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Regional nested tide-resolving real-time JCOPET modeling system for coastal waters of southern Japan

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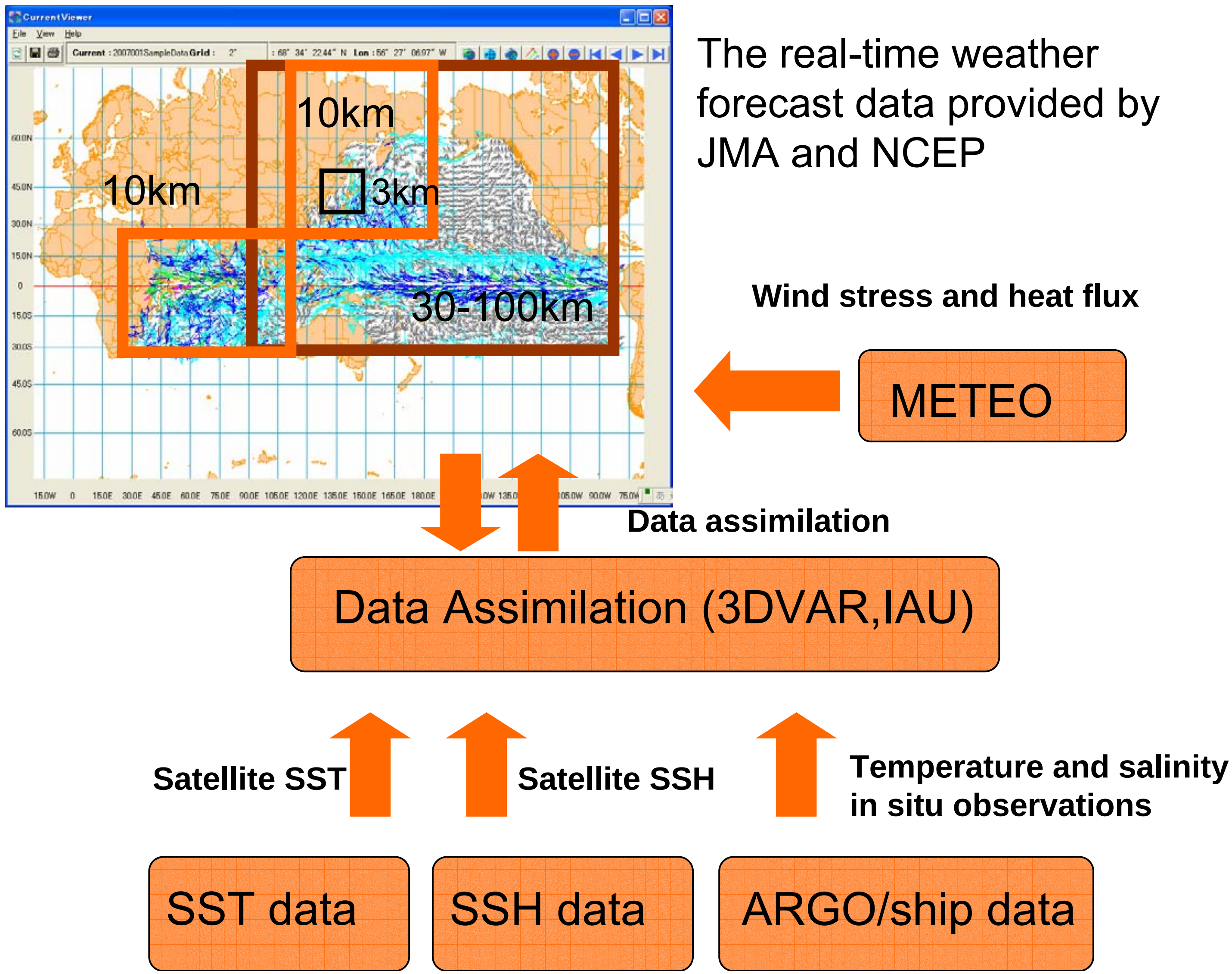
JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY

Vocabulary

JAMSTEC	**Japan Agency for Marine-Earth Science and Technology,** Yokohama
JCOPE	**Japan Coastal Ocean Predictability Experiment**, the program run by JAMSTEC as a contribution on the way to the **Operational Oceanography**: moving from ocean climate simulation and studies to ocean weather understanding and prediction
JCOPET	the tide-resolving regional nested subsystem of JCOPE
JMA	Japan Meteorological Agency
NAO	Japan National Astronomic Observatory

JAMSTEC JCOPE Ocean Forecast System

Ocean models covers both the North Pacific and Indian Oceans; semi-global model version is in the pre-operational test phase (1/10 degree).



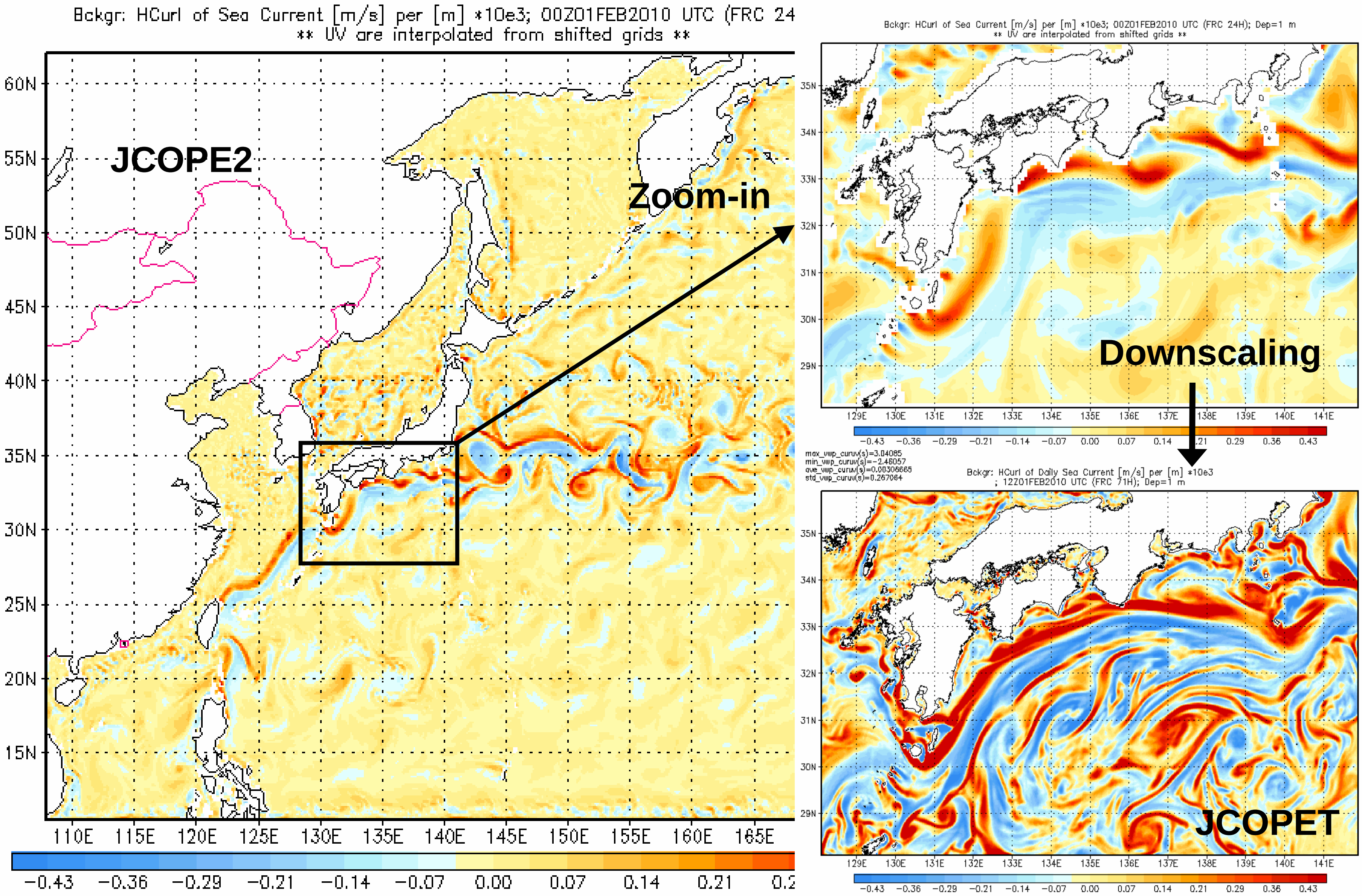
North-Western Pacific JCOPE system status

- **JCOPE2** basin-scale real-time modeling system:
  - Updated weekly
  - Produces daily-mean NW Pacific Ocean status estimates immediately available online
  - results include an assimilated analyses and up to 2.5 months ocean forecast
  - ~10 km resolution (1/12 degree), eddy resolving
- **Downscaling activities**:
  - The regional nested tide-resolving ocean modeling system is operated
  - Daily operational cycle
  - Hourly ocean conditions are estimated and predicted up to 1 week; results are immediately available online
  - ~3 km resolution (with the planned further downscaling to ~1km, ~300m resolution)
  - Hierarchy of non-tidal regional models is also operated (weekly)

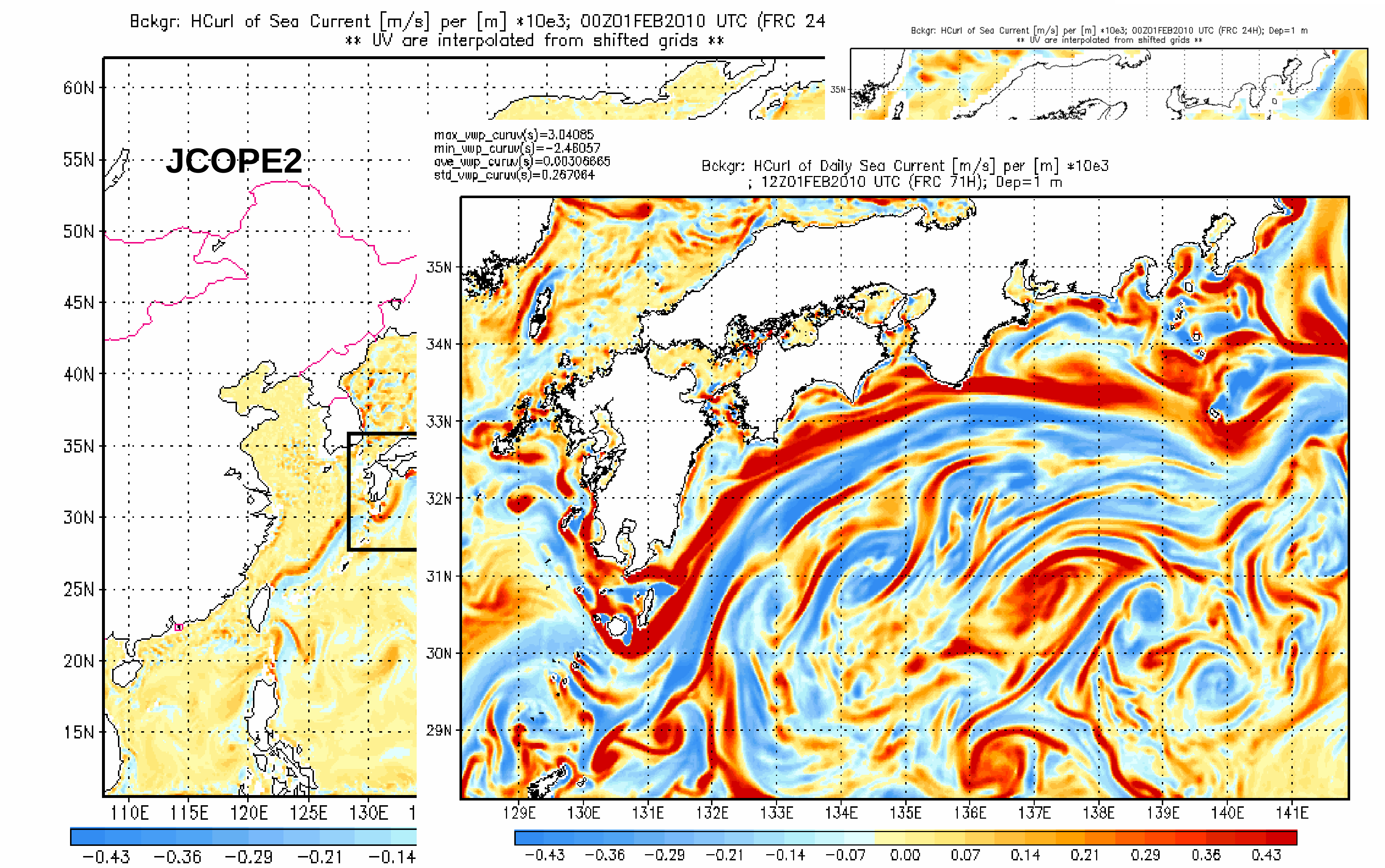
Relative vertical vorticity

JCOPE2 – 1/12 degree, weekly (daily output)

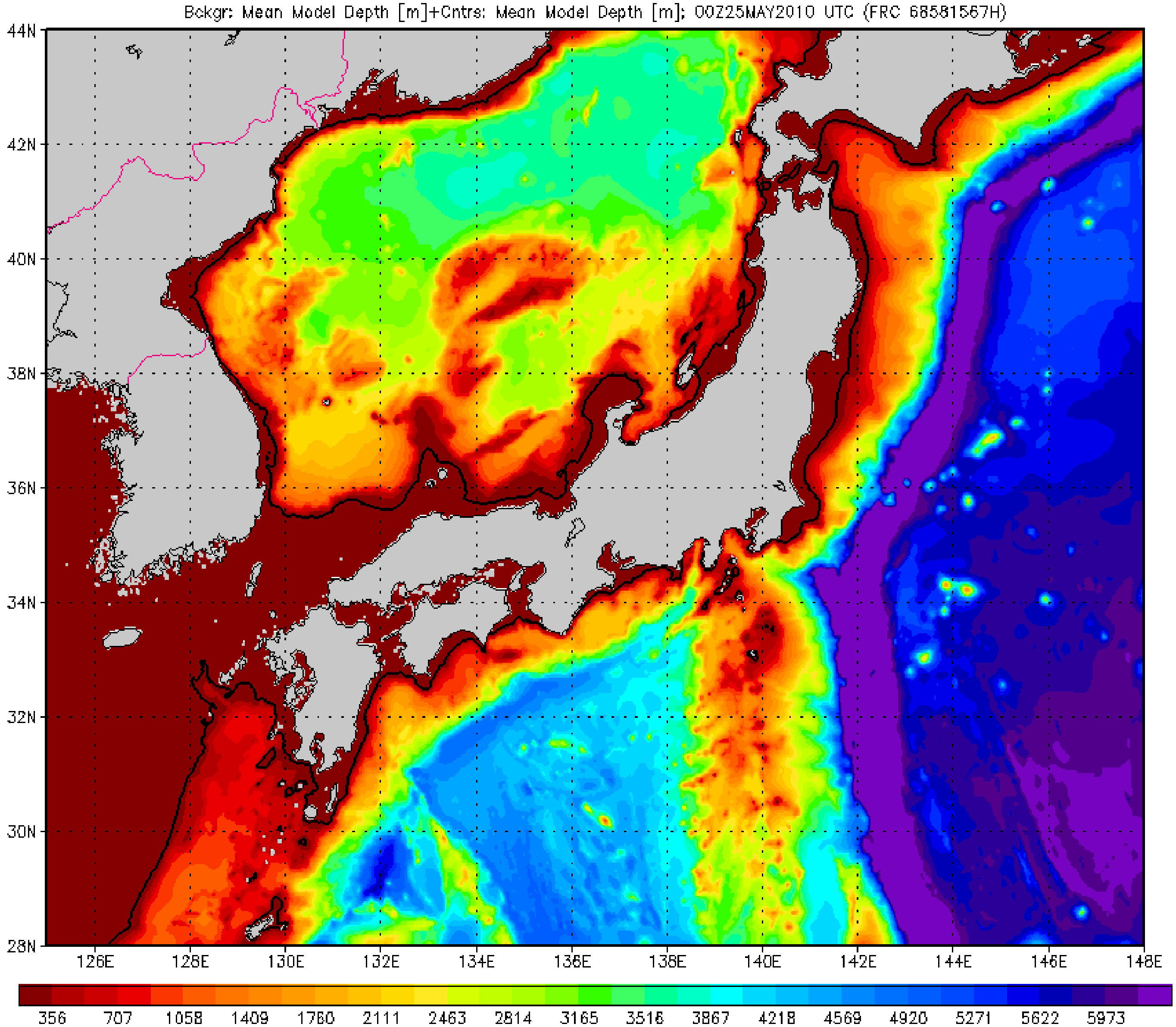
JCOPET – 1/36 degree tide resolving , daily (hourly output)



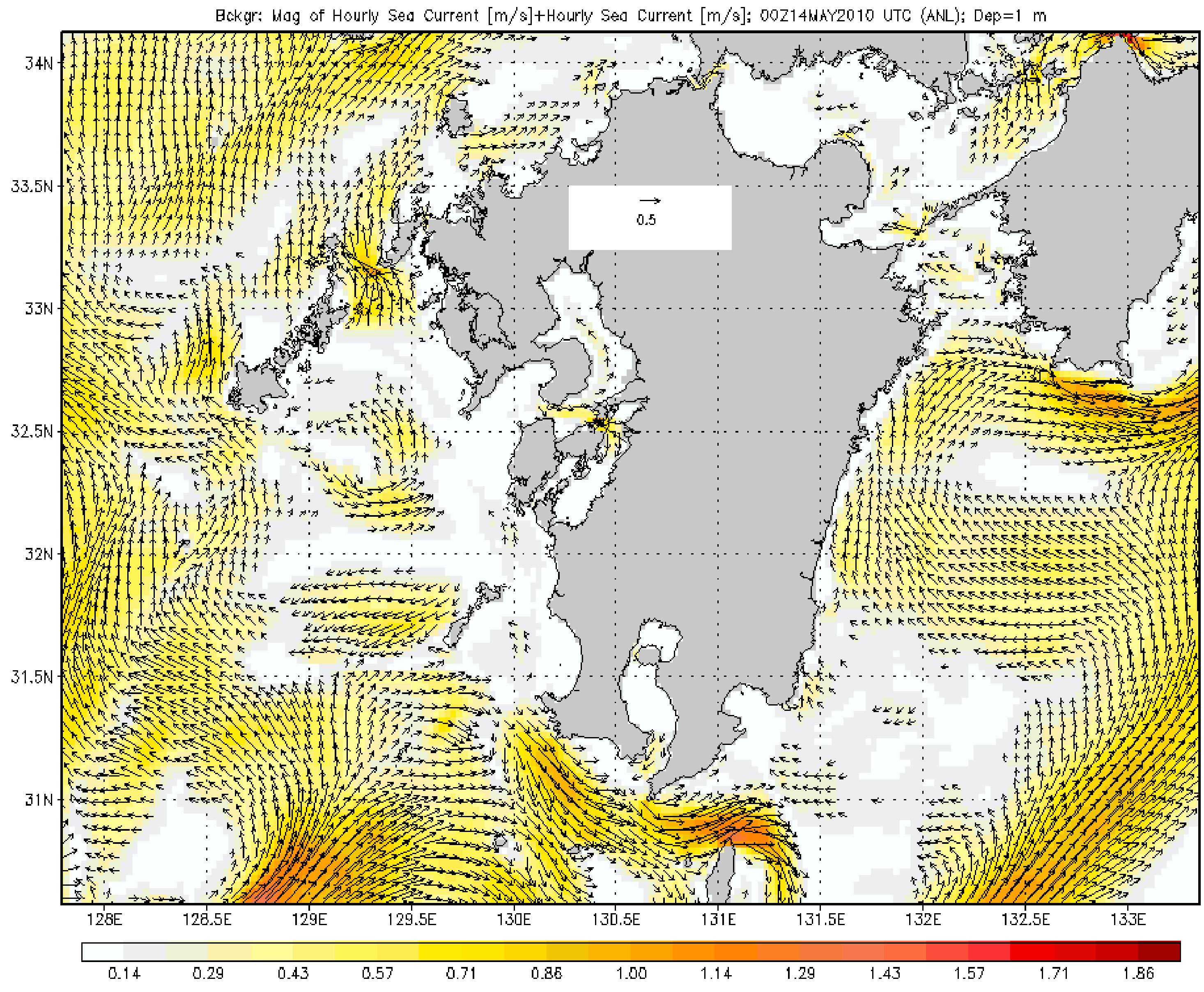
Japan Coastal Ocean Predictability Experiment, relative vorticity
JCOPE2 – 1/12 degree, weekly (daily output)
JCOPET – 1/36 degree tide resolving , daily (hourly output)



Domain of JCOPET real-time regional tide resolving 1/36 degree model (from the May 2010)



Simulation example: sea surface circulation in coastal waters around Kyushu, May 15-17, 2010 (time step 1 hour)



Potential expectations in coastal ocean modeling:

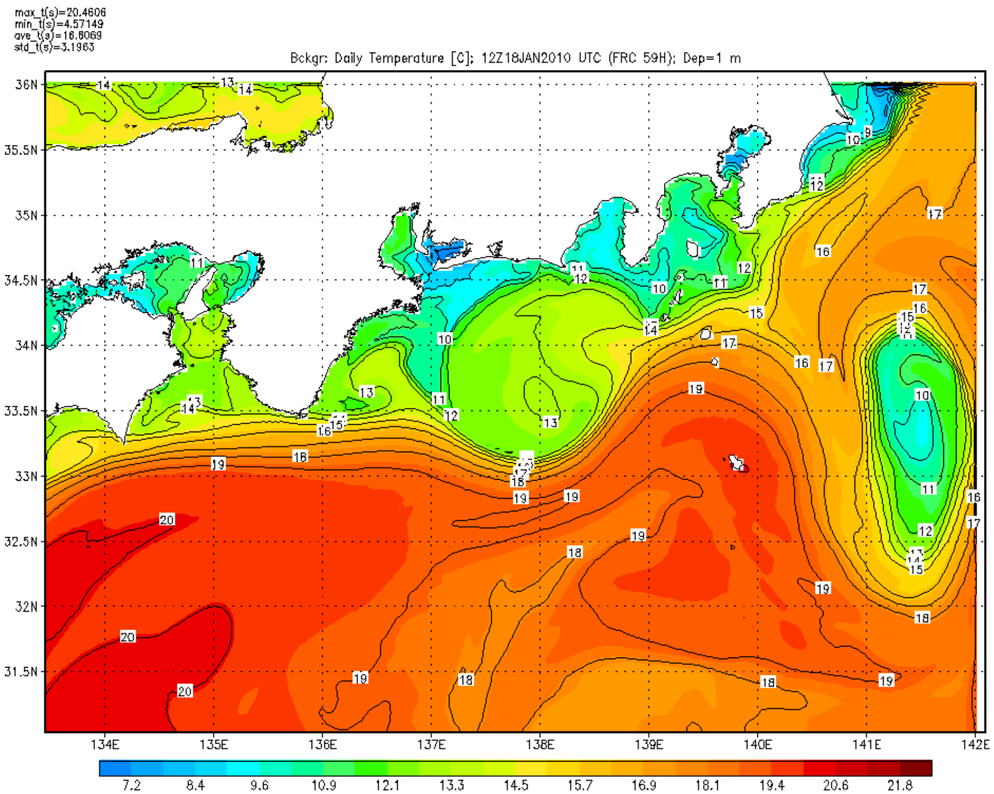
- Barotropic tides
- Storm surges, sudden intensification of sea currents [“Kyucho”] etc.
- River plumes
- Coastal topographic waves
- Upwelling, downwelling and alongshore currents
- Mesoscale instability eddies
- Countour currents and standing meanders
- Internal tides – often aperiodic (although with the external tidal “carrier frequency”) due to the mesoscale variations
- Surface fronts and sub-mesoscale vortices
- Wakes
- Littoral currents

Ref: J. C. McWilliams, Targeted coastal circulation phenomena in diagnostic analyses and forecasts, Dynamics of Atmospheres and Oceans, 48 (2009)

JCOPET coastal downscaling subsystem parameters - 1

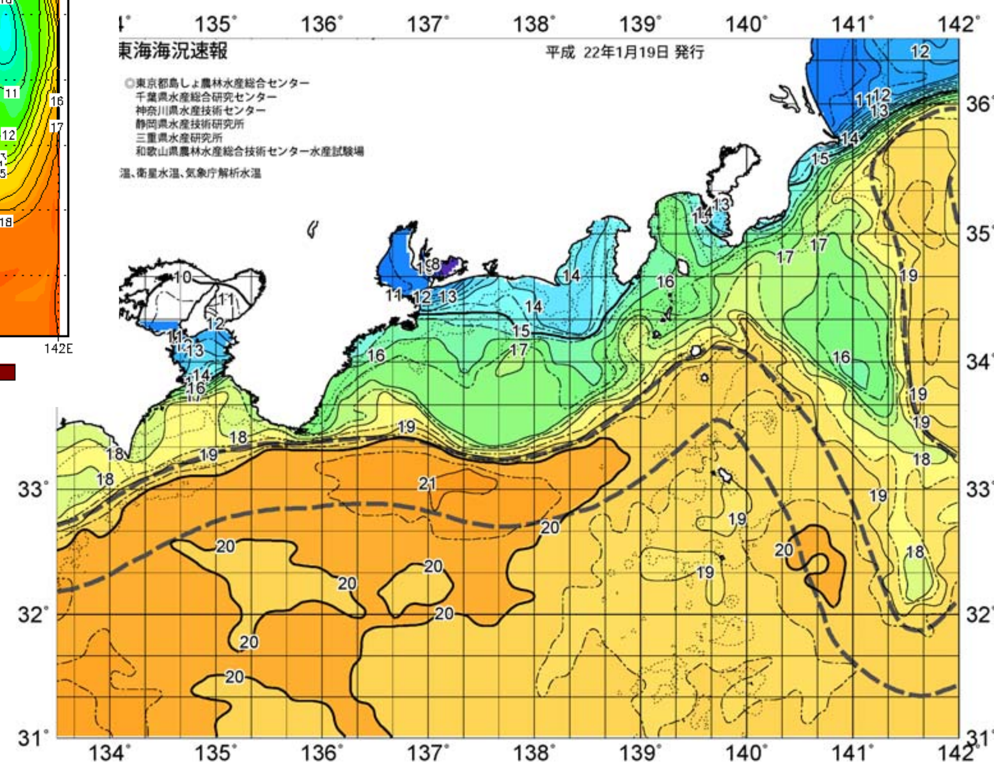
- Regional nested JCOPE (POM) model version with the external tidal forcing as body force and as boundary tidal 2D volume fluxes and boundary SSHA adjustment (locally conservative);
  one way nested to NW Pacific JCOPE2 model
- Vertical resolution: 47 generalized sigma levels; min total depth 5 m; upper layers thickness: 2,3,5,7,…m
- Horizontal resolution: 1/36 degree, ~ 3 km
- Horizontal viscosity: harmonic, Smagorinsky type
- Horizontal diffusivity: harmonic, constant
- Important: permanent tests of the CFL criteria for the vertical cross-interfacial velocity
- dt_{ext} = 2 sec, isplit=30 (dt_{int}=60 sec), leap-frog time integration scheme with the Asselin filtering

Example: harmonic Smagorinsky viscosity [0.3], large harmonic diffusivity [~5 m2/s], JCOPET vs observations, January 18, 2010



Model daily mean SST

Observed (analyzed) SST

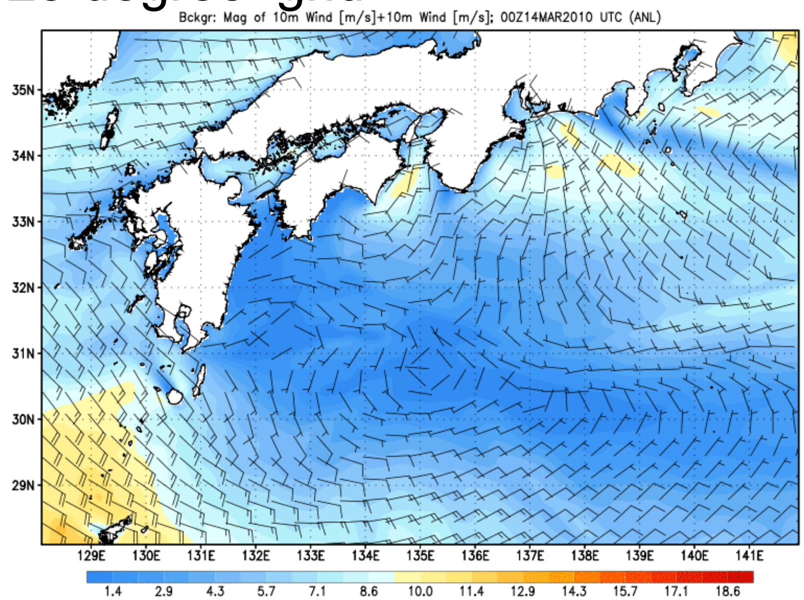


JCOPET coastal downscaling subsystem parameters - 2

- Assimilation scheme:
  - assimilation is done in the JCOPE2 system (SSHA, SST, TS profiles);
  - tidal signals are treated as noise and formally removed by time averaging (7 days time window);
  - in the JCOPET goes nudging of model time-filtered (~2 days mean) TS fields to the JCOPE2 interpolated values
  - no nudging at the depth H < 20 m
- Tides are introduced both as a gravitational or “body” force and by means of open boundary conditions
- Used are up to 16 short-term harmonics (Q1,O1,M1,P1,K1,J1,Oo1,2N2,Mu2,N2,Nu2,M2,L2,T2,S2,K2) and 6 long-term harmonics (Mm, Mf, Ssa, Sa, Mtm, Msqm), for the SSHA,U,V (NAO2000)

JCOPET coastal downscaling subsystem parameters - 3

- Meteorological data: Wind, SLP, Ta, Hum, precipitated water, clouds
  - **JMA MSM** hourly data, updated 8 times per day.
    Analyses and 32h forecasts, 1/16 x 1/20 degree grid
  - **JMA GSM**, hourly data. SRF up to 3d15h updated 4 times per day (hourly data up to 3d15h) and MRF [reserve] up to 8d - once per day
    1/4 x 1/5 degree grid
  - **NCEP GFS**, 3 hourly data, updated 4 times per day.
    SRF up to 7d12h on gaussian ~0.3125 [1/3] degree grid,
    MRF up to 16d – on gaussian ~0.625 degree grid



- Fluxes: TOGA-COARE bulk algorithm
- Rivers discharge: do not included yet in this version

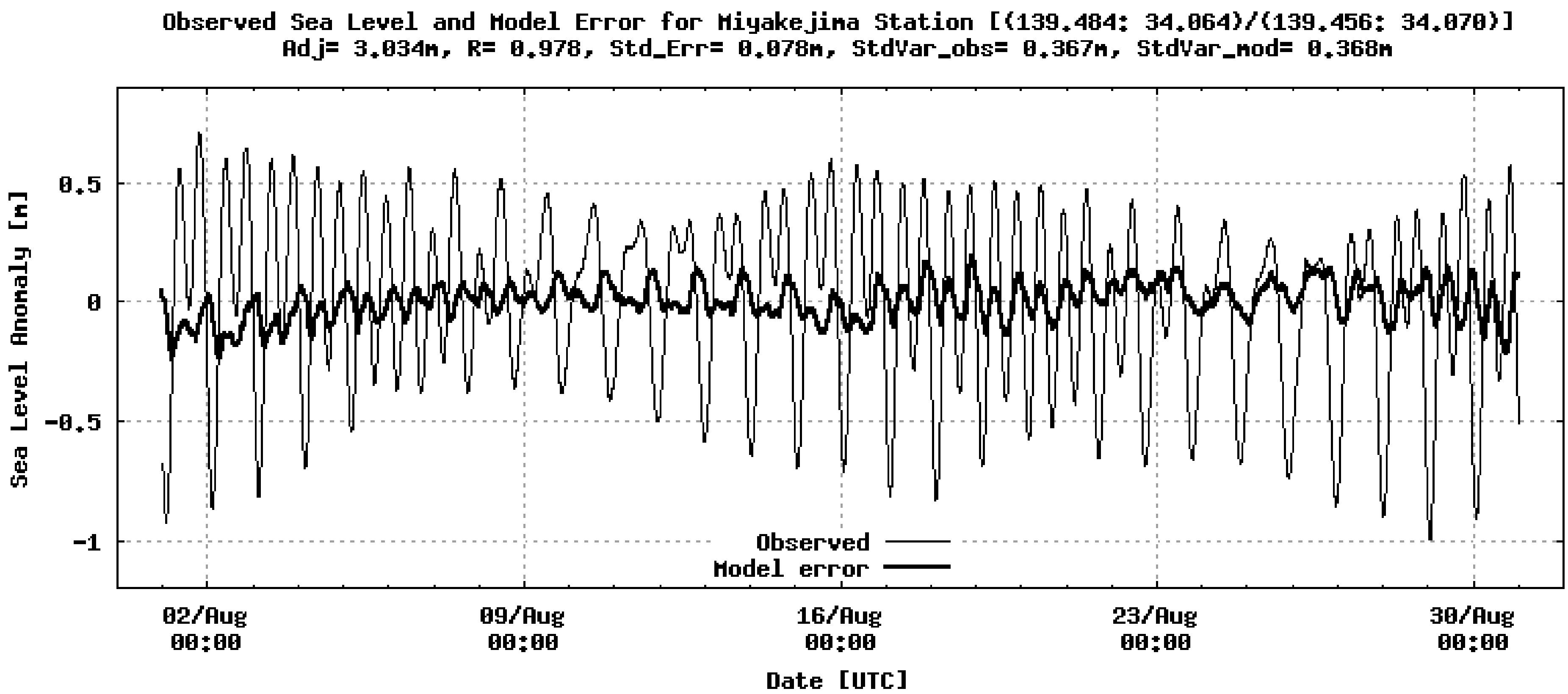
MSM-GSM-GFS hourly wind
(March 14-[18]-23, 2010)

Simulation schedule: daily forecasts, weekly assimilation

Job types:

1. **Cold Start** – very first run or recovery from the system crash
2. **Auto** – system selects one of:
   1. "Assimilation" Run
      - Each Friday, restart 2.5 weeks backward with nudging to the latest JCOPE2 analyses
      - Continue in forecast mode up to 15 days forward
   2. Forecast Run
      - All other days, restart from the latest Regular Restart Point
      - Run in forecast mode up to 15 days forward from the bulletin date
   3. Recovery Run
      - Continue Assimilation Run or Forecast Run simulation stopped due to the time limit of NQS

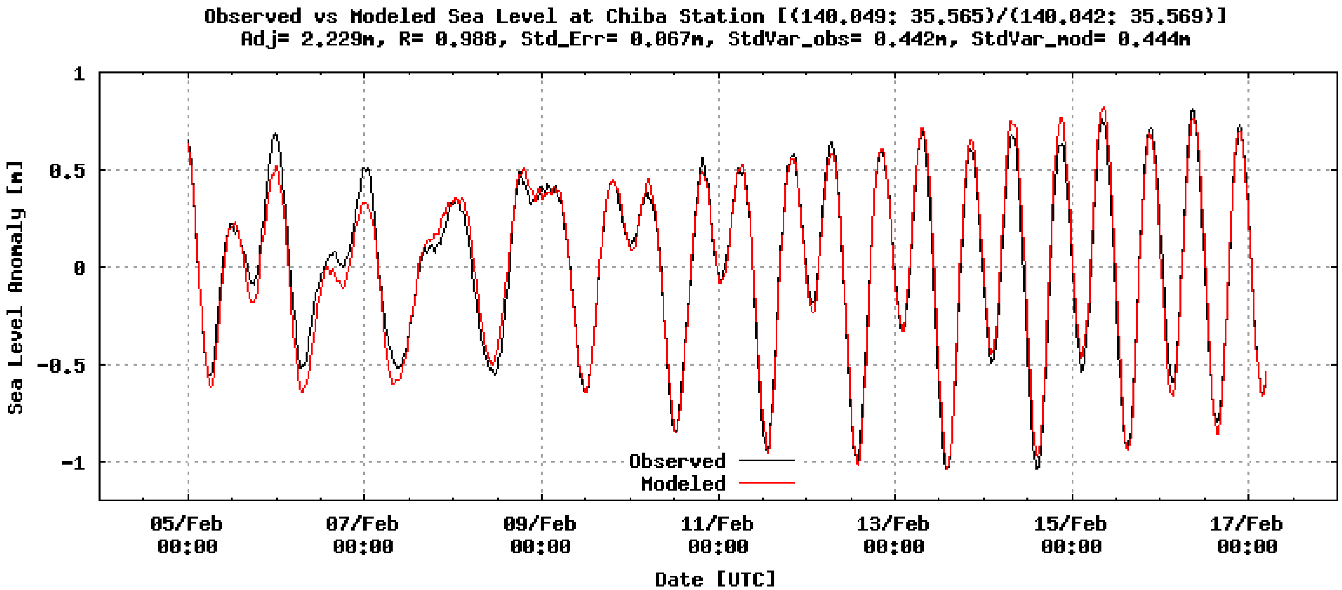
Some model validation: Barotropic tides
Example: Miyakejima st.



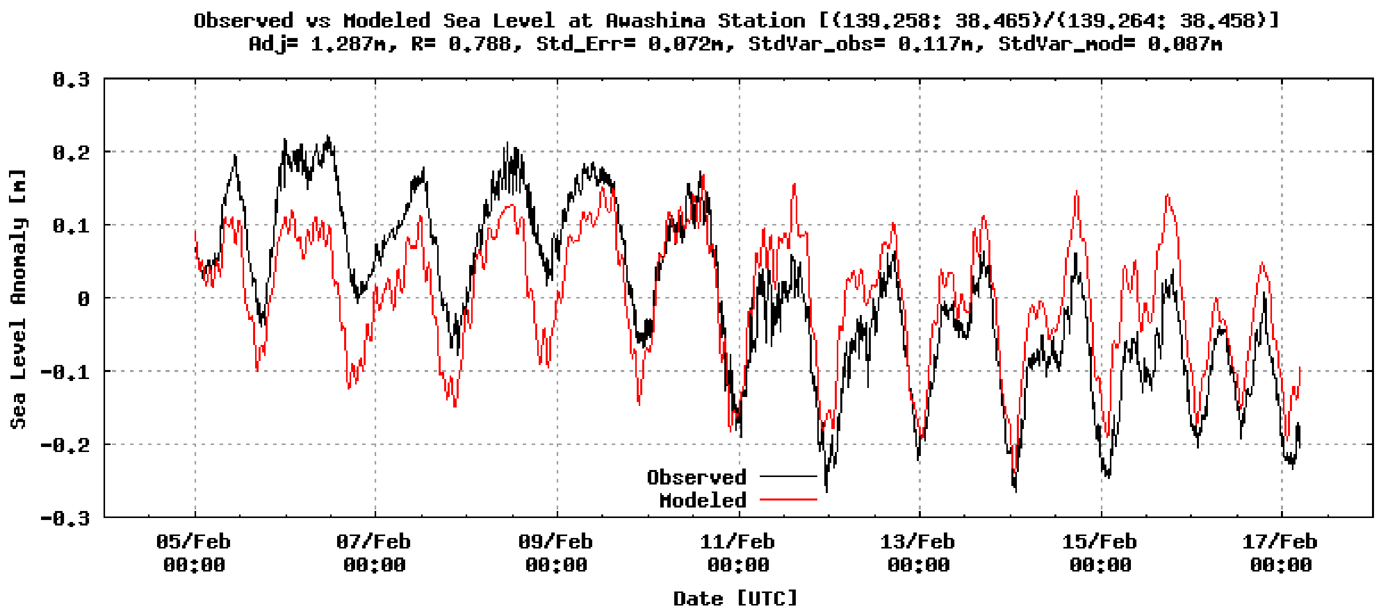
Model validation: tides

	Station	R	rms Err, m	rms Obs, m	rms Mod, m	Lon	Lat	Adj, m
Japan Sea, East-China Sea								
1	Hakata	0.984	0.08	0.44	0.46	130.41	33.62	2.34
2	Izuhara	0.984	0.09	0.42	0.47	129.29	34.19	2.42
3	Sasebo	0.995	0.12	0.70	0.79	129.73	33.15	3.34
Pacific Ocean Coast and Islands								
4	Naze	0.983	0.09	0.50	0.51	129.50	28.38	2.45
5	Nakanoshima	0.981	0.10	0.53	0.51	129.85	29.84	2.26
6	Odomari	0.992	0.08	0.62	0.62	130.69	31.02	3.54
7	Nishinoomote	0.989	0.08	0.52	0.52	130.99	30.73	2.79
8	Miyakejima	0.974	0.08	0.37	0.37	139.48	34.06	3.03
9	Kouzushima	0.979	0.08	0.40	0.37	139.14	34.20	2.46
10	Hachijojima	0.677	0.28	0.34	0.36	139.81	33.13	1.70
Tokyo Bay								
11	Chiba	0.968	0.12	0.46	0.42	140.05	35.56	2.54
12	Yokosuka	0.972	0.10	0.40	0.37	139.66	35.28	2.24
Seto Inland Sea								
13	Oita	0.980	0.24	0.52	0.73	131.69	33.26	3.82
14	Hiroshima	0.962	0.56	0.86	1.34	132.47	34.35	3.85
15	Tokuyama	0.986	0.41	0.75	1.12	131.80	34.04	3.31

Barotropic tide with extended model domain



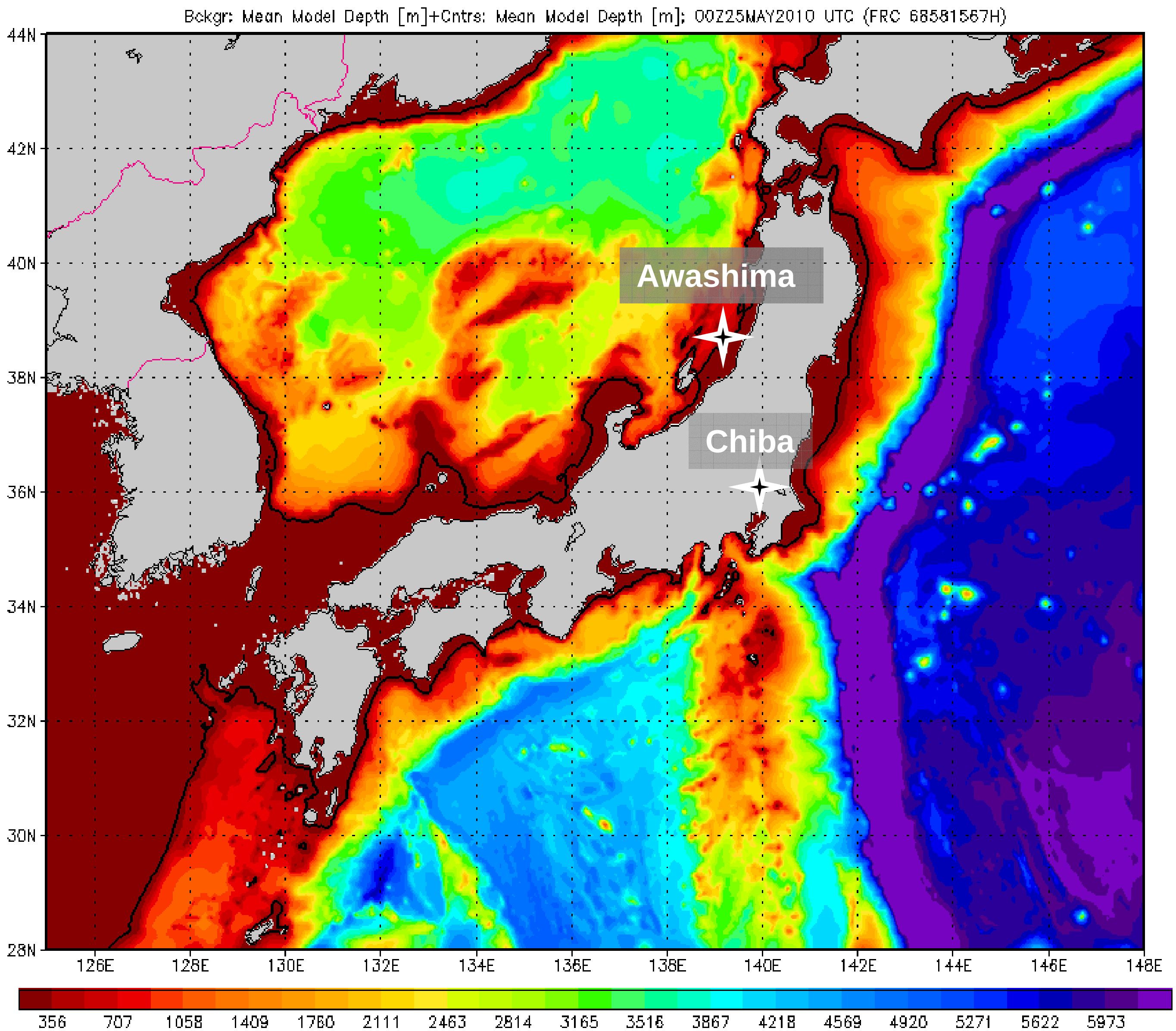
Chiba, Tokyo Bay:
improved



Central Japan Sea,
Awashima

Model do not well represents the low frequency
sea level changes

Domain of JCOPET real-time regional tide resolving 1/36 degree model from May, 2010



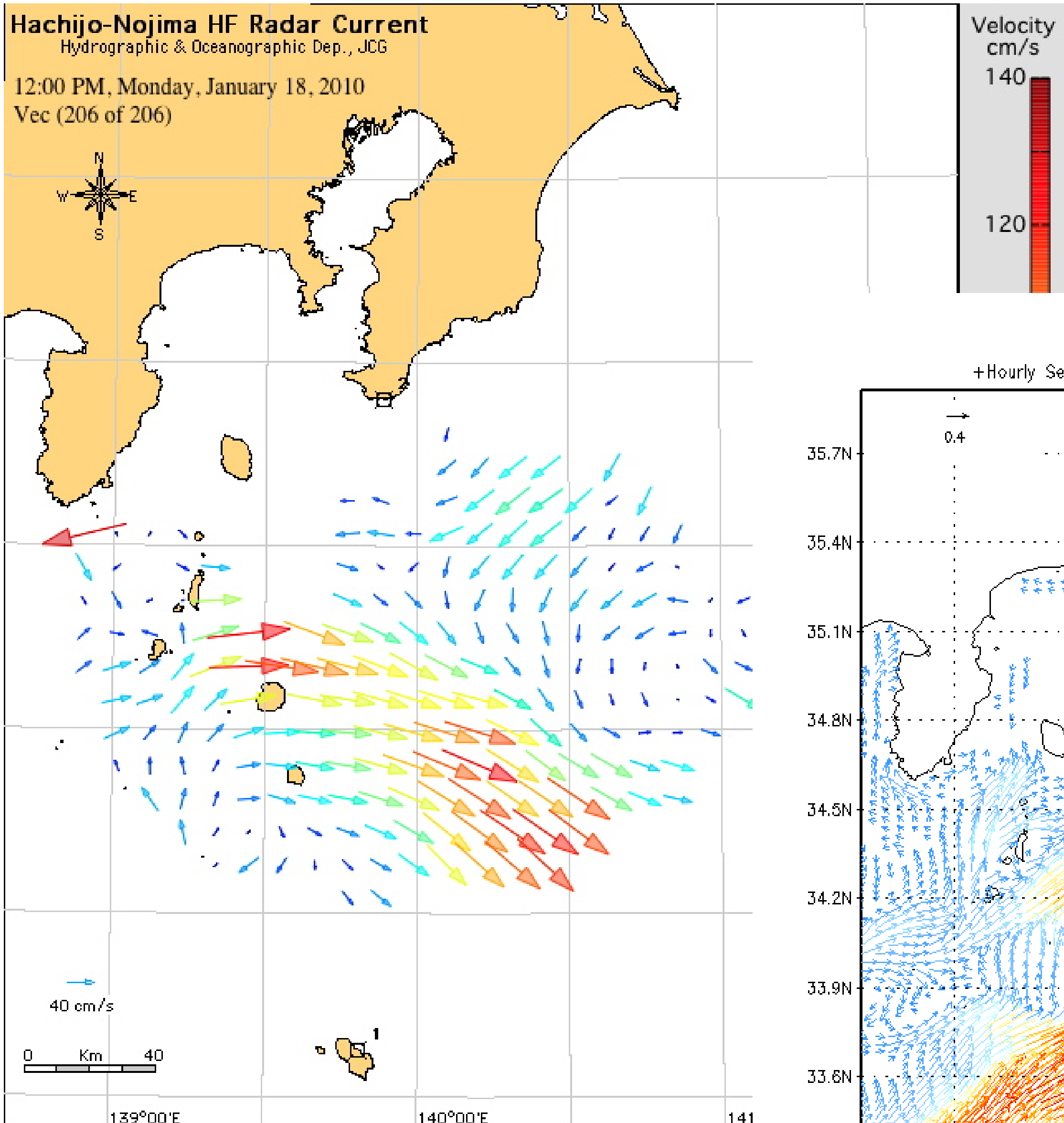
Example of surface sea currents variability and comparison with HF radar data

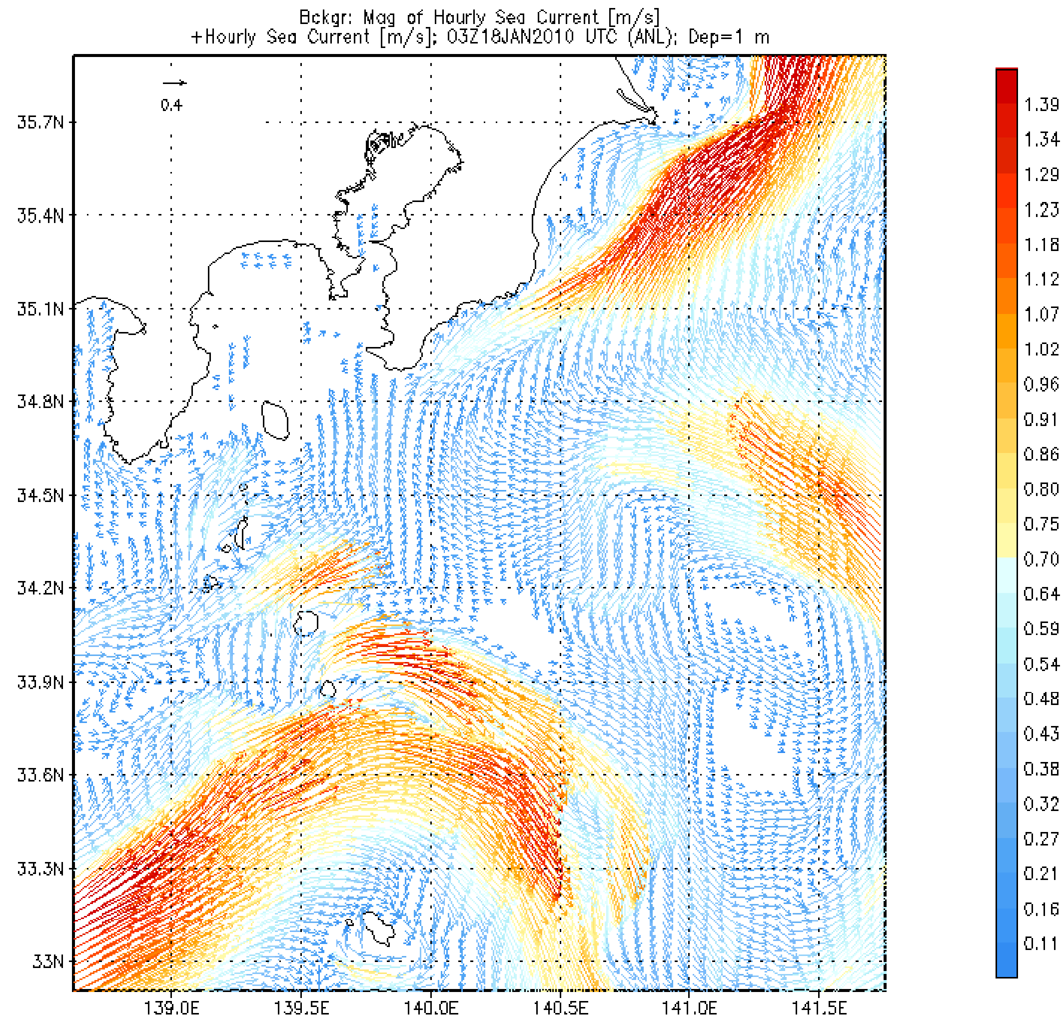
Maps of surface sea current estimates by

(1) JCG Long-Range HF Radar for Current Measurement (3h)
http://www1.kaiho.mlit.go.jp/KANKYO/KAIYO/hfradar/kairyu_inform.cgi

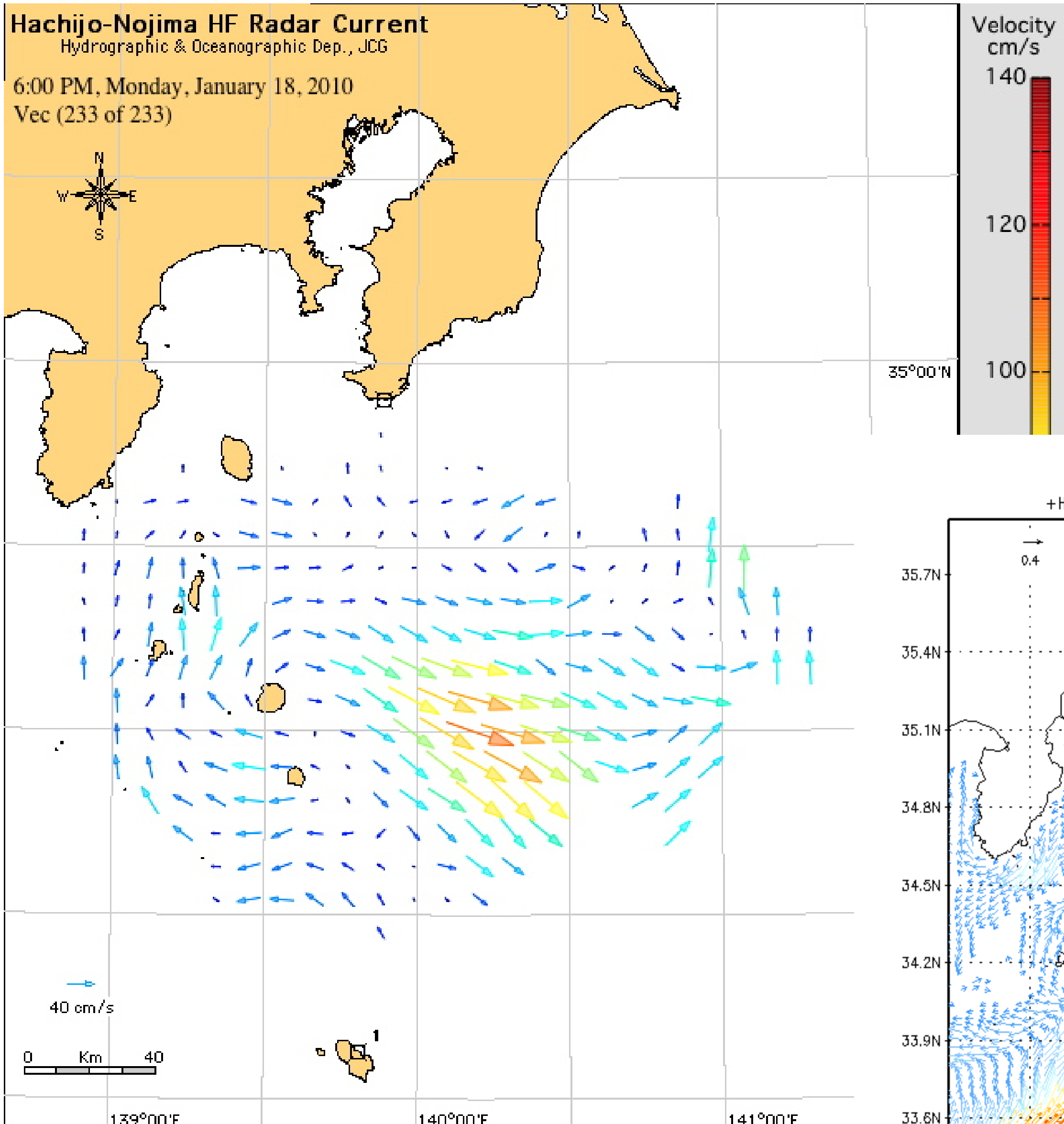
(2) RIAM Tsushima Strait HF Radar System (1h)
http://le-web.riam.kyushu-u.ac.jp/radar/index.html

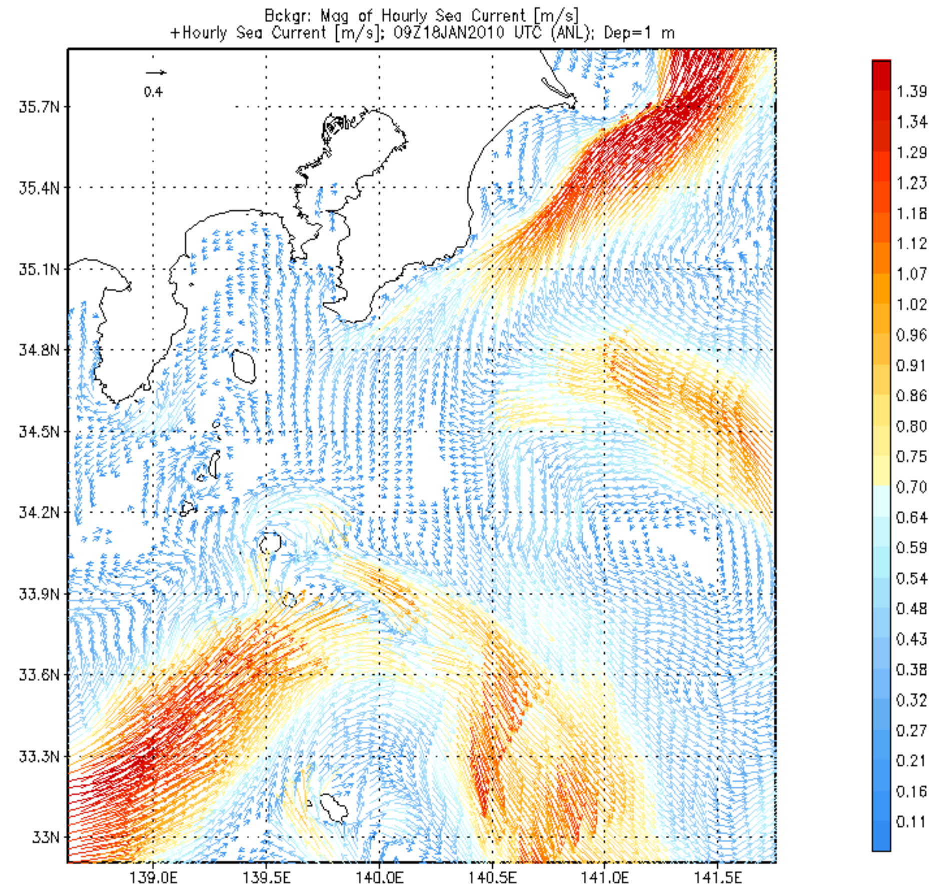
January 18, 2010 12 JST





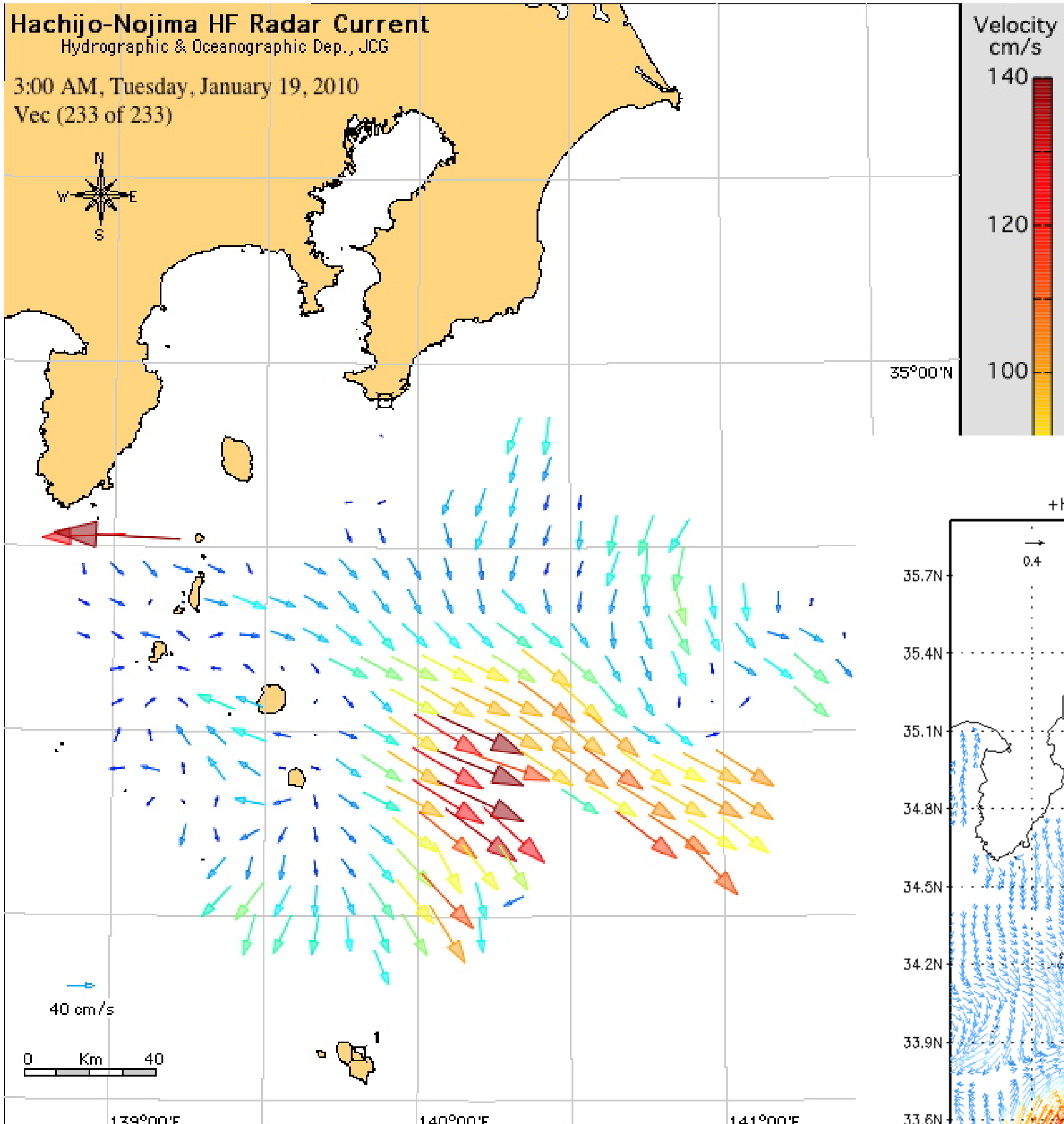
January 18, 2010 18 JST

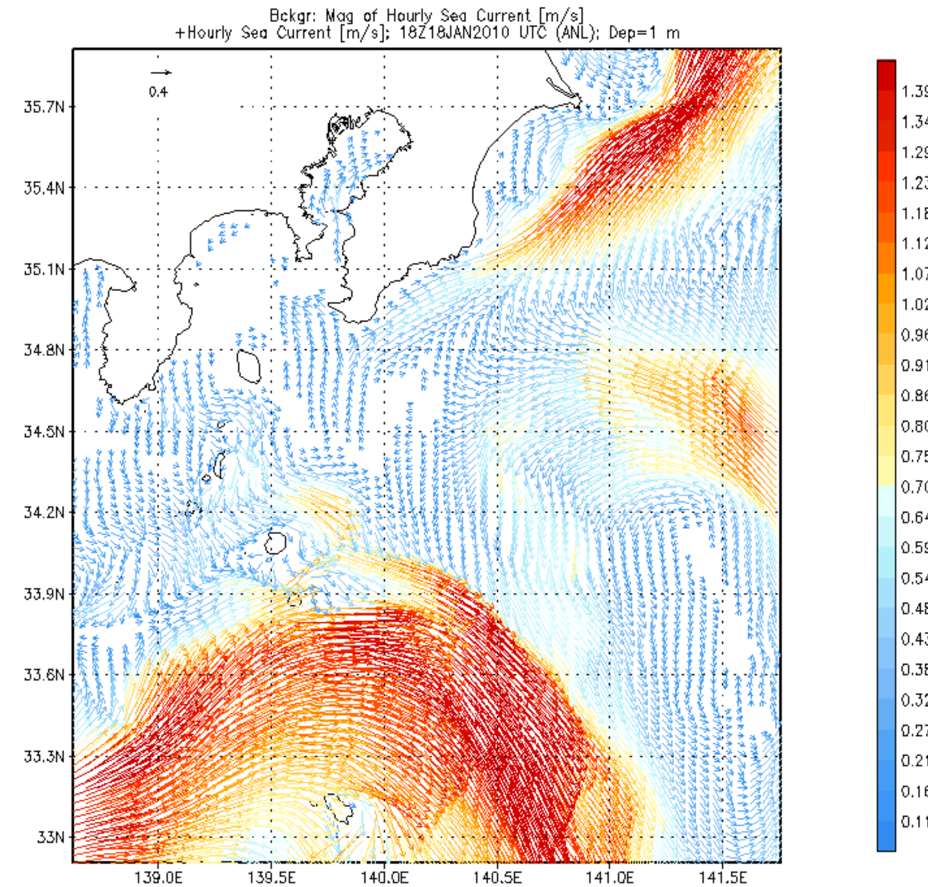




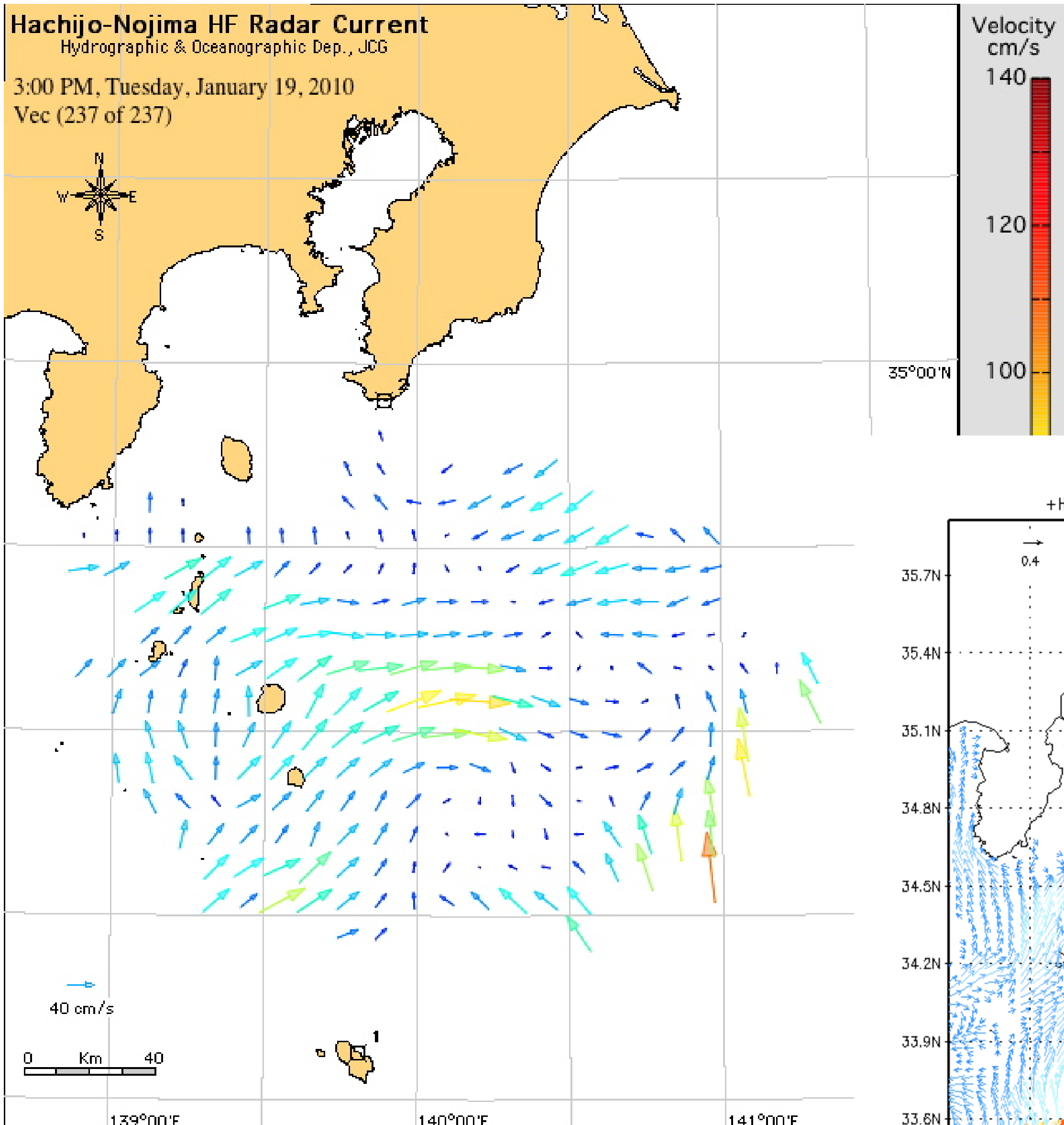
January 19, 2010 03 JST

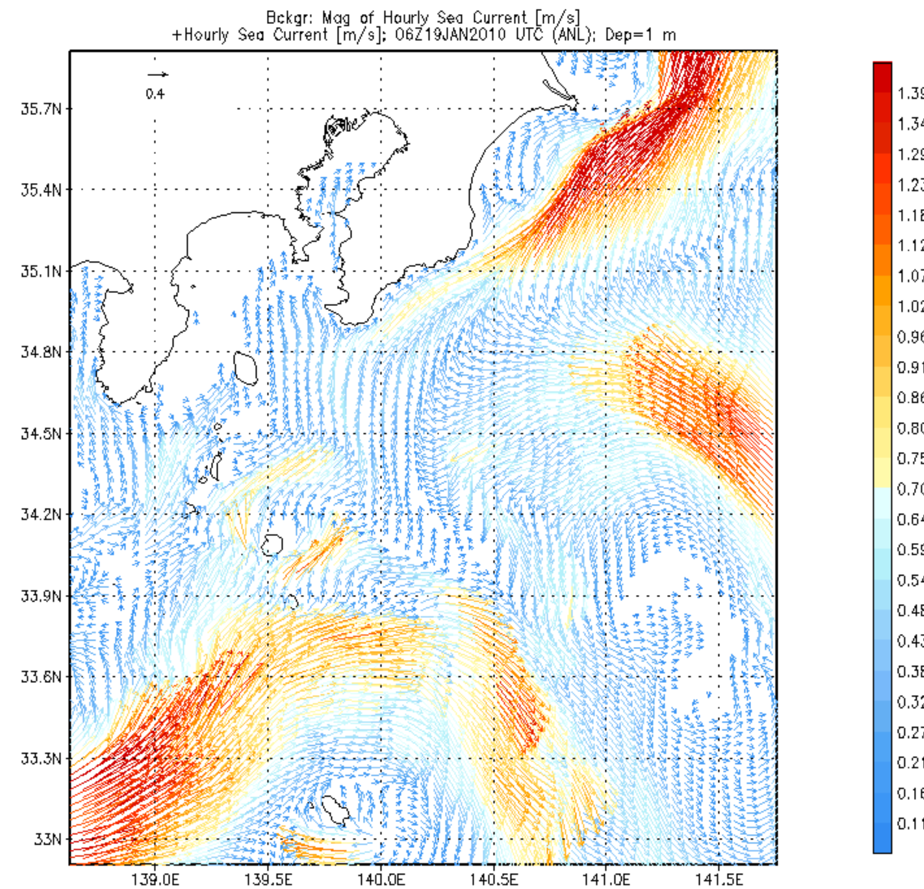
Inconsistency SW of Mikurajima





January 19, 2010 15 JST





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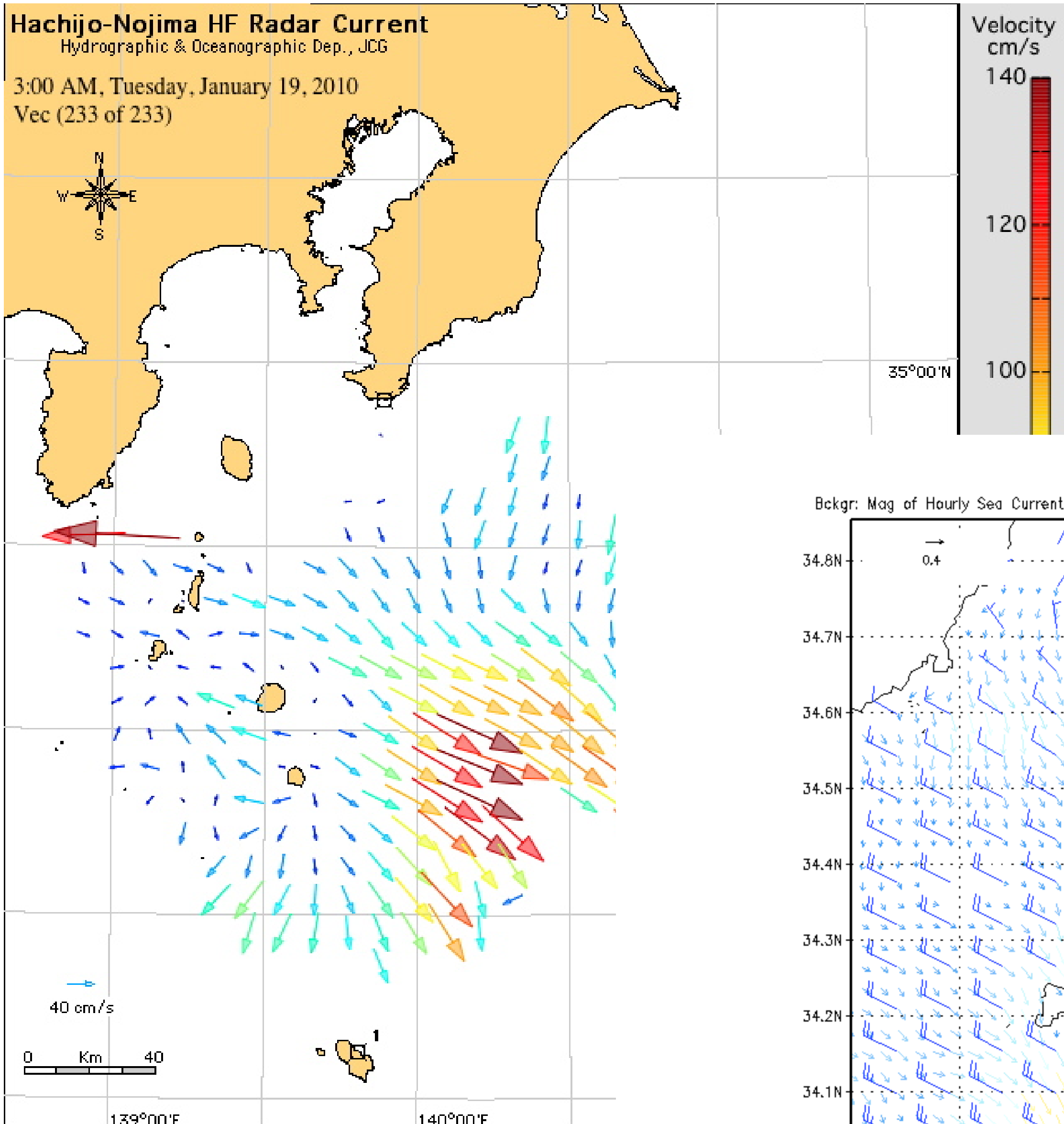
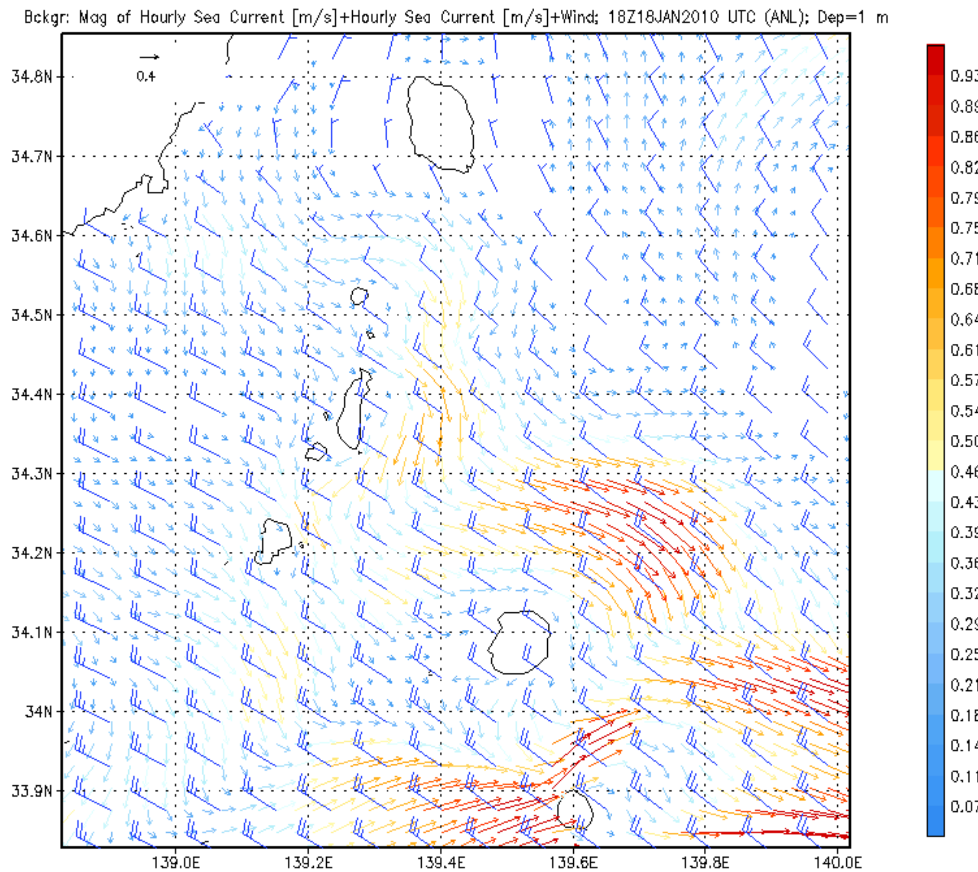


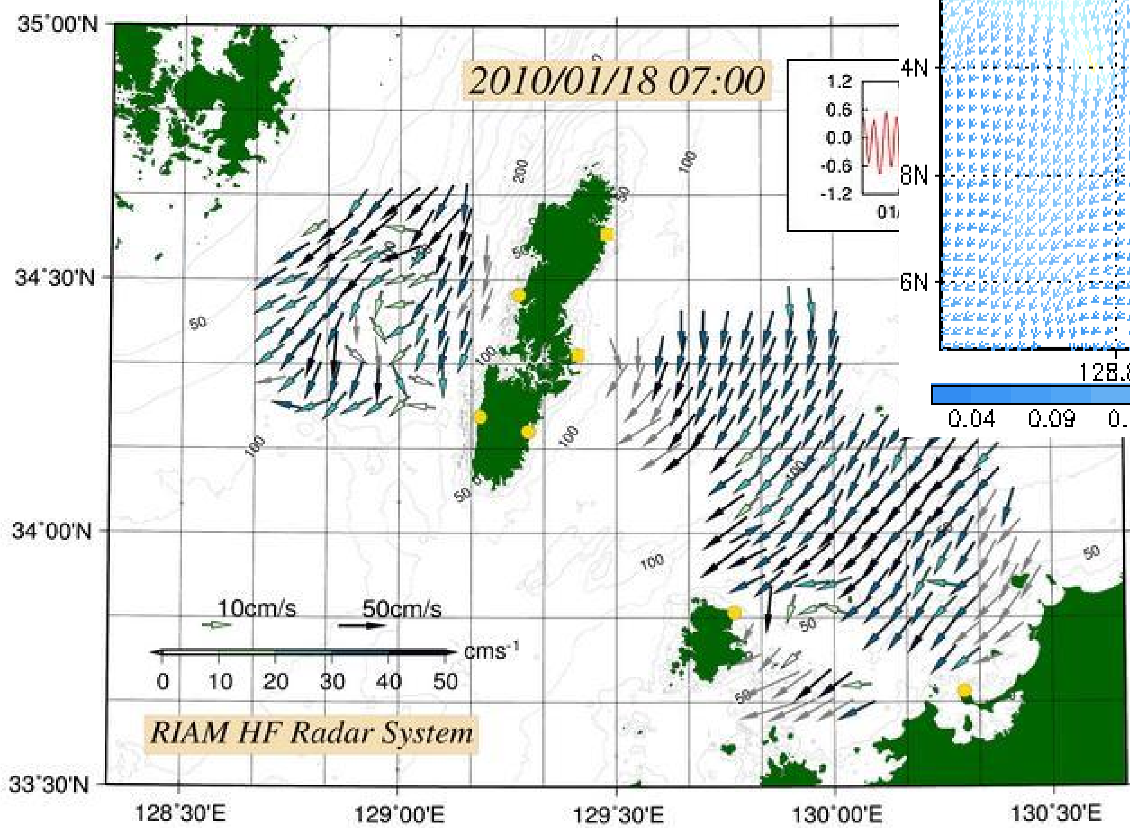
"Zoomed" Ooshima-Miyakejima area with surface wind field added

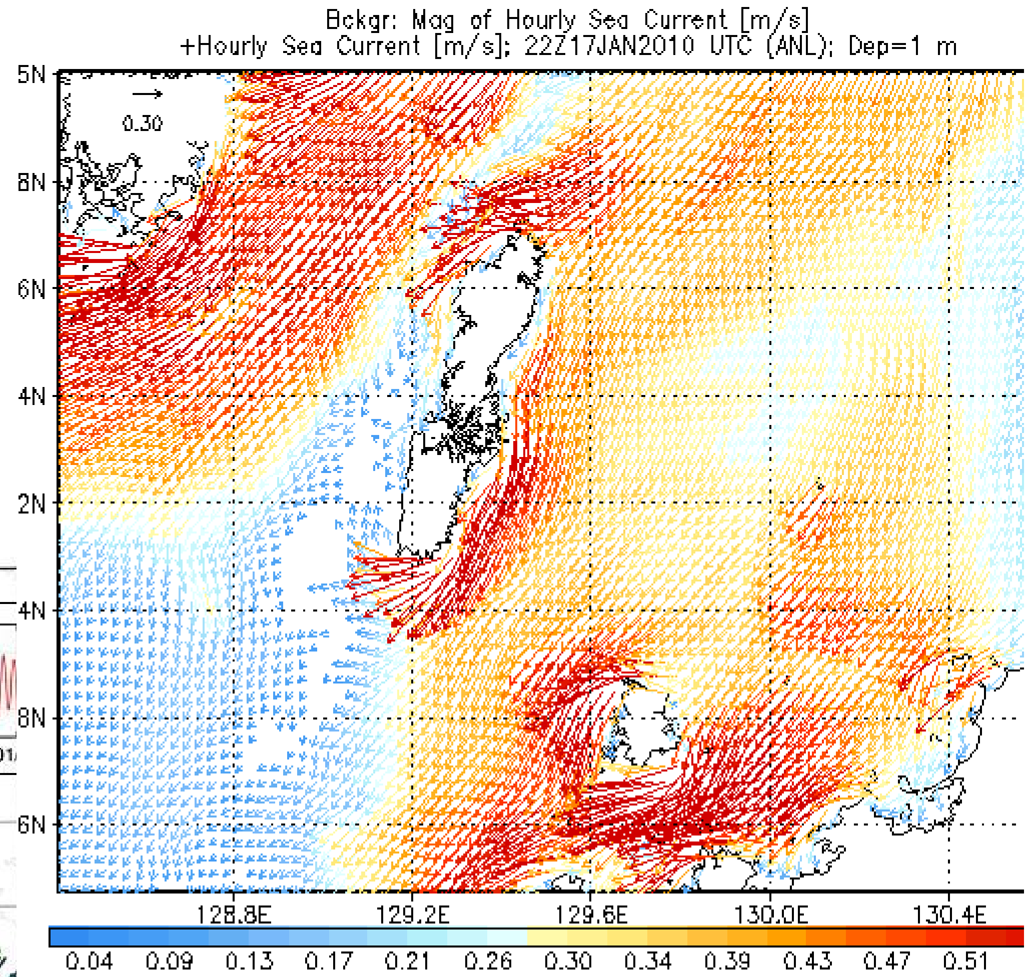


Tsushima Strait area

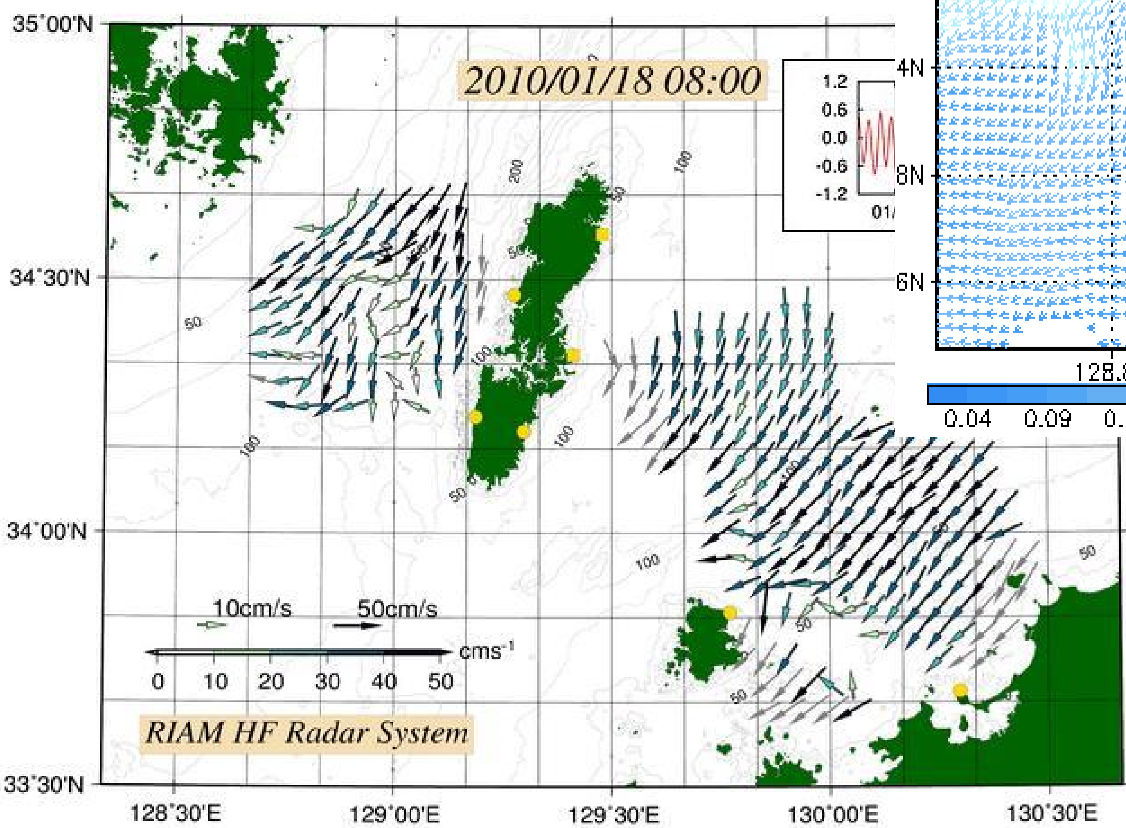
- This area is relatively shallow and has prominent tidal variability

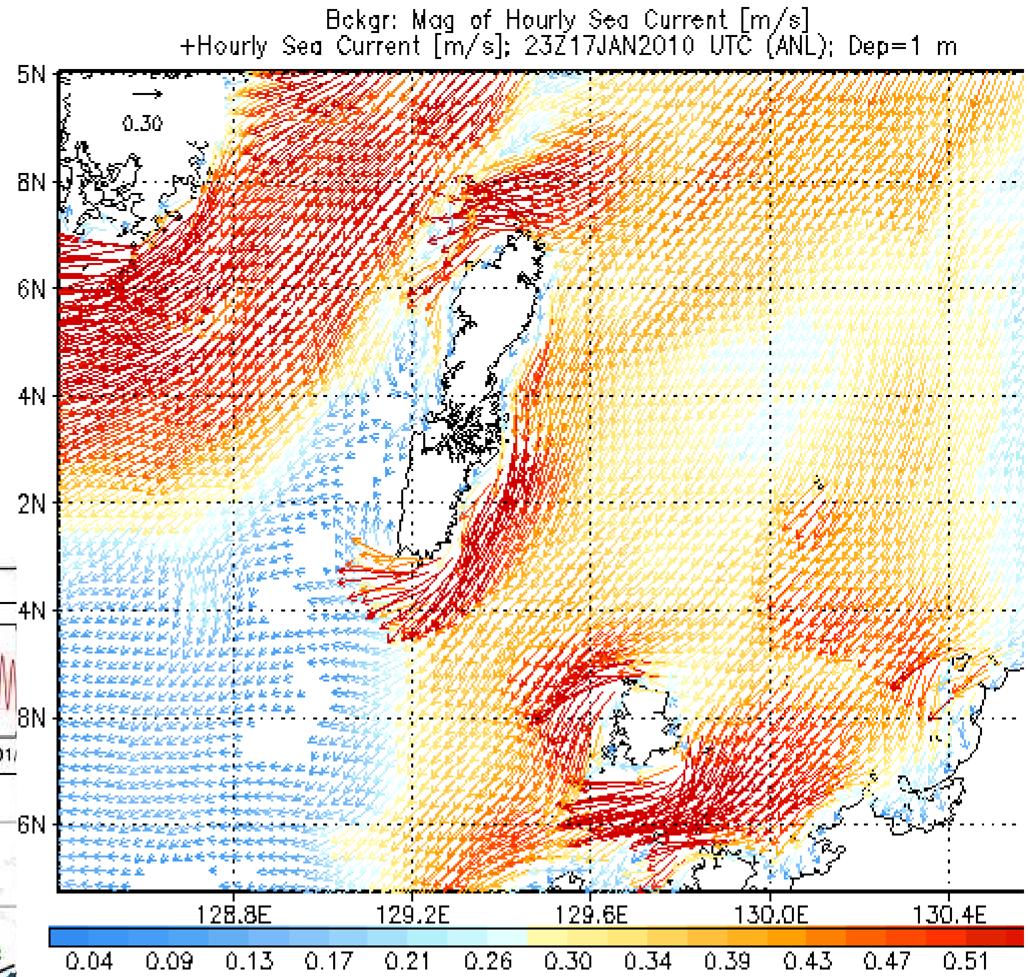
January 18, 2010 07 JST



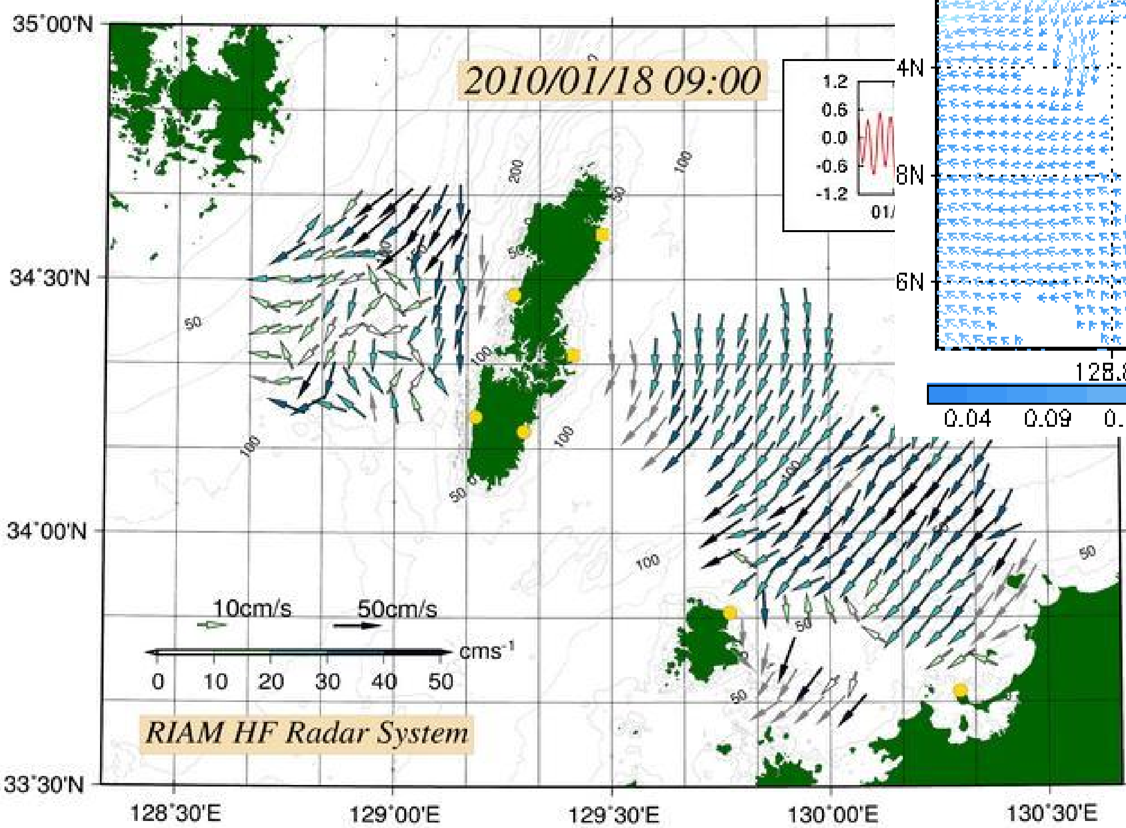


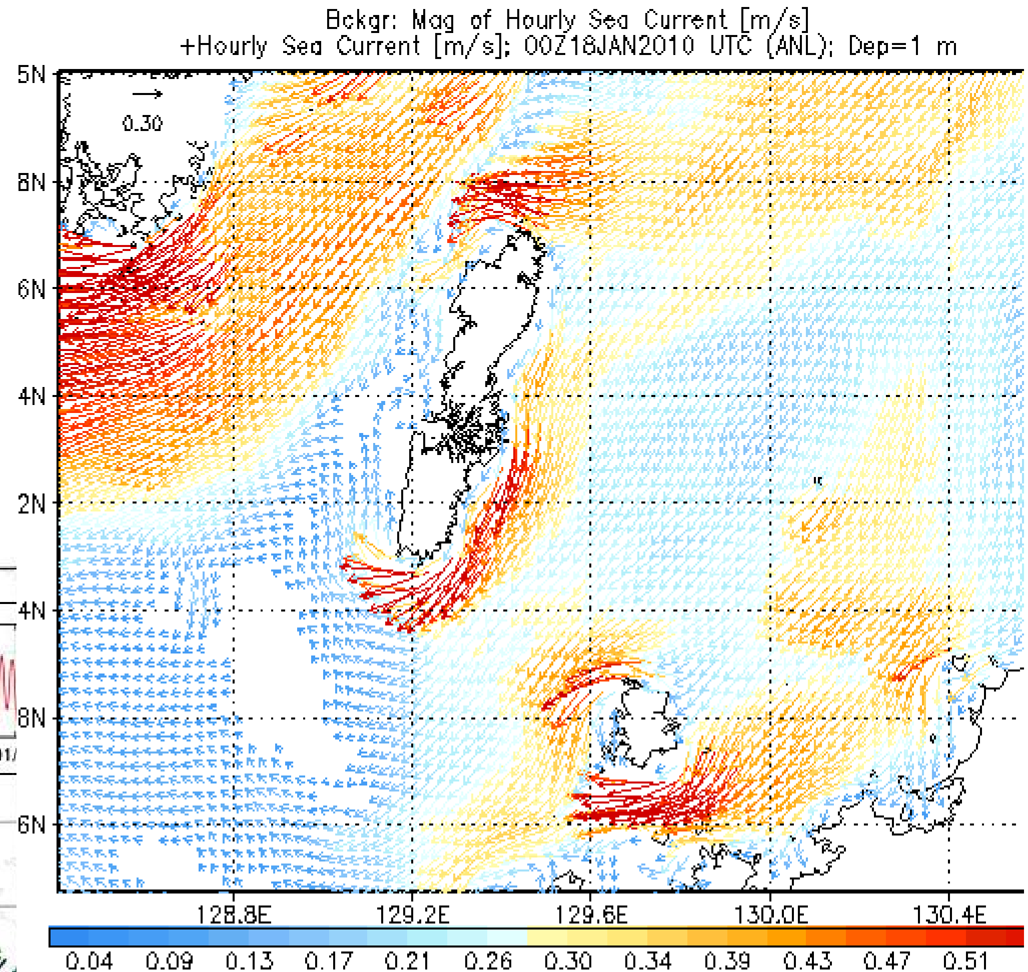
January 18, 2010 08 JST





January 18, 2010 09 JST





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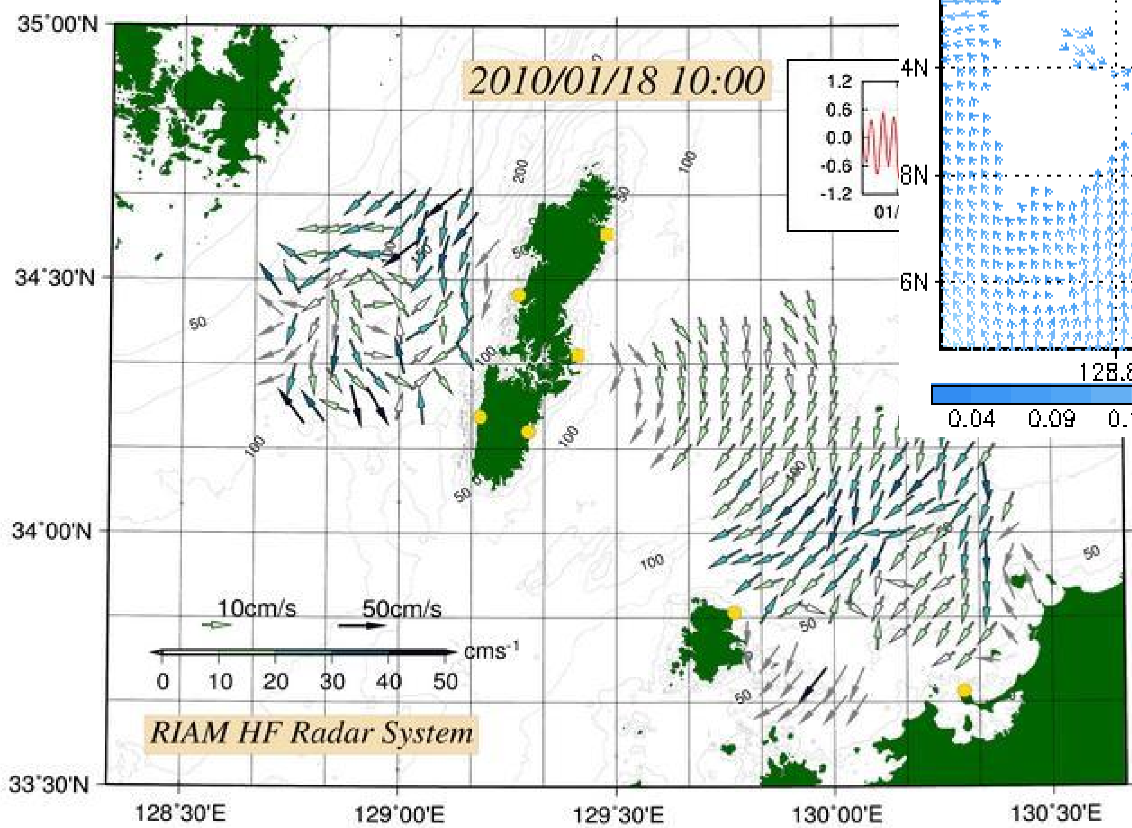
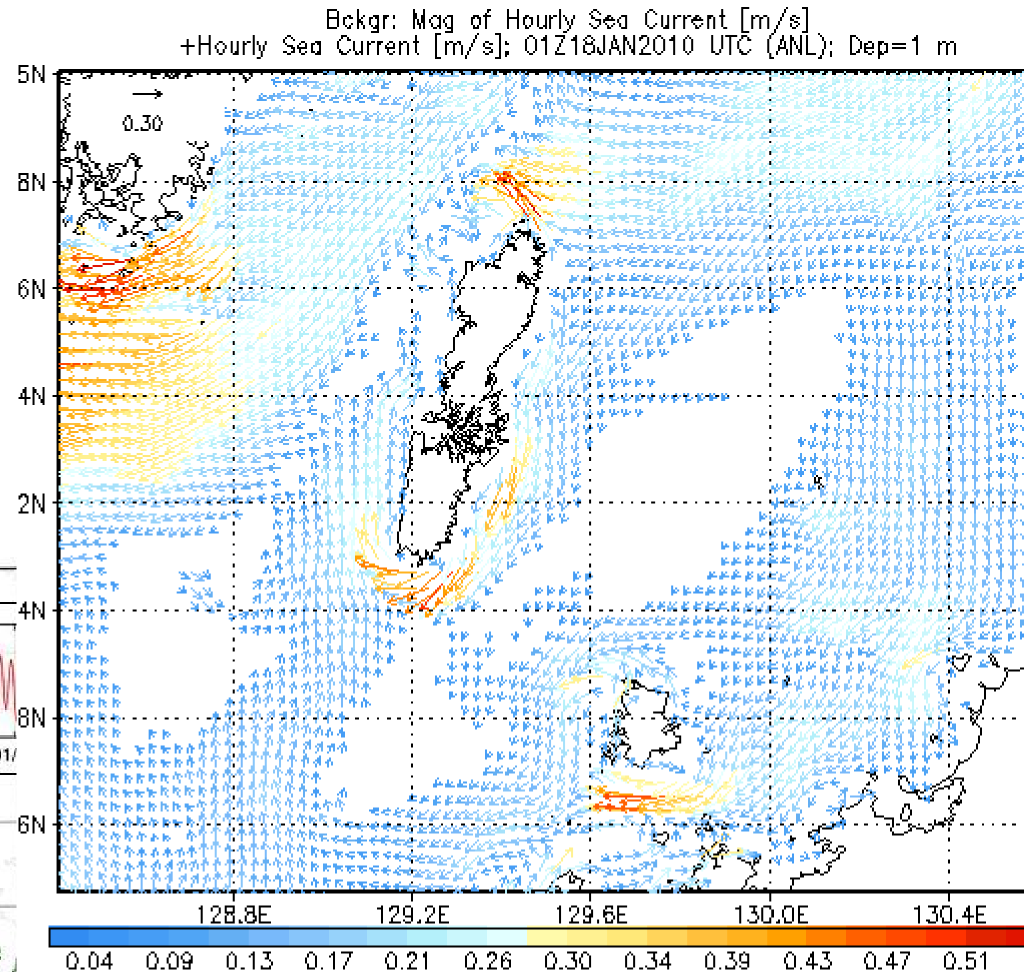
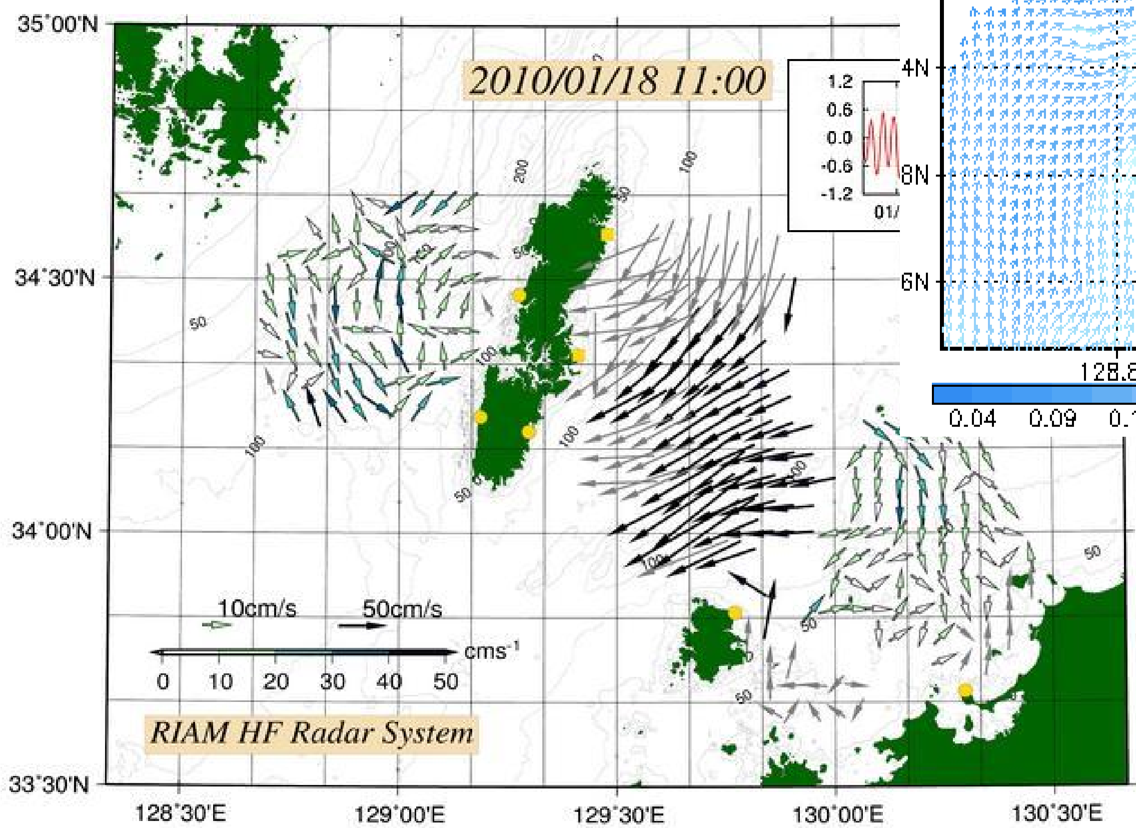
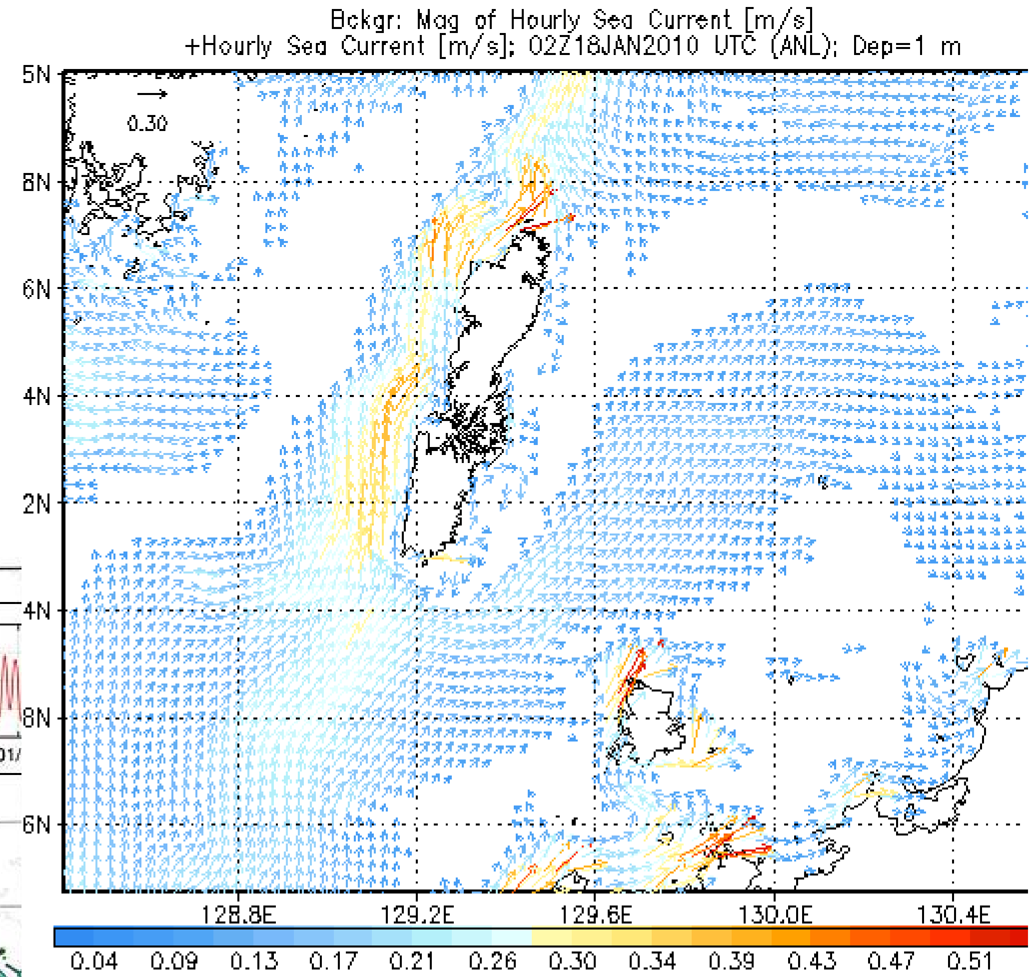




January 18, 2010 11 JST

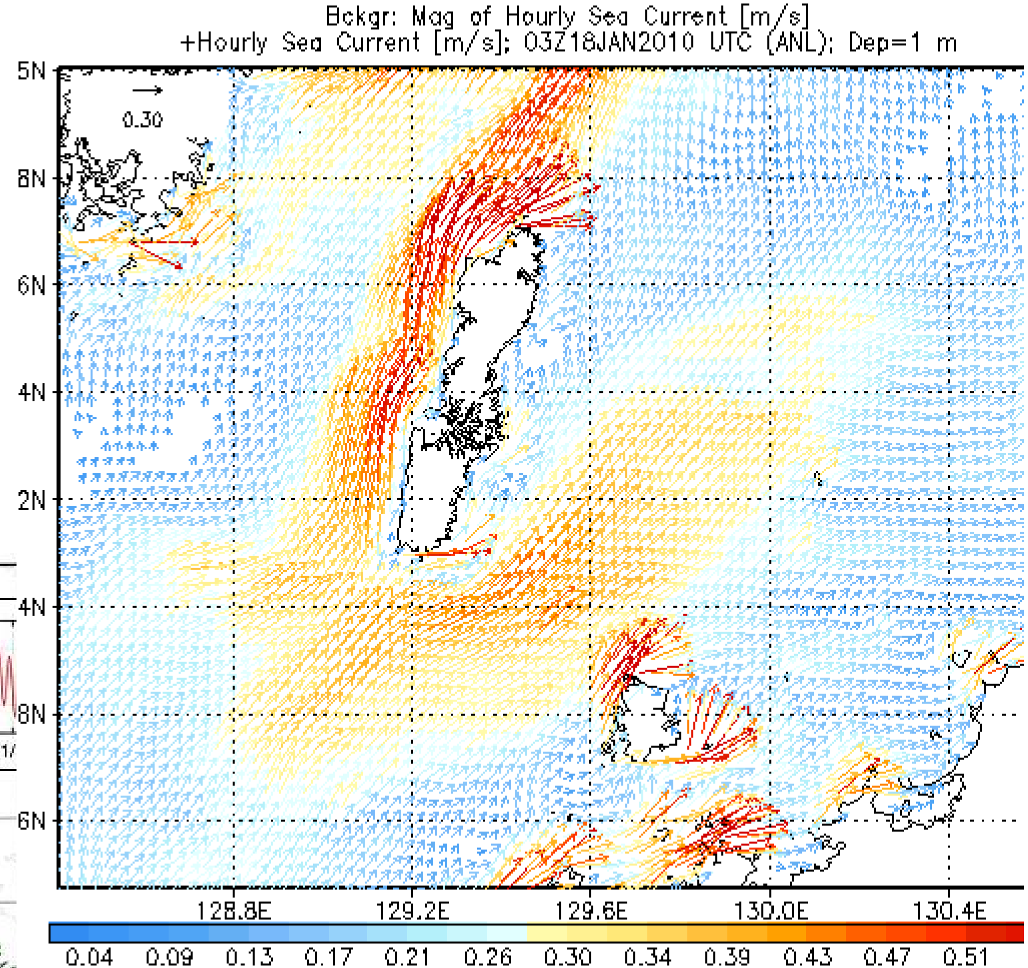
Inconsistency in Eastern Channel, HF radar shows “return” of outflow tidal current

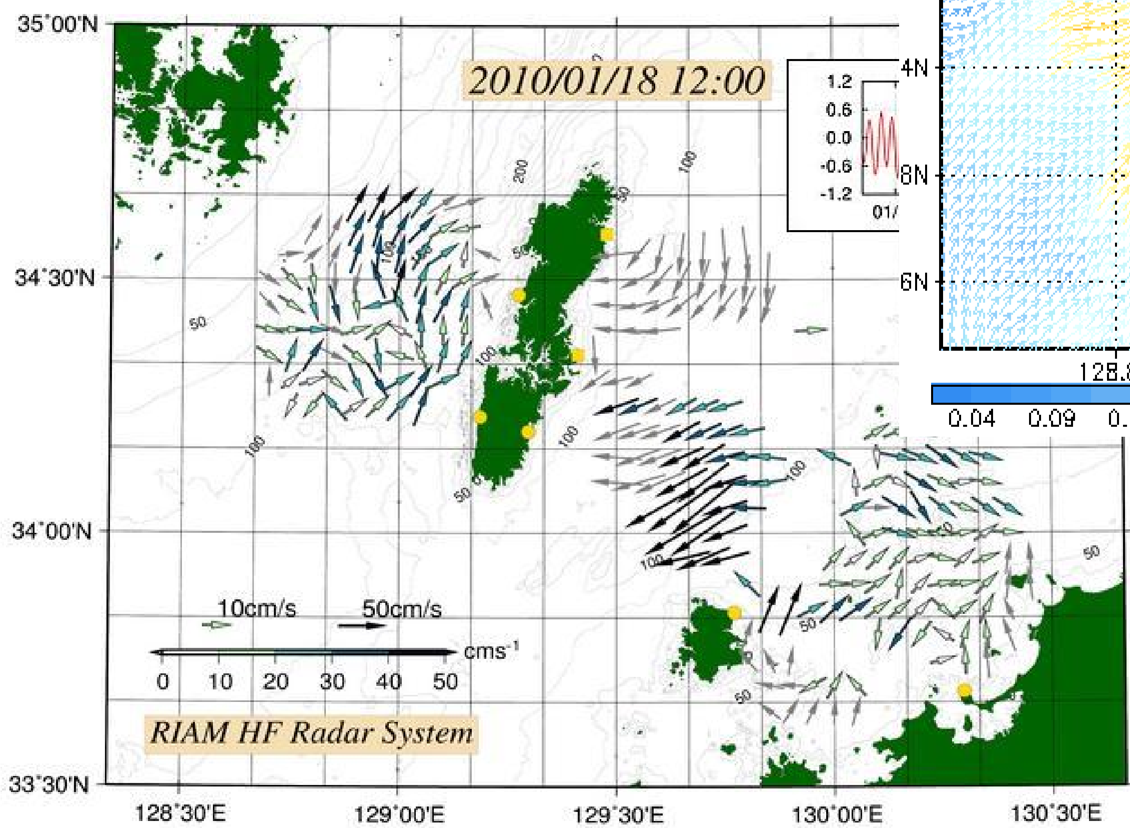




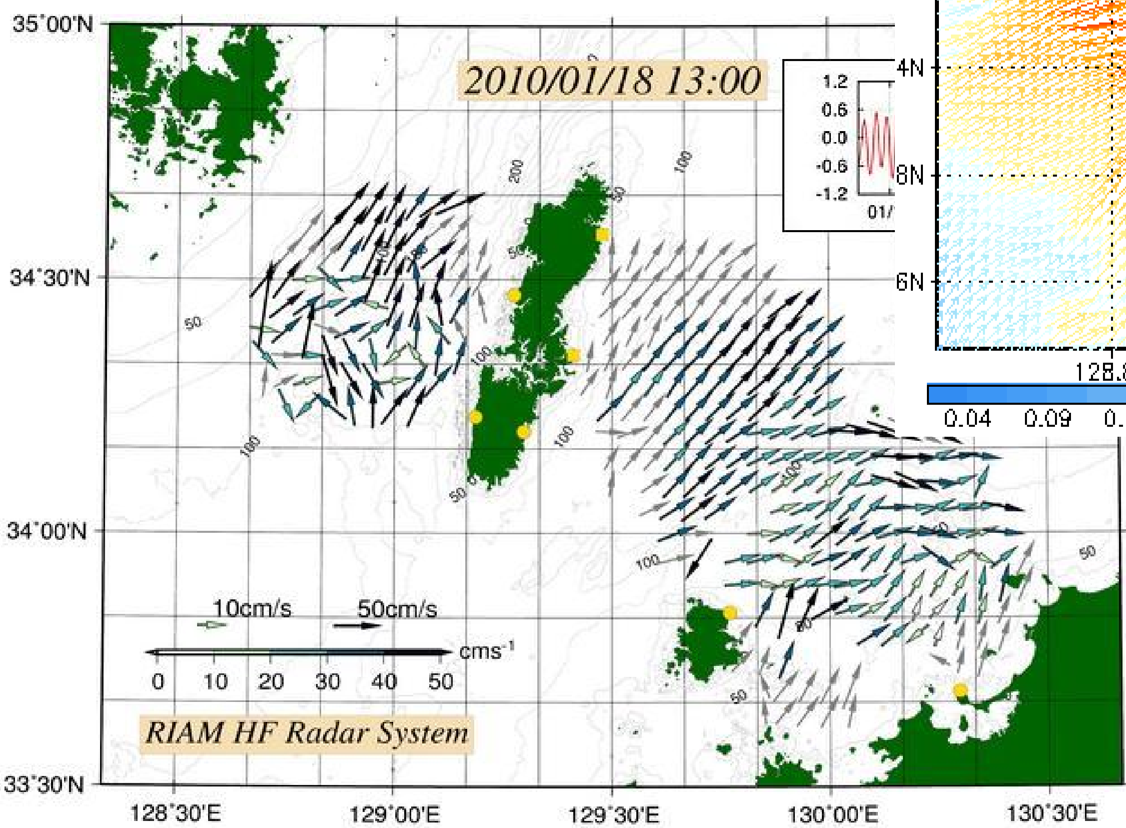
January 18, 2010 12 JST

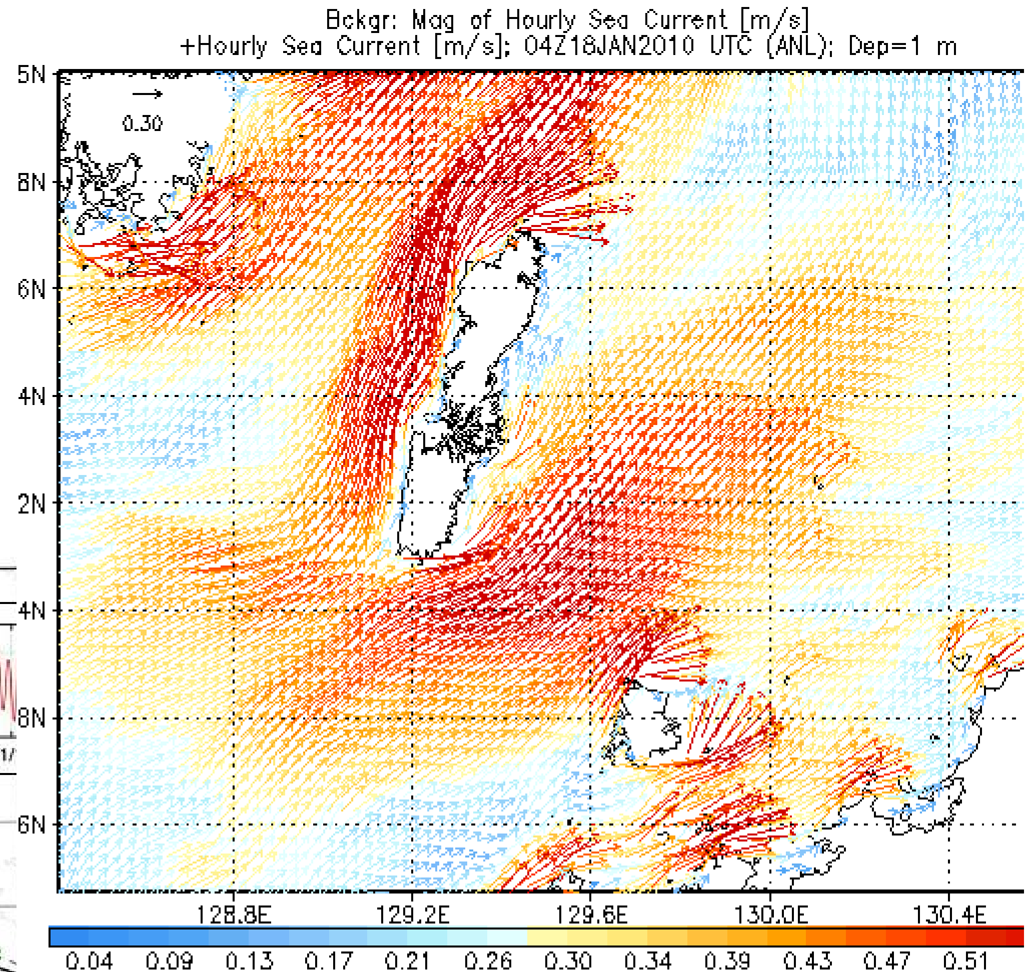
Inconsistency in Eastern Channel



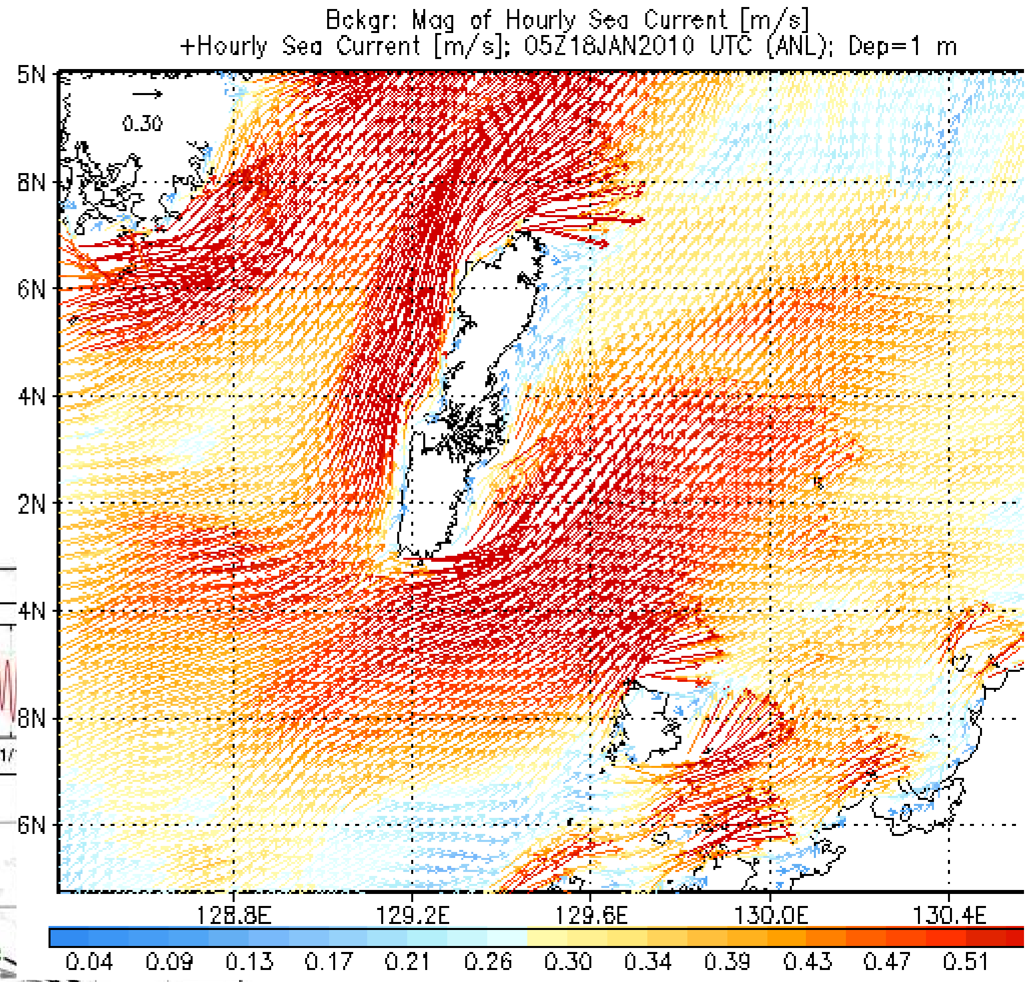


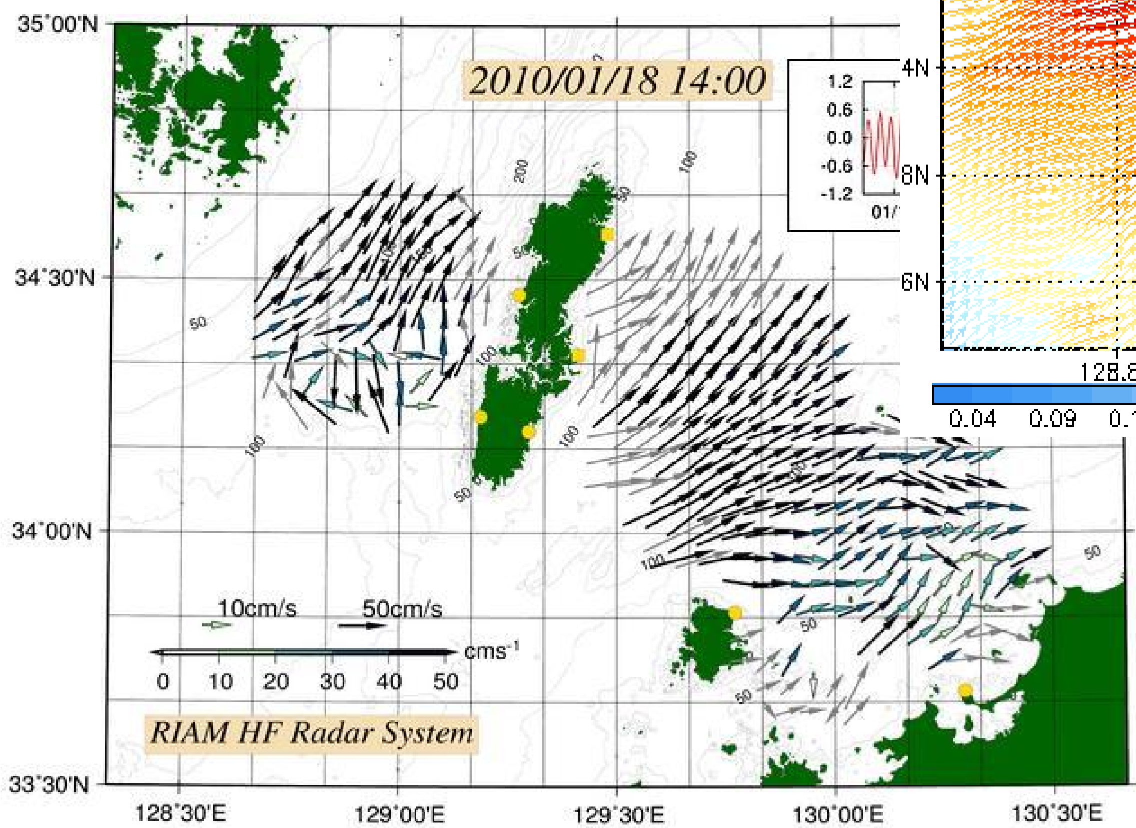
January 18, 2010 13 JST





January 18, 2010 14 JST



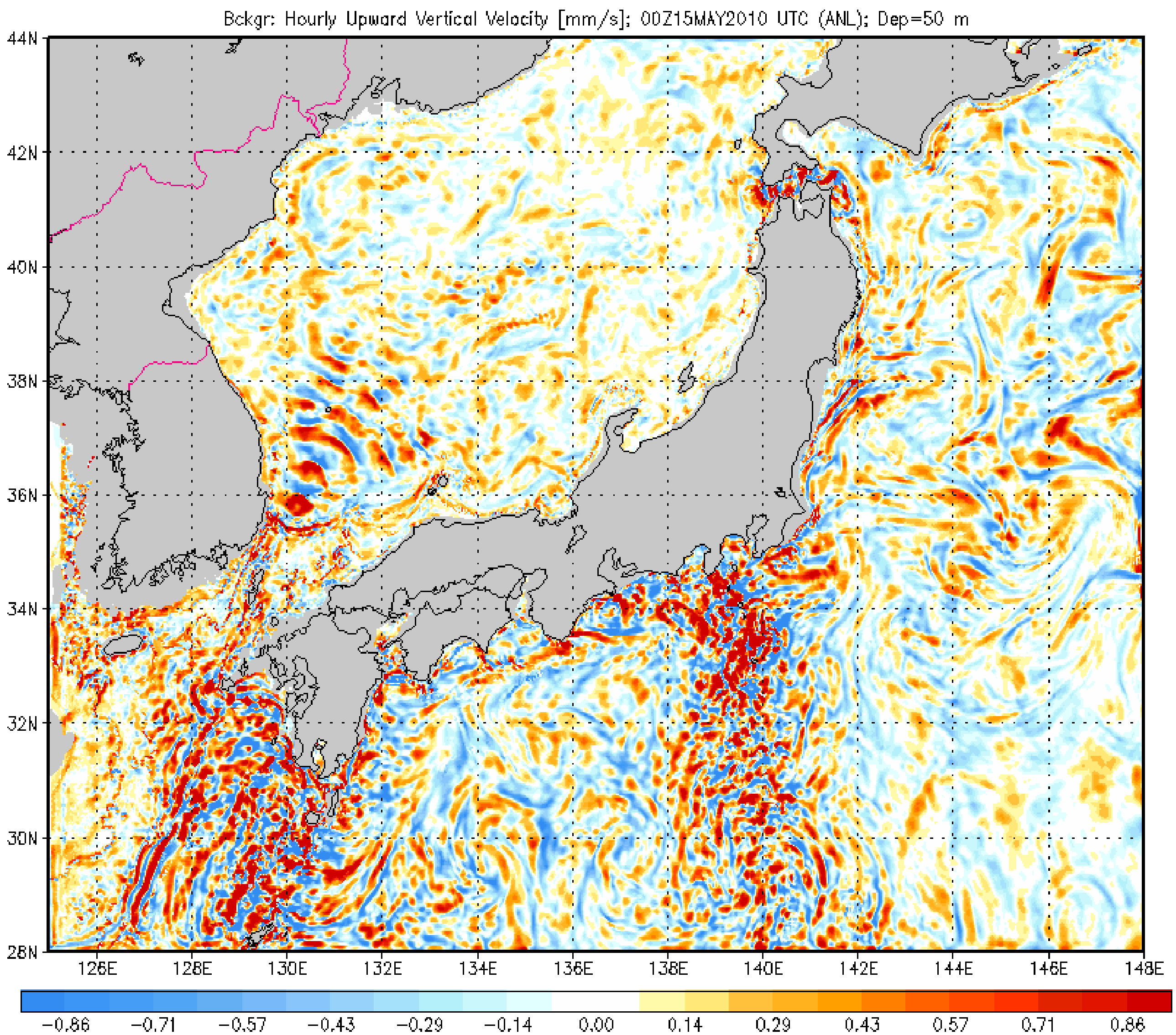


Internal tides:

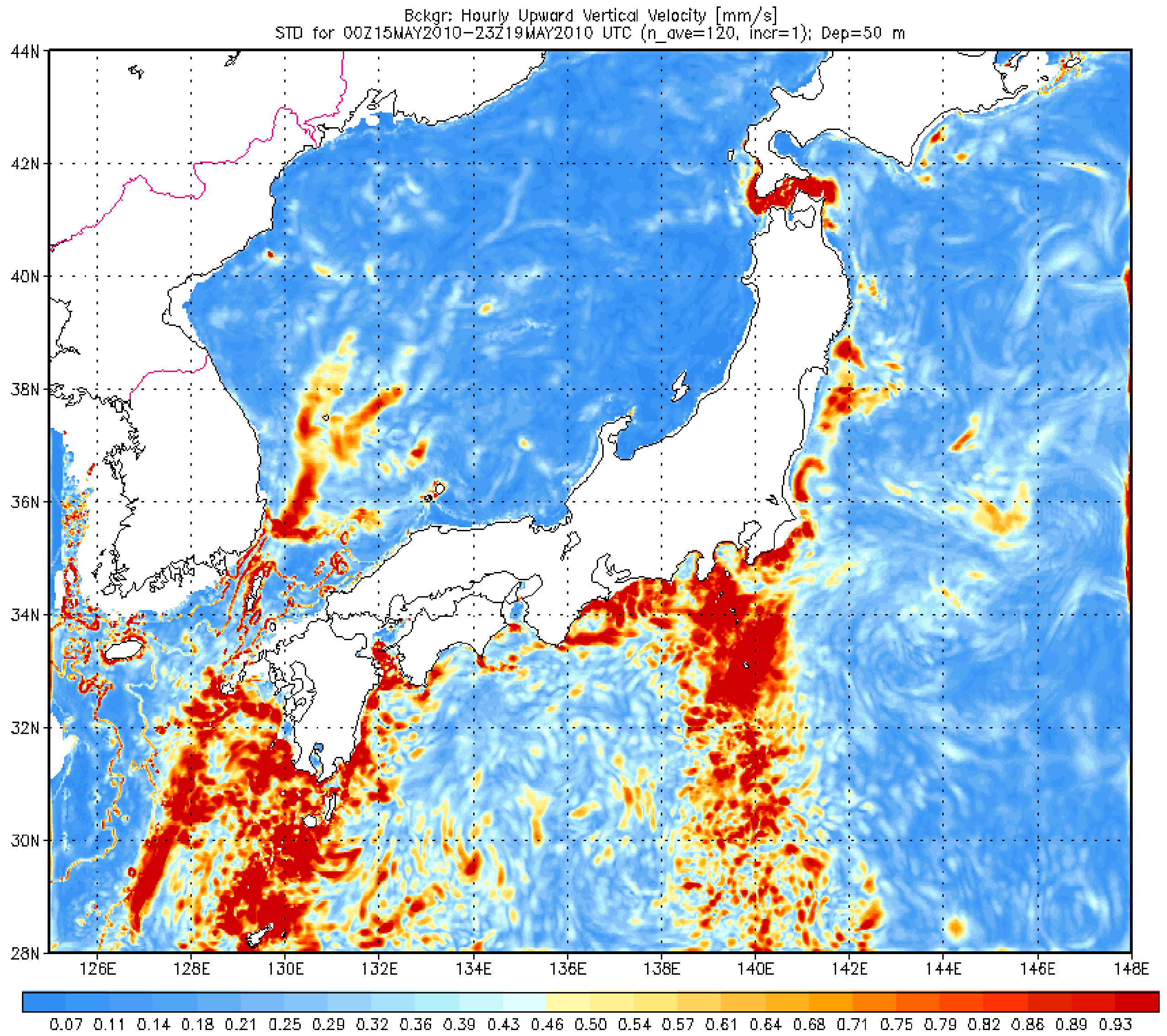
what means

“often aperiodic although with the external tidal ’carrier frequency’ due to the mesoscale variations ”

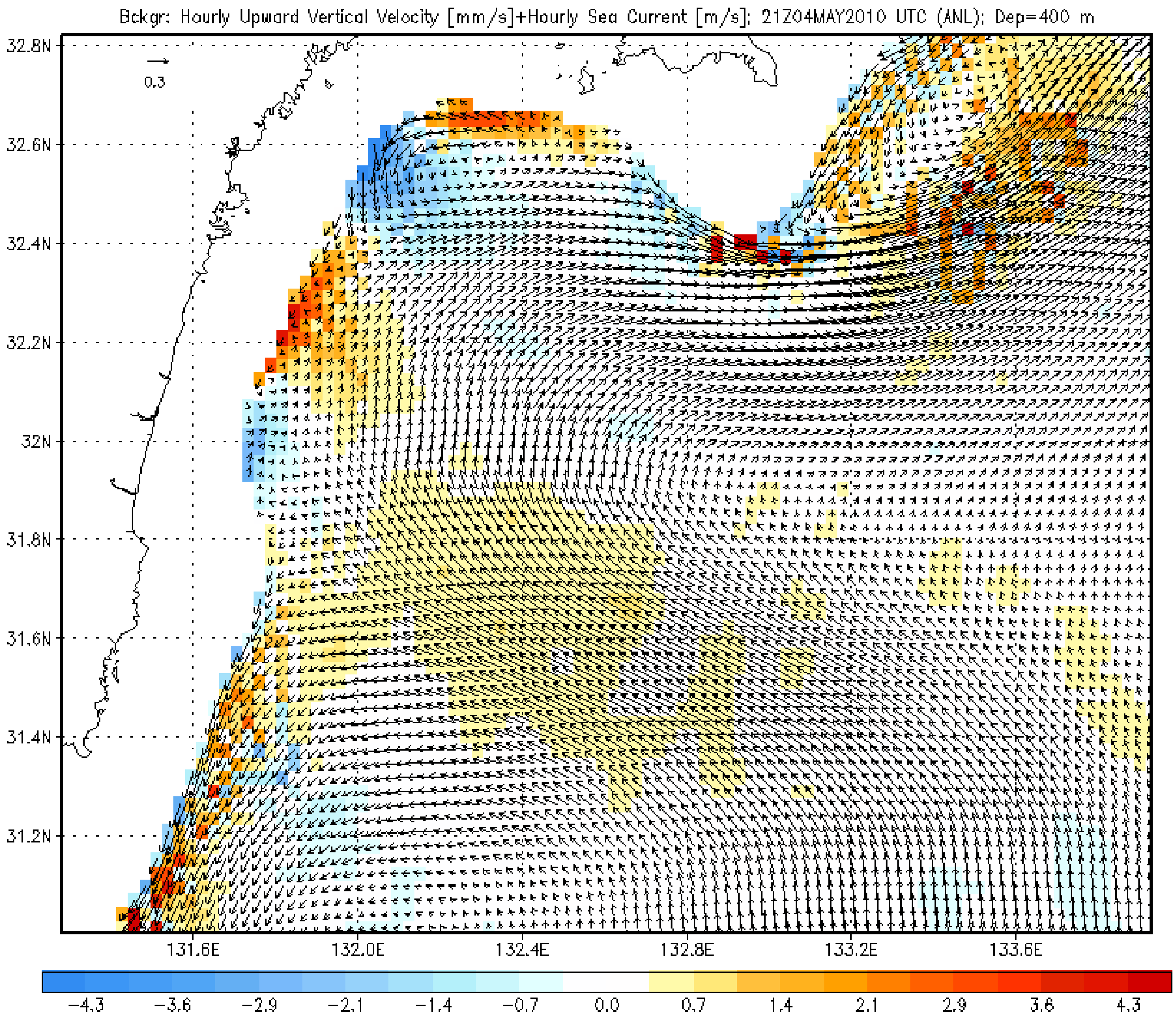
JCOPET: Wz(z=50m), May 15-20, 2010



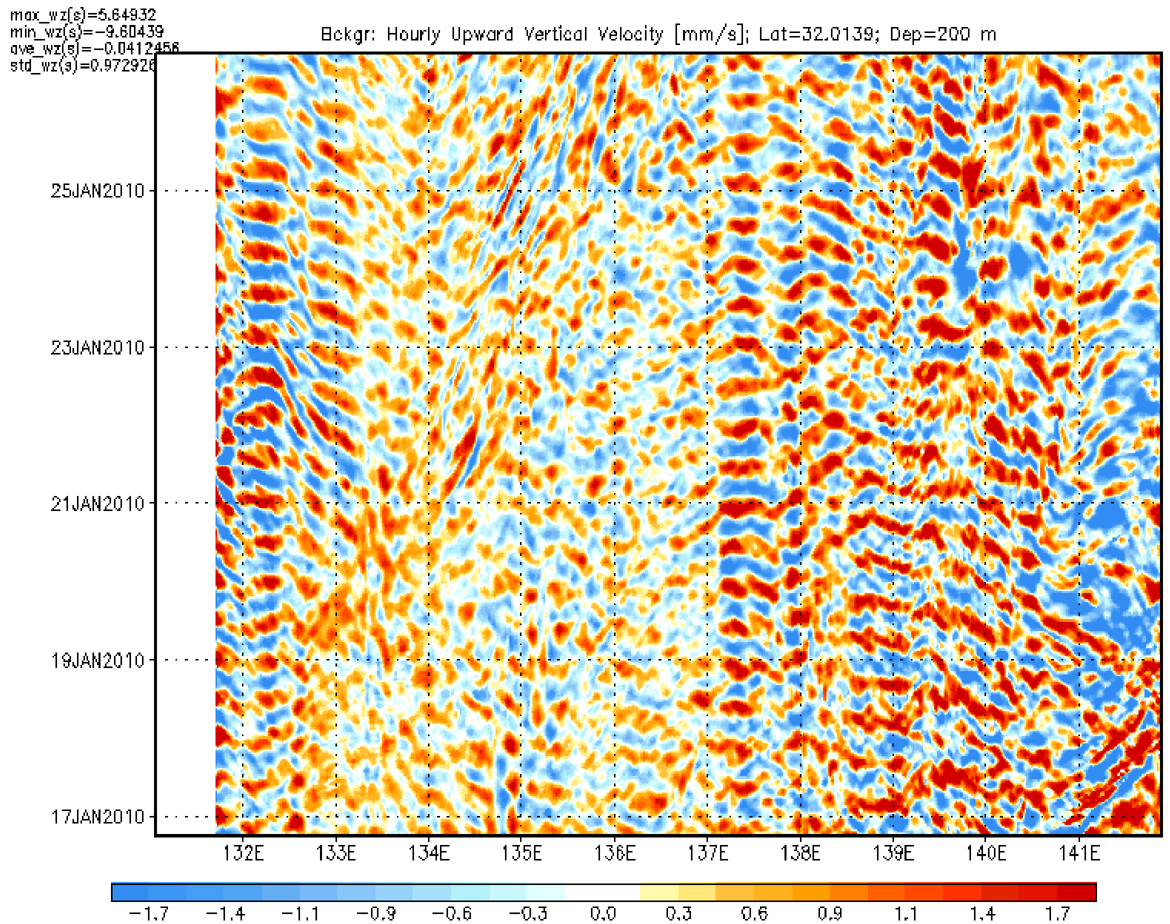
Standard variability of Wz, 50m, 5 days mean
Red zoned exceed 1 mm/s, max > 10 mm/s



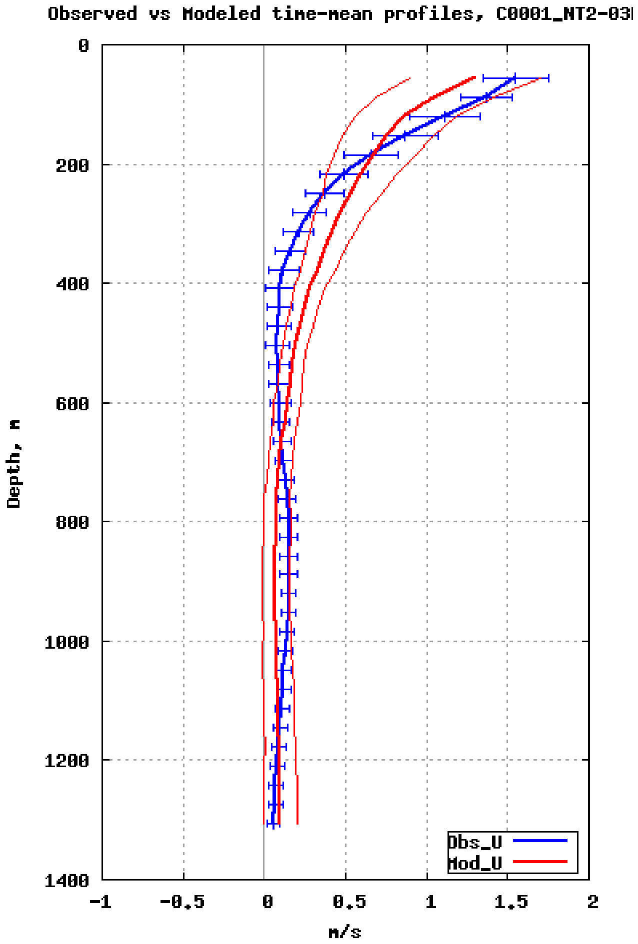
Z=400m, Pacific ocean shelf slope east of Kyushu and south of Shikoku, May 4-6, 2010: shades: vertical velocity, vectors: horizontal velocity

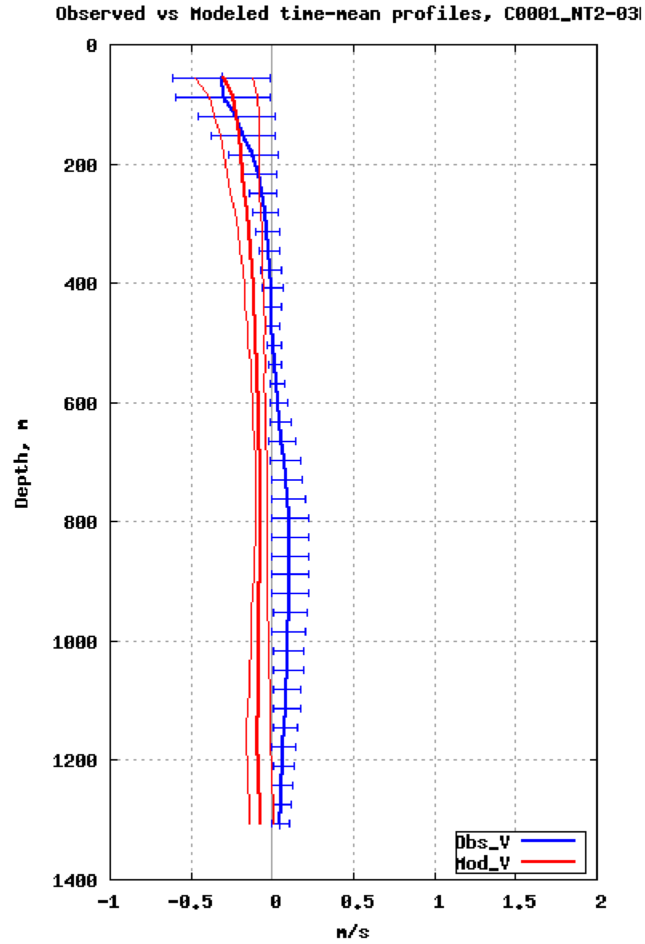


Other variability examples: longitude-time section of W(z=200m) along 32N off Kyushu

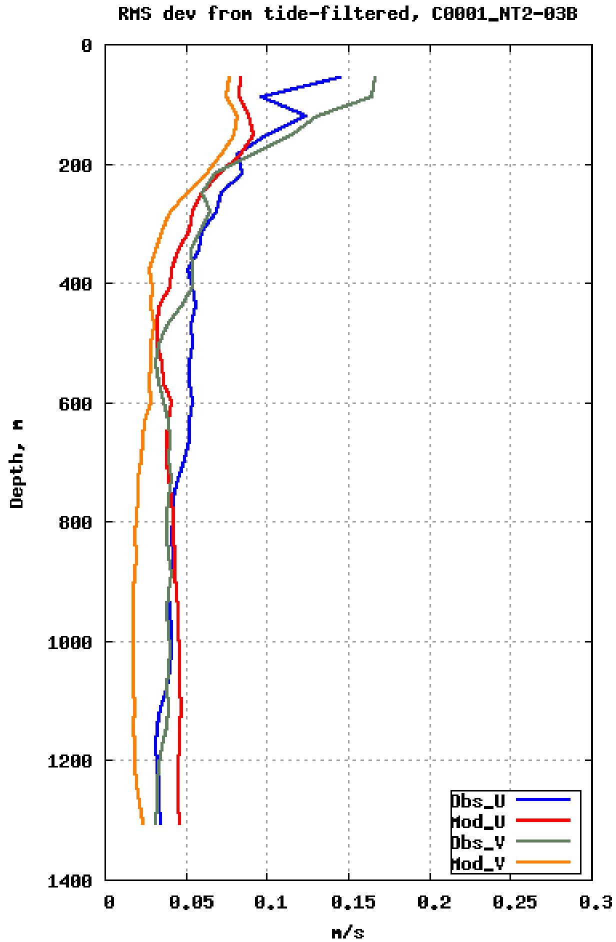


ADCP vs Model: 12-days statistics, point C0001_NT2-03

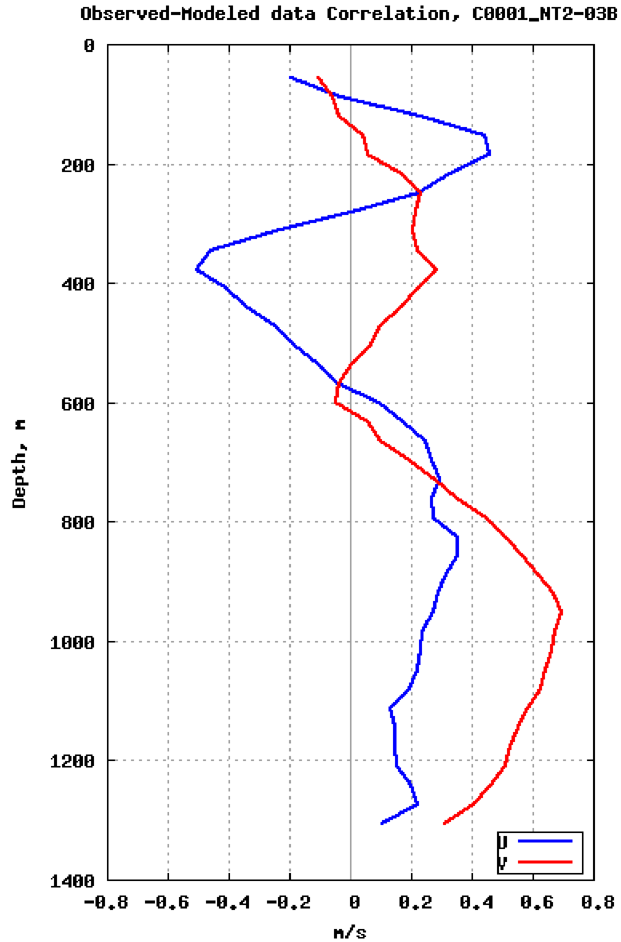




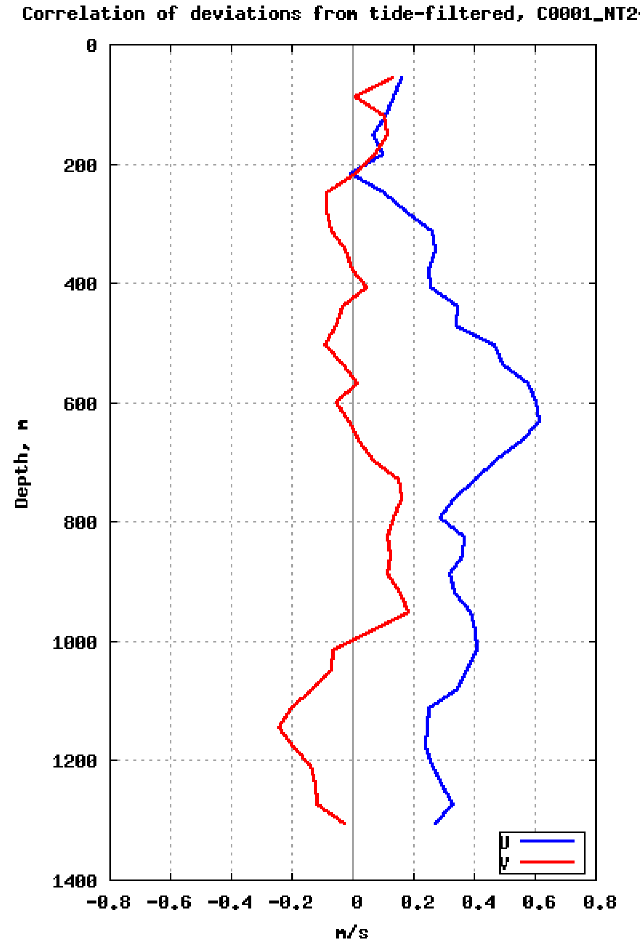
ADCP vs Model: 12-days statistics



RMS variability



Correlation of abs velocity component



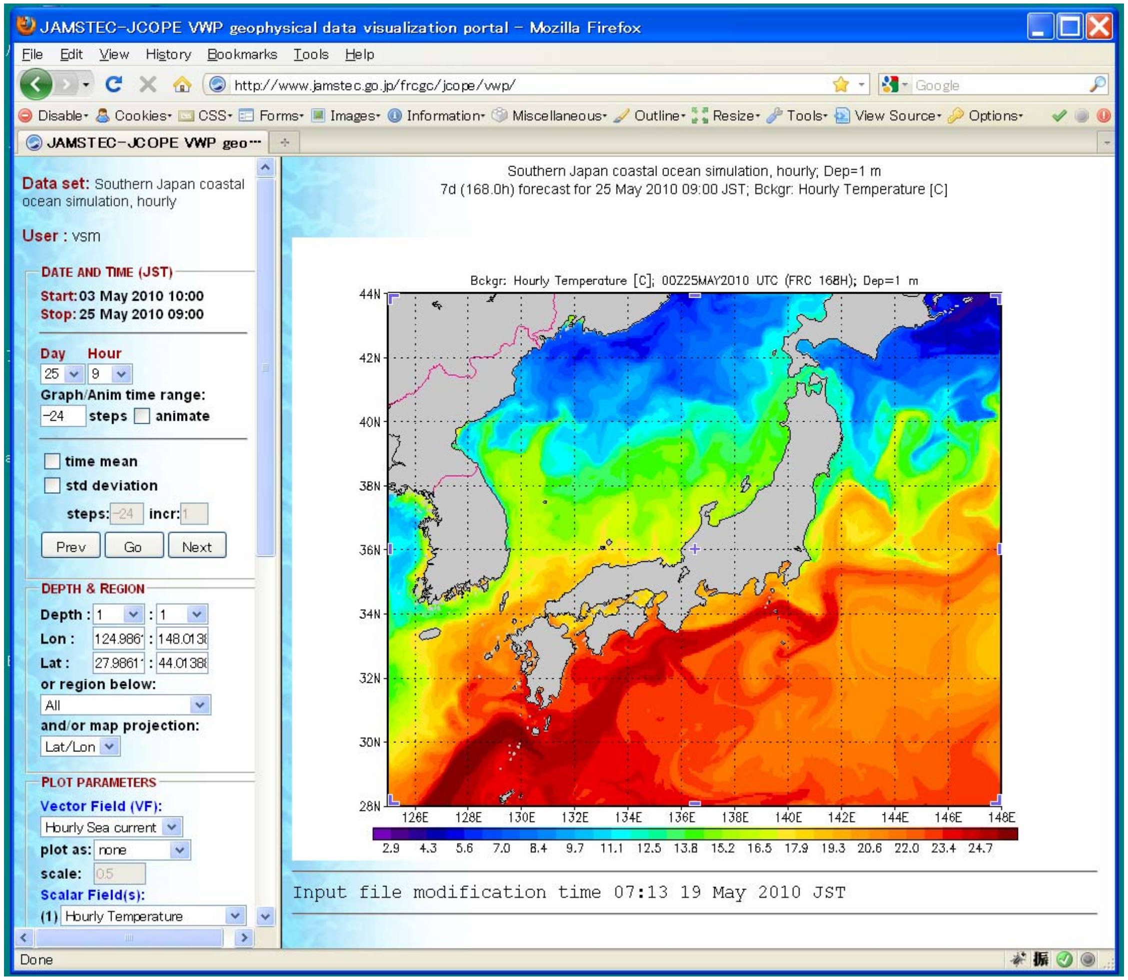
Correlation for deviations from tide-filtered

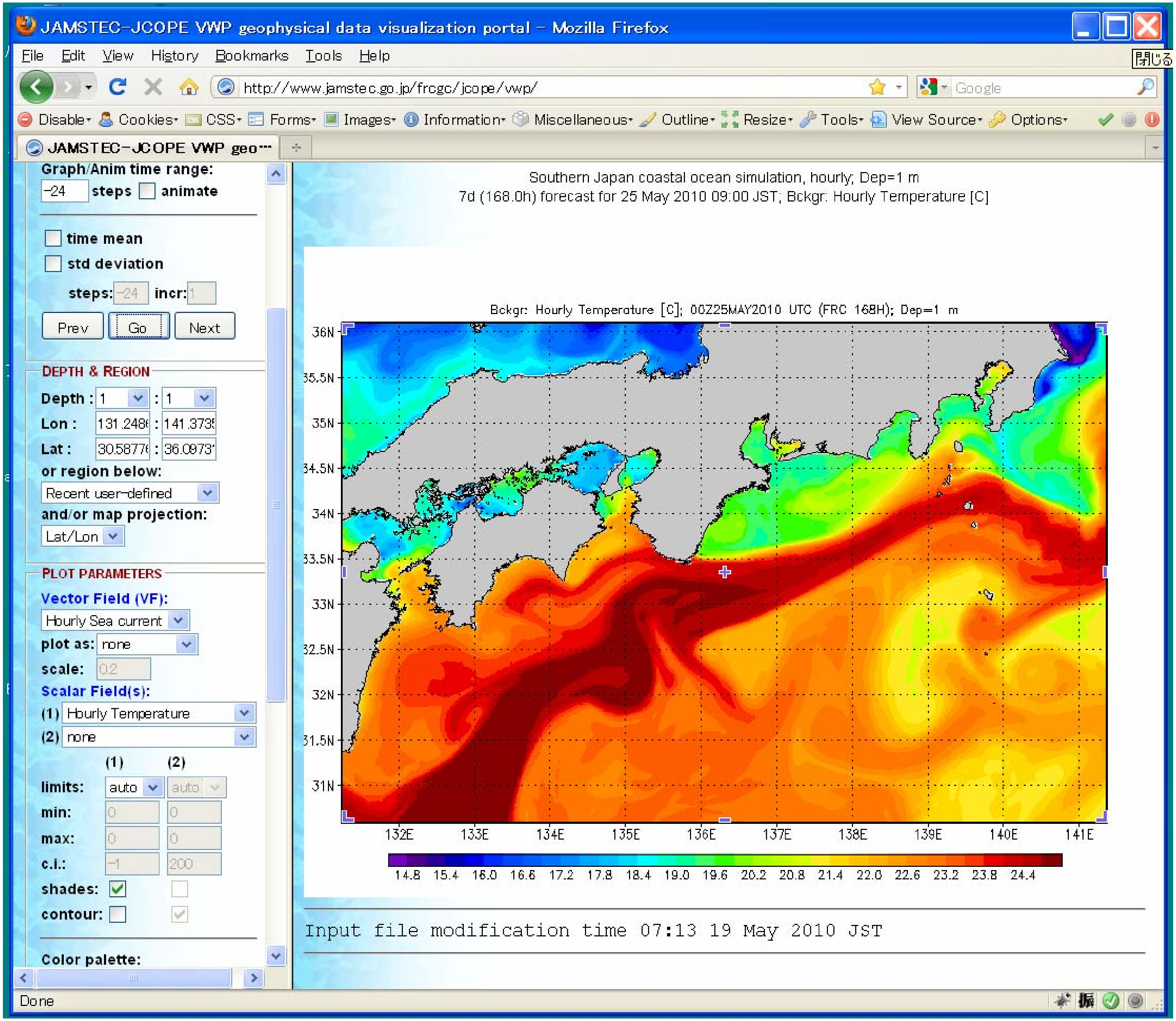
Resume

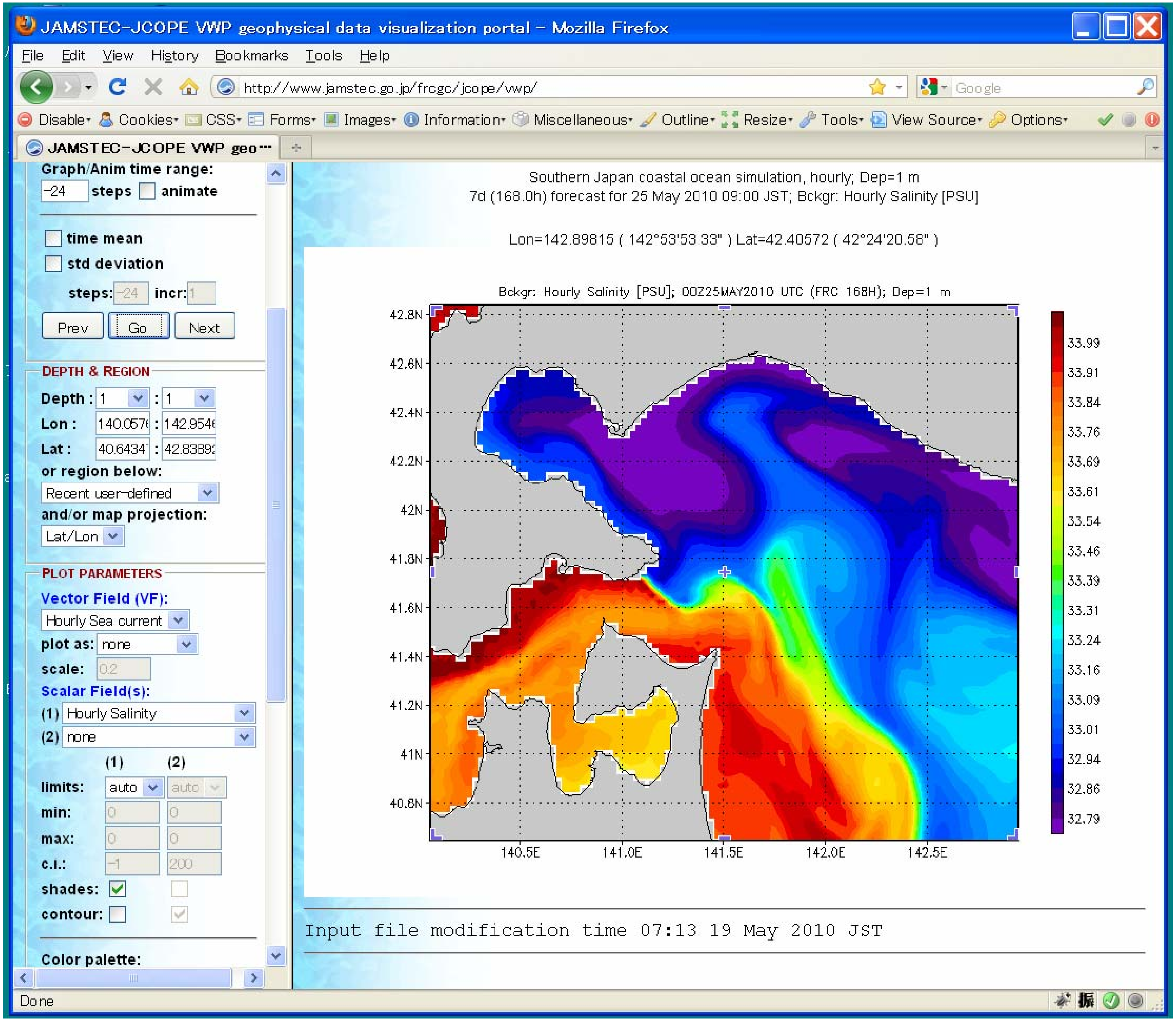
- High resolution tide-resolving JCOPET downscaling system is developed and is operated daily in automatic mode
- Some processes like coastal circulation and circulation over the ocean shelf has relatively good (deterministic) predictability [direct forcing is primary]
- Processes controlled by inertial forces and instabilities like formation of mesoscale jets and eddies etc. require futher improvement of model initialization and assimilation schemes and data
  Potentially, the variability in such zones could be predicted only statistically from ensemble of simulations due to the lack of deterministic predictability
- Modeling system improvement and validation is going

Web portal for JCOPE2-FRA re-analysis (free access) and JCOPE real-time products (please register or use temporary user name “visitor”, password “no”):

http://www.jamstec.go.jp/frcgc/jcope/vwp/




JAMSTEC-JCOPE VWP geophysical data visualization portal - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://www.jamstec.go.jp/frcgc/jcope/vwp/
Disable Cookies CSS Forms Images Information Miscellaneous Outline Resize Tools View Source Options
JAMSTEC-JCOPE VWP geo…
Graph/Anim time range:
-24 steps animate
time mean
std deviation
steps: -24 incr: 1
Prev Go Next
DEPTH & REGION
Depth : 1 : 1
Lon : 131.248 : 141.373
Lat : 30.5877 : 36.0973
or region below:
Recent user-defined
and/or map projection:
Lat/Lon
PLOT PARAMETERS
Vector Field (VF):
Hourly Sea current
plot as: none
scale: 0.2
Scalar Field(s):
(1) Hourly Temperature
(2) none
(1) (2)
limits: auto auto
min: 0 0
max: 0 0
c.i.: -1 200
shades:
contour:
Color palette:
Southern Japan coastal ocean simulation, hourly; Dep=1 m
7d (168.0h) forecast for 25 May 2010 09:00 JST; Bckgr: Hourly Temperature [C]
Bckgr: Hourly Temperature [C]; 00Z25MAY2010 UTC (FRC 168H); Dep=1 m
36N
35.5N
35N
34.5N
34N
33.5N
33N
32.5N
32N
31.5N
31N
132E 133E 134E 135E 136E 137E 138E 139E 140E 141E
14.8 15.4 16.0 16.6 17.2 17.8 18.4 19.0 19.6 20.2 20.8 21.4 22.0 22.6 23.2 23.8 24.4
Input file modification time 07:13 19 May 2010 JST
Done


JAMSTEC-JCOPE VWP geophysical data visualization portal - Mozilla Firefox
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http://www.jamstec.go.jp/frcgc/jcope/vwp/
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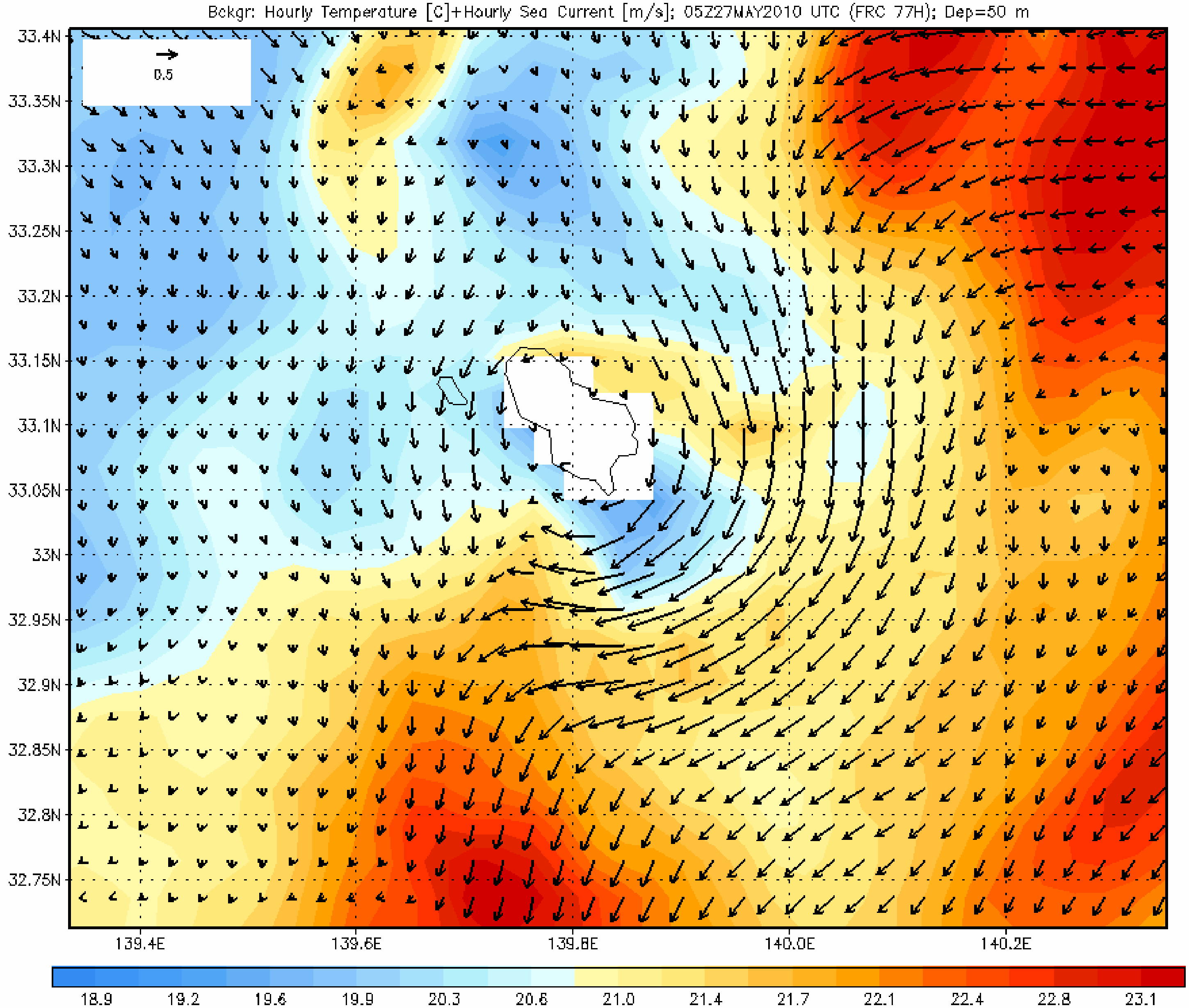
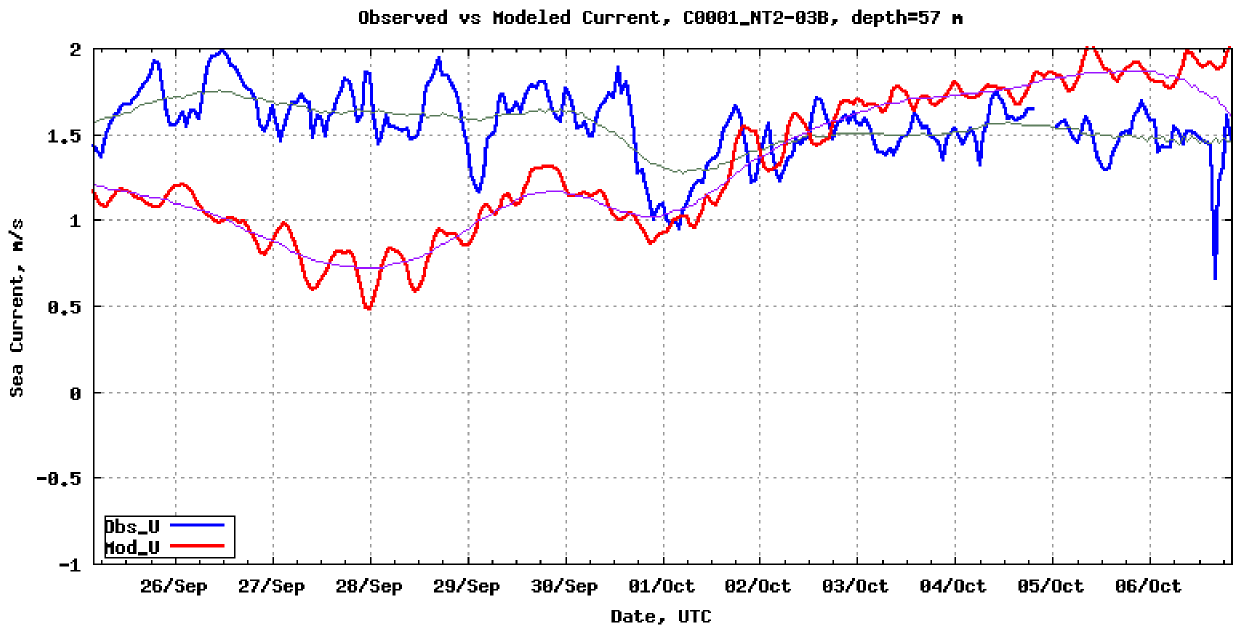
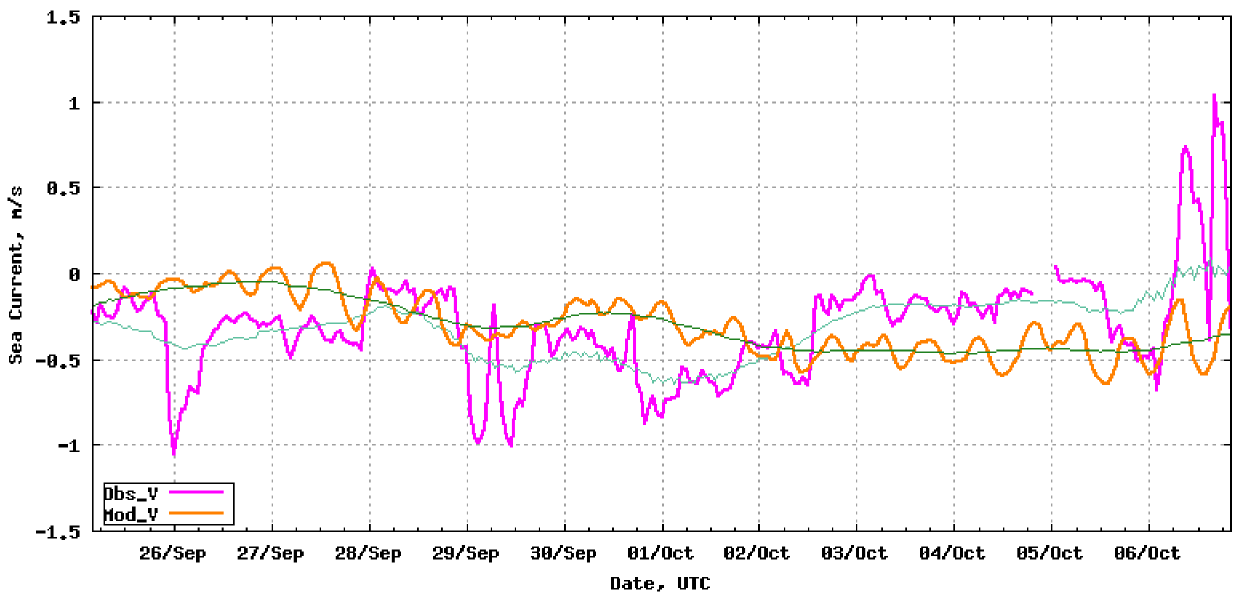
Disable Cookies CSS Forms Images Information Miscellaneous Outline Resize Tools View Source Options
JAMSTEC-JCOPE VWP geo…
Graph/Anim time range:
-24 steps animate
time mean
std deviation
steps: -24 incr: 1
Prev Go Next
DEPTH & REGION
Depth : 1 : 1
Lon : 140.0576 : 142.9546
Lat : 40.6434 : 42.8388
or region below:
Recent user-defined
and/or map projection:
Lat/Lon
PLOT PARAMETERS
Vector Field (VF):
Hourly Sea current
plot as: none
scale: 0.2
Scalar Field(s):
(1) Hourly Salinity
(2) none
(1) (2)
limits: auto auto
min: 0 0
max: 0 0
c.i.: -1 200
shades:
contour:
Color palette:
Southern Japan coastal ocean simulation, hourly; Dep=1 m
7d (168.0h) forecast for 25 May 2010 09:00 JST; Bckgr: Hourly Salinity [PSU]
Lon=142.89815 (142°53'53.33") Lat=42.40572 (42°24'20.58")
Bckgr: Hourly Salinity [PSU]; 00Z25MAY2010 UTC (FRC 168H); Dep=1 m
42.8N
42.6N
42.4N
42.2N
42N
41.8N
41.6N
41.4N
41.2N
41N
40.8N
140.5E
141.0E
141.5E
142.0E
142.5E
33.99
33.91
33.84
33.76
33.69
33.61
33.54
33.46
33.39
33.31
33.24
33.16
33.09
33.01
32.94
32.86
32.79
Input file modification time 07:13 19 May 2010 JST
Done

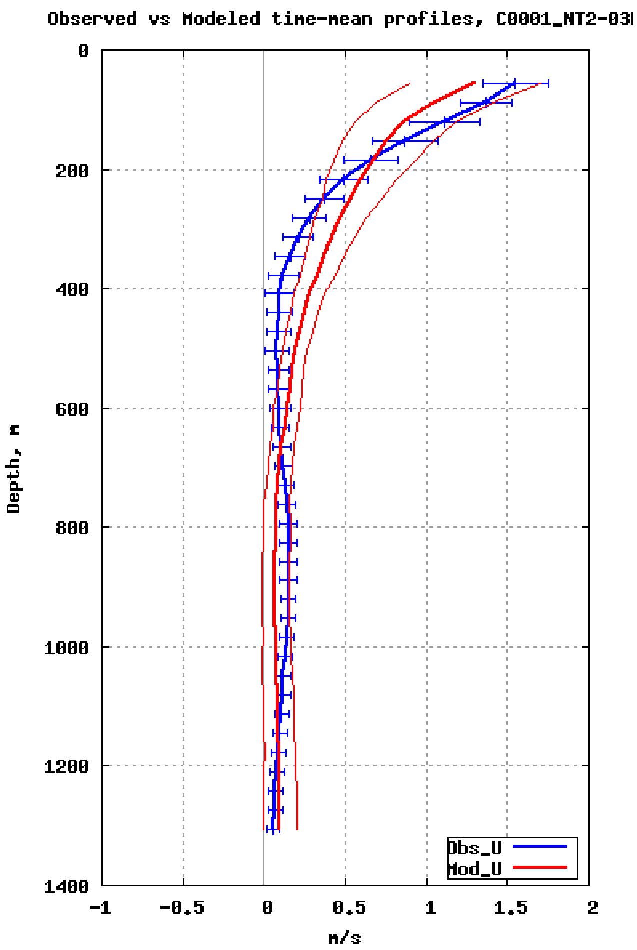


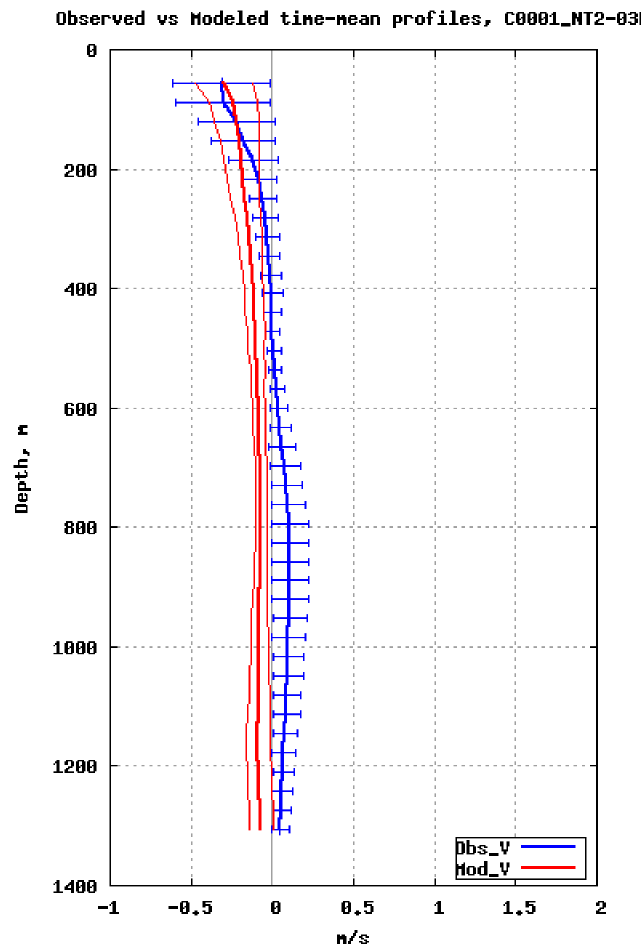
Bckgr: Hourly Temperature [C]+Hourly Sea Current [m/s]; 05Z27MAY2010 UTC (FRC 77H); Dep=50 m
0.5
33.4N
33.35N
33.3N
33.25N
33.2N
33.15N
33.1N
33.05N
33N
32.95N
32.9N
32.85N
32.8N
32.75N
139.4E
139.6E
139.8E
140.0E
140.2E
18.9
19.2
19.6
19.9
20.3
20.6
21.0
21.4
21.7
22.1
22.4
22.8
23.1

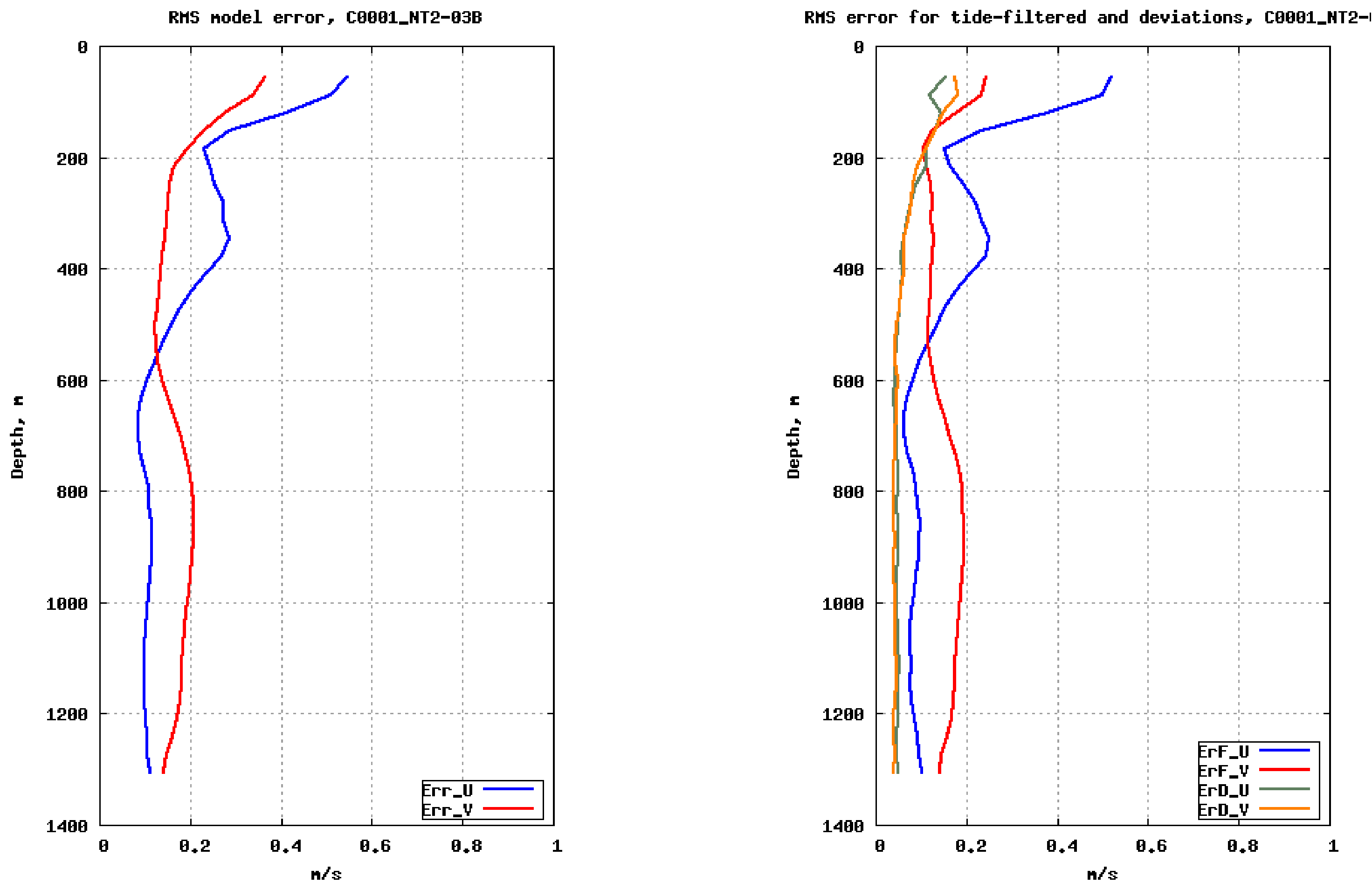

Observed vs Modeled Current, C0001_NT2-03B, depth=57 m
Sea Current, m/s
2
1.5
1
0.5
0
-0.5
-1
Obs_U
Mod_U
26/Sep
27/Sep
28/Sep
29/Sep
30/Sep
01/Oct
02/Oct
03/Oct
04/Oct
05/Oct
06/Oct
Date, UTC

Observed vs Modeled Current, C0001_NT2-03B, depth=57 m

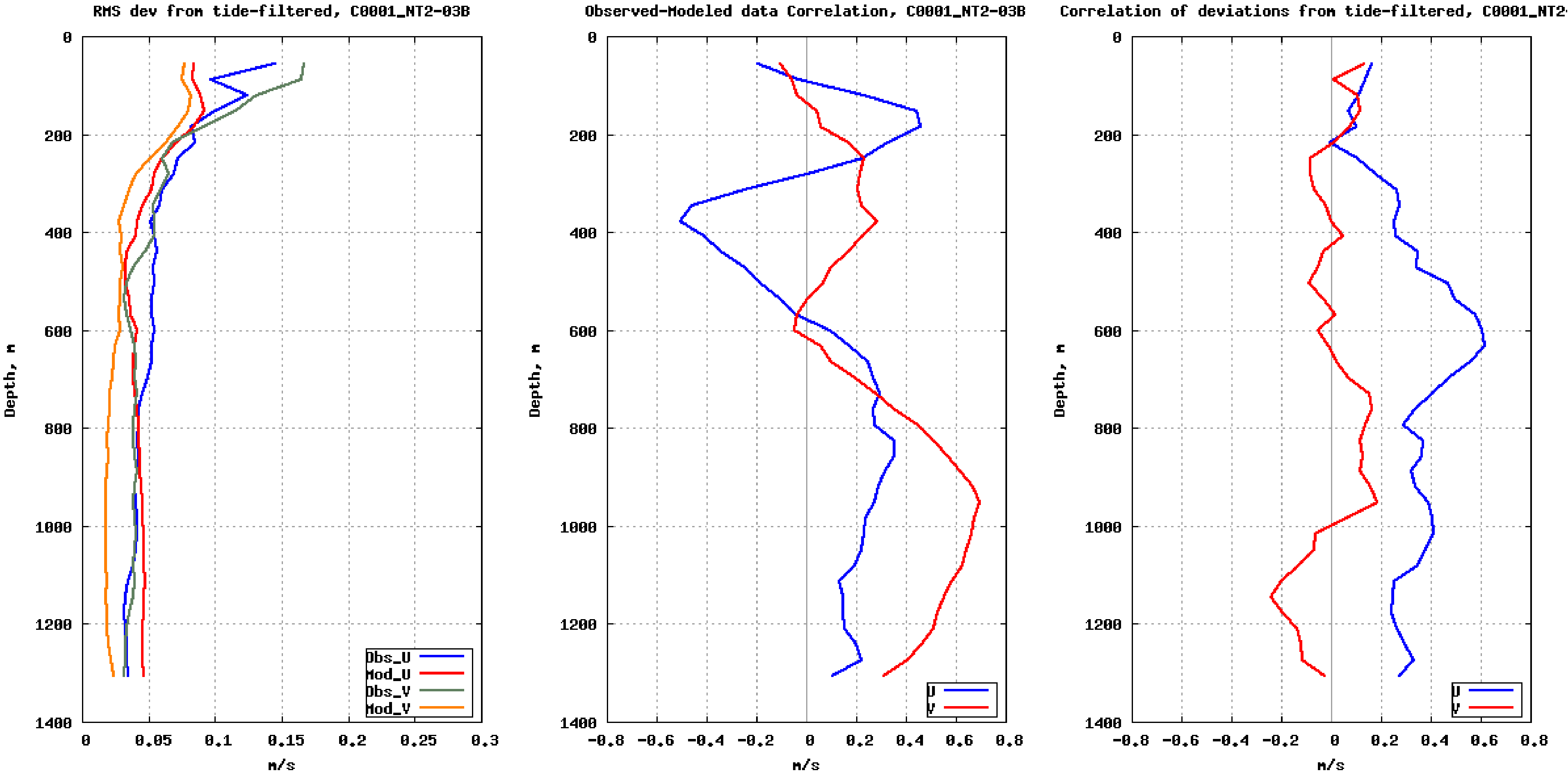


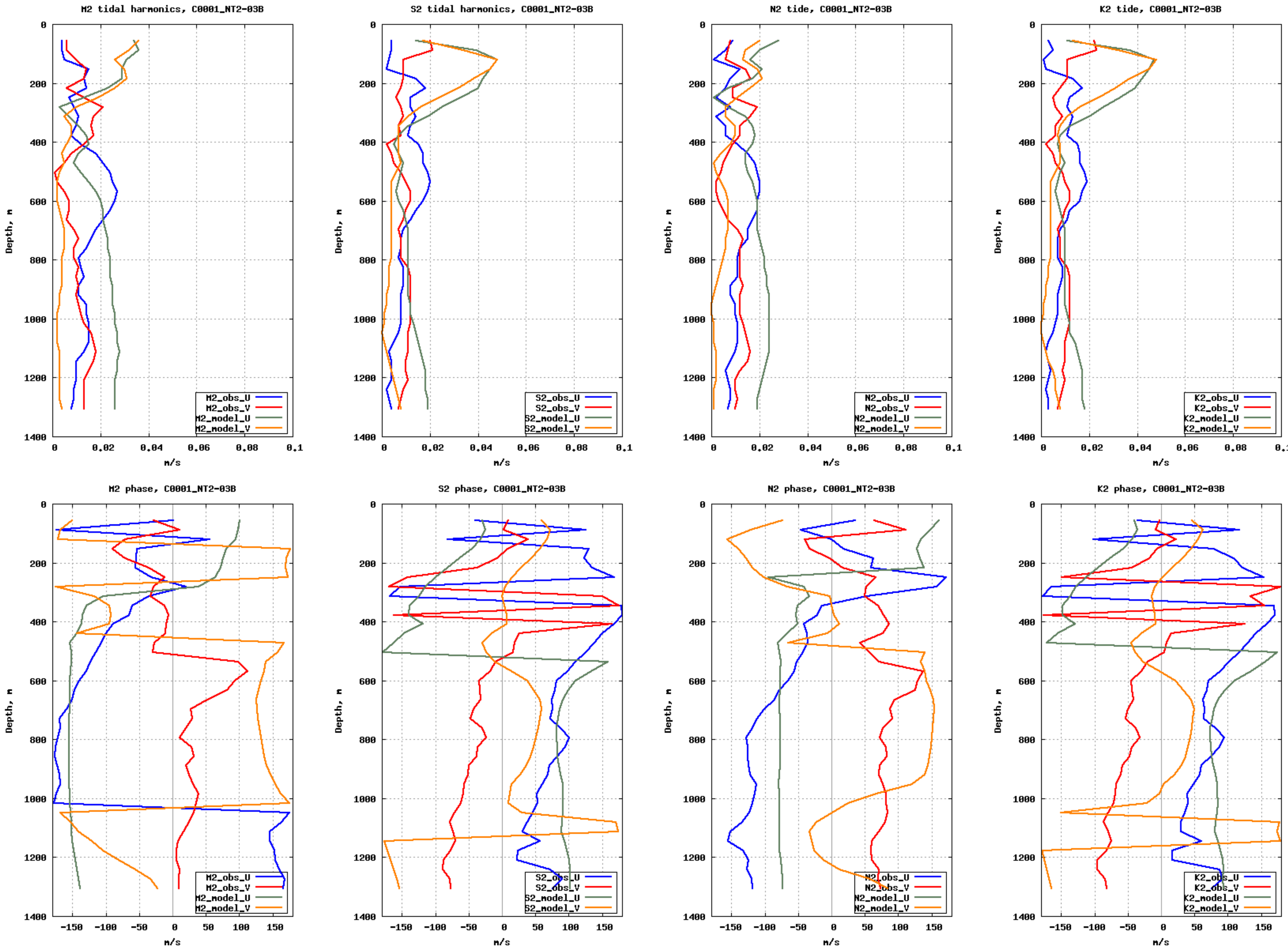

Observed vs Modeled time-mean profiles, C0001_NT2-03I
Depth, m
m/s
Obs_U
Mod_U

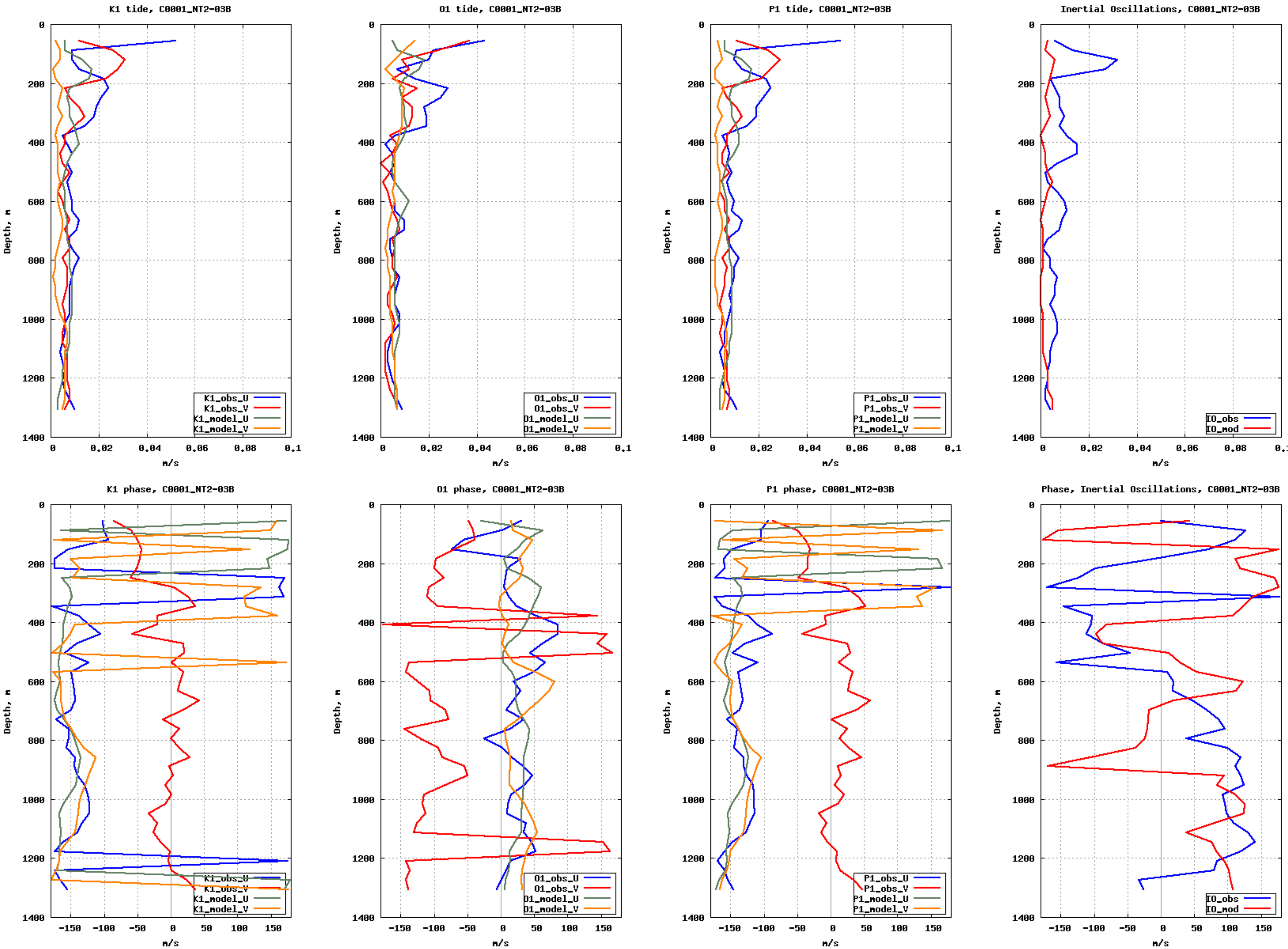

Observed vs Modeled time-mean profiles, C0001_NT2-03I
Depth, m
m/s
Obs_V
Mod_V



RMS model error, C0001_NT2-03B
Depth, m
m/s
Err_U
Err_V
RMS error for tide-filtered and deviations, C0001_NT2-
Depth, m
m/s
ErF_U
ErF_V
ErD_U
ErD_V


RMS dev from tide-filtered, C0001_NT2-03B
Depth, m
m/s
Obs_U
Mod_U
Obs_V
Mod_V
Observed-Modeled data Correlation, C0001_NT2-03B
Depth, m
m/s
U
V
Correlation of deviations from tide-filtered, C0001_NT2
Depth, m
m/s
U
V


M2 tidal harmonics, C0001_NT2-03B
S2 tidal harmonics, C0001_NT2-03B
N2 tide, C0001_NT2-03B
K2 tide, C0001_NT2-03B
M2 phase, C0001_NT2-03B
S2 phase, C0001_NT2-03B
N2 phase, C0001_NT2-03B
K2 phase, C0001_NT2-03B
Depth, m
m/s
0
200
400
600
800
1000
1200
1400
0 0.02 0.04 0.06 0.08 0.1
-150 -100 -50 0 50 100 150
M2_obs_U
M2_obs_V
M2_model_U
M2_model_V
S2_obs_U
S2_obs_V
S2_model_U
S2_model_V
N2_obs_U
N2_obs_V
N2_model_U
N2_model_V
K2_obs_U
K2_obs_V
K2_model_U
K2_model_V


K1 tide, C0001_NT2-03B
O1 tide, C0001_NT2-03B
P1 tide, C0001_NT2-03B
Inertial Oscillations, C0001_NT2-03B
K1 phase, C0001_NT2-03B
O1 phase, C0001_NT2-03B
P1 phase, C0001_NT2-03B
Phase, Inertial Oscillations, C0001_NT2-03B
Depth, m
m/s
K1_obs_U
K1_obs_V
K1_model_U
K1_model_V
O1_obs_U
O1_obs_V
O1_model_U
O1_model_V
P1_obs_U
P1_obs_V
P1_model_U
P1_model_V
IO_obs
IO_mod

Introducing tides to the regional model - 1

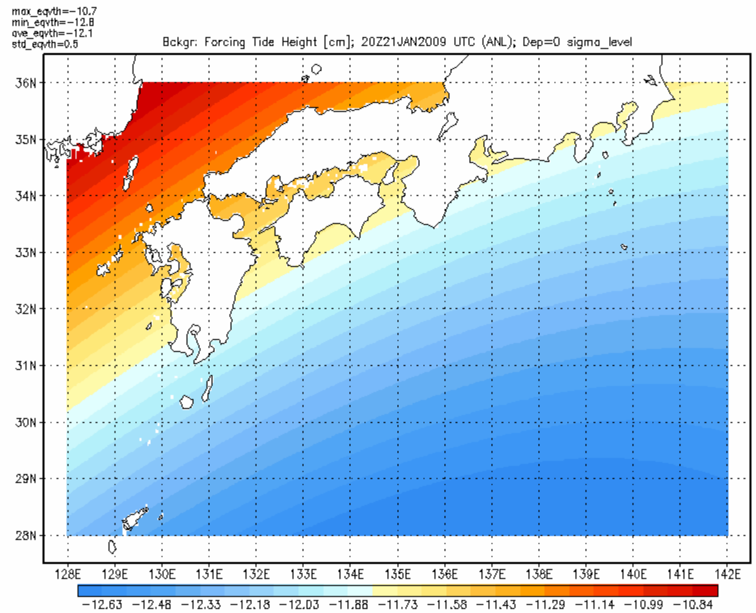
- Astronomic (gravitational or "body") force – relatively simple but has a small impact on small coastal models. Has analytical presentation and for the real – time simulations need only nodal factors.

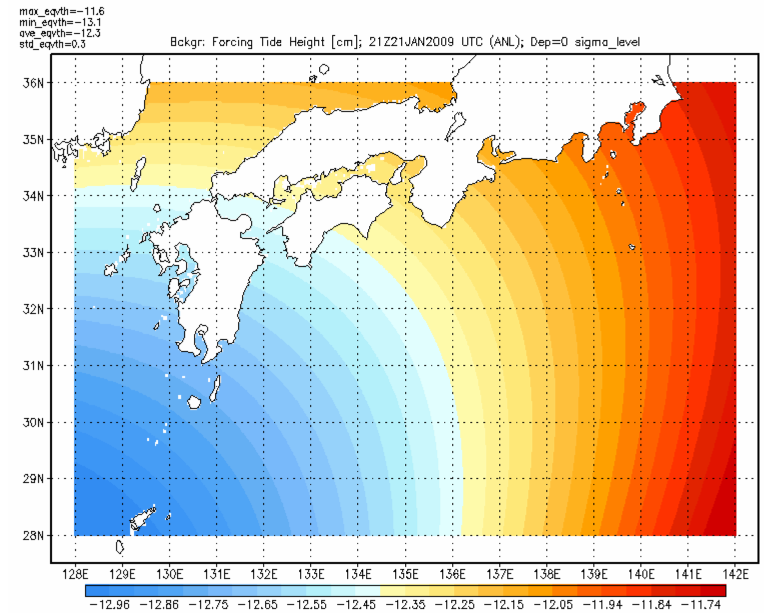
- Applied: 16 short-term harmonics (Q1,O1,M1,P1,K1,J1,Oo1,2N2,Mu2,N2,Nu2,M2,L2,T2, S2,K2) and 6 long-term harmonics (Mm, Mf, Ssa, Sa, Mtm, Msqm)

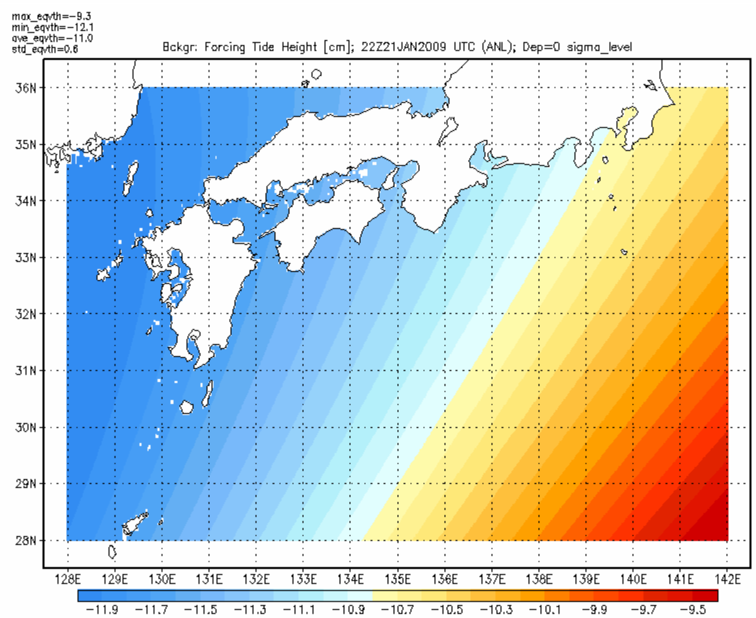
- Introduced by means of "equivalent tide" $\eta_{et}(x,y,t)$

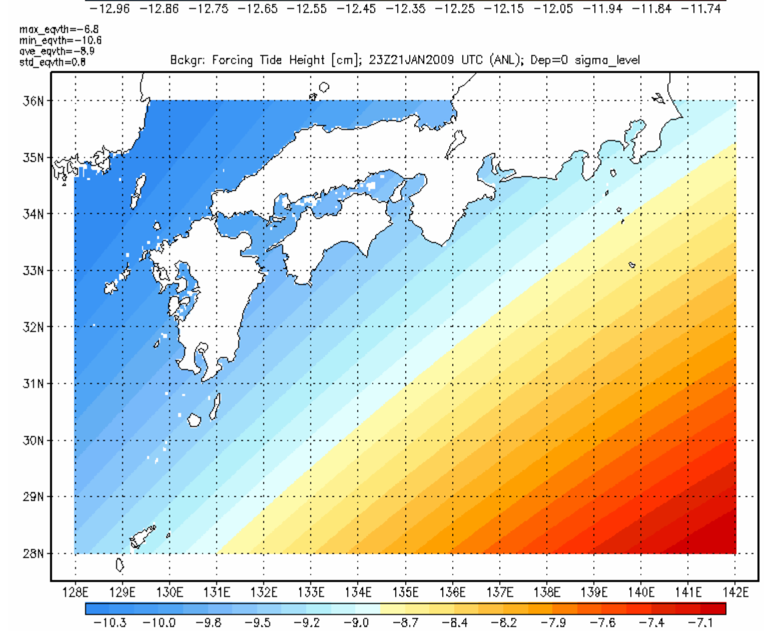
$$\frac{\partial \eta}{\partial x_i} \rightarrow \frac{\partial(\eta - \eta_{et})}{\partial x_i}$$

Hourly equivalent tide snapshot maps for nest74 domain









Introducing tides to the regional model - 2

- Tidal waves passing through the open boundaries of regional model domain are often more important for the observed tidal variability compared with astronomic forcing

- Natural open boundary conditions for the hydrostatic models are these for the boundary velocity. Sea level is estimated diagnostically.

- For the “single” tidal wave it is possible estimate the barotropic tidal velocity from the sea level anomaly assuming that propagation direction is known:

$$V = \pm \mathrm{sqrt}(g/h)*\eta$$

- For superposition of different tidal waves and, especially for the case of waves both entering and leaving model domain it is difficult to establish such simple relation.

Introducing tides to the regional model - 3

- Sea level variations at the JCOPE boundary i=1,IM and j=1,JM do not have any impact on the model, so sea level in the internal model points i=2,IM-1 and j=2,JM-1 has to be modified.

$$\eta' = \eta' + \alpha_\eta \cdot (\eta_{tide} - \eta'),$$

$$\alpha_\eta \approx 2/split \quad \text{- adjust in} \approx 0.5 \text{ of internal mode step}$$

- Modification of simulated sea level artificially modifies barotropic cell volume, broke conservation features of model and generate artificial biases or even destabilize model.

- To overcome it there are at least 2 possibilities:
  do changes in conservative way (JCOPET)
  or
  apply special measures to suppress impact of non-conservative adjustment (like “flow relaxation” near the open boundaries etc.)

Introducing tides to the regional model - 4

- To support volume conservation, normal to open boundary barotropic velocity is corrected immediately following the sea level adjustment:

$$Va'_{\perp} = Va_{\perp} + V_{adj}, \quad \text{where}$$

$$V_{adj} = \pm\alpha_{\eta} \cdot (\eta_{tide} - \eta') \cdot A / [(H + \eta) \cdot D_{\perp} \cdot DTE2]$$

- After each external time step specify new boundary barotropic velocity used for the next step sea level estimation:

$$V_{\perp} = V_{\perp}^{JCOPE} + V_{\perp}^{NAO}$$

Introducing tides to the regional model - 5

Parameter	JCOPET default	Flather
EL	1. Volume conservation 2. Sea level adjustment $El_{b+1}^{fin} = El_{b+1} + El_{adj}$ $El_{adj} = \alpha(El_{tide} - [El_{b+1} - El_{b+1}^{mean}])$ 3. BVF adjustment $U_{adj} = \frac{El_{adj} \cdot A}{(H + El) \cdot \Delta l \cdot \Delta t}$	1. Volume conservation Equal if $\alpha = \sqrt{g(H + El)}\frac{\Delta t}{\Delta n}$
UA	$U_b = U_{mean} + U_{tide}$	$U_b = U_{mean} + U_{tide} + U_{adj}$ $U_{adj} = \sqrt{\frac{g}{H}}(El_{tide} - [El_{b+1} - El_{b+1}^{mean}])$