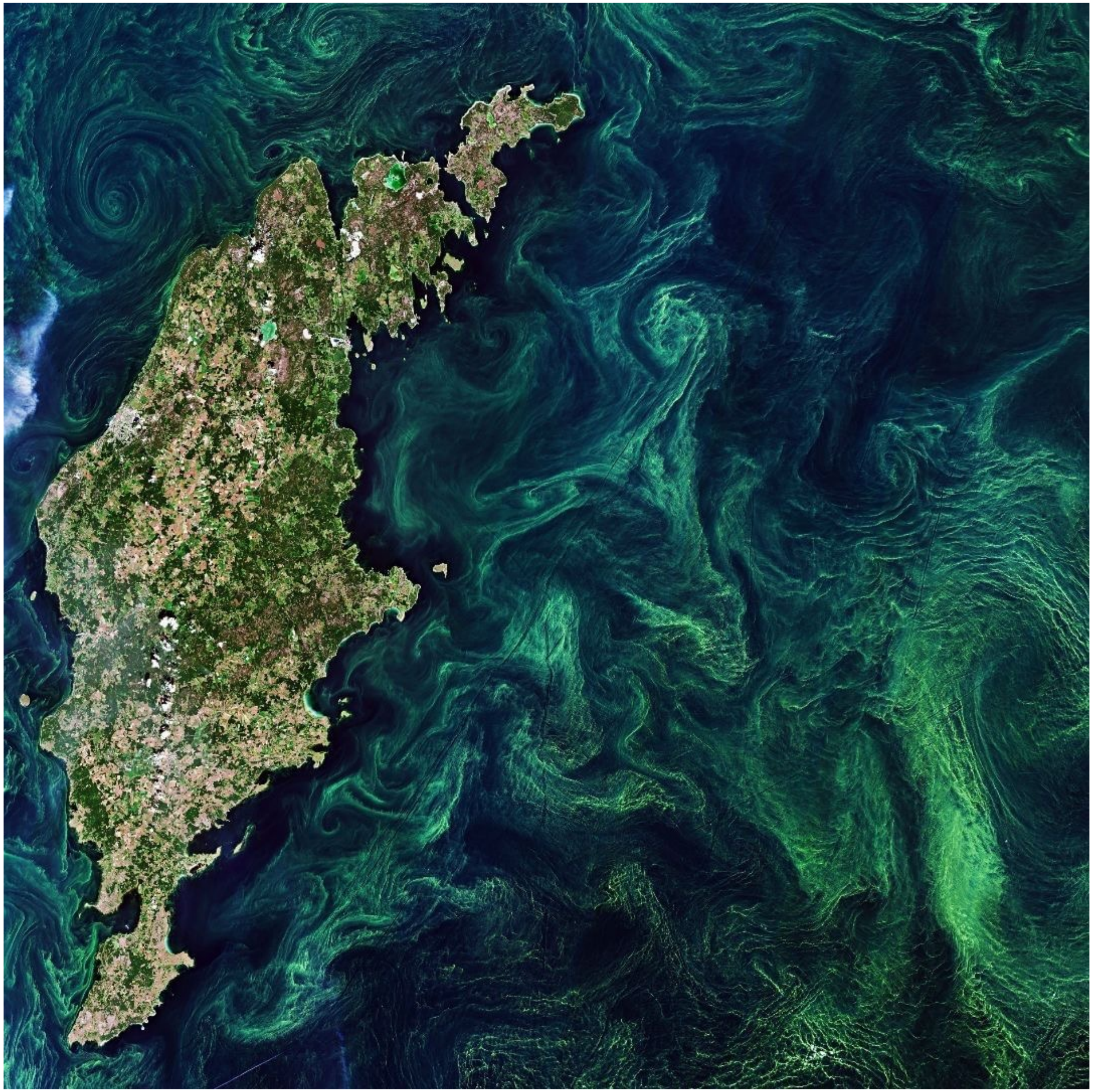
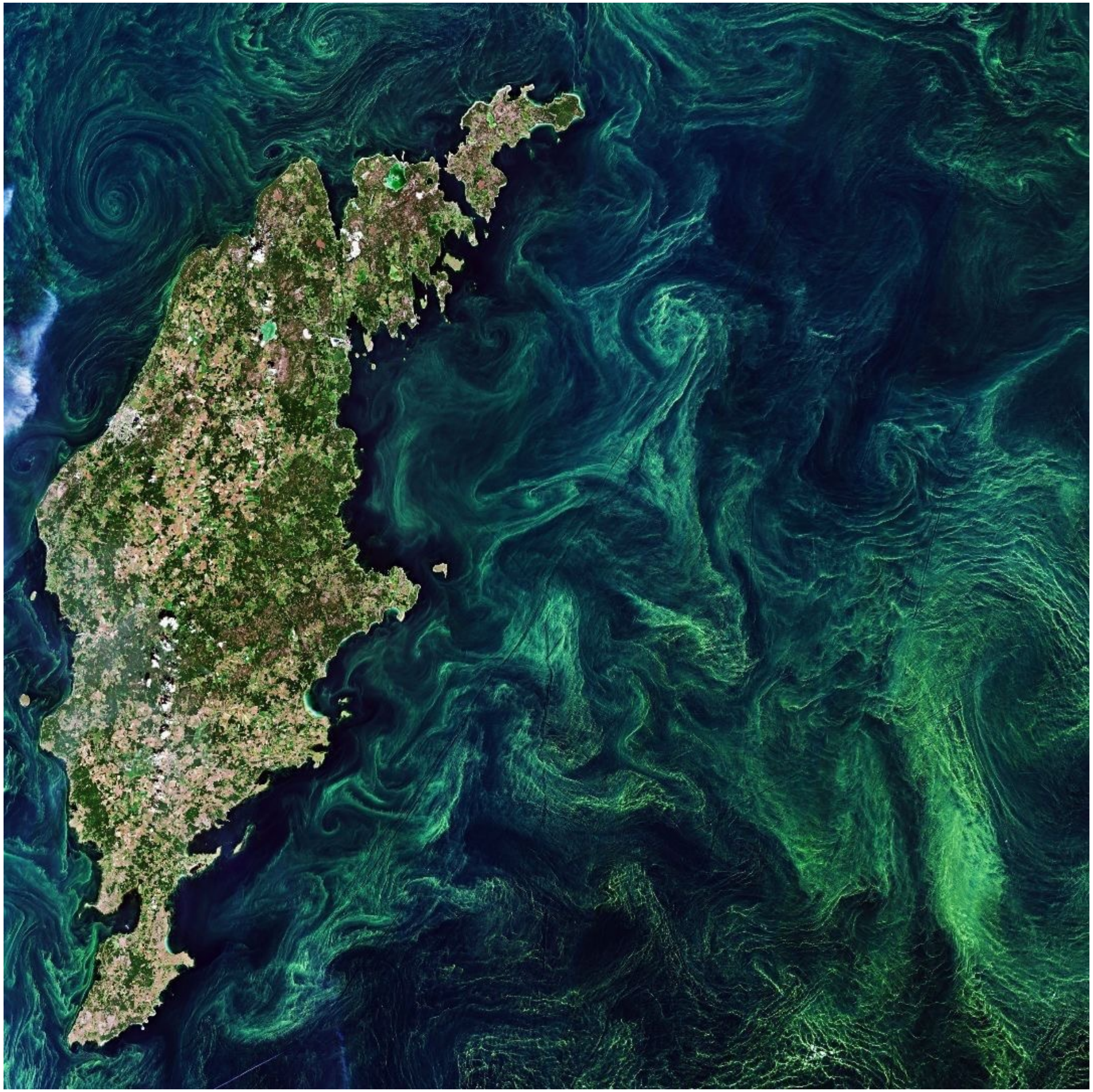


Fluidodinamica Geofisica

979SM

Stefano Salon
ssalon@ogs.it
Dirigente Ricerca
OGS
Gruppo ECHO
(video, video)



Fluidodinamica Geofisica

979SM

⇒ **VALUTAZIONE DIDATTICA**

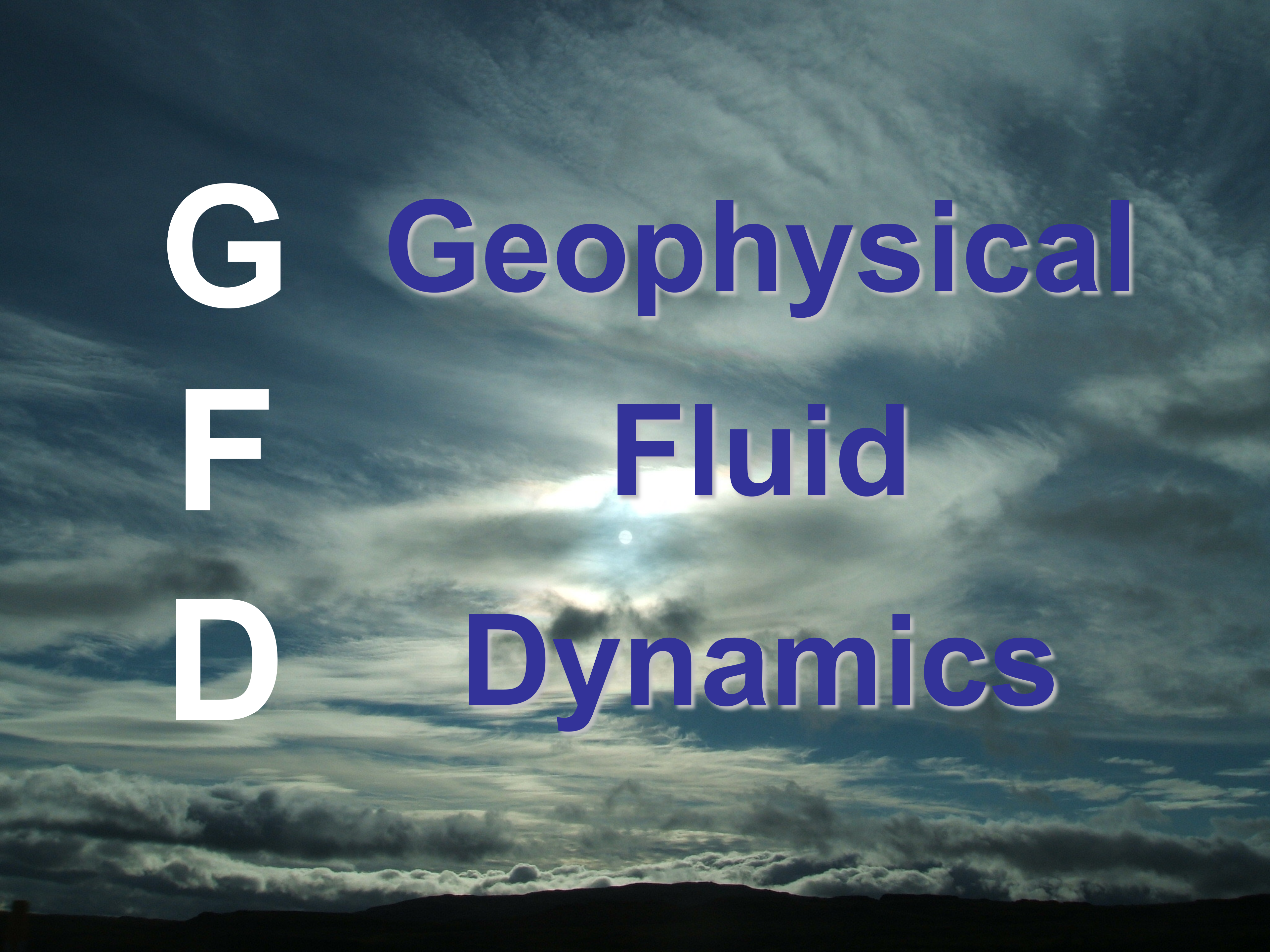
- compilare il questionario prima della fine delle lezioni
- importanza della rilevazione per il miglioramento didattica

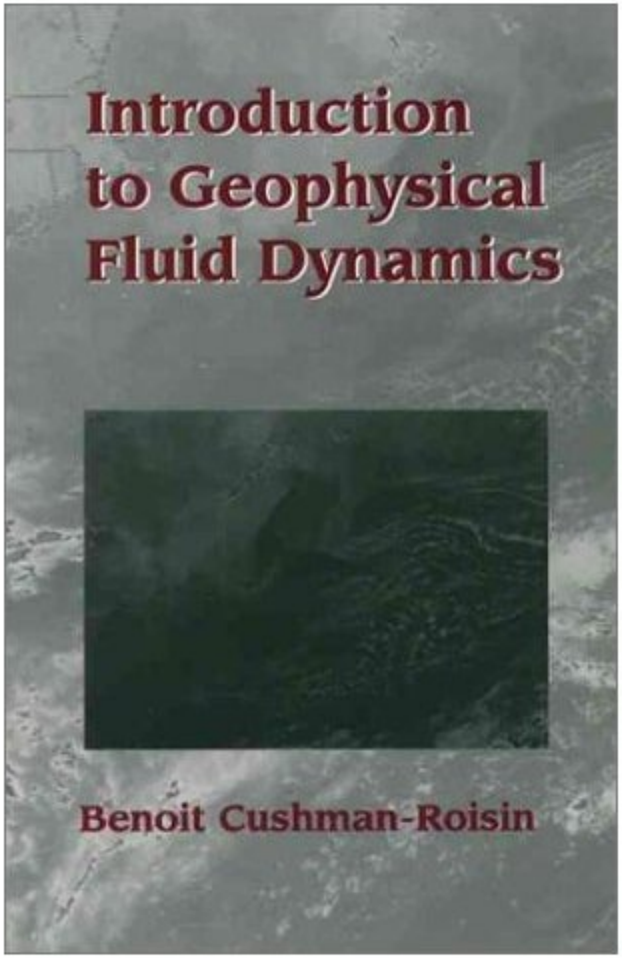
Corso: 979SM – FLUIDODINAMICA GEOFISICA
Lecturers: R. Farneti, S. Salon

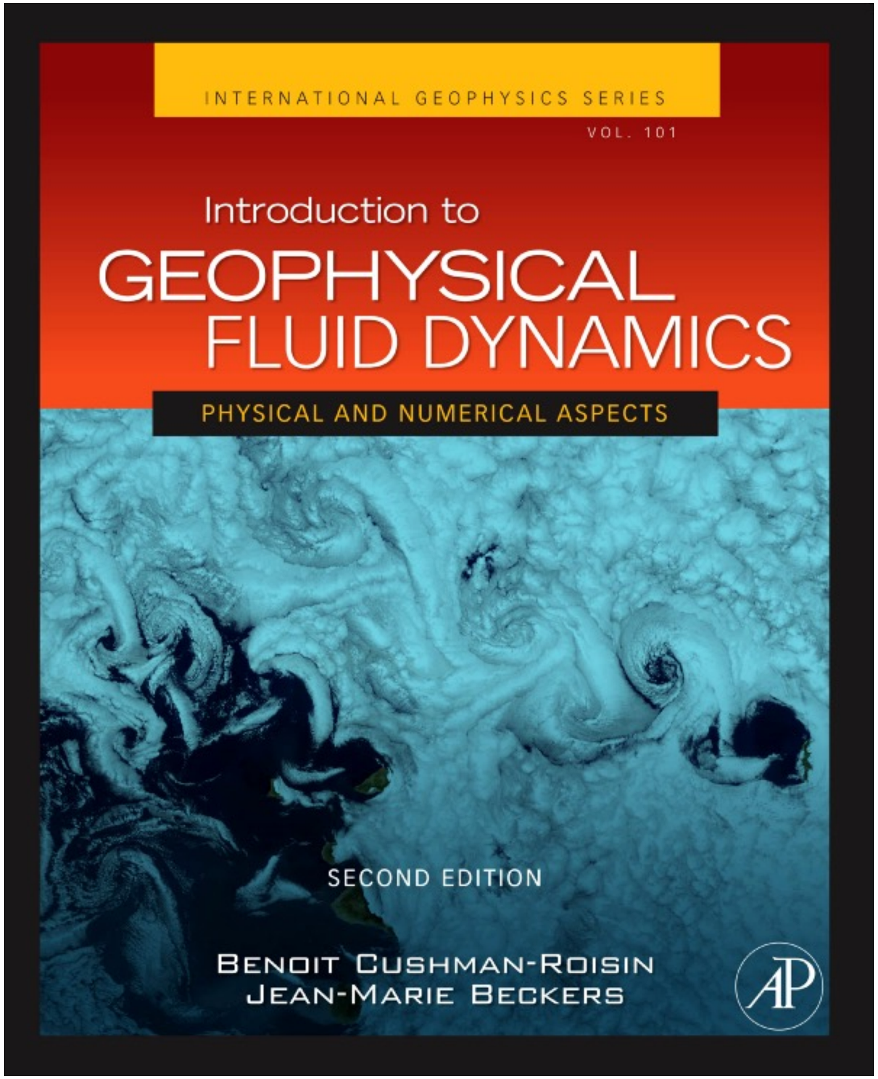
Scopo: introduzione ai **temi principali della Geophysical Fluid Dynamics - GFD**

Syllabus:

1. Introduction to Geophysical FD: scales of motion, rotation/stratification in atmosphere and ocean
2. Rotating frame of reference: Coriolis force, inertial oscillations, acceleration on a 3-D rotating planet
3. Governing equations of GFD: momentum, mass conservation, energy, equation of state
4. Boussinesq approximation; scale analysis and further simplifications of governing equations; Rossby, Ekman, Reynolds numbers
5. Geostrophy: geostrophic flows; Taylor-Proudman theorem; non-geostrophic flows; vorticity dynamics
6. Friction and rotation 1: Prandtl hypothesis, Bottom Ekman layers
7. Friction and rotation 2: Surface Ekman layer, Ekman pumping, Ekman layers in real geophysical flows
8. Barotropic waves 1: hypotheses, Kelvin waves, Poincarè waves
9. Barotropic waves 2: Rossby waves, topographic waves and their analogies
10. Stratification: static stability, Froude number, combination of rotation and stratification
11. Mixing 1: mixing of stratified fluids, Kelvin-Helmoltz instability – Instability of a stratified shear flow
12. Mixing 2: Taylor-Goldstein equation, Richardson number; turbulence in a stratified shear flow


G Geophysical
F Fluid
D Dynamics





PDF file will be provided during the course

WHAT ?

WHY ?

HOW ?

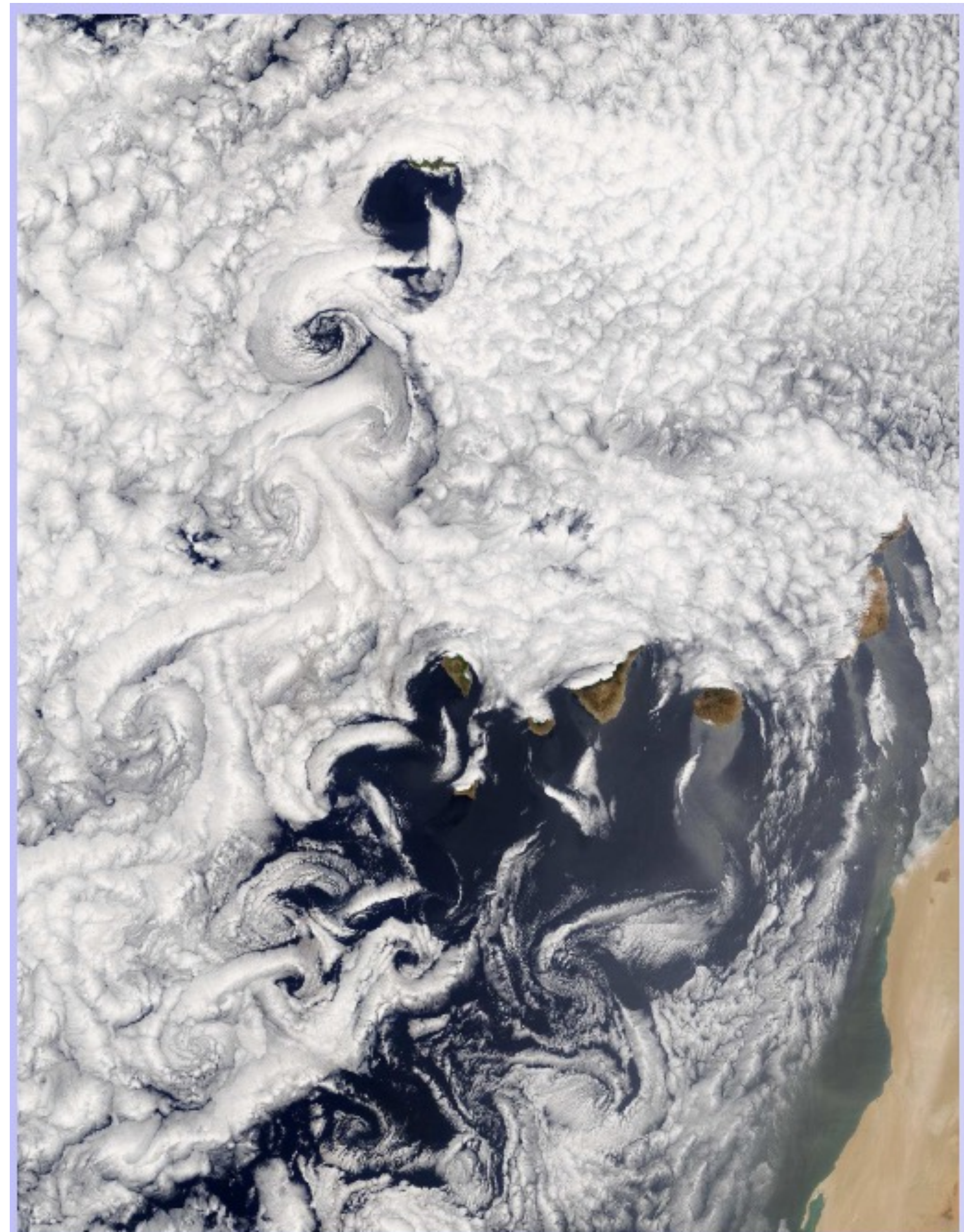
WHAT ?

WHY ?

HOW ?

http://wwwrses.anu.edu.au/research/a nnrep/ar2006/cover-mountains.png

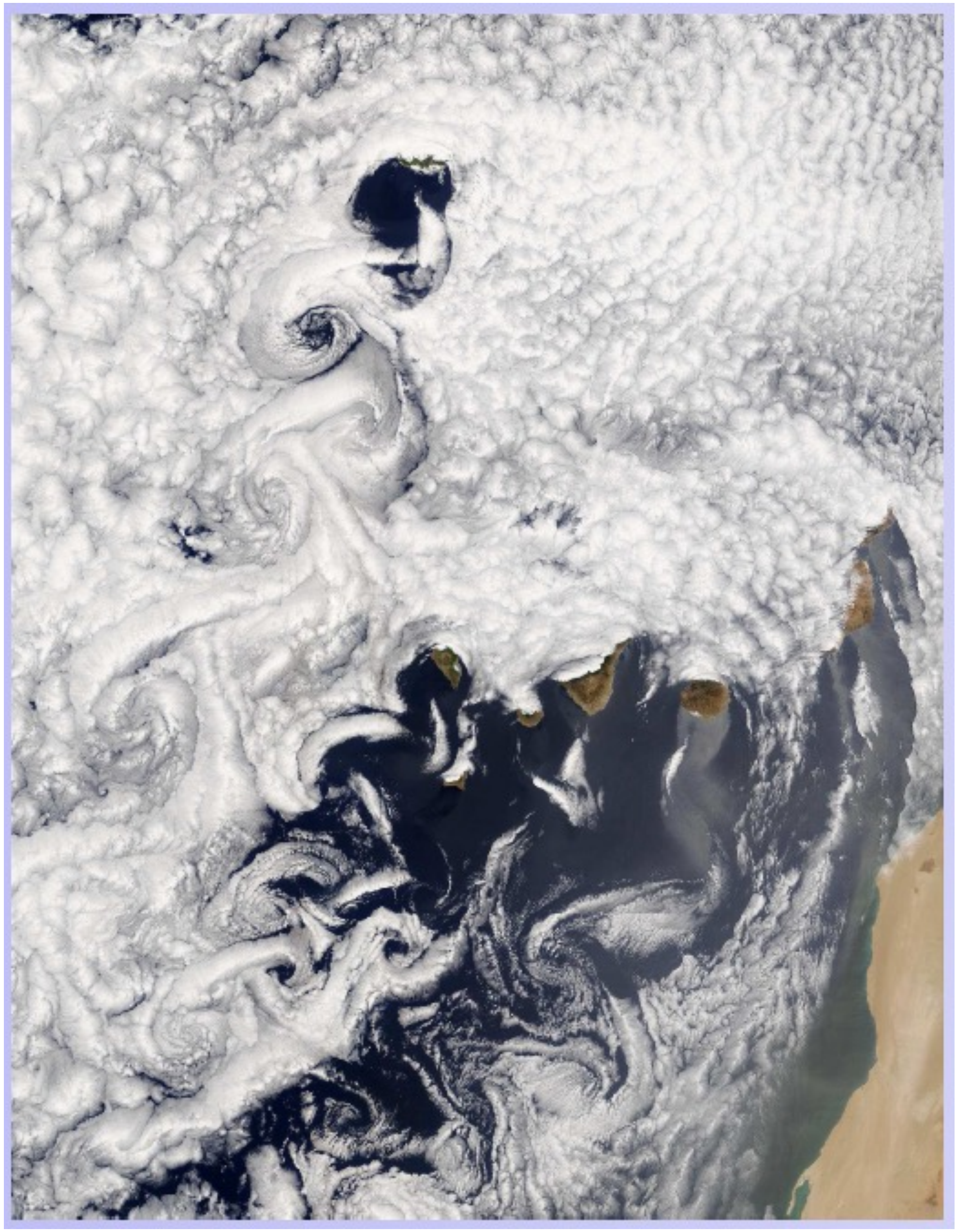
http://www.math.uio.no/research/ groups/FluidMechanics/images/spl ash.jpg



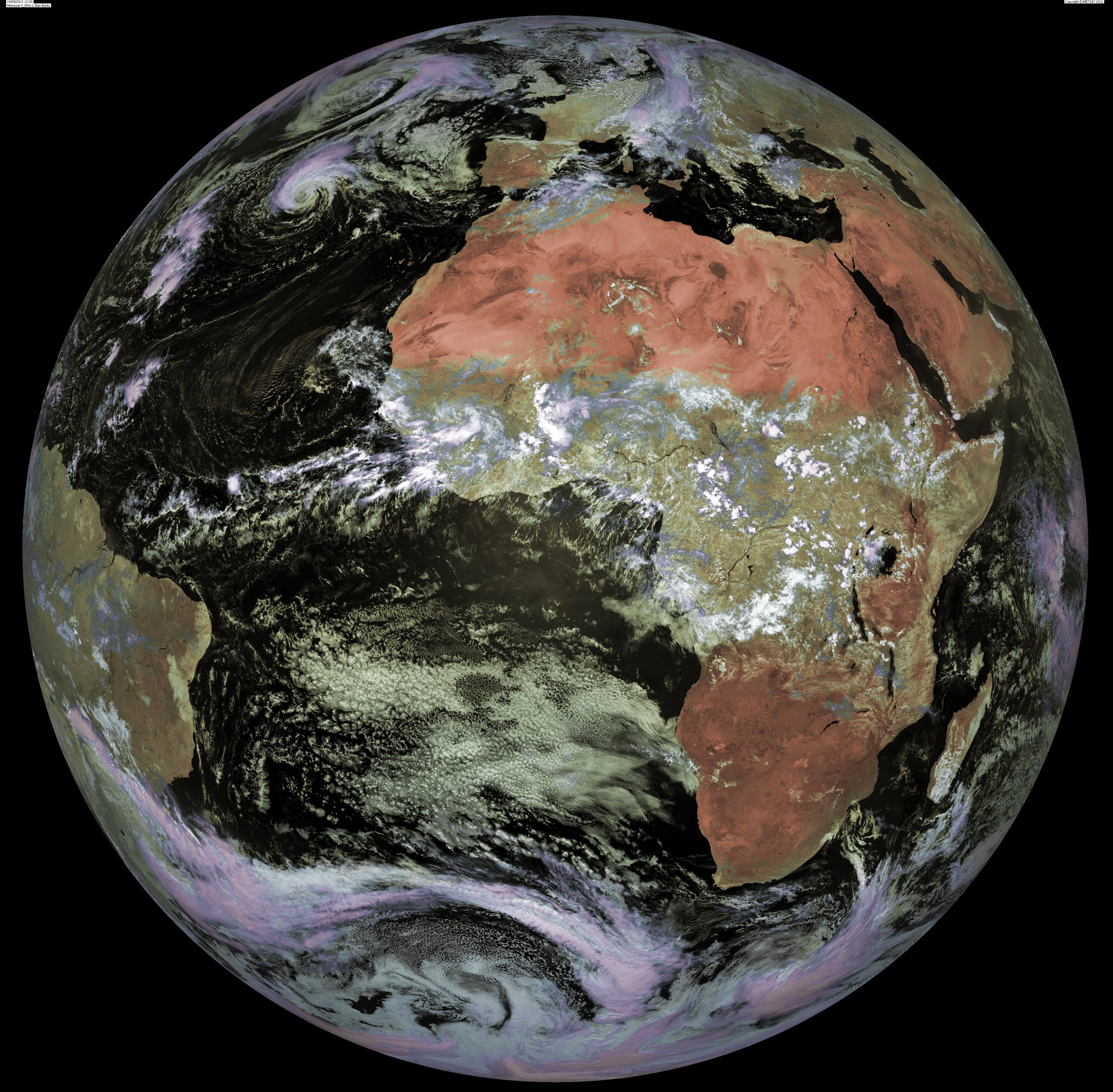
Vortex street near Canary Islands as seen from the Terra satellite (*Image courtesy of MODIS Rapid Response Project at NASA/GSFC.*)

http://wwwrses.anu.edu.au/research/annrep/ar2006/cover-mountains.png

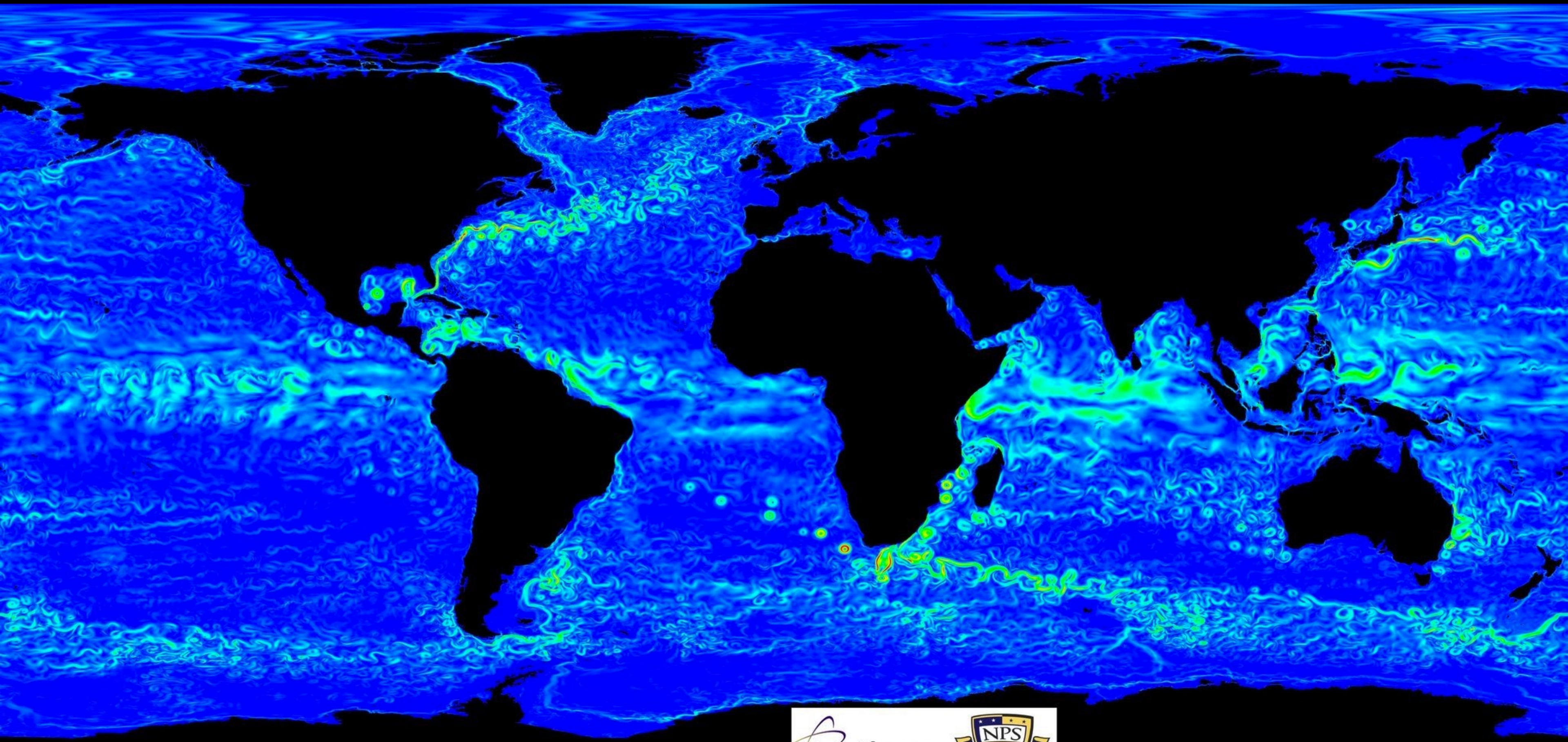
http://www.math.uio.no/research/groups/FluidMechanics/images/splash.jpg



Vortex street near Canary Islands as seen from the Terra satellite (*Image courtesy of MODIS Rapid Response Project at NASA/GSFC.*)



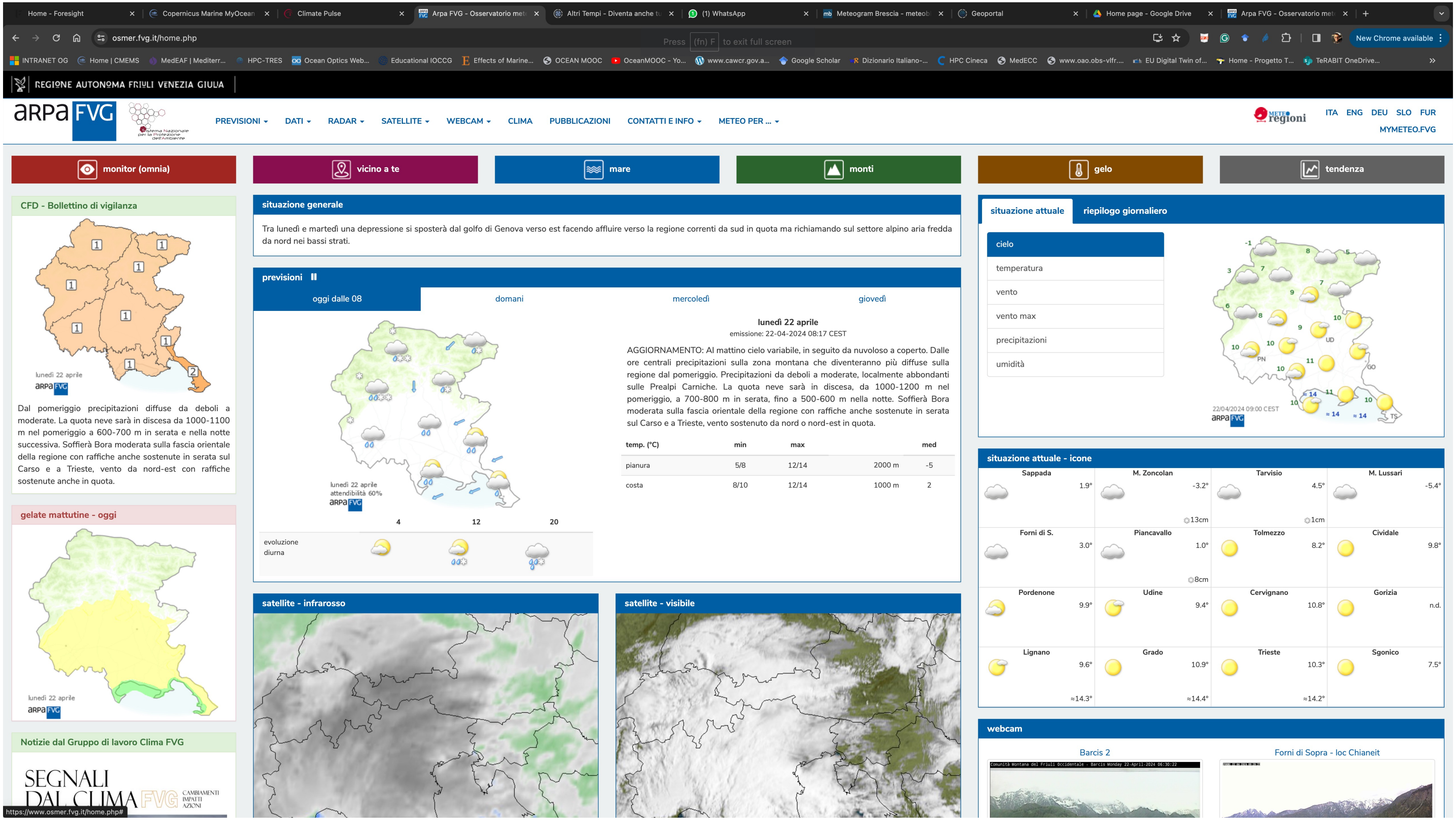
http://www.geo-web.org.uk/MSGimagery_files/met9_fulldisk-190912.jpg



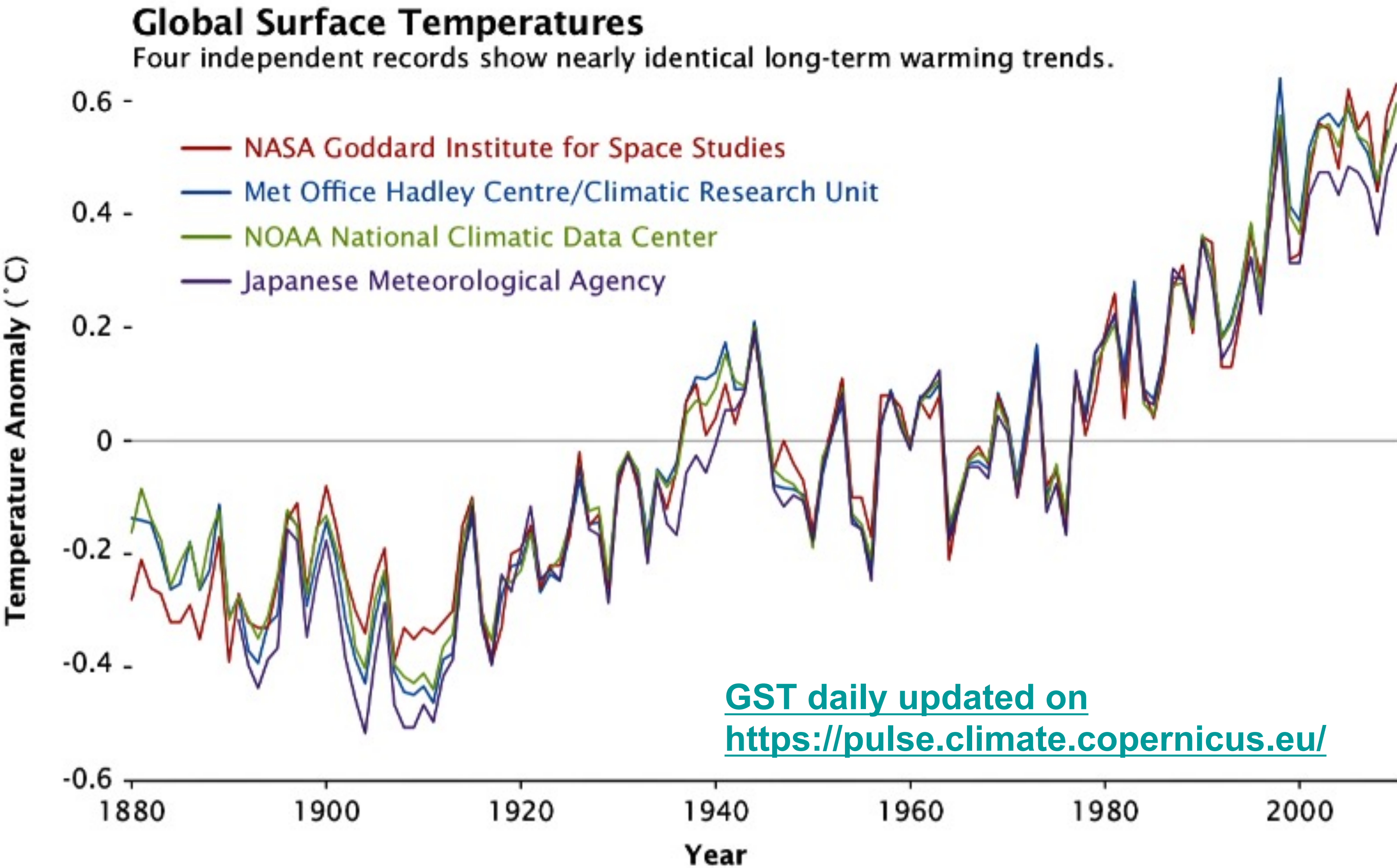
Los Alamos
NATIONAL LABORATORY

NPS
PRAESTANTIA PER SCIENTIAM

https://sos.noaa.gov/kml/resources/2048_rolled/speed.0003.jpg



https://www.osmer.fvg.it/home.php

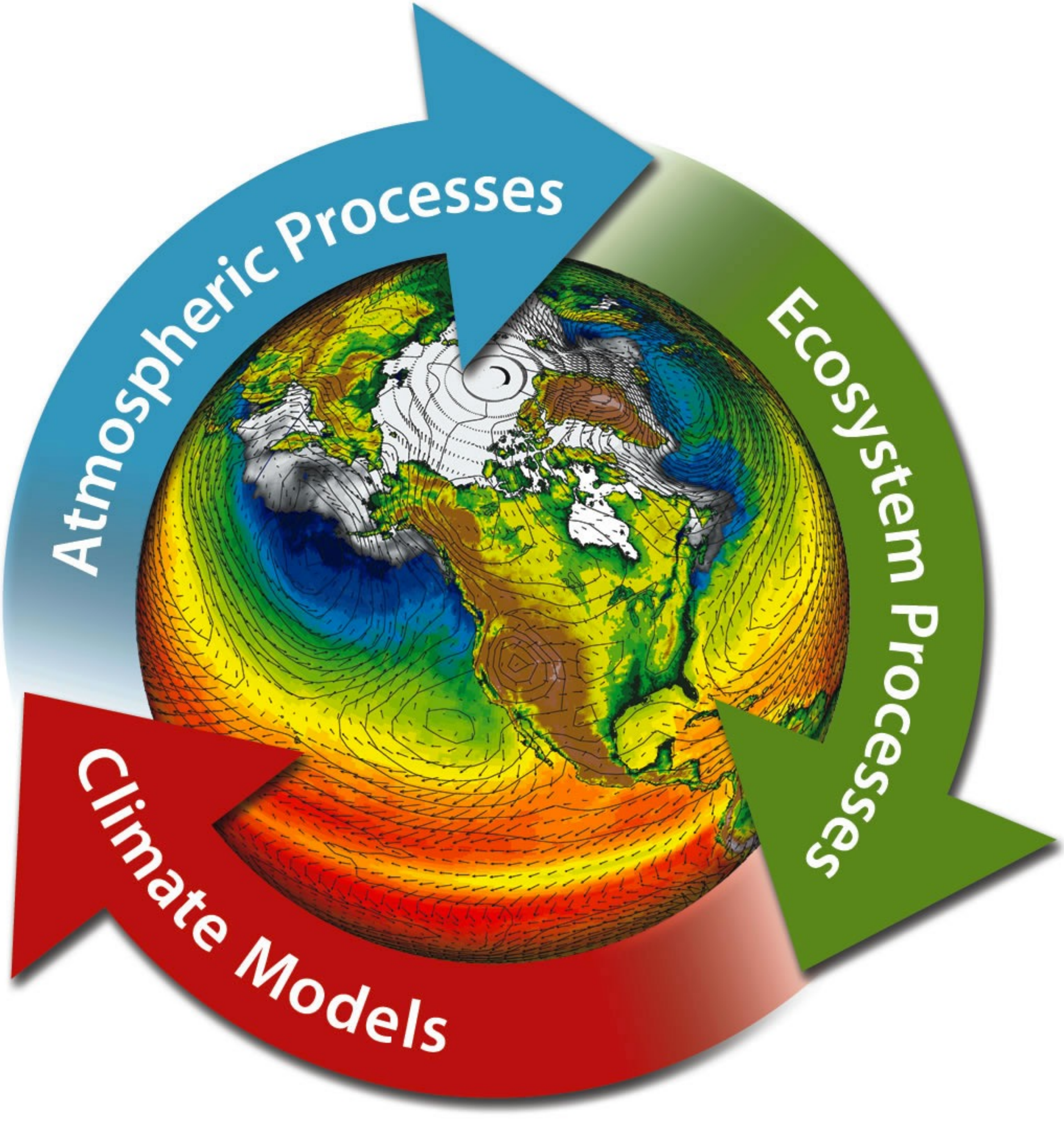


GST daily updated on https://pulse.climate.copernicus.eu/

Credit: NASA Earth Observatory/Robert Simmon

Data Sources: NASA Goddard Institute for Space Studies, NOAA National Climatic Data Center, Met Office Hadley Centre/Climatic Research Unit, and the Japanese Meteorological Agency.

http://www.icsusa.org/media/pictures/articles/2011-2-1p.png



http://www2.hawaii.edu/~rmjones7/Climate_Placemat_arrows2PC.jpg

GFD on rotating planets

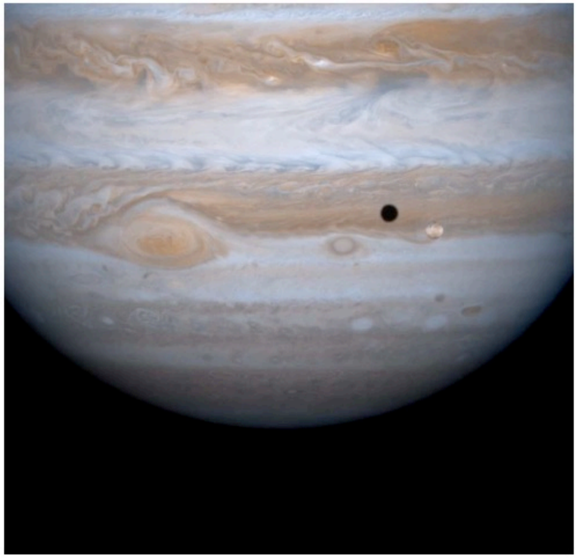


Figure 1-5 Southern Hemisphere of Jupiter as seen by the spacecraft *Cassini* in 2000. The Jupiter moon Io, of size comparable to our moon, projects its shadow onto the zonal jets between which the Great Red Spot of Jupiter is located (on the left). For further images visit http://photojournal.jpl.nasa.gov/target/Jupiter. (Image courtesy of NASA/JPL/University of Arizona)

NASA's Juno spacecraft soared directly over Jupiter's south pole when JunoCam acquired this image on February 2, 2017, from an altitude of about 101,000 km above the cloud tops.

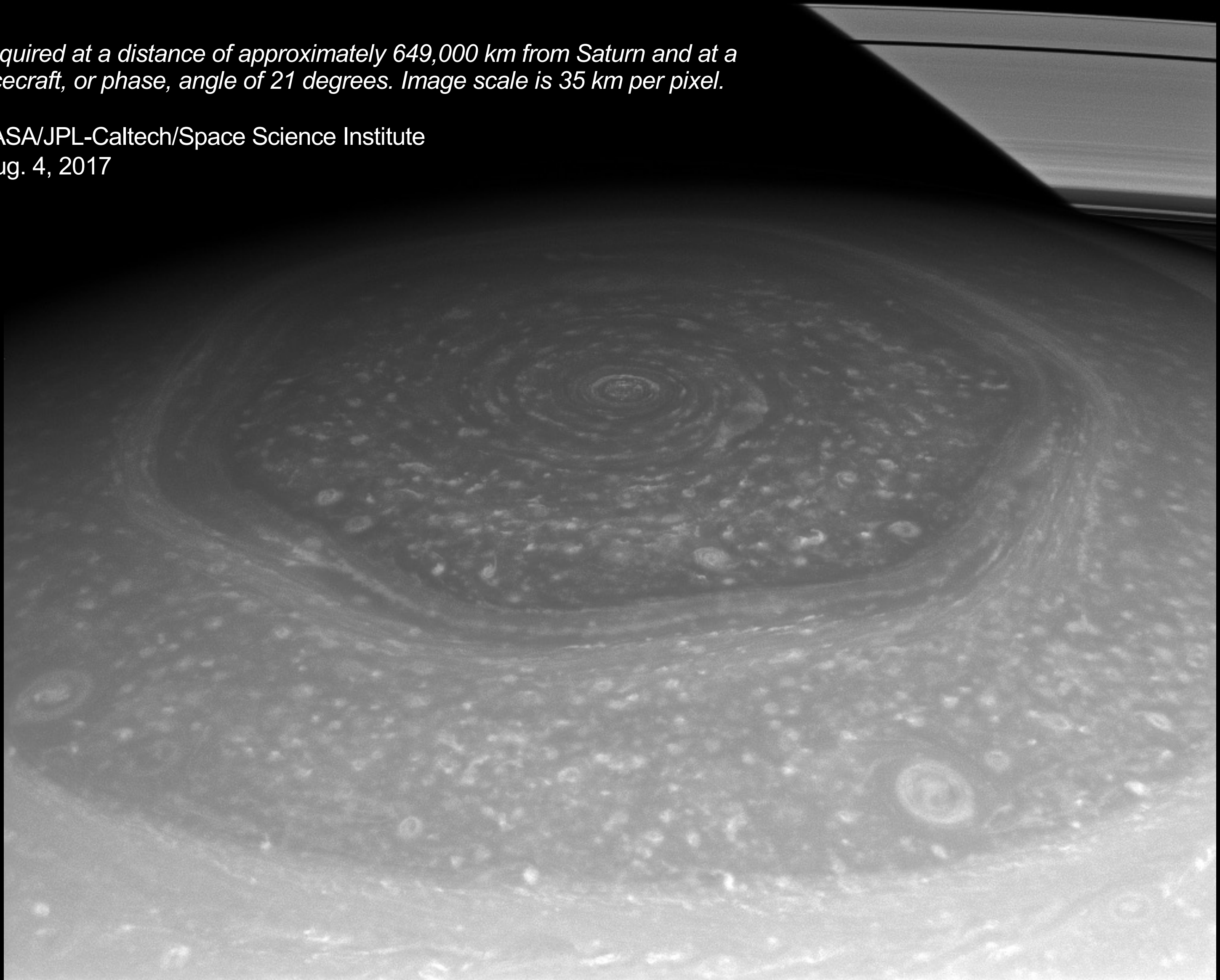
https://www.jpl.nasa.gov/news/news.php?feature=6752

Saturn's north polar hexagon basks in the Sun's light now that spring has come to the northern hemisphere. Many smaller storms dot the north polar region and Saturn's signature rings, which appear to disappear on account of Saturn's shadow, put in an appearance in the background.

The image was taken with the Cassini spacecraft's wide-angle camera on Nov. 27, 2012 using a spectral filter sensitive to wavelengths of near-infrared light centered at 750 nanometers.

The view was acquired at a distance of approximately 649,000 km from Saturn and at a Sun-Saturn-spacecraft, or phase, angle of 21 degrees. Image scale is 35 km per pixel.

Image Credit: NASA/JPL-Caltech/Space Science Institute
Last Updated: Aug. 4, 2017



https://www.nasa.gov/sites/default/files/images/729530main_PIA14646-full_full.jpg

Full story

WHAT ?

WHY ?

HOW ?

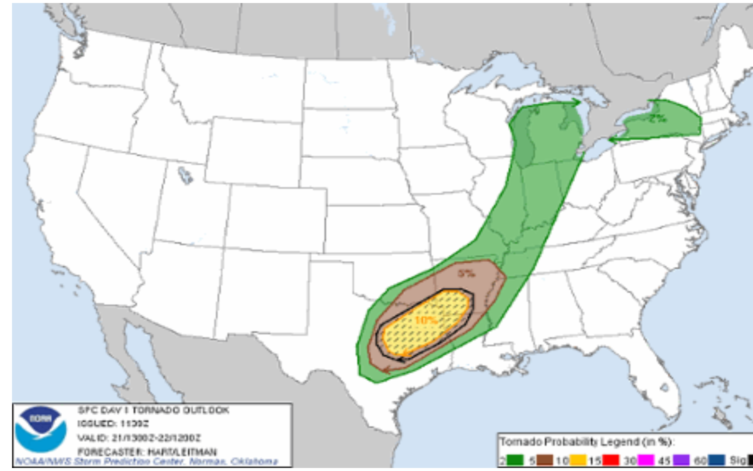
da Vinci, c.1500: *Sketch of Turbulent Flow*

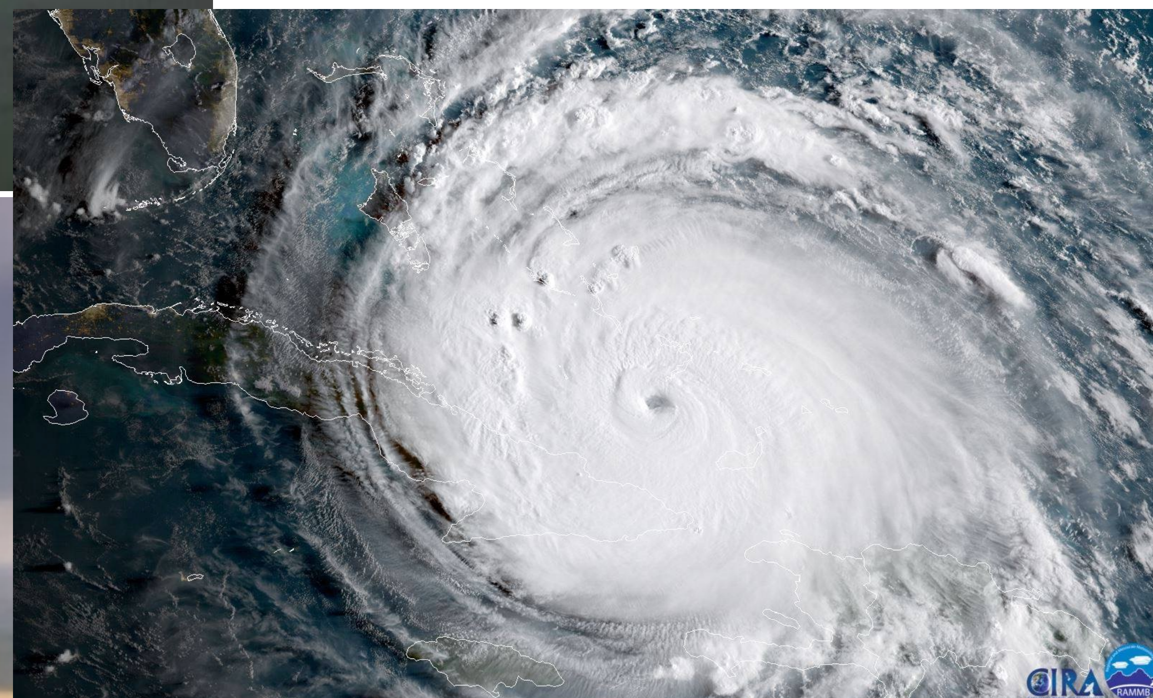
W. Turner (1812)
http://it.wikipedia.org/wiki/Bufera_di_neve:_Annibale_e_il_suo_esercito_attraversano_le_Alpi

Hokusai, c.1850: *The Great Wave*

http://ceae.colorado.edu/~crimaldi/teaching.html

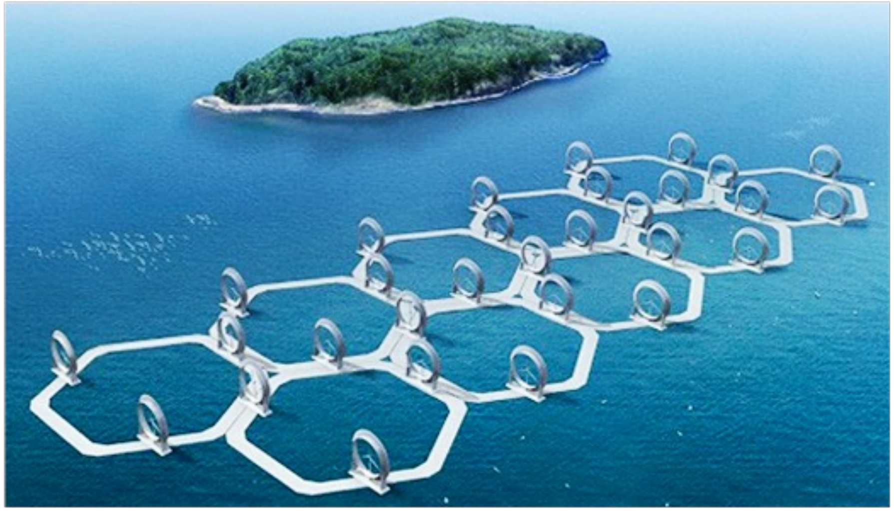
W. Homer (1899)
http://en.wikipedia.org/wiki/The_Gulf_Stream_(painting)





https://www.nasa.gov/image-feature/geocolor-image-of-hurricane-irma (Geocolor image of Hurricane Irma passing the eastern end of Cuba at about 8:00 a.m. EDT on Sept. 8, 2017 captured by the NOAA satellite GOES-16)

http://www.spc.noaa.gov/ - http://www.nssl.noaa.gov/ - http://www.nhc.noaa.gov/



http://cdn.oilprice.com/uploads/AA9002.png

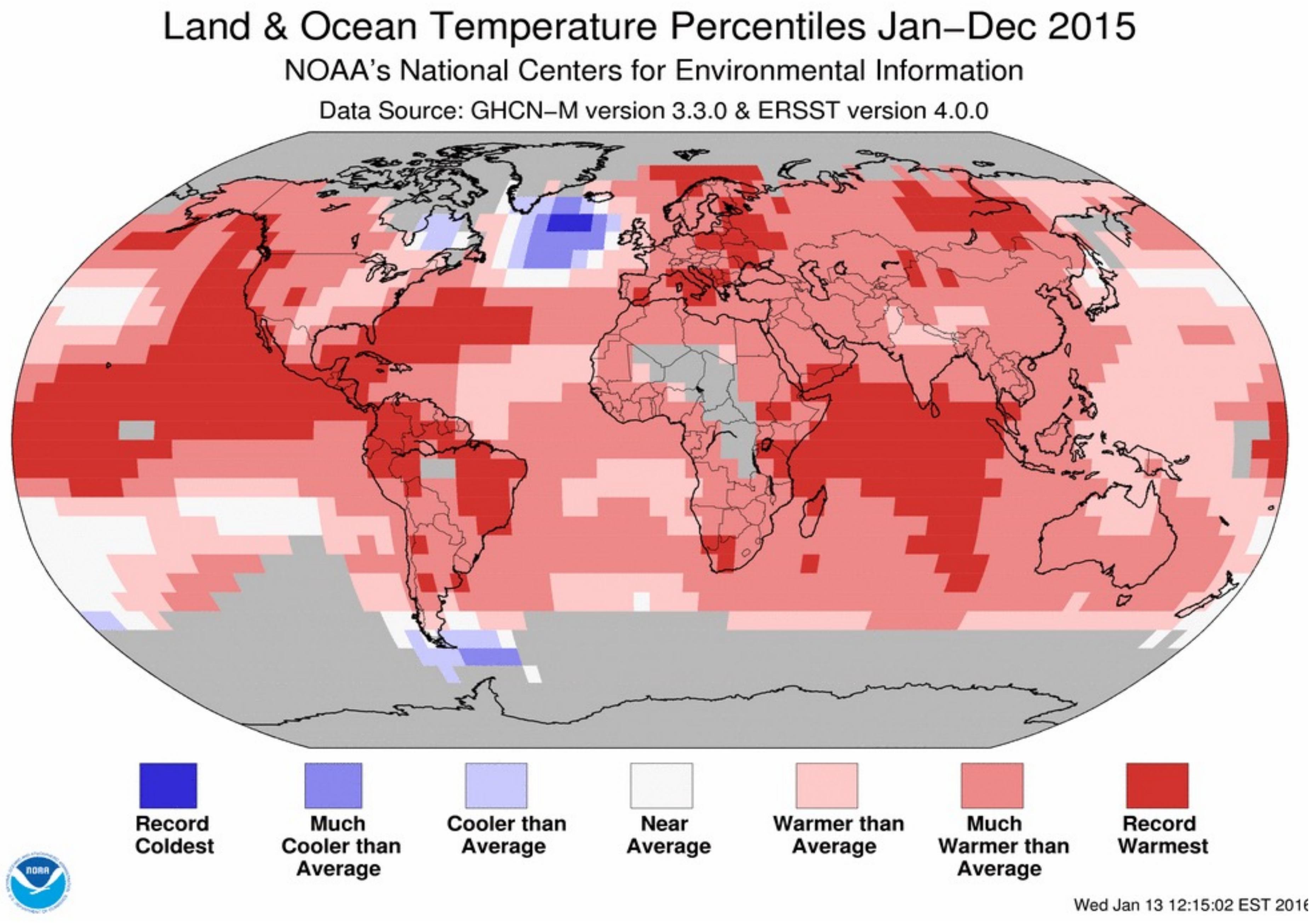
http://www.midcoastgreencollaborative.org/articles/images/Stone_Windmill.jpg

http://marine.unc.edu/files/2015/09/wind-energy-free-desktop-wallpaper_1920x1200_81824.jpg

The **Global Wind Energy Council** is the international trade association for the wind power industry.

[***In 2014 it was less than 7%***]

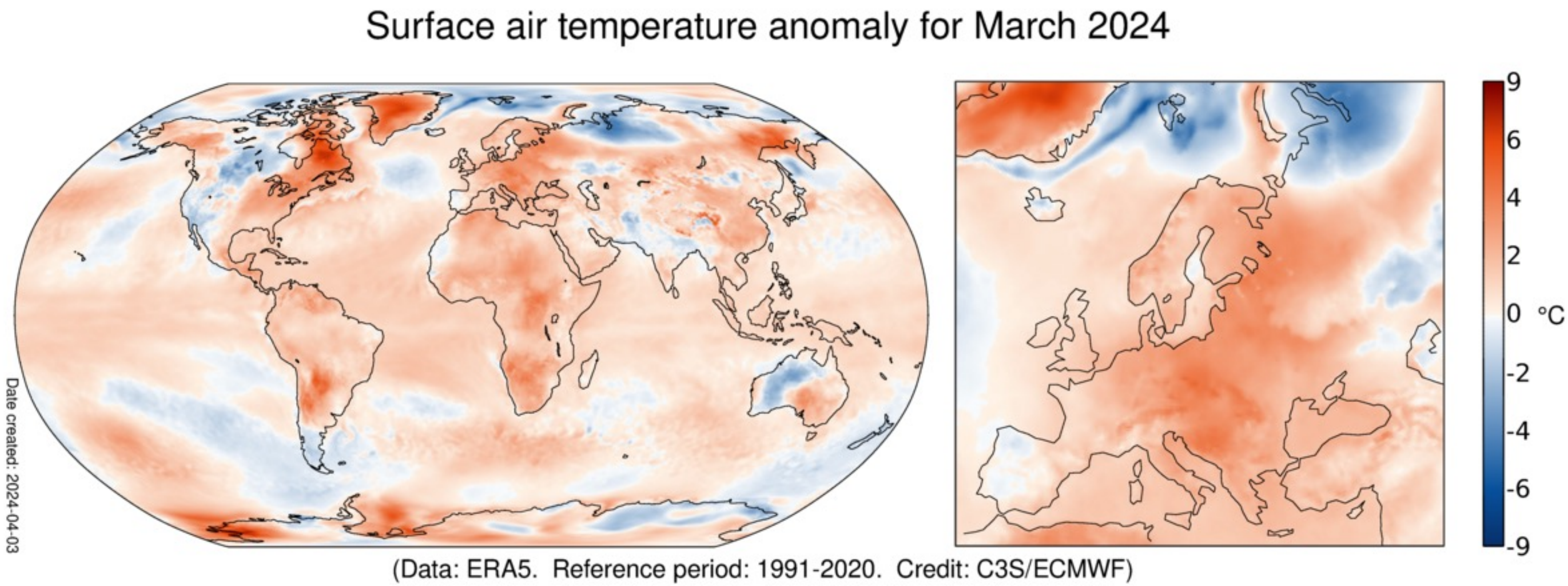
http://www.gwec.net/wp-content/uploads/2014/10/GWEO2014_19percent.jpg



http://www.icsusa.org/media/pictures/articles/2016-2-1p.png

Surface air temperature anomaly for March 2024 relative to the March average for the period 1991-2020. Source: ERA5.

(Credit: Copernicus Climate Change Service / ECMWF)



PROGRAMME OF THE EUROPEAN UNION · Copernicus Europe's eyes on Earth · IMPLEMENTED BY ECMWF · Climate Change Service

March 2024 highlights [https://climate.copernicus.eu/climate-bulletins]:

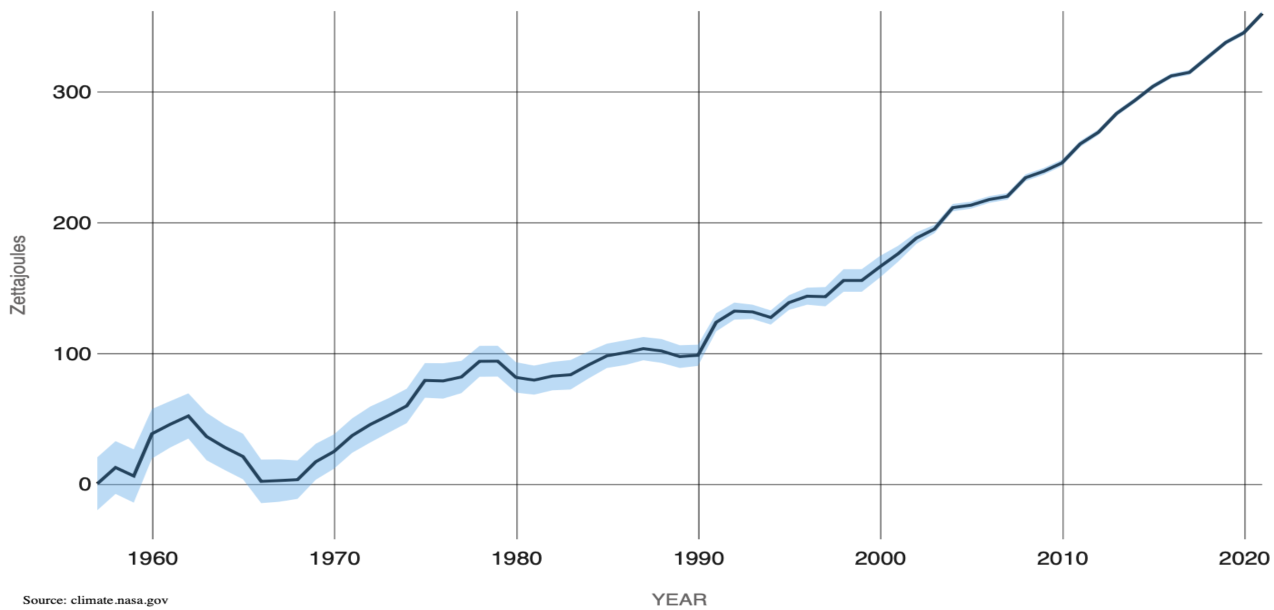
• **warmer globally than any previous March in the data record**, with an average ERA5 surface air temperature of 14.14 C, 0.73 C above the 1991-2020 average for March and 0.10 C above the previous high set in March 2016. **This is the tenth month in a row that is the warmest on record for the respective month of the year.**

• **The average European temperature for March 2024 was 2.12 C above the 1991-2020 average for March,** making the month the second warmest March on record for the continent, only a marginal 0.02 C cooler than March 2014. Temperatures were most above average in central and eastern regions.

OCEAN HEAT CONTENT CHANGES SINCE 1955 (NOAA)

Data source: Observations from various ocean measurement devices, including conductivity-temperature-depth instruments (CTDs), Argo profiling floats, and eXpendable BathyThermographs (XBTs). Credit: NOAA/NCEI World Ocean Database

https://climate.nasa.gov/vital-signs/ocean-heat/



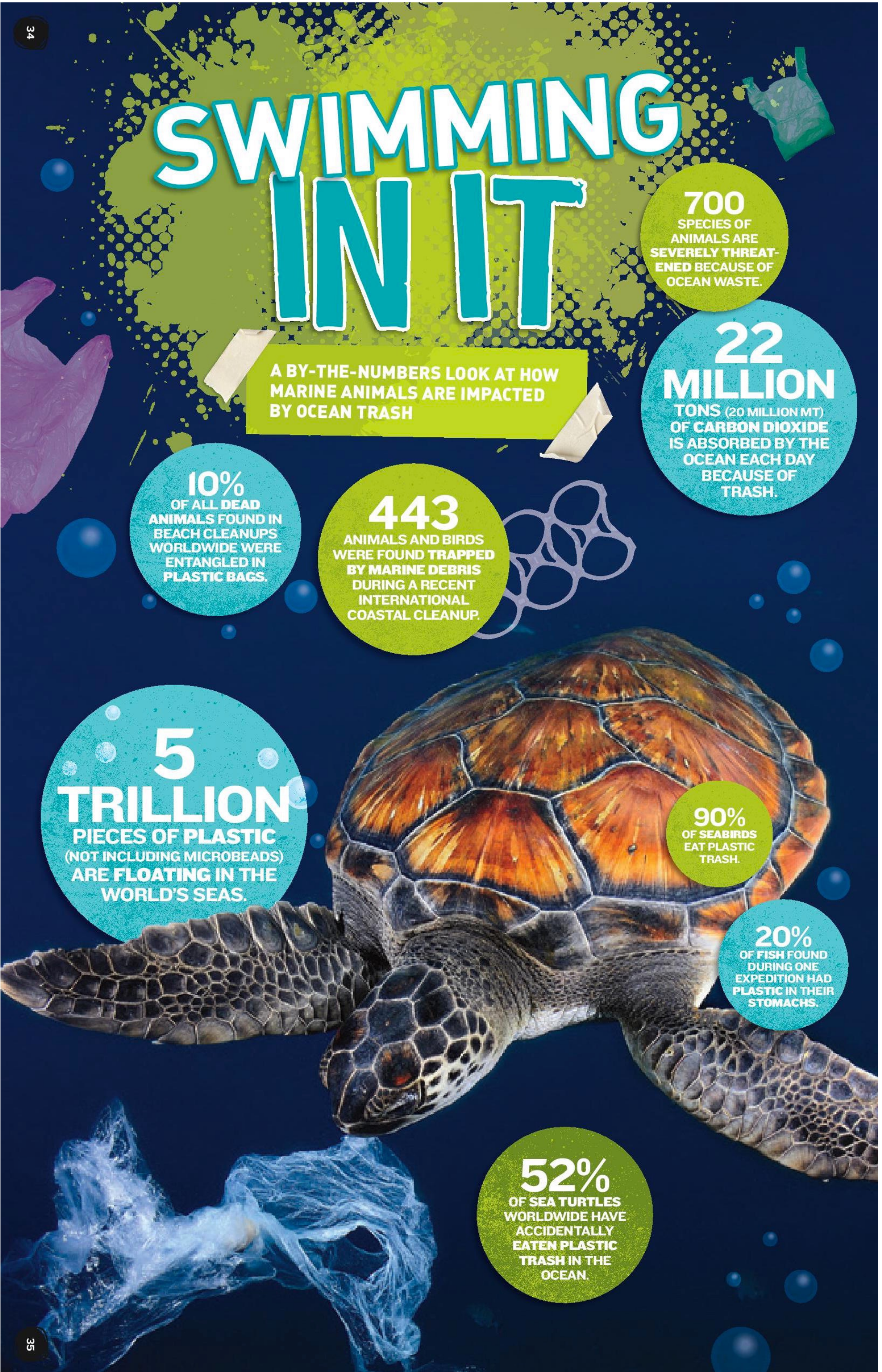
LATEST MEASUREMENT (December 2023) = 360 (± 2) zettajoules (10^{21} Joules) since 1955

- 90% of global warming is occurring in the ocean, causing the water's internal heat to increase since modern record-keeping began in 1955 (shaded blue region indicates the 95% margin of uncertainty; plot shows annual estimates for the first 2,000 meters of ocean depth; each data point in the plot represents a 5-year average).
- Heat stored in the ocean causes its water to expand, which is responsible for one-third to one-half of global sea level rise. Most of the added energy is stored at the surface, at a depth of zero to 700 meters. The last 10 years were the ocean's warmest decade since at least the 1800s. The year 2023 was the ocean's warmest recorded year.

http://www.vos.noaa.gov/MWL/aug_08/tropicalareas.shtml

http://www.thehindu.com/sci-tech/energy-and-environment/rena-sea-disaster/article2531689.ece

http://www.unep.org/ecosystemmanagement/water/regionalseas40/KeyIssues/MarineLitter/tabid/132275/Default.aspx



https://www.netflix.com/it/title/80164032

WHAT ?

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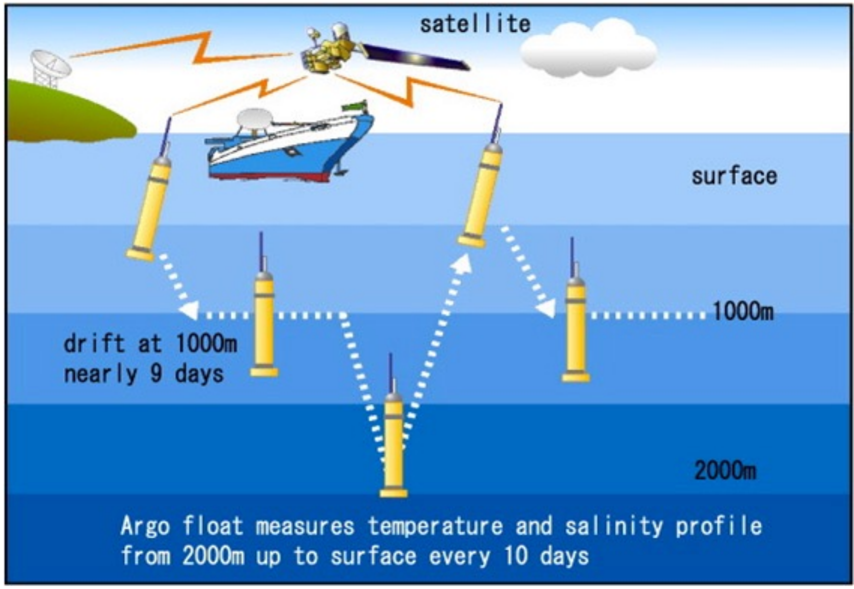
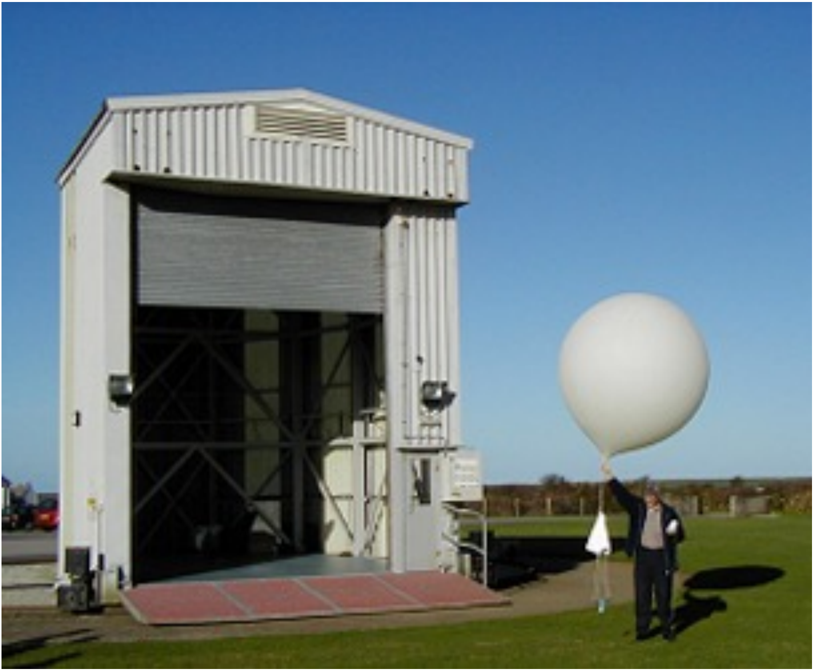
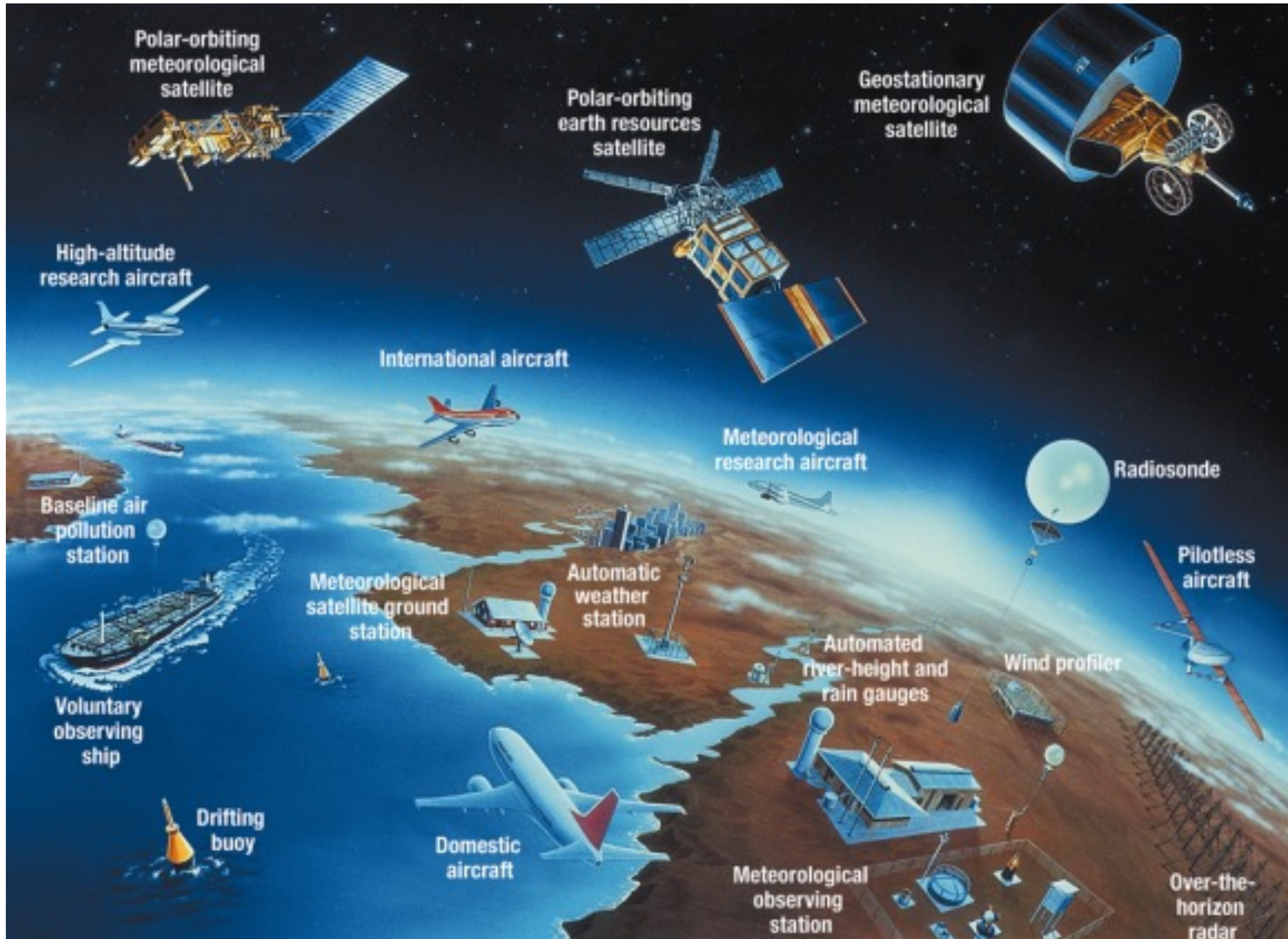


http://www.jamstec.go.jp/e/about/press_release/20160129/img/image002.jpg




NATIONAL SEVERE STORMS LABORATORY
NORMAN, OK


1703


Polar-orbiting meteorological satellite
Polar-orbiting earth resources satellite
Geostationary meteorological satellite
High-altitude research aircraft
International aircraft
Meteorological research aircraft
Radiosonde
Baseline air pollution station
Meteorological satellite ground station
Automatic weather station
Pilotless aircraft
Automated river-height and rain gauges
Wind profiler
Voluntary observing ship
Drifting buoy
Domestic aircraft
Meteorological observing station
Over-the-horizon radar

http://www.dii.unina.it/images/laboratori/navale/3.jpg

Doklady Physics, Vol. 49, No. 2, 2004, pp. 127–131. Translated from Doklady Akademii Nauk, Vol. 394, No. 5, 2004, pp. 626–630.

MECHANICS

Analytical Solutions of Navier–Stokes Equations for Axisymmetric and Plane Flows of a Viscous Incompressible Fluid

A. V. Shcheprov

Presented by Academician A.A. Petrov September 4, 2003

Received September 8, 2003

Solving the Navier–Stokes equations with Cauchy data on a certain line, one can obtain, as in a particular case [1], systems of vortex structures in a fluid that are unknown to date. These equations for axisymmetric flows have singularities on the axis. The Kovalevskaya theorem for analytic data on the axis is generalized. In addition, the size of the domain where the solution is analytic is estimated, and an example is given. Similar analysis is also made for the plane case, when the Kovalevskaya theorem is valid in its original form, and the size of the domain where the solution is analytic is estimated.

First, we consider axisymmetric flows. The current function $\varphi(x, r)$ of the cylindrical coordinates (x, r) is introduced as

$$d\varphi = r v_x dr - r v_r dx,$$

where v_x and v_r are axial and radial velocity components multiplied by the Reynolds number, respectively. In this work, flow curl around the symmetry axis is limited by the potential dependence, when the azimuthal velocity component has the form $V = \frac{W}{r}$, where W is an arbitrary constant. In terms of the differential operator

$$L = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial r^2} - \frac{1}{r}\frac{\partial}{\partial r}$$

and auxiliary function $\sigma(x, r)$, the Navier–Stokes equation is represented in the form

$$L\varphi = \sigma, \quad L\sigma = \frac{1}{r}\left(\frac{\partial\varphi}{\partial r}\frac{\partial\sigma}{\partial x} - \frac{\partial\varphi}{\partial x}\frac{\partial\sigma}{\partial r}\right) + \frac{2\sigma}{r^2}\frac{\partial\varphi}{\partial x}. \quad (1)$$

A solution to system (1) is sought in the form of the series

$$\varphi(x, r) = \sum_{m=0}^{\infty} f_m(x) r^m, \quad \sigma(x, r) = \sum_{m=0}^{\infty} \omega_m(x) r^m. \quad (2)$$

The substitution of expansions (2) into Eqs. (1) gives

$$\sum_{m=0}^{\infty} [f''_m r^m + m(m-2) f_m r^{m-2}] = \sum_{m=0}^{\infty} \omega_m r^m,$$
$$\sum_{m=0}^{\infty} [\omega''_m r^m + m(m-2)\omega_m r^{m-2}] \quad (3)$$
$$= \sum_{k,l=0}^{\infty} [(2-l) f'_k \omega_l + k f_k \omega'_l] r^{k+l-2},$$

where prime means the derivative of a function with respect to its argument.

For analytic solutions, $\varphi = \frac{\partial\varphi}{\partial r} = 0$ on the symmetry axis, and it is necessary that $f_0 = f_1 \equiv 0$. Equating the sums of coefficients of the same r powers in Eqs. (3), we arrive at the relations $\omega_0 = 0$ and $f_l = \omega_l \equiv 0$ for $l = 2n - 1$, $n = 1, 2, \ldots$. According to Eqs. (3), the coefficients f_{2n} and ω_{2n} of even r powers in series (2) for $n \geq 2$ satisfy the chain of equations

$$f_{2n} = \frac{1}{4n(n-1)}(\omega_{2n-2} - f''_{2n-2}), \quad (4)$$
$$\omega_{2n} = \frac{1}{2n(n-1)}\sum_{k=1}^{n-1} [(k+1-n) f'_{2k}\omega_{2n-2k} + k f_{2k}\omega'_{2n-2k}] - \frac{1}{4n(n-1)}\omega''_{2n-2}.$$

In this case, the functions $f_2(x)$ and $\omega_2(x)$ can be chosen arbitrarily. System (4) for given f_2 and ω_2 functions,

Computer Center, Russian Academy of Sciences, ul. Vavilova 40, Moscow, 117333 Russia

http://tech.mit.edu/V129/N48/graphics/obama-0.jpg

$$\nabla \cdot \mathbf{u} = 0$$

$$\rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) = -\nabla p + \mu \nabla^2 \mathbf{u}$$

http://hpc-asia.com/real-hardware-including-prototype-hpc-server-showed-off-by-open-power/

CLICK !

https://earth.nullschool.net/


天河
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BIG
DATA
INFORMATION
STORAGE
LARGE
SOFTWARE
SAN
NAS
SETS
MILLION
SCIENCE
FUTURE
DEVELOPMENT
TECHNOLOGY
VOLUME
PROCESS
GOVERNMENT
TECHNOLOGIES
MANAGEMENT
PROCESSING
DATABASES
SIZE
EXABYTES
PETABYTES
ANALYSIS
RESEARCH
SEARCH
INTERNET
LEARNING
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BASED
NEW
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ECONOMIC
TERABYTES
SOCIAL
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REPLICATION
HANDLE
SOURCES
CHALLENGES
LIMITS
COMPLEX
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DEFINITION
BETWEEN
EFFECTIVE
USING
STATISTICS
VISUALIZATION
DETERMINE
WELL
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SIMULATIONS
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USERS
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APPLICATIONS
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PRIVACY
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IMPLEMENTATION
BECOMES
SECOND
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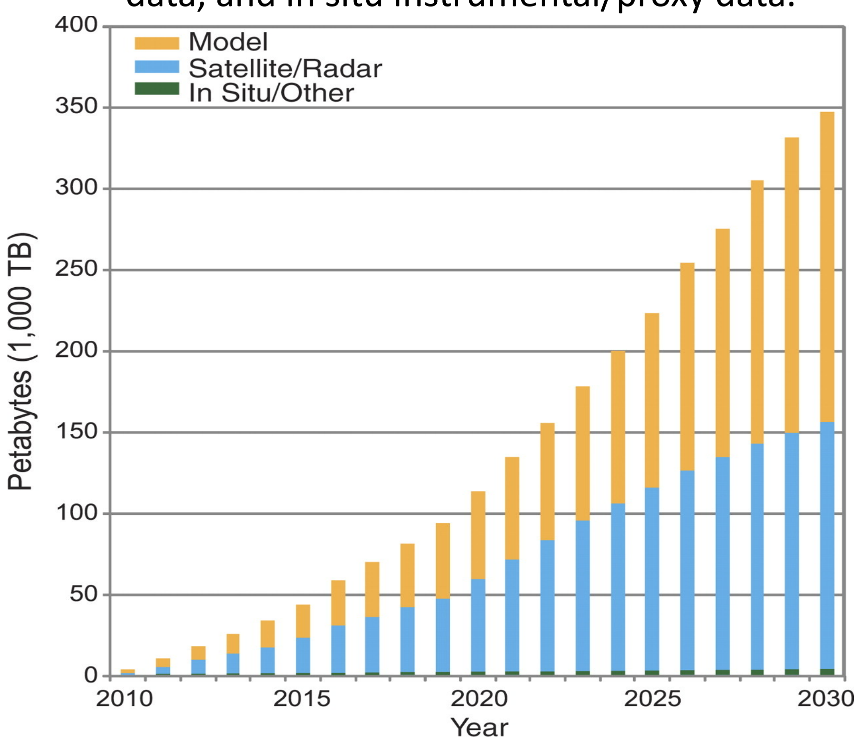
INTELLIGENCE
APPROACHES
PROCESSES
FLOW
PARADIGM
FUNDING
INSIGHT
TOOLS
CENTER
RECORDS
COST
DISTRIBUTED
PER
PROJECT
RELEVANT
ANNUAL
NOW
USED
VARIETY
WOULD
MARKET
SENSOR
RELATED
TIME

IF you like numerical models, you have to consider also some related technological challenges: HPC fast development, BigData, energy efficiency

The volume of **worldwide climate data** is expanding rapidly, creating challenges for both physical archiving and sharing, as well as for ease of access and finding what's needed, particularly if you are not a climate scientist. The figure shows the projected increase in global climate data holdings for climate models, remotely sensed data, and in situ instrumental/proxy data.



J. T. Overpeck et al. Science 2011;331:700-702

Science AAAS

ROADMAP TO EXASCALE

Systems	2009	2011	2015	2018
System Peak Flops/s	2 Peta	20 Peta	100-200 Peta	1 Exa
System Memory	0.3 PB	1 PB	5 PB	10 PB
Node Performance	125 GF	200 GF	400 GF	1-10 TF
Node Memory BW	25 GB/s	40 GB/s	100 GB/s	200-400 GB/s
Node Concurrency	12	32	0(100)	0(1000)
Interconnect BW	1.5 GB/s	10 GB/s	25 GB/s	50 GB/s
System Size (Nodes)	18,700	100,000	500,000	0(Million)
Total Concurrency	225,000	3 Million	50 Million	0(Billion)
Storage	15 PB	30 PB	150 PB	300 PB
I/O	0.2 TB/s	2 TB/s	10 TB/s	20 TB/s
MTTI	Days	Days	Days	0(1Day)
Power	6 MW	~10 MW	~10 MW	~20 MW

- FLOPS vs IOPS = HPC is today compute-centric → evolution towards **data-centric**
- scientific computing needs **data accessibility** rather than computing speed + energy sustainability

computing 1 calculation ≈ 1 picojoule	**moving 1 calculation ≈ 100 picojoule**

IDC Direction, 2013

- GEOPHYSICAL: ROTATION AND STRATIFICATION
- FLUID: GAS (ATMOSPHERE) AND LIQUID (OCEAN)
- DYNAMICS: EVOLUTION OF A FLUID UNDER THE INFLUENCE OF BODY FORCES (gravity) AND SURFACE FORCES (friction)
- GFD treats the physical aspects of the dynamics of fluids on Earth-like planets
- only LARGE-SCALE MOTIONS
- SIMILARITY exists among different systems e.g. *Great Red Spot*
- **WHAT** does GFD deal with? ATMOSPHERE VARIABILITY (weather and climate) and OCEAN VARIABILITY (waves, eddies, currents)… but also: dynamo effects in the Earth interior, vortices on planets, convection in stars …
- **WHY** study GFD? Importance for Life, Nature, Economy, Energy…
- **HOW** to tackle with GFD? Observations AND mathematical/physical description of phenomena by means of analytical theory, numerical models, laboratory experiments → comparison with measurements

- **ROTATION** AND **STRATIFICATION** => GFD ≠ FD
- **Rotation** introduces 2 acceleration terms acting on fluid parcels: Coriolis & centrifugal
- Coriolis will introduce «*vertical rigidity*» in rapidly rotating homogeneous fluids
- in Atm/Oc large-scale motions rotation is not fast enough and density is not uniform to mask other processes BUT motions have a tendency to manifest columnar behaviour [ex. currents in Western North Atlantic extend over 4000 m without significant change in amplitude and direction]
- **Stratification** is due to density variations in fluids
- gravitational force tends to lower the heaviest and raise the lightest
- in equilibrium, fluids are stably stratified = vertically stacked horizontal layers
- motions disturbances destroy stability and gravity tends to restore equilibrium
- small perturbations => internal waves (3d analogous of surface waves)
- large perturbations => mixing and convection (ex. general circulation)

• SCALES OF MOTION help to understand whether a physical process is dynamically important in any particular situation

• SCALES OF MOTION = dimensional quantities expressing the overall magnitude of the variables under consideration → esitmates or orders of magnitude (L, T, U, ρ_0, $\Delta\rho$, H)

• Ex:

- ➢ L = 300 km (~3° lat),
- ➢ T = 2×10^5 s (~2 days),
- ➢ U = 70 km/h (H5)

• Selection of T reflects the particular choice of physical processes studied in the system

• «*Scales selection is more an art than a science*»

• Choose relevant quantities, simple to establish

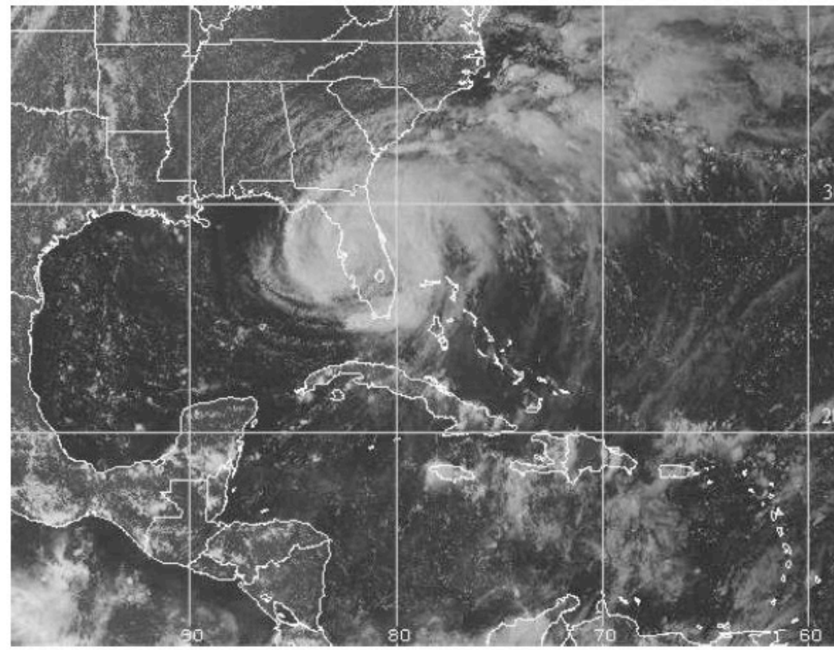


Figure 1-1 Hurricane Frances during her passage over Florida on 5 September 2004. The diameter of the storm is about 830 km and its top wind speed approaches 200 km per hour. (Courtesy of NOAA, Department of Commerce, Washington, D.C.)

- SCALES OF MOTION :
- L → space
- T → time
- U → velocity
- ρ_0 → average density
- $\Delta\rho$ → range of density variations → different role in ATM / OC
- H → height over which $\Delta\rho$ occurs

- Usually H ~ total depth of the fluid, since GFD flows are generally bounded in the vertical => H chosen as the smaller between the total depth and height over which $\Delta\rho$ occurs