The GES DISC MEaSUREs Working Group (MWG) Meeting
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Reprocessing of Goddard Satellite-based Surface Turbulent Fluxes (GSSTF) Dataset for Global Water and Energy Cycle Research

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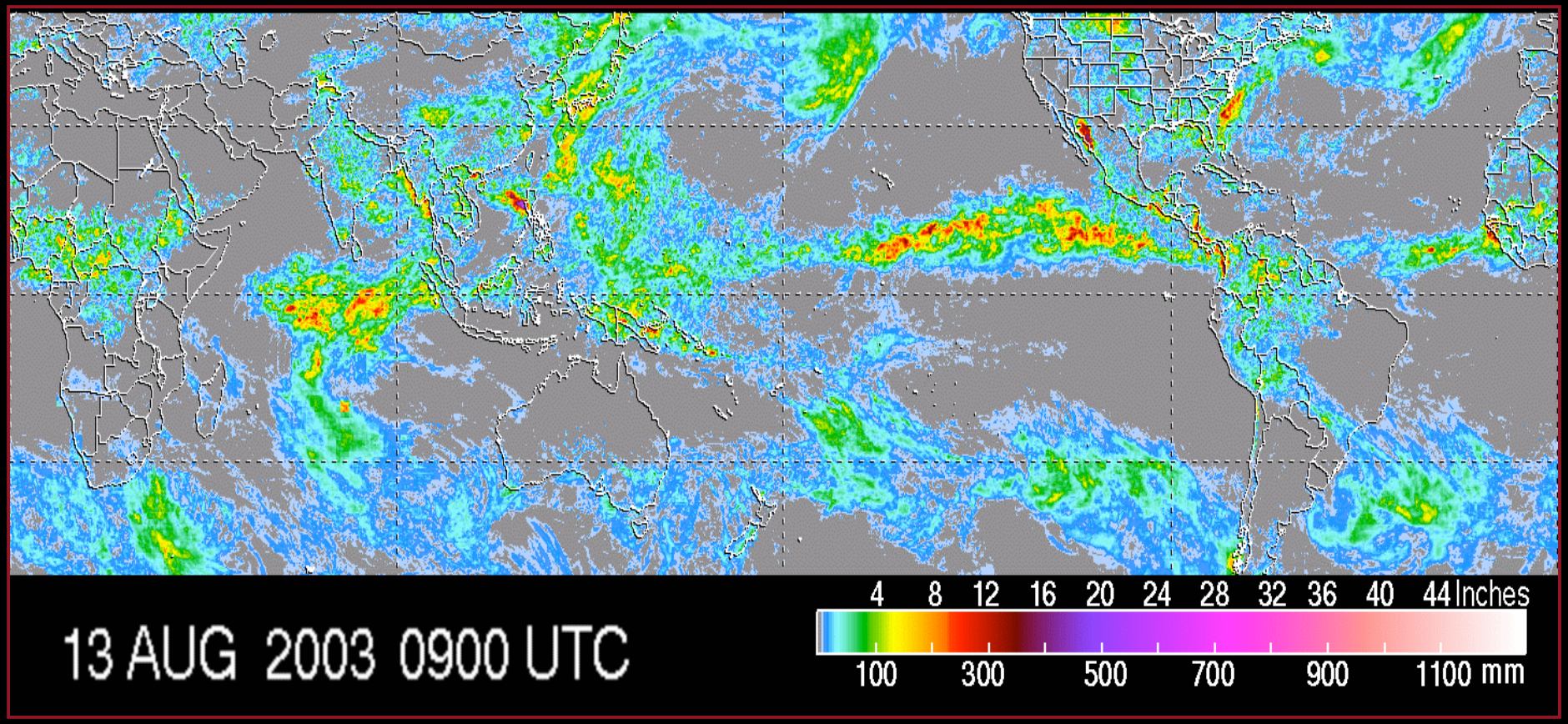
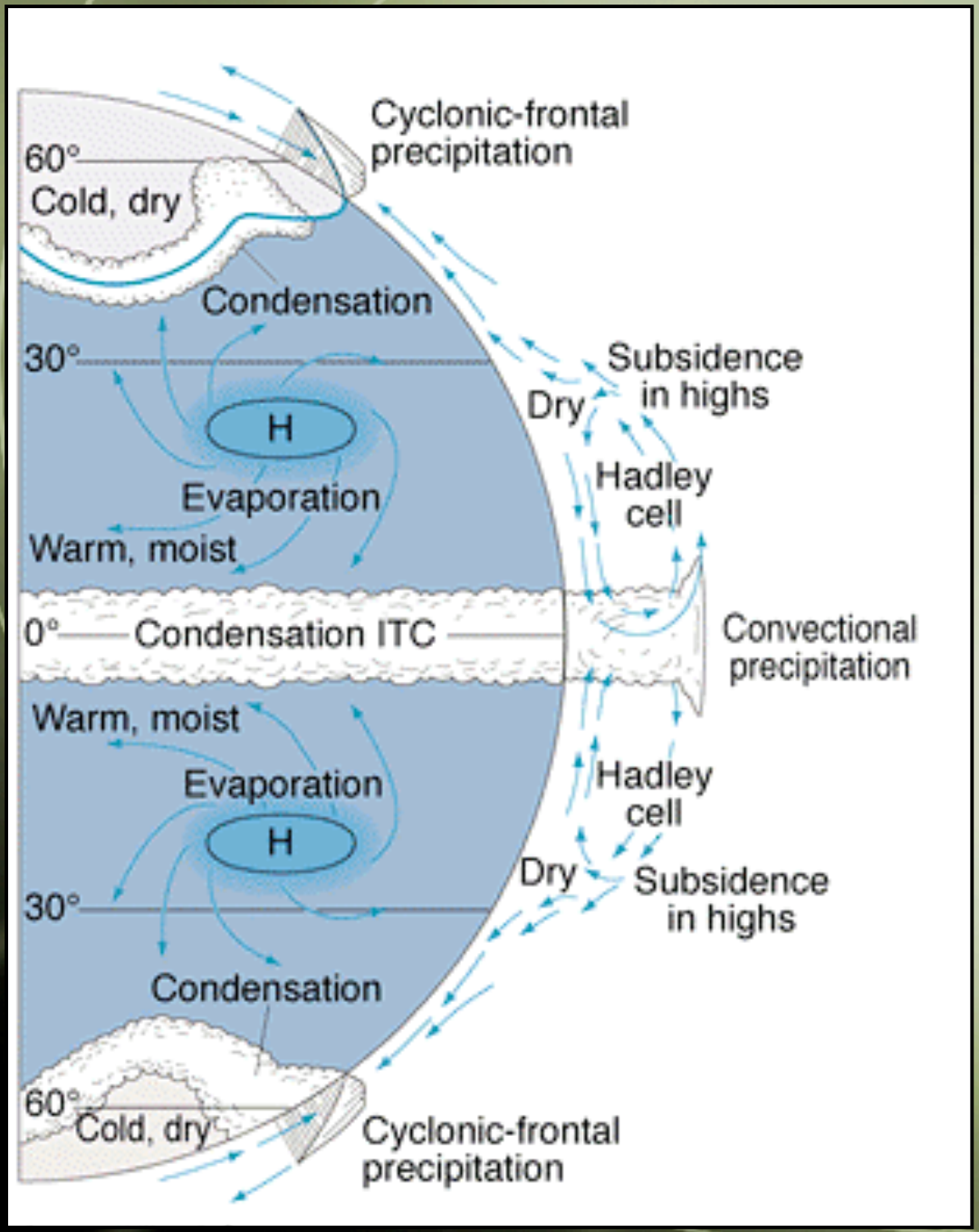
UMBC/GEST

NASA/GSFC

Background

Two-thirds of global precipitation mainly contributed by air-sea surface fluxes falls in the tropics, providing **three-fourths** of the energy driving global atmospheric circulation through latent heating

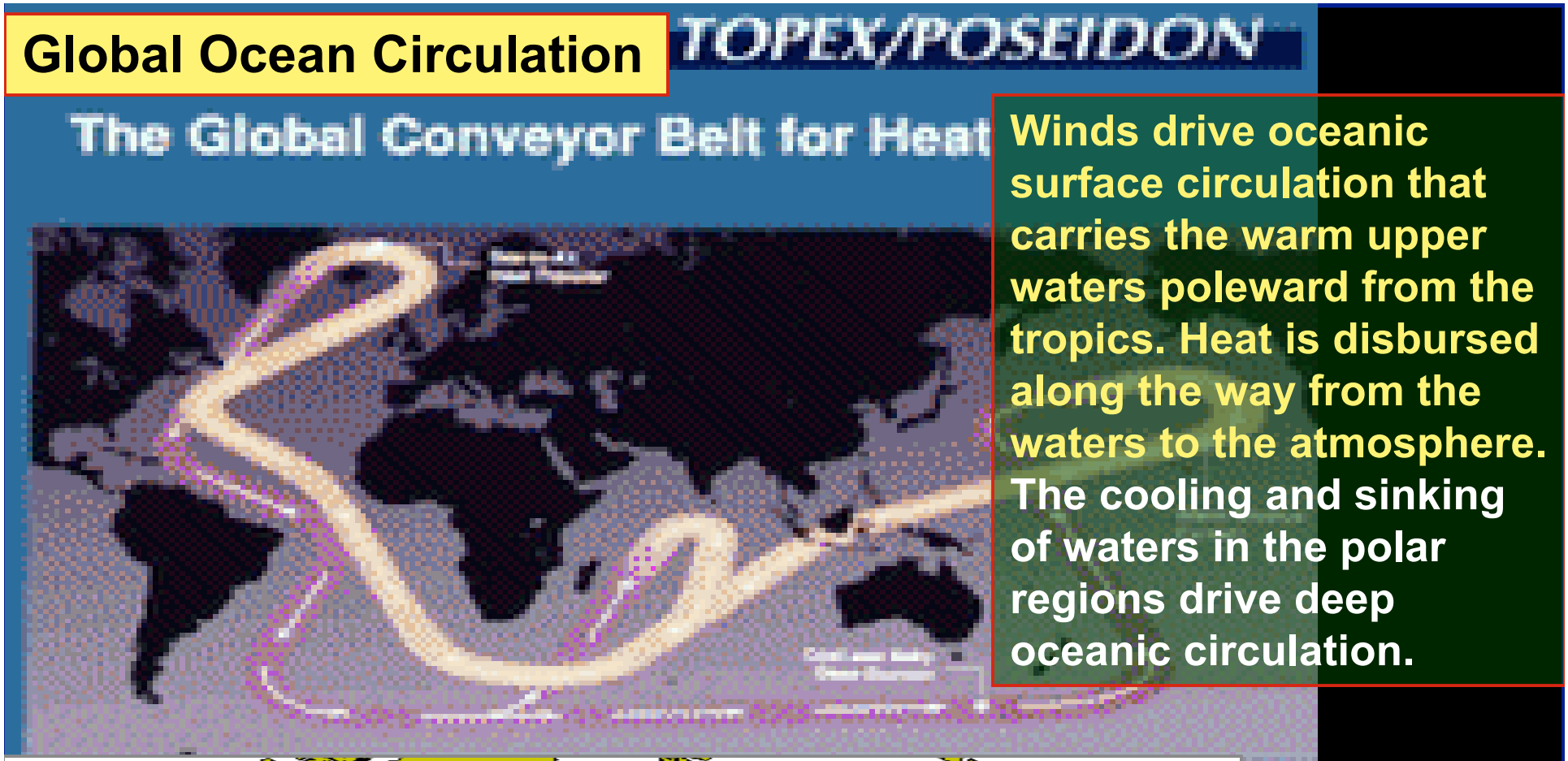




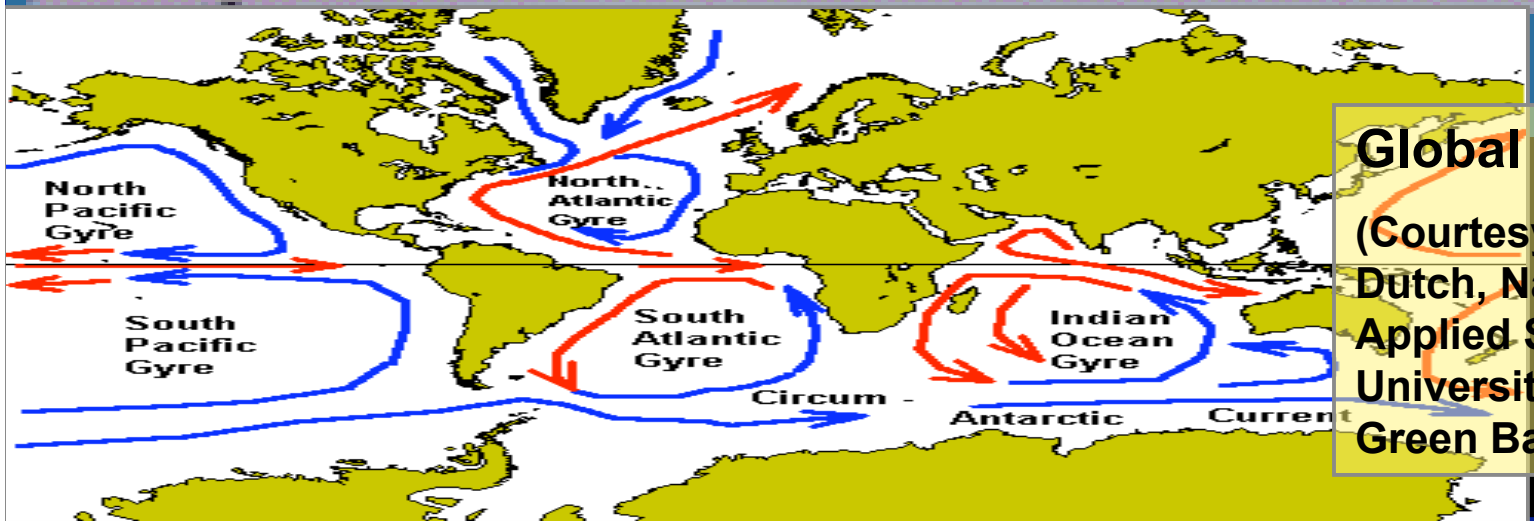
The release of latent heat in precipitating tropical clouds promotes vertical motion and the formation of the Hadley cell.

The Hadley cell transports energy towards higher latitudes, strongly influencing global circulation and weather patterns.

Global Ocean Circulation



Winds drive oceanic surface circulation that carries the warm upper waters poleward from the tropics. Heat is disbursed along the way from the waters to the atmosphere. The cooling and sinking of waters in the polar regions drive deep oceanic circulation.



Global Ocean Gyre

(Courtesy of Steven Dutch, Natural and Applied Science, University of Wisconsin-Green Bay)

Air-Sea Turbulent Fluxes

- ***Include:***
  - **Latent Heat Flux (LH)**
  - **Sensible Heat Flux (SH)**
  - **Momentum Flux (Wind Stress WS)**
- ***Exchange of heat, moisture (fresh water), and momentum between atmosphere and ocean***
- ***Important in air-sea interaction, climate variations and oceanic circulations of multiple temporal / spatial scales***

Observations of Oceanic Fluxes

- ***Direct 'measurements' over ocean rare***
  - **In-situ observations of u', v', w', T', q'… at very high frequency using specific instruments (Supersonic et al)**

- ***Estimation from mean oceanic and atmospheric state variables (temperature, wind speed, humidity) through***

  BULK FLUX ALGORITHMS
  - **In-situ observation (ship, buoys..)**
  - **Satellite observation**
  - **Model simulations**

Oceanic Flux Products

- ***GSSTF-2 (Chou, Shie et al. 2001, 2003)***
  - **Goddard Satellite-based Surface Turbulent Flux Version 2**
  - **Monthly / Daily time series (July 1987-December 2000)**
  - **Satellite observations (SSM/I)**
  - **Global / 1° lat/lon**
- ***SEAFLUX***
  - **An international project under GEWEX (Coordinator: Judy Curry, Collaborator: Carol Ann Clayson)**
  - **Inter-comparison and assessment of oceanic fluxes**

GSSTF Version 2

- *Developed by S.-H. Chou, C.-L. Shie et al. [Chou et al. 2003]*
- *Inputs*
  - SSM/I surface (10-m) wind speed (U) from RSS Retrieval Products V4
  - SSM/I total precipitable water (W) from RSS Retrieval Products V4
  - SSM/I bottom atmosphere humidity (WB) from RSS Wentz TB data V4
  - Retrieved surface air specific humidity (Q) based on an EOF algorithm
  - NCEP weekly OI sea surface temperature V1 (SST) and saturation specific humidity (Qs)
  - CDAS1 Sea Level Pressure (SLP)
  - CDAS1 Air Temperature at 2m (T2m)
- *Bulk Flux Algorithm*
  - Based on Francey and Garratt (FG, 1981)
  - Chou, Shie et al. (1997, JGR) and Chou, Shie et al. (2003, J. Climate)
- *Outputs*
  - Latent heat (LH), sensible heat (SH), and momentum (WS) fluxes [partitioned into zonal and meridional components based on vector wind analysis by Atlas et al. (1996) or QuikSCAT (future)]
  - July 1987 – December 2000
- *Status*
  - GSSTF2/GSSTF1 issued in 2001/2000
  - Project of producing GSSTF2b/GSSTF3 funded for May 2008-May 2011

GSSTF Version 2 (conti.)

- ***1x1 degree** Daily, Monthly, Climatology of SH, LH and WS and related parameters. Monthly only if grid contain > 10 day data. Climatology interpolated by weighting neighboring 8 points.*

- **Chou, S.-H., C.-L. Shie, R.M. Atlas, and J. Ardizzone, 1997: (GSSTF1). JGR, 102, 12705-12726.**

  Chou, S.-H., E. Nelkin, J. Ardizzone, R. M. Atlas, and C-L. Shie, 2003: (GSSTF2). J. Climate, 16, 3256-3273.

- **Chou, S.-H., C.-L. Shie, R. Atlas, and J. Ardizzone, 2000: The Goddard Satellite-Based Surface Turbulent Fluxes Dataset --- Version 1 (GSSTF1) [global (grid of 2^ox2.5^o) daily air-sea surface fluxes from July 1987 to December 1994] distributed by Goddard DISC at "http://disc.sci.gsfc.nasa.gov/precipitation/gsstf1.0.shtml" .**

  Chou, S.-H., E. Nelkin, J. Ardizzone, R. Atlas, and C.-L. Shie, 2001: The Goddard Satellite-Based Surface Turbulent Fluxes Dataset --- Version 2 (GSSTF2) [global (grid of 1^ox1^o) daily air-sea surface fluxes from July 1987 to December 2000] distributed by Goddard DISC at "http://disc.sci.gsfc.nasa.gov/precipitation/gsstf2.0.shtml" .

EOF method for Qa Retrieval
(Chou et al., 1995 & 1997)

$$q(t, r, \sigma) = \overline{q}(\sigma) + \sum_{i=1}^{n} C_i(t,r) F_i(\sigma) \quad (1)$$

$\sigma = (p - p_t)(p_s - p_t)^{-1}$, p is pressure, p_s is the surface pressure, p_t is the top pressure (200mb), t is time, r is location, $\overline{q}$ is the spatial and temporal average of q for a climatic regime, F_i is the ith EOF of the covariance matrix of q, and C_i is the corresponding principle component. The profile of and F_i are derived from a sample population of q in a climatic regime. **(23,177 First Global Atmospheric Research Program (GARP) Global Experiment (FGGE) IIb humidity soundings, 64 stations, 12/78-11/79)**

$$Q(t, r) = \overline{Q} + C_1(t, r)\, Q_1 + C_2(t, r)\, Q_2 \quad (2)$$
$$W(t, r) = \overline{W} + C_1(t, r)\, W_1 + C_2(t, r)\, W_2 \quad (3)$$
$$W_B(t, r) = \overline{W}_B + C_1(t, r)\, W_{B1} + C_2(t, r)\, W_{B2} \quad (4)$$

Solve C_1 and C_2 based on (3) & (4)
Obtain $Q(t, r)$ using (2)

$\overline{Q}$, Q_1, and Q_2 are the values of $\overline{q}$, F_1, and F_2 at $\sigma = 1$; $\overline{W}$, W_1, W_2 and , $\overline{W}_B$, W_{B1}, W_{B2} are the total and bottom-layer precipitable water corresponding to the profiles of $\overline{q}$, F_1, and F_2,
C_1 and C_2 are the principal components for the **first** and **second** EOFs.

Bulk Flux Formula
(surface layer similarity theory)

LH (潛熱通量) = $-\rho_a L_v u^* q^*$

SH (可感熱通量) = $-\rho_a c_p u^* \theta^*$

WS (風應力) = $\rho_a u^{*2}$

- ***Scaling parameters for wind or friction velocity (u^*), temperature θ^*, and humidity (q^*).***

Bulk Aerodynamic Algorithm

LH (潛熱通量) = $\rho_a L_v C_E (U-U_s)(q_s - q_a)$

SH (可感熱通量) = $\rho_a c_p C_H (U-U_s)(\theta_s - \theta_a)$

WS (風應力) = $\rho_a C_D (U-U_s)^2$

- *Physical constants* $[L_v, c_p]$
- *State Variable* $[\rho_a, U, q_s, q_a, \theta_s, \theta_a]$
- *Bulk Transfer/Turbulent Exchange Coefficients* $[C_E, C_H, C_D]$

GSSTF2 Current Flux Products

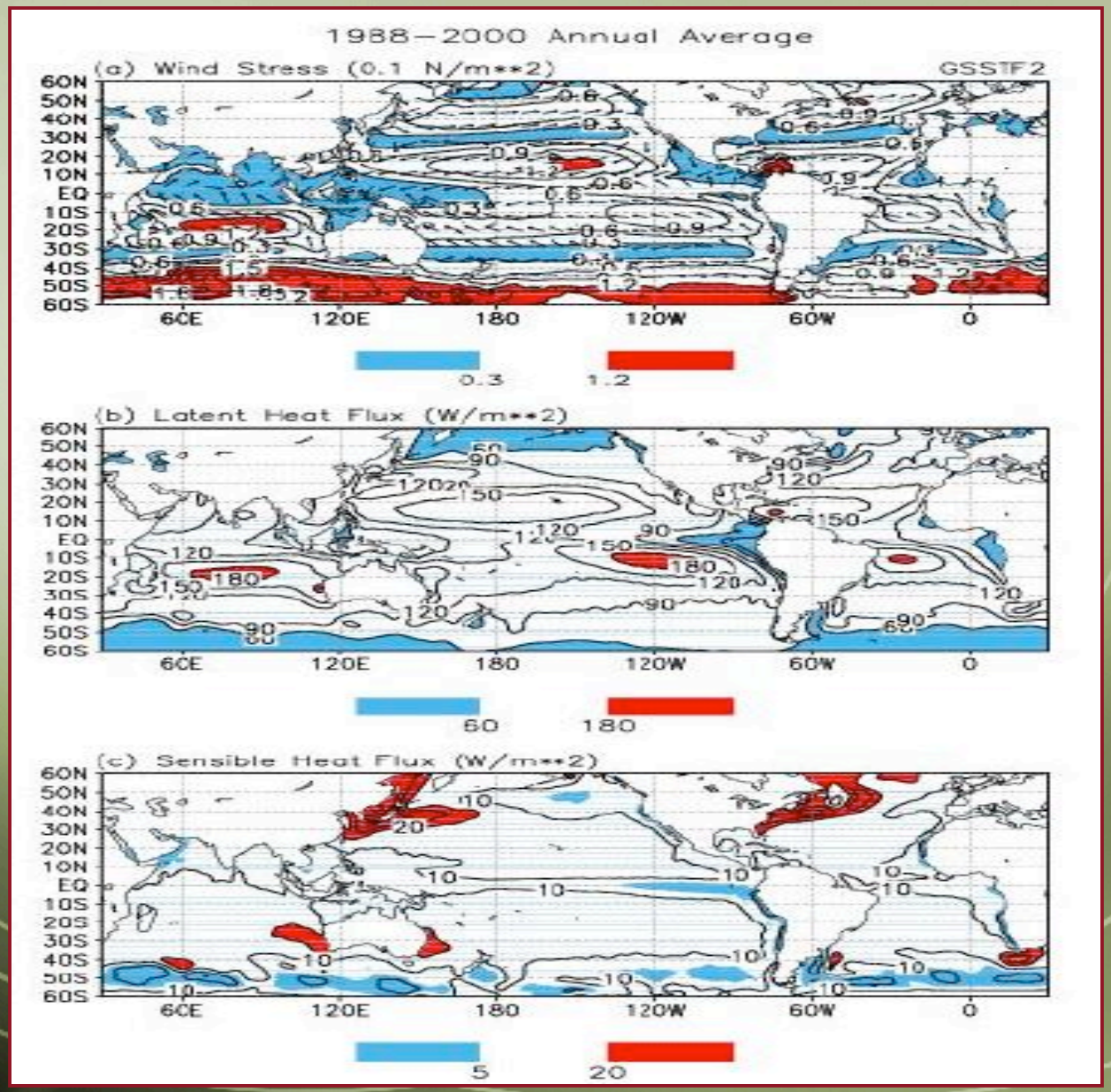
GSSTF2 Annual-mean (1988-2000)

(a) Wind stress,

(b) Latent heat flux,

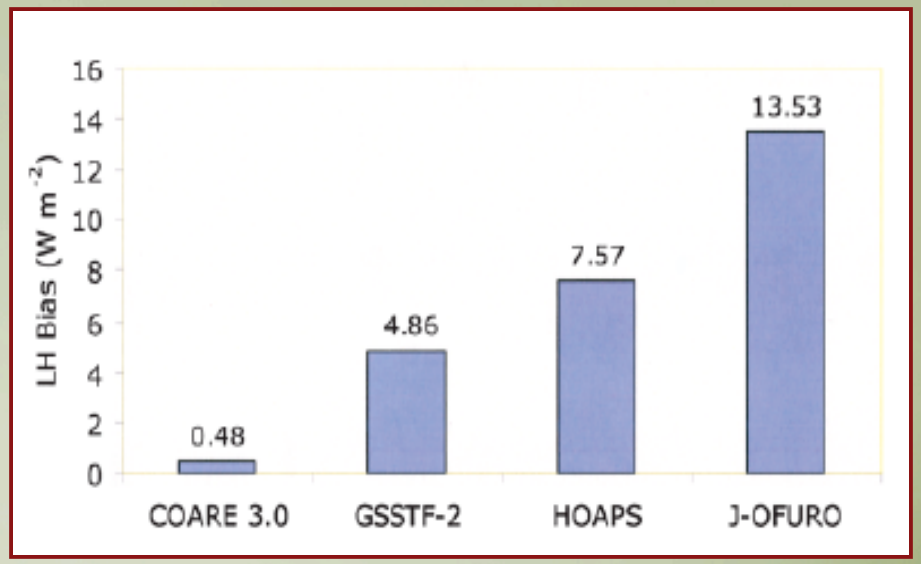
(c) Sensible heat flux

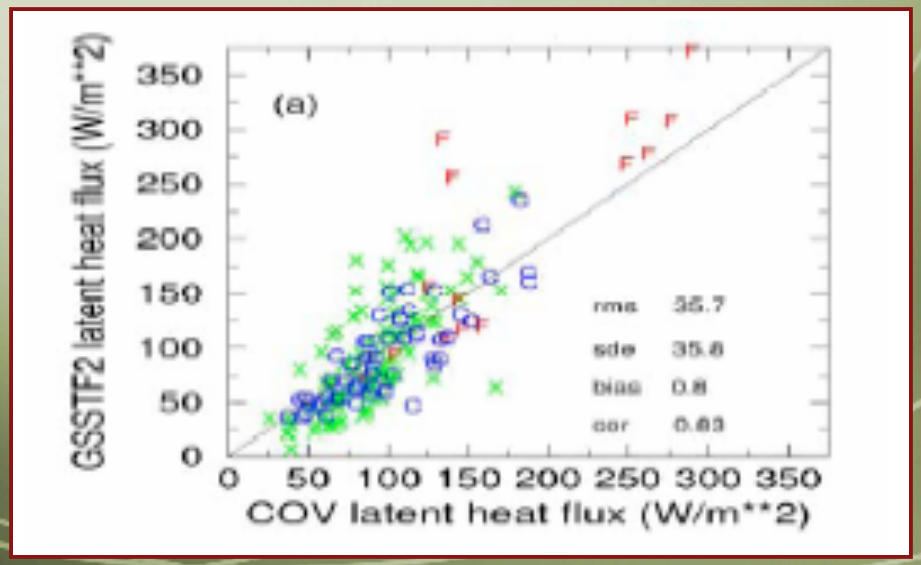
Arrows indicate wind stress direction.



Evaluation/Inter-Comparisons

- *Curry et al. (2004) (SEAFLUX)*
- *Chou et al. (2004)*
- **GSSTF2 is one of the best & widely used oceanic flux products**
- **GSSTF2 used to have the longest temporal coverage (July 1987–December 2000)**
- **GSSTF2 has been verified particularly favorable for the Tropical region (Carol A. Clayson's talk at NASA NEWS Science Meeting, 3-5 Nov 2008)**



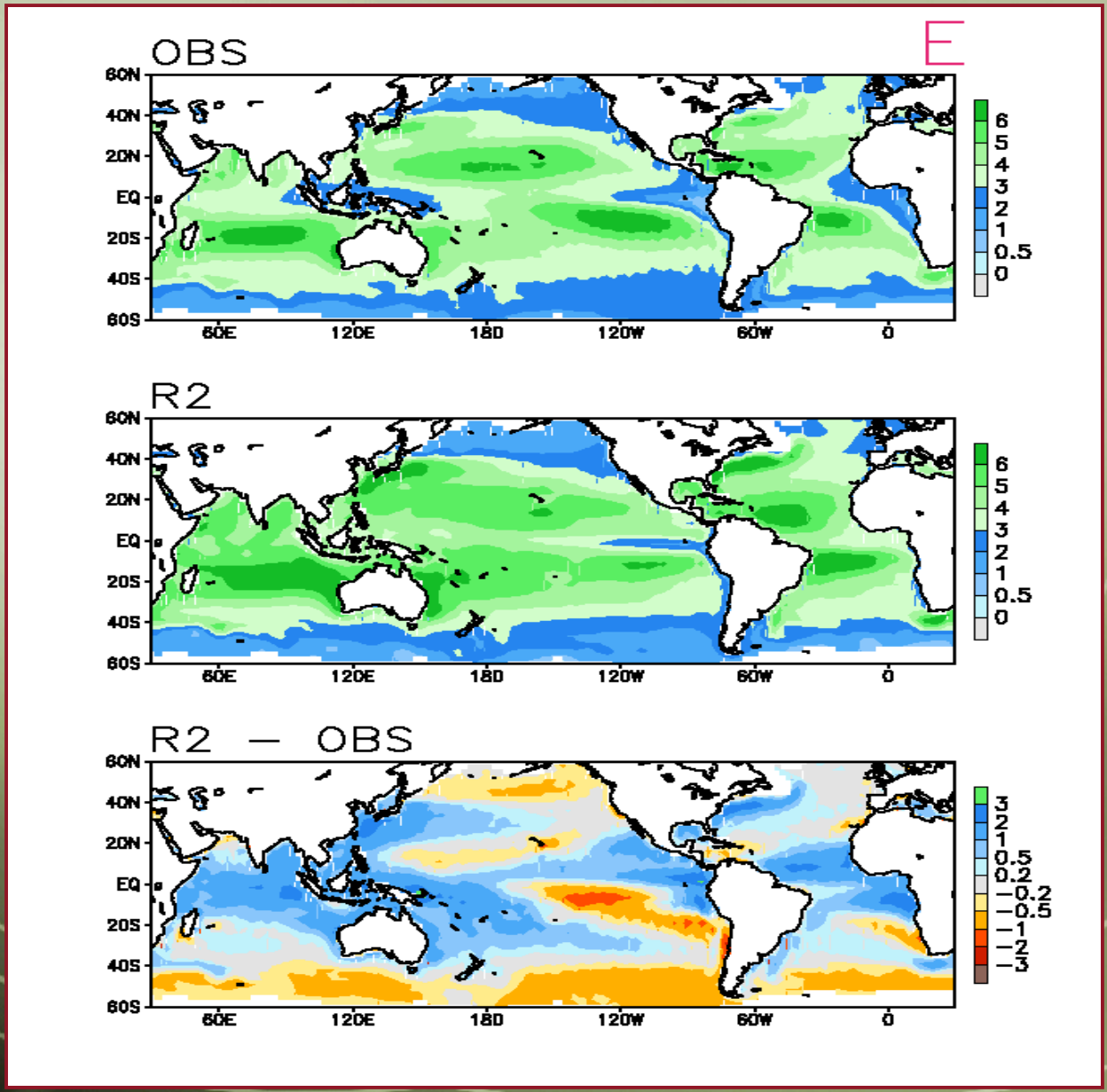


LHF GSSTF2 v.s. NCEP/CDAS2

- **1988 – 2000 annual mean/climatology (mm/day)**

- **Excessive E in Reanalysis 2 (R2) over Indian Ocean, western Tropical Pacific Ocean and Atlantic Ocean**

- **Deficit E in R2 over high-latitude oceans**

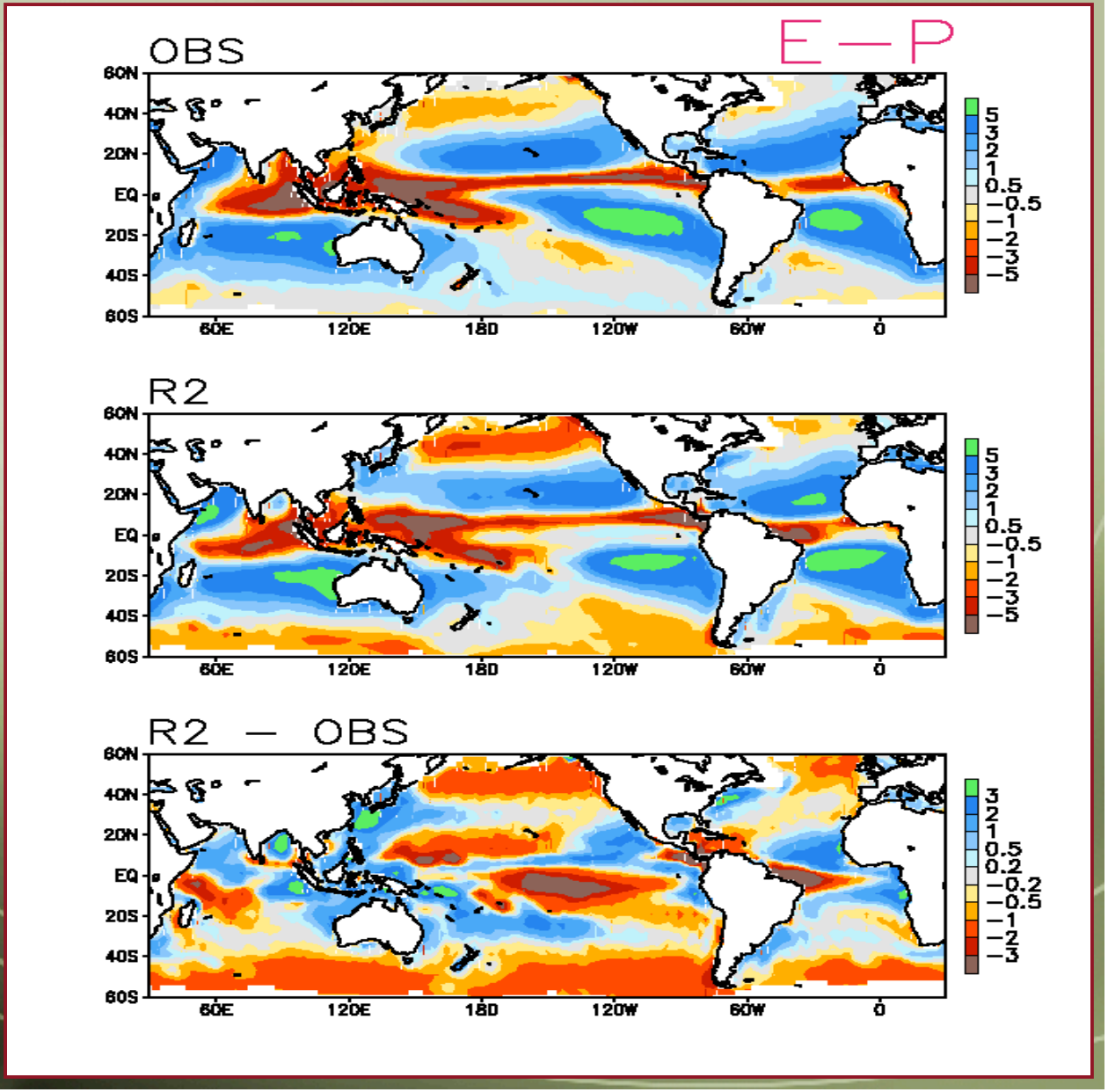


E-P "Obs" v.s. NCEP/CDAS2

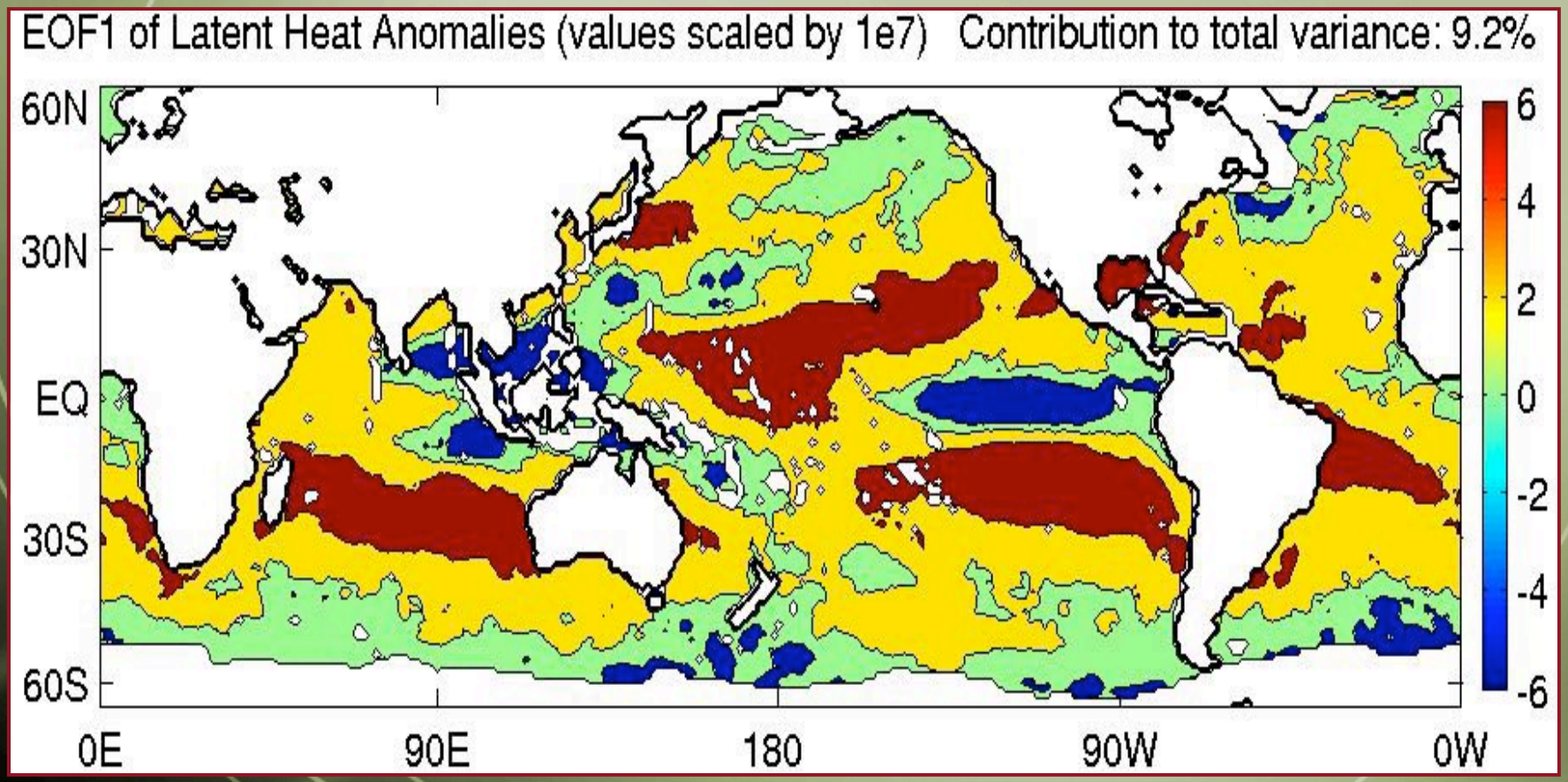
- **1988 – 2000 annual mean/climatology (mm/day)**

- **Excessive E-P in Reanalysis 2 (R2) over eastern Indian Ocean and western Pacific Ocean**

- **Deficit E-P in R2 over central Pacific Ocean and high-latitude oceans**

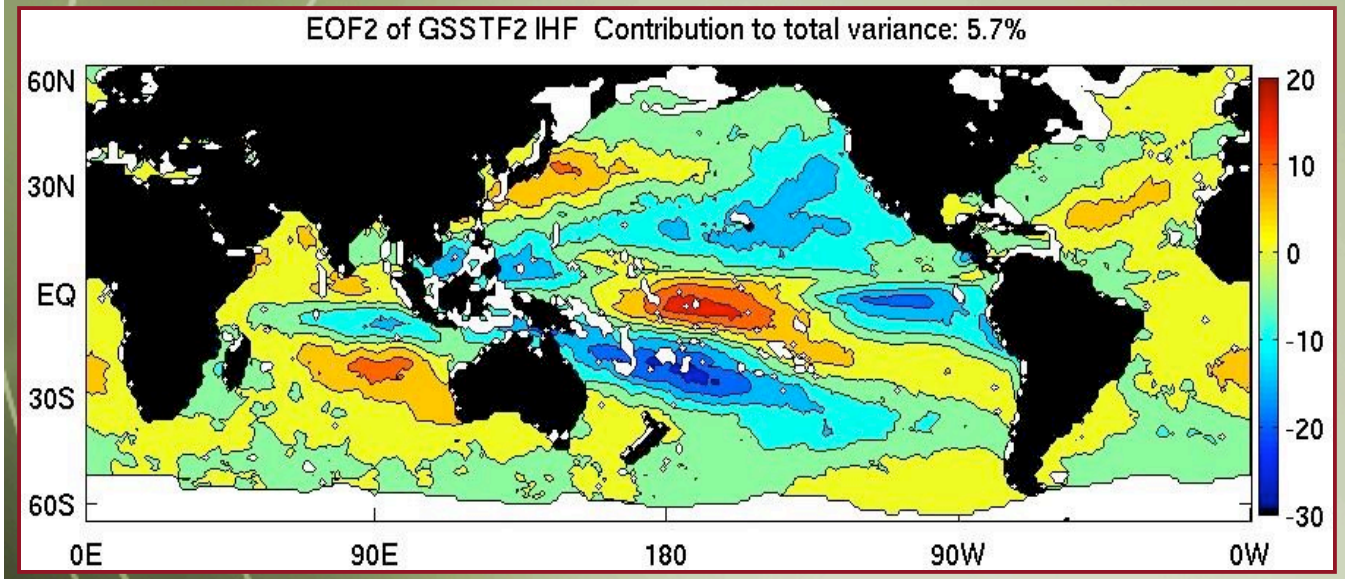


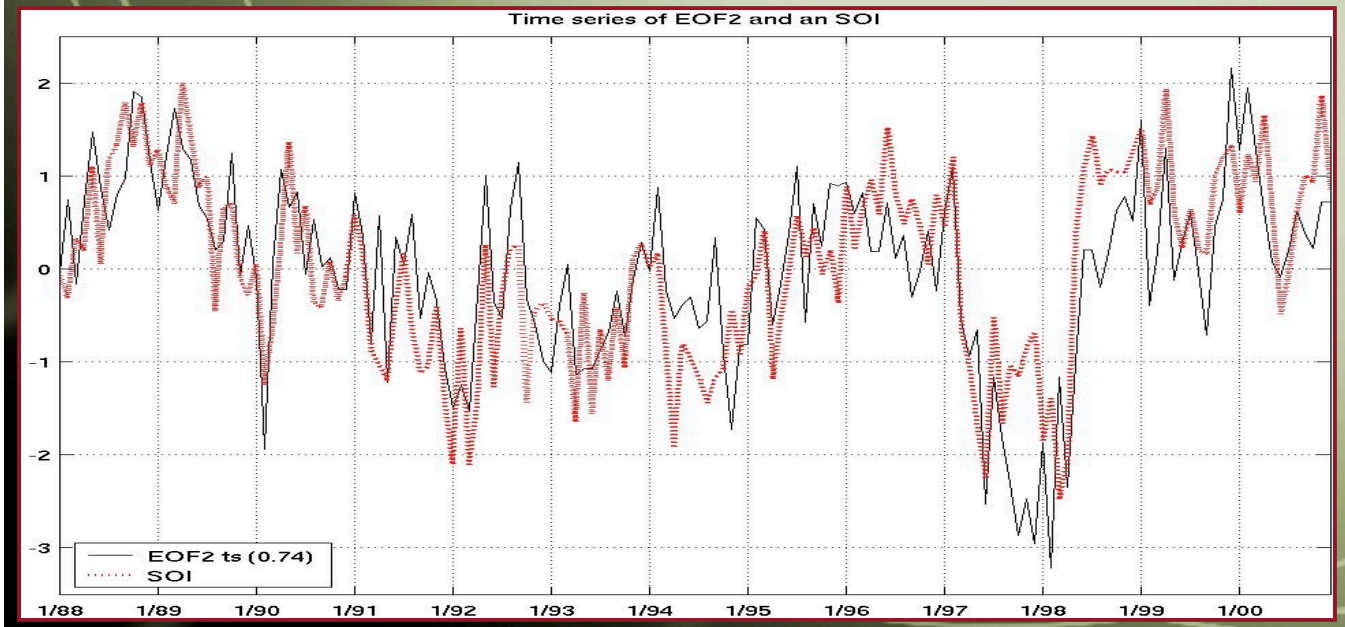
EOF1 of GSSTF2 LHF Related to an Enhanced Hadley Cell



Spatial distribution of EOF1 of the GSSTF2 LHF anomaly data. It exhibits a pattern that may be related to an enhanced Hadley circulation . (Courtesy of Y. Xing and L. Chiu, 2003)

EOF2 of GSSTF2 LHF vs ENSO Signal (SOI)





Spatial distribution of EOF2 of the GSSTF2 LHF data. It exhibits a dipole structure with the negative and positive centers over central and western Pacific, respectively. (Courtesy of Y. Xing and L. Chiu, 2003)

EOF2 (5.7% contri.) of the GSSTF2 LHF data has a time series that is highly correlated with the SOI (Southern Oscillation Index) at 0.74. (Courtesy of Y. Xing and L. Chiu, 2003)

To Revive & Improve GSSTF

- ***A joint effort by scientists from UMBC-GSFC, GMU-CUHK, CPC, and NTU***
- ***General Goal***
  - **Reprocess and improve GSSTF dataset to cover the entire SSM/I observation period of 1987 – present, using improved input datasets (e.g., RSS SSM/I V6) and upgraded spatial and temporal resolutions (GSFC)**
  - **Establish a system to generate the oceanic flux fields on a real-time basis for climate monitoring and assessments (CPC)**
- ***Current Status***
  - **A newly NASA funded project currently ongoing at UMBC-GSFC**
  - **A real-time system currently developing at CPC**

How To Improve GSSTF

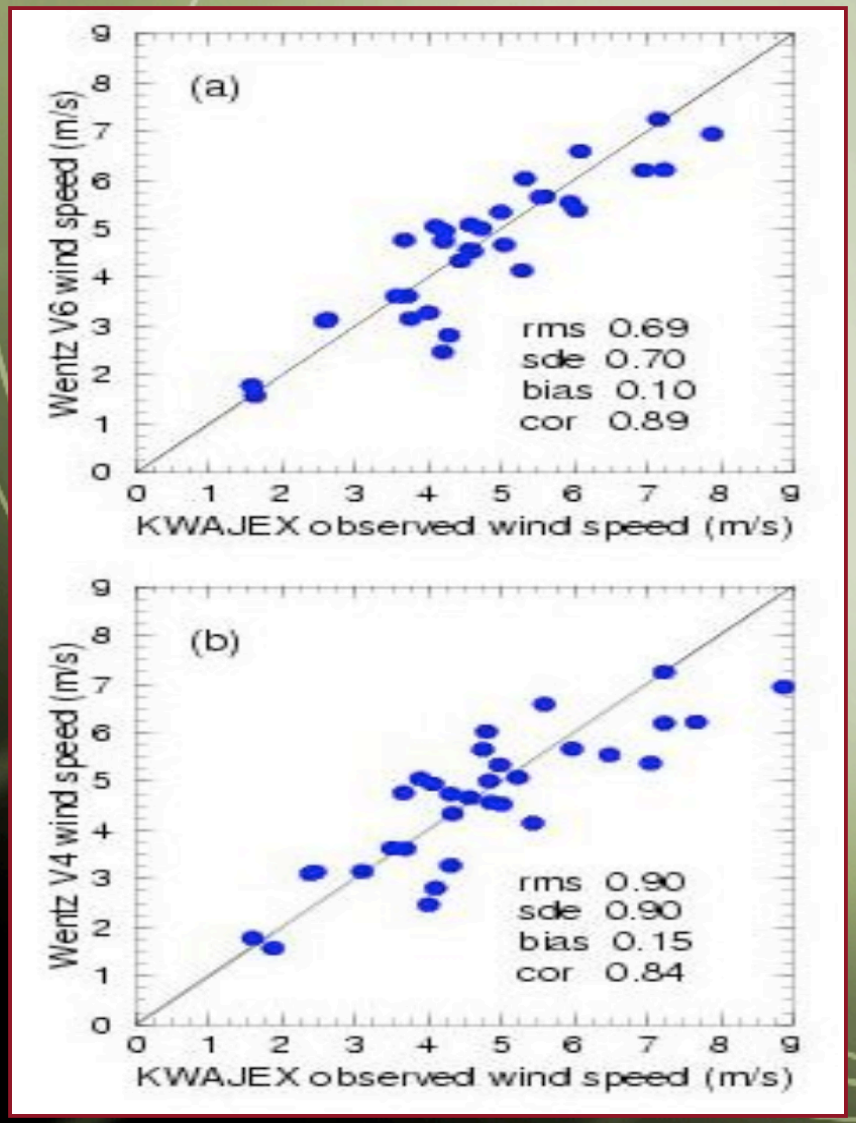
Datasets	GSSTF2	GSSTF2b	GSSTF3
C_E (transfer coeffi.)	Chou (1993)	PDB[1] (high wind)	PDB (high wind)
U (speed)	Wentz V4 (1997)	Wentz V6 (2006)	Wentz V6 (2006)
U (vector)	Atlas et al. (1996)	Atlas et al. (1996) or QuikSCAT	QuikSCAT and ADEOS2-SeaWinds
W/WB	Wentz V4 (1997)	Wentz V6 (2006)	Wentz V6 (2006)
SST	NCEP Reanalysis (V1) Reynolds and Smith (1994)	NCEP Reanalysis (V2) Reynolds et al. (2002)	AMSR-E & TMI
Q_a	Chou et al. (1995, 1997)	Chou et al. (1995, 1997)	Chou et al. (1995, 1997)
Tair/SLP	NCEP	NCEP	NCEP
Spatial resolution	1° by 1°	1° by 1°	0.25° by 0.25°
Spatial coverage	Global Oceans	Global Oceans	"Global Oceans"[2]
Temporal resolution	Daily and monthly	Daily and monthly	12-hr and monthly
Temporal coverage	Jul. 1987 – Dec. 2000	Jul. 1987 – Dec. 2010	July 1999 – Dec. 2010

[1]Stands for Powell et al., 2003; Donelan et al., 2004; Black et al., 2006. [2]Likely a smaller domain than 90Nx90S

Characteristics of proposed satellite input data for GSSTF3

Datasets	Time length	Spatial sample	Data domain	Data Freq.
TRMM/TMI *SST*	12/97 - present	pixel resolution of 0.25 degree	40Nx40S	Twice daily
AMSR-E *SST*	06/02 - present	pixel resolution of 0.25 degree	90Nx90S	Twice daily
QuikSCAT *Wind direction*	07/99 - present	pixel resolution of 0.25 km	90Nx90S (90% ice free ocean)	Twice daily
ADEOS2-SeaWinds *Wind direction*	04/03 – 10/03	pixel resolution of 0.25 degree	90Nx90S (90% ice free ocean)	Twice daily

Improved retrieved surface wind speed by Wentz of Remote Sensing Systems

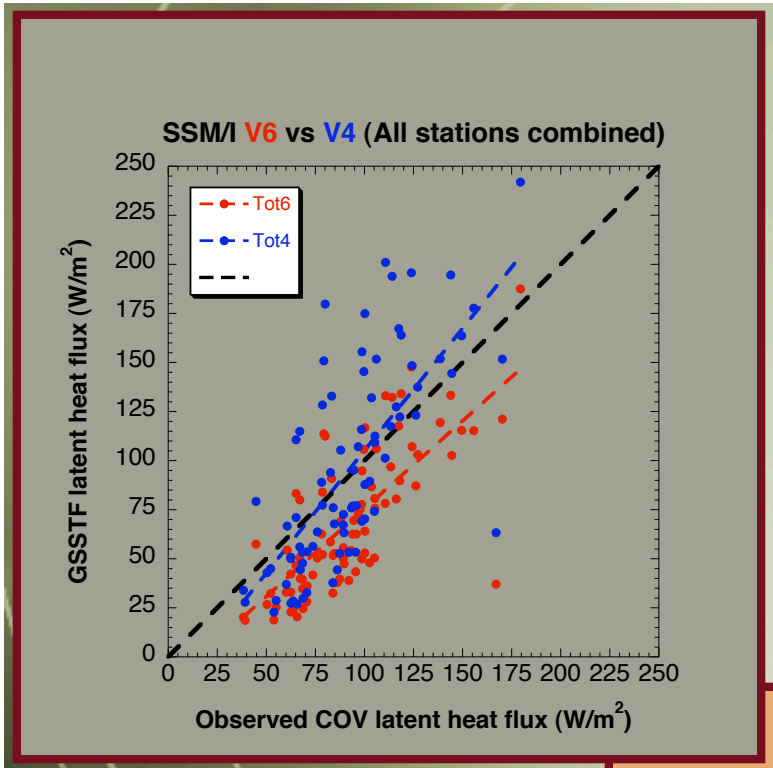


(a) Wentz (RSS) Version 6 (combined F13 and F14) daily surface wind speed vs. Kwajalein Experiment (KWAJEX) observed wind speed, adjusted for surface, at 9N, 167E, 28 July - 11 September 1999.

(b) As in (a), except for Wentz (RSS) Version 4 (combined F13 and F14) daily wind speed.

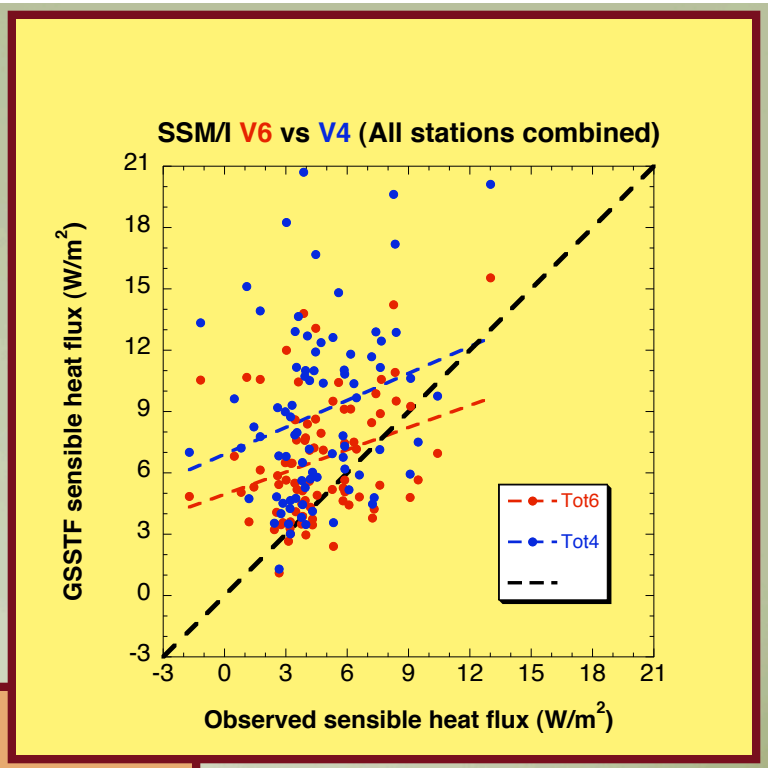
(Labels of x/y axis need to be swapped)

V6 vs V4 Total

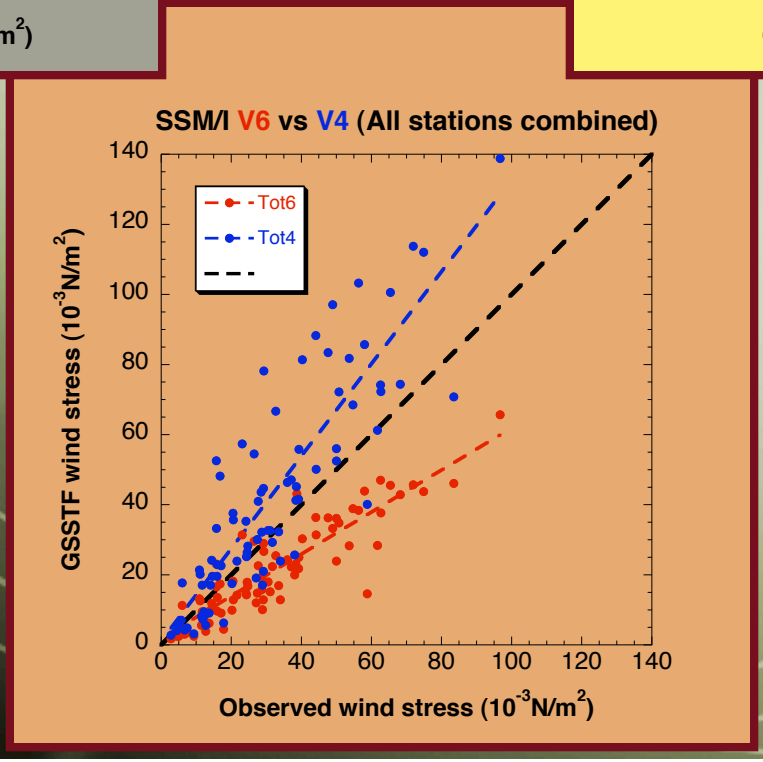


LHF

WST



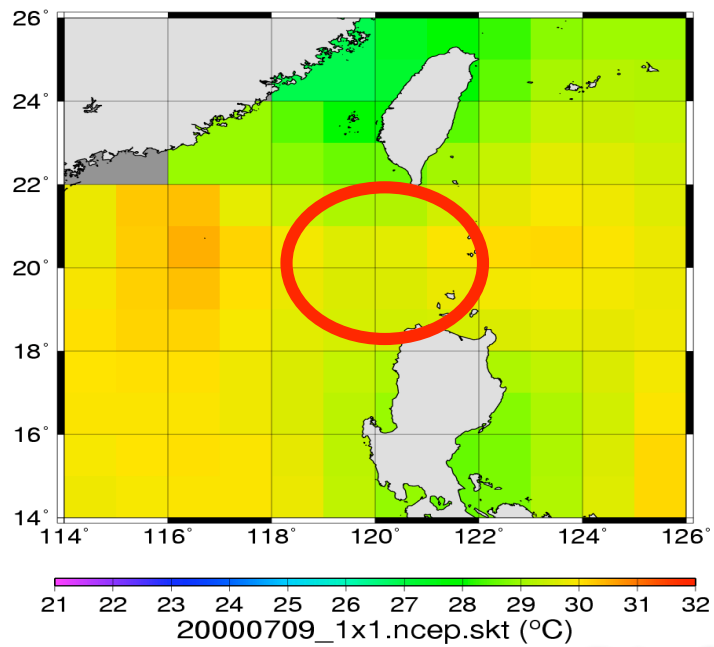
SHF



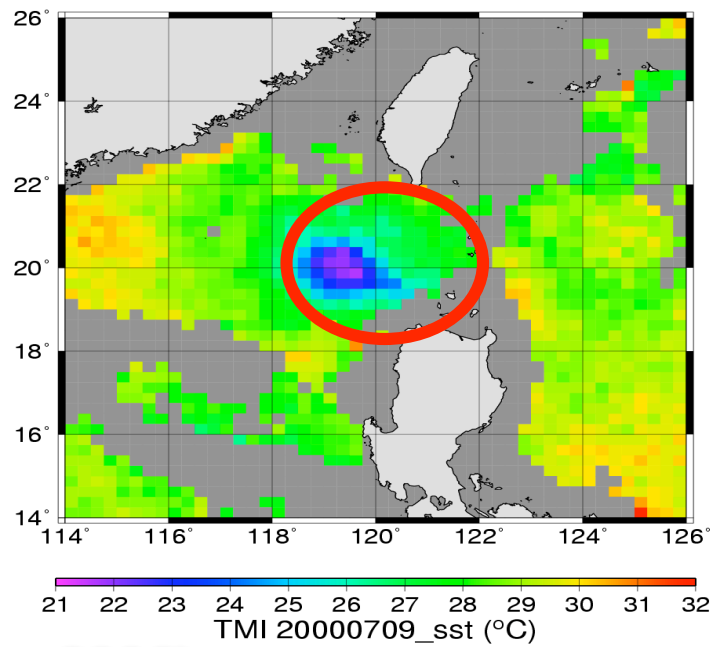
Improvement on SST using Cloud-penetrating TRMM/TMI and AMSR-E

Current SST is based on the NCEP 7-day average SST (composite using cloud-limiting AVHRR), thus many dynamic air-sea processes, e.g. typhoon-induced cooling and associated processes can not be studied using existing scheme.

1°×1°



0.25°×0.25°



(Lin & Wang, 2006)

Improvement on Spatial and Temporal Resolution

Using advanced remote sensing, i.e., synergy of 2 satellites for

- SST: TRMM/TMI (1998-) and AMSR-E (2002-)

- Surface wind vectors: QuikSCAT (1999-) and ADEOS2/SeaWinds (2003)

In their hurricane study, Wang & Lin improve

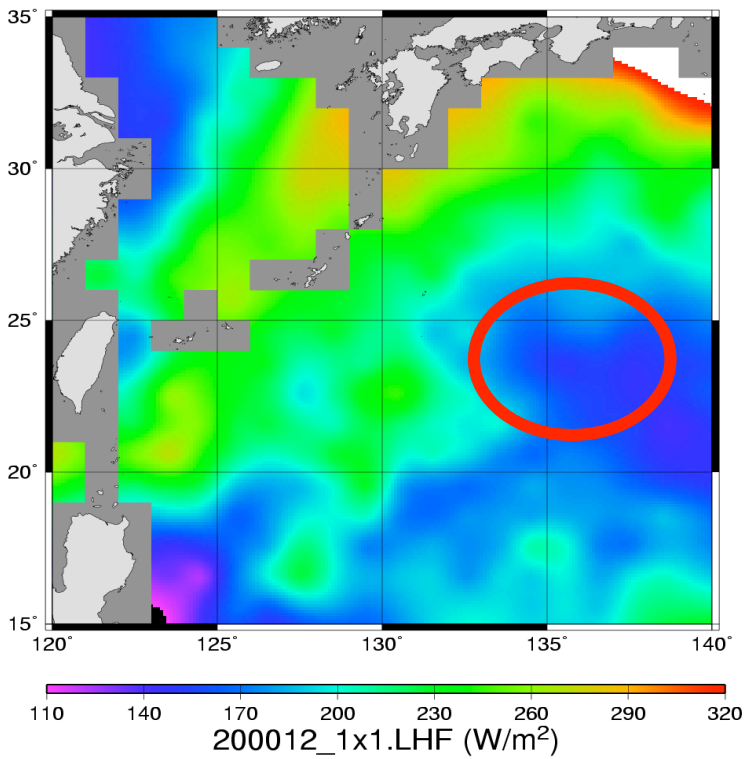
- The spatial resolution from 1 degree to 0.25 degree

- The temporal resolution from daily to 2-4 passes daily

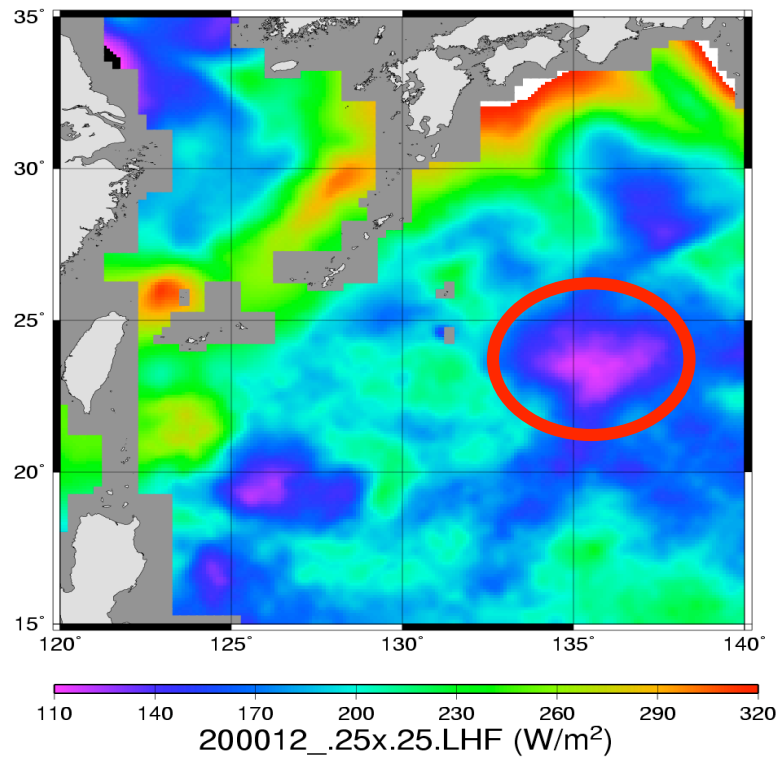
(Lin & Wang, 2006)

Improved estimated LHF at the Kuroshio region with higher spatial resolution

1°×1°



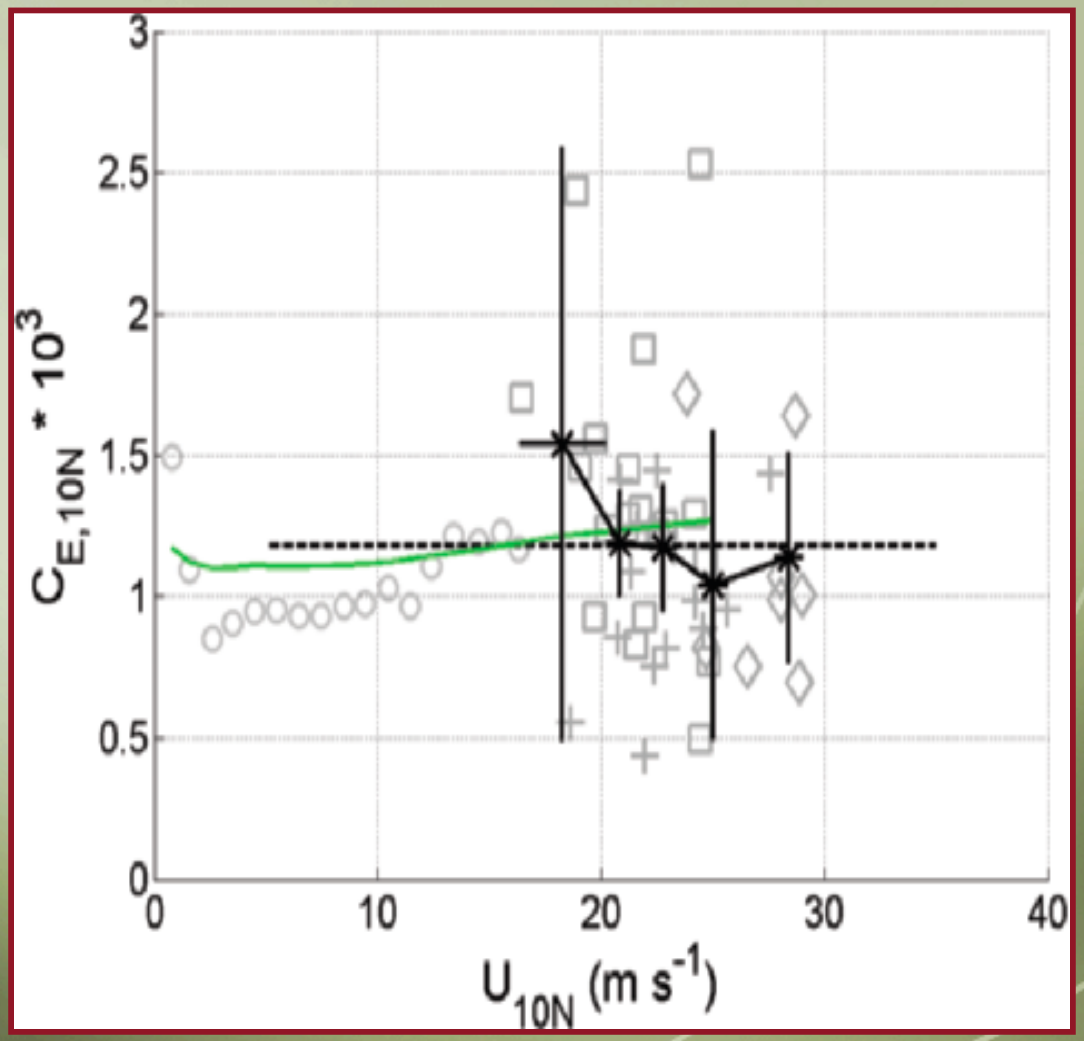
0.25°×0.25°



(Lin & Wang, 2006)

Transfer Coefficients for High winds

Moisture exchange coefficient (Dalton number) estimates derived from CBLAST stepped-descent flight legs in Hurricanes Fabian and Isabel (2003). The "asterisks" represent average values in 2.5 m s–1 bins, and the "bars" show 95% confidence limits. The "squares" are from flight legs in the right-front quadrant of the storms, "plus" signs from the right-rear quadrant, and "diamonds" from the left-front quadrant. The black dashed line represents the HEXOS line (DeCosmo et al. 1996), modified as per Fairall et al. (2003) and extended to 36 m s–1. The green solid line is the COARE 3.0 curve (Fairall et al. 2003), and the gray circles are from CBLAST-Low (Edson et al. 2007).



Courtesy of Black et al., 2007 BAMS

Current/Future Works

- *Process the improved GSSTF2b & GSSTF3 products for the entire data period (UMBC-NASA)*
- *Evaluation and inter-comparison (GMU-CUHK)*
- *Extended scientific applications, e.g., air-sea interactions due to Typhoon/Hurricane (NTU)*
- *Design and generate products for specific CPC applications, e.g., oceanic monitoring (CPC)*

Final Goals

- ***Continually producing a uniform data set of sea surface turbulent fluxes that continue to be useful for global energy and water flux research and applications***

- ***Improving CPC's capacity to perform monitoring, assessments and analysis of***
  - **Global Water Cycle [fresh water budget]**
    - **Precipitation, Evaporation, Runoffs**
  - **Global Energy Budget**
    - **Latent/sensible heat, Shortwave / Longwave Radiation**
  - **Global Oceanic Momentum Flux**
    - **Wind Stress**

Prospects

- Promising features shown in preliminary results
- The proposed GSSTF products, i.e., the daily 1° x 1° GSSTF2b (July 1987-Dec 2008) and the 12-hr 0.25^ox0.25^o GSSTF3 (July 1999-Dec 2009) expected to be released for research community use by late 2009 and early 2011, respectively
- Scientific applications (SEAFLUX, hurricane and etc.)
- An objective system developed at CPC to generate the GSSTF on a quasi real-time basis
- Products need to be designed and generated for specific CPC applications in monitoring, assessment and analysis

Appendix:
The Current GSSTF2 Product

Variables:

(1) "lhflx": latent heat flux (W/m**2),
(2) "ustr": zonal wind stress (N/m**2),
(3) "vstr": meridional wind stress (N/m**2),
(4) "shflx" : sensible heat flux (W/m**2),
(5) "shum10m" : surface air (~10-m) specific humidity (g/kg),
(6) "prwtr" : lowest 500-m precipitable water (g/cm**2),
(7) "wind10m" : 10-m wind speed (m/s),
(8) "humdif" : sea-air humidity difference (g/kg).

Levels: one level
Temporal Coverage: July 9, 1987- December 31, 2000
Temporal Resolution: daily mean
Spatial Resolution: 1.0 lat * 1.0 lon, global
Source: http://disc.sci.gsfc.nasa.gov/precipitation/data-holdings/access/gsstf2.0.shtml/
Volume: eight variables, 2.1Mb per day

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Appendix: The Daily GSSTF2

(i) Daily Product

Temporal Coverage:	Daily data from July 1987 to December 2000
Spatial Coverage:	1° latitude x 1° longitude, global (90N-90S)
Distribution Method:	Anonymous FTP
Number of Files:	1 file per month
Volume:	~62.5 MB (uncompressed)
Documentation:	GSSTF – Version 2
File Type:	Binary
File Name (e.g., for July 1987):	198707.1x1.daily.bin

Appendix: The Monthly GSSTF2

(ii) Monthly-mean Product

Temporal Coverage:	Monthly-mean data from July 1987 to December 2000
Spatial Coverage:	1° latitude x 1° longitude, global (90N-90S)
Distribution Method:	Anonymous FTP
Number of Files:	1 file per month
Volume:	~2.1 MB (uncompressed)
Documentation:	GSSTF – Version 2
File Type:	Binary
File Name (e.g., for Dec. 2000):	200012.1x1.monthly.bin

Appendix:
The Annual & Climatology GSSTF2

(iii) Monthly- and Annual-mean Climatology Products

Temporal Coverage:	Monthly- and annual-mean data from Jan 1988 to Dec 2000
Spatial Coverage:	1° latitude x 1° longitude, global (90N-90S)
Distribution Method:	Anonymous FTP
Number of Files:	13 files
Volume:	~2.1 MB (uncompressed)
Documentation:	GSSTF – Version 2
File Type:	Binary
File Name (e.g., for Dec.):	198800clm.1x1.dec.bin

Thanks!