wege entstehen, indem wir sie gehen
paths emerge in that we walk them

EUMETSAT ROM SAF

IROWG INTERNATIONAL RADIO OCCULTATION WORKING GROUP

EUMETSAT ROM SAF - IROWG 2019

Konventum, Helsingør (Elsinore), Denmark

19 - 25 September 2019

IGAM/IP IVWL geo raum ISIS IPHIL IEW

Wegener Center
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UNI GRAZ

ISSI-BJ Forum on Exploring Greenhouse Gases, Water and Climate Changes by LEO-LEO Occultation: Main Results and Next Steps

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Setting the scene – previous context: the 2016 ESA Living Planet Symp Workshop, fulfilling an IROWG action, and reporting back in the context of OPAC IROWG 2016:

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Progress in LEO-LEO occultation: results from the May 2016 interagency workshop on cooperation options towards a LEO-LEO mission

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1) Wegener Center, University of Graz, Austria

2) ESA/ESTEC, Noordwijk, Netherlands

3) EUMETSAT, Darmstadt, Germany

Thanks to all colleagues joining the workshop and the LEO-LEO forum! (see Minutes)

Imported from: LEO-LEO workshop report presentation to IROWG-5, OPAC-IROWG 2016, Seggau/Leibnitz, Austria, 9 Sep 2016

Ok, here's about the lines along which we will walk through...

First a quick LEO-LEO refresher to furnish us a decent prep:

- Beyond GNSS radio occultation (GRO): LMO, LIO, LMIO
- How it works: LMIO measurement concepts and performance
  - Aspects of exciting extensions/add-ons to LEO-LEO: Focus on simple VIS/IR clouds & water vapor imaging add-on to LMO and on NIDAR near-surf carbon monitoring add-on to LIO

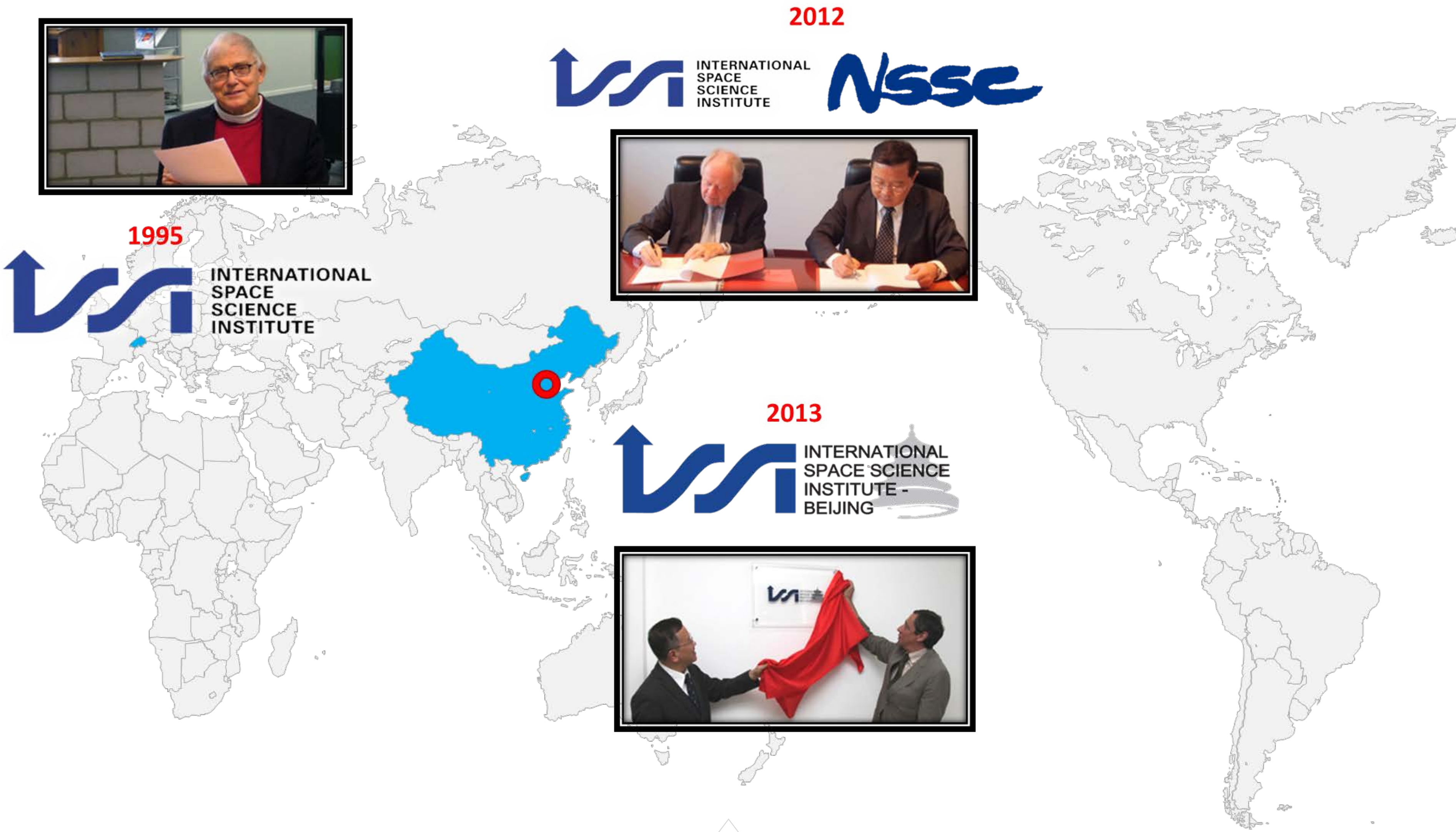
Then, well prepared, the results from the LEO-LEO workshop:

- The WS Agenda based on the IROWG-4 recommendation
- The Minutes of Meeting incl. summary and discussion record
- Some (strange)Backinfos and Summary of main outcomes…
- Conclusion and prospects: link *https://irowg.org/leoleo-forum*
  - Contains the Agenda and MoM of this 2016 meeting…soon:)

The Minutes of Meeting of the 2016 workshop for ref:

Setting the scene – now in July 2019: the ISSI-BJ Forum welcome slide... ...and participant group

Setting the scene – the ISSI, the form of mtg, its objectives, and results as "readily accessible scient.magazine article"



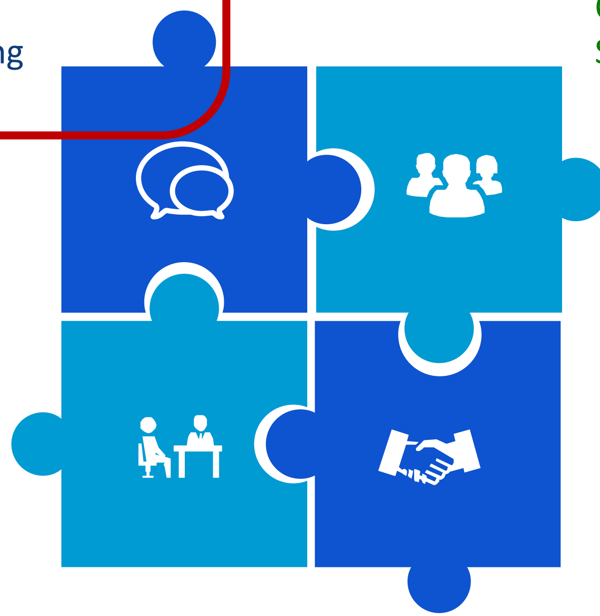
ISSI-BJ Basic "Tools"

FORUMS

Objectives: **Open** discussions
Participants: **20-30** scientists
Duration: 2 days
Output: **Taikong** magazine
Support: Accommodation in Beijing

INTERNATIONAL TEAMS

Objectives: Research on **focused** topics
Participants: **10-15** scientists
Duration: 2 years, 1-2 meetings/year
Output: **Papers** in scientific journals
Support: **Per diem** + **accommodation** in Beijing



WORKSHOPS

Objectives: **Broad** scientific area
Participants: **~40** scientists
Duration: One week
Output: **Book** (peer reviewed)
Support: **Per diem** + **accommodation** in Beijing
Book **publication cost**

VISITING SCIENTISTS

Objectives: **Research** (specific to visitor)
Duration: As necessary
Output: **Publications / Management** tasks
Support: **Travel** + **accommodation** in Beijing

How to use the ISSI tools?

FORUMS

- **No annual call**
- May be **suggested any time**
- Submit an idea on max 1 page
- Ideas evaluated by the Science Committee

WORKSHOPS

- **No annual call**
- May be **suggested any time**
- Submit an idea on max 1 page
- Ideas evaluated by the Science Committee

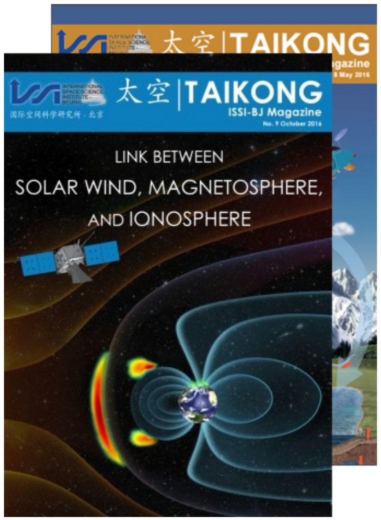
INTERNATIONAL TEAMS

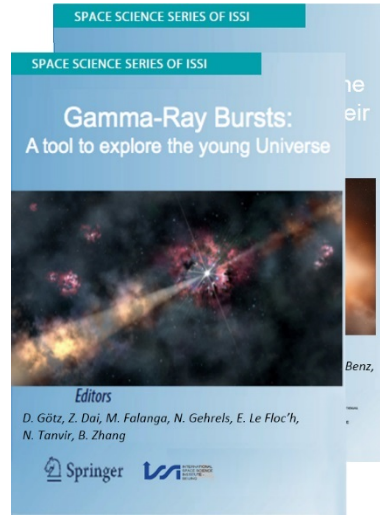
- **Call** for proposals released every year **on January**
- Proposals evaluated by the Science Committee

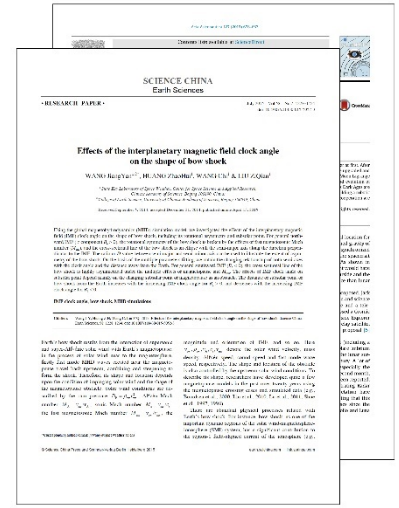
VISITING SCIENTISTS

- **Invited** by the Directorate and External Scientists
- Selected by the Directorate

ISSI Publications – *TAIKONG* for Forum outcome







Taikong

- Forum outcome
- Magazine with popular articles
- 14 issues

Annual Reports

- Summary of the yearly activities and publications
- Financial overview

Space Sciences Series of ISSI

- Workshops outcome
- 3 ISSI-BJ issues
- 1 Scientific Report

Individual papers

- Peer-reviewed international journals
- ISSI-BJ affiliation or with acknowledgement to ISSI-BJ

Obligations for reporting outcomes of ISSI-BJ Forums…

Final report -> TAIKONG Magazine

- Report sent to the PR & Editorial Manager
- Magazine published online & printed

Exploring greenhouse gases, water and climate changes by LEO-LEO occultation

a little draft style still…;)

Foreword

(Maurizio Falanga and Laura Baldis, please revise this section.)

This is the eighth successfully organized forum by the International Space Science Institute in Beijing (ISSI -BJ) in the framework of the Space Science Strategic Pioneer Project of the Chinese Academy of Sciences (CAS). ISSI -BJ forums are informal and free debates, brainstorming meeting, among some twen ty-five high -level participants on open questions of scientific nature.

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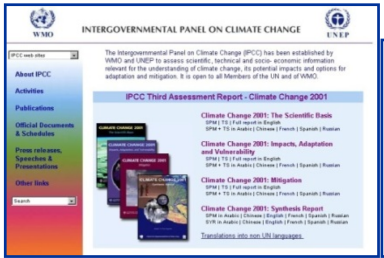
We must solve the global atmosphere & climate monitoring problem with *benchmark data* techniques since…

…these unique data serve as fundamental backbone and “true” reference standard to atmosphere and climate science & applications,

more specifically, three major reasons:

- to rigorously observe and learn, independent of models, how weather, climate and composition variability and change evolve, over weekly, monthly, seasonal, interannual, and decadal scales
- to test and guide the improvement of weather, climate and constituent models and thereby enhance their predictive skills for simulating future weather, climate and chemical composition
- to use the benchmark data as accurate observational constraints for natural and anthropogenic climate and composition change detection and attribution

• *and many other science objectives…*



*...from the 9 **“high priority areas for action”** noted in the **IPCC 2001 report** (Summary for Policymakers, IPCC WG I, p. 17) - **still valid 18 years later in 2019:***

*“- **sustain and expand the observational foundation for climate studies by providing accurate, long-term, consistent data including implementation of a strategy for integrated global observations**.”*

Climate monitoring principles

- Traceability to reliable reference standards

Fundamental Climate Data Records (FCDRs)

- long-term stability
- homogeneity & reproducibility
- global coverage
- accuracy
- adequate resolution in space and time

Focus on Essential Climate Variables (ECVs)

Example upper-air temperature in UTLS:

- horizontal resolution: 25 km in UT, 100 km in LS
- vertical resolution: 1 km UT, 2 km LS
- accuracy (root-mean-square) < 0.5 K
- stability of 0.05 K per decade UTLS (GCOS, 2016)

[GCOS-107 2006, GCOS-143 2010, GCOS-154 2011, GCOS-200 2016]

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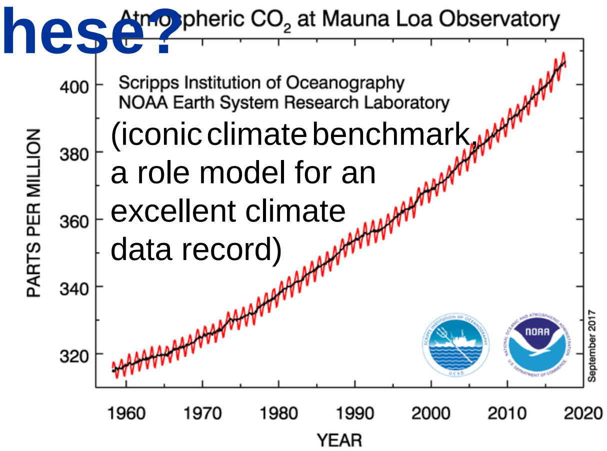
So, which properties need benchmark data to have and can RO and LEO-LEO (LLO) provide these?



Key properties:

- accurate (traceable to SI standards)
- long-term stable (over decades and longer)
- globally available (all weather, same above land and oceans, etc.)
- measure sensitive indicators of atmosphere and climate change, in a physically consistent manner, in particular: <u>=> GCOS Essential Climate Variables (ECVs)</u> (in the atmosphere: temperature, water vapor, wind, greenhouse gases, etc.) [e.g., GCOS Guideline, GCOS-143(WMO/TD No. 1530), May 2010]

…basically, RO can provide such data for thermodynamic core ECVs over the troposphere and stratosphere (with focus on TBL upwards); <u>LLO can do so for a near-complete set of atmospheric ECVs</u>

Ok, again some lines along which we can walk through...

(starting here's now a range of 16 excerpt slides from the ISSI-BJ Forum sci.challenges pres)

- Why care? – Why monitor GHGs, water and climate changes with benchmark data? And which techniques can achieve this?
- Beyond GNSS radio occultation (RO): LEO-LEO microwave and IR-laser occultation (LMO, LIO; LMIO; LLO) to vastly expand the RO Essential Clim Vars (ECVs) by GHGs, water,...
- How it works: LMIO measurement concept and performance
- Aspects of exciting extensions/add-ons to LEO-LEO (focus on VIS/IR clouds & water vapor imaging add-on to LMO; and mention NIDAR near-surf carbon monitoring add-on to LIO)
- Conclusions and next steps (this closing slide also contains a weblink towards on-line access to WEGC-related papers cited in this presentation)

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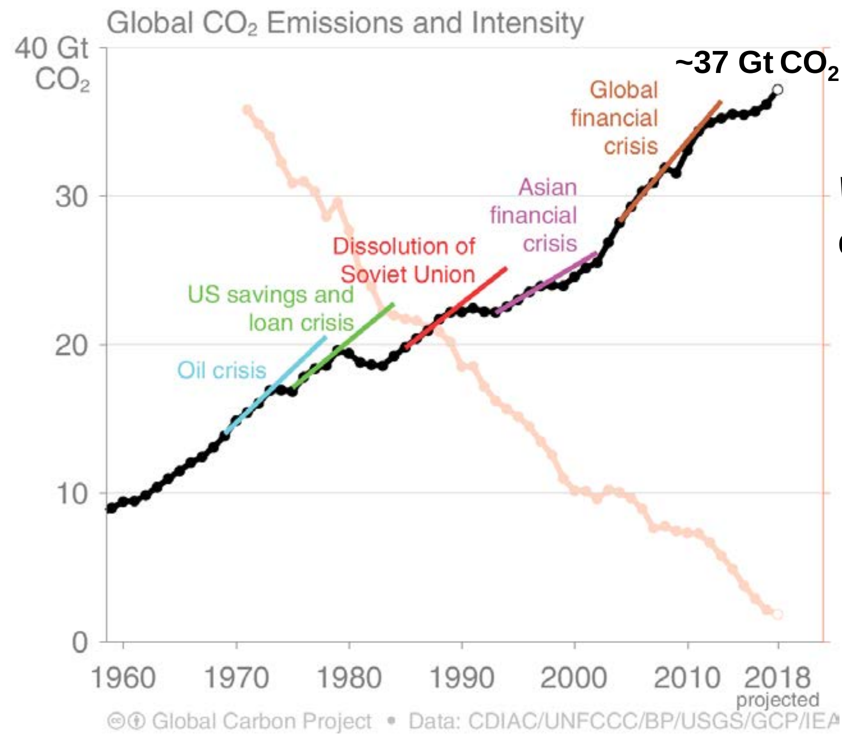
- Over the most recent decade (2006-2015) CO_2 emissions still rose faster than in any decade before – quo vadis?

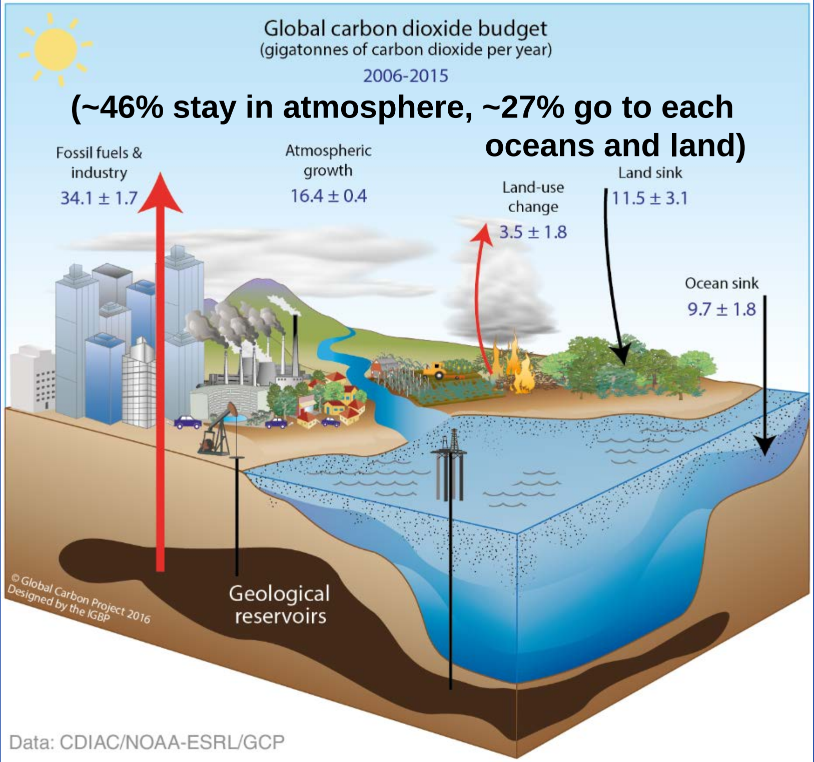


~37 Gt CO_2 in 2018

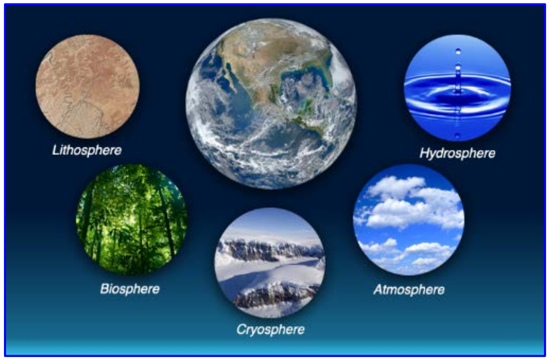
[GCP-Global Carbon Project, 2016-2018]

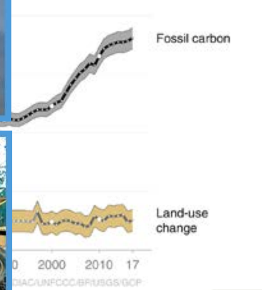
Where does the Carbon go? – esp. the anthropogenic emissions of ~40 $GtCO_2$/yr mainly from fossil fuels?

(land use change emissions add ~10% to the fossil-fuel&cement CO_2 emissions shown)

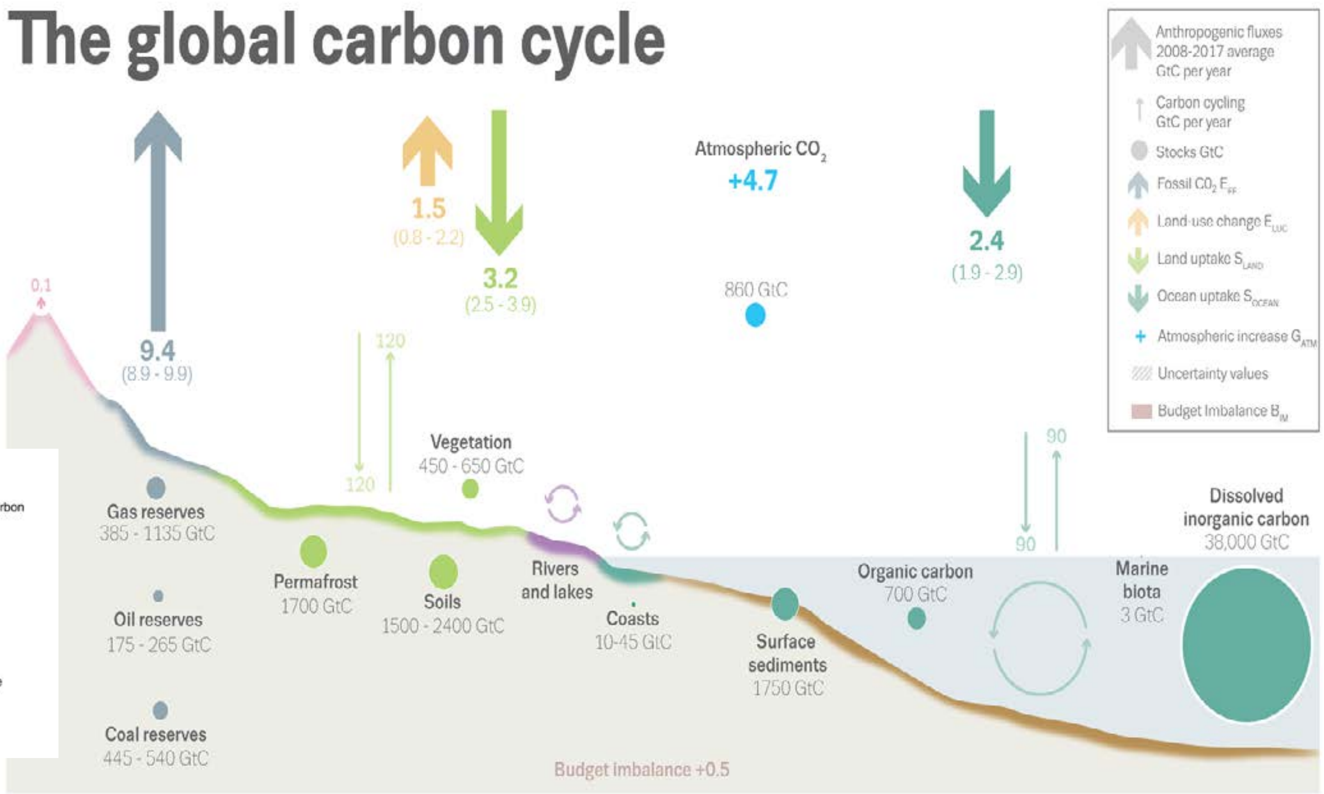


Where does the carbon go? – the excess carbon of ~11 GtC per year?





Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2008–2017 (GtC/yr)

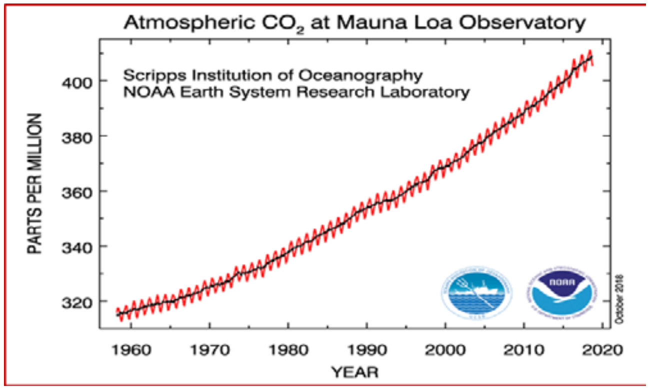


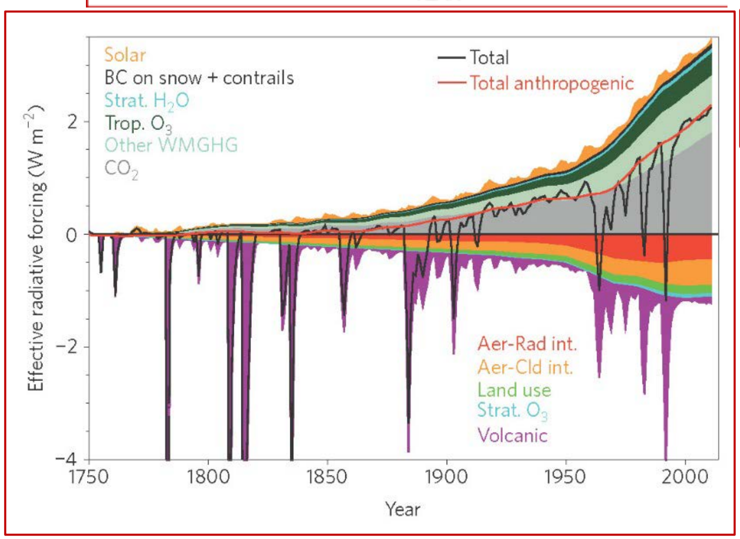
The budget imbalance is the difference between the estimated emissions and sinks.

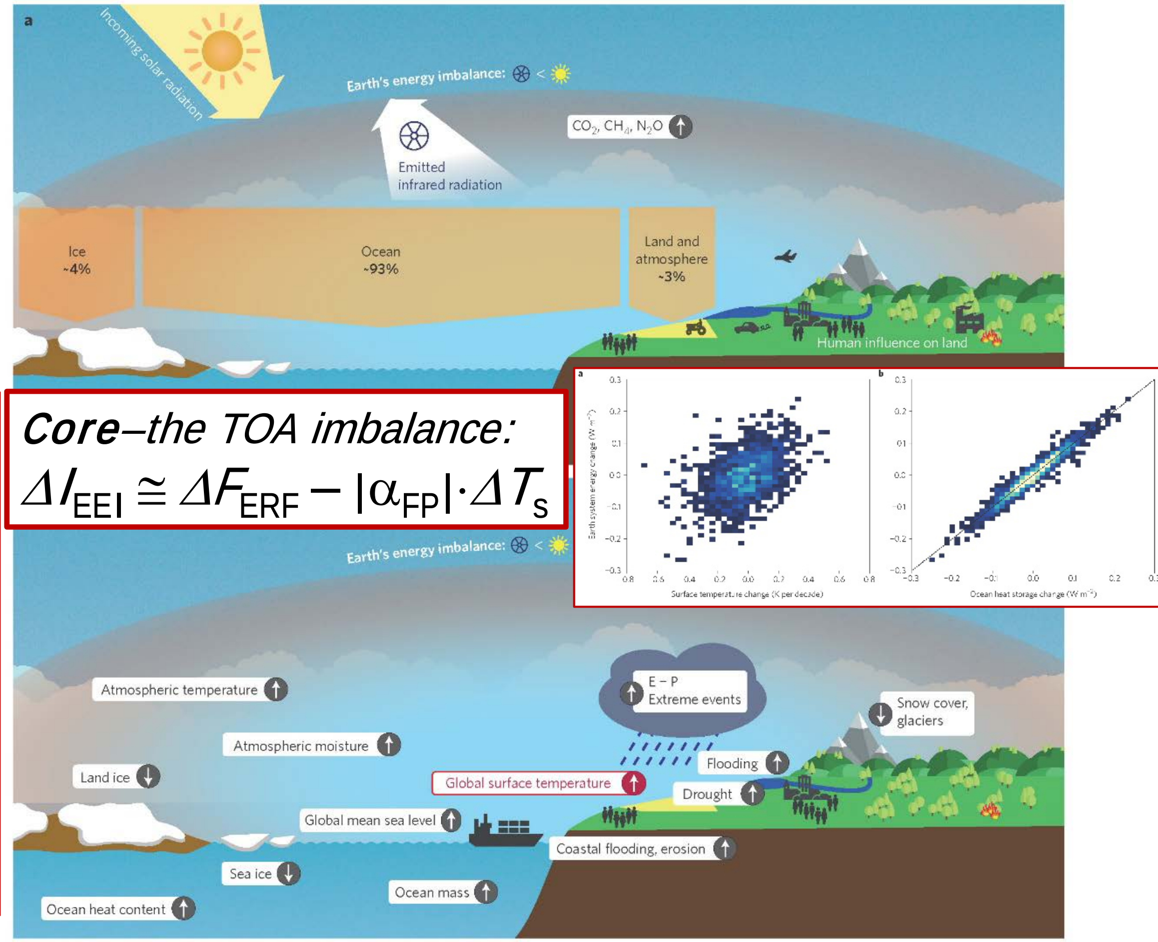
Source: CDIAC; NOAA-ESRL; Le Quéré et al 2018; Ciais et al. 2013; Global Carbon Budget 2018

GHG drivers, rad. forcing, energy imbalance, climate change,...

Where does the Energy go? – the excess energy of ~0.8 $Jm^{-2}s^{-1}$ (~13 ZJ/yr) due to the ***EEI*** ?





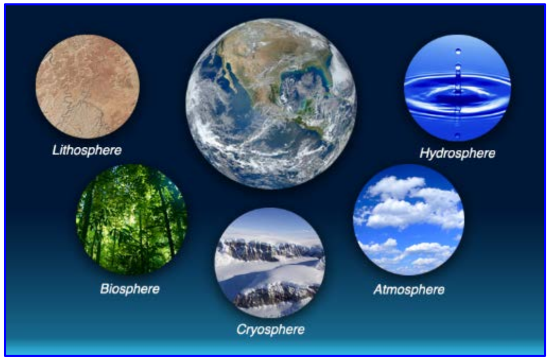


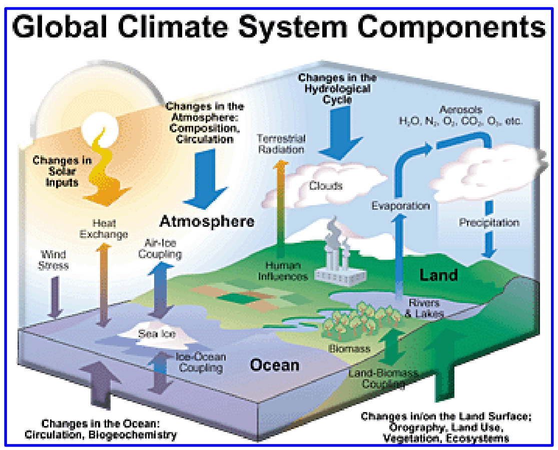
Core*–*the TOA imbalance:

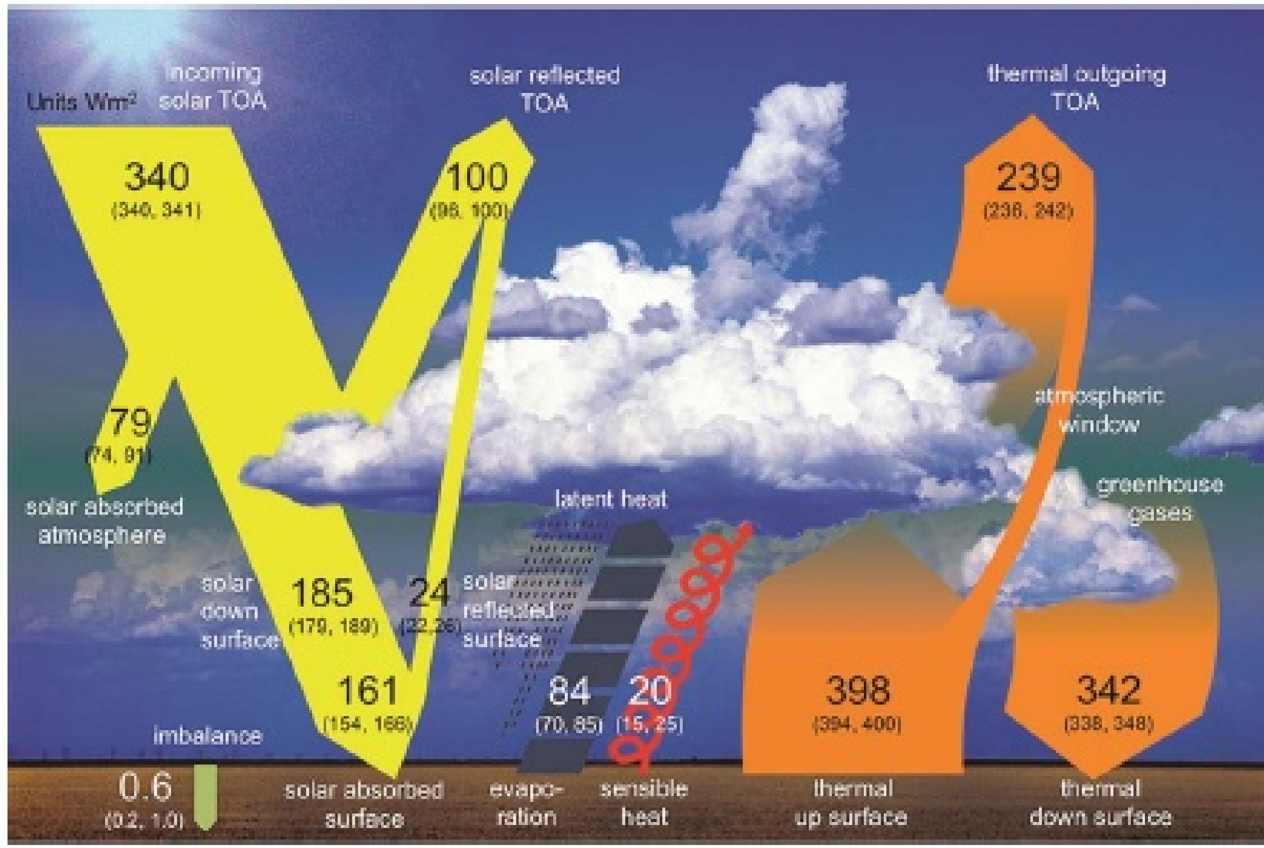
$$\Delta I_{EEI} \cong \Delta F_{ERF} - |\alpha_{FP}| \cdot \Delta T_s$$

[upper left: NOAA, 2018; other panels: v.Schuckmann et al., *NatureCC*, 2016; insert equ.: WEGC, 2019]

Where does the energy go? – the excess energy of ~0.8 J per m^2 per sec?







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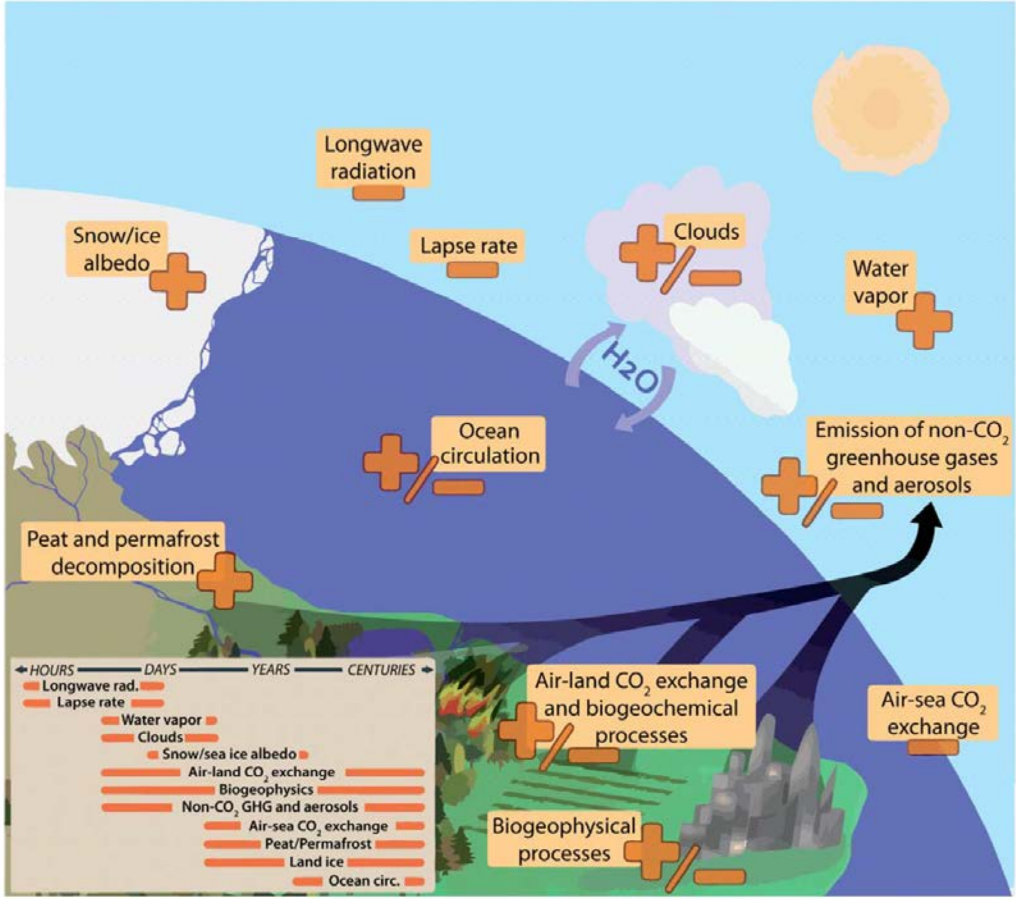
Where does the energy go? – this is strongly co-determined by climate feedbacks…



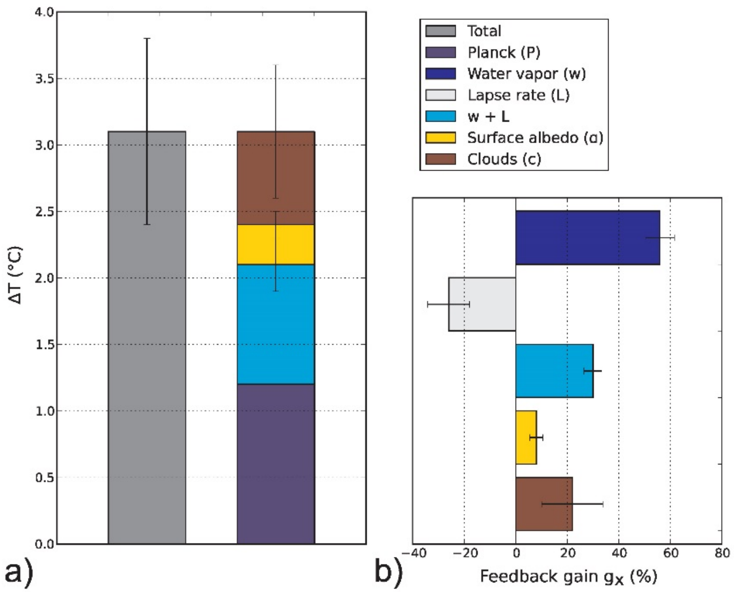
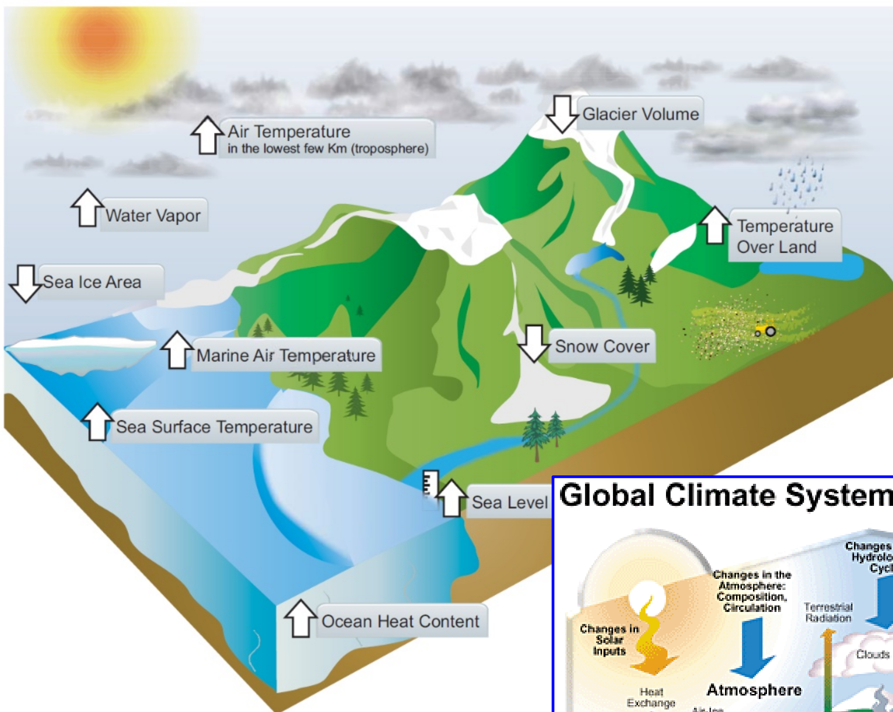
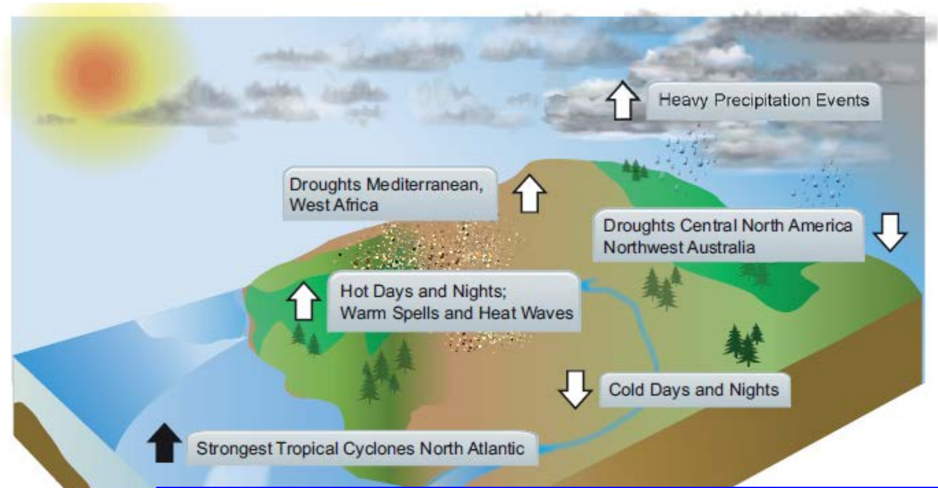
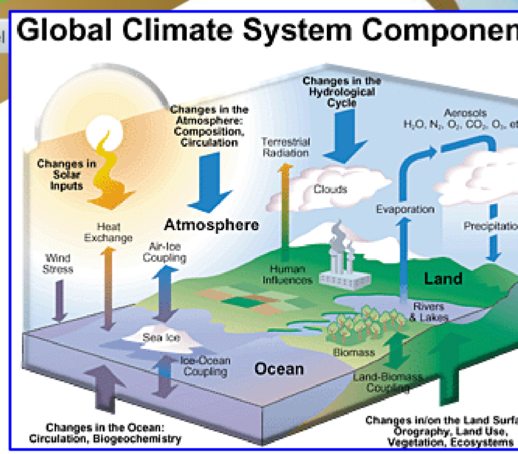


Fig. 5. For a CO_2 doubling, (a) equilibrium temperature change and contributions to this temperature change because of the Planck response, combined water vapor and lapse-rate feedback, surface albedo feedback, and cloud feedback and (b) relative contribution of each feedback to the equilibrium temperature change reported in (a). The multimodel mean and plus or minus one standard deviation for 12 CMIP3 models are shown using results of Dufresne and Bony (2008).

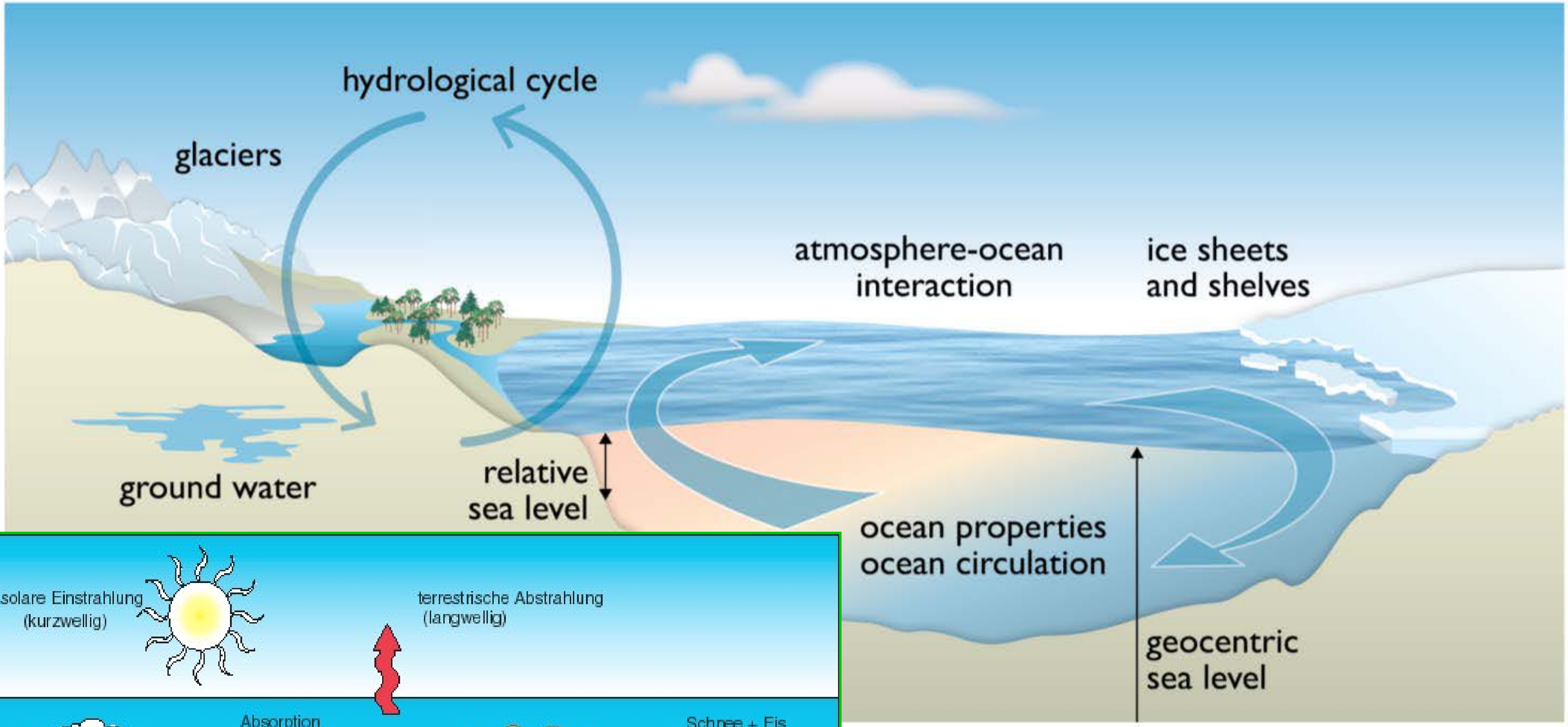
Where does the energy go? – into transient changes and changes in extremes…

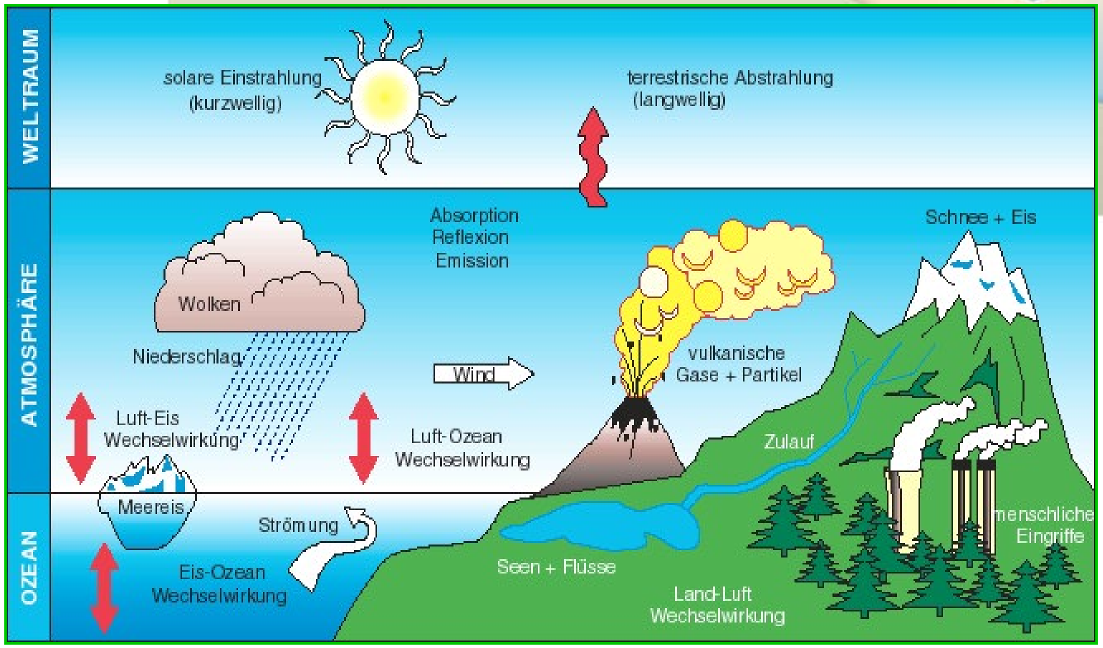






And how does the water change? – in all subsystems and all phases of water…





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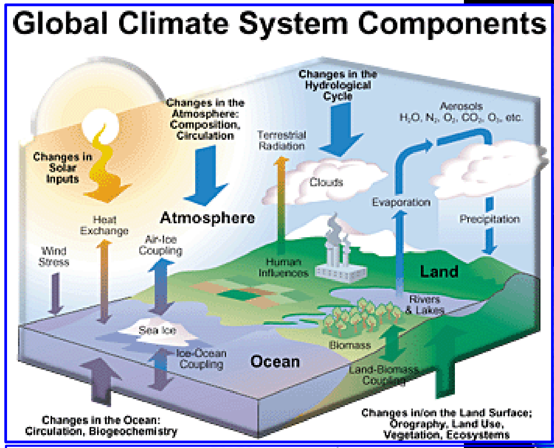
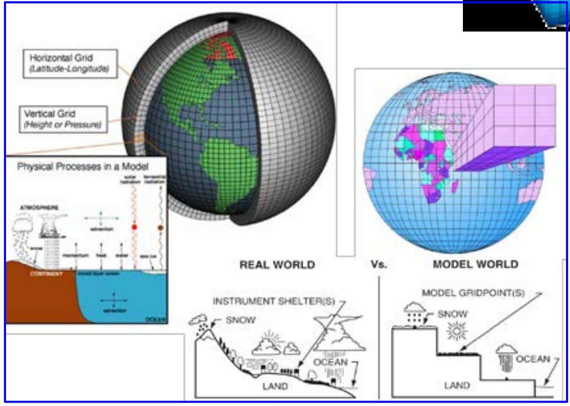
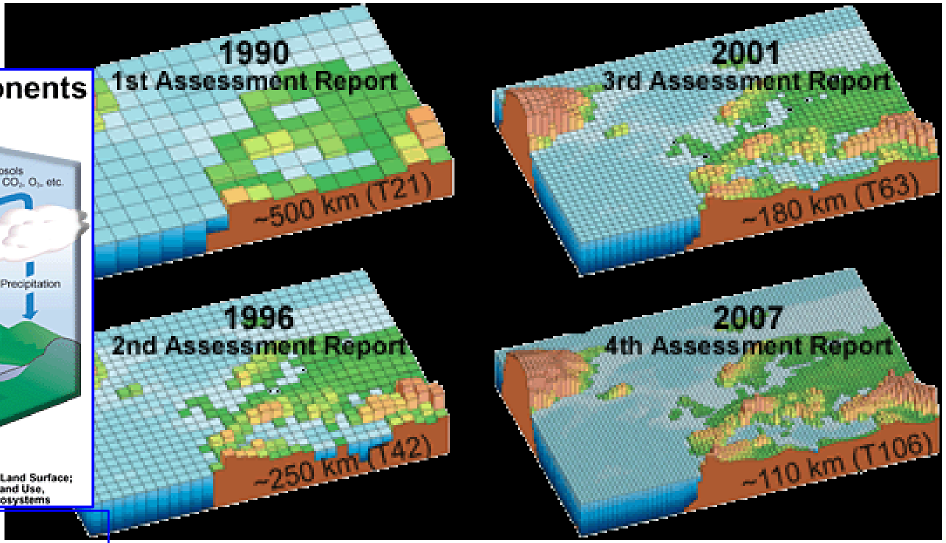
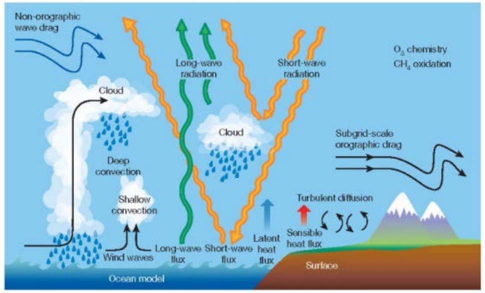
And how to model all these changes? – a formidable challenge at all scales…



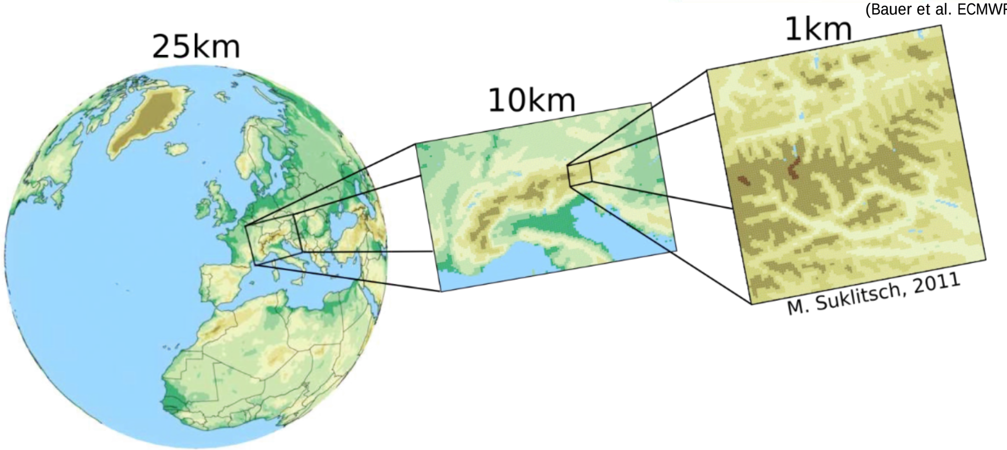




meshing challenges: topography, small-scale (weather) processes
– grid spacing, resolution, parameterization,...



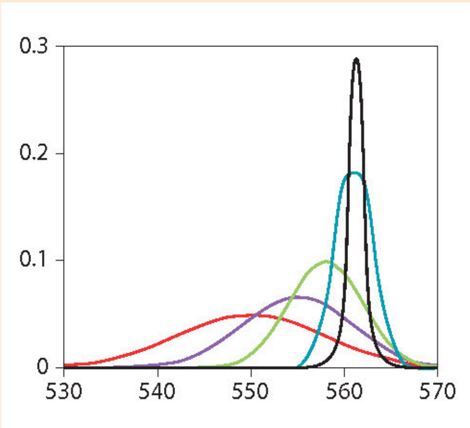
(Bauer et al. ECMWF Newsl. 145, 2015)



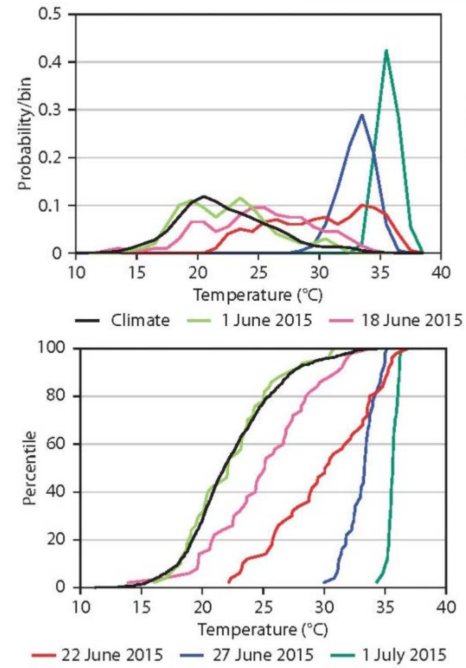
predictablility of weather & climate by phys-math modeling – prediction (forecast), projection (scenario)

The concept of a skilful probabilistic forecast

A



The concept of a skilful probabilistic forecast has been used as the basis to estimate the forecast skill horizon of ECMWF ensemble forecasts. The climatological (reference) probability density function (red line) has only a small overlap with the observation, represented by a probability density function which becomes arbitrarily narrow in the limit of zero observation error (black line). By contrast, the forecast probability density functions (violet, green and blue) match the observation probability density function increasingly well as the forecast time shortens. Consistently, the forecast cumulative distribution functions (defined by integrating the probability density functions; not shown) also approach the observation cumulative distribution function. To measure how close the forecast and observed distributions are, the Continuous Ranked Probability Score (CRPS), which is equal to the mean squared distance between the forecast cumulative distribution function and the observed cumulative distribution function, can be used.



(Magnusson et al. ECMWF Newsl. 145, 2015)

Weather and climate prediction (forecast ensembles)

(Buizza et al. ECMWF Newsl. 145, 2015)

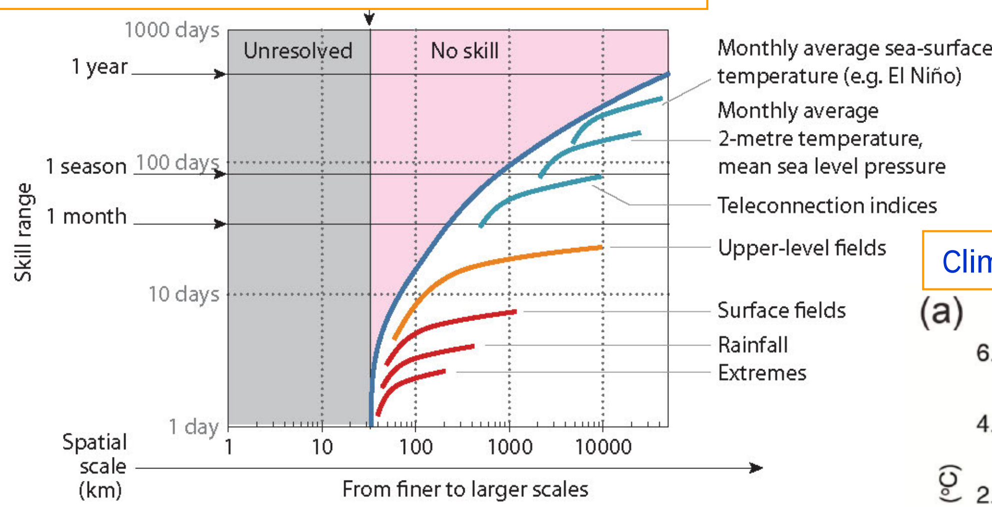
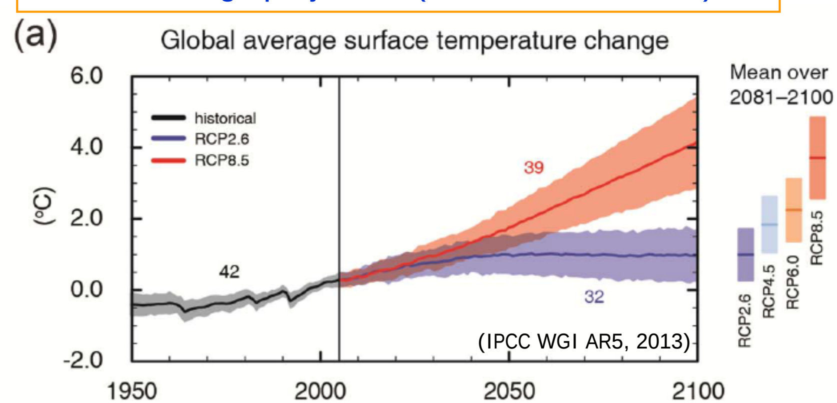


Figure 5 The forecast skill horizon of ECMWF operational forecasts, constructed using published skill measures of (ENS) and seasonal (S4) forecasts.

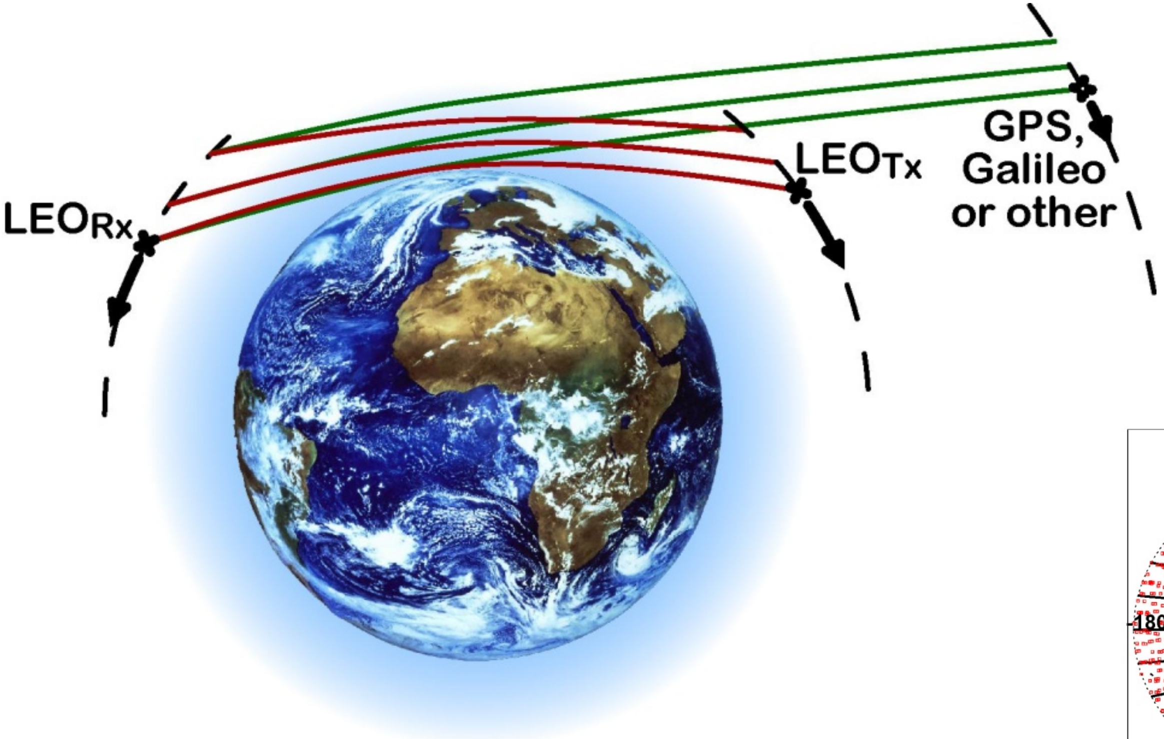
Climate change projection (scenario ensembles)



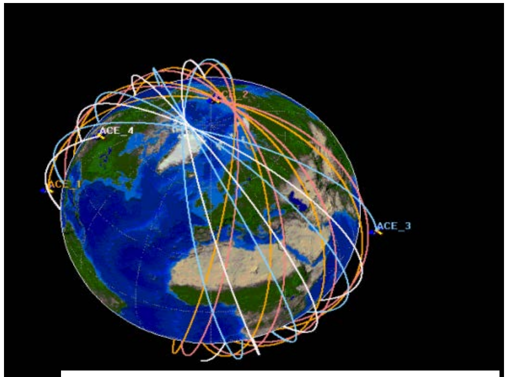
(IPCC WGI AR5, 2013)

LEO-LEO Microwave and Infrared-laser Occultation (LLO):

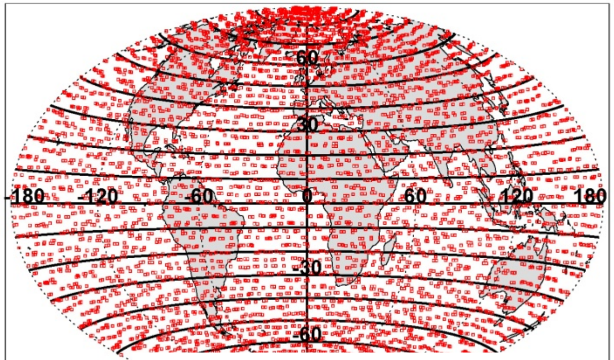
from RO decimeter-wave L band signals to RO-type coherent signals at cm-mm (microwave) and μm (IR-laser) wavelengths



(Schweitzer et al., JGR, 116, D10301, 2011)



LMIO constellation 2Rx+2Tx



LMIO coverage 30d, 2Rx+2Tx

(Kirchengast-Schweitzer GRL 2011, AM fig S1)

…in general "LLO", specifically "ACCURATE concept"

Backinfo#1: Which type of highly accurate X-meter is LLO?

X-meters in stock:

- Radiometer
- **Refractometer**
- **Absorptometer**
- Barometer
- Thermometer
- Hygrometer, etc.

So which one? (and at which altitudes?)

Backinfo#1 answer:

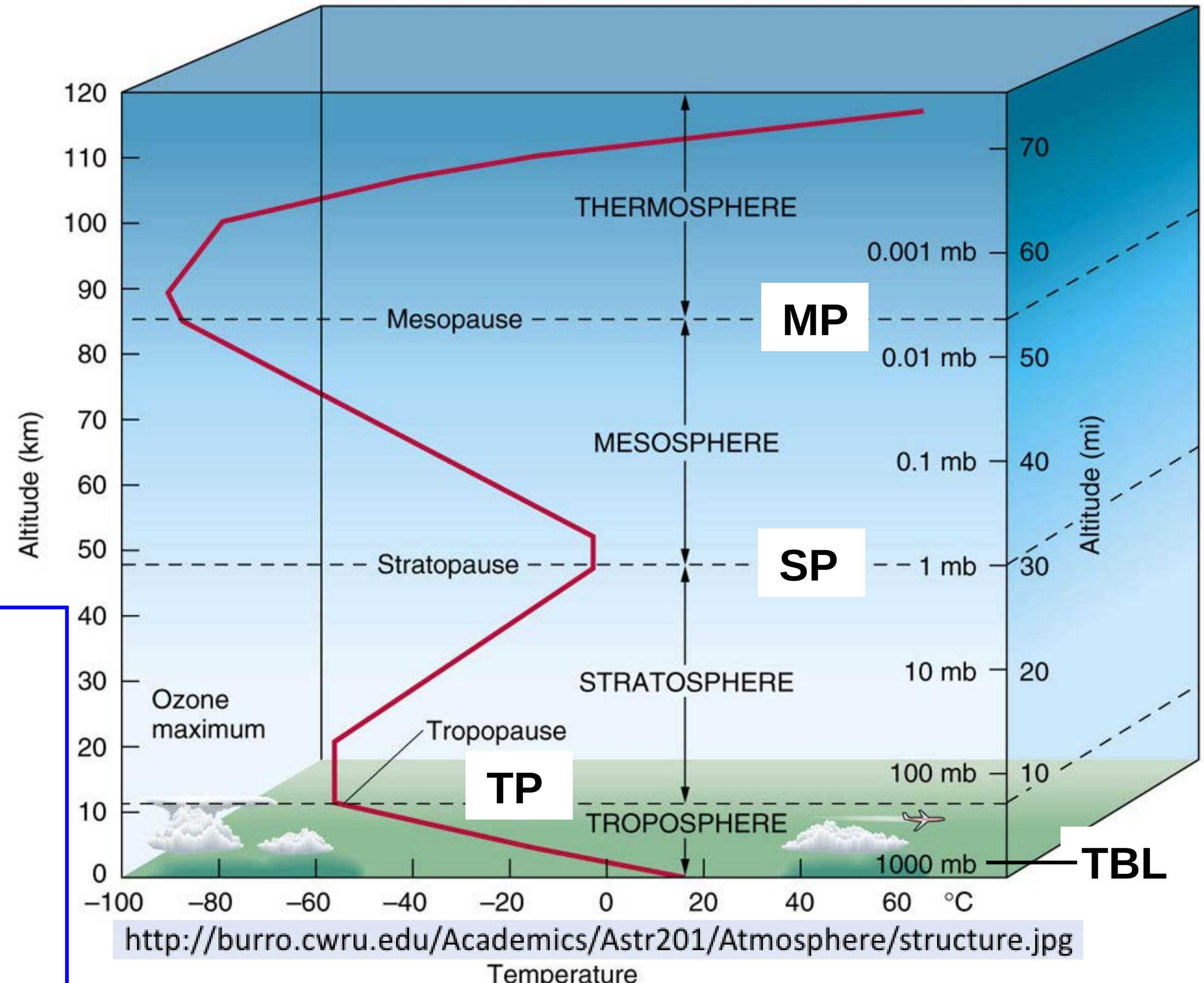
1. Refractometer (~TBL-MP)

2. Absorptometer (~TBL-SP)

3. Barometer (~TBL-MP)

3. Thermometer (~TBL-MP)

4. Hygrometer (~TBL-TP)



http://burro.cwru.edu/Academics/Astr201/Atmosphere/structure.jpg

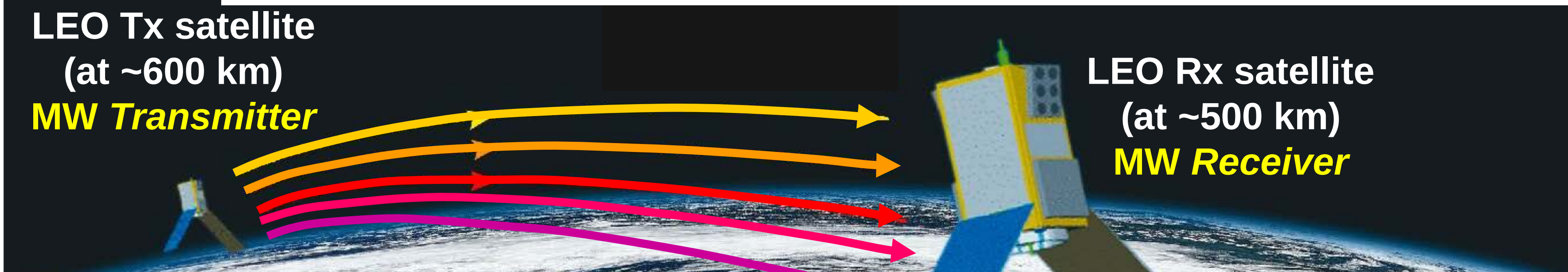
TakehomeMessage: *It‘s near’all these meters! But you‘ve to work properly t’dig out the barometer, thermometer and hygrometer under the refractometer and absorptometer.*

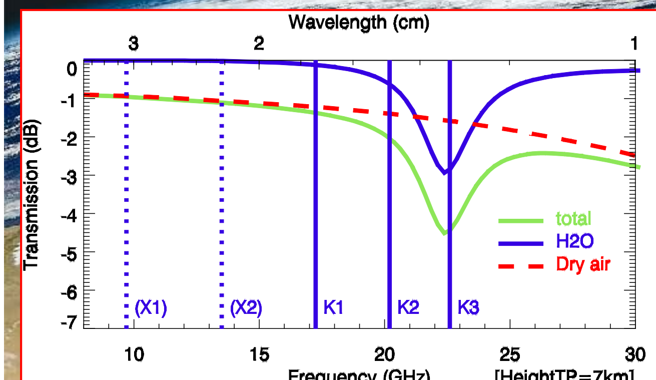
Wegener Center
www.wegcenter.at

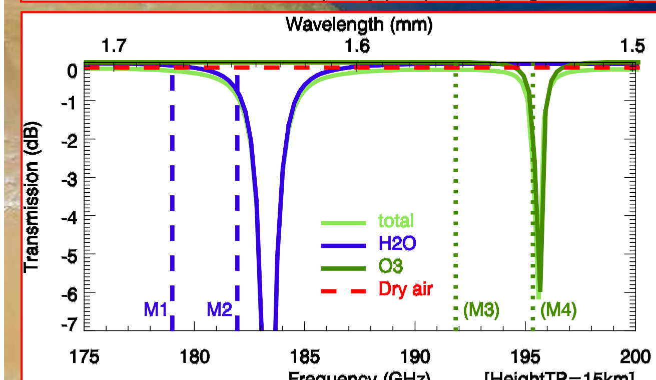
Backinfo#1a Absorptometer? LEO-LEO Occultation

LMO: MW refraction&absorption: established by GNSS RO heritage and ACE+ and ATOM(M)S concepts…

[Detailed LMO performance study: Schweitzer et al., JGR 116, D10301, 2011]







- Exploits refraction and (differential) transmission of MW signals (~17.25, 20.2, 22.6; opt. 179, 182 GHz, at the 22 / 183 GHz water vapor absorption lines; the Fig. left also indicates an optional ozone line) between LEO Tx and LEO Rx satellites.
- Measurements of phase delay & amplitude → bending angle & transmission → refractivity & absorption coeff. (*freq*) → pressure, temperature, humidity (independently over full UTLS domain).

Example: LMO lower tropo profiling (high-lat)

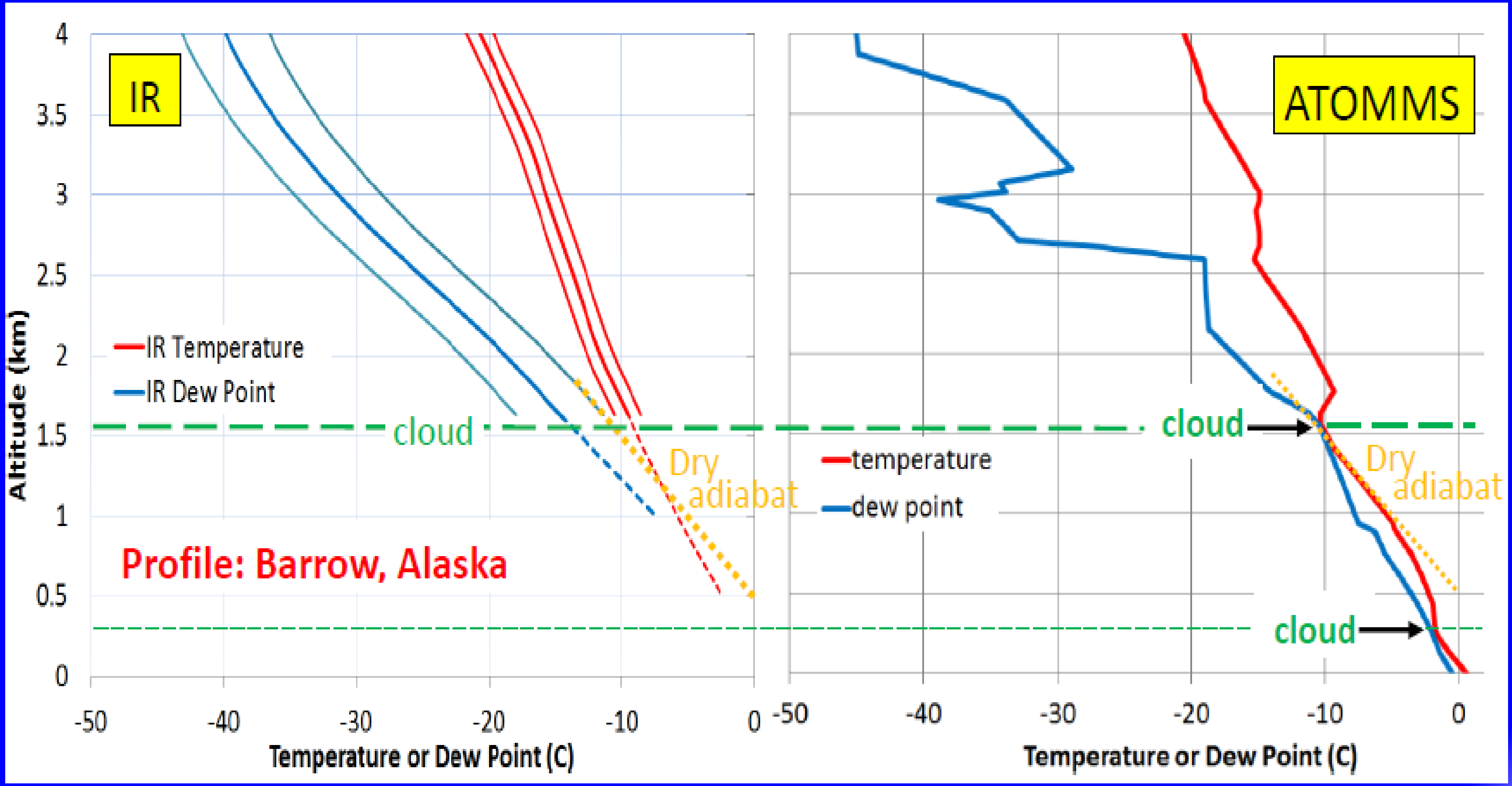
Large spread among sea ice melting predictions

- Uncertainties in modeled clouds & energy fluxes

Passive obs limited utility due to vertical resolution & sensitivity to surface emissivity & clouds

ATOMMS: routinely profile atmospheric structure to surface, **sonde-like with better accuracy**

- **Resolve near surface temperature, stability, water vapor & cloud LWC structure**



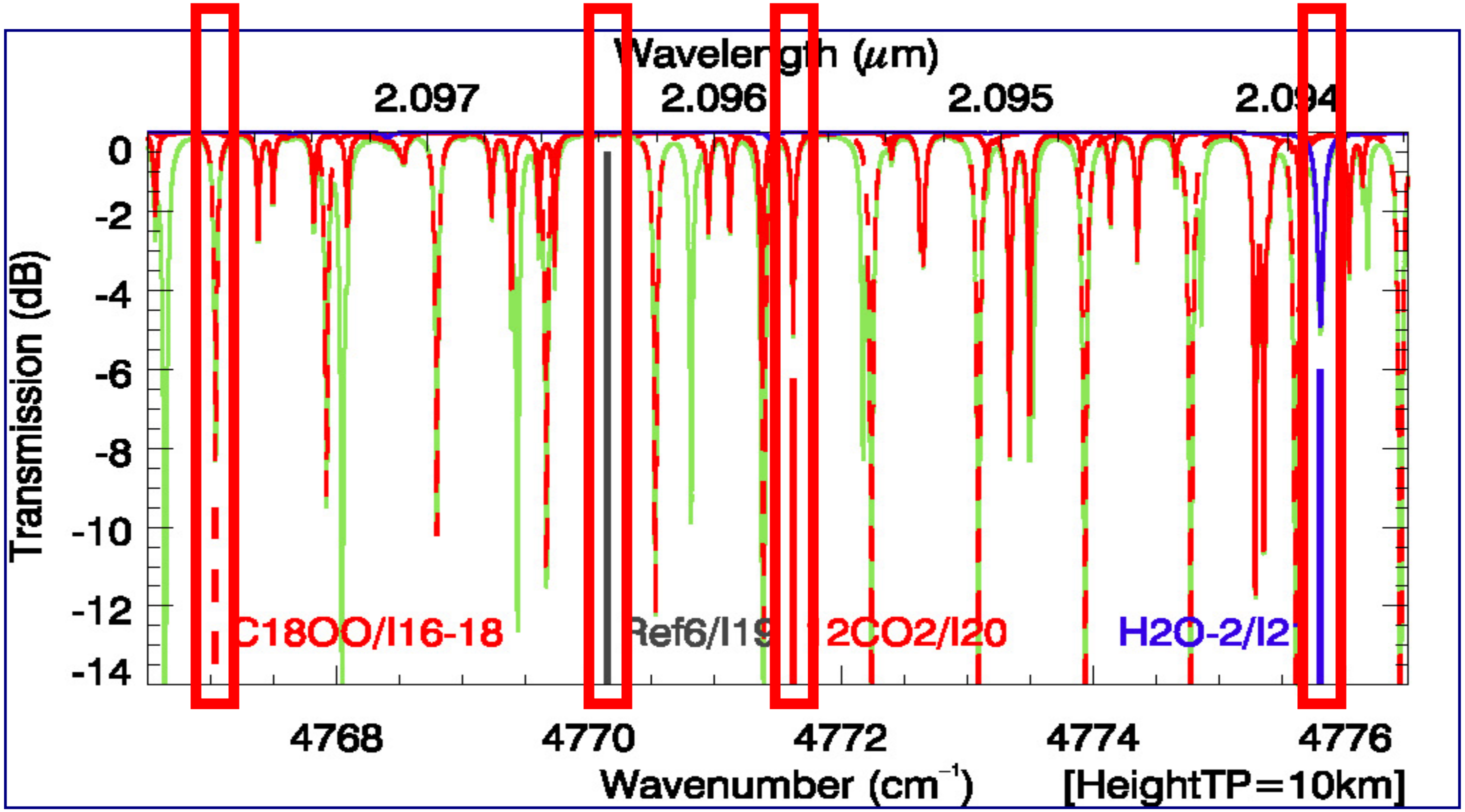
Kursinski et al. AGU 2015 **from AGU Fall Meeting 2015 pres (session A43H)**

Backinfo#1b Absorptometer? ***LEO-LEO Occultation***

LIO: differential log-transmission over *narrow delta-freq in IR-laser occultation* ("differential absorption principle")

=> accurate profiles of GHGs and line-of-sight wind speed, building on LMO *T,p,z*.

abs. channel $C^{18}OO$ **ref. channel** **abs. channel $^{12}CO_2$** **abs. channel H_2O**



[Details on LIO channel selections etc: Kirchengast and Schweitzer, GRL 38, L13701, 2011;
on accurate line spectroscopy needs: Harrison, Bernath, Kirchengast, JQSRT 112, 2347, 2011]

- **GNSS RO** (Global Navigation Satellite System radio occultation), or, more specifically so far, GPS RO (U.S. Global Positioning System radio occultation), for deriving tropospheric **pressure**, **temperature**, and **humidity** profile information, via atmospheric refractivity.
=> it's extremely simple, elegant & reliable in delivering its mission
(despite any confusion I may create; since it uses refractometric vertical atmospheric profiling set as a well-posed boundary value problem with direct signal reception – rather than using radiometric sounding set as an ill-posed inversion problem, or backscattered signal reception set as a high-power radar/lidar problem. Comment: I truly *like* radiometers, radars, and lidars for what they can deliver!)

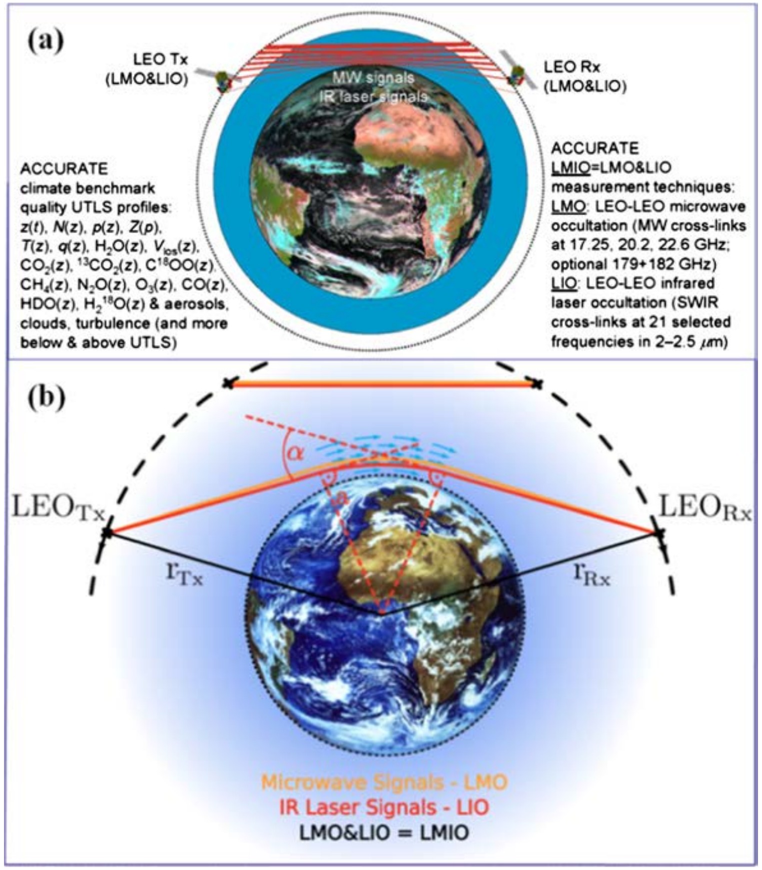
- **LEO-LEO MO** (Low Earth Orbit X/K band microwave occultation), for deriving tropospheric **pressure**, **temperature**, **humidity**, and **liquid water** profile information, via refractivity and differential absorption, complemented by simple **Clouds & Water Vapor Imager (CWAVI)**.
=> more to do but still simple, elegant & reliable in delivering its job
(as it uses refractometric&diff.absorption profiling, plus just photos:)

- *more info on this recent ISSI Berne workshop: >www.issibern.ch/workshops/shallowclouds/*

Comprehensive review of LEO-LEO microwave and IR-laser occultation

Liu, C.L., G. Kirchengast, S. Syndergaard, E.R. Kursinski, Y.Q. Sun, W.H. Bai, Q.F. Du
A review of low Earth orbit occultation using microwave and infrared-laser signals for monitoring the atmosphere and climate
Adv. Space Res., 60, 2776-2811, doi:10.1016/j.asr.2017.05.011, 2017.

		LMO				
		Temperature		Sp. Humidity		
Requirement		Target	Thres	Target	Thres	Units
Horizontal domain		global				
Horizontal sampling (mean distance of adjacent profiles) to be achieved within:		500	1000	500	1000	[km]
Time sampling[1]		12	24	12	24	[hrs]
No. of profiles per grid box per month[2]		40	30	40	30	
Vertical domain[3]		1-80	3-50	1-50	3-18[4]	[km]
Vertical sampling	LT UT LS US	0.5 0.5 0.5 1	1 1 1 2	0.5 0.5 0.5 1	1 1 1 2	[km] [km] [km] [km]
RMS accuracy[5]	LT	best-effort basis				Temp [K] Humi [%]
	UT-bottom UT-≥10km LS US	1 0.5 0.5 1	2 1 1 2	5 10 10 20	10 20 20 -	
Long-term stability (per decade)		0.1	0.15	2	3	
		[K/dec]		[%RH[6]/dec]		
Timeli-ness	Climate NWP[7]	7 1.5	14 3	7 1.5	14 3	[days] [hrs]
Time domain[8]		> 3				[years]



...for LEO-LEO microwave (LMO) in context see also this review...

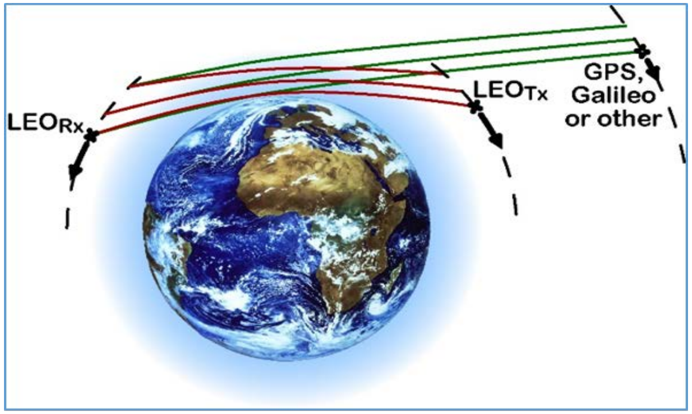
Wegener Center UNI GRAZ

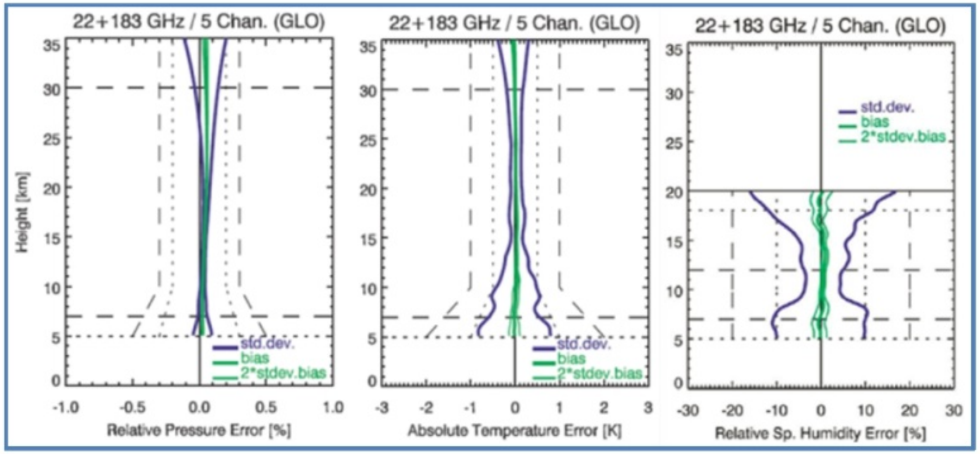
Review on new key technologies for observing water vapor, including LMO

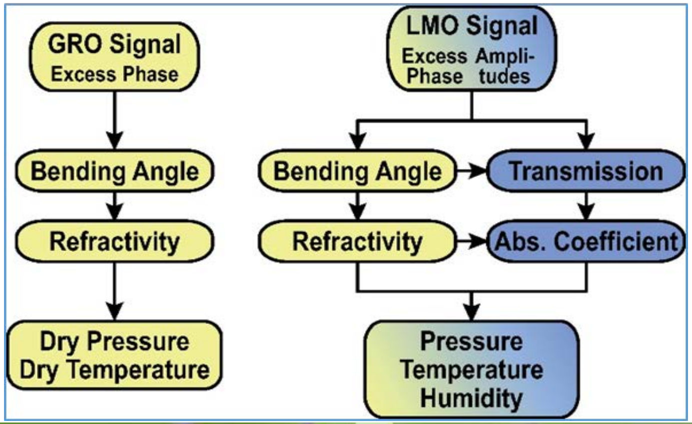
Nehrir, A.R., C. Kiemle, M.D. Lebsock, G. Kirchengast, S.A. Buehler, U. Löhnert, C.L. Liu, P.C. Hargrave, M. Barrera-Verdejo, and D.M. Winker

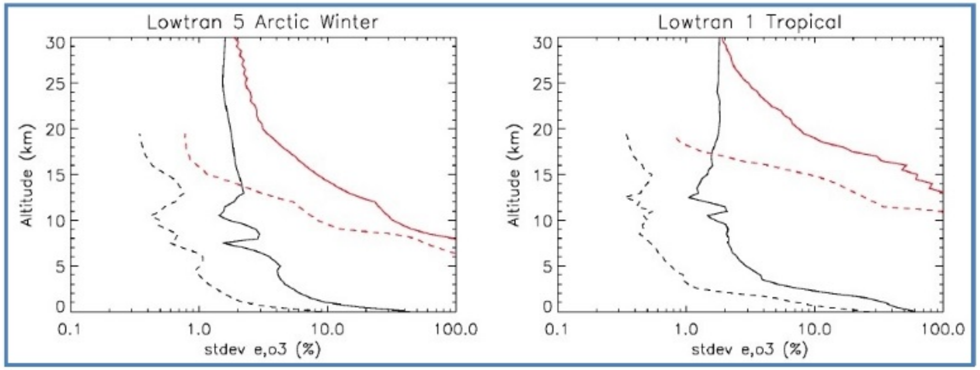
Emerging technologies and synergies for airborne and space-based measurements of water vapor profiles

Surv. Geophys., 38, 1445-1482, doi:10.1007/s10712-017-9448-9, 2017.









ISSI BJ Forum Taikong special issue

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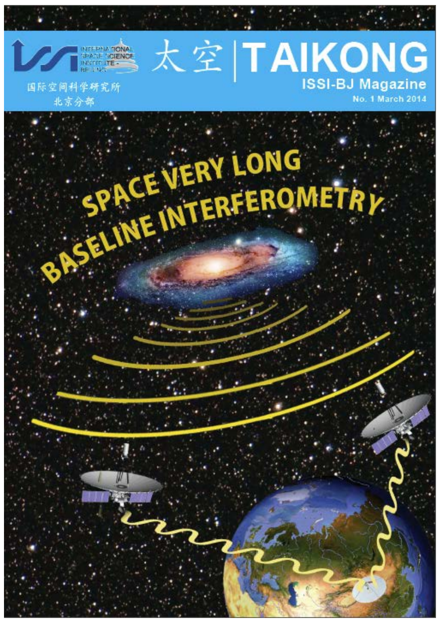
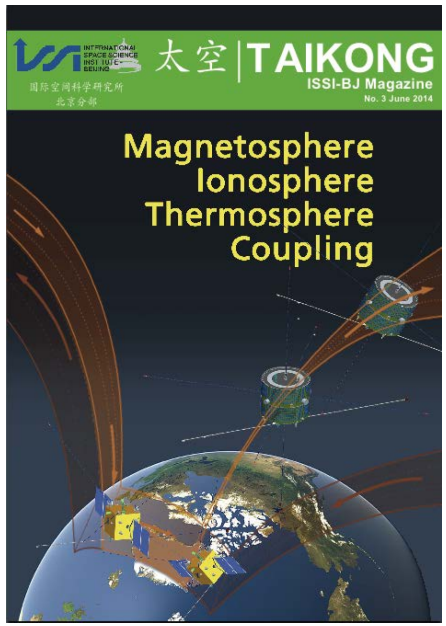
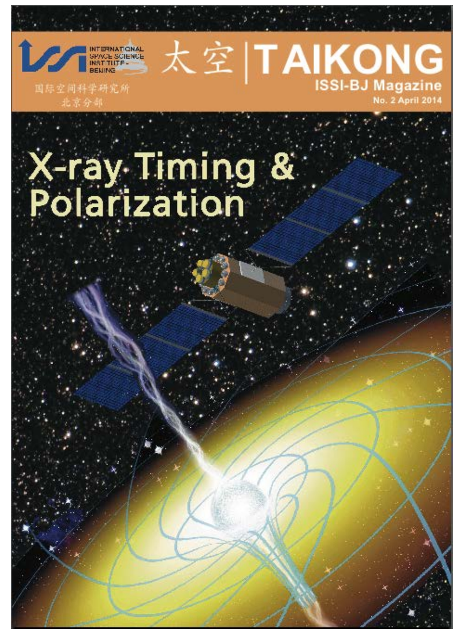
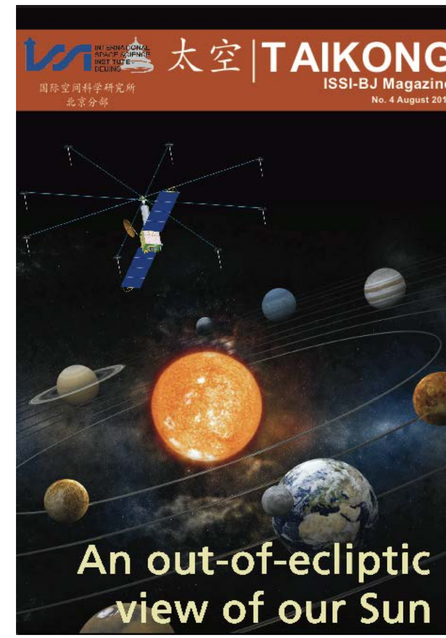








TAIKONG in English means SPACE, and it's a journal host by ISSI Beijng, to publish the outcomes of ISSI Beijing Forums and Workshops. Meanwhile, a concise related paper will be published in the Chinese Journal of Space Science

So, next is: ISSI-BJ Forum Taikong special issue…

Exploring greenhouse gases, water and climate changes by LEO-LEO occultation

Outline:

Foreword

Maurizio Falanga

Introduction

Give an overview of this ISSI Beijing LEO-LEO forum.

Congliang Liu, Gottfried Kirchengast and …

Challenging Requirements in forcing and feedback in climate change and water cycle processes

Gottfried Kirchengast, Daren Lv, Congl… and …

Observation from Space

In this section we may specific the GNS… technique

Gottfried Kirchengast, Yueqiang Sun, Conglia… Liu and …

LLO techniques in terms of principles, algorithms

Gottfried Kirchengast, Stig Syndergaard, Kerri Cahoy, Congliang Liu and …

CACES mission

Overview of the Chinese mission

Daren Lv, Xin Wang, Congliang Liu and …

Scientific objectives

Gottfried Kirchengast, Da… …gliang Liu and …

Mission Concept… …n

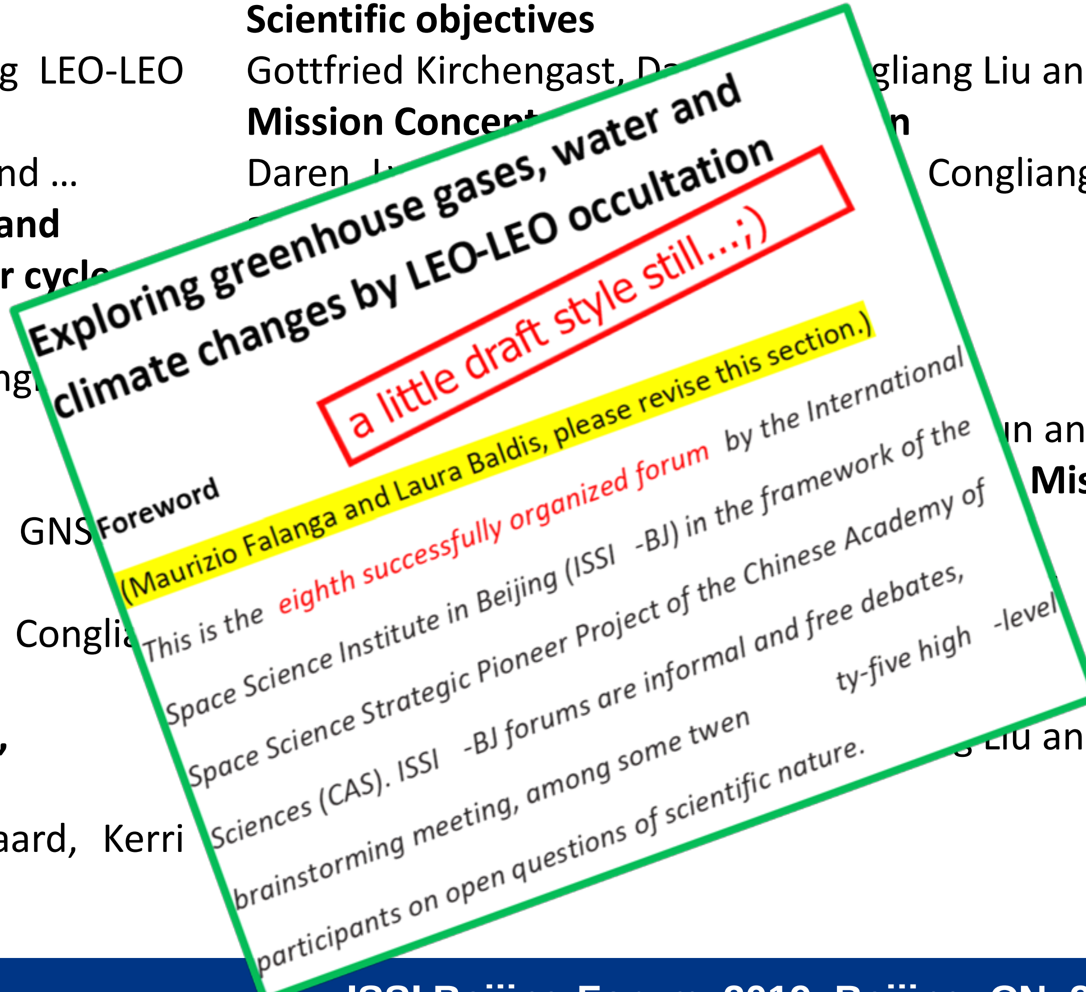
Daren L… … Congliang Liu

…n and …

Mission

Sun,

…Liu and …


Exploring greenhouse gases, water and climate changes by LEO-LEO occultation

a little draft style still…;)

Foreword

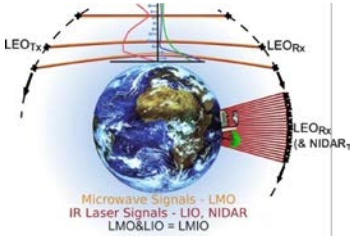
(Maurizio Falanga and Laura Baldis, please revise this section.)

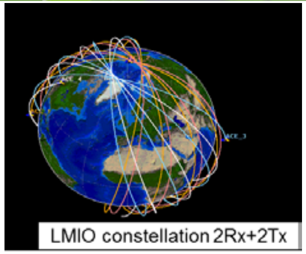
This is the eighth successfully organized forum by the International Space Science Institute in Beijing (ISSI -BJ) in the framework of the Space Science Strategic Pioneer Project of the Chinese Academy of Sciences (CAS). ISSI -BJ forums are informal and free debates, brainstorming meeting, among some twen ty-five high -level participants on open questions of scientific nature.

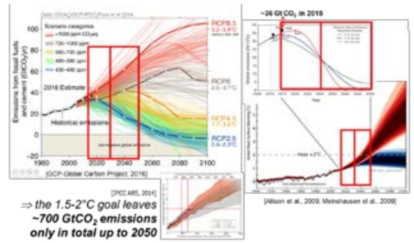
Overall LLO prospects: conclusion and next steps

Wegener Center

UNI GRAZ




LMIO constellation 2Rx+2Tx



Joint Laboratory on Occultations for Atmosphere and Climate

JLOAC

掩星探测与大气气候应用
国际联合实验室

1. LLO to provide benchmark data of thermodynamic variables (LMO), GHGs and aerosol (LIO) in Earth's free atmosphere
   Exploratory scientific studies, technical feasibility work, and ground demos encouraging –> unique scientific potential –> continue work towards LLO mission (& CWAVI; NIDAR).

2. Go for CACES: realize a first LEO-LEO explorer mission
   The JLOAC partners, plus further partners, may implement a pioneering LMIO science&demo mission, or initially a first-time LMO smallsat science&demo mission.

[Note if interested in papers:
most papers are accessible on-line via
>www.wegcenter.at/en/arsclisys-publ; otherwise contact
gottfried.kirchengast@uni-graz.at or the first authors]

Thank you for your attention!...

Finally…Huairou, can you hear me? *Yes, here KX11!*

(glimpse into KX11-CACES perspectives…an insider view:)

Wegener Center

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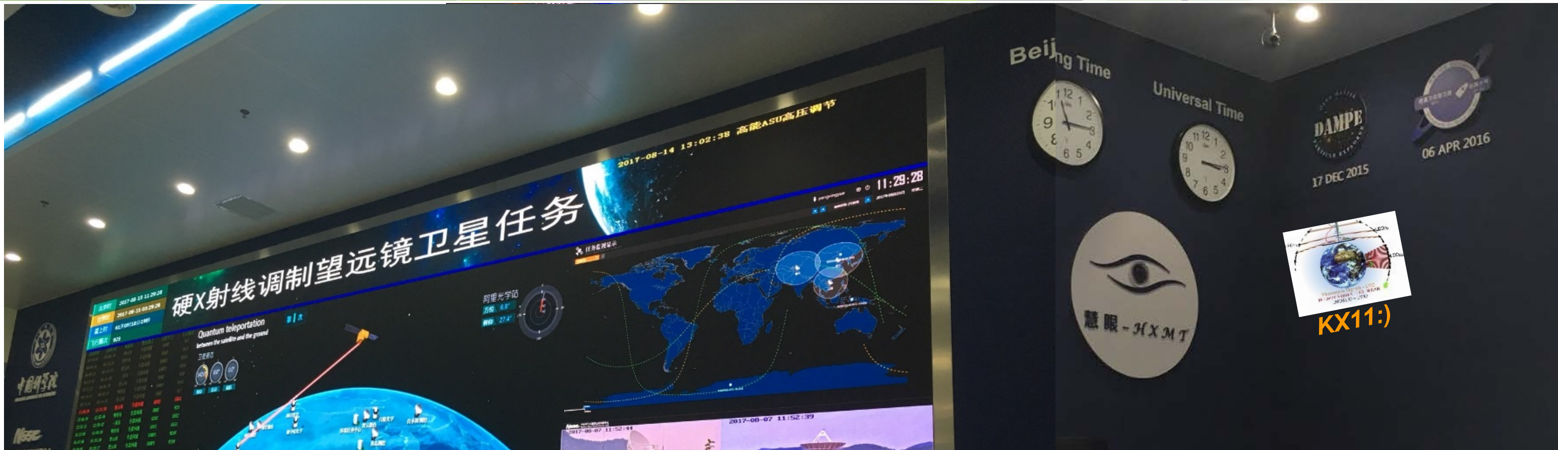

KX11:)

(KX02/QUESS mission data downlink ongoing)

(KX11/CACES mission data downlink follows:)

(checking for LMO ground demo on roof of new main building)

…感谢 for the *KX11* mission track! ☺

(thank you nssc-cas/photos courtesy of JLOAC team 14-15 Aug 2017)