AMS 95th Annual Meeting - 2015

#153

Validation of Ocean Model Simulations Using Satellite Ocean Color Fields

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Motivation:

To understand the impact of satellite ocean color (chlorophyll) fields on ocean modeling representativeness, with the objective of integrating quasi-near-real-time ocean color (chlorophyll) data into NOAA's operational ocean models.

Abstract:

Solar shortwave heating of the ocean's upper layers, which is dependent the incoming radiation and the optical properties of the water column, correlates with chlorophyll concentration through the modulation of absorption and subsequent conversion to heat. Through changes in the near-surface vertical density profile, differential heating patterns cause baroclinic pressure gradients, which, in turn, impact the upper-ocean's three-dimensional circulation patterns. Thus, we examine changes heat content and velocity in the top 300 m of the water column. Anomalous build-up of equatorial Pacific Ocean heat content is an important variable for the recharge-discharge oscillator theory for the evolution of El Niño events. Here, differences in the chlorophyll data inputs are shown to cause significant changes in tropical Pacific Ocean heat-content anomalies. Thus, it is important for seasonal predictions that the impact that ocean color data sets have on the quality of ocean forecasts be studied. Possible implications of temperature and salinity changes on air-sea carbon dynamics include: changes in estimates of metabolic rates and primary productivity and corresponding CO_2 uptake by phytoplankton; changes in CO_2 flux due to changes in oceanic thermal structure and lower-atmospheric response; and changes in estimates total alkalinity.

Satellite Ocean Color Fields:

Sea-viewing Wide Field-of-View Sensor (SeaWiFS) satellite ocean color (chlorophyll) data sets, interpolated to the model grid:

- Current (**base)** operational data set: **1997-2001 monthly climatology**;
- **Extended monthly climatology** encompassing 1998-2010;
- **Sequential monthly** SeaWiFS data for the period 1998-2010;
- **Sequential daily** composited SeaWiFS fields for the period 1998-2010.

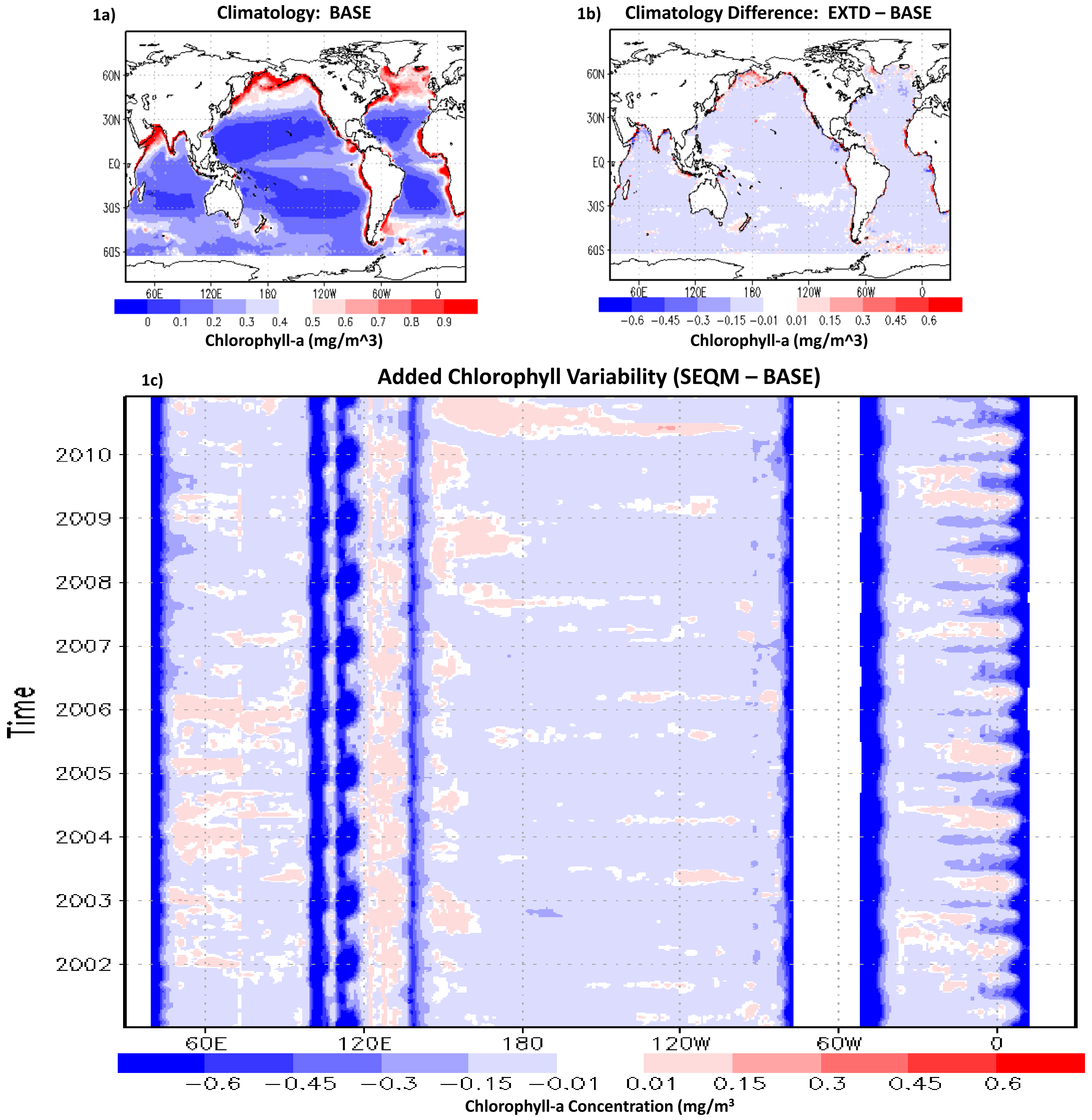
Model and Observations:

NOAA's National Center for Environmental Prediction (NCEP) operational near-global Modular Ocean Model v.4 (MOM4), half-degree resolution, forced with daily NCEP Climate Forecast System Reanalysis (CFSR; Saha *et al*., 2010) and relaxed to daily satellite sea-surface temperature (SST) fields and monthly climatological sea-surface salinity (SSS) fields. All runs were initiated from the same ocean initial condition and run for 2001-2010. For validation, the simulations are compared with analyses from NOAA's Global Ocean Data Assimilation System (GODAS) (Behringer, 2007), the ocean component of NOAA's operational coupled seasonal-interannual Climate Forecast System (CFS), and gridded ARGO monthly profiles obtained from the International Pacific Research Center, Hawaii (Lebedev et al., 2010).

SIMULATIONS:

- **BASE** = MOM4 simulation in the **operational configuration**; monthly-mean annual cycle of SeaWiFS CHL-a data (1997-2001);
- **EXTD** = MOM4 simulation with **extended monthly** climatological SeaWiFS CHL-a fields (1998-2010);
- **SEQM** = MOM4 simulation with **sequential monthly** SeaWiFS CHL-a fields (1998-2010);
- **SEQD** = MOM4 simulation with **sequential daily** composited SeaWiFS CHL-a fields (1998-2010).

Satellite Ocean Color: Chlorophyll-a Fields



1a) Climatology: BASE

1b) Climatology Difference: EXTD – BASE

1c) Added Chlorophyll Variability (SEQM – BASE)

Figure 1. Chlorophyll-a fields: a) BASE global annual mean, b) EXTD minus BASE annual mean climatology difference, and c) longitude-time diagram at the equator (2^0S-2^0N) of chlorophyll-a variability added by using sequential monthly CHL-a fields.

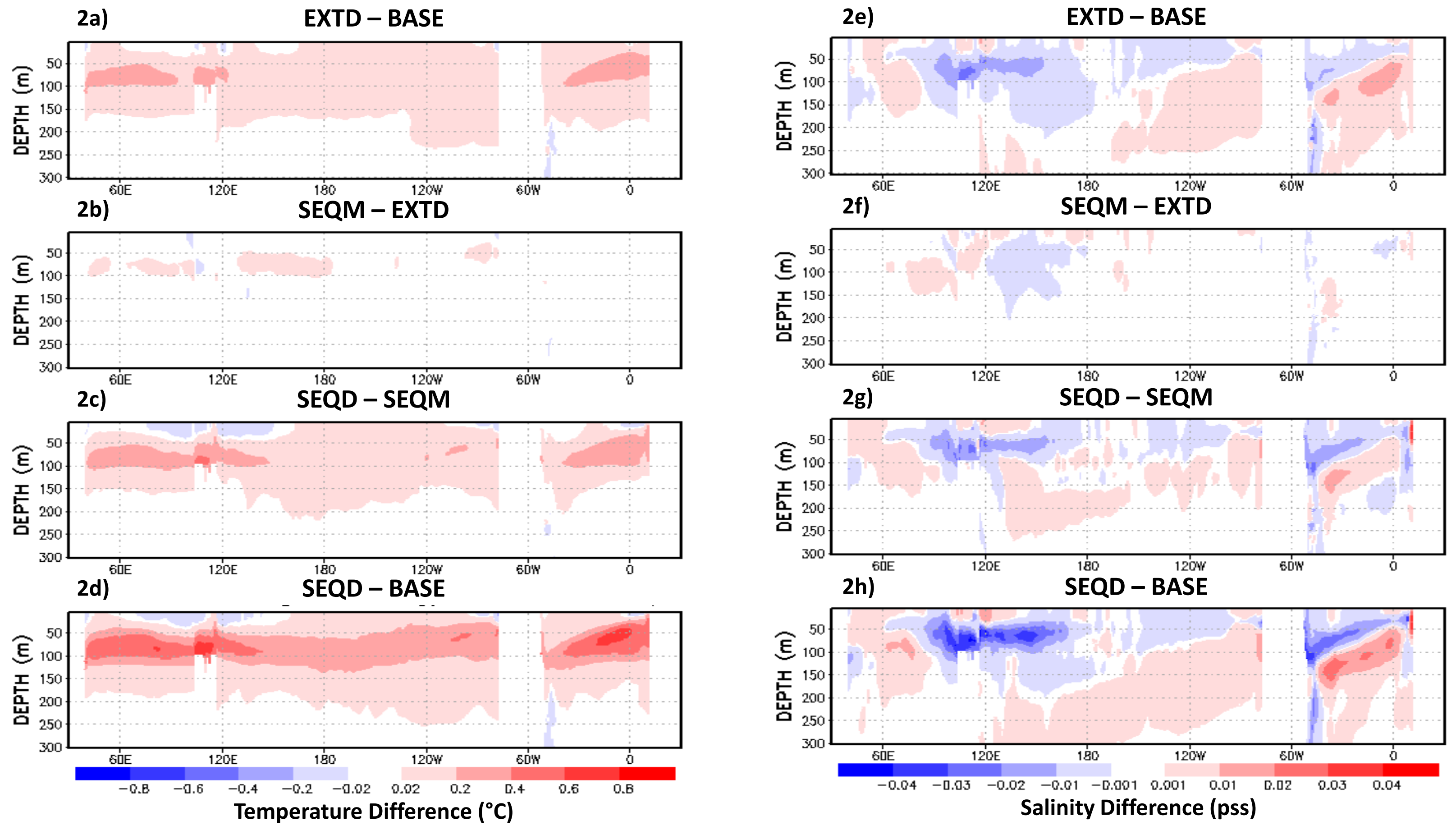
Figure 1b shows that the base chlorophyll-a monthly-mean climatology (1997-2001) used operationally is not representative over extrapolated periods, likely due to distortion from the very strong 1997-1998 El Niño. Notice that the extended monthly climatology has lower values of CHL-a everywhere, and there are some greater differences between the BASE and the EXTENDED data sets in the equatorial oceans, particularly in the eastern Pacific. Figure 1c highlights the strong inter-annual variability provided by using sequential monthly-mean data, rather than a cyclical annual cycle of monthly-mean values. This interannual variability contributes to near-surface ocean heat content variability, modification of the ocean's near-surface stability, and associated variability of air-sea heat flux.

Model Sensitivity to Ocean Color (Chlorophyll-a)

Equatorial Band (5°S – 5°N)

MEAN TEMPERATURE DIFFERENCES

MEAN SALINITY DIFFERENCES



2a) EXTD – BASE

2b) SEQM – EXTD

2c) SEQD – SEQM

2d) SEQD – BASE

2e) EXTD – BASE

2f) SEQM – EXTD

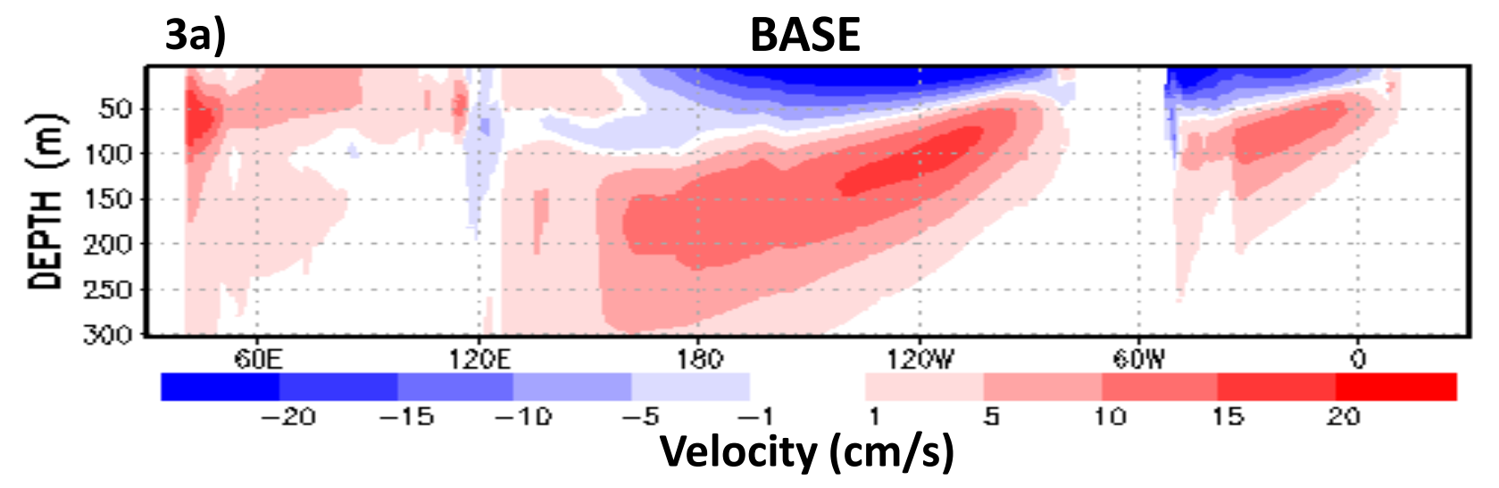
2g) SEQD – SEQM

2h) SEQD – BASE

Figure 2. Mean equatorial (5^0S-5^0N) differences: 1) Temperature a) EXTD minus Base, b) SEQM minus EXTD, c) SEQD minus SEQM, and d) net difference SEQD minus BASE; 2) Salinity e) through)h comparable to a) through d).

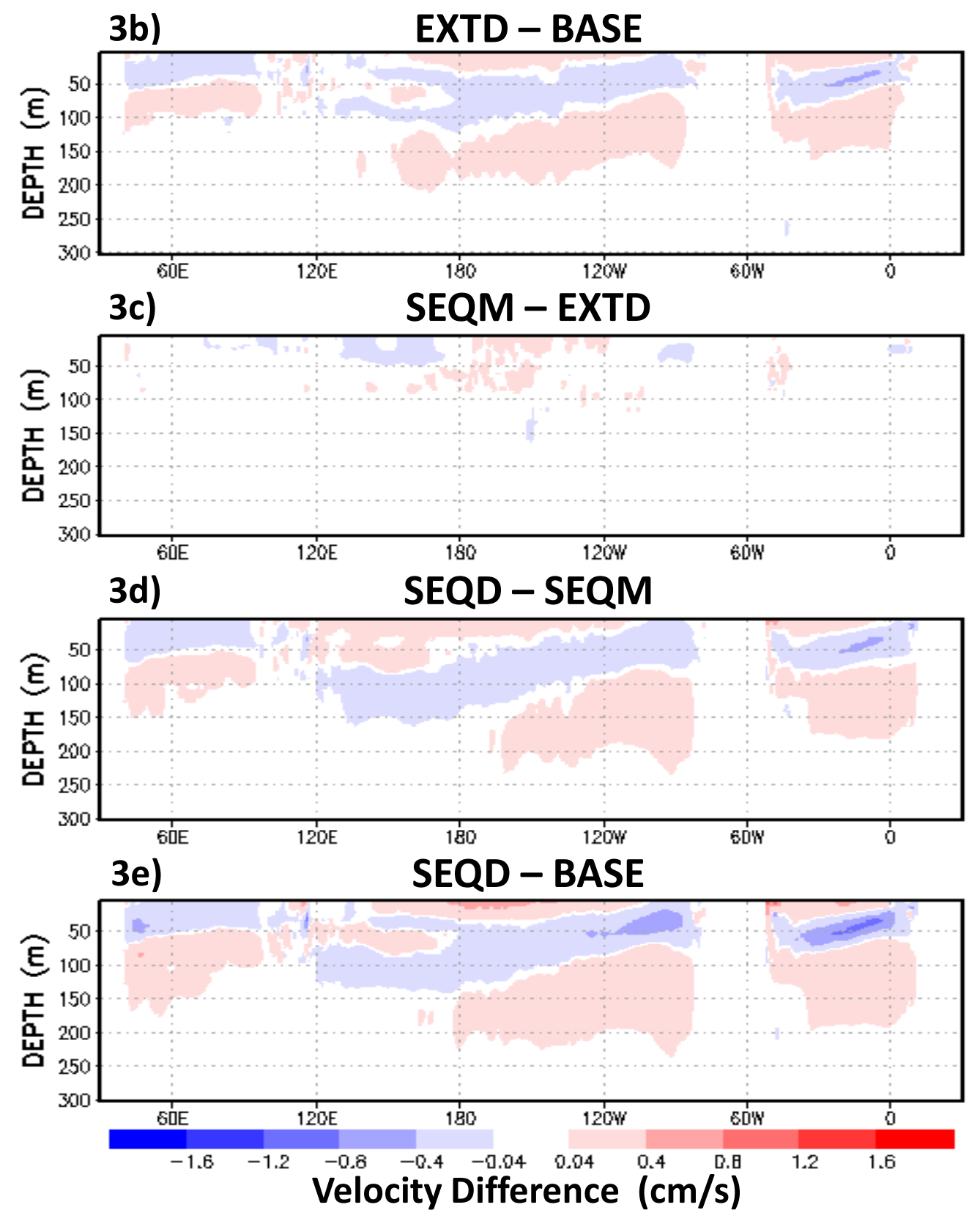
Two different attributes of the ocean color (chlorophyll-a) data have impacts of comparable magnitude on the modeled equatorial ocean temperature: one from using more representative climatological data from extending the record period (Figure 2a) and the other from including higher-frequency variability (Figures 2c and 2d). Similar impacts are seen in the modeled equatorial ocean salinity. Temperature and salinity impacts are confined to the near-surface, approximately 300m or less depth.

Mean Zonal Velocity



3a) BASE

Mean Zonal Velocity Difference



3b) EXTD – BASE

3c) SEQM – EXTD

3d) SEQD – SEQM

3e) SEQD – BASE

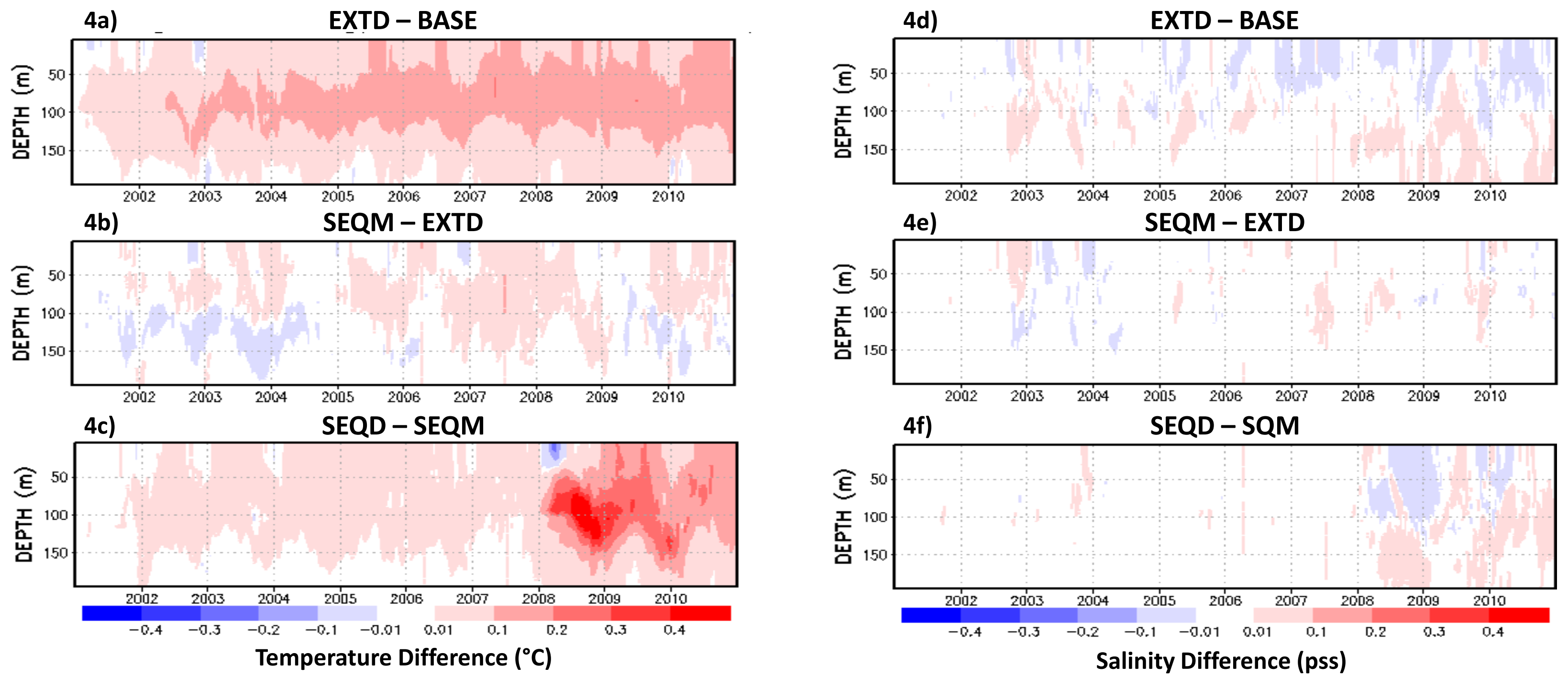
Figure 3. Mean zonal vertical velocity structure along the equator (5^0S-5^0N): a) Mean velocity for BASE case; Mean velocity difference b) EXTD minus BASE, c) SEQM minus EXTD, d) SEQD minus SEQM, and e) the net impact SEQD minus BASE.

The circulation patterns are not very sensitive to prescribed ocean color fields. In most parts of the equatorial oceans, differences in mean zonal velocity are less than 10 percent. The most noticeable changes are between the EXTD and BASE cases, with the differences between SEQD and SEQM similar in magnitude and structure. The SEQM and EXTD mean zonal velocity profiles are very similar, indicating that higher-frequency information (SEQD-SEQM) likely is a driver. The net significance of enhanced exploitation of satellite ocean color data in NOAA's operational seasonal-interannual ocean modeling is depicted in Figure 3e (SEQD minus BASE)

Niño 3.4 Box (5°N - 5°S, 170°W – 120W°)

Mean Temperature Difference

Mean Salinity Difference (x 5)



4a) EXTD – BASE

4b) SEQM – EXTD

4c) SEQD – SEQM

4d) EXTD – BASE

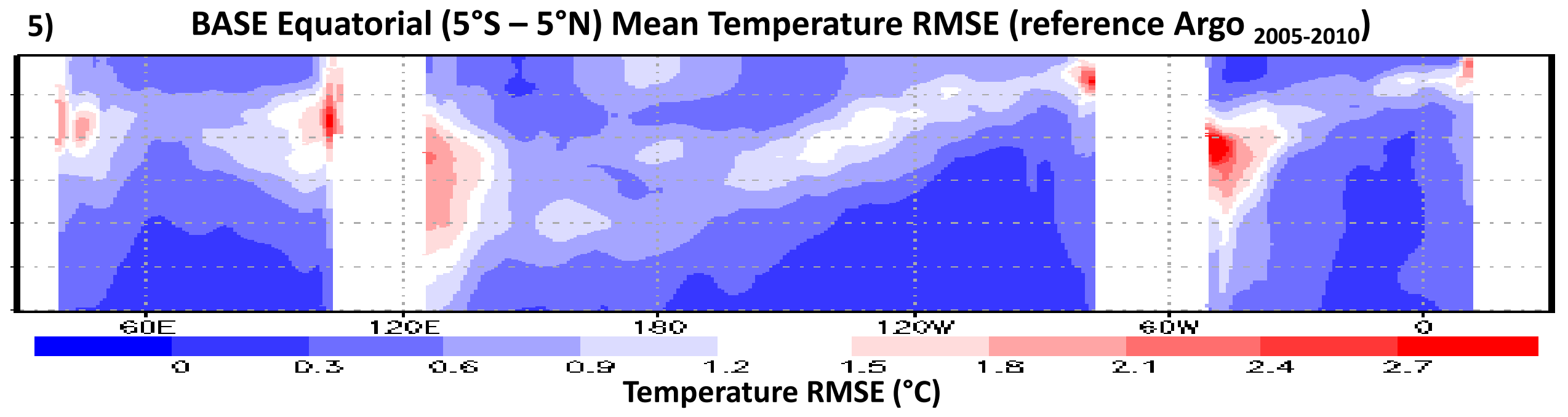
4e) SEQM – EXTD

4f) SEQD – SQM

Figure 2. Time-evolution of simulation differences in the NINO3.4 (170^0W-120^0W; 5^0S-5^0N) region: Temperature a) EXTD minus BASE, b) SEQM minus EXTD, c) SEQD minus SEQM; Salinity d) EXTD – BASE, (e) SEQM – EXTD, and (f) SEQD – SEQM.

Persistent extensive temperature differences exist between EXTD and BASE and between SEQD and SEQM, with the SEQD minus SEQM differences having the most intense episode, signifying the importance of including higher-frequency variability. The large difference between EXTD and BASE can be attributed to representation inadequacies of the BASE 4-year climatology. Salinity response differences are quite muted and not persistent.

Validation: RMS Error Reduction

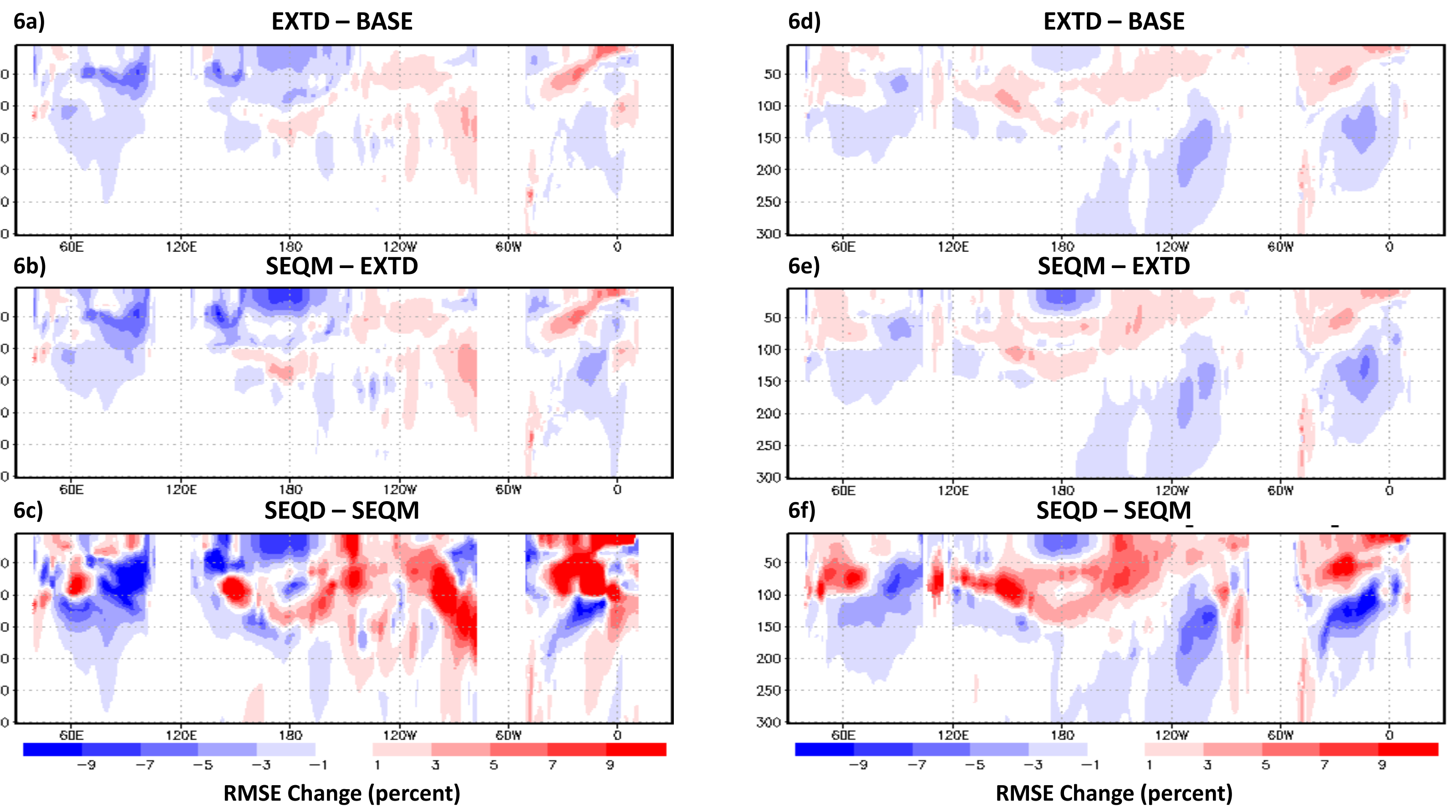


5) BASE Equatorial (5°S – 5°N) Mean Temperature RMSE (reference Argo $_{2005\text{-}2010}$)

Figure 5. BASE near-surface temperature RMS error, referenced to Argo (2005-2010) observations.

Reference Argo $_{2005\text{-}2010}$

Reference GODAS $_{2001\text{-}2010}$



6a) EXTD – BASE

6b) SEQM – EXTD

6c) SEQD – SEQM

6d) EXTD – BASE

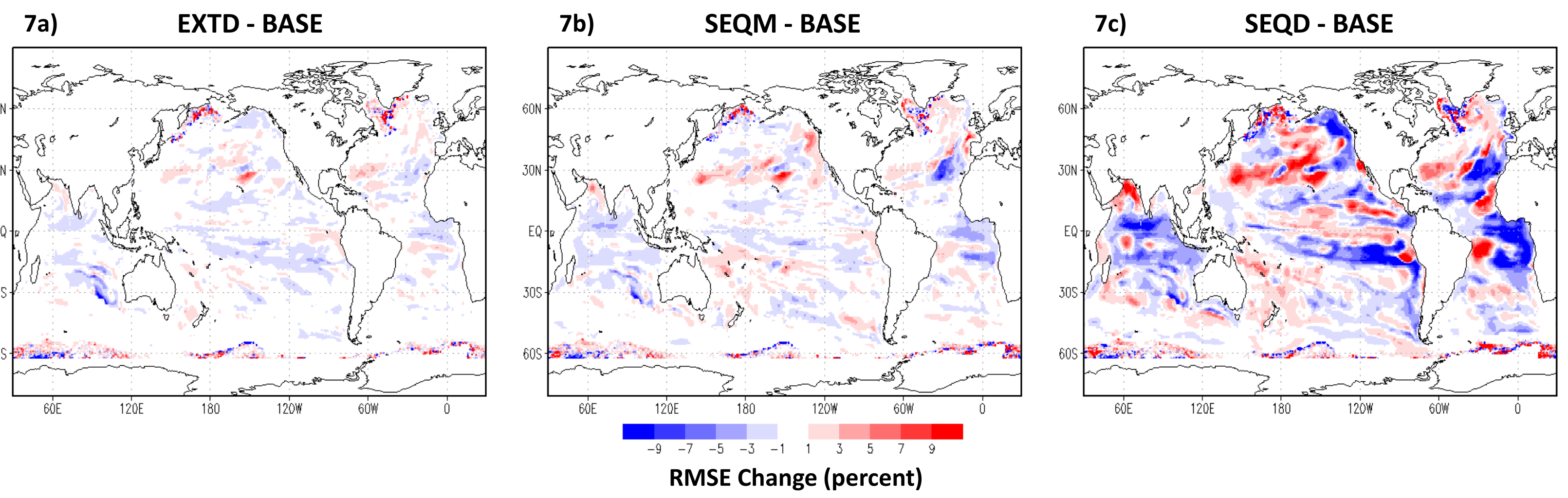
6e) SEQM – EXTD

6f) SEQD – SEQM

Figure 6. RMSE percent change due to choice of ocean color forcing: first, referenced to gridded ARGO temperature profiles (2005-2010) a) EXTD minus BASE, b) SEQM minus BASE, and c) SEQD minus BASE; and second, referenced to GODAS pentad observations (2001-2010) d) EXTD minus BASE, e) SEQM minus BASE, and f) SEQD minus BASE.

Validating the model results against Argo observations (Figure 6a-c) reveals a progression of difference intensification with increased representativeness of the chlorophyll data for both reductions and increases in RMSE, while the patterns largely remain constant. While patterns differ somewhat when examining the RMS errors referenced to NOAA's operational seasonal-interannual model (GODAS) results (Figure 6d-f), the same intensification response with respect to the chlorophyll data used is seen.

Validation: Ocean Heat Content (0-300m)



7a) EXTD - BASE

7b) SEQM - BASE

7c) SEQD - BASE

Figure 7. RMSE percent change due to how the ocean color field is specified, referenced to gridded ARGO temperature and salinity profiles (2005-2010): a) EXTD minus BASE, b) SEQM minus BASE, and c) SEQD minus BASE.

Again, it is evident that using sequential, rather than cyclical, monthly forcing mildly intensifies modeled results; however, using more frequent sequential updates notably and globally intensifies the impact of chlorophyll-a data on modeled near-surface ocean heat content by up to ± 10%. These results indicate that the assimilation of sequential daily satellite ocean color (chlorophyll-a) data is important for adequately modeling upper-ocean stability and air-sea heat flux, particularly for coupled ocean-atmosphere models.

Summary and Conclusions

- The model simulations are sensitive to which ocean color field is used, as well as the update frequency.
- Significant improvement was obtained from using a more representative ocean color climatology (13 –year versus 4-year SeaWiFS climatology).
- Using daily sequential ocean color data notably contributes to the intensification of model differences from the current operational (BASE) configuration, both reductions and increases in RMS errors.

References:

- Behringer, D.W., 2007, "*The global ocean data assimlation system at NCEP,*" in 11th Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface, American Meteorological Society 87th Annual Meeting, San Antonio, TX.
- Lebedev, K. V., S. DeCarlo, P. W. Hacker, N. A. Maximenko, J. T.Potemra, and Y. Shen (2010), Argo Products at the Asia-Pacific Data-Research Center, Eos Trans. AGU, 91(26), Ocean Sci. Meet. Suppl.,Abstract IT25A-01.
- Saha, et al., 2010, "The NCEP Climate Forecast System Reanalysis," *Bull. Amer. Meteor. Soc. (19) 1015-1057*.

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