The Global Observing System

Tony McNally

DA Training Course 2015
Overview

• Which observations do we have and what do they measure?

• What are observations used for?

• Assessing the impact of observations

• Which observations are most important?

• Summary
Operational Global Observing Network

- Geo-stationary satellites
  - Atmospheric motion vector – 750,000
- Polar-orbiting satellites
  - Ozone – 124,000
  - SCATT – 2,800,000
  - Radiances – 4,400,000
- GPS satellites – 2,200
- AIRCRAFT – 150,000
- SYNOP – Ship – 10,000
- Buoys – Drifting – 35,000
  - Moored – 1,500
- Dropsondes – 10
- PILOT – 800
- TEMP – 1,300
- Profiler/RADAR wind – 6,000
- SYNOP – Land – 70,000
- METAR – 45,000
Operational Global Observing Network

~ 80,000,000 observations used every 12 hours
Conventional / in-situ observations

and

Satellite Observations
Conventional / in-situ observations
# In situ Observations

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Parameters</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYNOP SHIP METAR</td>
<td>temperature, dew-point temperature, wind</td>
<td>Land: 2m, ships: 25m</td>
</tr>
<tr>
<td>BUOYS</td>
<td>temperature, pressure, wind</td>
<td>2m</td>
</tr>
<tr>
<td>TEMP TEMPSHIP DROPSONDES</td>
<td>temperature, humidity, pressure, wind</td>
<td>Profiles</td>
</tr>
<tr>
<td>PROFILERS</td>
<td>wind</td>
<td>Profiles</td>
</tr>
<tr>
<td>Aircraft</td>
<td>temperature, pressure wind</td>
<td>Profiles Flight level data</td>
</tr>
</tbody>
</table>
Snap-shot Example of 6hrs data coverage:
28 Jan 2015
Observed variables

- **Composition**
  - Ozone sondes
  - Air quality stations

- **Mass** (temperature/pressure)
  - Aircraft Buoys
  - Synop Ship

- **Wind**
  - Profilers

- **Moisture**
  - Soil moisture
  - Rain gauge
Issues related to in situ observations

• Temporal and Spatial data voids
• If we measure temperature at a point location is it representative of model grid resolution?
• Non homogeneous data quality – some radiosondes are good quality, others less so; absolute calibration can vary with age

• But, they are a direct, in situ measurement
• Interpretation is usually more straightforward than for satellite observations
Satellite Observations
Geostationary and Low-Earth-Orbit Satellites

GEO

75° W
GOES-8

LEO

start orbit #1

Meteosat
Elektro
FY-2
GMS
GOES-W
GOES-E
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Early morning orbit</th>
<th>Mid Morning orbit</th>
<th>Afternoon orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>High spectral resolution IR sounder</td>
<td></td>
<td>Metop-A+B IASI</td>
<td>Aqua AIRS NPP CrIS</td>
</tr>
<tr>
<td>Microwave T sounder</td>
<td>F17 SSMIS</td>
<td>Metop-A+B AMSU-A FY3C MWTS2 DMSP F18 SSMIS Meteor-M N1 MTVZA</td>
<td>NOAA-15, 18, 19 AMSU-A Aqua AMSU-A NPP ATMS</td>
</tr>
<tr>
<td>Microwave Q sounder + imagers</td>
<td>F17 SSMIS</td>
<td>Metop-A+B MHS DMSP F18 SSMIS FY3A MWHS2+MWRI</td>
<td>NOAA-18, 19 MHS FY3B MWHS+MWRI NPP ATMS GCOM-W/AMSR-2</td>
</tr>
<tr>
<td>Broadband IR sounder</td>
<td></td>
<td>Metop-A+B HIRS FY3C IRAS</td>
<td>FY3B IRAS</td>
</tr>
<tr>
<td>IR Imagers</td>
<td></td>
<td>Metop-A+B AVHRR Meteor-M N1 MSU-MR</td>
<td>Aqua+Terra MODIS NOAA-15, 16, 18, 19 AVHRR</td>
</tr>
<tr>
<td>Composition (ozone etc.)</td>
<td></td>
<td></td>
<td>NOAA-19 SBUV AURA OMI, MLS GOSAT</td>
</tr>
</tbody>
</table>
### Sun-Synchronous Polar Satellites (2)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Early morning orbit</th>
<th>Morning orbit</th>
<th>Afternoon orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scatterometer</td>
<td></td>
<td>Metop-A+B ASCAT (Coriolis Windsat)</td>
<td></td>
</tr>
<tr>
<td>Radar</td>
<td></td>
<td></td>
<td>CloudSat</td>
</tr>
<tr>
<td>Lidar</td>
<td></td>
<td></td>
<td>Calipso</td>
</tr>
<tr>
<td>L-band imagery</td>
<td>SMOS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SAC-D/Aquarius</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Non Sun-Synchronous Observations

<table>
<thead>
<tr>
<th>Instrument</th>
<th>High inclination (&gt; 60°)</th>
<th>Low inclination (&lt;60°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio occultation</td>
<td>GRAS, GRACE-A, COSMIC</td>
<td></td>
</tr>
<tr>
<td>MW Imagers</td>
<td></td>
<td>TRMM/TMI, GPM/GMI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meghatropics SAPHIR MADRAS</td>
</tr>
<tr>
<td>Radar Altimeter</td>
<td>JASON-2 RA + SAR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cryosat</td>
<td></td>
</tr>
</tbody>
</table>
Example of 6hr satellite data coverage: 28 Jan 2015

MW Sounders

Scatterometers

Satellite Geo Winds

MW all-sky

IASI

Radio Occultation
Radio occultation

Geo IR and Polar MW Imagers

Feature tracking in imagery (e.g. cloud track winds), scatterometers and doppler winds

Geo IR Sounder

Polar IR + MW sounders

Sub-mm, and near IR plus Visible (e.g. Lidar)

Radar and GPS total path delay

Composition

Mass (temperature/pressure)

Wind

Moisture

“Observed” Variables

IR = InfraRed
MW = MicroWave
Issues related to satellite observations

- An indirect and potentially complex measurement that may be difficult to interpret (see lecture later this week)
- Nadir Sounders have degraded vertical resolution, limb sounders have degraded horizontal resolution
- No spatial or temporal data voids, but some conditions make observations difficult to use (e.g. clouds)
- Vast volumes of data must be handled

- Globally available measurements, often with good temporal repeat cycle.
- Satellite pixel footprints generally more representative of NWP model scales
## WMO OSCAR website

**WMO Observing Requirements Database**

**Details for Atmospheric temperature...**

<table>
<thead>
<tr>
<th>Full name</th>
<th>Atmospheric temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>3D field of the atmospheric temperature</td>
</tr>
<tr>
<td>Measuring Units</td>
<td>K</td>
</tr>
<tr>
<td>Uncertainty Units</td>
<td>K</td>
</tr>
<tr>
<td>Horizontal Res Units</td>
<td>km</td>
</tr>
<tr>
<td>Vertical Res Units</td>
<td>km</td>
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</table>

**Comment:** Includes atmospheric stability index (LT)

**Last modified:**

### REQUIREMENTS DEFINED FOR ATMOSPHERIC TEMPERATURE

<table>
<thead>
<tr>
<th>Id</th>
<th>Layer</th>
<th>Application Area</th>
<th>Uncert. Goal</th>
<th>Uncert. Thresh</th>
<th>HR Goal</th>
<th>HR Thresh</th>
<th>VR Goal</th>
<th>VR Thresh</th>
<th>CC Goal</th>
<th>CC Thresh</th>
<th>Avail Goal</th>
<th>Avail Thresh</th>
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<tbody>
<tr>
<td>16</td>
<td>LT</td>
<td>Aviation Weather</td>
<td>2 K</td>
<td>5 K</td>
<td>50 km</td>
<td>100 km</td>
<td>0.15 km</td>
<td>0.5 km</td>
<td>60 min</td>
<td>3 h</td>
<td>60 min</td>
<td>2 h</td>
</tr>
<tr>
<td>2/4</td>
<td>HSBM</td>
<td>Global Modeling</td>
<td>1 K</td>
<td>3 K</td>
<td>50 km</td>
<td>500 km</td>
<td>km</td>
<td>km</td>
<td>3 h</td>
<td>12 h</td>
<td>30 d</td>
<td>60 d</td>
</tr>
<tr>
<td>2/7</td>
<td>HT</td>
<td>Global Modeling</td>
<td>0.5 K</td>
<td>3 K</td>
<td>50 km</td>
<td>500 km</td>
<td>km</td>
<td>km</td>
<td>3 h</td>
<td>12 h</td>
<td>30 d</td>
<td>60 d</td>
</tr>
<tr>
<td>2/8</td>
<td>LS</td>
<td>Global Modeling</td>
<td>0.5 K</td>
<td>3 K</td>
<td>50 km</td>
<td>500 km</td>
<td>km</td>
<td>km</td>
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<td>3 K</td>
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<td>500 km</td>
<td>km</td>
<td>km</td>
<td>3 h</td>
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<td>30 d</td>
<td>60 d</td>
</tr>
<tr>
<td>2/4</td>
<td>HSBM</td>
<td>Global WNP</td>
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<td>5 K</td>
<td>50 km</td>
<td>500 km</td>
<td>0.3 km</td>
<td>3 km</td>
<td>60 min</td>
<td>24 h</td>
<td>6 min</td>
<td>6 h</td>
</tr>
<tr>
<td>2/5</td>
<td>HT</td>
<td>Global WNP</td>
<td>0.5 K</td>
<td>3 K</td>
<td>15 km</td>
<td>500 km</td>
<td>0.3 km</td>
<td>3 km</td>
<td>60 min</td>
<td>24 h</td>
<td>6 min</td>
<td>6 h</td>
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<tr>
<td>2/6</td>
<td>LS</td>
<td>Global WNP</td>
<td>0.5 K</td>
<td>3 K</td>
<td>15 km</td>
<td>500 km</td>
<td>0.3 km</td>
<td>3 km</td>
<td>60 min</td>
<td>24 h</td>
<td>6 min</td>
<td>6 h</td>
</tr>
<tr>
<td>2/7</td>
<td>LT</td>
<td>Global WNP</td>
<td>0.5 K</td>
<td>3 K</td>
<td>15 km</td>
<td>500 km</td>
<td>0.3 km</td>
<td>3 km</td>
<td>60 min</td>
<td>24 h</td>
<td>6 min</td>
<td>6 h</td>
</tr>
<tr>
<td>3/3</td>
<td>HT</td>
<td>High Res WNP</td>
<td>0.5 K</td>
<td>3 K</td>
<td>2 km</td>
<td>50 km</td>
<td>0.3 km</td>
<td>1 km</td>
<td>15 min</td>
<td>6 h</td>
<td>15 min</td>
<td>2 h</td>
</tr>
<tr>
<td>3/4</td>
<td>LT</td>
<td>Aviation Weather</td>
<td>0 K</td>
<td>0 K</td>
<td>1 km</td>
<td>200 km</td>
<td>km</td>
<td>km</td>
<td>60 min</td>
<td>0 y</td>
<td>0 y</td>
<td>0 y</td>
</tr>
<tr>
<td>3/5</td>
<td>LS</td>
<td>High Res WNP</td>
<td>0.5 K</td>
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<td>1 km</td>
<td>3 km</td>
<td>15 min</td>
<td>6 h</td>
<td>15 min</td>
<td>2 h</td>
</tr>
</tbody>
</table>

**Classification**

- **Domain:** Atmosphere
- **Theme:** Basic atmosphere
- **Variable:** Atmospheric temperature
- **Measured in Layers:**
  - HSBM
  - LS
  - HT
  - LT

**Used in Application Areas:**
- Aviation Meteorology
- Agricultural Meteorology
- Climate-AGCP
- Global Modeling
- Global WNP
- High Res WNP
- Measuring
- SPARC
- Synoptic Meteorology

What are observations used for?

- Constraining model error growth for **data assimilation** and NWP
- Providing ground truth for improving model parameterisations
What are observations used for?

- Constraining model error growth in data assimilation and NWP

- Providing ground truth for improving model parameterisations
What is Data Assimilation?

- Models give a complete description of the atmospheric, but errors grow rapidly in time.

- Observations provide an incomplete description of the atmospheric state, but bring up to date information.

- Data assimilation combines these two sources of information to produce an optimal (best) estimate of the atmospheric state.

- This state (the analysis) is used as initial conditions for extended forecasts.
Data Assimilation (single window)
Data Assimilation (quasi-continuous)
What are observations used for?

- Constraining model error growth for data assimilation and NWP
- Providing ground truth for improving model parameterisations
Using SSMIS to improve cloud physics

Comparing SSM/IS 37V observations with values simulated from the model fields suggest an excess of liquid water in the front and a deficiency of liquid water in the cold air outbreak behind.
Using SSMIS to improve cloud physics

Changes to the modelling of super-cooled liquid water reduce values of LWP in frontal zones and increase LWP in the cold air convection regions.
Using SSMIS to improve cloud physics

Comparing SSM/IS 37V observations with values simulated from the model fields suggest an excess of liquid water in the front and a deficiency of liquid water in the cold air outbreak behind.
Assessing the impact of Observations on NWP systems
How do we measure observation impact?

• Observing System Experiments (OSE)
  – Denial or addition experiments
  – Periodic statistical evaluations
  – Case studies

• Adjoint Sensitivity Diagnostics (ASD)
  – Impact assessed without denial
  – Periodic statistical evaluations
Measuring Observation Impact

- **Observing System Experiments (OSE)**
  - Denial or addition experiments
  - Periodic statistical evaluations
  - Case studies

- **Adjoint sensitivity Diagnostics (ASD)**
  - Impact assessed without denial
  - Periodic statistical evaluations
  - Case studies

See lecture by Carla Cardinali later this week
Observing System Experiments
(we run a CONTROL system A)
Observing System Experiments
(we run a reduced system B)

Control assimilation system with all observations

Assimilation system with some observations denied
Observing System Experiments
(we launch extended forecasts from both)
Observing System Experiments
(we verify forecasts from A)
Observing System Experiments
(we verify forecasts from B)
Then....

We can compare **statistics** of forecast scores from system **A** versus system **B** over a long period.

Or...

We compare the performance of forecasts from system **A** versus system **B** in specific **case studies**.
Statistics of Observation Impact

We can compare the average scores of each system as a function of forecast range.
Statistics of Observation Impact

A > B

Or (increasingly) we can compare normalised score differences as a function of forecast range

B > A
Observation impact determined from individual case studies for important events
Case Study Observation Impact
Results from the most recent statistical evaluation of Observation Impact in the ECMWF NWP system
Observations considered in the study

<table>
<thead>
<tr>
<th>Observations</th>
<th>Code</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>All conventional (in situ) data</td>
<td>CONV</td>
<td>TEMP/AIRCRAFT/SYNOP/SHIP/BOUY/PROFILERS</td>
</tr>
<tr>
<td>All Satellite Data</td>
<td>SAT</td>
<td></td>
</tr>
<tr>
<td>Microwave sounding radiances</td>
<td>MWS</td>
<td>7 x AMSUA, 1 x ATMS, 4 x MHS</td>
</tr>
<tr>
<td>Infrared sounding radiances</td>
<td>IRS</td>
<td>2 x IASI, 1 x AIRS, 1 x HIRS</td>
</tr>
<tr>
<td>All GEO data (AMVs and radiances)</td>
<td>GEO</td>
<td>2 x GOES, 2 x METEOSAT, 1 x MTSAT, polar AMVs</td>
</tr>
<tr>
<td>GPS-RO bending angle data</td>
<td>GPS</td>
<td>COSMIC, 2 x METOP-GRAS</td>
</tr>
<tr>
<td>Microwave imager radiances</td>
<td>MWI</td>
<td>1 x TMI, 1 x SSM/IS</td>
</tr>
<tr>
<td>Scatterometer surface wind data</td>
<td>SCAT</td>
<td>2 x ASCAT</td>
</tr>
</tbody>
</table>
Experimental Setup

• Period covered (March 1\textsuperscript{st} to June 30\textsuperscript{th} 2014)
• Version 40R1 of the ECMWF analysis / forecasting system
• T511 Horizontal resolution (~40km) with 137 vertical levels (surface to 0.01hPa)
• For OSEs the various data types are \textit{denied} from the system
• Verification is with the ECMWF operational analyses and in-situ observations
Satellites observations

v

Conventional (in situ) data
Importance of Satellites versus Conventional (in situ) data N.Hemis

500hPa geopotential
Root mean square error
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
Date: 20140314 00UTC to 20140630 00UTC
rdx, an rd lwpda 00UTC | Mean method: fair
Importance of Satellites versus Conventional (in situ) data N.Hemis

500hPa geopotential
Root mean square error
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
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rdx, an rd lwda 00UTC | Mean method: fair

1/2 day of skill lost!
Importance of Satellites versus Conventional (in situ) data S.Hemis

500hPa geopotential
Root mean square error

SHeM Extratropics (lat -90.0 to -20.0, lon -180.0 to 180.0)
Date: 20140314 00UTC to 20140731 00UTC
rdx_an rd lda 00UTC | Mean method: fair
Importance of Satellites versus Conventional (in situ) data S. Hemis

500hPa geopotential
Root mean square error
SHem Extratropics (lat -90.0 to -20.0, lon -180.0 to 180.0)
Date: 20140314 00UTC to 20140731 00UTC
rdx_an rd_lwda 00UTC | Mean method: fair

2 days of skill lost!
Which individual satellite observation types are most important?
Observations considered in the study

<table>
<thead>
<tr>
<th>Observations considered in the study</th>
<th>Source</th>
<th>Data Provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>All conventional (in situ) data</td>
<td>CONV</td>
<td>TEMP/AIRCRAFT/SYNOP/SHIP/BOUY/PROFILERS</td>
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</tr>
</tbody>
</table>
Day 3 Forecast Errors when Different Observations are denied
500hPa Z over NH

- NO SAT
- NO CONV
- NO MWI
- NO SCAT
- NO GEO
- NO GPS
- NO MWS
- CTRL
- NO IRS
Day 3 Forecast Errors when Different Observations are denied

500hPa Z over NH
Observations ranked by impact upon day-3 NH forecasts of Z500
Ranked percentage loss of skill in day-3 Forecasts of 500hPa Z over NH

CONV data more important than any individual satellite
 Ranked percentage loss of skill in day-3 Forecasts of 500hPa Z over NH

Microwave and Infrared sounders most important
Summary of overall ranking of Observations

1. All satellite observations
2. All conventional observations
3. Microwave Sounding Radiances
4. Infrared Sounding Radiances
5. GPS RO data
6. GEO/SCAT/MWI (niche impacts on other parameters)
Observation impact determined from individual case studies for important events
Results from a recent Case Study

Hurricane Sandy
Experimental setup

• re-run ECMWF operations from the 20th October at full resolution (T1279)

• The denial experiments are identical to the control - except that different satellite observations are deliberately withheld

• Key day five forecasts launched from the 25th
Hurricane Sandy
Hurricane Sandy
Forecast differences of failed (NO – LEO SAT) forecast

MSLP in Control (red and black solid)
NO-LEO SAT (blue and black dash) VT:2012103000z
LEO satellite data coverage (2012102500z)

- **Infrared sounding**: Good in the N.Pacific
- **microwave sounding**: Bad in the immediate vicinity of the storm due to cloud
Satellite impact on Hurricane Sandy

Changes to the initial conditions from removing LEO satellite data were small and located **far from the storm**

Forecasts **with** / **without** LEO data

- Day-3
- Day-4
- Day-5
Are case studies valuable?

• Yes – they are typically the only thing that can actually convince decision makers!
• Yes – if the case is representative of a very common meteorological regime
• Yes – if the case is an extremely high impact event (e.g. Sandy)
• Yes – if we show (and publish) the good and the bad!!
But we need to take great care when making statements about the importance of different observations!
Factors that determine impact?

- Observation quality
- Observed quantity (important? already known?)
- Observation usability (ambiguity)
- Observation spatial coverage
- Observation time
- Tuning of the assimilation system (correct specification of B, R, BC, QC)
- Reliability of verification!!
Factors that determine impact?

- Observation quality
- Observed quantity (important? already known?)
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- Observation spatial coverage
- Observation time
- Tuning of the assimilation system (correct specification of B, R, BC, QC)
- Reliability of verification!!
Putting the same satellite in a different orbit (13:30 compared to 07:30 orbit)

In the context of considering which orbit a new Chinese satellite should occupy, OSE studies showed that putting a microwave sounder in a morning orbit (07:30) meant it had a much bigger impact than if exactly the same data were obtained from an afternoon orbit (13:30).
Factors that determine impact?

• Observation quality
• Observed quantity (important? already known?)
• Observation usability (ambiguity)
• Observation spatial coverage
• Observation time

• Tuning of the assimilation system (correct specification of B, R, BC, QC)
• Reliability of verification!!
Correct tuning of the assimilation system (e.g. background errors)

ALL OBSERVATIONS

NO SAT OBSERVATIONS
Retuning background errors for an extreme OSE

500hPa geopotential
Root mean square error
SHem Extratropics (lat -90.0 to -20.0, lon -160.0 to 180.0)
Date: 20140314 00UTC to 20140630 00UTC
rdx_an rd lwda 00UTC | Mean method: fair

1 day of skill recovered from retuning background errors!
2 days of skill lost!
Sensitivity to Background Errors
Factors that determine impact?

• Observation quality
• Observed quantity (important? already known?)
• Observation usability (ambiguity)
• Observation spatial coverage
• Observation time
• Tuning of the assimilation system (correct specification of B, R, BC, QC)
• Reliability of verification!!
Verification (what is truth?)

• Conventional (in situ) Observations?
  – Poor (biased) spatial coverage
  – They have errors (RS z500 ~ 10m)

• NWP analyses
  – They have errors (z500 ~ ??)
How accurate are our analyses?

**UKMO analysis against ECMWF analysis**

500hPa geopotential
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
T+0
oper_an od egr 0001

![Graph showing analysis accuracy over time](image)

5-10m
Analysis uncertainty in verification

500hPa geopotential
Root mean square error
NHem Extratropics (lat 20.0 to 90.0, lon -180.0 to 180.0)
Date: 20140314 00UTC to 20140530 00UTC
rdx_an rd lwda 00UTC | Mean method: fair

50-60m @ day 6

5-10m @ day 1
Summary

• NWP systems rely completely on observations to make usable weather forecasts (either for DA or model development)
• Collectively satellite data dominate forecast accuracy everywhere, but conventional data are still important (more than any single SAT system).
• Of these, microwave and infrared sounding dominate the medium-range headline scores, but other SAT observations have impact on other parameters (and ranges)
• Case studies are valuable and a very potent tool to convince decision makers
Thank you for your attention (questions ?)