Measurement Science and the Environment

Martin Milton

Director, BIPM.

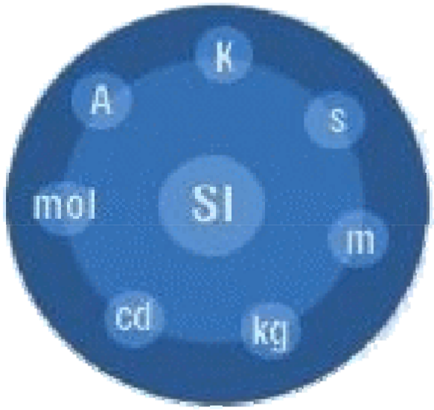
NCSLI, August 2014

Bureau
International des
Poids et
Mesures

BIPM

The International Bureau of Weights and Measures

- Intergovernmental organization
- Established in 1875 to:
- **"ensure and promote the global comparability of measurements, including providing a coherent international system of units (the SI)"**
- 70 staff members
- Annual budget of approximately 12 Meuro
- 56 Member States and 41 Associate States/economies, who operate 245 NMIs and Designated Institutes, organised into 5 Regional Metrology Organisations.



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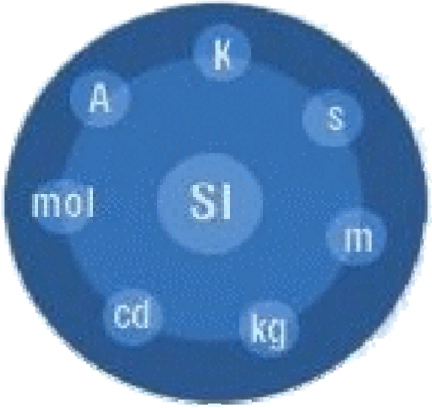
Examples from the work programme:

- Disseminate UTC
- Maintain the International Prototype of the kg
- Develop and use transportable quantum devices.
- Maintain international facilities for comparing: measurements of radioactivity and ozone.
- Coordinate the 10 consultative committees of the CIPM.



Measurement Science and the Environment

- What are we trying to measure – and why is it different?
- How are measurements made?
- Examples from: temperature, noise, radioactivity, greenhouse gases, earth observation
- What can we expect next?

- **What is the role of measurement data that is traceable to the SI?**

Addressing policy issues

- Global policy
- National policy
- Local/site policy

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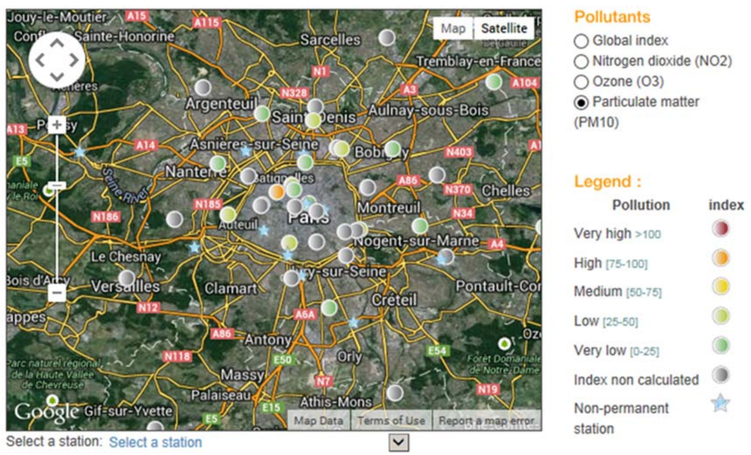

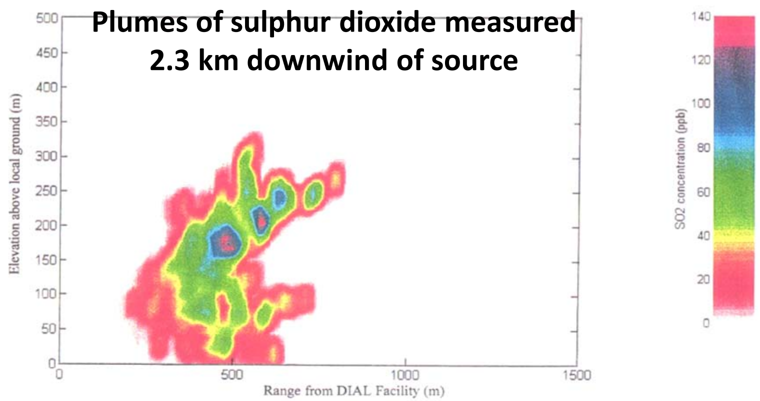

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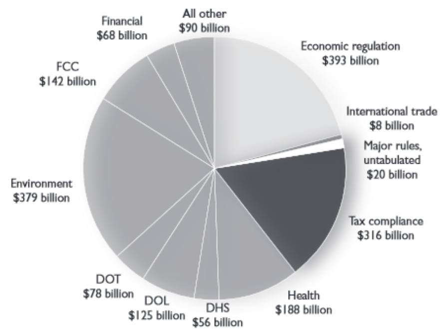
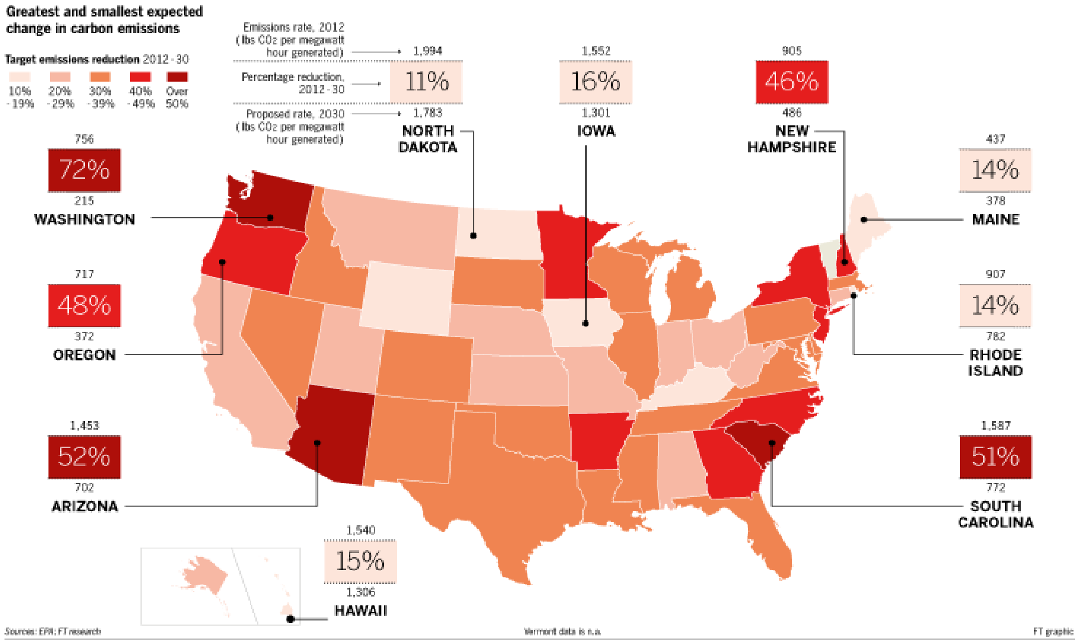
- Strong academic interest too.

Environmental measurements often influence decisions with large $ values

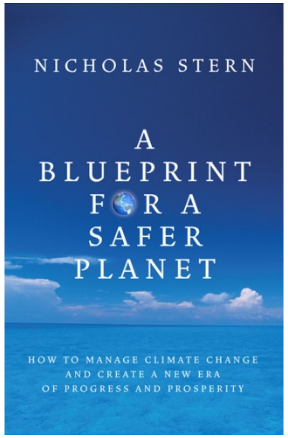
- Cost of compliance
- Carbon reduction targets

Figure 1. Annual Cost of Federal Regulation 2012, $1.863 Trillion



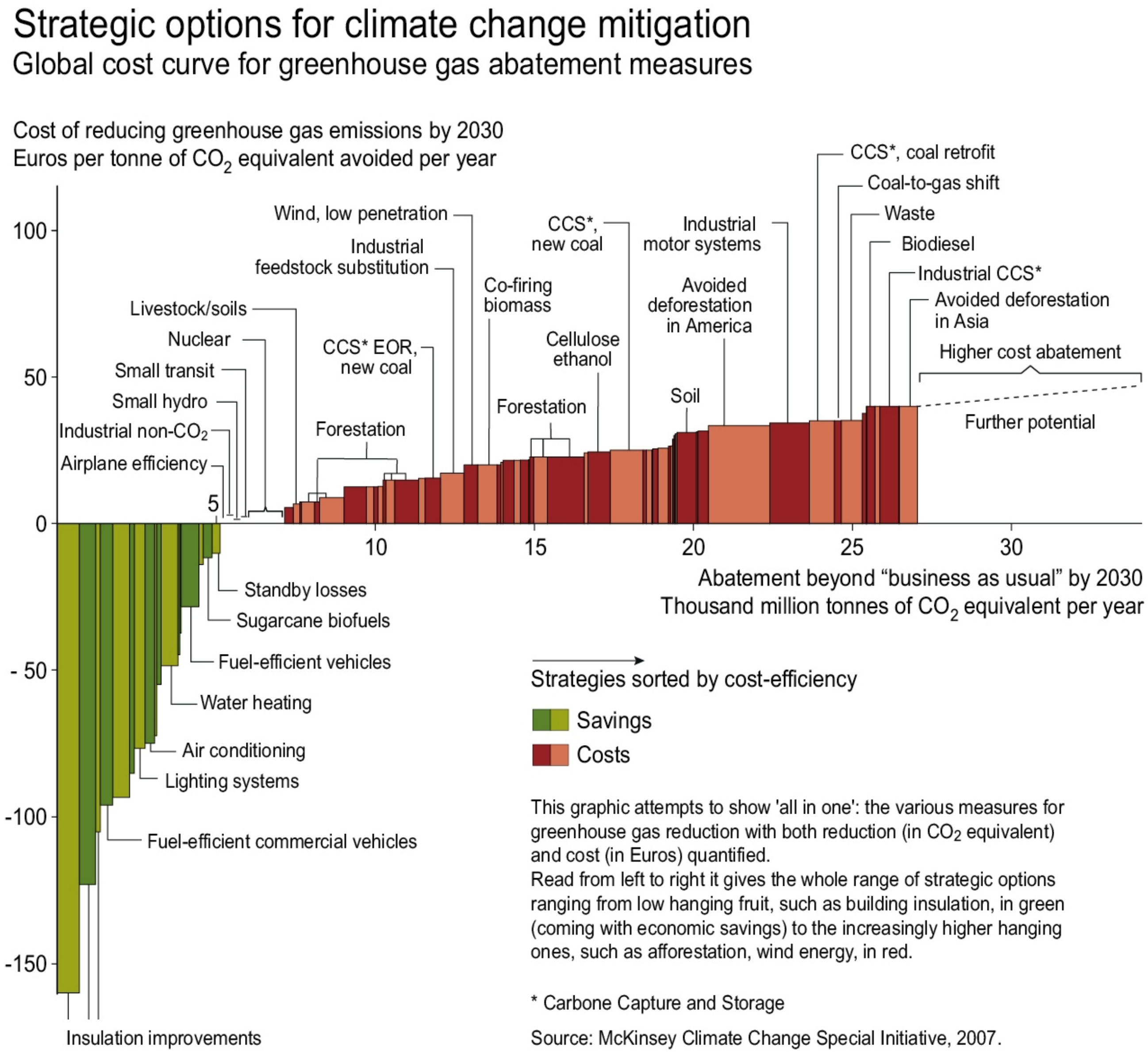


Environmental measurements often influence decisions with large $ values



"**All approaches require the measurement of carbon emitted, but the burdens of measurement differ**":

- CDM - project specific, against a project specific baseline
- Carbon Tax – at point of use
- Cap-and-trade – higher up the chain



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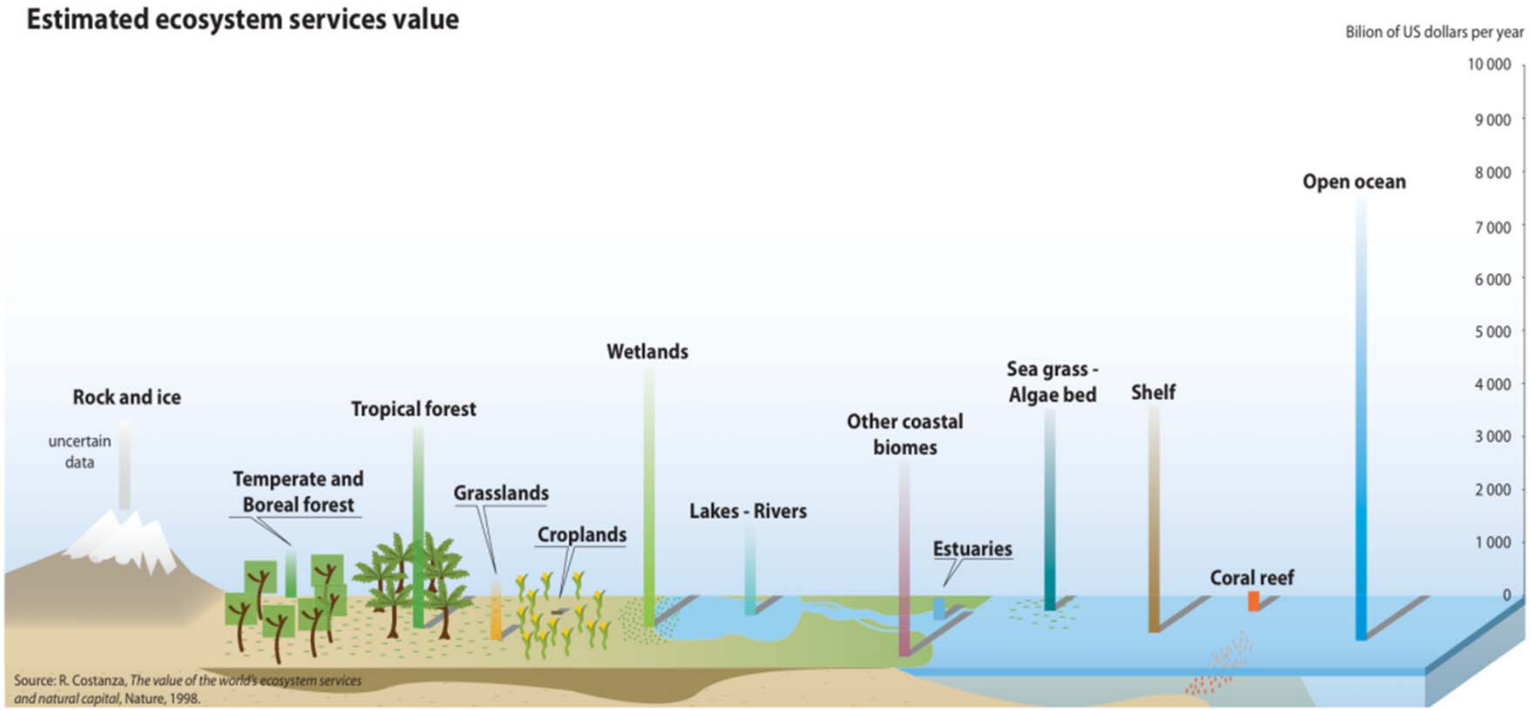
Environmental measurements often influence decisions with large $ values

- Carbon reduction targets
- Cost of compliance
- Ecosystem services



Measurement accuracy is crucial when detecting trends

- A direct link can be made between the value of a data set and its measurement stability/accuracy and therefore cost.

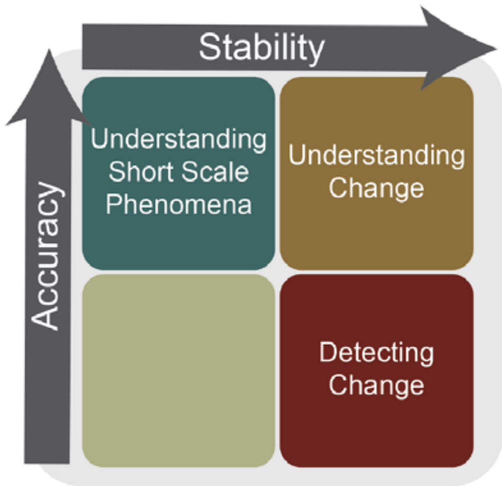
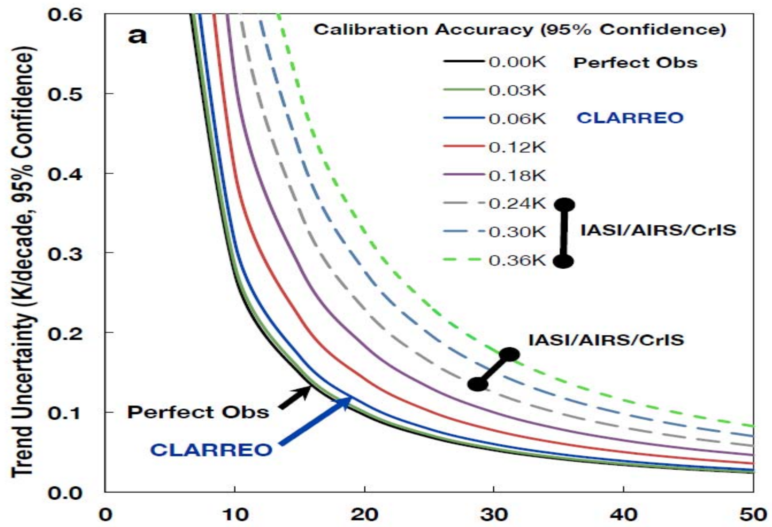
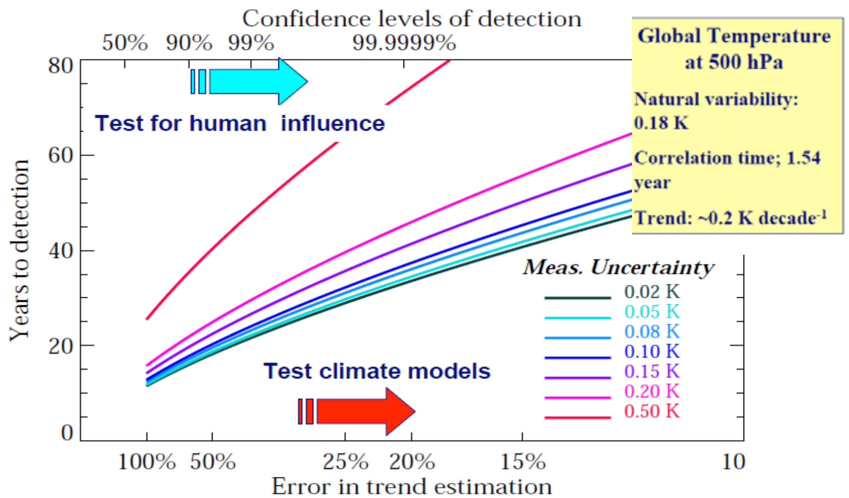


Figure 3.1: Accuracy vs. stability diagram following Ohring et al. (2004)

- *"The requirement for stability is 1/5 of the predicted change that is sufficient to narrow down the spread of current climate model simulations"*





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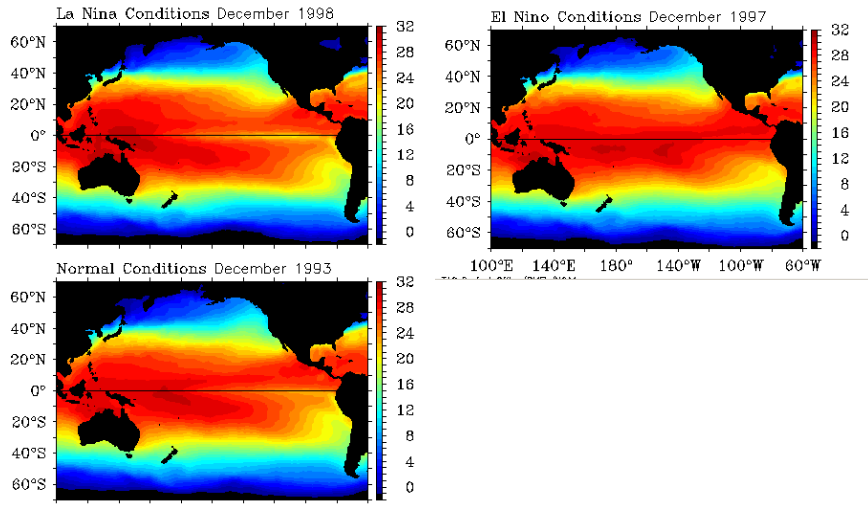
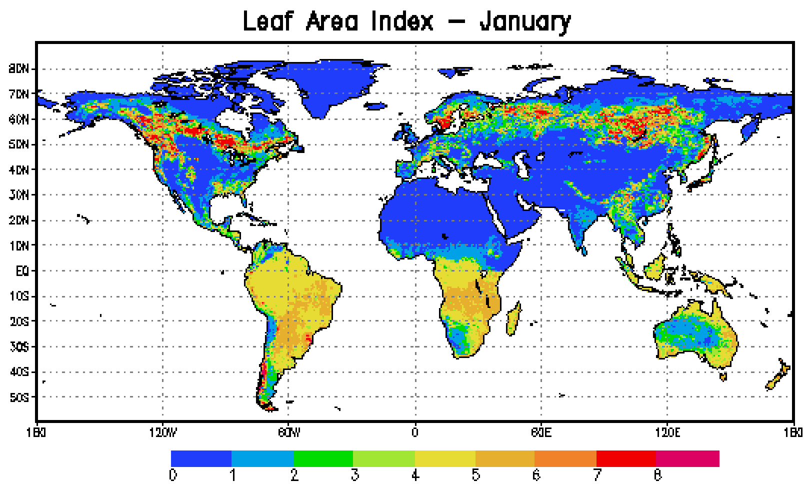
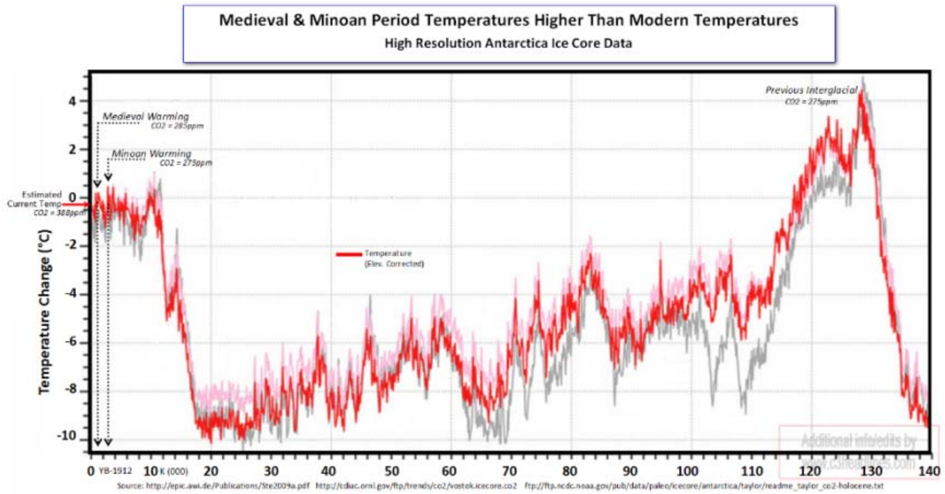
The scale of applications presents challenges for their accuracy

- Length scales
- Time scales
- Unusual quantities
  - Dimensionless quantity that characterizes plant canopies
  - **leaf area index** - "the one-sided green leaf area per unit ground surface area







Environmental measurements - summary

- Address policy issues
- Very significant costs
- Can effect high-value decisions
- “Scale” of measurements is very large

- Where are the challenges for metrology?
- What is the basis of traceability?

Using observational records for climate monitoring

IPCC 5th Assessment Report 2015

- **"The vast majority of historical (and modern) weather observations were not made explicitly for climate monitoring purposes.**
  - Measurements have changed in nature as demands on the data, observing practices and technologies have evolved.
  - The uncertainty in observational records encompasses instrumental/ recording errors, effects of representation (e.g., exposure, observing frequency or timing), as well as effects due to physical changes in the instrumentation (such as station relocations or new satellites).
- Because there is no unique, unambiguous, way to identify and account for non-climatic artefacts in the vast majority of records, there must be a degree of uncertainty as to how the climate system has changed.
- The only exceptions are certain atmospheric composition and flux measurements whose measurements and uncertainties are rigorously tied through an unbroken chain to internationally recognized absolute measurement standards (e.g., the CO_2 record at Mauna Loa; Keeling et al., 1976a)".

Dealing with uncertainty in the temperature record

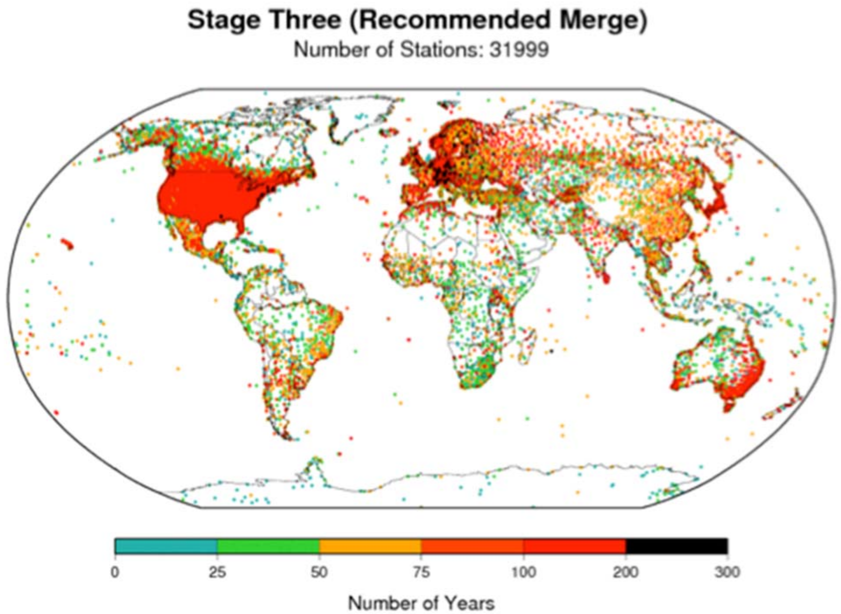
Introduce "points" with traceable measurements to the system

eg simultaneous calibration of temperature, pressure and humidity

ISTITUTO NAZIONALE DI RICERCA METROLOGICA

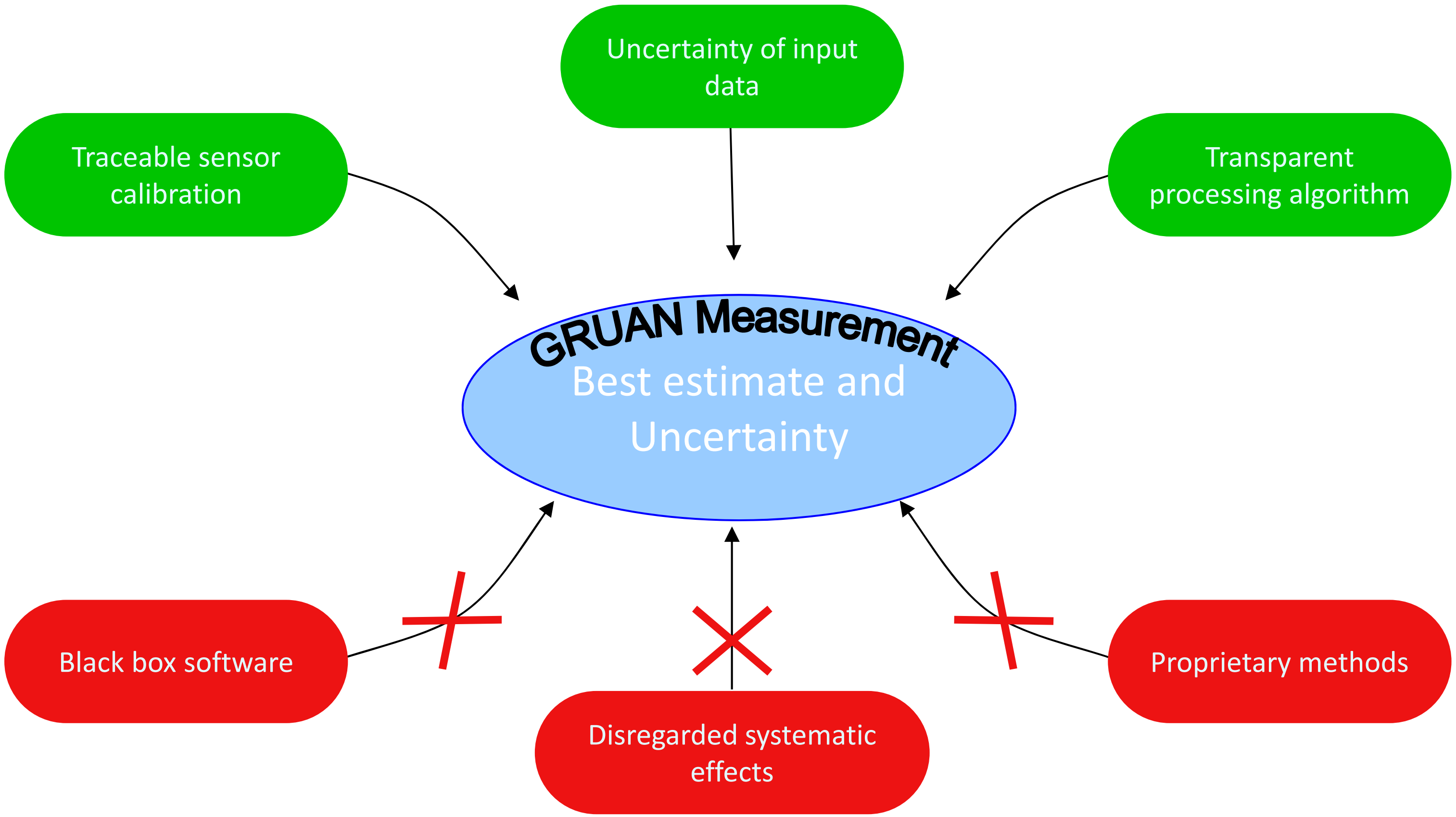
es

"to facilitate creation of the best possible surface air temperature records over land to meet the myriad of data demands by science and society"



International Surface Temperature Initiative

Establishing reference quality data

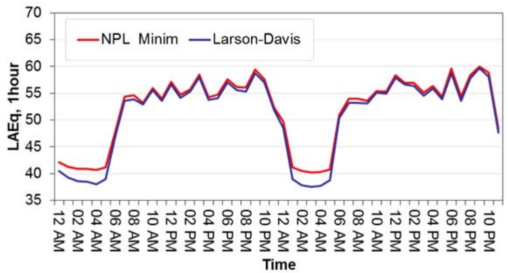


Literature:

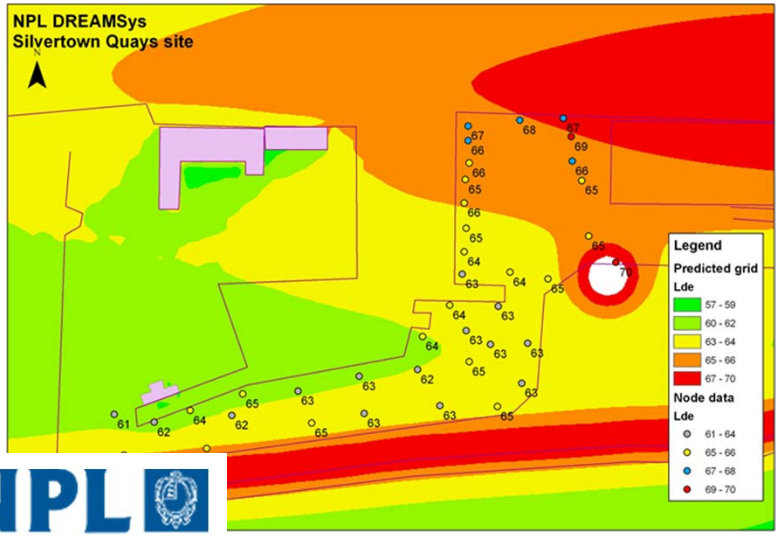
- Guide to the expression of uncertainty in measurement (GUM, 1980)
- Reference Quality Upper-Air Measurements: Guidance for developing GRUAN data products, Immler et al. (2010), Atmos. Meas. Techn.

Predicting and measuring environmental noise

- Noise sources are typically modelled and mapped in isolation to maintain simplicity
- Measurement data can validate modeling results.
- Measurements can then be used to supplement and improve modelling in specific regions.



Quantity	Minim	Larson -Davis	Difference
L_{den} (dB)	58.3	57.6	0.7



NPL
National Physical Laboratory

Mapping noise fields

- Although consumer product microphones are not fit-for -purpose as measurement devices…… MEMS microphones have inherent potential to meet requirements for high performance
- Such systems provide the basis for a new approach to noise measurement using distributed sensor networks and address the vision for future noise measurement.

Environmental radioactivity

Traceability for specific activity (mBq/g) is underpinned by comparisons of reference materials at environmental levels: eg

- CCRI(II)-S9 (Rice)
- APMP.RI(II)-S3 (Brown rice)
- A planned comparison on a wheat matrix.

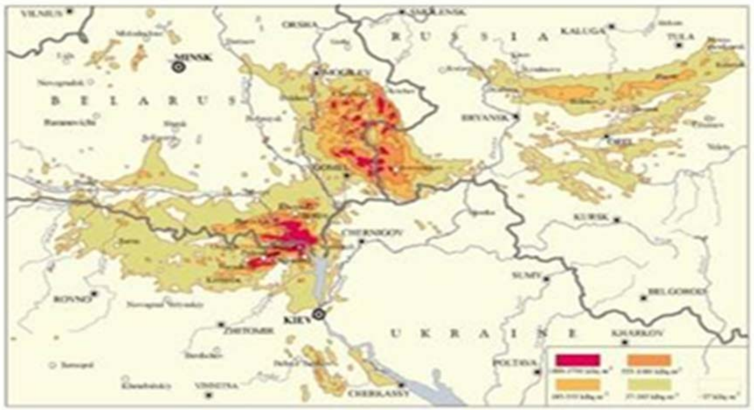
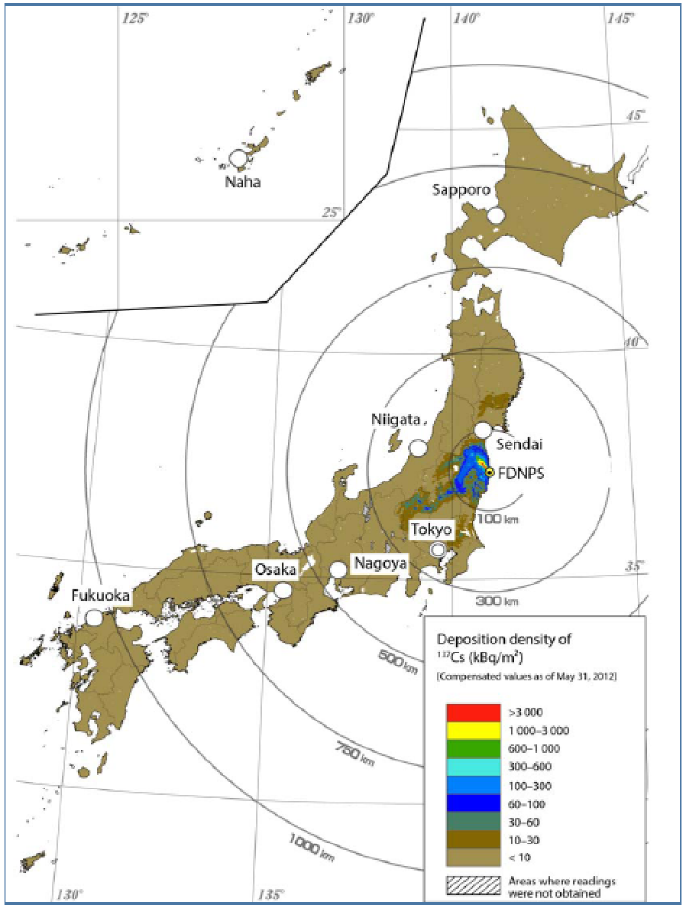


Figure B-VIII. Measurement results of the airborne monitoring surveys conducted by MEXT (deposition density of ^{137}Cs) [N18]



Environmental radioactivity

- Environmental radioactivity comparisons in matrix materials are undertaken as Supplementary Comparisons (at the RMOs or CCRI) to:
  - validate reference materials/methods in support of CMCs,
  - respond to specific needs (food contamination, fallout exposure)

- Problems of environmental materials:
  - variability of natural matrix
    - sampling, homogeneity, grain size,
    - water content, stabilization, density, …
  - extraction of radionuclides from the matrix
  - preparation of the source : solid/liquid, measurement method(s)
  - low counting statistics, higher uncertainty

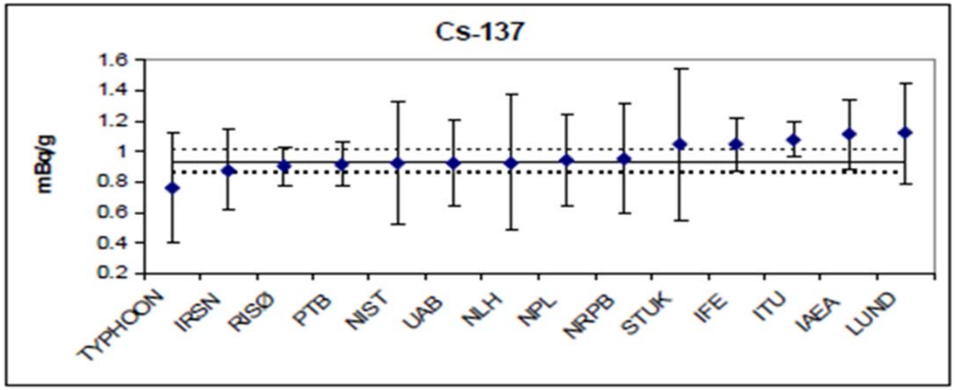
- Traceability for activity established for pure radionucleides:
  - BIPM.RI(II)-K1 (Système International de Référence - SIR)
  - allows NMIs to check the equivalence of primary methods on single radionuclide

Environmental radioactivity (eg in Cs-137 in seaweed)

Seaweed reference material needed for monitoring radioactivity in the marine environment . Organic material is widely available and naturally accumulates radionuclides from sea water.

CCRI(II)-S1 (seaweed)

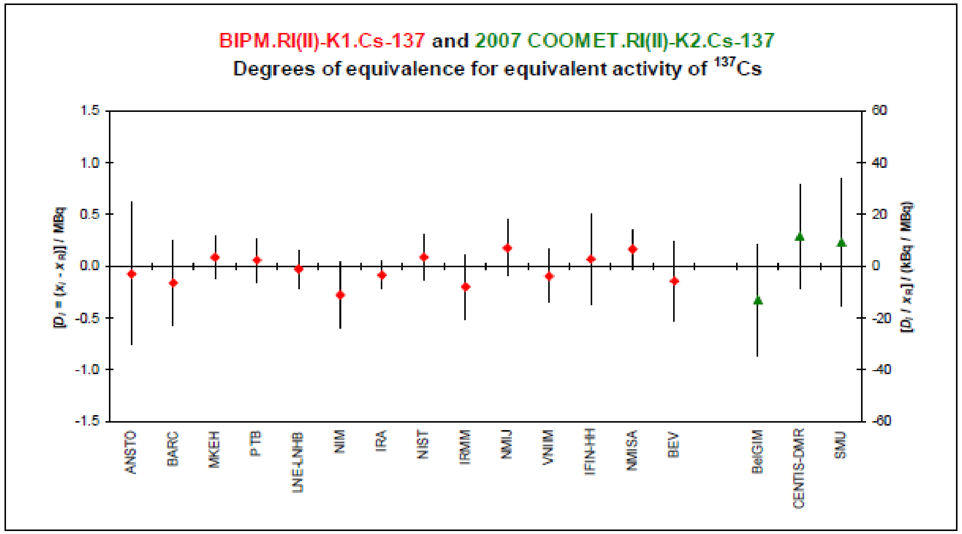
- Piloted by NIST
- Major environmental aggregator
- 24 laboratories from 16 countries
- 13 radionuclides
- Typical uncertainties are ten times larger than for pure radionucleides.



Metrologia 2013, **50**, *Tech. Suppl.*, 06014

Table 6. Uncertainty components for CCRI(II)-S1

Radionuclide	Relative expanded uncertainty, % (k=2)
^{40}K	5.9
^{137}Cs	8.0
^{210}Pb	14.5
^{210}Po	7.3
^{228}Ra	13.9
^{232}Th	12.7
^{234}U	11.2
^{235}U	11.7
^{238}U	6.2
^{238}Pu	4.2
^{239}Pu	3.9
^{239,240}Pu	5.8
^{241}Am	14.8



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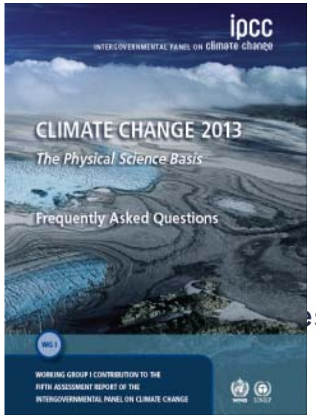
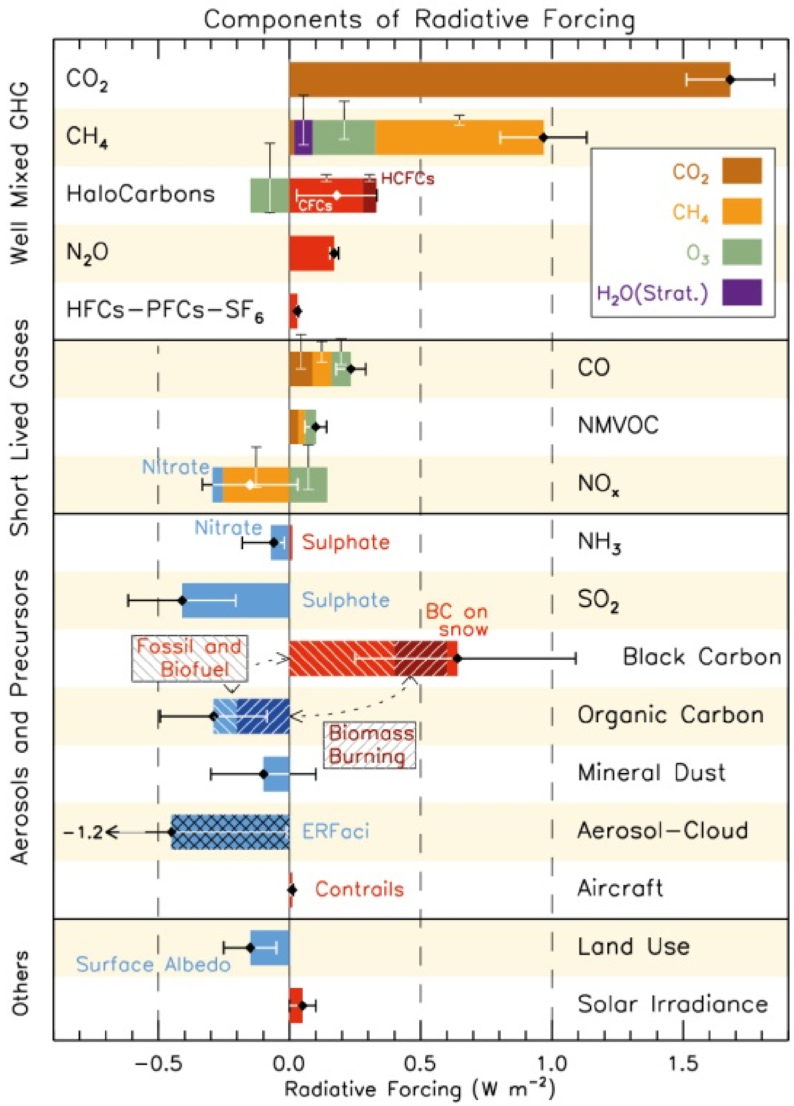
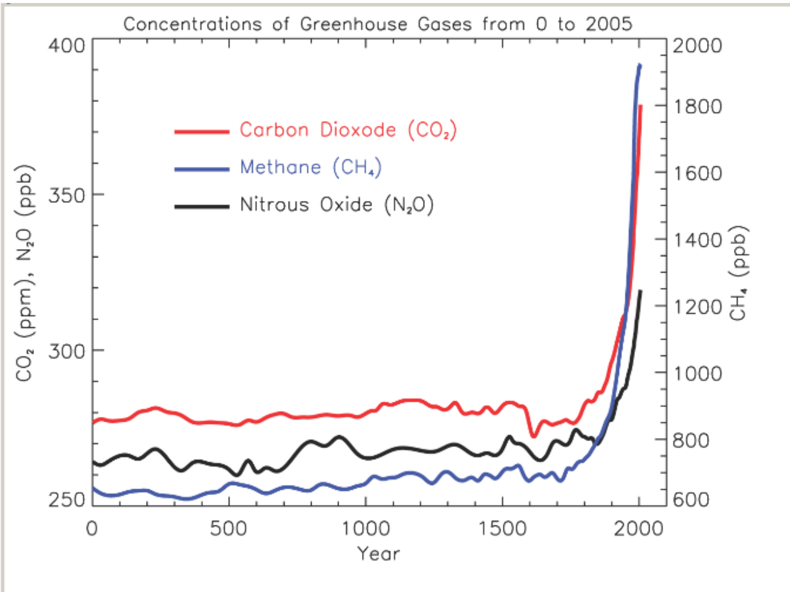
Contributions to radiative forcing

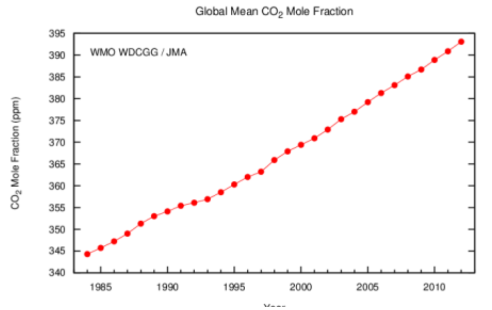
- Radiative forcing for the period 1750–2011 based on emitted compounds (gases, aerosols or aerosol precursors) or other changes.
- The vertical bars indicate the relative uncertainty of the RF induced by each component. Their length is proportional to the thickness of the bar, that is, the full length is equal to the bar thickness for a ±50% uncertainty.
- The net impact of the individual contributions is shown by a diamond symbol and its uncertainty (5 to 95%).
- Ref IPCC - WG1 – AR5 Fig 8-17

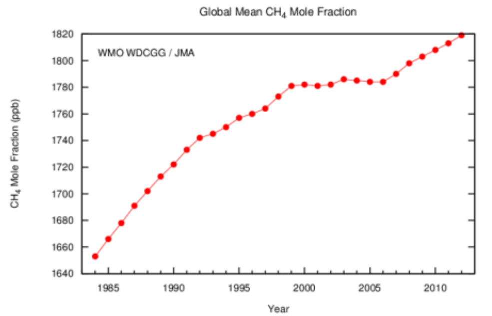


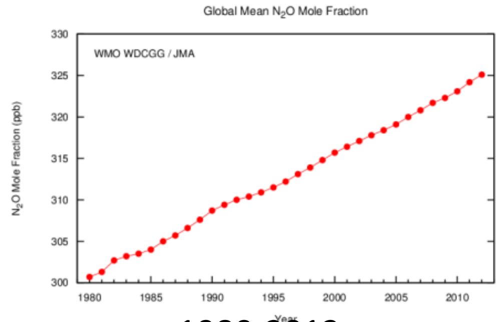


CO_2, CH_4 and N_2O









1980-2013

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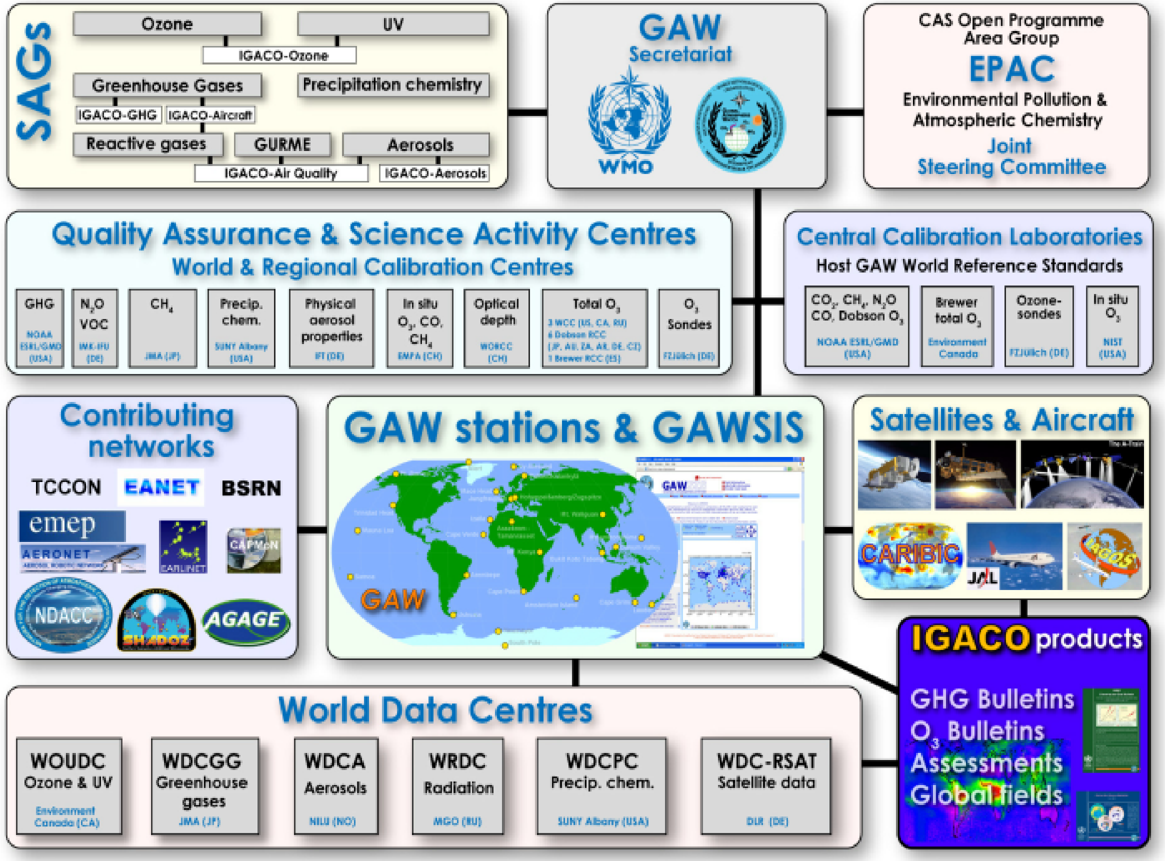
WMO Global Atmosphere Watch
World Data Centre for Greenhouse Gases
GAW WDCGG

The Global Atmospheric Watch



- GAW is a collaborative programme organized by the WMO
- include standards and quality assurance activities - the NMIs are now collaborating

GAW

Data Quality Objectives (DQOs) for GAW

Component	Inter-Laboratory comparability
CO_2	± 0.1 ppm (± 0.05 ppm in the southern hemisphere)
$\delta^{13}C\text{-}CO_2$	± 0.01 ‰
$\delta^{18}O\text{-}CO_2$	± 0.05 ‰
$\Delta^{14}C\text{-}CO_2$	± 1 ‰
O_2/N_2	± 1 per meg
CH_4	± 2 ppb
CO	± 2 ppb
N_2O	± 0.1 ppb
H_2	± 2 ppb
SF_6	± 0.02 ppt

Source: WMO/TD-No. 1487, 14th WMO/IAEA Meeting of Experts on Carbon dioxide, other Greenhouse Gases and Related Tracers Measurement Techniques (2007)

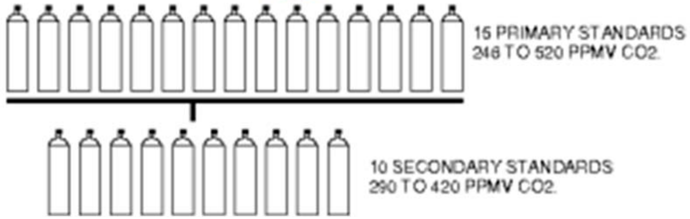
GAW

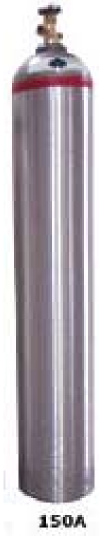
WMO method for CO_2 scale dissemination

Niwot Ridge air

Volumetric addition of pure CO_2, CH_4 etc

Repeatability ~ 100ppb

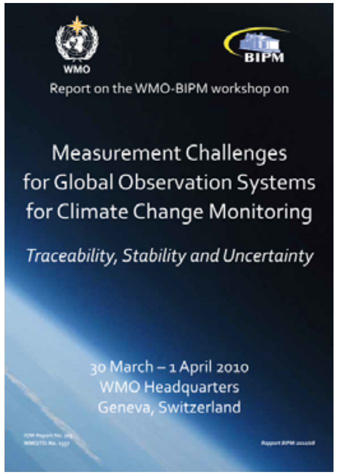


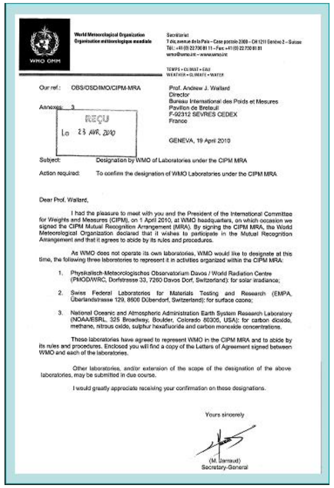


Noise (1 sec) ~ 20ppb

- Value on certificate comes from comparison of standard versus secondary standards

WMO sign the CIPM MRA (April 2010)





WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

Secrétariat

TEMPS • CLIMAT • EAU
WEATHER • CLIMATE • WATER

Our ref.: OBS/OSD/IMO/CIPM-MRA

Annexes: 3

REÇU
Le 23 AVR. 2010

Prof. Andrew J. Wallard
Director
Bureau International des Poids et Mesures
Pavillon de Breteuil
F-92312 SEVRES CEDEX
France

GENEVA, 19 April 2010

Subject: Designation by WMO of Laboratories under the CIPM MRA

Action required: To confirm the designation of WMO Laboratories under the CIPM MRA

Dear Prof. Wallard,

I had the pleasure to meet with you and the President of the International Committee for Weights and Measures (CIPM), on 1 April 2010, at WMO headquarters, on which occasion we signed the CIPM Mutual Recognition Arrangement (MRA). By signing the CIPM MRA, the World Meteorological Organization declared that it wishes to participate in the Mutual Recognition Arrangement and that it agrees to abide by its rules and procedures.

As WMO does not operate its own laboratories, WMO would like to designate at this time, the following three laboratories to represent it in activities organized within the CIPM MRA:

1. Physikalisch-Meteorologisches Observatorium Davos / World Radiation Centre (PMOD/WRC, Dorfstrasse 33, 7260 Davos Dorf, Switzerland): for solar irradiance;
2. Swiss Federal Laboratories for Materials Testing and Research (EMPA, Überlandstrasse 129, 8600 Dübendorf, Switzerland): for surface ozone;
3. National Oceanic and Atmospheric Administration Earth System Research Laboratory (NOAA/ESRL, 325 Broadway, Boulder, Colorado 80305, USA): for carbon dioxide, methane, nitrous oxide, sulphur hexafluoride and carbon monoxide concentrations.

These laboratories have agreed to represent WMO in the CIPM MRA and to abide by its rules and procedures. Enclosed you will find a copy of the Letters of Agreement signed between WMO and each of the laboratories.

Other laboratories, and/or extension of the scope of the designation of the above laboratories, may be submitted in due course.

I would greatly appreciate receiving your confirmation on these designations.

Yours sincerely

(M. Jarraud)
Secretary-General

WMO-BIPM Workshop
Geneva
April 2010

Shared objective:
to bring the WMO "scales" and NMI standards in line.

Three laboratories designated by the WMO

NOAA/ESRL for CO_2, CH_4, N_2O, SF_6 and CO
EMPA for surface ozone
PMOD/WRC for solar irradiance

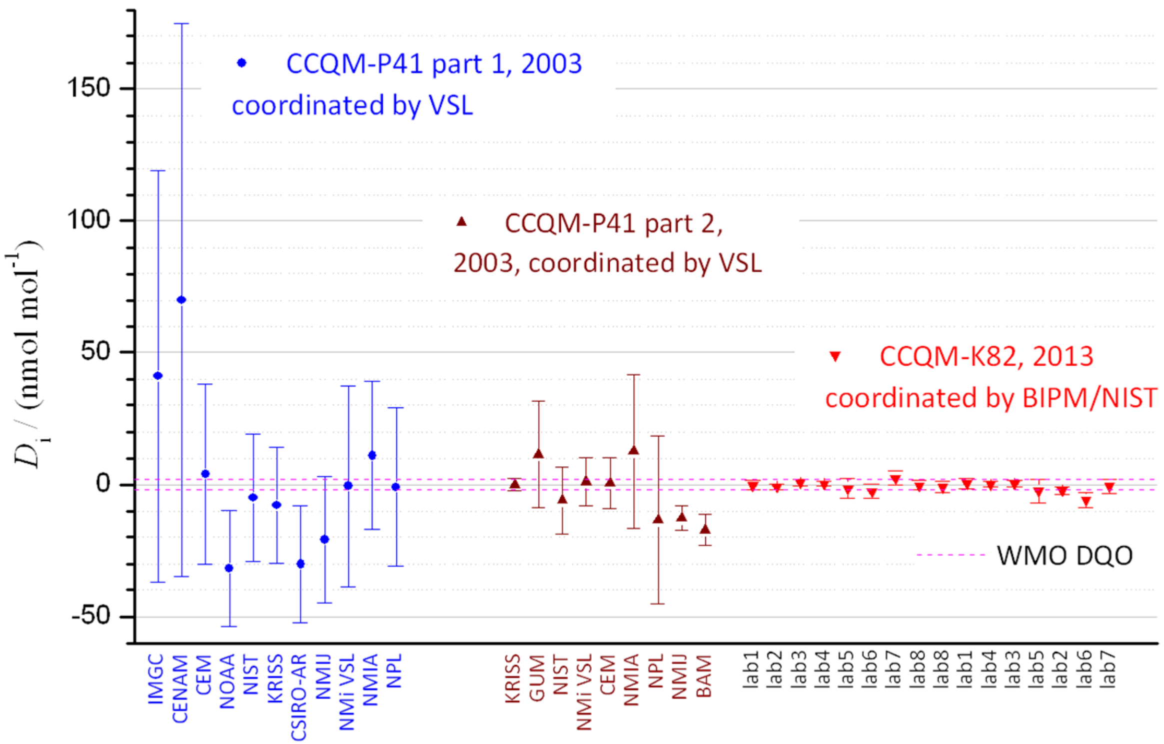
- will take part in future international comparisons organised by the NMIs

- gives visibility of the relationship between SI traceable values from the NMIs and the WMO scales

Demonstrating the comparability of standards and scales for CH_4 in air

Comparisons on Methane in air at atmospheric levels

(2 µmol mol^{-1}) for climate change monitoring



Comparison results vs. Data Quality Objectives of WMO-GAW

DQO = ± 2 nmol/mol

For CCQM-K82:

Smallest $u(x)$ = 0.5 nmol/mol

$\sigma_{(CCQM\text{-}K82)}$ = 1.17 nmol/mol

For interchangeability of standards

$u(x)$, $\sigma_{(CCQM\text{-}Kxx)} \leq$ DQO/8

$u(x)$, $\sigma_{(CCQM\text{-}Kxx)} \leq$ 0.25 nmol/mol

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CCQM GAWG

The basis for (environmental) measurements

Metrological traceability - "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations each contributing to the measurement uncertainty" – VIM (2007)

Traceability to the SI

Rationale

Values disseminated that are traceable to the SI as realised by a primary method.

Benefits

- Highly coherent and accurate
  - Good "absolute" data
- Possibility for more than one source.

Disadvantages

- Values may change (in absolute terms) within stated uncertainties but will always "improve".

Traceability to a "scale"

Rationale

Values disseminated that are traceable to a collection ("family") of artefacts carefully, monitored and maintained

Benefits

- Highly consistent ("precise")
  - Good trend data

Disadvantages

- Responsibility / cost of maintenance concentrated at one institution
- Impossible to regenerate or develop independently
- (May be) insensitive to drift in the reference artefacts

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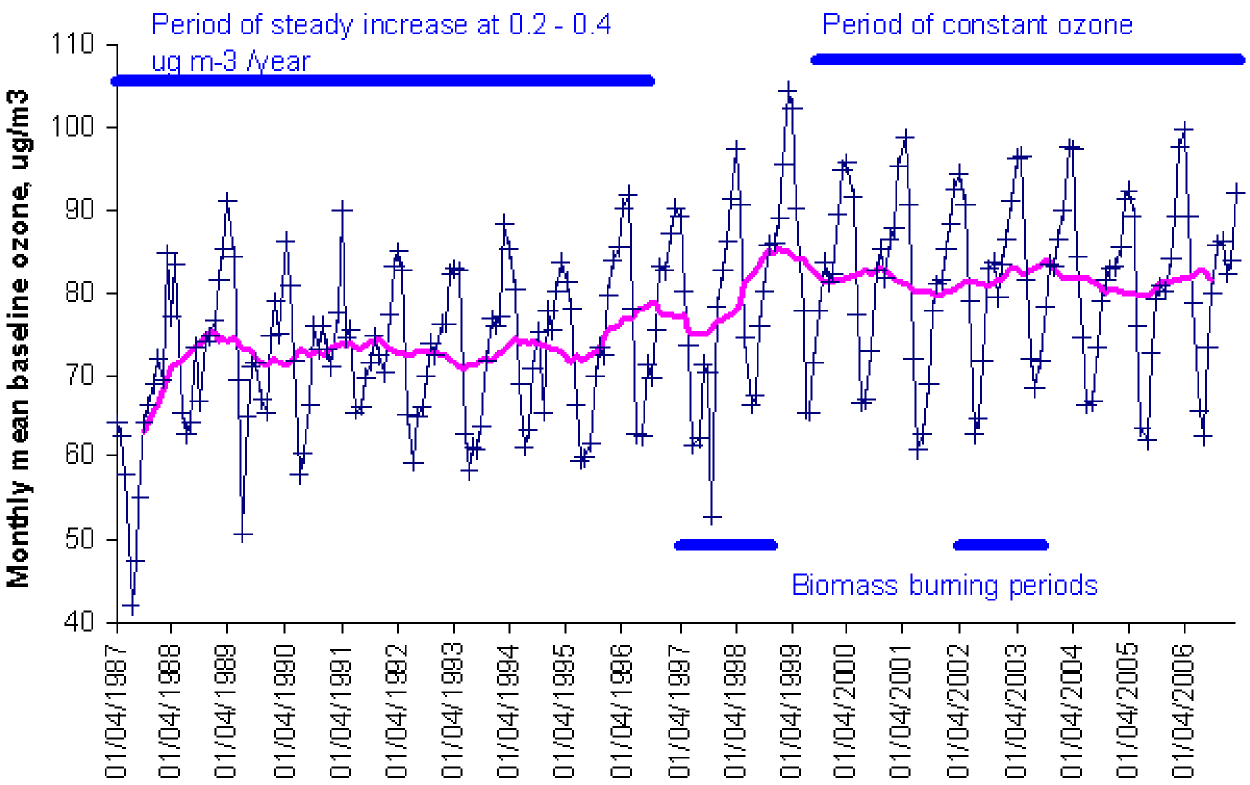
But does "coherence"matter in environmental applications?

Why is ozone important?

- Ambient ozone – contributes to photochemical smog, severe irritant to asthma sufferers, damages plants etc



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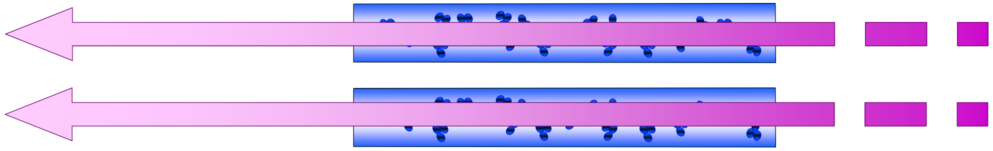
Reference method for (surface) ozone



x **mole fraction of ozone in dry air (nmol/mol)**

$$x = \frac{-1}{2\sigma L_{opt}} \frac{T}{P} \frac{R}{N_A} \ln(D)$$

T Temperature in the cells

P Pressure in the cells

L_{opt} light path length

s Ozone absorption cross-section at 253.64 nm under standard conditions of temperature and pressure

D Product of transmittance of the two cells

R Gas constant

N_A Avogadro constant

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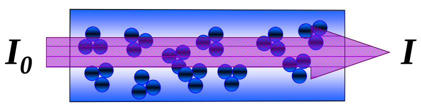
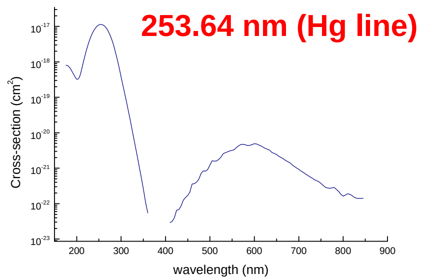
UV photometry and GPT traceability chains

Pure ozone concentration *c* assessed by pressure measurements

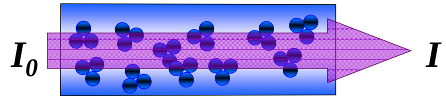


$$\sigma(\lambda) = -\frac{1}{L_{opt} \cdot c} \ln\left(\frac{I}{I_0}\right)$$

→ $\sigma(\lambda)$ →

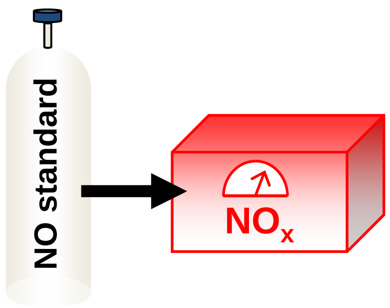


Primary UV photometer



$$c' = -\frac{1}{L_{opt} \cdot \sigma(\lambda)} \ln\left(\frac{I}{I_0}\right)$$

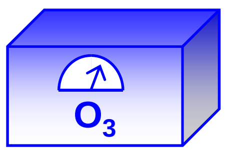
Equivalent ?



Chemiluminscence NO_x analyser calibrated by gravimetric NO standard

→ **GPT stoichiometric reaction** →

$$NO + O_3 \rightarrow NO_2 + O_2$$



Calibration of O_3 analyser

Future work – resolve this difference !

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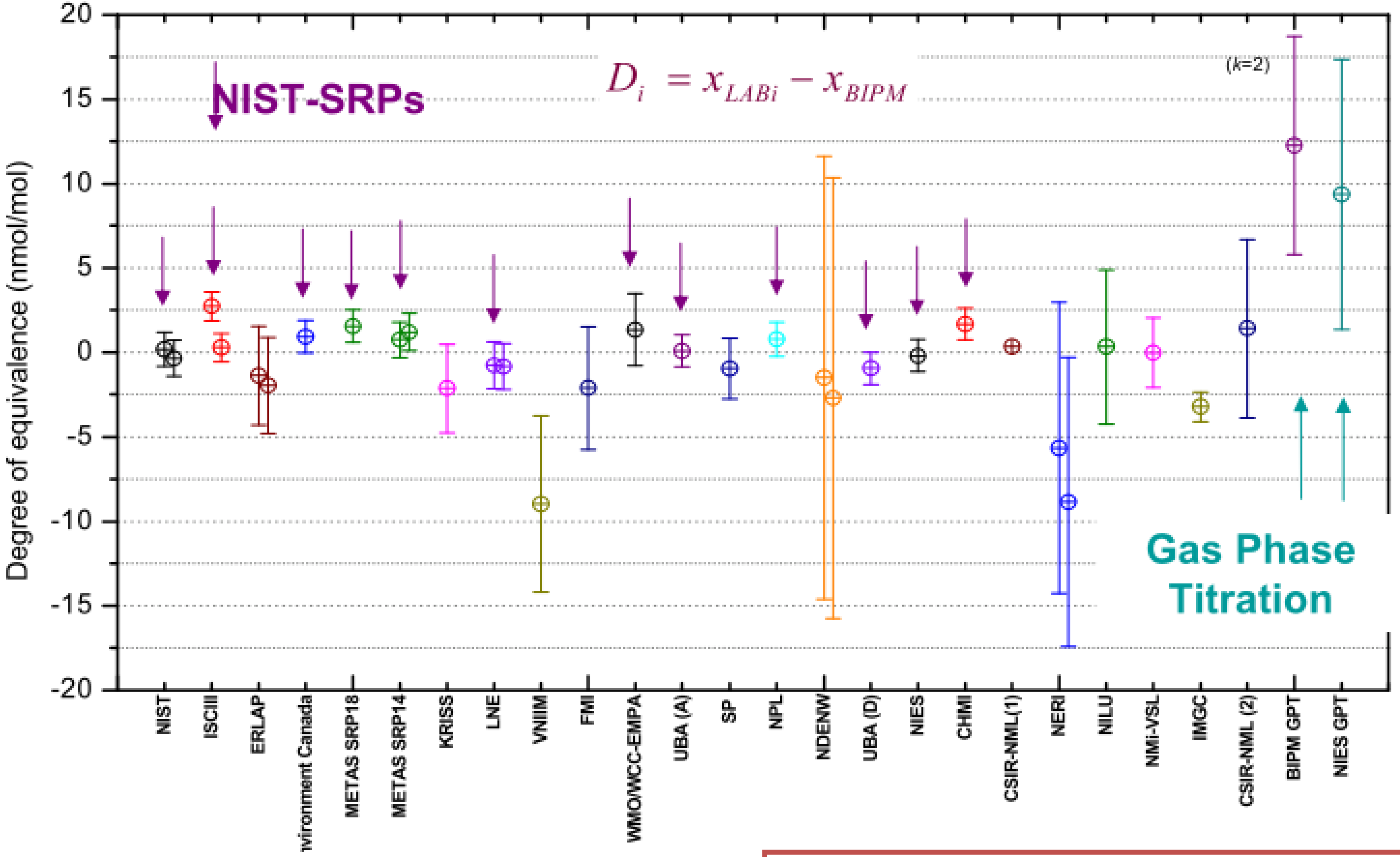
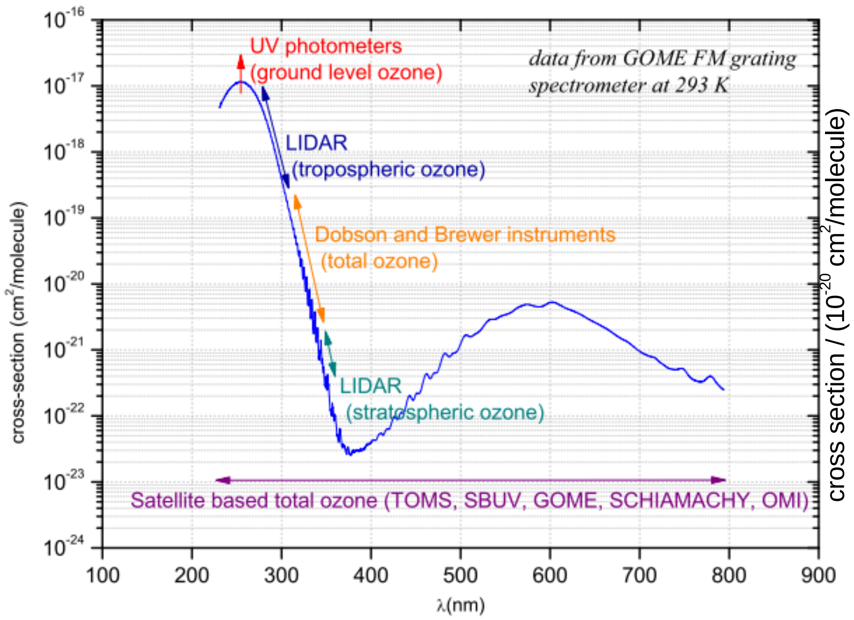
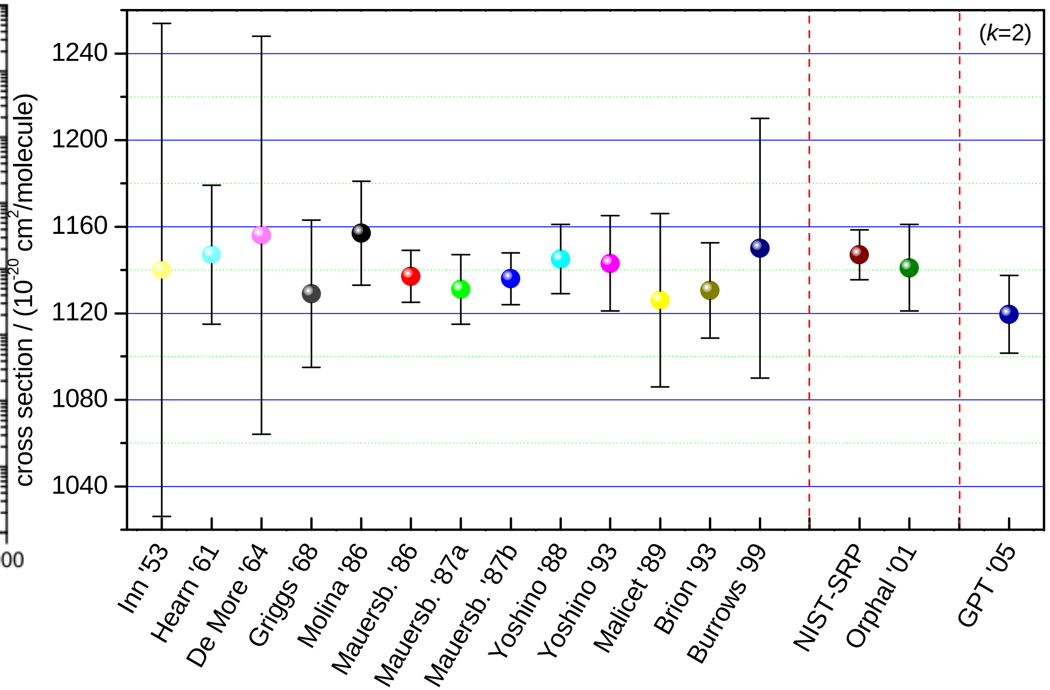
International comparison of ozone



(at 420 nmol/mol)

Ozone cross section at 253.7 nm





The value of the ozone absorption cross section at 253 nm has a direct influence on the cross section used at other wavelengths for other applications

Do we want measurements of ozone to give different results according to what part of the atmosphere they are taken in!

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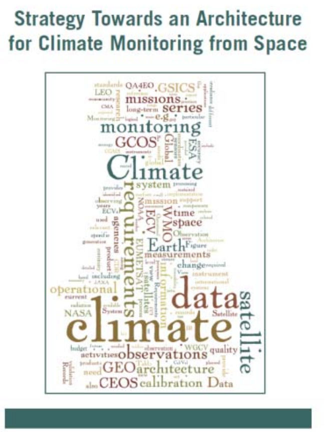
Essential Climate Variables

- GCOS has defined a list of 50 essential climate variables required to support UNFCC and IPCC.
- All are technically and economically feasible to monitor.
- How do we determine where the impact of providing traceability for ECVs will be greatest?

Domain	GCOS Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:**[1] Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget. **Upper-air:**[2] Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance). **Composition:** Carbon dioxide, Methane, and other long-lived greenhouse gases[3], Ozone and Aerosol, supported by their precursors[4].
Oceanic	**Surface:**[5] Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers.
Terrestrial	River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.

- More than 1/3rd of the ECVs are derived from primary radiometric parameters .

Essential Climate Variables

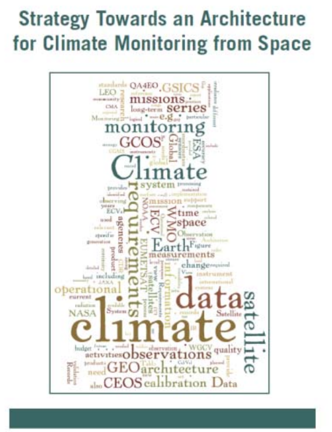


CEOS / WMO 2013

Instrument or mission type	Current or planned satellite missions including measurements of that category		Essential Climate Variable potentially supported
LEO - Multi-purpose VIS/IR imagery and IR and MW sounding	NOAA series (NOAA) Meteor series (Roshydromet) Metop series (EUMETSAT) FY-1 and FY-3 series (CMA) GCOM-C series (JAXA)	EOS-Terra and Aqua (NASA) NPP, JPSS series (NOAA) DMSP and DWSS series (DOD) Megha-Tropiques (ISRO, CNES)	Temperature, Water vapour, Cloud properties, Aerosols, Surface radiation budget, Albedo, Ozone, Methane, CO, CO_2, NO_2, Sea surface temperature, Permafrost, Snow cover, FAPAR, Leaf Area Index, Biomass, Fire disturbance, Precipitation
GEO - Multi-purpose VIS/IR imagery and IR sounding	GOES series (NOAA) Meteosat (MFG, MSG, MTG) series (EUMETSAT) FY-2/FY-4 series (CMA) MTSAT/Himawari series (JMA)	INSAT/ Kalpana series (ISRO/IMD) Elektro-L (Roshydromet) COMS series (KMA)	Water vapour, Cloud properties Wind speed and direction Aerosols, Surface radiation budget, Albedo Sea surface temperature Temperature Precipitation
LEO – Radio-occultation sounding	COSMIC-1, 2 (NOAA) SAC-C and SAC-D (CONAE) KOMPSAT-5 (KARI) Tandem-X (DLR) Meteor-M N3 (Roshydromet) Metop series (EUMETSAT)	FY-3 E, G (CMA) Oceansat-2, 3 (ISRO) Megha-Tropiques (ISRO, CNES) CHAMP (DLR) GRACE (NASA/DLR)	Atmospheric temperature Water vapour Cloud properties
LEO and GEO - Earth radiation budget	ACRIMSAT (NASA) SORCE (NASA) JPSS-1 (NOAA)	Earth care (ESA/JAXA) FY-3 A, B, C, E, G (CMA) Meteosat (EUMETSAT)	Earth radiation budget Surface radiation budget

CEOS
Committee on Earth Observation Satellites

Essential Climate Variables



CEOS / WMO 2013

- *"In some areas (eg passive microwave observations), SI traceability of sufficient accuracy will not be achievable within the next 10 years as the radiometric uncertainties reached using current in-lab standards from National Metrology Institutes (NMIs) are at the same level as those required from satellite sensors in orbit".*

Objectives for SI traceability	Climate Requirement	Pre-flight	In-flight	Terrestrial	Primary
Solar Irradiance	0.01%	0.2%	?	0.2%	0.01%
Spectral radiance (clouds, albedo)	0.3%	2% - 5%	?	-1%	<0.05%
Water-leaving radiance (Ocean Colour)	1%	5%	-5%	-1%	<0.05%

Committee on Earth Observation Satellites

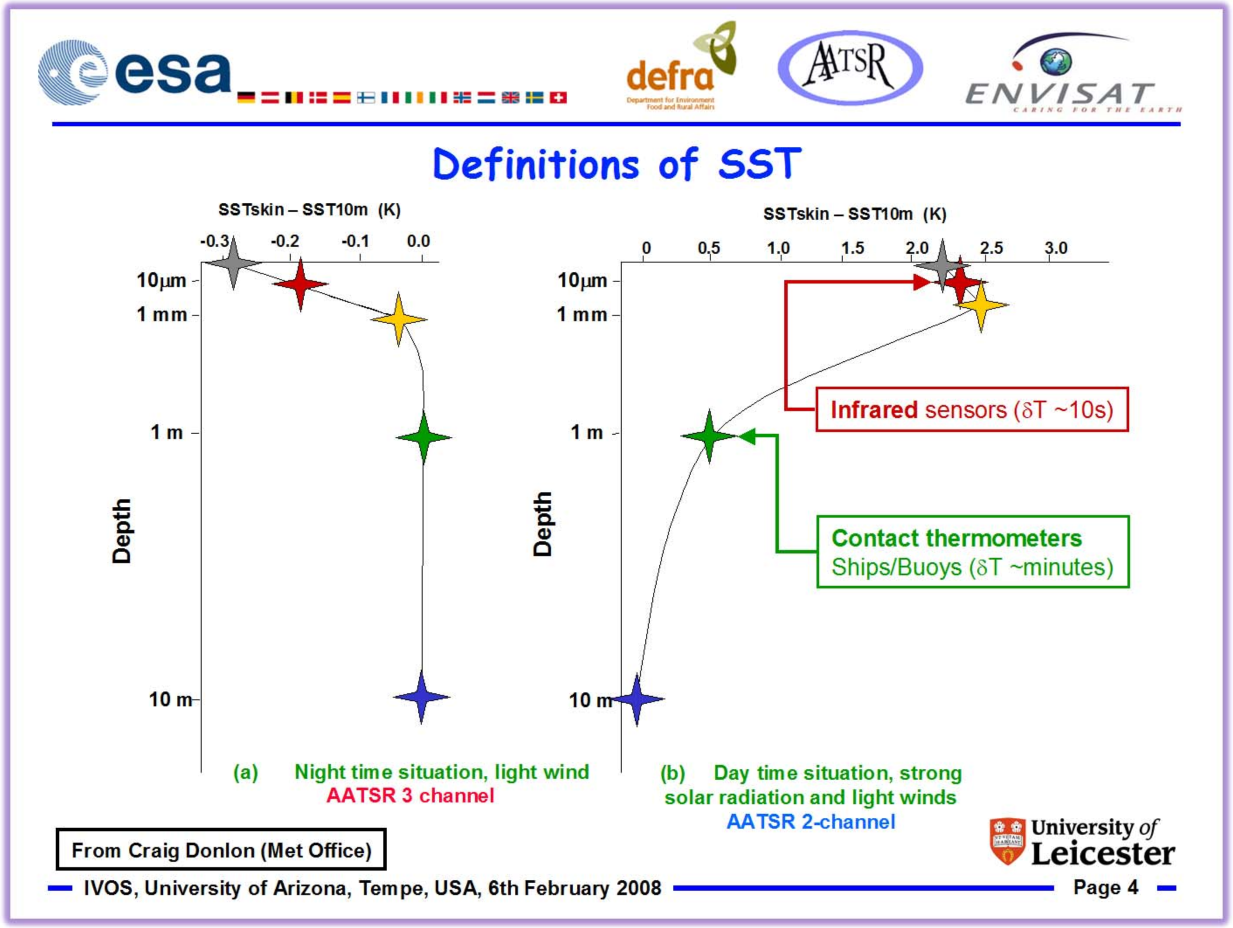
The measurand can be difficult to define

- Oceans are a big heat sink of energy; temperature changes very slowly,
- an indicator of climate warming and leads to expansion and hence sea level rises
- **Climate models predict SST to change by approximately 0.2 K per decade**

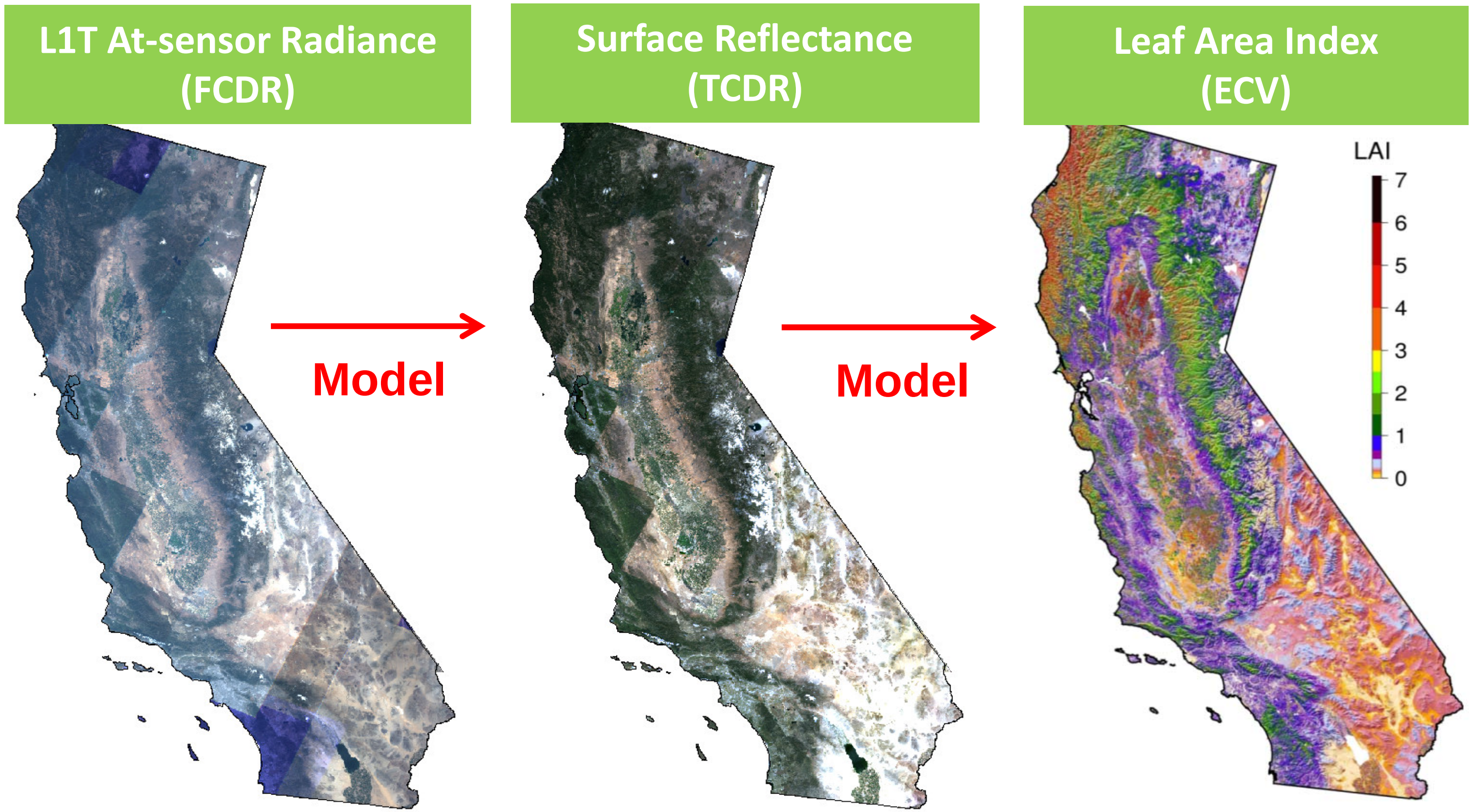
How to measure?

- Ship sampling
  - Buckets
  - Hull thermometers
  - Radiometers
- Ocean buoys
  - Drifting
  - Tethered
  - Robotic
- Satellites

But, they all different.



Raw measurement to required Information



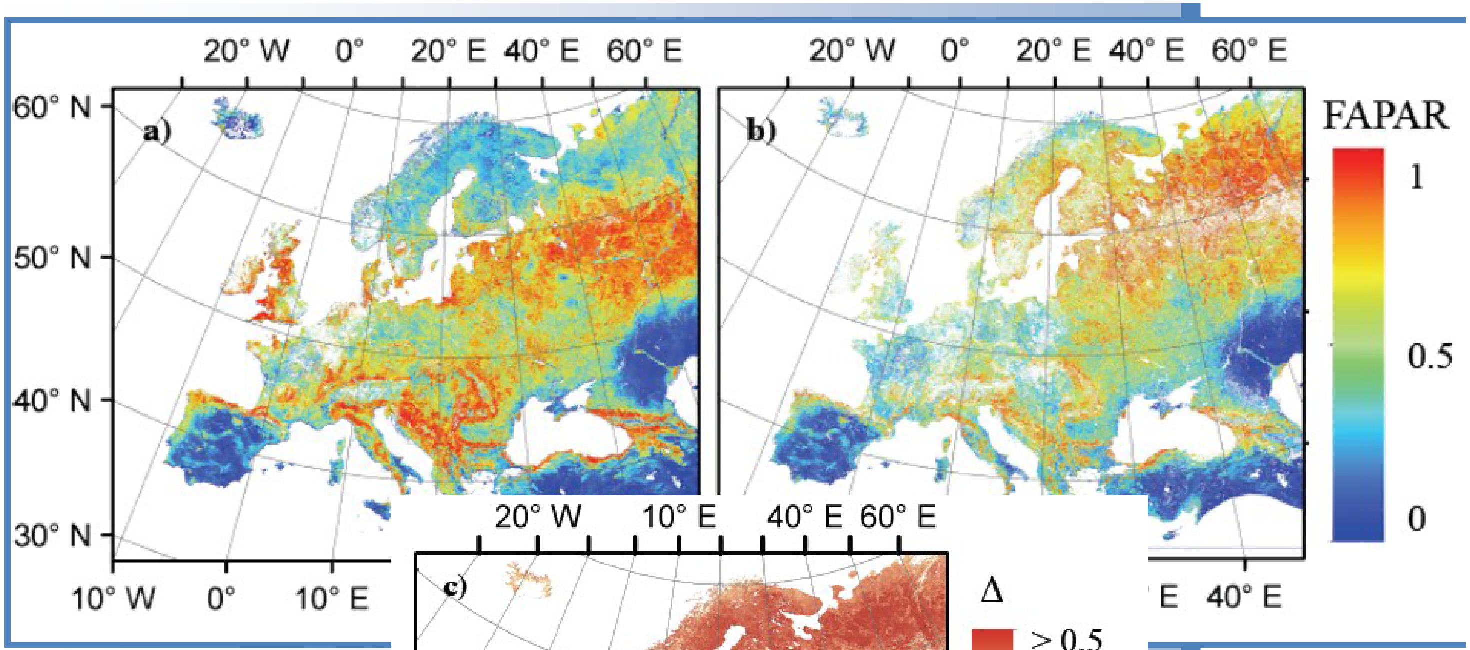
Many ECV's are bio-geo-physical parameters

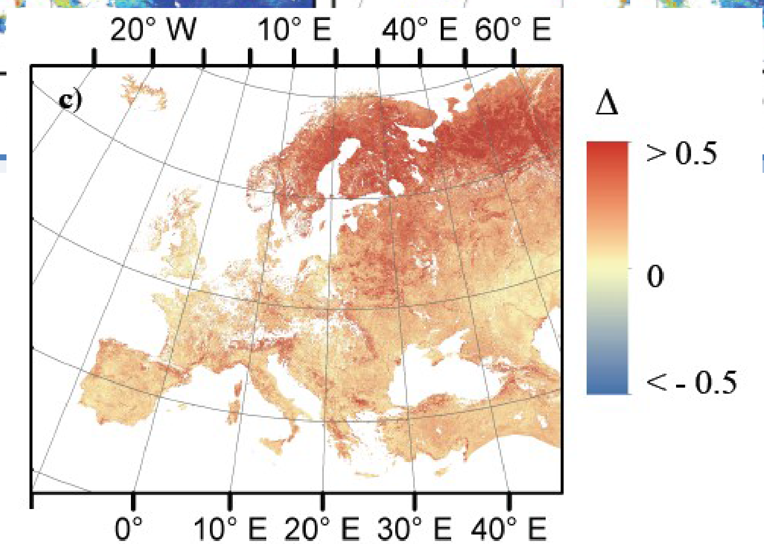
- Measured quantity is a proxy or first step to the desired measurand
- Assessing uncertainty on that parameter (e.g. Leaf Area Index (LAI) or carbon stored in a forest) requires retrieval algorithms.
- Scaling can be a major issue (leaf scale to 300 m pixels to global)

Courtesy Rama Nemani, NASA Ames Research Center

Raw measurement to required Information

FAPAR (Fraction of Absorbed photo-synthetically active Radiation)
An ECV for which GCOS requires uncertainty <10% and stability <3%





FAPAR calculated using same input satellite data different methods.

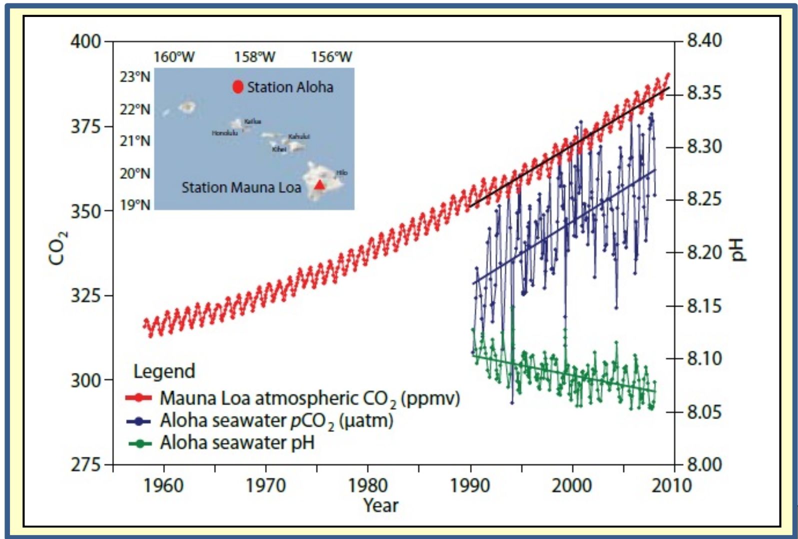
**Difference between methods –
up to 5X uncertainty needed using same data set!!**

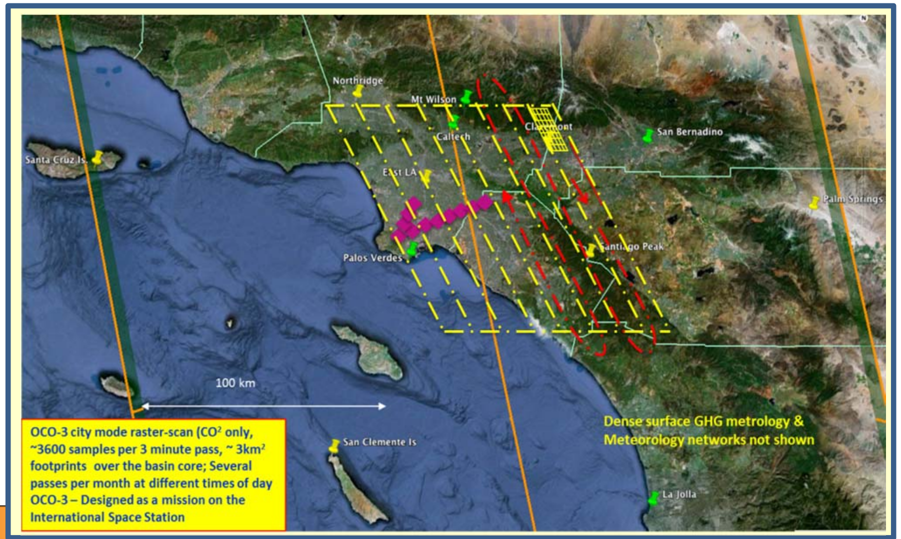
Dodorico *et al*
Rem Sens of Env **142,** p 141 (2013)

Reconciling “bottom-up” with “top-down” measurement data

Courtesy of: J. Whetstone (NIST) “**Greenhouse Gas and Climate Science Measurements Research at NIST**”
Talk in Session 1

Reconciling top-down and bottom-up measurement data

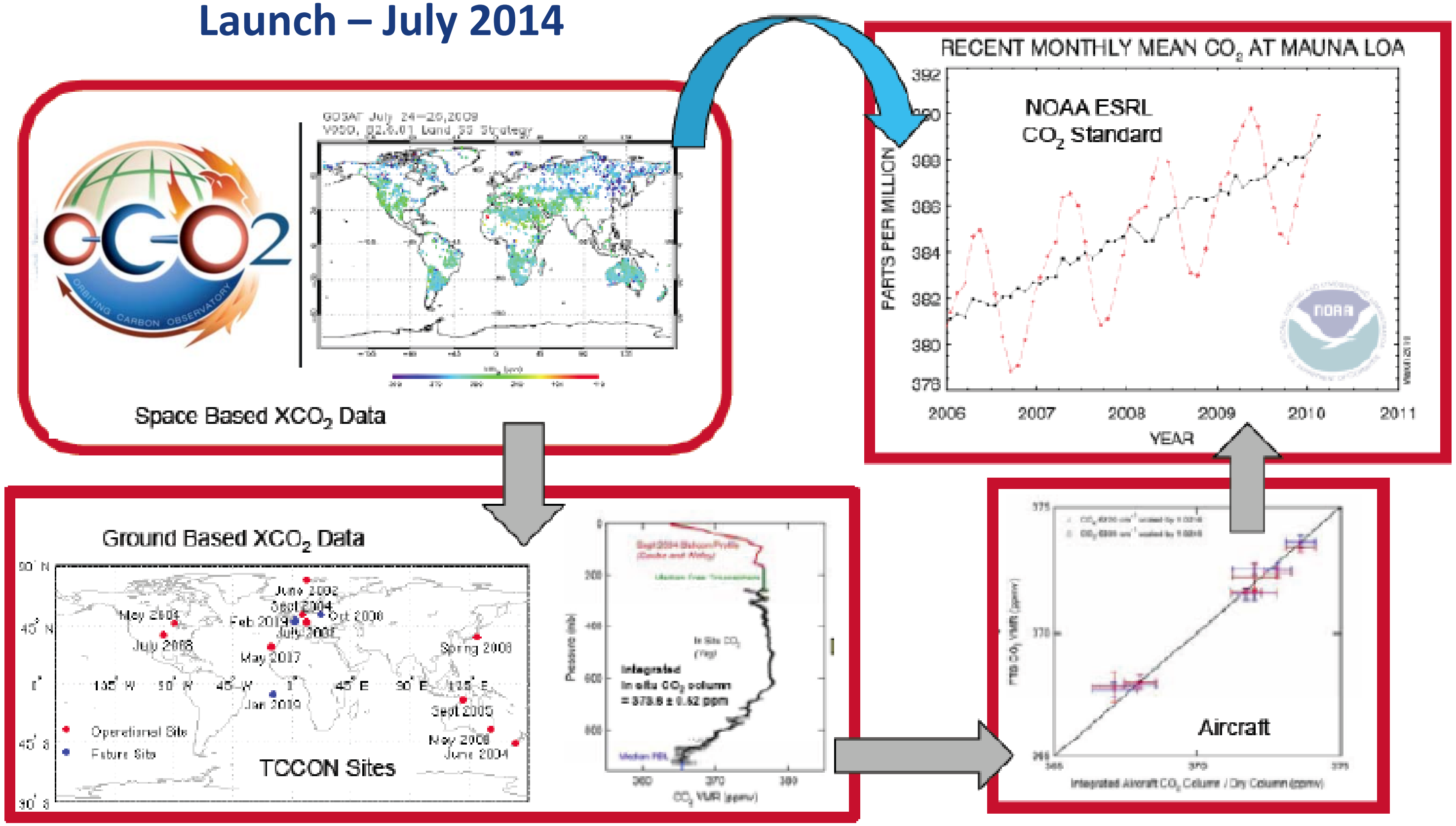




Courtesy of: J. Whetstone (NIST) "**Greenhouse Gas and Climate Science Measurements Research at NIST**"
Talk in Session 1

Orbiting Carbon Observatory (2) - validation

Launch – July 2014



TCCON - Ground-based FTS instruments with clear-sky rms calibrated X_{CO2} accuracy of <=0.3%.

Aircraft and balloon overflights calibrated to WMO standards.

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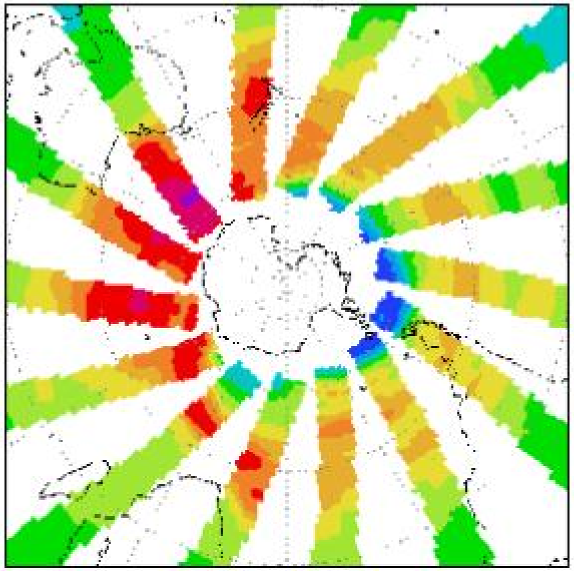
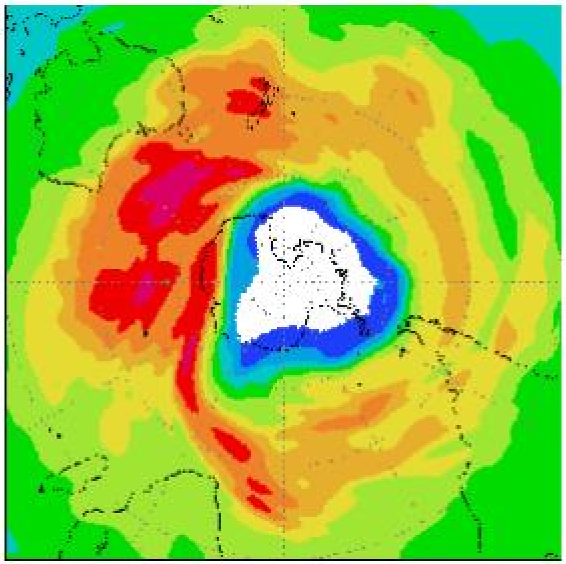
Data assimilation – a "different paradigm"

"Data assimilation is the combining of different sources of information to estimate at best the state of a system. These sources generally are observations and a numerical model".





Advantages:

- Data for different measurands can combined in the model,
- Sparse data, distributed unevenly, from different instruments to be used
- Chemical models can be used to link chemical parameters

BUT - the model becomes the basis for the "accuracy" of observations.

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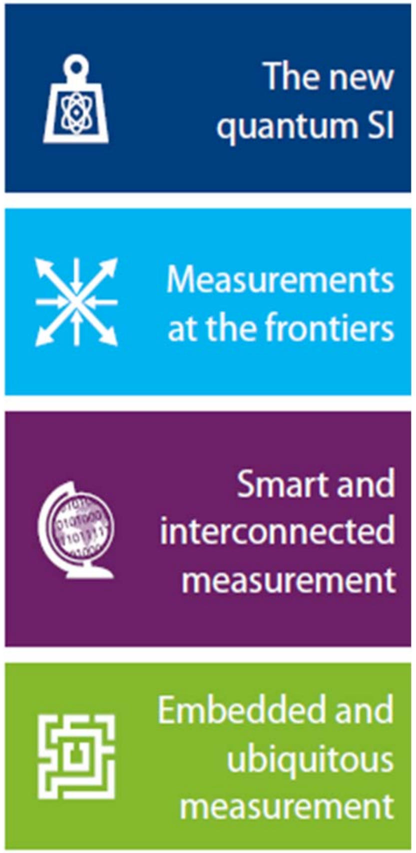
Metrology for the 2020s

A foresight project - “In the 2020s, metrology will develop in four areas”



NPL
National Physical Laboratory

http://www.npl.co.uk/2020vision/

Metrology for the 2020s

Examples of metrology in the 2020s applied to

Monitoring the state of the planet

The new quantum SI	Direct traceability for Earth observation systems at uncertainties of 0.01% for incoming and 0.3% for reflected radiation to enable detection of decadal climate change.
Measurements at the frontiers	Sensitive and accurate methods developed to measure the long-term integrity of carbon capture and storage facilities, for example by monitoring carbon dioxide at ambient levels with ppb accuracy.
Smart and interconnected measurement	Networks of self-calibrating sensors monitoring chemical species in the atmosphere. Such networks will make use of new mathematical strategies that exploit the 'internet of things' to provide real-time data verification and quality assurance.
Embedded and ubiquitous measurement	Traceable environmental data publicly accessible in real time from sensors embedded in vehicles and mobile devices. For example, providing data for citizens to minimise their personal exposure.

New challenges - “Citizen science”

- Noise Tube
  - *“Turn your mobile phone into an environmental sensor and participate in the monitoring of noise pollution”*

- Air quality egg
  - *“The Air Quality Egg is a sensor system designed to allow anyone to collect very high resolution readings of NO2 and CO concentrations outside of their home”.*

- How radioactive is our ocean?
  - *“Help us by mobilizing your community, to raise the money it takes to analyze 20 liters of seawater for signs of radiation from Fukushima. We'll send you everything you need to take a sample and return it to us”.*

What standards are needed/used?
How is quality assured?

Why traceability to the SI?

Measurement results (and uncertainties) that are traceable to the SI are:

- **Stable**
  - The same measurement made against the same references will be stable over time.
- **Comparable**
  - Results of the same measurements against the same references in a different laboratory will be comparable (the same!).
- **Coherent**
  - Results of the same measurements against different references will be coherent (the same!)..

- Environmental measurements require all three of these.
- Other approaches to standardisation only provide the first two

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Conclusions

- There are many examples of good measurement informing us about the state of the environment.

- To have further success we must:
  - **Build the case for measurement results that are traceable (to the SI)**
  - **Develop new ways to disseminate traceability (eg reference networks)**
  - **Prepare for new approaches to measurement (eg citizen science, big data – network of things)**
  - **Expect high standards from society for transparency**

Thank you

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