Review

Not peer-reviewed version

Observational Studies of Ocean Fronts: A Systematic Review of Chinese-Language Literature

Xin-Tang Shen and Igor M Belkin *

Posted Date: 18 July 2023

doi: 10.20944/preprints202307.1128.v1

Keywords: ocean fronts; front detection; satellite oceanography; remote sensing; China Seas

Review

Observational Studies of Ocean Fronts: A Systematic Review of Chinese-Language Literature

Xin-Tang Shen [1] and Igor M. Belkin[1,*]

[1] College of Marine Science and Technology, Zhejiang Ocean University, Zhoushan 316022, China
* Correspondence: igormbelkin@gmail.com

Abstract: This review will serve as an entry point for international researchers who would like to tap into the vast scientific potential of Chinese-language literature on oceanic fronts. We focused on observational studies in descriptive physical oceanography of marine fronts. A thorough bibliographic search netted 93 papers published in 1982-2023, with a sharp increase of the total number of papers after 2010. This trend continued unabated through the early 2020s. Regionally, the overwhelming majority of papers is focused on the China Seas, particularly the East China Seas (Bohai, Huanghai, and Donghai, especially the Yangtze River Plume) and northern South China Sea (Guangdong Shelf). Elsewhere, a number of papers were dedicated to the Southern Ocean and North Atlantic. Thematically, papers on remote sensing of ocean fronts dominate, with special attention to the development of new advanced front-detection algorithms applied to satellite data on sea surface temperature and chlorophyll. Numerous papers on marine fronts in the China Seas present important results that have to be considered by international researchers. Overall, this review emphasizes the significant contributions made by Chinese oceanographers, particularly to the frontal oceanography of the China Seas.

Keywords: ocean fronts; front detection; satellite oceanography; remote sensing; China Seas

1. Introduction

This century saw English becoming a truly global international language, a veritable *lingua franca* of science and technology. As the total number of English-language journals and papers published in these journals skyrocketed, the relevance of non-English-language publications is sometimes questioned. Yet China and Chinese language are exceptions since there are more scientists in China than in all other countries combined. Therefore, the importance of Chinese-language publications is self-evident. The global community of scientists is keenly interested in accessing results of studies conducted in China and published in Chinese. The need to examine the contribution of Chinese-language papers to our research field provided a strong impetus for this study.

Seas around China feature numerous fronts. These fronts have various structure and physical nature as they are formed and maintained by different physical mechanisms such as tides, wintertime thermal convection, summertime surface heating by solar radiation, water mass convergence, river discharge, coastal wind-driven upwelling, and topographic upwelling. In terms of physical diversity and sheer number of individual fronts, the China Seas (from the Bohai Sea in the north to the South China Sea and Gulf of Thailand in the south) stand out as the world's richest frontal region. Most fronts in the China Seas persist year-around, being best defined in winter. The fronts affect various aspects of maritime activities of people that populate countries around the China Seas, particularly China. Therefore, Chinese oceanographers and marine biologists traditionally paid attention to oceanic fronts. Over the last few decades, Chinese studies of fronts extended far beyond the China Seas and encompassed the entire World Ocean. These days, the great majority of Chinese studies are published in English-language international journals that are freely available to the international community online and offline. Yet at the same time, numerous studies of significant value are still published in Chinese-language domestic journals. Such journals are not readily available outside China, and many of them are not indexed by either Scopus or Web of Science. The desire to increase

the awareness of the international community about various achievements of Chinese researchers, both past and present, was the main incentive for this review.

We limited the scope of this review by *observational* studies. Well-planned observational studies retain their value for a long time. Moreover, in the context of climate change, older observations of the past physical, chemical and biological conditions in the ocean become even more valuable since historical observational data can serve as a reference point in comparison studies of the present state of the ocean vs. its past state. As the old adage goes, the past is key to the future.

This paper is structured as follows: Section 2 describes bibliographic data sources, main principles of search strategy, and methodology of this review. Section 3 presents results of our review chronologically, regionally and thematically; these results are augmented by a selection of most impactful studies. Section 4 contains a brief discussion of some trends that transpired from this study. Section 5 sums up a few conclusions.

2. Data and Methods

Main principles of search strategy: First, the search focused on oceanic fronts that play a key role in marine realm. Second, the search focused on observational physical oceanography, including satellite oceanography. Papers on biological oceanography and geological oceanography were included provided they reported observations on physical and biochemical fronts. Papers on air-sea interactions in frontal zones were identified and included in this review. Papers on various applications of frontal studies were sought in such fields as, e.g., fisheries oceanography, aquaculture, environment protection and conservation, and pollution control, prevention, and mitigation. Theoretical and modeling papers on fronts were excluded with a few exceptions. Several papers on acoustical oceanography were identified; all of them reported numerical experiments and therefore were excluded.

Principal bibliographic sources: The China National Knowledge Infrastructure (CNKI) Database was our main bibliographic resource. The CNKI is the largest and most comprehensive database of Chinese papers. To ensure repeatability of our work, we (1) limited our survey to those sources that are freely available online at no charge, (2) provided a DOI or URL for each source; (3) hyperlinked all sources to their respective references. In addition to CNKI, we used Scopus, Web of Science, and Google Scholar.

Systematic review: An attempt was made to meet the following criteria of a systematic review: (1) Clearly defined problem/goal; (2) Unambiguously formulated data selection criteria (data inclusion and exclusion criteria); (3) Search strategy algorithm; (4) Structured analysis of results; (5) Rigorous appraisal of data selected; (6) Adequate, representative, and comprehensive data sources; (7) Objective and unbiased approach to the presentation of results.

Goals, objectives, and search criteria: Our goal was to identify and review Chinese-language studies that present results on (1) spatial distribution and temporal variability of fronts in the World Ocean, (2) three-dimensional structure of these fronts; (3) biological, chemical, and geological manifestations of fronts. The main inclusion-exclusion criteria was the observational nature of studies as opposed to theoretical and modeling studies that hopefully will be reviewed by other scholars. The second most important inclusion-exclusion criteria was the fundamental nature of studies as opposed to various applications of front-oriented studies. The search results are presented chronologically, thematically, and regionally.

Duplicate papers: We did our best to identify and exclude duplicate papers. In the past, it was a common practice among non-native-English-speaking authors to publish first in their mother's tongue, then publish the same paper in English as a new paper. These days, this practice is considered self-plagiarism, and it is prohibited by most publishers who use anti-plagiarism software to identify duplicate submissions. The strict enforcement of the anti-plagiarism policy by publishers in China and elsewhere has resolved the problem of duplicate publications. During our bibliographic search we only found two cases of duplicate papers, which constitutes about 1% of the total number of papers selected for this review.

Further refinement of bibliographic search: Papers selected for this review were screened for the completeness and accessibility to international readers, including the availability of English-language abstracts and the completeness of bibliographic information, the latter being a fairly standard requirement to any review. Of some 130 papers initially identified by keyword searches, less than 10 papers failed to meet the above requirements. The total number of papers eventually selected for this review is 93. This number is too small to justify a full-scale statistical analysis of results. However, some chronological, thematical, and regional trends became obvious at the analysis stage. These trends are presented in respective sections.

3. Results

Overview: **Table 1** presents all studies selected for this review, sorted alphabetically by first authors' surnames. Thus, Table 1's structure is identical to our reference list. However, to comply with the MDPI citation style, the reference list will be reformatted at the production stage, with all references to be numbered and cited by the numbers.

Table 1. Observational studies of oceanic fronts published in Chinese-language journals. Acronyms: BS, Bohai Sea; YS, Yellow Sea (Huanghai); ECS, East China Sea; SCS, South China Sea; NSCS, Northern SCS; GIN Seas, Greenland-Iceland-Norwegian Seas; SOC, Southern Ocean; ROFI, Region of Freshwater Influence; TS, Taiwan Strait.

First Author	Year	Region	Subject; Data; Comments
BAO Dao-Yang	2017	Yangtze ROFI	Salinity intrusion and river discharge
CAO Pei-Kui	1996	Yangtze ROFI	Suspended particle front and sediment transport
CAO Zhi-Yong	2016	NSCS	East Hainan Upwelling Front
CHEN Biao	2002	Global	Front detection from spaceborne SAR images
CHEN Biao	2016	NSCS	SST fronts east of Hainan and south of Guangdong
CHEN Biao	2018	Global	SST fronts
CHEN Shen-Liang	2001	Yangtze ROFI	Barrier effect of plume front
DANG Zhen-Zhong	2016	ECS	Kuroshio temperature front from *in situ* data
GAO Guo-Ping	2003	SOC	Fronts along Australia-Antarctic sections
GUO Bing-Huo	1995	ECS	Wavelike frontal features and their kinematics
HAN Yan-Song	2023	YS, ECS	Shandong Peninsula front; Sedimentation
HE Yan	2011	GIN Seas	Distributions and seasonal variations of fronts
HONG Ying	1999	NSCS	Summertime shelf-slope front in Taiwan Strait
HU Fang-Xi	1995	Yangtze ROFI	Salinity fronts in the Changjiang River estuary
HU Jian-Yu	2000	Taiwan Strait	Surface waters in Taiwan Strait in August 1998
HUANG Wei-Gen	2006	ECS, NSCS	Thermal fronts in Taiwan Strait
KUANG Cui-Ping	2022	Yangtze ROFI	Salinity front's response to the Yangtze discharge
LI An-Zhou	2017	Global	Front detection
LI Ting-Ting	2018	Global	Front detection from SAR images
LI Li	2000	NSCS	Southern Taiwan Strait
LI Wei	2011a	Off Taiwan	Kuroshio front east of Taiwan
LI Wei	2011b	Off Taiwan	Kuroshio front east of Taiwan
LI Yu-Yang	2007	Kuroshio	Detection of Kuroshio front
LIN Chuan-Lan	1986	ECS	Kuroshio Front and fisheries
LIU Bao-Yin	1982	ECS	Kuroshio SST fronts
LIU Chuan-Yu	2009	Yellow Sea	SST fronts
LIU Dong-Yan	2022	China Seas	Review of shelf fronts and their ecological effects
LIU Feng-Yue	1989	Yellow Sea	Yellow River (Huanghe) plume front
LIU Jian-Bin	2015	SOC	Seasonal variability of the Antarctic Polar Front
LIU Jian-Bin	2015	Ind. Ocean	Spatial and temporal variations of SST fronts
LIU Jian-Bin	2016	Alboran Sea	Alboran Sea front

LIU Jian-Bin	2016	Benguela	Benguela Upwelling front
LIU Jian-Bin	2016	GIN Seas	Denmark Strait Front
LIU Lin	2012	SOC	Ocean-atmosphere interaction over ocean fronts
LIU Hao	2007	Bohai Sea	Stratification and tidal fronts (numerical simulation)
LIU Peng	2017	Arabian Sea	Upwelling fronts
LIU Peng	2018	Equat. Pacific	Space-time variability of fronts
LIU Xing-Quan	2015	Yangtze ROFI	Circulation and temperature structure
LU Xiao-Ting	2013	China Seas	Feature models
LUO Lin	2003	NSCS	Thermal fronts in Beibu Gulf
MAO Zhi-Chang	1995	Yangtze ROFI	Salinity fronts
NING Xiu-Ren	2004	Yangtze ROFI	Hangzhou Bay bioproductivity front
PING Bo	2013	Kuroshio	Front detection (new method)
PING Bo	2014	Bohai Sea	Front detection using BJ-1 satellite data
PU Shu-Zhen	1994	SOC	Drake Passage
QIU Chun-Hua	2017	NSCS	Guangdong coastal thermal front
QU Jie	2016	SOC	Seasonal variability of the Sub-Antarctic Front
QU Xiang-Yu	2020	Global	Front tracking algorithm for AUVs
REN Shi-He	2015	China Seas	Review of fronts and frontal forecasting
SHI Zhong	2002	Yangtze ROFI	Secondary plume front
SHI Ying-Ni	2018	ECS	Kuroshio front detection from ocean color data
SUN Gen-Yun	2012	BS, YS, ECS	Front detection in the East China Seas from SST
SUN Xiang-Ping	1992	Kuroshio	Thermal fronts on the Kuroshio's inner (left) side
TANG Yu-Xiang	1992	ECS	Kuroshio front
TANG Yu-Xiang	1996	ECS	Distribution and seasonal variability of SST fronts
WANG Yong-Zhi	2013	YS, ECS	Shandong Peninsula front and suspended sediments
WEI Hao	1993	Yellow Sea	Tidal-mixing fronts in the southern Yellow Sea
WEI Qin-Sheng	2010	Yellow Sea	Fronts and their ecological effects
WU Jie	2016	Yangtze ROFI	Suspended sediment fronts from GOCI data
WU Qu-Ran	2015	Global	Front detection: Improvement and validation
WU Yun-Long	2022	Yangtze ROFI	Salinity fronts in dry season
XU Jia-Jing	2021	Yangtze ROFI	Chlorophyll-*a* and plume front, summer 2019
XU Su-Qin	2015	China Seas	Space-time variability of SST fronts
XU Mi-Mi	2012	ECS	Ocean-to-atmosphere forcing over SST front
XUE Cun-Jin	2007	Global	Front detection using wavelet analysis
YANG Chun-Hua	2017	NSCS	East Hainan Upwelling Front in summer
YANG Hai-Jun	1998	SCS	Seasonal variability of thermal fronts
YANG Ting-Long	2021	Japan Sea	Space-time variability of SST fronts
YANG Wei	2020	SOC	Front locations in the Southwest Pacific
YANG Yang	2012	YS, ECS	Suspended sediment sub-front
YING Zhi-Fu	1994	NSCS	Zhujiang River Estuary front and sedimentation
YU Jie	2020	NSCS	SST fronts
YUAN Ping	2019	BS, YS, ECS	Fronts and sediment transport and deposition
ZANG Zheng-Chen	2015	Yellow Sea	Fronts and sediment transport and deposition
ZENG Yi-Gang	2022	NSCS	East Guangdong Shelf Front in summer
ZHANG Ran	2016	ECS	Seasonal variability of SST fronts
ZHANG Wei	2014	Global	Front detection (new method)
ZHAO Bao-Hong	2012	SCS	Inter-annual variability of salinity front
ZHAO Bao-Ren	1985	Yellow Sea	Tidal mixing fronts of the Huanghai cold water mass
ZHAO Bao-Ren	1987a	Yellow Sea	Fronts and the Huanghai cold water mass
ZHAO Bao-Ren	1987b	Yellow Sea	Tidal mixing fronts of the Huanghai Sea

 doi:10.20944/preprints202307.1128.v1

ZHAO Bao-Ren	1992	Yellow Sea	Tidal mixing front along the 34°N section
ZHAO Bao-Ren	1993	Yellow Sea	Shallow water front off the Subei Shoal
ZHAO Bao-Ren	2001	Bohai Sea	Tidal mixing fronts
ZHAO Ning	2016	NW Pacific	Temperature fronts: Frontogenesis and frontolysis
ZHENG Yan-Ming	2009	Yangtze ROFI	Salinity plume front in summer-autumn 2004
ZHENG Shu	2017	NSCS	Pearl River Estuary front, river discharge and wind
ZHENG Yi-Fang	1985	YS, ECS	Spatial distribution of fronts
ZHOU Feng	2008	Yellow Sea	Tidal mixing fronts in the Huanghai Sea
ZHOU Run-Jie	2022	SOC	Statistical characteristics of major fronts
ZHU Jian-Rong	2003	Yangtze ROFI	Plume front, August 2000; Yangtze Shoal ship survey
ZHU Feng-Qin	2014	SCS	Space-time variability of SST fronts
ZHUANG Wei	2003	NSCS	Surface T and S in July-August 2000

[END of TABLE 1]

Chronology: Temporal distribution of 93 papers is presented in **Table 2**, which makes evident a sharp increase of the total number of papers after 2010 that continued unabated though the early 2020s. This clear-cut trend is important. It shows that Chinese researchers expand their publication activity in Chinese in parallel with the well-known global trend of using English as an international language of science and technology.

Table 2. Temporal distribution of papers from Table 1.

Years	**1982-1990**	**1991-1995**	**1996-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021-2023**
Papers	7	10	6	9	8	21	24	8

Regional coverage: The spatial distribution of papers listed in Table 1 is extremely non-uniform as evidenced by **Table 3**. The overwhelming majority of papers is focused on the China Seas, particularly the East China Seas (Bohai, Yellow, and East China Sea, especially the Yangtze River Estuary and Plume) and northern South China Sea. Elsewhere, a significant number of papers are dedicated to the Southern Ocean. Few papers focus on the Atlantic and Indian Oceans. The paucity of papers on the open North Pacific is puzzling given the proximity and importance of this region to China.

Table 3. Regional distribution of papers from Table 1.

Region	**No. of papers**
Global	8
China Seas	4
Bohai Sea	5
Yellow Sea	17
East China Sea	16
Yangtze River Estuary and Plume	14
South China Sea	3
Northern South China Sea	13
Kuroshio	5
Japan Sea	1
Taiwan Strait	1
Northwest Pacific	1
Equatorial Pacific	1
Southern Ocean	7
North Atlantic: GIN Seas	2
North Atlantic: Alboran Sea	1

 doi:10.20944/preprints202307.1128.v1

South Atlantic: Benguela	1
Indian Ocean	1
Indian Ocean: Arabian Sea	1

[END of TABLE 3]

Thematical coverage: Thematically, papers on remote sensing of ocean fronts dominate (**Table 4**), with special attention to the development of new advanced front-detection algorithms applied to satellite data on sea surface temperature and chlorophyll.

Table 4. Main subject areas of papers from Table 1.

Subject	No. of papers
Remote sensing: Spatial and temporal variability of fronts	48
Remote sensing: Front detection algorithms	12
Long-term climatology of fronts from in situ and satellite data	28
Descriptive oceanography of fronts from in situ data (ship surveys and sections)	26
River plume fronts	16
Ocean-atmosphere interaction over marine fronts	2
Physical fronts and bioproductivity	5
Physical fronts and their impact on sediment transport and deposition	8

[END of TABLE 4]

Content analysis: The two tables below sum up the most important results on space-time variability of oceanic fronts (**Table 5**) and on front detection algorithms (**Table 6**), both from papers in Table 1.

Table 5. Principal results on space-time variability of oceanic fronts (from papers in Table 1).

Source	Main results
Cao ZY et al. (2016)	Ship survey of the East Hainan Upwelling Front in July 2012
Chen B et al. (2016)	Fronts of the Eastern Hainan and Western Guangdong Shelf (18-22°N, 109-113°E) from GHRSST L4 gridded data (2006-2013) with 0.05° resolution
Chen B et al. (2016)	Global review of SST fronts; Climatology of China Seas' SST fronts
Gao GP et al. (2003)	CTD/XBT CHINARE sections between Zhongshan Station (Antarctica) and Fremantle (Australia) in 1998, 1999, 2000, 2002; Locations and main characteristics of all major fronts (subtropical, subantarctic, polar, and slope)
Han YS et al. (2023)	Long-term (2011-2020) monthly climatology of the Shandong Peninsula Front from MURSST gridded data with 0.01° resolution
He Y, Zhao JP (2011)	Long-term (1953-2002) monthly climatology of fronts in GIN Seas from in situ HydroBase 2 gridded data with 0.25° resolution
Hong Y, Li L (1999)	Ship survey of fronts in northern SCS, Aug-Sep 1994
Hu JY et al. (2000)	Ship survey of fronts in the Taiwan Strait, August 1998
Huang WG et al. (2006)	Fronts in the Taiwan Strait from AVHRR SST, 1989-2001
Li L et al. (2000)	Review of fronts in southern Taiwan Strait from in situ and remote sensing data
Liu CY, Wang F (2009)	Long-term (1985-2002) seasonal climatology of the Yellow Sea SST fronts from AVHRR Pathfinder monthly and 8-day data
Liu DY et al. (2022)	Review of shelf fronts in the China Seas
Liu JB, Zhang YG (2015)	Long-term (1955-2012) seasonal climatology of the Antarctic Polar Front from WOD13 gridded in situ data with 0.25° resolution

 doi:10.20944/preprints202307.1128.v1

Liu JB, Zhang YG (2015)	Long-term (1955-2012) seasonal climatology of tropical fronts (along 5°S and 15°S) in the South Indian Ocean from WOD13 gridded in situ data with 0.25° resolution
Liu JB, Zhang YG (2016)	Long-term (1955-2012) seasonal climatology of temperature and salinity fronts in the Denmark Strait from WOD13 gridded in situ data with 0.25° resolution
Liu P et al. (2017)	Long-term (1955-2012) seasonal climatology of the Arabian Sea Upwelling Front from WOD13 gridded in situ temperature data with 0.25° resolution
Liu P et al. (2018)	Long-term seasonal climatology of temperature fronts in the Equatorial Pacific from WOD13 gridded in situ data
Pu SZ et al. (1994)	Review of circumpolar fronts in the Drake Passage
Qiu CH et al. (2017)	Seasonal variability of the Guangdong coastal thermal front from daily GHRSST L4 gridded data with 0.05° (~5 km) resolution
Qu J et al. (2016)	Long-term (1955-2012) seasonal variability of the Subantarctic Front from WOD13 gridded in situ data with 0.25° resolution
Ren SH et al. (2015)	Review of fronts in the China Seas
Tang YX (1996)	Seasonal variability of temperature fronts in the ECS from historical in situ data (1934-1988)
Wang YZ et al. (2013)	Shandong Peninsula Front: Seasonal variability and its impact on sediment transport and deposition
Wei QS et al. (2011)	Biochemical and physical fronts of western Yellow Sea from CTD ship survey in summer 2006
Wu J et al. (2016)	Suspended sediment fronts in the Yellow and East China Seas from GOCI satellite data in 2012-2013
XU JJ et al. (2021)	Physical and biochemical fronts of the Yangtze River Estuary and freshwater discharge region in summer 2019
Xu MM et al. (2012)	Atmospheric response to an SST front in the ECS
Xu SQ et al. (2015)	Thermal fronts of the China Seas: Review and monthly statistics of SST fronts from OSTIA data (2006-2012)
Yang CH et al. (2017)	CTD survey of the East Hainan Upwelling Front in July 2012
Yang TL et al. (2021)	Fronts of the Japan Sea from SODA reanalysis, 1980-2015
Yang W et al. (2020)	Southern Ocean fronts in the Southwest Pacific from XCTD sections in 2013-2018 and MODIS SST data
Yang Y, Pang CG (2012)	Suspended sediment fronts in the East China Seas and Taiwan Strait from SeaWiFS data, 1998-2002
Yu J et al. (2020)	Long-term monthly climatology of SST fronts in the northern SCS in 2003-2017
Yuan P et al. (2019)	HYCOM-derived temperature and salinity fronts in the East China Seas and their impact on sediment transport and deposition
Zeng YG et al. (2022)	East Guangdong Shelf Front in summer from CTD surveys and ROMS simulation
Zhang BH et al. (2011)	Seasonal variability of temperature and salinity fronts in the SCS from the SODA reanalysis, 1958-2007
Zhao BH et al. (2012)	Interannual variability of salinity fronts in the SCS from the SODA reanalysis, 1958-2007
Zhao BR (1985)	Vertical structure of tidal mixing fronts in the Yellow Sea

[END of TABLE 5]

 doi:10.20944/preprints202307.1128.v1

Table 6. Principal results on front detection algorithms (from papers in Table 1).

Source	Main results
Li TT et al. (2018)	Front detection in SAR imagery and comparison with SST fronts east of Hainan Island using ENVISAT's ASAR and SST data
Li AZ et al. (2017)	Comparison of algorithms for front detection in satellite imagery with examples from the ECS and northern SCS
Ping B et al. (2013)	Front detection algorithm and its application to the Kuroshio
Ping B et al. (2014)	Front detection algorithms: Comparison in the Bohai Sea
Qu XY, Li YP (2020)	Front-tracking algorithm for AUVs
Shi YN et al. (2018)	Front detection from ocean color vs. SST (Kuroshio region)
Sun GY et al. (2012)	Front detection with Jensen-Shannon divergence off East China
Wu QR et al. (2015)	Front detection algorithm; Guangdong coastal front
Xue CJ et al. (2007)	Front detection using wavelet analysis
Zhang W et al. (2014)	Front detection based on Canny and mathematical morphology

[END of TABLE 6]

4. Discussion

Several trends transpire upon a close inspection of Tables 1 through 6. Thematically, papers on remote sensing of fronts dominate. Numerous studies on SST fronts in the Bohai, Yellow, East China and northern South China Seas were published. Most of these studies are based on widely available Pathfinder AVHRR data, MODIS Aqua data, and OSTIA GHRSST multi-sensor data. At the same time, SST data from other satellite missions are under-utilized, e.g., VIIRS and Sentinel. There are very few studies of chlorophyll fronts using ocean color data that are generally as easily available as SST data. Also, satellite altimetry data on sea surface height (SSH) are barely utilized. Regionally, the overwhelming majority of studies are focused on the China Seas, which is fully justified. However, the paucity of studies centered on the open Northwest Pacific is difficult to explain and hard to justify given the proximity and importance of this region to China. Despite the proliferation of remote sensing studies of ocean fronts and availability of advanced front detection algorithms, the repertoire of various algorithms used by most researchers is very limited. Most researchers resort to rather simple gradient methods that have been traditionally used since the advent of satellite era. Fortunately, the development and improvement of front detection algorithms is gaining speed, which is commendable. However, the current lack of rigorous comparison and validation studies of such algorithms is notable. As ocean front detection becomes a mature field, algorithm comparison, testing, and validation studies should be promoted. In situ data have been traditionally used in conjunction with satellite data. The widespread use of WOD13 (World Ocean Database 2013) published by the National Oceanographic Data Center (NODC/NOAA) had a positive impact, especially when such data were analyzed together with concurrent and collocated satellite data. The latest major release of this data base is World Ocean Database 2018 (WOD18), which includes 16 mln oceanographic casts (https://www.ncei.noaa.gov/products/world-ocean-database). The next release is expected in 2023.

5. Conclusions

This review demonstrated that the body of knowledge contained in Chinese-language publications on descriptive physical oceanography of marine fronts is a valuable addition to papers published in international English-language journals. While our review only covered the last 40+ years (1982-2023), there is no doubt that valuable contributions to this field were made by Chinese oceanographers long before the 1980s and published in Chinese journals that are not yet digitized, hence not easily accessible, especially to international readers worldwide. Any efforts should be encouraged to digitize and make available those legacy contributions to the present-day researchers, teachers, and society at large.

Author Contributions: Conceptualization, I.M.B. and X.T.S.; Methodology, I.M.B. and X.T.S.; Data Procurement and Curation: X.T.S.; Writing–original draft, I.M.B.; Writing–review & editing, X.T.S. and I.M.B.; Supervision, I.M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Zhejiang Ocean University.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: I.B. was supported by the Zhejiang Ocean University.

Conflicts of Interest: The authors declare no conflict of interest.

References*

*By default, all references are in Chinese with English abstract.

1. BAO Dao-Yang, ZHU Jian-Rong, 2017. The effects of river regime changes in the Changjiang Estuary on hydrodynamics and salinity intrusion in the past 60 years. Ⅲ. Saltwater intrusion. *Haiyang Xuebao*, 2017, **39**(4), 1-15. https://doi.org/10.3969/j.issn.0253-4193.2017.04.001.
2. CAO Pei-Kui, YAN Su-Zhuang, 1996. Suspended sand front and its impact on material transport in the Yangtze Estuary. *Journal of East China Normal University (Natural Science)*, 1996, No. 1, 85-94.
3. CAO Zhi-Yong, CAO Rui-Xue, ZHANG Shu-Wen, YI Xiao-Fei, JIANG Chen, 2016. A preliminary study of frontal characteristics in the continental shelf of the eastern Hainan Island. *Journal of Guangdong Ocean University*, 2016, **36**(3), 82-88. https://doi.org/10.3969/j.issn.1673-9159.2016.03.014.
4. CHEN Biao, ZHANG Ben-Tao, HE Wei-Ping, 2002. Detection of ocean fronts from spaceborne SAR images. *Remote Sensing Technology and Application*, 2002, **17**(4), 177-180.
5. CHEN Biao, WANG Jing, JING Zhi-You, LI Min, 2016. Seasonal and interannual variation of thermal fronts off the east coast of Hainan Island and the west coast of Guangdong. *Journal of Tropical Oceanography*, 2016, **35**(5), 1-9. https://doi.org/10.11978/2015141.
6. CHEN Biao, MA Liang, ZHANG Chun-Hua, LI Bing, LIU Hong-Wei, 2018. Ocean front analysis in subdivided sea areas by using satellite remote sea surface temperature data. *The Ocean Engineering*, 2018, **36**(2), 108-118. https://doi.org/10.16483/j.issn.1005－9865.2018.02.013.
7. CHEN Shen-Liang, GU Guo-Chuan, HU Fang-Xi, 2001. The barrier effect of plume front on the submerged delta development of Yangtze River Estuary. *Marine Sciences*, 2001, **25**(5), 55-57.
8. DANG Zhen-Zhong, ZHOU Li-Jia, LIU Jian-Bin, DONG Hui-Chao, NIU Hong-Xuan, LIU Xin, 2016. Analysis on the Characteristics of the Kuroshio Temperature Front in the East China Sea Based on WOA13 Data. *Journal of Ocean Technology*, 2016, **35**(4), 26-30. https://doi.org/10.3969/j.issn.1003-2029.2016.04.005.
9. GAO Guo-Ping, HAN Shu-Zong, DONG Zhao-Qian, YANG Shi-Ying, 2003. Structure and variability of fronts in the South Indian Ocean along sections from Zhongshan Station to Fremantle. *Acta Oceanologica Sinica*, 2003, **25**(6), 9-19.
10. GUO Bing-Huo, WAN Bang-Jun, TANG Yu-Xiang, 1995. Wavelike features and evolution of the oceanic fronts in the East China Sea. *Journal of Oceanography of Huanghai & Bohai Seas*, 1995, **13**(2), 1-10.
11. HAN Yan-Song, ZHANG Lu, QIAO Lu-Lu, ZHONG Yi, LIAO Hong-Bing, 2023. Multi-time-scale variations of suspended sediment concentration over the eastern Shandong Peninsula under ocean front. *Acta Sedimentologica Sinica*, 2023, **41**(3), 778-790. https://doi.org/10.14027/j.issn.1000-0550.2021.118.
12. HE Yan, ZHAO Jin-Ping, 2011. Distributions and seasonal variations of fronts in GIN seas. *Advances in Earth Science*,2011,**26**(10), 1079-1091.
13. HONG Ying, LI Li, 1999. A first-step study on shelf-slope front found in summer in southern Taiwan Strait and its adjacent waters. *Journal of Oceanography in Taiwan Strait*, 1999, **18**(2), 159-167.
14. HU Fang-Xi, HU Hui, GU Guo-Chuan, SU Chen, GU Xue-Jun, 1995. Salinity fronts in the Changjiang River estuary. *Oceanologia et Limnologia Sinica*, 1995, **26**(5, Supplement), 23-31.
15. HU Jian-Yu, HONG Hua-Sheng, HE Zhi-Gang, ZHANG Xue-Bin, CHEN Zhao-Zhang, ZHANG Cai- Yun, LI Hong, 2000. An analysis on temperature and salinity of surface water in Taiwan Strait in August, 1998. *Tropic Oceanology*, 2000, **19**(4), 15-22.
16. HUANG Wei-Gen, LIN Chuan-Lan, LOU Xiu-Lin, XIAO Qing-Mei, SHI Ai-Qin, JIN Wei-Min, 2006. Satellite observations of the thermal front in the Taiwan Strait and its adjacent seas. *Acta Oceanologica Sinica*, 2006, **28**(4), 49-55.
17. KUANG Cui-Ping, CHEN Kuo, WU Yun-Long, WANG Jie, 2022. Response characteristics of horizontal salinity front to runoff in the Yangtze River Estuary. *Journal of Tongji University (Natural Science)*, 2022, **50**(10), 1458-1470. https://doi.org/10.11908/j.issn.0253-374x.21354.

18. LI An-Zhou, ZHOU Wei-Feng, FAN Xiu-Mei, 2017. Research progress of methods for the extraction of mesoscale ocean fronts and eddies based on remote sensing data. *Journal of Image and Graphics*, 2017, **22**(6), 709-718. https://doi.org/10.11834/jig.160637.
19. LI Ting-Ting, XU Su-Qin, CHEN Jie, 2018. A method for oceanic front detection based on SAR images. *Journal of Ocean Technology*, 2018, **37**(5), 40-45. https://doi.org/10.3969/j.issn.1003-2029.2018.05.007.
20. LI Li, GUO Xiao-Gang, WU Ri-Sheng, 2000. Oceanic fronts in southern Taiwan Strait. *Journal of Oceanography in Taiwan Strait*, 2000, **19**(2), 147-156.
21. LI Wei, WANG Qi, MA Ji-Rui, HAN Gui-Jun, ZHANG Xue-Feng, 2011a. Study on the features and frontogenesis mechanism of Kuroshio front to the east of Taiwan. *Marine Science Bulletin*, 2011, **30**(4), 401-408.
22. LI Wei, WANG Qi, MA Ji-Rui, HAN Gui-Jun, ZHANG Xue-Feng, 2011b. Study on the meso-scale process of the Kuroshio front to the east of Taiwan. *Marine Science Bulletin*, 2011, **30**(5), 518-528.
23. LI Yu-Yang, 2007. Research on Kuroshio front characteristics extraction supported by GIS. *Journal of Zhengzhou Institute of Surveying and Mapping*, 2007, **24**(S0), 7-9.
24. LIN Chuan-Lan, 1986. Oceanographic characteristics of the Kuroshio Front in the East China Sea and the relationship with fisheries. *Donghai Marine Science*, 1986, **4**(2), 8-16.
25. LIU Bao-Yin, 1982. The interpretation on the surface temperature fronts of Kuroshio in the East China Sea using NOAA IR data. *Journal of Shandong College of Oceanology*, 1982, **12**(3), 1-20. https://doi.org/10.16441/j.cnki.hdxb.1982.03.002.
26. LIU Chuan-Yu, WANG Fan, 2009. Distributions and intra-seasonal evolutions of the sea surface thermal fronts in the Yellow Sea warm current origin area. *Marine Sciences*, 2009, **33**(7), 87-93.
27. LIU Dong-Yan, LÜ Ting, LIN Lei, WEI Qin-Sheng, 2022. Review of fronts and its ecological effects in the shelf sea of China. *Advances in Marine Science*, 2022, **40**(4), 725-741. https://doi.org/10.12362/j.issn.1671-6647.20220719001.
28. LIU Feng-Yue, 1989. Observation of Yellow River plume and its frontal zone. *Marine Sciences*, 1989, No. 5, 33-36.
29. LIU Jian-Bin, ZHANG Yong-Gang, 2015. Study on the seasonal variance of the Antarctic Polar Front. *Journal of Zhejiang Ocean University (Natural Science)*, 2015, **34**(1), 80-85.
30. LIU Jian-Bin, ZHANG Yong-Gang, 2015. Characteristics of the spatial and temporal variation of the front at west sea of Indonesia. *Marine Forecasts*, 2015, **32**(5), 14-23. https://doi.org/10.11737/j.issn.1003-0239.2015.05.003.
31. LIU Jian-Bin, ZHANG Yong-Gang, 2016. Temporal and spatial climate variation characteristics of Alboran sea front. *Marine Forecasts*, 2016, **33**(1), 37-44. https://doi.org/10.11737/j.issn.1003-0239.2016.01.005.
32. LIU Jian-Bin, ZHANG Yong-Gang, 2016. Study on temporal and spatial variation characteristics of Benguela upwelling front. *Marine Science Bulletin*, 2016, **35**(3), 340-350. https://doi.org/10.11840/j.issn.1001-6392.2016.03.013.
33. LIU Jian-Bin, ZHANG Yong-Gang, 2016. Study on the temporal and spatial variational characteristics of Denmark Strait Ocean Front. *Journal of Marine Sciences*, 2016, **34**(2), 1-10. https://doi.org/10.3969/j.issn.1001-909X.2016.02.001.
34. LIU Lin, GAO Li-Bao, 2012. Vertical structure of the low-level atmosphere around the southeast Indian Ocean fronts. *Chinese Journal of Polar Research*, 2012, **24**(2), 136-142. https://doi.org/10.3724/SP.J.1084.2012.00136.
35. LIU Hao, PAN Wei-Ran, 2007. Numerical simulation of the seasonal variations of the stratification and tidal front in the Bohai Sea. *Advances in Water Science*, 2007, **18**(3), 398-403. https://doi.org/10.14042/j.cnki.32.1309.2007.03.015.
36. LIU Peng, ZHANG Yong-Gang, LIU Jian-Bin, 2017. Analysis on the temporal and spatial distribution characteristics of the upwelling front in the Arabian Sea. *Journal of Ocean Technology*, 2017, **36**(3), 13-17. https://doi.org/10.3969/j.issn.1003-2029.2017.03.003.
37. LIU Peng, ZHANG Yong-Gang, LIU Jian-Bin, 2018. Analysis on the spatial and temporal distribution characteristics of ocean fronts in the Equatorial Pacific. *Journal of Ocean Technology*, 2018, **37**(1), 62-67. https://doi.org/10.3969/j.issn.1003-2029.2018.01.011.
38. LIU Xing-Quan, HOU Yi-Jun, YIN Bao-Shu, YANG De-Zhou, 2015. Dynamics of circulation and temperature-salinity structures in Changjiang River mouth and its adjacent sea. III. The temperature structure. *Oceanologia et Limnologia Sinica*, 2015, **46**(3), 526-532. https://doi.org/10.11693/hyhz20140900260.
39. LU Xiao-Ting, PU Xing-Xiao, LI Yu-Yang, 2013. Development of feature models for typical ocean fronts in offshore area around China. *Marine Sciences*, 2013, **37**(6), 37-41.
40. LUO Lin, WANG Dong-Xiao, LIU Yun, LI Shi-Yu, 2003. Seasonal and interannual variabilities of thermal fronts in Beibu Gulf, South China Sea. *Journal of Tropical Oceanography*, 2003, **22**(4), 60-67.
41. MAO Zhi-Chang, 1995. A study on salt fronts in the Changjiang River Estuary. *Oceanologia et Limnologia Sinica*, 1995, **26**(6), 643-649.

42. NING Xiu-Ren, SHI Jun-Xian, CAI Yu-Ming, LIU Cheng-Gang, 2004. Biological productivity front in the Changjiang Estuary and the Hangzhou Bay and its ecological effects. *Acta Oceanologica Sinica*, 2004, **26**(6), 96-106.
43. PING Bo, SU Fen-Zhen, DU Yun-Yan, MENG Yun-Shan, SU Wei-Guang, 2013. Application of the model of universal gravity to oceanic front detection near the Kuroshio front. *Journal of Geo-Information Science*, 2013, **15**(2), 187-192. https://doi.org/10.3724/SP.J.1047.2013.00187.
44. PING Bo, SU Fen-Zhen, DU Yun-Yan, SU Wei-Guang, 2014. Bohai Sea front detection using BJ-1 small satellite data. *Journal of Remote Sensing*, 2014, **18**(3), 686-695. https://doi.org/10.11834 /jrs.20143221.
45. PU Shu-Zhen, YU Hui-Ling, XU Xian-Jun, ZHANG Hong-Nuan, 1994. Progress in studies on circumpolar current and fronts at Drake Passage. *Marine Science Bulletin*, 1994, **13**(3), 77-88.
46. QIU Chun-Hua, CUI Yong-Sheng, HU Shi-Qi, HUO Dan, 2017. Seasonal variation of Guangdong coastal thermal front based on merged satellite data. *Journal of Tropical Oceanography*, 2017, **36**(5), 16-23. https://doi.org/10.11978/2016125.
47. QU Jie, LIU Jian-Bin, HONG Yuan-Yuan, 2016. Study on the seasonal variation characteristics of the Sub-Antarctic Front based on WOA13 data. *Journal of Ocean Technology*, 2016, **35**(2), 83-86. https://doi.org/10.3969/j.issn.1003-2029.2016.02.015.
48. QU Xiang-Yu, LI Yi-Ping, 2020. An AUV front tracking algorithm based on temperature dynamic estimation. *Journal of Ocean Technology*, 2020, **39**(4), 29-35. https://doi.org/10.3969/j.issn.1003-2029.2020.04.005.
49. REN Shi-He, WANG Hui, LIU Na, 2015. Review of ocean front in Chinese marginal seas and frontal forecasting. *Advances in Earth Science*, 2015, **30**(5), 552-563. https://doi.org/10.11867/j.issn.1001-8166.2015.05.0552.
50. SHI Zhong, WANG Yun, WANG You-Jun, JIANG Kun, 2002. On secondary plume in the southern waters of the Changjiang River Estuary. *Marine Science Bulletin*, 2002, **21**(6), 1-8.
51. SHI Ying-Ni, SHI Li-Jian, ZHANG Gao-Ying, ZHANG Gen-Sheng, ZHANG Chun-Hua, WANG Wei-Hua, 2018. Study on East China Sea Kuroshio front detection based on satellite ocean color merging data. *Journal of Ocean Technology*, 2018, **37**(2), 43-49. https://doi.org/10.3969/j.issn.1003-2029.2018.02.008.
52. SUN Gen-Yun, GUO Min, WANG Xiao-Long, LI Sheng-Xue, 2012. Application of edge detection to the sea surface temperature fronts of China East Coast. *Remote Sensing Information*, 2012, **27**(5), 61-66. https://doi.org/10.3969/j.issn.1000-3177.2012.05.011.
53. SUN Xiang-Ping, KANEKO Ikuo, 1992. Thermal fronts on the inner side (left side) of the large meander of the Kuroshio. *Journal of Oceanography of Huanghai & Bohai Seas*, 1992, **10**(1), 1-11.
54. TANG Yu-Xiang, 1992. On regional difference of the Kuroshio front in the East China Sea. *Journal of Oceanography of Huanghai & Bohai Seas*, 1992, **10**(3), 1-9.
55. TANG Yu-Xiang, 1996. Distributional features and seasonal variations of temperature fronts in the East China Sea. *Oceanologia et Limnologia Sinica*, 1996, **27**(4), 436-444.
56. WANG Yong-Zhi, QIAO Lu-Lu, YANG Zuo-Sheng, BAO Xian-Wen, ZHAO Mei-Xun, WANG Guan-Suo, 2013. Suspended sediment transport and deposition due to strong regional shear current front: an example from the shelf waters off eastern Shandong Peninsula. *Acta Sedimentologica Sinica*, 2013, **31**(3), 486-496. https://doi.org/10.14027/j.cnki.cjxb.2013.03.012.
57. WEI Hao, YANG Dian-Rong, 1993. The distribution of tidal-mixing fronts in the southern Yellow Sea in summer. *Transactions of Oceanology and Limnology*, 1993, No.1, 1-7. https://doi.org/10.13984/j.cnki.cn37-1141.1993.01.001.
58. WEI Qin-Sheng, Lü Xin-Gang, WANG Zong-Xing, WANG Shou-Qiang, ZANG Jia-Ye, 2010. A preliminary analysis of the characteristics of the continental shelf front and its ecological effects in the Yellow Sea. *Advances in Earth Science*, 2010, **25**(4), 435-443.
59. WEI Qin-Sheng, GE Ren-Feng, ZANG Jia-Ye, LI Rui-Xiang, 2011. Characteristics of the ecological environment in cross-frontal sections and a viewpoint of the frontal region ecosystem in the southern Huanghai Sea in summer. *Acta Oceanologica Sinica*, 2011, **33**(3), 74-84.
60. WU Jie, ZHANG Ting-Lu, HU Jing-Wen, 2016. Temporal and spatial distribution of suspended sediment fronts in Yangtze River Estuary and adjacent waters based on GOCI satellite data. *Transactions of Oceanology and Limnology*, 2016, No.2, 1-7. https://doi.org/10.13984/j.cnki.cn37-1141.2016.02.001.
61. WU Qu-Ran, HU Jian-Yu, SUN Zhen-Yu, ZHU Jia, 2015. Improvement and validation of a statistical modeling approach to ocean front detection. *Journal of Xiamen University (Natural Science)*, 2015, **54**(2), 199-206. https://doi.org/10.6043/j.issn.0438-0479.2015.02.009.
62. WU Yun-Long, CHEN Kuo, KUANG Cui-Ping, WANG Jie, 2022. Response characteristic of salinity front to Deep-Water Channel and Hengsha East Shoal Siltation project in dry season of the Yangtze River Estuary. *Chinese Journal of Hydrodynamics*, 2022, **37**(1), 115-124. https://doi.org/10.16076/j.cnki.cjhd.2022.01.015.
63. XU Jia-Jing, ZHOU Peng, LIAN Er-Gang, WU Hao, LIU Dong-Yan, 2021. Spatial distribution of chlorophyll *a* and its relationships with environmental factors influenced by front in the Changjiang River Estuary and

its adjacent waters in summer 2019. *Marine Science Bulletin*, 2021, **40**(5), 541-549. https://doi.org/10.11840/j.issn.1001-6392.2021.05.006.

64. XU Su-Qin, CHEN Biao, TAO Rong-Hua, ZHANG Chun-Hua, LIU Hong-Wei, 2015. The temporal and spatial distribution characteristics of thermal front in the China Seas. *Journal of Telemetry, Tracking and Command*, 2015, **36**(3), 62-70. https://doi.org/10.13435/j.cnki.ttc.002705.
65. XU Mi-mi, XU Hai-Ming, ZHU Su-Xing, ZHOU Lin-Yi, 2012. Ocean-to-atmosphere forcing in the vicinity of the sea surface temperature front in the East China Sea—Seasonal variations. *Chinese Journal of Atmospheric Sciences*, 2012, **36**(3), 590-606. https://doi.org/10.3878/j.issn.1006-9895.2011.11113.
66. XUE Cun-Jin, SU Fen-Zhen, ZHOU Jun-Qi, 2007. Extraction of ocean fronts based on wavelet analysis. *Marine Science Bulletin*, 2007, **26**(2), 20-27.
67. YANG Chun-Hua, JIANG Chen, MA Yong-Gui, ZHANG Shu-Wen, 2017. Analysis of jet front and parameterization model of frontal mixing on the continental shelf east of Hainan Island in summer. *Journal of Guangdong Ocean University*, 2017, **37**(6), 74-83. https://doi.org/10.3969/j.issn.1673-9159.2017.06.012.
68. YANG Fan, WANG Hua, GAO Wen-Dian, YANG Xiao-Xin, WANG Xing, 2023. Distribution characteristics of the Kuroshio temperature front in the East China Sea. *Transactions of Oceanology and Limnology*, 2023, **45**(2), 87-93. https://doi.org/10.13984/j.cnki.cn37-1141.2023.02.011.
69. YANG Hai-Jun, LIU Qin-Yu, 1998. The seasonal features of temperature distributions in the upper layer of the South China Sea. *Oceanologia et Limnologia*, 1998, **29**(5), 501-507.
70. YANG Ting-Long, LIU Na, FANG Yue, KONG Bin, WANG Ying-Jie, 2021. Spatial distribution and seasonal variation of ocean fronts in the Sea of Japan. *Advances in Marine Science*, **39**(3), 379-392. https://doi.org/10.3969/j.issn.1671-6647.2021.03.005.
71. YANG Wei, LI Bing-Rui, GAO Li-Bao, LI Rui-Xiang, LIU Chang-Jian, MA Lei, 2020. Ocean front locations in the Southwest Pacific. *Chinese Journal of Polar Research*, 2020, **32**(4), 469-482. https://doi.org/10.13679/j.jdyj.20200030.
72. YANG Yang, PANG Chong-Guang, 2012. Suspended sediment sub-front and its seasonal variability in Yellow and East China seas. Journal of Sediment Research, 2012, 41-46. https://doi.org/10.16239/j.cnki.0468-155x.2012.02.001.
73. YING Zhi-Fu, 1994. The frontal classification and its influence on sedimentation in Lingdingyang, Zhujiang River Estuary. *Tropic Oceanology*, 1994, **13**(2), 25-32.
74. YU Jie, CHEN Guo-Bao, TANG Zhen-Zhao, ZENG Lei, 2020. Characteristics of the sea surface temperature strong front in the Northern South China Sea. *Marine Environmental Science*, 2020, **39**(3), 367-373. https://doi.org/10.13634/j.cnki.mes.2020.03.007.
75. YUAN Ping, WANG Hou-Jie, BI Nai-Shuang, WU Xiao, ZHANG Yong, 2019. Temporal and spatial variations of oceanic fronts and their impact on transportation and deposition of fine-grained sediments in the East China Shelf Seas. *Marine Geology & Quaternary Geology*, 2019, **40**(3), 25-42. https://doi.org/10.16562/j.cnki.0256-1492.2019050602.
76. ZANG Zheng-Chen, WANG Hou-Jie, XUE Zuo, BI Nai-Shuang, WU Xiao, ZHANG Yong, 2015. Temporal and spatial variability of nearshore fronts in the Yellow Sea and its influence on sediment transport and deposition. *Marine Geology Frontiers*, 2015, **31**(7), 1-10. https://doi.org/10.16028/j.1009-2722.2015.07001.
77. ZENG Yi-Gang, JING Zhi-You, HUANG Xiao-Long, ZHENG Rui-Xi, 2022. Analysis of the dynamic characteristics of the east Guangdong shelf front in the northern South China Sea in summer. *Journal of Tropical Oceanography*, 2022, **41**(4), 136-145. https://doi.org/10.11978/2021172.
78. ZHANG Ran, XU Hai-Ming, ZHANG Bai-Chao, 2016. Seasonal variation of the SST front in the East China Sea and its causes. *Journal of the Meteorological Sciences*, 2016, **36**(2), 203-211. https://doi.org/10.3969/2014jms.0103.
79. ZHANG Wei, CAO Yang, LUO Yu, 2014. An ocean front detection method based on the Canny operator and mathematical morphology. *Marine Science Bulletin*, 2014, **33**(2), 199-203. https://doi.org/10.11840/j.issn.1001-6392.2014.02.013.
80. ZHAO Bao-Hong, LIU Yu-D, FU Bang-Yu, 2012. Inter-annual variability of salinity front in the South China Sea. *Marine Forecasts*, 2012, **29**(6), 74-83.
81. ZHAO Bao-Ren, 1985. The fronts of the Huanghai Sea cold water mass induced by tidal mixing. *Oceanologica et Limnologica Sinica*, 1985, **16**(6), 451-460.
82. ZHAO Bao-Ren, 1987a . A preliminary study of continental shelf fronts in the western part of southern Huanghai Sea and circulation structure in the front region of the Huanghai cold water mass (HCWM). *Oceanologica et Limnologica Sinica*, 1987, **18**(3), 217-226.
83. ZHAO Bao-Ren, 1987b. The continental shelf fronts induced by tidal mixing in the Huanghai Sea. *Journal of Oceanography of Huanghai & Bohai Seas*, 1987, **5**(2), 16-23.
84. ZHAO Bao-Ren, TU Deng-Zhi, BI Ya-Wen, 1992. Multi-year variations of the tidal front in the section 34°N on the continental shelf of the western Yellow Sea and numeric model of the circulations in the section across the front. *Marine Sciences*, 1992, No.2, 41-45.

85. ZHAO Bao-Ren, TU Deng-Zhi, BI Ya-Wen, 1993. Observations and analyses of the shallow water front in the outside of the Subei shoal. *Studia Marina Sinica*, 1993, No.34, 51-60.
86. ZHAO Bao-Ren, CAO De-Ming, LI Wei-Fei, WANG Qi-Mao, 2001. Tidal mixing characters and tidal fronts phenomenons in the Bohai Sea. *Acta Oceanologica Sinica*, 2001, **23**(4), 113-118.
87. ZHAO Ning, HAN Zhen, LIU Xian-Bo, 2016. Preliminary study on the frontogenesis and frontolysis of the oceanic temperature front in the northwest Pacific Ocean. *Marine Sciences*, 2016, **40**(1), 123-131. https://doi.org/10.11759/hykx20130419002.
88. ZHENG Yan-Ming, KANG Jian-Cheng, ZHONG Wei, ZHOU Shang-Zhe, WANG Fang, XU Ren, SUN Rui-Wen, WU Tao, 2009. Salinity distribution of diluted water and plume front of early summer & late autumn in 2004 off Changjiang (Yangtze) Estuary. *Oceanologia et Limnologia Sinica*, 2009, **40**(3), 275-282.
89. ZHENG Shu, CAI Shu-Qun, 2017. A model study of the effects of river discharges and interannual variation of winds on the plume front in winter in Pearl River Estuary. *Pearl River*, 2017, **38**(7), 1-9. https://doi.org/10.3969/j.issn.1001-9235.2017.7.001.
90. ZHENG Yi-Fang, DING Liang-Mo, TAN Duo, 1985. Distribution characteristics of marine fronts in the southern Huanghai Sea and the Donghai Sea. *Journal of Oceanography of Huanghai & Bohai Seas*, 1985, **3**(1), 9-17.
91. ZHOU Feng, HUANG Da-Ji, WAN Rui-Jing, SU Ji-Lan, ZHANG Tao, DING Tao, ZHOU Bei-Feng, 2008. Observations and analysis of tidal fronts in the southwestern Huanghai Sea. *Acta Oceanologica Sinica*, 2008, **30**(3), 9-15.
92. ZHOU Run-Jie, WANG Tian-Yu, DU Yan, 2022. Statistical characteristics of major fronts and eddies in the Southern Ocean based on altimetry observations and a model dataset. *Marine Sciences*, 2022, **46**(2), 1-16. https://doi.org/10.11759/hykx20210204002.
93. ZHU Jian-Rong, DING Ping-Xing, HU Dun-Xin, 2003. Observation of the diluted water and plume front off the Changjiang River Estuary during August 2000. *Oceanologia et Limnologia Sinica*, 2003, **34**(3), 249-255.
94. ZHU Feng-Qin, XIE Ling-Ling, CHENG Yin-He, 2014. Distribution and seasonal variations of temperature front in the South China Sea. *Oceanologia et Limnologia Sinica*, 2014, **45**(4), 695-702. https://doi.org/10.11693/hyhz20130600075.
95. ZHUANG Wei, HU Jian-Yu, HE Zhi-Gang, ZENG Gan-Ning, CHEN Zhao-Zhang, 2003. An analysis on surface temperature and salinity from southern Taiwan Strait to Zhujiang River Estuary during July-August, 2000. *Journal of Tropical Oceanography*, 2003, **22**(4), 68-76. https://doi.org/10.3969/j.issn.1009-5470.2003.04.009.