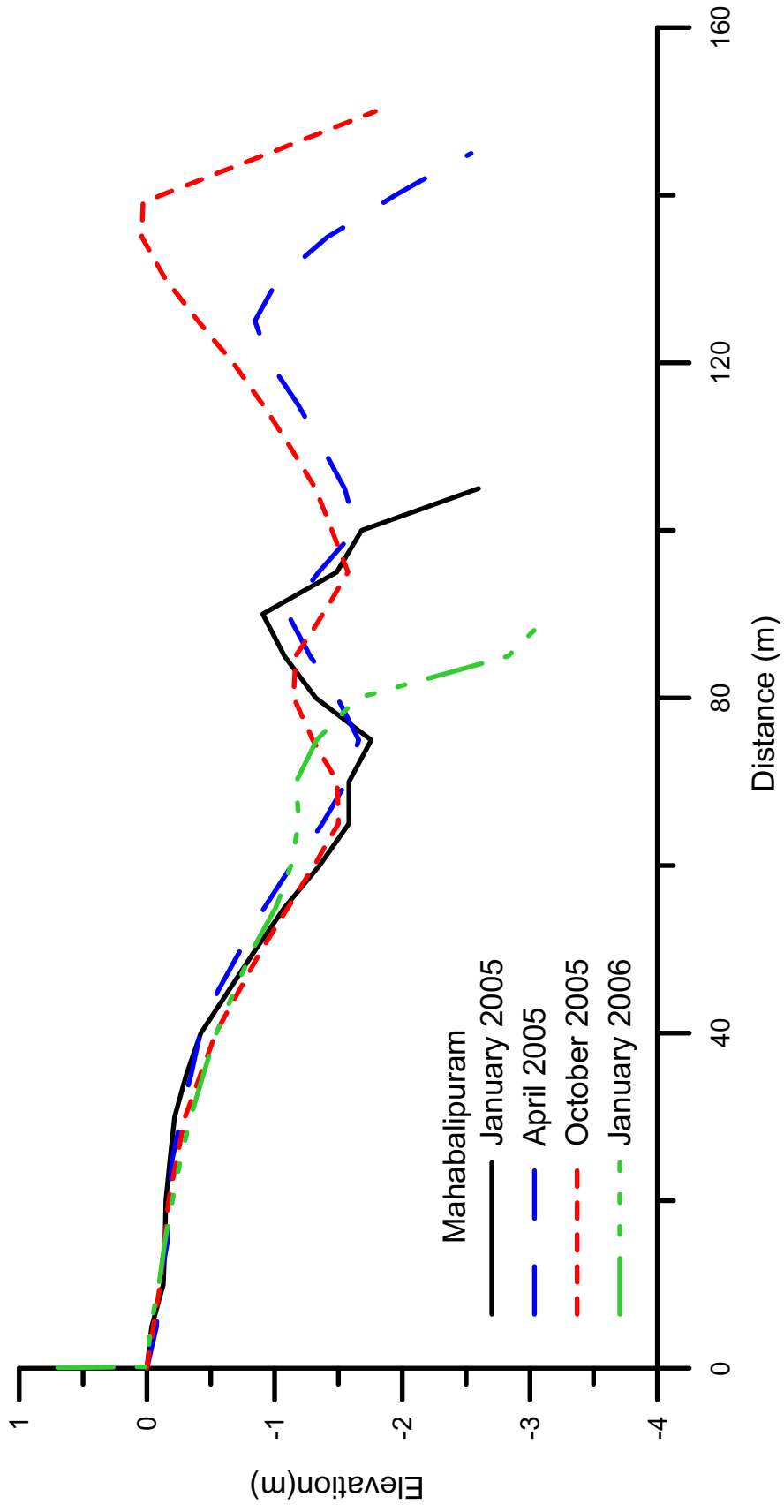


Figure 3

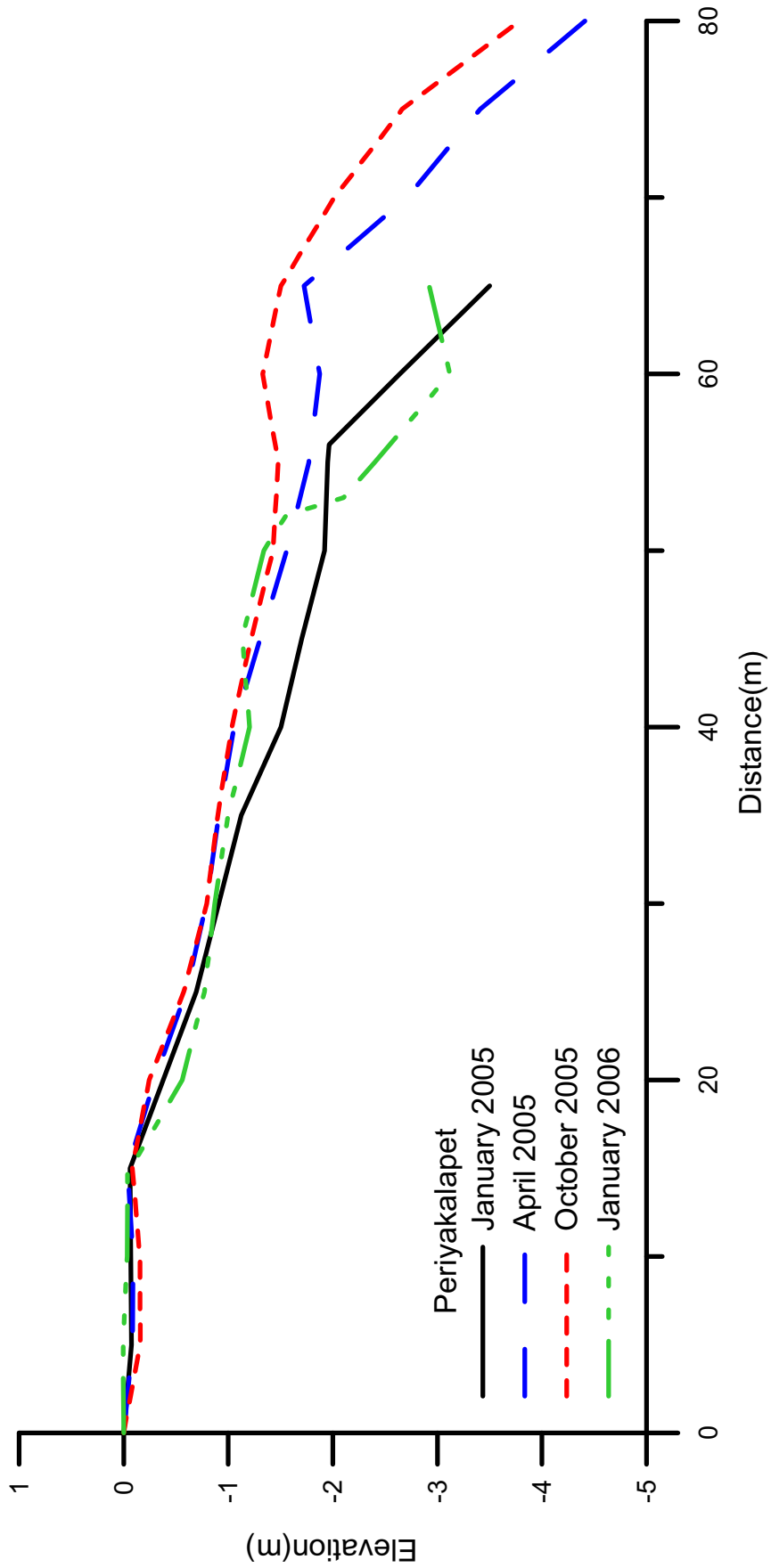


Figure 4

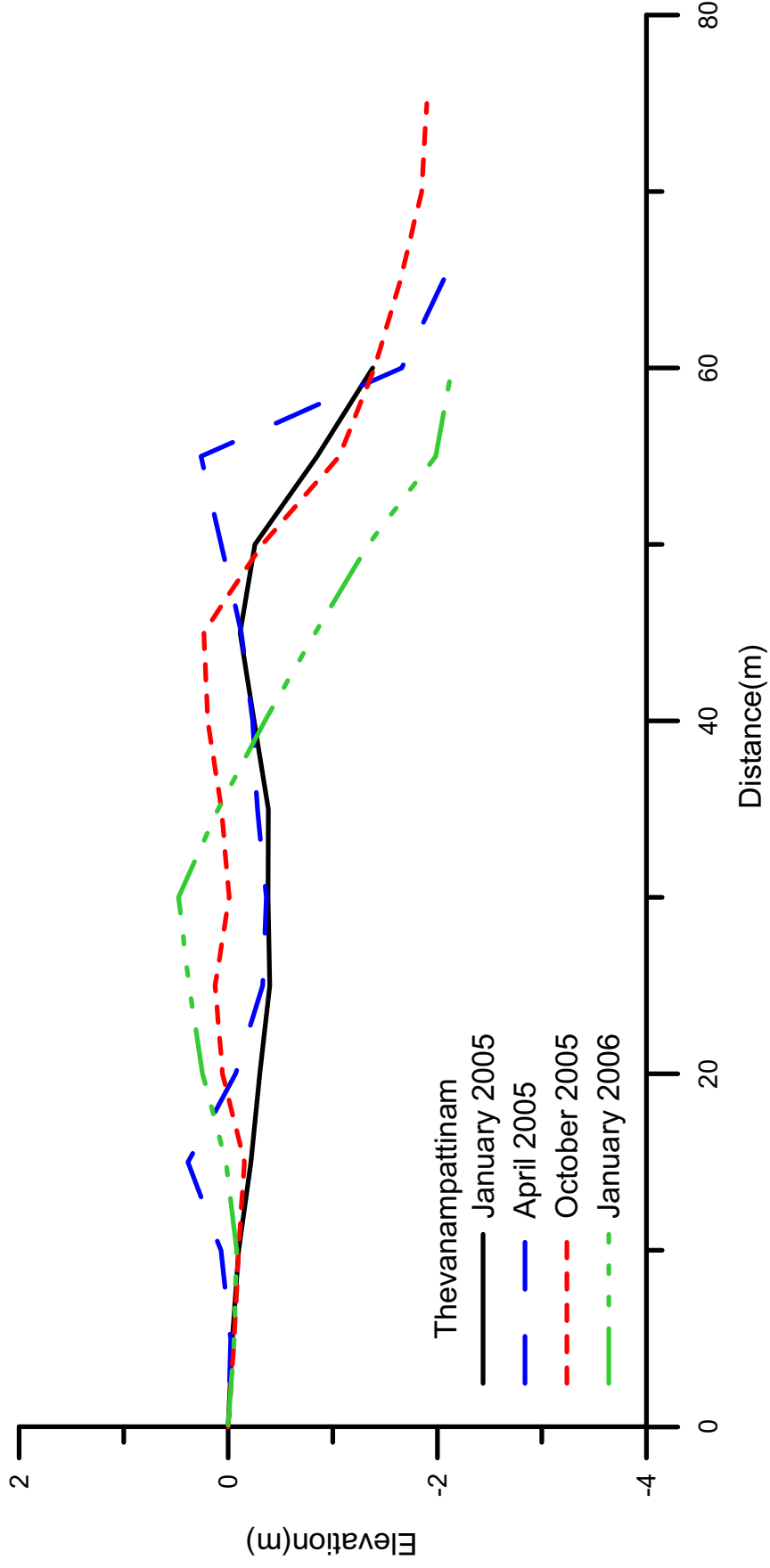


Figure 5



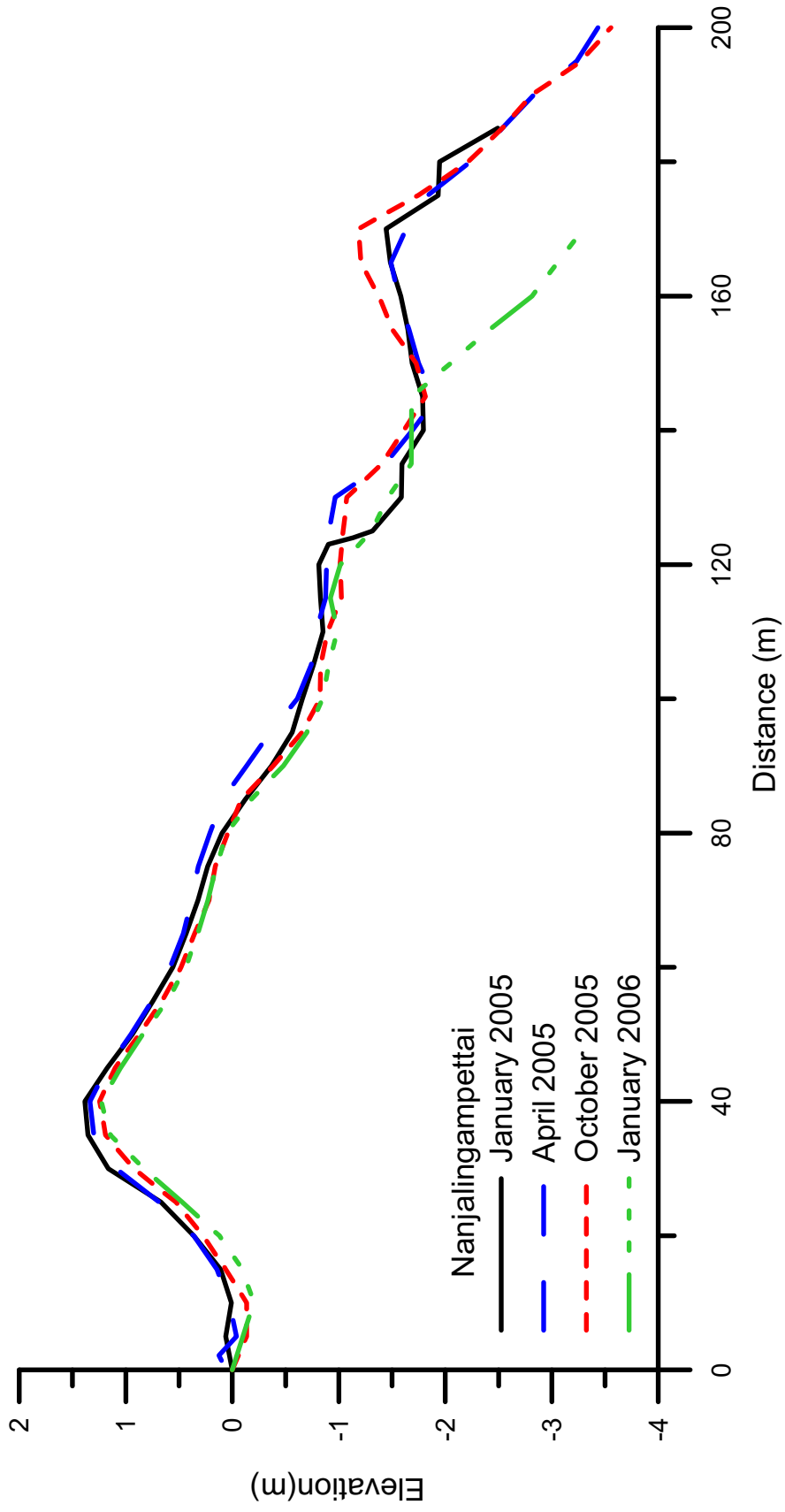


Figure 6

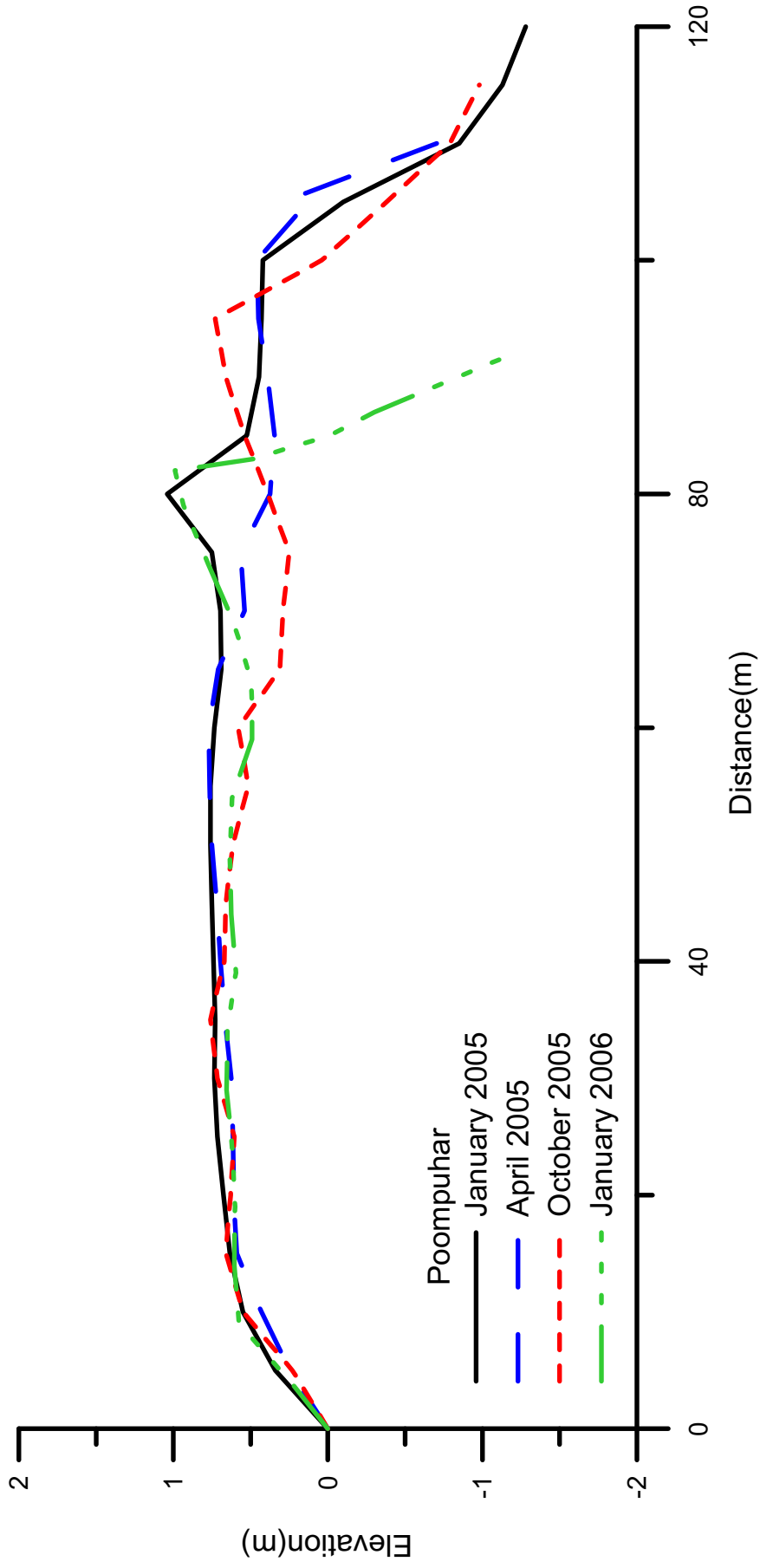


Figure 7

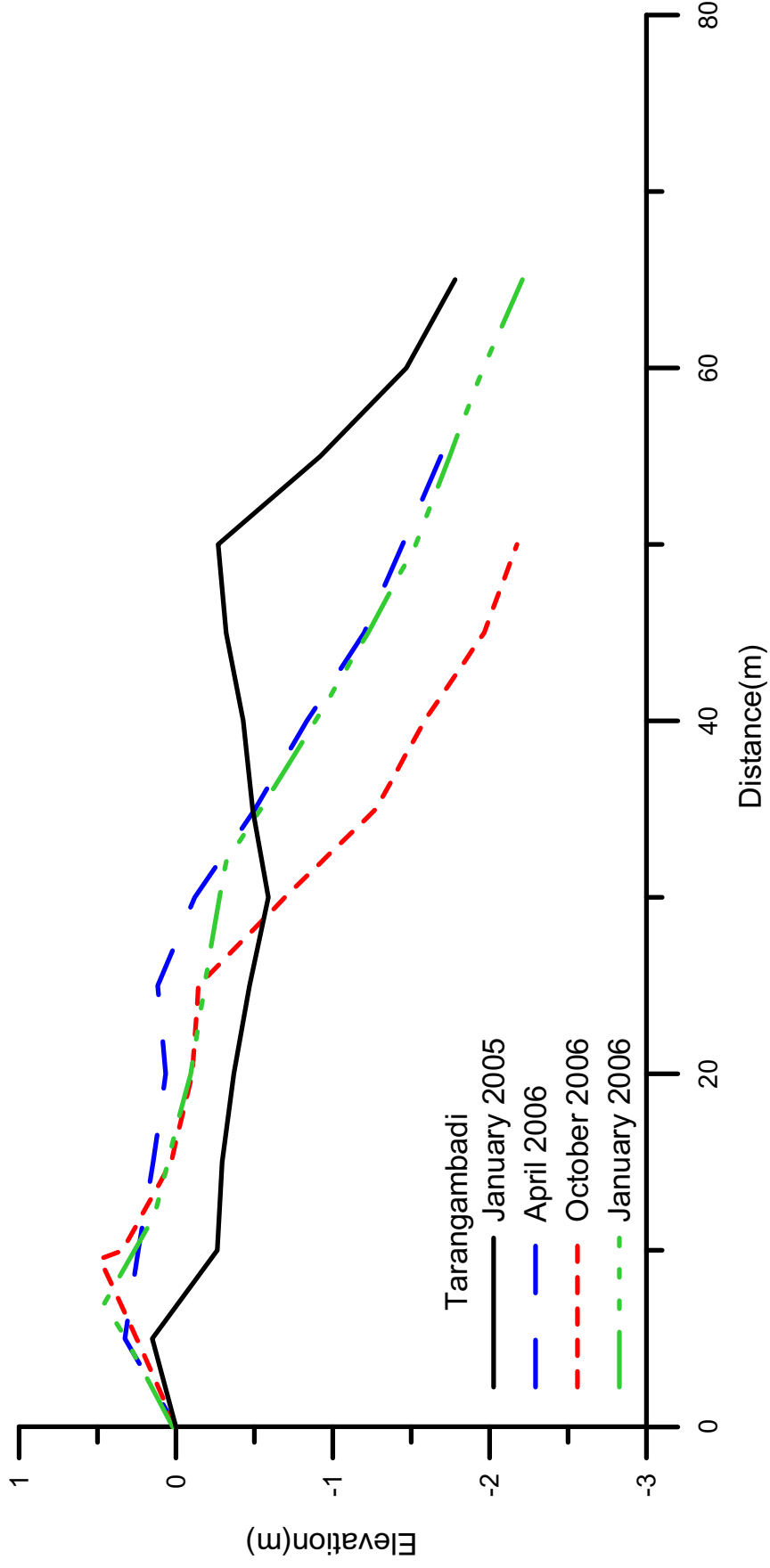


Figure 8

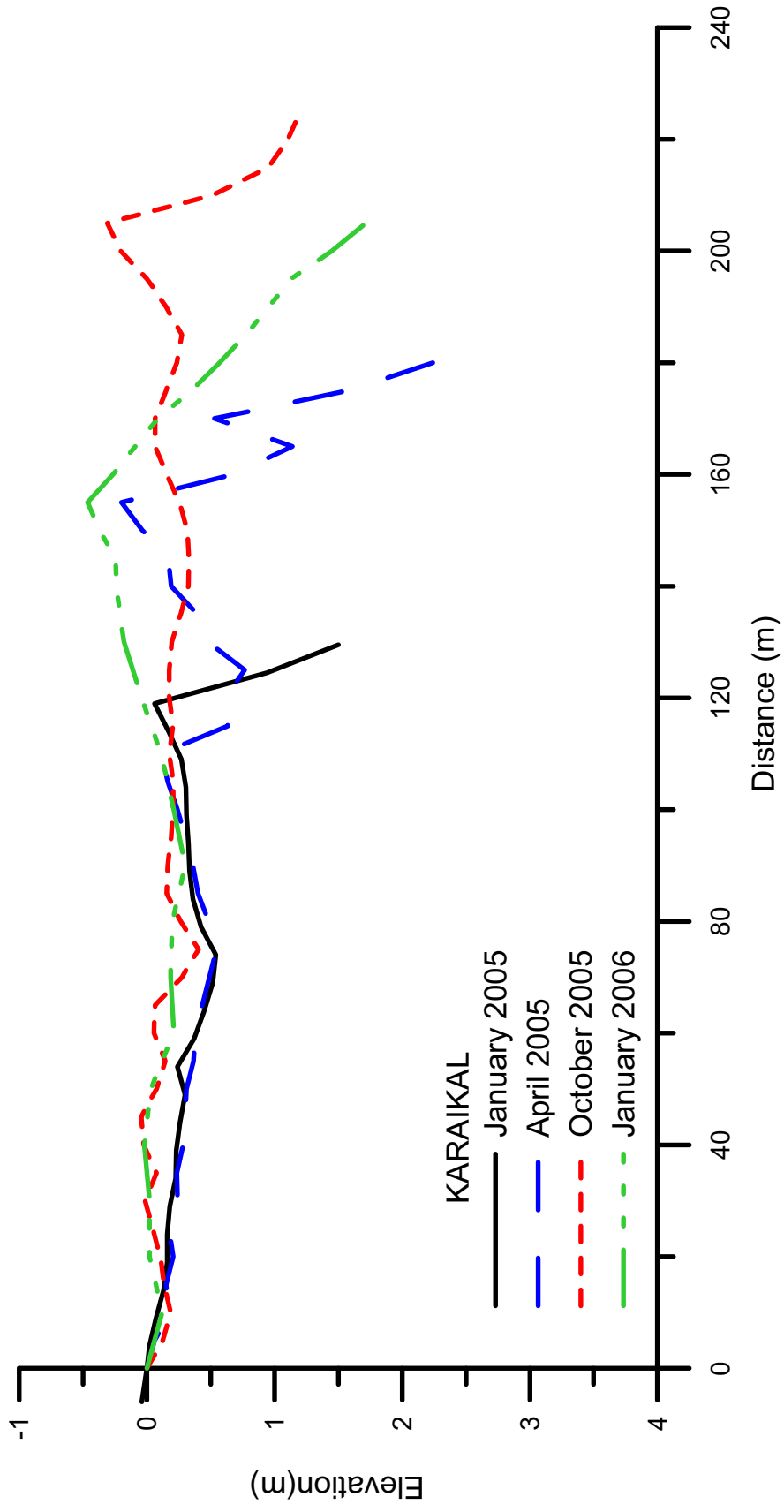


Figure 9

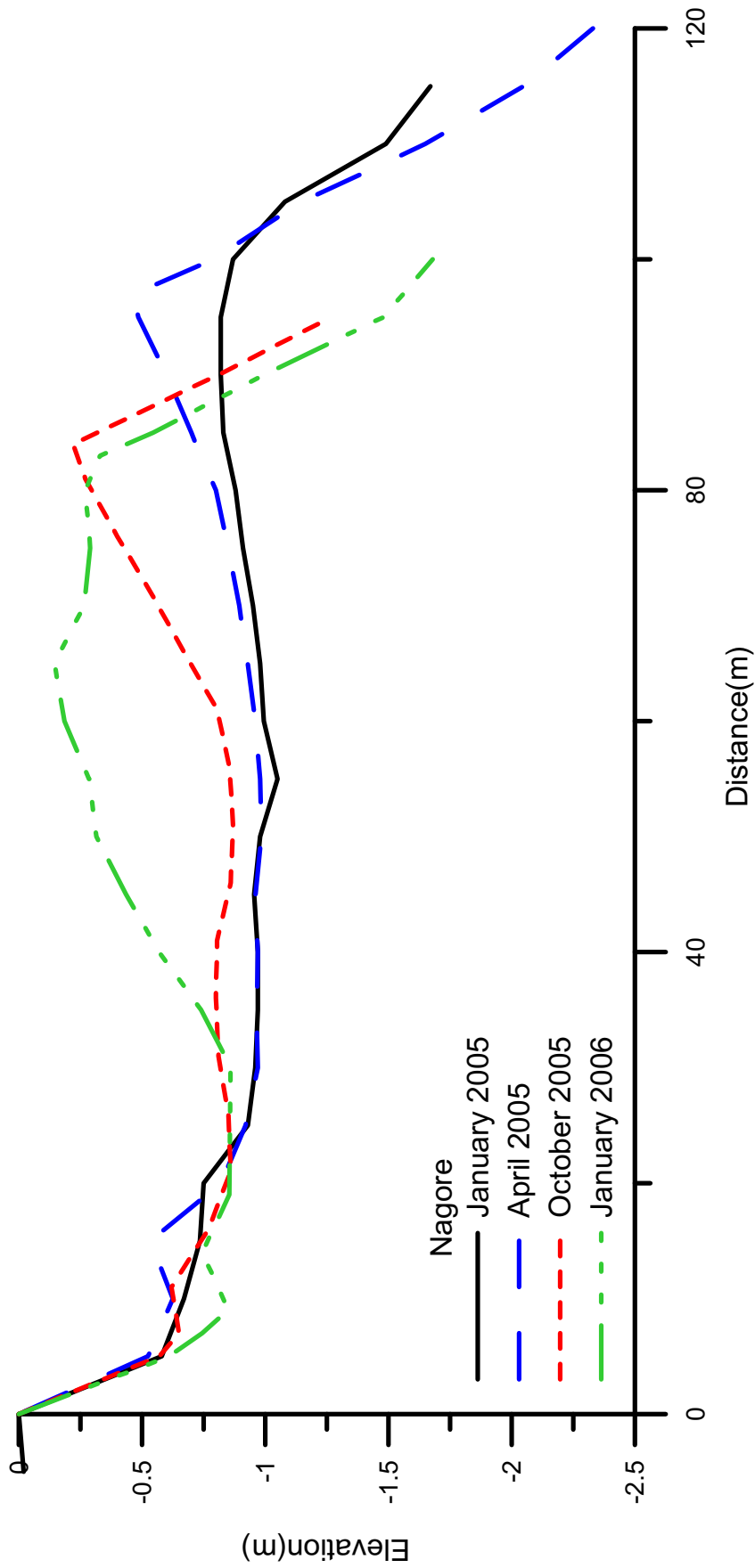


Figure 10

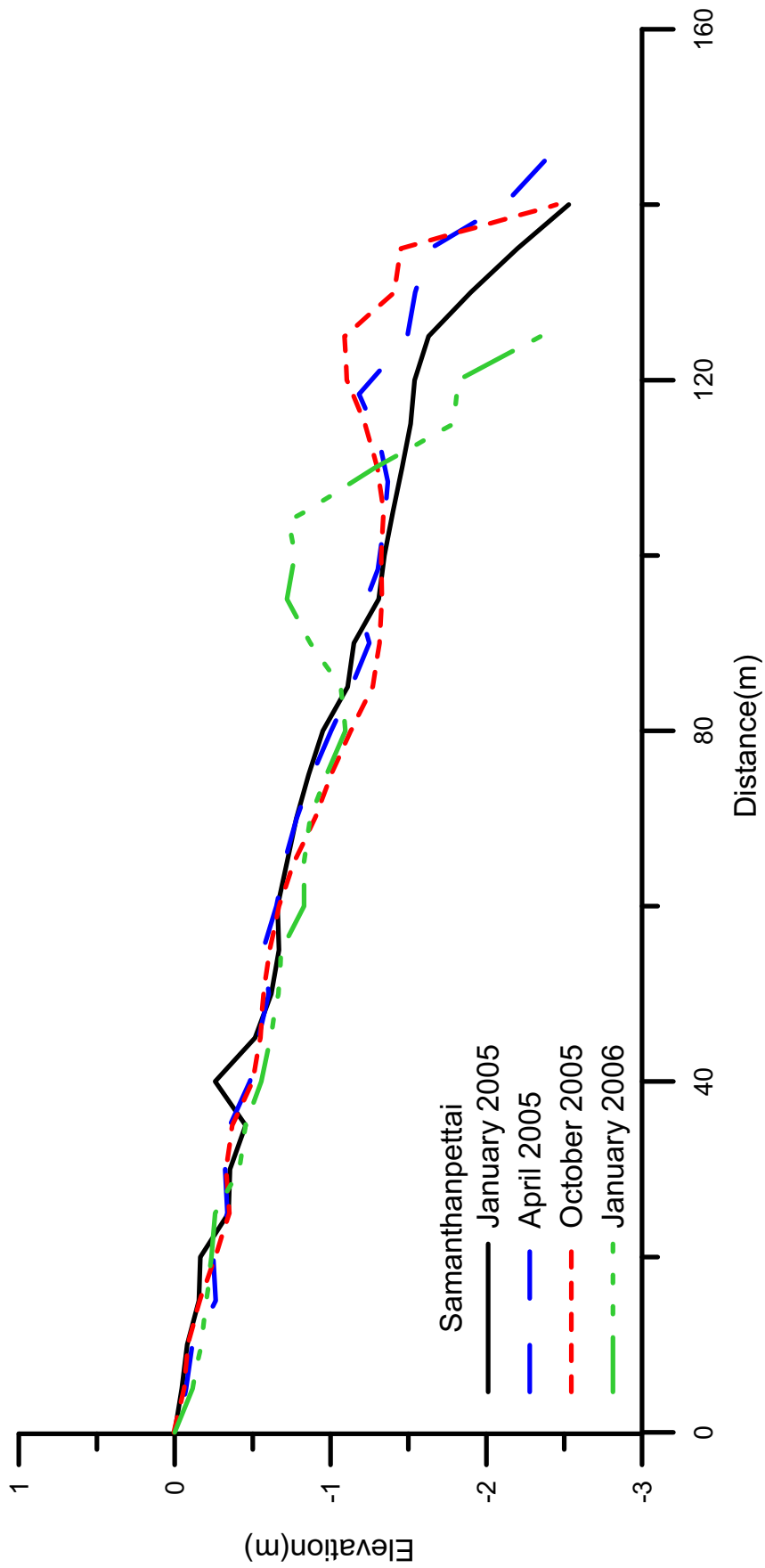


Figure 11

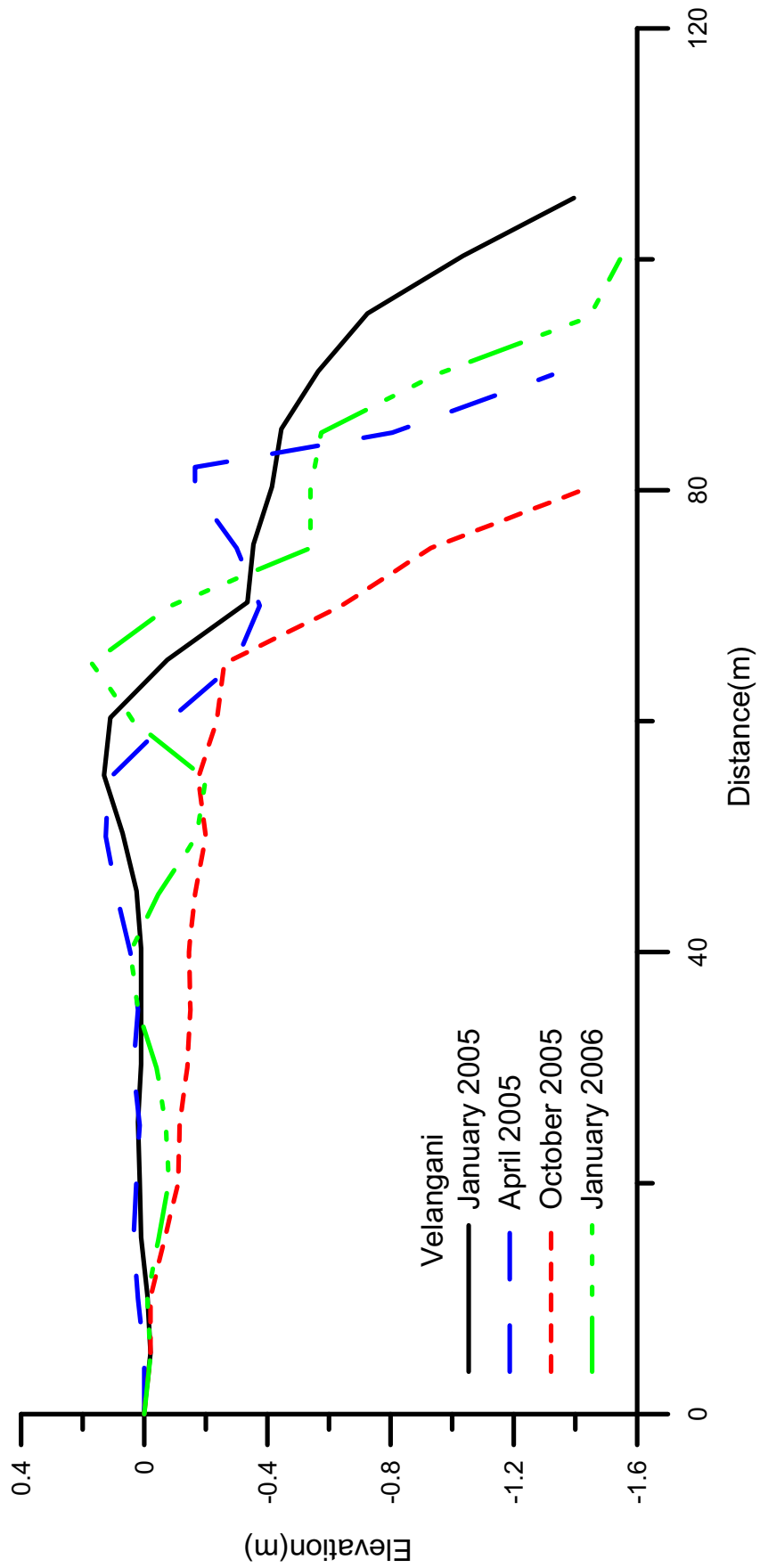


Figure 12