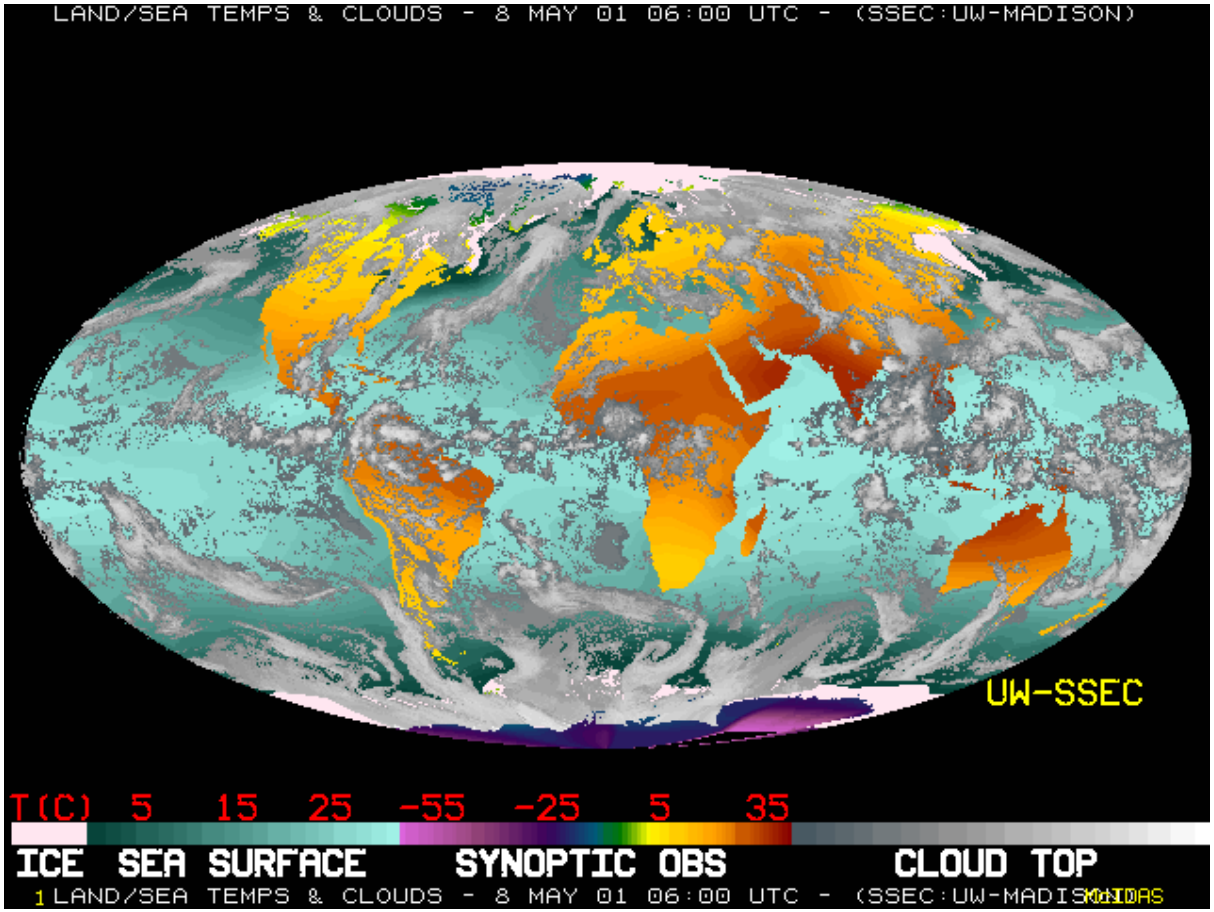
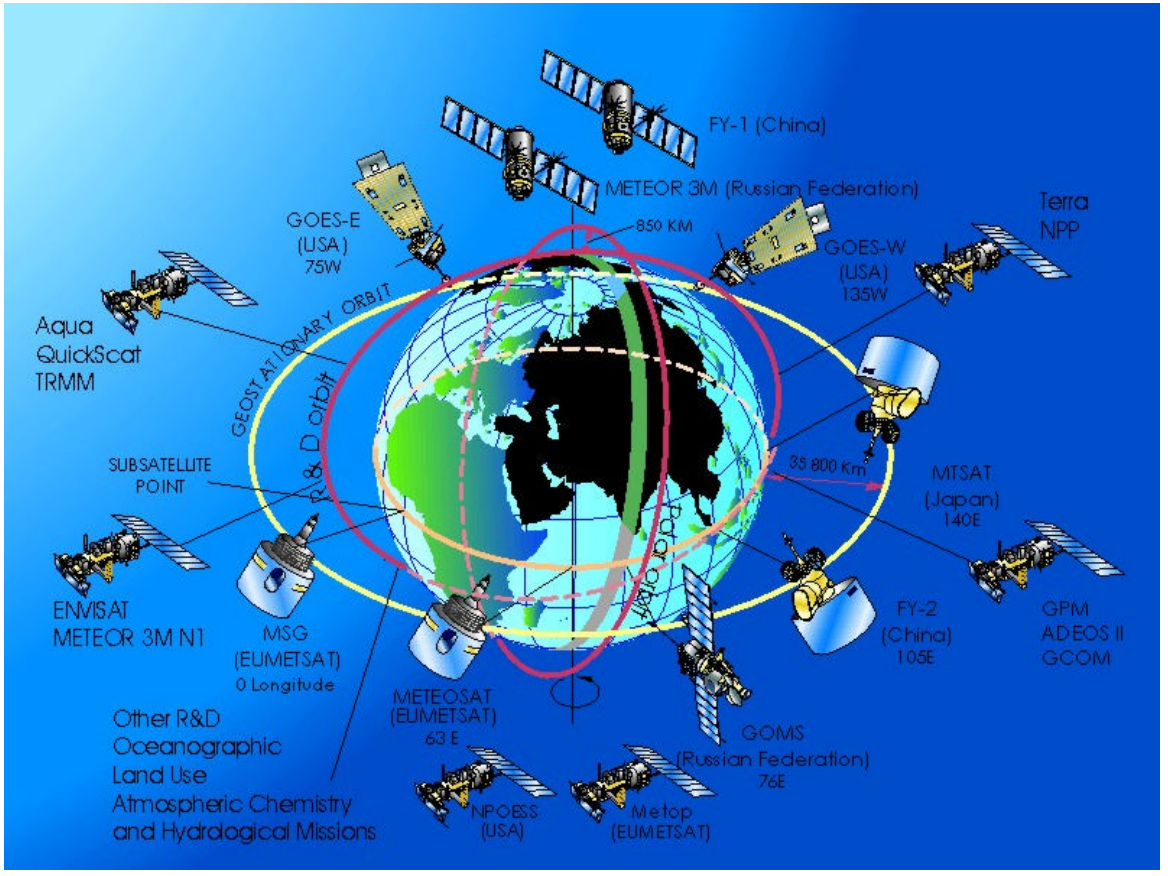
Applications of Data Assimilation in Earth System Science

Alan O'Neill
Data Assimilation Research Centre
University of Reading

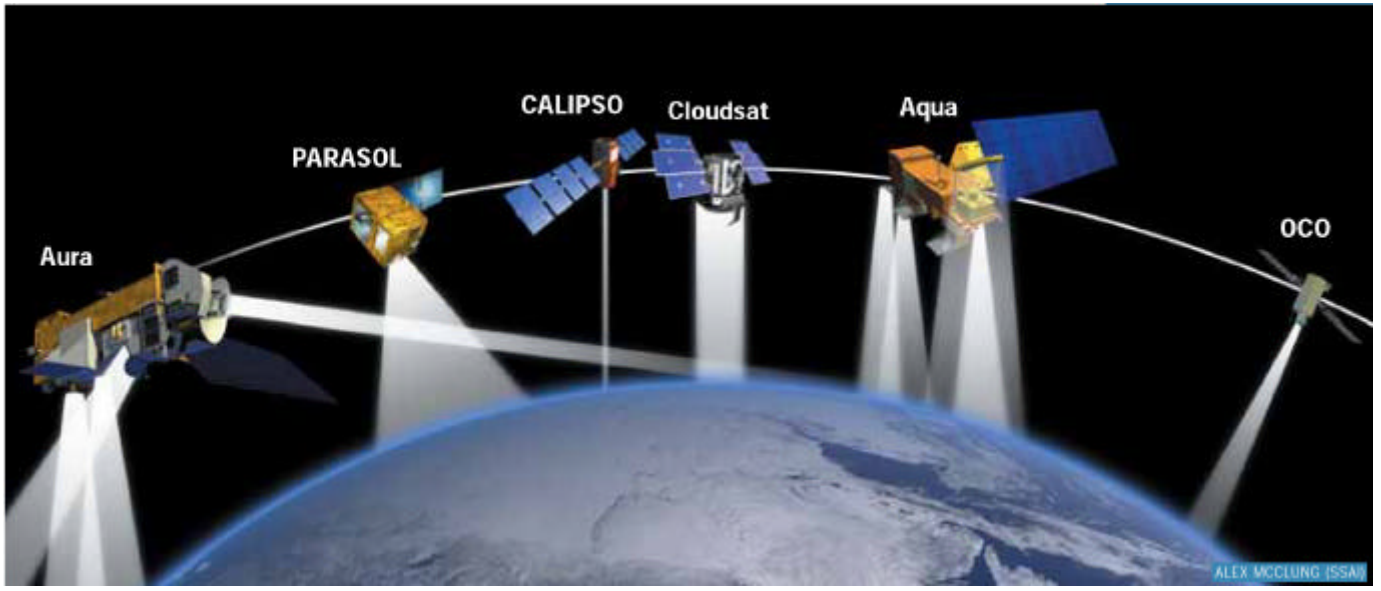

LAND/SEA TEMPS & CLOUDS - 8 MAY 01 06:00 UTC - (SSEC:UW-MADISON)
UW-SSEC
T(C) 5 15 25 -55 -25 5 35
ICE SEA SURFACE SYNOPTIC OBS CLOUD TOP
1 LAND/SEA TEMPS & CLOUDS - 8 MAY 01 06:00 UTC - (SSEC:UW-MADISON)

DARC

Current & Future Satellite Coverage



Formation Flying - Afternoon Constellation



AURA Launch

19 June 2004

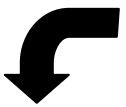
Ascending node crossing times and launch dates.

OCO (1:15)	August 2007
Aqua (1:30)	May 2002
Cloudsat (1:31)	April 2005
Calipso (1:31:15)	April 2005
Parasol (1:33)	October 2004 (?)
Aura (1:38)	June 2004

2020 VISION

- By 2020 the Earth will be viewed from space with better than 1km/1min resolution
- Computer power will be over 1000 times greater than it is today
- To exploit this technological revolution, the world must be digitised

Welcome to Music World



What experts get

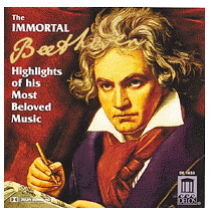
10 soundtracks

High-tech Sampler

Synthesis of tracks

What end-users want

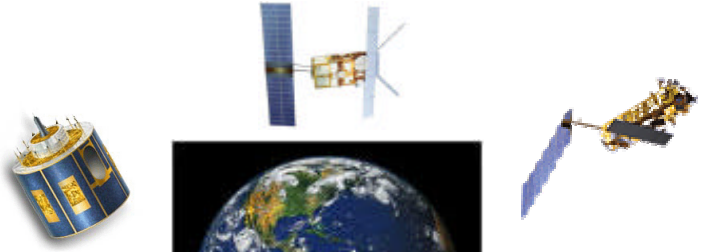
Well-balanced high-quality blended music



Vital to ensure Return On Investment!

Courtesy PP Mathieu

Welcome to Digi World



What users get

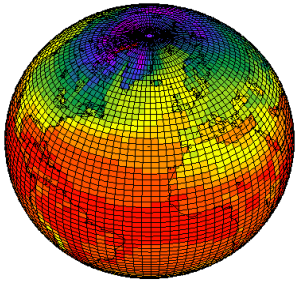
Level 2 for individual sensor

High-tech Sampler

Synthesis via Assimilation of EO data into Earth System Model

What end-users want

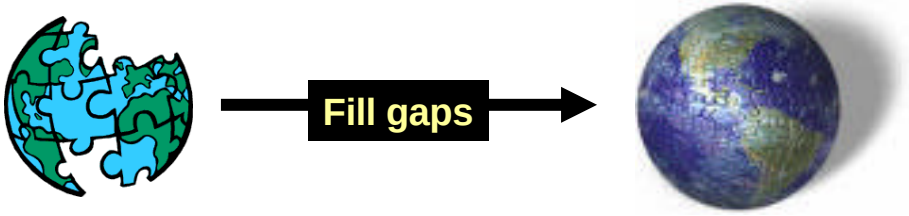
4D digital movie of the Earth System



Courtesy PP Mathieu

(1) Physical interpolation

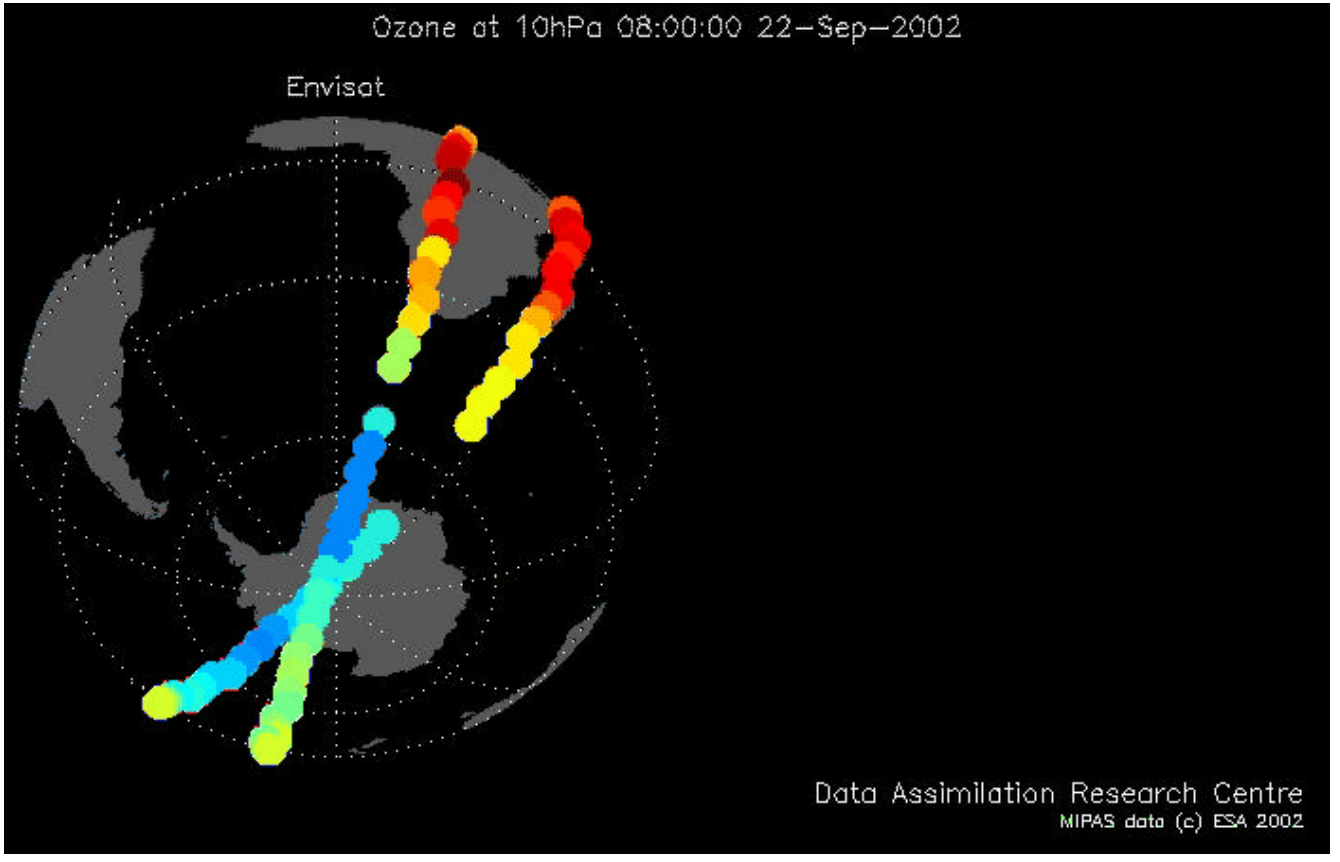
EO data provide a global view ..... but have a limited & sequential sampling .....



Assimilation of data into models provides an optimal synthesis of heterogeneous observations taking account of errors and dynamical principles ...

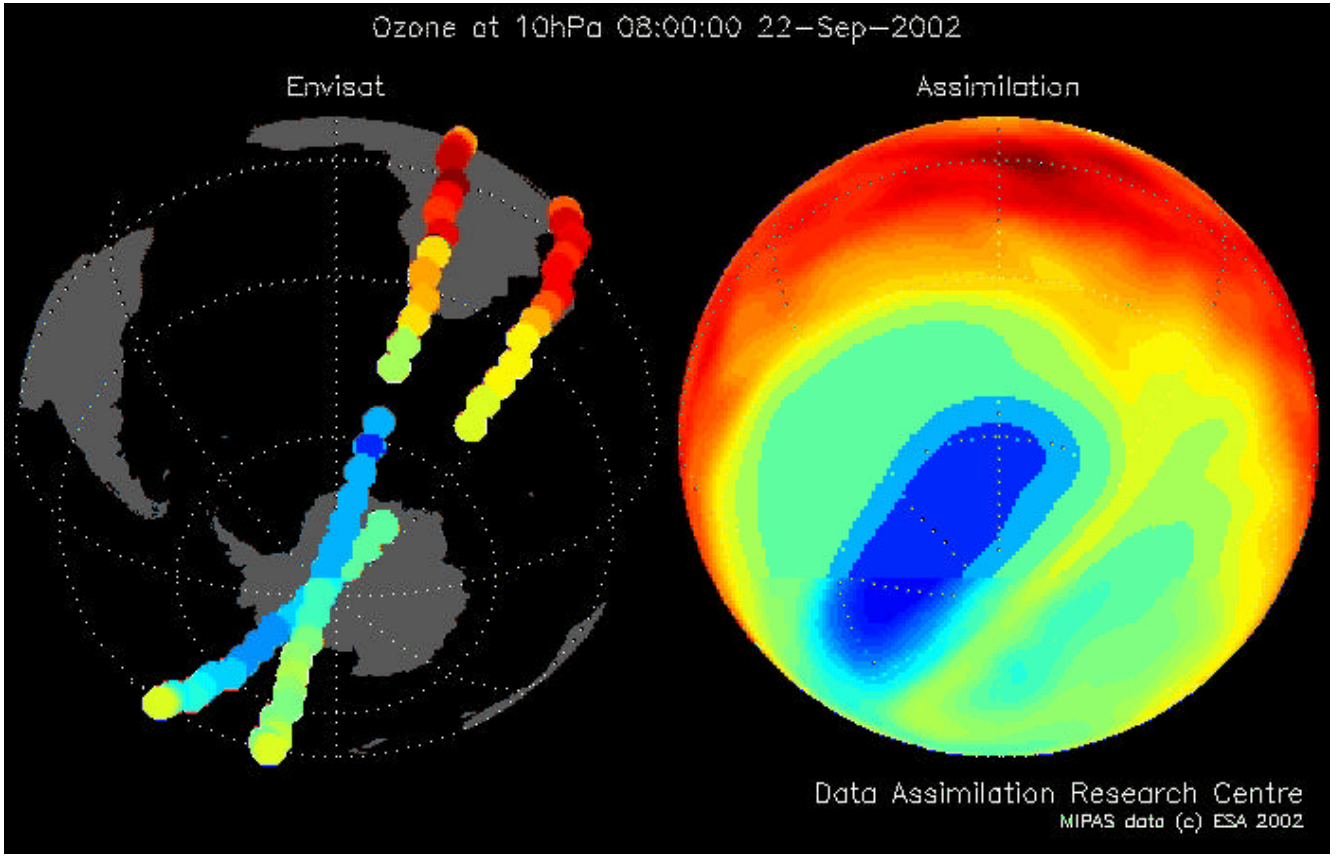
Courtesy PP Mathieu

Chemical analysis



O_3 measured by MIPAS/Envisat

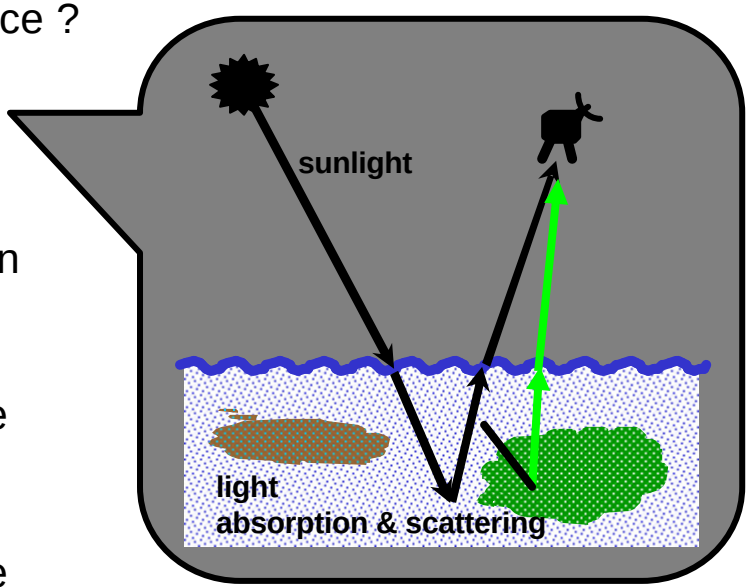
Assimilation of O3 data into GCM



Ocean Remote Sensing

After 40 years of Satellite Oceanography what Ocean properties can we measure from Space ?

- Visible light radiometry
  - Ocean colour
  - Chlorophyll concentration
- Infrared radiometry
  - Sea surface temperature
- Microwave radiometry
  - Sea surface temperature
  - Surface wind
  - Salinity (?)
- Active microwave (radar) instruments



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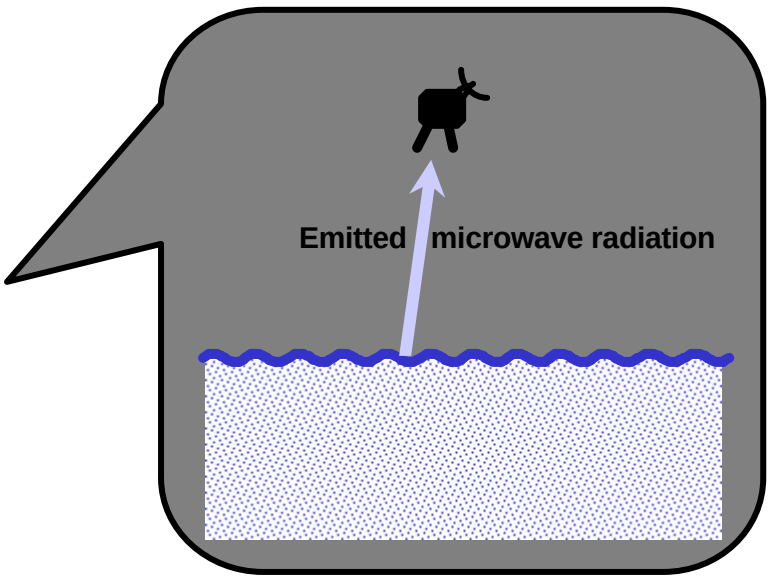

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- Active microwave (radar) instruments
  - Scatterometers
    - Vector winds
  - Imaging radars
    - Surface roughness patterns
      - Upper ocean dynamical phenomena and processes
      - Surface slicks
  - Altimeters
    - Surface height & slope
      - Ocean currents
    - Sea state
    - Wind speed

Ocean Remote Sensing

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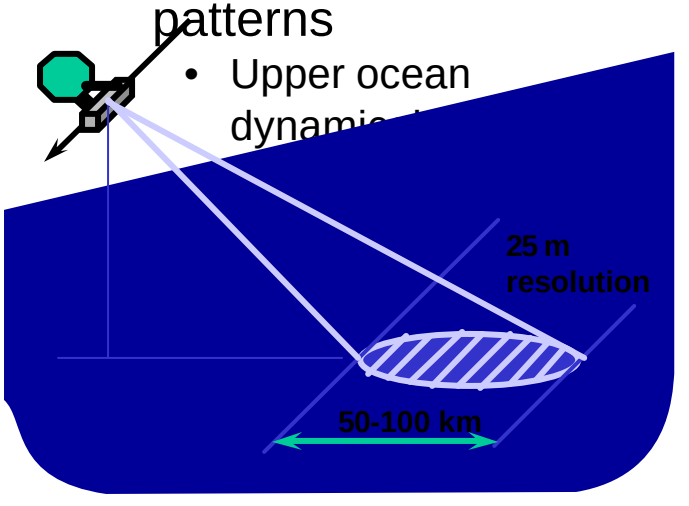
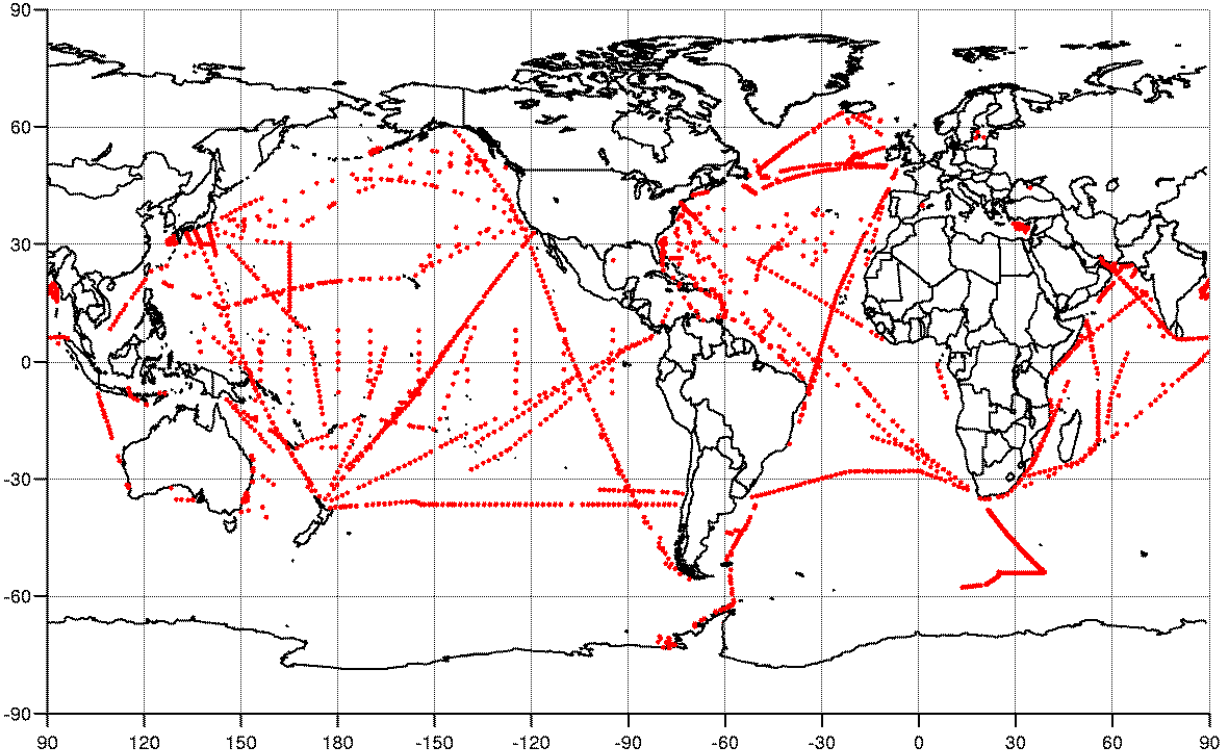
      - Upper ocean dynamics

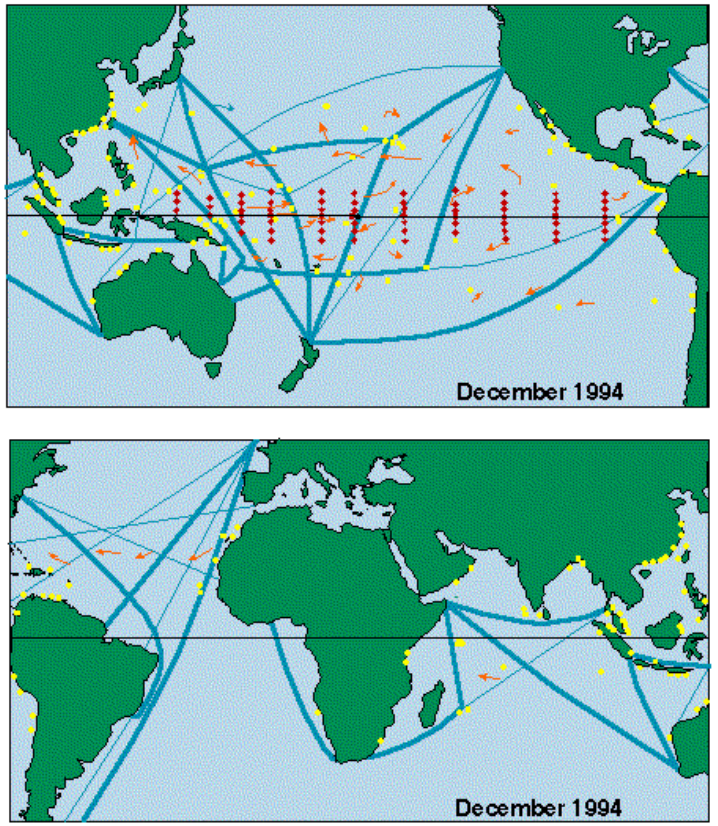


XBT data assimilated in March 1996.



DARC

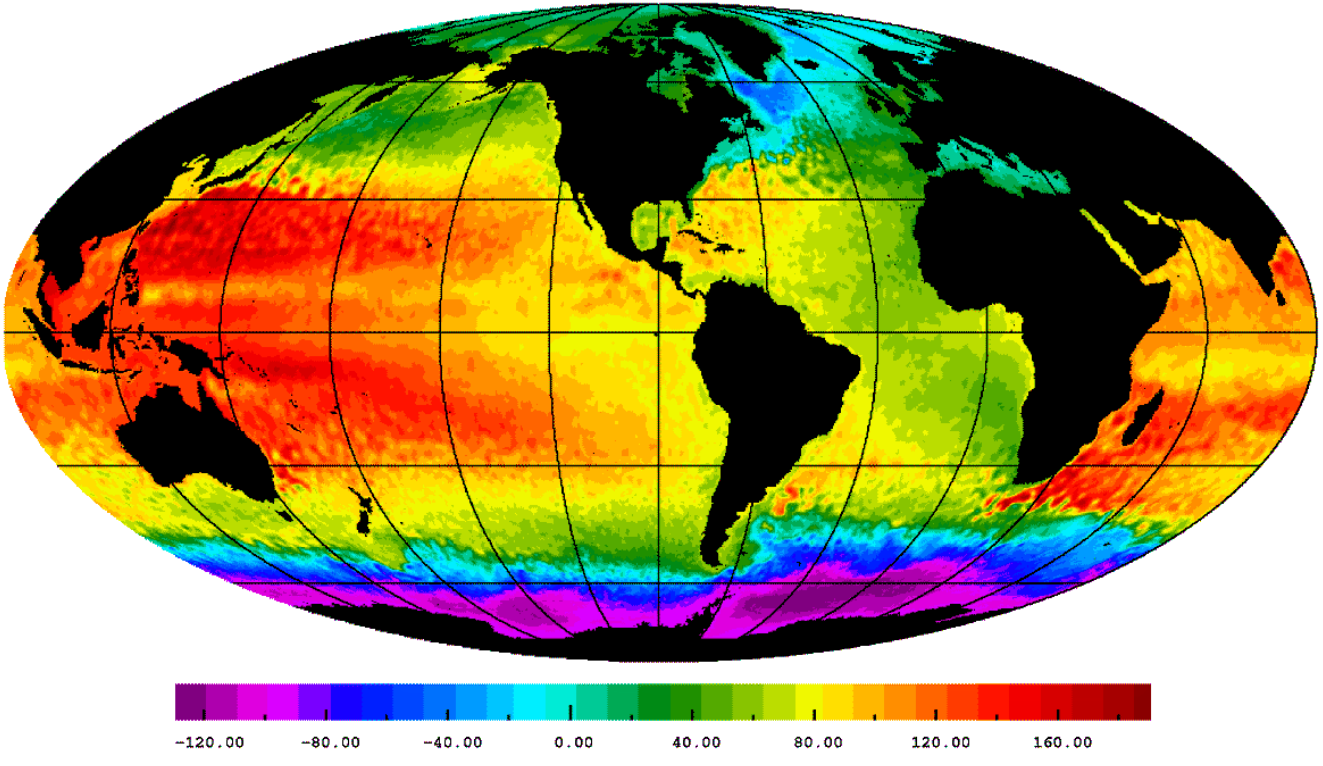
TOGA In Situ Ocean Observing System
Global Tropics



DARC

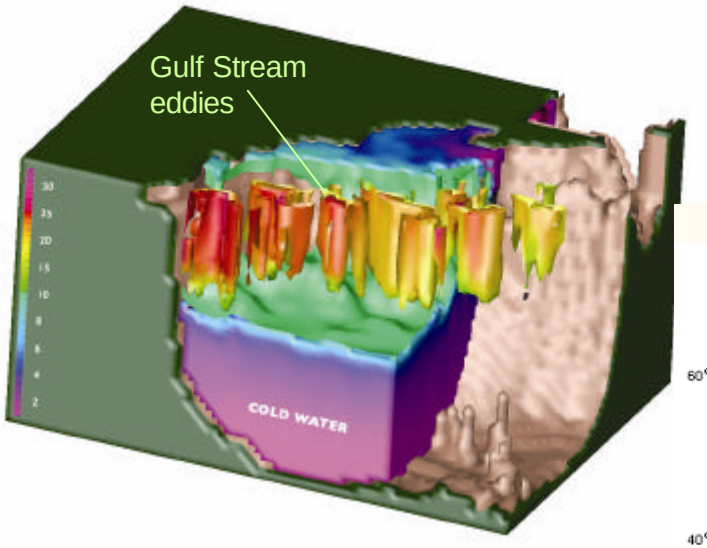
What is special about the view of the ocean from a satellite?

- A spatially detailed view
  - Spatial resolution from 25m to 50km
  - A synoptic picture that is 100 km - 10 000 km wide
- Regularly repeated views
  - Revisit intervals between 30 min. and 35 days
  - Continuously repeated over years to decades
- A view with global coverage
  - Satellites see the parts where ships rarely go
  - Single-sensor consistency - no intercalibration uncertainties
- Measures parameters that cannot be observed *in situ*
  - Surface slope (a few cm over 100s of kilometres)
  - Surface roughness at short length scales (2-50 cm)

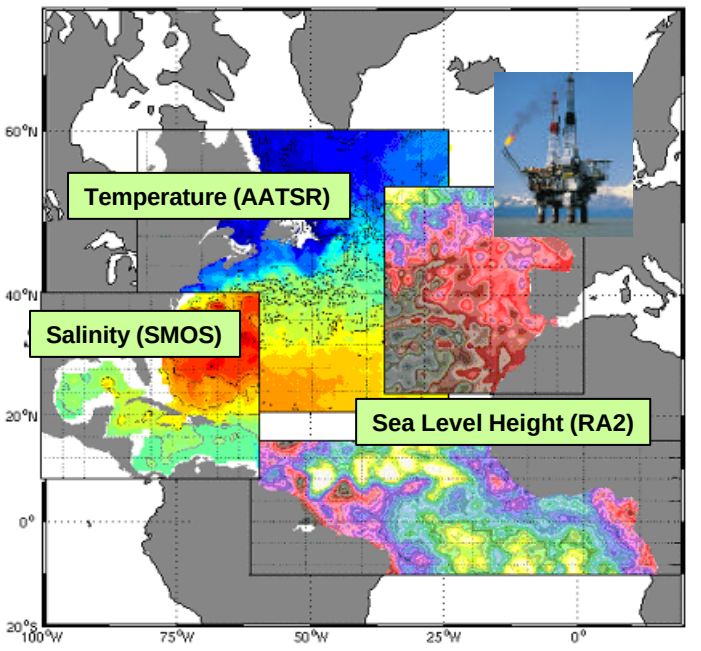


DARC

Operational oceanography



Model dynamics transports EO information from surface (data-rich region) to depth (data-poor region).

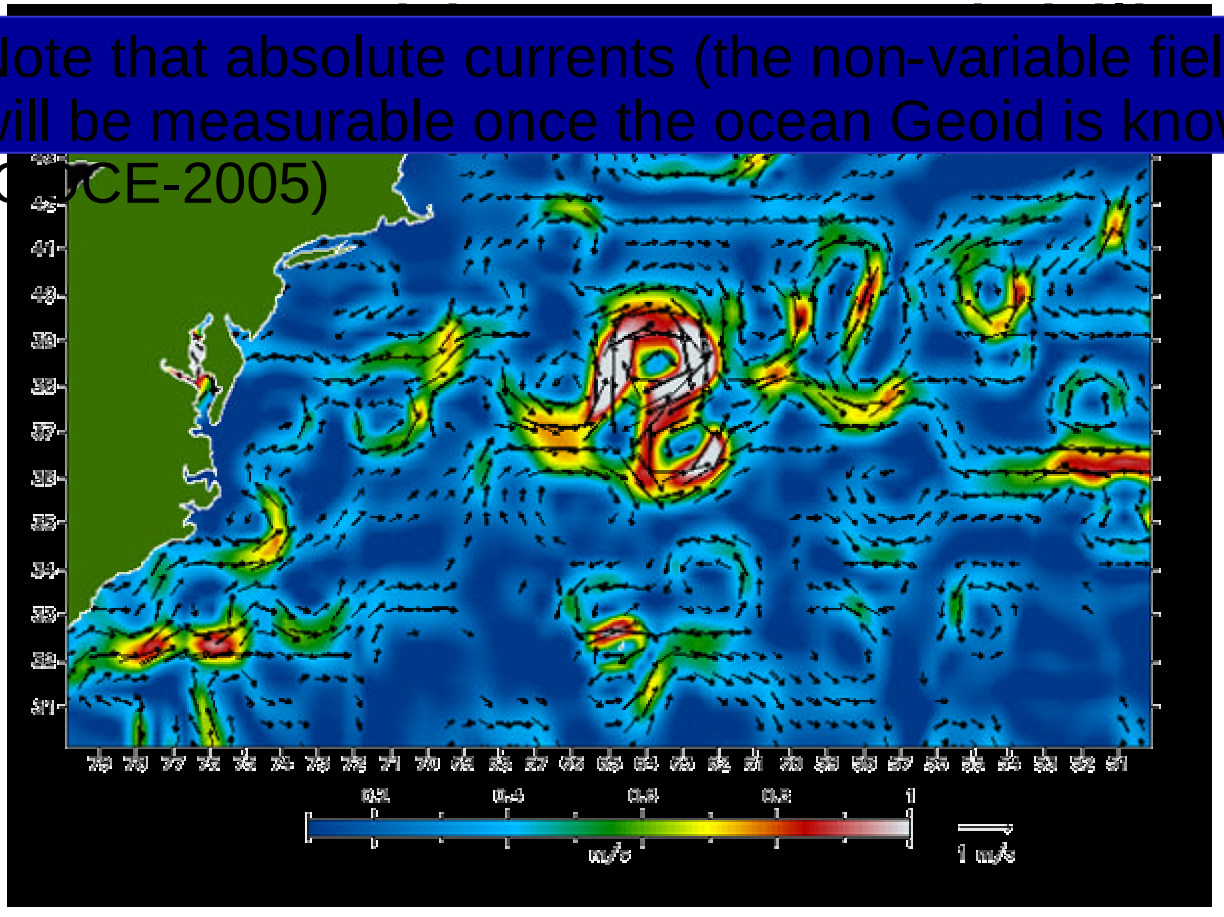


Assimilation of EO data into ocean models provides the best available quantitative picture of the ocean state.

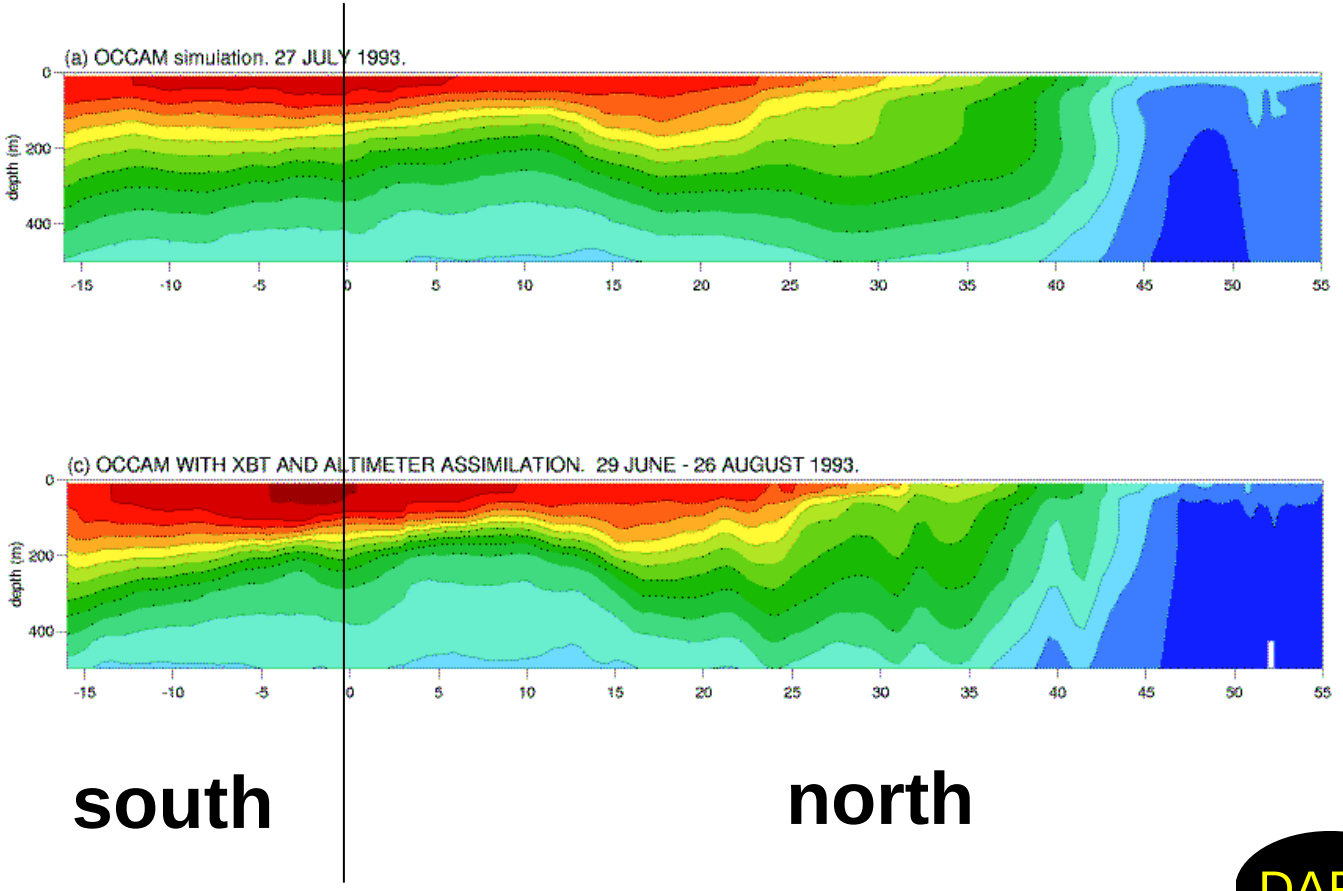
Essential building block for the development of operational marine services (ROSES).

Courtesy LEGI

- Note that absolute currents (the non-variable field) will be measurable once the ocean Geoid is known (GOCE-2005)



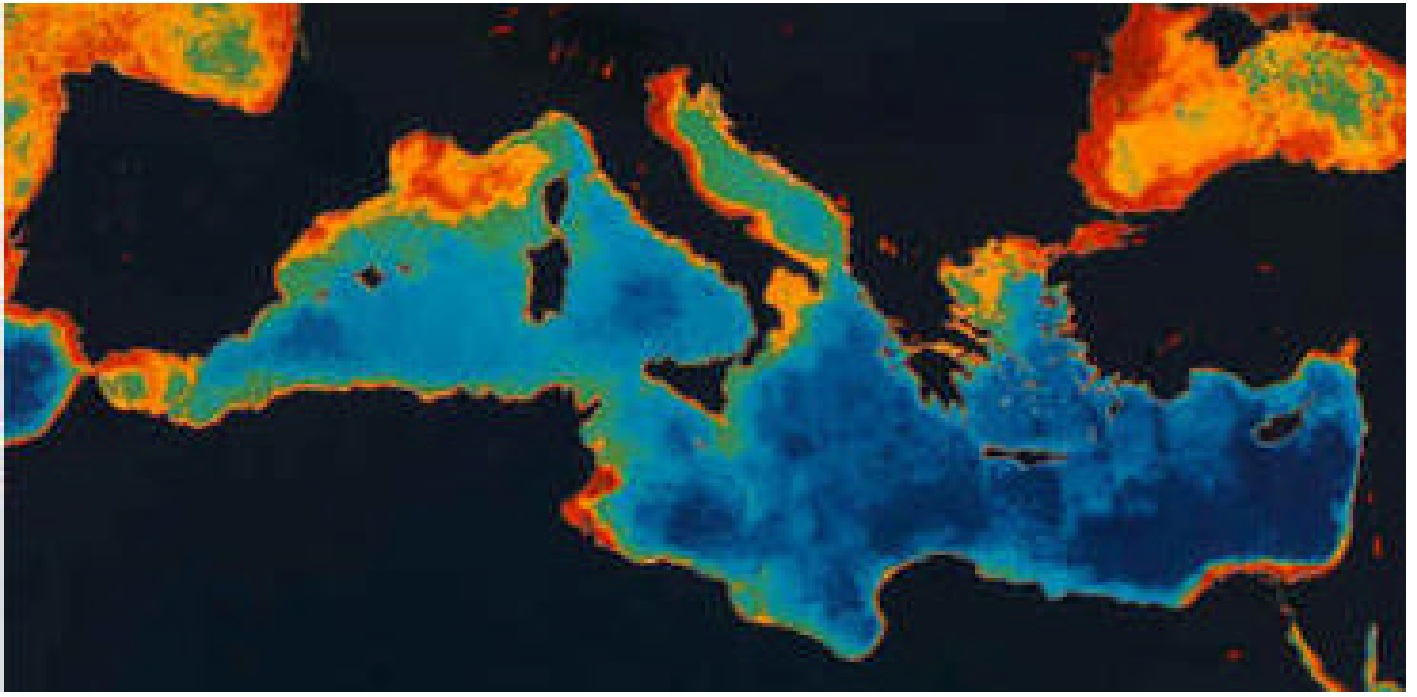
Cross-section in mid Atlantic



south **north**

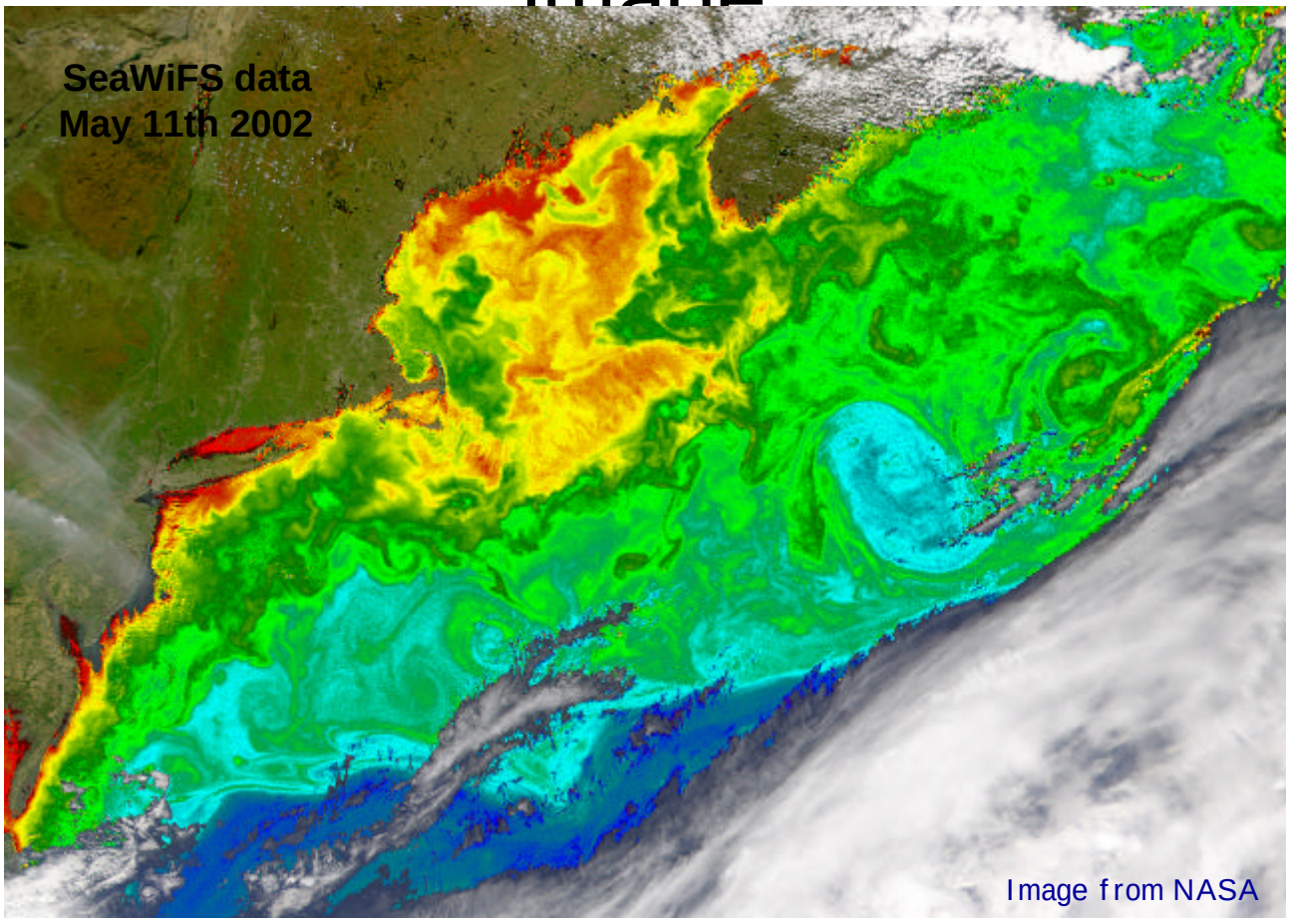
DARC

MERIS ocean colour

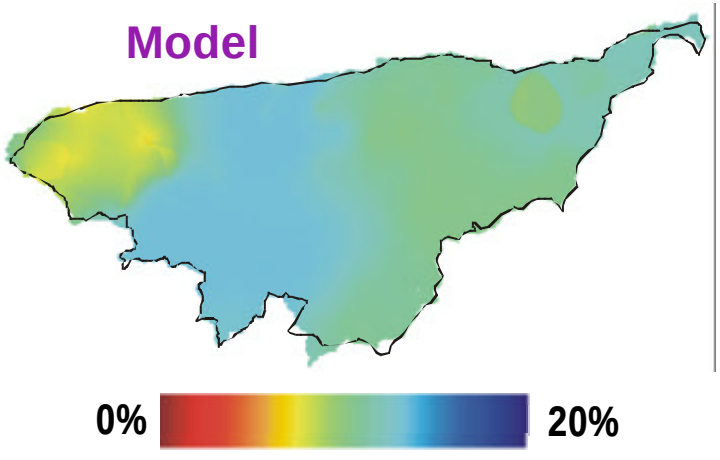


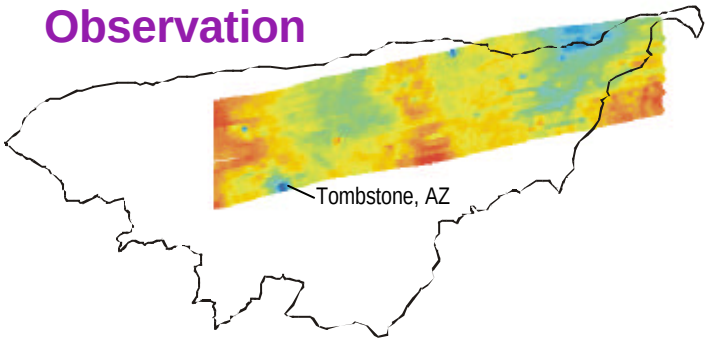
DARC

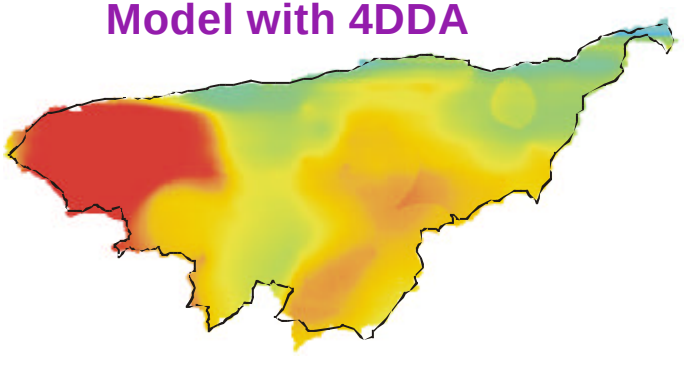
Ocean eddies in a chlorophyll image

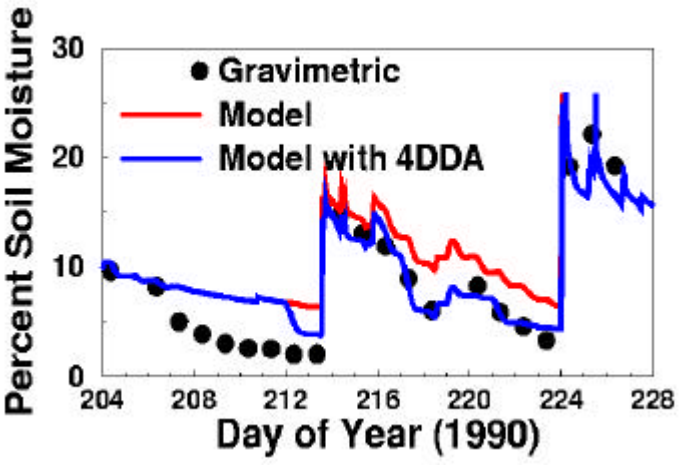


Regional Scale: *Walnut Gulch (Monsoon 90)*





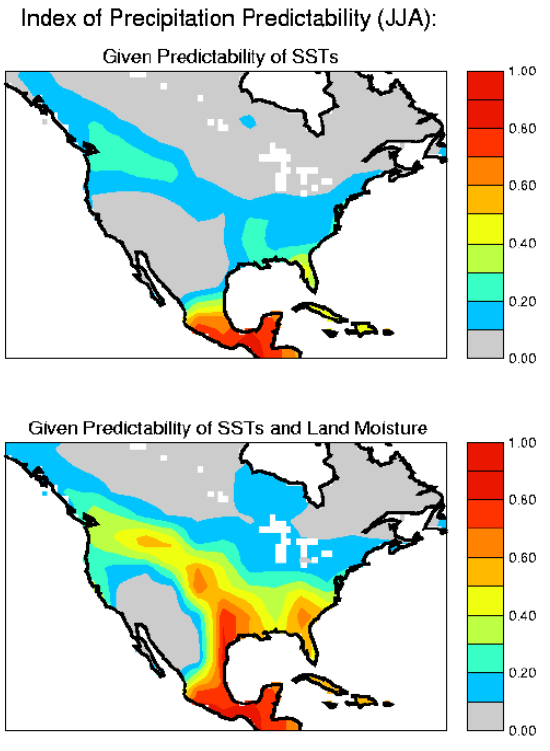


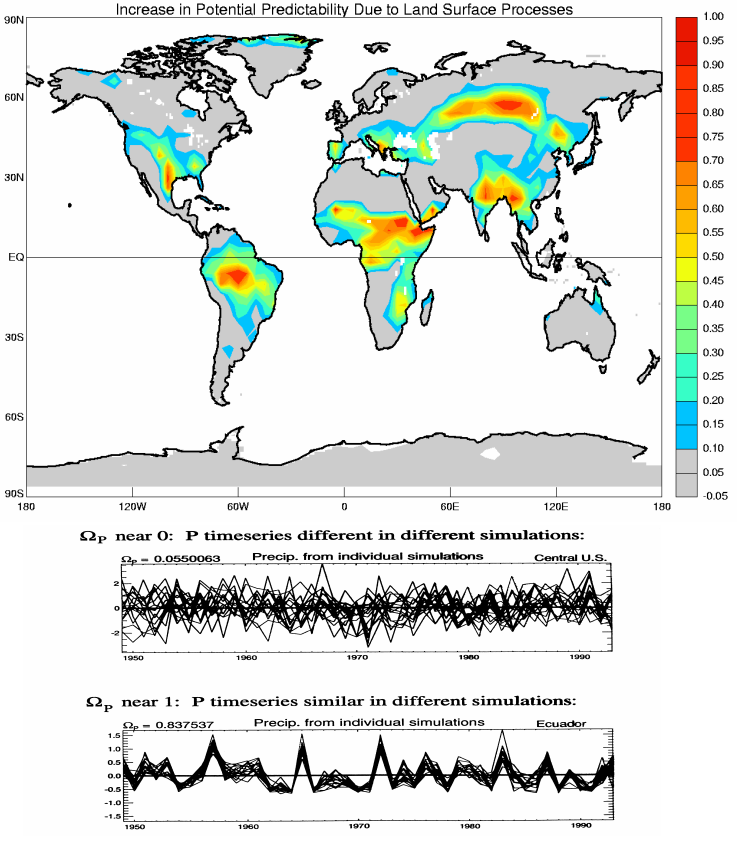


Houser et al., 1998

Land Initialization: Motivation

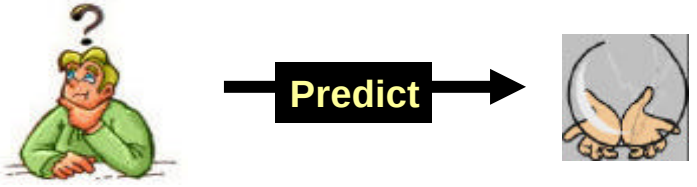
- Knowledge of soil moisture has a greater impact on the predictability of summertime precipitation over land at mid-latitudes than Sea Surface Temperature (SST).





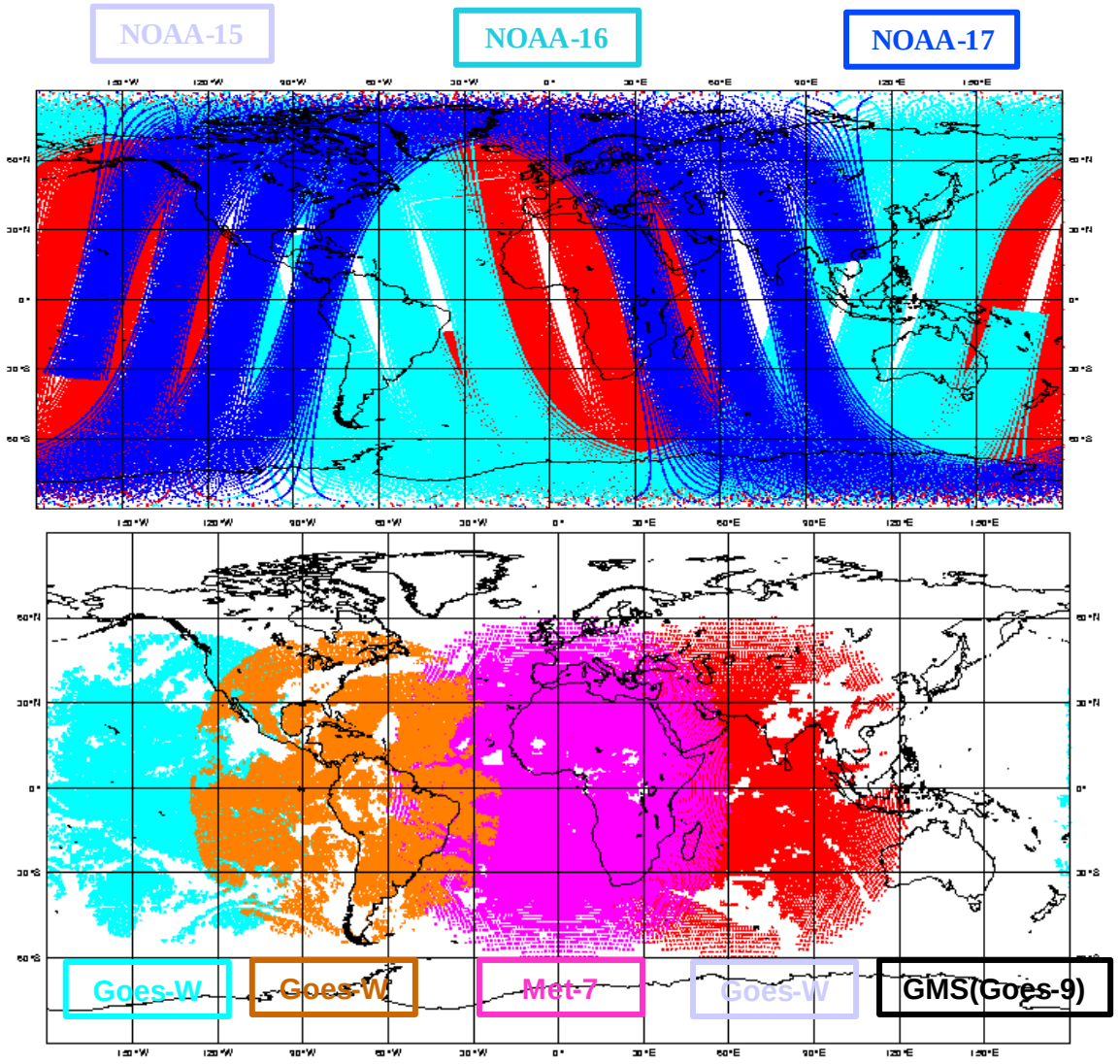
(2) Environmental Forecast

EO data are critical for monitoring the global environment but managing risks requires forecast .....

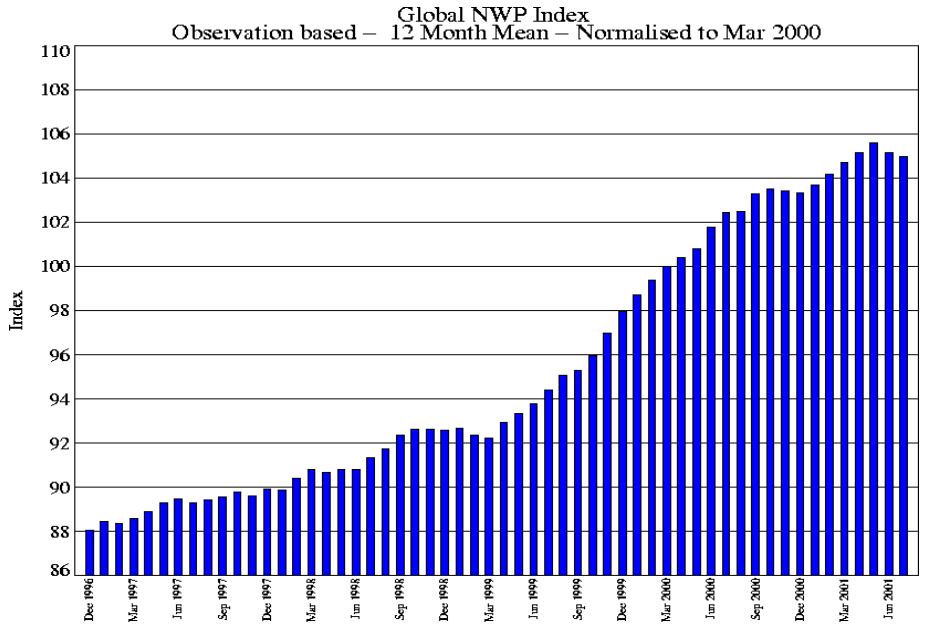


Assimilation of data into models is at the heart of operational prediction ....

Courtesy PP Mathieu


NOAA-15
NOAA-16
NOAA-17
Goes-W
Goes-W
Met-7
Goes-W
GMS(Goes-9)

Impact on NWP at the Met Office



Mar 99. 3D-Var and ATOVS

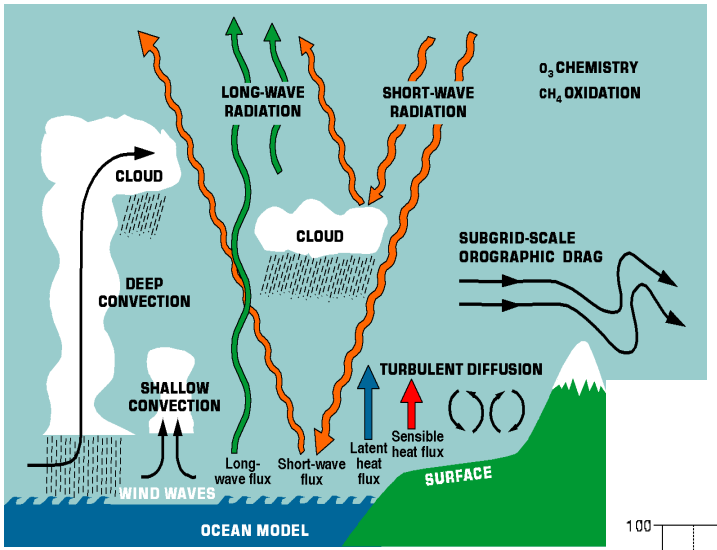
Jul 99. ATOVS over Siberia, sea-ice from SSM/I

Oct 99. ATOVS as radiances, SSM/I winds

May 00. Retune 3D-Var

Feb/Apr 01. 2nd satellites, ATOVS + SSM/I

Weather forecasting

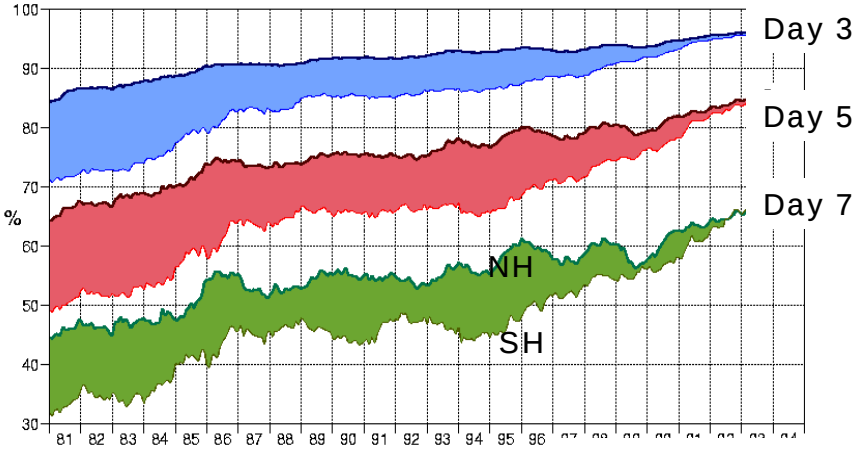


Numerical Weather Prediction:

- **Sophisticated atmospheric models.**
- **Most mature assimilation techniques (able to ingest sounding radiances).**
- **Very big user of EO data.**

Satellite data have contributed to the continuous improvement of forecast quality with enormous benefits for society.

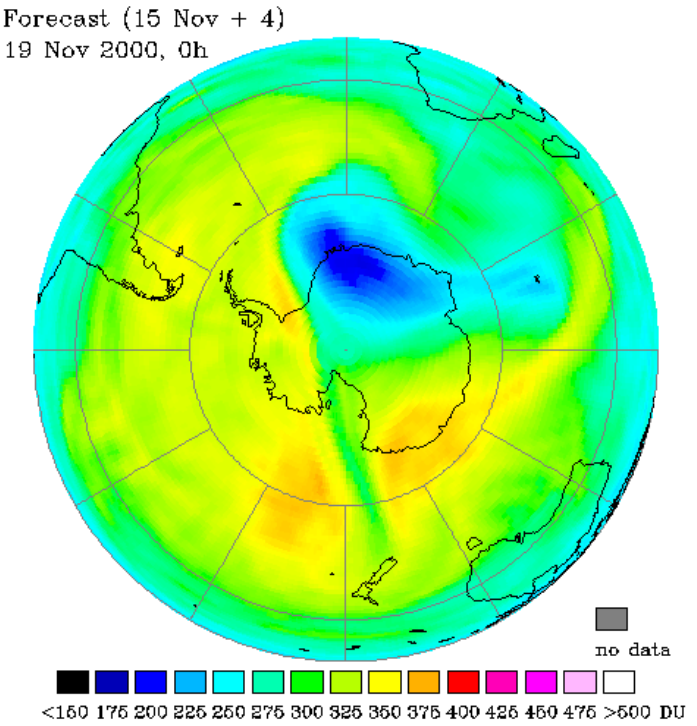
NWP Forecast Skill



Courtesy PP Mathieu & ECMWF

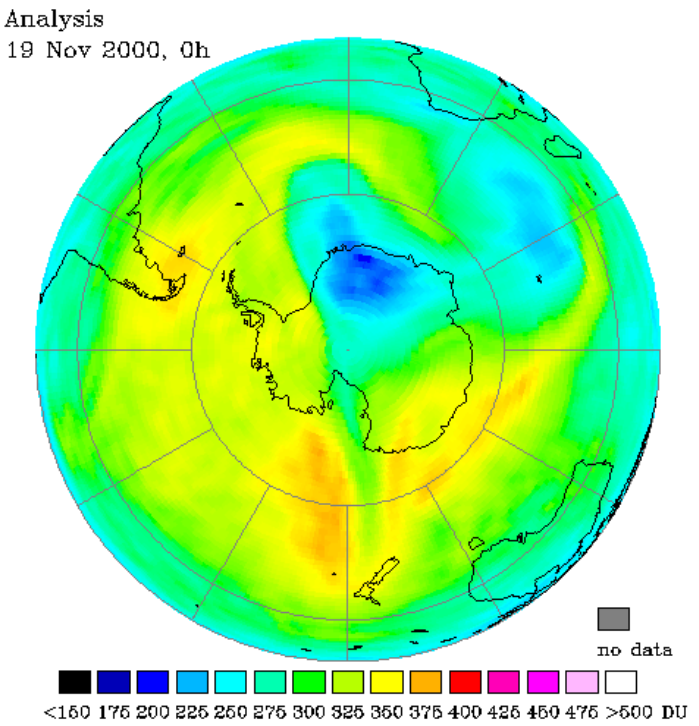
Breakup 2000 ozone hole

19 November 2000
4-day forecast



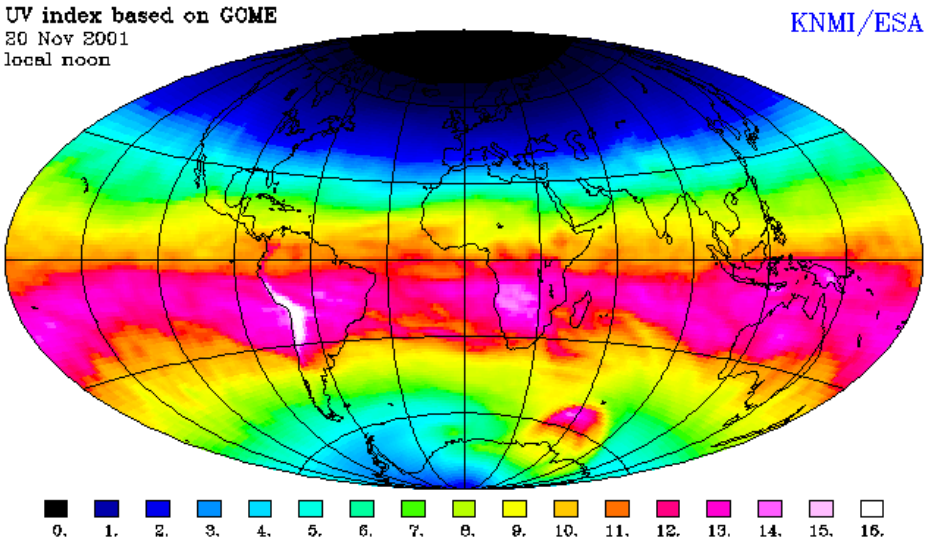
Breakup 2000 ozone hole

19 November 2000 analysis

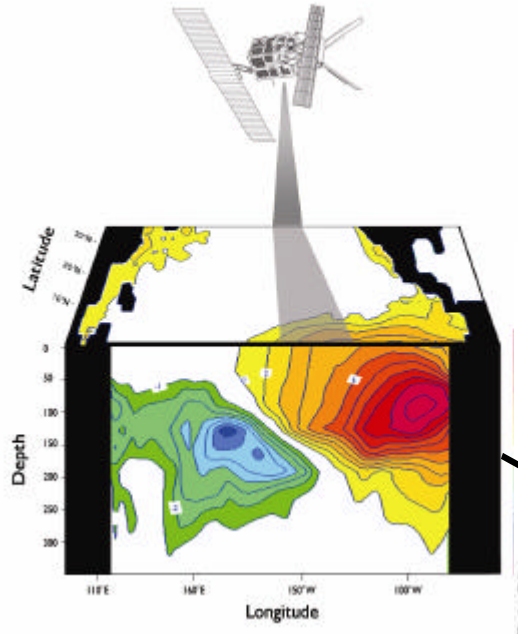


UV forecast

20 November 2001
(5-day forecast)

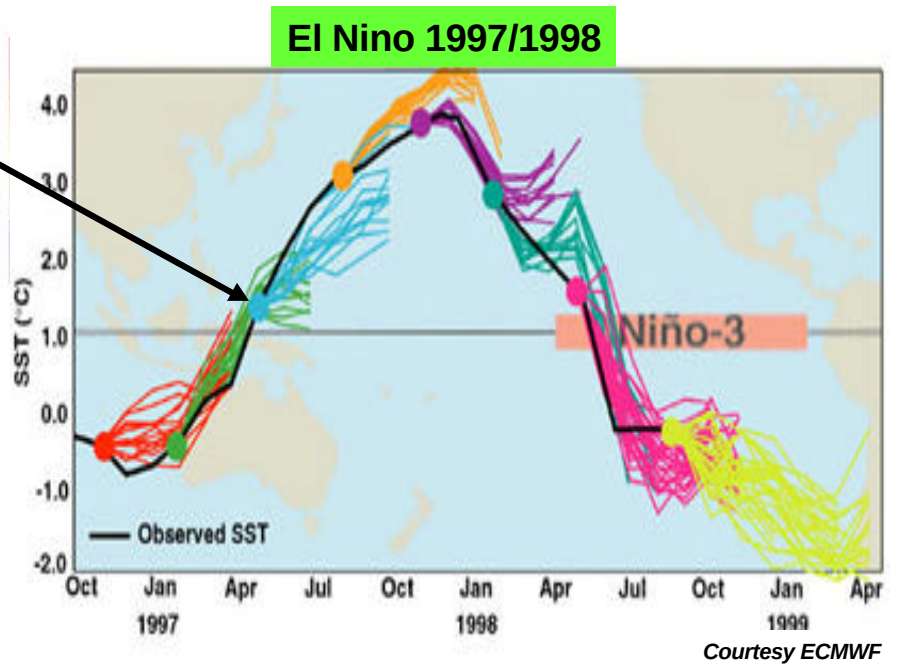


Seasonal Prediction



Coupled models are now routinely used to make probabilistic prediction of the mean state of climate several months ahead. Enormous potential for EO!.

High-quality ocean analysis are vital to initialise coupled models and make accurate ensemble predictions.

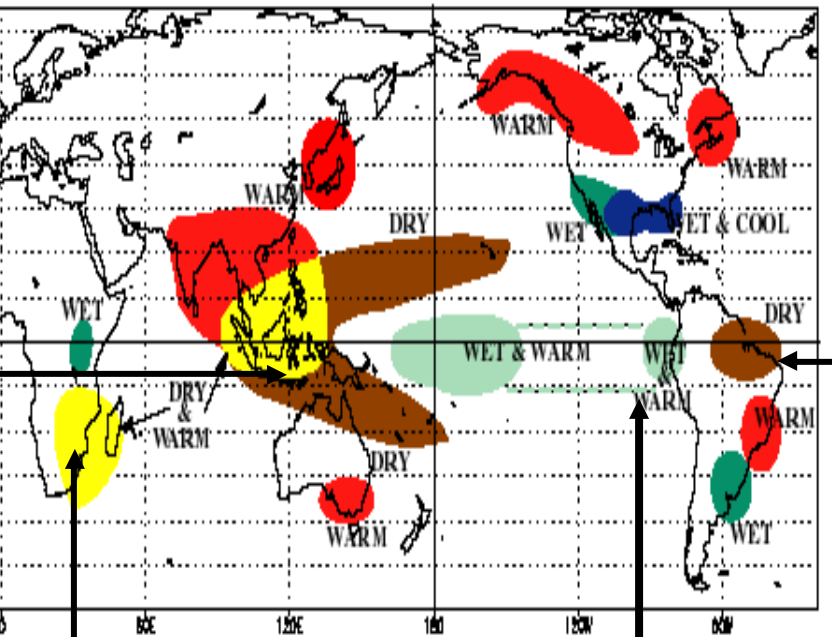


Courtesy ECMWF

Worldwide impact of El Nino

ENSO teleconnections have dramatic societal and economic impacts around the globe (e.g. U.S. impact of ENSO 1997/98 $25billions).

Crop Damage

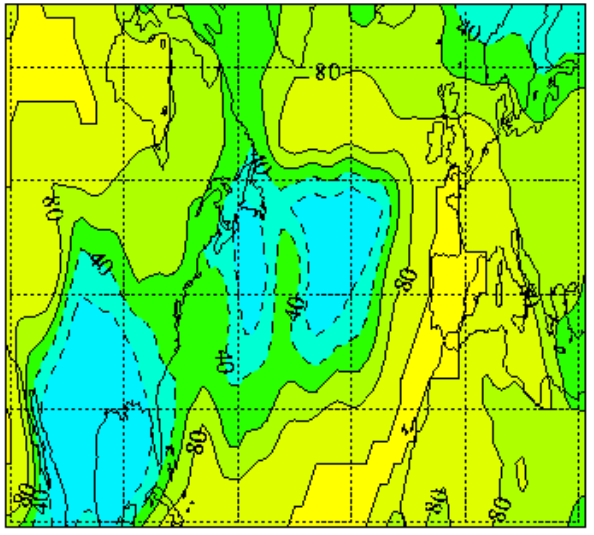


Water Rationing

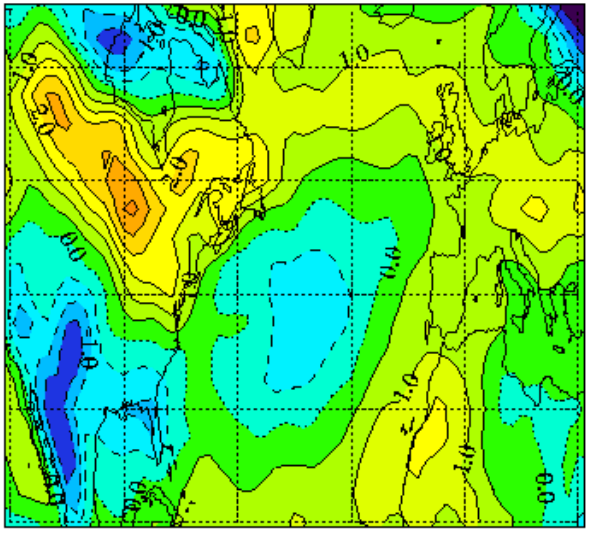
Wildfire Fatalities

Fishery disruption

Seasonal Forecasts for Europe (DJF 1997/98)



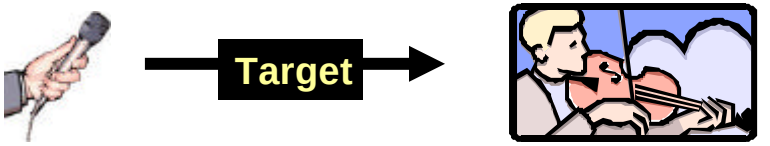
Forecast probability of above average temperatures



Measured temperature anomaly

(3) Observing System Design

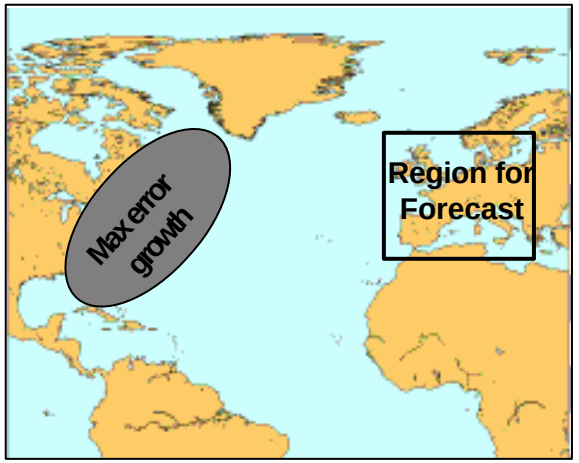
Observing systems should help to advance our current state of knowledge .....



Model sensitivity experiments allow us to target observations and to evaluate objectively the incremental value of EO data. Potential cost savings!

Courtesy PP Mathieu

Numerical Laboratory

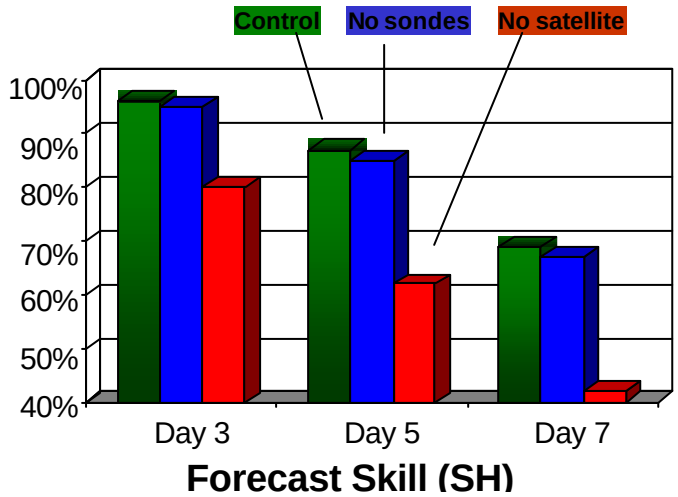


Where/What should we measure?

Data Assimilation helps to identify sensitive regions where observations would maximise benefits for forecast.

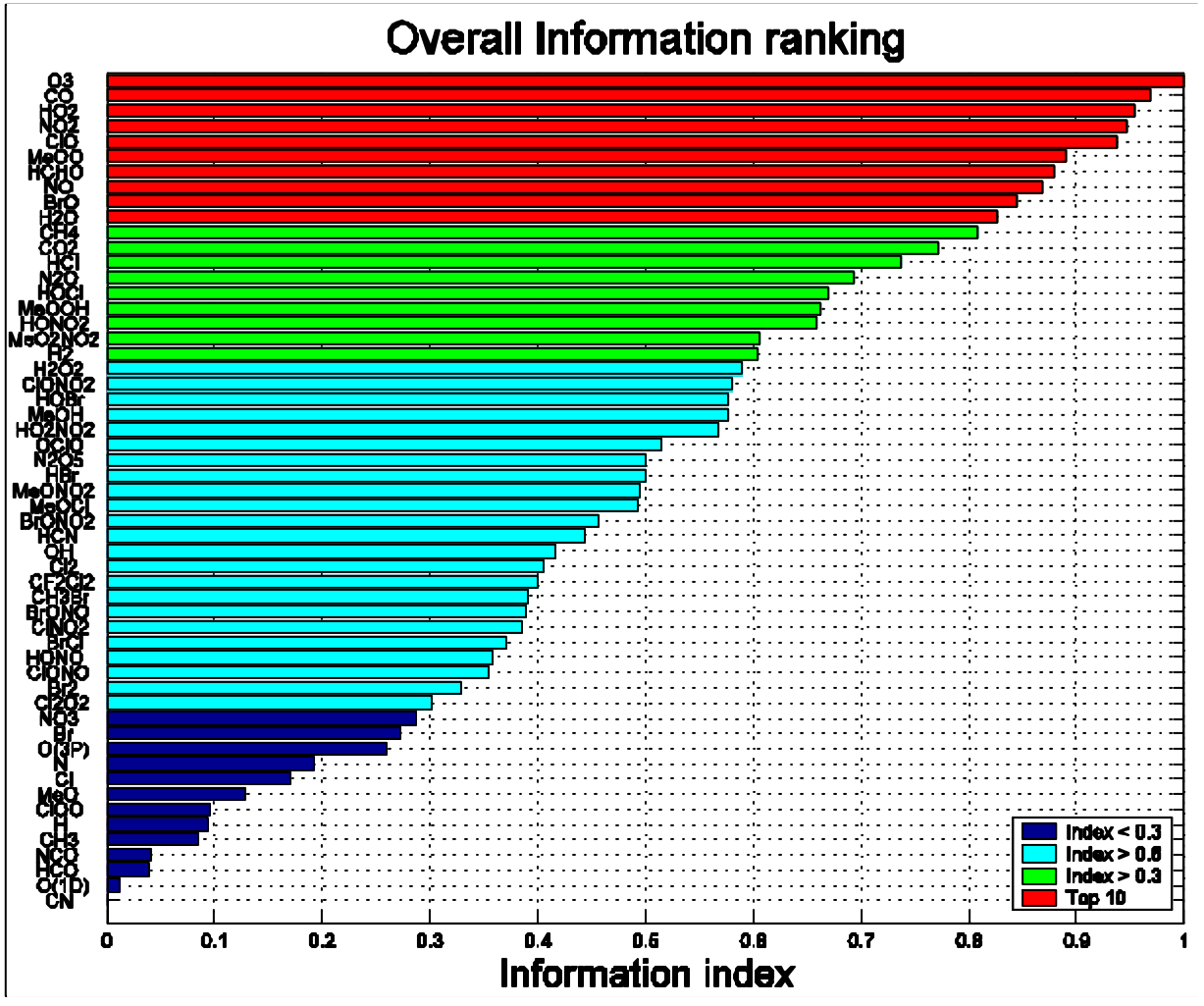
What is the added value of EO?

Observing System experiments help to quantify the impact of withdrawing various (synthetic) data streams on forecast skill (e.g. evaluation of Swift mission before launch!).



Courtesy PP Mathieu & ECMWF

Best observations to make to characterize the chemical system



(4) Inverse Modelling

EO provides an indirect measure of the quantity of interest .....

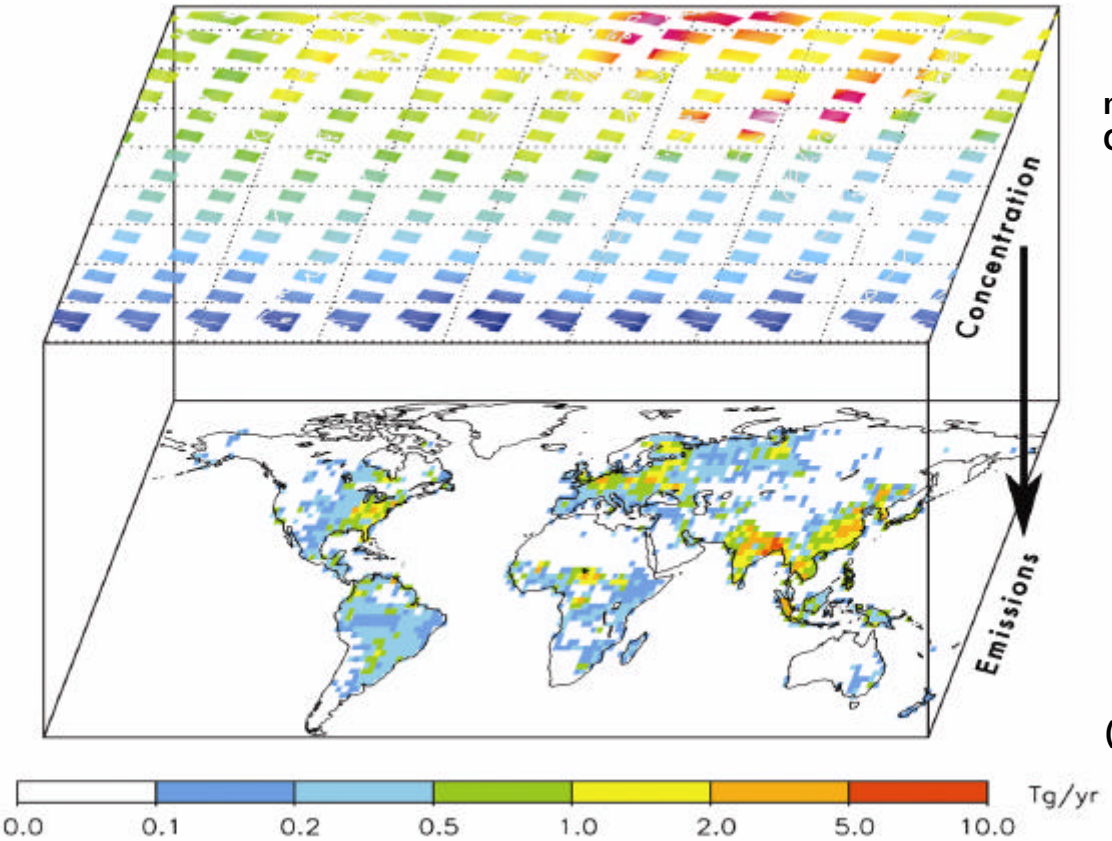
Infer

Assimilation of data into models enables to infer [non-observable] geophysical quantities of interest by exploiting physical/chemical linkages in the system.

Courtesy PP Mathieu

GHG sources & sinks

Models play a diagnostic role by helping to interpret observations (e.g. causal relationships)



Synthetic SCIAMACHY measurements of CH_4 total column

⇩

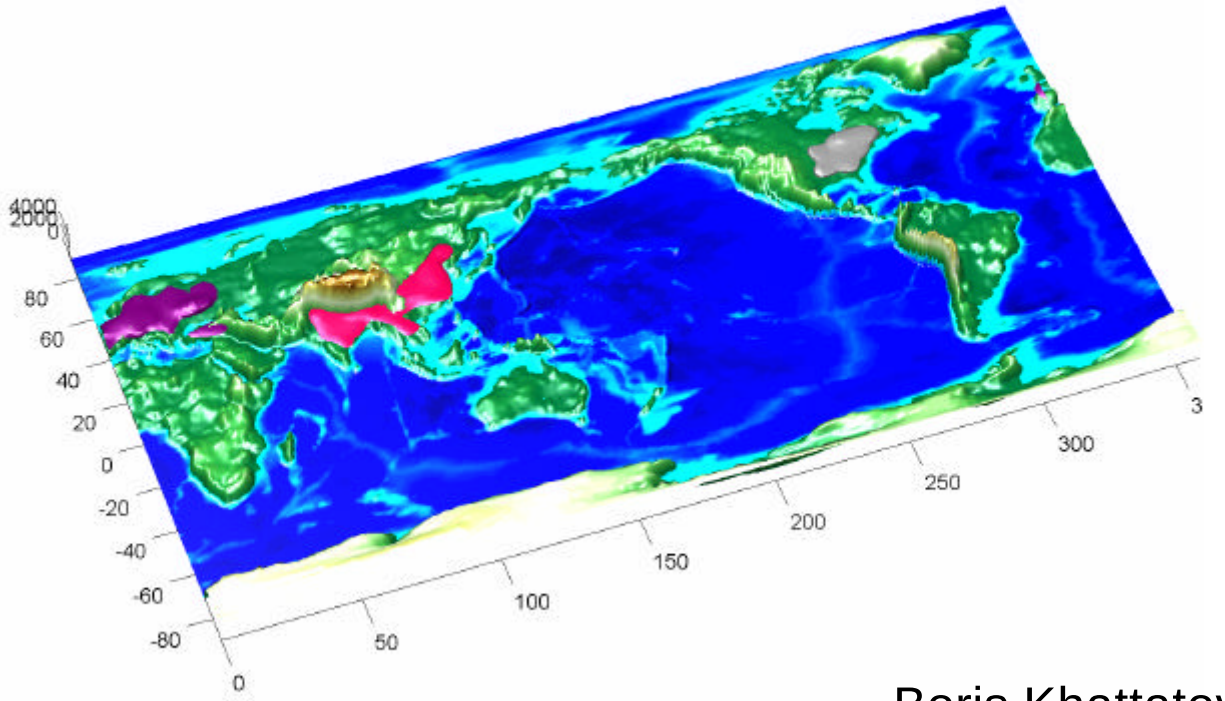
Assimilation into a Chemical Transport model

⇩

Methane Emissions (critical for Kyoto inventories)

Courtesy KNMI

CO “colors”, day 1



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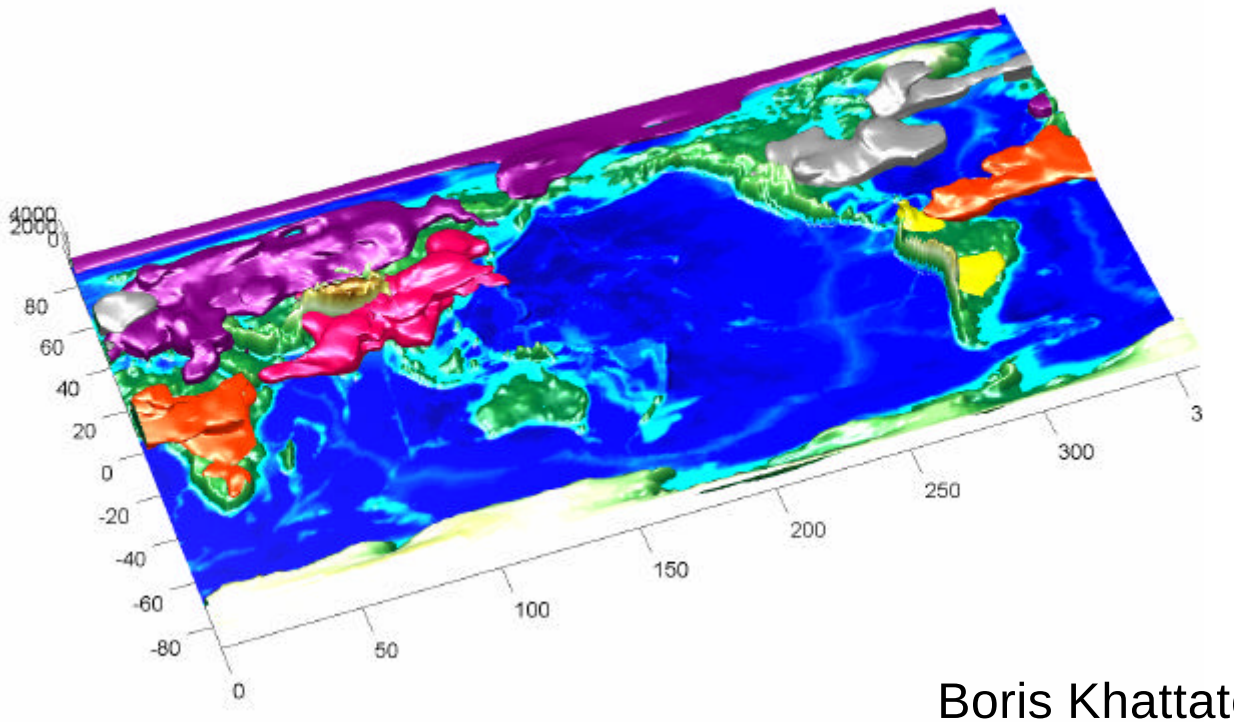
CO “colors”, day 65



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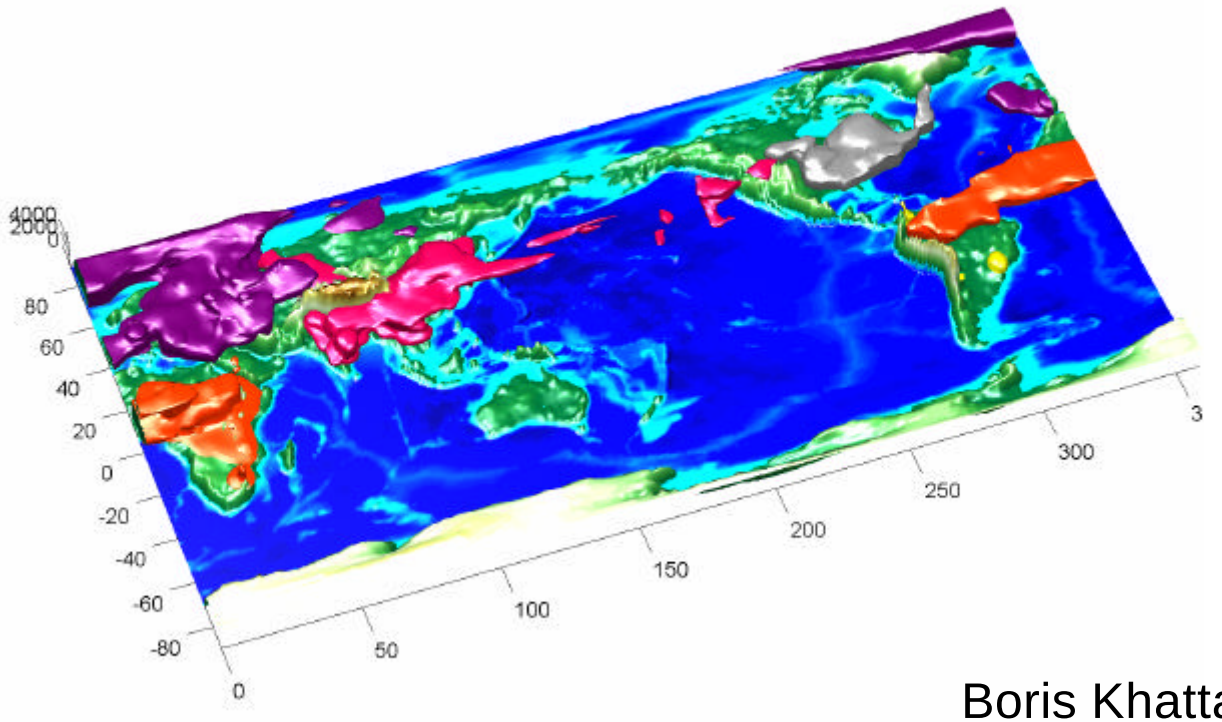
CO “colors”, day 85



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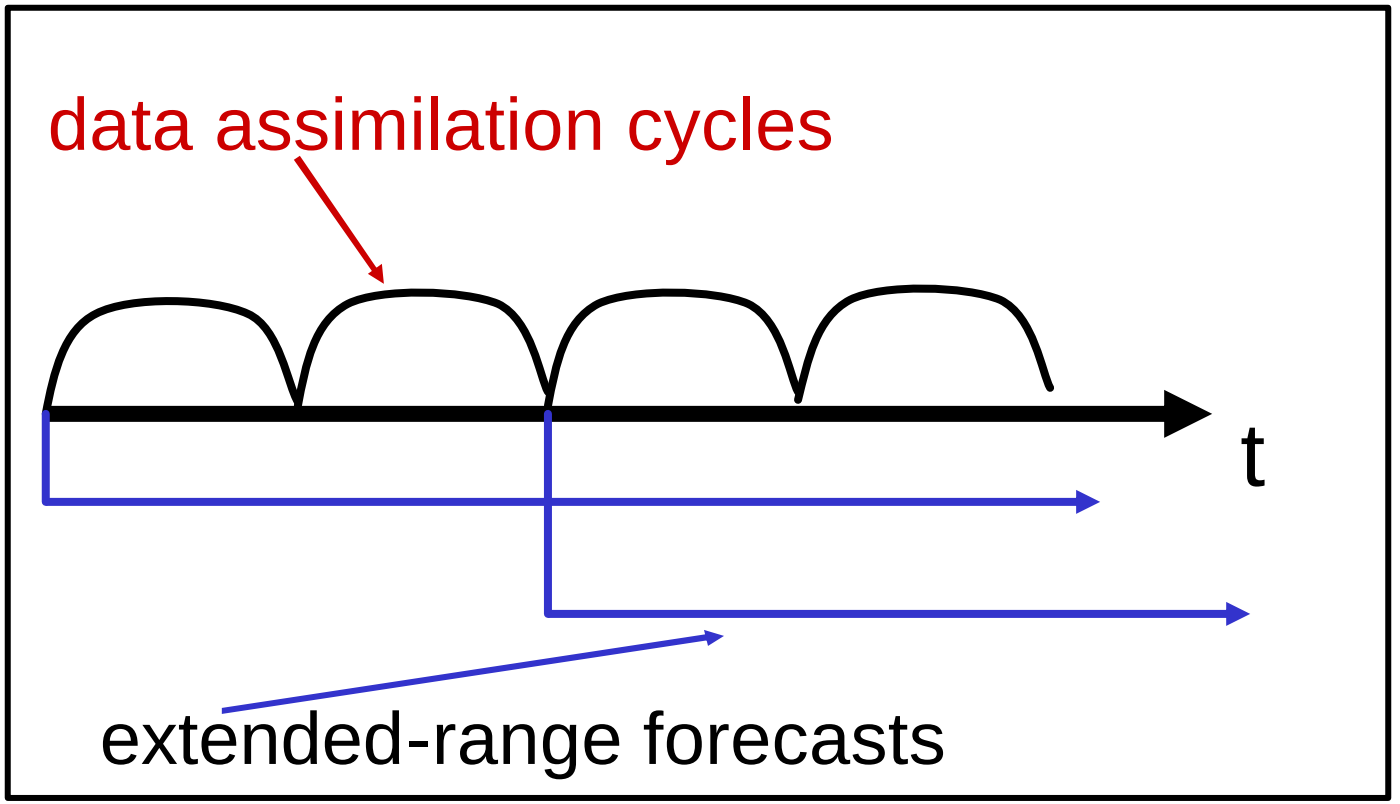
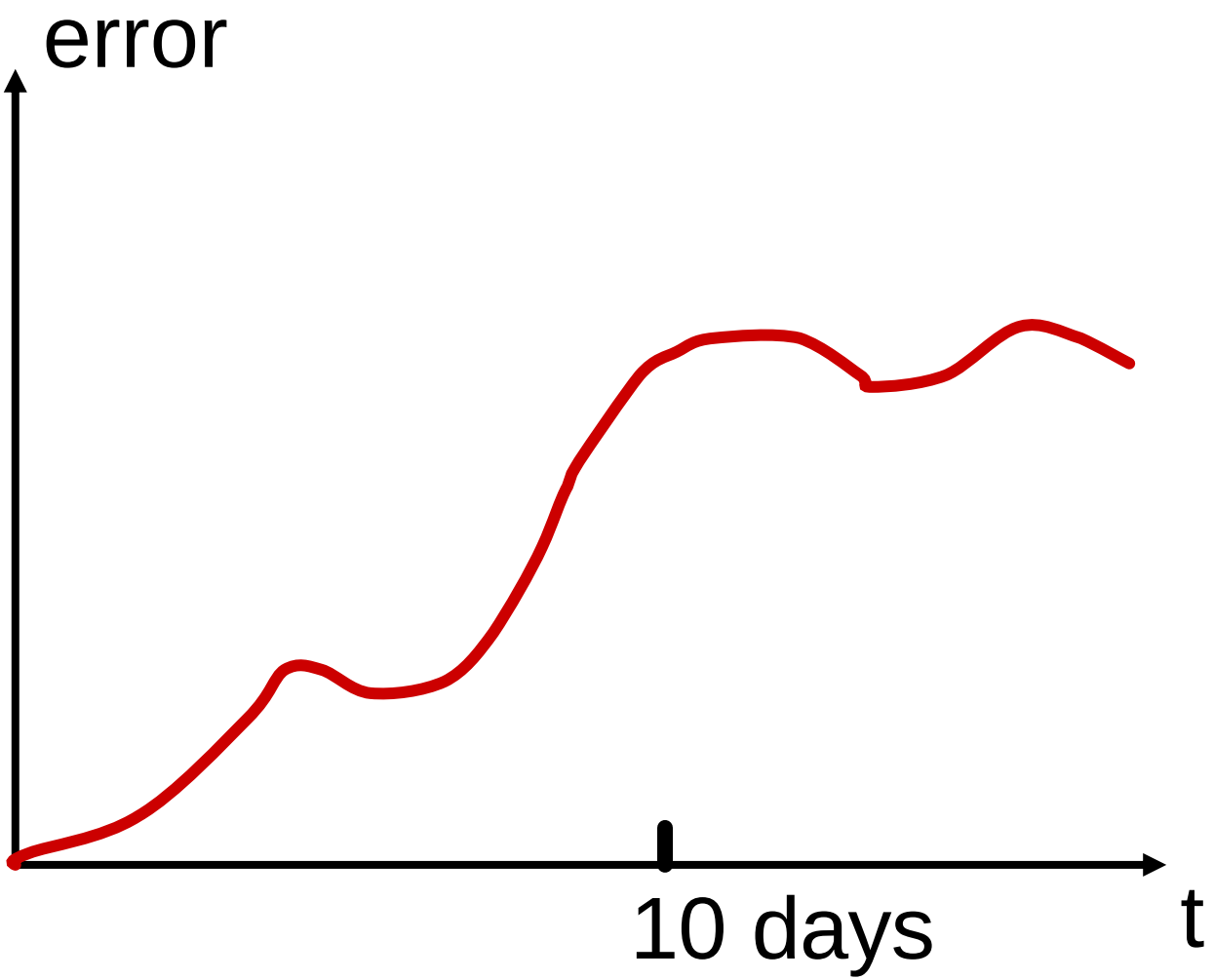
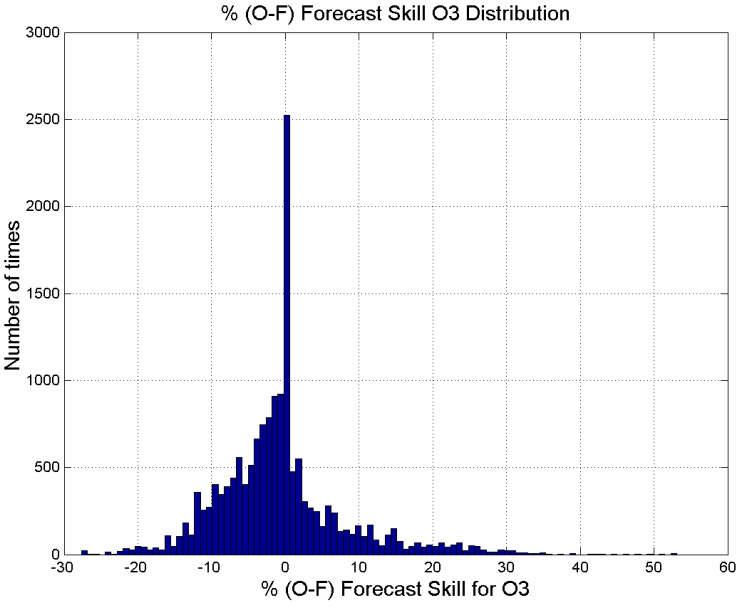
(5) Testing Climate Models

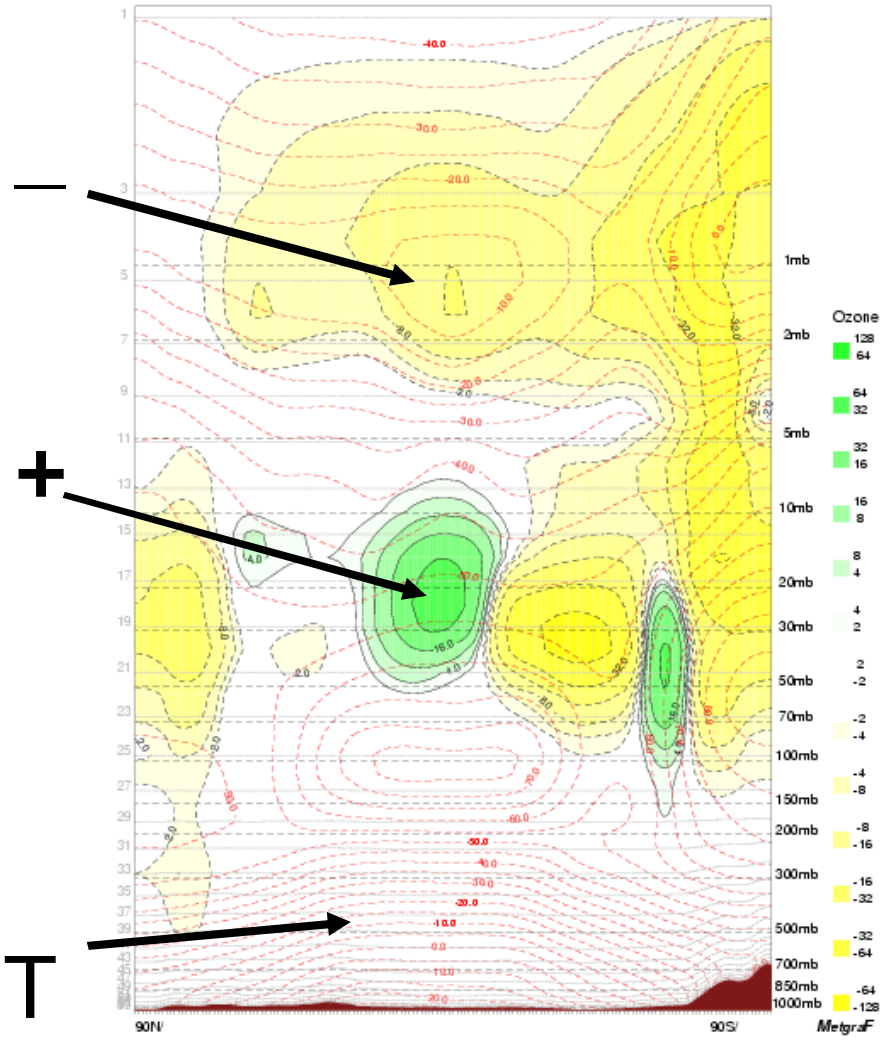



error
10 days
t

Skill Measures: Observation Increment, (O-F)

- The difference between the forecast from the first guess, F, and the observations, O, also known as observed-minus-background differences or the innovation vector.
- This is probably the best measure of forecast skill.



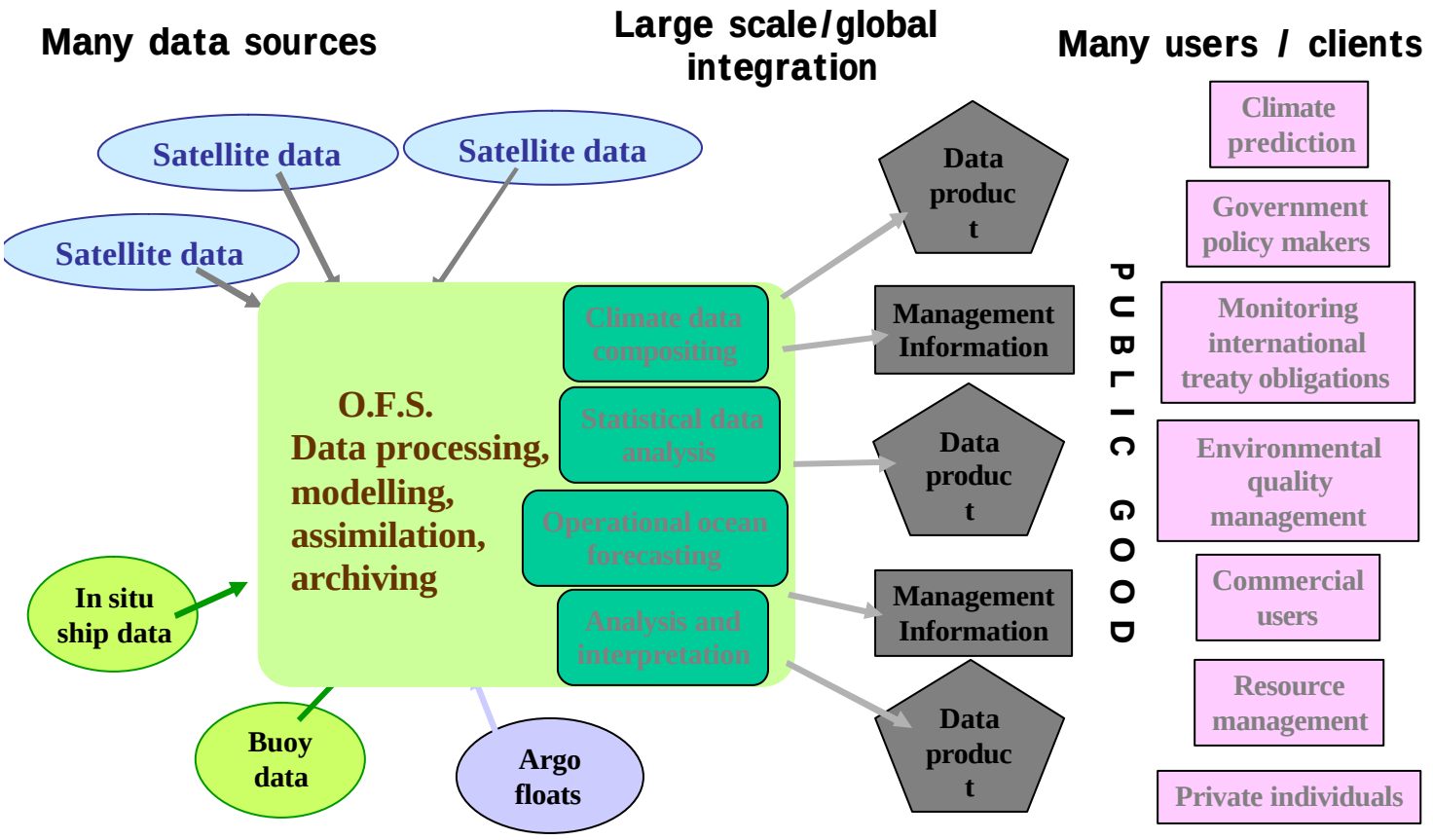


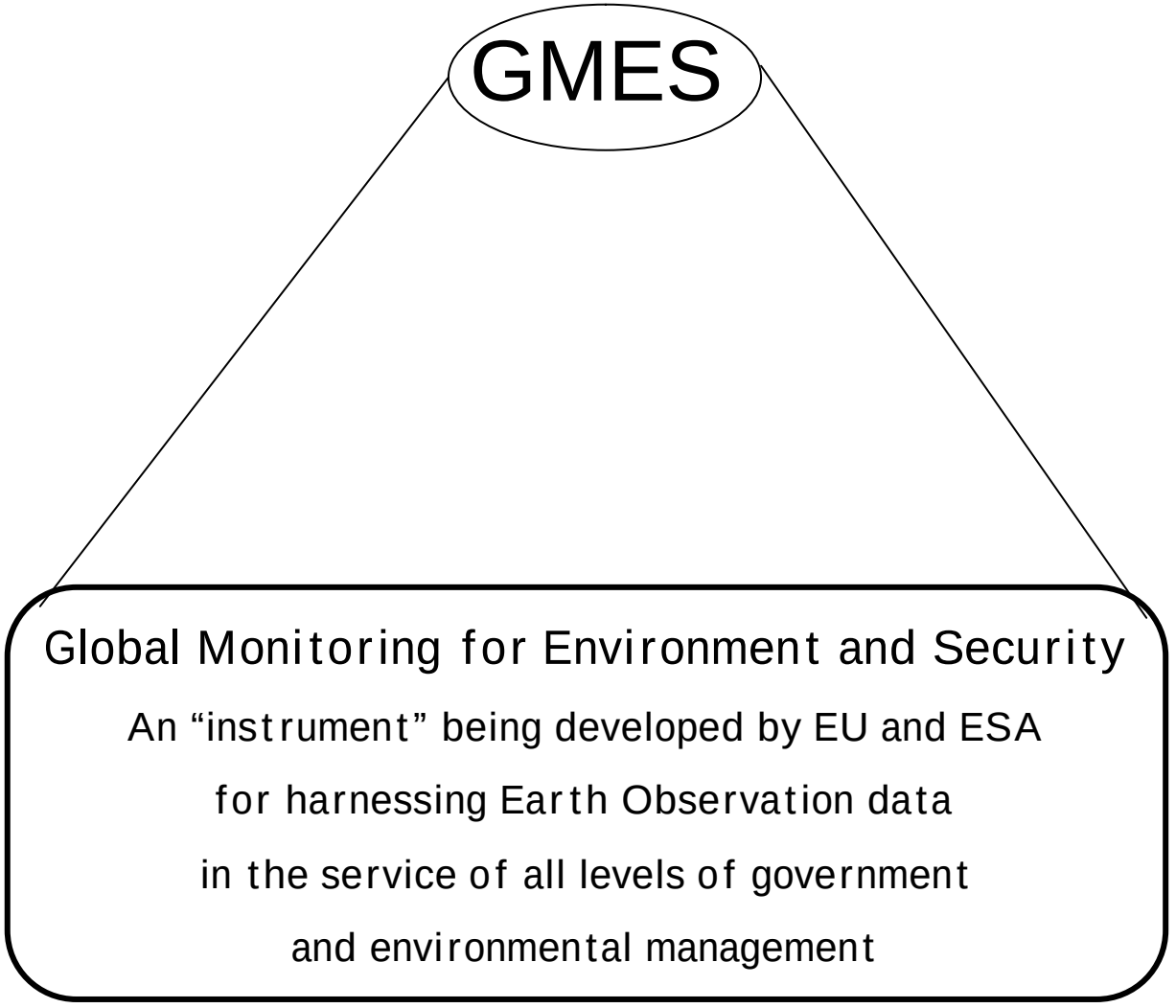
ECMWF

Ozone monthly-mean analysis increment.

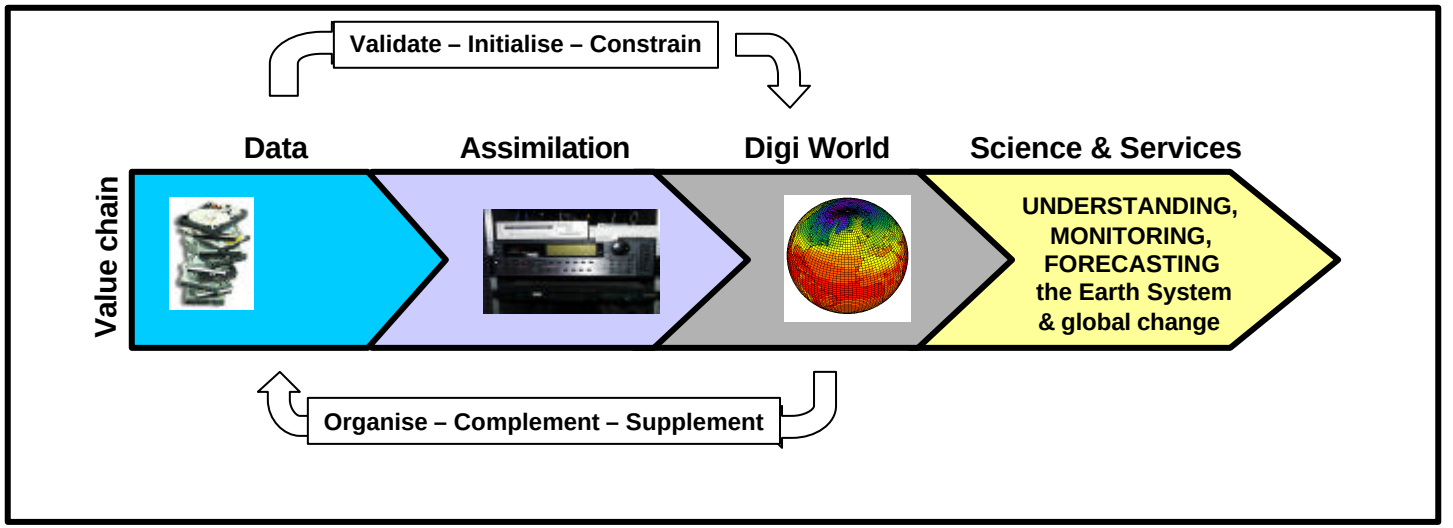
Sept. 1986

GMES


Many data sources
Large scale/global integration
Many users / clients
Satellite data
Satellite data
Satellite data
In situ ship data
Buoy data
Argo floats
O.F.S.
Data processing, modelling, assimilation, archiving
Climate data compositing
Statistical data analysis
Operational ocean forecasting
Analysis and interpretation
Data product
Management Information
Data product
Management Information
Data product
PUBLIC GOOD
Climate prediction
Government policy makers
Monitoring international treaty obligations
Environmental quality management
Commercial users
Resource management
Private individuals


GMES
Global Monitoring for Environment and Security
An “instrument” being developed by EU and ESA
for harnessing Earth Observation data
in the service of all levels of government
and environmental management

Conclusion



Courtesy PP Mathieu