An Interdisciplinary Ocean Observatory and Development of a High Resolution Coastal Circulation Model

多学科间的海洋观测平台 以及近海环流数模的开发和应用

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1. An Interdisciplinary Ocean Observatory

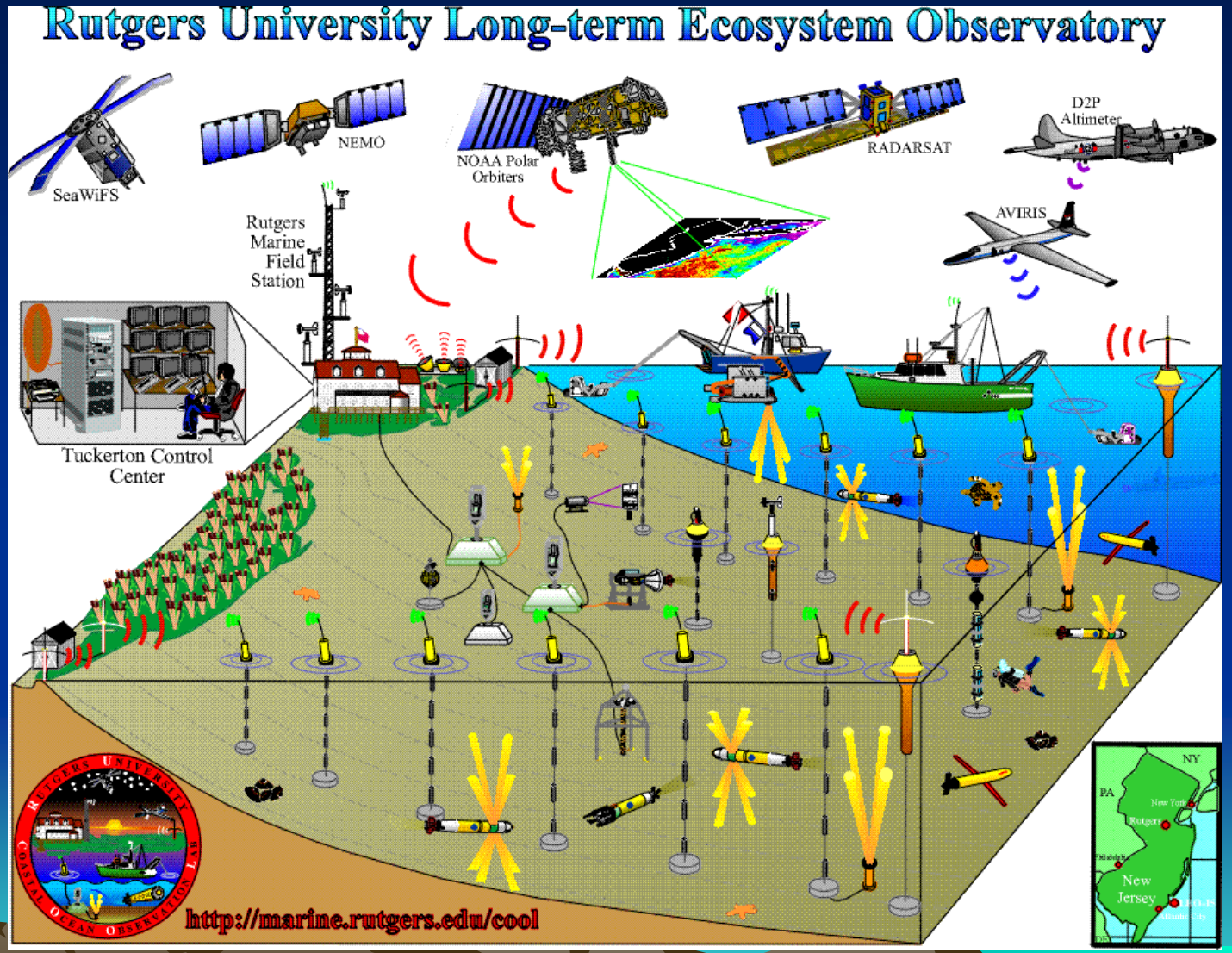
多学科间的海洋观测平台

- Ocean sciences are moving from the exploration phase to the understanding and prediction phases. （海洋科学正从单一的探险阶段走向理解和预报阶段）。

- Ocean observatories represent a fundamentally new enabling technology that permits research efforts to examine processes on space and time scales that were not previously achievable （海洋观测平台的不断兴建得力于新兴观测技术的开发， 使得那些过去在时空尺度上无法实现的机理研究成为可能) (Jahnke et al., 2002)。

- There are several ocean observatiories established, including LEO, GoMOOS, LCO, etc. (已建立的海洋观测平台有， 美国的LEO ， GoMOOS ， 英国的LCO， 加拿大的CMEP 等)。

Schematic Diagram of an Advanced Ocean Observatory
海洋观测平台示意图

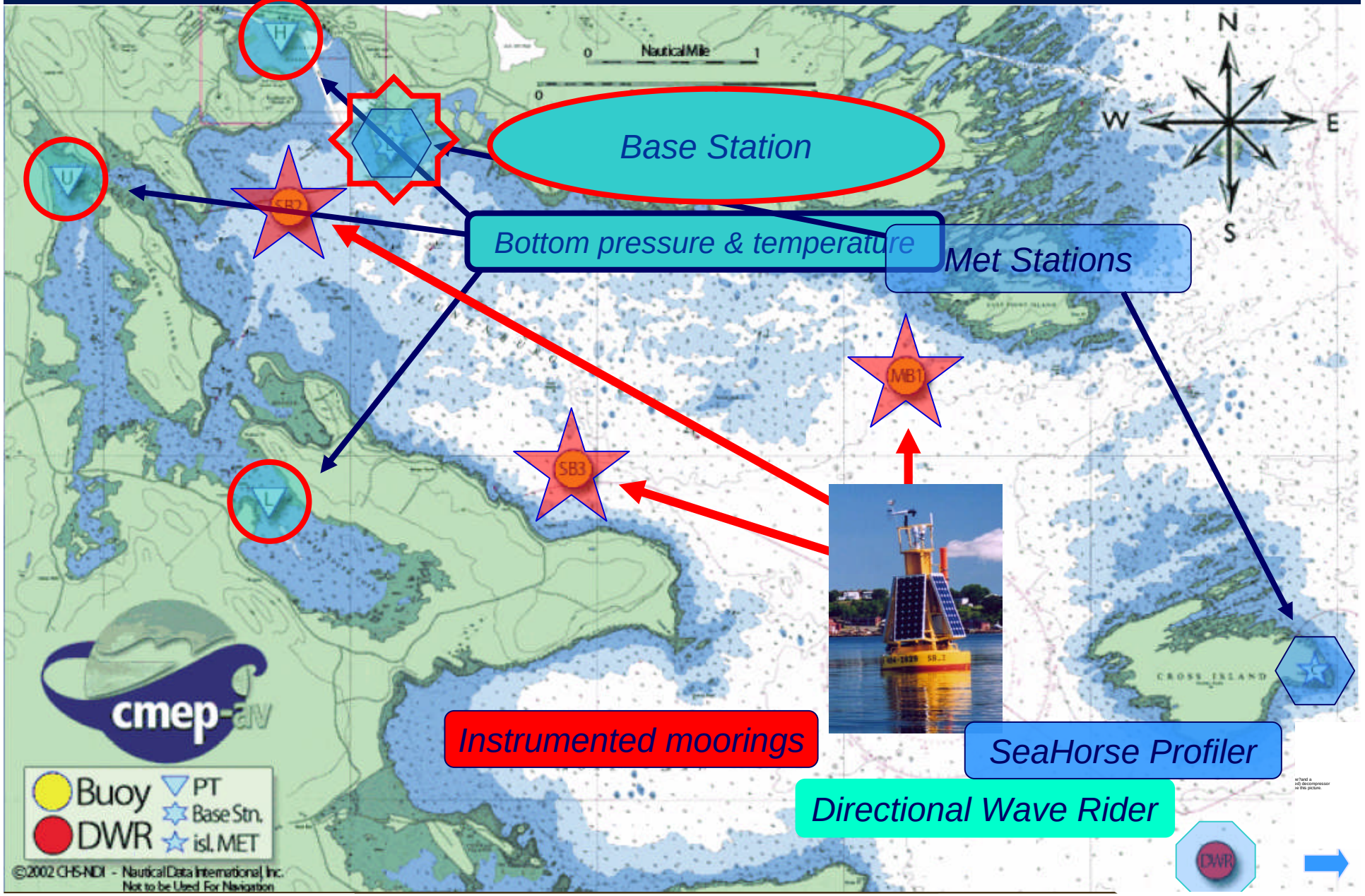


Center of Marine Environmental Prediction (CMEP)
（加拿大东海岸） 海洋环境预报站

- **Canadian scientists established an ocean observatory in Lunenburg Bay, Nova Scotia, as part of an research project of marine environmental prediction in the Atlantic Ocean of Canada.** (作为海洋环境预报研究课题的一部份，加拿大科学家们在新斯科舍省的卢嫩堡海湾建立了海洋观测站）
- **Funding agencies provided ~$3.6 millions for research infrastructure and ~$2.5 millions for research funding.**(加拿大国家基金部门为观测站提供了约三百六十万加元用于购买研究基础设施，二百五十万加元用于研究经费）
- **The observatory infrastructure includes computer resources, an observing system in Lunenburg Bay, etc.** （观测站的基础设施包括计算机资源和海洋观察仪器等）
- **The system measures physical, biological, chemical and atmospheric variables**(观察量包括物理，生物，化学和大气变 量等）。

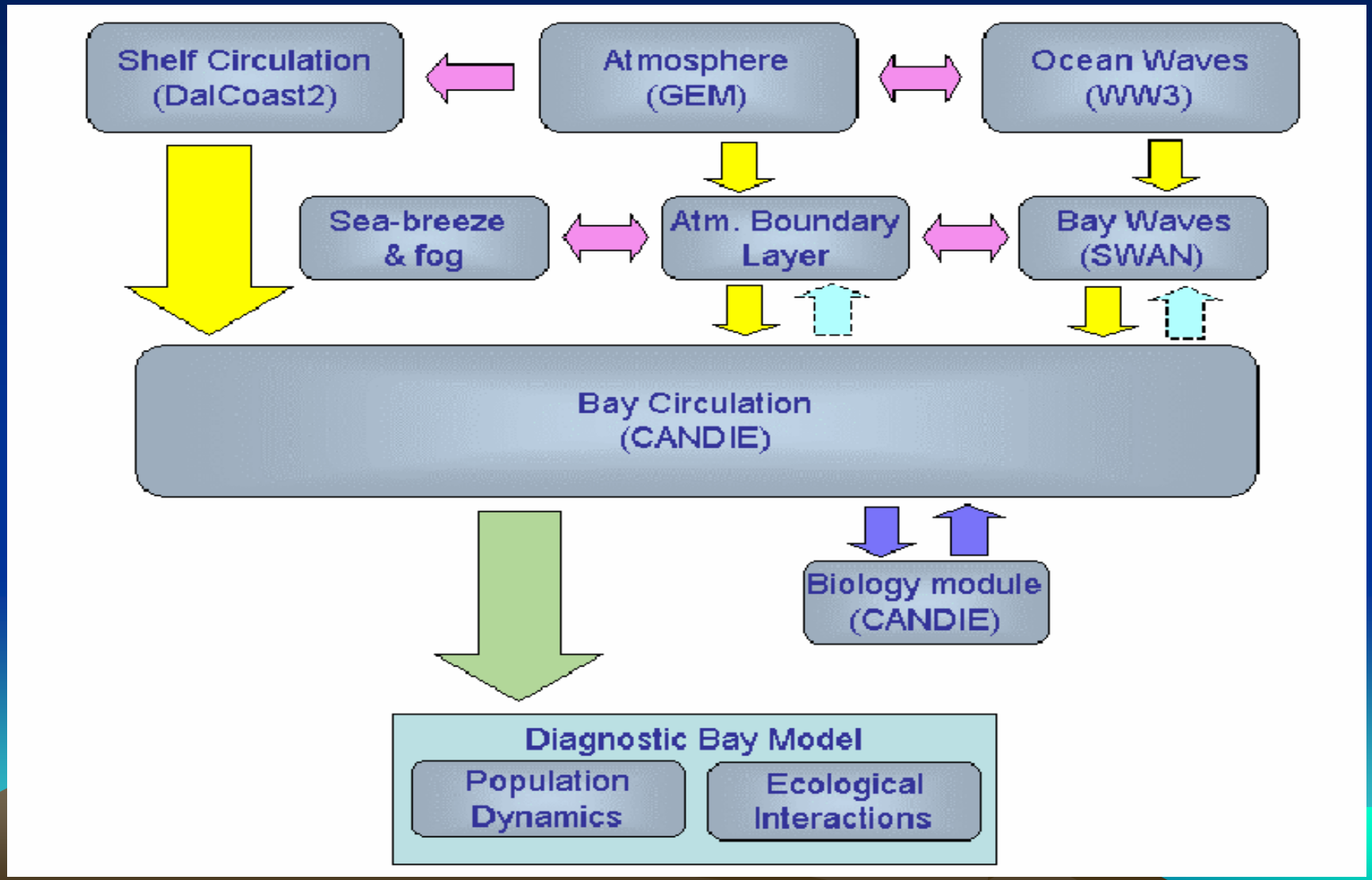
A buoy site in Lunenburg Bay
卢嫩堡海湾中的海洋浮标之一

MEPS - Bay Observatory: real-time, multidisciplinary, integrated



An interdisciplinary coupled modelling system

多学科间的耦合式数值模型系统



2. Coastal ocean circulation model

近海环流数值模式

- Lunenburg Bay was chosen as a testbed for marine environmental prediction under development. (卢嫩堡海湾被选择为海洋环境观测和预报的试验地）。
- My group is responsible for developing a fine resolution data-assimilative coastal circulation model for Lunenburg Bay.（由报告人领导的研究小组负责开发高分辨率的，并具有数据同化功能的近海环流模式）。
- As the first step, we developed a barotropic circulation model that is used in this study.（我们首先开发了高分辨率的正压环流模式）。

CANDIE Model 海流数值模式

- CANDIE stands for CANadian version of DIEcast

  (Sheng et al. 1998; Lu et al. 2001; Davidson et al. 2001; Sheng 2001; Sheng et al. 2001; Sheng and Tang 2003 and 2004; Sheng and Wang, 2004； Sheng et al., 2005a, 2005b).

- - z-level model, - three dimensional,
- - primitive-equation, - implicit free-surface,
- - finite-difference, - fourth-order numerics

Website:

www.phys.ocean.dal.ca/programs/CANDIE

Governing Equations 模式的控制方程

$$\frac{\partial u}{\partial t} + \mathcal{L}u - fv = -\frac{1}{\rho_o}\frac{\partial p}{\partial x} + \mathcal{F}_m u$$

$$\frac{\partial v}{\partial t} + \mathcal{L}v + fu = -\frac{1}{\rho_o}\frac{\partial p}{\partial y} + \mathcal{F}_m v$$

$$\frac{\partial p}{\partial z} = -\rho g$$

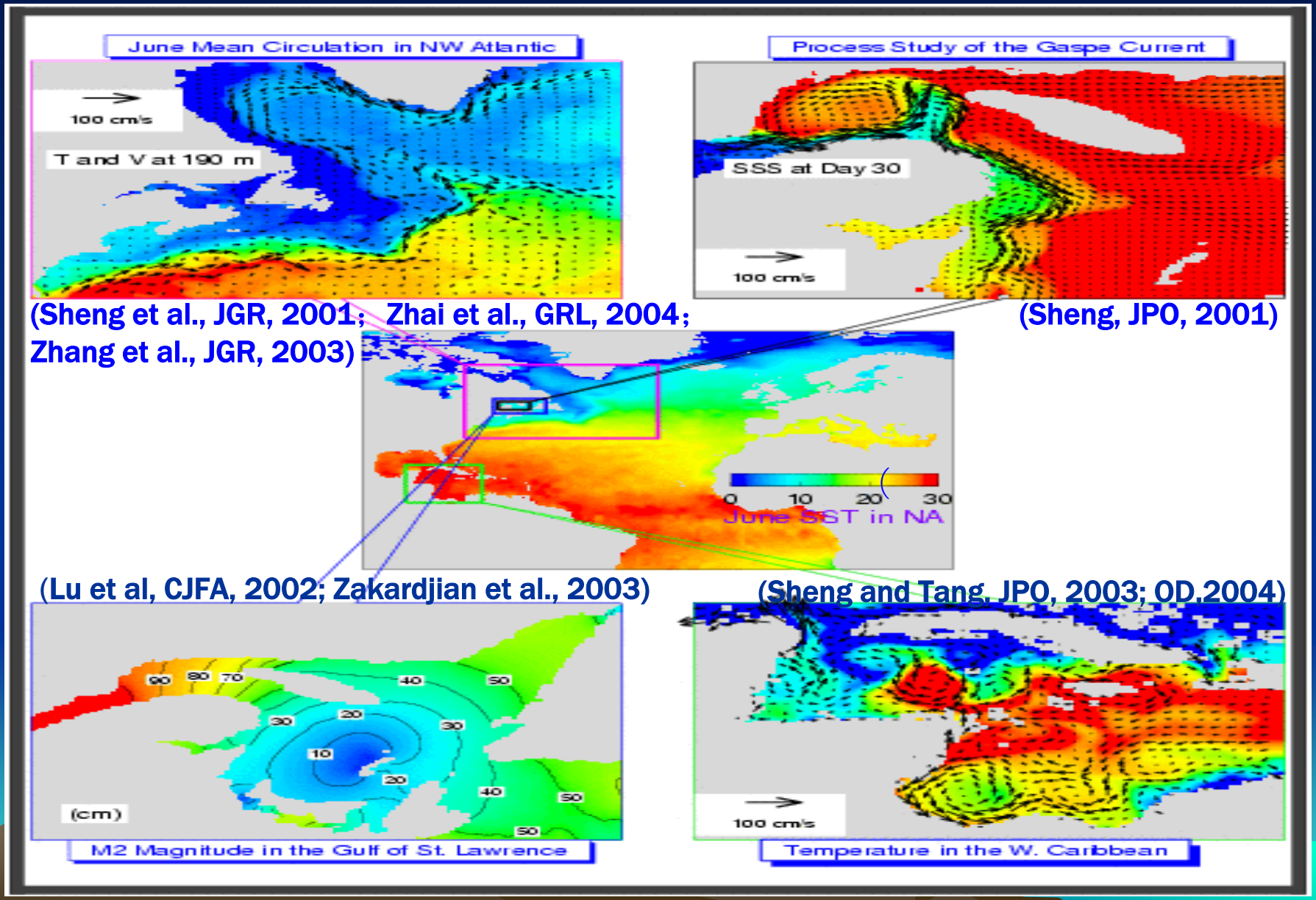
$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\mathcal{L}Q = \frac{\partial uQ}{\partial x} + \frac{\partial vQ}{\partial y} + \frac{\partial wQ}{\partial z}$$

$$\mathcal{F}_m Q = \mathcal{D}_m Q + \frac{\partial}{\partial z}(K_m \frac{\partial Q}{\partial z})$$

$$\mathcal{D}_m Q = \frac{\partial}{\partial x}(A_m \frac{\partial Q}{\partial x}) + \frac{\partial}{\partial y}(A_m \frac{\partial Q}{\partial y})$$

CANDIE的应用及在国际刊物上已发表的文献



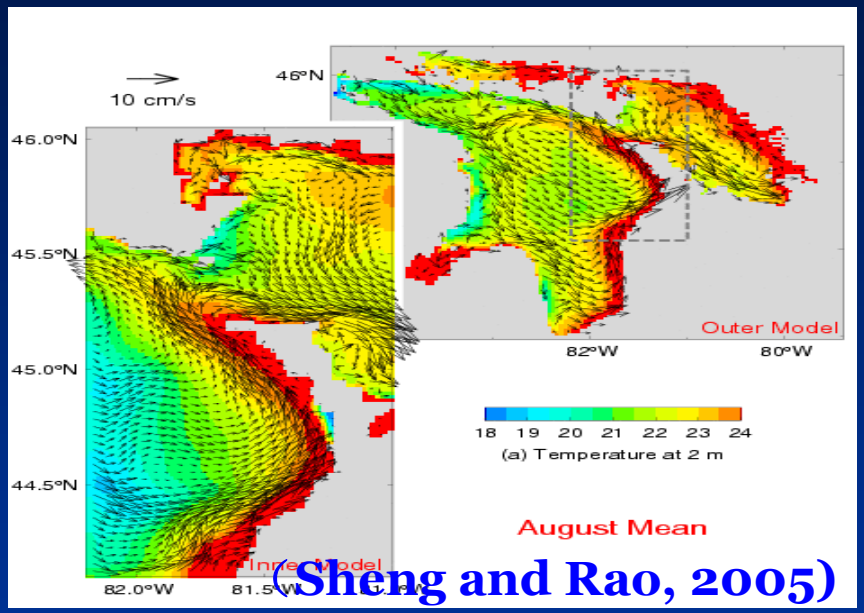
(Sheng et al., JGR, 2001； Zhai et al., GRL, 2004；Zhang et al., JGR, 2003)

(Sheng, JPO, 2001)

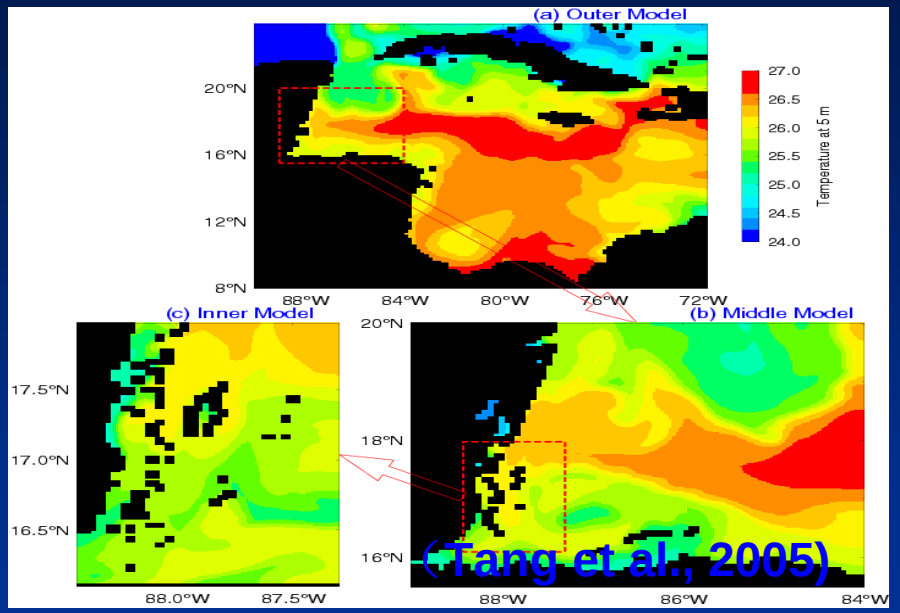
(Lu et al, CJFA, 2002; Zakardjian et al., 2003)

(Sheng and Tang, JPO, 2003; OD,2004)

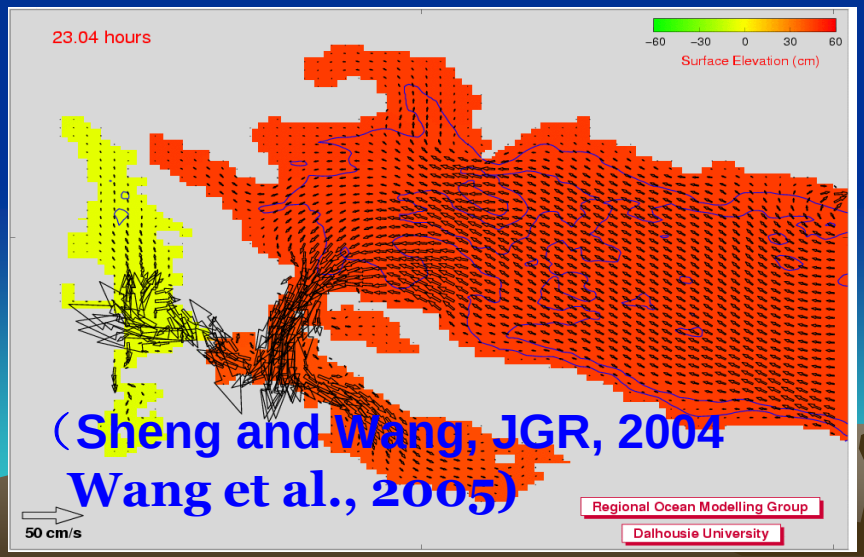
CANDIE的应用及在国际刊物上将要发表的文献



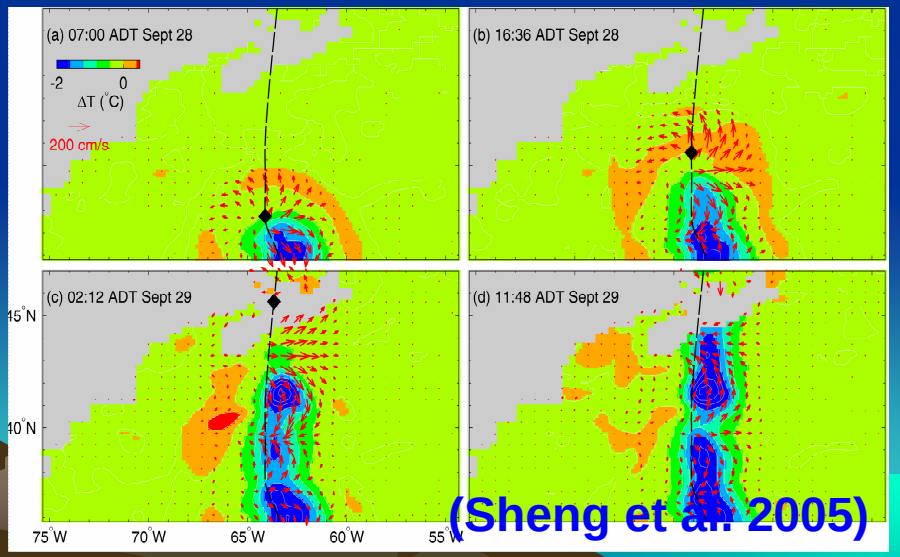
(Sheng and Rao, 2005)



(Tang et al., 2005)

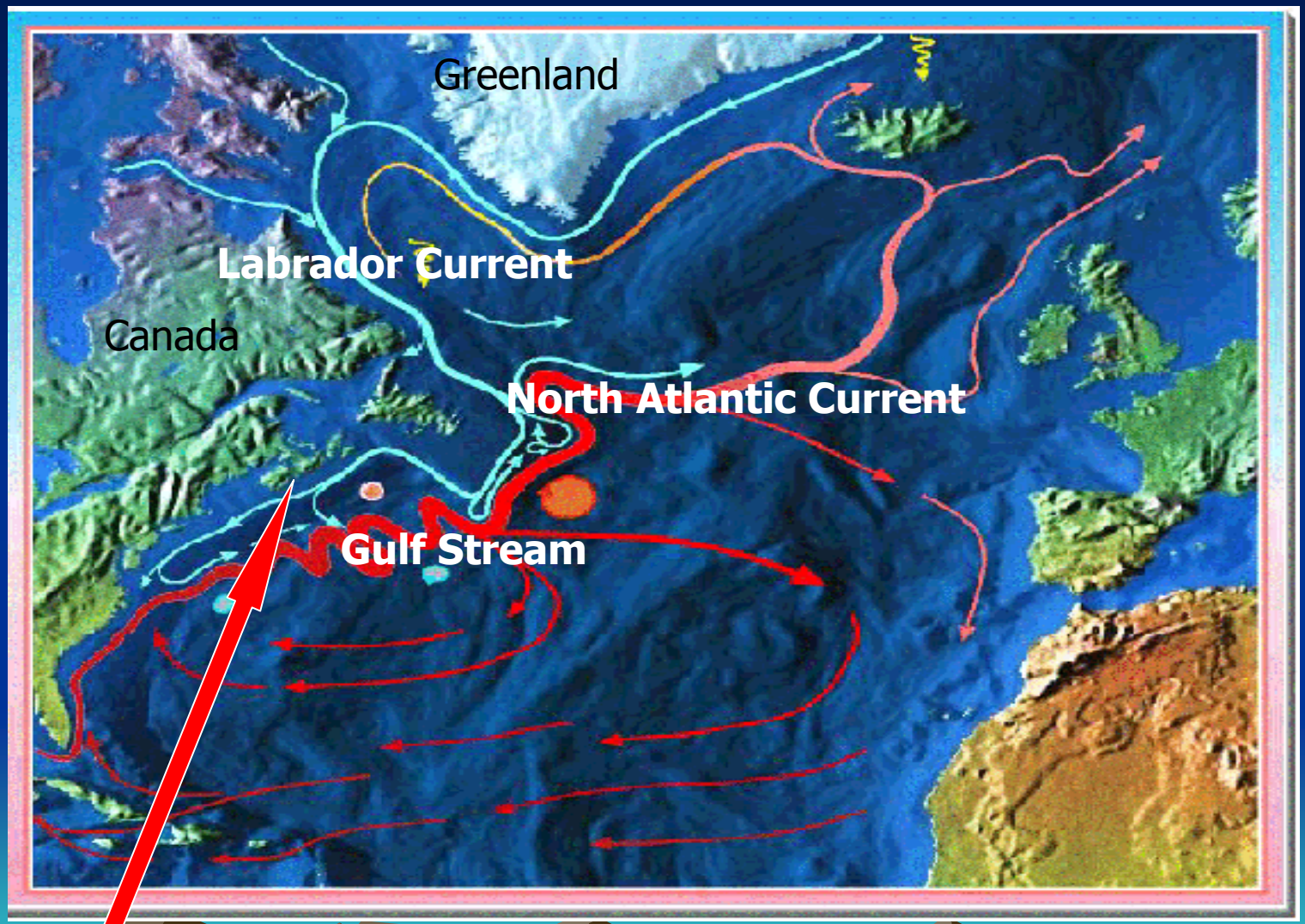


（Sheng and Wang, JGR, 2004
Wang et al., 2005)



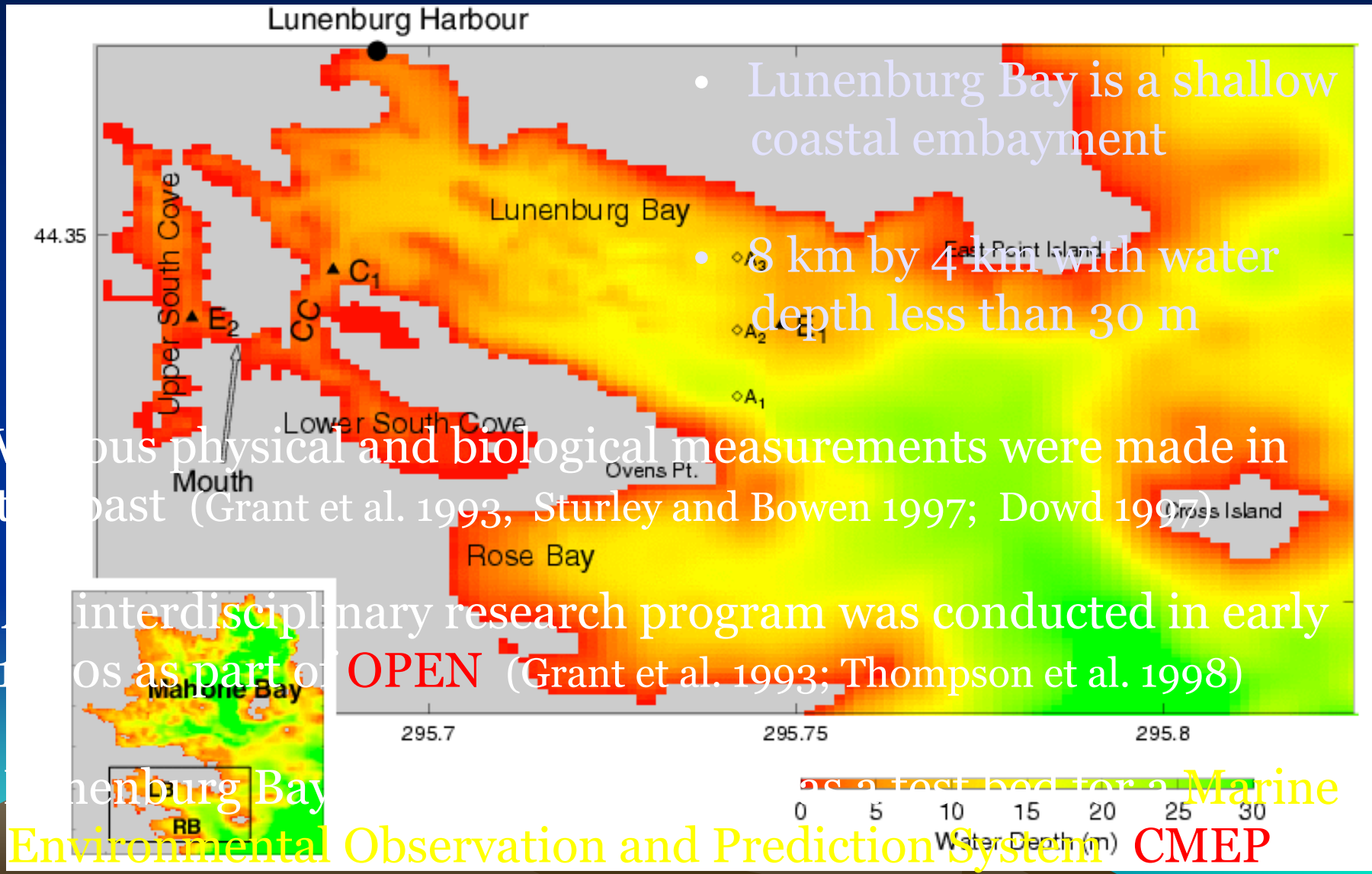
(Sheng et al. 2005)

Schematic of near-surface circulation in the North Atlantic
北大西洋表层洋流示意图



Lunenburg Bay, Nova Scotia 新斯科舍省卢嫩堡海湾

新斯科舍省卢嫩堡海湾地型图



- Lunenburg Bay is a shallow coastal embayment
- 8 km by 4 km with water depth less than 30 m
- V…ous physical and biological measurements were made in t…past (Grant et al. 1993, Sturley and Bowen 1997; Dowd 1997)
- A… interdisciplinary research program was conducted in early 1…0s as part of OPEN (Grant et al. 1993; Thompson et al. 1998)
- L…enburg Bay … as a test … for a Marine Environmental Observation and Prediction System CMEP

Previous modelling studies in Lunenburg Bay
文献回顾

- Sturley, Thompson and Bowen (1993) developed a 3D, nonlinear tidal circulation model and used the model to examine the tidal asymmetry between flooding and ebbing.

- Sturley and Bowen (1996) used the above model to further examine the tidal asymmetry, inter-cove exchange and flushing regimes in USC.

- Thompson et al. (1998) used the same model to interpret the synthetic aperture radar (SAR) images of lines and whorl-like features associated with tidally advected surface slicks.

- Sheng and Wang (2004) developed a new coastal model based on CANDIE and studies the nonlinear tidal dynamics using the new model.

Model parameters 模式的参数

- Model resolution: 60 m (horizontal)
  模式的分辨率 23 z-levels (vertical)
- Time step: $\Delta t = 17$ s
  时间步长

- Sub-grid mixing parameterizations
  次网格混合系数的参数化
  - Smagorinsky Horizontal Mixing Scheme (1963)
  - Vertical Mixing Scheme (Davies, 1998; Csanady, 1982)

$$A_m = \sqrt{A_t^2 + A_s^2}$$

$$K_m = K_f + K_w$$

- Quadratic Bottom Stress:
  非线性的海底摩擦应力

$$\tau_b = \rho C_d \mid \vec{U}_b \mid \vec{U}_b$$

Model open boundary Condition
模型的开边界条件

We follow Davies and Flather (1978) and use the following radiation condition at the model open boundary:

$$U = U_t + U_s + \frac{C}{h}(\eta - \eta_t - \eta_s)$$

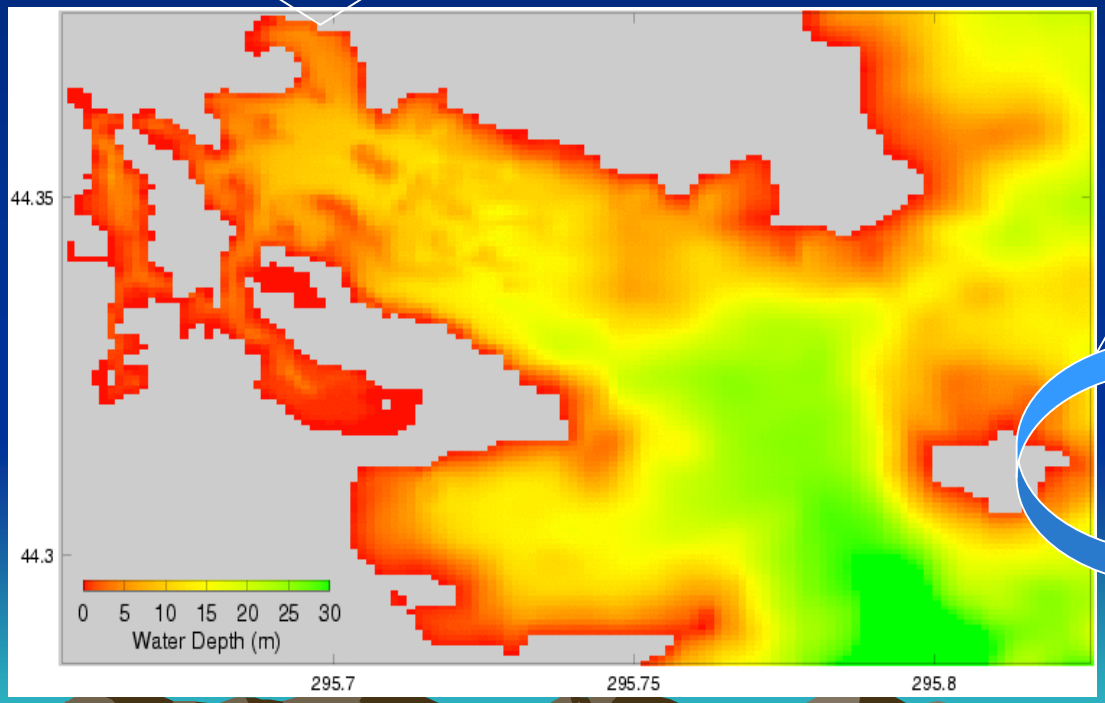
U and η : model-calculated currents and elevation.

U_t, U_s, η_t, η_s : prescribed currents and elevations.

We set (U_t, U_s) is zero and use a simplified version of the incremental approach (Lu et al. 2001) to infer (η_t, η_s) from the water level prediction made by the Canadian Hydrographic Services and observation in Lunenburg Bay.

Determining ζ_t using the simplified incremental approach

ζ^{CHS} was made by CHS



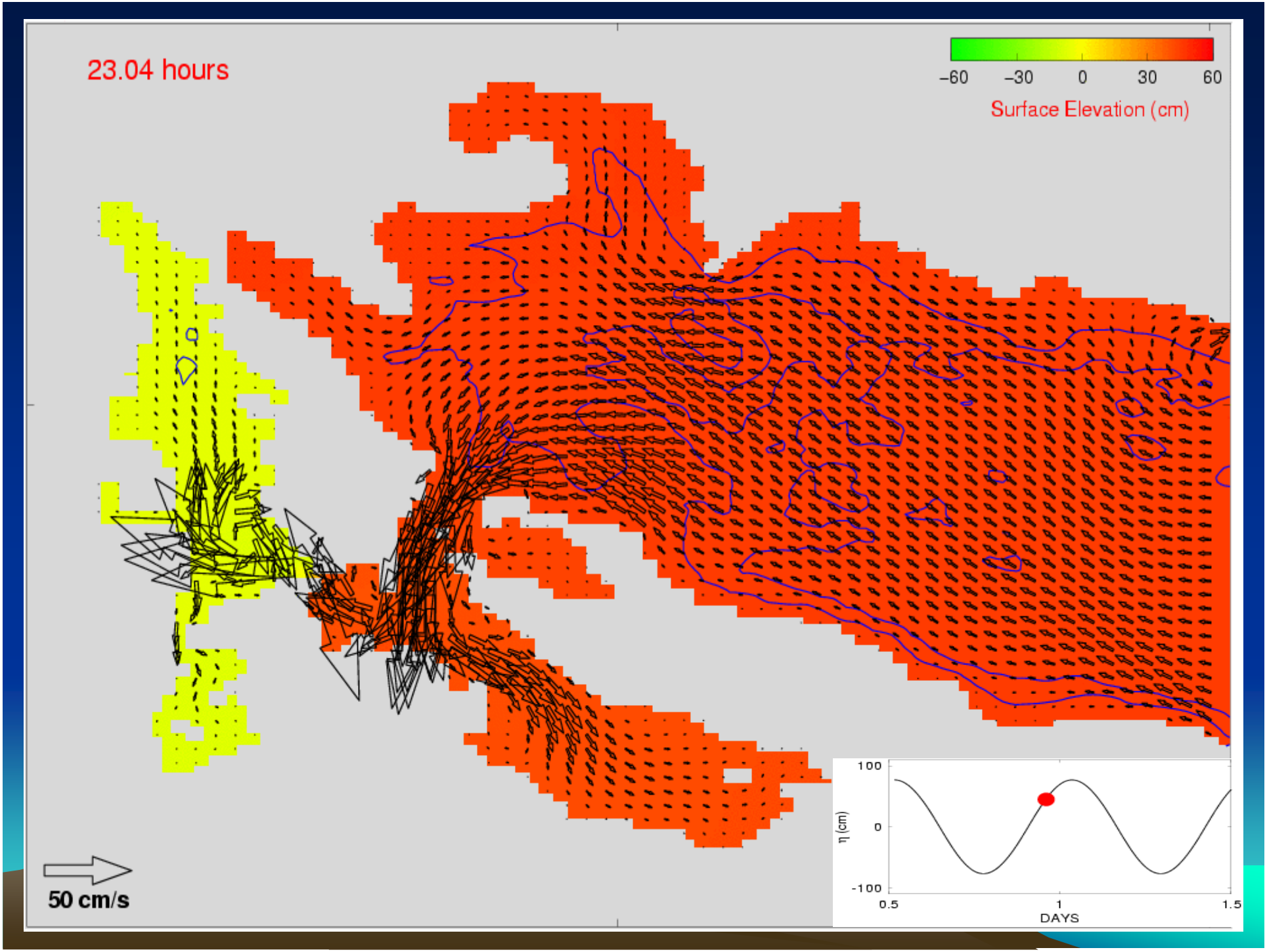
$u=c/h*(\zeta-\zeta_t)$

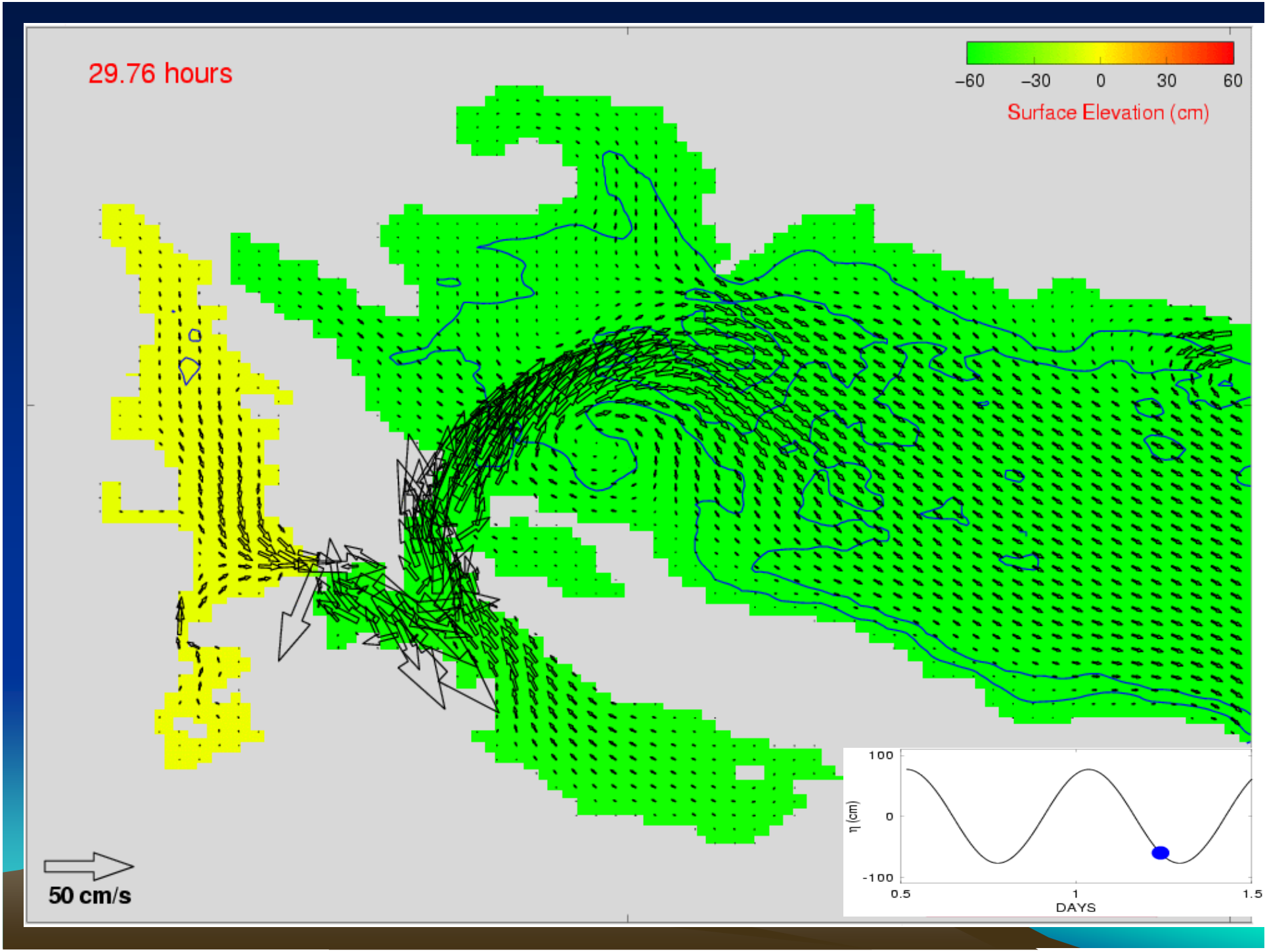
Let $\zeta_t = \zeta^{CHS}$

Run the Model

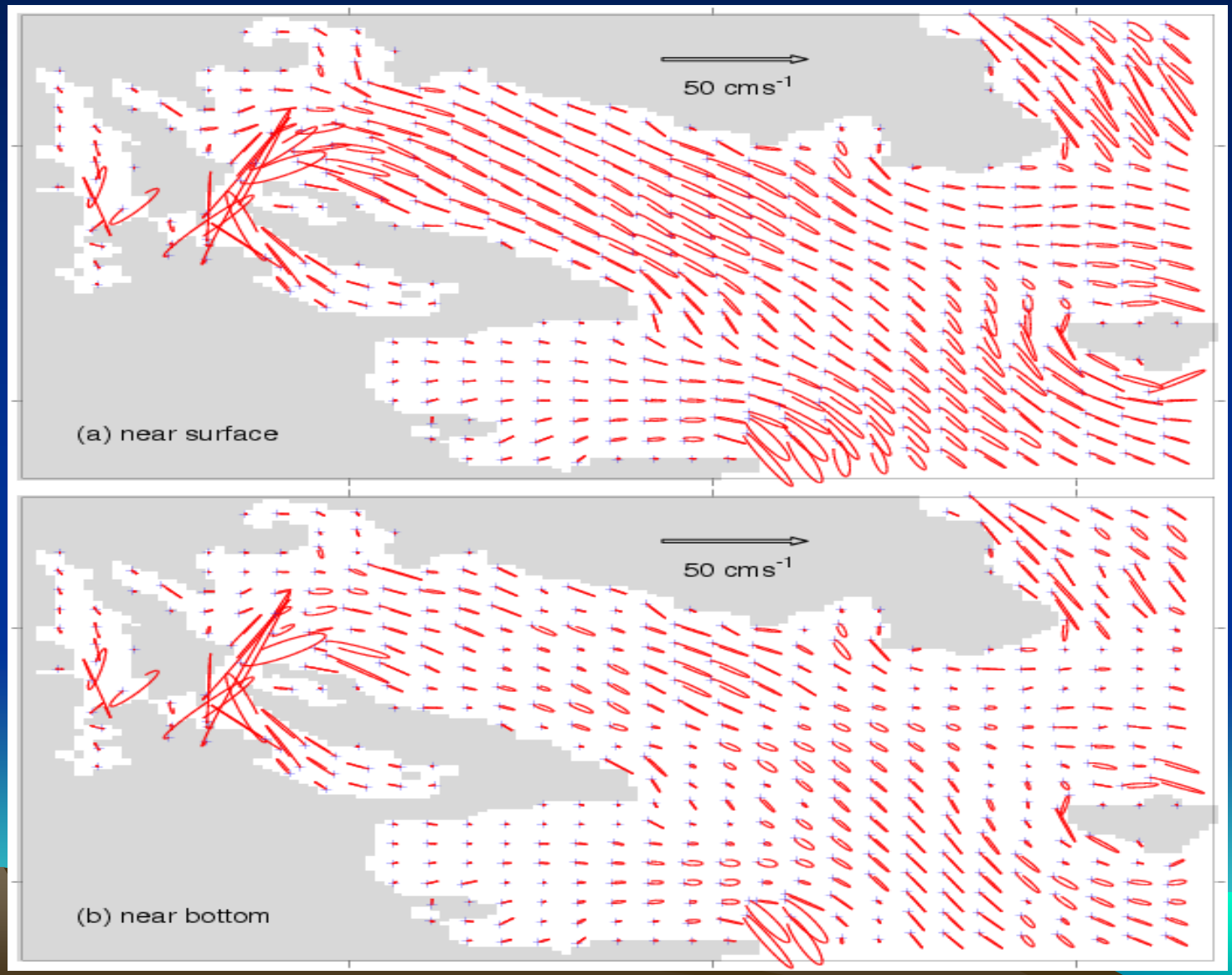
Compare ζ^m with ζ^{CHS}

New ζ_t


23.04 hours
−60
−30
0
30
60
Surface Elevation (cm)
50 cm/s
100
0
-100
η (cm)
0.5
1
1.5
DAYS


29.76 hours
−60
−30
0
30
60
Surface Elevation (cm)
50 cm/s
100
0
-100
η (cm)
0.5
1
1.5
DAYS

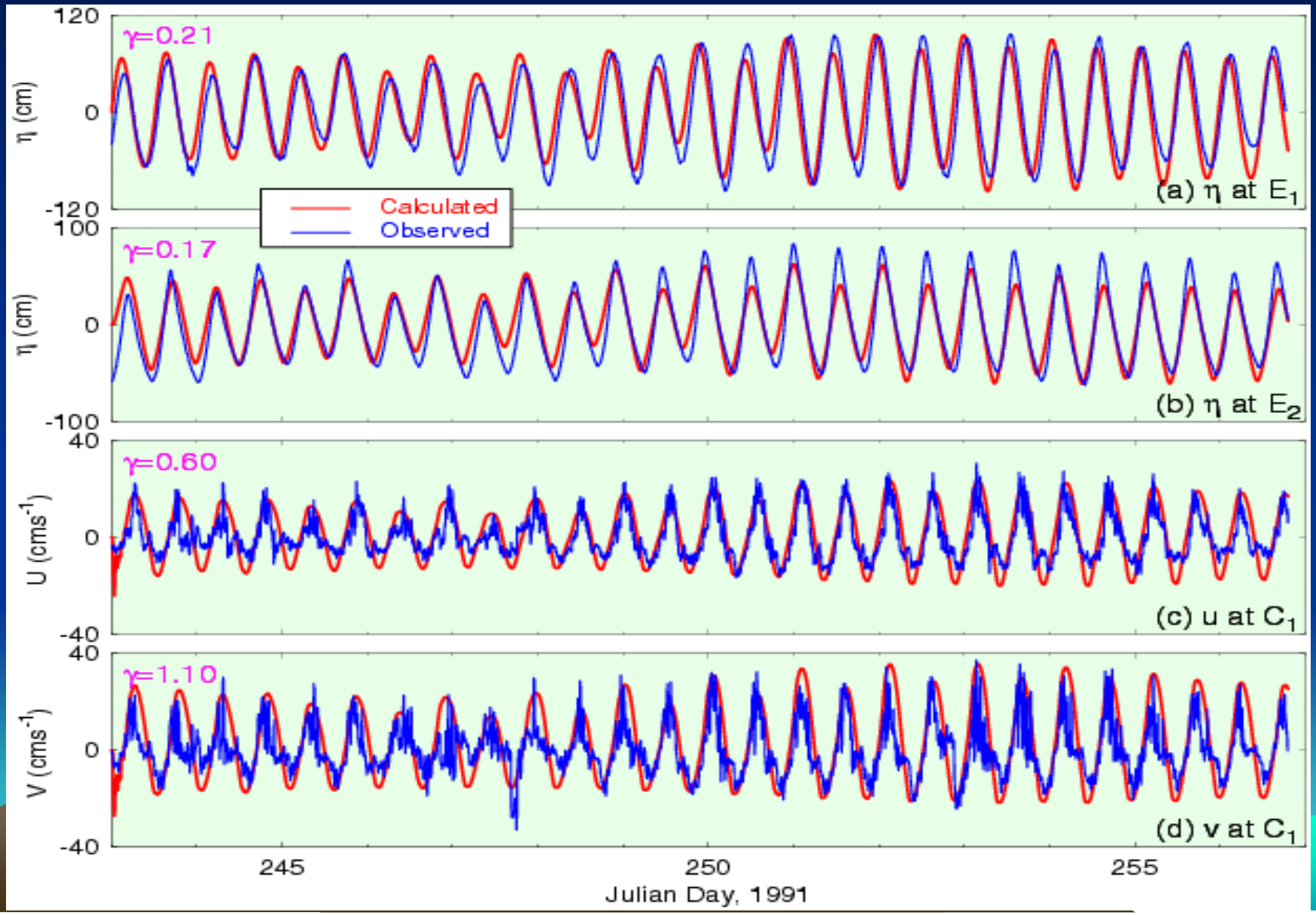
Model calculated tidal current ellipses in Lunenburg Bay
卢嫩堡海湾潮流椭圆图



数模运行性能的评估

Comparison of Observed and simulated sea elevations and currents

卢嫩堡海湾水位与湾流的实测资料和模拟结果比较



数模运行性能的评估

To quantify the importance of the tidal forcing, we use:

$$\gamma^2_{min} = \frac{Var(O - O_{tide})}{Var(O)}$$

Where *Var* denotes the variance, O and O_{tide} denote observed variables and associated tidal components determined by the tidal harmonic analysis.

Similarly, we quantify the performance of the tidal circulation model using

$$\gamma^2 = \frac{Var(O - M)}{Var(O)}$$

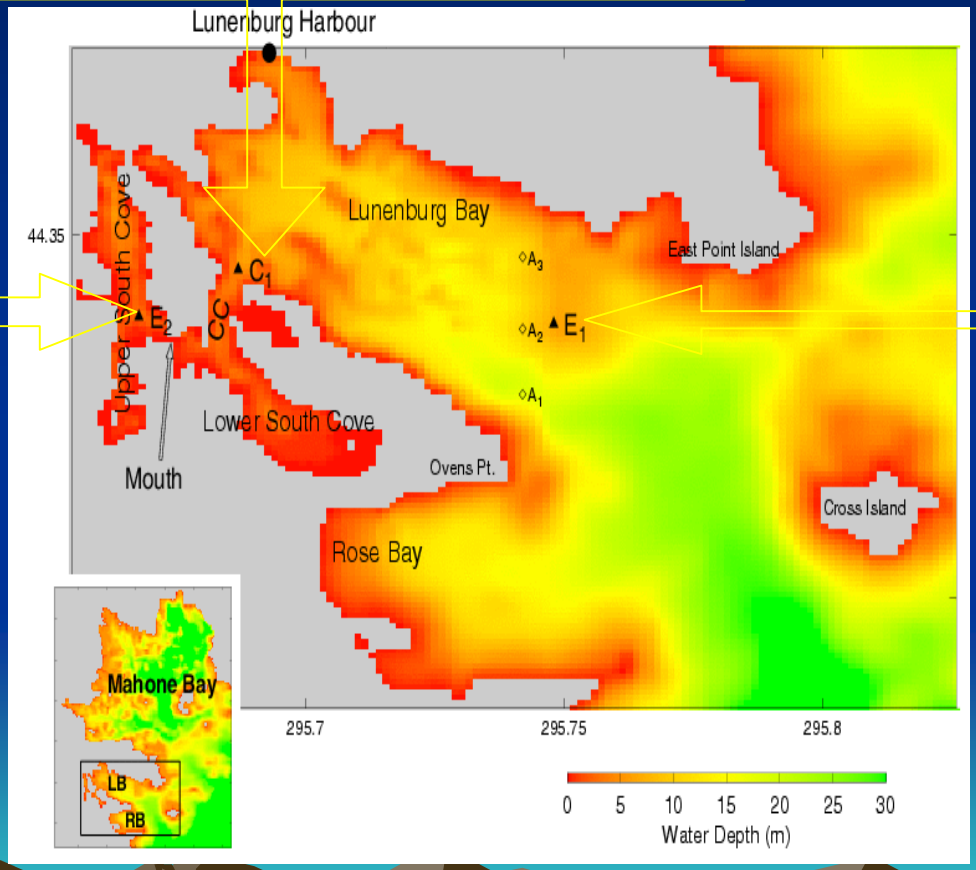
Where M denotes the simulated variables.

$\gamma^2_{min} = 0.28$ $\gamma^2 = 0.60$

$\gamma^2_{min} = 0.38$ $\gamma^2 = 1.10$

$\gamma^2_{min} = 0.13$ $\gamma^2 = 0.17$

$\gamma^2_{min} = 0.09$ $\gamma^2 = 0.21$



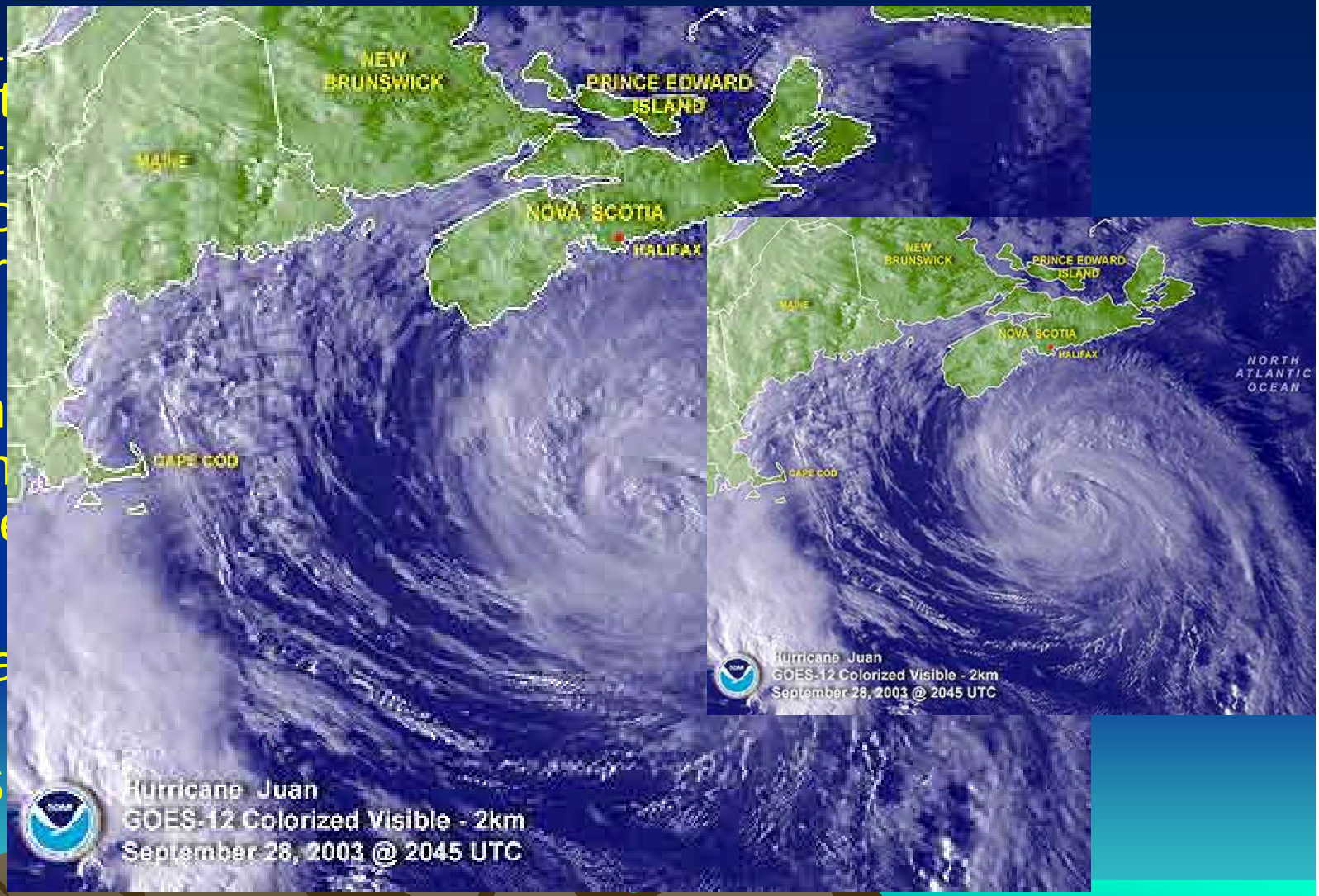
数模运行性能的评估

Circulation during Hurricane Juan 飓风期间的湾流

- Hurrica
on Sept
straight
coast c
categor

- Juan m
Septem
sustaine

- Juan ca
coastal
Nova S

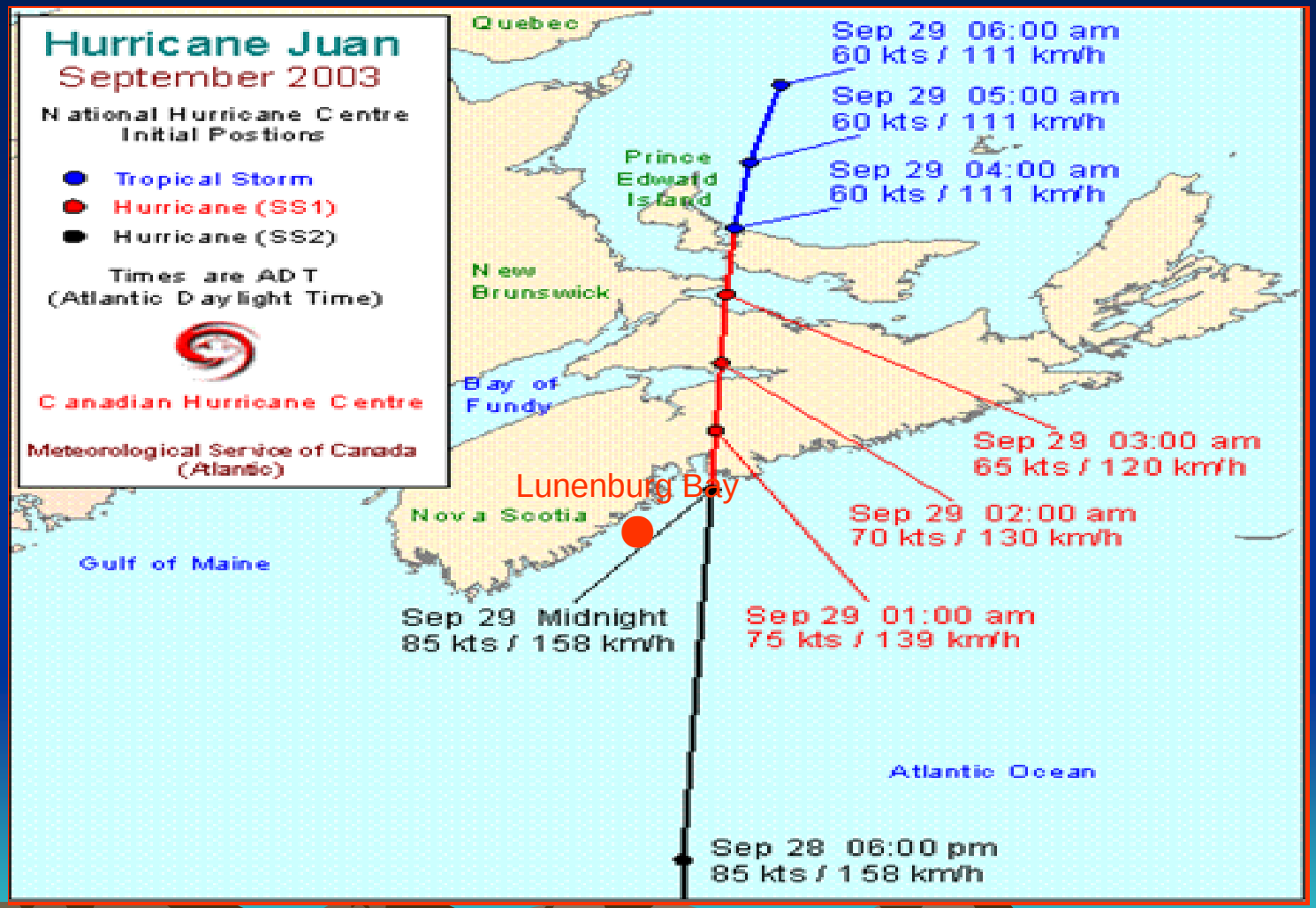


Damages Made by Juan (Sept. 29, 2003)

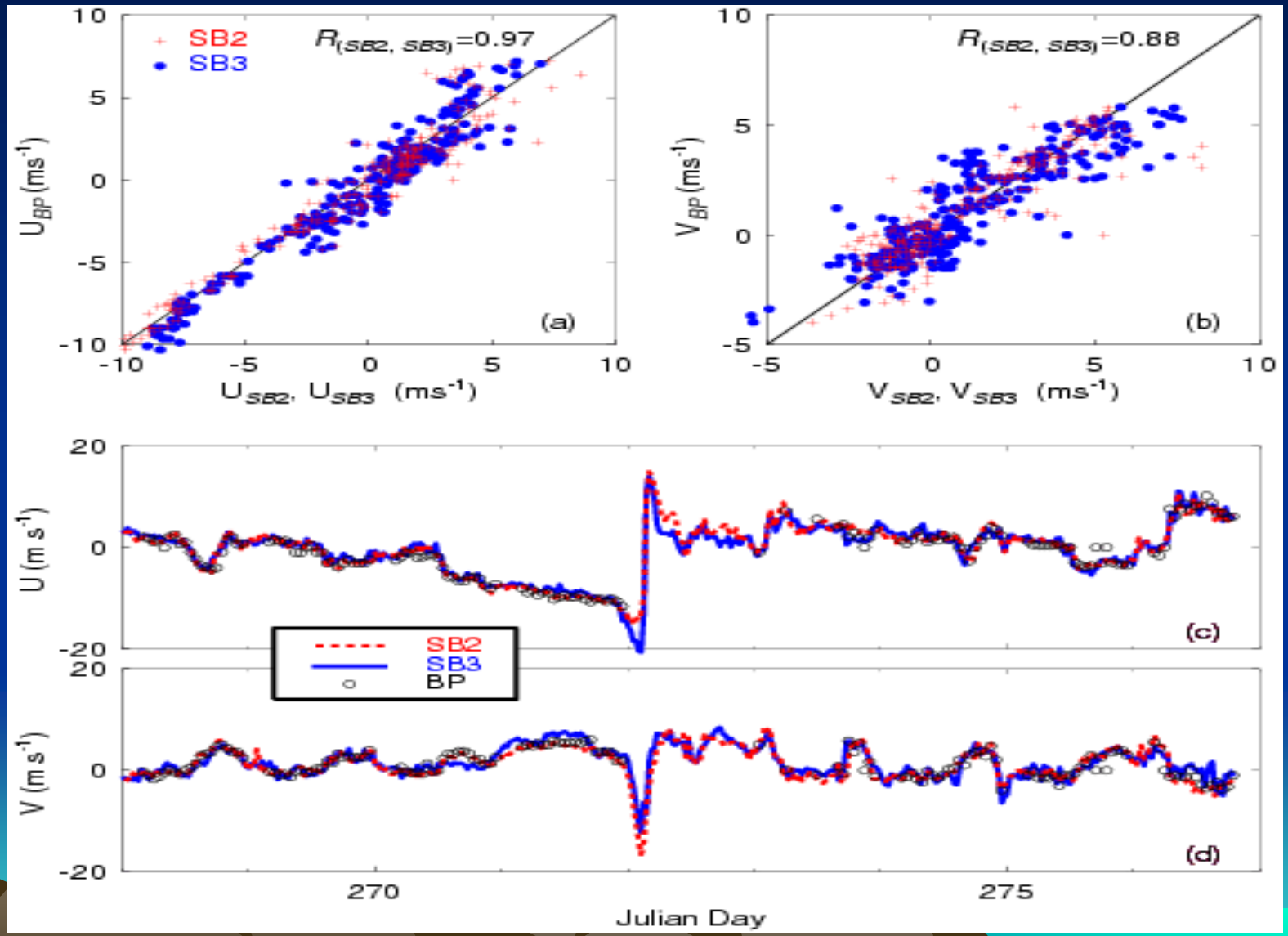
飓风过境时所引起的灾害

(Adopted from MSC webpage)

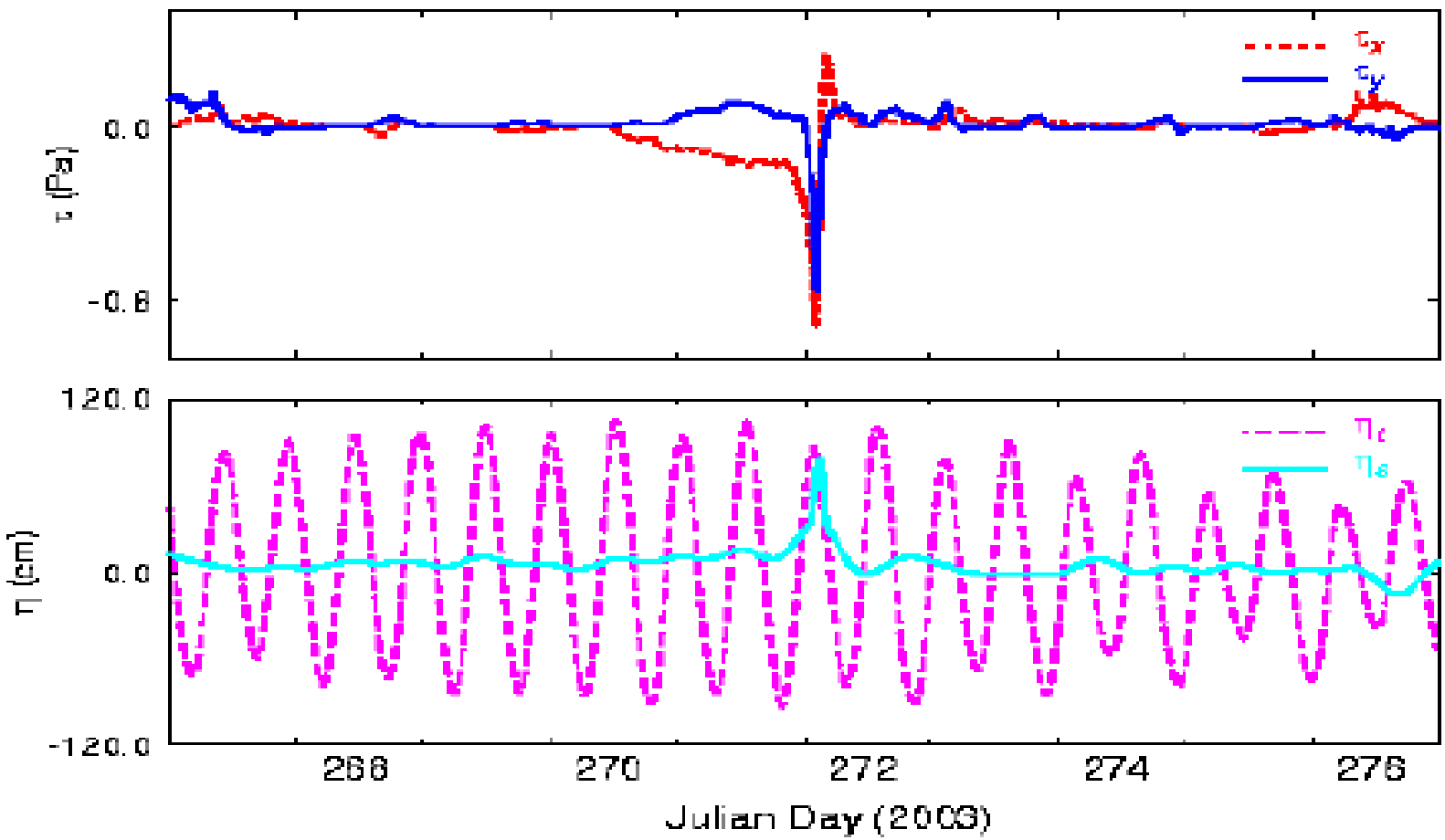
Storm Track of Hurricane Juan 飓风的路径图



Observed winds in Lunenburg Bay 卢嫩堡海湾的风速观察资料

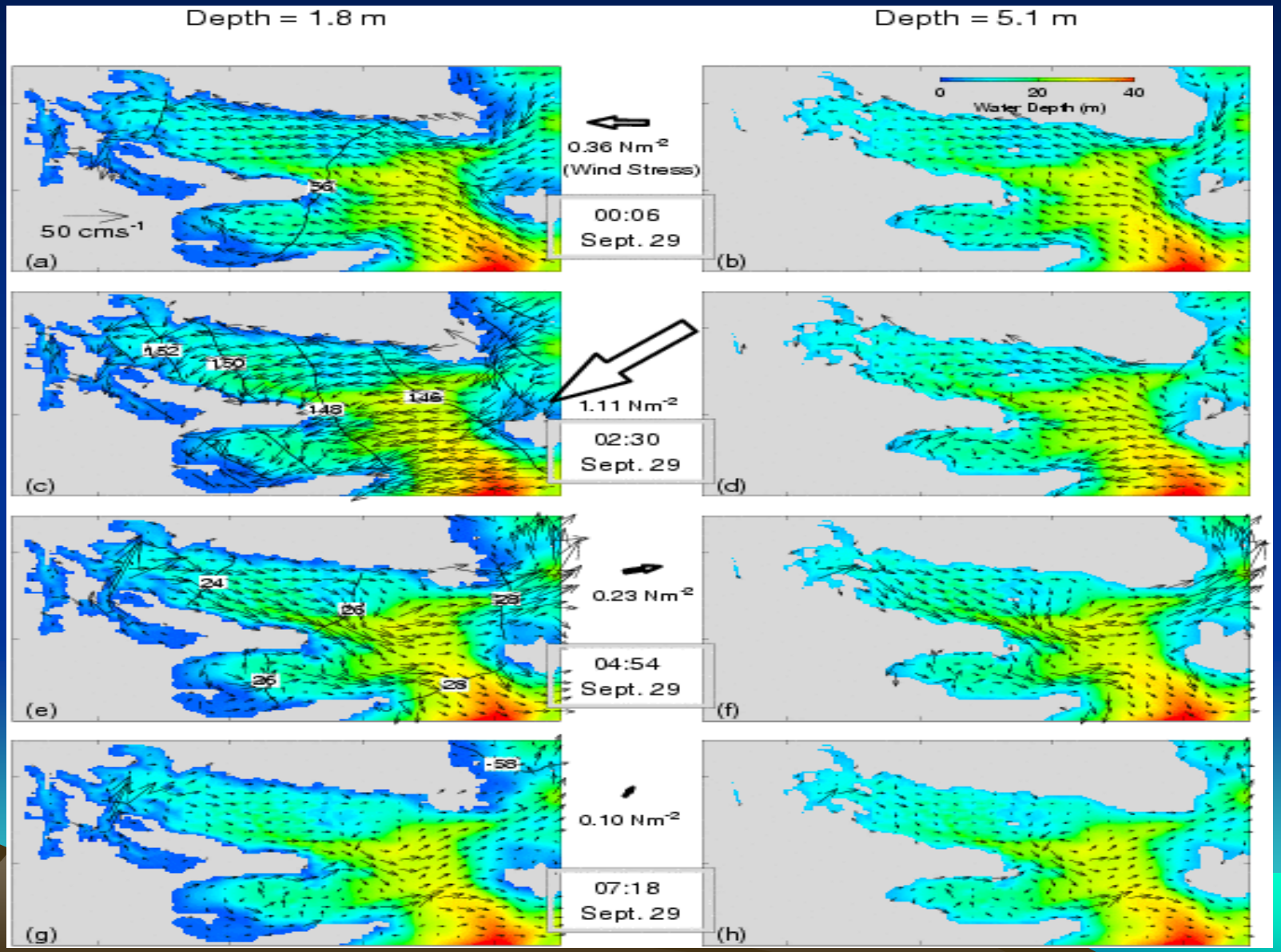


Model External Forcing 驱动数模的强迫力



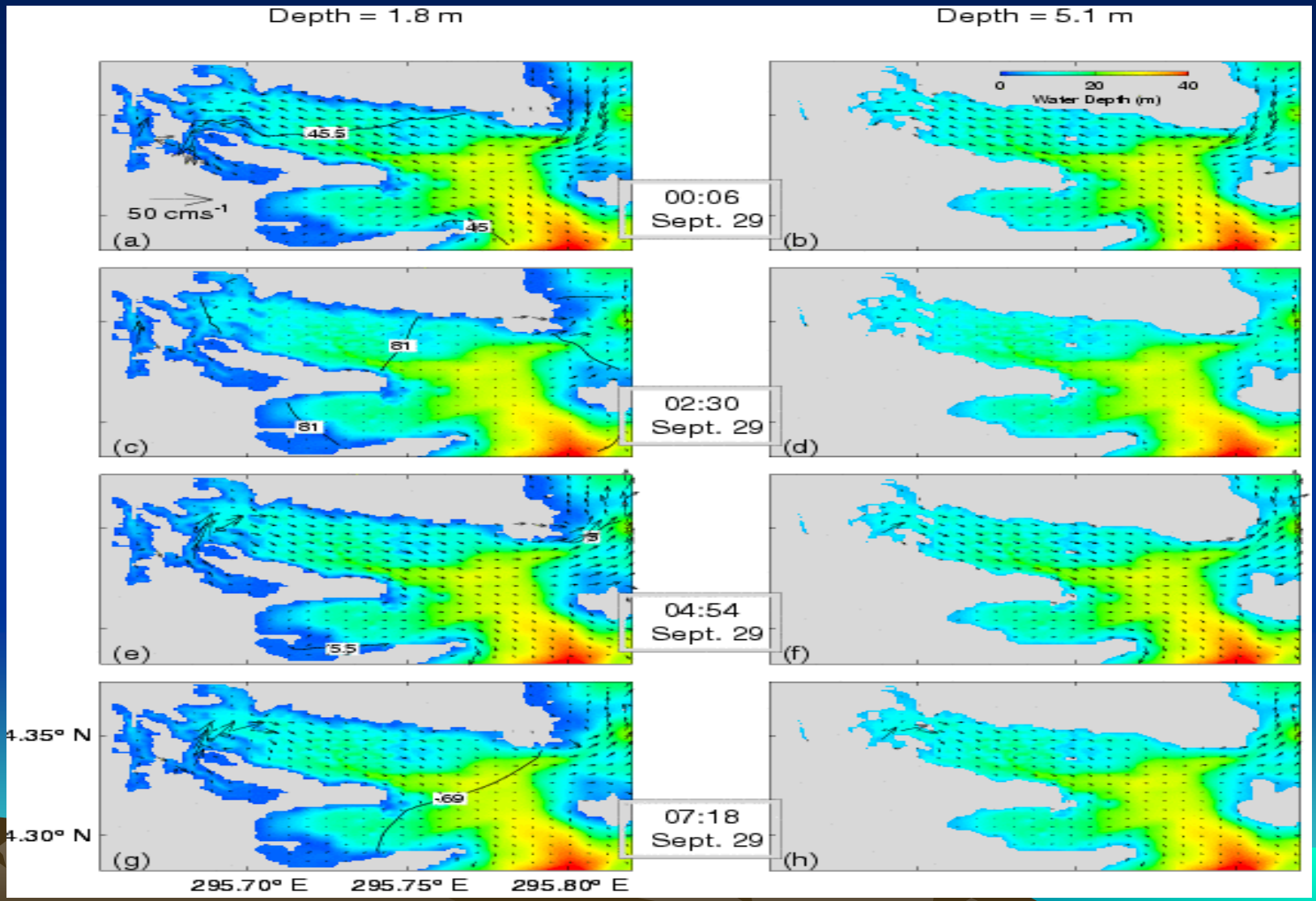
Simulated currents during Hurricane Juan

飓风期间水位和湾流的模拟



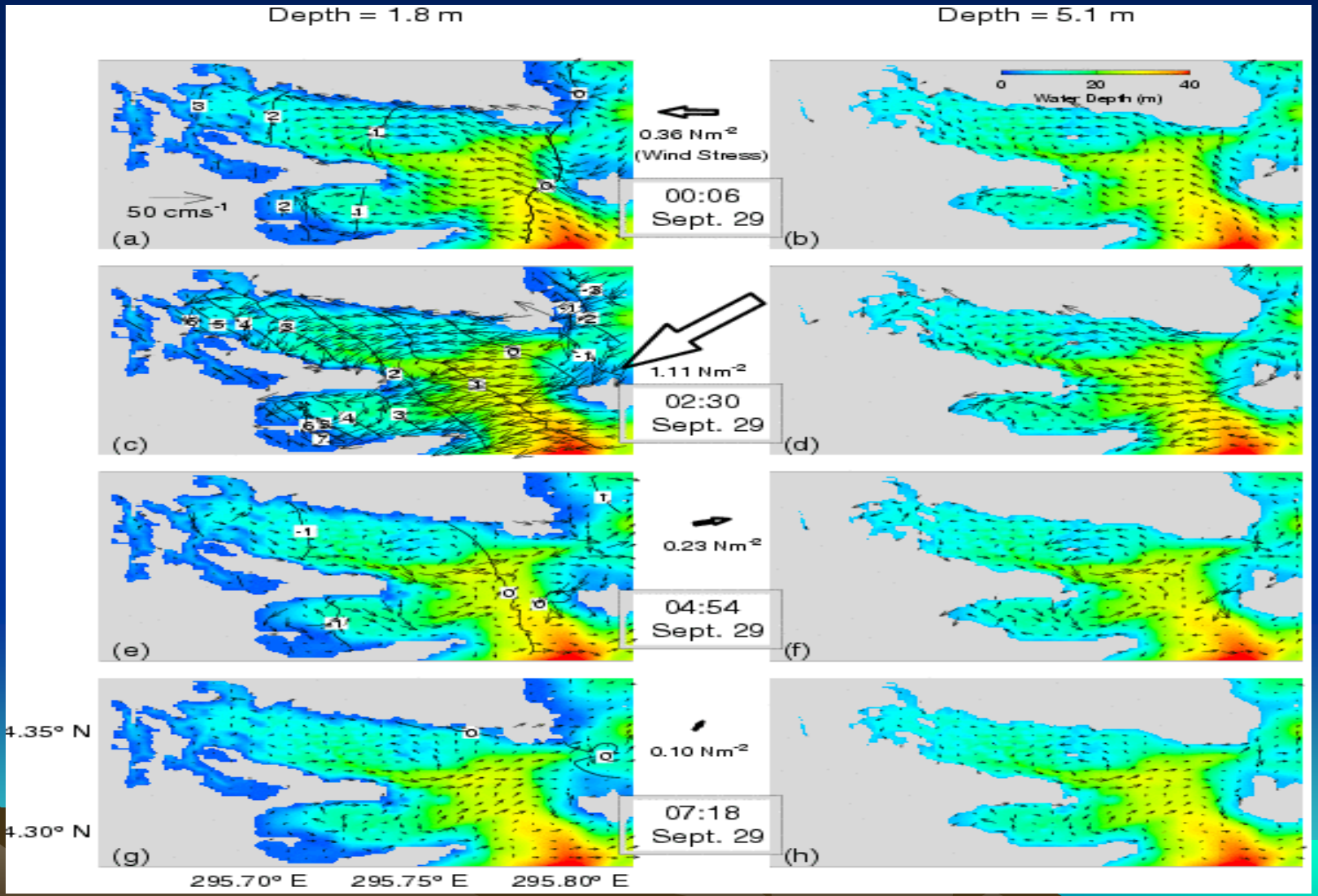
Simulated tidal currents during Hurricane Juan

飓风期间潮汐引起的水位和湾流的变化



Simulated wind-driven currents during Hurricane Juan

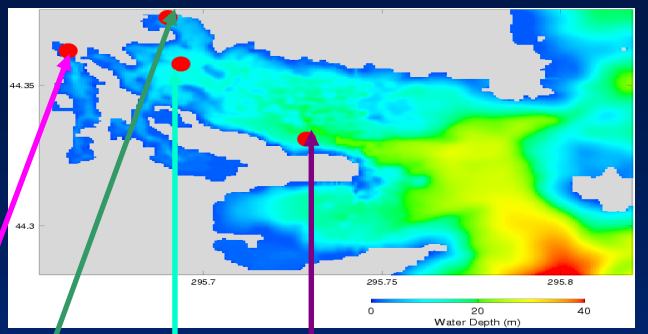
飓风期间风暴引起的水位和湾流的变化

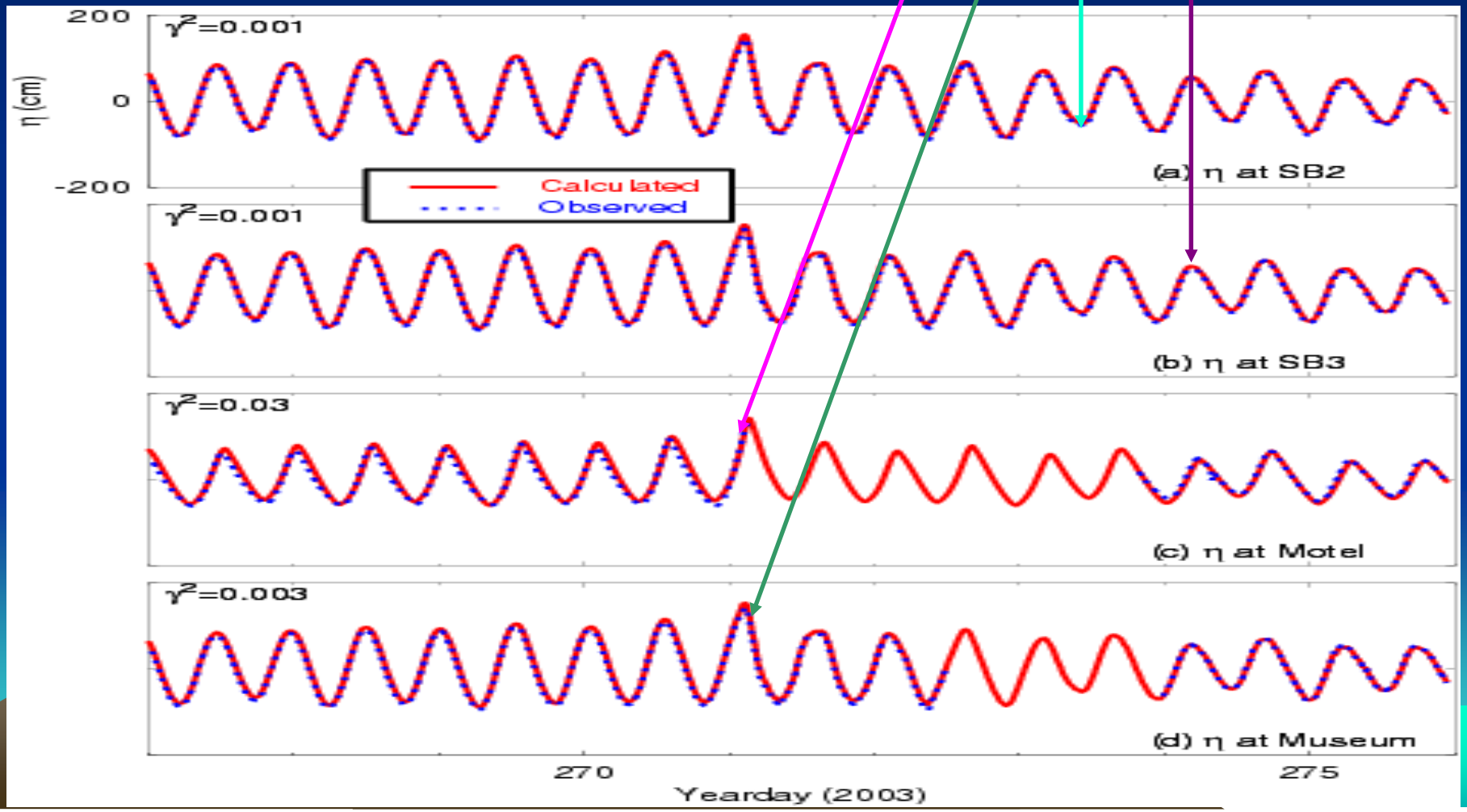


数模运行性能的评估

Comparisons of surface elevations

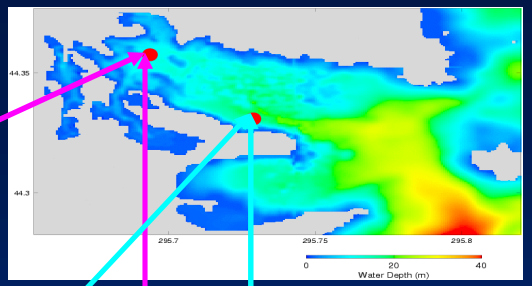
$$\gamma^2 = \frac{Var\ (O - M)}{Var\ (O)}$$

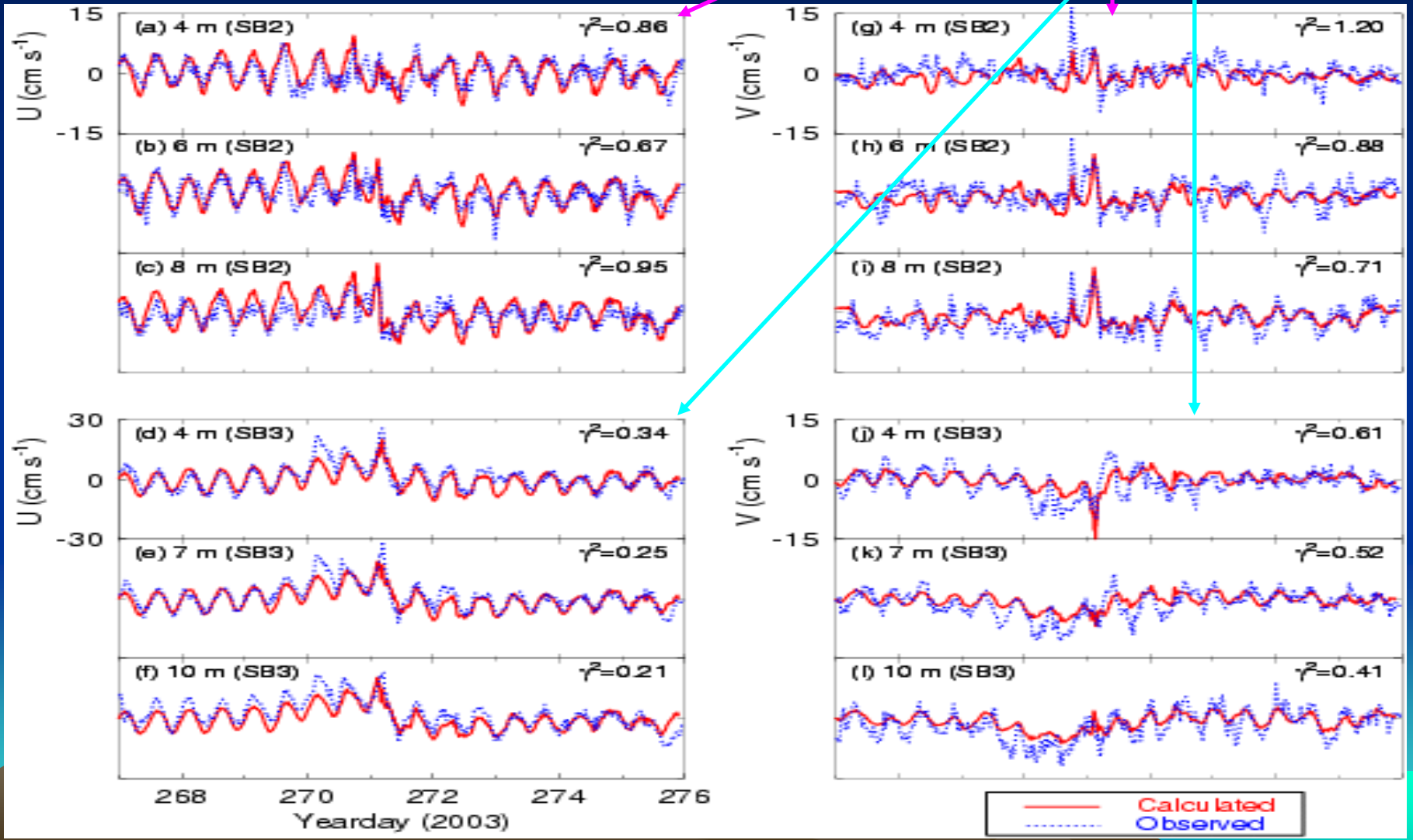




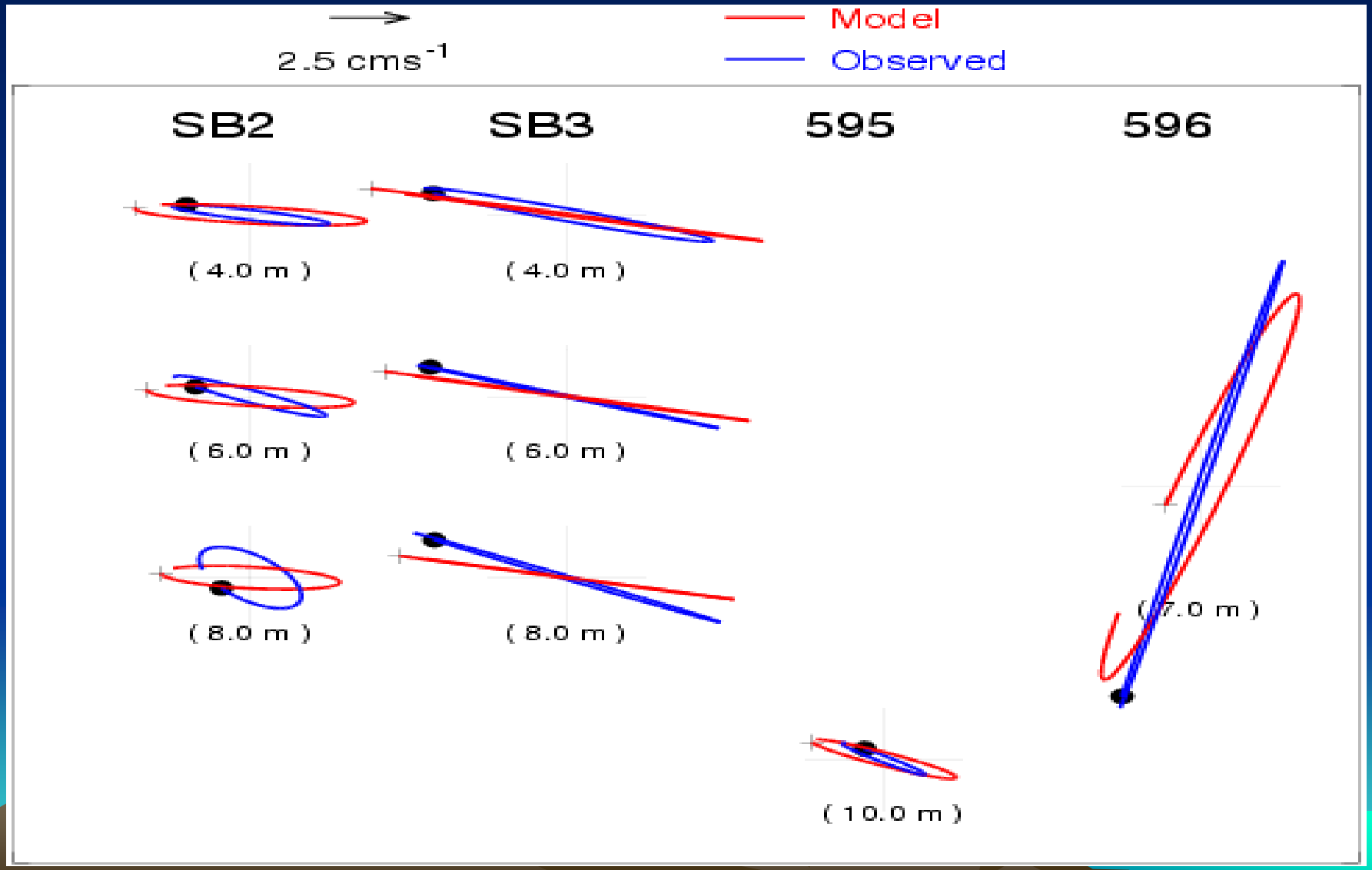
Observed and simulated currents at SB2 and SB3

卢嫩堡海湾水流的实测资料和模拟结果比较



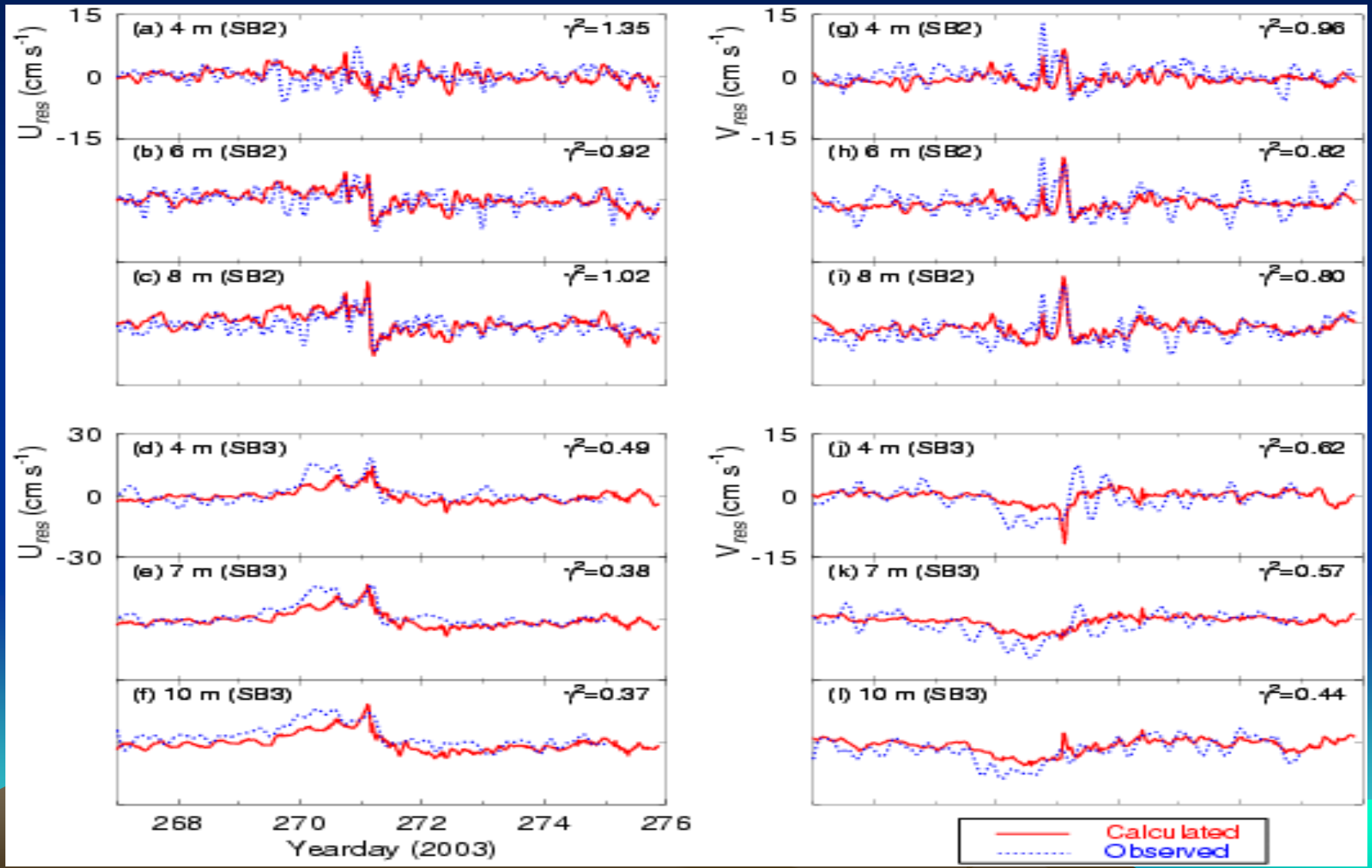


Observed and simulated M_2 tidal ellipses
卢嫩堡海湾潮流椭圆的实测资料和模拟结果比较

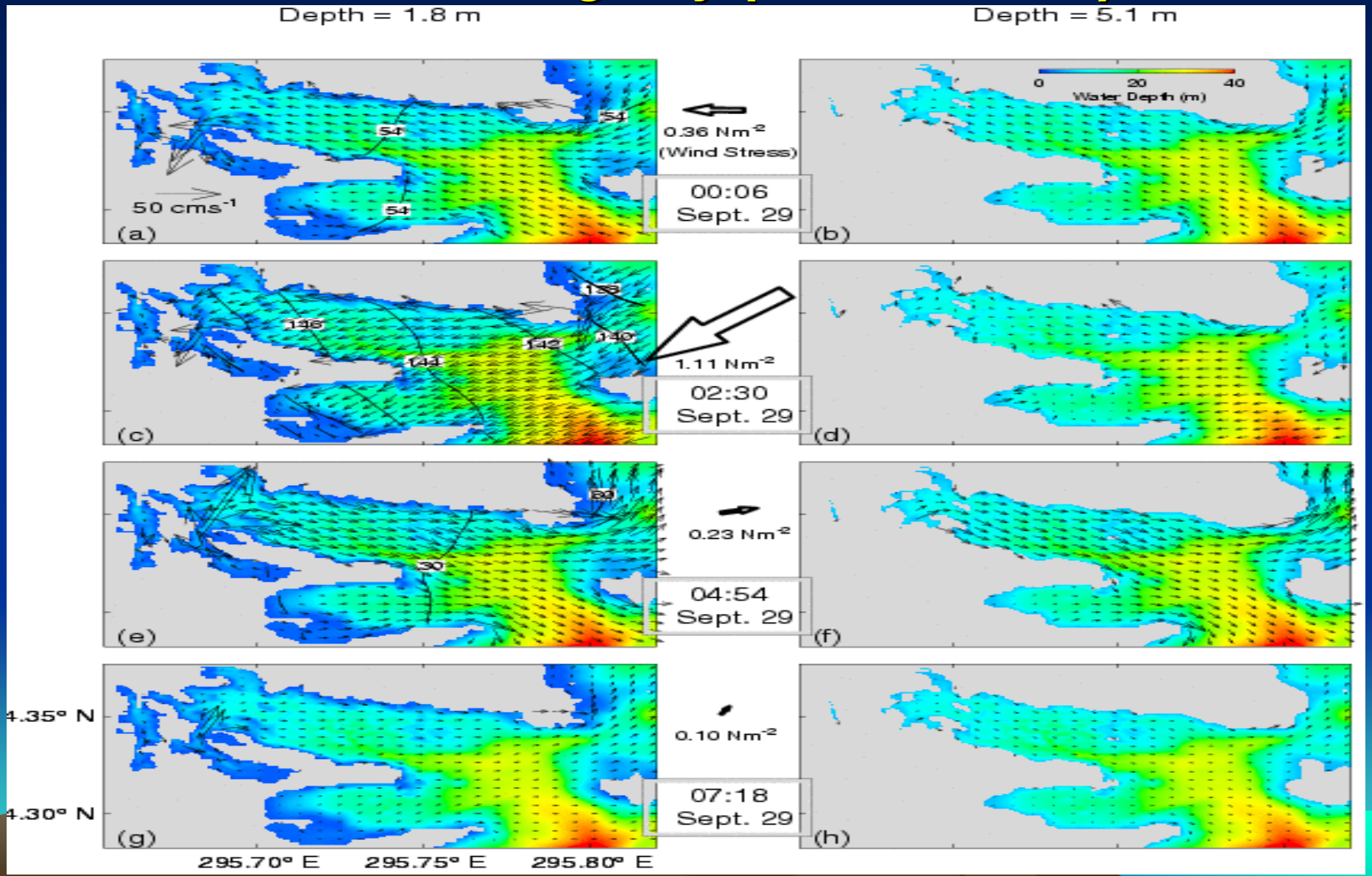


Comparisons of observed and simulated residual flows

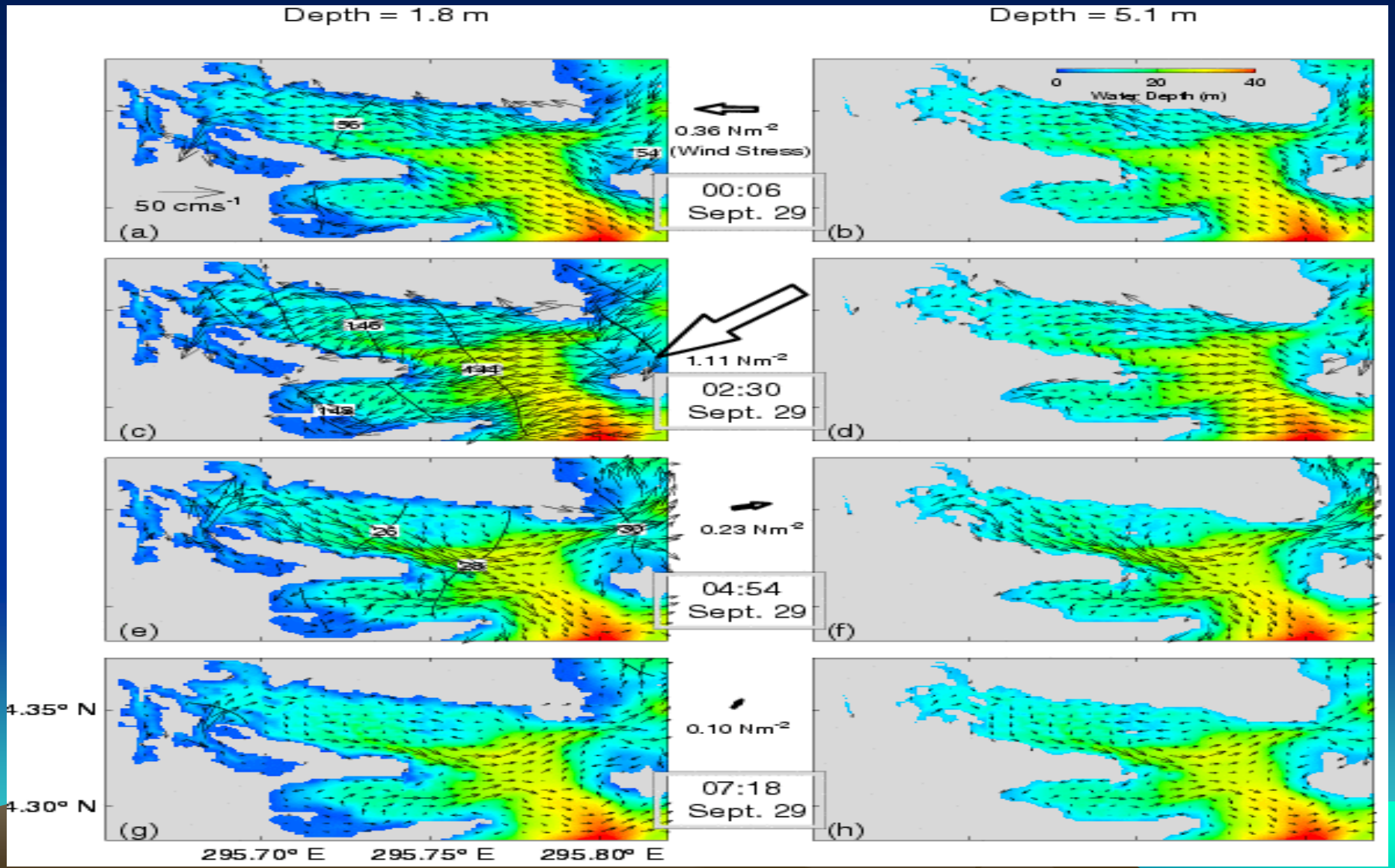
卢嫩堡海湾潮汐余流的实测资料和模拟结果比较



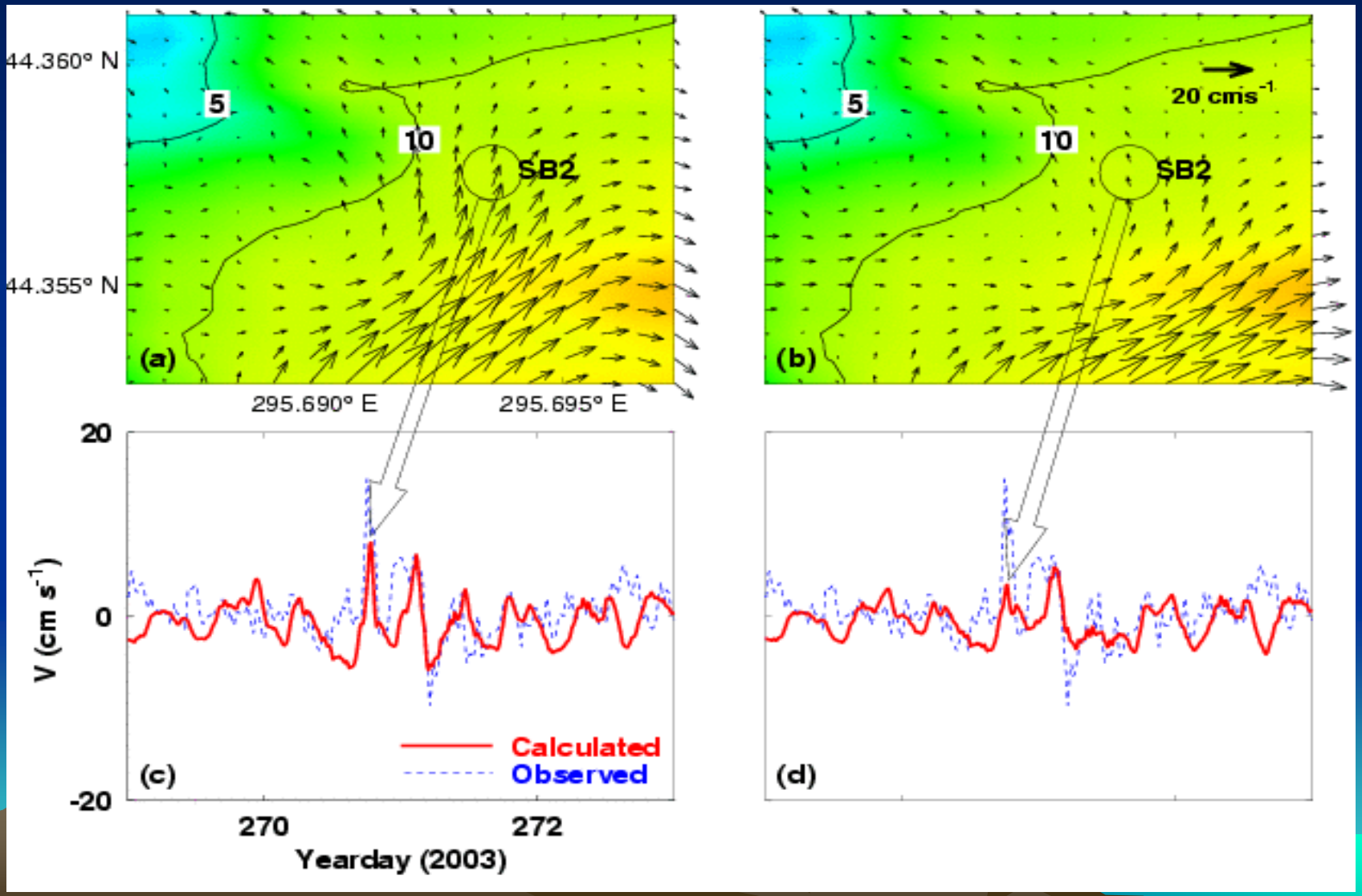
Model-simulated currents and surface elevations in Lunenburg Bay (Linear model)

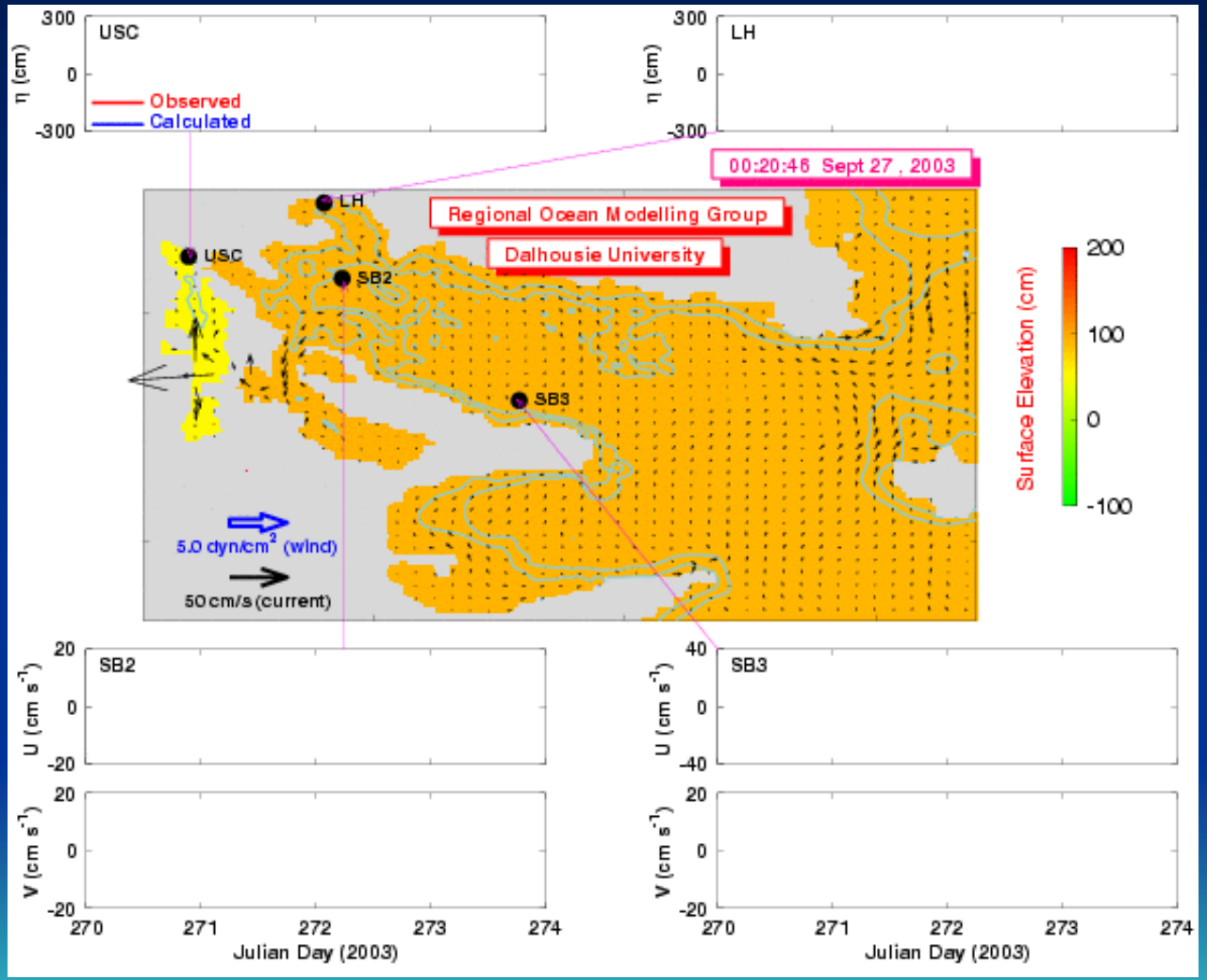


Model-simulated currents and surface elevations in Lunenburg Bay (using quadratic bottom friction)



Influence of local winds on jet flow during Hurricane Juan




USC
LH
SB2
SB3
η (cm)
Observed
Calculated
00:20:46 Sept 27 , 2003
Regional Ocean Modelling Group
Dalhousie University
Surface Elevation (cm)
200
100
0
-100
5.0 dyn/cm^2 (wind)
50 cm/s (current)
U (cm s^{-1})
V (cm s^{-1})
Julian Day (2003)
270
271
272
273
274

Summary 结语

- **An interdisciplinary ocean observatory was established in Lunenburg Bay.**
  加国的科学人员在新斯科舍省的卢嫩堡海湾建立了多学科间的海洋观测平台。

- **A three-dimensional nested-grid coastal circulation model has been developed for the observatory.**
  作为观测平台的重要组成部分，我们开发了三维嵌套近海环流模式。

- **The model results reproduce reasonably well the observed coastal circulation in the study region**
  近海模式成功地模拟了飓风登陆期间卢嫩堡海湾的风暴潮和湾流。

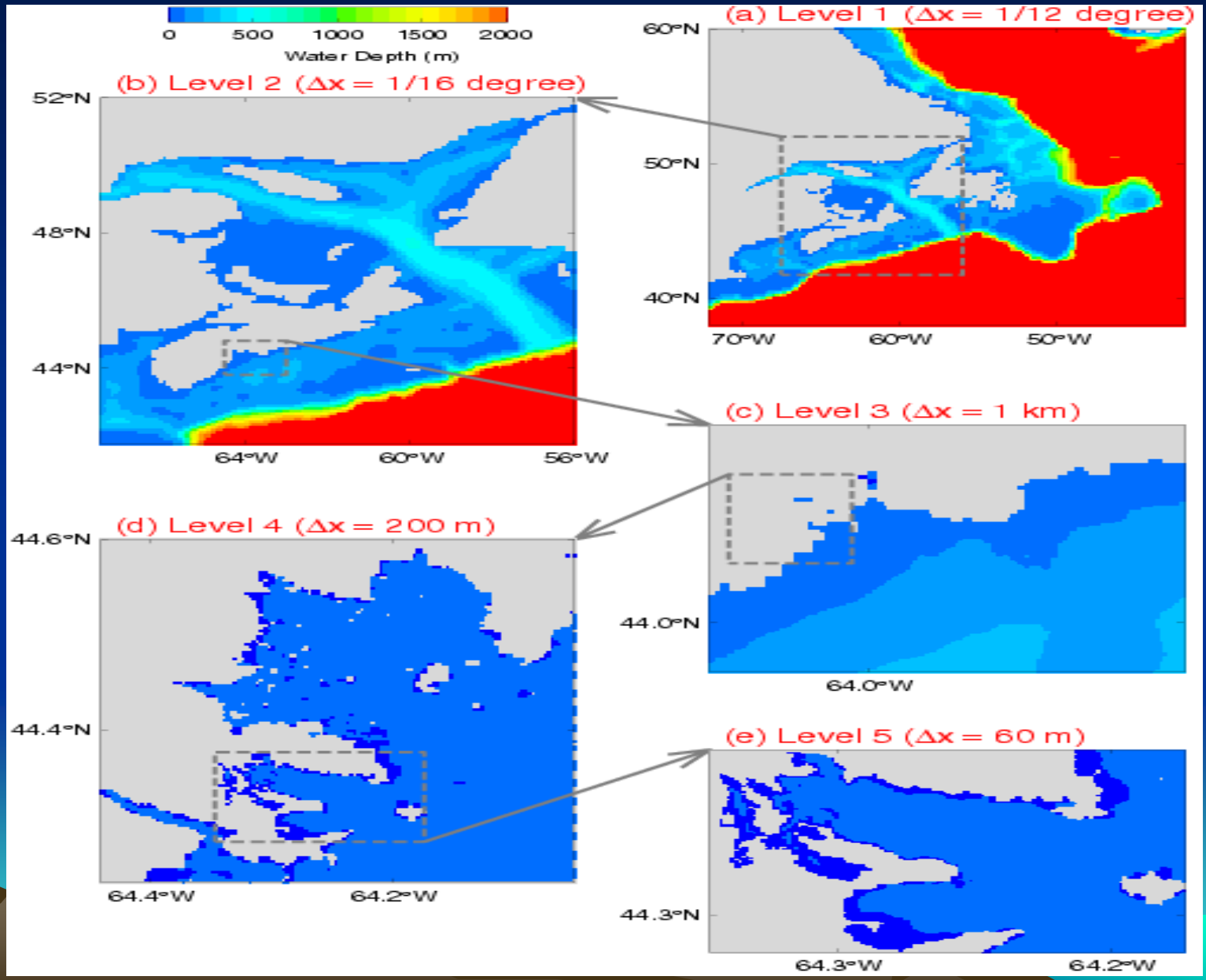
Future work 今后的研究方向

- **Simulate baroclinic circulation in the bay.**
  研究卢嫩堡海湾的斜压湾流机理。

- **Develop a data assimilation scheme to assimilate temperature and salinity observations into the model.**
  研究并开发一个有效的数据同化方法，将温度和盐度的观察值同化入数学模式。

- **Develop a nested-grid coastal circulation model and couple the model to the shelf circulation model known as DALCOAST2**
  进一步研究并开发嵌套式近海环流数学模式，并与DALCOAST进行动力耦合。

嵌套式近海环流数学模式研究计划



Thank You !