Operational Ocean Data Assimilation and Prediction System in JMA and MRI

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Outline

1. Introduction to
   status of operational data assimilation
   (of physical oceanography)
   (under GOOS/GODAE, CLIVAR/GSOP)

2. JMA/MRI_system: MOVE/MRI.COM
   Systems for Ocean weather & Ocean climate
   Validation with analysis/reanalysis data
   Nowcasting & forecasting of ocean state

Appendix.

Analyses of 2004 Kuroshio Large Meander

Future (on going) direction and recommendation: OSE, CDAS, Coastal Appl.

Data Assimilation

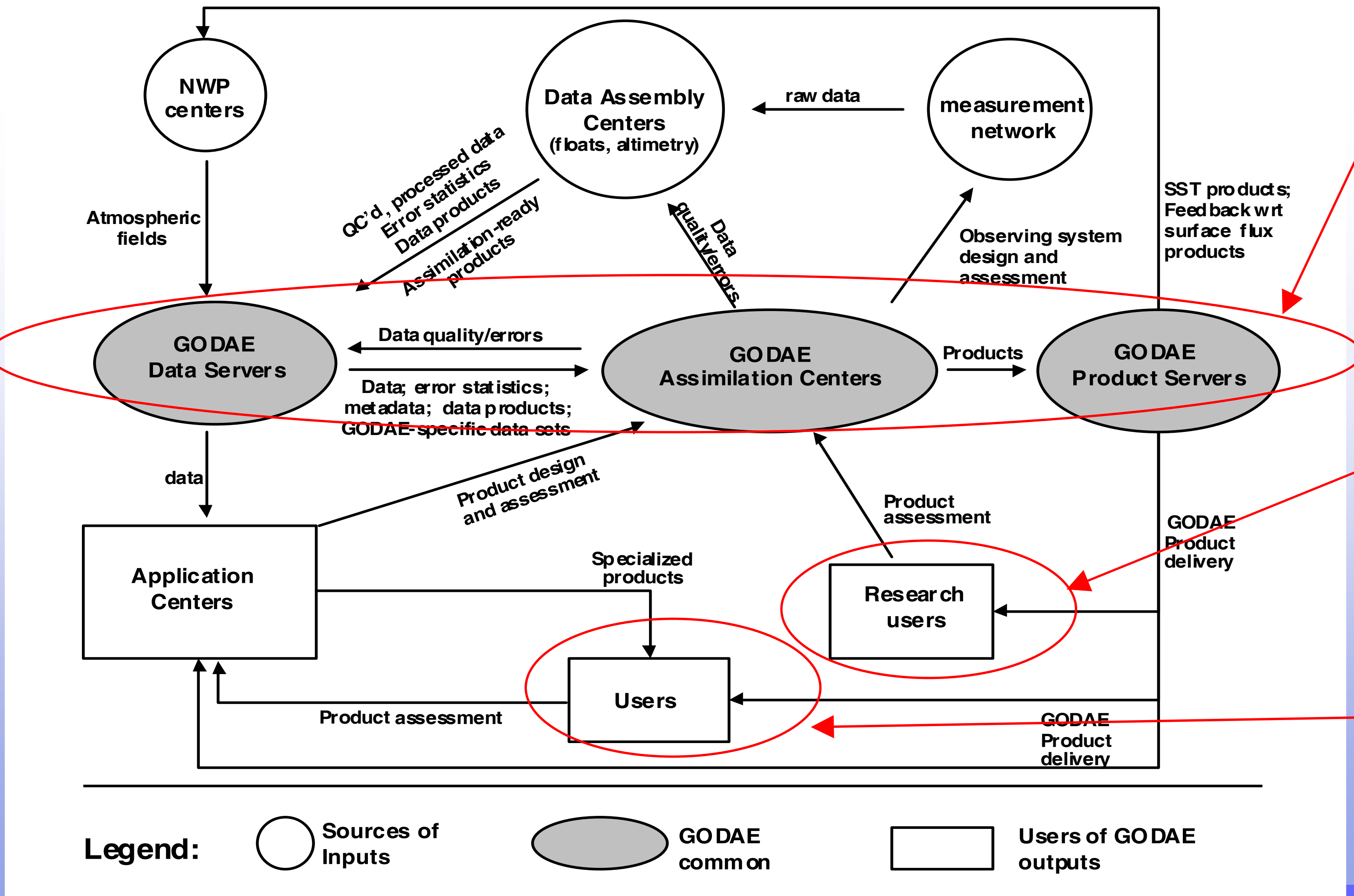
Data assimilation is
a procedure that subtracts information from models and observations, and combines them as an optimum estimate.

The aims are

1. **to obtain optimum initial condition for prediction**
2. **to obtain optimum boundary condition**
3. **to obtain optimum parameter (parameter estimation)**
4. **to understand phenomena with 4D data set (reanalysis)**
5. **to estimate observing system and develop optimum system (through OSE/OSSE/sensitivity/SV analyses)**

Total System is Important (GODAE)

see "GODAE Implementation Plan" at http://www.godae.org/

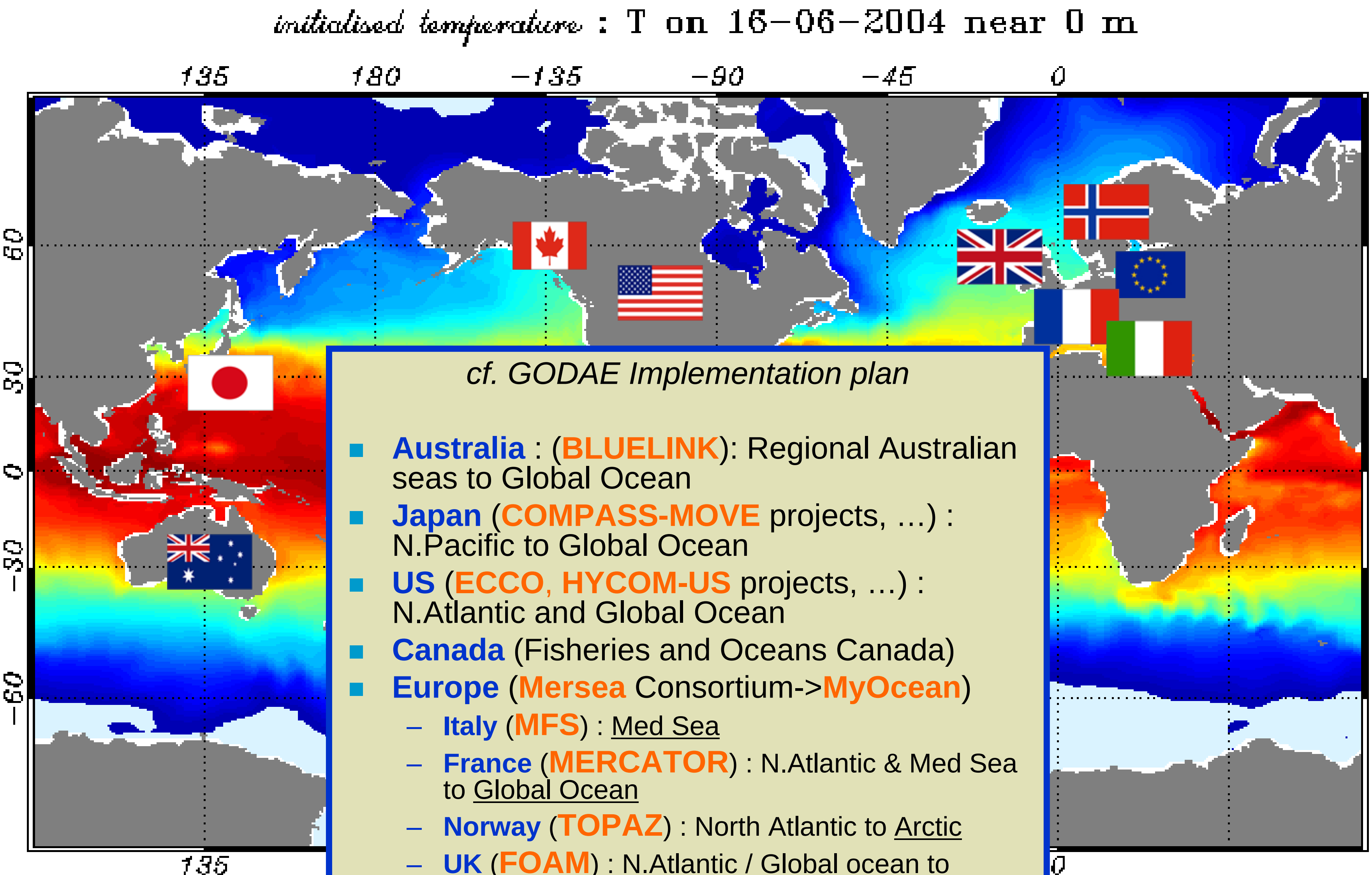


Operation or Research

Middle users (mainly Research Community)

End users

GODAE
Modelling/Assimilation Centers



cf. GODAE Implementation plan

- **Australia** : (**BLUELINK**): Regional Australian seas to Global Ocean
- **Japan** (**COMPASS-MOVE** projects, …) : N.Pacific to Global Ocean
- **US** (**ECCO, HYCOM-US** projects, …) : N.Atlantic and Global Ocean
- **Canada** (Fisheries and Oceans Canada)
- **Europe** (**Mersea** Consortium->**MyOcean**)
  - **Italy** (**MFS**) : Med Sea
  - **France** (**MERCATOR**) : N.Atlantic & Med Sea to Global Ocean
  - **Norway** (**TOPAZ**) : North Atlantic to Arctic
  - **UK** (**FOAM**) : N.Atlantic / Global ocean to Northern Shelves

Japan GODAE partner

Status of Japan-GoDAE Partners 2006/05/01

Group	Kyoto Univ. & Jpn Mar Sci Foundation (Res. System) Ishikawa, Inn Awaji **KU-JMSF**	Frontier (IMRP) & Kyoto Univ. **K-7** (Res. Syst.) Masuda, Sugiura Awaji	Kyushu Univ. (RIAM) (Res. Syst.) Hirose Yoon **RIAMOM** & Fisheries Agency **JADE(FRA)**	Frontier (FRCGC) & Tokyo Univ. & Fisheries Agency **J-COPE2** (Res. Syst.) Miyazawa, Yamagata **FRA-JCOPE**	JMA/MRI **MOVE/MRI.COM-NP** (Res. Syst. & JMA-next oper.) Usui, Tsujino, Fujii, Kamachi	JMA/MRI **MOVE/MRI.COM-G** (Res. Syst. & JMA-next oper.) Fujii, Yasuda, Matsumoto, Yamanaka Kamachi	JMA/HQ (MarPredDiv) COMPASS-K (Oper. Syst.) Kuragano, Ishizaki, Sakurai Kamachi	JMA/HQ (ClimInfoDept) ODAS (Oper. Syst.) Ishikawa Ishikawa Soga Takaya Yamanaka 、
Forcing	NCEP2	NCEP2	ERA40 JMA-NWP	NCEP2, QSCAT ERS-1,2 wind Reynolds SST	NCEP2 ERA40 JRA25 JMA-NWP	NCEP2 ERA40 JRA25 JMA-NWP	JMA-NWP JRA25	JMA-NWP JRA25
Data	Jason GHRSST GTSPP TAO-TRITON Argo	Jason GHRSST GTSPP TAO-TRITON Argo	Jason+ENVISAT GHRSST GTSPP TAO-TRITON Argo	Jason+ENVISAT GHRSST GTSPP TAO-TRITON Argo	Jason+ENVISAT GHRSST GTSPP TAO-TRITON Argo	Jason+ENVISAT GHRSST GTSPP TAO-TRITON Argo	GTS-T,S Jason+ENVISAT ->T,S (correlation) GHRSST TAO-TRITON Argo	GTS-T,S Jason+ENVISAT ->T,S (correlation) GHRSST TAO-TRITON Argo
Assim.	4DVAR	4DVAR (OGCM-4DVAR) (CGCM-4DVAR)	Kalman Filter	2DOI +z-correlation +IAU ->3DVAR	3DVAR (SEEK-VAR -TSEOF, IAU) 4DVAR	3DVAR (SEEK-VAR -TSEOF, IAU) 4DVAR	Multivariate -scale dependent -4DOI Nudging	3DVAR (Derber & Rosati)
Others (Future Plan)	Coastal	OSSE Metrics (N & Eq. Pac, class-1-3)	Finer scale (coastal ?)	Coastal Wind-wave	Metrics (N.Pac class-1-4) OSSE Sea-ice (Wind-wave) (High-tide B.C.) (coastal?) Regional OGCM For IPCC-CGCM	Metrics (Eq. Pac, Class-1-3) OSSE Indian Ocean Seasonal forecast Global OGCM for IPCC-CGCM	Next generation: MOVE /MRI.COM-NP	Next generation: MOVE /MRI.COM-G Seasonal Forecast

Ocean Data Assimilation Systems in Japan Meteorological Agency & Meteorological Research Institute

Area	Global	Western North Pacific
Aim	Initial Condition for ElNino & Seasonal Forecasting	Initial condition for Ocean Forecasting around Japan
Operation	JMA ODAS	COMPASS-K
	(simple) 3DVAR	4DOI
Research (Next Operation)	MOVE/MRI.COM	
	Multi-variate 3DVAR	Multi-variate 3D/4DVAR

JMA-MRI Ocean Data Assimilation System: MOVE/MRI.COM

MRI has been developing ocean data assimilation systems (MOVE/MRI.COM: Multivariate Ocean Variational Estimation).

Aims

1. **Optimum Initial Conditions for operational forecasting in JMA**
   Ocean Climate: Seasonal - Interannual (ElNino) prediction
   Ocean Weather: Ocean state estimstion & prediction around Japan

2. **Analysis-reanalysis (3 types) for understanding climate variability:**

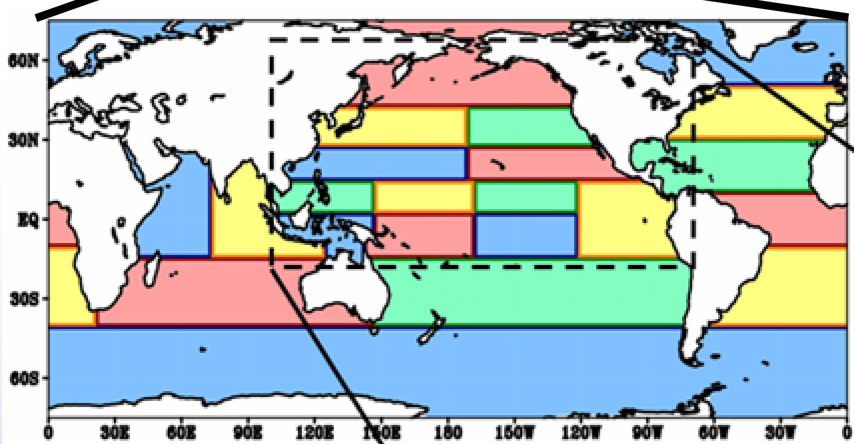
   Western North Pacific : 1985-2006+ (0.1deg) 1full-time+3part-time+4oper
   North Pacific : 1948-2006+ (0.5deg) (1full-time+3part-time)
   Global : 1948-2006+ (1.0deg) 1full-time+5part-time+3oper

   Reanalysis dataset will be opened through JMA Japan_GODAE server and IPRC/APDRC data centers for contribution to international intercomparison projects under GOOS/OOPC/GODAE and CLIVAR/GSOP

3. **OSE (OSSE, SV analyses with 4DVAR-adjoint system)**
4. **Coupled atmosphere-ocean data assimilation for S-I prediction**
5. **Coastal application for disaster prevention**

Five Assimilation/Prediction Systems
(oper. three systs.)

MOVE-C With atmospheric model



MOVE-G

Lat. 0.3(Eq)~1 degree

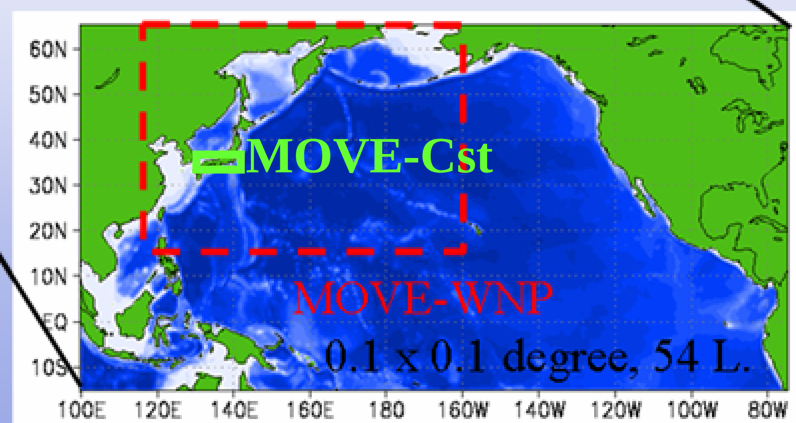
Lon. 1 degree

50 layers

MOVE-NP

0.5 x 0.5 degree

54 Layers



Global Model-1 :
(1×1 deg.:
1/3° tropical region
54 Layers)

Nested-1 N-Pac Model :
15S-65N, 100E-75W
(0.5×0.5 deg.,
54 Layers)

Nested-2 Kuroshio Model :
15N-65N, 115E-160W
(0.1×0.1 deg.,
54 Layers)

Nested-3 Coastal Model
2km mesh, 54 layer

Usui et al. (2005)

JMA-MRI Ocean Data Assimilation System: MOVE/MRI.COM

MRI MOVE/MRI.COM (Multivariate Ocean Variational Estimation) system

OGCM: MRI.COM (MRI Community Ocean Model) (similar to MOM)

Method: Multivariate 3D-VAR

with vertical coupled T-S Empirical Orthogonal Function (EOF) modal decomposition with area partition (control variable: amp. of EOF mode)
horizontal Gaussian function (inhomogeneous decorrelation scales)
nonlinear constraints (dynamic QC, density inversion)
bias correction

Source Data:

Satellite Altimetry (TOPEX/POSEIDON, ERS-1 &-2, ENIVISAT, Jason),

SST (COBESST or GHRSST),

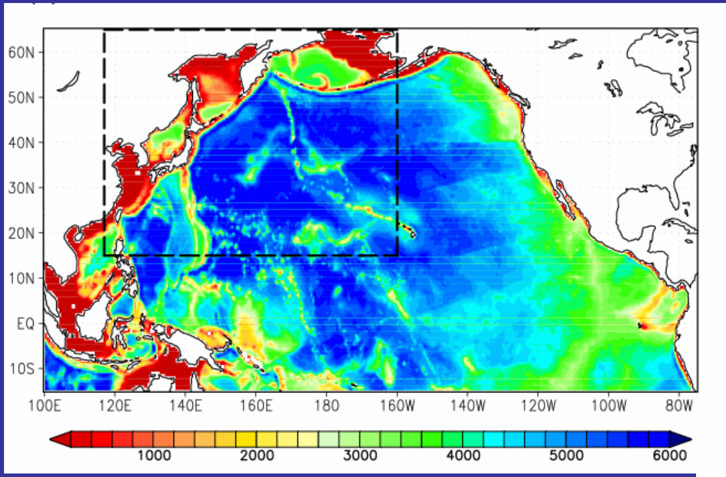
in situ T & S (GTSPP, ARGO, Tao/Triton, drifter),

with QC in each data centers

Atmospheric forcing (NCEP-R1&R2, ERA40, JRA25)

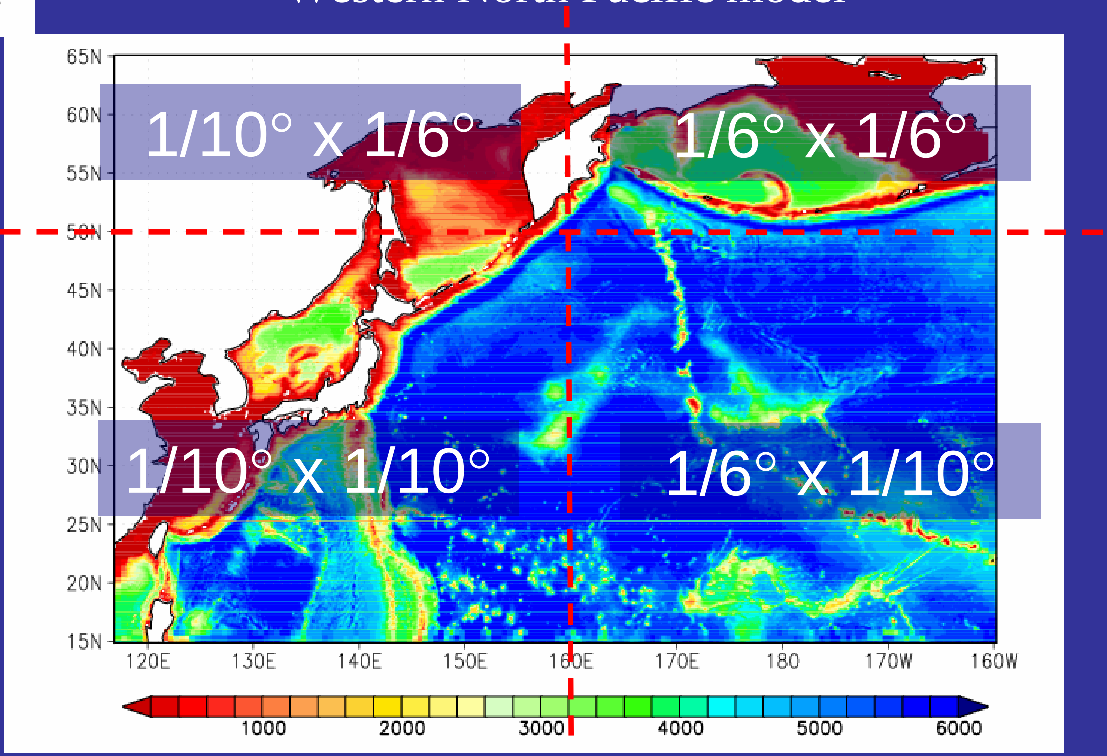
4DVAR, Quasi-Coupled AOGCM 3DVAR

MOVE/MRI.COM-NP and -WNP



← North Pacific model（1/2° x 1/2°）

Western North Pacific model



Vertical 54 levels

0.5, 1.5, 4, 7, 12, 18, 26, 38, 50, 66, 82, 100, 118, 138, 158, 178, 200, 222, 246, 270, 300, 330, 360, 400, 440, 480, 540, 600, 670, 740, 820, 900, 1000, 1100, 1200, 1350, 1500, 1650, 1800, 2000, 2250, 2500, 2750, 3000, 3250, 3500, 3750, 4000, 4250, 4500, 4750, 5000, 5250, 5500 [m]

OGCM: MRI.COM

- vertical hybrid of z- and σ- coordinate with free surface
- turbulent mixed layer model Noh and Kim (1999) $\alpha = 15.0, \quad m = 300.0$
- horizontal viscosity: biharmonic Smagorinsky (Griffies and Hallberg 2000): $c^* = 2.5$
- heat flux bulk formula (Kondo 1975)
- tidal boundary mixing (St. Laurent et al. 2002)
- local Laplacian viscosity on steep bottom topography (Tsujino et al., 2006)
- sea ice model
  - 0-layer (no heat content) sea ice & snow (Mellor and Kantha 1989)
  - Elast-visco-plastic rheology (EVP: continum) (Hunke and Dukowicz 2002)

Ishikawa et al., 2005, Tsujino et al. 2006

Cost function in MOVE/MRI.COM

Multi-variate system: horizontal inhomogeneous Gaussian, vertical T-S EOF .
Optimal amplitudes of T-S EOF (**y**) are calculated by minimizing the cost function (*J*) with a nonlinear descent scheme “POpULar”. Model insertion: IAU

Analysis Increment is represented by the linear combination of the EOF modes.

$$\mathbf{x}(\mathbf{y}) = \mathbf{x}_f + \mathbf{S}\sum_l w_l \mathbf{U}_l \Lambda_l \mathbf{y}_l$$

→ Amplitudes of EOFs

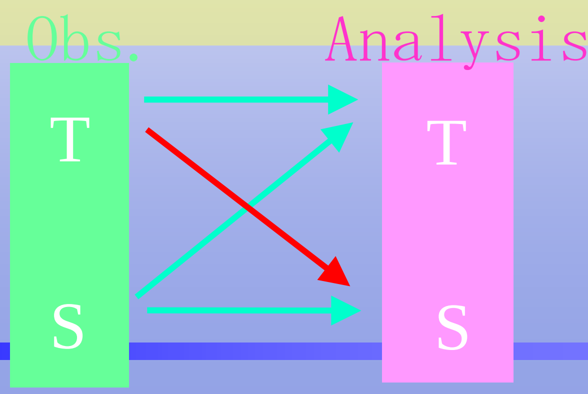
Background Constraint **Constraint for T, S observation**

$$J = \frac{1}{2}\sum_m \sum_l \mathbf{y}_{m,l}{}^T \mathbf{B}_l^{-1} \mathbf{y}_{m,l} + \frac{1}{2}\left[\mathbf{Hx}(\mathbf{y}) - \mathbf{x}^0\right]^T \mathbf{R}^{-1}\left[\mathbf{Hx}(\mathbf{y}) - \mathbf{x}^0\right]$$

$$+ \frac{1}{2}\left[\mathbf{h}(\mathbf{x}(\mathbf{y})) - \mathbf{h}^0\right]^T \mathbf{R}_h^{-1}\left[\mathbf{h}(\mathbf{x}(\mathbf{y})) - \mathbf{h}^0\right] + \alpha(\mathbf{y})$$

Constraint for quality control

Constraint for SSH observation



Seek the amplitudes of EOF modes **y** minimizing the cost function *J*.

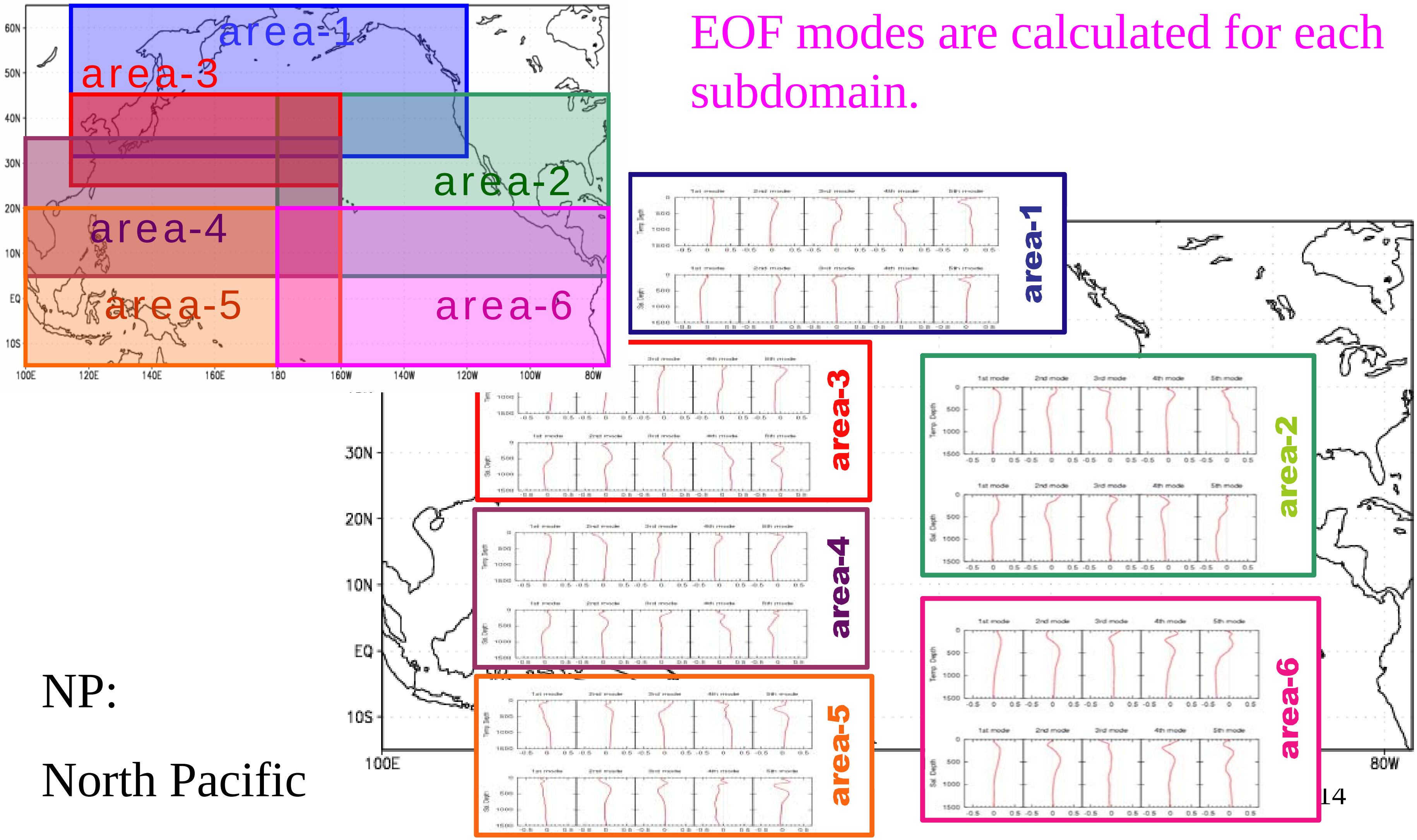
→Analysis increment of T and S will be correlated.

Fujii and Kamachi, 2003a,b,c

★ Model domain partitioning

Partitioning MOVE-NP

EOF modes are calculated for each subdomain.

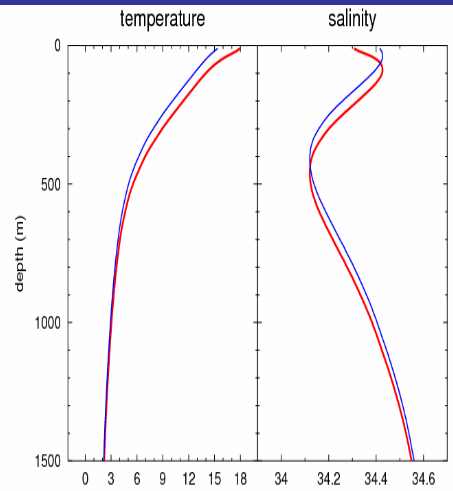


NP:

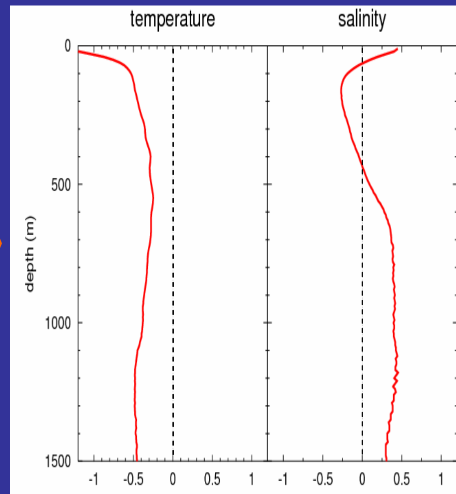
North Pacific

T-S coupled vertical EOF modes

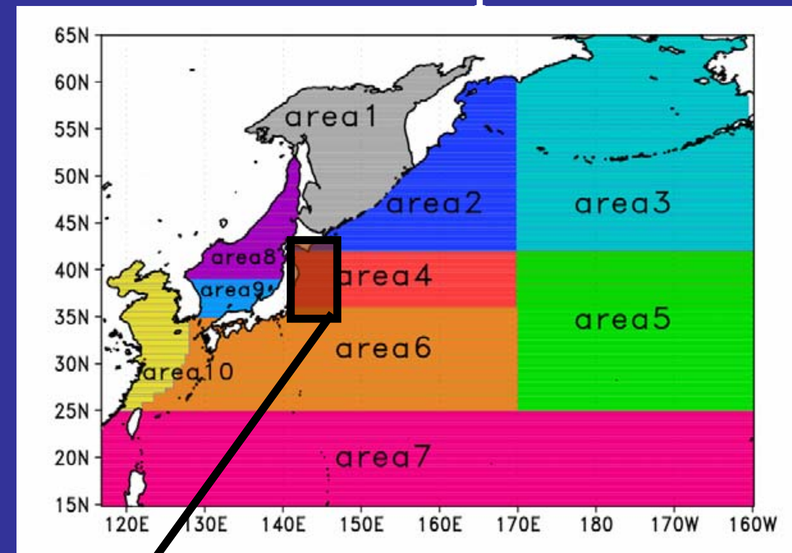
Mean profile (**red**) -> Upward 50m (**blue**)



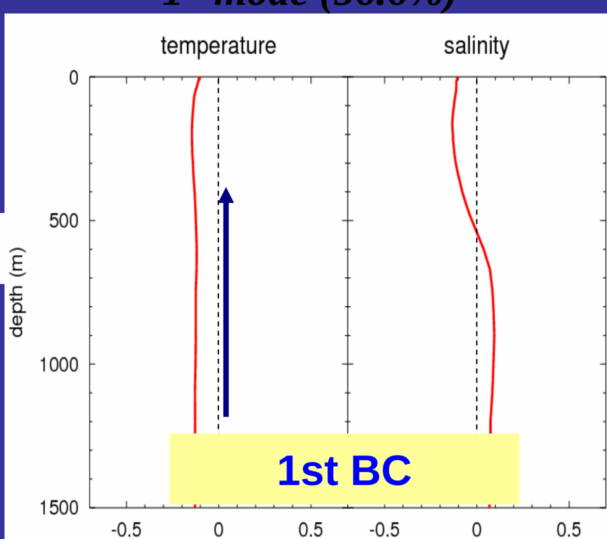
Normalized difference of **blue** and **red**



MOVE-WNP partition

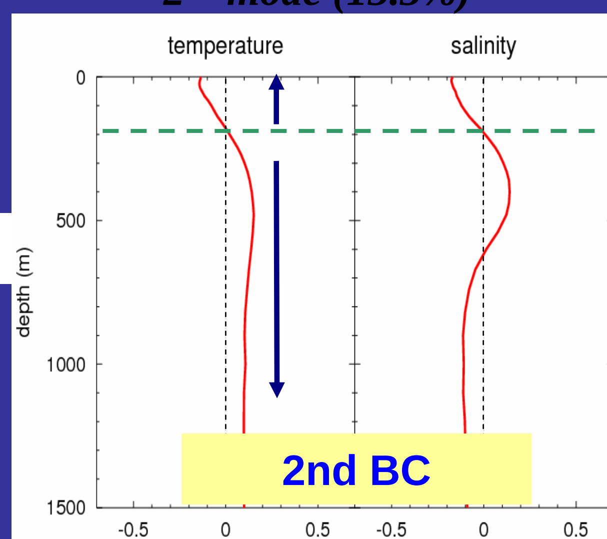


1st mode (56.6%)



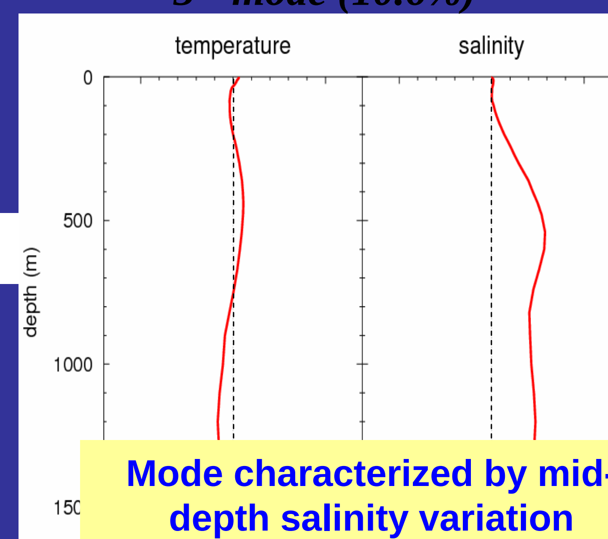
1st BC

2nd mode (13.3%)



2nd BC

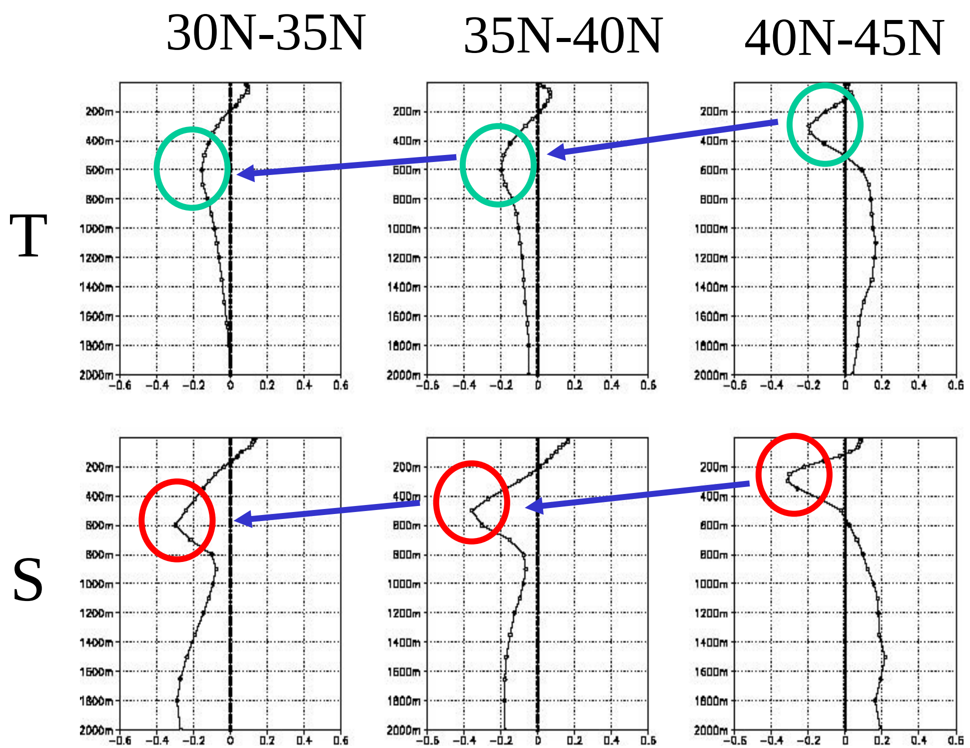
3rd mode (10.6%)



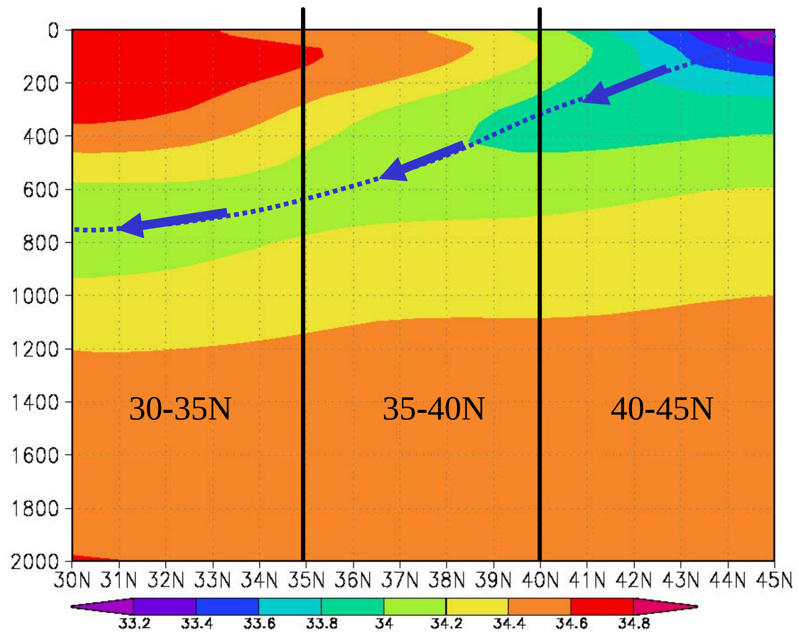
Mode characterized by mid-depth salinity variation

☆Example of Coupled T-S EOF modes

EOF modes representing North Pacific Intermediate Water (NPIW)



TS Climatology in the vertical section of 155E

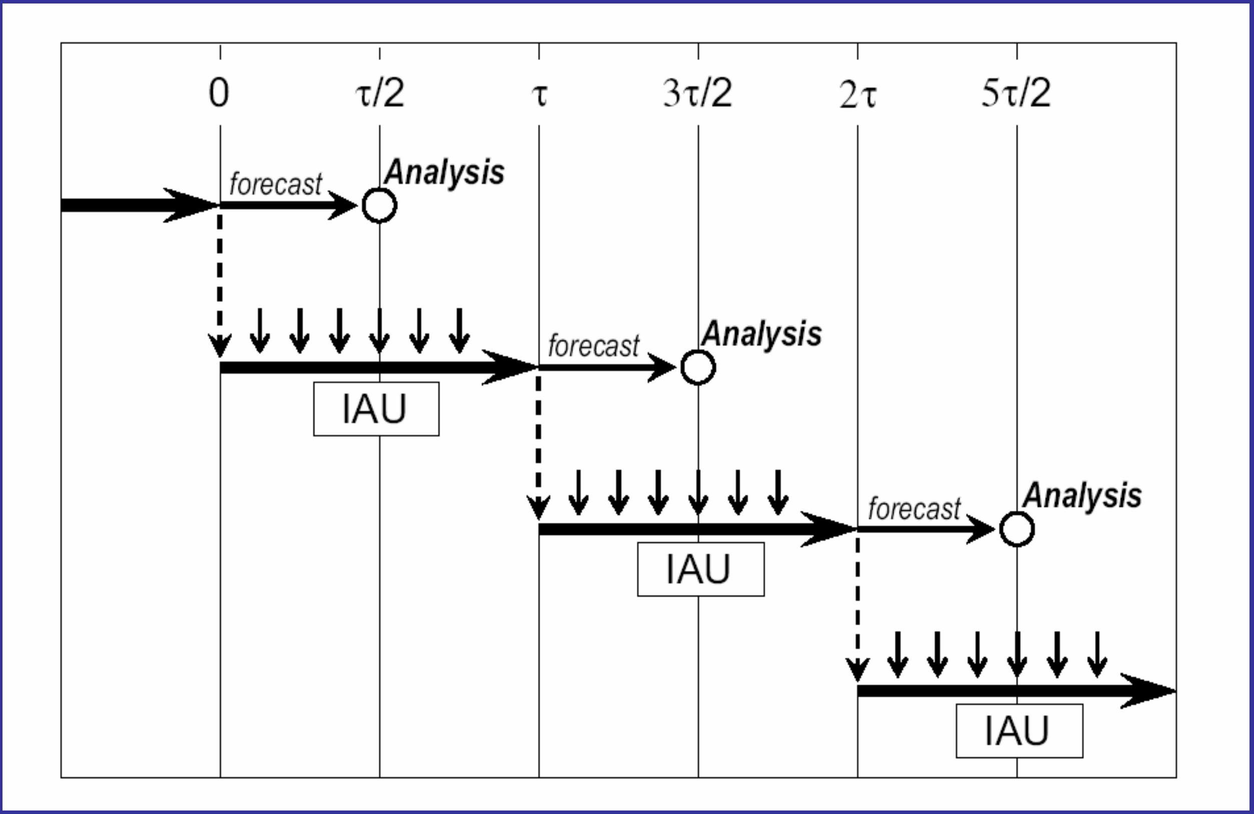


This mode represents

Low salinity water of NPIW → cold water

Model insertion:

Incremental Analysis Updates (IAU; Bloom et al. 1996)



Assimilation cycle in IAU (τ : assimilation window)

Forecast run:

$$\frac{\partial \mathbf{x}(t)}{\partial t} = \mathcal{M}\left[\mathbf{x}\left(t\right)\right]$$

IAU run:

$$\frac{\partial \mathbf{x}(t)}{\partial t} = \mathcal{M}\left[\mathbf{x}(t)\right] + \boxed{\frac{\Delta \mathbf{x}}{\tau}}$$

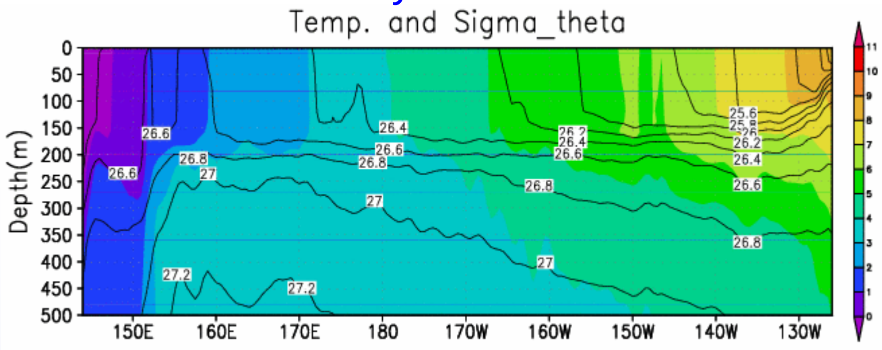
Correction term

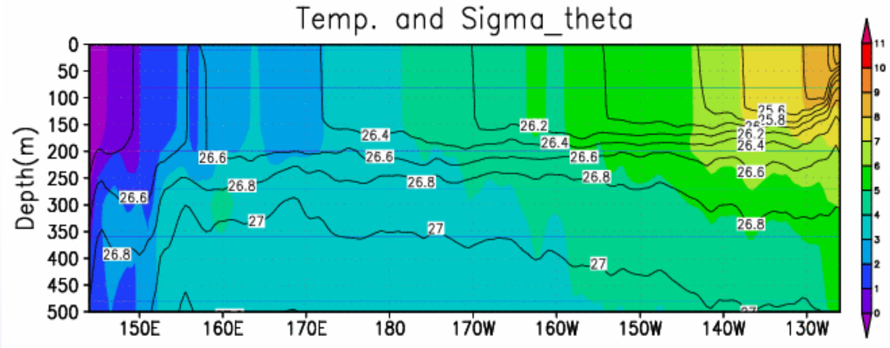
Salinity effect (with Argo float)

Salinity impact on the dichothermal structure

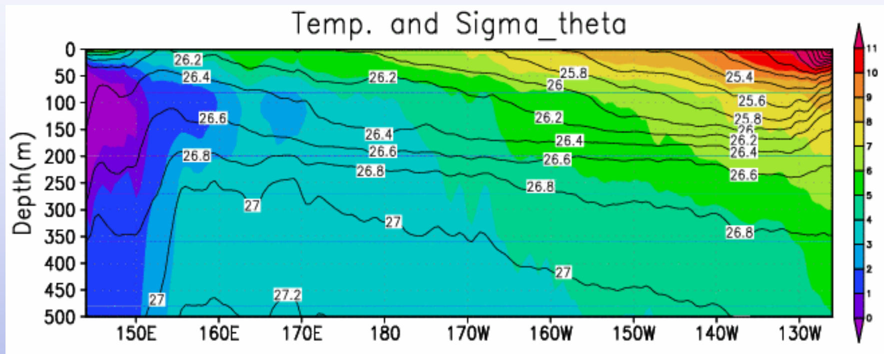
1997-2002 mean   Color: Temperature   Contour: σ_θ

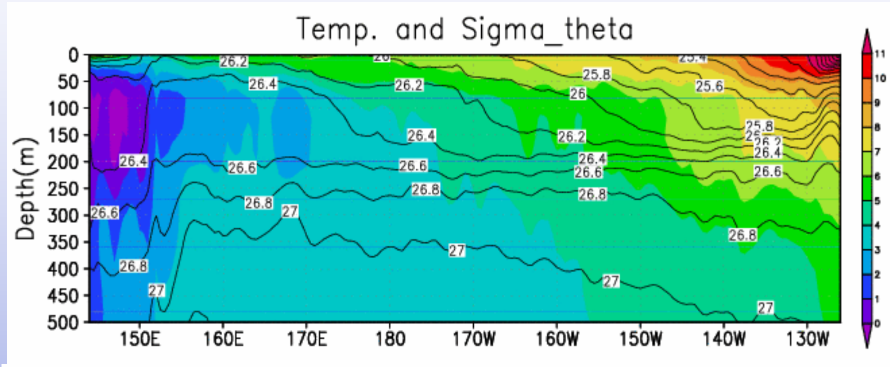
With salinity correction | **Without salinity correction**



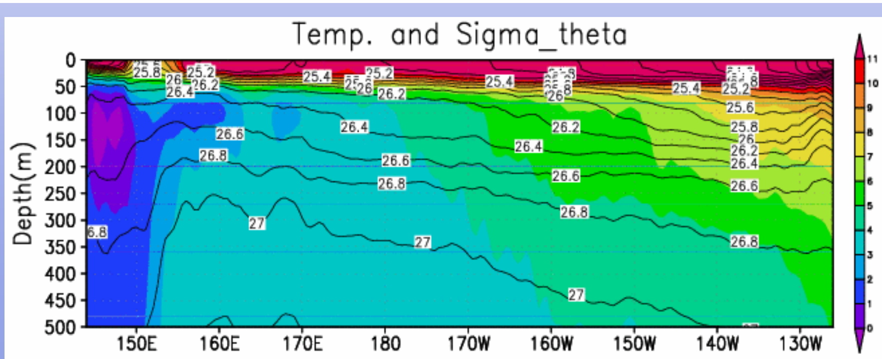


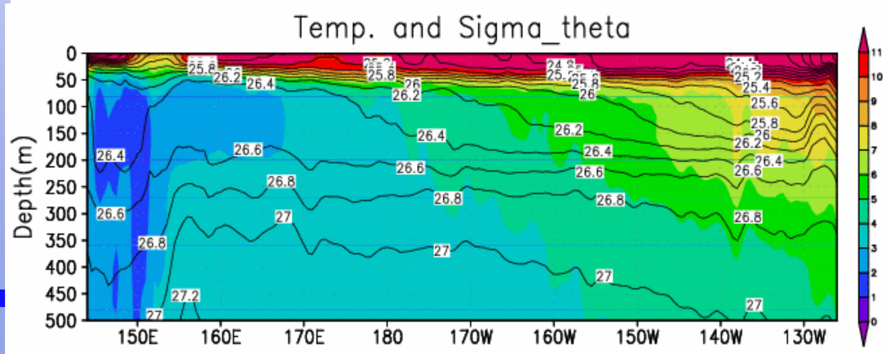
Mar.





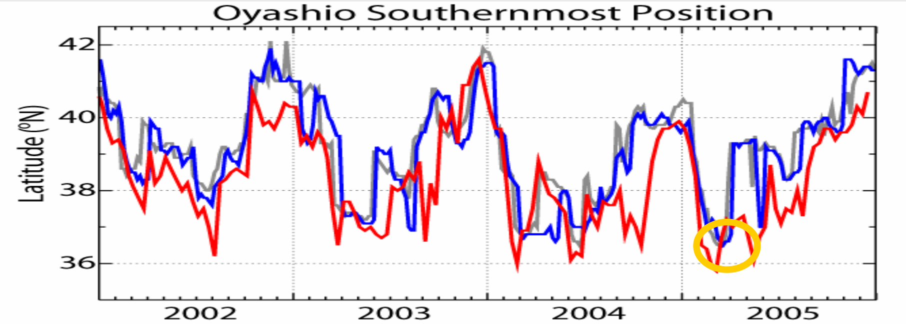
Jun

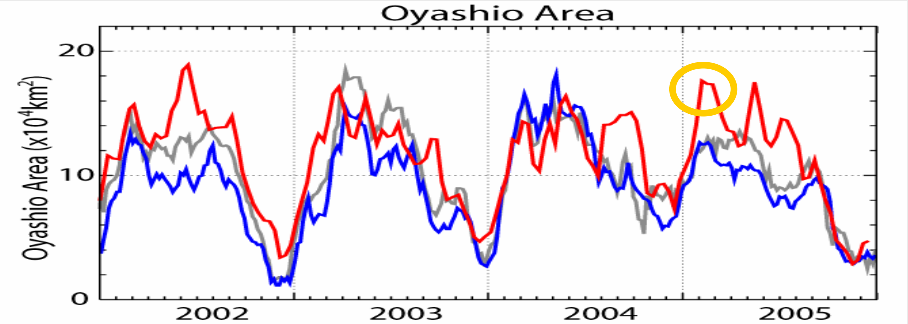




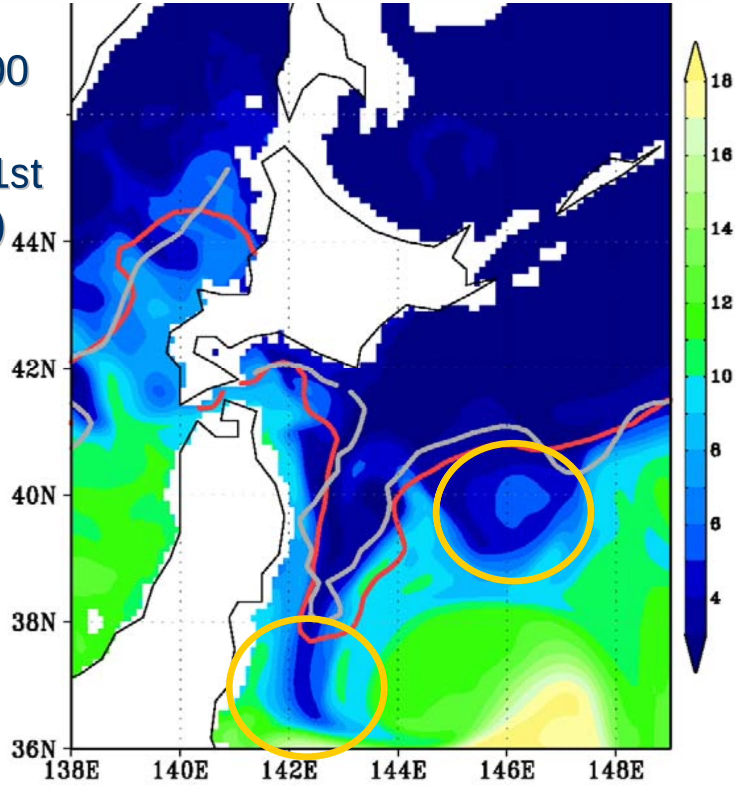
Sep.

Oyashio in subarctic gyre

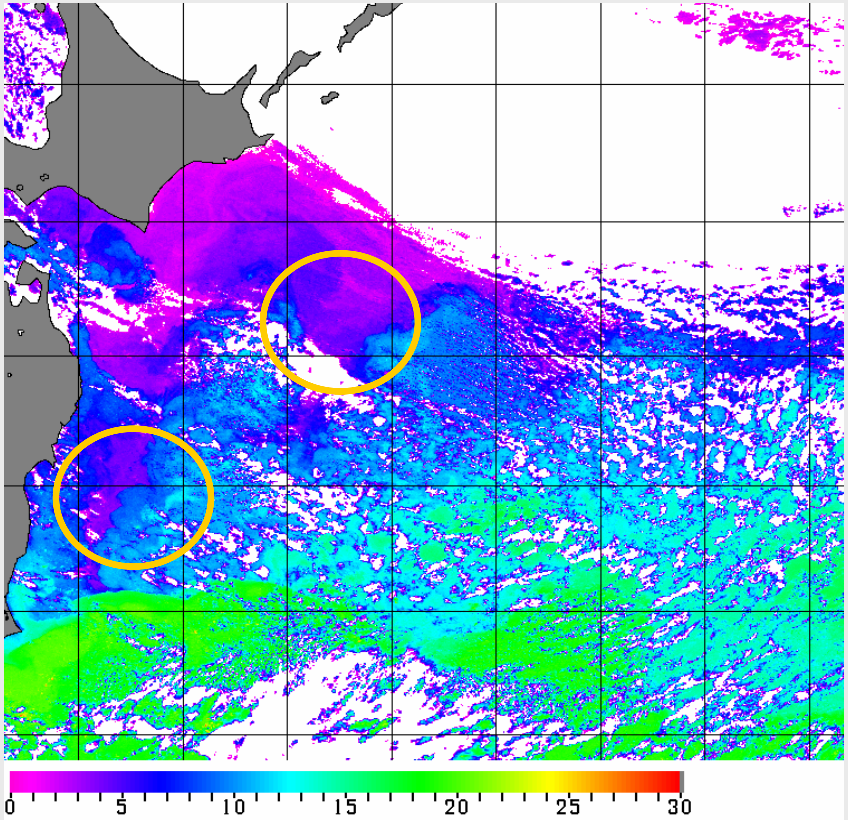




Temp(100 m) (2005/2/1st 10days)



Satellite SST(NOAA@2005/2/3)

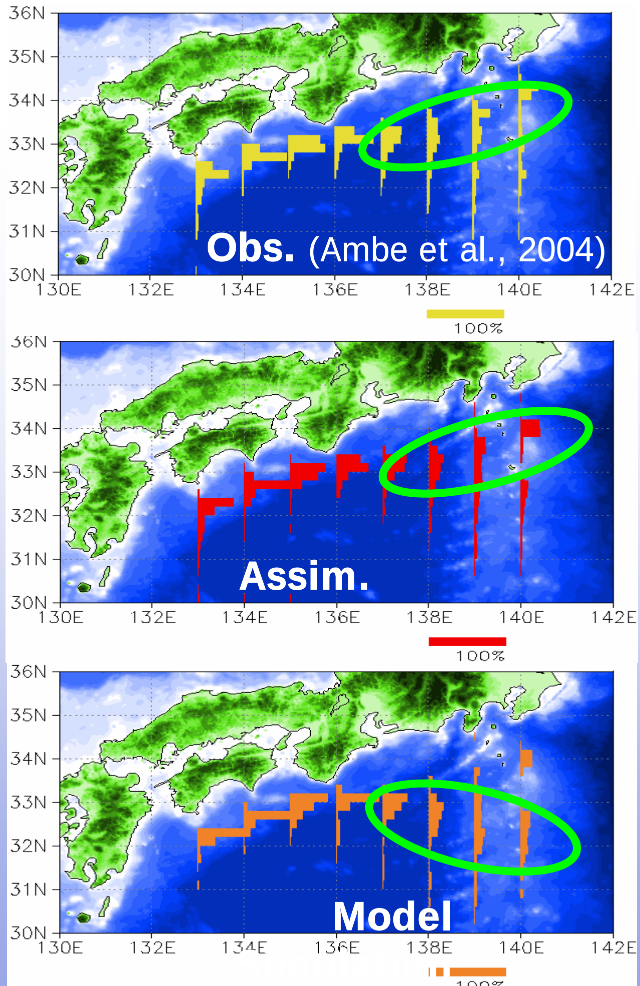


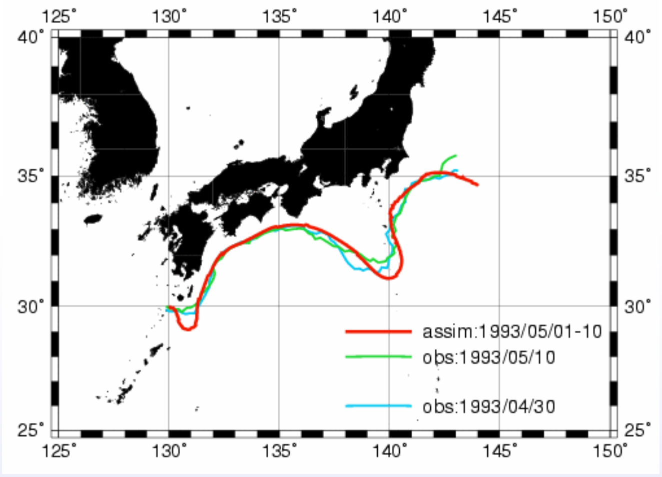
Color：MOVE-WNP

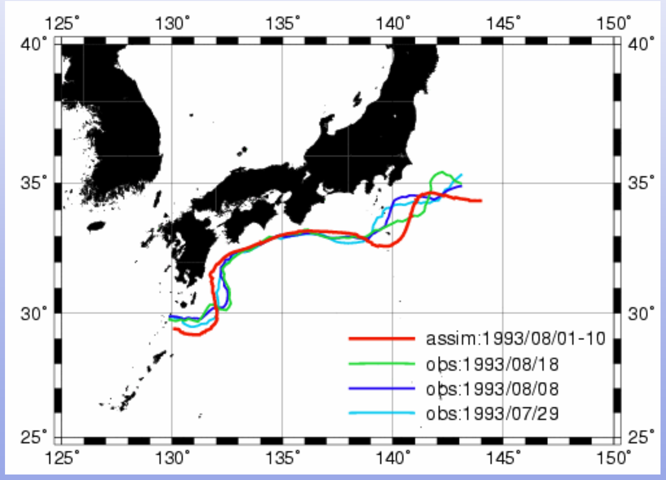
Red：5℃(COMPASS-K) Gray：5℃(Obs-OI)

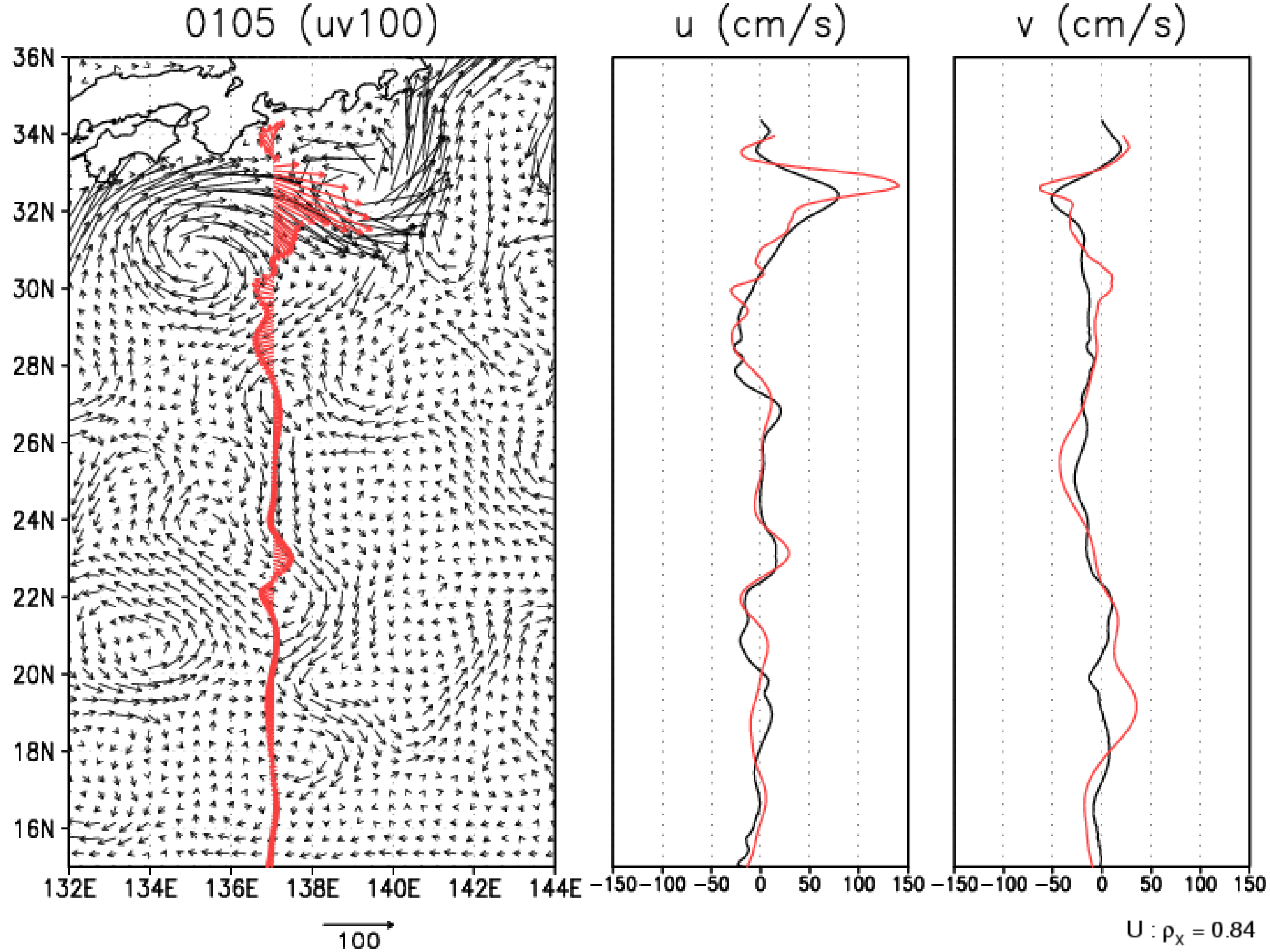
Kuroshio Axis (Representation of Kuroshio front)

Histgram of the Kuroshio axis position







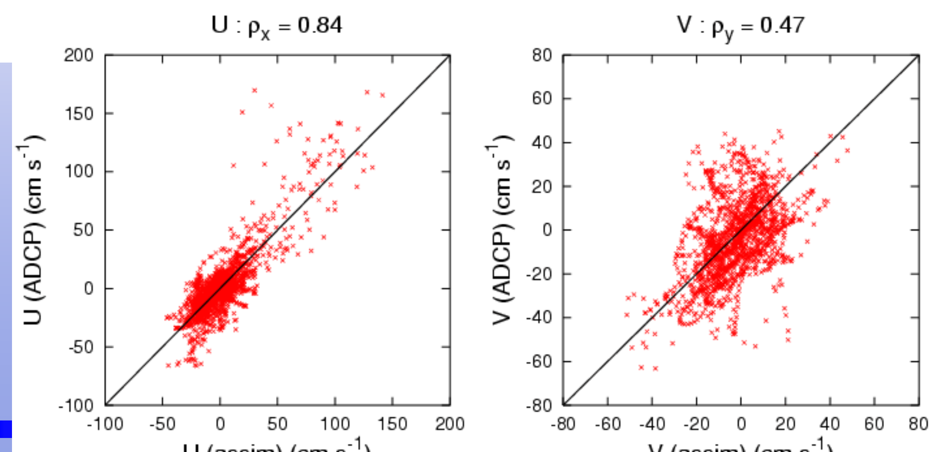


Horizontal Velocity

2005/1

Black: Assim (MOVE)

Red: Independent Obs. (ADCP)



Correlation Coefficient

V variability is smaller->difficult

Comparison with Umisachi buoy #1(2000-2006)

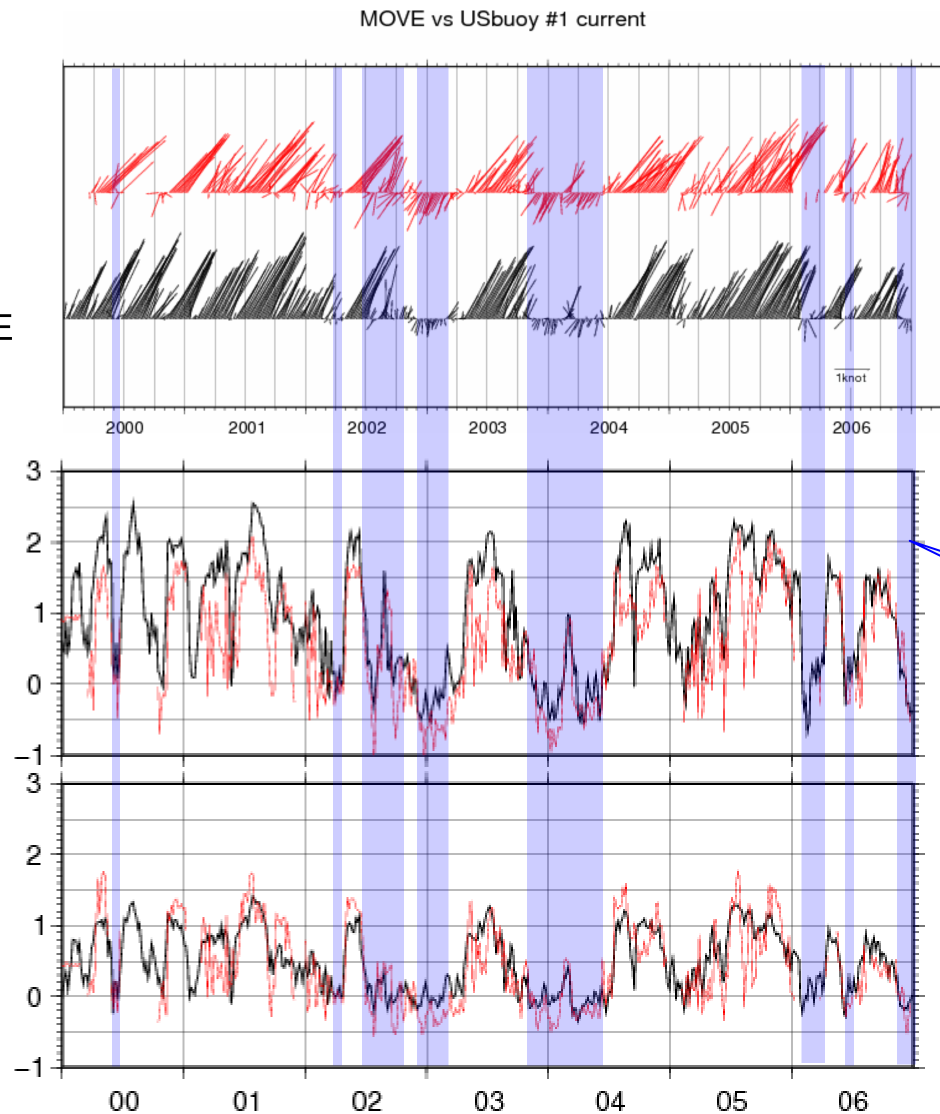
US1

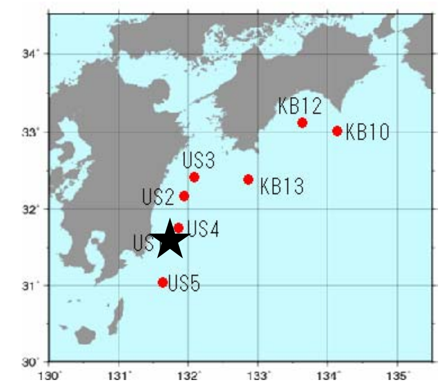
velocity

MOVE

North-south (knot)

East-west (knot)

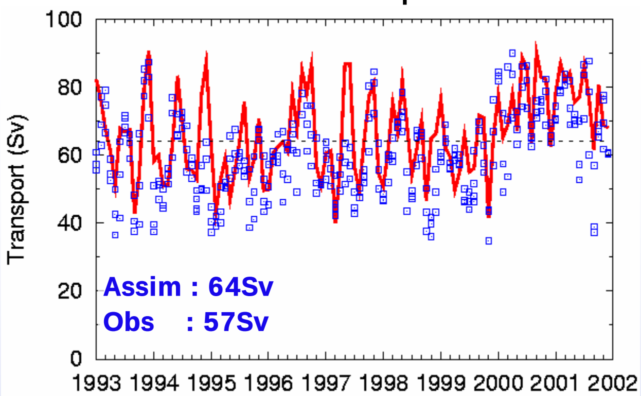


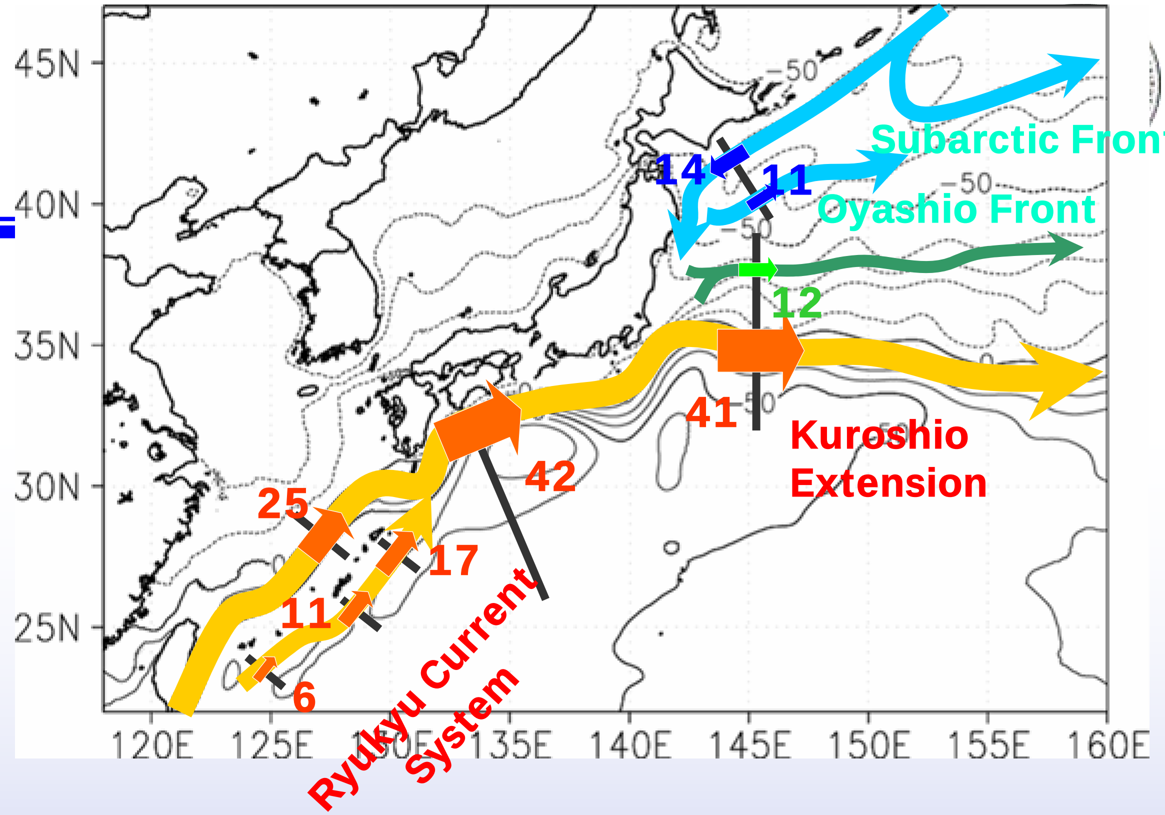


Shaded region:
Small meander period

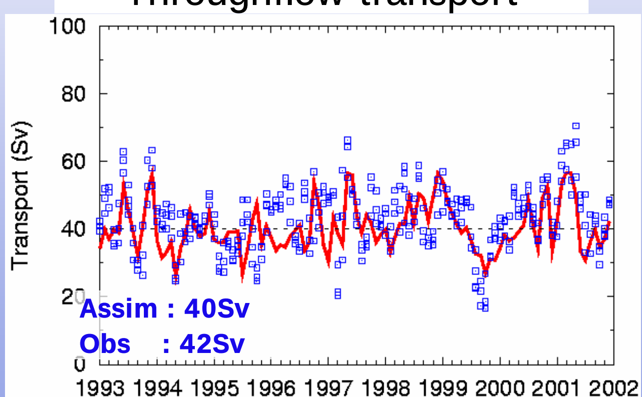
Kuroshio volume transport

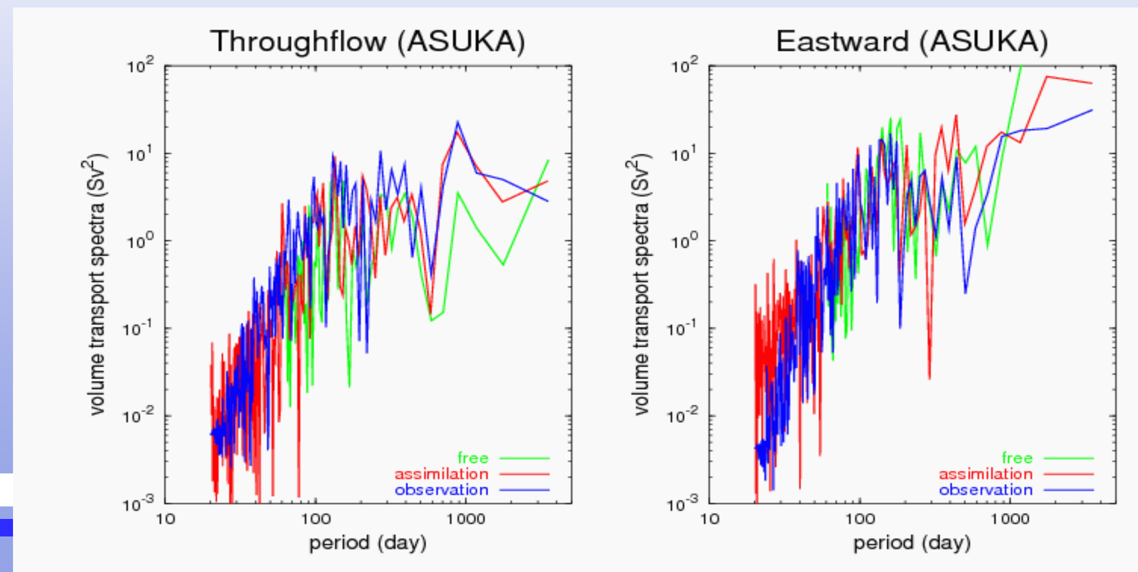
Eastward transport





Throughflow transport



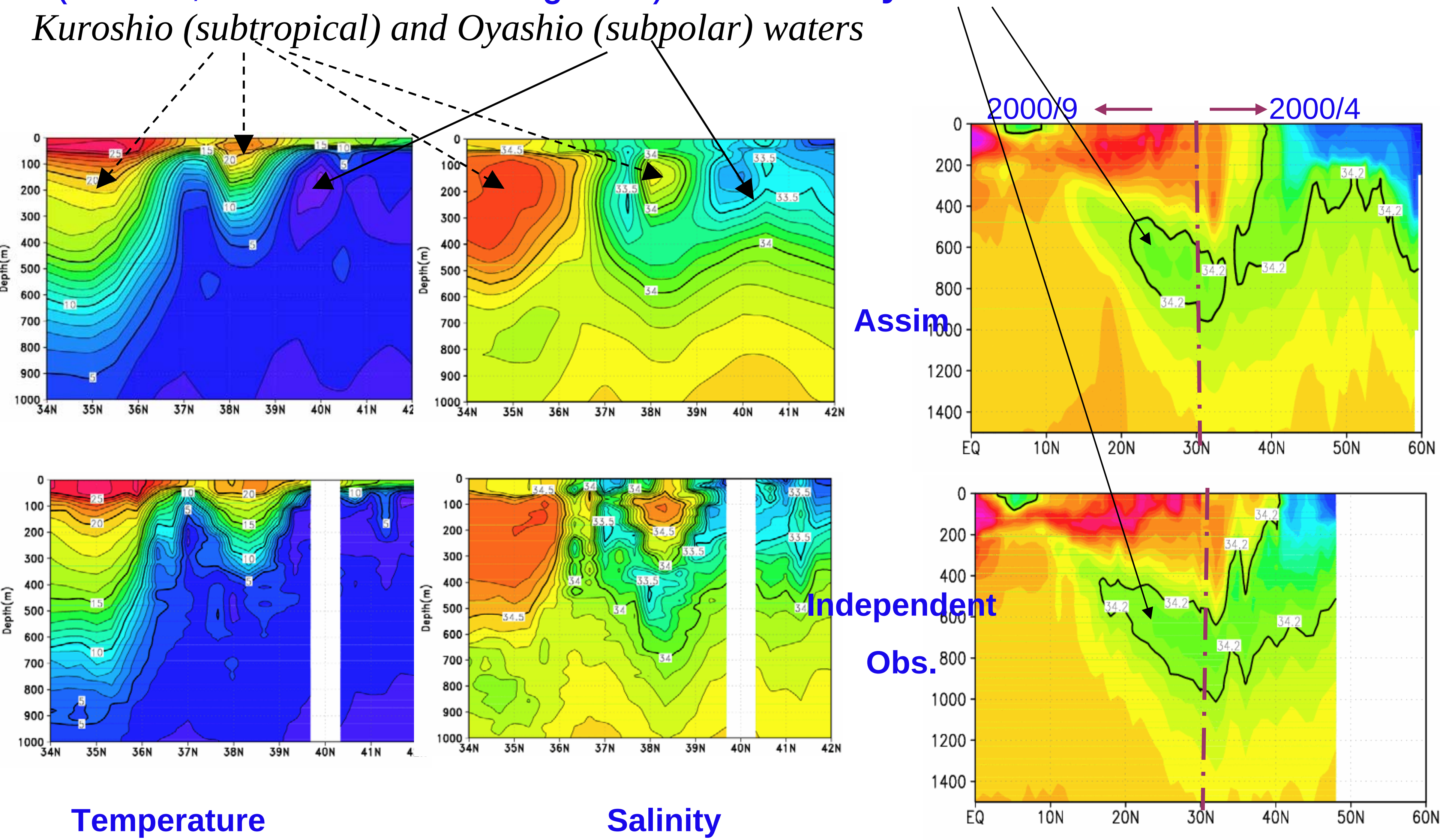


throughflow = eastward – westward

Examples of Water Mass in the North Pacific

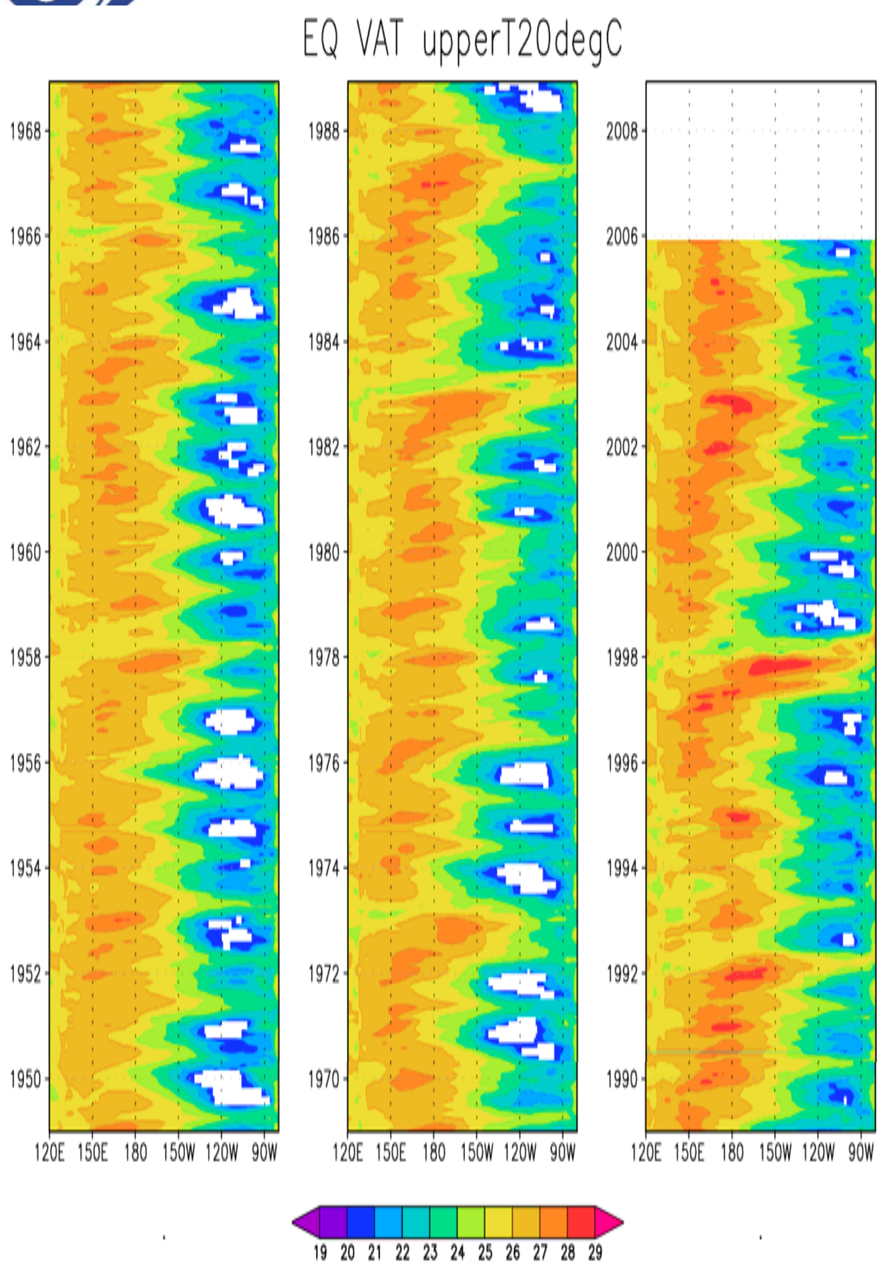
Mesoscale eddy and water mass
(2000/10, vertical section along 144E)

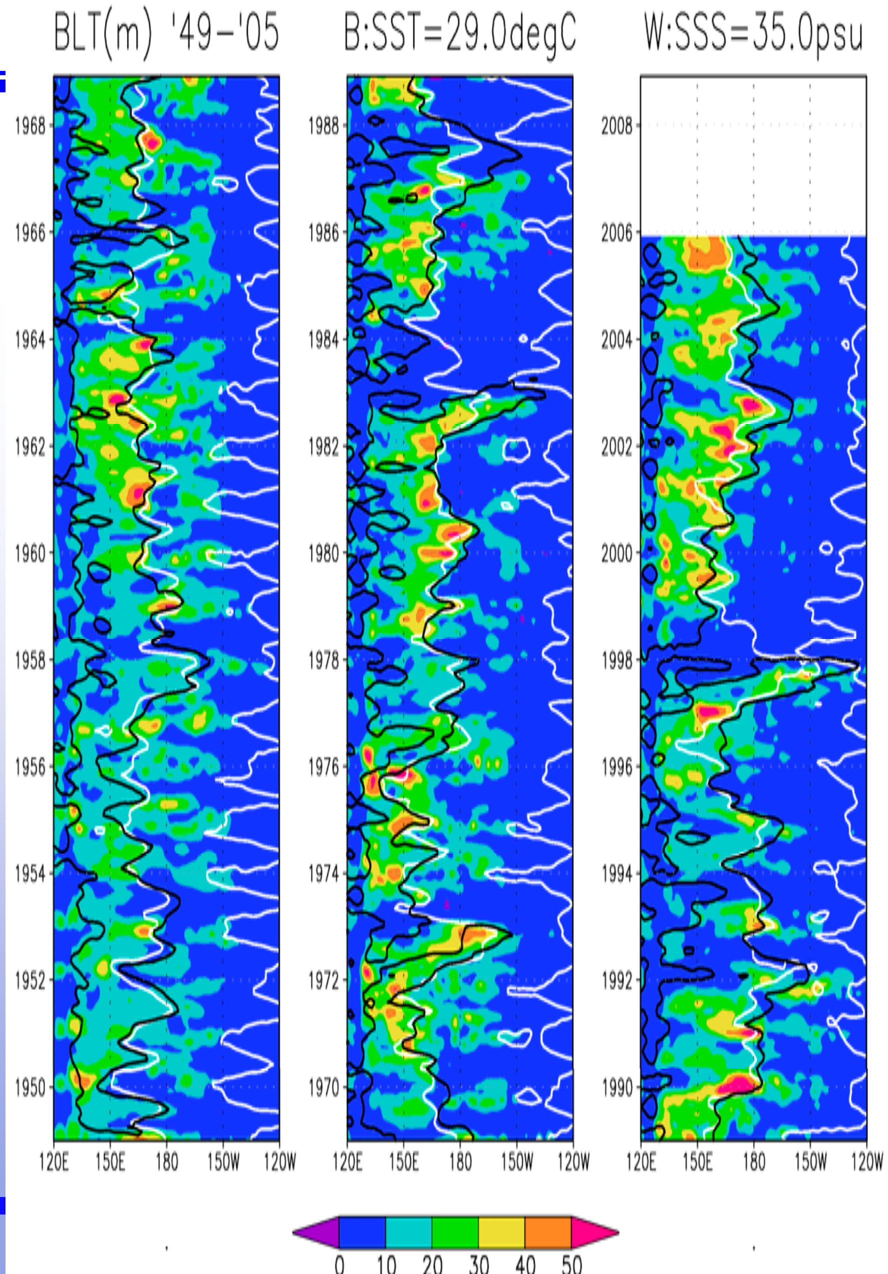
North Pacific Intermediate Water
Salinity-min.（165E，2000/4 and 9）



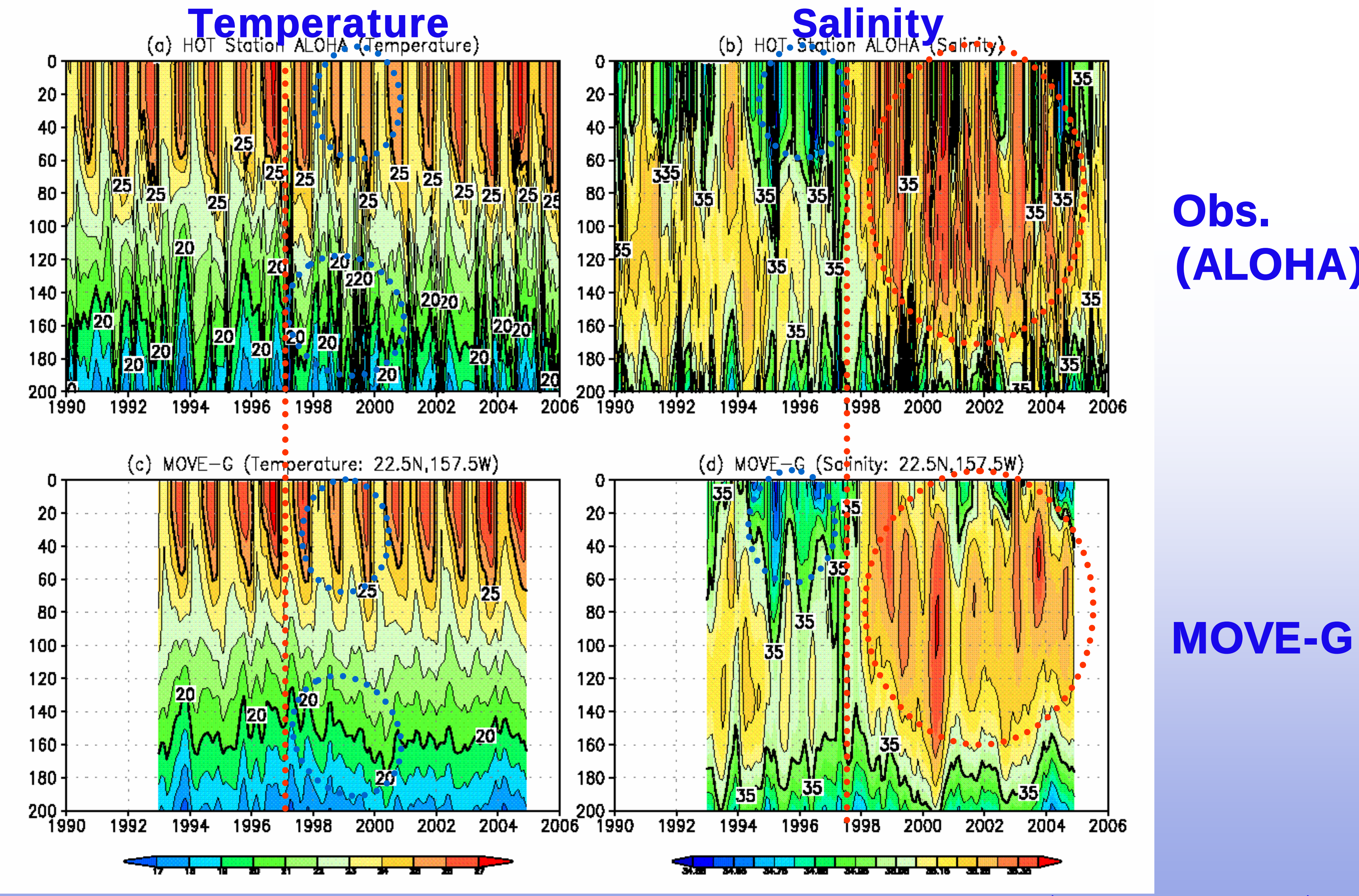
OHC (mean T) and BLT (1949-2005) Eq. Pac.

BLT (color), SST (29.0deg.,





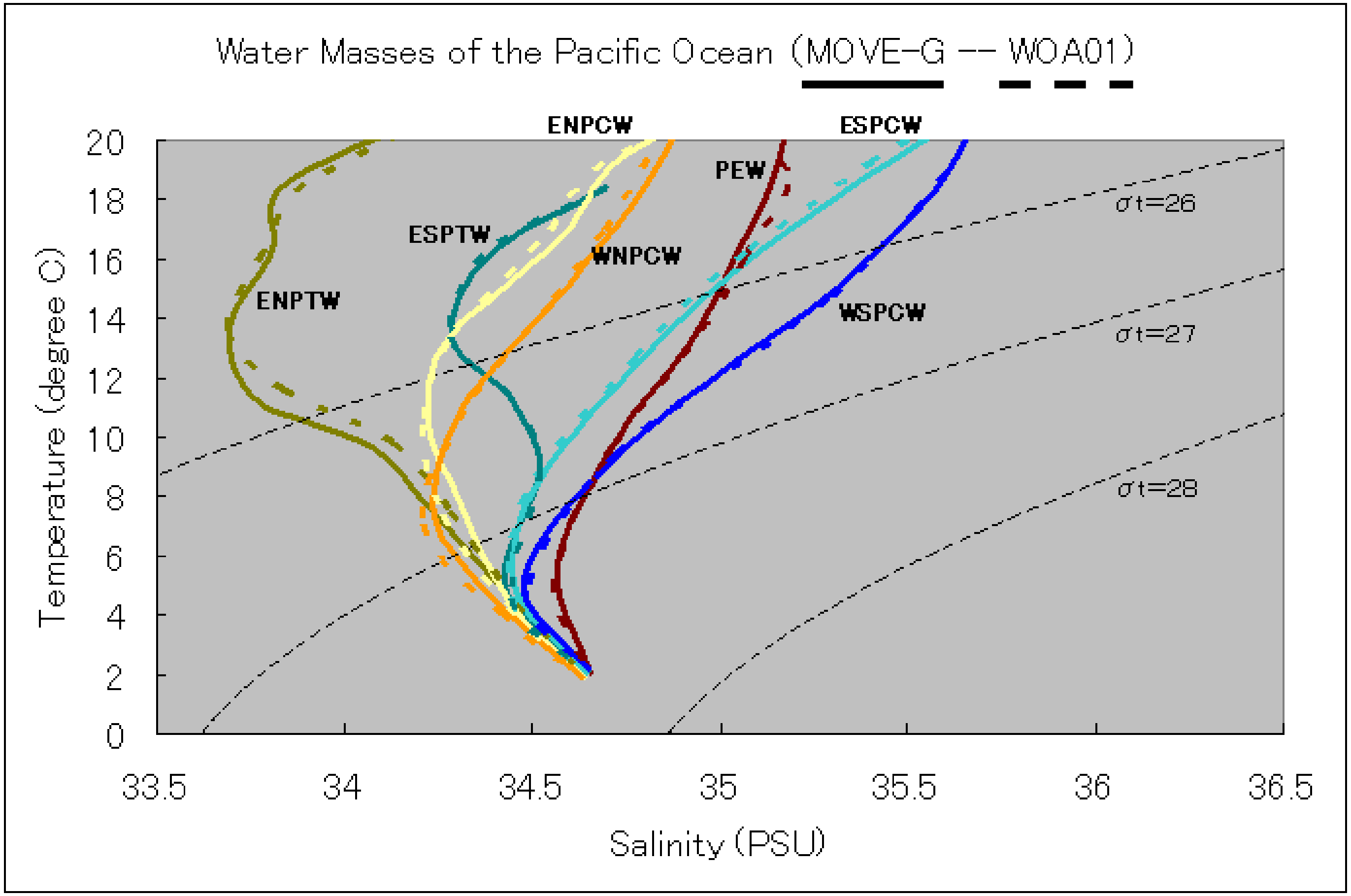
Interannual variability
(Time series comparison with HOT Station ALOHA)



1997/98 El Nino: dried near Hawaii → higher Salinity (Lukas, 2001)

Interannual variation of the subtropical gyre (Nakano et al, 2008)

Example of water mass analysis using reanalysis dataset

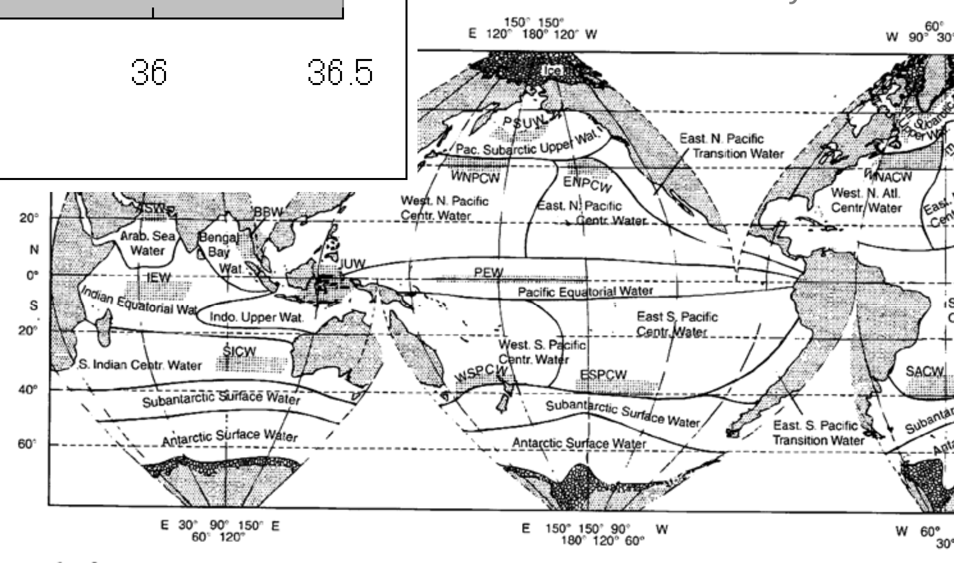


Water Type (Mean value in 1949-2005 vs. Climatology)

Take mean in time
->
Take mean in each region
and
on each density surface

WATER TYPES AND WAT

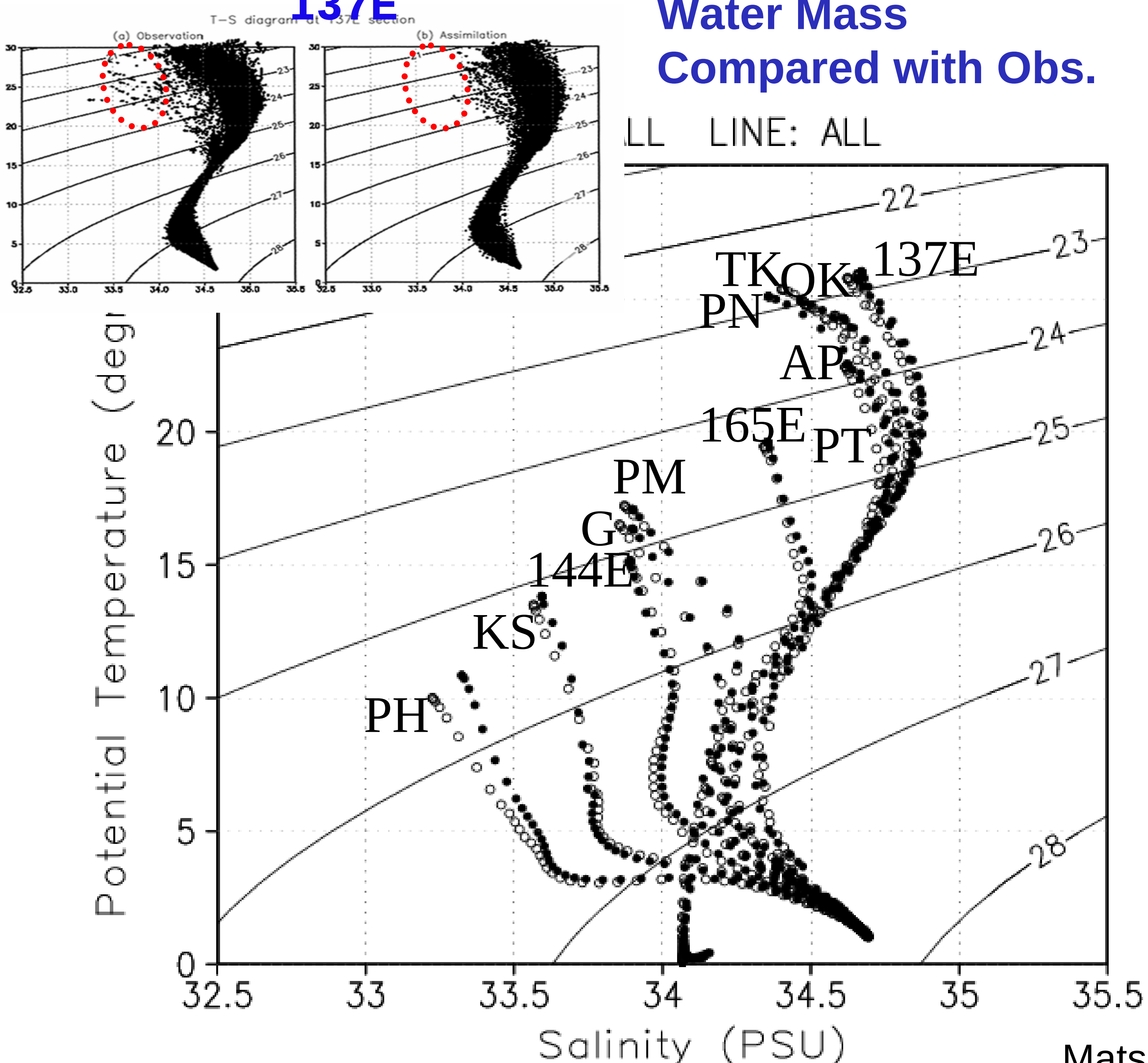
Emery 2001



ENPTW: Eastern North Pacific Tropical Water
ESPTW: South
ENPCW: Eastern North Pacific Central Water
WNPCW: Western
PEW: Pacific Equatorial Water
ESPCW: Eastern South Pacifc Central Water
WSPCW: Western

Matsumoto et al.. 2008

Water Mass Compared with Obs.



○: Observation

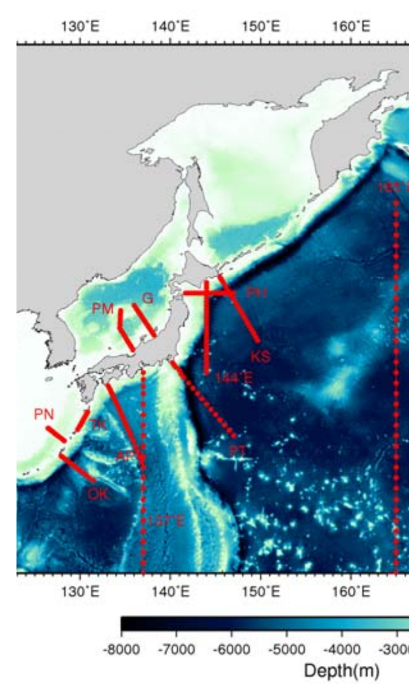
●: MOVE-WNP

Mean value in 1993 to 2005

Mean along each line (same obs. point, depth, period)

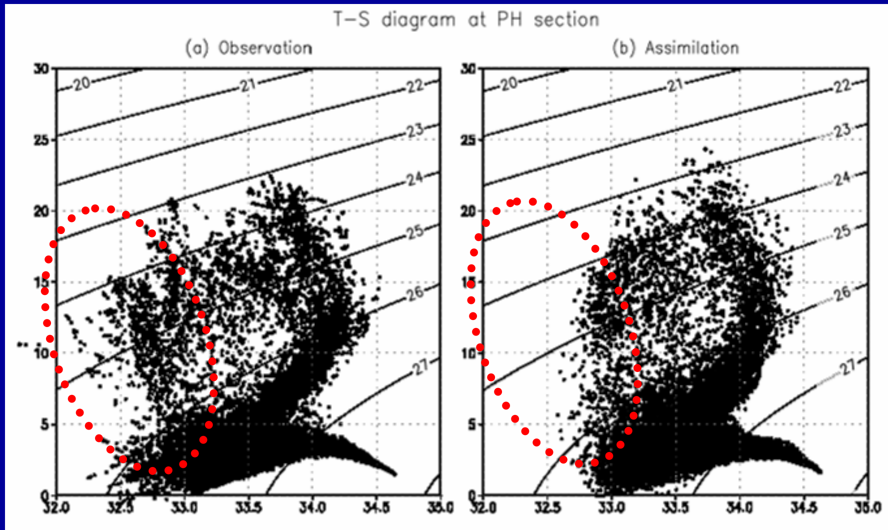
Bias in depth, density (T & S)

Model bias z>800m in Japan Sea (PM)

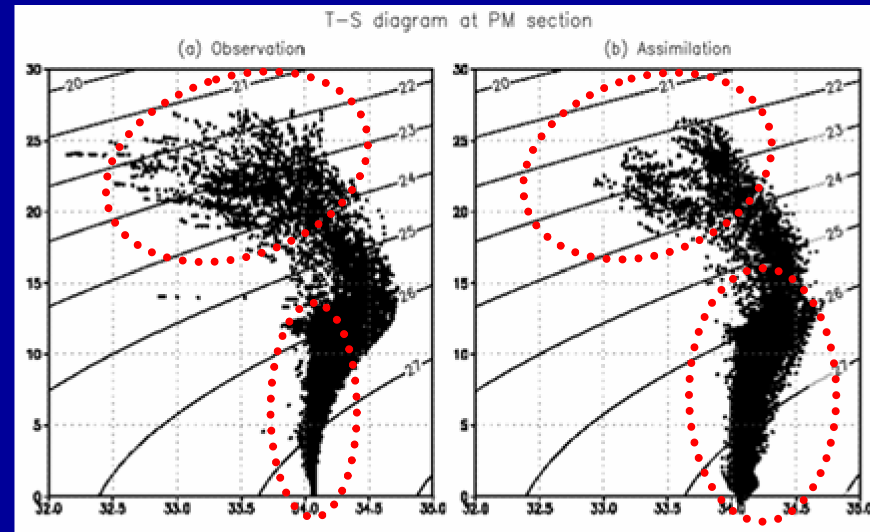


Matsumoto et al., 2008

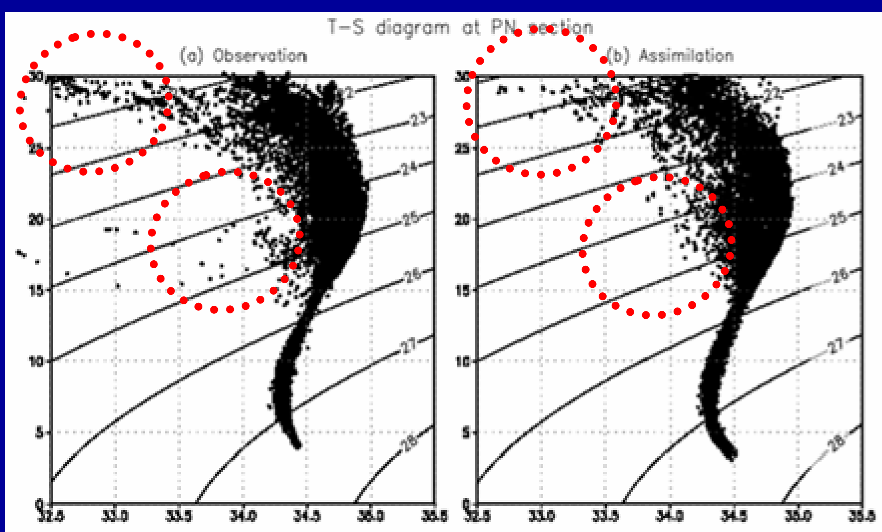
PH


T–S diagram at PH section
(a) Observation
(b) Assimilation

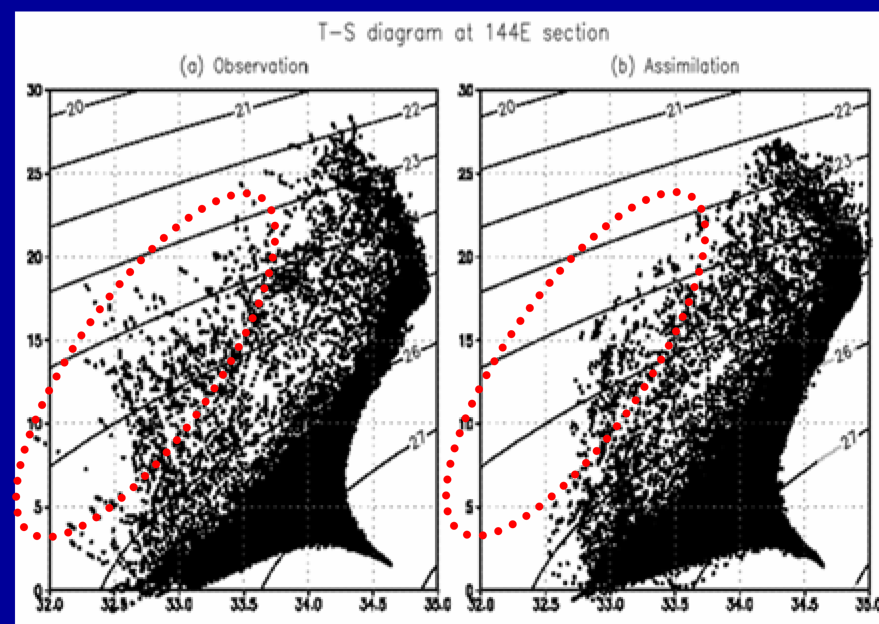
PM


T–S diagram at PM section
(a) Observation
(b) Assimilation

PN


T–S diagram at PN section
(a) Observation
(b) Assimilation

144E


T–S diagram at 144E section
(a) Observation
(b) Assimilation

COMPASS-K
(former Operational Ocean Assimilation/Prediction System in Japan Meteorological Agency)
Success of 60-day Prediction of the 2004 Kuroshio Large Meande

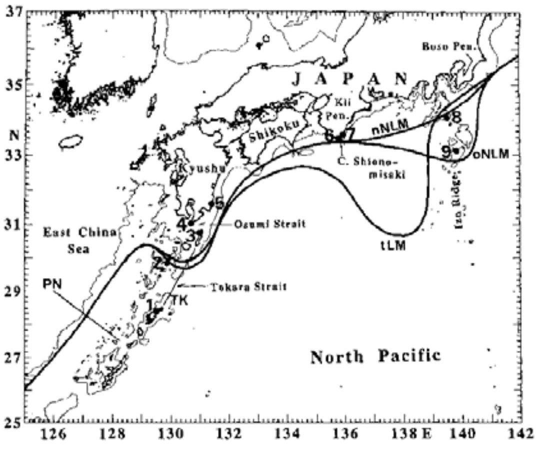
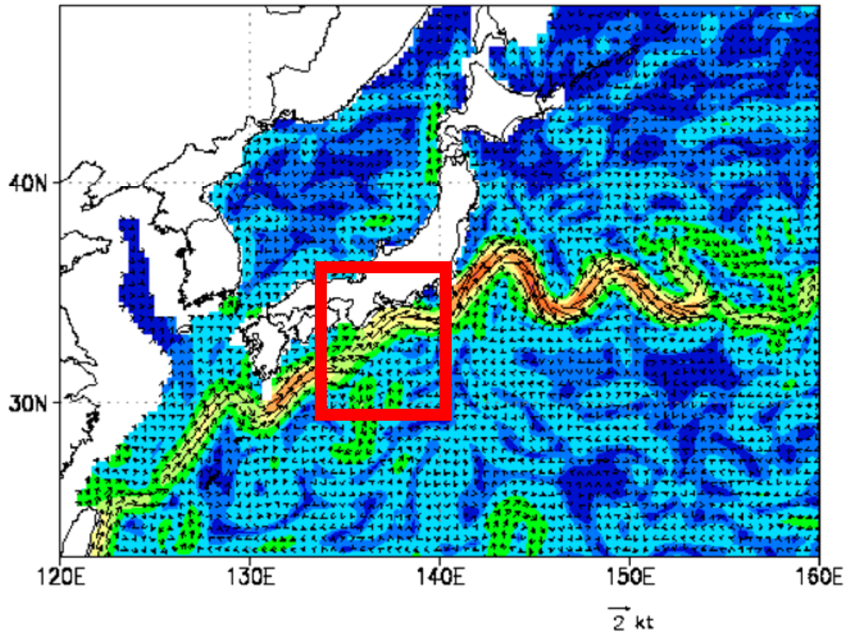
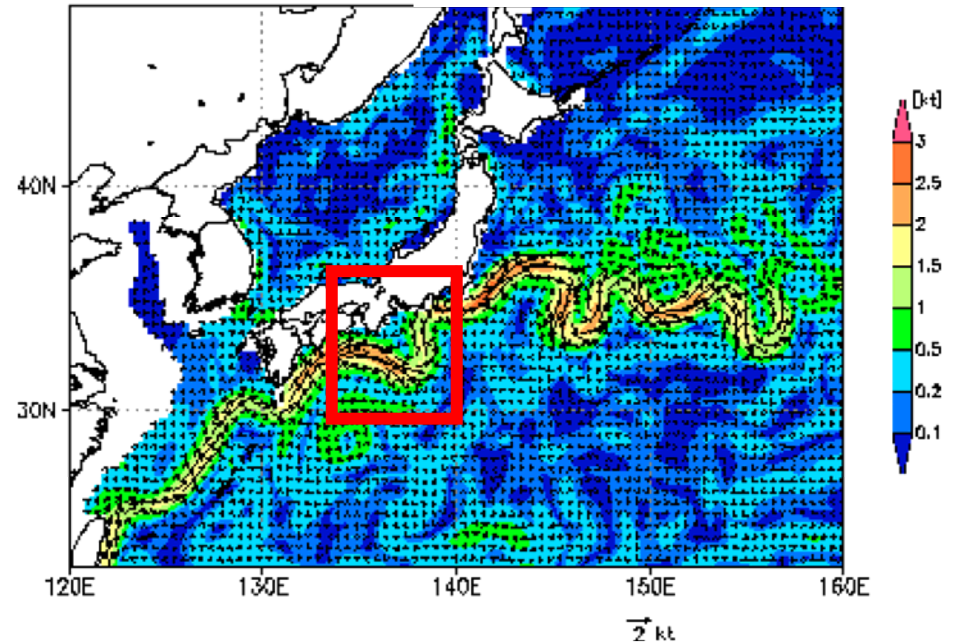


FIG. 1. Tide stations and the typical paths of the Kuroshio. Thin lines are 500-m isobaths. The lines of PN and TK are CTD lines of the JMA Nagasaki Marine Observatory's: 1) Naze, 2) Nakano-shima, 3) Nishinoomote, 4) Odomari, 5) Aburatsu, 6) Kushimoto, 7) Uragami, 8) Miyake-jima, 9) Hachijo-jima. nNLM is the nearshore non-large-meander (NLM) path; oNLM is the offshore NLM path; tLM is the typical large-meander (LM) path.



Assim/initial state (2004/05/09)



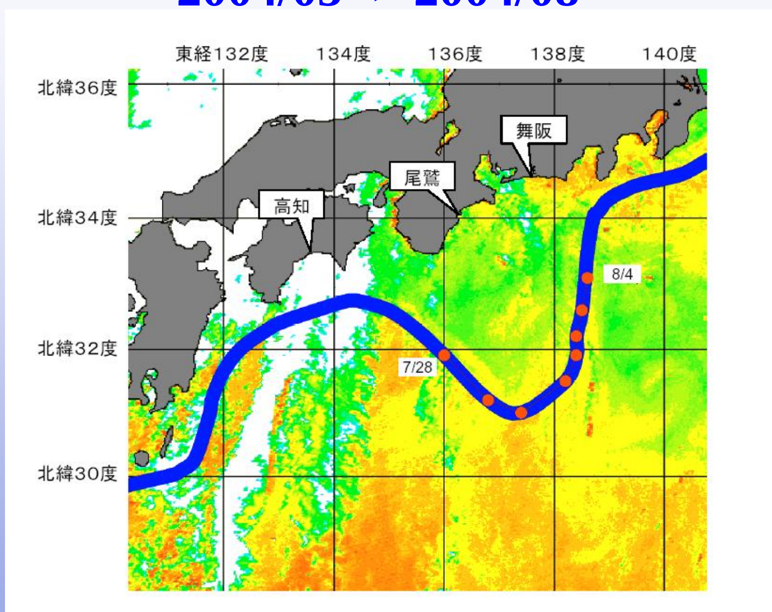
Forecast (2004/06/30)

JMA Japan-GODAE SERVER **http://godae.kishou.go.jp/**

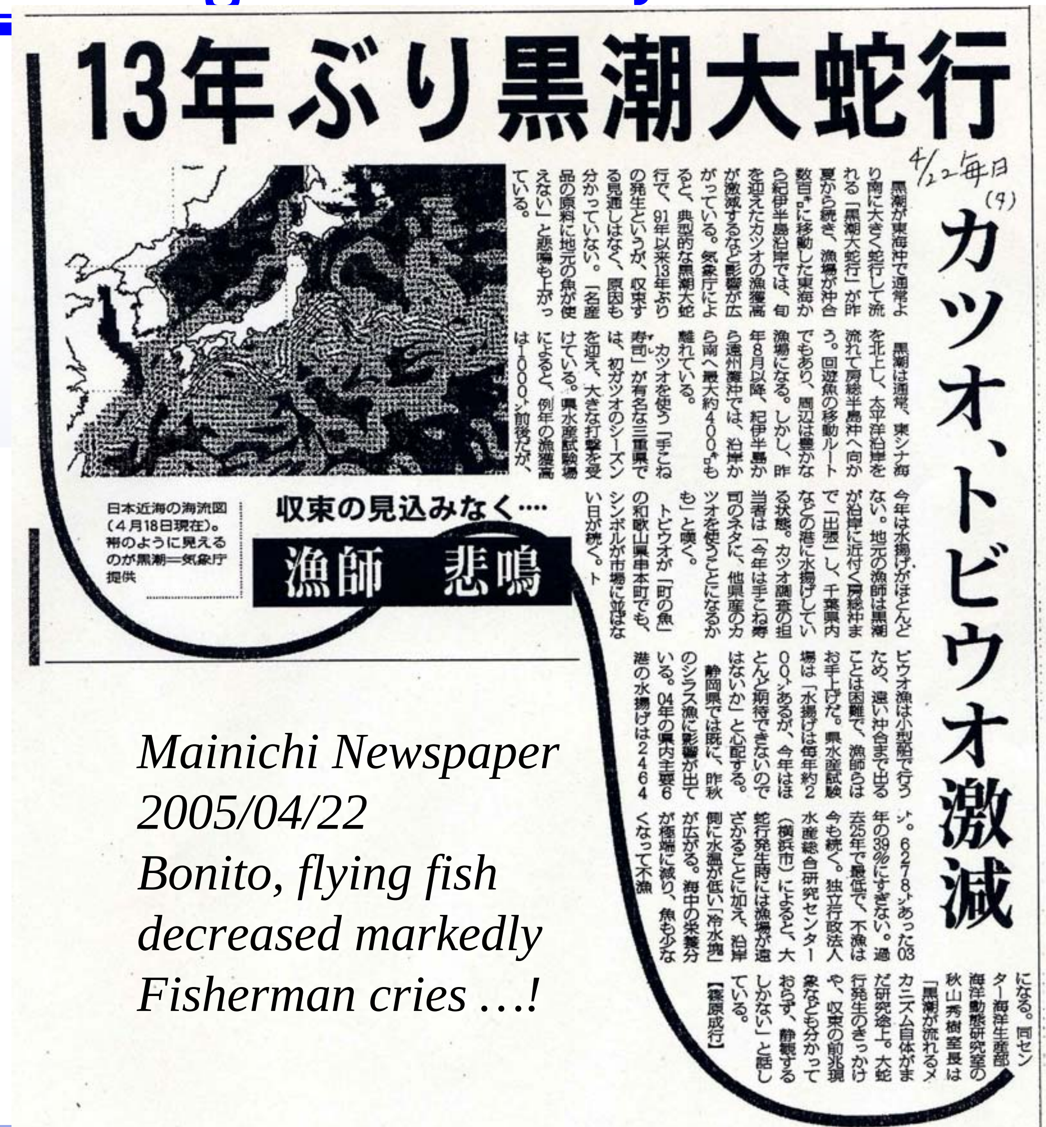
Press Release
(Kuroshio Large Meander)

JMA called societies attention to the Kuroshio large meander's influence to fisheries and shipping industries etc. in May 2004.

2004/05 -> 2004/08



8月4日現在の黒潮の推定流路



13年ぶり黒潮大蛇行

4/22 毎日 (9)

カツオ、トビウオ激減

黒潮が東海沖で通常より南に大きく蛇行して流れる「黒潮大蛇行」が昨夏から続き、漁場が沖合数百㌔に移動した東海から紀伊半島沿岸では、旬を迎えたカツオの漁獲高が激減するなど影響が広がっている。気象庁によると、典型的な黒潮大蛇行で、91年以来13年ぶりの発生というが、収束する見通しはなく、原因も分かっていない。「名産品の原料に地元の魚が使えない」と悲鳴も上がっている。

日本近海の海流図（4月18日現在）。帯のように見えるのが黒潮＝気象庁提供

収束の見込みなく…
漁師　悲鳴

黒潮は通常、東シナ海を北上し、太平洋沿岸を流れて房総半島沖へ向かう。回遊魚の移動ルートでもあり、周辺は豊かな漁場になる。しかし、昨年8月以降、紀伊半島から遠州灘沖では、沿岸から南へ最大約400㌔も離れている。

カツオを使う「手こね寿司」が有名な三重県では、初ガツオのシーズンを迎え、大きな打撃を受けている。県水産試験場によると、例年の漁獲高は1000㌧前後だが、今年は水揚げがほとんどない。地元の漁師は黒潮が沿岸に近付く房総沖まで「出張」し、千葉県内などの港に水揚げしている状態。カツオ調査の担当者は「今年は手こね寿司のネタに、他県産のカツオを使うことになるかも」と嘆く。

トビウオが「町の魚」の和歌山県串本町でも、シンボルが市場に並ばない日が続く。トビウオ漁は小型船で行うため、遠い沖合まで出ることは困難で、漁師らはお手上げだ。県水産試験場は「水揚げは毎年約200㌧あるが、今年はほとんど期待できないのではないか」と心配する。

静岡県では既に、昨秋のシラス漁に影響が出ている。04年の県内主要6港の水揚げは2464㌧。6278㌧あった03年の39%にすぎない。過去25年で最低で、不漁は今も続く。独立行政法人水産総合研究センター（横浜市）によると、大蛇行発生時には漁場が遠ざかることに加え、沿岸側に水温が低い「冷水塊」が広がる。海中の栄養分が極端に減り、魚も少なくなって不漁になる。同センター海洋生産部海洋動態研究室の秋山秀樹室長は「黒潮が流れるメカニズム自体がまだ研究途上。大蛇行発生のきっかけや、収束の前兆現象なども分かっておらず、静観するしかない」と話している。【篠原成行】

Mainichi Newspaper
2005/04/22
Bonito, flying fish decreased markedly
Fisherman cries …!

Prediction

MOVE-WNP (0.1 deg.)

- The small meander propagates east-ward and develops in July.
- The Kuroshio has a large meandering path (tLM-type in Fig. 1) in the middle of August.

- Many features in the real state (development of small meander, the period of rapid growth of meander, amplitude of the large meander, etc) are successfully predicted.
- It is because the seed of the meander is properly assimilated in the initial condition.

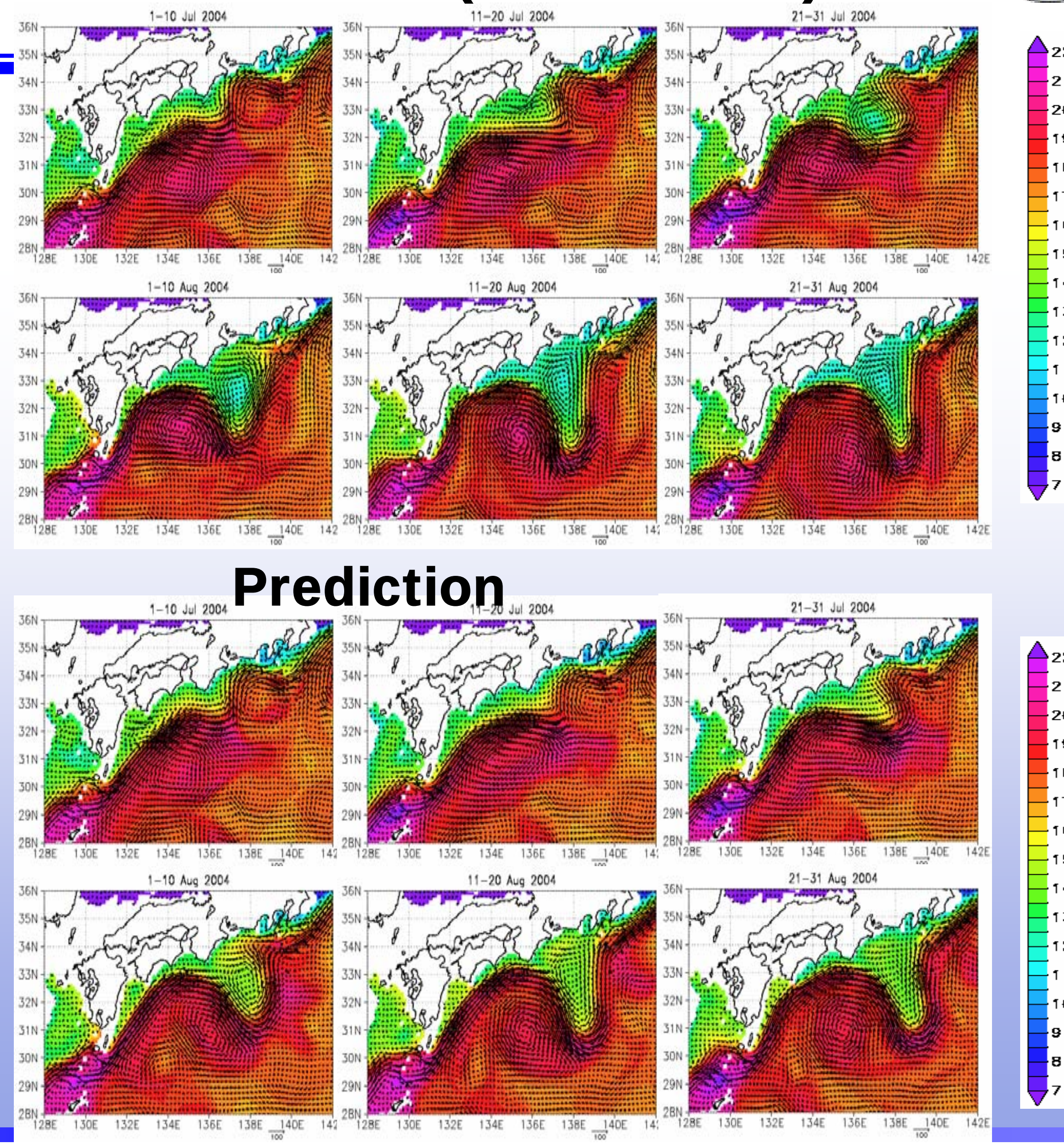
Real state (assimilation)

July

August

July

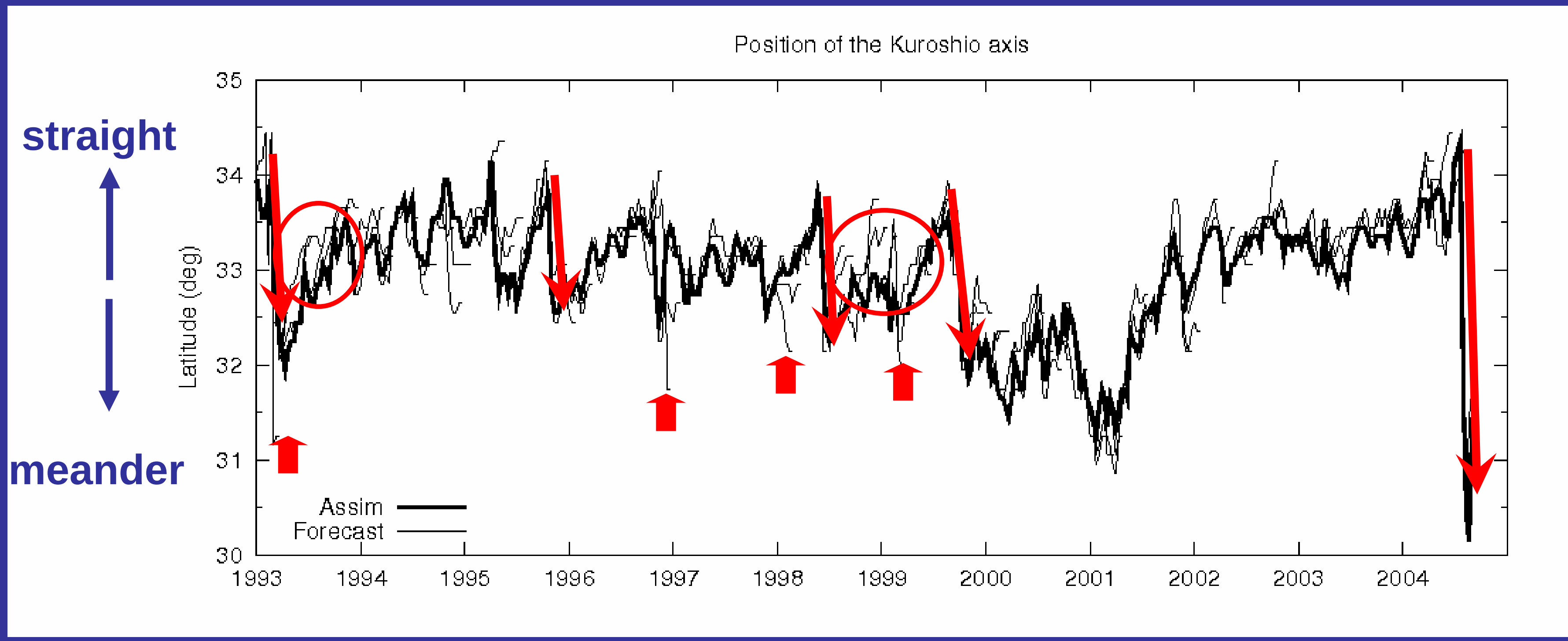
August



Horizontal velocity (vector) and temperature (color) at 200m depth.

Prediction of the Kuroshio axis

north-south variation of the axis at 138ºE



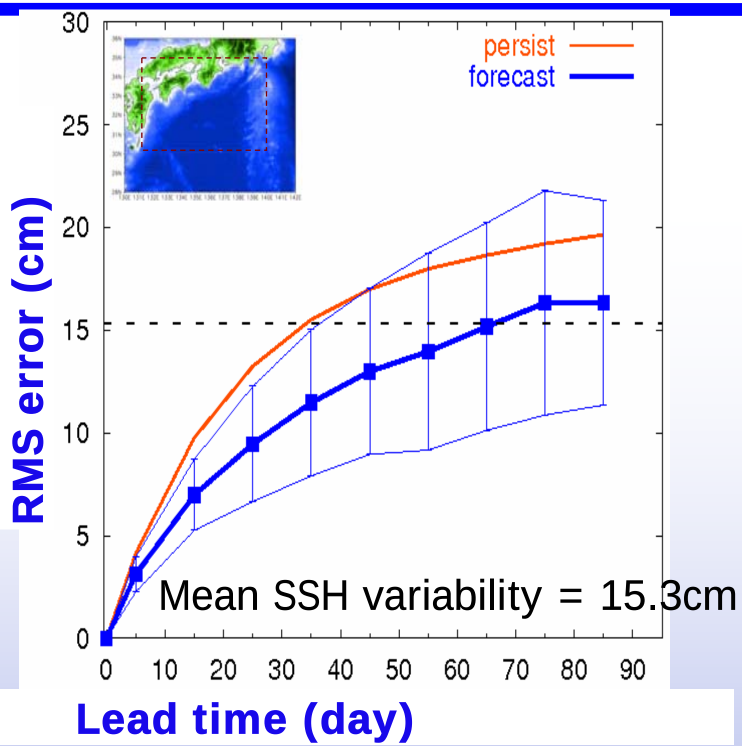
Predictability

- **Straight to meander : OK A+**
- **Meander to straight : prediction is a bit earlier**
- **Sometime stronger meander**

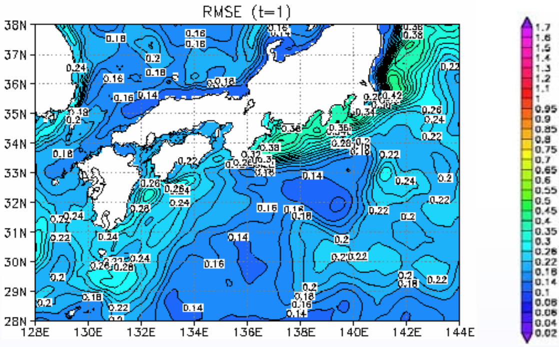
Predictability (single prediction)

Time evolution of SSHA prediction error

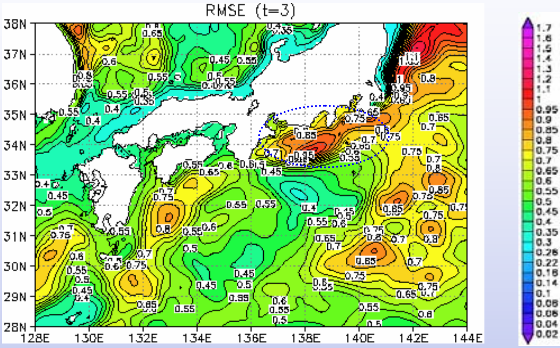
JMA's new Operational Forecasting System (everyday, Real time, 2 months Forecast)



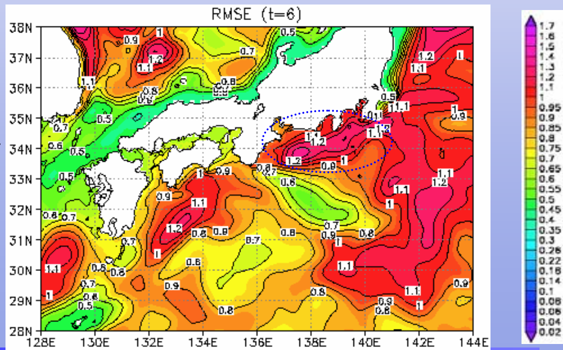
10 day



30 day



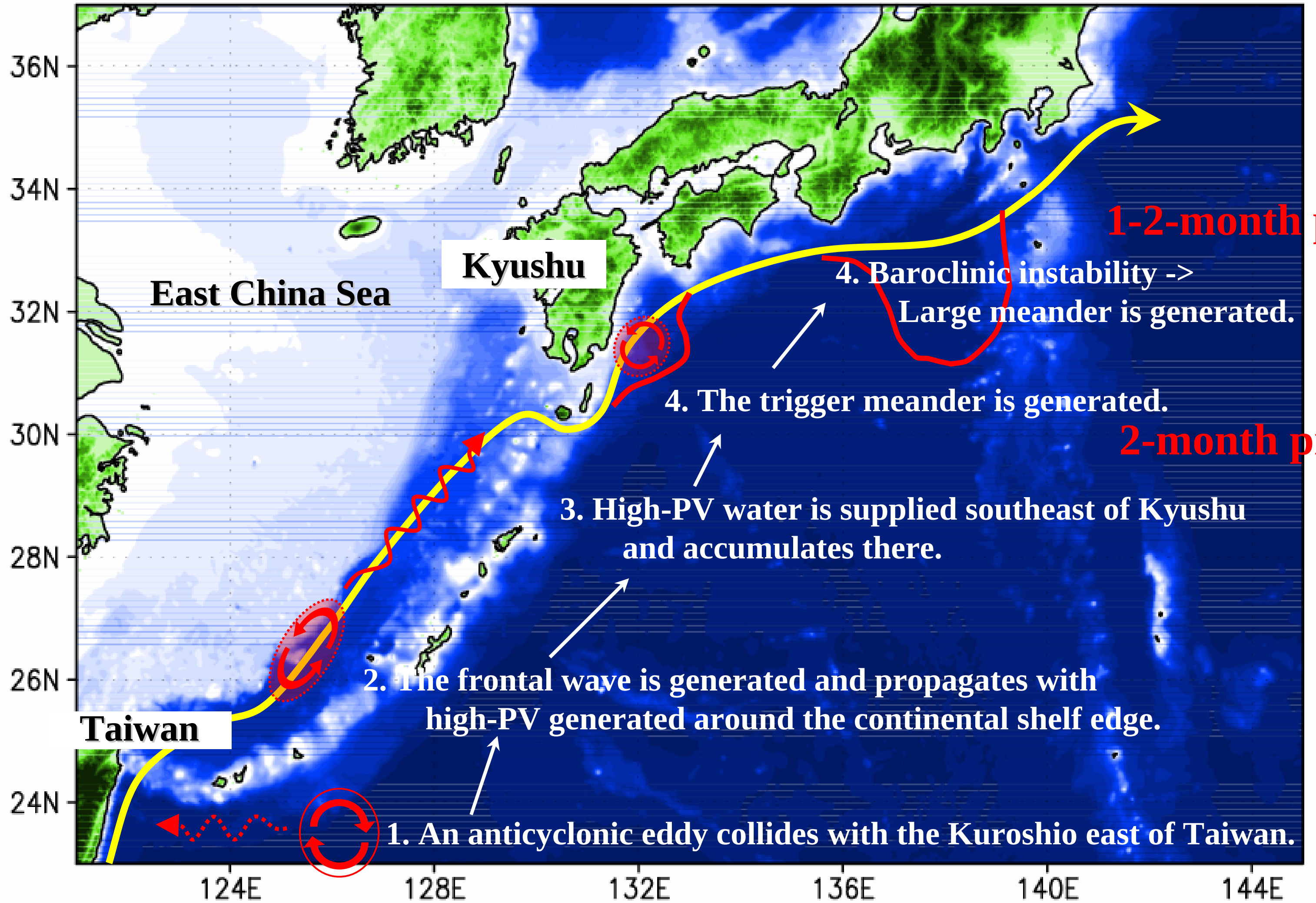
60 day



- **Predictive limit of our system is roughly 40-60 days. This fine resolution model is better than ¼ deg. model**
- Predictive limit is much longer than the persistence.
- The spatial distribution of SSH RMSE shows the largest error south of Tokai (pointed area in Fig. 11).
- The largest error reflects the faster eastward progression speed of the meander as discussed in previous.
- Ensemble prediction is better.

Analyses of mesoscale eddy near Taiwan, roles of frontal wave in the East China Sea, small trigger meander, baroclinic instability on the Kuroshio path variation

USUI et al., (2008a,b,c)



These proposed processes suggest an importance of large-scale GODAE products for reproducing oceanic conditions in the ECS and southern coast of Japan.

Data Server

- NEARGOOS Regional Real Time Data Base

  http://goos.kishou.go.jp/

- JMA Japan-GODAE LAS server

  http://godae.kishou.go.jp/

Summary & Future/On-going Research

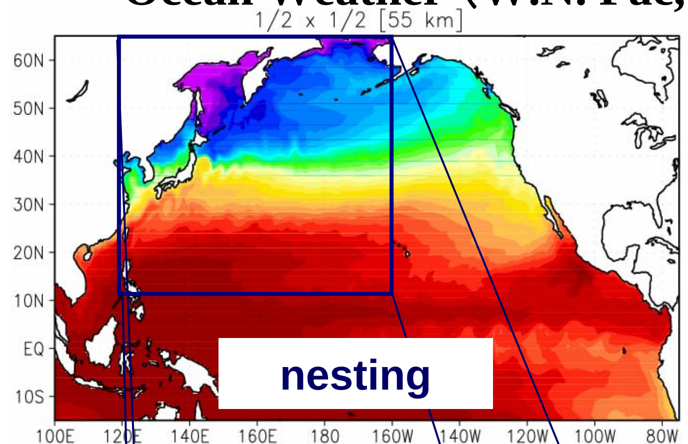
1. An Example of operational/research systems of JMA and MRI
   - ocean state estimation
   - Kuroshio prediction

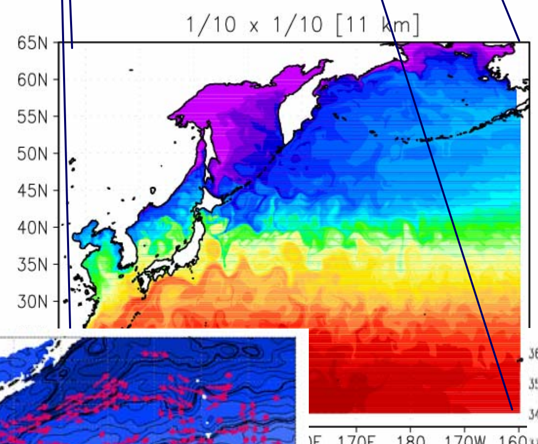
2. Future/on-going directions
   - OSE type leads estimation/reconstruction of observation
   - Ocean-Atmosphere Coupled Data Assimilation
   - Coastal-shelf sea application
   - Interaction of wind wave and current
   - Earth system model (coupled physical biogeochemical and ecosystem, with atmospheric model/assimilation)
   - Reanalysis & Prediction with 4DVAR adjoint system

On-going developments

Present systems

Global Warming, SI-predictions (Global, 1°)
Ocean Climate: (N. Pac, 1/2°)
Ocean Weather (W.N. Pac, 0.1°)





Coupling to Atom.

Global Copled A-O Assim MOVE-C

Global:1 /12°(10km) MOVE-G2

Local weather-climate model (strong currents, Frontal structure)

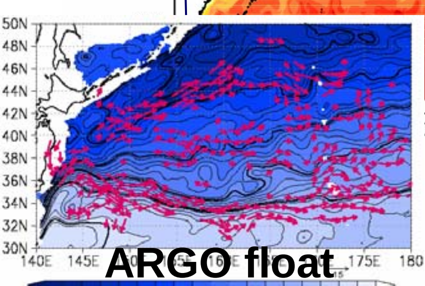
Finer resolution (x6)

Regional:1 /60°(2km)

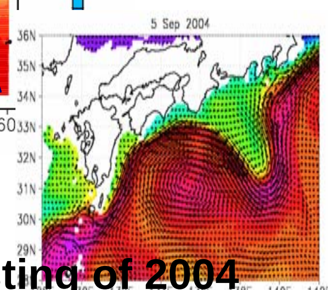
Coastal ocean (Storm surge forecasting for disaster prevention)

Coastal:1 /120°(1km)

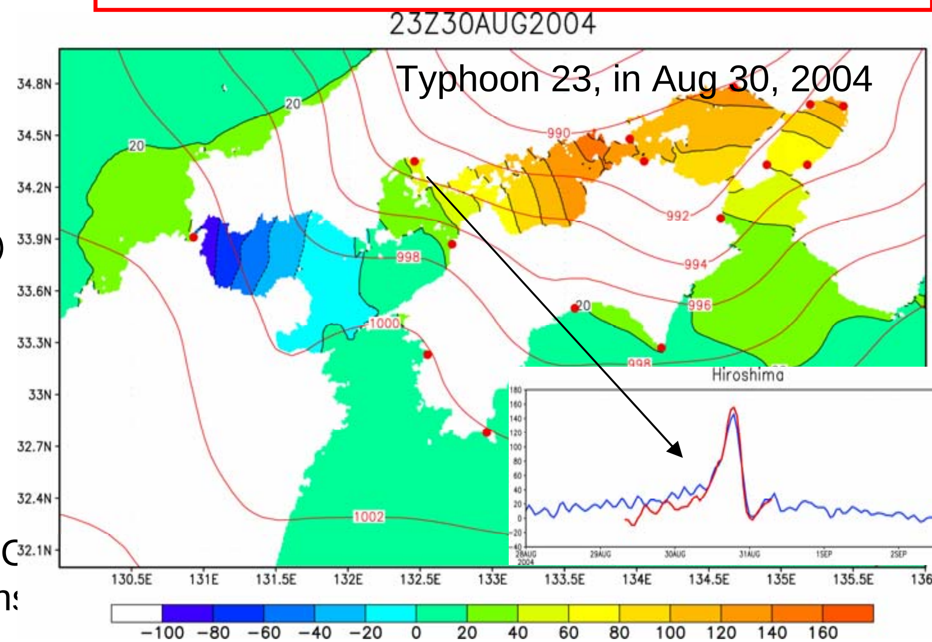
Regional (1/10 [11km]) (Forecasting around Japan)



ARGO float assimilation



Forecasting of 2004 Kuroshio Large Meander



Appendix: 2004 Kuroshio Large Meander

Analyses of eddy activities, small meander, baroclinic instability to large meander

1. From Taiwan to East China Sea: Frontal wave

2. Developing and stationary conditions of small meander south-east of Kyushu

3. Developing to Large Meander with baroclinic instability as a necessary condition and a diagram of sufficient conditions