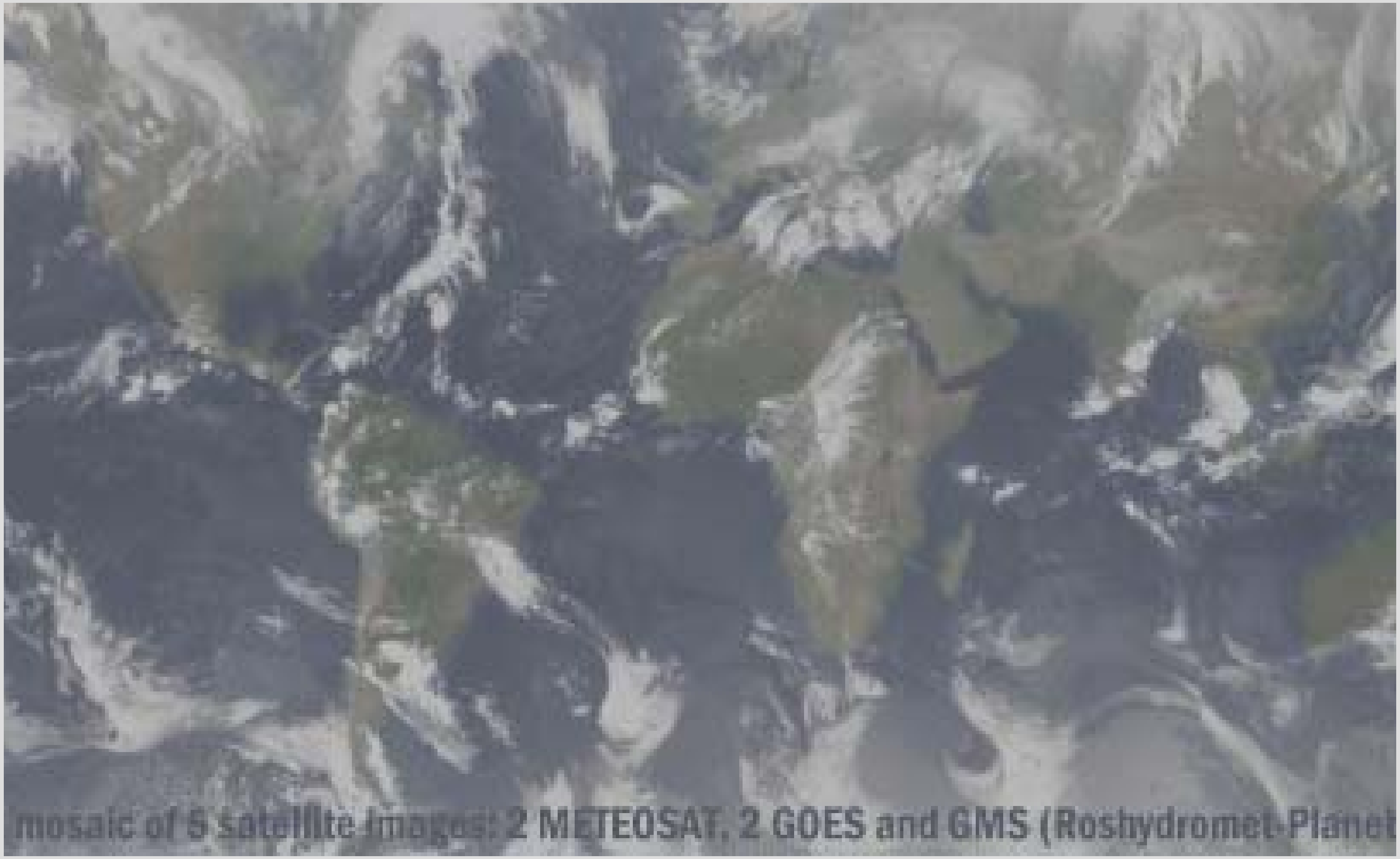
Observation Impact Monitoring for NAVDAS-NOGAPS

20 Sep 2006

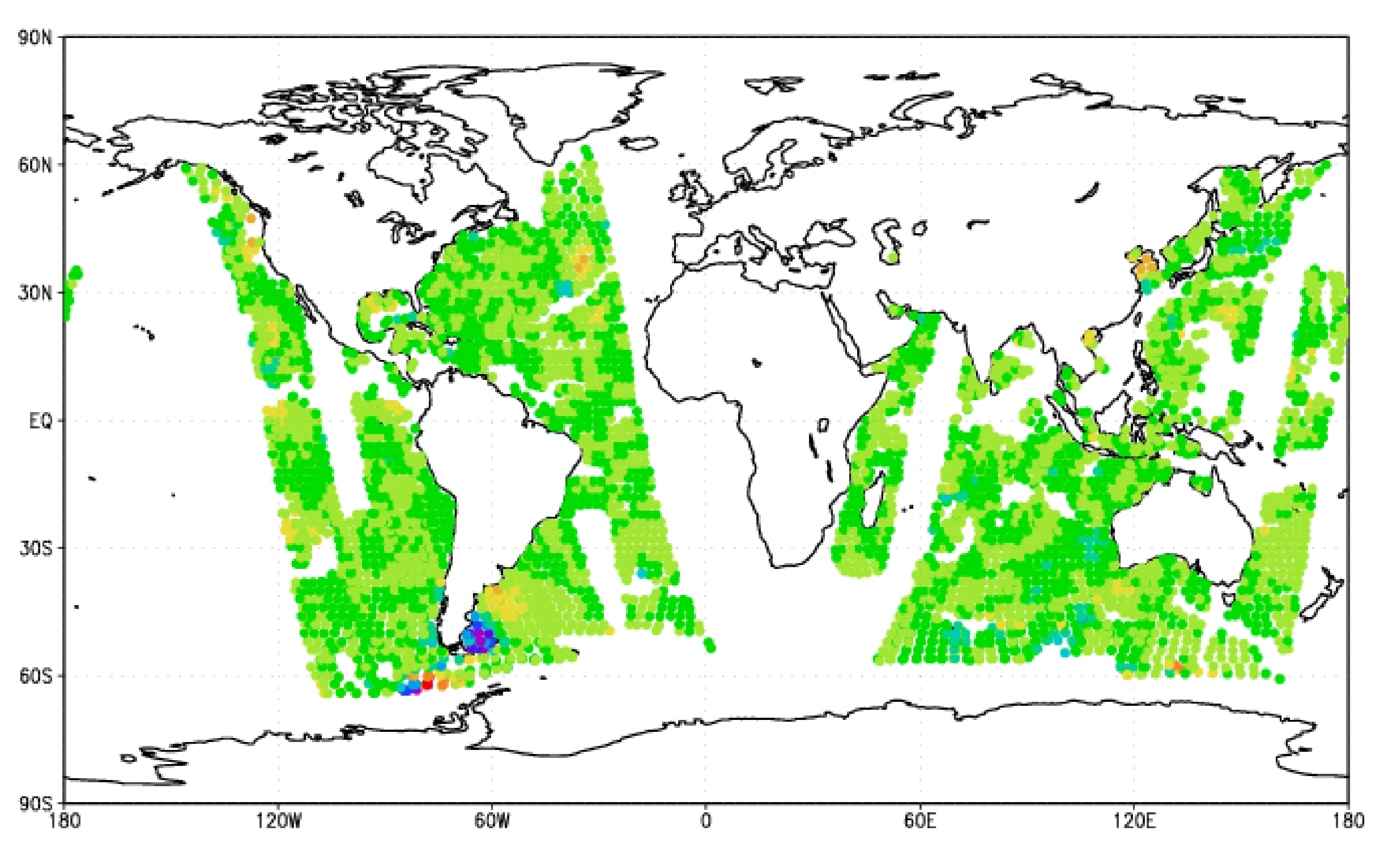


Rolf Langland

Naval Research Laboratory- Monterey, CA

Acknowledgments: Nancy Baker, Randy Pauley

IMPACT OF OBSERVATIONS ON FORECAST ERROR
OBSERVATION DISTRIBUTION



1. Motivation

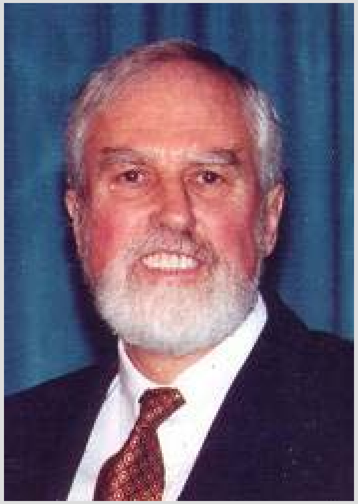
The data volumes entailed by future observing systems will massively increase over the next 10 years … new approaches to ingest, process, monitor, quality control, assimilate and archive the data will have to be developed.

ECMWF 10-year plan, 2006-2015

Observation Sensitivity Equation

NAVDAS adjoint

$$\frac{\partial J}{\partial \mathbf{y}} = [\mathbf{H}\mathbf{P}_\mathrm{b}\mathbf{H}^\mathrm{T} + \mathbf{R}]^{-1}\mathbf{H}\mathbf{P}_\mathrm{b}\frac{\partial J}{\partial \mathbf{x}_\mathrm{a}}$$



The results of targeted observing field programs can be interpreted by extending the adjoint sensitivity vector into observation space --- Roger Daley

Outline of Talk

1. Motivation
2. Methodology: equations and computational steps
3. NAVDAS observation impact results
4. Summary and future work

2. Observation Impact Methodology

- Adjoints of NAVDAS and NOGAPS
- New mathematical technique using adjoint models derived at NRL-Monterey
- Use operational analysis fields and operational innovation vectors of NAVDAS / NOGAPS
- Procedure runs once per day at 00UTC
- Results provided on web page (under development), and in periodic summaries of observation impact

Data Assimilation Equation

ANALYSIS

BACKGROUND (6h) FORECAST

K

$$\mathbf{x}_a - \mathbf{x}_b = \underbrace{\mathbf{P}_b\mathbf{H}^T[\mathbf{H}\mathbf{P}_b\mathbf{H}^T + \mathbf{R}]^{-1}}_{\mathbf{K}}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

OBSERVATIONS

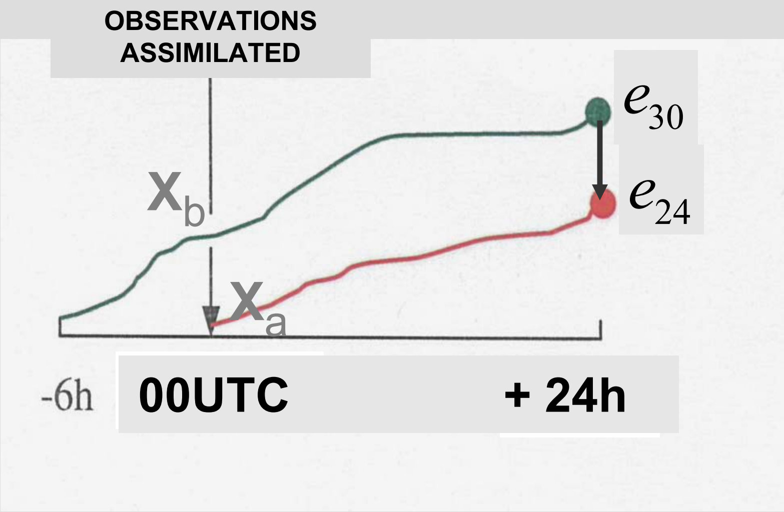
Temperature

Moisture

Winds

Pressure

Observations, model trajectories and forecast error



Observations move the model state from the "**background**" trajectory to the new "**analysis**" trajectory

The forecast error difference, $e_{24} - e_{30}$, is due to the combined impact of all observations assimilated at 00UTC

Energy-weighted forecast error norm (moist TE-norm)

$$e_f = \left\langle \left(\mathbf{x}_\mathrm{f} - \mathbf{x}_\mathrm{t}\right)^T, \mathbf{C}\left(\mathbf{x}_\mathrm{f} - \mathbf{x}_\mathrm{t}\right) \right\rangle$$

C = matrix of energy-weighting coefficients

f = NOGAPS forecast

t = verifying NAVDAS / NOGAPS analysis

x = NOGAPS state vector $\left(\mathrm{u, v, \theta, q, p_t}\right)$

e_f has units of J kg^{-1}

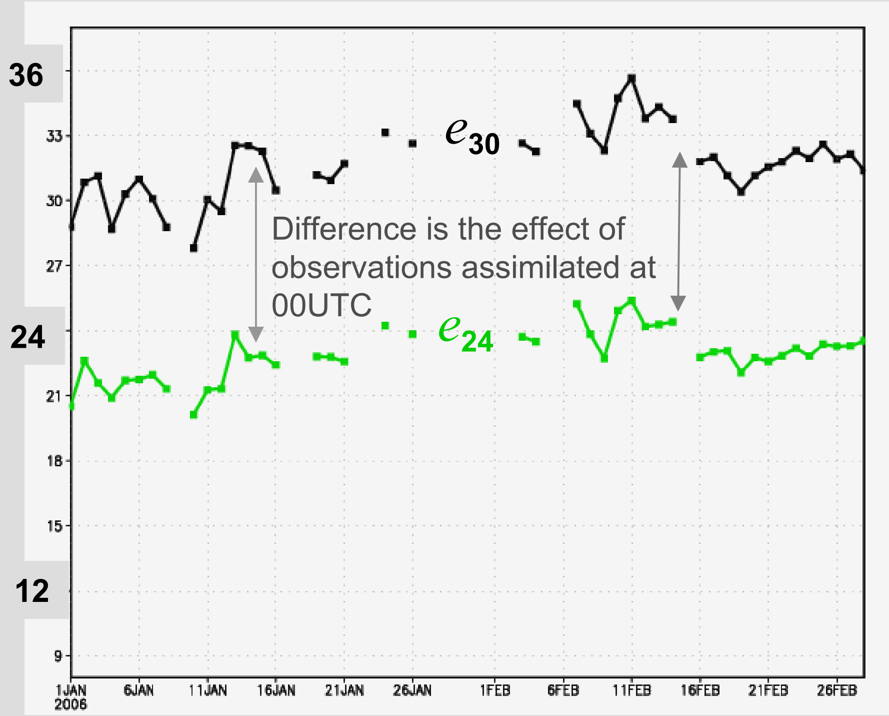
$\langle \;,\; \rangle$ = scalar inner product

NOGAPS moist error-norms: global domain

Units of e-norm = J kg^{-1}

30h forecast from 18UTC (background trajectory)

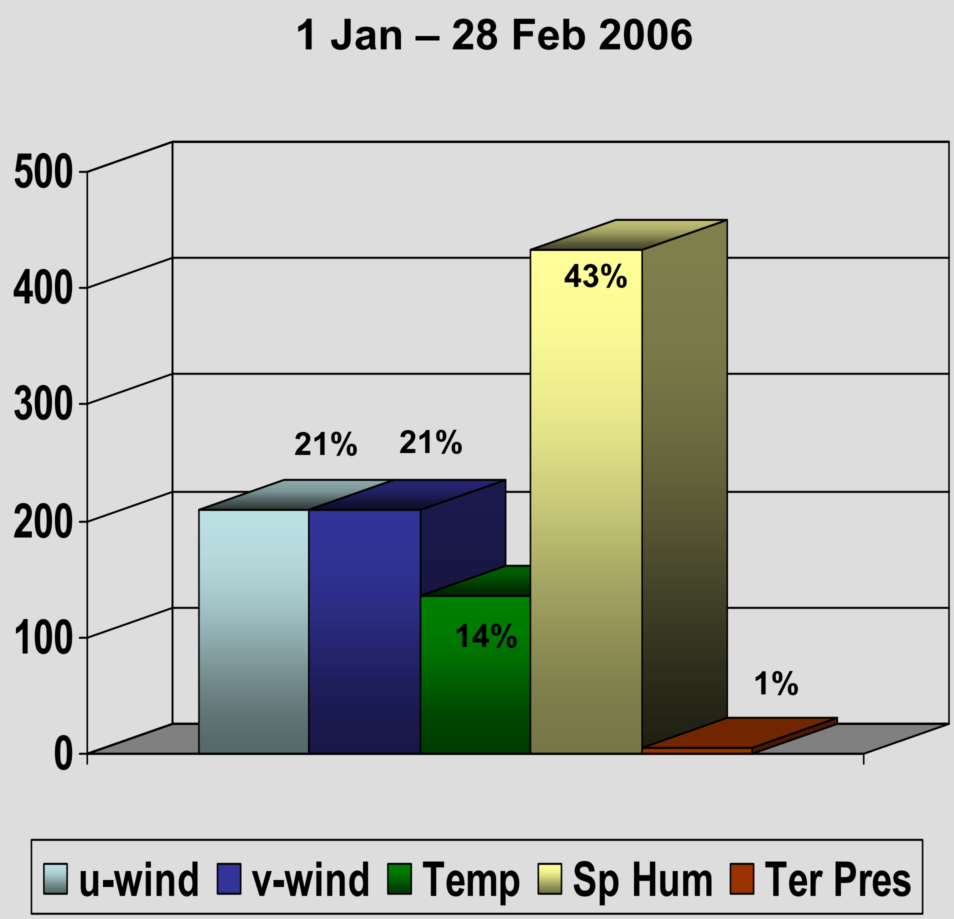
24h forecast from 00UTC (analysis trajectory)



1 Jan – 28 Feb 2006

Contributions to NOGAPS moist error norm e_{24}

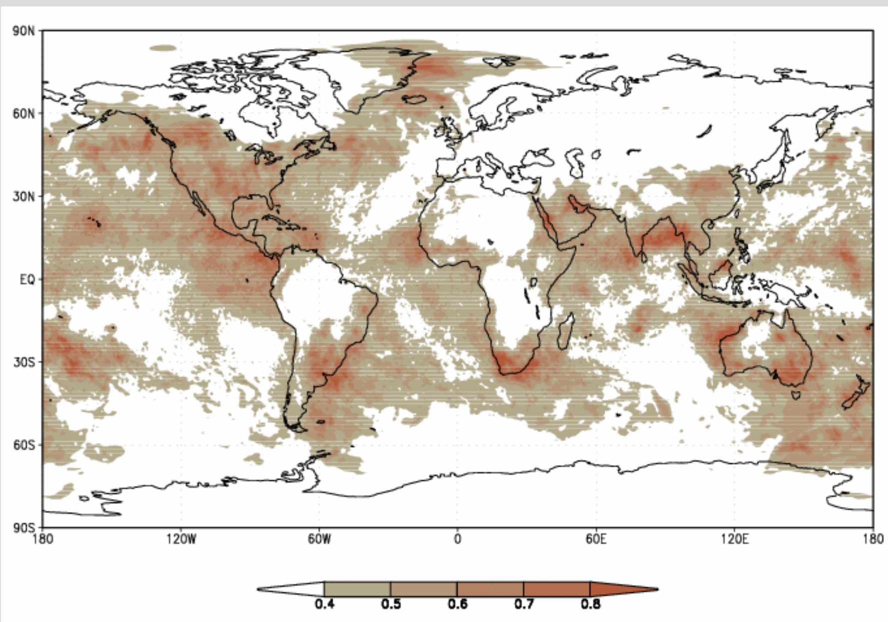
Units of e-norm = J kg^{-1}



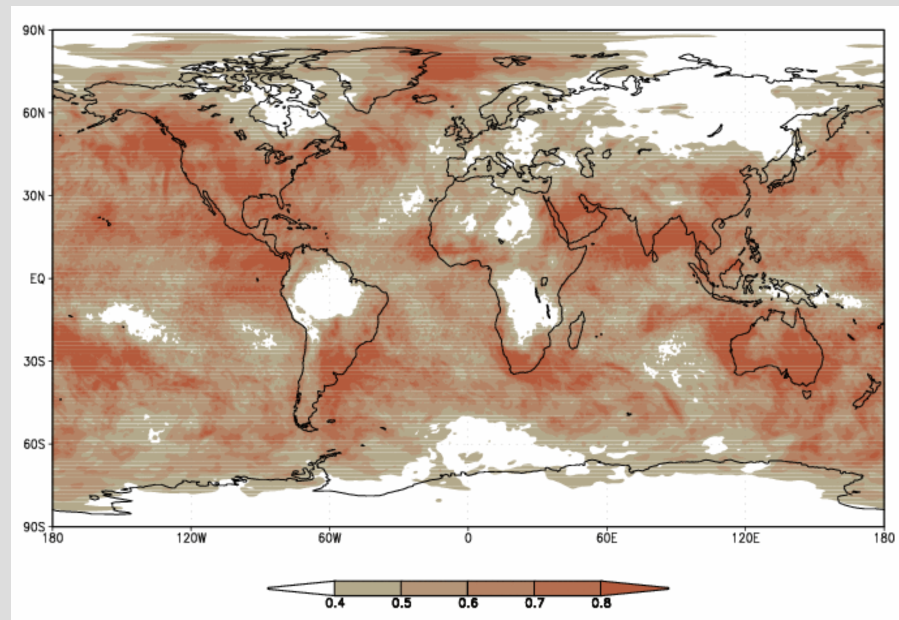
NOGAPS: e-weighted forecast error

1 Jan – 28 Feb 2006

Forecast error e_{24} (00UTC initial conditions)



Forecast error e_{30} (18UTC initial conditions)

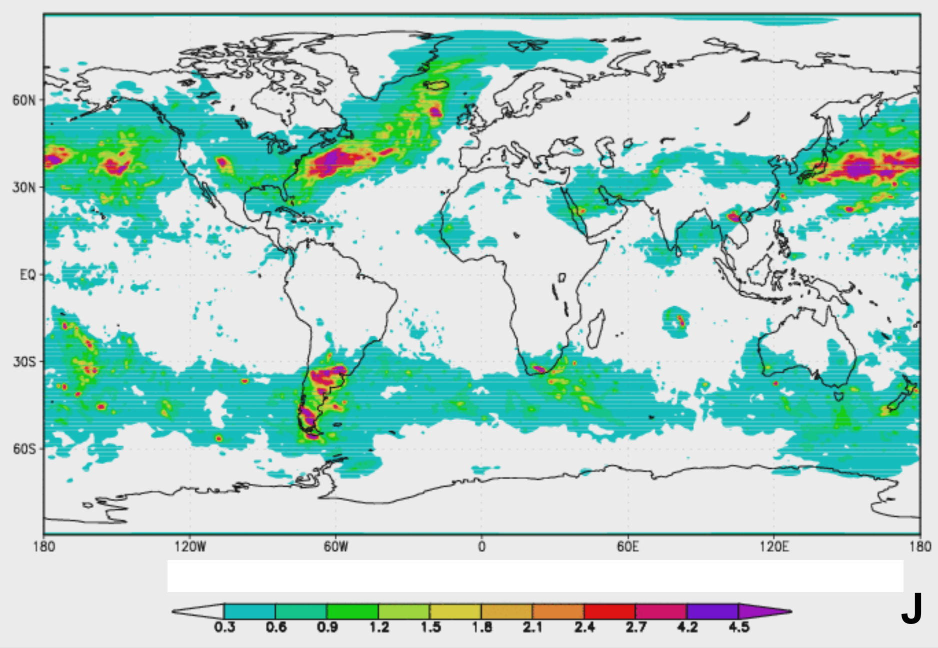


10^{-2} J kg^{-1}

NOGAPS: sensitivity of forecast error to ICs

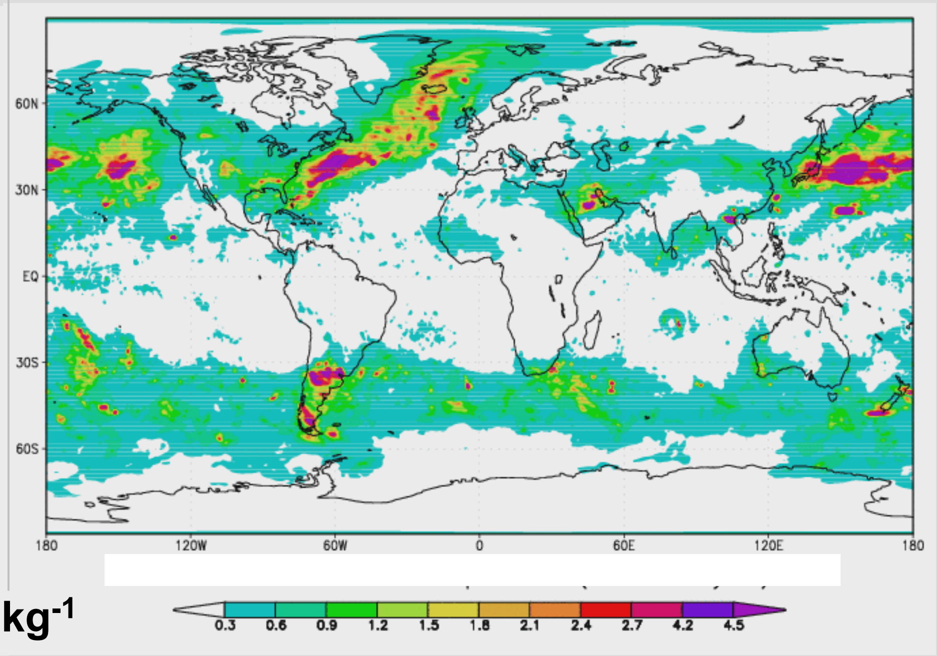
1 Jan – 28 Feb 2006

Energy-weighted sensitivity of e_{24} to x_a 00UTC



J kg^{-1}

Energy-weighted sensitivity of e_{30} to x_b 18UTC



Steps in observation impact calculation -

NAVDAS analysis and background

FNMOC ops

$$\mathbf{x}_{\mathrm{a}}\,(00\mathrm{UTC}),\quad \mathbf{x}_{\mathrm{b}}\,(6h\ \mathrm{fcst\ from\ 18UTC})$$

NOGAPS forecasts & error norms

T239L30, full physics

$$\left\{\begin{array}{l}\mathbf{x}_{24} = M(\mathbf{x}_{\mathrm{a}}) \\ \mathbf{x}_{30} = M(\mathbf{x}_{\mathrm{b}})\end{array}\right.$$

NOGAPS adjoint

T239L30, includes large-scale precip

$$\left\{\begin{array}{l}\partial e_{24} / \partial \mathbf{x}_{\mathrm{a}} = \mathbf{L}^T \left[\mathrm{C}\left(\mathbf{x}_{24} - \mathbf{x}_{\mathrm{t}} \right) \right] \\ \partial e_{30} / \partial \mathbf{x}_{\mathrm{b}} = \mathbf{L}^T \left[\mathrm{C}\left(\mathbf{x}_{30} - \mathbf{x}_{\mathrm{t}} \right) \right]\end{array}\right.$$

Forecast errors

Sensitivity gradients in model grid-point space

Steps in observation impact calculation -

Sensitivity gradient in observation space

NAVDAS adjoint

0.5 deg, current to ops version of NAVDAS

$$\frac{\partial(e_{24}-e_{30})}{\partial(\mathbf{y}-\mathbf{H}\mathbf{x}_\mathrm{b})}=\mathbf{K}^T\left[\frac{\partial e_{24}}{\partial \mathbf{x}_\mathrm{a}}+\frac{\partial e_{30}}{\partial \mathbf{x}_\mathrm{b}}\right]$$

Observation Impact

(J kg^{-1})

$$\delta e_{24}^{30}=\left\langle(\mathbf{y}-\mathbf{H}\mathbf{x}_\mathrm{b}),\frac{\partial(e_{24}-e_{30})}{\partial(\mathbf{y}-\mathbf{H}\mathbf{x}_\mathrm{b})}\right\rangle$$

Innovations assimilated for Xa

Langland and Baker (Tellus, 2004)

Observation impact interpretation -

For any observation / innovation … using this error measure

$\delta e_{24}^{30} < \mathbf{0.0}$ **the observation is BENEFICIAL**

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 $\mathbf{x_b}$, e.g. forecast error decrease

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$\delta e_{24}^{30} > \mathbf{0.0}$ **the observation is NON-BENEFICIAL**

e.g., forecast error increase

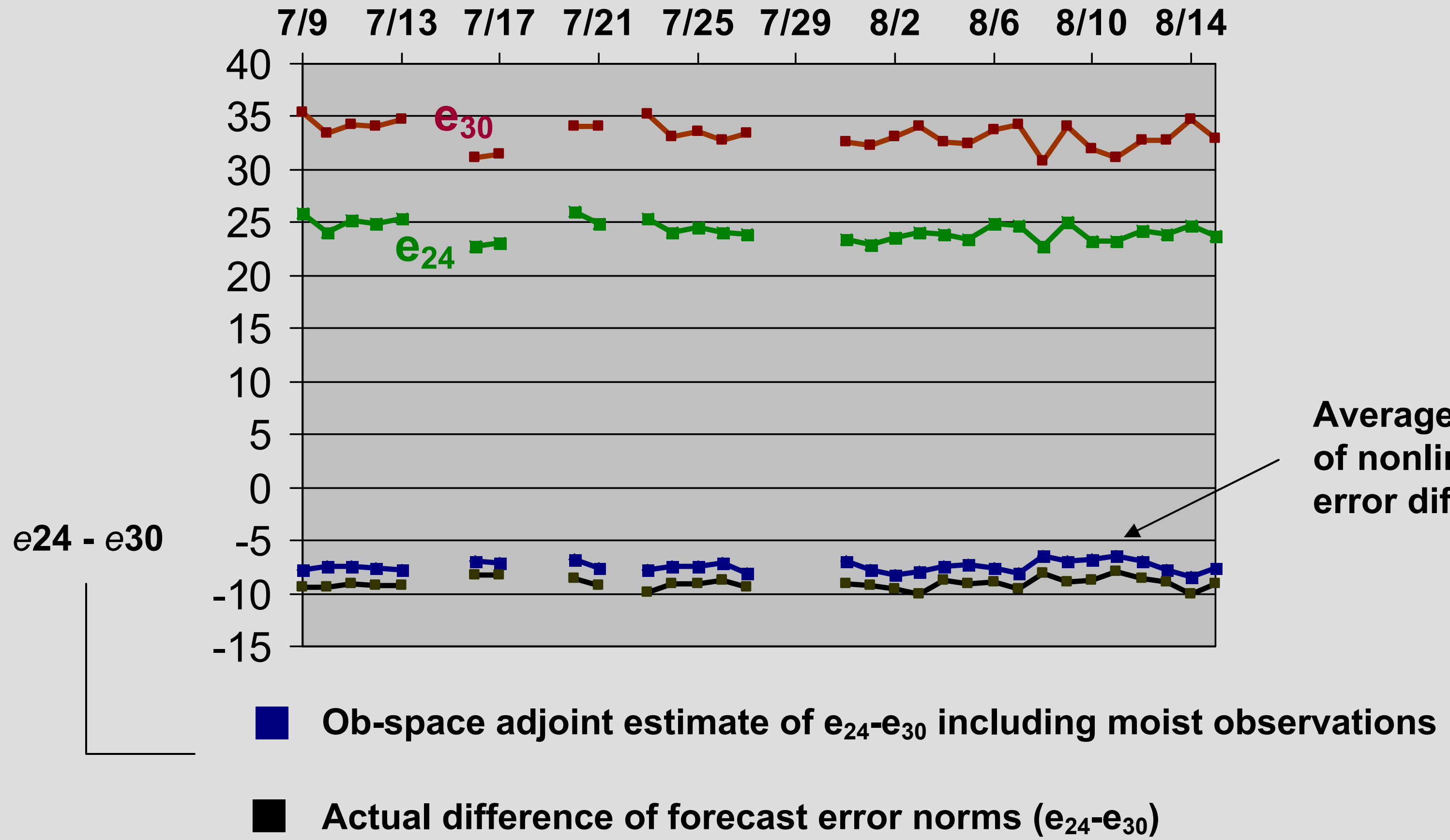
Observation impact interpretation

When summed over the entire innovation vector including *n* observations…

$$\sum_n \delta e_{24}^{30}$$ **is an approximation of** $e_{24} - e_{30}$

Adjoint-based estimate of observation impact

Units of e-norm = J kg^{-1} 2006



Accuracy is improved by using two trajectories

The technique of combining linear adjoint sensitivity gradients on two trajectories (those of X_a and X_b) gives higher than first-order accuracy in the estimation of $e_{24} - e_{30}$

Conventional (one trajectory) adjoint sensitivity estimations have the accuracy of a first-order Taylor series approximation

A possible interpretation “caveat” ….

Note that the gradient $\partial e_{24} / \partial \mathbf{x}_{\mathrm{a}}$ is a function of the analysis, which is produced using all observations…

There may be some ambiguity in the attribution of “impact” to subsets of observations or to individual observations. Our results to date have not shown this to be a significant limitation. (Examples to follow)…

Limitations and assumptions in calculation

- Tangent linear approximation in NOGAPS adjoint
- NOGAPS adjoint simplified physics – convection under development
- Some nonlinearity in NAVDAS operators (SSM/I winds, etc.)
- Classified observations not available for calculation
- Interpolation of sensitivity from NOGAPS grid to NAVDAS grid **

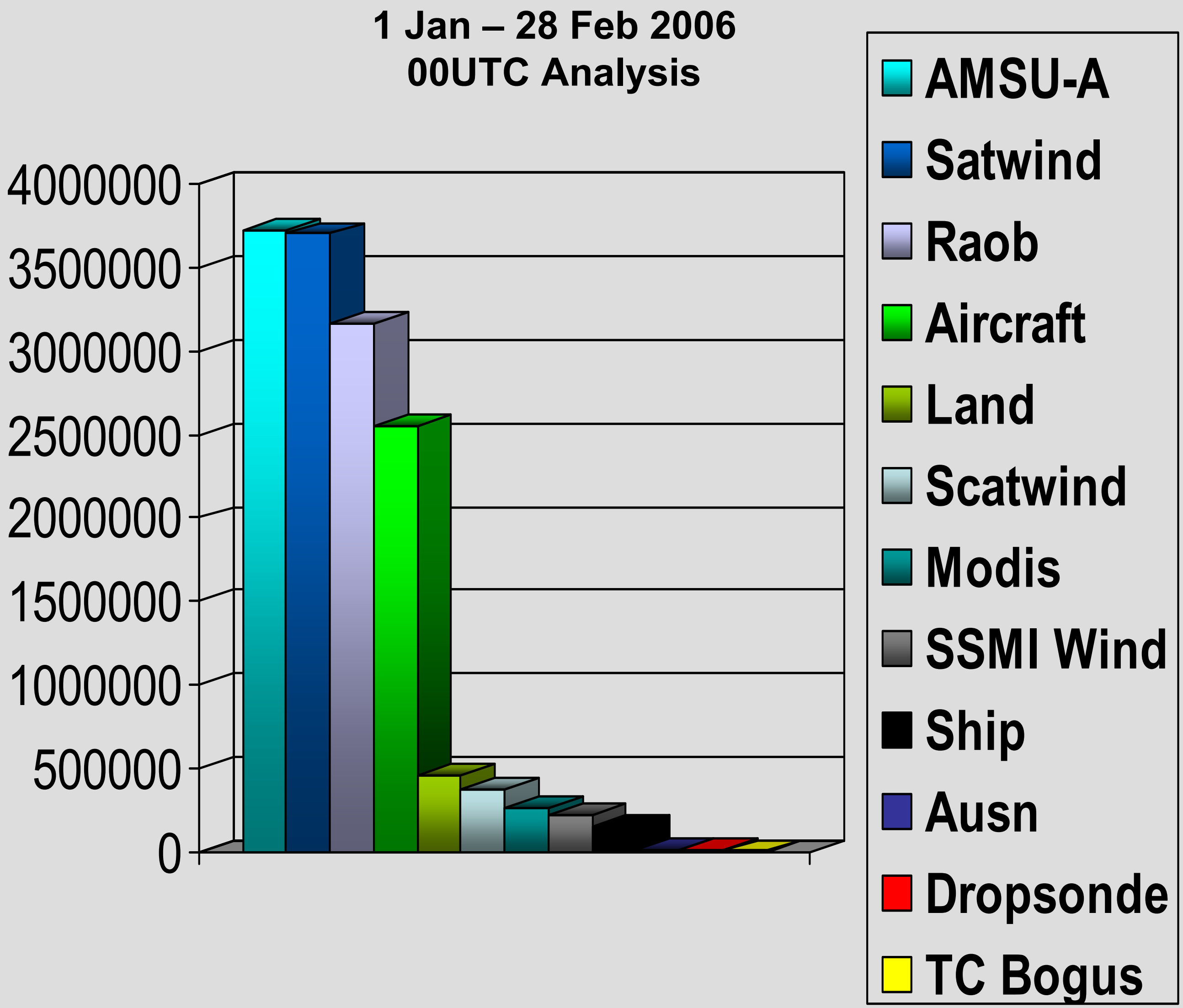
** *NAVDAS-AR corrects this issue*

3. NAVDAS Observation Impact Results

- Summary of results for Jan-Feb 2006

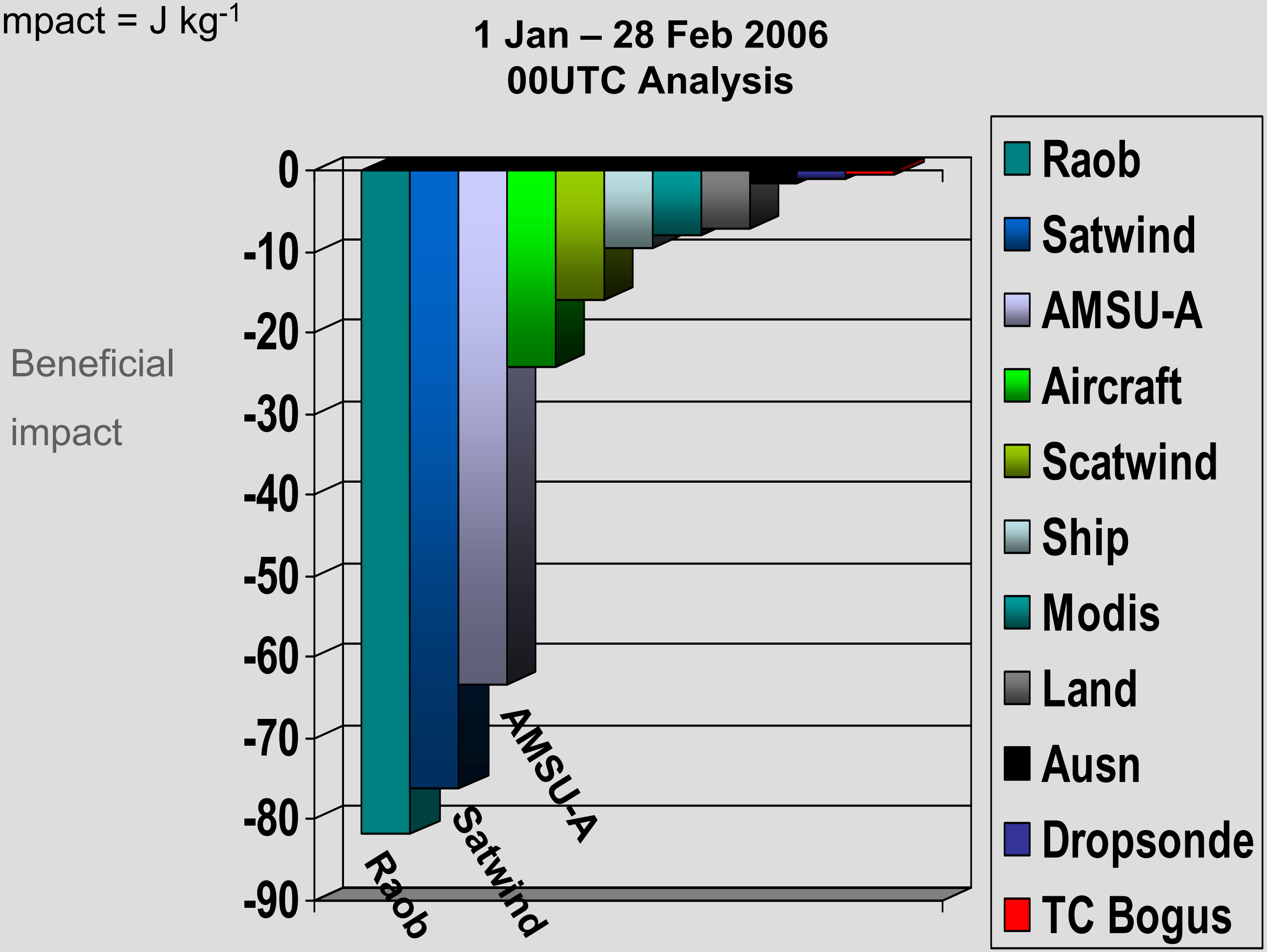
- Examples of data quality / assimilation issues – 2004-2006

Instrument type data count



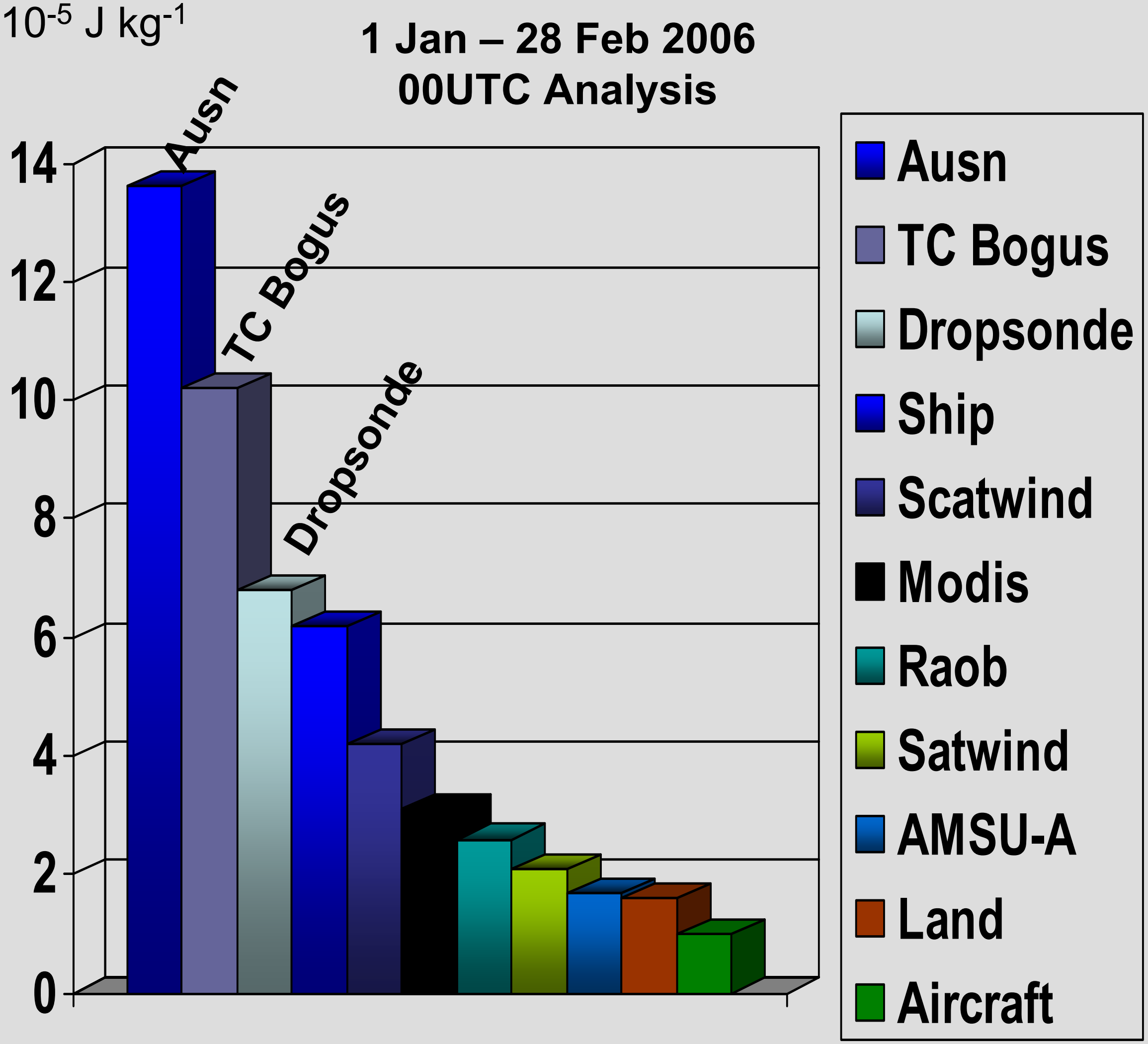
Total impact by observation instrument type

Units of impact = J kg^{-1}

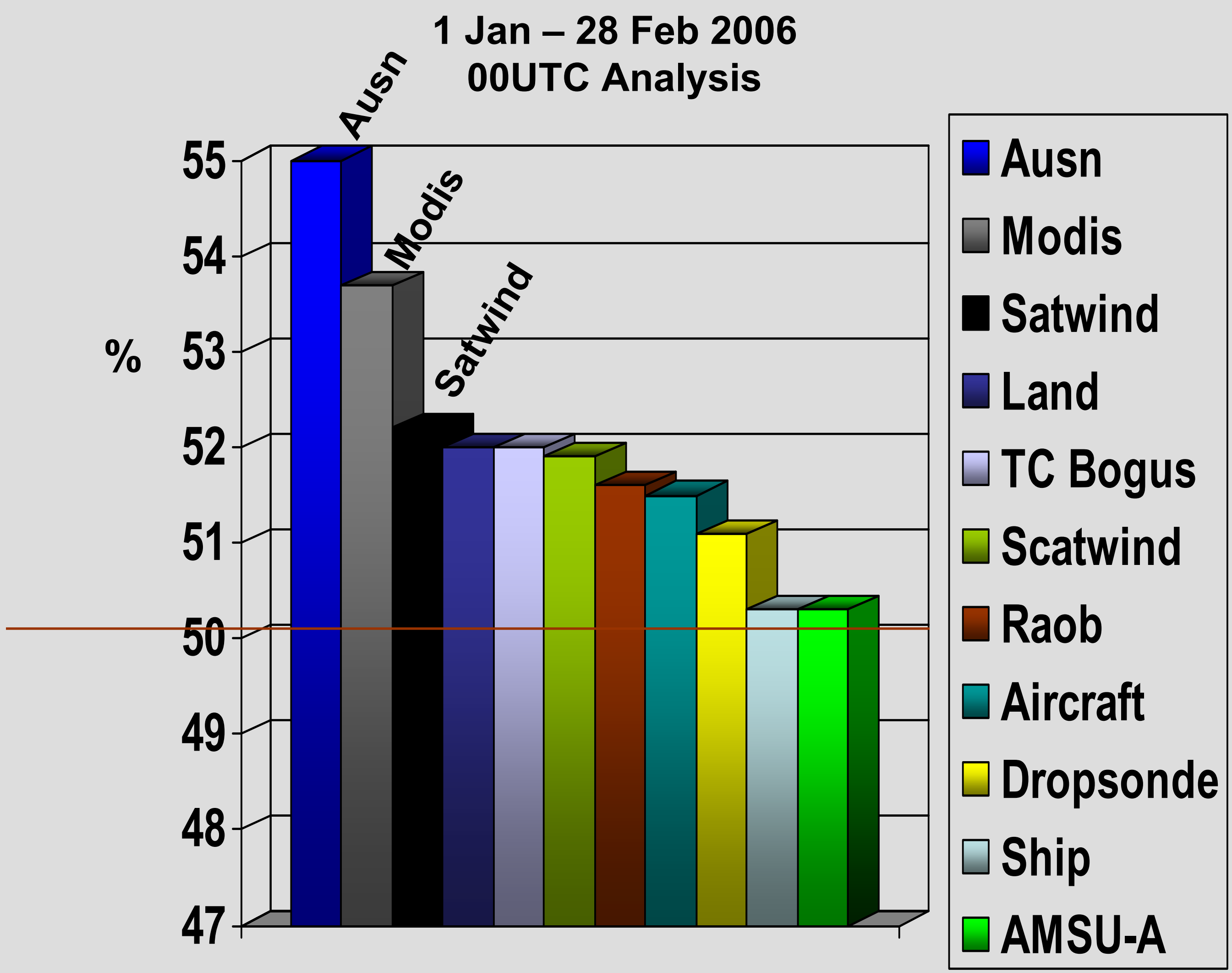


Impact magnitude per observation by instrument type

Units of impact = 10^{-5} J kg^{-1}



Percent beneficial impact by instrument type



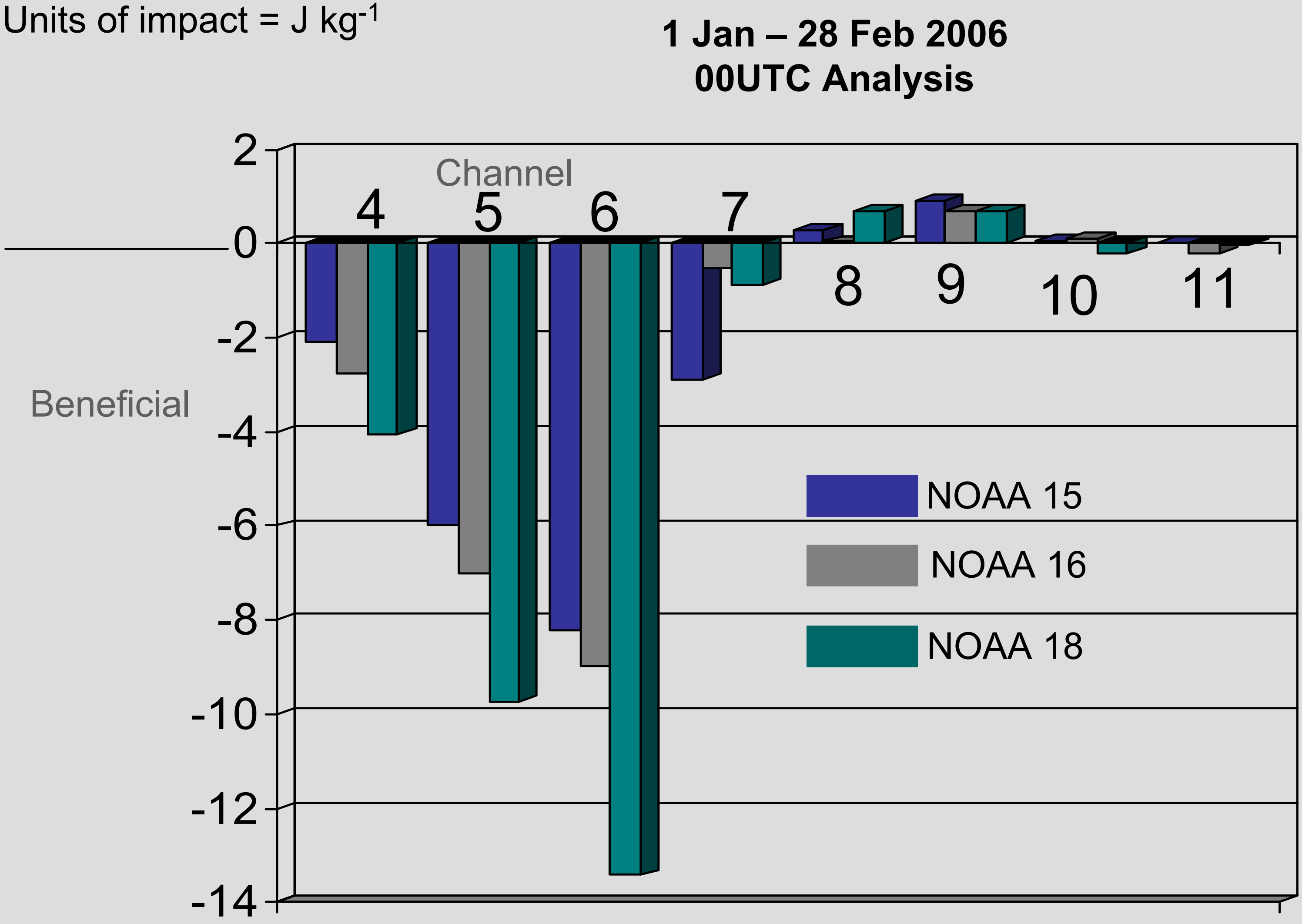
How can “good data” have non-beneficial impact ?

- Observation and background error statistics for data assimilation cannot be precisely specified
- This implies a statistical distribution of beneficial and non-beneficial observation impacts
- Assimilating the global set of observations improves the analysis and forecast – however, it is not possible for the impact of every observation, every day, to be beneficial

Information about the impact of individual observations and subsets of observations can be used to improve the data assimilation and observation selection procedures

Impact for AMSU-A channels

Units of impact = J kg^{-1}



Ch. peak near

11: 20mb

10: 50mb

9: 90mb

8: 150mb

7: 250mb

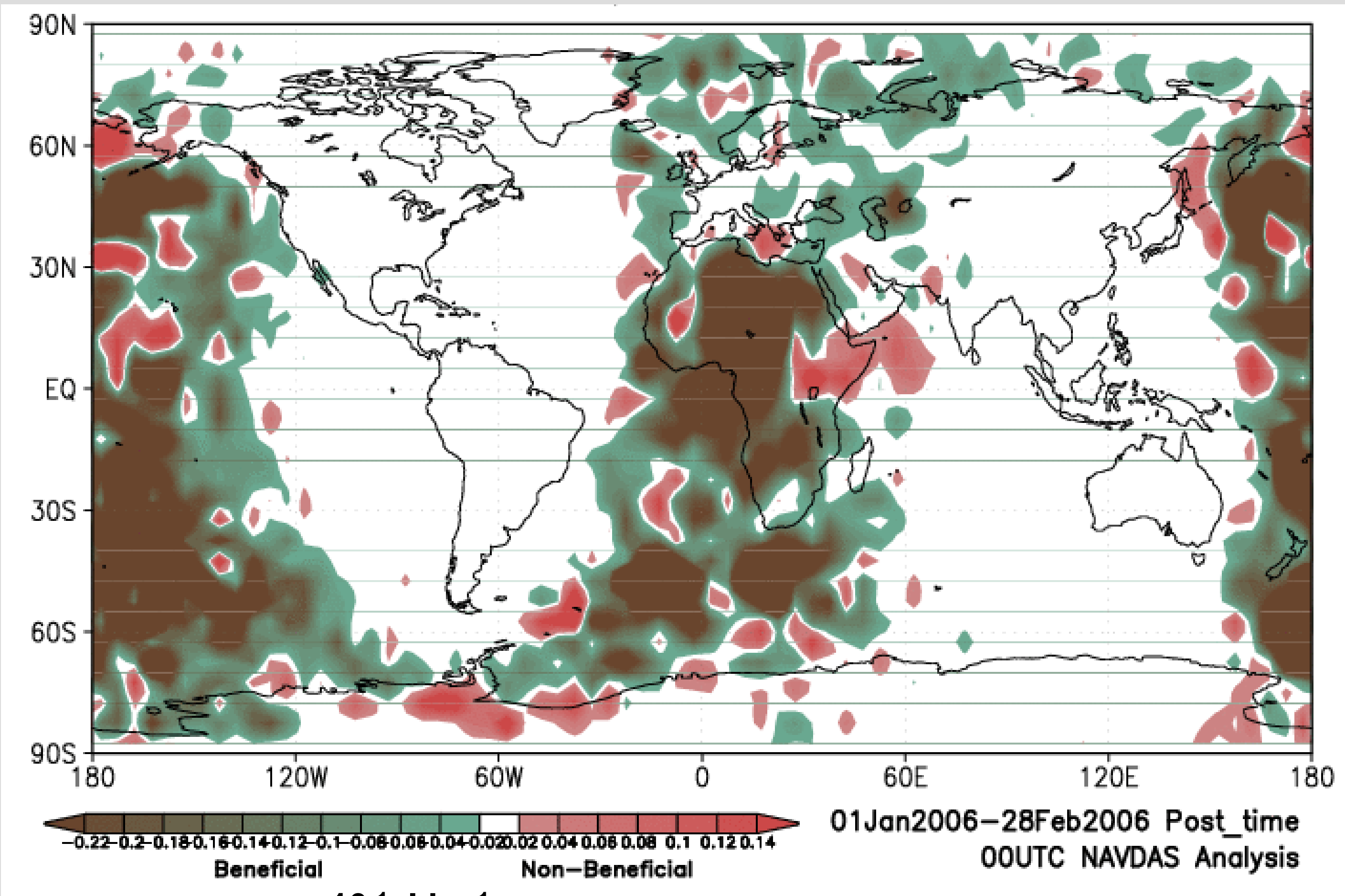
6: 350mb

5: 600mb

4: surface

Two-month cumulative observation impact (binned)

AMSU-A NOAA-18: Ch 6 (peak near 350mb)



10^{-1} J kg^{-1}

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 strategy: many observations which produce small to moderate impacts, not few observations which produce large impacts …

Largest non-beneficial observation impacts
00UTC 26 Mar 2006

OB IMPACT GREATER THAN (+) 0.01 J/kg

num	lat	lon	**impact**	inst	iob	pres	header
16	-89.90	0.00	0.0104	101	2	400.0	89009 80 4aRRA10trd_raob
3912	-74.70	164.10	0.0109	1	1	979.2	89662 asfc_lnd d_surface
39063	-47.38	129.50	0.0120	51	3	409.3	JMAMTSAT1WVCLR Sd_cld_wnd
60388	-40.80	145.40	0.0125	10	3	1014.5	VJIK ship_fx d_surface
74841	-35.20	331.50	0.0105	10	3	1017.0	S0029 ship d_surface
83977	-34.92	130.47	0.0113	38	3	274.5	AU0088 AU0088 trd_amdar
127540	-17.50	112.20	0.0108	190	3	500.0	BOGUS99999sea 10tc_syn
280289	27.80	339.50	0.0101	10	3	1018.9	S0020 ship d_surface
284498	**25.40**	**285.20**	**0.0190**	**10**	**3**	**1015.5**	**KIRF ship d_surface** ←

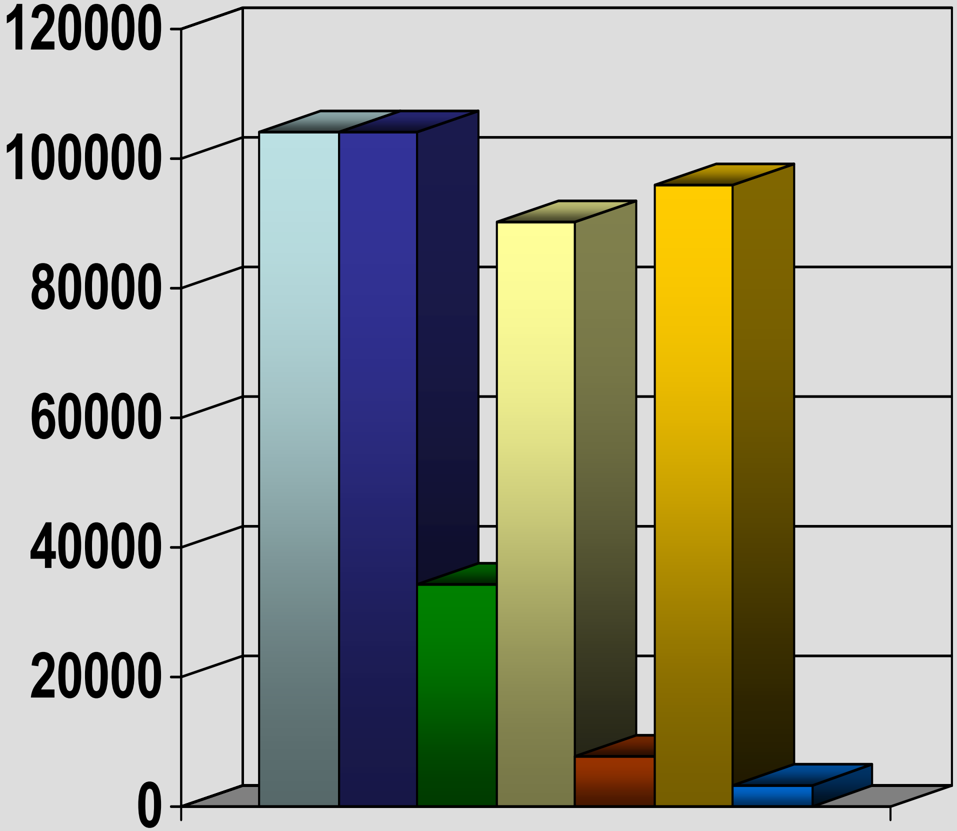
Largest beneficial observation impacts
00UTC 26 Mar 2006

OB IMPACT GREATER THAN (-) 0.01 J/kg

num	lat	lon	**impact**	inst	iob	pres	header
7165	-66.67	140.02	-0.0109	101	2	925.0	89642 56 5aRRV10trd_raob
16607	-56.24	238.33	-0.0127	210	13	4.1	AMSU-A ch 6 11NOAA16 25
25910	-53.79	241.99	-0.0132	210	13	0.2	AMSU-A ch 5 16NOAA18 19
39273	-44.50	132.25	-0.0190	51	4	402.5	JMAMTSAT1WVCLR Sd_cld_wnd
39279	**-43.25**	**132.75**	**-0.0195**	**51**	**4**	**379.5**	**JMAMTSAT1WVCLR Sd_cld_wnd** ←
69214	-34.68	128.50	-0.0112	38	4	274.5	AU0088 AU0088 trd_amdar
72164	-35.12	135.77	-0.0104	38	3	300.9	AU0088 AU0088 trd_amdar
74405	-35.80	316.10	-0.0143	10	4	1016.1	VOCC ship d_surface
78529	-35.57	322.34	-0.0103	59	3	843.5	UW MET8 SWIR 7S23595
84005	-32.13	133.70	-0.0105	101	3	636.0	94653 3 55g 04trd_pibal
84007	-32.13	133.70	-0.0110	101	3	612.4	94653 3 55g 04trd_pibal
84009	-32.13	133.70	-0.0119	101	3	567.3	94653 3 55g 04trd_pibal
105048	-25.49	112.19	-0.0109	190	4	1000.0	BOGUS99999sea 10tc_syn
123049	-19.50	112.20	-0.0107	190	3	700.0	BOGUS99999sea 10tc_syn
180921	-1.38	311.52	- 0.0100	101	2	700.0	82193-99-9aRRX10trd_raob
219571	9.15	18.38	-0.0108	101	3	850.0	64750 1 44g 10trd_pibal
231801	11.70	332.50	-0.0134	10	4	1016.0	DFRZ ship d_surface
267552	22.60	288.80	0.0170	10	4	1013.0	WGJT ship d_surface
276415	27.90	102.27	-0.0107	101	3	500.0	56571-99-9aRRX10trd_raob
428142	53.97	54.71	-0.0129	35	3	503.0	EU2301 LH3213 trd_amdar

Observation Data Count and Error Reduction

Ob Data Count



PERCENT of Observation:

	Count	Error Reduction
u-wind	23.7	21.3
v-wind	23.7	25.8
Temp	7.8	8.7
Moisture	20.4	16.0
Height	1.8	4.2
bTemp	21.8	23.1
Speed	0.8	0.9

00UTC 02 Aug 2006

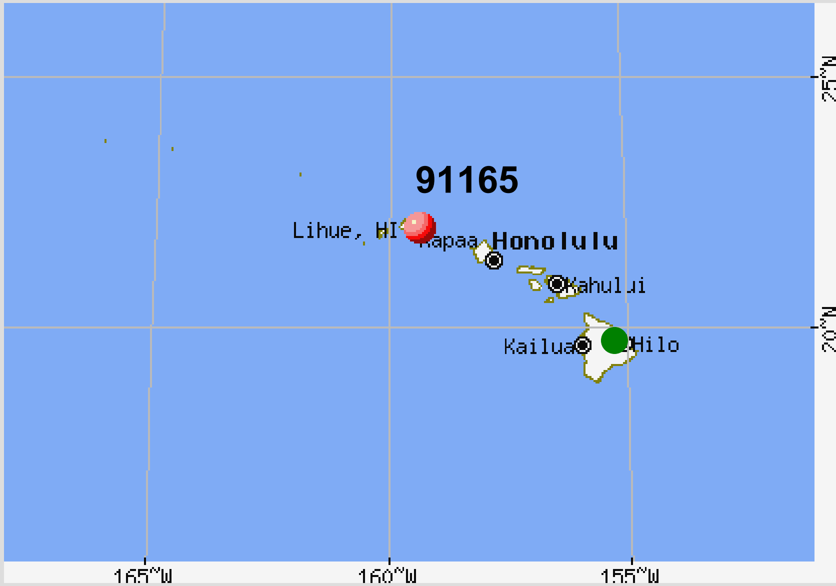
Total = 439,092 data assimilated

Example 1: Lihue radiosonde (Stn. 91165)

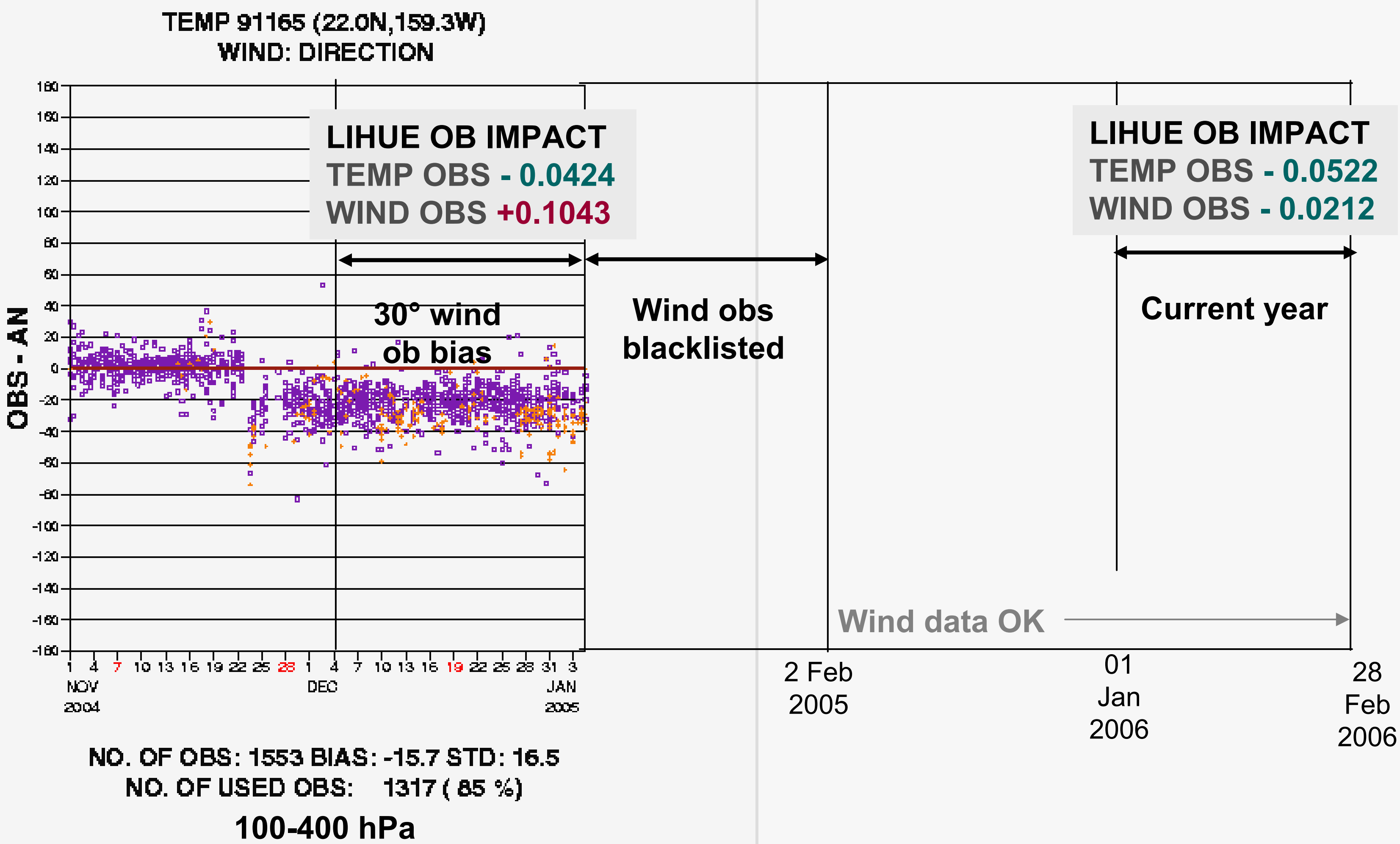
Date: Nov2004-Jan2005

Issue: Instrument bias affecting wind observations

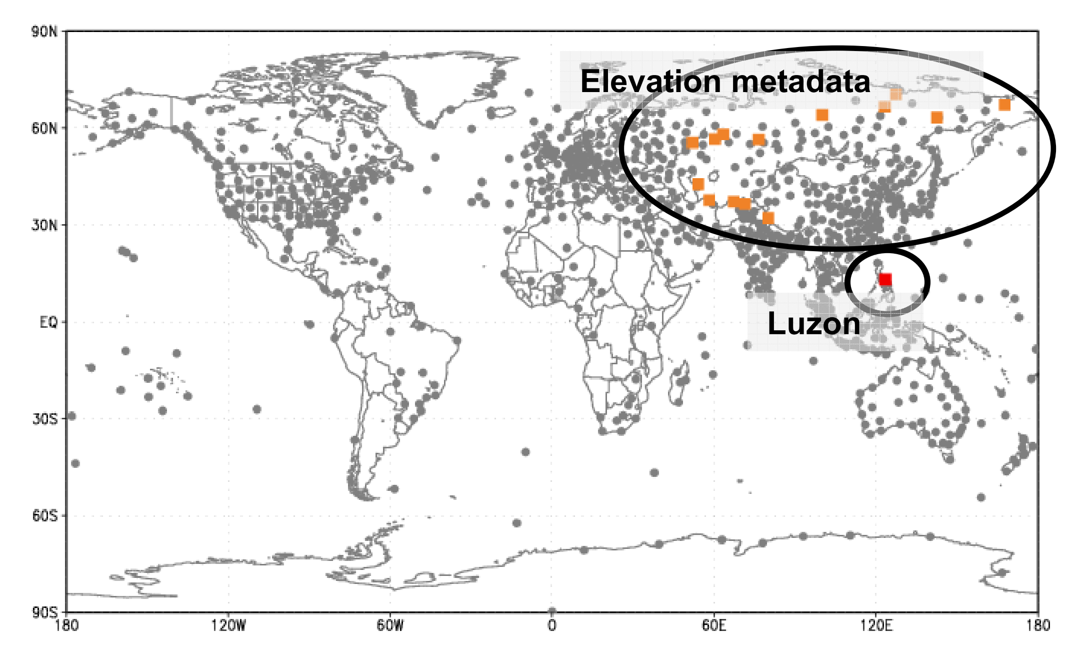
Action Taken: Wind ob data for 91165 blacklisted from 7Jan - 2 Feb 2005



Example 1: Lihue radiosonde (continued)



Example 2: Other radiosonde issues

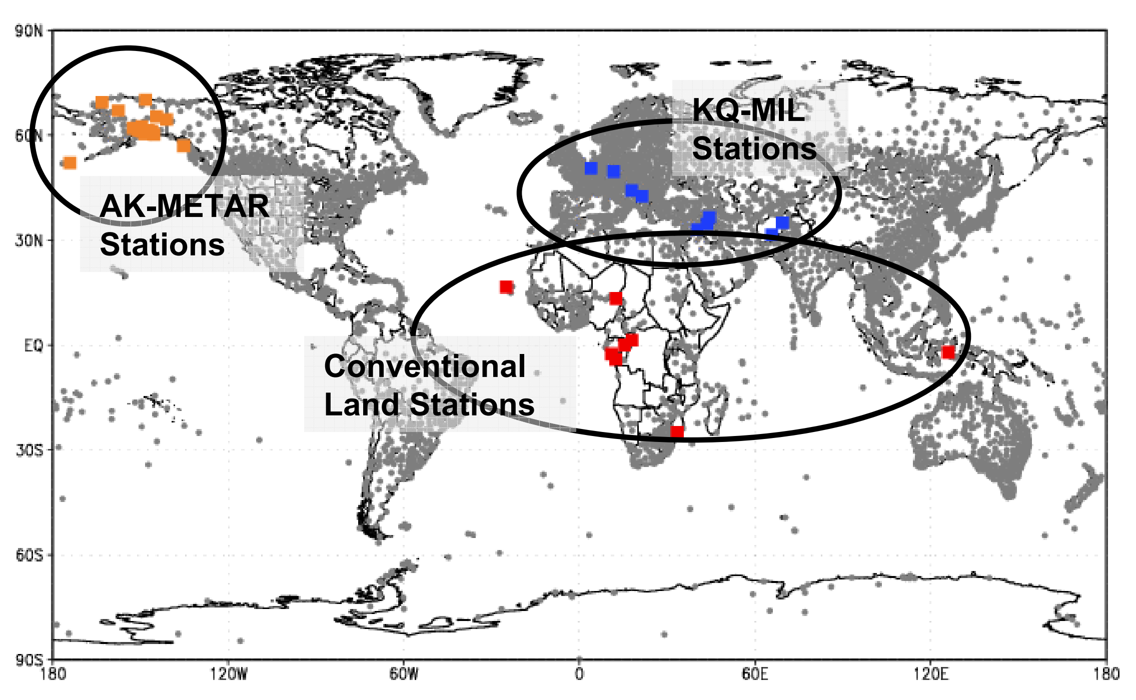


Date: Jan-Feb 2005

Issue: Radiosonde problems linked to inaccurate station elevation metadata

Actions Taken: Elevation information corrected by checking WMO and Russian websites, some stations blacklisted – Luzon radiosonde wind reporting error, blacklisted until corrected – radiosonde wind error at upper levels increased to match ECMWF for all radiosonde stations

Example 3: Land stations



Date: Jan-Feb 2005

Issue: Land station observation problems linked to high elevation and cold surface temperatures (METAR), also problems with station elevation metadata (MIL, conventional)

Actions Taken: Selected stations blacklisted, data flagged if stations above 740m, or above 300m and background temperature below -15°C

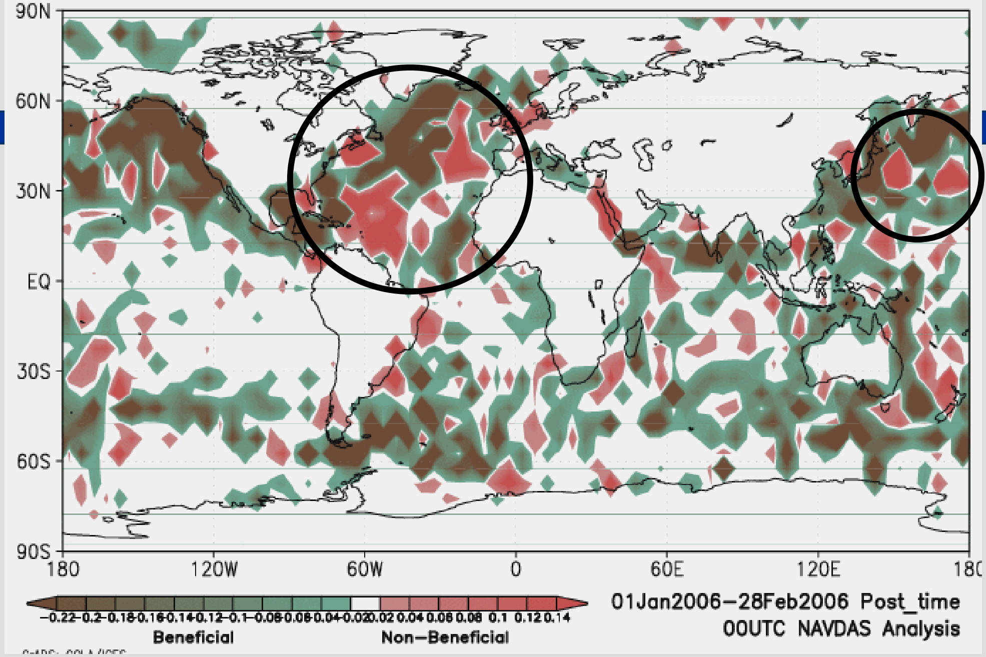
Example 4: Ship data

Date: Jan-Feb 2006

Issue: Some ship data having non-beneficial impact

Actions Taken: Ship ID blacklist implemented; increase wind observation error for ship data (previously was equal to radiosonde surface wind error)

Ship Observation Impact - binned



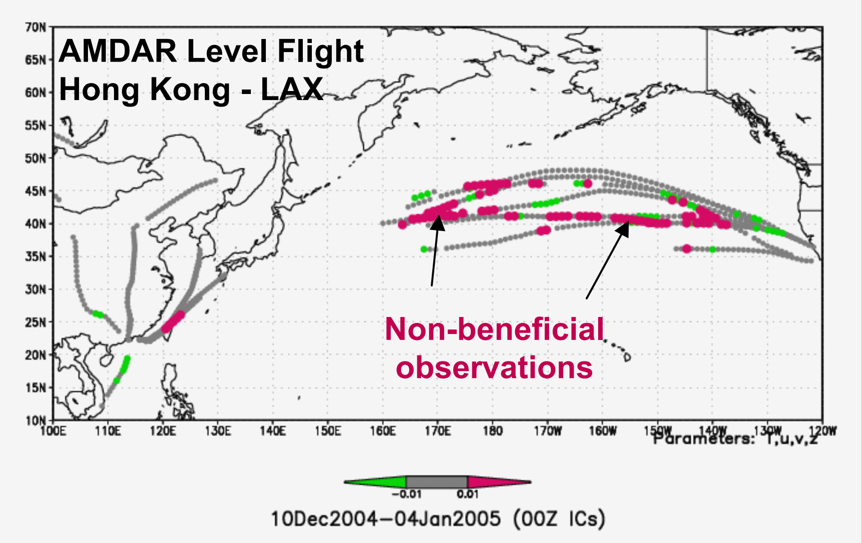
SEA ARCTICA – one of the “problem” ships

Example 5: Isolated aircraft tracks

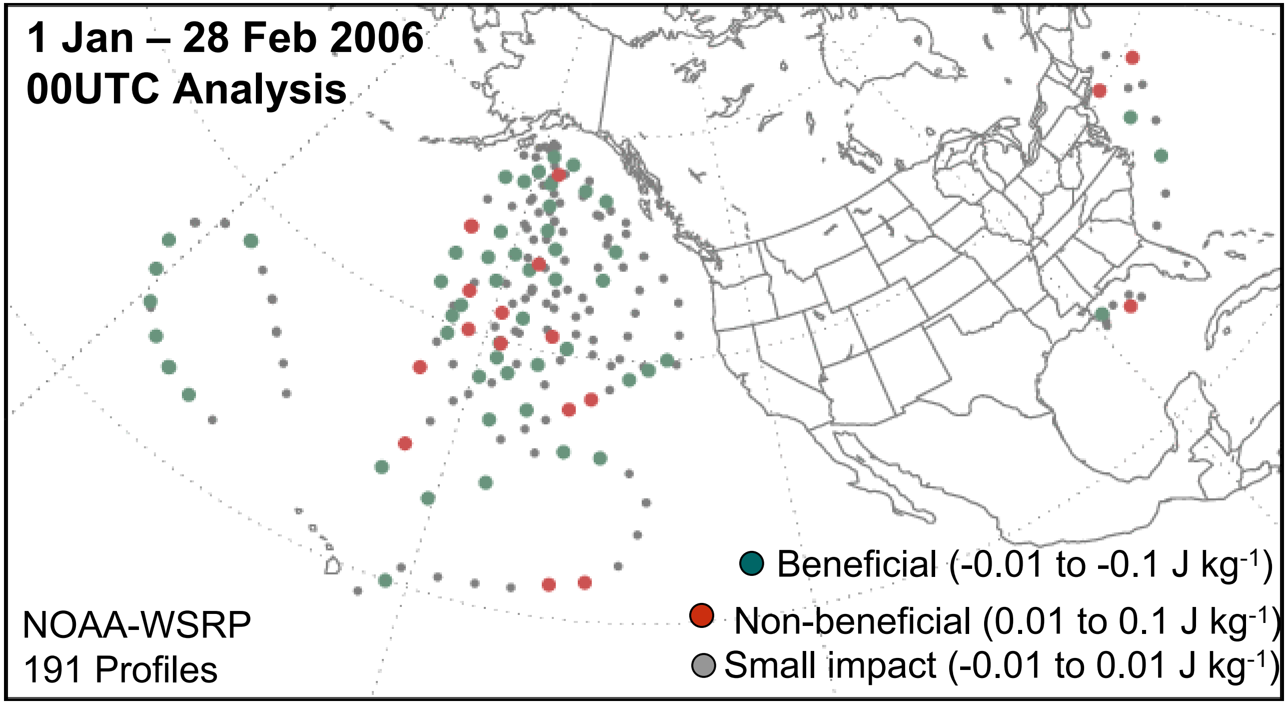
Date: First noticed Jan 05, ongoing in several regions

Issue: aircraft flies in jet max eastbound, outside of jet max westbound: observation error representativeness problem ?

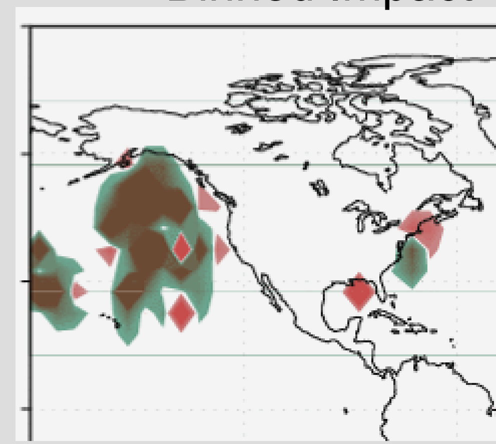
Action Taken: Issue being studied for possible action



Example 6: WSRP targeted dropsondes



Binned Impact



Date: Jan-Feb 2006

Issue: Average dropsonde ob impact is beneficial and ~2-3x greater than average radiosonde impact

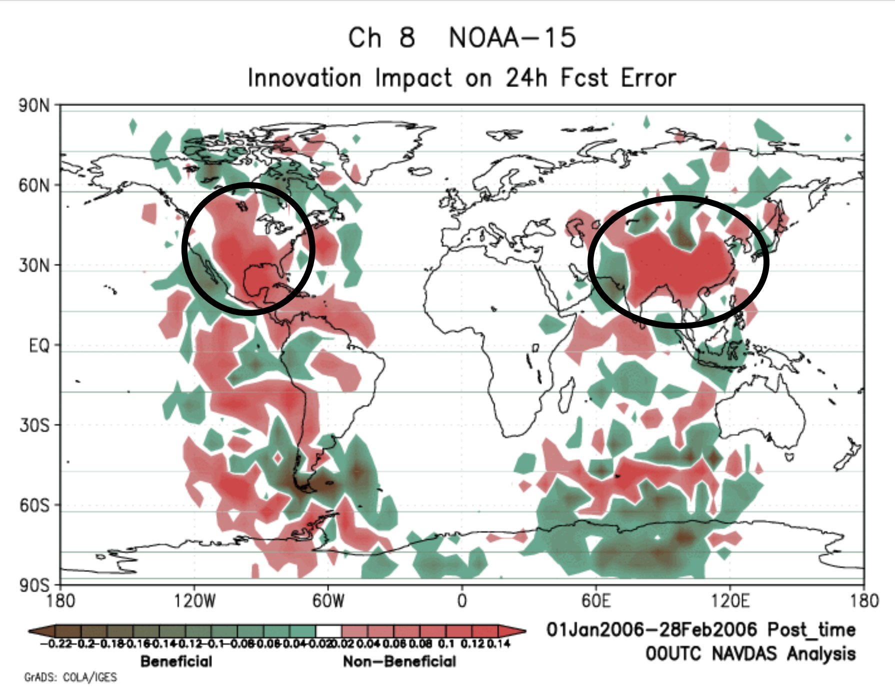
Action Taken: Targeted observing programs continue

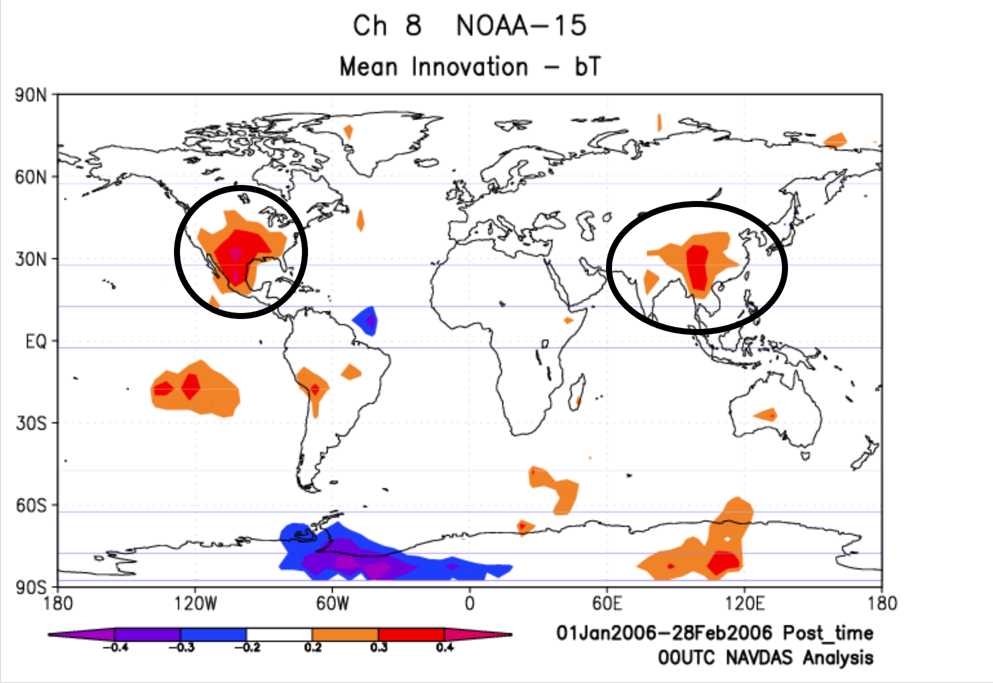
Example 7: AMSU-A over land surface

Date: Jan-Feb 2006

Issue: Some AMSU-A channels over-land surfaces produce non-beneficial impact

Action Taken: Investigate bias correction dependence on land surface temperature



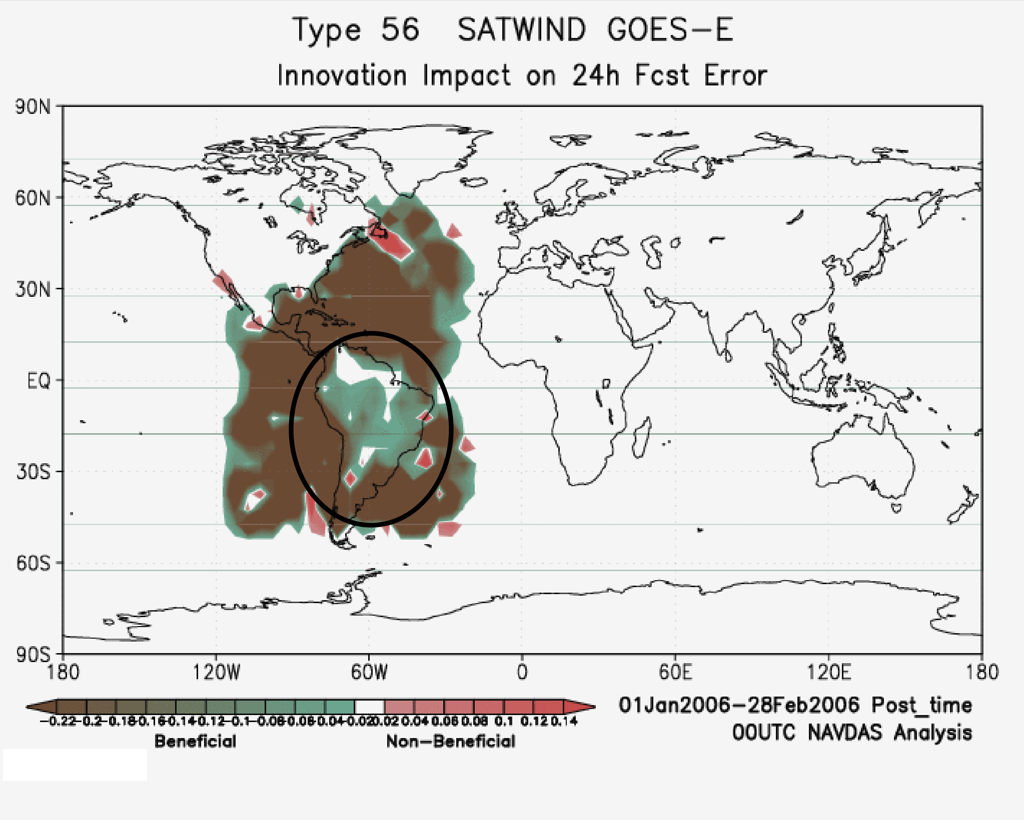


Example 8: SATWIND data over land

Date: Jan-Feb 2006

Issue: Satwind obs over land surfaces are providing beneficial ob impact, prob. due to improved data quality

Action Taken: FNMOC will test additional satwind data for beneficial impact over land areas

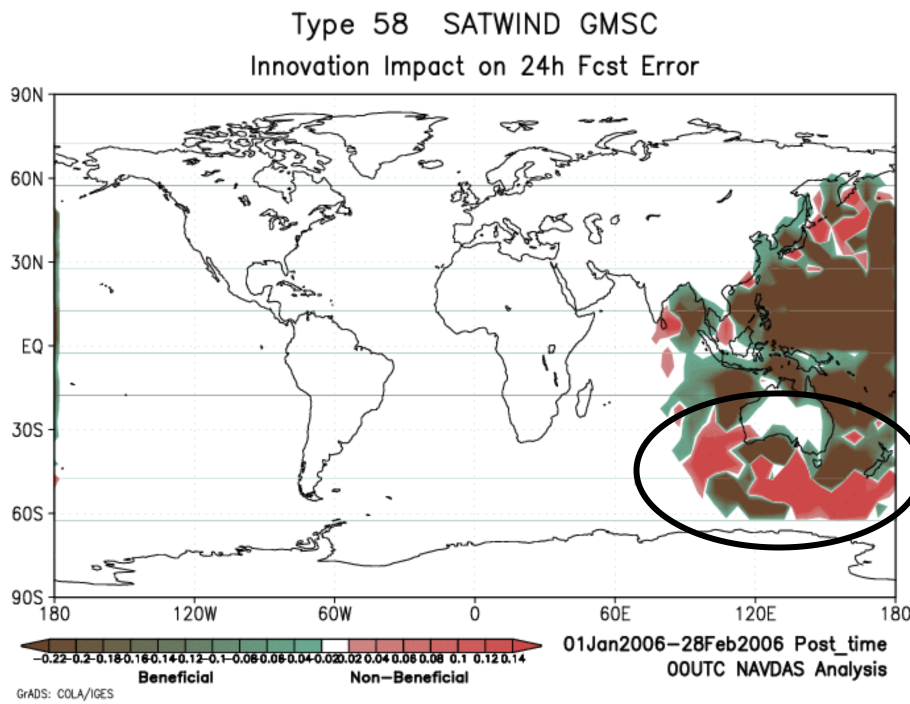


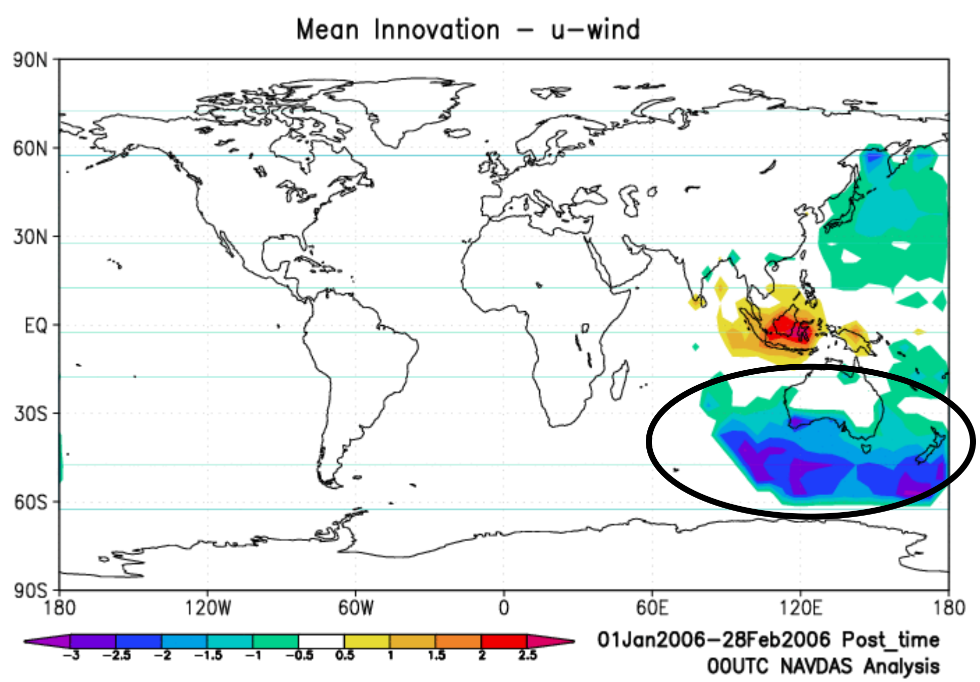
Example 9: SATWIND data denial experiment

Date: Jan-Feb 2006

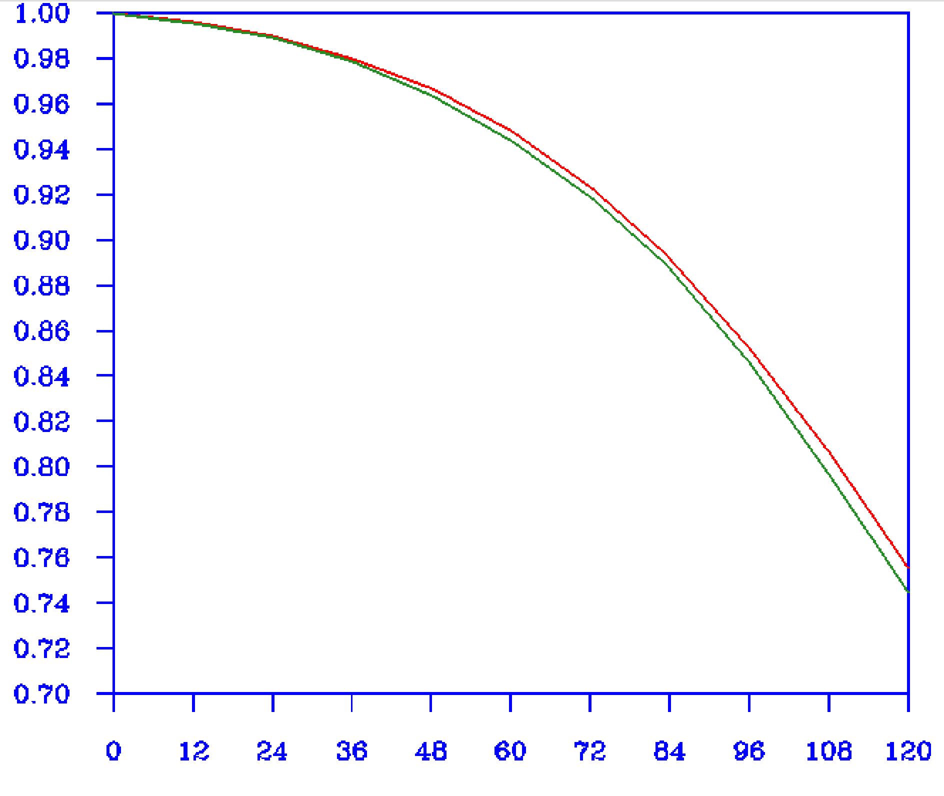
Issue: Large innovations and non-beneficial impact from satwinds at edge of coverage areas

Action Taken: Ob data removed if > 39° from satellite sub-point – gave 3-hr improvement in SHEM NOGAPS forecast skill





Restricting SSEC MTSAT Winds
500 mb Height Anomaly Correlation



Southern Hemisphere

Restricted Winds **Control**

February 16 – March 27, 2006

4. Conclusion

Adjoints of NAVDAS and NOGAPS can be used to quantify and visualize impact of observations on short-range forecast skill

Key Results

- Adjoint-based observation impact information is a valuable supplement to “conventional” data impact studies (OSEs, OSSEs)
- Provides quantitative information about every observation that is assimilated and spatial patterns in observation impact
- Identifies possible problems with NAVDAS (observation and background error, bias correction issues)
- Information is relevant to QC issues and daily monitoring of observations in FNMOC operational data assimilation

Ongoing and future work

- Develop additional ways to display, statistically analyze, and correlate the observation impact information
- Satellite Channel Selection (AIRS, HIRS, etc.)
- Develop ob impact technique in NAVDAS-AR adjoint (4d-Var)
- Compare results with other adjoint systems (NASA, ECMWF)
- NAVOBS display web page (under development)

NAVOBS – NAVDAS-adjoint **Ob**servation monitoring **S**ystem

End of Presentation !

questions ?