Upper-ocean response to Hurricane Ivan in a 1/25° nested Gulf of Mexico HYCOM#

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Ocean's Response to a hurricane

Two stages [*Price et al.* 1994]

- **Forced stage**: SST cooling, mixed-layer currents, surface heat fluxes mainly latent heat loss, geostrophic currents and associated sea level changes
- **Relaxation stage**: Inertial-gravity oscillations excited by the storm.

Objectives

1. To assess the model's ability to reproduce the observed behavior of the oceanic response to hurricane Ivan ***with*** and ***without*** data-assimilation
2. To quantify the physical processes controlling the upper-ocean cooling during Ivan's passage

Outline

- Model description
  - Initial and boundary conditions
  - Data assimilation
  - Model experiments
- Results
  - Model-data comparison
  - Upper-ocean response to Ivan
  - Heat-budget
  - Sensitivity to initial conditions
- Conclusions

Model Description

Model: HYCOM

Domain: Gulf of Mexico (north of 18.1°N, west of 77.4°W)

Horizontal resolution: 1/25° (~4 km)

Vertical: 20 hybrid layers

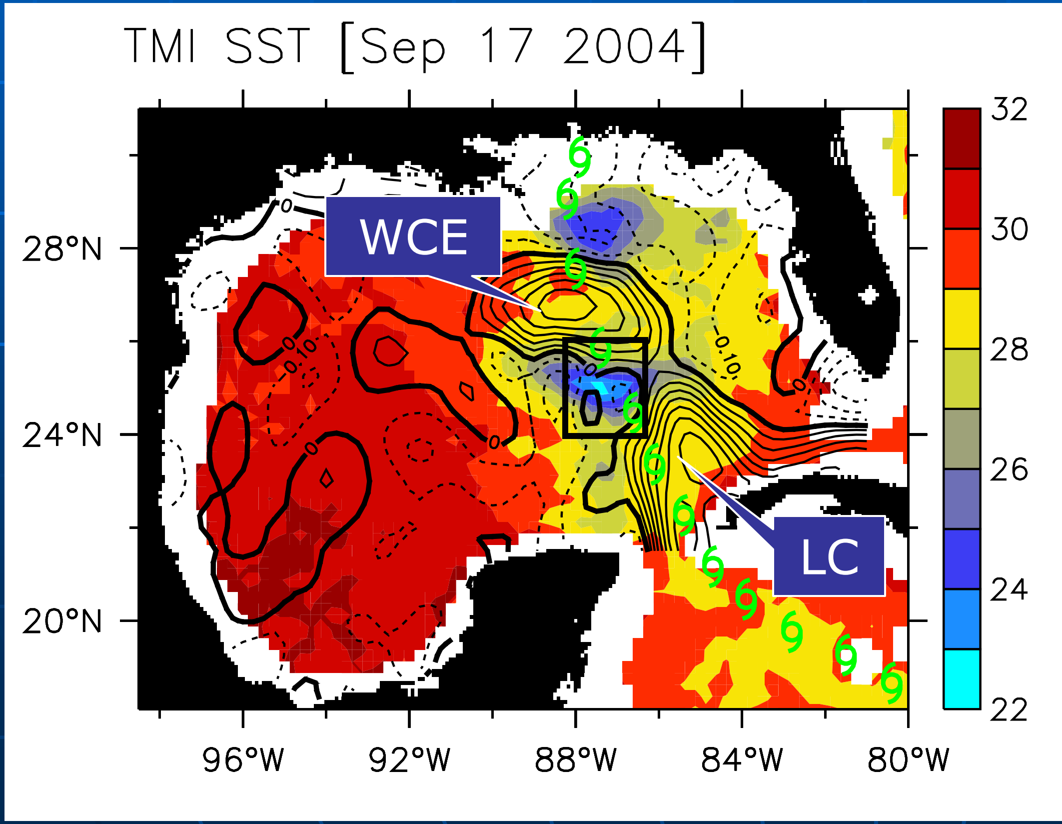
Vertical mixing scheme: GISS level 2 [NASA Goddard Institute for Space Studies, *Canuto et al*. 2001, 2002]

Surface forcing: 1° NOGAPS [wind-speed, wind-stress, air-temperature, humidity, precipitation, surface shortwave and long-wave heat fluxes]

Heat flux exchange coefficients: *Kara et al*. [2002] formulation, latent, sensible heat fluxes are calculated using model SST

Boundary Conditions (BCs)

- 1/12° (~8 km) North Atlantic data-assimilative HYCOM system provides BCs [*Chassignet et al*. 2005]
- BCs are updated every day
- 1-10 days e-folding relaxation time
- 20 grid-points wide relaxation zone



Ivan: 14-16 Sept 2004 in GoM
Category 5 on 12 Sept

maximum SST cooling occurred outside the **WCE** and **LC** regions

WCE -> Warm Core Eddy
LC -> Loop Current

2°x2° box 88°-86°W, 24°-26°N

Model Experiments

Experiments	Model simulation	Period
NAS	**Non-assimilation**	Jan-Dec 2004
AS	**Assimilation**	Jan-Dec 2004

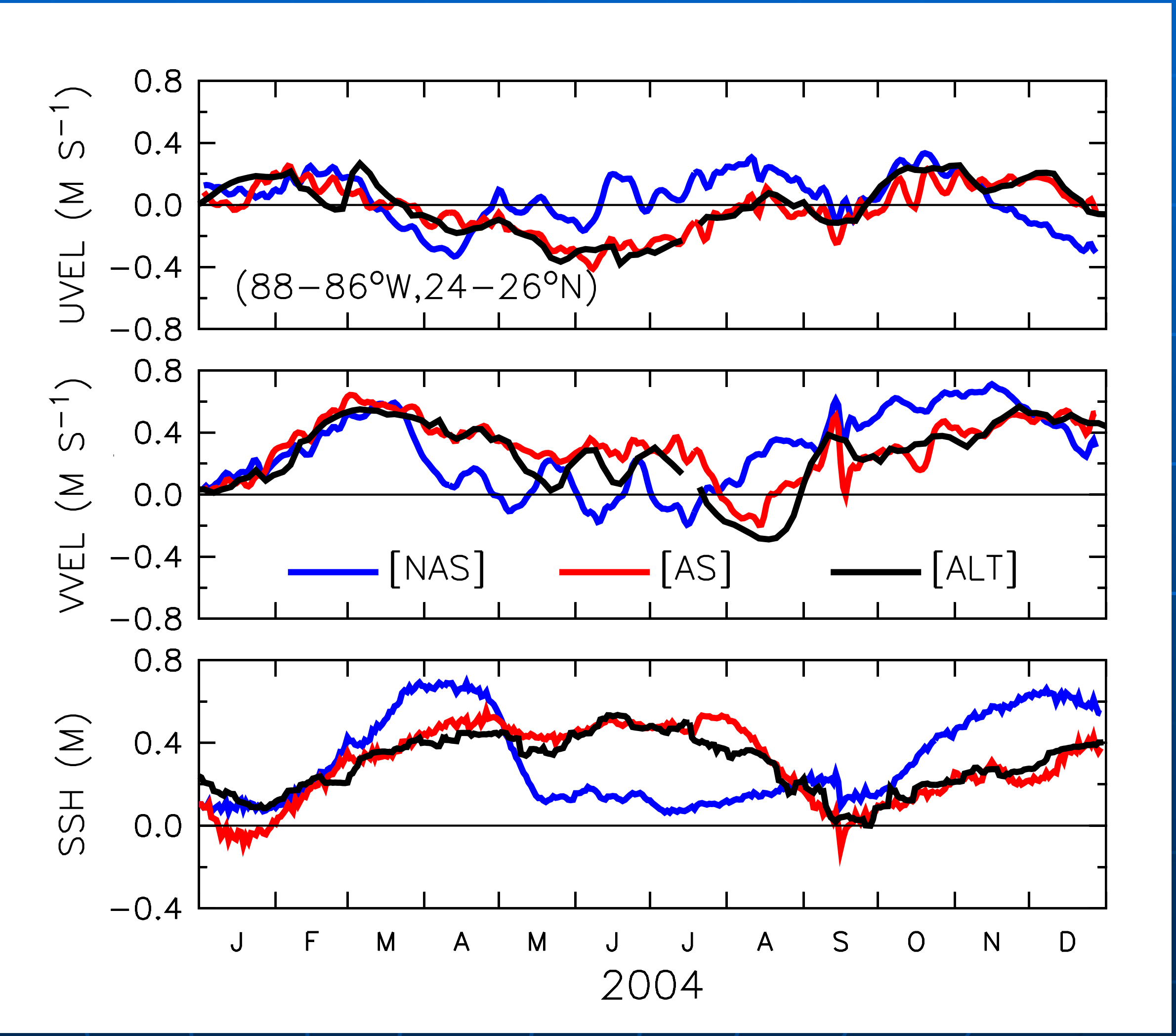
Data Assimilation

- Assimilating daily operational Modular Ocean Data Assimilation System (MODAS) 1/4° SSH real-time altimeter observations
- *Cooper and Haines* [1996] technique is used to project the surface information to the interior of the ocean.
- Relaxation to the MODAS SST is **not included**

Impact of data-assimilation

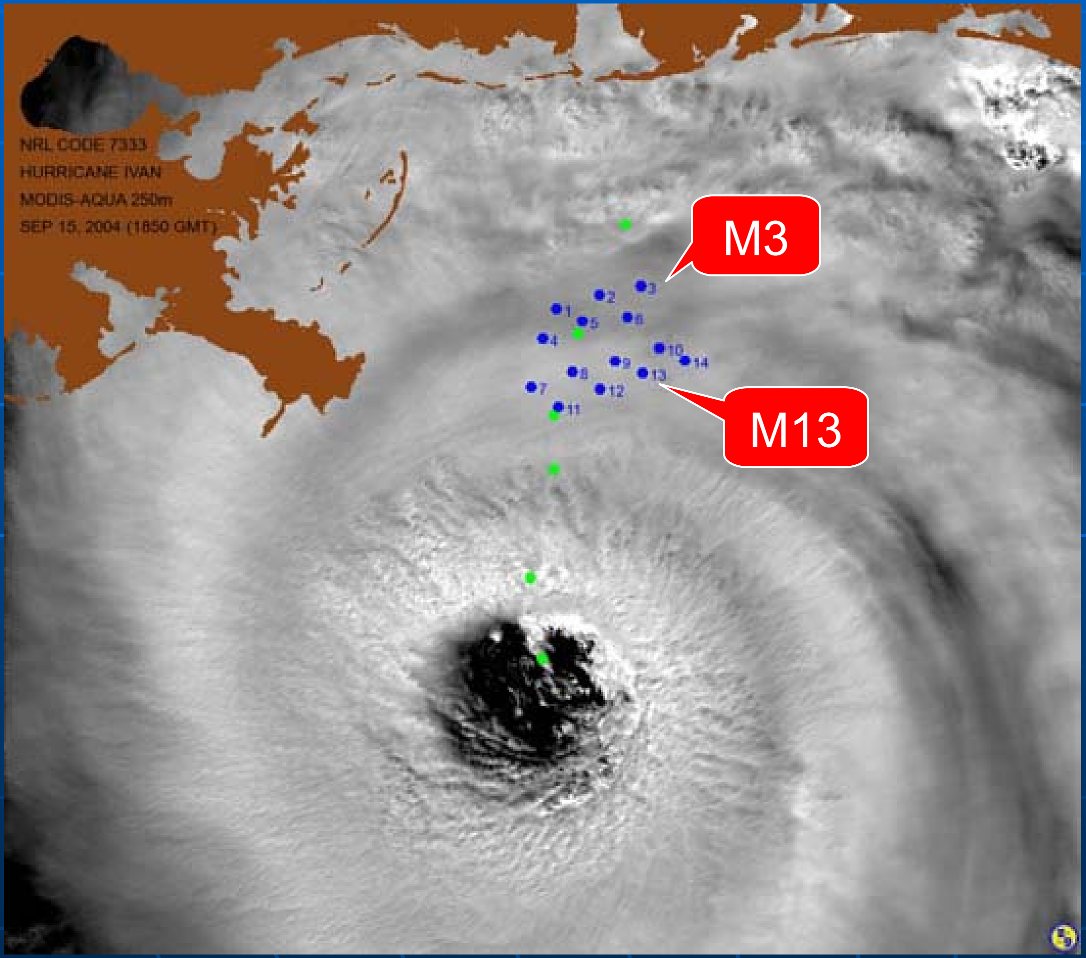
- simulation with data-assimilation showed improved agreement with observations
- WCE separation in NAS occurred in April instead of August as in AS which is consistent with observations

A comparison of zonal, meridional vel. and SSH



Impact of data-assimilation

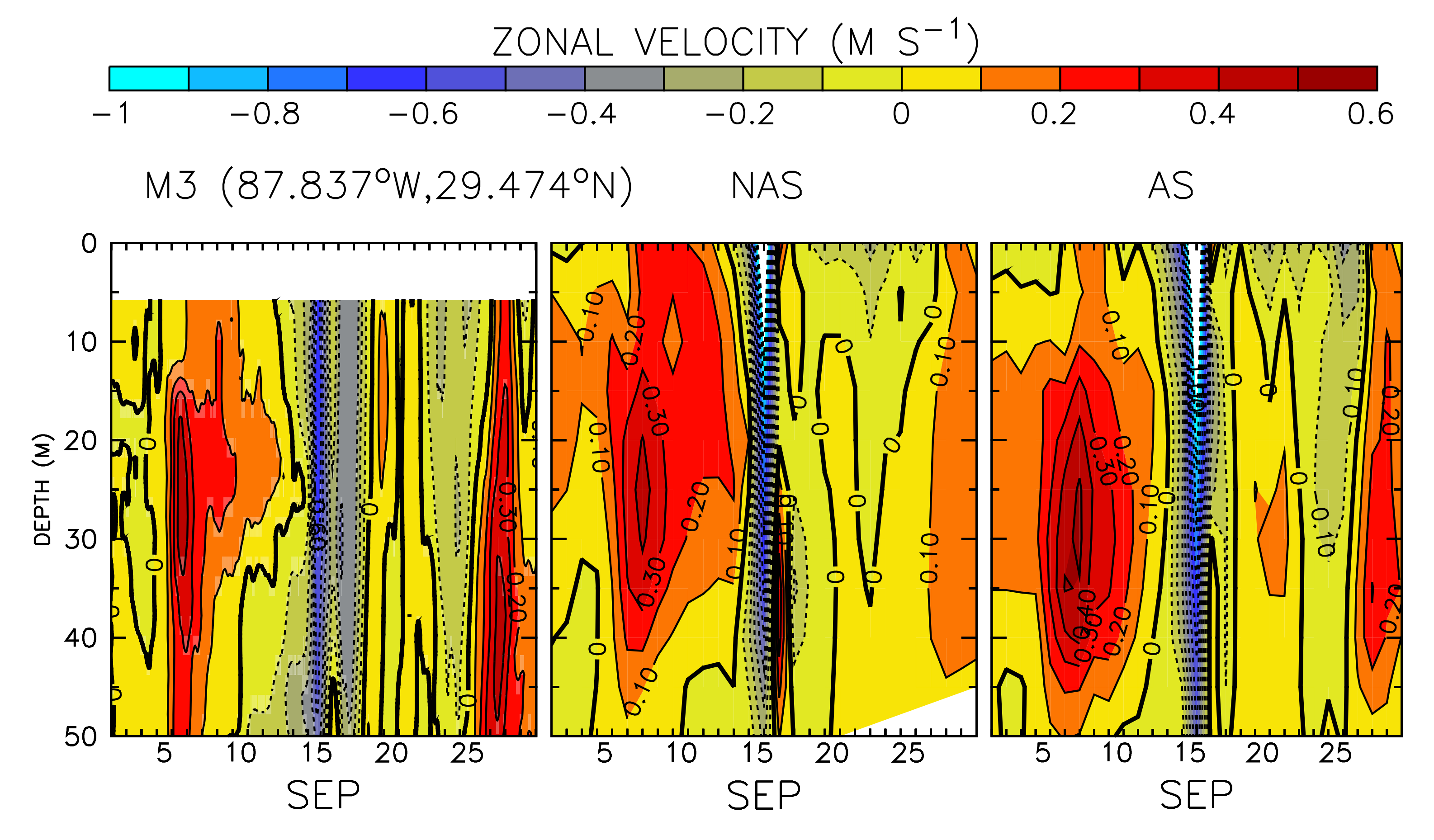
A comparison with SEED ADCP data



- 14 acoustic Doppler current profilers (ADCPs) were deployed on the shelf and down slope, as part of the NRL Slope to Shelf Energetics and Exchange Dynamics (SEED) project
- Ivan passed directly through the array
- currents in excess of 2 m/s were measured on the shelf

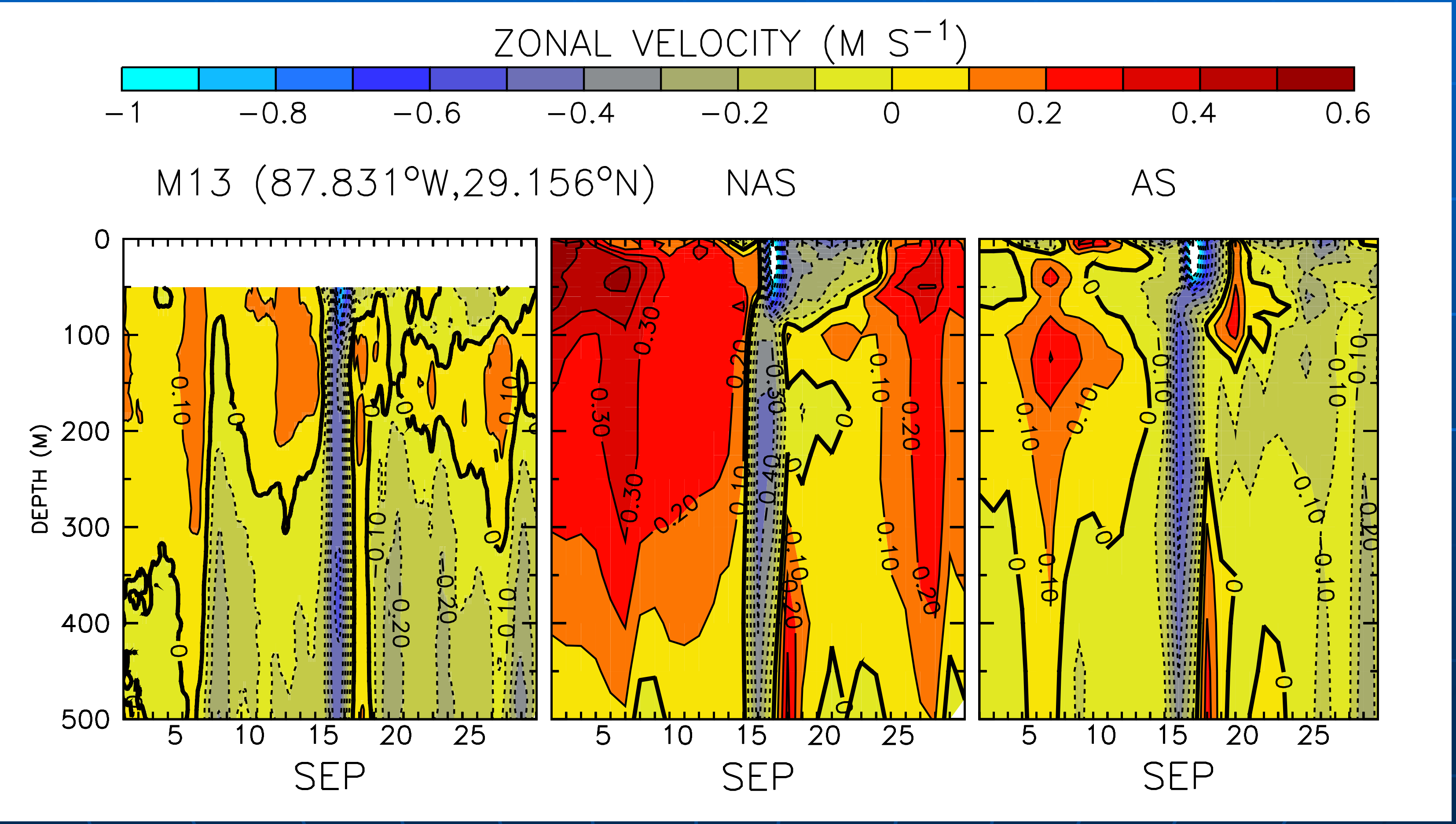
Impact of data-assimilation

A comparison with SEED ADCP data (outer shelf)



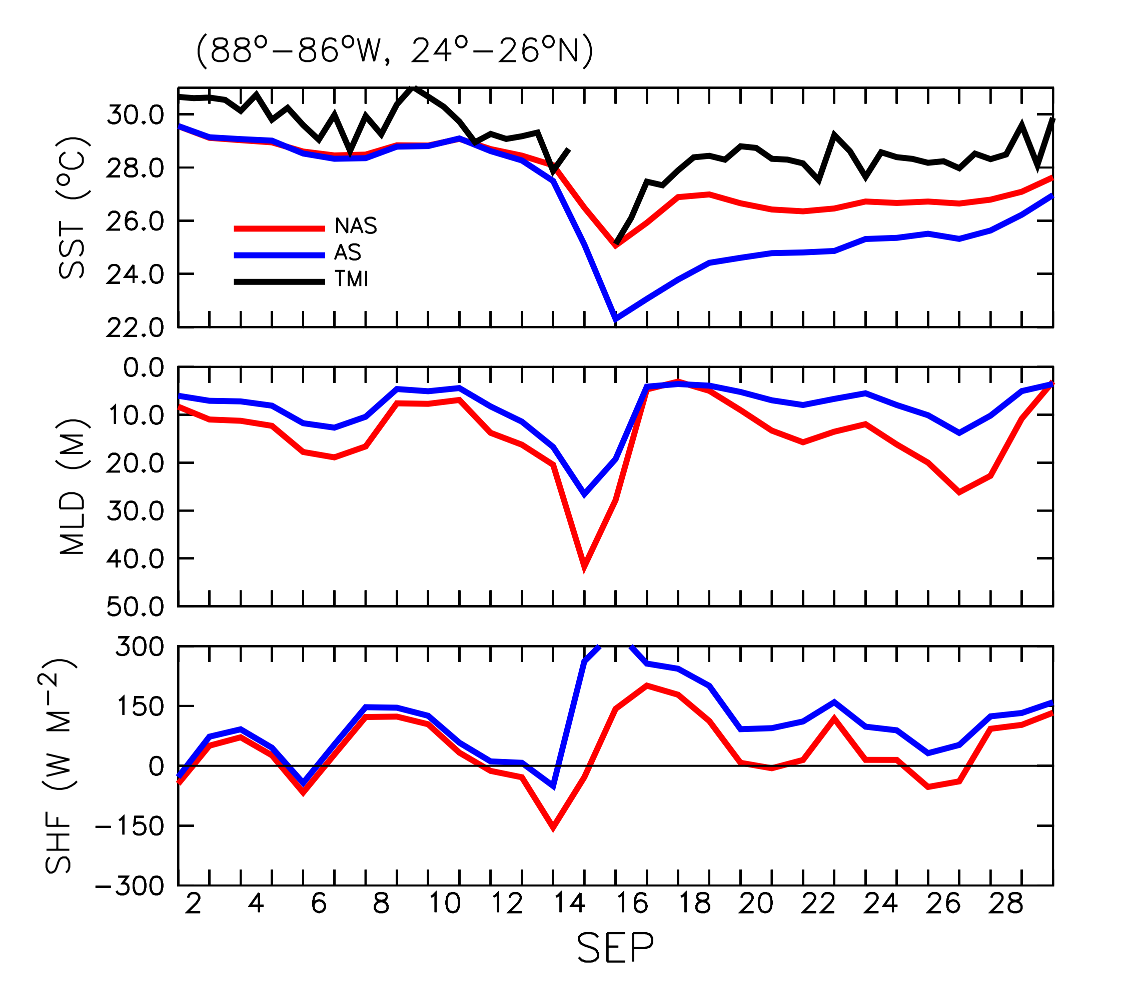
Impact of data-assimilation

A comparison with SEED ADCP data (continental slope)

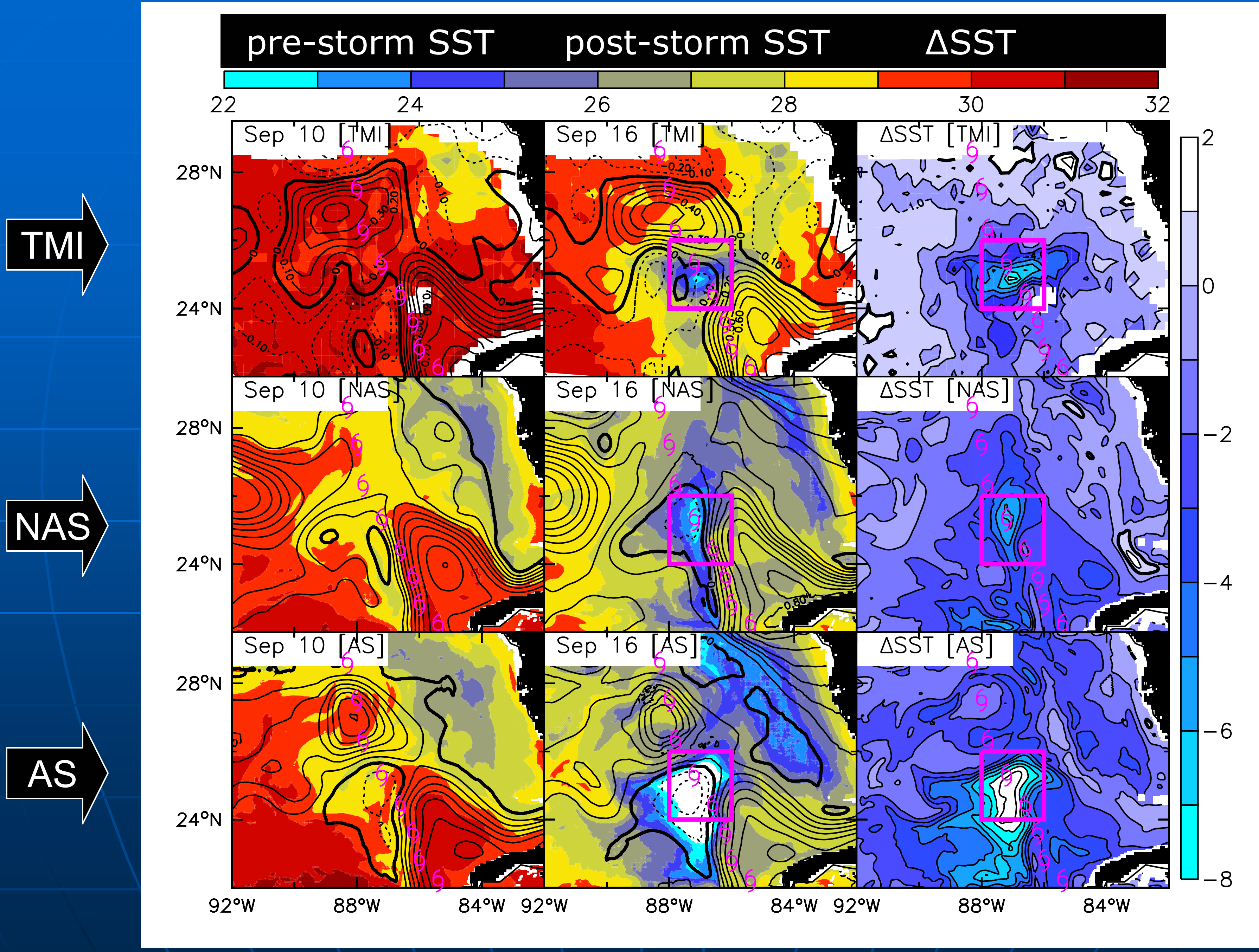


Upper-ocean response to Ivan

Simulated SST, MLD and SHF



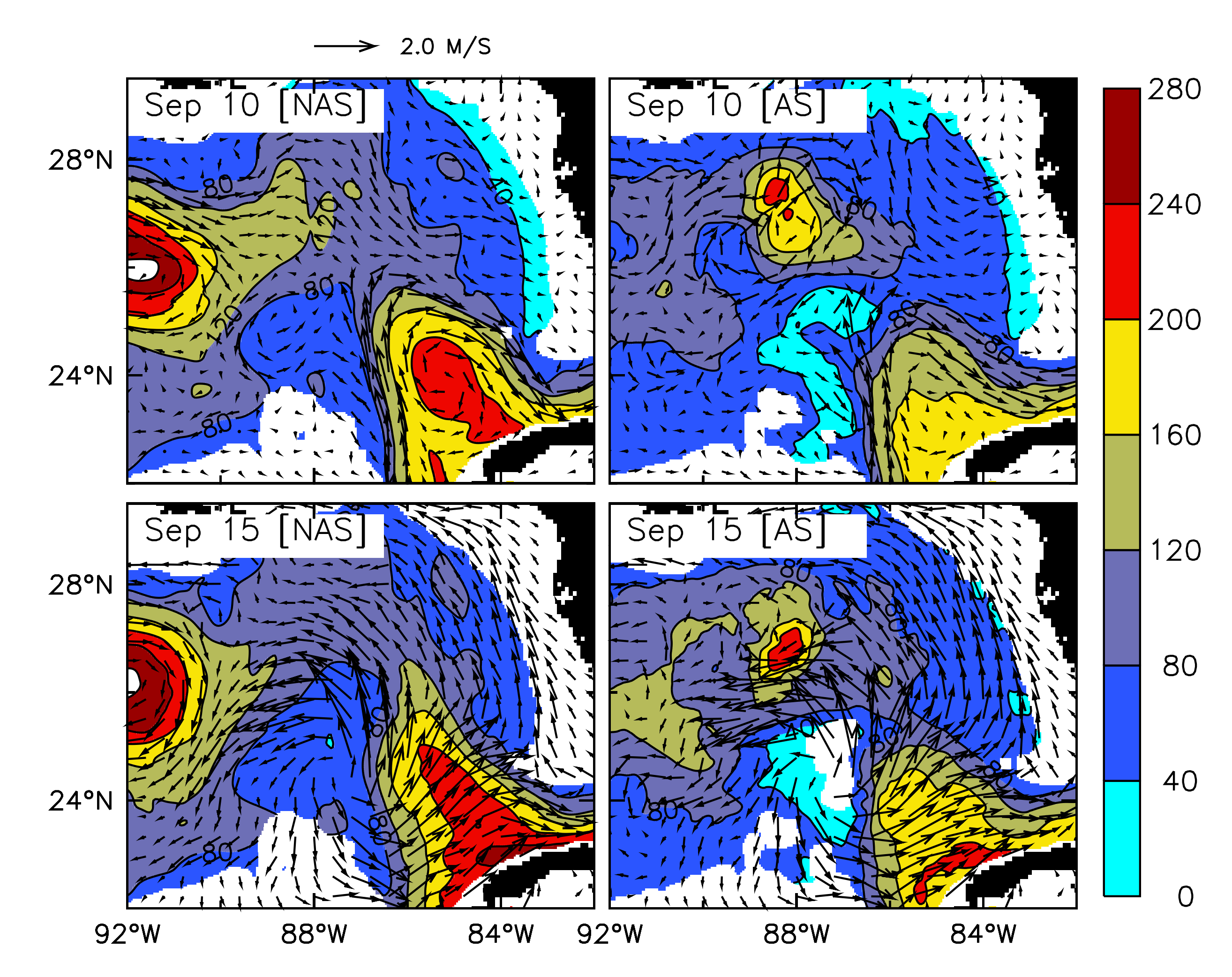
- pre-storm MLD of 10 m increased to 45 m during the storm and SST decreased from 28.5°C to 25°C in NAS
- colder SST, shallower MLD and weaker surface heat loss in AS
- post-storm warming due to surface heat gain by the ocean



TMI
NAS
AS
pre-storm SST
post-storm SST
ΔSST
22
24
26
28
30
32
Sep 10 [TMI]
Sep 16 [TMI]
ΔSST [TMI]
Sep 10 [NAS]
Sep 16 [NAS]
ΔSST [NAS]
Sep 10 [AS]
Sep 16 [AS]
ΔSST [AS]
28°N
24°N
92°W
88°W
84°W
2
0
−2
−4
−6
−8

Upper-ocean response to Ivan

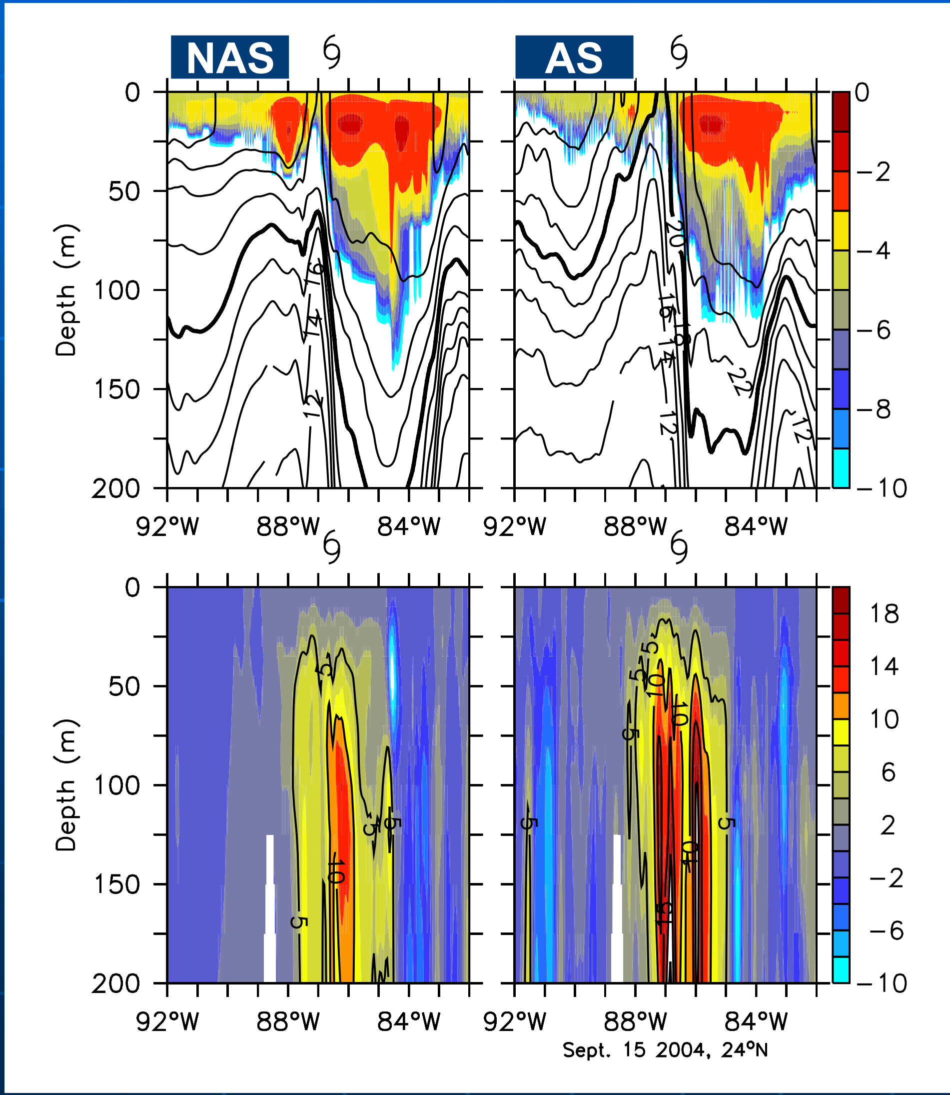
surface currents and depth of 20°C isotherm



- storm - wind-driven currents dominated the surface circulation
- shallower thermocline in the assimilative run
- deep thermocline in the LC and WCE regions

Upper-ocean response to Ivan

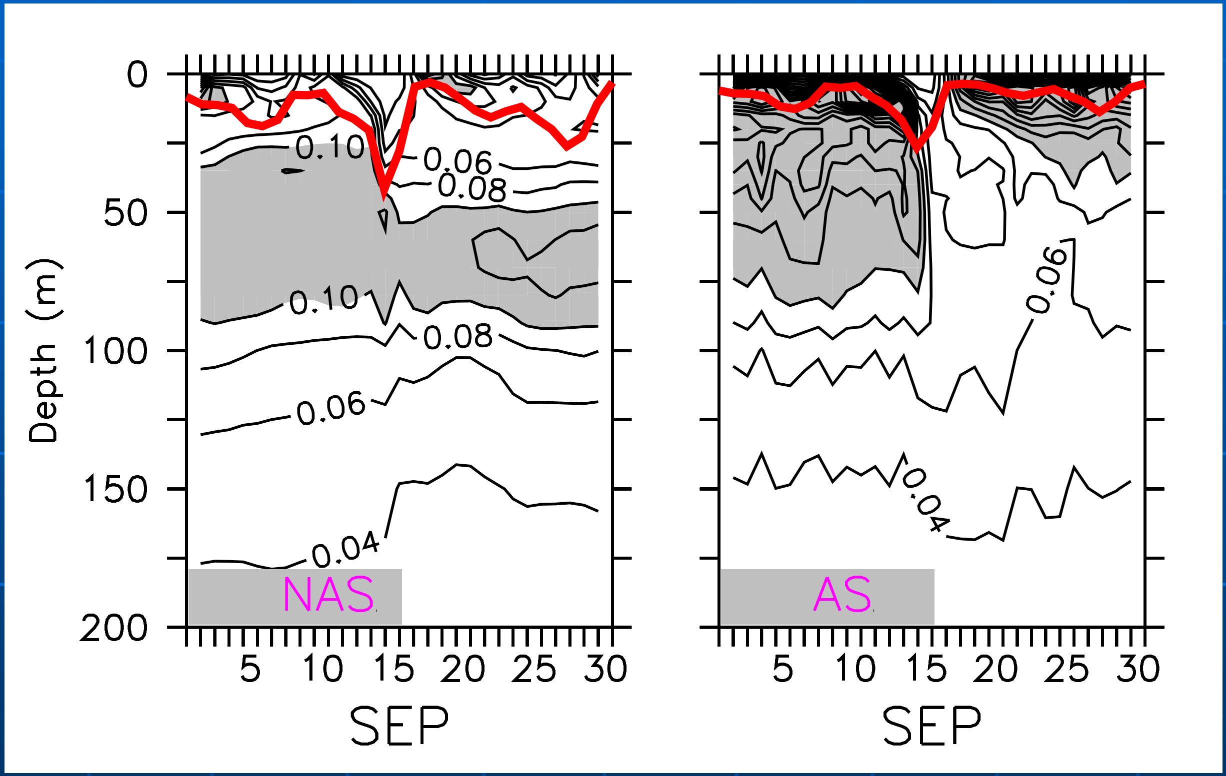
vertical temp. diffusion coefft. $\ln(K_T)$



- maximum vertical mixing occurred to the right of the storm
- lack of rightward bias in SST cooling was due to the underlying thermal structure of the water column
- vertical mixing occurred simultaneously with upwelling – shallow MLD and enhanced SST cooling
- vertical velocity of the assimilative run predicted slightly higher values

Upper-ocean response to Ivan

vertical temperature gradient and MLD



Box average 88°-86°W, 24°-26°N

- AS – thin pre-storm ML and strong upper-thermocline temperature gradient enhanced upper-ocean cooling
- NAS – weak vertical temperature gradient resulted in less SST cooling

What are the physical processes affecting the upper-ocean cooling?

Heat-budget analysis

Heat-budget terms can be written as

$Q_T = -Q_{U+V} - Q_W + Q_S + Q_{DV} + Q_{DH}$;

Q_T = rate of change of heat (dT/dt)

Q_{U+V} = horizontal advection

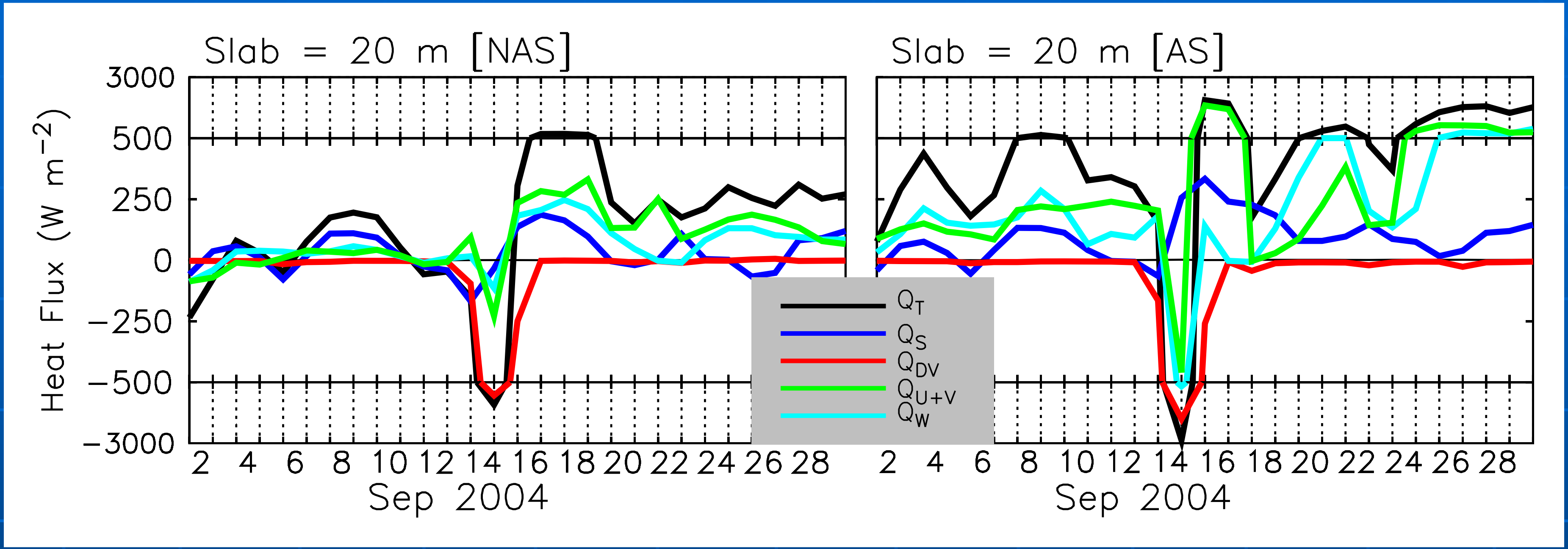
Q_W = vertical advection

Q_S = surface heat flux

Q_{DV} = vertical diffusion

Q_{DH} = horizontal diffusion (small, not included)

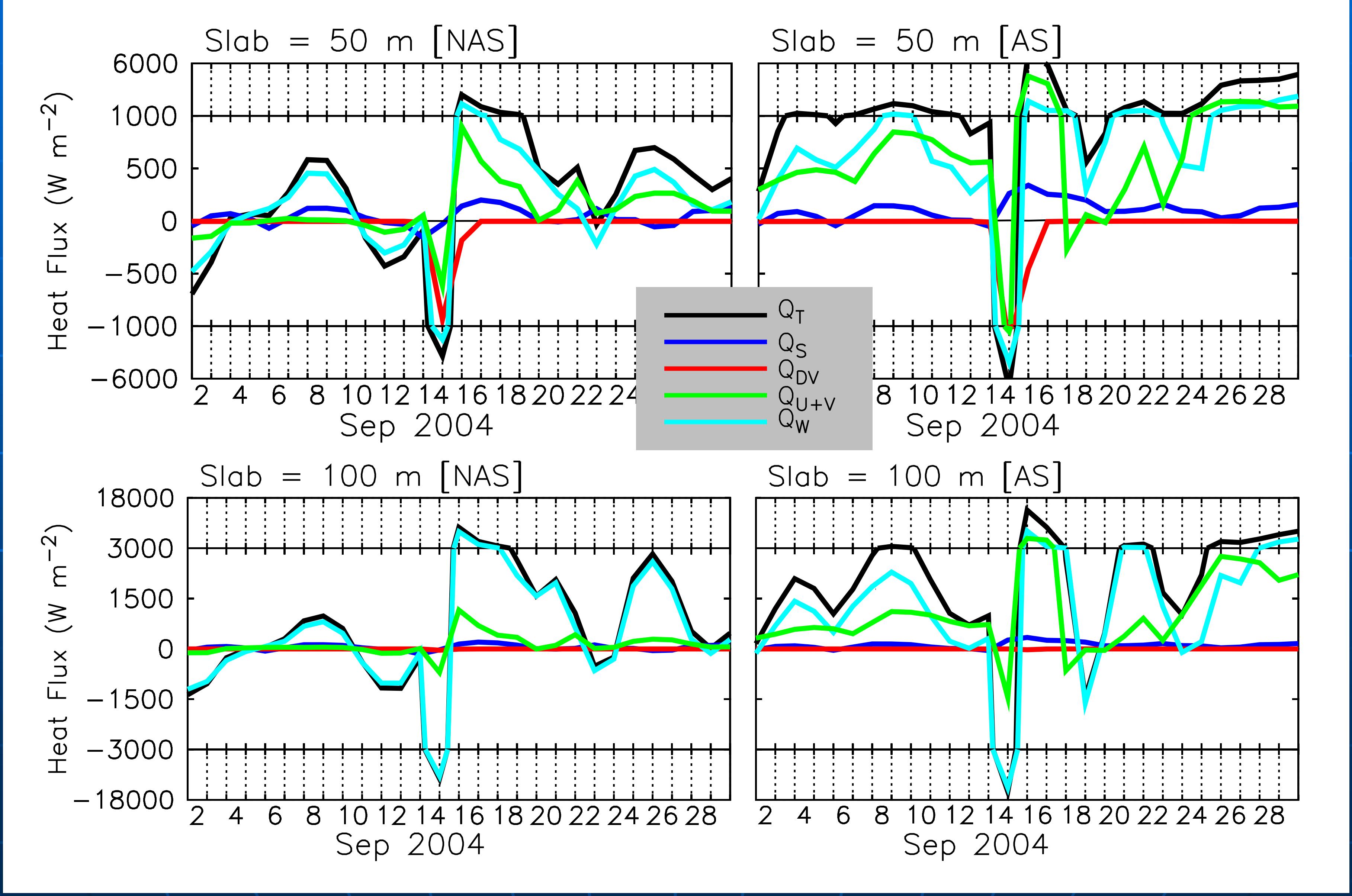
heat-budget terms averaged for 2°x2° box (88°-86°W, 24°-26°N)



Date	September 15	
Expts	**NAS**	**AS**
Q_T (W m^{-2})	-1421	-2870
Q_S (%)	2.4	-8.9
Q_{DV} (%)	**73.6**	**69.8**
Q_{U+V} (%)	16.1	16.0
Q_W (%)	**8.0**	**23.2**

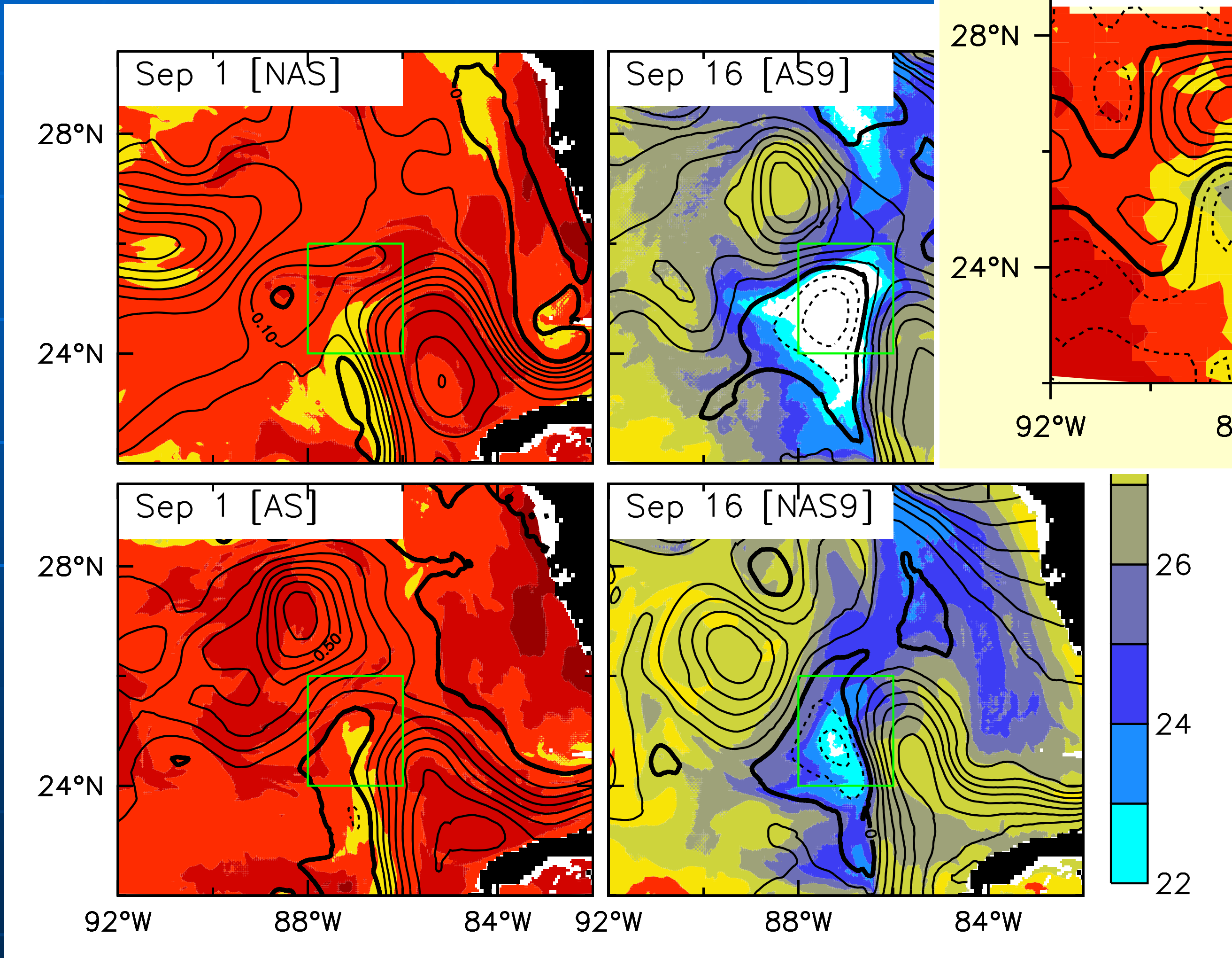
- surface heat-flux term was small
- wind-driven mixing dominated the cooling
- same horizontal advective cooling
- ~3 times vertical advective cooling in AS

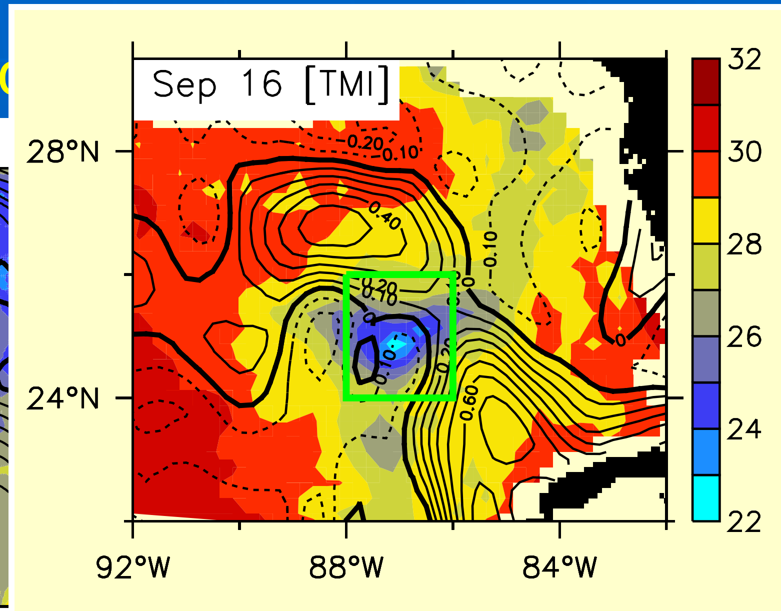
heat-budget terms at 50 m and 100 m (88°-86°W, 24°-26°N)



Sensitivity to initial conditions

model SST (shaded) and SSH (c



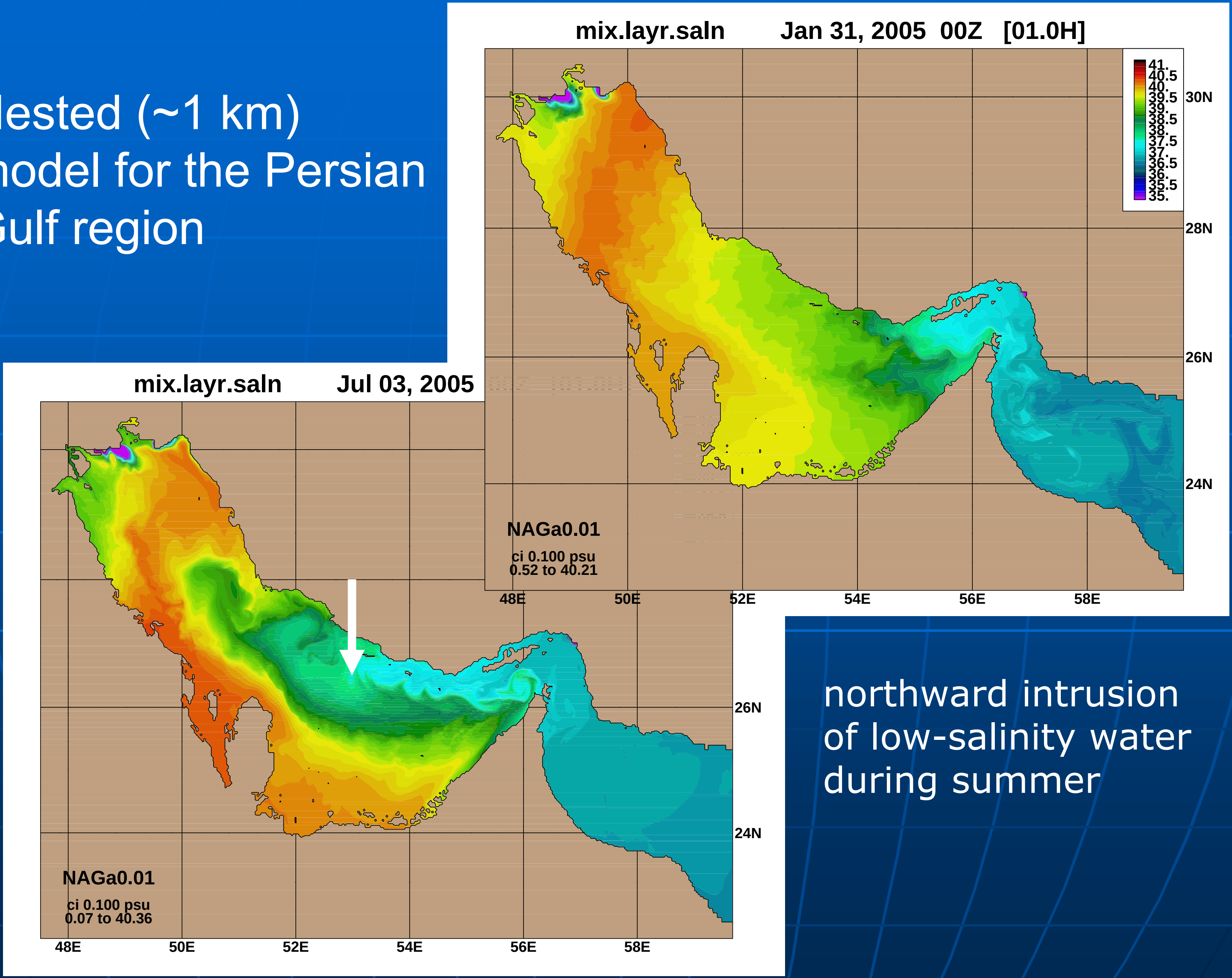


- simulation initialized with assimilation fields reproduced the observed changes in the upper-ocean reasonably well

Conclusions

- A comparison of simulated zonal and meridional velocities using data assimilation showed improved agreement with ADCP observations
- Model simulated amplitude of the cold wake (-6°C) compared reasonably well with the observed changes in SST
- While the simulated location of WCE and LC in the assimilation run showed better agreement with satellite altimetry, the storm-induced SST cooling was 40-50% greater than the observed cooling
- Overall, 72% of the upper-ocean cooling was due to wind-driven vertical mixing
- There was a three-fold increase in the vertical advective cooling in the assimilative run
- Surface heat-flux contribution to the mixed-layer heat budget was only ~4%.

Nested (~1 km) model for the Persian Gulf region



northward intrusion of low-salinity water during summer

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