Adjoint-based impact studies of surface-based observation types at the UK Met Office

Richard Marriott, Met Office, UK

5th WMO Workshop on the Impact of Various Observing Systems on NWP, Sedona, AZ, USA (May 2012)

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Specific questions addressed

- **S3AMDAR**: Coverage of AMDAR - What is the impact of current AMDAR observations? What are the priorities for expansion of the network?

- **S4ASAP**: Coverage of ASAP - What is the impact of current coverage of profiles from the Automated Shipboard Aerological Programme (ASAP)? How might coverage be optimised for a given level of resources?

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Contents:

- Overview of the UKMO FSO system
- The observation impact of conventional, surface-based observation types
- E-ASAP case-study
- **S4ASAP** – Current ASAP impact
  - Ideas for optimisation of coverage
- UK AMDAR case-study
- **S3AMDAR** – Impact of AMDAR observations
  - Priorities for expansion of the network?

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The Met Office FSO system

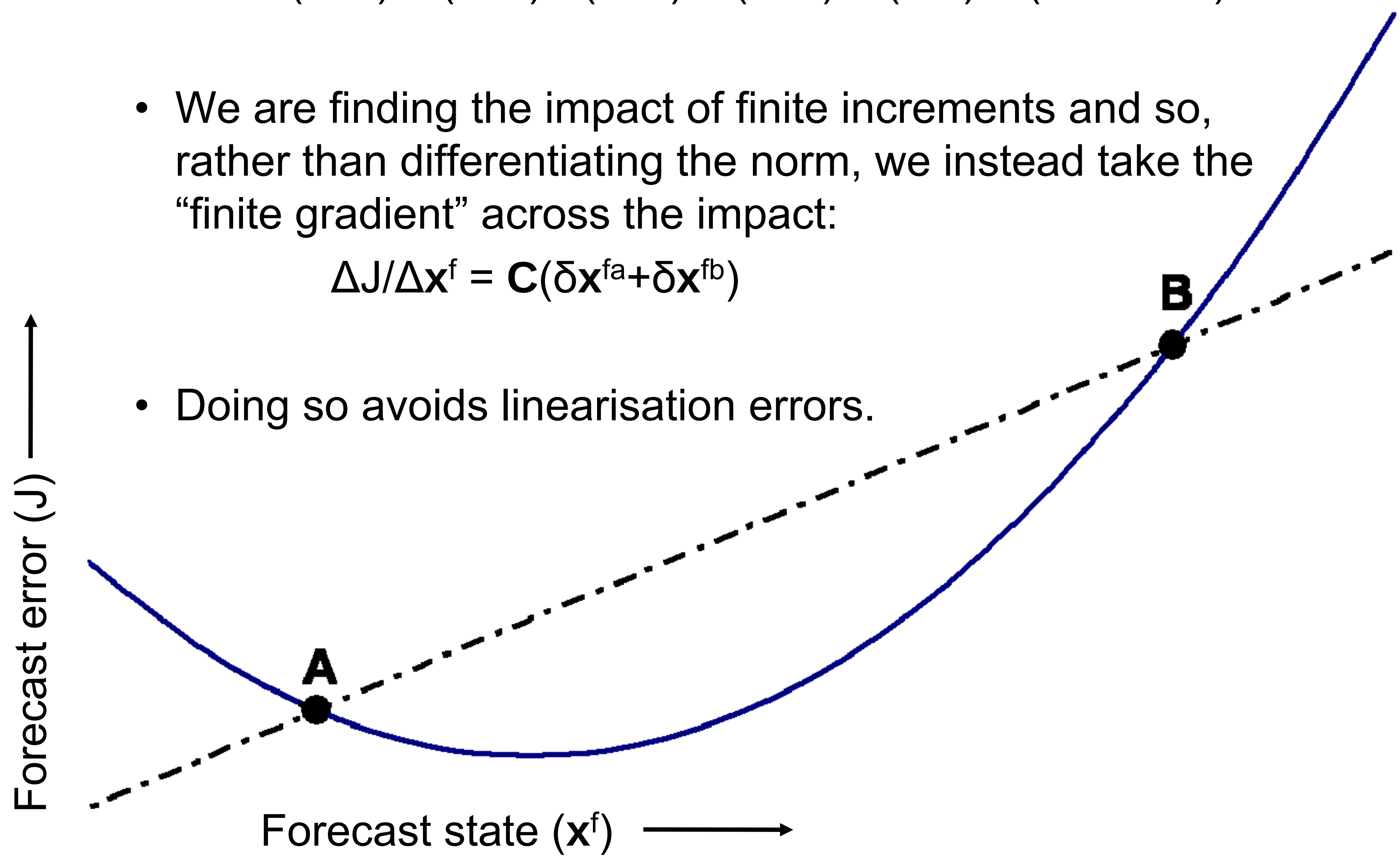
- The forecast impact, ΔJ, is given by:

  $\Delta J = (\delta \mathbf{x}^{fa})^T \mathbf{C} (\delta \mathbf{x}^{fa}) - (\delta \mathbf{x}^{fb})^T \mathbf{C} (\delta \mathbf{x}^{fb}) = (\Delta \mathbf{x}^{f})^T \mathbf{C} (\delta \mathbf{x}^{fa} + \delta \mathbf{x}^{fb})$

- We are finding the impact of finite increments and so, rather than differentiating the norm, we instead take the “finite gradient” across the impact:

$$\Delta J / \Delta \mathbf{x}^{f} = \mathbf{C} (\delta \mathbf{x}^{fa} + \delta \mathbf{x}^{fb})$$

- Doing so avoids linearisation errors.



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The Adjoint Forecast Model

- Averaging the forecast error gradients at T+24 also means we only need perform a single integration of the adjoint forecast model.
- Our observation sensitivities are calculated using the following:

$$\frac{\Delta J}{\Delta \mathbf{y}^{\circ}} = \mathbf{K}^{T}\left(\frac{\Delta \mathbf{x}^{f}}{\Delta \mathbf{x}_{0}}\right)^{T}\left(\frac{\Delta J}{\Delta \mathbf{x}^{f}}\right) = \mathbf{K}^{T}\mathbf{M}_{PF}{}^{T}\mathbf{C}(\delta\mathbf{x}^{fb} + \delta\mathbf{x}^{fa})$$

(I have expressed $\mathbf{M}_{PF}{}^{T}$ using finite notation to emphasize that our PF model is designed to approximate the growth of finite perturbations in a nonlinear model.)

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Overview of the UKMO FSO system

- Implemented in **global** model
- Impact on **24-hour** forecasts measured
- Moist energy-norm (u, v, theta, p, q) up to **150hPa** using latent heat of condensation
- Penalty calculations and adjoint steps performed at Var-resolution on **simplified forecast states**
- **Finite forecast sensitivity** calculated
- **Single adjoint model integration** (linearised about **averaged trajectory**) with moist physics enabled
- $\mathbf{K}^T$ **linearised about analysis** – no outer-loop but nonlinear inner-loop
- $\mathbf{K}^T$ evaluated by **minimisation of FSO cost-function**. I.e. not line-by-line adjoint or Lanczos vectors. **~55 iterations** performed to get close to full convergence.

$$J(\hat{\mathbf{a}}) = \tfrac{1}{2}(\hat{\mathbf{a}} - \hat{\mathbf{v}})^T (\hat{\mathbf{a}} - \hat{\mathbf{v}}) + \tfrac{1}{2}\hat{\mathbf{a}}^T \mathbf{U}^T \mathbf{G}^T \mathbf{R}^{-1} \mathbf{G} \mathbf{U} \hat{\mathbf{a}}$$

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Results

Most results shown here come from the trial detailed below. (Exceptions will be mentioned explicitly.)

Period: 22nd Aug to 19th Sept 2010

System: Operational copy from March-July 2011

Forecast model res.: N320L70 (~40km)

Var res.: N108/N216L70 (~60km)

VarAdjoint res.: N216L70 (~60km)

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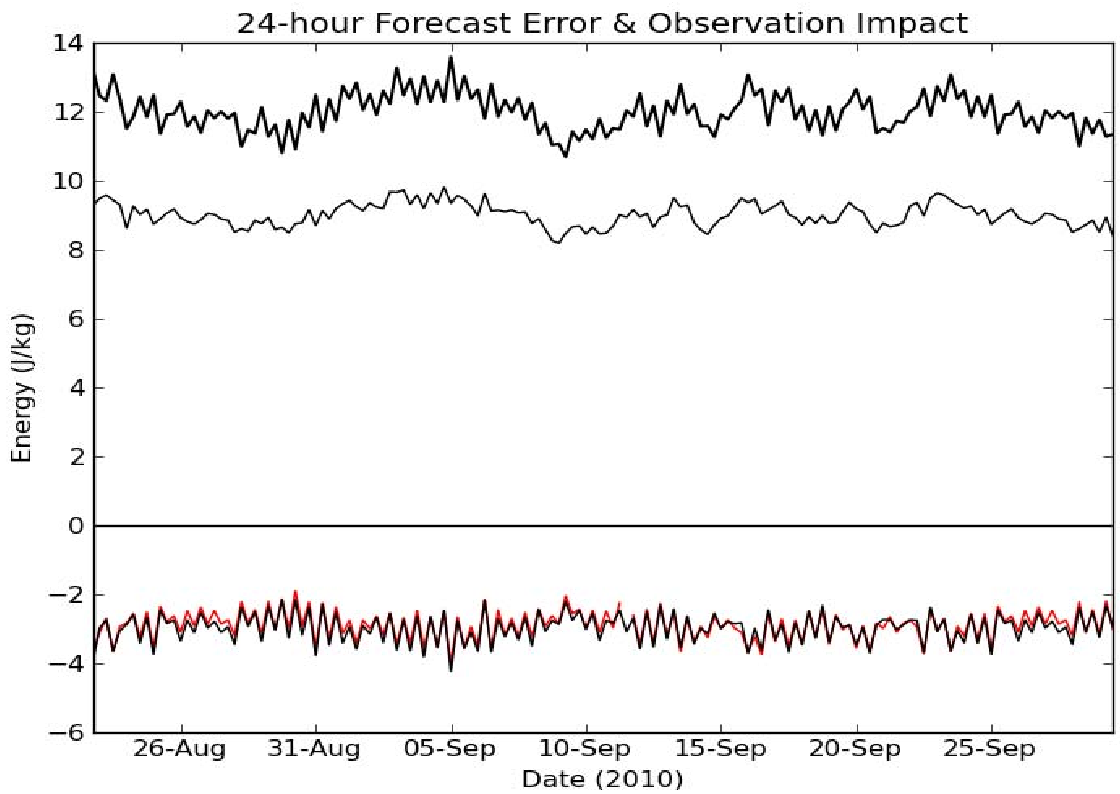
Forecast impacts



- 24.8% error reduction during period from an average of 12.0 to 9.0 J/kg.
- Observation impacts calculated to an accuracy of 97.2%.
- (Dry: 26.2% from 7.8 → 5.7 J/kg. Moist aspect contributes ~33%)

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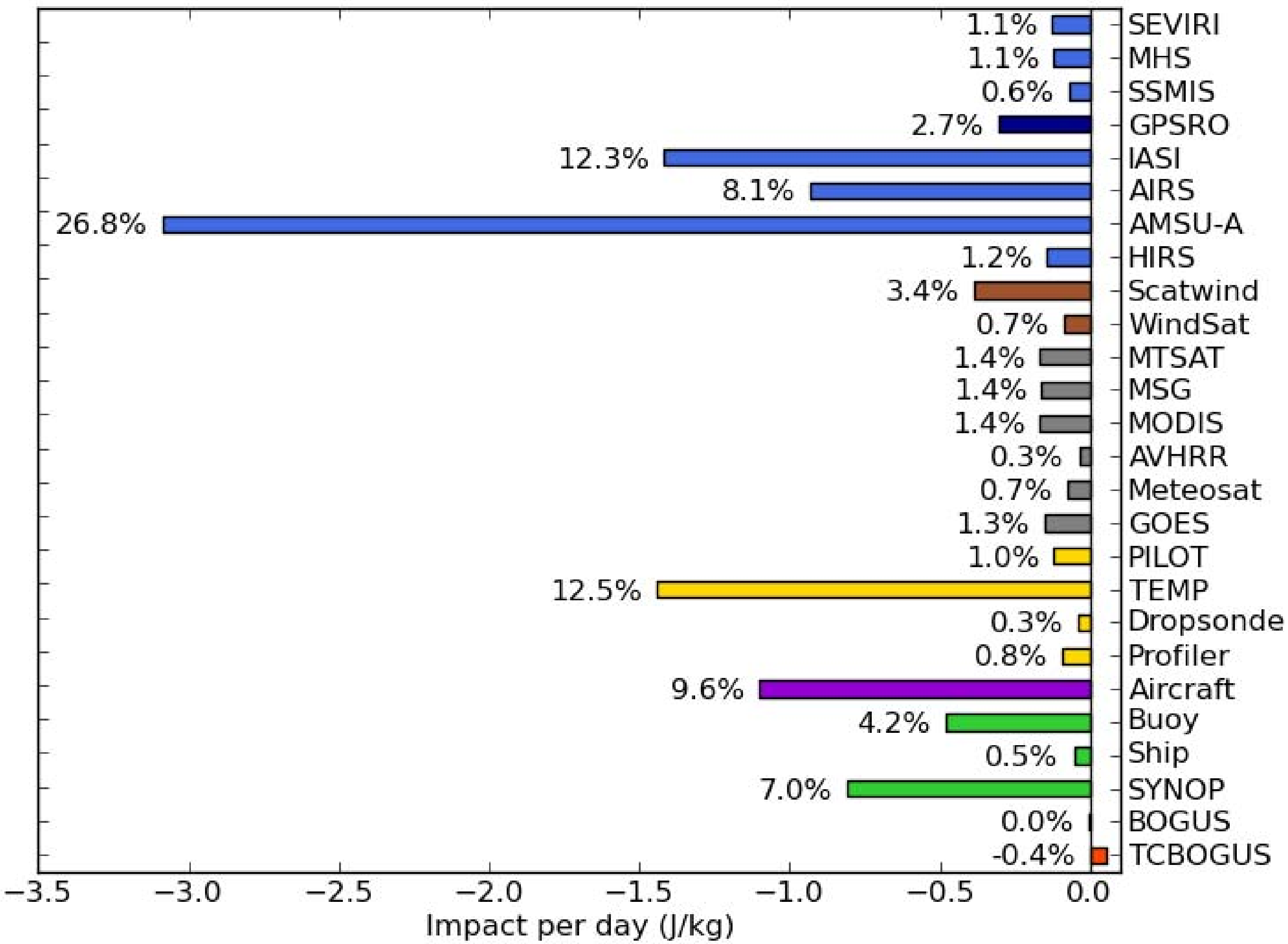
Observation impacts per day



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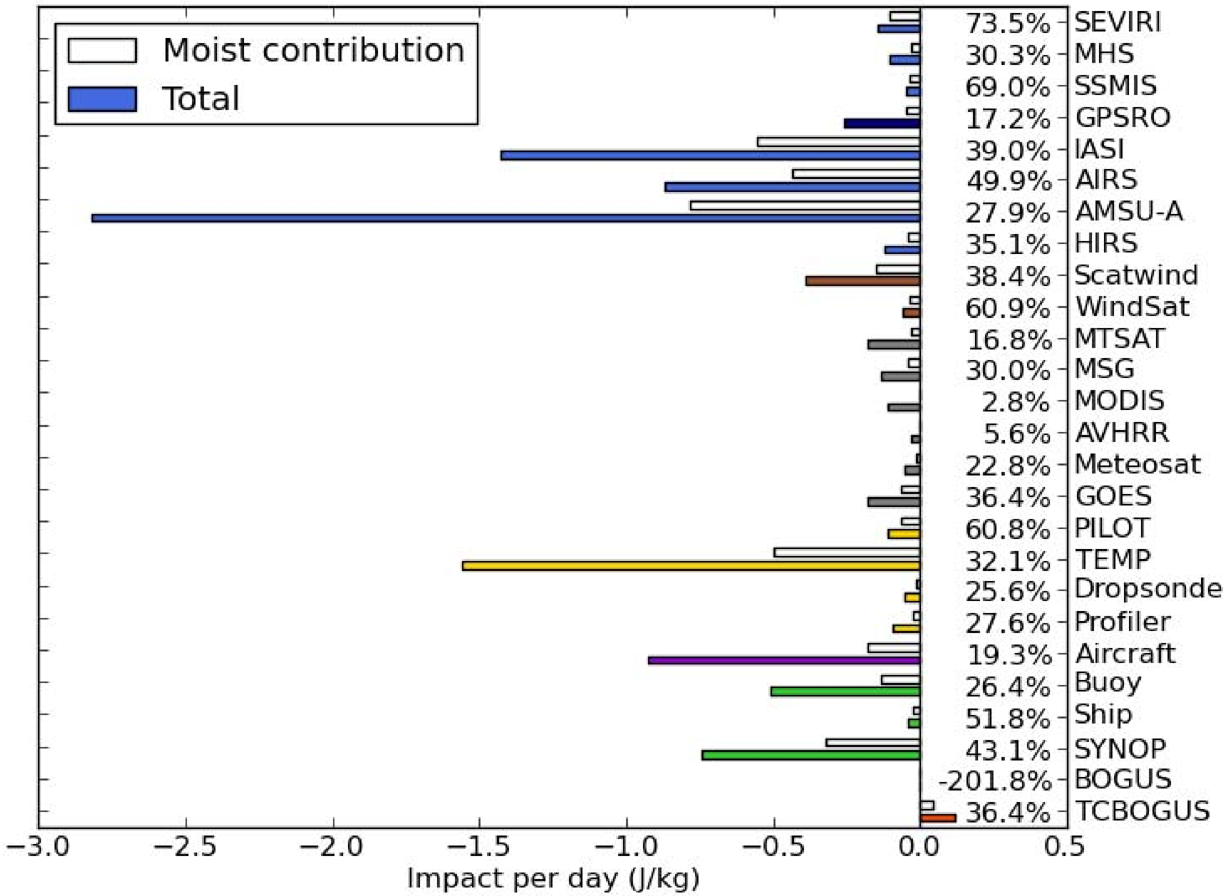
Observation impacts per day
(Moist contributions)



- These results for a 3-day period only.

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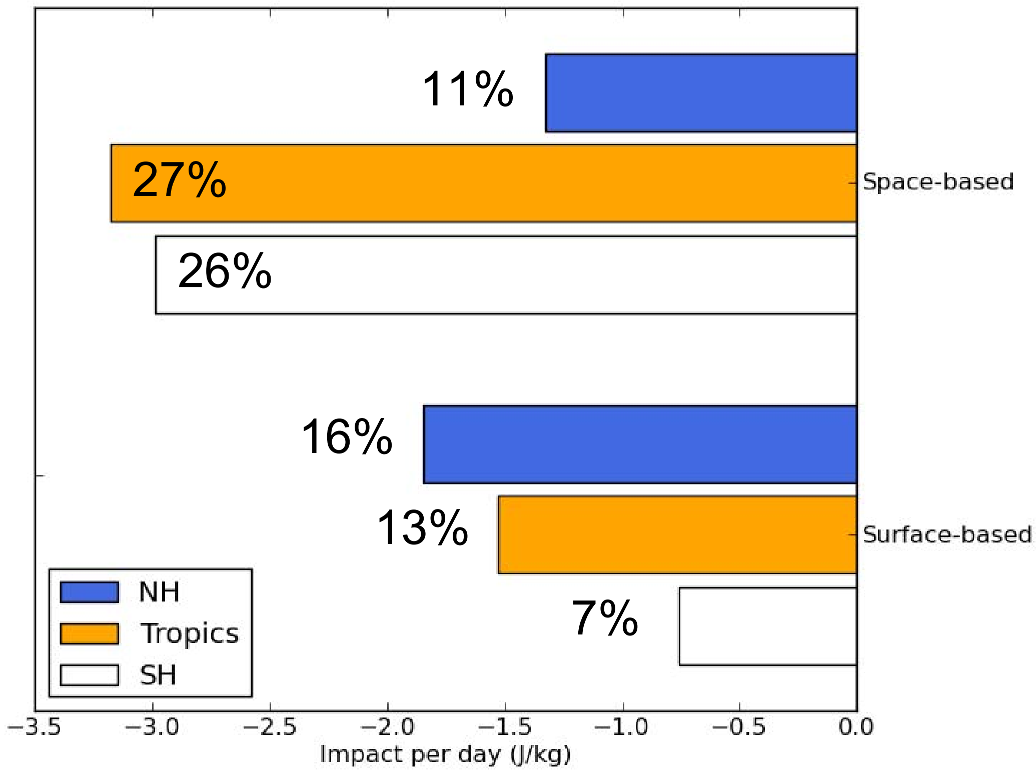
Surface-based observation impacts in context



- Surface-based ob-types account for 36% of the total 24-hour forecast impact.

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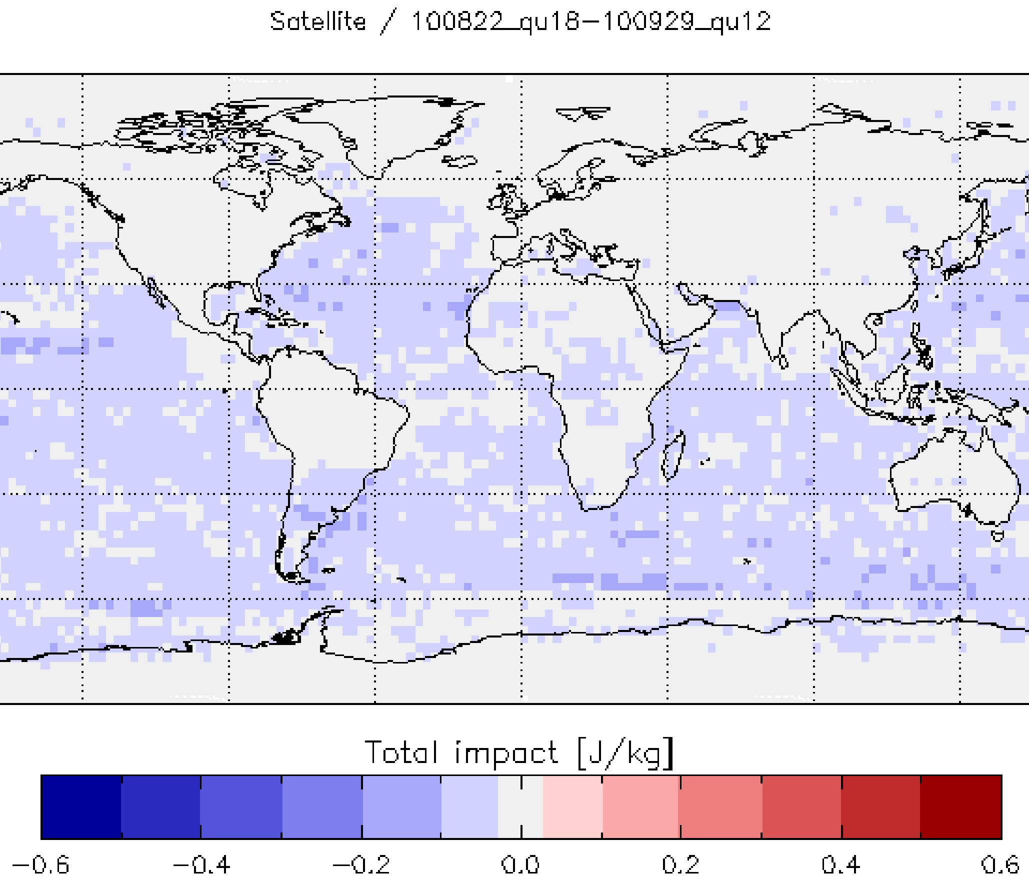
Surface-based observation impacts in context
(Satellite impact)



- Consistently good impact over ocean
- Small but beneficial over land

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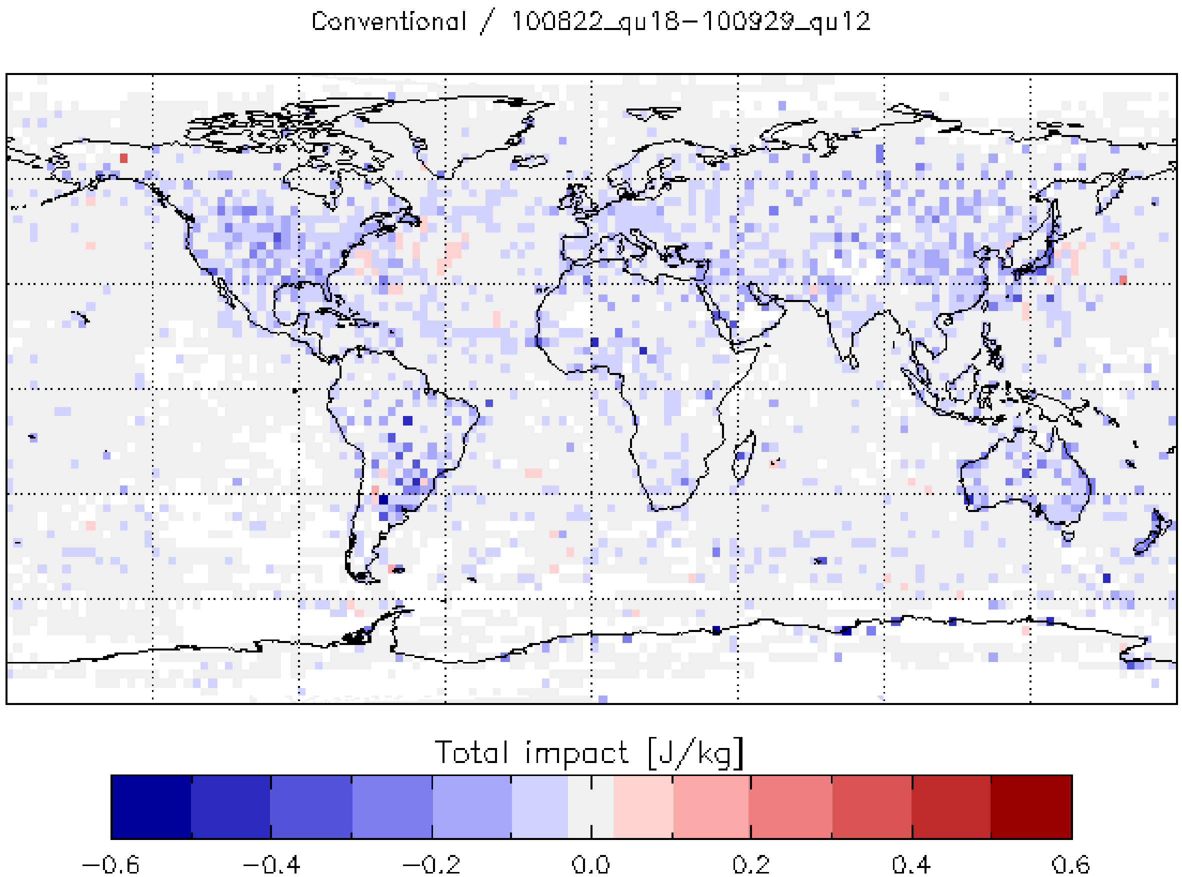
Surface-based observation impacts in context
(Surface-based impact)



- Impacts larger but fewer than for satellite.
- (Red square is NOAA wind profiler 70197)

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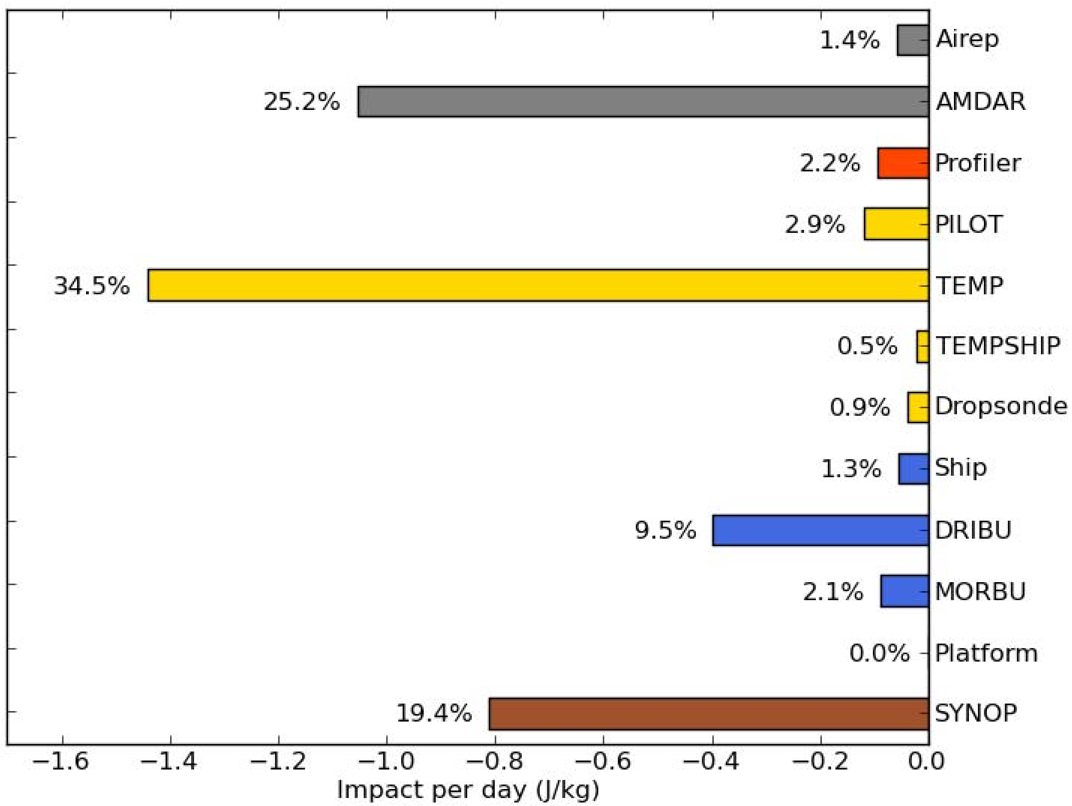
The observation impact of conventional, surface-based observation types



- Of the 36%, impacts are distributed as above.
- SYNOP impact possibly an overestimate.

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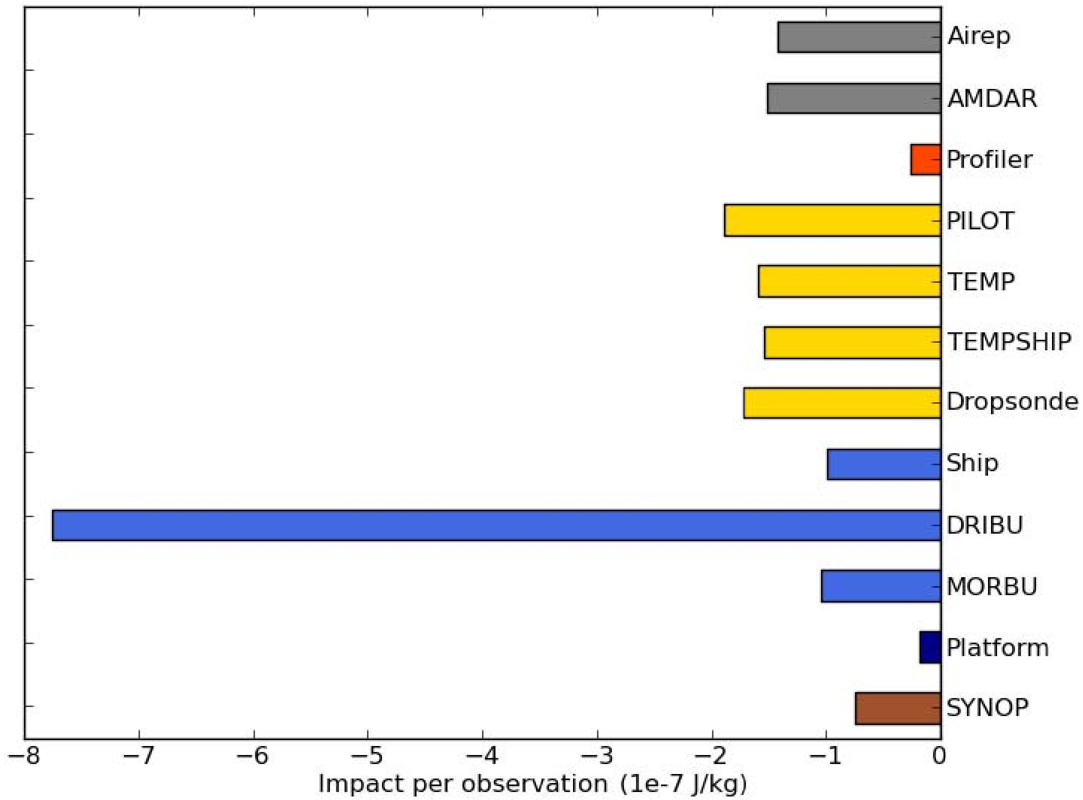
Impacts per observation



- Large impact per ob from drifters but remember there are many more observations per “station” for other ob-types (aircraft, profilers and sonde)
- Globally, TEMPSHIP is the weakest-impacting sonde type. However, there are no TEMPSHIPs in the southern hemisphere.

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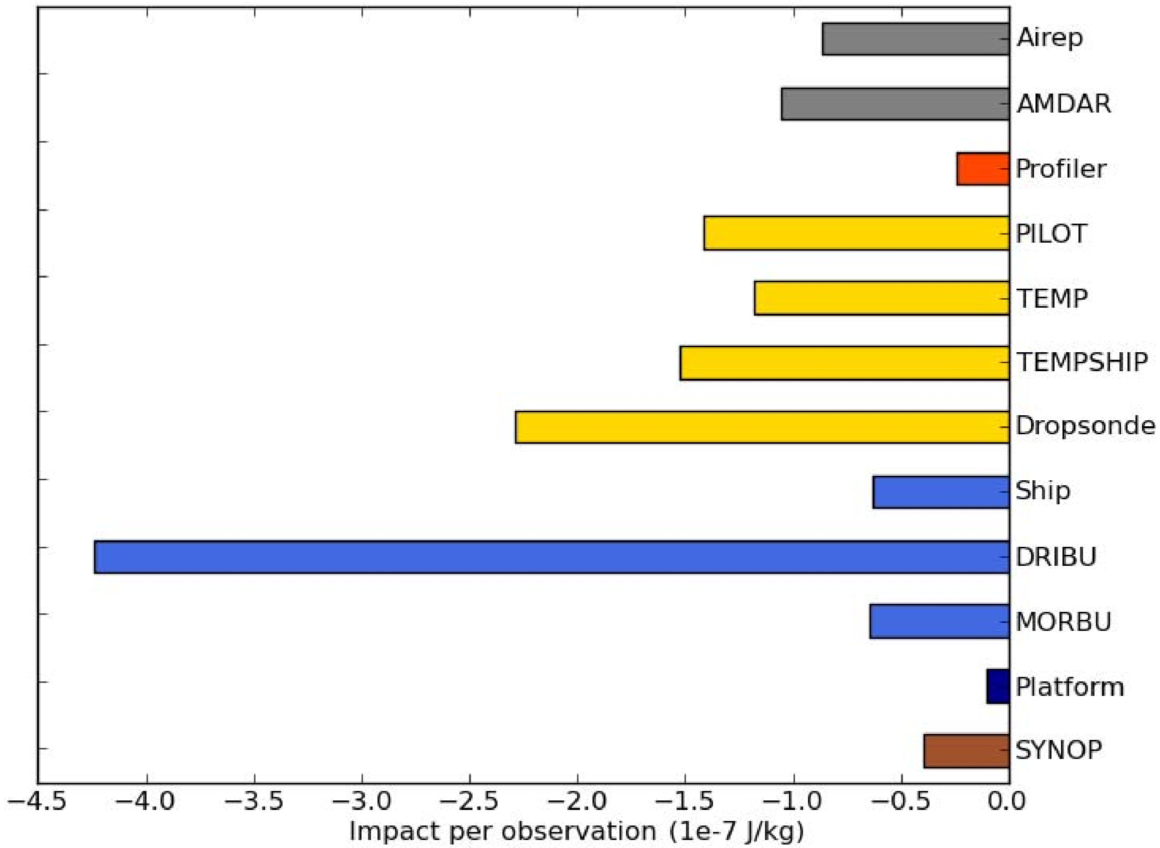
Impacts per observation – NH (30N-90N)



- TEMPSHIP impact per ob larger than for PILOT and TEMP in the NH.

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ASAPs

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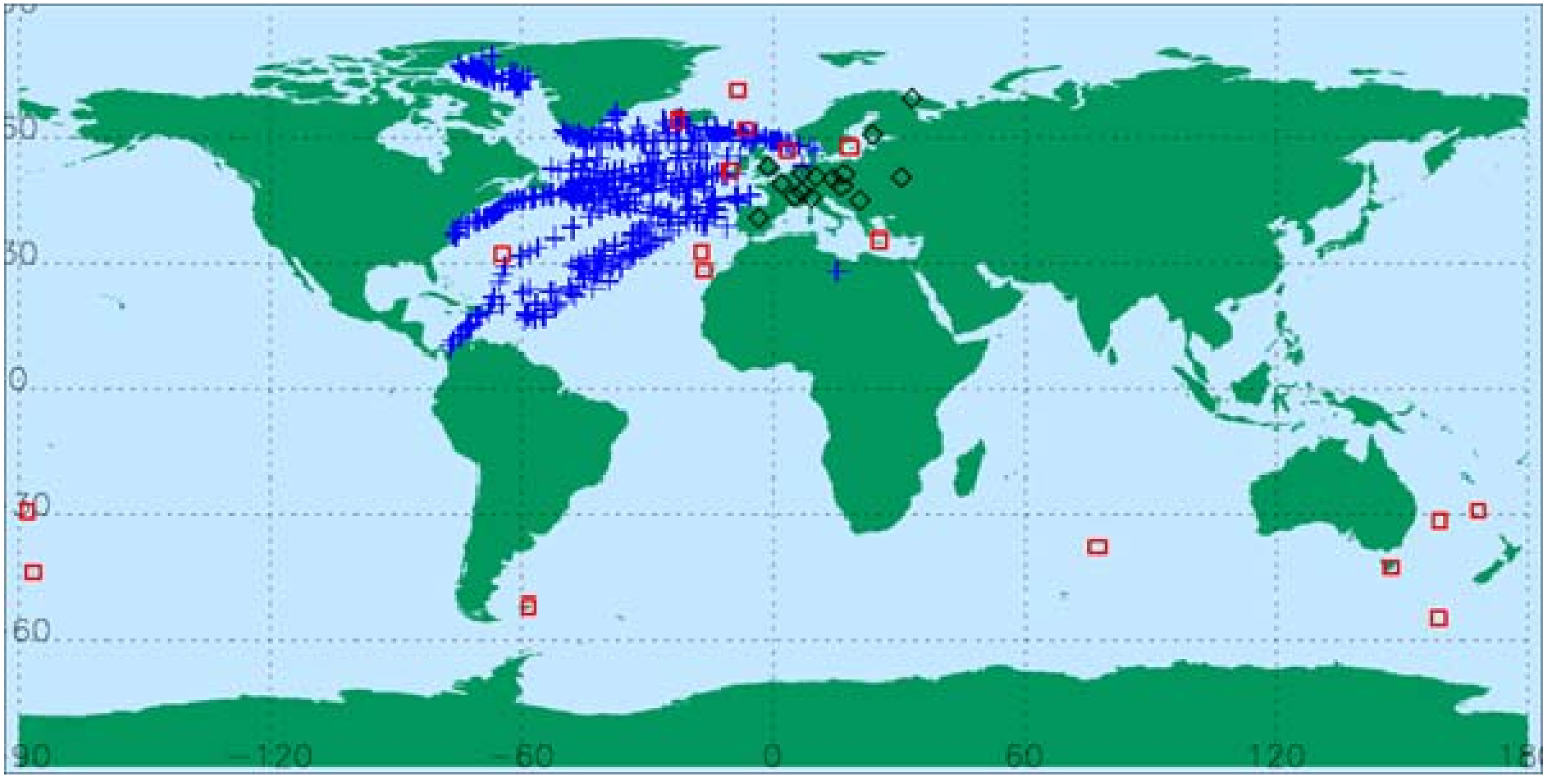
E-ASAP case-study



- Three similarly located groups of ~20 sondes assessed: ASAP sondes, "remote" island-based sondes and continental "inland" sondes.
- (Notice the ship in Libya.)

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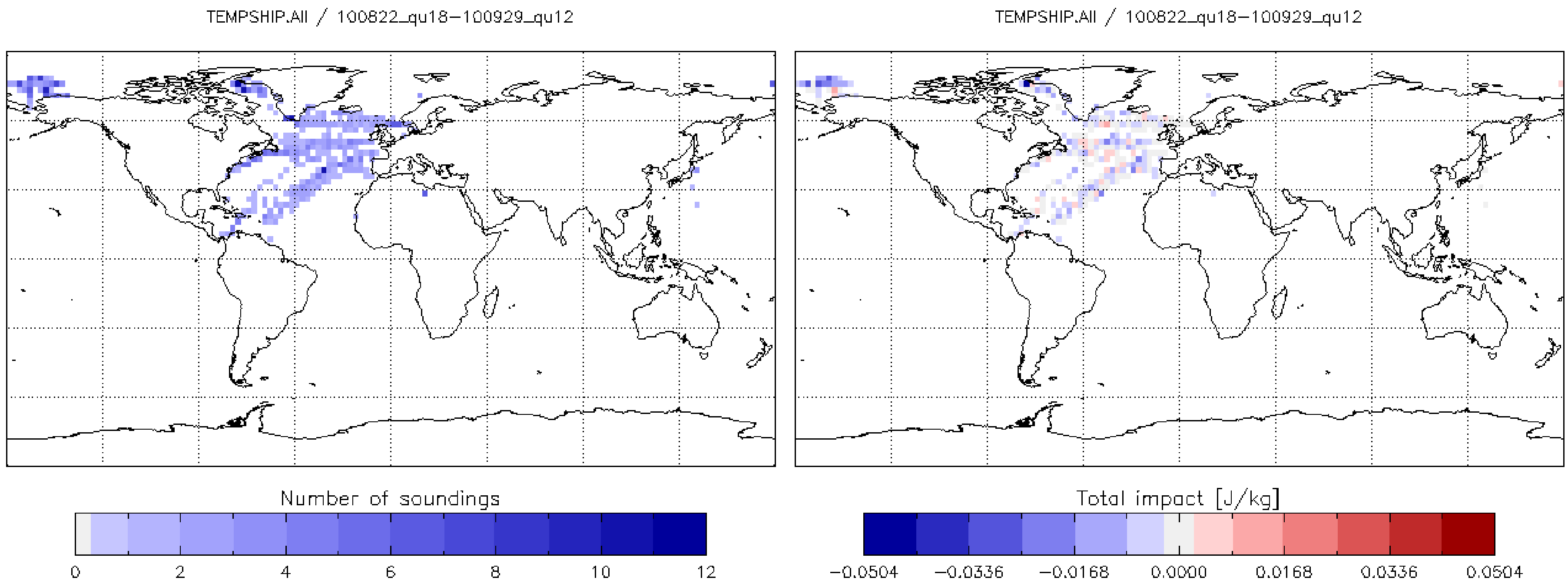
ASAP impacts



- Some detrimental impacts but the sample at any one location is small for this period.

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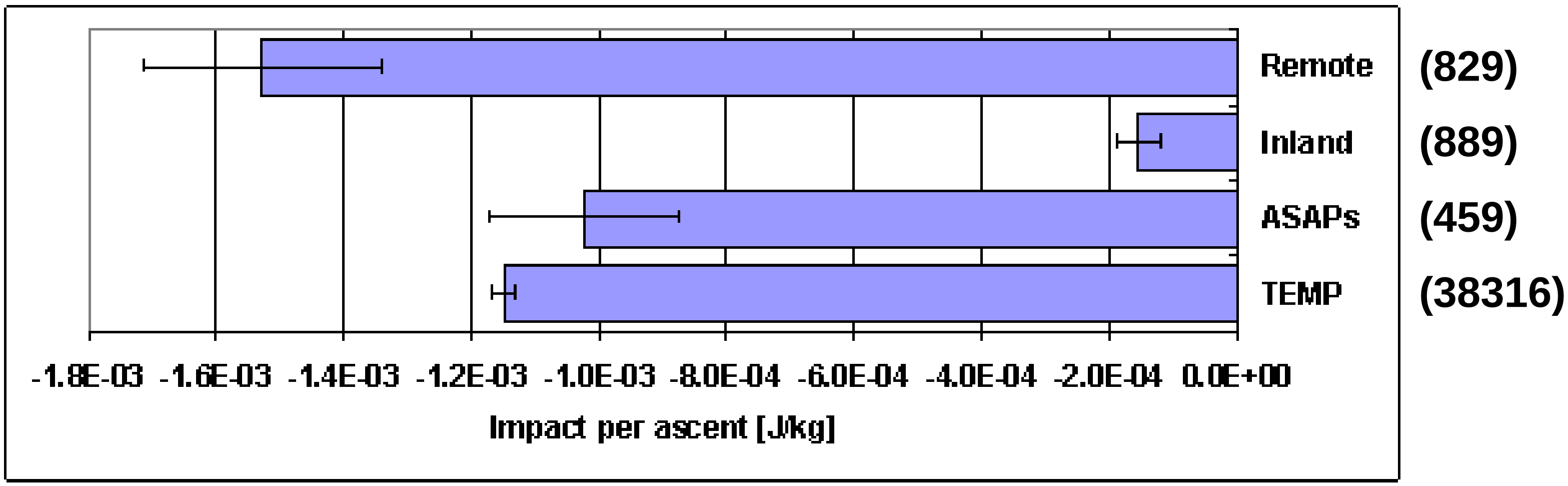
ASAP impacts



- Average ASAP impacts not as high as remote sondes.
- However, 8/18 remote sondes are in the SH and we have already seen that impacts there are larger.
- (Error bars denote the standard error in the mean, i.e. σ/√n

  Is this valid…?)

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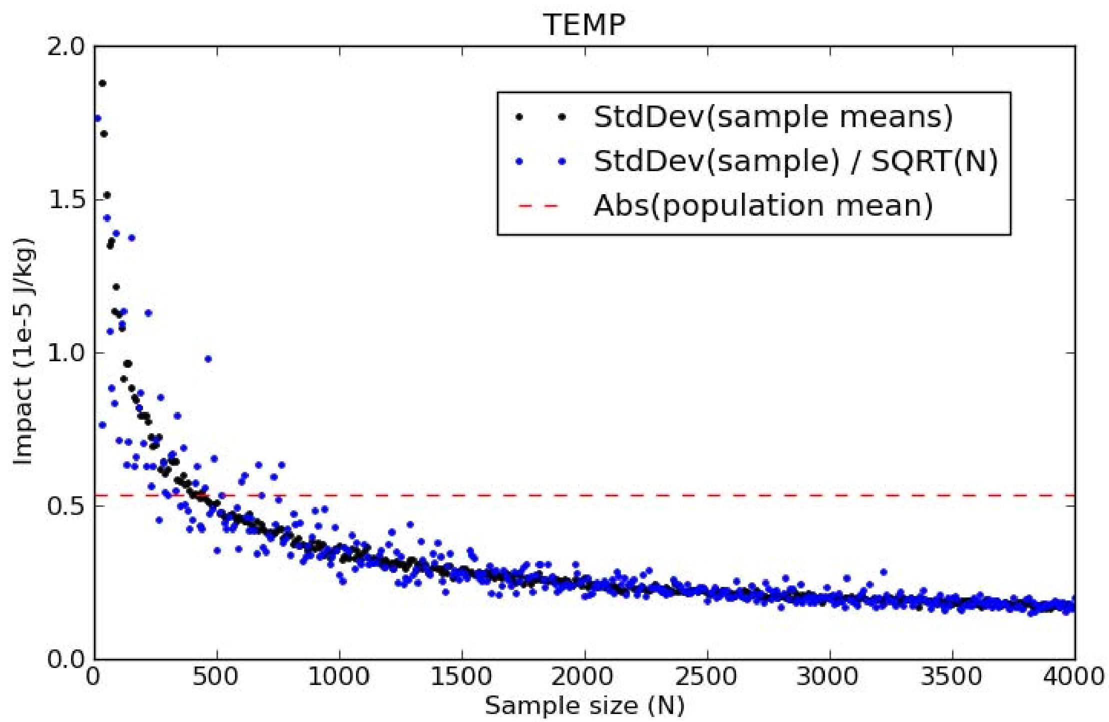
A quick note on confidence intervals

- Black dots represent the stdev of the mean of many random samples of obs from the full set (500 samples of N impacts from 119,670).
- Blue dots represent σ/√n for a single sample of N impacts.
- The red line is the absolute value of the mean for the 119,670 impacts.



- Quite large errors in σ/√n until larger sample sizes are reached.
- You can only have confidence in your confidence intervals after about 1500 to 2000 obs.

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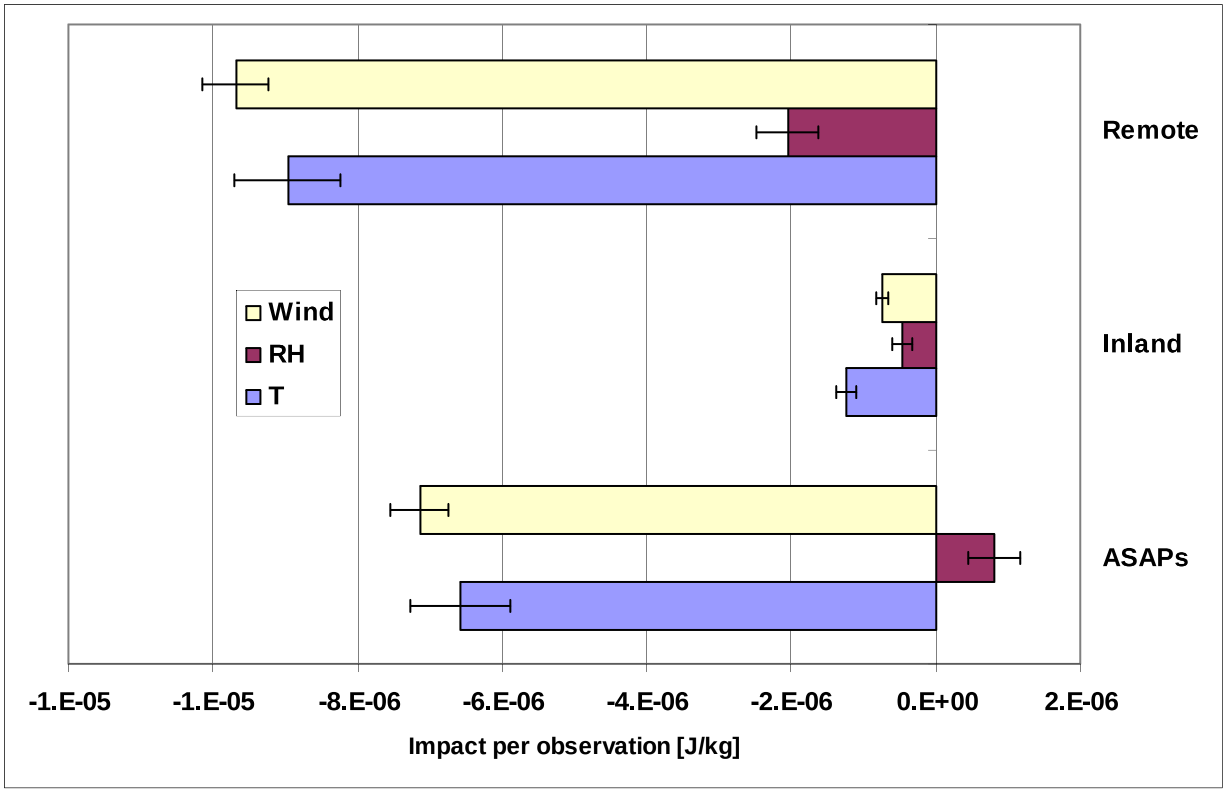
Impact breakdown



(103896)
(51348)
(55857)
(128530)
(55403)
(64528)
(57706)
(27188)
(30623)

- Problem with ASAP RH?

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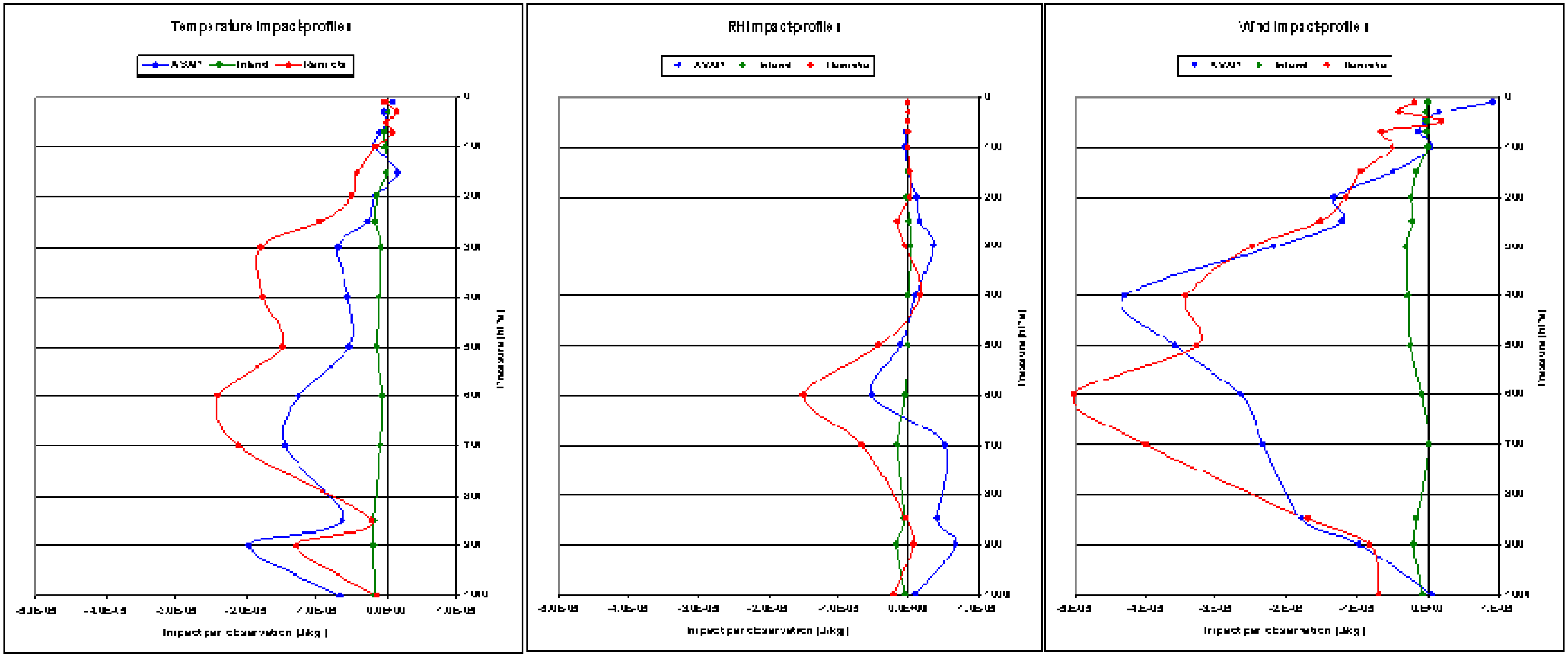
Impact breakdown



- ASAP profiles have similar features to remote island sondes.
- Possible model boundary layer RH problem over oceans?

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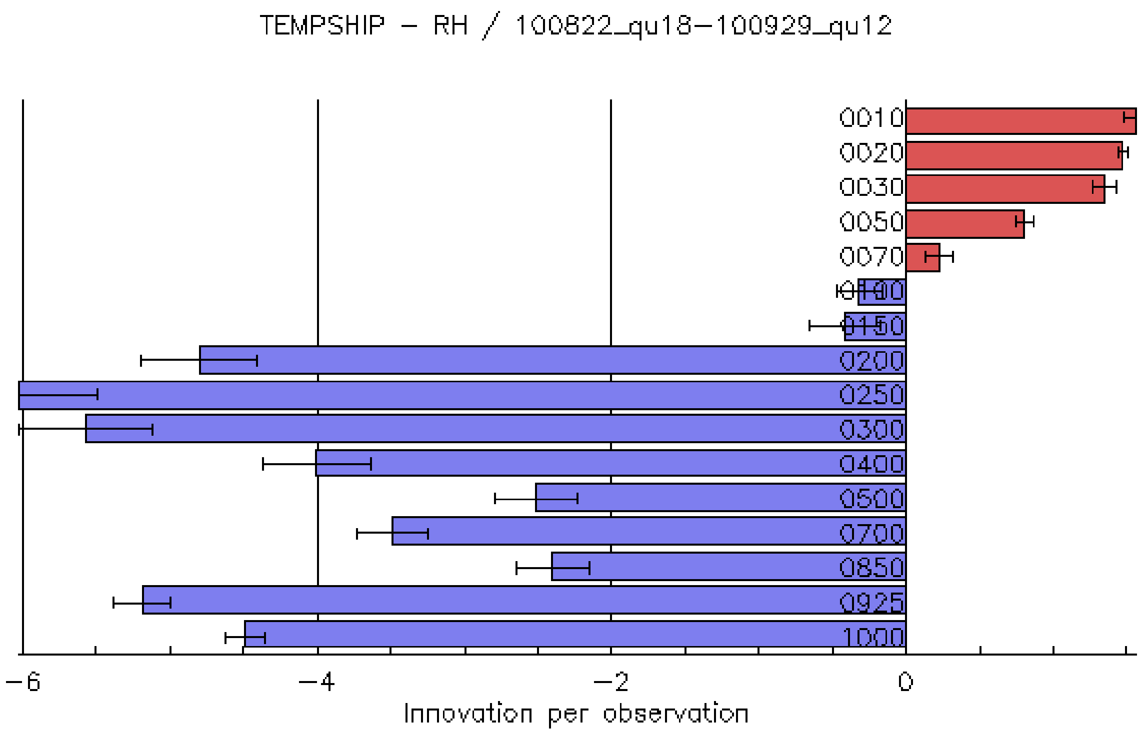
ASAP O-Bs



- Evidence of bias in O-Bs.
- Model boundary layer problem?
- Radiative-drying effects up to tropopause (~200 hPa)? (No RH bias correction is performed at UKMO.)

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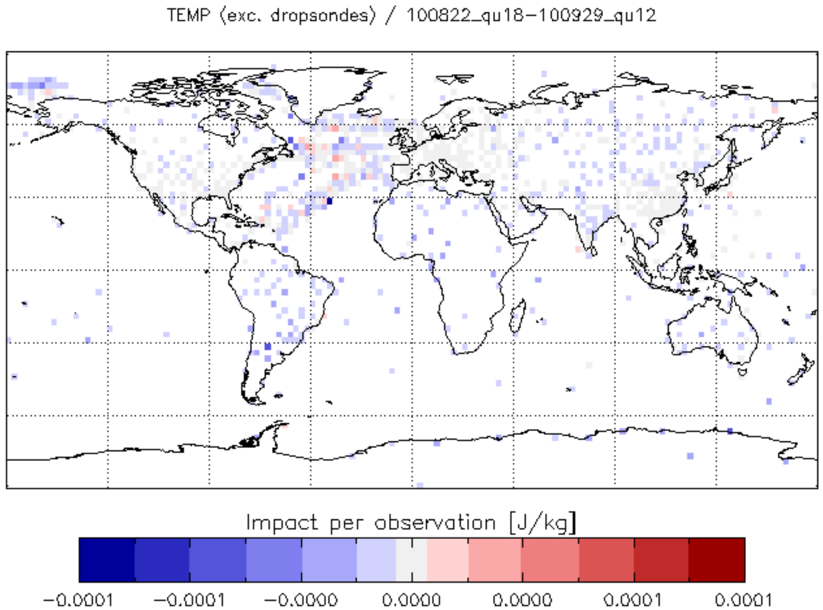
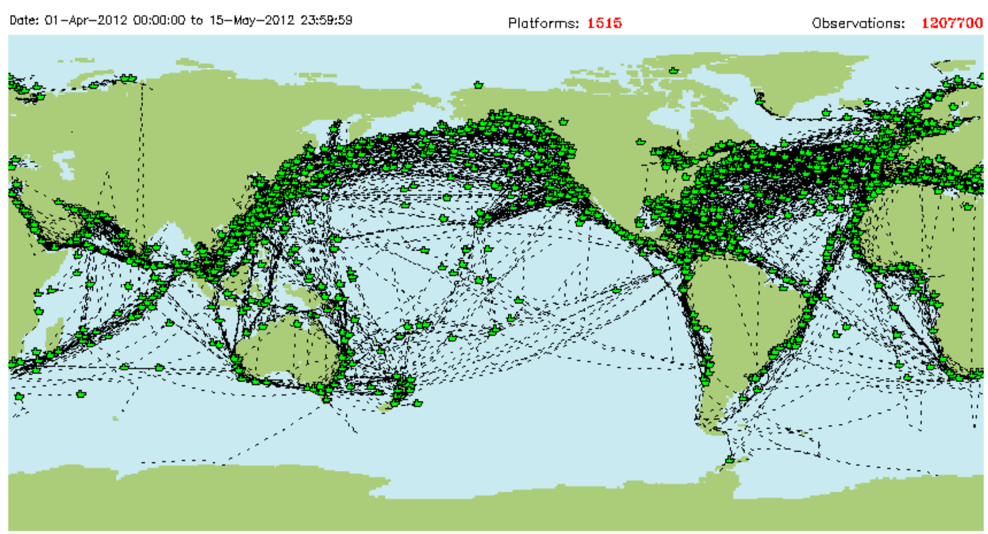
TEMP impacts



- TEMP impact per observation is generally largest over the Atlantic.
- Impact per observation likely to be larger still over tropical and SH ocean.



VOS shipping routes (Apr/May 2012)

- No ASAPs for the Spain → South America route. (At least not in 2010.)
- Make use of Pacific/Indian Ocean ships?

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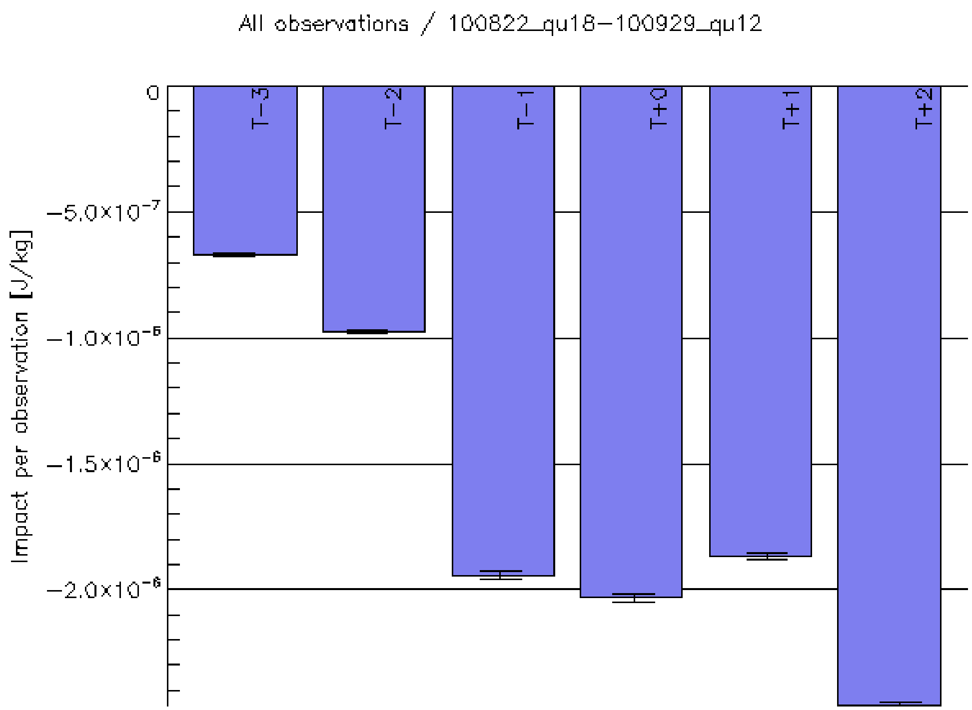
Observation times



- In 4D-Var systems observations towards the end of the assimilation time-window have a larger impact.
- This is because the error-modes which are corrected are those which have grown and will ultimately affect the forecast.

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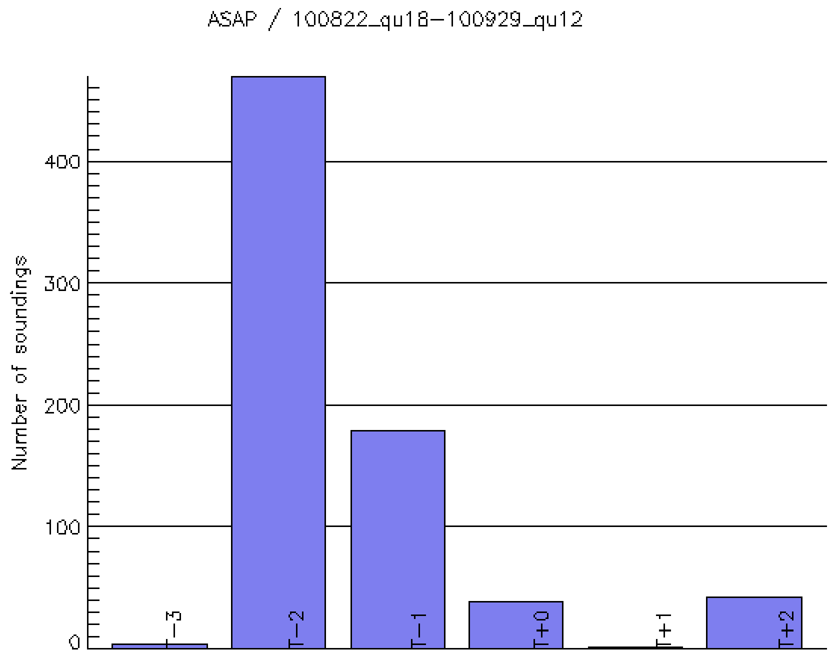
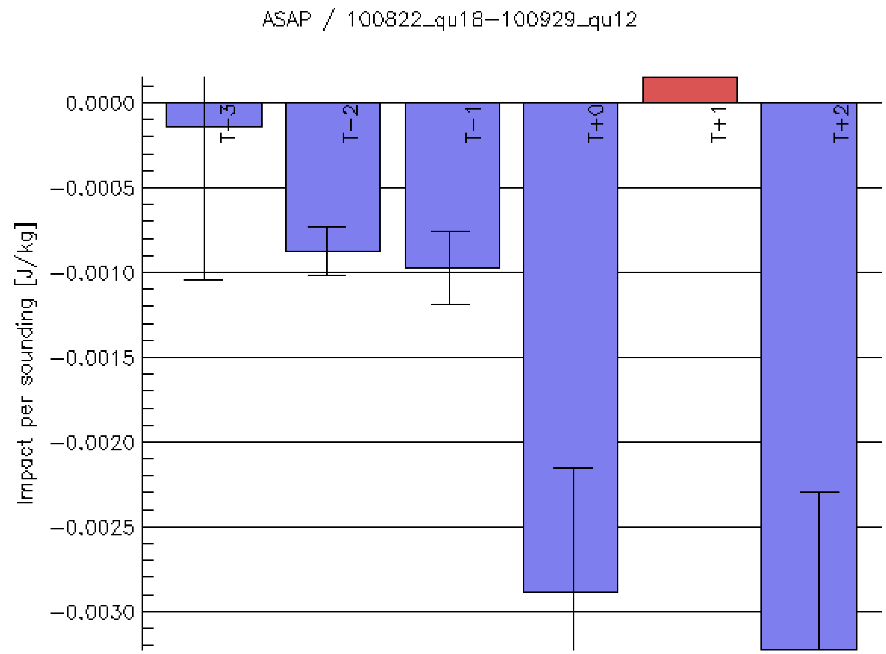
ASAP launch-time





- ASAP launch procedure (which apparently takes 20 mins) is usually started 60-90 mins before the main synoptic hour, presumably because the ascent can last up to ~2 hours.
- Impacts in 4D-Var systems could be greatly improved by releasing later (although probably to the detriment of 3D-Var systems).
- Improvements might also be gained by assimilating sonde obs using the actual observation time rather than the time of release.

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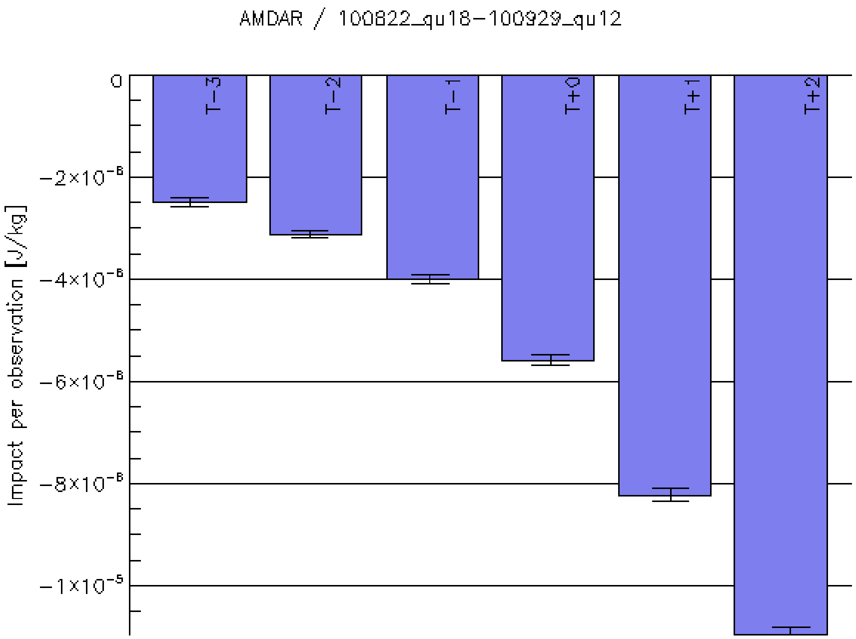
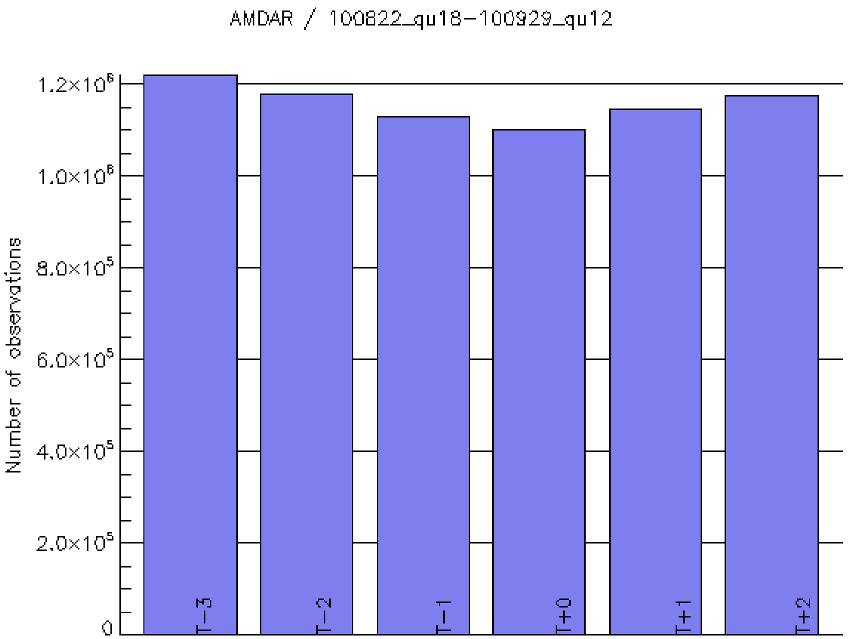
AMDAR observation times





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Ideas for ASAP network improvements

- Encourage the initiation of Pacific/Indian Ocean programs. (ASAP sondes are far more beneficial than inland sondes, at least in Europe.)
- Try to make more use of shipping routes which pass into the tropics and SH.
- Instruct observers to always use default (GPS-based) locations.
- Use the reported time at each observed level in 4D-Var to gain advantage of the larger impacts to be had later in the assimilation time-window.

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AMDARs

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UK AMDARs case-study

- Additional AMDARs received from easyJet flights throughout the UK on a trial basis from Nov 2010 – May 2011.
- Extending the supply period would mean committing to a three-year contract at a cost of roughly US $15,000 per month.
- AMDAR data from regional UK airports seen as one of the solutions for meeting convective-scale NWP requirements for higher temporal and spatial resolution data.
- Only global FSO results available for Sept - Dec 2010 and for 12 UTC runs only.

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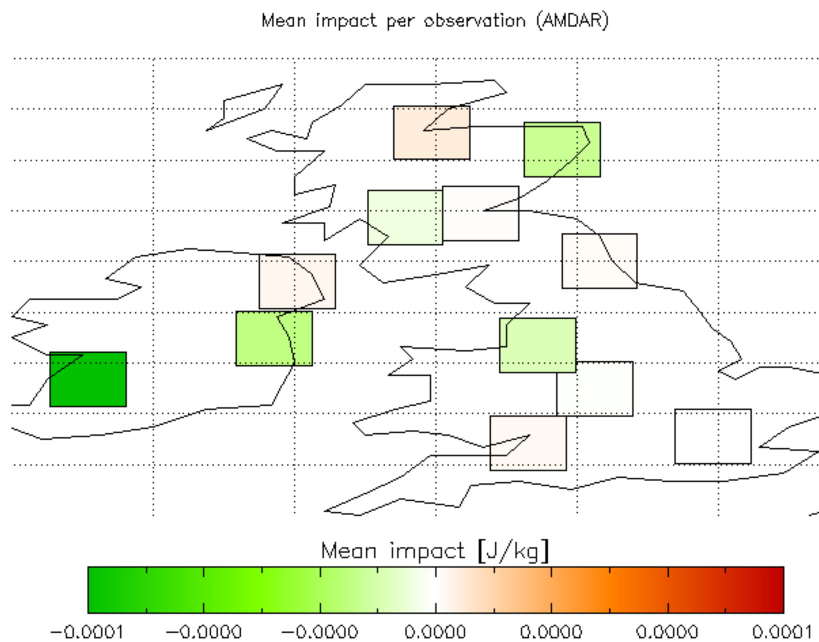
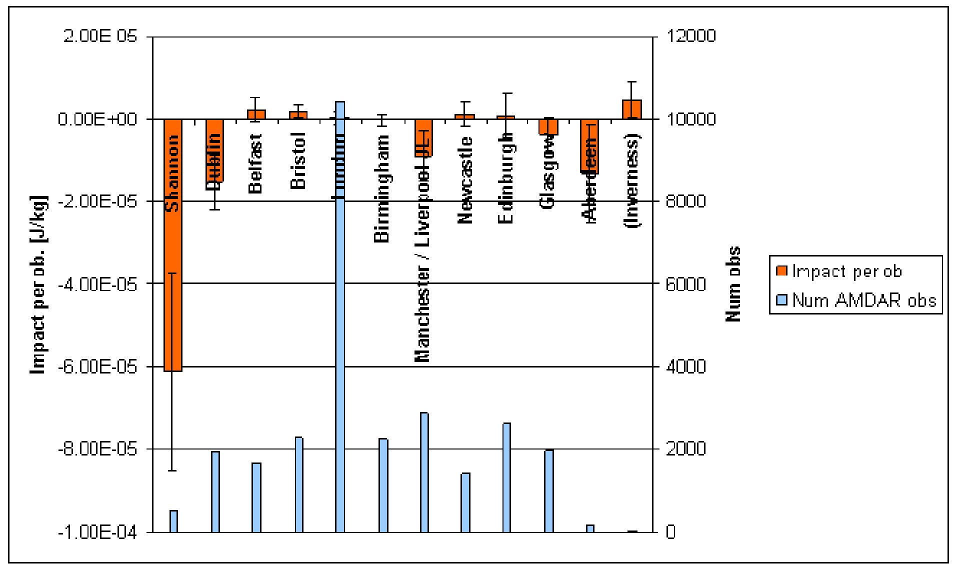
UK AMDARs





- Results suggest that we may be paying for AMDARs over London airports which are having no measurable impact.
- Remember though that the high-density data could be having a beneficial impact in regional models.

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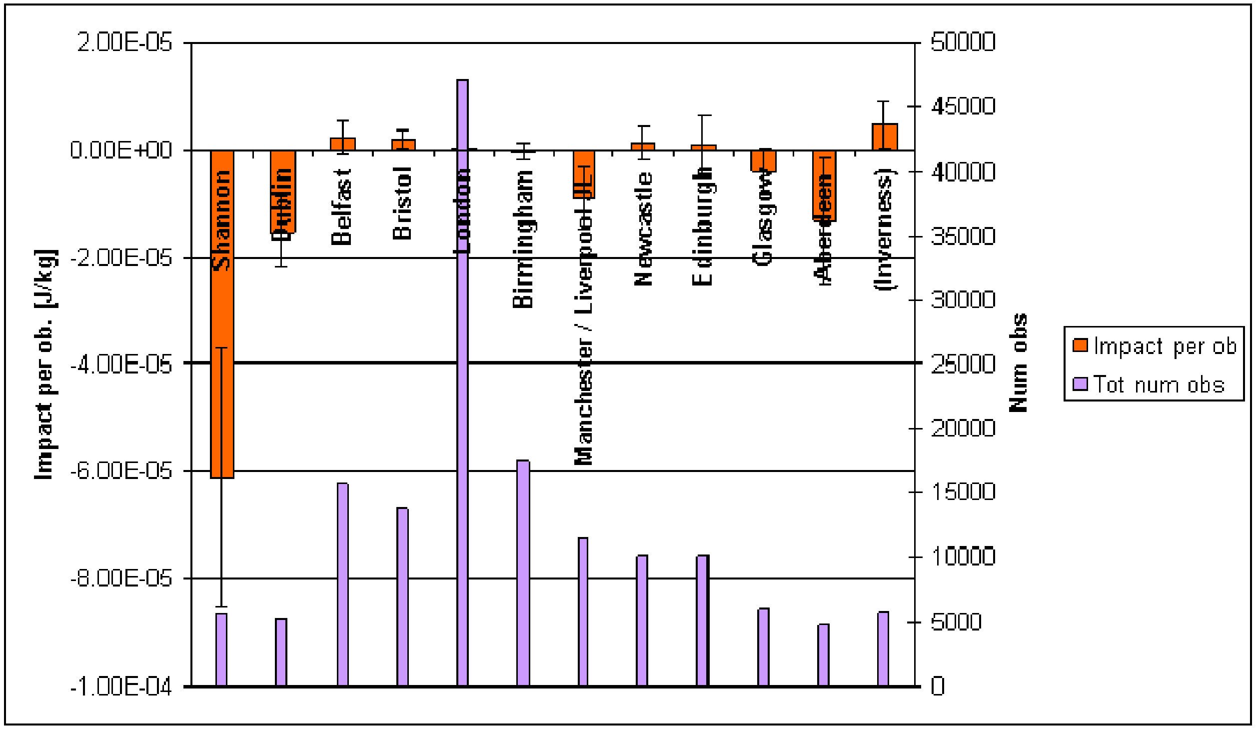
UK AMDARs



- All statistically significant impacts are beneficial.
- There is correlation between impact per AMDAR observation and the total number of observations in the region.
- **Lesson** – we need obs in data-sparse areas!

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Global AMDAR network considerations

- Number of vertical profiles from each airport.
- Ascent/descent sample rates.
- Locations for flight-level sampling.
- Flight-level sample rates.
- Data targeting strategies. (Which airports/airlines to collaborate with.)
- Cost.
- NWP data-thinning strategies.

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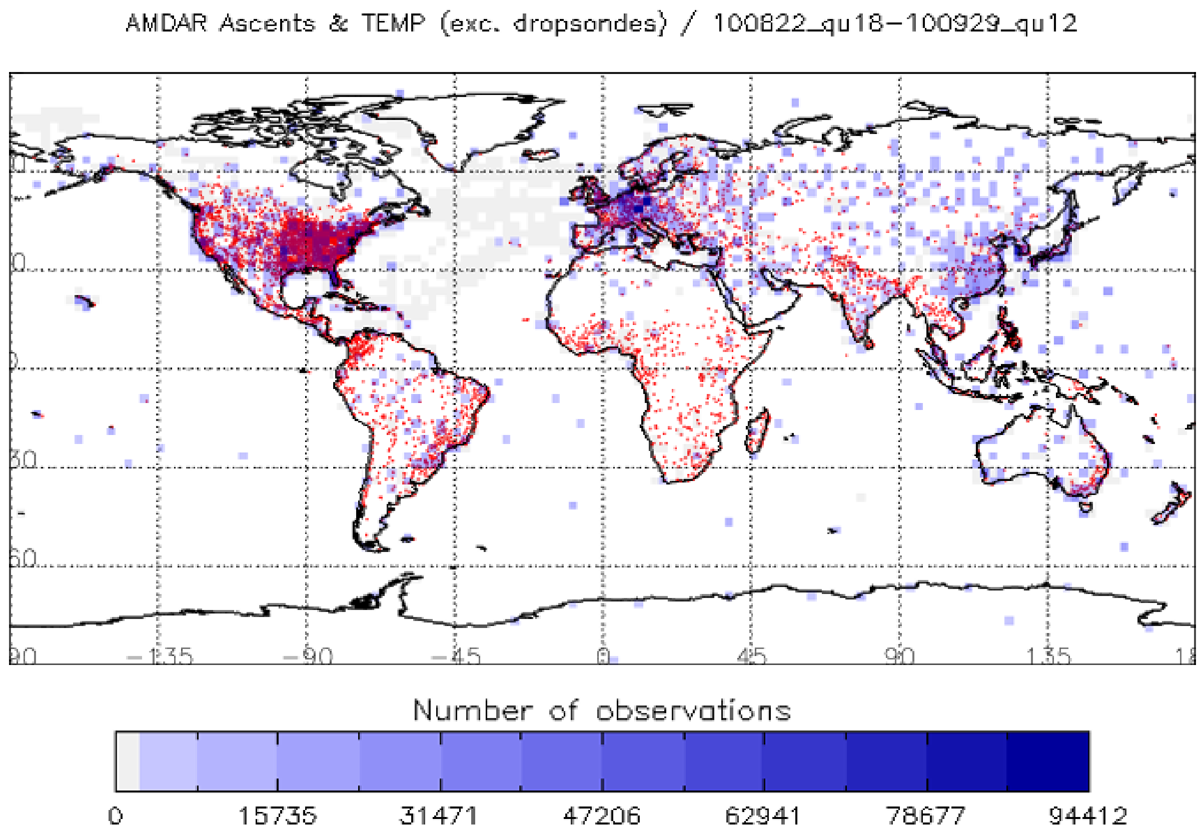
AMDAR and Sonde profile coverage

Airports shown in red

- Together with sondes there is a good land coverage of vertical temperature and wind profiles - except for over Africa.
- There looks to be an untapped crop of airports spread over Africa and also in Colombia/Venezuela.
- (African coverage currently provided by EUMETNET and South Africa.)
- (South American coverage currently provided by USA and EUMETNET.)



- What is the status of the EUMETNET ASECNA collaboration project in Africa?

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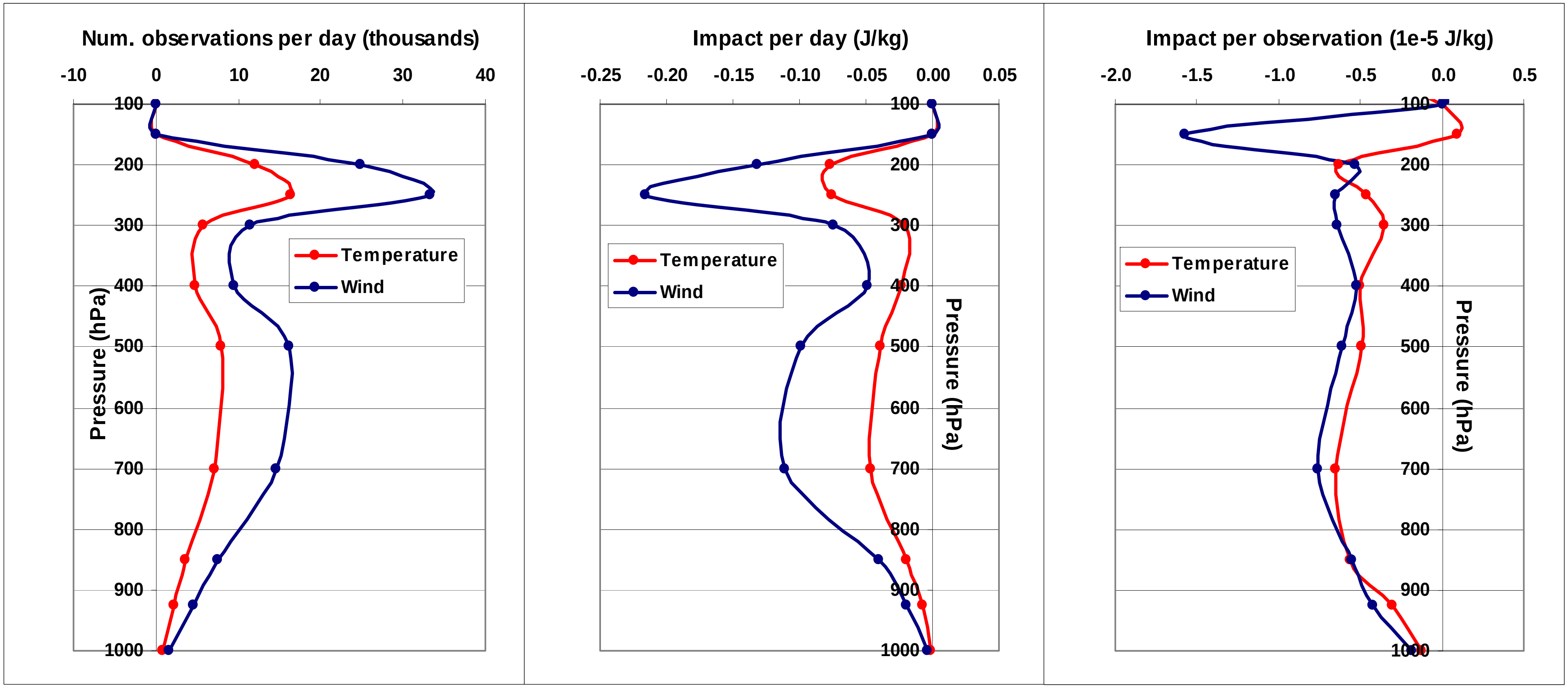
Global AMDAR impact



- Obs beneficial at all levels.
- Slightly more impact from flight-level obs in total (>400 hPa).
- Twice as much impact from wind observations.

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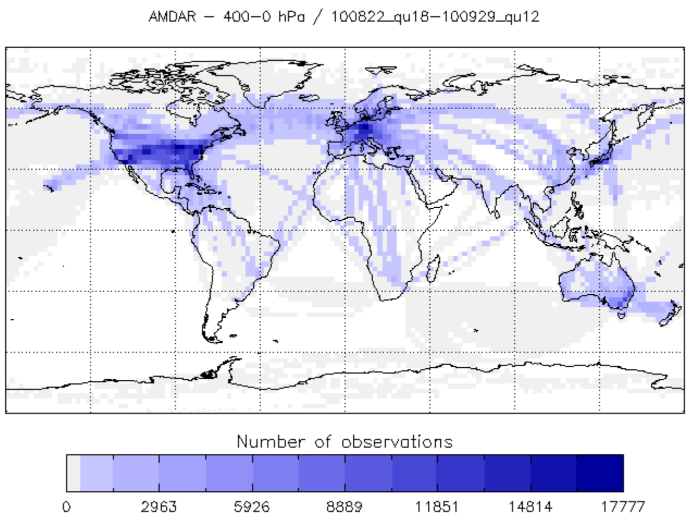
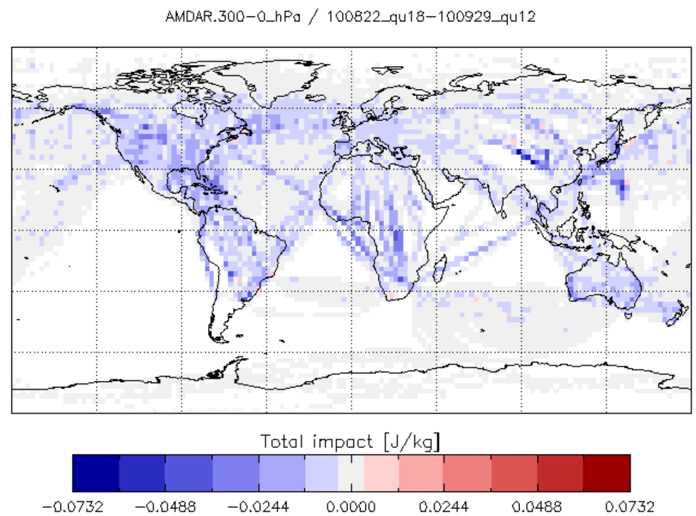
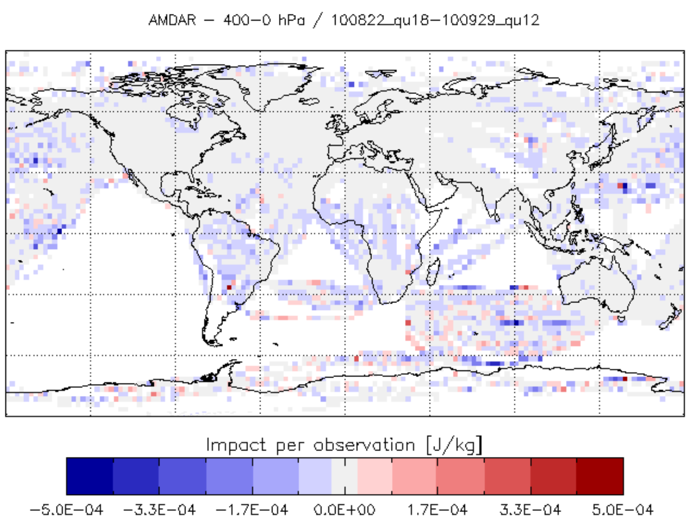
Global AMDAR impact

Flight-level (400-0 hPa)







- Fairly uniform total impact globally despite concentrated regions of observations over Europe and USA.
- Impact per ob. large over southern Indian Ocean, South Atlantic and Pacific but total impact is small.
  - Increase flight-level sampling rate in those locations?

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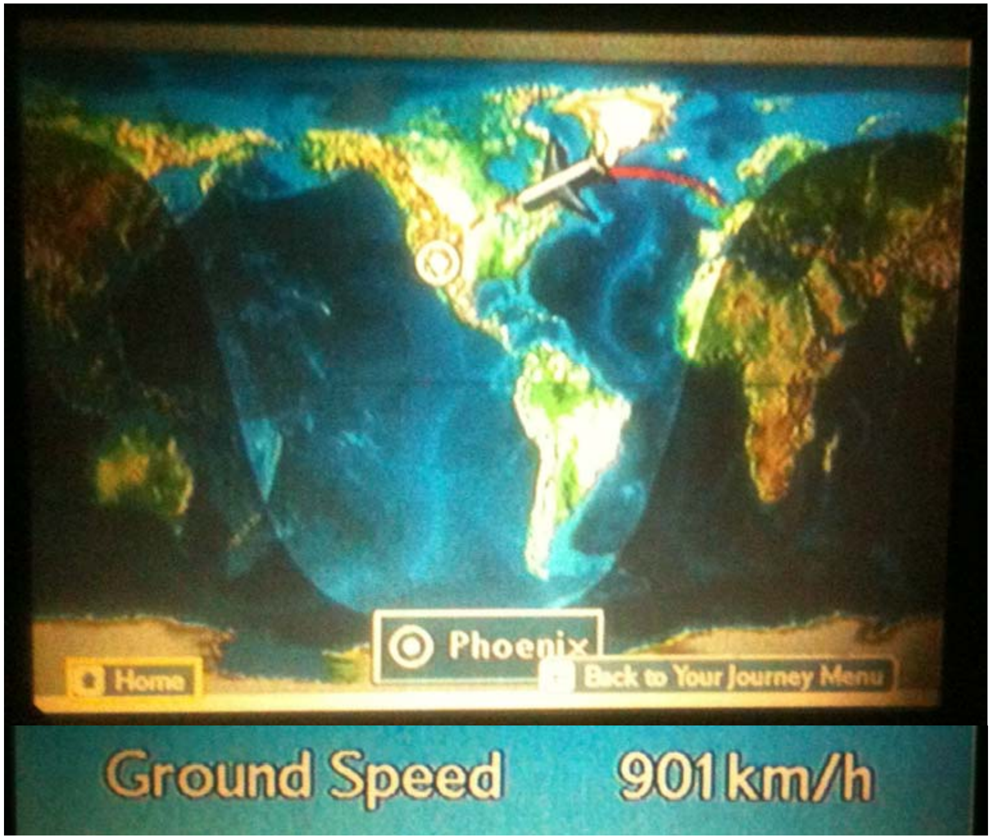
AMDAR flight-level sampling rates



- Current UKMO AMDAR thinning: 80km, 120mins, 50hPa.
  - At a speed of 900 km/h, 1 ob every 80km requires a sample interval of 5.3mins.
- N216 Var (~60km) should be able to cope with one ob. every 4.0mins.
- N320 Var (~40km): 2.7mins
- Default flight-level AMDAR sampling interval of 7mins.

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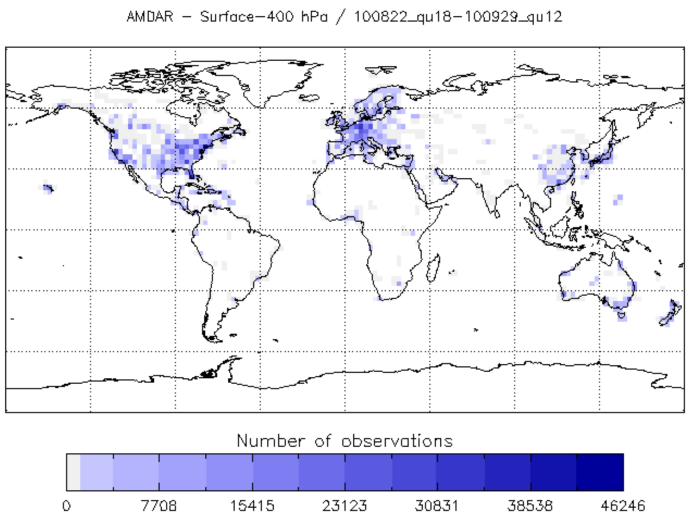
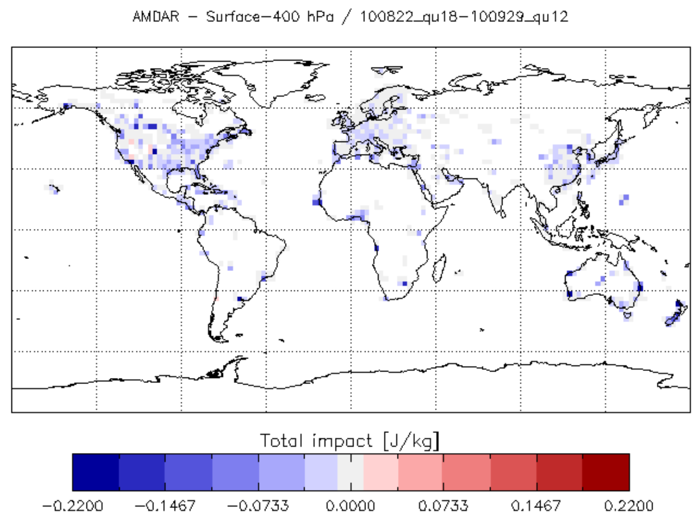
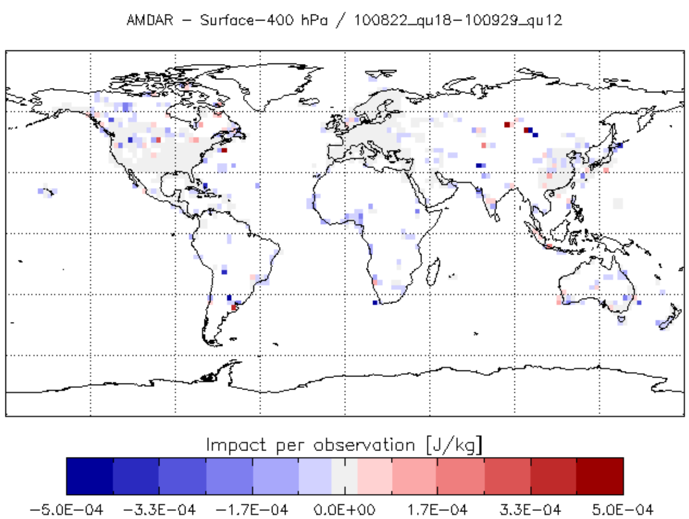
Global AMDAR impact

Ascent/Descent (Surface-400 hPa)







- Very non-uniform coverage at lower levels.
- Impacts mixed but detrimental impacts tend to be small – could be sampling errors.
- Impacts per ob. very small over Europe and USA.
  - Could decrease sample rates although obs are cheaper over land anyway.

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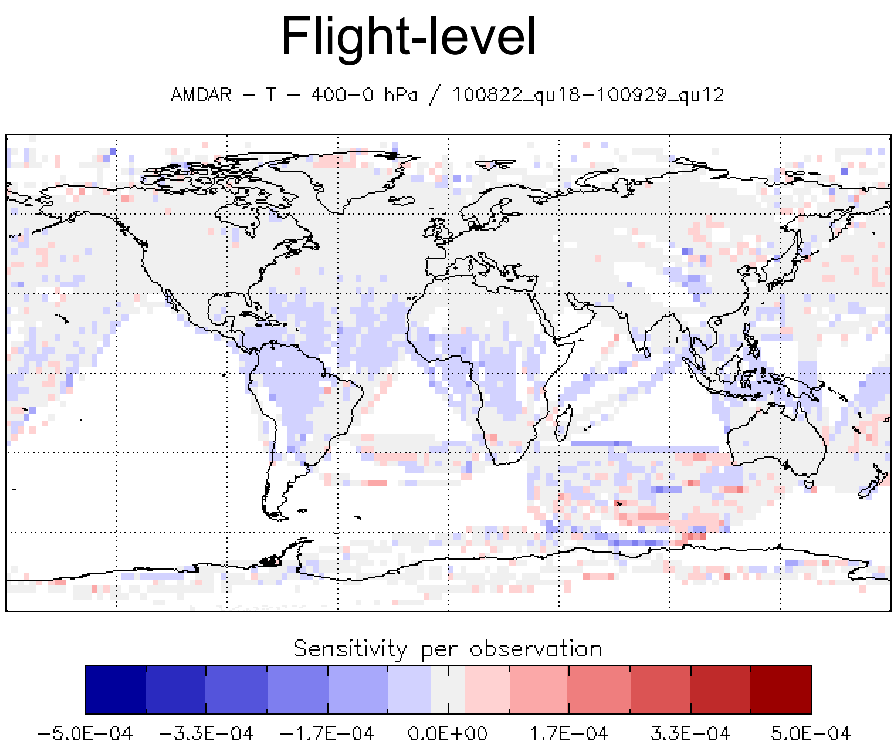
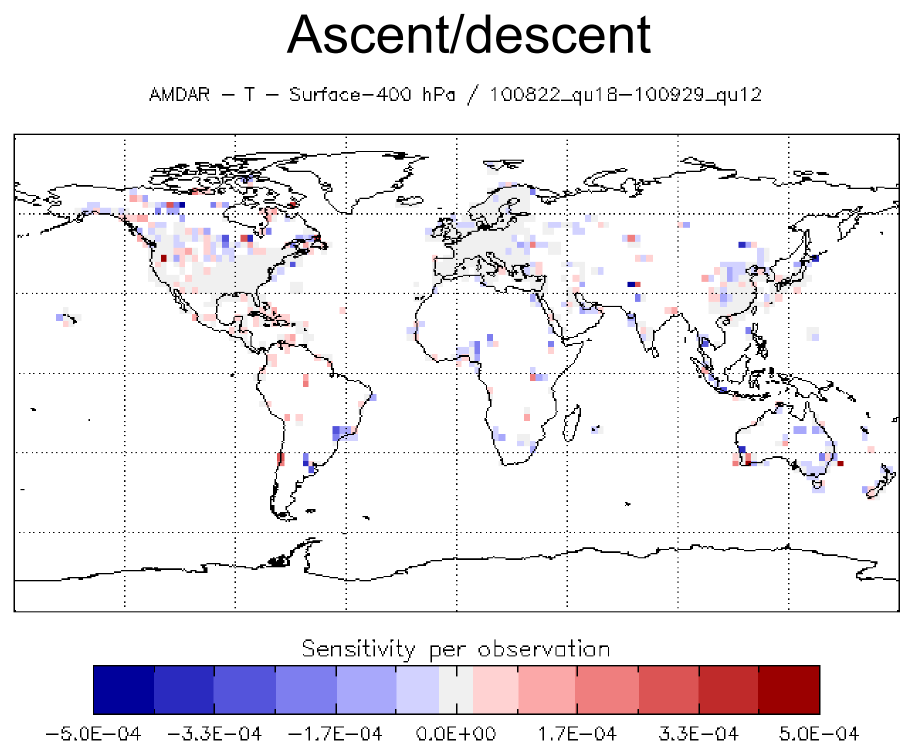
Global AMDAR impact

Sensitivity to temperature observations





- Little sensitivity to flight-level temperature obs in the NH.
- Fairly uniform sensitivity at lower levels (except over Europe and USA). This implies that we can probably still benefit from more (good quality) profiles in the NH.

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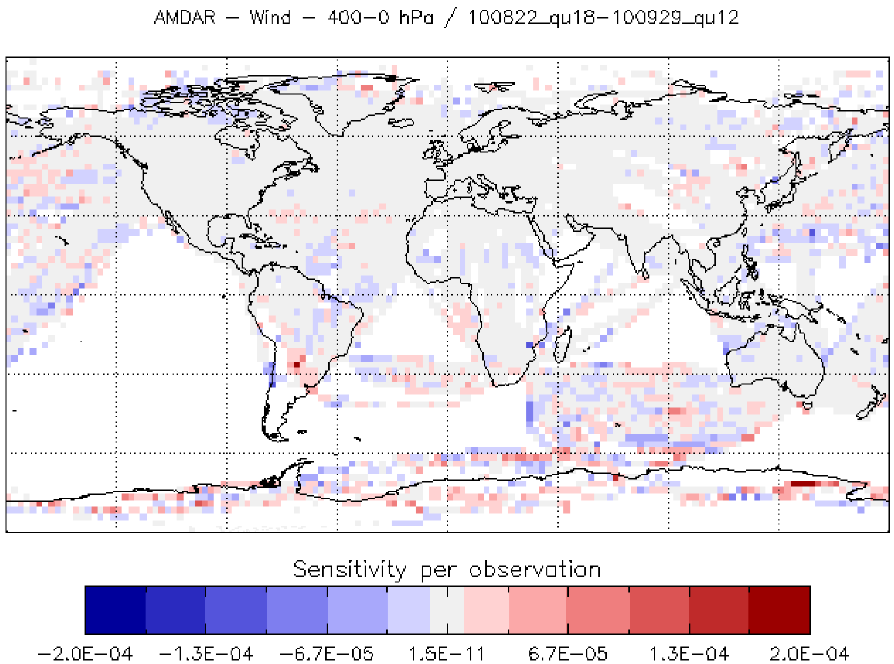
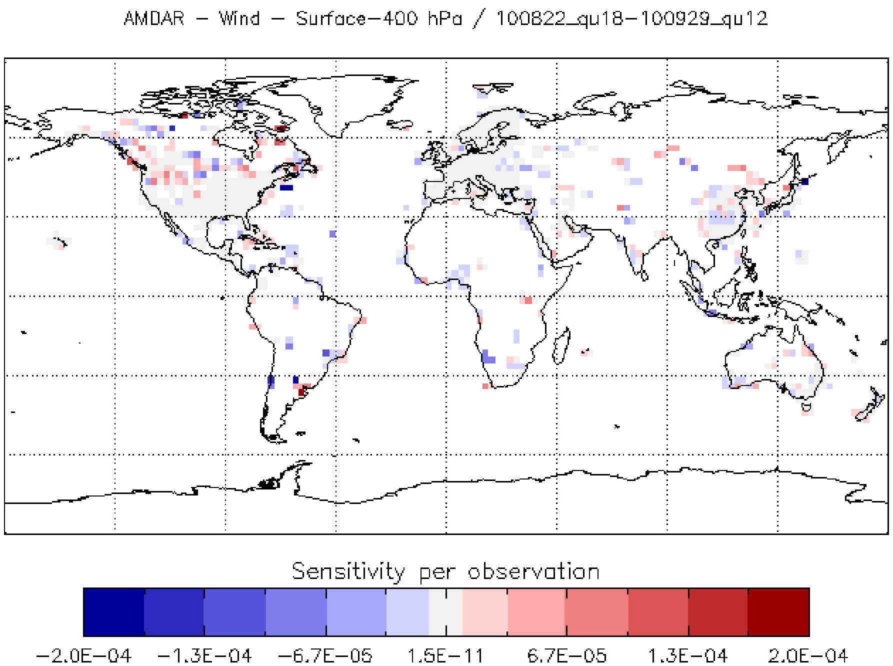
Global AMDAR impact

Sensitivity to wind observations

Flight-level



Ascent/descent



- Similar result for sensitivity to wind observations.

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Ideas for AMDAR network improvements

- Increase number of vertical profiles outside USA and Europe.
  - Ensure any collaboration projects with South America and Africa (ASECNA) come to fruition.
- Increase flight-level sample rates over southern Indian Ocean, South Atlantic and Pacific.
- Potential cost-savings over USA and Europe. Convective-scale results would be interesting.

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Summary

- Conventional data more important than satellite data in the NH.
- TEMP and AMDAR most important conventional ob-types (followed by SYNOP).
- ASAP impact per ob is high but there are few of them. (Four times per day? TR/SH Atlantic shipping routes + Pacific/Indian Oceans?)
- Use true sonde observation times in 4D-Var assimilations.
- UK AMDAR study showed information saturation in the global model and correlation between large impacts and few other observations.
- Scope for more AMDAR profiles in Africa and northern South America.
- Low AMDAR saturation over southern Indian Ocean, South Atlantic and Pacific. - Room for increased sample rates in modern DA systems.

Questions...

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