Ocean reanalysis at the GMAO

Guillaume Vernieres, Siegfried Shubert, Robin Kovach, Yuri Vikhliaev, Christian Keppenne, Santha Akella, Matt Thompson, Richard Cullather, Bin Zhao, Anna Borovikov, Gregg Watson, Cecile Rousseaux, Nathan Kurtz, …, the forgotten

Overview of MERRAOcean (1978-present)

- Models
- Ocean observing system
- Assimilation methodology
- Some diagnostics

Current development

- Modeling/DA:
  - SST (Santha)
  - Wave (Matt, Santha)
  - $\frac{1}{4}$ degree Ocean modeling (Yuri)
  - Carbon fluxes (Watson, Cecile)
- New observing systems:
  - SSS (Aquarius Ludovic, Emanuel, Santha, …)
  - Sea-Ice Freeboard (CryoSat, OIB, … Nathan Kurtz)
  - GRACE
  - Reconstructed Sea-level

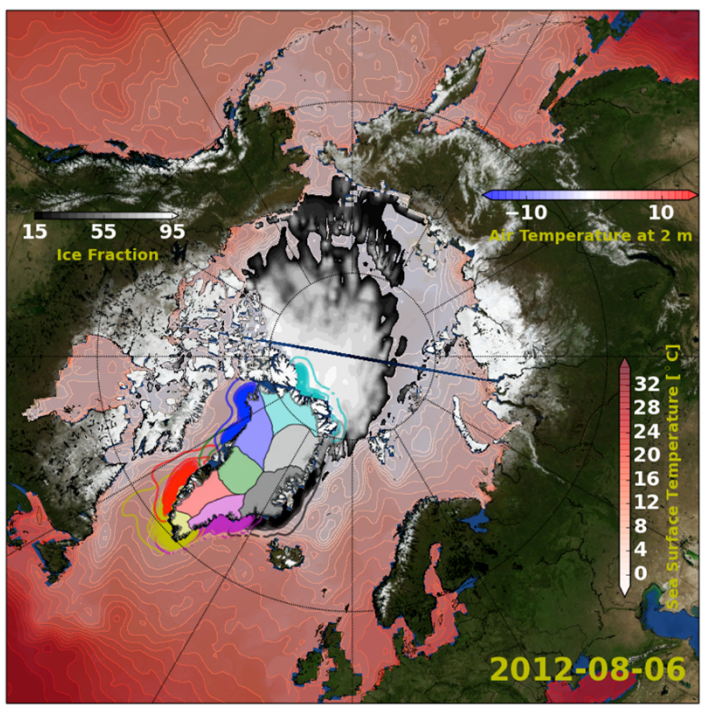
Coupled GEOS for the current MERRAOcean*(GMAO Ocean Sea-Ice reanalysis*

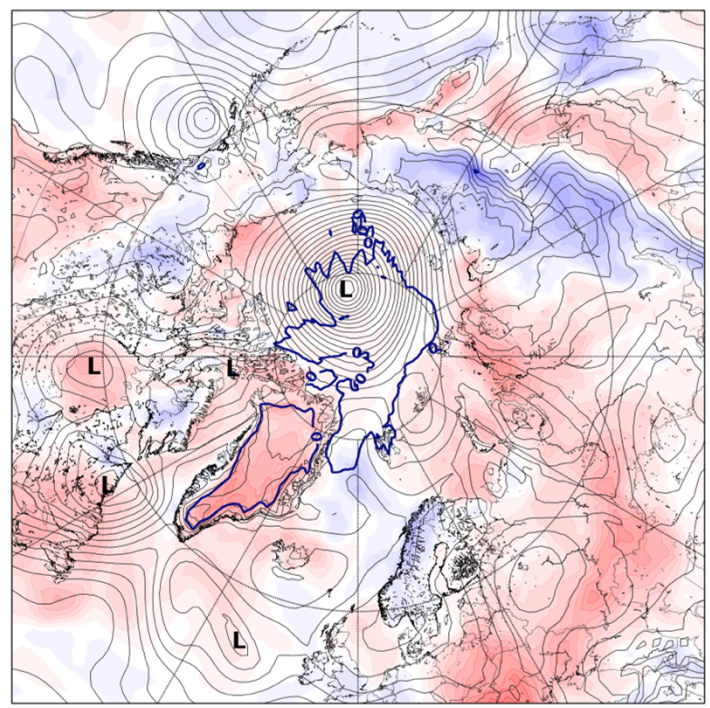
Ocean: MOM4p1 ($\frac{1}{2}$ degree tripolar ocean grid resolution, 40 vertical levels)

Sea-Ice: CICE (Los Alamos National Laboratory)

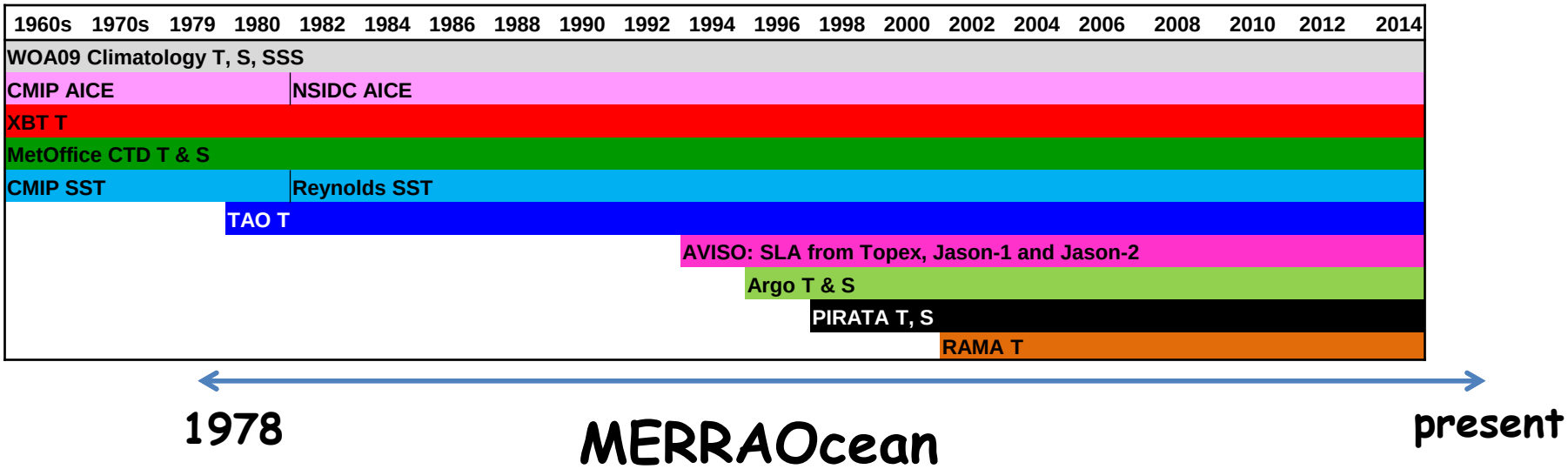
Atmosphere: Fortuna 2.5 constrained to MERRA

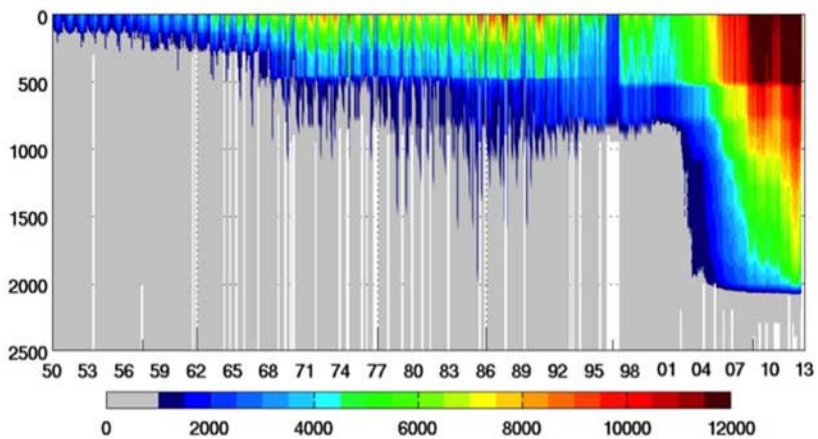
Ex: 2012 minimum sea-ice extent





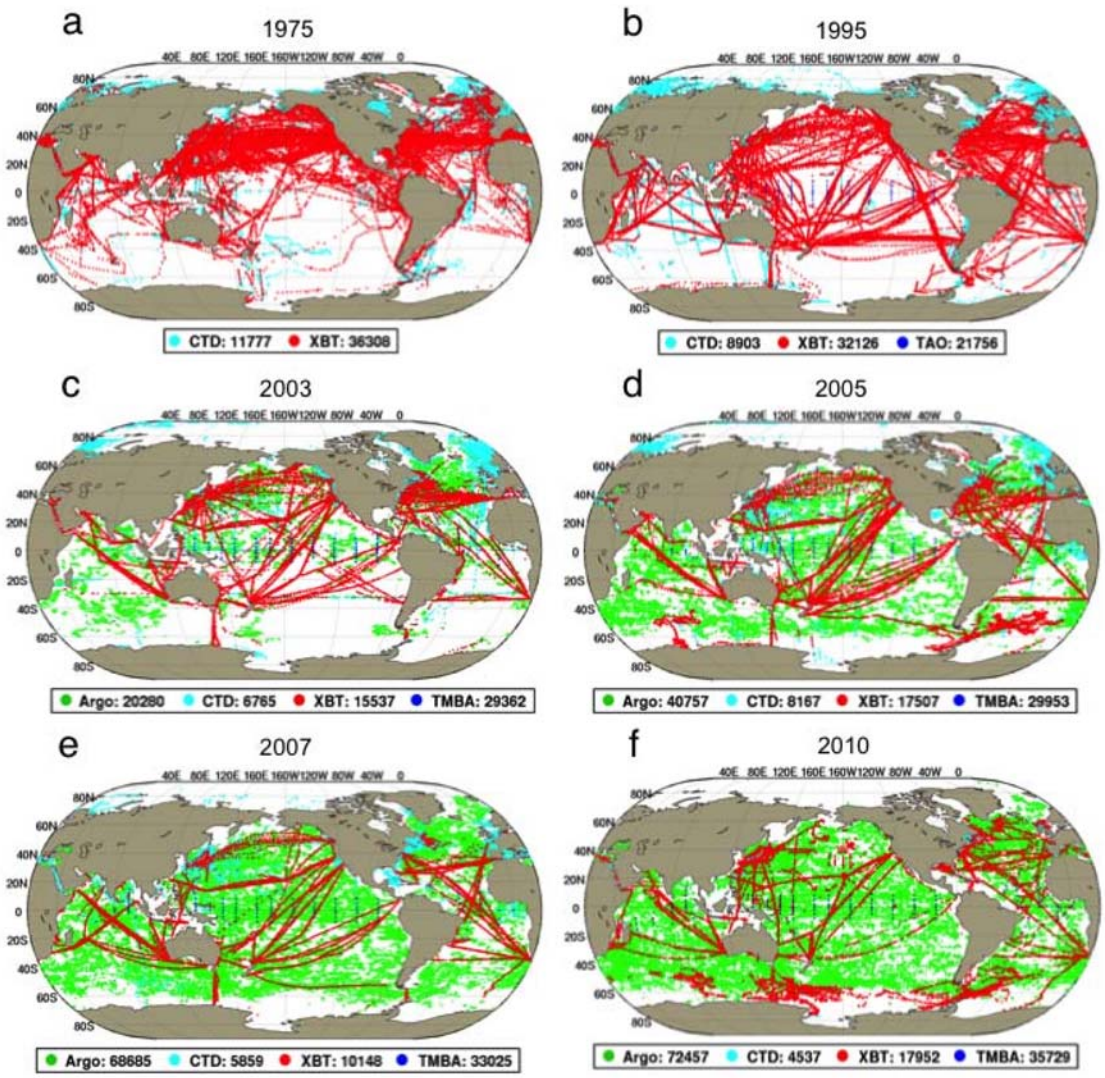
Ocean Sea-Ice Observing System





In-situ obs count as a function of depth [obs/month]

Ocean Sea-Ice Observing System



Mostly Temperture profiles,
very few Salinity measurements

Distribution of *In-situ* observations

Assimilation methodology: EnOI

Static ensemble from EOFs of hindcast anomalies (T, S, U,V, SSH, …)

Background state X_b

Observations Y_o

iODAS ***(Keppenne, 2008)***

$$X_a - X_b = \rho P H^T (H \rho P H^T + R)^{-1} (Y_o - H X_b)$$

Analysis increment applied to MOM and CICE using IAU *(Bloom et al., 1995)*

Assimilation methodology: EnOI

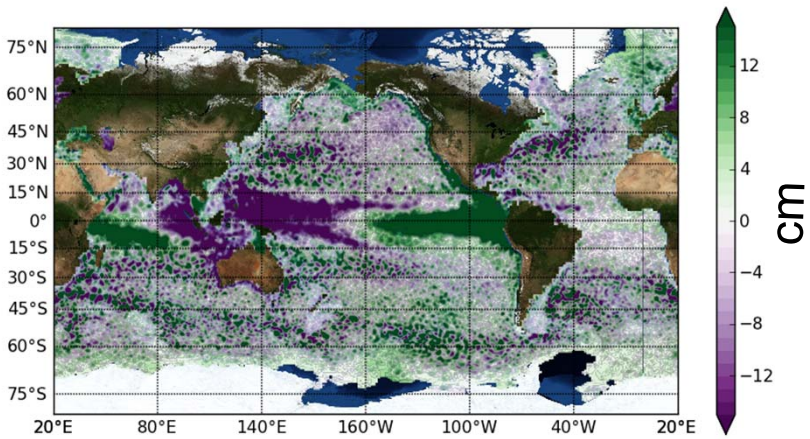
Use covariances from static background error to:

- Estimate S from T observations
- Estimate Ocean density from altimeter

Assimilation methodology: EnOI

Sea level anomaly as a predictor of the 3D ocean temperature

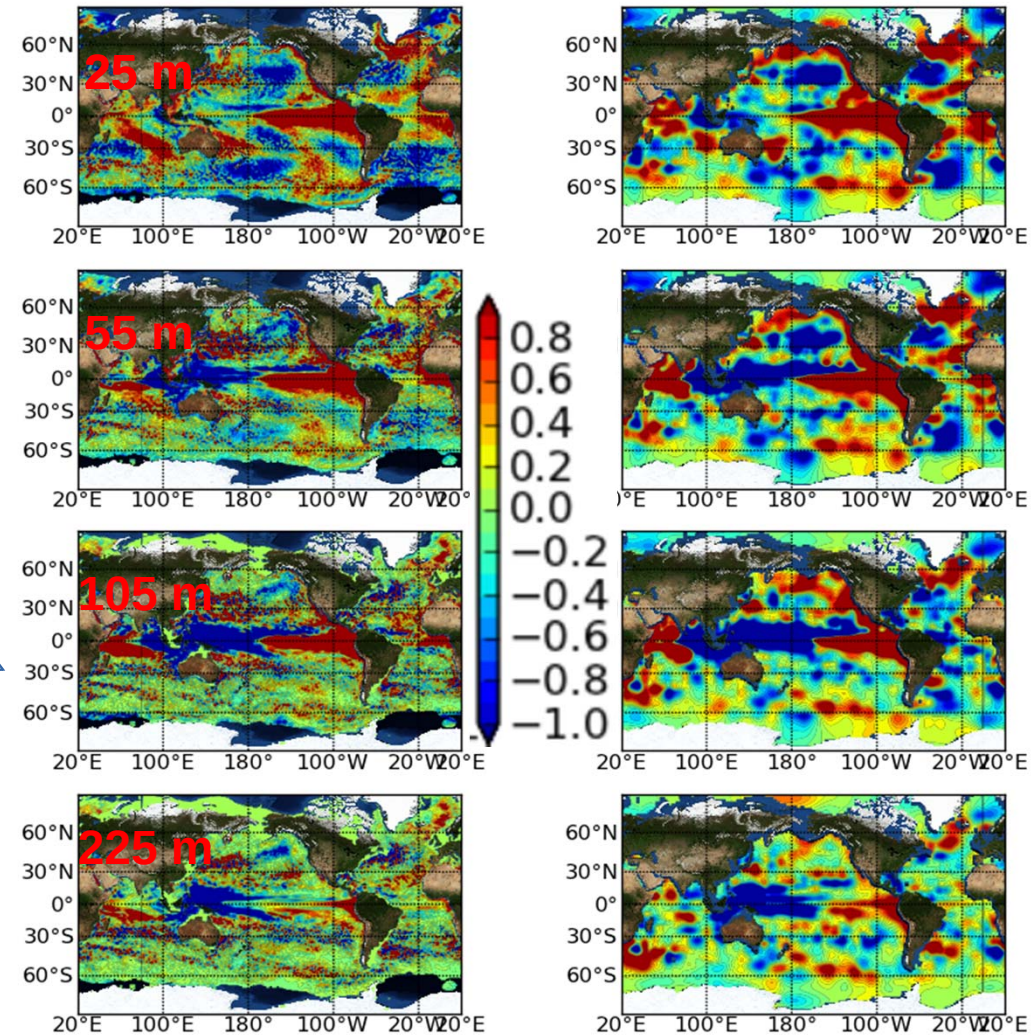
Sea level anomaly (SLA) DEC 1997



Projection of SLA onto the 3D Ocean Temperature using Covariances estimated from the joint EOFs of the GEOS5 coupled system

Temperature anomaly DEC 1997 (Celsius)

Estimate from SLA | **EN3 (*in-situ* based analysis)**



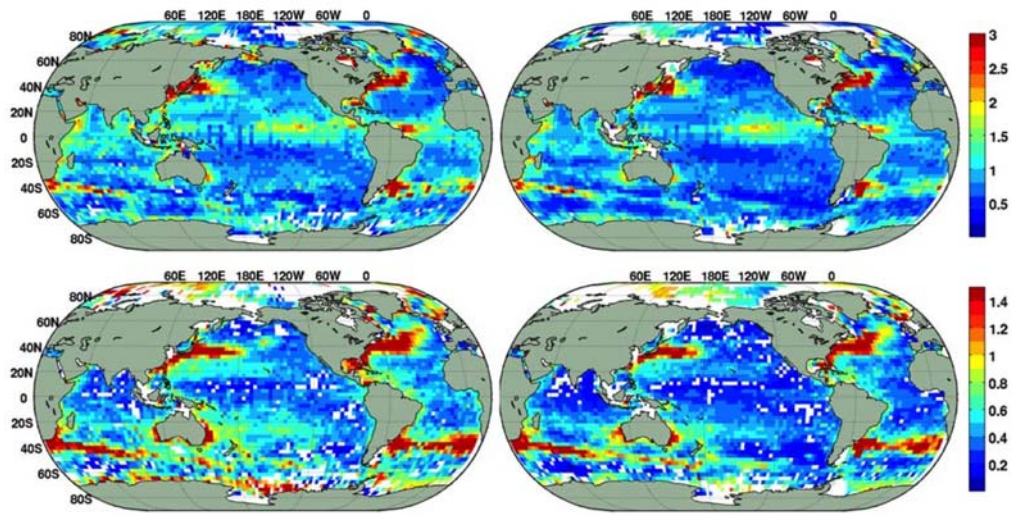
Diagnostics: RMS of OMF

1993-2005 2005-2011

Temperature [°C]

0-300 m

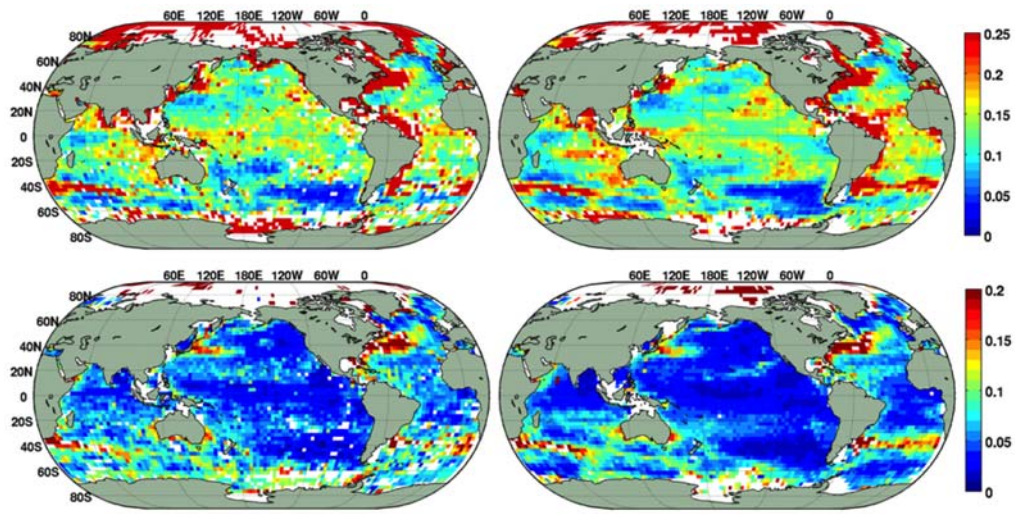
300-1000 m



Salinity [psu]

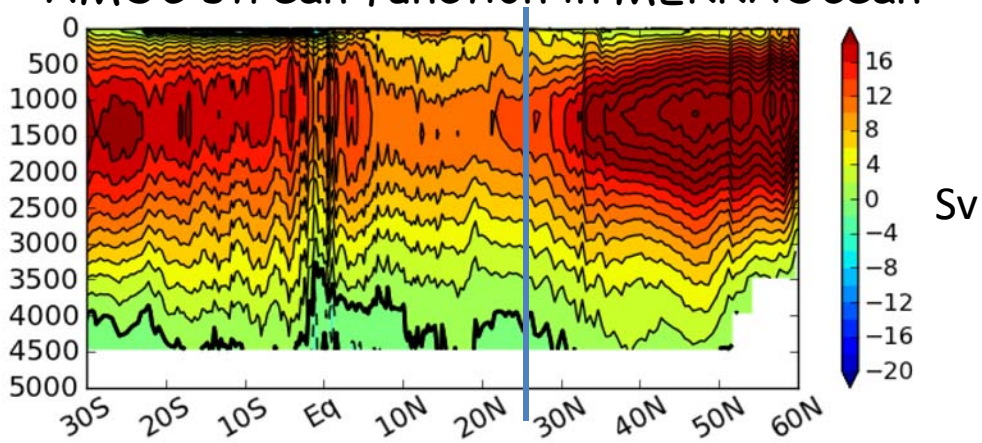
0-300 m

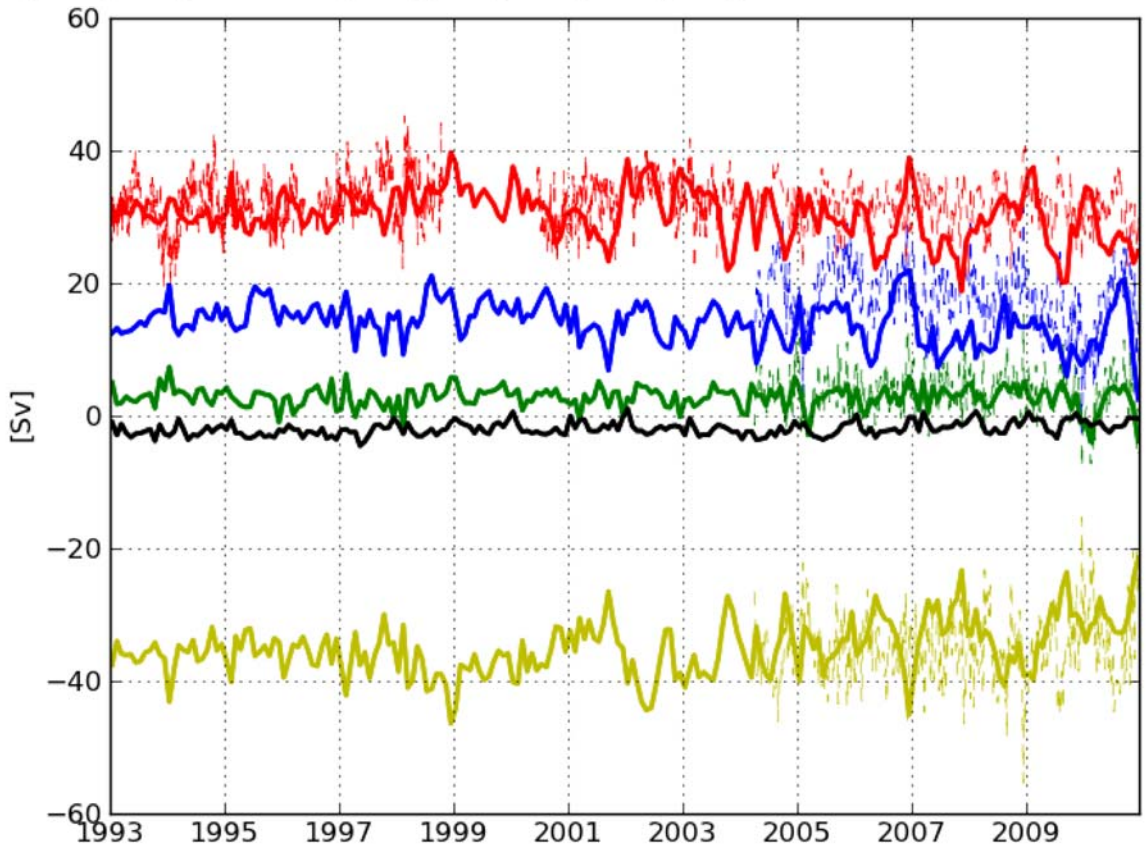
300-1000 m



Diagnostics: Over turning circulation (RAPID array)

AMOC strean function in MERRAOcean





Source: NASA/JPL-Caltech

Transports at 26.5N:

Total
Florida strait
Ekman
Mid-Ocean
AMOC

Current development

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Skin SST development (modeling & analysis)

Santha Akella

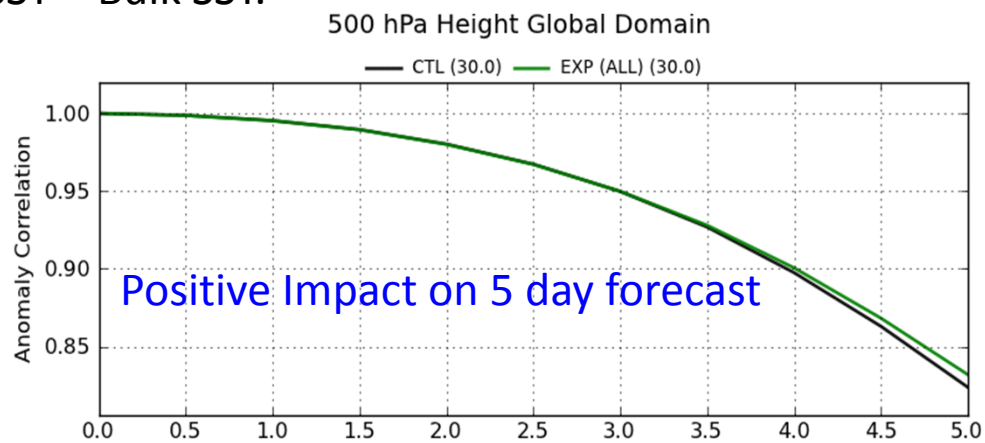
Current Atmospheric DAS configuration: Skin SST ≈ Bulk SST.

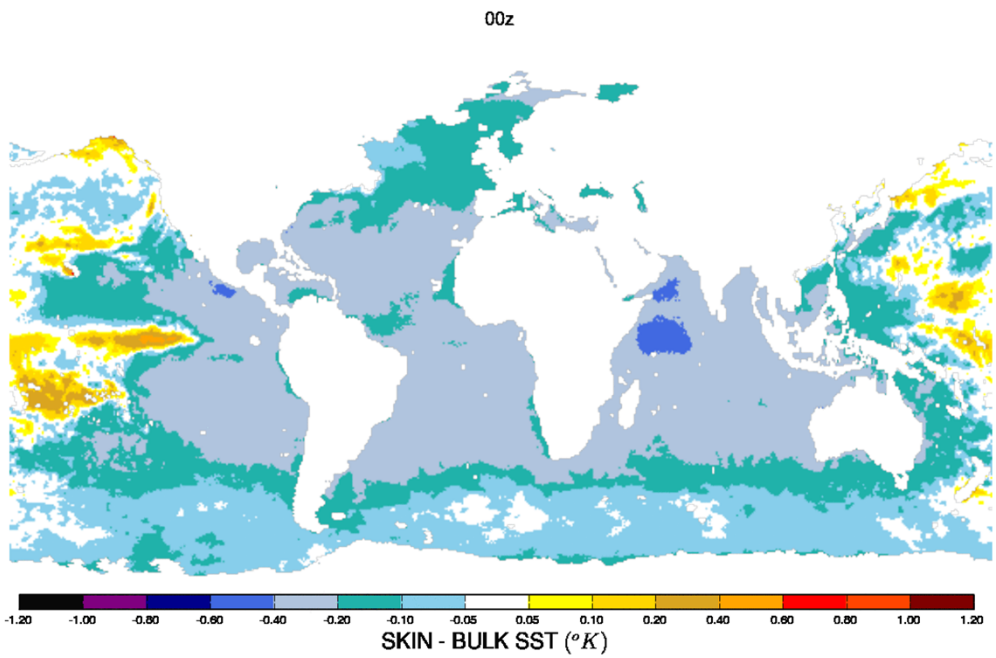
New system:

Skin SST = Bulk SST +

Diurnal warming – Cool skin +

Ana Increment





Analysis Increment:

- All surface-sensitive IR
- including 3 AVHRR channels
- MW (GMI, AMSR-2) in-progress

Bulk SST is from UKMO OSTIA

Skin SST development (modeling & analysis)

Weakly coupled- system:

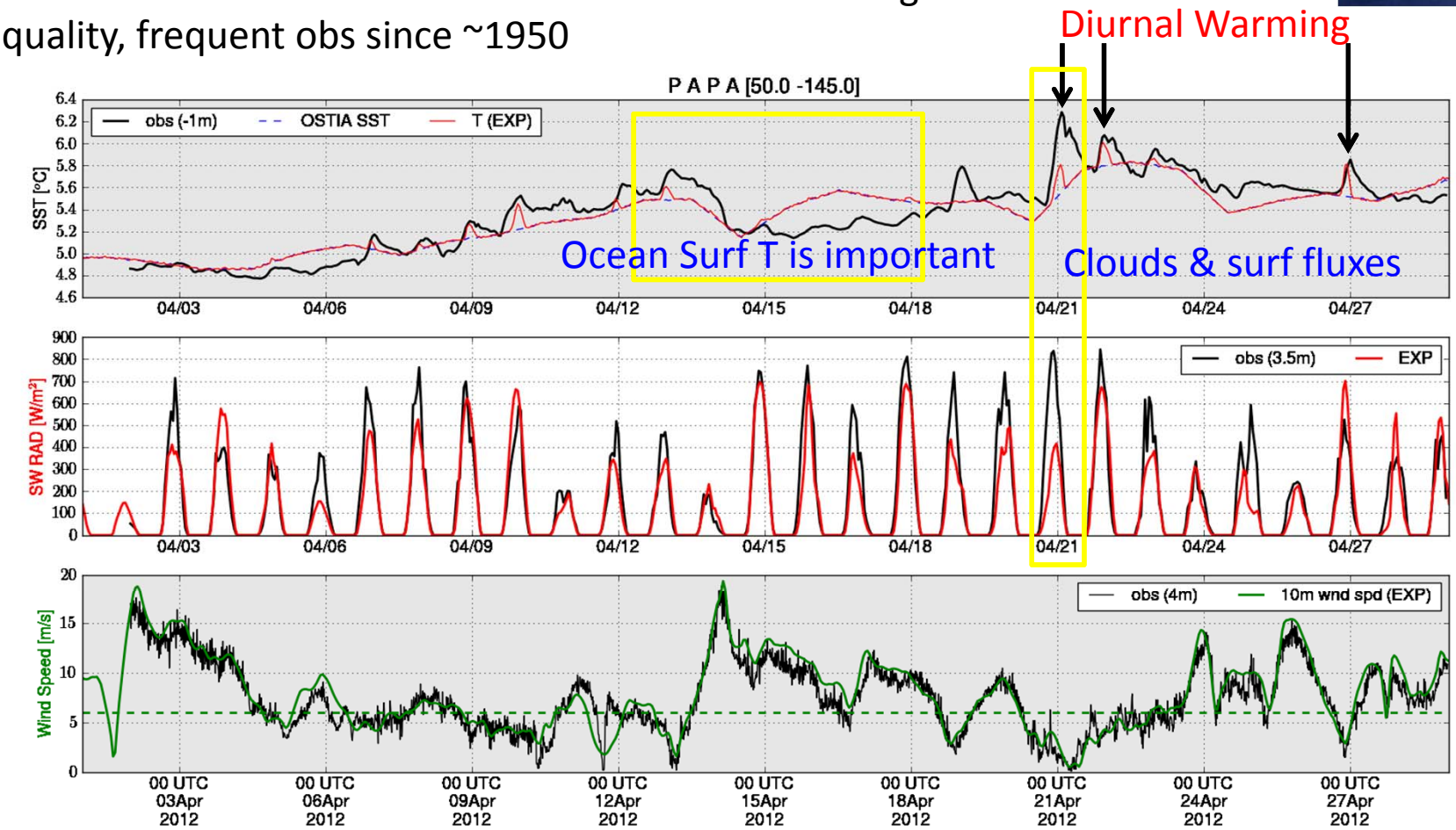
Skin SST = **Ocean surface T** + Diurnal warming – Cool skin + Atmos Ana Increment

Ocean surface T:

Model T + Ocean Ana Increment

NOAA-PMEL Ocean Climate Stn. PAPA "reference" mooring

High quality, frequent obs since ~1950

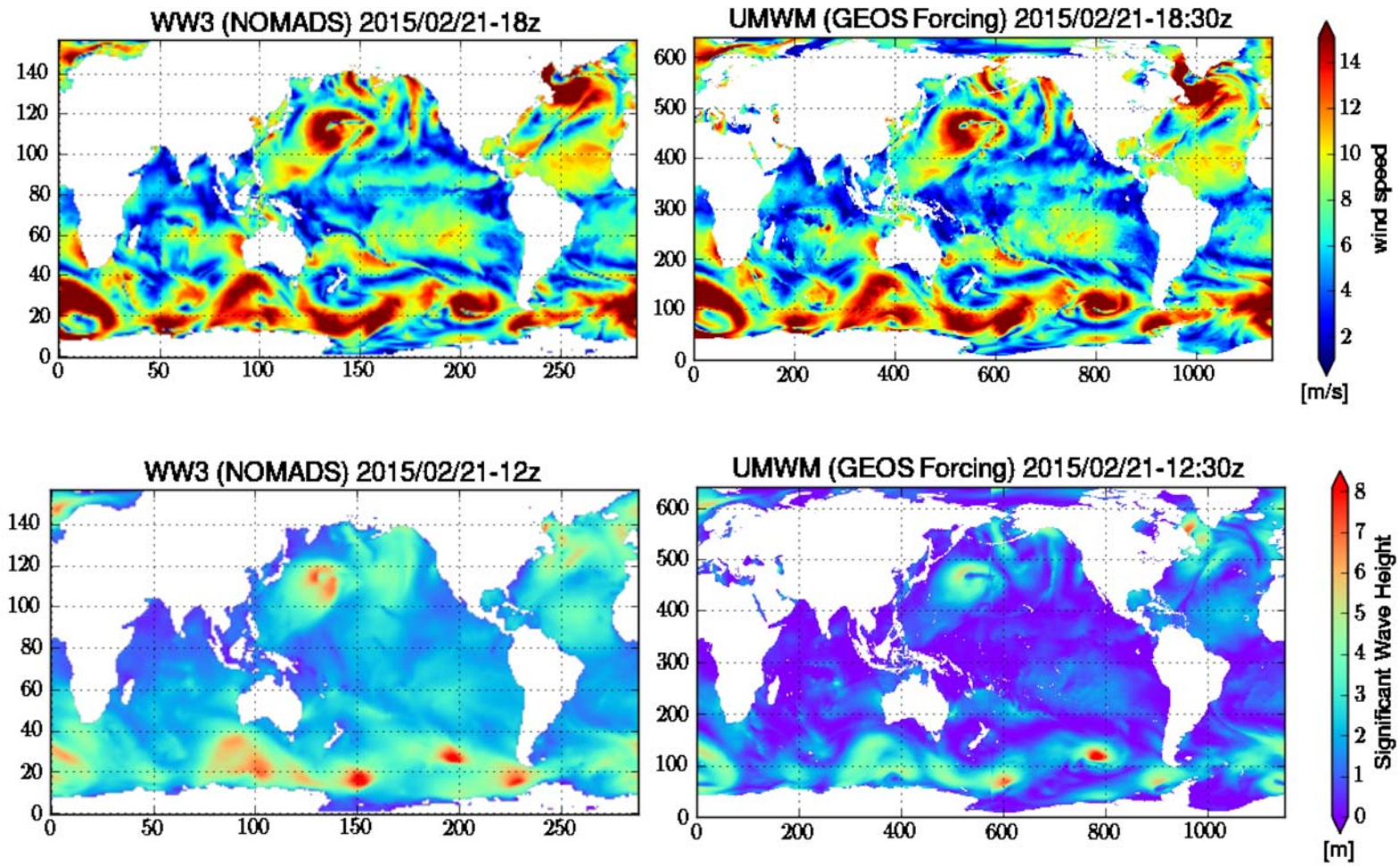


Wave Model

Santha Akella, Matt Thompson

University of Miami Wave Model (UMWM)

Validation: Comparison with WaveWatch III



¼ degree Ocean model for the next seasonal predicton system

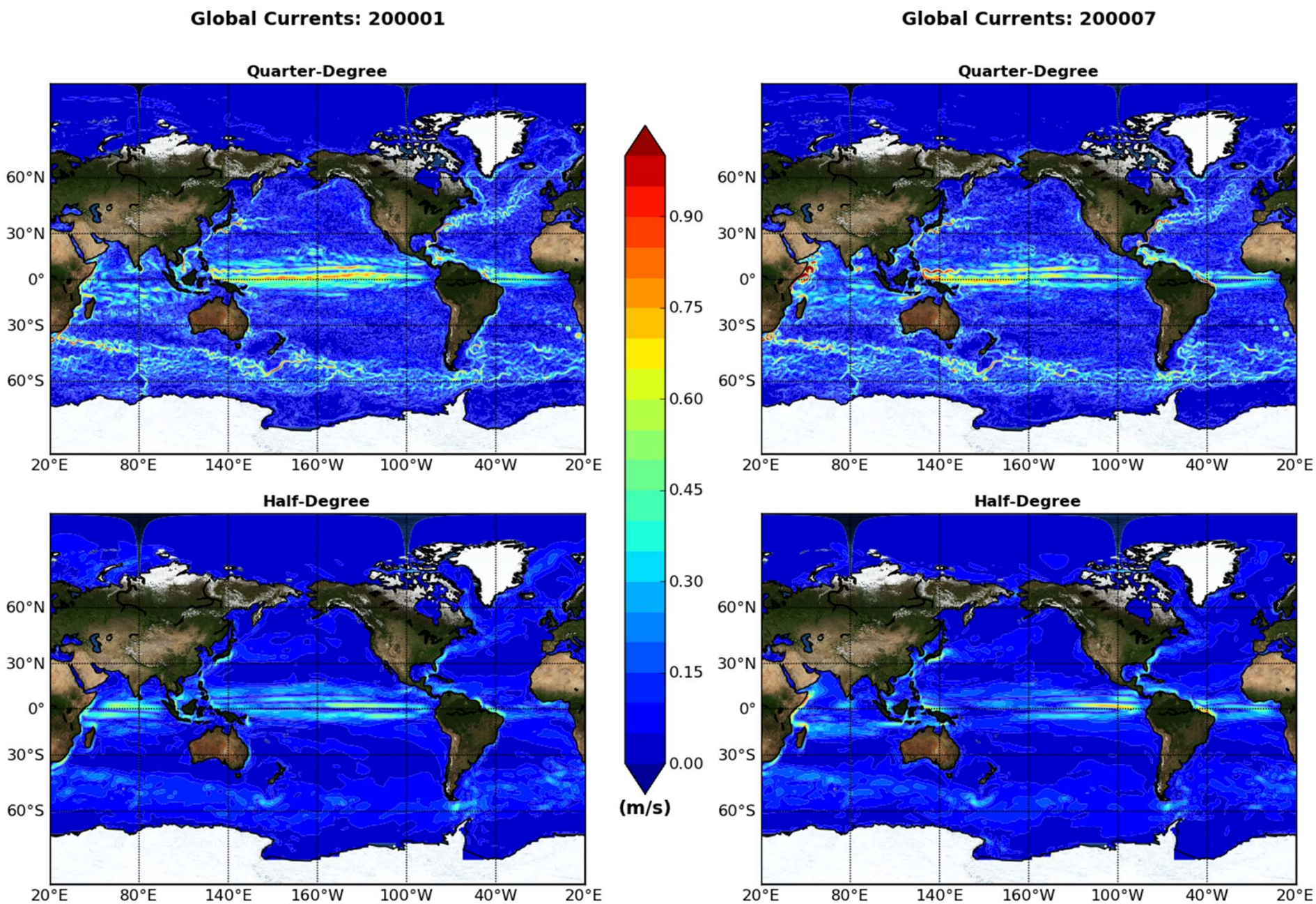
Yuri Vikhliaev (0.25 deg Ocean) and Christian Keppenne (0.1 deg Ocean)

Configuration:

AGCM: 0.50 cube sphere, 72 vertical levels;

OGCM: 1/4 tripolar, 50 vertical levels (MOM5).

¼ degree Ocean model for the next seasonal predicton system



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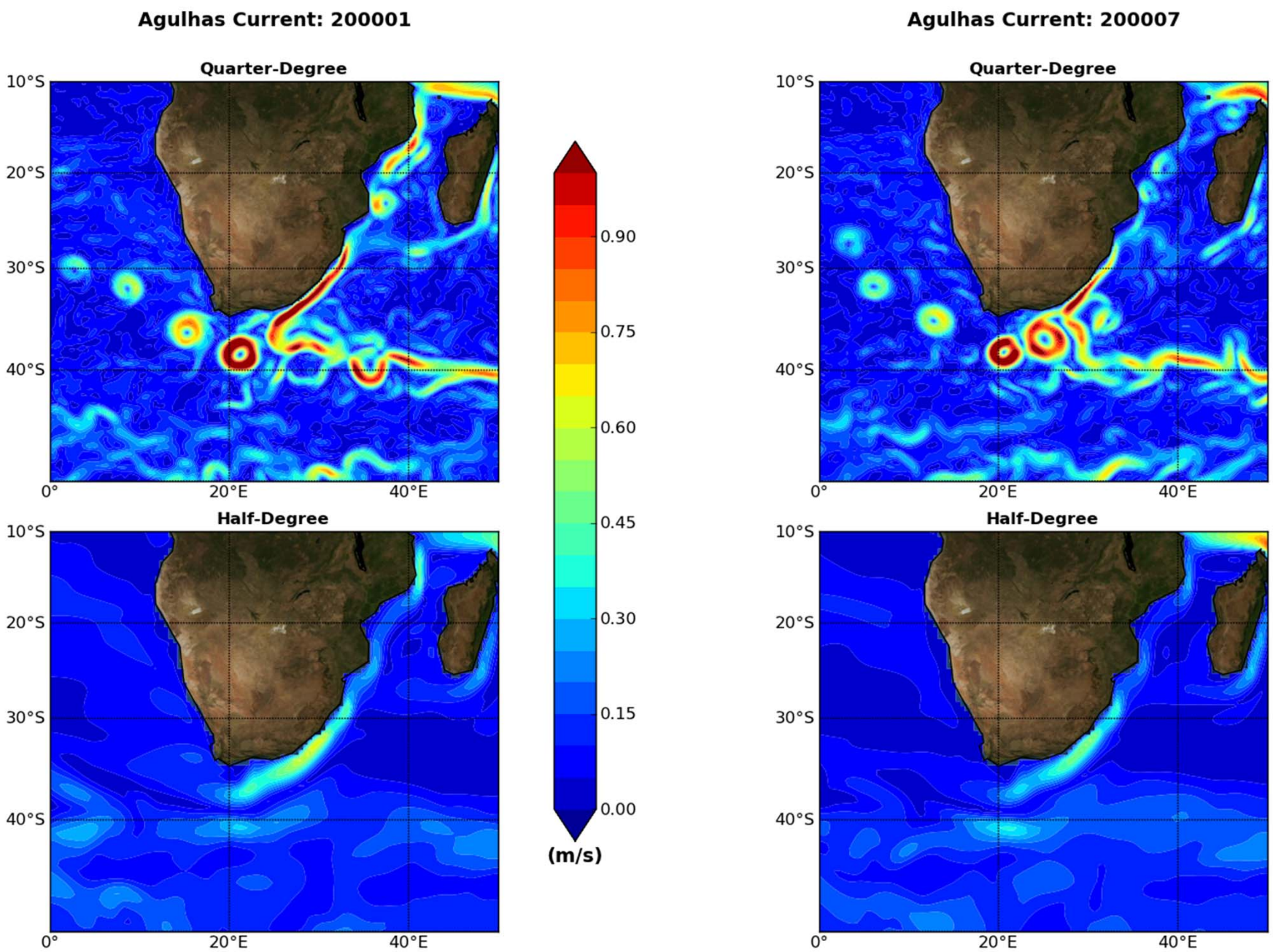

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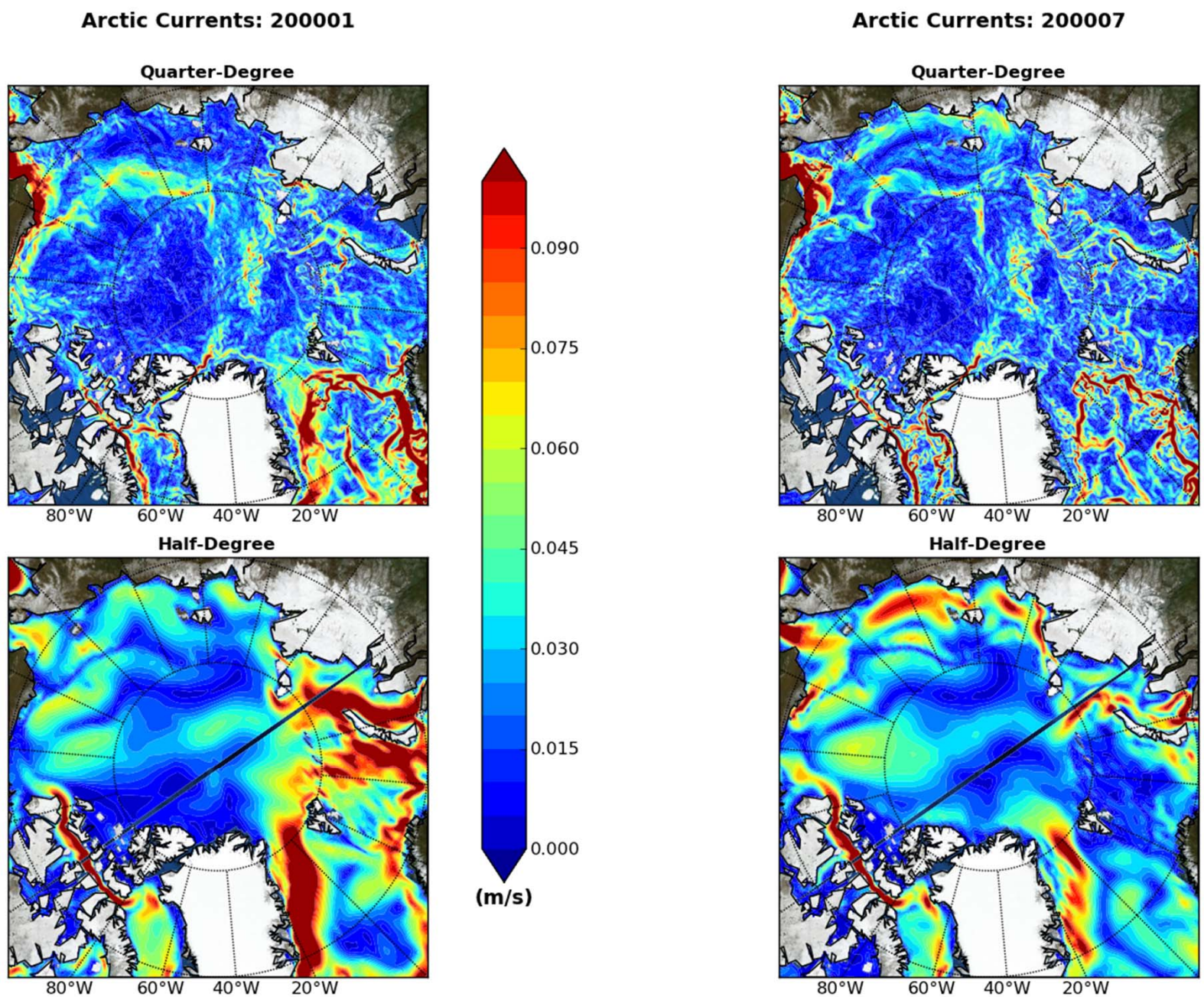

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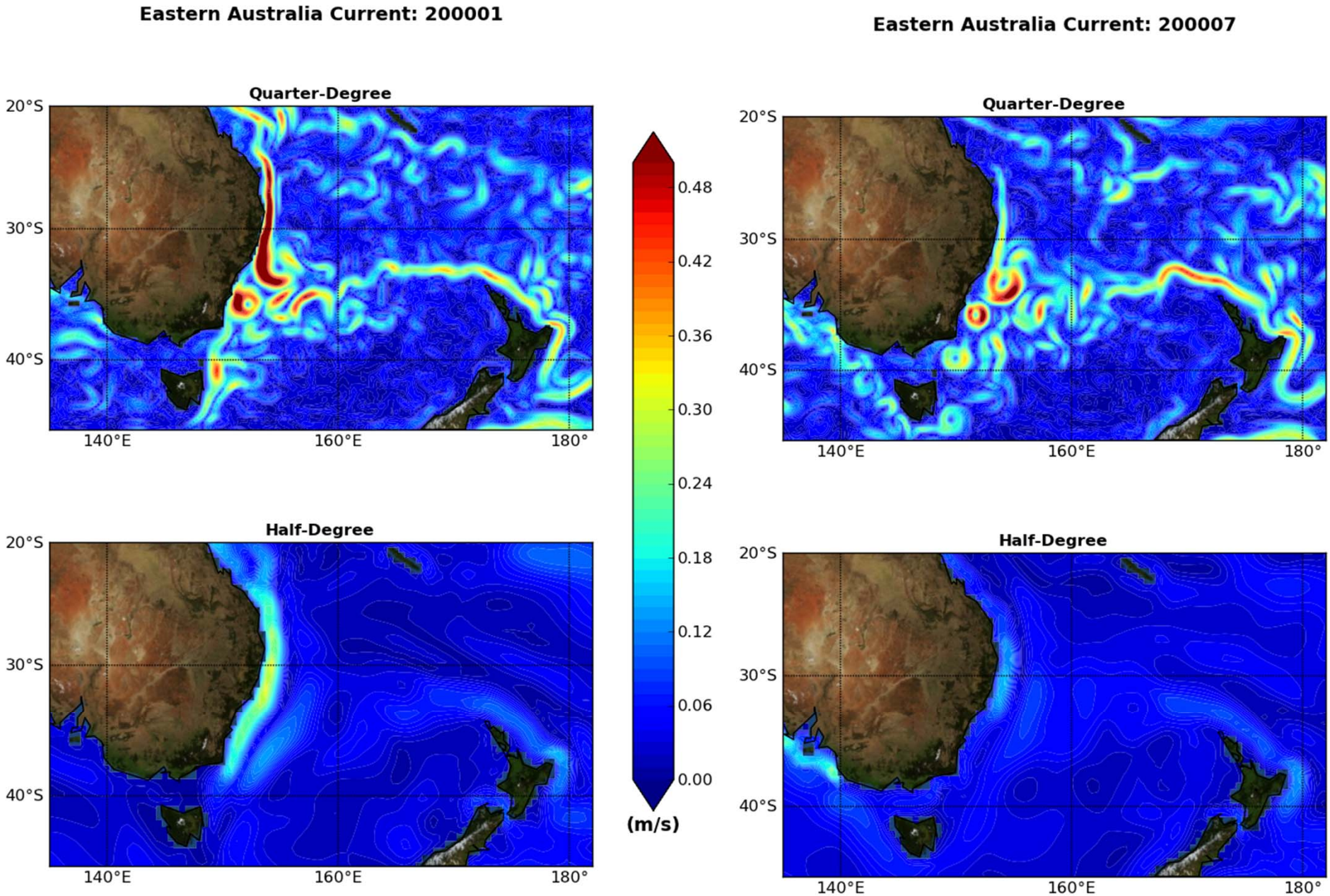

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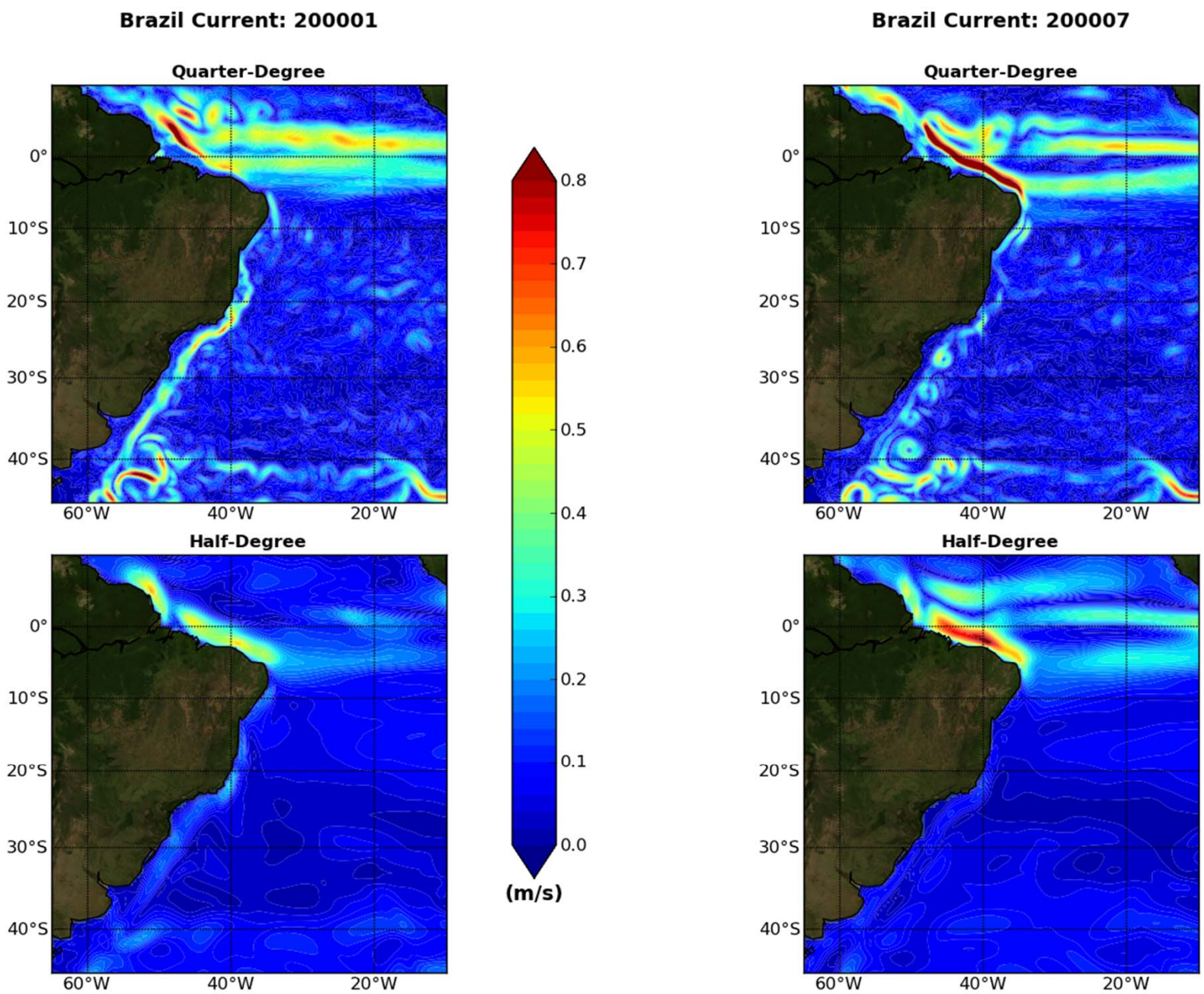

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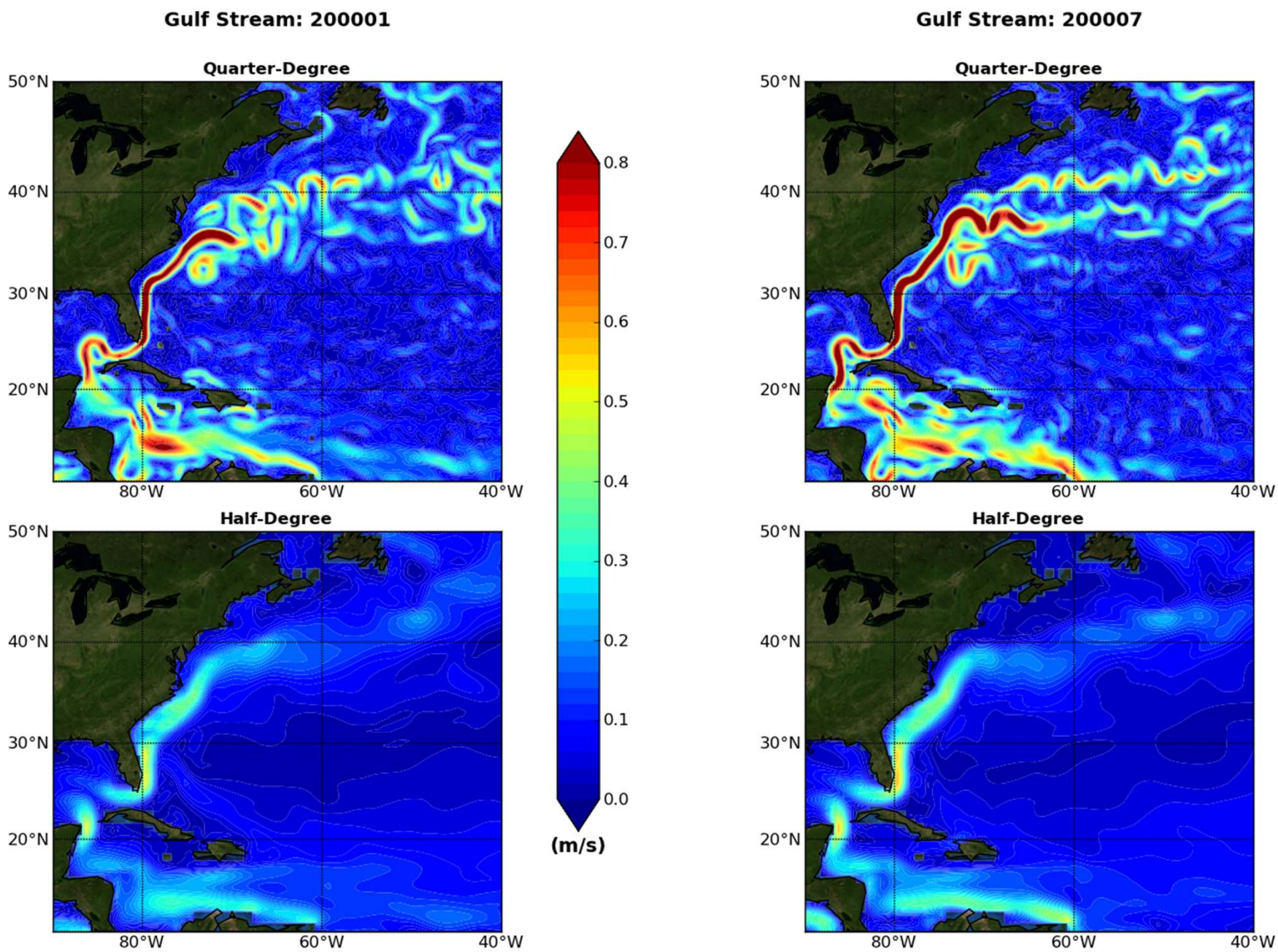

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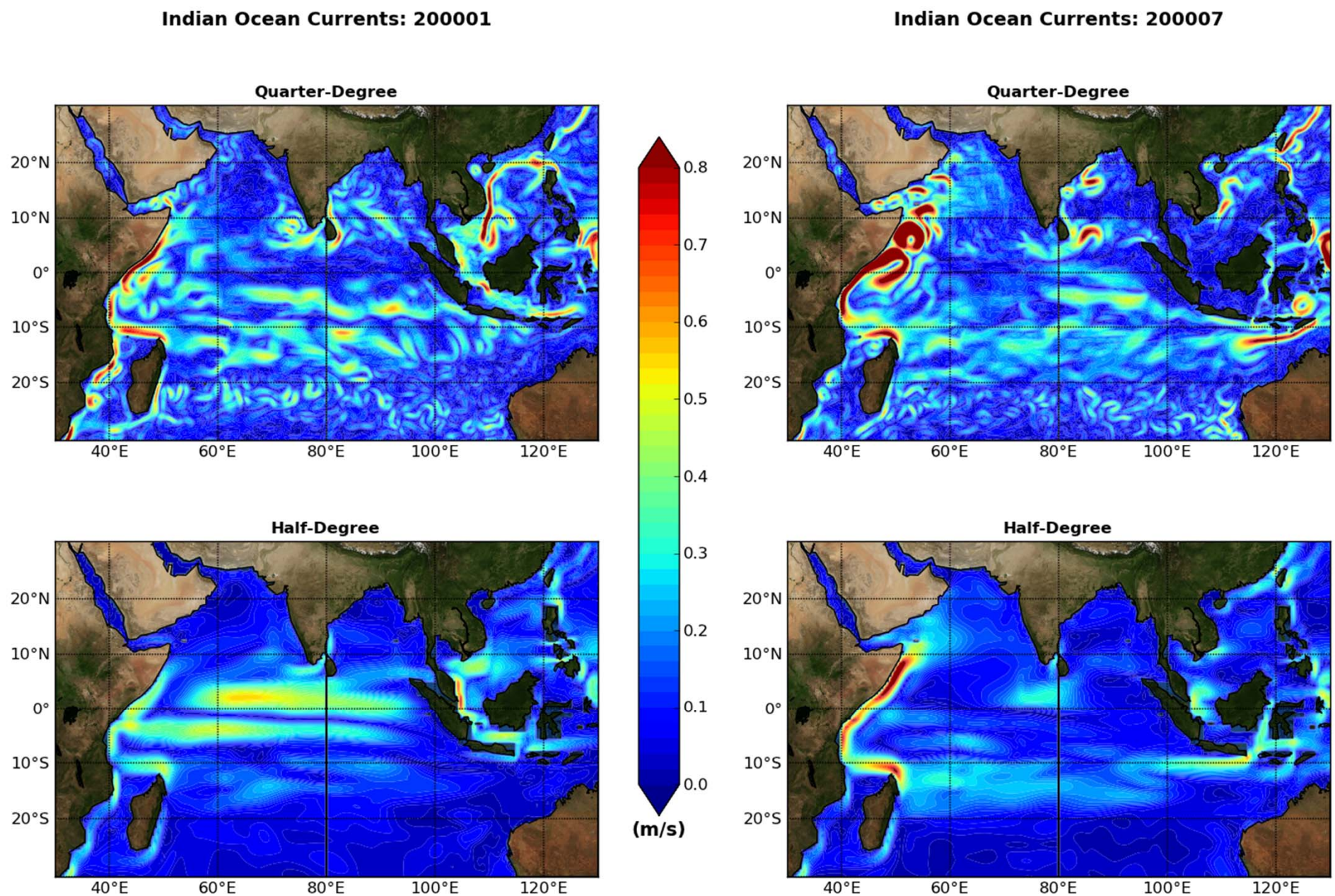

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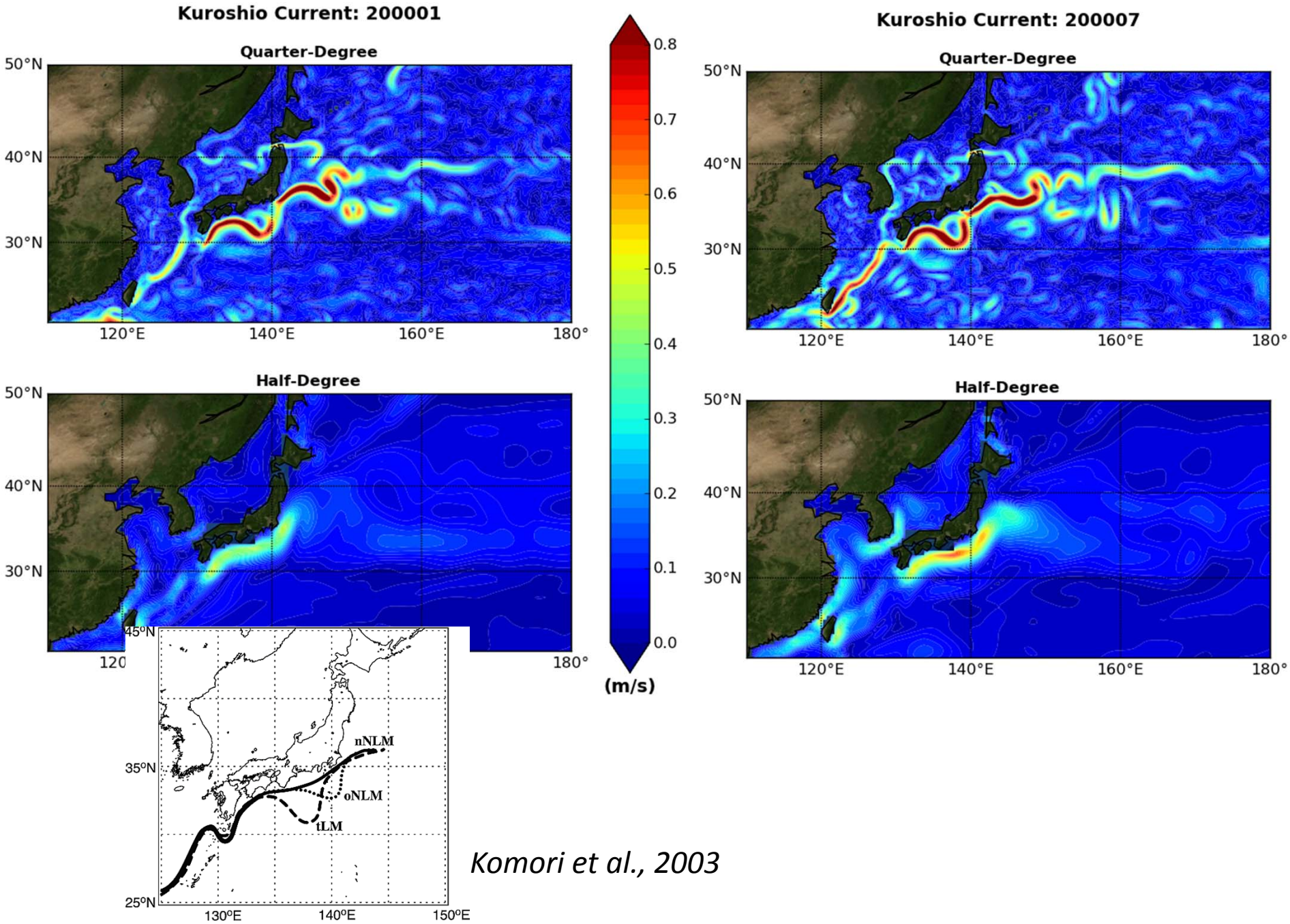
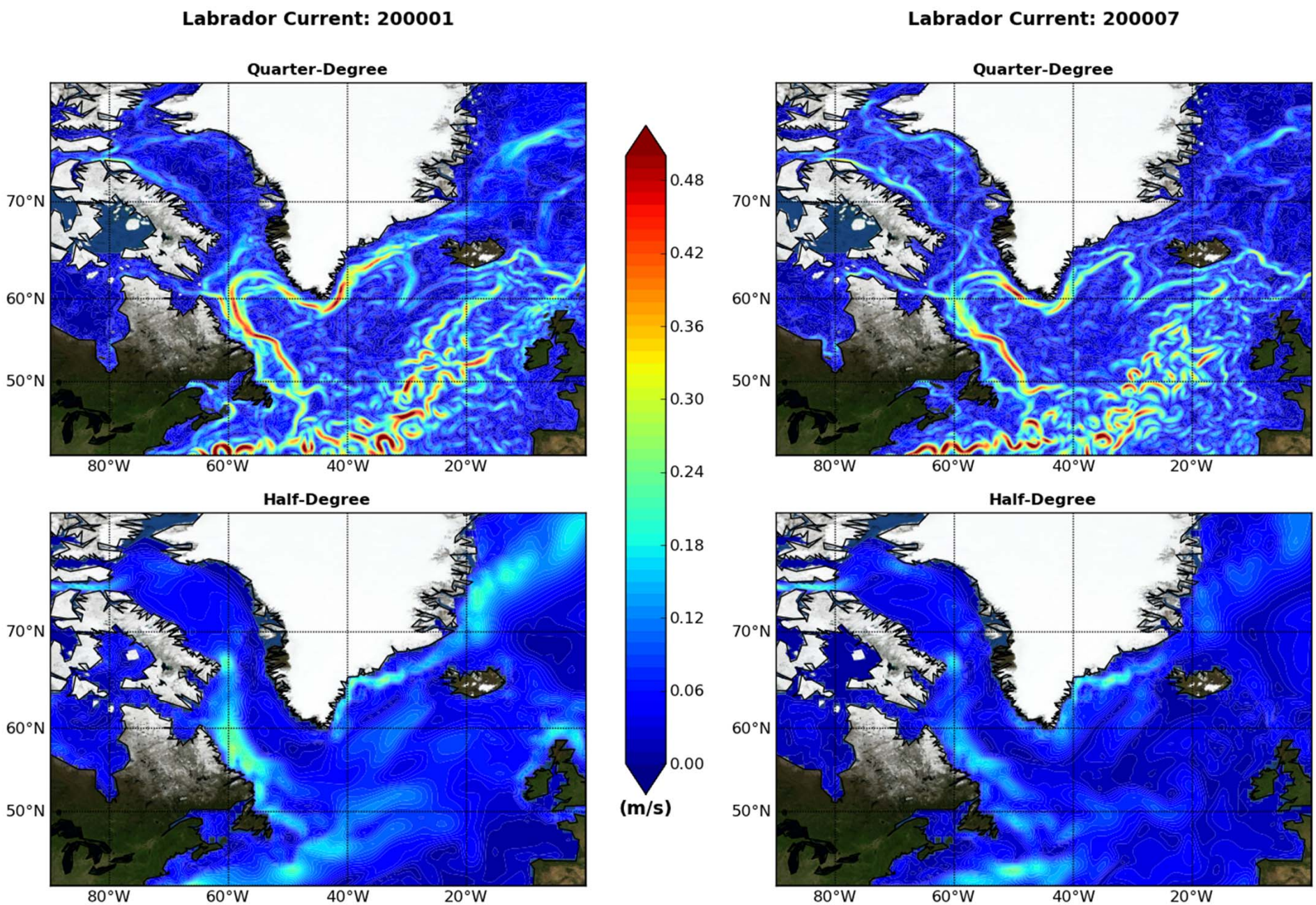
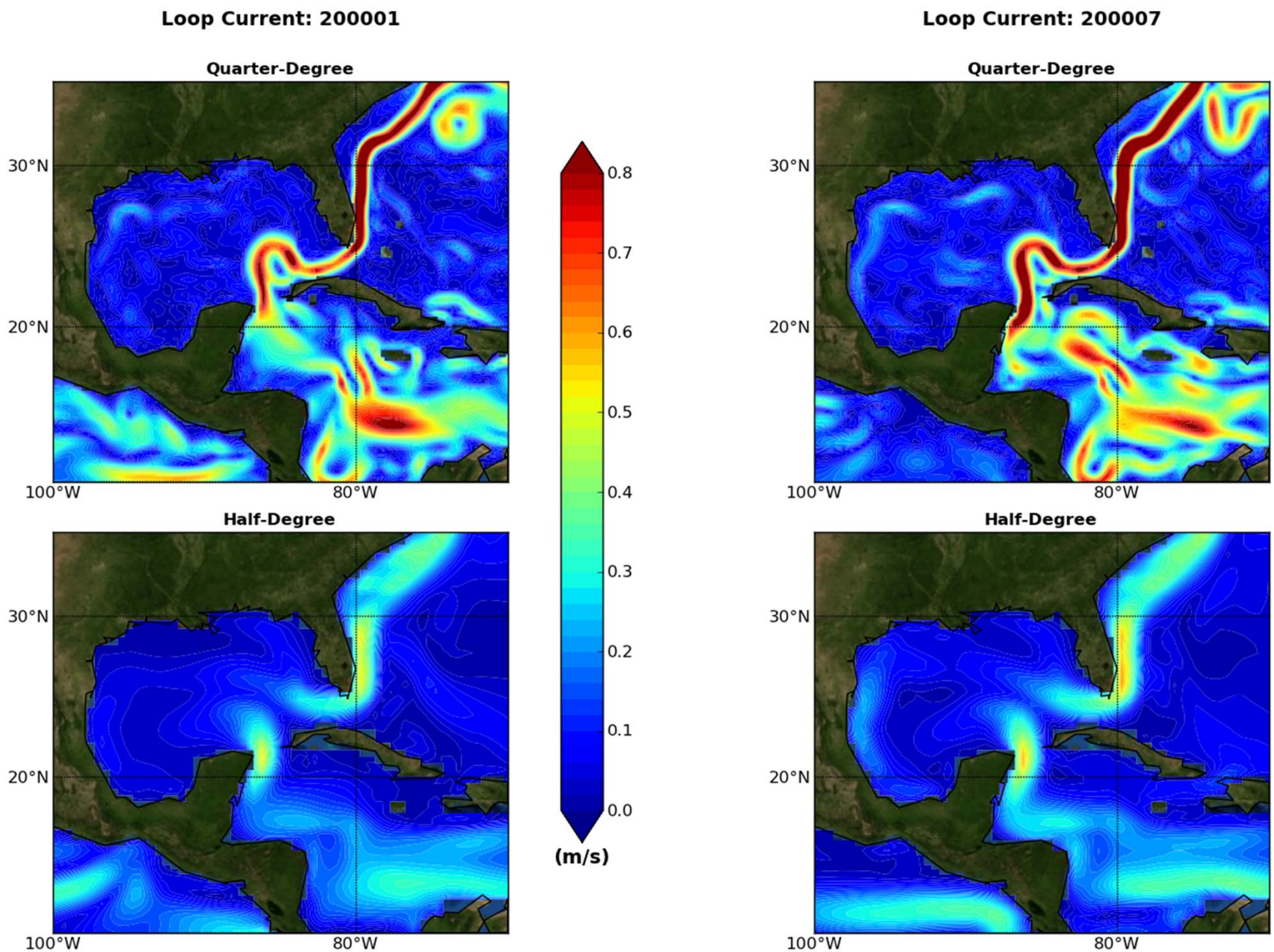


Komori et al., 2003

¼ degree Ocean model for the next seasonal predicton system



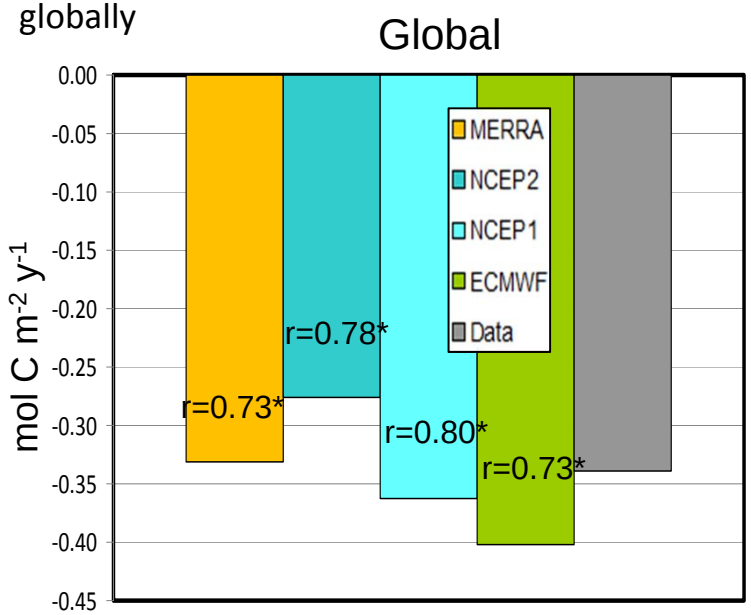
¼ degree Ocean model for the next seasonal predicton system



Carbon Fluxes using the NASA Ocean Biogeochemical Model (NOBM) *(Gregg, W.W. & Rousseaux, C.S.- Carbon Monitoring System)*

Existing Product:

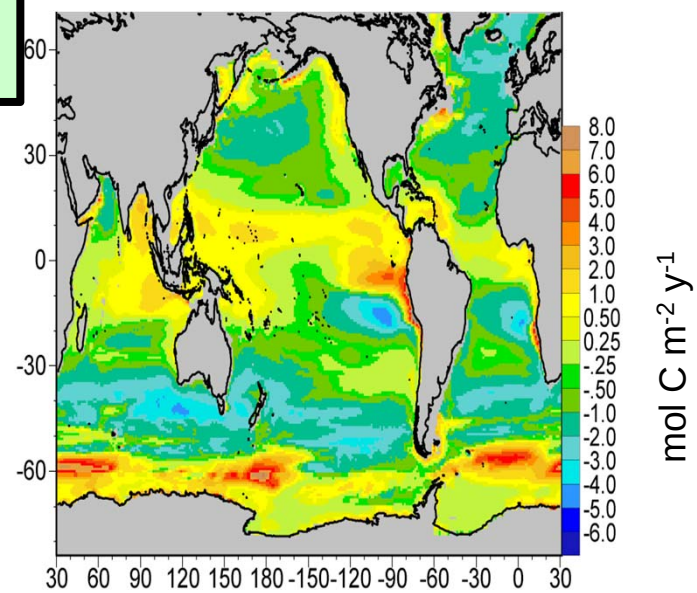
- Ocean pCO_2 and CO_2 fluxes from the NOBM-Poseidon
- Publicly available at carbon.nasa.gov for 2003-2012
- Current pCO_2 and CO_2 fluxes show agreement with in situ data
- Different reanalysis forcing data produce flux estimates within 20% globally



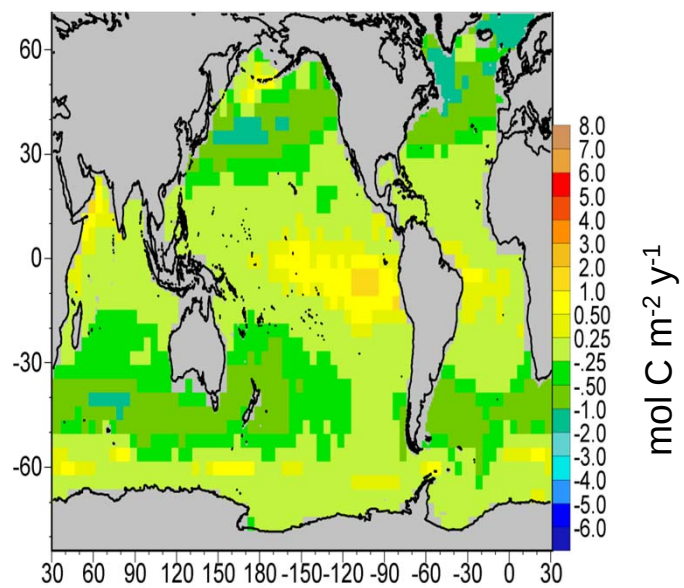
Development:

- pCO_2 and CO_2 fluxes from the NOBM using Modular Ocean Model (both offline using Carbon Tracker data and online using GEOS-5)
- Assimilation of both chlorophyll and Particulate Inorganic Carbon

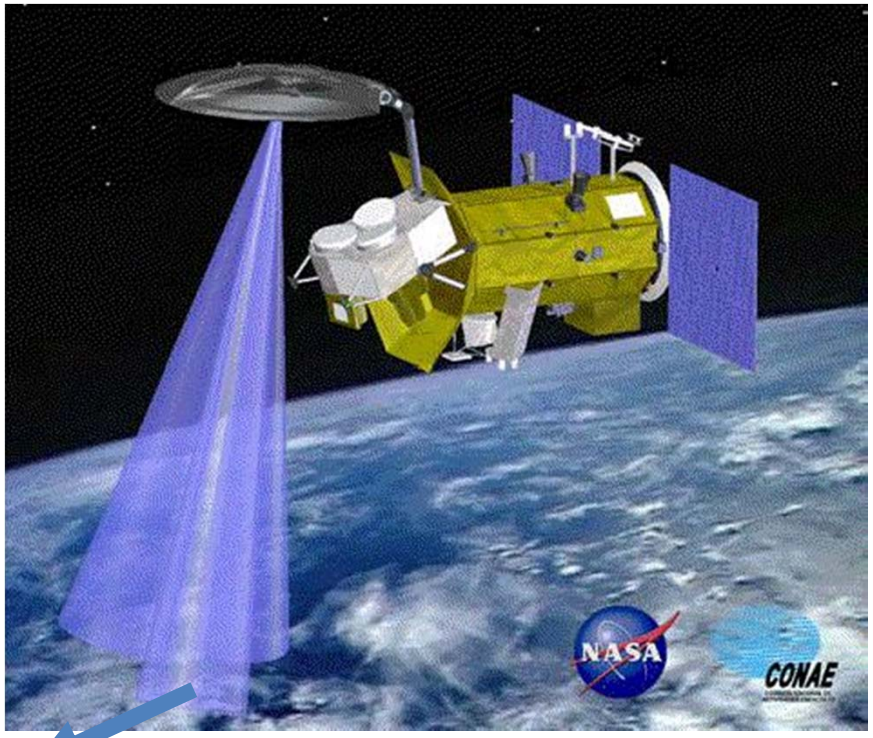
MERRA-Forced Model CO_2 Fluxes



Ship based estimate of estimate Of $CO_{2\ fluxes}$ (Takahashi et al., 2006)



New observing systems: L2 Aquarius SSS



Overview of SAC-D/Aquarius observation scheme (image credit: NASA, CONAE)

Retrieved SSS

$$T_b = e(T, S, Freq, \ldots)I$$

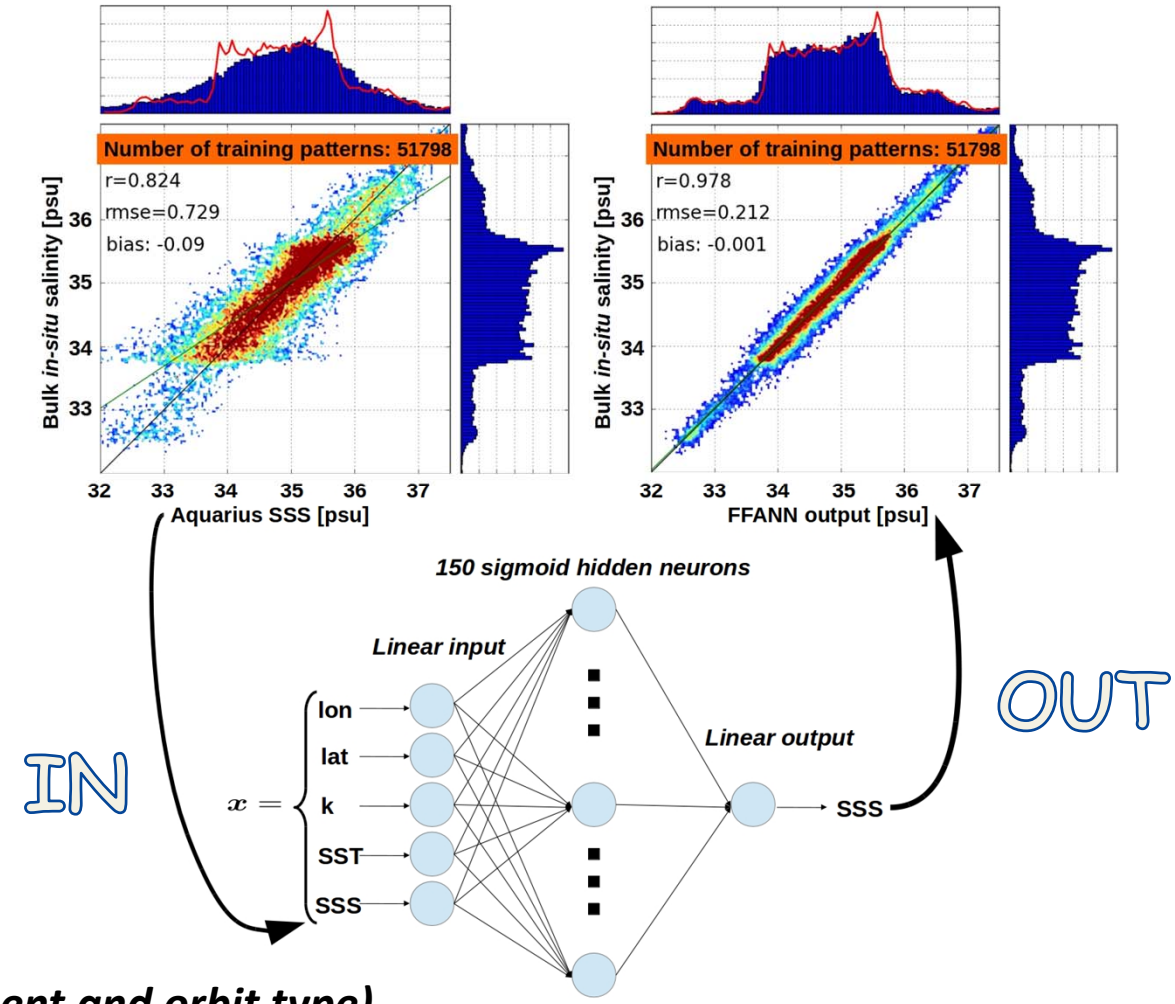
Tb Estimated from the 3 Aquarius radiometer operating at 1.4Ghz

$$\frac{T_b}{T} = e(sss, sst, freq, \ldots)$$

NOAA OISST (Reynolds)

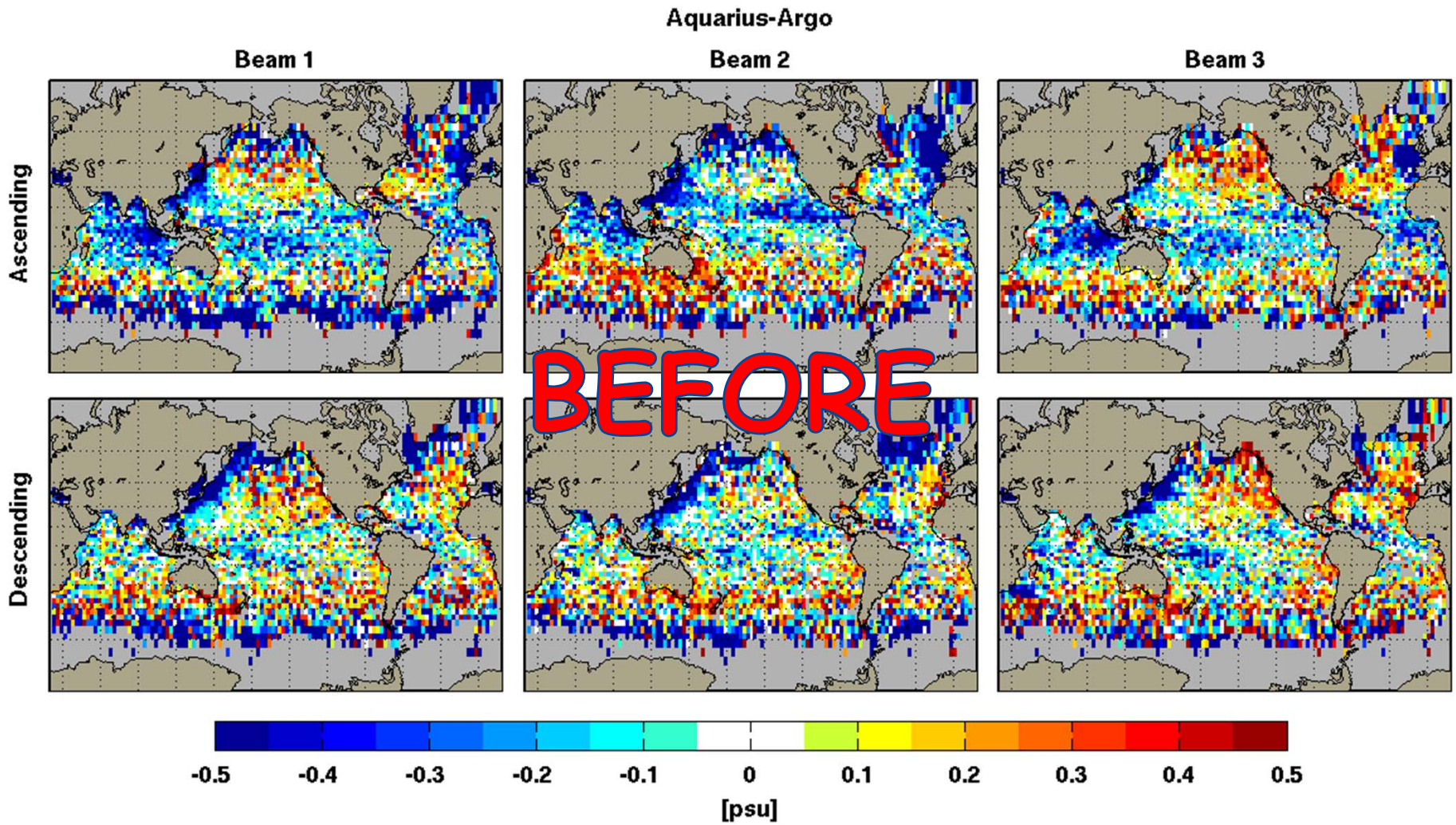
New observing systems: L2 Aquarius SSS

Correction of the L2 SSS

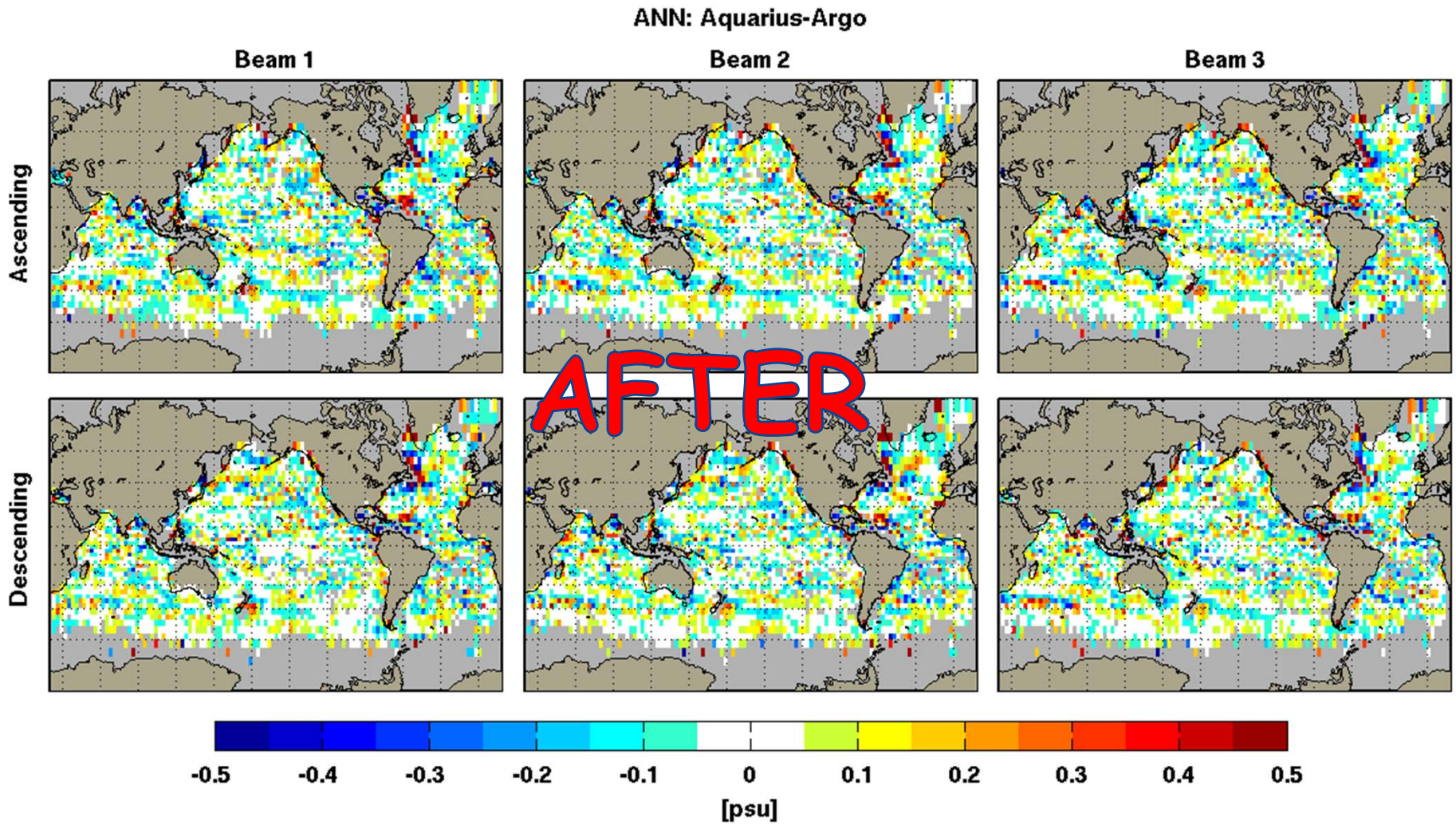


k=1,…,6 (intrument and orbit type)

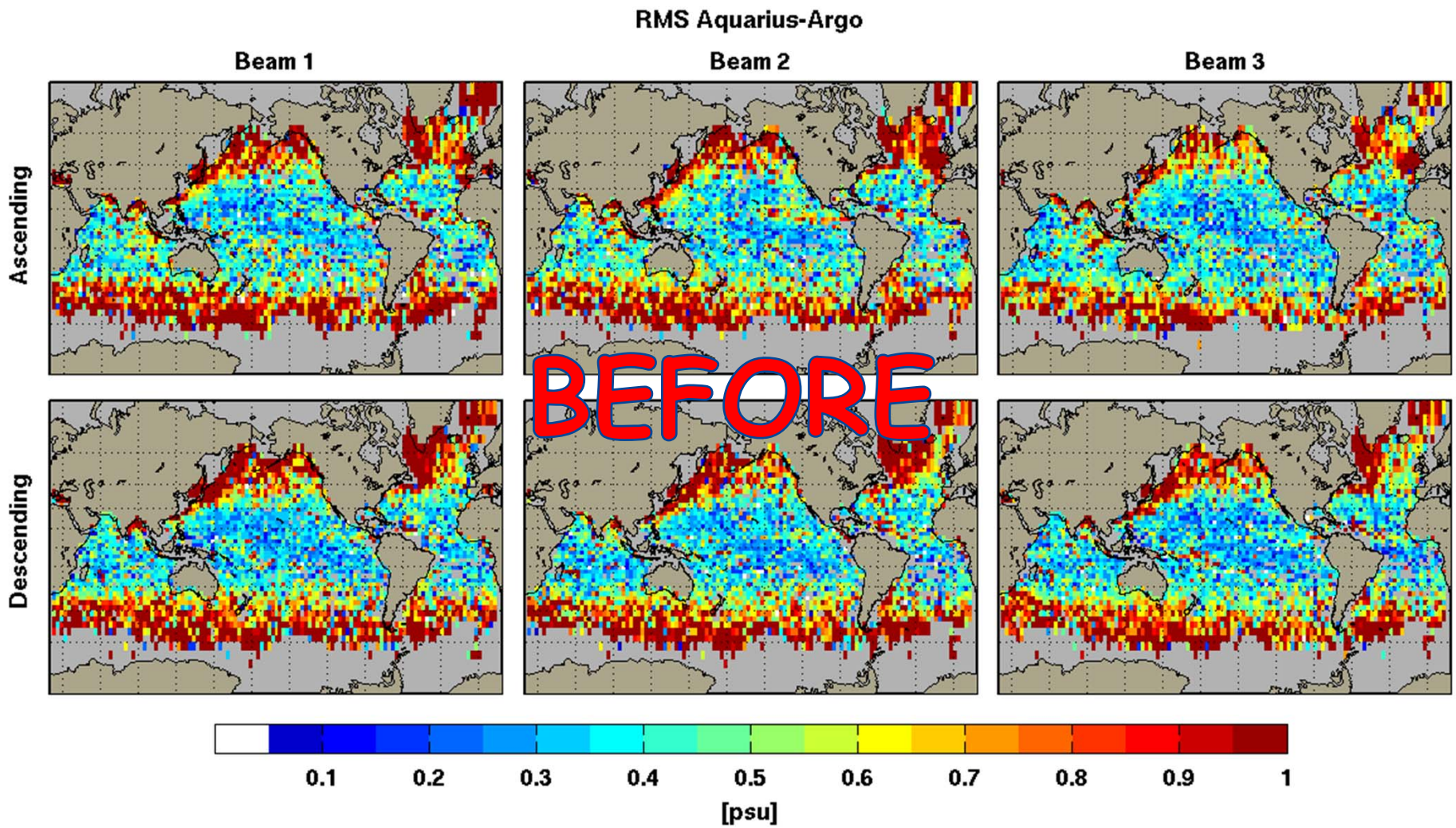
New observing systems: L2 Aquarius SSS BIAS



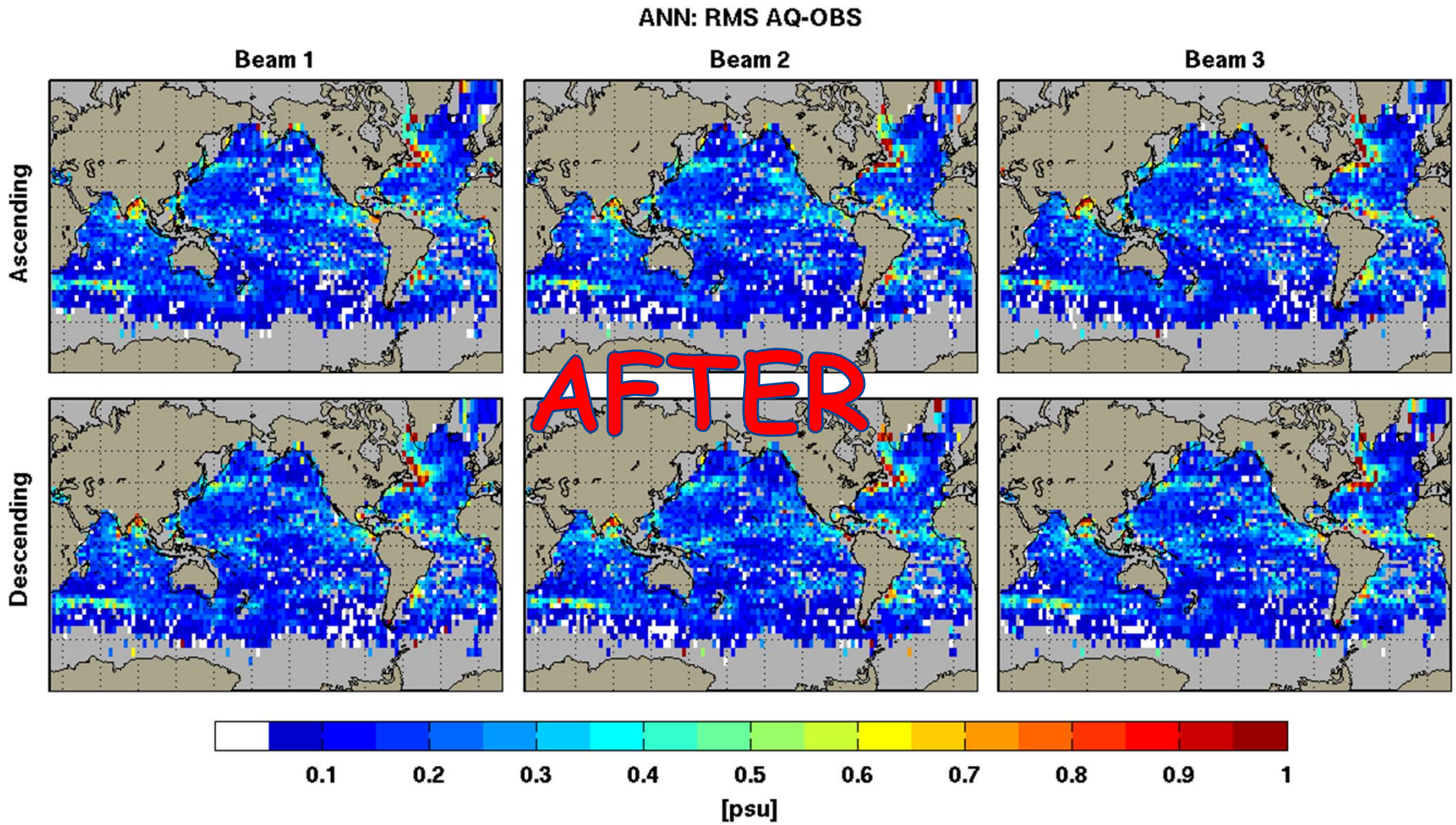
New observing systems: L2 Aquarius SSS BIAS



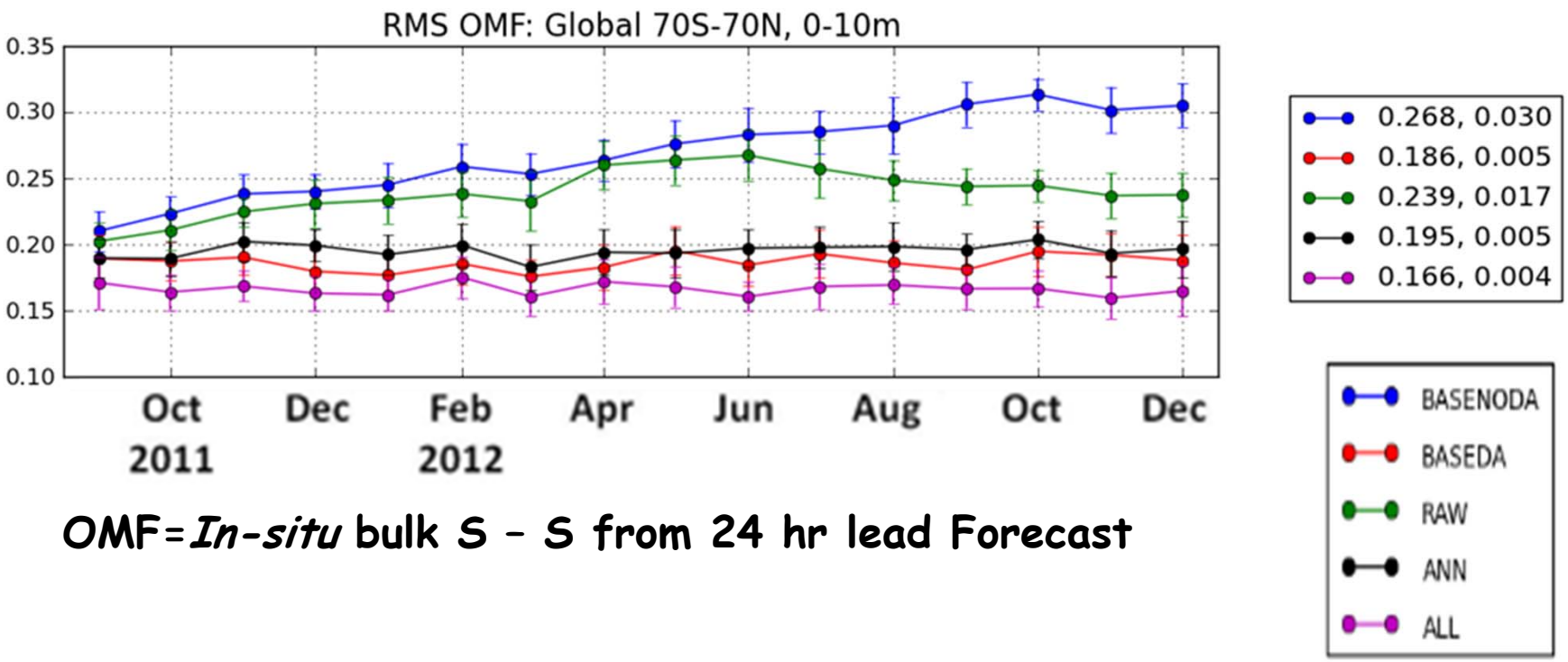
New observing systems: L2 Aquarius SSS
RMSD



New observing systems: L2 Aquarius SSS
RMSD



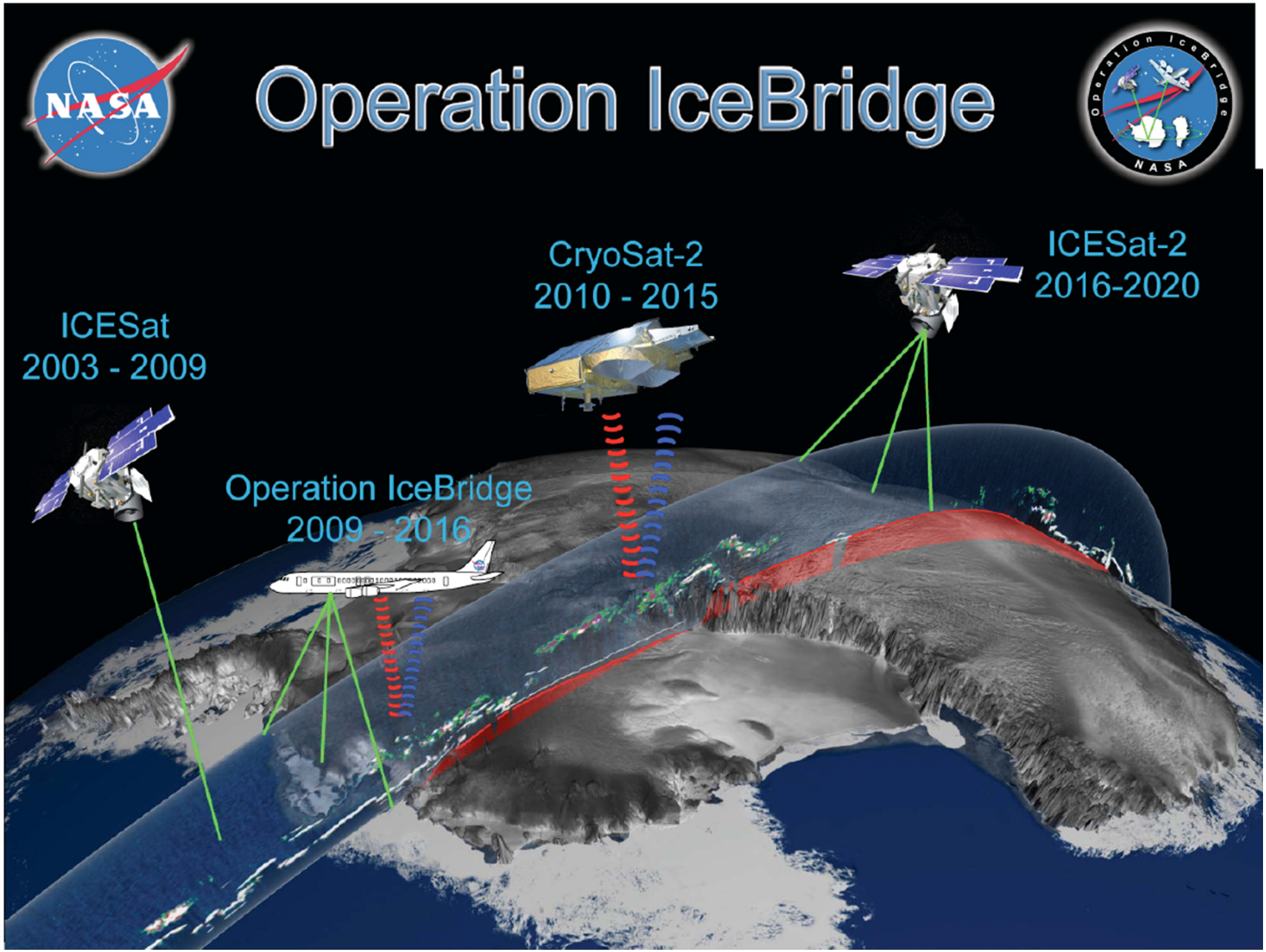
New observing systems: L2 Aquarius SSS
DA experiments



OMF=*In-situ* bulk S – S from 24 hr lead Forecast

<u>New observing systems</u>: Monthly average estimate of Sea Ice Thickness

Nathan Kurtz

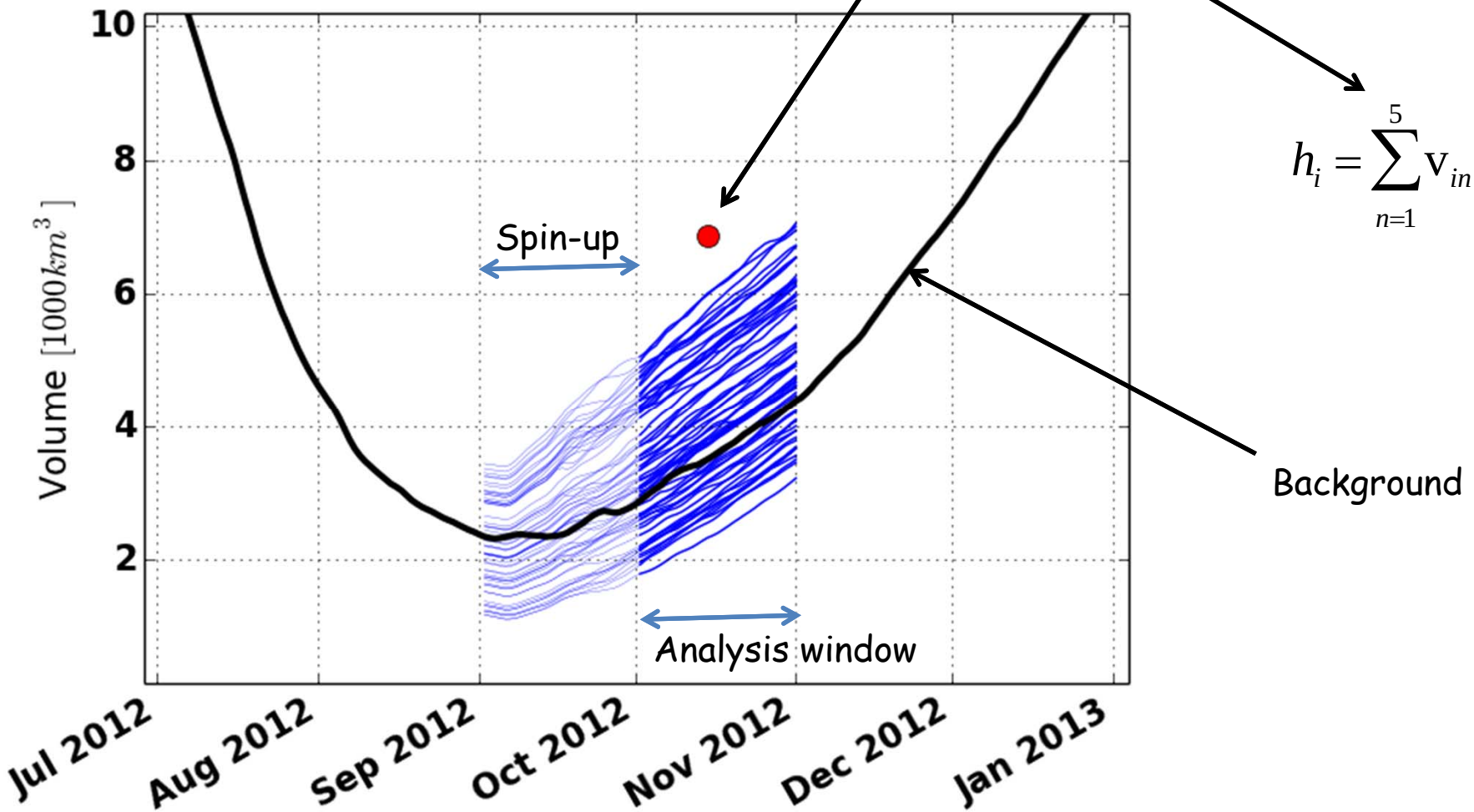


New observing systems: Monthly average estimate of Sea Ice Thickness

Analysis methodology:
Ensemble (62 members) Kalman Smoother to assimilate monthly mean

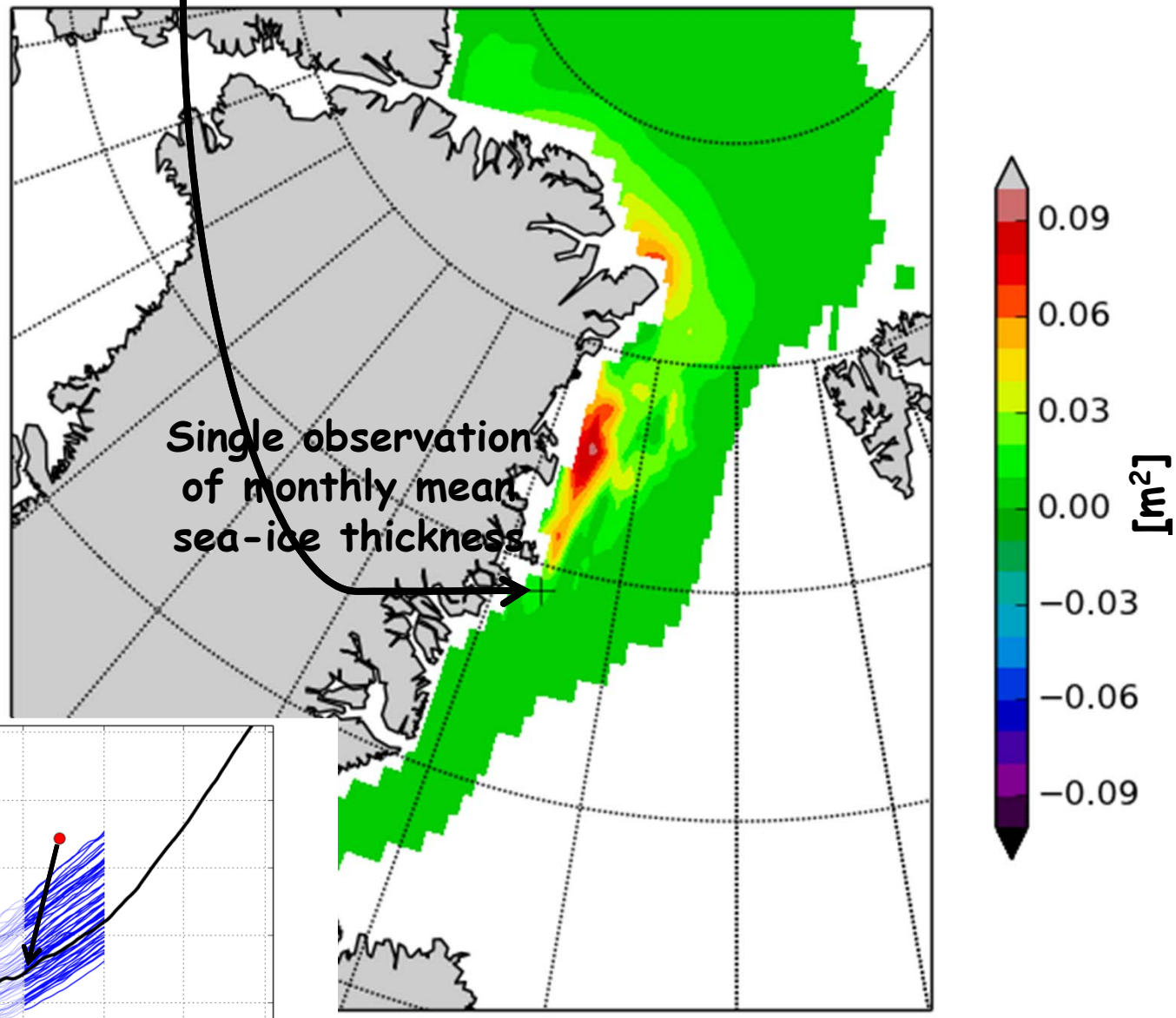
$$X_a = X_b + \rho P H^T (H \rho P H^T + R)^{-1} (Y_o - H X_b)$$

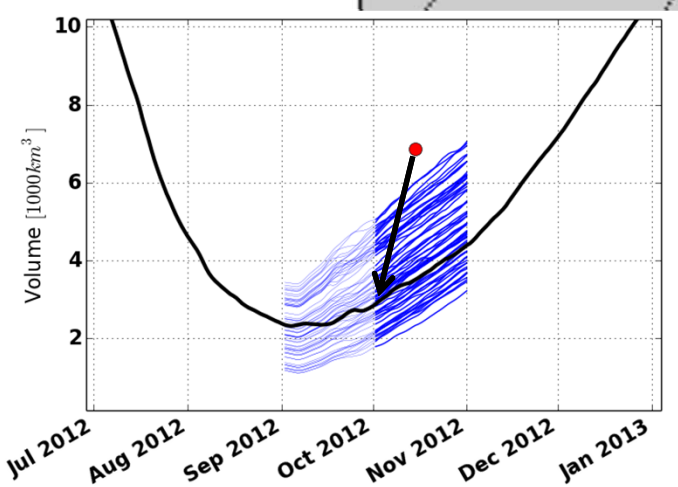
$$h_i = \sum_{n=1}^{5} \mathrm{v}_{in}$$



New observing systems: Monthly average estimate of Sea Ice Thickness

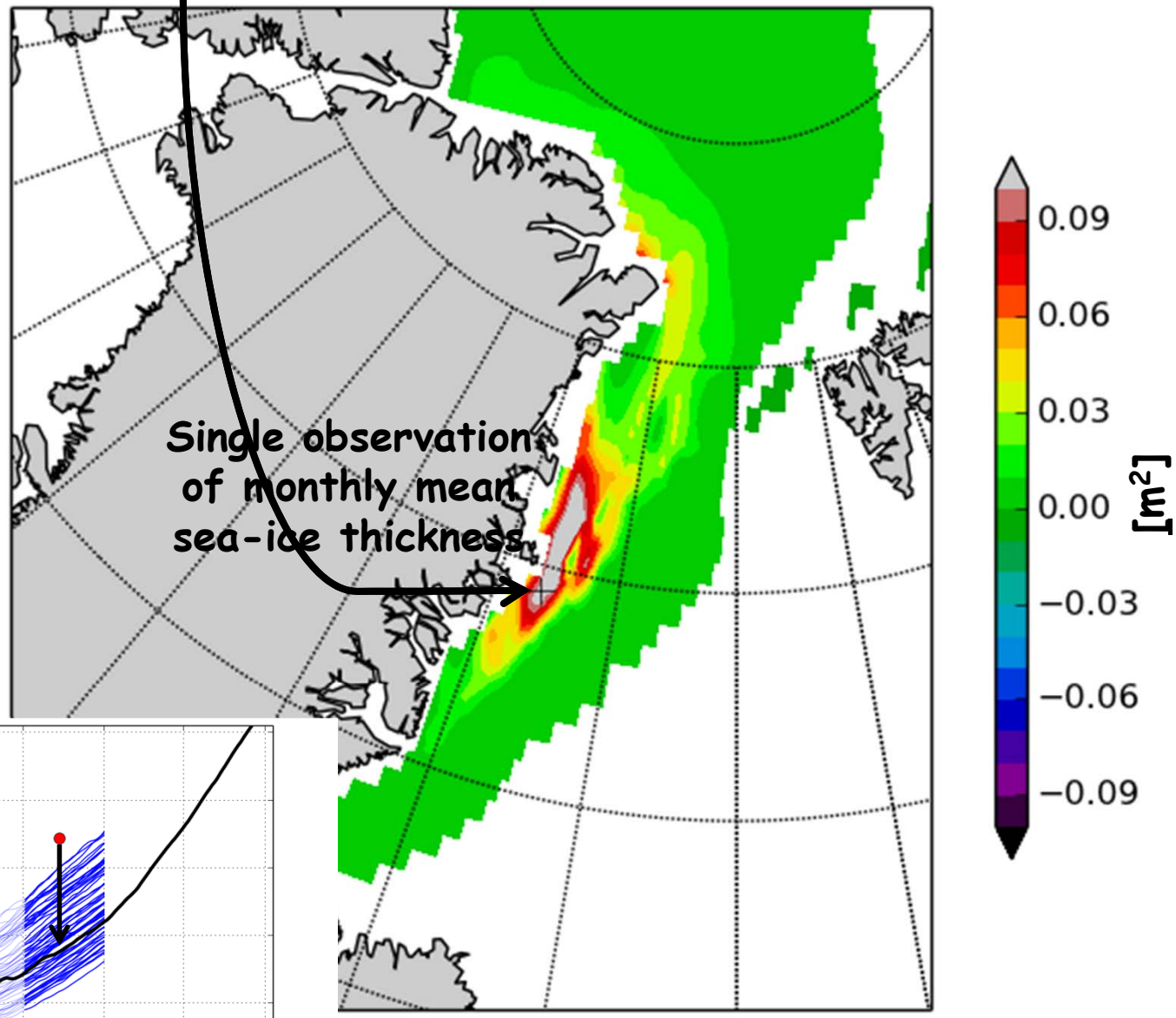
Cov(+, sea-ice thickness 2012 Oct 1)

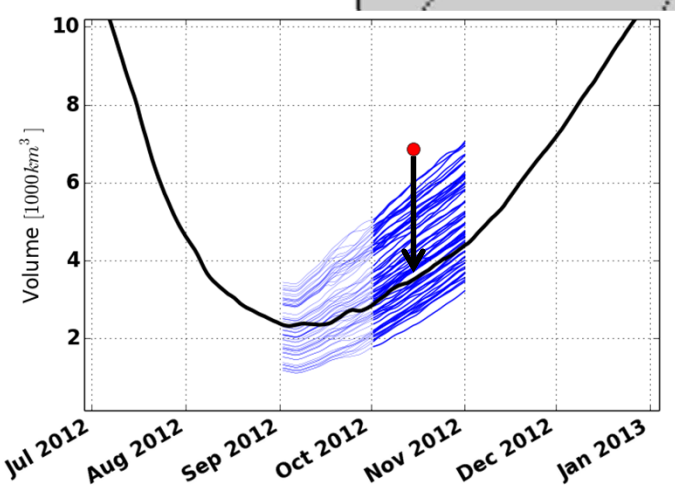




New observing systems: Monthly average estimate of Sea Ice Thickness

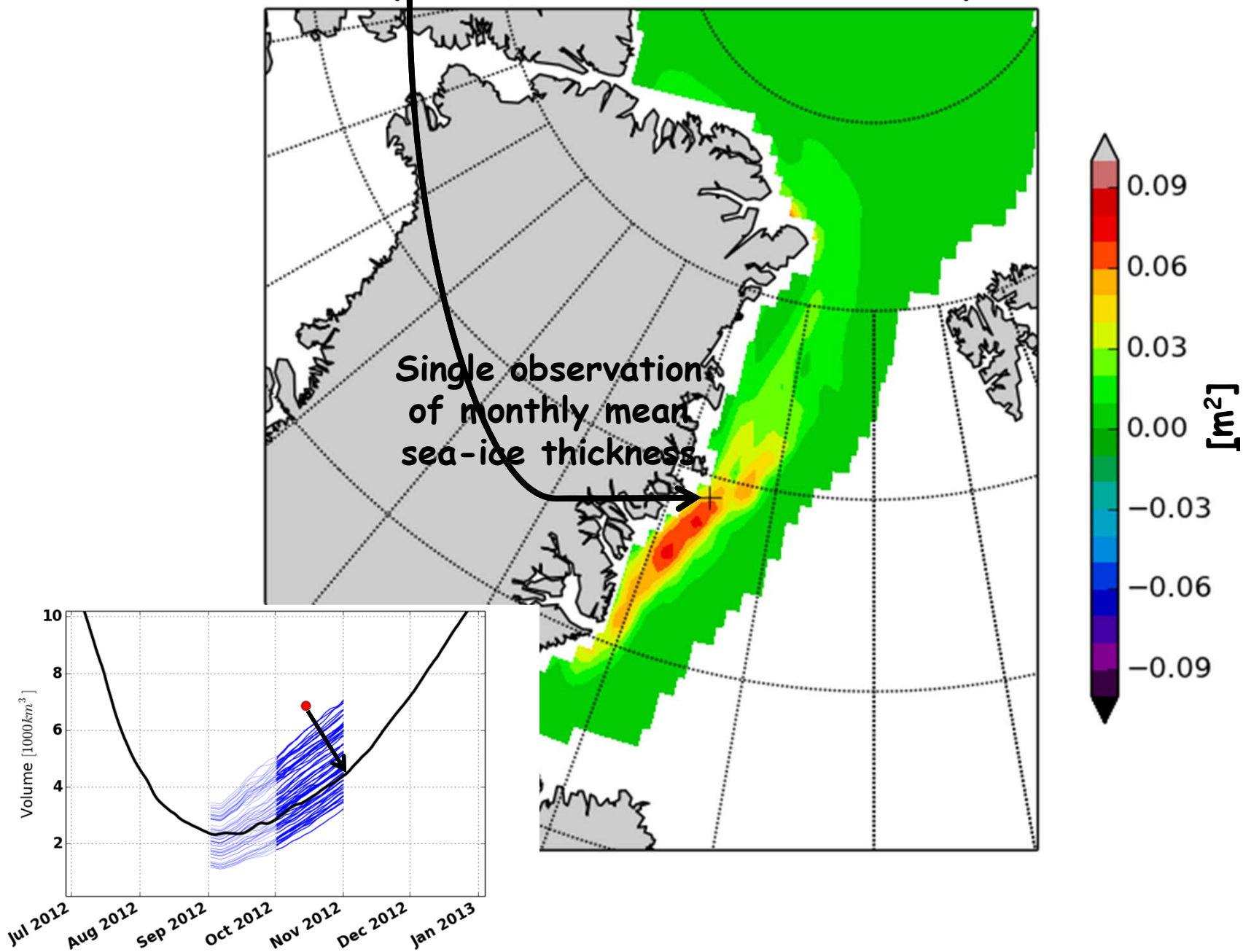
Cov(+, sea-ice thickness Oct 15 2012)



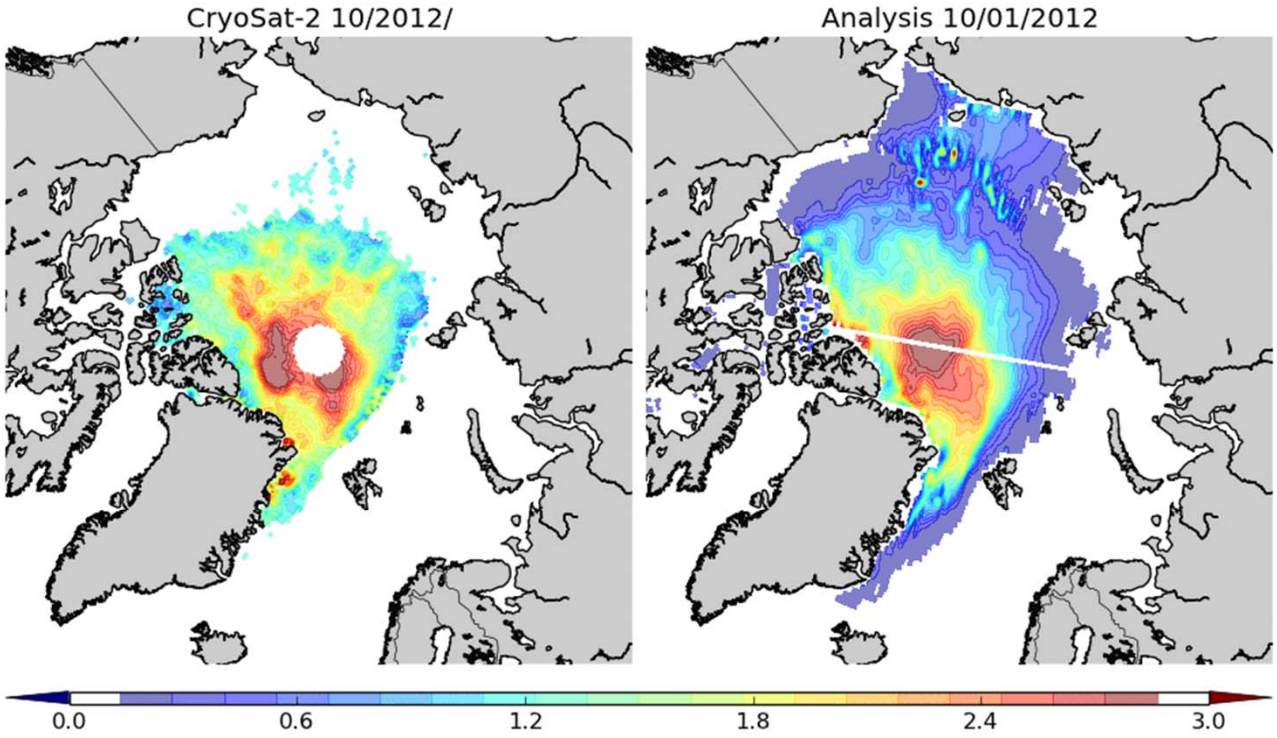


New observing systems: Monthly average estimate of Sea Ice Thickness

Cov(+, sea-ice thickness Nov 1 2012)



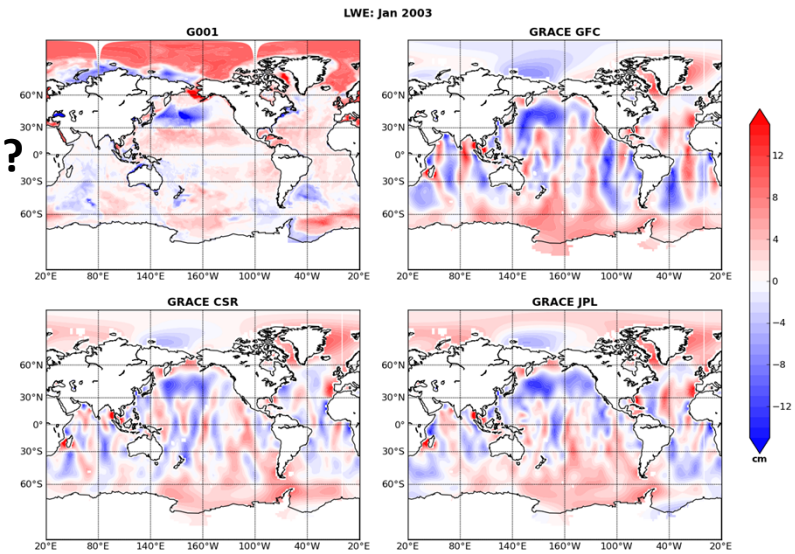
New observing systems: Monthly average estimate of Sea Ice Thickness

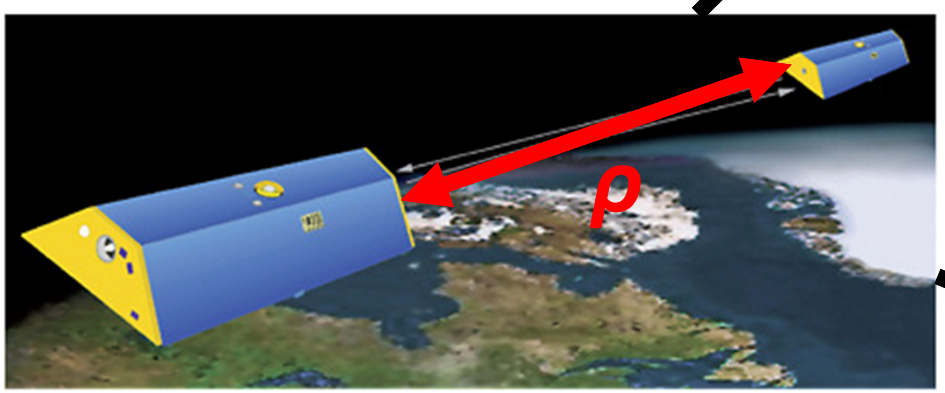


New observing systems: Estimate of Ocean Bottom Pressure (GRACE)

Scott Luthcke, Richard Ray, Briant Loomis, Brian Beckley, Frank Lemoine

bottom pressure retrieval?



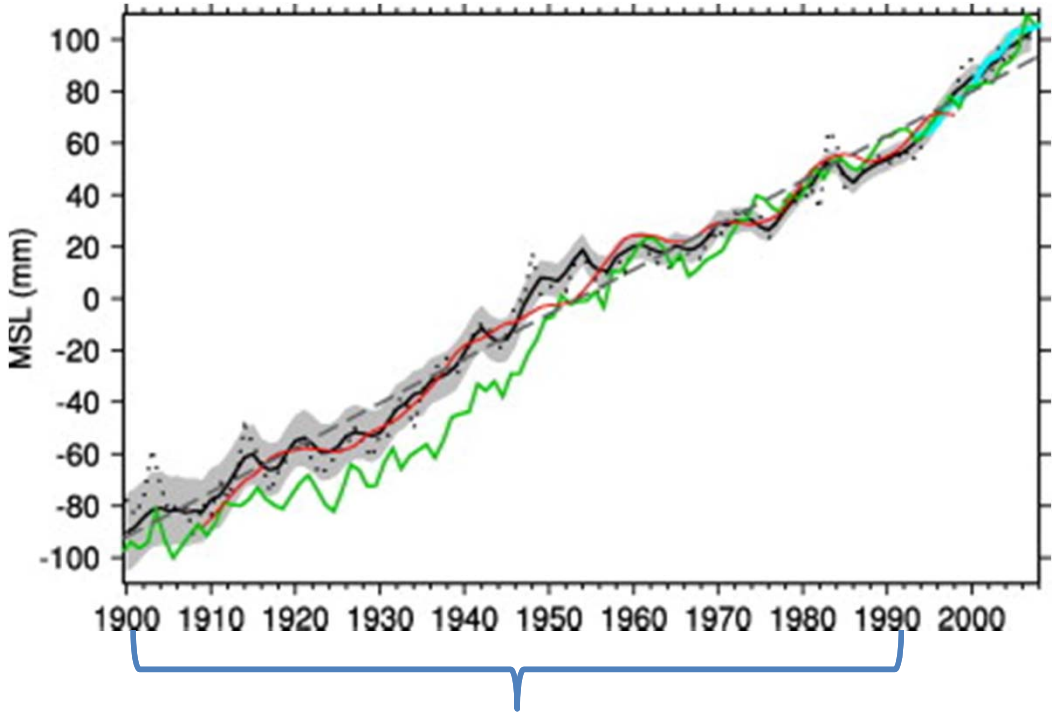
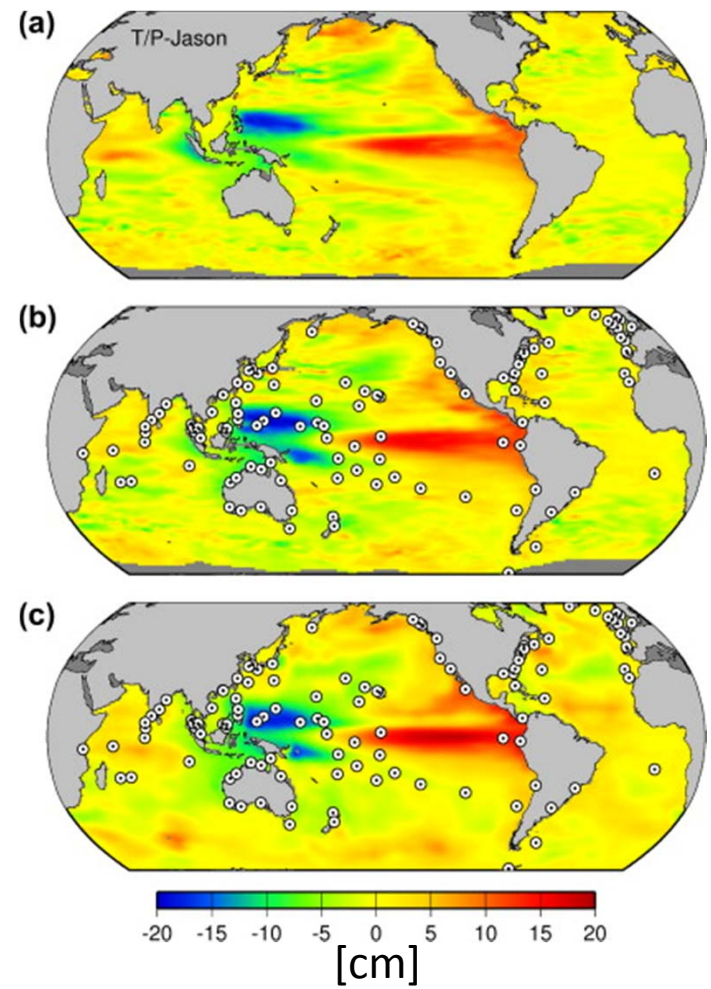


Range rate?

$$\frac{\partial \rho}{\partial t} = U_{12}^{Earth} + U_{12}^{N-body} + U_{12}^{tides} + \underbrace{U_{12}^{Ocean} + U_{12}^{Atmo} + U_{12}^{hydro} + U_{12}^{Ian-ice}}_{\text{From GMAO}} + \varepsilon$$

<u>New observing systems</u>: ~Monthly average reconstructed Sea Level

Richard Ray, Scott Luthcke, Briant Loomis, Brian Beckley, Frank Lemoine



Use statistical reconstruction
To constrain the 3D ocean T