Chapter IV.

Water Pollution Mechanisms

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A summary of the field survey results, undertaken in rainy, dry and transient seasons of 2000 to 2001, is described in this chapter, providing insight into the water pollution mechanisms of the estuary in the final section. Details of the survey results are given in the Supporting Report version of the present report.

1. Physical Oceanography

1.1. Overview of Existing Data and Information

Numerous studies on the physical oceanography of the Pear River Estuary have been undertaken, not only by Chinese organizations but also by foreign entities in cooperation with the Chinese government. Descriptions found in published literature are similar with respect to the physical environment of the Pearl River Estuary, such as the river discharge conditions, hydro-meteorology, and physical oceanography.

The major physical features of the estuary are as follows.

- Discharge of the Pearl River system is highly variable depending on flood conditions in the upstream and tidal conditions.
- Range of the discharge commonly found in literature is between 2,000 and 40,000 m^3/s.
- Generally, the discharge peaks in the rainy season (80% of annual discharge), and bottoms in the dry season (20% of annual discharge).
- Diurnally, the discharge during ebb tide is greater than during flood tide.
- Irregular semi-diurnal tides dominate in the Pearl River Estuary with substantial diurnal inequalities in tide level.
- The maximum tidal range in the basin spatially varies from 0.8 m to 3.6 m. The range is greater in the eastern area than in the western area, and is greater in the upper bay area than in the bay mouth area.
- Currents in the estuary are very strong as a result of the combined effect of shallowness, large tidal range, and large volume of the river inflows.
- The maximum current magnitude ranges spatially from 50 cm/s to 200 cm/s and that of the residual current from 10 to 40 cm/s.
- Surface water temperatures in the estuary vary within a range14 ℃ in the winter to 31℃ in the summer.
- Vertically, water temperature stratification ranges from 0 to 2 ℃ annually.
- Surface salinity in the estuary ranges from 4 to 34 annually.
- Vertical the salinity stratification ranges from 0 to 14 annually.

1.2. Tide

Tidal level changes in a regular diurnal cycle in the Estuary. The semidiurnal component is dominant with a substantial diurnal inequality. Characteristic difference in tides between rainy and dry season is not evident.

Tidal range, i.e. the difference in water level between the high and low tide, reaches nearly 3 m in the upper bay (Humen) during the spring tide, and approximately 1.5 m during the neap tide. The range in the bay mouth (Zhuhai and Guishan) is smaller.

Results of harmonic analysis showed that the semidiurnal component M_2 was the greatest followed by the diurnal components K_1 and O_1. The ranges were M_2: 40 to 65 cm, K1: 35 to 55 cm, and O1: 25 to 35 cm, respectively.

The time of high tide in the upper bay (Humen) trails 2 to 3 hours behind that in the bay mouth (Guishan). The phase difference also occurs in the western area (Zhuhai), with the range of 0.5 to 1.5 hours trailing behind that in the eastern area (Guishan).

1.3. Currents

Basically, water currents in the estuary change direction and magnitude in a regular diurnal cycle with the tide. Water moves northward during the flood tide, and southward during ebb tide. The largest current magnitude occurs during ebb tide, which is accelerated by a strong river discharge.

The maximum current magnitude during ebb tide is greater in the rainy season than in the dry season as a result of increased river discharge. It ranges from 75 to 190 *cm/s* in the rainy season and from 30 to 180 *cm/s* in the dry season, both occurring in the upper layer during ebb tide.

Horizontally, variation in the maximum current magnitude is:
- greater in the upper bay than in the bay mouth, and
- greater in the west than in the east.

Harmonic analysis indicates that the semidiurnal constituent is predominant in the estuary.

Some irregularities in current direction are observed at some survey points. In the upper layer, for example, the southerly current persists, while in other layers its flow shifts around to northerly. Such a tendency is clearer in the dry season than in the rainy season. This happens because the influence of river discharge is reduced in the dry season and, as a result, the effect of a tidal residual current is magnified.

The residual current magnitude in the upper layer ranges from 0.58 to 57.57 cm/s in rainy the season, and from 5.41 to 32.9 cm/s in the dry season.

Figures 1.3.1 and 1.3.2 show the horizontal distribution of residual currents in the rainy and dry seasons of 2000. The residual current directions in the upper layer in both seasons were nearly all southerly. Those in the middle and the bottom layers in the east and in the upper bay tended to be northerly.

Overall, the circulation system in the estuary may be summarized as follows.
- Outer seawater enters the estuary through the middle and the bottom layers at the eastern side of the estuary.
- A portion of the water mass moves northward to the upper bay.
- The remaining portion of the water mass changes its direction south at around Neilingding Island, and exits to the outer sea through the western opening of the estuary.
- In the upper layer, the current is southerly in the entire estuary.

Vertical velocity profiles measured in the vicinity of Neilingding Island by an ADCP (Acoustic Doppler Current Profiler) did not show distinct directional characteristics in all the layers other than that M_2 components were dominant throughout the depth.

The magnitude of residual current peaks in the surface layer and bottoms at the 3.5 m depth, which coincides with the middle layer of the nearby current-meter survey location. At this depth, the direction of residual current also turns from northerly above to southerly below. This turning-depth in residual-current direction and magnitude in the middle layer has also been noted in the results of the current-meter survey for the three layers.

1.4. Temperature and Salinity

Figures 1.4.1 and 1.4.2 show the vertical distribution of salinity and temperature at the central transection line during the spring tide in two seasons.

The distribution of temperature in the rainy season is horizontally dissimilar to that in dry season. The difference of temperature between the upper and the bottom layer is about 7 ^oC. Thus the stratification of temperature is strong even during spring tide.

The difference in temperature between the upper and bottom layer in the dry season is approximately less than 2 ^oC. Stratification of temperature is barely observable.

Low salinity water mass whose value is less than 10 (shown in color, from red to yellow in the Figure) spreads about 50 *km* from the upper bay (P01) during spring tide in the rainy season. During neap tide in the rainy season, it stretches as far as 75 *km*, because of the greater river discharge. However, in the dry season, extension of low salinity water mass is not seen except for the upper bay during spring tide. At the bottom layer during neap tide in the dry season, significantly high salinity water mass whose value is over 20 enters from the bay mouth up to the upper bay.

Stratification of salinity in the rainy season is strong and it persists even during spring tide. In the dry season, however, the stratification is not observed during spring tide and is very weak during neap tide.

Figures 1.4.3 and 1.4.4 show the time series of temperature, salinity, and current vectors at P11 and P12, and of tide level at the nearest point, Zhuhai for P11 and Guishan for P20. Stratification of salinity and/or temperature becomes undistinguishable by vertical mixing between the upper and bottom layer induced by a high-speed current.

Characteristics of vertical distribution of salinity and/or temperature in the rainy season survey is summarized as follows;

- Distribution pattern of salinity and/or temperature is vertical during spring tide and horizontal during neap tide.
- Distribution of temperature and salinity depend on the condition of tide and tidal current, i.e.,
    - ♦ stratification of salinity and/or temperature exists at flood tide or when northerly tidal current flows and,
    - ♦ stratification of salinity and/or temperature disappears or becomes weaker at ebb tide or when southerly tidal current is dominant.

- Degree of stratification of salinity and temperature during neap tide is stronger than during spring tide. Stratification exists at most points through the survey in the rainy season, regardless of strength and direction of tidal currents.
- On the other hand, stratification of salinity and/or temperature are not clearly recognized in the dry season survey, as a result of reduced river discharge and narrower temperature range.

In Figure 1.4.4, high salinity water mass is recognized below 10 *m* every 6 *hours* on a regular basis. A weak stratification exists at approximately 5 *m* depth throughout the time except when the above-mentioned phenomena occur. This may indicate the existence of upwelling from the deep sea, as has been suggested by the Steering Committee. A time series of temperature shows the same tendency as those of salinity; the same phenomena such as weak vertical mixing and upwelling of cold water mass are recognized. A brief explanation of upwelling is explained in Section 1.4.3 and Figure 1.4.2 of chapter 3.

1.5. Turbidity

Figure 1.5.1 shows the vertical distribution of turbidity at the central transection line during spring tide in two seasons. During spring tide in both seasons, the red colored area in the figure (with high turbidity of over 200 FTU) is wider than that during neap tide. Horizontal distribution pattern of high turbidity areas are the same in both seasons, indicating that the high current magnitude has significant influence on the distribution of turbidity in this study area. During neap tide in the rainy season, the significantly high turbidity area spreads wider than that in the dry season, resulting from the influence of greater current magnitude, compared to that during a spring tide, induced by increased river discharge.

Figures 1.5.2 and 1.5.3 show a time series of turbidity, light quantum attenuation rate, current vector, and water level at P11 during spring tide in the rainy and dry seasons. Vertical distribution of turbidity is closely related to current magnitude, particularly to the bottom layer current, i.e., turbidity becomes greater along with the increment of current speed at the bottom layer, when re-suspension of bottom sediment occurs. The boundary current magnitude, when turbidity exceeds 50 FTU, is approximately 50 cm/s in the bottom layer, and 100 cm/s with turbidity over 200 FTU. Turbidity exceeds 200 FTU in all layers when the current magnitude is over 100 cm/s. These relationships are conspicuous at the survey points where water depths are shallower than 10 m. At the survey points where water depths are deeper than 10 m, high turbidity water mass caused by tidal current in the bottom layer rarely reaches the water surface.

1.6. Light Quanta

Figure 1.6.1 shows the vertical distribution of light quanta attenuation rate of the central traverse line during the spring and neap tides in the rainy and dry seasons of 2000.
The distribution pattern of the light compensation depth, which refers to 1% of the attenuation rate, was not very different between the two seasons. The compensation depth during the spring tide was greater than that during the neap tide in both seasons. Distribution of the compensation depth appears to be closely related to the distribution of turbidity.

The compensation depth ranged from 1 to 3 m in the upper bay and from 4 to 10 m in the bay mouth during the spring tide. During the neap tide, the compensation depth ranged from 3 to 6 m in the upper bay and from 6 to 16 m in the bay mouth.

Figure 1.5.2 and 1.5.3 show time series of turbidity, light quantum attenuation rate, current vector, and water level at P11 during the spring tide in the rainy and dry seasons. The compensation depth became shallower in relation to the increment of turbidity, induced by tidal current, in both seasons.

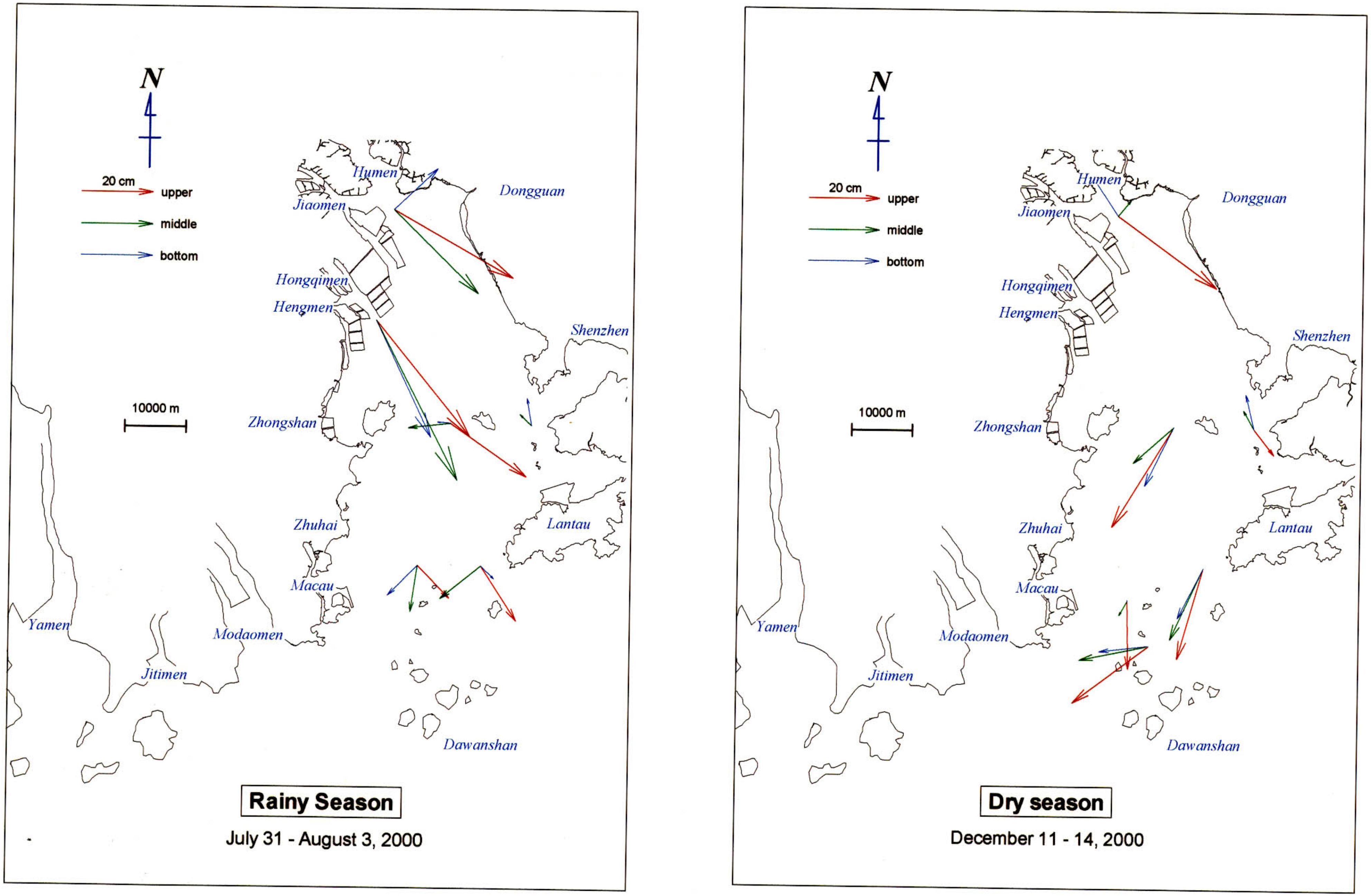


Figure 1.3.1 Residential Currents during Spring Tide

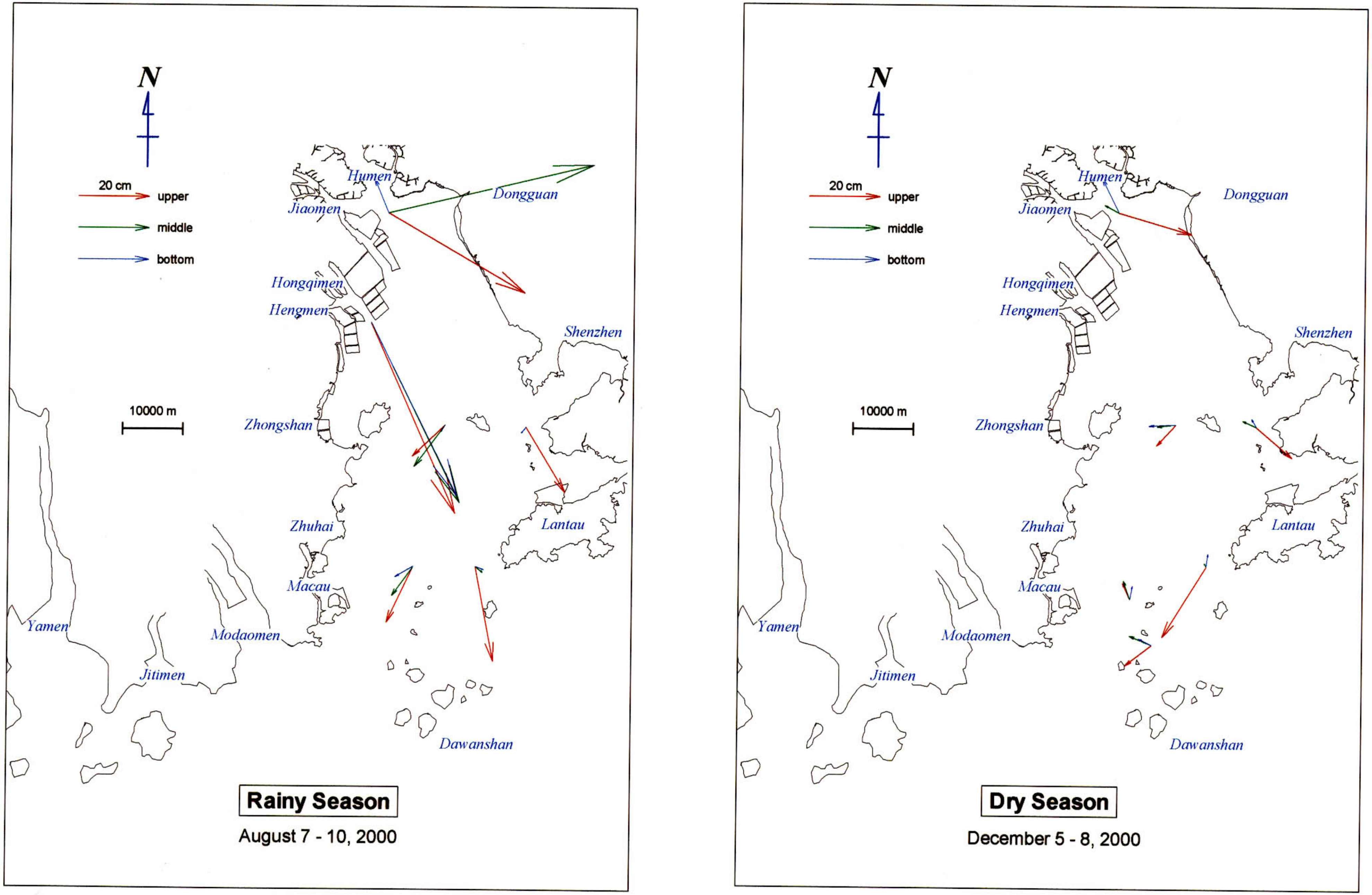


Figure 1.3.2 Residential Currents during Neap Tide

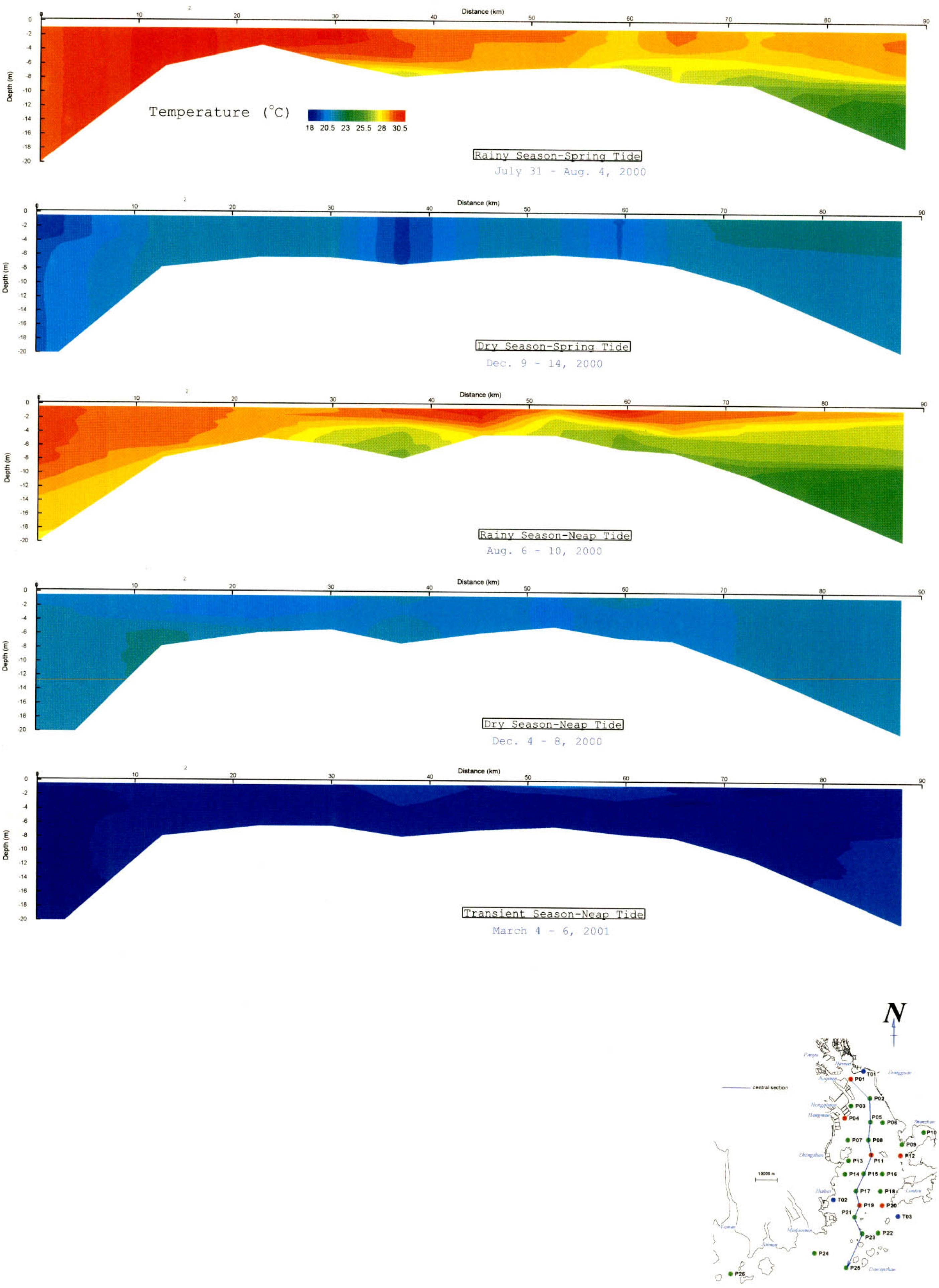


Figure 1.4.1 Vertical Distribution of Temperature at the Central Traverse Line

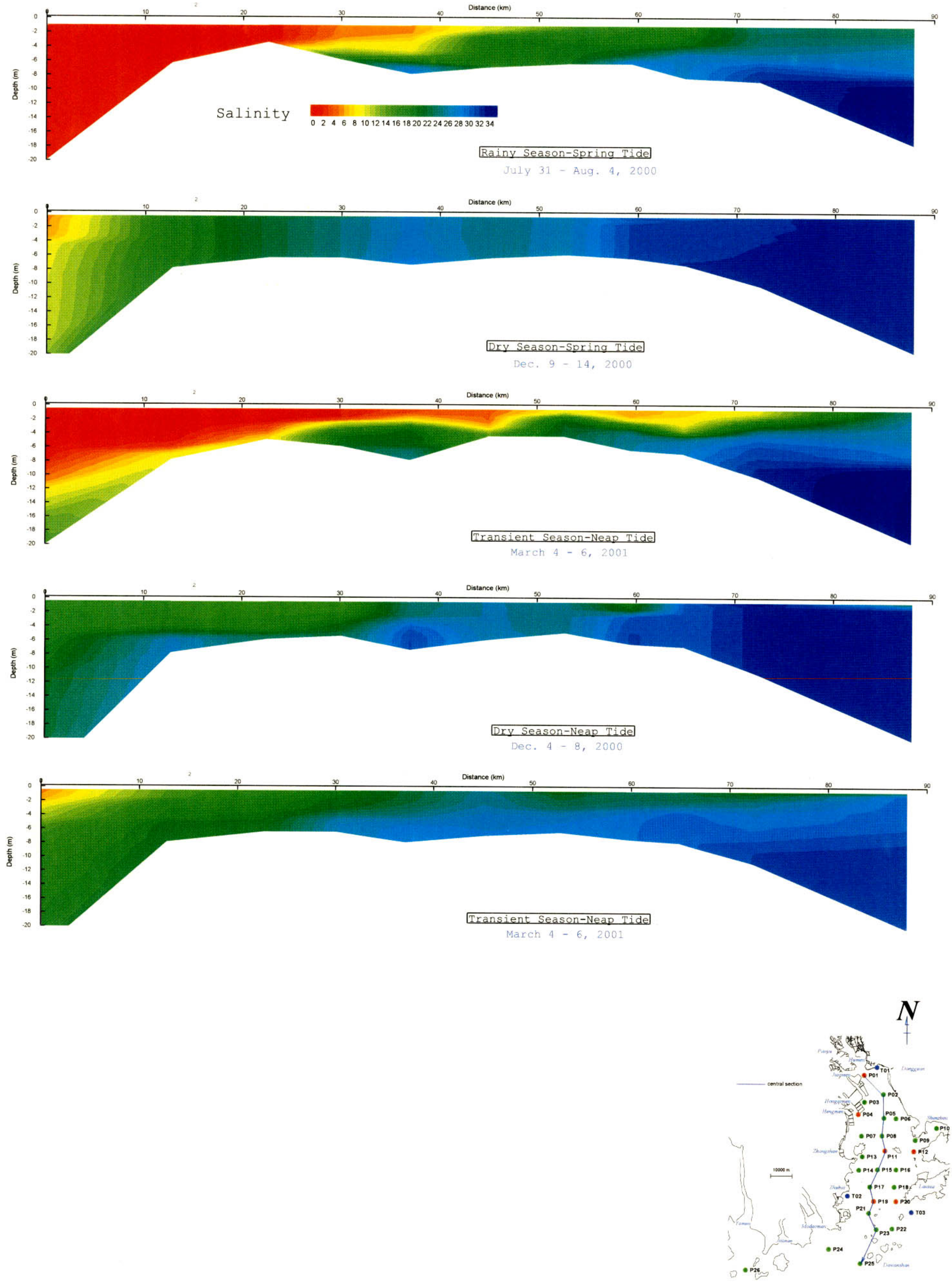
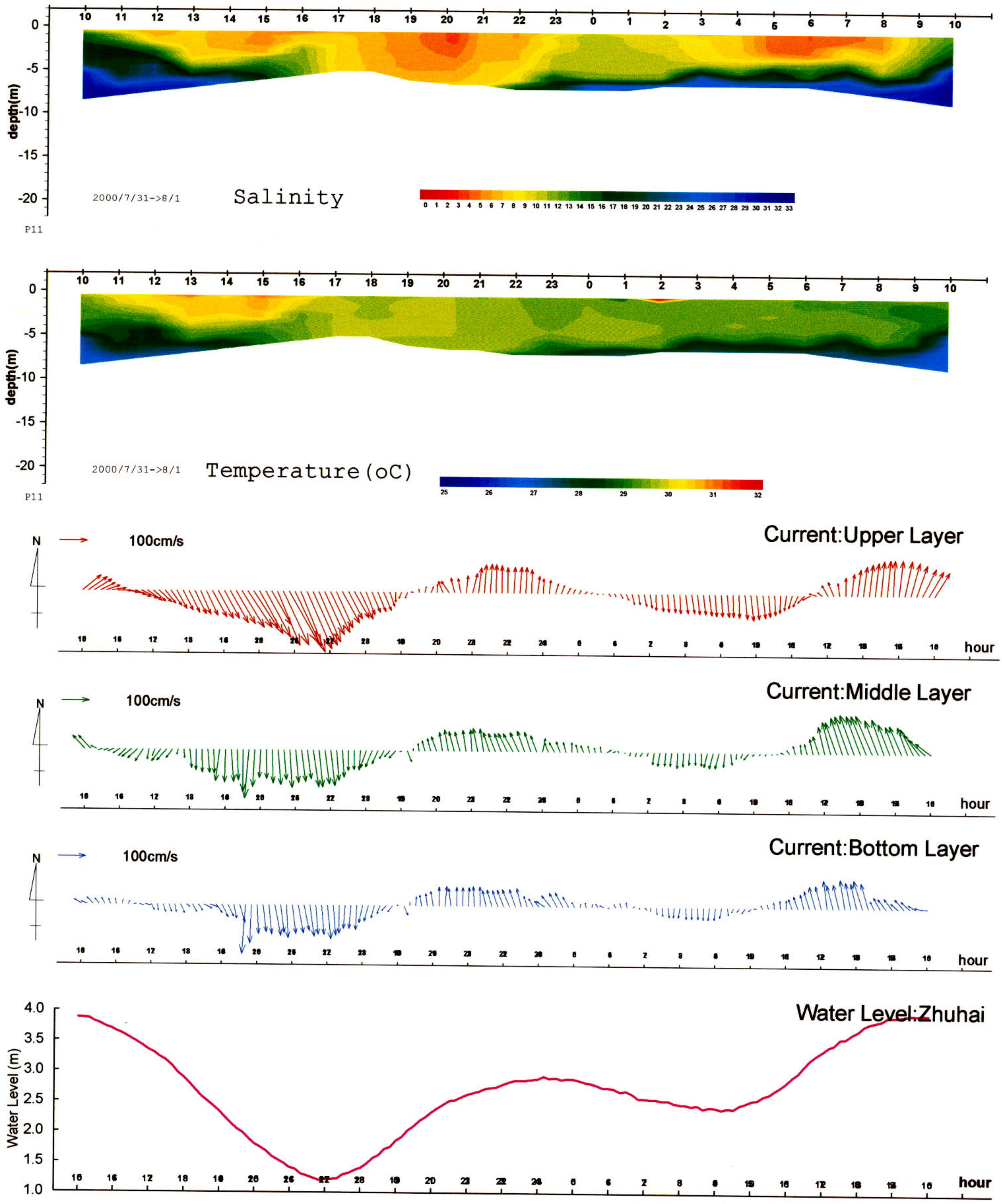


Figure 1.4.2 Vertical Distribution of Salinity at the Central Traverse Line



Rainy Season - P11-SpringTide (Jul. 31 - Aug. 1 , 2000)

Figure 1.4.3 Time Series of Salinity, Temperature, Current Vector and Water Level

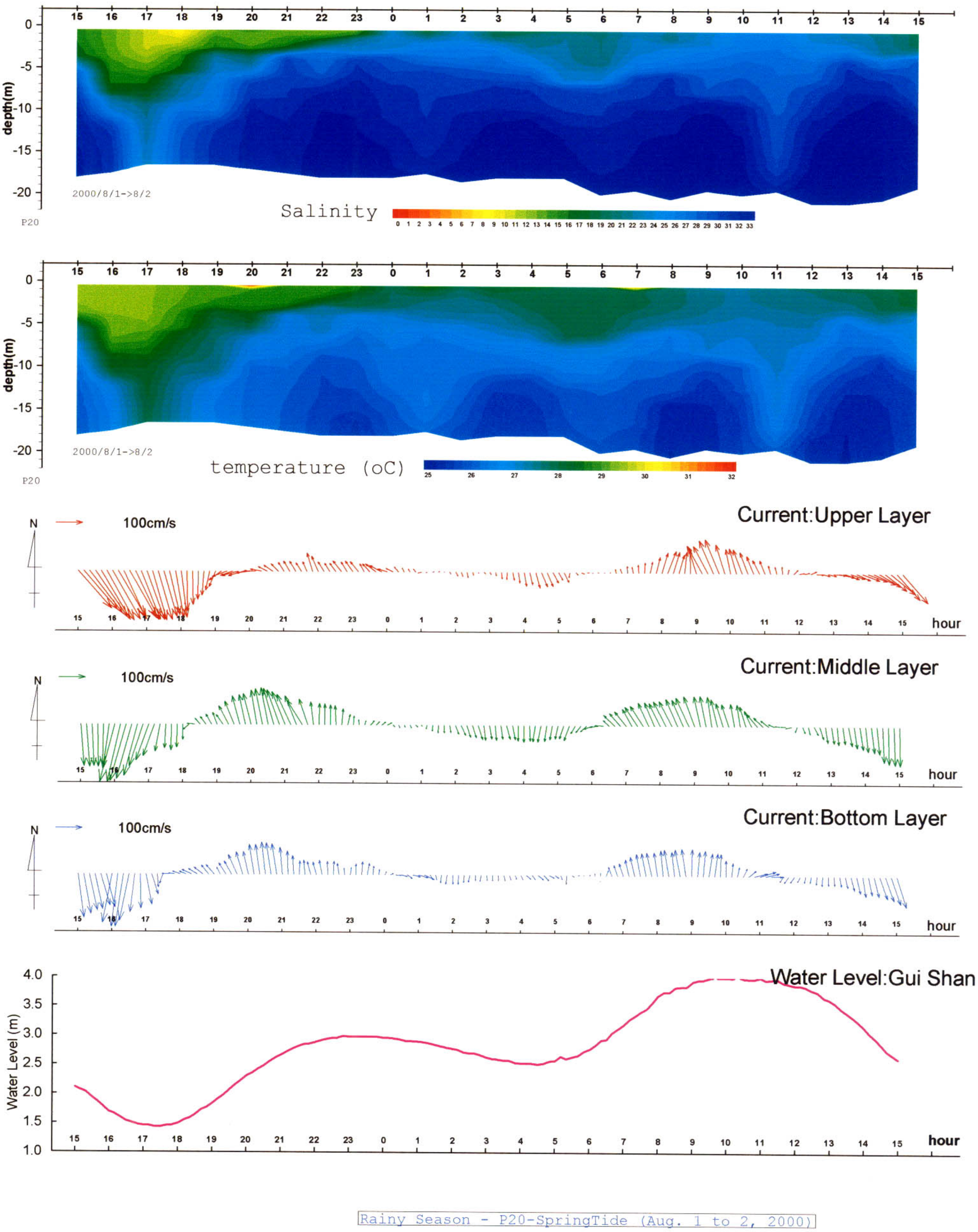


Figure 1.4.4 Time Series of Salinity, Temperature, Current Vector and Water Level