觀測資料對中央氣象局WRF模式預報誤差影響之評估

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Outline

- Introduction of FSO (Concept of FSO)
- Implementation in WRF
- Applications
- Summary
- Limitations and improvements

Introduction of FSO

- Forecast Sensitivity to Observations (FSO) is a diagnostic tool.
- Using an adjoint technique, we can trace it back to the observations used in the analysis.
- It is possible to evaluate the accuracy of NWP forecasts.
- We can determine quantitatively which observations improved or degraded the forecast.
- NWP centers (NRL,NASA,ECMWF,NCAR….) use FSO routinely to monitor their Data Assimilation and Global Observing System.

Concept of FSO

$$\delta e_f^g = \left\langle \left(y - Hx_b\right), \frac{\partial J_f^g}{\partial y} \right\rangle = \left\langle \delta x_a, \frac{\partial J_f}{\partial x_a} + \frac{\partial J_g}{\partial x_b} \right\rangle \approx \left\langle (x_f - x_g), \frac{\partial J_f}{\partial x_f} + \frac{\partial J_g}{\partial x_g} \right\rangle$$

Obs space

(Linear)

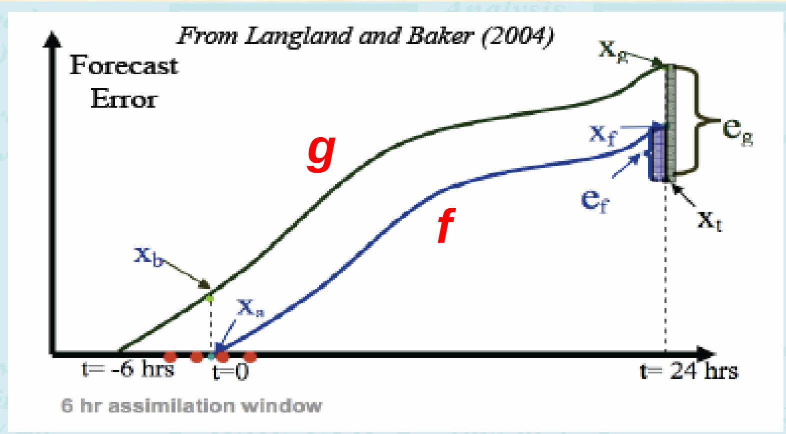
Grid point space

(Linear)

Direct from model

(Nonlinear)

Two nonlinear forecasts *Xf* and *Xg*
Xf start from analysis (Xa)
Xg start from background (Xb)
All verify analysis (Xt)



Define quadratic measures of two forecast errors

$$e_f = \left\langle (x_f - x_t), C(x_f - x_t) \right\rangle \quad \text{(A0)}$$

$$e_g = \left\langle (x_g - x_t), C(x_g - x_t) \right\rangle \quad \text{(A1)}$$

The difference between the errors of forecasts

Xf and *Xg* is

$$\Delta e_f^g = e_f - e_g \quad \text{(A2)}$$

$$\delta x_a = x_a - x_b = K(y - Hx_b)$$

$$J_f = \frac{1}{2} e_f = \frac{1}{2} \left\langle (x_f - x_t), C(x_f - x_t) \right\rangle \quad \text{(A3)}$$

$$J_g = \frac{1}{2} e_g = \frac{1}{2} \left\langle (x_g - x_t), C(x_g - x_t) \right\rangle \quad \text{(A4)}$$

$$\frac{\partial J_f}{\partial x_f} = C(x_f - x_t) \quad \text{(A5)}$$

$$\frac{\partial J_g}{\partial x_g} = C(x_g - x_t) \quad \text{(A6)}$$

$$\Delta e_f^g = \left\langle (x_f - x_g), \frac{\partial J_f}{\partial x_f} + \frac{\partial J_g}{\partial x_g} \right\rangle$$

"Nonlinear" (A7) exact

"Direct from model"

If we assume this initial difference evolves in a tangent linear sense into a good approximation of the forecast difference $e_f - e_g$

We can estimate $x_f - x_g$ using $\delta x_a = x_a - x_b$ and sensitivity gradients which the adjoint model had mapped back to initial time along the two forecast trajectories ***(f,g)***

$$\delta e_f^g = \left\langle \delta x_a, \frac{\partial J_f}{\partial x_a} + \frac{\partial J_g}{\partial x_b} \right\rangle$$

"Linear" (A8) not exact

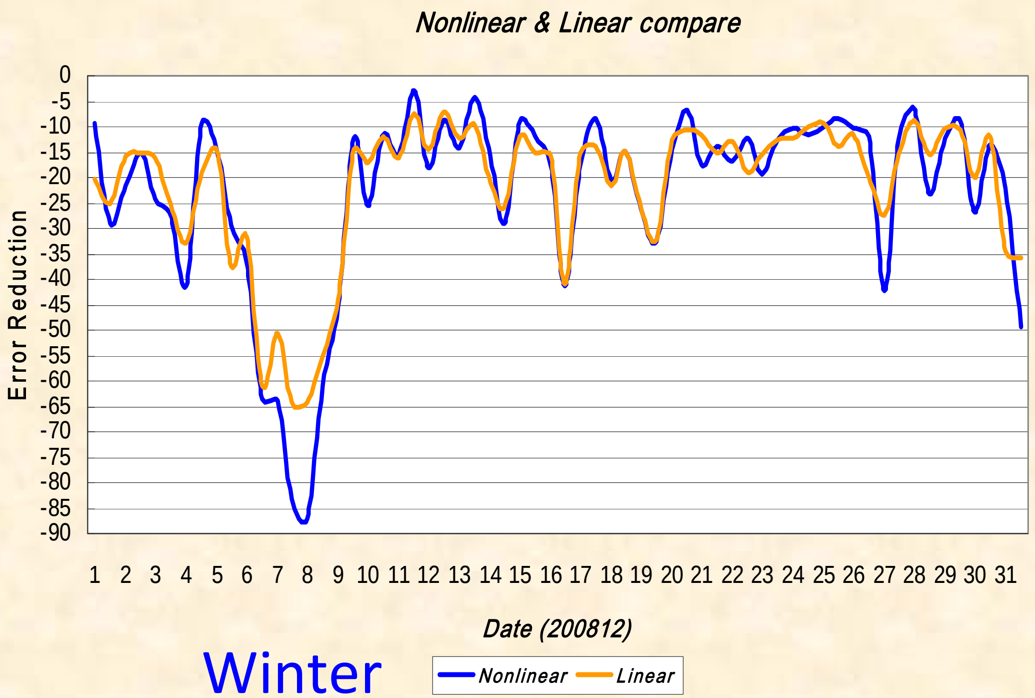
"Grid point space"

$$\delta e_f^g = \left\langle (y - Hx_b), \frac{\partial J_f^g}{\partial y} \right\rangle$$

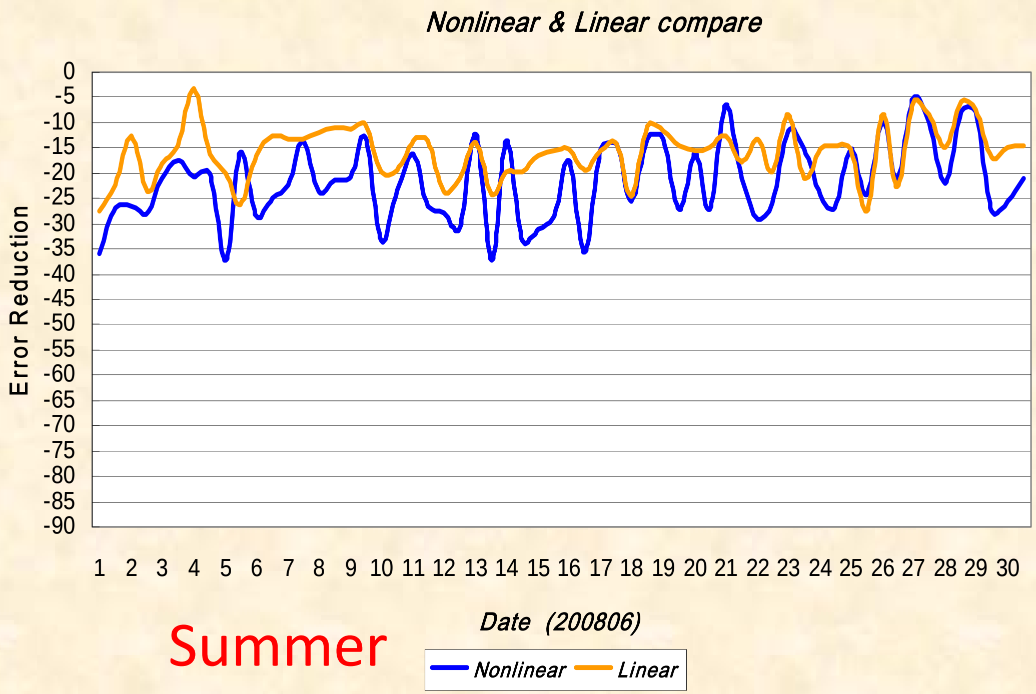
"Linear" (A9) not exact

"Observation space"

Non-Linear and Linear Comparison



Winter



Summer

Obs space

(Linear)

Grid point space

(Linear)

$$\delta e_f^g = \left\langle (y - Hx_b), \frac{\partial J_f^g}{\partial y} \right\rangle = \left\langle \delta x_a, \frac{\partial J_f}{\partial x_a} + \frac{\partial J_g}{\partial x_b} \right\rangle$$

$$\approx \left\langle (x_f - x_g), \frac{\partial J_f}{\partial x_f} + \frac{\partial J_g}{\partial x_g} \right\rangle$$

Direct from model

(Nonlinear)

夏季:非線性與線性差異較大

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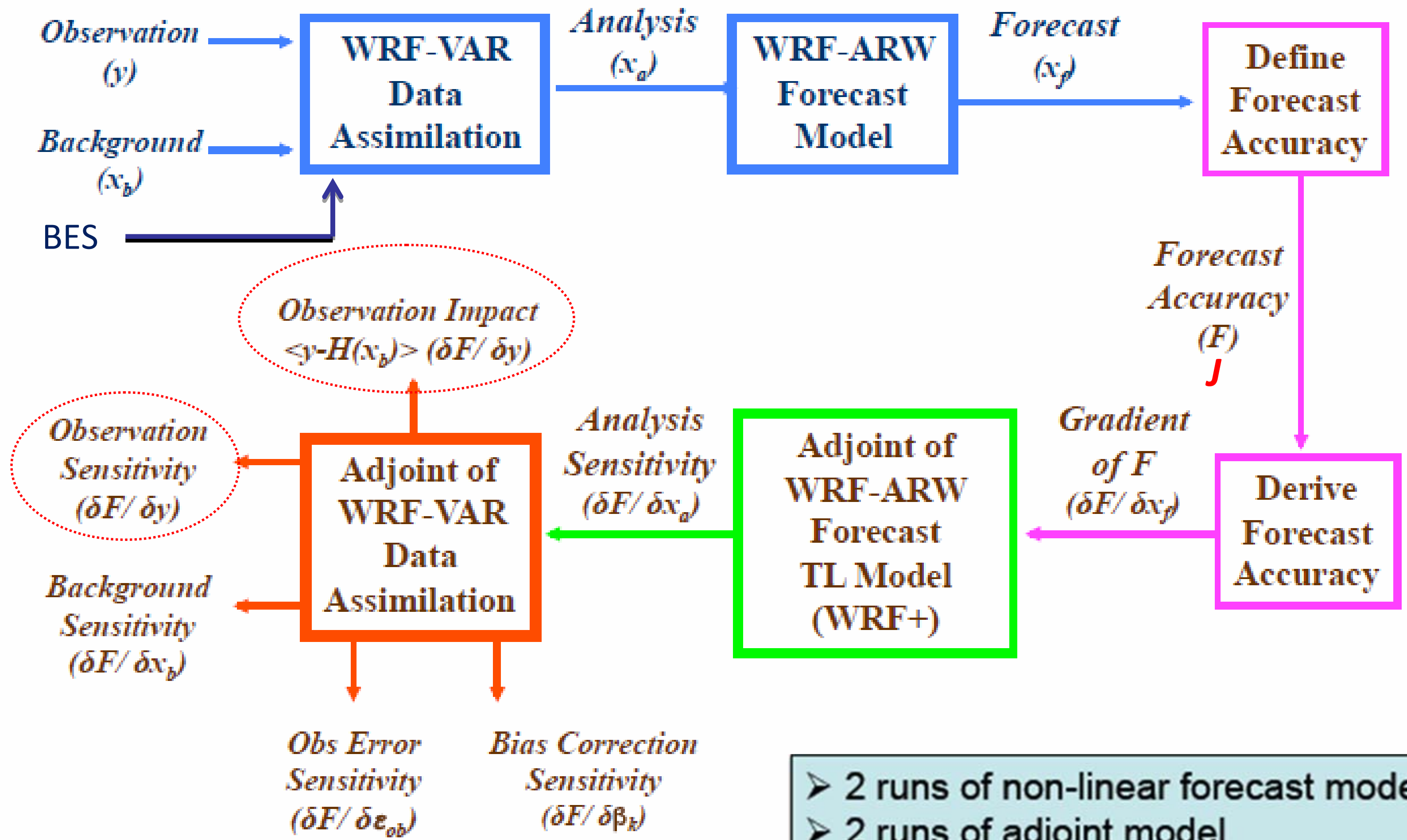
Implementation in WRF



- 2 runs of non-linear forecast model
- 2 runs of adjoint model
- 1 run of adjoint of analysis
- The computer cost is estimated to 10-15 times the cost of the forecast model.

- **Reference state**: Namelist `ADJ_REF` is defined as
  - 1: X^t = Own (WRFVar) analysis
  - 2: X^t = NCEP (global GSI) analysis ★
  - 3: X^t = Observations

- **Forecast Aspect**: depends on reference state
  - 1 and 2: Total Dry Energy ★

$$<\mathbf{x},\mathbf{x}> = \frac{1}{2}\iiint_{\Sigma}[u'^2 + v'^2 + \left(\frac{g}{\bar{N}\bar{\theta}}\right)^2 \theta'^2 + \left(\frac{1}{\bar{\rho}c_s}\right)^2 p'^2]d\Sigma$$

According to the characteristics of the WRF model, we define the dry energy norm using the WRF variables, especially the potential temperature and pressure:

$$J = \langle \mathbf{x}, \mathbf{x} \rangle = \frac{1}{2}\sum_{i,j,k}[u'^2 + v'^2 + (\frac{g}{\bar{N}\bar{\theta}})^2\theta'^2 + (\frac{1}{\bar{\rho}c_s})^2 p'^2] \quad (13)$$

where u', v', θ' and p' are the zonal, meridional winds, potential temperature and pressure perturbations, respectively, $\bar{N}$, $\bar{\theta}$, $\bar{\rho}$ and c_s are Brunt-Vaisala frequency, potential temperature, density, and speed of sound, respectively, at the reference level, $\mathbf{x}$ is the vector representing the atmospheric state and $\sum_{i,j,k}$ represents the selected model grids for verification. Please note that the current calculation of the J (13) in WRFDA FSO application is not a volume integration of the total dry energy norm within the verified domain and it is just a simple summation of the dry energy norm over all selected grid points. It will impact the

- Script variable `ADJ_MEASURE` defined as:
  - 1: first order
  - 2: second order
  - 3: third order
  - 4: variant of third order ★

Augmented third-order approximation

- Use WRF+ code to compute WRF-ARW adjoint with Namelist `ADJ_SENS=true`:
  - Activate pressure in the adjoint
  - Switch off intermediate forcing
- WRF+ is run for both trajectories from x_a and x_b
- Finally, both sensitivities are added together

Applications

Experiments design:

- **Model version (CWB OP24)**
  - WPS V3.3.1
  - WRFDA V3.3.1
  - WRF V3.3.1
  - WRFPLUS V3.3.1 (2011 version)
- **Period**

  Summer : 2008060100~2008063012

  Winter : 2008120100~2008123112
- **Focus** ：24hr forecast error

  Only run 00Z & 12Z
- **Reference** : NCEP analysis

CWB WRFDA

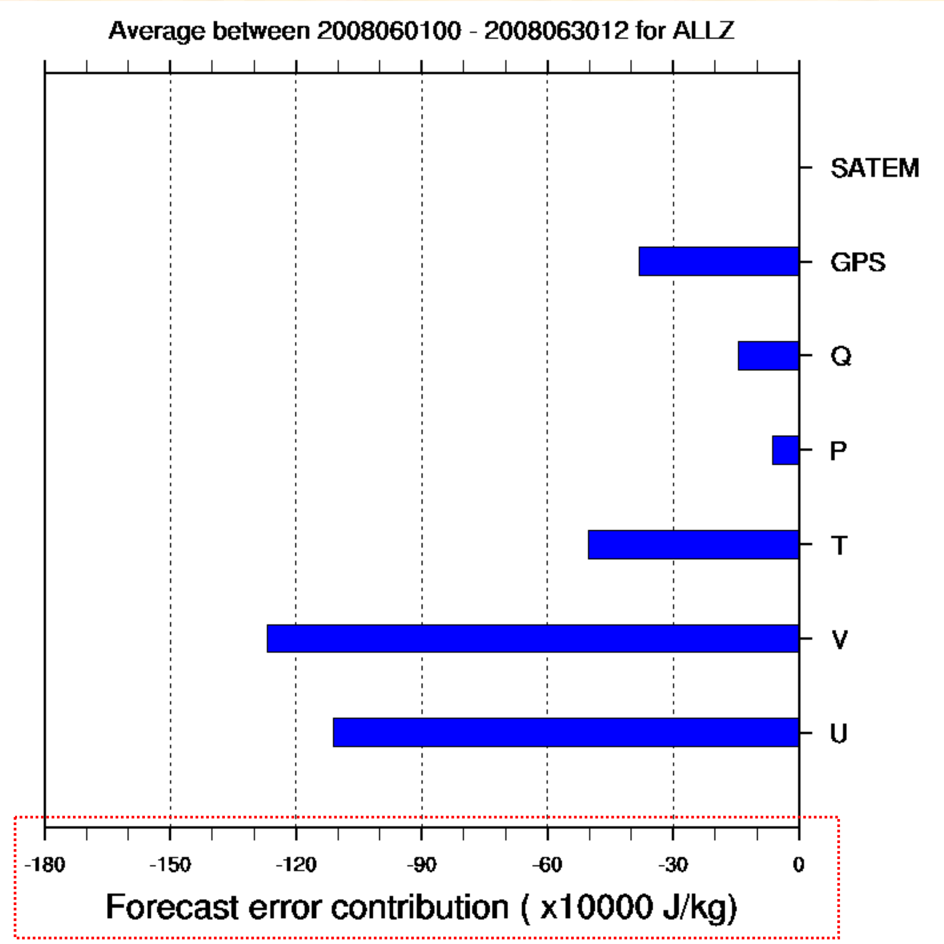
Ingested obs data :

Sound
Sonde_sfc
Synop
Geoamv
Pilot
Metar
Ship
Qscat
Buoy
Airep
Satem
Gpsro
EC_bogus

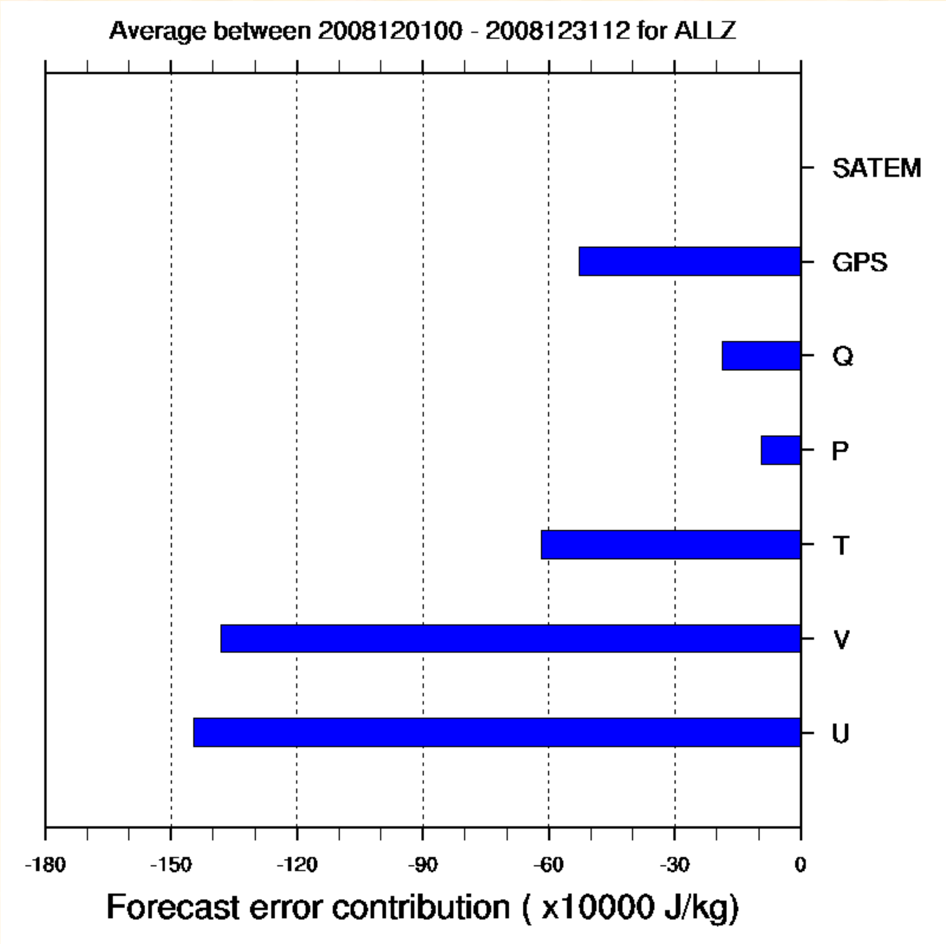
Results

2008

Summer & Winter

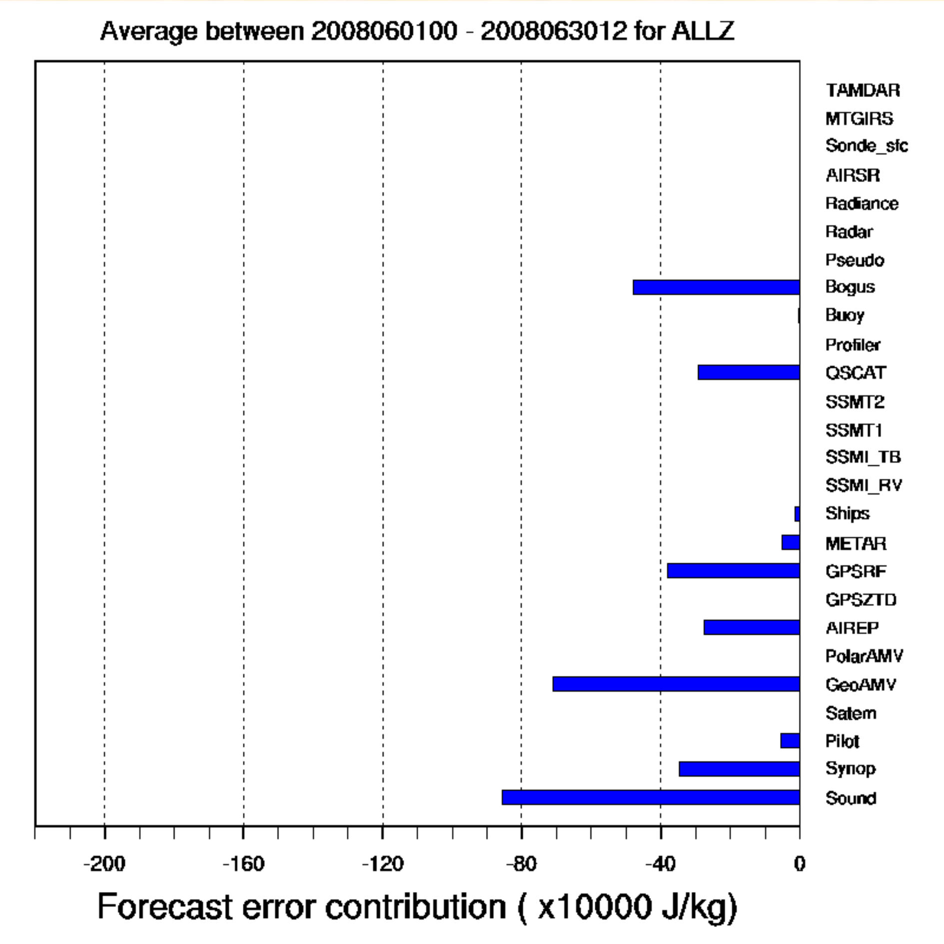


Summer

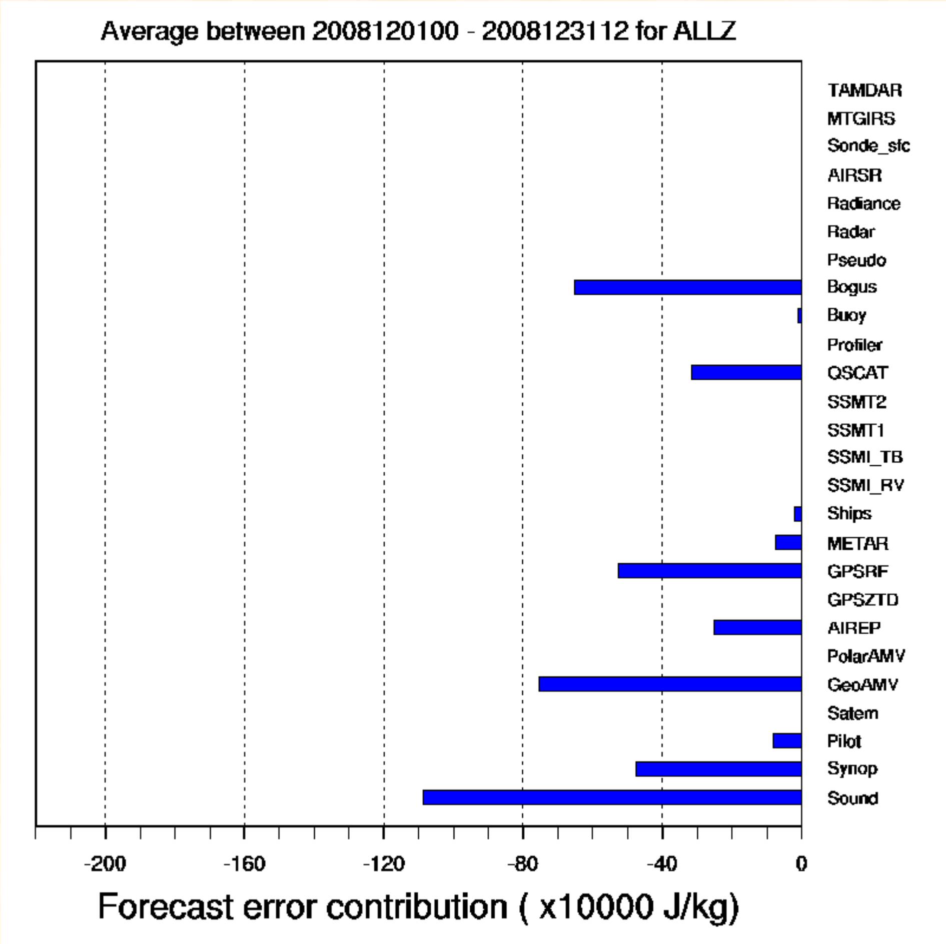


Winter

1. 觀測資料在冬季降低24hr預報誤差之效益大於夏季
2. 風場是貢獻最大的氣象變數



Summer



Winter

從冬夏兩季結果得知，最有影響力的觀測資料前五名依序是Sound、GeoAMV、EC Bogus、Gpsrf、Synop

時間序列-Time Series
依貢獻量級分成三類

$$\left(10^{6}, 10^{5}, 10^{4} \right)$$

$$Order : 10^6$$

Sound

EC Bogus

GeoAMV

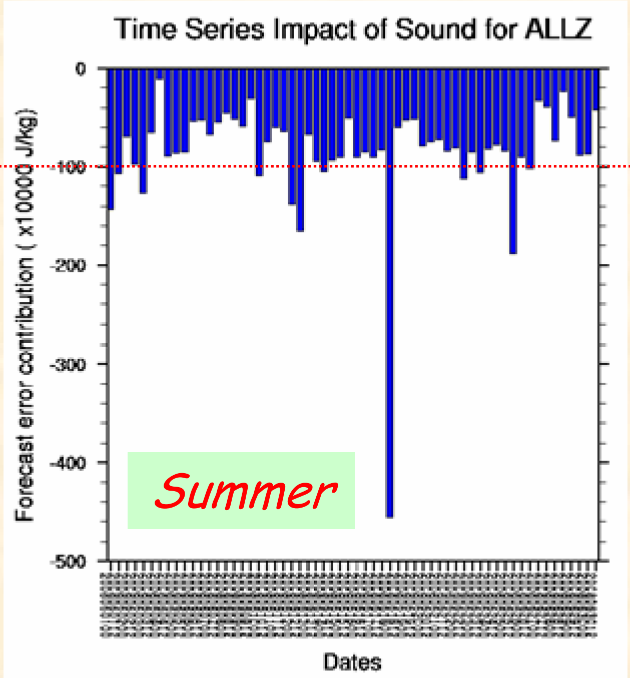
Synop

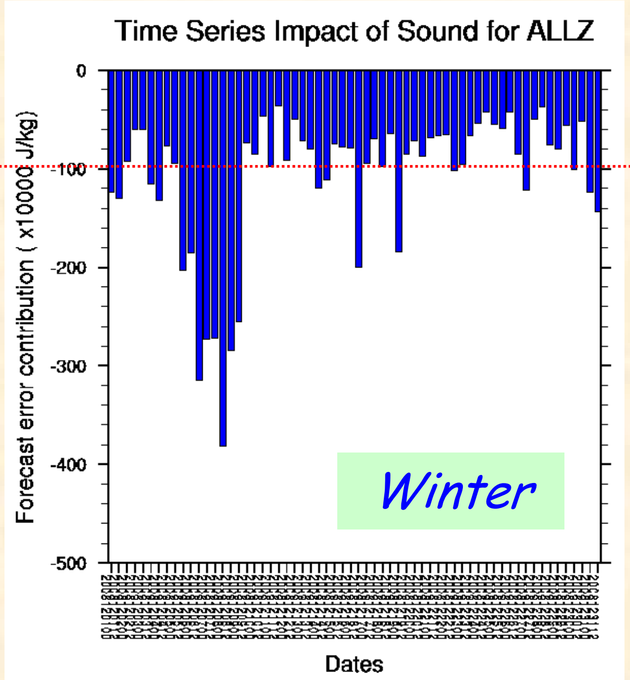
Gpsrf

Qscat

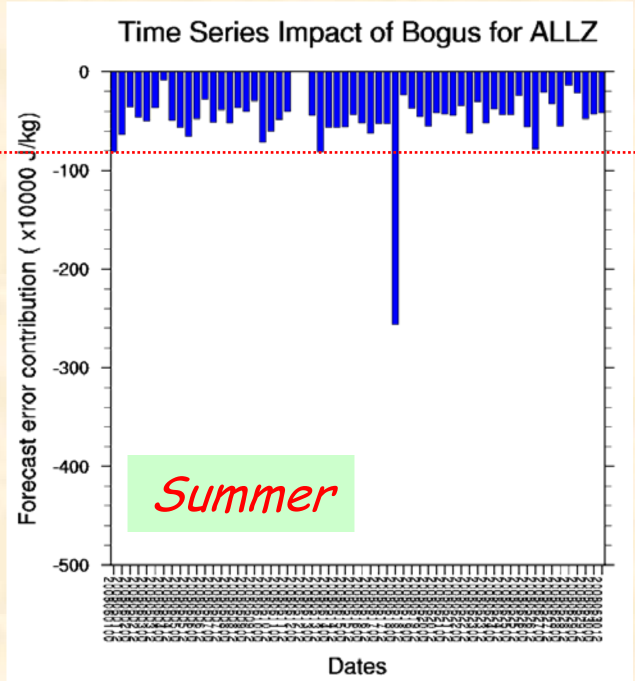
Airep

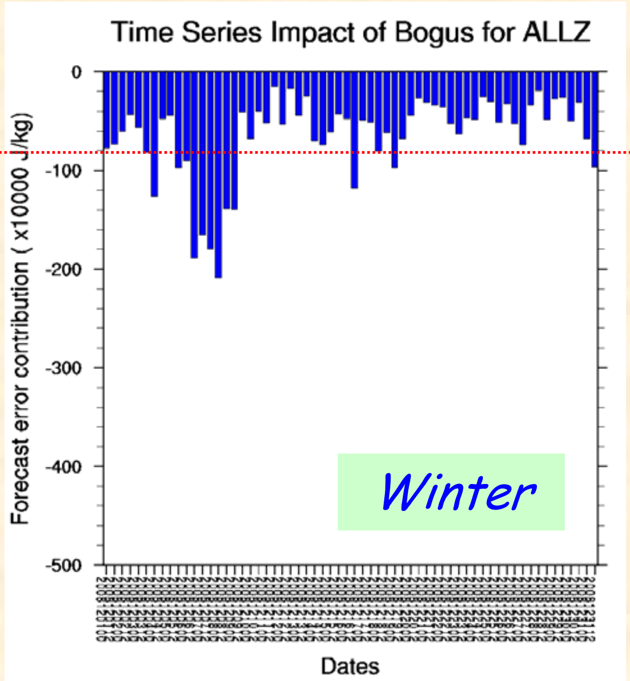
Sound資料對24hr預報誤差之改進 ： 冬季大於夏季



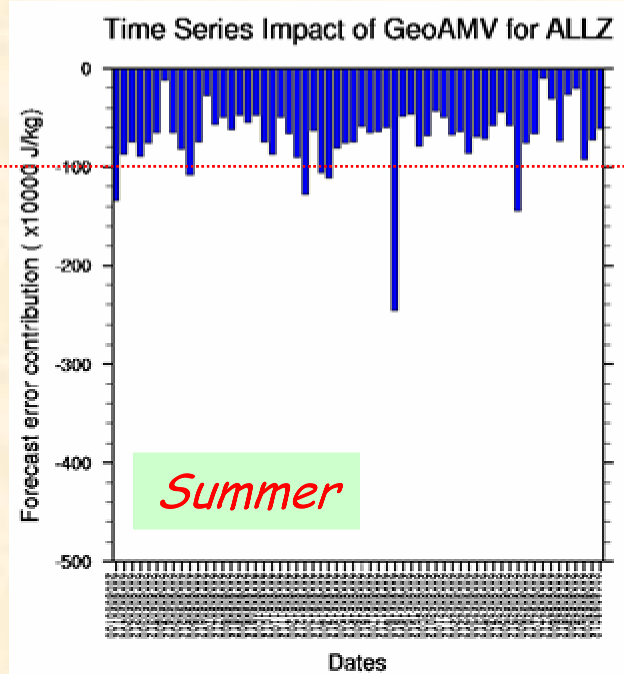


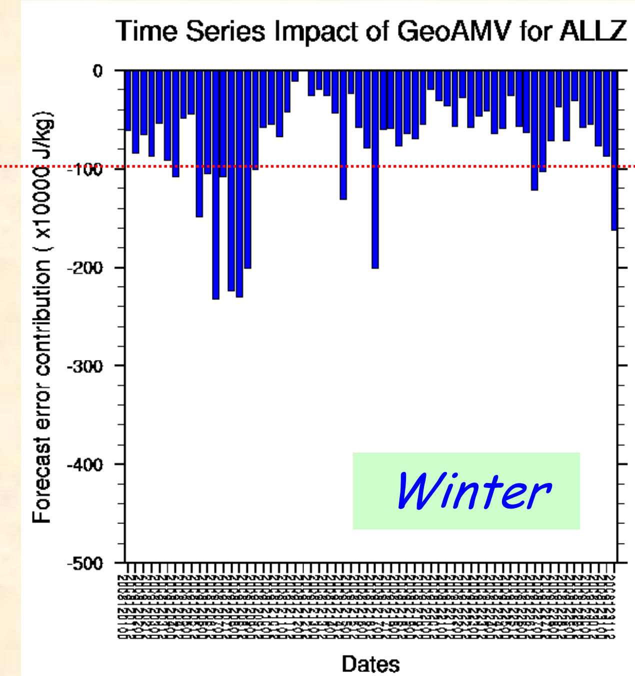
EC Bogus資料對24hr預報誤差之改進 ： 冬季大於夏季





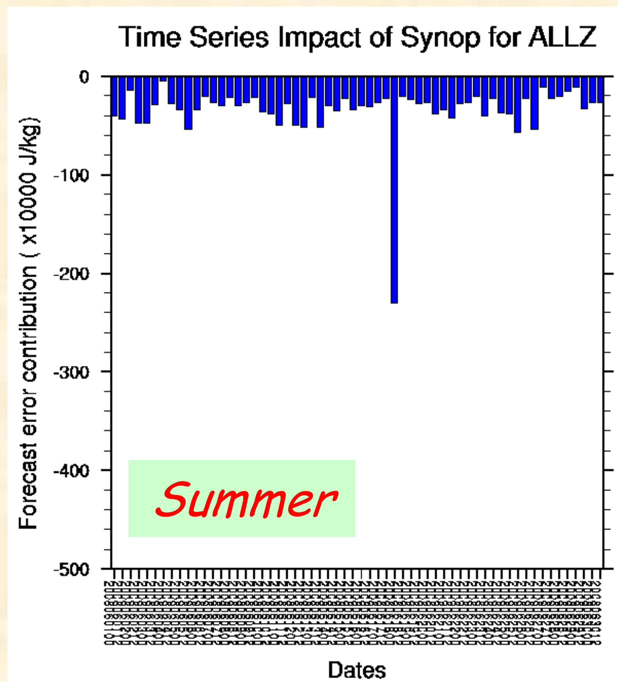
GeoAMV資料對24hr預報誤差之改進：冬季略大於夏季

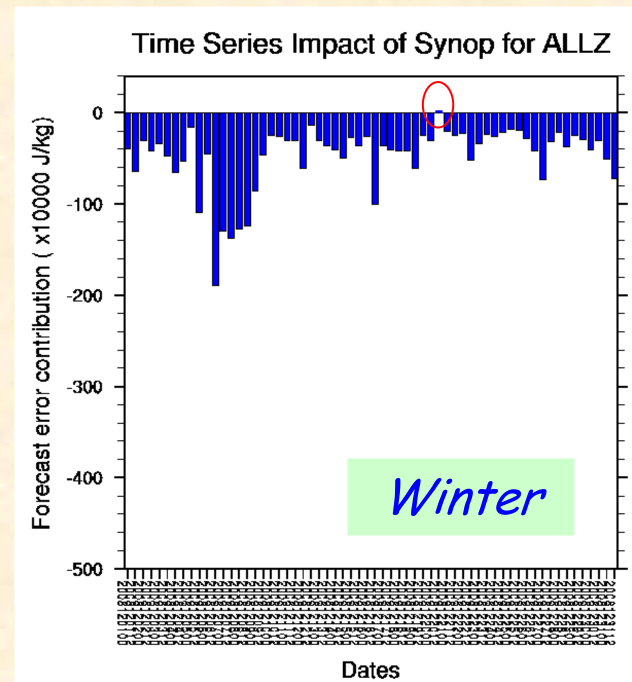




Synop資料對24hr預報誤差之改進：冬季大於夏季

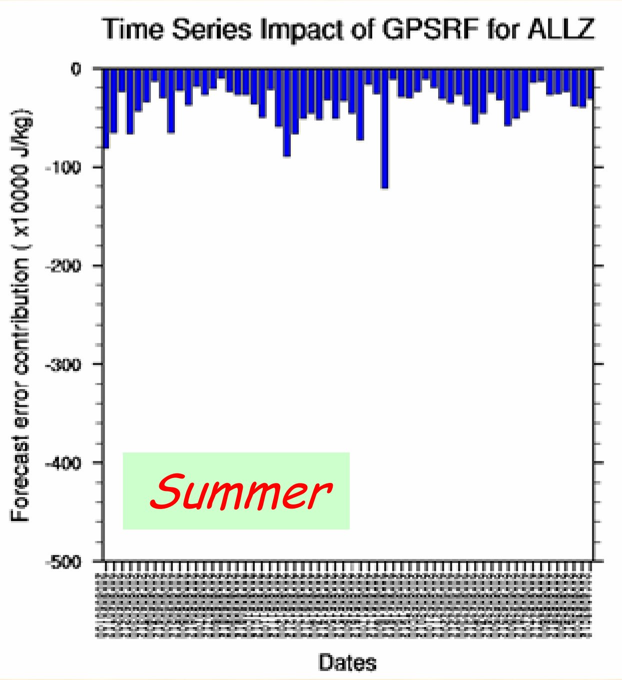
但冬季有1個時間點呈現負效應

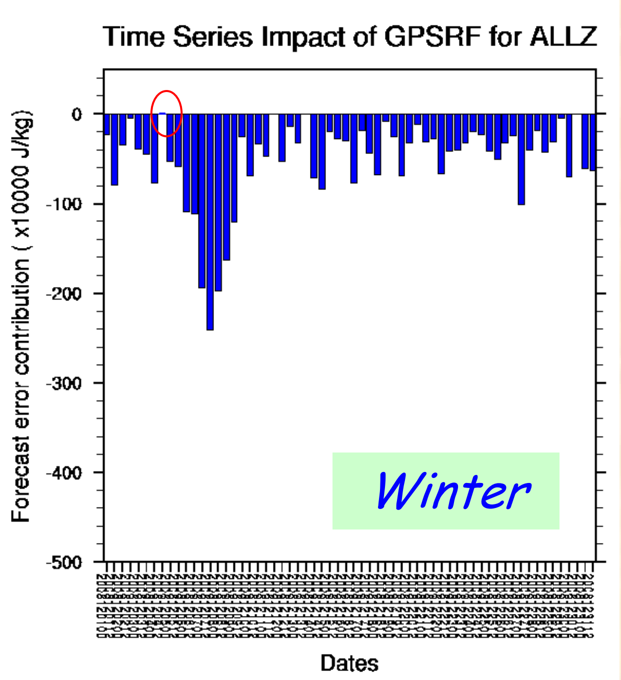




Gpsrf資料對24hr預報誤差之改進 : 冬季大於夏季

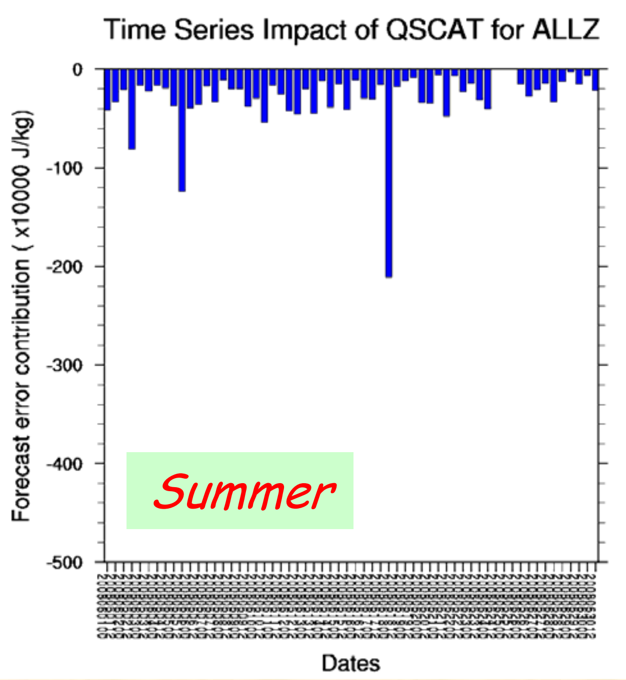
但冬季有1個時間點呈現負效應

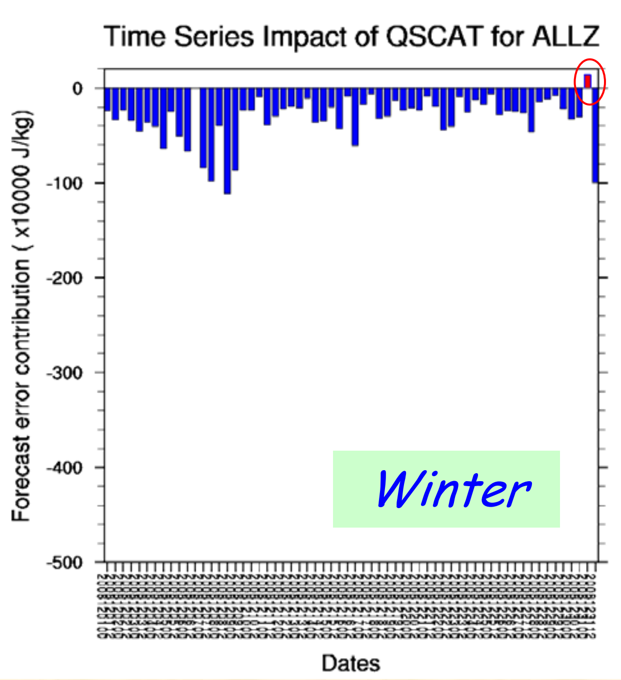


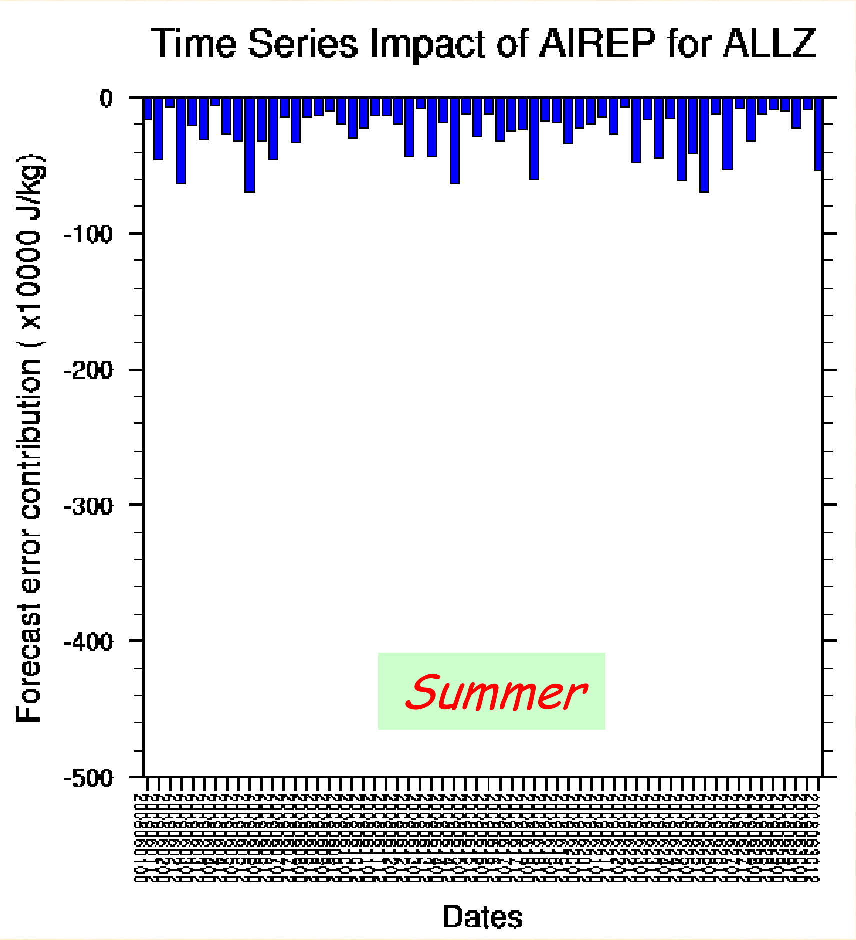


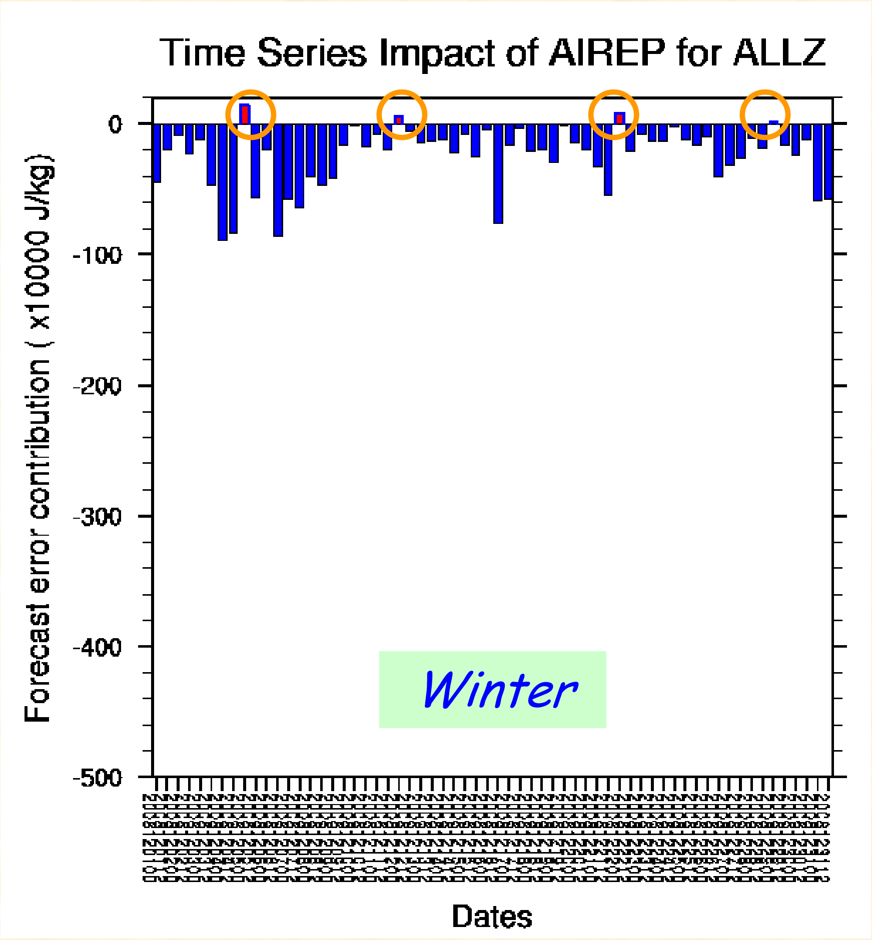
Qscat資料對24hr預報誤差之改進 : 冬季略大於夏季

但冬季有1個時間點呈現負效應









Airep資料對24hr預報誤差之改進 ： 冬季略小於夏季

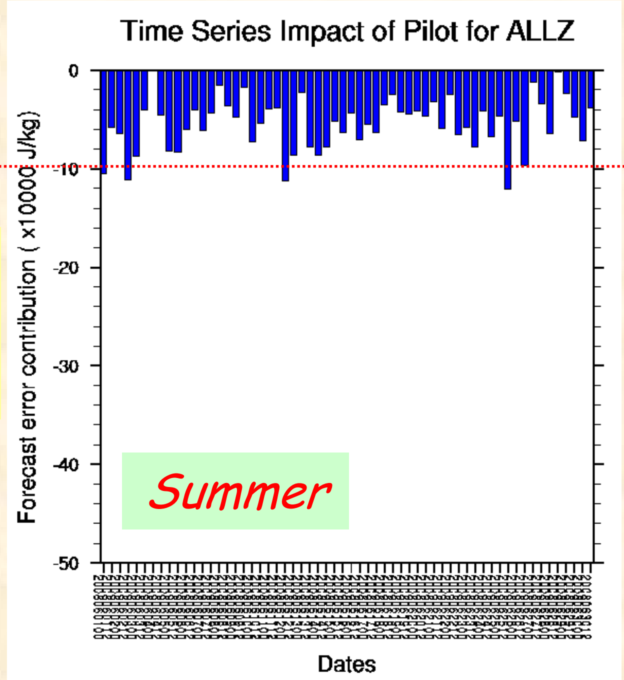
但冬季有4個時間點呈現負效應

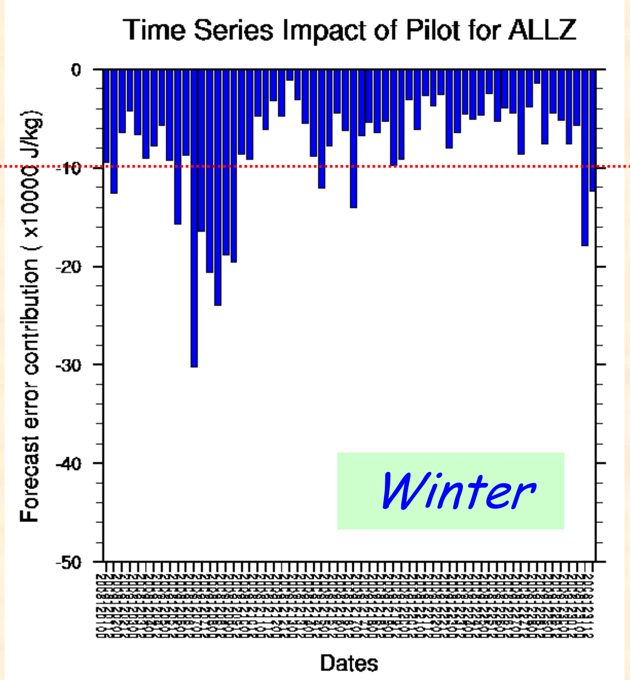
$$Order: 10^5$$

Pilot

Metar

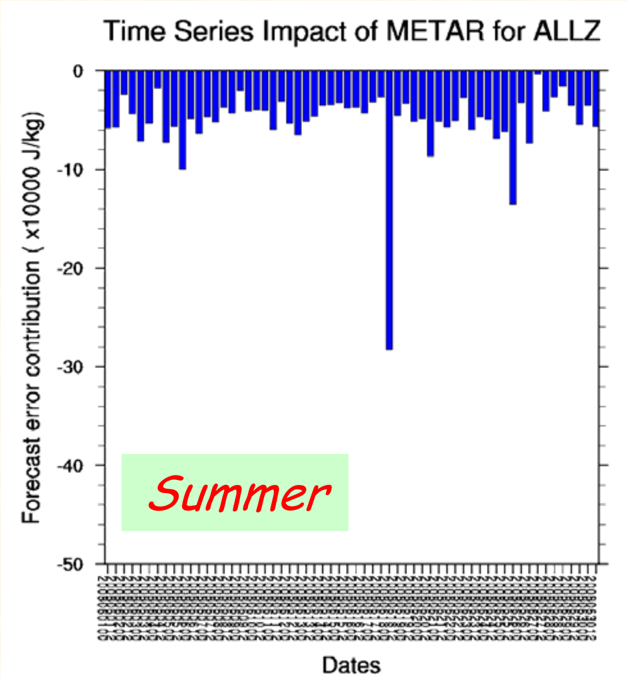
Pilot資料對24hr預報誤差之改進：冬季大於夏季

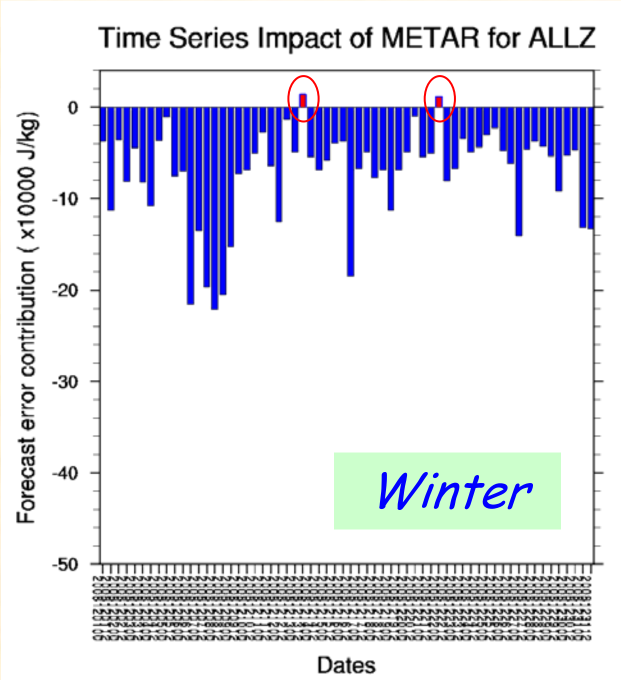




Metar資料對24hr預報誤差之改進：冬季明顯大於夏季

但冬季有2個時間點呈現負效應





$$Order: 10^4$$

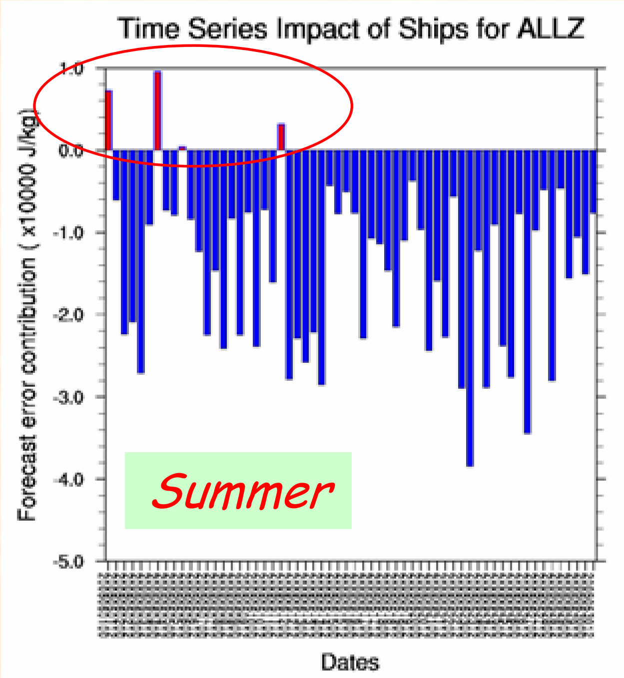
Ships

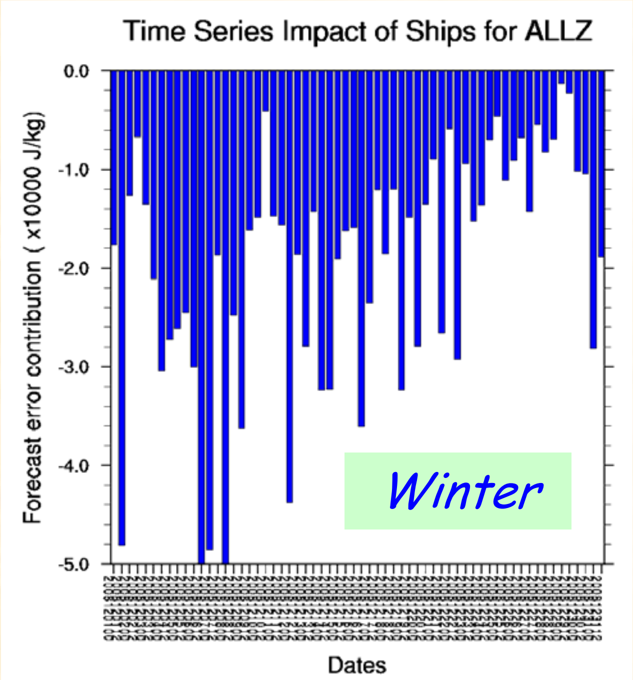
Buoy

Satem

Ships資料對24hr預報誤差之改進 ： 冬季明顯大於夏季

夏季有4個時間點呈現負效應

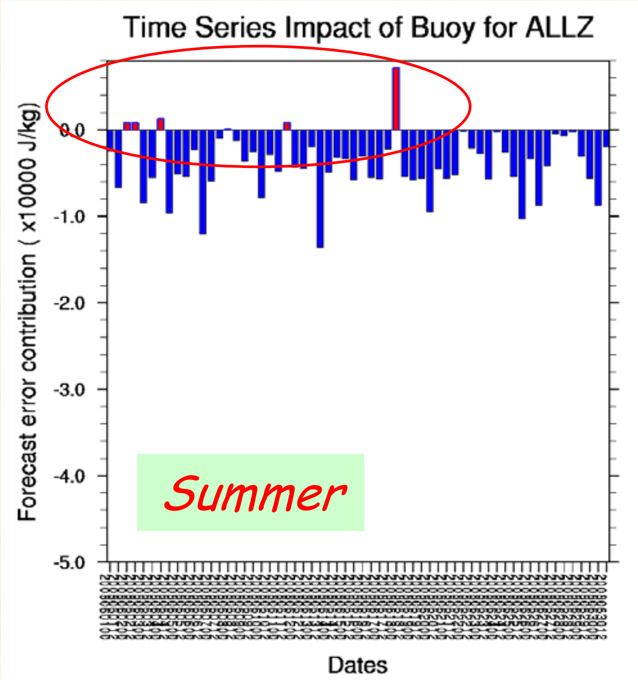


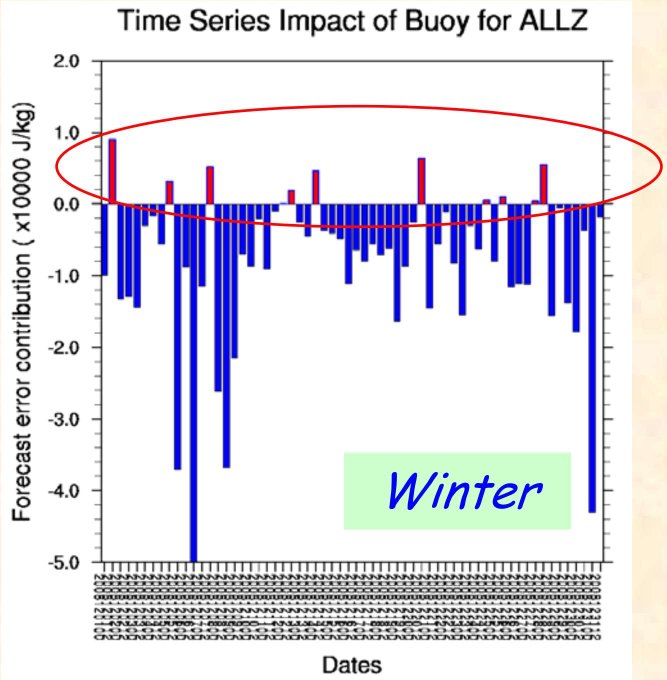


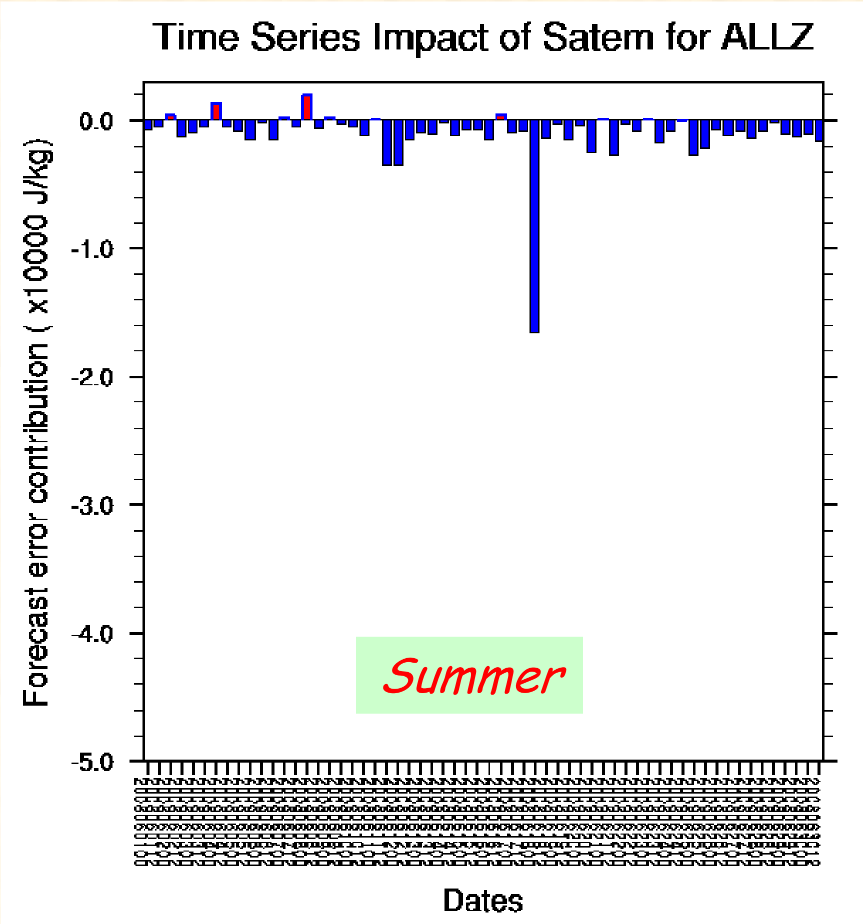
Buoy資料對24hr預報誤差之改進 ： 冬季明顯大於夏季

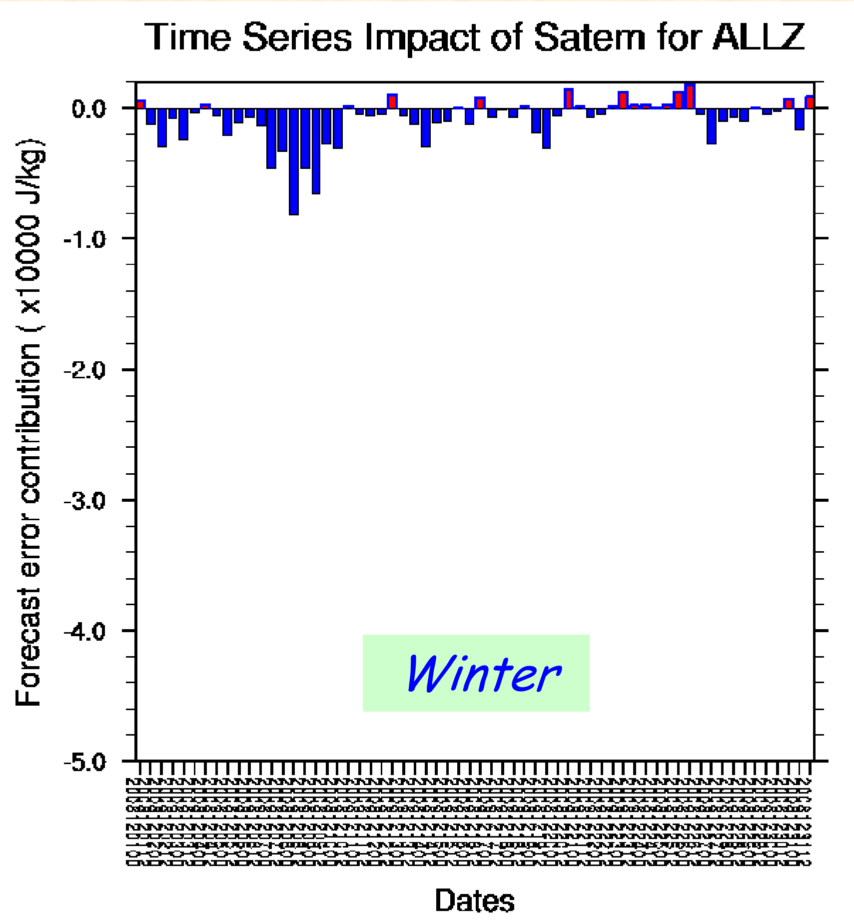
夏季有6個時間點呈現負效應

冬季有11個時間點呈現負效應







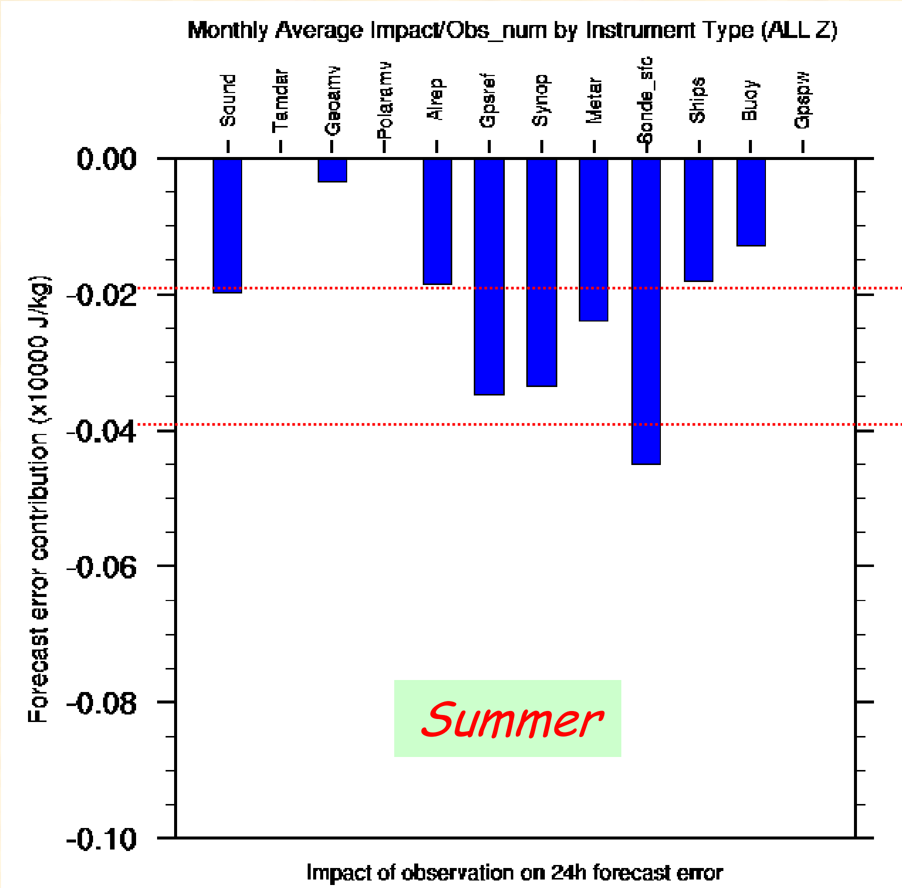


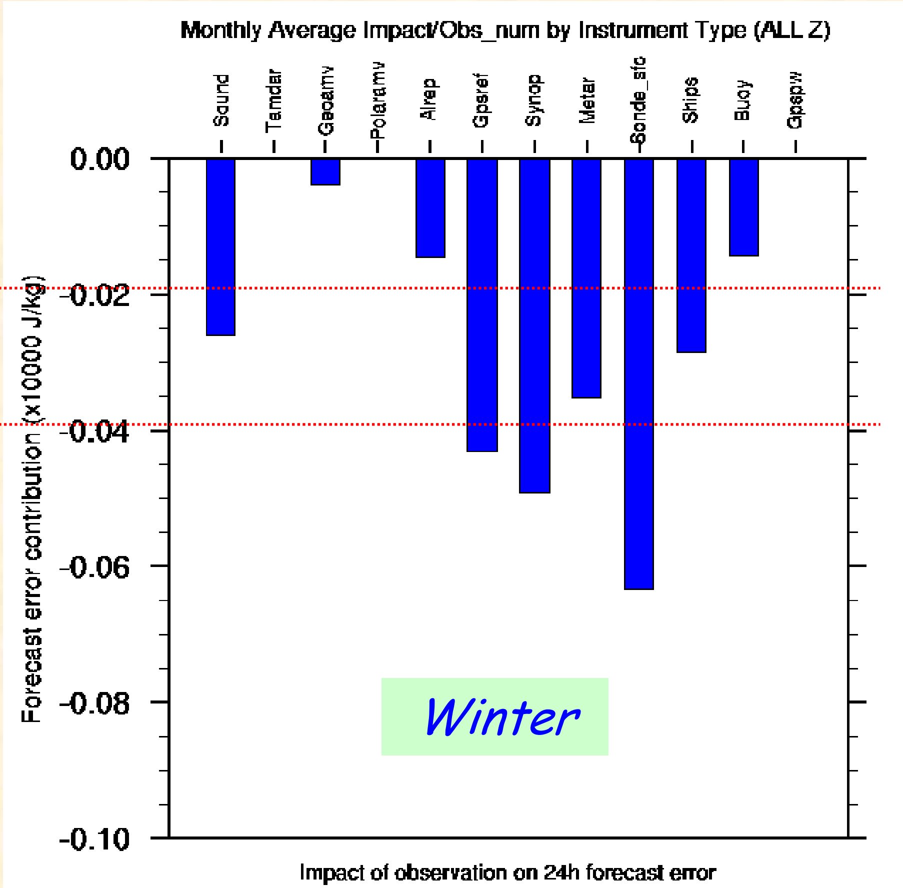
Satem資料對24hr預報誤差之改進：冬、夏季差異不大

夏季有9個時間點呈現負效應

冬季有20個時間點呈現負效應

月平均效益/觀測資料量





分析〝月平均效益/觀測資料量〞結果：

1. Sonde_sfc效益最高(資料點較少但貢獻程度高)
2. 其次依序為Gpsrf、Synop
3. GeoAMV之貢獻在除以資料量後發現其貢獻皆是量多所導致
4. 冬季所有觀測資料之貢獻皆高於夏季（除Airep外）

Summary

- 由冬夏兩季的實驗結果分析得到以下幾點結論 :
  1. 觀測資料改進24hr預報誤差之程度，冬季大於夏季(Airep 除外)。
  2. 分析時間序列圖結果，雖然觀測資料在冬季改進程度較大，但卻有較多時間點呈現負貢獻(尤其在Buoy與Satem資料最明顯)。
  3. 風場(U&V)是貢獻最大的氣象要素，其原因應是所有觀測資料幾乎都有“風”這氣象變數。
  4. 最有影響力的觀測資料前五名依序是Sound、GeoAMV、EC Bogus、Gpsrf、Synop。
  5. Satem是對於24hr預報誤差改進效益量級與值最小的觀測資料，也是最多負貢獻的觀測資料。

- 若將月平均效益除以觀測資料量 :
  1. Sonde_sfc、Gpsrf、Synop為最有效益之前三名觀測資料。
  2. 仍可看出所有資料在冬季貢獻大於夏季。
  3. 資料量最多的GeoAMV在除以資料量後，其效益就大幅降低。

Limitations & improvements

- Different definition or calculation of *J* will gives different impact results (dry energy norm, moist energy norm, verify against precipitation).

- If *J* or the model is nonlinear, there will likely be a perturbation size for which the linearization becomes inadequate in the sense that both using a tangent linear model and using an adjoint suggest the wrong response to the perturbation in the nonlinear model.

- In current WRFPLUS, there are three simplified physics packages: large scale condensation, simplified CUDU cumulus scheme and vertical diffusion. These three packages pass the basic tangent linear and adjoint check, but their performances are still not very clear.

- The boundary condition treatment in the current FSO system.

- Improving the physics packages in WRFPLUS.

- Case Study.

Thanks