

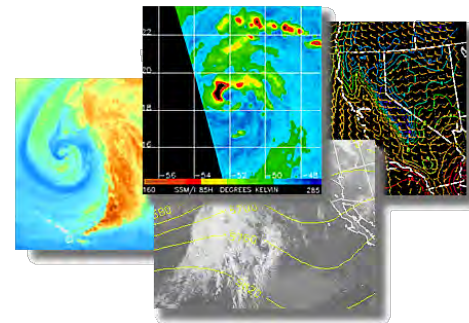
SATELLITE AND RADAR REMOTE SENSING OF INTENSE ATMOSPHERIC PRECIPITATION

Frank S. MARZANO

**Dip. Ingegneria dell'Informazione
Sapienza Università di Roma
&**

**Centro di Eccellenza CETEMPS
Università dell'Aquila**

**E-mail: frank.marzano@uniroma1.it
*IEEE Fellow, RMetS Fellow***



15 OCTOBER 2015

FLOOD in the BENEVENTANO

LA STAMPA CRONACHE

SEGUICI SU   ACCEDI 

SEZIONI

Cerca...

Il bambino e l'ostia spezzata per il papà risposato: il racconto commuove il

A Roma deraglia treno della metro, passeggeri a piedi lungo i binari

A Bologna cede il controsoffitto in tribunale, ferita una donna

Frane e allagamenti, due morti a Benevento

Frane e allagamenti, due morti a Benevento

Esonda il Calore: città allagata. Appello del sindaco. Danni anche in Sicilia e Puglia



Alcune auto rimaste sommerse per l'esondazione per oltre due metri del fiume Calore a Benevento

Condividi   

ISCRIVITI  

15/10/2015

Maltempo in Campania: a Benevento esonda il fiume Calore

Sei in: HOME > ITALIA MONDO > MALTEMPO. ALLUVIONE A BENEVENTO, DUE...

Maltempo. Alluvione a Benevento, due morti

Esondato il fiume Calore, la città è allagata. Ieri tre vittime nel centro Italia. Continua la perturbazione sul centro-sud Italia, nubifragi in Sicilia e in Puglia

R.I.

NAPOLI

Cerca nel sito

METEO

Home

Cronaca

Sport

Foto

Ristoranti

Annunci Locali

Cambia Edizione

Video

Benevento, straripa il fiume Calore. Due morti. La Regione chiede lo stato di calamità



Foto Riccardo Siano

Al lavoro l'esercito. Scuole chiuse. Il sindaco: "Città martoriata. Nessuno ci ha avvertiti". Emergenza maltempo in tutta la Campania, 300 operazioni dei vigili del fuoco. Massima allerta fino a domani pomeriggio

FLOOD in the BENEVENTANO

The same story



2 OTTOBRE
1949

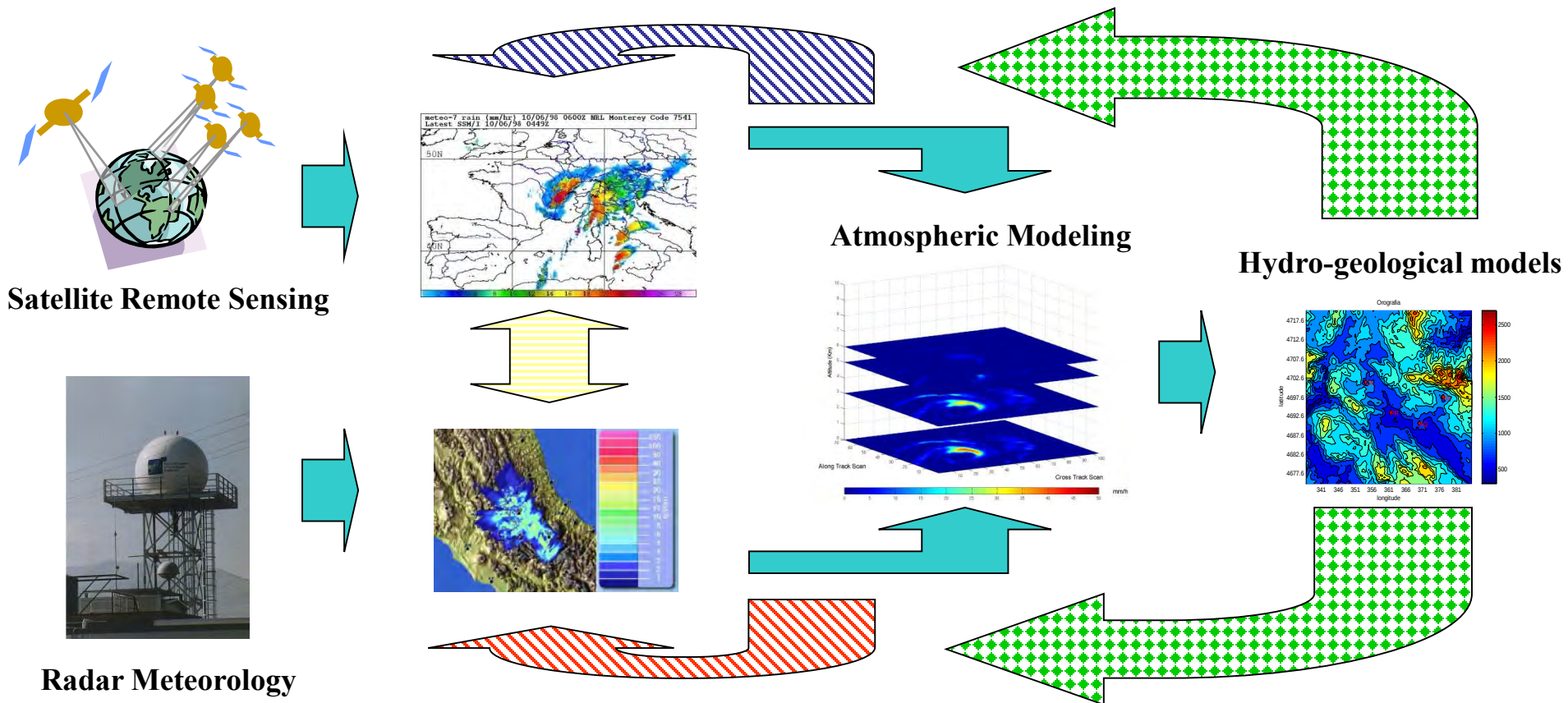


15 OTTOBRE
2015



WHAT TO DO?

Conceptual diagram



PRESENTATION

Skeleton

RAINFALL REMOTE SENSING

- **Principles of electromagnetic remote sensing**
- **Inverse and forward problems**
- **Precipitating clouds**

SATELLITE METEOROLOGY

- **Principles of satellite remote sensing**
- **Research aspects on modeling and inversion**

RADAR METEOROLOGY

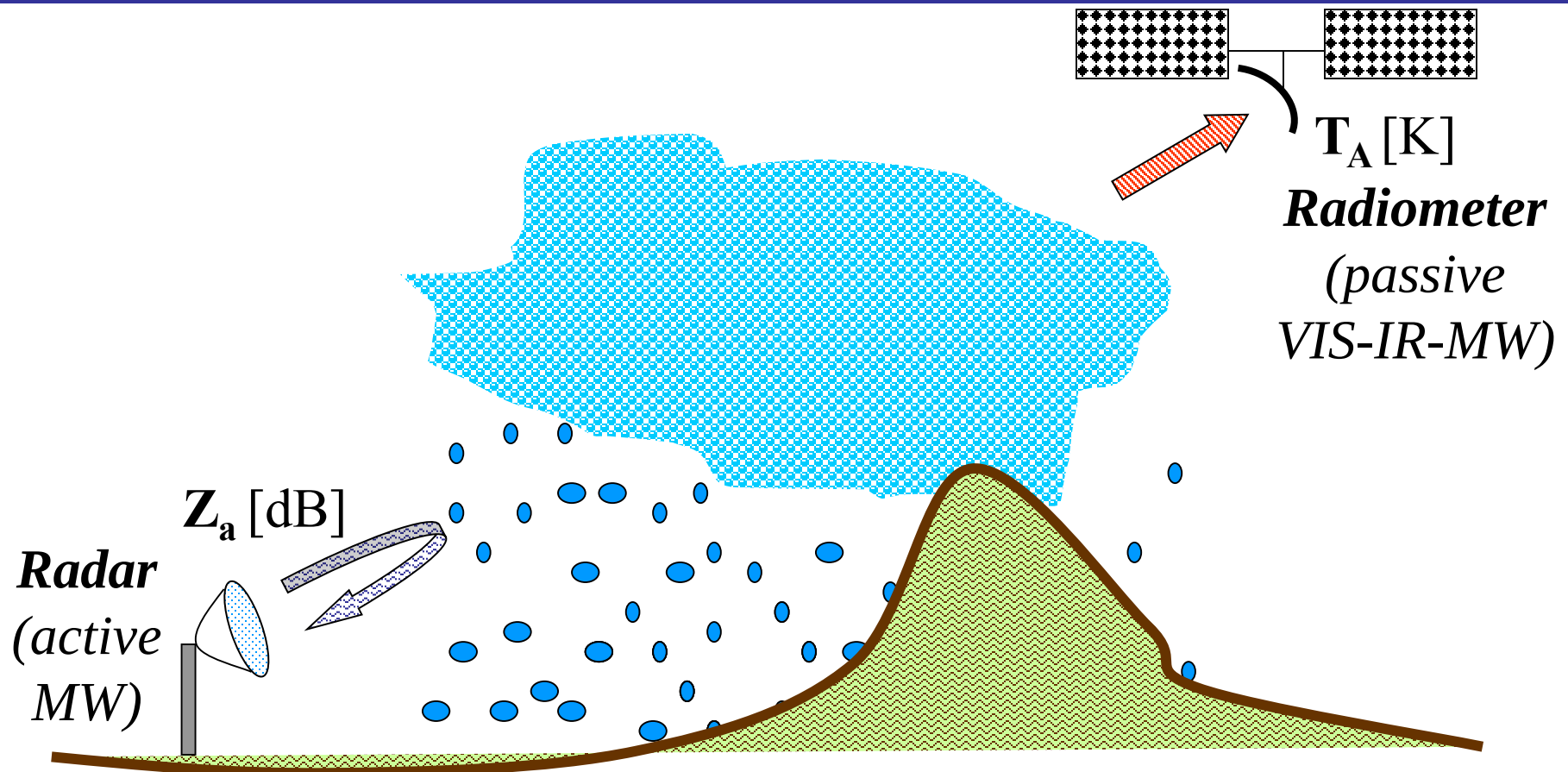
- **Principles of weather radar meteorology**
- **Research aspects in complex orography**

PRECIPITATION EXTREMES AND CLIMATOLOGY

- **Extreme case study analysis**
- **Reanalysis and trends**

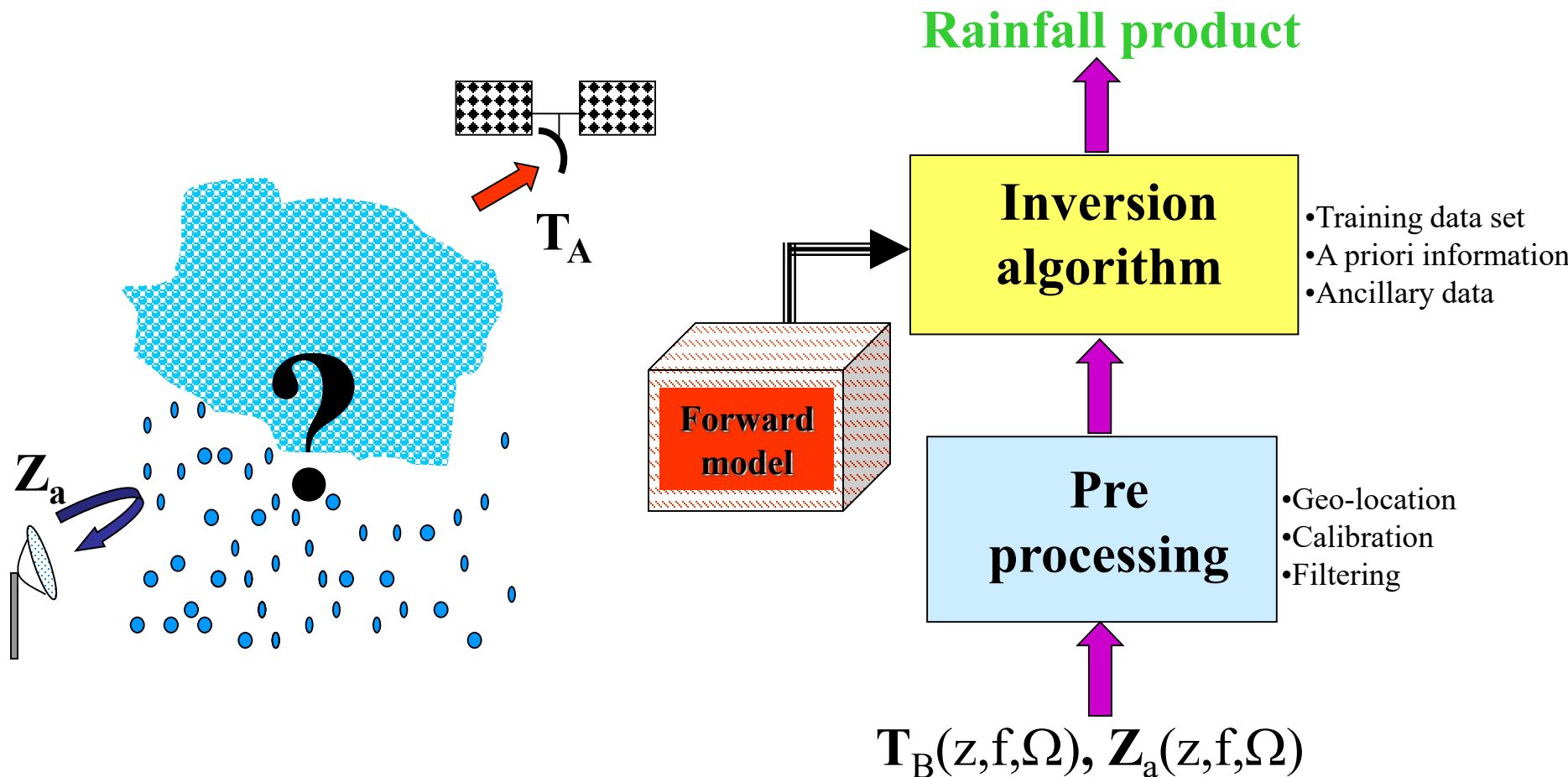
RAINFALL REMOTE SENSING

Principles



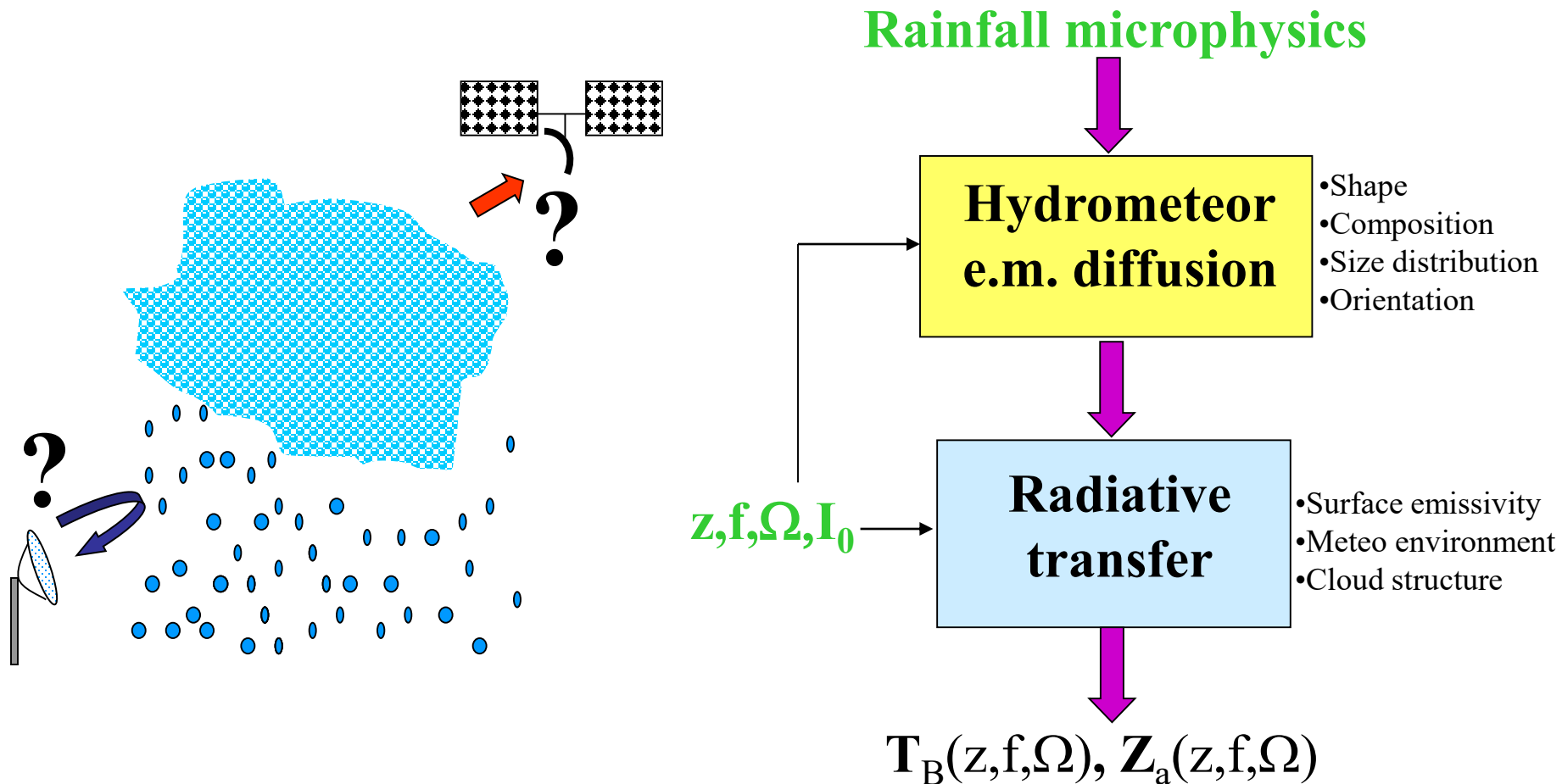
RAINFALL REMOTE SENSING

Inverse problem



RAINFALL REMOTE SENSING

Forward problem



PRECIPITATING CLOUDS

Role and characteristics

- **Hydrological cycle and budgets**
 - latent heat release and evaporation
 - Earth-radiation, sea-salinity and soil-humidity
- **Stratiform and cumuliform**
 - Nimbostratus (↗ melting process)
 - Cumulonimbus (↗ convective process)
- **Time and space scales of rain**
 - depending on cloud genus and system
 - micro, meso and macro spatial scales

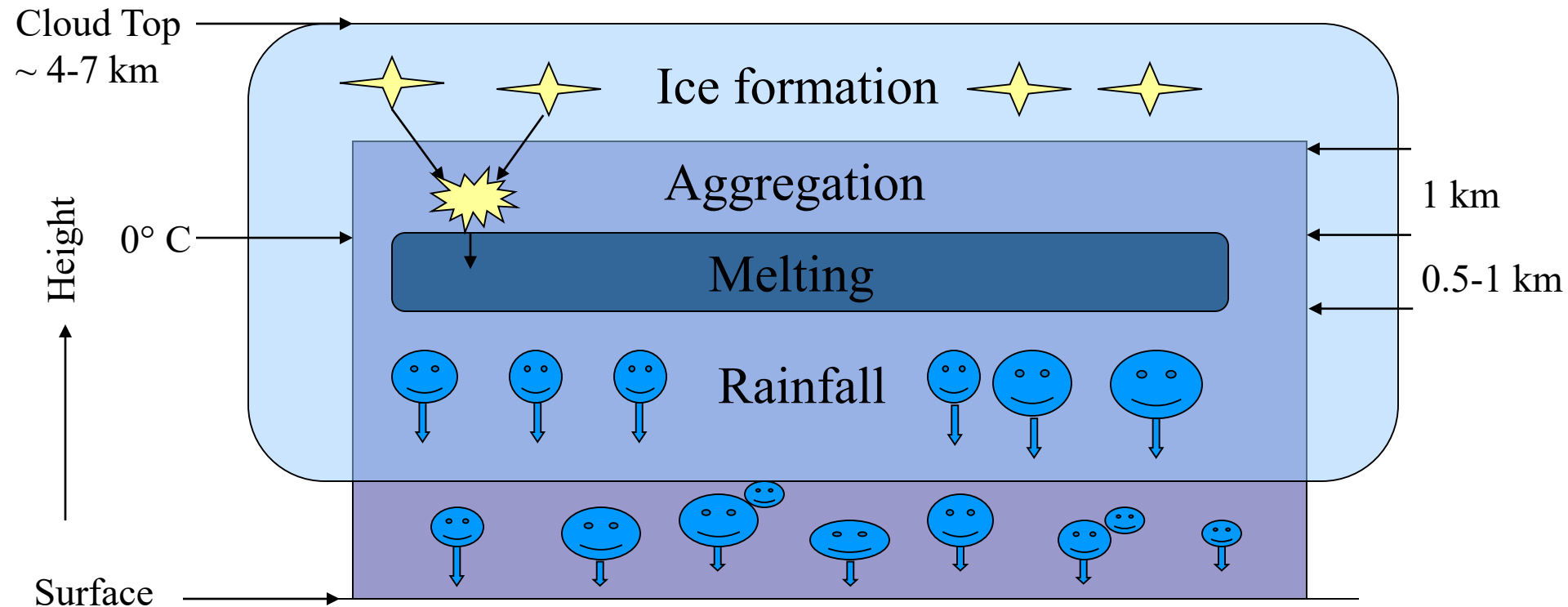
PRECIPITATING CLOUDS

Time and space scales

		CHARACTERISTIC TIME						
		1 day- 1 month	1 hour – 1 day	1 hour – 1 minute				
H O R I Z O N T A L S C A L E	200 - 2000 km	- <i>Fronts</i> - <i>Hurricanes</i> (tens of days)			Meso- α scale			
	20 - 200 km				- <i>Squall lines</i> - <i>Cloud clusters</i> - <i>Mountain and lake disturbances</i> (2 hours to 1 day)			Meso- β scale
	2 - 20 km	- <i>Thunderstorms</i> (tens of minutes to hours)						Meso- γ scale
	0.2 - 2 km				- <i>Tornadoes</i> - <i>Deep convection</i> (few minutes to 1 hour)			Micro- α scale
	0.02 - 0.2 km							- <i>Thermals</i> (few minutes) - <i>Plumes</i> - <i>Turbulence</i> (less than a few minutes)
	0.001 - 0.02 km				Micro- γ scale			

PRECIPITATING CLOUDS

Stratiform process

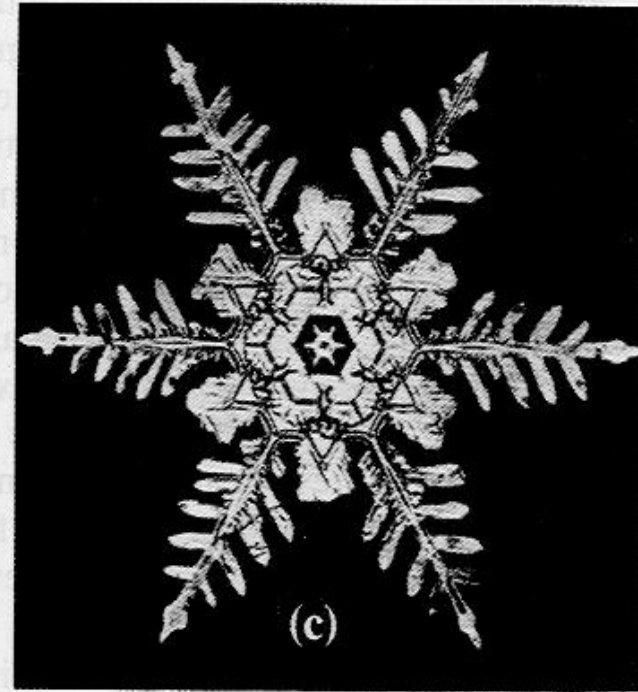
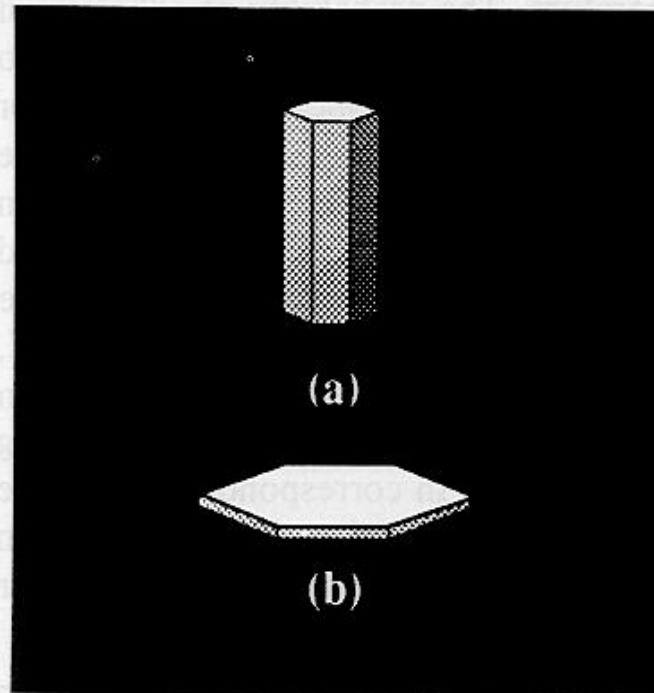


PRECIPITATING CLOUDS

Ice crystals

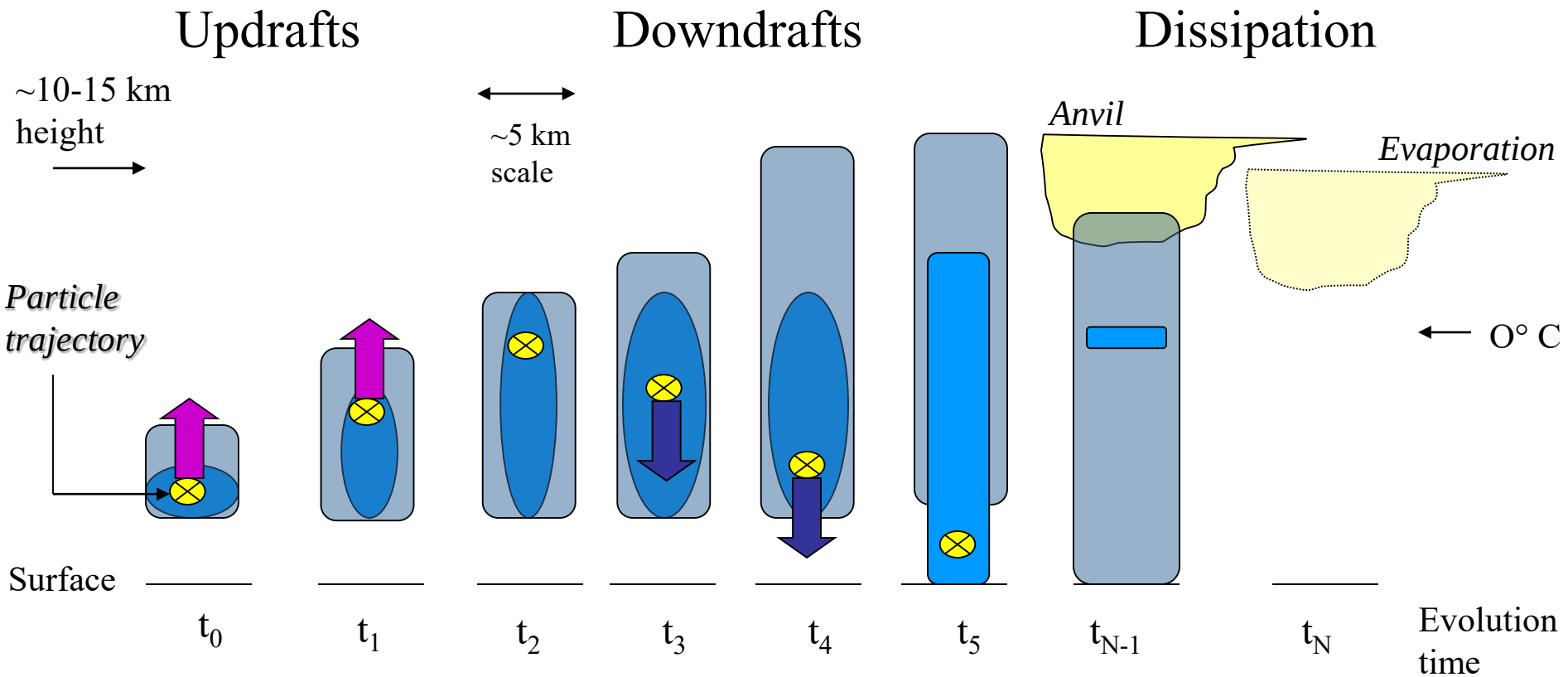
As for droplets (condensation/evaporation), ice crystals can initially grow by *vapor deposition* and evaporate by *sublimation*. The probability of presence of ice particles in a cloud increases with decreasing temperature below zero. At -10°C the probability to find ice is around 50%, while at -20°C it raises to 95%.

Main ice crystal shapes are: (a) columnar or prismatic, (b) disc, (c) dendrite



PRECIPITATING CLOUDS

Convective process



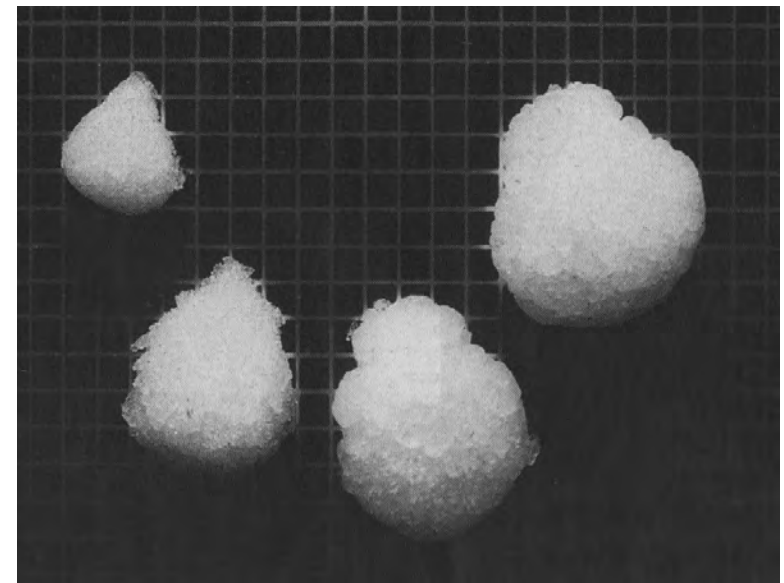
PRECIPITATING CLOUDS

Graupel particles

GRAUPEL FORMATION BY RIMING

- Ice crystals fall through supercooled cloud droplets
- Supercooled droplets, that hit ice crystals, freeze to it
- Eventually the frozen droplet can hide the original shape
- Due to strong updrafts, hailstones can form

Natural graupels (boxes are 2 mm on a side)



	Rimed crystal	Hexagonal graupel	Conelike graupel
Without tumbling (rotation)	Plane crystal	a ₁	a ₂
		b ₁	b ₂
		c ₁	c ₂
	Columnar crystal	d ₁	d ₂
	Radiating assemblage of plane branches	e ₁	e ₂
	Frozen drop	f ₁	f ₂
With tumbling (rotation)	Rimed crystal		Lump graupel
	Columnar crystal	g ₁	g ₂
	Radiating assemblage of plane branches	h ₁	h ₂
	Frozen drop	i ₁	i ₂

PRESENTATION

Skeleton

RAINFALL REMOTE SENSING

- Principles of electromagnetic remote sensing
- Inverse and forward problems
- Precipitating clouds

SATELLITE METEOROLOGY

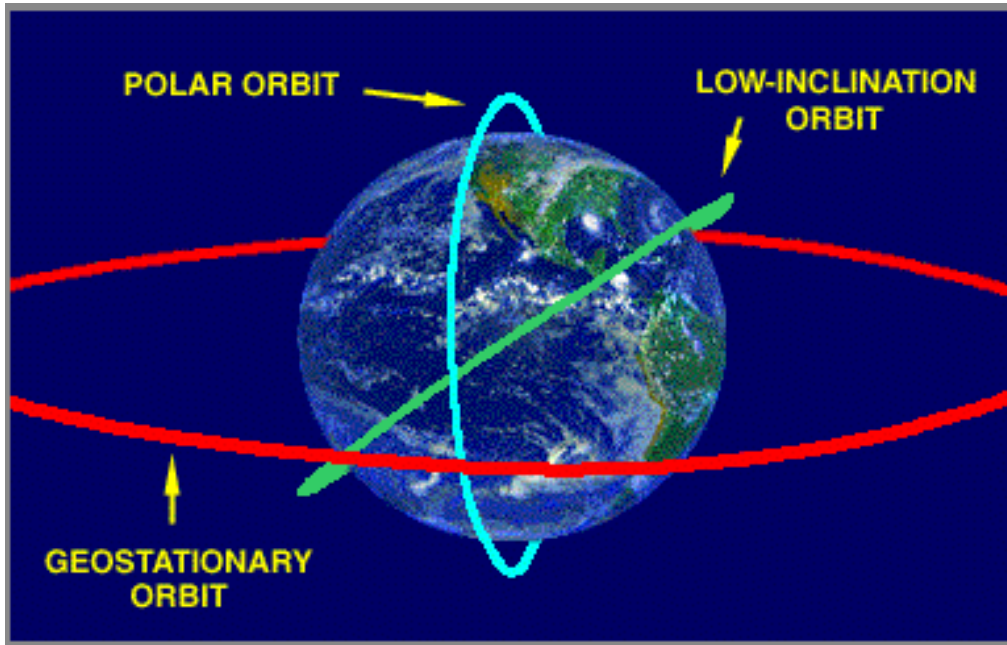
- Principles of satellite remote sensing
- Research aspects on modeling and inversion

RADAR METEOROLOGY

- Principles of weather radar meteorology
- Research aspects in complex orography

PRECIPITATION EXTREMES AND CLIMATOLOGY

- Extreme case study analysis
- Reanalysis and trends



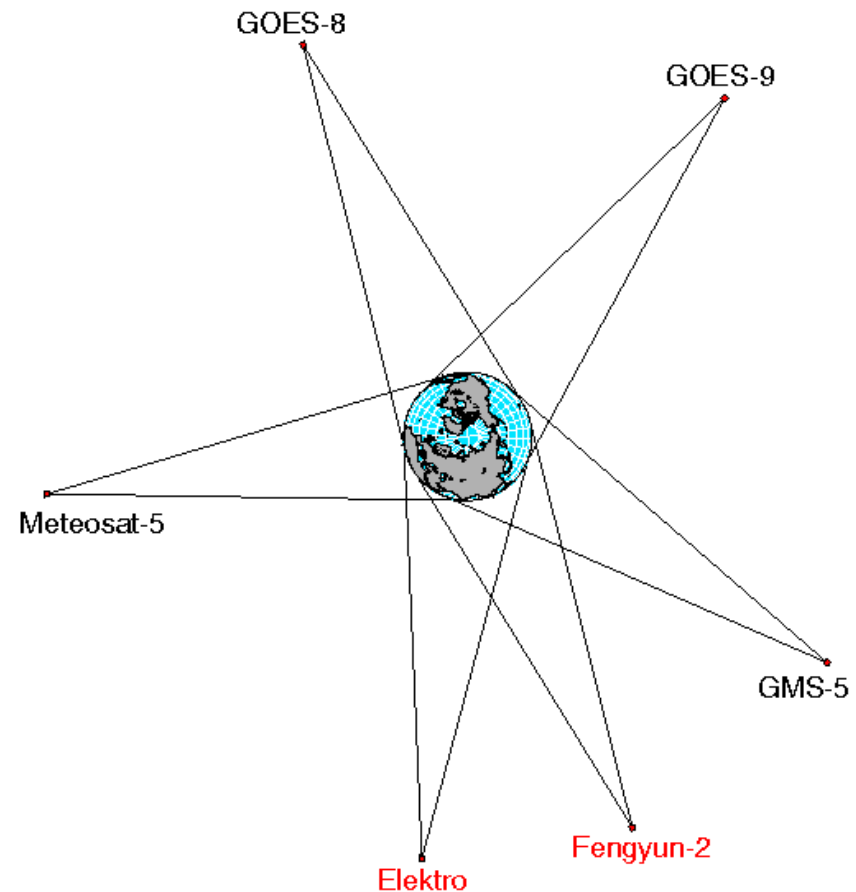
Orbit *geostazionary*: 36000 km

Orbit *near-polar*: 600-800 km

SATELLITE METEOROLOGY

Geo-stationary (GEO)

- **Orbit specifications**
 - satellite height : ~36000 km
 - revolution period: 24 hours
- **Temporal sampling**
 - high repetition
 - ⇒ every half an hour or less
- **Spatial resolution**
 - low
 - ⇒ at thermal IR band, about 5 km at mid-latitudes
 - ⇒ at MW band, more than 100 km at mid latitudes !!!
- **Coverage**
 - partial
 - ⇒ high latitude and polar regions excluded



SATELLITE METEOROLOGY

Low-Earth Orbit (LEO)

- **Orbit specifications**

- height: 600 to 1000 km
- period: ~100 minutes
- inclination: 35° to 100°

- **Temporal sampling**

- low repetition
 - ⇒ swath: 100 to 3000 km
 - ⇒ 12 hours to 26 days

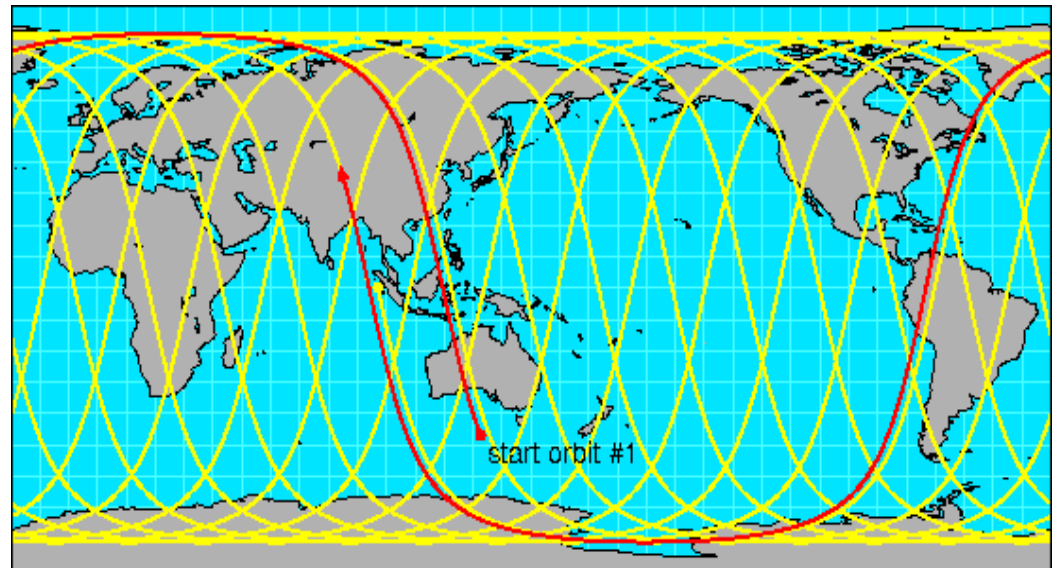
- **Spatial resolution**

- low to high
 - ⇒ VIS-IR: 10 m to 1 km
 - ⇒ MW: 5 to 60 km

- **Coverage**

- global
 - ⇒ best near poles for sun-synchronous orbit

Examples of meteorological platforms:
NOOA-K, DMSP, TRMM, ADEOS, AQUA



SATELLITE METEOROLOGY

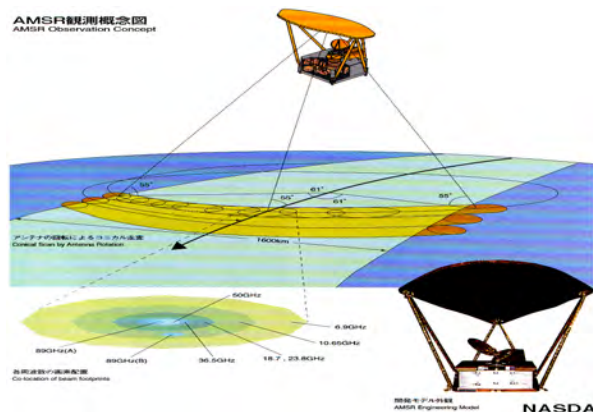
Microwave & Infrared radiom.

- **Microwave channels**

- Window frequencies
⇒ 10, 19, 37 and 85 GHz

- **MW radiometers on LEO sat.**

- Special Sensor Microwave Imager (**SSM/I**) on **DMSP** (from 1987)
- TMI on TRMM (from 1997)
- AMSU-A on NOAA-K (from 1998)

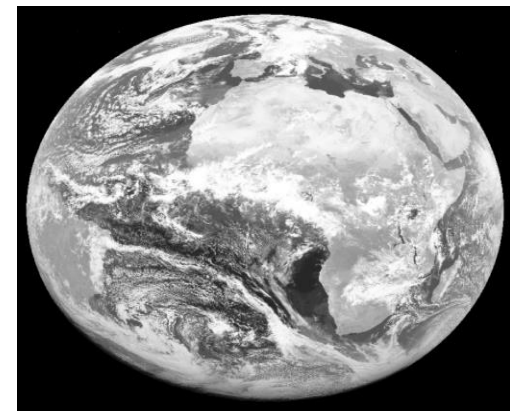


- **Infrared channels**

- Window wavelengths
⇒ 8 to 11 μm

- **IR radiometers on GEO sat.**

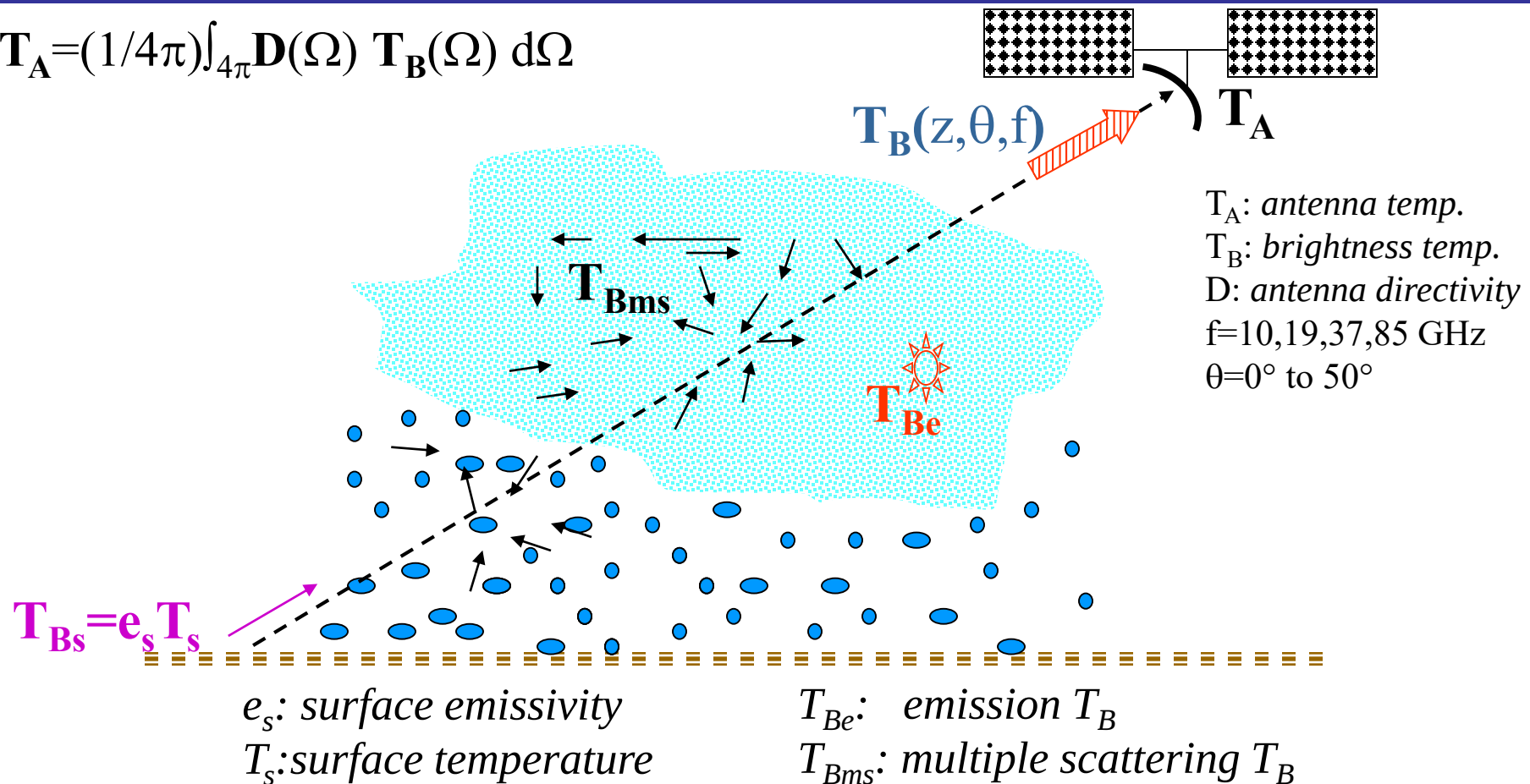
- Visible Infrared Spinning Scanning Radiometer (**VISSR**) on **METEOSAT**
- From 2002 Meteosat Second Generation (**MSG**)



SATELLITE METEOROLOGY

Radiative transfer model

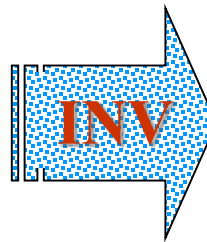
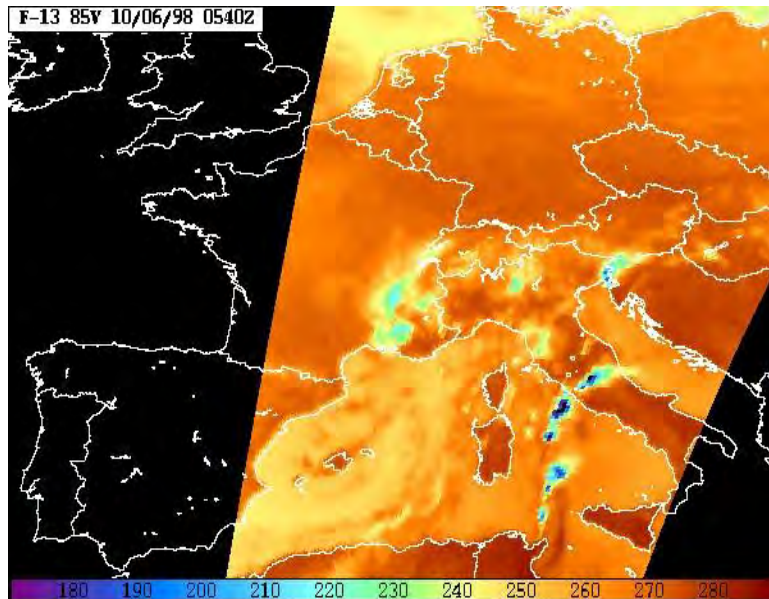
$$T_A = (1/4\pi) \int_{4\pi} D(\Omega) T_B(\Omega) d\Omega$$



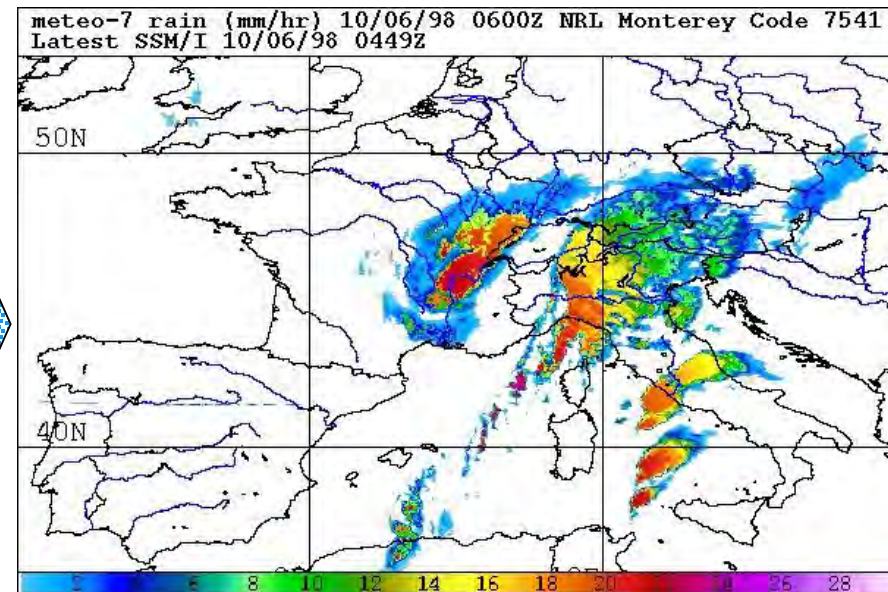
SATELLITE METEOROLOGY

Case study by MW radiometry

SSM/I 85-GHz radiance image [K]



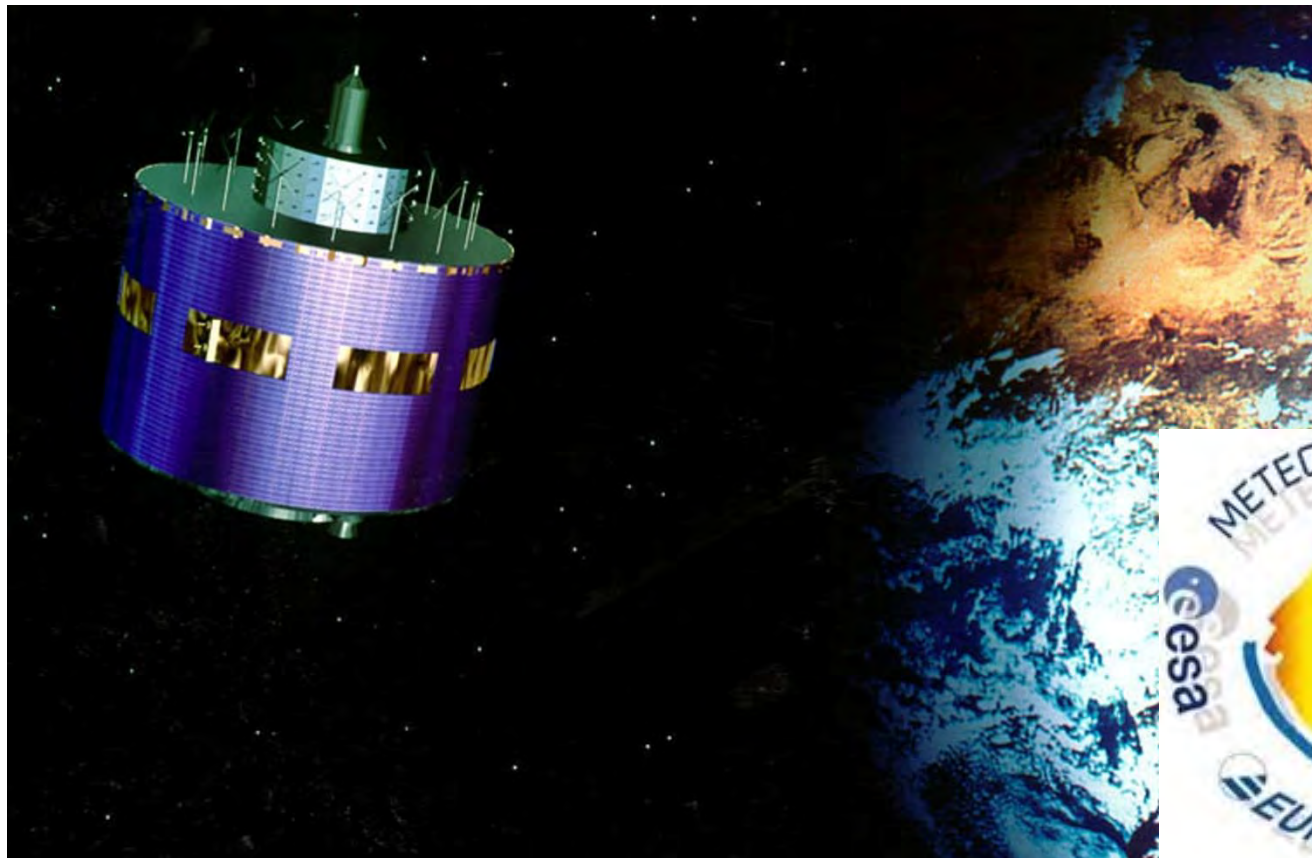
Surface rainfall rate [mm/h]



October 6, 1998

SATELLITE METEOROLOGY

Meteosat Second Generation



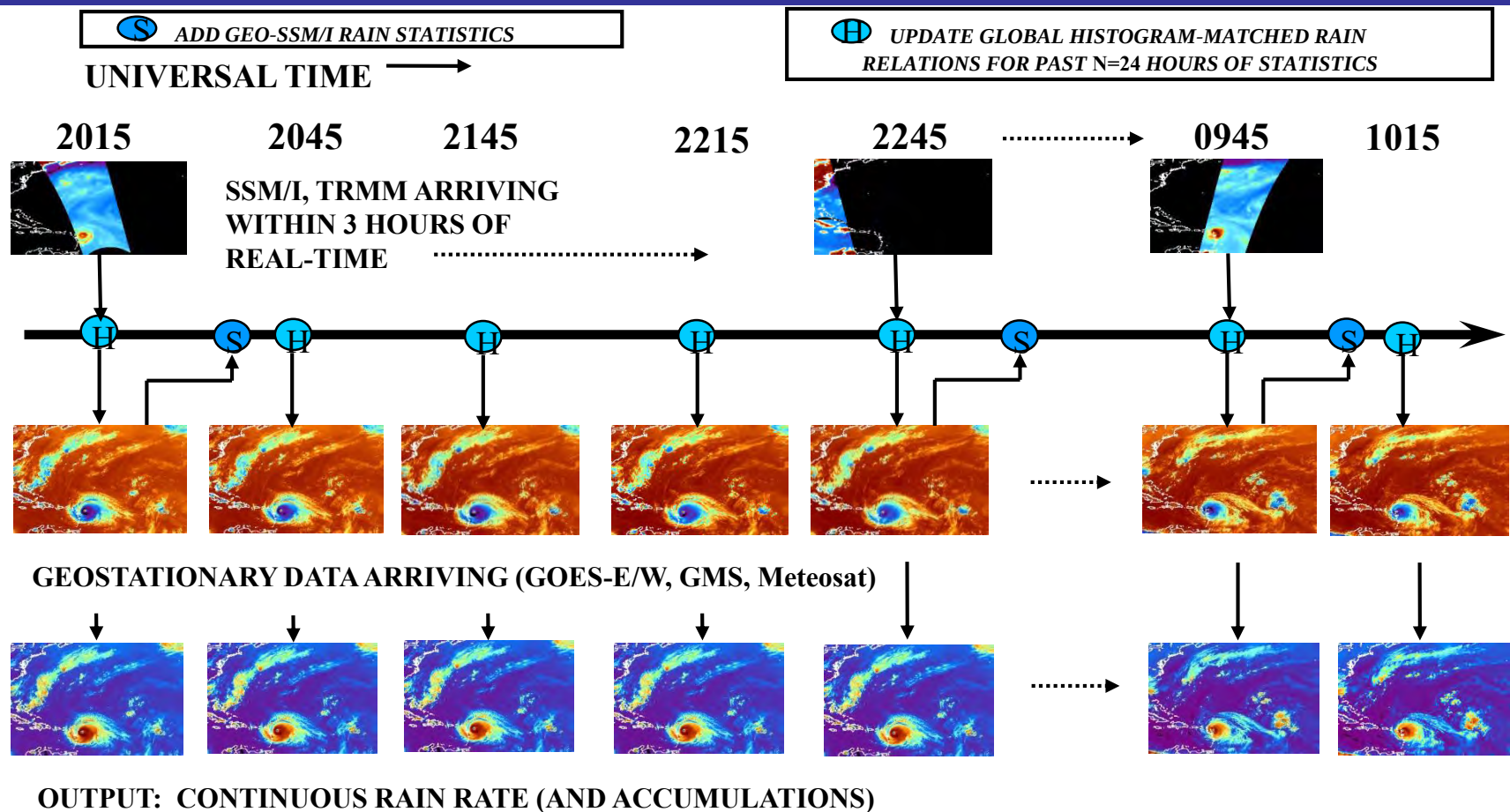
SATELLITE METEOROLOGY

Meteosat geostationary satellite

 EUMETSAT	Meteosat	MSG
Visible spectrum	0.5-0.9	0.75 um broadband 0.56-0.71 0.74-0.88 1.50-1.78
Water vapor spectrum	6.4	5.35-7.15 6.85-7.85
Infrared windows	11.5	3.48-4.36 8.30-9.10 9.80-11.80 11.0-13.0
Pseudo-sounding		9.38-9.44 12.4-14.4
Sampling distance	2.25-km (visible) 4.5-km (others)	1-km (hi-res visible) 3-km (others)
On-Earth pixel resolution	2.25-km (visible) 5-km (others)	1.4-km (hi-res visible) 4.8-km (others)
Update cycle	30-minutes	15-minutes

SATELLITE METEOROLOGY

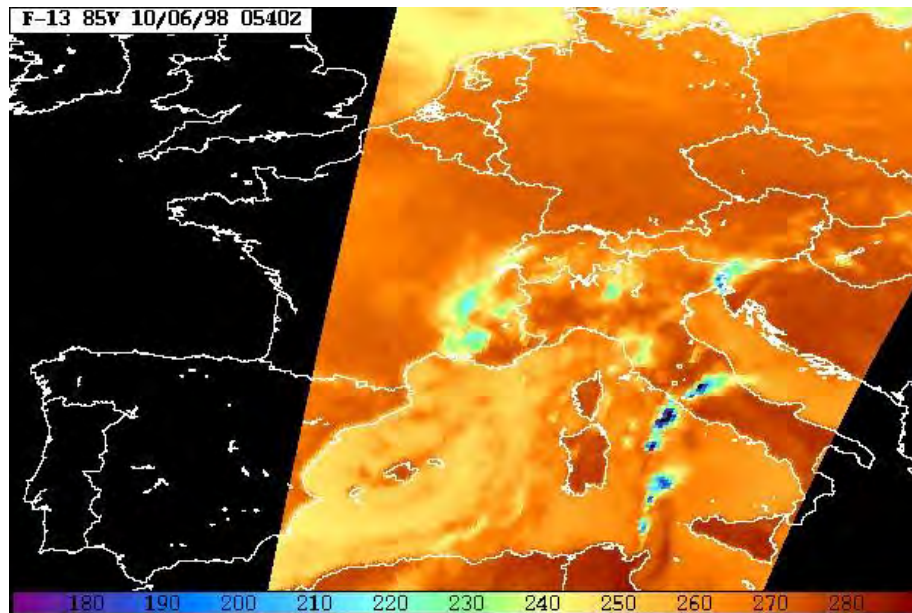
LEO and GEO integration



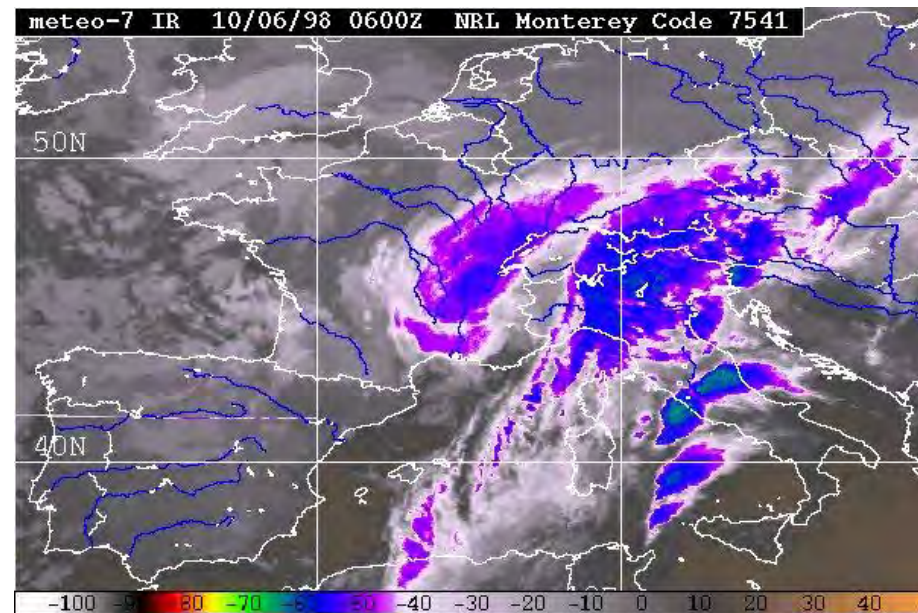
SATELLITE METEOROLOGY

Case study: images

SSM/I 85-GHz Brightness Temperature



METEOSAT 10.5- μ m Infrared Temperature

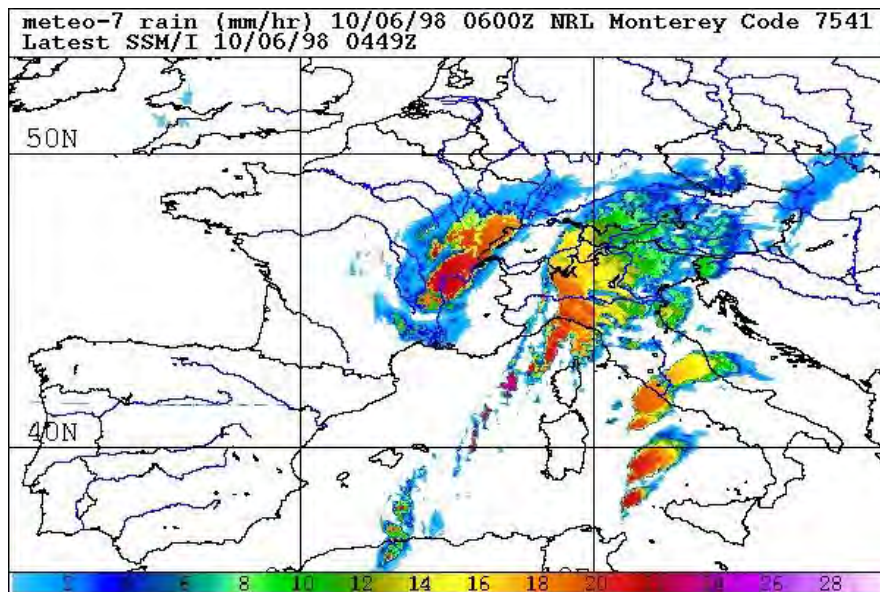


October 6, 1998

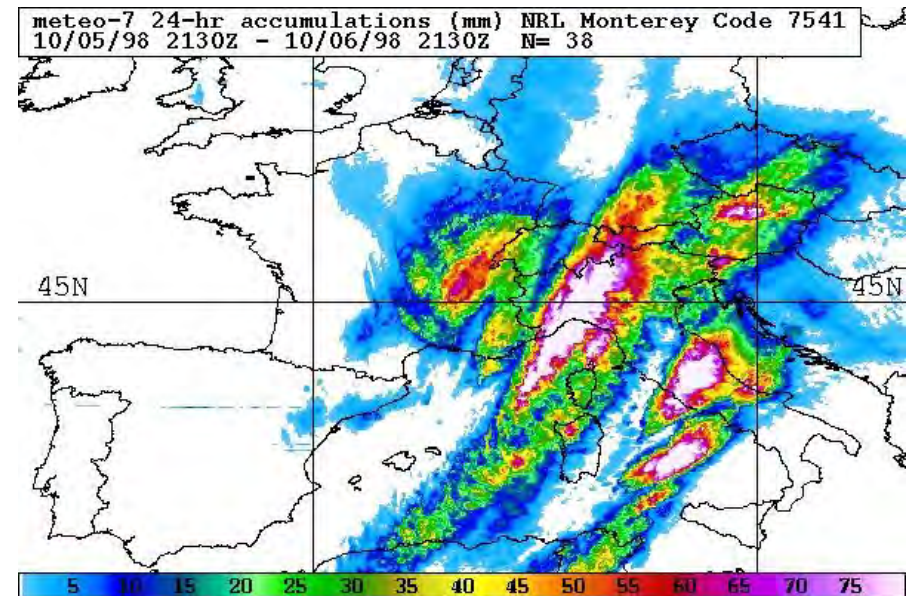
SATELLITE METEOROLOGY

Case study: products

Instantaneous rain-rate at 0600 UTC



Accumulated rain-rate in 24 hours (2130 UTC)



October 6, 1998

PRESENTATION

Skeleton

RAINFALL REMOTE SENSING

- **Principles of electromagnetic remote sensing**
- **Inverse and forward problems**
- **Precipitating clouds**

SATELLITE METEOROLOGY

- **Principles of satellite remote sensing**
- **Research aspects on modeling and inversion**

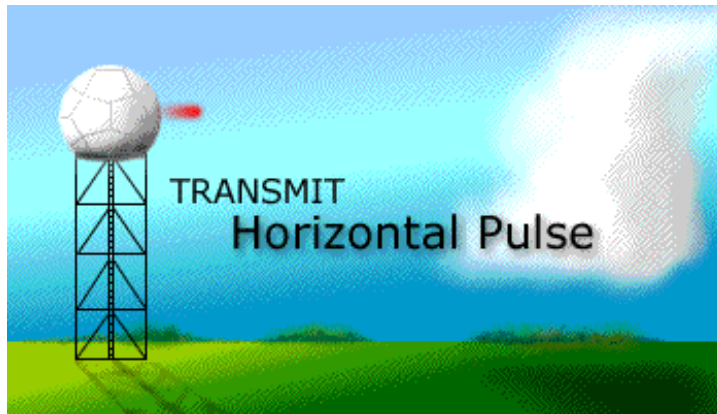
RADAR METEOROLOGY

- **Principles of weather radar meteorology**
- **Research aspects in complex orography**

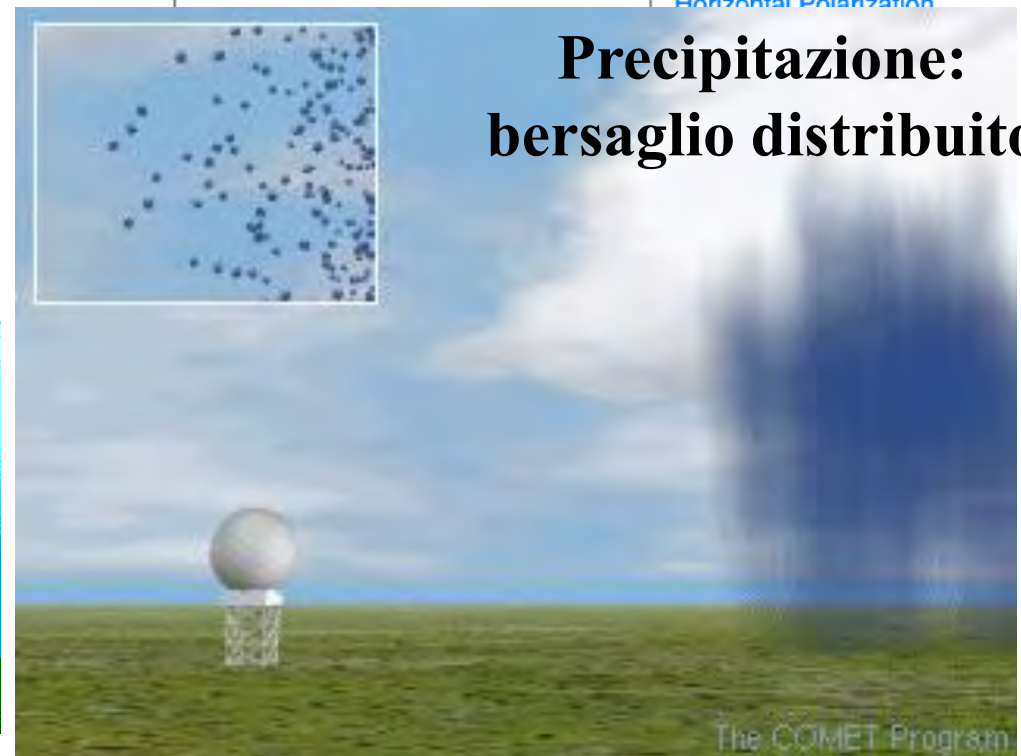
PRECIPITATION EXTREMES AND CLIMATOLOGY

- **Extreme case study analysis**
- **Reanalysis and trends**

Principio di misura di radar meteorologici



Radar polarimetrico



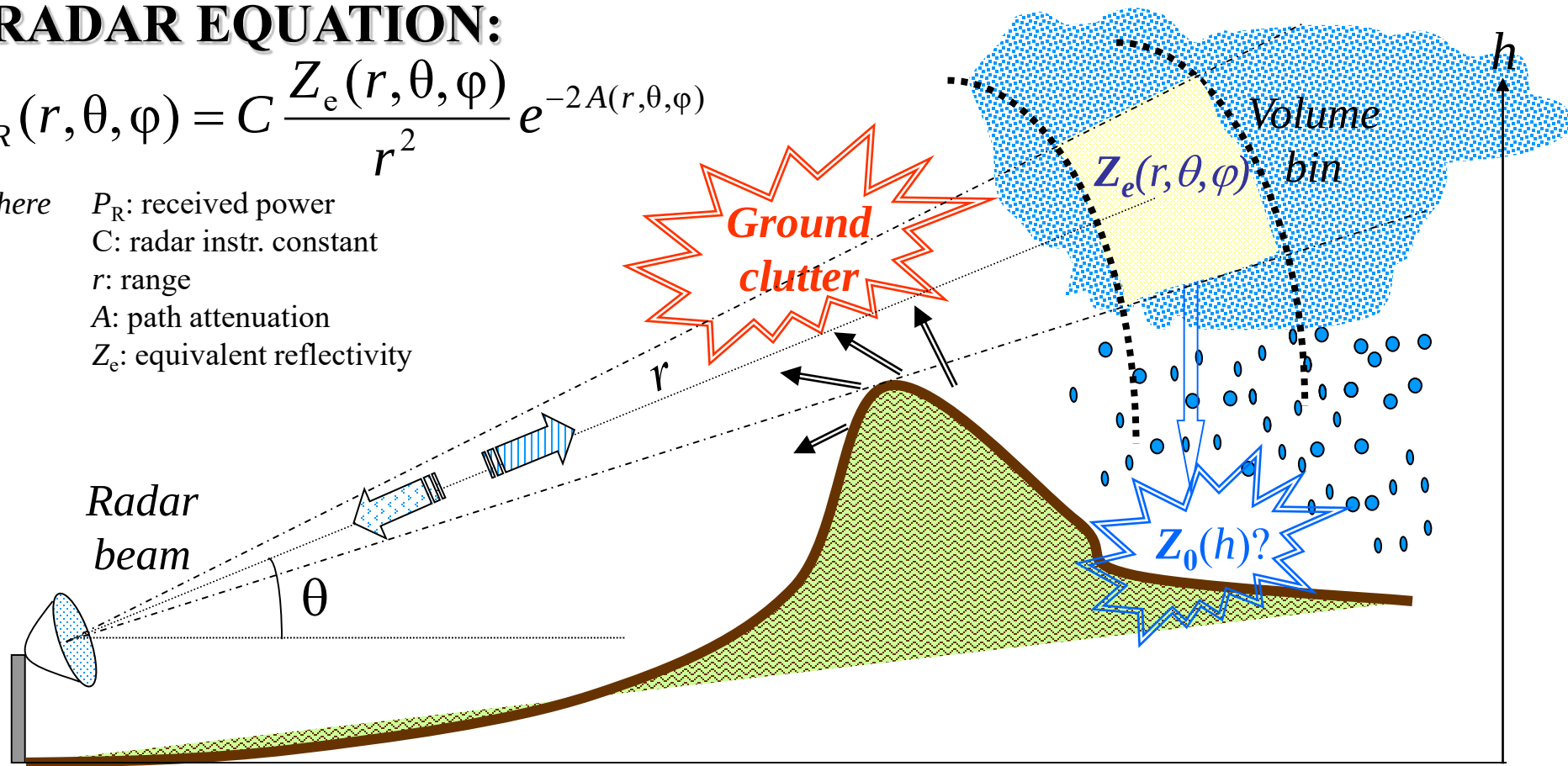
RADAR METEOROLOGY

Picturing the problem

RADAR EQUATION:

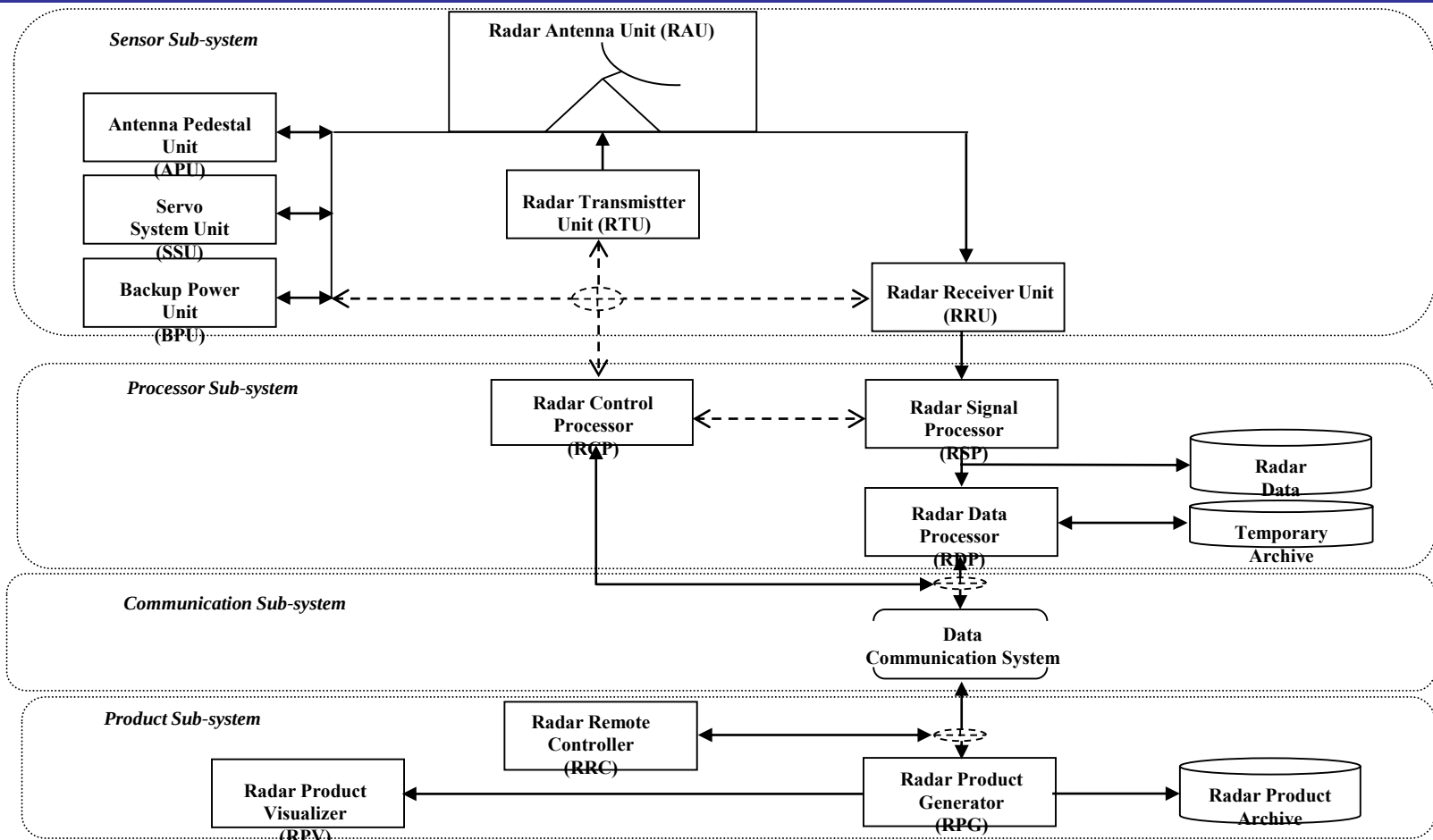
$$P_R(r, \theta, \varphi) = C \frac{Z_e(r, \theta, \varphi)}{r^2} e^{-2A(r, \theta, \varphi)}$$

where P_R : received power
 C : radar instr. constant
 r : range
 A : path attenuation
 Z_e : equivalent reflectivity



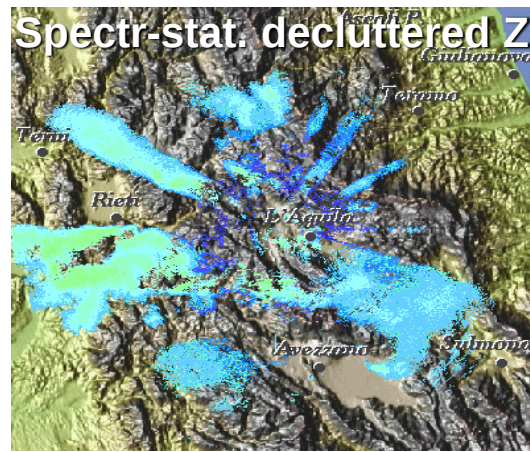
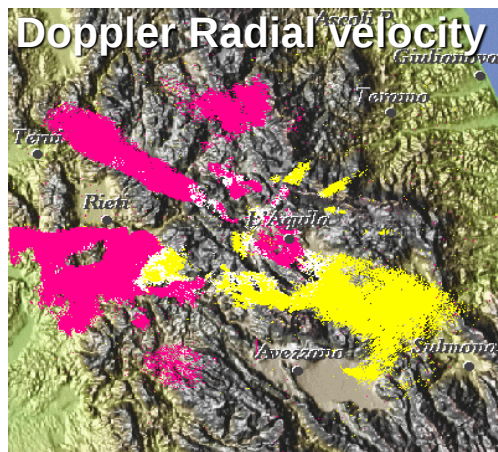
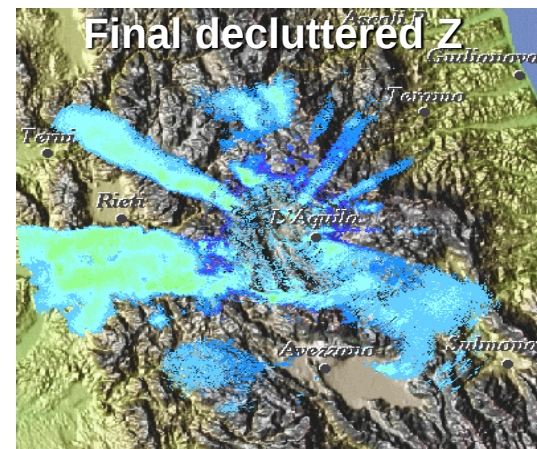
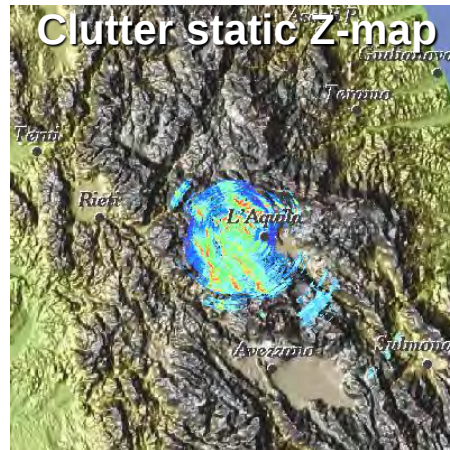
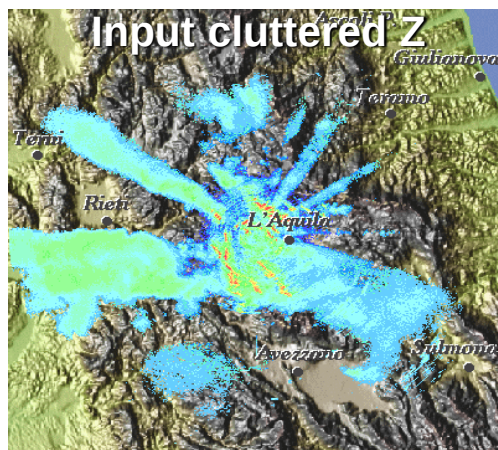
RADAR METEOROLOGY

System conceptual diagram



RADAR METEOROLOGY

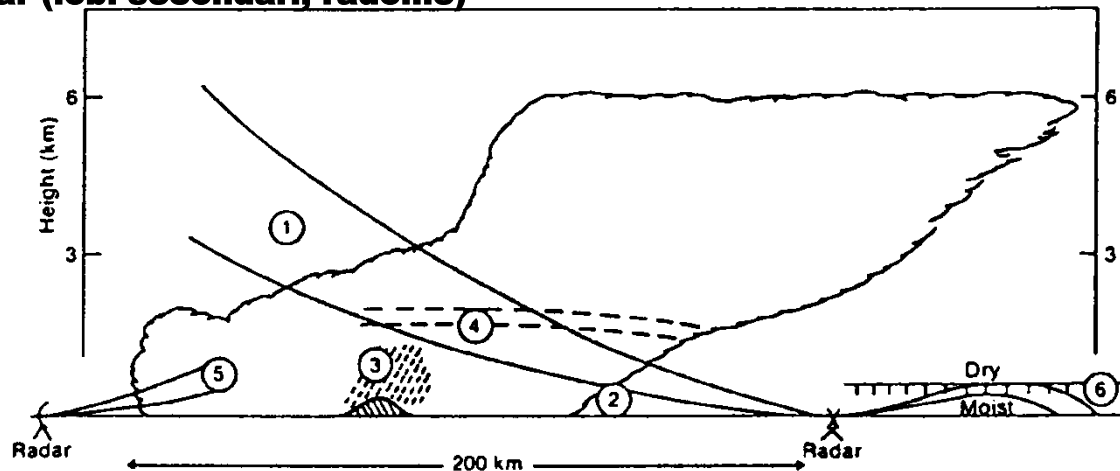
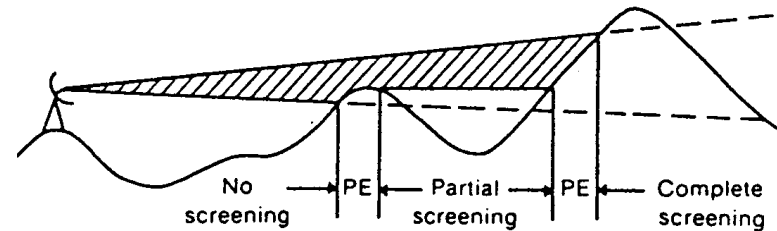
De-cluttering example



PROBLEMS

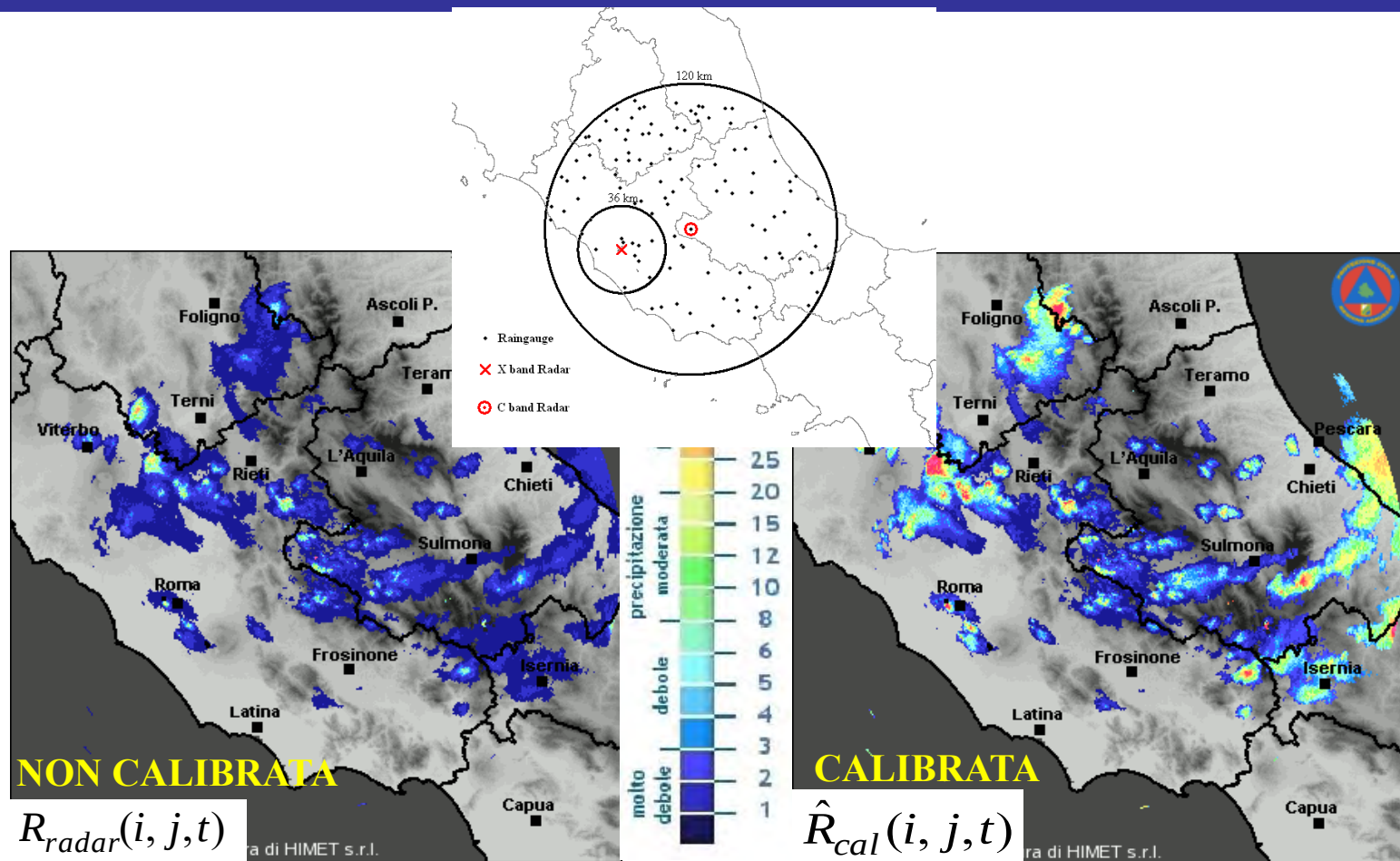
Errors in radar measurements

1. Precipitazioni presenti al di sotto del fascio radar
2. Evaporazioni presenti al di sotto del fascio radar
3. Effetti orografici
4. Banda brillante dovuta a liquefazione di neve
5. Attenuazione da gas e da idrometeore
6. Propagazione anomala - echi di seconda scala
7. Presenza di ostacoli fissi
8. Errori nel sistema radar (lobi secondari, radome)



RAINGAUGE CALIBRATION

Correcting radar estimates



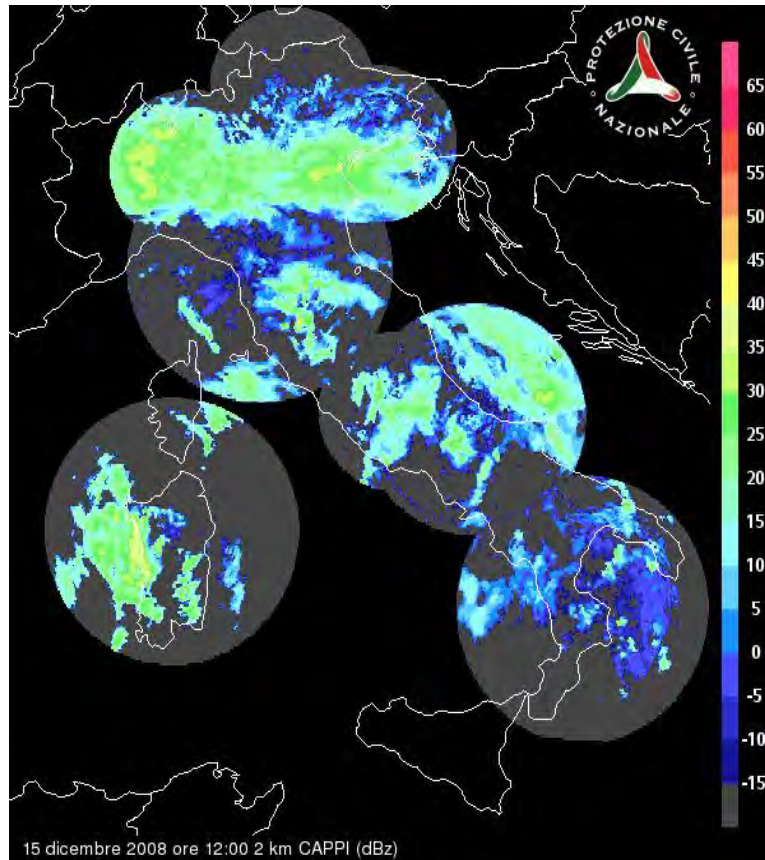
ITALIAN RADAR NETWORK

Radar sites

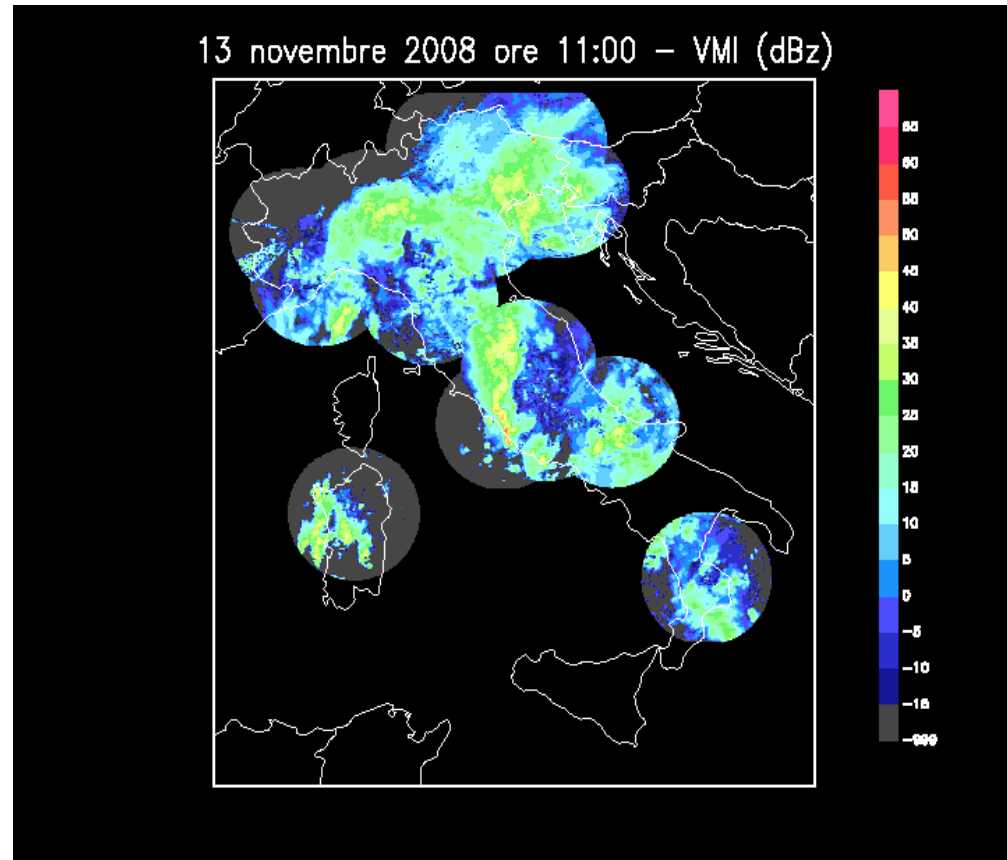


ITALIAN RADAR NETWORK

Examples



15 Dicembre 2008 ore 12.00



13 Novembre 2008 ore 11.00

PRESENTATION

Skeleton

RAINFALL REMOTE SENSING

- Principles of electromagnetic remote sensing
- Inverse and forward problems
- Precipitating clouds

SATELLITE METEOROLOGY

- Principles of satellite remote sensing
- Research aspects on modeling and inversion

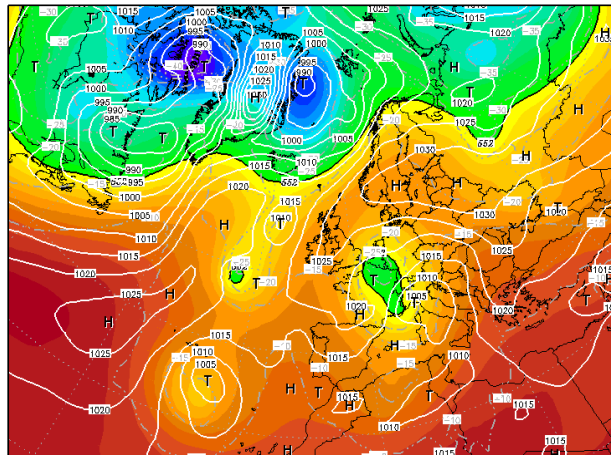
RADAR METEOROLOGY

- Principles of weather radar meteorology
- Research aspects in complex orography

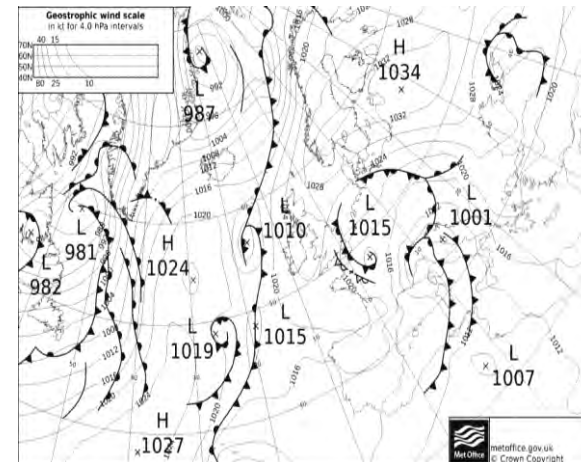
PRECIPITATION EXTREMES AND CLIMATOLOGY

- Extreme case study analysis
- Reanalysis and trends

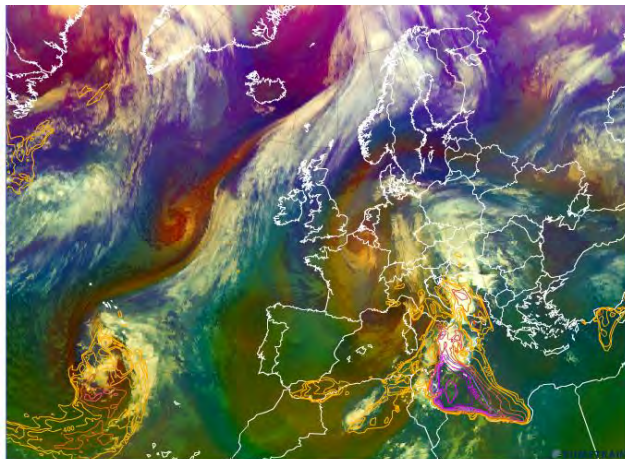
15 OCTOBER 2015 SYNOPTIC ANALYSIS



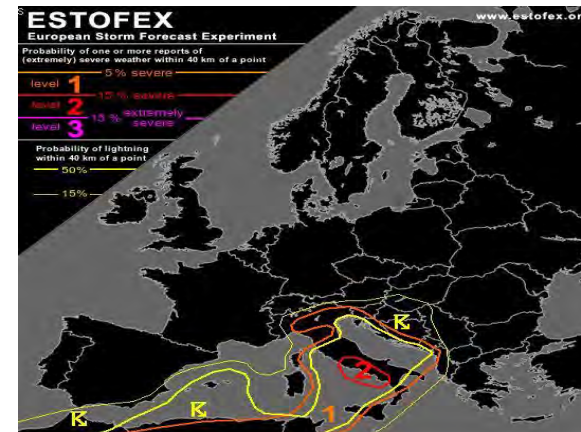
**Carta in quota del
geopotenziale e
temperatura alla
500hPa
valida alle 00UTC del
15 ottobre 2015**



**Carta di
analisi
valida alle
00UTC del
15 ottobre
2015**

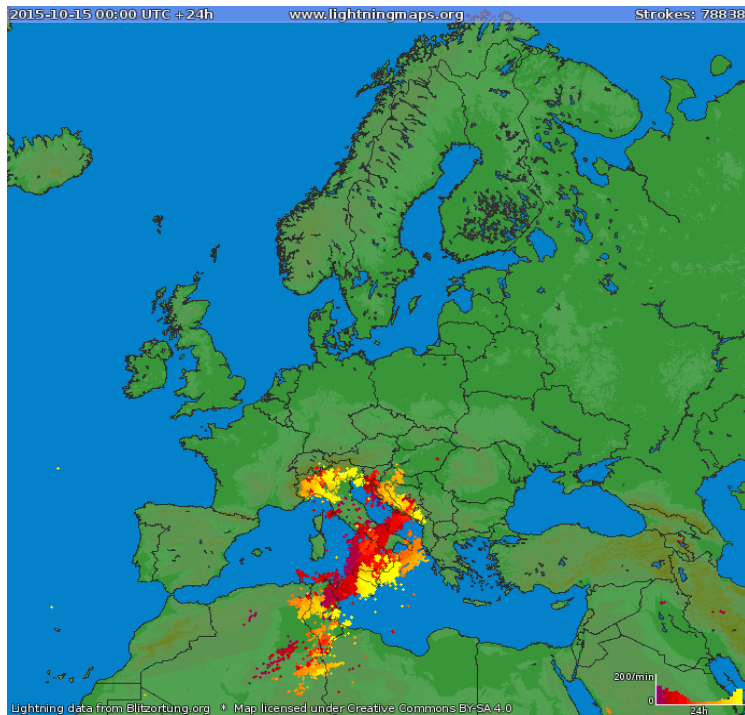


**Sovrapposizione di
Convective Available
Potential Energy ed
Air mass RGB alle
00UTC del 15 ottobre
2015;
isolinee in mandarino
800 J kg⁻¹, in magenta
2.500 J kg⁻¹, in viola
3000/4000 J kg⁻¹**

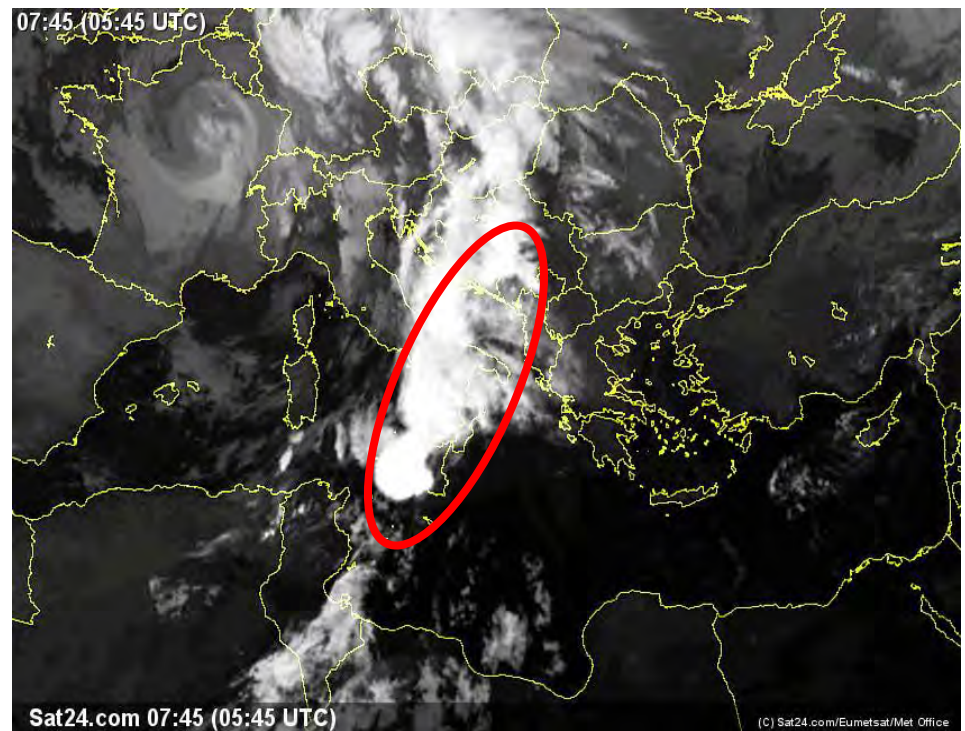


**European
Storm Forecast
Experiment
valido da
mercoledì 14
ottobre 2015
alle 06UTC
a giovedì 15
ottobre 06UTC**

15 OCTOBER 2015 OBSERVATION ANALYSIS



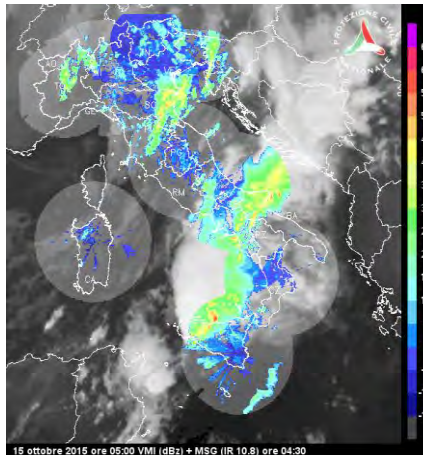
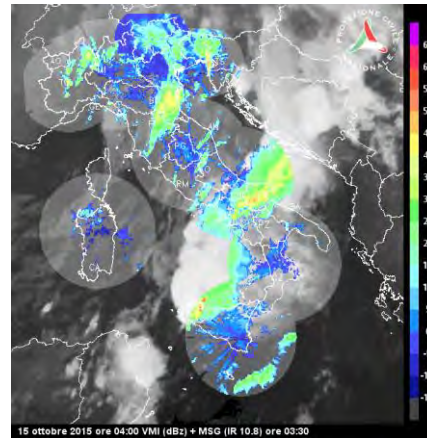
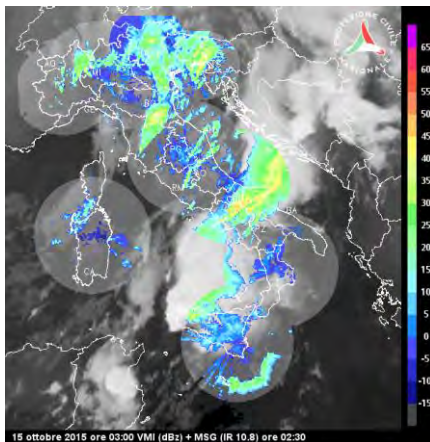
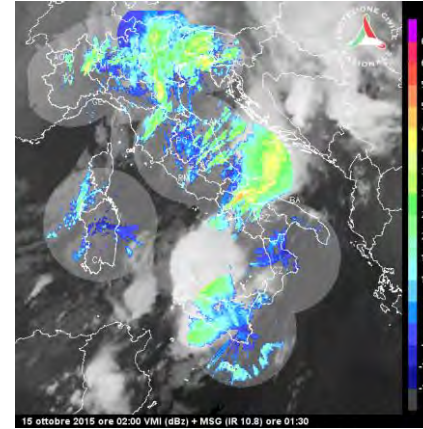
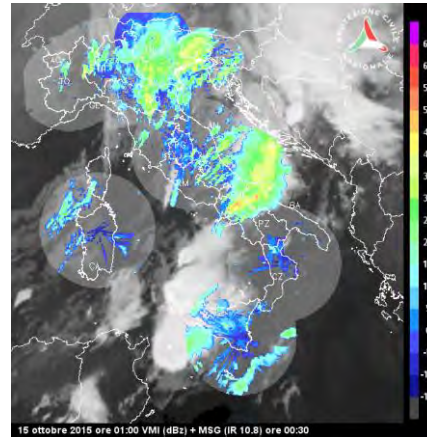
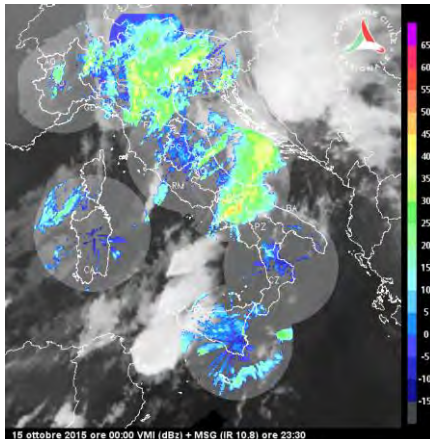
**Mappa dei fulmini caduti in 24 ore
dalle 00UTC del 15 ottobre 2015**



Meteosat IR alle 5:45UTC

15 OCTOBER 2015

RADAR ANALYSIS

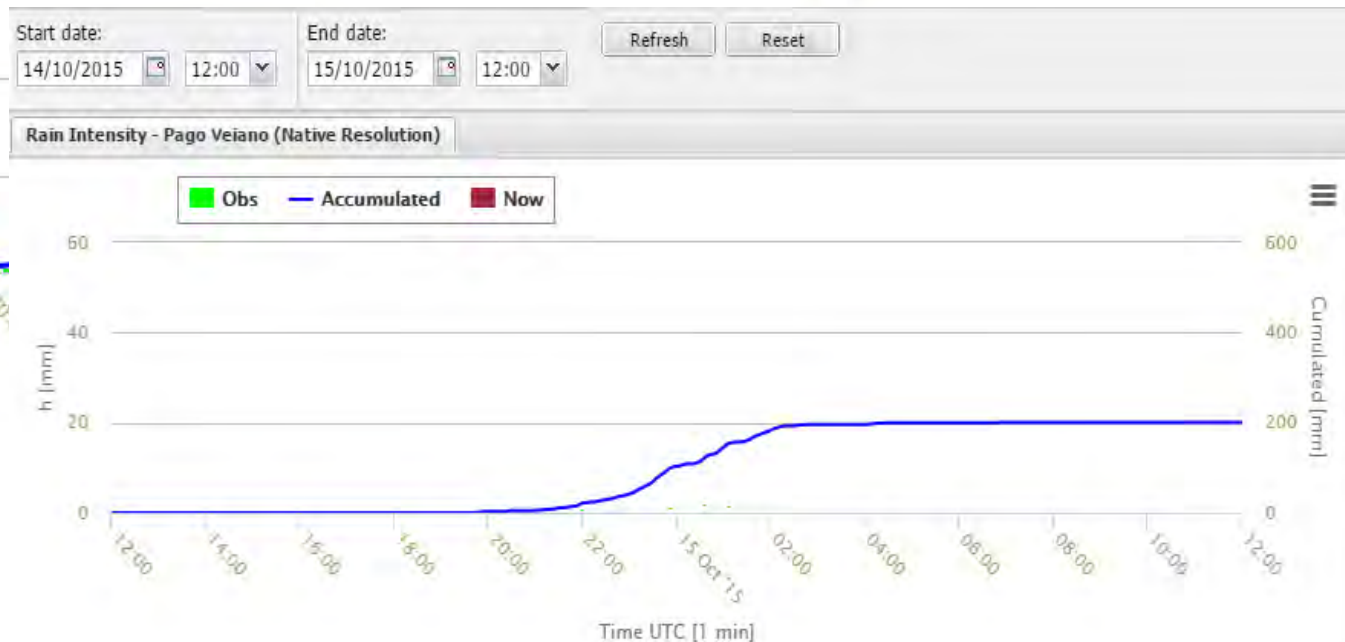
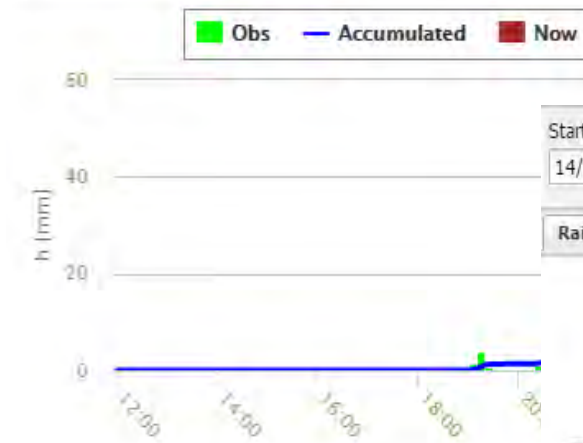


**Evoluzione
oraria
composita del
RADAR VMI
del mosaico
radar
nazionale
(dalle 00LT del
15 ottobre alle
06LT del 15
ottobre 2015)**

15 OCTOBER 2015 RAINGAUGE ANALYSIS

Start date: 14/10/2015 12:00 End date: 15/10/2015 12:00 Refresh Reset

Rain Intensity - S.Agata dei Goti (Native Resolution)



*Si ringrazia: CIMA
Research Foundation e
Dipartimento Protezione
Civile Nazionale*

15 OCTOBER 2015

CETEMPS FORECAST SYSTEM



CETEMPS
cetemps.aquila.infn.it

ECMWF
Analyses
0.125°

WRF-ARW
12km

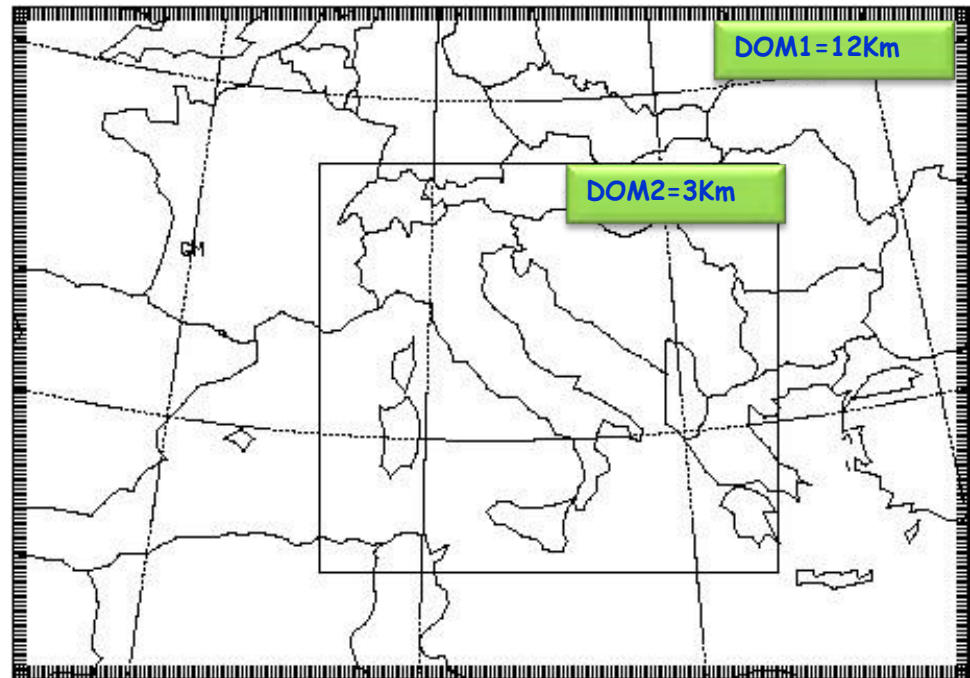
Rain gauges
Radar

WRF-ARW
3km

CHyM
Hydrological model

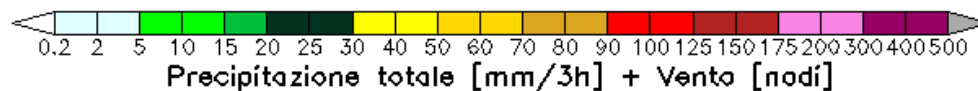
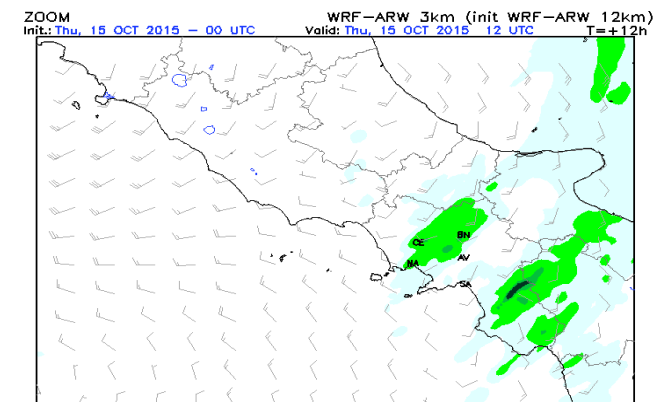
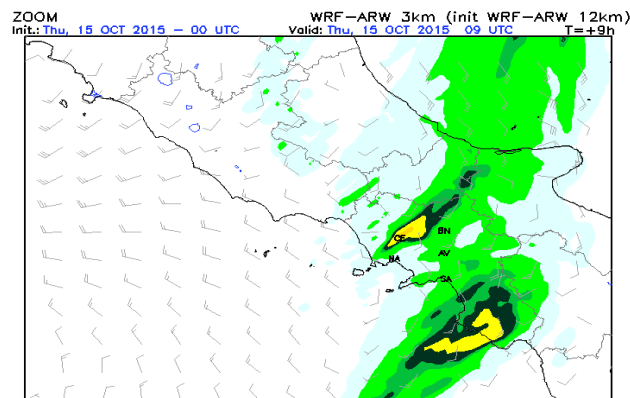
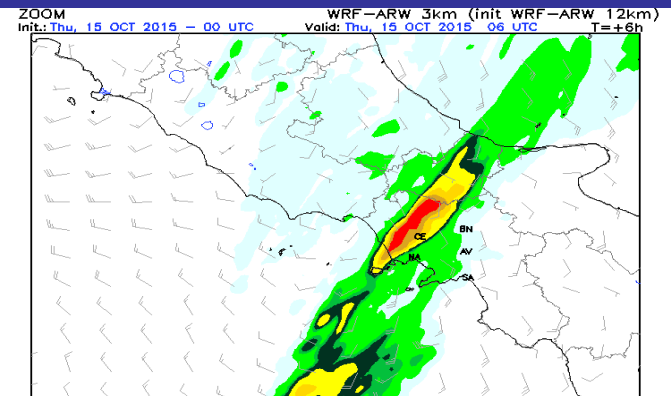
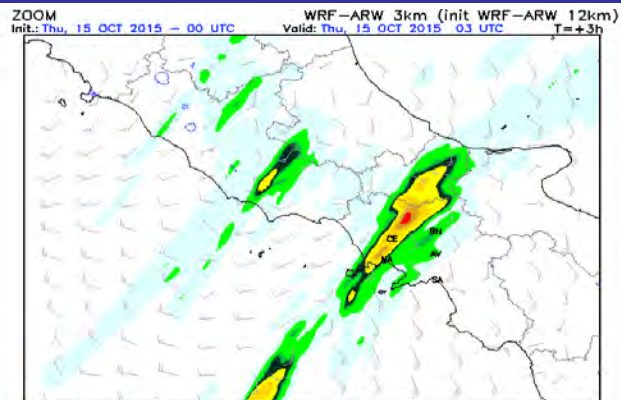
CAI2 Index

BDD Index



15 OCTOBER 2015

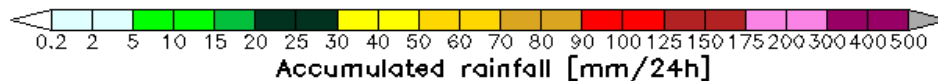
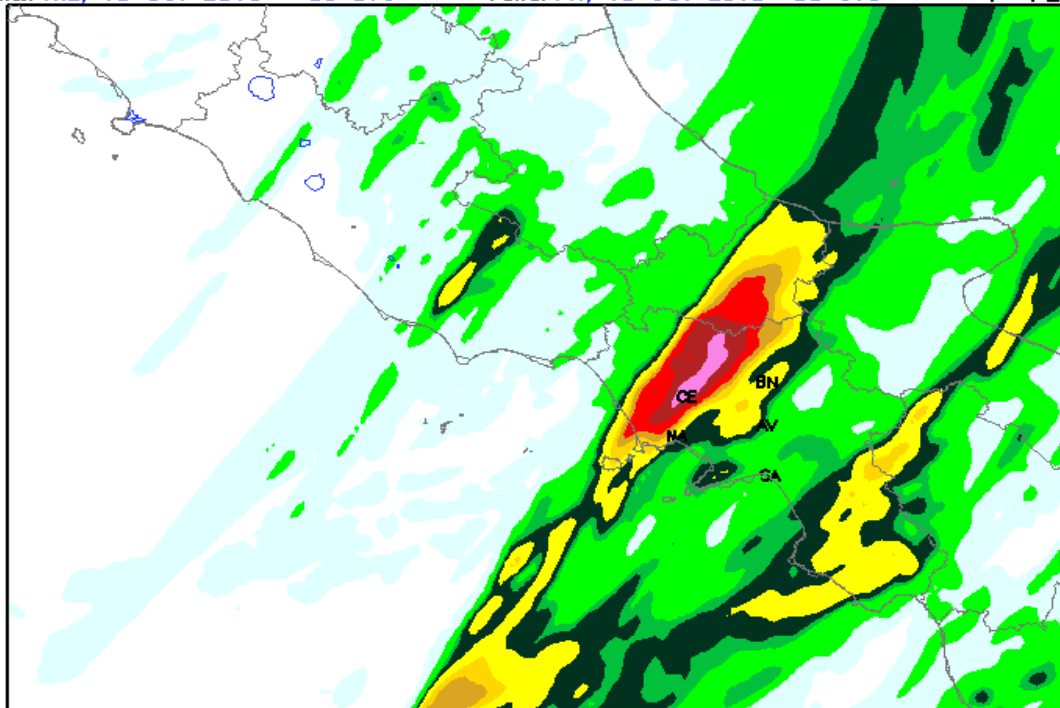
CETEMPS RAIN FORECAST



15 OCTOBER 2015

CETEMPS RAIN FORECAST

ZOOM
Init.: Thu, 15 OCT 2015 - 00 UTC
WRF-ARW 3km (init WRF-ARW 12km)
Valid: Fri, 16 OCT 2015 00 UTC
T=+24h



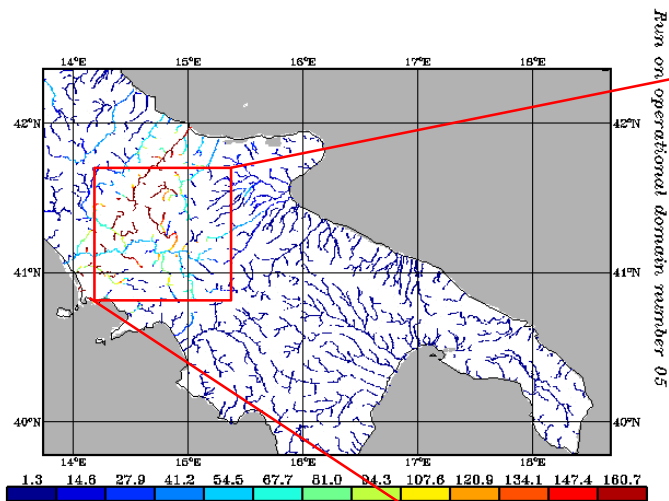
Zoom da dominio a 3km della cumulata a 24 ore da modello valida alle 00:00UTC del 16 ottobre
2015

15 OCTOBER 2015

CETEMPS RIVER FORECAST



CHyM - CAI - (mm/day)



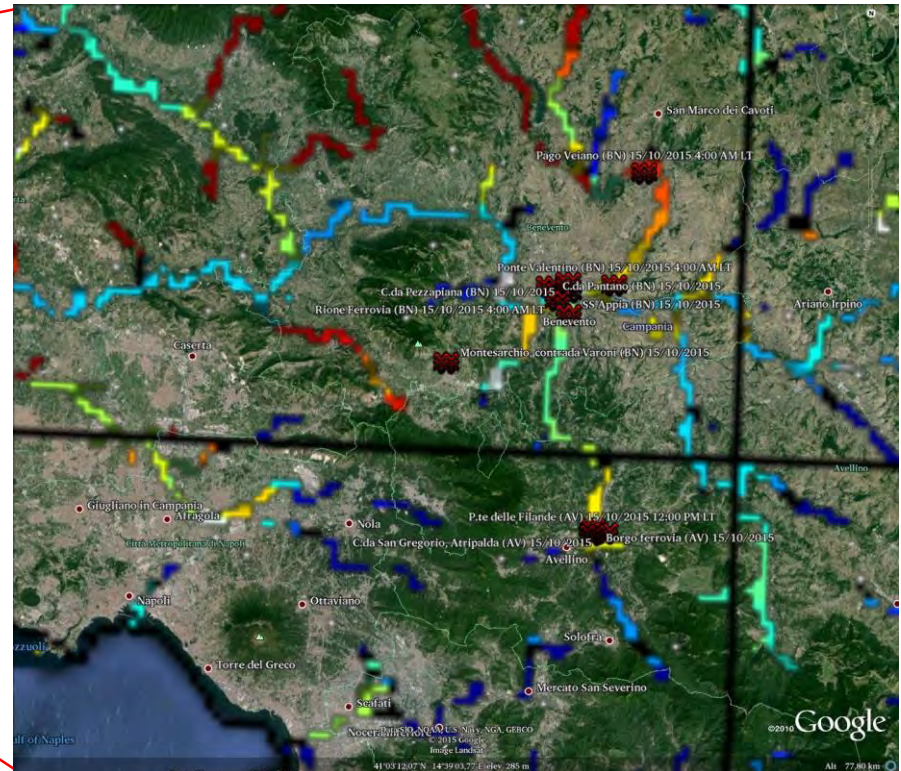
Simulation on October 15, 2015 h: 4.00 UTC

CAI:

Esprime il rapporto tra la precipitazione disponibile per il runoff drenata da ogni singola cella e la sua area drenata a monte.

Rappresenta la precipitazione media drenata dalla cella i -esima durante un tempo t corrispondente al tempo di runoff.

Stress idrologico calcolato dall'indice **CAI** - 15 ottobre 2015 4:00 UTC Zoom sulle aree interessate e sovrapposizione con Google Earth® con indicazione dei punti di esondazione



PRECIPITATION SCIENCE

Issues and Background

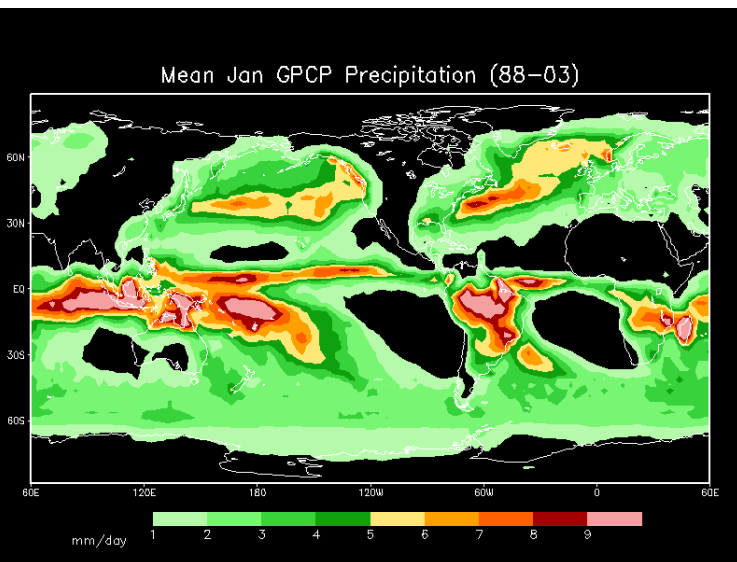
Science questions:

- Is the **intensity and frequency of extreme precipitation** increasing at global and regional (Mediterranean?) scale?
- How much precipitation occurs **over the globe?** (i.e. what is the strength of the global hydrological cycle?)
- How does global mean precipitation **vary with time?** (i.e. how is the hydrological cycle changing and what is its trend?)
- Can coupled **climate models** reproduce the observed changes in global mean precipitation?

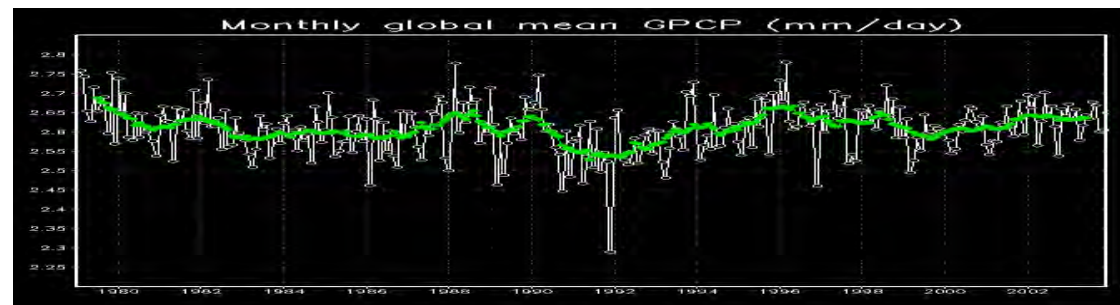
DATA ANALYSIS

Integrating Precipitation Observations

- **Analysis – creating complete (in time and space) fields from varying and incomplete observations**
- **Satellite-derived estimates have complementary characteristics (geostationary IR is more complete but has poor accuracy, low Earth orbit PMW is more accurate but has sparse sampling) so combining them makes sense (CMAP, GPCP, CMORPH, TMPA, GSMaP...)**
- **Rain gauges are helpful to reduce biases in satellite-derived estimates**
- **Model-generated precipitation may be useful in regions where neither gauges nor satellite estimates are skillful**

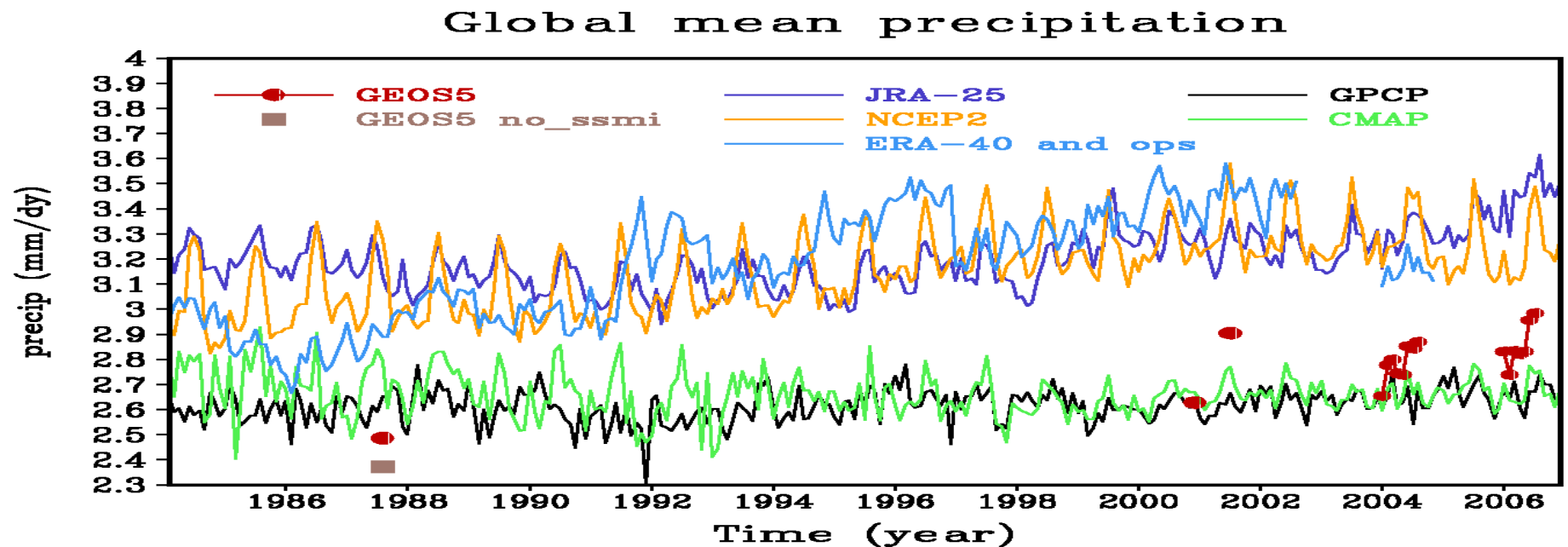


- GPCP mean annual cycle (left) and global mean precipitation (below)
- Monthly/5-day; 2.5° lat/long global
- CMAP has similar characteristics



DATA REANALYSIS

Global Mean Precipitation



- Modern reanalyses give global means considerably greater than GPCP (Global Precipitation Climatology Project - WMO) and CMAP
- Reanalyses, which should be most realistic model-based product (since they use observations) are also higher than most AR4 Climate model simulations
 - Figure courtesy Junye Chen, NASA/GMAO-MERRA

CONCLUSIONS?

Maybe ...

LESSONS AND HINTS

- Remote sensing is more than (or is NOT) a **MEASUREMENT**
- Need of physical and mathematical **BACKGROUND**
- Don't use remote sensing data **BLINDLY** and ask for data/measurement **ERROR**
- **ISSUES**
 - Is precipitation localization and frequency increasing?
 - Is the precipitation intensity increasing?
 - Vulnerability and exposition effects on risk assessment?

Thank
you

