Quantifying, Predicting, and Exploiting Uncertainty Modeling (DA and Uncertainty) Group Report

Pierre F.J. Lermusiaux, Bruce Cornuelle, Julie McClean, Bruce Howe, Steve Finette, Kevin Heaney, Hans Graber, Sen Jan and Charles Holland

Thanks to Patrick J. Haley and Oleg Logutov (MIT); Yoo Yin Kim, Peter Niiler (Scripps)

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1. **Group questions and Introduction with Brief Summary of some Literature**
2. **Global Modeling and North Philippine/East China Seas impacts**
3. **Large-scale Modeling and Kuroshio**
4. **Mesoscale Modeling and Taiwan Straits/Kuroshio effects**
5. **Answer to Questions**

http://modelseas.mit.edu

Second QPE Meeting, Arlington, VA, June 18-19 , 2007

Glen's Questions for Group Leaders

1. What are environmental uncertainty keys necessary for measuring in field program?
2. What tools or methods should be used?
3. Where should measurements be made?
4. When should we do field work?
5. What processes to be exploited to improve SNR?
6. What further needs for environmental information in assessing uncertainty (Pilot)?

Some of the Main Components of a Modeling System

Bathymetry

Domains (nesting, stand-alone, etc)

Grid and Resolution (vertical, horizontal, etc)

Initial Conditions

Open and Land Boundary Conditions

Forcing

- Tides, Rivers
- Atmospheric

Data Utilized and Assimilation Scheme

Model Dynamics

Parameterizations and Parameters

- Mixing, sub-grid-scale, boundary layers, etc

Model Numerics

Platforms and Compiler used

The Modeler

Importance of Initial Conditions

"Smart" Initialization Surveys to Reduce Background Uncertainties

Smart Initialization Surveys

- Has to be multi-scale
- Has account for multi-disciplinary objectives
- Has to account for sampling constraints
- Needed for modeling but also vital for process studies
- Without it, uncertainties will remain close to full variability

Impact of background initial state on model estimates

Example: for MB06 in the Monterey Bay, if HOPS is initialized with ROMS or with NCOM-ICON fields, the ocean state in HOPS remain as that of ROMS or NCOM-ICON for at least one week

Liang, Tang et al, DSR, 2003

West of Luzon: a branch of Kuroshio enters SCS, flows northward into the Taiwan Strait, rejoining the main Kuroshio north of Taiwan.

East of Taiwan: Kuroshio deflected by I-Lan Ridge and Taiwan shelfbreak, with one branch intruding onto the shelf.

Seasonal variations strongest on the shelfs, limited for Kuroshio

Deeper currents controlled by remote oceanic forcing

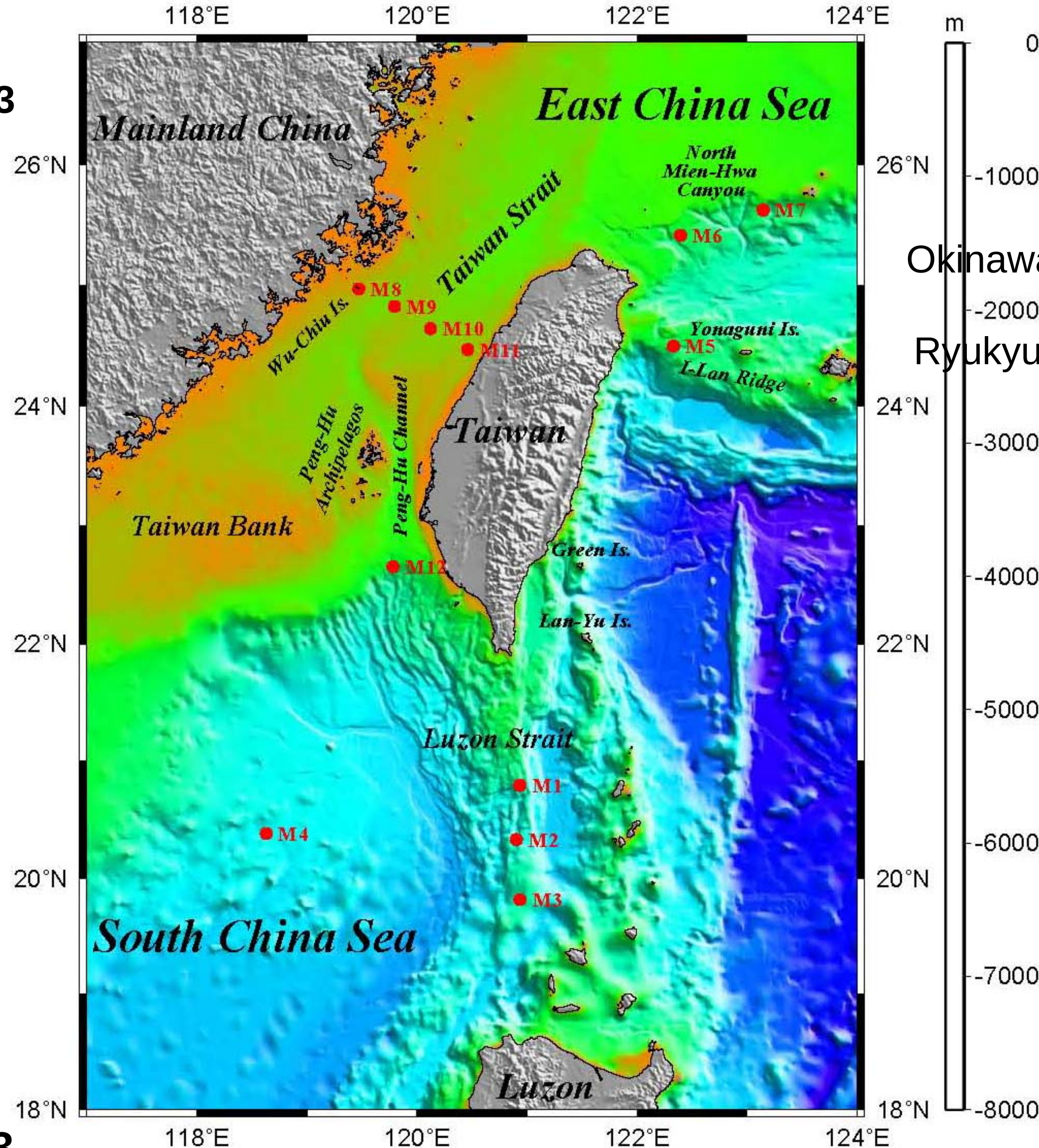


Fig. 1. Bathymetric chart showing areas around Taiwan and mooring locations.

DSR, Special Issue 2003

Oceanic Responses to Atmospheric Forcing:
Monsoon and Typhoon (July- August)

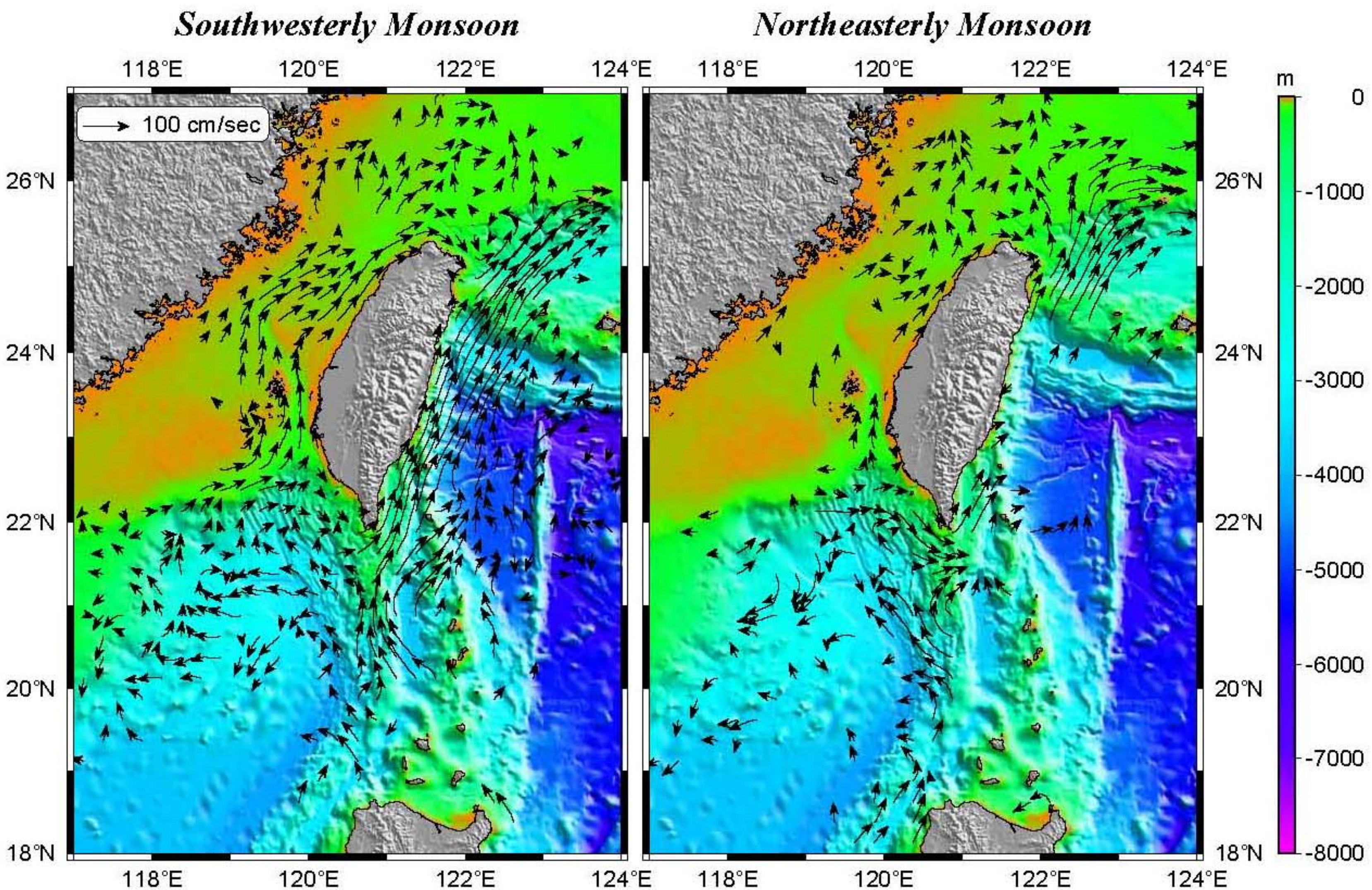
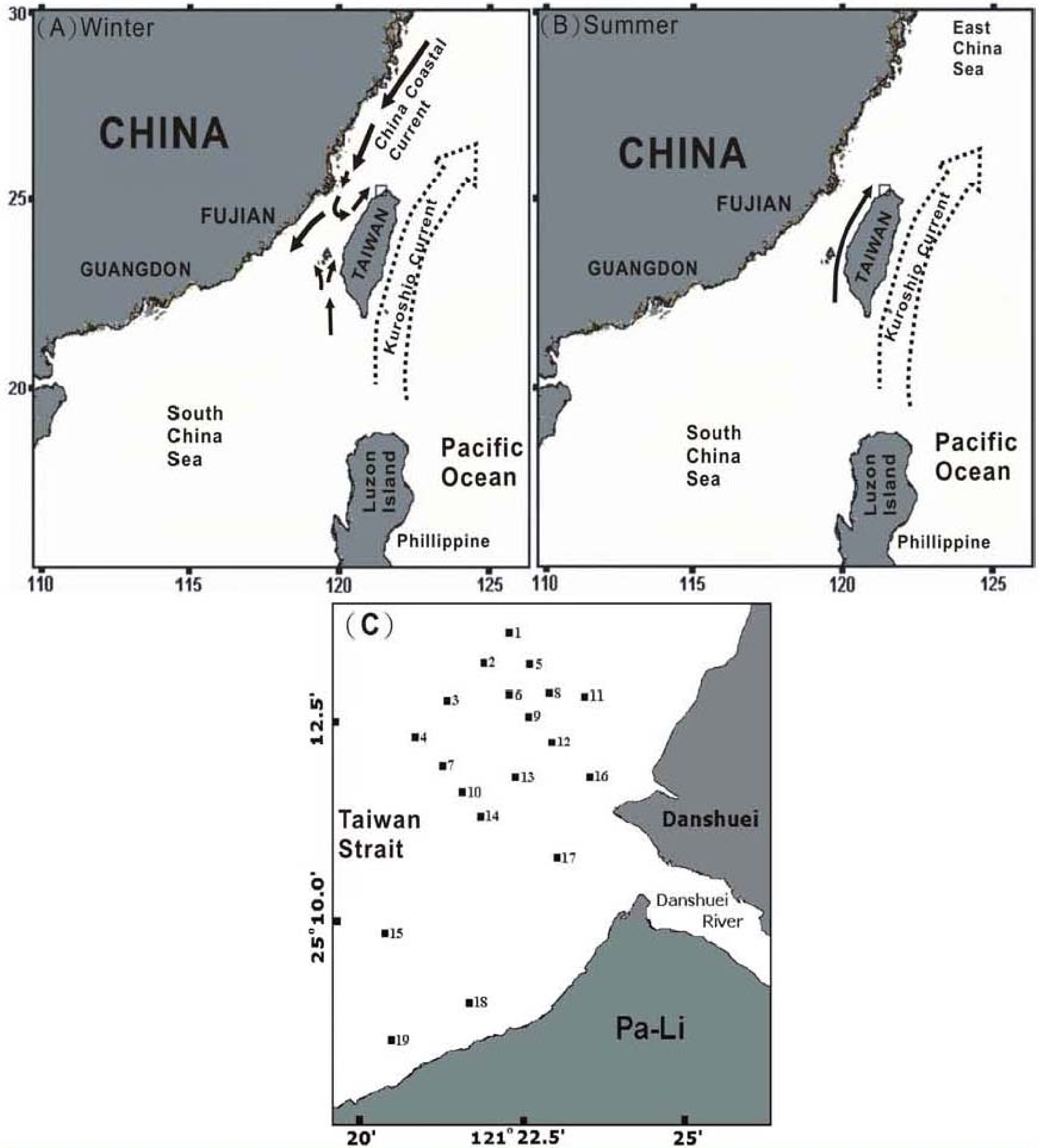


Fig. 5. Composite of the Sb-ADCP current velocity vectors at 30 m depth around Taiwan. The left and right panels represent the seasons of southwesterly monsoon and northeasterly monsoon, respectively.

Hwang et al, JPR, 2006



“Seasonal” Variations of volume Transport in the Taiwan Strait: Penghu Channel

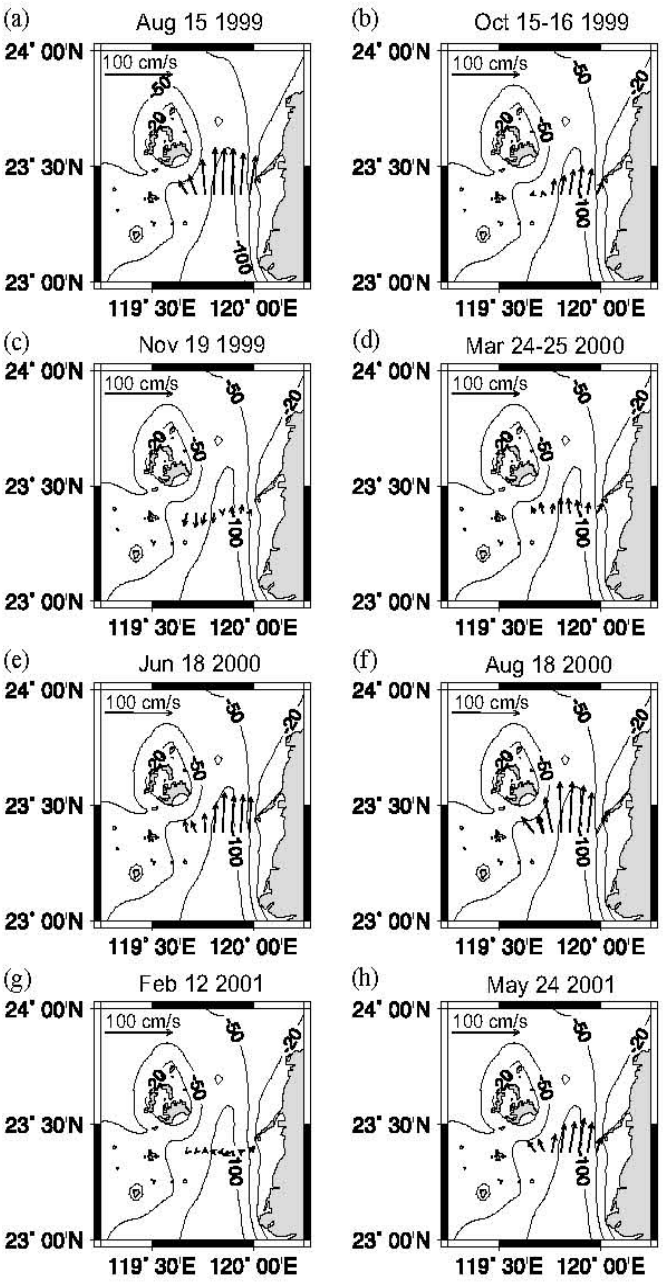


Fig. 5. Horizontal distribution of the depth-averaged velocities calculated from the semidiurnal-averaged currents along the track for the eight measurements.

Sen Jan and Shenn-Yu Chao (DSR 2003)

Continental Slope Flow Northeast of Taiwan
Tang et al, JPO-1999

“The Cold Dome”

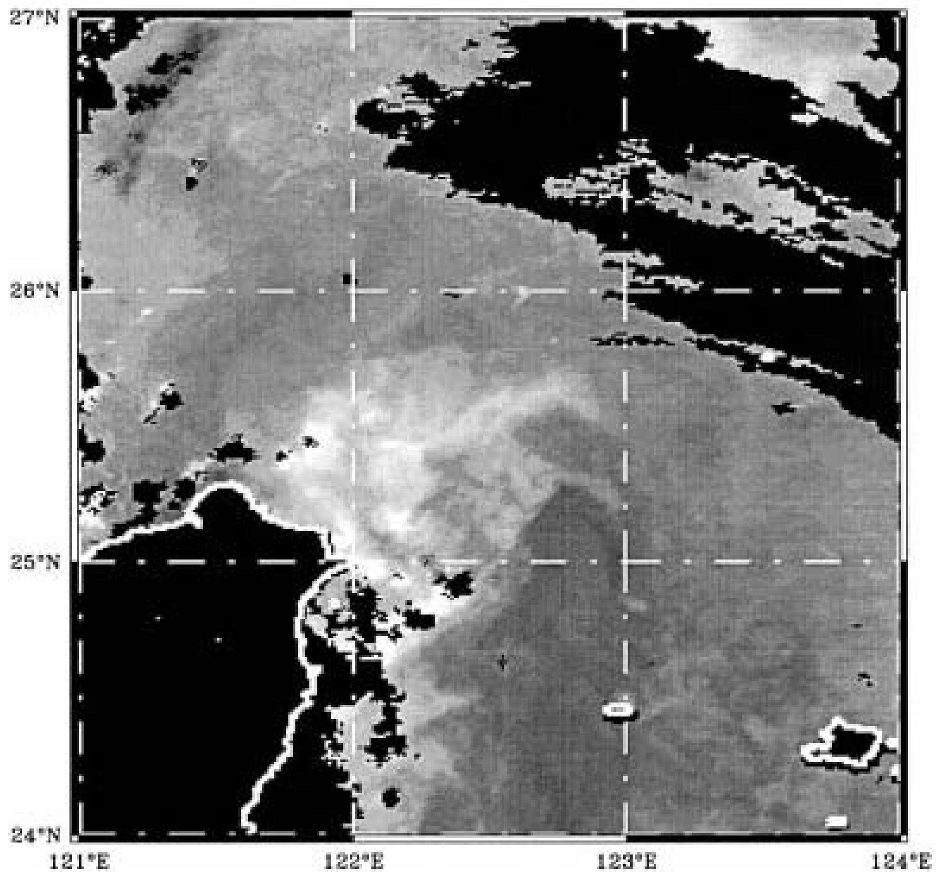


FIG. 6. Infrared image of the sea surface temperature in the study area obtained by NOAA-11 on 12 August 1994. Light shading indicates low surface temperature.

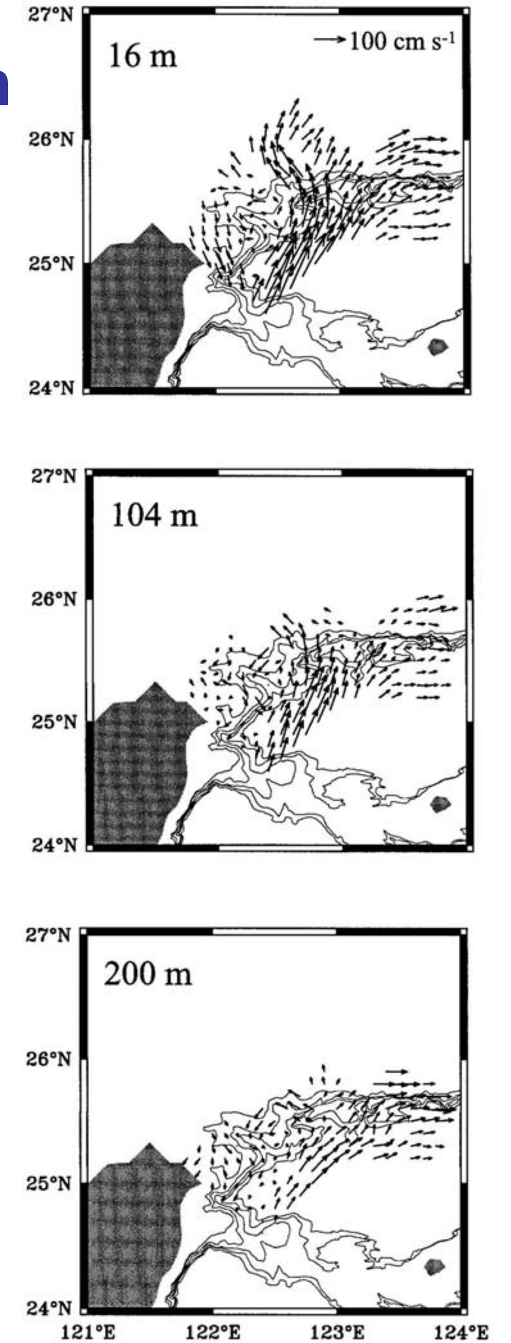


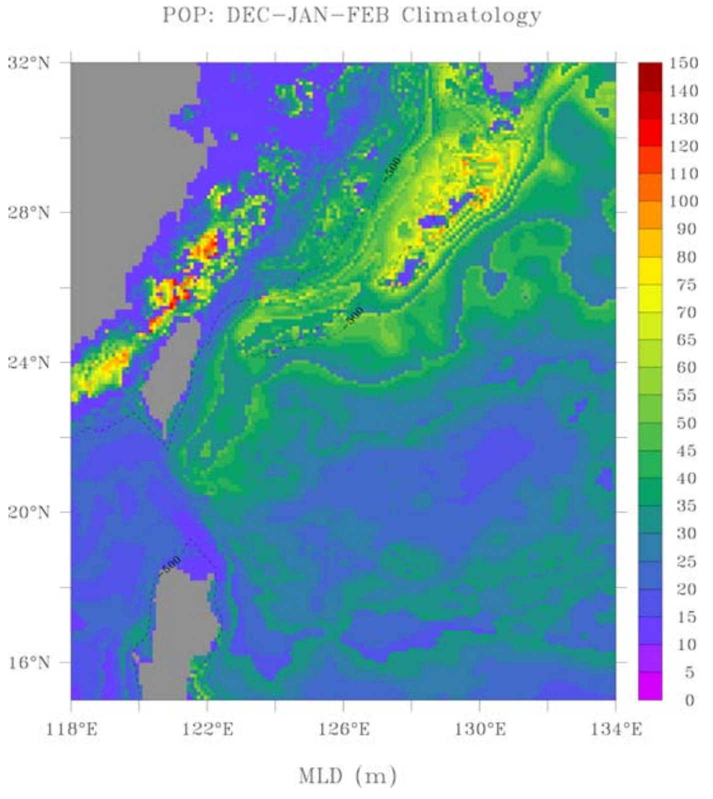
FIG. 2. Phase-averaged current vectors from SADCP observations at depth (a) 16, (b) 104, and (c) 200 m. The bathymetry is shown with thin depth contours from 200 to 1000 m at intervals of 200 m.

The North Philippine/East China Seas Region in POP

by

Julie McClean, Yoo Yin Kim

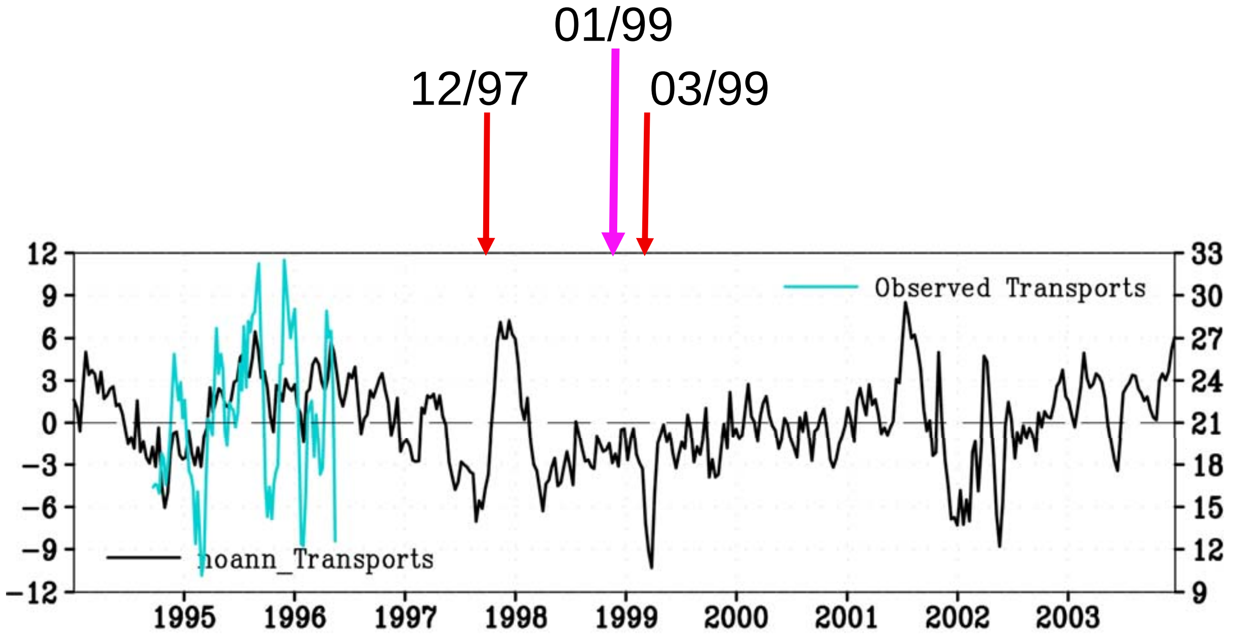
Peter Niiler and Bruce Cornuelle



Mixed Layer Depth:
POP DJF Climatology

Threshold criterion of $\Delta\sigma_\theta$=0.03 kg m^{-3} from 10 m

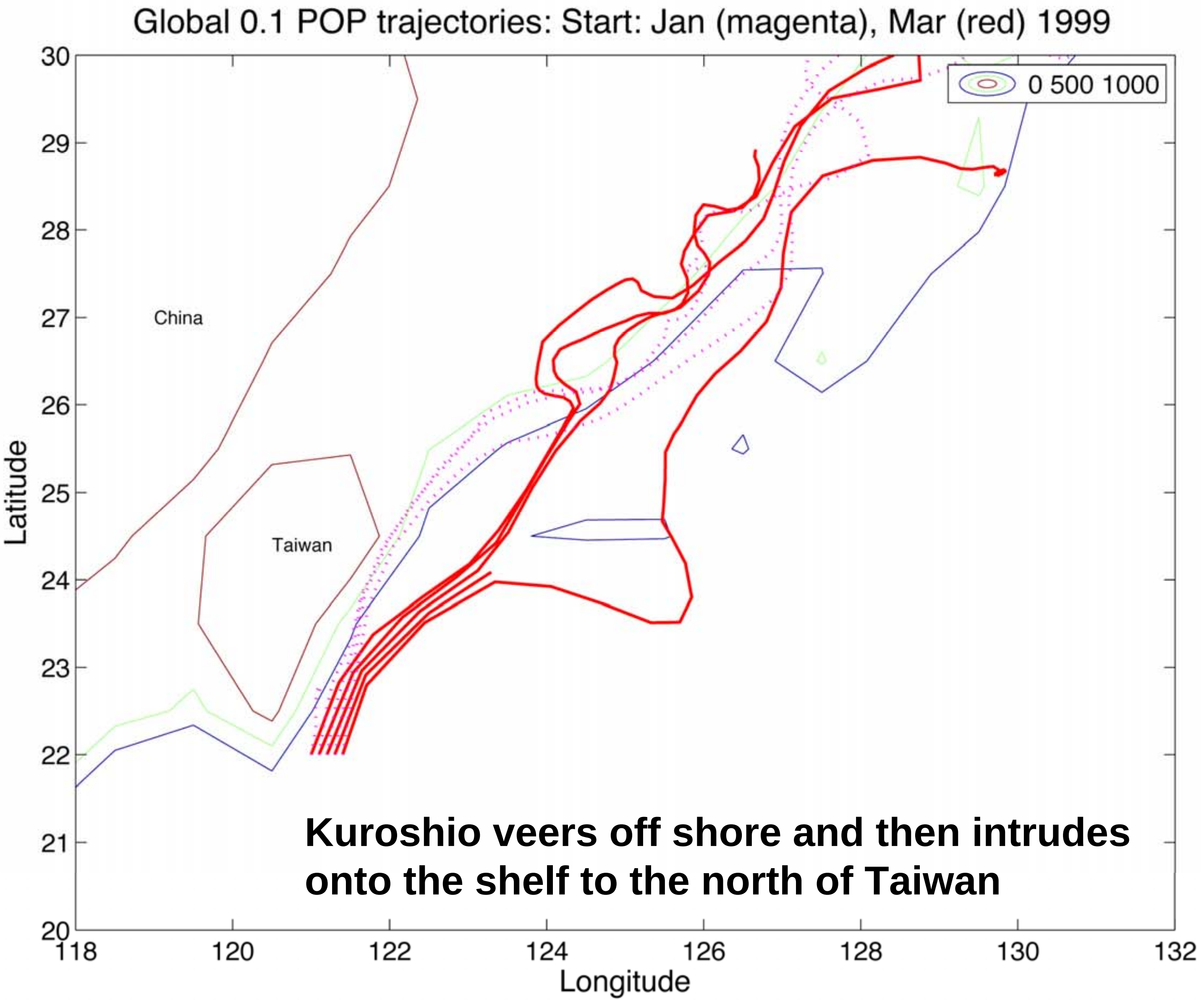
Kuroshio Volume Transport Anomalies (Sv) **across the East Taiwan Channel** from 0.1° POP: mean and annual cycle removed. Observed transports: PCM-1 array from Zhang et al. (2001, JGR)



Do POP trajectories initialized to the east of Taiwan in the Kuroshio intrude onto the East China Sea shelf during low transport events as is observed? Consider the 03/99 event.

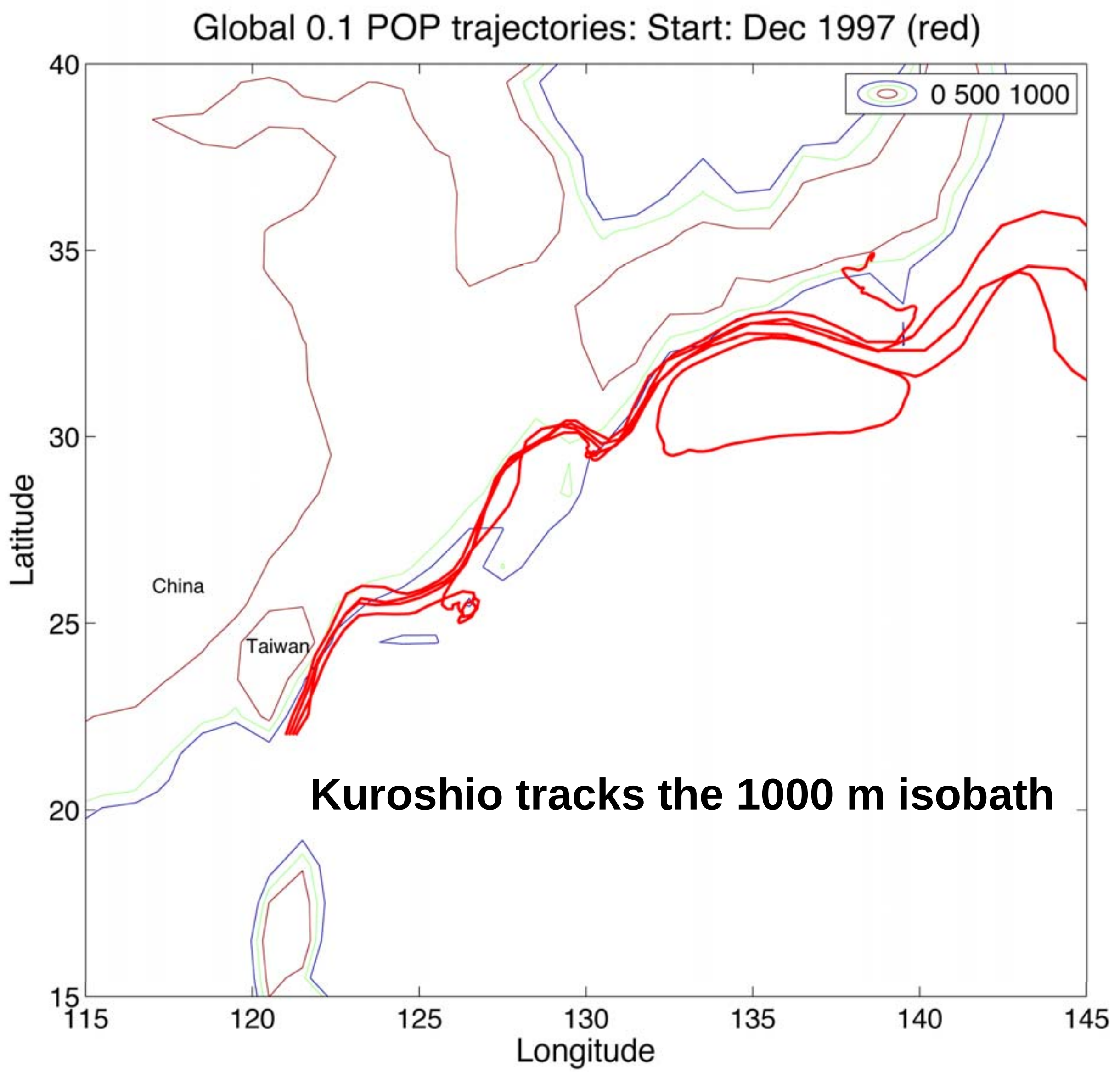
Low Transport Event: Red Trajectories

YES!

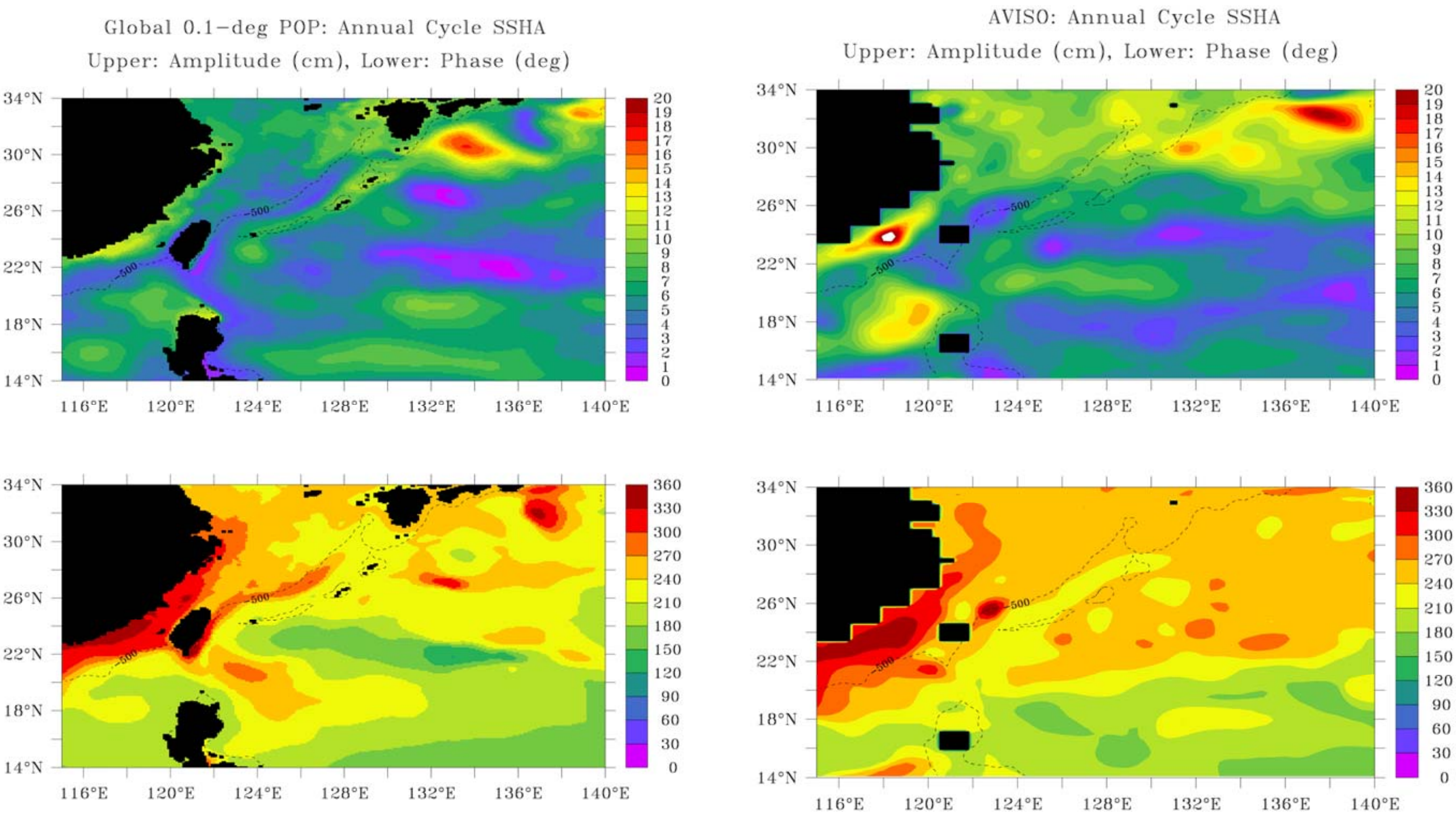


Magenta: zero anomaly transport case

High Transport Event: Red Trajectories



Sea Surface Height Anomaly Annual Cycle:1994-2001: Amplitude & Phase: 0.1° POP (LHS), T/P & ERS(RHS)



Predictability of the transport in the PCM-1 region from Sea Surface Height (SSH)

Bruce Cornuelle, Julie McClean and Yoo Yin Kim

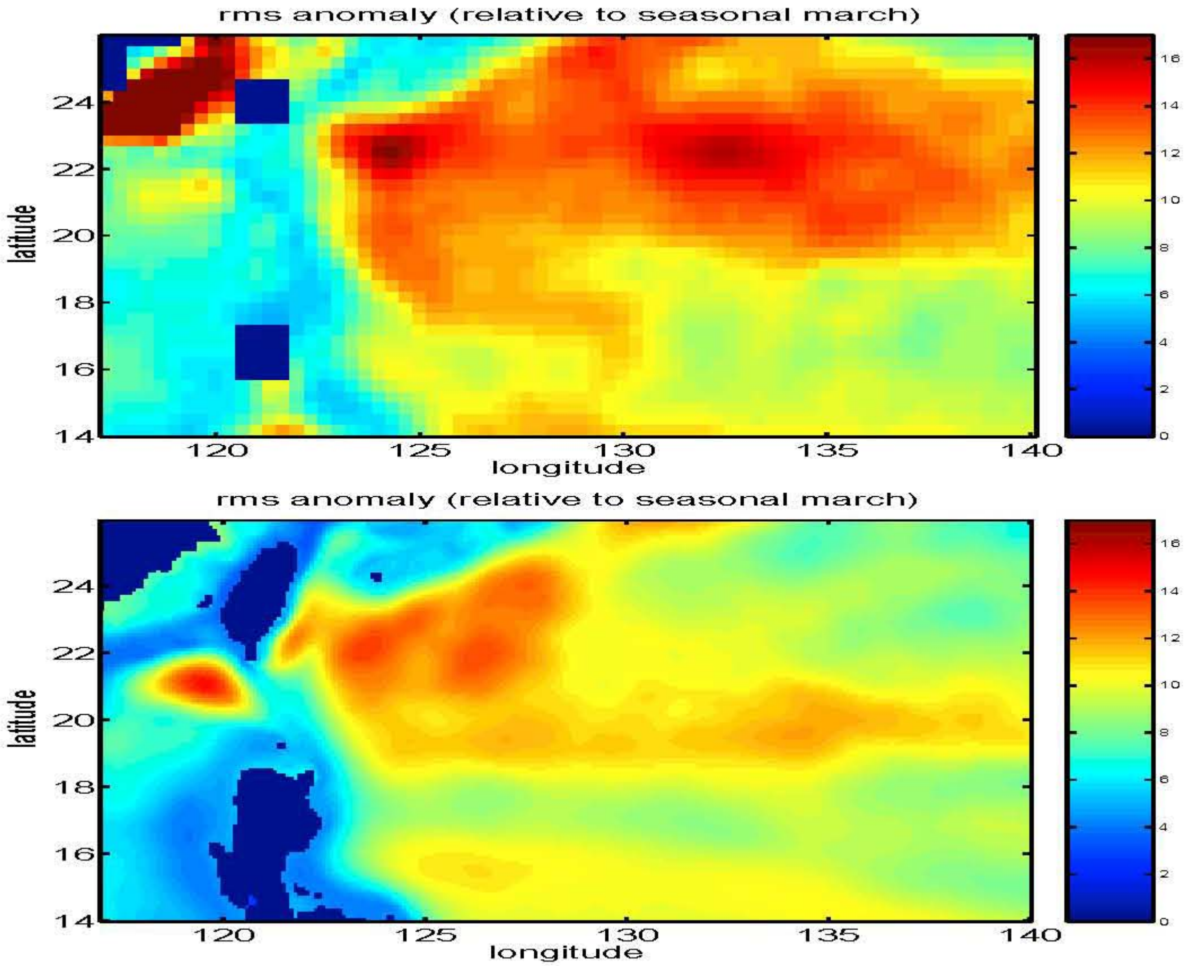


Figure 3. RMS SSH. Averaged from 10 years of weekly data. Top panel: AVISO, bottom panel: POP model. (14 26 domain).

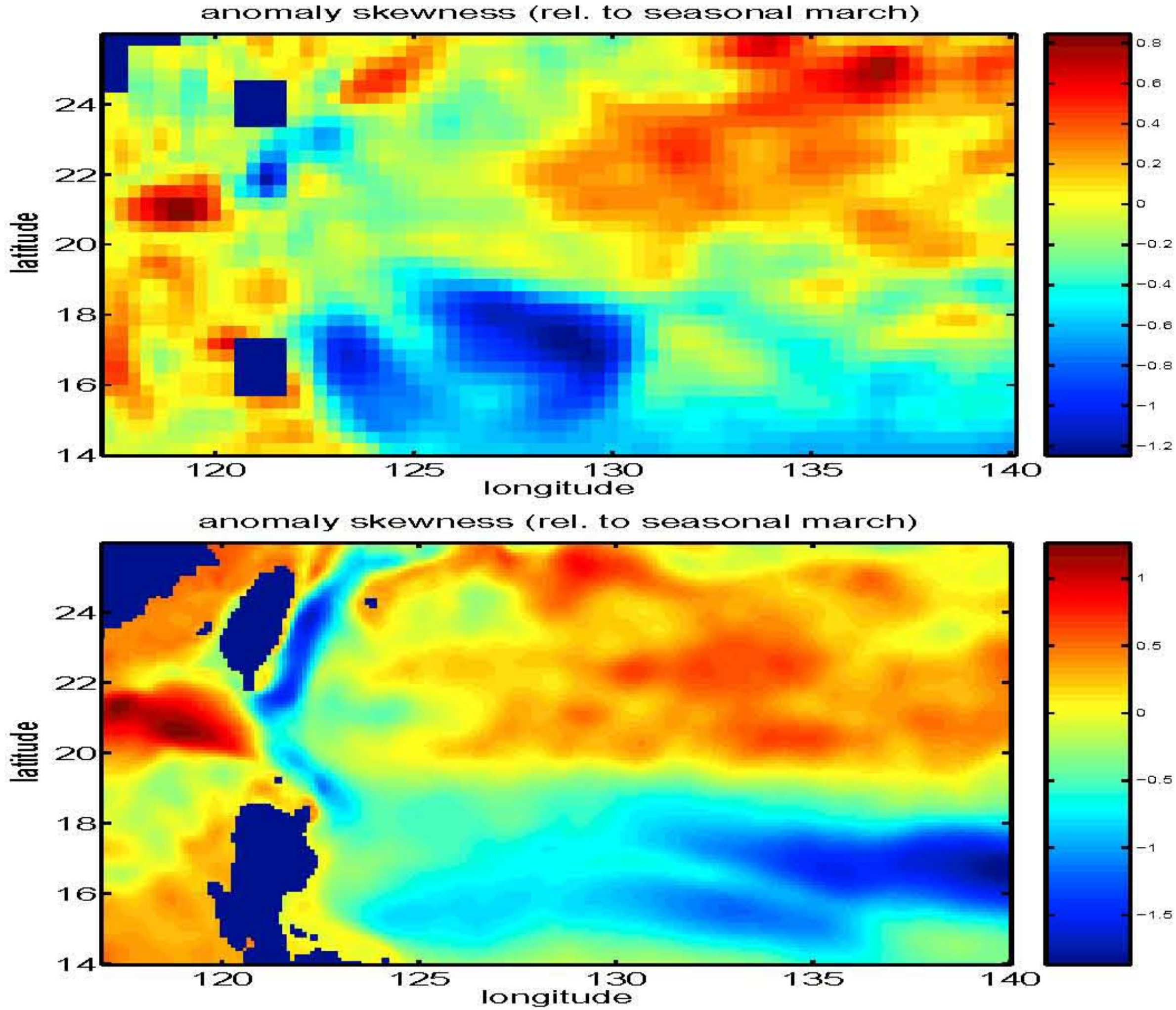


Figure 4. SSH skewness. Top panel: AVISO, bottom panel: POP model. (14 26 domain).

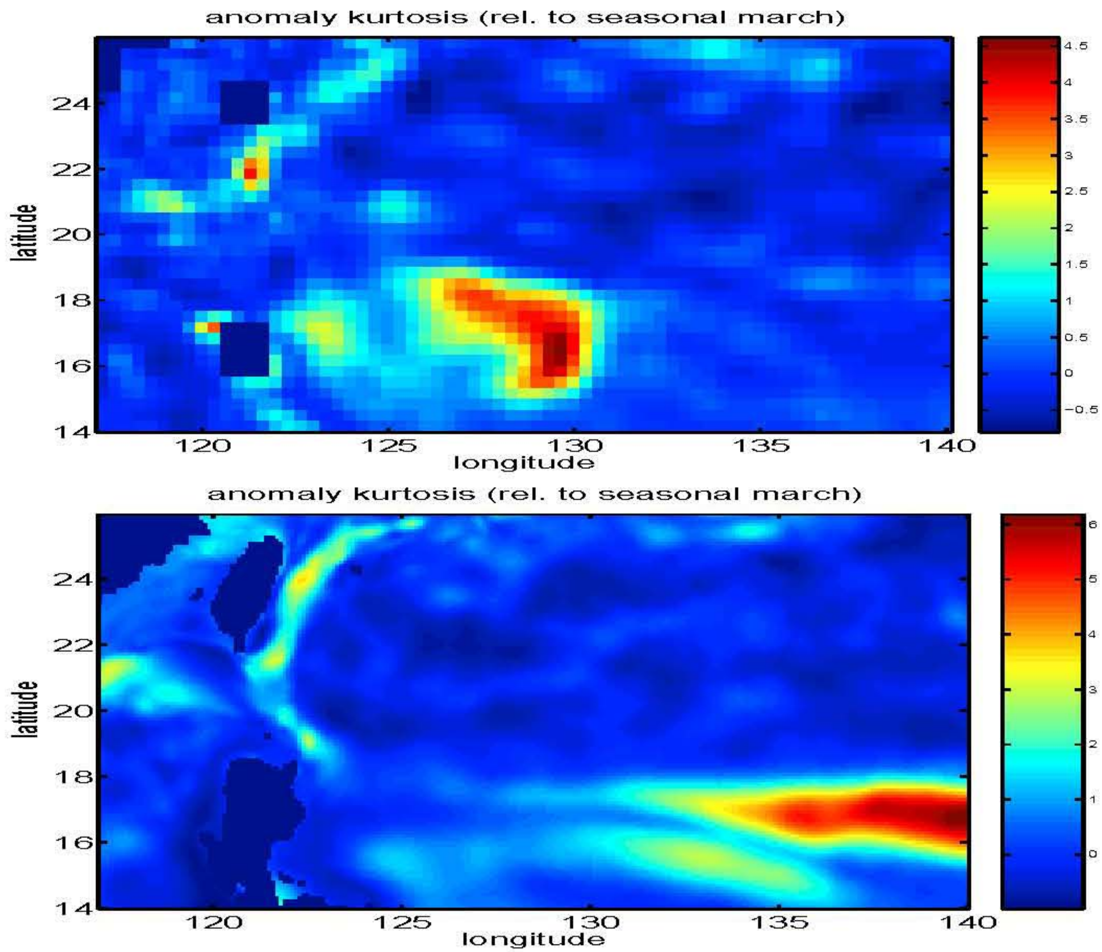


Figure 5. SSH kurtosis. Top panel: AVISO, bottom panel: POP model. (14 26 domain).

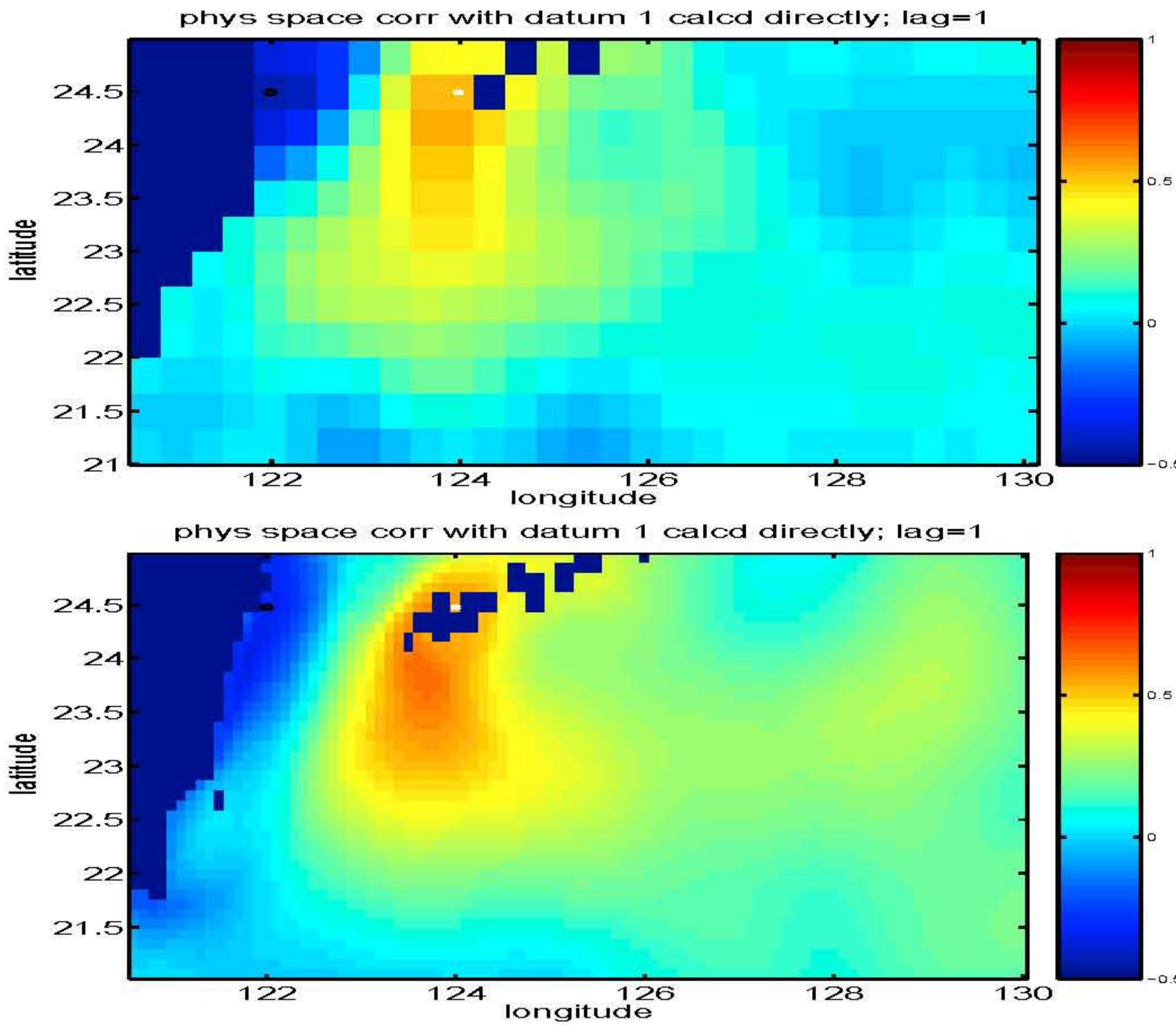


Figure 35. Correlation between SSH difference across the strait and the rest of the domain in the past. One week lag. Top panel: AVISO, bottom panel: POP model. (small domain).

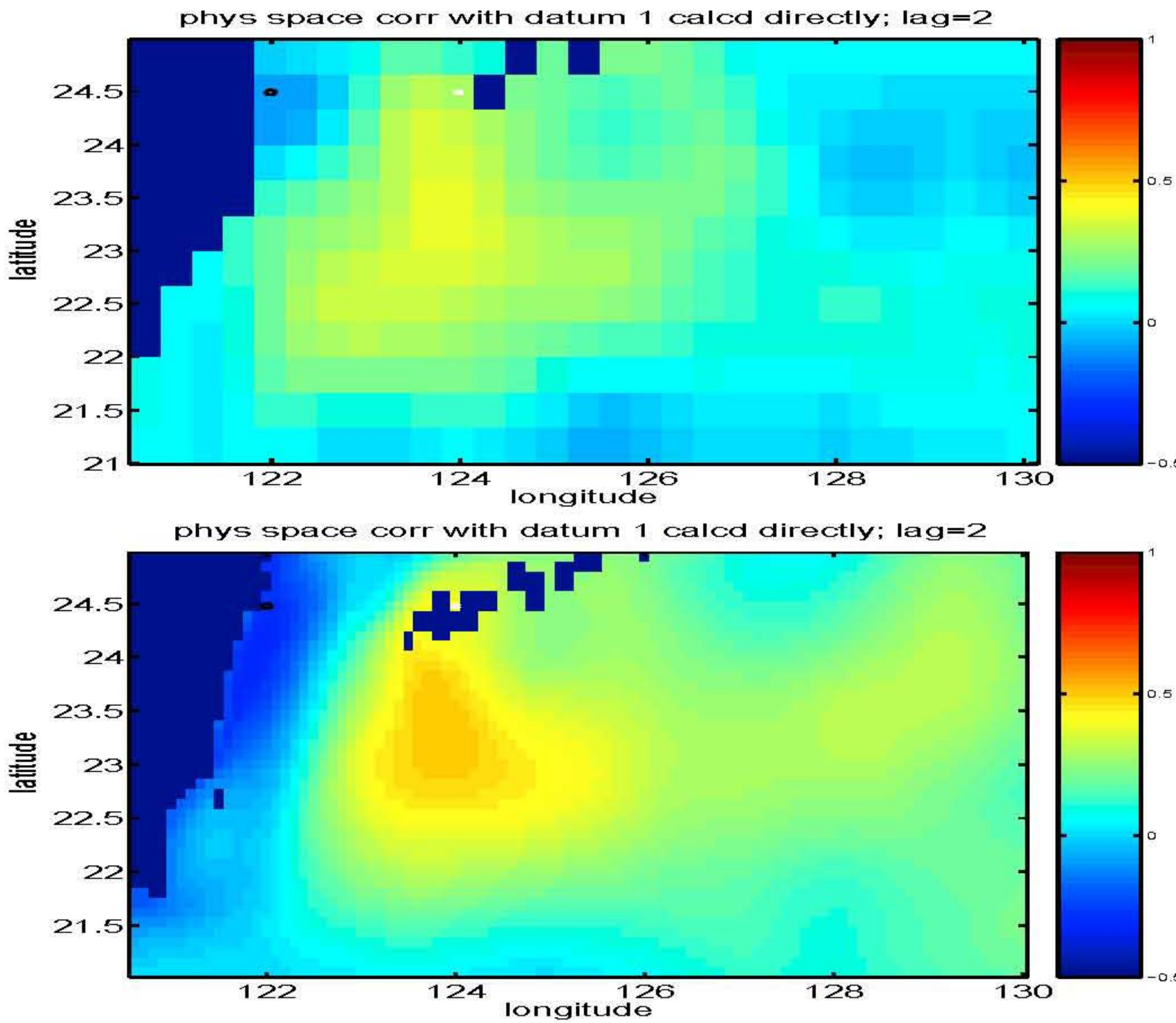


Figure 36. Correlation between SSH difference across the strait and the rest of the domain in the past. Two week lag. Top panel: AVISO, bottom panel: POP model. (small domain).

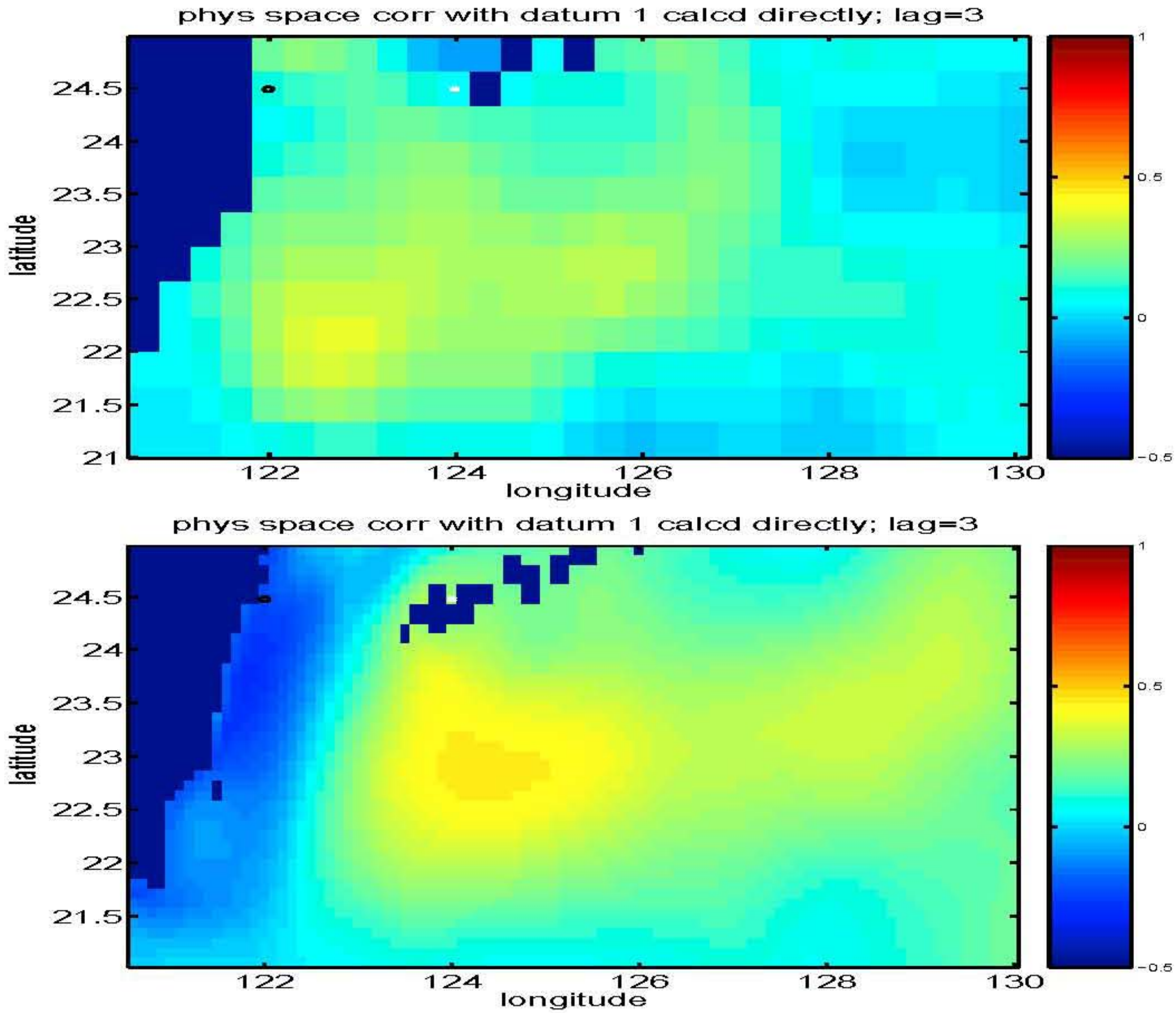


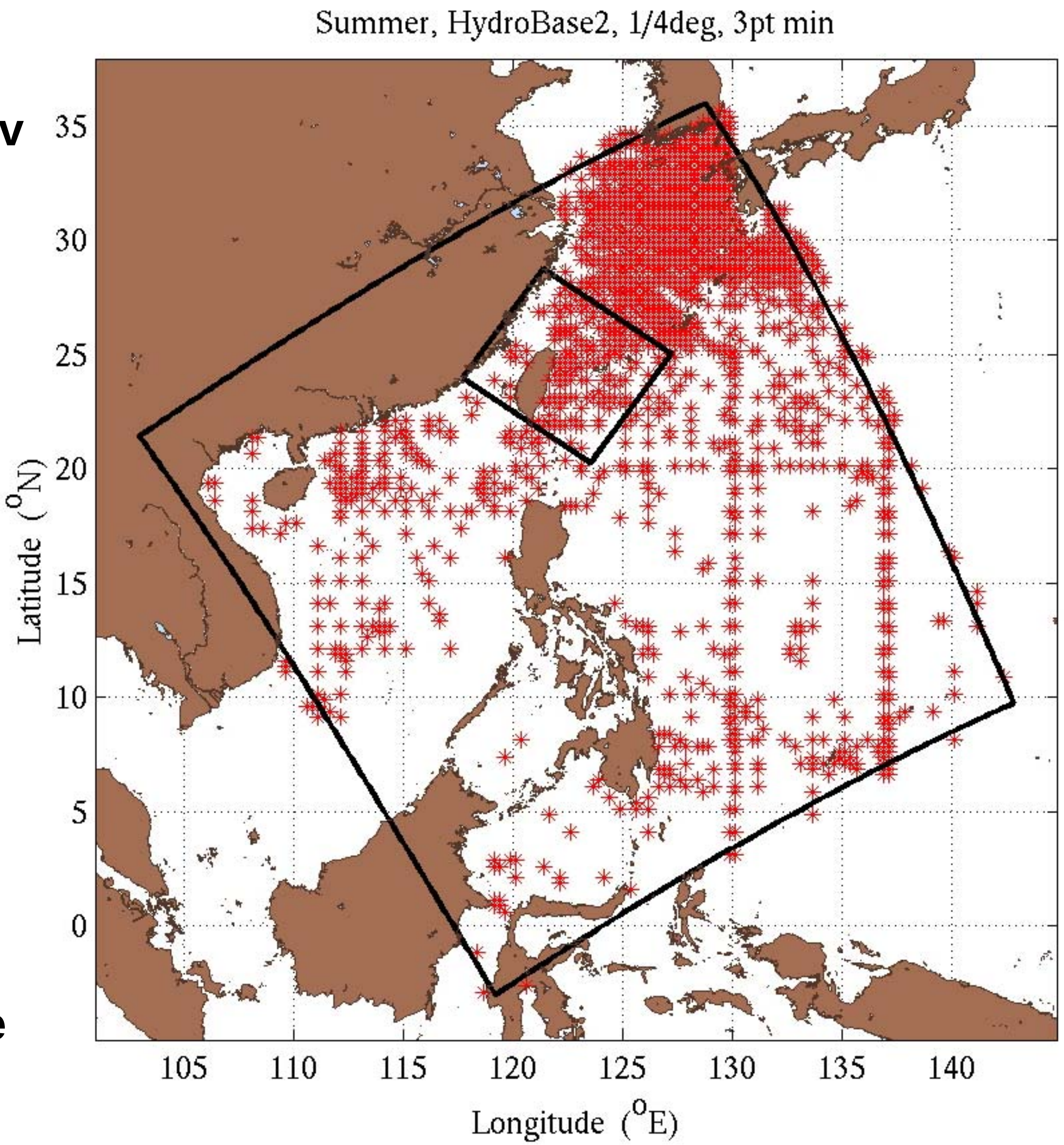
Figure 37. Correlation between SSH difference across the strait and the rest of the domain in the past. Three week lag. Top panel: AVISO, bottom panel: POP model. (small domain).

Mesoscale Modeling and Taiwan Straits/Kuroshio effects

Lermusiaux, Haley and Logutov

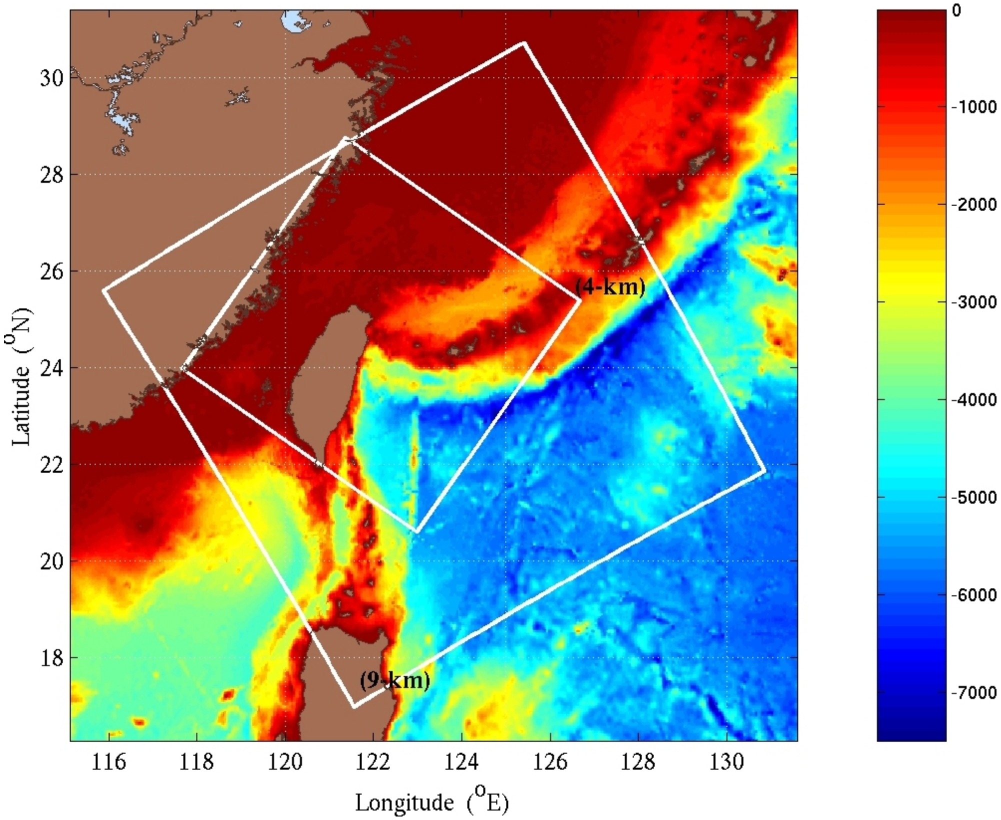
Where to sample?

What controls the cold dome?

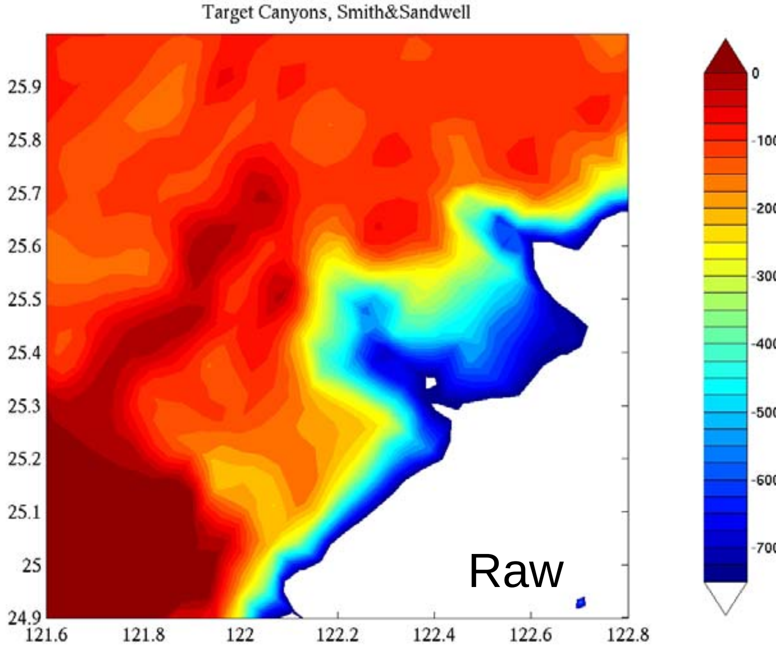


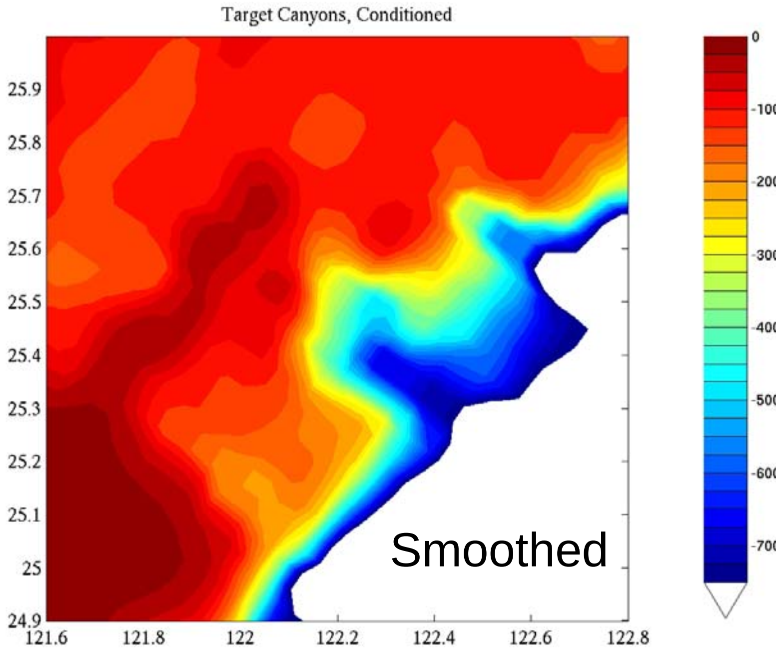
Position of hydrographic profiles used to build a climatology (with HydroBase and LOC software)

Bathymetry and Uncertainties (Data and Smoothing)

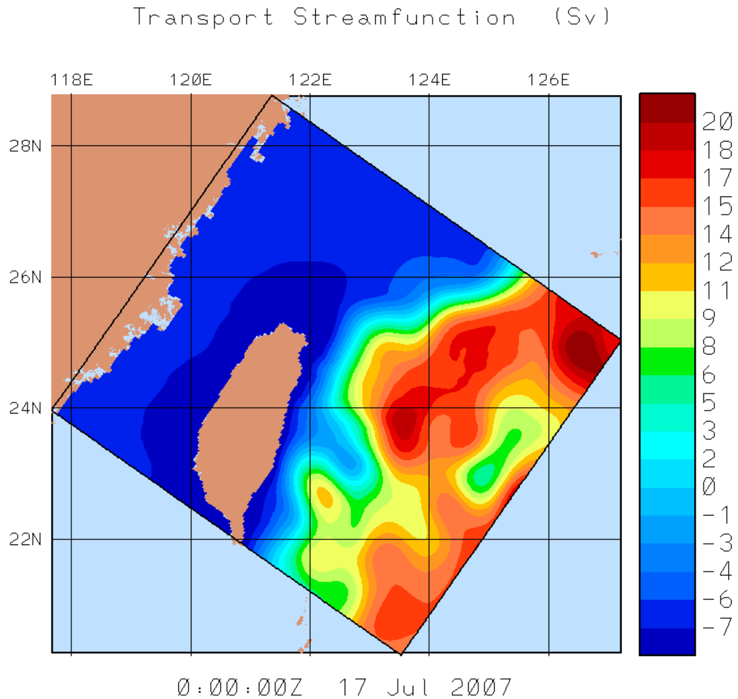


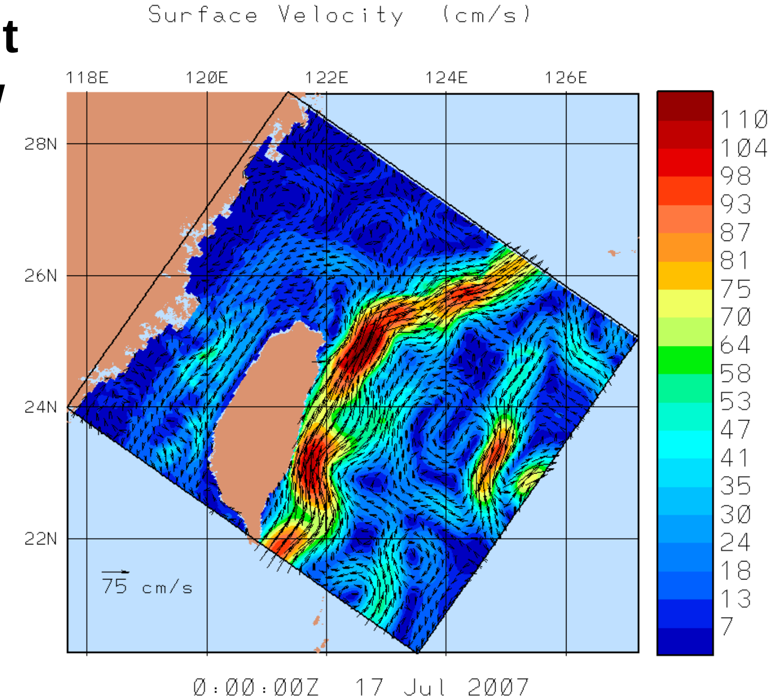
Smith and Sandwell (as ETOPO2)



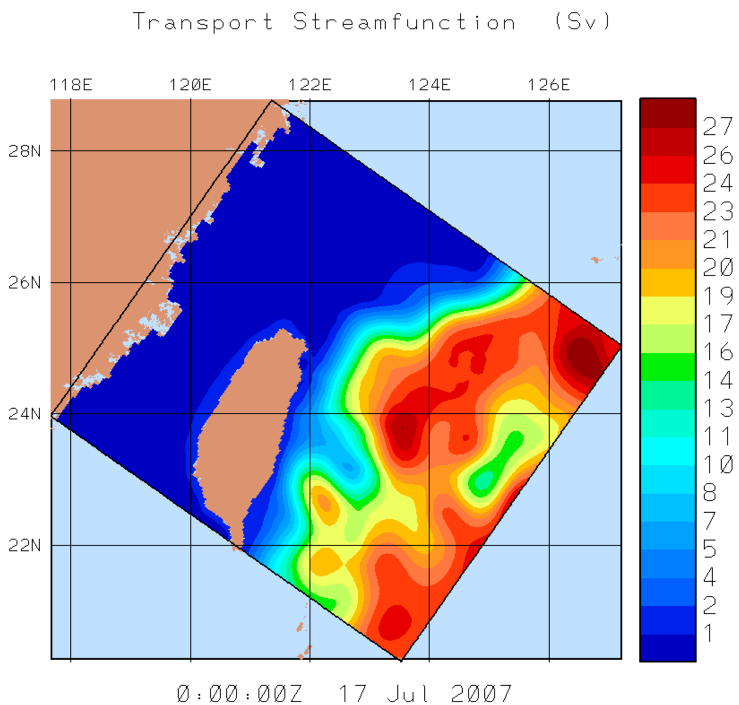


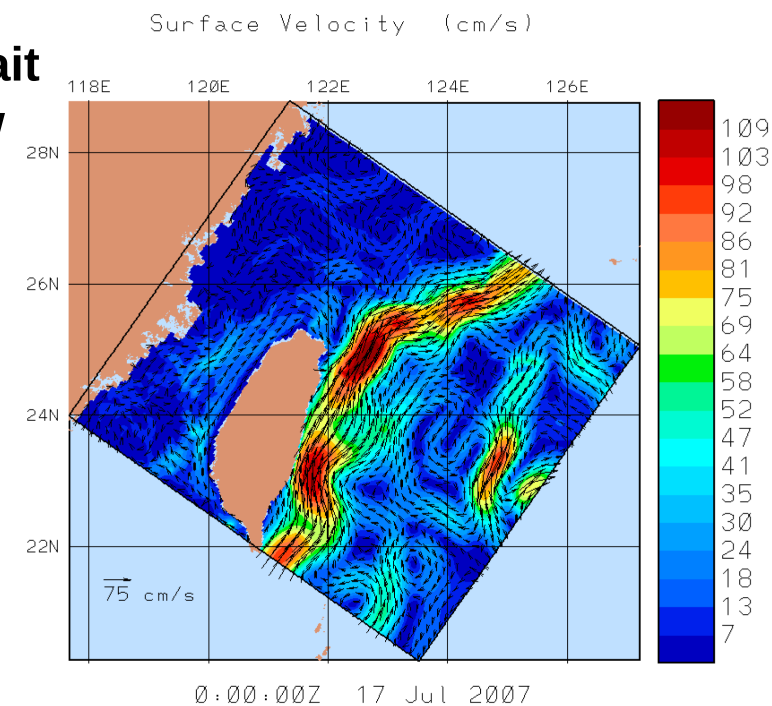
No Taiwan Strait Northward Flow



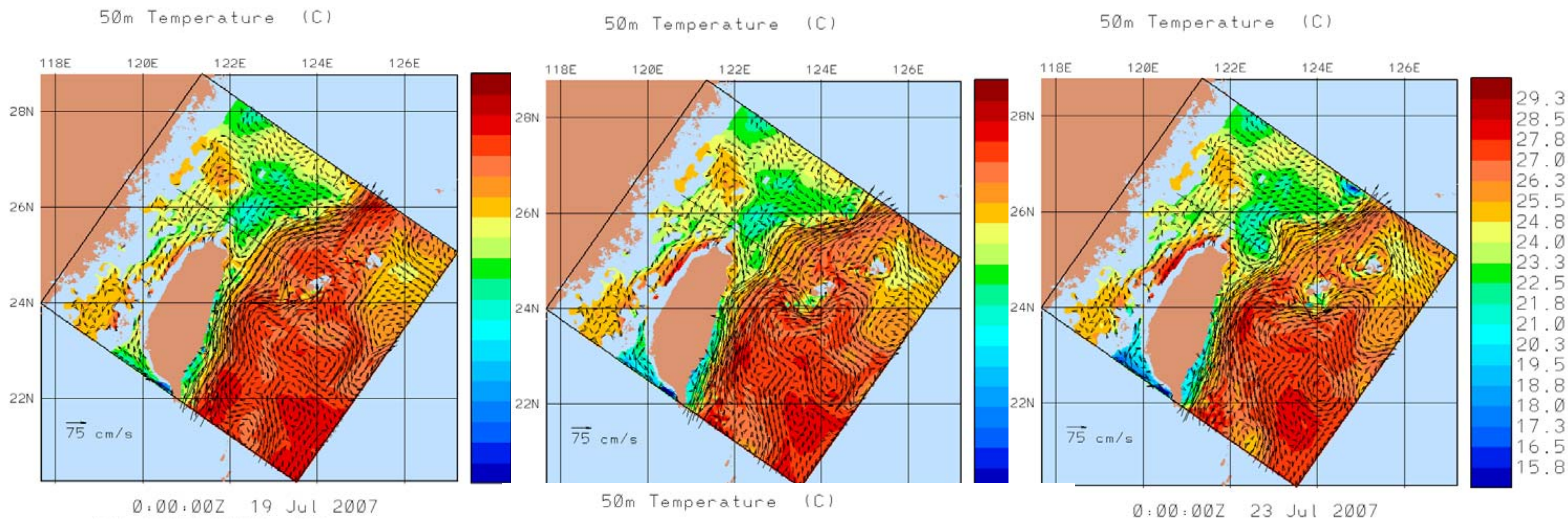


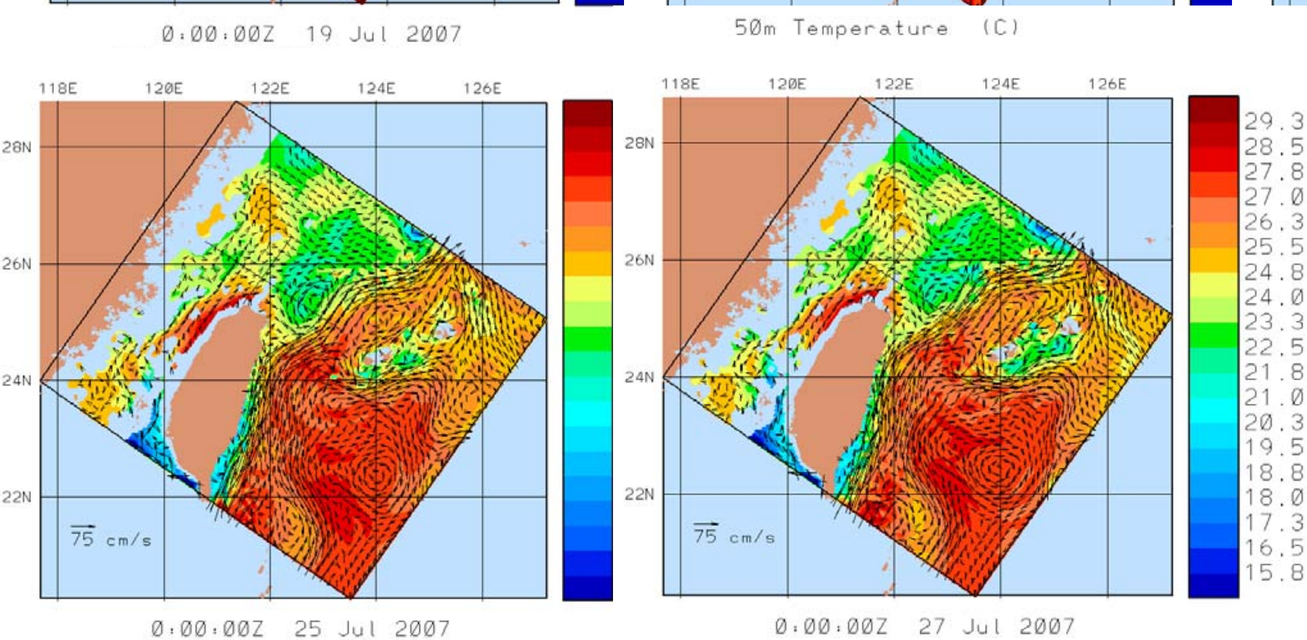
1Sv Taiwan Strait Northward Flow





Temperature at 50m, 1Sv Taiwan Strait Northward Flow

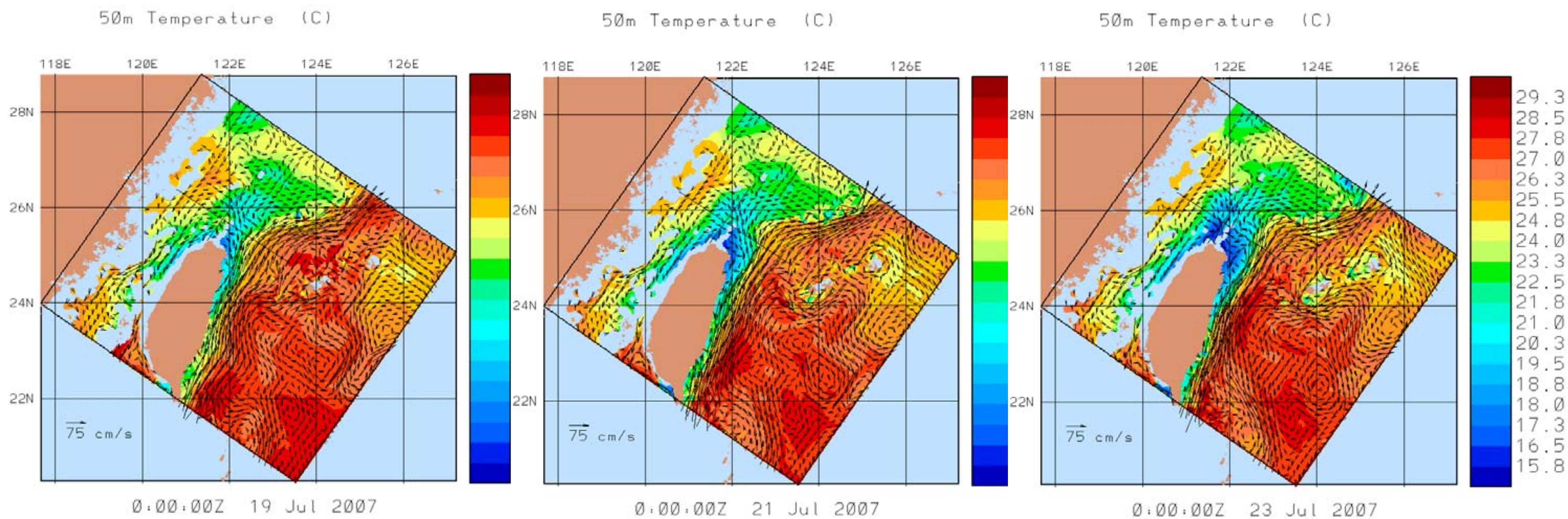


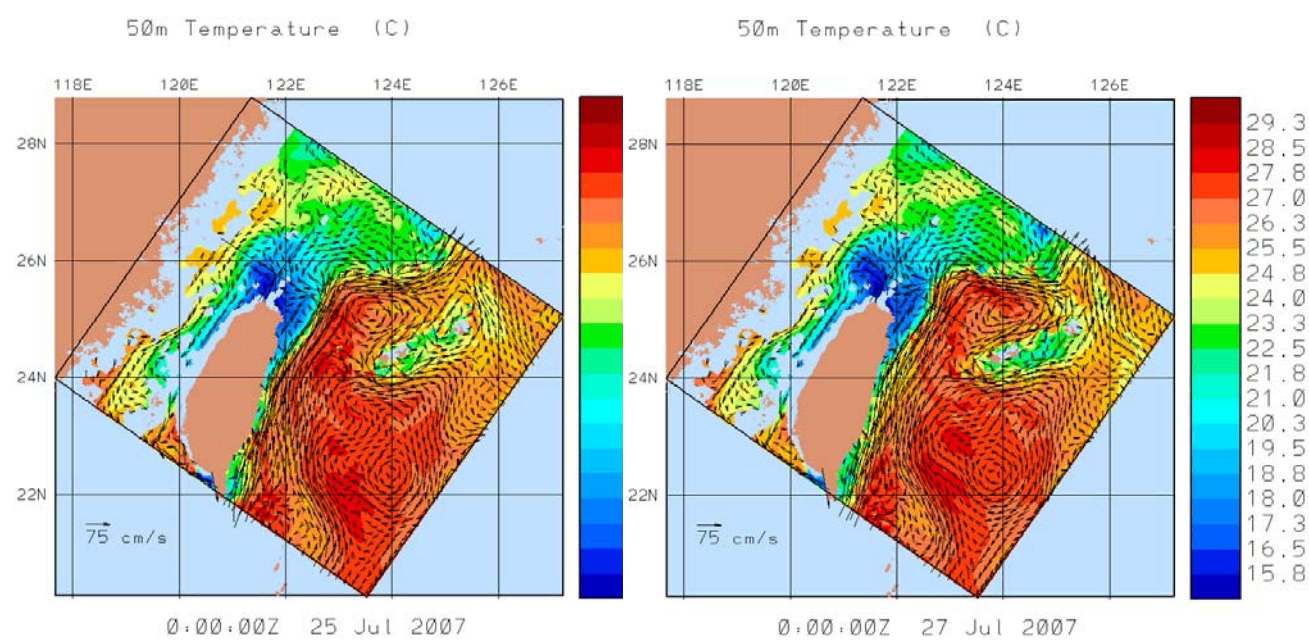


Eddies (Cyclonic) form and are advected

Limited Kuroshio Intrusion

Temperature at 50m, No/Weak Taiwan Strait Northward Flow





Cold Dome forms

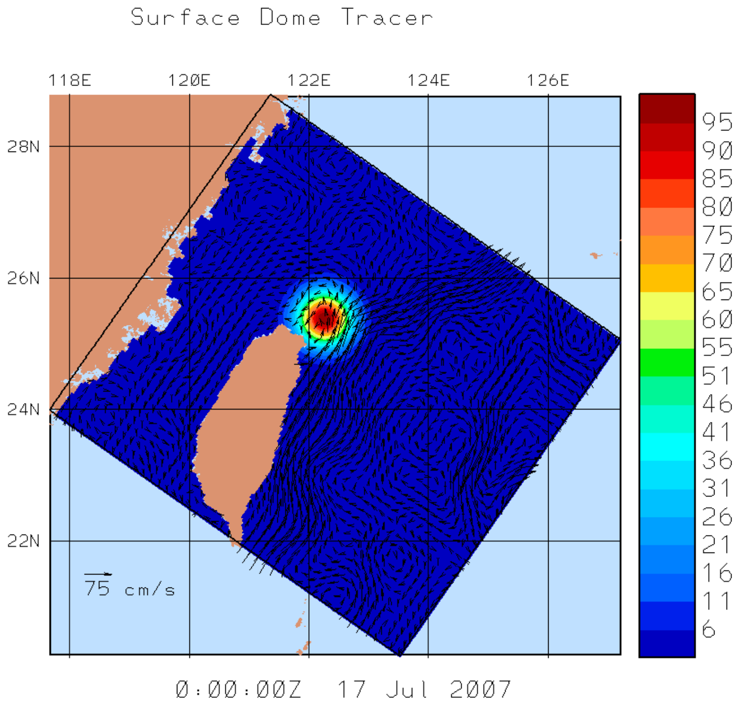
Ageostrophic effect of Jet above topography and with no shelf support

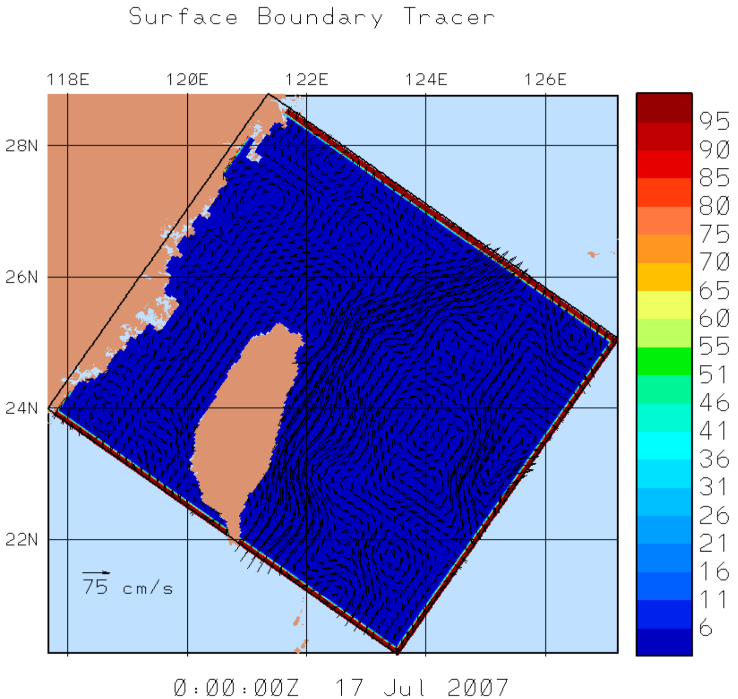
Vertical upwelling cell

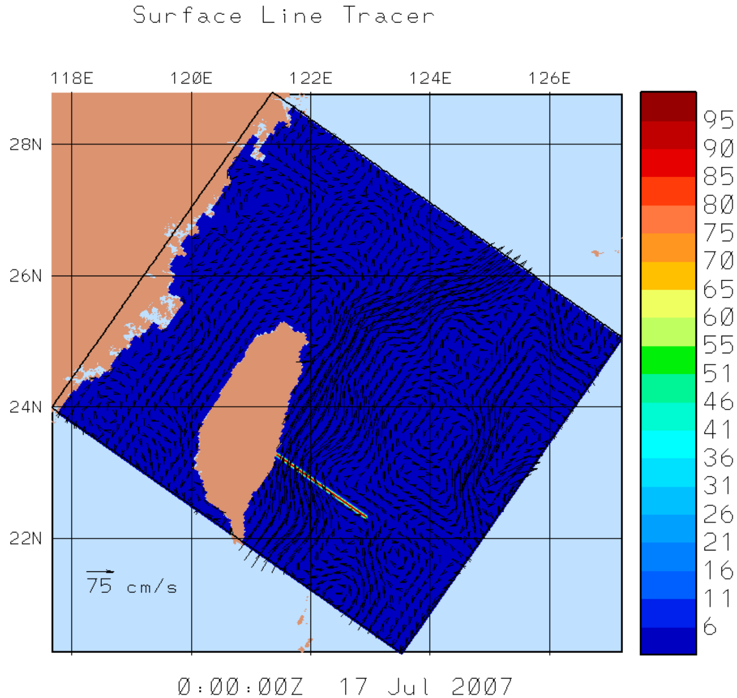
Intrusion

Impacts of Open Boundary, Local (Dome) and Remote (Kuroshio) Measurements

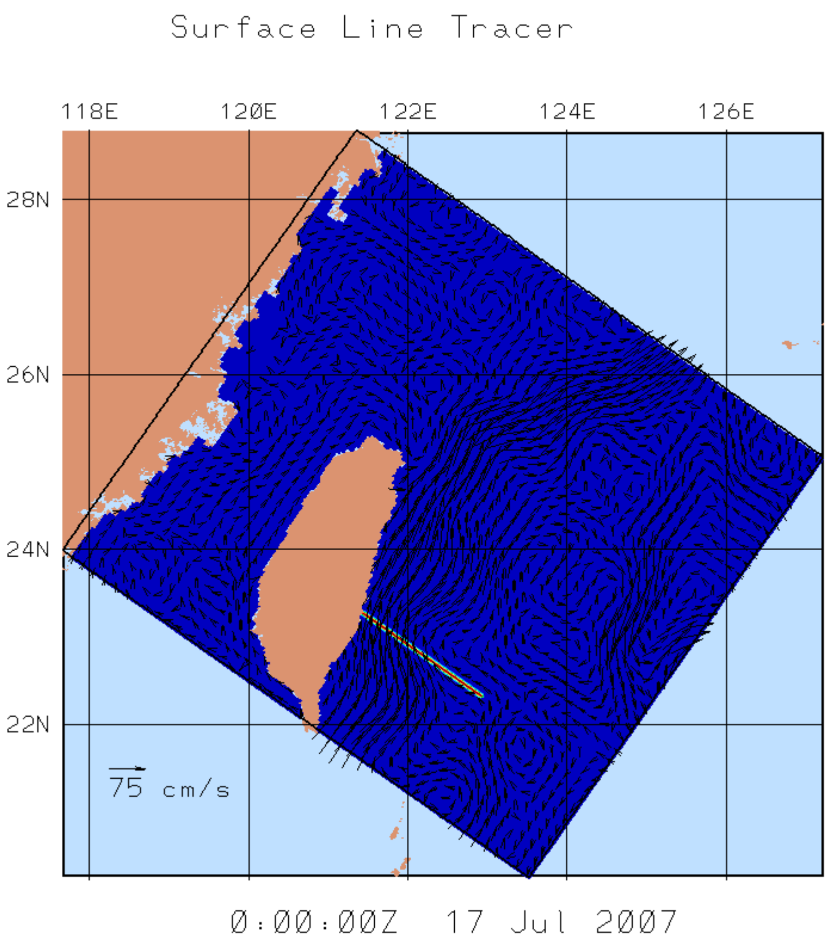
“Fake Tracer” Simulations

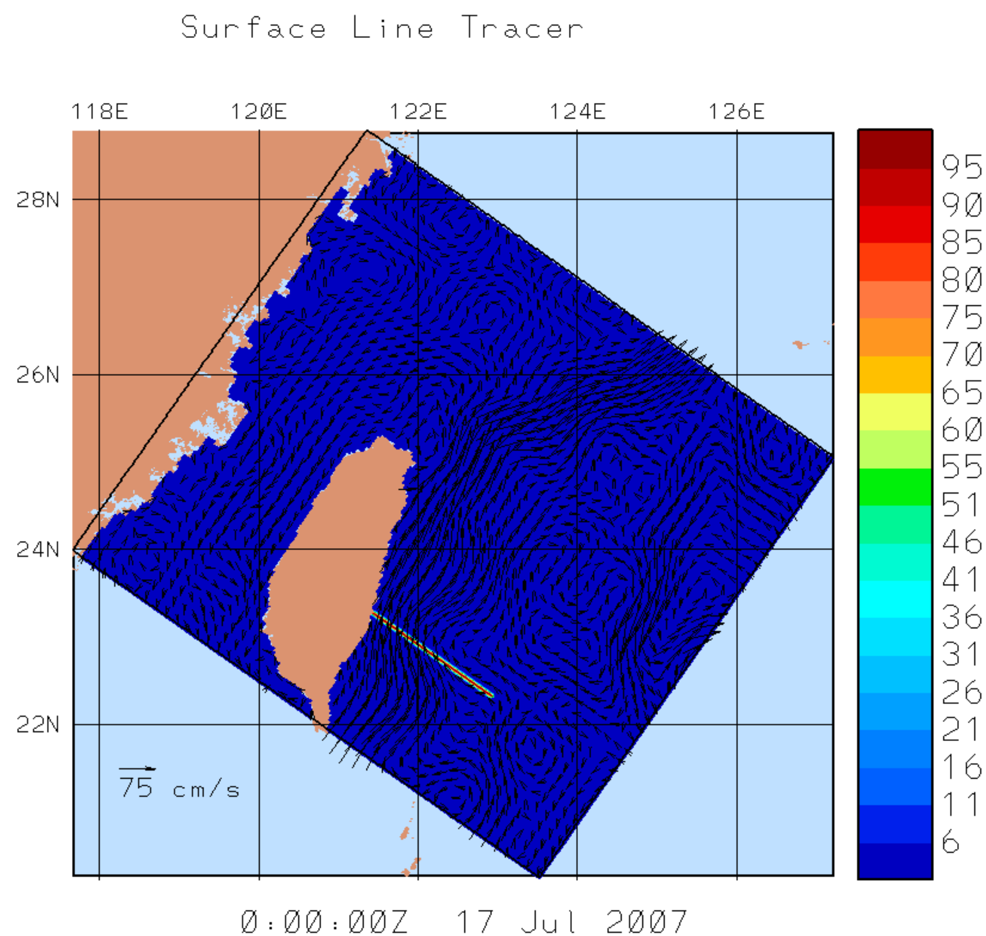






Impacts of Remote Data (Kuroshio- East of Taiwan)

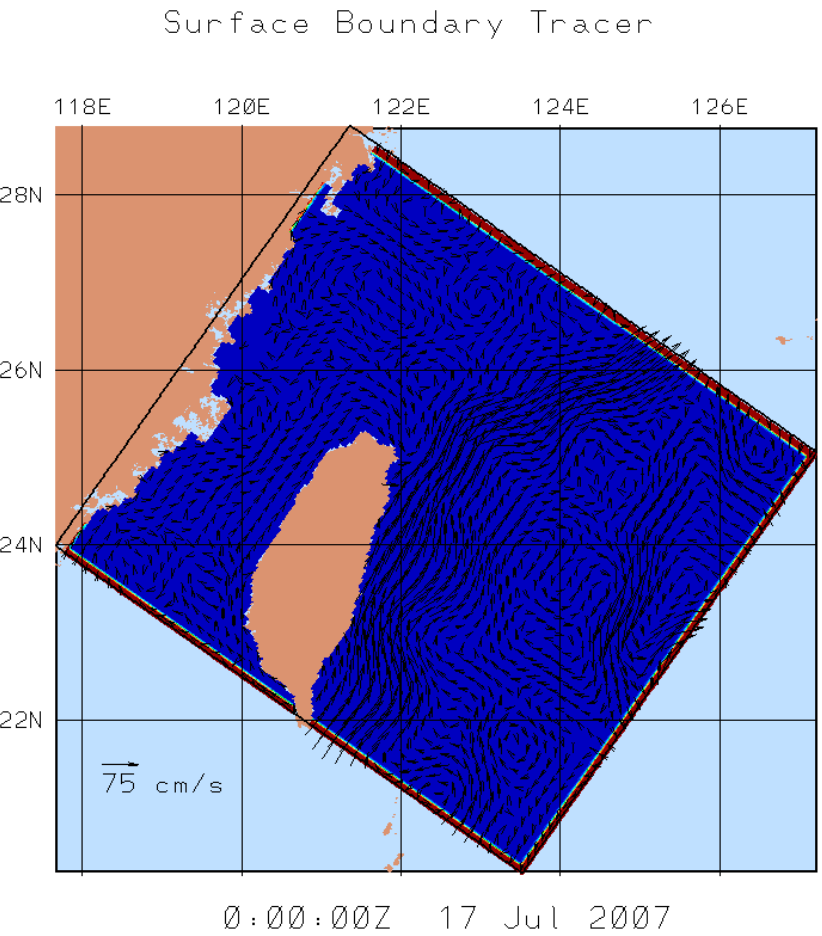


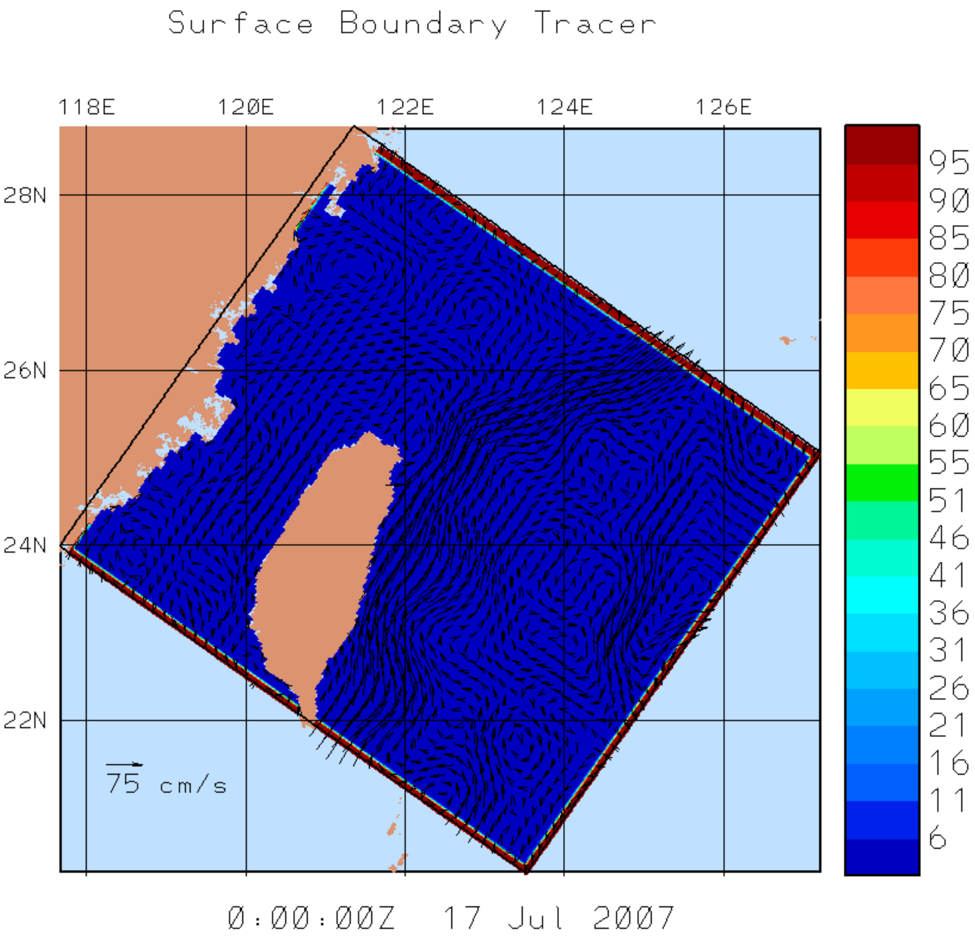


1Sv Taiwan Strait Northward Flow

No Taiwan Strait Northward Flow

Impacts of Open Boundary

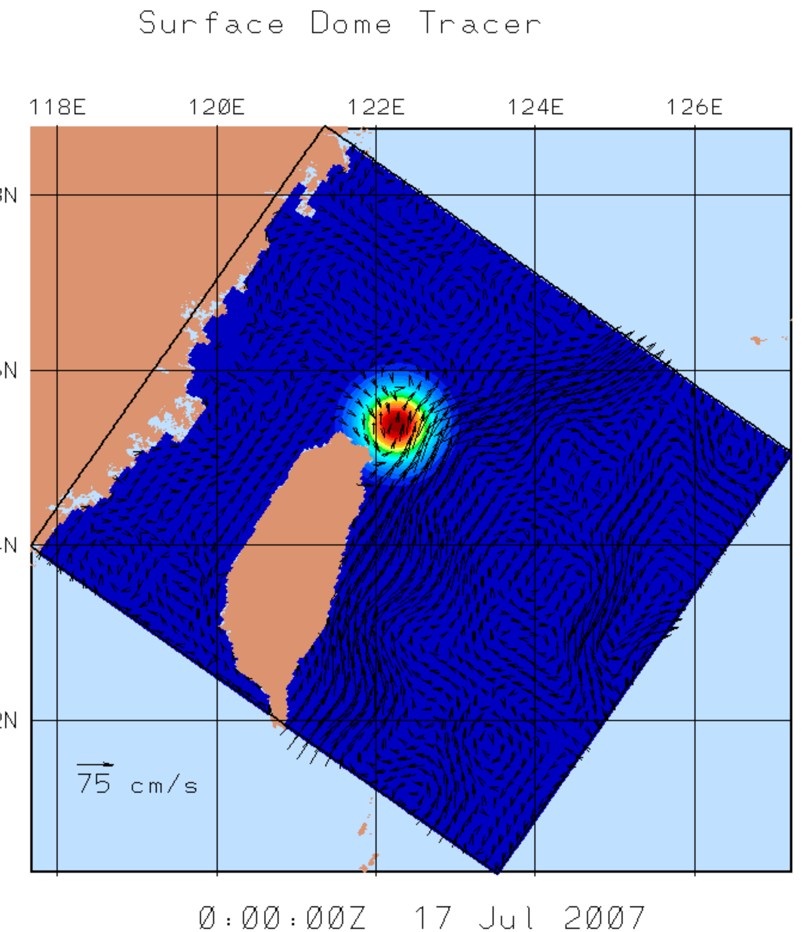




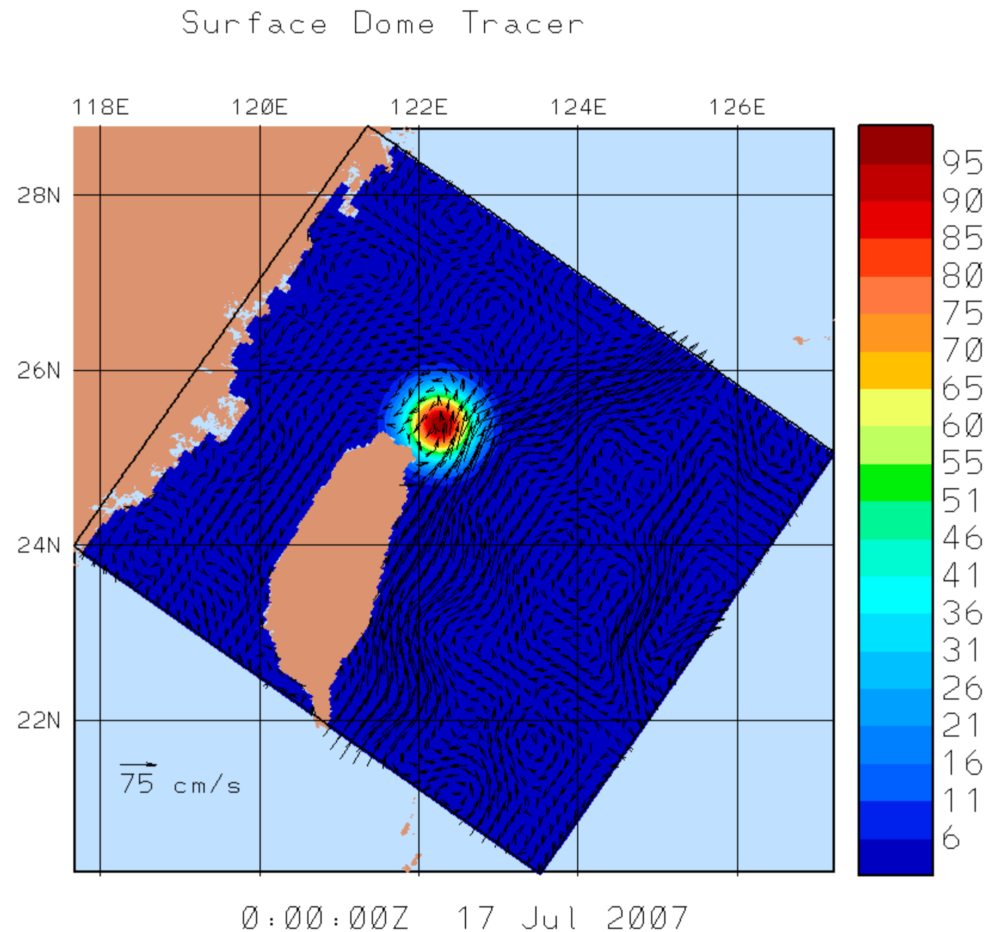
1Sv Taiwan Strait Northward Flow

No Taiwan Strait Northward Flow

Impacts of Local (Dome) Measurments

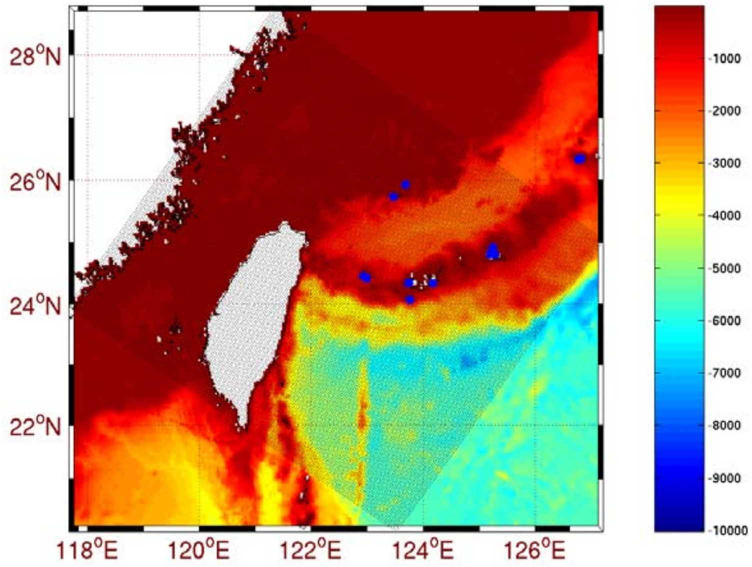


1Sv Taiwan Strait Northward Flow



No Taiwan Strait Northward Flow

Tidal Processes and Modeling



Available Tidal Gauges (blue dots)

Bottom Topography [m]

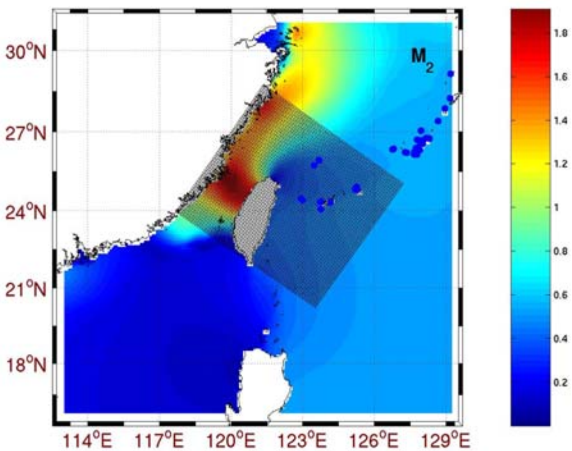
- **Baro tidal currents 50-100 cm/s**
- **Internal tides**
- **Tidal mixing fronts?**

- **HOPS forced at bndry with regional estimates of baro tides**

1. **Baro tides are predominantly semi-diurnal, with M2, S2, K1 and O1 most important (55%, 25%, 10%, 5%)**
2. **We developed software to compute regional high-resolution baro tides, given B.C.s from global model.**
   (Solves shallow water equations in the frequency domain. Uses representer method to assimilate tide gauges/adcps)
3. **OSU global tidal model** (assimilates Topex/Poseidon altimetry) **utilized to specify B.C.s.**
4. **Diurnal constituents close to critical freq. within the domain (e.g. K1 period ~23.93 hrs and T inertial 2*pi/f ~23.93 hrs at lat=30). Coastal modes might develop in solution for diurnal although not clear if they are real**
5. **ADCP data (historical Ok) desirable for validating diurnal constituents**

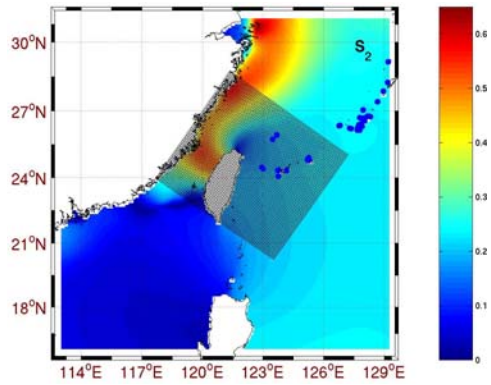
Barotropic Tides from OSU model, Yellow Sea domain

M2



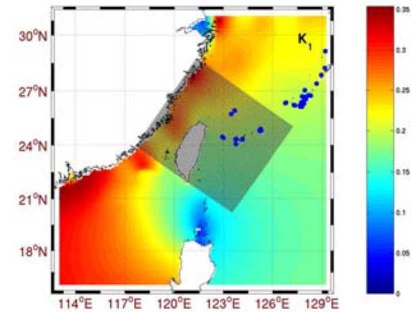
[SSH upto ~2 m]

S2



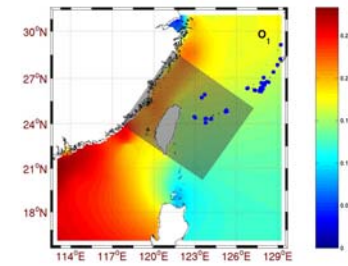
[SSH upto ~0.7 m]

K1



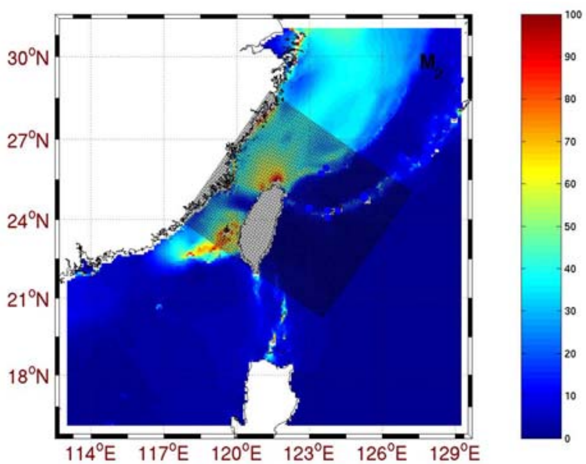
[SSH upto ~0.35 m]

O1



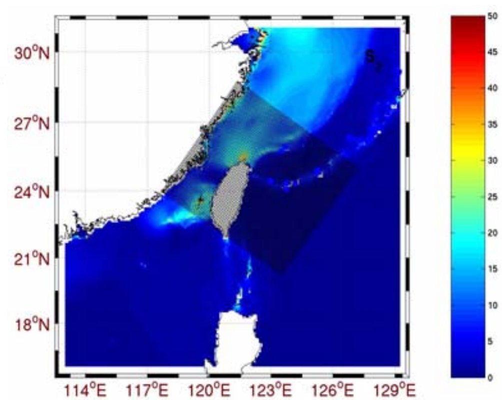
[SSH upto ~0.3 m]

M2



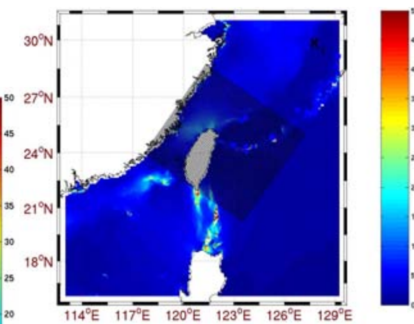
Vel. ellipse major axis:
upto ~100 cm/s

S2



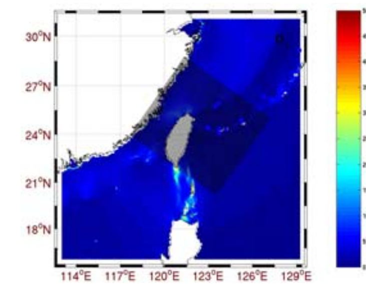
Vel. ellipse major axis:
upto ~50 cm/s

K1



Vel. ellipse major axis:
upto ~30 cm/s

O1



Vel. ellipse major axis:
upto ~20 cm/s

Diurnal comps need validation

Resolution: 1/12 degree

Modeling Uncertainties

Total Uncertainty

= Initial/boundary condition uncertainty

+ Model uncertainty

+ Integration by the dynamics of these uncertainties

Methods

- ❖ "Adjoint Methods" account for all uncertainties (linear backward in time), but do not compute them directly
- ❖ "Ensemble Methods" aim to only account for dominant uncertainties (linear) and compute them
- ❖ Both very useful and can do more than DA/uncertainty

Physical-Acoustical Adaptive Sampling

Predicting the types and locations of observations that are expected to be most useful, based on given estimation objectives and the constraints of the available assets
(Requires accurate Predictions)

Four Approaches and Methods:

- ❖ Heuristic estimation of the ideal future sampling based on predictions of ocean fields (features, uncertainties or dynamics)

- ❖ Adaptive Sampling based Error Subspace Statistical Estimation (ESSE) and on the nonlinear prediction of the impact of future observations on the predicted ocean state and uncertainty.

- ❖ Path planning based on Mixed Integer Programming (Yilmaz, Patrikalakis et al, 2007): quantitative version of the heuristic adaptive sampling approach.

- ❖ Path Planning (Heaney et al, 2006) or Adaptive Onboard Routing (Wang et al, 2007) for Acoustical-Physical Fields: Optimization of multi-component cost function via Genetic Algorithms

Glen's Questions for Group Leaders

1. What are environmental uncertainty keys necessary for measuring in field program?
   - Strength and position of Kuroshio inflows (South and East of Taiwan)
   - Taiwan Strait currents and transports
   - Depth of Mixed layer (especially under strong atmospheric forcing)
   - Deep Intrusions and associated gradients
   - Internal tides, waves and solitons: phases, directions and amplitudes

2. What tools or methods should be used?
   - Nested (global/large/meso/sub-meso) and stand-alone Modeling
   - Coupled Acoustics-Seabed-Ocean Physics Modeling
   - Data assimilation (OI, Adjoint, ESSE)
   - Adaptive sampling schemes
   - Multi-Model Fusion Schemes
   - Lagrangian Coherent Structures Extraction for Planning of Drifter Release

Glen’s Questions for Group Leaders

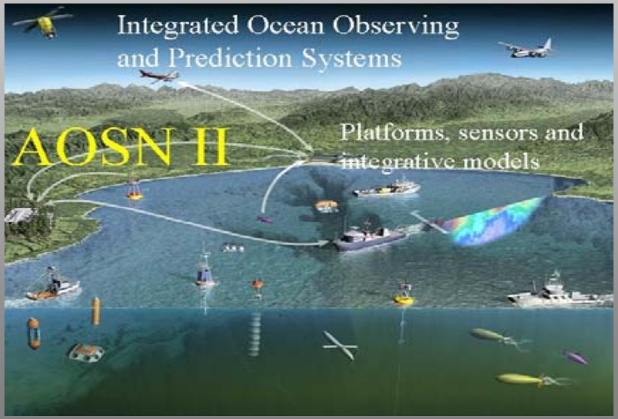
3. Where should measurements be made?
   - “Smart” Initialization survey
   - South and/or East of Taiwan <u>glider converyor belt</u>
   - Taiwan Strait or south of Taiwan if Strait not possible
   - Cold Dome area
   - River Forcing?
4. When/Where should we do field work?
   - Any time from the end of May to end of August (or January)
   - Intensive Cold Dome region (cross-shelf more useful than alongshelf)
   - Smart, coarser regions of influence
5. What processes to be exploited to improve SNR?
   - “Predictable” ocean environment processes and uncertainties to forecast TL and range of the day and uncertainties
   - Tidally forced processes (frequencies known prior to experiment)
6. What further needs for environmental information in assessing uncertainty (Pilot)?
   - Acoustic-Seabed Modeler (Kevin? with Bruce/Pierre, NPS/RAM codes)

Extra Slides

Multi-Model Fusion for Ocean Prediction based on Adaptive Uncertainty Estimation

- ✓ ***A Methodology for Multi-Model Forecast Fusion***
- ✓ ***Adaptive Uncertainty Estimation Schemes***
  - *Bias Correction followed by Error Variance Estimation*

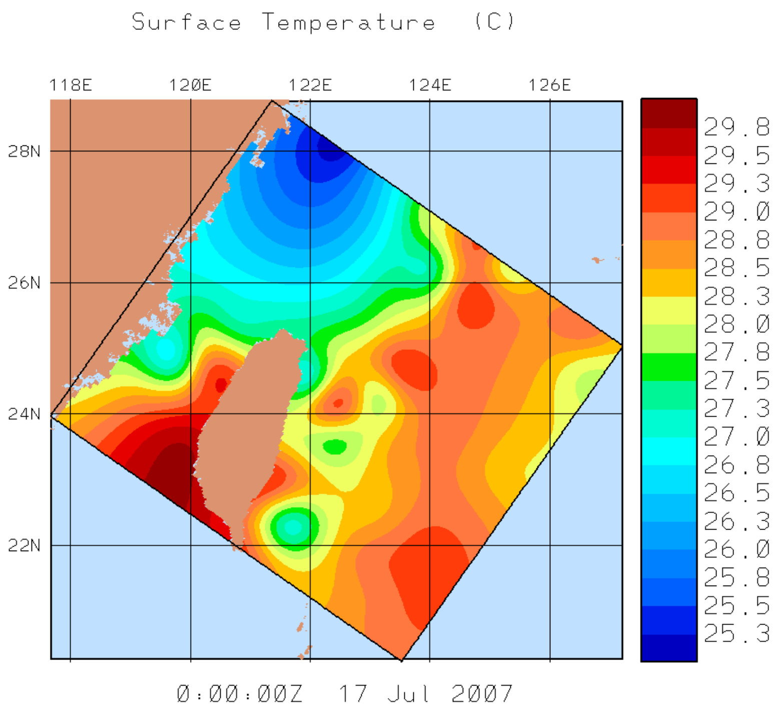
Multiple Models

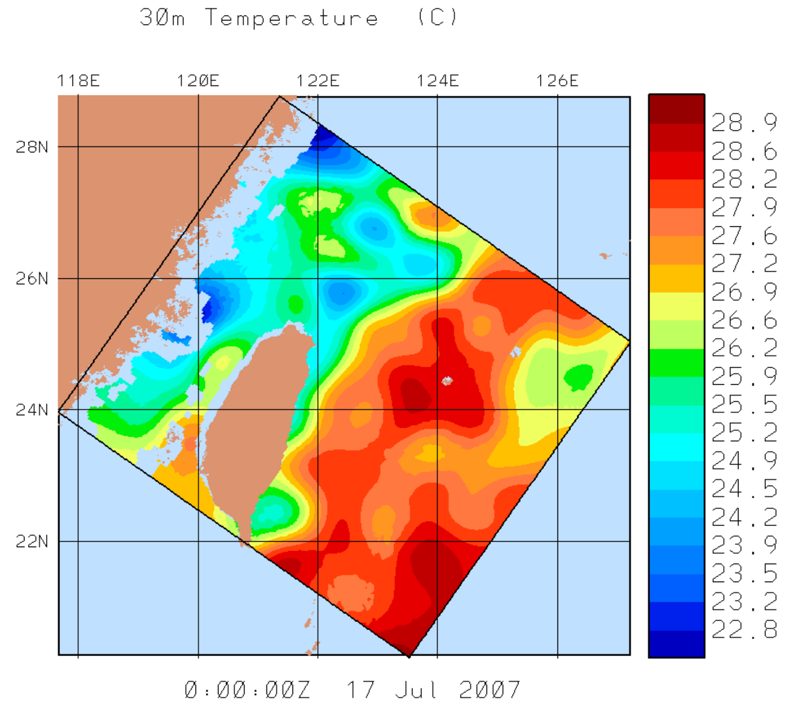


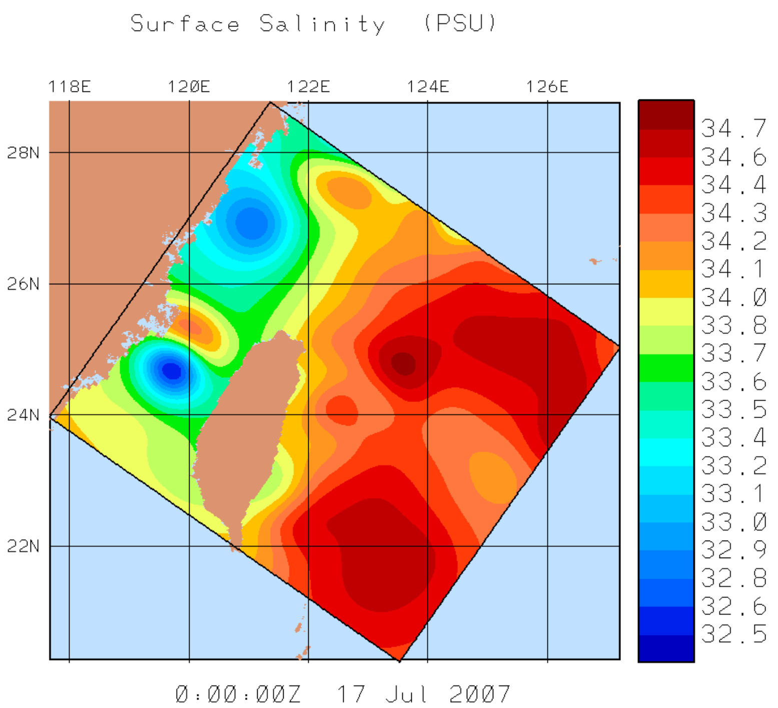
Observing Systems

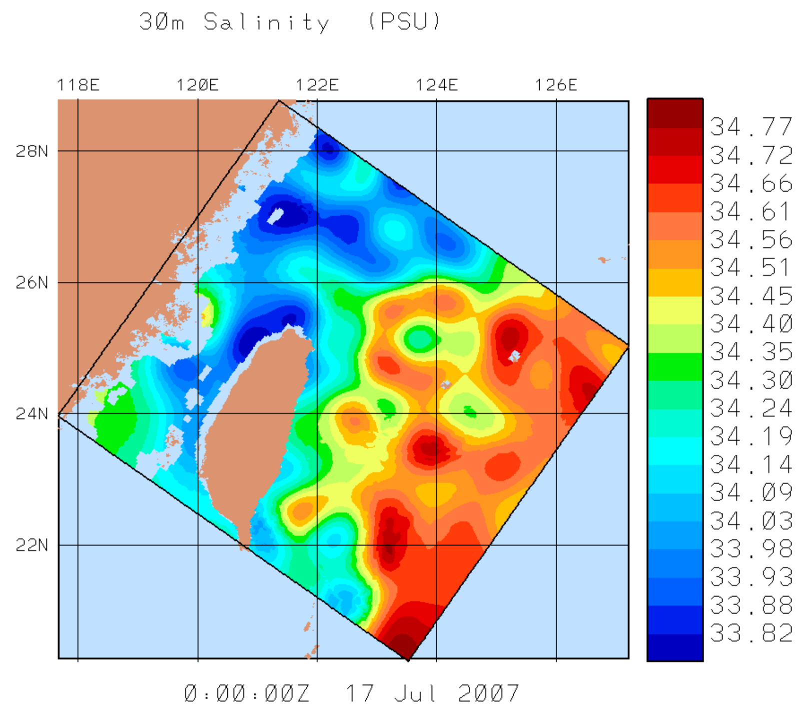
A useful methodology should be:

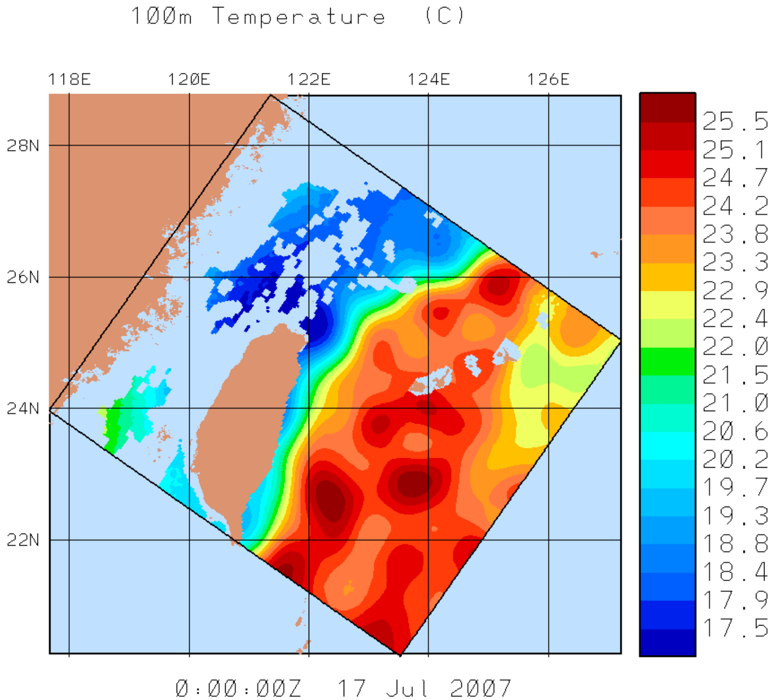
- ✓ **Capable of operating with observational data that are limited and sparse (in space and in time) with respect to the dominant ocean scales**
- ✓ **Adaptive/sequential, using the small samples of error estimation events (possibly 1 event)**

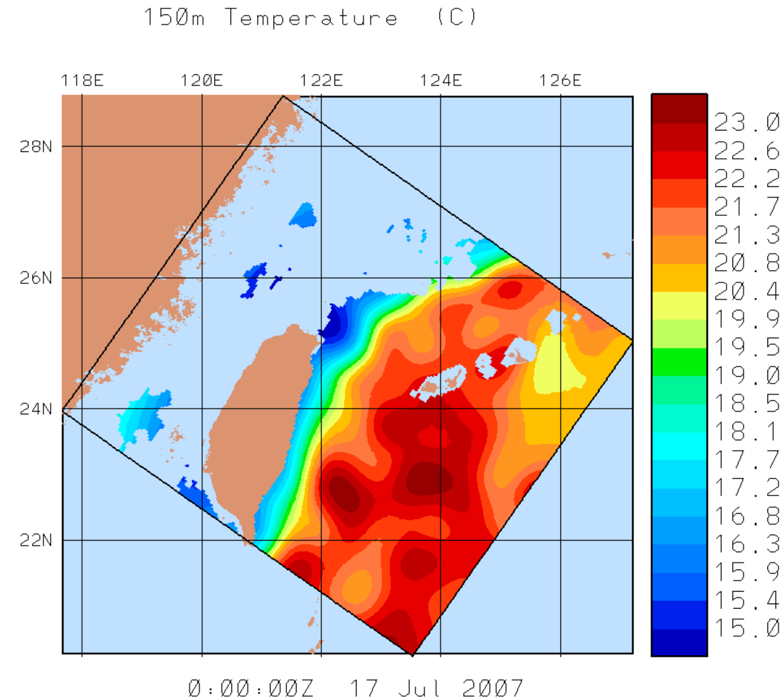

Surface Temperature (C)
118E
120E
122E
124E
126E
28N
26N
24N
22N
29.8
29.5
29.3
29.0
28.8
28.5
28.3
28.0
27.8
27.5
27.3
27.0
26.8
26.5
26.3
26.0
25.8
25.5
25.3
0:00:00Z 17 Jul 2007

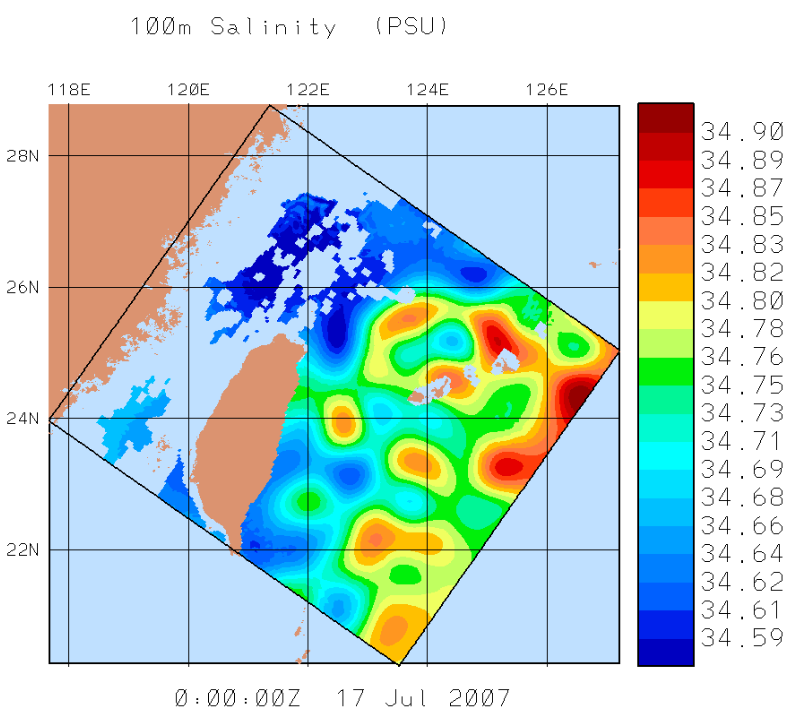

30m Temperature (C)
118E
120E
122E
124E
126E
28N
26N
24N
22N
28.9
28.6
28.2
27.9
27.6
27.2
26.9
26.6
26.2
25.9
25.5
25.2
24.9
24.5
24.2
23.9
23.5
23.2
22.8
0:00:00Z 17 Jul 2007

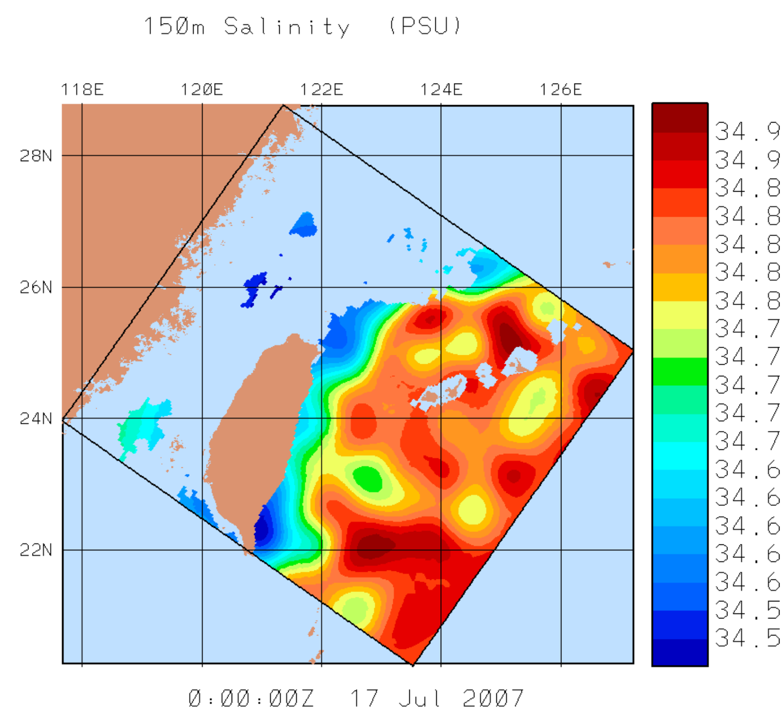

Surface Salinity (PSU)
118E
120E
122E
124E
126E
28N
26N
24N
22N
34.7
34.6
34.4
34.3
34.2
34.1
34.0
33.8
33.7
33.6
33.5
33.4
33.2
33.1
33.0
32.9
32.8
32.6
32.5
0:00:00Z 17 Jul 2007


30m Salinity (PSU)
118E
120E
122E
124E
126E
28N
26N
24N
22N
34.77
34.72
34.66
34.61
34.56
34.51
34.45
34.40
34.35
34.30
34.24
34.19
34.14
34.09
34.03
33.98
33.93
33.88
33.82
0:00:00Z 17 Jul 2007


100m Temperature (C)
118E 120E 122E 124E 126E
28N 26N 24N 22N
25.5 25.1 24.7 24.2 23.8 23.3 22.9 22.4 22.0 21.5 21.0 20.6 20.2 19.7 19.3 18.8 18.4 17.9 17.5
0:00:00Z 17 Jul 2007


150m Temperature (C)
118E 120E 122E 124E 126E
28N 26N 24N 22N
23.0 22.6 22.2 21.7 21.3 20.8 20.4 19.9 19.5 19.0 18.5 18.1 17.7 17.2 16.8 16.3 15.9 15.4 15.0
0:00:00Z 17 Jul 2007


100m Salinity (PSU)
118E 120E 122E 124E 126E
28N 26N 24N 22N
34.90 34.89 34.87 34.85 34.83 34.82 34.80 34.78 34.76 34.75 34.73 34.71 34.69 34.68 34.66 34.64 34.62 34.61 34.59
0:00:00Z 17 Jul 2007


150m Salinity (PSU)
118E 120E 122E 124E 126E
28N 26N 24N 22N
34.92 34.90 34.88 34.86 34.84 34.82 34.80 34.78 34.76 34.74 34.72 34.70 34.68 34.66 34.64 34.62 34.60 34.58 34.56
0:00:00Z 17 Jul 2007