



*Assessment of Observation Impact Using a  
Variational Assimilation Adjoint System*

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# Observing and Data Assimilation Challenges

- Where do we need improved observation coverage?
- What is the optimal horizontal and vertical resolution of observations for ocean prediction?
- What instruments and variables are most needed?
- What are the accuracy requirements of the observations?
- Will we reach observation redundancy?
- What improvements to data assimilation and/or quality control procedures are most needed?

# ALL OBSERVATIONS DO NOT HAVE VALUE!

EQUAL

- In terms of forecast error reduction
- How can we quantify observation impact?

## Adjoint technique

- shows impact on all observation types
- computationally inexpensive
- can be implemented in operational DA suite
- routine generation of impact statistics

# Background -

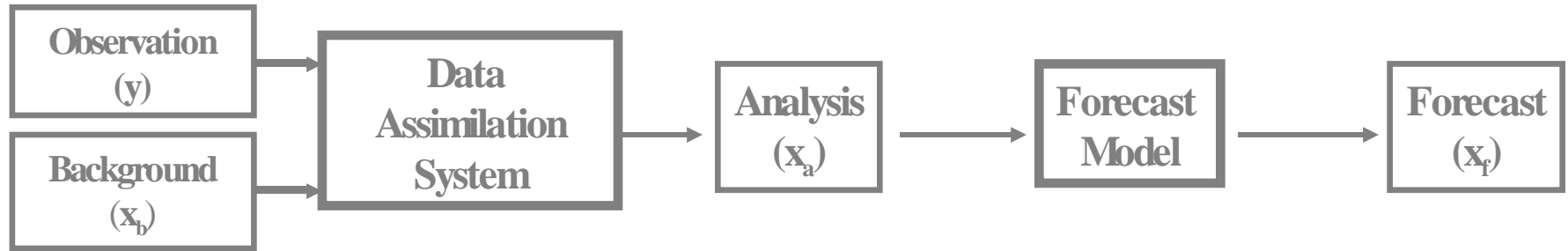
Variational adjoint system presented here is operational in Navy  
NWP: NOGAPS and NAVDAS-3DVAR  
(adjoint for NAVDAS-4DVAR now available)

Nancy Baker, Roger Daley, Rolf Langland, Tom Rosmond

References: Baker and Daley (2000) *QJRM* 126:1431-1454  
Langland and Baker (2004) *Tellus* 56A:189-201

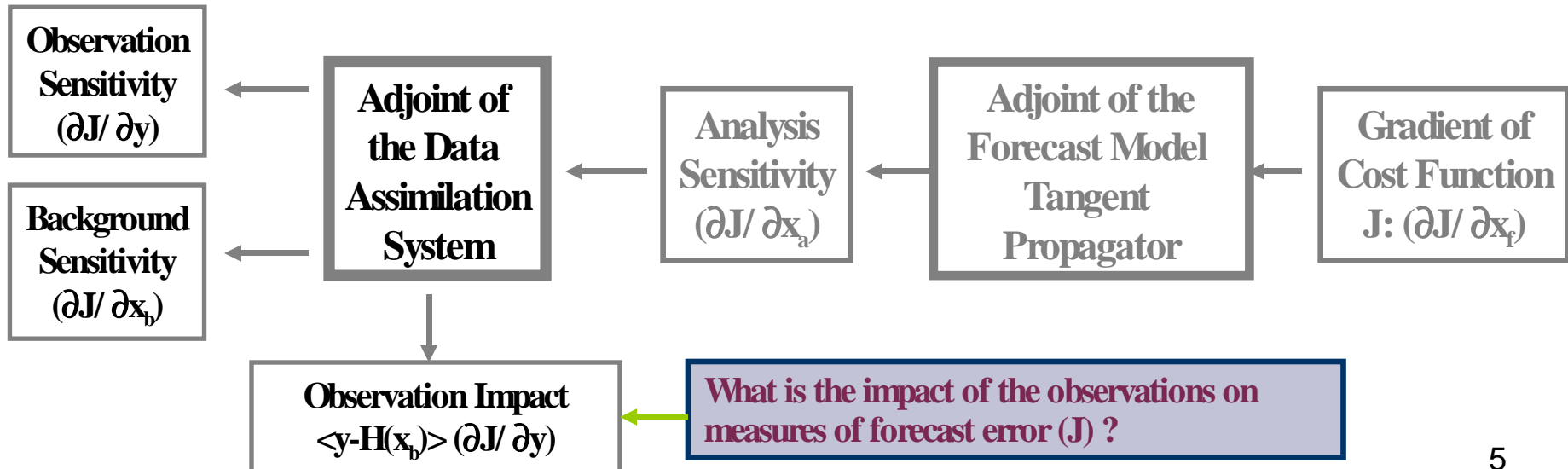
No fundamental issues applying variational adjoint system in the  
ocean

# Analysis – Forecast System

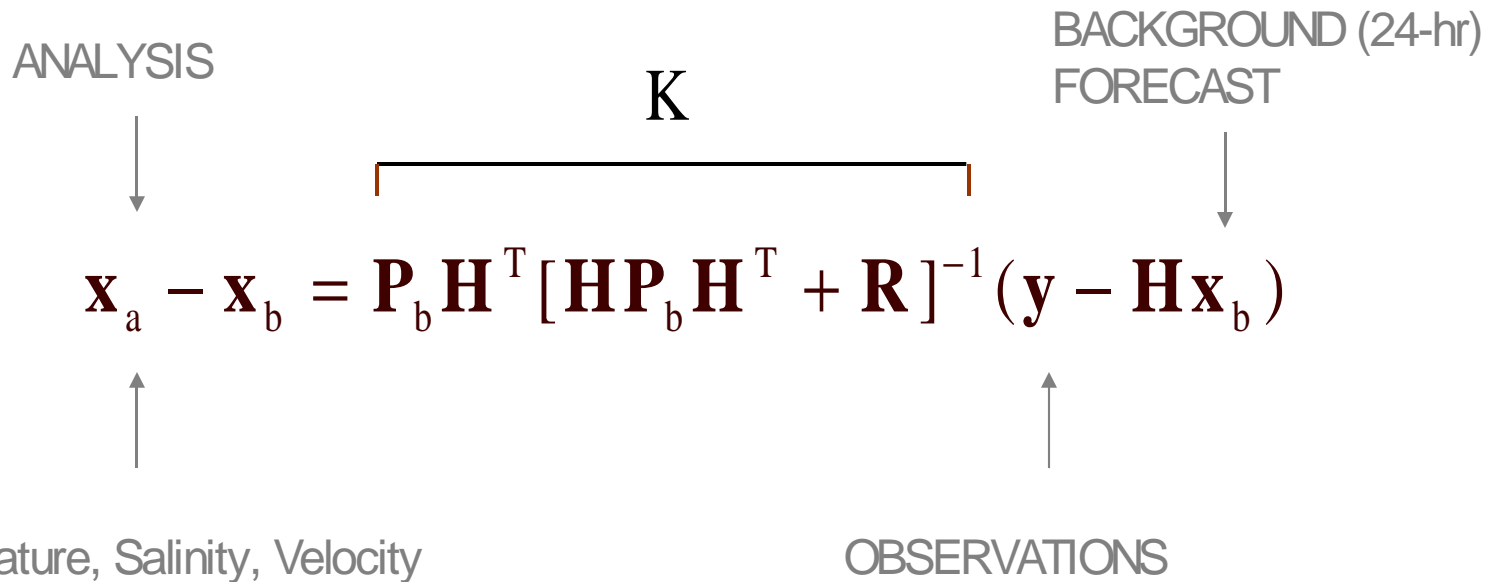


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# Adjoint System



# Data Assimilation Equation and Adjoint



## Assimilation Adjoint

$$\frac{\partial J}{\partial \mathbf{y}} = [\mathbf{H} \mathbf{P}_b \mathbf{H}^T + \mathbf{R}]^{-1} \mathbf{H} \mathbf{P}_b \frac{\partial J}{\partial \mathbf{x}_a}$$

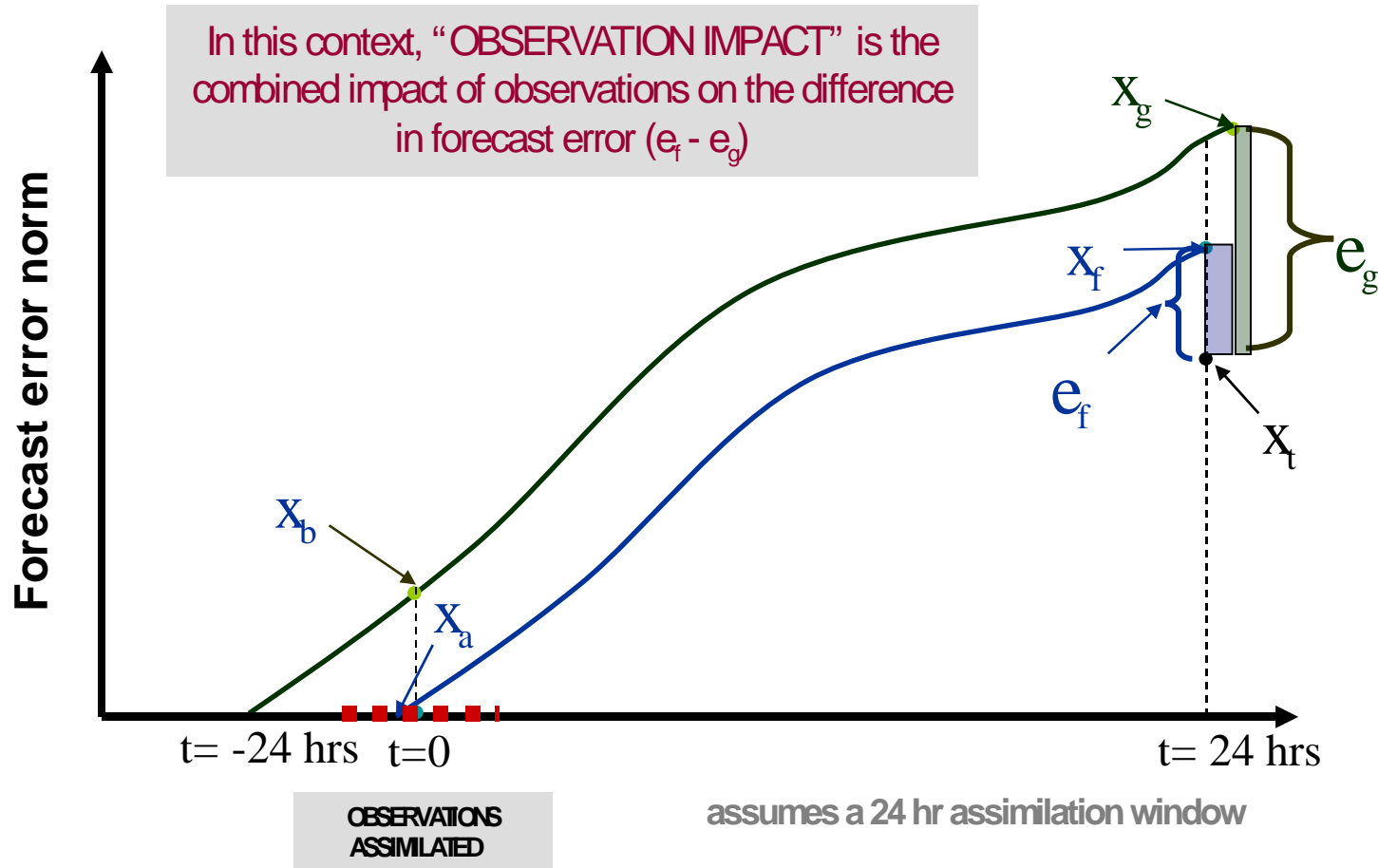
Baker and Daley (QJRM, 2000)

$\mathbf{H} \mathbf{P}_b$  is the adjoint of the post-multiplication step  $\mathbf{P}_b \mathbf{H}^T$

$[\mathbf{H} \mathbf{P}_b \mathbf{H}^T + \mathbf{R}]^{-1}$  is self adjoint

# Observation Impact Concept

Observations move the forecast from the **background trajectory** to the **trajectory starting from the new analysis**



# Observation Impact Equation

- difference between forecast errors ( $e_f - e_g$ ) is due solely to the assimilation of observations at  $t = 0$
- no observations assimilated at  $t = 0$  will result in  $e_f$  equal to  $e_g$  since the trajectory at  $t = -24$  will be unchanged ( $\mathbf{x}_a = \mathbf{x}_b$ )
- for the purpose of calculating observation impact it is appropriate to use a measure of the forecast error difference as a cost function
- using observation sensitivity gradients, observation impacts can be estimated (Baker and Daley 2000) from

$$\delta e_f^g = \left\langle (\mathbf{y} - \mathbf{H}\mathbf{x}_b), \mathbf{K}^T \left\{ \frac{\partial e_f}{\partial \mathbf{x}_a} + \frac{\partial e_g}{\partial \mathbf{x}_b} \right\} \right\rangle$$

$\mathbf{K}^T$  is the operator representing the adjoint of the data assimilation procedure and

$\langle \cdot, \cdot \rangle$  is a scalar inner product

$$\frac{\partial J_f^g}{\partial \mathbf{y}} = \mathbf{K}^T \left( \frac{\partial J_f}{\partial \mathbf{x}_a} + \frac{\partial J_g}{\partial \mathbf{x}_b} \right)$$

# Steps in observation impact calculation -

**Analysis and  
Background**

$\mathbf{x}_a, \mathbf{x}_b$  (24 *hr* forecast)

**Model Forecasts &  
Forecast Errors**

$$x_{24} = M(x_a)$$

$$x_{48} = M(x_b)$$

Forecast errors

**Forecast Adjoint**

$$\partial e_{24} / \partial x_a = L^T [C(x_{24} - x_t)]$$

$$\partial e_{48} / \partial x_b = L^T [C(x_{48} - x_t)]$$

Sensitivity gradients in  
model grid-point space

$L^T$  is the operator representing the adjoint of the forecast model

# Steps in observation impact calculation -

**Assimilation Adjoint**

$$\frac{\partial (e_{24} - e_{48})}{\partial (y - Hx_b)} = K^T \left[ \frac{\partial e_{24}}{\partial x_a} + \frac{\partial e_{48}}{\partial x_b} \right]$$

Sensitivity gradient in observation space

Adjoint of assimilation

**Observation Impact**

$$\delta e_{24}^{48} = \left\langle (y - Hx_b), \frac{\partial (e_{24} - e_{48})}{\partial (y - Hx_b)} \right\rangle$$

Innovations assimilated for  $X_a$

# Observation impact interpretation -

For any observation / innovation ... using this error measure

$\delta e_{24}^{48} < 0.0$  the observation is **BENEFICIAL**

forecast errors decrease

– the

effect of the observation is to make the error of the forecast started from  $\mathbf{x}_a$  less than the error of the forecast started from  $\mathbf{x}_b$

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$\delta e_{24}^{48} > 0.0$  the observation is **NON-BENEFICIAL**

forecast errors increase

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When summed over the entire innovation vector of  $n$  observations

$\sum \delta e_{24}^{48}$  is an approximation of  $e_{24} - e_{48}$

$n$  – can be used to check accuracy of cost function

# Identify extreme observation impacts -

- **Non-beneficial impacts:**

- look for data QC issues, instrument accuracy, specification of observation and background errors, bias correction, or model (background) problems

- **Beneficial impacts:**

- associated with heavily weighted observations in sensitive regions; good, but extreme, impacts indicate need for greater observation density

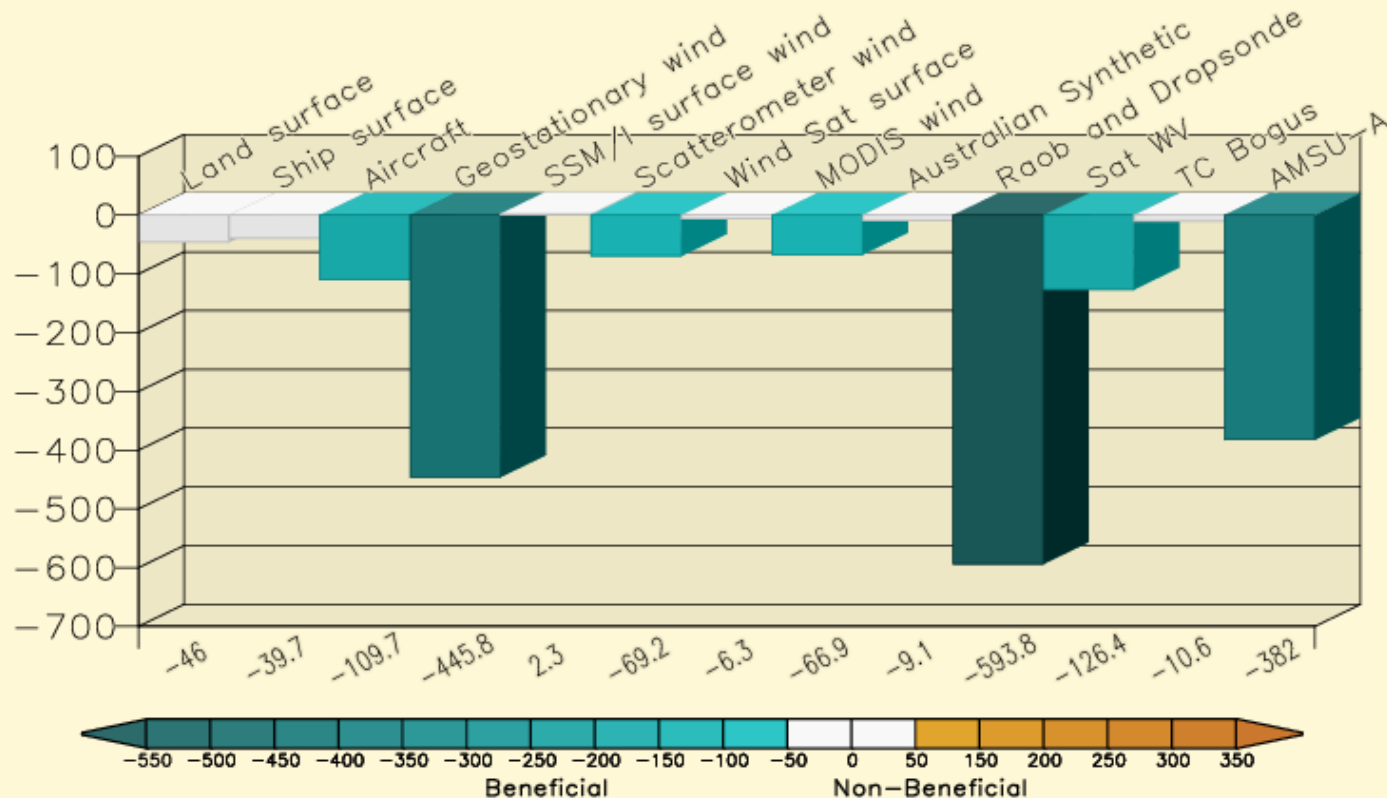
## **Best Outcome:**

- many observations that produce small to moderate impacts, not few observations that produce large impacts

# Impact of Observations in NAVDAS-NOGAPS

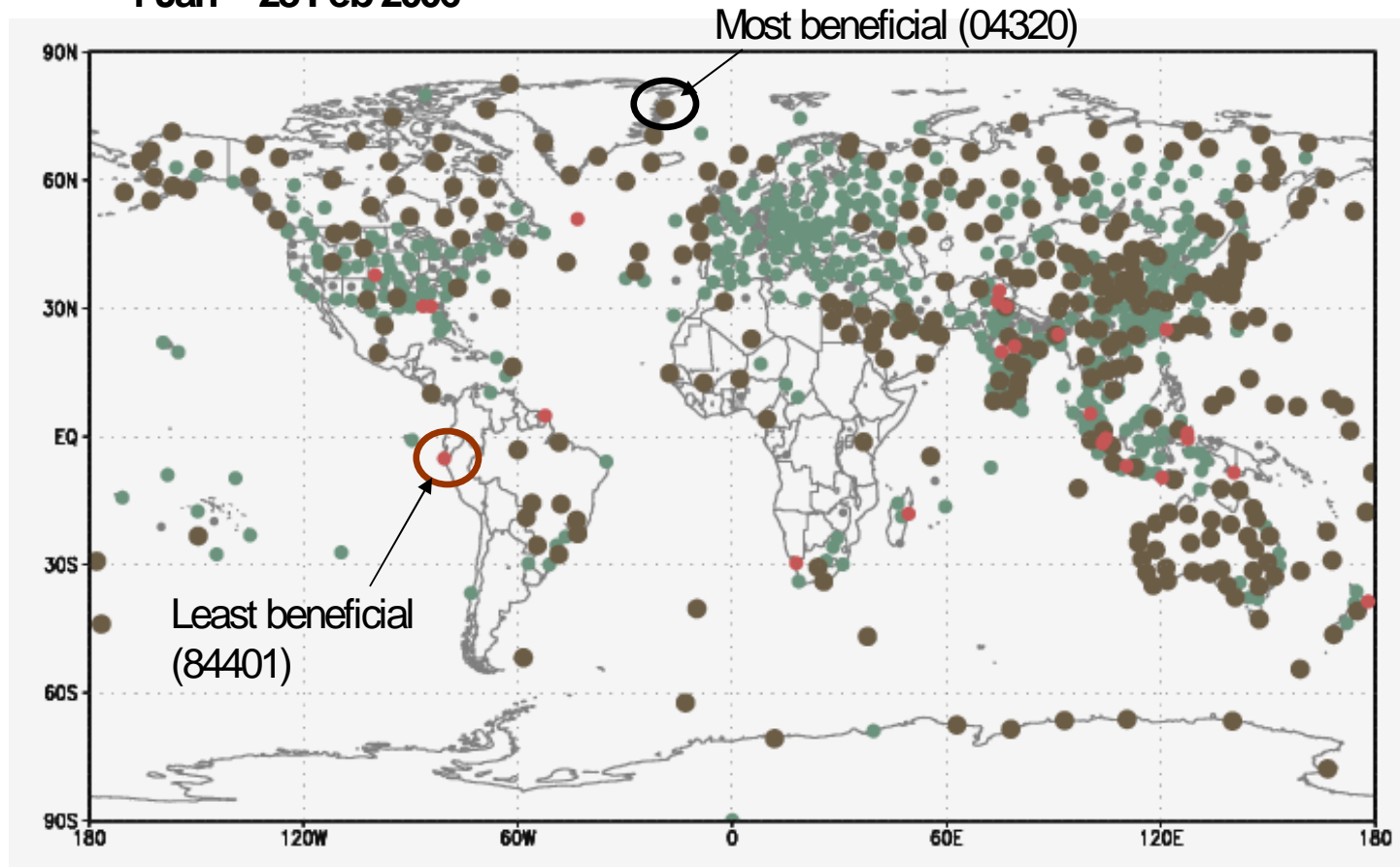
## Year Impact Sum by Instrument Type

Impact of 00UTC observations on 24h global forecast error – moist total energy norm ( $J\ kg^{-1}$ )  
1 year ending 24 Apr 2007



# Radiosonde profile observation impact -

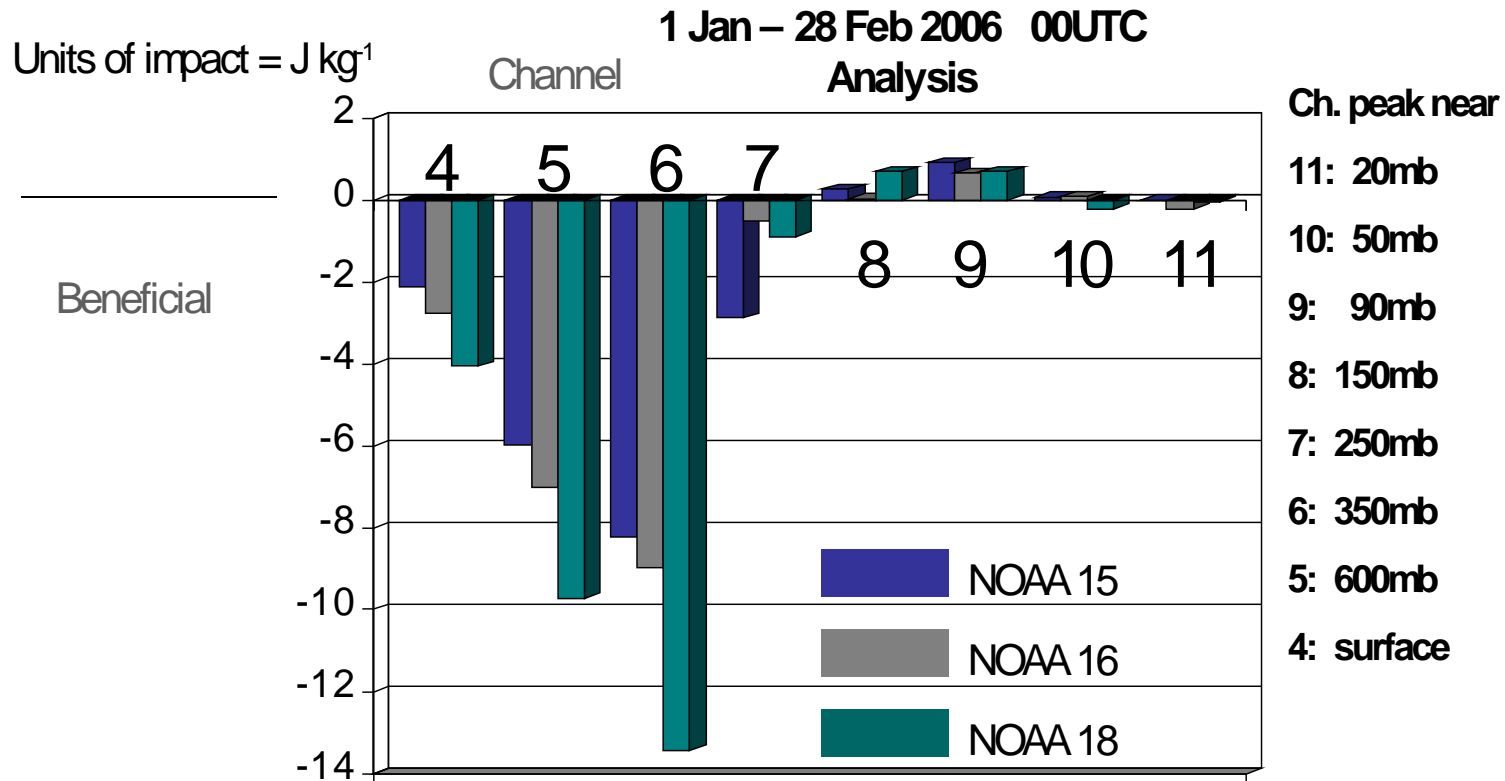
1 Jan – 28 Feb 2006



- Most beneficial ( $< -0.1 \text{ J kg}^{-1}$ )
- Beneficial ( $-0.01 \text{ to } -0.1 \text{ J kg}^{-1}$ )
- Non-beneficial ( $0.01 \text{ to } 0.1 \text{ J kg}^{-1}$ )

**Oceanographic analog for this chart would be impact of the Argo array**

# Impact of AMSU Channels -



Results suggest a problem with assimilation of ch 8 and 9 -  
 Source of problem was operational bias correction and insufficient model  
 and analysis vertical resolution at channel peaks

# Advantages of adjoint method -

- Efficient method – computational cost same as single run of the model and assimilation system
  - adjoint method can easily be integrated into operational DA suite
- Provides quantitative information about every observation assimilated and spatial patterns of observation impact
  - stratify results by instrument type, obs variable, geographic region
- Adjoint-based observation impact information is a valuable supplement to “conventional” data impact studies (OSEs, OSSEs)
  - no need to selectively add or remove data (which change constraints on remaining data)
- Helps to identify possible problems with the assimilation (observation and/or background errors, bias correction issues, etc.)
  - provide information relevant to quality control issues and daily monitoring of observations in operational data assimilation

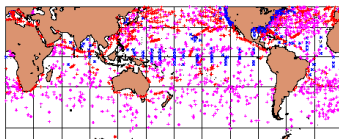
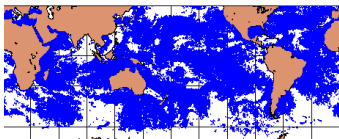
# Limitations and assumptions in calculations -

- Observation impact is relevant only for the selected cost function
  - integrated measure of errors in position and strength of important oceanographic features
  - effect of observations on other aspects of the forecast may not be directly estimated unless multiple cost functions are used
- Tangent linear approximations and simplified physics in forecast model adjoint
  - accuracy of observation impact equation subject to same limitations that apply to the adjoint of the forecast model
- Nonlinearity in 3D or 4DVAR operators (e.g., altimeter SSH)
  - method assumes assimilation procedure is nearly linear
- Impacts depend strongly on assimilation and forecast model
  - different results likely with different DA procedures and models

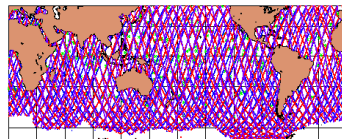
# Conclusions -

- Variational adjoint method planned for HYCOM / NCODA forecasting system
  - operational at Naval Oceanographic Office in 2008
    - <http://www7320.nrlssc.navy.mil/GLBhycom1-12/skill.html>
  - HYCOM adjoint available, NCODA adjoint available from port of NAVDAS 3DVAR to ocean
- Large scale system – performs 5-day hindcast and 5-day forecast each day (24-hr update cycle)
  - 4500 x 3298 x 42 analysis grid points
  - assimilates > 1 million obs each update cycle
  - computational efficiency of adjoint method appropriate for such a large system

SST (827,151)

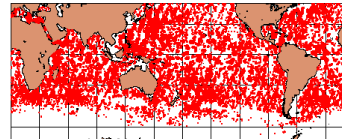
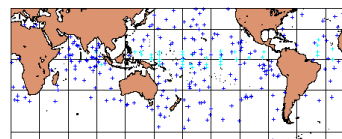


SSH (342,573)



Obs Assimilated 7 Oct 2007

Profiles (683,907)



This is an official U.S. Navy web site.  
 Naval Research Laboratory  
 HYCOM Consortium for Data-Assimilative Ocean Modeling ([Home page](#))  
**Real-time experiment with the 1/12° Global HYCOM**  
 (Note that this run was re-initialized on 4 January 2007)  
 (Starting on 2 May 2007 the NCODA analysis is performed at 18Z)  
[System information](#)  
  
 Click on the ocean of interest to see regional plots  
[Atlantic Ocean](#) [Indian Ocean](#) [Pacific Ocean](#) [Polar Oceans](#) [Global](#)

SSH date: Nov 03, 2007 90.3  
 20071029  
 of 4.0  
 182 to 173

Comparison with in situ data  
  
[NCODA Observations](#)  
 Send questions or comments to: [Webmaster](#)  
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**End**

