Development of a coastal monitoring and forecasting system at MRI/JMA

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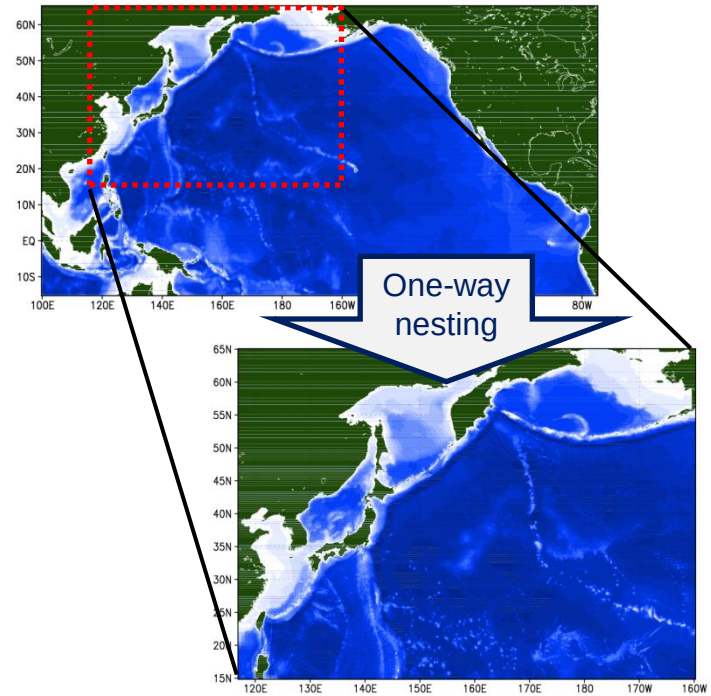
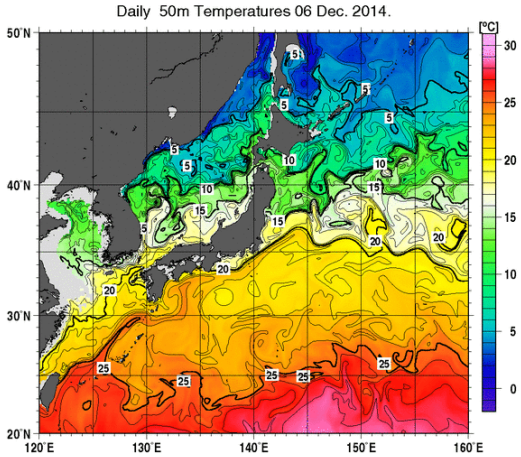
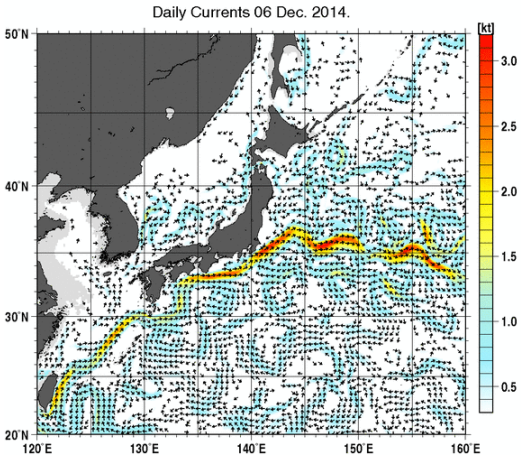
JMA operational ocean forecast system

MOVE/MRI.COM-WNP

- operated since 2008
- western North Pacific model
- 10km resolution
- data assimilation with 3DVAR
- targeting mesoscale phenomena in the open ocean (Kuroshio, Oyashio, mesoscale eddies,…)
- **cannot resolve coastal processes**

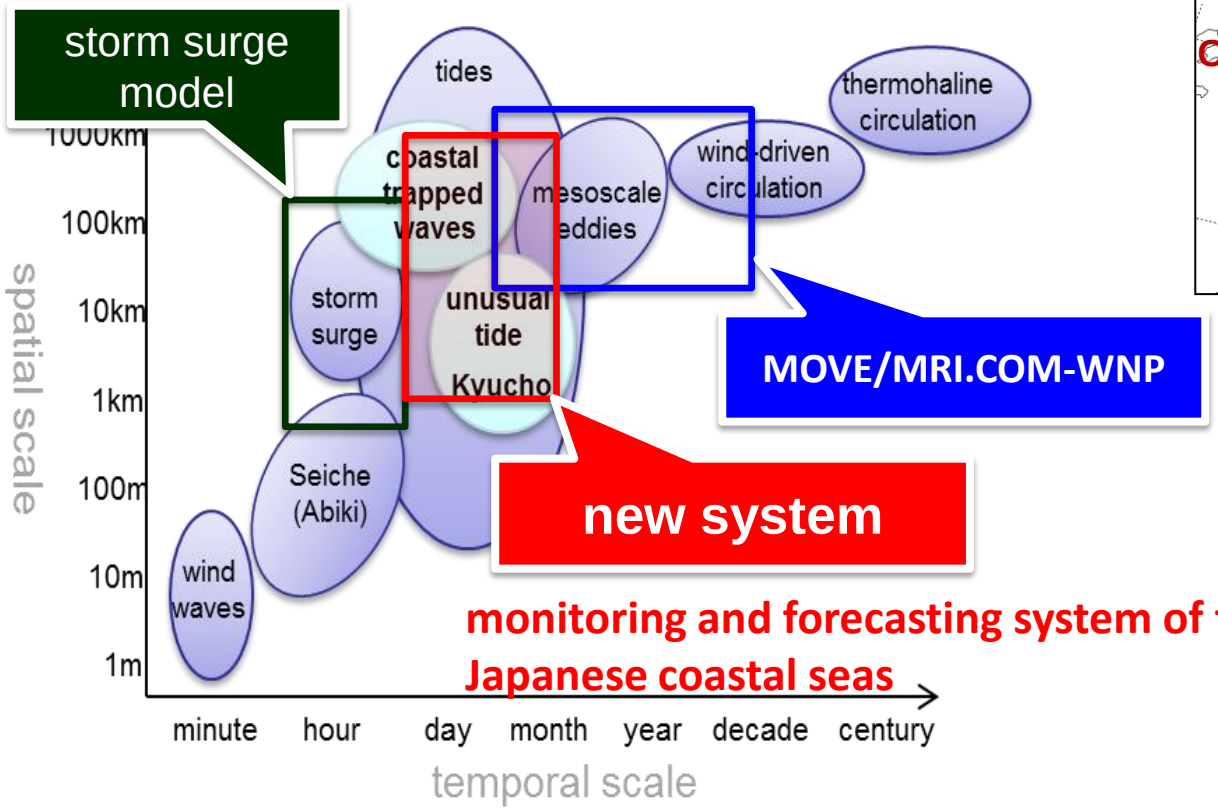






http://www.data.jma.go.jp/gmd/kaiyou/shindan/index.html

Need for coastal system



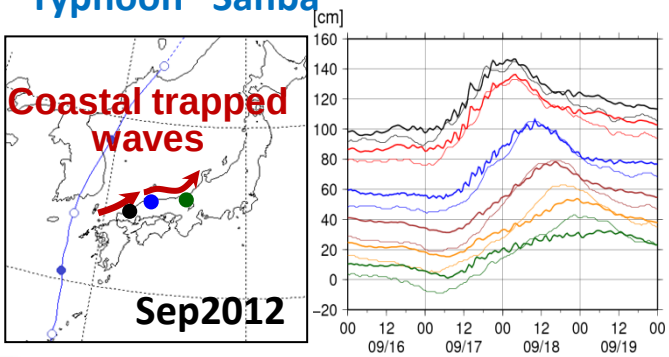
storm surge model

MOVE/MRI.COM-WNP

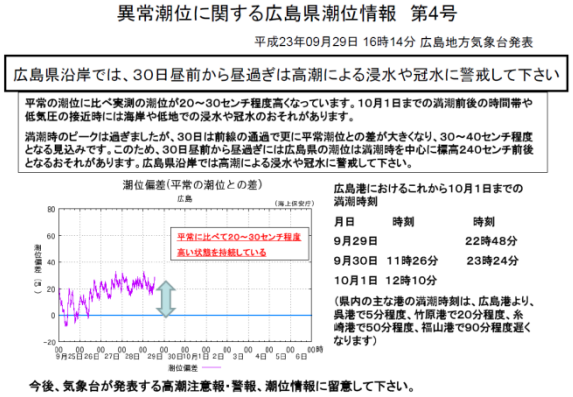
new system

monitoring and forecasting system of the Japanese coastal seas

Typhoon “Sanba”



Sea-level information (Hiroshima local meteorological office)



異常潮位に関する広島県潮位情報　第4号

平成23年09月29日 16時14分 広島地方気象台発表

広島県沿岸では、30日昼前から昼過ぎは高潮による浸水や冠水に警戒して下さい

平常の潮位に比べ実測の潮位が20～30センチ程度高くなっています。10月1日までの満潮前後の時間帯や低気圧の接近時には海岸や低地での浸水や冠水のおそれがあります。

満潮時のピークは過ぎましたが、30日は前線の通過で更に平常潮位との差が大きくなり、30～40センチ程度となる見込みです。このため、30日昼前から昼過ぎには広島県の潮位は満潮時を中心に標高240センチ前後となるおそれがあります。広島県沿岸では高潮による浸水や冠水に警戒して下さい。

潮位偏差（平常の潮位との差）

平常に比べて20～30センチ程度高い状態を持続している

広島港におけるこれから10月1日までの満潮時刻

月日	時刻	時刻
9月29日		22時48分
9月30日	11時26分	23時24分
10月1日	12時10分	

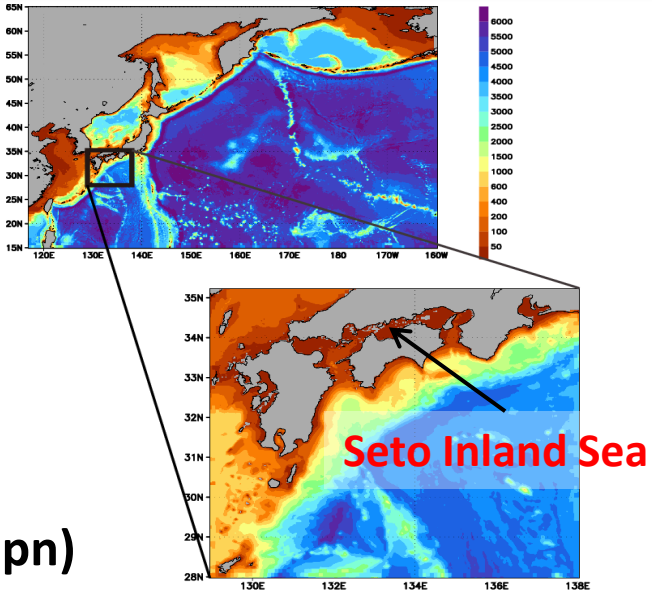
（県内の主な港の満潮時刻は、広島港より、呉港で5分程度、竹原港で20分程度、糸崎港で50分程度、福山港で90分程度遅くなります）

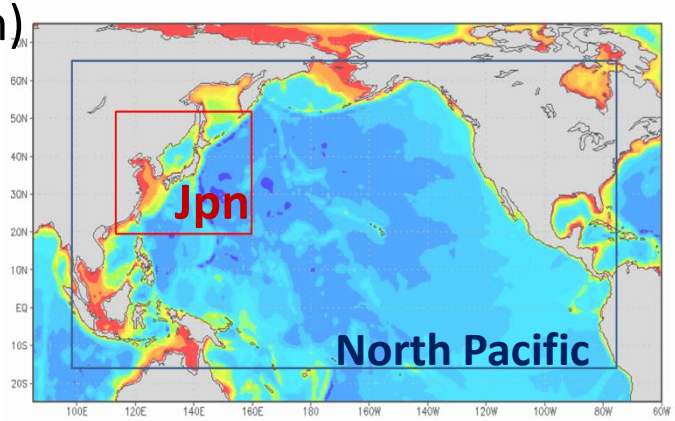
今後、気象台が発表する高潮注意報・警報、潮位情報に留意して下さい。

Plan for development of coastal systems

Target area:

- **Seto Inland Sea (MOVE/MRI.COM-Seto)**
  - **2km** coastal model (MRI.COM-Seto)
  - **4DVAR** assimilation model with 10km grid (MOVE-4DVAR)
  - under preparation for operational use at JMA
- **Whole coastal regions of Japan (MOVE/MRI.COM-Jpn)**
  - Model Japan with 2km resolution (MRI.COM-Jpn)
  - 4DVAR assimilation model in the North Pacific





Roadmap

2015- MOVE/MRI.COM-Seto → Several years later MOVE/MRI.COM-Jpn

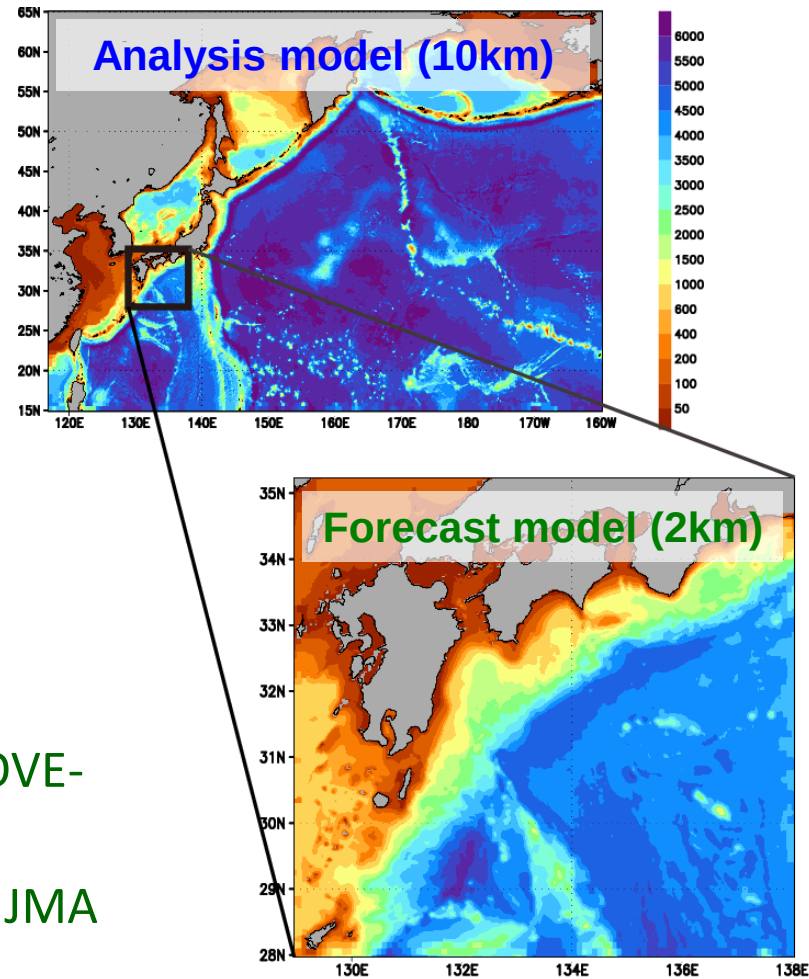
MOVE/MRI.COM-Seto

☐ Analysis model (MOVE-4DVAR)

- ✓ WNP model (MRI.COM-WNP)
- ✓ 10km resolution
- ✓ Optimize T and S fields with 4DVAR
- ✓ 30 years analysis/reanalysis (1985-2014+) (FORA)

☐ Forecast model (MOVE-Seto)

- ✓ Seto Inland Sea model（MRI.COM-Seto）
- ✓ 2km resolution
- ✓ Initialized with 10km analysis fields of MOVE-4DVAR
- ✓ high-resolution atmospheric forcing from JMA operational models (MSM, GSM)

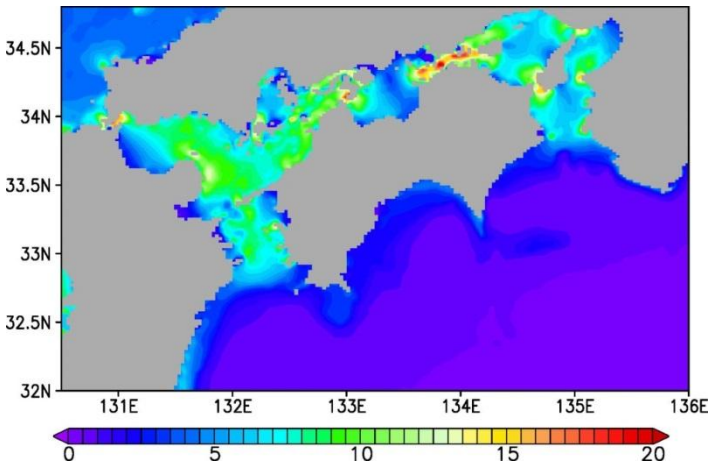


This system will be in operation at JMA soon

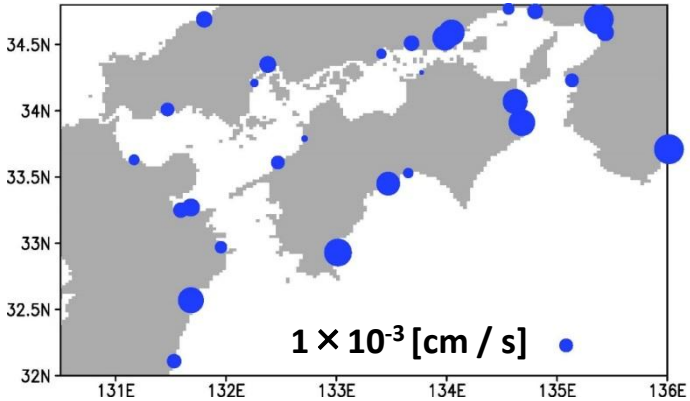
Configuration of MRI.COM-Seto

Model	MRI Community Ocean Model (MRI.COM) ver. 3.2
coordinates	free surface sigma-z, polar coordinates
Hori. resolution	1/33° ×1/50° (~2km)
Vert. resolution	4-600m (50 layers)
Tracer advection	Second-order Momentum closure (Prather 1986)
Hori. mixing	Smagrosinky bi-harmonic
Vert. mixing	Noh and Kim (1999)
Tides	Tidal mixing parameterization (Lee et al. 2006)
Lateral boundaries	MOVE-WNP- 4DVAR (10km)
Nesting	Off-line one-way nesting
Atmos. forcing	JMA operational model outputs (GSM + MSM)
River run-off	Monthly climatology of 28 major rivers
others	SSS restore to climatology with 29.2day
Time step	2.5 min

Background vertical diffusivity



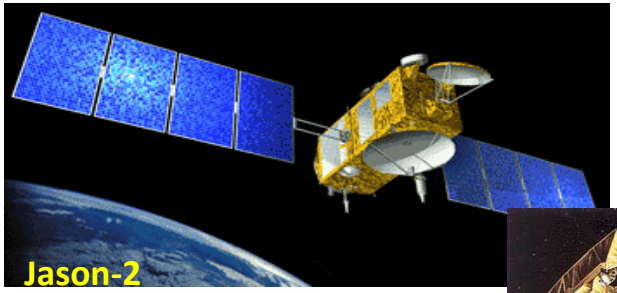
River runoff



Observations used for data assimilation

☐ Satellite altimeter (along track)

- TOPEX/Poseidon, Jason-1/2
- ERS-1/2, Envisat, Cryosat-2
- GFO, SARAL/AltiKa, HY-2

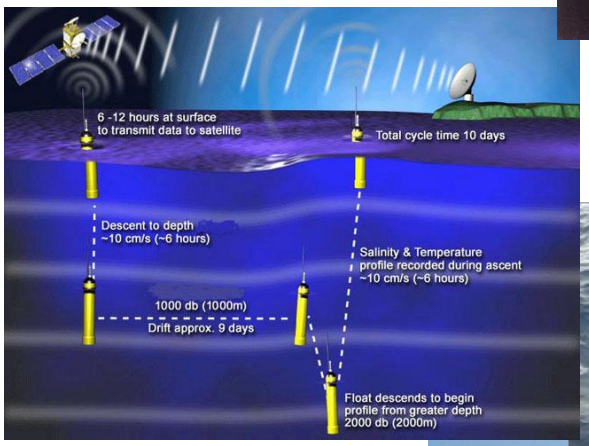


☐ Gridded SST

- MGDSST (JMA SST product)
  - Merged satellite and in-situ data
  - 0.25deg x 0.25deg

☐ In-situ observations (T and S)

- Argo
- Ship
- Buoy
- …

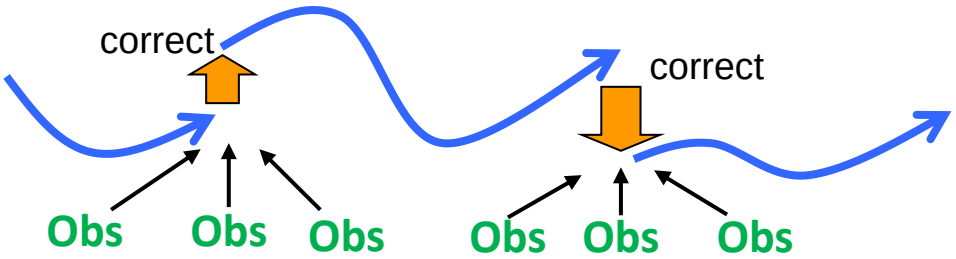


- **Density-related observations (T and S)**
- **Use of velocity data is future subject**

Difference between 3DVAR and 4DVAR

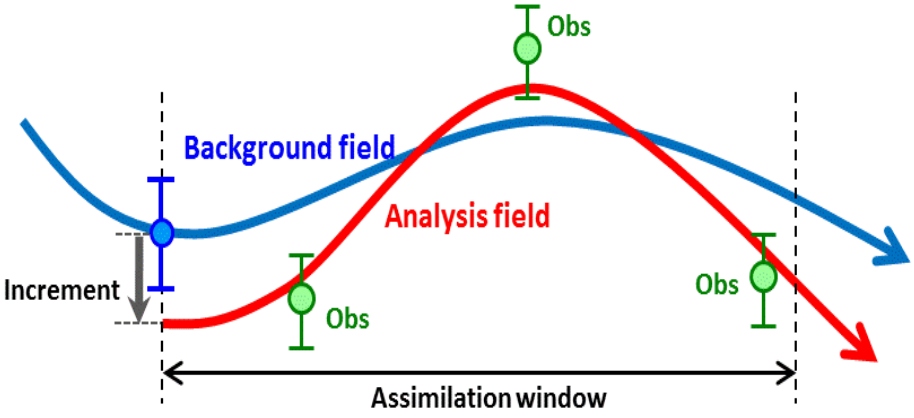
3DVAR
(Three-dimensional variational method)

- Does not use a numerical model for ocean state estimate
- Estimates ocean state at a fixed time
- Treats observations as if valid at an analysis time (-> F-GAT)



4DVAR
(Four-dimensional variational method)

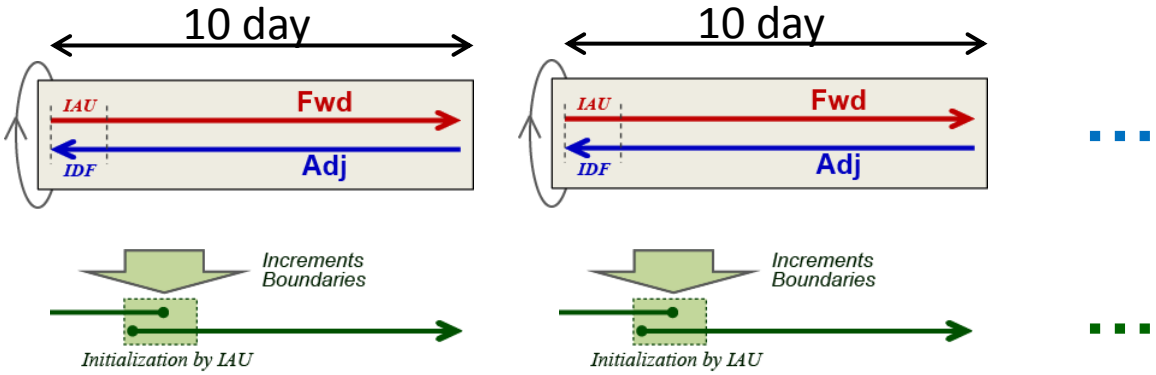
- Utilizes a numerical model
- Optimizes a model trajectory within an assimilation window
- Uses obs at their actual time of measurement
- Easy to assimilate any variables related to prognostic variables



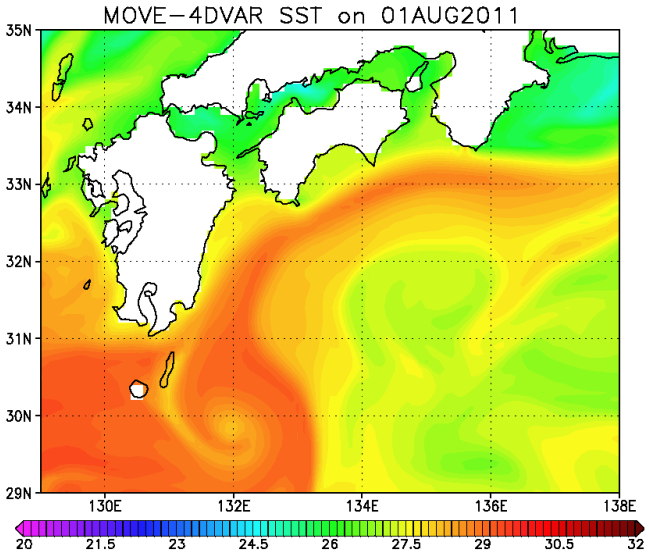
Assimilation cycle

MOVE-4DVAR (10km analysis model)

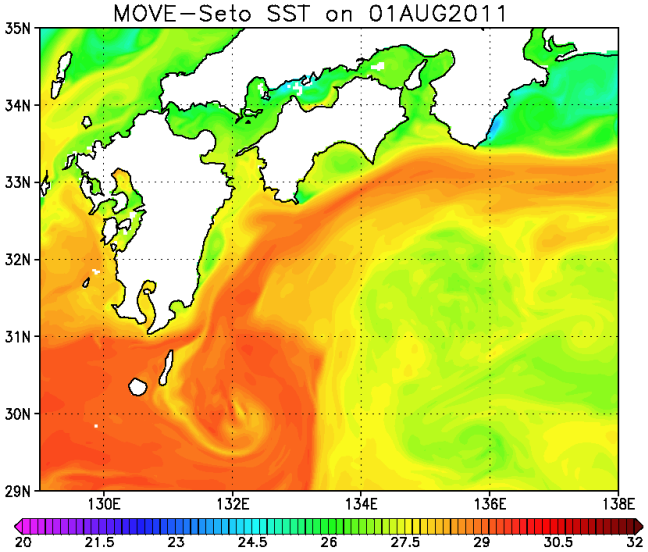
MOVE-Seto (2km forecast model)



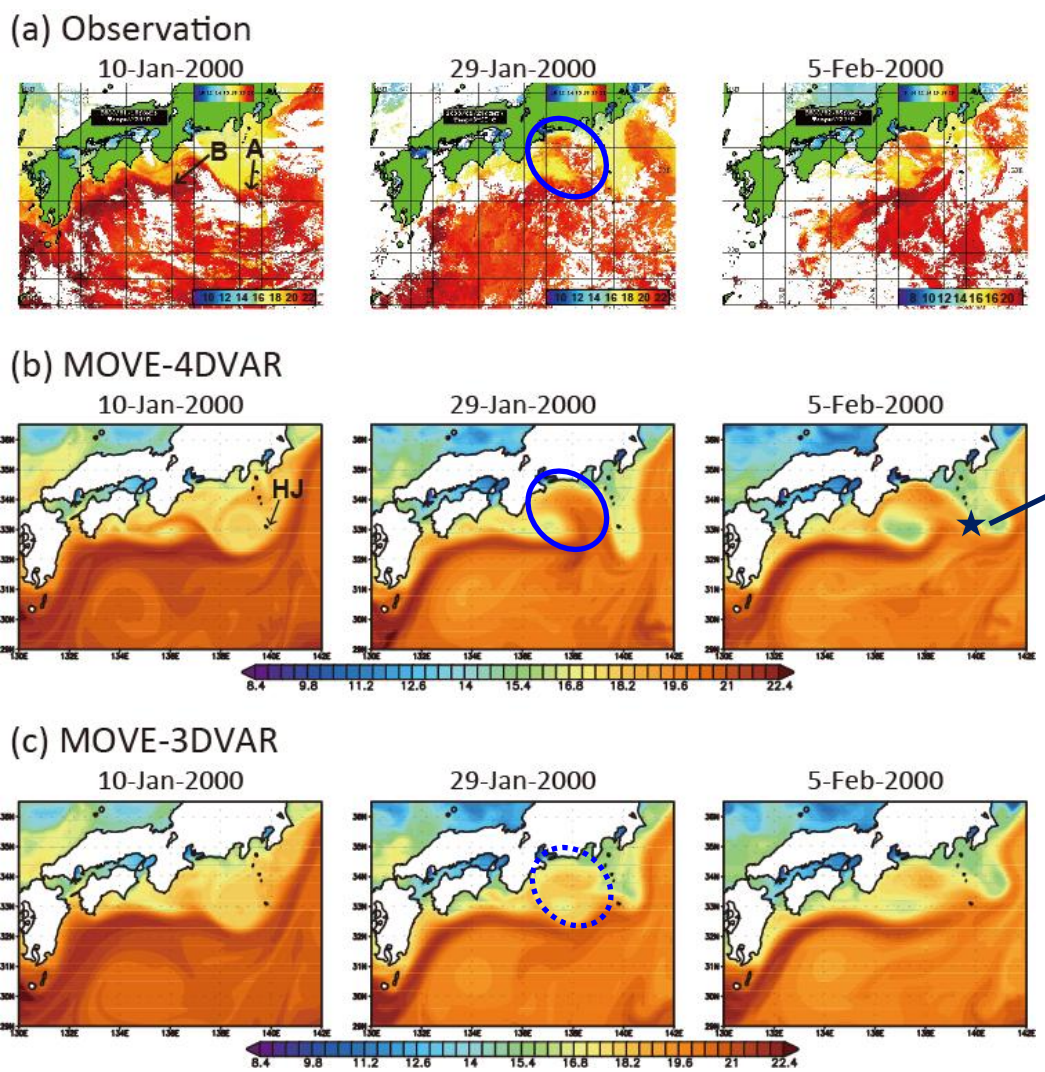
MOVE-4DVAR SST（10km）



MOVE-Seto SST（2km）

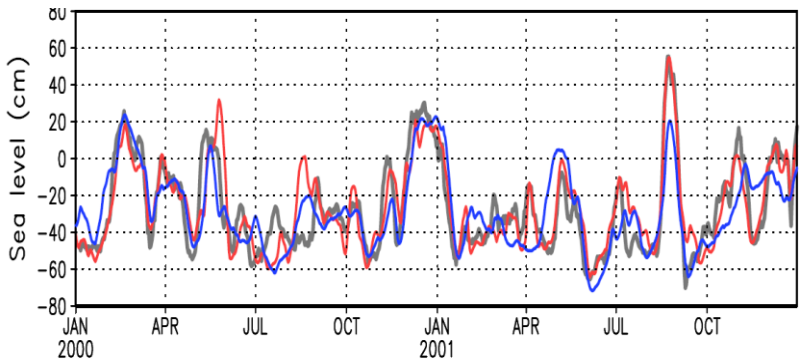


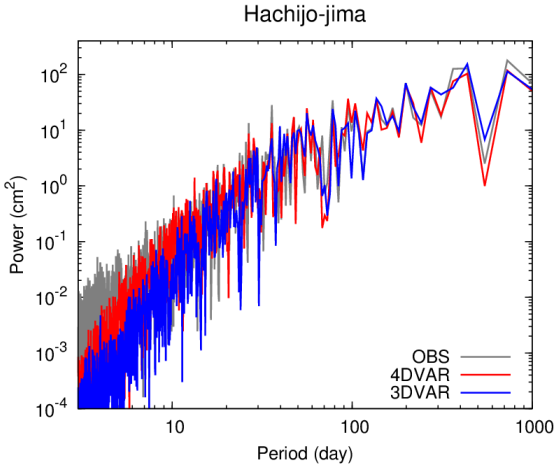
Comparison between 3DVAR and 4DVAR analysis fields



Tide gauge
MOVE-3DVAR
MOVE-4DVAR

Sea level at Hachijo-jima

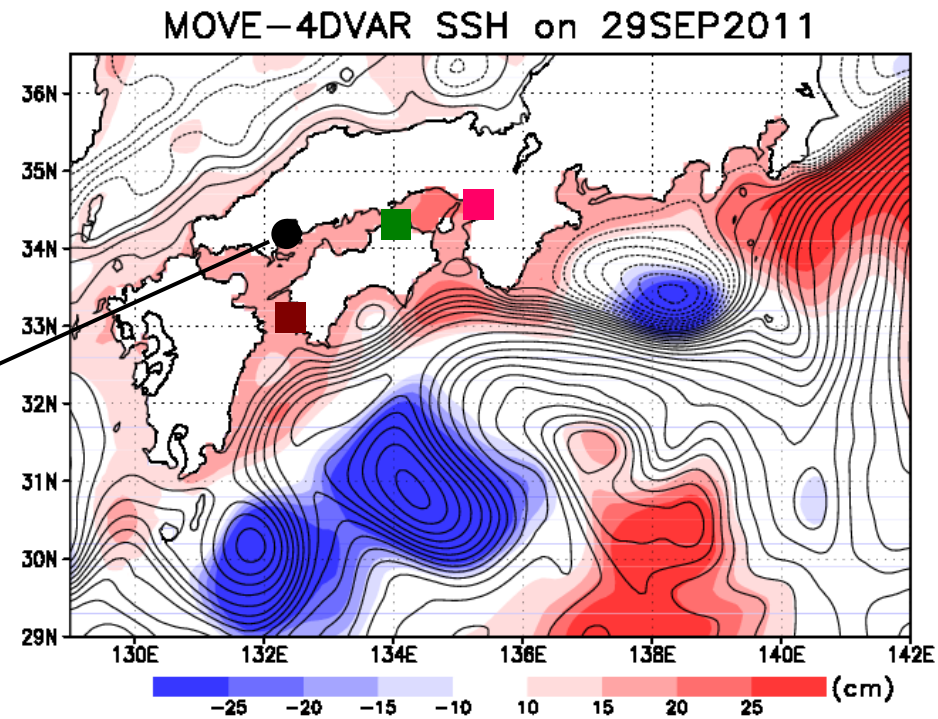




Unusual high tide in September 2011

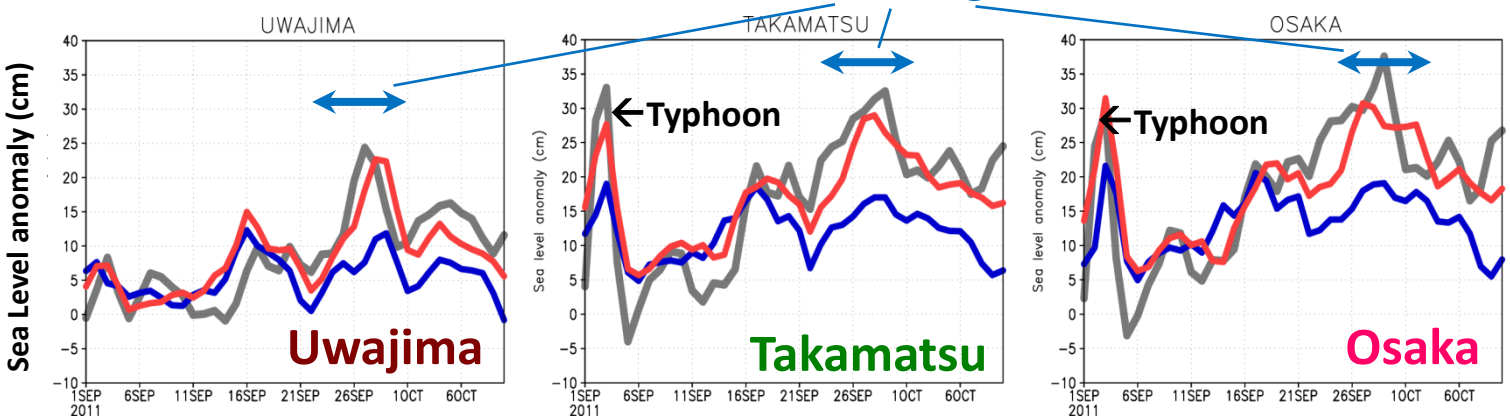
- SLAs exceed 20cm at south coast of Japan in the end of Sep 2011

Itsukushima shrine



SSH (contour) and SSH anomaly (shade)

Unusual high tide



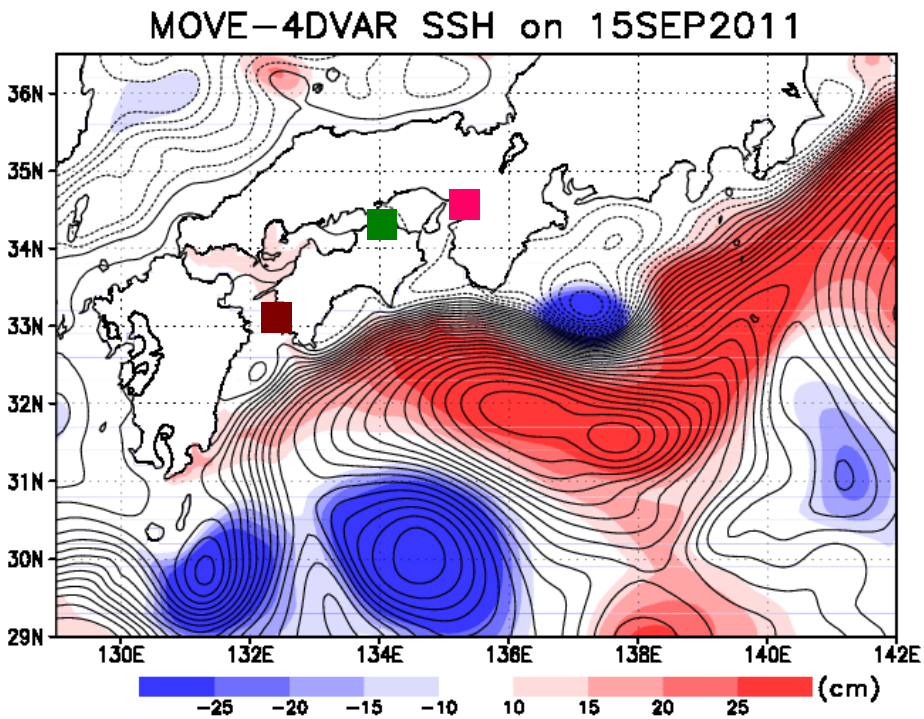
Tide-gauge

Present system (MOVE-WNP)

New system (MOVE-Seto)

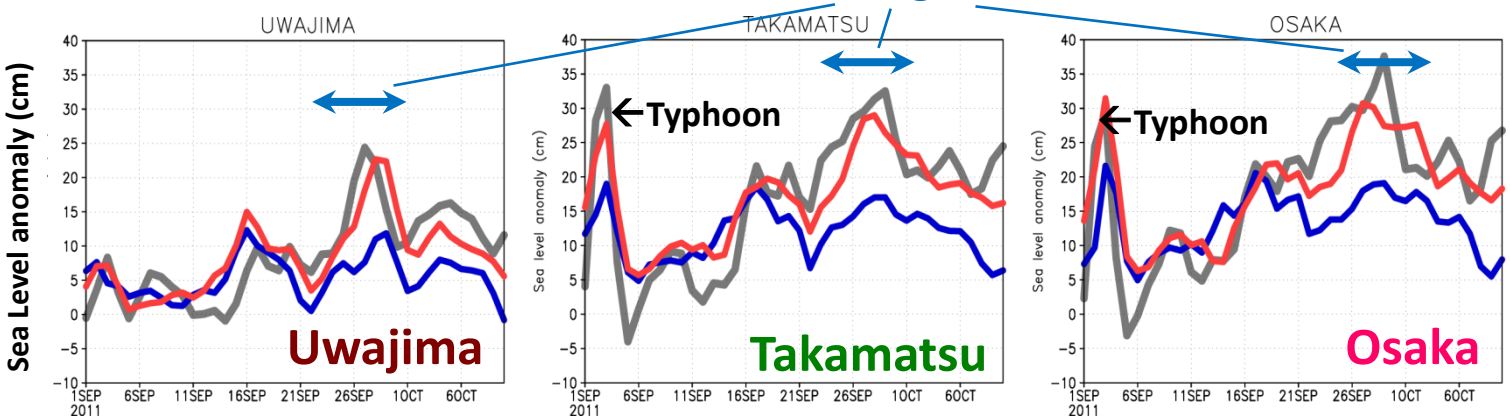
Unusual high tide in September 2011

- SLAs exceed 20cm at south coast of Japan in the end of Sep 2011
- The new system succeeded in reproducing this event
- The sea-level rise associated with this event was caused by coastal trapped waves induced by a Kuroshio path fluctuation



SSH (contour) and SSH anomaly (shade)

Unusual high tide



Tide-gauge

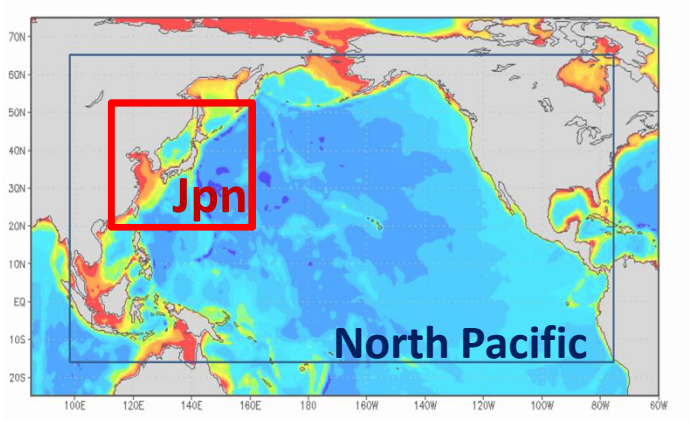
Present system (MOVE-WNP)

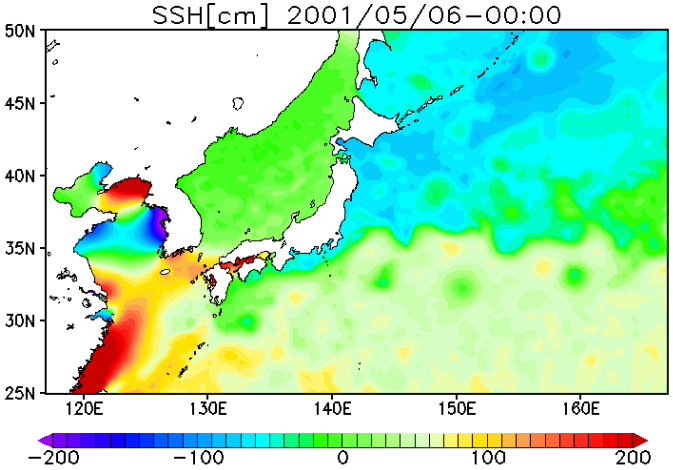
New system (MOVE-Seto)

Toward development of MOVE/MRI.COM-Jpn

Model configuration:

- Model Japan (MRI.COM-Jpn)
  - Covers the whole coastal regions of Japan
  - Same numerical model (MRI.COM)
  - Same horizontal resolution (~ 2km)
- Uses up-to-date schemes
  - Explicit tidal forcing (Sakamoto et al. 2013)
  - Improves river runoff using JMA operational NWP products
  - Incorporates sea ice model
  - Introduces Z*-coordinate
  - New turbulence closure (GLS)
  - Online two-way nesting

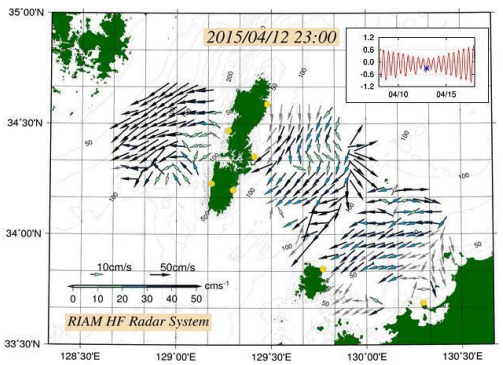




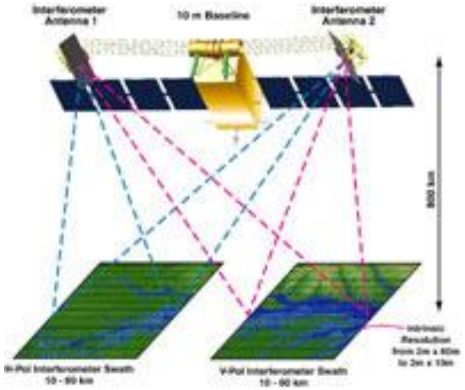
Toward development of MOVE/MRI.COM-Jpn

Data assimilation:

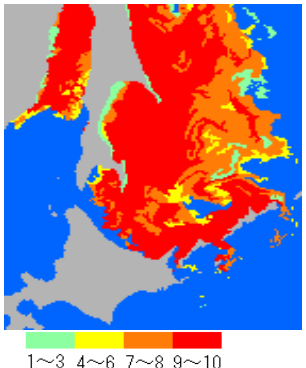
- Improve DA scheme
  - Extends control variables (velocity, external forcing, …)
  - Effective method to initialize high-resolution coastal model
- Use of new observations for assimilation
  - Velocity observations (HF radars)
  - High-resolution 2D SSH (SWOT, COMPIRA)
  - Coastal sea-level (tide gauge observations)
  - Sea ice concentration (for Sea of Okhotsk)



http://le-web.riam.kyushu-u.ac.jp/radar/



https://swot.jpl.nasa.gov/



Sea ice concentration

Summary

- Coastal monitoring and forecasting system around the Seto Inland Sea (MOVE/MRI.COM-Seto)
  - Will be in operation at JMA soon
  - Fine resolution coastal model (MRI.COM-Seto)
    - 2km resolution
    - Represents realistic short-term and small-scale processes
  - 4DVAR assimilation scheme (MOVE-4DVAR)
    - Enhances short-term variability compared to 3DVAR
    - Succeeds in reproducing the unusual tide event in September 2011
- Next generation system: MOVE/MRI.COM-Jpn
  - Covers the whole coastal regions of Japan with 2km resolution
  - Use of up-to-date model schemes
  - Use of new observations for data assimilation

Thank you

3DVAR 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**

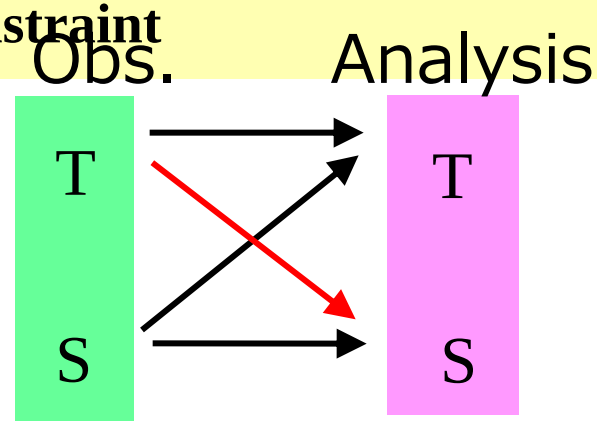
$$J = \frac{1}{2}\sum_m \sum_l \mathbf{y}_{m,l}{}^T \mathbf{B}_l^{-1} \mathbf{y}_{m,l} + \frac{1}{2}\left[\mathbf{H}\mathbf{x}(\mathbf{y}) - \mathbf{x}^0\right]^T \mathbf{R}^{-1}\left[\mathbf{H}\mathbf{x}(\mathbf{y}) - \mathbf{x}^0\right]$$

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

Constraint for SSH observation **Constraint**

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