Assessing the Impact of (Wind) Observations in the NASA GEOS-5 Forecast System Using the Adjoint Method

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Background

The **GEOS-5 atmospheric data assimilation system** provides real-time analyses and forecast support for NASA instrument teams, field campaigns and other science users

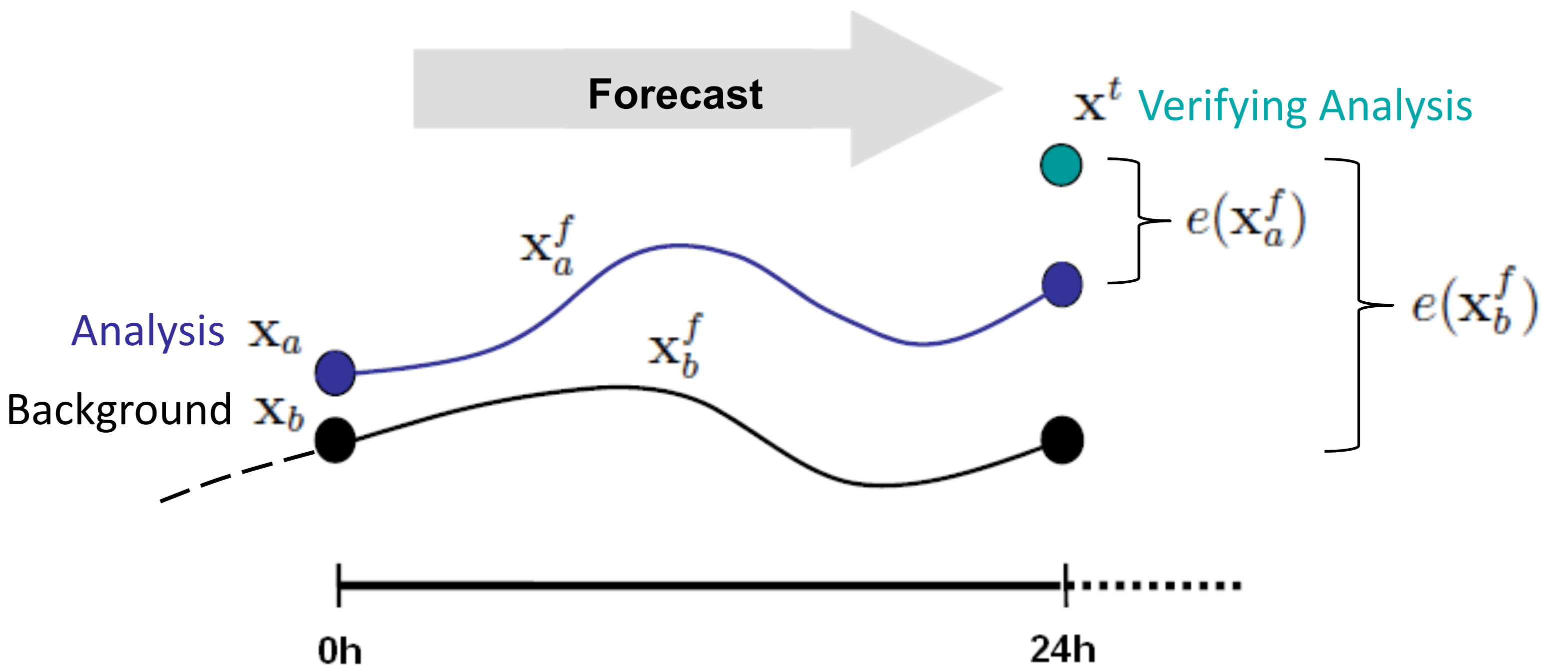
- **GEOS-5 AGCM** (~¼° L72) + **GSI analysis** (~½° L72)
- 6-h assimilation cycle (currently 3DVar)
- 5-day forecasts at 00z and 12z
- NCEP GDAS/GFS observation set

The **adjoint** (transpose) of the GEOS-5 ADAS has been developed, and is run routinely to measure the impact of observations on the 24h forecast from 00z…part of a system-wide upgrade in fall 2010

This talk describes the adjoint method for computing observation impact and shows initial results with focus on the impact of (all) wind observations currently assimilated

Definition of Observation Impact

following Langland and Baker (2004)



Forecast Error Measure: $e = (\mathbf{x}^f - \mathbf{x}^t)^{\mathrm{T}}\mathbf{C}(\mathbf{x}^f - \mathbf{x}^t)$

Observation Impact: $\delta e = e(\mathbf{x}_a^f) - e(\mathbf{x}_b^f)$

...where $\mathbf{C}$ is a norm defined later

Estimation of Observation Impact in a Linear Analysis

- Observation-space estimate (LB04)

$$\delta e \approx \langle \underbrace{\mathbf{K}^{\mathrm{T}}}_{\text{adjoint analysis scheme}}\mathbf{g}, \underbrace{\mathbf{d}}_{\text{innovations (O-F departures)}} \rangle$$

where $$\mathbf{g} = \mathbf{M}_b^{\mathrm{T}}\mathbf{C}\left(\mathbf{x}_b^f - \mathbf{x}^t\right) + \mathbf{M}_a^{\mathrm{T}}\mathbf{C}\left(\mathbf{x}_a^f - \mathbf{x}^t\right)$$

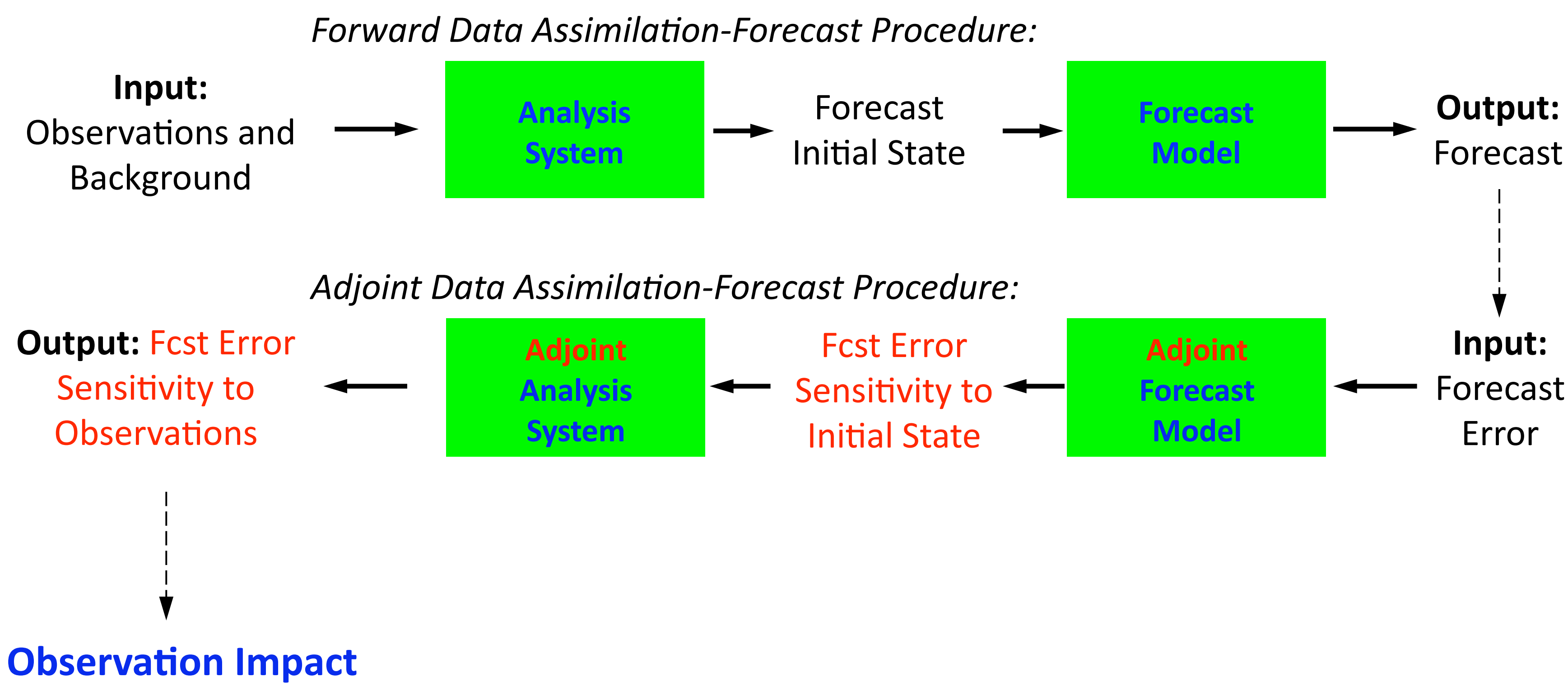
adjoint forecast model

- Impact computed for all observations <u>simultaneously</u>

- The impact of any subset of observations, $\boldsymbol{S}$, can be easily quantified using a partial sum

$$\delta e_S \approx \sum_{i \in S} (\mathbf{K}^{\mathrm{T}}\mathbf{g})_i \mathbf{d}_i$$

Schematic Forward and Adjoint Data Assimilation Systems



Some Differences Between the Adjoint Method and OSEs

ADJ: measures the impacts of observations in the context of all other observations present in the assimilation system

OSE: removal of observations changes or degrades the system… assimilation system differs for each experiment

❖

ADJ: measures the impact of observations in each analysis cycle separately and against the control background

OSE: measures the impact of removing information from both the background and analysis in a cumulative manner

❖

ADJ: measures the response of a single (short-range) forecast metric to all perturbations of the observing system

OSE: measures the effect of a single perturbation on all forecast metrics

methods compared in Gelaro and Zhu (Tellus, 2009)

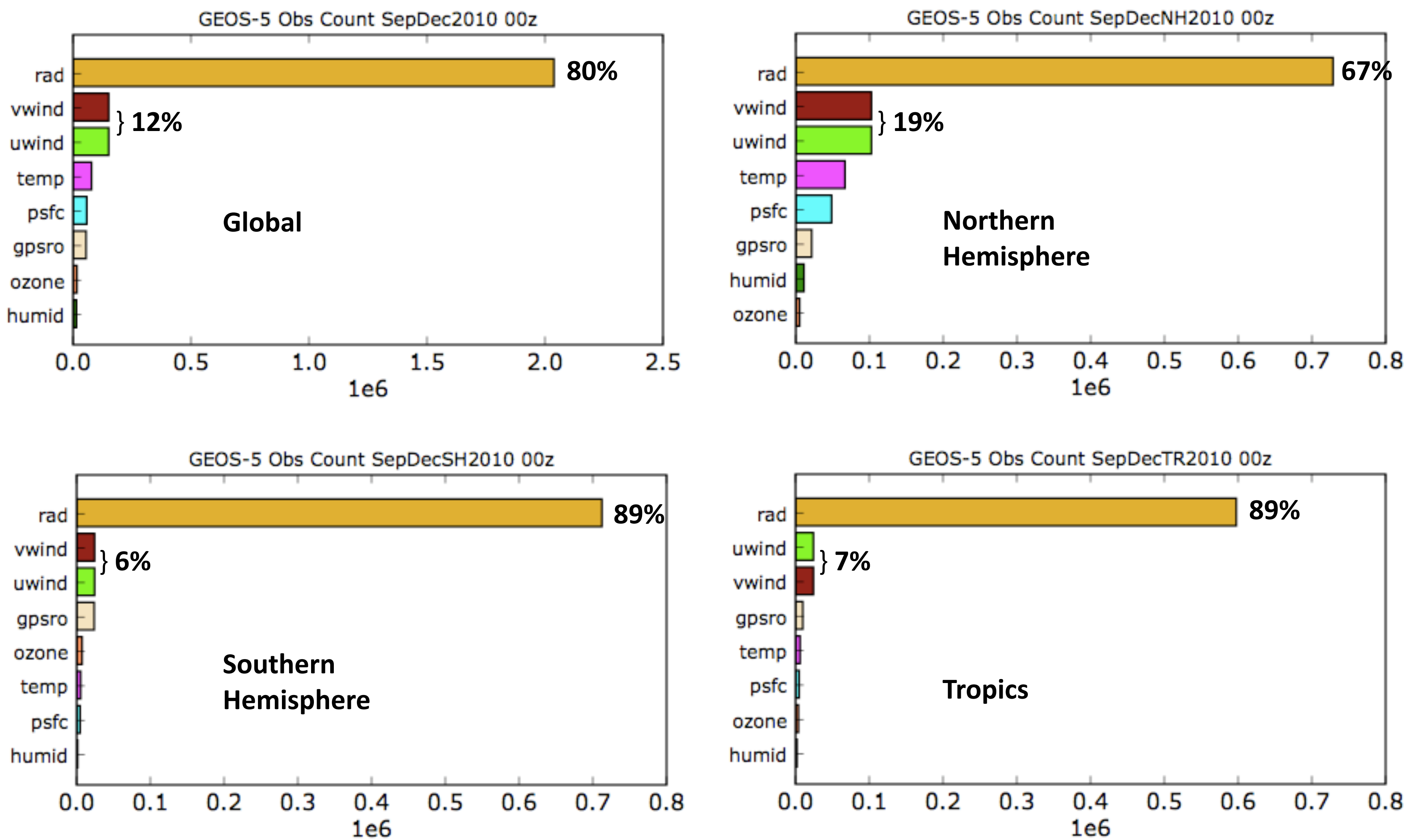
Results Shown

- 01 Sep – 31 Dec 2010 (averages for 00z)
- ~2.5 million obs/6-h assimilated, includes
  - 5 AMSU-A
  - 5 HIRS-3/4
  - AIRS
  - IASI
  - 5-7 GPSRO
  - Satellite Winds (AMVs)
  - Conventional
- Observation Impact
  - **Global 24-h forecast error measure, sfc-150 hPa**
  - **Dry total energy norm*** (u, v, T, $p_s \rightarrow$ J/kg)
  - **Dry adjoint model physics***

** impacts of moisture observations likely under-represented in current results and should be interpreted with proper caution*

Observation Counts by Data Type and Region

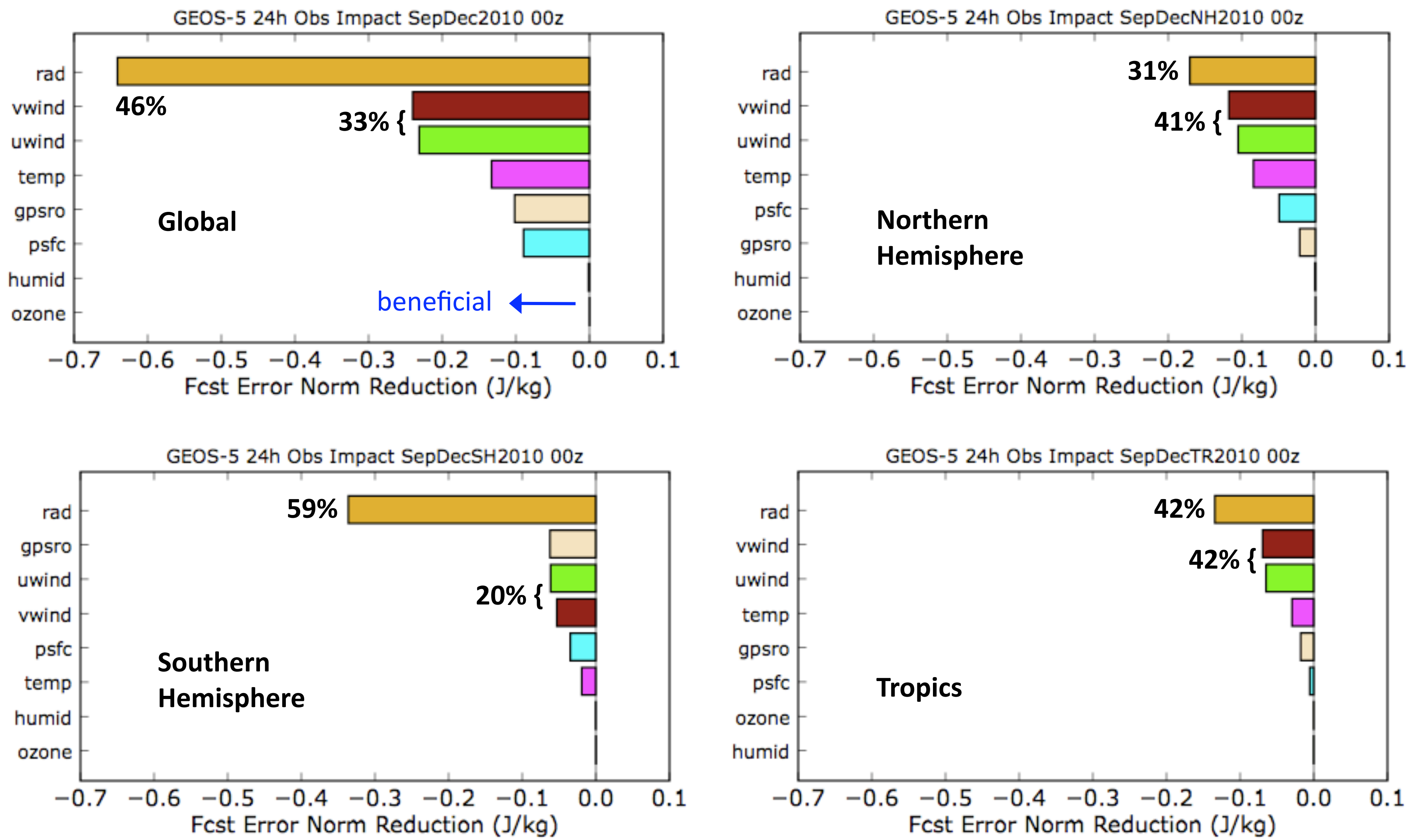
01 Sep – 31 Dec 2010 00z



Radiances are by far the dominant data type (in terms of number) in all regions

Observation Impacts by Data Type and Region

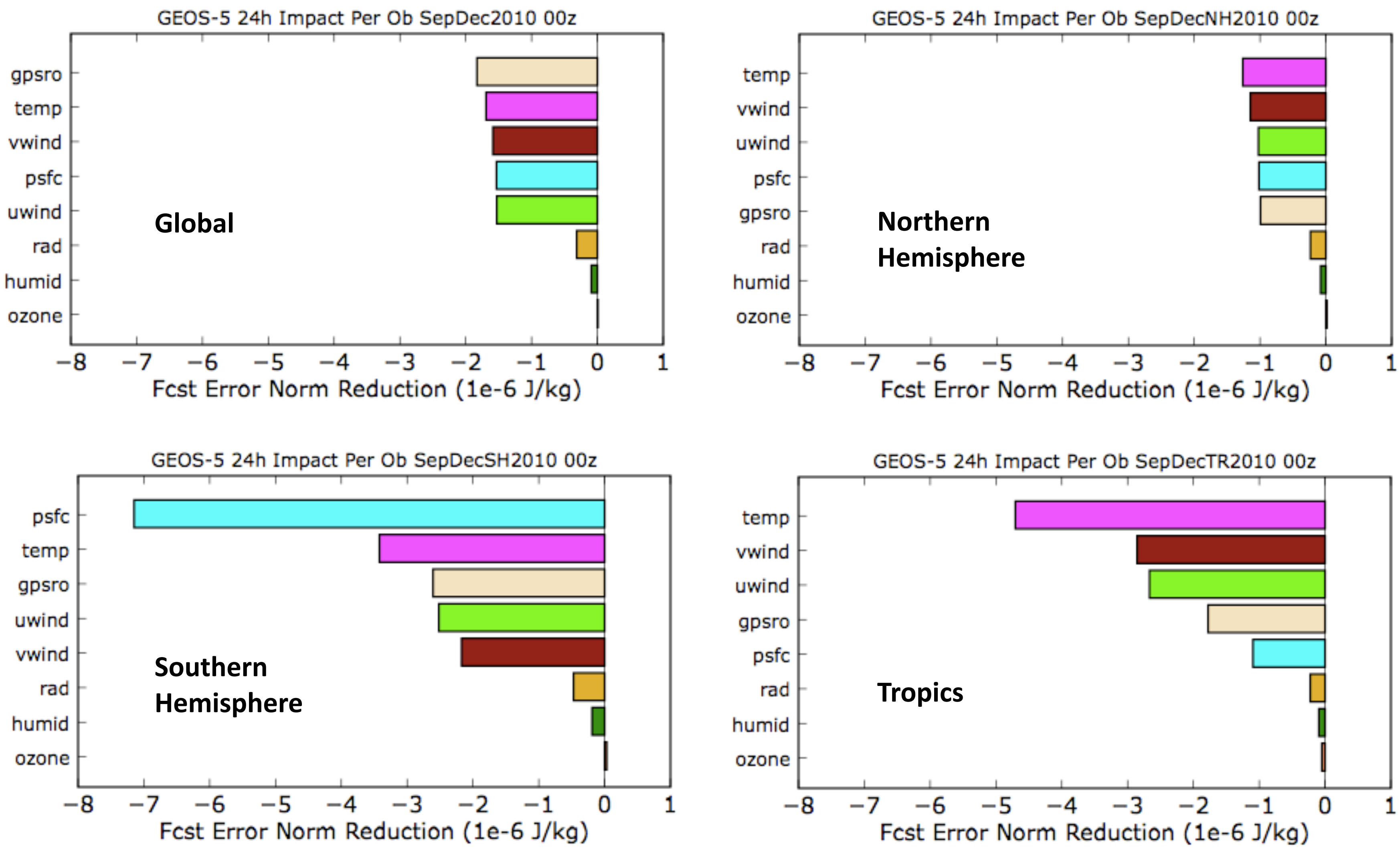
01 Sep – 31 Dec 2010 00z



Wind (and other conventional) data have much larger impact proportionately than do radiances

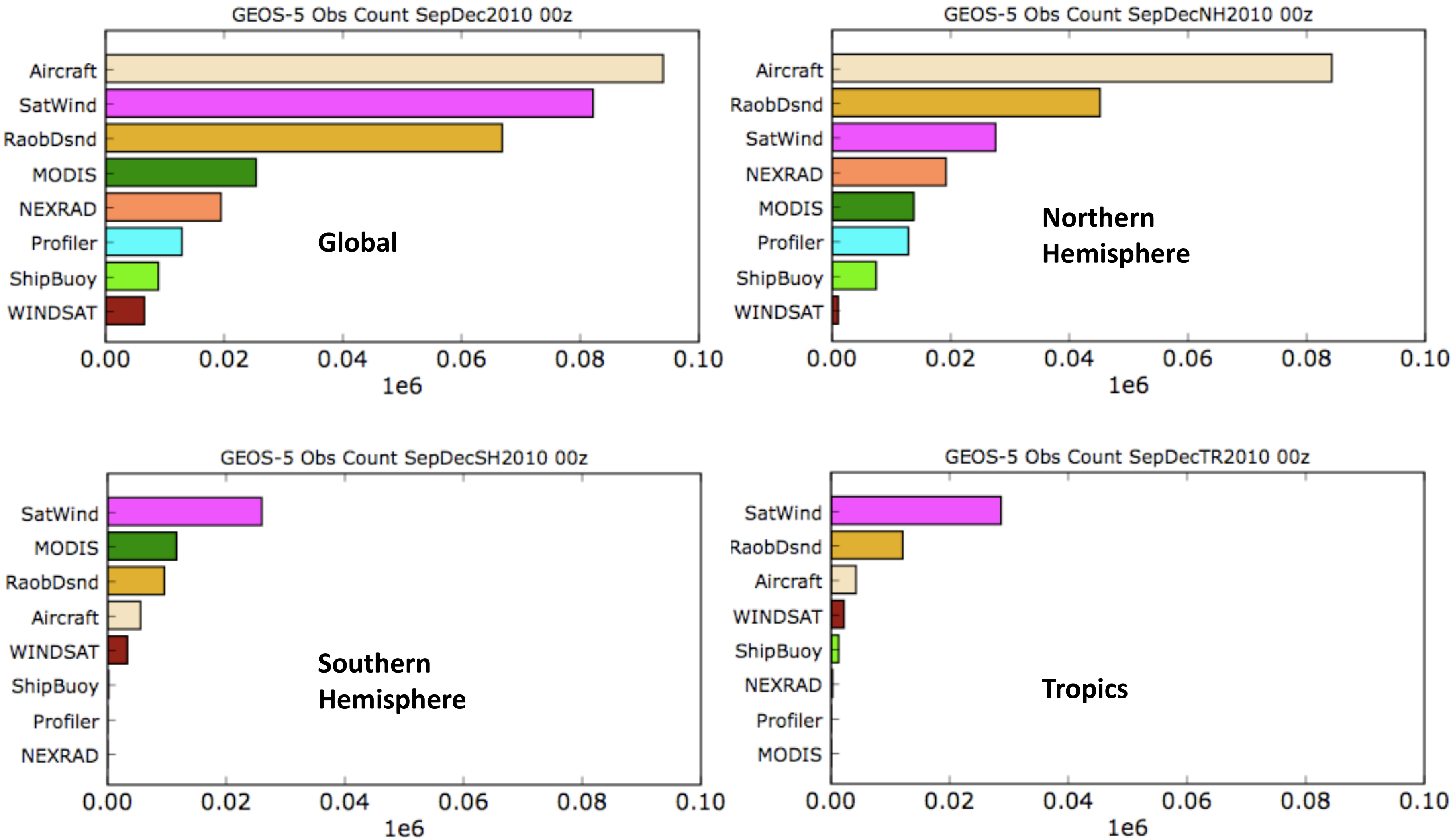
Impact per Observation by Data Type and Region

01 Sep – 31 Dec 2010 00z



Wind Observation Counts* by Instrument and Region

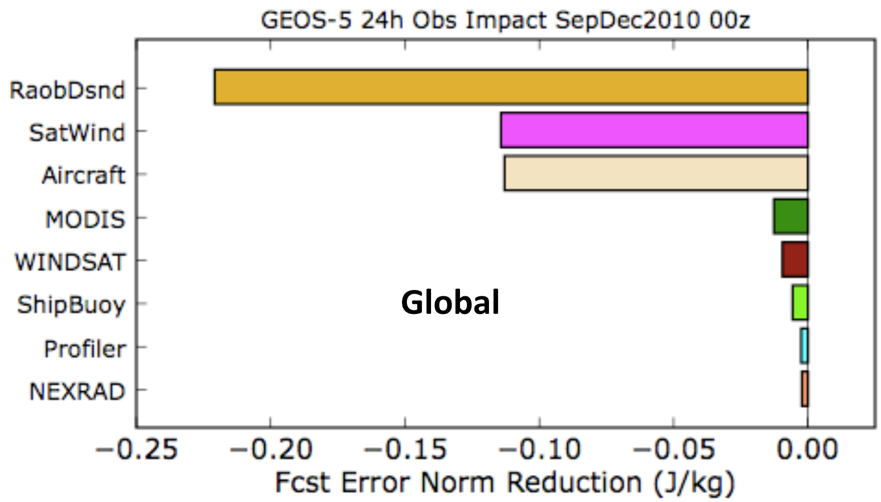
01 Sep – 31 Dec 2010 00z

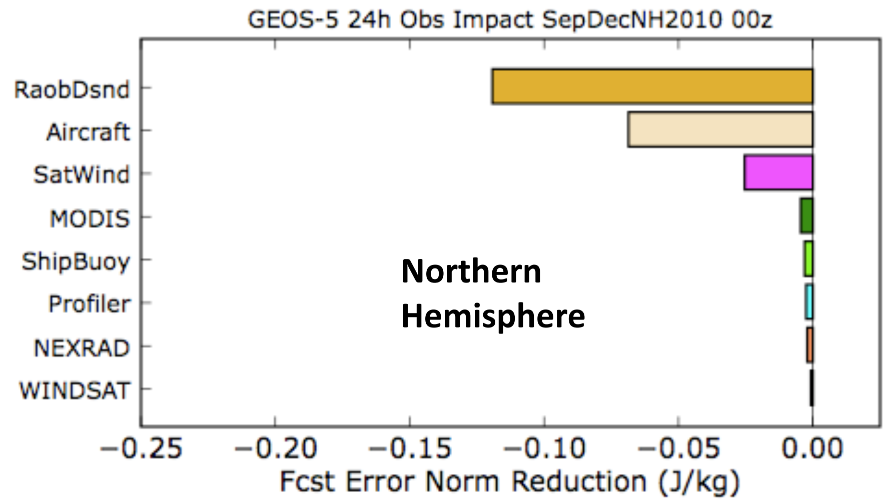


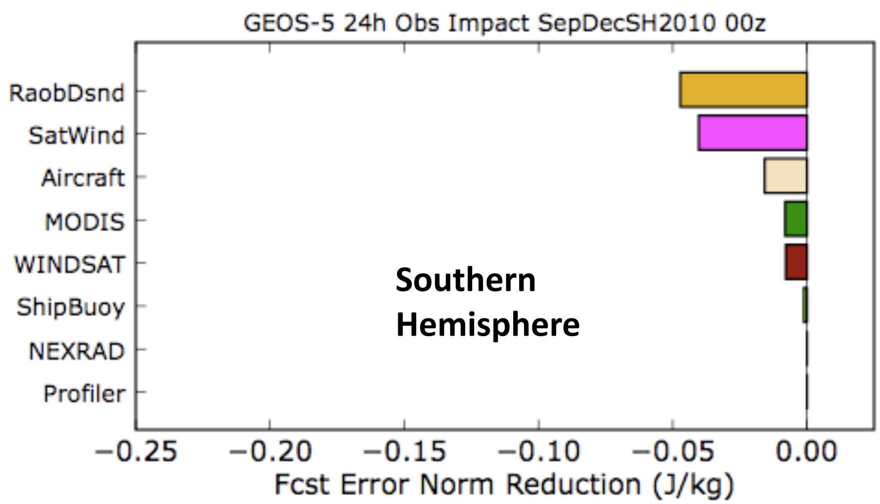
*Recall that together these data represent only 12% (globally) of the total observations used

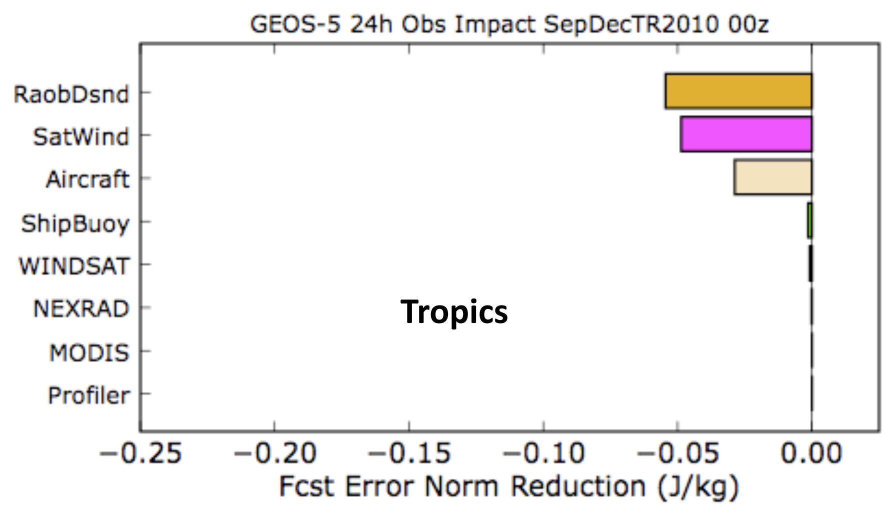
Wind Observation Impacts by Instrument and Region

01 Sep – 31 Dec 2010 00z



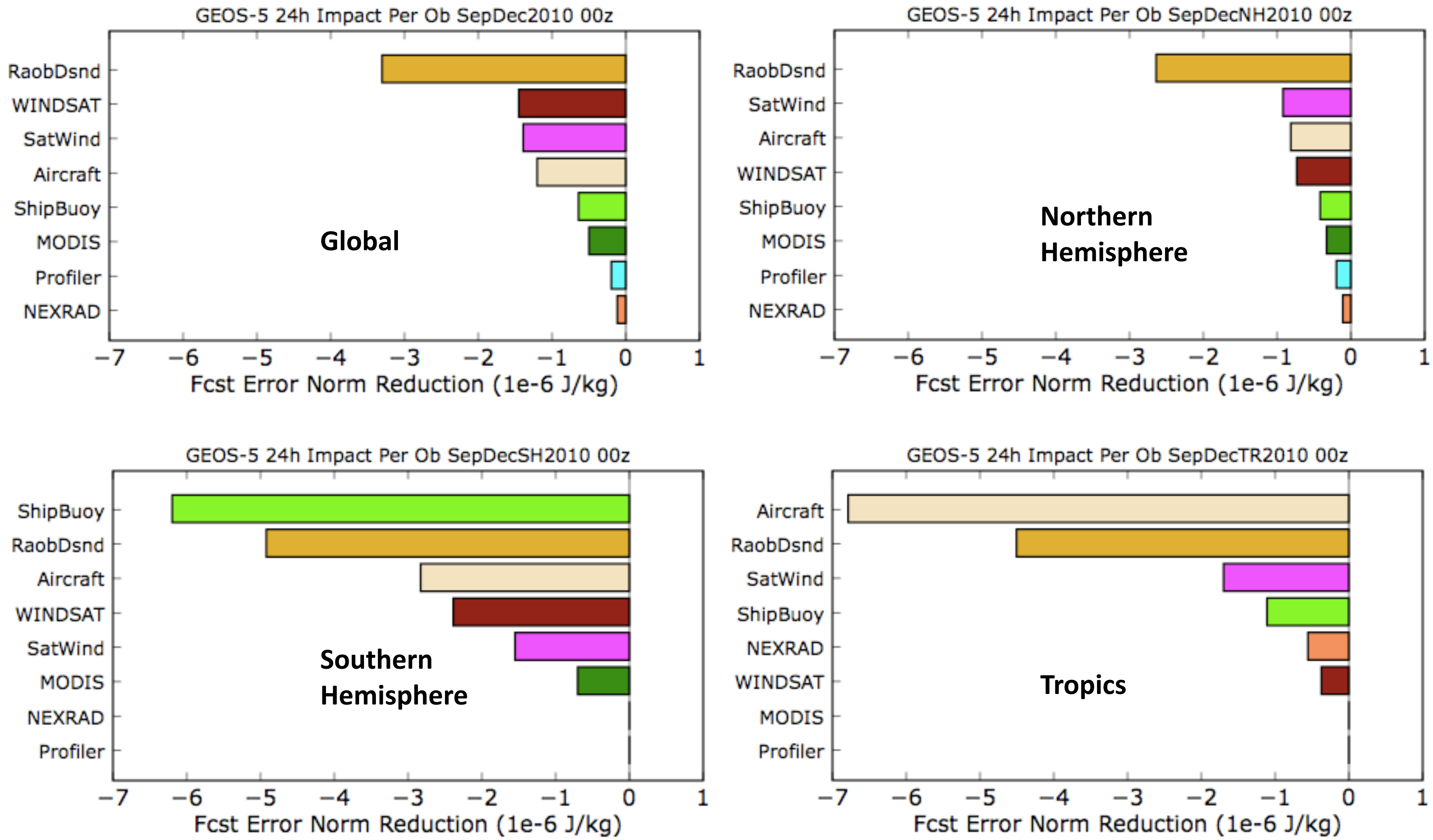






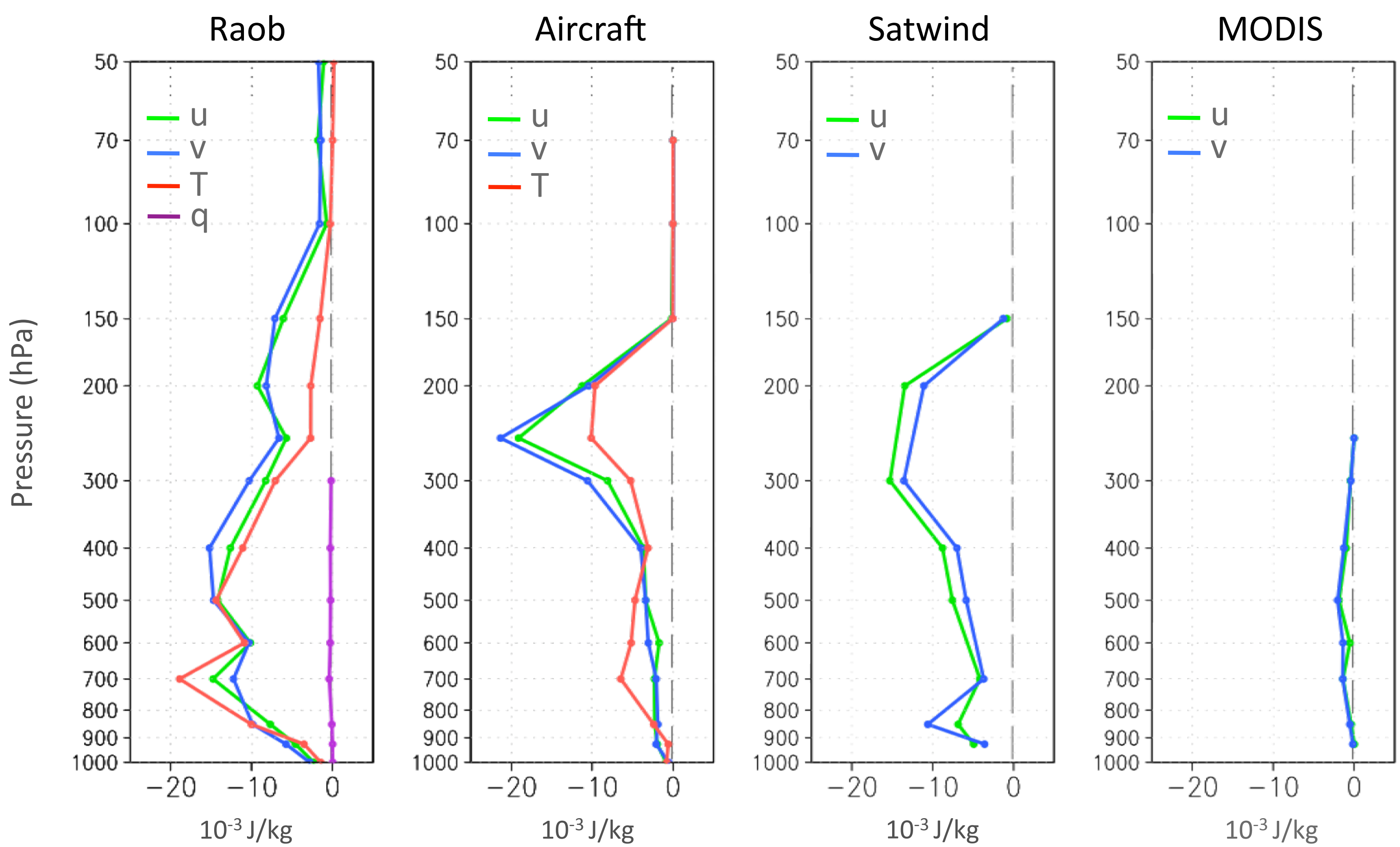
Impact per Wind Observation by Instrument and Region

01 Sep – 31 Dec 2010 00z



Vertical Distribution of Observation Impacts (Global)

01 Sep – 31 Dec 2010 00z

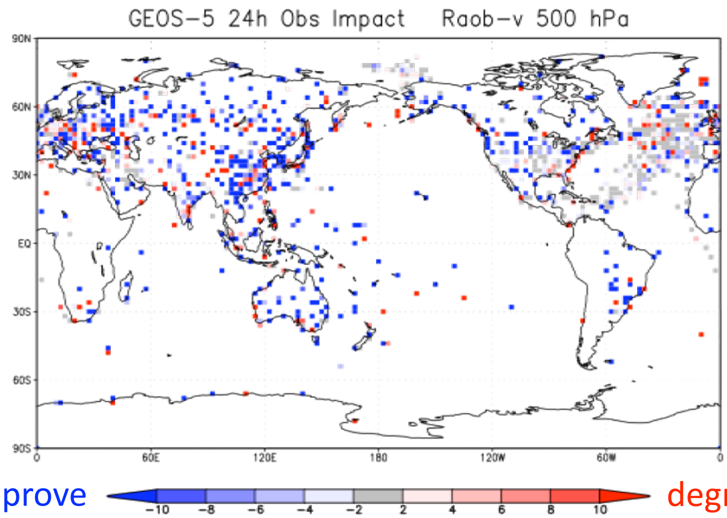


Spatial Patterns of Wind Observation Impacts

01 Sep – 31 Dec 2010 00z

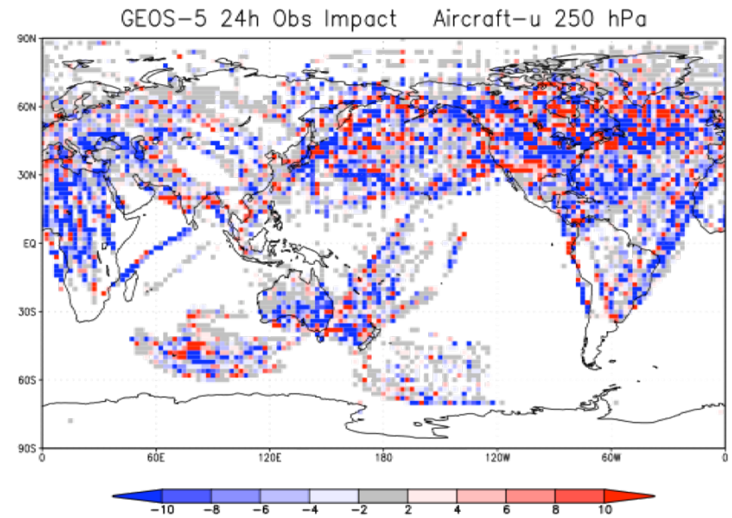
(2° x 2° bins)

Raob
v-500

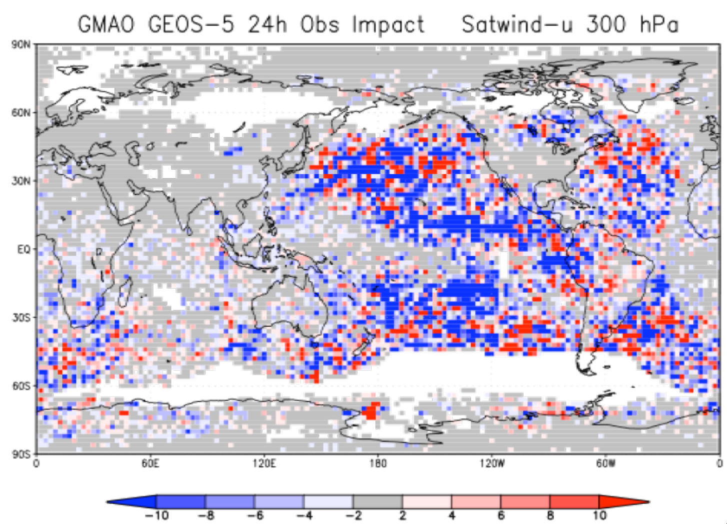


improve degrade

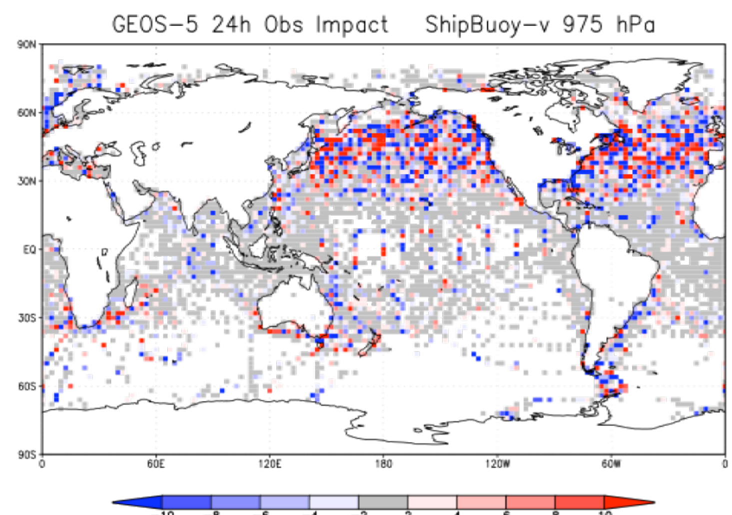
Aircraft
u-250



Satwind
MODIS
u-300



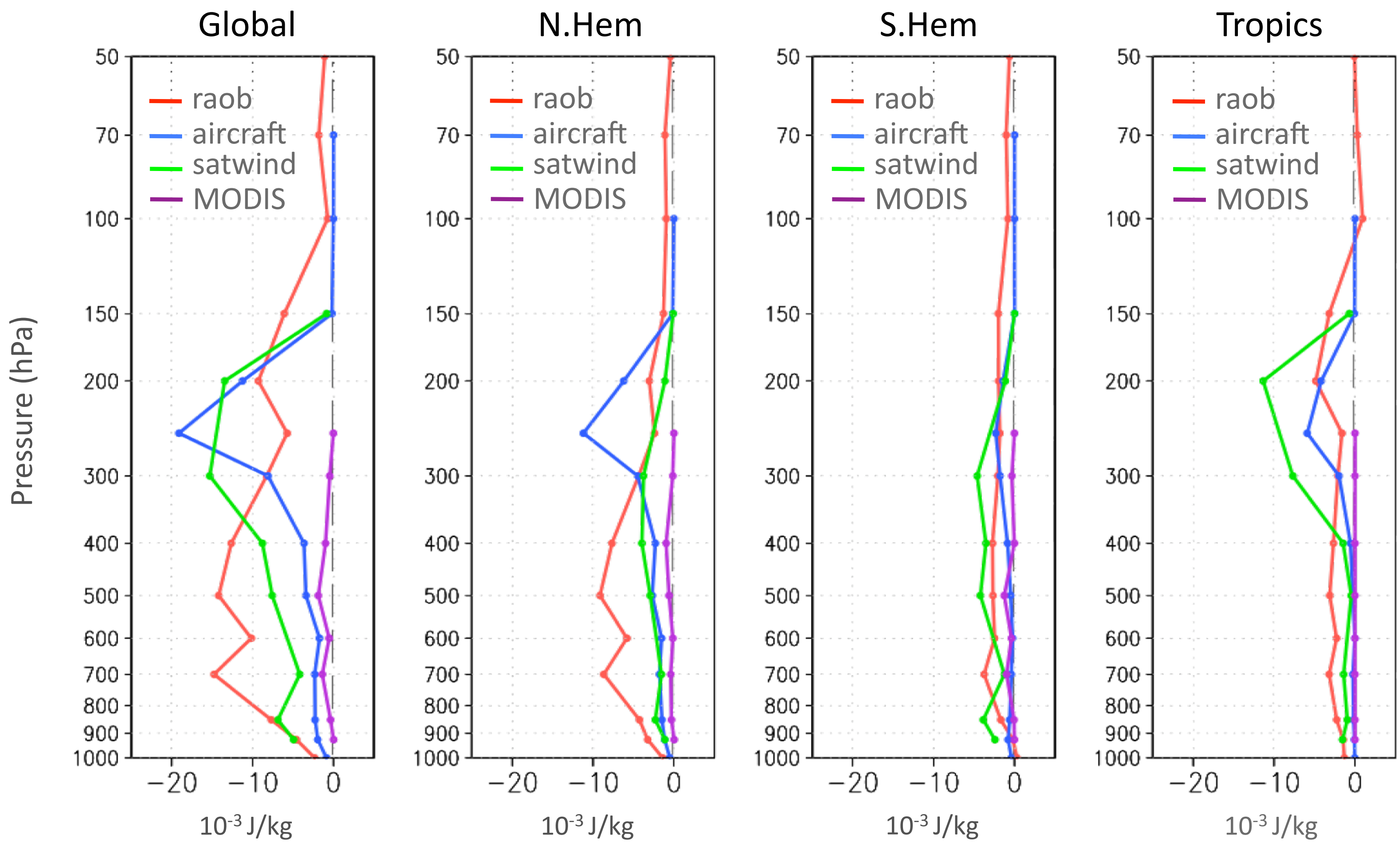
Ships
Buoys
v-975



1e-6 J/kg

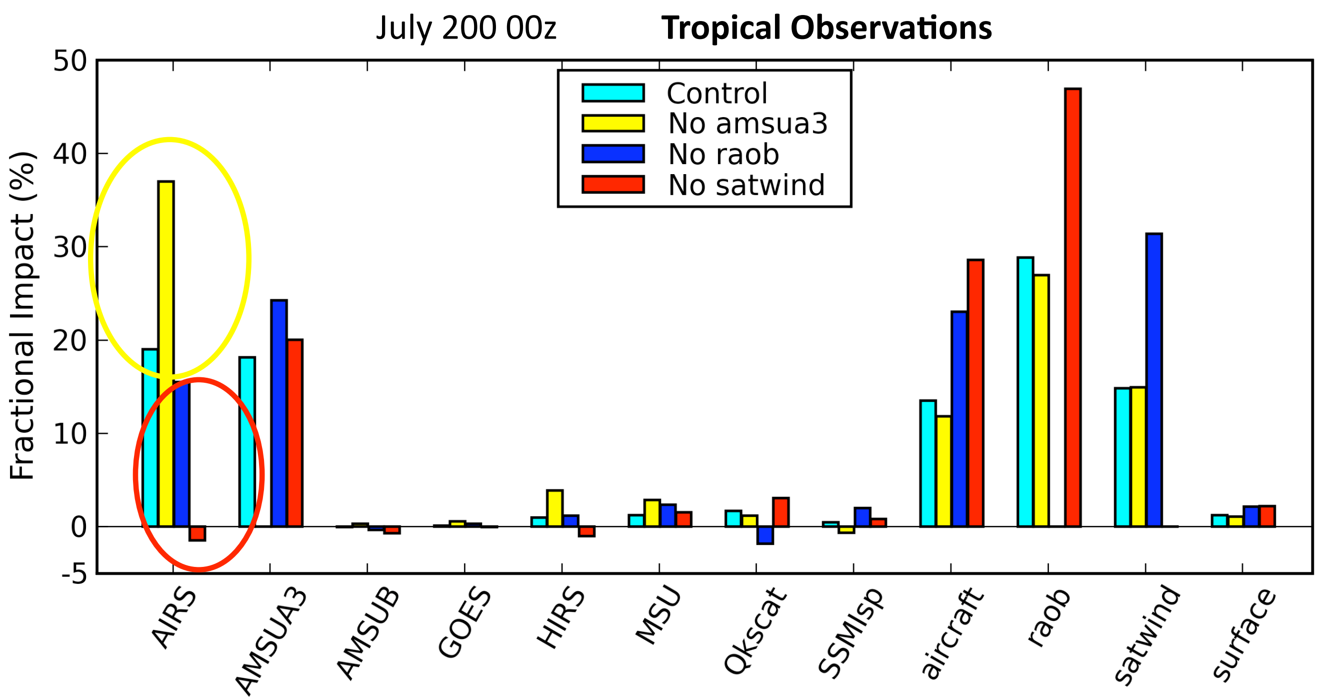
Vertical Distribution of Zonal Wind Observation Impacts by Region

01 Sep – 31 Dec 2010 00z



Changing the 'mix' of observations can change their impacts

Adjoint impacts computed for control and perturbed OSE members



Gelaro and Zhu (*Tellus*, 2009)

- Removal of AMSUA results in large increase in AIRS impact in tropics
- **Removal of wind observations** results in significant **decrease** in AIRS impact in tropics (in fact, AIRS degrades forecast without satwinds!)

Summary

The adjoint of a data assimilation system allows accurate and efficient estimation of the impacts of *all observations simultaneously* on short-range forecasts…well suited for routine monitoring; complement but not replace OSEs

Satellite radiances are by far the most numerous data type in current NWP systems, but winds and other conventional data types have a larger impact proportionately

While they are relatively few in number in the tropics and SH, winds from raobs, aircraft and ships/buoys have large impact per observation

…a niche for wind lidar?

Understanding how the 'mix' of observations affects their impacts appears to be an important consideration for making optimal use of any new observing system