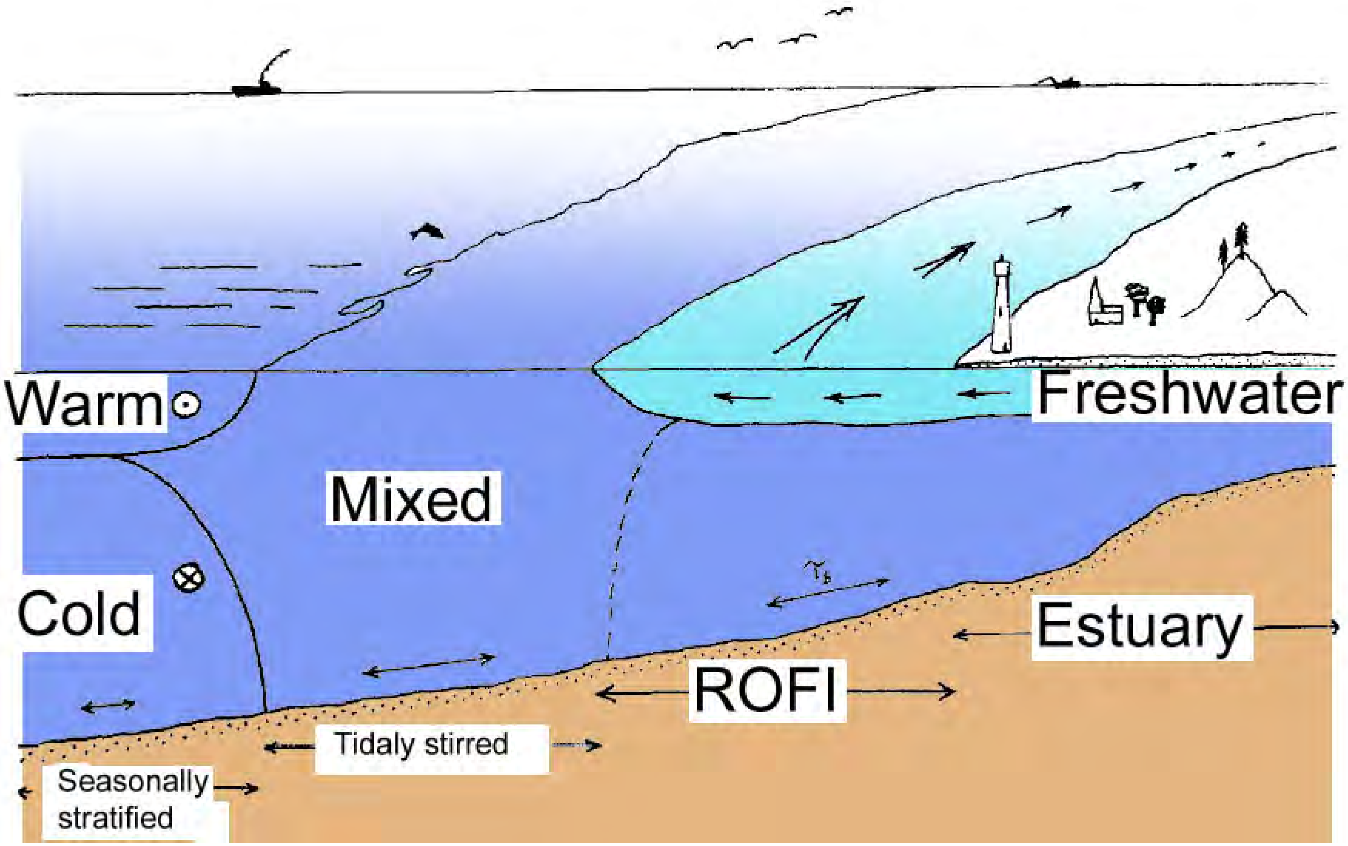
Coupled land-ocean model for the coastal fisheries in a Region of Freshwater Influence (ROFI): A case study in Funka Bay

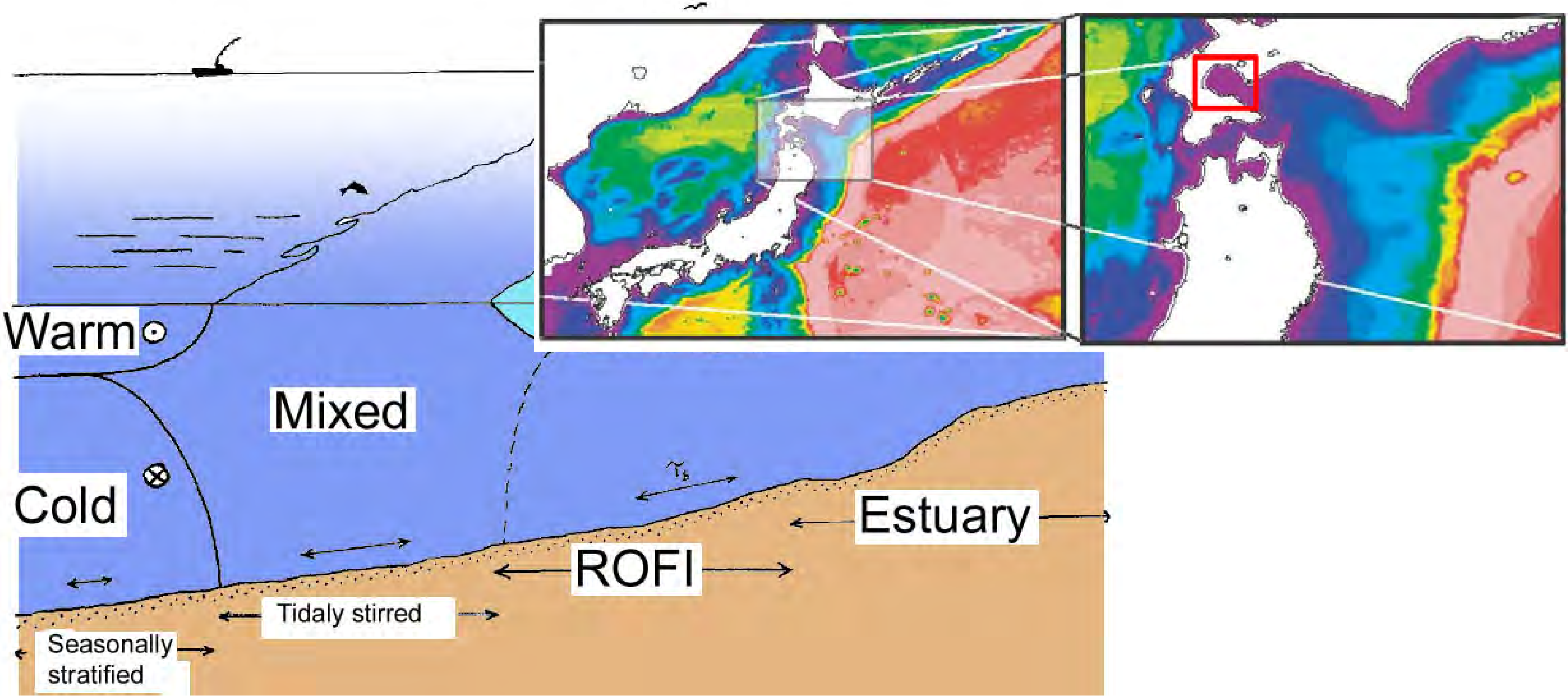
Satoshi **Nakada**[1],
Yoichi Ishikawa[1], Toshiyuki Awaji[1]
and Sei-ichi Saitoh[2]

[1]Department of Geophysics, Kyoto University
[2]Faculty of Fisheries Sciences, Hokkaido University

Funka Bay (FB) is one of Regions Of Freshwater Influence: ROFIs (Simpson, 1997)



Funka Bay (FB) is one of Regions Of Freshwater Influence: ROFIs (Simpson, 1997)



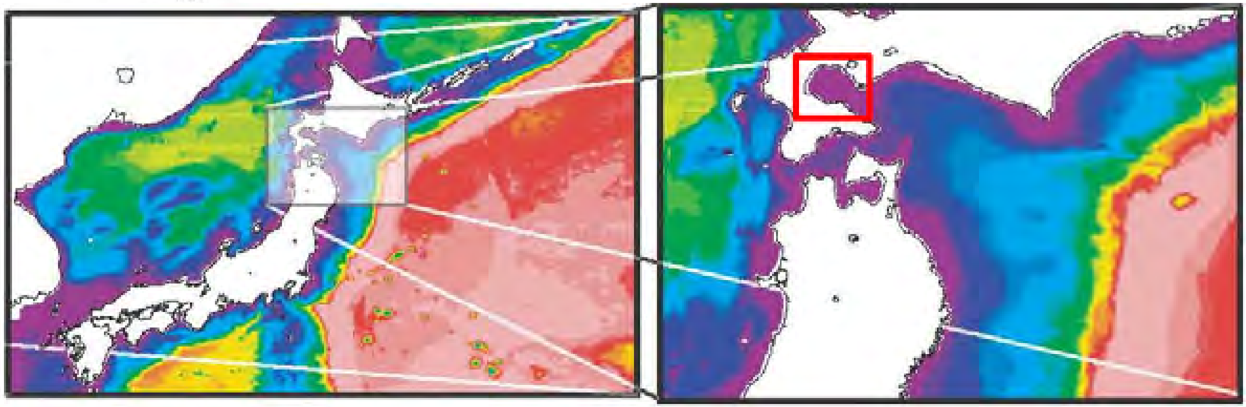
- So far, the bay circulations influence by “huge” rivers have been studied from many viewpoint of physical and fishery oceanography.

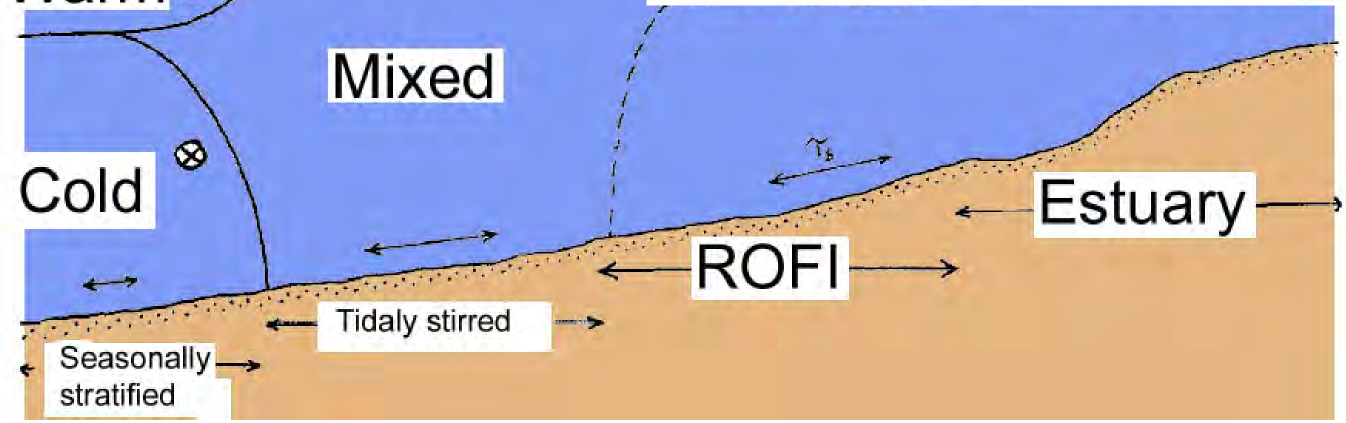
→ e.g., Chesapeake Bay with Potomac and Susquehanna River
Bohai with Yellow, Hai, Liao, and Luan Rivers

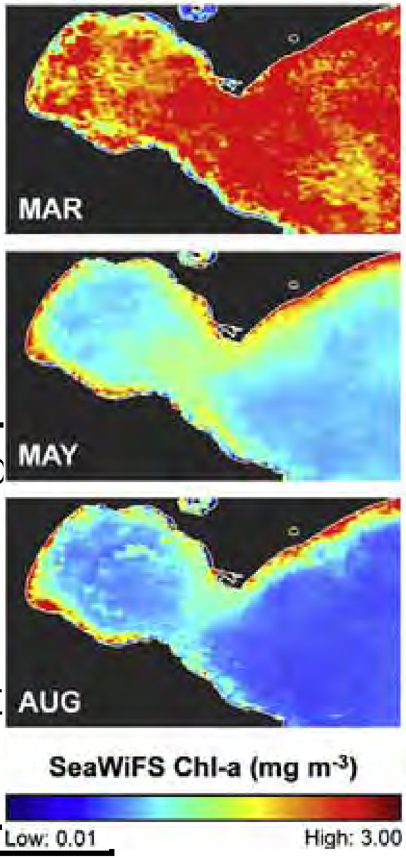
→ There are high-performance river & ocean model with sufficient data.

- Many bays have many small rivers influencing water circulation, ecosystem, and fishery yields, however, these have been still unclear.

Funka Bay (FB) is one of Regions Of Freshwater Influence: ROFIs (Simpson, 1997)

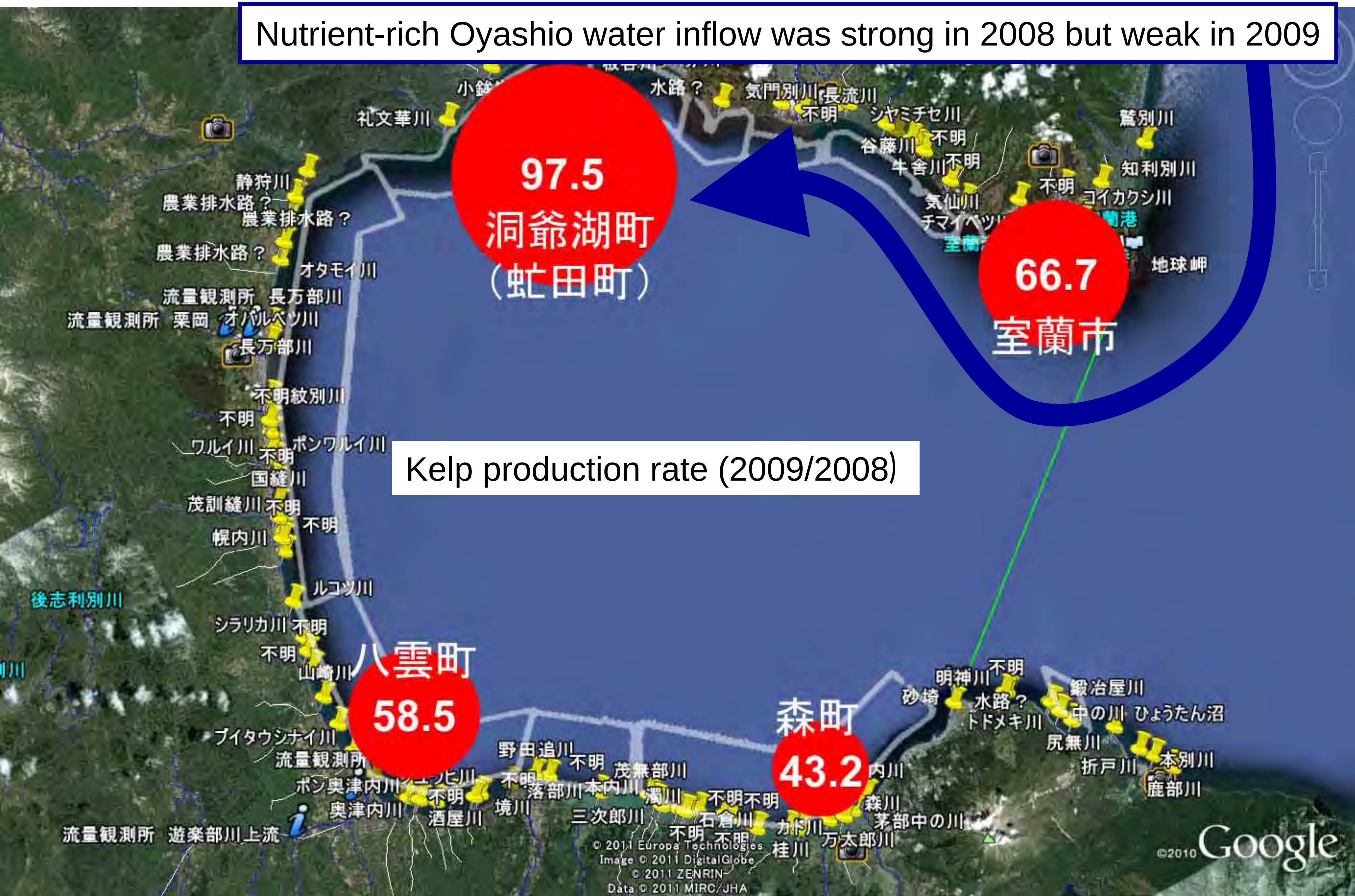






- So far, the bay circulations influence by “huge” rivers have been stuc from many viewpoint of physical and fishery oceanography.
→ e.g., Chesapeake Bay with Potomac and Susquehanna River
Bohai with Yellow, Hai, Liao, and Luan Rivers
→ There are high-performance river & ocean model with sufficient dat
- Many bays have many small rivers influencing water circulation, ecosystem, and fishery yields, however, these have been still unclear.

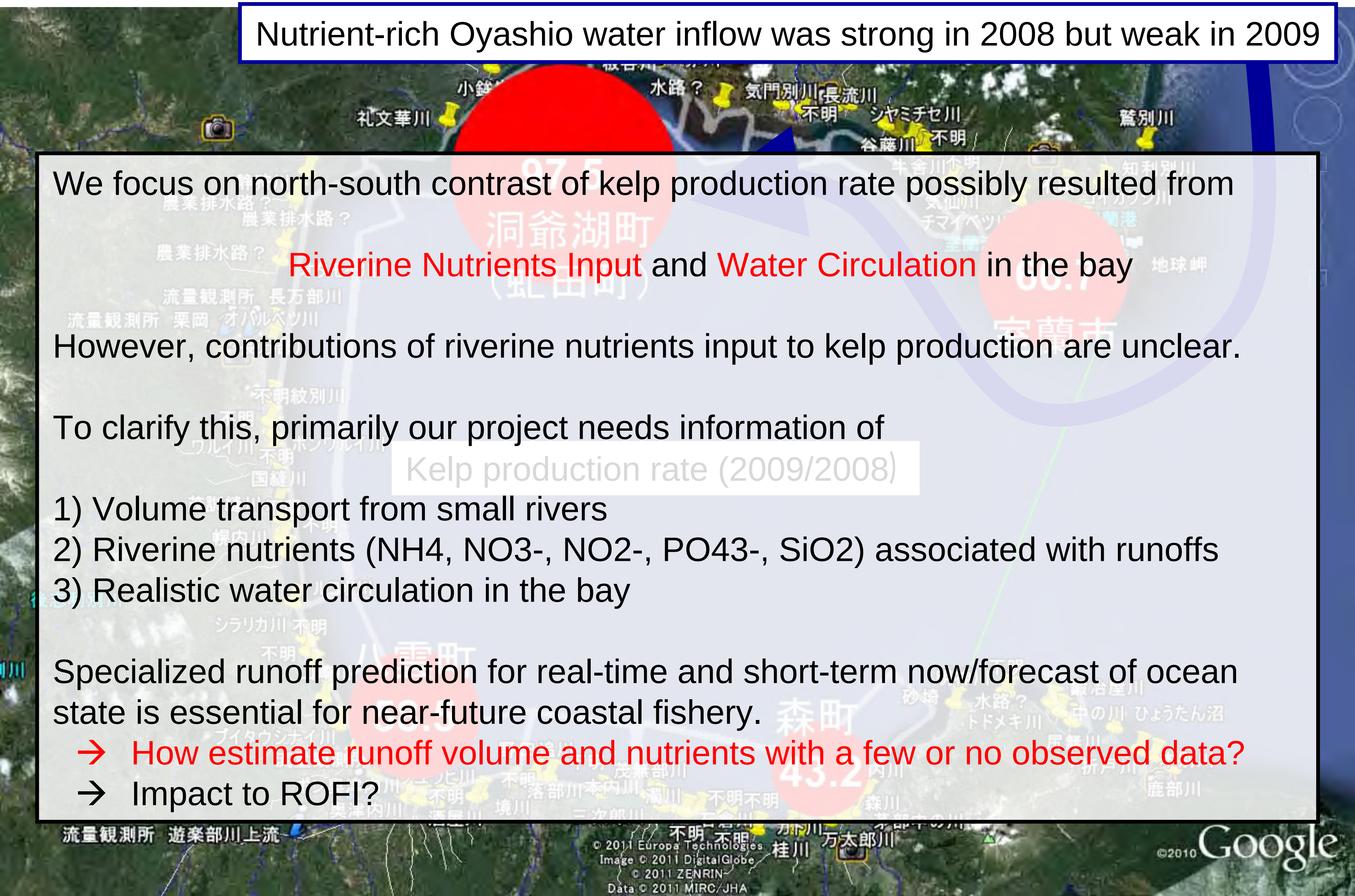
Small rivers flowing into FB (ROFI)



Nutrient-rich Oyashio water inflow was strong in 2008 but weak in 2009

Kelp production rate (2009/2008)

Small rivers flowing into FB (ROFI)



Nutrient-rich Oyashio water inflow was strong in 2008 but weak in 2009

We focus on north-south contrast of kelp production rate possibly resulted from

Riverine Nutrients Input and Water Circulation in the bay

However, contributions of riverine nutrients input to kelp production are unclear.

To clarify this, primarily our project needs information of

1) Volume transport from small rivers
2) Riverine nutrients (NH_4, NO_3^-, NO_2^-, PO_4^{3-}, SiO_2) associated with runoffs
3) Realistic water circulation in the bay

Specialized runoff prediction for real-time and short-term now/forecast of ocean state is essential for near-future coastal fishery.

→ How estimate runoff volume and nutrients with a few or no observed data?
→ Impact to ROFI?

Objectives

1) We propose procedures to estimate runoffs from small watersheds using meteorological data archiving low computational cost.

2) An application of locally coupled land-sea model are shown using the runoff model and OGCM around the FB.

3) By using the coupled model, we estimate nutrients loaded from river or land and understand relationship among nutrient inputs, kelp production, and water circulation by a numerical approach.

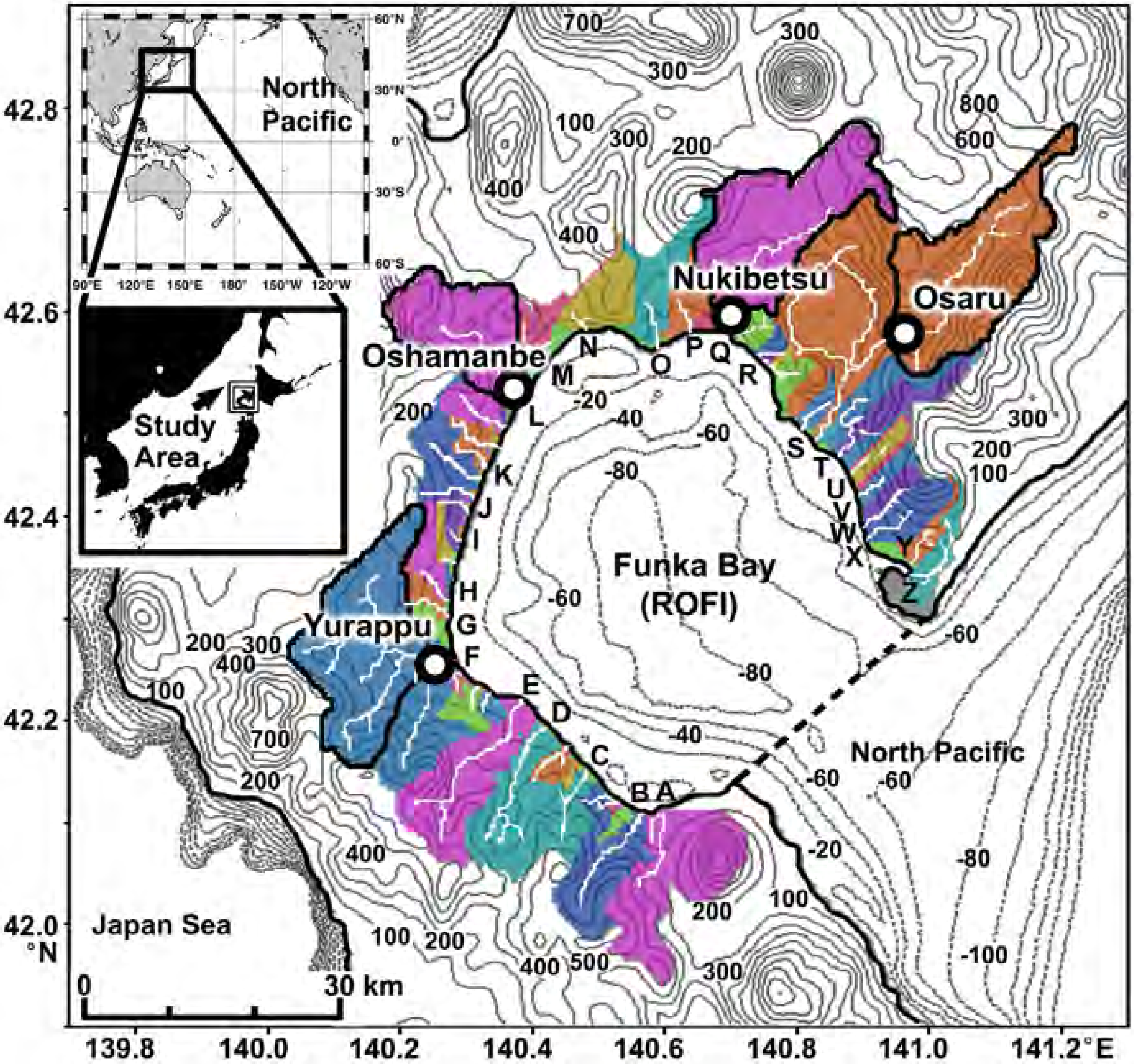
Numerical procedures

DATA used for river model

category		Abb	variables	data name	sources	mesh size	Interporation	mesh size
Input	weather	Ta	Air Temperature	GPV/MSM	Japan Meteor. Agency (JMA)	0.125x0.1° (11x11 km)	→ Spline →	500 x 500 m
		Wu	Wind Speed					
		rh	relative humidity					
		Cl	Cloudness					
		P	Precipitation					
	topograhy	Hd	Land Elevation	DM50m Grid	GSI	50x50m	→ Gaussian →	
		Hb	Bathymetry	JEGG500	JODC	500x500m		
		He	Topography	ETOPO1	NOAA	1x1 °		
		Hg	Land Elevation	GTOPO30	USGS	0.5x0.5°		
	river	Rp	River passage	W05-09_01	GSI	vector data		

Validation	river efflux	Q	River discharge	Runoff Table	Hokkaido Pref.
	weather	S	snow cover	AMeDAS	JMA

Watersheds around Funka Bay (FB)

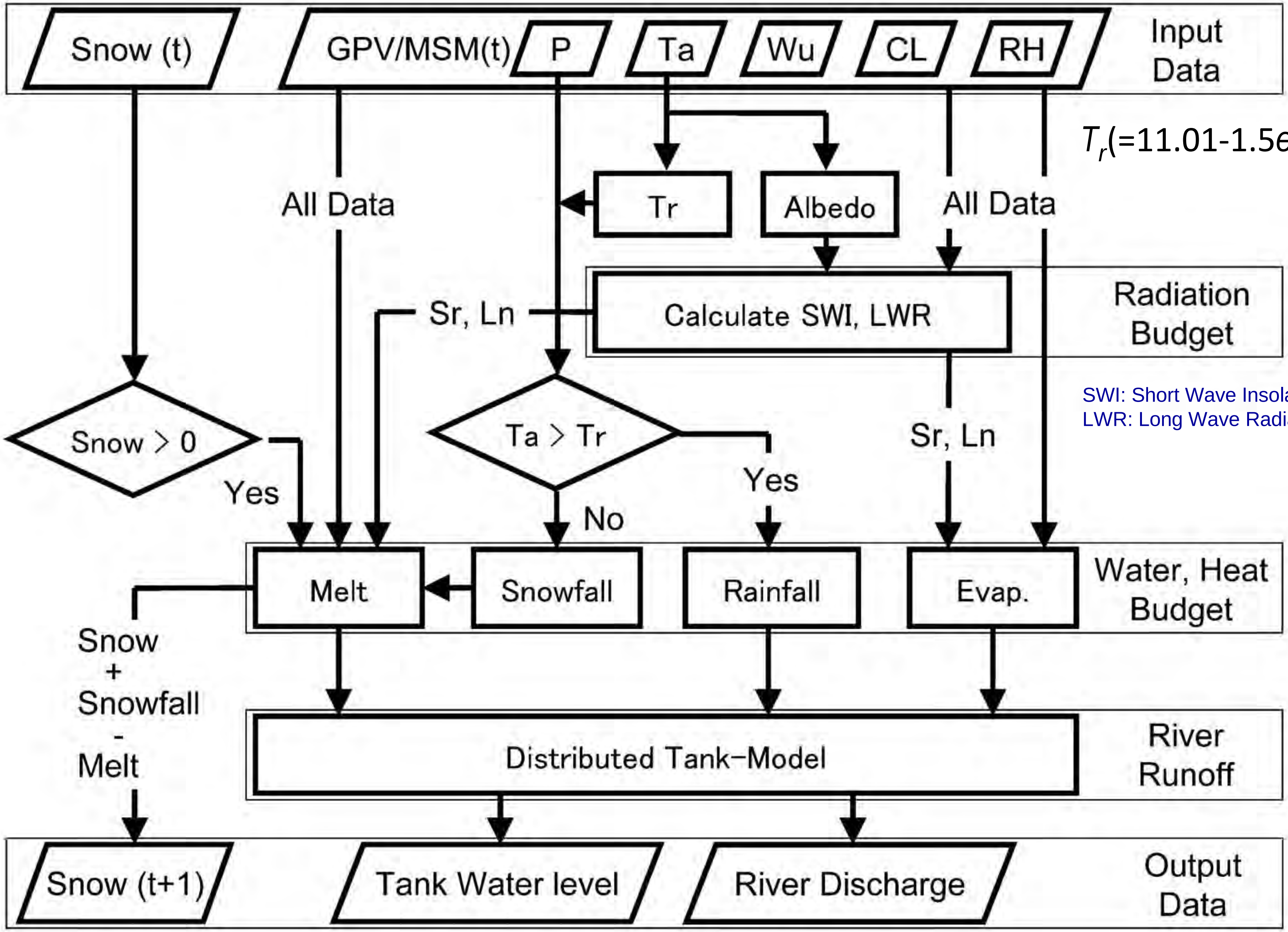


- A-Z are 26 main watersheds from all subtracted 106 watersheds.

Watershed areas		
Estimated	Reported	
351	351.8	Yurrapu
106	106.5	Osaru
143.5	112	Oshamanbe
229.3	237.6	Nukibetsu

	Watershed	Bay
Area	2624 km2	2270 km2
Elevation	800 (max.)	-107 (min.)
Discance from coast	35 km (max.)	26 km (Radius)
Gradient	1/25	1/243

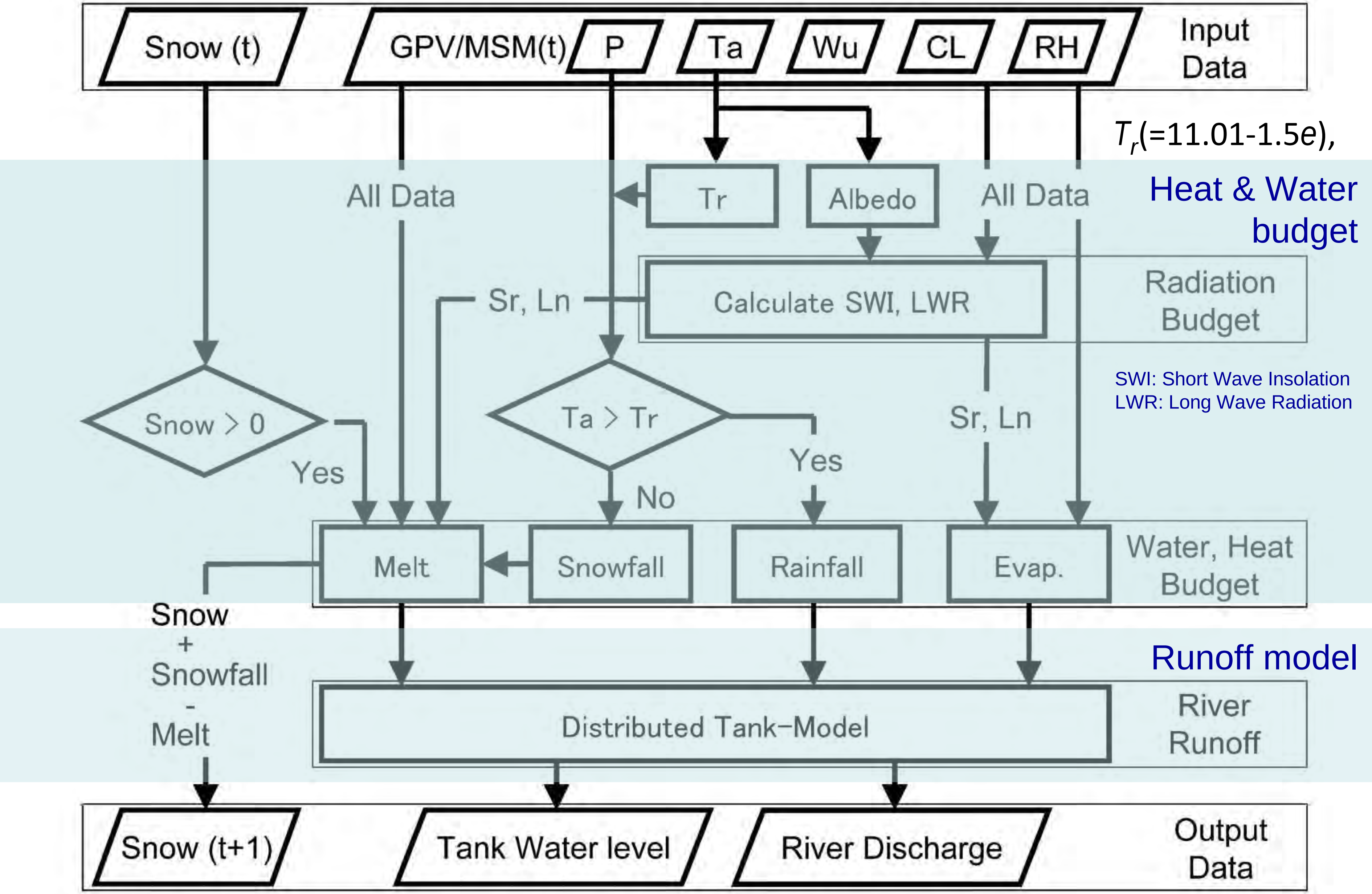
Flowchart of Estimation of Runoff



T_r(=11.01-1.5e),

SWI: Short Wave Insolation
LWR: Long Wave Radiation

Flowchart of Estimation of Runoff



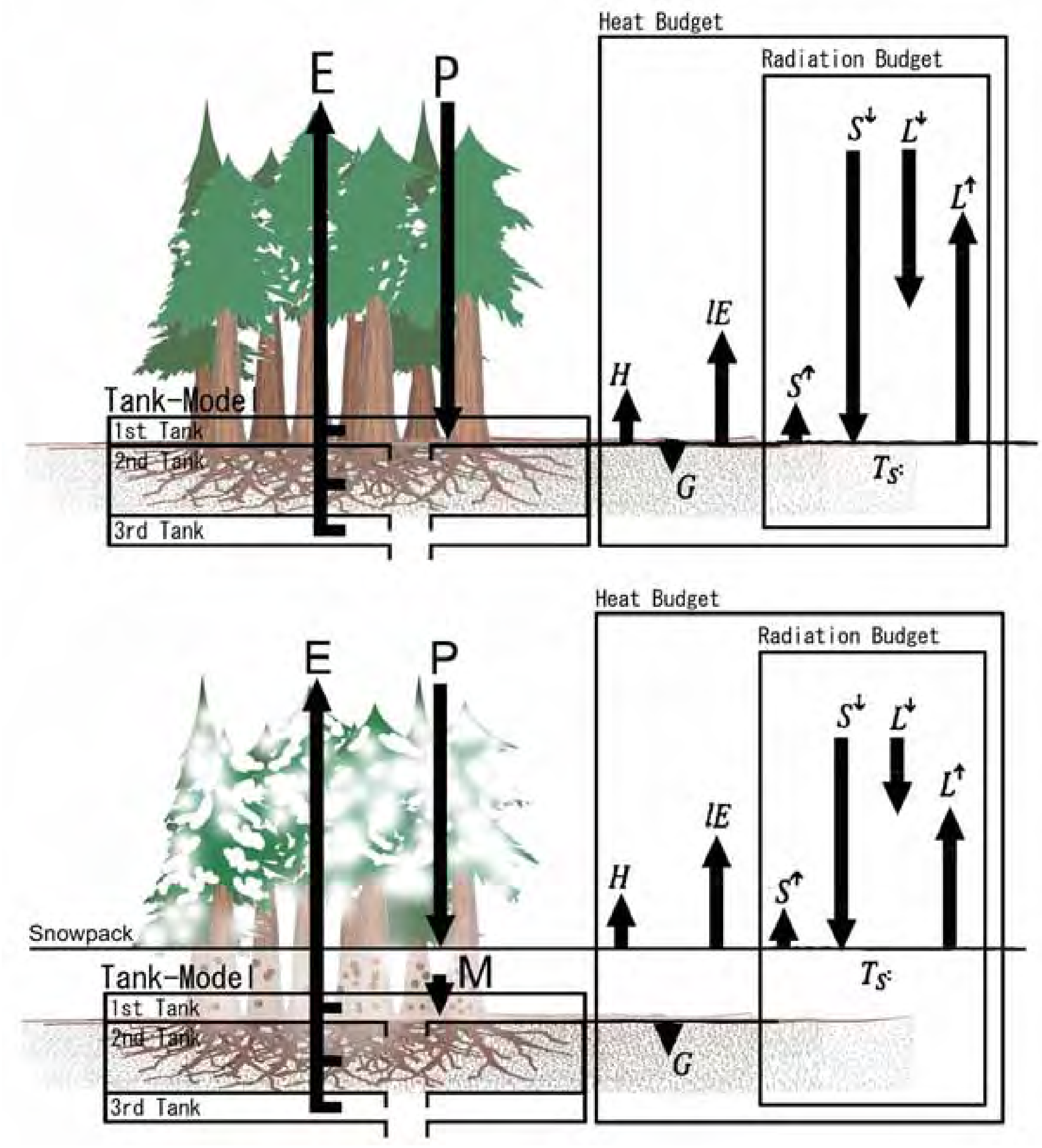
T_r(=11.01-1.5e),

Heat & Water budget

SWI: Short Wave Insolation
LWR: Long Wave Radiation

Runoff model

Schematics of Radiation, Heat, and Water Budget



- Radiation Budget

S↓: solar insolation
S↑: reflected insolation
L↓: downward radiation from sky and cloud
L↑: upward radiation from surfaces

$Rn = S{\downarrow} - S{\uparrow} + L{\downarrow} - L{\uparrow}$

- Heat Budget

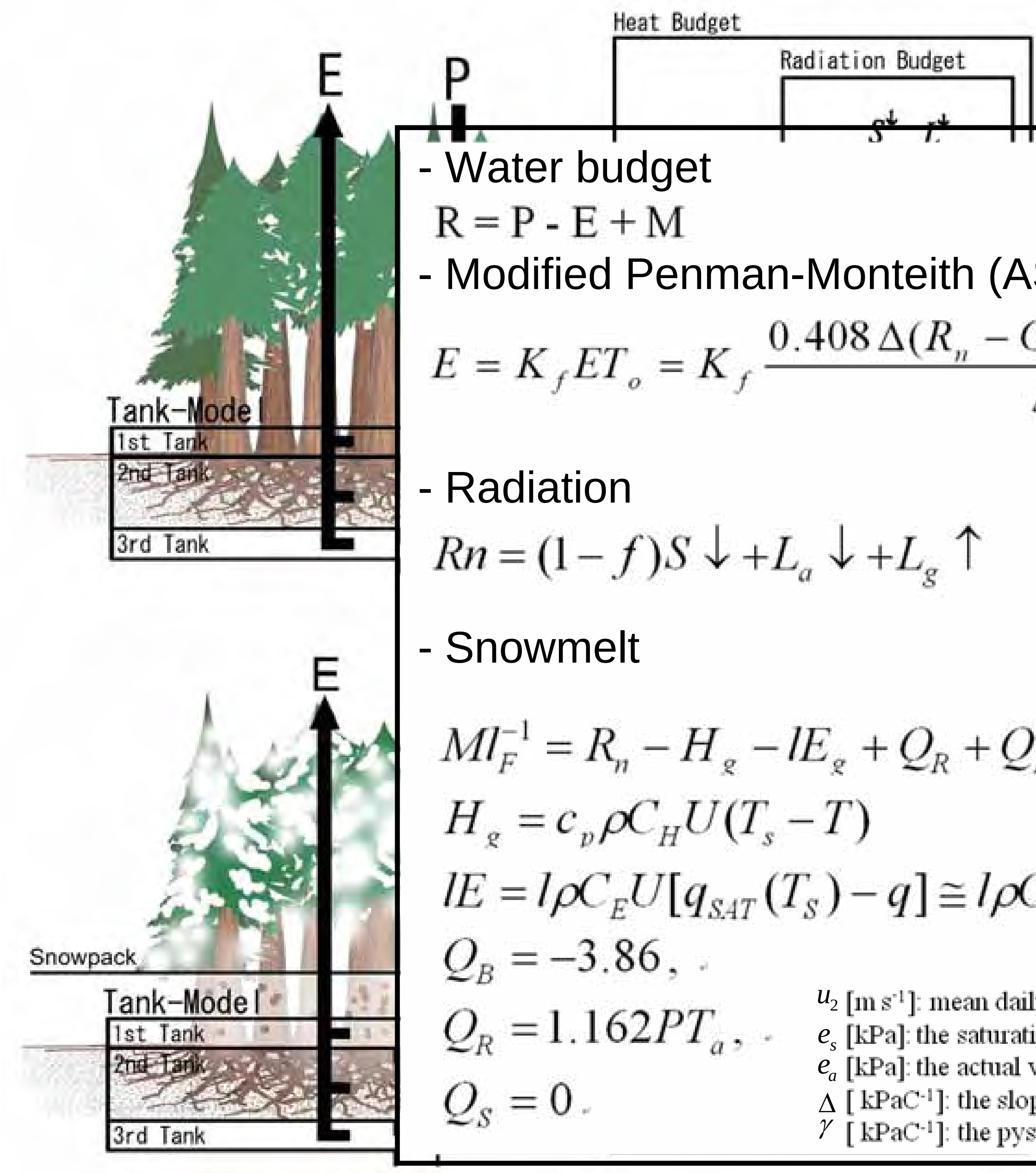
H: sensible heat flux
lE: latent heat flux
G: heat flux though ground surface

$Rn-G=H+lE$

- Water Budget

$R = P - E + M(\text{snow}>0)$

Schematics of Radiation, Heat, and Water Budget



- Radiation Budget
S↓: solar insolation
S↑: reflected insolation

- Water budget

$$R = P - E + M$$

- Modified Penman-Monteith (ASCE-EWRI, 2005)

$$E = K_f ET_o = K_f \frac{0.408\Delta(R_n - G) + \gamma C_n u_2 (e_s - e_a)/(T + 273)}{\Delta + \gamma(1 + C_d u_2)}$$

- Radiation

$$Rn = (1 - f)S\downarrow + L_a\downarrow + L_g\uparrow$$

Albedo:

$$f = 0.02\mathrm{T} + 0.554\,(0.4 \le f \le 0.9)$$

- Snowmelt

$$MI_F^{-1} = R_n - H_g - lE_g + Q_R + Q_B - Q_S$$

$$H_g = c_p \rho C_H U (T_s - T)$$

$$lE = l\rho C_E U[q_{SAT}(T_S) - q] \cong l\rho C_E U[(1 - rh)q_{SAT}(T) + \Delta \cdot (T_S - T)]$$

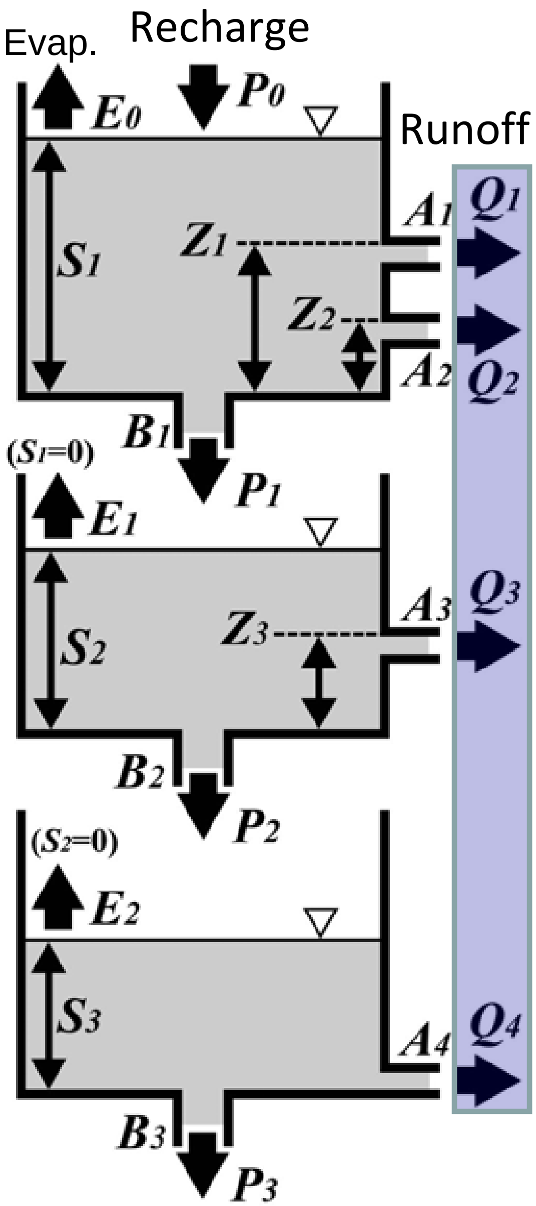
$$Q_B = -3.86,$$

$$Q_R = 1.162 P T_a,$$

$$Q_S = 0$$

u_2 [m s^{-1}]: mean daily or hourly wind speed at 2-m height (m s^{-1})
e_s [kPa]: the saturation vapor pressure at air temperature
e_a [kPa]: the actual vapor pressure of the air,
Δ [kPaC^{-1}]: the slope of the saturation vapor pressure versus temperature curve
γ [kPaC^{-1}]: the pyschrometric constant

Configuration of Tank (River Runoff) Model & "F" value method



- Concept

P: Input (Water migration to deeper tanks)
P_0 : Precipitation to 1st Tank
P_1 : Infiltration to 2nd Tank
P_2 : Infiltration to 3rd Tank
P_3 : Groundwater Recharge (SGD)

Q: Output (Discharge)
Q_1 : Surface flow at flood water (Z1)
Q_2 : Surface flow at high water (Z2)
Q_3 : Interflow at saturated water level (Z3)
Q_4 : Base-flow

E: Subtraction (Evapotranspiration)
E_0 : from 1st Tank
E_1 : from 2nd Tank (If $S_1 = 0$)
E_2 : from 3rd Tank (If $S_2 = 0$)

S: Water level (Storage)
S_1 : of surface (soil) water (1st Tank)
S_2 : of un- and saturated zone (2nd Tank)
S_3 : of groundwater (3rd Tank)

River runoff = Σ (Q_1(n) + Q_2(n) + Q_3(n) + Q_4(n))
Groundwater recharge or SGD = P_3(n)

n: watershed numbers

- Parameters

A: Discharge coefficients
A1(n)=A1·F(n)
A2(n)=A2·F(n)
A3(n)=A3·F(n)
A4(n)=A4·F(n)

New approach

B: Infiltration coefficients
B1(n)=B1/F(n)
B2(n)=B2/F(n)
B3(n)=B3/F(n)

New approach

Z: Orifices heights
Z1(n)=Z1·F(n)
Z2(n)=Z2·F(n)

New approach

- Response Factor (F-value) method

F(n) = f(A(n)) **α** EXP(-**β** A(n))
A: watershed areas

Find a relationships between area and discharge rate

- Optimize (Tune) **α & β** minimizing

1) Errors of Total Runoff Volume
→ Difference percentage within 5%
2) Errors of Temporal Runoff Variation
→ Highest Correlation

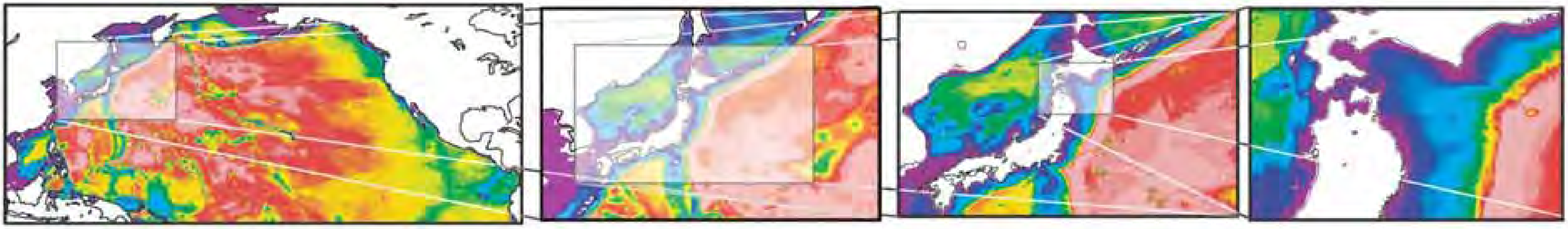
Kyoto OGCM Data Assimilation & Downscaling System

Nest0
Norh Pacific
climatological model

Nest1
Norhwestern Pacific
DA model

Nest2
Around Japan
Adjacent sea model

Nest3
Hokkaido-Tohoku
Coastal model



1/6 degree x 1/8 degree
Climatological surface flux

1/6 degree x 1/8 degree
(longitude) (latitude)
4D-Var

1/18 degree x 1/24 degree
(longitude) (latitude)

1/72 degree x 1/54 degree
(longitude) (latitude)
(1.55 km x 1.55 km grid size)

→ lateral open boundary condition

→ lateral open boundary & initial conditions

→ lateral open boundary condition

(Ishikawa et al., 2009)

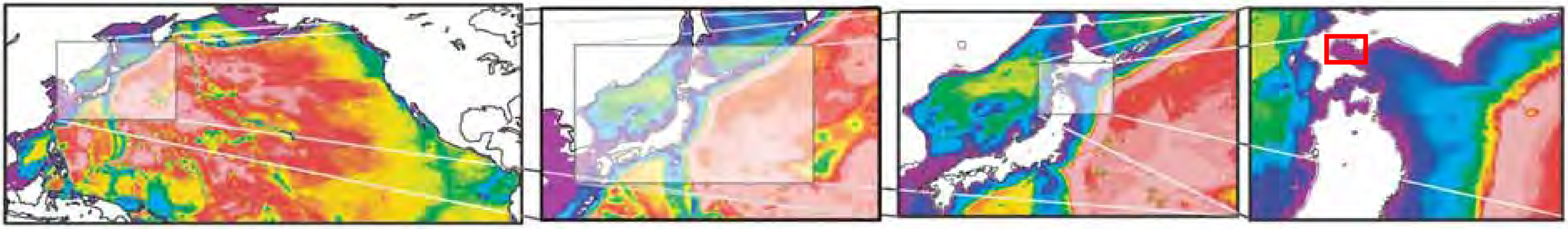
Kyoto OGCM Data Assimilation & Downscaling System

Nest0
Norh Pacific
climatological model

Nest1
Norhwestern Pacific
DA model

Nest2
Around Japan
Adjacent sea model

Nest3
Hokkaido-Tohoku
Coastal model



1/6 degree x 1/8 degree
Climatological surface flux

1/6 degree x 1/8 degree
(longitude) (latitude)
4D-Var

1/18 degree x 1/24 degree
(longitude) (latitude)

1/72 degree x 1/54 degree
(longitude) (latitude)
(1.55 km x 1.55 km grid size)

→ lateral open boundary condition

→ lateral open boundary & initial conditions

→ lateral open boundary condition

(Ishikawa et al., 2009)

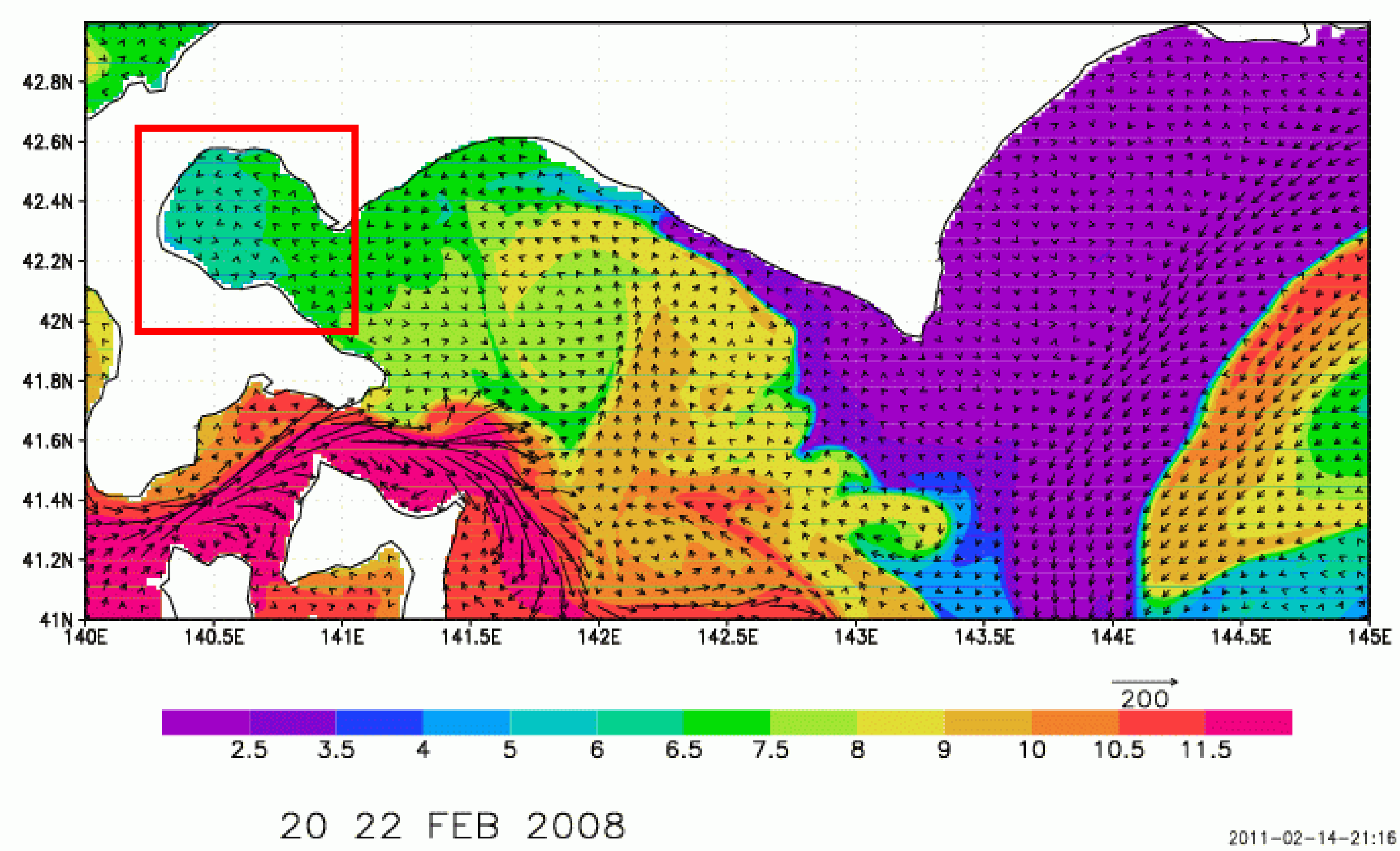
- The OGCM & river model are locally coupled around FB (red square)

Results

OGCM Result

Nutrient-rich Oyashio water (purple area) inflow into FB was clearly observed in 2008, in contrast the inflow in 2009 was not dominant, which led to the severe decrease of kelp production in 2009.

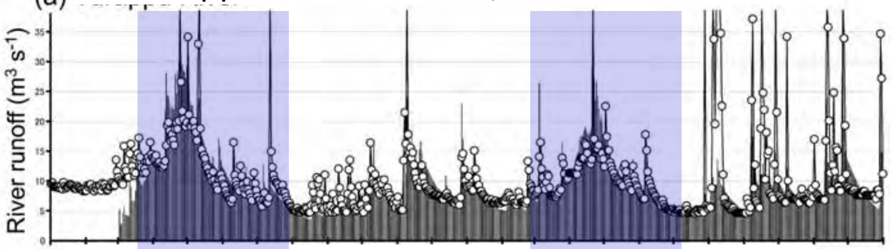
The our numerical results well reproduced the contrast between 2008 and 2009.



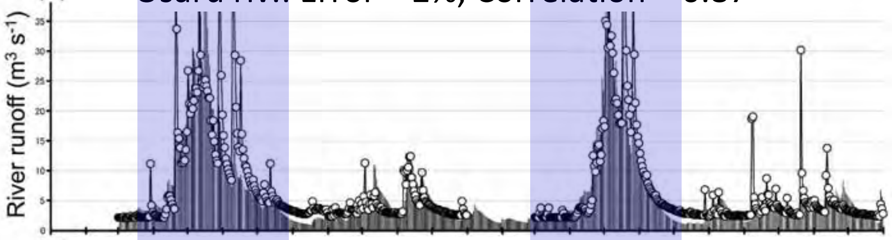
Runoff & Snow cover reproduced by river model

Model exhibits good performance (Estimated Error < 3%, Cor. = 0.63-0.87)
Large amount of runoff generated by snowmelt into the bay in spring (blue hatch)

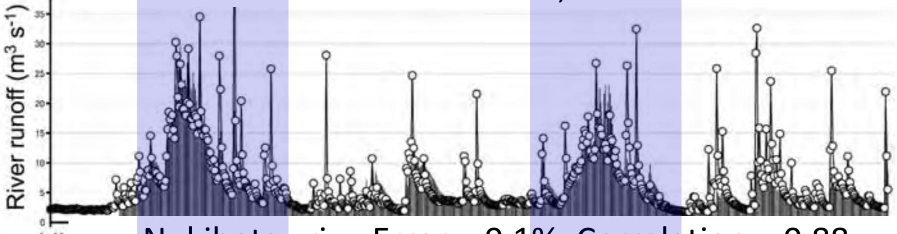
Yurappu riv.: Error = 1%, Correlation = 0.63



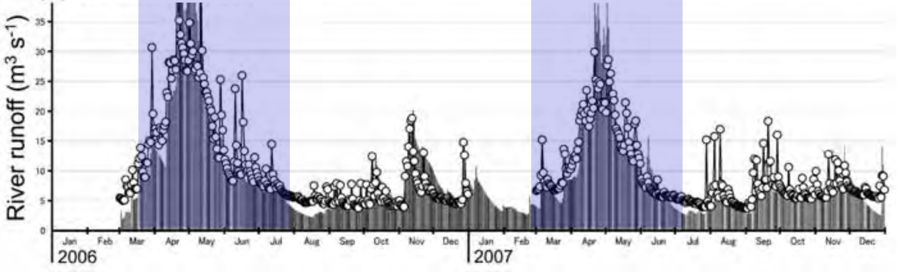
Osaru riv.: Error = 2%, Correlation = 0.87

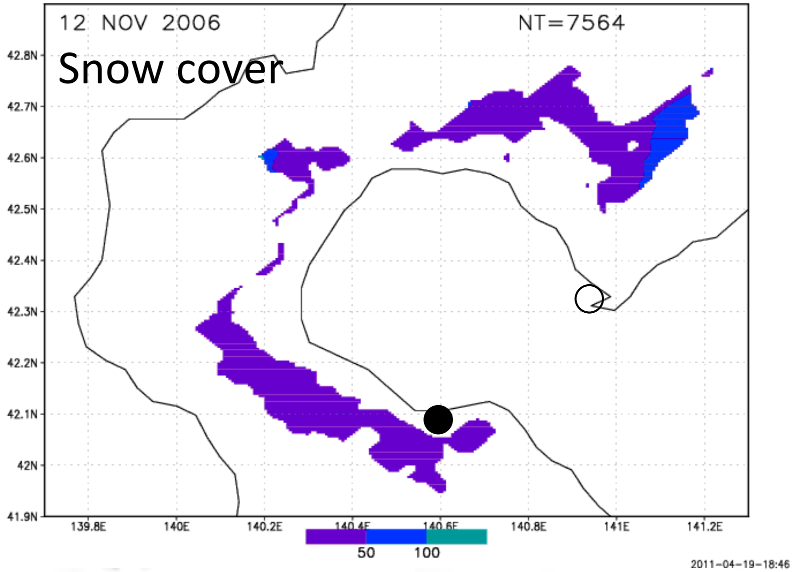


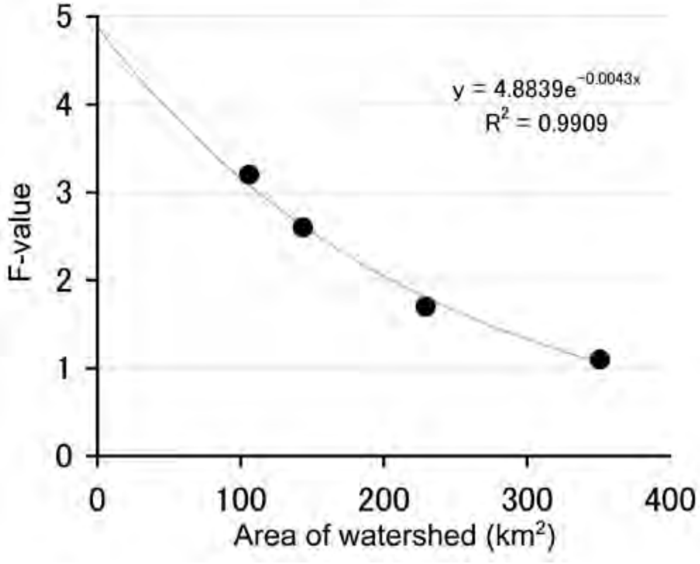
Oshamanbe riv.: Error = 3%, Correlation = 0.71



Nukibetsu riv.: Error = 0.1%, Correlation = 0.88



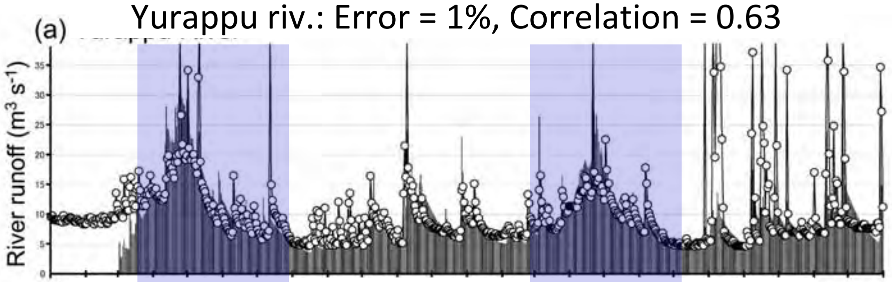




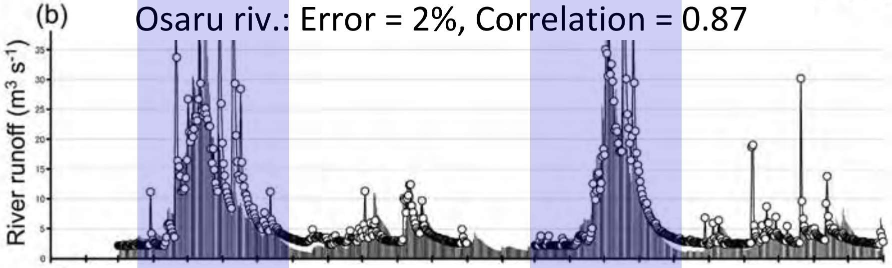
Runoff & Snow cover reproduced by river model

Model exhibits good performance (Estimated Error < 3%, Cor. = 0.63-0.87)
Large amount of runoff generated by snowmelt into the bay in spring (blue hatch)

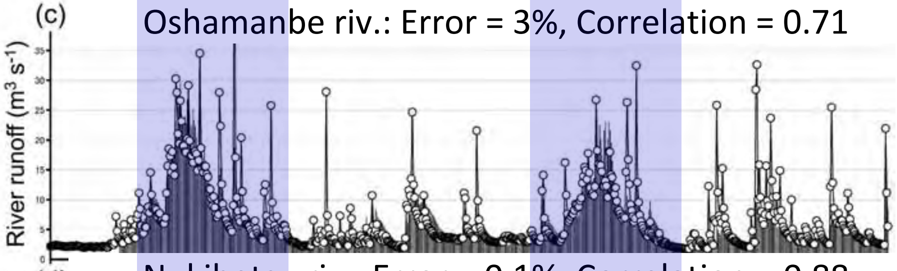
Yurappu riv.: Error = 1%, Correlation = 0.63



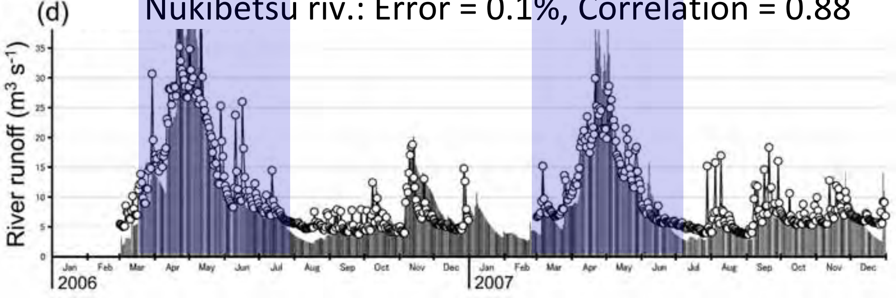
Osaru riv.: Error = 2%, Correlation = 0.87

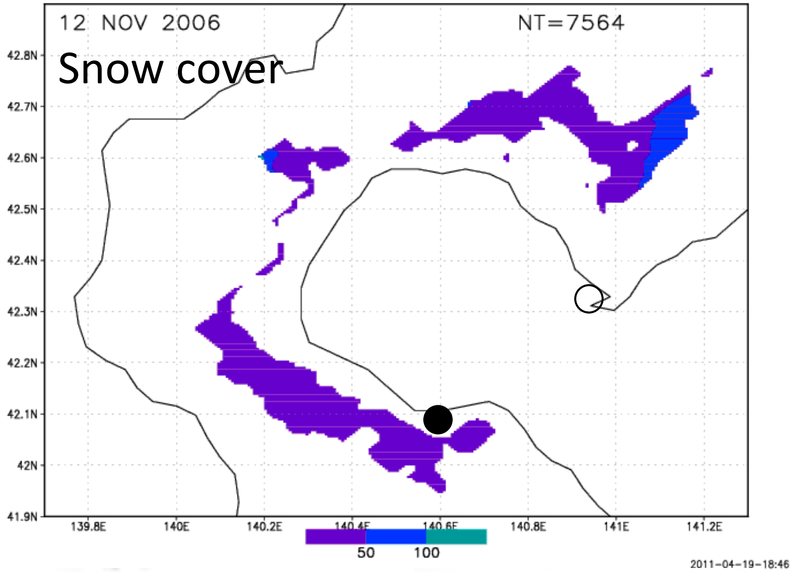


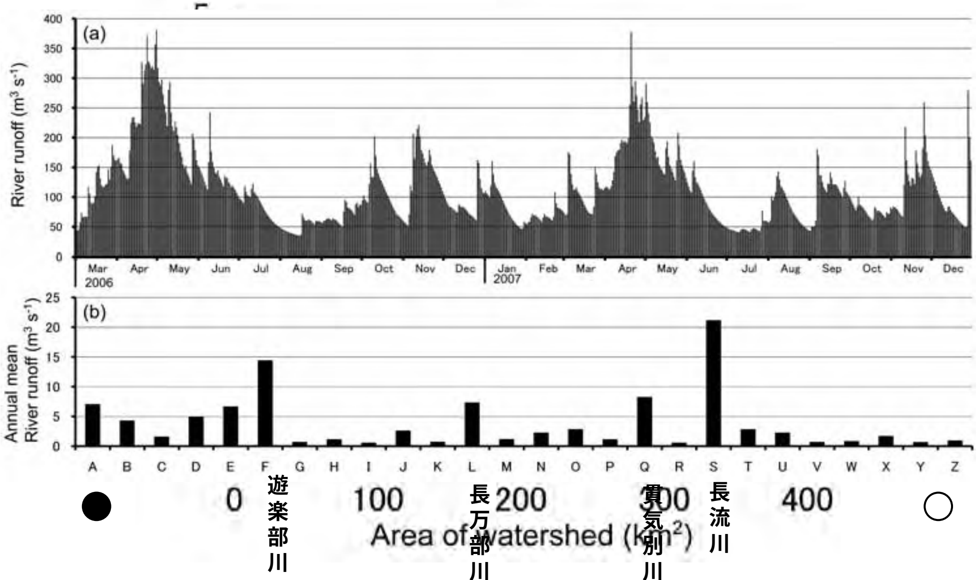
Oshamanbe riv.: Error = 3%, Correlation = 0.71



Nukibetsu riv.: Error = 0.1%, Correlation = 0.88

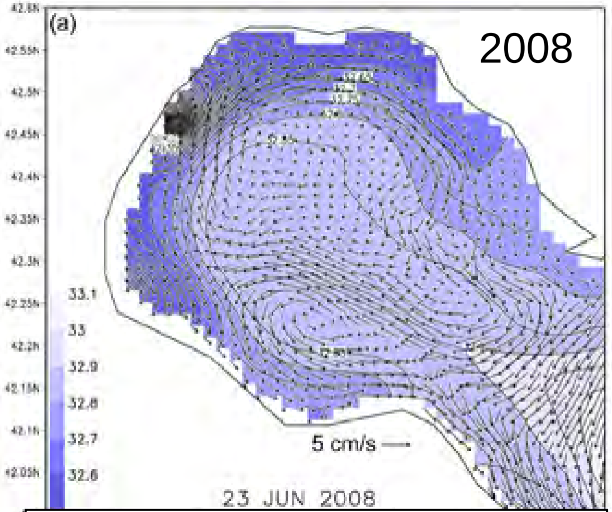




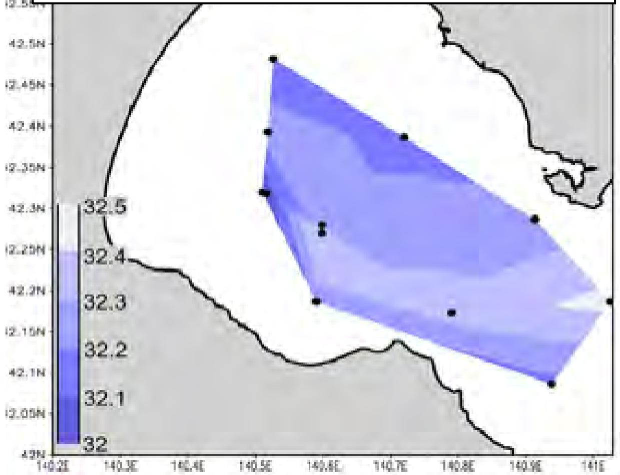


Summer-time clockwise circulation induced by buoyancy flux of runoff generated by snowmelt

Clockwise circulation



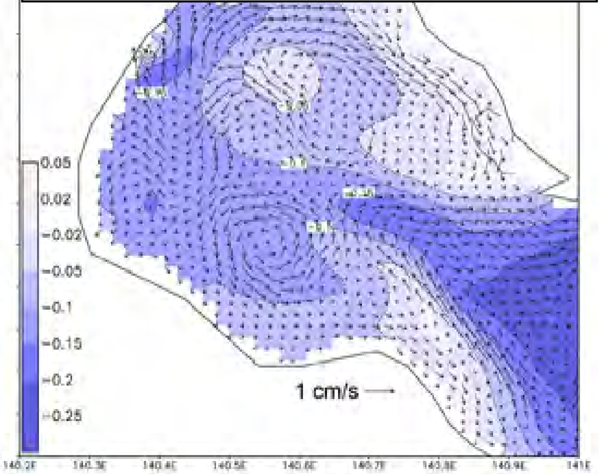
Observed salinity R/V Ushio



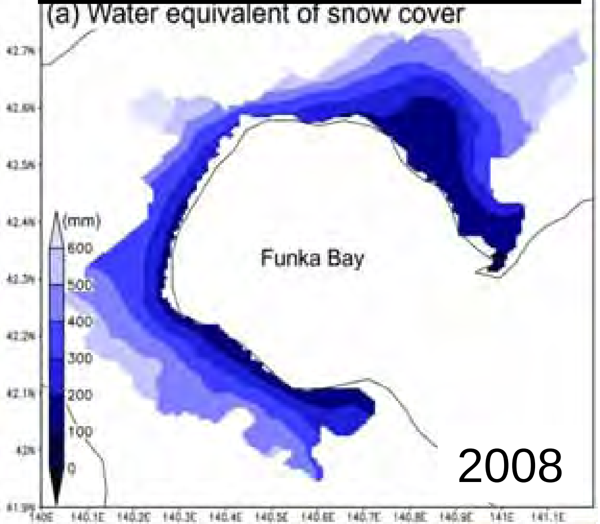
Strong clockwise circulation are generated by much more river runoff in 2009 than in 2008

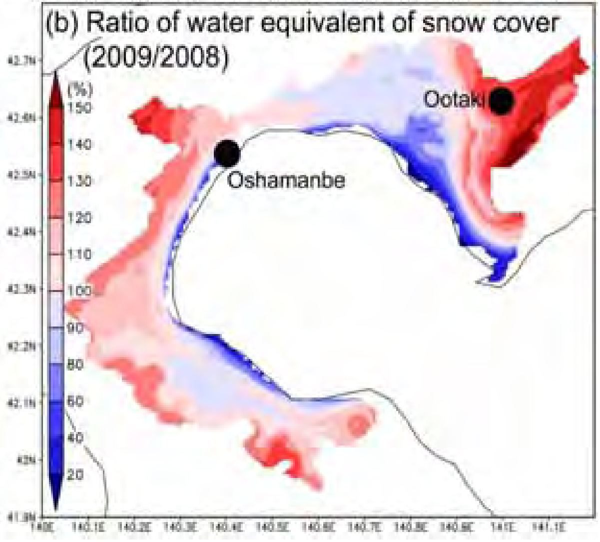
Averaged runoff (Apr - Aug)
2008 (172 m^3/s)
2009 (236 m^3/s)

Diff. 2009 minus 2008



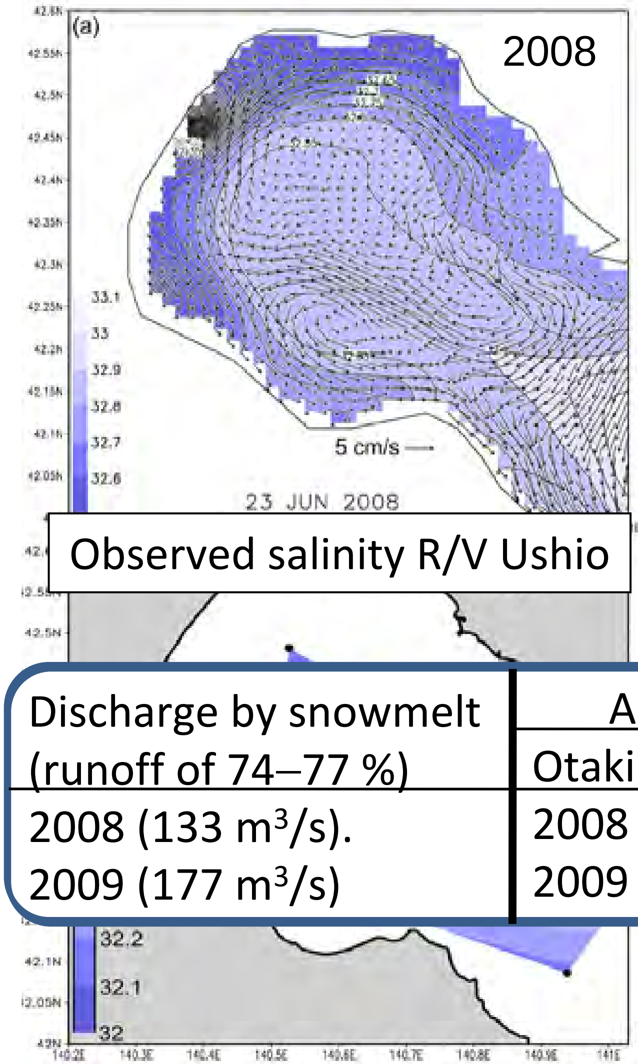
Difference of snow cover





Summer-time clockwise circulation induced by buoyancy flux of runoff generated by snowmelt

Clockwise circulation

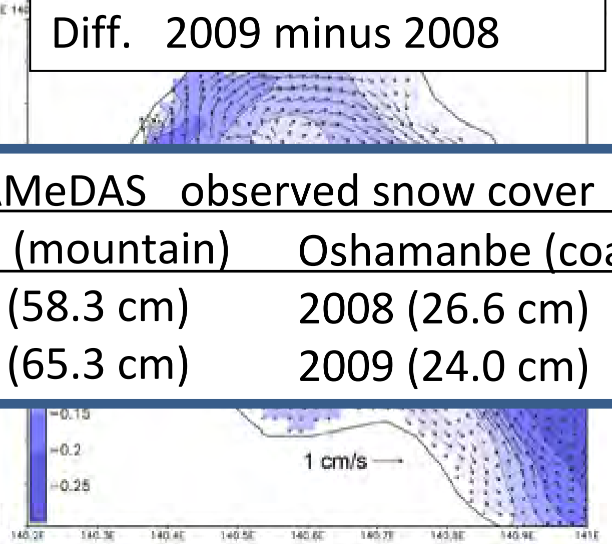


Observed salinity R/V Ushio

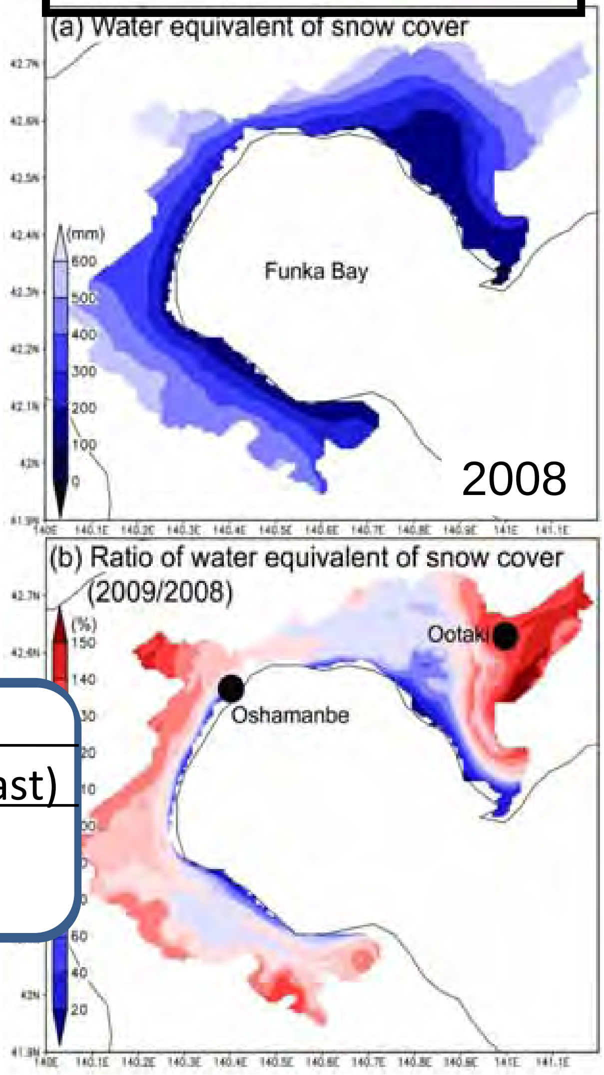
Strong clockwise circulation are generated by much more river runoff in 2009 than in 2008

Averaged runoff (Apr - Aug)
2008 (172 m^3/s)
2009 (236 m^3/s)

Diff. 2009 minus 2008



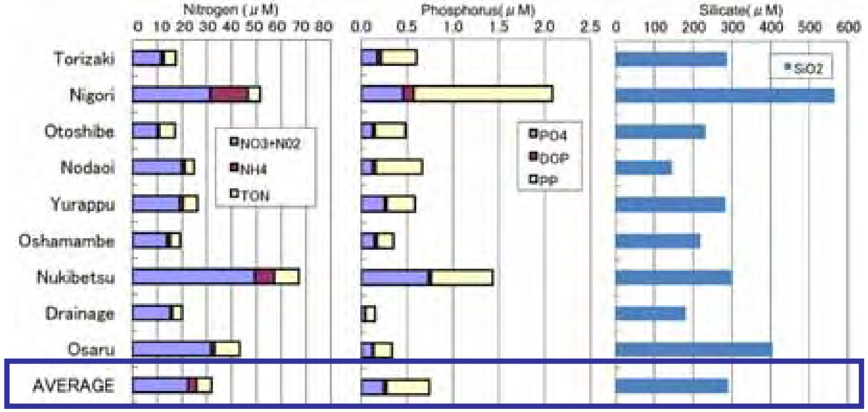
Difference of snow cover



Discharge by snowmelt (runoff of 74–77 %)	AMeDAS observed snow cover	
	Otaki (mountain)	Oshamanbe (coast)
2008 (133 m^3/s).	2008 (58.3 cm)	2008 (26.6 cm)
2009 (177 m^3/s)	2009 (65.3 cm)	2009 (24.0 cm)

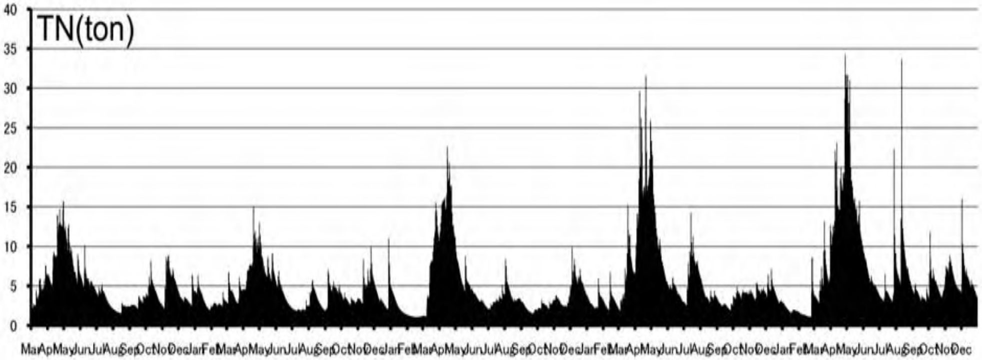
Riverine nutrient fluxes into FB

Nutrient concentration in major 8 river & avr.



(Yoshimura and Kudoh, 2003)

Nutrient fluxes = concentration x runoff



Averaged runoff (Apr - Aug)
2008 (172 m^3/s)
2009 (236 m^3/s)

Averaged nutrient fluxes from all rivers into the bay

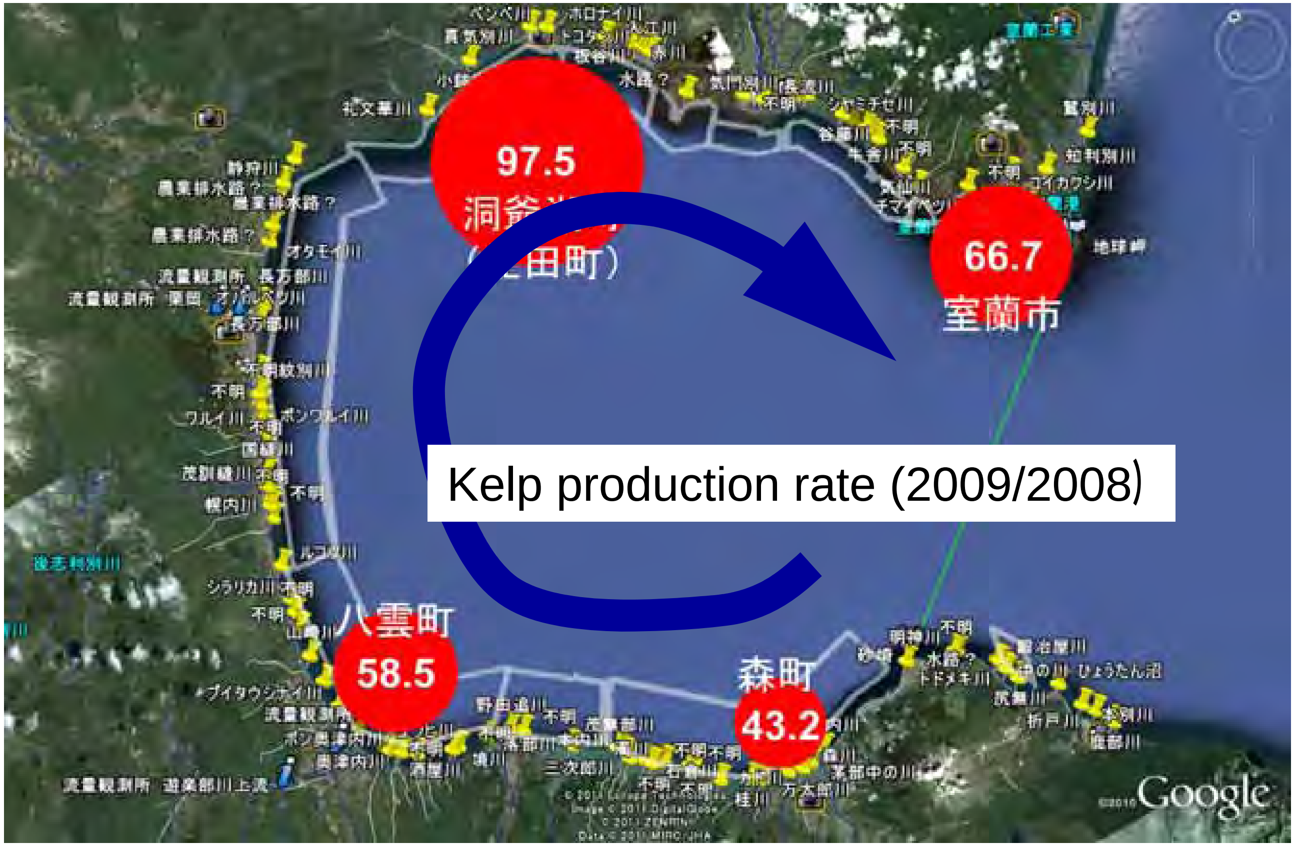
[ton/mon]	Nitrogen				Phosphorus				Silicate
	TN	TON	NH4	NO2+NO3	TP	PP	DOP	PO4	
2008	140.9	27.8	12.1	101.0	6.2	3.7	0.3	2.3	2489.2
2009	181.9	36.0	15.5	130.4	8.0	4.8	0.4	2.9	3238.3
%	129	130	128	129	129	129	130	128	130

Riverine nutrient fluxes in 2009 was 1.3 times in 2008

Speculation & Summary

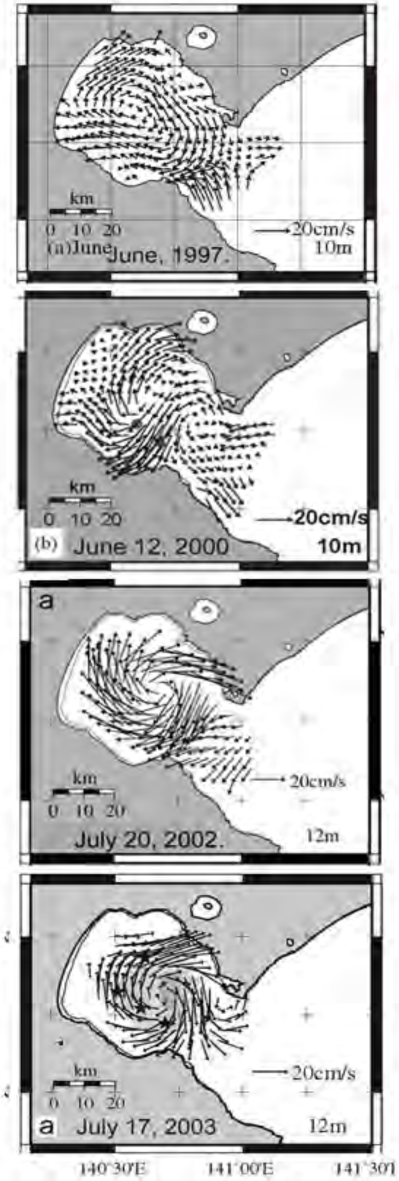
Speculation

- Snowmelt generates large runoffs and nutrients fluxes into FB.
- The riverine buoyant flux of runoff induces the clockwise circulation transporting nutrients toward northern coast.
- These advected high nutrients suppress decrease of kelp production around northern coast in weak Oyashio year.



Kelp production rate (2009/2008)

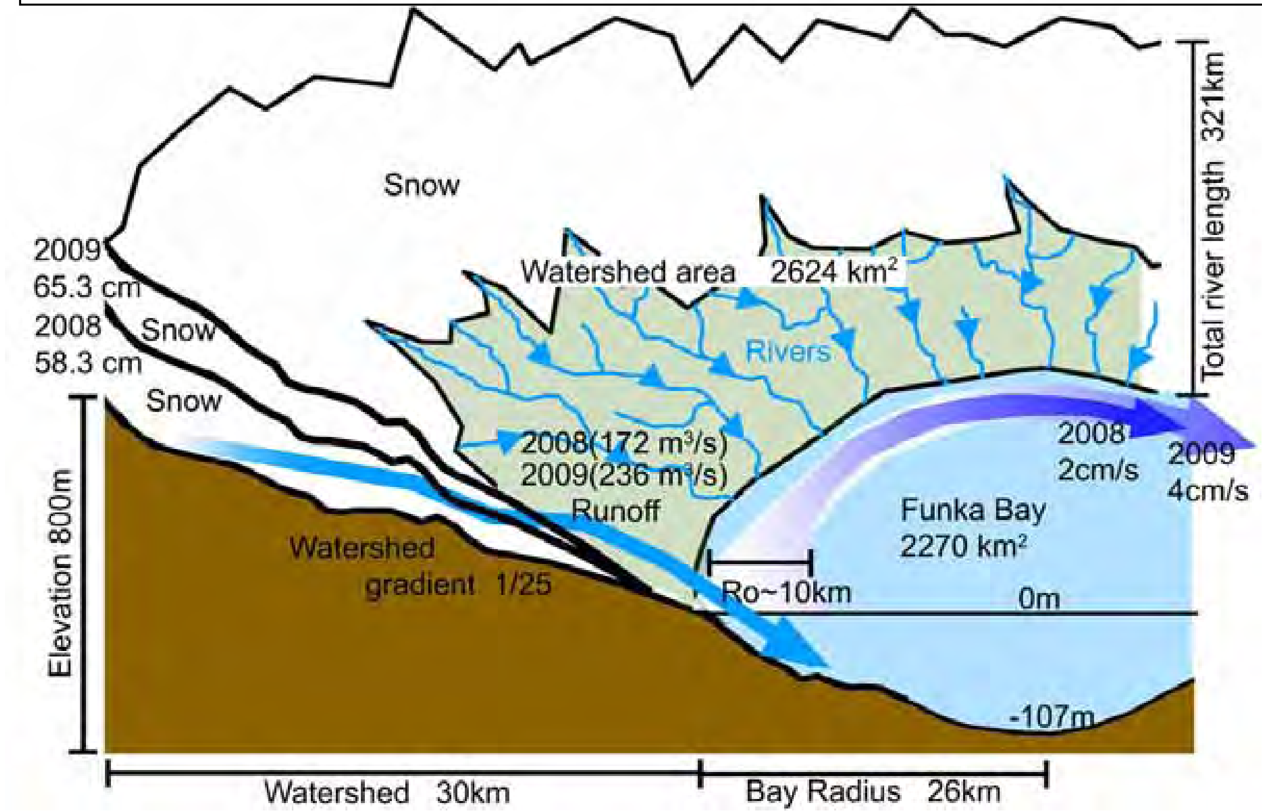
Observed evidence of clockwise circulation



e.g. Takahashi et al., 2010

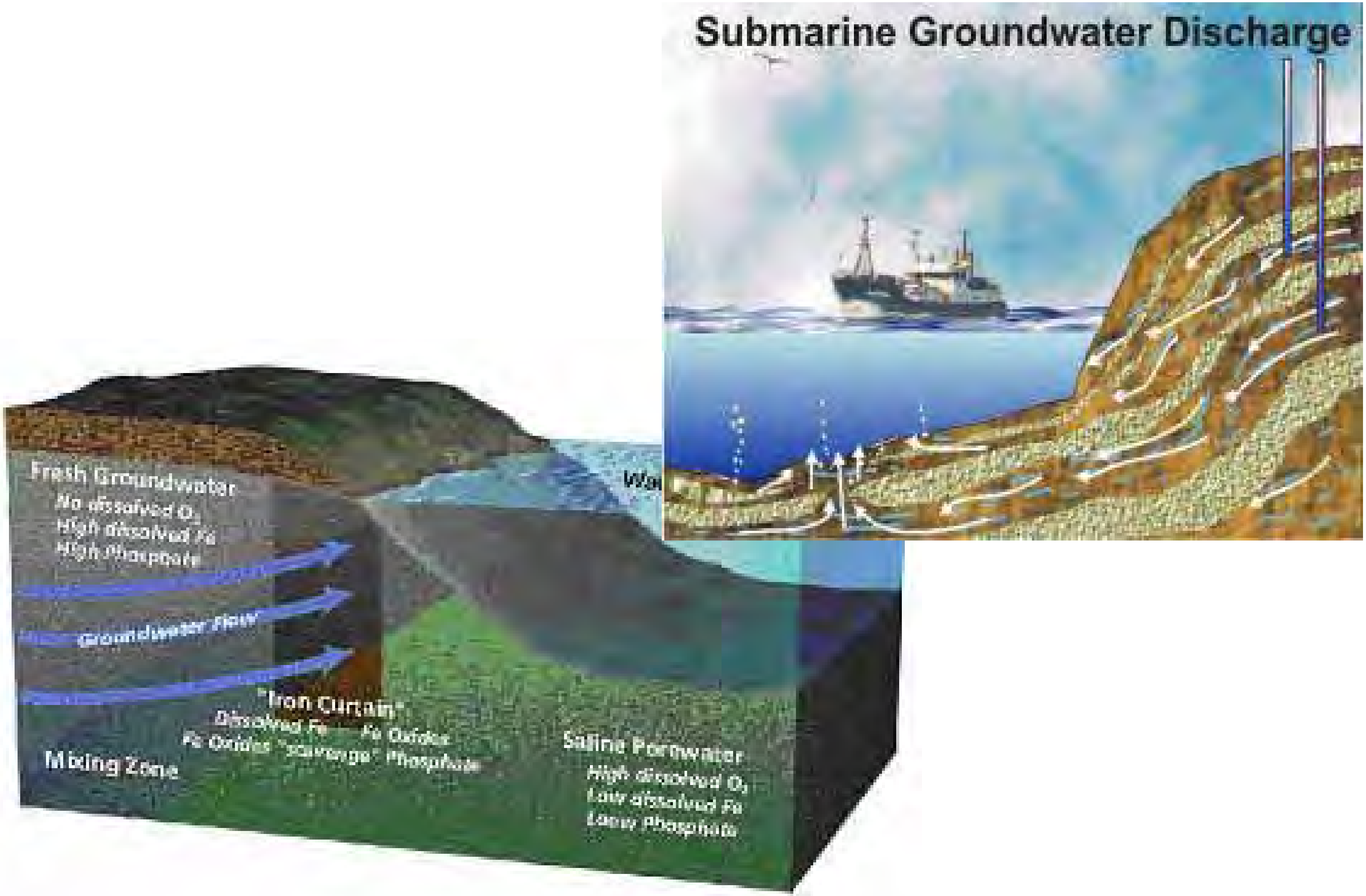
Summary

- We proposed the small river model to estimate runoff and nutrient fluxes from small rivers based on heat and water budget and tank model.
- The coupled OGCM & river model well improved the salinity and velocity field.
- Large runoffs associated with snowmelt induced the clockwise circulation and riverine nutrient fluxes into FB.
- Heavy snow at mountain in 2009 → much runoff with large snowmelt → intensified clockwise circulation → transport nutrients to northern coast → keep kelp production

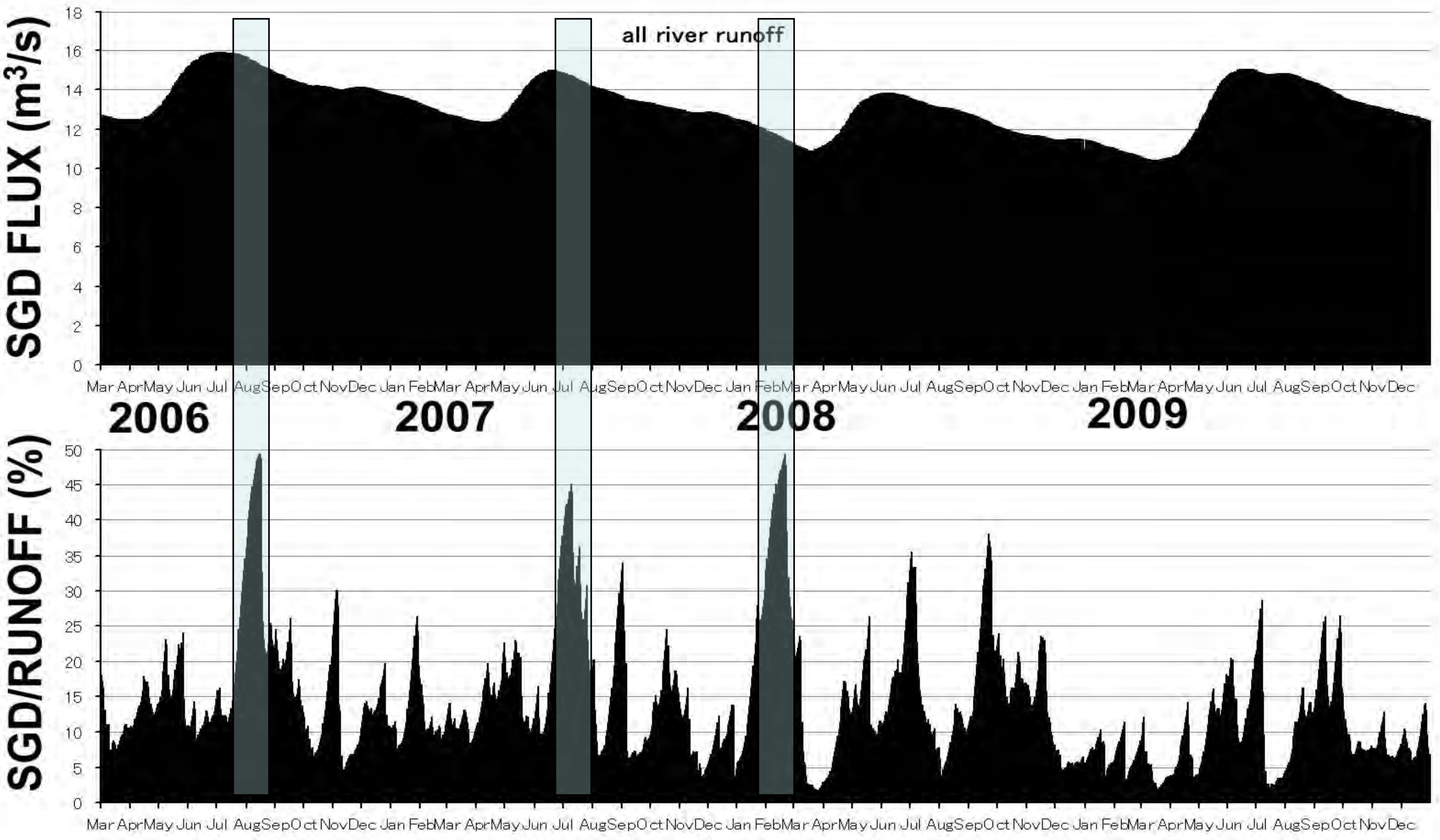


We show possibility of
Gulf-type fish-bleeding forest.

Submarine Groundwater Discharge (SGD)



Submarine Groundwater Discharge (SGD)



Todal SGD = 13.4 m^3/s, 10-50% of River Runoff