An example of operational ocean data assimilation and prediction

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JMA & MRI Ocean Data Assimilation Group

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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
   - Reanalysis, water mass representation
   - Prediction (Kuroshio, ElNino)

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

Data Assimilation

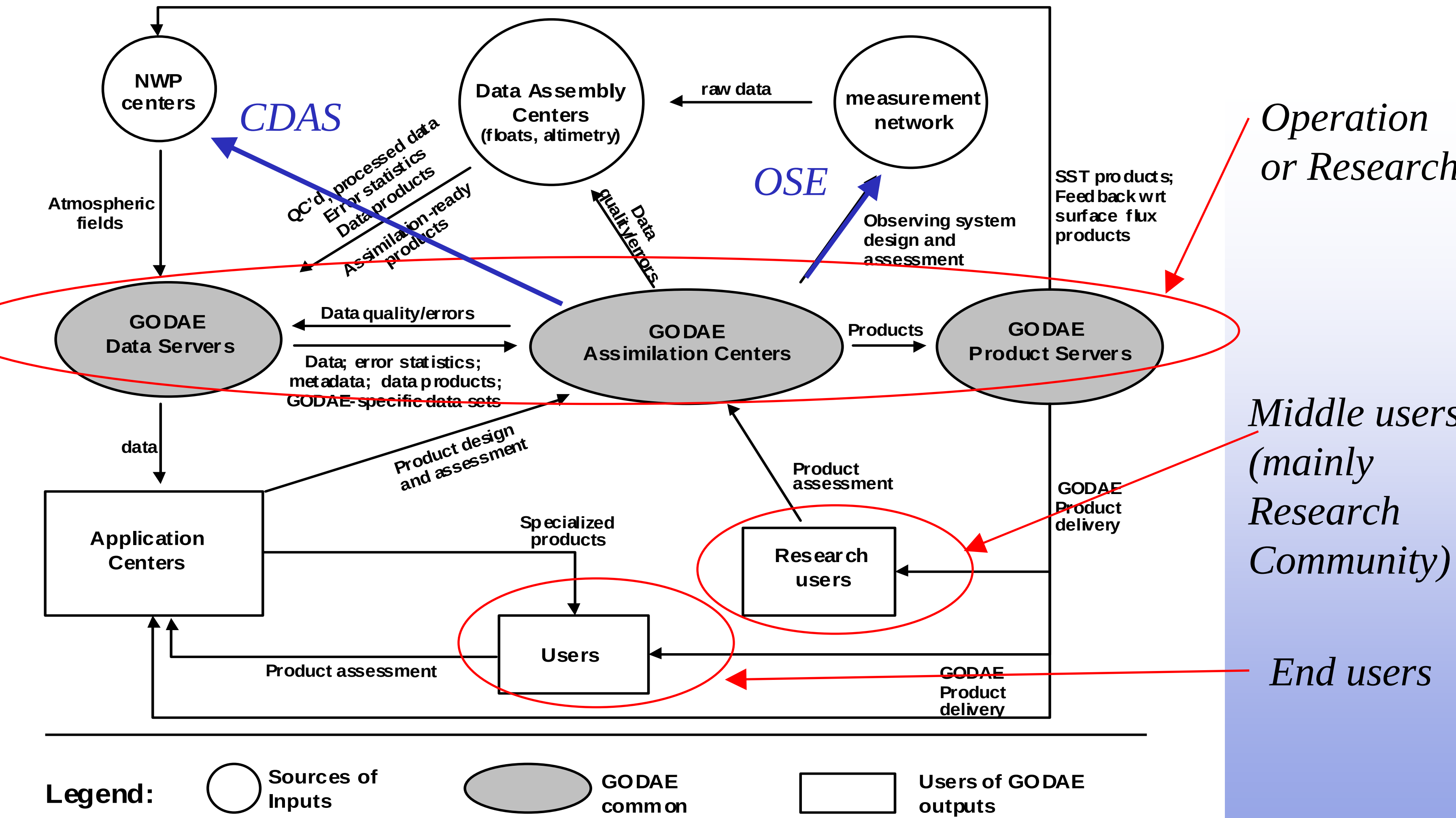
Data assimilation is
a procedure that subtracts information from models and observations, and combines them as an optimum estimate.

The aims are

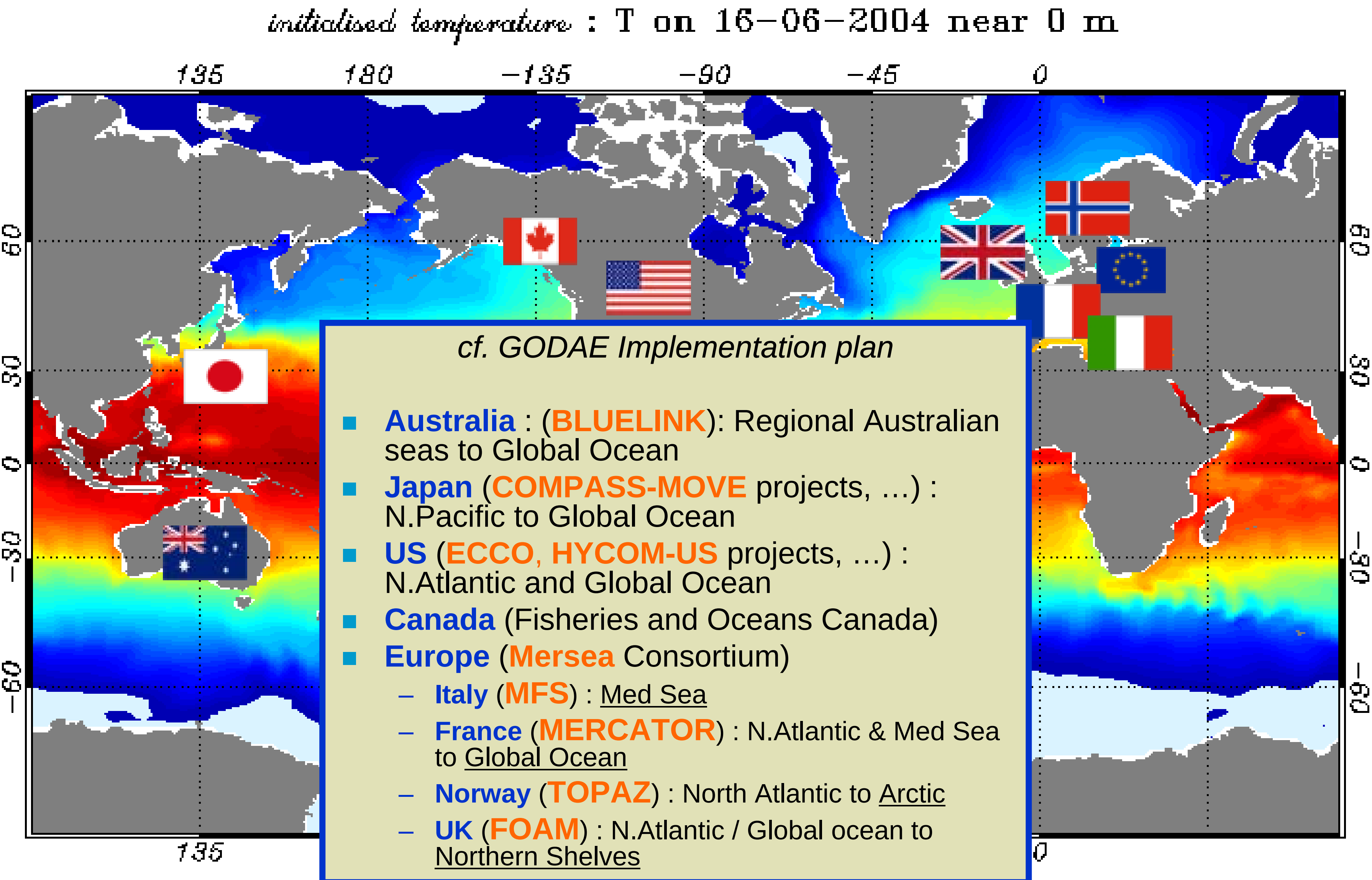
1. **to obtain optimum initial condition for prediction**
2. **to obtain optimum boundary condition**
3. **to obtain optimum parameter (parameter estimation)**
4. **to understand phenomena with 4D data set (reanalysis)**
5. **to estimate observing system and develop optimum system (through OSE/OSSE/sensitivity/SV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

Total System is Important
(GODAE)

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



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)
  - **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 (FRA-RIAMOM)	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、
Aim	Climate +Ocean Weather Pac-reanalysis Model improv. 90's EN Coastal prediction	Climate Pac-reanalysis (1993-2004) Model improv. 90's EN I.C.-CGCM	Ocean Weather Japan Sea Predictability Oil spill Kyuchou (coastal jet)	Ocean Weather Kuroshio Variability & predictability Kyuchou (coastal jet) Jelly fish	Ocean Weather Kuroshio, Oyashio, Western N. Pac Variability & Predictability Reanalysis (1993-2004, 1961-2004)	Climate El Nino variability Init Cond (I.C.) for CGCM Reanalysis (1993-2004, 1980-2004)	Ocean Weather Kuroshio predictability Reanalysis, Hindcast Now-Forecasting (Oper.) Japan GODAE server http:// godae.kishou.go.jp	Climate Operational Forecast. Nino3-SST (El Nino) Init Cond-CGCM SST for Season. Forecast
Model	MRI-Kyoto OGCM Global (1x1xz34) Coastal (1/12x1/12xz21) Arakawa-NL Momentum-Topogr. scheme MY-Noh-ML	OFES CFES Global (1x1xz34)	RIAMOM Japan Sea (1/12x1/12xz19)	POM (1996) North Pacific (1/4x1/4xσ21) Nested NW-Pac (1/12x1/12xσ45) Coastal version	MRI.COM (MRI Com Ocn Mdl) N. Pac Double nesting to global (1/2x/1/2xz54) (1/10x1/10x54) z-sigma hybrid Arakawa-NLmomentum Momentum-Topogr. Scheme, Noh-ML	MRI.COM Global (1x1x54) z-sigma hybrid Arakawa-NL Momentum-Topogr. scheme MY-ML	MRI-EGCM N. Pac (1/4x1/4xz21, variable) Arakawa-NL Arakawa-NL Momentum-Topogr. scheme	JMA-OGCM Global (2.0x2.5xz20, y0.5 EQ) NL-Horizontal Diffusion

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

MOVE/MRI.COM system

MRI MOVE/MRI.COM (Multivariate Ocean Variational Estimation) system uses three dimensional Variational (3D-VAR) method with vertical coupled T-S Empirical Orthogonal Function (EOF) modal decomposition with area partition and horizontal Gaussian function.

Obs. Data: Sat-Alt, SST, in situ T & S (e.g., ship, ARGO, Tao/Triton)

Aims

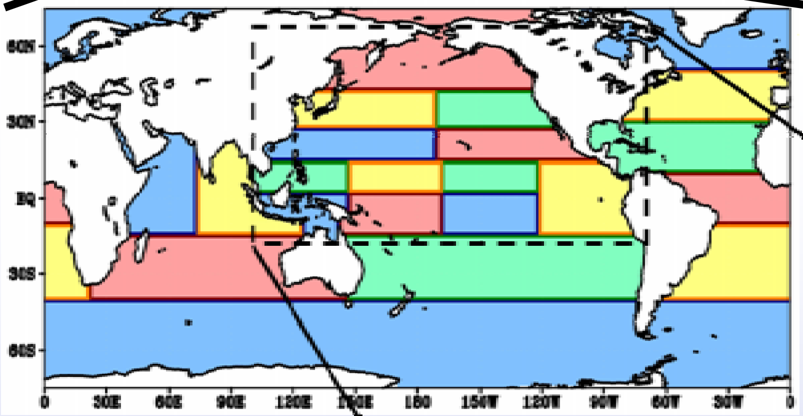
1. **Opt. Init. Cond. for Forecasting (Seasonal - Interannual (ElNino), Ocean state around Japan)**
2. **Reanalysis (ver.3):**

   Western North Pacific : 1985-2006
   North Pacific : 1948-2006
   Global : 1948-2006

   Reanalysis dataset will be opened through JMA Japan_GODAE server and IPRC/APDRC data centers.
3. **OSE, OSSE, SV analyses with 4DVAR-adjoint system**
4. **Coupled assimilation -> Seasonal Forecasting**
5. **Coastal application**

Five Assimilation Systems

MOVE-C With atmospheric model



MOVE-G

Lat. 0.3(Eq)~1 degree

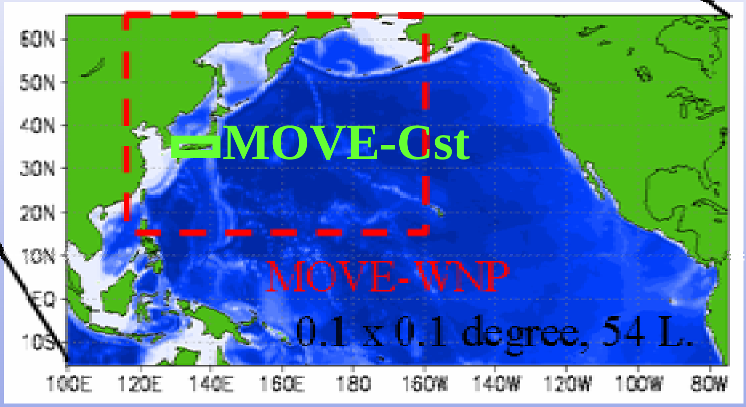
Lon. 1 degree

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 layers

Usui et al. (2005)

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**

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

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

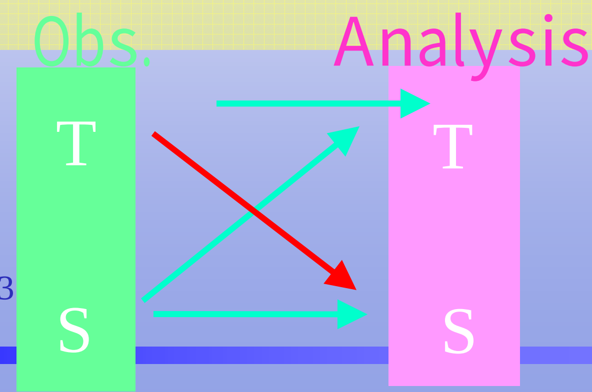
Constraint for quality control

Constraint for SSH observation

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

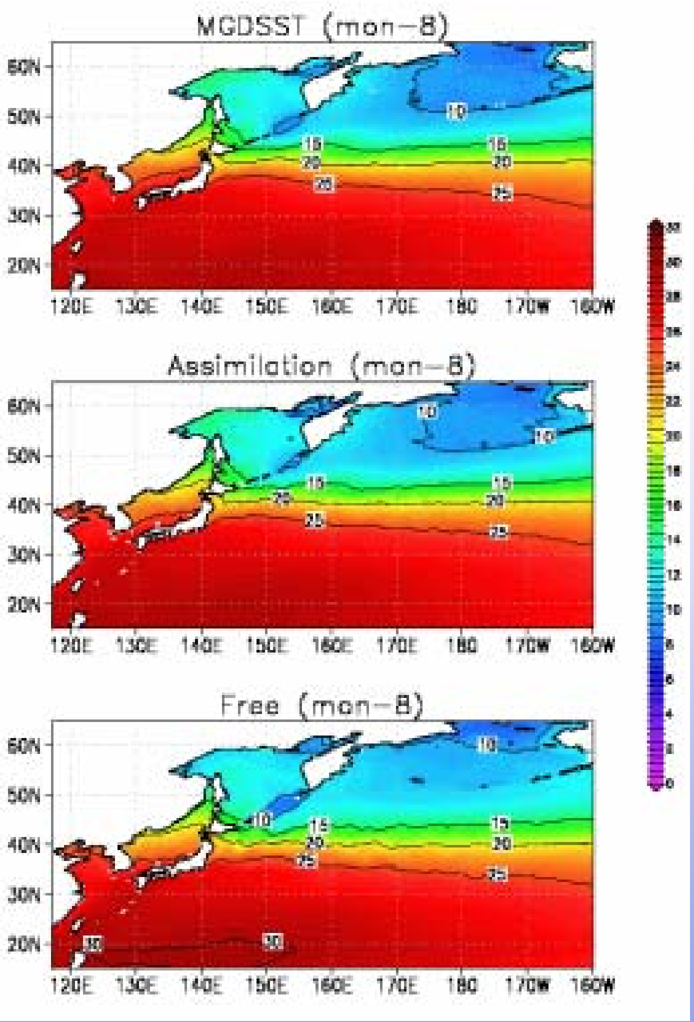
→Analysis increment of T and S will be correlated.

Fujii and Kamachi, JGR, 2003



SST (Climatology)

August

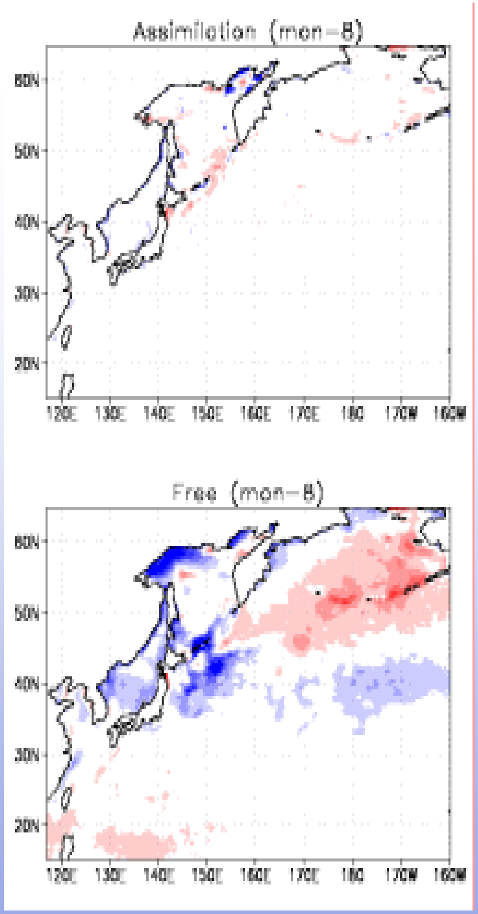


Obs. (MGDSST)

Assim.

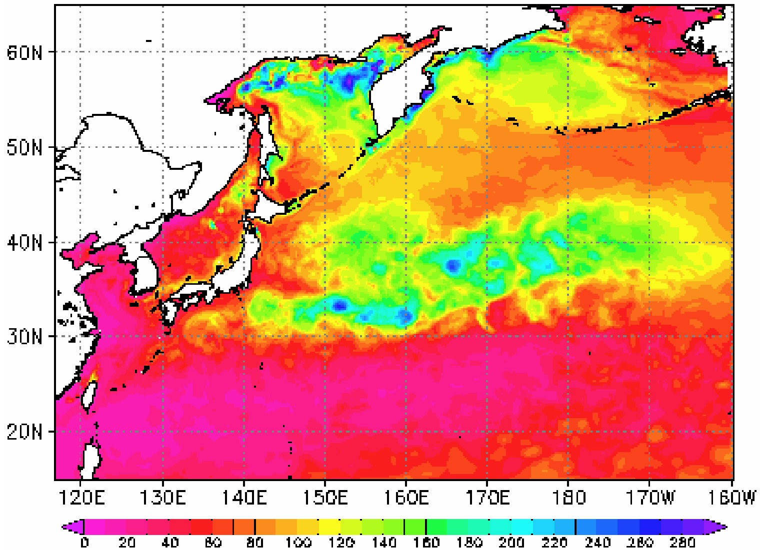
Model Simulation

difference

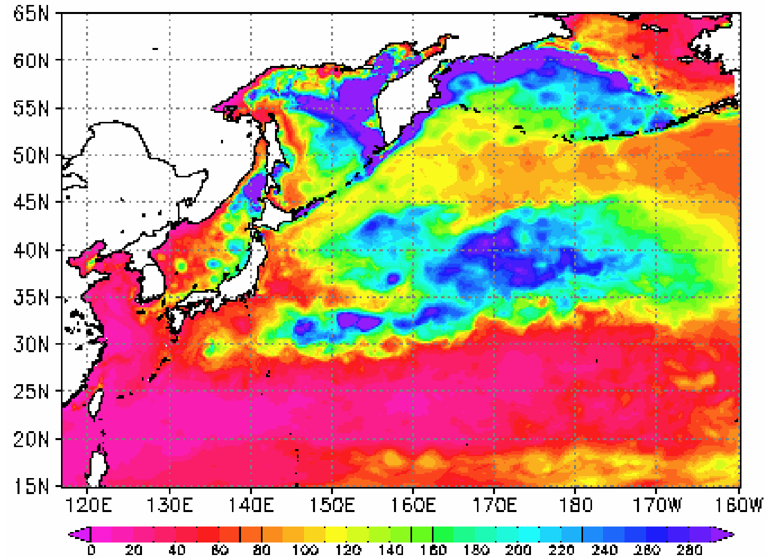


Climatology of Mixed Layer Depth **April**

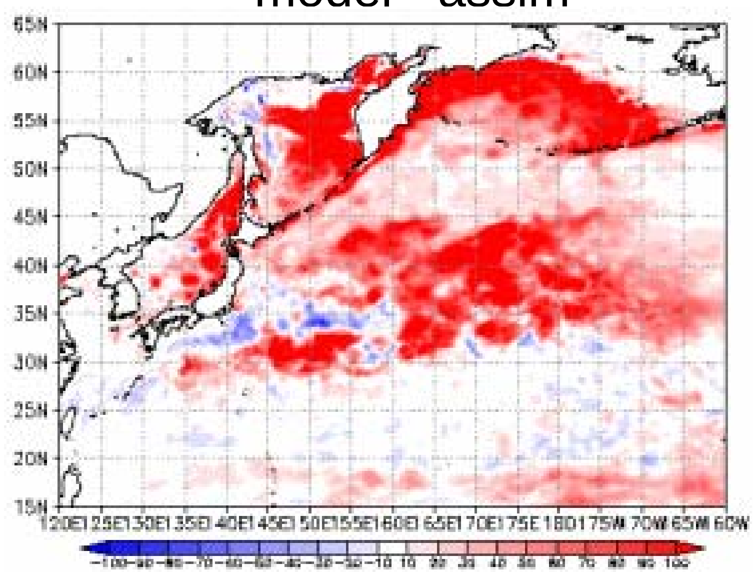
Assimilation



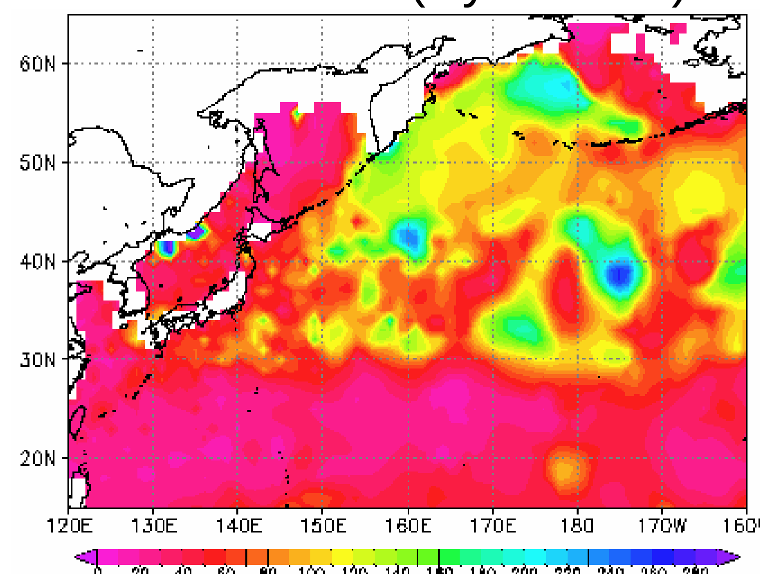
Model simulation



model - assim



Observation (Hydrobase)



GoDAE

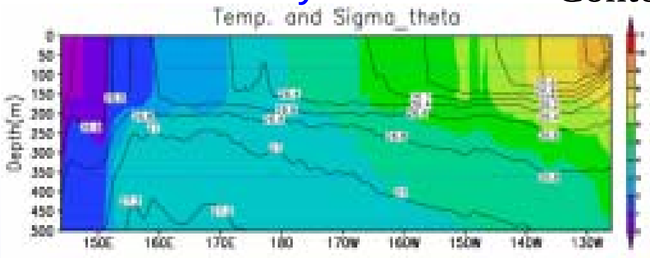
Salinity effect (with Argo float)

Salinity impact on the dichothermal structure

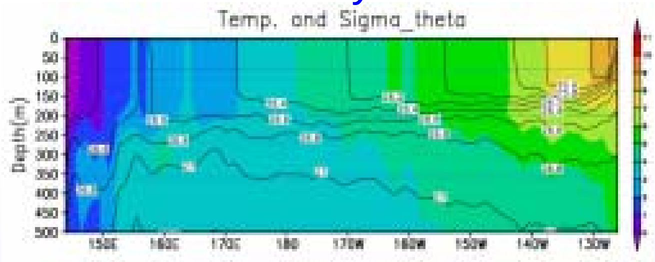
1997-2002 mean Color: Temperature Contour: σ_θ

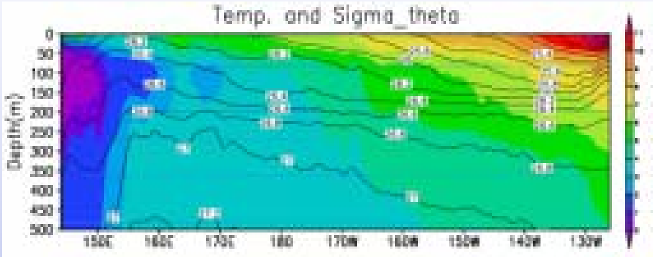
With salinity correction

Without salinity correction

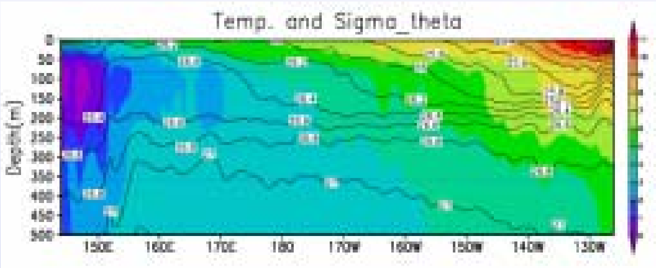


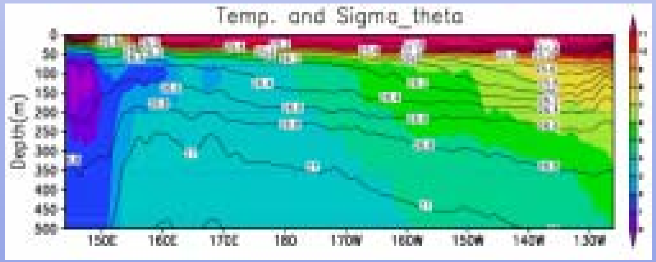
Mar.



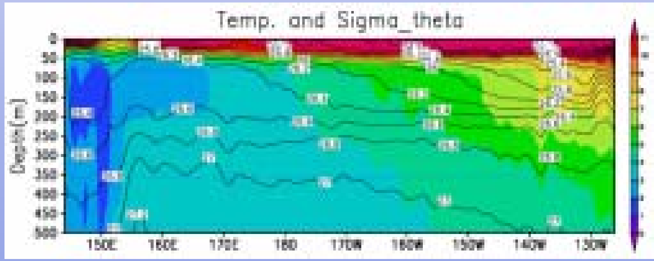


Jun

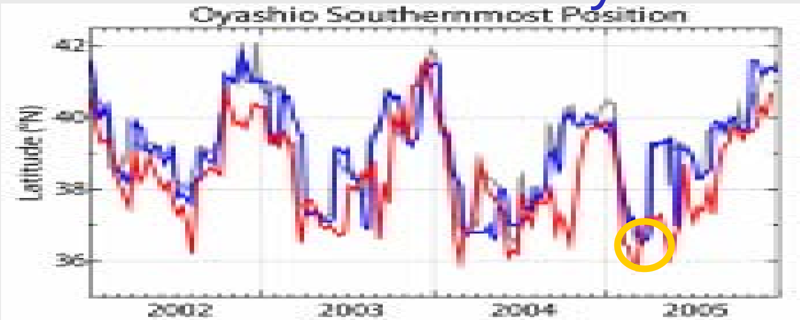


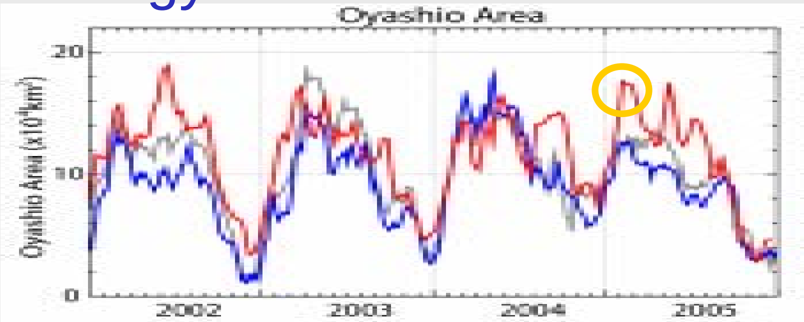


Sep.

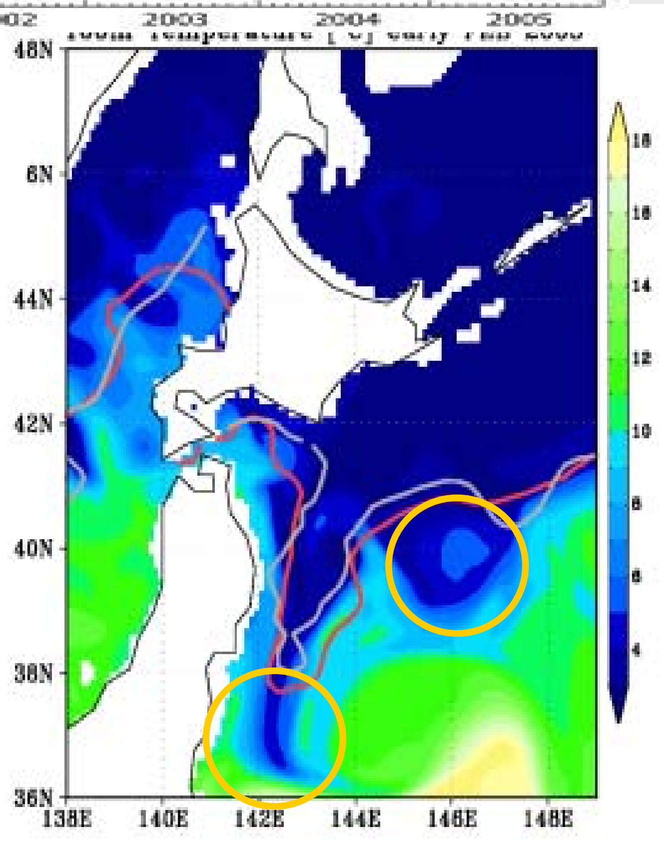


Oyashio in subarctic gyre





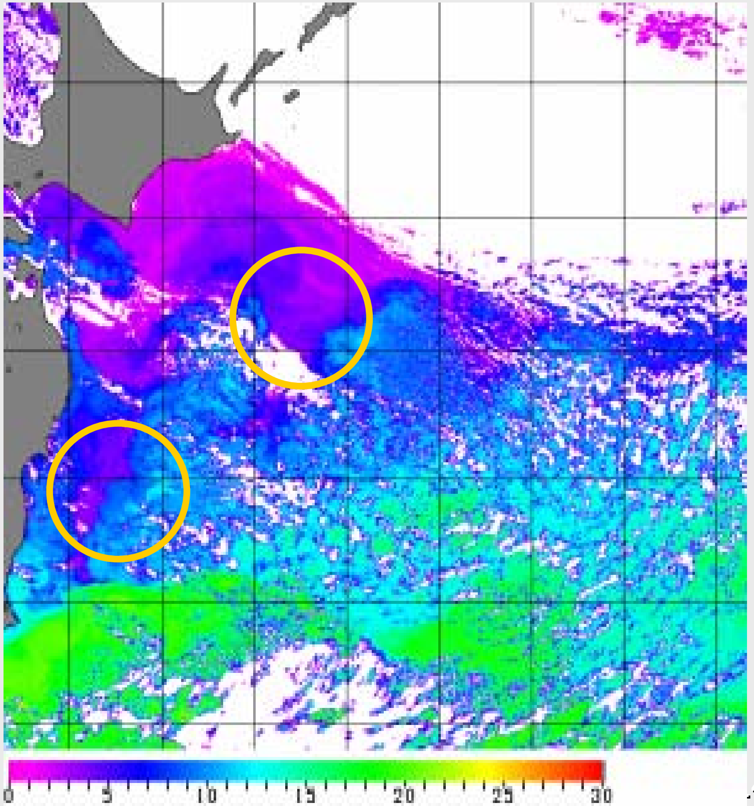
Temp(100m)
(2005/2/1st10days)



Color：MOVE-WNP

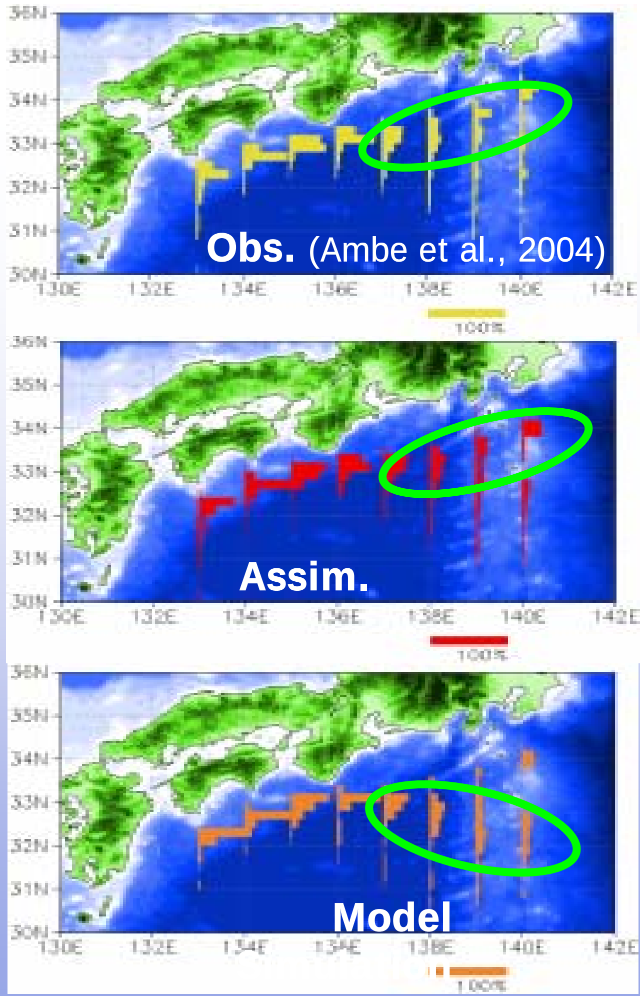
Red：5℃(COMPASS-K) **Gray：5℃(Obs-OI)**

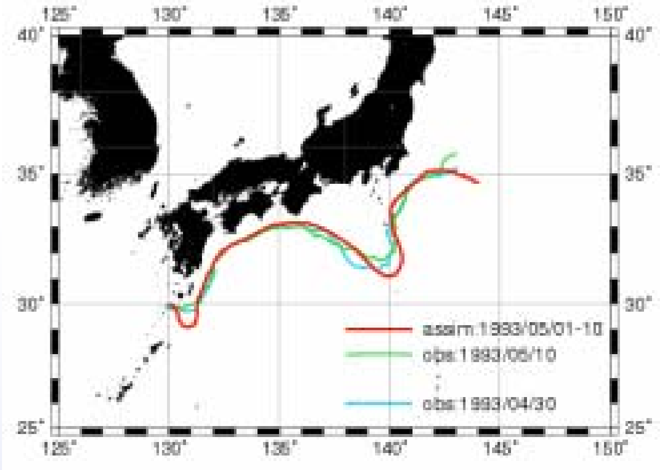
Satellite SST(NOAA@2005/2/3)

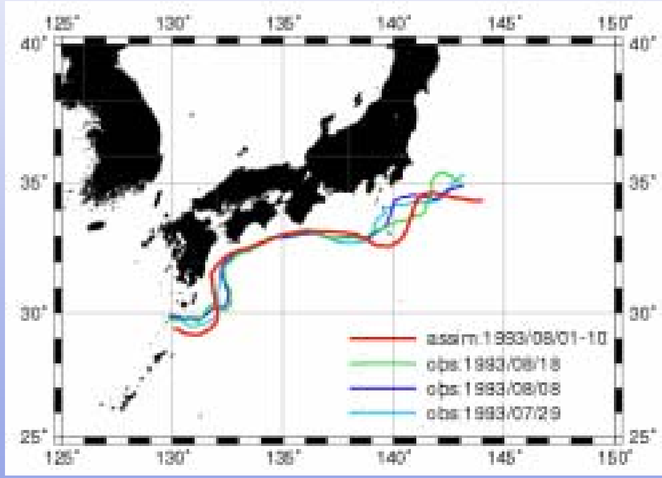


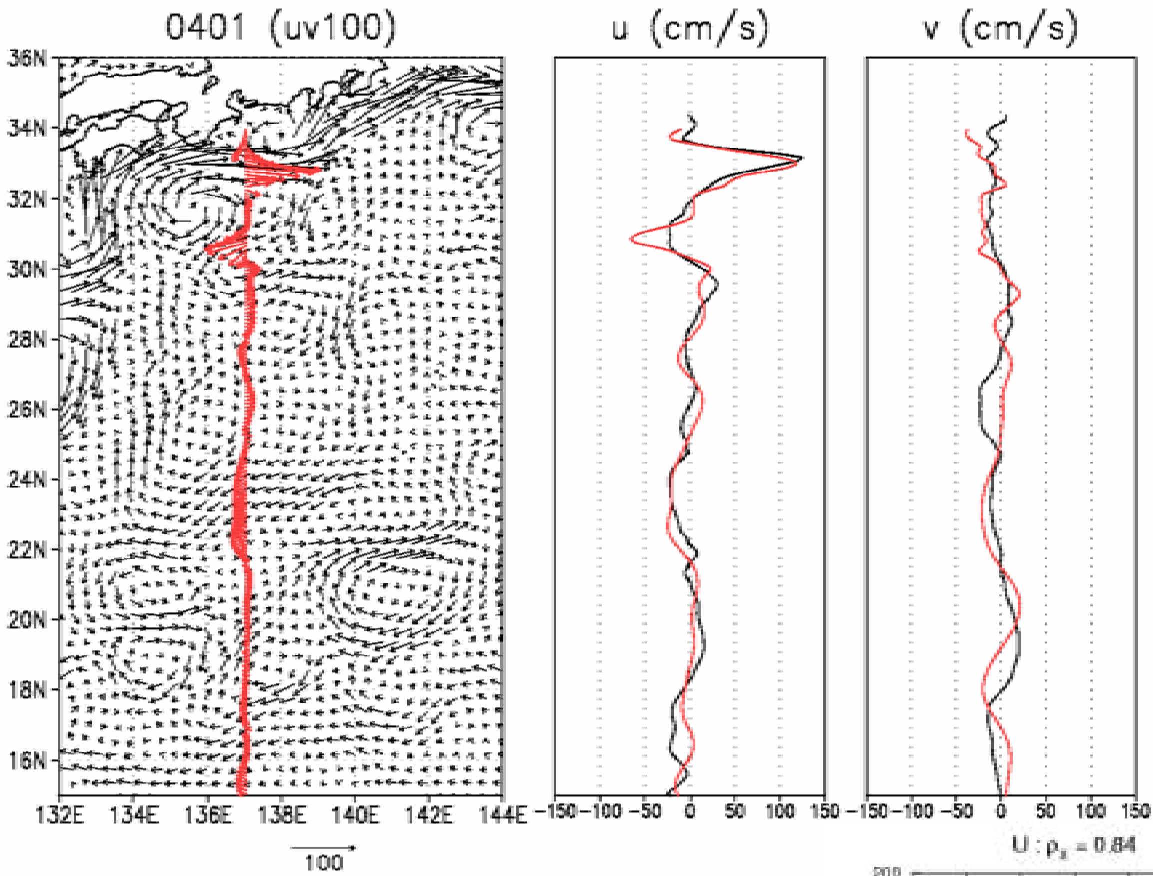
Kuroshio Axis (Representation of Kuroshio front)

Histgram of the Kuroshio axis position







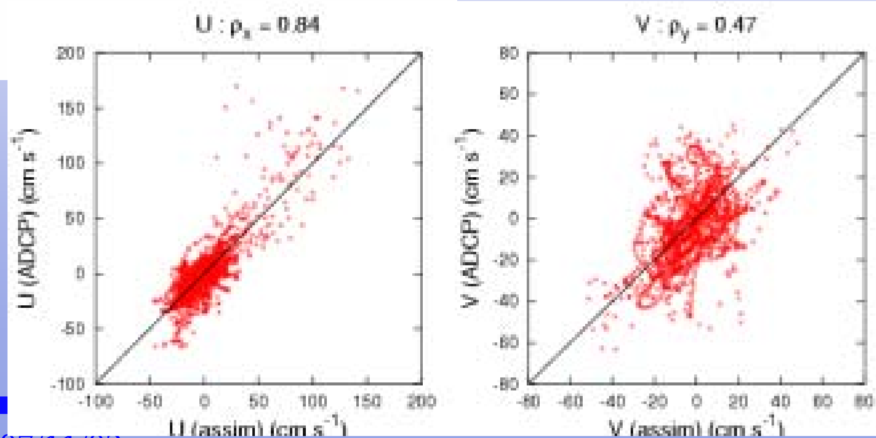


Horizontal Velocity

2004/1

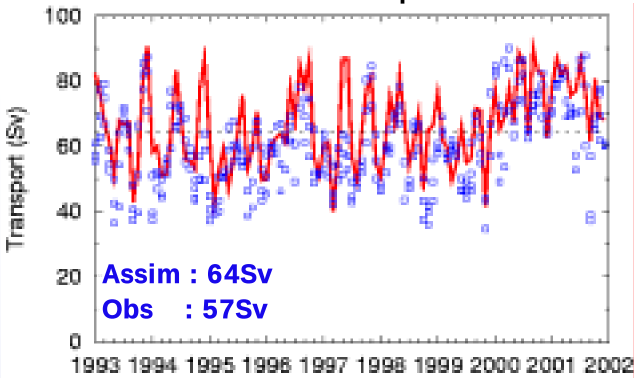
Correlation Coefficient

V variability is smaller->difficult

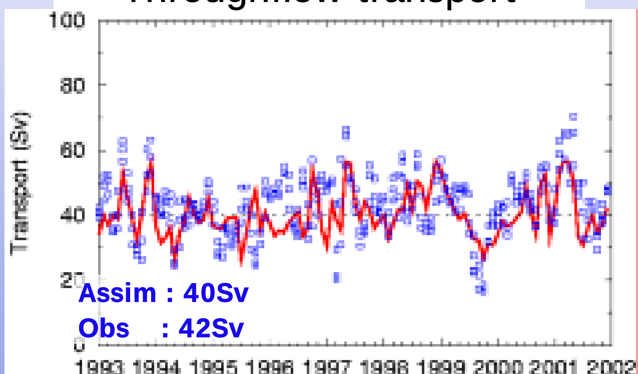


Kuroshio volume transport

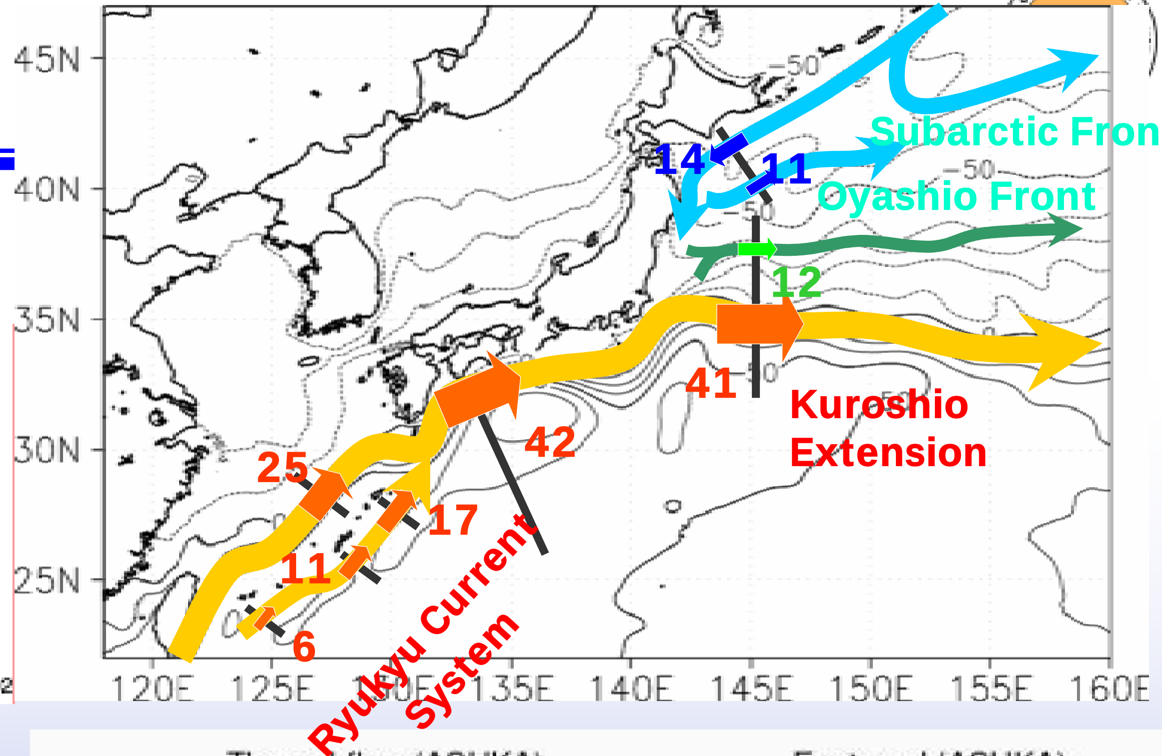
Eastward transport

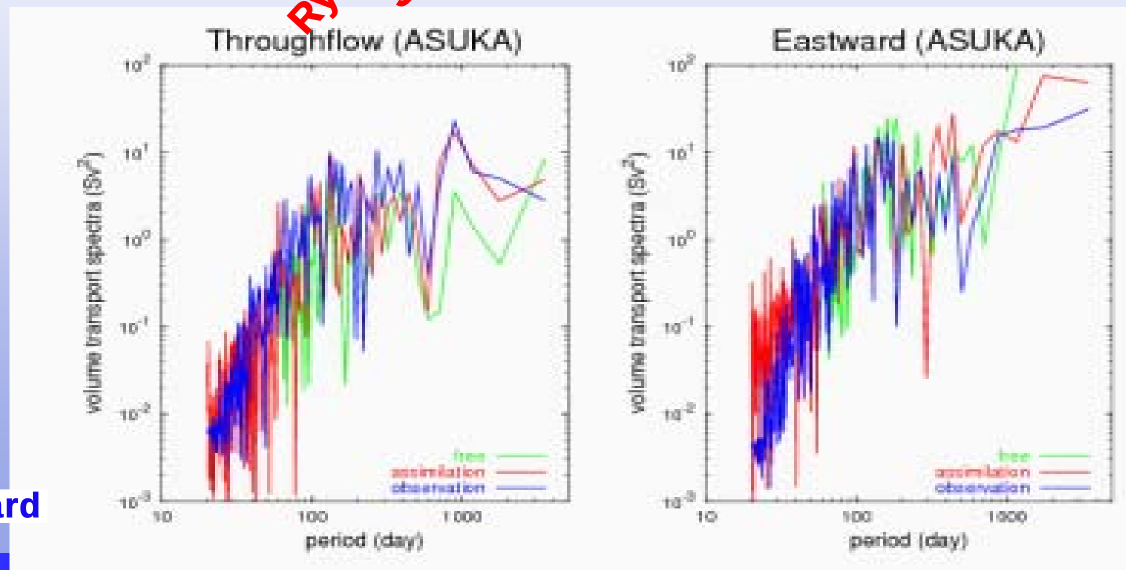


Throughflow transport



throughflow = eastward – westward





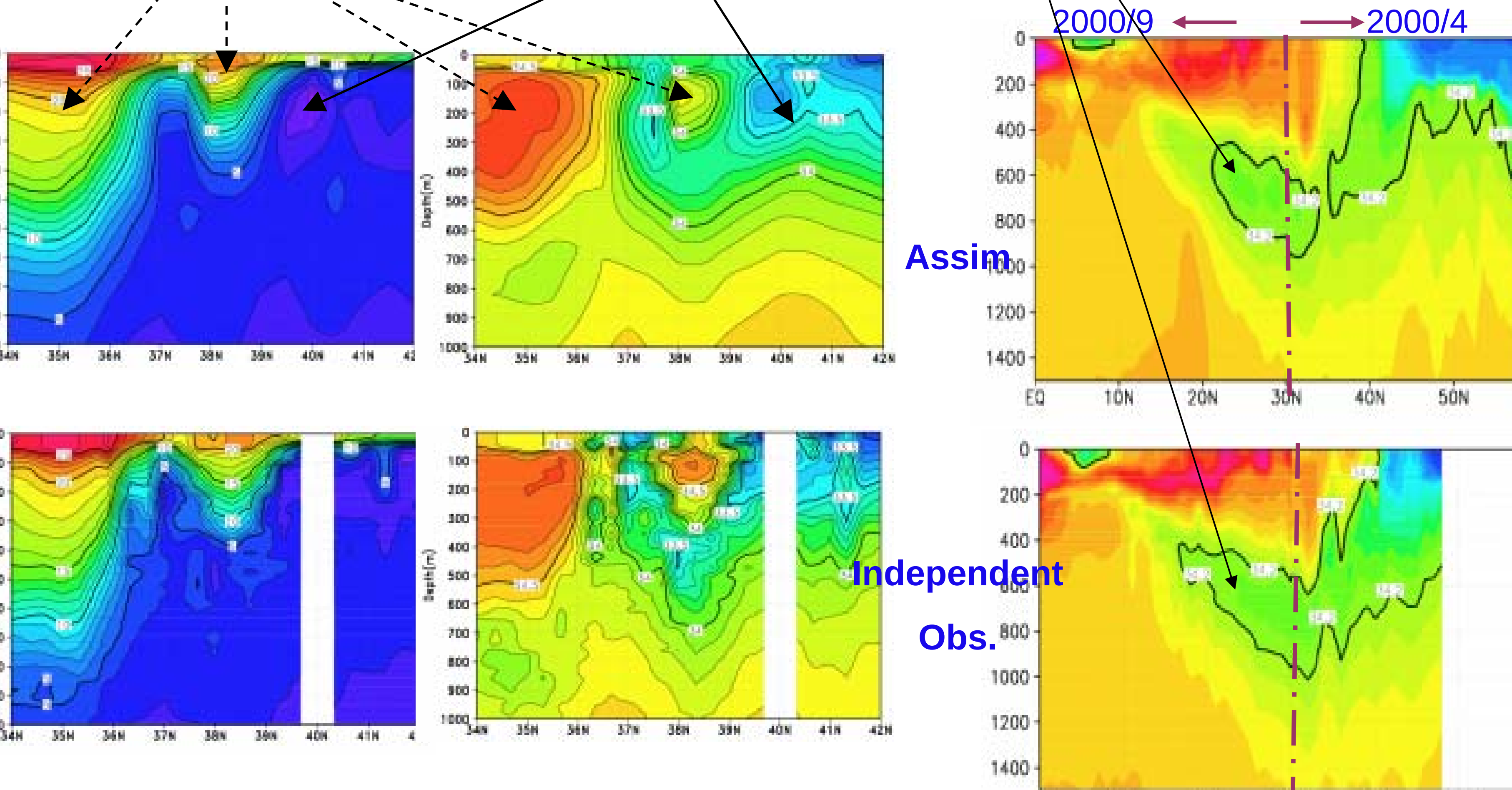
Examples of Water Mass in the North Pacific

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

Kuroshio (subtropical) and Oyashio (subpolar) waters

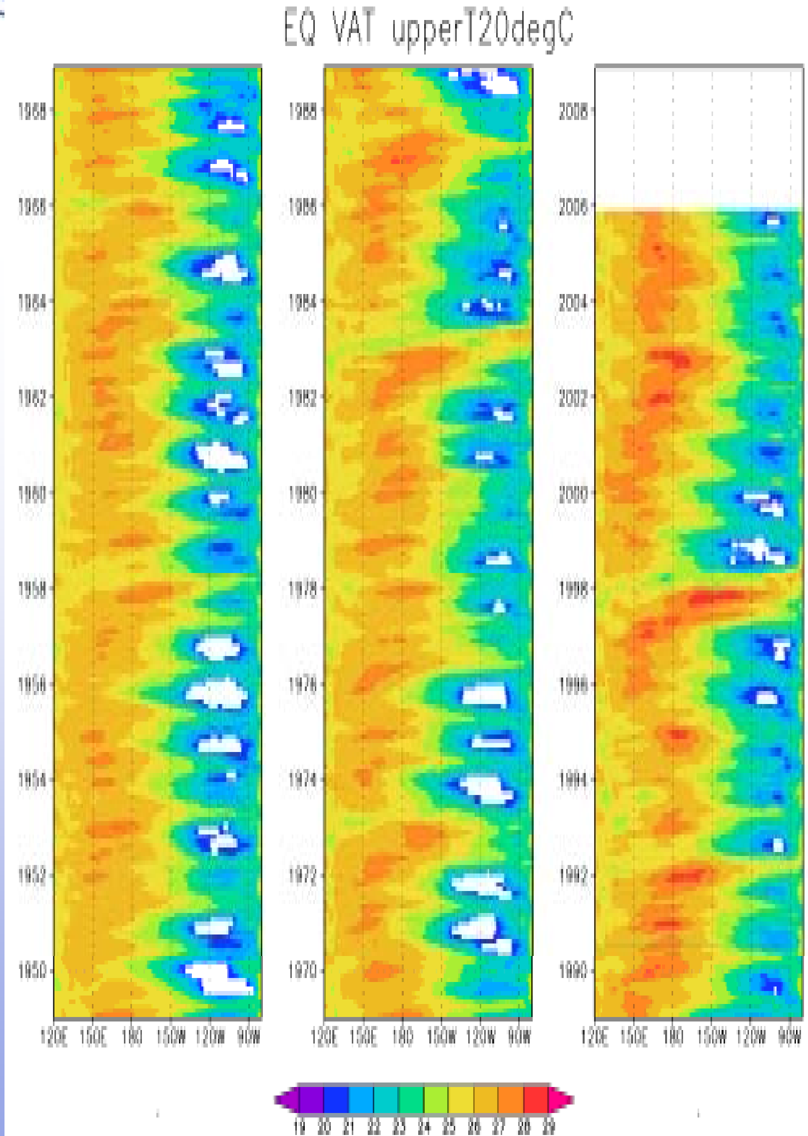
North Pacific Intermediate Water

Salinity-min. （165E，2000/4 and 9）

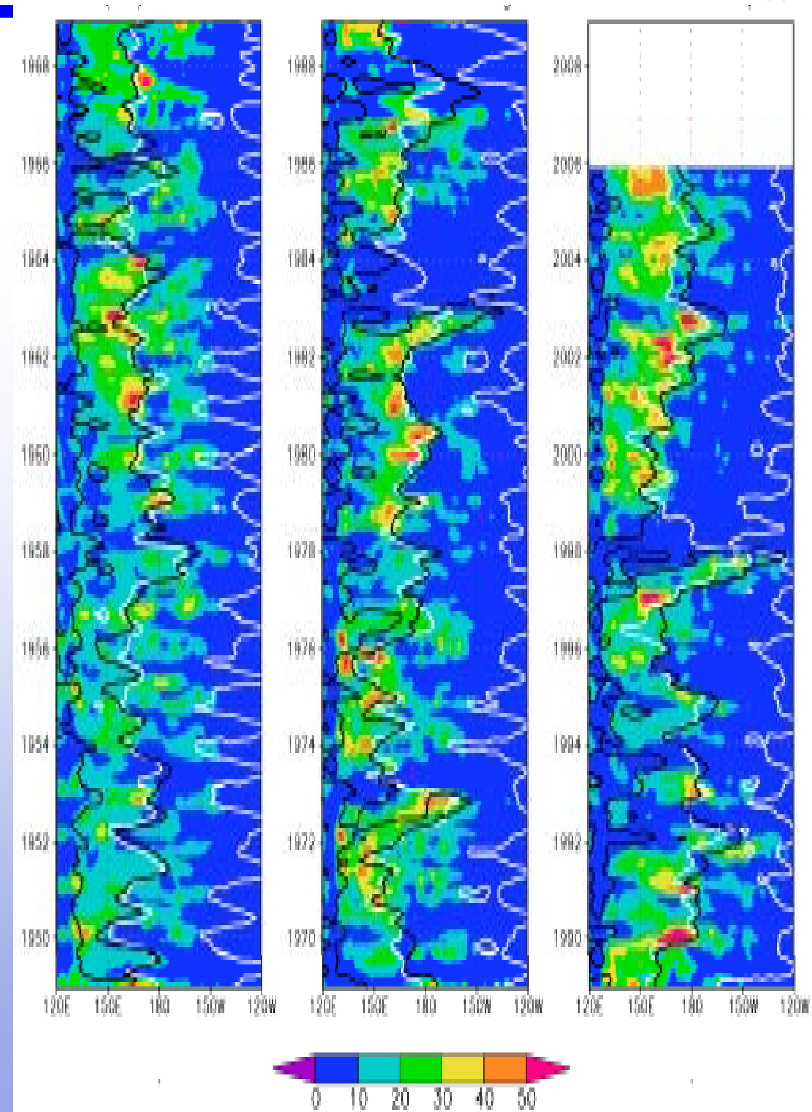


Temperature **Salinity**

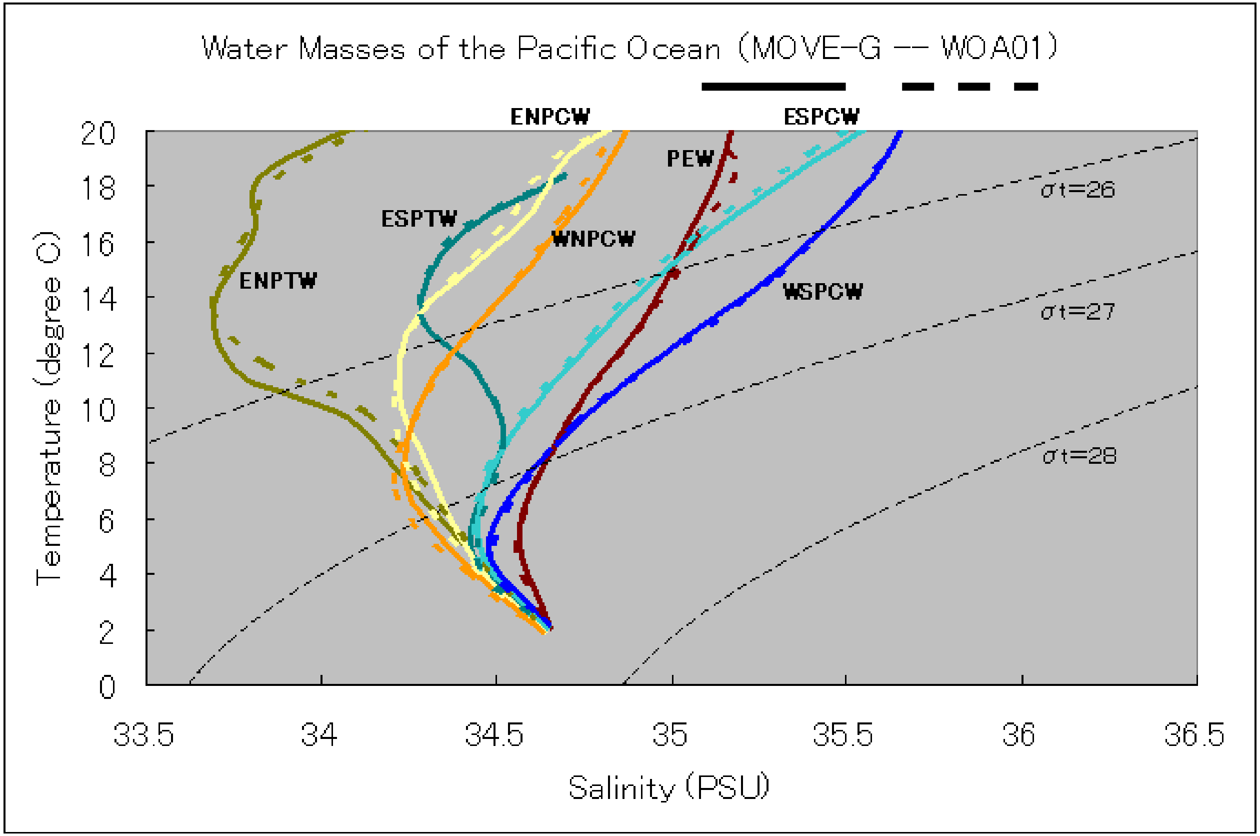
OHC (mean T) and BLT (1949-2005) Eq. Pac.



BLT (color), SST (29.0deg., black line), SSS (35.0psu, white line)



Example of water mass analysis using reanalysis dataset

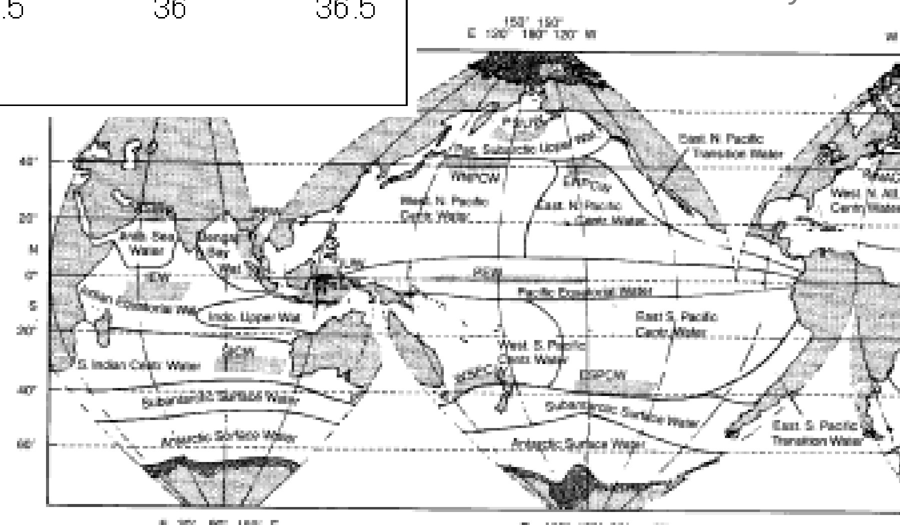


Water Type (Mean value in 1949-2005 vs. Climatology)

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

WATER TYPES AND

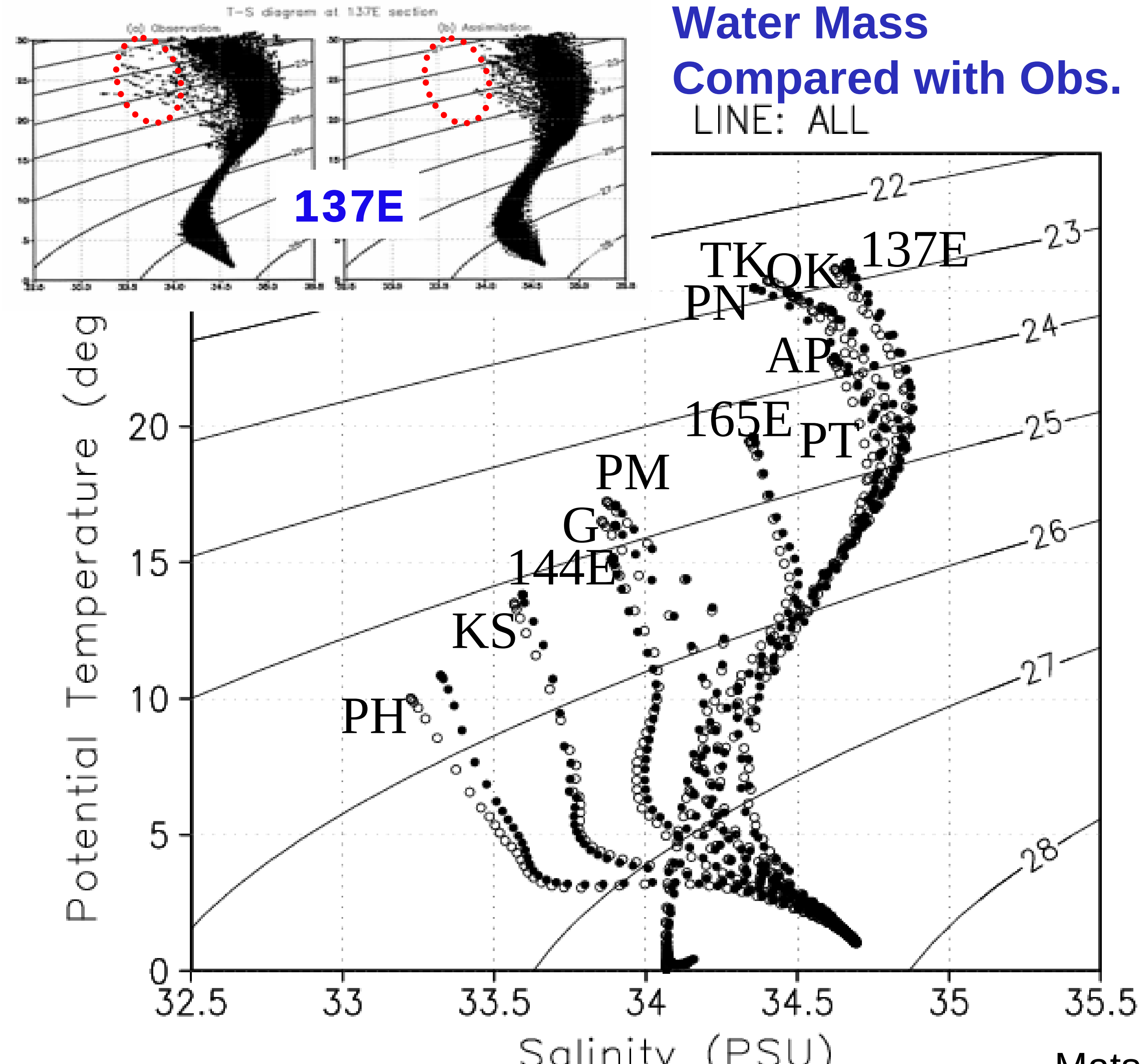
Emery 2001



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., 2007

Water Mass Compared with Obs.



○: Observation

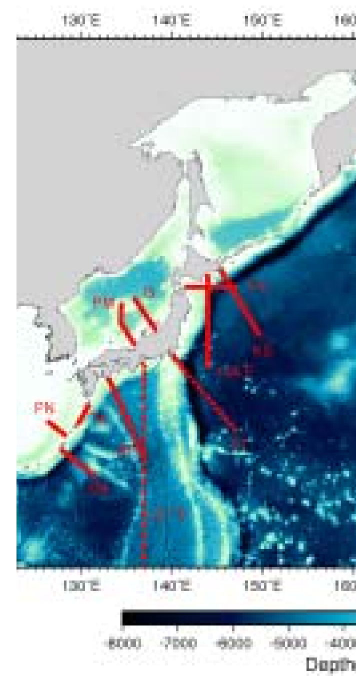
●: MOVE-WNP

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)



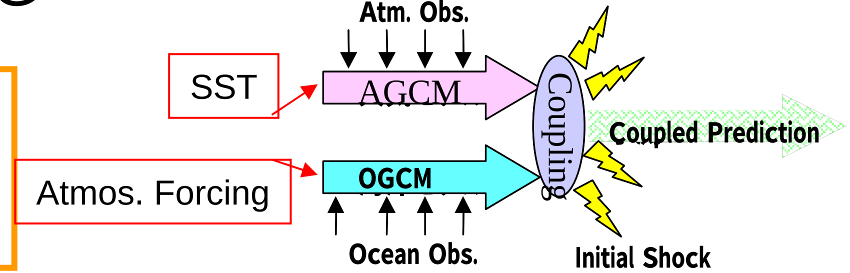
Matsumoto et al., 20

ENSO Forecast with MOVE-G

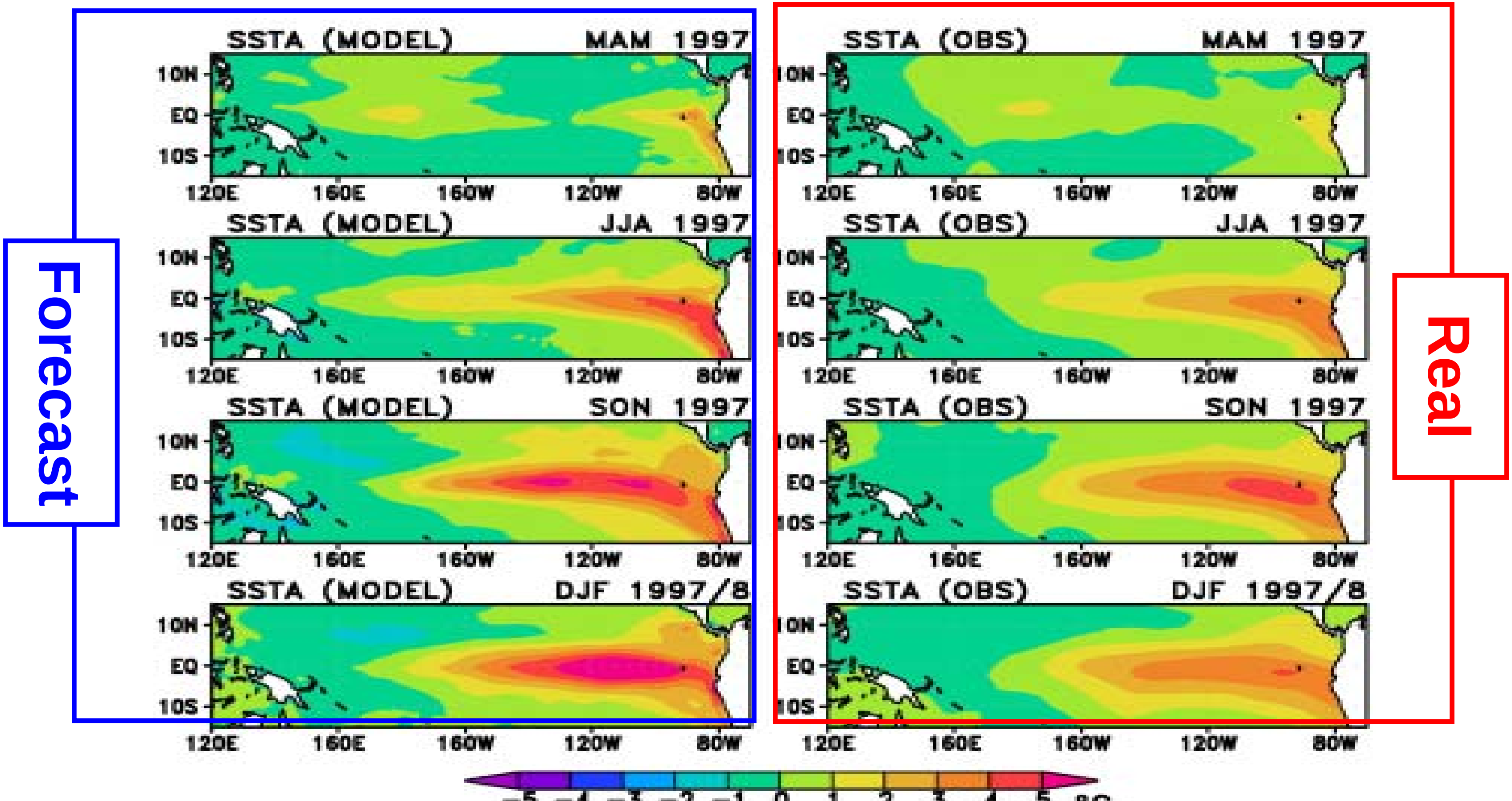
The ENSO forecasting system in JMA will be replaced next April.

MOVE-G provides initial state of the Ocean for the coupled model in the next system.

(a) Independent Systems (Conventional DAS)



SST Anomaly Initial: 1997/03/02



Best Demonstration:

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

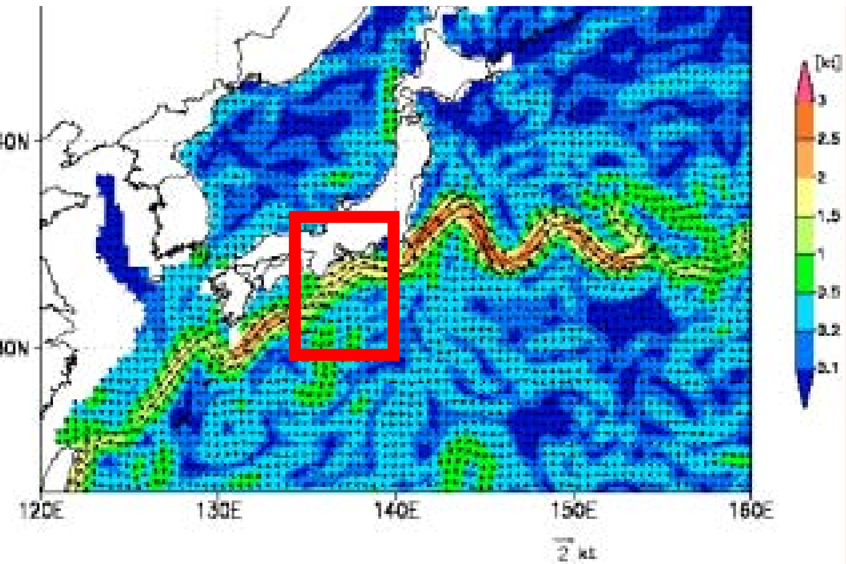


図1　最近の黒潮流路

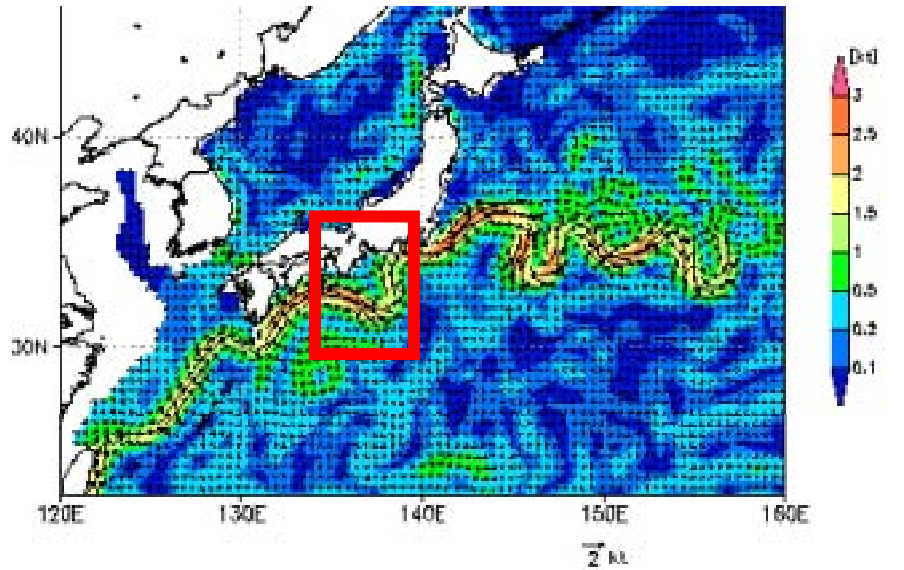


図2　気象研究所で開発中の海洋大循環モデルによる黒潮の数値予測結

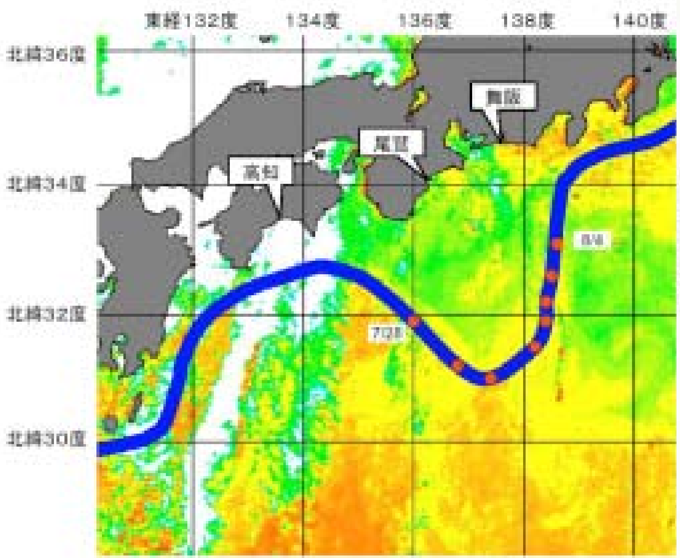
Assim/initial state (2004/05/09)　　**Forecast (2004/06/30)**

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

カツオ、トビウオ激減

収束の見込みなく…

漁師　悲鳴

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

Prediction

Real state (assimilation)

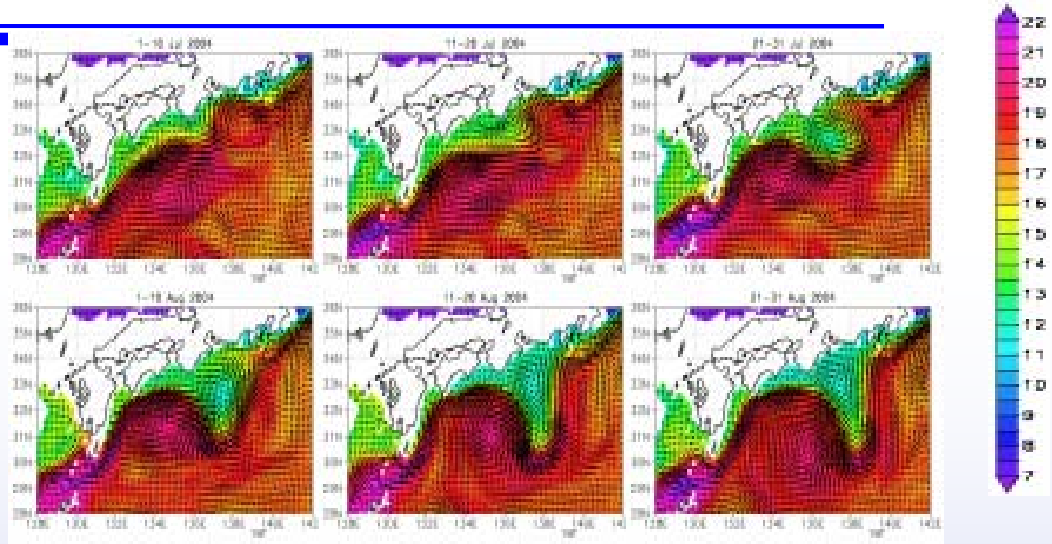
MOVE-WNP (0.1 deg.)

- 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.

July

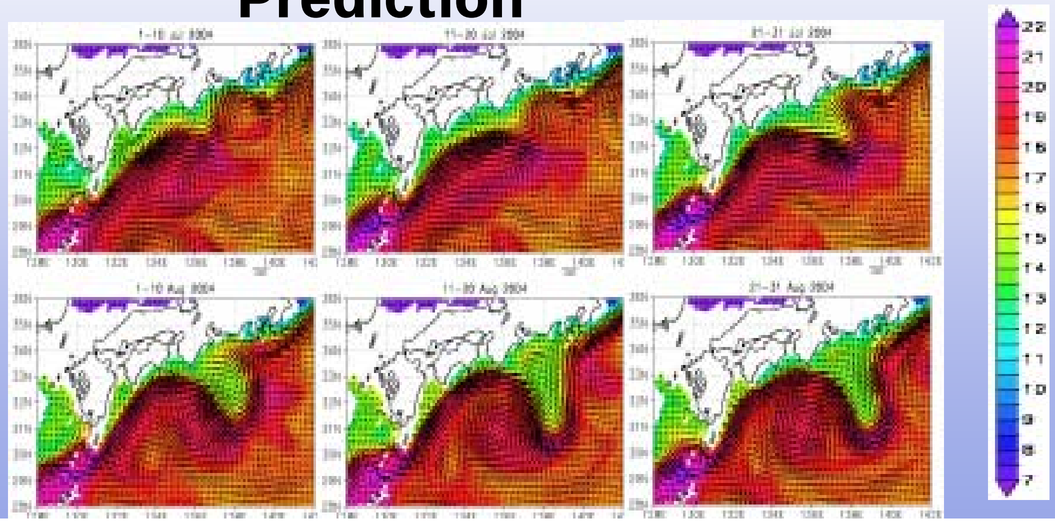
August



Prediction

July

August

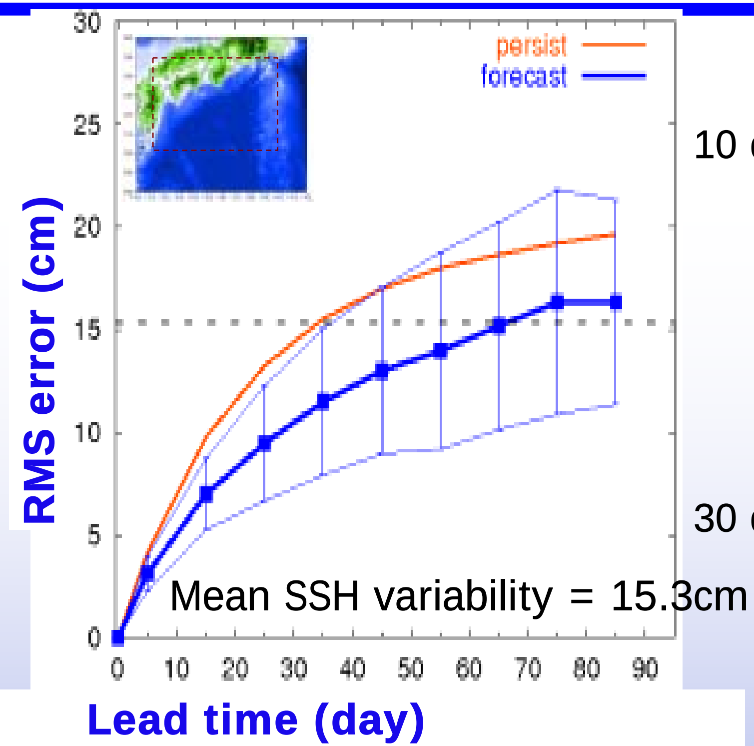


Horizontal velocity (vector) and temperature (color) at 200m depth.

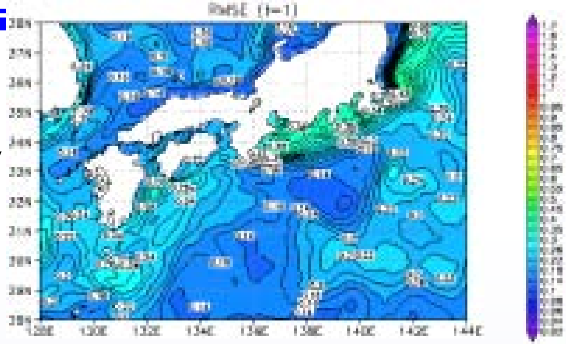
Predictability (single prediction)

time evolution of SSHA prediction error

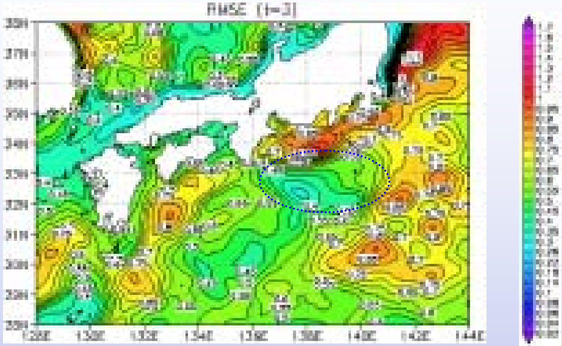
JMA's new Operational Forecasting System (everyday, Real time, 2 months Forecast)



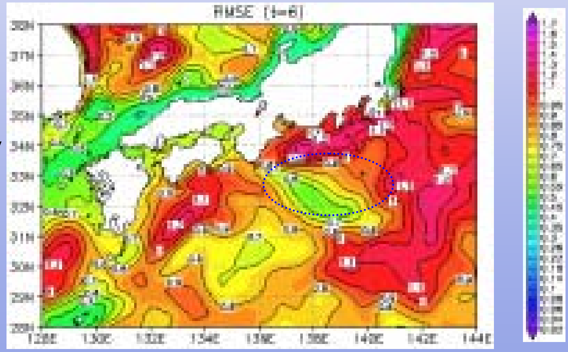
10 day



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.

Data Server

- NEARGOOS Regional Real Time Data Base

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

- JMA Japan-GODAE LAS server

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

Comments

1. An Example of Operational Systems of physical oceanography
2. Future directions

=> OSE type leads estimation/reconstruction of observation

Ocean-Atmosphere Coupled Data Assimilation

Coastal-shelf sea application

Earth system model (coupled physical biogeochemical and ecosystem, with atmospheric model/assimilation)

3.Recommendations

To Physical Oceanogr. group

=> Improve

Physics model with high resolution and high quality

Mixed Layer Depth, Vertical Mixing

(vertical velocity, vertical diffusivity)

To Biogeochemical & ecosystem oceanogr. group

=> Improve your physics model with data assimilation, when you assimilate observation into your biogeochemical/ecosystem.